Growing demands for downscaling of climate information – examples from predictions of future sea levels

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Abstract

2007 marked a shift in the perception of climate change. In Sweden, a wet and stormy winter coincided with increased coverage of climate change. Among the most important ones were the Stern report, IPCC:s Fourth assessment report (AR4) and the national investigation on climate and risk. During 2007, the demand for future climate information to support decision makers increased significantly.

According to IPCC, the global mean sea level is predicted to rise between 18 to 59 cm, and a further increase due to regional effects should be included for the Baltic Sea. In the Bothnian Sea, the post-glacial rebound is large and will continue to outweigh or balance the sea level rise during the next 100 years. However, in the southern Baltic, the apparent land uplift is negative, and sea level rise will lead to increasing problems with flooding, erosion and rising ground water levels.

SMHI water level observations show that the rate of sea level rise has increased during the last decades. Results from AR4 and four climate scenarios from the coupled Rossby center model for the Baltic Sea, RCAO, are used to provide scenarios of sea level rise in the Baltic Sea for 2071-2100. End users are local authorities in charge of land areas that will be heavily affected should sea levels rise or entrepreneurs who need background for construction design.

For decision makers, continued research on the effects of climate change regarding sea level and other climate factors is important for planning purposes, and continued observational and modelling efforts should be combined with downscaling of climate model output to enable information on a local or regional scale.

I. Introduction

Climate change has made the headlines for a while now. The publication of AR4 [1] followed the first comprehensive report on the cost of climate change [2]. The weather apparently having been more extreme than usual may have helped make the projected consequences of climate change clearer to all of us. In 2005, the extent of sea ice in the Arctic hit a record low since satellite measurements started in 1979. This record was surpassed in September 2007. The 2005 Atlantic hurricane season was the most vigorous in recorded history. In part due to the 2006 El Niño, the 2006 Atlantic hurricane season was weaker than initially predicted. However, 2006-2007 El Niño event led to severe drought in Australia. This was followed by extreme rains in 2008.

Natural variations or climate change? Regardless of which, extreme weather is a serious reminder of what some of the predicted consequences entail. Both the drought and flooding are coupled to El Niño, and scientists conclude that hurricane Katrina is not directly coupled to climate change. However, 2007 was the eight warmest year globally since the 1850's [3], and scientists working with sea ice claim that we may experience ice free summers in the Arctic by 2040.

In Sweden, the publication of AR4 coincided with a national evaluation of climate vulnerability; The Swedish Commission on Climate and Vulnerability [4]. The report combined results from regional climate models with knowledge on infrastructure, soil, agriculture, and a range of other parts of society, this assessment quantified the costs and benefits that projected climate changes would contribute to Swedish society. Increased flooding in the western parts of the country due to increased precipitation is one expected consequence; on the other hand, changes in the annual distribution of precipitation may lead to better hydro power conditions.

One expected change is a rise in sea level. This will be of minor importance to the northern regions of Sweden and Finland in the next hundred years due to the ongoing land uplift. At its highest level, the absolute land uplift is 1 cm/year, outbalancing even for the highest projected rise of mean sea level. However, in the south of Sweden (as well as the rest of the southern Baltic), land uplift is negligible. A global increase in sea level will lead to increased coastal erosion and flooding.

This paper aims to show some of the needs that Swedish society has when dealing with risks connected to climate change, in particular the need for local information on sea level change for various planning purposes. Different case studies are used to exemplify the needs and who the interested parties are. The Swedish municipalities also need better information on rainfall, extreme rainfall and flooding. River floods can become more extreme if they coincide with high sea levels.

II. Sea level in Sweden

Sea level has been measured daily in Sweden since 1886. Figure 1 shows the average sea level change from 13 stations between 1886-2007. The land uplift has been eliminated from the stations. The sea level has increased with ca 1.3 mm/year for the whole period, and the sea level rise has accelerated over the last decades. In the southern Sweden where land uplift is small, sea level has increased relative to land during the whole period. In central and northern Sweden, land uplift has been larger than the sea level change, and there is positive apparent land uplift. The past decades, sea level rise has accelerated, and for 1993-2006 the annual sea level rise is 3 mm/year.

