Faculty of Sciences,
Technology
and Communication

Global Navigation Satellite System (GNSS) at Tide Gauge Installations in the South Atlantic Ocean

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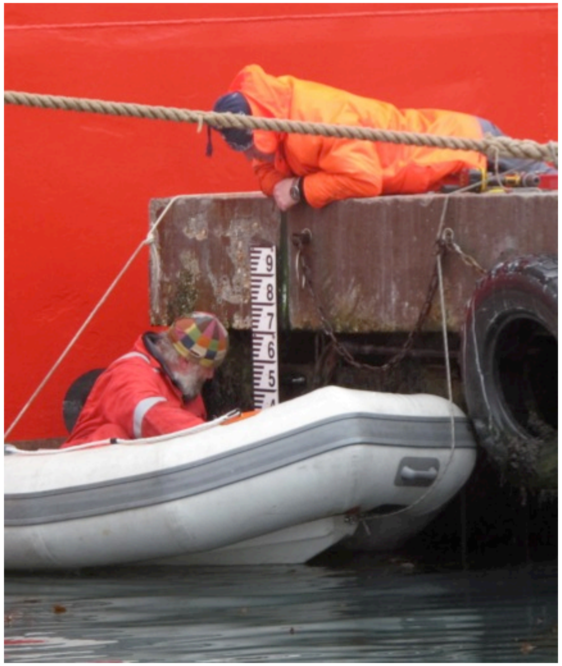
Lecture at the University of Cape Town, 19 September 2017

Overview

- Global Navigations Satellite Systems (GNSS)
- Tide Gauges
  - Relative and geocentric sea level
- South Atlantic Ocean work
- Tristan da Cunha



Tide board installation at King Edward Point Research Station, South Georgia Island in 2014.

Global Navigation Satellite Sytems (GNSS)

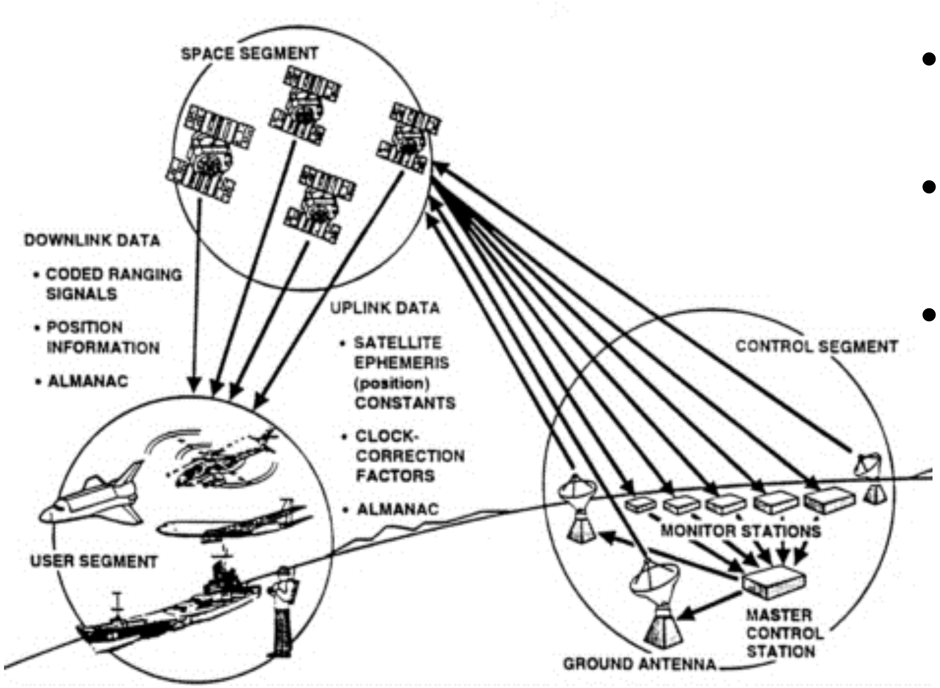
- GPS (Global Positioning System)
  - US, operated since 1980
  - Most widely used GNSS, ubiquitous to modern society
- GLONASS (*Globalnaja Nawigazionnaja Sputnikowaja Sistema)*
  - *Russian, operated since 1982*
  - *Full constellation in 1996, dropped to just 7 satellites in 2002, full constellation since October 2011*
- Galileo
  - European, with two validation satellites in orbit since 2005 and 2008
  - Currently 18 satellites (ok: 14)
- BeiDou (BDS)
  - Chinese, with a first validation satellite on orbit since 2007
  - Currently 15 satellites
- Others (QZSS, IRNSS,…)

Global Positioning System (GPS)

- Supports an unlimited number of receivers capable of tracking the signals of all satellites simultaneously in view (usually between 4 and 12)
- Revolutionized positioning and high-precision applications in geodesy and geophysics
- Largest benefit through the establishment of networks of continuously recording stations

- This enabled Applications such as:
  - GNSS geocentric satellite positions for the entire day (accurate to few cm)
  - GNSS satellite clock corrections (accurate to a few ten picoseconds)
  - Mean receiver coordinates per day (accurate to a few mm)
  - Position of the Earth's rotation axis on the Earth's surface
  - Length of day (daily estimates, accurate to a few microseconds)
  - Tropospheric zenith delays for all stations (which in turn allow GPS to estimate the total water vapour content over the station - provided station pressure and temperature are available) with high time resolution
  - time and (in particular) frequency transfer between time laboratories (sub-nanosecond accuracy)

GNSS Segments

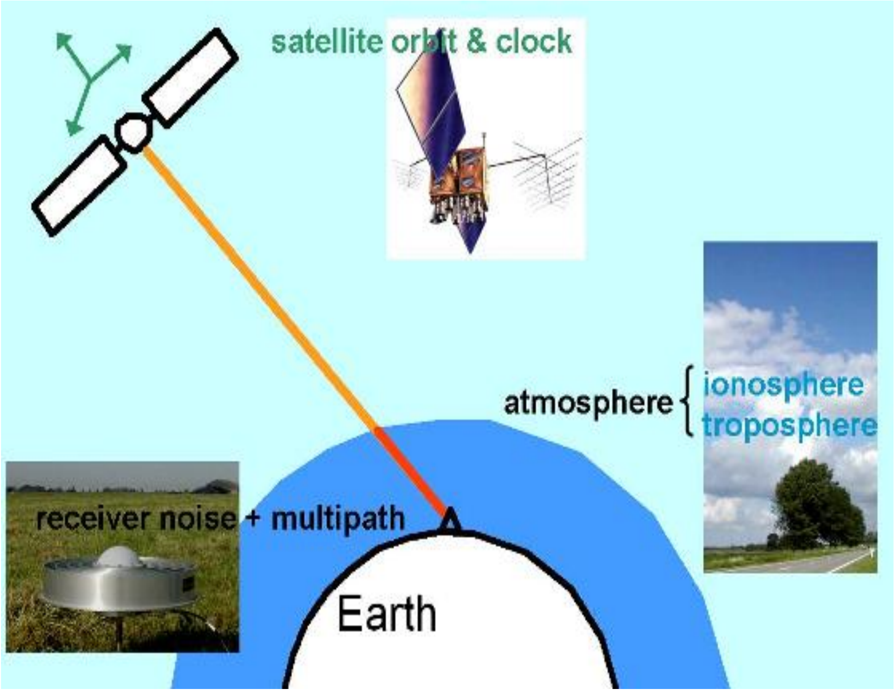


Segments of a GNSS

- Provide position information
- Global coverage
- 3 Segments
  - Space segment: Satellites
  - Control segment: Control & Monitoring stations
  - User segment: Receivers (multiple uses)

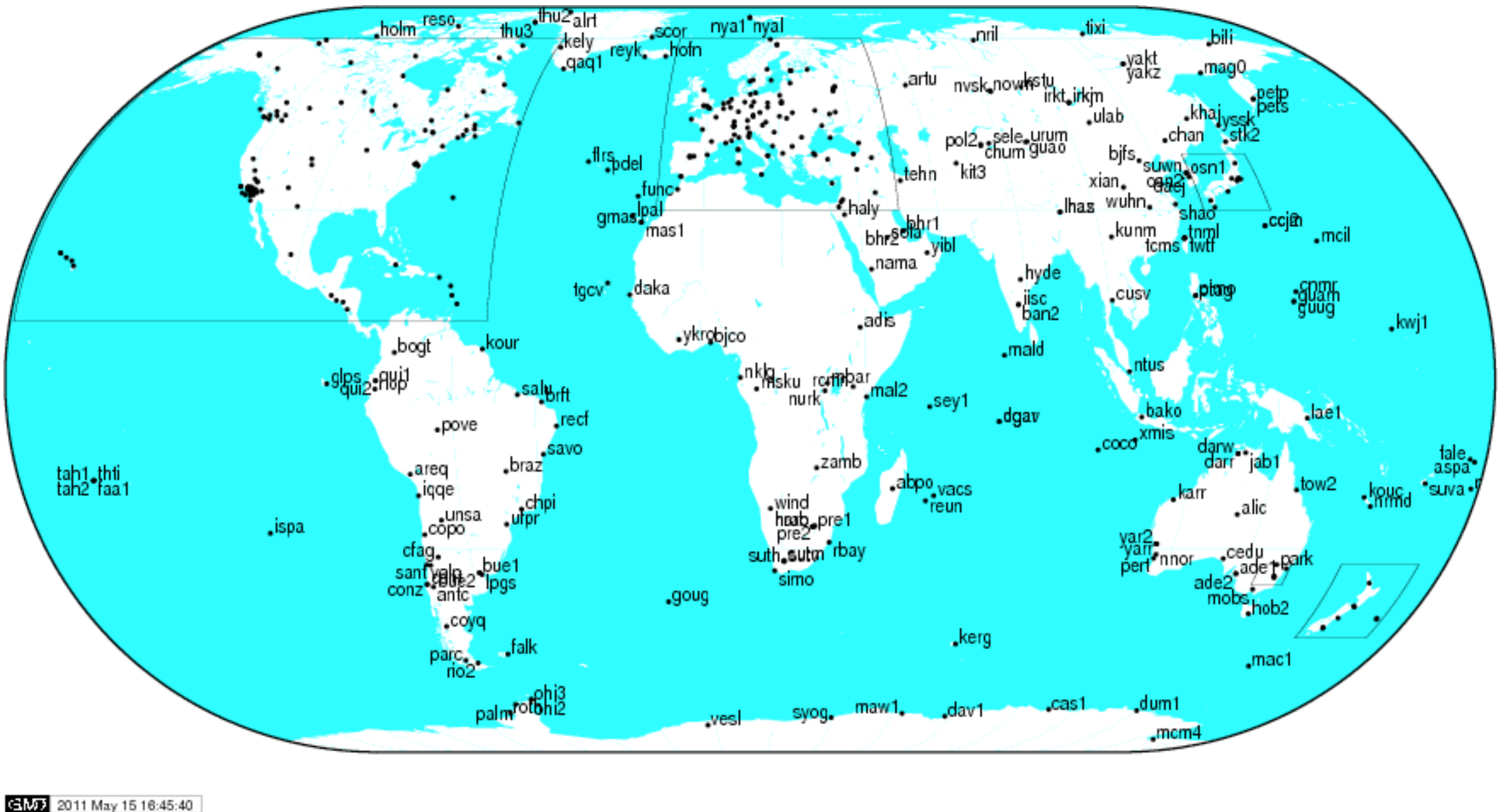
Error sources for GNSS observations

- Orbit errors: error in position of the satellite in the orbit
- Clock errors: lack of synchronization between transmitter and receiver clocks
- Signal delay in Earth's atmosphere: due to difference in refractivity
- Receiver environment: multipath, receiver noise



