Kartverket

REPORT:

National report of Norway 2022: The Norwegian Tide Gauge Network

Authors:

Oda Roaldsdotter Ravndal[1], oda.ravndal@kartverket.no

Kristian Breili[2], kristian.breili@kartverket.no

November 4th, 2022

Content

[1] Norwegian Mapping Authority, Hydrographic Service, P.O. Box 60, 4001 Stavanger, NORWAY

[2] Norwegian Mapping Authority, Geodetic Institute, P.O. Box 600 Sentrum, 3507 Hønefoss, NORWAY

Overview of the network

The Norwegian Mapping Authority operates the Norwegian sea level observing system, consisting of tide gauges and GNSS receivers along the Norwegian coast.

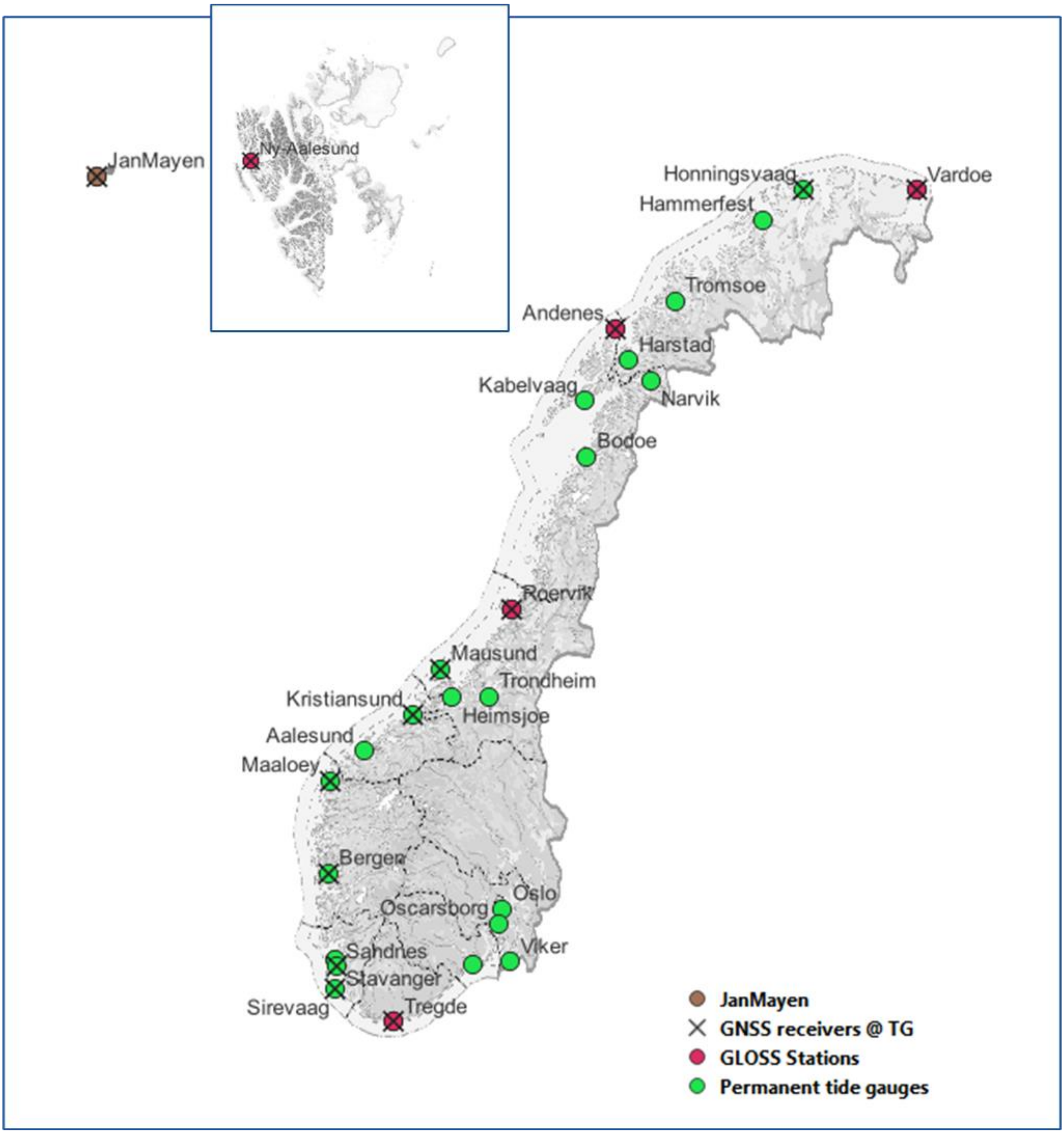


Figure 1: Overview of Norwegian tide gauges, GLOSS stations and GNSS receivers co-located with tide gauges

Tide gauge network

There are, as of October 2022, 25 tide gauges along the Norwegian coast and one in Ny-Ålesund in Svalbard, see Figure 1 and Table 1.

All the permanent tide gauges are either of the stilling well type with a float gauge, or a radar gauge. Most of the gauges have a sampling frequency of 1 Hz, and 1-minute averages are transferred to the Norwegian Mapping Authority in near real-time and stored in a database. The one-minute values are quality controlled using an automatic routine. If the data pass the quality control successfully, they are low pass filtered (Butterworth filter) and decimated to produce ten-minute values. The ten-minute values are directly available online (API and website). If the data do not pass the automatic quality control, a manual control is required. Software developed in-house is used for data control, processing, and analysis.

Most of the gauges are mounted on solid rock and are levelled with about three years intervals. The Norwegian Mapping Authority is responsible for the levelling.

Temporary tide gauge network

In addition to the permanent tide gauge network the Mapping Authority operates a network of temporary tide gauges. This network consists of shorter time series spanning from a couple of days to a few years mostly measured using pressure sensors. The data are now mainly used for improving models (tide and water level, vertical datums) and in relation to work done by the coastal administration.

