SMHI

The Swedish Sea Level Network

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Introduction

The Swedish Sea Level Network, operated by the Swedish Meteorological and Hydrological Institute (SMHI), records sea level at 23 locations (Figure 1 and Table 1). The network is considered as the official Swedish sea level network. SMHI is responsible both for the network, data and the levelling of the stations. The Swedish sea level records constitute some of the longest and most robust sea level records in the world. Also, the Swedish Maritime Administration, records sea level at more than 30 locations (Appendix 1).

Figure 1. The Swedish Sea Level Network operated by SMHI in September 2015.

Figure 2. Two Swedish GLOSS-stations; Göteborg-Torshamnen and Stockholm.

The Swedish sea level network

The first systematic Swedish observations of the sea level started 1774 at the sluice in the harbour of Stockholm. At the end of 19th century the Swedish king decided to establish seven mareographs, where several are still operating or have been substituted by other stations. In 1889 the Nautical-Meteorological Bureau (a predecessor of SMHI) established a continuously recording sea level station in the bedrock (mareograph) on the island Skeppsholmen, located close to the sluice. This mareograph has since then recorded the Stockholm sea level and is now operated by SMHI. The sea level series in Stockholm constitutes the longest sea level record in the world (Figure 3).

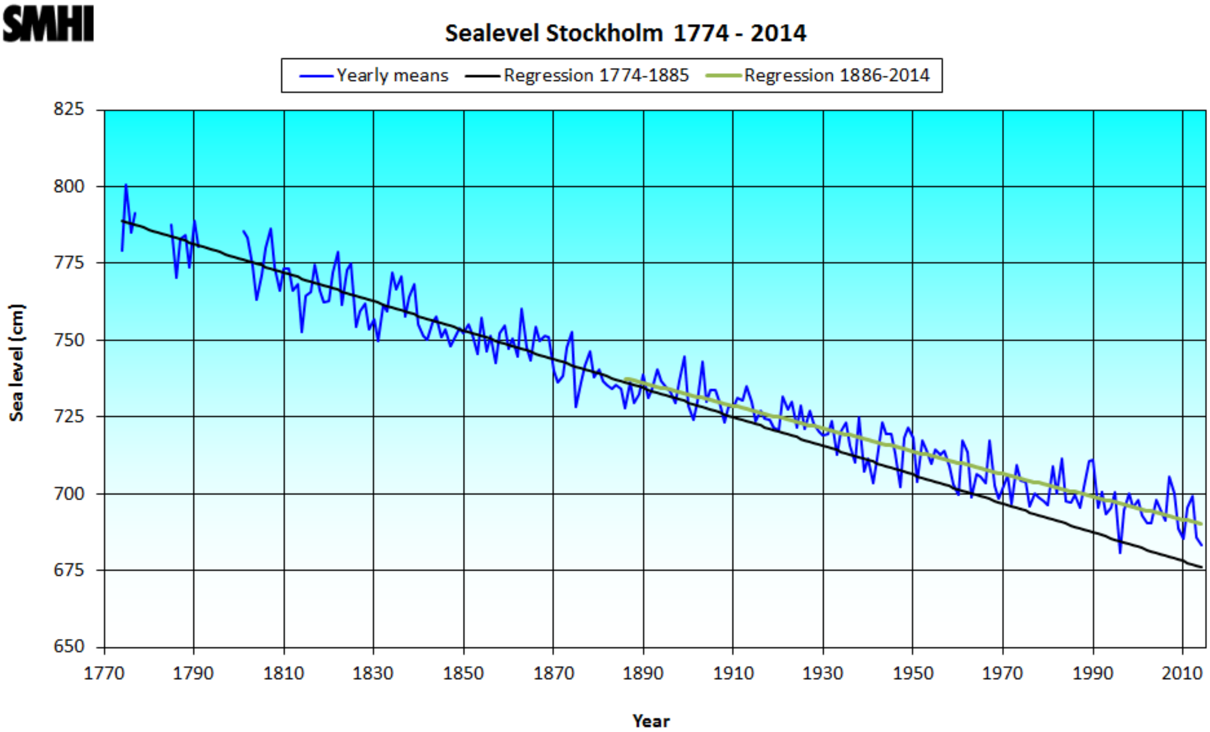

Figure 3. Annual mean sea levels in Stockholm since 1774, with the regression line (corresponding to land uplift) for 1774-1885 and its extension into modern times. The increased sea level rise since the late 19th century appears as a deviation from the regression line.