Error Sources

IGS Tracking Network



International GNSS Service

Formerly the International GPS Service

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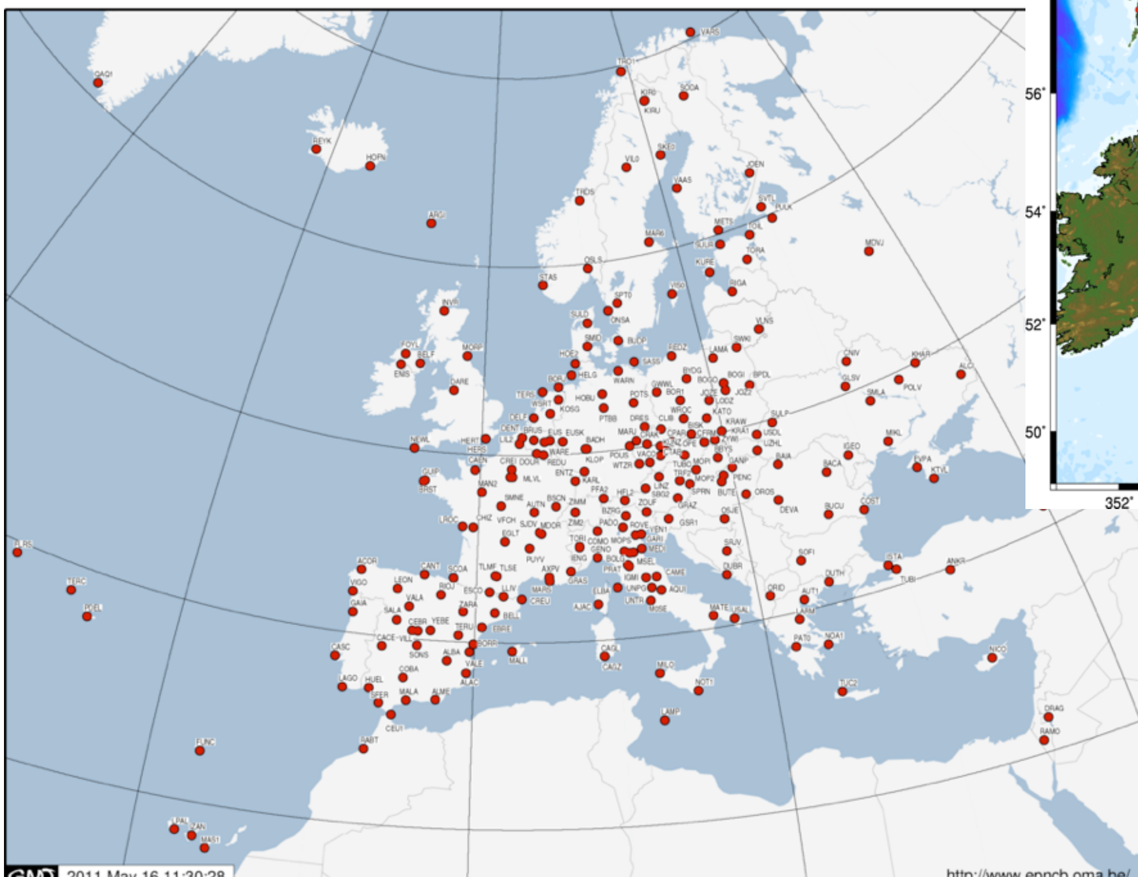
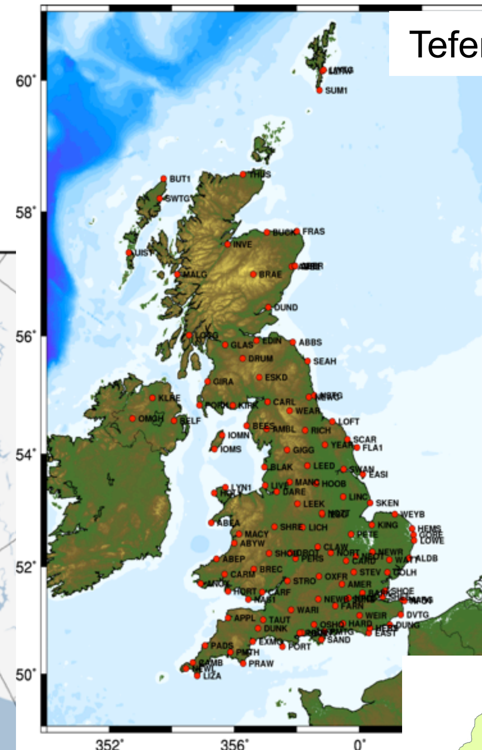
Regional and National GNSS Networks

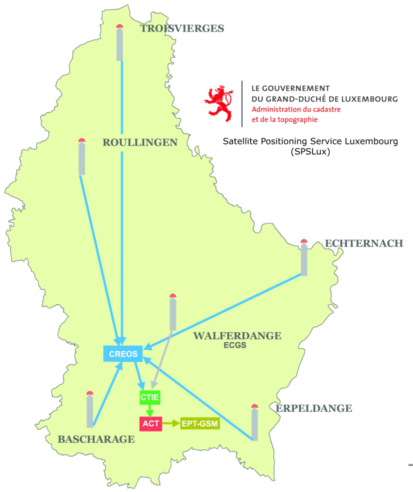
EUREF Tracking Network



Teferle et al (2009)



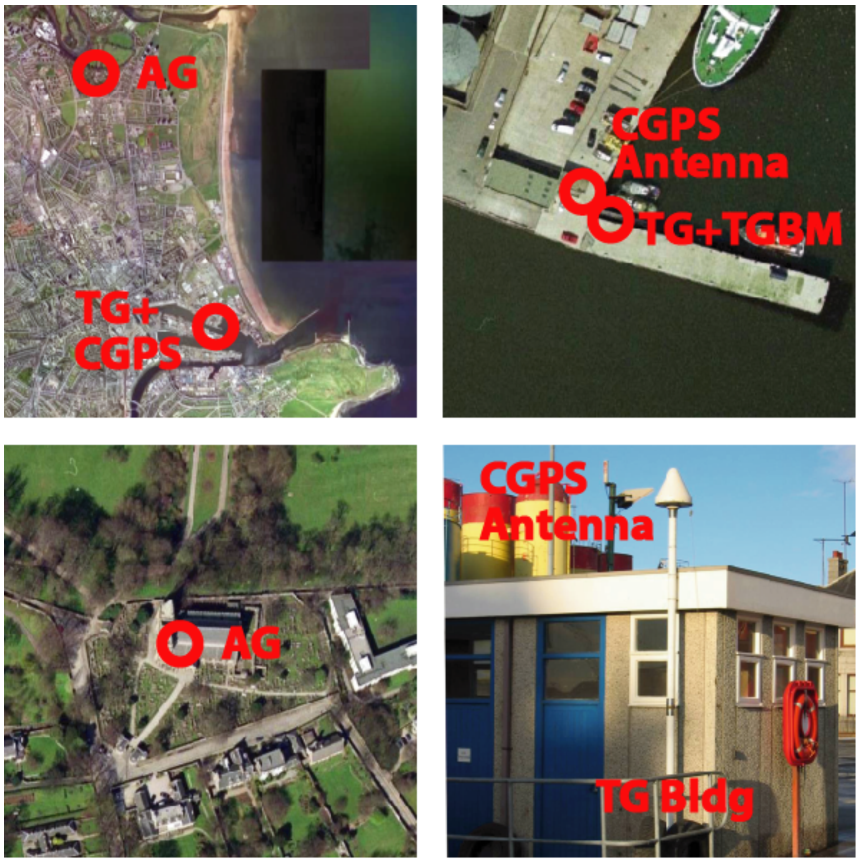
ACT (2011)

