Small Publications in Historical Geophysics

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Changes in Winter Climate Variability Deduced from the Baltic Sea Level, and the Winter that Never Arrived

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1. The winter index

A winter oscillation index for northern Europe 1774 - 2000 was presented in an earlier publication by the author; see Ekman (2003). The index is based on the winter mean sea level of the Baltic Sea in Stockholm, which is shown to very well reflect the winter mean atmospheric circulation pattern over northern Europe; cf. also Andersson (2002).

Ekman's winter index, ΔH, is defined as the difference (in cm) at Stockholm between winter mean sea level (January - March), H_W, and normal sea level, H:

$$\Delta H = H_W - H \tag{1}$$

Here

$$H_W = (H_J + H_F + H_M)/3 - 0.7 \cos (115° - 19.34°(T - 2000)) \tag{2}$$

and

$$H = 277.4 - 0.489(T - 1800) \qquad \text{before 1865} \tag{3a}$$
$$H = 193.5 - 0.389(T - 2000) \qquad \text{after 1865} \tag{3b}$$

T being the year. The expressions (3a) and (3b) take into account the effects of postglacial land uplift and global sea level rise on the normal sea level, and (2) takes into account the small perturbing effect of the lunar nodal tide on the winter mean sea level. A graphic illustration of the winter index 1774 - 2000 is shown in Figure 1. A table of the index values for all years is given by Ekman (2003); it can also be found on the home page of the Permanent Service for Mean Sea Level (PSMSL).

The winter index is connected to the south-north winter mean air pressure difference (in hPa) across the North Sea, Δp_N, through a linear relation (Ekman, 2003):

$$\Delta p_N = 0.240\, \Delta H + 3.0 \tag{4}$$

A similar relation holds for the south-north air pressure difference across the whole of Europe. These air pressure differences govern the west-east geostrophic wind field and, thereby, to a large extent the winter climate in northern and central Europe. The winter index of Ekman is thus very suitable for studying changes in the winter climate related to the atmospheric circulation since 1774.

