The French Subantarctic and Antarctic Sea Level Observing Network

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Introducing the ROSAME network

The Laboratory of Space Geophysical and Oceanographic Studies (LEGOS) of the Midi-Pyrénées Observatory (OMP) in Toulouse, France, is in charge of the **Subantarctic and Antarctic Sea Level Observing Network** (Réseau d'Observation Subantarctique et Antarctique du niveau de la MEr - **ROSAME**). Created in the early 1990s and accredited by the National Institute for Earth Sciences and Astronomy (CNRS/INSU) in 1997, it is now part of the National Coastal Water Level Observing Service (SNO SONEL, a member of the France's Research Infrastructure for coastal ocean observation ILICO) and the Global Sea Level Observing System (GLOSS). ROSAME consists of a network of co-located coastal tide gauge and GNSS stations in the French Southern and Antarctic Lands (TAAF, **figure 1**) in the districts of Kerguelen (at Port-aux-Français since 1993), Saint-Paul/Amsterdam (since 1994) and Crozet (on the La Possession island from 1995 to 2015), all in the Southern Ocean. Since 1997, a coastal station has been installed on the Antarctic continent near the French scientific base of Dumont d'Urville. Scientific applications mainly concern the study of ocean tides and sea level variations, as well as the validation of satellite observations.

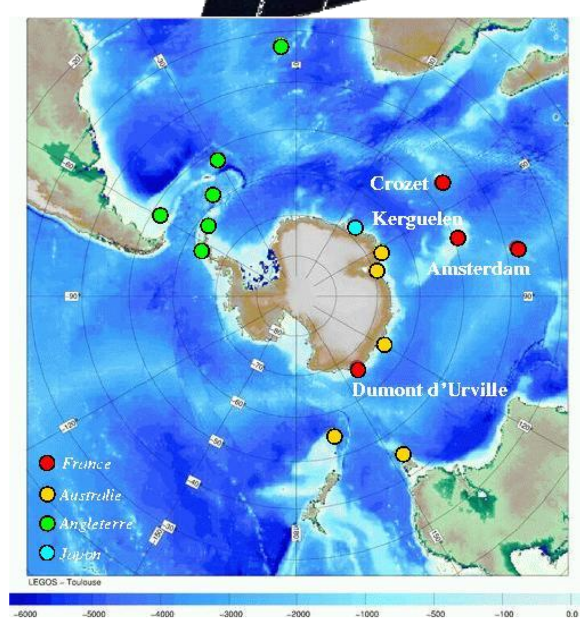

Figure 1: Coastal measurement sites (in red) of ROSAME tide gauge stations in the Southern Ocean and on the Antarctic continent.

Figure 2: Coastal tide gauge sites on Kerguelen (**left**) and Saint-Paul (**right**) featuring a stilling tube with pressure tide gauge and radar. A permanent GNSS station is installed above the Saint-Paul tide gauge.

Measured parameters

On each measurement site, the tide gauge station developed by INSU's Technical Division (DT) in Brest automatically acquires measurements of bottom pressure, temperature and conductivity together with atmospheric pressure triggered at the same time. The Kerguelen and Saint-Paul sites (**figure 2**) are also equipped with radars for high-frequency measurements. The tide gauge station builds a message containing the measurements transmitted in real time to LEGOS via the Argos and VSAT satellite systems. They are also stored in memory and retrieved at regular intervals during "NIVeau de la MER" (sea level - NIVMER) cruises in the TAAF. The Kerguelen site is part of the Indian Ocean tsunami warning system. All ROSAME sites are equipped with GNSS stations to measure and monitor the geodetic stability of the measurement sites.

Measurement processing and follow-up

Every day, around 300 messages are received from the tide gauge sites and activate an automatic processing in LEGOS. Quality control is performed and an e-mail alert is sent when a problem occurs during message and measurement processing. Real-time monitoring is accessible via dynamic web pages that bring together sensor measurement curves (**figure 3**) and information for operational monitoring of tide gauge stations. Once the sea level has been calculated, its quality is checked against a tidal forecast. Comparisons between tide gauge sea level and tidal scale readings are carried out every month at Kerguelen (**figure 4**).

Data distribution

Real-time data are available on the LEGOS website (**ftp.legos.obs-mip.fr/pub/soa/niveau_mer/rosame**), from the French Naval Hydrographic and Oceanographic Service (Shom, **https://www.shom.fr/en**), on the Intergovernmental Oceanographic Commission of UNESCO (UNESCO/IOC, **https://www.ioc-sealevelmonitoring.org**) sea level monitoring website. Monitored data are available from GLOSS data centers: SONEL (**https://www.sonel.org**) and University of Hawaii Sea Level Center (UHSLC, **https://gloss-sealevel.org**).