Every year a campaign of temporary tide gauge measurements is carried out when the Mapping Authority is carrying out seabed mapping around Svalbard. The water level data collected in these campaigns are of shorter duration (maximum 2 months) but gives an understanding of the tidal regime around Svalbard (see Figure 2). To tie the water level data to benchmarks or the ellipsoid, new sensors and measurement campaigns would be required. There is also a need for more accurate water level data on the east coast of Svalbard, both for improving models and for navigational purposes.

Kartverket

Figure 2: Left: Map showing the locations of existing time series on Svalbard. Quality and duration vary. Right: Crew on from the survey vessel Hydrograf on the way to collect data from a temporary tide gauge, summer of 2022. Photo: Ingeborg Andrea Sylte-Raanes

GNSS measurements

By October 2022, fourteen continuous GNSS receivers (CGPS) are installed at thirteen Norwegian tide gauges (including Jan Mayen), see Figure 1. In Vardø, Andenes, Tregde and Sandnes the antennas are installed directly at the tide gauge, on the other stations the GNSS receivers are several hundred meters away. In Ny-Ålesund the GNSS receivers are installed near the old VLBI-station (Very Long Baseline Interferometry), which is located about 1.5 km from the tide gauge. In some locations the tie between the tide gauge and the GNSS receiver is difficult due to the placement of the GNSS receiver. The Norwegian Mapping Authority is responsible for the continuous GNSS measurements and analyses of the data.

Expansion of the network

The Mapping Authority has, over the past years, identified that the main challenge with the existing tide gauge network is the lack of geographic coverage. There are large stretches (e.g., between Bodø and Rørvik, Stavanger and Tregde) and long fjords (for instance the Hardangerfjord and the Sognefjord) without any permanent tide gauges. As data from the tide gauges are increasingly being used for prediction of meteorological surge (including preparedness to extreme surges), products related to e-navigation (e.g., S104 from IHO) and adaptation to a changing climate, being able to provide reliable information to all interested parties is required.
To answer the need for better geographical coverage of the tide gauge network, a project was launched in 2021. The main aim of the project is to expand the tide gauge network with at least 10 new locations over the next 5 years.

