Components of a Tide Gauge Record and General Principles of Quality Control

St Lucia, 17th-21st October 2016

Angela Hibbert, Phil Woodworth
National Oceanography Centre, Liverpool

Sea Level Variability

Sea levels vary on different time scales and for different reasons:

- Tsunamis (10s of minutes to an hour)
- Seiches (minutes to hours)
- Tides (diurnal, semi-diurnal, mixed)
- Storm surges (few days)
- Seasonal cycle (annual, semiannual)
- Mean sea level changes (months – millennia)

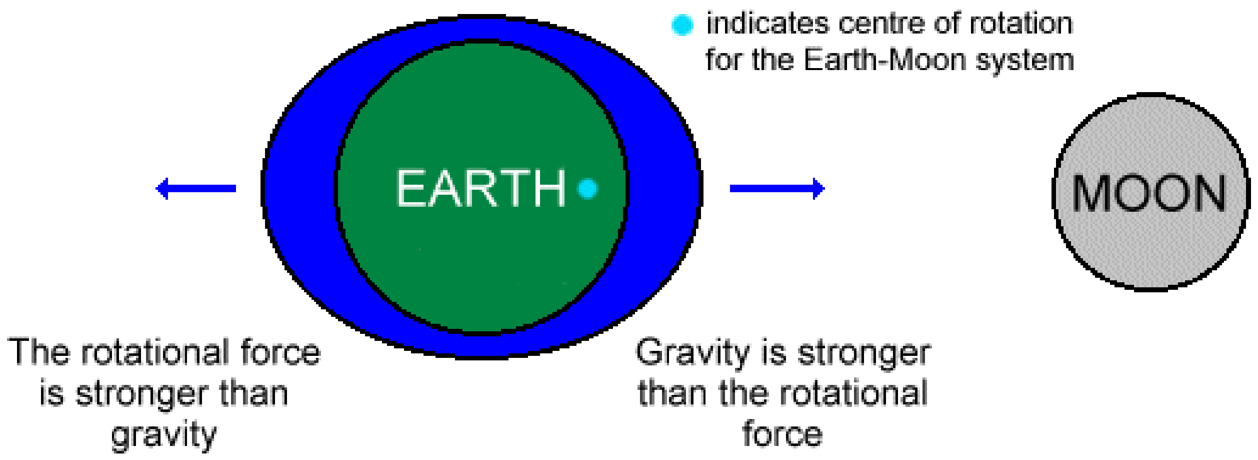
1 min sampling or less

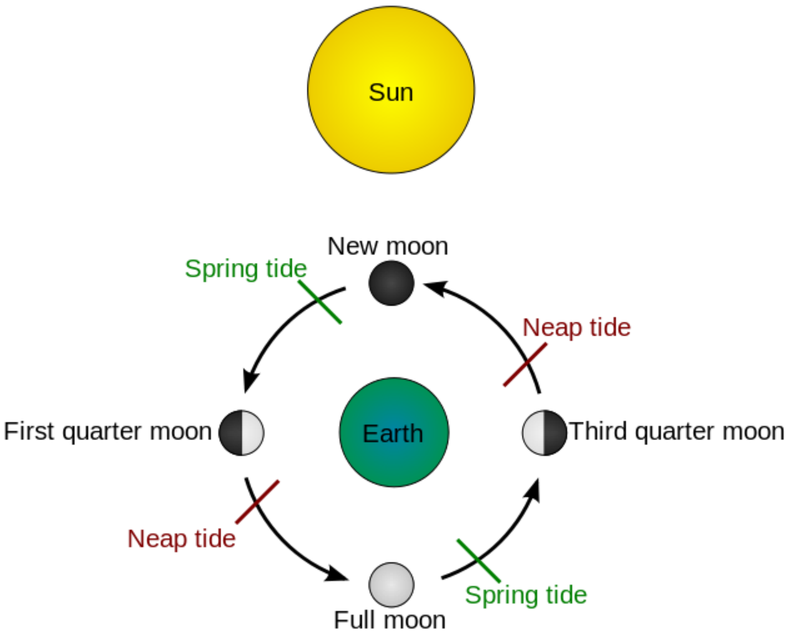
5 to 15 min sampling

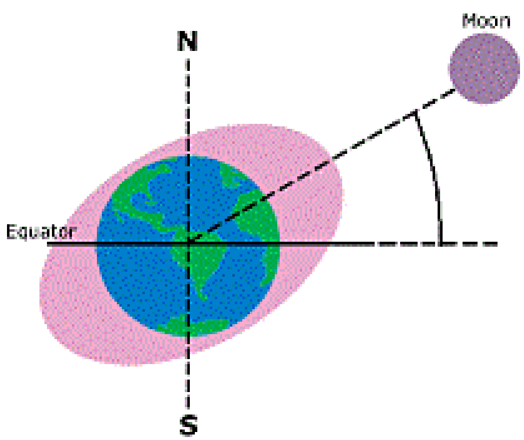
Sea level is measured by a tide gauge which take either spot-measurements at regular time intervals, or averages (called integrations) over the time intervals.

Tides

Periodic movements which are directly related in amplitude and phase to variations of the tidal gravitational potential on the surface of the earth, caused by regular movements of the Moon-Earth and Earth-Sun systems.

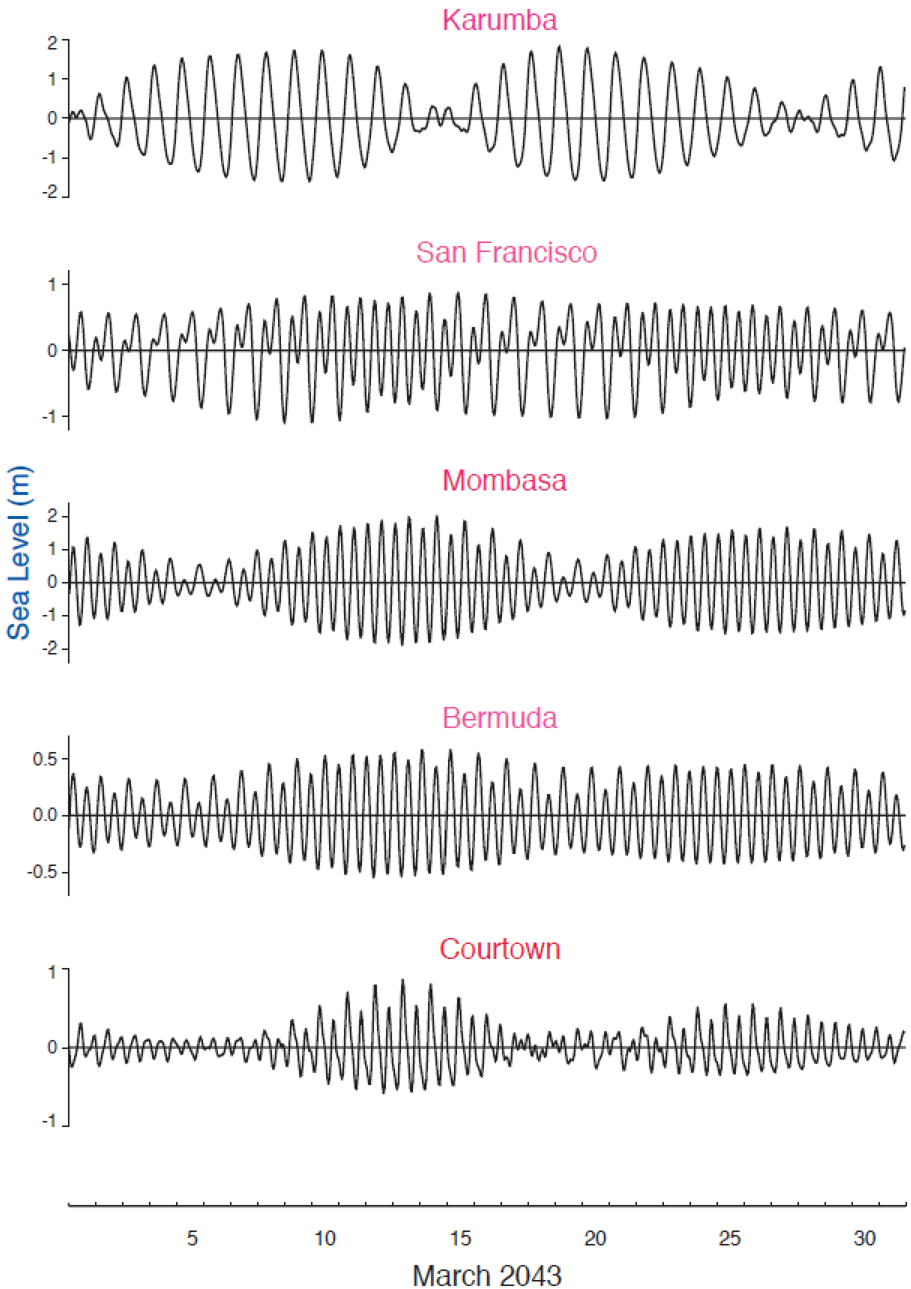






- Synodic or lunar month - 29.53 days
- Lunar orbit – 27.55 days and 8.85y cycle
- Lunar declination – 27.21 day and 18.61 year cycles

