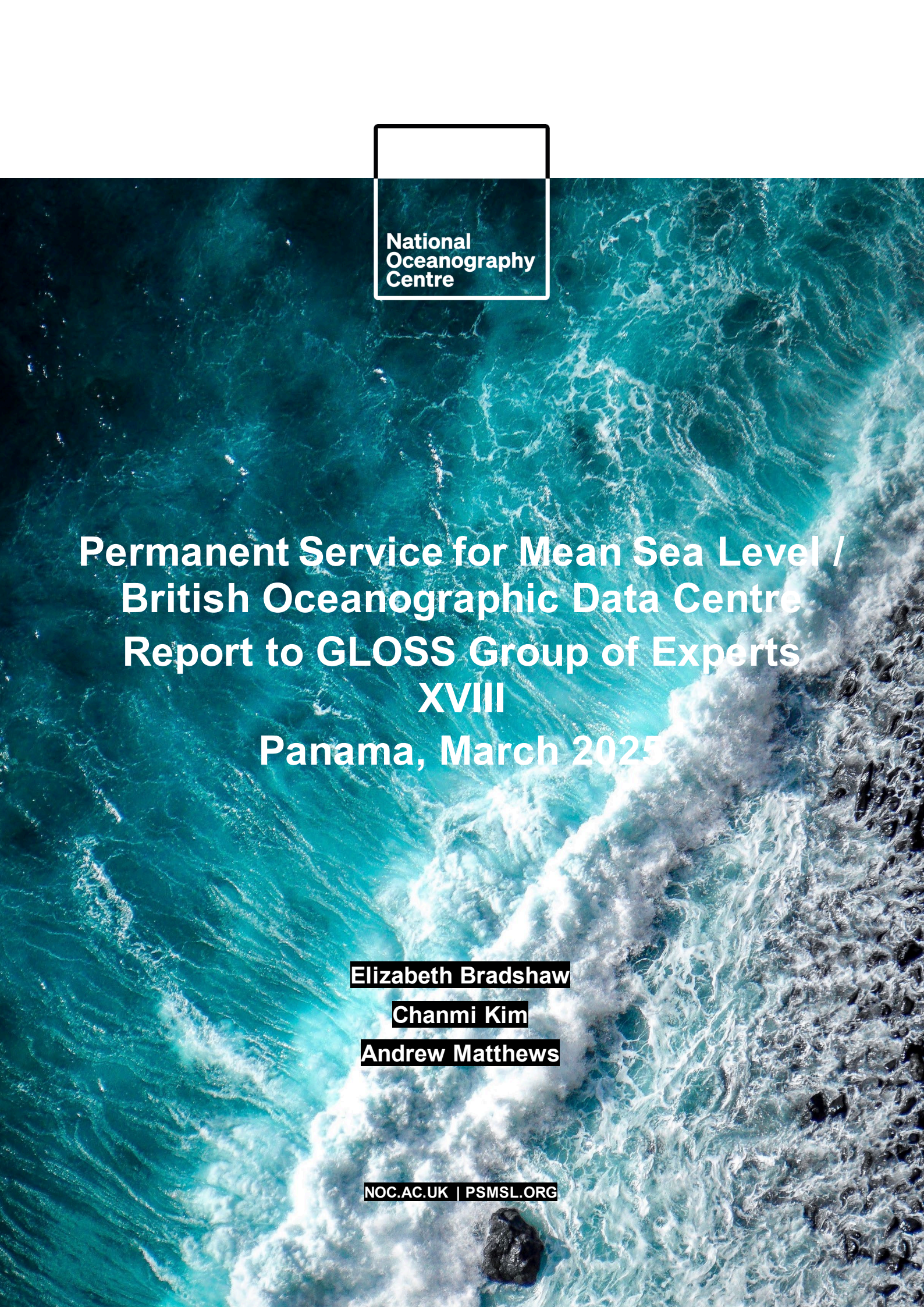

National Oceanography Centre

Permanent Service for Mean Sea Level / British Oceanographic Data Centre Report to GLOSS Group of Experts XVIII Panama, March 2025

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Permanent Service for Mean Sea Level (PSMSL) update

For over 200 years, we have been observing the height of the ocean using tide gauges. Perhaps more accurately called water level sensors, as they can be used in areas where there is little or no tide, they can be used to monitor variations in heights across a wide range of timescales, from high frequency waves, storm surges and tides, to long term changes in ocean currents, changes due to the expansion of warming water, and the melting of glaciers and ice caps.

The Permanent Service for Mean Sea Level (PSMSL) is GLOSS's data centre for monthly mean sea level information, but our origins go back to the IUGG General Assembly held in Lisbon in 1933, when our first director, Joseph Proudman, was tasked with collating and publishing mean sea level data from sites around the world. Today we remain a permanent service of two of IUGG's constituent unions, for Oceanography and Geodesy.