During the 20th century more stations were established. The technique used from the beginning was the stilling well technique. The Sea Level Network was completely modernised during the 1980s. The traditional stilling well was still used, but the gauges were converted from analogue to digital with automatic data transfer to SMHI. Earlier the recording was only done with a chart recording apparatus. This mechanical equipment is nowadays used as a backup for the digital recording equipment, mainly to prevent gaps in the time-series.

A new modernisation of the network was completed at the end of 2005. A new data logger (Vaisala MAWS) was installed that is more capable of delivering near real time data. The data recorded by the measurement equipment is transferred to SMHI once an hour through the telephone line and stored in a database. From there, the data can be presented in real-time on our website and distributed further to the users.

Quality controlled data are distributed to users via national and international exchange on a continuous basis. A software application connected to the database is used for validation and correction of the data. We can fill gaps with data from paper charts or predictions and add or subtract a constant offset to the data. The original data and all manual readings are stored in separate tables in the database.

At present we store data 10-minute values and also the maximum and minimum records every hour are stored. In the future we will store all data recorded by the equipment (one minute values) in our database. In order to check the status of a station and validate real-time data an observer visits the station once a week. The sea level station is connected to several Bench Marks. The Swedish mapping, cadastral and land registration authority (Lantmäteriet) does the precise levelling, i.e. they are responsible for determining the distance between the Contact Point and the Bench Marks. SMHI is responsible for keeping Tide Gauge Zero (TGZ) a fixed distance below the Contact Point. Most of the gauges are installed in the bedrock, but some are located in slightly unstable areas. Levelling is done once a year. The levelling often shows no significant vertical motion on the majority of the sea level stations.

Figure 4 shows the basic structure of a typical sea level station (mareograph). Sea level is measured in a deep well beneath the mareograph building. The well is connected to the sea through a narrow underwater pipe, to damp out short-period fluctuations of the sea level.

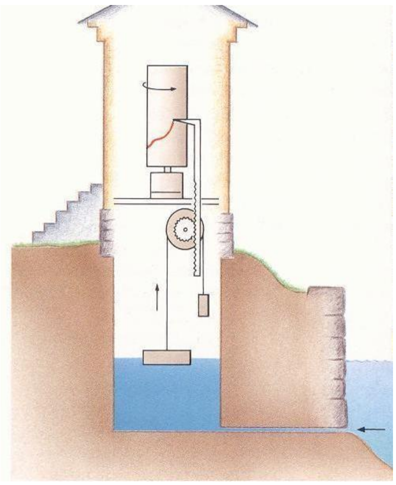

Figure 4. Basic structure of a typical sea level station or mareograph.

The mechanical part of the measurement equipment is constructed of a float, floating on the water surface, connected to a counterweight with a steel band. The steel band is attached on a wheel, which is connected to the digital equipment. When the sea level varies and the float follows it up and down, the equipment registers the rotation of the wheel, which is transformed into a digital reading using an encoder (Vaisala QSE 102).

