National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

Datum Control of a Tide Gauge, Relative Sea Level Changes, Vertical Land Movements and GNSS (GPS) at Tide Gauges

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Sea Level Training Course, St Lucia, 17-21 October 2016

Datum Control of the Tide Gauge

- The first essential step for any installation is to ensure that the tide gauge is providing good Relative Sea Level data
- It is not enough to have a gauge provide ‘sea level’ without knowing what that level is relative to
- The sea level should always be expressed relative to the tide gauge Contact Point, the level of which is subsequently determined relative to the Tide Gauge Bench Mark (TGBM)
- The TGBM is considered to be the most stable BM near to the gauge, but GLOSS standards require about 5 other ancillary marks to as to check the TGBM’s stability

Whatever the type of gauge – they have to be calibrated and levelled to local benchmarks

Benchmarks

A set of at least 5 benchmarks near to the gauge is required by GLOSS standards, of which one will be the main Tide Gauge Benchmark (TGBM). The 5 are needed to check the stability of the TGBM.

These should be levelled regularly (e.g. annually) and their levels should be documented by means of 'RLR diagrams', with the information passed to PSMSL etc.

In many ways the benchmarks are more important than the tide gauges themselves!

TGBM at Newlyn, UK

Various marks used by the USC&GS

Benchmark

A benchmark (BM) is a fixed point of reference for the height of the tide gauge Contact Point.

Permanent BM at Port Louis in the Falklands

Other Types

Type of Domed Benchmark used by NOC

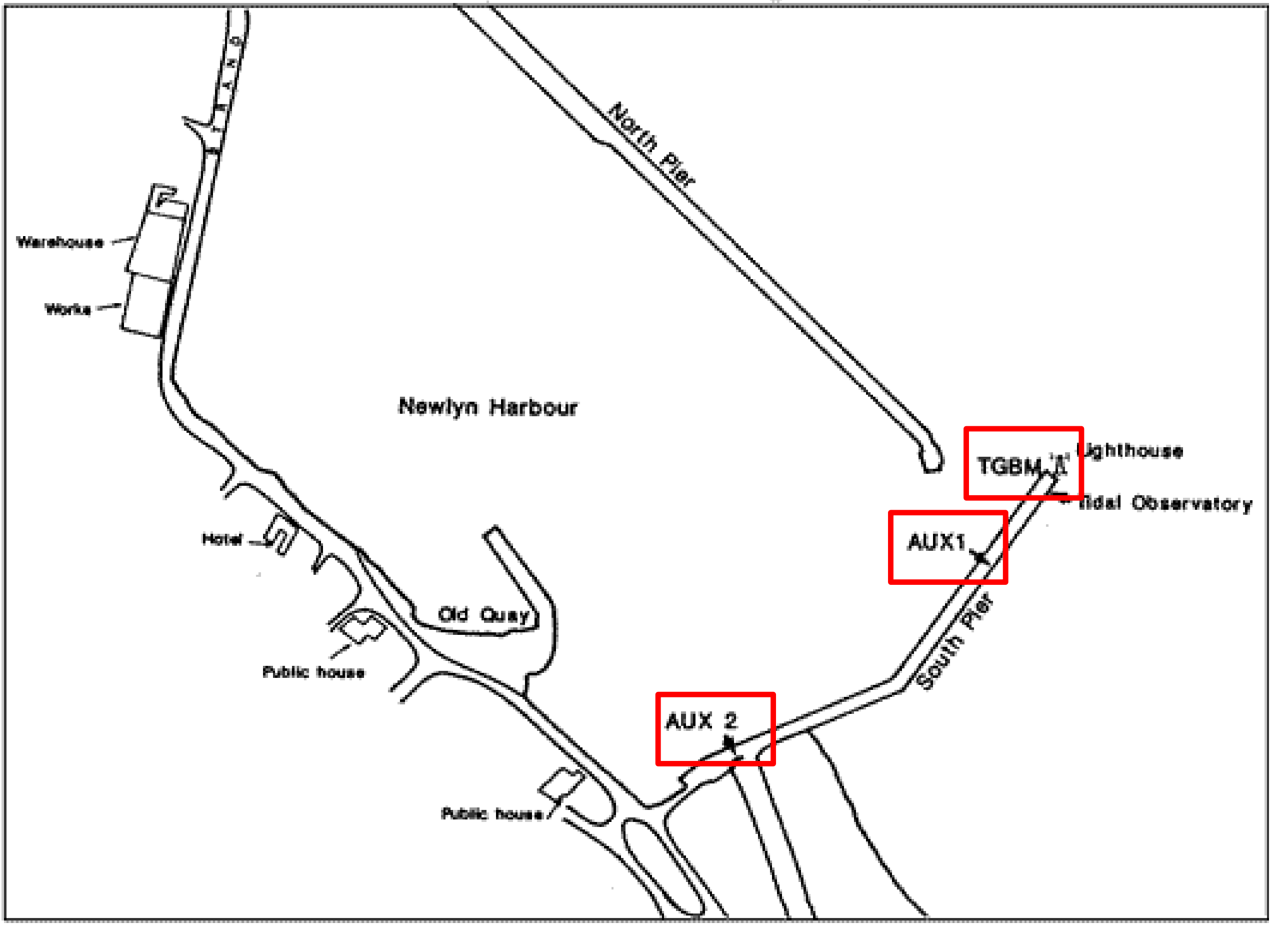
Marks on Walls

Ordnance Survey (UK) cut mark and flush bracket mark

Why 5? BM installed by RAN at Port Vila after earthquake

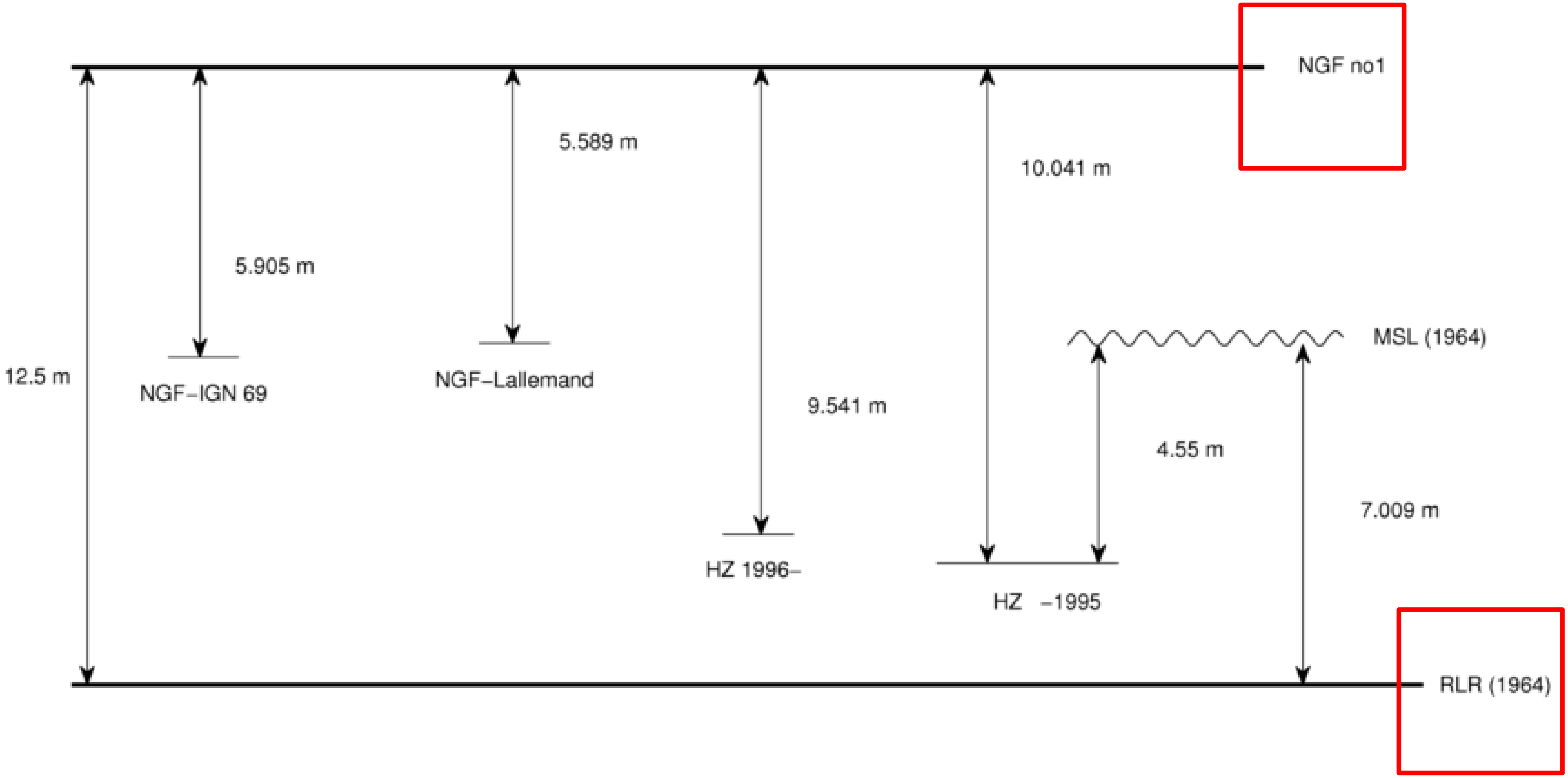
Levelling of the Benchmarks

- GLOSS calls for annual levelling of the marks at a tide gauge site
- A map of the marks must be made
- Also descriptions and photos provided
- A ‘BM diagram’ must be made including the TGBM and the BM at a nearby GPS receiver
- As the marks may be unstable the BM diagram will need to have a date attached to it



Bench Marks	National Grid co-ords	Description
TGBM	SW46762855	Ordnance Survey Bench Mark Bolt inside hut adjacent to well
AUX 1	SW46732851	Flush Bracket 1565 on NW face of South Pier wall, 17.8m SW of tidal observatory
AUX 2	SW46592841	Flush Bracket 1520 on NW face of wall on SE side of South Pier Road

Benchmark map for Newlyn

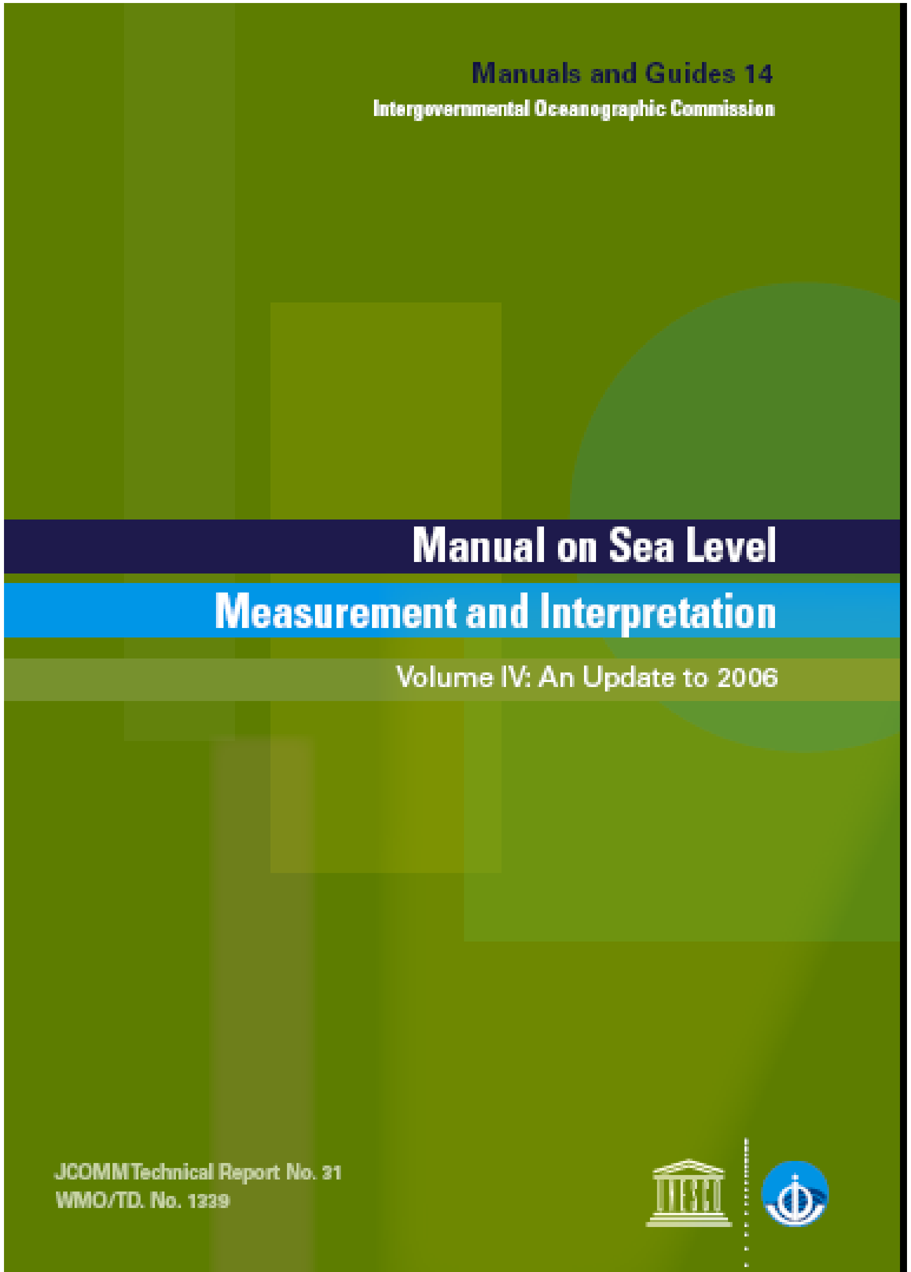


The ‘BM diagram’ is essentially the same as the ‘RLR diagram’ used by the PSMSL – in this case for Brest

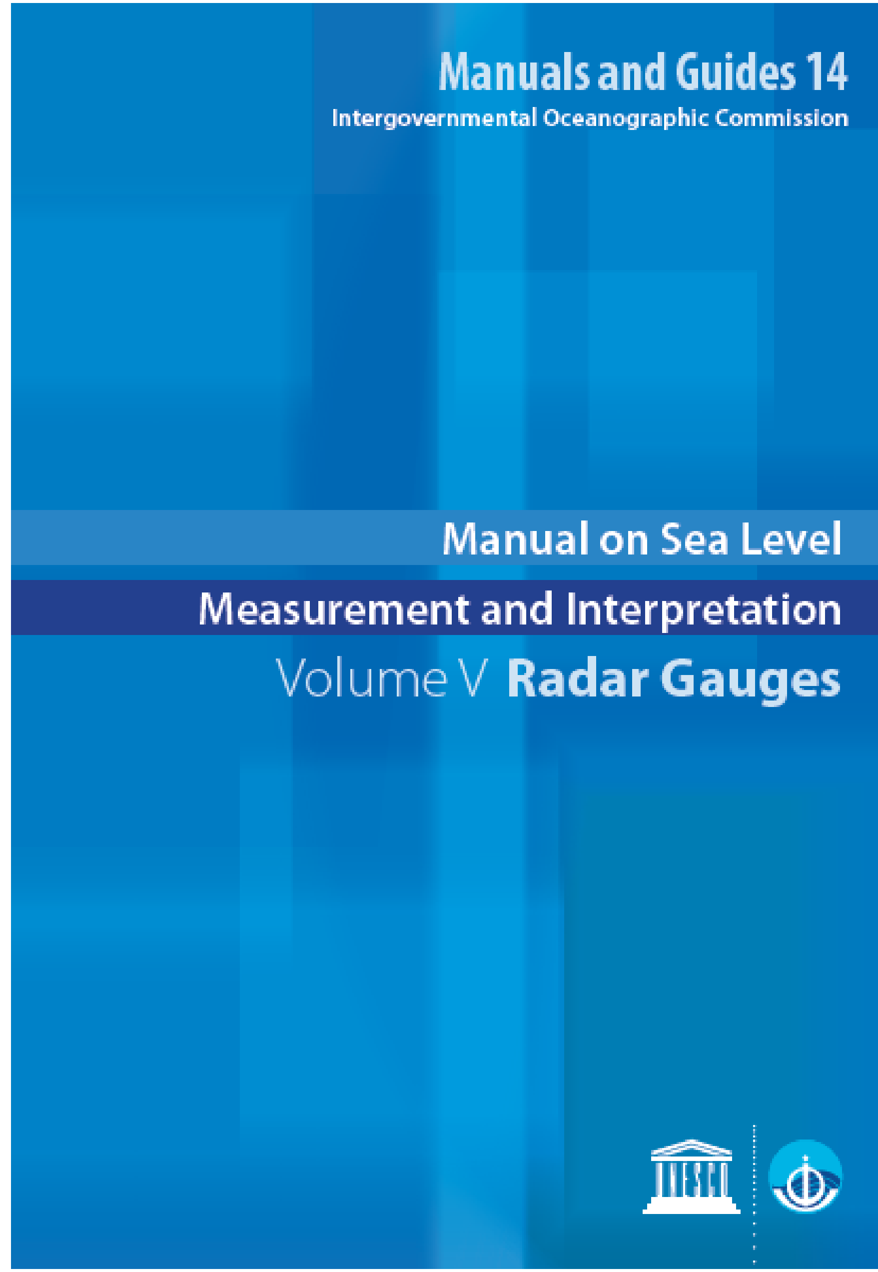
RLR datum is the level to which PSMSL data are expressed

To Summarise

- The choice of 5 BM's at each site is essential, and regular levelling must take place to check the stability of the TGBM which is the level to which the tide gauge data are referenced.
- This levelling must take place regularly (annually), whether the station also has GPS or not. (I'll come on to that next)
- The results of the annual levelling must be clearly documented and archived.