Different types of tide:



Diurnal

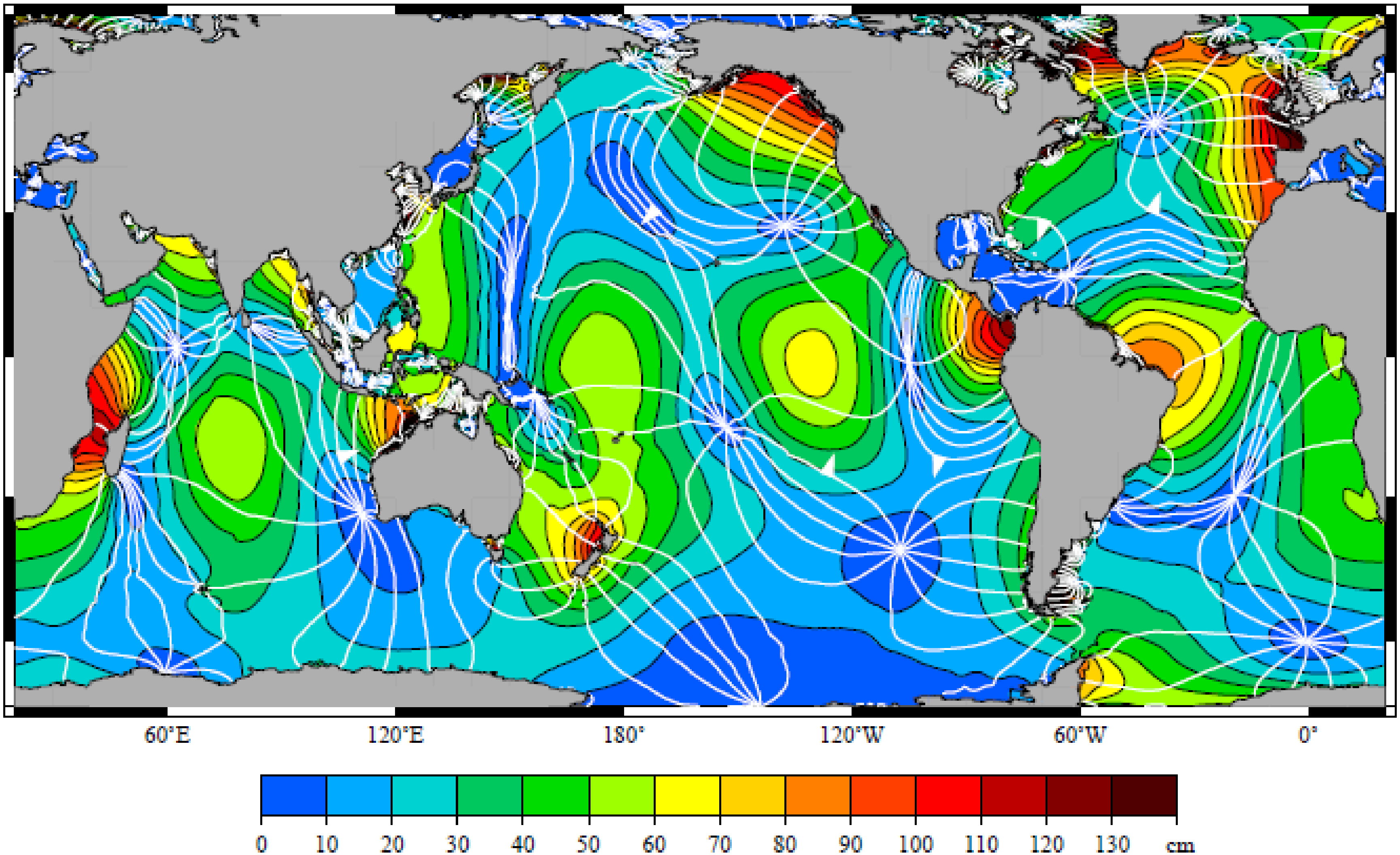
Mixed

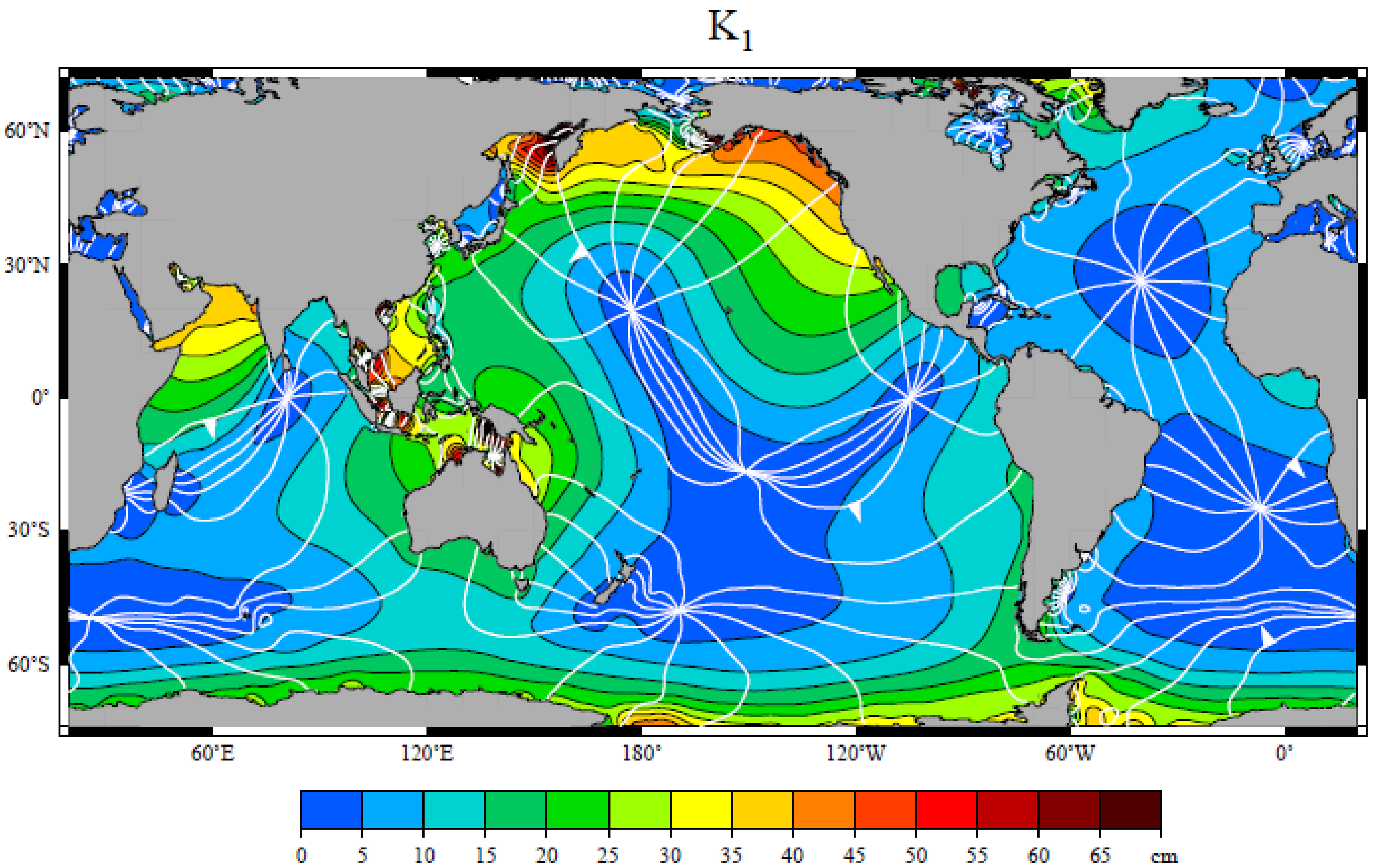
Semi-diurnal

Semi-diurnal

Shallow sea distortions

M_2


60°N
30°N
0°
30°S
60°S
60°E
120°E
180°
120°W
60°W
0°
0
10
20
30
40
50
60
70
80
90
100
110
120
130
cm


K1
60°N
30°N
0°
30°S
60°S
60°E
120°E
180°
120°W
60°W
0°
0
5
10
15
20
25
30
35
40
45
50
55
60
65
cm

Non-Tidal Variability

Non-tidal components might include:

- Storm surges caused by changes in air pressure and winds
- Seiches due to resonant behaviour of harbours and bays
- Tsunamis caused by earthquakes, submarine landslides etc
- Seasonal changes due to changes in water density
- Long-term trends due to climate change

Storm surges

Storm surges occur due to a combination of:

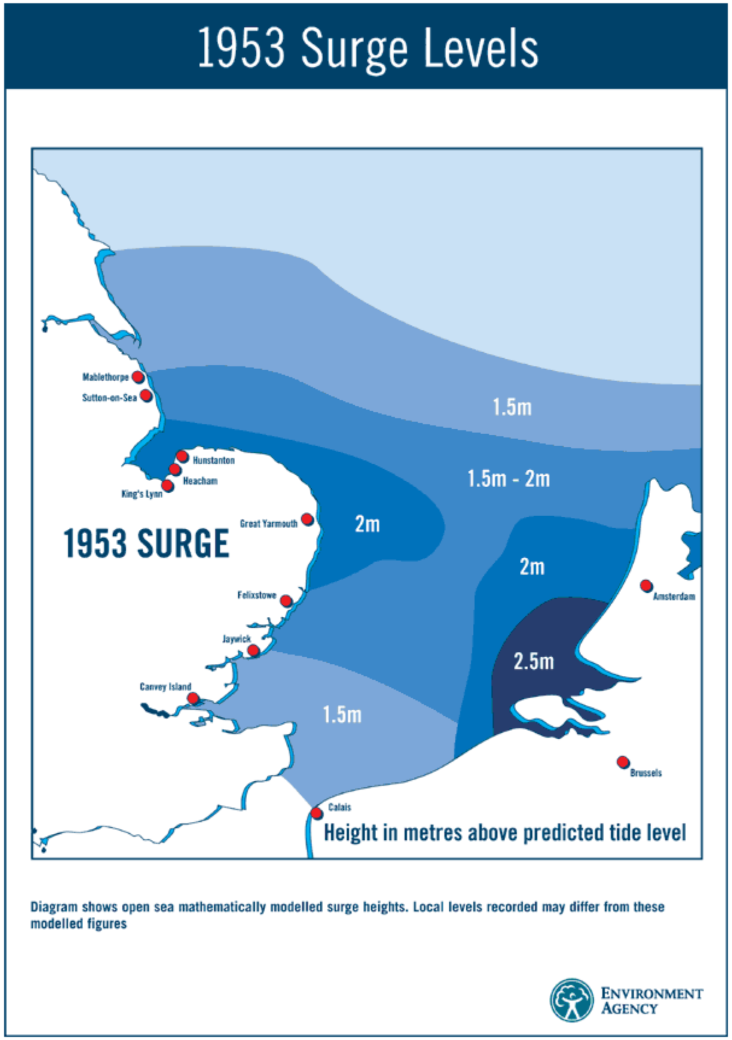
1. Low air pressure (1 mbar reduction raises sea level by 1 cm, known as the Inverse Barometer Effect)

2. Wind stress in shallow water, the surge being proportional to Stress/Depth

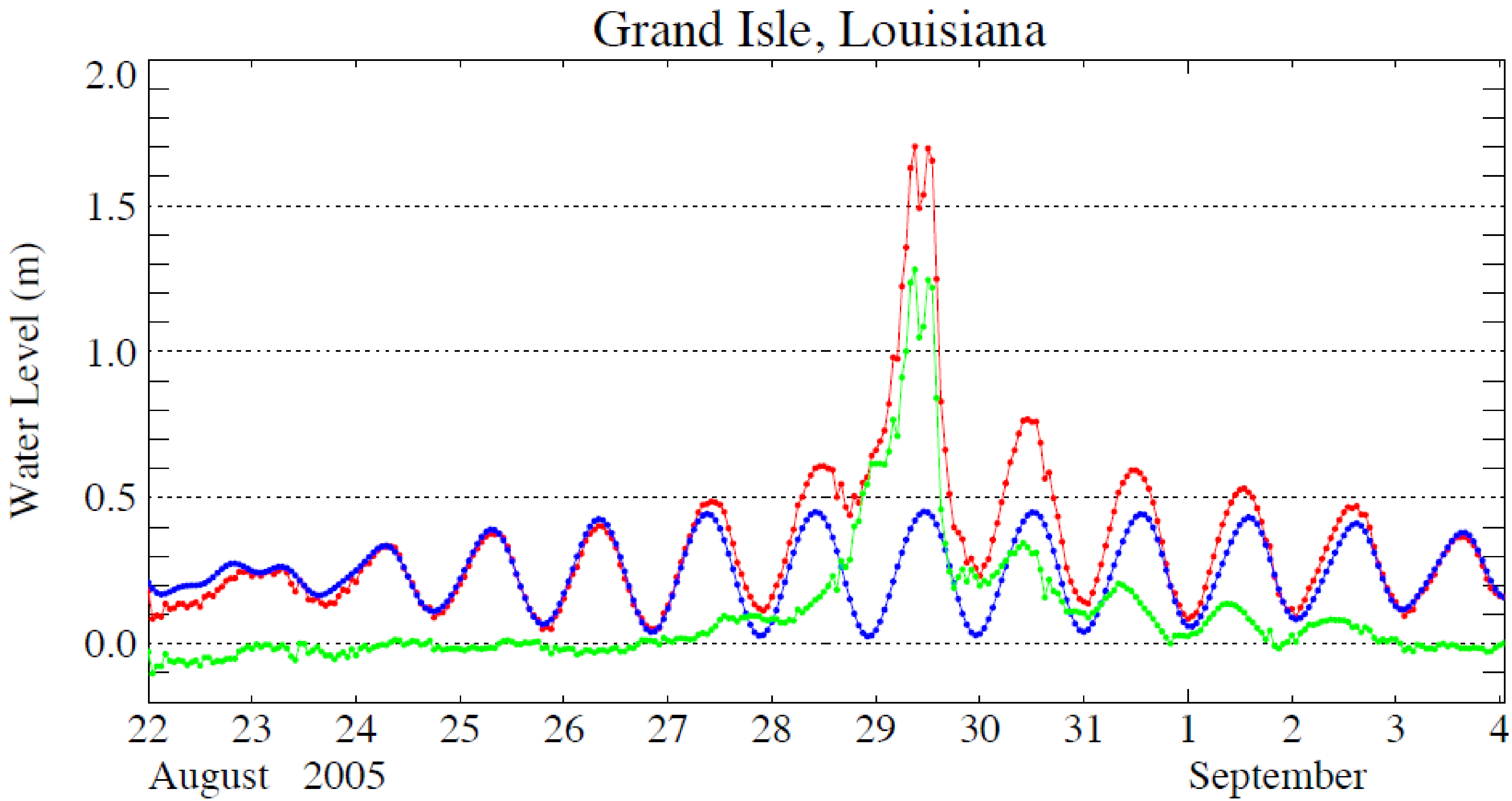
North Sea storm surge of 1953

Sea Palling, Norfolk (1 Feb 1953)

Thames Barrier



New Orleans after the Katrina storm surge



A tide gauge near New Orleans during Hurricane Katrina

Seiches

- Seiches are due to resonance in bays, harbours etc. with fundamental frequency that is proportional to 1/sqrt (depth)

- Sometimes they can be many decimetres in amplitude and have associated currents that can damage shipping e.g. in the Mediterranean (Rissaga)

