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The North Atlantic Oscillation and sea level variations in the Baltic Sea

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The long-term trend in the mean sea level of the Baltic Sea is dominated by the rise in global sea level and, in the northern part of the area, by land uplift. Long-term variations around this general trend are strongly correlated with the long-term changes of the North Atlantic Oscillation index (NAO). The short-term, intra-annual variations also show long-term changes. During the high NAO index of recent decades the sea level in the Gulf of Finland has no longer decreased with the land uplift. This, together with the observed increase in the probability of extremely high sea levels, has resulted in more pronounced erosion of the coastal areas than before.

Keywords: Baltic Sea, mean sea level, NAO.

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Besides the rise in global sea level and land uplift, the water balance plays an important role in the mean sea level of the Baltic Sea. The amount of water in the Baltic Sea varies by some 370 km^3 on a time scale of a few weeks, which corresponds to a change of about 1 m in the sea level. Short-term variations on a scale of days are mainly related to windstress and differences in air pressure, but on a scale of months the water balance of the Baltic Sea is important. The variability is dominated by the exchange of water through the Danish Straits, and because the Baltic Sea is nearly enclosed long-term variations in the water balance do not average out on the annual scale, nor even on a 15-year time scale. The annual mean sea level may deviate by as much as 10 cm from the long-term average.

It is clear that the water balance should somehow be correlated with meteorological factors. Correlations have been reported with air temperature (Lisitzin, 1958) and river run-off of the Vuoksi (Launiainen *et al.*, 1987). In Vermeer *et al.* (1988) it was shown, however, that high river run-off cannot be the reason for a high sea level. If that were the case, the river run-off would be high earlier or at the same time as the increased water level, but in fact the high mean sea level precedes a high river run-off by about half a year. This clearly points toward a common external cause – the cyclonic weather disturbances passing over Finland and releasing rain and snow, and at the same time pushing water from the North Sea into the Baltic Sea.

Attempts to explain the water balance in the Baltic Sea by local winds or pressure distributions have been unsatisfactory. When the area was extended to include the North Atlantic, a correlation between water levels and air pressure patterns was observed by Heyen *et al.* (1994, 1996).

The dominant component of the air pressure patterns that influence the Baltic Sea water balance seems to be well described by the North Atlantic Oscillation (NAO) (Kahma, 1999; Johansson *et al.*, 2001). The NAO index is defined as the normalized pressure difference between Gibraltar and Iceland, and is a measure of the strength of the westerly flow.

The NAO index varies most during the winter and the best correlation seems to be between the long-term mean sea level and the mean of winter-time NAO. Figure 1 shows the 15-year running mean of winter-time NAO index (Jones *et al.*, 1997) and the residual water level at Hanko. The correlation coefficient for these long-term changes is 0.8. At the annual level the correlation coefficient is only 0.6, but the correlation is statistically more significant owin to more degrees of freedom.

The same high correlation between the winter NAO index and the residual variations in the sea level is evident in all the tide gauges along the Finnish coast (Johansson *et al.*, 2001). Using the regression equation between NAO and the residual long-term variations of the sea level at Hanko, a hindcast for the mean sea level can be made.

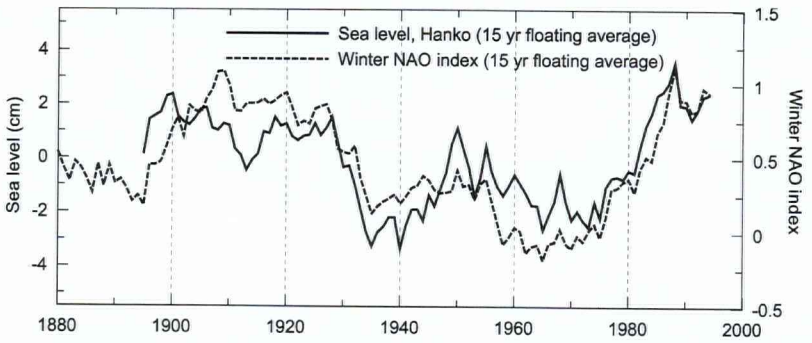

Figure 1. When the linear trend of land uplift and global sea level rise has been removed from the sea level data from Hanko, the residual shows a marked correlation with the winter-time North Atlantic Oscillation index.

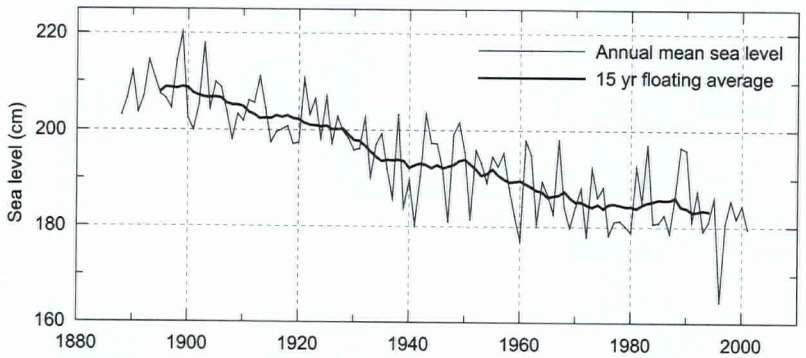

Figure 2. The mean sea level in the mouth of the Gulf of Finland (Hanko).

As Figure 2 shows, the apparent steady long-term trend from the beginning of the 20th century changed in 1970. This situation continued in the 1990s. In the Southern Baltic Sea this has meant a rise in the mean sea level of about 3 mm year^{-1}. In the Gulf of Finland, land and sea are both rising at approximately the same speed, which means that the shoreline has become steady after centuries of slow shifting. While this is the most conspicuous feature of the 1990s in the mean sea level of the Baltic Sea, the properties of short-term variations have changed, too. The probability distribution of sea levels has widened and the probability of extremely high sea levels has increased. The annual maximum when referenced to the annual mean sea level has increased from 1888 to 2000, whereas the minima have remained the same. This has led to increased erosion of vulnerable shores, except in the Gulf of Bothnia. For example, Kont (2000) has reported that in Estonia there has been erosion of sandy beaches almost everywhere in recent decades, and in some places the sea is advancing again.

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