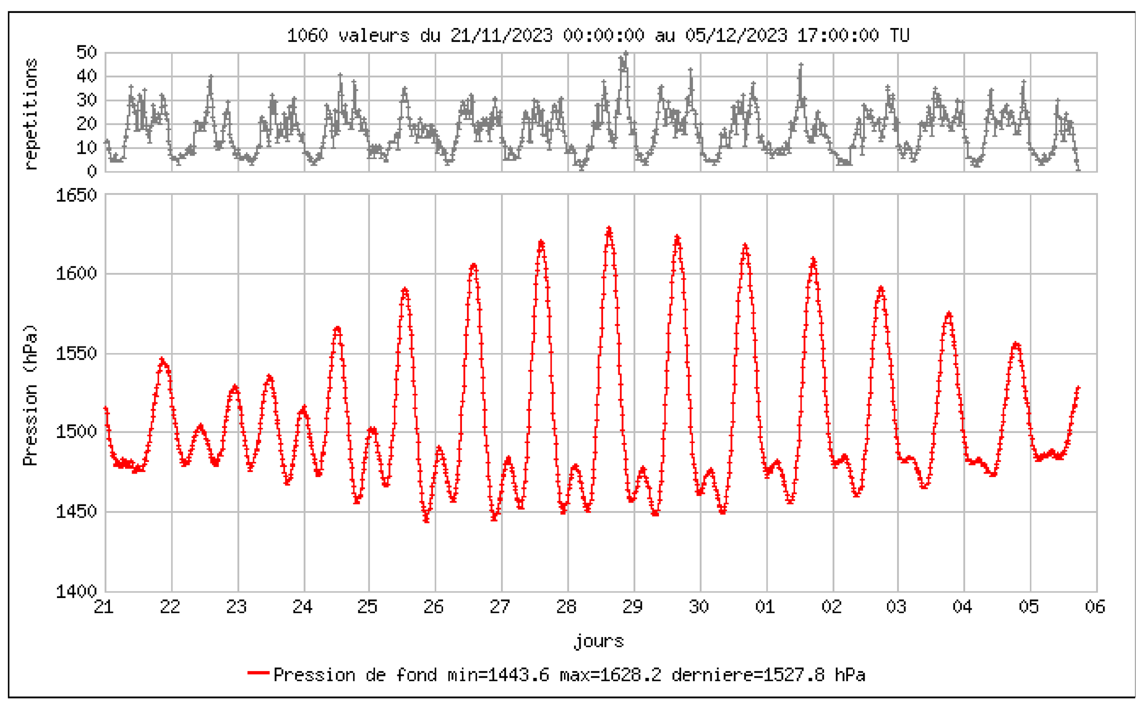

Figure 3: Bottom pressure measurements from the Dumont d'Urville tide gauge monitored on the ROSAME website.