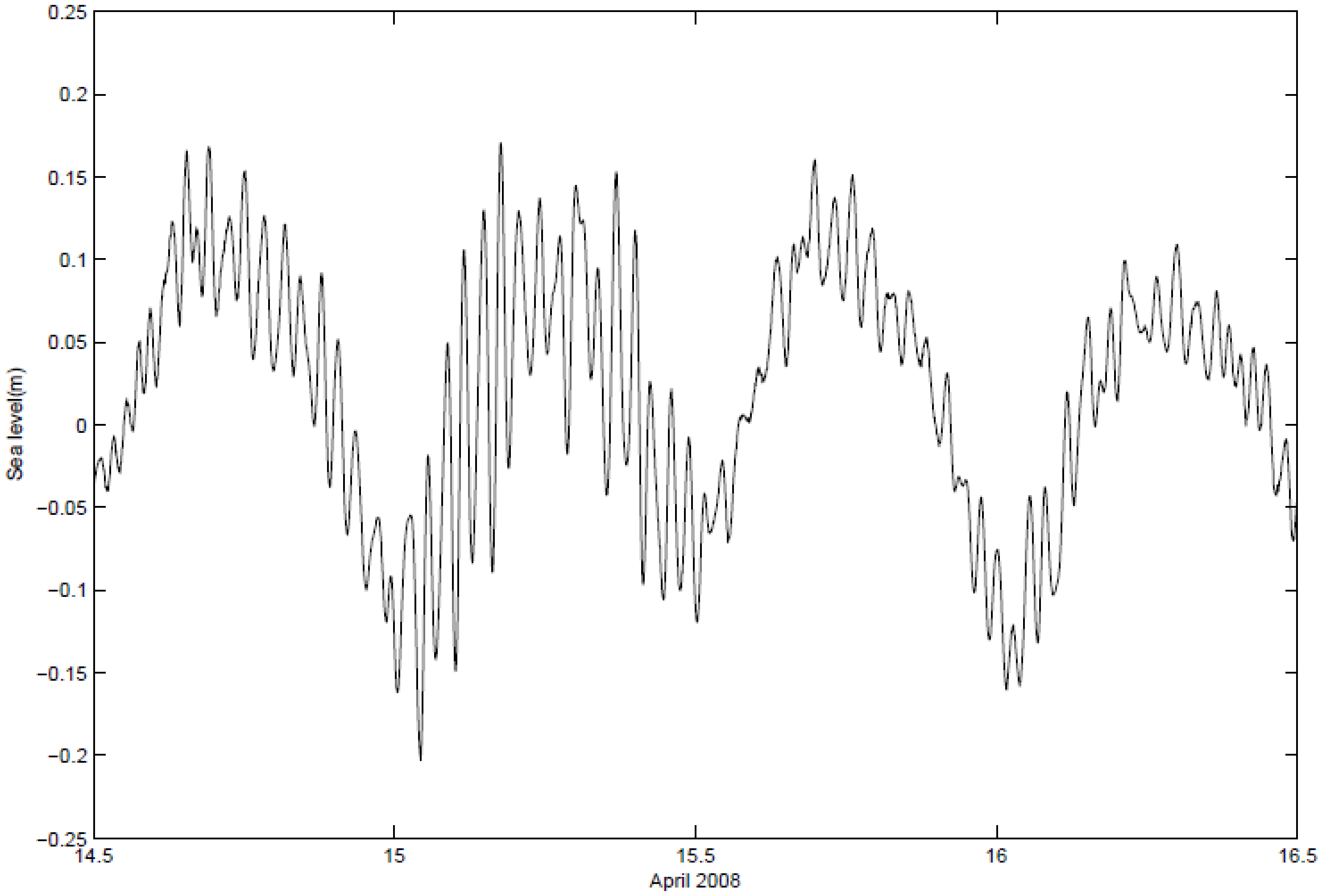
- In practice, they occur in all sea level records and can be readily identified given high frequency sampling.

Seiches can be generated by:

- Rapid meteorological changes
- Tides
- Internal tides
- Other ocean processes
- Earthquakes
- Landslides
- Tsunamis

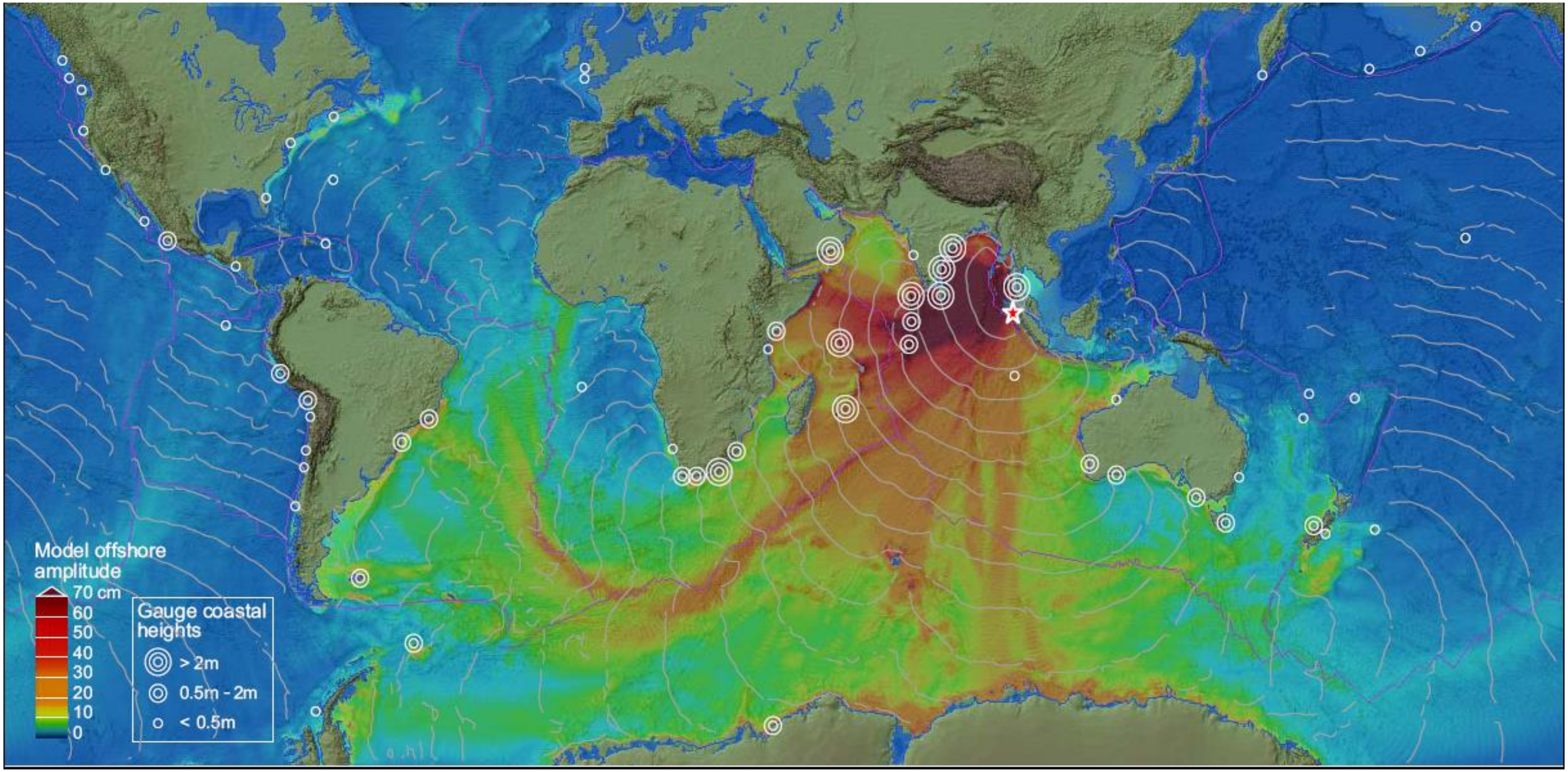
and any other disturbance that initiates resonance

