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# The western Baltic sea ice season in terms of a mass-related severity index: 1879–1992
# Part I. Temporal variability and association with the north Atlantic oscillation

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ABSTRACT

The variability of the severity of ice winters in the Western Baltic between 1879 and 1992 is statistically investigated using a time series of the accumulated areal ice volume (or $V_{A\Sigma}$) from the Baltic coast of Schleswig-Holstein. Lowpass filtering of the original time series shows the level of ice production in the mid 1980s to have been the same as that almost 100 years ago. A vivid interpretation is made possible of the variations in ice production by classifying $V_{A\Sigma}$ according to ice winter severity types. The increased variability of ice production since the 1920s is seen in the more frequent occurrence both of very strong and weak ice winters, while moderate and strong ice winters have decreased. The time series of the accumulated areal ice volume is negatively correlated with a temporally corresponding series of the NAO winter index, a measure of the strength of the zonal atmospheric circulation above the North Atlantic. Pearson's correlation coefficient, $r_P = -0.47$, exceeds the 99.9% confidence limit. In addition, a contingency table analysis revealed that this inverse correlation is due to the preferential occurrence of (a) weak ice winters with strong westerlies (NAO winter index $>1$) and (b) strong to very strong ice winters with weak westerlies (NAO winter index $< -1$).

## 1. Introduction

### 1.1. *Background*

The question of interannual and long-term variations in the amount of ice in the Baltic Sea is not only of economic interest (to what extent is shipping restricted in the winter?). It is also gaining in importance owing to looming global warming because sea ice is a sensitive indicator of climate change.

Previous investigations have been based on the time series of the annual maximum ice extent in the Baltic Sea dating back to 1830 (e.g., Alenius and Makkonen, 1981; Leppäranta and Seinä, 1985). This parameter is a useful measure of the severity of the sea ice season in the Northern Baltic Sea. However, by definition, ice extent includes occasionally extensive areas of open water within the ice limits. Sea ice volume is potentially a more meaningful measure as it also reflects the thickness of the ice. No long-term ice volume record exists for the entire Baltic Sea, however, as neither actual ice area (ice extent minus open water) nor ice thickness were routinely observed before 1970. It is only for a small subregion, the Baltic coast of Schleswig-Holstein, that a volume- or mass-related sea ice series could be reconstructed back to 1879.

### 1.2. *Significance of $V_{A\Sigma}$*

This analysis of the sea ice season along the Baltic coast of Schleswig-Holstein is based on areal ice volume $V_A$, i.e., the ratio of ice volume ($V$) to

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ice extent ($A$). $V_A$ can be visualized as an equivalent ice thickness $h_{eq}$. While $h$ is the average ice thickness of the actual ice area $A_{act}$, $h_{eq}$ is the thickness of the slab of extent $A$ that can be formed by uniformly distributing the mass or volume $V = A_{act} h$ over $A$. As the average ice concentration within the ice limits is $N = A_{act}/A$, $V_A$ could be derived from observations of $N$ and $h$ using the equivalent definition $V_A = h_{eq} = Nh$.

In an earlier investigation, one of the authors (Koslowski, 1989) showed the *accumulated areal ice volume*, or $V_{A\Sigma}$, to be a suitable measure of the severity of the ice winter along the coast of Schleswig-Holstein. In analogy to *accumulated degrees of frost* (cf. Glossary of Meteorology, 1959), $V_{A\Sigma}$ is obtained by adding up daily estimates of $V_A$ until the end of each ice season. Better evidence of the severity of ice winters in areas of maritime climate is obtained by taking account of the duration of the ice cover than by considering the areal ice volume at the time of maximum ice cover only which is difficult to define. In the coastal areas of the Western Baltic, thaws are a common occurrence. When one sets in, the ice not only stops growing in thickness, but very often melts again, only to refreeze during subsequent cold spells. This is why winters frequently occur in which the same state of maximum ice cover is reached twice or three times.

