Sea Level Measurement Technologies

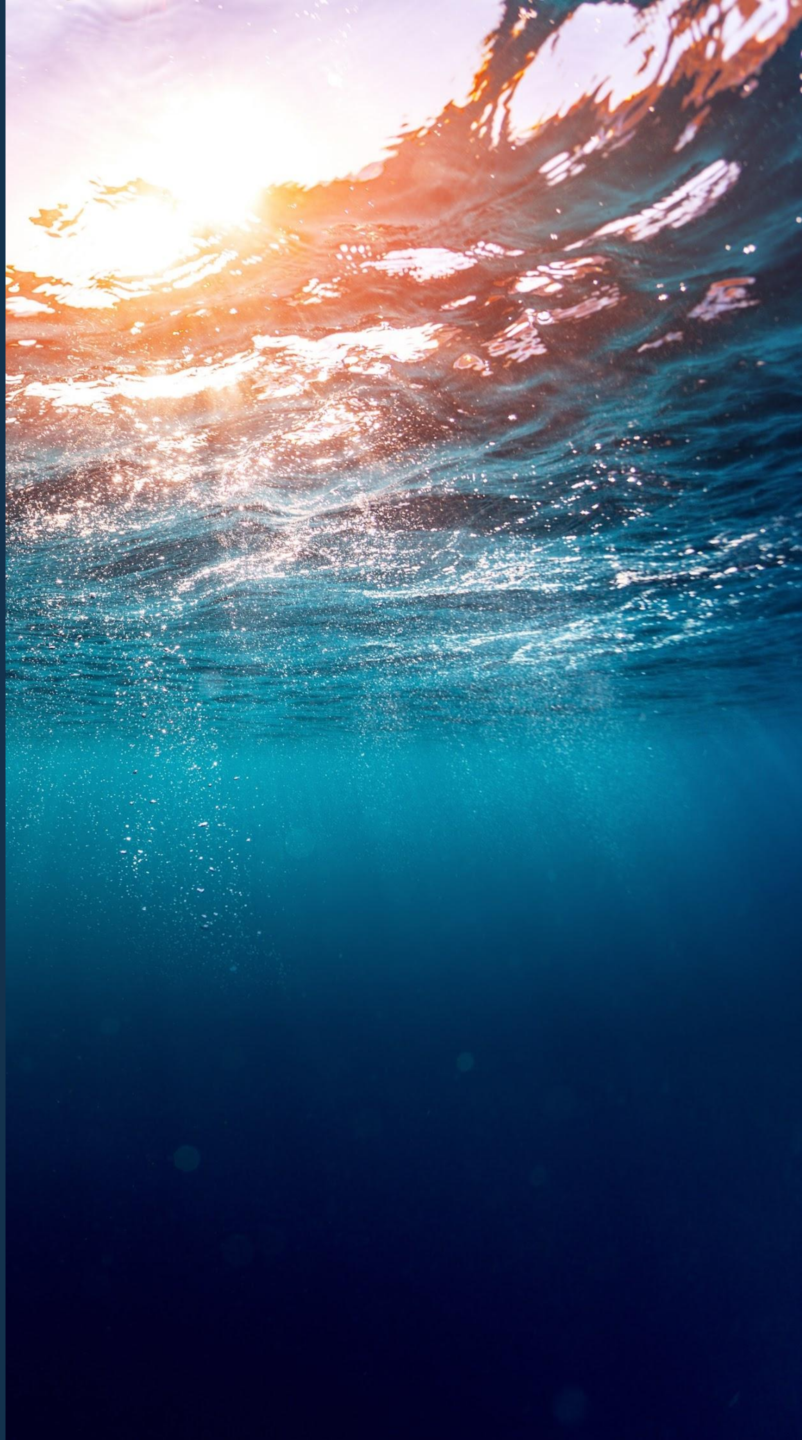
Angela Hibbert

Caribbean Training Course Barbados

17th-21st November

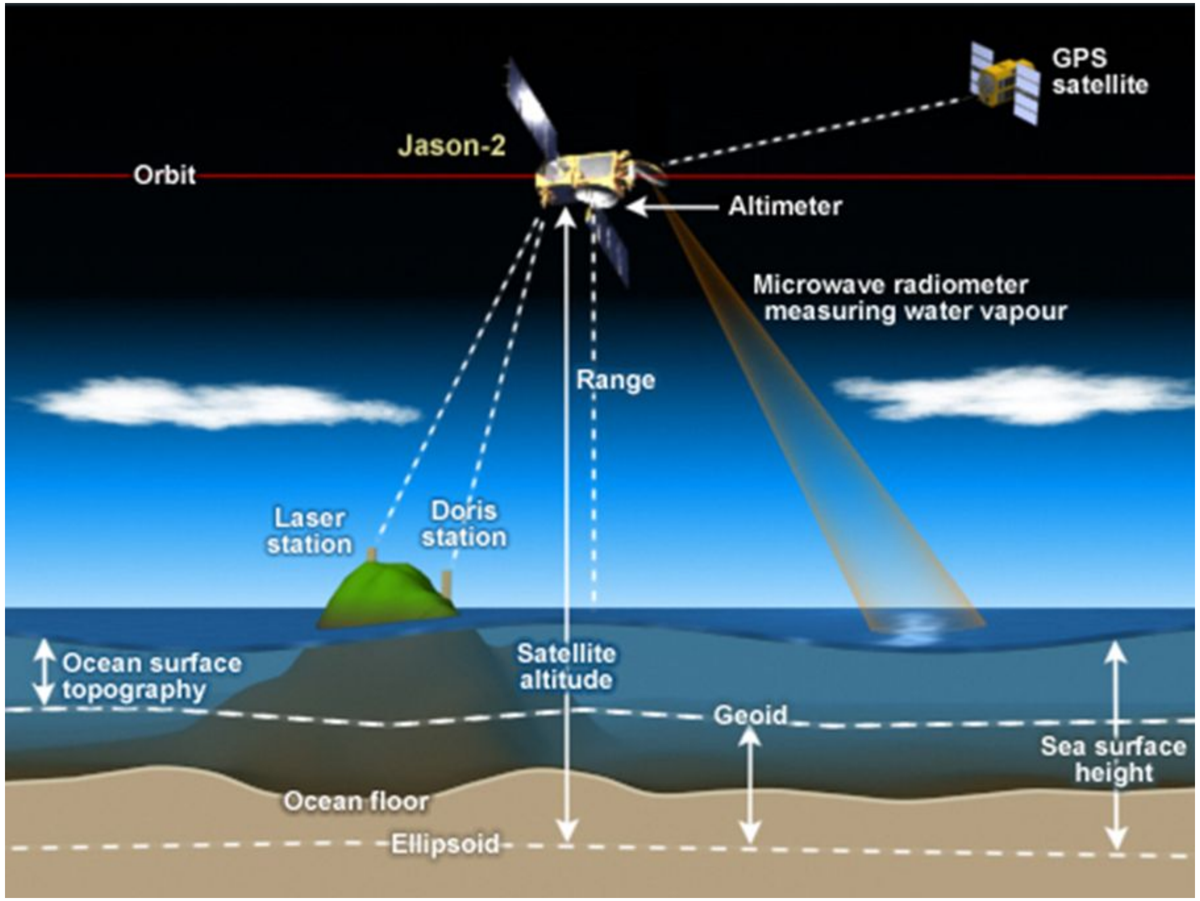
National Oceanography Centre

Satellite Altimetry



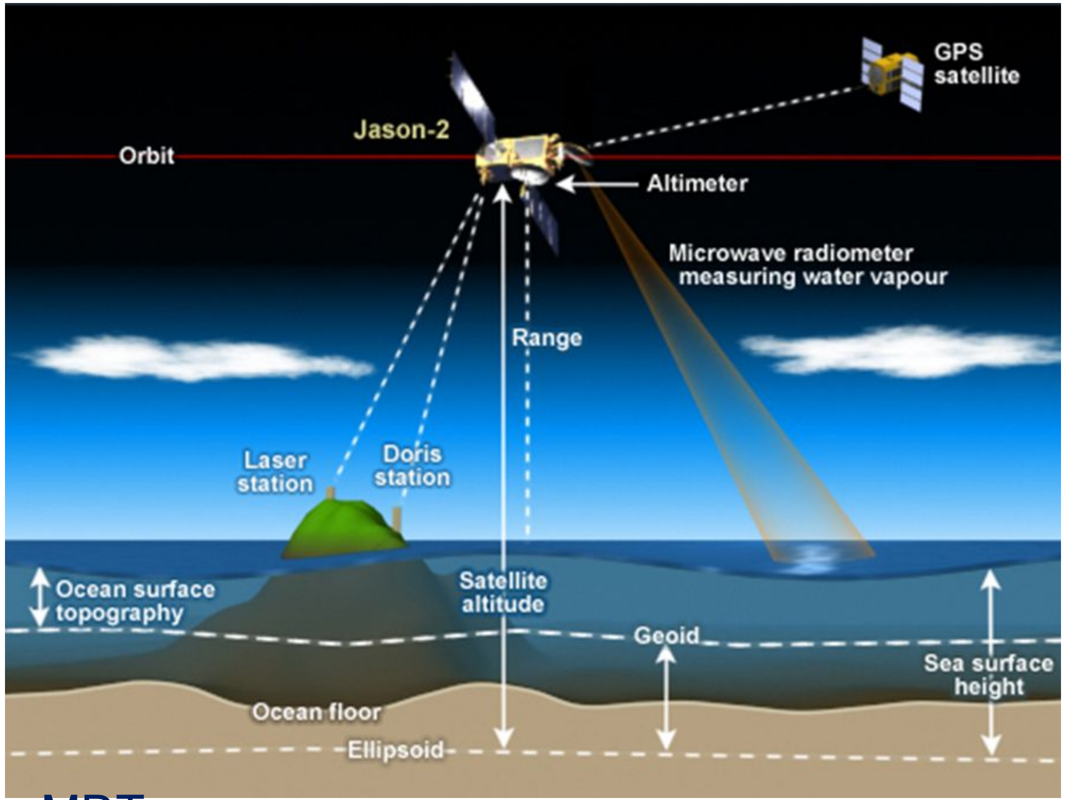
Satellite Altimetry

- Radar altimeters transmit signals and receive the echo from the Earth's surface
- By timing it, we measure the distance between the satellite and sea (range)
- We know the position of satellite (precise orbit) and so determine height of sea surface with respect to the reference ellipsoid
- We can also measure wave height and wind speed
- Near the coast (<50km) the footprint of the radar is contaminated by landforms



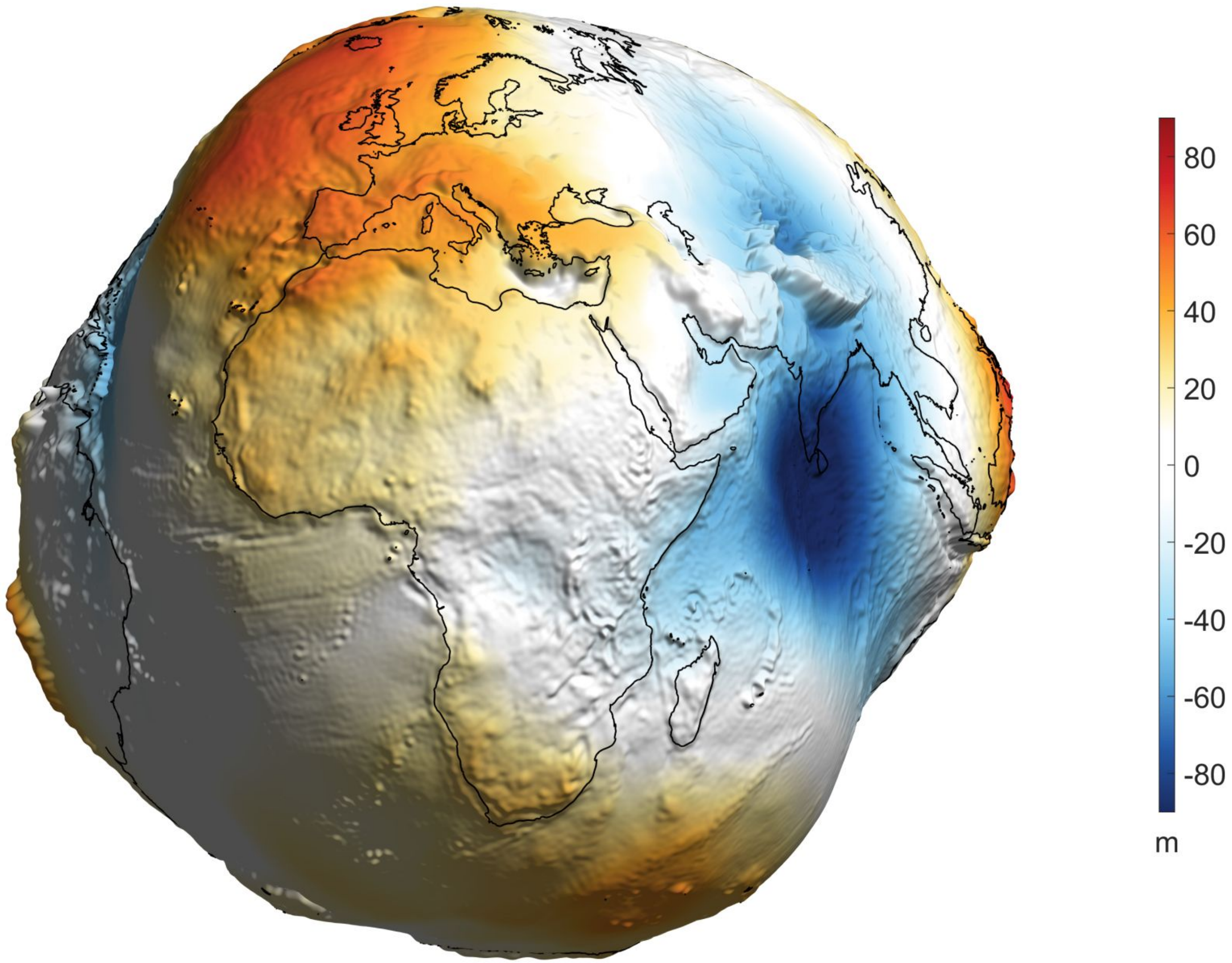
Reference Surfaces

- The **reference ellipsoid** is a rough approximation of the Earth's shape
- The **geoid** is an equipotential surface that coincides with the shape that the sea surface would take in the absence of perturbing forces (currents, wind, etc.)
- The **mean dynamic topography** (MDT) is the semi-stationary component of the ocean dynamic topography (i.e. associated with persistent temperature patterns and currents).

