SMHI

Swedish Sea Level Series

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A Climate Indicator

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The mareograph building on the island Skeppsholmen in Stockholm, where SMHI and its predecessor have performed sea level recordings since 1889.

Introduction

Global ocean levels have always fluctuated with changes in our climate. During the last ice age, about 10 000 years ago, some of the ocean's water was frozen in ice sheets and the global sea level was more than 100 meters below the present level. As ice melted, sea level rose. Some of the effect still lingers, but over the last century, the global ocean level has started to rise faster. This is due to increasing melting of glaciers and thermal expansion of sea water, brought about by the present global warming. Reports from many stations around the world indicate a rising sea level, which is further confirmed by the more recent satellite measurements. Continuous sea level data are important for the understanding of the effects of global warming.

Observations of sea level

The Swedish official Sea Level Network, operated by the Swedish Meteorological and Hydrological Institute (SMHI), records sea level at 23 locations (figure 1). SMHI is responsible for the network, the 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.

Nr	Time series	Start	a (cm/year)
1	Furuögrund	1916	1.00
2	Ratan	1891	0.94
3	Draghällan/Spikarna	1897	0.88
4	Björn/Forsmark	1891	0.78
5	Stockholm	1774	0.52
6	Landsort	1886	0.43
7	Visby	1916	0.32
8	Ölands Norra Udde	1851	0.25
9	Kungsholmsfort	1886	0.14
10	Ystad/Skanör	1886	0.06
11	Malmö/Klagshamn	1924	0.12
12	Varberg/Ringhals	1886	0.20
13	Göteborg	1887	0.30
14	Smögen	1910	0.32

Figure 1. To the left, the present Swedish Sea Level Network operated by SMHI. Table to the right shows 14 long Swedish sea level series with start year and absolute land uplift for each location. Values are based upon Continuous Global Positioning (CGPS) measurements (source: The Swedish mapping, cadastral and land registration authority).

Stockholm sea level series

The first systematic Swedish observations of 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. Of these, several are still operating. Some have been substituted by newer 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 the longest homogenous sea level record in the world.

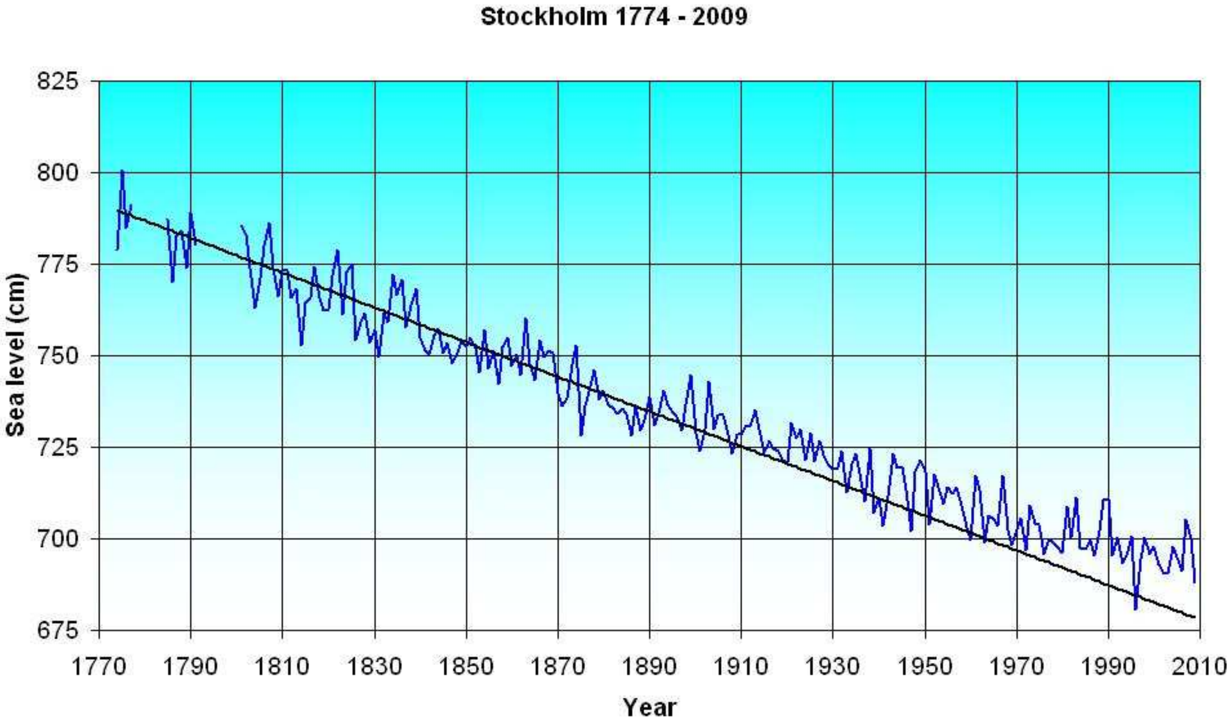

Figure 2. Annual mean sea levels in Stockholm since 1774, with the regression line (corresponding to land uplift) for 1774-1888 and its extension into modern times. The increased sea level rise since the late 19th century appears as a deviation from the regression line.

