Small Publications in Historical Geophysics

No. 3

Anomalous Winter Climate coupled to Extreme Annual Means in the Baltic Sea Level during the last 200 Years

Martin Ekman

Summer Institute for Historical Geophysics
Åland Islands

1997

Small Publications in Historical Geophysics

No. 3

Anomalous Winter Climate coupled to Extreme Annual Means in the Baltic Sea Level during the last 200 Years

Martin Ekman

Contents

Summer Institute for Historical Geophysics
Åland Islands

1997

1. Introduction

In an earlier publication in this series by the author, extreme annual means in the level of the Baltic Sea were studied; see Ekman (1996). An annual mean of the sea level was considered extreme if it deviates from normal sea level by more than twice the standard deviation (2σ). The 200-year-long sea level series of Stockholm was used, both because of its unique length and because of its ideal location. The latter relates to the fact that long-term variations in the Baltic sea level (which are our concern) are quite large at Stockholm, while short-term variations (which form perturbations in our case) have their minimum there. Using the Stockholm series (1774 - 1991) 13 extreme sea level years were identified, their annual means deviating more than 11.5 cm from the normal sea level, i.e. the regression line. There are 8 high water years and 5 low water years:

High	Low
1775	1804
1807	1831
1822	1875
1863	1941
1899	1947
1903	
1989	
1990	

The investigation revealed a specific behaviour of the Baltic Sea during such years. The normal seasonal variation of sea level, with a minimum in spring and a maximum in autumn, is during extreme sea level years replaced by a variation with a pronounced maximum during winter, for high water years, and correspondingly a pronounced minimum also during winter, for low water years.

This behaviour is a long-term phenomenon in the sense of Samuelsson & Stigebrandt (1996), who have shown that the Baltic sea level variations longer than one month are externally driven. Hence, the origin of the phenomenon must be sought in the relation between the North Sea and the Baltic Sea, especially in the wind conditions over the Baltic entrance. We may suspect that the high water years are related to prevailing (south)westerly winds there during winter, while the low water years are related to prevailing (north)easterly winds there during the same season. If so, we should expect also a relation between extreme sea level years and anomalous winter temperatures. The purpose of the present publication is to study these matters.

The sea level series of Stockholm commences in 1774, see Ekman (1988). Thus we need wind series and temperature series at least equally long. Fortunately a few such series are available. We will make use of the wind series from Lund, close to the Baltic entrance, which begins in 1741. The temperature series we will use is the one from Stockholm, starting in 1756. There is one even longer climatological record, from Uppsala, going back to 1722 (Bergström, 1990). Since Uppsala is situated further to the north, i.e. more distant from the Baltic entrance, it will not be used here. Finally we will also take into account a long series of the ice extent in the Baltic Sea.

2. Winter winds during extreme sea level years

We start by investigating the winds during the winters of the extreme sea level years. The wind data of Lund from 1741 onwards were first studied by Tidblom (1876). The whole series has recently been compiled and published by Jönsson (1997). It is tabulated in the form of seasonal mean winds, the winter season being defined as December - February. There is a difference between this and the winter season January - March in the sea level study of Ekman (1996), but this should not be disadvantageous bearing in mind the time delay between winds over the Baltic entrance and sea level effects in the Baltic Sea (cf. Matthäus & Schinke, 1994).

The wind is given as a vector, with a direction and a magnitude. The direction α is the azimuth, counted from north towards east - south - west, of the dominating wind. The magnitude s is a number between 0 and 1, 1 corresponding to all winds coming from the dominating direction, 0 corresponding to the lack of such a direction. Over the Baltic area there is a tendency to a bi-directional wind situation, with one primary maximum and one secondary maximum in the wind direction; we will use the primary maximum only.

Let us now study the winter wind vectors for the high water years and the low water years, respectively. They are listed in Tables 1 and 2. The results are unequivocal. All high water years show winter wind directions of $205° < \alpha < 265°$ (SSW - W) with an average of

$$\alpha = 235° \pm 7°$$

(close to SW). All low water years show winter wind directions of $35° < \alpha < 90°$ (NNE - E) with an average of

$$\alpha = 65° \pm 9°$$

Table 1. Winter wind vectors for extreme high water years. Unit (for α): degrees from north.

Year	α	*s*
1775	207	0.51
1807	233	0.54
1822	245	0.81
1863	215	0.37
1899	252	0.55
1903	263	0.35
1989	250	0.73
1990	213	0.83
Aver.	235	0.59

Table 2. Winter wind vectors for extreme low water years. Unit (for α): degrees from north.

Year	α	*s*
1804	35	0.46
1831	87	0.27
1875	67	0.36
1941	59	0.34
1947	79	0.50
Aver.	65	0.39

(close to ENE). Moreover, the average magnitude is $s = 0.6$ for high water years and $s = 0.4$ for low water years (compared to $s = 0.2$ for normal years), indicating that the obtained wind directions are clearly dominant ones.