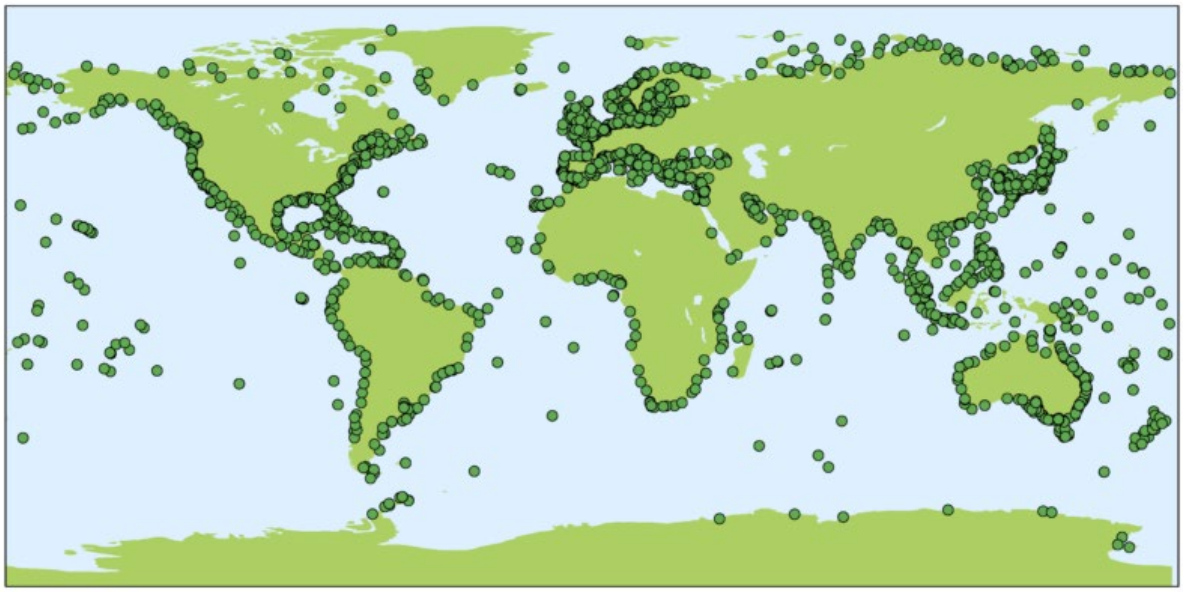


Figure 1. All stations in the PSMSL databank

The PSMSL is based at the Liverpool site of the UK's National Oceanography Centre (NOC) who have committed to supporting its operations in the long term. The NOC is an independent self-governing organisation – a charitable company limited by guarantee, which is funded by UK Research and Innovation to work on National Capability programmes.

PSMSL staff

The core PSMSL team is embedded within the NOC's Sea Level and Ocean Climate subgroup, and consists of the following members.

- Elizabeth Bradshaw, Head of the PSMSL
- Andrew Matthews, Technical lead, PSMSL
- Chanmi Kim, PSMSL data manager

Elizabeth is also the British Oceanographic Data Centre's (BODC) lead for sea level data management, including GLOSS, and the UK's coastal flood forecasting tide gauge network.

We are supported by other members of NOC staff, who provide expertise and guidance in a variety of areas, occasionally represent PSMSL at conferences, and aid us in our remit to provide training and support to operators of tide gauges and users of data.

The PSMSL has an internal advisory group made up of the following NOC staff:

- Angela Hibbert, capacity building
- Chris Hughes, scientific advisor
- Svetlana Jevrejeva, projections, impact and adaptation
- Joanne Williams, surges, extremes and tides
- Simon Williams, GNSS and VLM
- Chris Wilson, ocean circulation and modelling
- Philip Woodworth, scientific advisor and former director
- Lesley Rickards, former director

The PSMSL has been served by an external Advisory Group, but the group is currently under review.

Mean sea level dataset

The fundamental purpose of the PSMSL is to acquire, quality control, and make available mean sea level data. The PSMSL MSL dataset has continued to grow from 2020 to 2024.

Year	2020	2021	2022	2023	2024
No. of stations	790	636	688	693	730
Station years	1361	1099	1325	1350	1796

Table 1. Data added to the PSMSL databank

Figure 2 shows the stations that were updated in 2023 and 2024. More detail about the number of stations added in recent years can be found in Annex 1 and Annex 2 details the organisations that supplied the data, and how many stations they added.

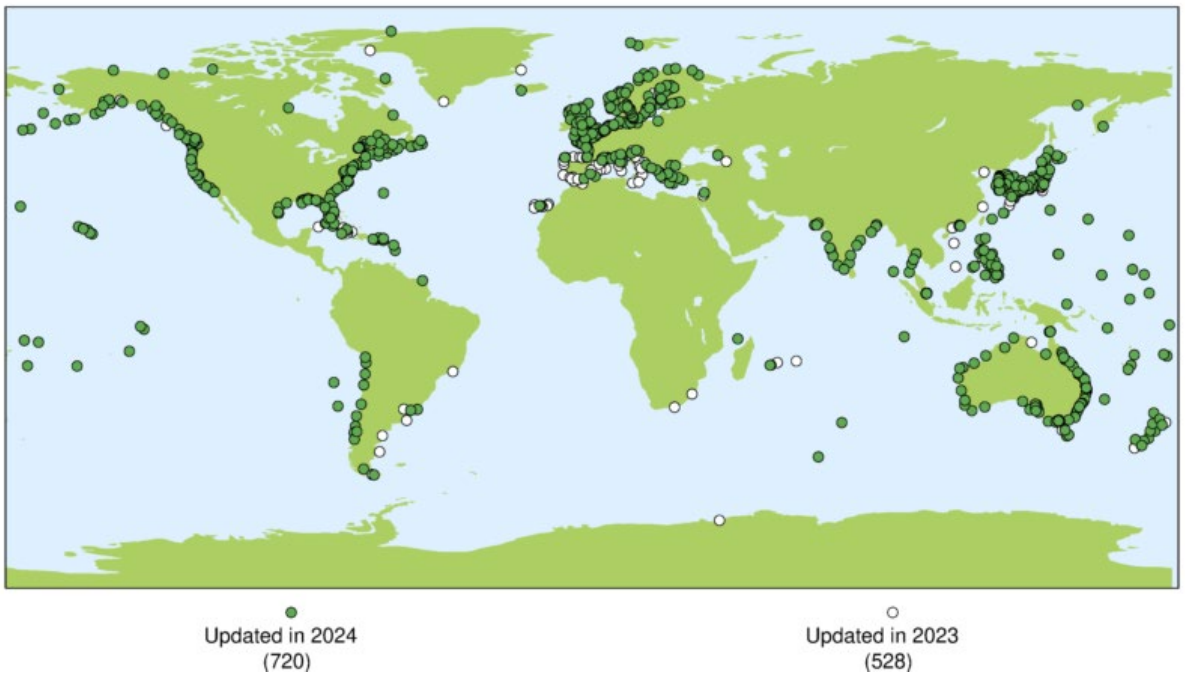


Figure 2. Stations updated in 2023 and 2024

Figure 3 shows the most recent data received from each station in the PSMSL databank. Some sites have not contributed data for over 20 years, and it may be that these stations have ceased to function. One concern is that many of these older stations are in the Arctic and Antarctic and are key gaps in the dataset. In 2022, the head of the PSMSL wrote a letter of support for the Southern Ocean Sea Level Monitoring Network as part of Australian Antarctic Division Decadal planning activities to highlight the need for data in the Southern Ocean.