Seiches for 2 days at Trincomalee Bay, east coast of Sri Lanka

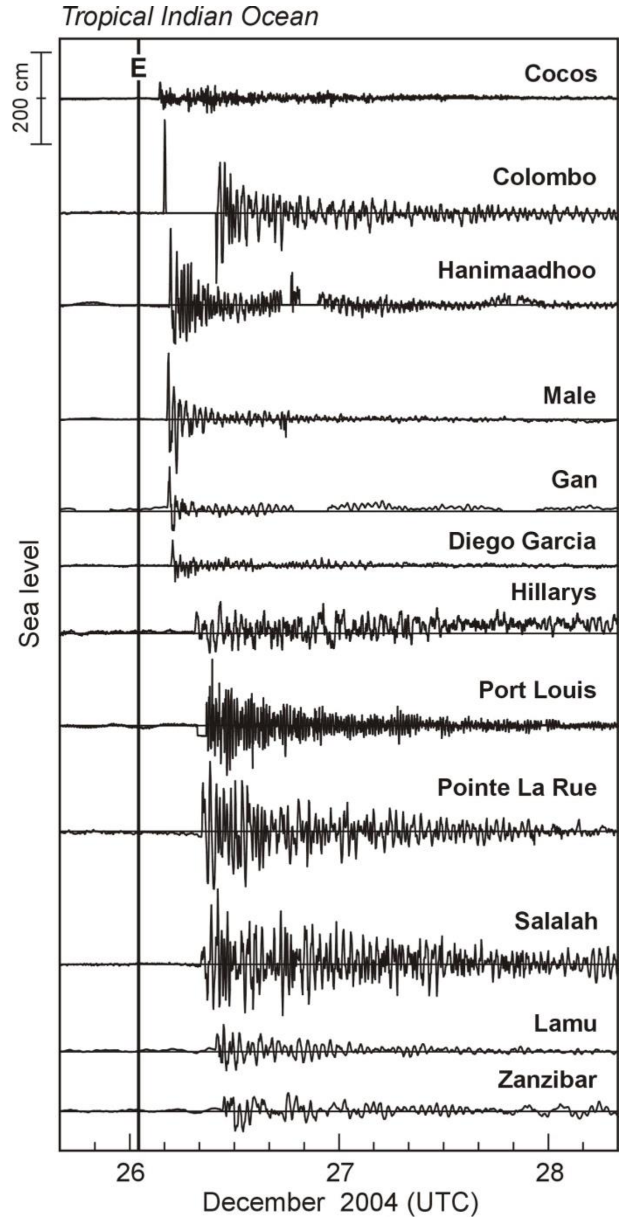


Tsunamis

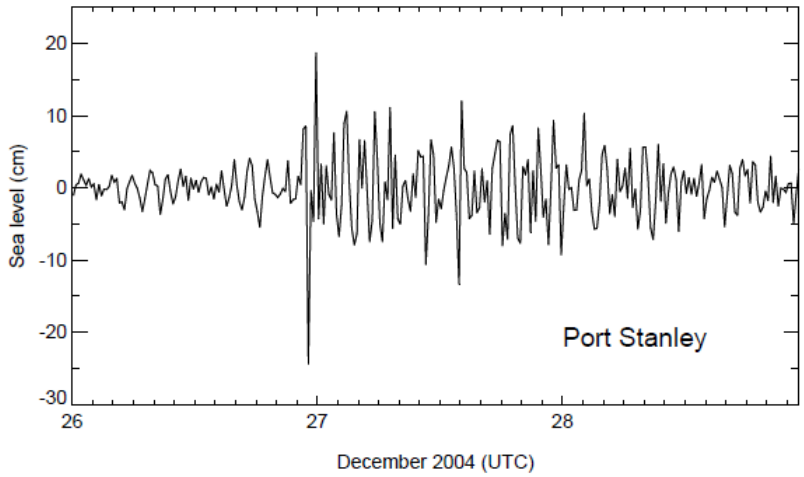
- Caused by undersea earthquakes, submarine landslides, terrestrial landslides, volcanic eruptions, asteroid and comet impacts, man-made explosions.
- A big subject with lots of literature. Stuart Weinstein will discuss in more detail in his talk.



26 December 2004 Sumatra tsunami



South Atlantic

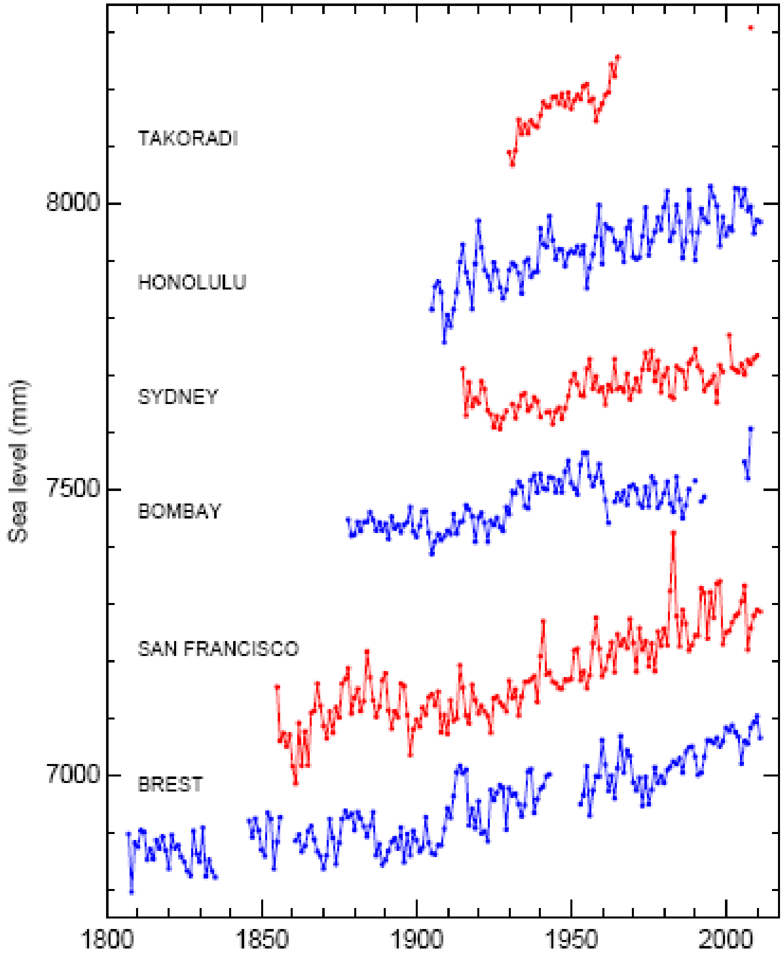


The 26 December 2004 tsunami was observed in tide gauge records on many coastlines

Indian Ocean gauges

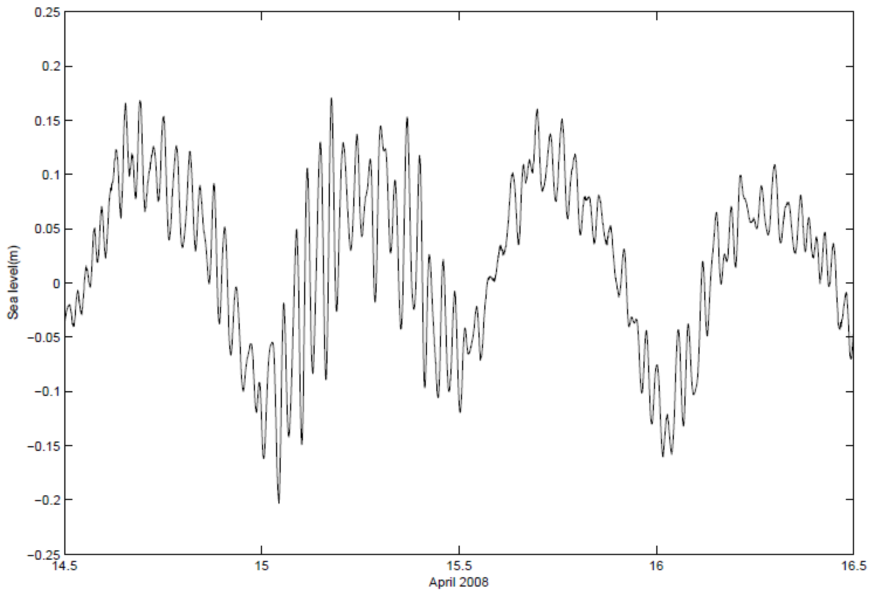
Long Term Changes

- Long term changes e.g. IPCC concluded that there has been a global rise of approximately 10-20 cm during the past 100 years



Tidal Analysis and Quality Control

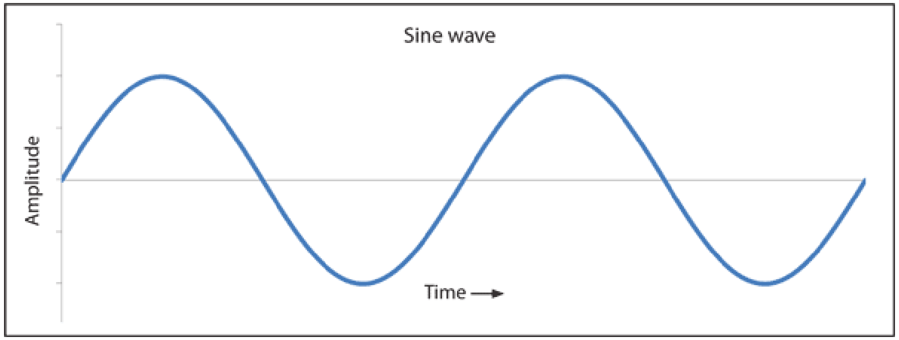
Some of the variations we have seen are so extreme that they are obviously identifiable in raw tide gauge records:



However, some variations can be masked by tides. Therefore, tidal and non-tidal components of a sea level record are often separated, making the non-tidal variations much clearer.

How does a tidal analysis work?

The tide is parameterised in terms of harmonics with periods specified by the orbits of the Moon and Sun but with unknown amplitudes and phase i.e.