Manuals and Guides 14
Intergovernmental Oceanographic Commission
Manual on Sea Level
Measurement and Interpretation
Volume IV: An Update to 2006
JCOMM Technical Report No. 31
WMO/TD. No. 1339



Manuals and Guides 14
Intergovernmental Oceanographic Commission
Manual on Sea Level
Measurement and Interpretation
Volume V Radar Gauges

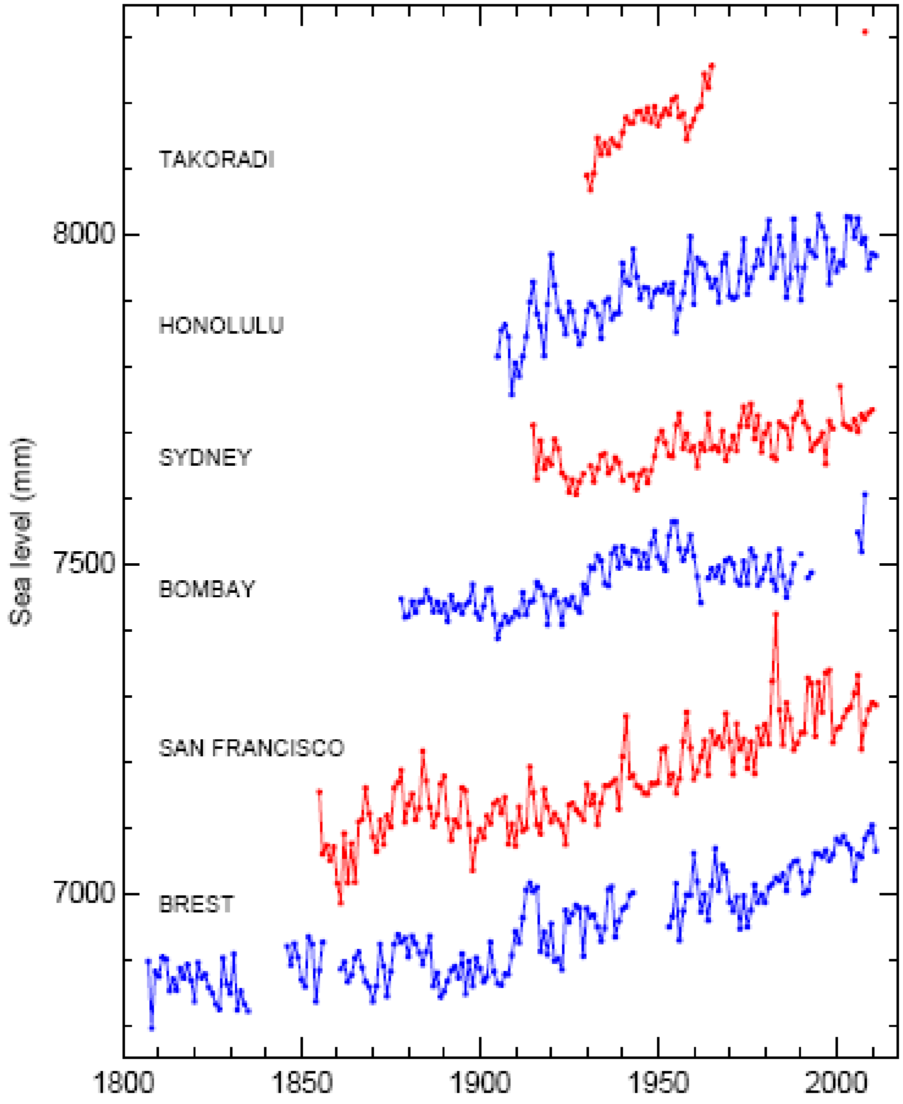
Relative Sea Level

- We now have a tide gauge to measure the level of the sea relative to the TGBM on land
- This is called Relative Sea Level and (when averaged over months and years) is the same as the Mean Sea Level archived by the PSMSL

Land Level as well as Sea Level Changes

- A problem is that Relative Sea Level can contain information on land level change as well as true sea level change
- The land could be submerging (e.g. Bangkok) or emerging (e.g. Sweden) relative to the centre of the Earth at a rate faster than sea level itself is changing
- So we also need to monitor the land level changes using modern geodetic techniques – this will give us Geocentric Sea Level

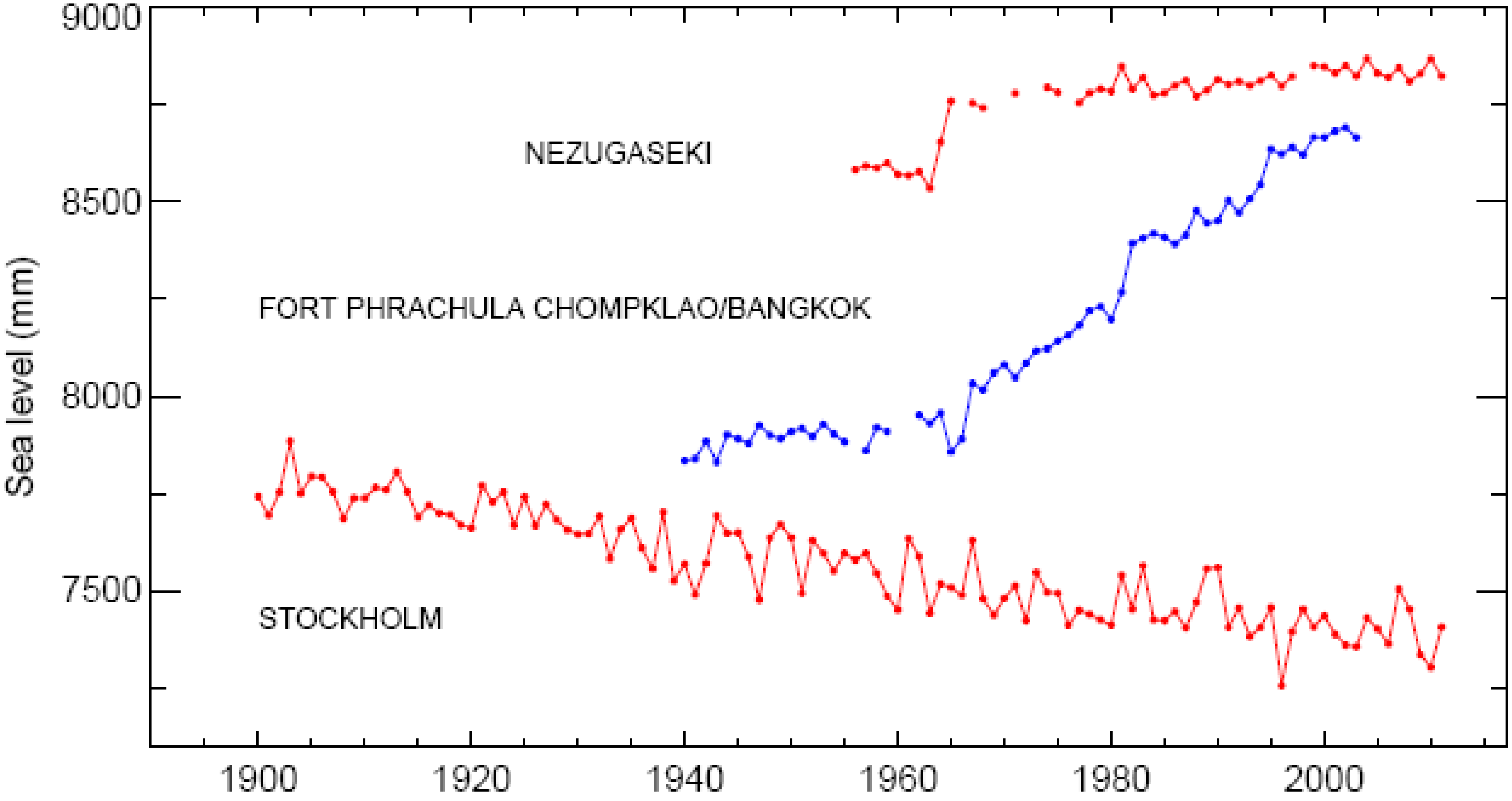
Long records from each continent



Most records show evidence for rising sea levels during the past century

IPCC concluded that there has been a global rise of approximately 10-20 cm during the past 100 years

But some records are clearly affected by land movements



The effects of earthquakes (Japan), ground water extraction (Thailand) and glacial isostatic adjustment (Sweden)

Vertical Land Movements can be:

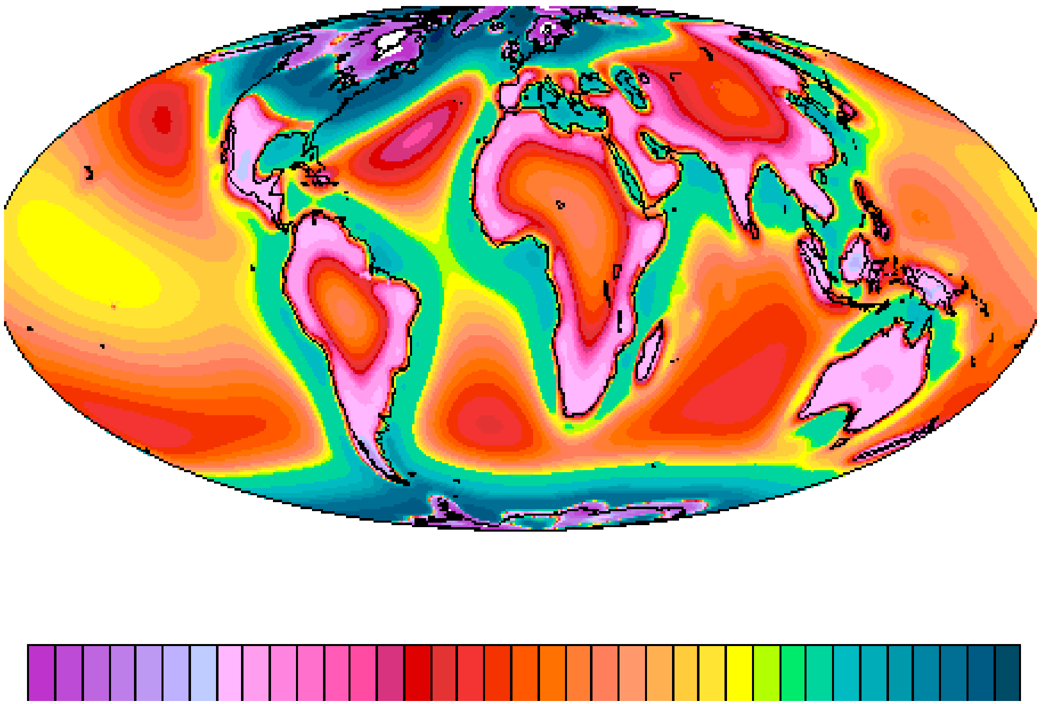
- Slow and monotonic e.g. Glacial Isostatic Adjustment (Post Glacial Rebound)

or

- Fast and irregular e.g. tectonics in Chile, Alaska etc.

Geodynamic models of the solid Earth exist only for GIA and even they are not perfect.

GIA models for VLM corrections



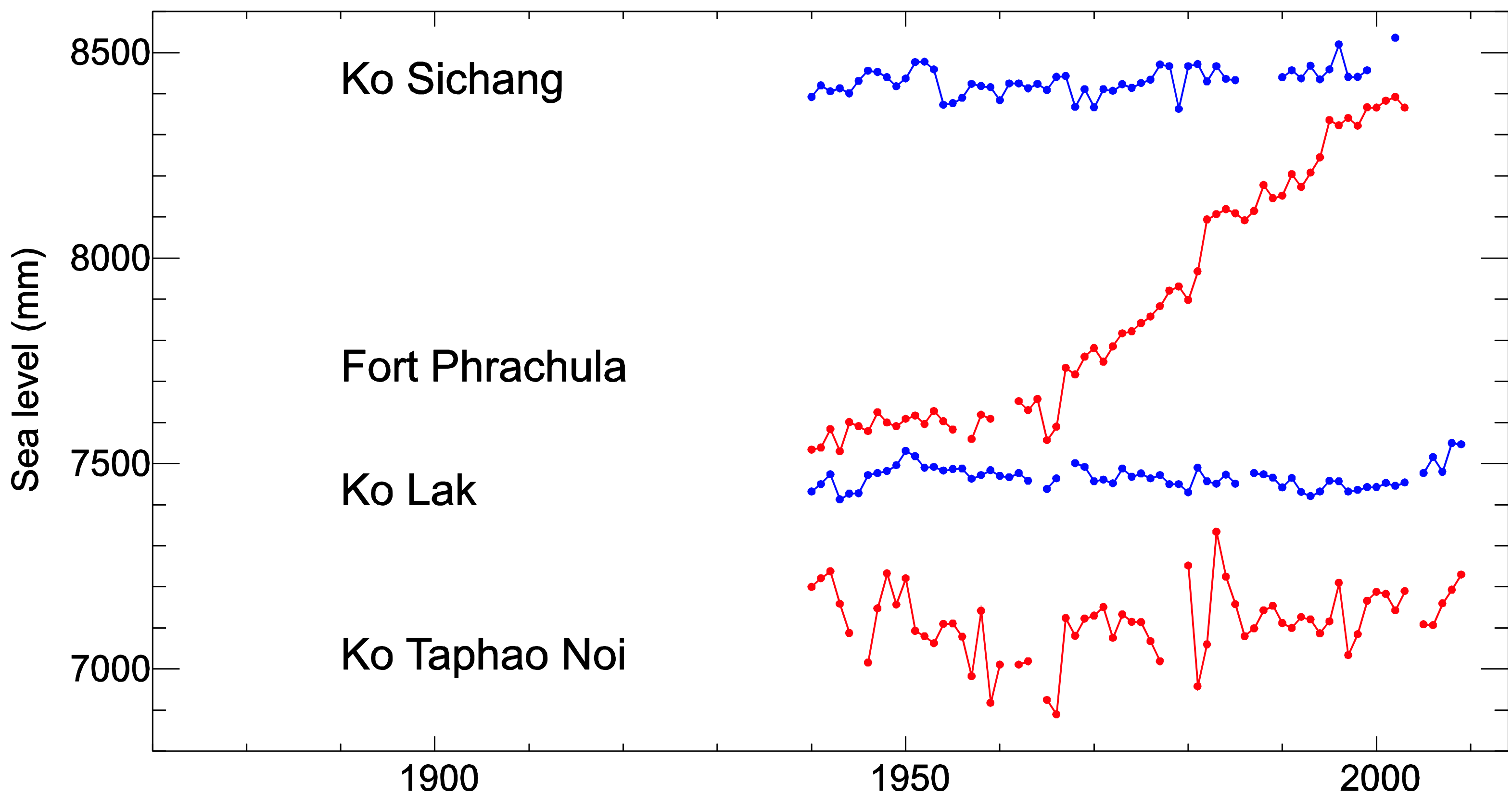
Peltier ICE-4G GIA model

Later models (ICE-5G and ICE-6G) are similar but with different ‘ice histories’. There is nowhere on Earth which does not experience some effect of GIA.

Raised beaches in Hudson Bay

Celsius Rock in northern Sweden

Some land movements can be very local



Ko Taphai Noi (Indian Ocean) 0.6 mm/year. Ko Lak (Pacific) 0.0.
Fort Phachula (Pacific) 14.8. Ko Sichang (Pacific) 0.8 mm/year.