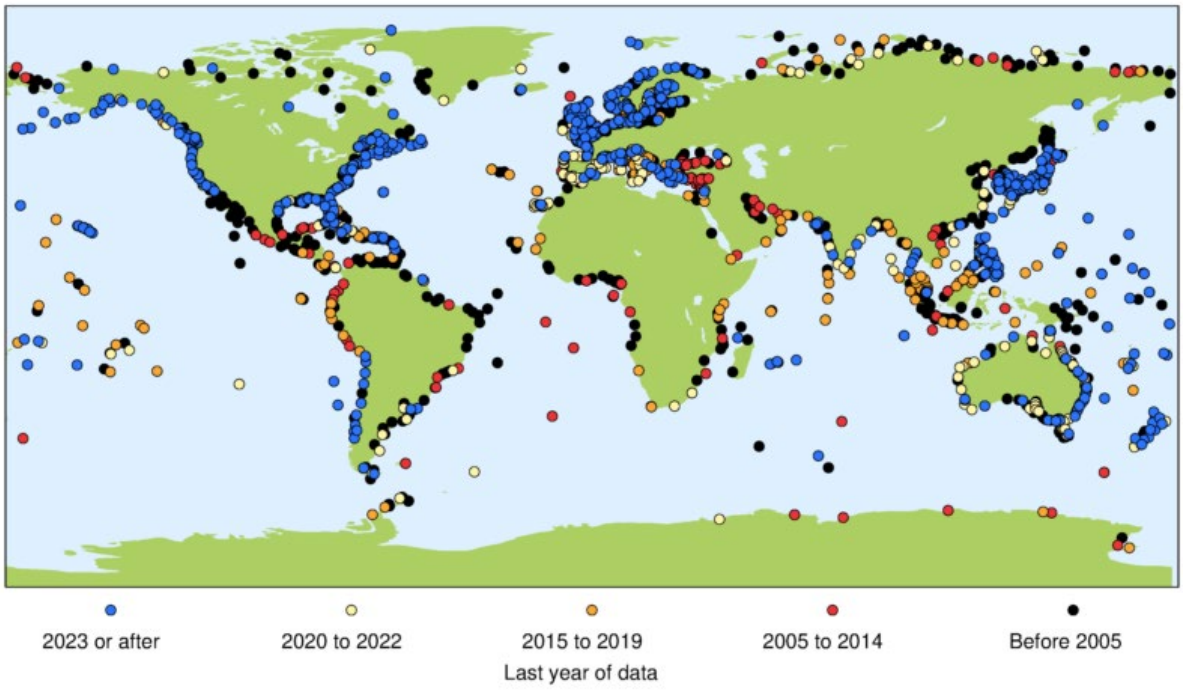


Figure 3. Year of most recent data received by PSMSL

Figure 4 also highlights the more data sparse regions. There are no datum-controlled records at PSMSL longer than 100 years for the Arctic, Africa, South America or Antarctica.

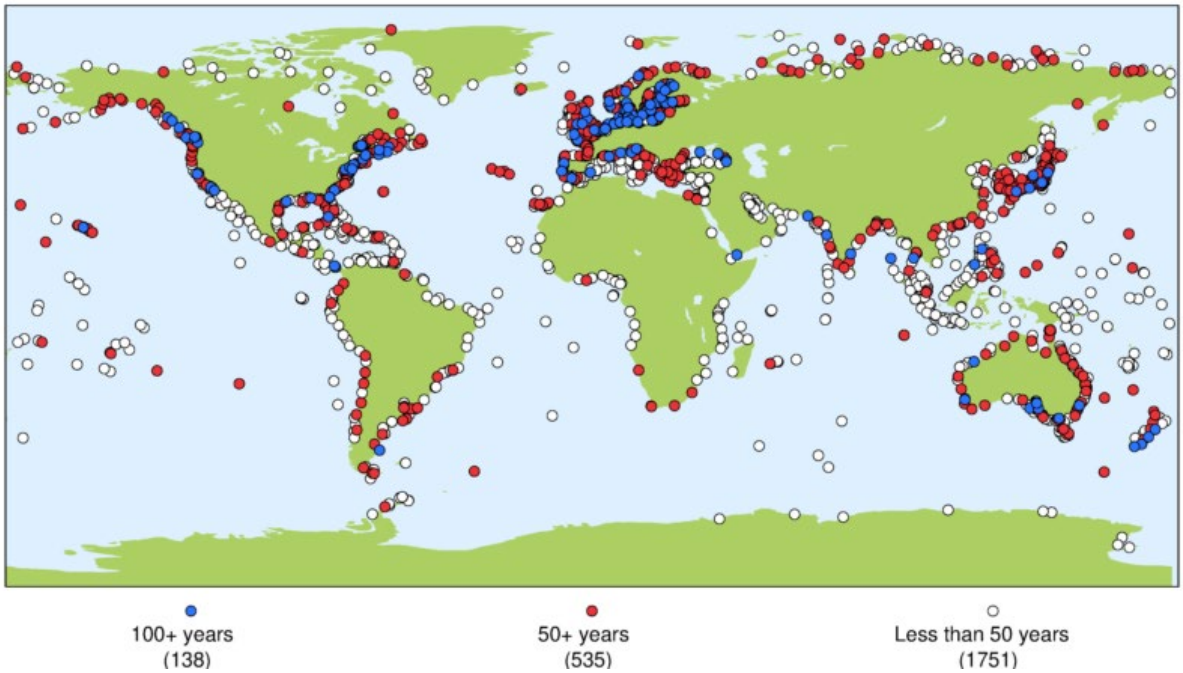


Figure 4. Distribution of long tide gauge records

Figure 5 highlights the continuing disparity of data between the Northern hemisphere (no. of stations shown in red) and the Southern hemisphere (no. of stations shown in blue). There has been a continued downward trend in number of stations provided to the PSMSL. We are aware that some stations continue to operate in near real time, but data are not being quality controlled and mean sea level data are not being calculated. We hope that the continued development of automatic quality control software may help reverse this trend.