### *1.3. Scope of this study*

The main objective of this paper is to analyze the severity of the Western Baltic sea ice season in terms of $V_{A\Sigma}$. Examination of the characteristic variations of ice winter severity is restricted here to a statistical analysis in the time domain. For a spectral analysis the reader is referred to Loewe and Koslowski (1993).

The variations can be interpreted only in an atmospheric context that is established here in terms of the so-called North-Atlantic Oscillation (NAO) (Walker and Bliss, 1932; Lamb and Peppler, 1987). Experience shows that ice production in the Baltic Sea is low when zonal atmospheric circulation is enhanced, but that it is often high when circulation above the North Atlantic is weak (see also Rogers and van Loon, 1979). Using the NAO winter index as a simple measure of the strength of zonal circulation (Rogers, 1984), the dependence of ice production in the Western Baltic on atmospheric forcing is investigated.

## 2. Data sets, processing and classification

### *2.1. Ice data*

The accumulated areal ice volume summarizes the observations of six particular stations (Fig. 1) which evenly reflect the specific ice conditions along the coast of Schleswig-Holstein. It is given by

$$V_{A\Sigma} = \tfrac{1}{6} \sum_k \sum_j (Nh)_{jk}, \tag{1}$$

where $N$ = ice concentration, $h$ = ice thickness, $j$ = index of days during the winter, and $k$ = index of the six stations. Note that replacing $Nh$ in (1) with $Nh\,\Delta t$ ($\Delta t = 1$ day) would not affect the numerical value of $V_{A\Sigma}$ but change dimensions to $m$ times day. This modified definition is analogous to *accumulated freezing degree-days* (cf. Glossary of Meteorology, 1959). While better reflecting the meaning of $V_{A\Sigma}$ as an approximation to the station-averaged time integral of $V_A(t)$ over the ice season, definition (1) is retained for consistency with historical practice.

It should be noted that ice thickness only refers to level ice. In the few instances when deformed ice (rafted, compacted or ridged ice) occurred off the coast, account was taken only of the thickness of the level ice subject to the deformation.

$V_{A\Sigma}$ is based on observations of ice concentration and ice thickness only for the period 1940–1992. Earlier data were deduced from the station average of the number of days of ice occurrence, using a regression formula relating this

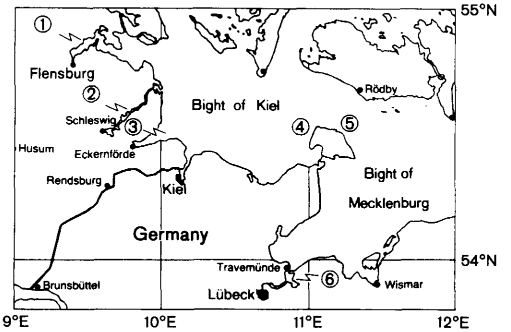


*Fig. 1.* Map of the Western Baltic showing the location of the 6 stations along the coast of Schleswig-Holstein used in estimating the accumulated areal ice volume ($V_{A\Sigma}$).

parameter to $V_{A\Sigma}$ during the period 1940–1987 (Koslowski, 1989).

In Koslowski (1989), it was shown that the accumulated areal ice volume can help in characterising ice conditions in coastal waters and on the high seas if values are grouped in certain classes. These ice winter classes were derived from the frequency distribution of $V_{A\Sigma}$ and are defined as follows: weak $\leqslant 0.36$ m < moderate $\leqslant 3$ m < strong $\leqslant 10$ m < very strong. The previous classes *very weak* and *weak* as well as *very strong* and *extreme* have been combined to give *weak* and *very strong*. The severity types resulting from this classification of $V_{A\Sigma}$ agree with those which can be derived from the ice charts of the German Ice Service by considering typical states of maximum ice cover in the Western Baltic.