Bangkok Subsidence

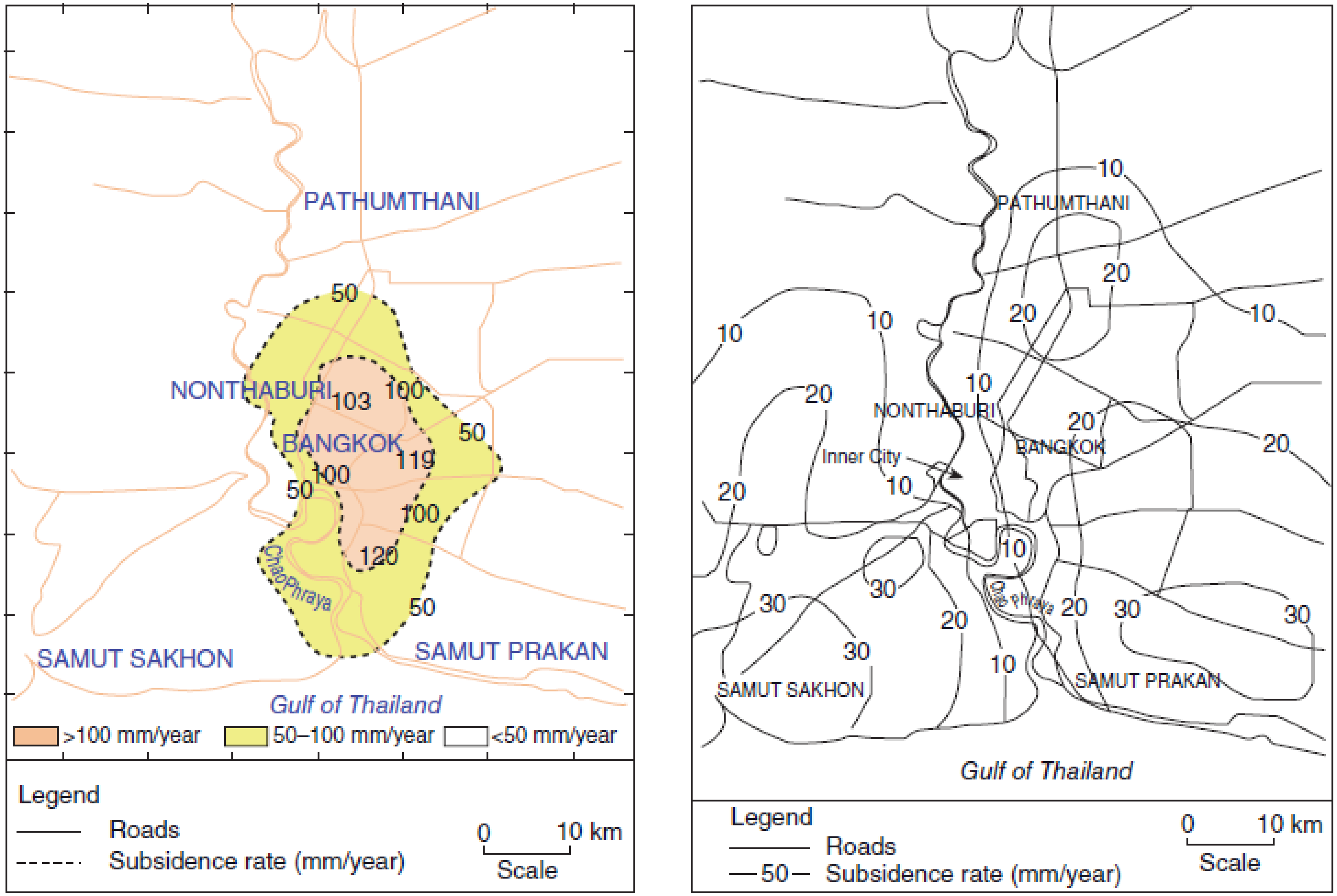
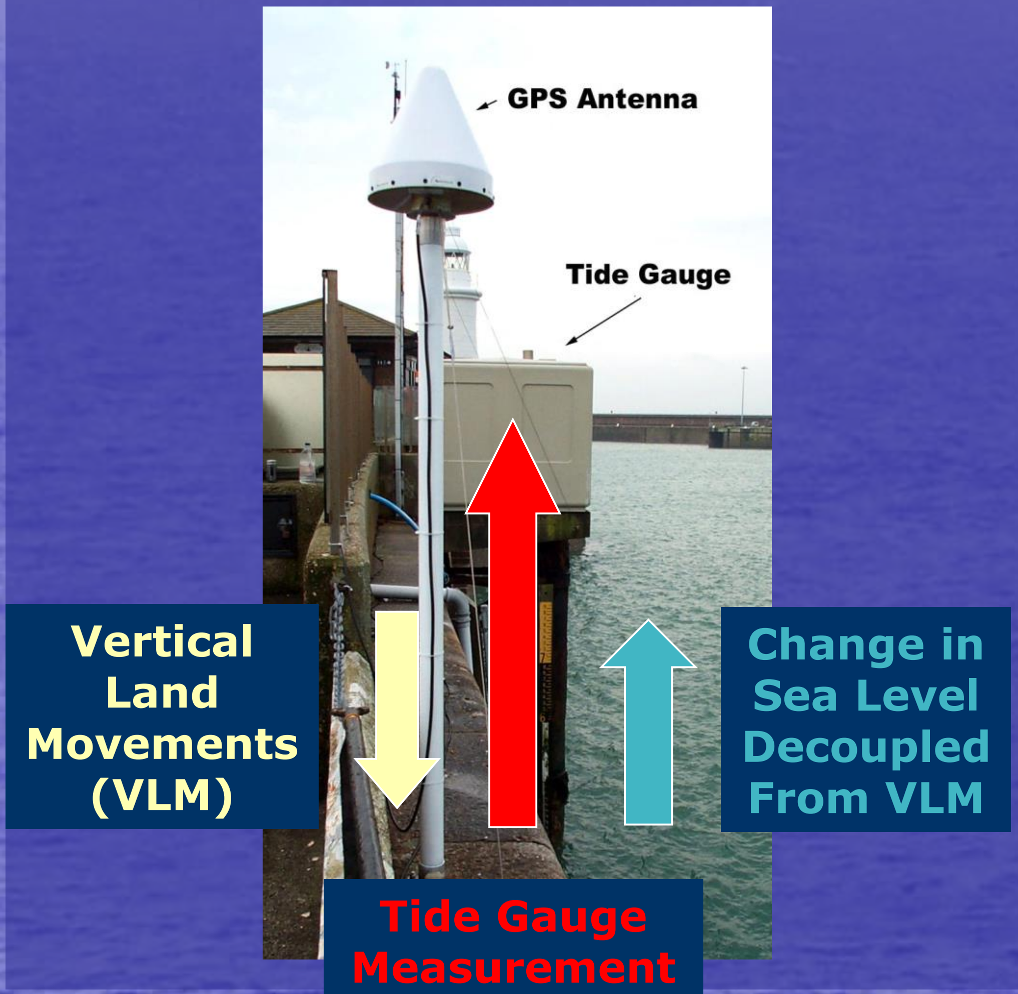


Figure 2.5 Contour lines of the rate of land subsidence for Bangkok, Thailand. Left: 1981; right: 2002. (Reproduced from Phien-Wej et al. 2006, with permission from Elsevier.)

Geocentric Sea Level

- For science we would like to adjust the sea level measured by the gauge for the effects of land movements
- One way to do this is to monitor the vertical movement of the TGBM (or a BM near to it) using GNSS (GPS)
- In practice the GPS may be installed exactly at the tide gauge or some distance from it. In the latter case, the GPS BM must be included in the regular levelling to the TGBM and included in the BM diagram
- (GPS provides many other advantages to the tide gauge station – see IOC Manuals 4 and 5)

Continuous GPS (CGPS) at tide gauges to give geocentric sea level and thereby decouple relative sea and land levels

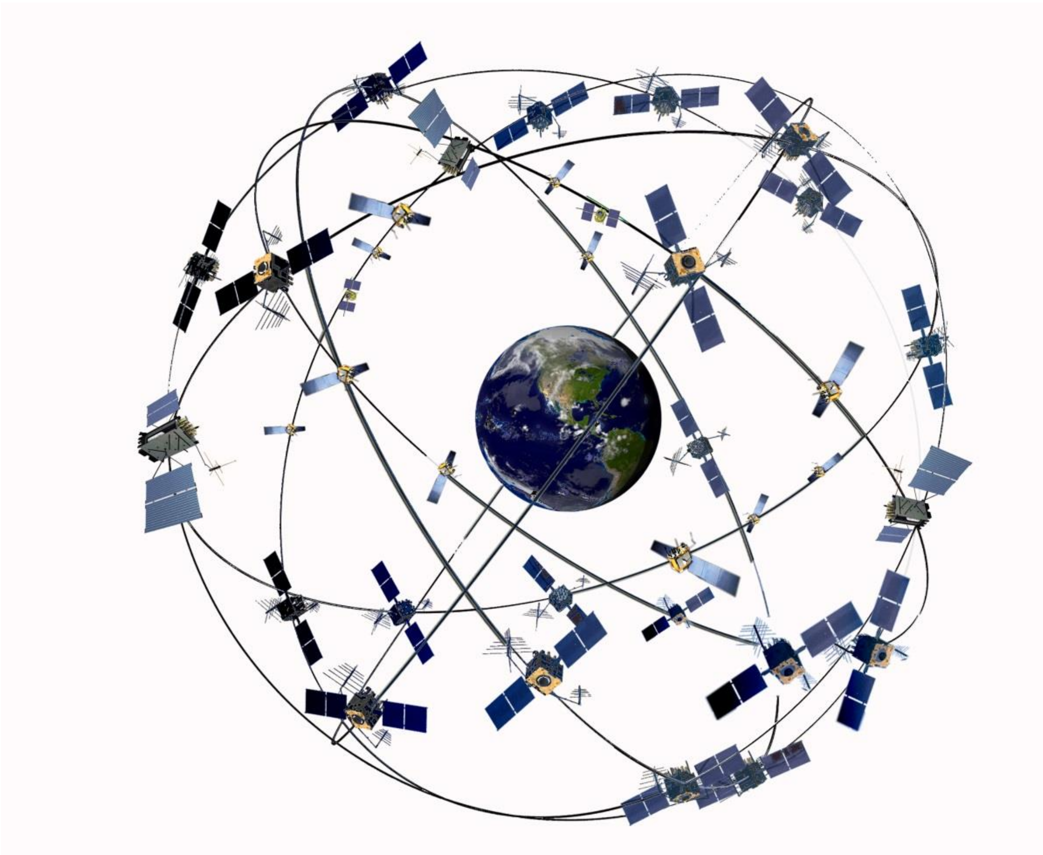


- Tide gauges (TG) measure relative sea level
- Vertical land movements (VLM) are determined from GPS at or close to the tide gauge
- The change in sea level de-coupled from VLM can be inferred

Global Navigation Satellite System (GNSS) Includes

- GPS (US)
- GLONASS (Russia)
- Galileo (Europe)
- China (BeiDou)
- Japan (QZSS)

GPS Constellation



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

GNSS provides coordinates (e.g. of the antenna of a GPS station near a tide gauge) in an Earth-centred (geocentric) coordinate system called the International Terrestrial Reference Frame (ITRF).

i.e. X,Y,Z which is usually then expressed as an ‘ellipsoidal height’ (height above a reference ellipsoid)

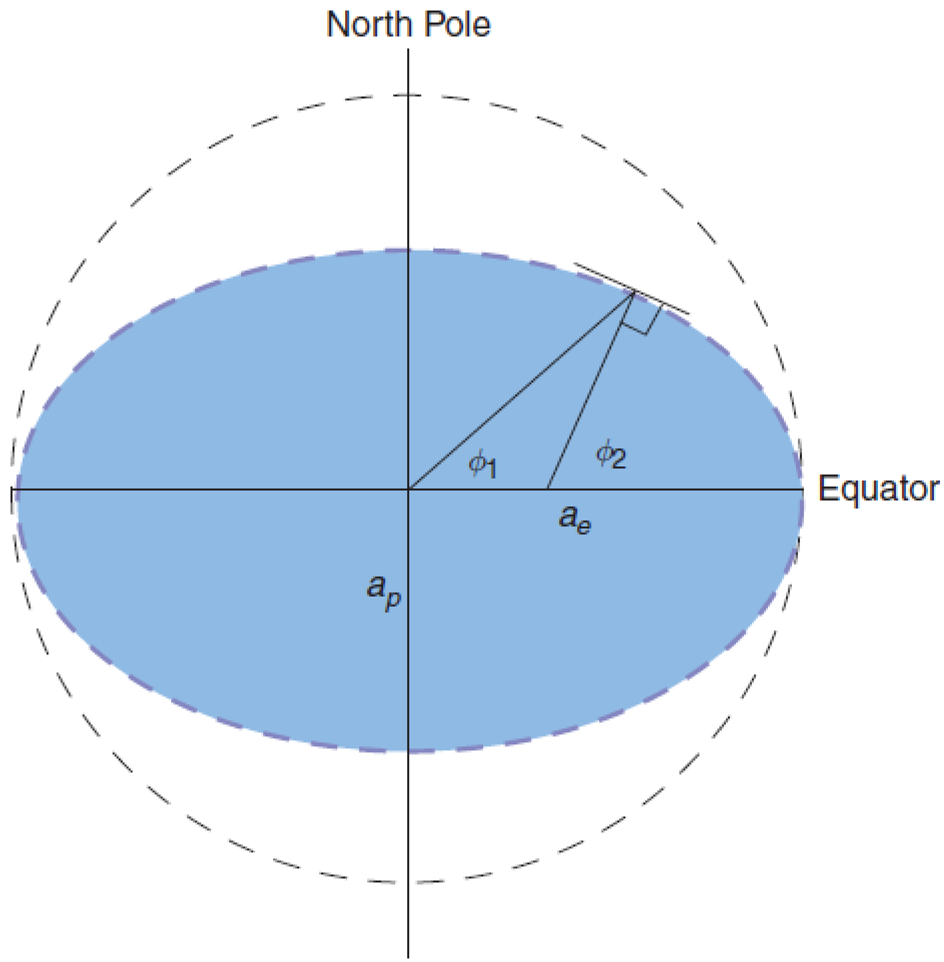


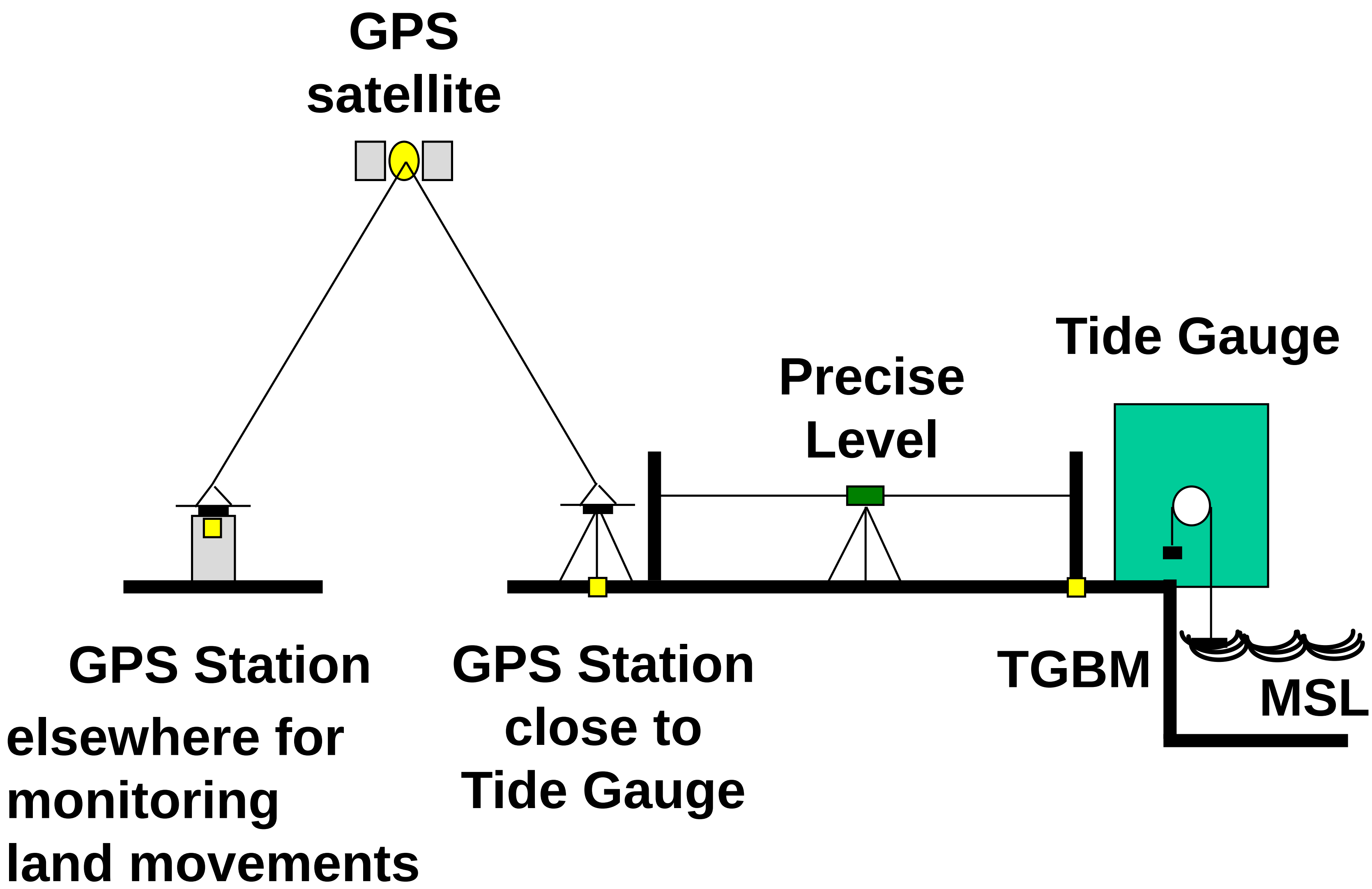
Figure 9.4 Schematic of a standard ellipsoid defined by an equatorial radius a_e and flattening coefficient $f = \frac{(a_e - a_p)}{a_e}$. ϕ_1 and ϕ_2 indicate geocentric and geodetic latitude.