Station	Latitude	Longitude	Digital data available from	Installation and type of CGPS	Distance CGPS (km)	Install-ation of AG
Kalix	65º 41' 49'' N	23º 05' 46'' E	1974	No	-	No
Furuögrund	64º 54' 57'' N	21º 13' 50'' E	1916	1993A	9.5	1992
Ratan	63º 59' 10'' N	20º 53' 42'' E	1891	2006A	0.1	2007
Skagsudde*	63º 11' 26'' N	19º 00' 45'' E	1982	No	-	No
Spikarna	62º 21' 48'' N	17º 31' 52'' E	1968	No	-	No
Forsmark	60º 24' 31'' N	18º 12' 39'' E	1975	No	-	No
Stockholm	59º 19' 27'' N	18º 04' 54'' E	1889	1992A/B	15.3/3.4	No
Landsort Norra	58º 46' 08'' N	17º 51' 32'' E	2004	No	-	No
Marviken	58º 33' 13'' N	16º 50' 14'' E	1964	No	-	No
Visby	57º 38' 21'' N	18º 17' 04'' E	1916	1993A	5.2	2004
Ölands norra udde*	57º 21' 58'' N	17º 05' 50'' E	1851	2004B	13.5	No
Oskarshamn	57º 16' 30'' N	16º 28' 41'' E	1960	No	-	No
Kungsholmsfort	56º 06' 19'' N	15º 35' 22'' E	1886	2004A	0.1	No
Simrishamn	55º 33' 27'' N	14º 21' 28'' E	1982	No	-	No
Skanör	55º 25' 00'' N	12º 49' 46'' E	1992	2002B	1.8	No
Klagshamn	55º 31' 20'' N	12º 53' 37'' E	1929	No	-	No
Barsebäck	55º 45' 23'' N	12º 54' 12'' E	1937	2002B	5.9	No
Viken	56º 08' 32'' N	12º 34' 45'' E	1976	No	-	No
Ringhals	57º 14' 59'' N	12º 06' 45'' E	1967	1991A	19.7	1993
Göteborg-Torshamnen	57º 41' 05'' N	11º 47' 26'' E	1967	2004B	12.8	1976
Stenungsund*	58º 05' 36'' N	11º 49' 57'' E	1962	No	-	No
Smögen	58º 21' 13'' N	11º 13' 04'' E	1910	2002A	0.05	2004
Kungsvik	58º 59' 48'' N	11º 07' 38'' E	1976	2005B	7.4	No

Table 1. List of stations in the Sea Level Network operated by SMHI. Stations marked * are non-realtime reporting stations. CGPS marks places where Continuous Global Positioning is installed and measurements of the absolute land uplift are being carried out. Type of CGPS: A denotes complete stations (EUREF reference stations with antennas placed on solid bedrock), B simplified stations (mounted on buildings). Distance CGPS is the distance between the CGPS antenna and the sea level station. Only CGPS-stations located less than 20 km from a sea level station are included. AG means that the station has a platform for observing Absolute Gravity. More sea level data is available from discontinued stations.

Co-location of geodetic observing system at mareographs

Lantmäteriet has developed the geodetic infrastructure at several of the mareographs to include connection to the national height levelling network, continuous GNSS as well as absolute gravity. The main purpose of these techniques has been to develop a model to describe the post glacial rebound. One of the main tasks for the geodetic research division at Lantmäteriet is to develop, monitor and maintain the national reference systems and frames in all dimensions (3D, horizontal, height) as well as gravity so that the need of the society is satisfied.

The national levelling network was levelled during the third precise levelling of Sweden during 1978-2001 and resulted in the height system RH2000, which is the Swedish realization of the European height system EVRS. GNSS at mareographs was first done as a GPS-campaign during the European project EUVN in 1997. The monuments have later been equipped with CGPS, see Table 1, and are now part of the Swedish CORE network named SWEPOS™.

Lately, several different Nordic institutions as well as other international actors have observed gravity with absolute gravimeters in the Nordic and Baltic area. These efforts have been co-ordinated through the working group of geodynamic within NKG (Nordic Commission of Geodesy). The main purpose of these measurements has been to detect the change of gravity over time, mainly caused by the post glacial rebound. Several mareographs are today equipped with an absolute gravity platform (Figure 5).

Figure 5. Smögen, a mareograph (hut to the left) also combined with CGPS (monument to the right) and absolute gravity platform (hut in the middle).

Historical sea level data

During 2013 SMHI have made all the oceanographic data available for free. From an INSPIRE-oriented web-site it is possible to download the long time series of data (hourly values): http://opendata-catalog.smhi.se/explore/

In September 2013 the sea level database at SMHI contained more than 3000 years with digital sea level observations, where about 1700 years are from continued stations. Most of the data are hourly values, but for the past years, the resolution has been increased to 10-minute values. A complete station list showing the content of the data base on a yearly basis can be found here:
http://www.smhi.se/hfa_coord/BOOS/dbkust/Availability_Sealevel_SMHI.htm

Climate changes in sea level data

From our long time series we can detect the global sea level rise after reducing the yearly means with the land-uplift effect (Figure 6). A regression analysis indicates a sea level rise around 3 mm per year for the last 30 years and approximately 1.5 mm per year since 1886. Where the land-uplift is low, as around the coasts of southern Sweden, the sea level has risen by about 20 centimeters since 1886.

