The 2022 GCOS ECVs Requirements

GCOS – 245

GLOBAL CLIMATE OBSERVING SYSTEM
KEEPING WATCH OVER OUR CLIMATE
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The 2022 GCOS ECVs Requirements

Chair, Publications Board

World Meteorological Organization (WMO)

7 bis, avenue de la Paix

P.O. Box 2300

CH-1211 Geneva 2, Switzerland

Tel.: +41 (0) 22 730 84 03

Fax: +41 (0) 22 730 80 40

E-mail: Publications@wmo.int

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1. INTRODUCTION

This document is a supplement to the 2022 GCOS Implementation Plan (GCOS 244) and presents the updated list of Essential Climate Variables (ECVs) requirements.
An ECV is a physical, chemical or biological variable (or group of linked variables) that critically contributes to the characterization of Earth's climate.
An ECV product, is a measurable parameter needed to characterize the ECV.
GCOS has asked its expert panels, informed by the wider community, to define requirements for the ECV products of all ECVs detailed in this document. A complete list of contributors is provided in GCOS-244 Appendix 3.

The requirements are expressed in terms of five criteria:

1. Spatial Resolution - horizontal and vertical (if needed).
2. Temporal resolution (or frequency) – the frequency of observations e.g. hourly, daily or annual.
3. Measurement Uncertainty – the parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand (GUM)[1]. It includes all contributions to the uncertainty, expressed in units of 2 standard deviations, unless stated otherwise.
4. Stability – The change in bias over time. Stability is quoted per decade.
5. Timeliness - The time expectation for accessibility and availability of data.

In this Implementation Plan, for each of these criteria, a goal, breakthrough and threshold value are presented. These are defined as:

- Goal (G): an ideal requirement above which further improvements are not necessary.
- Breakthrough (B): an intermediate level between threshold and goal which, if achieved, would result in a significant improvement for the targeted application. The breakthrough value may also indicate the level at which specified uses within climate monitoring become possible. It may be appropriate to have different breakthrough values for different uses.
- Threshold (T): the minimum requirement to be met to ensure that data are useful.

For each ECV product, a definition and units are provided together with the requirements.

2. EVOLUTION OF ECVS REQUIREMENTS

The ECV framework has evolved since the publication of the previous list of ECVs requirements in the GCOS IP 2016. The list of ECVs and ECVs products has changed as well, and the following table illustrates those changes.

Atmosphere			
ECV	**ECV Product 2016**		**ECV Product 2022**
Surface Pressure	Pressure (surface)		Air Pressure (near surface)
Surface Temperature	Temperature (surface)		Air Temperature (near surface)
Surface wind Speed and Direction	Surface wind Speed and Direction		Wind Speed (near surface)
			Wind Direction (near surface)
			Wind Vector (near surface)
	Water Vapour (surface)		Dew Point Temperature (near surface)

[1] https://www.bipm.org/documents/20126/2071204/JCGM_100_2008_E.pdf/cb0ef43f-baa5-11cf-3f85-4dcd86f77bd6

Surface Water Vapour			Relative Humidity (near surface)
			Air Specific Humidity (near surface)
Precipitation	Estimates of Liquid and Solid Precipitation		Accumulated precipitation
Surface Radiation Budget	Surface ERB Short-Wave		Downward Short-Wave Irradiance at Earth Surface
	Surface ERB long-Wave		Downward Long-Wave Irradiance at Earth Surface
			Upward Long-Wave Irradiance at Earth Surface
Upper-air Temperature	Tropospheric Temperature Profile		Atmospheric Temperature in the Boundary Layer
	Stratospheric Temperature Profile		Atmospheric Temperature in the Free Troposphere
			Atmospheric Temperature in the Upper Troposphere and Lower Stratosphere
	Temperature of the Deep Atmospheric Layers		Atmospheric Temperature in the Middle and Upper Stratosphere
			Atmospheric Temperature in the Mesosphere
Upper-air Wind Speed and Direction	Upper-Air Wind Retrievals		Wind (horizontal) in the Boundary Layer
			Wind (horizontal) in the Free Troposphere
			Wind (horizontal) in the Upper Troposphere and Lower Stratosphere
			Wind (horizontal) in the Middle and Upper Stratosphere
			Wind (horizontal) in the Mesosphere
			Wind (vertical) in the Boundary Layer
			Wind (vertical) in the Free Troposphere
			Wind (vertical) in the Upper Troposphere and Lower Stratosphere
			Wind (vertical) In the Middle and Upper Stratosphere
			Wind (vertical) in the Mesosphere
Upper-air Water Vapour	Tropospheric and Lower-Stratospheric profile of Water Vapour		Water Vapour Mixing Ratio in the Upper Troposphere and Lower Stratosphere
			Water Vapour Mixing Ratio in the Middle and Upper Stratosphere
			Water Vapour Mixing Ratio in the Mesosphere
	Upper Tropospheric Humidity		Relative Humidity in the Boundary Layer
			Relative Humidity in the Free Troposphere
			Relative Humidity in the Upper Troposphere and Lower Stratosphere
			Specific Humidity in the Boundary Layer
			Specific Humidity in the Free Troposphere
	Total Column Water Vapour		Integrated Water Vapour
Earth Radiation Budget	Solar Spectral Irradiance		Solar Spectral Irradiance
	Total Solar Irradiance		Downward Short-Wave Irradiance at Top of the Atmosphere
	Top of the Atmosphere ERB Long-Wave		Upward Long-Wave Irradiance at Top of the Atmosphere
	Top of the Atmosphere ERB Short-Wave		Upward Short-Wave Irradiance at Top of the Atmosphere
			Radiation Profile
Cloud Properties	Cloud Amount		Cloud Cover
	Cloud Water Path (liquid and ice)		Cloud Liquid Water Path
			Cloud Ice Water Path

	Cloud Effective particle radius (liquid and ice)		Cloud Drop Effective Radius
	Cloud Optical Depth		Cloud Optical Depth
	Cloud Top Temperature		Cloud Top Temperature
	Cloud Top Pressure		Cloud Top Height
Lightning	Lightning		Total Lightning Stroke Density
			Schumann Resonances
Carbon Dioxide, Methane and Other Greenhouse Gases	Tropospheric CO_2		CO_2 Mole Fraction
	Tropospheric CO_2 Column		CO_2 Column Average Dry Air Mixing Ratio
	Tropospheric CH_4		CH_4 Mole Fraction
	Stratospheric CH_4		
	Tropospheric CH_4 Column		CH_4 Column Average Dry Air Mixing Ratio
			N_2O Mole Fraction
Ozone	Troposphere Ozone		Ozone Mole Fraction in the Troposphere
	Ozone Profile in Upper and Lower Stratosphere		Ozone Mole Fraction in the Upper Troposphere/ Lower Stratosphere
	Ozone Profile in Upper Stratosphere and Mesosphere		Ozone Mole Fraction in the Middle and Upper Stratosphere
	Total Column Ozone		Ozone Total Column
			Ozone Tropospheric Column
			Ozone Stratospheric Column
Precursors (Supporting the aerosol and ozone ECVs)	CO Tropospheric Column		CO Tropospheric Column
	CO Tropospheric Profile		CO Mole Fraction
	SO_2, HCHO Tropospheric Columns		HCHO Tropospheric Column
			SO_2 Tropospheric Column
			SO_2 Stratospheric Column
	NO_2 Tropospheric Column		NO_2 Tropospheric Column
			NO_2 Mole Fraction
Aerosols Properties	Aerosol Extinction Coefficient Profile		Aerosol Light Extinction Vertical Profile (Troposphere)
			Aerosol Light Extinction Vertical Profile (Stratosphere)
	Aerosol Optical Depth		Multi-wavelength Aerosol Optical Depth
	Single Scattering Albedo		Aerosol Single Scattering Albedo
	Aerosol Layer Height		
			Chemical Composition of Aerosol Particles
			Number of Cloud Condensation Nuclei
			Aerosol Number Size Distribution

Ocean			
ECV	**ECV Product 2016**		**ECV Product 2022**
Sea-Surface temperature	Sea-Surface temperature		Sea-Surface temperature
Subsurface Temperature	Interior Temperature		Interior Temperature
Sea-Surface Salinity	Sea-Surface Salinity		Sea-Surface Salinity
Subsurface Salinity	Interior Salinity		Interior Salinity
Surface Currents	Surface Geostrophic Current		Surface Geostrophic Current
			Ekman Currents
Subsurface Currents	Interior Currents		Vertical Mixing
Sea Level	Regional Sea Level		Regional Mean Sea Level
	Global Mean Sea Level		Global Mean Sea Level

Sea State	Wave Height		Wave Height
Surface Stress	Surface Stress		Surface Stress
Ocean Surface Heat Flux	Radiative Heat Flux		Radiative Heat Flux
	Sensible Heat Flux		Sensible Heat Flux
	Latent Heat Flux		Latent Heat Flux
Sea Ice	Sea Ice Concentration		Sea Ice Concentration
	Sea Ice Thickness		Sea Ice Thickness
	Sea Ice Drift		Sea Ice Drift
	Sea Ice Extent/Edge		Sea Ice Age
			Sea Ice Surface Temperature (IST)
			Sea ice Surface Albedo
			Snow Depth on Sea Ice
Oxygen	Interior Ocean Oxygen Concentration		Dissolved Oxygen Concentration
Nutrients	Interior Ocean Concentrations of Silicate, Phosphate, nitrate		Silicate
			Phosphate
			Nitrate
Ocean Inorganic Carbon	Interior Ocean Carbon Storage. (At least 2 of DIC, TA or pH)		Total Alkalinity (TA)
			Dissolved Inorganic Carbon (DIC)
			pCO_2
Transient Tracers	Interior Ocean CFC-11, CFC-12, SF_6, ^{14}C, tritium, ^{3}He, ^{39}Ar		^{14}C
			SF_6
			CFC-11
			CFC-12
Ocean nitrous oxide N_2O	Interior Ocean Nitrous Oxide N_2O		Interior Ocean Nitrous Oxide N_2O
	N_2O Air-Sea Flux		N_2O Air-Sea Flux
Ocean Colour	Water Leaving Radiance		Water Leaving Radiance
	Chlorophyll-a concentration		Chlorophyll-a concentration
Plankton	Zooplankton		Zooplankton Diversity
			Zooplankton Biomass
	Phytoplankton		Phytoplankton Diversity
			Phytoplankton Biomass
Marine Habitat Properties	Coral Reefs, mangrove forests, seagrass beds, Macroalgal Communities		Mangrove Cover and Composition
			Seagrass Cover (areal extent)
			Macroalgal Canopy Cover and Composition
			Hard coral cover and composition

Terrestrial			
ECV	**ECV Product 2016**		**ECV Product 2022**
Groundwater	Groundwater Volume Change		Groundwater Storage Change
	Groundwater Level		Groundwater Level
	Groundwater Recharge		
	Groundwater Discharge		
	Wellhead Level		
	Water Quality		
Lakes	Lake Water Level		Lake Water Level (LWL)
	Water Extent		Lake Water Extent (LWE)
	Lake Surface-Water Temperature		Lake Surface Water Temperature (LSWT)
	Lake Ice Cover		Lake Ice Cover (LIC)
	Lake Ice Thickness		Lake Ice Thickness (LIT)
	Lake Colour (Lake Water-Leaving Reflectance)		Lake Water-Leaving Reflectance
River Discharge	River Discharge		River Discharge
	Water Level		Water Level

	Flow Velocity		
	Cross-Section		
Soil Moisture	Surface Soil Moisture		Surface Soil Moisture
	Freeze/Thaw		Freeze/Thaw
	Surface Inundation		Surface Inundation
	Root-Zone Soil Moisture		Root Zone Soil Moisture
Terrestrial Water Storage[2]			Terrestrial Water Storage Anomaly
Snow	Area Covered by Snow		Area Covered by Snow
	Snow Depth		Snow Depth
	Snow-Water Equivalent		Snow-Water Equivalent
Glaciers	Glacier Area		Glacier Area
	Glacier Elevation Change		Glacier Elevation Change
	Glacier Mass Change		Glacier Mass Change
Ice Sheets and Ice Shelves	Surface Elevation Change		Surface Elevation Change
	Ice Velocity		Ice Velocity
	Ice Mass Change		Ice Volume Change
	Grounding Line Location and Thickness		Grounding Line Location and Thickness
Permafrost	Thermal State of Permafrost		Permafrost Temperature (PT)
	Active Layer Thickness		Active Layer Thickness (ALT)
			Rock Glacier Velocity (RGV)
Fraction of FAPAR	Maps of FAPAR for Modelling		Fraction of Absorbed Photosynthetically Active Radiation
	Maps of FAPAR for Adaptation		
Leaf Area Index	Maps of LAI for Modelling		Leaf Area Index (LAI)
	Maps of LAI for Adaptation		
Albedo	Maps of DHR Albedo for Adaptation		Spectral and Broadband (Visible, Near Infrared and Shortwave) DHR & BHR with Associated Spectral Bidirectional Reflectance Distribution Function (BRDF) Parameters
	Maps of BHR Albedo for Adaptation		
	Maps of DHR Albedo for Modelling		
	Maps of BHR Albedo for Modelling		
Land-Surface Temperature	Maps of Land-Surface Temperature		Land Surface Temperature (LST)
			Soil Temperature[3]
Above-Ground Biomass	Maps of AGB		Above-Ground Biomass (AGB)
Land Cover	Maps of Land Cover		Land Cover
	Maps of High-Resolution Land Cover		Maps of High-Resolution Land Cover
	Maps of Key IPCC Land Use, Related Changes and Land-Management Types		Maps of Key IPCC Land Classes, Related Changes and Land Management Types
Soil Carbon	% Carbon in Soil		Carbon in Soil
	Mineral Soil Bulk Density to 30 Cm and 1 M		Mineral Soil Bulk Density
	Peatlands Total Depth of Profile, Area and Location		Peatlands
Fire	Burnt Areas		Burned Area
	Active Fire Maps		Active Fires
	Fire Radiative Power		Fire Radiative Power (FRP)

[2] This is the only new ECV approved by GCOS Steering Committee in 2020.

[3] Soil Temperature is a new ECV product temporarily included under the ECV Land-Surface Temperature. Its positioning will be subject to evaluation by the TOPC Panel and the GCOS Steering Committee.

Anthropogenic Greenhouse-Gas Fluxes	Emissions from Fossil Fuel Use, Industry, Agriculture and Waste Sectors		Anthropogenic CO_2 Emissions from Fossil Fuel Use, Industry, Agriculture, Waste and Products Use
			Anthropogenic CH_4 Emissions from Fossil Fuel, Waste, Agriculture, Industrial Processes and Fuel Use
			Anthropogenic N_2O Emissions from Fossil Fuel Use, Industry, Agriculture, Waste and Products Use, Indirect from N-Related Emissions/Depositions
			Anthropogenic F-Gas Emissions from Industrial Processes and Product Use
	Estimated Fluxes by Inversions of Observed Atmospheric Composition – National		Total Estimated Fluxes by Coupled Data Assimilation/Models with Observed Atmospheric Composition – National
	Estimated Fluxes by Inversions of Observed Atmospheric Composition – Continental		Total Estimated Fluxes by Coupled Data Assimilation/Models with Observed Atmospheric Composition - Continental
	Emissions/ Removals by IPCC Land Categories		Anthropogenic CO_2 Emissions/Removals by Land Categories
	High-Resolution CO_2 Column Concentrations to Monitor Point Sources		High-Resolution Footprint Around Point Sources
Evaporation from Land	TOPC was considering the practicality of this being an ECV (Latent and Sensible Heat Fluxes) and, if so, what the requirements might be.		Sensible Heat Flux
			Latent Heat Flux
			Bare Soil Evaporation
			Interception Loss
			Transpiration
Anthropogenic Water Use	Anthropogenic Water Use		Anthropogenic Water Use

3. ECVS REQUIREMENTS TABLES

In this section the requirements for the ECVs and their products are presented in 3 different sections Atmospheric, Ocean and Terrestrial.

Units are expressed according to the International System of units. For the time unit, the following abbreviations are used:

Minute (min); day (d); month (month); year (y).

Atmospheric ECVs

1. SURFACE

1.1 ECV: Air Pressure

1.1.1 ECV product: Atmospheric Pressure (near surface)

Name	Atmospheric Pressure (near surface)				
Definition	Air pressure at a known height above the surface with the height specified in the metadata.				
Unit	hPa				
Note	Observations made over the ocean are not static, being mostly recorded by mobile ships and drifting buoys (Kent et al., 2019). Requirements for marine surface observations must therefore be defined in terms of the composite accuracy and sampling of the marine observing networks to achieve comparable uncertainty thresholds at similar resolution. The primary application of pressure in monitoring relates to the use of reanalysis and so these requirements have been set in this regard. Timeliness does not preclude delayed mode acquisition via e.g. data rescue. Important also, but not covered in the table, is the observation location information. A mis-placed observation of surface pressure (particularly the station elevation) will have substantial implications for reanalysis applications.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	Resolution is consistent with other surface ECVs
			B	100	
			T	500	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	
			B	6	
			T	12	
Timeliness	h		G	6	
			B	24	
			T	720	monthly
Required Measurement Uncertainty (2-sigma)	hPa		G	0.5	
			B	1	
			T	1	
Stability	hPa/decade		G	0.02	
			B	0.1	
			T	0.2	
Standards and References	Kent, E.C., Rayner, N.A., Berry, D.I., Eastman, R., Grigorieva, V.G., Huang, B., Kennedy, J.J., Smith, S.R. and Willett, K.M., 2019: Observing Requirements for Long-Term Climate Records at the Ocean Surface. Frontiers in Marine Science 6, Article 441, doi:10.3389/fmars.2019.00441.				

1.2 ECV: Surface Temperature

1.2.1 ECV Product: Air Temperature (near surface)

Name	**Air Temperature (near surface)**
Definition	Air temperature at a known height above surface, with the height specified in the metadata.
Unit	K
Note	The terminology used here for Tx (maximum daily temperature) and Tn (minimum daily temperature) and the observing cycle only applies to land-based meteorological stations. Observations made over the ocean are not static, being mostly recorded by mobile ships and drifting buoys (Kent et al., 2019). Requirements for marine surface observations must therefore be defined in terms of the composite accuracy and sampling of the marine observing networks to achieve comparable uncertainty thresholds at similar resolution, for example through the construction of gridded data products. Breakthrough targets are generally needed for reanalysis to make good use of these data. Temporal resolution: For better Reanalysis, we need more sampling down to 100km and sub-daily (hourly or 3-hourly). This is also needed for monitoring of extremes. For determining global annual temperature averages, the current network of land stations and ship and buoy measurements is adequate, but regional and higher temporal resolution averages can be highly uncertain (e.g. the 500 km sampling doesn't get made in many regions, such as Africa, the polar regions and the Southern Ocean).Even if we got to the goal sampling, the uncertainty in the monthly global average temperatures would be reduced, but not by much from what it is now. However, these more stringent requirements will allow regional monthly averages to be calculated. Even if we got to the goal sampling, the uncertainty in the monthly global average temperatures would be reduced, but not by much from what it is now. However, these more stringent requirements will allow regional monthly averages to be calculated. Timeliness requirements are for routine applications related to climate monitoring, such as assimilation into reanalyses or the update of monitoring products. Observations that miss these timeliness requirements remain useful for some climate applications and can, for example, be used in periodic revisions to climate monitoring products.

Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	10	Thorne et al. (2018)
			B	100	Thorne et al. (2018)
			T	500	Threshold for horizontal resolution is based on the literature and specifically over land where correlation distances tend to be smaller than over the oceans. Thorne et al. (2018) showed via repeat sub-sampling of CRUTEM4 that well-spaced networks of the order 180 stations over the globe could recreate full-field global mean land surface air temperature estimates (see details in Jones et al., 1997) for the monthly timescale. For surface air temperature over the ocean which is taken predominantly by ships and buoys this can be challenging in remote Ocean basins (see the earlier note and Kent et al., 2019)
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	< 1	Sub-hourly. Required for derivation of extreme indices.
			B	1	Required for Climate Data Assimilation System (CDAS)-mode reanalysis assimilation. Breakthrough is the monthly average necessary to inform the global, regional and national monitoring statements from WMO and members. Captures most of the variability in the diurnal cycle
			T	3	Minimum sampling of diurnal cycle (daily Tx/Tm)
Timeliness	h		G	6	Allows use in near-real time reanalysis
			B	24	Required for CDAS-mode reanalysis assimilation. Allows use in daily climate monitoring products
			T	720	Monthly average is necessary to inform the global, regional and national monitoring statements from WMO

					and members. Allows use in monthly climate monitoring products
Required Measurement Uncertainty (2-sigma)	K		G	0.1	Uncertainty is assumed to include random and systematic effects. Thorne et al. (2018) Jones et al. (1997)
			B	0.5	
			T	1	
Stability	K/decade		G	0.01	Required for large-scale averages over century scales
			B	0.05	Required for large-scale averages over multi-decadal scales
			T	0.1	Required for regional averages over multi decadal scales
Standards and References	Jones, P.D., Osborn, T.J. and Briffa, K.R., 1997: Estimating sampling errors in large-scale temperature averages. J. Climate 10, 2548-2568. Kent, E.C., Rayner, N.A., Berry, D.I., Eastman, R., Grigorieva, V.G., Huang, B., Kennedy, J.J., Smith, S.R. and Willett, K.M., 2019: Observing Requirements for Long-Term Climate Records at the Ocean Surface. Frontiers in Marine Science 6, Article 441, doi:10.3389/fmars.2019.00441. Thorne, P.W., Diamond, H.J., Goodison, B., Harrigan, S. Hausfather, Z., Ingleby, N.B., Jones, P.D., Lawrimore, J.H., Lister, D.H., Merlone, A., Oakley, T., Palecki, M., Peterson, T.C., de Podesta, M., Tassone, C., Venema, V. and Willett, K.M., 2018: Towards a global land surface climate fiducial reference measurements network. Int. J. Climatol. 38, 2760-2774, https://doi.org/10.1002/joc.5458.				

1.3 ECV: Surface Wind Speed and Direction

1.3.1 ECV Product: Wind Direction (near surface)

Name	**Wind Direction (near surface)**				
Definition	Direction from which wind is blowing at a known height above the surface which is to be specified in the metadata.				
Unit	Degree true				
Note	Wind directions are normally reported as an average due to their high variability. The averaging period should be reported as metadata. Timeliness requirements are for routine applications related to climate monitoring, such as assimilation into reanalyses or the update of monitoring products. Observations that miss these timeliness requirements remain useful for some climate applications and can, for example, be used in periodic revisions to climate monitoring products.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	10	
			B	100	For consistency with other surface ECV
			T	500	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	<1	Sub-hourly
			B	1	Captures most of the variability in the diurnal cycle
			T	3	Minimum sampling of diurnal cycle
Timeliness	h		G	6	Allows use in near-real time reanalysis
			B	24	Allows use in daily climate monitoring products
			T	720	Allows use in monthly climate monitoring products
Required Measurement Uncertainty (2-sigma)	degrees		G	1	
			B	5	
			T	10	
Stability	degrees/decade		G	1	
			B	2	
			T	5	
Standards and References	Kent, E.C., Rayner, N.A., Berry, D.I., Eastman, R., Grigorieva, V.G., Huang, B., Kennedy, J.J., Smith, S.R. and Willett, K.M., 2019: Observing Requirements for Long-Term Climate Records at the Ocean Surface. Frontiers in Marine Science 6, Article 441, doi:10.3389/fmars.2019.00441.				

1.3.2 ECV Product: Wind Speed (near surface)

Name	Wind Speed (near surface)				
Definition	Speed of air at a known height above the surface which is to be specified in the metadata.				
Unit	m s^{-1}				
Note	Wind speeds are normally reported as an average due to their high variability. The averaging period should be reported as metadata. Observations made over the ocean are not static, being mostly recorded by mobile ships and drifting buoys (Kent et al., 2019). Requirements for marine surface observations must therefore be defined in terms of the composite accuracy and sampling of the marine observing networks to achieve comparable uncertainty thresholds at similar resolution.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B	100	
			T	500	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	< 1	Sub-hourly
			B	1	Captures most of the variability in the diurnal cycle
			T	3	Minimum sampling of diurnal cycle
Timeliness	h		G	6	Allows use in near-real time reanalysis
			B	24	
			T	720	Monthly
Required Measurement Uncertainty (2-sigma)	m s^{-1}		G	0.1	
			B	0.5	
			T	1	
Stability	m s^{-1}/ decade		G	0.1	
			B	0.25	
			T	0.5	
Standards and References	Kent, E.C., Rayner, N.A., Berry, D.I., Eastman, R., Grigorieva, V.G., Huang, B., Kennedy, J.J., Smith, S.R. and Willett, K.M., 2019: Observing Requirements for Long-Term Climate Records at the Ocean Surface. Frontiers in Marine Science 6, Article 441, doi:10.3389/fmars.2019.00441.				

1.3.3 ECV Product: Wind Vector (near surface)

Name	Wind Vector (near surface)				
Definition	Horizontal wind vector, at a known height above the surface which is to be specified in the metadata.				
Unit	m s^{-1}				
Note	Wind directions are normally reported as an average due to their high variability. The averaging period should be reported as metadata.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B	100	
			T	500	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	<1	Sub-hourly
			B	1	Captures most of the variability in the diurnal cycle
			T	3	Minimum sampling of diurnal cycle
Timeliness	h		G	6	
			B	24	
			T	720	Monthly
Required Measurement Uncertainty (2-sigma)	m s^{-1}		G	0.1	
			B	0.5	
			T	1	
Stability	m s^{-1}/ decade		G	0.1	
			B	0.25	
			T	0.5	
Standards and References	Kent, E.C., Rayner, N.A., Berry, D.I., Eastman, R., Grigorieva, V.G., Huang, B., Kennedy, J.J., Smith, S.R. and Willett, K.M., 2019: Observing Requirements for Long-Term Climate Records at the Ocean Surface. Frontiers in Marine Science 6, Article 441, doi:10.3389/fmars.2019.00441.				

1.4 ECV: Surface Water Vapour

1.4.1 ECV Product: Dew Point Temperature (near Surface)

Name	Dew Point Temperature (near surface)				
Definition	Temperature to which air must be cooled to become saturated with water vapor at a known height above surface, with the height specified in the metadata.				
Unit	K				
Note	Observations made over the ocean are not static, being mostly recorded by mobile ships and drifting buoys (Kent et al., 2019). Requirements for marine surface observations must therefore be defined in terms of the composite accuracy and sampling of the marine observing networks to achieve comparable uncertainty thresholds at similar resolution, for example through the construction of gridded data products. Willett et al. 2008 show that spatial scales of near surface dew point temperature are comparable to those of temperature so the same horizontal resolution should be broadly applicable. Timeliness requirements are for routine applications related to climate monitoring, such as assimilation into reanalyses or the update of monitoring products. Observations that miss these timeliness requirements remain useful for some climate applications and can, for example, be used in periodic revisions to climate monitoring products.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	Willett et al. 2008, based on analogy with temperature
			B	100	
			T	500	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	<1	Sub-hourly
			B	1	Captures most of the variability in the diurnal cycle
			T	3	Minimum sampling of diurnal cycle
Timeliness	h		G	6	Allows use in near-real time reanalysis
			B	24	Allows use in daily climate monitoring products
			T	720	Allows use in monthly climate monitoring products
Required Measurement Uncertainty (2-sigma)	K		G	0.1	
			B	0.5	
			T	1	
Stability	K/decade		G	0.01	Required for large-scale averages over century scales
			B	0.05	Required for large-scale averages over multi-decadal scales
			T	0.1	Required for regional averages over multi decadal scales
Standards and References	Kent, E.C., Rayner, N.A., Berry, D.I., Eastman, R., Grigorieva, V.G., Huang, B., Kennedy, J.J., Smith, S.R. and Willett, K.M., 2019: Observing Requirements for Long-Term Climate Records at the Ocean Surface. Frontiers in Marine Science 6, Article 441, doi:10.3389/fmars.2019.00441. Willett, K. M., Dunn, R. J. H., Thorne, P. W., Bell, S., de Podesta, M., Parker, D. E., Jones, P. D., and Williams Jr., C. N.: HadISDH land surface multi-variable humidity and temperature record for climate monitoring, Clim. Past, 10, 1983-2006, doi:10.5194/cp-10-1983-2014, 2014. Willett, K. M., Williams Jr., C. N., Dunn, R. J. H., Thorne, P. W., Bell, S., de Podesta, M., Jones, P. D., and Parker D. E., 2013: HadISDH: An updated land surface specific humidity product for climate monitoring. Climate of the Past, 9, 657-677, doi:10.5194/cp-9-657-2013.				

1.4.2 ECV Product: Relative Humidity (near surface)

Name	Relative Humidity (near surface)				
Definition	Relative humidity at a known height above surface, with the height specified in the metadata. Relative humidity is the ratio of the amount of atmospheric moisture present relative to the amount that would be present if the air were saturated with respect to water or ice to be specified in the metadata.				
Unit	%				
Note	Observations made over the ocean are not static, being mostly recorded by mobile ships and drifting buoys (Kent et al., 2019). Requirements for marine surface observations must therefore be defined in terms of the composite accuracy and sampling of the marine observing networks to achieve comparable uncertainty thresholds at similar resolution. Relative humidity is often derived from temperature and dewpoint temperature. It is important that the conversions be applied at the observation scale so as not to introduce both random and systematic effects into the analysis. Formulae to convert between the various water vapour metrics (Specific Humidity, Relative Humidity and Dewpoint are given in Willett et al. (2008). The observation requirements for each of the humidity variables is based on those for dewpoint temperature and are approximate, for more detailed information see Bell (1996).				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	By analogy with near surface dewpoint temperature via near surface air temperature, requirement therefore tentative.
			B	100	
			T	500	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	<1	Sub-hourly
			B	1	
			T	3	
Timeliness	h		G	6	
			B	24	
			T	720	Monthly
Required Measurement Uncertainty (2-sigma)	%RH		G	0.5	
			B	2.5	
			T	5	
Stability	%RH/decade		G	0.05	
			B	0.25	
			T	0.5	
Standards and References	S. Bell, Guide to the measurement of humidity, Guide 103, NPL, 1996. Kent, E.C., Rayner, N.A., Berry, D.I., Eastman, R., Grigorieva, V.G., Huang, B., Kennedy, J.J., Smith, S.R. and Willett, K.M., 2019: Observing Requirements for Long-Term Climate Records at the Ocean Surface. Frontiers in Marine Science 6, Article 441, doi:10.3389/fmars.2019.00441. Willett, K. M., Dunn, R. J. H., Thorne, P. W., Bell, S., de Podesta, M., Parker, D. E., Jones, P. D., and Williams Jr., C. N.: HadISDH land surface multi-variable humidity and temperature record for climate monitoring, Clim. Past, 10, 1983-2006, doi:10.5194/cp-10-1983-2014, 2014. Willett, K. M., Williams Jr., C. N., Dunn, R. J. H., Thorne, P. W., Bell, S., de Podesta, M., Jones, P. D., and Parker D. E., 2013: HadISDH: An updated land surface specific humidity product for climate monitoring. Climate of the Past, 9, 657-677, doi:10.5194/cp-9-657-2013.				

1.4.3 ECV Product: Air Specific Humidity (near surface)

Name	Atmospheric Specific Humidity (near Surface)				
Definition	Air specific humidity at a known height above surface, with the height specified in the metadata. Specific humidity is the ratio of the mass of water vapour and the mass of moist air.				
Unit	g kg^{-1}				
Note	Observations made over the ocean are not static, being mostly recorded by mobile ships and drifting buoys (Kent et al., 2019). Requirements for marine surface observations must therefore be defined in terms of the composite accuracy and sampling of the marine observing networks to achieve comparable uncertainty thresholds at similar resolution. Willett et al 2008 show that spatial scales of surface specific humidity are comparable to those of temperature so the same horizontal resolution should be broadly applicable. Specific humidity is generally derived from temperature and dewpoint temperature. It is important that the conversions be applied at the observation scale so as not to introduce both random and systematic effects into the analysis. Formulae to convert between the various water vapour metrics (Specific Humidity, Relative Humidity and Dewpoint are given in Willett et al. (2008). Given the orders of magnitude variation in specific humidity between the tropics and the polar regions there is a strong case for latitudinally varying requirements for uncertainty and stability which would be more stringent in polar than extra-tropical than tropical climates. Current values are a compromise which may be indicative of extra-tropical locations.				
	Requirements				
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B	100	
			T	500	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	<1	Sub-hourly
			B	1	
			T	3	
Timeliness	h		G	6	
			B	24	
			T	720	Monthly
Required Measurement Uncertainty (2-sigma)	g kg^{-1}		G	0.1	
			B	0.5	
			T	1	
Stability	g kg^{-1}/ decade		G	0.01	
			B	0.05	
			T	0.1	
Standards and References	Kent, E.C., Rayner, N.A., Berry, D.I., Eastman, R., Grigorieva, V.G., Huang, B., Kennedy, J.J., Smith, S.R. and Willett, K.M., 2019: Observing Requirements for Long-Term Climate Records at the Ocean Surface. Frontiers in Marine Science 6, Article 441, doi:10.3389/fmars.2019.00441. Willett, K. M., Dunn, R. J. H., Thorne, P. W., Bell, S., de Podesta, M., Parker, D. E., Jones, P. D., and Williams Jr., C. N.: HadISDH land surface multi-variable humidity and temperature record for climate monitoring, Clim. Past, 10, 1983-2006, doi:10.5194/cp-10-1983-2014, 2014. Willett, K. M., Williams Jr., C. N., Dunn, R. J. H., Thorne, P. W., Bell, S., de Podesta, M., Jones, P. D., and Parker D. E., 2013: HadISDH: An updated land surface specific humidity product for climate monitoring. Climate of the Past, 9, 657-677, doi:10.5194/cp-9-657-2013.				

1.5 ECV: Precipitation

1.5.1 ECV Product: Accumulated Precipitation

Name	Accumulated precipitation				
Definition	Integration of solid and liquid precipitation rate reaching the ground over a time period defined in the metadata.				
Unit	mm				
Note	This ECV is designed to monitor the amount of precipitation globally in order to investigate the impact on the hydrological cycle, agriculture, drinking water supply or droughts. It is driven to support studies on a continental to global scale. This implies, that it is not designed to monitor extremes globally on a local to regional scale in space and time, as the requirements are different to answer both scientific questions.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	50	
			B	125	
			T	250	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1	Daily aggregation over period which defines the upper limit of temporal sampling
			B	30	Monthly aggregation over period which defines the upper limit of temporal sampling
			T	365	Annual aggregation over period which defines the upper limit of temporal sampling
Timeliness	d		G	1	
			B	7	
			T	30	
Required Measurement Uncertainty (2-sigma)	mm		G	1	
			B	2	
			T	5	
Stability	mm/decade		G	0.02	
			B	0.05	
			T	0.1	
Standards and References					

1.6 ECV: Surface radiation budget

1.6.1 ECV Product: Upward Long-Wave Irradiance at Earth Surface

Name	Upward Long-Wave Irradiance at Earth Surface
Definition	Flux density of terrestrial radiation emitted by the Earth surface.
Unit	W m^{-2}
Note	Main driver of the uncertainty in the components of the surface radiation budget is the composition of the atmosphere (e.g. Water vapour, Aerosols, Clouds)". The Required Measurement Uncertainty (2-sigma) (see the VIM & GUM) includes both random and systematic components. The uncertainty is meant to be an uncertainty for the measurement device / instrument / ECV algorithm. The uncertainty of spatially and temporally averaged global mean value might be smaller.

Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	10	
			B	50	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	
			B	24	
			T	720	
Timeliness	d		G		
			B		
			T	30	1 month after the observations period
Required Measurement Uncertainty (2-sigma)	W m^{-2}		G	1	
			B	5	
			T	10	
Stability	W m^{-2}/ decade		G	0.2	
			B	0.5	
			T	1	
Standards and References					

1.6.2 ECV Product: Downward Long-Wave Irradiance at Earth Surface

Name	Downward Long-Wave Irradiance at Earth Surface				
Definition	Flux density of radiation emitted by the gases, aerosols and clouds of the atmosphere to the Earth's surface.				
Unit	W m-²				
Note	Main driver of the uncertainty in the components of the surface radiation budget is the composition of the atmosphere (e.g. Water vapour, Aerosols, Clouds)". The Required Measurement Uncertainty (2-sigma) (see the VIM & GUM) includes both random and systematic components. The uncertainty is meant to be an uncertainty for the measurement device / instrument / ECV algorithm. The uncertainty of spatially and temporally averaged global mean value might be smaller.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B	50	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	
			B	24	
			T	720	
Timeliness	d		G		
			B		
			T	30	1 month after the observations period
Required Measurement Uncertainty (2-sigma)	W m-²		G	1	
			B	5	
			T	10	
Stability	W m-²/decade		G	0.2	
			B	0.5	
			T	1	
Standards and References					

1.6.3 ECV Product: Downward Short-Wave Irradiance at Earth Surface

Name	**Downward Short-Wave Irradiance at Earth Surface**				
Definition	Flux density of the solar radiation at the Earth surface.				
Unit	W m^{-2}				
Note	Main driver of the uncertainty in the components of the surface radiation budget is the composition of the atmosphere (e.g. Water vapour, Aerosols, Clouds)". The Required Measurement Uncertainty (2-sigma) (see the VIM & GUM) includes both random and systematic components. The uncertainty is meant to be an uncertainty for the measurement device / instrument / ECV algorithm. The uncertainty of spatially and temporally averaged global mean value might be smaller.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	10	
			B	50	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	
			B	24	
			T	720	
Timeliness	d		G		
			B		
			T	30	1 month after the observations period
Required Measurement Uncertainty (2-sigma)	W m^{-2}		G	1	
			B	5	
			T	10	
Stability	W m^{-2}/ decade		G	0.2	
			B	0.5	
			T	1	
Standards and References					

2. UPPER AIR

2.1 ECV: Upper-air temperature

2.1.1 ECV Product: Atmospheric Temperature in the Boundary Layer

Name	Atmospheric Temperature in the Boundary Layer
Definition	3D field of the atmospheric temperature in the Boundary Layer.
Unit	K
Note	The following requirements are inferred mainly from the viewpoint of reanalysis and its near-real-time continuation in operational analyses as well as with respect to the magnitude of typical temperature variations at relevant spatial and temporal scales. Some additional considerations are also made, for which explanations are given in notes below this table. The requirements for temperature in the boundary layer are mainly driven by needs for monitoring of fluxes for the goal threshold. Stability assumes independence of measurements between instruments permitting partial cancellation and is based upon need to be able to detect current trends which are c.0.2 K/decade. Boundary layer temperature is assumed to share spatial characteristics with surface temperature for which this has been characterized in e.g. Thorne et al., 2018.

Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	15	Hersbach et al. (2018), Thorne et al. (2005, 2018). This has been changed from the original 10km to 15 km to be consistent with Numerical Weather Prediction (NWP), although it is suggested that NWP should be at 10km. Roughly corresponds to the current global NWP model resolution, which would be used for next generation reanalyses, and resolves features influenced by local factors such as proximity of water bodies or significant topography.
			B	100	Hersbach et al. (2018), Thorne et al. (2005, 2018). A typical horizontal error correlation length in first guess fields and typical scale of mesoscale features that, especially when occurring frequently or with significant amplitude, can affect global climate. For example, Waller et al. (2016) found that error correlations of surface temperature in observation-minus-background and observation-minus-analysis residuals from the Met Office high-resolution model range between 30 km and 80 km.
			T	500	Hersbach et al. (2018), Thorne et al. (2005, 2018). Minimum resolution needed to resolve synoptic-scale features. Thorne et al., 2005 show typical e-folding correlation distances in radiosonde-measured tropospheric temperatures of at least several 100km and more generally 1000km, with larger values in the tropics. Surface and boundary layer are tightly coupled, particularly in the lowermost boundary layer.
Vertical Resolution	m		G	1	This high resolution allows different users the option to subsample or process the data in ways that suit their applications (Ingleby et al. 2016). Determining fluxes requires this high vertical fidelity. Thus, this value has not been changed to be consistent with requirements for NWP as NWP thresholds would demonstrably fail to meet needs to quantify fluxes and close energy budget.
			B	10	Roughly corresponds to the assimilating model resolution (Fujiwara et al. 2017)
			T	100	Minimum resolution considering the layer depth
Temporal Resolution	h		G	<1	Sub-hourly. A typical 4D-Var timeslot length, a sub-division into which observations are grouped for processing (ECMWF 2018)
			B	6	A typical time interval between numerical analyses and/or the typical time scale of subsynoptic features

			T	12	Minimum resolution needed to resolve synoptic-scale waves. For this reason, it has not been changed to ensure consistency with NWP requirements.
Timeliness	h		G	1	A typical cut-off time of the operational NWP cycle analysis (JMA 2019), which might also be used for climate monitoring
			B	3	A typical cut-off time for the Climate Data Assimilation System (a near-real time continuation of reanalysis)
			T	24	A typical master decoding cut-off time, beyond which observations are not automatically decoded and incorporated into the operational observation archive
Required Measurement Uncertainty (2-sigma)	K	RMS	G	0.1	These values are inferred based on the standard deviations of 6-hourly analysis with respect to the monthly climatology. (T) corresponds to regions of high variability, (B) of medium variability and (G) of low variability. RMS departures of observed values from first guess field values, in accordance with the practical verification schemes applied by the GUAN Monitoring Centre for upper-air observations.
			B	0.5	
			T	1	
Stability	K/decade		G	0.01	These values are based on the need to detect temperature trends such as those observed in recent decades (IPCC 2013). (T) corresponds to regions of large trend or 50% of observed global-mean trend, (B) regions of medium trend or 20% of global-mean trend, and (G) regions of small trend or 10% of global-mean trend.
			B	0.05	
			T	0.1	
Standards and References	ECMWF, 2018: IFS documentation – Cy45r1, Part I: Observations. ECMWF, UK, 82p. Available at https://www.ecmwf.int/en/elibrary/18711-part-i-observations. Fujiwara, M., 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems, Atmos. Chem. Phys., 17, 1417–1452, https://doi.org/10.5194/acp-17-1417-2017, 2017. Hersbach et al. (2018): Operational global reanalysis: progress, future directions and synergies with NWP. ERA Report Series, 27. http://dx.doi.org/10.21957/tkic6g3wm. Ingleby et al., 2016: Progress toward high-resolution, real-time radiosonde reports. Bull. Amer. Meteor. Soc., 97, 2149-2161. https://doi.org/10.1175/BAMS-D-15-00169.1. IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp. JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Appendix to WMO Technical Progress Report on the Global Data-processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research. Japan Meteorological Agency, Tokyo, Japan. Available at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm. Thorne, P. W., D. E. Parker, et al. (2005). "Revisiting radiosonde upper air temperatures from 1958 to 2002." Journal of Geophysical Research-Atmospheres 110(D18), doi:10.1029/2004JD005753 Thorne, P.W. et al. (2018), Towards a global land surface climate fiducial reference measurements network. IJOC, http://onlinelibrary.wiley.com/doi/10.1002/joc.5458/full. Waller, J. E.,* S. P. Ballard, S. L. Dance, G. Kelly, N. K. Nichols, and David Simonin, 2016: Diagnosing horizontal and inter-channel observation error correlations for SEVIRI observations using observation-minus-background and observation-minus-analysis statistics. Remote Sens. 2016, 8(7), 581, doi:10.3390/rs8070581				

2.1.2 ECV Product: Atmospheric Temperature in the Free Troposphere

Name	Atmospheric Temperature in the Free Troposphere				
Definition	3D field of the atmospheric temperature in the troposphere.				
Unit	K				
Note	The following requirements are inferred mainly from the viewpoint of reanalysis and its near-real-time continuation in operational analyses as well as with respect to the magnitude of typical temperature variations at relevant spatial and temporal scales. Some additional considerations are also made, for which explanations are given in notes below this table.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	15	Hersbach et al. (2018), Thorne et al. (2005) This has been changed from the original 10km to 15 km to be consistent with Numerical Weather Prediction (NWP), although it is suggested that NWP should be at 10km. Roughly corresponds to the current global NWP model resolution, which would be used for next generation reanalyses, and resolves features influenced by local factors such as proximity of water bodies or significant topography.
			B	100	Hersbach et al. (2018), Thorne et al. (2005). A typical horizontal error correlation length in first guess fields and typical scale of mesoscale features that, especially when occurring frequently or with significant amplitude, can affect global climate. Hersbach et al. (2018) shows examples of the background error covariances prescribed for the latest-generation reanalysis, where the horizontal correlation decreases below 1/e within the length of 500 km or less in the troposphere. It should be noted that the correlation length depends on the data assimilation system used as well as the observing system assimilated for making initial conditions. In general, the correlation length tends to be shorter when the data assimilation system has a higher resolution and is more advanced as well as when the observations assimilated have a higher density. In order to produce reanalysis data with accuracy comparable to NWP, the requirements need to be similar to those for NWP, as already proposed in the table.
			T	1000	Hersbach et al. (2018), Thorne et al. (2005) Minimum resolution needed to resolve synoptic-scale waves. Thorne et al., (2005) show typical e-folding correlation distances in radiosonde-measured tropospheric temperatures of at least several 100km and more generally 1000km, with larger values in the tropics.
Vertical Resolution	km		G	0.01	This high resolution allows different users the option to subsample or process the data in ways that suit their applications (Ingleby et al. 2016). This has not been changed to be consistent with NWP requirements as NWP has requirements that are too coarse for some such applications, e.g. determining fluxes requires high vertical fidelity.
			B	0.1	Roughly corresponds to the assimilating model resolution (Fujiwara et al. 2017)
			T	1	Minimum resolution considering the layer depth
Temporal Resolution	h		G	1	A typical 4D-Var timeslot length, a sub-division into which observations are grouped for processing (ECMWF 2018)
			B	12	A typical time interval between numerical analyses and/or the typical time scale of subsynoptic features

			T	24	Minimum resolution needed to resolve synoptic-scale waves
Timeliness	h		G	1	A typical cut-off time of the operational NWP cycle analysis (JMA 2019), which might also be used for climate monitoring
			B	3	A typical cut-off time for the Climate Data Assimilation System (a near-real time continuation of reanalysis)
			T	6	A typical master decoding cut-off time, beyond which observations are not automatically decoded and incorporated into the operational observation archive
Required Measurement Uncertainty (2-sigma)	K	RMS	G	0.1	These values are inferred based on the standard deviations of 6-hourly analysis with respect to the monthly climatology. (T) corresponds to regions of high variability, (B) of medium variability and (G) of low variability. RMS departures of observed values from first guess field values, in accordance with the practical verification schemes applied by the GUAN Monitoring Centre for upper-air observations
			B	0.5	
			T	1	
Stability	K/decade		G	0.01	IPCC (2013) These values are based on the need to detect temperature trends such as those observed in recent decades (IPCC 2013; Lübken et al. 2013). (T) corresponds to regions of large trend or 50% of observed global-mean trend, (B) regions of medium trend or 20% of global-mean trend, and (G) regions of small trend or 10% of global-mean trend.
			B	0.02	
			T	0.05	
Standards and References	ECMWF, 2018: IFS documentation – Cy45r1, Part I: Observations. ECMWF, UK, 82p. Available at https://www.ecmwf.int/en/elibrary/18711-part-i-observations. Fujiwara, M., 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems, Atmos. Chem. Phys., 17, 1417–1452, https://doi.org/10.5194/acp-17-1417-2017, 2017. Hersbach et al. (2018): Operational global reanalysis: progress, future directions and synergies with NWP. ERA Report Series, 27. http://dx.doi.org/10.21957/tkic6g3wm. Ingleby et al., 2016: Progress toward high-resolution, real-time radiosonde reports. Bull. Amer. Meteor. Soc., 97, 2149-2161. https://doi.org/10.1175/BAMS-D-15-00169.1. IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp. JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Appendix to WMO Technical Progress Report on the Global Data-processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research. Japan Meteorological Agency, Tokyo, Japan. Available at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm. Lübken, F.-J., Berger, U., and Baumgarten, G. (2013), Temperature trends in the midlatitude summer mesosphere, J. Geophys. Res. Atmos., 118, 13,347-13,360, doi:10.1002/2013JD020576. Thorne, P. W., D. E. Parker, et al. (2005). "Revisiting radiosonde upper air temperatures from 1958 to 2002." Journal of Geophysical Research-Atmospheres 110(D18), doi:10.1029/2004JD005753				

2.1.3 ECV Product: Atmospheric Temperature in the Upper Troposphere and Lower Stratosphere

Name	Atmospheric Temperature in the Upper Troposphere and Lower Stratosphere				
Definition	3D field of the atmospheric temperature in the UTLS				
Unit	K				
Note	The following requirements are inferred mainly from the viewpoint of reanalysis and its near-real-time continuation in operational analyses as well as with respect to the magnitude of typical temperature variations at relevant spatial and temporal scales. Some additional considerations are also made, for which explanations are given in notes below this table. For vertical resolution, high vertical resolution is required to diagnose both multiple tropopauses but also trends in tropopause height.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	15	Hersbach et al. (2018), Thorne et al. (2005) Roughly corresponds to the current global Numerical Weather Prediction (NWP) model resolution, which would be used for next generation reanalyses.
			B	100	Hersbach et al. (2018), Thorne et al. (2005). A typical horizontal error correlation length in first guess fields and typical scale of mesoscale features that, especially when occurring frequently or with significant amplitude, can affect global climate.
			T	500	Hersbach et al. (2018), Thorne et al. (2005) Minimum resolution needed to resolve synoptic-scale waves. Thorne et al., 2005 show typical e-folding correlation distances in radiosonde-measured tropospheric temperatures of at least several 100km and more generally 1000km, with larger values in the tropics.
Vertical Resolution	m		G	25	Thorne et al (2005). This high resolution allows different users the option to subsample or process the data in ways that suit their applications (Ingleby et al. 2016). Neither the current NWP resolution of 3km, nor the NWP goal of 300m, is adequate for locating the tropopause.
			B	100	Roughly corresponds to the assimilating model resolution (Fujiwara et al. 2017)
			T	250	Minimum resolution considering the layer depth
Temporal Resolution	h		G	1	A typical 4D-Var timeslot length, a sub-division into which observations are grouped for processing (ECMWF 2018)
			B	12	A typical time interval between numerical analyses and/or the typical time scale of subsynoptic features
			T	24	Minimum resolution needed to resolve synoptic-scale waves
Timeliness	h		G	1	A typical cut-off time of the operational NWP cycle analysis (JMA 2019), which might also be used for climate monitoring
			B	3	A typical cut-off time for the Climate Data Assimilation System (a near-real time continuation of reanalysis)
			T	6	A typical master decoding cut-off time, beyond which observations are not automatically decoded and incorporated into the operational observation archive
Required Measurement Uncertainty (2-sigma)	K	RMS	G	0.1	These values are inferred based on the standard deviations of 6-hourly analysis with respect to the monthly climatology. (T) corresponds to regions of high variability, (B) of medium variability and (G) of low variability. RMS departures of observed values from first guess field values, in accordance with the practical verification schemes applied by the GUAN Monitoring Centre for upper-air observations.
			B	0.5	
			T	1	

Stability	K/decade		G	0.01	These values are based on the need to detect temperature trends such as those observed in recent decades (IPCC 2013; Lübken et al. 2013). (T) corresponds to regions of large trend or 50% of observed global-mean trend, (B) regions of medium trend or 20% of global-mean trend, and (G) regions of small trend or 10% of global-mean trend.
			B	0.02	
			T	0.05	

Standards and References

ECMWF, 2018: IFS documentation – Cy45r1, Part I: Observations. ECMWF, UK, 82p. Available at https://www.ecmwf.int/en/elibrary/18711-part-i-observations.

Fujiwara, M., 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems, Atmos. Chem. Phys., 17, 1417–1452, https://doi.org/10.5194/acp-17-1417-2017, 2017.

Hersbach et al. (2018): Operational global reanalysis: progress, future directions and synergies with NWP. ERA Report Series, 27. http://dx.doi.org/10.21957/tkic6g3wm.

Ingleby et al., 2016: Progress toward high-resolution, real-time radiosonde reports. Bull. Amer. Meteor. Soc., 97, 2149-2161. https://doi.org/10.1175/BAMS-D-15-00169.1.

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Appendix to WMO Technical Progress Report on the Global Data-processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research. Japan Meteorological Agency, Tokyo, Japan. Available at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm.

Lübken, F.-J., Berger, U., and Baumgarten, G. (2013), Temperature trends in the midlatitude summer mesosphere, J. Geophys. Res. Atmos., 118, 13,347-13,360, doi:10.1002/2013JD020576.

Thorne, P. W., D. E. Parker, et al. (2005). "Revisiting radiosonde upper air temperatures from 1958 to 2002." Journal of Geophysical Research-Atmospheres 110(D18), doi:10.1029/2004JD005753

2.1.4 ECV Product: Atmospheric Temperature in the Middle and Upper Stratosphere

Name	Atmospheric Temperature in the Middle and Upper Stratosphere
Definition	3D field of the atmospheric temperature in the middle and upper stratosphere.
Unit	K
Note	The following requirements are inferred mainly from the viewpoint of reanalysis and its near-real-time continuation in operational analyses as well as with respect to the magnitude of typical temperature variations at relevant spatial and temporal scales. Correlation distances on climate timescales are much larger in the stratosphere than the troposphere. The dynamical processes are distinct as is the degree of stratification which leads to lower requirements for both vertical and spatial resolution. Some large-scale waves are common to the upper stratosphere and lower mesosphere, with horizontal scales of around 2500 km. Historical and projected future trends are larger so commensurately the stability requirements can be relaxed accordingly.