GPS at a Tide Gauge

- GPS at a tide gauge consists of a receiver (computer) connected by a cable to the GPS antenna, which is a measured height above the GPS BM.
- The receiver can be connected by phone or internet
- GLOSS requires Continuous (Permanent) GPS installations (CGPS)
- GPS data from tide gauges are collected and analysed by SONEL www.sonel.org.

Tide gauge and GPS in Indonesia

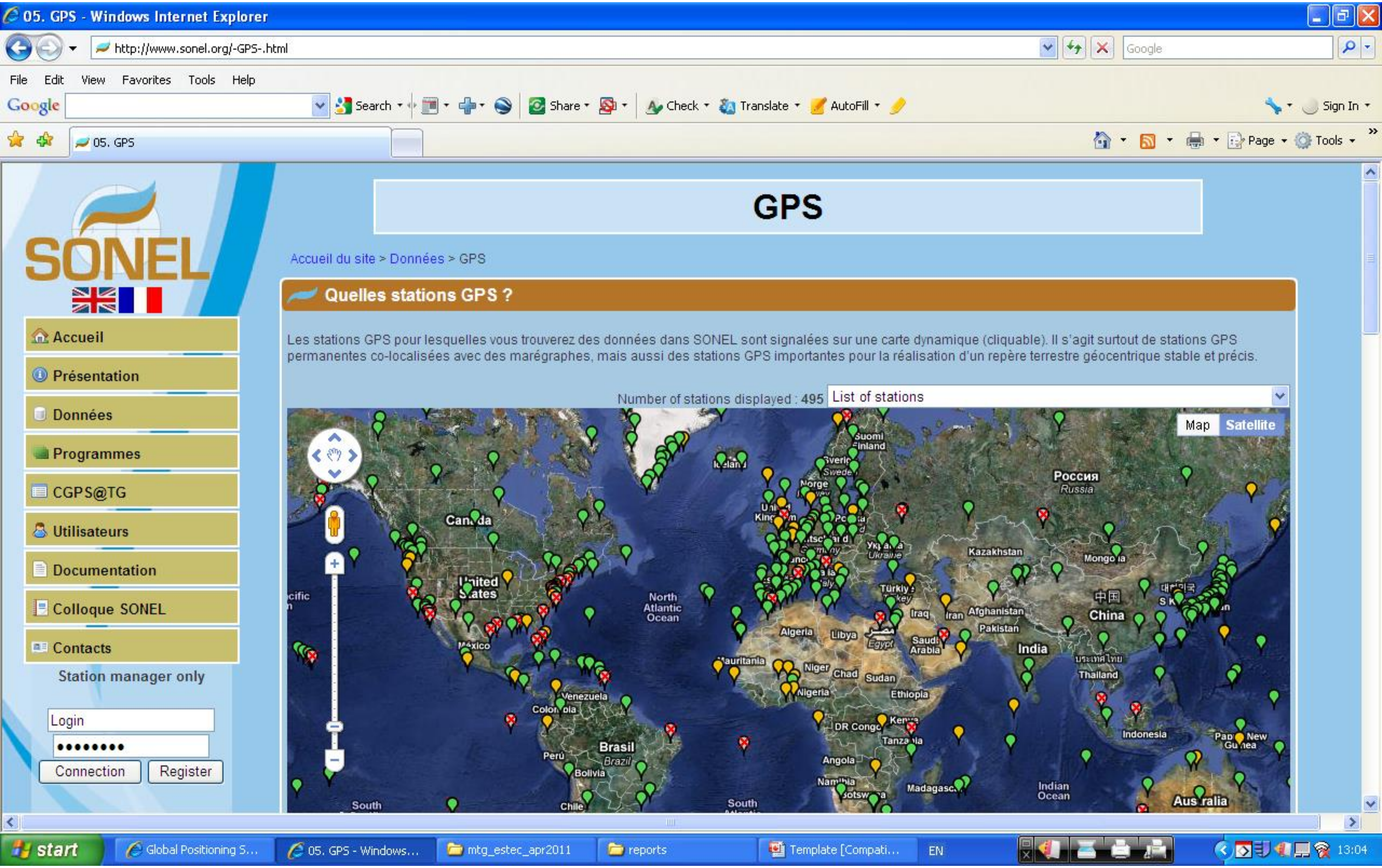
GPS at a Tide Gauge



Trimble Net R9
GNSS receiver

Suitable receivers are available from several manufacturers

This is connected by modem to a telephone, or to a satellite system such as BGAN so the GPS data gets to a data centre.



www.sonel.org

Tide gauge and GPS in Tasmania

Tide gauge and GPS in USA

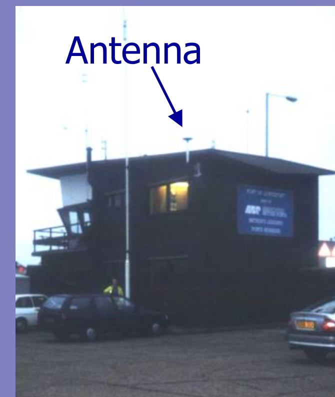
Tide gauge and GPS in Norway

GPS at UK tide gauges

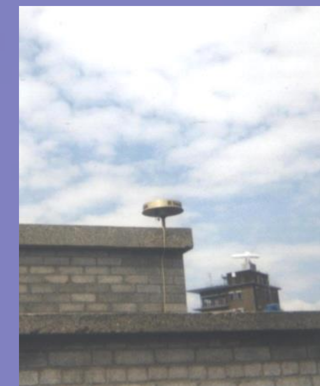
Lerwick

Aberdeen

North Shields



Lowestoft



Sheerness

Dover

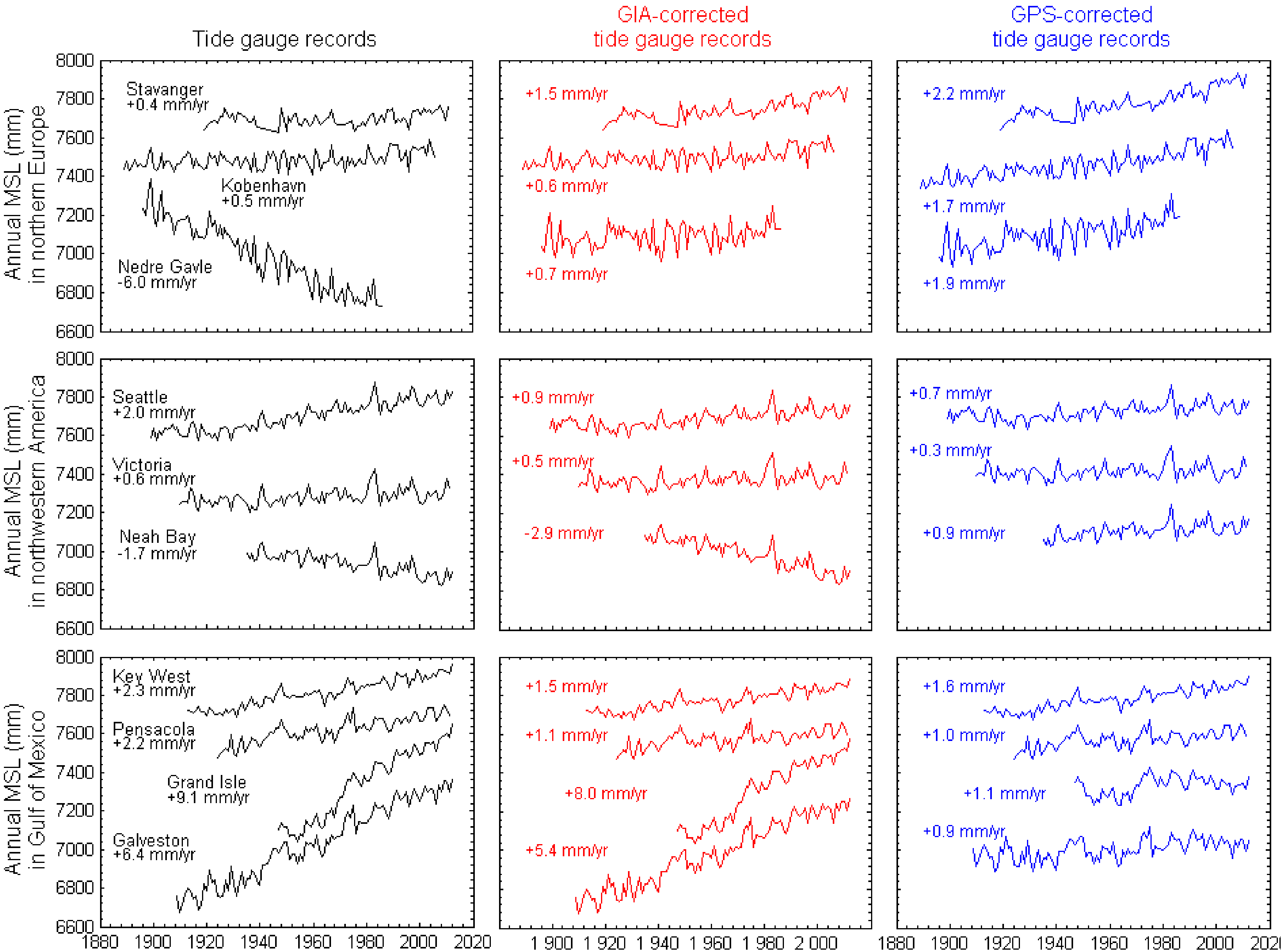
Portsmouth

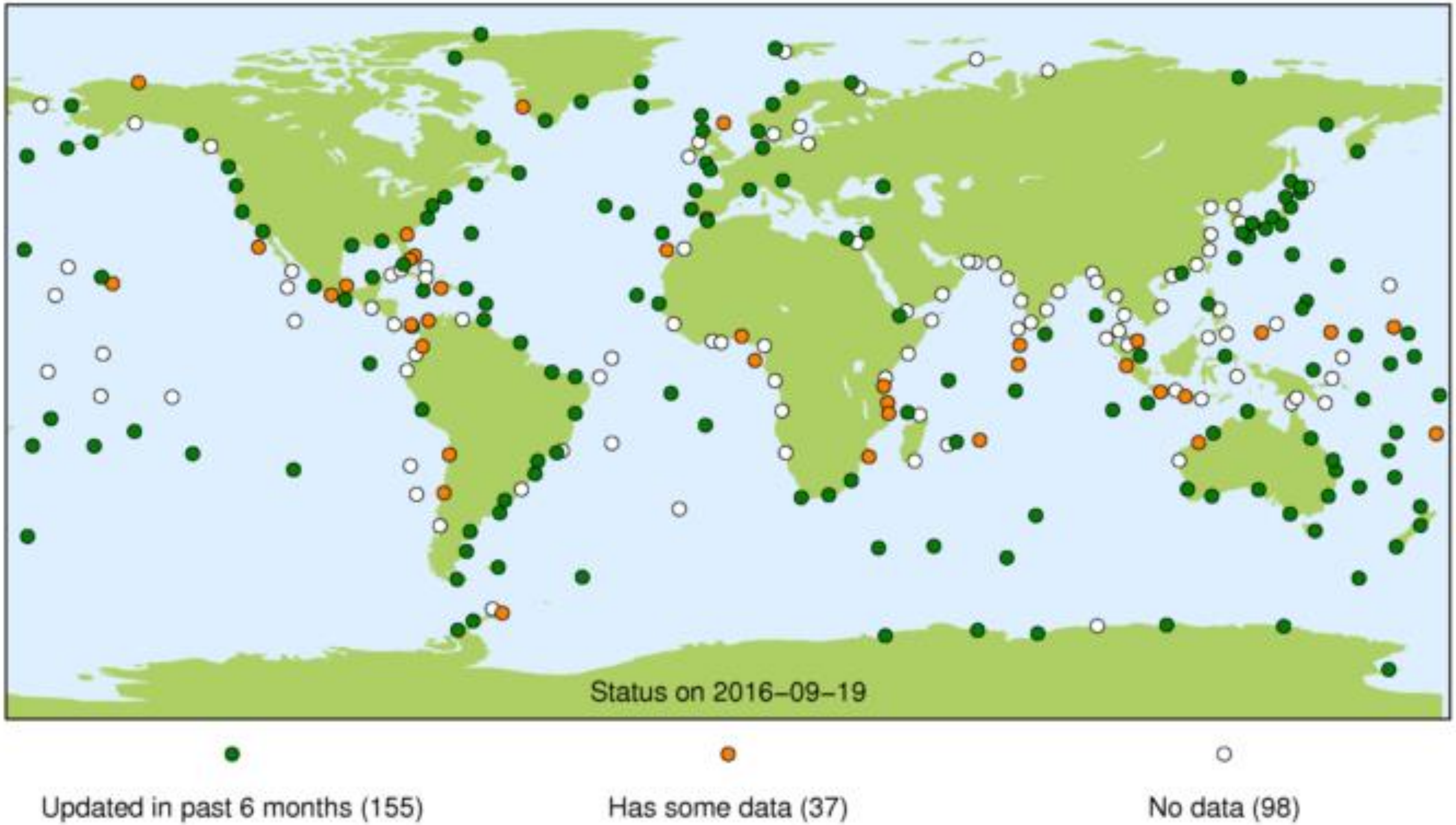
Newlyn

Liverpool

Stornoway

Removal of land movements from records





Stations in GLOSS with GPS near to the gauges

TIde GAuge (TIGA) project

- The use of GNSS (GPS) at tide gauges is studied within GLOSS by means of the TIGA (TIde GAuge) project, see http://adsc.gfz-potsdam.de/tiga/

- TIGA makes use of the data at the SONEL data bank www.sonel.org

- See presentation by Tilo Schöne in 4th Caribbean sea level course 2014.


CGPS@TG Home Page - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://www.soest.hawaii.edu/cgps_tg/
CGPS@TG
Getting Started
Latest Headlines
CGPS@TG
WEBSITE
A TECHNICAL FORUM ON CONTINUOUS
GPS POSITIONING OF TIDE GAUGES
INTRODUCTION
BACKGROUND
CASE STUDIES
MEETING ARCHIVES
brought to you by the
CGPS@TG Working Group
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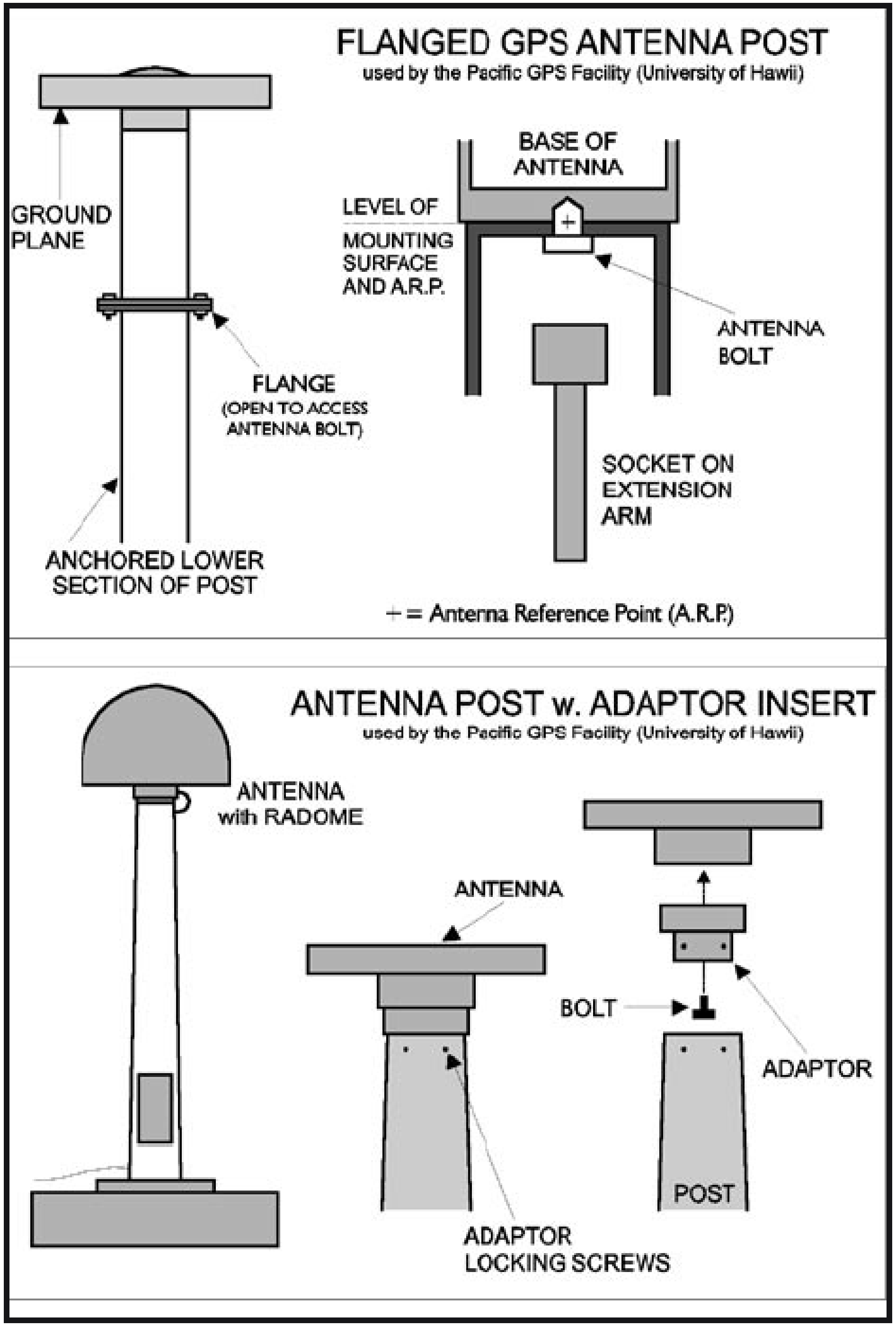


Advice on how to mount a GPS antenna is available from GLOSS

Tide Gauge vs. GNSS data rates

- A tide gauge transmits typically 1-minute values of sea level over systems such as GOES. i.e. few 100K /day.
- GPS monitoring every 20 seconds = 1-2 MB/day so requires a phone line or BGAN, IRIDIUM etc.
- GPS for seismics is an order of magnitude higher rate, hence BGAN, IRIDIUM or VSAT.