III. Sea level in a future climate

The projected change in sea level from ~1990- ~2100 is 18-59 cm globally. This means that the land rise will seize to balance sea level change even in central parts of Sweden. Piers, buildings and land areas near the sea will become steadily more vulnerable. Regional variations in sea level rise give an even larger sea level rise in the North Sea and Skagerrak [1]. Moreover, the recent indications of increased glacial melting indicate that the levels given in AR4 may be conservative.

At Rossby Centre, the Baltic Sea water level was simulated using a regional model [5]: - Sea levels of the Baltic Sea in past and future climates were investigated based upon 6-hourly regional model results. For the future climate, the Rossby Centre Atmosphere Ocean model was used to perform a set of 30 yr time slice experiments. For each of the 2 driving global models HadAM3H and ECHAM4/OPYC3, one control run (1961 to 1990) and 2 scenario runs (2071 to 2100) based upon the scenarios A2 and B2 of the Special Report on Emission Scenarios (SRES) were conducted. To estimate uncertainties in the global and regional models, 3 sea level scenarios for the Baltic Sea were compiled assuming global average sea level rises between 0.09 and 0.88 m (IPCC:s third assessment report used 9-88 cm as the upper and lower bound for sea level rise) and considering land uplift and the impact of regional changes in wind direction and velocity from the time slice experiments. In the scenarios forced with ECHAM4/OPYC3 the mean sea level between October and April increases significantly compared to the control climate, and storm surges increase even more than monthly mean sea level.

These results have been used for assessments of future mean and extreme sea levels for different areas along the Swedish coast. Customers are local authorities, architects, and city planners, and the purpose is to provide decision support in physical planning. Below some of these areas and results are presented. Sea level rise also leads to further problems upstream, and combined efforts between river runoff and sea level rise projections are also of interest.

There are still large uncertainties in the changes in storm climate. Some of the scenarios lead to increase in storm activity, leading to a larger proportion of extreme sea levels. Combined with increasing mean sea levels, sea level return periods are likely to decrease during this century.

