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. 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. Also, the Swedish Maritime Administration (SjöV), records sea level at 30 locations, but these stations are not included in this report. The Swedish sea level records constitute some of the longest and most robust sea level records in the world.

Figure 1. The Swedish Sea Level Network operated by SMHI, April 2009.

Figure 2. The Swedish GLOSS-station, Göteborg-Torshamnen.

Station	Latitude	Longitude	Digital data available from	Installation of CGPS	Type of CGPS	Distance CGPS (km)	Installation of AG	Distance AG (km)
Kalix	65º 42' N	23º 06' E	1974	No	-	-	No	-
Furuögrund	64º 55' N	21º 14' E	1916	1993	A	9.5	1992	9.5
Ratan	64º 00' N	20º 55' E	1891	2006	A	0.1	2007	3.3
Skagsudde*	63º 12' N	19º 01' E	1982	No	-	-	No	-
Spikarna	62º 22' N	17º 32' E	1968	No	-	-	No	-
Forsmark	60º 24' N	18º 13' E	1975	No	-	-	No	-
Stockholm-Skeppsholmen	59º 19' N	18º 05' E	1889	1992	B A	3.4 15.3	No	-
Landsort Norra	58º 46' N	17º 52' E	2004	No	-	-	No	-
Marviken	58º 33' N	16º 50' E	1964	No	-	-	No	-
Visby*	62º 22' N	17º 32' E	1916	1993	A	5.2	2004	5.2
Ölands norra udde*	57º 22' N	17º 06' E	1851	2004	B	13.5	No	-
Oskarshamn	57º 16' N	16º 34' E	1960	No	-	-	No	-
Kungsholmsfort	56º 06' N	15º 35' E	1886	2004	A	0.1	No	-
Simrishamn	55º 33' N	14º 21' E	1982	No	-	-	No	-
Skanör	55º 25' N	12º 50' E	1992	2002	B	1.8	No	-
Klagshamn	55º 31' N	12º 55' E	1929	No	-	-	No	-
Barsebäck	55º 45' N	12º 54' E	1937	2002	B	5.9	No	-
Viken	56º 09' N	12º 34' E	1976	No	-	-	No	-
Ringhals	57º 15' N	12º 07' E	1967	1991	A	19.7	1993	19.7
Göteborg-Torshamnen	57º 41' N	11º 48' E	1967	2004	B	12.8	1976	-
Stenungsund*	58º 05' N	11º 48' E	1962	No	-	-	No	-
Smögen	58º 22' N	11º 13' E	1910	2002	A	0.05	2004	0.05
Kungsvik	59º 00' N	11º 08' E	1976	2005	B	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 (measurements of the absolute land uplift). Type of CGPS: A denotes complete stations (EUREF reference stations with antennas placed on solid bedrock), B simplified stations (mounted on buildings). Distance CGPS means the distance between the CGPS antenna and the tide gauge. Only CGPS-stations located less than 20 km from a tide gauge are included. AG means that the station has a platform for observing Absolute Gravity. More tide gauge data are available from discontinued stations (some located close to the continuing stations above).

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.

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 in our FTP-box. Real-time data is also transmitted through the GTS-net. Quality controlled data are distributed to users via national and international exchange on a continuous basis. The software MATLAB is used for editing and correcting the data. We can delete data, fill gaps with data from paper charts or predictions and add/subtract a constant offset to the data. The original data are stored in a separate table 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 3 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.

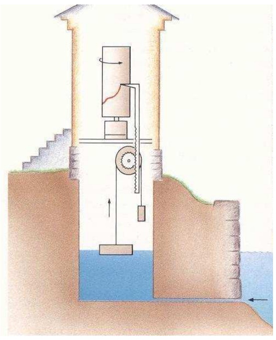

Figure 3. Basic structure of a typical sea level station or mareograph.

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).

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 RH 2000, that is a 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. In the campaign monuments were built at. These monuments has later been equipped with CGPS, se table 1, and are now part of the Swedish CORS 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 4. Smögen, a mareograph (hut in the background) also combined with CGPS (monument in the front) and absolute gravity platform (hut to the right).

Sea level data

In April 2009 the sea level database at SMHI contained about 3000 years with digital sea level observations, where about 1500 years are from continued stations. Most of the data are hourly values. More information about the time series stored in the database can be found here:
http://www.smhi.se/n0206/dbkust02_eng.htm