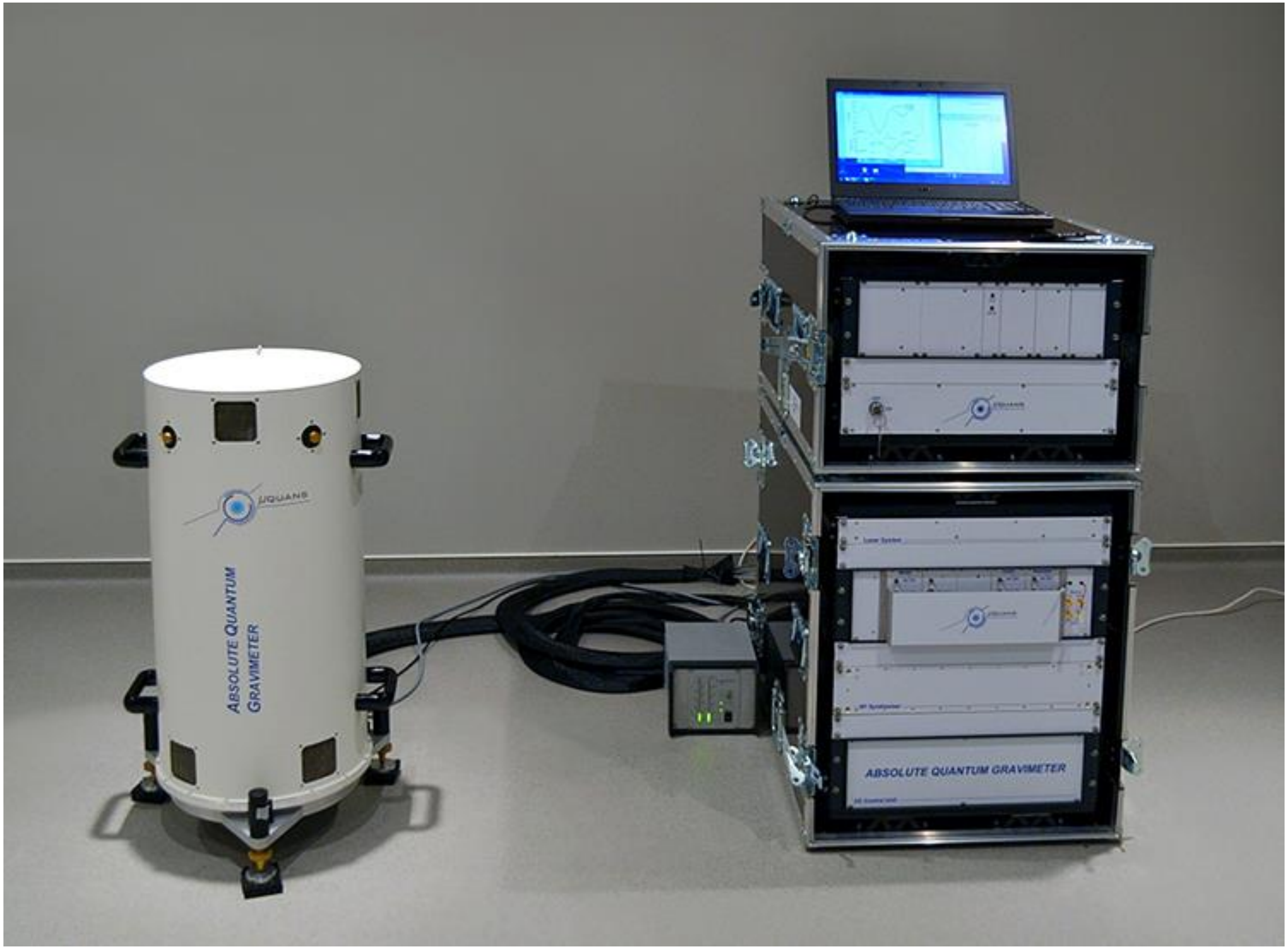
Two Main Geodetic Tools for Measuring Land Level Changes

GPS

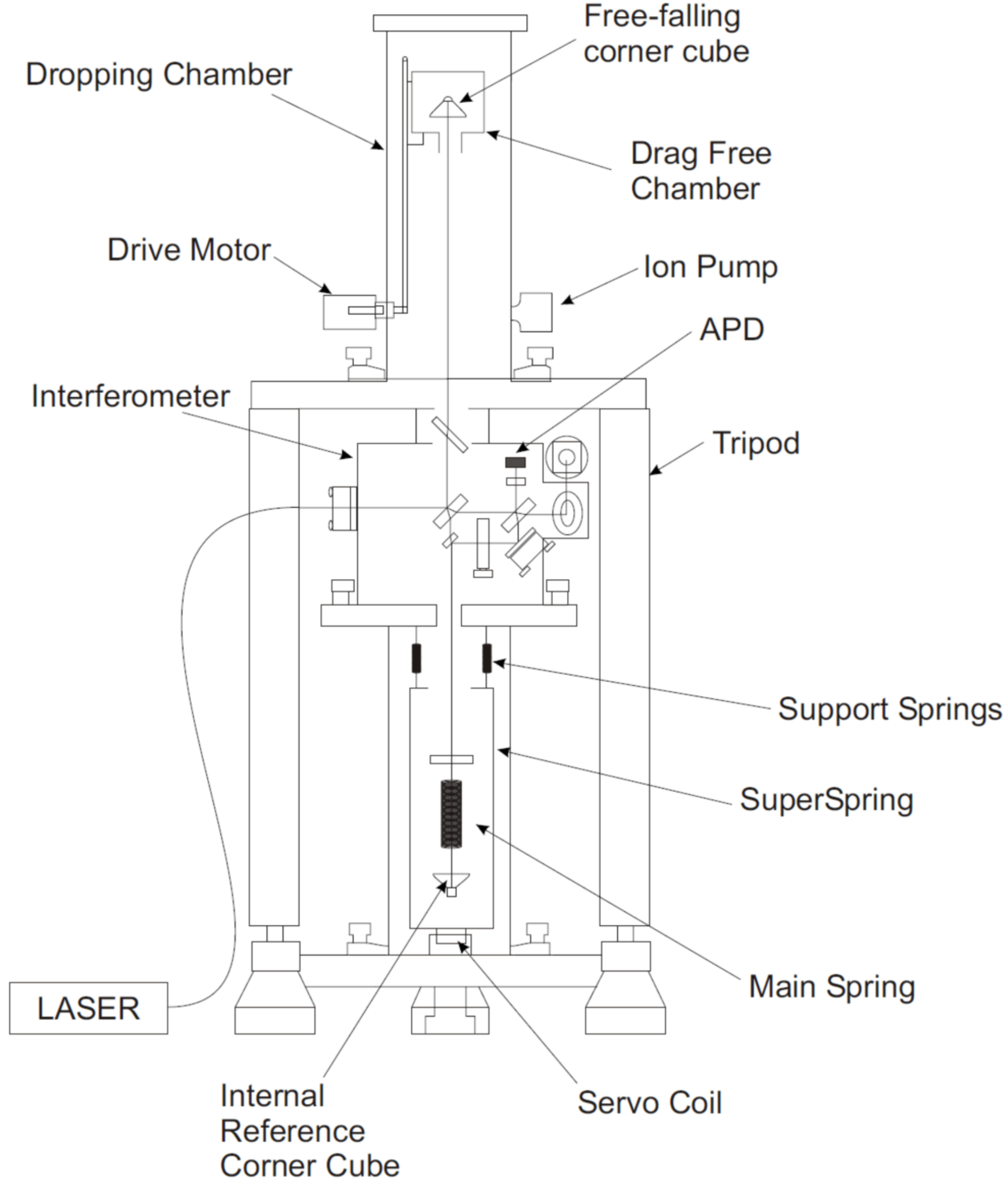
Absolute Gravity
Near to (but not at) a Tide Gauge

Land movements can also be measured using Absolute Gravity

Micro-g FG5 Absolute Gravity Meter



Muquans Absolute Quantum Gravity Meter

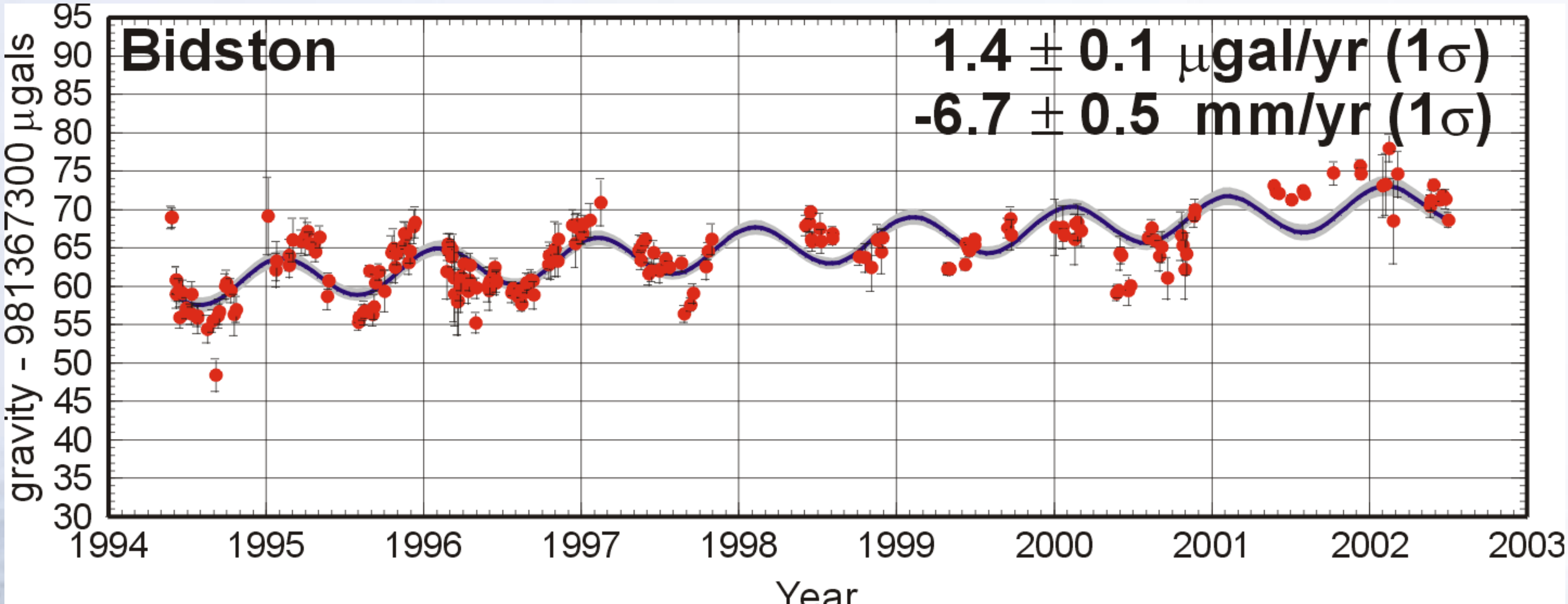


Free-falling
corner cube
Dropping Chamber
Drag Free
Chamber
Drive Motor
Ion Pump
APD
Interferometer
Tripod
Support Springs
SuperSpring
Main Spring
LASER
Internal
Reference
Corner Cube
Servo Coil

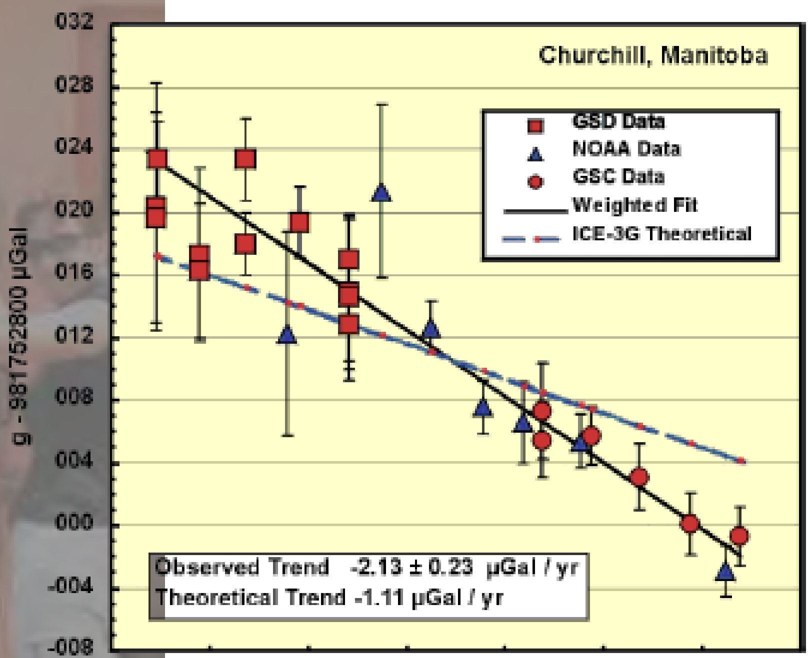
Absolute Gravity

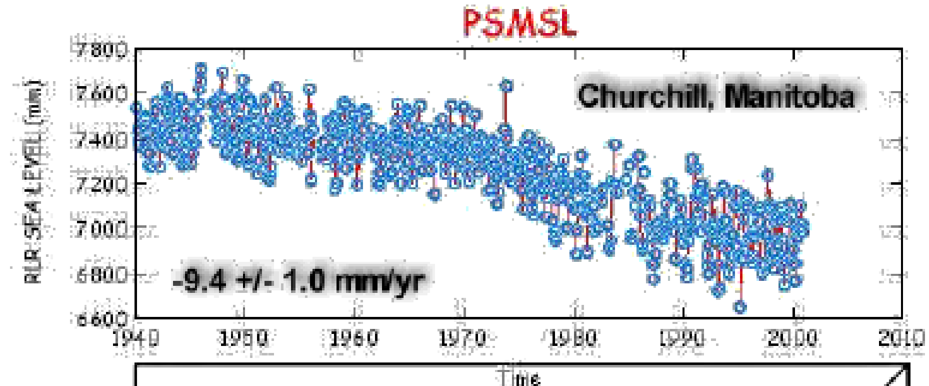
- Absolute Gravity is complementary to GPS but does not replace it
- Ground water affects the AG record
- But is otherwise a highly precise technique and can be used to constrain GPS network data
- The machines are expensive (and so, so far, have been research equipment but have a precision and accuracy of about 1-2 μgal (1 μgal $=10^{-8}$ ms^{-2}, or 10^{-9} of gravity), or approx. 5 mm.

