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3. Climate change during the last 200 years

Anna Rutgersson, **Uppsala University, Uppsala, Sweden**

3.2 Atmosphere

Anna Rutgersson, Uppsala University, Sweden
Jaak Jaagus, University of Tartu, Estonia
Frederik Schenk, Helmholtz-Zentrum Geesthacht, Germany
Martin Stendel, DMI,Denmark

Lars Bärring, SMHI, Sweden
Agrita Briede, University of Latvia, Latvia
Björn Claremar, Uppsala University, Sweden
Inger Hanssen-Bauer, Norwegian Meteorological Institute, Norway
Jari Holopainen, University of Helsinki, Dept. of Geosciences and Geography, Helsinki, Finland
Anders Moberg, Stockholm University, Sweden
Øyvind Nordli, Norwegian Meteorological Institute, Oslo, Norway
Egidijus Rimkus, Vilnius University, Lithuania
Joanna Wibig University of Lodz, Poland

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3.3 Land

3.3.1 Hydrology

Jukka Käyhkö, University of Turku, Finland

Elga Apsite, University of Latvia, Latvia
Anna Bolek, Institute of Meteorology and Water Management, Warsaw
Nikolai Filatov, Northern Water Problems Institute KRC RAS, Russia
Sergey Kondratyev, Institute of Limnology RAS, Russia
Johanna Korhonen, Finnish Environment Institute, Helsinki
Jurate Kriauciuniene, Lithuanian Energy Institute, Lithuania
Göran Lindström, SMHI, Sweden
Anna Pyrh, Estonian Meteorological and Hydrological Institute, Estonia
Marzenna Sztobryn, Institute of Meteorology and Water Management, Poland

3.3.4 Terrestrial cryosphere

Sirpa Rasmus, Finnish Game and Fisheries Res. Institute, Finland

Jan Boelhouwers, Uppsala University, Sweden
Agrita Briede, University of Latvia, Latvia
Ian Brown, University of Stockholm, Sweden
Malgorzata Falarz,University of Silesia, Poland
Susanne Ingvander, University of Stockholm, Sweden
Jaak Jaagus, University of Tartu, Estonia
Lev Kitaev, Institute of Geography RAS, Russia
Andrew Mercer, University of Stockholm, Sweden
Egidijus Rimkus, Vilnius University, Lithuania

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3.4 Baltic Sea

3.4.1 Marine circ. and stratification

Jüri Elken, Tallinn University of Technology, Estonia
Andreas Lehmann, GEOMAR Helmholtz Centre for Ocean Research, Germany
Kai Myrberg, Finnish Environment Institute (SYKE), Finland

3.4.2 Sea ice

Jari Haapala, Finnish Meteorological Institute, Finland
Iina Ronkainen, University of Helsinki, Finland)
Natalija Schmeltzer, Bundesamt für Seeschifffahrt und Hydrographie, Germany
Marzenna Sztobryn, Instytut Meteorologii i Gospodarki Wodnej, Poland

3.4.3 Sea level and wind waves

Birgit Hünicke, Helmholtz-Zentrum Geesthacht, Germany
Tarmo Soomere Tallinn University of Technology, Estonia
Kristine Skovgaard Madsen, Danish Meteorological Institute, Denmark
Milla Johansson, Finnish Meteorological Institute, Finland
Ülo Suursaar University of Tartu, Estonia
Eduardo Zorita Helmholtz-Zentrum Geesthacht, Germany

Summary

- In general the conclusions from BACC (2008) are confirmed.
  - Important to stress the extremely high inter-annual and inter-decadal variability in most variables.
  - Variability is much higher than long-term trends, trends depend very much on the selected period.
- New results includes:
  - Persistence of weather types has increased.
  - Upwelling analysis
  - Evidence of recent sea water warming (indicated in BACC 2008, now verified).
  - More extensive results for several parameters, in particularly on sea level.
  - Runoff explained by temperature, warmer means less runoff in southern regions and more runoff in northern regions.

Summary

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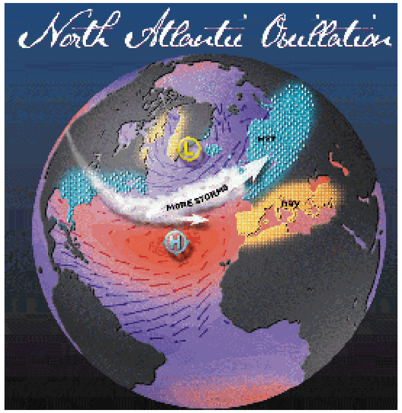
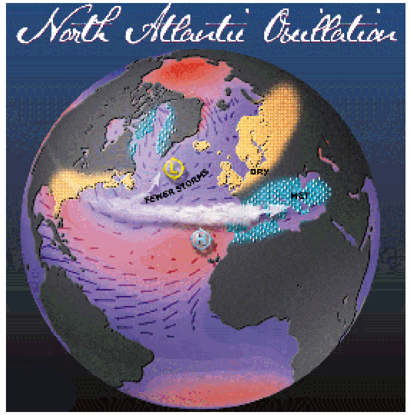
- Disagreements in literature includes:
  - Winter storminess: a significant long-term increase in winter storminess since 1871 is shown by for example Donat et al. (2011). This is suggested by several other studies to be an artefact due to the changes in density of stations over time.
- Missing knowledge:
  - Changes in circulation patterns due to less ice in the Arctic (cold winters, moist summers are suggested).
  - Ground frost properties.
  - Trends in extreme events.
  - Lack of data for some parameters for example clouds and radiation.

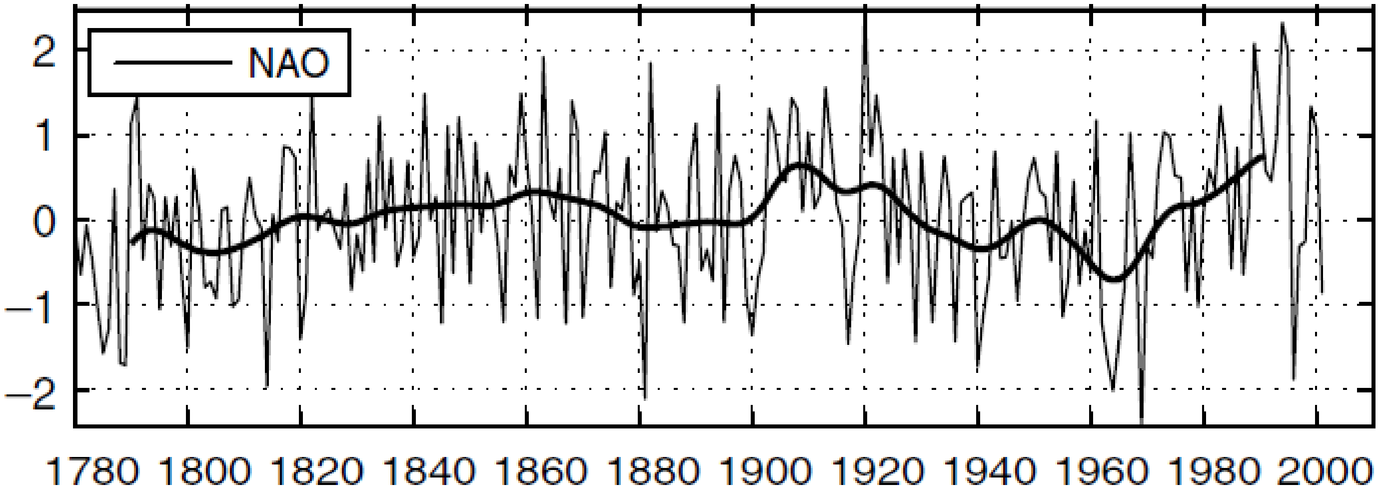
Atmospheric Circulation

The climate of the Baltic Sea region is to a large extent determined by the circulation.

- NAO
  - positive (warm, wet winters)
  - negative (cold, dry winters)







Reconstructed NAO index (Luterbacher et al., 2002). Thick curves are filtered with a Gaussian filter (σ = 4) to focus on interdecadal variations (Bärring and Fortuniak 2009).

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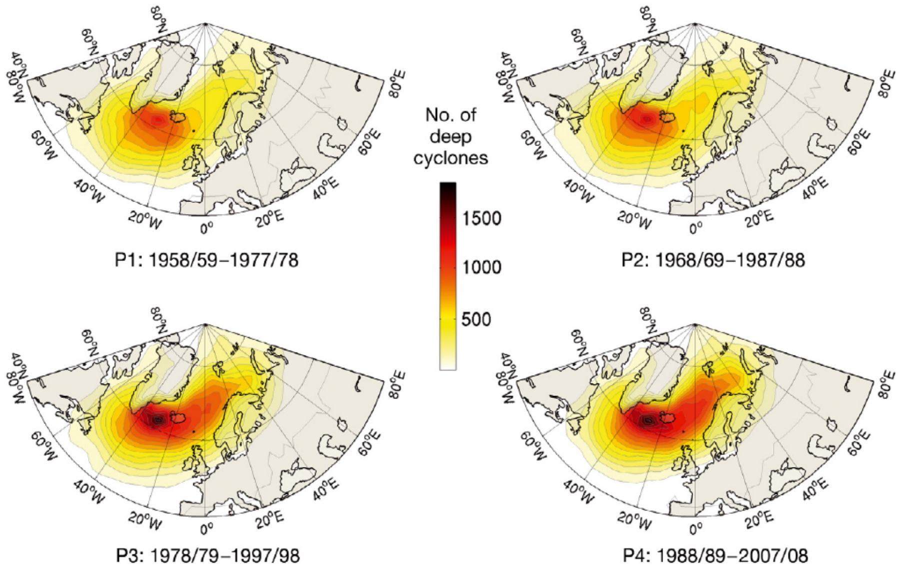
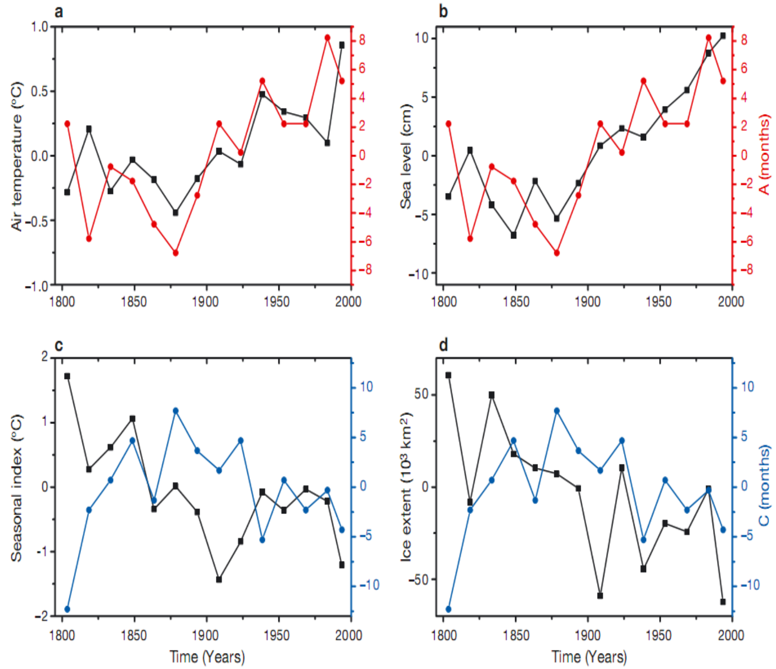
Atmospheric Circulation

- Northward shift of low pressure tracks agrees with increased frequency of anticyclonic circulation.
- Increased frequency of westerlies.
- Increase in number of **deep** cyclones (not total number of cyclones).