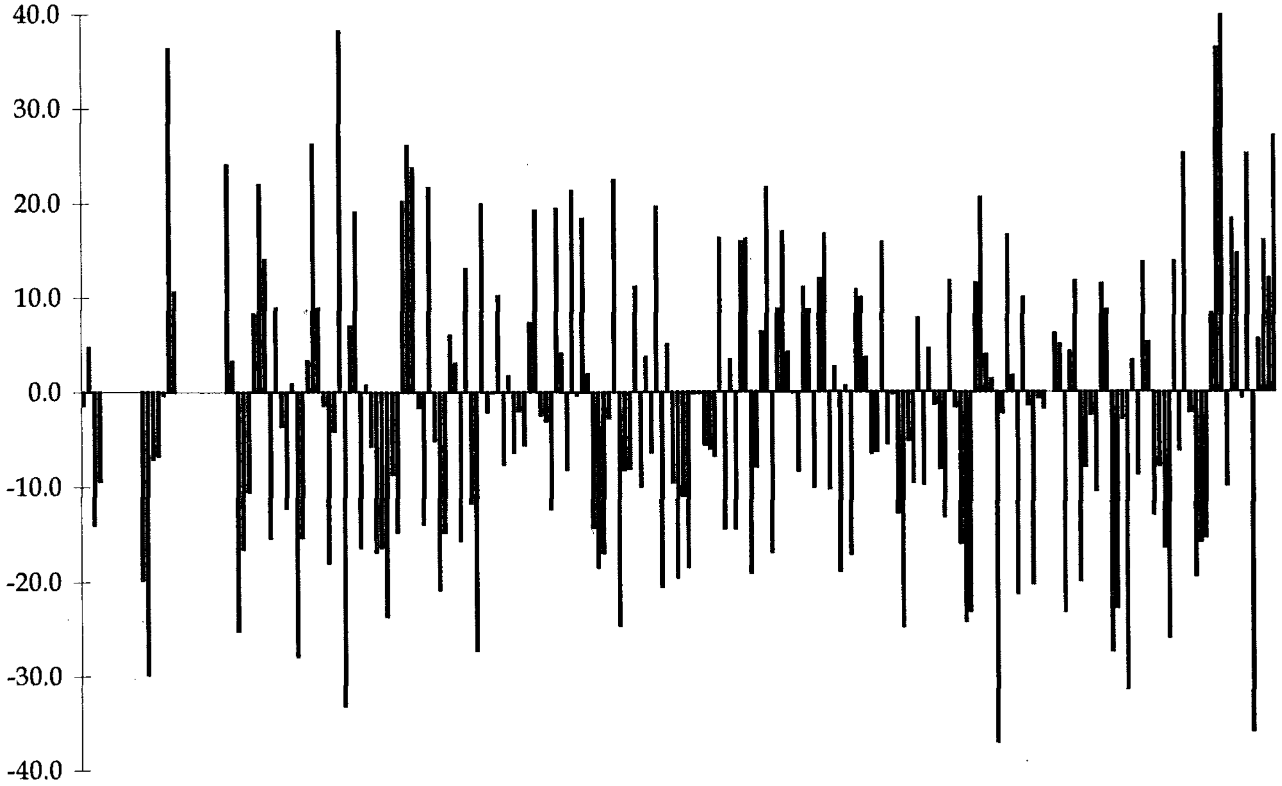


Figure 1. Winter index of Ekman (2003) for the years 1774 - 2000.

2. Long-term changes in winter climate variability

Dividing the whole index period (1774 - 2000) into one early period of about 60 years, 1774 - 1840, one central period of 100 years, 1841 - 1940, and one late period of 60 years, 1941 - 2000, Ekman (2003) found a statistically highly significant change in the variability (standard deviation) of the winter index. His result shows that there was a decrease in index variability from the early period 1774 - 1840 to the central period 1841 - 1940, and then an increase in index variability from the same central period to the late period 1941 - 2000. Both these changes are statistically significant at the 99 % level. Hence, both changes reveal systematic changes in the winter atmospheric circulation pattern over Europe.

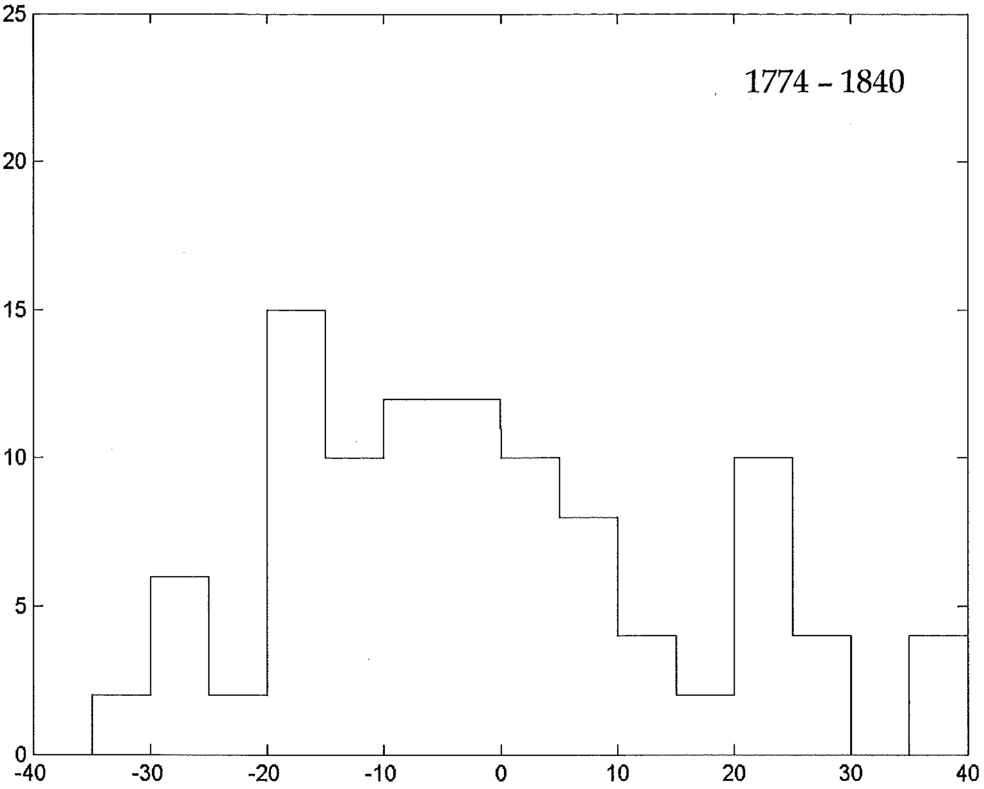
It is interesting to study the changes in the winter index variability somewhat closer. We will do so by comparing the distribution of the index values for the three periods in question. The index distribution is obtained by simply calculating the percentage of winters within the index intervals 40 - 35, 35 - 30 etc. The results are presented in Figures 2 - 4, one for each period.