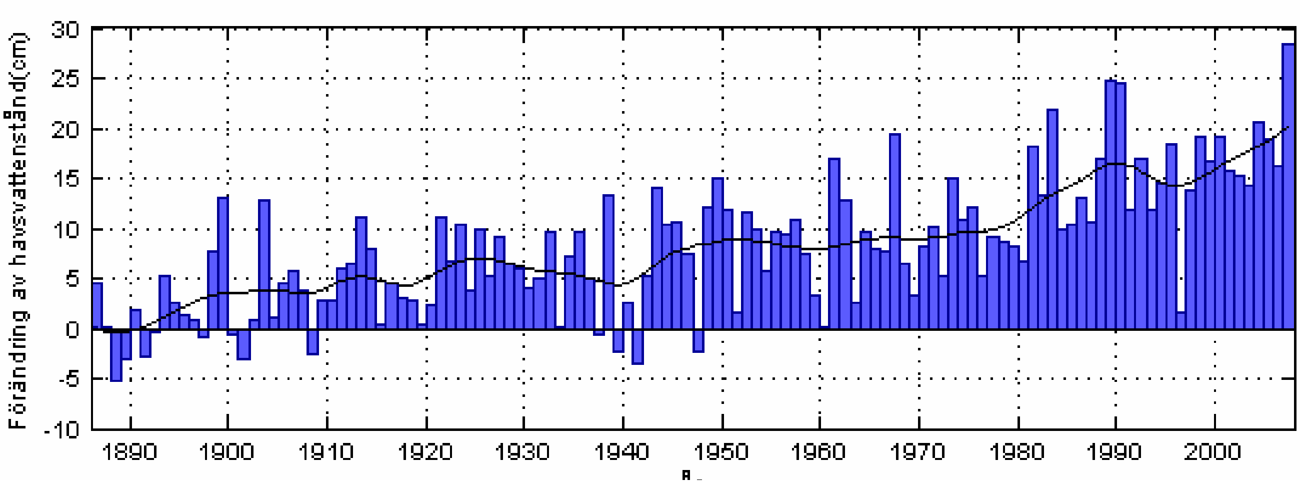

Figure 1. Sea level in Sweden calculated from 13 stations. Land uplift has been eliminated. For 1886-2004, the sea level rise was ca 1.3 mm/year. The past 15 years, the sea level rise has been almost 3 mm/year.

Focuses on Math Calc

IV. Case studies

Different cases are presented below with the kind courtesy of each project's owners.

A. Methods

Observations and model data are combined to find probable mean and extreme sea levels for the Swedish coast. The RCO model is well validated in the Baltic proper, but due to the course resolution, it should not be used too close to the sounds. SMHI´s calculations of present and future seawater levels encompass low, average and extreme levels, and an assessment on how often each situation may arise. The results are based on conclusions reached by the UN´s Panel on Climate Change [1]and future scenarios from SMHI´s climate research [3]. The sea level calculations also take account of land elevations.

B. Case studies

Skåne and Blekinge in Southern Sweden

Southern Sweden is very vulnerable to sea level rise due to the negligible land uplift. In 2007, SMHI contributed to a report compiled by regional authorities on the risks of sea level rise for the area. The report comprised an evaluation of statistical probabilities of return times for eight sea level mareografs, representing the coastline from Kalmar to northern Öresund, and a compilation of height data from the region as well as an assessment of infrastructure and land use and possible consequences.

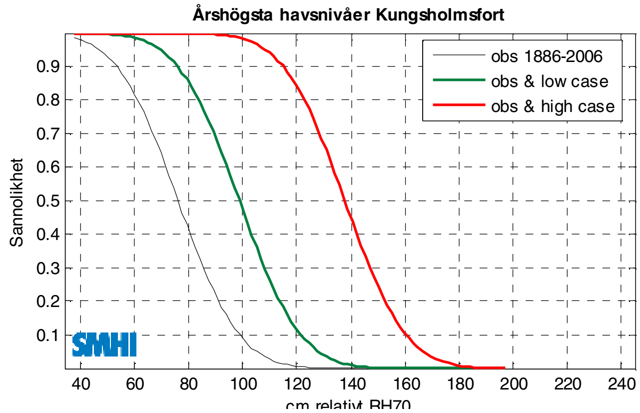

Figure 2. The likelihood of a sea level occurring for today's climate (observations) and for a future climate (low and high scenario).

Calculations show that the mean sea level in the area is likely to rise with ca 25-70 cm from the 1990s to 2100 depending on location (land uplift) and scenario. There are large areas that will be under water if this happens [6].

For most of the coast, flooding will occur only during times of extreme sea levels. Figure 2 shows the distribution of annual highest sea levels measured at Kungsholmsfort, together with distributions for a low and high case climate scenario. A value of 0.5 means that the likelihood of this level