### *2.2. NAO data*

As in Rogers (1984) the index of the NAO is defined as the difference between the normalized pressure anomalies in winter (DJF) at Ponta Delgada (37°45′N, 25°43′W), Azores and Akureyri (65°41′N, 18°5′W), Iceland:

$$NAO_i = \left.\frac{p_i - \bar{p}}{\sigma}\right|_{\mathrm{PD}} - \left.\frac{p_i - \bar{p}}{\sigma}\right|_{\mathrm{A}} \quad \forall i \in [1879, 1992]. \tag{2}$$

However, here, $\bar{p}_{\mathrm{PD}}$ (= 1020.15*h* Pa) and $\bar{p}_{\mathrm{A}}$ (= 1003.38*h* Pa) denote the 30-year mean DJF sea level pressures for 1961–1990 (CLIMATOLOGICAL NORMALS), while $\sigma_{\mathrm{PD}}$ (= 4.00*h* Pa) and $\sigma_{\mathrm{A}}$ (= 6.53*h* Pa) are the corresponding interannual standard deviations at Ponta Delgada (PD) and Akureyri (A).

The NAO index has been evaluated using genuine data sources (A: World Weather Records (1879–1970), Vedráttan (1971–1992); PD: British Meteorological Office (1879–1893), World Weather Records (1894–1970), National Climatic Data Center (1971–1992)). For the winter of 1918/19 and December 1919, pressure data at Grimsey (66°33′N, 17°18′W) were taken from Meteorologisk Årbøger (1918, 1919) to fill a gap in the Akureyri record.

A useful classification of the index data is based on the definition of three categories: high, normal and low. A high index ($NAO_i > 1$) is associated with a strong westerly flow, while a low index ($NAO_i < -1$) represents weak westerlies. A normal index covers the midrange $-1$ to $+1$ and stands for a zonal circulation of average strength.

## 3. Temporal variations in ice winter severity

### *3.1. General characteristics*

Fig. 2 shows the accumulated areal ice volume of winters from 1879 to 1992. Some important statistics are: median = 0.625 m, arithmetic mean = 2.961 m, standard deviation = ±5.409 m, skewness = 2.828, kurtosis = 8.412, variation coefficient = 182.7 %.

The arithmetic mean lies just at the transition between moderate and strong ice winters. The distribution is positively skew as weak and moderate ice winters predominate (frequency of 75.4 %) and strong and very strong ice winters only occur now and again (24.6 %). The mean as well as the variance of $V_{A\Sigma}$ are greatly determined by the very strong ice winters (10.5 %) which exceed the mean by more than one standard deviation. It is remarkable that in the 1940s three of the most severe ice winters on record occurred in succession and concurrently with an extreme multiannual ENSO warm episode (1939–42). This correspondence may be more than coincidental (cf. also Fraedrich, 1990), although the linear correlation between the 1935–1982 Southern Oscillation Index in the autumn (taken from Parker, 1983) and $V_{A\Sigma}$ in the following winter is rather weak (−0.28, significant at the 95 % level).

### *3.2. Linear trend vis-à-vis other studies*

The linear trend indicated by the checked boxes in Fig. 2 is only slightly positive, i.e., $V_{A\Sigma}$ has increased at a rate of 0.31 m per 100 year. This trend is confirmed by the decrease in winter air temperature along the Baltic coast of southern Sweden between 1860 and 1987 (cf. Fig. 9 in Alexandersson and Eriksson, 1989). According to Schönwiese and Stähler (1991, cf. their Fig. 5a) northwestern Europe, including the Western Baltic, is one of the few areas in the Northern Hemisphere showing secular cooling of winter temperatures.

In their analysis of the seasonal maximum ice extent for the entire Baltic Sea ($\simeq 420 \times 10^3$ km$^2$), Leppäranta and Seinä (1985) find a decrease in ice