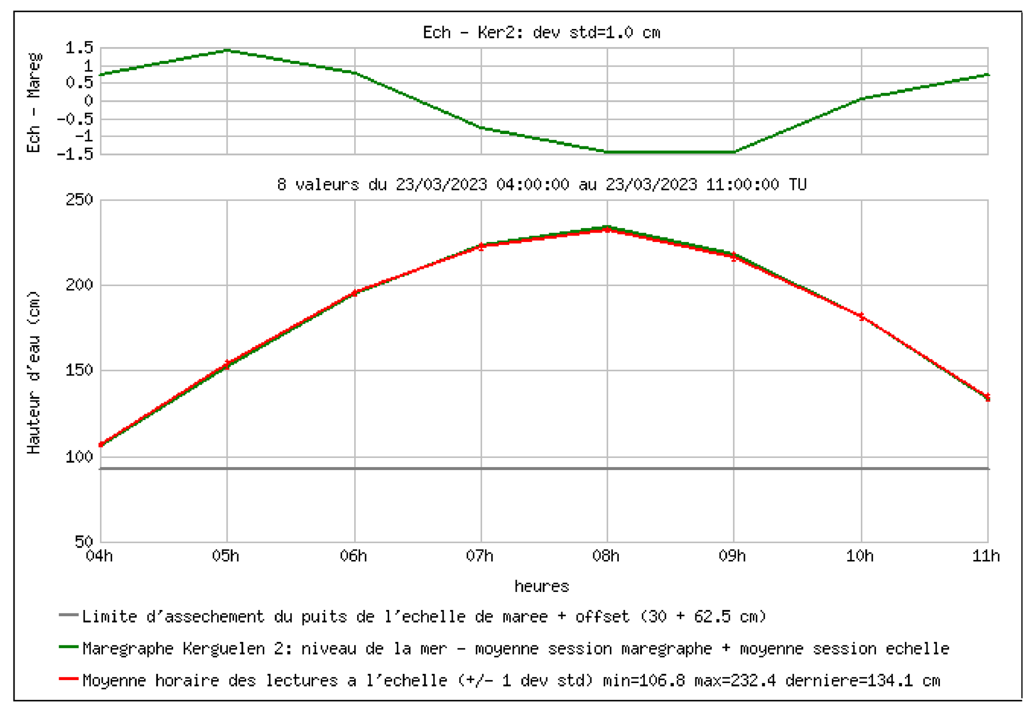

Figure 4: Comparison of tide gauge sea level with tidal scale readings taken by Kerguelen overwintering personnel on March 23, 2023.

Figure 5: **Left**: Autonomous tide gauge station on the deck of the Marion-Dufresne ship waiting to be moored. **Right**: Raising the continental shelf tide gauge station on board the Marion-Dufresne ship.

NIVMER cruises

Between 1986 and 2018, autonomous tide-gauge stations were deployed on the edge of the continental shelf, then recovered the following year. They enable observations made on the coast to be linked to offshore sea level variations, and to be compared with data from altimetry satellites. These operations of shelf stations mooring and lifting (**figure 5**) are carried out at the same time as maintenance visits and data retrieval from memory of coastal stations during the NIVMER cruises and a rotation of the Marion Dufresne ship possible only during the austral summer and managed each year within the framework of the French Polar Institute Paul-Emile Victor (IPEV) projects and with the support of the DT/INSU.

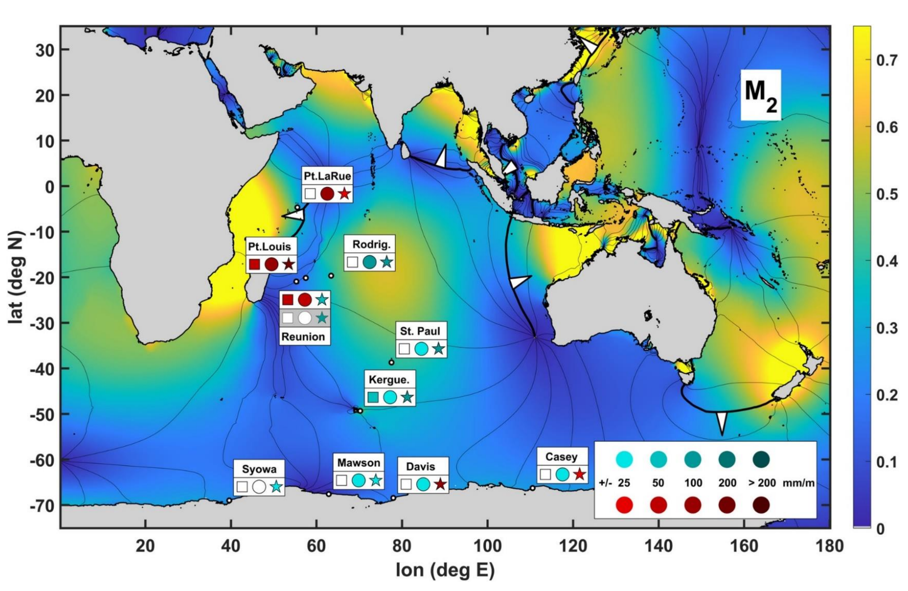

Figure 6: M_2 tidal anomaly correlations in the Indian Ocean at open ocean locations and Antarctica for three different frequency bands: squares are the sub-annual band, circles are the annual band and stars are the interannual band. Station names are indicated. Color shading of the symbols indicate positive (shades of red) and negative (shades of blue) tidal anomaly correlation according to legend at the bottom right. Background colors show tidal amplitudes (corresponding to the color bar at the right in units of meters) and phases (solid lines, in increments of 30°) from the TPXO 7.2 global solution (Egbert & Erofeeva, 2002).

Some scientific results

As sea level measurements are rare in the Southern Ocean, those acquired by ROSAME tide gauge stations represent a significant contribution to the global GLOSS program and are often used in global or regional studies. The Indian Ocean experiences significant sea level rise and tidal variability yet has been less studied due to a sparse network of tide gauges. However, since the beginning of the 21st century, more tide gauges have been established in a wider geographical area, bringing the possibility of better estimates of tidal and mean sea level variability. In their 2020 paper, **Devlin et al.** improve a tidal anomaly correlation approach to 73 tide gauges in the Indian Ocean (including the Kerguelen and Saint-Paul tide gauges, **Figure 6**) to better quantify tidal variability in these under-studied regions, finding that the majority of locations exhibit significant correlations of tides and mean sea level.