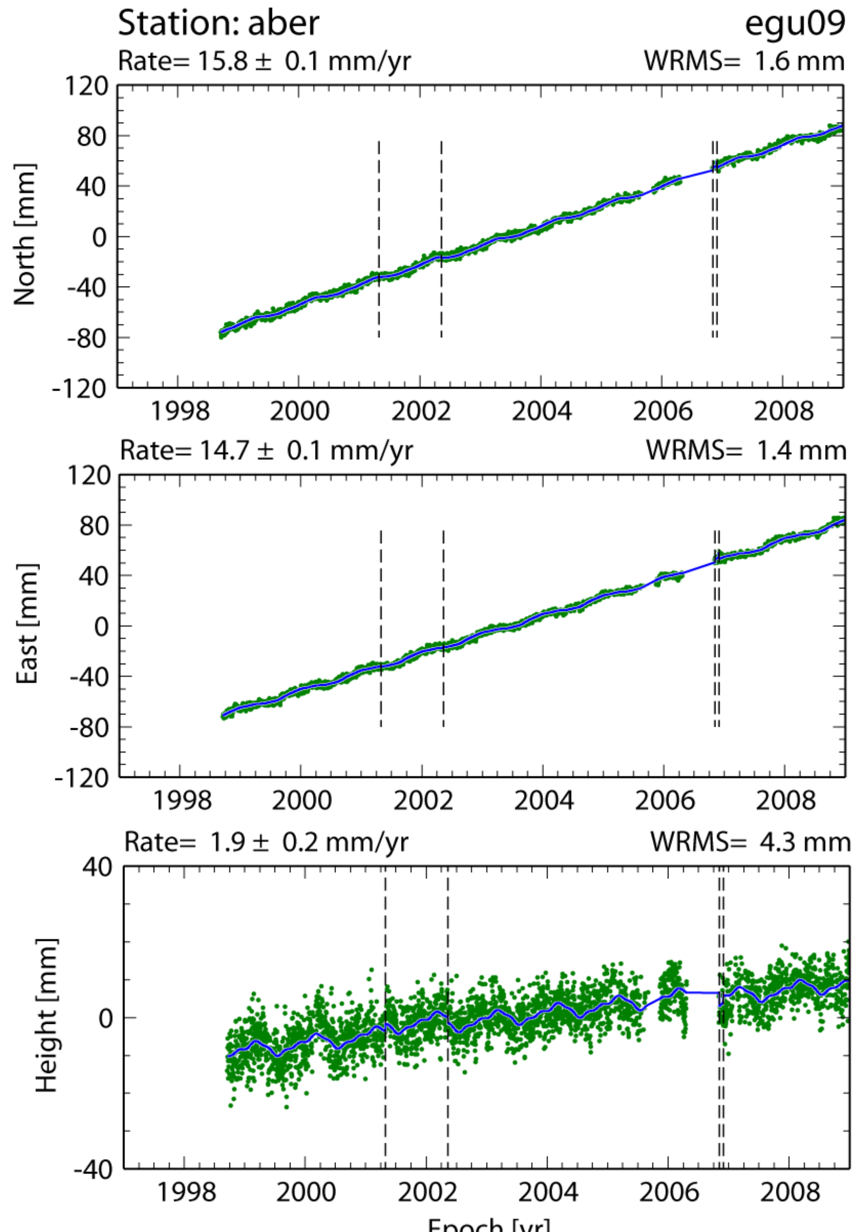


Details of repro2 at BLT

Software	**Bernese GNSS Software Version 5.2 (BSW5.2)**
Satellite Systems	GPS
Elevation cutoff angle	deg and elevation dependent weighting
Ionosphere	Ionospheric-free linear combination (L3) including 2nd orders corrections
Antenna PCV	IGS absolute elevation and azimuth dependent PCV igs08.atx file
Troposphere	1.GMF and DRY GMF mapping for the a priori values and while estimating hourly ZWD parameters using WET GMF 2. VMF mapping for the a priori values and ZWD estimate using WET VMF
Troposphere Gradients	Chen Herring for tropospheric gradient estimation
Conventions	IERS2010
Ocean tides	FES2004
Gravity Field	EGM2008
Ambiguity Resolution	Resolved to integers up to 6000 km using different techniques depending on the baseline length
Datum	No-Net-Rotation (NNR) and No-Net-Translation (NNT) with respect to IGb08
Network	Upwards 450 stations
Time period	1994 to 2015
Data	Double-differenced phase and code observations

Aberdeen





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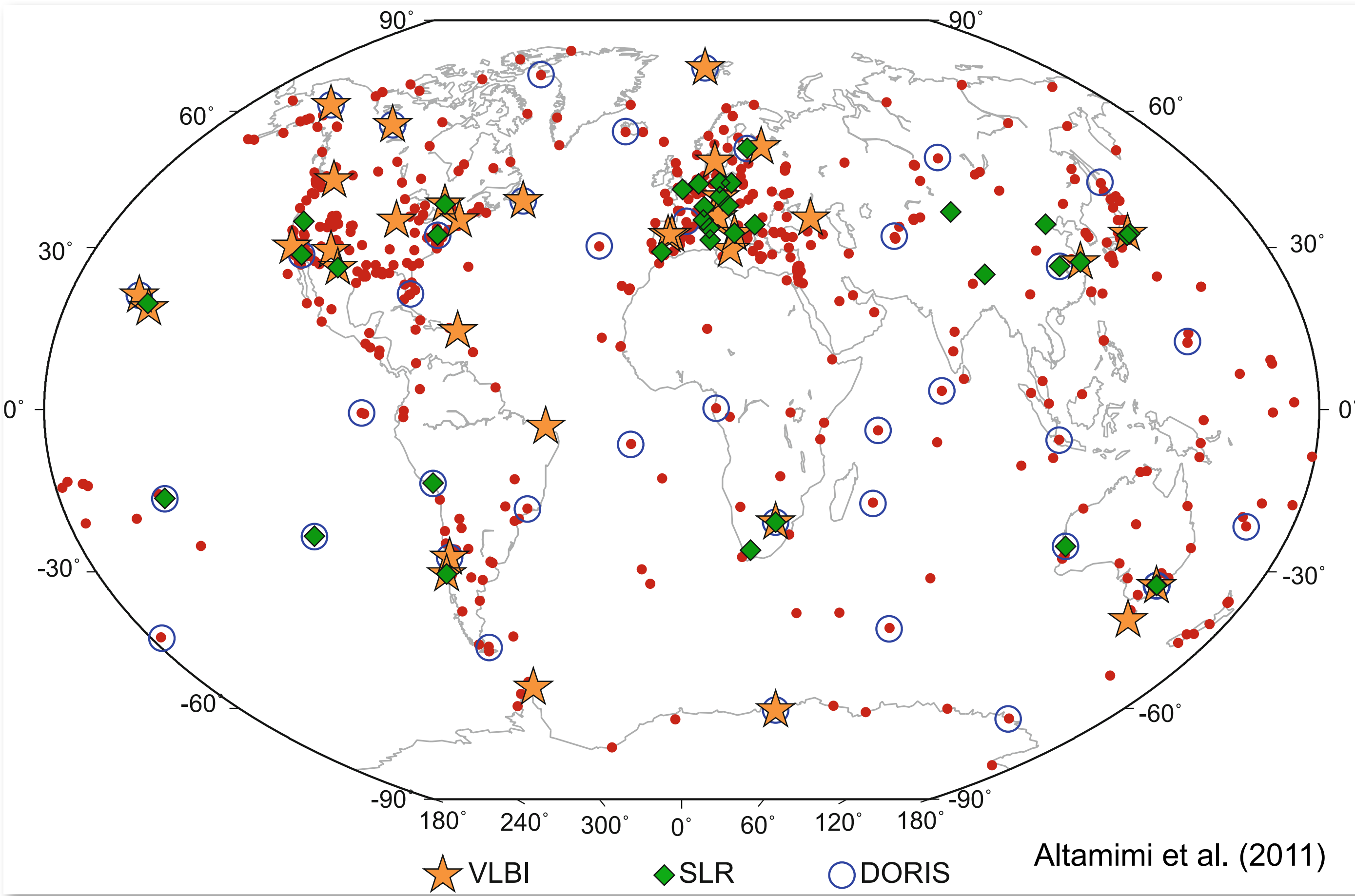
The ITRF2008 Network

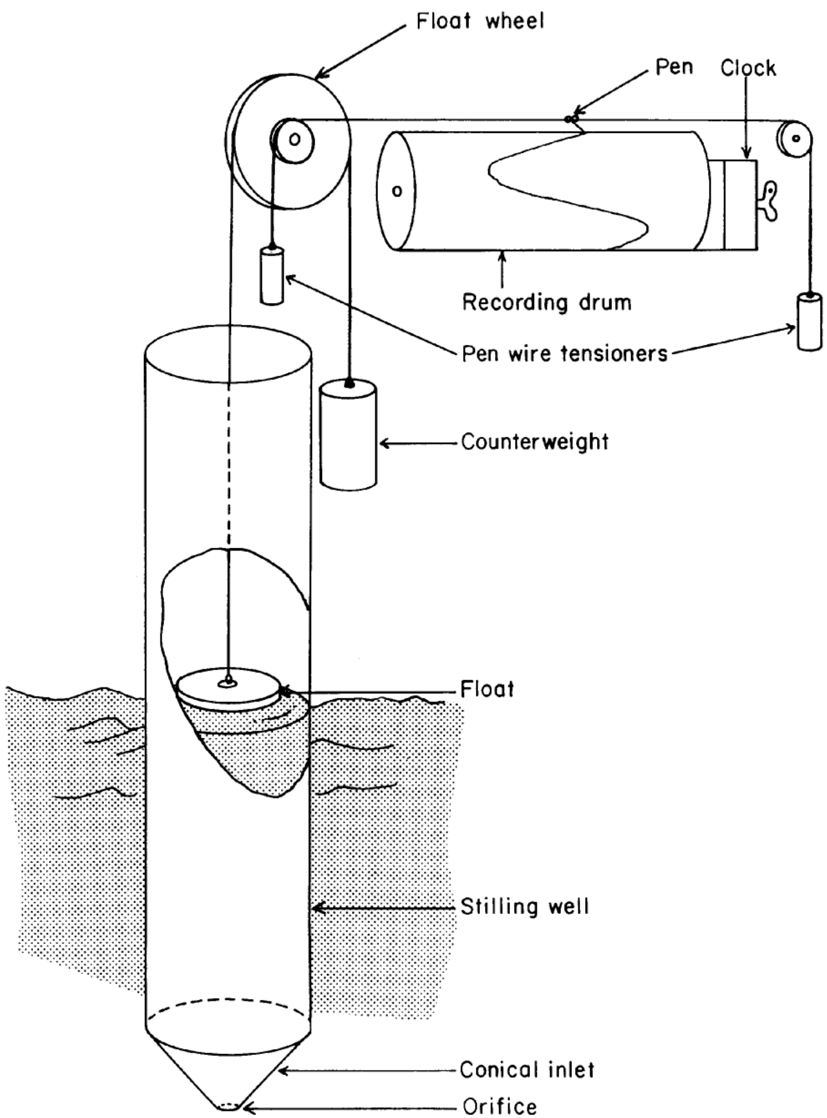


ITRF2008:
934 Stations
580 Sites
463 N. Hem.
117 S. Hem.
84 co-location Sites

Accuracy:
Origin: 1 cm
Scale: 1.2ppb

Classical Float Tide Gauge

Introduced in the 1830s and used in many ports around the world by the late 19th century.