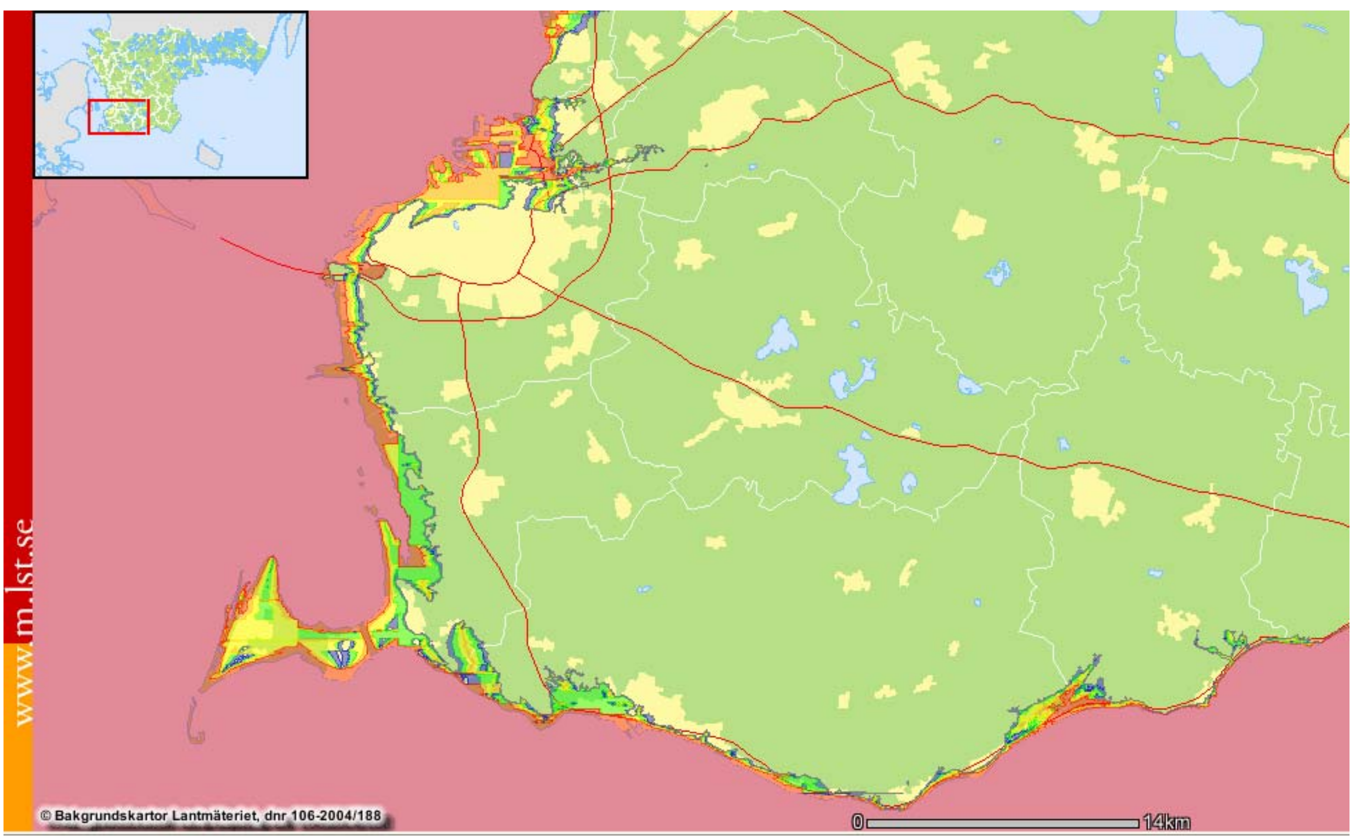

Figure 3. Map of land height data (every 1 m) from Skåne in Southern Sweden. Orange colored areas are flooded for sea level > 1 m, yellow areas are flooded for sea level > 2 m, green > 3 m, light green >4 m and blue > 5 m- The red lines show major roads. Along the southern coast, the road will be flooded for high sea level. The peninsula of Falsterbo and central parts of Malmö will be affected already for sea levels around 1-2 m.

occurring is 50 %, in other words, an event that happens every other year. For a low case, this level is 1 m in the height system RH70, and this is more than 20 cm higher than today's values. For the high case scenario, sea levels of almost 140 cm given in the national height system RH70 (6 cm lower than mean sea level) is likely to occur every second year. A likelihood of 0.1 means 1 in 10 years.

The municipal governments in Skåne and Blekinge compiled height data for their coasts.

