Meteorol. Z. (Contrib. Atm. Sci.), PrePub DOI 10.1127/metz/2020/0986

DACH 2019

Regional distributed trends of sea ice volume in the Baltic Sea for the 30-year period 1982 to 2019

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(Manuscript received June 29, 2019; in revised form May 18, 2020; accepted May 19, 2020)

Abstract

Since more than 100 years, winters in the Baltic Sea have been classified according to their strength and have been compared to each other. In the beginning, the winter strength was only related to the ice coverage along the coasts. However, since the 1980s, also the ice thickness was observed consistently and has therefore been included into the classification scheme. Owing to the international cooperation between the European ice services, we have all the needed information about the winter strength, sea ice coverage, distribution and mass for the entire Baltic Sea available. Thus, we have been able to compute changes in the sea ice conditions for this area covering the last decades and to compare them with changes in the air and sea surface temperatures. For the first time, we show the distribution of the mean accumulated sea ice concentration and sea ice volume as well as its trends for the Baltic Sea. Consistently data reveal a decreasing amount of sea ice that is produced over a winter season for nearly all the sections of the Baltic Sea. The reduced sea ice production correlates generally well with the increase in air and sea surface temperatures over winter months.

Keywords: sea ice, sea ice volume, Baltic Sea, climate change, sea surface temperature

1 Introduction

Sea ice forms every winter at least in the northern parts of the Baltic Sea and has been subject to several studies concerning its physical behavior, changes and interactions with the atmosphere, ocean and biosphere (see, e.g., Stigebrandt and Gustafsson, 2003; Granskog et al., 2006; Feistel et al., 2008; Lehmann et al., 2011; Haapala et al., 2015). However, studies concerning its changes concentrate on maximum winter sea ice extent (e.g., Omstedt et al., 2004; Haapala et al., 2015), or focus only on special regions of interest (e.g., Schmelzer et al., 2012 for the southern Baltic Sea; Jevrejeva et al., 2004, only for coastal areas; Jaagus, 2006, only for the Estonian coast). These studies discovered a general decrease in maximal sea ice extent by 2 % per decade over the past 100–200 years. Nevertheless, sea ice extent is highly variable to changes in the wind field and cannot reveal how the entire ice mass that is produced in each winter has changed. A more significant parameter for sea ice changes is the sea ice volume, as it comprises changes in sea ice coverage and those in sea ice thickness. Therefore, we calculated in this study the regional distributed changes in the accumulated sea ice volume for the Baltic Sea from 1982 through 2019 as linear trend for the entire winter season as well as for single months. Furthermore, we discuss the response of sea ice volume to changes of atmospheric teleconnection patterns as well as sea surface and air temperatures, such as those are the main drivers for changes in both sea ice parameters. Sea surface temperatures (SST) in the Baltic Sea have been analyzed by, e.g., Bradtke et al. (2010), Stramska and Białogrodzka (2015) and Høyer and Karagali (2016). They used different data sets but consistently found that SST has mostly increased in the Baltic Sea by about 0.3°C–0.7 °C per decade. SST changes are closely related to those in the air temperature (T_{air}, Omstedt and Hansson, 2006), which are also known to increase in the Baltic Sea (Omstedt et al., 2004; Stigebrandt and Gustafsson, 2003). With this study, we want to present for the first time the spatial and temporal (in terms of which winter months shows the largest trends) distribution of accumulated sea ice volume trends over the Baltic Sea and want to answer the question whether these trends are consistent with those observed for SST and T_{air}. Section 2 describes the data used for this study. In Section 3 we show how the accumulated sea ice concentration (ASIC) and volume (ASIV) has changed over the last decades, and in Section 4 we look at the changes in SST and T_{air}. Section 5 discusses how the trends found correlate to each other and gave a discussion on uncertainties. In Section 6 we summarize the most important findings of this study.

2 Data description

2.1 Sea ice data

Our study is based on sea ice data collected over six decades at the Bundesamt für Seeschifffahrt und Hydrographie (BSH) combining sea ice concentration and sea ice thickness information. The ice data originate from

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DOI 10.1127/metz/2020/0986

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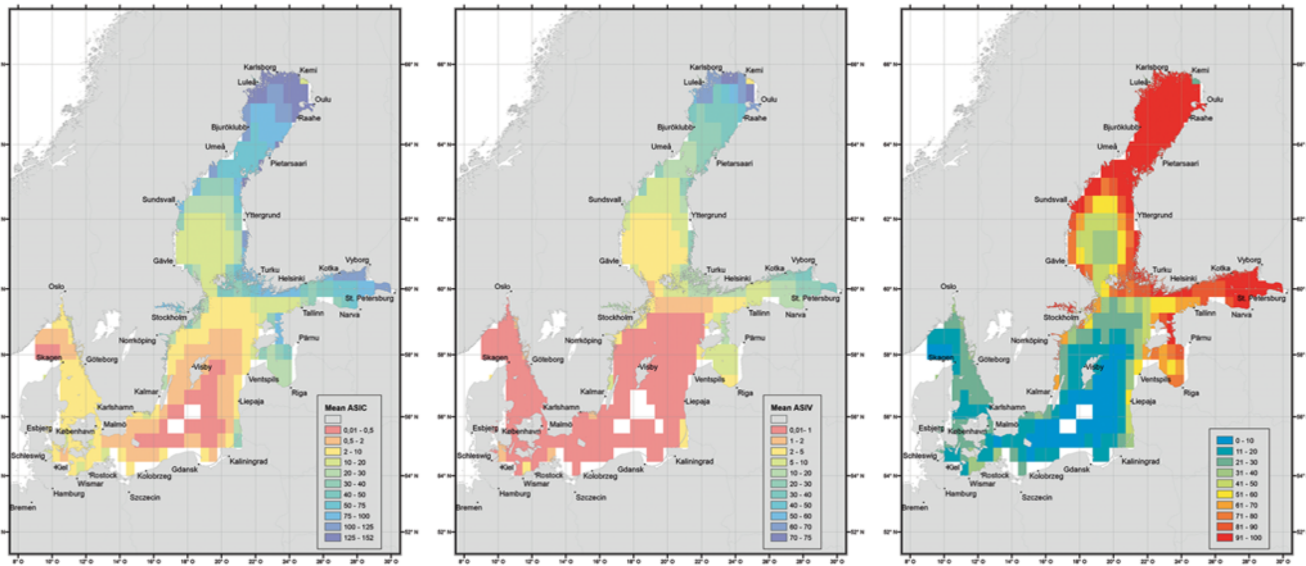