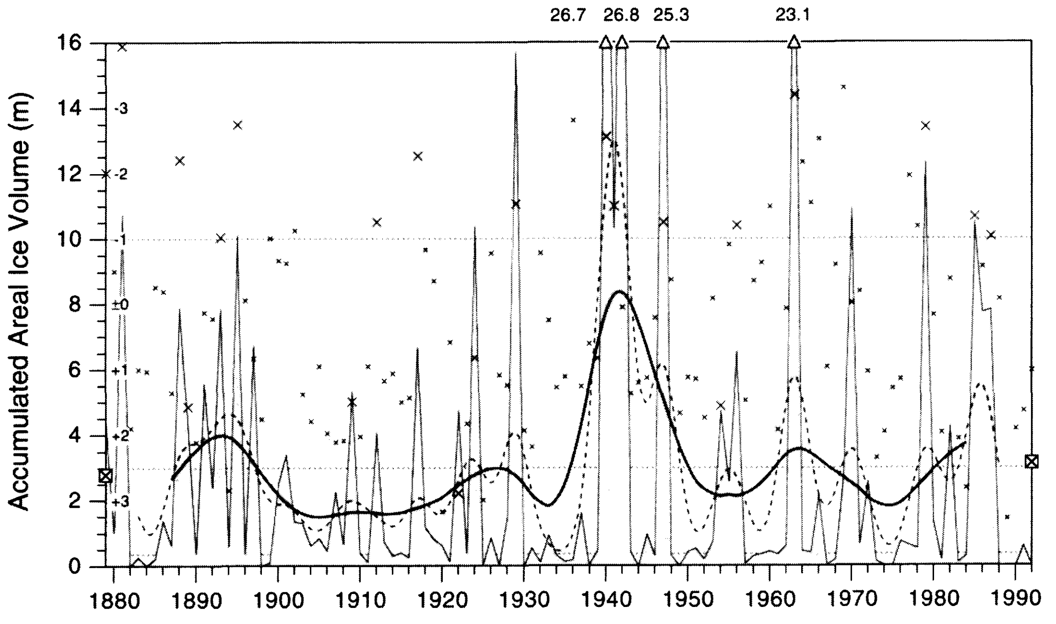


*Fig. 2.* The accumulated areal ice volume ($V_{A\Sigma}$) from 1879 to 1992. Triangles mark extremely strong ice winters as identified by the labels on top. Horizontal dotted lines separate weak, moderate, strong and very strong ice winters from one another. Checked squares on the left and right axis indicate the linear trend of the series. The dashed and heavy solid curves represent smoothed $V_{A\Sigma}$ series obtained by applying a Gaussian lowpass filter of 10 and 20 year cutoff period, respectively. Crosses mark the NAO winter index, more clearly shown in Fig. 5, but added here for easier comparison (at the same scale, as indicated by the labels to the right of the left axis). Large crosses additionally identify the coincidence of strong and very strong ice winters with weak (16 cases) or strong westerly flow (4 cases, see also Table 2).

extent of $-42103$ km$^2$ per 100 year for the period 1830–1984. However, if the trend of their ice extent series is re-evaluated for the period 1879–1992, a much lesser decrease of $-9356$ km$^2$/100 year is obtained.

### *3.3. Interdecadal variations*

In Fig. 2, the long-term variations of $V_{A\Sigma}$ are shown by dashed and thick lines. These curves (hereafter referred to as LP10 and LP20) were obtained by applying a Gaussian low-pass filter with a 10- and 20-year cut-off period to the original series. The course of the curves, in particular that of LP10, is determined by the frequency and intensity of the strong and very strong ice winters ($V_{A\Sigma} > 3$ m). From the maximum of the LP20 curve around the mid-1890s, these winters become far less frequent and around 1910 reach the absolute minimum of the whole period. The increase that sets in around 1920 culminates in the absolute maximum at the beginning of the 1940s. Other, less intense maxima do not occur again until the 1960s and 1980s. Three unusually severe ice winters occurred in succession in the 1940s and 1980s.

The LP20 curve shows that the $V_{A\Sigma}$ level around the mid 1980s was the same as almost 100 years ago.

