Celebrating 30 Years of the South Atlantic Tide Gauge Network

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May 2015 will be a milestone for staff at the National Oceanography Centre (NOC) Liverpool, as it will mark 30 years since the foundation of the South Atlantic Tide Gauge Network (SATGN) (Figure 1). SATGN was created in 1985 at the instigation of David Cartwright (Director of what was then the Institute of Oceanographic Sciences, Bidston) under the auspices of the ACCLAIM programme (ACCLAIM = Antarctic Circumpolar Current Levels from Altimetry and Island Measurements). Since variability of transport in the Antarctic Circumpolar Current (ACC) was poorly understood at that time, a primary aim of both the programme and the SATGN network itself was to provide a means of monitoring ACC variability and of validating numerical models. This objective eventually led to one of the key activities of the World Ocean Circulation Experiment (WOCE).

The open-ocean islands of many British Overseas Territories in the South Atlantic are ideal locations for tide gauges used to calibrate satellite altimeters. Islands are preferred for this role because the near-shore dynamics of continental coastal sites are more likely to influence the sea level measured by a gauge; also, the echo from land is different from that from the ocean and can distort the processed altimetry signal.

Another objective of SATGN was to initiate measurements of long-term sea-level change in the South Atlantic – an historically under-sampled region. SATGN contributes data to the Global Sea Level Observing System (GLOSS)* of the Intergovernmental Oceanographic Commission (IOC), and to the major databanks such as the Permanent Service for Mean Sea Level. In this way, information on long-term sea-level change and variability in this data-sparse region could be input to programmes such as WOCE, and scientific assessments such as those of the Intergovernmental Panel on Climate Change.

The first SATGN gauge was established at Clarence Bay, Ascension Island, in May 1985, and was rapidly followed by installations at Tristan da Cunha and St Helena. By the early 1990s, there were also systems at Port Stanley (East Falkland), Rothera (on the Antarctic Peninsula) and at Signy Island (one of the South Orkney Islands). An additional pressure gauge was established at Vernadsky (formerly Faraday), Antarctica, in 1997, complementing a stilling well and float gauge that had been installed by the British Antarctic Survey in 1958. The network in its present form (Figure 1) was completed in 2008, with the addition of a tide gauge at King Edward Point, South Georgia. A new tide gauge at Gibraltar is also now considered part of the network.

Since its inception, NOC engineers have used SATGN to develop ground-breaking sea-level technology, whilst NOC scientists have surpassed the original aims of the ACCLAIM programme, making significant advances in our understanding of processes affecting sea level in the South Atlantic and Southern Ocean.

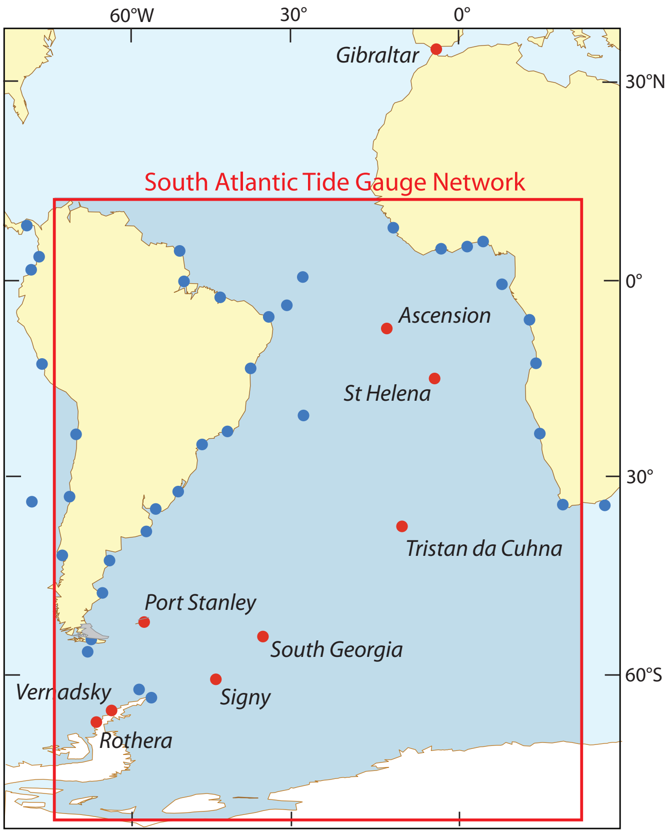

Figure 1 *Sites of coastal tide gauges belonging to the UK South Atlantic Tide Gauge Network (red dots). Gibraltar is also part of this network. Blue dots are gauges (not necessarily operational) committed to the GLOSS programme by other countries.*