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	50	Vincent (2015) The stratospheric effective resolution of most Numerical Weather Prediction (NWP) systems
			B	100	Vincent (2015) A typical horizontal error correlation length in first guess fields and typical scale of mesoscale features that, especially when occurring frequently or with significant amplitude, can affect global climate.
			T	1500	Vincent (2015) Minimum resolution needed to resolve synoptic-scale features.
Vertical Resolution	km		G	0.5	This high resolution allows different users the option to subsample or process the data in ways that suit their applications (Ingleby et al. 2016).
			B	1	Roughly corresponds to the assimilating model resolution (Fujiwara et al. 2017)
			T	3	Minimum resolution considering the layer depth
Temporal Resolution	h		G	1	A typical 4D-Var timeslot length, a sub-division into which observations are grouped for processing (ECMWF 2018)
			B	12	A typical time interval between numerical analyses and/or the typical time scale of subsynoptic features
			T	24	Minimum resolution needed to resolve synoptic-scale waves
Timeliness	h		G	1	A typical cut-off time of the operational NWP cycle analysis (JMA 2019), which might also be used for climate monitoring
			B	3	A typical cut-off time for the Climate Data Assimilation System (a near-real time continuation of reanalysis)
			T	6	A typical master decoding cut-off time, beyond which observations are not automatically decoded and incorporated into the operational observation archive
Required Measurement Uncertainty (2-sigma)	K	RMS	G	0.1	These values are inferred based on the standard deviations of 6-hourly analysis with respect to the monthly climatology. (T) corresponds to regions of high variability, (B) of medium variability and (G) of low variability. RMS departures of observed values from first guess field values, in accordance with the practical verification schemes applied by the GUAN Monitoring Centre for upper-air observations.
			B	0.5	
			T	1	
Stability	K/decade		G	0.05	These values are based on the need to detect temperature trends such as those observed in recent decades (IPCC 2013; Lübken et al. 2013). (T) corresponds to regions of large trend or 50% of observed global-mean trend, (B) regions of medium trend or 20% of global-mean trend, and (G) regions of small trend or 10% of global-mean trend.
			B	0.1	
			T	0.2	

					IPCC (2013)
Standards and References	ECMWF, 2018: IFS documentation – Cy45r1, Part I: Observations. ECMWF, UK, 82p. Available at https://www.ecmwf.int/en/elibrary/18711-part-i-observations. Fujiwara, M., 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems, Atmos. Chem. Phys., 17, 1417–1452, https://doi.org/10.5194/acp-17-1417-2017, 2017. Ingleby et al., 2016: Progress toward high-resolution, real-time radiosonde reports. Bull. Amer. Meteor. Soc., 97, 2149-2161. https://doi.org/10.1175/BAMS-D-15-00169.1. IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp. JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Appendix to WMO Technical Progress Report on the Global Data-processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research. Japan Meteorological Agency, Tokyo, Japan. Available at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm. Lübken, F.-J., Berger, U., and Baumgarten, G. (2013), Temperature trends in the midlatitude summer mesosphere, J. Geophys. Res. Atmos., 118, 13,347-13,360, doi:10.1002/2013JD020576. Vincent, R. A., 2015: The dynamics of the mesosphere and lower thermosphere: a brief review.				

2.1.5 ECV Product: Atmospheric Temperature in the Mesosphere

Name	Atmospheric Temperature in the Mesosphere
Definition	3D field of the atmospheric temperature in the mesosphere.
Unit	K
Note	The following requirements are inferred mainly from the viewpoint of reanalysis and its near-real-time continuation in operational analyses as well as with respect to the magnitude of typical temperature variations at relevant spatial and temporal scales. Horizontal resolution, vertical resolution, temporal sampling, and uncertainty thresholds are based on the scales and amplitudes of typical dynamical features of the mesosphere. Trends and current uncertainties are larger than in the troposphere, so stability criteria can also be relaxed.

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	50	Garcia (2005), Vincent (2015) Roughly corresponds to the current global Numerical Weather Prediction (NWP) model resolution, which would be used for next generation reanalyses.
			B	100	Garcia (2005), Vincent (2015) A typical horizontal error correlation length in first guess fields and typical scale of mesoscale features that, especially when occurring frequently or with significant amplitude, can affect global climate.
			T	1500	Garcia (2005), Vincent (2015) Minimum resolution needed to resolve synoptic-scale waves. Thorne et al., (2005) show typical e-folding correlation distances in radiosonde-measured tropospheric temperatures of at least several 100km and more generally 1000km, with larger values in the tropics.
Vertical Resolution	km		G	0.5	Garcia (2005), Vincent (2015) This high resolution allows different users the option to subsample or process the data in ways that suit their applications (Ingleby et al. 2016).
			B	1	Garcia (2005), Vincent (2015) Roughly corresponds to the assimilating model resolution (Fujiwara et al. 2017)
			T	3	Garcia (2005), Vincent (2015) Minimum resolution considering the layer depth
Temporal Resolution	h		G	1	A typical 4D-Var timeslot length, a sub-division into which observations are grouped for processing (ECMWF 2018)
			B	12	A typical time interval between numerical analyses and/or the typical time scale of subsynoptic features
			T	24	Minimum resolution needed to resolve synoptic-scale waves
Timeliness	h		G	1	A typical cut-off time of the operational NWP cycle analysis (JMA 2019), which might also be used for climate monitoring
			B	3	A typical cut-off time for the Climate Data Assimilation System (a near-real time continuation of reanalysis)
			T	6	A typical master decoding cut-off time, beyond which observations are not automatically decoded and incorporated into the operational observation archive
Required Measurement Uncertainty (2-sigma)	K	RMS	G	0.1	Garcia (2005), Vincent (2015) These values are inferred based on the standard deviations of 6-hourly analysis with respect to the monthly climatology. (T) corresponds to regions of high variability, (B) of medium variability and (G) of low variability. RMS departures of observed values from first guess field values, in accordance with the practical verification schemes applied by the GUAN Monitoring Centre for upper-air observations.
			B	0.5	
			T	1	
Stability	K/decade		G	0.05	Lübken et al. (2013)

			B	0.1	These values are based on the need to detect temperature trends such as those observed in recent decades (IPCC 2013; Lübken et al. 2013). (T) corresponds to regions of large trend or 50% of observed global-mean trend, (B) regions of medium trend or 20% of global-mean trend, and (G) regions of small trend or 10% of global-mean trend.
			T	0.2	
Standards and References	ECMWF, 2018: IFS documentation – Cy45r1, Part I: Observations. ECMWF, UK, 82p. Available at https://www.ecmwf.int/en/elibrary/18711-part-i-observations. Fujiwara, M., 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems, Atmos. Chem. Phys., 17, 1417–1452, https://doi.org/10.5194/acp-17-1417-2017, 2017. Garcia, R. A., 2005: Large-Scale waves in the mesosphere and lower thermosphere Observed by SABER. Journal of Atmospheric Sciences, 62, 10.1175/JAS3612.1. Ingleby et al., 2016: Progress toward high-resolution, real-time radiosonde reports. Bull. Amer. Meteor. Soc., 97, 2149-2161. https://doi.org/10.1175/BAMS-D-15-00169.1. IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp. JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Appendix to WMO Technical Progress Report on the Global Data-processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research. Japan Meteorological Agency, Tokyo, Japan. Available at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm. Lübken, F.-J., Berger, U., and Baumgarten, G. (2013), Temperature trends in the midlatitude summer mesosphere, J. Geophys. Res. Atmos., 118, 13,347-13,360, doi:10.1002/2013JD020576. Thorne, P. W., D. E. Parker, et al. (2005). "Revisiting radiosonde upper air temperatures from 1958 to 2002." Journal of Geophysical Research-Atmospheres 110(D18), doi:10.1029/2004JD005753 Vincent, R. A., 2015: The dynamics of the mesosphere and lower thermosphere: a brief review.				

2.2 ECV: Upper-air wind speed and direction

2.2.1 ECV Product: Wind (horizontal) in the Boundary Layer

Name	Wind (horizontal) in the Boundary Layer				
Definition	3D field of the horizontal vector component (2D) of the 3D wind vector in the boundary layer.				
Unit	m s^{-1}				
Note	The following requirements are inferred mainly from the viewpoint of reanalysis and its near-real-time continuation as users of this ECV. Some additional considerations are also made, for which explanations are given in notes below this table. Additional goal requirements for the lowermost part of the boundary layer (values in parentheses) are for better sampling of micrometeorological phenomena and accurate calculation of fluxes.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	15	Roughly corresponds to the current global Numerical Weather Prediction (NWP) model resolution, which would be used for next generation reanalyses
			B	100	A typical horizontal error correlation length in first guess fields.
			T	500	Minimum resolution needed to resolve synoptic-scale waves.
Vertical Resolution	m		G	10(1)	Global NWP requirements are not adequate for accurate calculation of fluxes and these have not been changed. This high resolution allows different users the option to subsample or process the data in ways that suit their applications (Ingleby et al. 2016). The value in parentheses is for the lowermost part of the boundary layer (up to 100 m above the ground)
			B	50(10)	Roughly corresponds to the assimilating model resolution (Fujiwara et al. 2017)
			T	100	Minimum resolution considering the layer depth
Temporal Resolution	min		G	30(1)	Global NWP requirements are not adequate for accurate calculation of fluxes and these have not been changed. A typical 4D-Var timeslot length, a sub-division into which observations are grouped for processing (ECMWF 2018). Given large diurnal cycle in the boundary layer, higher temporal sampling is required. The value in parentheses is for the lowermost part of the boundary layer (up to 100 m above the ground)
			B	60	A typical time interval between numerical analyses and/or the typical time scale of subsynoptic features.
			T	720	Minimum resolution needed to resolve synoptic-scale waves
Timeliness	h		G	6	A typical cut-off time of the operational NWP cycle analysis (JMA 2019), which might also be used for climate monitoring
			B	18	A typical cut-off time for the Climate Data Assimilation System (a near-real time continuation of reanalysis)
			T	48	A typical master decoding cut-off time, beyond which observations are not automatically decoded and incorporated into the operational observation archive
Required Measurement Uncertainty (2-sigma)	m s^{-1}	RMS	G	0.5	These values are inferred based on the standard deviations of 6-hourly analysis with respect to the monthly climatology (Figs. 1, 2). (T) corresponds to regions of high variability, (B) of medium variability and (G) of low variability. RMS departures of observed values from first guess field values, in accordance with the practical
			B	3	
			T	5	

					verification schemes applied by the GUAN Monitoring Centre for upper-air observations (Fig.3).
Stability	m s^{-1}/ decade		G	0.1	These values are inferred based on the RMS trends of monthly analysis for the 1981-2010 period (Fig. 1). (T) corresponds to regions of large trend, (B) of medium trend and (G) of small trend.
			B	0.3	
			T	0.5	
Standards and References	ECMWF, 2018: IFS documentation – Cy45r1, Part I: Observations. ECMWF, UK, 82p. Available at https://www.ecmwf.int/en/elibrary/18711-part-i-observations. Fujiwara et al., 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems. Atmos. Chem. Phys., 17, 1417-1452. https://doi.org/10.5194/acp-17-1417-2017. Ingleby et al., 2016: Progress toward high-resolution, real-time radiosonde reports. Bull. Amer. Meteor. Soc., 97, 2149-2161. https://doi.org/10.1175/BAMS-D-15-00169.1. JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Appendix to WMO Technical Progress Report on the Global Data-processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research. Japan Meteorological Agency, Tokyo, Japan. Available at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm.				

2.2.2 ECV Product: Wind (horizontal) in the Free Troposphere

Name	Wind (horizontal) in the Free Troposphere				
Definition	3D field of the horizontal vector component (2D) of the 3D wind vector in the troposphere.				
Unit	m s^{-1}				
Note	The following requirements are inferred mainly from the viewpoint of reanalysis and its near-real-time continuation as users of this ECV. Some additional considerations are also made, for which explanations are given where needed.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	15	Roughly corresponds to the current global Numerical Weather Prediction (NWP) model resolution, which would be used for next generation reanalyses
			B	100	A typical horizontal error correlation length in first guess fields.
			T	1000	Minimum resolution needed to resolve synoptic-scale waves.
Vertical Resolution	m		G	10	Global NWP requirements are not adequate to monitor large-scale vertical circulation (e.g. the Hadley and Walker circulation) and these have not been changed. This high resolution allows different users the option to subsample or process the data in ways that suit their applications (Ingleby et al. 2016).
			B	100	Roughly corresponds to the assimilating model resolution (Fujiwara et al. 2017)
			T	1500	Minimum resolution considering the layer depth. The threshold for vertical resolution roughly corresponds to the resolution of the standard levels for the traditional radiosonde observation.
Temporal Resolution	h		G	1	A typical 4D-Var timeslot length, a sub-division into which observations are grouped for processing (ECMWF 2018).
			B	6	A typical time interval between numerical analyses and/or the typical time scale of subsynoptic features.
			T	12	Minimum resolution needed to resolve synoptic-scale waves
Timeliness	h		G	6	A typical cut-off time of the operational NWP cycle analysis (JMA 2019), which might also be used for climate monitoring
			B	18	A typical cut-off time for the Climate Data Assimilation System (a near-real time continuation of reanalysis)
			T	48	A typical master decoding cut-off time, beyond which observations are not automatically decoded and incorporated into the operational observation archive
Required Measurement Uncertainty (2-sigma)	m s^{-1}	RMS	G	1	These values are inferred based on the standard deviations of 6-hourly analysis with respect to the monthly climatology (Figs. 1, 2). (T) corresponds to regions of high variability, (B) of medium variability and (G) of low variability. RMS departures of observed values from first guess field values, in accordance with the practical verification schemes applied by the GUAN Monitoring Centre for upper-air observations (Fig.3).
			B	3	
			T	5	
Stability	m s^{-1}/ decade		G	0.1	These values are inferred based on the RMS trends of monthly analysis for the 1981-2010 period (Fig. 1). (T) corresponds to regions of large trend, (B) of medium trend and (G) of small trend.
			B	0.3	
			T	0.5	
Standards and References	ECMWF, 2018: IFS documentation – Cy45r1, Part I: Observations. ECMWF, UK, 82p. Available at https://www.ecmwf.int/en/elibrary/18711-part-i-observations.				

	Fujiwara et al., 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems. Atmos. Chem. Phys., 17, 1417-1452. https://doi.org/10.5194/acp-17-1417-2017. Ingleby et al., 2016: Progress toward high-resolution, real-time radiosonde reports. Bull. Amer. Meteor. Soc., 97, 2149-2161. https://doi.org/10.1175/BAMS-D-15-00169.1. JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Appendix to WMO Technical Progress Report on the Global Data-processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research. Japan Meteorological Agency, Tokyo, Japan. Available at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm.

2.2.3 ECV Product: Wind (horizontal) in the Upper Troposphere and Lower Stratosphere

Name	**Wind (horizontal) in the Upper Troposphere and Lower Stratosphere.**				
Definition	3D field of the horizontal vector component (2D) of the 3D wind vector in the UTLS.				
Unit	m s^{-1}				
Note	The following requirements are inferred mainly from the viewpoint of reanalysis and its near-real-time continuation as users of this ECV. Some additional considerations are also made, for which explanations are given where needed.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	15	Roughly corresponds to the current global Numerical Weather Prediction (NWP) model resolution, which would be used for next generation reanalyses
			B	100	A typical horizontal error correlation length in first guess fields.
			T	500	Minimum resolution needed to resolve synoptic-scale waves.
Vertical Resolution	m		G	25	Global NWP requirements (0.3 km for goal and 3 km for threshold) are not adequate to infer tropopause region behavior and thus we are not changing these except that the goal requirement has been relaxed from 10 m to 25 m. This high resolution allows different users the option to subsample or process the data in ways that suit their applications (Ingleby et al. 2016).
			B	100	Roughly corresponds to the assimilating model resolution (Fujiwara et al. 2017)
			T	500	Minimum resolution considering the layer depth. To infer tropopause region behavior, such as tropopause folding (e.g. Lamarque and Hess 2015), higher vertical resolution is required.
Temporal Resolution	h		G	1	A typical 4D-Var timeslot length, a sub-division into which observations are grouped for processing (ECMWF 2018).
			B	6	A typical time interval between numerical analyses and/or the typical time scale of subsynoptic features.
			T	12	Minimum resolution needed to resolve synoptic-scale waves
Timeliness	h		G	6	A typical cut-off time of the operational NWP cycle analysis (JMA 2019), which might also be used for climate monitoring
			B	18	A typical cut-off time for the Climate Data Assimilation System (a near-real time continuation of reanalysis)
			T	48	A typical master decoding cut-off time, beyond which observations are not automatically decoded and incorporated into the operational observation archive
Required Measurement Uncertainty (2-sigma)	m s^{-1}	RMS	G	1	These values are inferred based on the standard deviations of 6-hourly analysis with respect to the monthly climatology (Figs. 1, 2). (T) corresponds to regions of high variability, (B) of medium variability and (G) of low variability. RMS departures of observed values from first guess field values, in accordance with the practical verification schemes applied by the GUAN Monitoring Centre for upper-air observations (Fig.3).
			B	3	
			T	5	
Stability	m s^{-1}/ decade		G	0.1	These values are inferred based on the RMS trends of monthly analysis for the 1981-2010 period (Fig. 1). (T) corresponds to regions of large trend, (B) of medium trend and (G) of small trend.
			B	0.3	
			T	0.5	
Standards and References	ECMWF, 2018: IFS documentation – Cy45r1, Part I: Observations. ECMWF, UK, 82p. Available at https://www.ecmwf.int/en/elibrary/18711-part-i-observations.				

Fujiwara et al., 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems. Atmos. Chem. Phys., 17, 1417-1452. https://doi.org/10.5194/acp-17-1417-2017.

Ingleby et al., 2016: Progress toward high-resolution, real-time radiosonde reports. Bull. Amer. Meteor. Soc., 97, 2149-2161. https://doi.org/10.1175/BAMS-D-15-00169.1.

JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Appendix to WMO Technical Progress Report on the Global Data-processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research. Japan Meteorological Agency, Tokyo, Japan. Available at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm.

Lamarque, J. F., and P. Hess, 2015: Stratosphere/troposphere exchange and structure – local process. Encyclopedia of Atmospheric Sciences (Second Edition), 262-268. https://doi.org/10.1016/B978-0-12-382225-3.00395-9.

2.2.4 ECV Product: Wind (horizontal) in the Middle and Upper Stratosphere

Name	Wind (horizontal) in the Middle and Upper Stratosphere.				
Definition	3D field of the horizontal vector component (2D) of the 3D wind vector in the middle and upper stratosphere.				
Unit	m s^{-1}				
Note	The following requirements are inferred mainly from the viewpoint of reanalysis and its near-real-time continuation as users of this ECV. Some additional considerations are also made, for which explanations are given where needed.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	50	Roughly corresponds to the current global Numerical Weather Prediction (NWP) model resolution, which would be used for next generation reanalyses
			B	100	A typical horizontal error correlation length in first guess fields
			T	3000	Minimum resolution needed to resolve planetary-scale waves
Vertical Resolution	km		G	1	Consistent with Global NWP.
			B	2	Roughly corresponds to the assimilating model resolution (Fujiwara et al. 2017)
			T	3	Minimum resolution considering the layer depth.
Temporal Resolution	h		G	1	A typical 4D-Var timeslot length, a sub-division into which observations are grouped for processing (ECMWF 2018)
			B	6	A typical time interval between numerical analyses and/or the typical time scale of subsynoptic features.
			T	24	Minimum resolution needed to resolve planetary waves
Timeliness	h		G	6	A typical cut-off time of the operational NWP cycle analysis (JMA 2019), which might also be used for climate monitoring
			B	18	A typical cut-off time for the Climate Data Assimilation System (a near-real time continuation of reanalysis)
			T	48	A typical master decoding cut-off time, beyond which observations are not automatically decoded and incorporated into the operational observation archive
Required Measurement Uncertainty (2-sigma)	m s^{-1}	RMS	G	1	These values are inferred based on the standard deviations of 6-hourly analysis with respect to the monthly climatology (Figs. 1, 2). (T) corresponds to regions of high variability, (B) of medium variability and (G) of low variability. RMS departures of observed values from first guess field values, in accordance with the practical verification schemes applied by the GUAN Monitoring Centre for upper-air observations (Fig.3).
			B	5	
			T	10	
Stability	m s^{-1}/ decade		G	0.1	These values are inferred based on the RMS trends of monthly analysis for the 1981-2010 period (Fig. 1). (T) corresponds to regions of large trend, (B) of medium trend and (G) of small trend.
			B	0.5	
			T	1	
Standards and References	ECMWF, 2018: IFS documentation – Cy45r1, Part I: Observations. ECMWF, UK, 82p. Available at https://www.ecmwf.int/en/elibrary/18711-part-i-observations. Fujiwara et al., 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems. Atmos. Chem. Phys., 17, 1417-1452. https://doi.org/10.5194/acp-17-1417-2017. Ingleby et al., 2016: Progress toward high-resolution, real-time radiosonde reports. Bull. Amer. Meteor. Soc., 97, 2149-2161.https://doi.org/10.1175/BAMS-D-15-00169.1. JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Appendix to WMO Technical Progress Report on the Global Data-processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research. Japan Meteorological Agency, Tokyo, Japan. Available at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm.				

2.2.5 ECV Product: Wind (horizontal) in the Mesosphere

Name	Wind (horizontal) in the Mesosphere				
Definition	3D field of the horizontal vector component (2D) of the 3D wind vector in the mesosphere.				
Unit	m s^{-1}				
Note	The following requirements are inferred mainly from the viewpoint of reanalysis and its near-real-time continuation as users of this ECV. Some additional considerations are also made, for which explanations are given where needed.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	50	Roughly corresponds to the current global Numerical Weather Prediction (NWP) model resolution, which would be used for next generation reanalyses
			B	100	A typical horizontal error correlation length in first guess fields
			T	3000	Minimum resolution needed to resolve planetary-scale waves
Vertical Resolution	km		G	1	
			B	2	Roughly corresponds to the assimilating model resolution (Fujiwara et al. 2017)
			T	3	Minimum resolution considering the layer depth.
Temporal Resolution	h		G	1	This has been changed from the original 0.5 h to 1 h to be consistent with Global NWP. A typical 4D-Var timeslot length, a sub-division into which observations are grouped for processing (ECMWF 2018).
			B	6	A typical time interval between numerical analyses and/or the typical time scale of subsynoptic features
			T	24	Minimum resolution needed to resolve planetary-scale waves
Timeliness	h		G	6	A typical cut-off time of the operational NWP cycle analysis (JMA 2019), which might also be used for climate monitoring
			B	18	A typical cut-off time for the Climate Data Assimilation System (a near-real time continuation of reanalysis)
			T	48	A typical master decoding cut-off time, beyond which observations are not automatically decoded and incorporated into the operational observation archive
Required Measurement Uncertainty (2-sigma)	m s^{-1}	RMS	G	1	These values are inferred based on the standard deviations of 6-hourly analysis with respect to the monthly climatology (Figs. 1, 2). (T) corresponds to regions of high variability, (B) of medium variability and (G) of low variability. RMS departures of observed values from first guess field values, in accordance with the practical verification schemes applied by the GUAN Monitoring Centre for upper-air observations (Fig.3).
			B	5	
			T	10	
Stability	m s^{-1}/ decade		G	0.1	These values are inferred based on the RMS trends of monthly analysis for the 1981-2010 period (Fig. 1). (T) corresponds to regions of large trend, (B) of medium trend and (G) of small trend.
			B	0.5	
			T	1	
Standards and References	ECMWF, 2018: IFS documentation – Cy45r1, Part I: Observations. ECMWF, UK, 82p. Available at https://www.ecmwf.int/en/elibrary/18711-part-i-observations. Fujiwara et al., 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems. Atmos. Chem. Phys., 17, 1417-1452. https://doi.org/10.5194/acp-17-1417-2017. Ingleby et al., 2016: Progress toward high-resolution, real-time radiosonde reports. Bull. Amer. Meteor. Soc., 97, 2149-2161. https://doi.org/10.1175/BAMS-D-15-00169.1. JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Appendix to WMO Technical Progress Report on the Global Data-processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research. Japan Meteorological Agency, Tokyo, Japan. Available at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm.				

2.2.6 ECV Product: Wind (vertical) in the Boundary Layer

Name	Wind (vertical) in the Boundary Layer
Definition	3D field of the vertical component of the 3D wind vector in the boundary layer.
Unit	cm s^{-1}
Note	The following requirements are inferred mainly from the viewpoint of reanalysis and its near-real-time continuation as users of this ECV. Some additional considerations are also made, for which explanations are given where needed. Additional goal requirements for the lowermost part of the boundary layer (values in parentheses) are for better sampling of micrometeorological phenomena and accurate calculation of fluxes.

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	15	Roughly corresponds to the current global Numerical Weather Prediction (NWP) model resolution, which would be used for next generation reanalyses
			B	200	This has been changed from the original 100 km to 200 km to be consistent with Global NWP.
			T	500	Minimum resolution needed to resolve synoptic-scale waves
Vertical Resolution	m		G	10(1)	This high resolution allows different users the option to subsample or process the data in ways that suit their applications (Ingleby et al. 2016). The value in parentheses is for the lowermost part of the boundary layer (up to 100 m above the ground)
			B	100	Roughly corresponds to the assimilating model resolution (Fujiwara et al. 2017)
			T	500	Minimum resolution considering the layer depth
Temporal Resolution	min		G	30(1)	Global NWP requirements are not adequate for accurate calculation of fluxes and these have not been changed except that the goal requirement has been relaxed from 10 min to 30 min as has been done for Horizontal Wind Velocity in the same layer. A typical 4D-Var timeslot length, a sub-division into which observations are grouped for processing (ECMWF 2018). Given large diurnal cycle in the boundary layer, higher temporal sampling is required. The value in parentheses is for the lowermost part of the boundary layer (up to 100 m above the ground)
			B	60	A typical time interval between numerical analyses and/or the typical time scale of sub-synoptic features.
			T	720	Minimum resolution needed to resolve synoptic-scale waves
Timeliness	h		G	6	A typical cut-off time of the operational NWP cycle analysis (JMA 2019), which might also be used for climate monitoring
			B	18	A typical cut-off time for the Climate Data Assimilation System (a near-real time continuation of reanalysis)
			T	48	A typical master decoding cut-off time, beyond which observations are not automatically decoded and incorporated into the operational observation archive
Required Measurement Uncertainty (2-sigma)	cm s^{-1}	RMS	G	0.5	These values are inferred based on the standard deviations of 6-hourly analysis with respect to the monthly climatology (Figs. 4, 5). (T) corresponds to regions of high variability, (B) of medium variability and (G) of low variability. RMS departures of observed values from first guess field values, in accordance with the practical verification schemes applied by the GUAN Monitoring Centre for upper-air observations.
			B	1	
			T	1.5	
Stability	cm s^{-1}/ decade		G	0.05	These values are inferred based on the RMS trends of monthly analysis for the 1981-2010 period (Fig. 4). (T) corresponds to regions of large trend, (B) of medium trend and (G) of small trend.
			B	0.1	
			T	0.15	

Standards and References	ECMWF, 2018: IFS documentation – Cy45r1, Part I: Observations. ECMWF, UK, 82p. Available at https://www.ecmwf.int/en/elibrary/18711-part-i-observations. Fujiwara et al., 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems. Atmos. Chem. Phys., 17, 1417-1452. https://doi.org/10.5194/acp-17-1417-2017. Ingleby et al., 2016: Progress toward high-resolution, real-time radiosonde reports. Bull. Amer. Meteor. Soc., 97, 2149-2161. https://doi.org/10.1175/BAMS-D-15-00169.1. JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Appendix to WMO Technical Progress Report on the Global Data-processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research. Japan Meteorological Agency, Tokyo, Japan. Available at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm.

2.2.7 ECV Product: Wind (vertical) in the Free Troposphere

Name	Wind (vertical) in the Free Troposphere				
Definition	3D field of the vertical component of the 3D wind vector in the troposphere.				
Unit	cm s^{-1}				
Note	The following requirements are inferred mainly from the viewpoint of reanalysis and its near-real-time continuation as users of this ECV. Some additional considerations are also made, for which explanations are given where needed.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	15	Roughly corresponds to the current global Numerical Weather Prediction (NWP) model resolution, which would be used for next generation reanalyses
			B	200	Consistent with Global NWP
			T	1000	Minimum resolution needed to resolve synoptic-scale waves.
Vertical Resolution	m		G	10	Global NWP requirements are not adequate to monitor large-scale vertical circulation (e.g. the Hadley and Walker circulation) and these have not been changed. This high resolution allows different users the option to subsample or process the data in ways that suit their applications (Ingleby et al. 2016).
			B	100	Roughly corresponds to the assimilating model resolution (Fujiwara et al. 2017)
			T	1500	Minimum resolution considering the layer depth
Temporal Resolution	h		G	1	A typical 4D-Var timeslot length, a sub-division into which observations are grouped for processing (ECMWF 2018)
			B	6	A typical time interval between numerical analyses and/or the typical time scale of sub-synoptic features
			T	12	Minimum resolution needed to resolve synoptic-scale waves
Timeliness	h		G	6	A typical cut-off time of the operational NWP cycle analysis (JMA 2019), which might also be used for climate monitoring
			B	18	A typical cut-off time for the Climate Data Assimilation System (a near-real time continuation of reanalysis)
			T	48	A typical master decoding cut-off time, beyond which observations are not automatically decoded and incorporated into the operational observation archive
Required Measurement Uncertainty (2-sigma)	cm s^{-1}	RMS	G	0.5	These values are inferred based on the standard deviations of 6-hourly analysis with respect to the monthly climatology (Figs. 4, 5). (T) corresponds to regions of high variability, (B) of medium variability and (G) of low variability. RMS departures of observed values from first guess field values, in accordance with the practical verification schemes applied by the GUAN Monitoring Centre for upper-air observations
			B	1.5	
			T	2.5	
Stability	cm s^{-1}/ decade		G	0.05	These values are inferred based on the RMS trends of monthly analysis for the 1981-2010 period (Fig. 4). (T) corresponds to regions of large trend, (B) of medium trend and (G) of small trend
			B	0.15	
			T	0.25	
Standards and References	ECMWF, 2018: IFS documentation – Cy45r1, Part I: Observations. ECMWF, UK, 82p. Available at https://www.ecmwf.int/en/elibrary/18711-part-i-observations. Fujiwara et al., 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems. Atmos. Chem. Phys., 17, 1417-1452. https://doi.org/10.5194/acp-17-1417-2017. Ingleby et al., 2016: Progress toward high-resolution, real-time radiosonde reports. Bull. Amer. Meteor. Soc., 97, 2149-2161. https://doi.org/10.1175/BAMS-D-15-00169.1. JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Appendix to WMO Technical Progress Report on the Global Data-				

	processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research. Japan Meteorological Agency, Tokyo, Japan. Available at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm.

2.2.8 ECV Product: Wind (vertical) in the Upper Troposphere and Lower Stratosphere

Name	**Wind (vertical)in the Upper Troposphere and Lower Stratosphere.**				
Definition	3D field of the vertical component of the 3D wind vector in the UTLS.				
Unit	cm s^{-1}				
Note	The following requirements are inferred mainly from the viewpoint of reanalysis and its near-real-time continuation as users of this ECV. Some additional considerations are also made, for which explanations are given where needed.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	15	Roughly corresponds to the current global Numerical Weather Prediction (NWP) model resolution, which would be used for next generation reanalyses
			B	200	Consistent with Global NWP
			T	500	Minimum resolution needed to resolve synoptic-scale waves
Vertical Resolution	m		G	25	Global NWP requirements (0.3 km for goal and 3 km for threshold) are not adequate to infer tropopause region behavior and thus we are not changing these except that the goal requirement has been relaxed from 0.01 km to 0.025 km. This high resolution allows different users the option to subsample or process the data in ways that suit their applications (Ingleby et al. 2016).
			B	100	Roughly corresponds to the assimilating model resolution (Fujiwara et al. 2017)
			T	500	To infer tropopause region behavior, such as tropopause folding (e.g. Lamarque and Hess 2015), higher vertical resolution is required.
Temporal Resolution	h		G	1	A typical 4D-Var timeslot length, a sub-division into which observations are grouped for processing (ECMWF 2018)
			B	6	A typical time interval between numerical analyses and/or the typical time scale of sub-synoptic features
			T	12	Minimum resolution needed to resolve synoptic-scale waves
Timeliness	h		G	6	A typical cut-off time of the operational NWP cycle analysis (JMA 2019), which might also be used for climate monitoring
			B	18	A typical cut-off time for the Climate Data Assimilation System (a near-real time continuation of reanalysis)
			T	48	A typical master decoding cut-off time, beyond which observations are not automatically decoded and incorporated into the operational observation archive
Required Measurement Uncertainty (2-sigma)	cm s^{-1}	RMS	G	0.5	These values are inferred based on the standard deviations of 6-hourly analysis with respect to the monthly climatology (Figs. 4, 5). (T) corresponds to regions of high variability, (B) of medium variability and (G) of low variability. RMS departures of observed values from first guess field values, in accordance with the practical verification schemes applied by the GUAN Monitoring Centre for upper-air observations.
			B	1.5	
			T	2.5	
Stability	cm s^{-1}/ decade		G	0.05	These values are inferred based on the RMS trends of monthly analysis for the 1981-2010 period (Fig. 4). (T) corresponds to regions of large trend, (B) of medium trend and (G) of small trend
			B	0.15	
			T	0.25	
Standards and References	ECMWF, 2018: IFS documentation – Cy45r1, Part I: Observations. ECMWF, UK, 82p. Available at https://www.ecmwf.int/en/elibrary/18711-part-i-observations. Fujiwara et al., 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems. Atmos. Chem. Phys., 17, 1417-1452. https://doi.org/10.5194/acp-17-1417-2017.				

Ingleby et al., 2016: Progress toward high-resolution, real-time radiosonde reports. Bull. Amer. Meteor. Soc., 97, 2149-2161. https://doi.org/10.1175/BAMS-D-15-00169.1.

JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Appendix to WMO Technical Progress Report on the Global Data-processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research. Japan Meteorological Agency, Tokyo, Japan. Available at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm.

Lamarque, J. F., and P. Hess, 2015: Stratosphere/troposphere exchange and structure – local process. Encyclopedia of Atmospheric Sciences (Second Edition), 262-268. https://doi.org/10.1016/B978-0-12-382225-3.00395-9.

2.2.9 ECV Product: Wind (vertical) in the Middle and Upper Stratosphere

Name	Wind (vertical) In the Middle and Upper Stratosphere				
Definition	3D field of the vertical component of the 3D wind vector in the middle and upper stratosphere.				
Unit	cm s^{-1}				
Note	The following requirements are inferred mainly from the viewpoint of reanalysis and its near-real-time continuation as users of this ECV. Some additional considerations are also made, for which explanations are given where needed.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	50	Roughly corresponds to the current global Numerical Weather Prediction (NWP) model resolution, which would be used for next generation reanalyses
			B	200	Consistent with Global NWP
			T	3000	Minimum resolution needed to resolve planetary-scale waves
Vertical Resolution	km		G	0.5	
			B	2	Consistent with Global NWP. Roughly corresponds to the assimilating model resolution (Fujiwara et al. 2017)
			T	3	Minimum resolution considering the layer depth
Temporal Resolution	h		G	1	Consistent with Global NWP. A typical 4D-Var timeslot length, a sub-division into which observations are grouped for processing (ECMWF 2018)
			B	6	A typical time interval between numerical analyses and/or the typical time scale of sub-synoptic features
			T	24	Minimum resolution needed to resolve planetary-scale waves
Timeliness	h		G	6	A typical cut-off time of the operational NWP cycle analysis (JMA 2019), which might also be used for climate monitoring
			B	18	A typical cut-off time for the Climate Data Assimilation System (a near-real time continuation of reanalysis)
			T	48	A typical master decoding cut-off time, beyond which observations are not automatically decoded and incorporated into the operational observation archive
Required Measurement Uncertainty (2-sigma)	cm s^{-1}	RMS	G	1	These values are inferred based on the standard deviations of 6-hourly analysis with respect to the monthly climatology (Figs. 4, 5). (T) corresponds to regions of high variability, (B) of medium variability and (G) of low variability. RMS departures of observed values from first guess field values, in accordance with the practical verification schemes applied by the GUAN Monitoring Centre for upper-air observations
			B	3	
			T	5	
Stability	cm s^{-1}/ decade		G	0.05	These values are inferred based on the RMS trends of monthly analysis for the 1981-2010 period (Fig. 4). (T) corresponds to regions of large trend, (B) of medium trend and (G) of small trend.
			B	0.15	
			T	0.25	
Standards and References	ECMWF, 2018: IFS documentation – Cy45r1, Part I: Observations. ECMWF, UK, 82p. Available at https://www.ecmwf.int/en/elibrary/18711-part-i-observations. Fujiwara et al., 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems. Atmos. Chem. Phys., 17, 1417-1452. https://doi.org/10.5194/acp-17-1417-2017. Ingleby et al., 2016: Progress toward high-resolution, real-time radiosonde reports. Bull. Amer. Meteor. Soc., 97, 2149-2161. https://doi.org/10.1175/BAMS-D-15-00169.1. JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Appendix to WMO Technical Progress Report on the Global Data-processing and				

	Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research. Japan Meteorological Agency, Tokyo, Japan. Available at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm.

2.2.10 ECV Product: Wind (vertical) in the Mesosphere

Name	Wind (vertical) in the Mesosphere.				
Definition	3D field of the vertical component of the 3D wind vector in the mesosphere.				
Unit	cm s^{-1}				
Note	The following requirements are inferred mainly from the viewpoint of reanalysis and its near-real-time continuation as users of this ECV. Some additional considerations are also made, for which explanations are given where needed.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	50	Roughly corresponds to the current global Numerical Weather Prediction (NWP) model resolution, which would be used for next generation reanalyses
			B	200	Consistent with Global NWP
			T	3000	Minimum resolution needed to resolve planetary-scale waves.
Vertical Resolution	km		G	1	
			B	2	Roughly corresponds to the assimilating model resolution (Fujiwara et al. 2017)
			T	3	Minimum resolution considering the layer depth
Temporal Resolution	h		G	1	Consistent with Global NWP A typical 4D-Var timeslot length, a sub-division into which observations are grouped for processing (ECMWF 2018).
			B	6	A typical time interval between numerical analyses and/or the typical time scale of sub-synoptic features
			T	24	Minimum resolution needed to resolve planetary-scale waves
Timeliness	h		G	6	A typical cut-off time of the operational NWP cycle analysis (JMA 2019), which might also be used for climate monitoring
			B	18	A typical cut-off time for the Climate Data Assimilation System (a near-real time continuation of reanalysis)
			T	48	A typical master decoding cut-off time, beyond which observations are not automatically decoded and incorporated into the operational observation archive
Required Measurement Uncertainty (2-sigma)	cm s^{-1}	RMS	G	2	These values are inferred based on the standard deviations of 6-hourly analysis with respect to the monthly climatology (Figs. 4, 5). (T) corresponds to regions of high variability, (B) of medium variability and (G) of low variability. RMS departures of observed values from first guess field values, in accordance with the practical verification schemes applied by the GUAN Monitoring Centre for upper-air observations.
			B	6	
			T	10	
Stability	cm s^{-1}/ decade		G	0.1	These values are inferred based on the RMS trends of monthly analysis for the 1981-2010 period (Fig. 4). (T) corresponds to regions of large trend, (B) of medium trend and (G) of small trend.
			B	0.2	
			T	0.3	
Standards and References	ECMWF, 2018: IFS documentation – Cy45r1, Part I: Observations. ECMWF, UK, 82p. Available at https://www.ecmwf.int/en/elibrary/18711-part-i-observations. Fujiwara et al., 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems. Atmos. Chem. Phys., 17, 1417-1452. https://doi.org/10.5194/acp-17-1417-2017. Ingleby et al., 2016: Progress toward high-resolution, real-time radiosonde reports. Bull. Amer. Meteor. Soc., 97, 2149-2161. https://doi.org/10.1175/BAMS-D-15-00169.1. JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Appendix to WMO Technical Progress Report on the Global Data-processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research. Japan				

	Meteorological Agency, Tokyo, Japan. Available at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm.

2.2.11 Figures

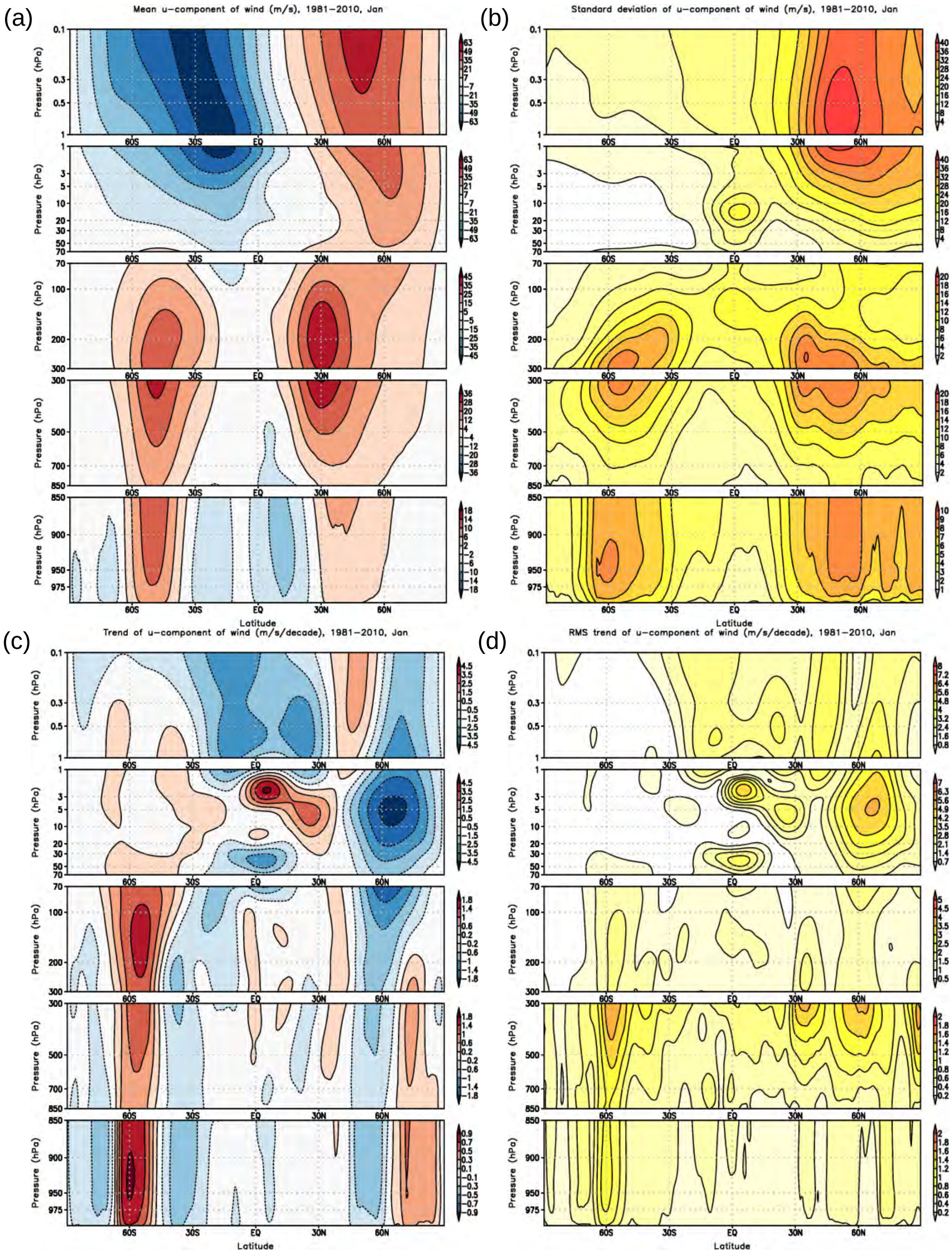

Figure 1. U-component of wind from JRA-55 for January
(a) zonal means averaged over the 1981-2010 period, (b) standard deviations of 6-hourly analysis with respect to the monthly climatology, (c) zonal mean trends of monthly analysis for the 1981-2010 period and (d) RMS trends.

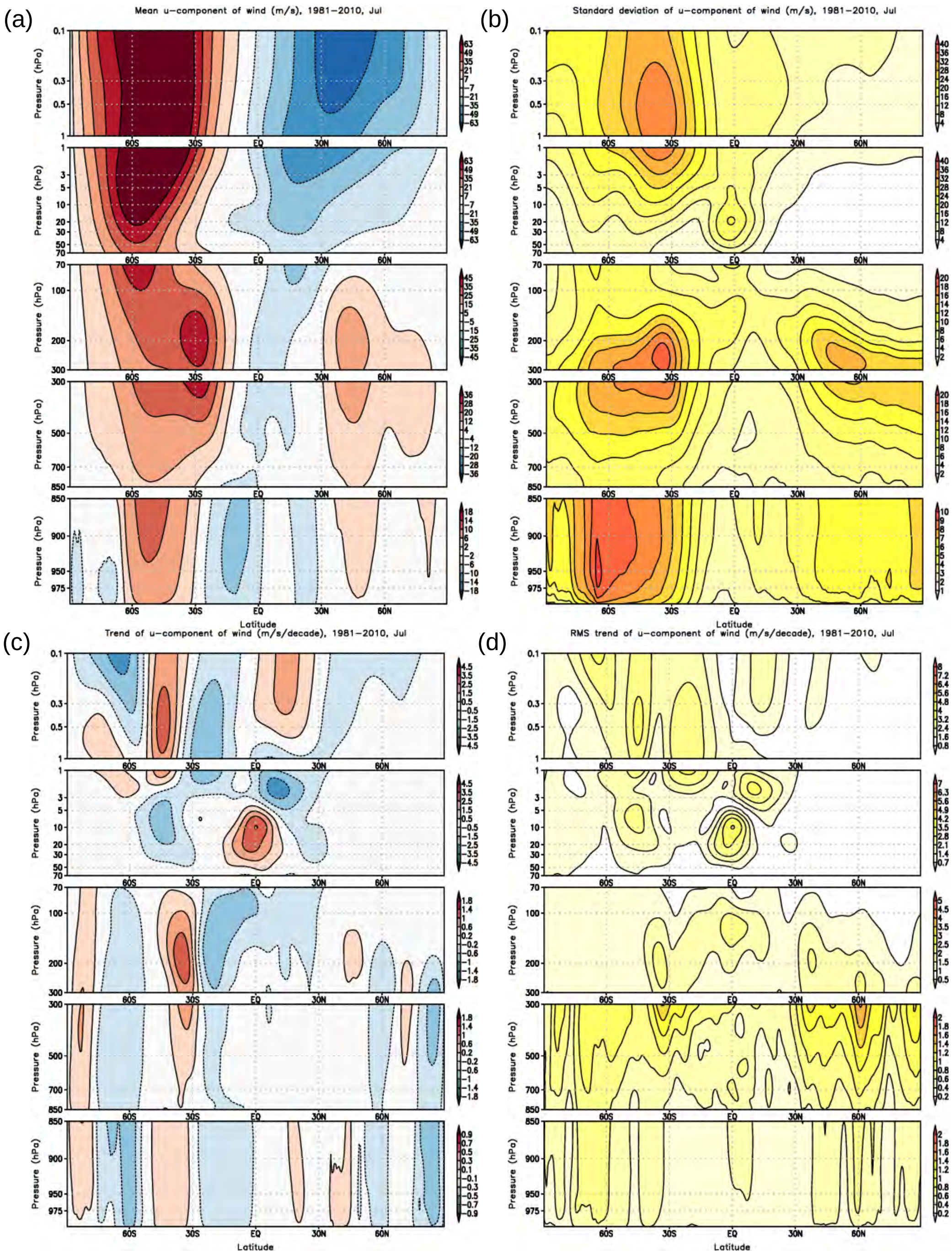

Figure 2. As Figure 1 but for July.

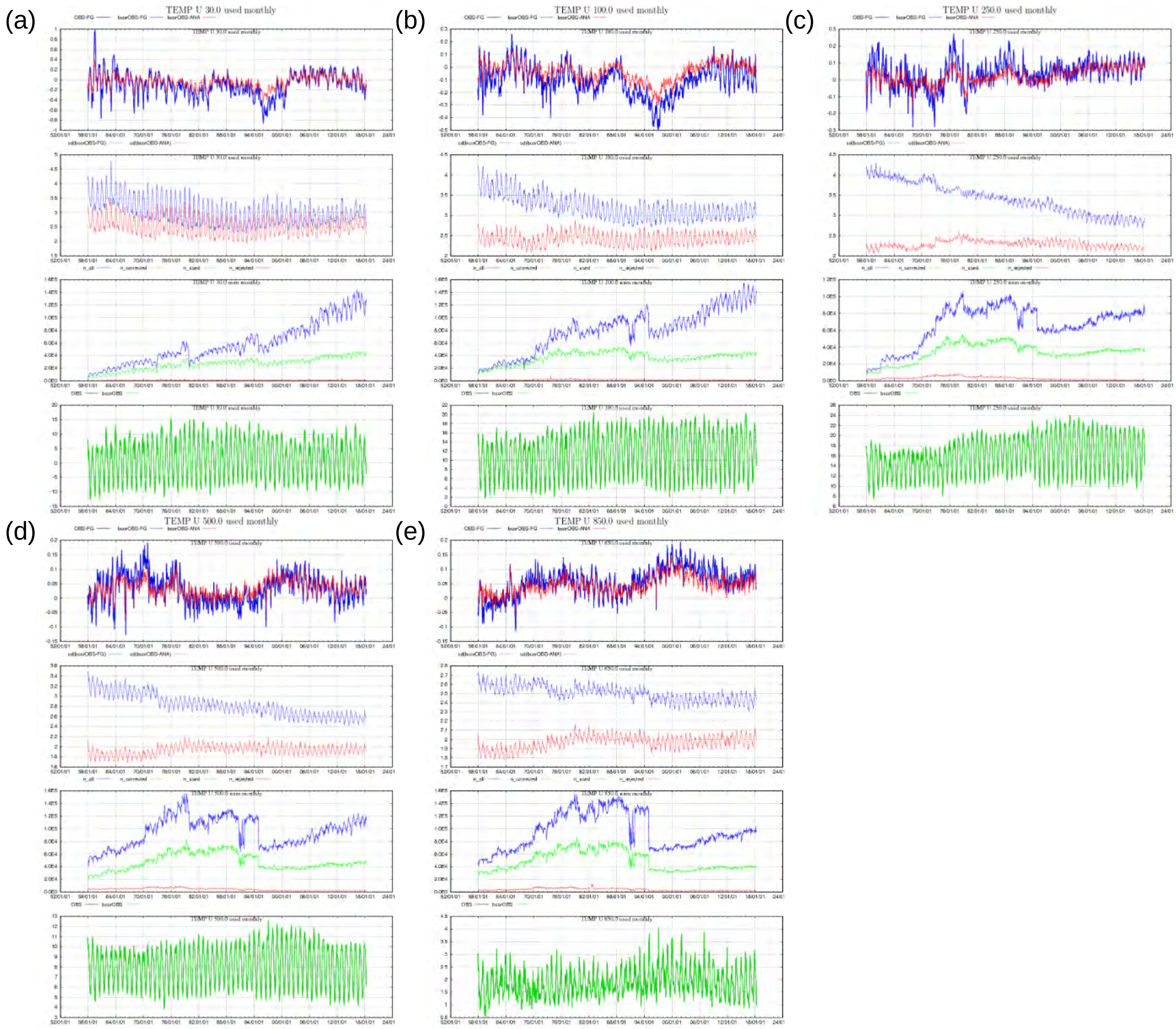

Figure 3. (Top) global mean and (2nd) standard deviation of departure, (3rd) the number and (bottom) global mean observed values of radiosonde u-component of winds used in JRA-55 for (a) 30 hPa, (b) 100 hPa, (c) 250 hPa, (d) 500 hPa and (e) 850 hPa.

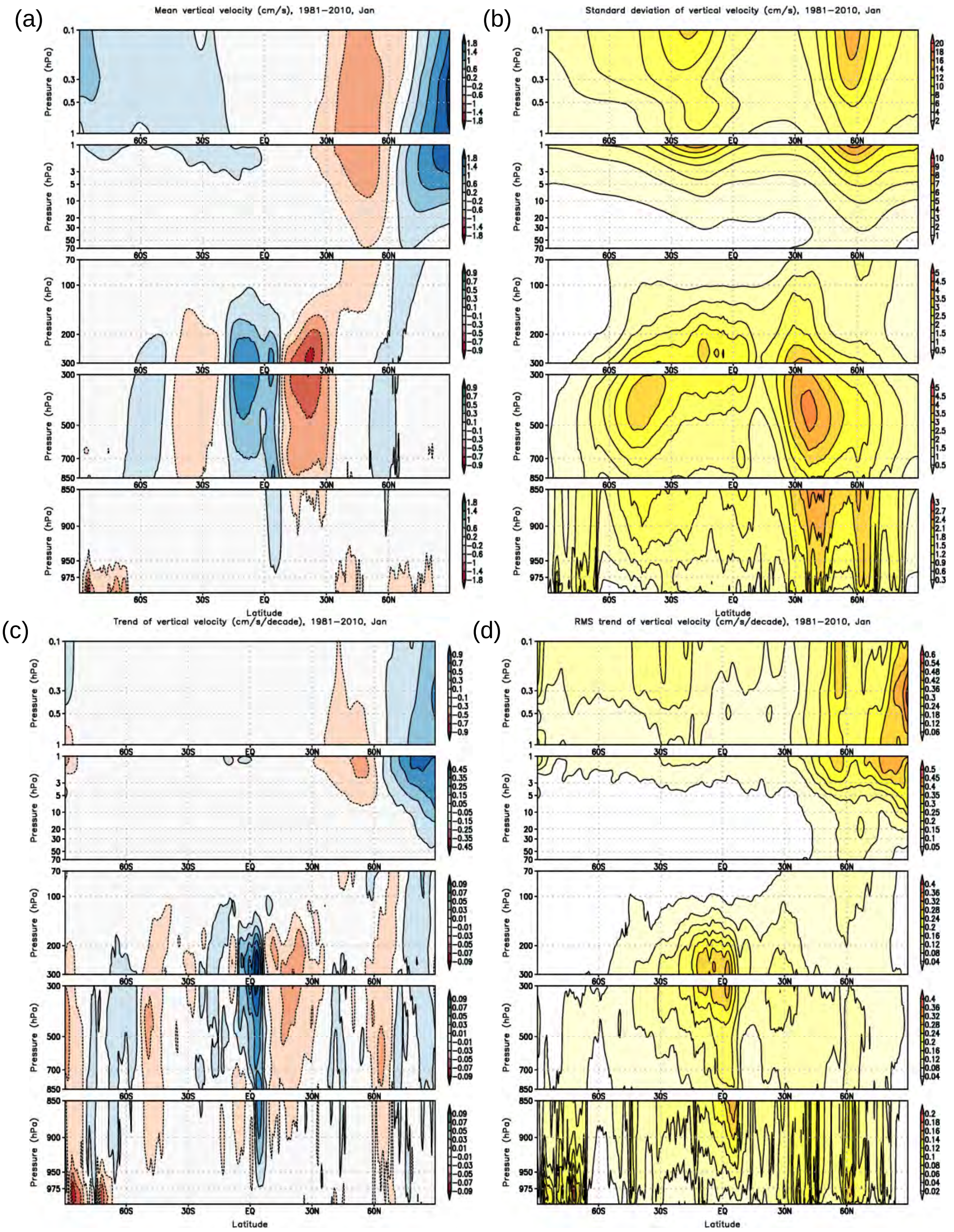

Figure 4. As Figure 1. but for vertical velocity from JRA-55.
Note that the vertical velocity shown here is computed from the horizontal wind velocities using the continuity equation, thus the values represent averages for the horizontal resolution of JRA-55, which is approximately 55 km.