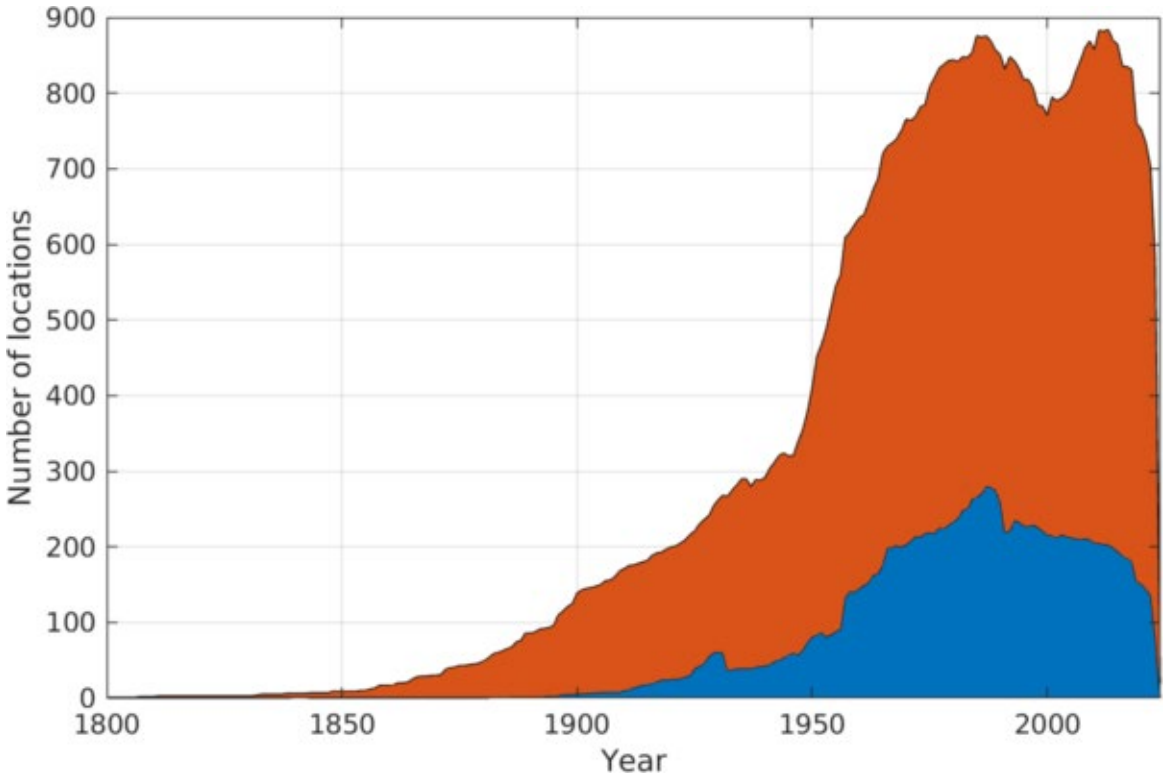


Figure 5. North-South hemisphere distribution of data received by PSMSL

Citations of PSMSL data

One of the ways in which we monitor the success of the PSMSL databank is to collate statistics on the number of peer-reviewed papers that are published citing the PSMSL data paper e.g.

Permanent Service for Mean Sea Level (PSMSL), 2025, "Tide Gauge Data", Retrieved 21 February 2025 from http://www.psmsl.org/data/obtaining/.

Simon J. Holgate, Andrew Matthews, Philip L. Woodworth, Lesley J. Rickards, Mark E. Tamisiea, Elizabeth Bradshaw, Peter R. Foden, Kathleen M. Gordon, Svetlana Jevrejeva, and Jeff Pugh (2013) New Data Systems and Products at the Permanent Service for Mean Sea Level. Journal of Coastal Research: Volume 29, Issue 3: pp. 493 – 504. doi:10.2112/JCOASTRES-D-12-00175.1.

Each paper was checked to ensure that the study had used the data or metadata, and not just referenced the service. It is likely that we are underreporting the studies that use the PSMSL dataset, which is one of our key reasons for working towards assigning a Digital Object Identifier (DOI) to the dataset.

In the years 2018-2022 there were 451 papers published in 182 journals. 14 of these journals had an Impact Factor greater than 10, and 38 papers were published in these 14 journals. The top three journals in terms of Impact Factor were Nature, Reviews of Geophysics and Nature Climate Change. The top three journals in terms of publications were Advances in Space Research (21 publications), Remote Sensing (18) and Geophysical Research Letters (16). It is interesting to note the wide-ranging subject areas of publication e.g. from climate studies, satellite altimetry, marine engineering, environmental assessment and geology. Figure 6 shows the number of publications in each journal.

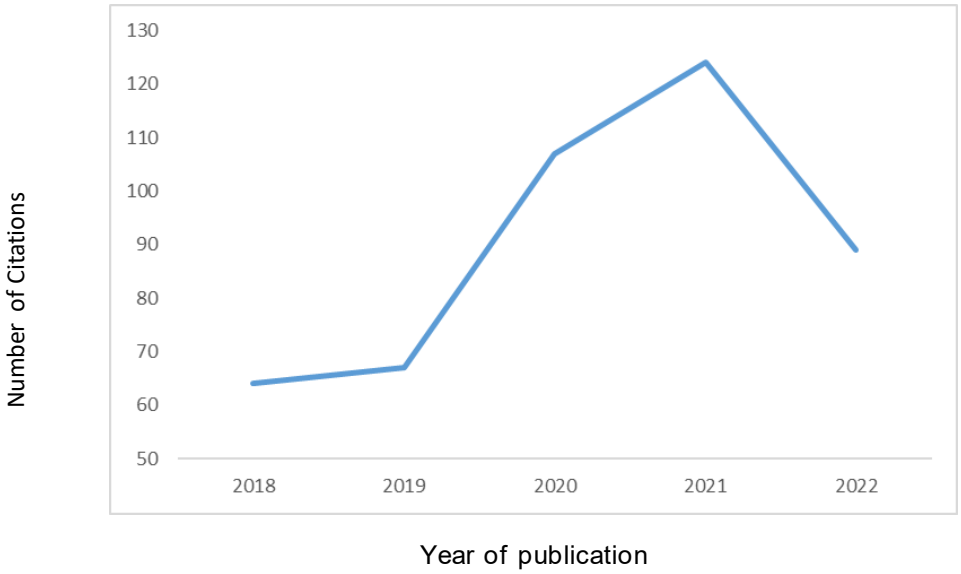


Figure 6. Number of dataset citations from 2018-2022

GNSS-IR

In addition to the main mean sea level dataset, the PSMSL continues to host a repository of sea level data extracted from GNSS receivers using interferometric reflectometry (GNSS-IR). This technique exploits the multipath errors caused when the main signal from the satellite is interfered with by versions of the signal reflected off surfaces in the vicinity of the receiver. Noise changes as sea rises and falls and sea level data can be extracted from signal-to-noise ratio