### *3.4. Non-stationarity of mean and variance*

The almost coincident course of the LP10 and LP20 curves (Fig. 2) before 1930 shows that variations with periods of 10–20 year were only weak. The LP10 curve in particular is an indicator of the strong variability of ice production that has been prevalent along the Baltic coast of Schleswig-Holstein since around 1930. This increase in variability is illustrated further in Fig. 3 which shows the temporal evolutions of the arithmetic mean and the variance of $V_{A\Sigma}$ for overlapping

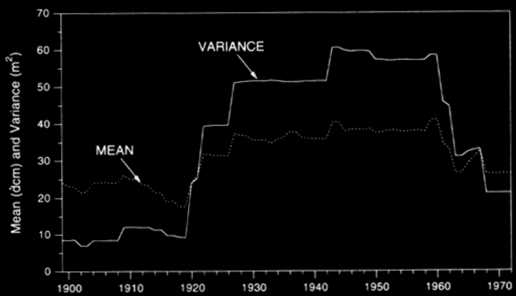


*Fig. 3.* Temporal evolution of arithmetic mean and variance of $V_{A\Sigma}$. The means and variances of overlapping 41 year intervals are plotted against the central year of the proper time intervals.

41 year intervals. Variance between 1920 and 1930 increases fivefold and reaches its highest values between 1940 and 1960. A substantial decrease in variance can be seen since 1960; its values around 1970 are nevertheless much higher than those before 1920.

It might be surmised that the non-stationarity of mean and variance is an artifact of piecing together regressed and directly observed $V_{A\Sigma}$ values in 1939/40 (cf. Subsection 2.1). The jump-like changes in variance, however, do occur in the ice days series, too (not shown). Moreover, the ice extent series of Leppäranta and Seinä (1985) also exhibits the same jumps (Loewe and Koslowski, 1993).

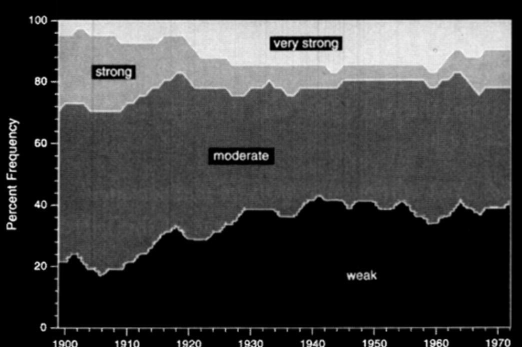


*Fig. 4.* Moving percent frequencies of classified ice winters. The relative frequencies obtained for overlapping 41 year intervals have been stacked against the central years and are thus given by the heights of the shaded areas.

Table 1. *Winter type frequencies and frequency trends*

| Ice winter severity | % freq. 1879–1992 | Trends (%/100 yr) for 21 and 41 year bins | |
|---|---|---|---|
| weak | 34.2 | 26.7 | 28.1 |
| moderate | 41.2 | −14.8 | −18.5 |
| strong | 14.1 | −23.1 | −22.3 |
| very strong | 10.5 | 11.2 | 12.7 |

### 3.5. *Change in ice wintertype frequencies*

The enhanced variability of ice production since about 1930, accompanied as it is by a reduction in the strength of the zonal atmospheric circulation above the Northern North Atlantic (see Section 4), also shows in a change in the frequency distribution of ice winter severity. In Fig. 4 the relative frequencies of the classified $V_{A\Sigma}$ values, as obtained for moving 41 year time intervals, are displayed versus the central year of the proper interval. Not only very strong ice winters but also weak ice winters have increased since the 1920s, while moderate and strong ice winters have decreased. The linear trends of the relative frequency of each severity type are given in Table 1 which also shows the frequency distribution for the full period 1879–1992. The relative frequency trends also given for intervals of only 21 years underline the stability of the result.

## 4. Temporal variations in the NAO index

Fig. 5 shows the NAO winter index time series for 1879–1992 (note the inverted scale). Certain periods are characterized by an increased or diminished occurrence of weak zonal atmospheric circulation (NAO index $< -1$). They are sometimes termed blocked or westerly periods respectively (Hay, 1967).