New technology

The existing tide gauges are mainly float gauges in stilling wells. For the new tide gauges, we decided that radar technology was the most promising. The new system consists of two radar sensors (Vega PULS 61 and Vega PULS C23). The Vega PULS 61 could be mounted in a steel tube for locations with sea ice. The system has a Scanmatic 5059 datalogger and is equipped with battery backup and an IP-VPN router making real-time data transfer possible.

New stations

Figure 3 The test site installed in Sandnes in December 21

A first test site was installed in December 2021, in Sandnes – close to the existing permanent tide gauge in Stavanger. In addition to the tide gauge, we installed a permanent geodetic station. The tide gauge was installed in collaboration with and partly financed by the municipality and the port of Sandnes with the aim of improving the climate change adaptation strategies in the municipality.

In September 2022, a new station was installed in the small port of Sirevåg. The coastline between Stavanger and Tregde has a strong meteorological signal and small astronomical tide due to an amphidromic point off the coast, and water level and vertical datums for the area have been difficult to estimate. The new tide gauge will hence be an important addition to the network. There was an existing GNSS receiver in the area, approximately 300 m across the port.

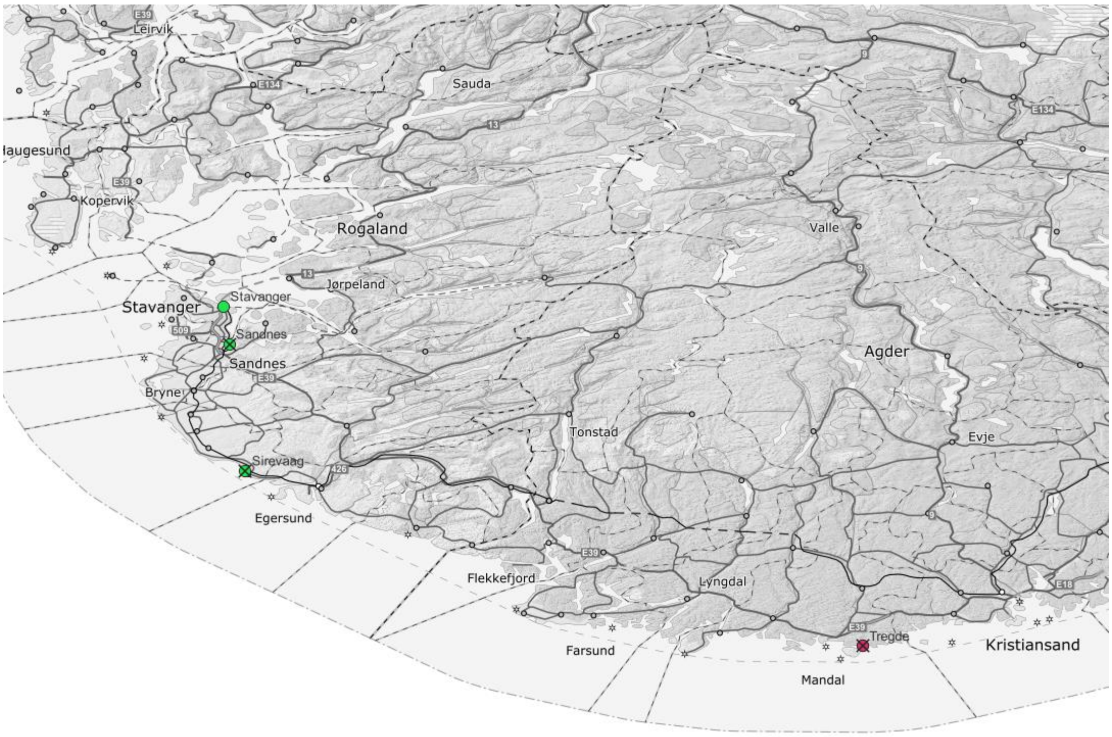


Figure 4: Map showing the new stations in Sirevåg and Sandnes in addition to the existing ones in Stavanger and Tregde