Figure 3 shows Southern Sweden and the area south of Malmö. The mean sea level is indicated in pink. Areas that are flooded for a sea level of 1 m are colored orange, areas that are flooded for a sea level of 2 m are yellow, etc. The peninsula Falsterbo-Skanör is particularly at risk if no countermeasures are taken.

Stockholm-Slussen

The big lakes in Sweden have always been subject to debate and conflicting interests [7]. They are very attractive for recreational life and shore-near living, they are used for water supply and shipping and they cause flooding problems from time to time. On top of this the prospect of global warming has added a new dimension to the management of these lakes and risks along their shore-lines. After flood problems in the years 2000 and 2001 it was clear that the operation rules and the old decrees by the water court were not sufficient to safeguard the shores and downstream conditions of some of the biggest Swedish lakes, a situation that also affects the two largest cities in Sweden, Stockholm and Gothenburg. The Swedish Commission on Climate and Vulnerability was given the task to analyse the situation and suggest means to alleviate the problems, with focus on Lakes Vänern, Mälaren and Hjälmaren.

Lake Mälaren is number three in size in Sweden. It is strategically located upstream of Stockholm and is discharging through its down town areas into the Baltic Sea. Bergström, Hellström and Andréasson [7] presented the problems as follows:

"1. The lake level is controlled by several outlets and a decree for regulation from 1943.

2. The pressure on exploitation of the shore-lines of Lake Mälaren is very high in this metropolitan area. Experience has shown that many central facilities, including the subway of Stockholm, are in danger even under today's climate conditions.

3. A permanent lowering of the lake will influence navigation, ecosystems and recreational activities around the lake. The average level of the lake is only some 50 cm above sea level.

4. There is no river downstream, so increased discharge capacities can be achieved. The need has been estimated to a doubling of today's capacities.

5. Climate scenarios show that the moderate flooding problems are likely to increase due to global warming while the most extreme ones will not get any worse.

6. Sea level rise is not likely to increase the discharge problems, as it is more or less compensated for by the uplift of land, which is as high as 4 mm/year in the Stockholm area."

This is the so-called apparent land uplift, which is the net effect of land uplift and sea level changes, and is what one experiences from land.

In a study of sea levels for the high case for Stockholm, it was shown that the sea level may increase for a high scenario, leading to an increased problem with #6. When considering building new locks to meet these problems, the aspect of raised sea levels was also included. And even though the mean sea level may stay constant; fluctuations in sea level will influence the flow rates, and high sea level will lead to reduced flow rates from Lake Mälaren.

In terms of flow rates, instantaneous flow rates are of little importance. It is the long-term mean that sets the pace. Thus, time series from Stockholm were filtered and the long-term mean used as input to hydrological calculations. Return times for a sea level with certain duration was calculated, and used for input to the hydrological model.

The absolute land uplift is 0.52 cm/year for Stockholm. Observations show that during 1993-2007, sea level rise and land uplift has been in balance (however, year-to-year variations are large). Even the global high case, 59 cm in 110 years is balanced by land uplift, however, the estimated regional increase leads to a net sea level rise even for Stockholm.

Östhammar

Östhammar is a coastal municipality north of Ålands hav. In the work with planning a new housing area, SMHI were contracted to supply information on the flooding risks due to sea level rise. Land uplift is fairly large here, and the mean sea level change from 1990-2100 ranges from +/- 20 cm depending on scenario. Extreme sea level is estimated to reach more than 1.5 m higher than the mean. Figure 4 shows the areas that will be flooded for an estimated return time of 100 years, including local wind effects and using the upper bound of a 95 % confidence interval. Light pink shows the flooded areas for a low scenario, the dark pink shows areas flooded for a high scenario, with the return time of 100 years.