Number of deep cyclones counted for four 20-year periods P1 to P4 (December-March) (Lehmann et al., 2011).



Anomalies and circulation types that describe the vorticity of the atmospheric circulation. Red indicates anticyclonic and blue cyclonic circulation. (a) air temperature, (b) sea level, (c) difference between summer (JJA) and winter (DJF) seasonal temperatures, and (d) ice cover, Omstedt et al. (2004).

Atmospheric Circulation

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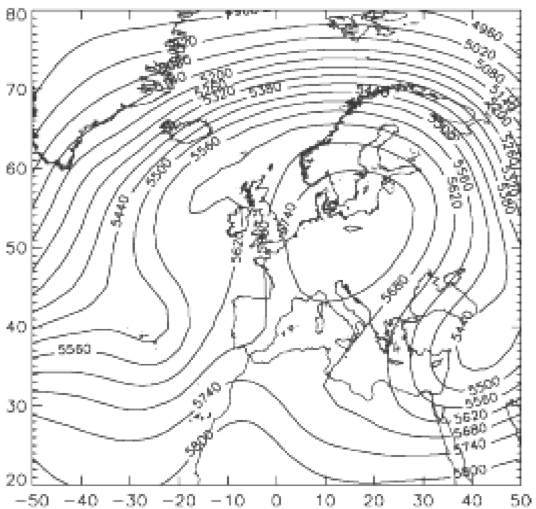
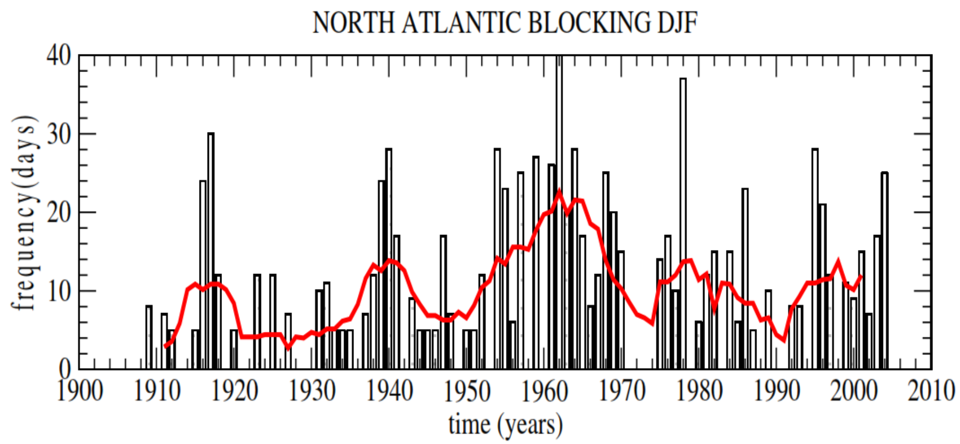
- Blocking situations are quasi-stationary and often related to extreme weather.
  - Winter: warm conditions over southwestern Greenland are related to high blocking activity and a negative phase of the NAO.
  - Summer, however, warm conditions over southwestern Greenland are related to low blocking activity and a positive phase of the NAO.



The 500 hPa height field on March 6, 1948, showing a typical blocking situation. From Barriopedro et al. (2006).



Blocking index (bars) and its decadal variation (seven year running mean; red) for boreal winter (December-February) 1908 to 2005. From Rimbu and Lohmann (2011).

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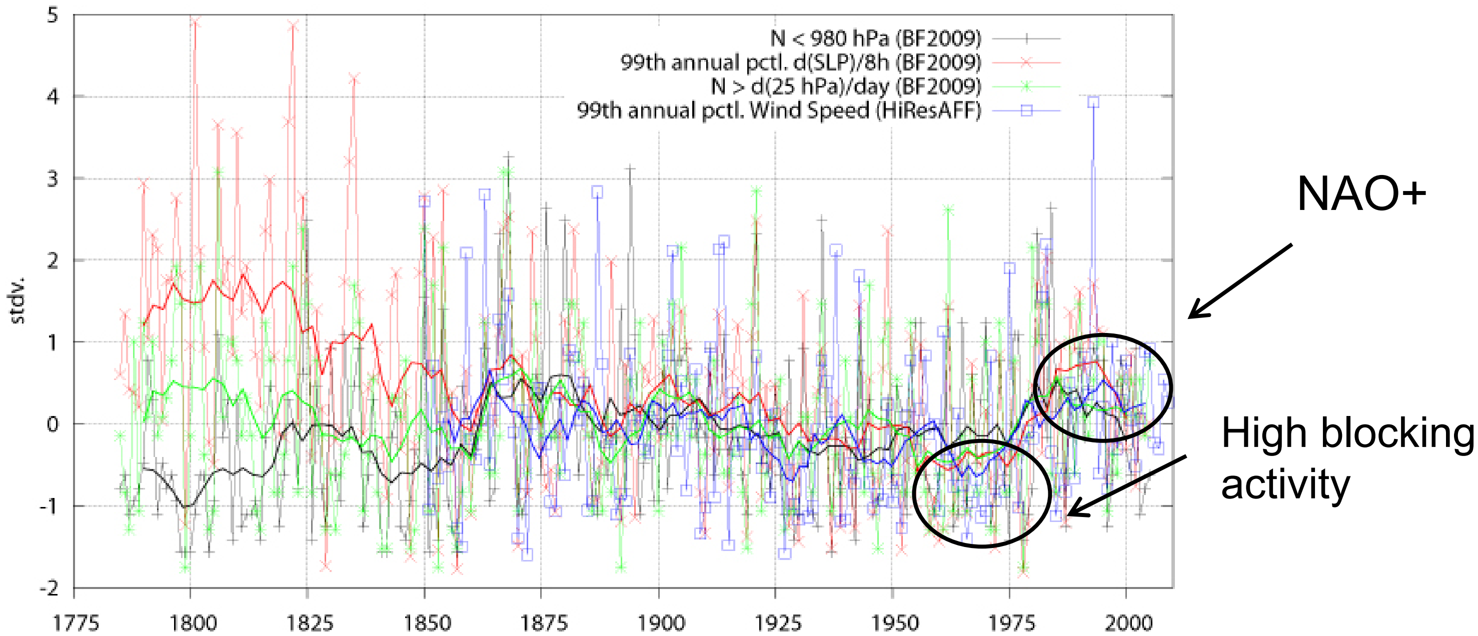
Wind

The wind climate is strongly connected with circulation.

- Wind climate show large decadal variations but **no robust long-term trends** for annual storminess



Storminess indices for Stockholm 1785-2005 (Bärring and Fortuniak 2009), 99th percentile of wind speeds in the vicinity of Stockholm 1850-2009 from HiResAFF (Schenk and Zorita 2011, 2012). Data normalized with respect to the period 1958-2005. Bold lines represent the 11y-running mean to highlight decadal variations.

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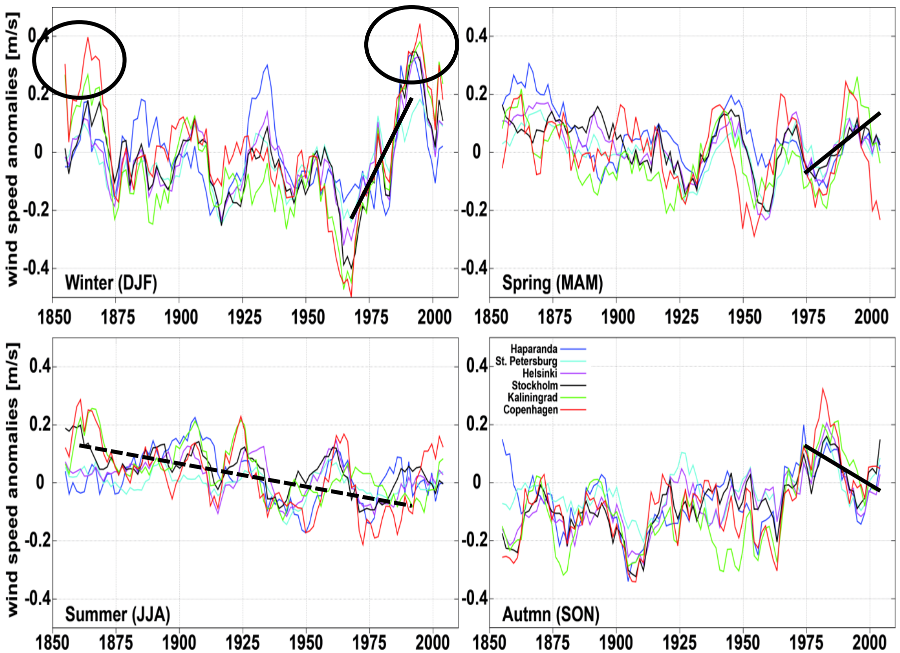
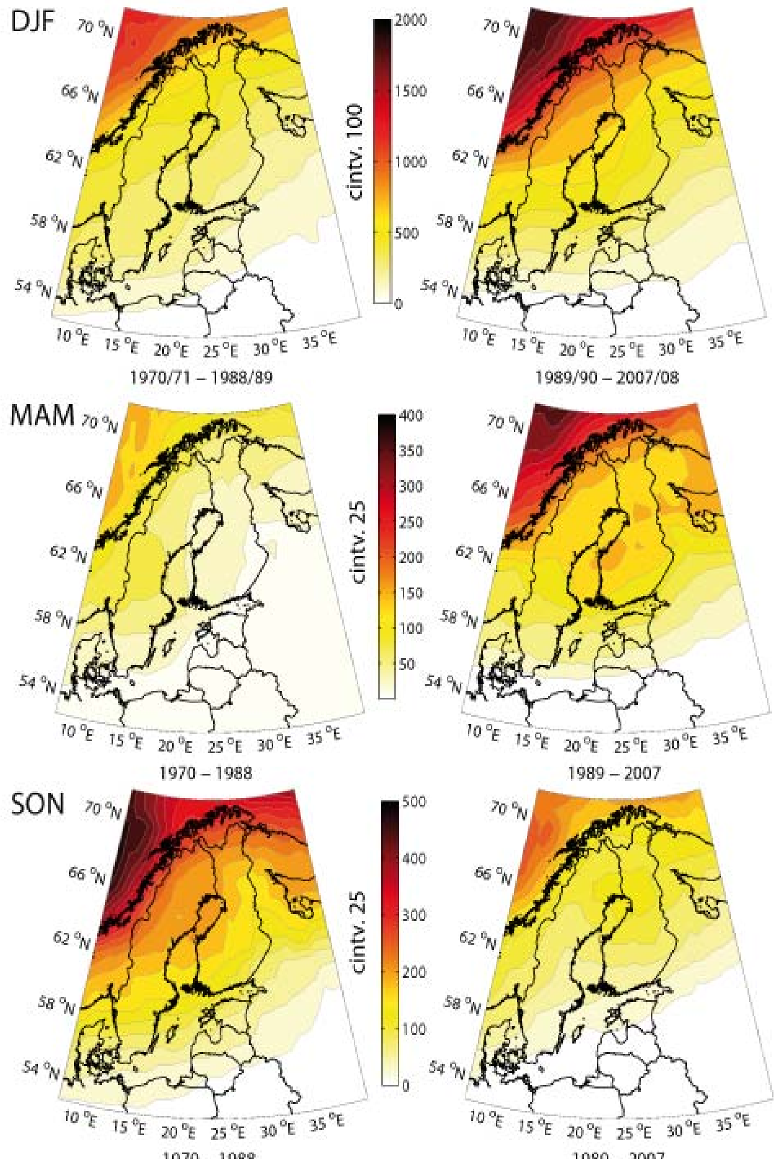
Wind/circulation

Seasonal differences:

- Increase **and northeastward shift** of **deep** cyclones in winter and spring
- Decrease in fall



Sliding decadal (11-y) mean seasonal wind speed anomalies for the Baltic Sea regions for 1850-2009 (Schenk and Zorita, 2011, 2012).