Figure 1: Mean values of accumulated sea ice concentration (left) and accumulated sea ice volume (middle) over an entire winter, averaged over the period 1982 to 2019. Highest values (blue) occur in the northern parts were a compact sea ice cover exists nearly throughout the entire winter every year. Lowest values (red) are found in the southern and western Baltic Sea, where sea ice at sea occurs only in strong winters. The right panel shows frequency of ice occurrence in % of all winters. In the northern Bay of Bothnia, nearly every year ice occurs (red fields) while in the southern central parts, ice occurs only in some few years with severe winters.

ice charts, which were mostly drawn twice per week for the entire Baltic Sea over the winter season until 2011. Afterwards, ice charts were drawn at least once per week and in times with rapid sea ice changes twice per week. All the ice charts are based on visual observations from trained ice observers, on ship-based observations, on airborne observations (in former years) and on satellite data since about three decades. In the ice charts, sea ice concentration and sea ice thickness is not given in absolute values but rather in intervals. That means, ice concentration is given in terms like 10–30 % and sea ice thickness in intervals like 5–10 cm. For the regular grid, these values were averaged, i.e. for the mentioned example, sea ice concentration would be 20 % and sea ice thickness 7.5 cm. The charts before 2005 have been manually digitalized onto a regular 0.5° × 0.5° grid (Feistel et al., 2008). Newer charts are available as vector data and were mapped in an automated fashion onto the same grid. Due to the better resolution of the newer charts, inconsistencies may appear sometimes in narrow, near coastal sections like the Vistula Lagoon, as the newer charts captured this near coastal ice, which (if present in the charts) were often not taken into account in the manual gridding process. This data has already been used in a comparison between maximum ice volume and maximum ice extent for the Baltic (Schmelzer and Holfort, 2014), and both time series showed in general good correlation. However, in some years interesting differences appeared which showed us that it is reasonable to study sea ice volume, too.

In this study we use only data covering the period 1982 to 2019, as ice thicknesses have not been collected consistently before 1982. So, in order to avoid high uncertainties in the accumulated sea ice volume fields, data before 1982 have not been taken into consideration. For the comparison of sea ice changes to those of the sea surface temperature only data from 1982–2011 are used, as the SST data (described below) is only available for this time span. We analyzed the local cumulative ice concentration and ice volume sum, which are the integrals over the season of the ice concentration and volume, respectively, here to be named as accumulated sea ice concentration (ASIC) and accumulated sea ice volume (ASIV). The idea of the cumulative ice volume sum was introduced by Koslowski (1989). Using the accumulated values instead of mean or maximum values for ice concentration and ice volume, we believe to get a more reliable mean for the winter severity. To account for the irregular sampling times (once or twice per week only), data between two subsequent ice chart dates were linearly interpolated to daily data and were then summed up over the entire winter or over single months. The ASIC is expressed as percent per square meter and the ASIV in volume per square meter, so its dimension is meter. The distribution of averaged ASIC and ASIV over the entire winter season is shown in Fig. 1 and is combined with the information of ice frequency, indicating how often a grid cell has been covered by ice in the observation period. Mean values for ASIC (ASIV) over the entire winter range from 0.5 percent m^{-2} (0.5 m) at the German Baltic coast to about 152 percent m^{-2} (75 m) in the northern part of the Bay of Bothnia where nearly the entire winter is covered by a compact sea ice cover. For single months, mean values of up to 30 percent m^{-2} (18 m) are found (not shown). The temporal variability of ASIC and ASIV can

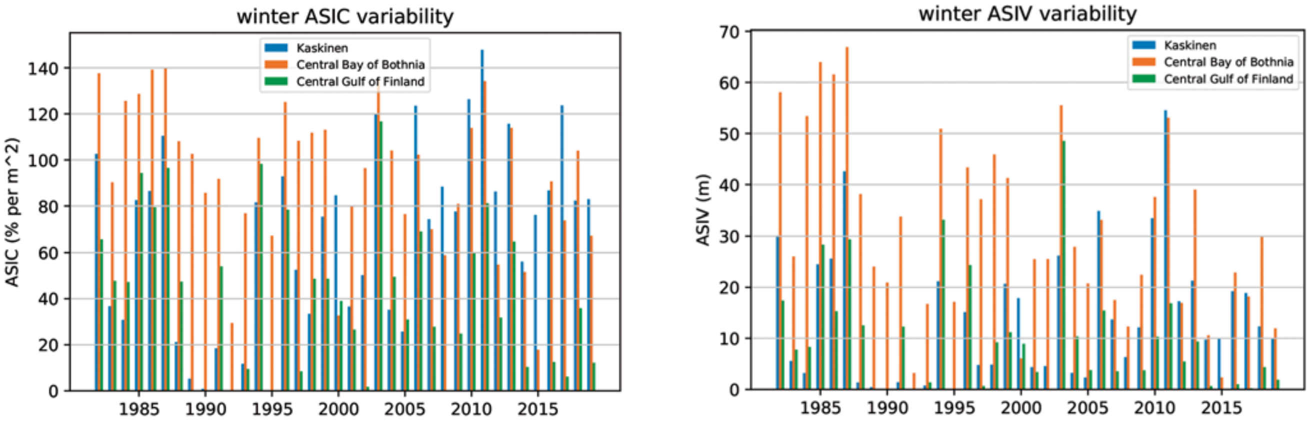

Figure 2: Temporal variability of total winter ASIC and ASIC, exemplarily for the central Bay of Bothnia (22.5° E / 65° N), Kaskinen (representing near coastal ice, 21° E / 62.5° N) and the central Gulf of Finland (26° E / 60° N).

be quite high, depending on the winter strength, and differs regionally, as Fig. 2 illustrates. Shown are the SIC and SIV accumulated over the entire winter for each winter season, exemplarily for a grid cell in the central Bay of Bothnia, central Gulf of Finland and at Kaskinen, which represents a grid cell close to the coast in the Sea of Bothnia. As is expected, ASIC and ASIV are the highest in the central Bay of Bothnia, as in this northern most region, ice growth starts early and ice disappears only in the end of the winter. The other two positions show varying patterns: in some years, Kaskinen, which is further north than the Gulf of Finland, has less ice, in other years, more ice can be found compared to the Gulf of Finland. This reflects the impact of the underlying atmospheric patterns on ice growth, as in some years, cold air is advected from the eastern continent (earlier ice growth in the Gulf of Finland) and in other years from the Polar Regions (earlier ice growth in the Gulf of Bothnia).