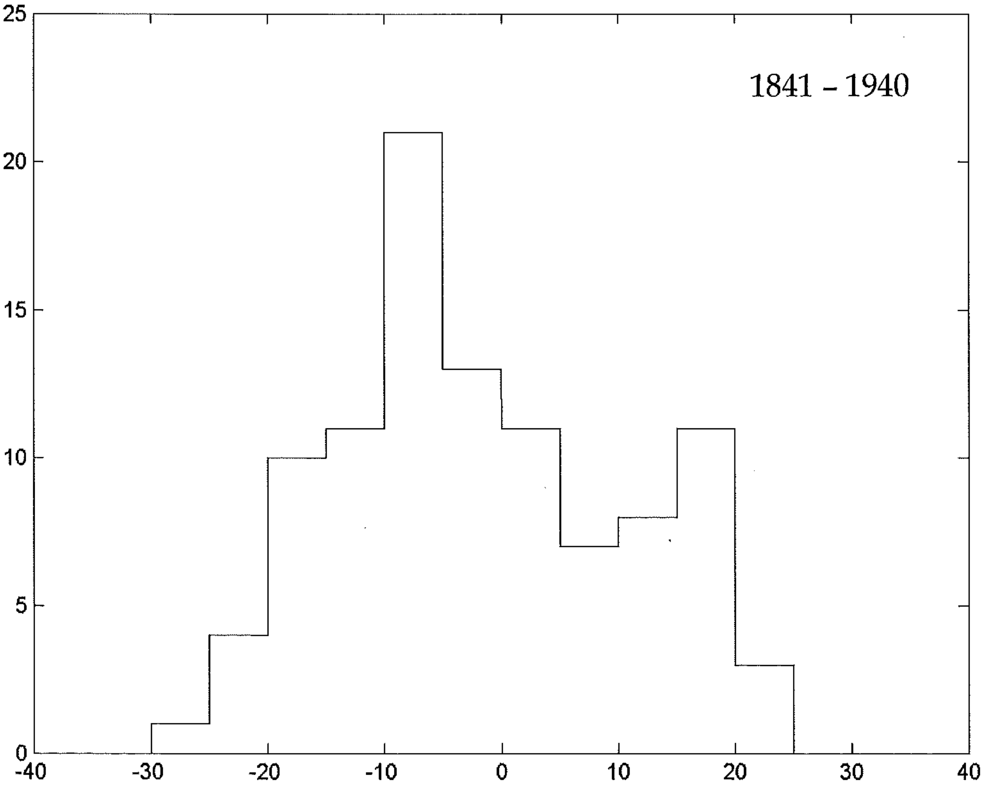
The three figures clearly show the contrast between a more concentrated index distribution during the central period (1841 - 1940) and a wider distribution during the early (1774 - 1840) and late (1941 - 2000) periods. The change in the variability produces a considerable change in the occurrence of extreme winters. As can be seen from the figures, the winter index during the central period spans between approximately - 25 and + 25, whereas it during the early and late periods spans between nearly - 40 and + 40.

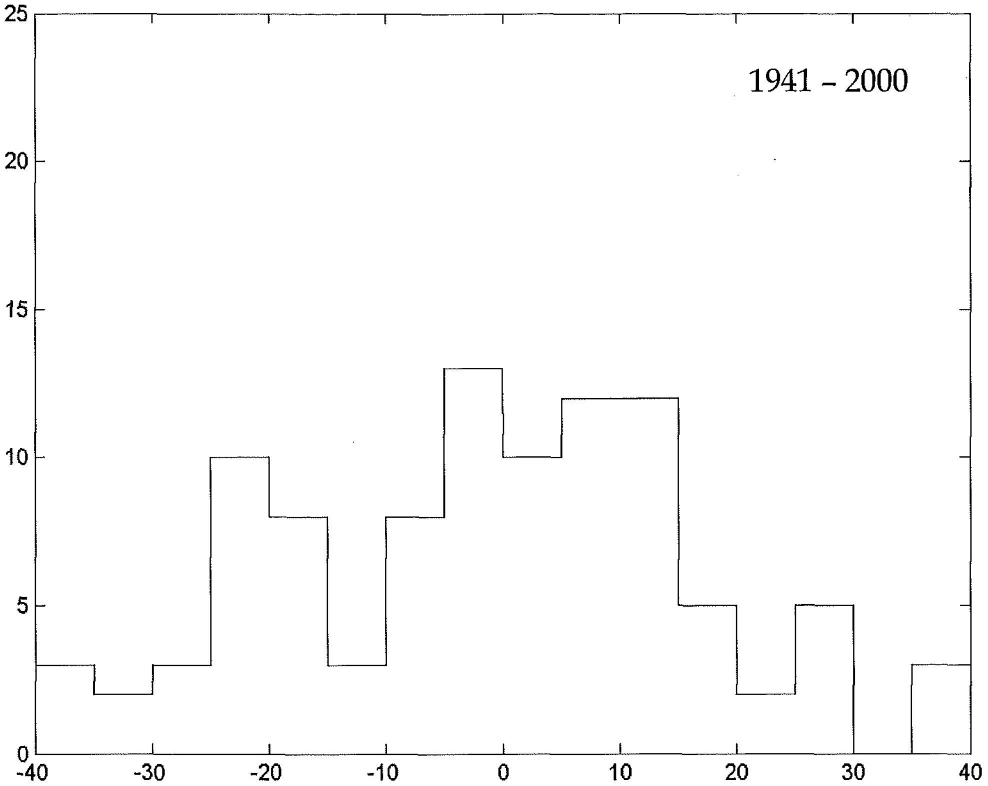
Table 1. Number of winters, during the three different time periods, with a winter index exceeding certain limits.