Thus, extremely high annual means in the Baltic sea level are always coupled to winters with prevailing winds around southwest, while extremely low annual means are always coupled to winters with prevailing winds around east-nortneast.

3. Winter temperatures during extreme sea level years

We next investigate the temperatures during the winters of the extreme sea level years. The temperature data of Stockholm from 1756 onwards were first studied by Wargentin (1778). The whole series has recently been homogenized and published by Moberg & Bergström (1997). It is tabulated in the form of monthly means. From these we compute winter means based on the months January - March. The normal winter temperature, calculated as the average of all winter means during 1756 - 1995, becomes - 2.2°C. Alternatively, normal winter temperatures could have been calculated taking into account a small increasing trend, but this has not been done here.

Let us now study the deviations Δt of the winter temperatures from the normal value, and do so for the high water years and the low water years, respectively. The values of Δt are listed in Tables 3 and 4. The year 1899 is put within brackets and not used in the averaging due to its anomalous character described in Ekman (1996). The results are almost as clear as in the wind study, as could partly be expected because of the correlation between wind direction and temperature during the winter season (cf. Jönsson & Holmquist, 1995). All high water years (except 1899) have warmer winters than normal, most of them considerably warmer. The average temperature deviation amounts to

$$\Delta t = 3.4 \pm 0.8\ °\mathrm{C}$$

Correspondingly, all low water years have considerably colder winters than normal. The average temperature deviation in this case amounts to

$$\Delta t = -3.3 \pm 0.3\ °\mathrm{C}$$

Consequently, winters during high water years are as much as 7° warmer than winters during low water years.

Table 3. Winter temperatures and their deviations from normal for extreme high water years. Unit: °C.

Year	t	Δt
1775	- 1.2	1.0
1807	- 2.2	0.0
1822	2.7	4.9
1863	1.2	3.4
(1899	- 2.6	- 0.4)
1903	1.1	3.3
1989	3.3	5.5
1990	3.5	5.7
Aver.	1.2	3.4

Table 4. Winter temperatures and their deviations from normal for extreme low water years. Unit: °C.

Year	t	Δt
1804	- 5.1	- 2.9
1831	- 4.8	- 2.6
1875	- 5.2	- 3.0
1941	- 6.2	- 4.0
1947	- 6.0	- 3.8
Aver.	- 5.5	- 3.3

One of the high water years, 1807, does not fit so well into the pattern. This winter, however, had a warm start with high temperatures in December the year before.

It should be mentioned here that Lisitzin (1958), dealing only with winter sea levels, found a correlation between those and winter temperatures. Using 70-year-long records she obtained a correlation coefficient of 0.67.

4. Ice extent during extreme sea level years

Finally we will deal with the ice extent in the Baltic Sea during the extreme sea level years. The ice data, going back to 1720, were originally compiled from a lot of different sources by Jurva (1953, unpublished). The data before 1846 are, thereby, somewhat uncertain. The series has been completed to recent years and published by Seinä & Palosuo (1996). It is tabulated as maximum ice extent for each year. The normal maximum ice extent, calculated as the average of all the years 1720 - 1995, is 217 000 km^2. This is very close to half the area of the Baltic Sea, which is 420 000 km^2 (including the Kattegat).

Let us now study the deviations Δi of the ice extent from the normal value as well as the ice extent percentage i_p (of the area of the Baltic Sea), for both the high water years and the low water years. The values of Δi and i_p are given in Tables 5 and 6. As before, the year 1899 within brackets is not used in the averaging. Neither is the year 1775, as discussed below. The results are again very clear, as might be anticipated from the close correlation between temperature and ice extent (cf. Seinä, 1993). All high water years, except 1775, show smaller ice extents than normal, most of them much smaller. The average ice extent deviation amounts to $\Delta i = -(131 \pm 12)\ 10^3\ km^2$. This corresponds to an ice extent percentage of only

$$i_p = 20 \pm 3\ \%$$

Correspondingly, all low water years show much larger ice extents than normal. The average deviation in this case amounts to $\Delta i = (139 \pm 18)\ 10^3\ km^2$. This corresponds to an ice extent percentage of no less than

$$i_p = 85 \pm 4\ \%$$

Consequently, during low water years the ice covers an area more than four times as large as that during high water years; see Figure 1. This also reflects the considerable sensitivity of the ice extent to climatic fluctuations, discussed by e.g. Omstedt & Leppäranta (1997).

Table 5. Ice extent, its deviation from normal, and its percentage of the Baltic Sea, for extreme high water years. Units: 10^3 km^2 and (for i_p) %.

