3.B.iii Sea ice

Lead author : Jari Haapala (Finnish Meteorological Institute, Helsinki, Finland)

Contributing authors :

Iina Ronkainen (University of Helsinki, Finland)

An importance of understanding variability and changes of sea ice has recognized more than a century. The regular observational network was established in late 19th century among the Baltic Sea countries to provide mainly guidance for a shipping, but later the collected data resulted for an scientific analysis of ice conditions (Speerschneider, 1927; Jurva, 1938; Palosuo, 1953) and since then the Baltic Sea ice climatology has received much attention. The recent reviews by BACC, 2008, Schmeltzer et al, 2008 and Vihma and Haapala, 2009 provide an extensive summaries of the existing publications and thus this chapter is an update of those reviews and don't repeat the extensive discussions already published.

State of sea ice depends on the surface energy balance, momentum flux and water flux. Some of the climate related state variables, like ice extent or freezing date are mainly driven by the energy balance and observed variability of those variables are very closely reflecting large scale air temperature variability. However, many variables, like ice thickness, ice types and duration of ice covered period are also very dependent on winds and ocean currents and may reflect changes occurring in local scale, addressing an importance of unified analysis of several ice parameters for quantifying sea ice changes in climate scales. An alternative approach for analysis of directly measured geophysical parametersss is to use particular “Sea ice index” for an general indicator of ice conditions (Koslowski and Glaser, 1995; Sztobryn et al, 2009). In the Baltic Sea, all these variables display large inter-annuall variability and are very closely related to the variability of the large scale atmospheric circulation (Omstedt and Cheng, 2001; Vihma and Haapala, 2009).

The recent years highlight a magnitude of inter-annual variability of ice conditions in the Baltic. The winters 2008 and 2009 were very mild, sea ice was formed only in the Bay of Bothnia and coastal areas of Bothnia Sea and Gulf of Finland. The maximum ice extent was only 49 000 km^2 and 110 000 km^2 on 2008 and 2009, respectively. On a contrary, the winters 2010 and 2011 are classified to be severe ice winters, the extent was 244 000 km^2 and 309 000 km^2. More importantly, the ice was thick and severe storms induced pack ice compression events caused major hindrance for a winter navigation. In the past, similar relative short periods covering both extremes of ice seasons has been also been occurred (1873-1876, 1938-1941, 1985-1990).

The BACC (2008) concluded that a climate warming can be detected from the time series of MIB and the length of the ice season. That conclusion was based on the publications utilizing the observations extending only until year 2000. The present review is is very much based on Ronkainen et al. (2012) work who conducted an up to date analysis where the observations until 2011 were taken account, but analysis was limited to the three stations at the Northern Baltic Sea and maximum ice extent time series.

1. Ice extent

The annual maximum ice extent of the Baltic Sea (MIB) is the most widely used indicator of the sea ice changes because it integrates winter period weather over the entire basin, it has been rather accurately observed since the last 100 year, but also it can be reconstructed since 1720 (Jurva, 1937, Palosuo, 1953, Seinä and Palosuo, 1996). The MIB displays large year-to-year natural variability variability due to the large scale atmospheric circulation variability, commonly described by the North-Atlantic Oscillation (NAO). Vihma and Haapala (2009) showed that that during the positive NAO stages (NAO > 0.5) the mean MIB is 121,000 km^2, with a range from 45,000 to 337,000 km^2, while during negative NAO stages (NAO < 0.5) , the average MIB is 259,000 km^2, with a range from 150,000 to 405,000 km^2 (Figure 3.B.iii.1)

All the previous studies have reported significant decreasing trend in MIB (BACC, 2008, Vihma and Haapala,2009). Including observations until 2011 into considerations, the trend of MIB during the last 100 years is - 34 000 km^2/100 years. An other apparent change is that an occurrence of severe winters has decreased during the last 20 years. The figure 3.B.iii.2 shows that the modal probability of the MIB has remained same regardless the period considered is the last 100, 30 or 20 years, but mild ice season has become more common and the years when the Baltic is nearly completely ice covered hasn't been occurred any more.

2. Length of the ice season

The most extensive analysis of ice season changes has been compiled by Jevrejeva et al. (2004) who used time series at 37 coastal stations around the Baltic Sea. In general, the observations showed a tendency towards milder ice conditions. Among variables studied, the largest change has occurred in the length of the ice season, which has decreased by 14–44 days in a century, and it is mostly due to the earlier ice break-up.

According to the Northern Baltic Sea coastal stations observations, trend to to shorter ice covered period is confirmed (Figure 3.B.iii.3 and Table 3.B.iii.1). In the Bay of Bothnia (Kemi), where the ice season is self evidently longest, the trend is -18 days/ 100 years. In the Eastern Gulf of Finland, where sea ice is also formed every winter, larger changes have been observed. The length of ice season has decreased 41 days/100 years, the trend based on the last 50 observations is -62 days/100 years.