2.2 Sea surface and air temperatures

Sea surface temperature (SST) data was obtained from the Copernicus Marine Environment Monitoring Service Baltic Sea- Sea Surface Temperature Reprocessed data set (Høyer and Karagali, 2016). These data are available for the period January 1982 to December 2011. SST calculations are based on infrared satellite observations from NOAA AVHRR and ERS/Envisat. Spatial resolution is with $0.03^\circ \times 0.03^\circ$ higher than in other SST products, temporal resolution is 24 hours. In order to account for sea ice in winter months, which has a much lower temperature than the water, a sea ice concentration mask based on the high resolution ice information from the Swedish Meteorological and Hydrological Institute (SMHI) has been used to set grid cells with more than 30 percent of sea ice to a constant SST of -1 °C. For more detailed information on the SST data set, please see Høyer and Karagali (2016). As we have analyzed monthly accumulated SIC and SIV and their changes in this study, we calculated monthly fields from the daily SST before trends were calculated.

For an analysis of the atmospheric drivers of sea ice changes we have examined monthly mean 2-m air temperatures from the National Center for Environmental Predictions/National Center for Atmospheric Research (NCEP/NCAR, hereinafter referred to as NCEP data) Reanalysis 1 Project (Kalnay et al., 1996). The respective mean fields in the NCEP data are composites of observations – when and where available – and model simulations (where no observations are available).These data have a coarser resolution ($2.5^\circ \times 2.5^\circ$) than the sea ice and SST data. However, the temporal resolution covers the entire study period in contrast to other products with higher spatial resolution, like ECMWF ERA-40 (only to 2002) or COSMO-REA (only from 1995).

3 Observed changes in sea ice coverage and accumulated sea ice volume

The trends in winter seasons ASIC and ASIV for the Baltic Sea over the whole period are shown in Fig. 3, the 30-year period from 1982 to 2011 shows similar trends. In most regions, the trend is negative. Trends in ASIC vary between $-33\,\%\,\mathrm{m}^{-2}\,\mathrm{dec}^{-1}$ to $+41\,\%\,\mathrm{m}^{-2}\,\mathrm{dec}^{-1}$, with the majority of grid cells showing a decrease between $0\,\%\,\mathrm{m}^{-2}\,\mathrm{dec}^{-1}$ and $18\,\%\mathrm{m}^{-2}\,\mathrm{dec}^{-1}$. The strongest decrease is observed in the Gulfs of Bothnia, Finland and Riga. In the central Baltic Sea, trends are lower, certainly due to the fact that the absolute values are smaller to start with. Along the coasts, there are regionally some grid cells which show an increase in ASIC, which is caused by a very low data coverage in the beginning of the observation period. Some positive trends are most probably due to the fact, that with newer satellite data new ice is better detected; and with 100 % concentration have a strong impact on the trend. Due to the small thickness of new ice, the effect is not very pronounced on the sea ice volume.

ASIV shows in most regions a decrease and the highest trends in the same regions as ASIC. Mostly, the trends vary between -22.5 m and 11.5 m per decade