Changes to the network and upgrades of infrastructure

Jan Mayen

At Jan Mayen, there are about 40 years of continuous measurements from the inside of a well. The well is only partly connected to the sea and the measurements are therefore of poor quality. We have also compared the sea-level rate observed by the tide gauge with the sea-level rate calculated from the Copernicus Marine Environment Monitoring Service gridded altimetry product. Over the period 1993-2022, we found a difference of about 3 mm/yr, which is larger than expected and reinforces the impression of tide gauge observations that are difficult to interpret and not to be trusted. The data collection from the well will therefore most likely be discontinued due to the poor connection with the sea level.

The data collection from the well will most likely be discontinued due to the poor connection with the sea level. There have been several failed attempts of installing a permanent station and although the Mapping Authority would be interested in such a station, there are no immediate plans for a new attempt.

Hammerfest

Due to port renovation the tide gauge in Hammerfest was moved in the middle of February 2022. The station was moved approximately 150 meters to the west, see Figure 5, and the equipment has been upgraded (new sensors, datalogger and communication).

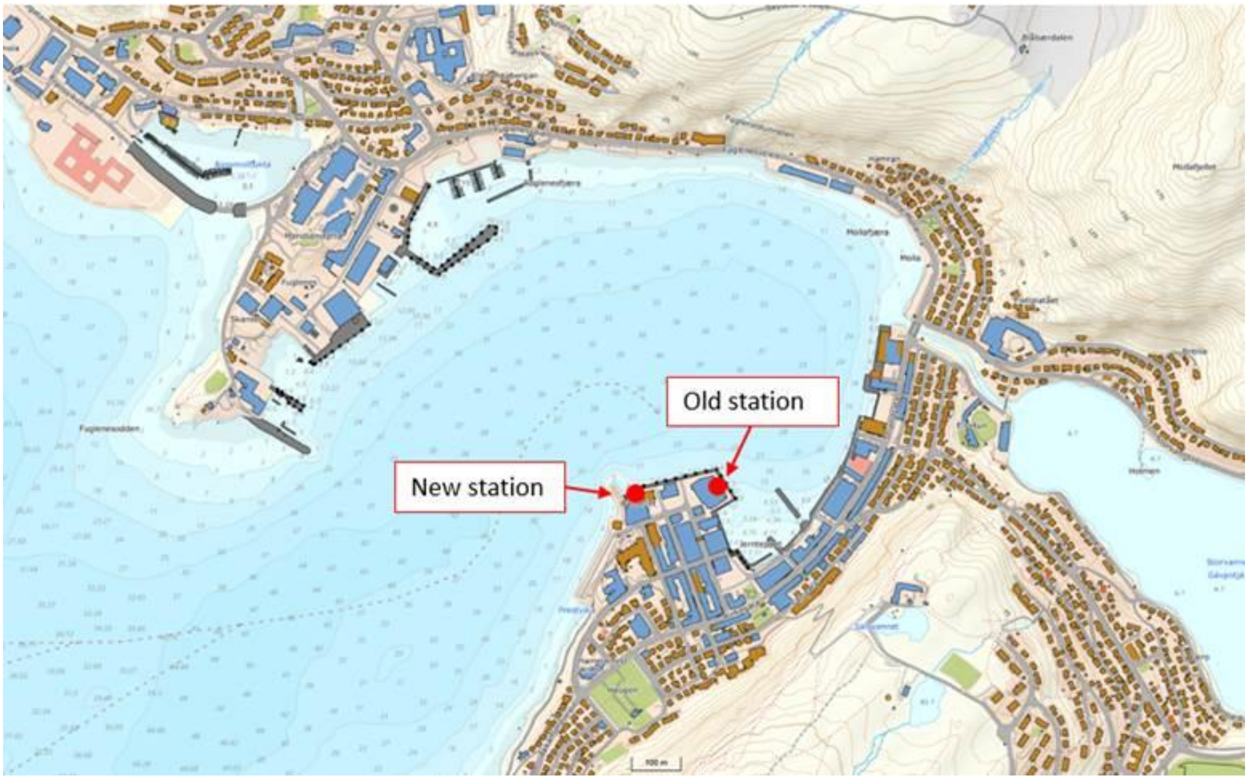


Figure 5: Location of old and new tide gauge in Hammerfest

Figure 6: The new tide gauge in Hammerfest.

From March 1st the data from the new station is the official data from Hammerfest and available online. All benchmarks are levelled and vertical datums have been transferred.

Upgrades and calibration of existing tide gauges

Calibration of float gauges

Water level data from the existing float gauges was in 2019 corrected for known errors. This was done for data back to 2008 and an additional quality control was performed.