Changes in the number of deep cyclones (core pressure < 980 hPa) between 1970-88 and 1989-2008 over the Baltic Sea region for winter, spring and autumn (Lehmann et al., 2011).

Waves

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No significant changes in the average wave activity of the entire Baltic Sea basin.

- Changes in spatial patterns:
  - Long term variability in areas with large wave intensity, probably caused by systematic changes in wind direction (more from SW than SE).

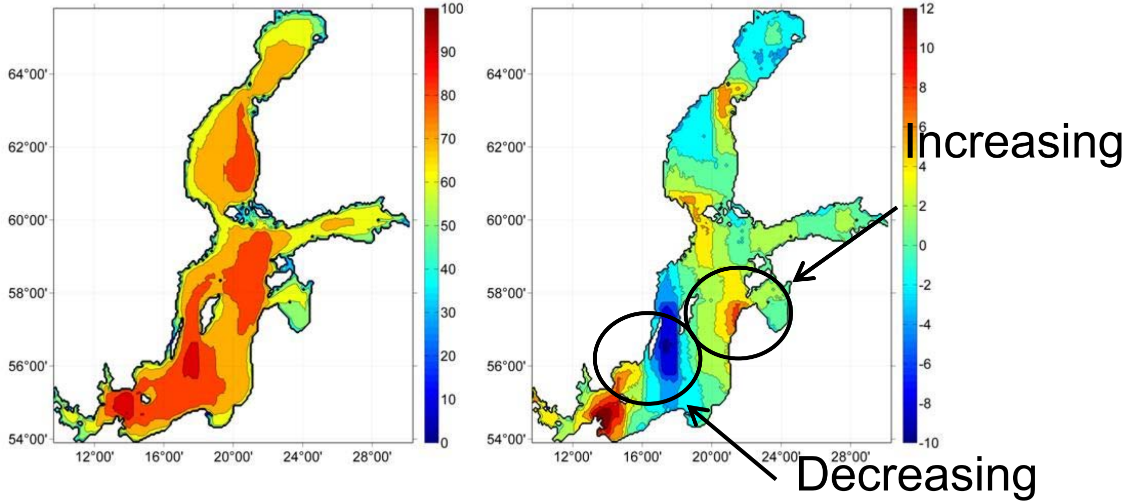

Fig.3.4.3-16 (left) Numerically simulated average significant wave height (colour bar, cm; isolines plotted after each 10 cm) in the Baltic Sea in 1970–2007 (from Räämet and Soomere 2010); (right) Long-term changes in the annual average significant wave height (cm, based on the linear trend, isolines plotted after each 2 cm) for 1970–2007 (from Soomere and Räämet 2011).

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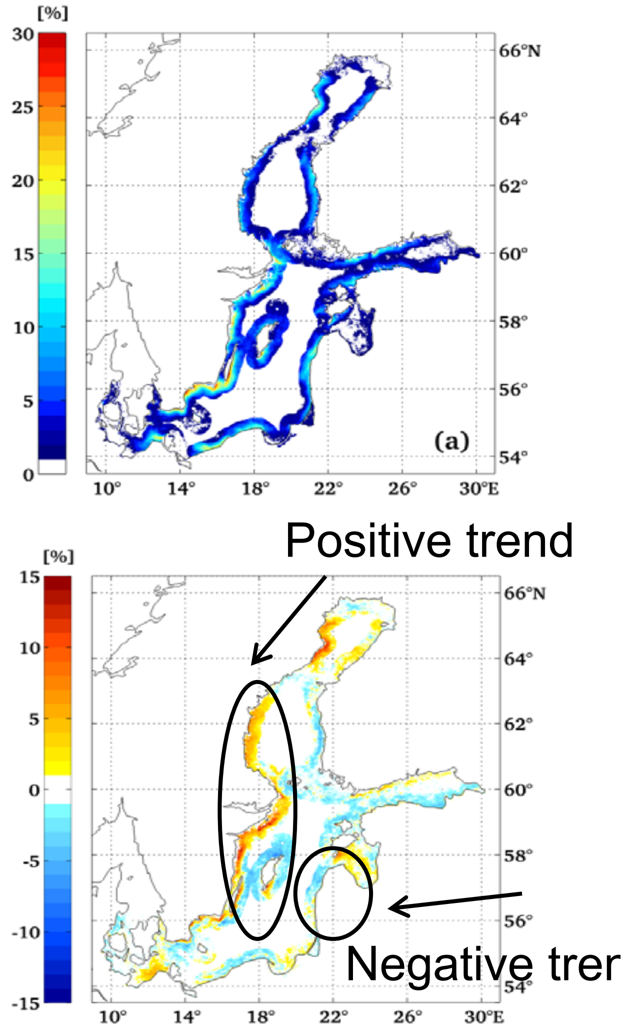
Upwelling

Upwelling occur 5-40% along the coasts

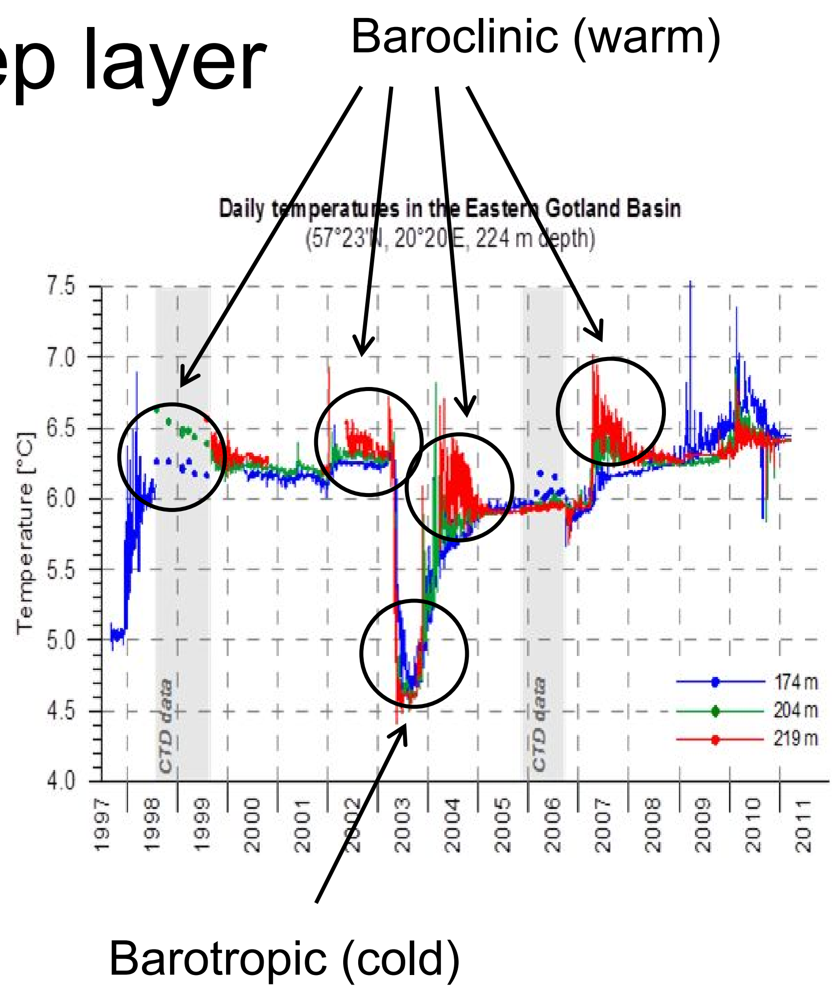
- Most frequent along the swedish coast.
- Positive trend (1990-2009) along the swedish coast.
- Negative trend along the Polish and Estonian coasts.
- Changes are connected to changes in wind direction.
  - there is a positive trend of south-westerly and westerly wind conditions along the Swedish coast and the Finnish coast of the Gulf of Finland favoring upwelling in these regions.
- Trends correspond to changes in SST along the coasts.



Upwelling frequencies [%] obtained from the automatic detection method for upwelling based on 443 SST maps for the period 1990–2009, May-September (left) and trend for upwelling frequencies May-September, 1990–2009 (right; Lehmann et al., 2012).

Ventilation of deep layer

- Freshwater discharge from land and restricted exchange with the North Sea create strong salinity stratification.
- Water exchange with the North Sea is intermittent – major Baltic Inflows carrying large volumes of high saline water occur sporadically.
- An exceptionally long stagnation period 1977 until 1993.
- Recent large inflows in summers of 1997, 2002, 2003 and 2006 were of two-layer (baroclinic) origin that transported high-saline, but warm and low-oxygen water to the deep layers of the Baltic.
- The low temperatures apparent in the figure during 2003 reflect the normal barotropic inflow in winter 2002/2003.