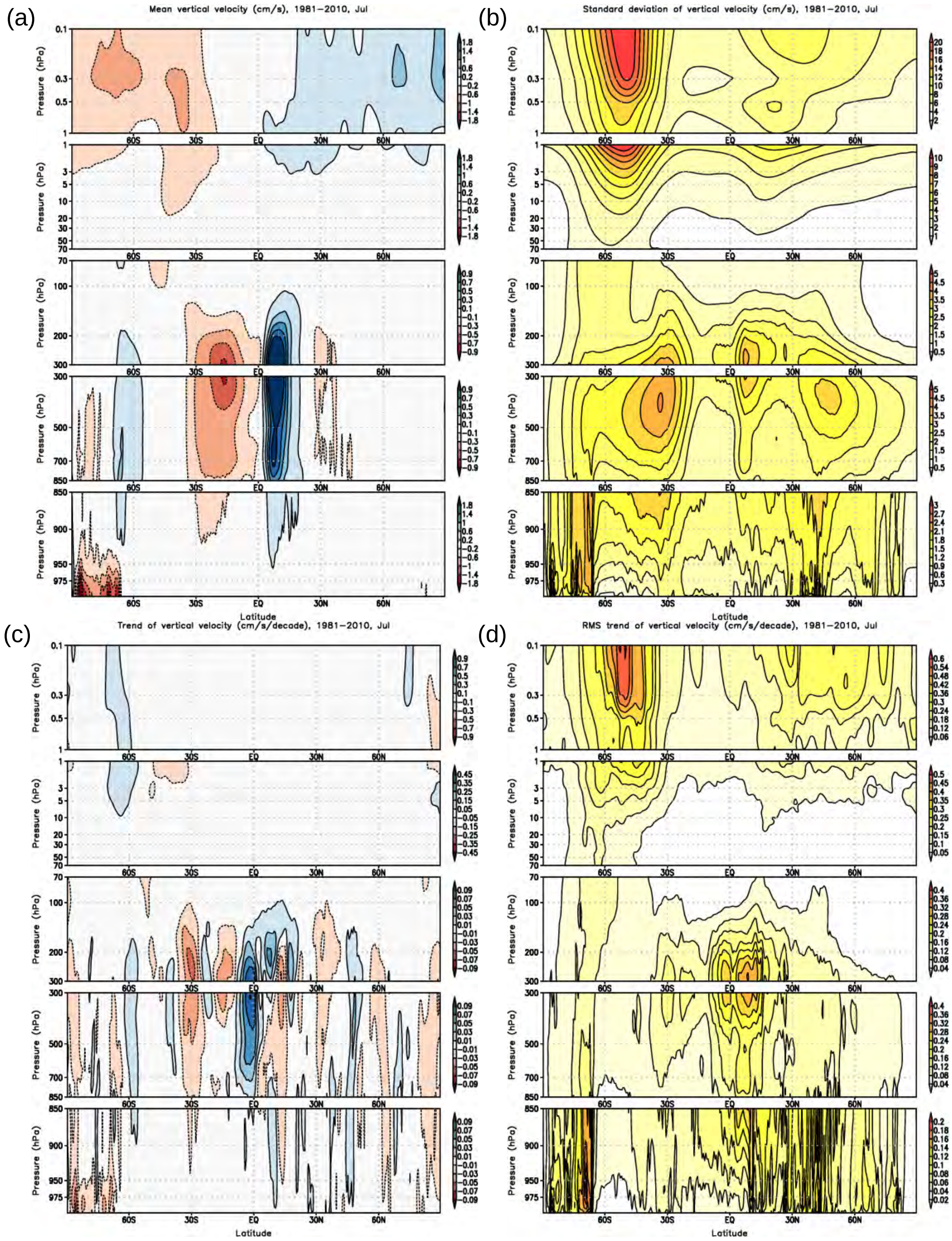

Figure 5. As Figure 4. but for July.

2.3 ECV: Upper-air Water Vapour

2.3.1 ECV Product: Water Vapour Mixing Ratio in the Upper Troposphere and Lower Stratosphere

Name	Water Vapour Mixing Ratio in the Upper Troposphere and Lower Stratosphere				
Definition	3D field of water vapour mixing ratios in the UTLS. Mixing ratio is the mole fraction of a substance in dry air.				
Unit	ppm				
Note	Consistency with temperature requirements for the same layer was used as a primary guiding consideration for horizontal resolution. Vertical resolution needed for determining fine layer cirrus and complex tropopause				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	15	
			B	100	
			T	500	
Vertical Resolution	km		G	0.01	
			B	0.1	
			T	0.25	
Temporal Resolution	h		G	3	
			B	6	
			T	24	
Timeliness	h		G	1	
			B	120	
			T	720	
Required Measurement Uncertainty (2-sigma)	ppmv	.	G	0.1	Dessler et al. (2013)
			B	0.25	Solomon et al. (2010)
			T	0.5	Uncertainty requirements are based on interannual variability and data quality needed to study supersaturation and dehydration.
Stability	ppmv/decade		G	<0.1	Dessler et al. (2013)
			B	0.1	Solomon et al. (2010)
			T	0.25	Stability requirements are based on magnitudes of seasonal and longer-term trends.
Standards and References	Dessler, A. E., Schoeberl, M. R., Wang, T., Davis, S. M., & Rosenlof, K. H. (2013). Stratospheric water vapor feedback. Proceedings of the National Academy of Sciences of the United States of America, 110(45), 18087–18091. doi:10.1073/pnas.1310344110 Solomon, S., Rosenlof, K. H., Portmann, R. W., Daniel, J. S., Davis, S. M., Sanford, T. J., & Plattner, G.-K. (2010). Contributions of Stratospheric Water Vapor to Decadal Changes in the Rate of Global Warming. Science, 327(5970), 1219-1223. doi:10.1126/science.1182488				

2.3.2 ECV Product: Water Vapour Mixing Ratio in the Middle and Upper Stratosphere

Name	Water Vapour Mixing Ratio in the Middle and Upper Stratosphere				
Definition	3D field of water vapor mixing ratios in the middle and upper stratosphere. Mixing ratio is the mole fraction of a substance in dry air.				
Unit	ppm				
Note	Consistency with temperature requirements for the same layer was used as a primary guiding consideration for horizontal resolution. However, for the breakthrough, there is no justification to use the same value as for temperature that is significantly smaller.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	50	
			B	500	
			T	1500	
Vertical Resolution	km		G	0.5	
			B	1	
			T	3	
Temporal Resolution	h		G	3	
			B	6	
			T	72	
Timeliness	h		G	1	
			B	168	
			T	720	
Required Measurement Uncertainty (2-sigma)	ppmv		G	0.1	Dessler et al. (2013) Solomon et al. (2010) Uncertainty requirements are based on observed seasonal and interannual variability.
			B	0.25	
			T	0.5	
Stability	ppmv/decade		G	<0.2	Dessler et al. (2013) Solomon et al. (2010) Stability requirements are based on magnitudes of longer-term trends.
			B	0.2	
			T	0.5	
Standards and References	Dessler, A. E., Schoeberl, M. R., Wang, T., Davis, S. M., & Rosenlof, K. H. (2013). Stratospheric water vapor feedback. Proceedings of the National Academy of Sciences of the United States of America, 110(45), 18087–18091. doi:10.1073/pnas.1310344110 Solomon, S., Rosenlof, K. H., Portmann, R. W., Daniel, J. S., Davis, S. M., Sanford, T. J., & Plattner, G.-K. (2010). Contributions of Stratospheric Water Vapor to Decadal Changes in the Rate of Global Warming. Science, 327(5970), 1219-1223. doi:10.1126/science.1182488				

2.3.3 ECV Product: Water Vapour Mixing Ratio in the Mesosphere

Name	Water Vapour Mixing Ratio in the Mesosphere				
Definition	3D field of water vapour mixing ratios in the mesosphere. Mixing ratio is the mole fraction of a substance in dry air.				
Unit	ppm				
Note	Consistency with temperature requirements for the same layer was used as a primary guiding consideration for horizontal resolution. However, for the breakthrough, there is no justification to use the same value as for temperature that is significantly smaller.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	50	
			B	500	
			T	1500	
Vertical Resolution	km		G	0.5	
			B	1	
			T	3	
Temporal Resolution	h		G	3	
			B	6	
			T	72	
Timeliness	h		G	1	
			B	168	
			T	720	
Required Measurement Uncertainty (2-sigma)	ppmv		G	0.1	Dessler et al. (2013)
			B	0.25	Solomon et al. (2010)
			T	0.5	Uncertainty requirements are based on observed seasonal and interannual variability.
Stability	ppmv/decade		G	<0.2	Dessler et al. (2013)
			B	0.2	Solomon et al. (2010)
			T	0.5	Stability requirements are based on magnitudes of longer-term trends.
Standards and References	Dessler, A. E., Schoeberl, M. R., Wang, T., Davis, S. M., & Rosenlof, K. H. (2013). Stratospheric water vapor feedback. Proceedings of the National Academy of Sciences of the United States of America, 110(45), 18087–18091. doi:10.1073/pnas.1310344110 Solomon, S., Rosenlof, K. H., Portmann, R. W., Daniel, J. S., Davis, S. M., Sanford, T. J., & Plattner, G.-K. (2010). Contributions of Stratospheric Water Vapor to Decadal Changes in the Rate of Global Warming. Science, 327(5970), 1219-1223. doi:10.1126/science.1182488				

2.3.4 ECV Product: Relative Humidity in the Boundary Layer

Name	Relative Humidity in the Boundary Layer				
Definition	3D field of the relative humidity in the PBL. Relative humidity is the amount of water vapor in air divided by the temperature-dependent amount of water vapor in saturated air. RH can be expressed relative to water or ice saturation (to be specified in the metadata).				
Unit	%				
Note	Vertical resolution is required for calculation of fluxes in the lower part of the boundary layer. McCarthy, 2007 notes significant spatial heterogeneity related to latitude of the observation.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	15	McCarthy, (2007), consistency with T
			B	100	McCarthy, (2007)
			T	500	McCarthy, (2007
Vertical Resolution	m		G	1	
			B	10	
			T	100	
Temporal Resolution	h		G	<1	Sub-hourly
			B	6	
			T	12	
Timeliness	h		G	1	
			B	120	
			T	720	
Required Measurement Uncertainty (2-sigma)	%RH		G	0.1	
			B	0.5	
			T	1	
Stability	%RH/decade		G	0.1	Assumption that stability is per measurement system leads to partial cancellation across a network of sites performing measurements.
			B	0.5	
			T	1	
Standards and References	McCarthy, 2007 https://doi.org/10.1002/joc.1611				

2.3.5 ECV Product: Relative Humidity in the Free Troposphere

Name	Relative Humidity in the Free Troposphere				
Definition	3D field of the relative humidity in the free troposphere. Relative humidity is the amount of water vapor in air divided by the temperature-dependent amount of water vapor in saturated air. RH can be expressed relative to water or ice saturation (to be specified in the metadata).				
Unit	%				
Note	McCarthy, 2007 notes significant spatial heterogeneity related to latitude of the observation.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	15	McCarthy, (2007)
			B	100	McCarthy, (2007)
			T	1000	McCarthy, (2007)
Vertical Resolution	km		G	0.01	
			B	0.1	
			T	1	
Temporal Resolution	h		G	<1	Sub-hourly
			B	6	
			T	12	
Timeliness	h		G	1	
			B	120	
			T	720	
Required Measurement Uncertainty (2-sigma)	%RH		G	0.1	
			B	0.5	
			T	1	
Stability	%RH/decade		G	0.1	
			B	0.5	
			T	1	
Standards and References	McCarthy, 2007 https://doi.org/10.1002/joc.1611				

2.3.6 ECV Product: Relative Humidity in the Upper Troposphere and Lower Stratosphere

Name	Relative Humidity in the Upper Troposphere and Lower Stratosphere				
Definition	3D field of the relative humidity in the UTLS. Relative humidity is the amount of water vapor in air divided by the temperature-dependent amount of water vapor in saturated air. RH can be expressed relative to water or ice saturation (to be specified in the metadata).				
Unit	%				
Note	Vertical resolution needed for determining fine layer cirrus and complex tropopause				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	15	
			B	100	
			T	500	
Vertical Resolution	km		G	0.01	
			B	0.1	
			T	0.25	
Temporal Resolution	h		G	3	
			B	6	
			T	24	
Timeliness	h		G	1	
			B	120	
			T	720	
Required Measurement Uncertainty (2-sigma)	%RH	.	G	0.5	Dessler et al. (2013)
			B	1	Solomon et al. (2010)
			T	2	Uncertainty requirements are based on interannual variability and data quality needed to study supersaturation and dehydration.
Stability	%RH/decade		G	<0.5	Dessler et al. (2013)
			B	0.5	Solomon et al. (2010)
			T	2	Stability requirements are based on magnitudes of seasonal and longer-term trends.
Standards and References	Dessler, A. E., Schoeberl, M. R., Wang, T., Davis, S. M., & Rosenlof, K. H. (2013). Stratospheric water vapor feedback. Proceedings of the National Academy of Sciences of the United States of America, 110(45), 18087–18091. doi:10.1073/pnas.1310344110 Solomon, S., Rosenlof, K. H., Portmann, R. W., Daniel, J. S., Davis, S. M., Sanford, T. J., & Plattner, G.-K. (2010). Contributions of Stratospheric Water Vapor to Decadal Changes in the Rate of Global Warming. Science, 327(5970), 1219-1223. doi:10.1126/science.1182488				

2.3.7 ECV Product: Specific Humidity in the Boundary Layer

Name	Specific Humidity in the Boundary Layer				
Definition	3D field of the specific humidity in the PBL. The specific humidity is the ratio between the mass of water vapour and the mass of moist air.				
Unit	g Kg^{-1}				
Note	Vertical resolution is required for calculation of fluxes in the lowermost boundary layer. McCarthy, 2007 notes significant spatial heterogeneity related to latitude of the observation.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	15	McCarthy, (2007)
			B	100	McCarthy, (2007)
			T	500	McCarthy, (2007)
Vertical Resolution	m		G	1	
			B	10	
			T	100	
Temporal Resolution	h		G	<1	Sub-hourly
			B	1	
			T	3	
Timeliness	h		G	1	
			B	120	
			T	720	
Required Measurement Uncertainty (2-sigma)	g Kg^{-1}		G	0.1	
			B	0.5	
			T	1	
Stability	g Kg^{-1}/ decade		G	0.01	
			B	0.05	
			T	0.1	
Standards and References	McCarthy, 2007 https://doi.org/10.1002/joc.1611				

2.3.8 ECV Product: Specific Humidity in the Free Troposphere

Name	Specific Humidity in the Free Troposphere				
Definition	3D field of the specific humidity in the free troposphere. The specific humidity is the ratio between the mass of water vapour and the mass of moist air.				
Unit	g Kg^{-1}				
Note	McCarthy 2007) notes significant spatial heterogeneity related to latitude of the observation.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	15	McCarthy, (2007)
			B	100	McCarthy, (2007)
			T	1000	McCarthy, (2007)
Vertical Resolution	km		G	0.01	
			B	0.1	
			T	1	
Temporal Resolution	h		G	<1	Sub-hourly
			B	1	
			T	3	
Timeliness	h		G	1	
			B	120	
			T	720	
Required Measurement Uncertainty (2-sigma)	g Kg^{-1}		G	0.1	
			B	0.5	
			T	1	
Stability	g Kg^{-1}/ decade		G	0.01	
			B	0.05	
			T	0.1	
Standards and References	McCarthy, 2007 https://doi.org/10.1002/joc.1611				

2.3.9 ECV Product: Integrated Water Vapour

Name	**Integrated Water Vapour (IWV)**
Definition	Total amount of water vapour present in a vertical atmospheric column.
Unit	Kg m^{-2}
Note	Implicit assumption that IWV is intrinsically linked to boundary layer and surface humidity given the predominance of the water vapour in these regions in contributing to the column total. Because IWV scales with temperature, uncertainty and stability should be split latitudinally. The applied values here are for mid-latitude locations. They would be stricter (more relaxed) for polar (tropical) locations and in winter than summer.

Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	25	
			B	250	
			T	1000	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	0.20	
			B	1	
			T	24	
Timeliness	h		G	24	
			B	120	
			T	720	
Required Measurement Uncertainty (2-sigma)	Kg m^{-2}		G	0.1	Varies by latitude (See note above)
			B	0.5	
			T	1	
Stability	Kg m^{-2}/ decade		G	0.1	Varies by latitude (See note above)
			B	0.2	
			T	0.5	
Standards and References					

2.4 ECV: Earth radiation budget

2.4.1 ECV Product: Radiation Profile

Name	Radiation Profile				
Definition	Vertical profile of upward and downward Long Wave (LW) and Short Wave (SW) radiation components.				
Unit	W m^{-2}				
Note	For the application area of global climate monitoring no requirements exist. Thus, the requirements of the individual components are taken				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	10	
			B	50	
			T	100	
Vertical Resolution	km		G	1	
			B	2	
			T	4	
Temporal Resolution	h		G	1	resolving diurnal cycle
			B	24	
			T	720	
Timeliness	h		G	1	
			B	24	
			T	720	
Required Measurement Uncertainty (2-sigma)	W m^{-2}		G	0.1/0.2	Shortwave radiation/Longwave radiation
			B	0.2/0.4	A factor of 2 was applied to gain the breakthrough value and a factor of 4 was applied to estimate the threshold value.
			T	0.4/0.8	
Stability	W m^{-2}/ decade		G	0.025/0.05	Shortwave radiation/Longwave radiation
			B	0.05/0.1	
			T	0.1/0.2	
Standards and References					

2.4.2 ECV Product: Solar Spectral Irradiance

Name	Solar Spectral Irradiance				
Definition	Downward Short-Wave Irradiance at Top of the Atmosphere when measured as a function of wavelength it is the spectral irradiance.				
Unit	W m-2 μm-1				
Note	Downward Short-Wave Irradiance at Top of the Atmosphere is also known as Solar Spectral Irradiance (SSI)				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	mm		G	10	
			B	50	
			T	100	
Spectral resolution			G		
	< 290 nm		B	1nm	
	290-1000 nm			2nm	
	1000-1600 nm			5nm	
	1600-3200 nm			10nm	
	3200-6400 nm			20nm	
	6400-10020nm			40nm	
	10020-160000 nm			20000nm	
			T		
Temporal Resolution	h		G	3	
			B	12	Current TSIS-1 Level 3 sampling
			T	24	Current TSIS-1 Level 3 sampling
Timeliness	h		G	1	
			B	10	
			T	90	
Required Measurement Uncertainty (2-sigma)	%		G	0.3	(200-3000 nm)
			B	1.5	
			T	3	
Stability	%/decade		G	0.03	(200-3000 nm)
			B	0.15	
			T	0.3	
Standards and References					

2.4.3 ECV Product: Downward Short-Wave Irradiance at Top of the Atmosphere

Name	Downward Short-Wave Irradiance at Top of the Atmosphere				
Definition	Flux density of the solar radiation at the top of the atmosphere.				
Unit	W m^{-2}				
Note	This EVC is formerly/also known as Total Solar Irradiance (TSI).				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B	50	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	
			B	6	Current TSIS-1 Level 3 sampling
			T	24	Current TSIS-1 Level 3 sampling
Timeliness	h		G	1	
			B	24	
			T	720	
Required Measurement Uncertainty (2-sigma)	W m^{-2}		G	0.04	
			B	0.08	
			T	0.12	
Stability	W m^{-2}/ decade		G	0.01	
			B	0.02	
			T	0.04	
Standards and References					

2.4.4 ECV Product: Upward Short-Wave Irradiance at Top of the Atmosphere

Name	Upward Short-Wave Irradiance at Top of the Atmosphere				
Definition	Flux density of solar radiation, reflected by the Earth surface and atmosphere, emitted to space at the top of the atmosphere.				
Unit	W m-²				
Note	The measurand for this ECV is radiance (W·sr^{-1}·m^{-2}). The current approach adopted by the Clouds and Earth's Radiant Energy System (CERES) is to derive irradiances (Wm^{-2}) from measured radiances using observed anisotropy factors over various scene types.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B	50	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	
			B	24	Resolves the diurnal cycle
			T	720	Allows a regional monitoring
Timeliness	h		G	1	
			B	24	
			T	720	
Required Measurement Uncertainty (2-sigma)	W m-²		G	0.2	NOAA Tech Rep. NESDIS 134;
			B	0.5	Ohring et al. (2005)
			T	1	A factor of 2 was applied to gain the breakthrough value and a factor of 4 was applied to estimate the threshold value.
Stability	W m-²/ decade		G	0.06	NOAA Tech Rep. NESDIS 134
			B	0.15	
			T	0.3	
Standards and References	Ohring et al. 2005: https://doi.org/10.1175/BAMS-86-9-1303 NOAA Tech Rep. NESDIS 134: Report from the Workshop on Continuity of Earth Radiation Budget (CERB) Observations: Post-CERES Requirements. John J. Bates and Xuepeng Zhao, May 2011				

2.4.5 ECV Product: Upward Long-Wave Irradiance at Top of the Atmosphere

Name	Upward Long-Wave Irradiance at Top of the Atmosphere				
Definition	Flux density of terrestrial radiation emitted by the Earth surface and the gases, aerosols and clouds of the atmosphere at the top of the atmosphere.				
Unit	W m-²				
Note	The measurand for this ECV is radiance ($W \cdot sr^{-1} \cdot m^{-2}$). The current approach adopted by the Clouds and Earth's Radiant Energy System (CERES) is to derive irradiances (Wm^{-2}) from measured radiances using observed anisotropy factors over various scene types.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B	50	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	
			B	24	Based on resolved diurnal cycle
			T	720	Based on resolved diurnal cycle
Timeliness	h		G	1	
			B	24	
			T	720	
Required Measurement Uncertainty (2-sigma)	W m-²		G	0.2	NOAA Tech Rep. NESDIS 134;
			B	0.5	Ohring et al. 2003 / 2005)
			T	1	A factor of 2 was applied to gain the breakthrough value and a factor of 4 was applied to estimate the threshold value.
Stability	W m-²/decade		G	0.05	NOAA Tech Rep. NESDIS 134
			B	0.1	Requirements for decadal stability and bias can be derived from theoretical assumptions about the minimum anticipated signal to detect climate trends (Ohring 2004, 2005). Ohring et al. assume the required stability to be 1/5 of the expected climate signal. To detect a climate signal the stability should be better than 10 % of the uncertainty.
			T	0.2	
Standards and References	Ohring et al. 2004: Satellite Instrument Calibration for Measuring Global Climate Change. NIST Rep. NISTIR 7047, 101 pp Ohring et al. 2005: https://doi.org/10.1175/BAMS-86-9-1303 NOAA Tech Rep. NESDIS 134: Report from the Workshop on Continuity of Earth Radiation Budget (CERB) Observations: Post-CERES Requirements. John J. Bates and Xuepeng Zhao, May 2011				

2.5 ECV Cloud Properties

2.5.1 ECV Product: Cloud cover

Name	Cloud Cover				
Definition	2D field of fraction of sky filled by cloud.				
Unit	Unitless (percentage)				
Note	These requirements include: Global, continental, and regional Climate monitoring, feedback and improved knowledge about the interaction between clouds, aerosols and atmospheric gases				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	25	To perform regional climate monitoring. Higher spatial resolution is needed with a resolution as high as 10 km required for resolving convective clouds in the tropics.
			B	100	To perform continental climate monitoring
			T	500	Global climate monitoring is performed on a monthly time scale with an averaged global number for which ~500 km for horizontal resolution is sufficient.
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	To resolve the diurnal cycle for all kinds of clouds on the global scale and investigating cloud related climate feedbacks which are e.g. connected to rainfall, surface temperature, convection demand a temporal observing resolution of hourly to daily.
			B	24	To perform climate monitoring of clouds on the global scale, a daily observing cycle will be sufficient.
			T	720	To characterize seasonal and interannual changes
Timeliness	h		G	1	
			B	3	
			T	12	
Required Measurement Uncertainty (2-sigma)	%		G	3	Breakthrough is estimated with a factor of 2 times the goal value, whereas the threshold is calculated with a factor of 4 times the goal value.
			B	6	
			T	12	
Stability	%/decade		G	0.3	Ohring et al. 2005
			B	0.6	Breakthrough is estimated with a factor of 2 times the goal value, whereas the threshold is calculated with a factor of 4 times the goal value.
			T	1.2	
Standards and References	Ohring et al. 2005: https://doi.org/10.1175/BAMS-86-9-1303				

2.5.2 ECV Product: Cloud Liquid Water Path

Name	Cloud Liquid Water Path				
Definition	2D Field of atmospheric water in the liquid phase (precipitating or not), integrated over the total column.				
Unit	Kg m^{-2}				
Note	This variable is identical to the also used "Cloud liquid water total column" which is given in g/m^2 and often used in NWP and climate models. The uncertainty values are below would then by re-scaled from Kg m^{-2} to g m^{-2}. These requirements include: Global, continental, and regional Climate monitoring, feedback and improved knowledge about the interaction between clouds, aerosols and atmospheric gases.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	25	To perform regional climate monitoring. Higher spatial resolution is needed with a resolution as high as 10 km required for resolving convective clouds in the tropics
			B	100	To perform continental climate monitoring.
			T	500	Global climate monitoring is performed on a monthly time scale with an averaged global number for which ~500 km for horizontal resolution is sufficient
Vertical Resolution			G		N/A
			B		
			T		
Temporal Resolution	h		G	1	To resolve the diurnal cycle for all kinds of clouds on the global scale and investigating cloud related climate feedbacks which are e.g. connected to rainfall, surface temperature, convection demand a temporal observing resolution of hourly to daily.
			B	24	To perform climate monitoring of clouds on the global scale, a daily to monthly observing cycle will be sufficient
			T	720	To characterize seasonal and interannual changes
Timeliness	h		G	1	
			B	3	
			T	12	
Required Measurement Uncertainty (2-sigma)	Kg m^{-2}		G	0.05	Breakthrough is estimated with a factor of 2 times the goal value, whereas the threshold is calculated with a factor of 4 times the goal value
			B	0.1	
			T	0.2	
Stability	Kg m^{-2}/ decade		G	0.005	Ohring et al. 2005
			B	0.01	Breakthrough is estimated with a factor of 2 times the goal value, whereas the threshold is calculated with a factor of 4 times the goal value
			T	0.02	
Standards and References	Ohring et al. 2005: https://doi.org/10.1175/BAMS-86-9-1303				

2.5.3 ECV Product: Cloud Ice Water Path

Name	**Cloud Ice Water Path**				
Definition	2D Field of atmospheric water in the solid phase (precipitating or not), integrated over the total column.				
Unit	kg m^{-2}				
Note	This variable is identical to the also used "Cloud ice water total column" which is given in g/m² and often used in NWP and climate models. The uncertainty values are below would then by re-scaled from kg/m² to g/m². These requirements include: Global, continental, and regional Climate monitoring, feedback and improved knowledge about the interaction between clouds, aerosols and atmospheric gases.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	25	To perform regional climate monitoring. Higher spatial resolution is needed with a resolution as high as 10 km required for resolving convective clouds in the tropics.
			B	100	To perform continental climate monitoring.
			T	500	Global climate monitoring is performed on a monthly time scale with an averaged global number for which ~500 km for horizontal resolution is sufficient.
Vertical Resolution	N/A		G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	To resolve the diurnal cycle for all kinds of clouds on the global scale and investigating cloud related climate feedbacks which are e.g. connected to rainfall, surface temperature, convection demand a temporal observing resolution of hourly to daily.
			B	24	To perform climate monitoring of clouds on the global scale, a daily to monthly observing cycle will be sufficient.
			T	720	To characterized seasonal and interannual changes
Timeliness	h		G	1	
			B	3	
			T	12	
Required Measurement Uncertainty (2-sigma)	kg m^{-2}		G	0.05	Breakthrough is estimated with a factor of 2 times the goal value, whereas the threshold is calculated with a factor of 4 times the goal value.
			B	0.1	
			T	0.2	
Stability	kg m^{-2}/ decade		G	0.005	Ohring et al. 2005
			B	0.01	Breakthrough is estimated with a factor of 2 times the goal value, whereas the threshold is calculated with a factor of 4 times the goal value.
			T	0.02	
Standards and References	Ohring et al. 2005: https://doi.org/10.1175/BAMS-86-9-1303				

2.5.4 ECV Product: Cloud Drop Effective Radius

Name	Cloud Drop Effective Radius				
Definition	Ratio of integral of water droplets size distribution in volume divided by integral in area (µm).				
Unit	µm				
Note	These requirements include: Global, continental, and regional Climate monitoring, feedback and improved knowledge about the interaction between clouds, aerosols and atmospheric gases. Requirements for this ECV is are for the cloud top				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	25	To perform regional climate monitoring. Higher spatial resolution is needed with a resolution as high as 10 km required for resolving convective clouds in the tropics.
			B	100	To perform continental climate monitoring
			T	500	Global climate monitoring is performed on a monthly time scale with an averaged global number for which ~500 km for horizontal resolution is sufficient.
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	To resolve the diurnal cycle for all kinds of clouds on the global scale and investigating cloud related climate feedbacks which are e.g. connected to rainfall, surface temperature, convection demand a temporal observing resolution of hourly to daily.
			B	24	To perform climate monitoring of clouds on the global scale, a daily to monthly observing cycle will be sufficient.
			T	720	To characterize seasonal and interannual changes
Timeliness	h		G	1	
			B	3	
			T	12	
Required Measurement Uncertainty (2-sigma)	µm	As metric the uncertainty (RMS) is chosen which is given for 1-sigma	G	1/2	Breakthrough is estimated with a factor of 2 times the goal value, whereas the threshold is calculated with a factor of 4 times the goal value.
			B	2/4	
			T	4/8	
Stability	µm /decade		G	0.1/0.2	Values given separately for cloud water and ice effective particle size as water/ice. Ohring et al. 2005 specifies stability and accuracy requirements separately for cloud water particle size as percentage forcing, and ice particle size as percentage feedback. Breakthrough is estimated with a factor of 2 times the goal value, whereas the threshold is calculated with a factor of 4 times the goal value.
			B	0.2/0.4	
			T	0.4/0.8	
Standards and References	Ohring et al. 2005: https://doi.org/10.1175/BAMS-86-9-1303				

2.5.5 ECV Product: Cloud Optical Depth

Name	Cloud Optical Depth				
Definition	Effective depth of a cloud from the viewpoint of radiation extinction. OD = exp(-K.Δz) where K is the extinction coefficient [km-1], Δz the vertical path [km] between the base and the top of the cloud and the reference wavelength to be specified in the metadata.				
Unit	Dimensionless (percentage)				
Note	These requirements include: Global, continental, and regional Climate monitoring, feedback and improved knowledge about the interaction between clouds, aerosols and atmospheric gases.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	25	To perform regional climate monitoring. Higher spatial resolution is needed with a resolution as high as 10 km required for resolving convective clouds in the tropics.
			B	100	To perform continental and regional climate monitoring higher spatial resolution is needed
			T	500	Global climate monitoring is performed on a monthly time scale with an averaged global number for which ~500 km for horizontal resolution is sufficient.
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	To resolve the diurnal cycle for all kinds of clouds on the global scale and investigating cloud related climate feedbacks which are e.g. connected to rainfall, surface temperature, convection demand a temporal observing resolution of hourly to daily.
			B	24	To perform Performing climate monitoring of clouds on the global scale, a daily to monthly observing cycle will be sufficient.
			T	720	To characterize seasonal and interannual changes
Timeliness	h		G	1	
			B	3	
			T	12	
Required Measurement Uncertainty (2-sigma)	%		G	20	Breakthrough is estimated with a factor of 2 times the goal value, whereas the threshold is calculated with a factor of 4 times the goal value.
			B	40	
			T	80	
Stability	%/decade		G	2.0	Ohring et al. 2005 lists the stability requirements for cloud optical thickness as 2% with a 10% accuracy. Breakthrough is estimated with a factor of 2 times the goal value, whereas the threshold is calculated with a factor of 4 times the goal value.
			B	4.0	
			T	8.0	
Standards and References	Ohring et al. 2005: https://doi.org/10.1175/BAMS-86-9-1303				

2.5.6 ECV Product: Cloud Top Temperature

Name	Cloud Top Temperature				
Definition	Temperature of the top of the cloud (highest cloud in case of multi-layer clouds).				
Unit	K				
Note	These requirements include: Global, continental, and regional Climate monitoring, feedback and improved knowledge about the interaction between clouds, aerosols and atmospheric gases.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	25	To perform regional climate monitoring. Higher spatial resolution is needed with a resolution as high as 10 km required for resolving convective clouds in the tropics.
			B	100	To perform continental and regional climate monitoring higher spatial resolution is needed
			T	500	Global climate monitoring is performed on a monthly time scale with an averaged global number for which ~500 km for horizontal resolution is sufficient.
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	To resolve the diurnal cycle for all kinds of clouds on the global scale and investigating cloud related climate feedbacks which are e.g. connected to rainfall, surface temperature, convection demand a temporal observing resolution of hourly to daily.
			B	24	To perform Performing climate monitoring of clouds on the global scale, a daily to monthly observing cycle will be sufficient.
			T	720	To characterize seasonal and interannual changes
Timeliness	h		G	1	
			B	3	
			T	12	
Required Measurement Uncertainty (2-sigma)	K		G	2	Breakthrough is estimated with a factor of 2 times the goal value, whereas the threshold is calculated with a factor of 4 times the goal value.
			B	4	
			T	8	
Stability	K/decade		G	0.2	Ohring et al. 2005 lists the stability requirement for cloud top temperature as 0.2K/cloud emissivity per decade with accuracy as 1 K/cloud emissivity per decade. Breakthrough is estimated with a factor of 2 times the goal value, whereas the threshold is calculated with a factor of 4 times the goal value.
			B	0.4	
			T	0.8	
Standards and References	Ohring et al. 2005: https://doi.org/10.1175/BAMS-86-9-1303				

2.5.7 ECV Product: Cloud Top Height

Name	Cloud Top Height
Definition	Height of the top of the cloud (highest cloud in case of multi-layer clouds.
Unit	km
Note	These requirements include: Global, continental, and regional Climate monitoring, feedback and improved knowledge about the interaction between clouds, aerosols and atmospheric gases. 3-D cloud top information are required where possible. This can be achieved via a combination of cloud optical depth vs cloud top height histograms

Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	25	To perform regional climate monitoring. Higher spatial resolution is needed with a resolution as high as 10 km required for resolving convective clouds in the tropics.
			B	100	To perform continental and regional climate monitoring higher spatial resolution is needed
			T	500	Global climate monitoring is performed on a monthly time scale with an averaged global number for which ~500 km for horizontal resolution is sufficient.
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	To resolve the diurnal cycle for all kinds of clouds on the global scale and investigating cloud related climate feedbacks which are e.g. connected to rainfall, surface temperature, convection demand a temporal observing resolution of hourly to daily.
			B	24	To perform climate monitoring of clouds on the global scale, a daily to monthly observing cycle will be sufficient.
			T	720	To characterize seasonal and interannual changes
Timeliness	h		G	1	
			B	3	
			T	12	
Required Measurement Uncertainty (2-sigma)	km		G	0.30	Breakthrough is estimated with a factor of 2 times the goal value, whereas the threshold is calculated with a factor of 4 times the goal value.
			B	0.60	
			T	1.2	
Stability	km/decade		G	0.03	Ohring et al. 2005 lists the required stability for cloud top height as 30 m/decade with accuracy of 150 m/decade. Breakthrough is estimated with a factor of 2 times the goal value, whereas the threshold is calculated with a factor of 4 times the goal value.
			B	0.06	
			T	0.12	
Standards and References	Ohring et al. 2005: https://doi.org/10.1175/BAMS-86-9-1303				

2.6 ECV: Lightning

2.6.1 ECV Product: Schumann Resonances

Name	Schumann Resonances				
Definition	Extremely Low Frequency (ELF) magnetic and electric field of the three first resonance modes (8 Hz, 14 Hz, 20 Hz).				
Unit	$pT^2\ Hz^{-1}$ (magnetic field); $V^2\ m^{-2}\ Hz^{-1}$ (electric field)				
Note	Regular measurements of two horizontal magnetic field components at a location are enough to monitor globally Schumann Resonances. The magnetic field should be monitored at a level of ~0.1 $pT^2\ Hz^{-1}$. Additionally, to the magnetic measurements, one vertical electric measurement would document the full transverse electromagnetic (TEM) waveguide component at any given location. Note the estimate of the electric intensity assumes the wave impedance is half that of free space (377 ohms). In this context, the electric field should be monitored at a level of ~2.3 x 10-9 $V^2\ m^{-2}\ Hz^{-1}$.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution			G	-	One value represents the globe, so no horizontal resolution required
			B	-	
			T	-	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1/24	Suitable for investigation of the strong diurnal variation of tropical “chimney” regions and for use in multi-station inversion methods for global lightning activity
			B	1	Suitable for investigation of intraseasonal variations (5-day wave; MJO)
			T	30	Suitable for investigation of the global seasonal and annual variation, and the interannual ENSO variation
Timeliness	d		G	1	For use in building a representative monthly estimate for climate purposes
			B	-	
			T	30	For climate-related studies; responsiveness of lightning to long-term temperature changes
Required Measurement Uncertainty (2-sigma)	$fT^2\ Hz^{-1}$		G	1	Absolute coil calibration is feasible at the 1% level/ (Calibration of the vertical electric field is difficult, but possible)
			B	-	
			T	5	Absolute coil calibration at the 5% level
Stability	$fT^2\ Hz^{-1}$		G	1	Given lightning sensitivity to temperature at the 10% per K level, one needs absolute calibration and stability at the 1% level to see fraction of 1K temperature changes
			B	-	
			T	5	Coil calibration should be checked and maintained to at least this level
Standards and References	Nickolaenko, A.P. and M. Hayakawa, Resonances in the Earth–ionosphere cavity. Kluwer Academic Publisher, Dordrecht, London, 2002. Nickolaenko, A.P. and M. Hayakawa, Schumann Resonance for Tyros: Essentials of Global Electromagnetic Resonance in the Earth–ionosphere Cavity. Springer, Tokyo/Heidelberg/New York/Dordrecht/London, 2014. Polk, C., Schumann Resonances, in CRC Handbook of Atmospherics. Volume 1, Ed., H. Volland, CRC Press, Boca Raton, Florida, 1982. Sátori G, V. Mushtak, and E. Williams, Schumann resonance signature of global lightning activity. In: Betz, HD, U. Schumann and P. Laroche (eds), Lightning: Principles, Instruments and Applications: Review of Modern Lightning Research. Springer, Berlin, pp 347–386. 2009. Sentman, D.D., Schumann Resonances. In Volland, H., Ed., Handbook of Atmospheric Electrodynamics, CRC Press, Boca Raton, 267-296, 1995.				

2.6.2 ECV Product: Total lightning stroke density

Name	Total lightning stroke density			
Definition	Total number of detected strokes in the corresponding time interval and the space unit. The space unit (grid box) should be on the order of the horizontal resolution and the accumulation time to the observing cycle.			
Unit	Strokes per km^2 y^{-1}			
Note	Data sets at the 1-map-per-month level require limited data storage, and thus should be simply posted on a publicly accessible website. The larger data sets reaching down to global resolutions of 0.1 degree with time resolution of a few hours should be maintained by the network managers and provided to the user community as needed. Metadata should include sufficient information to validate the detection efficiency at the maximum spatial and temporal scales.			
Requirements				

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	Degree pixels		G	0.1x0.1	Thunderstorms are complex, with different dynamics in different parts of the storm, for example the updraft region and the trailing stratosphere region. Therefore, the net influence on global currents and climatology is likely to be very different from different sub-storm scales.
			B	0.25x0.25	This is the convection scale and will help identify climate variability at the storm level
			T	1x1	Ideally these data would be provided as both maps as well as digital files, along with the Metadata with adequate time resolution to address both long term and short term detection efficiency variations within these data sets.
Vertical Resolution	N/A		G	-	N/A
			B	-	N/A
			T	-	N/A
Temporal Resolution	d		G	1/24	Lifetime of thunderstorm cell, diurnal cycle. For high resolution climatology, also necessary to validate thunder day data in order to extend time series of lightning activity back in time
			B	1	Weather patterns, weekly and intraseasonal patterns like MJO
			T	30	Climate Scale
Timeliness	d		G	10	For high resolution climatology. It can be important for special occasions to see direct impacts of events or mitigation immediately in order to react.
			B	30	Forecasting and model input
			T	365	For lightning climatology studies the provision of yearly data within one year of data collection, and to prepare their data back as far as it is available from their network is necessary.
Required Measurement Uncertainty (2-sigma)	dimensionless		G	1	For high resolution climatology, also necessary to validate thunder day data in order to extend time series of lightning activity back in time
			B	-	
			T	15	For climatologies
Stability	%		G	1	For high resolution climatology, also necessary to validate thunder day data in order to extend time series of lightning activity back in time
			B	-	–
			T	10	For climatologies
Standards and References	Algorithm Theoretical Basis Document (ATBD) for L2 processing of the GOES-R Geostationary Lightning Mapper (GLM, Goodman et al., 2013) and MTG Lightning Imager data (Eumetsat, 2014) Meteosat Third Generation (MTG) End-User Requirements Document (EURD) (Eumetsat, 2010) GOES-R Product Definition and Users' Guide (PUG, Rev. 2018) and Data Book (Rev., 2019) Nag et al., 2015 Virts, K.S. et al, 2013, Highlights of a New Ground-Based, Hourly Global Lightning Climatology, BAMS, 94 (9), https://doi.org/10.1175/BAMS-D-12-00082.1				

	GOES-R Series, 2018. Product Definition and Users' Guide. Volume 3: Level 1b Products, 1 November 2018 DCN 7035538, Revision 2.0, available at https://www.goes-r.gov/users/docs/PUG-L1b-vol3.pdf. GOES-R Series Data Book, 2019. CDRL PM-14 Rev A. May 2019, NOAA-NASA. Available at https://www.goes-r.gov/downloads/resources/documents/GOES-RSeriesDataBook.pdf.

3. ATMOSPHERIC COMPOSITION

3.1 ECV: Greenhouse Gases

3.1.1 ECV Product: N_2O mole fraction

Name	N_2O mole fraction				
Definition	3D field of amount of N_2O (expressed in moles) divided by the total amount of all constituents in dry air (also expressed in moles).				
Unit	ppb				
Note	N_2O was not an ECV product in the GCOS IP but should be added as it is a strong GHG.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	100	
			B	500	
			T	2000	
Vertical Resolution	km		G	0.1	
			B	1	
			T	3	
Temporal Resolution	h		G	1	
			B	24	
			T	168	
Timeliness	d		G	1	
			B	30	
			T	180	
Required Measurement Uncertainty (2-sigma)	ppb		G	0.05	Expert judgement and GAW Rep. No. 242 network compatibility
			B	0.1	Expert judgement and GAW Rep. No. 242 extended network compatibility
			T	0.3	Expert judgement, larger than B.
Stability	ppb/decade		G	0.05	Within accuracy
			B	0.05	Within accuracy/2
			T	0.2	Within accuracy/2
Standards and References	GAW Report, 242. 19th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2017) Crotwell Andrew; Steinbacher M.; World Meteorological Organization (WMO) - WMO, 2018 https://library.wmo.int/doc_num.php?explnum_id=5456 GAW Report, 255. 20th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2019) Crotwell A.; Lee, H.; Steinbacher M.; World Meteorological Organization (WMO) - WMO, 2020 https://library.wmo.int/doc_num.php?explnum_id=10353				

3.1.2 ECV Product: CO_2 mole fraction

Name	CO_2 mole fraction				
Definition	3D field of amount of CO_2 (Carbon dioxide, expressed in moles) divided by the total amount of all constituents in dry air (also expressed in moles).				
Unit	ppm				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	100	
			B	500	
			T	2000	
Vertical Resolution	km		G	0.1	
			B	1	
			T	3	
Temporal Resolution	h		G	1	
			B	24	
			T	168	
Timeliness	day		G	1	
			B	30	
			T	180	
Required Measurement Uncertainty (2-sigma)	ppm		G	0.1	GAW Rep. No. 242
			B	0.2	GAW Rep. No. 242
			T	0.5	Expert judgement, larger than B.
Stability	ppm/decade		G	0.1	Within accuracy
			B	0.1	Within accuracy/2
			T	0.3	Within accuracy/2
Standards and References	GAW Report, 242. 19th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2017) Crotwell Andrew; Steinbacher M.; World Meteorological Organization (WMO) - WMO, 2018 https://library.wmo.int/doc_num.php?explnum_id=5456 GAW Report, 255. 20th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2019) Crotwell A.; Lee, H.; Steinbacher M.; World Meteorological Organization (WMO) - WMO, 2020 https://library.wmo.int/doc_num.php?explnum_id=10353				

3.1.3 ECV Product: CO_2 column average dry air mixing ratio

Name	CO_2 column average dry air mixing ratio				
Definition	2D column integrated number of molecules of the target gas (CO2) divided by that of dry air expressed in mole fraction.				
Unit	µmol mol^{-1}				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	1	imaging
			B	5	~OCO-2/3
			T	10	CO_2M, CEOS document - LEO, GEO
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	geostationary
			B	12	Blue report
			T	72	CO_2M
Timeliness	d		G	1	
			B	7	
			T	14	
Required Measurement Uncertainty (2-sigma)	ppm		G	0.6	1-sigma: 0.3ppm TCCON / Green report
			B	1	1-sigma: 0.5ppm Expert judgment based on improving CO_2M requirements
			T	1.6	1-sigma: 0.8ppm CO_2M requirements, WMO Report #242
Stability	ppm/decade		G	0.1	Within accuracy / 5
			B	0.2	Within accuracy / 5
			T	0.3	Within accuracy / 5
Standards and References	Blue Report, 2015: Towards a European Operational Observing System to Monitor Fossil CO_2 emissions https://www.copernicus.eu/sites/default/files/2019-09/CO2_Blue_report_2015.pdf Red Report, 2017: Baseline Requirements, Model Components and Functional Architecture https://www.copernicus.eu/sites/default/files/2019-09/CO2_Red_Report_2017.pdf Green Report, 2019: Needs and High Level Requirements for in situ Measurements https://www.copernicus.eu/sites/default/files/2019-09/CO2_Green_Report_2019.pdf CO_2M https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_High_Priority_Candidates MRD, v 2.0: https://esamultimedia.esa.int/docs/EarthObservation/CO2M_MRD_v2.0_Issued20190927.pdf ESA Climate Change Initiative (CCI) User Requirements Document Version 2.1 (URDv2.1) for the Essential Climate Variable (ECV) Greenhouse Gases (GHG) http://www.esa-ghg-cci.org/?q=node/85 CEOS documents: http://ceos.org/ourwork/virtual-constellations/acc/ CEOS GHG report/white paper: http://ceos.org/document_management/Virtual_Constellations/ACC/Documents/CEOS_AC-VC_GHG_White_Paper_Publication_Draft2_20181111.pdf GAW Report, 242. 19th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2017) Crotwell Andrew; Steinbacher M.; World Meteorological Organization (WMO) - WMO, 2018 https://library.wmo.int/doc_num.php?explnum_id=5456 GAW Report, 255. 20th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2019) Crotwell A.; Lee, H.; Steinbacher M.; World Meteorological Organization (WMO) - WMO, 2020 https://library.wmo.int/doc_num.php?explnum_id=10353				

3.1.4 ECV Product: CH_4 mole fraction

Name	CH_4 mole fraction				
Definition	3D field of amount of CH_4 (Methane, expressed in moles) divided by the total amount of all constituents in dry air (also expressed in moles).				
Unit	ppb				
Note					
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	100	
			B	500	
			T	2000	
Vertical Resolution	km		G	0.1	
			B	1	
			T	3	
Temporal Resolution	h		G	1	
			B	24	
			T	168	
Timeliness	d		G	1	
			B	30	
			T	180	
Required Measurement Uncertainty (2-sigma)	ppb		G	1	Expert judgement based on GAW Rep. No. 242 network compatibility
			B	2	Expert judgement based on GAW Rep. No. 242 extended network compatibility
			T	5	Expert judgment, larger than B.
Stability	ppb/decade		G	1	Within accuracy
			B	1	Within accuracy/2
			T	3	Within accuracy/2
Standards and References	Green Report, 2019: Needs and High Level Requirements for in situ Measurements https://www.copernicus.eu/sites/default/files/2019-09/CO2_Green_Report_2019.pdf GAW Report, 242. 19th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2017) Crotwell Andrew; Steinbacher M.; World Meteorological Organization (WMO) - WMO, 2018 https://library.wmo.int/doc_num.php?explnum_id=5456 GAW Report, 255. 20th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2019) Crotwell A.; Lee, H.; Steinbacher M.; World Meteorological Organization (WMO) - WMO, 2020 https://library.wmo.int/doc_num.php?explnum_id=10353				

3.1.5 ECV Product: CH_4 column average dry air mixing ratio

Name	CH_4 column average dry air mixing ratio				
Definition	2D column integrated number of molecules of the target gas (CH_4) divided by that of dry air expressed in mole fraction.				
Unit	nmol mol^{-1}				
Note	Temporal resolution and timeliness are kept the same/compatible with CO_2				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	0.3	Imaging, permafrost region
			B	1	Improved TROPOMI
			T	10	TROPOMI/S5P
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	Geo constellation + LEO
			B	12	In the middle between threshold and goal
			T	72	TROPOMI revisit, single geostationary
Timeliness	d		G	1	
			B	7	
			T	14	
Required Measurement Uncertainty (2-sigma)	ppb		G	7	1-sigma: 3.5ppb GeoCARB and MERLIN mission requirements, 0.2% of current CH_4 burden
			B	10	1-sigma:5ppb Expert judgement based on expected improvement of TROPOMI/S5P
			T	20	1-sigma: 10ppb TROPOMI/S5P, CEOS doc, advancing from GCOS 2011
Stability	ppb/decade		G	1	Within accuracy / 5
			B	2	within accuracy / 5
			T	4	within accuracy / 5
Standards and References	Blue Report, 2015: Towards a European Operational Observing System to Monitor Fossil CO_2 emissions https://www.copernicus.eu/sites/default/files/2019-09/CO2_Blue_report_2015.pdf Red Report, 2017: Baseline Requirements, Model Components and Functional Architecture https://www.copernicus.eu/sites/default/files/2019-09/CO2_Red_Report_2017.pdf Green Report, 2019: Needs and High Level Requirements for in situ Measurements https://www.copernicus.eu/sites/default/files/2019-09/CO2_Green_Report_2019.pdf CO_2M:https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_High_Priority_Candidates MRD, v 2.0: https://esamultimedia.esa.int/docs/EarthObservation/CO2M_MRD_v2.0_Issued20190927.pdf ESA Climate Change Initiative (CCI) User Requirements Document Version 2.1 (URDv2.1) for the Essential Climate Variable (ECV) Greenhouse Gases (GHG) http://www.esa-ghg-cci.org/?q=node/85 CEOS documents:http://ceos.org/ourwork/virtual-constellations/acc/ CEOS GHG report/white paper: http://ceos.org/document_management/Virtual_Constellations/ACC/Documents/CEOS_AC-VC_GHG_White_Paper_Publication_Draft2_20181111.pdf GAW Report, 242. 19th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2017) Crotwell Andrew; Steinbacher M.; World Meteorological Organization (WMO) - WMO, 2018 https://library.wmo.int/doc_num.php?explnum_id=5456 GAW Report, 255. 20th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2019) Crotwell A.; Lee, H.; Steinbacher M.; World Meteorological Organization (WMO) - WMO, 2020 https://library.wmo.int/doc_num.php?explnum_id=10353				

3.2 ECV: Ozone

3.2.1 ECV Product: Ozone mole fraction in the Troposphere

Name	Ozone mole fraction in the troposphere				
Definition	3D field of amount of O3 (expressed in moles) in the troposphere divided by the total amount of all constituents in dry air (also expressed in moles).				
Unit	% (directly transferrable to mixing ratios, mol/mol)				
Note	The team of ozone experts unanimously agreed that the uncertainty and stability requirements for each of these ozone data products should be expressed as % and %/decade in the tables. Defining requirements in units of mixing ratios or Dobson Units would require each uncertainty and stability requirement be a wide range of values. We therefore found it more definitive and intuitive that each table entry is one number in % or %/decade. To help translate the requirements in % or %/decade to absolute units we have put a footnote beneath each table that quantitatively describes the wide range of mixing ratios or Dobson Units corresponding to that data product. This helps to explain why the requirements in the tables are not expressed in units of mixing ratio or DU. Requirements in absolute units are easily calculated by multiplying the % (or %/decade) in the table by the mixing ratio or DU ranges in the footnotes.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	1	1, 2, 3, 4,5,6,7
			B	20	
			T	100	
Vertical Resolution	km		G	1	1,2,3,4,5,6,7
			B	3	
			T	5	
Temporal Resolution	d		G	1/24	1, 2, 3, 4,5,6,7
			B	1/4	
			T	30	
Timeliness	d		G	1/24	
			B	1	
			T	30	
Required Measurement Uncertainty (2-sigma)	%		G	2	1, 2, 3, 4,5,6,7,8
			B	5	Requirements for uncertainty (%) and stability (%/decade) translate to wide mixing ratio requirement ranges based on a 20 to 80 ppb range of ozone mixing ratios in the troposphere.
			T	10	
Stability	%/decade		G	<1	1, 2, 3, 4,5,6,7,8
			B	2	Requirements for uncertainty (%) and stability (%/decade) translate to wide mixing ratio requirement ranges based on a 20 to 80 ppb range of ozone mixing ratios in the troposphere.
			T	3	
Standards and References	1. Ozone Climate Change Initiative User Requirements Document http://cci.esa.int/sites/default/files/filedepot/incoming/Ozone_cci_urd_v3.0_final.pdf 2. WMO (World Meteorological Organization), Stratospheric Ozone Changes and Climate in Scientific Assessment of Ozone Depletion: 2018, Global Ozone Research and Monitoring Project–Report No. 58, 588 pp., Geneva, Switzerland, 2018. https://www.esrl.noaa.gov/csd/assessments/ozone/2018/downloads/Chapter5_2018OzoneAssessment.pdf 3. Climate Monitoring User Group CCI Requirements Baseline Documents http://ensembles-eu.metoffice.com/cmug/CMUG_PHASE_2_D1.1_Requirements_v0.6.pdf 4. WMO (World Meteorological Organization), Update on Global Ozone: Past, Present and Future in Scientific Assessment of Ozone Depletion: 2018, Global Ozone Research and Monitoring Project–Report No. 58, 588 pp., Geneva, Switzerland, 2018. https://www.esrl.noaa.gov/csd/assessments/ozone/2018/downloads/Chapter3_2018OzoneAssessment.pdf 5. Gaudel, A., et al. (2018), Tropospheric Ozone Assessment Report: Present-day distribution and trends of tropospheric ozone relevant to climate and global atmospheric chemistry model evaluation, Elem. Sci. Anth., 6(1), 39, https://doi.org/10.1525/elementa.291 6. Tarasick, D. W., I. E. Galbally, O. R. Cooper, M. G. Schultz, G. Ancellet, T. Leblanc, T. J. Wallington, J. Ziemke, X. Liu, M. Steinbacher, J. Staehelin, C. Vigouroux, J. W. Hannigan, O.				