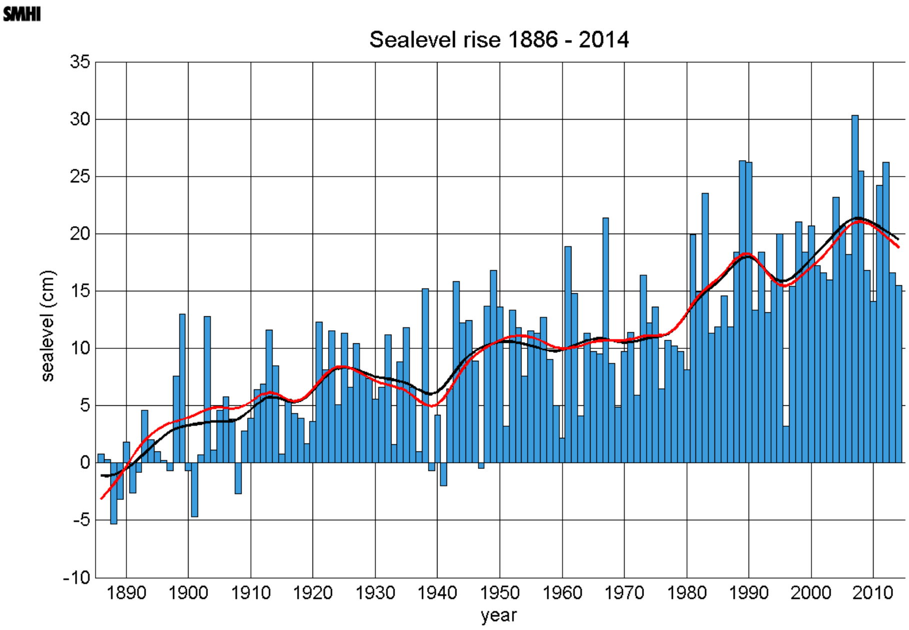

Figure 6. Sea levels corrected for the absolute land uplift (isostatic adjustment). Blue bars show the annual sea level averaged for 14 sea level records, compared to the 1886 level. The black and red line shows the gauss-filtered average and Stockholm sea level, respectively.

International data exchange

Both real-time data and delayed mode data are routinely made available through several national and international programmes (Table 2). Real-time data have undergone gross error checking only, using a standard quality control protocol. Delayed mode has been screened and quality controlled using the procedures described by GLOSS, Copernicus and others. http://www.smhi.se/en/weather/sweden-weather/ocean-observations/havsvst_en.htm

Programme	Data host	Frequency	Resolution	Media	Notes
PSMSL	NOC	Yearly	Month	Mail	All stations (23)
COPERNICUS	IFREMER	Daily	HiRes*	FTP	All stations (23)
GLOSS/NEAMTWS	VLIZ	Hourly	HiRes*	FTP	GLOSS stations (3)
BOOS/NOOS	SMHI	Hourly	Hour	FTP	All stations (23)
www.smhi.se	SMHI	Hourly	Hour	www	Real-time stations (19)
www.boos.org	DMI	Hourly	Hour	www	Real-time stations (19)

* 10-minute values and hourly maximum and minimum values. Minute-values are available for some periods, especially during severe storm periods.

Table 2. Sea level data are routinely made available through these programmes.

BOOS Sea Level stations

The exchange of oceanographic data in the Baltic Sea is for the time being very well developed. Within the BOOS (Baltic Operational Oceanographic System) community we have developed an easy FTP-box system for exchange of data between the different institutions on a routinely basis (usually every hour). The resolution of the data is from about 5 minutes up to several hours, with the highest resolution for sea level data.