The theory behind the calibration is that when the counterweight of the float is submerged, the buoyancy causes a decrease in the freeboard of the float, in turn causing an error in the measured water level. The amount of chain on either side of the wheel also changes the freeboard of the float, due to changes in the weight distribution. The error resulting from these two features has been derived theoretically and confirmed with laser measurements. The data needed to apply corrections for these errors, e.g., total length of chain and masses of float and counterweight, are available back to about 2008. The data has been collected, and corrections are applied to the time series from 23 float gauges along the Norwegian coast and on Svalbard.
Additional quality control was done manually by 1) visual inspection of the residual time series, and 2) time series from level switches. In each stilling well, three level switches are mounted at fixed heights. The switches use a small float to turn the switch on or off, and thus are on when the float is submerged. By comparing the

measured water level at the time these switches change state to the known level the switches are mounted at, we can identify incidents of chain crawl easily.

Upgrade of hardware and software

The equipment in use and the data acquisition system from the existing float tide was old and some components were unsupported and obsolete. To sustain and prepare the network for the future, several components were upgraded in September 2022.

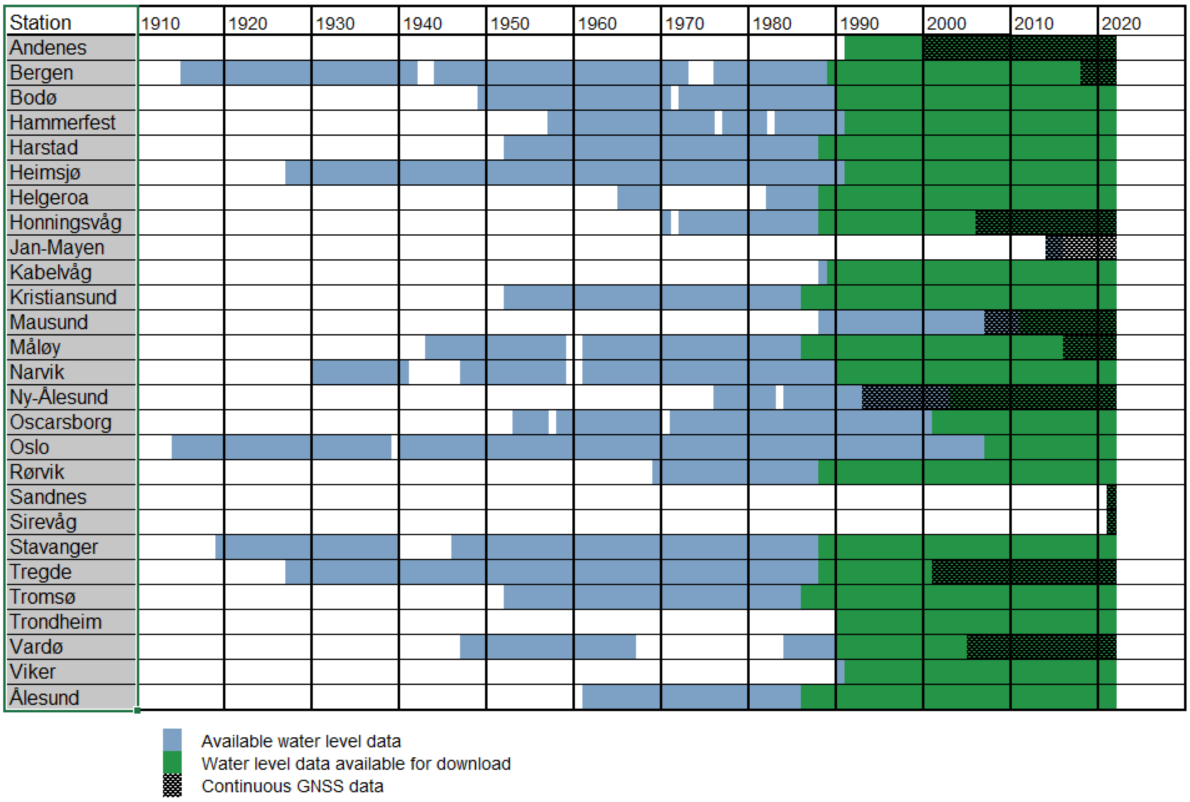
- All existing tide gauges are equipped with Scanmatic 5059 dataloggers
- The communication system on all the tide gauges have been upgraded– with new IP-VPN routers that allows for better redundance and security in the communication and possibility of data acquisition in near real time (data collection currently every 5 minutes)
- New data acquisition system to allow for increased security and real-time data acquisition