* In addition to coastal tide gauges, there are sea-bed pressure recorders which are used to monitor sea level in open ocean locations, such as those shown at http://www.psmsl.org/data/bottom_pressure/

Technological innovations

By their nature, SATGN stations must be equipped with tide gauge instrumentation that is suited to hostile environments in remote locations – a factor which has been fundamental to the development of NOC sea-level monitoring technology. One key issue affecting these remote sites is that datum control (i.e. the referencing of tide gauge measurements to a fixed point on land) can be difficult because the measuring points of the gauges are submerged, and traditional methods of imposing a datum, such as employing manual observations using a tide pole, are impractical. Yet datum control is essential if tide gauge records are to be used to assess long-term trends in sea level.

To overcome this problem, NOC devised the 'B' gauge, which incorporates an additional measuring point at approximately mean sea level, which is exposed for half of the tidal cycle. The essential point is that the height of this mid-tide sensor can be related to the heights of benchmarks on land using conventional levelling. By fitting the rectified tidal curve of the mid-tide sensor to the curve of the fully submerged sensor, it is possible to provide precise datum control to the fully submerged sensor.

Figure 2 The GPS receiver at King Edward Point, South Georgia
(Photo by courtesy of Norman Teferle)

To further improve datum control of SATGN, NOC staff are currently working in collaboration with colleagues at the University of Luxembourg to install Global Navigation Satellite System (GNSS) receivers at South Atlantic tide gauge sites. These are usually Global Positioning System (GPS) receivers, such as that on South Georgia (Figure 2). Positioning GPS receivers close to tide gauges is useful, because as well as geographical position, GPS systems record vertical land movement due to various geophysical processes such as glacial isostatic adjustment (i.e. post-glacial rebound of the land). This allows us to estimate long-term trends in both absolute and relative sea level at a tide gauge site and thereby contribute to studies of both climate change and solid Earth processes.

A further challenge to operating remote tide gauge systems is the need for robust communications systems that rarely fail and are capable of storing large amounts of data locally in the event of a failure. As a result, NOC Liverpool engineers designed a real-time telemetry system that connects tide gauges (sampling at intervals of between 1 and 40 seconds) to a Linux-based data logger which returns data through the Inmarsat Broadband Global Area Network (BGAN) system every 15 minutes (Figure 3). Importantly, the system allows remote configuration of tide gauges – ideal for operating in remote locations. Such was the success of this system that in 2008 it was adopted by the IOC as one of the main forms of telemetry for the Indian Ocean Tsunami Monitoring System.

To further improve the resilience of SATGN, at a number of sites NOC Liverpool engineers have installed specialist data-loggers capable of storing data for up to 5 years in the event of communications failures. They are also currently experimenting with low-powered communications systems that use Iridium/cellular technology, and aim to test these in the Network during 2015–16.

One final issue that hinders sea-level measurements in hostile environments is the maintenance of underwater equipment, particularly at the highest latitude gauges in the Southern Ocean. In an attempt to address this, in the past few months NOC Liverpool engineers have custom-designed a radar gauge (Figure 4), which will be fitted to a stilling well that is insulated and heated to keep it ice-free. The major advantage of this instrument is that the radar is situated above the sea surface and so is easily accessible for maintenance purposes. The pilot installation will be made at Rothera later this year and will become the most southerly radar gauge in the world.

Figure 3 The BGAN telemetry system, as used in the Indian Ocean Tsunami Monitoring System (see Further Reading).