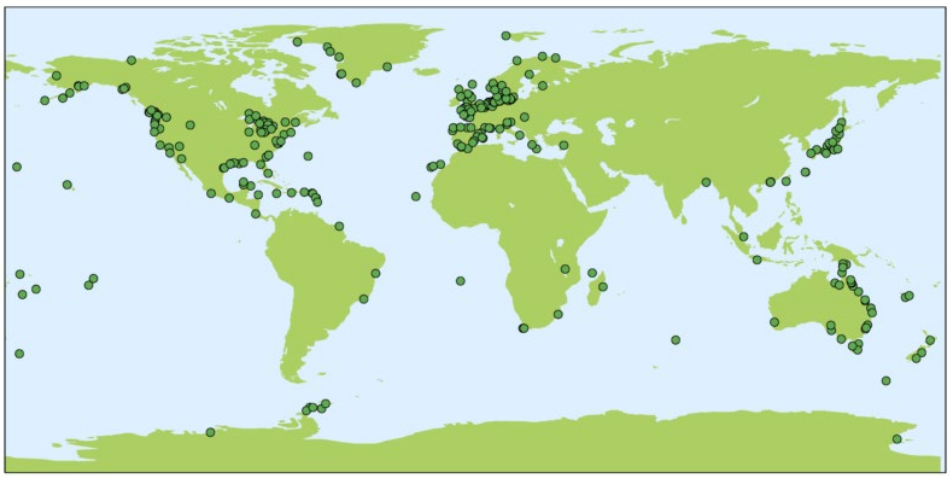


Figure 7. GNSS-IR sea level records available from PSMSL

The PSMSL initially created the portal with funding from the European Union Horizon 2020 EuroSea project, and are now maintaining it using core NOC funding. Over the past two years we have expanded the portal from about 250 sites to nearly 350. We have also improved the documentation on the website, including adding Python notebooks illustrating the available parameters in the data files, and details of metadata files that will help those wishing to access data programmatically.

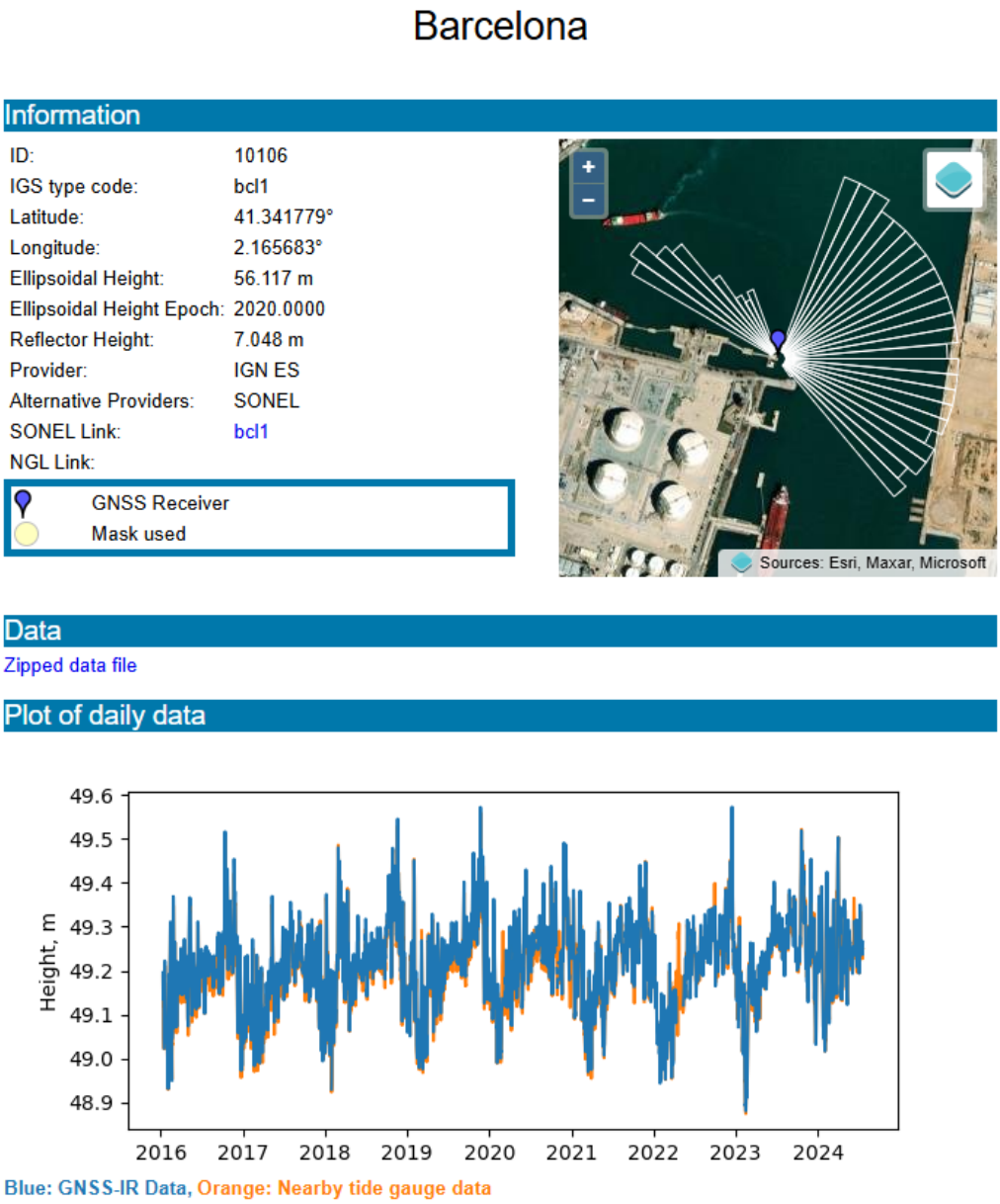


Figure 8. An example GNSS-IR data available from the PSMSL website (https://psmsl.org/data/gnssir/site.php?id=10106)

BODC developments

Over the past two years, the British Oceanographic Data Centre (BODC) have renewed their code used to quality control sea level data. The previous package used had become difficult to maintain due do its complexity and the current IT team's relative unfamiliarity with the code and its underlying purpose. Other groups in NOC were involved to ensure consistent use of tidal predictions across the organisation. With the aid of PSMSL sea level scientists, BODC developers have been able to modernise the package using commonly used libraries and best practices in software development.