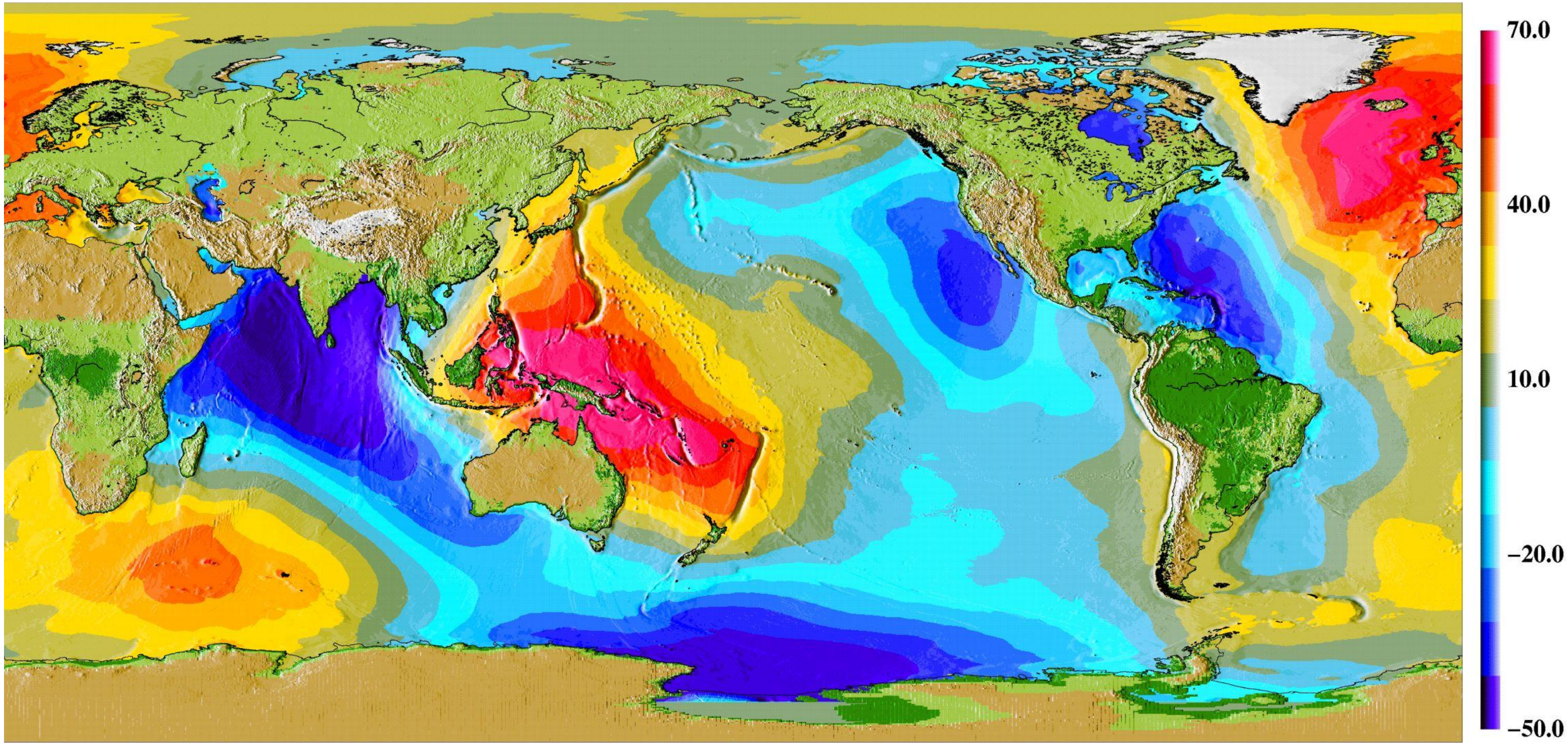


- The **mean sea surface** (MSS) is the sum of the geoid and the MDT
- The **sea surface height** is the sea surface height wrt the reference ellipsoid.
- The **sea level anomaly** (SLA) is the sea surface height wrt the MSS

The geoid



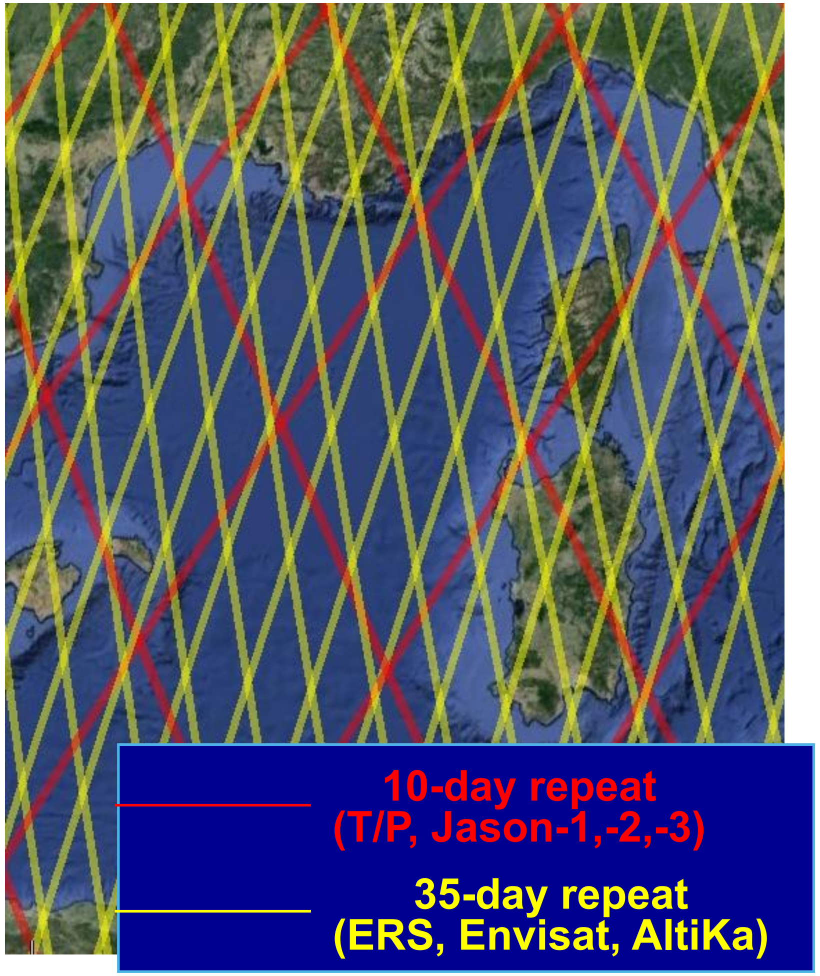
Mean Sea Surface wrt the reference ellipsoid



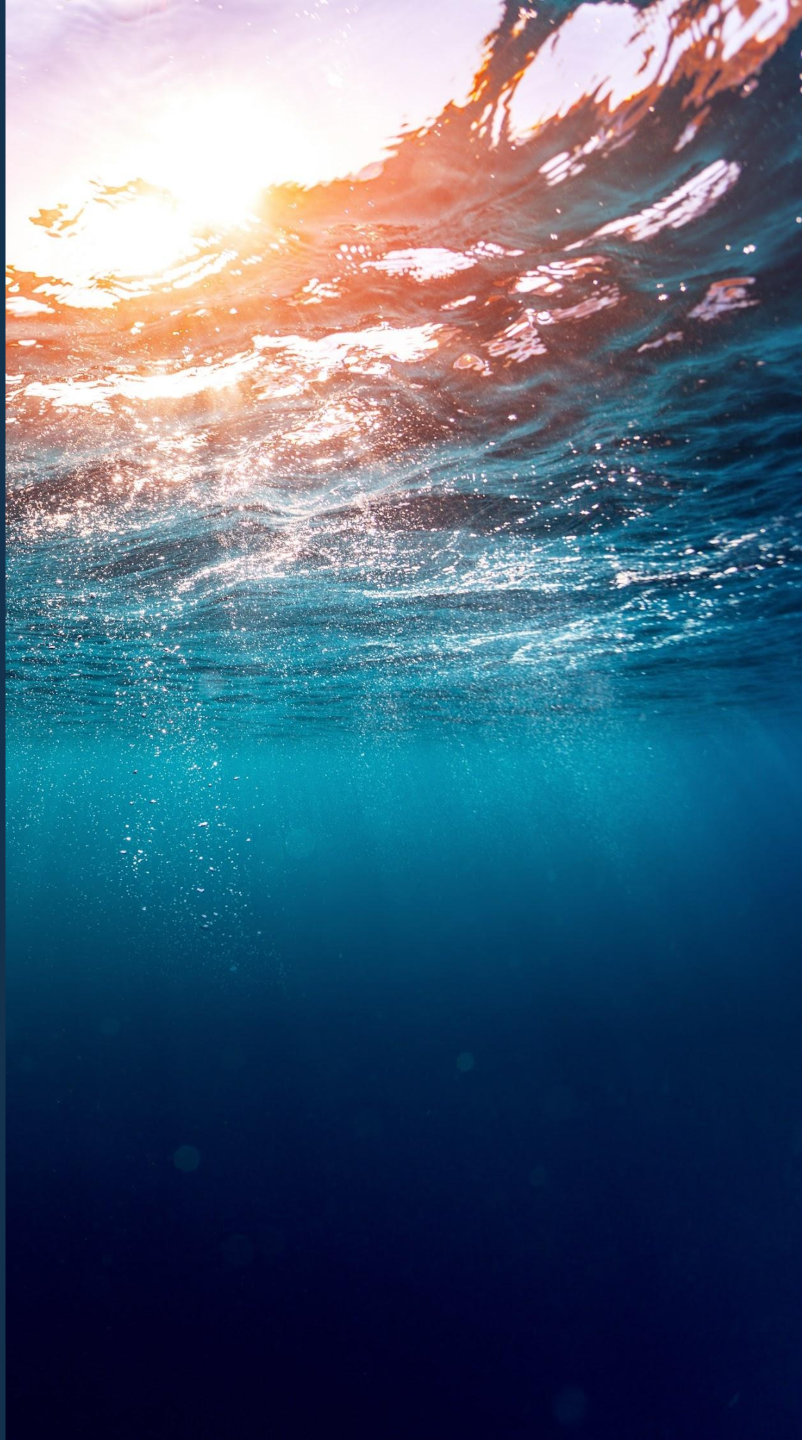
The MSS departs from the standard ellipsoid by ± 100 metres because of the density composition of the solid Earth

Satellite altimetry

- Near-global, gridded spatial coverage
- Lower frequency sampling than tide gauges (every 10 to 35 days)
- Does not capture higher frequency variations e.g. waves, seiches, tides
- Measures **geocentric** or **absolute** sea level relative to a reference ellipsoid
- Problematic near the coast
- Precise observations since 1992



Tide Gauges



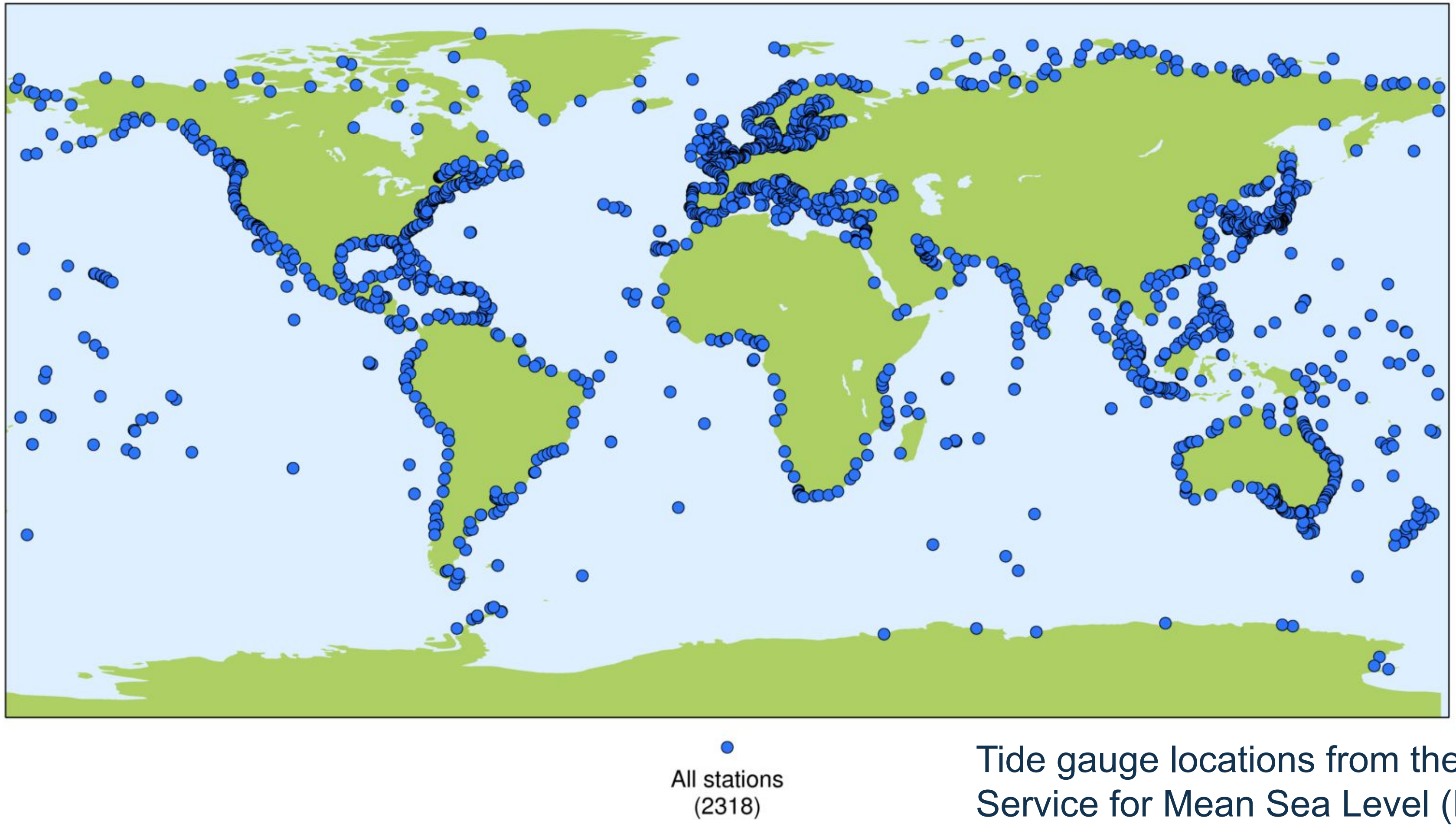
Tide Gauges

- Used for >200 years
- Long records, used in IPCC reports
- In-situ observations at the coast
- Sampling intervals of 1 sec to 1 hr
- Measure relative sea level i.e. sea level relative to a fixed point on land
- Land levels could be moving, so we often also measure vertical land motion at a tide gauge