SMHI is responsible for coordination of the data exchange and to implement routines for real-time quality control, validation and distribution of all sea level data coming from the Baltic Sea. For the moment, the system consists of about 120 sea level stations (Figure 7). Together with other institutes in Europe we have also developed harmonized ways to exchange data in different EU-projects, such as MyOcean (now Copernicus). This work will continue in the following years. A web page with station information and other metadata has been developed:
http://www.smhi.se/hfa_coord/BOOS/dbkust/BOOS_Oceanographic_Stations.html

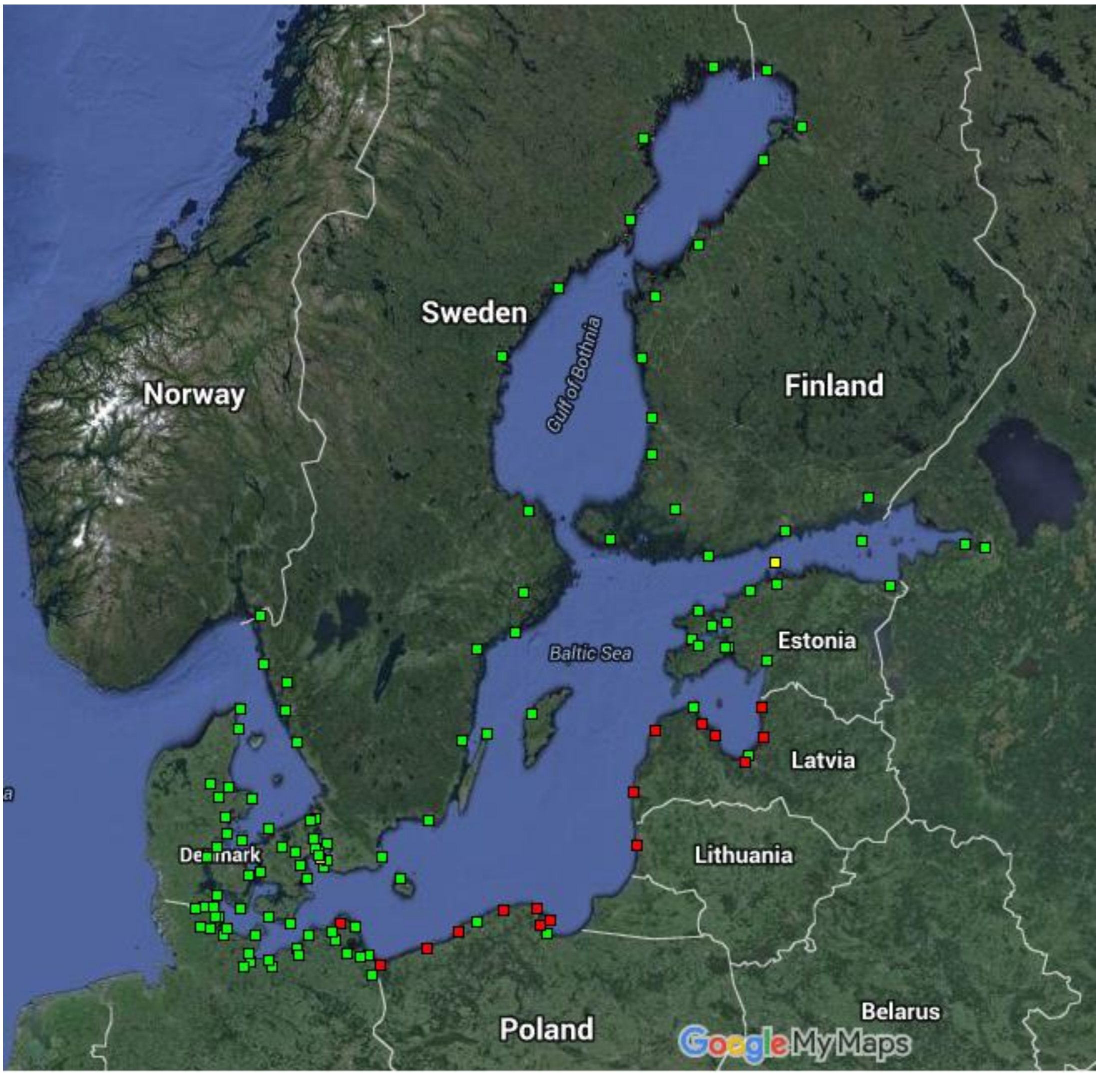

Figure 7. Sea level stations available through the BOOS Cooperation. Stations marked in green are available in real-time. Stations marked in red are not available.