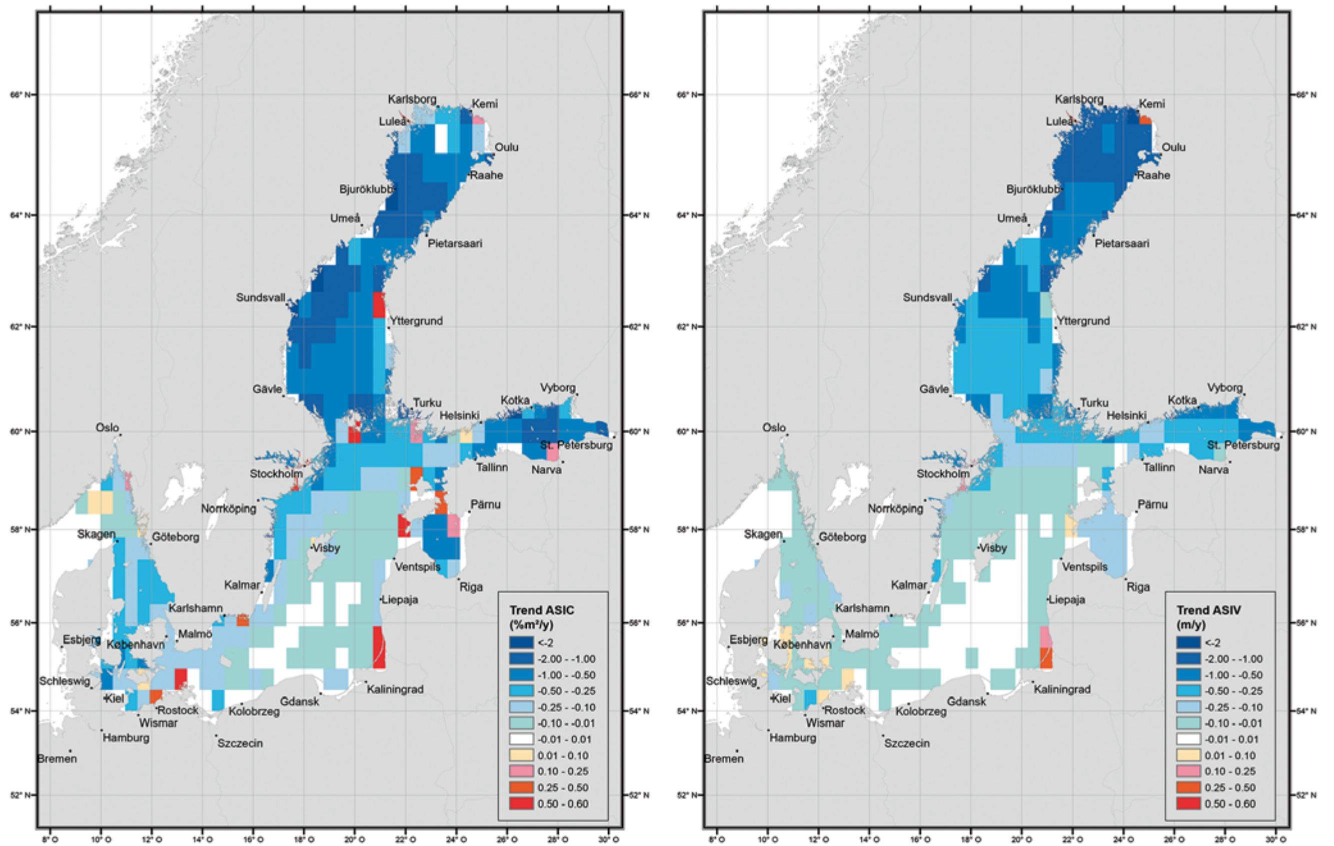

Figure 3: Linear trend of accumulated sea ice concentration (left) and accumulated sea ice volume over the entire winter for the period 1982 to 2019. Blue areas show negative, red areas positive trends. The trend in accumulated sea ice concentration varies between −2.98 and +3.26 % m^{-2} per year and the trend for accumulated sea ice volume ranges from −2.25 to +1.14 m per year. However, the majority of grid cells has a trend between −2 and +0.6 % m^{-2} per year (m per year) for ASIC (ASIV).

with the majority of grid cell having trends between −8 m and 0 m per decade over the winter season. As for ASIC, also in the ASIV product some grid cells show an increase. These positive trends are proven to be not realistic (see discussion).

In order to see, when the largest changes in ASIV occur within a season, trends were calculated for monthly ASIV. The results for the months January to April are shown in Fig. 4. In December and May, any trends are small all over the Baltic Sea. From February to April, ASIV decreases strongest in the Bay of Bothnia while in the Sea of Bothnia, the highest negative trends occur in March and April. In the Gulf of Finland and Riga, ASIV changes show hardly any seasonal variability. Monthly trends vary between −3.5 m and +2.2 m per month.

4 Corresponding changes in sea surface temperature and meteorological conditions from 1982 to 2011

Basically, changes in sea ice concentration and sea ice thickness are caused by atmospheric and oceanographic conditions. Here we analyse the impact of these conditions on sea ice for the period 1982 to 2011, as the SST data are available only for this period. To keep the comparison consistent, also the impact of air temperature changes on sea ice is analysed for this time span. The most important influencer is the air temperature (T_{air}), which also links to sea surface temperature (SST). Oversimplifying, with SST well above freezing, no sea ice is present (or is melting). Around the freezing point sea ice formation can occur and with sea ice present SST is at the freezing point. So there is no direct linear relationship between SST and sea ice, but we expect that monthly means are negatively correlated. Therefore, we correlated the detrended SST and winter ASIC (ASIV), and, as expected, the correlation is usually negative. In regions, where a large amount of ice forms every winter, coefficients of down to -0.9 are reached. However, in regions where ice occurs only in few years (in particular the central Sea of Bothnia) and along the eastern coast of the Gulf of Bothnia, correlation is mostly weak. Trends for monthly SST are shown in Fig. 5 for the months January to April. In January, SST increases by between 0.1 °C to 0.5 °C per decade in the Gulf of Bothnia. However, in the northernmost Bay of Bothnia, along the coast, a light decrease of up to 0.1 °C per decade occurs. Further south, trends lie between −0.1 °C per decade close to the coasts in the east and up to +0.25 °C per decade towards the Swedish coast.

