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Baltic Earth
Earth System Science for the Baltic Sea Region

Climate change in the Baltic Sea Basin

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and the BACCII author team

Baltic Sea Climate Change assessment (

Baltic Earth -
Earth system science for the Baltic Sea region

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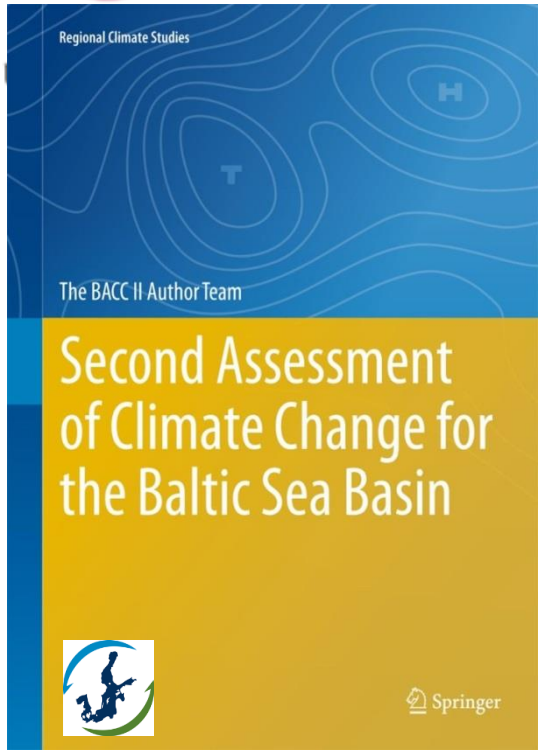
Vision of the programme

To achieve an improved Earth System understanding of the Baltic Sea region

- **Interdisciplinary** and **international**
- **Holistic view** on the Earth system of the Baltic Sea, processes in the **atmosphere**, on **land** and in the **sea** and also in the **anthroposphere**
- "**Service to society**" in the respect that **thematic assessments** provide an overview over knowledge gaps
- **Education** (summer schools)
- Inherits the **BALTEX** network of scientists and infrastructuren

Baltic Earth



Second Assessment of Climate Change for the Baltic Sea region (BACC II)

New book following the format of BACC I as OPEN ACCESS, 7 years after

Extended summaries of the scientific material

- → **In all 9 languages of the Baltic Sea region plus English (Danish, Swedish, Finnish, Russian, Estonian, Latvian, Lithuanian, Polish, German)**
- → **Understandable for non-scientists**
- → **Emphasizing on regional conditions**

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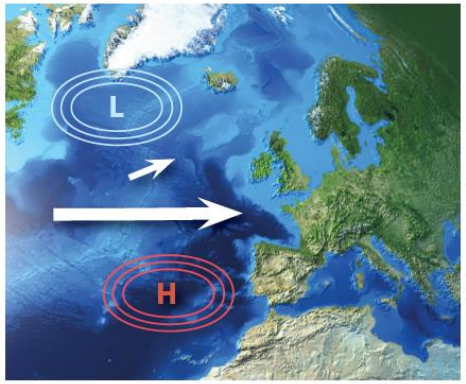
Initial comments

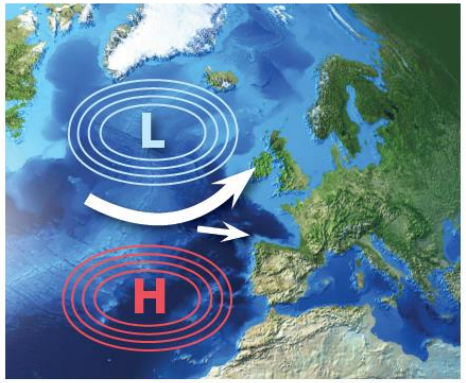
- Last 200 years:
  - Instrumental records
  - Indications of anthropogenic impacts possible
- Internal variability large:
  - Difficult to distinguish changes
  - Changes in extreme events in particularly difficult.
- Changes atmosphere, sea, land

a/ NAO +



b/ NAO –

c/ EA +



d/ EA –

e/ Scandinavian Pattern

f/ Sc Atlantic Ridge

NAO: strength of pressure difference.

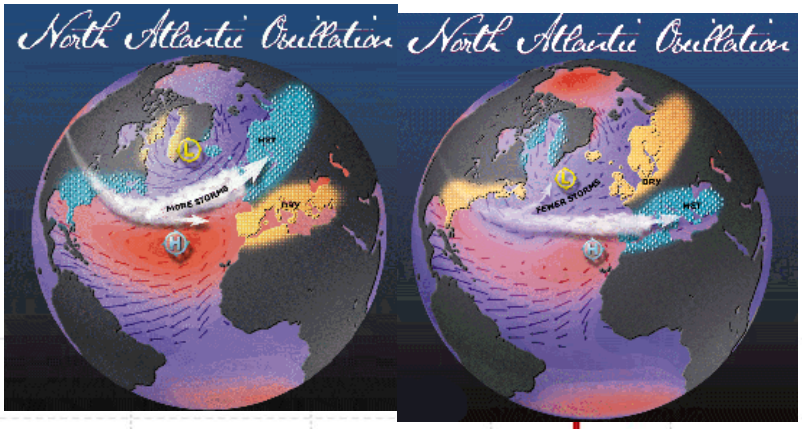
EA: East Atlantic Pattern, represents north-south location of the NAO.