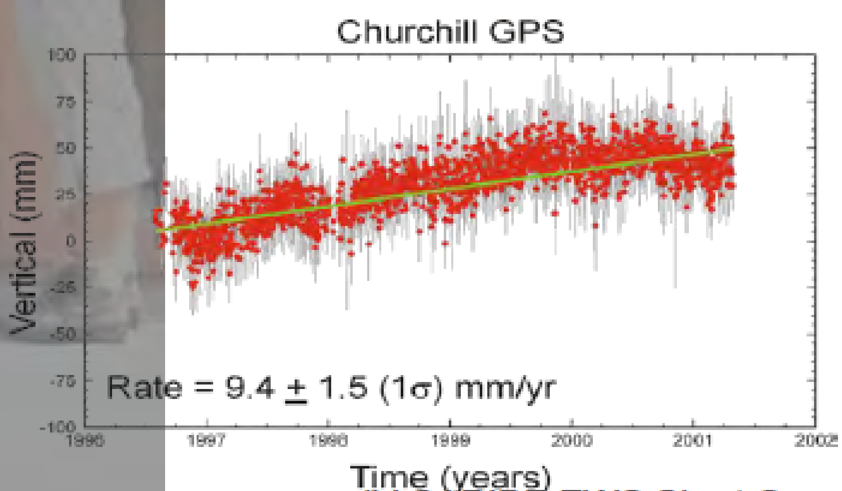
Bidston Observatory Absolute Gravity time series

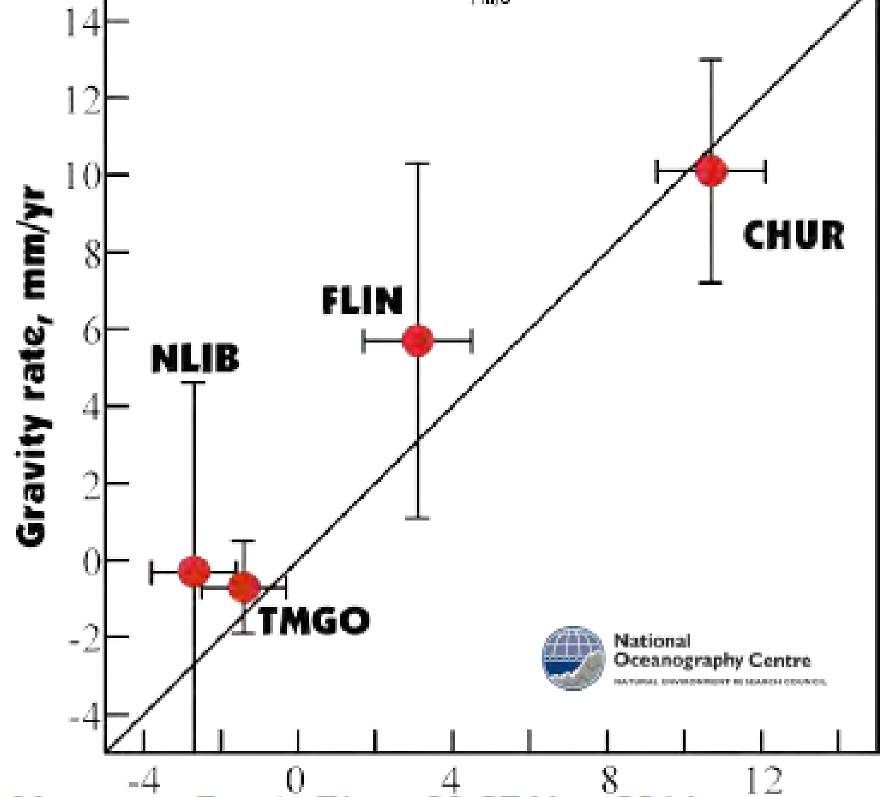


GPS versus Absolute Gravity and Vertical Land Movement









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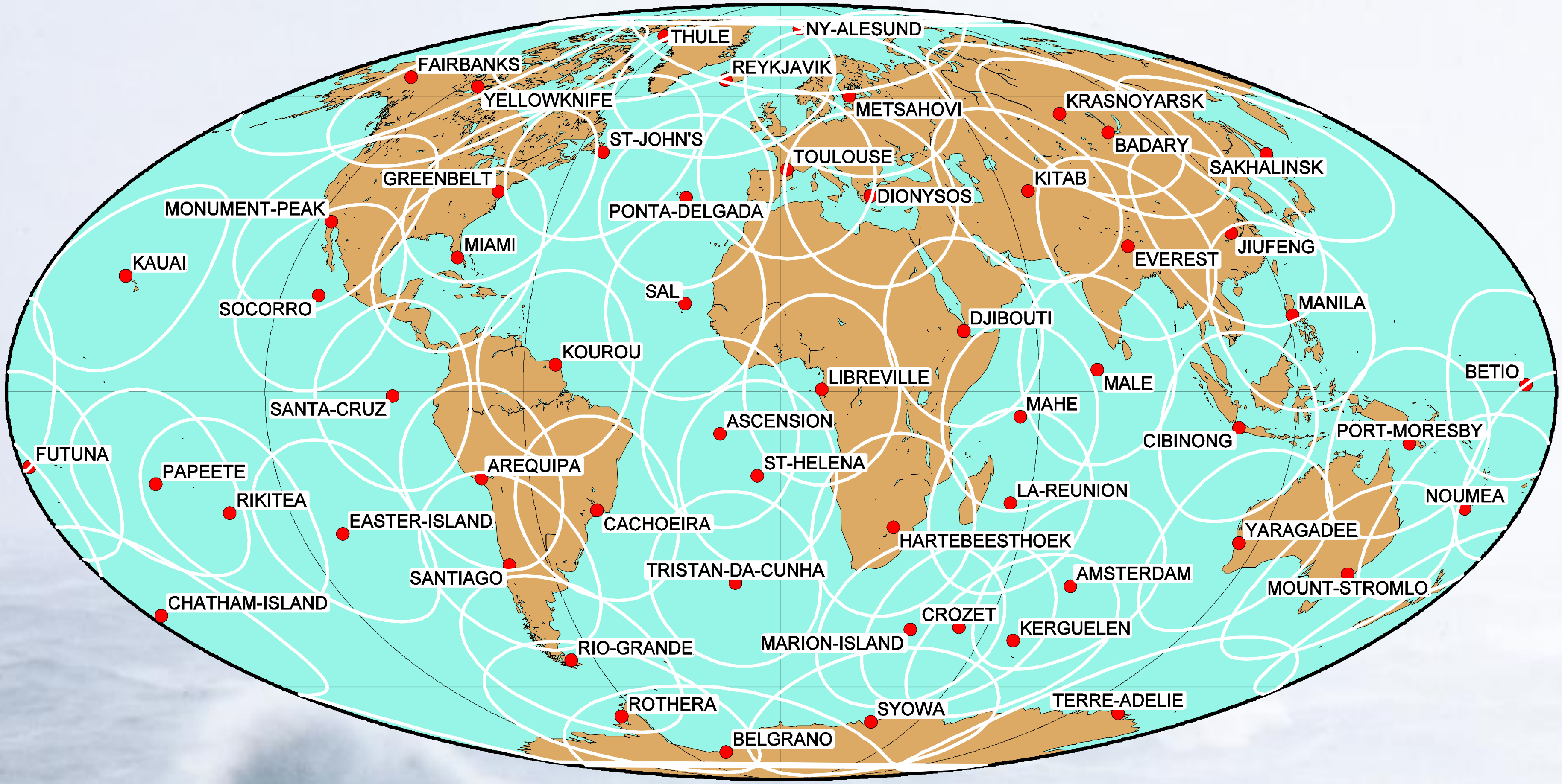

THULE
NY-ALESUND
FAIRBANKS
REYKJAVIK
YELLOWKNIFE
METSAHOVI
KRASNOYARSK
ST-JOHN'S
BADARY
TOULOUSE
SAKHALINSK
GREENBELT
KITAB
DIONYSOS
MONUMENT-PEAK
PONTA-DELGADA
MIAMI
JIUFENG
EVEREST
KAUAI
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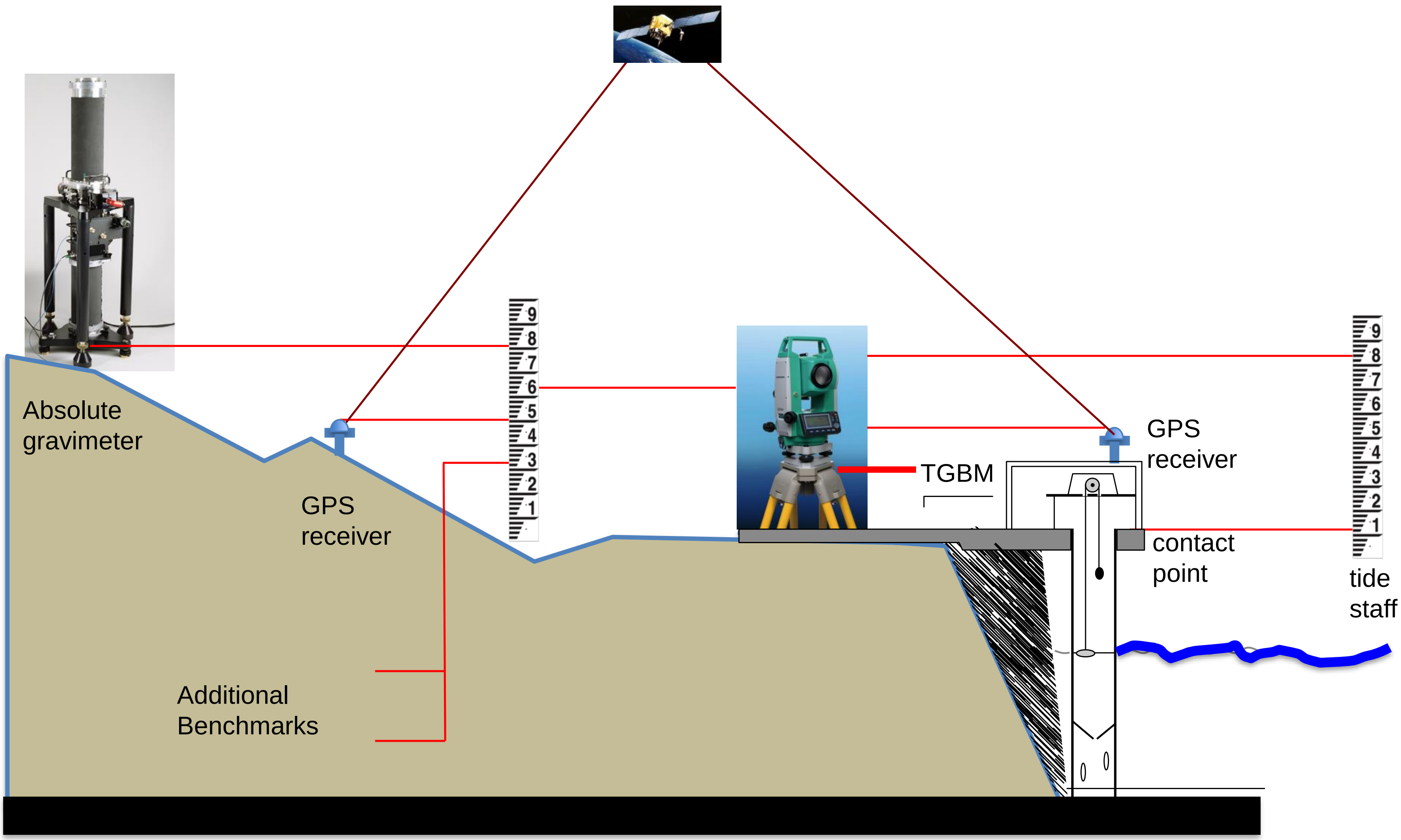
SOCORRO
MANILA
DJIBOUTI
KOUROU
LIBREVILLE
MALE
BETIO
SANTA-CRUZ
MAHE
ASCENSION
PORT-MORESBY
CIBINONG
FUTUNA
PAPEETE
AREQUIPA
ST-HELENA
RIKITEA
LA-REUNION
NOUMEA
EASTER-ISLAND
CACHOEIRA
YARAGADEE
HARTEBEESTHOEK
SANTIAGO
TRISTAN-DA-CUNHA
AMSTERDAM
MOUNT-STROMLO
CHATHAM-ISLAND
CROZET
KERGUELEN
MARION-ISLAND
RIO-GRANDE
ROTHERA
SYOWA
TERRE-ADELIE
BELGRANO

Summary of Geodetic Measurements at/near a Tide Gauge

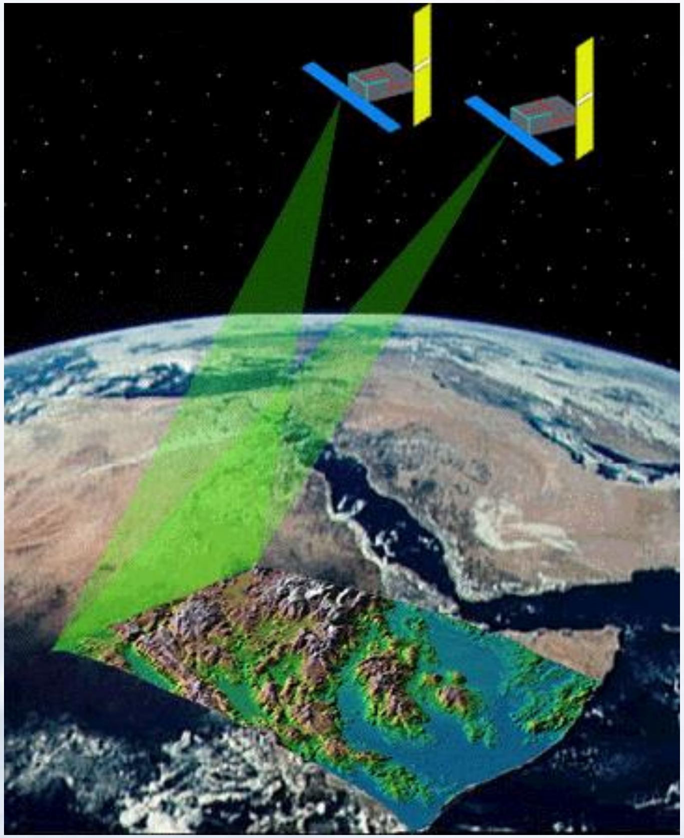


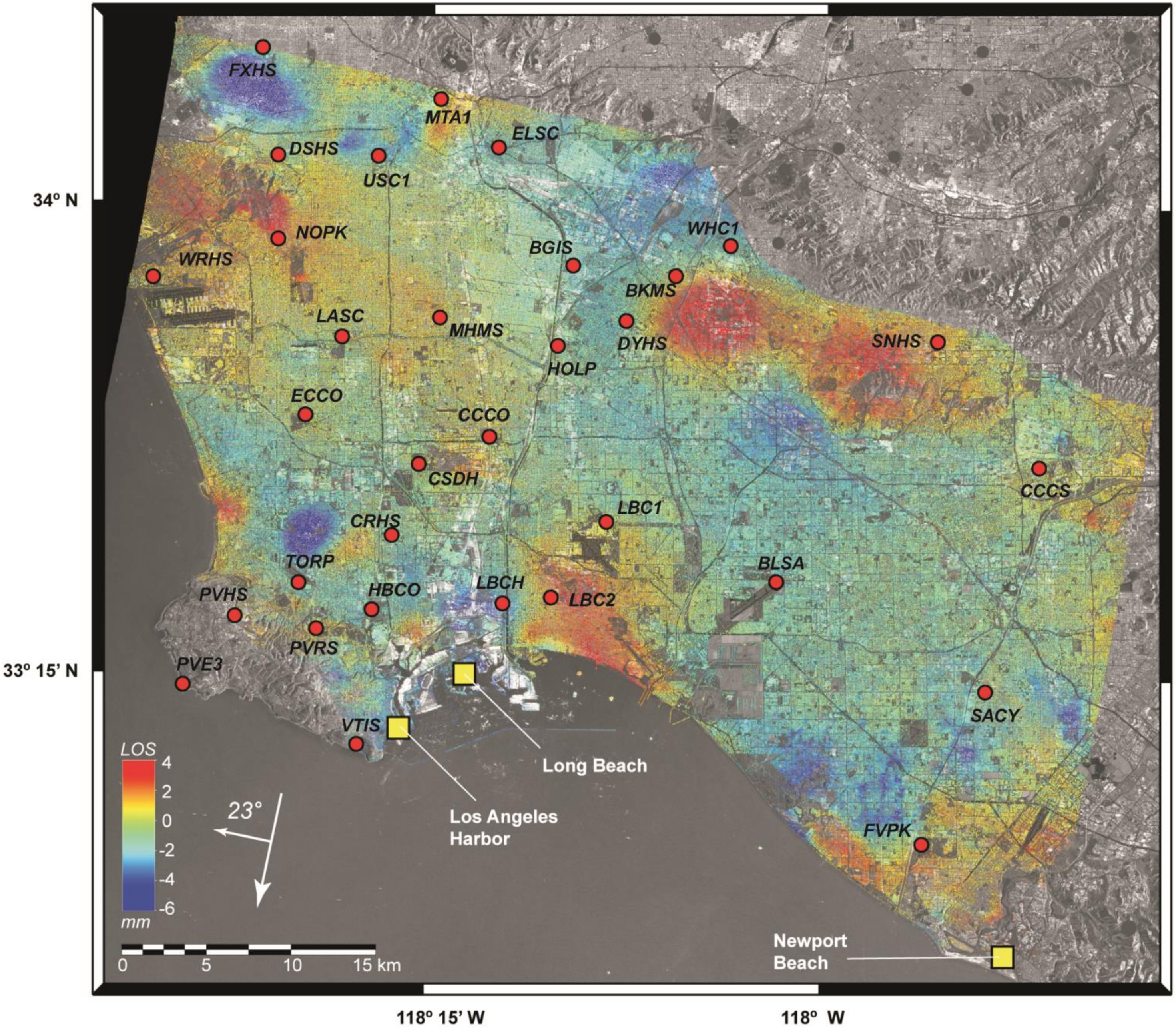
Remote Sensing Measurement of Vertical Land Movement: Interferometric Synthetic Aperture Radar (INSAR)

Interferometry : radar phase information of the same scene from two locations.