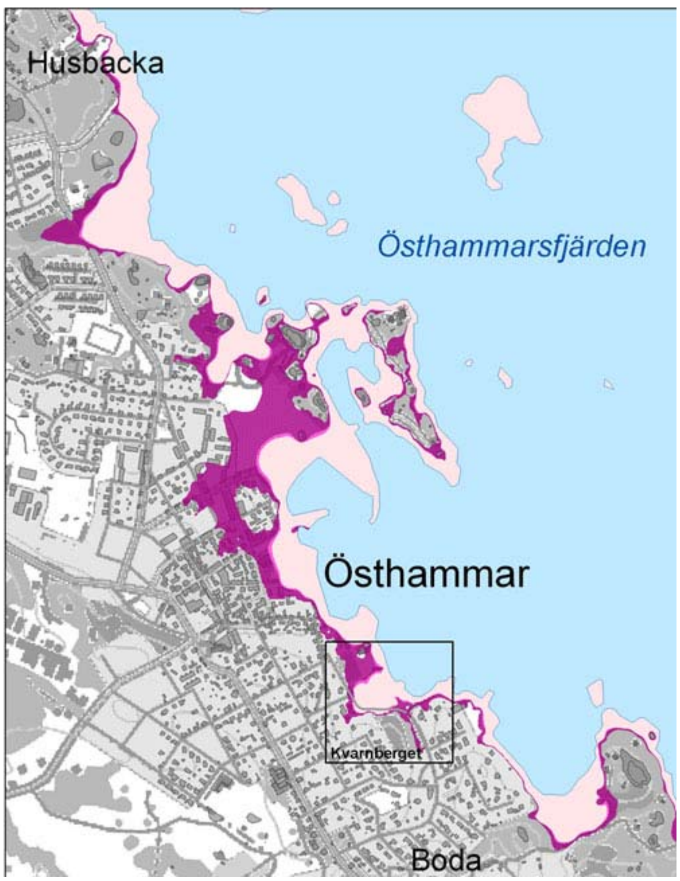

Figure 4. The level of extreme sea level for the coast of Östhammar. A low case, totay’s climate and a high case is shown in light to dark pink. The flooding maps are used for planning of new areas to build houses.

Gotland: Sea threatens new treatment plant

Construction is at an unprecedented level in Gotland, and one consequence is that the wastewater treatment plant at Slite is no longer adequate. Plans are well advanced to extend the plant to four times its current capacity, but the extreme long-term high seawater levels during the spring 2007 led local authority principals to stop and rethink. “There were acute problems getting the water from the plant to run out to sea, and there was a risk that seawater might flood into the treatment basins - which would have been absolutely devastating," says mechanical engineer Rikard Widén of Gotland Municipality.

One of the problems at the treatment plant is that the pressure from high seawater levels builds up at the opening of the discharge pipe some 100 metres out at sea, and prevents the water from the plant from flowing out. The higher the water levels, the greater the resistance faced by the outgoing water. Moreover, raised sea levels also increase the risk of seawater reaching the treatment basins and washing untreated water into the sea.

An inquiry into how high sea levels could rise was ordered. More on this investigation on the SMHI website [8].

SUMMARY

People want to live near the shore. How low can we build without being flooded? How should we prepare and protect our coasts and properties? The cases studies show that the impact of sea level rise can be substantial in many parts of Sweden. This is also true if we consider the uplift of land, which is a unique feature of Swedish geology. Sea level rise affects different aspects of society. Flooding of cities and rivers has been mentioned here, as well as the impact on runoff from rivers or lakes, and from treatment plants. Erosion is another problem, and certain coasts are more exposed than others. Decision makers need the best possible information in order to make well-educated regulations for future building projects and counter measure. Solving the riddles concerning inland ice and glacial melting appears to be the biggest issue when predicting local sea level change.

The very same planners who are concerned about sea level change also want to know if their rivers will flood more or less in the future, and whether or not they should increase water pipe dimensions. The demand for high quality climate information will become larger, not smaller, in the years ahead.

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