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3.2.2 ECV Product: Ozone mole fraction in the Upper Troposphere / Lower Stratosphere (UTLS)

Name	**Ozone mole fraction in the Upper Troposphere / Lower Stratosphere (UTLS)**				
Definition	3D field of amount of O3 (expressed in moles) in the upper troposphere/lower stratosphere (UTLS) divided by the total amount of all constituents in dry air (also expressed in moles).				
Unit	% (directly transferrable to mixing ratios, mol/mol)				
Note	The team of ozone experts unanimously agreed that the uncertainty and stability requirements for each of these ozone data products should be expressed as % and %/decade in the tables. Defining requirements in units of mixing ratios or Dobson Units would require each uncertainty and stability requirement be a wide range of values. We therefore found it more definitive and intuitive that each table entry is one number in % or %/decade. To help translate the requirements in % or %/decade to absolute units we have put a footnote beneath each table that quantitatively describes the wide range of mixing ratios or Dobson Units corresponding to that data product. This helps to explain why the requirements in the tables are not expressed in units of mixing ratio or DU. Requirements in absolute units are easily calculated by multiplying the % (or %/decade) in the table by the mixing ratio or DU ranges in the footnotes.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	10	1, 2, 3, 4,5
			B	50	
			T	200	
Vertical Resolution	km		G	0.5	1,2,3,4,5
			B	1	
			T	3	
Temporal Resolution	d		G	1/4	1, 2, 3, 4,5
			B	1	
			T	30	
Timeliness	d		G	1/4	
			B	1	
			T	30	
Required Measurement Uncertainty (2-sigma)	%		G	2	1, 2, 3, 4,5 Requirements for uncertainty (%) and stability (%/decade) translate o wide mixing ratio requirement ranges based on a 50 ppb to 3 ppm range of ozone mixing ratios in the UTLS.
			B	5	
			T	10	
Stability	%/decade		G	1	1, 2, 3, 4,5 Requirements for uncertainty (%) and stability (%/decade) translate to wide mixing ratio requirement ranges based on a 50 ppb to 3 ppm range of ozone mixing ratios in the UTLS.
			B	2	
			T	3	
Standards and References	1. Ozone Climate Change Initiative User Requirements Document http://cci.esa.int/sites/default/files/filedepot/incoming/Ozone_cci_urd_v3.0_final.pdf 2. WMO (World Meteorological Organization), Stratospheric Ozone Changes and Climate in Scientific Assessment of Ozone Depletion: 2018, Global Ozone Research and Monitoring Project–Report No. 58, 588 pp., Geneva, Switzerland, 2018. https://www.esrl.noaa.gov/csd/assessments/ozone/2018/downloads/Chapter5_2018OzoneAssessment.pdf 3. Climate Monitoring User Group CCI Requirements Baseline Documents http://ensembles-eu.metoffice.com/cmug/CMUG_PHASE_2_D1.1_Requirements_v0.6.pdf 4. WMO (World Meteorological Organization), Update on Global Ozone: Past, Present and Future in Scientific Assessment of Ozone Depletion: 2018, Global Ozone Research and Monitoring Project–Report No. 58, 588 pp., Geneva, Switzerland, 2018. https://www.esrl.noaa.gov/csd/assessments/ozone/2018/downloads/Chapter3_2018OzoneAssessment.pdf 5. Gaudel, A., et al. (2018), Tropospheric Ozone Assessment Report: Present-day distribution and trends of tropospheric ozone relevant to climate and global atmospheric chemistry model evaluation, Elem. Sci. Anth., 6(1), 39, https://doi.org/10.1525/elementa.291				

3.2.3 ECV Product: Ozone mole fraction in the Middle and Upper Stratosphere

Name	Ozone mole fraction in the Middle and Upper Stratosphere
Definition	3D field of amount of O3 (expressed in moles) in the Middle and Upper Stratosphere divided by the total amount of all constituents in dry air (also expressed in moles).
Unit	% (directly transferrable to mixing ratios, mol/mol)
Note	The team of ozone experts unanimously agreed that the uncertainty and stability requirements for each of these ozone data products should be expressed as % and %/decade in the tables. Defining requirements in units of mixing ratios or Dobson Units would require each uncertainty and stability requirement be a wide range of values. We therefore found it more definitive and intuitive that each table entry is one number in % or %/decade. To help translate the requirements in % or %/decade to absolute units we have put a footnote beneath each table that quantitatively describes the wide range of mixing ratios or Dobson Units corresponding to that data product. This helps to explain why the requirements in the tables are not expressed in units of mixing ratio or DU. Requirements in absolute units are easily calculated by multiplying the % (or %/decade) in the table by the mixing ratio or DU ranges in the footnotes.

Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	20	1, 2, 3, 4
			B	100	
			T	500	
Vertical Resolution	km		G	1	1,2,3,4
			B	3	
			T	10	
Temporal Resolution	d		G	1/4	1, 2, 3, 4
			B	1	
			T	30	
Timeliness	d		G	1/4	
			B	1	
			T	30	
Required Measurement Uncertainty (2-sigma)	%		G	5	1, 2, 3, 4 Requirements for uncertainty (%) and stability (%/decade) translate to wide mixing ratio requirement ranges based on a 3 to 10 ppm range of ozone mixing ratios in the middle and upper stratosphere.
			B	10	
			T	15	
Stability	%/decade		G	1	1, 2, 3, 4 Requirements for uncertainty (%) and stability (%/decade) translate to wide mixing ratio requirement ranges based on a 3 to 10 ppm range of ozone mixing ratios in the middle and upper stratosphere.
			B	2	
			T	3	
Standards and References	1. Ozone Climate Change Initiative User Requirements Document http://cci.esa.int/sites/default/files/filedepot/incoming/Ozone_cci_urd_v3.0_final.pdf 2. WMO (World Meteorological Organization), Stratospheric Ozone Changes and Climate in Scientific Assessment of Ozone Depletion: 2018, Global Ozone Research and Monitoring Project–Report No. 58, 588 pp., Geneva, Switzerland, 2018. https://www.esrl.noaa.gov/csd/assessments/ozone/2018/downloads/Chapter5_2018OzoneAssessment.pdf 3. Climate Monitoring User Group CCI Requirements Baseline Documents http://ensembles-eu.metoffice.com/cmug/CMUG_PHASE_2_D1.1_Requirements_v0.6.pdf 4. WMO (World Meteorological Organization), Update on Global Ozone: Past, Present and Future in Scientific Assessment of Ozone Depletion: 2018, Global Ozone Research and Monitoring Project–Report No. 58, 588 pp., Geneva, Switzerland, 2018. https://www.esrl.noaa.gov/csd/assessments/ozone/2018/downloads/Chapter3_2018OzoneAssessment.pdf				

3.2.4 ECV Product: Ozone Tropospheric Column

Name	Ozone Tropospheric Column				
Definition	2D field of total amount of O3 molecules per unit area in an atmospheric column extending from the Earth's surface to the tropopause.				
Unit	% (directly transferrable to Dobson units)				
Note	The team of ozone experts unanimously agreed that the uncertainty and stability requirements for each of these ozone data products should be expressed as % and %/decade in the tables. Defining requirements in units of mixing ratios or Dobson Units would require each uncertainty and stability requirement be a wide range of values. We therefore found it more definitive and intuitive that each table entry is one number in % or %/decade. To help translate the requirements in % or %/decade to absolute units we have put a footnote beneath each table that quantitatively describes the wide range of mixing ratios or Dobson Units corresponding to that data product. This helps to explain why the requirements in the tables are not expressed in units of mixing ratio or DU. Requirements in absolute units are easily calculated by multiplying the % (or %/decade) in the table by the mixing ratio or DU ranges in the footnotes.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	5	1, 2, 3, 4, 5
			B	20	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1/24	1, 2, 3, 4, 5
			B	1/4	
			T	30	
Timeliness	d		G	1/24	
			B	1	
			T	30	
Required Measurement Uncertainty (2-sigma)	%		G	5	1, 2, 3, 4, 5 Requirements for uncertainty (%) and stability (%/decade) translate to wide Dobson Unit requirement ranges based on a 20 to 45 DU range of ozone tropospheric columns.
			B	10	
			T	15	
Stability	%/decade		G	1	1, 2, 3, 4,5 Requirements for uncertainty (%) and stability (%/decade) translate to wide Dobson Unit requirement ranges based on a 20 to 45 DU range of ozone tropospheric columns.
			B	2	
			T	3	
Standards and References	1. Ozone Climate Change Initiative User Requirements Document http://cci.esa.int/sites/default/files/filedepot/incoming/Ozone_cci_urd_v3.0_final.pdf 2. WMO (World Meteorological Organization), Stratospheric Ozone Changes and Climate in Scientific Assessment of Ozone Depletion: 2018, Global Ozone Research and Monitoring Project–Report No. 58, 588 pp., Geneva, Switzerland, 2018. https://www.esrl.noaa.gov/csd/assessments/ozone/2018/downloads/Chapter5_2018OzoneAssessment.pdf 3. Climate Monitoring User Group CCI Requirements Baseline Documents http://ensembles-eu.metoffice.com/cmug/CMUG_PHASE_2_D1.1_Requirements_v0.6.pdf 4. WMO (World Meteorological Organization), Update on Global Ozone: Past, Present and Future in Scientific Assessment of Ozone Depletion: 2018, Global Ozone Research and Monitoring Project–Report No. 58, 588 pp., Geneva, Switzerland, 2018. https://www.esrl.noaa.gov/csd/assessments/ozone/2018/downloads/Chapter3_2018OzoneAssessment.pdf 5. Gaudel, A., et al. (2018), Tropospheric Ozone Assessment Report: Present-day distribution and trends of tropospheric ozone relevant to climate and global atmospheric chemistry model evaluation, Elem. Sci. Anth., 6(1), 39, https://doi.org/10.1525/elementa.291				

3.2.5 ECV Product: Ozone Stratospheric Column

Name	Ozone Stratospheric Column
Definition	2D field of total amount of O3 molecules per unit area in an atmospheric column extending from tropopause to stratopause.
Unit	% (directly transferrable to Dobson units)
Note	The team of ozone experts unanimously agreed that the uncertainty and stability requirements for each of these ozone data products should be expressed as % and %/decade in the tables. Defining requirements in units of mixing ratios or Dobson Units would require each uncertainty and stability requirement be a wide range of values. We therefore found it more definitive and intuitive that each table entry is one number in % or %/decade. To help translate the requirements in % or %/decade to absolute units we have put a footnote beneath each table that quantitatively describes the wide range of mixing ratios or Dobson Units corresponding to that data product. This helps to explain why the requirements in the tables are not expressed in units of mixing ratio or DU. Requirements in absolute units are easily calculated by multiplying the % (or %/decade) in the table by the mixing ratio or DU ranges in the footnotes. This data product must consider additional uncertainties introduced by errors in tropopause heights and must definitively state which tropopause definition was used.

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	20	1, 2, 3, 4
			B	100	
			T	500	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1/24	1, 2, 3, 4
			B	1	
			T	30	
Timeliness	d		G	1/4	
			B	1	
			T	30	
Required Measurement Uncertainty (2-sigma)	%		G	1	1, 2, 3, 4
			B	3	Requirements for uncertainty (%) and stability (%/decade) translate to wide Dobson Unit requirement ranges based on a 150 to 450 DU range of ozone stratospheric columns.
			T	5	
Stability	%/decade		G	1	1, 2, 3, 4
			B	2	Requirements for uncertainty (%) and stability (%/decade) translate to wide Dobson Unit requirement ranges based on a 150 to 450 DU range of ozone stratospheric columns.
			T	3	

Standards and References	
	1. Ozone Climate Change Initiative User Requirements Document http://cci.esa.int/sites/default/files/filedepot/incoming/Ozone_cci_urd_v3.0_final.pdf 2. WMO (World Meteorological Organization), Stratospheric Ozone Changes and Climate in Scientific Assessment of Ozone Depletion: 2018, Global Ozone Research and Monitoring Project–Report No. 58, 588 pp., Geneva, Switzerland, 2018. https://www.esrl.noaa.gov/csd/assessments/ozone/2018/downloads/Chapter5_2018OzoneAssessment.pdf 3. Climate Monitoring User Group CCI Requirements Baseline Documents http://ensembles-eu.metoffice.com/cmug/CMUG_PHASE_2_D1.1_Requirements_v0.6.pdf 4. WMO (World Meteorological Organization), Update on Global Ozone: Past, Present and Future in Scientific Assessment of Ozone Depletion: 2018, Global Ozone Research and Monitoring Project–Report No. 58, 588 pp., Geneva, Switzerland, 2018. https://www.esrl.noaa.gov/csd/assessments/ozone/2018/downloads/Chapter3_2018OzoneAssessment.pdf

3.2.6 ECV Product: Ozone Total Column

Name	Ozone Total Column
Definition	2D field of total amount of O3 molecules per unit area in an atmospheric column extending from the Earth's surface to the upper edge of the atmosphere.
Unit	% (directly transferrable to Dobson units)
Note	The team of ozone experts unanimously agreed that the uncertainty and stability requirements for each of these ozone data products should be expressed as % and %/decade in the tables. Defining requirements in units of mixing ratios or Dobson Units would require each uncertainty and stability requirement be a wide range of values. We therefore found it more definitive and intuitive that each table entry is one number in % or %/decade. To help translate the requirements in % or %/decade to absolute units we have put a footnote beneath each table that quantitatively describes the wide range of mixing ratios or Dobson Units corresponding to that data product. This helps to explain why the requirements in the tables are not expressed in units of mixing ratio or DU. Requirements in absolute units are easily calculated by multiplying the % (or %/decade) in the table by the mixing ratio or DU ranges in the footnotes.

Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	20	1, 2, 3, 4
			B	100	
			T	500	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1/24	1, 2, 3, 4
			B	1	
			T	30	
Timeliness	d		G	1/24	
			B	1	
			T	30	
Required Measurement Uncertainty (2-sigma)	%		G	1	1, 2, 3, 4
			B	2	Requirements for uncertainty (%) and stability (%/decade) translate to wide Dobson Unit requirement ranges based on a 200 to 500 DU range of ozone total columns.
			T	3	
Stability	%/decade		G	1	1, 2, 3, 4
			B	2	Requirements for uncertainty (%) and stability (%/decade) translate to wide Dobson Unit requirement ranges based on a 200 to 500 DU range of ozone total columns.
			T	3	
Standards and References	1. Ozone Climate Change Initiative User Requirements Document http://cci.esa.int/sites/default/files/filedepot/incoming/Ozone_cci_urd_v3.0_final.pdf 2. WMO (World Meteorological Organization), Stratospheric Ozone Changes and Climate in Scientific Assessment of Ozone Depletion: 2018, Global Ozone Research and Monitoring Project–Report No. 58, 588 pp., Geneva, Switzerland, 2018. https://www.esrl.noaa.gov/csd/assessments/ozone/2018/downloads/Chapter5_2018OzoneAssessment.pdf 3. Climate Monitoring User Group CCI Requirements Baseline Documents http://ensembles-eu.metoffice.com/cmug/CMUG_PHASE_2_D1.1_Requirements_v0.6.pdf 4. WMO (World Meteorological Organization), Update on Global Ozone: Past, Present and Future in Scientific Assessment of Ozone Depletion: 2018, Global Ozone Research and Monitoring Project–Report No. 58, 588 pp., Geneva, Switzerland, 2018. https://www.esrl.noaa.gov/csd/assessments/ozone/2018/downloads/Chapter3_2018OzoneAssessment.pdf				

3.3 ECV: Precursors (Supporting the aerosol and ozone ECVs)

3.3.1 ECV Product: CO Tropospheric Column

Name	CO Tropospheric Column				
Definition	2D field of total amount of CO molecules per unit area in an atmospheric column extending from the Earth's surface to the tropopause.				
Unit	ppb				
Note	Total column CO can approximate tropospheric CO. Observations exist for total column CO.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	10	In line with O3 & AOD & precursors
			B	30	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1/24	In line with O3 & AOD & precursors
			B	1	
			T	30	
Timeliness	d		G	1	
			B	7	
			T	30	
Required Measurement Uncertainty (2-sigma)	ppb		G	1	Relaxed from GAW #242
			B	5	
			T	10	
Stability	ppb/decade		G	<1	accuracy/5
			B	1	
			T	2	
Standards and References	GAW Report 242: GAW Report, 242. 19th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2017) Landgraf et al, 2016, AMT; https://doi.org/10.5194/amt-9-4955-2016 GAW Report, 255. 20th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2019) Crotwell A.; Lee, H.; Steinbacher M.; World Meteorological Organization (WMO) - WMO, 2020 https://library.wmo.int/doc_num.php?explnum_id=10353				

3.3.2 ECV Product: CO Mole fraction

Name	CO Mole fraction				
Definition	3D field of amount of CO (Carbon monoxide, expressed in moles) divided by the total amount of all constituents in dry air (also expressed in moles).				
Unit	Mole fraction				
Note	Tropospheric				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	close to the ozone requirements
			B	30	
			T	100	
Vertical Resolution	m		G	1	in line with ozone requirements
			B	3	
			T	5	
Temporal Resolution	d		G	1/24	in line with ozone requirements
			B	1	
			T	30	
Timeliness	d		G	1	
			B	7	
			T	30	
Required Measurement Uncertainty (2-sigma)	ppb		G	1	
			B	5	
			T	10	
Stability	ppb/decade		G	<1	
			B	1	
			T	3	
Standards and References	GAW Report, 242. 19th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2017) GAW Report, 255. 20th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2019) Crotwell A.; Lee, H.; Steinbacher M.; World Meteorological Organization (WMO) - WMO, 2020 https://library.wmo.int/doc_num.php?explnum_id=10353				

3.3.3 ECV Product: HCHO Tropospheric Column

Name	HCHO Tropospheric Column				
Definition	2D field of total amount of HCHO molecules per unit area in an atmospheric column extending from the Earth's surface to the tropopause.				
Unit	molecules cm^{-2}				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B	30	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1/24	in line with O3 & aerosols.
			B	1	
			T	30	
Timeliness	d		G	1	
			B	7	
			T	30	
Required Measurement Uncertainty (2-sigma)	molecules cm^{-2}		G	max (20%, 8E15)	Pre-launch accuracy requirements for TROPOMI were 40-80 %; Vigoroux et al., 2020; https://doi.org/10.5194/amt-13-3751-2020 Achievable with satellites, noting that accuracy is typically dominated by fit error, can be largely improved by temporal and spatial averaging
			B	max (40%,16E15)	
			T	max (100%,40E15)	
Stability	molecules cm^{-2}		G	max (4%, 8E15)	
			B	max (8%,8E15)	
			T	max (20%,8E15)	
Standards and References	Uncertainties in Hydrocarbon emission inventories (Cao et al, 2018, Kaiser et al 2018). Typical variability over continental regions, Zhu et al., 2016. Variability of the remote atmosphere, Wolfe et al 2019.				

3.3.4 ECV Product: SO_2 Tropospheric Column

Name	SO_2 Tropospheric Column				
Definition	2D field of total amount of SO_2 molecules per unit area in an atmospheric column extending from the Earth's surface to the tropopause.				
Unit	molecules cm^{-2}				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	in line with O3 & AOD & precursors
			B	30	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1/24	in line with O3 & AOD & precursors
			B	1	
			T	30	
Timeliness	d		G	1	
			B	7	
			T	30	
Required Measurement Uncertainty (2-sigma)	molecules cm^{-2}		G	max (30%,6E15)	Improved from Breakthrough
			B	max(60%, 12E15)	Driven by relaxed NO_2 accuracy (1.5* NO_2 accuracy in %)
			T	max(100%, 20E15)	Relaxed from Breakthrough, closer to achievable
Stability	Molecules cm^{-2}/ decade		G	max(6%,1.2E15)	Accuracy/5
			B	max(12%, 2.4E15)	
			T	max(20%, 4E15)	
Standards and References	Accuracy is typically dominated by fit error, can be largely improved by temporal and spatial averaging, AMF for tropospheric SO2 is smaller than for HCHO and NO_2				

3.3.5 ECV product: SO_2 Stratospheric Column

Name	**SO_2 Stratospheric Column**				
Definition	2D field of total amount of SO_2 molecules per unit area in an atmospheric column extending from the tropopause to the top of the atmosphere.				
Unit	Molecules cm^{-2}				
Note					
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	10	in line with O3 & AOD & precursors
			B	30	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1/24	in line with O3 & AOD & precursors
			B	1	
			T	30	
Timeliness	d		G	1	
			B	7	
			T	30	
Required Measurement Uncertainty (2-sigma)	molecules cm^{-2}		G	max(30%,6E15)	According to tropospheric SO_2 requirements
			B	max(60%, 12E15)	
			T	max(100%, 20E15)	
Stability	molecules cm^{-2} /decade		G	max(10%,3E15)	Accuracy/3
			B	max(20%,4E15)	
			T	max(30%, 7E15)	
Standards and References	Accuracy is typically dominated by fit error, can be largely improved by temporal and spatial averaging, AMF for tropospheric SO_2 is smaller than for HCHO and NO_2.				

3.3.6 ECV Product: NO_2 Tropospheric Column

Name	**NO_2 Tropospheric Column**				
Definition	2D field of total amount of NO_2 molecules per unit area in an atmospheric column extending from the Earth's surface to the tropopause.				
Unit	molecules cm^{-2}				
Note					
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	10	in line with O3 & AOD & precursors
			B	30	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1/24	in line with O3 & AOD & precursors
			B	1	
			T	30	
Timeliness	d		G	1	
			B	7	
			T	30	
Required Measurement Uncertainty (2-sigma)	molecules cm^{-2}		G	max(20%, 1E15)	Improved accuracy
			B	max(40%, 2E15)	Requirement according to 2016 IP
			T	max(100%, 5E15)	Achievable accuracy.
Stability	molecules cm^{-2}/ decade		G	max(4%, 1E15)	accuracy/5
			B	max(8%, 1E15)	
			T	max(20%, 1E15)	
Standards and References					

3.3.7 ECV Product: NO_2 Mole Fraction

	NO_2 Mole Fraction				
Name	3D field of amount of NO_2 (expressed in moles) divided by the total amount of all constituents in dry air (also expressed in moles) – in stratosphere.				
Unit	ppb				
Note					
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	20	in line with ozone profile
			B	100	
			T	500	
Vertical Resolution	km		G	1	in line with ozone profile
			B	3	in line with ozone profile
			T	5	Relaxed from breakthrough
Temporal Resolution	d		G	1/4	
			B	1	
			T	30	
Timeliness	d		G	1	in line with ozone profile
			B	7	
			T	30	
Required Measurement Uncertainty (2-sigma)	%		G	20	Achievable with solar occultation
			B	40	Limb scatter, stellar occultation, joint random & systematic uncertainty (1-sigma) around 20%
			T	60	Relaxed compared to limb scatter
Stability	%/decade		G	4	accuracy/5
			B	8	
			T	12	
Standards and References	https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/91JD01344 https://acp.copernicus.org/articles/8/5801/2008/acp-8-5801-2008.pdf Brochede et al, 2007; geophys comparison, https://doi.org/10.1029/2006JD007586 Tamminen et. Al 2010. doi:10.5194/acp-10-9505-2010 https://acp.copernicus.org/articles/7/3261/2007/ Fussen et al, 2019, https://doi.org/10.1016/j.jqsrt.2019.06.021				

3.4 ECV: Aerosols Properties

3.4.1 ECV Product: Aerosol Light Extinction Vertical Profile (Troposphere)

Name	Aerosol Light Extinction Vertical Profile (Troposphere)				
Definition	Spectrally dependent sum of aerosol particle light scattering and absorption coefficients per unit of geometrical path length.				
Unit	km^{-1}				
Note	As proxy where extinction profiles are not available a very useful information is the Aerosol Layer Height layer derived from lidar or thermal instruments				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	50	Extinction profiles are retrieved by lidar observations so they typically refer to punctual observations. The reported values in terms of horizontal resolution are here mutated from the AOD.
			B	100	
			T	500	
Vertical Resolution	km		G	0.2	Effective vertical resolution depends on the aerosol load strongly. The reported values refer to aerosol extinction @532 nm larger than 2.5 10-2 km-1
			B	1	
			T	2	
Temporal Resolution	d	All the indicated averaging times are assumed to be representative	G	1	
			B	30	
			T	90	
Timeliness	y		G	0,003	
			B	0.08	
			T	1	
Required Measurement Uncertainty (2-sigma)	%		G	20	Uncertainty is dependent on the atmospheric aerosol load. These relative uncertainties refer to extinction values @532nm larger than 2.5 10-2 km^{-1} The reference value above (2.5 10-2 km^{-1}), to which the uncertainty and stability and vertical resolution requirements apply, are related to the presence of aerosol. The value of 2.5 10-2 km-1 @532nm has been estimated within ACTRIS/EARLINET as indicative of the presence of an aerosol layer (ref : QC documentation available at www.earlinet.org)
			B	40	
			T	60	
Stability	% /decade		G	10	These percentages refer to extinction values @532nm larger than 2.5 10-2 km-1. Stability for users' requirements for this quantity are estimated from the corresponding AOD: for AOD the required stability is one half of the required uncertainty. This criterion has been adopted also for the aerosol extinction (which is the profiling analogue of AOD).
			B	20	
			T	30	
Standards and References	Samset, B. H., and G. Myhre, Climate response to externally mixed black carbon as a function of altitude, J. Geophys. Res. Atmos., 120, 2913–2927, doi:10.1002/2014JD022849, 2015. Pappalardo, G., Amodeo, A., Apituley, A., Comeron, A., Freudenthaler, V., Linné, H., Ansmann, A., Bösenberg, J., D'Amico, G., Mattis, I., Mona, L., Wandinger, U., Amiridis, V., Alados-Arboledas, L., Nicolae, D., and Wiegner, M.: EARLINET: towards an advanced sustainable European aerosol lidar network, Atmos. Meas. Tech., 7, 2389–2409, https://doi.org/10.5194/amt-7-2389-2014, 2014. Welton, E.J., J. R. Campbell, J. D. Spinhirne, and V. S. Scott. Global monitoring of clouds and aerosols using a network of micro-pulse lidar systems, Proc. SPIE, 4153, 151-158, 2001. Welton, E.J. K.J. Voss, H.R. Gordon, H. Maring, A. Smirnov, B. Holben, B. Schmid, J.M. Livingston, P.B. Russell, P.A. Durkee, P. Formenti, M.O. Andreae. Ground-based Lidar Measurements of Aerosols During ACE-2: Instrument Description, Results, and Comparisons with other Ground-based and Airborne Measurements, Tellus B, 52, 635-650, 2000. Anderson, T. L., R. J. Charlson, D. M. Winker, J. A. Ogren, and K. Holmén, Mesoscale variations of tropospheric aerosols, J. Atmos. Sci., 60, 119– 136, 2003. Shimizu, A., T. Nishizawa, Y. Jin, S.-W. Kim, Z. Wang, D. Batdorj and N. Sugimoto, Evolution of a lidar network for tropospheric aerosol detection in East Asia, Optical Engineering. 56 (3), 031219, 2016.				

3.4.2 ECV Product: Aerosol Light Extinction Vertical Profile (Stratosphere)

Name	Aerosol light extinction vertical profile in the stratosphere				
Definition	Spectrally dependent sum of aerosol particle light scattering and absorption coefficients per unit of geometrical path length.				
Unit	km^{-1}				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	200	Extinction profiles are retrieved by lidar observations so they typically refer to punctual observations. But they are also inverted from limb and occultation soundings from satellite for which the spatial resolution can be used when aggregating individual measurements In the stratosphere aerosols are fast spread in latitude bands. Therefore, higher resolution is required along meridians than within latitude bands Source: Aerosol_cci2 User Requirements Document v3.0, 2017
			B	500 (latitude) x 6000 (longitude)	
			T		
Vertical Resolution	km		G	1	Effective vertical resolution depends on the aerosol load strongly. The reported values refer to aerosol extinction @532 nm larger than 2.5 10-2 km^{-1} Finer vertical resolution is required near the tropopause so that small to medium sized volcanic eruptions can be detected. B: 1 at 10 km altitude; 2 at 30 km altitude Source: Aerosol_cci2 User Requirements Document v3.0, 2017
			B	1 (2)	
			T	2	
Temporal Resolution	d		G	5	All the indicated averaging times are assumed to be representative With 5 days also minor volcanic eruptions can be detected, with 30 days only medium to large eruptions can be detected Source: Bingen, et al., 2017 and Popp, et al., 2016
			B	5	
			T	30	
Timeliness	y		G		
			B		
			T	1	No near-real time usage foreseen; climate studies are main use
Required Measurement Uncertainty (2-sigma)	%		G	20	Uncertainty is dependent on the atmospheric aerosol load. These relative uncertainties refer to extinction values @532nm larger than 2.5 10-2 km-1 Source: Aerosol_cci2 User Requirements Document v3.0, 2017
			B	40	
			T		
Stability	% /decade		G	20	These percentages refer to extinction values @532nm larger than 2.5 10-2 km-1. Source: Aerosol_cci2 User Requirements Document v3.0, 2017
			B	40	
			T		
Standards and References	ESA Aerosol_cci2, User Requirements Document, v3., 12.03.2017 Christine Bingen, Charles E. Robert, Kerstin Stebel, Christoph Brühl, Jennifer Schallock, Filip Vanhellemont, Nina Mateshvili, Michael Höpfner, Thomas Trickl, John E. Barnes, Julien Jumelet, Jean-Paul Vernier, Thomas Popp, Gerrit de Leeuw, and Simon Pinnock, Stratospheric aerosol data records for the Climate Change Initiative: development, validation and application to Chemistry-Climate Modelling, Remote Sensing of Environment, 2017, http://dx.doi.org/10.1016/j.rse.2017.06.002 Section 4.4 of: Thomas Popp, Gerrit de Leeuw, Christine Bingen, Christoph Brühl, Virginie Capelle, Alain Chedin, Lieven Clarisse, Oleg Dubovik, Roy Grainger, Jan Griesfeller, Andreas Heckel, Stefan Kinne, Lars Klüser, Miriam Kosmale, Pekka Kolmonen, Luca Lelli, Pavel Litvinov, Linlu Mei, Peter North, Simon Pinnock, Adam Povey, Charles Robert, Michael Schulz, Larisa Sogacheva, Kerstin Stebel, Deborah Stein Zweers, Gareth Thomas, Lieuwe Gijsbert Tilstra, Sophie Vandenbussche, Pepijn Veefkind, Marco Vountas and Yong Xue, Development, Production and Evaluation of Aerosol Climate Data Records from European Satellite Observations (Aerosol_cci), Remote Sensing, 8, 421; doi:10.3390/rs8050421, 2016				

3.4.3 ECV Product: Multi-wavelength Aerosol Optical Depth

Name	Multi-wavelength Aerosol Optical Depth
Definition	Multi-wavelength AOD is the spectral dependent aerosol extinction coefficient integrated over the geometrical path length. (see note)
Unit	dimensionless
Note	Aerosol Optical Depth quantifies the extinction of the radiation while propagating in an aerosol layer and reflects the aerosol loading information in the view of remote sensing measurement. AOD varies with wavelength and this variation is related to the aerosol size and type. The GAW guidelines recommend AOD be measured at 3 or more wavelengths among 368, 412, 500, 675, 778, and 862 nm with a bandwidth of 5nm. 1) under some assumptions of aerosol models and surface reflectances, spectral-dependence of AOD permits retrieval of Fine-AOD and Coarse-AOD, defined as the fraction of total aerosol optical depth attributed to the “non-dust” and "dust" aerosols, respectively, which are important parameters to distinguish aerosol type. Also sea-salt is part of the coarse mode AOD 2) The absorption aerosol optical depth (AAOD) is the fraction of AOD related to light absorption and is defined as AAOD=(1−ωo)×AOD where ωo is the column integrated aerosol single scattering albedo.

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	20	
			B	100	
			T	500	
Vertical Resolution			G	-	N/A.
			B	-	
			T	-	
Temporal Resolution	d		G	0.01	All averages assumed to be representative
			B	1	
			T	30	
Timeliness	d		G	1	
			B	7	
			T	30	
Required Measurement Uncertainty (2-sigma)	% or AOD		G	4% or 0.02	
			B	10% or 0.030	
			T	20% or 0.06	
Stability	%/decade or AOD/decade		G	2% or 0.01	
			B	4% or 0.02	
			T	10% or 0.04	
Standards and References	Levy, R. C., Mattoo, S., Munchak, L. A., Remer, L. A., Sayer, A. M., Patadia, F., and Hsu, N. C.: The Collection 6 MODIS aerosol products over land and ocean, Atmos. Meas. Tech., 6, 2989–3034, https://doi.org/10.5194/amt-6-2989-2013, 2013 CIMO-WMO report No 1019, “Abridged final report with resolutions and recommendations”, 2006 Giles, D. M., Sinyuk, A., Sorokin, M. G., Schafer, J. S., Smirnov, A., Slutsker, I., Eck, T. F., Holben, B. N., Lewis, J. R., Campbell, J. R., Welton, E. J., Korkin, S. V., and Lyapustin, A. I.: Advancements in the Aerosol Robotic Network (AERONET) Version 3 database – automated near-real-time quality control algorithm with improved cloud screening for Sun photometer aerosol optical depth (AOD) measurements, Atmos. Meas. Tech., 12, 169–209, https://doi.org/10.5194/amt-12-169-2019, 2019 Cuevas, E., Romero-Campos, P. M., Kouremeti, N., Kazadzis, S., Räisänen, P., García, R. D., Barreto, A., Guirado-Fuentes, C., Ramos, R., Toledano, C., Almansa, F., and Gröbner, J.: Aerosol optical depth comparison between GAW-PFR and AERONET-Cimel radiometers from long-term (2005–2015) 1 min synchronous measurements, Atmos. Meas. Tech., 12, 4309–4337, https://doi.org/10.5194/amt-12-4309-2019, 2019				

Kazadzis, S., Kouremeti, N., Nyeki, S., Gröbner, J., and Wehrli, C.: The World Optical Depth Research and Calibration Center (WORCC) quality assurance and quality control of GAW-PFR AOD measurements, Geosci. Instrum. Method. Data Syst., 7, 39-53, https://doi.org/10.5194/gi-7-39-2018, 2018a.

Kazadzis, S., Kouremeti, N., Diémoz, H., Gröbner, J., Forgan, B. W., Campanelli, M., Estellés, V., Lantz, K., Michalsky, J., Carlund, T., Cuevas, E., Toledano, C., Becker, R., Nyeki, S., Kosmopoulos, P. G., Tatsiankou, V., Vuilleumier, L., Denn, F. M., Ohkawara, N., Ijima, O., Goloub, P., Raptis, P. I., Milner, M., Behrens, K., Barreto, A., Martucci, G., Hall, E., Wendell, J., Fabbri, B. E., and Wehrli, C.: Results from the Fourth WMO Filter Radiometer Comparison for aerosol optical depth measurements, Atmos. Chem. Phys., 18, 3185-3201, https://doi.org/10.5194/acp-18-3185-2018, 2018b.

Schutgens, N., Tsyro, S., Gryspeerdt, E., Goto, D., Weigum, N., Schulz, M., and Stier, P.: On the spatio-temporal representativeness of observations, Atmos. Chem. Phys., 17, 9761–9780, https://doi.org/10.5194/acp-17-9761-2017, 2017.

3.4.4 ECV product: Chemical Composition of Aerosol Particles

Name	Chemical Composition of Aerosol Particles				
Definition	Aerosol particles are chemically composed of inorganic salts (ammonium sulfates, ammonium nitrate, and sea salt), organic compounds, Elemental Carbon (EC), dust, and volcanic ash. These species are often internally mixed within a particle with mixtures depending on sources (primary particles and gas phase precursors), atmospheric processes (gas to particle conversion, cloud processing, and condensation), and atmospheric conditions (T, P, and RH). The chemical composition of aerosol particles is often expressed in µg m^{-3}.				
Unit	µg m^{-3}				
Note	Climate relevant properties of aerosol particles include hygroscopicity and refractive index. To a first approximation knowledge of the speciated amounts of key components (total inorganics – including sea-salt- , organics, Equivalent Black Carbon, mineral dust, and volcanic ash) is sufficient. Dust can be approximated from the difference between total Mass and sum of Inorganic, EC and OC. As a proxy for the chemical composition, combination of different properties can be used, e.g. size (from Extinction Angström exponent or Fine Mode fraction), absorption (from SSA or AAOD), absorption colour (Absorption Angström exponent). However, any such estimated characterization needs to be associated with a clear definition how a certain aerosol type was characterized and this should be part of the metadata in a product file.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	50	Horizontal definition based on Anderson et al., 2003
			B	100	
			T	500	
Vertical Resolution	km		G	1	Information on both single point AND integrated column are valuable as a threshold. More precise information can be obtained by using a profile at 5km resolution (breakthrough) or 1 km (Goal).
			B	5	
			T		
Temporal Resolution	d	All averages assumed to be representative	G	1	
			B	30	
			T	90	
Timeliness	d		G	0.1	
			B	1	
			T	365	
Required Measurement Uncertainty (2-sigma)	%		G	20	
			B	40	
			T	60	
Stability	% /decade		G	2	
			B	2	
			T	4	
Standards and References	Anderson, T. L., R. J. Charlson, D. M. Winker, J. A. Ogren, and K. Holmén, Mesoscale variations of tropospheric aerosols, J. Atmos. Sci., 60, 119– 136, 2003. Aas, W., Mortier, A., Bowersox, V. et al. Global and regional trends of atmospheric sulfur. Sci Rep 9, 953 (2019) doi:10.1038/s41598-018-37304-0. Putaud, J. P., Raes, F., Van Dingenen, R., Brüggemann, E., Facchini, M. C., Decesari, S., Fuzzi, S., Gehrig, R., Hüglin, C., Laj, P., Lorbeer, G., Maenhaut, W., Mihalopoulos, N., Müller, K., Querol, X., Rodriguez, S., Schneider, J., Spindler, G., Ten Brink, H., Tørseth, K., and Wiedensohler, A.: European aerosol phenomenology – 2: chemical characteristics of particulate matter at kerbside, urban, rural and background sites in Europe, Atmos. Environ., 38, 2579–2595, 2004.				

3.4.5 ECV Product: Number of Cloud Condensation Nuclei

Name	Number of Cloud Condensation Nuclei				
Definition	Number of aerosol particles which can activate to a cloud droplet at a given supersaturations of water. CCN is often indicated as a percent of the total CN for specific supersaturation typical of atmospheric cloud formation.				
Unit	Dimensionless				
Note	CCN depends on the supersaturation. Whenever provision of CCN for a range of supersaturation is not available, a typical value of 0.5% can be used as typical supersaturation under atmospheric conditions. The CCN number concentration can be approximated by the fraction of particles larger than a given diameter from the particle number size distribution, generally the number of particles larger than 100 nm, which provide a good approximation of particles activated at « typical » supersaturation. Where no other data are available, fine mode AOD can be used as a qualitative proxy for CCN				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	50	Horizontal definition based on Anderson et al., 2003, Sun et al., 2019 and Laj et al., submitted
			B	100	
			T	500	
Vertical Resolution	km		G	1	Information on both single point AND integrated column are valuable as a threshold. More precise information can be obtained by using a profile at 5km resolution (breakthrough) or 1 km (Goal).
			B	5	
			T		
Temporal Resolution	d	All averages assumed to be representative	G	0.5	
			B	1	
			T	30	
Timeliness	d		G	0.04	
			B	1	
			T	365	
Required Measurement Uncertainty (2-sigma)	%		G	20	
			B	40	
			T	60	
Stability	% /decade		G	-	Stability difficult to evaluate as no trend in CCN are currently available
			B	-	
			T	-	
Standards and References	Anderson, T. L., R. J. Charlson, D. M. Winker, J. A. Ogren, and K. Holmén, Mesoscale variations of tropospheric aerosols, J. Atmos. Sci., 60, 119– 136, 2003. Fanourgakis, GS, Kanakidou, M, Nenes, A, Bauer, SE, Bergman, T, Carslaw, KS, Grini, A, Hamilton, DS, Johnson, JS, Karydis, VA, Kirkevag, A, Kodros, JK, Lohmann, U, Luo, G, Makkonen, R, Matsui, H, Neubauer, D, Pierce, JR, Schmale, J, Stier, P, Tsigaridis, K, van Noije, T, Wang, HL, Watson-Parris, D, Westervelt, DM, Yang, Y, Yoshioka, M, Daskalakis, N, Decesari, S, Gysel-Beer, M, Kalivitis, N, Liu, XH, Mahowald, NM, Myriokefalitakis, S. Schrodner, R, Sfakianaki, M, Tsimpidi, AP, Wu, MX, Yu, FQ, “Evaluation of global simulations of aerosol particle and cloud condensation nuclei number, with implications for cloud droplet formation,” Atmos. Chem. Phys., 19, 8591-8617 DOI:10.5194/acp-19-8591-2019, 2019. Schmale, J., Henning, S., Henzing, J.S., Keskinen, H., Sellegri, K., Ovadnevaite, J., Bougiatioti, A., Kalivitis, N., Stavroulas, I., Jefferson, A., Park, M., Schlag, P., Kristensson, A., Iwamoto, Y., Aalto, P., Äijälä, M., Bukowiecki, N., Decesari, S., Ehn, M., Frank, G., Fröhlich, R., Frumau, A., Herrmann, E., Holzinger, R., Kos, G., Kulmala, M., Mihalopoulos, N., Motos, G., Nenes, A., O’Dowd, C.D., Paramonov, M., Petäjä, T., Picard, D., Poulain, L., Prévôt, A.S.H., Swietlicki, E., Pöhlker, M., Pöschl, U., Artaxo, P., Brito, J., Carbone, S., Wiedensohler, A., Ogren, J., Matsuki, A., Yum, S.S., Stratmann, F., Baltensperger, U. and Gysel, M. (2017) What do we learn from long-term cloud condensation nuclei number concentration, particle number size distribution and chemical composition at regionally representative observatories? Sci. Data 4:170003, doi: 10.1038/sdata.2017.3.				

3.4.6 ECV Product: Aerosol Number Size Distribution

Name	Aerosol Number Size Distribution
Definition	The particle number size distribution (PNSD) describes the number of particles in multiple specified size ranges.
Unit	dimensionless
Note	The PNSD can provide information about primary particle sources and secondary formation processes, as well as aerosol transport. PNSD can be directly measured in-situ or retrieved under some assumptions from AOD-related measurements or light extinction vertical profile measurements. For climate application, PNSD at ambient relative humidity is relevant. As a proxy for a directly measured aerosol number size distribution, the extinction (scattering) Angstrom exponent, defined as the dependence of ln(AOD) (or ln(σsp)) on ln(λ) can be used as a qualitative indicator of aerosol particle size distribution. Values near 1 indicate a particle size distribution dominated by coarse mode aerosol such as typically associated with mineral dust and sea salt. Values of near 2 indicate particle size distributions dominated by the fine aerosol mode (usually associated with anthropogenic sources and biomass burning). The total number of particles (i.e., condensation nuclei (CN)) is the integral of PNSD over all size ranges. It can be used to derive PNSD under some assumptions. Whenever PNSD is retrieved at dry size, ambient PNSD can be retrieved with the knowledge of particle composition and hydroscopic growth model under some assumptions Number of particles below 20 nm (in diameter) are highly variable due to the process of New Particle Formation and have little direct radiative impact. Regardless, the requirement for aerosol number size distribution ideally is provided for the full size spectrum (15 nm- 15 µm) (defined as goal). Very important climate application can be made with knowledge of PNSD into 2 size ranges (fine and coarse), defined as Threshold). Knowledge of PNSD into 4 size ranges (ultrafine, Aitken, Accumulation and coarse) is defined as breakthrough.

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	50	Horizontal definition based on Anderson et al., 2003, Sun et al., 2019 and Laj et al., submitted
			B	100	
			T	500	
Vertical Resolution	km		G	1	Information on both single point AND integrated column are valuable as a threshold. More precise information can be obtained by using a profile at 5km resolution (breakthrough) or 1 km (Goal).
			B	5	
			T		
Temporal Resolution	d	All averages assumed to be representative	G	0.04	
			B	1	
			T	30	
Timeliness	d		G	0,25	
			B	30	
			T	365	
Required Measurement Uncertainty (2-sigma)			G	40% in number and 20% on size	Size distribution is a 2-D variable thus uncertainty can either refer size or number. Uncertainty requirements are therefore provided for both dimensions. The uncertainty on size refers to the diameter of the mode of the distribution
			B	60% in number in 40% in size	
			T	40% in number for fine-mode (0.05-0.5um) and 100% in number for coarse-mode (0.5-15um)	
Stability			G	2	

	% /decade		B	4	
			T	10	
Standards and References	Laj et al., A global analysis of climate-relevant aerosol properties retrieved from the network of GAW near-surface observatories, submitted to AMT Anderson, T. L., R. J. Charlson, D. M. Winker, J. A. Ogren, and K. Holmén, Mesoscale variations of tropospheric aerosols, J. Atmos. Sci., 60, 119– 136, 2003. Sun, J., W. Birmili, M. Hermann, T. Tuch, K. Weinhold, G. Spindler, A. Schladitz, S. Bastian, G. Löschau, J. Cyrys, J. Gu, H. Flentje, B. Briel, C. Asbach, H. Kaminski, L. Ries, R. Sohmer, H. Gerwig, K. Wirtz, F. Meinhardt, A. Schwerin, O. Bath, N. Ma, A. Wiedensohler, Variability of black carbon mass concentrations, sub-micrometer particle number concentrations and size distributions: results of the German Ultrafine Aerosol Network ranging from city street to High Alpine locations, Atmospheric Environment, Volume 202, 2019, Pages 256-268, ISSN 1352-2310, https://doi.org/10.1016/j.atmosenv.2018.12.029. Wiedensohler, A., Birmili, W., Nowak, A., Sonntag, A., Weinhold, K., Merkel, M., Wehner, B., Tuch, T., Pfeifer, S., Fiebig, M., Fjäraa, A. M., Asmi, E., Sellegri, K., Depuy, R., Venzac, H., Villani, P., Laj, P., Aalto, P., Ogren, J. A., Swietlicki, E., Williams, P., Roldin, P., Quincey, P., Hüglin, C., Fierz-Schmidhauser, R., Gysel, M., Weingartner, E., Riccobono, F., Santos, S., Grüning, C., Faloon, K., Beddows, D., Harrison, R., Monahan, C., Jennings, S. G., O'Dowd, C. D., Marinoni, A., Horn, H.-G., Keck, L., Jiang, J., Scheckman, J., McMurry, P. H., Deng, Z., Zhao, C. S., Moerman, M., Henzing, B., de Leeuw, G., Löschau, G., and Bastian, S.: Mobility particle size spectrometers: harmonization of technical standards and data structure to facilitate high quality long-term observations of atmospheric particle number size distributions, Atmos. Meas. Tech., 5, 657–685, https://doi.org/10.5194/amt-5-657-2012, 2012.				

3.4.7 ECV Product: Aerosol Single Scattering Albedo

Name	Aerosol Single Scattering Albedo
Definition	Spectrally dependent ratio of particle light scattering coefficient to the particle light extinction coefficient.
Unit	dimensionless
Note	The Aerosol Single Scattering Albedo (ω0 or SSA) is defined as σsp/σep, or σsp/(σsp+ σap) where (σep), is the volumetric cross-section for light extinction and is commonly called the particle light extinction coefficient typically reported in units of Mm-1 (10-6 m-1). It is the sum of the particle light scattering (σsp) and particle light absorption coefficients (σap), σep = σsp + σap . All coefficients are spectrally dependent. Purely scattering aerosol particles (e.g., ammonium sulfate) have values of 1, while very strong absorbing aerosol particles (e.g., black carbon) may have values of around 0.3 at 550nm. The absorption aerosol optical depth(AAOD) is fraction of AOD related to light absorption and is defined as AAOD= (1−ωo)×AOD where ωo is the column integrated single scattering albedo. Under some circumstances, AAOD at 550 nm is not as highly uncertain as SSA (in particular for low AOD) and can be used as ECV proxy for absorption. By part of the community AAOD is regarded better suited than SSA which is highly uncertain at low AOD.

Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	50	Anderson et al., 2003
			B	200	Laj et al., submitted)
			T	500	
Vertical Resolution	km		G	1	Information on both single point AND integrated column are valuable as a threshold. More precise information can be obtained by using a profile at 5km resolution (breakthrough) or 1 km (Goal). SSA is not directly measurable as integrated column or profile but can be retrieved under some assumptions.
			B	5	
			T		
Temporal Resolution	d		G	0.01	All averages assumed to be representative
			B	1	
			T	30	
Timeliness	d		G	1	
			B	7	
			T	30	
Required Measurement Uncertainty (2-sigma)	dimensionless		G	0.1	
			B	0.2	
			T	0.4	
Stability	% /decade		G	0.1	Stability difficult to assess due to lack of clear trends observed
			B	0.4	
			T	1	
Standards and References	Laj et al., A global analysis of climate-relevant aerosol properties retrieved from the network of GAW near-surface observatories, submitted to AMT Collaud Coen et al., Multidecadal trend analysis of aerosol radiative properties at a global scale, submitted to ACP Sherman, J. P., Sheridan, P. J., Ogren, J. A., Andrews, E., Hageman, D., Schmeisser, L., Jefferson, A., and Sharma, S.: A multi-year study of lower tropospheric aerosol variability and systematic relationships from four North American regions, Atmos. Chem. Phys., 15, 12487–12517, https://doi.org/10.5194/acp-15-12487-2015, 2015. Schutgens, N., Tsyro, S., Gryspeerdt, E., Goto, D., Weigum, N., Schulz, M., and Stier, P.: On the spatio-temporal representativeness of observations, Atmos. Chem. Phys., 17, 9761–9780, https://doi.org/10.5194/acp-17-9761-2017, 2017.				

Ocean ECVs

4. PHYSICS

4.1 ECV: Sea-Surface Temperature

4.1.1 ECV Product: Sea-Surface Temperature

Name	Sea surface temperature				
Definition	Radiative skin sea surface temperature, or Bulk sea surface temperature at stated depth				
Unit	Kelvin (K)				
Note	The "bulk" temperature refers to the depth of typically 2 m, the "skin" temperature refers to within the upper 1 mm.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km	length	G	5	
			B		
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d	time	G	1/24	In situ measurements, daily in the case of satellite measurements
			B		
			T	7	
Timeliness	h	time	G	3	
			B		
			T	24	
Required Measurement Uncertainty (2-sigma)	K		G	0.05	Over 100 km scale
			B		
			T	0.3	Over 100 km scale
Stability	K/decade		G	0.01	Over 100 km scale
			B		
			T	0.1	Over 100 km scale
Standards and References	Johnson et al (2015): Informing Deep Argo Array Design Using Argo and Full-Depth Hydrographic Section Data; https://journals.ametsoc.org/doi/full/10.1175/JTECH-D-15- 0139.1; 5 x 5 degree array proposed with 15-day repeat cycle. Estimated reduction of sub-2000 m OHC error in decadal trends from +/- 17 TW to +/- 3TW. Desbruyeres et al (2017): Global and Full-Depth Ocean Temperature Trends during the Early Twenty-First Century from Argo and Repeat Hydrography; https://journals.ametsoc.org/doi/full/10.1175/JCLI-D-16-0396.1; "Estimate of global ocean heat uptake of 0.71 ± 0.09 W m−2 during 2006-2014 with < 2000m layer accounting for 90% of the observed change. Rayner (2017) User Requirements Document, SST_CCI-URD-UKMO-201, ESA. 2 https://climate.esa.int/media/documents/SST_CCI-URD-UKMO-201-Issue_2.1-signed.pdf Merchant, C.J., Embury, O., Bulgin, C.E. et al. Satellite-based time-series of sea- surface temperature since 1981 for climate applications. Sci Data 6, 223 (2019). https://doi.org/10.1038/s41597-019-0236-x				

4.2 ECV: Subsurface Temperature

4.2.1 ECV Product: Interior Temperature

Name	**Interior temperature**
Definition	Seawater temperature measured with depth.
Unit	Kelvin (K)
Note	This variable is referred to as "Ocean temperature" in WMO RRR, and a difference between Upper (<2000 m) and Deep (>2000 m) ocean is established.

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	Upper ocean
				100	Deep ocean
				1	Coastal
			B	100	Upper ocean
				250	Deep ocean
			T	300	Upper ocean
				500	Deep ocean
				10	Coastal
Vertical Resolution	m		G	1	Upper ocean
			B	2	Upper ocean
			T	10	Upper ocean
Temporal Resolution	d		G	1	Upper ocean
				1	Deep ocean
				1/24	Coastal
			B	10	Upper ocean
				15	Deep ocean
			T	30	Upper ocean
				30	Deep ocean
				30	Coastal
Timeliness	d		G	1	for real time
				90	in delayed mode
			B	1	for real time
				180	in delayed mode
			T	30	for real time
				365	in delayed mode
Required Measurement Uncertainty (2-sigma)	K		G	0.001	Upper ocean
				0.001	Deep ocean
			B		
			T	0.1	Upper ocean
				0.01	Deep ocean
				0.1	Coastal
Stability	K				
Standards and References	Johnson et al (2015): Informing Deep Argo Array Design Using Argo and Full-Depth Hydrographic Section Data; https://journals.ametsoc.org/doi/full/10.1175/JTECH-D-15-0139.1 ; 5 x 5 degree array proposed with 15-day repeat cycle. Estimated reduction of sub-2000 m OHC error in decadal trends from +/- 17 TW to +/- 3 TW. Palmer et al (2010): Future Observations for Monitoring Global Ocean Heat Content; http://www.oceanobs09.net/proceedings/cwp/Palmer-OceanObs09.cwp.68.pdf; Table 1 in the paper includes GCOS Observation Requirements in WMO/CEOS Database for upper ocean temperature and salinity Desbruyeres et al (2017): Global and Full-Depth Ocean Temperature Trends during the Early Twenty-First Century from Argo and Repeat				

	Hydrography; https://journals.ametsoc.org/doi/full/10.1175/JCLI-D-16-0396.1; "Estimate of global ocean heat uptake of 0.71 ± 0.09 W m−2 during 2006-2014 with < 2000m layer accounting for 90% of the observed change.