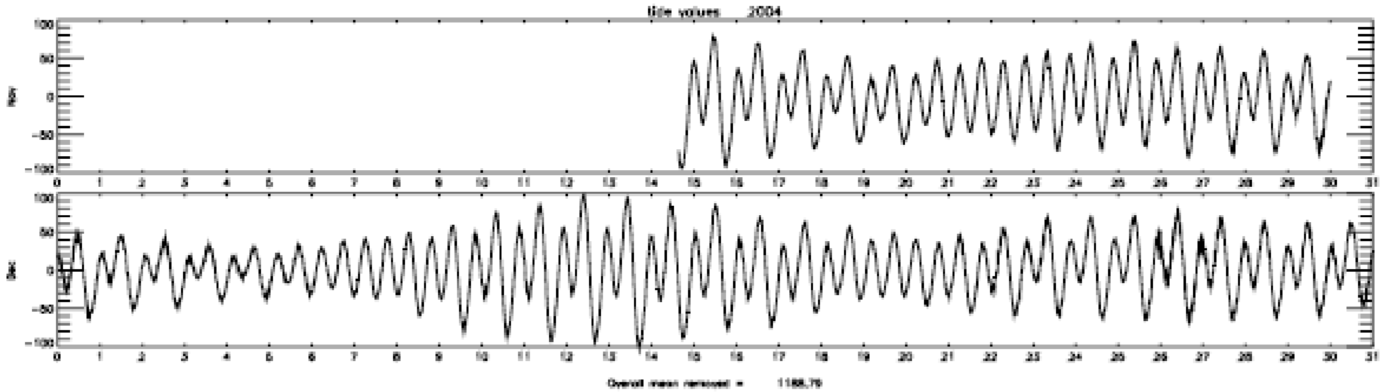
$$Tide = Z_0 + \sum_{j=1}^{N} H_j f_j \cos\left[\sigma_j t - g_j + \left(V_j + u_j\right)\right]$$

The unknown parameters are Z_0 and the (H_j, g_j).

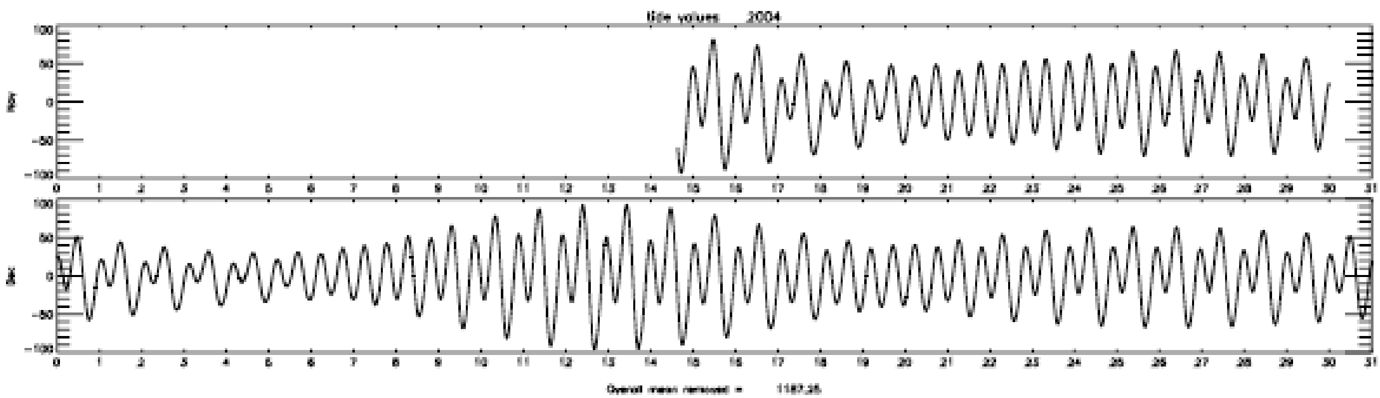
The fitting is adjusted so that the sum of the squares of the difference between the observed and computed tidal levels is minimized. The residuals to the fit are considered to be the 'non-tidal' terms.

An example from Port Stanley Nov-Dec 2004

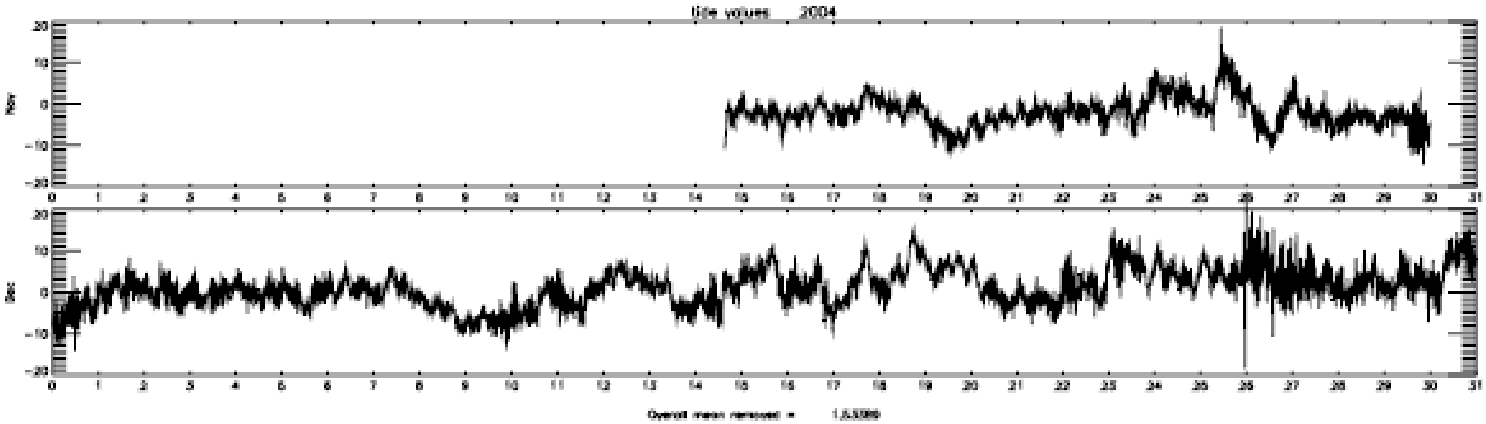
Measured



Tide



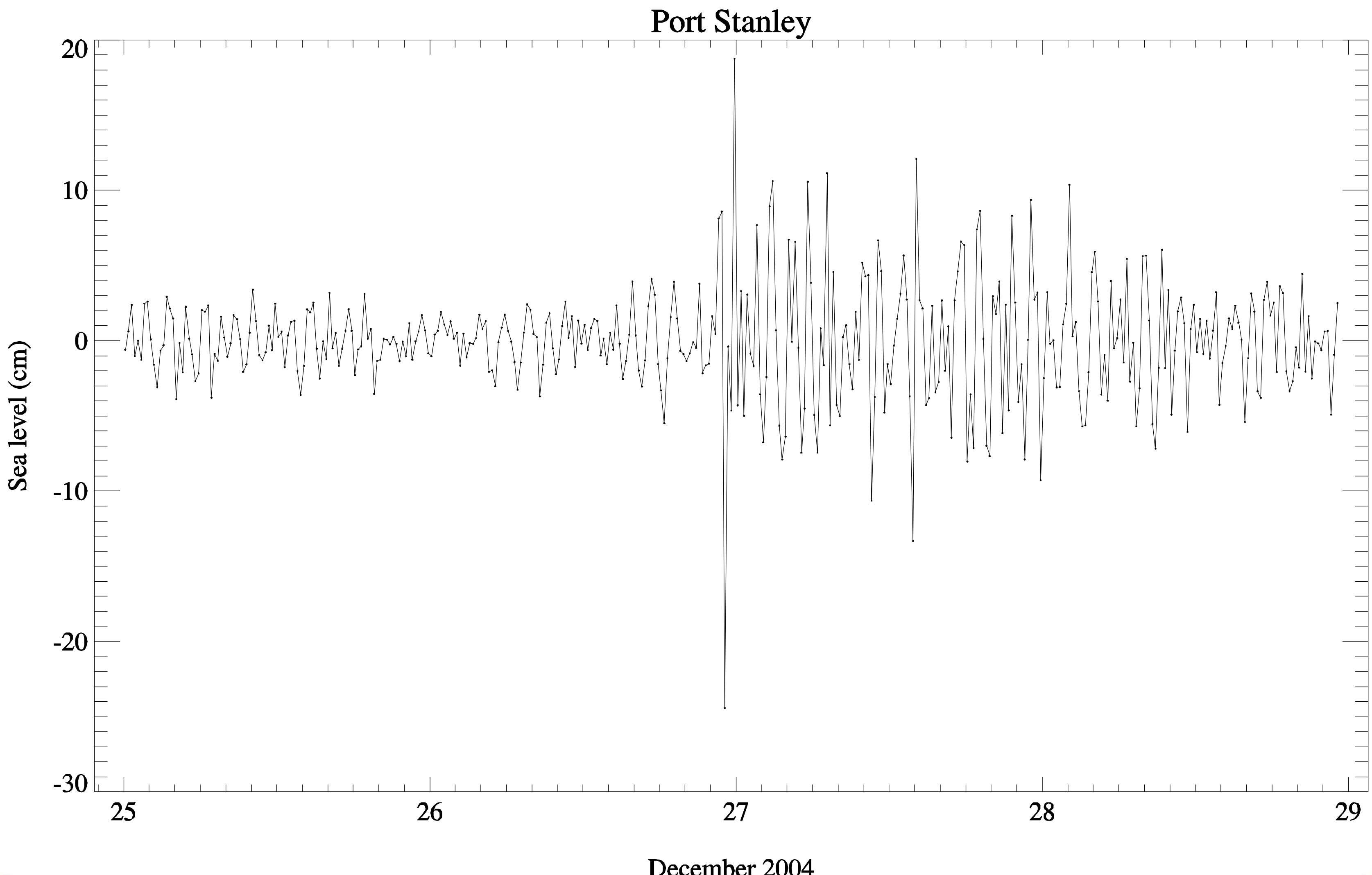
An example – Port Stanley, Falkland Islands



Non-tidal record shows:

1. No big storm surges (Southern Hemisphere summer)
2. A lot of high-frequency noise of a few cm due to harbour seiches
3. On 27 December arrival of the Sumatra tsunami (15 cm or so)

➔ None of this is evident from looking at the total measured record.