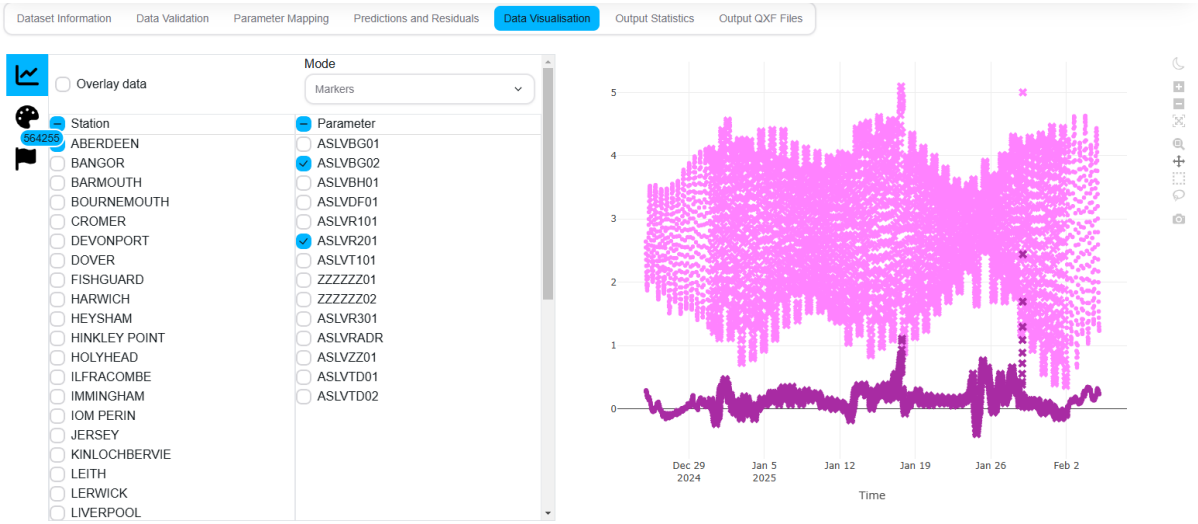


Figure 9. BODC's new quality control software

The new code is now being used to quality control sea level data from the UK's national tide gauge network.

The BODC have also continued to expand their use of an ERDDAP server to distribute data. Tide gauge data from two sites in the UK were initially added to BODC's ERDDAP server as part of the CreamT project which built a prototype dashboard to provide coastal flood monitoring to local policy makers.

In the past two years, the experiment was expanded to include sample data from the whole of the UK tide gauge network, and another prototype dashboard built on top to allow the dataset to the explored. This system could potentially form the backbone of the GLOSS data portal.

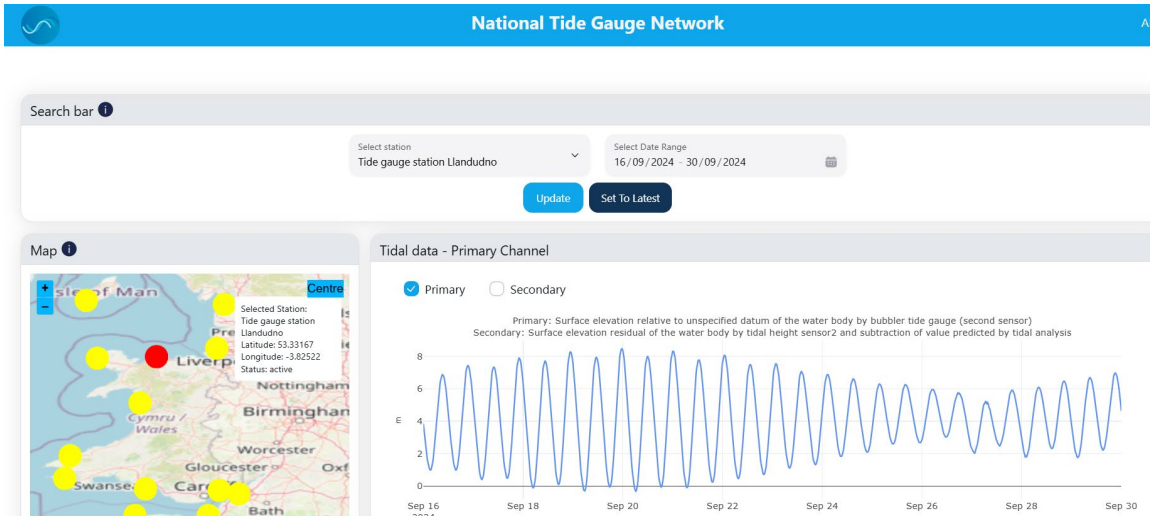


Figure 10. The prototype BODC dashboard for exploring the UK national tide gauge network

The PSMSL have also been reviewing their options for delivering data via ERDDAP, in order to make them available for available via the forthcoming aggregated GLOSS ERDDAP server (see Figure 9). Initial test netCDF files have been prepared for testing purposes, but the metadata distributed may need to change to match the final data model agreed by GLOSS.