4.3 ECV: Sea-Surface Salinity

4.3.1 ECV Product: Sea-surface Salinity

Name	Sea-surface salinity				
Definition	Salinity of seawater, at or near the surface.				
Unit	psu, pss, g/Kg, or no unit				
Note	For remote sensing, the measurement corresponds typically to 1 cm depth. For in situ, 1-2 m depth.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B		
			T	50-100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1-3	
			B		
			T	7	
Timeliness	d		G	7	
			B		
			T	30	
Required Measurement Uncertainty (2-sigma)	1		G	0.1	Synthesis of coordinated input from ESA based on community workshop and numerous published references. 0.1 psu for 50-km spatial average and monthly mean; mean in low-variability regions (where in-situ validation measurements are not subject to significant sampling errors).
			B		
			T	0.2	Synthesis of coordinated input from ESA based on community workshop and numerous published references. 0.2 psu for 100-km spatial average and monthly mean in low variability regions.
Stability	1/decade		G	0.01	0.01 psu/decade for 1000-km average in low-variability regions.
			B		
			T	0.1	Durach, Wijffel and Matear (2012) (showing trends of 0.4 psu over 5 decades on 1000-km scales) 0.1 psu/decade for 1000-km average in low-variability regions.
Standards and References	Durack, Paul J., Susan E. Wijffels and Richard J. Matear (2012): Ocean Salinities Reveal Strong Global Water Cycle Intensification During 1950 to 2000, Science, 336 (6080), pp 455-458. DOI: 10.1126/science.1212222 Sea Surface Salinity Climate Change Initiative Phase 1 - User Requirement Document (2019). Available at: https://climate.esa.int/sites/default/files/SSS_cci-D1.1-URD-v1r4_signed-accepted.pdf				

4.4 ECV: Subsurface Salinity

4.4.1 ECV Product: Interior Salinity

Name	Interior salinity				
Definition	Salinity of seawater measured with depth.				
Unit	psu, pss, g Kg^{-1}, or no unit				
Note	This variable is referred to as "Ocean salinity" in WMO RRR OSCAR database, and a difference between Upper (<2000 m) and Deep (>2000 m) ocean is established.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B		
			T	100	
Vertical Resolution	m		G	1 1	Upper ocean Deep ocean
			B		
			T	10 100	Upper ocean Deep ocean
Temporal Resolution	d		G	1	
			B		
			T	30	
Timeliness	d		G	1	
			B		
			T	30	
Required Measurement Uncertainty (2-sigma)	1		G	0.01 0.005	Upper ocean Deep ocean
			B		
			T	0.05 0.02	Upper ocean Deep ocean
Stability	1/decade		G		
			B		
			T		
Standards and References					

4.5 ECV: Surface Currents

4.5.1 ECV Product: Ekman Currents

Name	Ekman currents				
Definition	Ocean vector motion occurring over the depth of the Ekman layer as a result of the combined action of surface winds and Coriolis force.				
Unit	m s^{-1}				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B	20	
			T	25	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	
			B		
			T	6	
Timeliness	h		G	1	
			B		
			T	3	
Required Measurement Uncertainty (2-sigma)	m s^{-1}		G	0.02	
			B		
			T	0.1	
Stability			G		
			B		
			T		
Standards and References					

4.5.2 ECV Product: Surface Geostrophic Current

Name	Surface Geostrophic Current				
Definition	Ocean vector motion measured at or near the surface (at stated depth).				
Unit	m s^{-1}				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B	20	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1/4	
			B	1	
			T	7	
Timeliness	d		G		
			B		
			T	1	
Required Measurement Uncertainty (2-sigma)	m s^{-1}		G	0.02	
			B		
			T	0.1	
Stability			G		
			B		
			T		
Standards and References	Villas Bôas et al. (2019) Integrated Observations of Global Surface Winds, Currents, and Waves: Requirements and Challenges for the Next Decade. Front. Mar.Sci. 6:425. doi: 10.3389/fmars.2019.00425 http://globcurrent.ifremer.fr/products-data				

4.6 ECV: Subsurface Currents

4.6.1 ECV Product: Vertical Mixing

Name	Vertical mixing				
Definition	Ocean vector motion measured at or near the surface (3D, at stated depth).				
Unit	m s^{-1}				
Note	A difference between Upper (<2000 m) and Deep (>2000 m) ocean is established.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B		
			T	100	
Vertical Resolution	m		G	1 10	Upper ocean Deep ocean
			B		
			T	10 100	Upper ocean Deep ocean
Temporal Resolution	d		G	1	
			B	7	
			T	30	
Timeliness	d		G		
			B		
			T	30	
Required Measurement Uncertainty (2-sigma)			G	0.02	
			B		
			T	0.1	
Stability			G		
			B		
			T		
Standards and References					

4.7 ECV: Sea Level

4.7.1 ECV Product: Regional Mean Sea Level

Name	Regional mean sea level				
Definition	The Height of the Ocean Surface relative to a reference geoid or an agreed regional datum.				
Unit	m				
Note	Estimates of the regional mean sea level are obtained by averaging individual sea surface heights over a region during a given period.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B		
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1	
			B		
			T	7	
Timeliness	month		G	1	
			B		
			T	12	
Required Measurement Uncertainty (2-sigma)	mm		G		
			B		
			T	10	Over a grid mesh of 50-100 km
Stability	mm yr^{-1}		G	0.3	Regional mean, 90% CI (confidence level)
			B		
			T	<0.1	Over a grid mesh of 50-100 km
Standards and References	Ponte, R.M., Carson, M., Cirano, M., Domingues, C.M., Jevrejeva, S., Marcos, M., Mitchum, G., Van De Wal, R.S.W., Woodworth, P.L., Ablain, M. and Ardhuin, F., 2019. Towards comprehensive observing and modeling systems for monitoring and predicting regional to coastal sea level. Frontiers in Marine Science, p.437. Benveniste, J., Cazenave, A., Vignudelli, S., Fenoglio-Marc, L., Shah, R., Almar, R., et al. (2019). Requirements for a coastal zone observing system. Front. Mar. Sci. 6:348. doi: 10.3389/fmars.2019.00348				

4.7.2 ECV Product: Global Mean Sea Level

Name	**Global Mean Sea level**				
Definition	The height of the ocean surface relative to a reference geoid.				
Unit	m				
Note	Estimates of the global mean sea level are obtained by averaging individual sea surface heights over the global ocean during a given period.				
Requirements					
Item needed	**Unit**	**Metric**	[1]	**Value**	**Notes**
Horizontal Resolution	km		G	10	
			B		
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1	
			B		
			T	30	
Timeliness	d		G	30	
			B		
			T	365	
Required Measurement Uncertainty (2-sigma)	mm		G		
			B		
			T	2-4	Values for the global mean. The uncertainty over a global mesh is = 10 mm
Stability	mm yr^{-1}		G	<0.03	Target to be considered for the detection of permafrost melting. From the WCRP grand challenge on sea level and coastal impacts the required stability in GMSL is <0.03 mm/year (over a decade, 90%CI) to detect permafrost thawing.
			B	<0.1	Target to be considered for the estimation of deep ocean warming and Earth energy imbalance is 0.1 mm/year (over a decade, 90% CI).
			T	<0.3	Adapted for sea level impact detection (detection of a change in the rate of rise of the global mean sea level). From the WCRP grand challenge on sea level and coastal impacts the required stability in GMSL <0.3 mm/year (global mean, 90% CI) for the detection attribution of sea level rise.
Standards and References	The uncertainty budget of the global mean sea level derived from satellite altimetry strongly relies on the precise orbit determination of the platform, the instrumental, geophysical and environmental altimeter corrections used to derive the sea level anomalies. Meyssignac, B., Boyer, T., Zhao, Z., Hakuba, M.Z., Landerer, F.W., Stammer, D., Köhl, A., Kato, S., L'ecuyer, T., Ablain, M. and Abraham, J.P., 2019. Measuring global ocean heat content to estimate the Earth energy imbalance. Frontiers in Marine Science, 6, p.432. Cazenave, A., Hamlington, B., Horwath, M., Barletta, V.R., Benveniste, J., Chambers, D., Döll, P., Hogg, A.E., Legeais, J.F., Merrifield, M. and Meyssignac, B., 2019. Observational requirements for long-term monitoring of the global mean sea level and its components over the altimetry era. Frontiers in Marine Science, p.582.				

4.8 ECV: Sea State

4.8.1 ECV Product: Wave Height

Name	Wave Height				
Definition	The distance between the trough of the wave and the adjacent crest of the wave. The significant wave height is the mean wave height (trough to crest) of the highest third of the waves in a wave spectrum.				
Unit	cm				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	1	Needed to resolve sea state variability in the coastal zone
			B	25	Needed to resolve mesoscale variability
			T	100	Needed to resolve synoptic scales associated with atmospheric systems
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	Needed to resolve sea state variability in the coastal zone (tidal modulation of the sea state)
			B	3	Needed to resolve sea state variability at the scale of storm events
			T	24	Needed to compute robust monthly statistics
Timeliness	d		G	7	To support assessment of extreme storm/cyclonic event
			B	30	To support assessment of seasonal extreme event
			T	365	For assessment and reanalysis
Required Measurement Uncertainty (2-sigma)	%	Normalized root-mean-squared error	G	5	Uncertainty goal, as proposed by Ardhuin et al., 2019
			B		
			T		
Stability	cm/decade		G	1	Needed to account for wave impact (wave setup) on coastal sea level
			B		
			T	10	Needed to detect the largest trends. Existing long-term observations show maximum
Standards and References	Ardhuin, F. et al. 2019. Observing Sea States. Front. Mar. Sci. 6.				

4.9 ECV: Ocean Surface Stress

4.9.1 ECV Product: Ocean Surface Stress

Name	Ocean Surface Stress				
Definition	The two-dimensional vector drag at the bottom of the atmosphere and the dynamical forcing at the top of the ocean.				
Unit	N m^{-2}				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B		
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	
			B		
			T	24	
Timeliness	d		G	7	
			B		
			T	30	
Required Measurement Uncertainty (2-sigma)	N m^{-2}		G	0.004 or 2%	International Ocean Vector Wind Science Team; Cronin et a. (2019), https://doi.org/10.3389/fmars.2019.00430
			B		
			T	0.02 or 8%	International Ocean Vector Wind Science Team; Cronin et a. (2019), https://doi.org/10.3389/fmars.2019.00430
Stability	N m^{-2}		G	0.0006	International Ocean Vector Wind Science Team; Cronin et a. (2019), https://doi.org/10.3389/fmars.2019.00430
			B		
			T	0.0001	International Ocean Vector Wind Science Team; Cronin et a. (2019), https://doi.org/10.3389/fmars.2019.00430
Standards and References					

4.10 ECV: Ocean Surface Heat Flux

4.10.1 ECV Product: Radiative Heat Flux

Name	Radiative Heat Flux
Definition	The net difference between radiation leaving the sea surface (reflected and emitted) and downward radiation impinging on the sea surface; commonly divided into an infrared or longwave and a visible or shortwave component ($Q_{LW,net} + Q_{SW,net}$): $Q_{LW,net} = LW\uparrow - LW\downarrow = \epsilon\, \sigma_{SB} T_s^4 + (1-\epsilon)\, LW\downarrow - LW\downarrow = \epsilon\, (\sigma_{SB} T_s^4 - LW\downarrow)$ and $Q_{SW,net} = Q_{SW}\uparrow - Q_{SW}\downarrow = Q_{SW}\downarrow(\alpha - 1)$ where ϵ is the IR surface emissivity ($\epsilon = 1$ for black-body emission), σ_{SB} is Stefan-Boltzmann constant, and T_s is the sea surface (skin) temperature that is emitting the IR-radiation, in degrees Kelvin. Upward shortwave flux is reflected sunlight, often determined by parameterization of surface albedo (α).
Unit	W m^{-2}
Note	Surface heat flux is the rate of exchange of heat, per unit area, crossing the sea surface from ocean to atmosphere. Sign conventions vary; heat fluxes are sometimes reported with positive values for heat into the ocean. The net heat flux is the sum of turbulent (latent and sensible) fluxes and the radiative (short wave and long wave) components. Downward shortwave at the surface is predominantly visible light. While sensible, latent, and longwave heat fluxes occur at the sea surface, the shortwave radiation penetrates seawater, with red light absorbed close to the surface and blue light absorbed at deeper depths. These turbulent and radiative surface fluxes are major contributors to energy and moisture budgets, and are largely responsible for thermodynamic coupling of the ocean and atmosphere on all scales. Variability of these fluxes is in part related to largescale variability in weather (climate) patterns. For most regions, the two major components are the net shortwave gain by the ocean and the latent heat flux loss by the ocean.

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B	25	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	
			B	3	
			T	24	
Timeliness			G	7	
			B	30	
			T	365	
Required Measurement Uncertainty (2-sigma)	W m^{-2}		G	10	.
			B	15	
			T	20	
Stability	W m^{-2}/ decade		G	1	
			B	2	
			T	3	
Standards and References	Meghan F. Cronin et al. (2019). Air-Sea Fluxes with a Focus on Heat and Momentum, Frontiers in Marine Science, 6, article 430, p1-30. https://www.frontiersin.org/articles/10.3389/fmars.2019.00430/full Meyssignac, Benoit, et al. Measuring global ocean heat content to estimate the Earth energy imbalance" Frontiers in Marine Science 6 (2019): 432.				

4.10.2 ECV Product: Sensible Heat Flux

Name	Sensible Heat Flux
Definition	The heat exchanged between the atmosphere and ocean when a warmer ocean warms the air above or when a cooler ocean cools the air above.
Unit	W m^{-2}
Note	The net surface heat flux is the rate of exchange of heat, per unit area, crossing the sea surface from ocean to atmosphere. Sign conventions vary; heat fluxes are sometimes reported with positive values for heat into the ocean. The net heat flux is the sum of turbulent (latent and sensible) fluxes and the radiative (short wave and long wave) components. Sensible heat flux is the rate at which heat is transferred from the ocean to the atmosphere by conduction and convection. Commonly, the ocean is warmer than the atmosphere, leading to a sensible heat flux that warms the atmosphere. A surface sensible heat flux which warms the atmosphere will tend to cause unstable (convective) conditions and enhanced mixing, while an atmosphere cooled by the ocean tends to be stratified, which inhibits mixing. In the tropics, latent heat flux is typically an order of magnitude greater than sensible heat flux, but in polar regions they are similar in magnitude. These fluxes are major contributors to energy and moisture budgets, and are largely responsible for thermodynamic coupling of the ocean and atmosphere on all scales. Variability of these fluxes is in part related to largescale variability in weather (climate) patterns. For most regions, the two major components are the net shortwave gain by the ocean and the latent heat flux loss by the ocean.

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B	25	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	
			B	3	
			T	24	
Timeliness			G	7	
			B	30	
			T	365	
Required Measurement Uncertainty (2-sigma)	W m^{-2}		G	10	.
			B	15	
			T	20	
Stability	W m^{-2}/ decade		G	1	
			B	2	
			T	3	
Standards and References	Meghan F. Cronin et al (2019). Air-Sea Fluxes with a Focus on Heat and Momentum, Frontiers in Marine Science, 6, article 430, p1-30. https://www.frontiersin.org/articles/10.3389/fmars.2019.00430 Meyssignac, Benoit, et al. "Measuring global ocean heat content to estimate the Earth energy imbalance." Frontiers in Marine Science 6 (2019): 432.				

4.10.3 ECV Product: Latent Heat Flux

Name	Latent Heat Flux				
Definition	The latent heat exchanged between the ocean and atmosphere associated with the phase change from liquid to gas during evaporation of seawater or from gas to liquid during condensation. During the more common process of surface evaporation, heat is extracted from the ocean, cooling the surface ocean. The moistened parcel of air can be carried aloft and the latent heat released to the atmosphere through condensation, which plays a crucial role in cloud formation and precipitation.				
Unit	$W\ m^{-2}$				
Note	The net surface heat flux is the rate of exchange of heat, per unit area, crossing the sea surface from ocean to atmosphere. Sign conventions vary; heat fluxes are sometimes reported with positive values for heat into the ocean. The net heat flux is the sum of turbulent (latent and sensible) fluxes and the radiative (short wave and long wave) components. Latent heat flux is associated with the phase change of water during evaporation or condensation and proportional to evaporation. The energy required for surface evaporation cools the ocean surface and moistens the near surface air adding to its buoyancy. The moistened parcel of air can be carried aloft, and the latent heat released to the atmosphere through condensation, which plays a crucial role in cloud formation and precipitation. Surface measured precipitation is often out of balance with evaporation (P-E), which implies moisture convergence/divergence in the atmosphere. In the tropics, latent heat flux is typically an order of magnitude greater than sensible heat flux, but in polar regions they are similar in magnitude. These fluxes are major contributors to energy and moisture budgets, and are largely responsible for thermodynamic coupling of the ocean and atmosphere on all scales. Variability of these fluxes is in part related to largescale variability in weather (climate) patterns. For most regions, the two major components are the net shortwave gain by the ocean and the latent heat flux loss by the ocean.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10	
			B	25	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	
			B	3	
			T	24	
Timeliness	d		G	7	
			B	30	
			T	365	
Required Measurement Uncertainty (2-sigma)	$W\ m^{-2}$		G	10	.
			B	15	
			T	20	
Stability	$W\ m^{-2}$/ decade		G	1	
			B	2	
			T	3	
Standards and References	Meghan F. Cronin et al (2019). Air-Sea Fluxes with a Focus on Heat and Momentum, Frontiers in Marine Science, 6, article 430, p1-30. https://www.frontiersin.org/articles/10.3389/fmars.2019.00430/full Meyssignac, Benoit, et al. "Measuring global ocean heat content to estimate the Earth energy imbalance." Frontiers in Marine Science 6 (2019): 432.				

4.11 ECV: Sea Ice

4.11.1 ECV Product: Sea Ice Concentration

Name	Sea Ice Concentration (SIC)				
Definition	Fraction of ocean area covered with sea ice.				
Unit	% (or 1)				
Note	Sea ice concentration (in %) or sea ice area fraction (0 … 1) is a parameter that requires a spatial scale for reference; it is the fraction of a known ocean area (whatever size) covered with sea ice. Sea-ice extent (= the total area of all grid cells covered with sea ice above a certain threshold, often 15%) and sea-ice area (= the total area of all grid cells covered with sea ice using the actual sea-ice area fraction as weight) are indicators derived from sea-ice concentration. Some products report sea-ice concentration intervals, others are ice/water binary masks. The border of the sea ice covered area (below a given threshold, often 15% SIC) defines a sea ice edge.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	1	Near-coast applications (e.g. Canadian Arctic Archipelago). Possibly not as sea-ice concentration but as ice / no-ice (edge).
			B	5 25	Regional analysis Trend analysis, global monitoring
			T	50	Limit for trend analysis, evaluation of global GCM simulations
Vertical Resolution	N/A		G	<1	SIC vary on a sub-daily time scale (opening/closing of leads)
			B	1 7	Ocean and Atmosphere reanalyses, daily monitoring of the sea- ice cover
			T	30	
Temporal Resolution	d		G	<1	SIC vary on a sub-daily time scale (opening/closing of leads)
			B	1 7	Ocean and Atmosphere reanalyses, daily monitoring of the sea-ice cover
			T	30	
Timeliness	d		G	1-2	
			B	7	Operational monitoring with climate indicators, update of reanalyses
			T	30	Update of monthly climate indicators
Required Measurement Uncertainty (2-sigma)	% SIC		G	5	
			B		
			T	10	
Stability	%/dec		G	5	
			B		
			T		
Standards and References	Lavergne and Kern, et al. (2022). A New Structure for the Sea Ice Essential Climate Variables of the Global Climate Observing System, BAMS, DOI 10.1175/BAMS-D-21-0227.1. Ono, J., H. Tatebe, and Y. Komuro, 2019: Mechanisms for and Predictability of a Drastic Reduction in the Arctic Sea Ice: APPOSITE Data with Climate Model MIROC. J. Climate, 32, 1361–1380, https://doi.org/10.1175/JCLI-D-18-0195.1.				

4.11.2 ECV Product: Sea Ice Thickness

Name	**Sea Ice Thickness**				
Definition	The vertical distance between sea ice surface and sea ice underside of the ice-covered fraction of an area.				
Unit	m				
Note	Sea-ice thickness is together with the sea-ice area derived from the sea-ice concentration the key ingredient to compute the sea-ice volume and mass. Long-term sea-ice volume and mass changes are considered as the integral response of climate change exerted on the polar regions.				
Requirements					
Item needed	**Unit**	**Metric**	[1]	**Value**	**Notes**
Horizontal Resolution	km		G	1	Required to resolve small scale impacts of deformation events on sea-ice thickness distribution for more accurate estimation of dynamics on mass balance. Enables to resolve thickness distribution approaching floe scale for improved ice mass flux. Needed to obtain enhanced ice-type specific ice thickness information and more accurate estimates of ice production.
			B	25 distribution 25 mean & median	Required for the analysis of regional sea-ice thickness distributions Needed to further develop and improve GCMs and to improve regional climate analyses Needed to refine hemispheric trend analyses and to analyze basin-wide / regional sea-ice thickness and mass trends Required for the evaluation of the next generation of CMIP6 GCMs
			T	50	Minimum useful horizontal resolution to compute hemispheric trends in sea-ice thickness and mass and to evaluate GCMs / CMIP6
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	daily year-round	To resolve ice production in polynyas and during early freeze-up To resolve the impact of dynamic processes on the sea-ice thickness distribution To resolve snow-ice formation
			B	weekly year-round monthly year-round	To better monitor the impact of longer-lasting weather conditions on sea-ice formation and melt. To better monitor the full seasonal cycle of sea-ice thickness
			T	monthly wintertime	Minimum temporal resolution required to adequately monitor the winter-time sea-ice thickness and mass increase
Timeliness	d		G	1	Operational monitoring with climate indicators, update of reanalyses
			B	7	Update of monthly climate indicators
			T	30	
Required Measurement Uncertainty (2-sigma)	m		G	0.05	To improve monitoring of thin ice areas and associated heat fluxes To enhance sea-ice production estimation To monitor diurnal changes in sea-ice thickness during growth and melt
			B	0.1	To monitor regional- and large-scale sea-ice thickness changes in the Arctic towards the end of the growing season and in the Antarctic.
			T	0.25	Minimum useful uncertainty to be able to monitor basin-wide sea-ice thickness changes at monthly scale.
			G		

Stability	m/decade		B T		
Standards and References	Lavergne and Kern, et al. (2022). A New Structure for the Sea Ice Essential Climate Variables of the Global Climate Observing System, BAMS, DOI 10.1175/BAMS-D-21-0227.1.				

4.11.3 ECV Product: Sea Ice Drift

Name	**Sea Ice Drift**
Definition	Rate of movement of sea ice due to winds, currents or other forces.
Unit	km d^{-1}
Note	1) Sea Ice drift is a 2D vector, expressed with two components along two orthogonal directions. 2) The uncertainty requirements below are for both components (not the total velocity). 3) The uncertainty requirements below are for a reference displacement period of 24 hours.

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	1	Near-coast applications (e.g. Canadian Arctic Archipelago).
			B	5 25	Regional analysis, deformations, volume fluxes through narrow gates. Trend analysis, sea-ice tracking, volume fluxes
			T	50	Limit for trend analysis, evaluation of global GCM simulations
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	<1	Sea-ice motion can change very rapidly with winds or internal forces
			B	1 7	
			T	30	Large-scale circulation patterns and trends
Timeliness	d		G	1-2	
			B	7	Update of monthly climate indicators
			T	30	
Required Measurement Uncertainty (2-sigma)	km d^{-1}	see Note	G	0.25	Requires high-resolution imaging (e.g. SAR). For deriving deformation.
			B	3	
			T	10	
Stability	%/decade		G		
			B		
			T		
Standards and References	Lavergne and Kern, et al. (2022). A New Structure for the Sea Ice Essential Climate Variables of the Global Climate Observing System, BAMS, DOI 10.1175/BAMS-D-21-0227.1. Dierking, W., et al., Estimating statistical errors in retrievals of ice velocity and deformation parameters from satellite images and buoy arrays, The Cryosphere, 14(9), 2999-3016, 2020, https://doi.org/10.5194/tc-14-2999-2020				

4.11.4 ECV Product: Sea Ice Age

Name	Sea Ice Age
Definition	The age of an ice parcel is the time since its formation or since the last significant (e.g. summer) melt.
Unit	day
Note	An ice parcel formed during the freezing season is in its first year of existence and can be defined as first-year ice, its age is less than 1 year. When it survives the first exposure to significant melting (e.g. summer season) it becomes second-year ice (its age is between 1 and 2 years). This continues for each summer melt season the ice parcel survives. In other words, the age of an ice parcel is rounded up to the nearest integer year with each exposure to significant melting (typically the summer melt season). While in the Arctic, it has been common practice to use the date of the overall summer minimum extent for the reclassification of the sea ice, there are no well accepted definitions for the Southern Ocean and region-specific dates might be needed. Here we do not define any specific details what the definition of the significant melt is. The reclassification of sea ice into an older ice category at significant melt aims at linking the sea-ice age information to the physical properties of the ice, including its air bubbles content, density, salinity, surface roughness, etc. All these physical properties change drastically through melting and especially during the first summer melt. Sea ice age can be reported as the representative/dominating age in an area or as the distribution of ages within an area. Sea ice age can be computed with different approaches. Traditionally, sea-ice age has been derived from either Lagrangian tracking techniques and presented as areas with year classes (age = 1, 2, 3, etc.) or from analysis of microwave emissivity and backscattering and reported as age categories (e.g. first-year ice, second year ice, multiyear ice). The latter retrieval method often refers to the product as sea-ice type. Age concentration products exist that report some distribution of age within grid cells.

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	1	Needed to resolve spatial differences in age when refreezing occurs between larger ice floes and plates, or in divergent icefields. Will capture details in the Canadian Archipelago. Needed to optimally resolve the age of narrow land-fast ice areas fringing Antarctica.
			B	5 25	Needed for better capturing regions dominated by broken old ice (like the Beaufort Gyre), and elongated filaments of certain age classes. Needed to resolve the age of larger-scale land-fast ice areas in Antarctica important for buttressing ice shelves. Reasonable capability in Canadian Archipelago, except for narrower straits. Regional analysis. General mapping of ice classes, used for climate monitoring e.g. trend analysis, climate index of old ice. Also, used as background information for ice thickness retrieval. Lack of resolution for smaller areas, such as in the Canadian Archipelago.
			T	50	Limit for trend analysis
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	<1	
			B	1 7	The edges between ice classes can move a lot during a d however the areal coverage of the >1year classes is assumed not to have large daily variability.
			T	30	
Timeliness	d		G	1-2	Operational monitoring with climate indicators
			B	7	
			T	30	Useful for input into monthly altimeter-based sea ice thickness estimates.
Required Measurement Uncertainty (2-sigma)	d		G	7	Age information as “time since its formation or since the last significant (e.g. summer) melt”. We do report the age of the ice within the on-going freezing season.
			B	182	Age as year classes (1,2,3,...). Requirement on accuracy is 182 days (half a year) because we do not report the age of the ice within the on-going freezing season.

			T	> 1 year	As a minimum, a meaningful sea-ice age product should separate ice into seasonal ice and perennial ice, with a probability of correct classification of 70%. The dominating ice class is reported.
Stability	d		G		
			B		
			T		
Standards and References	Lavergne and Kern, et al. (2022). A New Structure for the Sea Ice Essential Climate Variables of the Global Climate Observing System, BAMS, DOI 10.1175/BAMS-D-21-0227.1.				

4.11.5 ECV Product: Sea Ice Temperature

Name	Sea Ice Surface Temperature (IST)				
Definition	The surface temperature of sea ice or snow on sea ice, either a calibrated radiometric or thermometric in situ measurement.				
Unit	Kelvin (K)				
Note	The IST requirements below are based on several requirement/recommendation documents from relevant communities and institutions, e.g. WMO, GCOS, GMES, Copernicus/CMEMS, ESA CCI, NOAA, and others. Requirements for IST range widely in both in values and metric and the given values are based on these documents and expert judgments from the OSISAF High Latitude team. Uncertainty requirements are valid for automatically cloud screened day and night time IST data compared with surface temperature reference data of high quality, e.g. radiometric in situ observations.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	1	GCOS, GMES, Copernicus/CMEMS
			B	5 10	GCOS, GMES, Copernicus/CMEMS
			T	50	WMO
Vertical Resolution			G	Skin	N/A
			B	Skin	
			T	Skin	
Temporal Resolution	d		G	3 h	to capture diurnal cycle, GCOS, Copernicus/CMEMS
			B	1	GCOS, Copernicus/CMEMS
			T	7	Can allow full coverage (cloud cover)
Timeliness	d		G	1-2	
			B	7	
			T	30	
Required Measurement Uncertainty (2-sigma)	K		G	1.0	Copernicus/CMEMS, GMES, EUMETSAT/OSISAF, Dybkjær et al., 2019
			B	3.0	Copernicus/CMEMS, GMES, EUMETSAT/OSISAF, Dybkjær et al., 2019
			T	6.0	Copernicus/CMEMS, GMES, EUMETSAT/OSISAF, Dybkjær et al., 2019
Stability	K/decade		G	0.1	As defined in the GCOS LST ECV requirements
			B	0.2	
			T	0.3	As defined in the GCOS LST ECV requirements
Standards and References	Lavergne and Kern, et al. (2022). A New Structure for the Sea Ice Essential Climate Variables of the Global Climate Observing System, BAMS, DOI 10.1175/BAMS-D-21-0227.1. CLiC (2012) Observational needs for sea ice models - Short note. Discussion note from CLiC Arctic Sea Ice Working Group, http://www.climate-cryosphere.org/about, 2012. CMEMS (2016) Bertino, L., L.A. Breivik, F. Dinesen, Y. Faugere, G. Garric, B. Hackett, J. A. Johannesen, T. Lavergne, P.-Y. LeTraon, L.T. Pedersen, P. Rampal, S. Sandven & H. Shyberg. Position paper Polar and snow cover applications User Requirements Workshop Brussels, Copernicus Marine Environment Monitoring Service, Mercator Ocean. CMEMS (2017) CMEMS requirements for the evolution of the Copernicus Satellite Component. Copernicus Marine Environment Monitoring Service, Mercator Ocean and CMEMS partners. CMEMS (2020) CMEMS Dashboard Upstream Satellite Data Requirements, V10.0 March 2020 (spreadsheet) Copernicus (2018a) Duchossois, G., P. Strobl, V. Toumazou (Eds.) User Requirements for a Copernicus Polar Mission Phase 1 Report - User Requirements and Priorities. JRC Technical Report, doi:10.2760/22832, 2018. Copernicus. (2018b) Duchossois, G., P. Strobl, V. Toumazou (Eds.) User Requirements for a Copernicus Polar Mission Phase 2 Report - High-level mission requirements. JRC Technical Report, doi:10.2760/44170, 2018. Dybkjær, G., R. Tonboe, M. Winstrup and J. L. Høyer (2019) Review of state-of-the-art methods and algorithms for Ice Surface Temperature retrieval algorithms - Including consolidate and refine output product requirements and software specification, Product requirement and baseline document, version 2.3. EUMETSAT document Reference Number: EUM/OPS-COPER/19/1065840.				

	GCOS (2016) The Global Observing System for Climate: Implementation Needs (World Meteorological Organization, GCOS-200). OSI SAF CDOP 3 (2018) Product Requirement Document, http://www.osi-saf.org/sites/default/files/dynamic/public_doc/osisaf_cdop3_gen_prd_1.4.pdf, Version: 1.4, 2018

4.11.6 ECV Product: Sea Ice Surface Albedo

Name	Sea Ice Surface Albedo				
Definition	Broadband snow or ice surface albedo				
Unit	1				
Note	Albedo is a measure of how much solar radiation incident at a surface of known area is reflected back; it is the ratio between incoming and outgoing surface short-wave radiation. The value range is 0 to 1. The surface albedo of sea ice covers almost the entire range with very thin ice such as dark nilas having an albedo of ~ 0.1 and sea ice with a fresh snow cover having an albedo of ~0.9. The albedo of bare (snow-free) sea ice depends strongly on sea-ice age. Predominantly in the Arctic, during summer, melt water forms complex patterns of melt ponds on top of the sea ice that reduce the albedo considerably - depending on areal fraction and depth of the ponds and on ice age. Thus, not only the surface albedo, but also its partition into surface types (openings in the sea ice cover, melt ponds, bare ice, snow, etc.) is critical to observe. Through its relation to surface melt processes, albedo observations are key to improving the satellite retrieval of other sea-ice variables, such as sea-ice concentration. Albedo is the key parameter describing the amount of solar energy available for ice melt and in-ice and under-ice primary production. Both the fact that the sea ice drifts and the difficulty to obtain adequate in-situ observations for ground truthing and evaluation of sea ice surface albedo climate data records determine that ECV requirements for sea-ice albedo differ from those of the terrestrial albedo.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	1	Needed for mapping of larger flooded ice areas in the Arctic during summer (e.g. in river estuaries, or fjords) Improved mapping of spring / summer melt progress in the Arctic as a function of ice age.
			B	5 10	Needed to reliably monitor albedo evolution of larger thin ice areas associated with polynyas. Needed to monitor albedo evolution in narrow passages such as the Canadian Archipelago or around the Antarctic Peninsula Needed to discriminate adequately between the albedo of ice of different age during melt and re-freeze in the Arctic. Needed to reliably detect surface melt / refreeze event-induced changes in snow surface albedo in the Antarctic
			T	50	Minimum horizontal resolution to derive basin-wide trends in albedo and solar energy input
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	3 h	Required for an optimal quantification of surface albedo (and hence solar energy input) under highly variable cloud / surface illumination (changes surface topography) / surface conditions (fresh snow and pond drainage change surface albedo at ~ hourly scale)
			B	1	Required to accurately quantify the seasonal cycle and cumulative amount of surface available solar radiation Enables us to take into account the impact of melt-pond surface area changes and snowfall on diurnal variations in albedo and surface available solar radiation
			T	7	Minimum temporal resolution required to derive basin-scale changes in seasonal surface available solar radiation input, melt onset, and commence of freeze-up as well as to estimate onset of under-ice primary production.
Timeliness	d		G	1-2	
			B	7	
			T	30	
Required Measurement Uncertainty (2-sigma)			G	0.01	Required to discriminate between new ice and open water and to detect submerged ice Needed to accurately observe sub-grid scale changes in ice surface conditions

			B	0.05	Required to reliably monitor changes in snow properties: fresh - old - melting and to be able to distinguish between melting snow and bare ice Needed to differentiate between melt ponds on ice of different age and to identify melt-pond freeze-up
			T	0.1	Minimum measurement uncertainty to discriminate between ice / no ice or cold snow-covered / bare ice or to identify melt ponds
Stability			G		
			B		
			T		
Standards and References	Lavergne and Kern, et al. (2022). A New Structure for the Sea Ice Essential Climate Variables of the Global Climate Observing System, BAMS, DOI 10.1175/BAMS-D-21-0227.1. Perovich, D. K., et al., Anatomy of a late spring snowfall on sea ice, Geophys. Res. Lett., 44(6), 2802-2809, 2017, https://doi.org/10.1002/2016GL071470 Ardyna, M. and K. R. Arrigo, Phytoplankton dynamics in a changing Arctic Ocean, Nat. Climate Change, 10(10), 892-903, 2020, https://doi.org/10.1038/s41558-020-0905-y				

4.11.7 ECV Product: Snow Depth on Sea Ice

Name	**Snow Depth on Sea Ice**
Definition	The vertical extent of the snow cover on top of the sea ice.
Unit	m
Note	Snow has a heat conductivity which is an order of magnitude smaller than that of sea ice. It is hence very efficient at isolating sea ice from the atmosphere already at a depth of a few centimeters. Snow reduces the ocean-atmosphere heat flux. Thick snow retards winter-time ice growth and summer-time ice melt onset. Snow therefore has a profound impact on the overall heat and sea-ice mass budget of the polar oceans. Snow has the highest short-wave albedo of the snow-sea ice-system. Snow-covered sea ice can reflect about 25% more solar radiation than any kind of bare sea ice. Snowfall during melt-onset can delay sea-ice melt for several days to a few weeks due to the surface albedo change imposed. Snow is a critically required parameter for sea-ice thickness retrieval using altimetry. Snow depth on sea ice has been retrieved using multi-frequency satellite microwave radiometer observations for decades. While the retrieval is mature and accurate over undeformed seasonal sea ice during winter conditions, deformation, melt conditions and multiyear ice pose challenges. To solve these is currently explored using innovative combinations of satellite microwave radiometer observations using even more frequencies than so far with radar and laser altimeter observations, in situ observations from buoys, airborne surveys and specifically developed snow models informed with meteorological data from numerical modeling.

Requirements

Item needed	**Unit**	**Metric**	[1]	**Value**	**Notes**
Horizontal Resolution	km		G	1	
			B	25 25	Distribution
			T	50	Minimum horizontal resolution to derive basin-wide trends Minimum spatial resolution to support sea-ice thickness retrieval from altimetry
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution			G	daily year-round	Needed for highly accurate year-round daily sea-ice thickness retrieval using satellite altimetry Required to define begin and end of spring snow melt on sea ice Needed to improve estimates of sea-ice melt progress or slow down Would enable estimation of the amount of snow-to-ice conversion related to flooding - refreeze events
			B	weekly year-round	Needed for year-round sea-ice thickness retrieval using satellite altimetry at weekly time scale Required to enhance evaluation of ocean-atmosphere heat flux estimates during the shoulder seasons and studies about sea-ice melt and freeze onset
				monthly year-round	Required for year-round sea-ice thickness retrieval using satellite altimetry
			T	monthly, wintertime	Minimum temporal resolution to support sea-ice thickness retrieval using satellite altimetry
Timeliness	d		G	1-2	
			B	7	
			T	30	
Required Measurement Uncertainty (2-sigma)	m		G	0.01	
			B	0.05	
			T	0.1	Minimum requirement to ensure a sea-ice thickness retrieval uncertainty < 0.5 m and < 0.8 m using radar and laser altimetry, respectively.
Stability	m/decade		G		

			B		
			T		
Standards and References	Lavergne and Kern, et al. (2022). A New Structure for the Sea Ice Essential Climate Variables of the Global Climate Observing System, BAMS, DOI 10.1175/BAMS-D-21-0227.1. Kwok, R., and G. F. Cunningham, ICESat over Arctic sea ice: Estimation of snow depth and ice thickness, J. Geophys. Res., 113, C08010, 2008, https://doi.org/10.1029/2008JC004753 Giles, K. A., et al., Combined airborne laser and radar altimeter measurements over the Fram Strait in May 2002, Rem. Sens. Environ., 111(2-3), 182-194, 2007, https://doi.org/10.1016/j.rse.2007.02.037				

5. BIOGEOCHEMISTRY

5.1 ECV: Oxygen

5.1.1 ECV Product: Dissolved Oxygen Concentration

Name	Dissolved Oxygen Concentration				
Definition	Concentration of dissolved oxygen (O_2) in the water column.				
Unit	μmol kg^{-1}				
Note	This Essential Ocean Variable (EOV)/ECV is a measurement of sub-surface dissolved oxygen (O_2) concentration in the ocean, expressed in units of μmol kg^{-1}. Data on dissolved oxygen is obtained by both discrete (chemical analysis) and continuous (sensor measurements) sampling performed on a number of observing platforms (ship-based, fixed-point, autonomous).				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	300 1-100	For global coverage, spatial resolution refers to distance between transects, not between sampling stations. Coastal
			B		
			T	2000 300	 Coastal
Vertical Resolution			G	-	
			B	-	
			T	-	
Temporal Resolution			G	monthly	
			B		
			T	decadal	
Timeliness	month		G	6	
			B		
			T	12	
Required Measurement Uncertainty (2-sigma)	μmol kg^{-1}		G	0.5	
			B		
			T	2	
Stability			G		
			B		
			T		
Standards and References	Requirements based on characteristic scales and magnitude of signal of phenomena to observe. See the EOV Specification Sheet for details and references (www.goosocean.org/eov).				

5.2 ECV: Nutrients

5.2.1 ECV Product: Silicate

Name	**Silicate**				
Definition	Concentration of $Si(OH)_4$ in the water column.				
Unit	µmol kg^{-1}				
Note	The availability of nutrients in seawater is estimated from measurements of concentration of inorganic macronutrients: nitrate (NO_3), phosphate (PO_4), silicic acid ($Si(OH)_4$), ammonium (NH_4), and nitrite (NO_2), expressed in umol kg^{-1} of seawater. Nutrients ECV products are primarily obtained from discrete sample measurements using analytical chemical methods (colorimetric reactions) but nitrate concentration is also measured by sensors using the ultraviolet absorption method. Linear combination of nitrate and phosphate, defined as N*, and the difference between silicic acid and nitrate concentrations, Si*, provide estimates of nutrient supply/removal relative to global Redfield stoichiometry and are widely used for mapping and detecting trends in global nutrient cycling.				
Requirements					
Item needed	**Unit**	**Metric**	[1]	**Value**	**Notes**
Horizontal Resolution	km		G	1000 0.1-100	 Coastal
			B		
			T	2000 100	 Coastal
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	month		G	3 1	 Coastal
			B		
			T	decadal	
Timeliness	month		G	6	
			B		
			T	12	
Required Measurement Uncertainty (2-sigma)	%		G	1	
			B		
			T	3	
Stability			G		
			B		
			T		
Standards and References	Requirements based on characteristic scales and magnitude of signal of phenomena to observe. See the EOV Specification Sheet for details and references (www.goosocean.org/eov).				

5.2.2 ECV Product: Phosphate

Name	Phosphate				
Definition	Concentration of PO_4 in the water column.				
Unit	µmol kg⁻¹				
Note	The availability of nutrients in seawater is estimated from measurements of concentration of inorganic macronutrients: nitrate (NO_3), phosphate (PO_4), silicic acid ($Si(OH)_4$), ammonium (NH_4), and nitrite (NO_2), expressed in umol kg^{-1} of seawater. Nutrients ECV products are primarily obtained from discrete sample measurements using analytical chemical methods (colorimetric reactions) but nitrate concentration is also measured by sensors using the ultraviolet absorption method. Linear combination of nitrate and phosphate, defined as N*, and the difference between silicic acid and nitrate concentrations, Si*, provide estimates of nutrient supply/removal relative to global Redfield stoichiometry and are widely used for mapping and detecting trends in global nutrient cycling.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	1000 0.1-100	 Coastal
			B		
			T	2000 100	 Coastal
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	month		G	3 1	 Coastal
			B		
			T	decadal	
Timeliness	month		G	6	
			B		
			T	12	
Required Measurement Uncertainty (2-sigma)	%		G	1	
			B		
			T	3	
Stability			G		
			B		
			T		
Standards and References	Requirements based on characteristic scales and magnitude of signal of phenomena to observe. See the EOV Specification Sheet for details and references (www.goosocean.org/eov).				

5.2.3 ECV Product: Nitrate

Name	Nitrate				
Definition	Concentration of NO_3 in the water column.				
Unit	µmol kg^{-1}				
Note	The availability of nutrients in seawater is estimated from measurements of concentration of inorganic macronutrients: nitrate (NO_3), phosphate (PO_4), silicic acid ($Si(OH)_4$), ammonium (NH_4), and nitrite (NO_2), expressed in umol kg^{-1} of seawater. Nutrients ECV products are primarily obtained from discrete sample measurements using analytical chemical methods (colorimetric reactions) but nitrate concentration is also measured by sensors using the ultraviolet absorption method. Linear combination of nitrate and phosphate, defined as N*, and the difference between silicic acid and nitrate concentrations, Si*, provide estimates of nutrient supply/removal relative to global Redfield stoichiometry and are widely used for mapping and detecting trends in global nutrient cycling.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	1000	
				0.1-100	Coastal
			B		
			T	2000	
				100	Coastal
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	month		G	3	
				1	Coastal
			B		
			T	decadal	
Timeliness	month		G	6	
			B		
			T	12	
Required Measurement Uncertainty (2-sigma)	%		G	1	
			B		
			T	3	
Stability			G		
			B		
			T		
Standards and References	Requirements based on characteristic scales and magnitude of signal of phenomena to observe. See the EOV Specification Sheet for details and references (www.goosocean.org/eov).				

5.3 ECV: Ocean Inorganic Carbon

5.3.1 ECV Product: Total Alkalinity (TA)

Name	Total Alkalinity (TA)				
Definition	Total concentration of alkaline substances.				
Unit	µmol kg^{-1}				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	1000 100	 Coastal
			B		
			T	2000 1000	 Coastal
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	month		G	3	
			B		
			T	decadal	
Timeliness	month		G	6	
			B		
			T	12	
Required Measurement Uncertainty (2-sigma)	µmol kg^{-1}		G	2	
			B		
			T	2	
Stability			G		
			B		
			T		
Standards and References	Requirements based on characteristic scales and magnitude of signal of phenomena to observe. See the EOV Specification Sheet for details and references (www.goosocean.org/eov). Additional requirements based on the Global Ocean Data Assimilation Project (GLODAP; www.glodap.info); for pH based on the Global Ocean Acidification Observing Network (GOA-ON) Implementation Strategy (http://goa-on.org/about/strategy.php); for pCO_2 from the Surface Ocean CO_2 Atlas (SOCAT; www.socat.info).				

5.3.2 ECV Product: Dissolved Inorganic Carbon (DIC)

Name	Dissolved Inorganic Carbon (DIC)				
Definition	Sum of dissolved inorganic carbon species (CO_2, HCO^-, $CO3^{2-}$) in water.				
Unit	µmol kg^{-1}				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	1000	
				100	Coastal
			B		
			T	2000	
				1000	Coastal
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	month		G	3	
			B		
			T	decadal	
Timeliness	month		G	6	
			B		
			T	12	
Required Measurement Uncertainty (2-sigma)	µmol kg^{-1}		G	2	
			B		
			T	2	
Stability			G		
			B		
			T		
Standards and References	Requirements based on characteristic scales and magnitude of signal of phenomena to observe. See the Essential Ocean Variables (EOV) Specification Sheet for details and references (www.goosocean.org/eov). Additional requirements based on the Global Ocean Data Assimilation Project (GLODAP; www.glodap.info); for pH based on the Global Ocean Acidification Observing Network (GOA-ON) Implementation Strategy (http://goa-on.org/about/strategy.php); for pCO_2 from the Surface Ocean CO_2 Atlas (SOCAT; www.socat.info).				

5.3.3 ECV Product: pCO_2

Name	pCO_2				
Definition	Surface ocean partial pressure of CO_2.				
Unit	µatm				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	100	
			B		
			T	1000 <1000	 Coastal
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution			G	monthly	
			B		
			T	decadal	
Timeliness	month		G	6	
			B		
			T	12	
Required Measurement Uncertainty (2-sigma)	µatm		G	2	
			B		
			T	2	
Stability			G		
			B		
			T		
Standards and References	Requirements based on characteristic scales and magnitude of signal of phenomena to observe. See the EOV Specification Sheet for details and references (www.goosocean.org/eov). Additional requirements based on the Global Ocean Data Assimilation Project (GLODAP; www.glodap.info); for pH based on the Global Ocean Acidification Observing Network (GOA-ON) Implementation Strategy (http://goa-on.org/about/strategy.php); for p CO_2 from the Surface Ocean CO_2 Atlas (SOCAT; www.socat.info).				

5.4 ECV: Transient tracers

5.4.1 ECV Product: ^{14}C

Name	^{14}C				
Definition	Ratio of sample to reference value (Δ14) in the water column.				
Unit	‰				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	2000 200	Regional Deep water formation areas
			B		
			T	2000	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	y		G	10 2	Regional Deep water formation areas
			B		
			T	10	
Timeliness	y		G	1	
			B		
			T	2	
Required Measurement Uncertainty (2-sigma)	‰		G	0.4	
			B		
			T		
Stability			G	decadal 1y	Regional Deep water formation areas
			B		
			T	decadal	
Standards and References	Requirements based on characteristic scales and magnitude of signal of phenomena to observe. See the EOV Specification Sheet for details and references (www.goosocean.org/eov).				

5.4.2 ECV Product: SF_6

Name	SF_6				
Definition	Concentration of SF_6 gas in the water column.				
Unit	fmol kg^{-1}				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	2000 200	Regional Deep water formation areas
			B		
			T	2000	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	y		G	10 2	Regional Deep water formation areas
			B		
			T	10	
Timeliness	y		G	1	
			B		
			T	2	
Required Measurement Uncertainty (2-sigma)	‰		G	0.4	
			B		
			T		
Stability			G	decadal 1y	Regional Deep water formation areas
			B		
			T	decadal	
Standards and References	Requirements based on characteristic scales and magnitude of signal of phenomena to observe. See the EOV Specification Sheet for details and references (www.goosocean.org/eov).				

5.4.3 ECV Product: CFC-11

Name	CFC-11				
Definition	Concentration of CFC-11 gas in the water column.				
Unit	pmol kg^{-1}				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	2000 200	Regional Deep water formation areas
			B		
			T	2000	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	y		G	10 2	Regional Deep water formation areas
			B		
			T	10	
Timeliness	month		G	6	
			B		
			T	6	
Required Measurement Uncertainty (2-sigma)	‰		G	1	
			B		
			T		
Stability			G	decadal 1y	Regional Deep water formation areas
			B		
			T	decadal	
Standards and References	Requirements based on characteristic scales and magnitude of signal of phenomena to observe. See the EOV Specification Sheet for details and references (www.goosocean.org/eov).				

5.4.4 ECV Product: CFC-12

Name	CFC-12				
Definition	Concentration of CFC-12 gas in the water column.				
Unit	pmol kg^{-1}				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	2000 200	Regional Deep water formation areas
			B		
			T	2000	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	y		G	10 2	Regional Deep water formation areas
			B		
			T	10	
Timeliness	month		G	6	
			B		
			T	6	
Required Measurement Uncertainty (2-sigma)	‰		G	1	
			B		
			T		
Stability			G	decadal 1y	Regional Deep water formation areas
			B		
			T	decadal	
Standards and References	Requirements based on characteristic scales and magnitude of signal of phenomena to observe. See the EOV Specification Sheet for details and references (www.goosocean.org/eov).				

5.5 ECV: Ocean Nitrous Oxide N_2O

5.5.1 ECV Product: Interior Ocean Nitrous Oxide N_2O

Name	Interior Ocean Nitrous Oxide N_2O				
Definition	Concentration of N_2O gas in the water column.				
Unit	nmol kg^{-1}				
Note	Nitrous oxide (N_2O) is an atmospheric trace gas which is measured in the water column of all major ocean basins at concentrations spanning three orders of magnitude. The ocean is a major source (around 25%) of N_2O gas to the atmosphere.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	<2000 <500	 Coastal
			B		
			T	2000	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	month		G	3	
			B		
			T	3 weekly to monthly	 Coastal
Timeliness	y		G	1	
			B		
			T	2	
Required Measurement Uncertainty (2-sigma)	%		G	<1	
			B		
			T	5	
Stability			G		
			B		
			T		
Standards and References	Values based on the characteristic scales of the phenomena which are observed using N_2O measurements. For more details and references see the Nitrous Oxide EOV Specification Sheet (www.goosocean.org/eov), publications from SCOR WG 143 (https://scor-int.org/group/143/) and the GOOS Report No. 225 (https://www.goosocean.org/index.php?option=com_oe&task=viewDocumentRecord&docID=20428).				

5.5.2 ECV Product: N_2O Air-sea Flux

Name	**N_2O Air-sea Flux**				
Definition	Amount of N_2O produced per area per year.				
Unit	µmol m^{-2} y^{-1}				
Note					
Requirements					
Item needed	**Unit**	**Metric**	[1]	**Value**	**Notes**
Horizontal Resolution	km		G	<2000 <500	 Coastal
			B		
			T	2000	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	month		G	3 weekly to monthly	 Coastal
			B		
			T	Decadal	
Timeliness	y		G	1	
			B		
			T	2	
Required Measurement Uncertainty (2-sigma)			G	<1	
			B		
			T	5	
Stability	%		G		
			B		
			T		
Standards and References	Values based on the characteristic scales of the phenomena which are observed using N_2O measurements. For more details and references see the Nitrous Oxide EOV Specification Sheet (www.goosocean.org/eov), publications from SCOR WG 143 (https://scor-int.org/group/143/) and the GOOS Report No. 225 (https://www.goosocean.org/index.php?option=com_oe&task=viewDocumentRecord&docID=20428).				

5.6 ECV: Ocean Colour

5.6.1 ECV Product: Chlorophyll-a

Name	Chlorophyll-a				
Definition	Concentration of chlorophyll-a pigment in the surface water.				
Unit	µg l-1				
Note	Ocean colour is the radiance emanating from the ocean normalized by the irradiance illuminating the ocean. Products derived from ocean colour remote sensing (OCRS) contain information on the ocean albedo and information on the constituents of the seawater, in particular, phytoplankton pigments such as chlorophyll-a.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	4	
			B		
			T	4	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1	
			B		
			T	7	
Timeliness			G		
			B		
			T		
Required Measurement Uncertainty (2-sigma)	%		G	30	
			B		
			T	30	
Stability	%/decade		G	3	
			B		
			T	3	
Standards and References	For more details and references see the Ocean Colour EOV Specification Sheet (www.goosocean.org/eov).				

5.6.2 ECV Product: Water Leaving Radiance

Name	Water Leaving Radiance				
Definition	Amount of light emanating from within the ocean.				
Unit					
Note	Ocean colour is the radiance emanating from the ocean normalized by the irradiance illuminating the ocean. Products derived from ocean colour remote sensing (OCRS) contain information on the ocean albedo and information on the constituents of the seawater, in particular, phytoplankton pigments such as chlorophyll-a.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	4	
			B		
			T	4	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1	
			B		
			T	1	
Timeliness			G		
			B		
			T		
Required Measurement Uncertainty (2-sigma)	%		G	5	Uncertainty specified for blue and green wavelengths.
			B		
			T	5	Uncertainty specified for blue and green wavelengths.
Stability	%/decade		G	0.5	
			B		
			T	0.5	
Standards and References	For more details and references see the Ocean Colour EOV Specification Sheet (www.goosocean.org/eov).				