Soufriere, St Lucia

Tide gauges

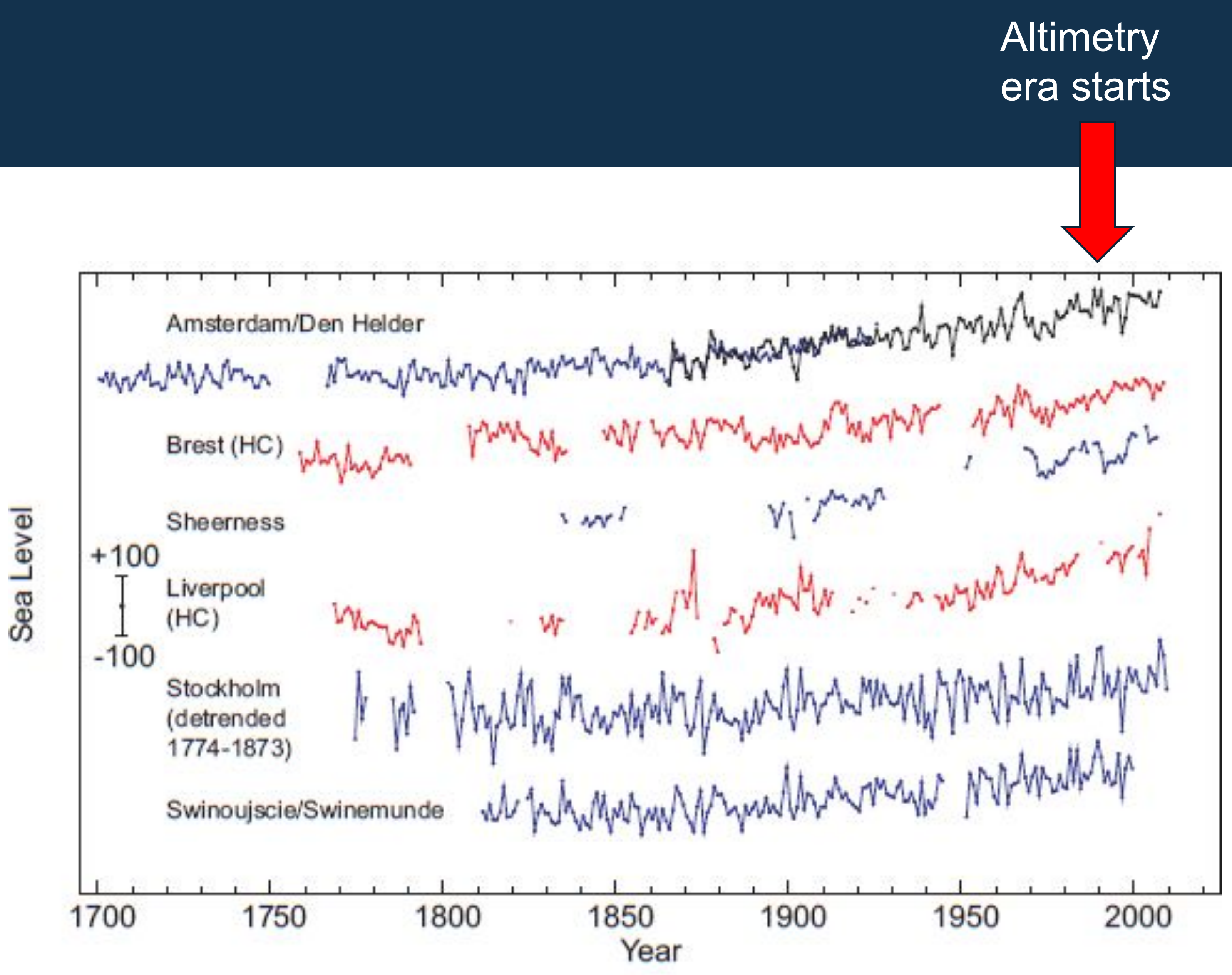
- Biased towards coasts, islands, Northern Hemisphere



Tide gauge locations from the Permanent Service for Mean Sea Level (PSMSL)

TIDE GAUGES

- Continuous, high frequency record
- Captures most variability
- Long records available (wrt altimetry)



Two methods of sea level measurement

- **Satellite Altimetry**
- Measures absolute (or geocentric) sea level
- Near-global, gridded spatial coverage
- Lower frequency sampling
- Does not capture higher frequency variations e.g. waves, seiches, tides
- Observations since 1992
- Problematic near the coast

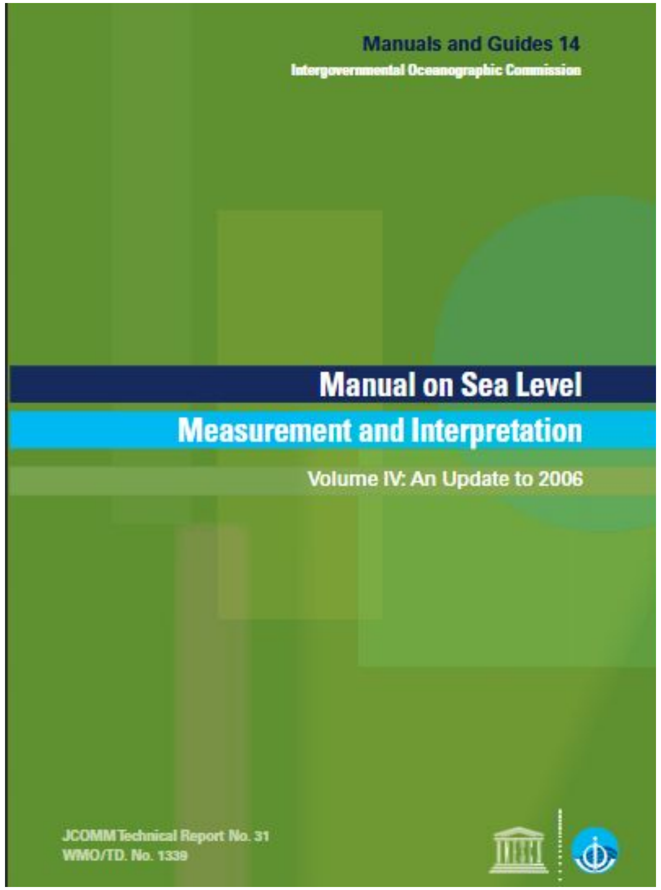
- **Tide Gauges**
- Measures relative sea level
- Biased towards coasts, islands, Northern Hemisphere
- Continuous, high frequency record
- Captures most variability
- Long records available >200 years

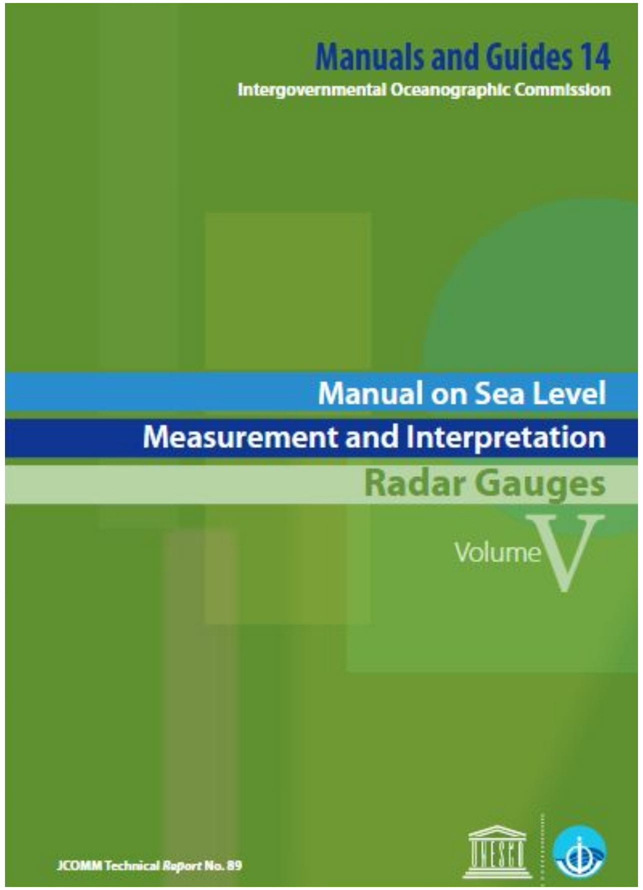
Tide gauge and altimetry data are complementary

GLOSS Manuals

https://gloss-sealevel.org/library/manuals-and-guides

Manual IV and V are essential reading





1. Tide poles/staffs

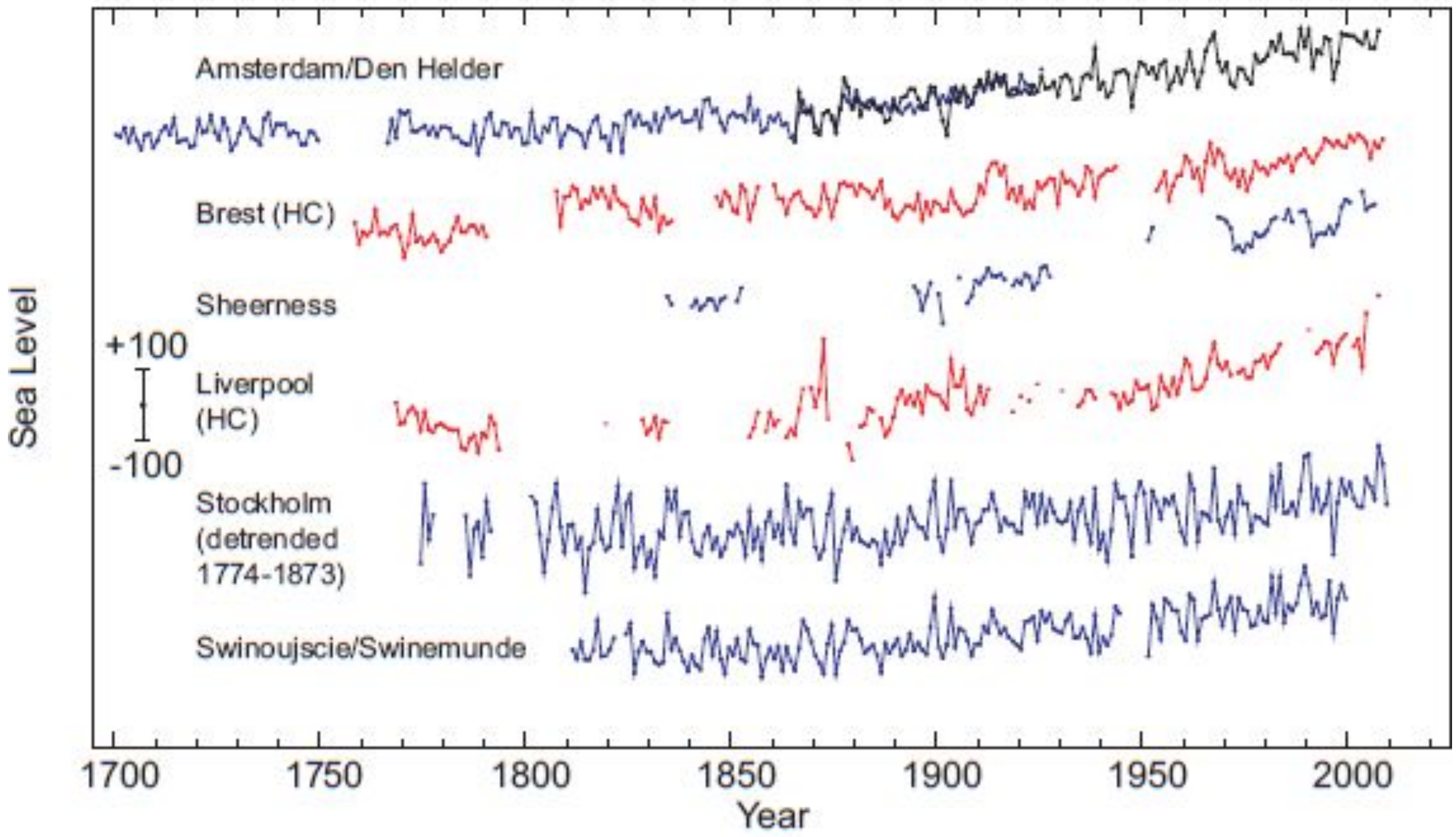
Tide Poles/Staffs

- The simplest possible system and lowest cost
- Important common sense ‘reality check’ alongside modern tide gauge systems
- Nowadays, not a primary source of sea level data.
- However, it is always worth having a simple tide pole at every gauge site as a check.

Falkland Islands 2009

Liverpool

Ganters Bay, St Lucia

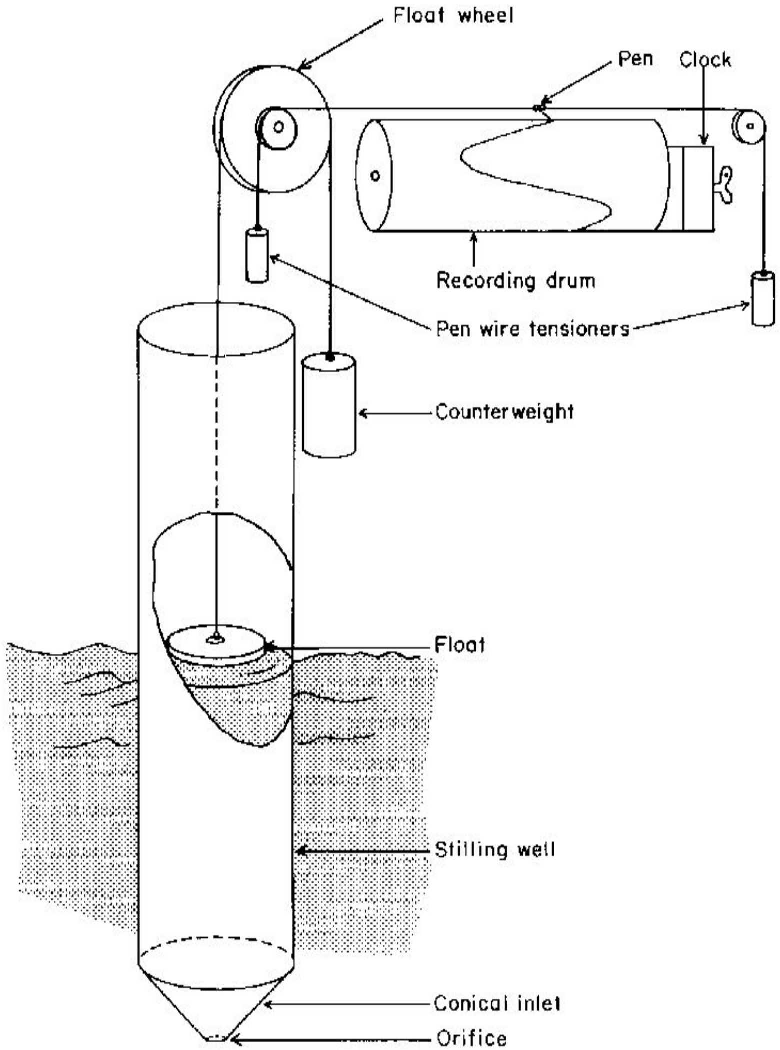


Long tide gauge records from northern Europe

Float Gauges

Classical float gauge

- Used for >200 years
- Some still in use today
- Mechanical system
- Well stills wave action (mechanical filter)
- Float is connected to a recording drum via a system of weights and pulleys
- Pen records tide on a paper chart attached to the drum