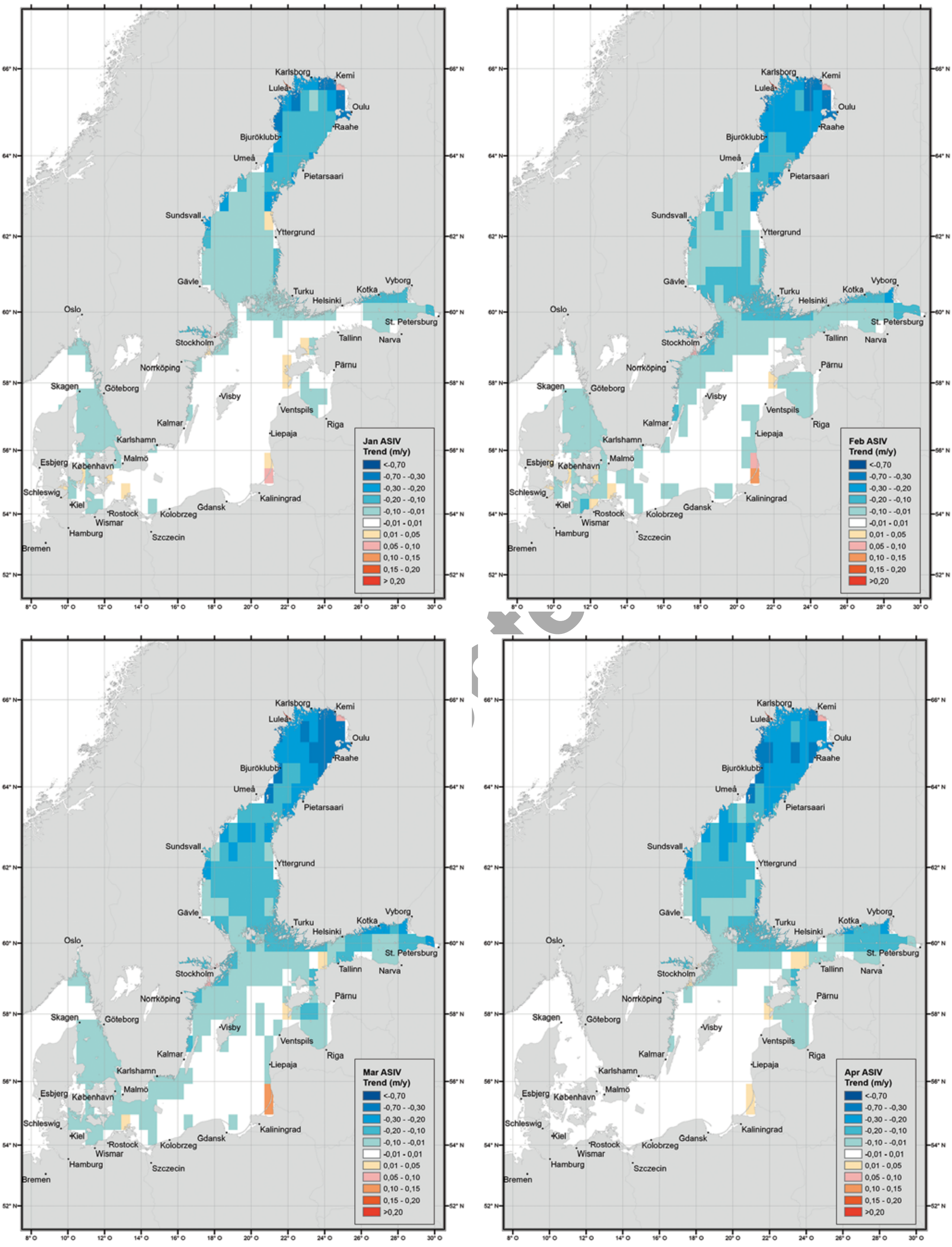

Figure 4: Linear trend in accumulated sea ice volume for the months January, February, March, and April for the period 1982 to 2019. Blue colors show negative trends, red colors show positive trends.

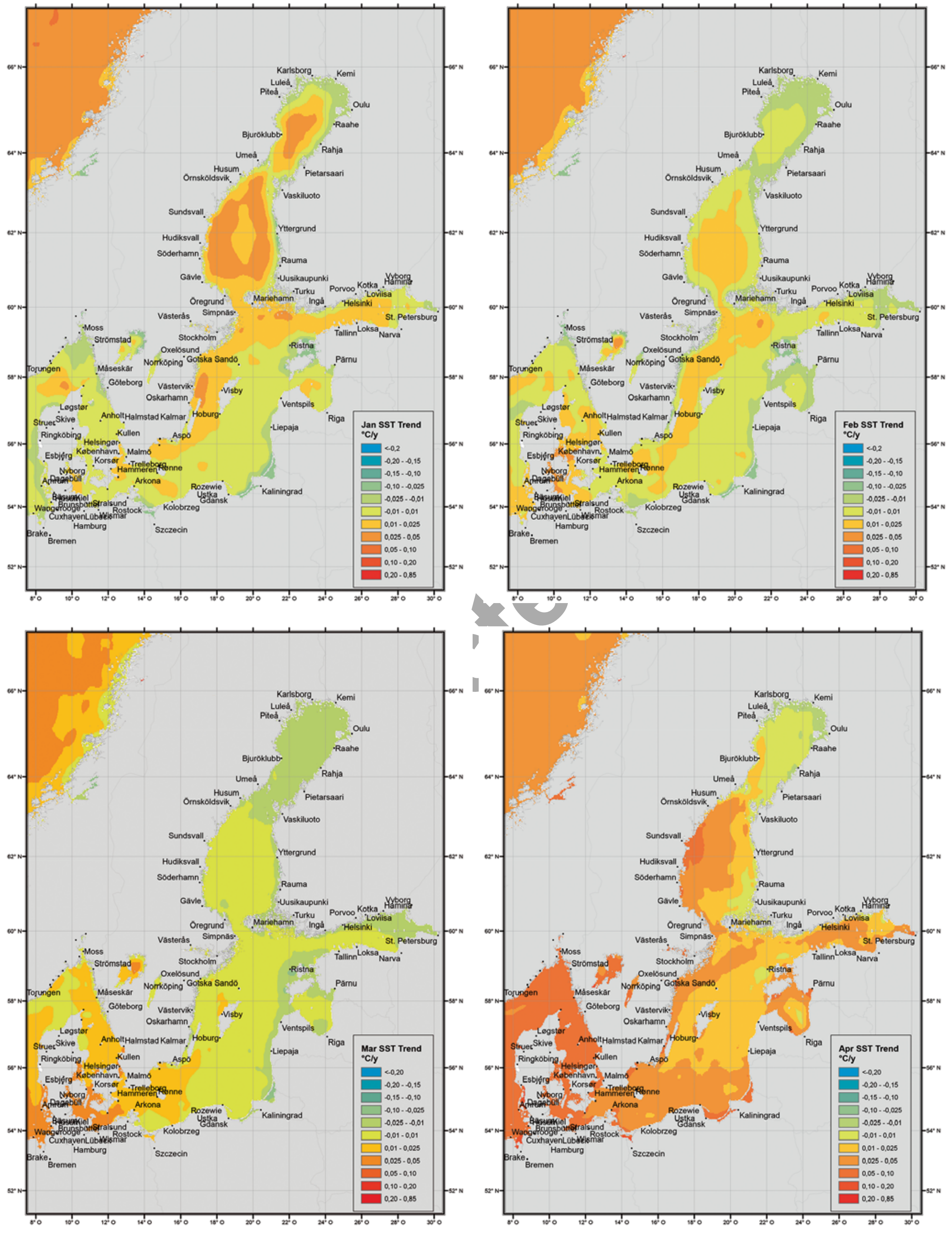

Figure 5: Trend in monthly sea surface temperature for the period 1982 to 2011. Red colors show a positive trend in SST, blue colors a negative trend.

Table 1: Correlation coefficients between ASIC/ASIV and air temperature trends for selected regions: all – the entire Baltic Sea region, SBS – Southern Baltic Sea with latitudes from 54° N to 57.5° N, CBS – Central Baltic Sea with latitudes from 58° N to 61.5° N, NBS – Northern Baltic Sea with latitudes from 62° N to 66° N.