6. BIOSPHERE

6.1 ECV: Plankton

6.1.1 ECV Product: Zooplankton Diversity

Name	Zooplankton Diversity				
Definition	Number of species, functional traits, molecular biology groups (Operational Taxonomic Unit/OUT, other) per unit seawater volume or unit sea surface area, or unit benthos area.				
Unit	[Number of Species per unit volume or area, [Number of traits per unit volume or area], [Number of molecular biology groups per unit volume or area].				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	100 0.1	offshore nearshore
			B	1 0.1	offshore nearshore
			T	2500 0.1	offshore nearshore
Vertical Resolution	m		G	10 nominal	Depends on method of collection: discrete samples, vertical imaging profiles, net tows (oblique vs open/closing), or continuous tow recorder/imaging
			B	10 nominal	
			T	surface	
Temporal Resolution	month		G	1	Phenology of zooplankton is critical for food web dynamics, and recruitment success for whales, birds, turtles, fish, and invertebrate success
			B	3	
			T	12	
Timeliness	y		G	1	
			B		
			T	2	
Required Measurement Uncertainty (2-sigma)	%, count, concentration, weight (biomass)		G		Depending on observation: Taxonomic unit, trait, molecular group, biomass (wet/dry weight, carbon, nitrogen, protein content)
			B		
			T	5	
Stability			G		
			B		
			T		
Standards and References	See the Zooplankton EOV Specification Sheet for more details and references (www.goosocean.org/eov).				

6.1.2 ECV Product: Zooplankton Biomass

Name	Zooplankton Biomass				
Definition	Weight of zooplankton by volume.				
Unit	mg l^{-1}				
Note	It can be dry weight or wet weight.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	100	
			B		
			T	2500	
Vertical Resolution	m		G	10	
			B		
			T	surface	
Temporal Resolution	month		G	1	
			B		
			T	12	
Timeliness	y		G	1	
			B		
			T	2	
Required Measurement Uncertainty (2-sigma)	%		G		
			B		
			T	5	
Stability			G		
			B		
			T		
Standards and References	See the Zooplankton EOV Specification Sheet for more details and references (www.goosocean.org/eov).				

6.1.3 ECV Product: Phytoplankton Diversity

Name	Phytoplankton Diversity				
Definition	Number of species per unit sample, number and concentration of pigment types per unit sample.				
Unit	Per unit volume or unit surface area				
Note	Phytoplankton are the foundation of near-surface food webs and the non-chemosynthetic support for deep ocean foodwebs through vertical fluxes of particulate organic matter. In addition to their biomass and diversity, measures of primary production are also important.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	100 0.1	offshore nearshore
			B	1 0.1	offshore nearshore
			T	2000 1	offshore nearshore
Vertical Resolution			G	10 nominal	Depends on method of collection: discrete samples, vertical imaging profiles, net tows (oblique vs open/closing), or continuous tow recorder/imaging
			B	10 nominal	
			T	surface	
Temporal Resolution	month		G	weekly-monthly	Phenology of phytoplankton is critical for food web dynamics and recruitment success for whales, birds, turtles, fish, and invertebrate success
			B	3	
			T	1	
Timeliness			G		
			B		
			T		
Required Measurement Uncertainty (2-sigma)	%		G		Depending on observation: Taxonomic unit, trait, molecular group, biomass (wet/dry weight, carbon, nitrogen, protein content)
			B		
			T	5	
Stability			G		
			B		
			T		
Standards and References	Field methods foundational reference for operational oceanography: Strickland, J.D., & Parsons, T.R. (1968). A practical handbook of seawater analysis. Fisheries Research Board of Canada. Bulletin 167. (plus numerous and more recent publications for specific methods) Remote sensing of phytoplankton links to the Ocean Colour EOV/ECV See the EOV Specification Sheet for more details and references (www.goosocean.org/eov).				

6.1.4 ECV Product: Phytoplankton Biomass

Name	Phytoplankton Biomass				
Definition	Weight of phytoplankton by volume.				
Unit	mg m^{-3}				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	100	
			B		
			T	2000	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	y		G	Weekly-seasonal	
			B		
			T	10	
Timeliness			G		
			B		
			T		
Required Measurement Uncertainty (2-sigma)	%		G		
			B		
			T	5	
Stability			G		
			B		
			T		
Standards and References	See the EOV Specification Sheet for more details and references (www.goosocean.org/eov).				

6.2 ECV: Marine Habitat Properties

6.2.1 ECV Product: Mangrove Cover and Composition

Name	**Mangrove Cover and Composition**				
Definition	Extent of mangroves and species types in coastal environments (percent or ha and number of species per area).				
Unit	Extent measured in quadrats (e.g. 10x10m), or by pixels (e.g. 30x30m)				
Note					
Requirements					
Item needed	**Unit**	**Metric**	[1]	**Value**	**Notes**
Horizontal Resolution	m^2	Pixel/point in space	G	30x30	
			B		
			T	50x50	
Vertical Resolution			G	-	
			B	-	
			T	-	
Temporal Resolution	month	Point in time	G	12	
			B		
			T	12	
Timeliness	month	Point in time	G	6	
			B		
			T	12	
Required Measurement Uncertainty (2-sigma)	Areal extent	Percent	G	10	
			B		
			T	20	
Stability	Percent cover/decade		G	10	
			B		
			T	50	
Standards and References	Requirements and approaches vary for field based and satellite mapping approaches. For in situ data collection for mangrove composition see https://www.daf.qld.gov.au/__data/assets/pdf_file/0006/63339/Data-collection-protocol.pdf and https://www.cifor.org/publications/pdf_files/WPapers/WP86CIFOR.pdf See the EOV Specification Sheet for more details and references (www.goosocean.org/eov).				

6.2.2 ECV Product: Seagrass Cover (areal extent)

Name	Seagrass Cover (areal extent)				
Definition	Areal extent of suitable physical habitat (shallow sediment shelf with adequate water quality) supporting seagrass.				
Unit	km^2				
Note	Seagrass areal extent is typically estimated by remote sensing, including satellite, photography from aircraft, and for smaller areas by Unoccupied Aerial vehicle (UAV), i.e., drone. Various methods of image post-processing have been used to convert imagery to seagrass habitat extent.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m		G	30	Muller-Karger et al., 2018
			B		
			T	250	Muller-Karger et al., 2018
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	y		G	1 week	Muller-Karger et al., 2018
			B		
			T	1	
Timeliness			G		
			B		
			T		
Required Measurement Uncertainty (2-sigma)	%		G		
			B		
			T	10	
Stability			G		
			B		
			T		
Standards and References	Requirements based on characteristic scales and magnitude of signal of phenomena to observe. See the EOV Specification Sheet for more details and references (www.goosocean.org/eov). Muller-Karger et al., 2018. https://doi.org/10.1002/eap.1682				

6.2.3 ECV Product: Macroalgal Canopy Cover and Composition

Name	Macroalgal Canopy Cover and Composition				
Definition	Abundance of layered macroalgal stands in marine coastal environments.				
Unit	percent or number of individuals/area				
Note	Percent cover measured within quadrats (e.g., 0.5 x 0.5 m) or transects (e.g., 50 x 5 m). For large macroalgae such as kelps, abundance can be measured as number of individuals per area.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m^2	point in space	G	0.25	
			B	1	
			T	250	
Vertical Resolution	m	linear extent	G	1	
			B	5	
			T	10	
Temporal Resolution	month	point in time	G	1	
			B	3	
			T	12	
Timeliness	month	point in time	G	4	
			B	6	
			T	12	
Required Measurement Uncertainty (2-sigma)	Percent cover		G	10	
			B	20	
			T	30	
Stability	Percent cover		G	20	
			B	30	
			T	50	
Standards and References	See the EOV Specification Sheet for more details and references (www.goosocean.org/eov).				

6.2.4 ECV Product: Hard Coral Cover and Composition

Name	Hard Coral Cover and Composition				
Definition	Percent cover of hard coral. For composition, this is broken down by taxonomic or functional groups.				
Unit	%				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	10-100	For resolution of climate impacts, down to 10 km would be ideal; but will require development of remote sensing tools that can distinguish coral cover
			B		
			T	1000	Currently global coral data is analyzed at country levels (100s to 1000s of km)
Vertical Resolution	m		G	10	for resolution of climate impacts, stratification in 10 m would be ideal
			B		
			T	≈	single layer, global coral data is summarized in a single bin.
Temporal Resolution	y		G	1	annual data ideal
			B		
			T	5-10	data gaps results in 5-10 y gaps/bins for global analyses
Timeliness	y		G	0.25	Establishment of open access integrated regional datasets would allow sub-annual access to data
			B	2	
			T	5	Current practice requires high-effort compilations
Required Measurement Uncertainty (2-sigma)	%		G		
			B		
			T	5	
Stability			G		
			B		
			T		
Standards and References	English, S., Wilkinson, C., and Baker, V. (1997). Survey Manual for Tropical Marine Resources. Townsville, Australia. Australian Institute of Marine Science. GCRMN (2018a). GCRMN Implementation and Governance Plan. International Coral Reef Initiative (ICRI). GCRMN (2018b). GCRMN Technical Note. International Coral Reef Initiative (ICRI). Obura DO, et al., (2019) Coral Reef Monitoring, Reef Assessment Technologies, and Ecosystem-Based Management. Front. Mar. Sci. 6:580. doi: 10.3389/fmars.2019.00580 See the EOV Specification Sheet for more details and references (www.goosocean.org/eov).				

Terrestrial ECVs

7. HYDROLOGY

7.1 ECV: Groundwater

7.1.1 ECV Product: Groundwater Storage Change

Name	Groundwater Storage Change				
Definition	The volumetric loss or gain of groundwater between two times period.				
Unit	$km^3 y^{-1}$ or $mm y^{-1}$				
Note	Ground water storage change is monitored at large spatial scales by satellite gravimetry. To isolate groundwater storage change from the total mass variations observed by satellite gravimetry, all other mass changes in the Earth system need to be subtracted by complementary observations or models.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km	Length/width of area that can be resolved	G	≤ 100	depends on size of aquifer, hydrogeological characteristics, and type of application. 100 km is defined as a goal/target value by ref#1
			B		
			T	200-300	horizontal resolution of GRACE water storage data, depending on product, signal strength, geographical location and time scale (ref #1, #2, #3)
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	month	time	G	0.5	Requirement for the analysis of the groundwater response to, e.g., recharge events or changes in (human) withdrawals.
			B	1	
			T	3	Seasonal, for assessing, e.g., the climatology of groundwater storage variations and long-term variations / trends.
Timeliness	month	time	G	<1	Near-real time. Requirement for risk management (droughts), short-term forecasts
			B	1	Requirement for, e.g., seasonal forecasts
			T	12	Annually. Minimum requirement to assess long-term storage variations
Required Measurement Uncertainty (2-sigma)	$mm y^{-1}$	Change in water storage in water equivalents (volume per area) between two time periods	G	1	Goal value to allow for a much larger number of aquifers or river basins of smaller size to be monitored than for threshold value (ref #1), or for detecting more subtle rates of groundwater storage change. Depending on the time scale of application (e.g., for the assessment of monthly anomalies or long-term trends), the required measurement uncertainties may vary. It should be noted that the measurement uncertainty based on satellite gravimetry varies largely and in a non-linear way with spatial resolution, i.e., it is given as 0.05, 1, 5, 50 mm/year for 400, 200, 150, 100 km spatial resolution (ref #1). Additional uncertainty is added by isolating groundwater storage from total mass changes observed by satellite gravimetry.
			B		
			T	10	Expert judgement, based on long-term groundwater trends as observed with GRACE for large aquifers (≥ 50000 km²) (ref #2, #4), given that these observations already provided valuable information on the status of large aquifers. Depending on the time scale of application (e.g., for the assessment of monthly anomalies or long-term trends), the required measurement uncertainties may vary.
Stability	$mm y^{-1}$		G	1	Based on subtle expected long-term groundwater trends in large aquifers
			B		

			T	10	Based on expected long-term groundwater trends as observed with GRACE for large aquifers (≥ 50000 km^2) (ref #2, #4)
Standards and References	#1 Pail, R., Bingham, R., Braitenberg, C., Dobslaw, H., Eicker, A., Güntner, A., Horwath, M., Ivins, E., Longuevergne, L., Panet, I., Wouters, B., and the IUGG Expert Panel (2015): Science and User Needs for Observing Global Mass Transport to Understand Global Change and to Benefit Society. Surveys in Geophysics, 36, 743-772, 10.1007/s10712-015-9348-9. #2 Frappart, F., and Ramillien, G. (2018): Monitoring Groundwater Storage Changes Using the Gravity Recovery and Climate Experiment (GRACE) Satellite Mission: A Review. Remote Sensing, 10, 10.3390/rs10060829. #3 Rodell, M., Famiglietti, J. S., Wiese, D. N., Reager, J. T., Beaudoing, H. K., Landerer, F. W., and Lo, M. H. (2018): Emerging trends in global freshwater availability, Nature, 557, 650-+, 10.1038/s41586-018-0123-1. #4 Chen, J. L., Famiglietti, J. S., Scanlon, B. R., and Rodell, M. (2016): Groundwater Storage Changes: Present Status from GRACE Observations. Surveys in Geophysics, 37, 397-417, 10.1007/s10712-015-9332-4.				

7.1.2 ECV Product: Groundwater Level

Name	Groundwater Level				
Definition	The level (depth or elevation) of the water table, the upper surface of the saturated portion of the soil or bedrock.				
Unit	m				
Note	Groundwater levels are measured in monitoring wells. The measurements are expressed in m (below ground surface or above sea level, depending on the reference system).				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	number of wells per 100 km²	spatial density of wells	G	-	Depends on hydrogeology. Expert judgment.
			B	-	Depends on hydrogeology. Expert judgment.
			T	1	Recommended by the U.S. Geological Survey (USGS).
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	Month	time	G	0.5	Expert judgment
			B	1	Expert judgment
			T	3	Seasonal (wet/dry). Expert judgment
Timeliness	y	time	G	2-3 (days)	Expert judgment. When resources are available, a real-time monitoring network with telemetry can be set up, allowing the public to get data immediately. When quality checks are performed, international experience shows that data can be released in 2 or 3 days.
			B	0.5	Expert judgment. International experience shows that when missions have to be carried out to measure groundwater levels, half a year is an adequate time span to go over all locations, measure the levels, come back to the office, perform data quality tests and upload the final data in the online database to make it available to the public through official channels.
			T	1	Timeliness is directly related to the use of technology to get the data (telemetry vs going to the field to collect the data).
Required Measurement Uncertainty (2-sigma)	mm		G	1	Depending on the size and gradient of the aquifer, higher uncertainties may have a significant impact on the estimation of the water table. Also, there are other parameters that could have a higher impact on the uncertainty of the recording, as ill-defined vertical datums, pumping wells disrupting groundwater flow patterns, inadequate location of the well, inadequate length of screen setting, etc.
			B		
			T	30	
Stability	mm y^{-1}		G	1	A stable trend can be defined as an average monthly change in groundwater levels that is less than a certain value (e.g. 10 cm), for a series of consecutive years (e.g. 5, 10 or 20 years). A specific number and density of point data are needed depending on the period to be considered. For 5 years trend, 10 or more data points are required, and at least one reading per year for 4 out of the 5 years. For 10 years trend, 20 or more data points are required, and at least one reading from each consecutive two-year period. For 20 years trend, 40 or more data points are required, and at least one reading from each consecutive four-year period. This method is the one used by the Bureau of Meteorology of Australia, which is one of the several methods used around the world to estimate a stable trend in groundwater levels.
			B		
			T	10	It is important to notice that each country might have its own threshold value depending on how marked seasonal fluctuations are (depending on precipitation regimen and hydrogeology, among others). The required measurement stability depends largely on the magnitude of the expected groundwater level trend.

Standards and References					

7.2 ECV: Lakes

7.2.1 ECV Product: Lake Water Level (LWL)

Name	Lake Water Level (LWL)				
Definition	Lake Water Level (LWL). Elevation of the free surface of a lake relative to a specified vertical datum.				
Unit	cm				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m		G	-	In situ observation by a point measurement on gauge
			B	-	
			T	100	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1	
			B	30	
			T	365	Annual summary in the form of yearbook
Timeliness	d		G	1	In some case it can be interesting to have near real time lake level changes (in case of extreme events)
			B	30	
			T	365	For yearbooks
Required Measurement Uncertainty (2-sigma)	cm		G	5	
			B		
			T	10	Allows to use the considered characteristic in global and regional climate models
Stability	cm /decade		G	1	
			B		
			T	10	Allows to use the considered characteristic in global and regional climate models
Standards and References	Technical Regulations, volume III, Hydrology, 2006 edition, WMO-No.49 Guide to Hydrological Practices, sixth edition,2008, WMO-No.168				

7.2.2 ECV Product: Lake Water Extent (LWE)

Name	**Lake Water Extent (LWE)**				
Definition	Areal extent of the surface of a lake.				
Unit	km^2				
Note	LWE is only measurable using satellite imagery. For shallow lakes the LWE variable is more relevant than the Lake Water Level to detect climate change signal (Mason et al., 1994).				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	m		G	10	Using Sentinel-2 missions. Allows to determine small extent variations.
			B	30	Using Landsat (5,7,8) missions. Still relevant for shallow lakes with high extent potential variations.
			T	1000	Useful to partition surface energy fluxes.
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	5	Reasonable for climate change studies. Consistent with possibilities offered by satellite technologies (Sentinel-2 constellation can provide in the best-case images every 5 days). Will allow detecting LWE changes linked to extreme events.
			B		
			T	30	For long term evolution of lake extent changes monthly basis is still acceptable and usable. Useful to partition surface energy fluxes.
Timeliness	d		G	5	To be consistent with temporal resolution and possibilities offered by satellite technologies (Sentinel-2 constellation can provide in the best-case images every 5 days).
			B		
			T	365	Climate scale
Required Measurement Uncertainty (2-sigma)	%		G	5	For LWE, the uncertainty relatively to the total surface makes sense.
			B		
			T		
Stability	% /decade		G	5	
			B		
			T		
Standards and References	Algorithm Theoretical Basis Document (ATBD) of LWE (Lake Water Extent) calculation under ESA's CCI (Climate change Initiative) program. Mason I.M., Guzkowska M.A.J., Rapley C.G., and Street-Perrot F.A., (1994). The response of lake levels and areas to climate change, *Climate Change* 27, 161-197.				

7.2.3 ECV Product: Lake Surface Water Temperature (LSWT)

Name	Lake Surface Water Temperature (LSWT)				
Definition	Temperature of the lake surface.				
Unit	°C				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	0.1	
			B	1	
			T	2	Using satellite technics
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	3	To capture diurnal cycles
			B	24	Daily
			T	240	Currently achievable with satellite observations. Annual summary in the form of yearbook can also provide useful long-timeseries.
Timeliness	D		G	1	
			B	30	
			T	365	For yearbooks
Required Measurement Uncertainty (2-sigma)	°C		G	0.1	
			B	0.3	
			T	0.6	
Stability	°C / decade		G	0.1	
			B		
			T	0.25	
Standards and References	Technical Regulations, volume III, Hydrology, 2006 edition, WMO-No.49.				

7.2.4 ECV Product: Lake Ice Cover (LIC)

Name	Lake Ice Cover (LIC)
Definition	Area of lake covered by ice.
Unit	km^2
Note	Based on lake-wide satellite observations. In situ observations of ice cover can be temporally and spatially consistent, and therefore be useful for climate monitoring, but capture variations and trends in ice cover that are spatially limited (i.e. not lake-wide but rather representative of some limited area observable from lake shore). Lake-wide ice phenology can be derived from LIC (freeze onset to complete freeze over (CFO) dates during the freeze-up period; melt onset to water clear of ice (WCI) dates during the break-up period; and ice cover duration derived from number of days between CFO and WCI dates over an ice year) (Duguay et al., 2015). For lakes that do not form a complete ice cover every year or in some years (e.g. Laurentian Great Lakes), maximum ice cover extent (timestamped with date) is also a useful climate indicator that can be derived; similarly minimum ice extent can be derived for High Arctic lakes that do not completely lose their ice cover in summer.

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m		G	50	Smaller water bodies as well as due to increased availability of synthetic aperture radar (SAR) and optical data at resolutions ≤ 50 m (e.g. Wang et al., 2018)
			B	100	Small water bodies (lakes, ponds) can be observed
			T	1000	Medium to large sized water bodies as demonstrated through ESA Lakes_cci
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	< 1	Detection of interannual variability and decadal shifts in ice cover and for improving ice, weather forecasting and climate models.
			B	1	Allows daily observations under variable cloud cover from optical satellite data
			T	3-7	Useful for contrasting extreme ice years, numerical weather forecasting, and assessing lake models used as parameterization schemes in climate models.
Timeliness	d		G	1	In support of ice forecasting systems (e.g. NOAA's Great Lakes Coastal Forecasting System, GLCFS).
			B		
			T	365	To support annual climate reporting
Required Measurement Uncertainty (2-sigma)	%		G	1	
			B		
			T	10	
Stability	%		G	0.1	
			B		
			T	1	

Standards and References	
	ATBD and URD of ESA Lakes_cci Duguay, C.R., M. Bernier, Y. Gauthier, and A. Kouraev, 2015. Remote sensing of lake and river ice. In *Remote Sensing of the Cryosphere*, Edited by M. Tedesco. Wiley-Blackwell (Oxford, UK), pp. 273-306. Wang, J., C.R. Duguay, and D.A. Clausi, V. Pinard, and S.E.L. Howell, 2018. Semi-automated classification of lake ice cover using dual polarization RADARSAT-2 imagery. *Remote Sensing*, 10(11), 1727; https://doi.org/10.3390/rs10111727.

7.2.5 ECV Product: Lake Ice Thickness (LIT)

Name	Lake Ice Thickness (LIT)				
Definition	Thickness of ice on a lake.				
Unit	cm				
Note	LIT measurements are largely based on in situ observational networks. Satellite-based retrieval algorithms are under development (research stage), not operational yet. On-ice snow depth measurements are also useful for both climate monitoring as well as for assessing and improving lake models.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m		G	50	From synthetic aperture radar (SAR)
			B	1000	
			T	10000	From radar altimetry and passive microwave data (Kang et al., 2014)
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	1	From satellite observations
			B	30	
			T	365	Annual summary of in situ measurements from yearbooks
Timeliness	d		G	1	Using satellite telecommunication systems for in situ measurements; also daily from satellites for numerical models such as NOAA's Great Lakes Coastal Forecasting System (GLCFS)
			B	30	
			T	365	To support annual climate reporting
Required Measurement Uncertainty (2-sigma)	cm		G	1	Achievable with in situ measurements
			B	10	Achievable from satellite measurements
			T	15	
Stability	cm		G	1	
			B		
			T	10	
Standards and References	National standards. Kang, K.-K., C. R. Duguay, J. Lemmetyinen, and Y. Gel, 2014. Estimation of ice thickness on large northern lakes from AMSR-E brightness temperature measurements. *Remote Sensing of Environment*, 150: 1-19, http://dx.doi.org/10.1016/j.rse.2014.04.016.				

7.2.6 ECV Product: Lake Water-Leaving Reflectance

Name	Lake Water Leaving Reflectance				
Definition	Water-leaving reflectance in discrete wavebands of electromagnetic radiation from near-UV through visible to near infrared and up to shortwave infrared, fully normalized for viewing and solar incident angles.				
Unit	dimensionless				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m		G	10	Small rivers and water bodies can be observed
			B	100	Water bodies included with resolution <300m, as demonstrated through Copernicus Global Land Service
			T	1000	Medium to large sized water bodies (up to 50% of global inland water surface area), as demonstrated through ESA Lakes_cci
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	<1	At equator. Allows daily observations under variable.
			B	1	At equator. Decade-scale shifts in biological components become detectable in individual water bodies.
			T	3-30	At equator. Decade-scale shifts in biological components become detectable within global lake biomes.
Timeliness	d		G	1	Episodic events can be detected in near real-time
			B	30	Satellite observations supplied with reliable meteorological ancillary data
			T	365	Annual extension of existing data records based on measurements supplied with reliable meteorological records
Required Measurement Uncertainty (2-sigma)	%		G	10	At peak reflectance amplitude. Expected to allow derived water column properties to be estimated within 0.1 mg m^{-3} chlorophyll-a and 1 g m^{-3} suspended matter or 1 NTU. See ESA Lakes_cci URD. Impact of observation uncertainty will vary with lake type (shape of reflectance spectrum).
			B	20	At peak reflectance amplitude
			T	30	At peak reflectance amplitude. A threshold cannot be clearly defined for all optical water types and lake morphologies. A larger number of observations (large lakes) may compensate for increased per-observation uncertainty.
Stability	% /decade		G	0.1	For in situ fiducial reference observations.
			B	0.5	
			T	1	Equates to 0.0001/decade for LWLR, 0.1 mg m^{-3} per decade for chlorophyll-a and 0.1 g m^{-3} for suspended matter or turbidity.
Standards and References	ATBD and URD of ESA Lakes_cci				

7.3 ECV: River Discharge

7.3.1 ECV Product: River Discharge

Name	River Discharge				
Definition	River Discharge is defined as the volume of water passing a measuring point or gauging station in a river in a given time.				
Unit	$m^3 s^{-1}$				
Note	For station calibration both, the flow velocity and the cross-sectional area has to be measured a few times a year. River Discharge measurements have essential direct applications for water management and related services, including flood protection. They are needed in the longer term to help identify and adapt to some of the most significant potential effects of climate change. The flow of freshwater from rivers into the oceans also needs to be monitored because it reduces ocean salinity, and changes in flow may thereby influence the thermohaline circulation. For climate applications a minimum number of 600 gauging stations globally would be needed to capture the freshwater influx from major rivers to the oceans (which in turn has an impact on ocean temperature and salinity which in turn has impacts on ocean currents and weather systems). A minimum of 4000 gauging stations would be required, in addition to global and regional hydrological data, for deriving changes in rainfall distribution and intensity, and determine climate signals in least anthropogenic impacted basins.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution			G	-	N/A. In situ observation by a point measurement on gauge.
			B	-	
			T	-	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	Hourly. Required to monitor single events and for assessment of extreme events.
			B	24	Daily. Suitable to determine general discharge patterns at regional and global scales
			T	720	Monthly. Suitable to support climate related modelling of terrestrial, oceanographic and atmospheric systems
Timeliness	month		G	1 (day)	Daily. For high resolution studies and for preparedness, mitigation during short term events
			B	1	Monthly. Regional forecasting and modelling
			T	12	Yearly. For climatology the provision of monthly data within one year after data collection is necessary
Required Measurement Uncertainty (2-sigma)	%		G	5	Improved measurement techniques and sufficient resources
			B	10	
			T	15	Discharge measurements are affected by a number of changing conditions and uncertainties due to complex calibration needs such as river cross section flow velocities, changing channel conditions, siltation, scour, weed growth, ice conditions.
Stability	$m\ y^{-1}$ / decade	Maximum drift over reference period	G	0.01	For high resolution climatology, necessary to validate discharge variability and extremes.
			B	0.05	
			T	0.1	For climatology
Standards and References	WMO Technical Regulations of Hydrology (WMO-No.49) and Guide to hydrological practices (WMO- No.168) ISO 1100-1 (1996) Measurement of liquid flow in open channels-Part I: Establishment and operation of a gauging station ISO 748 (1997) Measurement of liquid flow in open channels-Velocity area methods WMO (WMO-519) Manual on stream gauging Volume I-Fieldwork and Volume II-Computation of discharge ISO Technical Committee 113 is dealing with all standards related to Hydrometry ISO/TS 24154 (2005) The principles of operation, construction, maintenance and application of acoustic Doppler current profilers (ADCP)				

7.3.2 ECV Product: Water Level

Name	Water Level				
Definition	Water Level is the elevation of the water surface of a river (or a lake, reservoir) regarding a reference (the ellipsoid).				
Unit	m				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m		G	<20	In addition to global and regional hydrological data, measurement of least anthropogenic impacted basins to derive changes in rainfall distribution, intensity and determine climate signals.
			B	20-50	Measurement of changes in seasonal level patterns at regional level.
			T	>50	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	Hourly. Required to monitor single events and for assessment of extreme events
			B	24	Daily. Suitable to determine general river/lakes patterns at regional and global scales
			T	720	Monthly. Suitable to support climate related modelling of terrestrial, oceanographic and atmospheric systems
Timeliness	month		G	1 (day)	Daily. For high resolution studies and for preparedness, mitigation during short term events
			B	1	Monthly. Regional forecasting and modelling
			T	12	Yearly. For climatology the provision of monthly data within one year after data collection is necessary
Required Measurement Uncertainty (2-sigma)	cm		G	10	From in situ observations
			B		
			T	>10	From satellite observations
Stability	$m\ y^{-1}$ / decade	Maximum drift over reference period	G	0.01	For high resolution climatology and necessary to validate variability and extremes
			B		
			T	0.05	For climatology
Standards and References	WMO Technical Regulations of Hydrology (WMO-No.49) and Guide to hydrological practices (WMO- No.168) ISO 1100-1 (1996) Measurement of liquid flow in open channels-Part I: Establishment and operation of a gauging station ISO 748 (1997) Measurement of liquid flow in open channels-Velocity area methods WMO (WMO-519) Manual on stream gauging Volume I-Fieldwork and Volume II-Computation of discharge ISO Technical Committee 113 is dealing with all standards related to Hydrometry ISO/TS 24154 (2005) The principles of operation, construction, maintenance and application of acoustic Doppler current profilers (ADCP)				

7.4 ECV: Soil moisture

7.4.1 ECV Product: Surface Soil Moisture

Name	Surface Soil Moisture				
Definition	Soil Moisture refers to the average water content in the soil, which can be expressed in volumetric, gravimetric or relative (e.g. degree of saturation) units. Surface Soil Moisture is sometimes referred to as topsoil moisture, surface wetness, surface humidity.				
Unit	$m^3 m^{-3}$				
Note	The depth of the topmost soil layer is often only qualitatively defined as the actual sensing depth varies with measurement technique, water content, and soil properties and usually cannot be specified with any accuracy. All units can be inter-converted given the availability of soil property information (bulk density, porosity etc.), yet the use of the volumetric soil moisture content as the standard measurement unit is encouraged.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km		G	1	Needed to fully resolve highly-dynamic processes taking place at the land-atmosphere interface surface (convective rainfall, orographic effects, etc.).
			B	10	Many climate and earth system models are moving to a grid size of 10 km or finer.
			T	50	This definition reflects a practical understanding of the boundary between climate science and other related geoscientific fields such as hydrology, agronomy, or ecology.
Vertical Resolution			G	-	N/A. There is no proper vertical resolution as the surface is a single layer. However, for modelling bare soil evaporation and LST a very thin skin layer is required (e.g. Dorigo et al., 2017; ECMWF).
			B	-	
			T	-	
Temporal Resolution	h		G	6	Needed to fully resolve highly-dynamic processes taking place at the land-atmosphere interface surface; Needed to depict the interplay between soil moisture, precipitation, vegetation activity, and evaporation.
			B	24	Needed for closing water balance at daily scales.
			T	48	Important land-atmospheric processes are missed, but drying and wetting trends can be depicted.
Timeliness	h		G	3	For climate communication and improved preparedness.
			B	6	To support the assessment of on-going extreme events (droughts, extreme wetness).
			T	48	For assessments and re-analysis.
Required Measurement Uncertainty	$m^3 m^{-3}$	Unbiased root mean square error	G	0.03	More demanding goal is probably unrealistic due to high variability of soil moisture at small-scales due to changes in soil properties, topography, vegetation cover.
			B	0.04	Accuracy goal as first adopted for the dedicated soil moisture satellites SMOS and SMAP. Later adopted for GCOS and reconfirmed at the 4th Satellite Soil Moisture Validation and Application Workshop (Wagner et al. 2017).
			T	0.08	This value traces back to the accuracy goals as specified for the SMOS and SMAP satellites designed for measuring soil moisture.
Stability	$m^3 m^{-3}$ / decade		G	0.005	This value still lacks justification in the scientific literature and needs to be critically assessed.
			B	0.01	As above
			T	0.02	As above
Standards and References	Wagner, W., T.J. Jackson, J.J. Qu, R. de Jeu, N. Rodriguez-Fernandez, R. Reichle, L. Brocca, W. Dorigo (2017) Fourth Satellite Soil Moisture Validation and Application Workshop, GEWEX News, 28(4), 13-14. Gruber, A., De Lannoy, G., Albergel, C., Al-Yaari, A., Brocca, L., Calvet, J.-C., Colliander, A., Cosh, M., Crow, W., Dorigo, W., Draper, C., Hirschi, M., Kerr, Y., Konings, A., Lahoz, W., McColl, K., Montzka, C., Muñoz-Sabater, J., Peng, J., Reichle, R., Richaume, P., Rüdiger, C., Scanlon, T., Schalie, R.v.d., Wigneron, J.-P. and Wagner, W., 2020. Validation practices for satellite soil moisture retrievals: What are (the) errors? Remote Sensing of Environment, 244: 111806. 10.1016/j.rse.2020.111806. https://lpvs.gsfc.nasa.gov/PDF/CEOS_SM_LPV_Protocol_V1_20201027_final.pdf				

7.4.2 ECV Product: Freeze / Thaw

Name	Freeze / Thaw				
Definition	Flag indicating whether the land surface is frozen or not.				
Unit	Unitless				
Note	Freeze/Thaw is subsidiary variable of the ECV soil moisture. It is needed because most measurement techniques do not allow to measure soil moisture when the ground is frozen. Also, land-surface processes fundamentally change when the soil is frozen. Instead of binary values (e.g. thawed = 0 and frozen = 1) probabilities (i.e. probability that the soil is frozen) may be used.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km	Size of grid cell	G	1	Same as for Surface Soil Moisture: Needed to fully resolve highly-dynamic processes taking place at the land-atmosphere interface surface (convective rainfall, orographic effects, etc.).
			B	10	Same as for Surface Soil Moisture: Many climate and earth system models are moving to a grid size of 10 km or finer.
			T	50	Same as for Surface Soil Moisture: This definition reflects a practical understanding of the boundary between climate science and other related geoscientific fields such as hydrology, agronomy, or ecology.
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	6	Same as for Surface Soil Moisture: Needed to fully resolve highly-dynamic processes taking place at the land-atmosphere interface surface, and to depict the interplay between soil moisture, precipitation and evaporation
			B	24	Same as for Surface Soil Moisture: Needed for closing water balance at daily scales
			T	48	Same as for Surface Soil Moisture: Important land-atmospheric processes are missed, but drying and wetting trends can be depicted
Timeliness	h		G	3	Same as for Surface Soil Moisture: For climate communication and improved preparedness
			B	6	Same as for Surface Soil Moisture: To support the assessment of on-going extreme events (droughts, extreme wetness)
			T	48	Same as for Surface Soil Moisture: For assessments and re-analysis
Required Measurement Uncertainty	%	Overall classification accuracy (as this is a flag, this variable has an accuracy and not a sigma)	G	98	Same as for Surface Soil Moisture: More demanding goal is probably unrealistic due to high variability of soil moisture at small-scales due to changes in soil properties, topography, vegetation cover.
			B	95	Same as for Surface Soil Moisture: Accuracy goal as first adopted for the dedicated soil moisture satellites SMOS and SMAP. Later adopted for GCOS and reconfirmed at the 4th Satellite Soil Moisture Validation and Application Workshop (Wagner et al. 2017).
			T	90	Same as for Surface Soil Moisture: This value traces back to the accuracy goals as specified for the SMOS and SMAP satellites designed for measuring soil moisture.
Stability					

Standards and References	Required Measurement Uncertainty (2-sigma): Confusion matrices should be computed for different periods of the year. In particular, the transition periods from frozen to thawed conditions are most critical for assessing the accuracy of the freeze/thaw estimates. Wagner, W., T.J. Jackson, J.J. Qu, R. de Jeu, N. Rodriguez-Fernandez, R. Reichle, L. Brocca, W. Dorigo (2017) Fourth Satellite Soil Moisture Validation and Application Workshop, GEWEX News, 28(4), 13-14. Gruber, A., De Lannoy, G., Albergel, C., Al-Yaari, A., Brocca, L., Calvet, J.-C., Colliander, A., Cosh, M., Crow, W., Dorigo, W., Draper, C., Hirschi, M., Kerr, Y., Konings, A., Lahoz, W., McColl, K., Montzka, C., Muñoz-Sabater, J., Peng, J., Reichle, R., Richaume, P., Rüdiger, C., Scanlon, T., Schalie, R.v.d., Wigneron, J.-P. and Wagner, W., 2020. Validation practices for satellite soil moisture retrievals: What are (the) errors? Remote Sensing of Environment, 244: 111806. 10.1016/j.rse.2020.111806. https://lpvs.gsfc.nasa.gov/PDF/CEOS_SM_LPV_Protocol_V1_20201027_final.pdf

7.4.3 ECV Product: Surface Inundation

Name	Surface Inundation				
Definition	Flag indicating whether the land surface is inundated or not.				
Unit	Unitless				
Note	Surface inundation is subsidiary variable of the ECV soil moisture. It is needed because most measurement techniques do not allow to measure soil moisture when the soil surface is inundated. Also, land-surface processes fundamentally change when the soil is inundated. Instead of binary values probabilities (i.e. probability that the soil is inundated) may be used.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km	Size of grid cell	G	1	Same as for Surface Soil Moisture: Needed to fully resolve highly-dynamic processes taking place at the land-atmosphere interface surface (convective rainfall, orographic effects, etc.).
			B	10	Same as for Surface Soil Moisture: Many climate and earth system models are moving to a grid size of 10 km or finer.
			T	50	Same as for Surface Soil Moisture: This definition reflects a practical understanding of the boundary between climate science and other related geoscientific fields such as hydrology, agronomy, or ecology.
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	6	Same as for Surface Soil Moisture: Needed to fully resolve highly-dynamic processes taking place at the land-atmosphere interface surface, and to depict the interplay between soil moisture, precipitation and evaporation.
			B	24	Same as for Surface Soil Moisture: Needed for closing water balance at daily scales.
			T	48	Same as for Surface Soil Moisture: Important land-atmospheric processes are missed, but drying and wetting trends can be depicted.
Timeliness	h		G	3	Same as for Surface Soil Moisture: For climate communication and improved preparedness.
			B	6	Same as for Surface Soil Moisture: To support the assessment of on-going extreme events (droughts, extreme wetness).
			T	48	Same as for Surface Soil Moisture: For assessments and re-analysis.
Required Measurement Uncertainty	%	Overall classification accuracy (as this is a flag, this variable has an accuracy and not a sigma)	G	98	Same as for Surface Soil Moisture: More demanding goal is probably unrealistic due to high variability of soil moisture at small-scales due to changes in soil properties, topography, vegetation cover.
			B	95	Same as for Surface Soil Moisture: Accuracy goal as first adopted for the dedicated soil moisture satellites SMOS and SMAP. Later adopted for GCOS and reconfirmed at the 4th Satellite Soil Moisture Validation and Application Workshop (Wagner et al. 2017).
			T	90	Same as for Surface Soil Moisture: This value traces back to the accuracy goals as specified for the SMOS and SMAP satellites designed for measuring soil moisture.
Stability					
Standards	Wagner, W., T.J. Jackson, J.J. Qu, R. de Jeu, N. Rodriguez-Fernandez, R. Reichle, L. Brocca, W. Dorigo (2017) Fourth Satellite Soil Moisture Validation and Application Workshop, GEWEX News, 28(4), 13-14. Gruber, A., De Lannoy, G., Albergel, C., Al-Yaari, A., Brocca, L., Calvet, J.-C., Colliander, A., Cosh, M., Crow, W., Dorigo, W., Draper, C., Hirschi, M., Kerr, Y., Konings, A., Lahoz, W., McColl, K., Montzka, C., Muñoz-Sabater, J., Peng, J., Reichle, R., Richaume, P., Rüdiger, C., Scanlon, T., Schalie, R.v.d., Wigneron, J.-P. and Wagner, W., 2020. Validation practices for satellite soil moisture retrievals: What are (the) errors? Remote Sensing of Environment, 244: 111806. 10.1016/j.rse.2020.111806.				

7.4.4 ECV Product: Root Zone Soil Moisture

Name	**Root Zone Soil Moisture**				
Definition	The Root-Zone Soil Moisture content refers to the average water content in the root-zone.				
Unit	$m^3\ m^{-3}$				
Note	There is no agreed definition of the depth of the root-zone layer, as the actual root-zone of plants varies according to vegetation type, ground water table, and substrate. Considering that many in situ networks have sensors up to a depth of about 50 cm, a first definition of the root-zone layer may be 0-50 cm or similar ranges, although most land surface and vegetation models adopt a root zone of 100 cm or deeper (e.g. Muñoz-Sabater, 2021). Measuring the water content in the root-zone is either not possible (e.g. when using microwave satellites) or costly (e.g. using in situ measurements). Hence, the root-zone soil moisture content has initially not been considered by GCOS. However, as most applications require information about the soil moisture content in deeper soil layers, the root-zone soil moisture content was added to the ECV soil moisture in the GCOS 2016 Implementation Plan. Because it is relatively new variable, all specifications given in this table need to be regarded with care.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km	Size of grid cell	G	1	Same as for Surface Soil Moisture: Needed to fully resolve highly-dynamic processes taking place at the land-atmosphere interface surface (convective rainfall, orographic effects, etc.).
			B	10	Same as for Surface Soil Moisture: Many climate and earth system models are moving to a grid size of 10 km or finer.
			T	50	Same as for Surface Soil Moisture: This definition reflects a practical understanding of the boundary between climate science and other related geoscientific fields such as hydrology, agronomy, or ecology.
Vertical Resolution	cm		G	10	
			B	50	
			T	100	
Temporal Resolution	h		G	6	Same as for Surface Soil Moisture: Needed to fully resolve highly-dynamic processes taking place at the land-atmosphere interface surface; Needed to depict the interplay between soil moisture, precipitation and evaporation.
			B	24	Same as for Surface Soil Moisture: Needed for closing water balance at daily scales.
			T	48	Same as for Surface Soil Moisture: Important land-atmospheric processes are missed, but drying and wetting trends can be depicted.
Timeliness	month		G	0.25	Weekly. Same as for Surface Soil Moisture: For climate communication and improved preparedness
			B	1	Monthly. Same as for Surface Soil Moisture: To support the assessment of on-going extreme events (droughts, extreme wetness)
			T	12	Yearly. Same as for Surface Soil Moisture: for assessments and re-analysis
Required Measurement Uncertainty	$m^3\ m^{-3}$	Unbiased root mean square error	G	0.03	Same as for Surface Soil Moisture: More demanding goal is probably unrealistic due to high variability of soil moisture at small-scales due to changes in soil properties, topography, vegetation cover.
			B	0.04	Same as for Surface Soil Moisture: Accuracy goal as first adopted for the dedicated soil moisture satellites SMOS and SMAP. Later adopted for GCOS and reconfirmed at the 4th Satellite Soil Moisture Validation and Application Workshop (Wagner et al. 2017).
			T	0.08	Same as for Surface Soil Moisture: This value traces back to the accuracy goals as specified for the SMOS and SMAP satellites designed for measuring soil moisture.
Stability	$m^3\ m^{-3}$		G	0.005	Same as for Surface Soil Moisture: This value still lacks justification in the scientific literature and needs to be critically assessed.
			B	0.01	As above
			T	0.02	As above

Wagner, W., T.J. Jackson, J.J. Qu, R. de Jeu, N. Rodriguez-Fernandez, R. Reichle, L. Brocca, W. Dorigo (2017) Fourth Satellite Soil Moisture Validation and Application Workshop, GEWEX News, 28(4), 13-14.

Gruber, A., De Lannoy, G., Albergel, C., Al-Yaari, A., Brocca, L., Calvet, J.-C., Colliander, A., Cosh, M., Crow, W., Dorigo, W., Draper, C., Hirschi, M., Kerr, Y., Konings, A., Lahoz, W., McColl, K., Montzka, C., Muñoz-Sabater, J., Peng, J., Reichle, R., Richaume, P., Rüdiger, C., Scanlon, T., Schalie, R.v.d., Wigneron, J.-P. and Wagner, W., 2020. Validation practices for satellite soil moisture retrievals: What are (the) errors? Remote Sensing of Environment, 244: 111806. 10.1016/j.rse.2020.111806.

Muñoz-Sabater, J., Dutra, E., Agustí-Panareda, A., Albergel, C., Arduini, G., Balsamo, G., ... & Thépaut, J. N. (2021). ERA5-Land: A state-of-the-art global reanalysis dataset for land applications. Earth System Science Data, 13(9), 4349-4383.

https://lpvs.gsfc.nasa.gov/PDF/CEOS_SM_LPV_Protocol_V1_20201027_final.pdf

7.5 ECV: Terrestrial Water Storage (TWS)[4]

7.5.1 ECV Product: Terrestrial Water Storage Anomaly

Name	Terrestrial Water Storage Anomaly				
Definition	TWS is the total amount of water stored in all continental storage compartments (ice caps, glaciers, snow cover, soil moisture, groundwater, surface water bodies, water in biomass). The change of TWS over time balances the budget of the water fluxes precipitation, evapotranspiration and runoff, i.e., it closes the continental water balance.				
Unit	km^3 or mm water equivalent (kg/m^2)				
Note	Measuring TWS is possible by satellite and terrestrial gravimetry in relative terms only, not in absolute values. Thus, TWS is given as the deviation relative to a long-term mean (TWS				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km		G	1	Resolve the topography- and land cover-driven patterns of landscape-scale water storage dynamics, e.g., ref #2
			B	10	Many climate and Earth system models are moving to a grid size of 10 km or finer. Often a relevant local to regional water management scale
			T	200	Comprehensive continental-scale patterns of water storage changes, e.g., ref #1
Vertical Resolution			G	-	N/A, as total water storage represents an integrative value in the vertical, overall storage compartments and depths.
			B	-	
			T	-	
Temporal Resolution	d		G	1	To resolve water storage changes caused by heavy precipitation events and occurring during flood events
			B		
			T	30	To resolve major seasonal, intra- and inter-annual dynamics as well as long-term trends of water storage
Timeliness	d		G	1	Required latency for warning for and managing of extreme events, in particular floods, e.g. ref #3
			B		
			T	60-90	Current latency of GRACE-FO based TWS products, e.g. ref #4
Required Measurement Uncertainty (2-sigma)	mm		G	1	Order of magnitude required to resolve TWS effect of daily evapotranspiration
			B		
			T	20	Order of magnitude to resolve monthly TWS variations
Stability	mm y^{-1}		G	<1	Stability needed to detect subtle long-term TWS trends caused by global change and anthropogenic impacts on the water cycle
			B		
			T	<5	Stability needed to resolve major long-term TWS changes, e.g., related to melting ice sheets, groundwater depletion
Standards and References	Pail, R., Bingham, R., Braitenberg, C., Dobslaw, H., Eicker, A., Güntner, A., Horwath, M., Ivins, E., Longuevergne, L., Panet, I., Wouters, B., Panel, I.E. (2015): Science and User Needs for Observing Global Mass Transport to Understand Global Change and to Benefit Society. Surveys in Geophysics 36, 743-772. Güntner, A., Reich, M., Mikolaj, M., Creutzfeldt, B., Schroeder, S., Wziontek, H. (2017): Landscape-scale water balance monitoring with an iGrav superconducting gravimeter in a field enclosure. Hydrology and Earth System Sciences, 21(6), 3167-3182, doi: 10.5194/hess-21-3167-2017. Jäggi, A., Weigelt, M., Flechtner, F., Güntner, A., Mayer-Gürr, T., Martinis, S., Bruinsma, S., Flury, J., Bourgogne, S., Steffen, H., Meyer, U., Jean, Y., Sušnik, A., Grahsl, A., Arnold, D., Cann-Guthauser, K., Dach, R., Li, Z., Chen, Q., van Dam, T., Gruber, C., Poropat, L., Gouweleeuw, B., Kvas, A., Klinger, B., Lemoine, J.-M., Biancale, R., Zwenzner, H., Bandikova, T., Shabanloui, A. (2019): European Gravity Service for Improved Emergency Management (EGSIEM) - from concept to implementation. Geophysical Journal International, 218(3), 1572-1590, doi: 10.1093/gji/ggz238. Peter, H., Meyer, U., Lasser, M., Jäggi, A. (2022): COST-G gravity field models for precise orbit determination of Low Earth Orbiting Satellites. Advances in Space Research, 69(12), 4155-4168, doi: 10.1016/j.asr.2022.04.005				

[4] This is a new ECV approved by GCOS Steering Committee in 2020.

8. Cryosphere[5]

8.1 ECV: Snow

8.1.1 ECV Product: Area Covered by Snow

Name	Area Covered by Snow				
Definition	Snow cover refers to the % coverage solid surface (ground, ice sea ice, lake ice, glaciers, etc) in open areas and on top of vegetation cover that is present, such as forest canopies covered by snow at a given time. Sometimes called "viewable snow".				
Unit	km^2				
Note	Area covered by snow is observed in-situ and by satellite (Robinson, 2013; Frei et al., 2012). The visible satellite identifies the snow cover with few millimeters of snow depth. The microwave radiometer can detect at first from few centimeters of snow depth.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m	Size of grid cell	G	50	
			B	500	
			T	1000	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h	Frequency of measurement	G	6	
			B	24	
			T	48	
Timeliness	h		G	3	
			B	24	
			T	240	
Required Measurement Uncertainty (2-sigma)	%		G	5	
			B	15	
			T	20	
Stability	%		G	1	
			B	5	
			T	10	
Standards and References	Frei, A., Tedesco, M., Lee, S., Foster, J., Hall, D. K., Kelly, R. and Robinson, D. A. (2012): A review of global satellite-derived snow products, Advances in Space Research, 50, 1007–1029. Goodison, B. and Walker, A. (1994): Canadian development and use of snow cover information from passive microwave satellite data, B. Choudhuly et al. (ed), Passive Microwave Remote Sensing of Land-Atmosphere Interaction, Utrecht: VSP BV, 245-262. Robinson, D.A. (2013): Climate Data Record Program (CDRP): Climate Algorithm Theoretical Basis Document (C-ATBD) Northern Hemisphere Snow Cover Extent, CDRPATBD-0156. Asheville, North Carolina, USA 28 pp. Sturm, M., Taras, B., Liston, G. E., Derksen, C., Jonas, T. and Lea, J. (2010): Estimating Snow Water Equivalent Using Snow Depth Data and Climate Classes. Jour. Hydromet. 11, 1380-1394. Bormann, K., R. Brown, C. Derksen, and T. Painter. 2018. Estimating snow cover trends from space. Nature Climate Change. DOI: 10.1038/s41558-018-0318-3.005 WMO (2018), Guide to instruments and methods of observation: Volume II - Measurement of Cryospheric Variables, 2018th ed., World Meteorological Organization, Geneva, Switzerland, 52 pp. Fierz, C., Armstrong, R.L., Durand, Y., Etchevers, P., Greene, E., McClung, D.M., Nishimura, K., Satyawali, P.K., and Sokratov, S.A. (2009): The International Classification for Seasonal Snow on the Ground, UNESCO-IHP, Paris, France, viii+80 pp.				

[5] GCOS and GCW will be working together to harmonize the requirements for the cryosphere ECVs during the lifetime of this Implementation Plan.

8.1.2 ECV Product: Snow Depth

Name	Snow Depth				
Definition	Snow thickness is the perpendicular distance between snowpack surface and the underlying surface (ground, sea ice, lake ice, ice sheets, on ice shelves, glaciers, etc.).				
Unit	m				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km	Size of grid cell	G	0.5	
			B	5	
			T	25	The resolution 1km refers to the homogeneous snow coverage in the frat field and high local variation in the mountain areas.
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d		G	6	
			B	24	
			T	48	
Timeliness	h		G	1	
			B	6	
			T	24	
Required Measurement Uncertainty (2-sigma)	mm		G	10	
			B	25	
			T	50	
Stability	cm		G	1	
			B	2	
			T	5	
Standards and References	Frei, A., Tedesco, M., Lee, S., Foster, J., Hall, D. K., Kelly, R. and Robinson, D. A. (2012): A review of global satellite-derived snow products, Advances in Space Research, 50, 1007–1029. Goodison, B. and Walker, A. (1994): Canadian development and use of snow cover information from passive microwave satellite data, B. Choudhuly et al. (ed), Passive Microwave Remote Sensing of Land-Atmosphere Interaction, Utrecht: VSP BV, 245-262. Robinson, D.A. (2013): Climate Data Record Program (CDRP): Climate Algorithm Theoretical Basis Document (C-ATBD) Northern Hemisphere Snow Cover Extent, CDRPATBD-0156. Asheville, North Carolina, USA 28 pp. Sturm, M., Taras, B., Liston, G. E., Derksen, C., Jonas, T. and Lea, J. (2010): Estimating Snow Water Equivalent Using Snow Depth Data and Climate Classes. Jour. Hydromet. 11, 1380-1394. Pulliainen, J., Luojus, K., Derksen, C. et al. (2020). Patterns and trends of Northern Hemisphere snow mass from 1980 to 2018. Nature 581, 294–298. Doi: 10.1038/s41586-020-2258-0. WMO (2018), Guide to instruments and methods of observation: Volume II - Measurement of Cryospheric Variables, 2018th ed., World Meteorological Organization, Geneva, Switzerland, 52 pp. Fierz, C., Armstrong, R.L., Durand, Y., Etchevers, P., Greene, E., McClung, D.M., Nishimura, K., Satyawali, P.K., and Sokratov, S.A. (2009): The International Classification for Seasonal Snow on the Ground, UNESCO-IHP, Paris, France, viii+80 pp.				