The dataloggers and communication system is the same as for the new stations and the communication system is on the same platform as the system used by the Geodetic Institute for the GNSS receivers.

Distribution of data and products

Data availability and distribution

Figure 7 shows the data available from the permanent tide gauges. All data available online can be retrieved directly from an API-service (https://api.sehavniva.no/tideapi_en.html) free of charge. Data not available online, both from the temporary and the permanent network, can be obtained on request.



Kartverket

Figure 7: Availability of data from permanent tide gauges. GNSS availability from the stations Kristiansund and Rørvik has not been updated on this figure.

Data from the permanent tide gauges is distributed to international data portals.

Website

In addition to the API-service, the Norwegian Mapping Authority makes data and information available on the website [Se havnivå.]

The following products are available:

- Water level observations (from around 1990 to now), for all permanent tide gauges (see Figure 7)
- Historical monthly and annual means, for all permanent tide gauges and from the start of the time series (1914-1991 depending on station)
- Water level estimations, residuals, tidal predictions, vertical datums and water level prognosis (based on a model from the Norwegian Meteorological Institute) for almost all positions along the coast
- Projections of future sea level change in Norway for almost all positions along the coast

The official Norwegian tide tables are no longer published as a separate online publication (as of 2021), but the tide tables are still available for download at the website.

The web tool Se havnivå i kart (Visualize sea level) visualizes present-day storm surge levels and future sea level rise. The data and maps illustrate the potential scale of inundation along the Norwegian coast. The tool is used for preparedness and prevention in risk management and adaption to climate change. It is possible to get statistics on buildings, area and roads affected by coastal flooding in a community, and download inundation layers for custom GIS applications. The tool has been used extensively – both by community planners, in the media and by the general public.

All data and products available online are free of charge

Other activities

Separation models

The data from the Norwegian tide gauge network were an important part in the work leading to the publication of the first official gridded national separation model. These models make it possible to convert directly between different vertical datums for given positions and were made public in 2021. The models describe the relationship between the geoid, Mean sea level, Chart datum and the ellipsoid (EUREF89). The models facilitate seamless terrain models from the deepest fjords to the highest mountains, coastal zone management and Ellipsoidally Referenced Surveying (ERS). At this point, the models are valid from the coast to the territorial border, but it is planned to merge the models with altimetry derived models for the open ocean.