	January		February		March		April		May	
	ASIC	ASIV	ASIC	ASIV	ASIC	ASIV	ASIC	ASIV	ASIC	ASIV
all	−0.635	−0.671	0.157	0.593	0.331	0.659	−0.054	−0.205	−0.674	−0.571
SBS	−0.517	−0.408	−0.186	−0.134	−0.542	−0.332	0.119	0.151	Nan	Nan
CBS	−0.458	−0.363	−0.174	−0.095	0.288	0.362	0.301	0.329	−0.422	−0.307
NBS	−0.249	−0.542	−0.049	0.799	−0.285	0.375	−0.090	−0.581	−0.634	−0.661

In February, trends are generally lower, and in March, the entire Bay of Bothnia and also parts of the Gulf of Finland and the coastal areas in the eastern Baltic Sea south of the Gulf of Finland show interestingly a slight decrease in SST. This negative trend has also been observed in Bradtke et al. (2010) using the BSH SST data set for the period 1990 to 2008. In April, most regions show again a positive trend. Only the coastal area in the Bay of Bothnia still reveals decreasing SSTs. The generally positive trends in SST are well correlated with the decrease in ASIV and ASIC. The situation is different considering the negative trend in SST particularly in the Bay of Bothnia in March, where neither ASIC nor ASIV trends correlate with the decreasing SSTs. However, in these regions also the correlation between SST and ASIC and ASIV itself was low, indicating that sea ice at the eastern coast of the Gulf of Bothnia is influenced by other processes, like the predominantly westerly winds.

In contrast to the negative SST trends the air temperature shows a general positive trend. The highest trends in T_{air} (not shown) occur in January in the southern Baltic Sea and in February, when nearly the entire Baltic Sea reveals trends of 0.2 °C to more than 0.5 °C per decade. In March, trends are lower but still positive. So even if the low negative SST trends at the eastern coast of the Gulf of Bothnia are real, the observed trend in ASIC and ASIV are not inconsistent with the lower SST as the air temperature is increasing.

Table 1 lists the correlation coefficients between the regional distributed trends in T_{air} and ASIC (ASIV) for the months January to April. We analysed the trend correlation for selected regions: i) the entire Baltic Sea region, ii) the Southern Baltic Sea (54° N–57.5° N), iii) the Central Baltic Sea (58° N–61.5° N) and iv) the Northern Baltic Sea (62° N–66° N) in order to account for different ice conditions. We would expect a negative correlation as increasing temperatures are expected to force a decreasing amount of ice. In January, changes in air temperature can explain to a certain amount those of the sea ice, coefficients vary between −0.25 and −0.67. In January, usually, a large amount of sea ice forms and therefore we would expect a good correlation in this month. However, from February to April, correlation is weak and occasionally also positive, so that we can expect that air temperature changes are not the only drivers for sea ice changes in these months. In May, air temperature trends again correlate in a negative way with ASIC and ASIV. May is, as January, an important month, as during May, all the remaining ice melts away. Summarized: generally, the correlation between trends in T_{air} and ASIC (ASIV) is negative and the highest during the beginning and the end of the ice season. In between, other processes may have an additional impact on the changes in sea ice.

5 Discussion

We used accumulated values of sea ice concentration and sea ice volume instead of mean or maximum values in order to give a good representation of ice winter strength. Mean values are dependent on the number of days, but the length of the season and time of beginning and end of the ice season can be highly variable in the Baltic Sea, particularly in the southern areas. Furthermore, ice is not necessarily present all over the winter but rather may appear and disappear frequently. Hence, mean values would only make sense if we had chosen a fixed interval for the winter period, e.g. October to June, regardless when ice occurs in this time. This would have made numbers very small in regions where ice occurs only for few days within these nine months. We instead considered only the period in which ice was present. Doing so, comparing mean values is not suitable as it might happen that there is thick ice with high concentration for only a few days in the season in a certain region, which's average over the ice covered time could be as high or even higher than the average value in another region where ice was present all over the winter. Similar problems arise if using just the length of the season, the number of days, maximum concentration, etc.

Giving an error estimate for the ice data is difficult (Feistel et al., 2008). Projections, scales and requirements on the ice charts from which the sea ice data originates from have changed over time. The data used to draw the maps also changed. In former days, charts were based on in situ observations from the coast and reconnaissance flights with planes. Today, less in situ data but information from various satellite data is used.

Another delimiting factor for data accuracy is the fact that mostly discrete intervals are given in ice charts rather than absolute values. That means, ice concentration is subdivided in six categories from open water (<10 %) over very open ice (10–30 %) to very close ice (>90 %) and fast ice (100 %). The higher the ice concentration is the smaller the intervals are chosen. The same applies for sea ice thickness.

In addition to the inaccuracies of the data themselves, we have also found some inconsistencies in data samplings near the coast. This occurs particularly in the southern areas, e.g. in the Vistula Lagoon, where ship traffic was not important enough to consider ice situation in these narrow and shallow waters in the older ice charts but are included in the newer charts, which results in a positive trend in ice conditions. Fig. 6 shows an example for the temporal evolution of ice in the Vistula Lagoon, where positive trends in both ASIC and ASIV were found, and for the grid cell at the Finnish coast near Kaskinen, where ASIC has increased but ASIV has decreased.

For the Vistula Lagoon, it is clearly visible that the positive trend in ASIV is caused by some few low values in the beginning of the period and some few higher values at the end, with nearly no data in between. We found the same circumstances for the other grid cells showing an increase in ASIV. For the grid cell near Kaskinen, on the other hand, data coverage has been consistent over the 30 year period and the positive trend in ASIC may be a true signal.

In some regions, SSTs reveal a negative trend, which was also found by, e.g., Bradtke et al. (2010), who argued that the decade 1996 to 2005 shows annual minimum SSTs lower than those in the decade 1986 to 1995. Also Siegel et al. (2006) reported slight negative trends in SST for February and March. A weaker response of SST to the increasing T_{air} in winter can be explained by oceanographic changes (see Bradtke et al., 2010; Meier, 2006), but it is much harder to explain a negative SST trend if at the same time T_{air} is increasing and sea ice is decreasing (as SST is set to −1 °C if ice is present). It might be that the effect only arises from uncertainties of the trend statistics or because the SST data may be still influenced a bit by the sea ice signals, as the structure in the trends resemble the mean sea ice distribution.