From the course of the LP20 curve the first four decades of this century are identified as a westerly period. It contains only 5 of a total of 26 winters with greatly weakened westerly winds. This westerly period, for which van Loon and Madden (1983) note weak variability in the position and intensity of the Icelandic Low, is associated with a long-term increase in winter temperatures in Europe (Moses et al., 1987). The subsequent period ending around 1970, on the other hand, is

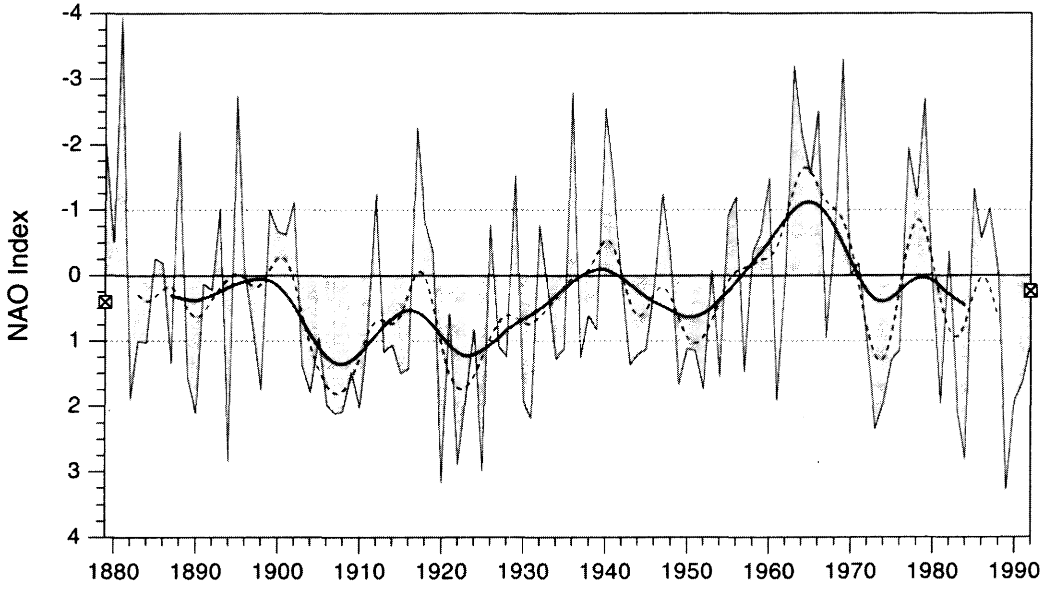


*Fig. 5.* Variations of the NAO winter index since 1879. The index is defined as the difference between the atmospheric pressure anomalies at mean sea level standardized relative to 1961–90 at Ponta Delgada and Akureyri. Horizontal dotted lines separate the categories weak, normal, and strong westerly flow from one another. Checked squares on the vertical axes indicate the linear trend. Dashed and heavy solid lines represent the smoothed time series obtained by applying a Gaussian lowpass filter of 10 and 20 year cutoff period, respectively.

characterized by a greater number of winters with weakened zonal circulation that peak in the 1960s. Van Loon and Madden (1983) draw attention to the strong variability of position and intensity of the Icelandic Low; this variability is apparently connected with the frequent occurrence of very severe winters in Europe. Like the period before the turn of the century, the post-1970 one is characterized by a circulation of mainly normal strength although there have been signs of a return to stronger westerlies in recent years (cf. also Flohn et al., 1990).

It is indeed interesting that the temperature anomalies, which as has just been noted accompany long-term changes in circulation, correspond qualitatively with the course of surface air temperature in the Northern Hemisphere since 1880 (cf., e.g., Hansen and Lebedeff, 1987).

## 5. Association between $V_{A\Sigma}$ and NAO

It seems appropriate to make a direct comparison between the NAO index (Fig. 5) and the $V_{A\Sigma}$ time series (Fig. 2). Fig. 2 also contains the NAO index values (shown by crosses) so that they can be accurately related to the temporally corresponding $V_{A\Sigma}$ values. The outline of the inverse behaviour of both data sets can clearly be seen: a low (high) index in general corresponds to a severe (weak) ice season. Both time series are negatively correlated.