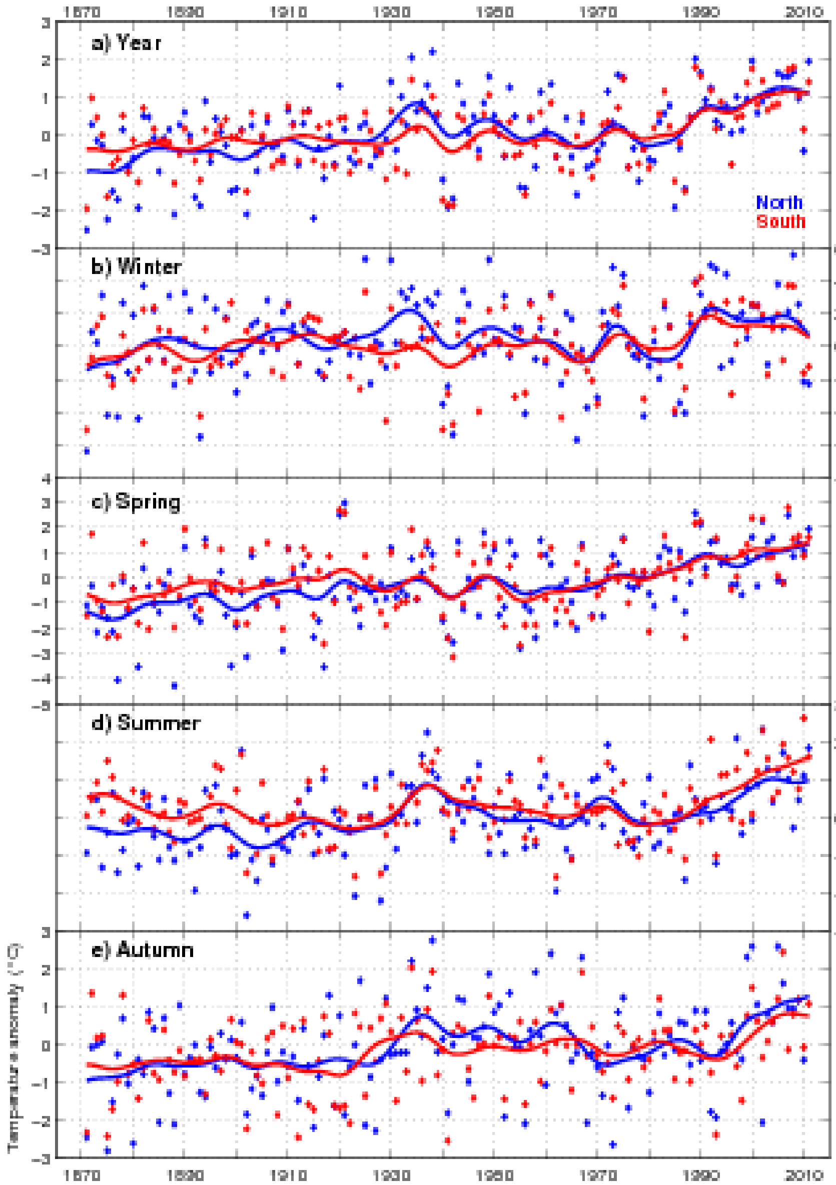
Deep temperature series August 1997– December 2010 of the Eastern Gotland Basin mooring near Gotland Deep at 174, 204 and 219 m depth. From Feistel et al, 2006.

Temperature: Air

The warming of the low level atmosphere is larger in the Baltic Sea regions than the global mean for the corresponding period.

- Warming continued for the last decade
  - Not in winter
  - Largest in spring
  - Largest for northern areas

Data sets	Year	Winter	Spring	Summer	Autumn
Northern area	**0.11**	0.10	**0.15**	**0.08**	**0.10**
Southern area	**0.08**	**0.10**	**0.10**	**0.04**	**0.07**



Annual and seasonal mean surface air temperature anomalies for the Baltic Sea Basin 1871-2011, Blue colour comprises the Baltic Sea basin to the north of 60°N, and red colour to the south of that latitude.

Temperature: Water

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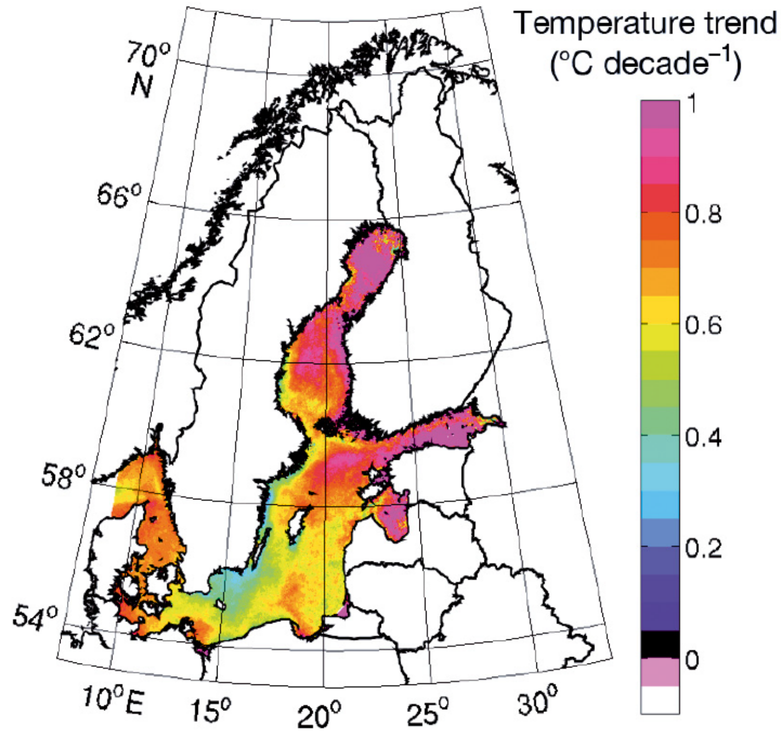
The warming of the water basin is significant during the last decades.

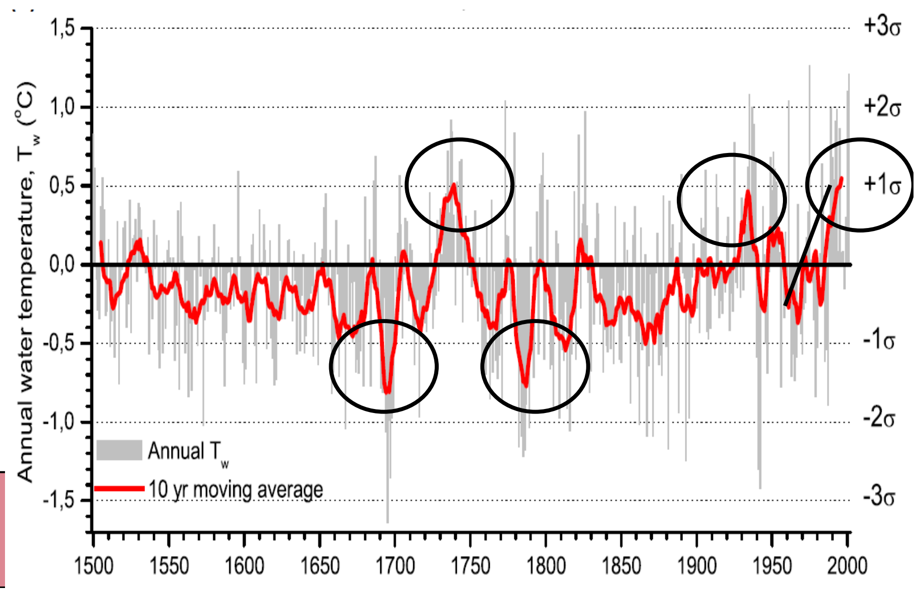
Highest linear trend of in the Bothnian Bay, Gulfs of Finland and Riga and in the Northern Baltic Proper .

Largest warming in August in Bothnian Bay.

Cooling in March.

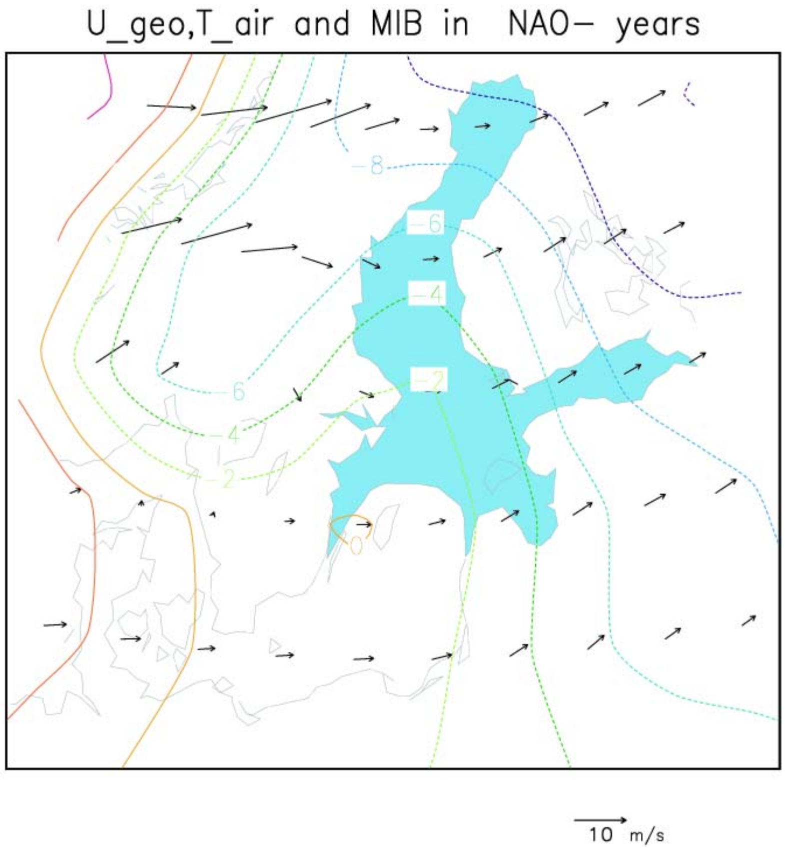
Longer perspective – present strong warming not unique.

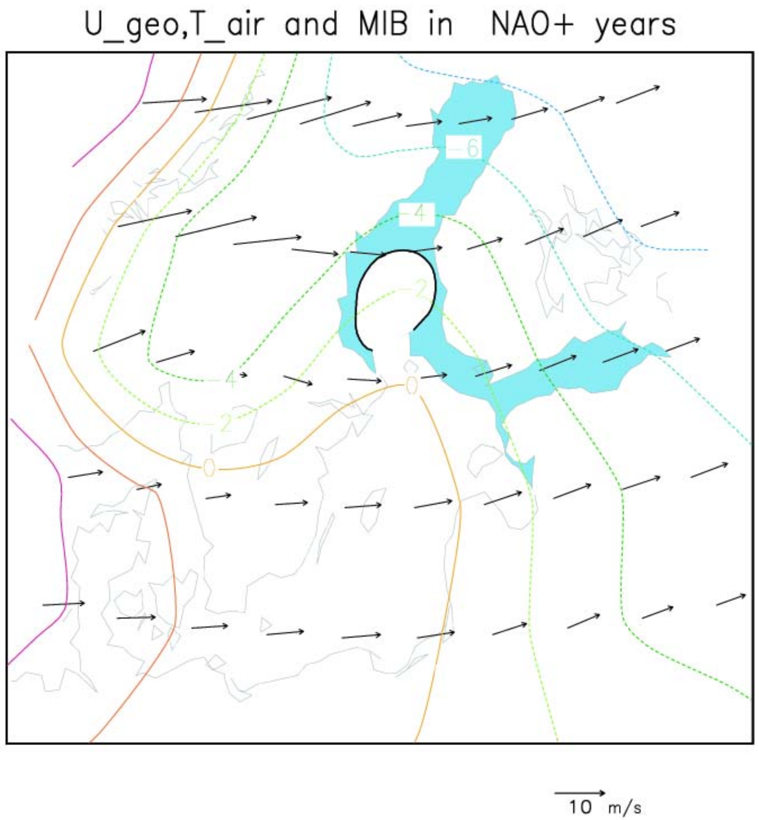




Baltic Sea Ice

Inter-annual variability in sea ice conditions is very largely driven by the large-scale atmospheric circulations. In particular, the winters of strong westerly circulation, i.e. NAO+ years, have manifested as a minimum ice cover in the Baltic Sea.