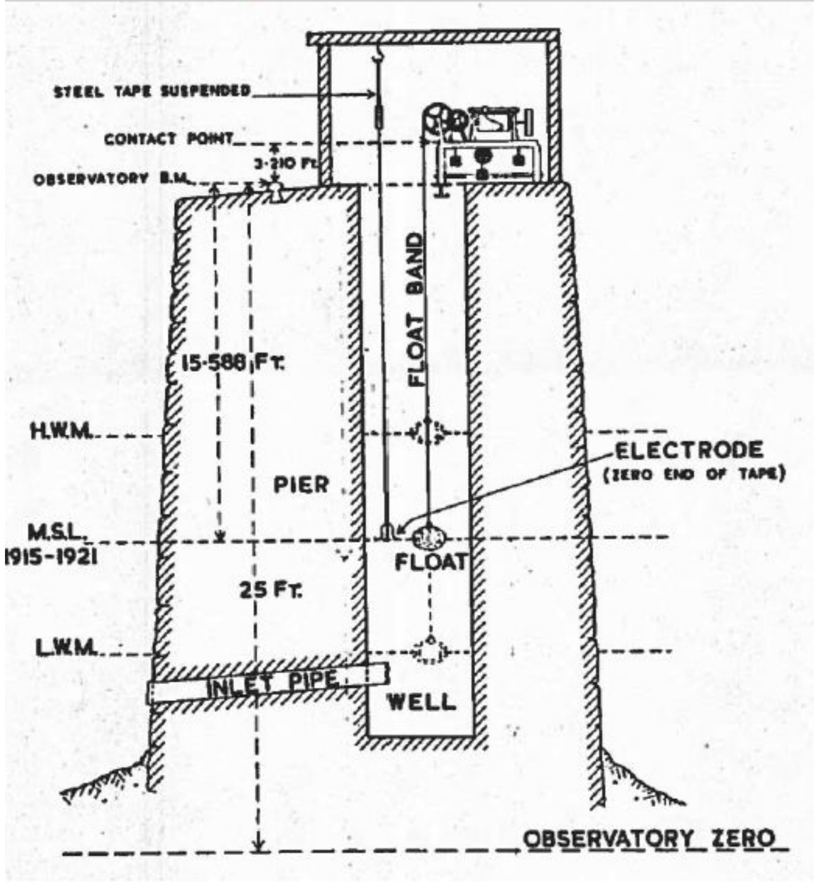


Importance of float gauges

- They still form a large part of the global network
- No need for paper charts now. They can be made digital with the use of shaft encoders
- Even if they are now being replaced with acoustic, pressure and radar systems, they were the source of most of the historical record

Two Stilling Wells with Float Gauges at Holyhead, UK

Float and stilling well gauge at Newlyn, UK



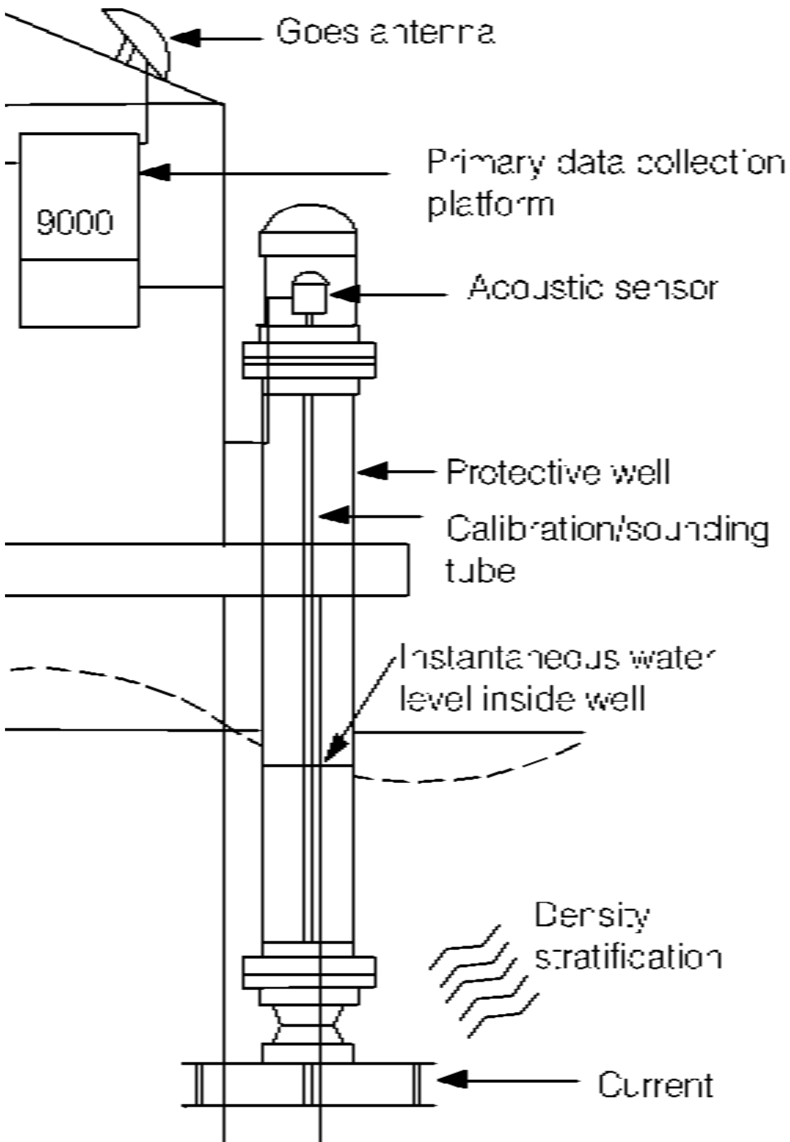
Used to define the national datum (Ordnance Datum Newlyn, ODN) 1915-21


VEGA
VEGA


Acoustic gauges

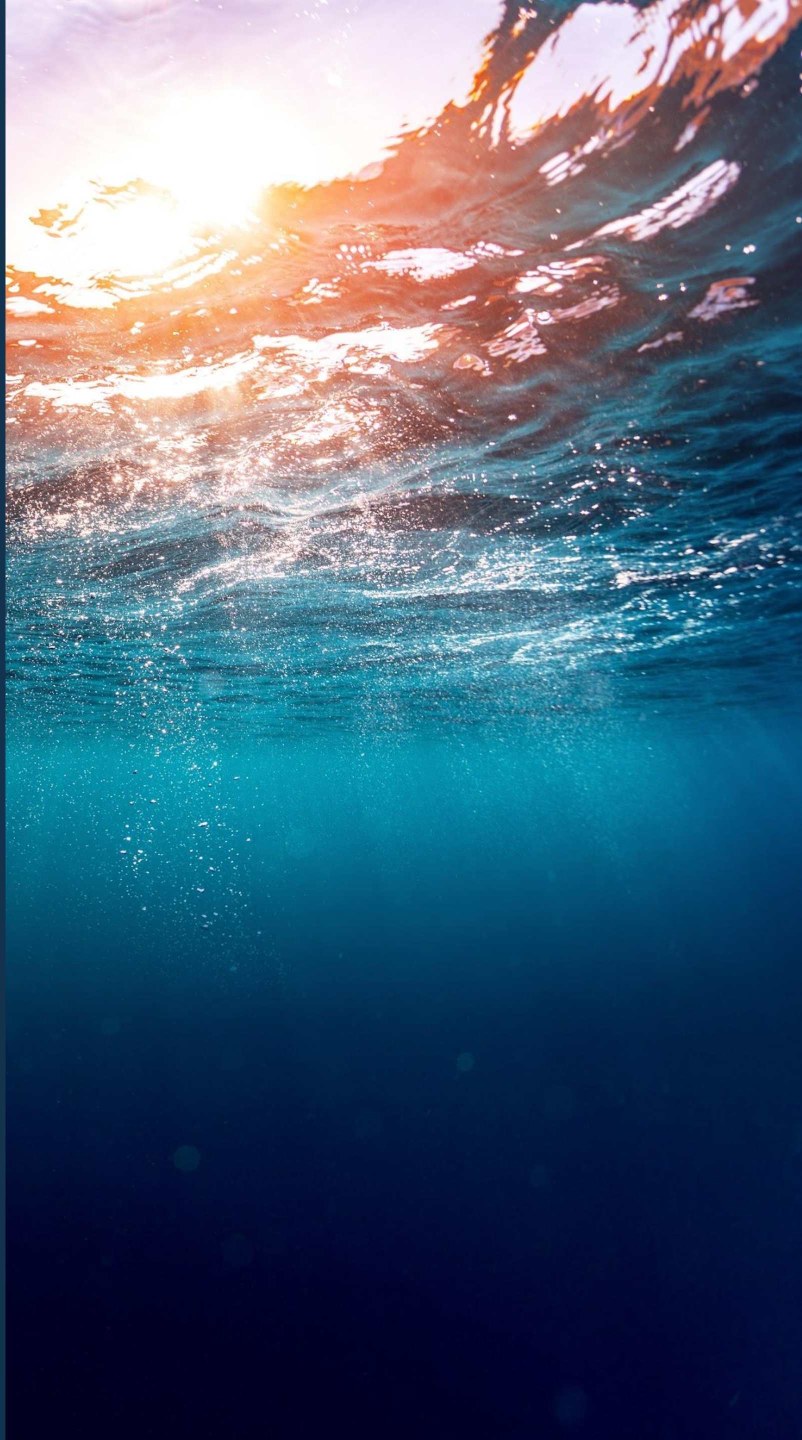
ACOUSTIC GAUGES

- Were a standard in many areas (e.g. USA, Australia)
- Acoustic systems in open air or inside the stilling wells of float gauges.
- Cheap but difficult to operate to good standards
- Require temperature control/correction



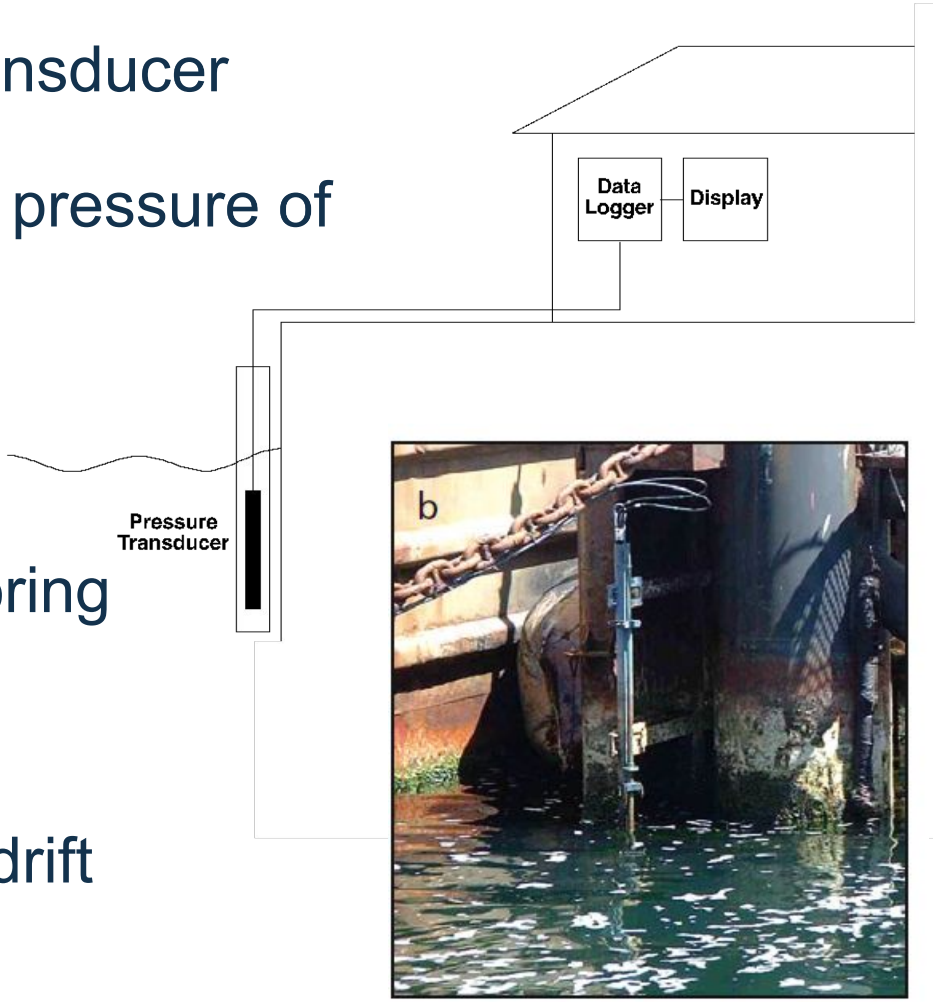
Acoustic gauges, Australia

Pressure gauges



Pressure gauges

- Underwater pressure transducer
- Measure the hydrostatic pressure of overlying water column
- Can't be overtopped
- Used for tsunami monitoring
- Difficult to maintain
- Prone to biofouling and drift