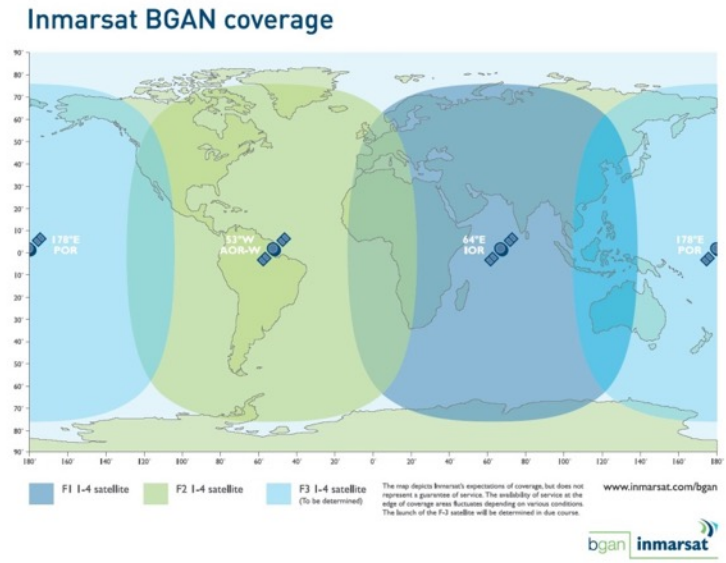


Float Gauge at Holyhead, UK

Float gauges are still important components of GLOSS and can be made into digital gauges with the use of encoders

Radar tide gauge provided by NOC and UNESCO to Alexandria

BGAN-enabled Tide Gauges



PSMSL Permanent Service for Mean Sea Level

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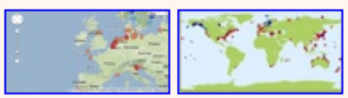
News

- Updated Trends
- Flag Changes
- MTL and MSL Changes
- New Notes from Hogarth Article
- ICSU World Data System Membership
- More News ...

Explore the Dataset

Map-Based Data Page

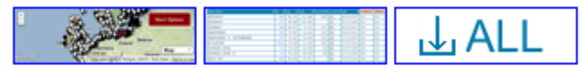


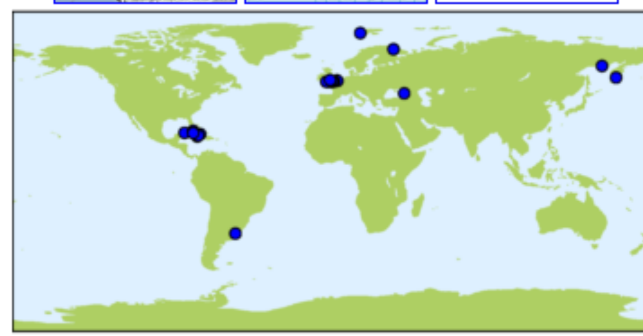
Trends and Anomalies

Welcome to the Permanent Service for Mean Sea Level (PSMSL)

Please read news items on changes to combined MTL and MSL records and flags.

PSMSL is the global data bank for long term sea level change information from tide gauges and bottom pressure recorders.





Tide gauge records updated in the 30 days prior to 23 Feb 2016

About Us:

Learn about PSMSL, contact us, read news items and annual reports

Data:

Obtain and submit tide gauge and bottom pressure data

Products:

Browse the data set via GoogleEarth or obtain derived products, view regional commentaries and author archives

Training & Information:

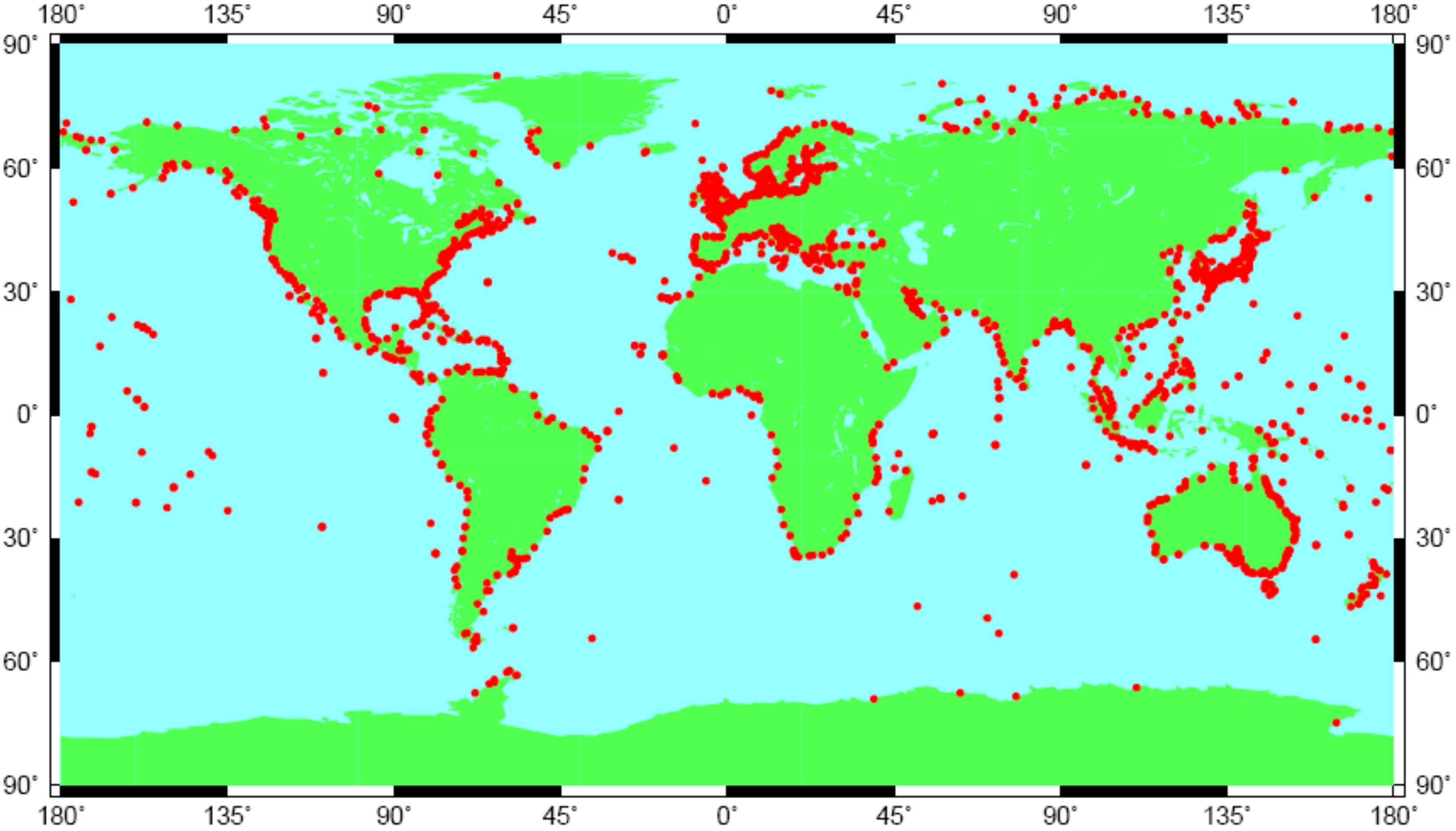
A wide variety of FAQs, training and software documentation, information on non-oceanographic signals in tide gauge records (e.g., glacial isostatic adjustment, atmospheric pressure, etc.)

Links:

Links to other networks and programs, as well as international sea level contacts

www.psmsl.org

Distribution of PSMSL Stations



1987: 27000 station-years of data
2014: 61000 station-years of data

www.psmsl.org

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!

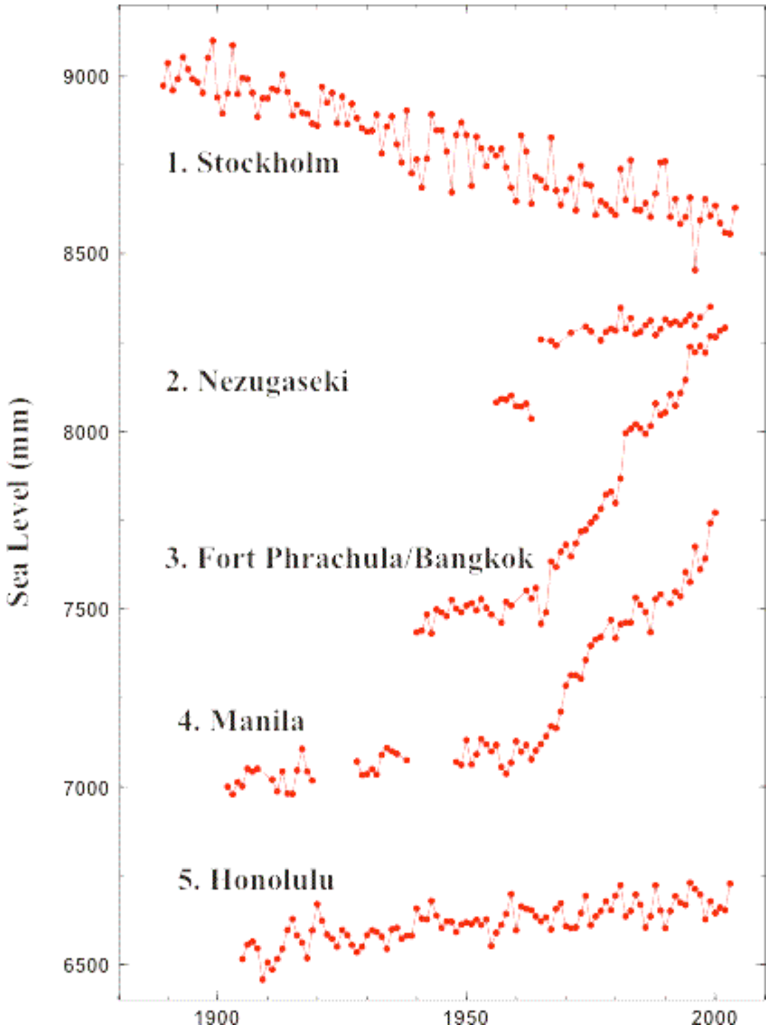
Relative Sea Level

- 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

Mean Sea Level (MSL) Records from PSMSL



- **Stockholm - Glacial Isostatic Adjustment** (GIA; sometimes called Post Glacial Rebound or PGR): Site near Stockholm shows large negative trend due to crustal uplift.
- **Nezugaseki - Earthquakes**: This sea level record from Japan, demonstrates an abrupt jump following the 1964 earthquake.
- **Fort Phrachula/Bangkok - Ground water extraction**: Due to increased groundwater extraction since about 1960, the crust has subsided causing a sea level rise.
- **Manila - Sedimentation**: Deposits from river discharge and reclamation work load the crust and cause a sea level rise.
- **Honolulu - A 'typical' signal** that is in the 'far field' of GIA and without strong tectonic signals evident on timescales comparable to the length of the tide gauge record.