8.1.3 ECV Product: Snow-Water Equivalent

Name	Snow-Water Equivalent				
Definition	Water equivalent of snow cover: the vertical depth of the water that would be obtained if the snow cover melted completely, which equates to the snow-cover mass per unit area.				
Unit	mm				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km	Size of grid cell	G	0.5	
			B	5	These horizontal resolutions apply to non-mountain snow covered regions only.
			T	25	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	6	
			B	24	
			T	48	
Timeliness	h		G	3	
			B	24	
			T	240	
Required Measurement Uncertainty (2-sigma)	mm		G	1	For mountain areas 20%
			B	5	For mountain areas 30%
			T	10	For mountain areas 40%
Stability	mm		G	5	
			B	8	
			T	10	
Standards and References	Frei, A., Tedesco, M., Lee, S., Foster, J., Hall, D. K., Kelly, R. and Robinson, D. A. (2012): A review of global satellite-derived snow products, Advances in Space Research, 50, 1007–1029. Goodison, B. and Walker, A. (1994): Canadian development and use of snow cover information from passive microwave satellite data, B. Choudhuly et al. (ed), Passive Microwave Remote Sensing of Land-Atmosphere Interaction, Utrecht: VSP BV, 245-262. Robinson, D.A. (2013): Climate Data Record Program (CDRP): Climate Algorithm Theoretical Basis Document (C-ATBD) Northern Hemisphere Snow Cover Extent, CDRPATBD-0156. Asheville, North Carolina, USA 28 pp. Sturm, M., Taras, B., Liston, G. E., Derksen, C., Jonas, T. and Lea, J. (2010): Estimating Snow Water Equivalent Using Snow Depth Data and Climate Classes. Jour. Hydromet. 11, 1380-1394. WMO (2018), Guide to instruments and methods of observation: Volume II - Measurement of Cryospheric Variables, 2018th ed., World Meteorological Organization, Geneva, Switzerland, 52 pp. Fierz, C., Armstrong, R.L., Durand, Y., Etchevers, P., Greene, E., McClung, D.M., Nishimura, K., Satyawali, P.K., and Sokratov, S.A. (2009): The International Classification for Seasonal Snow on the Ground, UNESCO-IHP, Paris, France, viii+80 pp. Luojus, K., Pulliainen, J., Takala, M., Lemmetyinen, J., Mortimer, C., Derksen, C., Mudryk, L., Moisander, M., Venäläinen, P., Hiltunen, M., Ikonen, J., Smolander, T., Cohen, J., Salminen, M., Veijola, K., and Norberg, J. (2021): GlobSnow v3.0 Northern Hemisphere snow water equivalent dataset. Scientific Data. doi: 10.1038/s41597-021-00939-2 Mortimer, C., Mudryk, L., Derksen, C., Luojus, K., Brown, R., Kelly, R., Tedesco, M. (2020): Evaluation of long term Northern Hemisphere snow water equivalent products. The Cryosphere. doi: 10.5194/tc-14-1579-2020				

8.2 ECV: Glaciers

8.2.1 ECV Product: Glacier Area

Name	Glacier Area				
Definition	Inventory of map-projected area covered by glaciers.				
Unit	km^2				
Note	Glacier area is the map-projected size of a glacier in km^2. The product comes as worldwide inventory of glaciers outlines with various related attribute fields (e.g. area, elevation range, glacier characteristics). Typically, a minimum size of 0.01 or 0.02 km^2 is applied, to avoid including small ice patches which do not flow and are therefore not glaciers.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m		G	1	Spatial resolutions better than 15 m (e.g. the 10 m from Sentinel 2) are preferable as typical characteristics of glacier flow (e.g. crevasses) only become visible at this resolution (Paul et al. 2016).
			B	20	The horizontal resolution of 15-30 m refers to typically used satellite sensors (Landsat and ASTER) to map glaciers.
			T	100	At coarser resolution the quality of the derived outlines rapidly degrades.
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	y		G	1	The temporal sampling “Annual” means that each year the availability of satellite (or aerial) images should be checked to identify the image with the best snow conditions (i.e. snow should not hide the glacier perimeter).
			B		
			T	10	Decadal data used to evaluate glacier change in regional scale.
Timeliness	y		G	1	
			B		
			T	10	For multi-temporal inventories at decadal resolution, the timeliness of the product availability is not so important.
Required Measurement Uncertainty	%	Random error of glacier outlines produced in dependency of remote sensing imagery used, with respect to the total glacier area	G	1	Glacier outlines mapped with a resolution of 1 m remote sensing images (take glacier area in average as 1 km^2)
			B	5	Glacier outlines mapped with a resolution of 15-30 m remote sensing images (take glacier area in average as 1 km^2)
			T	20	Glacier outlines mapped with a resolution of 100 m remote sensing images (take glacier area in average as 1 km^2)
Stability			G		Glacier area at different times extracted independently. No cumulative effect of the measurement system should be considered
			B		
			T		
Standards and References	Pfeffer, W. T. et al. The Randolph Glacier Inventory: a globally complete inventory of glaciers. J. Glaciol. 60, 537–552 (2014). Paul, F., S.H. Winsvold, A. Kääb, T. Nagler and G. Schwaizer (2016): Glacier Remote Sensing Using Sentinel-2. Part II: Mapping Glacier Extents and Surface Facies, and Comparison to Landsat 8. Remote Sensing, 8(7), 575; doi:10.3390/rs8070575. Zemp, M., Frey, H., Gärtner-Roer, I., Nussbaumer, S. U., Hoelzle, M., Paul, F., … Vincent, C. (2015). Historically unprecedented global glacier decline in the early 21st century. Journal of Glaciology, 61(228), 745–762. http://doi.org/10.3189/2015JoG15J017				

8.2.2 ECV Product: Glacier Elevation Change

Name	**Glacier Elevation Change**				
Definition	Glacier surface elevation changes from geodetic methods.				
Unit	m y^{-1}				
Note	Measured in-situ and remotely sensed using geodetic method (Cogley et al. 2011, Zemp et al. 2013)				
			Requirements		
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	m		G	1	The fine resolution (1-5 m) data be used to extract mass change and dynamic characteristics in area with abnormal topography (quite steep slope, ice fall, calving snout)
			B	25	A stable size of raster for measuring volume change (Joerg and Zemp, 2014)
			T	90	Resolution of SRTM, which most widely used as reference to extract elevation change
Vertical Resolution	m		G	0.01	Annual mass change of glaciers be evaluated with data with vertical resolution < 0.01 m (e.g. Xu et al., 2019)
			B	2	Roughly corresponding to the resolution needed for annual mean mass change if observed decadal
			T	5	The targets for vertical resolutions refer to requirements for differences of digital elevation models (dDEM) in mountainous terrain (e.g. Joerg and Zemp, 2014)
Temporal Resolution	y		G	1	To evaluate annual mass change and detect the signal of potential abnormal events (e.g. surge)
			B		
			T	10	The frequency "decadal" refers to the length of the time period needed between two geodetic surveys in order to safely apply a density conversion from volume to mass change (cf. Huss 2013, Zemp et al. 2013)
Timeliness			G		In view of the low need for temporal sampling, the timeliness is not so important.
			B		
			T		
Required Measurement Uncertainty	m	Glacier-wide (random) uncertainty estimate based on a quality assessment of the digital elevation model differencing product over stable terrain	G		
			B	2	Refers to the glacier-wide uncertainty estimate based on a quality assessment of the dDEM product over stable terrain. The value of (2m per decade = 0.2 m^{-2} a^{-1}) is set in relation to the corresponding uncertainty requirement of the glaciological method.
			T		
Stability	m / decade	Glacier-wide bias in elevation change measurements over a decade	G		
			B	2	The stability of 2m per decade refers to a bias in the glacier-wide change of 0.2 m m^{-2} a^{-1}, which is about one third to half of the average annual ice loss rate over the 20th century (Zemp et al. 2015) and is good enough for validation of glaciological series (Zemp et al. 2013)
			T		
Standards and References	Huss, M. (2013). Density assumptions for converting geodetic glacier volume change to mass change. The Cryosphere, 7(3), 877–887. http://doi.org/10.5194/tc-7-877-2013 Joerg, P. C., & Zemp, M. (2014). Evaluating Volumetric Glacier Change Methods Using Airborne Laser Scanning Data. Geografiska Annaler: Series A, Physical Geography, 96(2), n/a-n/a. http://doi.org/10.1111/geoa.12036 Zemp, M., Thibert, E., Huss, M., Stumm, D., Rolstad Denby, C., Nuth, C., Nussbaumer, S.U., Moholdt, G., Mercer, A., Mayer, C., Joerg, P.C., Jansson, P., Hynek, B., Fischer, A., Escher-Vetter, H., Elvehøy, H., and Andreassen, L.M. (2013): Reanalysing glacier mass balance measurement series. The Cryosphere, 7, 1227-1245, doi:10.5194/tc-7-1227-2013. Zemp, M., Frey, H., Gärtner-Roer, I., Nussbaumer, S. U., Hoelzle, M., Paul, F., … Vincent, C. (2015). Historically unprecedented global glacier decline in the early 21st century. Journal of Glaciology, 61(228), 745–762. http://doi.org/10.3189/2015JoG15J017 Xu, C., Li, Z., Li, H., Wang, F., & Zhou, P. (2018). Long-range terrestrial laser scanning measurements of summer and annual mass balances for Urumqi Glacier No. 1, eastern Tien Shan, China. The Cryosphere Discussions, 1-28. doi: 10.5194/tc-2018-128.				

8.2.3 ECV Product: Glacier Mass Change

Name	**Glacier Mass Change**				
Definition	Glacier Mass Changes from glaciological method.				
Unit	kg m^{-2}				
Note	Mass change is measured in-situ by the glaciological method (Cogley et al. 2011, Zemp et al. 2013)				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution			G		
			B		
			T		
Vertical Resolution	m		G		
			B	0.01	The vertical resolution "0.01 m or 10 kg m^{-2}" refers to the precision of ablation stake and snow pit readings at point locations
			T	0.05	Lowest requirement in glaciology
Temporal Resolution	month		G	1	Monthly observations in melting season to depict melting processes.
			B	3	Seasonal. The frequency "seasonal to annual" refers to the measurement campaigns which ideally are carried out at the time of maximum accumulation (spring) and of maximum ablation (end of hydrological year)
			T	12	Annual. The frequency "seasonal to annual" refers to the measurement campaigns which ideally are carried out at the time of maximum accumulation (spring) and of maximum ablation (end of hydrological year)
Timeliness	day		G		
			B		
			T	365	Ideally, glaciological measurement become available after completion of the annual field campaigns. The WGMS grants a one-year retention period to allow investigators time to properly analyze, document, and publish their data before submitting the data.
Required Measurement Uncertainty	kg m^{-2} a^{-1}	Glacier-wide (random) uncertainty estimate including uncertainties from point measurements, snow, firn and ice density conversions, and extrapolation to glacier-wide results.	G		
			B	0.2	2-sigma (200 kg m^{-2} a^{-1} = 0.2 m w.e. m^{-2} a^{-1}) refers to the glacier-wide annual balance which is interpolated from the point measurements. The target value was selected based on a review of long-term mass balance measurement series (Zemp et al. 2013).
			T	0.5	Lowest requirement in glaciology.
Stability	kg m^{-2} / decade	Glacier-wide bias in mass change measurements over a decade.	G		
			B		
			T	2	The stability can be assessed by validation and – if necessary – calibration of a glaciological times series with decadal results from the geodetic method (cf. Zemp et al. 2013). As a rule of thumb, stability is recommended to be better than 300 kg m^{-2} a^{-1} (cf. Zemp et al. 2013).
Standards and References	Zemp, M., Thibert, E., Huss, M., Stumm, D., Rolstad Denby, C., Nuth, C., Nussbaumer, S.U., Moholdt, G., Mercer, A., Mayer, C., Joerg, P.C., Jansson, P., Hynek, B., Fischer, A., Escher-Vetter, H., Elvehøy, H., and Andreassen, L.M. (2013): Reanalysing glacier mass balance measurement series. The Cryosphere, 7, 1227-1245, doi:10.5194/tc-7-1227-2013. Zemp, M., Frey, H., Gärtner-Roer, I., Nussbaumer, S. U., Hoelzle, M., Paul, F., … Vincent, C. (2015). Historically unprecedented global glacier decline in the early 21st century. Journal of Glaciology, 61(228), 745–762. http://doi.org/10.3189/2015JoG15J017 Zemp, M., Huss, M., Thibert, E. et al. Global glacier mass changes and their contributions to sea-level rise from 1961 to 2016. Nature 568, 382–386 (2019). https://doi.org/10.1038/s41586-019-1071-0				

8.3 ECV: Ice Sheets and Ice Shelves

8.3.1 ECV Product: Surface Elevation Change

Name	Surface Elevation Change				
Definition	Measurements of the change height above a reference (geoid or ellipsoid) of the snow-air surface or uppermost firn layers.				
Unit	Annual change in elevations above sea level measured in meters (m y^{-1})				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m	Spacing of measurements	G		
			B		
			T	100	
Vertical Resolution			G	-	N/A. One value per point of Earth's surface.
			B	-	
			T	-	
Temporal Resolution	month		G	1	
			B		
			T	12	
Timeliness			G		
			B		
			T		
Required Measurement Uncertainty	m a^{-1}	error of measured in-situ using the geodetic method and remotely sensed surface elevation	G		
			B		
			T	0.1	
Stability	m a^{-1}	as above	G		
			B		
			T	0.01	
Standards and References					

8.3.2 ECV Product: Ice Velocity

Name	Ice Velocity				
Definition	Surface-parallel vector of the surface ice flow.				
Unit	m y^{-1} (average speed in grid cell of surface ice flow)				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m	Grid cell size	G	50	
			B	100	
			T	1000	
Vertical Resolution			G	-	N/A. One value per point of Earth's surface.
			B	-	
			T	-	
Temporal Resolution	month	time	G	1	
			B		
			T	12	
Timeliness			G		
			B		
			T		
Required Measurement Uncertainty	m y^{-1}	error of measured in-situ using the geodetic method and remotely sensed surface elevation	G	10	
			B	30	
			T	100	
Stability	m s^{-1}	as above	G		
			B		
			T	10	
Standards and References	Hvidberg, C.S., et al., 2021. User Requirements Document for the Ice_Sheets_cci project of ESA's Climate Change Initiative, version 1.5, 03 Aug 2012.				

8.3.3 ECV Product: Ice Volume Change

Name	Ice Volume Change				
Definition	Direct measurement of local volume changes or inferred volume change from combining measurements.				
Unit	$km^3\ y^{-1}$				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km	Size of grid cell	G		
			B		
			T	50	
Vertical Resolution			G		N/A. One value per point of Earth's surface
			B		
			T		
Temporal Resolution	d	Time	G	30	
			B		
			T	365	
Timeliness			G		
			B		
			T		
Required Measurement Uncertainty	$km^3\ y^{-1}$	error of measured in-situ using the geodetic method and remotely sensed surface elevation	G		
			B		
			T	10	
Stability	$km^3\ y^{-1}$	as above	G		
			B		
			T	1	
Standards and References					

8.3.4 ECV Product: Grounding Line Location and Thickness

Name	Grounding Line Location and Thickness				
Definition	Location of the line (zone) where ice outflow to an ocean begins to float, and thickness of ice at that location.				
Unit	m (thickness), coordinates of location				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m		G	100	
			B		
			T	1000	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	y		G		
			B		
			T	1	
Timeliness			G		
			B		
			T		
Required Measurement Uncertainty (2-sigma)	m		G	1	
			B		
			T	10	
Stability	m		G		
			B		
			T	1	
Standards and References					

8.4 ECV: Permafrost

8.4.1 ECV Product: Permafrost Temperature (PT)

Name	Permafrost Temperature (PT)				
Definition	Permafrost is subsurface earth material that remains continuously at or below 0 °C throughout at least two consecutive years, usually for extended time periods. Product definition: Ground temperatures measured at specified depths along profiles.				
Unit	°C				
Note	Measurements made in boreholes, and usually presented as temperature profiles. Active layer = surface layer that thaws/freezes every year. ZAA = Zero Annual Amplitude, maximum penetration depth of seasonal variations.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	N/A	Spatial distribution of boreholes	G	Regular spacing	It is necessary to fill the spatial gaps in order to calibrate/compare with remote sensing products and climate modeling results.
			B	Transects	Longitudinal and latitudinal transects allow the assessment of gradients.
			B	Various settings	Various terrain with different ground/soil conditions (including varying moisture and ice content, thermal properties) and topoclimatic/microclimate conditions (e.g. vegetation, snow cover, slope, aspect). In mountain permafrost, various geomorphological and topo-climatic settings: rock-glaciers, rock walls, in various aspects. Allows for comparison of different reaction to climate change.
			T	Characterization of bioclimate zones	Boreholes in continuous, discontinuous, and sporadic permafrost areas. In discontinuous/sporadic permafrost, boreholes must be located in permafrost affected zones. Some boreholes in non-permafrost within permafrost areas can be useful for comparison, model comparison and for understanding evolution of regional permafrost conditions. Location of boreholes is strongly dependent on accessibility of borehole sites.
Vertical Resolution	N/A	Borehole depth, defined according to characteristic permafrost layers	G	Deeper than ZAA	Allows assessment of mid- to long term trends.
			B	Down to ZAA	Allows measurement of the full seasonal variations, and assessment of interannual trend.
			T	Below permafrost table	Allows calculation of active layer depth and measurement of the temperature of the uppermost permafrost at the permafrost table.
	m	Sensor spacing along borehole for continuous monitoring / measuring interval for manual measurement	G	Above ZAA: 0.2	Spacing typically increases with depth. Actual spacing has to be adapted to local conditions and should be higher on boundary values (active layer/permafrost, ZAA), to allow an accurate interpolation.
			B		
			T	Above ZAA: 0.5	
			G	Below ZAA: 5 to 10	
			B		
			T	Below ZAA > 10	
Temporal Resolution		Sampling interval for continuous monitoring/ periodicity for manual measures. Depends on depth, must be more frequent in active layer than below	G	Active layer: 1h	Only useful in topmost layers, affected by diurnal variations.
			B	Active layer: 1d	Assessment of rapid changes due for instance to water infiltration.
			T	Active layer: 1 month	Sites measured only once a year cannot be used for active layer monitoring
			G	Down to ZAA: 1d	Assessment of rapid variations in terrain with high thermal conductivity.
			B	Down to ZAA: 1	Assessment of seasonal variations.
			T	Down to ZAA: 1 year	Sites with manual measurement are measured only once a year.
			G	Below ZAA: 1 month	Allows detection of extreme seasonal variations.

		ZAA	B	Below ZAA: 1 year	Sites with manual measurement are measured only once a year.
			T	Below ZAA: 5 years	Sufficient for mid- to long-term trend.
Timeliness			G	Weekly /real time	Timely reporting, fast intervention in case of problems where possible reduces the risk of large data gaps
			B	1 year	Most site measurements are retrieved only once a year
			T	5 years	Some site measurements are not retrieved every year
Required Measurement Uncertainty	°C	Sensor uncertainty	G	0.01	Useful for finer definition of freeze/thaw dates
			B	0.1	Mean annual trends are often less than 0.1 °C. Reachable with high resolution sensors.
			T	0.2	Reachable with most standard sensors.
Stability	°C	Sensor drift over reference period. Assumed drift value of commonly used sensors. Sensor drift correction needs recalibration	G	0.01	
			B	0.05	Should be reached in order to maintain drift below trend.
			T	0.1	Commonly accepted value based on experience. Calibration of sensor probe is possible in case of manual measurement. It is often impossible for fixed sensor chains, that additionally can be blocked in the borehole due to e.g., shearing. Drift can be minimized by 3 or 4 wire mounting. In situ calibration/correction is possible for sub-surface sensors using “zero curtain”.
Standards and References	Streletskiy, Dmitry and Biskaborn, Boris and Smith, Sharon L. and Noetzli, Jeannette and Vieira, Gonçalo and Schoeneich, Philippe (2017) GTN-P Strategy and Implementation Plan 2016- 2020. Technical Report. Global Terrestrial Network for Permafrost.				

8.4.2 ECV Product: Active Layer Thickness (ALT)

Name	Active Layer Thickness
Definition	The surface layer of the ground, subject to annual thawing and freezing in areas underlain by permafrost.
Unit	cm
Note	There are three established methods for measuring ALT: mechanical probing, frost tubes and temperature interpolation (with the assumption that 0 °C = freeze point). In all three cases, the result is a depth/thickness value expressed in cm. Satellite based estimates of ALT using Interferometric Synthetic Aperture Radar (InSAR) (Liu et al, 2012, Schaefer et al., 2016) maybe used in the future.

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m	Spatial distribution of sites	G	Regular spacing	It is necessary to fill gaps in order to calibrate and compare with remote sensing products and climate modeling results
			B	Transects	
			T	sufficient sites to characterize each bioclimatic subzone	
Vertical Resolution	cm	Spacing of sensors	G	2	Vertical resolution of ground temperature sensor spacing for the interpolation
			B	10	
			T	20	
Temporal Resolution	y		G	1 (at end of thawing period)	ALT is an annual value, which is measured once a year at the end of the thawing period. In case of continuous measurement (borehole data), ALT is defined at time of maximal penetration of above 0°C temperature.
			B		
			T	1 (at end of thawing period)	
Timeliness	y		G	1	ALT is measured and provided once per year
			B		
			T	1	
Required Measurement Uncertainty	cm	mechanical probing penetration uncertainty / sensor uncertainty	G	1/5	Mechanical probing/frost tubes/ temperature interpolation from boreholes.
			B		
			T	2/15	
Stability	cm		G	1	A common cause of bias is due to surface subsidence in case of ice loss in ice-rich permafrost. Needs to be corrected in order to get the true thaw depth. In ice-rich terrain subject to thaw subsidence, monitoring of vertical movements by frost heave in winter and subsidence in summer are of critical importance. Field measurements may involve direct measurement towards borehole tube, optical survey or differential GPS technology.
			B	5	
			T	10	

Standards and References	
	Smith, Sharon and Brown, Jerry (2009) Assessment of the status of the development of the standards for the Terrestrial Essential Climate Variables - T7 - Permafrost and seasonally frozen ground. Streletskiy, Dmitry and Biskaborn, Boris and Smith, Sharon L. and Noetzli, Jeannette and Vieira, Gonçalo and Schoeneich, Philippe (2017) GTN-P - Strategy and Implementation Plan 2016- 2020. Technical Report. Global Terrestrial Network for Permafrost. Liu, L., Schaefer, K., Zhang, T., & Wahr, J. (2012). Estimating 1992–2000 average active layer thickness on the Alaskan North Slope from remotely sensed surface subsidence. Journal of Geophysical Research: Earth Surface, 117(F1).

8.4.3 ECV Product: Rock Glacier Velocity (RGV)

Name	**Rock Glacier Velocity (RGV)**				
Definition	Global dataset of surface velocity time series measured/computed on single rock glacier units.				
Unit	m y^{-1}				
Note	RGV can be measured/computed from terrestrial survey (e.g. repeated GNSS field campaigns, permanent GNSS stations) or remote sensing based approaches (e.g. InSAR, satellite-/air-/UAV-borne photogrammetry). The velocity values can be derived either from an annualized displacement measurement or from an annualized displacement computed from position measurements. RGV is defined for a single rock glacier unit that is expressed geomorphologicaly according to standards. Time series must be distinguished if they come from different units, even in a unique rock glacier system. Several time series can be measured/computed on the same rock glacier unit when derived from different methodologies. Rock glacier characteristics must be described according to the inventorying baseline concepts (Technical definition and standardized attributes of rock glaciers). In particular, the spatial connection to the upslope unit (e.g. connected to a glacier or not) leads to a specific evolution of rock glacier velocities and has to be documented.				
Requirements					
Item needed	**Unit**	**Metric**	[1]	**Value**	**Notes**
Horizontal Resolution		Spatial distribution of selected rock glaciers	G	Regional coverage	At least 30% of the active talus-connected and/or debris-mantled slope-connected rock glaciers should be selected in a region, which is a part of a mountain range, in order to represent its climatic context. Only possible with remote sensing approaches.
			B	Multiple sites in a defined regional context	Allows the definition of a regional trend.
			T	Isolated site	Continuous time series produced either from in situ measurements or remotely sensed measurements.
		Spatial resolution of the measurement. 1 value per selected rock glacier unit	G	Flow field	Velocity is computed/measured by aggregation over a target area on a rock glacier unit. The aggregation procedure and the target area should be consistent over time. Allows the best representation of the effective movement over the rock glacier unit.
			B	Few discrete points	Velocity is computed/measured as an aggregation of few measurement points over a target area on a rock glacier unit. The aggregation procedure and the target area should be consistent over time. Allows a better representation of the effective movement over the rock glacier unit.
			T	Velocity value at a point	Velocity is computed/measured on a single point. The location should be consistent over time and be spatially representative of the rock glacier unit it is taking part (i.e. located within a recognized moving area).
Vertical resolution		N/A	G		
			B		
			T		
Temporal Resolution	y	Frequency and Observation time window	G	1 and 1	Measured/computed once a year. The observation time window is 1 year and consistent over time.
			B	1 and <1	Measured/computed once a year. The observation time window is shorter than 1 year (e.g. observation on summer period only). It should not be shorter than 1 month and must be consistent over time. Allows a better representation of the annual behavior.
			T	2-5 and > 1	Frequency limited by an observation time window of 2-5 years. This time period corresponds to the common periodicity for aerial image coverages, and can be adapted according to regional/national specificities. Longer intervals are admissible for optical images, as well as for reconstructions from archives.
Timeliness	month		G	3	Minimum time needed for data processing.
			B		
			T	12	

Require d Measurement Uncertainty	%	Relative error of the velocity data	G	5%	Allowed relative error of the velocity data to produce a reliable analysis of long-term temporal changes in rock glacier velocity (RGV). The technique must be chosen in accordance with the absolute value measured/computed on the observed rock glacier and the goal relative error of the velocity data.
			B	10%	
			T	20%	Maximal allowed relative error of the velocity data to produce a reliable analysis of long-term temporal changes in rock glacier velocity (RGV). The technique must be chosen in accordance with the absolute value measured/computed on the observed rock glacier and the target relative error of the velocity data.
Stability	y	Overlapping	G	With overlap several years	Observation time window, horizontal resolution of the velocity value and methodologies/procedures used to measure/compute velocity value for a single time series must be consistent over time. If one of these elements is changing, two times series must be derived for the selected rock glacier unit. If these two time series have an overlap of several years ensuring consistency, they can be merged into a single time series. The merging procedure must be documented.
			B	With overlap 1 year	Observation time window, horizontal resolution of the velocity value and methodologies/procedures used to measure/compute velocity value for a single time series must be consistent over time. If one of these elements is changing, two time series must be derived for the selected rock glacier unit. If these two time series have an overlap of 1 year ensuring consistency, they can be merged into a single time series. The merging procedure must be documented.
			T	Without overlap	Observation time window, horizontal resolution of the velocity value and methodologies/procedures used to measure/compute velocity value for a single time series must be consistent over time. If one of this element is changing without overlap, two time series must be derived for the selected rock glacier unit.
Standards and References	IPA Action Group Rock glaciers inventories and kinematics (https://ipa.arcticportal.org/activities/action- groups) Standards and definitions: - Technical definition and standardized attributes of rock glacier (https://bigweb.unifr.ch/Science/Geosciences/Geomorphology/Pub/Website/IPA/CurrentVersion/Current_ Baseline_Concepts_Inventorying_Rock_Glaciers.pdf) - Rock glacier velocity (https://bigweb.unifr.ch/Science/Geosciences/Geomorphology/Pub/Website/IPA/CurrentVersion/Current_ RockGlacierVelocity.pdf				

9. BIOSPHERE

9.1 ECV: Above-Ground Biomass

9.1.1 ECV Product: Above-Ground Biomass (AGB)

Name	Above-Ground Biomass
Definition	Above-ground biomass is defined as the mass of live and/or dead organic matter in terrestrial vegetation.
Unit	Mg ha^{-1} (dry weight per unit area)
Note	Definition can vary for different observations/products, considering live and/or dead biomass and different vegetation compartments (woody, branches, and leaves). There are differences in what different satellite and in-situ observations actually measure. A clear definition needs to be provided with each measurement/product, and consistency is to be ensured, and ECV products might include flexibility in information to respond to different definition requirements (i.e. including different estimates for different compartments).

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m	Pixel-size	G	10	This resolution reflects the need to have biomass data at the scale of human-induced disturbance. Suitable resolution can vary by ecozone; biomass is a rapidly varying quantity in space and the variance when moving to more detailed spatial resolutions is getting enormous and very hard to be captured efficiently by varying observation sources, especially for natural and tropical forests. Current understanding practices suggest a horizontal resolution of 0.25 ha (50x50 m) outside the (sub-)tropics and a horizontal resolution of 1 ha (100x100 m) in the tropics for global products. In specific regions of interest and areas of active change (forest/land) higher resolution data can be helpful. Higher quality regional biomass maps can be used for the calibration and validation of global products.
			B	100	This resolution is suitable for most regional vegetation and carbon modeling and assessing the impact of climate extremes.
			T	1000	This resolution is suitable for global vegetation, carbon and climate models.
Vertical Resolution			G	-	N/A, since ECV products provide estimates as total over a certain area without further vertical discrimination. There is however evolving products on tree/vegetation height and structure that are very related to biomass and could eventually be considered as a "third" dimension for biomass ECV products.
			B	-	
			T	-	
Temporal Resolution	years	Changes in biomass stocks (Mg ha^{-1}) over time (i.e. per year) are important to assess forest carbon gains and losses	G	0.5	Intra-annual. Biomass data more detailed than annual time steps are of value for assessing and modeling the impact of disturbances such as fires and forest degradation, and for seasonal variability in biomass productivity. There is also interest for more near-real time updates and estimates of forest biomass changes for (local) enforcement and accounting applications.
			B	1-2	Annual and bi-annual time steps are used by many models and carbon accounting applications requiring biomass data.
			T	5-10	Temporal sampling increases are needed to track changes and for long-term biomass trends information every 5-10 years is suitable.
Timeliness	years		G	<1	Ideally, biomass measurements become available soon after the acquisition of the data for regular updating in regional hotspots, in case of major disturbances and climate extremes etc. Speed of delivery of biomass information might come at the risk that full quality assurance and independent validation cannot be completed in near-real time as well.
			B	1-5	Global biomass measurements become available at least one (to a few) year(s) after the acquisition of the data and quality processing and ECV product derivation and validation, as well as long-term consistency is to be ensured.

			T	>5	Regular reprocessing of historical records. Model applications require long-term consistent biomass datasets that should take advantage of the whole historical data record. Improved and reprocessed historical data records consistent with the recent higher quality ECV estimates should be provided on a regular basis.
Required Measurement Uncertainty	% (relative) and Mg (absolute) for different biomass classes/raring	Relative and absolute bias and confidence interval or RMSE, overall and by biomass class/range derived from using multi-date reference data of higher quality	G	10%	
			B	20%	
			T	30%	
Stability	% (relative) and Mg (absolute), for different biomass classes/ranges	Relative and absolute bias and confidence interval or RMSE, overall and by biomass class/range derived from using multi-date reference data of higher quality	G	5%	As for uncertainty, stability should be assessed using both relative and absolute bias and RMSE. The stability can be assessed by multi-date independent validation/uncertainty assessments. The stability requirements are tighter that for overall uncertainty since the aim for multi-date ECV data is to provide information on biomass changes.
			B	10%	
			T	20%	
Standards and References					

9.2 ECV: Albedo

9.2.1 ECV Product: Spectral and Broadband (Visible, Near Infrared and Shortwave) DHR & BHR[6] with Associated Spectral Bidirectional Reflectance Distribution Function (BRDF) Parameters

Name	Spectral and Broadband (visible, near infrared and shortwave) DHR & BHR with Associated Spectral Bidirectional Reflectance Distribution Function (BRDF) parameters (required to derive albedo from reflectance)				
Definition	The land surface albedo is the ratio of the radiant flux reflected from Earth's surface to the incident flux. Each spectral/broadband value depends on natural variations and is highly variable in space and time as a result of terrestrial properties changes, and with illumination conditions.				
Unit	Dimensionless				
Note	Length of record: Threshold: 20 years; Target: > 40 years				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m		G	10	Due to the heterogeneous nature of terrestrial surfaces, having surface albedo at such scale will increase accuracy for further assimilation of local/regional climate model.
			B		
			T	250	Enable assimilation in earth/climate model.
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	day		G	1	For climate change services. Multi-angular instruments (including geostationary) and/or accumulation of daily data for BRDF parameters retrieval.
			B		
			T	10	For assimilation in earth/climate model. Same as above as mono-angular
Timeliness	day		G	1	For climate change services.
			B		
			T	5	For NRT reanalysis.
Required Measurement Uncertainty	%	1 standard deviation or error covariance matrix, with associated PDF shape (functional form of estimated error distribution for the term)	G	3% for values ≥0.05; 0.0015 (absolute value) for smaller values	"A change of 1% to the Earth's albedo has a radiative effect of 3.4 W/m^2" Over snow-free and snow-covered land, climate, biogeochemical, hydrological, and weather forecast models require this uncertainty.
			B		
			T	5% for values ≥0.05; 0.0025 for smaller values	See Ohring, et al. 2005
Stability	% / decade	A factor of uncertainties to demonstrate that the 'error' of the product remains constant over the period, typically a decade or more	G	< 1 %	Rate of change of surface albedo over the available time period (per decade). The required stability is some fraction of the expected signal' (see Ohring, et al. 2005)
			B		
			T	< 1.5 %	
	Boussetta S., Balsamo G., Dutra E., Beljaars A., Albergel C. (2015). Assimilation of surface albedo and vegetation states from satellite observations and their impact on numerical weather prediction, Remote Sensing of Environment, pp. 111-126. DOI:10.1016/j.rse.2015.03.009 Ohring, G., Wielicki, B., Spencer, R., Emery, B., & Datla, R. (2005). Satellite instrument calibration for measuring global climate change: Report of a workshop. Bulletin of the American Meteorological Society, 86(9), 1303-1314.				

[6] DHR: Directional Hemispheric Reflectance; BHR: Bidirectional Hemispheric Reflectance.

9.3 ECV: Evaporation from Land

9.3.1 ECV Product: Sensible Heat Flux

Name	Sensible Heat Flux				
Definition	The land surface (terrestrial) sensible heat flux represents the conduction of heat between the land surface into the atmosphere.				
Unit	W m^{-2}				
Note	Current sensible heat flux datasets based on satellite data are often derived as a residual from the energy balance equation based on estimated latent heat fluxes. Due to their analogous use to that of latent heat fluxes by the climate and meteorology community, their user requirements are similar. However, giver their lower immediate value for the agricultural and water management community, some differences in the targeted goals are considered.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km	Size of grid cell	G	1	Scales needed to achieve a realistic estimation considering land cover heterogeneity that may be useful to determine the role of sensible heat fluxes during extreme events (Miralles et al., 2019).
			B	–	–
			T	25	Current spatial resolution of global datasets, which has so far been deemed sufficient for climatological applications.
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h	time	G	1	Sub-daily processes are needed to represent the evolution of the atmospheric boundary layer during flash droughts or heatwaves (Miralles et al., 2019).
			B	–	–
			T	24	Typical temporal resolution of current global datasets, which has so far been deemed sufficient for climatological applications.
Timeliness	d		G	1	Accurate forecasting of short-term droughts and heatwaves requires data in near real-time (Miralles et al., 2019).
			B	30	Scales needed to make sensible heat fluxes data useful for early drought diagnostic or to improve seasonal weather forecasts (expert judgement).
			T	365	Current latency for multiple global datasets, which has so far been deemed sufficient for climatological applications.
Required Measurement Uncertainty	%	relative root mean square error	G	10	This will involve an improved differentiation among ecosystems, and enable more efficient weather forecasts of extreme events (expert judgement).
			B	20	Intermediate compromise at which datasets can become useful as drought diagnostic (expert judgement).
			T	40	Current level of relative error that has so far been deemed sufficient for climatological applications.
Stability	W m^{-2} $year^{-1}$		G	0.015	Due to the scarcity of studies of sensible heat flux trends (Siemann et al., 2018), we refer to the same stability thresholds as for latent heat fluxes (and in the same units).
			B	–	–
			T	0.03	–
Standards and References	Siemann, A. L., Chaney, N. and Wood, E. F.: Development and Validation of a Long-Term, Global, Terrestrial Sensible Heat Flux Dataset, J. Climate, 31(15), 6073–6095, doi:10.1175/JCLI-D-17-0732.1, 2018. Miralles, D. G., Gentine, P., Seneviratne, S. I. and Teuling, A. J.: Land-atmospheric feedbacks during droughts and heatwaves: state of the science and current challenges, Ann. N.Y. Acad. Sci., 8, 469–17, doi:10.1111/nyas.13912, 2019.				

9.3.2 ECV Product: Latent Heat Flux

Name	Latent Heat Flux				
Definition	The land surface (terrestrial) latent heat flux is the energy flux associated with the evaporation occurring over land surfaces, and it may comprise three main sources or individual components: bare soil evaporation (direct evaporation of water from soils), interception loss (evaporation of water from wet canopies) and transpiration (plant water consumption), each of which are considered as sub-products.				
Unit	W m^{-2}				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km	Size of grid cell	G	0.1	The length scales required to detect spatially heterogeneous responses, particularly if agricultural applications are intended (Fisher et al., 2017; Martens et al., 2018).
			B	1	Scales needed to achieve a realistic partitioning of evaporation into different components considering land cover heterogeneity (Talsma et al., 2019; Miralles et al., 2016).
			T	25	Current spatial resolution of global datasets (McCabe et al. 2016; Miralles et al., 2016), which has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	hour	time	G	1	Water management and agricultural applications require to solve evaporation at timeframes associated with sub-daily irrigation decisions and scheduling (Fisher et al., 2017).
			B	6	Intermediate compromise in which sub-daily processes controlling the evolution of the atmospheric boundary layer can be resolved (McCabe et al. 2016; Miralles et al., 2016).
			T	24	Typical temporal resolution of current global datasets, which has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Timeliness	day		G	1	Water management and agricultural applications require data in near real-time (Fisher et al., 2017).
			B	30	Scales needed to make evaporation data useful for early drought diagnostic or to improve seasonal weather forecasts (expert judgement).
			T	365	Current latency for multiple global datasets, which has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Required Measurement Uncertainty	%	relative root mean square error	G	10	This will involve an improved differentiation of water use and water stress among different crops, species, and ecosystems, and will enable more efficient water management (Fisher et al., 2017).
			B	20	Intermediate compromise in which datasets can become useful as drought diagnostic or as a water management asset (expert judgement).
			T	40	Current level of relative error (McCabe et al. 2016); this level has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Stability	W m^{-2} y^{-1}		G	0.015	Approximately half of the current spread in the multi-datasets estimates of the global trend in evaporation (Zang et al., 2016).
			B	–	–
			T	0.03	Current estimates of the trend in the evaporation, but also the estimates of the spread in the estimates of these trends by different datasets (Zhang et al 2016).

Standards and References	Fisher, J. B., Melton, F., Middleton, E., Hain, C., Anderson, M., Allen, R., Mccabe, M. F., Hook, S., Baldocchi, D., Townsend, P. A., Kilic, A., Tu, K., Miralles, D. D., Perret, J., Lagouarde, J.-P., Waliser, D., Purdy, A. J., French, A., Schimel, D., Famiglietti, J. S., Stephens, G. and Wood, E. F.: The future of evapotranspiration: Global requirements for ecosystem functioning, carbon and climate feedbacks, agricultural management, and water resources, Water Resour. Res., 53(4), 2618–2626, doi:10.1002/2016WR020175, 2017. Martens, B., de Jeu, R., Verhoest, N., Schuurmans, H., Kleijer, J. and Miralles, D.: Towards Estimating Land Evaporation at Field Scales Using GLEAM, Remote Sensing, 10(11), 1720–25, doi:10.3390/rs10111720, 2018. Mccabe, M. F., Ershadi, A., Jiménez, C., Miralles, D. G., Michel, D. and Wood, E. F.: The GEWEX LandFlux project: evaluation of model evaporation using tower-based and globally gridded forcing data, Geosci. Model Dev., 9(1), 283–305, doi:10.5194/gmd-9-283-2016, 2016. Miralles, D. G., Jiménez, C., Jung, M., Michel, D., Ershadi, A., Mccabe, M. F., Hirschi, M., Martens, B., Dolman, A. J., Fisher, J. B., Mu, Q., Seneviratne, S. I., Wood, E. F. and Fernández-Prieto, D.: The WACMOS-ET project – Part 2: Evaluation of global terrestrial evaporation data sets, Hydrol. Earth Syst. Sci., 20(2), 823–842, doi:10.5194/hess-20-823-2016, 2016. Miralles, D. G., Gentine, P., Seneviratne, S. I. and Teuling, A. J.: Land-atmospheric feedbacks during droughts and heatwaves: state of the science and current challenges, Ann. N.Y. Acad. Sci., 8, 469–17, doi:10.1111/nyas.13912, 2019. Talsma, C., Good, S., Miralles, D., Fisher, J., Martens, B., Jiménez, C. and Purdy, A.: Sensitivity of Evapotranspiration Components in Remote Sensing-Based Models, Remote Sensing, 10(10), 1601–28, doi:10.3390/rs10101601, 2018. Zhang, Y., Peña-Arancibia, J. L., Mcvicar, T. R., Chiew, F. H. S., Vaze, J., Liu, C., Lu, X., Zheng, H., Wang, Y., Liu, Y. Y., Miralles, D. G. and Pan, M.: Multi-decadal trends in global terrestrial evapotranspiration and its components, Sci. Rep., 1–12, doi:10.1038/srep19124, 2016.

9.3.3 ECV Product: Bare Soil Evaporation

Name	Bare Soil Evaporation				
Definition	The component of the total latent heat flux that corresponds to the direct evaporation of soil moisture into the atmosphere.				
Unit	W m^{-2}				
Note	The requirements are analogous to those of the total latent heat flux, because the applications are the same. Several studies have shown, however, that the accuracy of the latent heat flux can still be adequate despite a higher uncertainty in the evaporation components (i.e. bare soil evaporation, transpiration and interception loss) – see e.g. Miralles et al. (2016), Talsma et al. (2018). For that reason, the uncertainty goals have been subjectively relaxed based on expert judgement.				
Requirements					
Item needed	**Unit**	**Metric**	[1]	**Value**	**Notes**
Horizontal Resolution	km	Size of grid cell	G	0.1	The length scales required to detect spatially heterogeneous responses, particularly if agricultural applications are intended (Fisher et al., 2017; Martens et al., 2018).
			B	1	Scales needed to achieve a realistic partitioning of evaporation into different components considering land cover heterogeneity (Talsma et al., 2019; Miralles et al., 2016).
			T	25	Current spatial resolution of global datasets (McCabe et al. 2016; Miralles et al., 2016), which has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h	time	G	1	Water management and agricultural applications require to solve evaporation at timeframes associated with sub-daily irrigation decisions and scheduling (Fisher et al., 2017).
			B	6	Intermediate compromise in which sub-daily processes controlling the evolution of the atmospheric boundary layer can be resolved (McCabe et al. 2016; Miralles et al., 2016).
			T	24	Typical temporal resolution of current global datasets, which has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Timeliness	d		G	1	Water management and agricultural applications require data in near real-time (Fisher et al., 2017).
			B	30	Scales needed to make bare soil evaporation data useful for early drought diagnostic or to improve seasonal weather forecasts (expert judgement).
			T	365	Current latency for multiple global datasets, which has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Required Measurement Uncertainty	%	relative root mean square error	G	20	This will enable more efficient water management (Fisher et al., 2017).
			B	30	Intermediate compromise in which datasets can become useful as drought diagnostic or as a water management asset (expert judgement).
			T	50	Current level of relative error (Talsma et al., 2018); this level has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Stability	W m^{-2} y^{-1}		G	0.015	Approximately half of the current spread in the multi-datasets estimates of the global trend in evaporation (Zang et al., 2016).
			B	–	–
			T	0.03	Current estimates of the trend in the evaporation, but also the estimates of the spread in the estimates of these trends by different datasets (Zhang et al 2016).

Standards and References	Fisher, J. B., Melton, F., Middleton, E., Hain, C., Anderson, M., Allen, R., Mccabe, M. F., Hook, S., Baldocchi, D., Townsend, P. A., Kilic, A., Tu, K., Miralles, D. D., Perret, J., Lagouarde, J.-P., Waliser, D., Purdy, A. J., French, A., Schimel, D., Famiglietti, J. S., Stephens, G. and Wood, E. F.: The future of evapotranspiration: Global requirements for ecosystem functioning, carbon and climate feedbacks, agricultural management, and water resources, Water Resour. Res., 53(4), 2618–2626, doi:10.1002/2016WR020175, 2017. Martens, B., de Jeu, R., Verhoest, N., Schuurmans, H., Kleijer, J. and Miralles, D.: Towards Estimating Land Evaporation at Field Scales Using GLEAM, Remote Sensing, 10(11), 1720–25, doi:10.3390/rs10111720, 2018. Mccabe, M. F., Ershadi, A., Jiménez, C., Miralles, D. G., Michel, D. and Wood, E. F.: The GEWEX LandFlux project: evaluation of model evaporation using tower-based and globally gridded forcing data, Geosci. Model Dev., 9(1), 283–305, doi:10.5194/gmd-9-283-2016, 2016. Miralles, D. G., Jiménez, C., Jung, M., Michel, D., Ershadi, A., Mccabe, M. F., Hirschi, M., Martens, B., Dolman, A. J., Fisher, J. B., Mu, Q., Seneviratne, S. I., Wood, E. F. and Fernández-Prieto, D.: The WACMOS-ET project – Part 2: Evaluation of global terrestrial evaporation data sets, Hydrol. Earth Syst. Sci., 20(2), 823–842, doi:10.5194/hess-20-823-2016, 2016. Miralles, D. G., Gentine, P., Seneviratne, S. I. and Teuling, A. J.: Land-atmospheric feedbacks during droughts and heatwaves: state of the science and current challenges, Ann. N.Y. Acad. Sci., 8, 469–17, doi:10.1111/nyas.13912, 2019. Talsma, C., Good, S., Miralles, D., Fisher, J., Martens, B., Jiménez, C. and Purdy, A.: Sensitivity of Evapotranspiration Components in Remote Sensing-Based Models, Remote Sensing, 10(10), 1601–28, doi:10.3390/rs10101601, 2018. Zhang, Y., Peña-Arancibia, J. L., Mcvicar, T. R., Chiew, F. H. S., Vaze, J., Liu, C., Lu, X., Zheng, H., Wang, Y., Liu, Y. Y., Miralles, D. G. and Pan, M.: Multi-decadal trends in global terrestrial evapotranspiration and its components, Sci. Rep., 1–12, doi:10.1038/srep19124, 2016.

9.3.4 ECV Product: Interception Loss

Name	Interception Loss				
Definition	The component of the total latent heat flux that corresponds to the precipitation that is intercepted by vegetation and evaporated directly.				
Unit	$W\ m^{-2}$				
Note	The requirements are analogous to those of the total latent heat flux, because the applications are the same. Several studies have shown, however, that the accuracy of the latent heat flux can still be adequate despite a higher uncertainty in the evaporation components (i.e. bare soil evaporation, transpiration and interception loss) – see e.g. Miralles et al. (2016), Talsma et al. (2018). For that reason, the uncertainty goals have been subjectively relaxed based on expert judgement.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km	Size of grid cell	G	0.1	The length scales required to detect spatially heterogeneous responses, particularly if agricultural applications are intended (Fisher et al., 2017; Martens et al., 2018).
			B	1	Scales needed to achieve a realistic partitioning of evaporation into different components considering land cover heterogeneity (Talsma et al., 2019; Miralles et al., 2016).
			T	25	Current spatial resolution of global datasets (McCabe et al. 2016; Miralles et al., 2016), which has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	Water management and agricultural applications require to solve evaporation at timeframes associated with sub-daily irrigation decisions and scheduling (Fisher et al., 2017).
			B	6	Intermediate compromise in which sub-daily processes controlling the evolution of the atmospheric boundary layer can be resolved (McCabe et al. 2016; Miralles et al., 2016).
			T	24	Typical temporal resolution of current global datasets, which has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Timeliness	d		G	1	Water management and agricultural applications require data in near real-time (Fisher et al., 2017).
			B	30	Scales needed to make interception loss needed to (e.g.) improve seasonal weather or hydrological forecasts (expert judgement).
			T	365	Current latency for multiple global datasets, which has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Required Measurement Uncertainty	%	relative root mean square error	G	20	This will enable more efficient water management (Fisher et al., 2017).
			B	30	Intermediate compromise in which datasets can become useful as a water management asset (expert judgement).
			T	50	Current level of relative error (Talsma et al., 2018); this level has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Stability	$W\ m^{-2}\ y^{-1}$		G	0.015	Approximately half of the current spread in the multi-datasets estimates of the global trend in evaporation (Zang et al., 2016).
			B	–	–
			T	0.03	Current estimates of the trend in the evaporation, but also the estimates of the spread in the estimates of these trends by different datasets (Zhang et al 2016).

Standards and References	Fisher, J. B., Melton, F., Middleton, E., Hain, C., Anderson, M., Allen, R., Mccabe, M. F., Hook, S., Baldocchi, D., Townsend, P. A., Kilic, A., Tu, K., Miralles, D. D., Perret, J., Lagouarde, J.-P., Waliser, D., Purdy, A. J., French, A., Schimel, D., Famiglietti, J. S., Stephens, G. and Wood, E. F.: The future of evapotranspiration: Global requirements for ecosystem functioning, carbon and climate feedbacks, agricultural management, and water resources, Water Resour. Res., 53(4), 2618–2626, doi:10.1002/2016WR020175, 2017. Martens, B., de Jeu, R., Verhoest, N., Schuurmans, H., Kleijer, J. and Miralles, D.: Towards Estimating Land Evaporation at Field Scales Using GLEAM, Remote Sensing, 10(11), 1720–25, doi:10.3390/rs10111720, 2018. Mccabe, M. F., Ershadi, A., Jiménez, C., Miralles, D. G., Michel, D. and Wood, E. F.: The GEWEX LandFlux project: evaluation of model evaporation using tower-based and globally gridded forcing data, Geosci. Model Dev., 9(1), 283–305, doi:10.5194/gmd-9-283-2016, 2016. Miralles, D. G., Gentine, P., Seneviratne, S. I. and Teuling, A. J.: Land-atmospheric feedbacks during droughts and heatwaves: state of the science and current challenges, Ann. N.Y. Acad. Sci., 8, 469–17, doi:10.1111/nyas.13912, 2019. Miralles, D. G., Jiménez, C., Jung, M., Michel, D., Ershadi, A., Mccabe, M. F., Hirschi, M., Martens, B., Dolman, A. J., Fisher, J. B., Mu, Q., Seneviratne, S. I., Wood, E. F. and Fernández-Prieto, D.: The WACMOS-ET project – Part 2: Evaluation of global terrestrial evaporation data sets, Hydrol. Earth Syst. Sci., 20(2), 823–842, doi:10.5194/hess-20-823-2016, 2016. Talsma, C., Good, S., Miralles, D., Fisher, J., Martens, B., Jiménez, C. and Purdy, A.: Sensitivity of Evapotranspiration Components in Remote Sensing-Based Models, Remote Sensing, 10(10), 1601–28, doi:10.3390/rs10101601, 2018. Zhang, Y., Peña-Arancibia, J. L., Mcvicar, T. R., Chiew, F. H. S., Vaze, J., Liu, C., Lu, X., Zheng, H., Wang, Y., Liu, Y. Y., Miralles, D. G. and Pan, M.: Multi-decadal trends in global terrestrial evapotranspiration and its components, Sci. Rep., 1–12, doi:10.1038/srep19124, 2016.

9.3.5 ECV Product: Transpiration

Name	Transpiration				
Definition	The component of the total latent heat flux that corresponds to the vegetation consumption of water.				
Unit	W m^{-2}				
Note	The requirements are analogous to those of the total latent heat flux, because the applications are the same. Several studies have shown, however, that the accuracy of the latent heat flux can still be adequate despite a higher uncertainty in the evaporation components (i.e. bare soil evaporation, transpiration and interception loss) – see e.g. Miralles et al. (2016), Talsma et al. (2018). For that reason, the uncertainty goals have been subjectively relaxed based on expert judgement.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km	Size of grid cell	G	0.1	Required to detect spatially heterogeneous responses, particularly if agricultural applications are intended (Fisher et al., 2017; Martens et al., 2018).
			B	1	Required to achieve a realistic partitioning of evaporation into different components considering land cover heterogeneity (Talsma et al., 2019; Miralles et al., 2016).
			T	25	Current spatial resolution of global datasets (McCabe et al. 2016; Miralles et al., 2016), which has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h		G	1	Water management and agricultural applications require to solve evaporation at timeframes associated with sub-daily irrigation decisions and scheduling (Fisher et al., 2017).
			B	6	Intermediate compromise in which sub-daily processes controlling the evolution of the atmospheric boundary layer can be resolved (McCabe et al. 2016; Miralles et al., 2016).
			T	24	Typical temporal resolution of current global datasets, which has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Timeliness	d		G	1	Water management and agricultural applications require data in near real-time (Fisher et al., 2017).
			B	30	Scales needed to make transpiration data useful for early drought diagnostic or to improve seasonal weather forecasts (expert judgement).
			T	365	Current latency for multiple global datasets, which has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Required Measurement Uncertainty	%	relative root mean square error	G	20	This will involve an improved differentiation of water use and water stress among different crops, species, and ecosystems, and will enable more efficient water management (Fisher et al., 2017).
			B	40	Intermediate compromise in which datasets can become useful as drought diagnostic or as a water management asset (expert judgement).
			T	50	Current level of relative error (Talsma et al., 2018); this level has so far been deemed sufficient for climatological applications (Fisher et al., 2017).
Stability	W m^{-2} $year^{-1}$		G	0.015	Approximately half of the current spread in the multi-datasets estimates of the global trend in evaporation (Zang et al., 2016).
			B	–	–
			T	0.03	Current estimates of the trend in the evaporation, but also the estimates of the spread in the estimates of these trends by different datasets (Zhang et al 2016).

Standards and References	Fisher, J. B., Melton, F., Middleton, E., Hain, C., Anderson, M., Allen, R., Mccabe, M. F., Hook, S., Baldocchi, D., Townsend, P. A., Kilic, A., Tu, K., Miralles, D. D., Perret, J., Lagouarde, J.-P., Waliser, D., Purdy, A. J., French, A., Schimel, D., Famiglietti, J. S., Stephens, G. and Wood, E. F.: The future of evapotranspiration: Global requirements for ecosystem functioning, carbon and climate feedbacks, agricultural management, and water resources, Water Resour. Res., 53(4), 2618–2626, doi:10.1002/2016WR020175, 2017. Martens, B., de Jeu, R., Verhoest, N., Schuurmans, H., Kleijer, J. and Miralles, D.: Towards Estimating Land Evaporation at Field Scales Using GLEAM, Remote Sensing, 10(11), 1720–25, doi:10.3390/rs10111720, 2018. Mccabe, M. F., Ershadi, A., Jiménez, C., Miralles, D. G., Michel, D. and Wood, E. F.: The GEWEX LandFlux project: evaluation of model evaporation using tower-based and globally gridded forcing data, Geosci. Model Dev., 9(1), 283–305, doi:10.5194/gmd-9-283-2016, 2016. Miralles, D. G., Gentine, P., Seneviratne, S. I. and Teuling, A. J.: Land-atmospheric feedbacks during droughts and heatwaves: state of the science and current challenges, Ann. N.Y. Acad. Sci., 8, 469–17, doi:10.1111/nyas.13912, 2019. Miralles, D. G., Jiménez, C., Jung, M., Michel, D., Ershadi, A., Mccabe, M. F., Hirschi, M., Martens, B., Dolman, A. J., Fisher, J. B., Mu, Q., Seneviratne, S. I., Wood, E. F. and Fernández- Prieto, D.: The WACMOS-ET project – Part 2: Evaluation of global terrestrial evaporation data sets, Hydrol. Earth Syst. Sci., 20(2), 823–842, doi:10.5194/hess-20-823-2016, 2016. Talsma, C., Good, S., Miralles, D., Fisher, J., Martens, B., Jiménez, C. and Purdy, A.: Sensitivity of Evapotranspiration Components in Remote Sensing-Based Models, Remote Sensing, 10(10), 1601–28, doi:10.3390/rs10101601, 2018. Zhang, Y., Peña-Arancibia, J. L., Mcvicar, T. R., Chiew, F. H. S., Vaze, J., Liu, C., Lu, X., Zheng, H., Wang, Y., Liu, Y. Y., Miralles, D. G. and Pan, M.: Multi-decadal trends in global terrestrial evapotranspiration and its components, Sci. Rep., 1–12, doi:10.1038/srep19124, 2016.