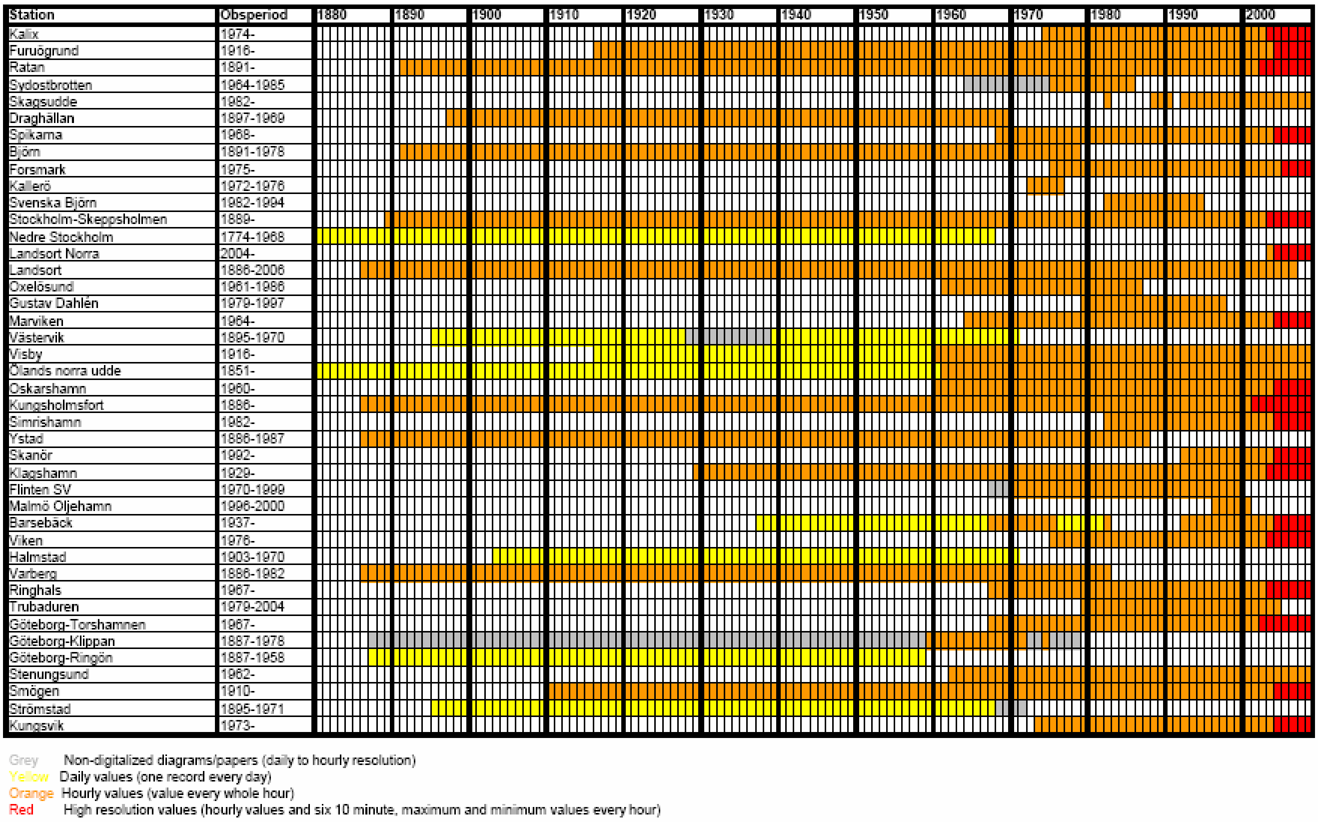

Figure 5. An overview of available digital time series over the years 1880-2008. The overview shows both continued and discontinued stations.

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. 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 small, around the southern coast-line of Sweden, the sea level rise since 1886 is about 20 centimeters.

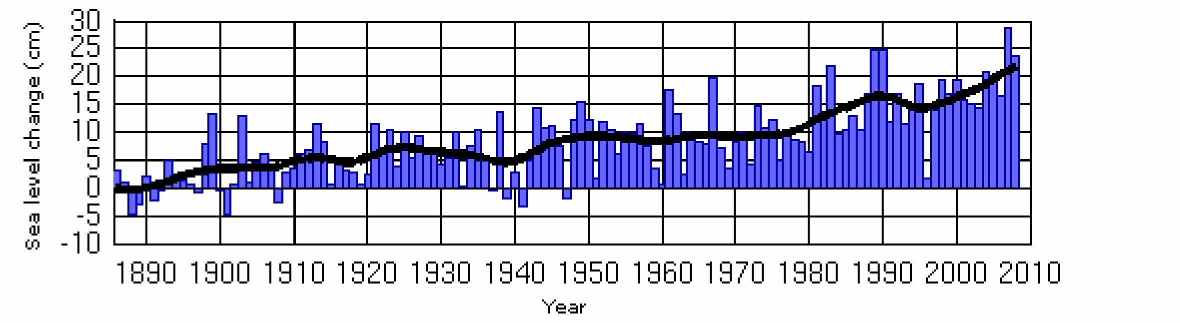

Figure 6. The sea level rise since 1886, calculated from 13 Swedish sea level stations.

International data exchange

Both real-time data and delayed mode data are routinely made available through several international programmes. 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 Swedish Meteorological and Hydrological Institute (SMHI) procedures and standards. Real-time data can be obtained via:
http://www.smhi.se/weather/havsvst/sealevel.htm

Programme	Data host	Frequency	Resolution	QC	Media
GLOSS	VLIZ	Hourly	HiRes*	No	FTP
ESEAS	Statkart.no	Hourly	HiRes*	No	FTP
PSMSL	POL	Yearly	Month	Yes	Mail
BOOS	DMI	Hourly	Hour	No	FTP
NOOS	DMI	Hourly	Hour	No	FTP
SEPRISE	SMHI	Hourly	Hour	No	FTP
www.smhi.se	SMHI	Hourly	Hour	No	www

* 10-minute values and hourly maximum and minimum values.

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