Vihma and Haapala,2009

NAO > 0.5 : mean MIB : 121,000 km^2, range 45,000 - 337,000 km^2,
NAO < 0.5 : mean MIB : 259,000 km^2, range 150,000 - 405,000 km^2

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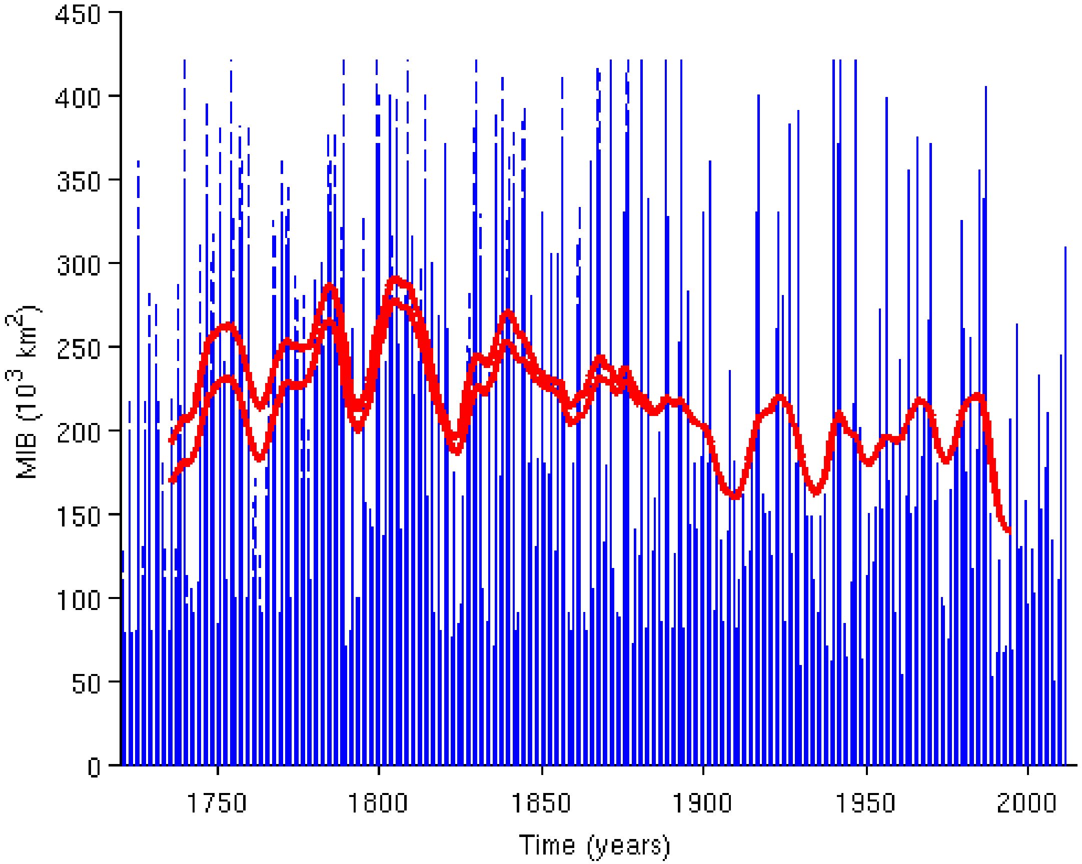
ICE EXTENT



Decreasing trend in annual maximum ice extent of the Baltic Sea (MIB). Trend of MIB during the last 100 years is - 34 000·km^2/100 years or ~ 20 % / 100 years.

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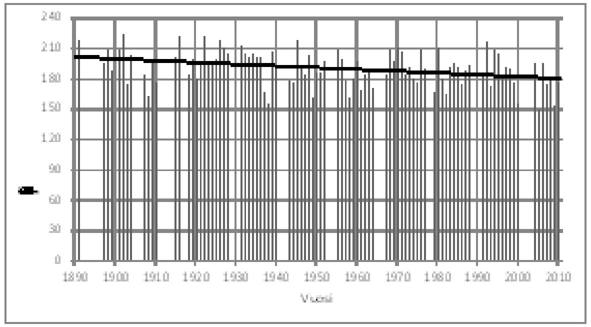
Ice thickness and length of ice season

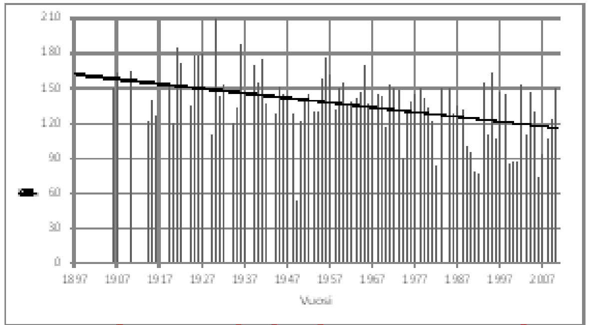
- Length of the ice season has decreased by 14–44 days in a century, mostly due to the earlier ice break-up.

- Ice thickness time series around the Baltic Sea coast don't obey any consistent trends, both decreasing and increasing trends are found.

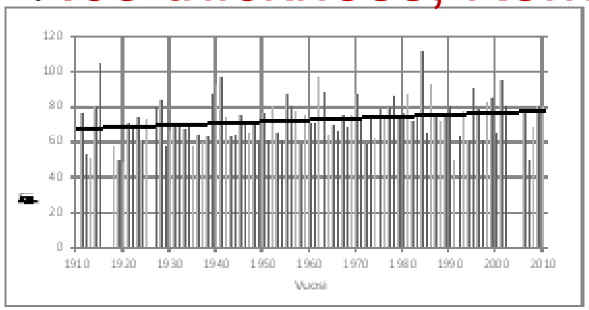
a) Ice season, Kemi



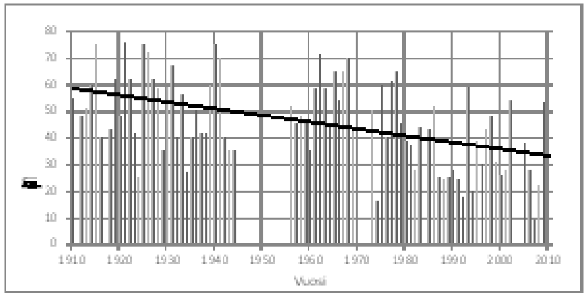
b) Ice season, Loviisa



c) Ice thickness, Kemi



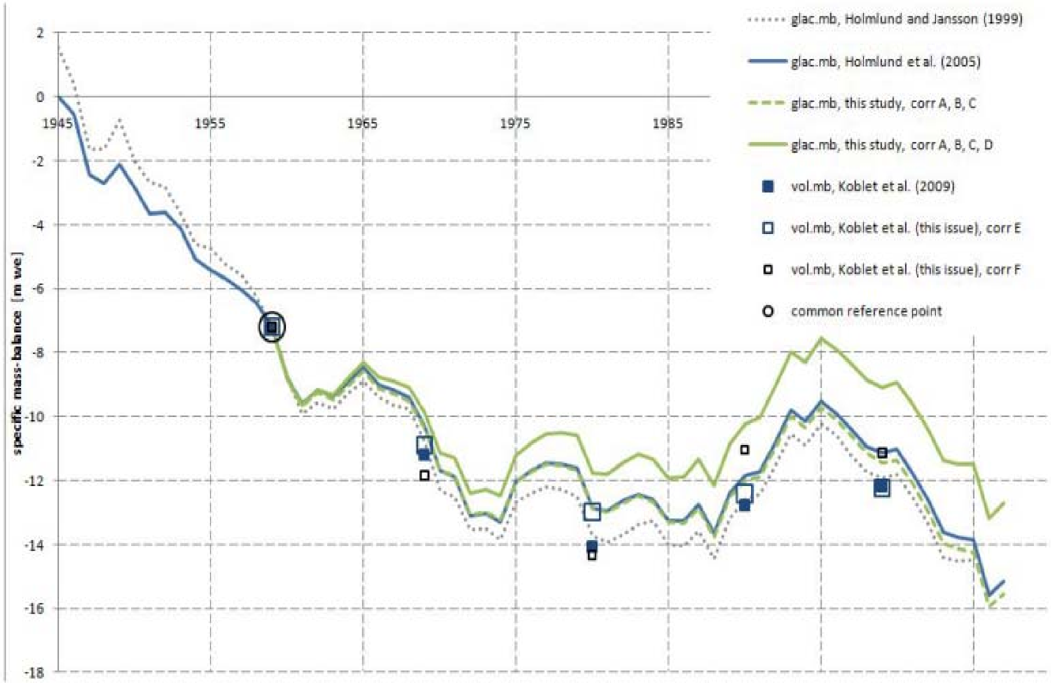
c) Ice thickness, Loviisa



Observed changes in a) length of ice season in Kemi, b) Loviisa, c) ice thickness in Kemi and d) in Loviisa (Ronkainen et al., 2012).

Terrestial cryosphere

In inland Scandinavia, **a cumulative loss in glacier ice thickness** and **decrease in glaciated area** during recent decades has been reported.



Cumulative glaciological and volumetric mass balance series of Storglaciären. Different lines represent different methods and corrections that have been used to estimate the mass balances (from Zemp et al., 2010).