	$\lvert \Delta H \rvert > 25$	$\lvert \Delta H \rvert > 30$
1774 - 1840	8	3
1841 - 1940	1	0
1941 - 2000	10	5

In Table 1 we summarize the winters with a winter index exceeding certain limits. Out of 19 such winters with $\lvert \Delta H \rvert > 25$, we find only 1 occurring during the central period (containing 100 years), but 18 occurring during the


1774 - 1840
0
5
10
15
20
25
-40
-30
-20
-10
0
10
20
30
40


1841 - 1940
0
5
10
15
20
25
-40
-30
-20
-10
0
10
20
30
40



Figures 2 – 4. Distribution (percentage) of the winter index for the three different time periods.

early and late periods (together containing just a little more than 100 years). Out of 8 extreme winters with $|\Delta H| > 30$ none has occurred during the central period; all of them are found during the early and late periods.

3. The most extreme winter season: 1821 - 1822

The most extreme winter index hitherto, $\Delta H = 39.9$, is from the late period, 1990. This means that mean sea level that year was nearly 40 cm above normal during the three index months January - March. The second most extreme winter index, $\Delta H = 38.2$, dates from the early period, 1822. This year, however, the high mean sea level was not restricted to the three index months but lasted for no less than five months, including the late autumn and early winter months at the end of the year before. The mean sea level was 36 cm above normal during November 1821 - March 1822, with the following deviations from normal for each individual month (based on Ekman, 2003):

November	32
December	35
January	42
February	29
March	44

In this respect the winter season 1821 - 1822 forms the most extreme one during the whole index period 1774 - 2000.

Based on the winter index and the mean sea level for the whole winter season, we should expect the winter 1821 - 1822 to stand out as exceptionally dominated by strong permanent westerly winds over northern Europe. The long wind series from Lund (Jönsson, 1998) confirms such a winter there, as regards wind direction; cf. also the reconstructed pressure distribution over Europe (Jones et al, 1999). This, in its turn, should result in an exceptionally warm winter over northern Europe.

It has already been noted earlier (Ekman, 2003) that the winter air temperature in 1822 in Stockholm was no less than 5°C above normal. To get a wider picture of the temperature excess this winter we have collected temperature data also from other reliable long-term stations in northern Europe. From east to west the stations are St. Petersburg (Jones & Lister, 2002), Tornedalen (Klingbjer & Moberg, 2003), Stockholm (Moberg et al, 2002), Uppsala (Bergström & Moberg, 2002), Berlin (Schaak, 1982), De Bilt (van Engelen & Nellestijn, 1995) and Central England (Manley, 1974). The stations and their winter temperature deviations (January - March) are listed in Table 2. As can be seen, the temperatures for all stations except the westernmost one are around 4 - 5 °C above normal. (By normal is here meant the average of the 50 years 1800 - 1849.) Thus the table confirms the existence of an extremely warm winter over most of northern Europe in 1822.

Table 2. Winter temperature deviations 1822 in °C for stations in northern Europe (with latitude and longitude), in order from east to west.