9.4 ECV: Fire

9.4.1 ECV Product: Burned Area

Name	Burned area				
Definition	Burned area is described by a grid where each cell is labelled as burnt if the majority of that cell is classified as containing burned vegetation.				
Unit	m^2				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Derivation and References and Standards
Horizontal Resolution	m	Minimum mapping unit to which the BA product refers	G	10	10 m goal reflects the need to better map small and spatially fragmented burned areas that cannot be resolved at lower spatial resolution & reflects the spatial resolution provided by recent (Sentinel-2) and planned (Landsat Next) global coverage EO missions.
			B	100	Products based on higher resolution have shown higher sensitivity to small fires, even though coarse resolution RS products still miss most small fires (Chuvieco et al. 2022)
			T	1000	1000 m threshold reflects experience using heritage AVHRR LAC data. Burned area products can be aggregated to lower spatial resolution (e.g. 0.25 degree grid cells) for climate modeling applications. Most climate modelers work at coarse resolution grids, 0.25 d is the most common. A recent review of users of RS BA products show that most of them work at this level of detail (https://www.esa-fire-cci.org/sites/default/files/Fire_cci_D1.1_URD_v5.2.pdf, updated by Heil 2019). A review of users of BA products can be found in Mouillot et al. 2014 and Chuvieco et al. 2019.
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	d	Minimum temporal period to which the BA product refers	G	1	Mostly for atmospheric modelers. A questionnaire to atmospheric and carbon modelers done in 2011 suggested 1-2 days (https://www.esa-fire-cci.org/sites/default/files/Fire_cci_D1.1_URD_v5.2.pdf, but it was recently updated to 1 day or even 6 hours: Heil 2019
			B	10	Based on a questionnaire to atmospheric and carbon modelers done in 2011: https://www.esa-fire-cci.org/sites/default/files/Fire_cci_D1.1_URD_v5.2.pdf, updated in Heil 2019
			T	30	Based on the same questionnaire as above
Timeliness	d	days when the BA product is accessible after fires occurred	G	10	Based on the same questionnaire as above
			B	120	
			T	360	
Required Measurement Uncertainty	%	Average omission and commission errors	G	5	Based on the same questionnaire as above
			B	15	
			T	25	
Stability	Measures of omission and commission over the available time period	Assessment of whether a monotonic trend exists based on the slope of the relationship between an accuracy	G	0	Some potential metrics of stability have been published in the last few years (Padilla et al. 2014), but it is not yet an international agreement on which one should be more suitable for measuring BA consistency. Padilla et al., proposed using the slope b of change of accuracy per year is estimated through a nonparametric linear regression. In addition, the temporal monotonic trend of accuracy (i.e. b different than zero) is tested with the Kendall's tau statistic (Conover 1999; Section 5.4). A statistically significant test result would indicate that accuracy measure m presents
			B	1	
			T	2	

		measure and time			temporal instability, as it would have a significant increase or decrease over time.

Standards and References	Chuvieco, E., Mouillot, F., van der Werf, G.R., San Miguel, J., Tanasse, M., Koutsias, N., García, M., Yebra, M., Padilla, M., Gitas, I., Heil, A., Hawbaker, T.J., & Giglio, L. (2019). Historical background and current developments for mapping burned area from satellite Earth observation. *Remote Sensing of Environment, 225*, 45-64. Chuvieco, E., Roteta, E., Sali, M., Stroppiana, D., Boettcher, M., Kirches, G., Khairoun, A., Pettinari, L., Franquesa, M., & Albergel, C. (2022). Building a small fire database for Sub-Saharan Africa from Sentinel-2 high-resolution images. Science of the Total Environment, Volume 845, 157139 Heil, A. (2019). ESA CCI ECV Fire Disturbance: D1.1 User requirements document, version 6.0. In. Available from: https://www.esa-fire-cci.org/documents Mouillot, F., Schultz, M.G., Yue, C., Cadule, P., Tansey, K., Ciais, P., & Chuvieco, E. (2014). Ten years of global burned area products from spaceborne remote sensing—A review: Analysis of user needs and recommendations for future developments. *International Journal of Applied Earth Observation and Geoinformation, 26*, 64-79. Padilla, M., Stehman, S.V., Litago, J., & Chuvieco, E. (2014). Assessing the Temporal Stability of the Accuracy of a Time Series of Burned Area Products. *Remote Sensing, 6*, 2050-2068. Roteta, E., Bastarrika, A., Storm, T., & Chuvieco, E. (2019). Development of a Sentinel-2 burned area algorithm: generation of a small fire database for northern hemisphere tropical Africa *Remote Sensing of Environment, 222*, 1-17.

9.4.2 ECV Product: Active Fires

Name	Active Fires
Definition	Presence of a temporal thermal anomaly within a grid cell. Those thermal anomalies that are permanent should be linked to other sources of thermal emission (volcanos, gas flaring, industrial or power plants). Generally, the active fire maps are defined by the satellite overpass time (date/hour) when the thermal anomaly was detected.
Unit	m^2
Note	

Requirements					
Item needed	Unit	Metric	[1]	Value	Derivation and References and Standards
Horizontal Resolution	m	Minimum mapping unit to which the AF product refers	G	50	This resolution reflects need to detect small and cool fires (including underground peat fires and fires occurring under forest canopies) and is mostly required by fire managers and fire extinction services
			B	250	Useful for fire risk assessment and better understanding of fire risk factors
			T	5000	5000m threshold reflects experience using legacy AVHRR GAC data. Most climate modelers work at coarse resolution grids, 0.25 d is the most common. A recent review of users of RS BA products show that most of them work at this level of detail (https://www.esa-fire-cci.org/sites/default/files/Fire_cci_D1.1_URD_v5.2.pdf, updated by Heil 2019).
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	min	Minimum temporal period to which the AF product refers (values specified regardless of cloud conditions)	G	5	5 min goal reflects need to detect rapidly moving and short-lived fires. For fire management purposes, active fire detection should be done very frequently. Atmospheric modelers also require updated information on fire activity
			B	120	2-hour breakthrough reflects need to monitor diurnal active fire variability
			T	720	12-hour threshold reflects experience with legacy fire data sets. Needed by atmospheric and carbon modelers.
Timeliness	d	Time lapse between satellite overpass and AF availability	G	1	Requirement values reflect need to analyse climate anomalies and their effects shortly after fire occurrence. A timeliness of 10 minutes (achievable using new geostationary satellites) will be needed by fire managers and atmospheric modelers of smoke impacts on human health
			B	7	
			T	365	Reporting on fire activity
Required Measurement Uncertainty	%	Average omission and commission errors	G	5% *	Based on a questionnaire to atmospheric and carbon modelers done in 2011: https://www.esa-fire-cci.org/sites/default/files/Fire_cci_D1.1_URD_v5.2.pdf, updated in Heil 2019
			B	5% **	Based on the same questionnaire as above
			T	5% ***	Based on the same questionnaire as above
Stability	Measures of omission and commission over the available time period	Assessment of whether a monotonic trend exists based on the slope of the relationship between an accuracy measure and time	G	0%	Percentage reflects the relative increase of decrease in reported global total count of active fire detection gridcells over a 10-year period
			B	1%	
			T	2%	

Standards and References	Giglio, L. et al. (2013) Analysis of daily, monthly, and annual burned area using the fourth-generation global fire emissions database (GFED4). Journal of Geophysical Research: Biogeosciences. [Online] 118 (1), 317–328. Giglio, L. (2007) Characterization of the tropical diurnal fire cycle using VIRS and MODIS observations. Remote Sensing of Environment. [Online] 108 (4), 407–421 Heil, A. (2019). ESA CCI ECV Fire Disturbance: D1.1 User requirements document, version 6.0. In. Available from: https://www.esa-fire-cci.org/documents Mouillot, F., Schultz, M.G., Yue, C., Cadule, P., Tansey, K., Ciais, P., & Chuvieco, E. (2014). Ten years of global burned area products from spaceborne remote sensing—A review: Analysis of user needs and recommendations for future developments. *International Journal of Applied Earth Observation and Geoinformation, 26*, 64-79. Wooster, M. J. et al. (2021) Satellite remote sensing of active fires: History and current status, applications and future requirements. Remote Sensing of Environment. [Online] 267112694.

* with respect to active fires burning with FRP equal to 5 MW km^{-2} in the detector ground footprint
** with respect to active fires burning with FRP equal to 10 MW km^{-2} in the detector ground footprint
*** with respect to active fires burning with FRP equal to 20 MW km^{-2} in the detector ground footprint

9.4.3 ECV Product: Fire Radiative Power (FRP)

Name	**Fire Radiative Power (FRP)**				
Definition	Energy per unit time released by all fires burning within the pixel footprint. This variable is a function of actual temperature of the active fire at the satellite overpass and the proportion of the grid cell being burned.				
Unit	W (or MW)				
Note					
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Derivation and References and Standards**
Horizontal Resolution	m	Minimum mapping unit to which the FRP product refers	G	50	Reflects need to characterize small and cool fires including underground peat fires and fires occurring under forest canopies
			B	250	
			T	5000	Reflects experience using legacy AVHRR GAC data
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	min	Minimum temporal period to which the FRP product refers (values specified regardless of cloud conditions)	G	5	5 min goal reflects need to characterize rapidly moving and short-lived fires
			B	120	2-hour breakthrough reflects need to monitor diurnal active fire variability
			T	720	12-hour threshold reflects experience with legacy fire data sets
Timeliness	d	Time lapse between satellite overpass and AF availability	G	1	For climate applications timeliness is less critical
			B	7	Requirement values reflect need to analyze climate anomalies and their effects shortly after fire occurrence
			T	365	
Required Measurement Uncertainty	MW km^{-2} of detector ground footprint	Average deviation between estimated and observed FRP	G	0.5	Goal based on need to quantify FRP of small and cool smoldering fires
			B	1	
			T	2	
Stability	%	Assessment of whether a monotonic trend exists based on the slope of the relationship between an accuracy measure and time	G	0	Percentage reflects the relative increase of decrease in reported global mean FRP for total burned area over a 10-year period
			B	1	
			T	2	
Standards and References	Giglio, L. et al. (2016) The collection 6 MODIS active fire detection algorithm and fire products. Remote Sensing of Environment. [Online] 17831–41. Roberts, G. et al. (2018) Investigating the impact of overlying vegetation canopy structures on fire radiative power (FRP) retrieval through simulation and measurement. Remote Sensing of Environment. [Online] 217158–171. Wooster, M. J. et al. (2021) Satellite remote sensing of active fires: History and current status, applications and future requirements. Remote Sensing of Environment. [Online] 267112694.				

9.5 ECV: Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)

9.5.1 ECV Product: Fraction of Absorbed Photosynthetically Active Radiation

Name	Fraction of Absorbed Photosynthetically Active Radiation
Definition	FAPAR is defined as the fraction of photosynthetically active radiation (PAR, i.e. the solar radiation reaching the surface in the 0.4-0.7µm spectral region) that is absorbed by vegetation canopy. Both black-sky (assuming only direct radiation) and white-sky (assuming that all the incoming radiation is in the form of isotropic diffuse radiation) FAPAR values may be considered. Similarly FAPAR can also be angularly integrated or instantaneous (i.e., at the actual sun position of measurement). Leaves-only FAPAR refers to the fraction of PAR radiation absorbed by live leaves only, i.e., contributing to the photosynthetic activity within leaf cells.
Unit	dimensionless
Note	FAPAR plays a critical role in assessing the primary productivity of canopies, the associated fixation of atmospheric CO2 and the energy balance of the surface. Length of record: Threshold: 20 years; Target: >40 years

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m		G	10	Application at 10 m for Climate Adaptation, CO_2 fluxnet up scaling. Best practices http://www.qa4ecv.eu/sites/default/files/D4.2.pdf
			B		
			T	250	Scale needed for regional and global climate modeling.
Vertical Resolution				-	N/A
				-	
				-	
Temporal Resolution	d		G	1	When assimilated by model, this value corresponds to the climate model temporal resolution. In order to derive a better phenology accuracy.
			B		
			T	10	When using for crops or ecosytems modeling, or Land Surface / Earth System Model evaluation.
Timeliness	d		G	1	In order to be useful in climate change services.
			B	5	In order to be useful in environmental change services. Can be longer (~months) for historic climate/environmental change assessments.
			T	10	In order to be useful in environmental change services.
Required Measurement Uncertainty	%	1 standard deviation or error covariance matrix, with associated PDF shape (functional form of estimated error distribution for the term)	G	5% for values ≥0.05; 0.0025 (absolute value) for smaller values	The values were assessed through physical link between FAPAR with the LAI and surface albedo uncertainties.
			B		
			T	10% for values >0.05; 0.005 (absolute value) for smaller values	The threshold value of uncertainty was assessed through physical link between FAPAR with the LAI and surface albedo uncertainties.
Stability	%	Assessment of whether a trend	G	<1.5	'The required stability is some fraction of the expected signal' (see Ohring, et. al. 2005.). In the case that we have data over 10 years (= one decade) N=10 and U=5%

		exists with respect to reference data, taken into the definition, i.e. white-sky or black-sky and total versus 'green foliage'.			Assuming U constant along the period It means S=SQRT(N*U^2)/N=SQRT(N)*U/N S=0.3*U = 0.31 * 10/100.0 = 1.5 % This number should be smaller than expected FAPAR trend.
			B		
			T	<3	Same as above with U = 10%
Standards and References					

9.6 ECV: Land Cover

9.6.1 ECV Product: Land Cover

Name	Land Cover				
Definition	Land cover is defined as the observed (bio)-physical cover on the Earth's surface for regional and global climate applications				
Unit	Primary units are categories (binary variables such as forest or cropland) or continuous variables classifiers (e.g. fraction of tree canopy cover in percent). Secondary outputs include surface area of land cover/use types and land cover/use changes (in ha). UN/FAO Land Cover Classification System (LCCS) + C3/C4 sub-classification should be used with cross-walking tables to other common classifications.				
Note	Land cover can be variable in time due to land changes and phenology.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m		G	100-300	Most climate users are satisfied by a horizontal resolution of 300m if they can be provided for long time spans.
			B	300-1 km	Suitable for regional (climate) modeling.
			T	>1 km	Suitable for global (climate) modelers.
Vertical Resolution			G	-	N/A, since ECV products provide estimates as total over a certain area with further vertical discrimination. There is currently no consideration of the third dimension for land ECV products though some of the definitions (such as forests) often use, among others, minimum height criteria.
			B	-	
			T	-	
Temporal Resolution	month	time	G	1	Monthly. Allows regrowth, phenology, changes in water extent related to seasonality to be detected.
			B	12	Yearly. Inter-annual changes can be detected.
			T	60	Every 5 years. Suitable scale for longer-term mapping, related to broader land cover change dynamics.
Timeliness	month		G	3	Seasonal. Ideally, land cover data become available soon after the acquisition of the data but quality processing and ECV product derivation and accuracy assessment, as well as, long-term consistency is to be ensured to track changes and trends. These frequent changes may be relevant for land managers who can react quickly to changes.
			B	12	Annual and bi-annual reporting applications. Policy makers will be able to develop and assess policies based on regular updates and observed changes.
			T	60	Every 5 years. Suitable for longer-term mapping, related to broader land cover change dynamics.
Temporal Extent (Time span)	year		G	>50	Historic changes which most users are interested in are captured. Only be achieved with modeling approaches using non-earth observation data sources (i.e. historical maps)
			B	10-50	Historic changes can be assessed for the Earth observation era.
			T	0 (one time only)	Only current and potentially future data are available, but this is useful for those who require current status products, for example for modelling, and static assessments.
Required Measurement Uncertainty	% for accuracy and errors of omission and commission and hectares for area estimates incl. 95	Primary: overall map accuracy and errors of omission and commission for individual land	G	5	For reporting purposes, this would allow sufficient accuracy, where all classes have high accuracies. An independent accuracy assessment using statistically robust, global or regional reference data of higher quality is required for any ECV land cover product.
			B	20	For other uses, this would be sufficient – it would be expected that some classes would have higher accuracy - for example confusion between built-up and forest would be lower, but confusion between agriculture and bare might be higher. An independent accuracy assessment using statistically robust, global or regional reference data of higher quality is required for any ECV land cover product.

	% confidence intervals	cover categories and types of change (incl. confidence interval). Secondary: bias for area estimates (incl. confidence intervals)			
			T	35	This threshold would be suitable for maximum commission/omission error for individual categories. Overall accuracy might be expected to be higher. An independent accuracy assessment using statistically robust, global or regional reference data of higher quality is required for any ECV land cover product.
Stability	% incl. 95 % confidence intervals	Primary: errors of omission and commission for individual land cover categories and types of change (incl. confidence interval)	G	5	Stability is important for long-term land cover datasets where multiple sensors are used to generate a time series dataset. High stability is required for assessing long-term trends. The stability can be assessed by multi-date independent accuracy assessment. The stability requirements are tighter that for overall uncertainty since the aim for multi- date ECV data is to provide information on changes and trends.
			B	15	
			T	25	
Standards and References					

9.6.2 ECV Product: Maps of High-Resolution Land Cover

Name	Maps of High-Resolution Land Cover
Definition	High Resolution Land Cover is the observed (bio)-physical cover on the Earth's surface for monitoring changes at local scales (suitable for adaptation and mitigation).
Unit	Primary units are categories (binary variables such as forest or cropland) or continuous variables classifiers (e.g. fraction of tree canopy cover in percent). Secondary outputs include surface area of land cover/use types and land cover/use changes (in ha).
Note	It can also be variable in time due to land changes and phenology.

Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	m	Size of grid cell	G	<10	Suitable for local land managers - specifically for targeted applications in climate change mitigation and adaptation. Small features such as green spaces within cities are visible and changes to water extent (in particular change in river courses) also become visible at this resolution. More detailed land cover descriptions are more.
			B	10-30	Can identify human induced land change at regional levels. Most features of interest are visible, and broad changes captured.
			T	30-100	Broad landscape typologies and changes across landscapes are visible, so suitable for landscape management.
Vertical Resolution			G	-	N/A, since ECV products provide estimates as total over a certain area with further vertical discrimination. There is currently no consideration of the third dimension for land ECV products though some of the definitions (such as forests) often use, among others, a minimum height criteria.
			B	-	
			T	-	
Temporal Resolution	month		G	1	Monthly. Allows regrowth, phenology, changes in water extent related to seasonality to be detected.
			B	12	Yearly. Inter-annual changes can be detected
			T	60	Every 5 years. Suitable scale for longer-term mapping, related to broader land cover change dynamics.
Timeliness	month		G	3	Seasonal. Ideally, land cover data become available soon after the acquisition of the data but quality processing and ECV product derivation and accuracy assessment, as well as, long-term consistency is to be ensured to track changes and trends. These frequent changes may be relevant for land managers who can react quickly to changes.
			B	12	Annual and bi-annual reporting applications. Policy makers will be able to develop and assess policies based on regular updates and observed changes.
			T	60	Every 5 years. Suitable scale for longer-term mapping, related to broader land cover change dynamics.
Temporal Extent (Time span)	Y		G	30-50	Historic changes which most users are interested in are captured. Only be achieved with modeling approaches using non-earth observation data sources (i.e. historical maps) – where more recent high resolution data sources (Landsat, Sentinel) are not available.
			B	10-30	Historic changes can be assessed for the Earth observation data which are required at this resolution.
			T	0 (one time only)	Only current and potentially future data are available, but this is useful for those who require current status products, for example for modelling, and static assessments.
Required Measurement Uncertainty	% for accuracy and errors of omission and	Primary: overall map accuracy and errors	G	5	For reporting purposes, this would allow sufficient accuracy, where all classes have high accuracies. An independent accuracy assessment using statistically robust, global or regional reference data of higher quality is required for any ECV land cover

	commission and hectares for area estimates incl. 95 % confidence intervals	of omission and commission for individual land cover categories and types of change (incl. confidence interval). Secondary: bias for area estimates (incl. confidence intervals)	B	20	For other uses, this would be sufficient – it would be expected that some classes would have higher accuracy. For example confusion between built-up and forest would be lower, but confusion between agriculture and bare might be higher. An independent accuracy assessment using statistically robust, global or regional reference data of higher quality is required for any ECV land cover product.
			T	35	This threshold would be suitable for maximum commission/omission error for individual categories. Overall accuracy might be expected to be higher. An independent accuracy assessment using statistically robust, global or regional reference data of higher quality is required for any ECV land cover product.
Stability	% incl. 95 % confidence intervals	Primary: errors of omission and commission for individual land cover categories and types of change (incl. confidence interval)	G	5	Stability is important for long-term land cover datasets where multiple sensors are used to generate a time series dataset. High stability is required for assessing long-term trends. The stability can be assessed by multi-date independent accuracy assessment. The stability requirements are tighter that for overall uncertainty since the aim for multi-date ECV data is to provide information on changes and trends.
			B	15	
			T	25	
Standards and References					

9.6.3 ECV Product: Maps of Key IPCC Land Classes, Related Changes and Land Management Types

Name	Maps of Key IPCC Land Classes, Related Changes and Land Management Types				
Definition	Land cover classes to be used for the estimation of GHG emissions and removals following the IPCC guidelines.				
Unit	Primary units are categories (binary variables such as forest or cropland) or continuous variables classifiers (e.g. fraction of tree canopy cover in percent). Secondary outputs include surface area of land cover/use types and land cover/use changes (in ha).				
Note	It can also be variable in time due to land changes and phenology. Crucially, this table refers to change products.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	m / degree	Size of grid cell	G	10-300	This would allow finer detail to be observed, and for land management to be assessed at smaller units.
			B	300-1000	For most climate users, 300 m is sufficient.
			T	1000-1 degree	For modelling for example at the global scale, this resolution is sufficient. More detailed land cover descriptions are more targeted for regional applications in climate change mitigation and adaptation purposes.
Vertical Resolution			G	-	N/A, since ECV products provide estimates as total over a certain area with further vertical discrimination. There is currently no consideration of the third dimension for land ECV products though some of the definitions (such as forests) often use, among others, minimum height criteria.
			B	-	
			T	-	
Temporal Resolution	month		G	1	Monthly. Allows regrowth, phenology, changes in water extent related to seasonality to be detected.
			B	12	Yearly. Inter-annual changes can be detected. Suitable for most international and national policy reporting cycles.
			T	60	Every 5 years. Suitable for longer-term mapping, related to broader land cover change dynamics.
Timeliness	month		G	1	Monthly. Ideally, land cover data become available soon after the acquisition of the data but quality processing and ECV product derivation and accuracy assessment, as well as, long-term consistency is to be ensured to track changes and trends.
			B	12	Yearly. Policy makers will be able to develop and assess policies based on these changes.
			T	60	Every 5 years. Suitable for longer-term mapping, related to broader land cover change dynamics.
Temporal Extent (Time span)	y		G	>100	For modelling over longer histories historic data are required.
			B	50	Near historic changes can be assessed.
			T	30	Only current maps using the current generation of satellites are used.
Required Measurement Uncertainty	% for accuracy and errors of omission and commission and hectares	Primary: overall map accuracy and errors of omission and commission for individual land cover categories	G	5	For reporting purposes, this would allow sufficient accuracy, where all classes have high accuracies.

	for area estimates incl. 95 % confidence intervals	and types of change (incl. confidence interval). Secondary: bias for area estimates (incl. Confidence intervals)	B	15	For other uses, this would be sufficient – it would be expected that some classes would have higher accuracy -for example confusion between built-up and forest would be lower, but confusion between agriculture and bare might be higher.
			T	25	This threshold would be suitable for maximum commission/omission error for individual categories. Overall accuracy might be expected to be higher.
Stability	% incl. 95 % confidenc	Primary: errors of omission and commission for individual land cover categories and types of change (incl. confidence interval)	G	5	Stability is important for long-term land cover datasets where multiple sensors are used to generate a time series dataset. High stability is required for assessing long-term trends. The stability can be assessed by multi-date independent accuracy assessment. The stability requirements are tighter that for overall uncertainty since the aim for multi-date ECV data is to provide information on changes and trends.
			B	15	
			T	25	
Standards and References					

9.7 ECV: Land Surface Temperature

9.7.1 ECV Product: Land Surface Temperature (LST)

Name	Land Surface Temperature
Definition	Land Surface Temperature (LST) is a measure of how hot or cold the surface of the Earth would feel to the touch. When derived from radiometric measurements of ground-based, airborne, and spaceborne remote sensing instruments, LST is the aggregated radiometric surface temperature of the ensemble of components within the sensor field of view.
Unit	K (average over grid cell)
Note	From a climate perspective, LST is important for evaluating land surface and land-atmosphere exchange processes, constraining surface energy budgets and model parameters, and providing observations of surface temperature change both globally and in key regions.

Requirements

Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km	Size of grid cell	G B T	< 1 < 1 1	Reflect the primary application of the climate users in the survey. The three most popular primary applications are model evaluation, evapotranspiration/vegetation or crop monitoring and urban climate, all of which may quite feasibly require data with a spatial resolution of 1 km or better. Only polar orbiting satellites can currently provide data at these resolutions.
Vertical Resolution	N/A		G B T		
Temporal Resolution	h		G B	< 1 1	Only Geostationary data can provide data at these resolutions but these are regional datasets. In contrast polar orbiting satellites cover the whole globe but are restricted to day/night temporal resolution.
			T	6	Very nearly met by day/night temporal resolution from polar orbiting satellite, which satisfies 70% of climate users in survey.
Timeliness	d		G B T	 2 30	A survey of 80 non-climate users for timeliness from the ESA DUE GlobTemperature Project revealed the a “threshold” need of 1 month for long-term data records, and a “breakthrough” of 48 hours for long-term data records.
Required Measurement Uncertainty	K	An estimate of the expected spread of the distribution of possible values	G B T	< 1 < 1 < 1	This is the required total uncertainty per pixel combining the four groups of uncertainty components: random, locally correlated atmospheric, locally correlated surface, and large scale systematic. There is a requirement for knowledge on correlation length scales
Stability	K / decade	Assessment of whether a monotonic trend exists with respect to ground-based Fiducial Reference Measurements or related ECV datasets (such as near-surface air temperature)	G B T	0.1 0.2 0.3	For climate modeling community long-term product stability is noted as high priority. Temporal stability of the LST products need to be sufficient for global and regional trends in LST anomalies to be calculated.

Standards and References	Bulgin, C., & Merchant, C. (2016). DUE GlobTemperature Requirements Baseline Document. Ghent, D., Veal, K., Trent, T., Dodd, E., Sembhi, H., and Remedios, J. (2019). A New Approach to Defining Uncertainties for MODIS Land Surface Temperature. Remote Sensing, 11, 1021. doi: 10.3390/rs11091021 Good, E. J., Ghent, D. J., Bulgin, C. E., & Remedios, J. J. (2017). A spatiotemporal analysis of the relationship between near-surface air temperature and satellite land surface temperatures using 17 years of data from the ATSR series. Journal of Geophysical Research: Atmospheres, 122(17), 9185-9210. doi:10.1002/2017JD026880 LST CCI (2018) User Requirements Document, Reference LST-CCI-D1.1-URD - i1r0 LST CCI (2019) End-to-End ECV Uncertainty Budget Document, Reference LST-CCI-D2.3-E3UB - i1r0 Merchant, C. J., Paul, F., Popp, T., Ablain, M., Bontemps, S., Defourny, P., Hollmann, R., Lavergne, T., Laeng, A., de Leeuw, G., Mittaz, J., Poulsen, C., Povey, A. C., Reuter, M., Sathyendranath, S., Sandven, S., Sofieva, V. F., and Wagner, W. (2017). Uncertainty information in climate data records from Earth observation. Earth System Science Data, 0, 511-527.

9.7.2 ECV Product: Soil Temperature[7]

Name	Soil Temperature				
Definition	Soil temperature at different depth.				
Unit	°C				
Note	The soil temperature at different depth could represent the thermal energy. The standard depths for soil temperature measurements are 5, 10, 20, 50 and 100 cm below the surface according to the CIMO guide (0cm is an additional in CMA); additional depths may be included. Secondly, LST is more difficult to measure using in situ thermometers or thermocouples s. The temperature sensor is difficult to fit tightly to the ground and remains stable. In the case of precipitation, the fitness will change and cause unstable measurement results. The position of the temperature sensor needs to be adjusted manually. Infrared temperature sensors are expensive, and require representative fields of view to that observed from satellites, so it is challenging to create a global network to represent all possible land covers. Soil temperature is easy to measure using thermometer (0/5/10 cm) or temperature sensor (5/10/20/50/100 cm).				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km	longitude	G	50	
			B	150	
			T	139-278	For the GSN, the horizontal distance between two network stations should not be less than the length of 2.5 degrees of longitude at that location (278 km at the equator). For stations beyond 60 degrees latitude (north or south) the minimum distance is fixed at the length of 2.5 degrees of longitude at 60 degrees latitude (139 km). Consequently, the minimum spacing varies from 278 km at the equator to 139 km in the polar regions.
Vertical Resolution	cm		G	0, 5, 10, 20, 50, 100, 180	The standard depths for soil temperature measurements are 5, 10, 20, 50 and 100 cm below the surface; additional depths may be included. LST is important for the satellite observation. So zero depth could be included. Goal: At the depth of 180cm the temperature is useful for long term climate monitor and prediction. Breakthrough: Automatic Weather Station observe could observe the soil temperature at these depths. Threshold: The thermometer can be used at this depth. Suitable for observing stations without automatic weather stations.
			B	0, 5, 10, 20, 50, 100	
			T	0, 5, 10, 20	
Temporal Resolution	h		G	3	
			B	6	Regarding surface synoptic observations: the main standard times shall be 0000, 0600, 1200 and 1800 UTC. The intermediate standard times shall be 0300, 0900, 1500 and 2100 UTC. Every effort should be made to obtain surface synoptic observations four times daily at the main standard times, with priority being given to the 0000 and 1200 UTC observations required for global exchanges.
			T	24	
Timeliness	h		G	3	
			B	6	
			T	48	
Required Measurement Uncertainty (2-sigma)	K		G	0.1	
			B	0.2	
			T	0.2	
Stability			G		
			B		
			T		
Standards and References	WMO Guide to Meteorological Instruments and Methods of Observation (WMO-No.8) Guide to the GCOS Surface Network (GSN) and GCOS Upper-Air Network (GUAN) (GCOS-144) (WMO/TD No. 1558)				

[7] Soil Temperature is a new ECV product temporary included under the ECV Land-Surface Temperature. His positioning will be subjected to evaluation of TOPC Panel and GCOS Steering Committee.

9.8 ECV: Leaf Area Index

9.8.1 ECV Product: Leaf Area Index (LAI)

Name	Leaf Area Index (LAI)				
Definition	Leaf Area Index of a plant canopy or ecosystem is defined as one half of the total green leaf area per unit horizontal ground surface area and measures the area of leaf material present in the specified environment (projection to the underlying ground along the normal to the slope).				
Unit	$m^2\ m^{-2}$				
Note	Effective Leaf Area Index is the LAI value that would produce the same indirect ground measurement as that observed assuming foliage distribution (LAIeff=LAItrue x canopy clumping index). The conversion of data measurements to true values is an essential step and requires additional information about the structure and architecture of the canopy, e.g. gap size distributions, at the appropriate spatial resolutions. Leaf Area Index controls important mass and energy exchange processes, such as radiation and rain interception, as well as photosynthesis and respiration, which couple vegetation to the climate system. Length of record: Threshold: 20 years; Target: >40 years.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	M		G	10	For (e.g.) climate adaptation and agricultural monitoring Best practices published here: http://www.qa4ecv.eu/sites/default/files/D4.2.pdf
			B	100	
			T	250	For regional and global climate modeling
Vertical Resolution				-	N/A. In theory, a vegetation canopy can be stratified into various layers to describe its vertical structure in a discrete way. However actual methods of LAI observation, e.g. optical sensors, can only measure the total canopy leaf area index. Therefore, no requirements for vertical resolution are set.
				-	
				-	
Temporal Resolution	D		G	1	When assimilated by model, this value corresponds to the climate model temporal resolution (to derive a better phenology accuracy).
			B		
			T	10	When using for crops or ecosystems modeling, or Land Surface / Earth System Model evaluation.
Timeliness	d		G	1	For climate change services.
			B	5	For environmental change services. Can be longer (~months) for historic climate/environmental change assessments.
			T	10	For NWP (ECMWF)
Required Measurement Uncertainty	% or $m^2\ m^{-2}$	1 sigma	G	10% for values ≥0.5; 0.05 (absolute value) for smaller values	One standard deviation or error covariance matrix with associated PDF shape (functional form of estimated error distribution for the term). The goal value of uncertainties were assessed through literature review of impact of climate change on LAI using various earth system models (see Mahowald, et. al., 2016; https://www.earth-syst-dynam.net/7/211/2016/). They show impact on LAI deviation at global scale using various RCP scenarios. If we take the models ensemble results, we demonstrate that the uncertainties should be less than Delta_LAI ~0.20 for a 2 deg. C deviation for an annual average LAI, that can be approximated to ~1.5. This means that the uncertainties should be smaller than 10% (~0.20/1.87*100.).
			B		
			T	20% for values ≥0.5; 0.1 (absolute value) for smaller values	Same as above but with Delta_LAI ~0.25

Stability	$m^2\ m^{-2}$ / decade	A factor of uncertainties to demonstrate that the 'error' of the product remains constant over at least a decade	G	<3%	The unit is rate of change of LAI over the available time period. 'The required stability is some fraction of the expected signal' (see Ohring, et. al. 2005). "It may represent a requirement on the extent to which the error of the product remains constant over a long period, typically a decade or more. It can be defined by the mean of uncertainties over a month …". In the case that we have data over 10 years (= one decade) N=10 and U=10% S=sqrt(sum(U^2))/N. Assuming U constant along the period It means S=SQRT(N*U^2)/N=SQRT(N)*U/N S=0.3*U = 0.31 * 10/100.0 = 3 % This number should be smaller than expected LAI trend. Ref: Jiang et al. 2017.
			B		
			T	<6%	Same as above but with threshold uncertainty.
Standards and References	Fang, H., Baret, F., Plummer, S., & Schaepman-Strub, G. (2019). An overview of global leaf area index (LAI): Methods, products, validation, and applications. Reviews of Geophysics. 57, 739– 799. https://doi.org/10.1029/2018RG000608 Boussetta S., Balsamo G., Dutra E., Beljaars A., Albergel C. (2015) Assimilation of surface albedo and vegetation states from satellite observations and their impact on numerical weather prediction, Remote Sensing of Environment, pp. 111-126. DOI:10.1016/j.rse.2015.03.009 Fernandes, R., Plummer, S., Nightingale, J., Baret, F., Camacho, F., Fang, H., Garrigues, S., Gobron, N., Lang, M., Lacaze, R., LeBlanc, S., Meroni, M., Martinez, B., Nilson, T., Pinty, B., Pisek, J., Sonnentag, O., Verger, A., Welles, J., Weiss, M., & Widlowski, J.L. (2014). Global Leaf Area Index Product Validation Good Practices. Version 2.0. In G. Schaepman-Strub, M. Román, & J. Nickeson (Eds.), Best Practice for Satellite-Derived Land Product Validation (p. 76): Land Product Validation Subgroup (WGCV/CEOS), doi:10.5067/doc/ceoswgcv/lpv/lai.002 C. Y. Jiang, Y. Ryu, H. Fang, R. Myneni, M. Claverie, Z. Zhu, (2017). Inconsistencies of interannual variability and trends in long-term satellite leaf area index products. Glob. Chang. Biol. 23, 4133–4146. Ohring, G., Wielicki, B., Spencer, R., Emery, B., & Datla, R. (2005). Satellite instrument calibration for measuring global climate change: Report of a workshop. Bulletin of the American Meteorological Society, 86(9), 1303-1314.				

9.9 ECV: Soil carbon

9.9.1 ECV Product: Carbon in Soil

Name	Carbon in Soil				
Definition	% of organic carbon in the topmost 30 cm and sub-soil 30-100cm.				
Unit	% of mass				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km	Grid cell size	G	20	
			B	100	
			T	1000	
Vertical Resolution			G	-	N/A
			B	-	N/A
			T	-	N/A
Temporal Resolution	y	Time between estimates	G	1	Consistent with LUC
			B	5	
			T	10	
Timeliness	y		G	1	
			B	1	
			T	1	
Required Measurement Uncertainty (2-sigma)	%		G	10	
			B	10	
			T	10	
Stability	%		G	1	
			B	1	
			T	1	
Standards and References	Nachtergaele, F.H., van Velthuizen, L. Verekst, and D. Widberg, Eds., 2012: Harmonized World Soil Database v1.2 Wieder et al, 2013, Nature Climate Change; Oertel et al., 2016, doi:10.1016/j.chemer.2016.04.002 Anan et al., 2013, nan et al., 2013, Todd-Brown et al., 2014, doi:10.5194/bg-11-2341-2014 Todd-Brown et al., 2014, doi:10.5194/bg-11-2341-2014				

9.9.2 ECV Product: Mineral Soil Bulk Density

Name	Mineral Soil Bulk Density				
Definition	Bulk density of dry soil averaged over the topmost 30 cm and topmost 1 m.				
Unit	Kg m^{-3}				
Note					
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	km	Grid cell size	G	0.1	For permafrost
			B	1	
			T	20	
Vertical Resolution			G	-	N/A
			B	-	N/A
			T	-	N/A
Temporal Resolution	y	Time between estimates	G	5	
			B	10	
			T	20	
Timeliness	y		G	1	
			B	1	
			T	1	
Required Measurement Uncertainty (2-sigma)	%		G	10	
			B	10	
			T	10	
Stability			G	1	
			B	1	
			T	1	
Standards and References	National Research Council (2014). Opportunities to Use Remote Sensing in Understanding Permafrost and Related Ecological Characteristics: Report of a Workshop. Washington, DC: The National Academies Press. https://doi.org/10.17226/18711				

9.9.3 ECV Product: Peatlands

Name	**Peatlands**				
Definition	Depth of peat measured on a regular grid (where peat exists).				
Unit	m				
Note	This provides the geographic extent of peatlands and their depth				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	m	Grid cell size	G	20	
			B	100	
			T	1000	
Vertical Resolution	m		G	0.1	
			B	0.5	
			T	1	
Temporal Resolution	y	Time between estimates	G	5	
			B	10	
			T	20	
Timeliness	y		G	1	
			B	1	
			T	1	
Required Measurement Uncertainty (2-sigma)	%		G	10	
			B	10	
			T	10	
Stability	%		G	1	
			B	1	
			T	1	
Standards and References	Minasny, B., O. Berglund, J. Connolly, C. Hedley, F. de Vries, A. Gimona, B. Kempen, D. Kidd, H. Lilja, B. Malone, A. McBratney, P. Roudier, S. O'Rourke, Rudiyanto, J. Padarian, L. Poggio, A. ten Caten, D. Thompson, C. Tuve and W. Widyatmanti (2019). "Digital mapping of peatlands - A critical review." Earth-Science Reviews 196. doi: 10.1016/j.earscirev.2019.05.014 Hugelius, G., J. Loisel, S. Chadburn, R. B. Jackson, M. Jones, G. MacDonald, M. Marushchak, D. Olefeldt, M. Packalen, M. B. Siewert, C. Treat, M. Turetsky, C. Voigt and Z. Yu (2020). "Large stocks of peatland carbon and nitrogen are vulnerable to permafrost thaw." Proceedings of the National Academy of Sciences 117(34): 20438-20446. doi: 10.1073/pnas.1916387117				

10. ANTHROPOGENIC

10.1 ECV: Anthropogenic Greenhouse Gas Fluxes

10.1.1 ECV Product: Anthropogenic CO_2 Emissions from Fossil Fuel Use, Industry, Agriculture, Waste and Products Use

Name	**Anthropogenic CO_2 Emissions from Fossil Fuel Use, Industry, Agriculture, Waste and Products Use**				
Definition	Anthropogenic long-cycle C emissions are mainly originating from combustion of fossil fuels, and for about 10% also from non-combustion sources, such as cement production, ferrous and non-ferrous metal production processes, urea production, agricultural liming and solvent use.				
Unit	Mg CO_2 y^{-1} for the region				
Note	This corresponds to UNFCCC reporting of anthropogenic emissions from non-LULUCF sources by country				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	Country-level	As defined by UNFCCC	G	By country and sector	IPCC 2006 Guidelines, UNFCCC Inventory Guidelines
			B		
			T	By country and sector	IPCC 2006 Guidelines, UNFCCC Inventory Guidelines
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	y		G	1	IPCC 2006 Guidelines, UNFCCC Inventory Guidelines
			B		
			T	1	IPCC 2006 Guidelines, UNFCCC Inventory Guidelines
Timeliness	y		G	Within 1.25 years	UNFCCC Inventory Reporting Guidelines
			B		
			T	Within 1.25 years	UNFCCC Inventory Reporting Guidelines
Required Measurement Uncertainty	%	Twice the estimated standard deviation of the total as a % of the total	G	Globally: 5% Nationally: 10%	IPCC 2006 Guidelines
			B		
			T	Globally: 10% Nationally: 30%	IPCC 2006 Guidelines
Stability			G		Follow times series consistency in 2006 Guidelines and 2019 Refinement
			B		
			T		
Standards and References	IPCC 2006 Guidelines (Optional: 2019 Refinement of the Guidelines; National inventory reports to UNFCCC)				

10.1.2 ECV Product: Anthropogenic CH_4 Emissions from Fossil Fuel, Waste, Agriculture, Industrial Processes and Fuel Use

Name	Anthropogenic CH_4 Emissions from Fossil Fuel, Waste, Agriculture, Industrial Processes and Fuel Use				
Definition	Anthropogenic CH_4 emissions are mainly originating from fermentation processes in waste (landfills), manure, enteric fermentation, but also from fossil fuel extraction, transmission and distribution and use, and industrial processes.				
Unit	Mg CH_4 y^{-1} for the region				
Note	This corresponds to UNFCCC reporting of anthropogenic emissions of methane, except from wetlands				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	Country-level	Country by country	G	By country and sector	IPCC 2006 Guidelines, UNFCCC Inventory Guidelines
			B		
			T	By country and sector	IPCC 2006 Guidelines, UNFCCC Inventory Guidelines
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	y	time	G	1	IPCC 2006 Guidelines, UNFCCC Inventory
			B		
			T	1	IPCC 2006 Guidelines, UNFCCC Inventory
Timeliness	y	time	G	within 1.25 years	UNFCCC Inventory Reporting Guidelines
			B		
			T	within 1.25 years	UNFCCC Inventory Reporting Guidelines
Required Measurement Uncertainty	%	Twice the estimated standard deviation of the total as a % of the total	G	20%	IPCC 2006 Guidelines
			B		
			T	40%	IPCC 2006 Guidelines
Stability			G		Follow times series consistency in 2006 Guidelines and 2019 Refinement
			B		
			T		
Standards and References	IPCC 2006 Guidelines (Optional: 2019 Refinement of the Guidelines; National inventory reports to UNFCCC)				

10.1.3 ECV Product: Anthropogenic N_2O Emissions from Fossil Fuel Use, Industry, Agriculture, Waste and Products Use, Indirect from N-Related Emissions / Depositions

Name	**Anthropogenic N_2O Emissions from Fossil Fuel Use, Industry, Agriculture, Waste and Products Use, Indirect from N-Related Emissions / Depositions**				
Definition	Anthropogenic N_2O emissions are mainly originating from fuel combustion, industry, agriculture, waste, products use (including indirect emissions from leaching and run-off, from NOx emissions).				
Unit	Mg N_2O y^{-1} for the region				
Note	This corresponds to UNFCCC reporting of anthropogenic emissions of nitrous oxide				
Requirements					
Item needed	**Unit**	**Metric**	[1]	**Value**	**Notes**
Horizontal Resolution	Country-level	Country by country	G	By country and sector	IPCC 2006 Guidelines, UNFCCC Inventory Guidelines
			B		
			T	By country and sector	IPCC 2006 Guidelines, UNFCCC Inventory Guidelines
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	y	time	G	1	IPCC 2006 Guidelines, UNFCCC Inventory Guidelines
			B		
			T	1	IPCC 2006 Guidelines, UNFCCC Inventory Guidelines
Timeliness	y	time	G	within 1.25 years	UNFCCC Inventory Reporting Guidelines
			B		
			T	within 1.25 years	UNFCCC Inventory Reporting Guidelines
Required Measurement Uncertainty	%	Twice the estimated standard deviation of the total as a % of the total	G	40%	IPCC 2006 Guidelines
			B		
			T	80%	IPCC 2006 Guidelines
Stability			G		Follow times series consistency in 2006 Guidelines and 2019 Refinement
			B		
			T		
Standards and References	IPCC 2006 Guidelines (Optional: 2019 Refinement of the Guidelines; National inventory reports to UNFCCC)				

10.1.4 ECV Product: Anthropogenic F-Gas Emissions from Industrial Processes and Product Use

Name	Anthropogenic F-Gas Emissions from Industrial Processes and Product Use				
Definition	F-Gas emissions are anthropogenic and mainly originating from chemical industrial processes and F- gas-related product use. The different F-gases have different, all very high global warming potentials.				
Unit	Mg CO_2eq y^{-1} for the region				
Note	This corresponds to UNFCCC reporting of anthropogenic emissions of fluorinated gases (HFC, PFC and SF_6) aggregated according to the GWP as agreed by the UNFCCC				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	Country -level	Country by country	G	By country and sector	IPCC 2006 Guidelines, UNFCCC Inventory Guidelines
			B		
			T	By country and sector	IPCC 2006 Guidelines, UNFCCC Inventory Guidelines
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	y	time	G	1	IPCC 2006 Guidelines, UNFCCC Inventory
			B		
			T	1	IPCC 2006 Guidelines, UNFCCC Inventory
Timeliness	y	time	G	within 1.25 years	UNFCCC Inventory Reporting Guidelines
			B		
			T	within 1.25 years	UNFCCC Inventory Reporting Guidelines
Required Measurement Uncertainty	%	Twice the estimated standard deviation of the total as a % of the total	G	10%	IPCC 2006 Guidelines
			B		
			T	50%	IPCC 2006 Guidelines
Stability			G		Follow times series consistency in 2006 Guidelines and 2019 Refinement
			B		
			T		
Standards and References	IPCC 2006 Guidelines (Optional: 2019 Refinement of the Guidelines; National inventory reports to UNFCCC)				

10.1.5 ECV Product: Total Estimated Fluxes by Coupled Data Assimilation / Models with Observed Atmospheric Composition – National

Name	**Total Estimated Fluxes by Coupled Data Assimilation / Models with Observed Atmospheric Composition – National**				
Definition	National estimates derived from highly resolved GHG emission gridmaps (modelled output, using proxy for the spatial distribution at fine-scale resolution).				
Unit	kg CO_2eq m^{-2} s^{-1}				
Note	Total estimated fluxes by coupled data assimilation/ inverse models at a national scale. This includes both "anthropogenic" and "natural" emissions and removals.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km	Size of country	G	10	
			B		
			T	100	
Vertical Resolution			G	-	Rather than vertical resolution there can be 4 Layers: 1- surface; 2- stack height (between 100m and 300m); 3- cruise height (10km) and 4- supersonic height (15 km).
			B	-	
			T	-	
Temporal Resolution	y	Time	G	1	IPCC 2019, UNFCCC Inventory Guidelines
			B		
			T	1	IPCC 2019, UNFCCC Inventory Guidelines
Timeliness	y	Time	G	within 1.25 years	To allow comparison with estimates made following the UNFCCC Inventory Reporting Guidelines
			B		
			T	within 1.25 years	To allow comparison with estimates made following the UNFCCC Inventory Reporting Guidelines
Required Measurement Uncertainty		Twice the estimated standard deviation of the total as a % of the total	G	10%	IPCC 2019
			B		
			T	30%	IPCC 2019
Stability			G		
			B		
			T		
Standards and References	IPCC 2019 refinement https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html Volume I, Chapter 6.10.2 Comparisons with atmospheric measurements GAW Report No. 245, An Integrated Global Greenhouse Gas Information System (IG3IS) Science Implementation PlanEC-CO2 report, Pinty et al., 2017: An operational anthropogenic CO_2 emissions monitoring & verification support capacity - Baseline requirements, Model components and functional architecture, European Commission Joint Research Centre, EUR 28736 EN, https://doi.org/10.2760/39384				

10.1.6 ECV Product: Total Estimated Fluxes by Coupled Data Assimilation / Models with Observed Atmospheric Composition – Continental

Name	**Total Estimated Fluxes by Coupled Data Assimilation / Models with Observed Atmospheric Composition - Continental**				
Definition	GHG emission gridmaps (modelled output, using proxy for the spatial distribution).				
Unit	kg CO_2eq m^{-2} s^{-1}				
Note	Total estimated fluxes by coupled data assimilation/ inverse models at a continental scale. This includes both “anthropogenic” and “natural” emissions and removals.				
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km	Size of continents	G	1000	
			B		
			T	10000	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	y	time	G	1	IPCC 2006 Guidelines, UNFCCC Inventory Guidelines
			B		
			T	1	IPCC 2006 Guidelines, UNFCCC Inventory Guidelines
Timeliness	y	time	G	within 1.25 years	To allow comparison with estimates made following the UNFCCC Inventory Reporting Guidelines
			B		
			T	within 1.25 years	To allow comparison with estimates made following the UNFCCC Inventory Reporting Guidelines
Required Measurement Uncertainty	%	Twice the estimated standard deviation of the total as a % of the total	G	10%	IPCC 2019
			B		
			T	25%	IPCC 2019
Stability			G		IPCC 2019
			B		
			T		IPCC 2019
Standards and References	IPCC 2019 refinement https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html Volume I, Chapter 6.10.2 Comparisons with atmospheric measurements. GAW Report No. 245, An Integrated Global Greenhouse Gas Information System (IG3IS) Science Implementation Plan.				

10.1.7 ECV Product: Anthropogenic CO_2 Emissions/Removals by Land Categories

Name	Anthropogenic CO2 Emissions/Removals by Land Categories				
Definition	Short and long cycle C emissions from land use, land-use and forestry (including carbon stock gains and losses of biomass burning, disease, harvest, net deforestation).				
Unit	Mg of CO2 y^{-1} (for the region)				
Note	This corresponds to UNFCCC reporting of anthropogenic emissions and removals from LULUCF				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution	Country-level	As defined by UNFCCC	G	By country/region	IPCC 2006 Guidelines, UNFCCC Inventory
			B		
			T	By country/region	IPCC 2006 Guidelines, UNFCCC Inventory
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	y	Time	G	1	IPCC 2006 Guidelines, UNFCCC Inventory
			B		
			T	1	IPCC 2006 Guidelines, UNFCCC Inventory
Timeliness	y	Time	G	within 1.25 years	UNFCCC Inventory Reporting Guidelines
			B		
			T	within 1.25 years	UNFCCC Inventory Reporting Guidelines
Required Measurement Uncertainty	% or Gg	Twice the estimated standard deviation of the total as a % of the total or mass of CO2	G	15% or 300Gg, whichever is largest	IPCC 2006 Guidelines
			B		
			T	20% or 400Gg – whichever is largest	IPCC 2006 Guidelines
Stability			G		
			B		
			T		
Standards and References	IPCC 2003 GPG, IPCC 2006 Guidelines; UNFCCC National Inventory Reports				

10.1.8 ECV Product: High-Resolution Footprint Around Point Sources

Name	**High-Resolution Footprint Around Point Sources**				
Definition	Spatially resolved GHG emission plume around local source.				
Unit	ppm (total column-averaged dry air mole fraction of CO_2)				
Note					
Requirements					
Item needed	**Unit**	**Metric**	**[1]**	**Value**	**Notes**
Horizontal Resolution	km	distance	G	1	
			B		
			T	2	
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	h	Repeat time of observations	G	4	IPCC 2019 Refinement
			B		
			T	144 (6 days)	
Timeliness	weeks		G	1	
			B		
			T	4	
Required Measurement Uncertainty	ppm	Twice the estimated standard deviation of the total	G	1	IPCC 2006 Guidelines
			B		
			T	5	IPCC 2006 Guidelines
Stability			G		
			B		
			T		
Standards and References	ESA Mission requirements document of CarbonSat, of CO_2M Sentinel (EOP-SM/3088/YM-ym, 82 pp., https://esamultimedia.esa.int/docs/EarthObservation/CO2M_MRD_v2.0_Issued20190927.pdf) References in Janssens-Maenhout et al., 2020: Toward an Operational Anthropogenic CO2 Emissions Monitoring and Verification Support Capacity, BAMS, https://doi.org/10.1175/BAMS-D.19-0017.1				

10.2 ECV: Anthropogenic Water Use

10.2.1 ECV Product: Anthropogenic Water Use

Name	Anthropogenic Water Use				
Definition	Volume of water used by country, by sector – agricultural, industrial and domestic.				
Unit	Volume of water used by country. $Gm^3\ y^{-1}$				
Note	AQUASTAT contains estimates of water use by county.				
Requirements					
Item needed	Unit	Metric	[1]	Value	Notes
Horizontal Resolution		By country	G		Medium-scale watersheds
			B		Country, plus major watersheds
			T		Country
Vertical Resolution			G	-	N/A
			B	-	
			T	-	
Temporal Resolution	month		G	1	
			B		
			T	12	
Timeliness			G		
			B		
			T		
Required Measurement Uncertainty (2-sigma)	%		G	10	
			B		
			T	20	
Stability			G		
			B		
			T		
Standards and References					

GCOS Secretariat
Global Climate Observing System
c/o World Meteorological Organization
7 *bis,* Avenue de la Paix
P.O. Box No. 2300
CH-1211 Geneva 2, Switzerland
Tel: +41 22 730 8067
Fax: +41 22 730 8181
Email: gcos@wmo.int