Port Stanley
20
10
0
-10
-20
-30
Sea level (cm)
25
26
27
28
29
December 2004

Uses of tidal analysis

1. The separation of the sea level record into tidal and non-tidal components is needed to produce tide tables or tidal predictions

2. The non-tidal signals (seiches, tsunamis) become clearly identified

3. Tidal analysis also enables errors in the sea level time series to be identified ➔ highest-quality data for subsequent analysis

Principles Of Quality Control

"To ensure the data consistency within a single data set and within a collection of data sets and to ensure that the quality and errors of the data are apparent to the user who has sufficient information to assess its suitability for a task." (Unesco, 1993)

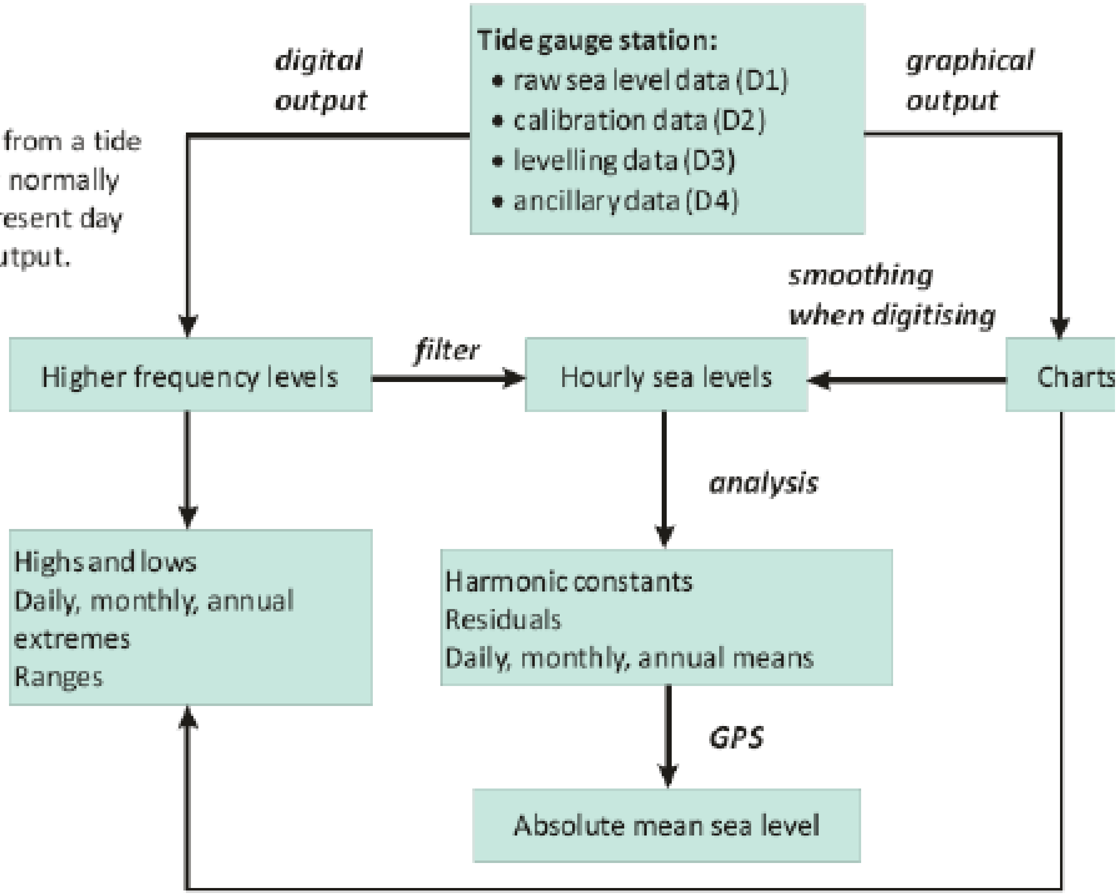
GLOBAL SEA LEVEL OBSERVING SYSTEM (GLOSS)

MANUAL ON QUALITY CONTROL OF SEA LEVEL OBSERVATIONS

Version 1.0

Principles Of Quality Control

Scheme of principal data available from a tide gauge station and the processing normally applied to sea level data. Most present day sensors will provide digital output.



Principles Of Quality Control

Quality control starts with: Good maintenance
Good record keeping

This helps to identify whether errors are random:

- Malfunctions
- Bad readings

Or systematic:

- Change in practice
- Change in instrumentation
- Change in environment

Principles Of Quality Control

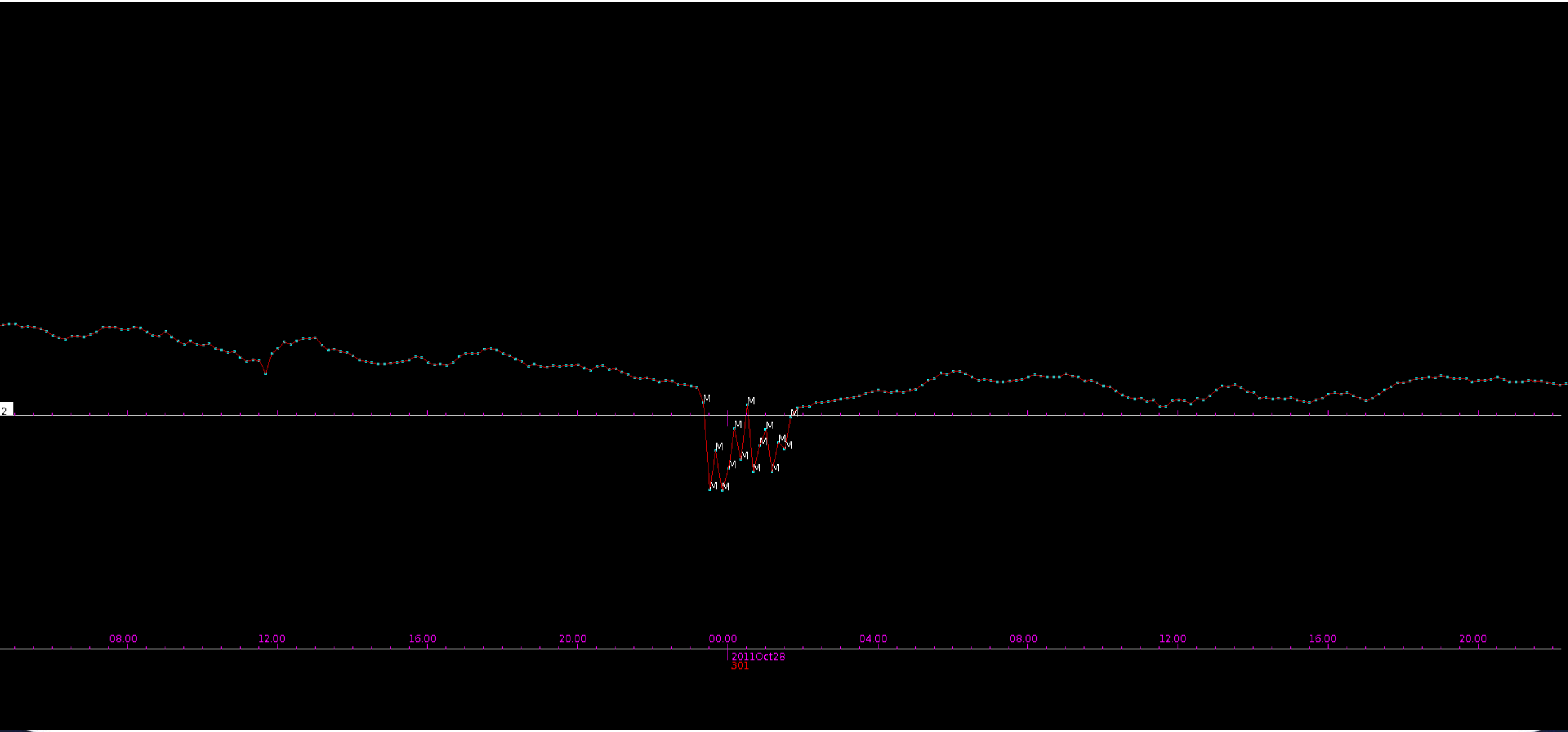
It will be immediately clear (especially with some experience) by looking at the residuals if there is:

- A spike or jump in the data due to instrumental faults
  These can be evaluated by ‘buddy checking’ and flagged using GLOSS QC standard flags
- Missing data (small gaps can be interpolated)
- Reference level changes
- A timing error
- And many other errors → see the IOC Manuals

These errors can then be fixed in the data set. The final data set is called the Quality Controlled Delayed-Mode data set.