Terrestial cryosphere

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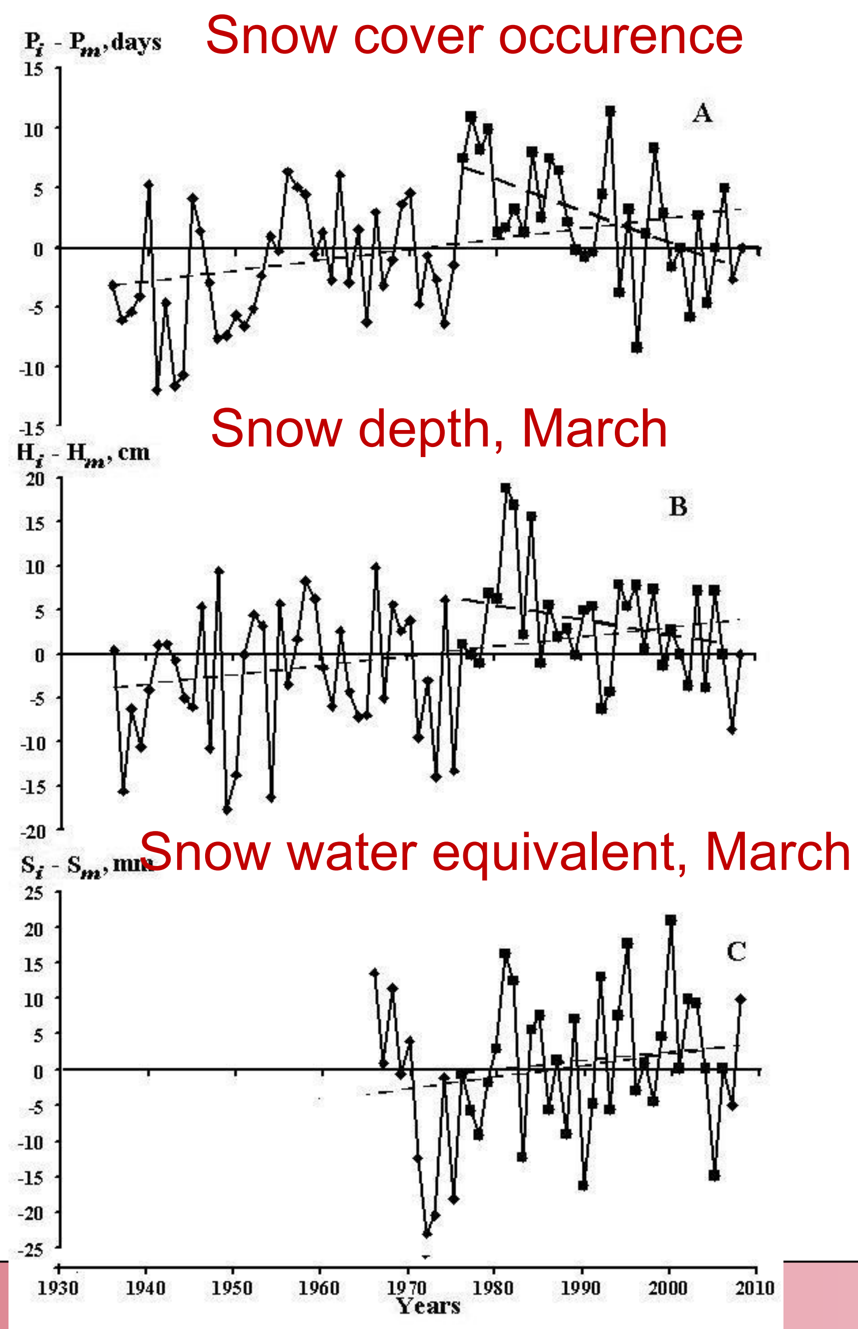
- **Shortening of the annual snow cover period especially during spring**, except in mountainous areas. Most of the negative trends are more pronounced during the last few decades.
- **a general decrease of annual maximum snow amount**
- **Warming trends are observed in soil temperatures, as well as decrease in seasonal frost duration.**
- **northward shift of the southern limit of patchy near-surface permafrost** from European Russia.



Variability of anomalies in Russian part of Baltic Sea drainage basin (Kitaev et al., 2007; 2010).

Precipitation

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Precipitation is much more variable and show less clear patterns than most other parameters, with large inter-annual and large inter-decadal variations.

- No clear long-term trend, some regional exeptions:
  - Summer precipitation increased in Finland
  - Annual precipitation increased in Norway

Precipitation

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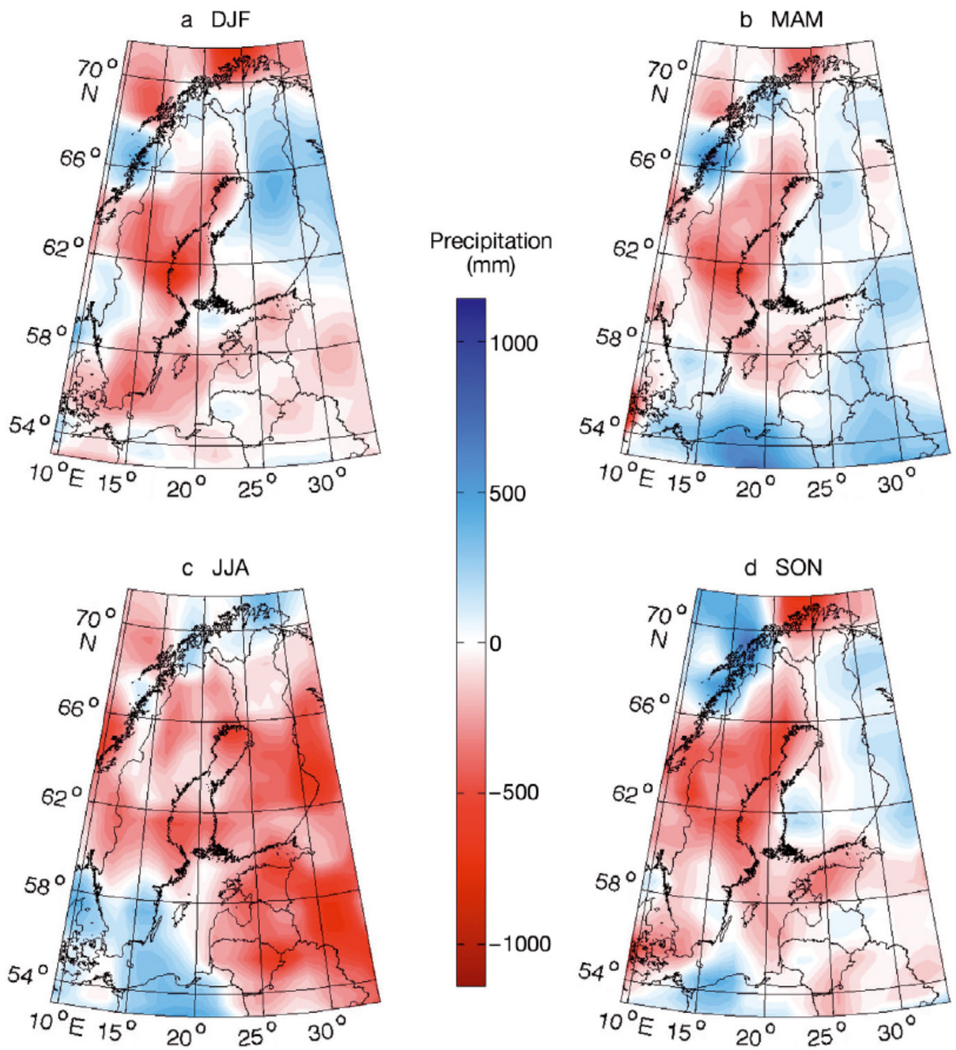
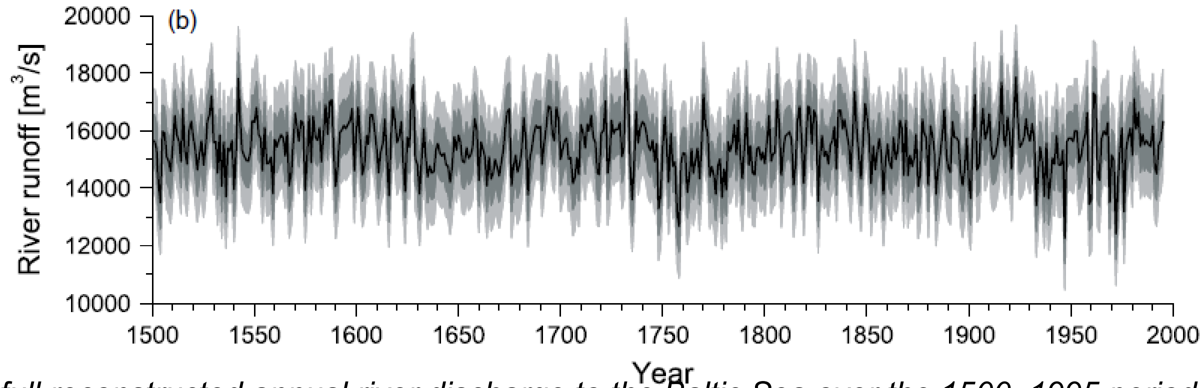
- For the last decades
  - General increase in winter and spring precipitation in northern Europe.
  - Highest increase in Sweden and eastern coast of the Baltic Sea.
- Comparing 1994-2008 to the previous 15 years:
  - Less precipitation in northern and central Baltic Sea.
  - More precipitation in the southern parts.
  - Winter precipitation increased on the westward side of the Scandinavian mountian range.



Seasonal differences in 15-year totals of precipitation, period 1994-2008 minus period 1979-1993, based on the SMHI database (Lehmann et al. 2011).

Runoff

No statistically significant trends have been detected in long term annual river discharge.



The full reconstructed annual river discharge to the Baltic Sea over the 1500–1995 period (Hansson et al. 2011).

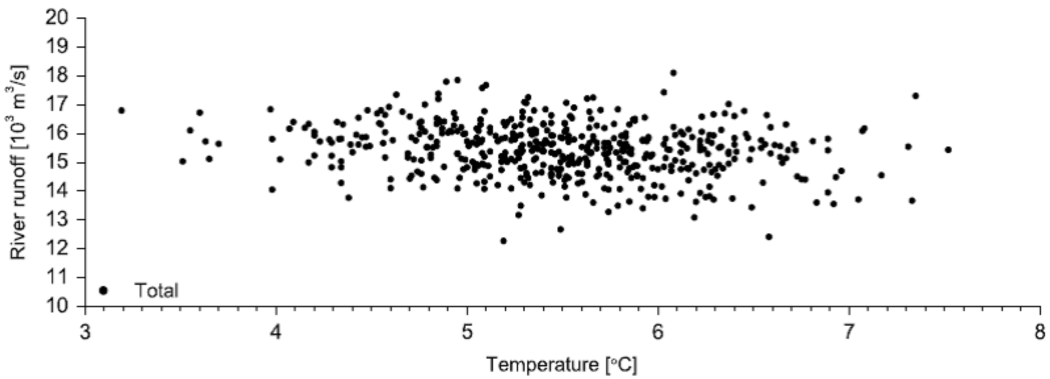
North: runoff linked to temperature, wind, rotational circulation.