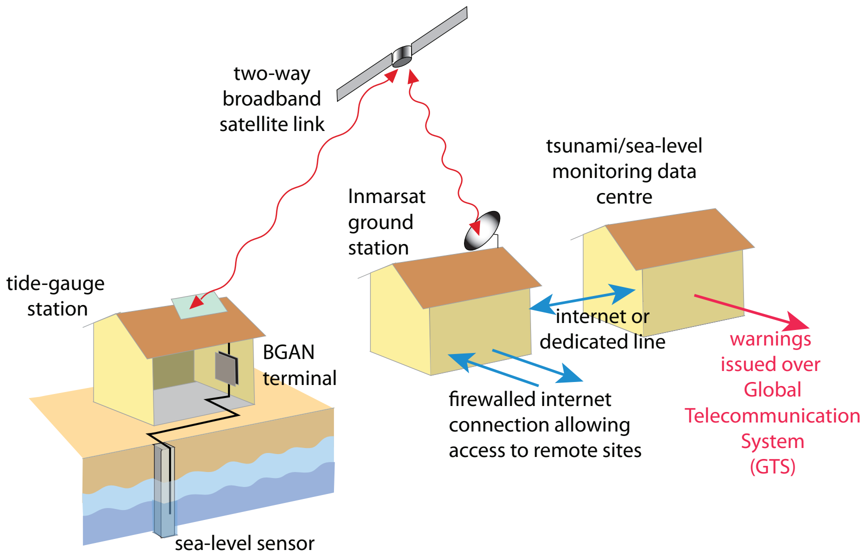

Figure 4 The radar gauge for installation at Rothera. This unit emits high-frequency microwave pulses which are reflected by the sea-surface, allowing the height above sea level to be inferred from the transit time between emission and detection of the signal. The pulses are guided down the stainless steel cable to prevent them from reflecting off the walls of the stilling well and the cable itself is weighted to minimise vertical movement.

Scientific developments

As described earlier, SATGN was, in part, established to improve understanding of ACC variability, and a number of NOC Liverpool scientists rose to the challenge – amongst them Phil Woodworth, Chris Hughes, Mike Meredith and Angela Hibbert. Using South Atlantic tide gauge data, they identified the 'Southern Ocean Coherent Mode' – a persistent, synchronised and ring-like pattern in sea level around Antarctica. This mode was found to covary with ACC transport on inter-annual and shorter time-scales and also to covary with an atmospheric pressure pattern known as the Southern Annular Mode which is an indicator of the strength of the westerly winds around Antarctica. Stronger westerlies would lead to an increased sea-level divergence around the Antarctic coast, causing the sea surface to tilt upwards from the coast. In response, an onshore flow would develop, but due to Earth's rotation, it would be deflected eastwards, increasing the flow of the ACC. This realisation was an important breakthrough, since it meant that sea-level slope could be used as a proxy for ACC transport. Interestingly, a further NOC study showed that the Southern Ocean Coherent Mode and ACC transport were modulated by a periodic reversal in the direction of the stratospheric winds in the Tropics. Most of these studies were focussed on interannual variability; decadal and longer term sea level and ACC variability are less clearly understood, which emphasises that the continuity of these tide gauge records is essential.

Since a secondary purpose of SATGN was calibration of satellite altimetry, an initial evaluation of this benchmarking was undertaken using data from Port Stanley. This showed that open-ocean island gauges such as that at Port Stanley were ideally positioned for this role, particularly given the accurate datum control that the tide gauges in question afforded. Consequently, many of the South Atlantic Network sites now form part of a subset of the GLOSS network which delivers 'ground-truth' for altimetry (Figure 5).

Over the past 30 years, numerous other studies have used SATGN data to explore sea-level variability on various time-scales. For example, tide gauge records from Port Stanley, and from decommissioned tide gauges at other sites in the Falklands, have been used to examine seiches, extreme events, tides and seasonal variability, as well as long-term trends. Port Stanley data have also been used to demonstrate that where tidal constituents K_1 and O_1 are of similar magnitude, they act as a carrier wave that is phase-locked with the M_2 tide, leading to asymmetry in the probability distribution function (PDF) of tidal elevation. Other studies evaluated the magnitude of the response of sea level to an increase in atmospheric pressure, known as the inverse barometer effect. Generally, an increase of ~1 mbar in atmospheric pressure will result in a ~1 cm drop in sea level, but studies using SATGN data showed how pressure waves in the Tropics caused significant departures from this standard response, even in extra-tropical areas (see Further Reading).