(PSMSL, 2015)

Geocentric Sea Level

- For science we would like to adjust the sea level measured by the gauge for the effects of land movements

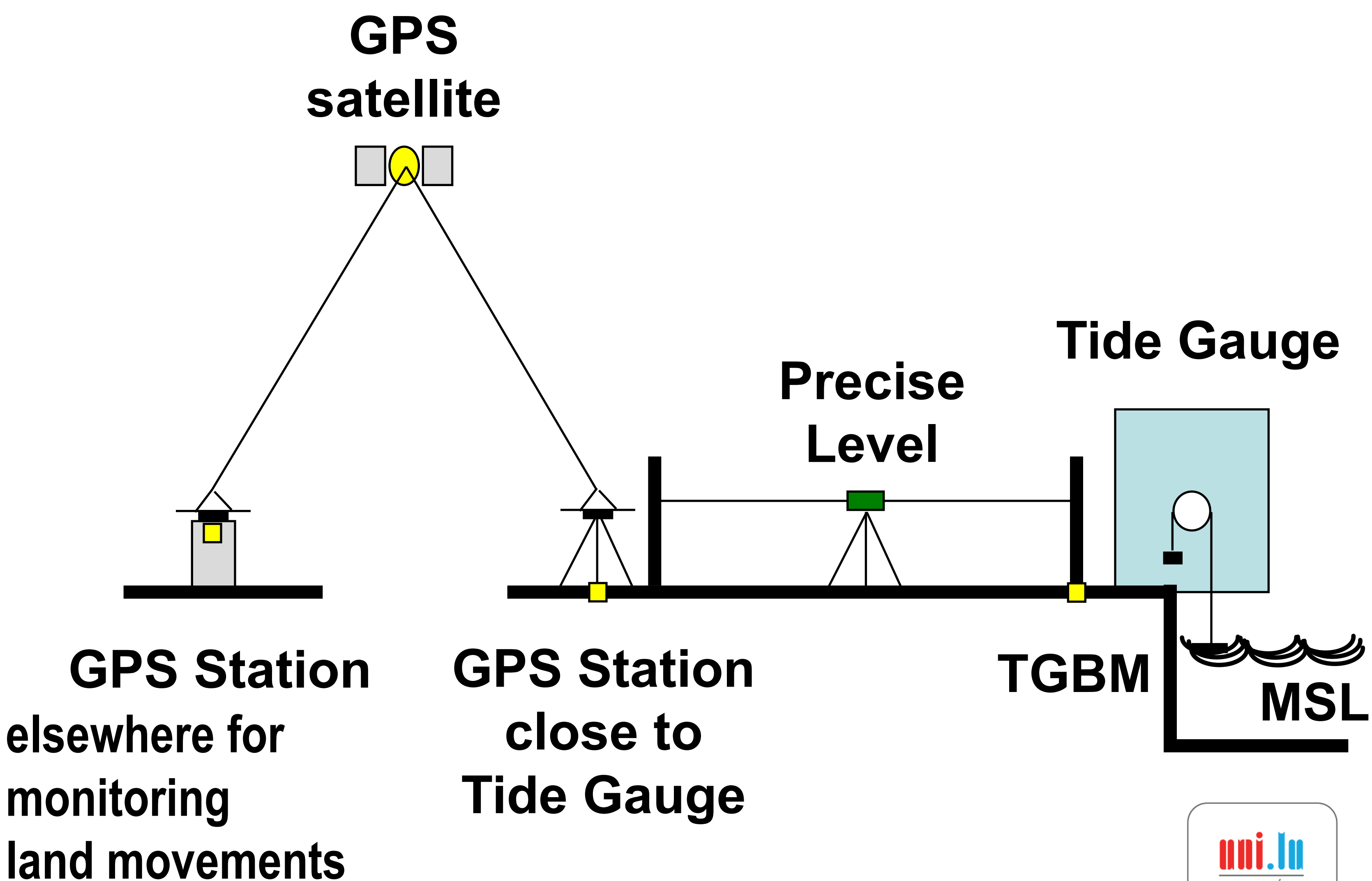
- One way to do this is to monitor the vertical movement of the TGBM (or a BM near to it) using GNSS (GPS)

- 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 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.

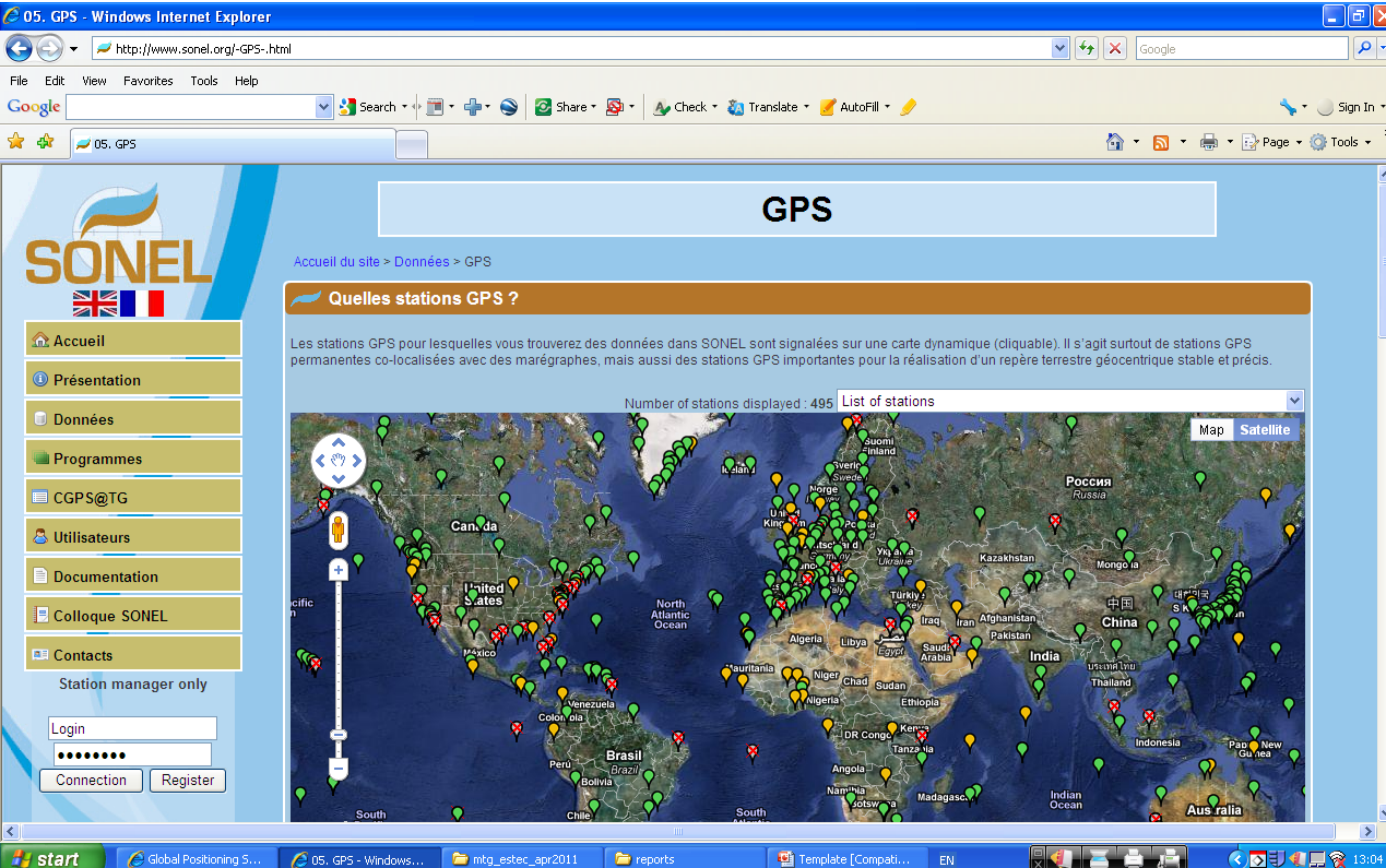
GPS at a Tide Gauge



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


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
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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
Done