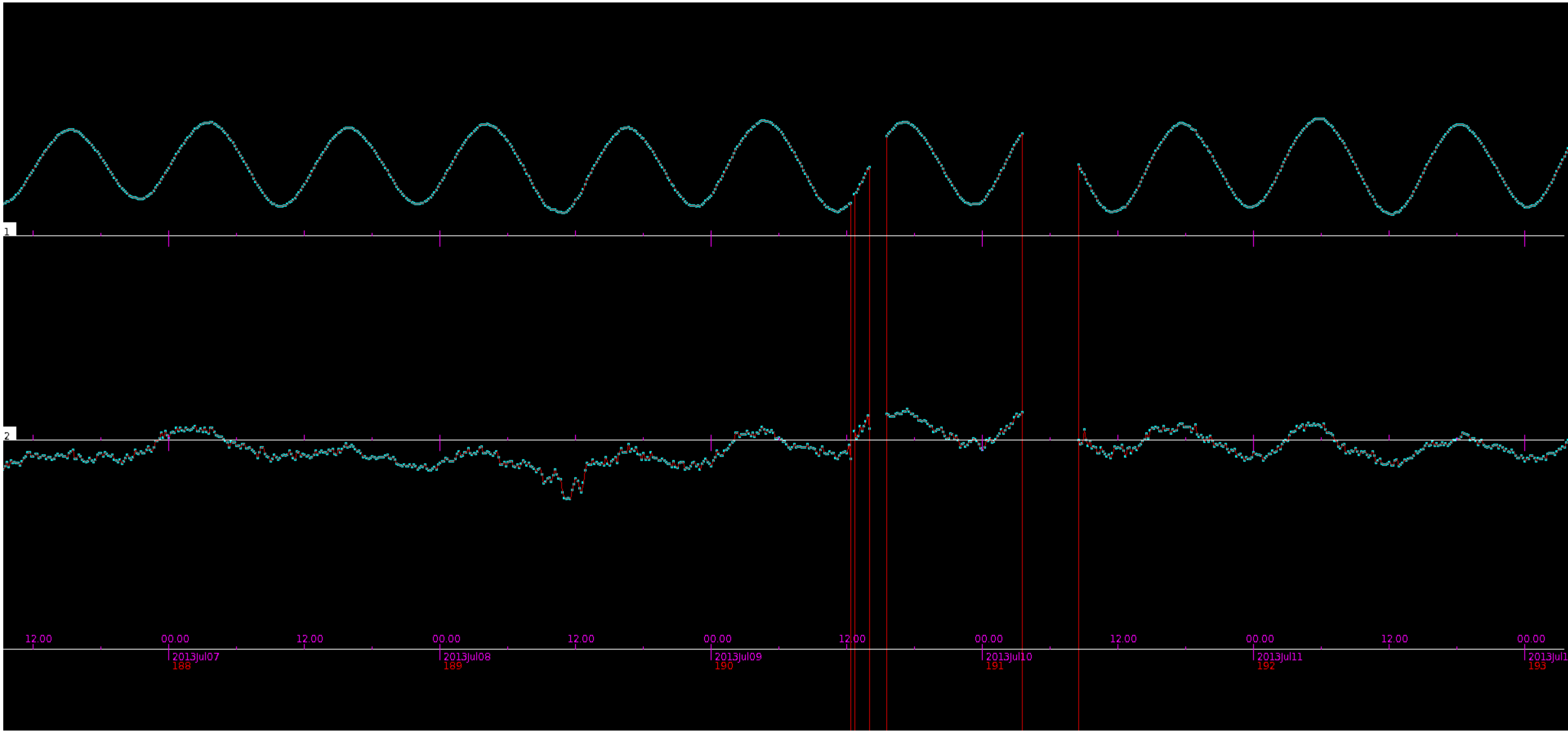
Principles Of Quality Control

- A spike or jump in the data due to instrumental faults



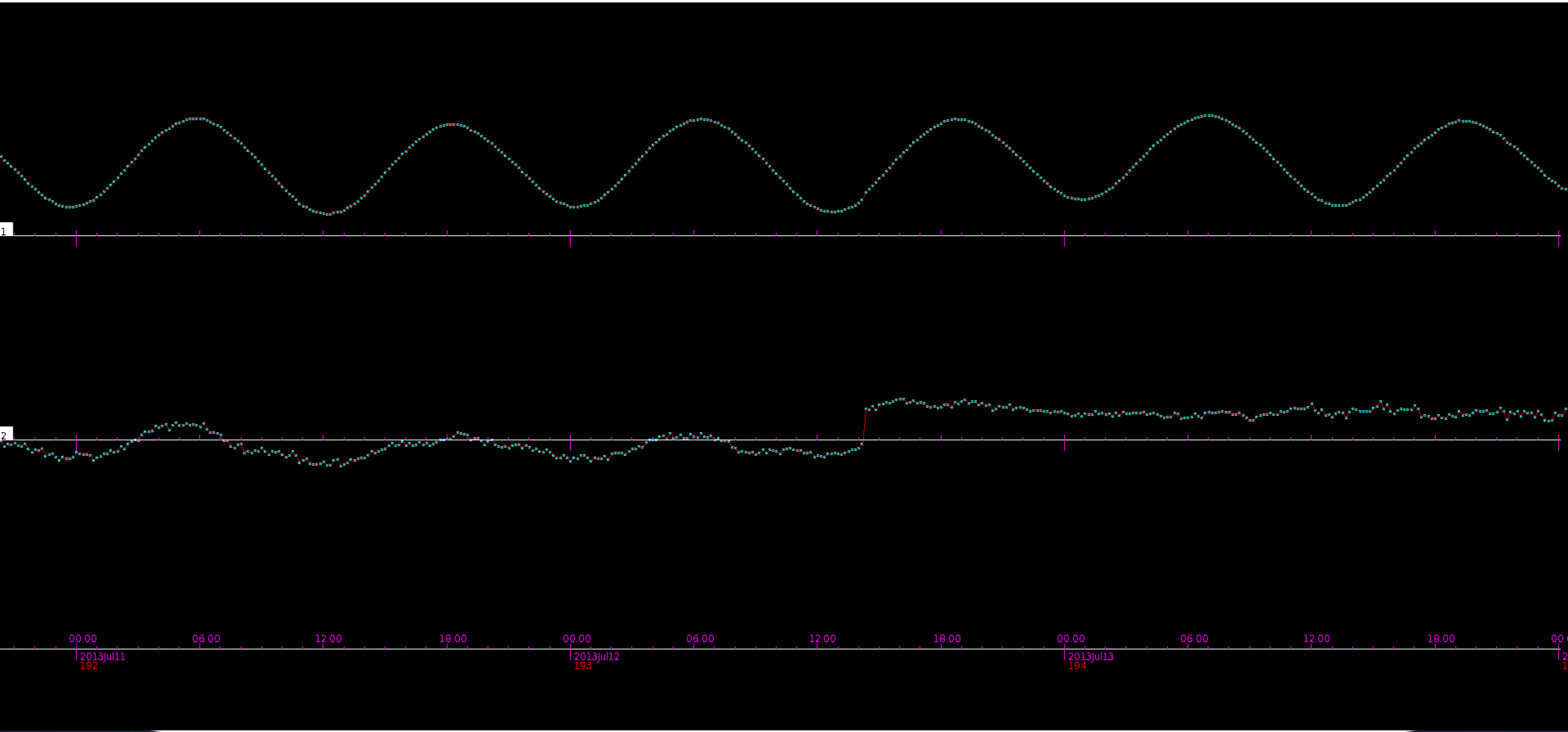
Principles Of Quality Control

- Missing data (small gaps can be interpolated)



Principles Of Quality Control

- Reference level changes



Summary

Sea levels vary on different time scales and for different reasons:

- Tsunamis
- Seiches
- Tides
- Storm surges
- Seasonal cycle
- Mean sea level changes

Tides are dominant, so separation of tidal and non-tidal components is important and facilitates generation of tidal predictions and quality control.