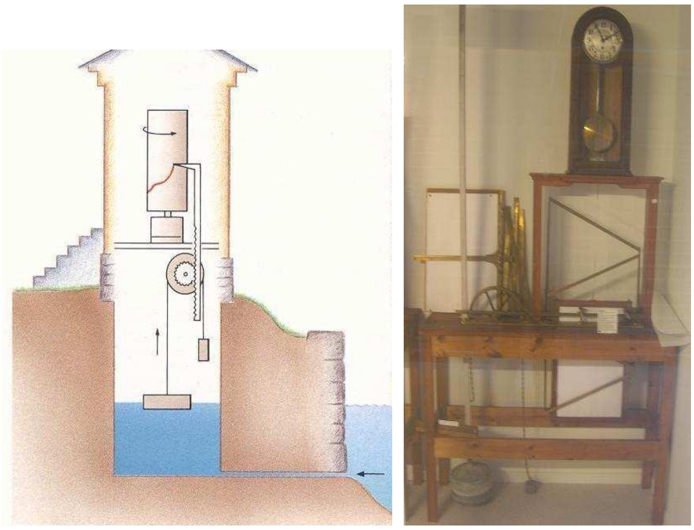

Figure 3. To the left, the principle of measuring sea level with float and well technique. To the right, a mareograph, the old equipment for continuous recording of sea level used by SMHI from 1886 to 1966.

Sea level as a climate indicator

From our long sea level records (figure 1) a "climate indicator" can be calculated. We use the sea level rise (sometimes known as eustatic sea level rise) as the climate indicator. To calculate it, we need annual means of sea levels and knowledge about the absolute land uplift (the isostatic rebound of the land after the last glacial period) at every station.

We use 14 of our long annual mean sea level records since 1886. Some of these stations started later and some older stations have been substituted by new stations. Via the relationship to the old national land-based height system RH00, data from two stations can be fitted together and two records can be handled as one long constituent time series.

These annual means are later corrected for the absolute land uplift, at every station. The linear regression line of the corrected sea level is levelled so that the same reference year (1886) is used regardless of the actual start years. The following formula describes the corrected and levelled sea level, AW:

AW (yy) = HW (yy) – a * (yy – 1886) + corrfactor, where

HW = annual mean of sea level (cm) in a local (unique) height system for every station
yy = year
a = absolute land uplift (cm/year) at every station
corrfactor = correction factor so that the regression line of AW passes through zero for the year 1886.

Results

From the regression line of AW we calculate the sea level rise for each station and calculate an average for all 14 time series (figure 4).

Since 1886 the sea level has risen by just under 20 cm along the Swedish coasts, at an average rate of 1.5 mm per year. Also, we can see an increased rate for the last 30 years. The regression analysis indicates a sea level rise around 3 mm per year for the last 30 years (1980-2009). The increased sea level rise cannot be explained by increasing winds over North Sea or the Baltic entrance (Wern and Bärring, 2009). Rather, the probable cause would seem to be the global warming, which causes the ocean water to expand as it heats up and also when water flows into the ocean from melting glaciers (IPCC 2007).

The sea level rise at Stockholm corresponds well to the average Baltic sea level rise, due to Stockholm's unique oceanographic position close to the nodal line in the central Baltic Sea (Ekman, 2003).

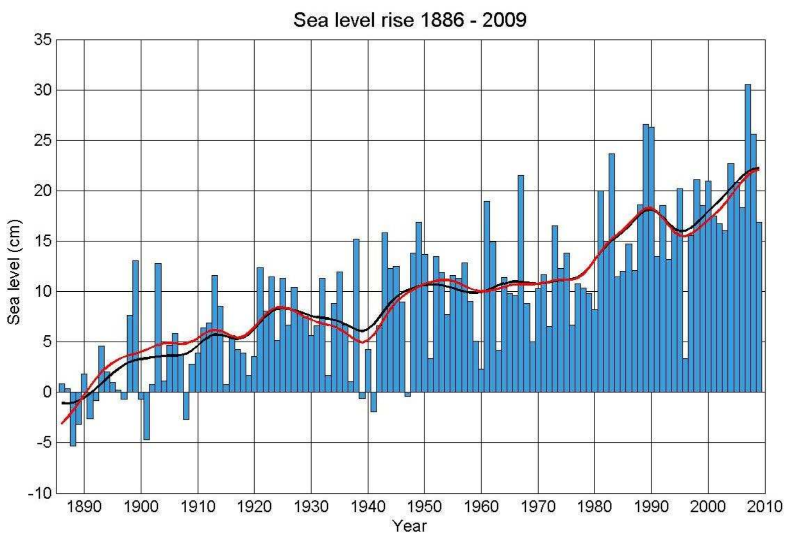

Figure 4. Sea levels corrected for the absolute land uplift. Blue bars show the annual sea level averaged for 14 Swedish sea level records, compared to the 1886 level. The black and red line shows the gauss-filtered average and Stockholm sea level, respectively.

References

▪ Ekman, M. 2003. The world´s longest sealevel series and winter oscillation index for Northern Europe 1774-2000.

▪ Wern, L. and Bärring, L. 2009. Sveriges vindklimat 1901-2008. Analys av förändring i geostrofisk vind. SMHI. Meteorologi Nr 138/2009.

▪ IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.