Tide gauge and GPS in Tasmania

Tide gauge and GPS in USA

Tide gauge and GPS in Norway

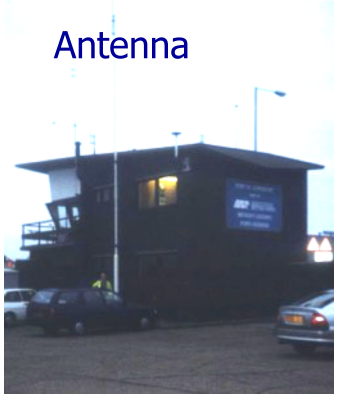
Tide gauge and GPS in Indonesia

GPS at UK tide gauges

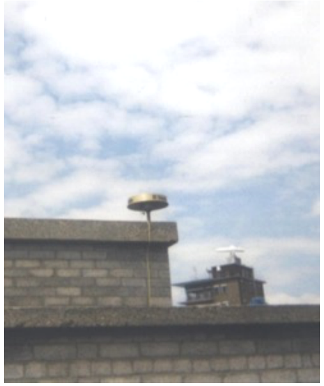
Lerwick

Aberdeen

North Shields



Lowestoft



Sheerness

Dover

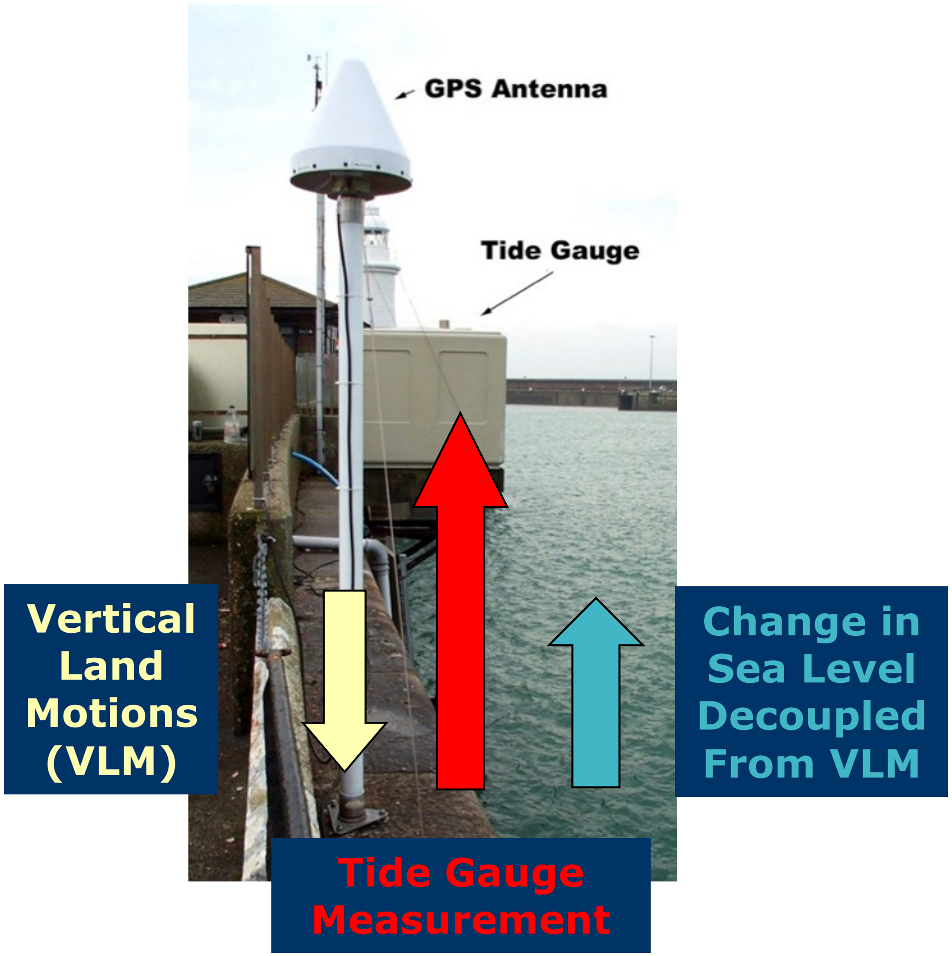
Portsmouth

Newlyn

Liverpool

Stornoway

Monitoring Vertical Land Motions at Tide Gauges



- Tide gauges (TG) measure local sea level
- Vertical land motions (VLM) are determined from CGPS and AG at or close to the tide gauge
- The change in sea level de-coupled from VLM can be inferred

NOC Sea Level Stations in the South Atlantic, Antarctica and Gibraltar

9 Sea Level Stations

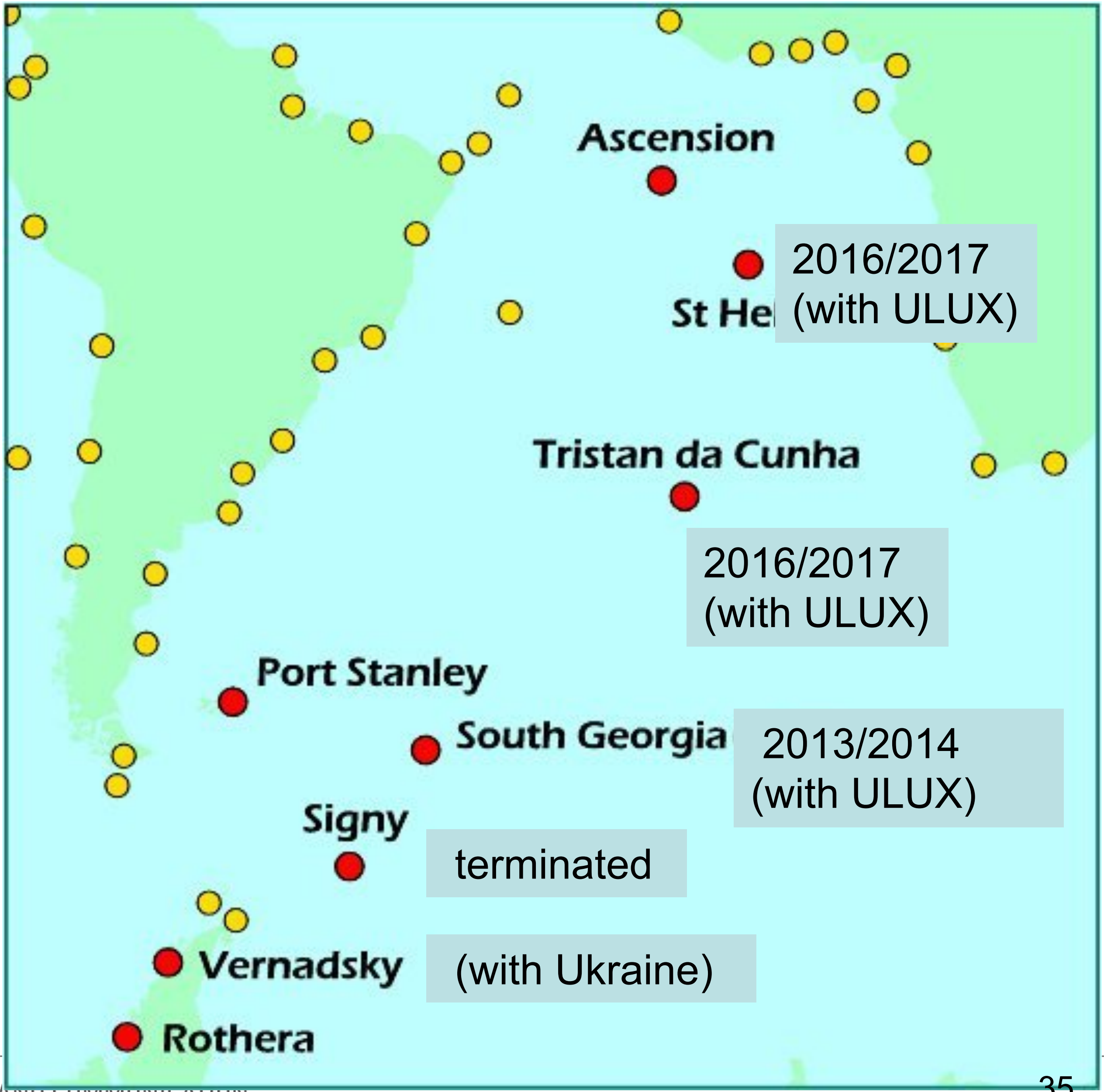
Real time telemetry:

Ascension Island
Saint Helena
Port Stanley
Tristan
Vernadsky (Faraday)
Rothera
Gibraltar

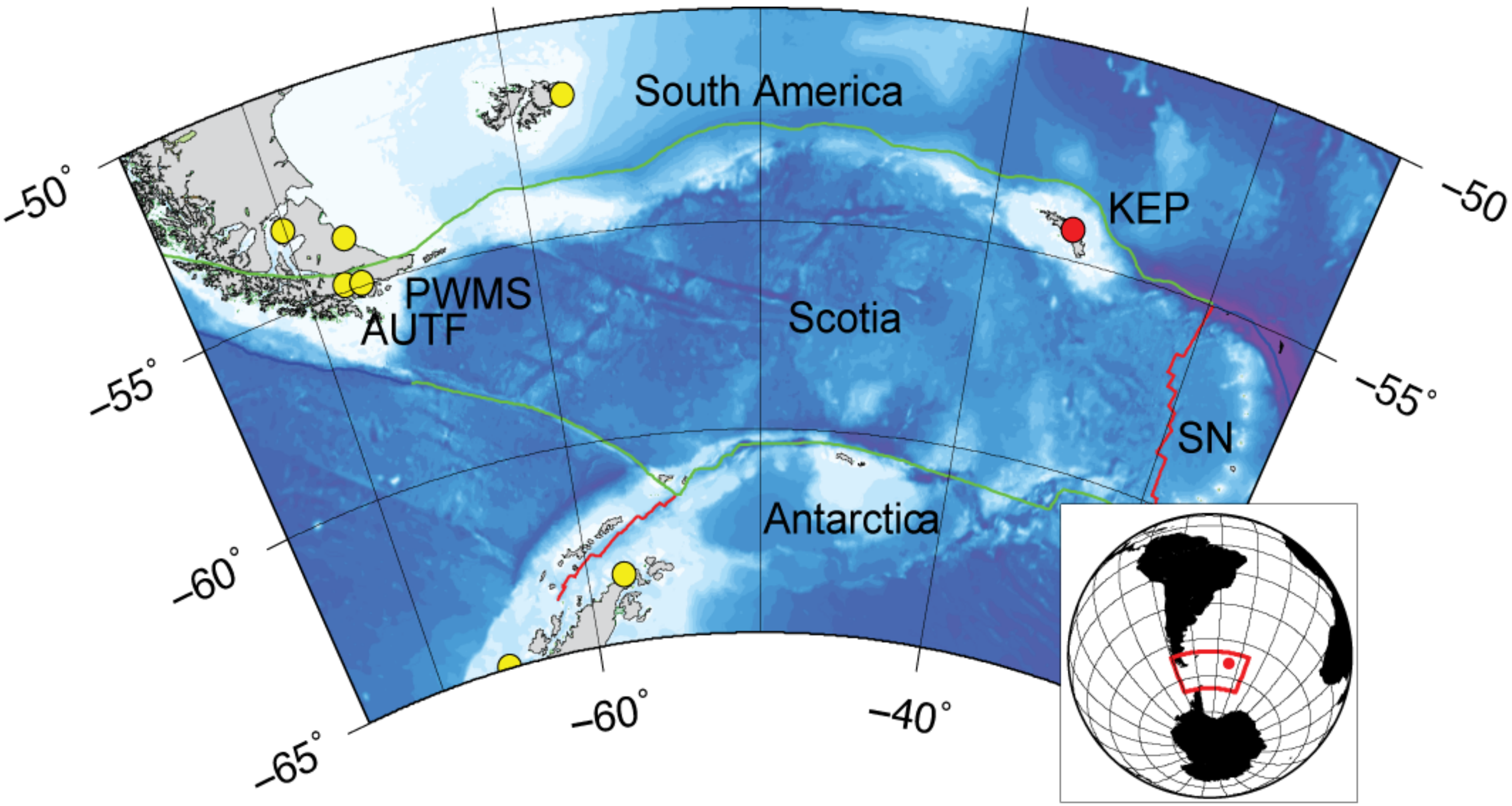
Delayed mode data:

Signy

St.Helena and Tristan recently re-built after storm damage



Regional Continuous GNSS Stations



The continuous GNSS Station KEPA

GNSS antenna and mast…good sky view on top of Brown Mt.