The local atmospheric forcing relevant for the total volume of sea ice in a winter also depends on the larger scale atmospheric patterns. The dominant patterns of atmospheric circulation over the north Atlantic and the north European area are the North Atlantic Oscillation (NOA, Jones et al., 1997), the Arctic Oscillation (AO, from the National Weather Service Climate Prediction Center: https://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/ao.shtml) as well as the Scandinavian pattern (SCAND, from https://www.cpc.ncep.noaa.gov/data/teledoc/scand.shtml). High values of the NAO Index, with increasing westerly winds, bring warmer air into the Baltic region. Therefore a negative correlation with the ice volume is expected. As we look at the cumulative ice volume sum, we are using the sum of the NAO index from January to March and to correlate it with the ASIV. As can be seen in Fig. 7, the correlation value varies across the region and reaches maximum absolute values above 0.6, but the mean correlation value is −0.40. So, the correlation is not very strong, but at least of the right sign. Correlation with the Arctic Oscillation gives a similar picture (not shown), with an only slightly lower mean correlation value (−0.36). The mean absolute value of the correlation with SCAND is lower (0.31) but is stronger than with the NAO in the Bay of Bothnia.

All three indices show a decreasing trend in the time span used. Considering the negative correlation of NAO and AO with the ice volume sum, this would imply an increasing ice volume over time whereas we observe a decrease in ASIV in most areas. The SCAND trend does not contradict the ASIV trend, so that the long-term ASIV trend is probably better related to the more regional SCAND atmospheric pattern than to the larger scale NAO and AO patterns.

6 Summary and conclusions

In this study we showed for the first time the regional distribution of accumulated sea ice concentration and sea ice volume in the Baltic Sea and their trends from 1982 to 2019. Both sea ice parameters have been compared to changes in SST and T_{air} for the 30 year period 1982–2011. The conclusion can be summarized as follows:

As expected, the highest mean ASIC and ASIV occur in the northernmost regions and decreases towards the central, southern and western Baltic Sea.

Most regions show a decrease in both ASIC and ASIV, which generally compares well with the positive trends in SST and T_{air}. However, both are not the only drivers of sea ice changes, as locally low correlation coefficients indicate. But changes in the atmospheric patterns described by NOA, AO and SCAND could also not better explain the observed changes in ASIV.

Some few regions reveal a negative trend in SST which is not reflected in the sea ice data. In these regions, also the correlation between detrended SST and ASIC/ASIV is low or even positive. The reason for this is still unknown and could also be the result from statistical errors. This has to be considered in more detailed investigations in the future.

The positive trends in most ASIC and all ASIV grid cells are found to be unrealistic. They are mainly caused by a low data record in the early years of the data set, where unfortunately also low concentrations and thicknesses were observed. All these data points are close to the coast, in areas where ship traffic was certainly not important enough to include ice information in the handmade historical ice charts, which is expected to be the reason for this inconsistent data distribution.

The regional distribution of accumulated sea ice concentration and sea ice volume in the Baltic Sea will be updated after each ice winter. For a geographical better resolved product, the ice charts after 2006 can easily be analyzed with higher spatial resolution. Older ice

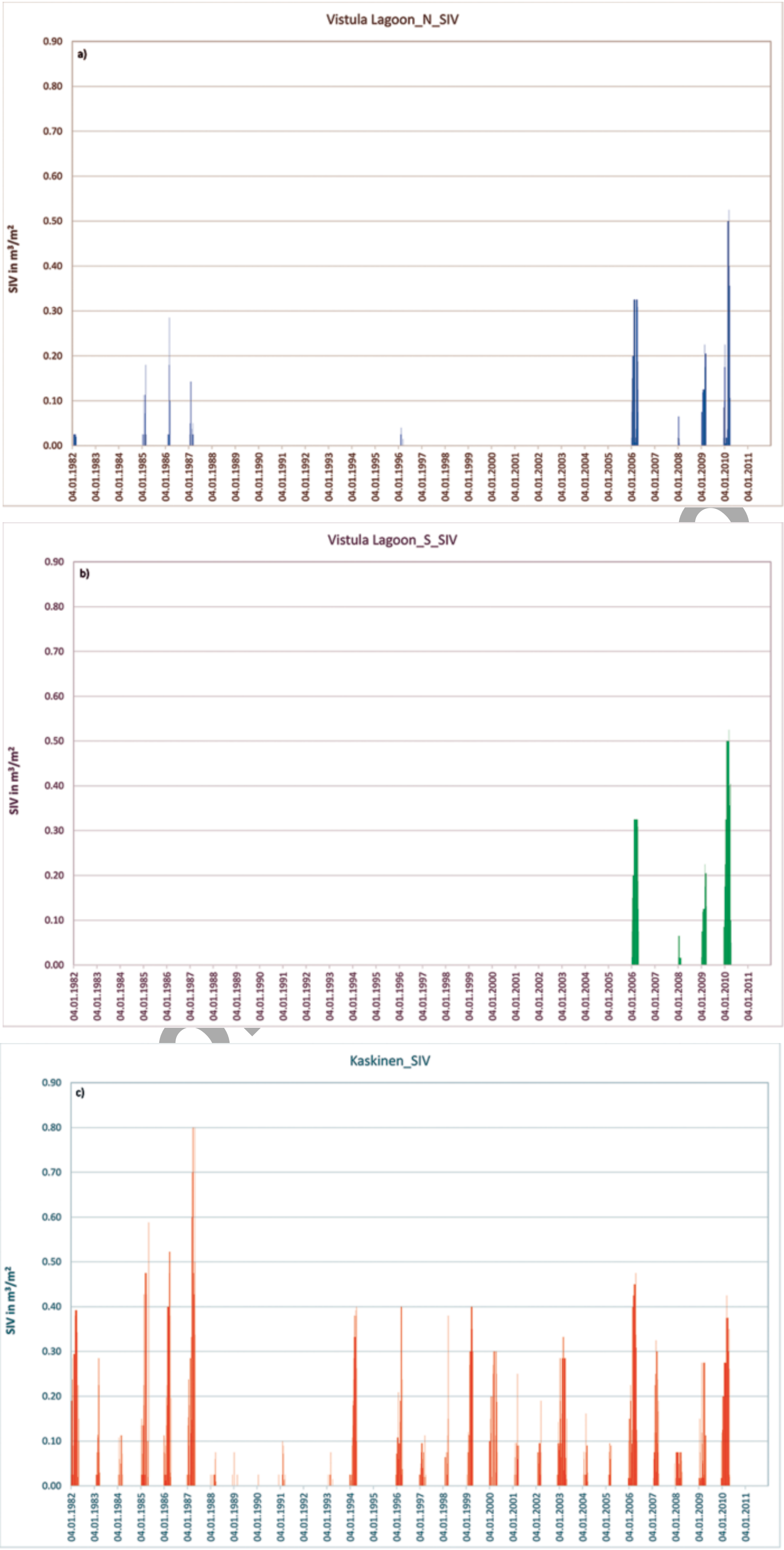

Figure 6: Sea ice volume variability in the Vistula Lagoon (a, b) and near Kaskinen (c). While in Kaskinen sea ice concentration and sea ice thickness was sampled frequently, in the Vistula Lagoon data occur only sporadically in the data set. This is why the observed increase in ASIV in the Vistula Lagoon is unrealistic.