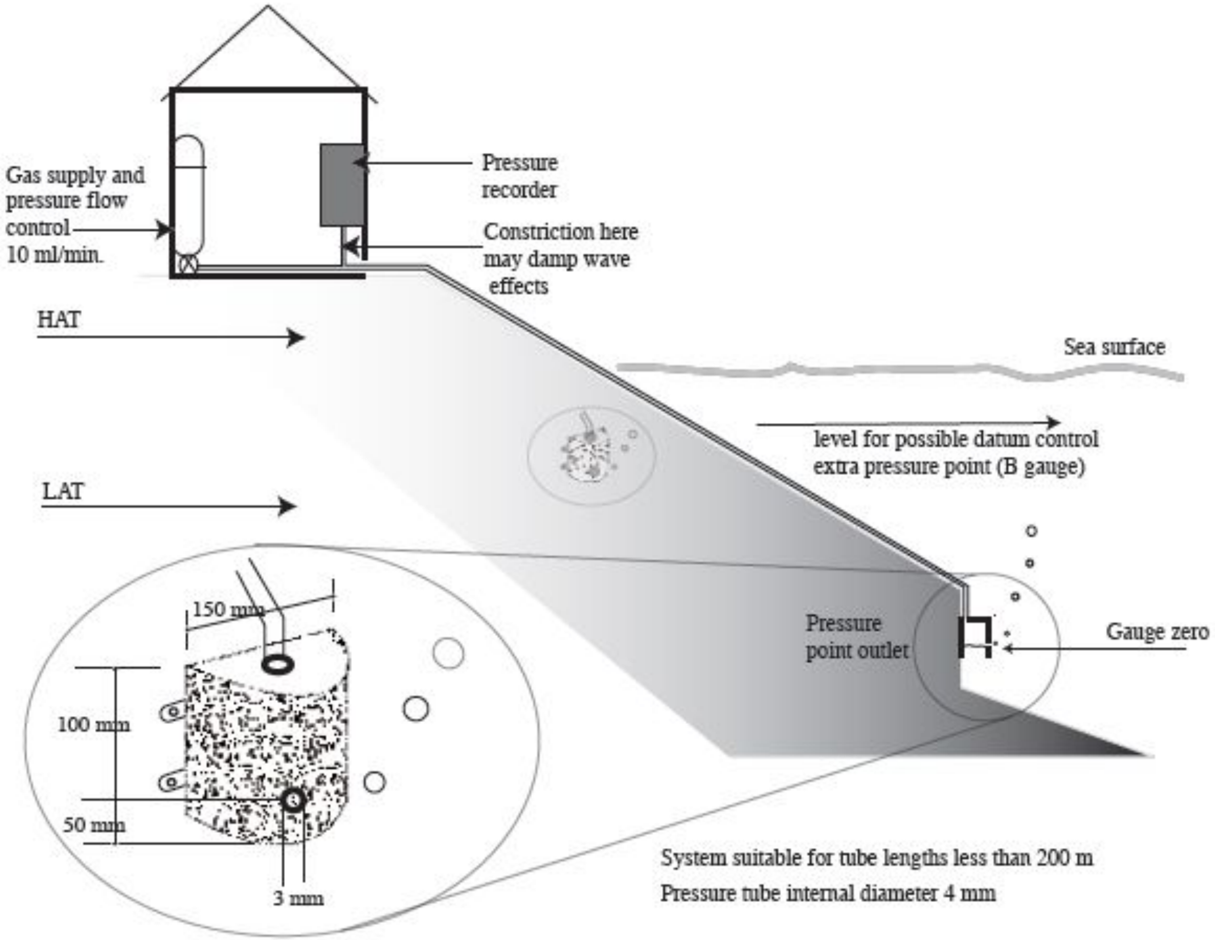


Stanley, Falklands

Ganters Bay, St Lucia

Pressure gauges

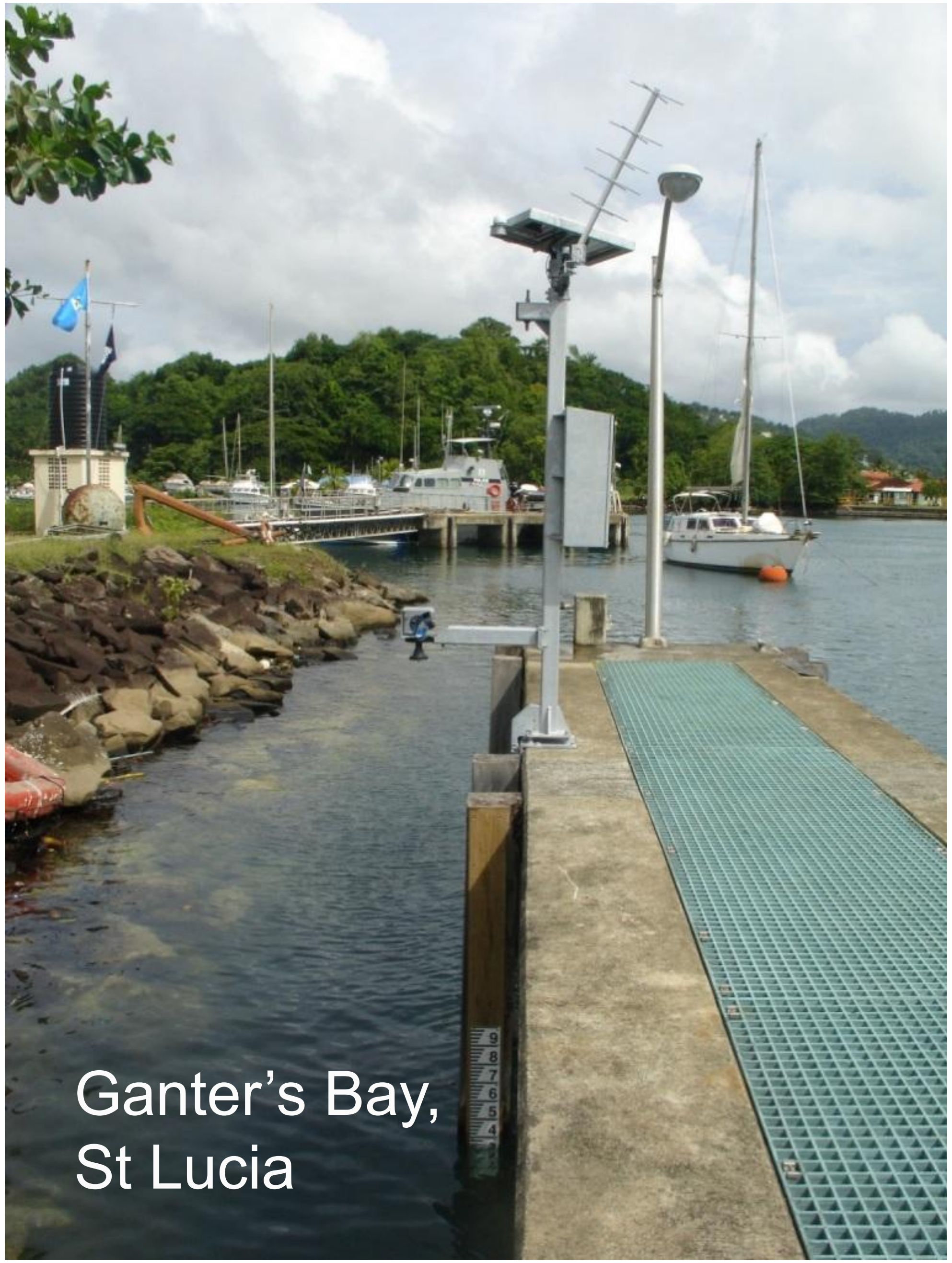
- Bubbler system
- Pressure sensors located on land, with an outlet below the sea surface
- Can't be overtopped
- High precision
- Costly to maintain
- Used extensively in UK since 1980's

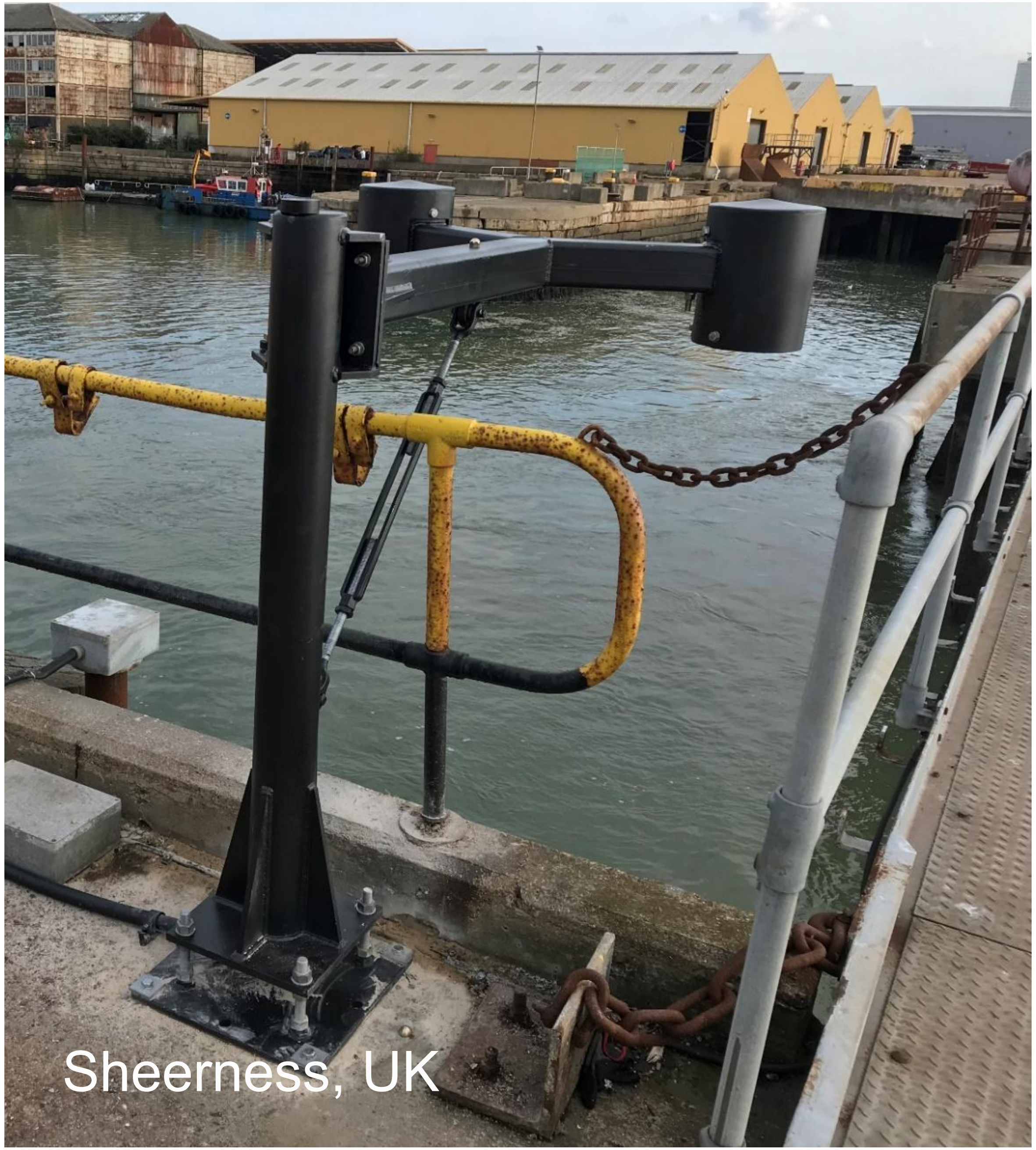


Radar gauges

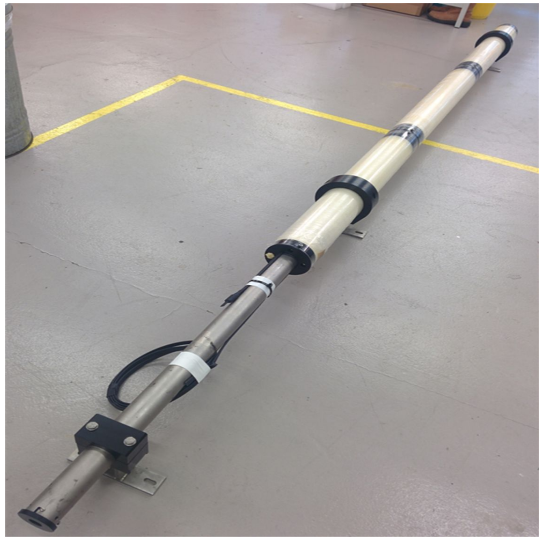
Radar gauges

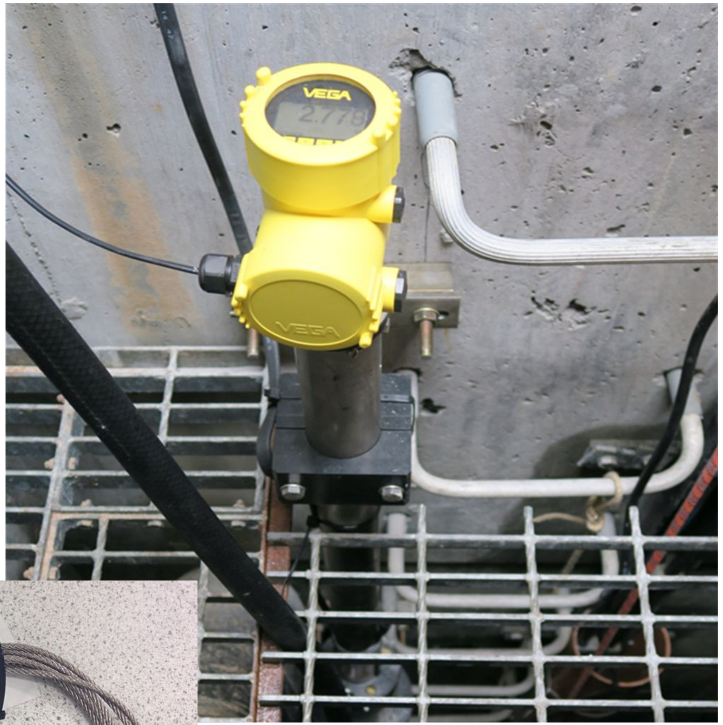
- Measure the time of flight of radar pulses
- Relatively cheap
- Easily installed (no need for divers or stilling wells etc.)
- Can be damaged/overtopped


Ganter’s Bay,
St Lucia


Sheerness, UK

Radars in polar regions – Rothera, Antarctic Peninsula





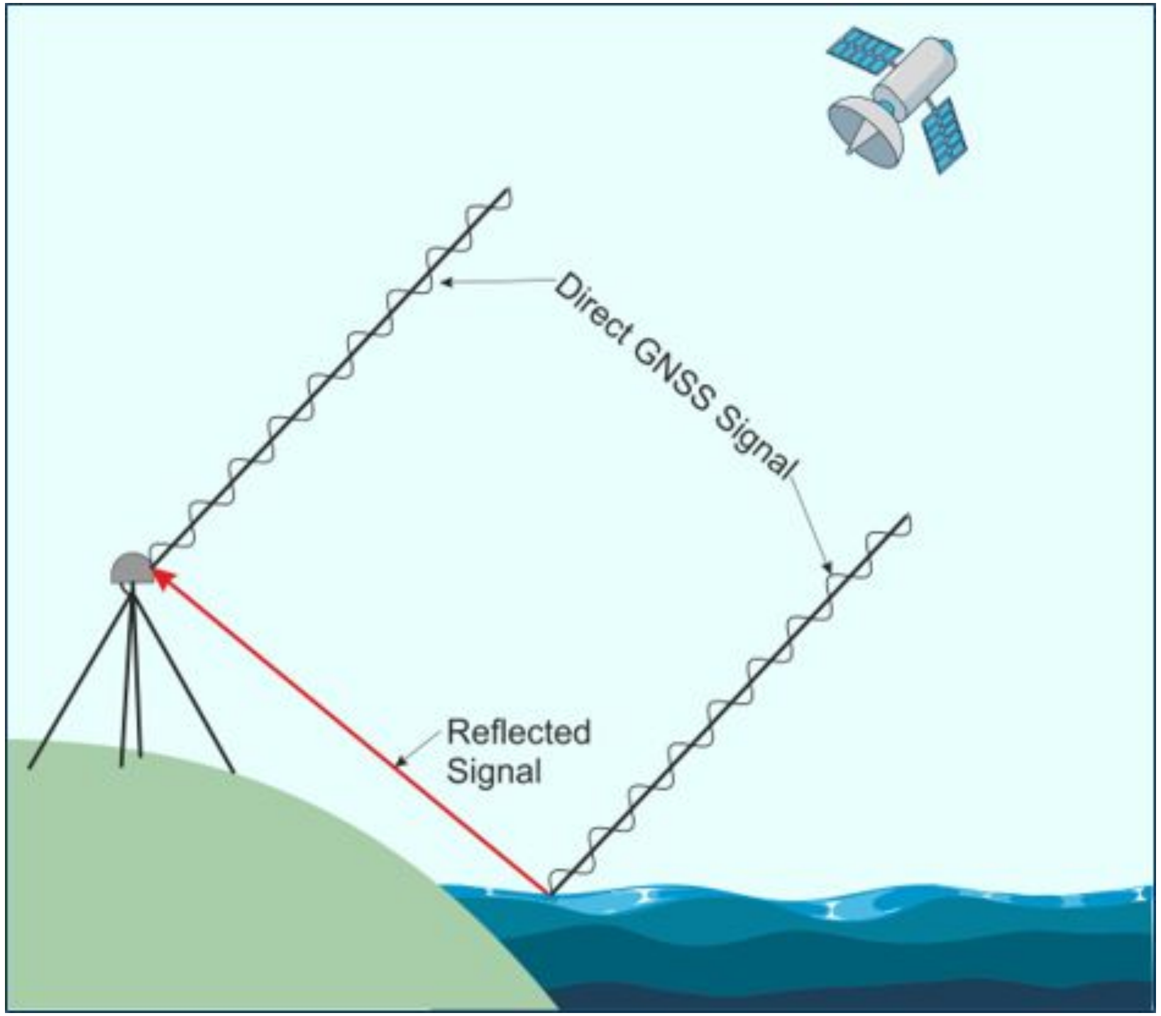
GNSS-IR gauges

What is GNSS?