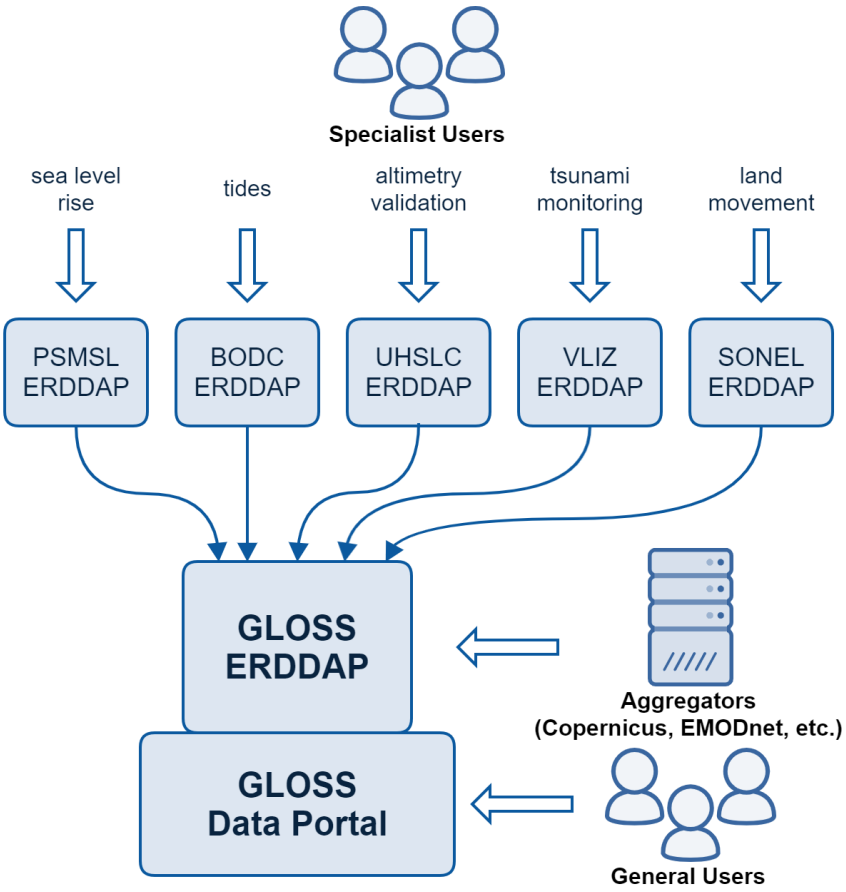


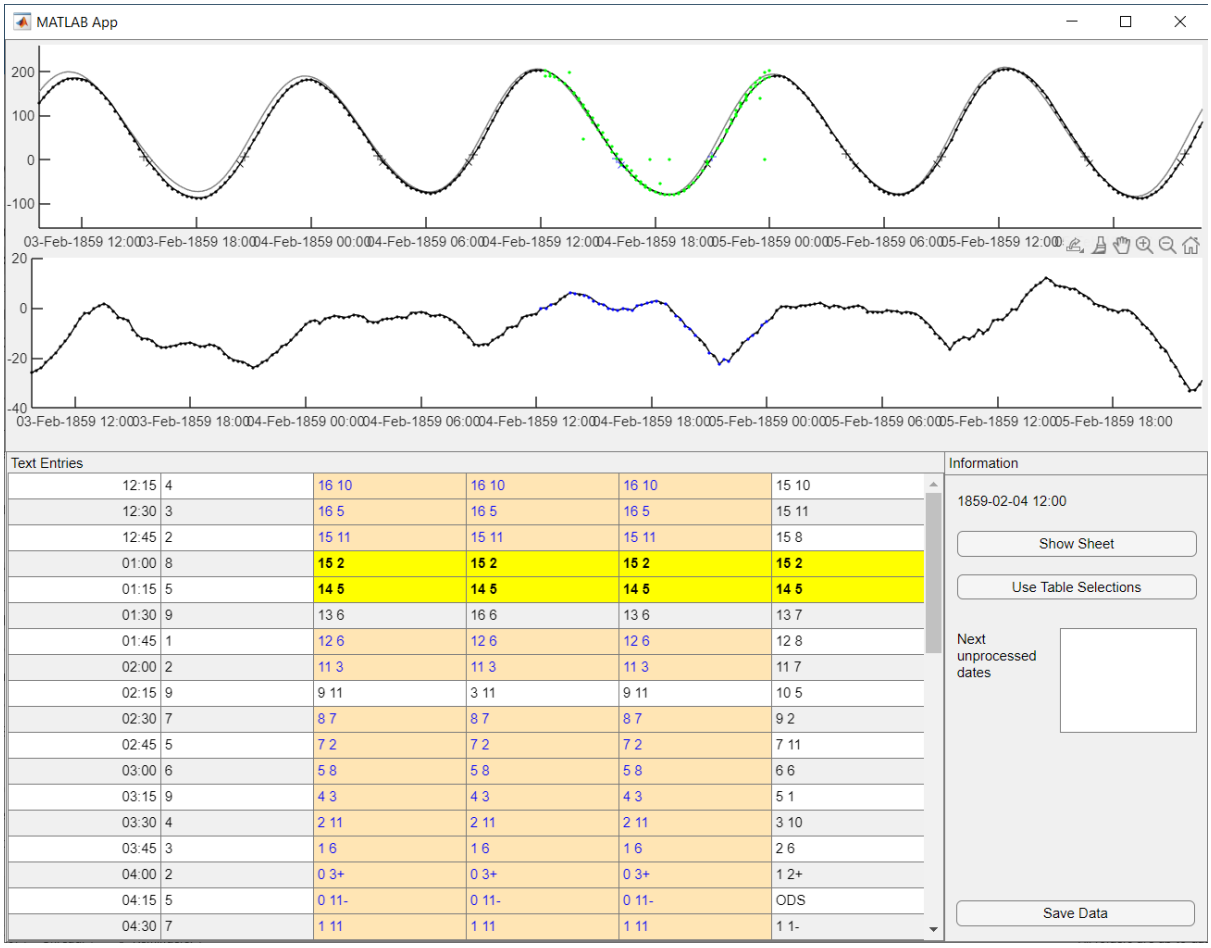
Figure 11. Schematic of the proposed unified GLOSS data portal, and how different users might interact with our data.

Other activities

Data Rescue

The PSMSL has continued to support attempts to recover sea level data from historical documents. We have finally completed quality controlling data recovered from two sites in Liverpool Bay recorded between 1853 and 1903 using the Zooniverse.org website. The final data has been submitted to BODC and is in the process of being ingested into their system. This data has already been used to validate the predicted storm surge from a reanalysis of a historical storm in 1902 (Hawkins et al., 2023[1]).

[1] Hawkins, E., Brohan, P., Burgess, S. N., Burt, S., Compo, G. P., Gray, S. L., Haigh, I. D., Hersbach, H., Kuijjer, K., Martínez-Alvarado, O., McColl, C., Schurer, A. P., Slivinski, L., and Williams, J.: Rescuing historical weather observations improves quantification of severe windstorm risks, Nat. Hazards Earth Syst. Sci., 23, 1465–1482, https://doi.org/10.5194/nhess-23-1465-2023, 2023.