Difference in phase is due to changes in length between targets on ground and the two antennas.

This includes topography, land movement (in the direction of the satellite) and atmospheric delay





Los Angeles relative vertical land movements by InSAR

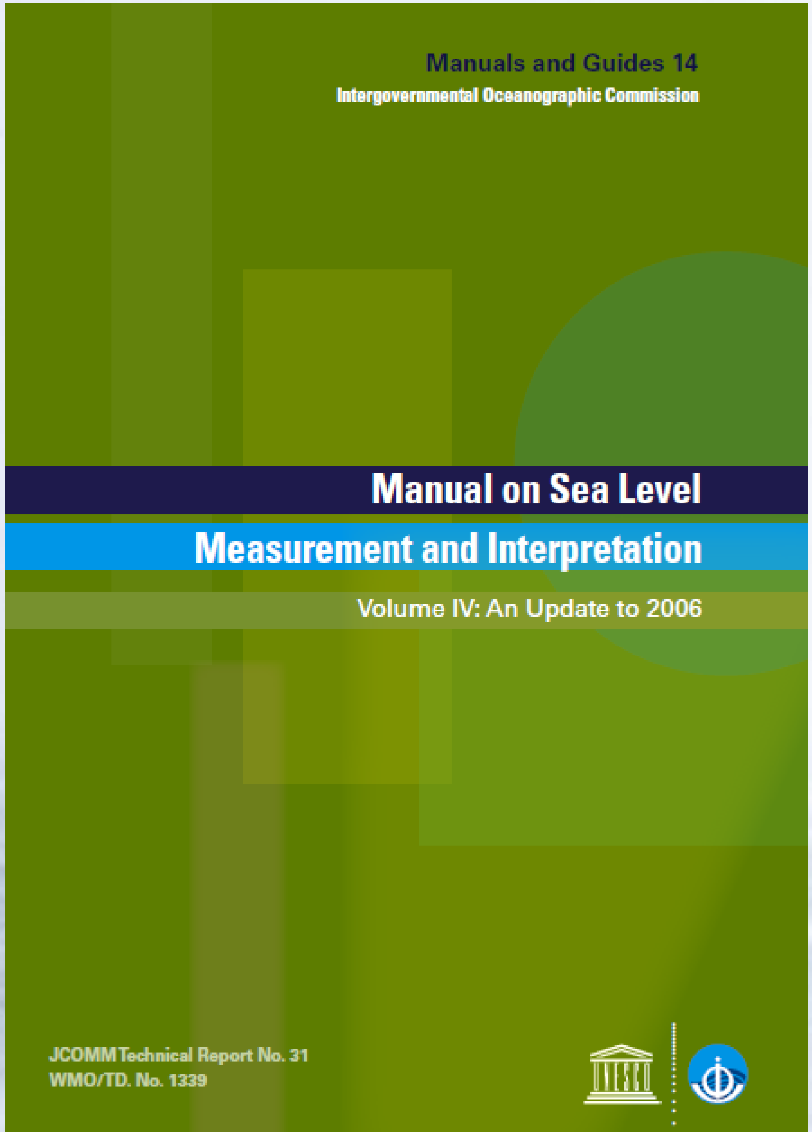
InSAR

- InSAR data comes from the European ERS, Envisat and Sentinel satellites, and also (at different frequency) Radarsat, TerraSAR-X and ALOS PALSAR.
- InSAR measurements of relative vertical land movements can be converted to absolute rates using transponders and GPS, sometimes at tide gauges where sea level can be measured also.

To Summarise

- The choice of 5 BM's at each site is essential, and regular levelling must take place to check the stability of the TGBM which is the level to which the tide gauge data are reference.
- This levelling must take place, whether the station also has GPS or not.
- But if it does have GPS, then the regular levelling must include the GPS BM
- With GPS one then has a measure of vertical land movement, and the data become useful for other geodetic studies (e.g. WHSU) and for providing seismic-type information for earthquakes.

In conclusion – please read



IOC Manual 4 – Chapter 4

GLOSS Imp Plan – Chapter 6

Manuals and Guides 14

Intergovernmental Oceanographic Commission

Manual on Sea Level

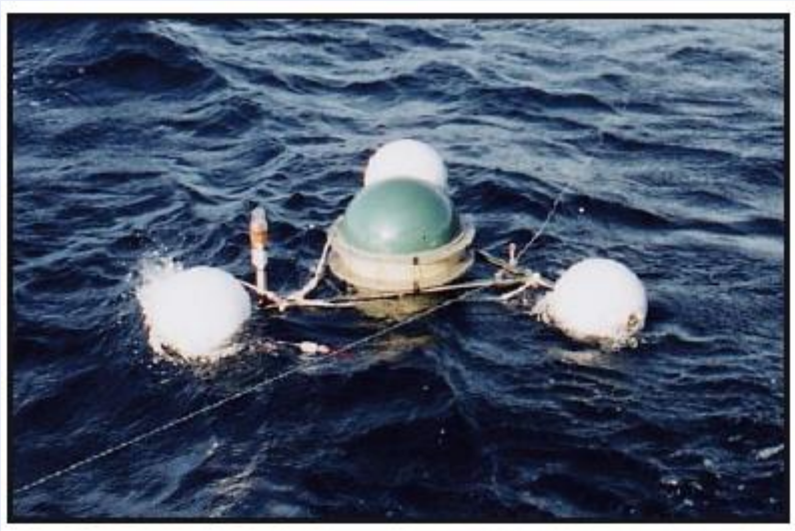
Measurement and Interpretation

Volume V Radar Gauges

GPS Technology

- GPS on buoys
- GPS reflection gauges

- N.B. These need technical expertise and are not (as yet) capable of providing science-quality long-term sea level records.



Univ. Tasmania

GFZ, Potsdam

Japan GPS buoy used for tsunamis

GPS Reflectometry

- Concept of using reflected GPS signals for environmental sensing was introduced by Martin-Neira in 1993

Signal to Noise Ratio Method

Consider the direct GPS signal to the receiver and also the reflected signal from the sea – which we usually call multipath and filter out. They interfere and create an alternating SNR (signal to noise) signal which depends on the height of the antenna above the sea.

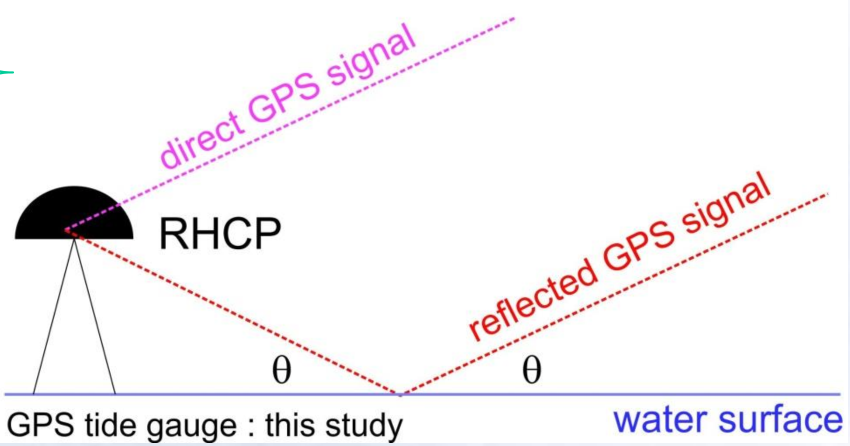
$$\delta SNR = A \cos\left\{ \frac{4\pi h}{\lambda} \sin(\theta) + \varphi) \right\}$$

A is amplitude

λ is GPS carrier wavelength

θ is satellite elevation angle

ϕ is phase offset

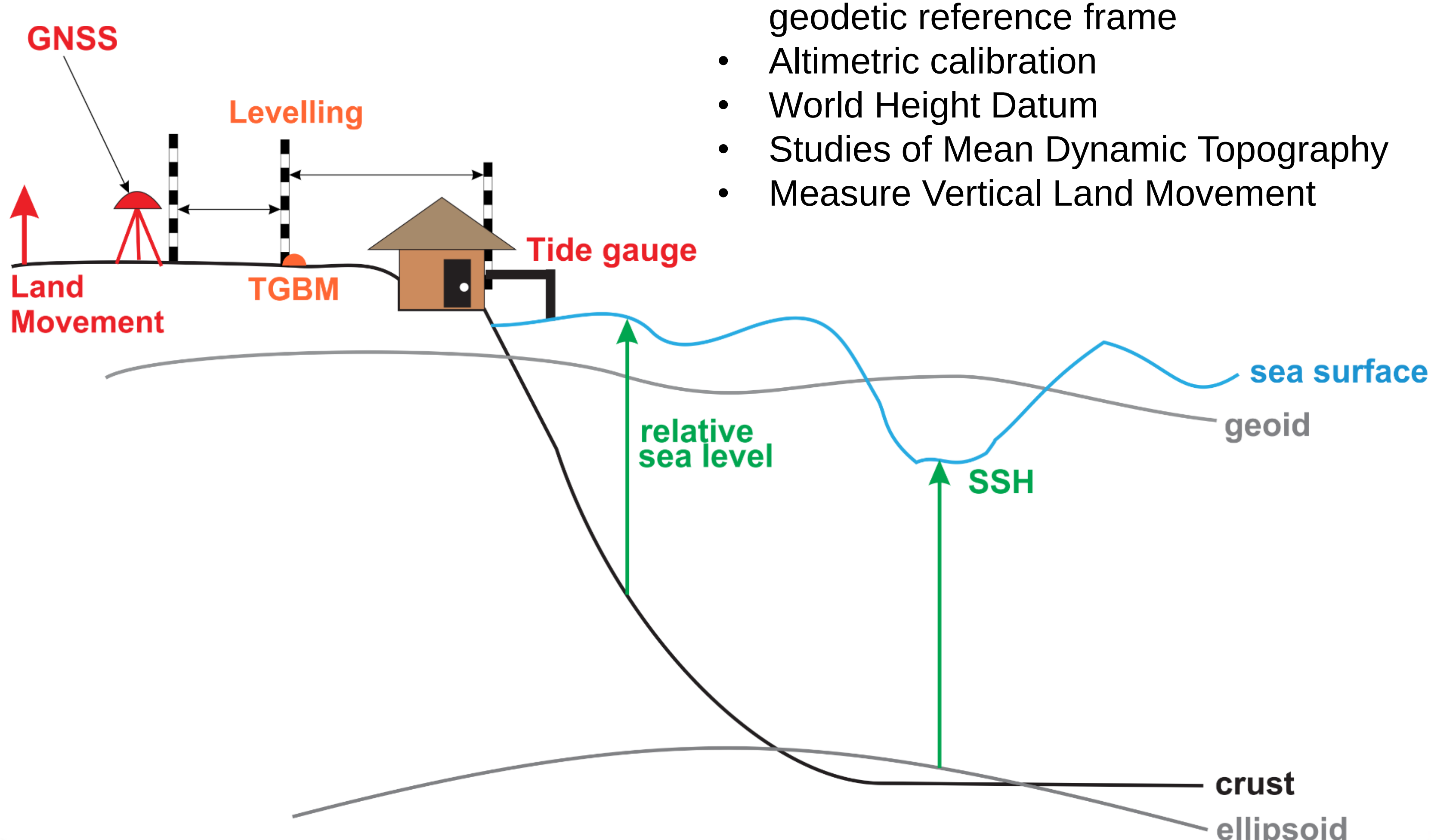


Newlyn tide gauge station, note the GPS antenna on the lighthouse used for GPS reflectometry test

GNSS Multipath Reflectometry

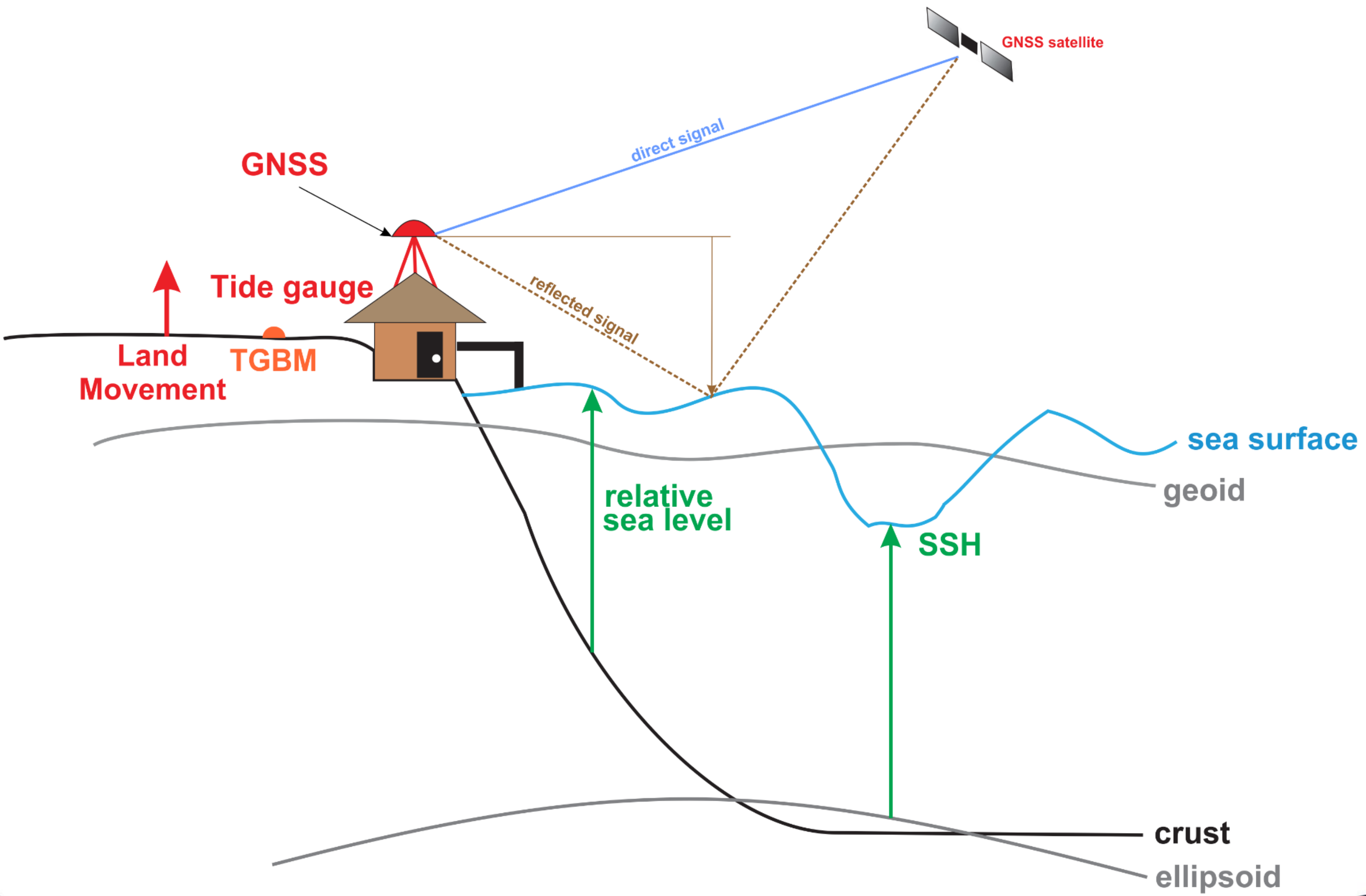
Interference between direct and reflected signals causes changes in the signal to noise ratio in the form of periodic signals

Traditional Implementation of a GLOSS CORE Network Site



GNSS required to….