- Global Navigation Satellite System (GNSS) receivers use satellite signals to calculate position of a receiver in a geocentric reference frame
- Examples: GPS (USA), GLONASS (Russia), BeiDou (China), Galileo (EU)
- Detect rates of vertical land motion (VLM)

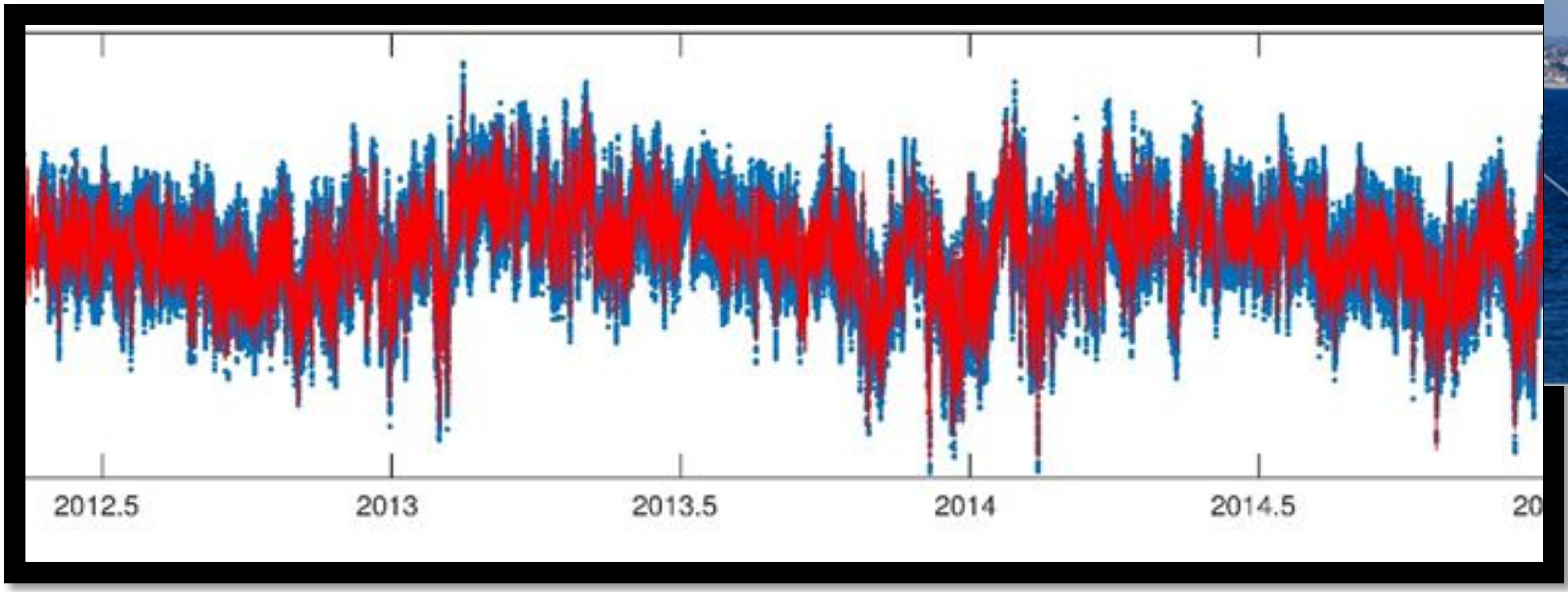
GNSS-Interferometric Reflectometry (GNSS-IR) Tide Gauges

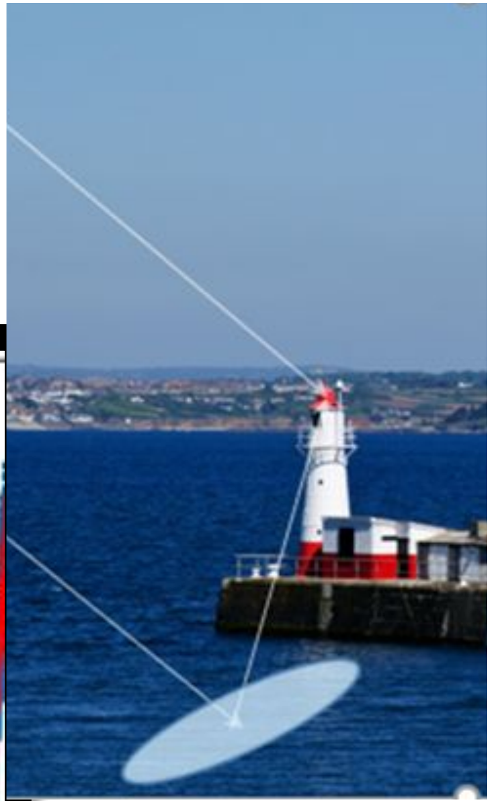
- Exploits a periodic variation in the signal-to-noise ratio between a direct GNSS signal and one that is reflected from a relatively flat surface (such as the sea),
- Allows the elevation of the flat surface (i.e. sea level height) to be inferred.
- At present, GNSS-IR does not offer high frequency sampling or low latency communications (best is ~15 mins)
- Less vulnerable to damage than conventional tide gauges
- Observes across a wide area



GNSS- Interferometric Reflectometry (GNSS-IR)

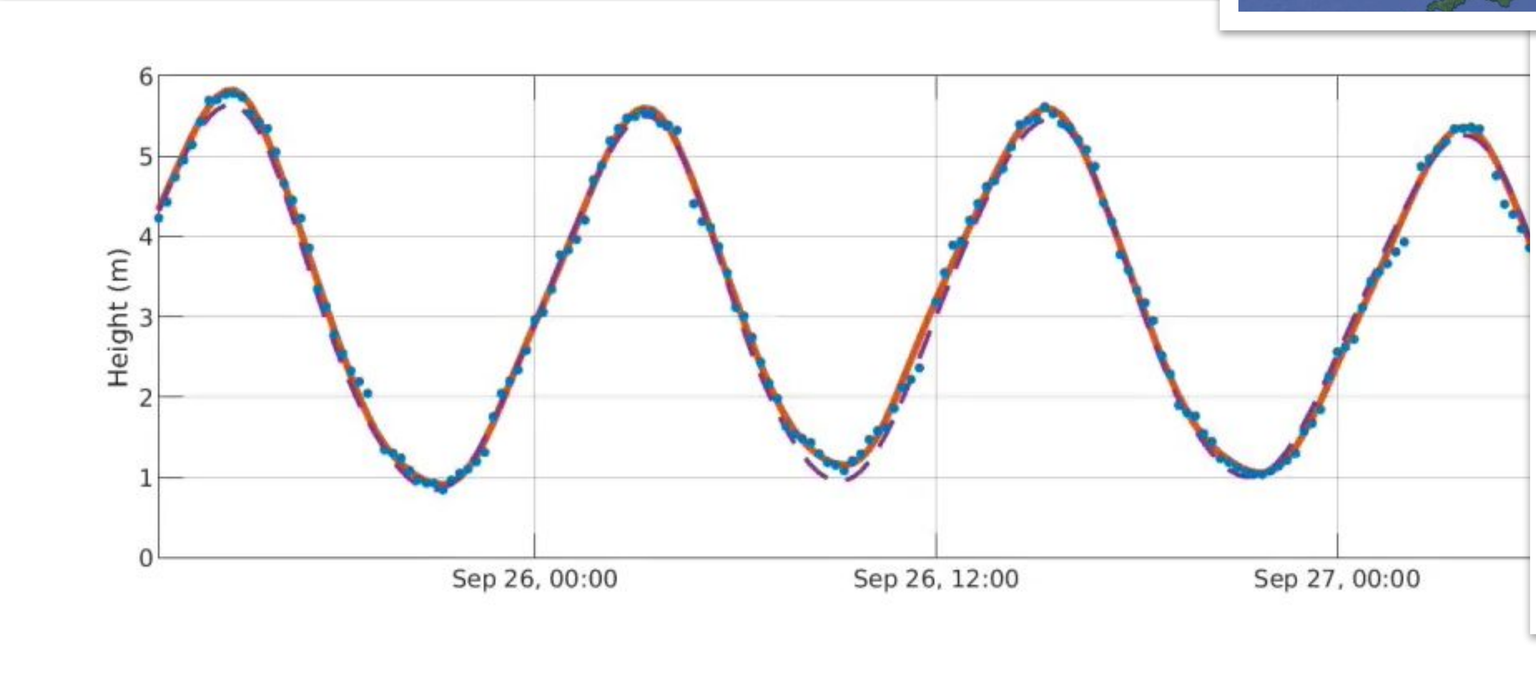
- There is an existing network of receivers

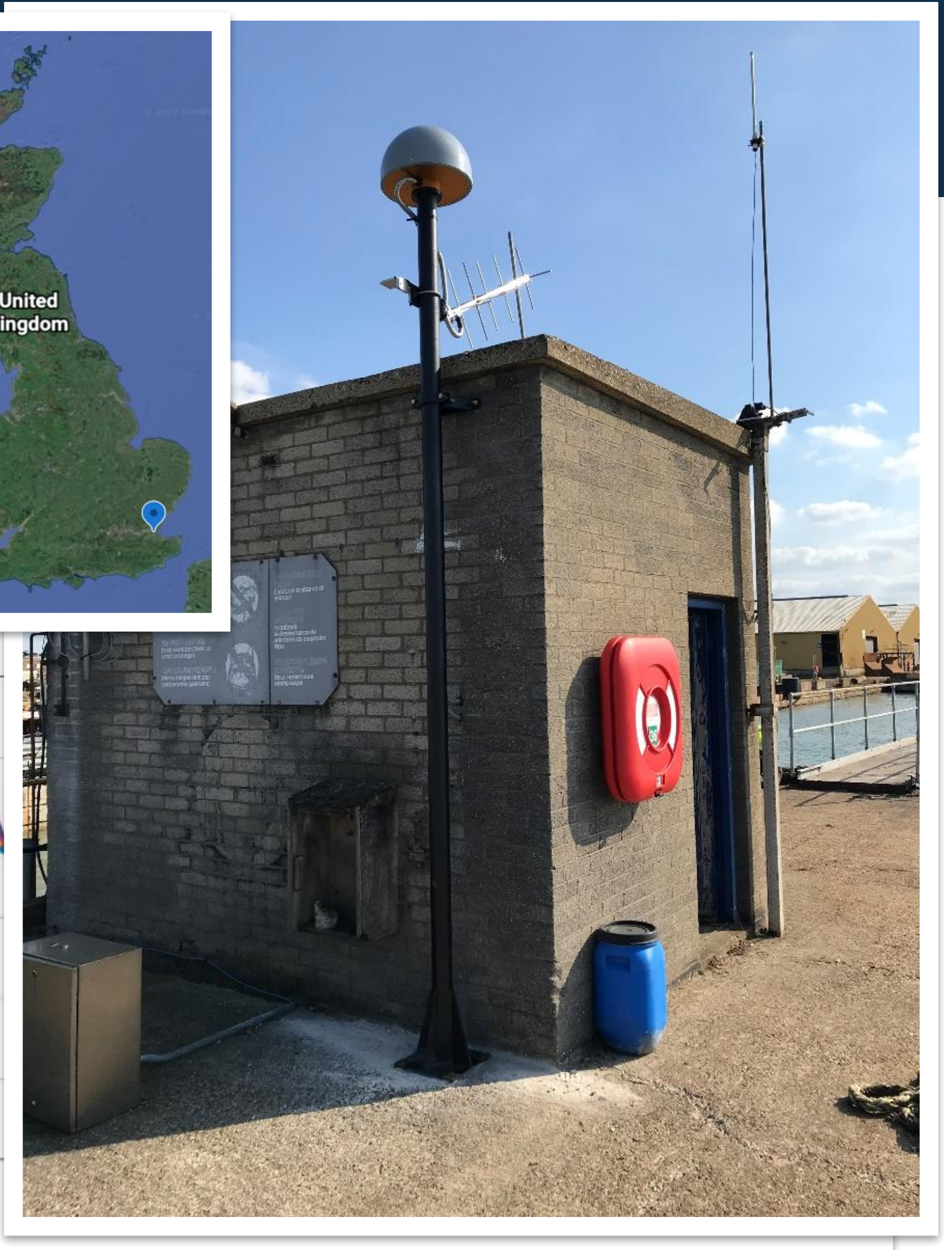




GNSS-IR Gauges

The World's first purpose-built GNSS tide gauge at Sheerness



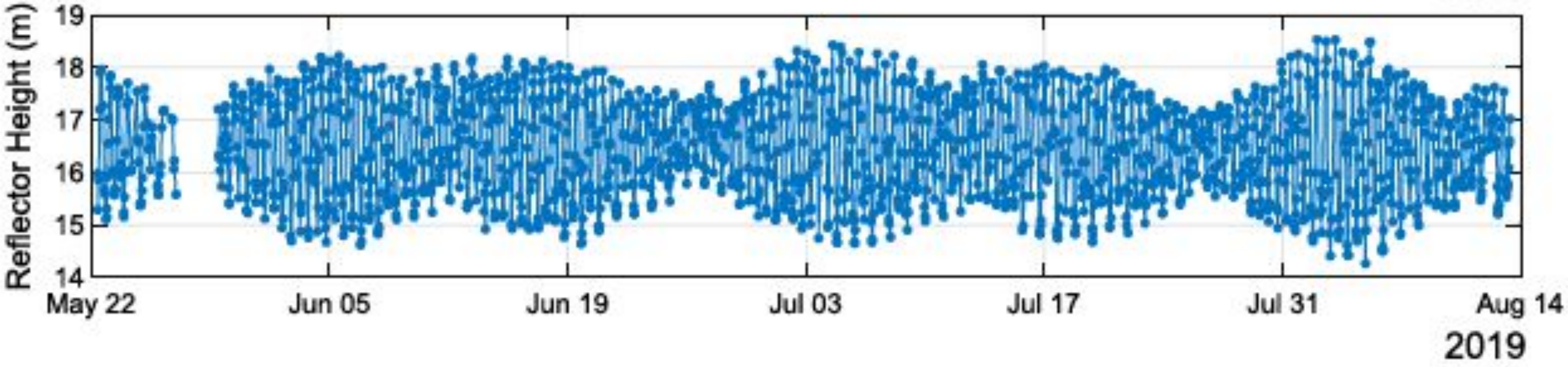


Low cost GNSS-IR tide gauges

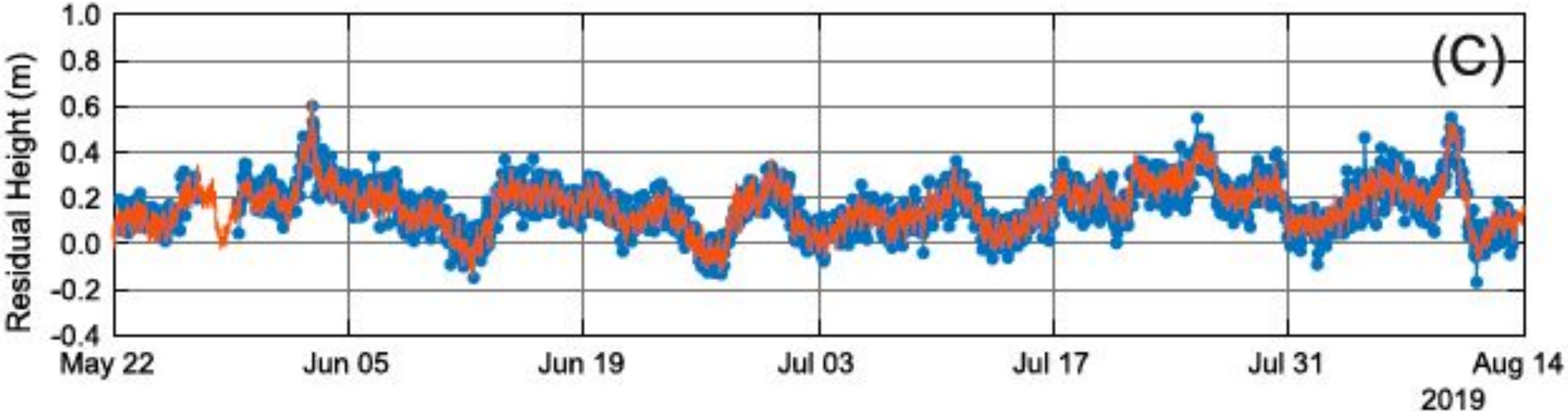
- GNSS for VLM cost ~£15k. Low-cost receivers start at ~£30
- Can low cost GNSS determine sea level height?
- Collaboration with RNLI in Sligo, Ireland to determine tides near a dangerous causeway
- Less prone to damage than standard tide gauges