South: runoff linked to rotational and deformational circulation components

Runoff

Temperature change seems to explain more than precipitation about runoff change

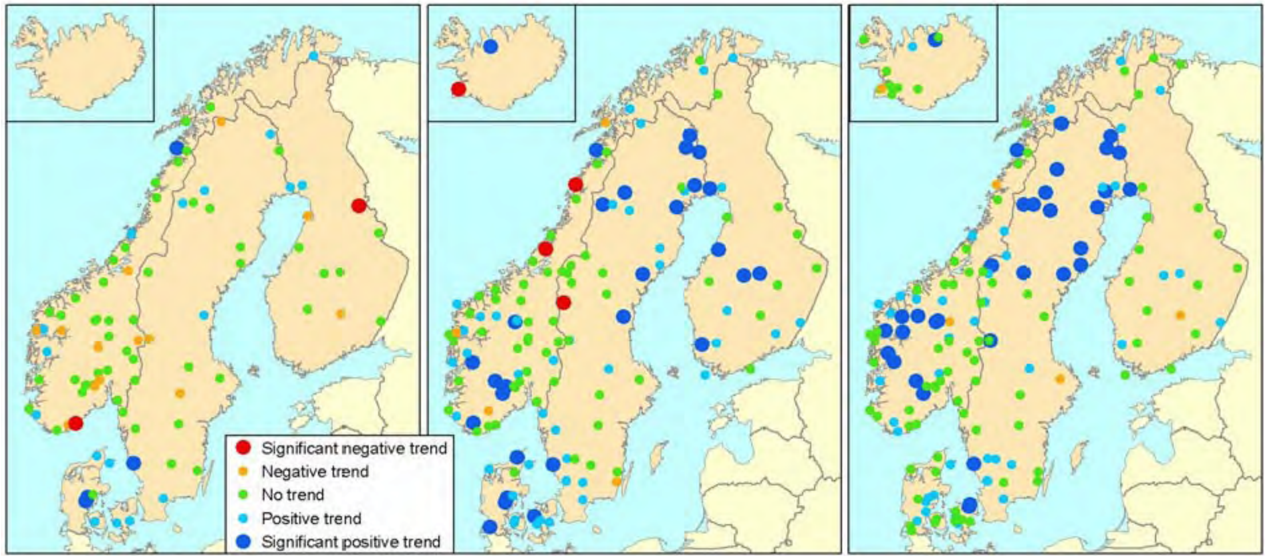
The total river runoff to the Baltic Sea has decreased in response to temperature increase by 3%, or 450 m3/s, per C°.



Reconstructed total river runoff as a function of temperature in the Baltic Sea. A change of 1 °C results in a decrease of 3% (450 m^3/s) (significant at 95% confidence level). (Hansson et al. 2011)

Runoff

Decadal variability:



Trends in annual stream flow for the periods 1920-2002 (left), 1941-2002 (middle) and 1961-2000 (right). (Hisdal et al. 2010).

Incresed stream flows in some regions in particularly during winter and spring.

Runoff

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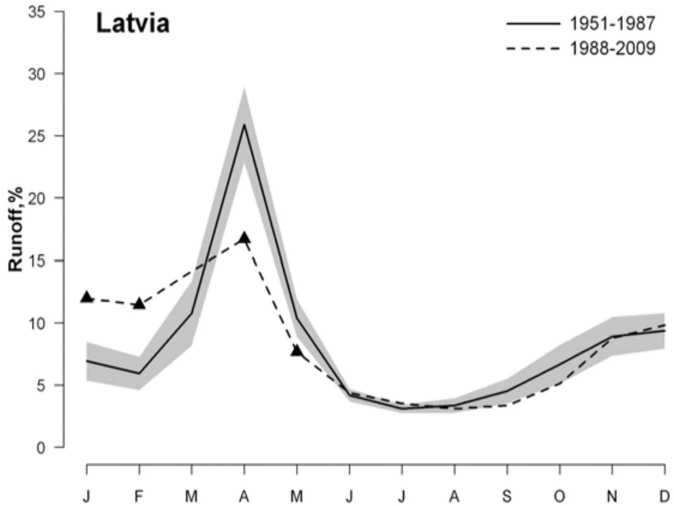
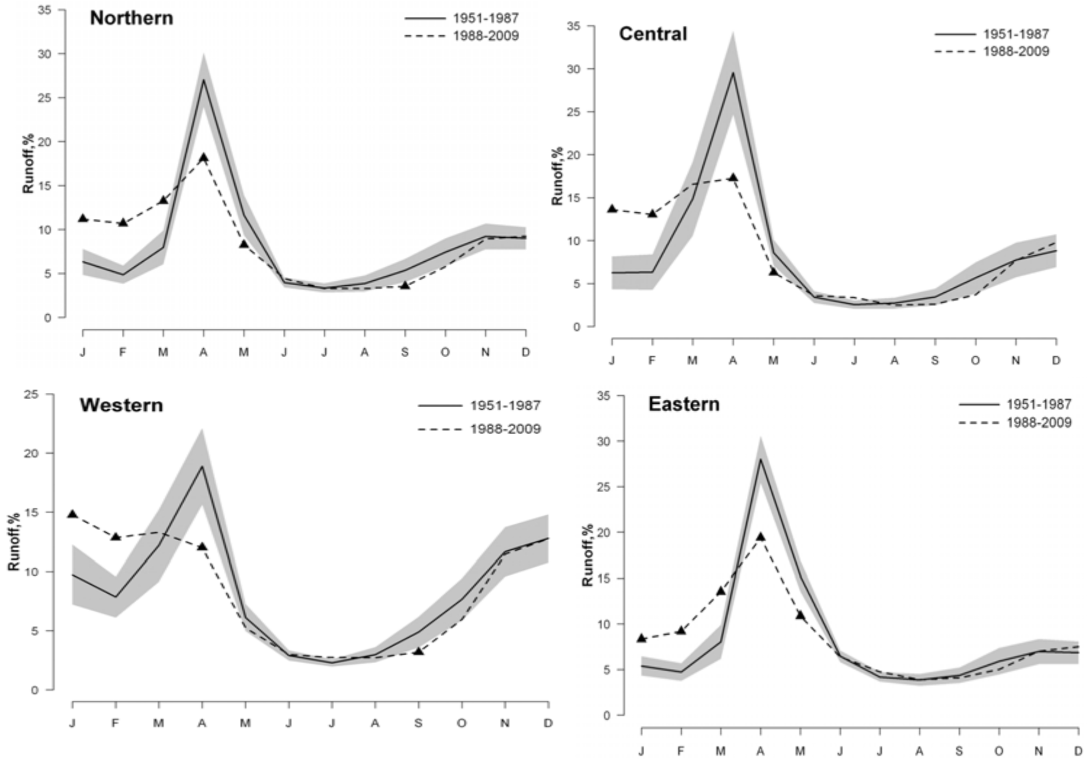
Seasonal variability:





Changes in river hydrographs between two study periods in hydrological districts and whole Latvia. (Apsite et al. 2012 [in press]).

- Winter discharges increase due to higher temperatures and subsequent snowmelt,while spring discharges decrease as less snow is available.

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River/lake ice

Ice regime has decreased with delayed ice formation and earlier breakup resulting inshorter duration

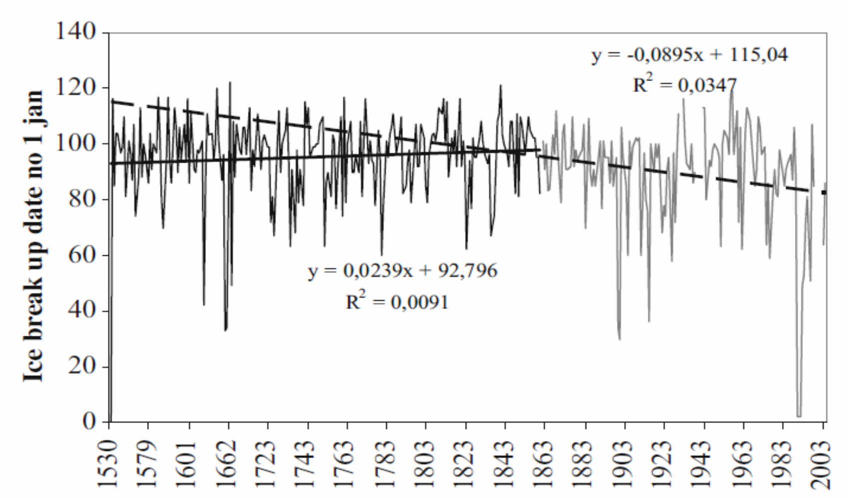
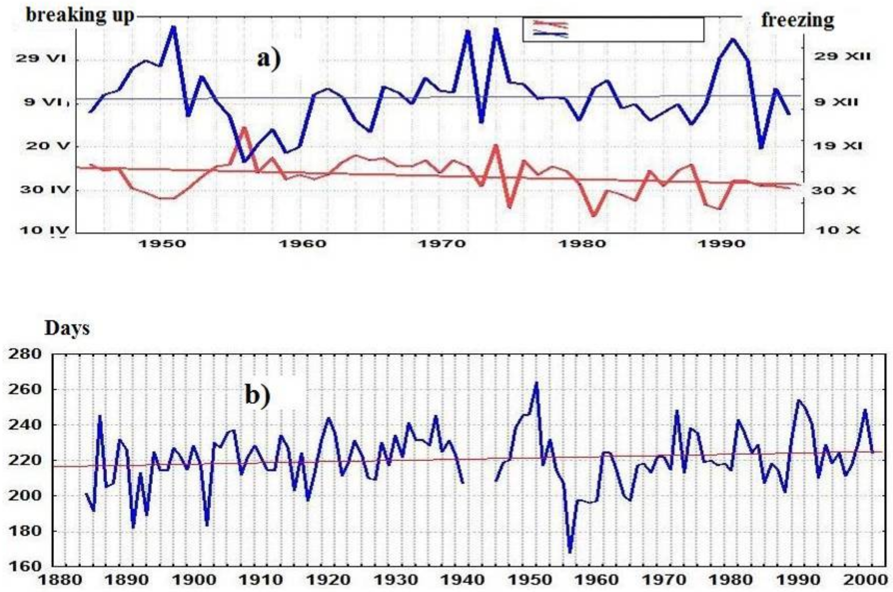


Fig. 3.3.1-18
Time series of ice break-up dates in River Daugava (dashed line shows trend from 1860 to 2003 and continuous line from 1530 to 1859) (Kļaviņš et al. 2009).

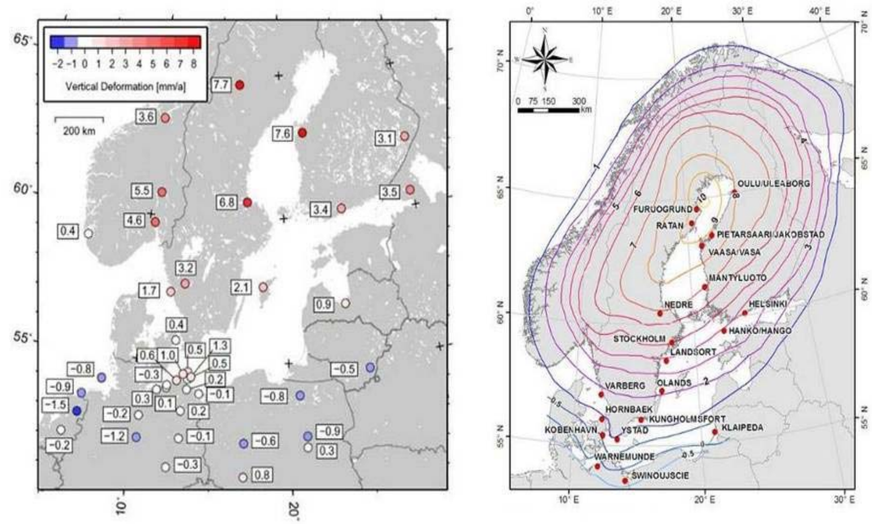


Dates of a) break-up and freezing, and b) duration of ice-free period on Lake Onego. (Salo and Nazarova 2011).

Sea Level

Variations in Baltic Sea mean sea level is the sum of global regional and local effects and changes due to wind, surface pressure, ocean currents, fresh water input and temperature.