Year	i	Δi	i_p
(1775	281	64	67)
1807	140	- 77	33
1822	76	- 141	18
1863	90	- 127	21
(1899	183	- 34	44)
1903	92	- 125	22
1989	52	- 165	12
1990	67	- 150	16
Aver.	86	- 131	20

Table 6. Ice extent, its deviation from normal, and its percentage of the Baltic Sea, for extreme low water years. Units: 10^3 km^2 and (for i_p) %.

Year	i	Δi	i_p
1804	320	103	76
1831	328	111	78
1875	340	123	81
1941	371	154	88
1947	420	203	100
Aver.	356	139	85

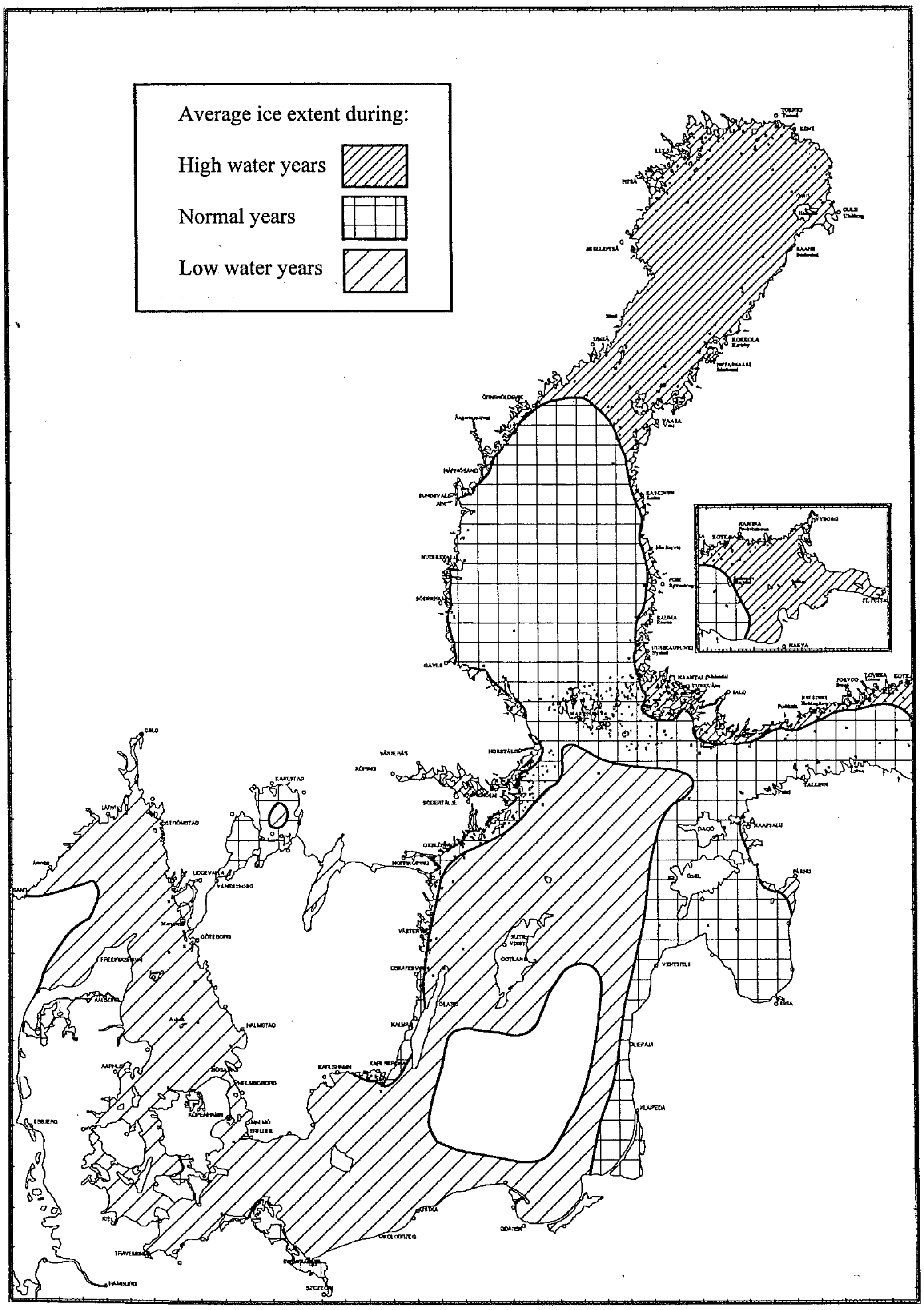

Figure 1. Average ice extent in the Baltic Sea during extreme high water years, normal years and extreme low water years (based on a map of mild, normal and severe winters in Omstedt & Nyberg, 1996).

The high water year 1775 that was excluded from the averaging is a somewhat uncertain year with regard to both the sea level data and the ice extent data. This might partly explain the fact that this year does not fit at all into the pattern above. In addition, November the year before was the coldest such month during the more than two centuries of the temperature series, favouring unusually early ice formation in spite of the mild winter season.