3. Ice thickness

For a climate studies, the sea ice thickness or more desirable the large scale sea ice thickness distribution should be the main indicator of sea ice changes since it is essentially same as the mass of the ice pack. However, interpretations of causes of the ice thickness changes aren't straightforward since in addition to the atmosphere-ocean energy balance, the sea ice thickness depends also on the snow thickness and ice dynamics.

The monitoring activity in the Baltic is limited on the land-fast ice regions, where the sea ice could be thinner than in the drift ice regions. According to the Jevrejeva et al. (2004) the ice thickness time series around the Baltic Sea coast don't obey any consistent trends, both decreasing and increasing trends was reported. Recent study by Ronkainen et al. (2012) is support those conclusions. In the Bay of Bothnia, station Kemi, the ice thickness display slight increasing trend (+9 cm/100 a) while in the Gulf of Finland thinning trend is observed (- 25 cm/100 a).

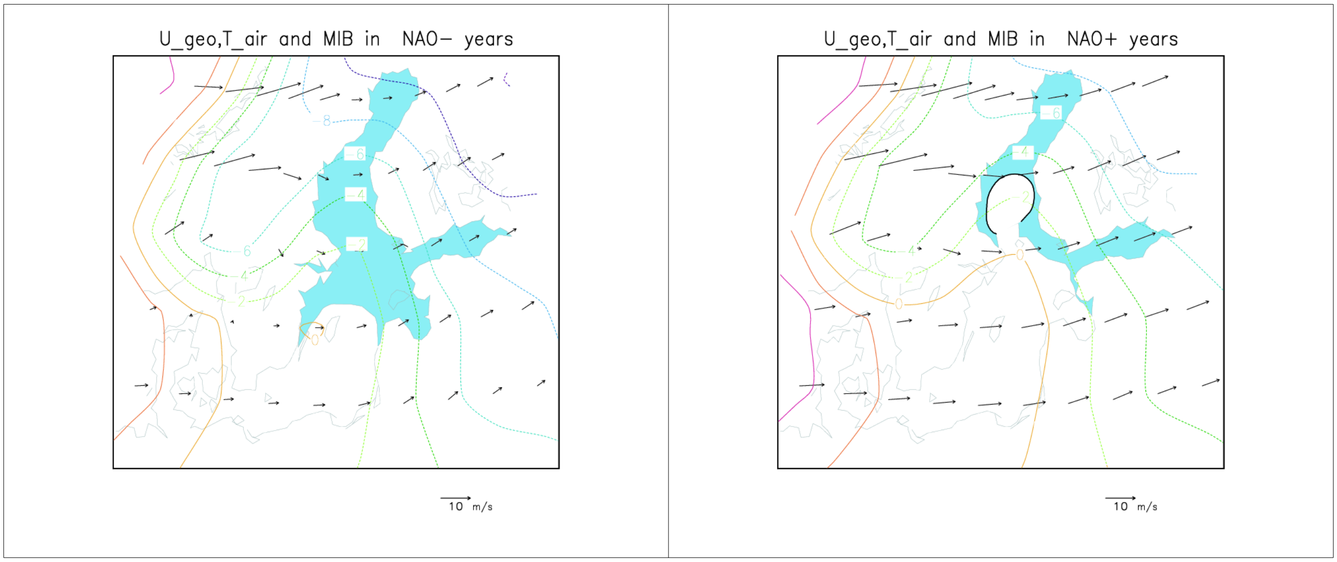

Figure 3.B.iii.1. Mean annual maximum ice extent , 2-m air temperature and 10-m wind vector over the Baltic Sea region during the negative and positive stage of the North-Atlantic Oscillation (Redraw from Vihma and Haapala, 2009).

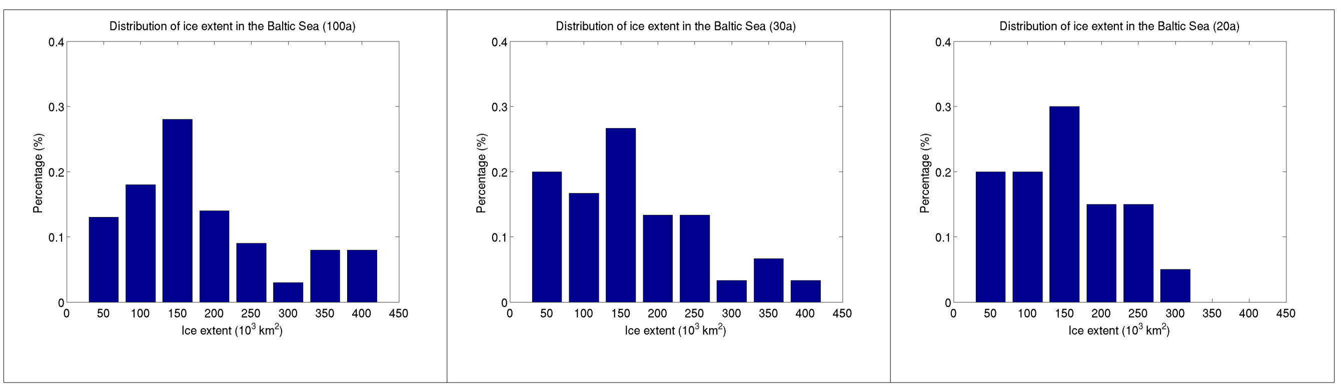

Figure 3.B.iii.2. Probability distributions of maximum ice extent during years 1911-2011, 1981-2011 and 1991-2011.