Satellite altimetry and gravimetry are used to determine the mean seasonal cycle in relative sea level, a quantity relevant to coastal flooding and related applications. In the paper published in 2021 by **Ray et al.**, the main harmonics (annual, semiannual, terannual) are estimated from 25 years of gridded altimetry, while several conventional altimeter "corrections" (gravitational tide, pole tide, and inverted barometer) are restored. To transform from absolute to relative sea levels, a model of vertical land motion is developed from a high-resolution seasonal mass inversion estimated from satellite gravimetry. A set of 544 tide gauges, including those of the ROSAME network (**Figure 7**), from which seasonal harmonics have been estimated from hourly measurements, is used to assess how accurately each adjustment to the altimeter data helps converge the results to true relative sea levels (**Figure 8**).

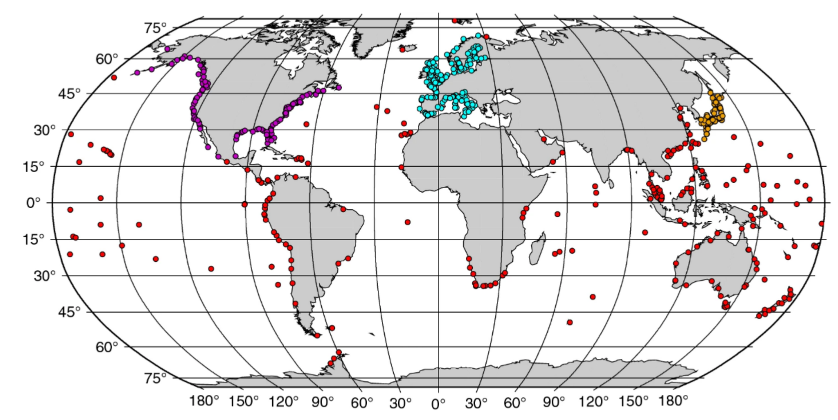

Figure 7: Locations of tide gauges used for comparison with altimetry. Source of these data was GESLA-2 (Global Extreme Sea Level Analysis version 2, of which the ROSAME tide gauges are a part, **Woodworth et al. 2017**).

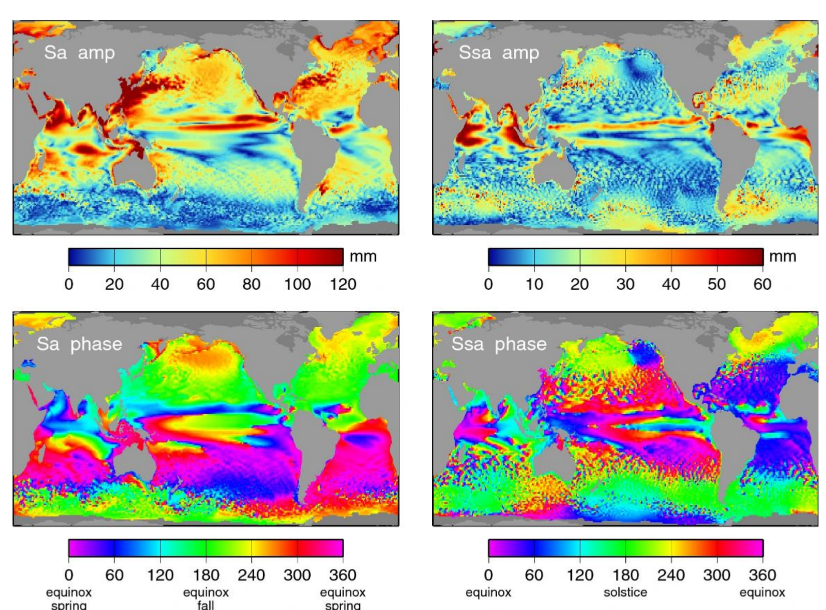

Figure 8: Amplitudes (top panels) and phase lags (bottom panels) of the estimated annual (Sa) and semiannual (Ssa) sea-level oscillations, deduced from DUACS (Data Unification and Altimeter Combination System) gridded altimeter time series. During construction of the altimeter time series, the data were "corrected" for tides and for the inverted barometer effect, so those effects do not contribute to this figure. Phase labels of "spring" and "fall" refer to northern hemisphere seasons.

References: - Devlin A. T., and Coauthors, 2020. Multi-Timescale Analysis of Tidal Variability in the Indian Ocean Using Ensemble Empirical Mode Decomposition. Journal Of Geophysical Research-oceans, 125(12), e2020JC016604, https://doi.org/10.1029/2020JC016604
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https://www.legos.omp.eu/rosame