5. A comment on two remarkable winters

The similar winters 1822 and 1990 were remarkable ones. From Table 1 we find that southwesterly winds were exceptionally dominant; they were more dominant than for almost any other winter during the 250 years of the Lund wind series. February - March these two years were the warmest such periods during all the 240 years of the Stockholm temperature series. Sea level was, as a consequence, nearly half a meter above normal for about two months these years (Ekman, 1996).

In Ekman (1995) the world's oldest preserved sea level gauge, Bomarsund on the Åland Islands in the central Baltic Sea, was investigated. It was concluded that the gauge was erected in the beginning of the 1820s, probably in the high water period of 1822 (which must have been ice-free there), and later on found too short and lengthened downwards. Thus it seems that the original short part of the Bomarsund gauge may be regarded as a remaining trace of the exceptionally warm winter of 1822. It was to take nearly 170 years before a similar winter occurred again.

6. Conclusions

We have found, using data from the last 200 years, that extreme annual means in the level of the Baltic Sea are closely related to anomalous climate during winter. Extreme high water years have dominating winter winds from SW, winter temperatures about 3 - 4 °C above normal, and only about 20 % ice cover in the Baltic Sea. Extreme low water years, on the other hand, have dominating winter winds from ENE, winter temperatures 3 - 4 °C below normal, and as much as 85 % ice cover in the Baltic Sea.

The understanding of the fundamental role played by the winter climate in creating extreme annual mean sea levels might be useful in trend analyses of long Baltic sea level series. It could provide a possibility of separating decadal sea level trends due to regional climate fluctuations from secular sea level trends due to postglacial uplift and global sea level rise, leading to improved estimates of the latter quantities. This will, hopefully, be discussed in a future paper.

References

Bergström, H (1990): The early climatological records of Uppsala. Geografiska Annaler, 72 A, 143-149.

Ekman, M (1988): The world's longest continued series of sea level observations. Pure and Applied Geophysics, 127, 73-77.

Ekman, M (1995): Postglacial uplift of the Åland Islands, and the world's oldest preserved sea level gauge. Small Publications in Historical Geophysics, 1, 15 pp.

Ekman, M (1996): Extreme annual means in the Baltic Sea level during 200 years. Small Publications in Historical Geophysics, 2, 15 pp.

Jönsson, P (1997): Meteorological observations from Lund, southern Sweden, since 1740: Wind direction. Paläoklimaforschung (in press).

Jönsson, P, & Holmquist, B (1995): Wind direction in southern Sweden 1740 - 1992: Variation and correlation with temperature and zonality. Theoretical and Applied Climatology, 51, 183-198.

Jurva, R (1953): An estimation of the annual variations in the maximum extent of ice cover in the Baltic. Unpublished, but main result included in Palosuo, E (1953): A treatise on severe ice conditions in the Baltic. Finnish Marine Research, 156, 130 pp.

Lisitzin, E (1958): Der Wasserstand in der Ostsee als Indikator der Strenge des Winters. Geophysica, 5, 162-176.

Matthäus, W, & Schinke, H (1994): Major atmospheric circulation patterns associated with major Baltic inflows. Deutsche Hydrographische Zeitschrift, 46, 321-339.

Moberg, A, & Bergström, H (1997): Homogenization of Swedish temperature data, part III: The long temperature records from Uppsala and Stockholm. International Journal of Climatology, 17, 667-699.

Omstedt, A, & Leppäranta, M (1997): On the Baltic Sea response to climate change: Model implications. Second Workshop on the Baltic Sea Ice Climate, Tartu University (in press).

Omstedt, A, & Nyberg, L (1996): Response of Baltic Sea ice to seasonal, interannual forcing and climate change. Tellus, 48 A, 644-662.

Samuelsson, M, & Stigebrandt, A (1996): Main characteristics of the long-term sea level variability in the Baltic Sea. Tellus, 48 A, 672-683.

Seinä, A (1993): Ice time series of the Baltic Sea. University of Helsinki, Report Series in Geophysics, 27, 87-90.

Seinä, A, & Palosuo, E (1996): The classification of the maximum annual extent of ice cover in the Baltic Sea 1720 - 1995. Meri (Report Series of the Finnish Institute of Marine Research), 27, 79-91.

Tidblom, A V (1876): Einige Resultate aus den meteorologischen Beobachtungen, angestellt auf der Sternwarte zu Lund in den Jahren 1741 - 1870. Lunds Universitets Års-skrift, 12/2, 1-77.

Wargentin, P (1778): Ytterligare anmärkningar om svenska climatet, hvad varme och köld angår. Kongl. Vetenskaps-Academiens Handlingar, 39, 3-19.