Low cost GNSS-IR tide gauges

Including tides

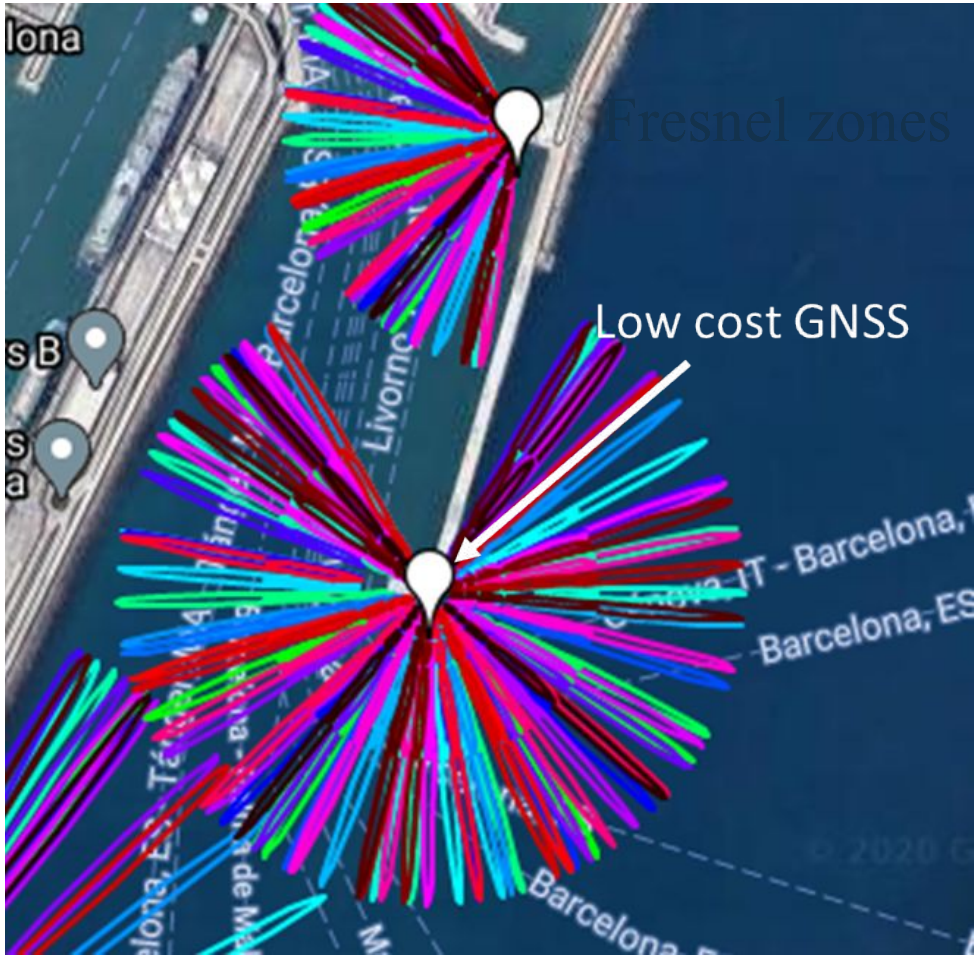


Detided and compared with conventional tide gauge observations (in red)

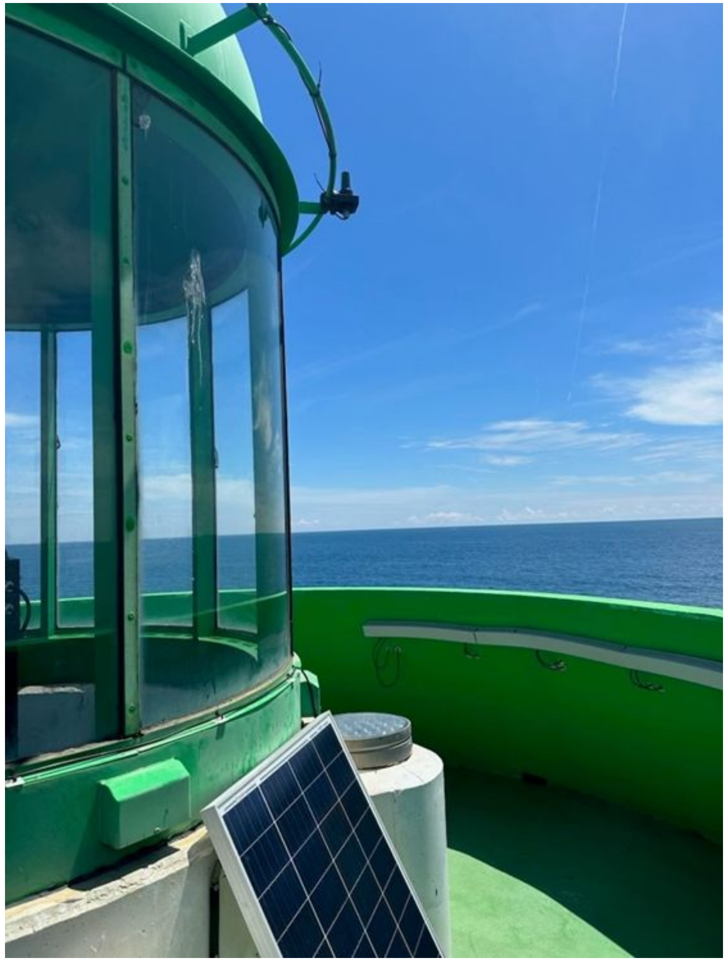


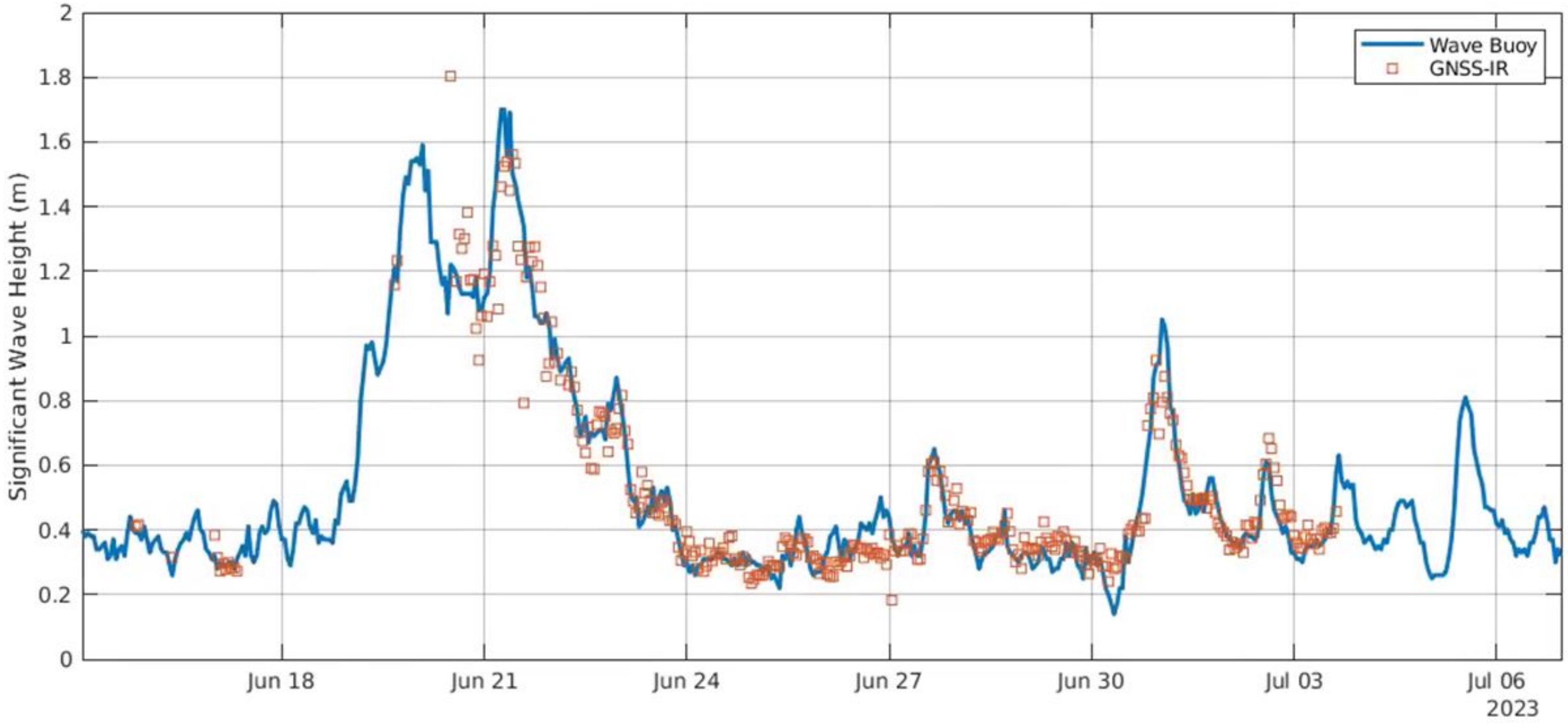
GNSS-IR for wave monitoring

- Barcelona – major container port with large swell waves outside the harbour and frequent overtopping of the pier
- Need to monitor wave height outside the harbour



GNSS-IR for wave monitoring



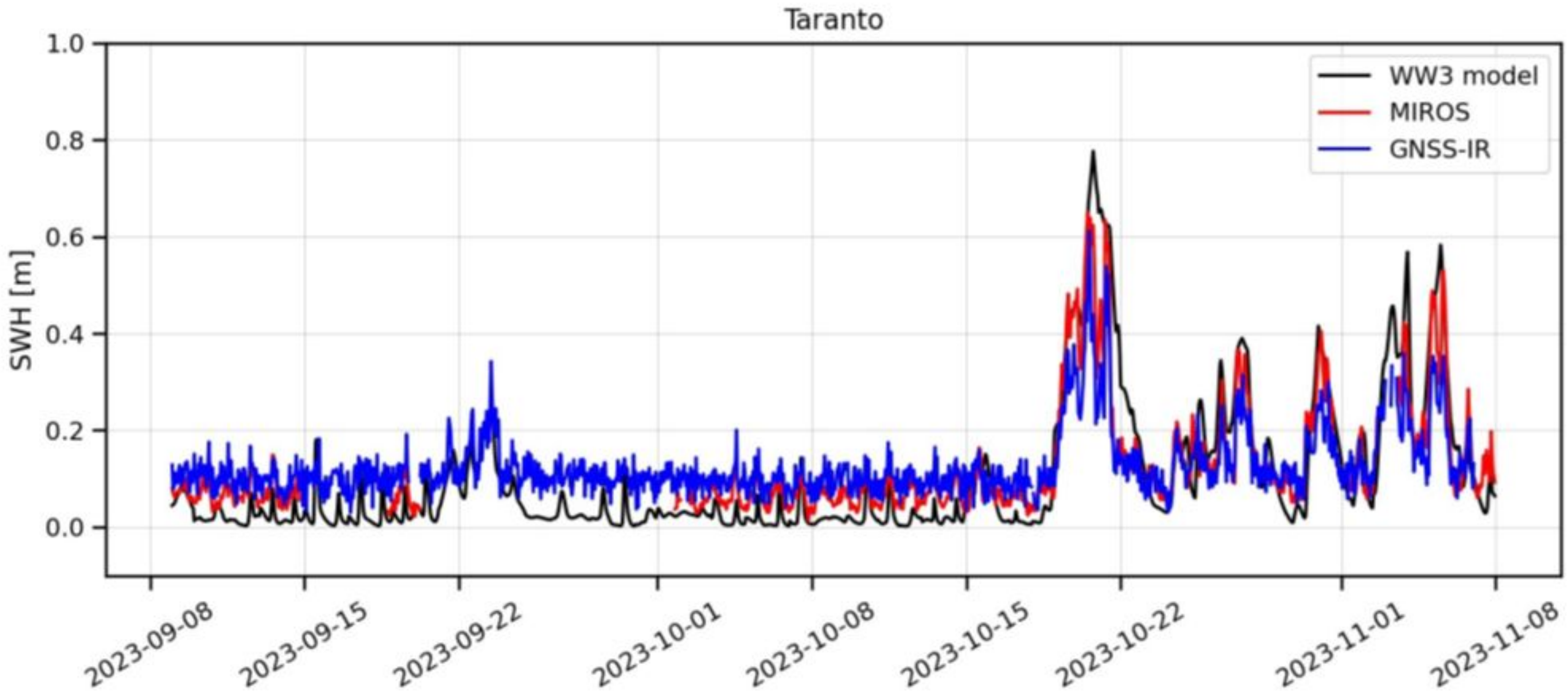


Performs well against a conventional (and expensive) wave buoy

GNSS-IR for wave monitoring

- Taranto (Italy) experiences swell waves across a large bay.
- Installed a geodetic GNSS for vertical land motion, sea level across the wider bay area and significant wave height (also across the bay area)
- Conventional radar for sea level at the coast
- MIROS radar for wave height at the coast

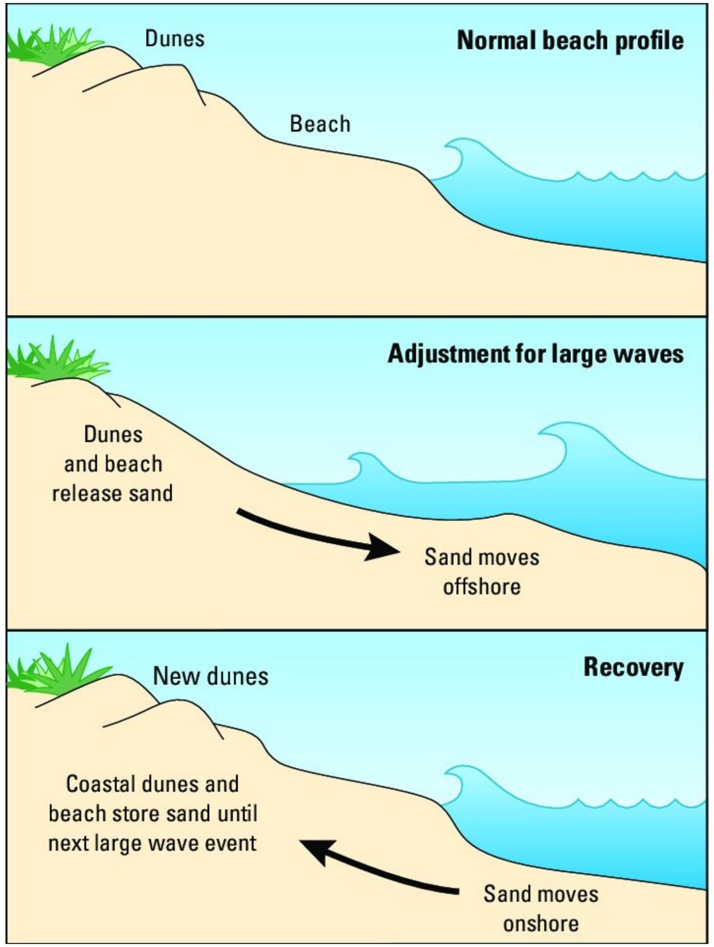
GNSS-IR for wave monitoring



GNSS-IR performs well wrt MIROS wave radar sensor and a WaveWatch3 model

Other applications of GNSS-IR

- GNSS-IR detects changes in a relative flat surface (like the sea surface) so, it can be applied to other surfaces, e.g. beach profile, vegetation (e,g, mangrove extent)
- Elevation of sensors and low cost are major advantages