St. Petersburg (60.0, 30.3)	5.3
Tornedalen (65.8, 24.1)	5.1
Stockholm (59.3, 18.1)	4.8
Uppsala (59.9, 17.6)	4.9
Berlin (52.5, 13.4)	4.4
De Bilt (52.1, 5.2)	3.4
Central England (52.5, -1.5)	2.4

Obviously, such a warm winter should cause very unusual ice conditions. As has been noted earlier (Ekman, 2003), the ice extent in the Baltic Sea that year was only about 18 % (Seinä & Palusuo, 1996), one third of an average year. The time for the ice break-up of Lake Mälaren, at Västerås west of Stockholm, was most remarkable. The ice break-up of 1822 occurred in the middle of March, one and a half month earlier than normally (Eklund, 1999); see also Table 3 in the following section. (An earlier break-up has occurred only once since then, namely in 1990, the year with the highest winter index as mentioned above.)

4. The winter that never arrived

As a result of the more or less permanently warm winter and westerly winds there should have been almost no snow but quite a lot of rain in fairly large parts of the Nordic and Baltic countries. This, in its turn, should have caused, contrary to normal, high flows in rivers during winter and lower flows during spring, the latter due to lack of ordinary melting away of snow. To check this, we make use of the long and reliable series of water level data from the Memel River in Lithuania (Kolupaila, 1930). The water levels of 1822 compared to a normal year confirms our predictions: The maximum level was reached already in the beginning of February, no less than two months earlier than normally; see also Table 3.

On the other hand, in the Scandinavian mountains the effects should have been the opposite. The permanent and warm westerly winds should have promoted repeated heavy snowfalls over the Scandinavian mountain range close to the Atlantic coast, at least over its southern part in south-western Norway. This, in its turn, should have caused an unusually thick snow cover there during winter, followed by a considerable melting of snow with a high risk for extreme flows in rivers during spring. There are no systematic data of this kind available from that time, but it so happens that two scientists were studying the Norwegian mountains that year; their findings were reported by Hisinger (1823). There we read about the mountain streams in southern Norway, again confirming our predictions:

"If these flows of water [during spring] are caused by a rapid melting of snow, the brooks grow to wild streams that destroy everything coming in their way. This spring (1822), a small mountain brook, ¼ of a Norwegian mile [3 km] north of Dovre church by the road to Lie, had in this way completely destroyed and swept away a farm with 17 houses, whereby also several people lost their lives."

From the Åland Islands in the middle of the Baltic Sea there is a careful meteorological diary covering the 25 years 1818 - 1842 (Johansson, 1929; Ekman, 1998). It confirms that winds during the winter 1822 were permanently around SW - W and quite strong. Its winter temperature deviation that year fits well into the scheme of Table 2. As a consequence, the times of arrival of early migratory birds and blooming of early spring flowers were heavily affected. The recorded arrival of the skylark was a whole month earlier than normal, as was also the blooming of the hepatica; see Table 3.

Table 3. Number of days before (-) or after (+) normal for various phenomena in nature during winter/spring 1822.

Ice break-up, Lake Mälaren	- 43
Maximum water level, Memel River	- 60
Arrival of skylark, Åland Islands	- 29
Blooming of hepatica, Åland Islands	- 33
Spawning of burbot, Central Baltic Sea	+ 30

Now, due to the extremely warm air throughout the whole winter also the sea water of the Baltic must have been extremely warm during the winter of 1822. There are no known measurements of sea water temperature from that time, but the Ålandic meteorological diary also contains data on the spawning times of fish. In case of very warm water we should expect the spawning times to be affected. The most heavily affected species of fish was the burbot. However, the burbot reacted in the opposite way to what might be expected: Its spawning was delayed by a whole month; see Table 3. Why did the burbot behave contradictory both to other fish and to flowers and birds? The background is that the burbot has its normal spawning time in winter, not in spring. So, while the others thought that spring was very early in 1822, the burbot had been waiting for a winter that never arrived!

5. Concluding remarks

It is noteworthy that all the different effects described in the last two sections, stemming from different geographical locations, can be more or less predicted from observations of one single quantity at one single spot: the sea level at Stockholm.

As a final illustration of the extreme winter season of 1821 – 1822 we will quote some lines from a personal diary kept by a Swedish lady at a large estate outside Stockholm (Reenstierna, 1822). These lines were written on the 20th of February, normally close to the peak of the winter, but now the year is 1822:

"Fresh nettles have been sold in the city since several days. At the barn there is new grass one inch high, the lark has been singing, and frogs are jumping around. Ants are dancing all the days, and bees were out yesterday to look around."

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