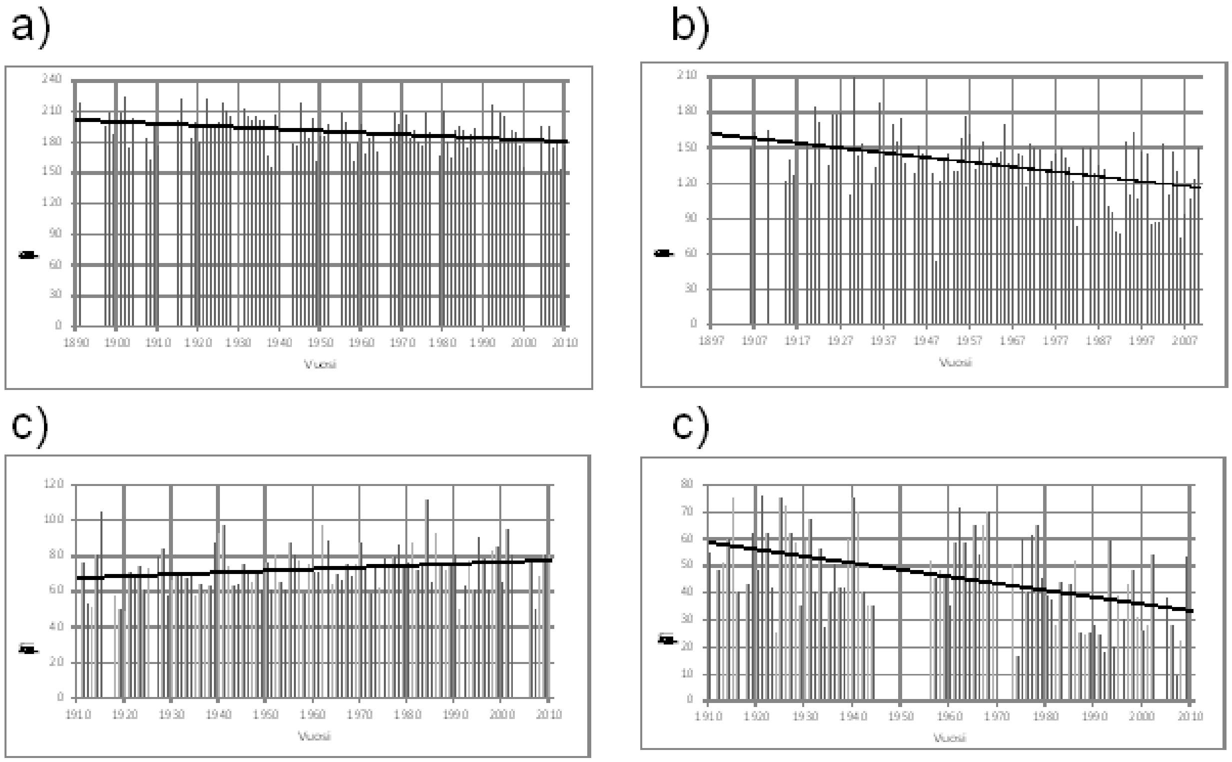

Figure 3.B.iii.3. Observed changes in a) length of ice season in Kemi, b) Loviisa, c) ice thickness in Kemi and d) in Loviisa.

Table 3.B.iii. Statistics of the freezing date, break-up date, length of ice season and ice thickness at Kemi (1890-2010), Utö (1889-2010) and Loviisa (1894-2010), (Ronkainen et al, 2012).

		Kemi	**Utö**	**Loviisa**
	probability of ice appearance	1,00	0,81	1,00
	trend/100 a	0	–0,19	0
Freezing date	number of observations	112	97	106
	mean	10.11.	(27.1.)	7.12.
	trend (d/100 a)	7	(24)	20
	trend –1950 (d/100 a)	12	(65)	25
	trend 1950– (d/100 a)	0	(–15)	24
Break-up date	Number of observations	113	97	105
	trend (d/100 a)	–11	(–16)	–20
	trend –1950 (d/100 a)	–5	(–1)	–8
	trend 1950– (d/100 a)	–17	(–34)	–38
Length of ice	number of observations	113	121	102

season				
	mean (d)	190	50	137
	trend (d/100 a)	–18	–46	–41
	trend –1950 (d/100 a)	–17	–84	–32
	trend 1950– (d/100a)	–16	–36	–62
Ice thickness	number of observations	94		81
	mean (cm)	73		46
	trend (cm/100 a)	9		–25
	trend –1950 (cm/100 a)	13		–29
	trend 1950– (cm/100a)	4		–52

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