### *5.1. Linear and rank correlation*

Pearson's correlation coefficient is $r_P = -0.47$ (accounts for 22% variance) and is highly significant (error probability $<0.1\%$). Because the $V_{A\Sigma}$ data do not follow a Gaussian distribution, it seemed appropriate to check this result using nonparametric methods of correlation. Both time series were thus replaced with rank numbers according to the numerical size of the values. Spearman's rank-order correlation coefficient, defined as the linear correlation coefficient between temporally connected rank pairs, is $r_S = -0.49$ (error probability $<0.1\%$). Another nonparametric statistic is Kendall's $\tau$. This correlation coefficient ($\tau = -0.34$) also confirms, with

Table 2. *Contingency table on the dependence of ice winter severity on westerly flow strength*

| Ice winter severity | Strength of westerly flow strong | normal | weak | Row totals |
|---|---|---|---|---|
| weak | 24 (17.5) | 13 (12.7) | 2 (8.9) | 39 |
| moderate | 23 (21.0) | 16 (15.3) | 8 (10.7) | 47 |
| strong | 4 (7.2) | 5 (5.2) | 7 (3.7) | 16 |
| very strong | 0 (5.4) | 3 (3.9) | 9 (2.7) | 12 |
| col. totals | 51 | 37 | 26 | 114 |

Cell values give the absolute frequencies of concurrent events. Expected cell frequencies are in parentheses. See Section 2 for a definition of the frequency bins in terms of $V_{A\Sigma}$ and the NAO index and Subsection 5.2 for additional explanation.

equal certainty, the reality of the association between $V_{A\Sigma}$ and the NAO index.

*5.2. Contingency table analysis*

Further insight into the association between $V_{A\Sigma}$ and the NAO index can be gained by evaluating the following contingency table (Table 2). It presents the joint frequency distribution of the 4 ice winter severity types and 3 NAO index classes. The row and column sums at the margins of the table represent the frequency distribution of each variate. The theoretical joint frequency of each pair of simultaneously occurring attributes is given in brackets. It was calculated from the observed individual frequency distributions under the null hypothesis $H_o$ that there is no relation between ice winter severity and the state of the NAO. In this case, the theoretical relative frequency or the probability of occurrence $\Pr\{E_1 E_2\}$ for a combined event (e.g., strong westerlies/weak winter) is determined by $\Pr\{E_1\}\ \Pr\{E_2\}$ (e.g., $\frac{51}{114} \times \frac{39}{114}$). Theoretical joint absolute frequencies (as given in the table) are arrived at after multiplication with the total number of realized combinations (114). Using the $\chi^2$ test, the null hypothesis, the observed deviations from the theoretical frequency distribution are accidental, can be checked statistically. With 6 degrees of freedom, $\chi^2 = 33.1$. This value greatly exceeds the significance threshold of $\chi^2_{0.999} = 22.5$ and thus $H_o$ is rejected with an error probability $<0.1\,\%$.

It is thus statistically safe to say that the occurrence of the different types of ice winter severity depends on the state of the NAO. Ice winter severity is strongly correlated both with strong and weak westerlies. There is no correlation, however, between ice winter severity and normal westerlies as observed frequencies almost match the theoretical ones.

*5.3. Discussion*

When appraising statistical results, it should be remembered that the NAO index refers to the mean strength of the zonal circulation from December to February and thus does not reflect intraseasonal variations. For ice production in the Western Baltic, which generally does not set in until January, air pressure differences in January and February are of prime importance. While conditions in December can affect the onset of ice formation, they have no bearing on the severity of the ice season: the linear correlation between $V_{A\Sigma}$ and the NAO index in December (calculated from monthly pressure data after (2)) is insignificant ($r_P = -0.07$).

Furthermore, the NAO index is merely a very simple measure of the strength of west wind circulation as it gives no information about the position, size, form or central pressure of the Icelandic Low and the Azores High.