Onsala mareograph

Also in 2015, a new mareograph (Figure 8) was installed at Råö on the Onsala peninsula, just south of Göteborg. This has been done in close cooperation with the Chalmers University in Göteborg. The station will be located close to a continuous GPS station (A-type), which is operated by Chalmers. Close to the new mareograph there is also a GNSS-reflectometer measuring sea level (Figure 9), installed in 2010.

The station is now delivering high-resolution values of sea level (1-minute values). A very precise levelling of the station has been performed and the station is very well connected to the national height system RH2000 as for the rest of our mareograph locations. The station is owned by Chalmers and SMHI are responsible for quality assurance, archiving and distribution of the data.

The mareograph will be a part of the Swedish Sea Level network (Figure 1) by the end of 2015.

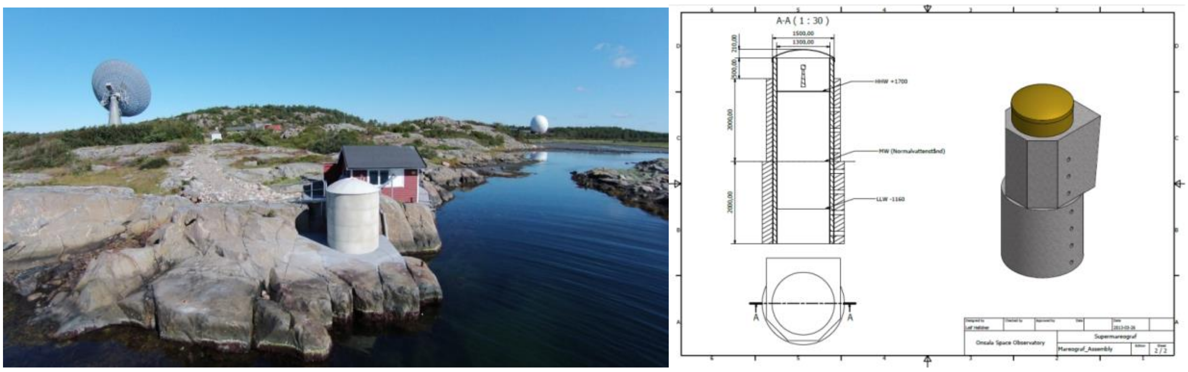

Figure 8. The Onsala mareograph installed 2015.