Solar power system, enclosures with batteries and electronics, structural frame, radio antenna, weather station.

Levelling: Monitoring Height Changes Locally

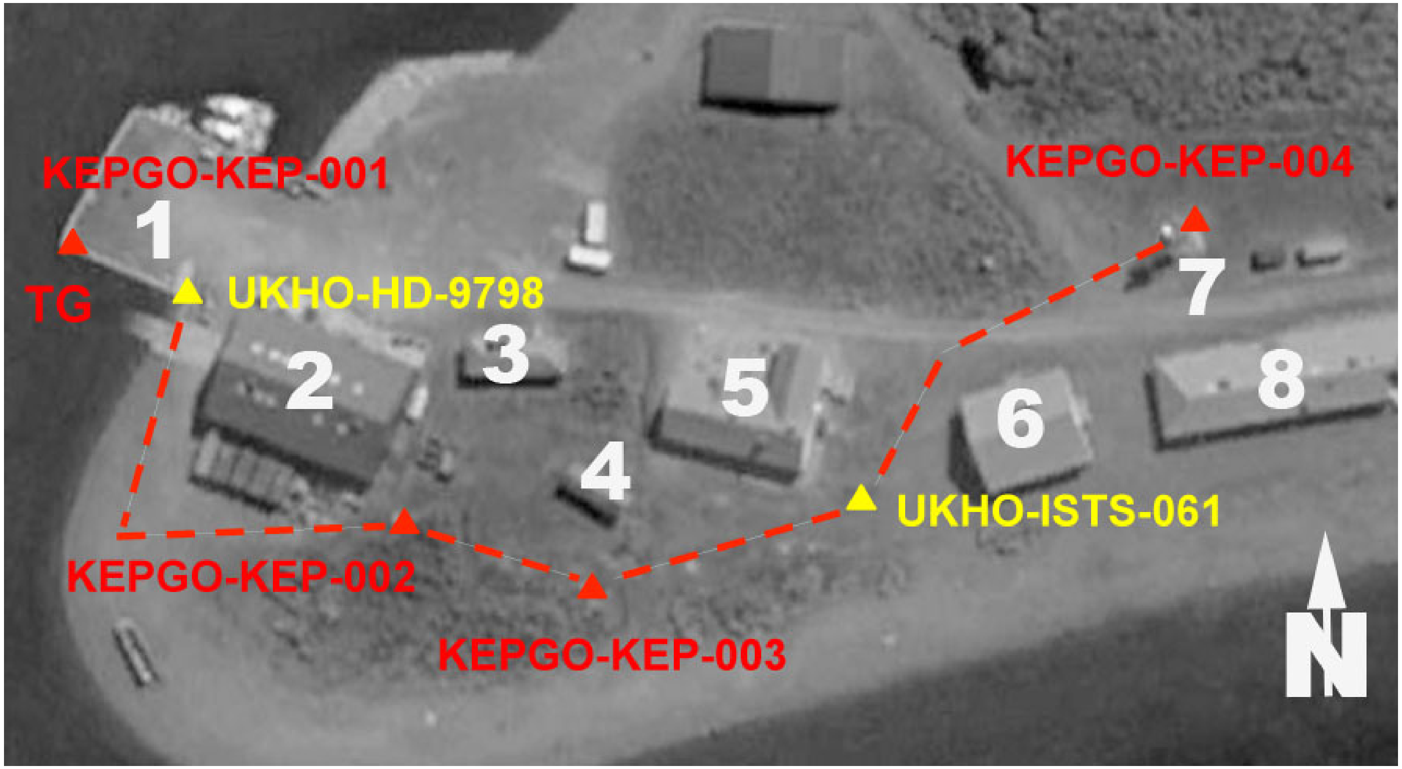


Figure 6: Network of TGBM at KEP research station. Existing TGBM (UKHO-HD-9798 and UKHO-ISTS-061) are in yellow and new TGBM (KEPGO-KEP-001 to KEPGO-KEP-004) in red. Dashed line shows the path of levelling work carried out during February 2013: from the tide gauge on the jetty (1) past the boatshed (2), over the grass area south to the food (3) and coal (4) stores, between Discovery House (5) and Carse House (6) and to the satellite tower (7).

Survey at Brown Mountain

We love Brown Mountain !?=`+”*

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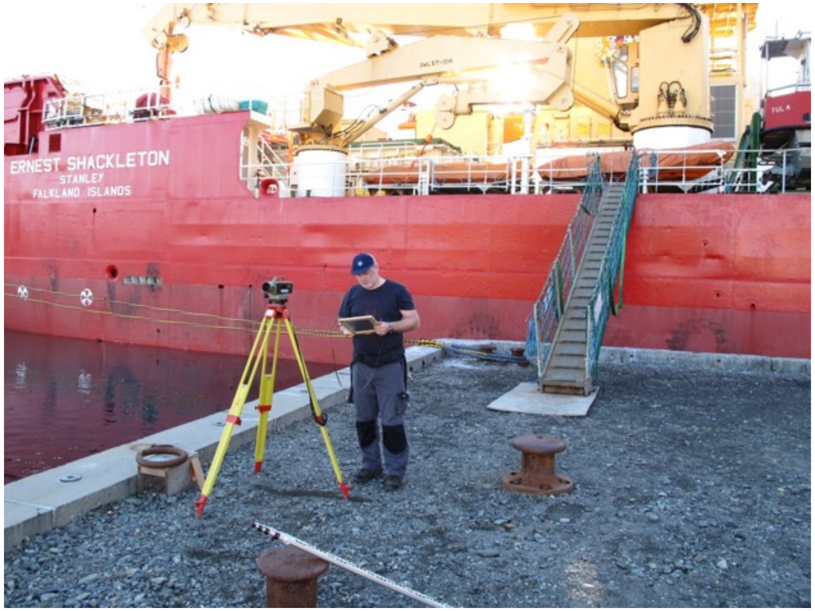
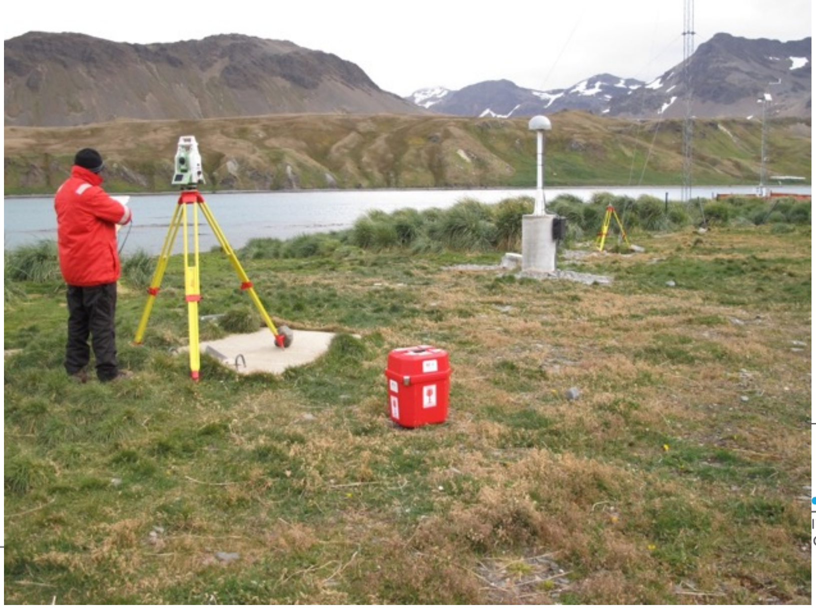
Survey at KEP





Tristan da Cunha

- GNSS station installation
- Pressure and radar tide gauge installation
- Establish a TGBM network
- Measure all geodetic ties to 1mm accuracy between all BMs (GNSS, DORIS and TGs)

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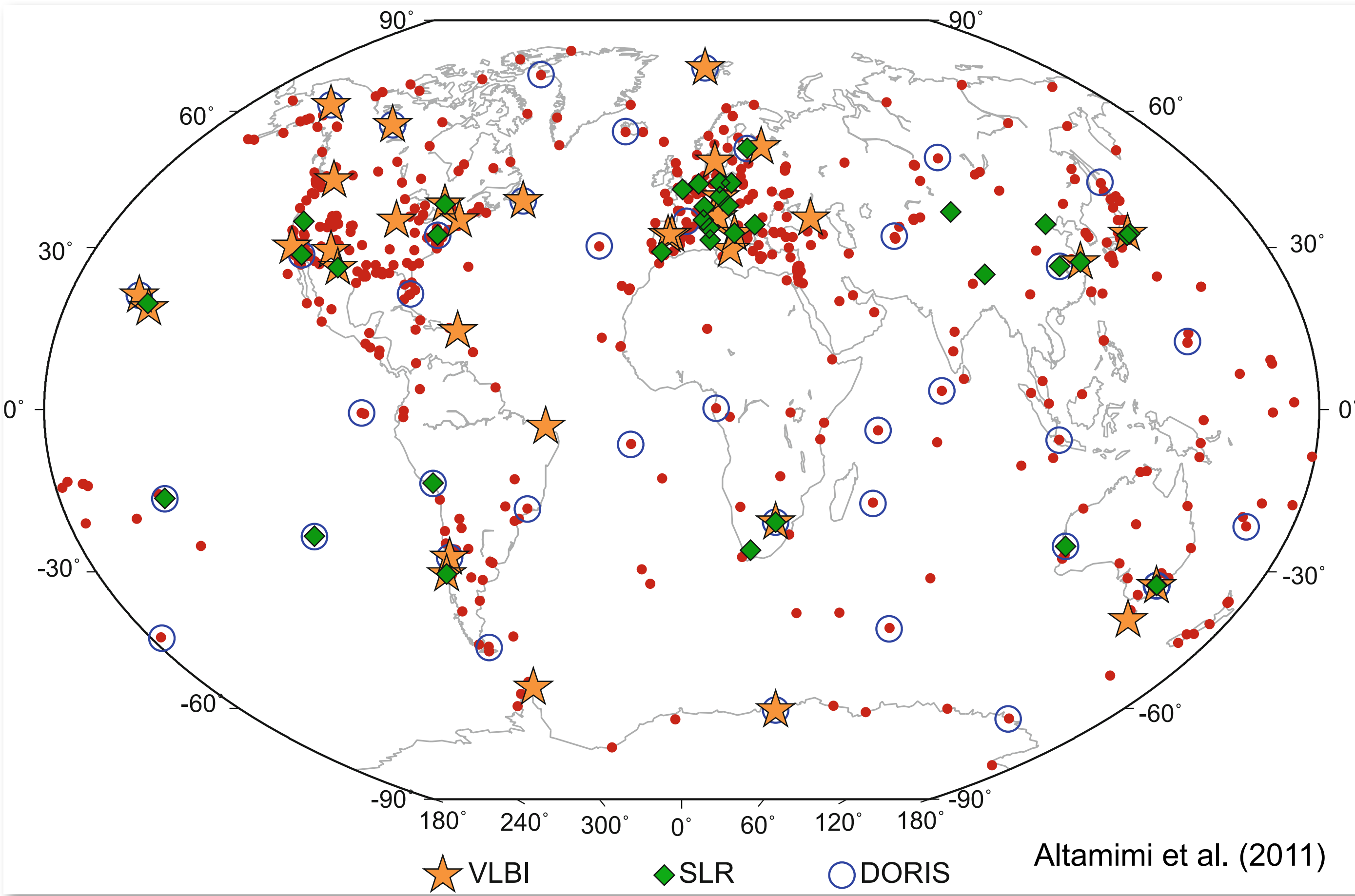
The ITRF2008 Network