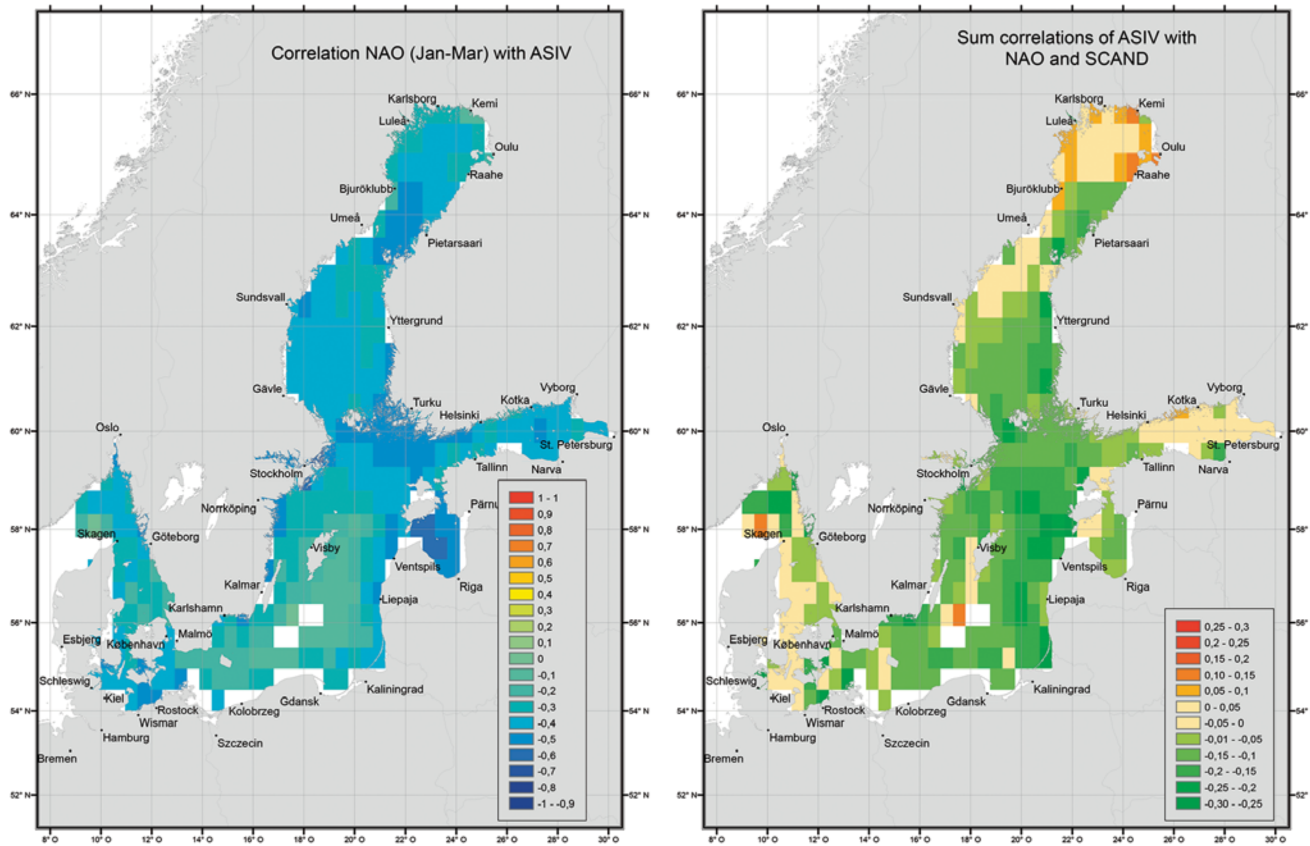

Figure 7: Correlation between total winter ASIV and the Northern Atlantic Oscillation Index (January to March sum, left) for the observation period 1982–2019. Positive NAO indices come together with increased westerly winds and a transport of warm air masses into the Baltic Sea, which would result in less sea ice volume. Hence, a negative correlation (blue) is expected. On the right hand side the sum of the correlations of ASIV with NAO and SCAND are depicted; with positive values, the correlation with SCAND is better than with NAO, and with negative values vice versa.

charts are still available in analog form, but a better-resolved digitization would be very tedious. Operational sea ice charts of the Baltic are also issued daily from the Swedish and Finnish ice services, but still not available in digital form for such a long time. Once available also the temporal resolution could be improved.

Acknowledgments

NCEP Reanalysis data were provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at https://www.esrl.noaa.gov/psd/. The AO and SCAND indexes were provided by the Climate prediction center at https://www.cpc.ncep.noaa.gov. Sea surface temperature data were provided by the Copernicus Marine environment monitoring service (CMEMS). We would like to thank numerous ice observers who have collected ice information and forced a big improvement of the ice product. We would also like to thank for the reviewer's valuable comments.

Abbreviation list

AO	Arctic Oscillation
ASIC	accumulated sea ice concentration
ASIV	accumulated sea ice volume
AVHRR	Advanced Very High Resolution Radar
BSH	Bundesamt für Seeschifffahrt und Hydrographie
CMEMS	Copernicus Marine environment monitoring service
ERS	European Remote Sensing
NAO	North Atlantic Oscillation
NCEP/NCAR	National Center for Environmental Predictions/National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
SCAND	Scandinavian Pattern
SMHI	Swedish Meteorological and Hydrological Institute
SST	Sea Surface Temperature
T_{air}	2-m air temperature

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