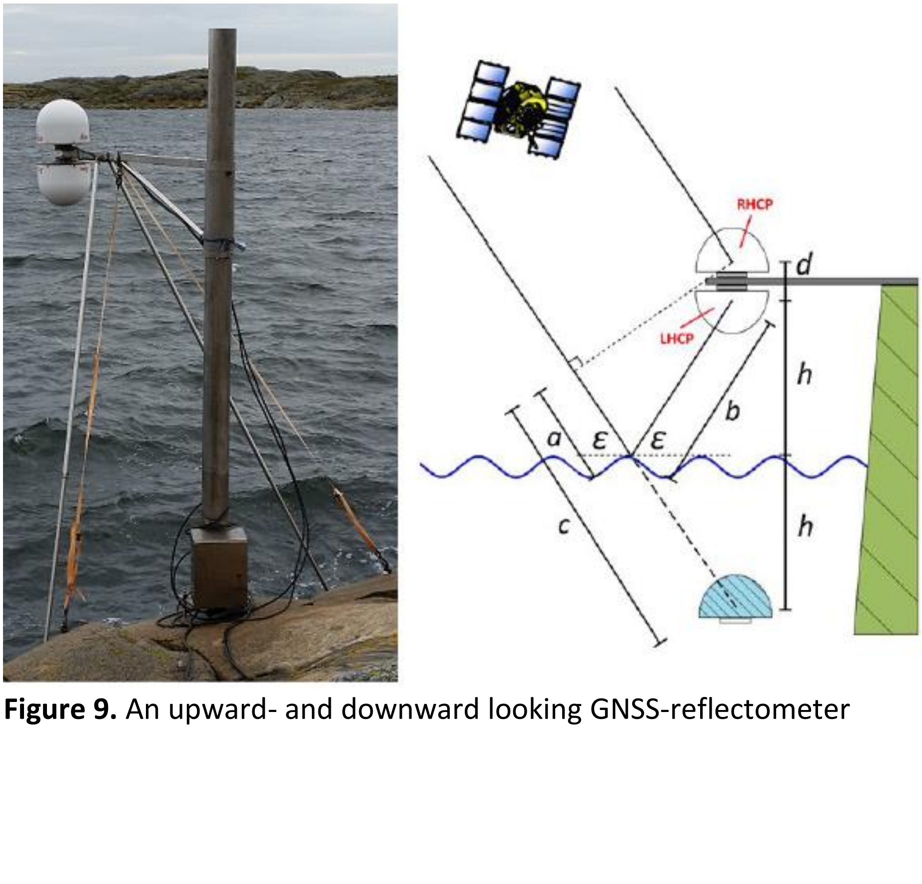

Figure 9. An upward- and downward looking GNSS-reflectometer

Mobile stations

Since 2011 have SMHI tested a new mobile system for sea level measurements, which is now operationalized.

In 2014 we installed the equipment at three locations; Uddevalla, Arkö and Haparanda. Uddevalla and Haparanda indicates higher sea level during severe storm events, so it is very interesting to validate our sea level model at these locations. Uddevalla is located north of Stenungsund in the Skagerack, Arkö at the entrance to the Bay of Bråviken and Haparanda, located at the northern most point of the Bay of Bothnia.

At the places we have pressure sensors, where sea level is adjusted for salinity and water temperature variations (also recorded). In Uddevalla we are also using a radar sensor, the same type as in Onsala. The stations are delivering high-resolution data every minute.

Figure 10. A mobile sea level station, which consist of a bubble-sensor (to the left) and radar sensor (to the right). During periods with ice conditions, the data from the radar sensor are neglected.

Appendix 1.

Sea level stations owned and operated by the Swedish Maritime Administration.
Real-time data from these stations can be obtained via:
http://vivakarta.sjofartsverket.se

Station	Latitude	Longitude
Kalix	65º 47' 21'' N	23º 18' 04'' E
Larsgrund	65º 32' 56'' N	22º 14' 20'' E
Skellefteå	64º 40' 33'' N	21º 17' 17'' E
Holmsund	63º 41' 45'' N	20º 20' 50'' E
SkagsUdde	63º 11' 27'' N	19º 00' 47'' E
Svanö	62º 53' 24'' N	17º 52' 09'' E
Spikarna	62º 21' 48'' N	17º 31' 51'' E
Iggesund	61º 37' 28'' N	17º 07' 44'' E
Ljusne Orrskärskajen	61º 12' 25'' N	17º 08' 44'' E
Bönan	60º 44' 20'' N	17º 19' 04'' E
Loudden	59º 20' 33'' N	18º 08' 29'' E
Nynäshamn	58º 55' 02'' N	17º 58' 07'' E
Södertälje Saltsjön	59º 11' 31'' N	17º 37' 56'' E
Landsort	58º 44' 35'' N	17º 52' 02'' E
Vinterklasen (Oxelösund)	58º 39' 41'' N	17º 07' 31'' E
Juten	58º 38' 03'' N	16º 19' 29'' E
Västerbådan	57º 44' 50'' N	16º 44' 31'' E
Visby	57º 38' 22'' N	18º 17' 06'' E
Slite	57º 42' 21'' N	18º 48' 37'' E
Kalmar	56º 39' 32'' N	16º 22' 42'' E
Karlshamn	56º 09' 20'' N	14º 49' 15'' E
Flinten16	55º 33' 40'' N	12º 48' 34'' E
Flinten7	55º 35' 22'' N	12º 50' 40'' E
Malmö Hamn	55º 37' 07'' N	12º 59' 06'' E
Helsingborg	56º 02' 41'' N	12º 41' 14'' E
Halmstad	56º 38' 59'' N	12º 50' 33'' E
Varberg	57º 06' 34'' N	12º 14' 30'' E
Vinga	57º 37' 53'' N	11º 36' 31'' E
Måvholmsbådan	57º 40' 20'' N	11º 42' 27'' E
Karet	57º 41' 16'' N	11º 52' 11'' E
Marstrand	57º 53' 13'' N	11º 35' 37'' E
Brofjorden	58º 20' 10'' N	11º 24' 17'' E