New sets of constituents through harmonic analysis

The Norwegian Mapping authority ran new harmonical analyses on their tide gauge network, and updated tide predictions and astronomical levels in August 2021. With updated constant sets from harmonic analysis follows updated tide predictions and astronomical levels for all the permanent tide gauges.

We ran the analyses on hourly water level time series, from 01.01.2006 - 31.12.2020 (except Mausund tide gauge which was installed in October 2010). SA varies widely from year to year, and we chose to analyze it over the period from 1993-2020 in a separate harmonic analysis. Together, this constitutes the final set of constants.

Altimetry and tide gauges

Data from the tide gauges have over the past years been used to validate data and products from altimetry satellites (e.g. Sentinel-3A/B).

Some references for the work that has been carried out are:

Breili K., Simpson M. J. R., Nilsen J. E. Ø. Observed Sea-Level Changes along the Norwegian Coast. *Journal of Marine Science and Engineering*. 2017; 5(3):29. https://doi.org/10.3390/jmse5030029

Ophaug, V., Breili, K., & Andersen, O. B. (2021). A coastal mean sea surface with associated errors in Norway based on new-generation altimetry. *Advances in Space Research*, 68(2), 1103-1115. https://doi.org/10.1016/j.asr.2019.08.010

New projections on sea level along the Norwegian coast

Sea level projections for Norway are planned to be updated following the release of the IPCC's Sixth Assessment Report. The work has been commissioned by the Norwegian Environment Agency and updated projections for Norway are expected to be available in 2023. In addition to sea level projections, new return levels for storm surges will be calculated. The new projections will be made available through the webservices of the Norwegian Mapping Authority both to the public and as an official basic map dataset for use by municipalities for planning and building purposes.

Appendix

Station	PSMSL ID	GLOSS ID	Latitude	Longitude	Water level data available from	GNSS station ID	GNSS available from
Viker	1759		59º02' N	10º57' E	1990		
Oslo	62		59º54' N	10º44' E	1914		
Oscarsborg	33		59º41' N	10º37' E	1953		
Helgeroa	1113		59º00' N	09º52' E	1965		
Tregde	302	321	58º00' N	07º34' E	1927	TGDE	2001
Sirevåg			58°30' N	05°47' E	2022	SIRC	
Stavanger	47		58º58' N	05º44' E	1919		
Sandnes			58°52' N	05°40' E	2021	SNES	2021
Bergen	58		60º24' N	05º18' E	1915	BERH	2019
Måløy	486		61º56' N	05º07' E	1943	MALO	
Ålesund	509		62º28' N	06º09' E	1961		
Kristiansund	682		63º07' N	07º45' E	1952	KRSU	
Heimsjø	313		63º26' N	09º07' E	1928		
Mausundvær			63º52' N	08º40' E	1988	FROC	2007
Trondheim	34		63º26' N	10º24' E	1989		
Rørvik	1241	234	64º52' N	11º15' E	1969	VIKC	
Bodø	562		67º18' N	14º24' E	1949		
Kabelvåg	45		68º13' N	14º30' E	1988		
Narvik	312		68º26' N	17º25' E	1931		
Harstad	681		68º48' N	16º33' E	1952		
Andenes	425	322	69º19' N	16º09' E	1991	ANDE	2000
Tromsø	680		69º39' N	18º58' E	1952		
Hammerfest	758		70º40' N	23º41' E	1957		
Honningsvåg	1267		70º59' N	25º59' E	1970	HONS	2006
Vardø	524	323	70º20' N	31º06' E	1947	VARS	2005
Ny-Ålesund	1421	345	78º56' N	11º57' E	1976	NYA1 NYAL	1997 1993

Table 1: List of Norwegian tide gauges with information on co-located GNSS receivers. GLOSS-stations are highlighted