ITRF2008:
934 Stations
580 Sites
463 N. Hem.
117 S. Hem.
84 co-location Sites

Accuracy:
Origin: 1 cm
Scale: 1.2ppb

Co-location of Instruments

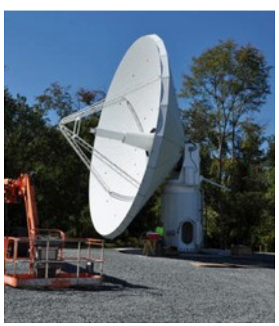
- None of space geodetic techniques is able to provide all the parameters necessary to completely define a TRF
  - **VLBI** strength(orientation), **SLR** strength(geocentre) , **GPS** strength (crustal movements)

- To define an accurate ITRF (Source GGOS 2020):

  < 1 mm reference frame accuracy

  < 0.1 mm/yr stability

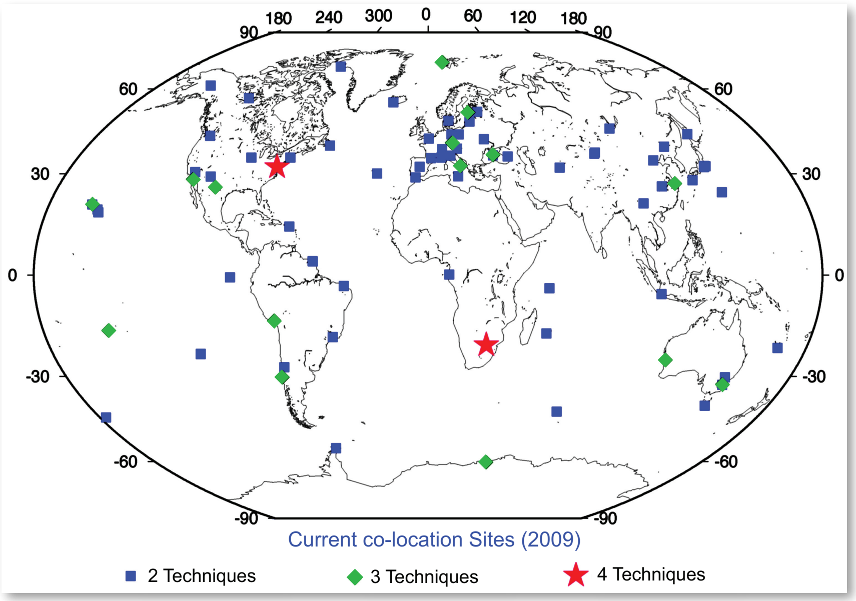
- Measurement of sea level is the primary driver improvement over current ITRF performance by a factor of 10-20.

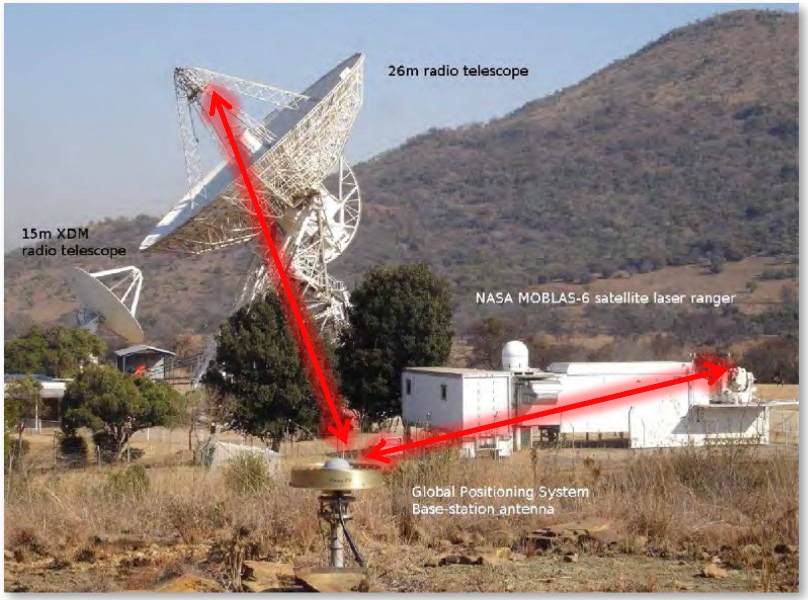


- The co-location of different and complementary instruments is crucial for several reasons:

- Without co-location sites and highly accurate local tie information, it is impossible to establish a unique and common global reference frame (TRF) for all major space geodetic techniques to answer key geophysics science questions.

Co-location of Geodetic Techniques

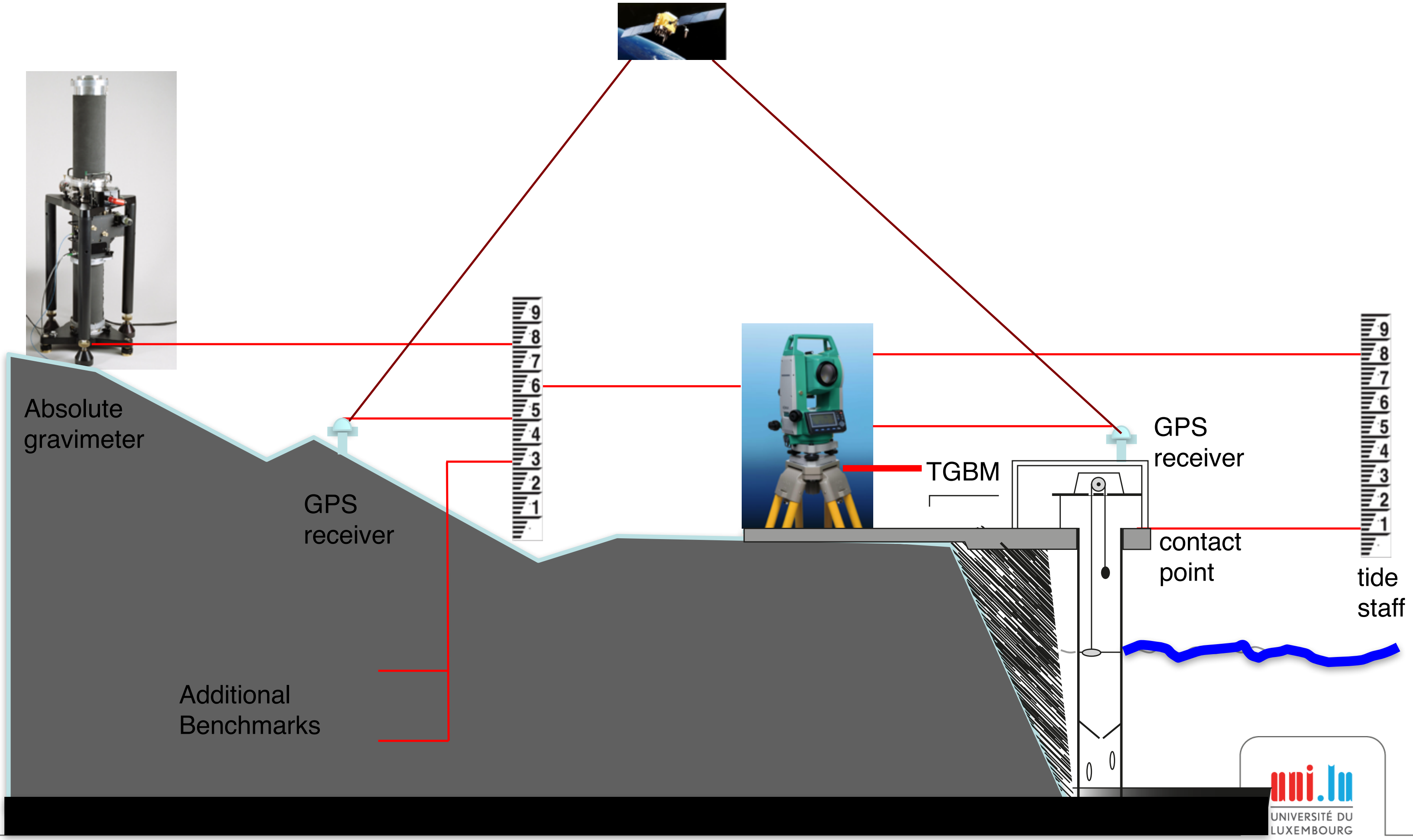




Altamimi et al. (2011)

Hartebeesthoek, South Africa

Summary of Geodetic Measurements at/near a Tide Gauge



Thank you for your attention!

Acknowledgements

- My special thanks go Phil Woodworth who shared a number of slides with me for this lecture.

- Thanks go to colleagues at
  - National Oceanography Centre, Liverpool, UK
    - Simon Williams, Jeffry Pugh, Angela Hibbert, Phil Woodworth
  - University of Luxembourg
    - Kibrum Ebuy Abraha, Addisu Hunegnaw
  - University of Nottingham, Nottingham, UK
    - Richard Bingley