Even higher frequency fluctuations were the subject of studies of propagation across the oceans of the 2004 Indonesian tsunami, which was recorded at Signy, Stanley and St Helena, and also propagation of the 2011 Tohoku (or Sendai) tsunami. A 1999 study of wave activity identified swell in excess of 1 m and 2 m at St Helena and Ascension respectively; the swell lasted several days and resulted from a North Atlantic hurricane one week earlier, demonstrating how Northern Hemisphere swell can impact coastal communities in the Southern Hemisphere (see Further Reading).

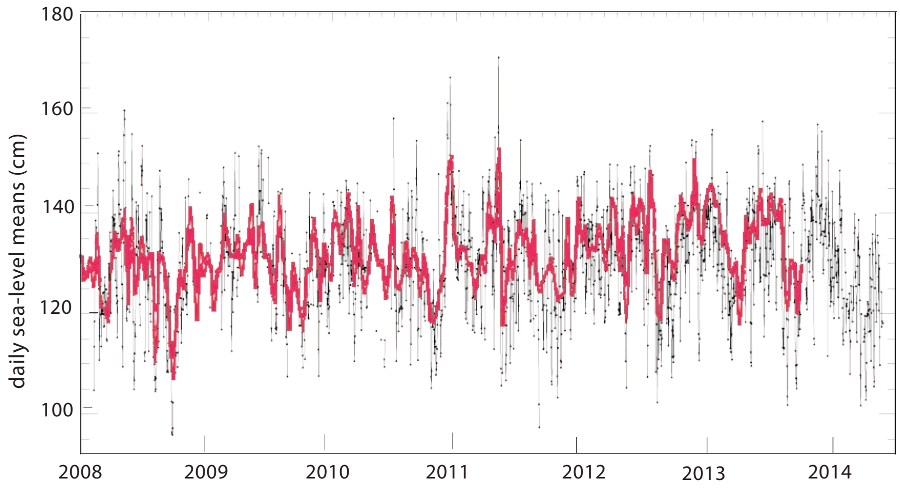

Figure 5 *Sea-level data from the King Edward Point tide gauge on South Georgia (black) and sea-level at the same location from satellite altimetry (red). (Neither has been corrected for the effect of atmospheric pressure.) (Altimetry time-series by courtesy of Brian Beckley)*

Clearly, data from SATGN have proved to be useful in many aspects of scientific research, and they have also been valuable in many practical applications such as the design of coastal infrastructure at Port Stanley. SATGN now contributes some of the longest Southern Hemisphere sea-level records to GLOSS, and has helped to improve understanding of long-term change in the region. For example, it has provided estimates of sea-level trends in the Falklands during recent decades, and has compared them with trends over much longer time-scales (i.e. since 1842, making use of measurements by James Clark Ross), establishing that sea level is now rising faster in this part of the world than previously. Similar studies have been made using data from Ascension Island (1955 onwards), again demonstrating a recent increase in the rate of sea-level rise. Furthermore, records from the Gibraltar tide gauge now span 50 years and have been employed in numerous studies of exchange flows between the Mediterranean Sea and the North Atlantic.

SATGN has been a great success in terms of meeting its original objectives, but NOC Liverpool believes that research using the network is far from complete. Sustained sea-level observations are extremely important in the context of climate change, particularly in data-sparse regions like the South Atlantic, and if we are to improve our understanding of interannual, decadal and longer term variability, SATGN is only just at the beginning of its useful life.

Further Reading

Holgate, S., P. Foden, J. Pugh and P. Woodworth (2008) Real time sea level data transmission from tide gauges for tsunami monitoring and long term sea level rise observations, *Journal of Operational Oceanography*, **1**, 3–8.

Mathers, E.L., P.L. Woodworth (2004) A study of departures from the inverse barometer response of sea level to air pressure forcing at a period of 5 days, *Quarterly Journal of the Royal Meteorological Society*, **130**, 725–38.

Vassie, J.M., P.L. Woodworth and J.W. Holt (2003) An example of North Atlantic deep-ocean swell impacting Ascension and St. Helena Islands in the Central South Atlantic. *Journal of Atmospheric and Ocean Technology*, **21**, 1095–103.

For more on different kinds of tide gauges see http://noc.ac.uk/science-technology/climate-sea-level/sea-level/tides/tide-gauges/tide-gauge-instrumentation?page=0,3

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Stop Press NERC recently announced that it will provide funding to allow all SATGN tide gauges to have customised radar gauges, GPS receivers, specialist data-loggers and Iridium/cellular communications technology.