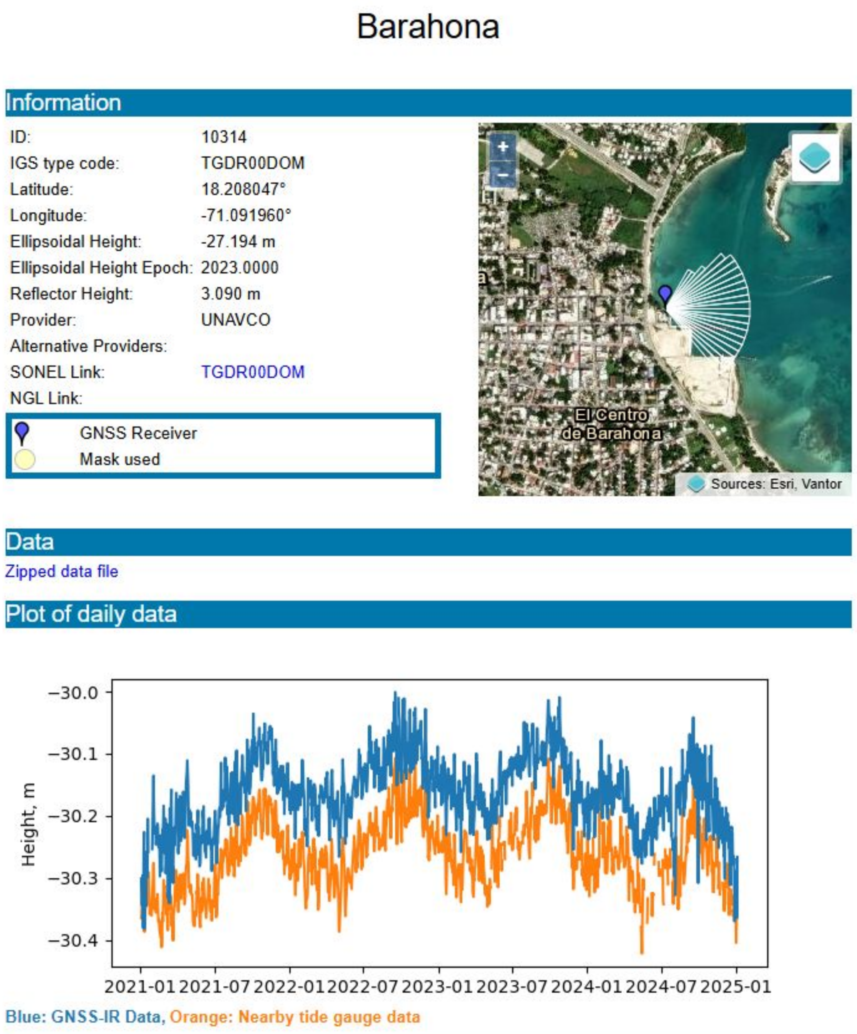


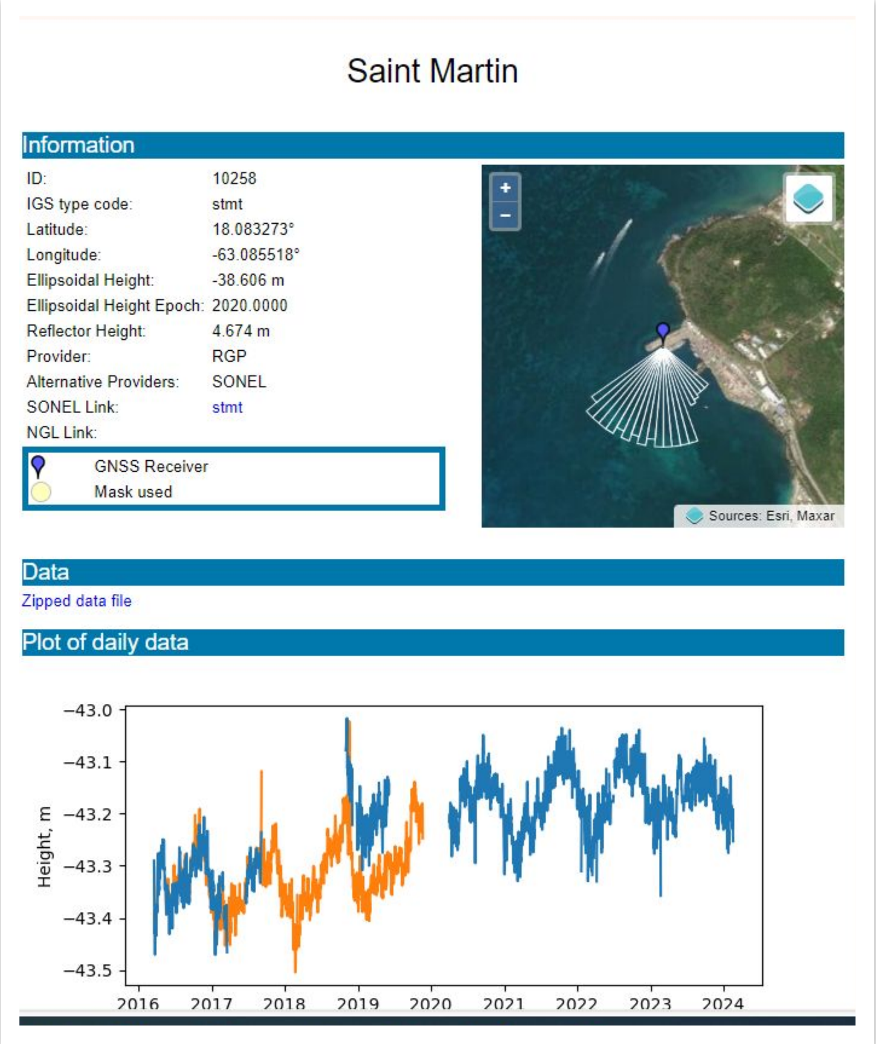
GNSS-IR Sea Level data

- Multiple parameters (sea level, VLM, wave height) can be measured using one instrument
- The technique can be applied to existing GNSS networks
- GNSS-IR sea level data portal at https://psmsl.org/data/gnssir

GNSS-IR sea level data

- GNSS-IR sea level data portal at https://psmsl.org/data/gnssir





Calibration of tide gauges

Tide Pole or dipping measurements

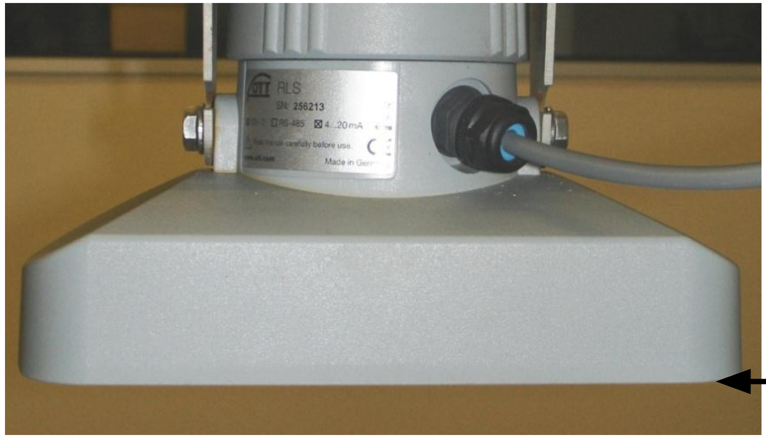
- To check that your system is measuring the sea level you think it is, also make some visual measurements using a tide pole, with the zero of the pole at a known distance below the TGBM.
- Document each step of your work: the range calibration, the levelling between CP and TGBM, and any tide pole or dipping measurements.

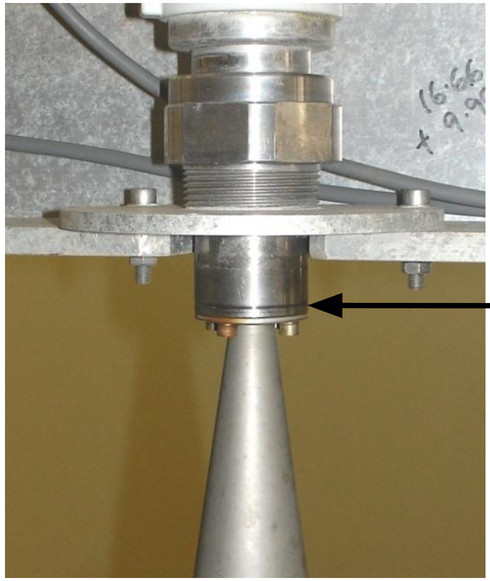
Calibration with dipping measurements

- Or, if you are using a stilling well, make dipping measurements (with the zero of the tape at a know distance below the TGBM).
- A simple dipper tests the level of water in a stilling well (or borehole).
- When the tip of the probe hits the water it completes an electric circuit and a bell rings and light flashes.

Calibration of radar gauges

- Calibration of the range measurement by the gauge is required for all radar gauges
- You must find any offset
- A first step is to find the stated reference level of the sensor (the Contact Point)
- Then make some range measurements to a surface which is a known distance from the Contact Point

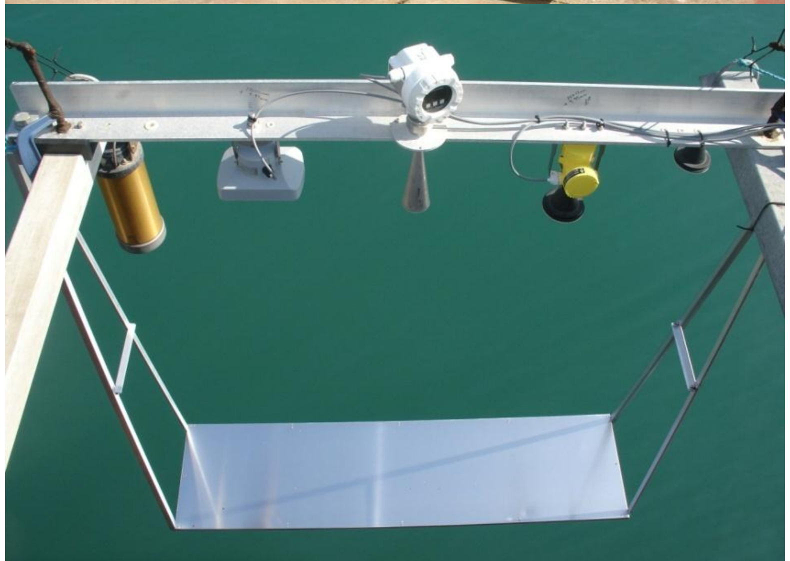




Radar Contact Points

Calibration of radar gauges - targets

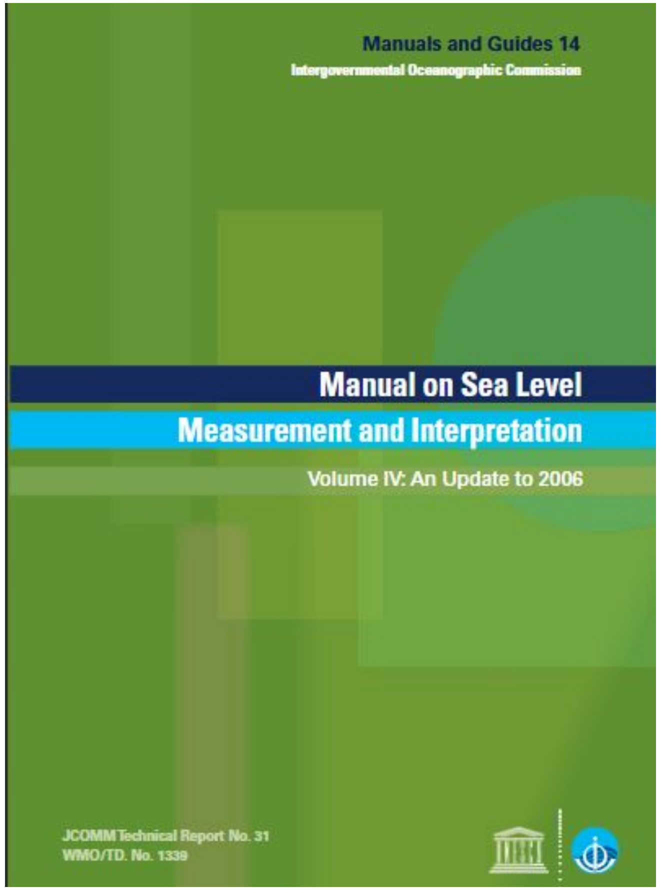


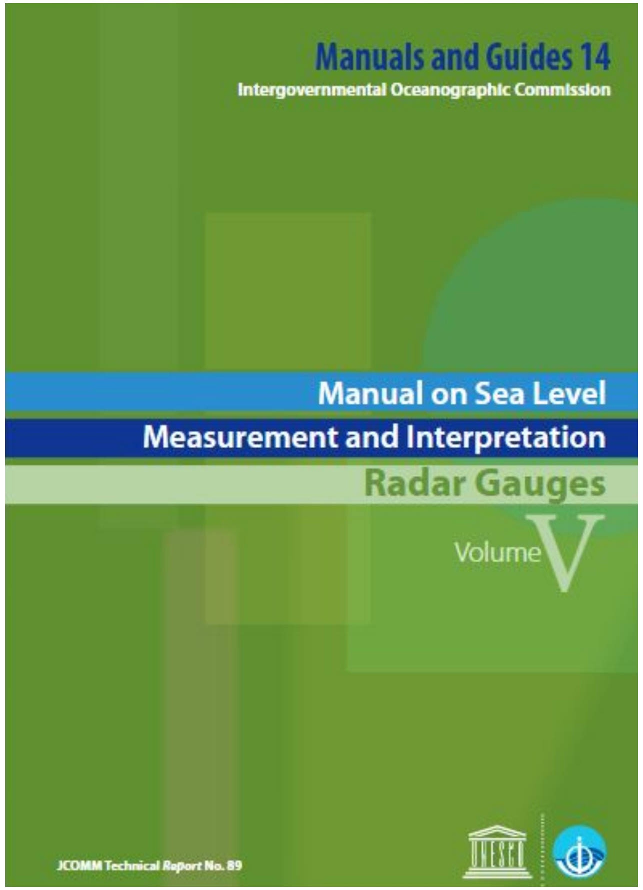



A reminder - further information about tide gauge technology

https://gloss-sealevel.org/library/manuals-and-guides

Manual IV and V are essential reading





ANY QUESTIONS?

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