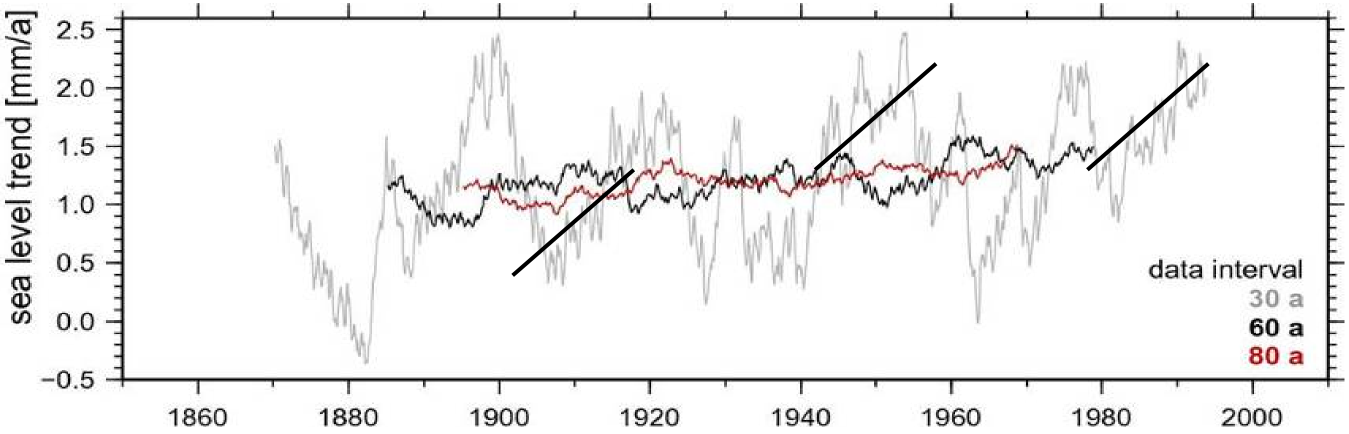
- Changes due to isostatic dynamics following the last glaciation, relative sea-level:
  - falling in the northern Baltic (crust is uplifting at roughly 10mm/yr)
  - rising in parts of the Southern Baltic (crust sinking at 1mm/yr).
  - recent studies: a more easterly peak uplift placed in the middle of the northern Gulf of Bothnia
  - **quasi-linear long-term trend in Baltic Sea-level is dominated by isostatic land movement effects**



Estimations of crustal deformation rates in the Baltic Sea Region derived by different methods. From Richter et al. (2011) and Harff et al. (2010).

Sea Level: long term

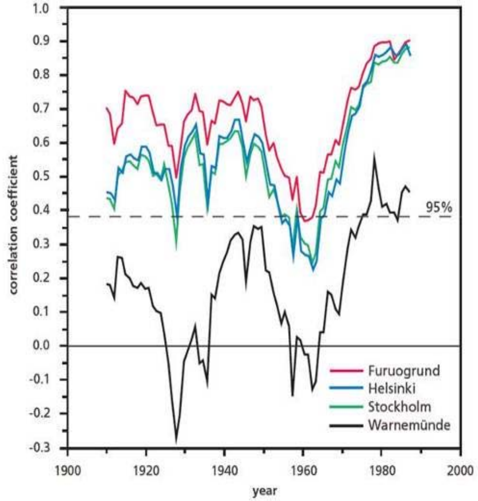
- Gauge records show an upward trend:
  - Absolute sea level increase (1800-2000): 1.3 mm/yr to 1.8 mm/yr. Lies within error bars of global mean (1.7 ±0.5mm/yr).
  - Present rates of Baltic sea level rise are not unprecedented in the observational record.

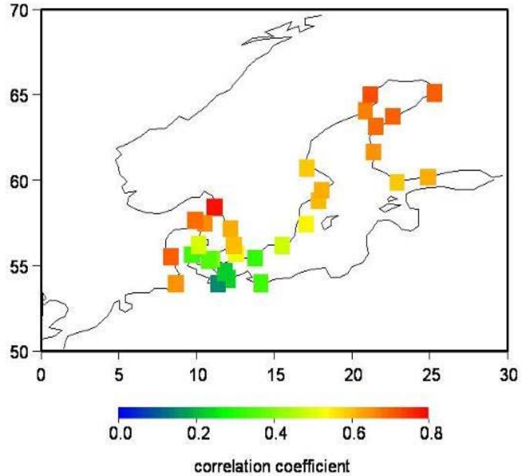


Linear trends calculated in sliding windows of fixed lengths of the annual sea-level record in Warnemünde (Germany). From Richter et al. (2011).

Sea Level: decadal variability

- Decadal variations vary seasonally and regionally:
  - **Decadal sea-level variability is regionally and seasonally influenced by different large-scale atmospheric forcing factors.**
  - Variability is strongly influenced by westerly winds
  - the correlations between sea-level and NAO index
  - Spatial heterogeneity: low values in southern Baltic parts





Correlation between winter means of the NAO index and winter mean (linearly detrended) Baltic Sea level (1900-2000). From Hünicke and Zorita (2006)

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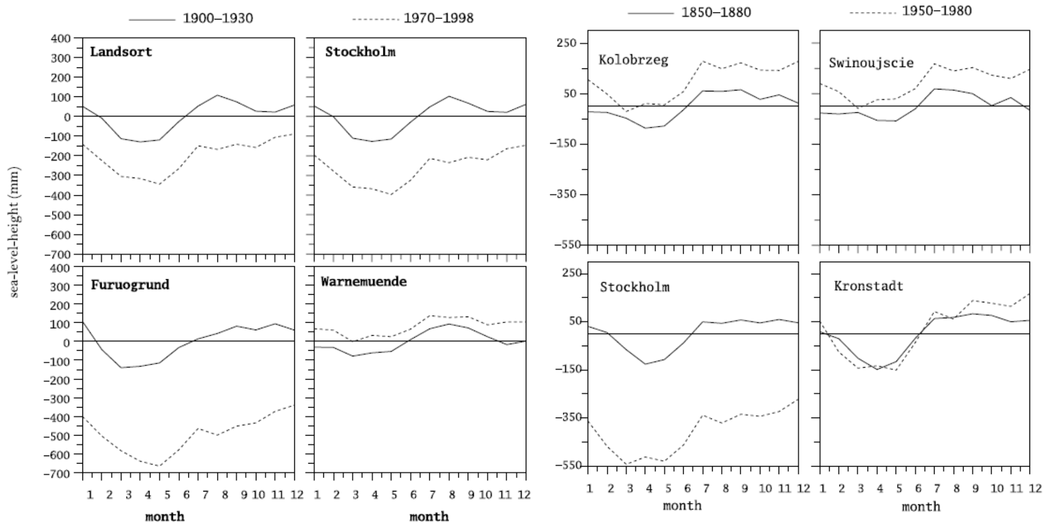
Sea Level: decadal variability

– Amplitude of the sea level annual cycle (high values in winter, low values in spring) is increasing



Sea level annual cycle derived from monthly means. Left panel: averaged in two different time periods in the 20th century (1900–1930 solid line, 1970–1998 dashed line) for selected stations in the Baltic Sea. Right Panel: averaged in one period in the 19th century (1850–1880 solid line) and one period in the 20th century (1950–1980 dashed line) (Hünicke and Zorita, 2008).

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Extreme events: last decades

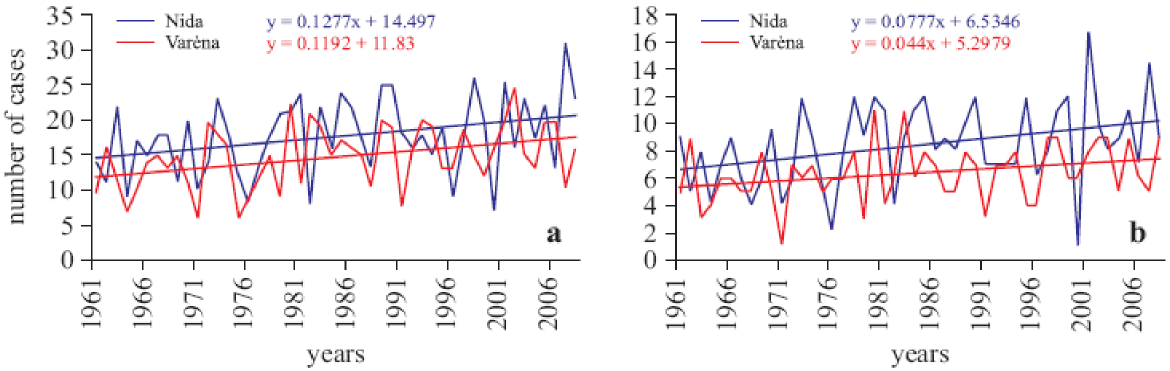
Often extreme events and changes in extreme situations are of more important than changes in mean climate.

- For all weather types (zonal, meridional or anticyclonic) an **increase in persistence is seen** (2-4 days from 1970s to 1990s).
  - Number of winter storms increased.
  - 10-percentile temperature events decreased (number of frost days decreased by 20-30 days).
  - Sum of number of wet and dry days increased in Estonia 1957-2006.

- Due to the rare occurrence of extreme events, statistically significant trends are difficult to detect.

Extreme events: last decades

– Number of days with heavy precipitation increased



Number of days with heavy precipitation (a) >10 mm per day and (b) >20 mm in three consecutive days in Nida (western Lithuania) and Varėna (south-eastern Lithuania) in 1961–2008. All trends are statistically significant according to a Mann-Kendall test (Rimkus et al 2011).

– Increased extreme precipitation events not reflected in occurence of flooding.

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Extreme events: long term

- Statistically significant trends:
  - Positive: in the number of tropical nights (T_{min}>20°C)
  - Positive: summer days (T_{max}>25°C)
  - negative trends: in the number of frost days (T_{min}<0°C)
  - Negative: ice days (T_{max}<0°C).
- Standard deviation of temperature in Poland:
  - The duration of extremely mild periods has increased significantly in winter
  - while the number of heat waves has increased in summer
- Very few statistically significant trends have been seen.
  - Increase in number of days with heavy precipitation in Latvia (1924-2008)
- Extreme relative sea level values are found to increase more rapidly or decreasing more slowly in regions with isostatic uplift.:
  - most obvious in the Northern Baltic Sea, but also seen e.g. in Estonia.
  - For the southern Baltic coastline of Germany and Poland, no climate driven changes in the magnitude of extreme water levels during the last 200 years could be detected.

Conclusions

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- Variability in general dominating over trends:

Variable	Long term trend	Last decades
Air temperature	positive	positive
Water temperature	positive	positive
Precipitation	no trend	Mainly positive
Wind	no trend	Mainly positive
Run off	no trend	positive
Sea level	positive	positive
Ice extent	negative	negative
Snow cover	negative	negative
Heavy precip	x	positive

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Conclusions

Variable	Long term trend	Short term trend
Clouds	x	Mainly negative
Radiation	x	Positive and negative
Diurnal temperature amplitude	negative	negative
Length of growing season	positive	positive