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01:45	1	12 6	12 6	12 6	12 8
02:00	2	11 3	11 3	11 3	11 7
02:15	9	9 11	3 11	9 11	10 5
02:30	7	8 7	8 7	8 7	9 2
02:45	5	7 2	7 2	7 2	7 11
03:00	6	5 8	5 8	5 8	6 6
03:15	9	4 3	4 3	4 3	5 1
03:30	4	2 11	2 11	2 11	3 10
03:45	3	1 6	1 6	1 6	2 6
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04:15	5	0 11-	0 11-	0 11-	ODS
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Figure 12. An example of quality controlling data recovered from ledgers in the UK Tides Zooniverse project

Meetings and Training

During the past two years, NOC staff have provided training on several occasions, including:

- Providing training in sea level monitoring and science to remote sensing PhD students in the UK (January 2023)
- Delivering training in tidal analysis and sea level variability to Madagascan stakeholders (January 2024)
- Visiting Anguilla to support their project to obtain tsunami ready accreditation from the IOC, including sessions on tide gauge maintenance and sea level science (March 2024)

In May 2023, members of the PSMSL helped organise a tide gauge workshop alongside the EuroGOOS Tide Gauge Task Team as part of the EuroSea programme. This was the second workshop under the EuroSea programme, and included sessions on global networks and data portals, GNSS-IR, and automatic quality control and data processing.

The PSMSL also held a workshop on best practices in tidal analysis as part of an ongoing IAPSO study group. This group is currently producing guidance to be submitted to https://www.oceanbestpractices.org/.

Reorganisation of PSMSL archives

During 2024, NOC carried out some refurbishment of its Liverpool office. As a result, we were required to relocate our large collection of paper archives built up over the PSMSL's history. We took the opportunity to review the contents, improve the organisation and catalogue, and dispose of some content that was no longer required.

Figure 13. A selection of mareograms from Australia contained in the PSMSL archives

Refurbishment of the Doodson-Légé tidal prediction machine

The Liverpool site of the NOC still hosts two analogue tidal prediction machines, on loan from National Museums Liverpool. In July 2024, one of the museum's metals conservators visited to carry out routine maintenance on the newer Doodson-Légé machine (see Figure 10).

In the 1950s, these machines were operated by a team of assistants known as "computers". As these computers retired, the knowledge of how to program these machines has been handed down, but we were at risk of losing this expertise, as only a few members of staff had previously carried out the task. We took the opportunity to train four more "computers" and document the process in order to properly preserve this important part of our history.

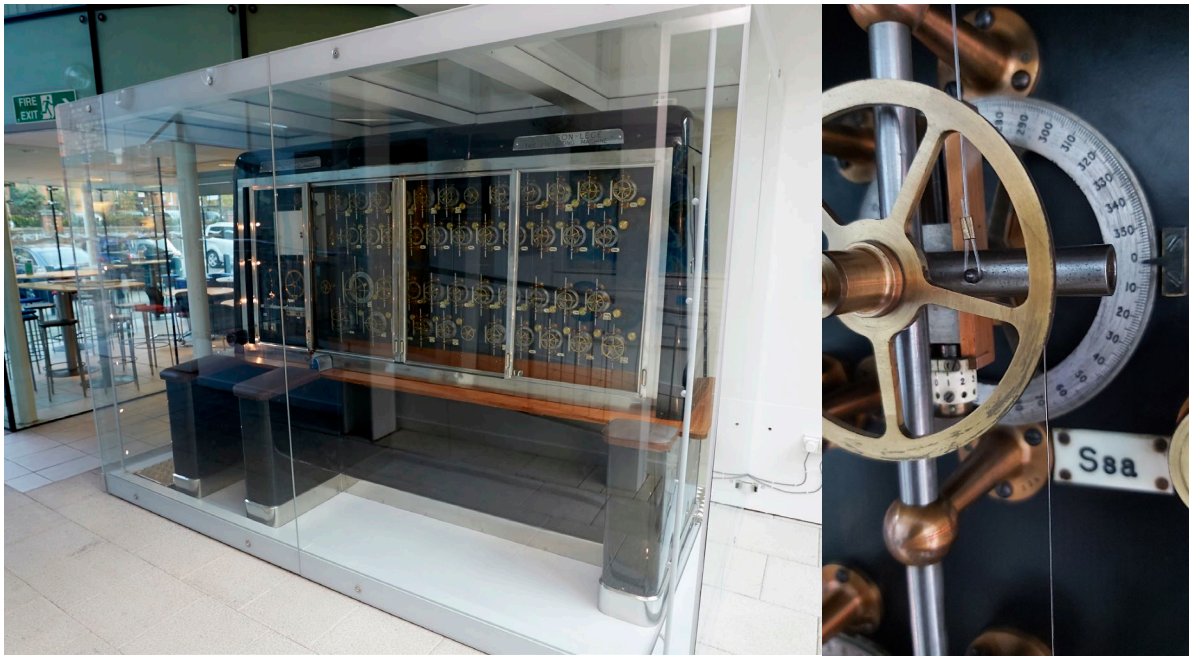

Figure 14. The Doodson-Légé Machine, and a close up of the mechanisms used to adjust the parameters for an individual constituent.

Summary and Future plans

2023 and 2024 have been typically busy years for the PSMSL and the BODC, with data acquisitions have been higher than in previous years. We've also continued to develop the GNSS-IR portal with an aim to making it a sustainable product in the long term. We've also been busy working with the sea level and wider scientific communities on a diverse range of projects and committees.

We expect 2025 to be just as busy, with our plans for future years including:

- Finalising the delivery of PSMSL and BODC data through ERDDAP servers
- Improving PSMSL metadata, particularly lineage metadata, so our data suppliers are properly credited
- Continuing investigation of the use of permanent identifiers to improve tide gauge metadata
- Further developing the use of GNSS-IR, in particular near real time delivery and significant wave height data.
- Continuing to explore methods of recovering historical sea level data

Some PSMSL publications

Over the past two years, PSMSL staff have been involved in the production of these publications:

Latapy, Alexa, et al. (2023) "Data rescue process in the context of sea level reconstructions: An overview of the methodology, lessons learned, up-to-date best practices and recommendations." *Geoscience Data Journal* 10.3: 396-425.

Lin-Ye, Jue, et al. (2023) "Delayed-mode reprocessing of in situ sea level data for the Copernicus Marine Service." *Ocean Science* 19.6: 1743-1751.
Kendon, Mike, et al. (2023) "State of the UK climate 2022." *International journal of climatology* 43: 1-83.
Kendon, Mike, et al. (2024) "State of the UK Climate 2023." *International Journal of Climatology* 44: 1-117.
Thompson, Philip R., et al. (2025) "Reply to “timing errors in global sea level observations” (Pan et al., 2025)." *Ocean Dynamics* 75.2: 1-6.