- Establish the measurements in a global geodetic reference frame
- Altimetric calibration
- World Height Datum
- Studies of Mean Dynamic Topography
- Measure Vertical Land Movement


GNSS satellite
direct signal
GNSS
reflected signal
Tide gauge
Land
Movement
TGBM
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SSH
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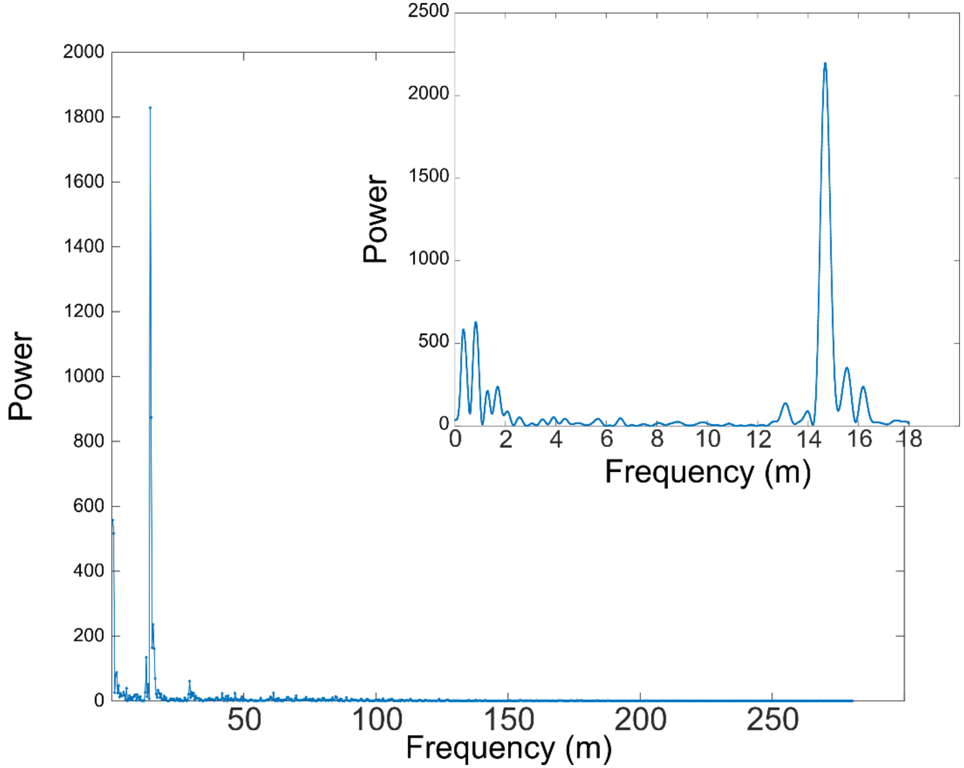
ellipsoid


Power
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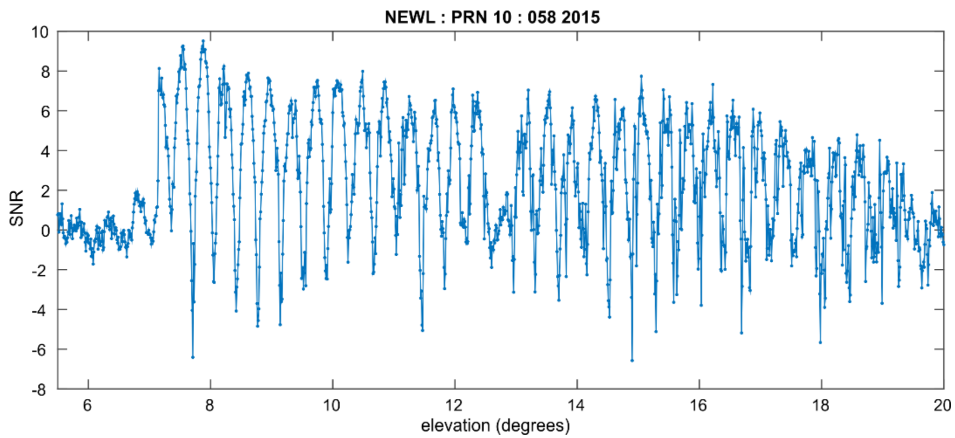
NEWL : PRN 10 : 058 2015
SNR
elevation (degrees)
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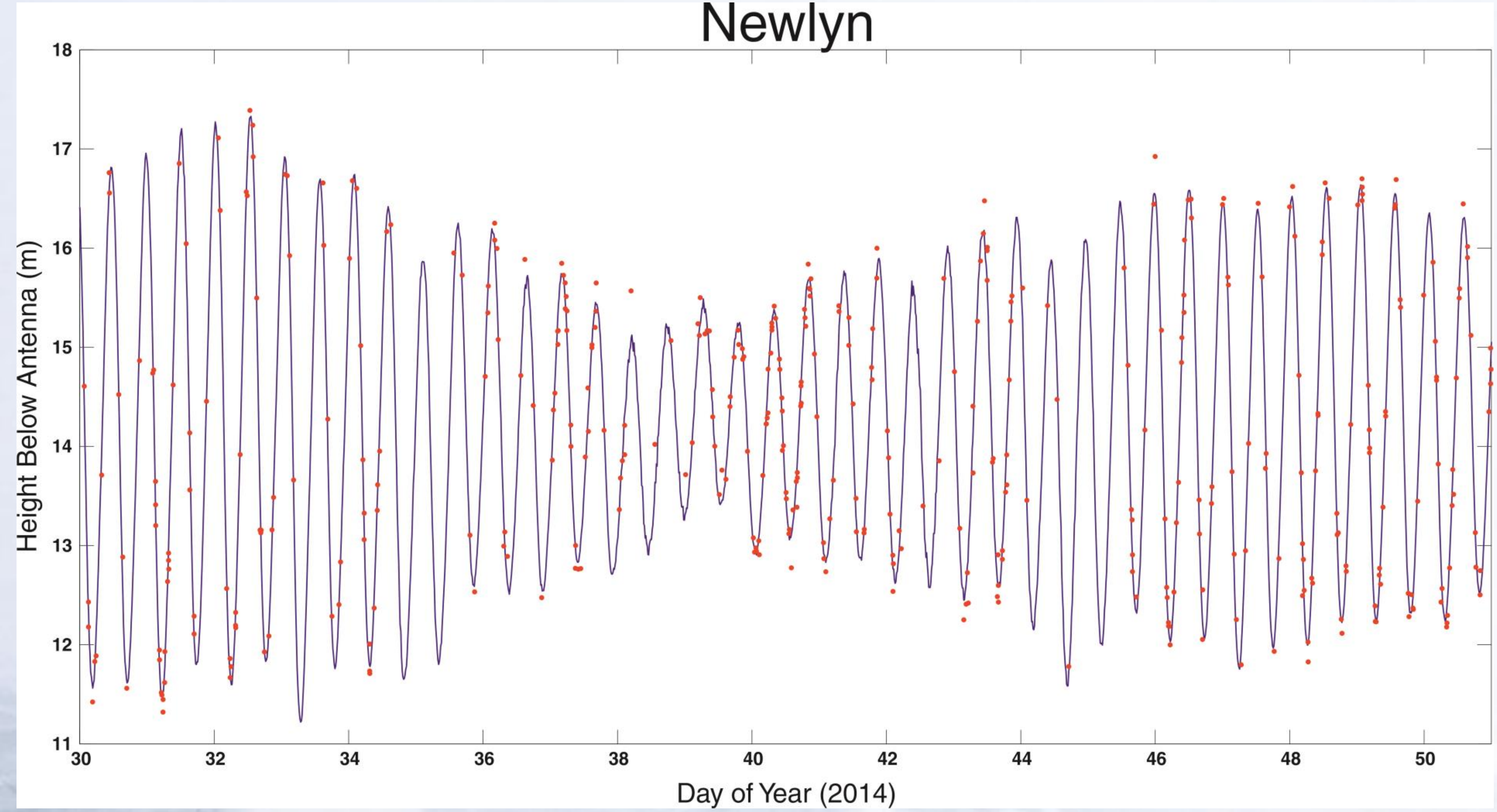
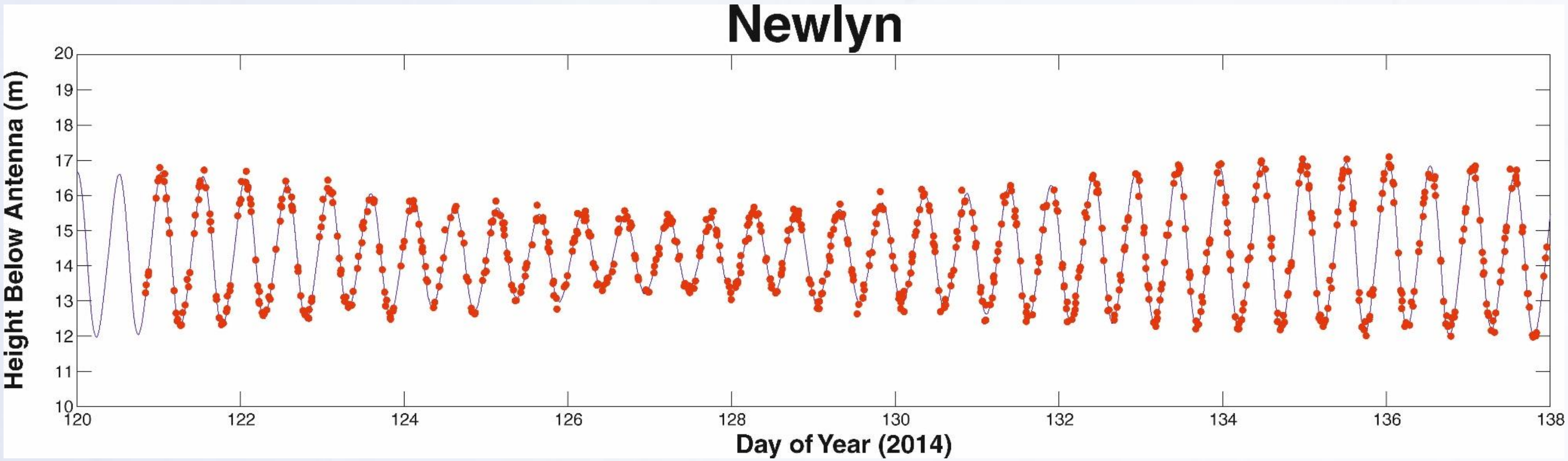
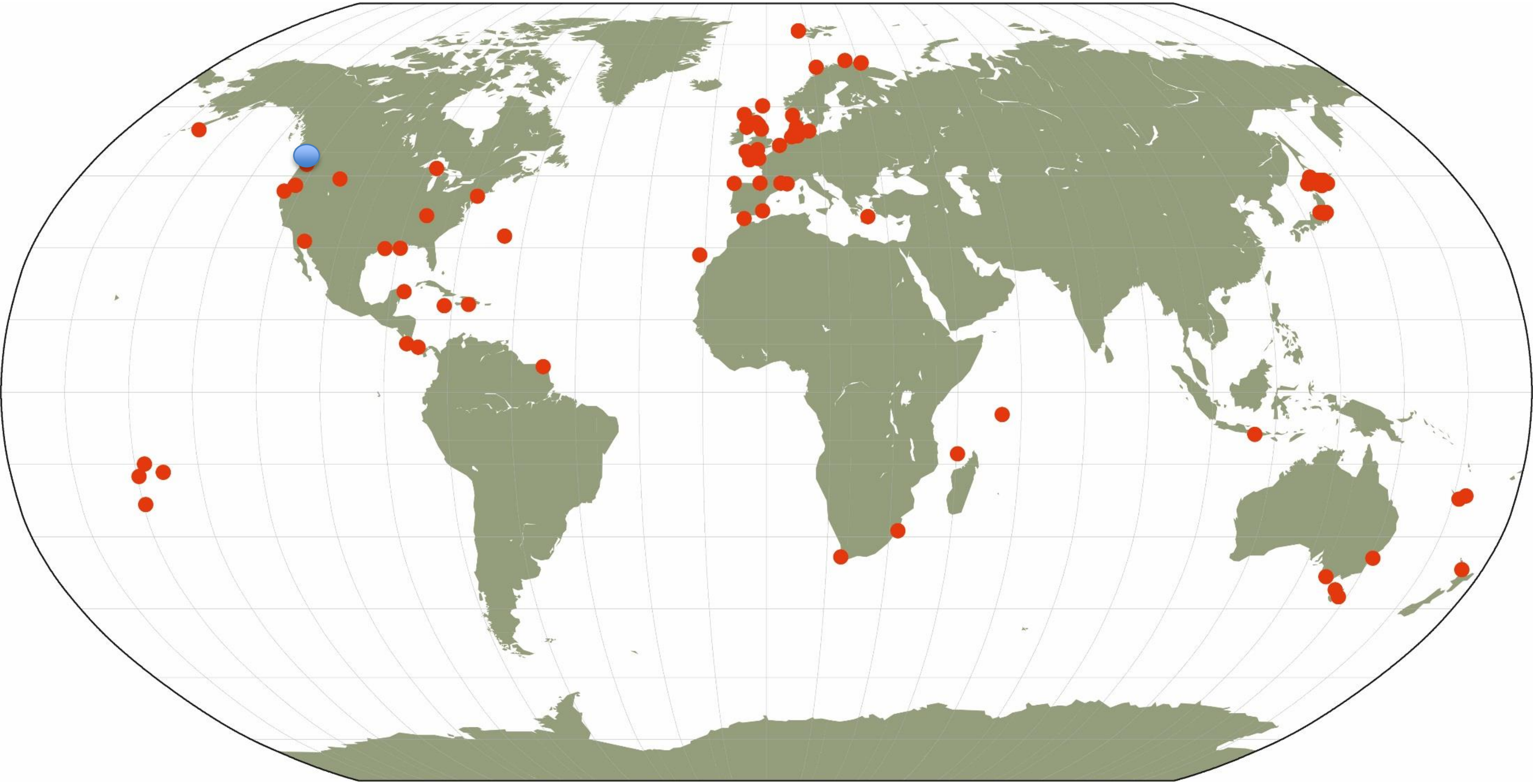


Tide gauge in blue and GPS reflectometry in red

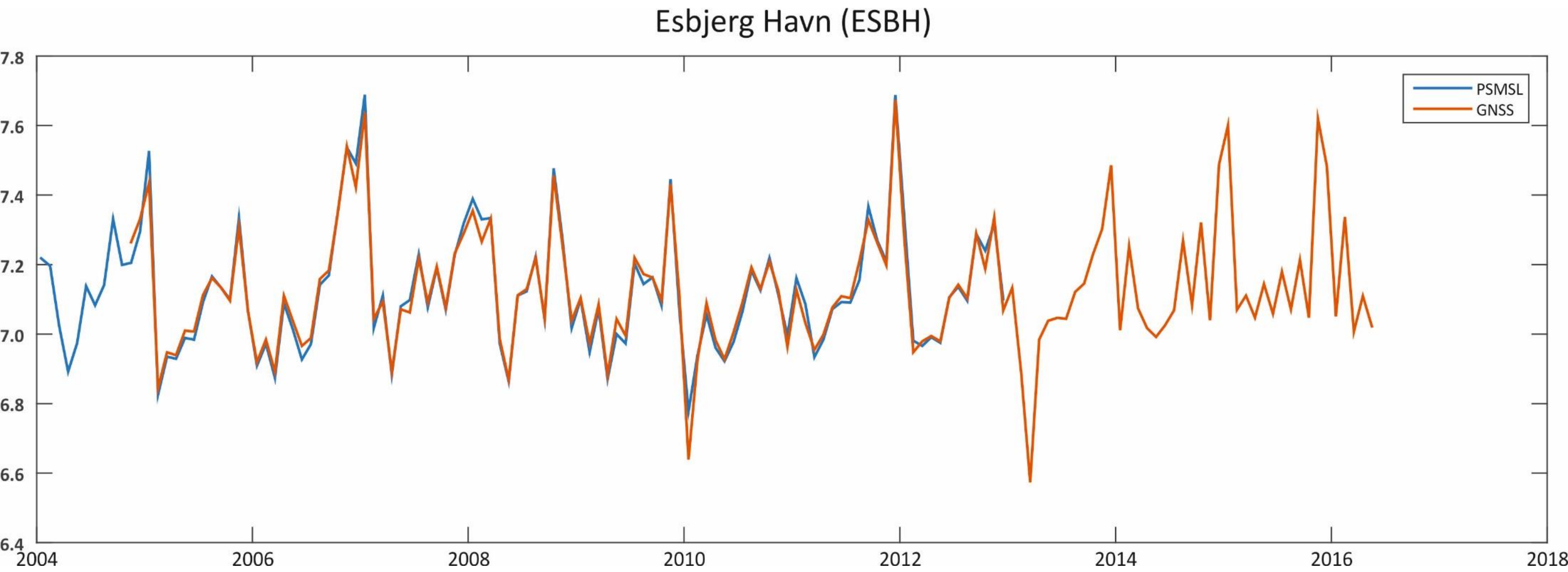


Tide gauge in black and GPS reflectometry in red

Current known GNSS water level sites



New contender for the longest GNSS tide gauge!



GPS Reflectometry

- The technique is presently a technical demonstration of using, and understanding, GPS
- But may be useful as a real tide gauge in certain circumstances
- The main advantage is that you need only the one receiver to measure sea and land levels