As to weak westerlies, which are characterized by a pronounced meridional upper air flow above the northeastern North Atlantic, the position of the upper high pressure ridge crucially influences the intensity of ice formation. If the axis of such a broad ridge of high pressure lies above Norway and if it is slightly tilted to the east, very cold and dry continental Arctic air from northern Russia can flow into the Baltic area, thereby creating the conditions for intense ice production. If an upper high pressure ridge is situated further to the west, e.g., above Iceland, less cold and moist polar air masses flow into central Europe. They merely cause coastal ice formation, the sea itself remains ice-free. Examples of this are the winters of 1959/60 and 1976/77 in which the accumulated areal ice volume amounted only to 0.44 m and 0.64 m respectively with an NAO index of −1.49 and −1.96 (weak westerlies). Similar conditions prevailed throughout the 1960s, when the NAO index assumed its absolute minimum (cf. Fig. 5). Out of a total of 10 weak and moderate ice winters under weak westerly flow (cf. Table 2) 5 occurred in that decade.

In rare cases a strong ice winter can still develop in spite of strong westerlies which are usually characterized by an enhanced zonal flow at high levels above the northeastern North Atlantic. An example is the winter of 1953/54 in which the NAO index was +1.56 and the accumulated areal ice volume was 4.74 m. In February of that winter, a narrow frontal zone crossing the North Atlantic was either directed to the north-east across the Norwegian Sea or moved into the Mediterranean area. During the first situation lasting a fortnight, cold to very cold and dry continental air masses continuously flowed from central Russia to central Europe along the south side of a high pressure area above central Scandinavia. Ice formation in the Western Baltic was intense because the heat content of the water there was already nearly exhausted.

## 6. Conclusions

The temporal variability of the severity of ice winters in the Western Baltic between 1879 and 1992 was statistically examined on the basis of the *accumulated areal ice volume* from the Baltic coast of Schleswig-Holstein. The Gaussian low-pass filtered time series (LP20) shows that the level of ice production in the Western Baltic around the mid-1980s was the same as that almost 100 years ago. This finding is in accordance with the slight reduction in winter air temperatures along the Baltic coast of Sweden between 1860 and 1987 (Alexandersson and Eriksson, 1989) as well as with a very weak negative linear trend in winter air temperatures over the Western Baltic in the period 1890 to 1985 (Schönwiese and Stähler, 1991).

The temporal evolution of arithmetic means and variances for overlapping 41 year intervals is characterized by a strong increase of these parameters in the 1920s. Variability is especially high between 1940 and 1960 when the four extremely strong ice winters of this observation period occurred and then decreases markedly. The non-stationarity of variance is accompanied by changes in the frequency distribution of ice winter severity. It can be seen that both very strong and weak ice winters have increased since the 1920s, while moderate and strong ice winters have decreased in number.

The variations in ice production in the Western Baltic have been examined within the context of the atmospheric circulation above the North Atlantic, as characterized here by the NAO winter index. In particular, it was found that the accumulated areal ice volume is negatively correlated with the NAO winter index: Spearman's rank-order correlation coefficient $r_S = -0.49$ exceeds the 99.9% confidence level. In addition, a contingency table analysis revealed a strong concurrence not only of weak ice winters and strong westerlies (NAO winter index $>1$) but also of strong to very strong ice winters and weak westerlies (NAO winter index $<-1$).

As the NAO index only refers to air pressure differences between the Azores and Iceland, it is a very simple measure of the strength of west wind circulation. More information about the atmospheric forcing behind ice production may be obtained by including the whole of the air-pressure field above the North Atlantic.

Another meaningful addition to this investigation is the spectral and cross spectral analysis of the $V_{A\Sigma}$ and NAO index time series. The temporal distribution of the stronger ice winters since about 1940 (cf. Fig. 2) would seem to indicate a quasi-periodic variation of 7 to 8 years, while the zigzag structure of the $V_{A\Sigma}$ series, especially before 1940, seems to indicate a high percentage of variance in the quasi-biennial frequency range. An interesting aspect here is whether the non-stationarity of the variance of the $V_{A\Sigma}$ series is connected with discontinuities of quasi-periodic variations. The second part of this investigation (Loewe and Koslowski, 1993) also addresses the question of a possible association between the severity of ice winters and the 11-year solar cycle.

## 7. Acknowledgements

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