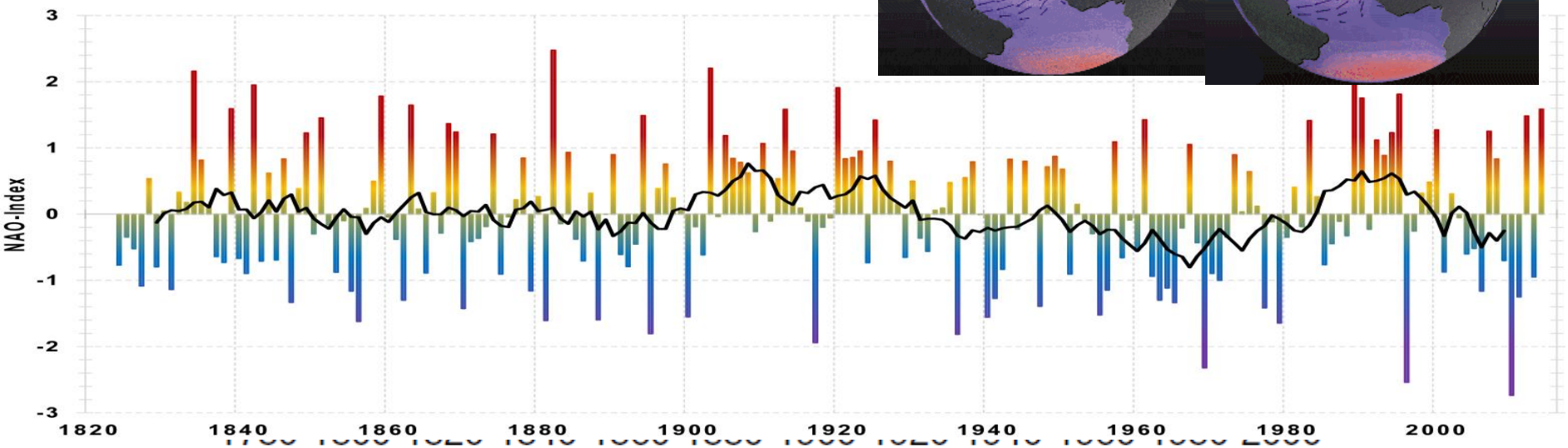
Scandinavian pattern: blocking, represents an east-west shift of the centres of variability.

Atmospheric Circulation

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

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

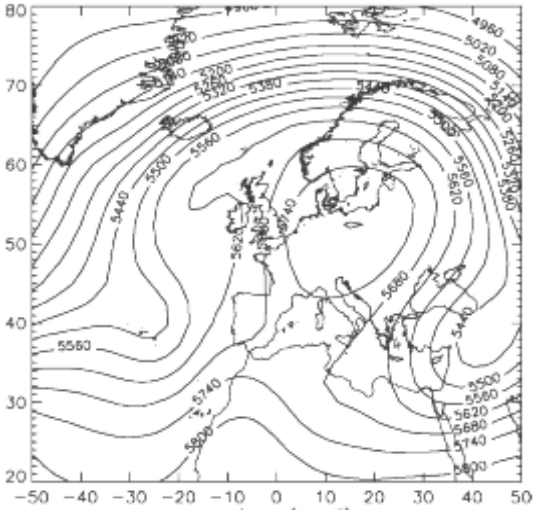




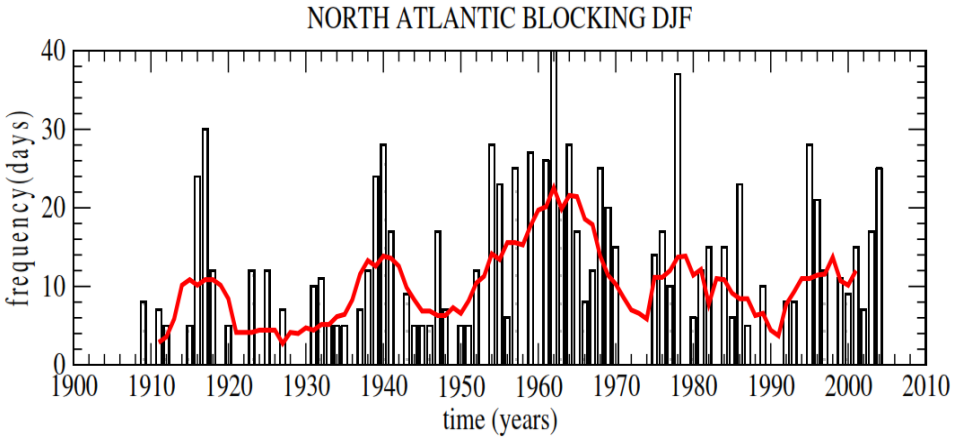
Reconstructed NAO index (Luterbacher et al., 2002). Thick curves are filtered with a Gaussian filter (σ = 4) to focus on interdecadal variations (Bärring and Fortuniak 2009).

Atmospheric Circulation

- 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.



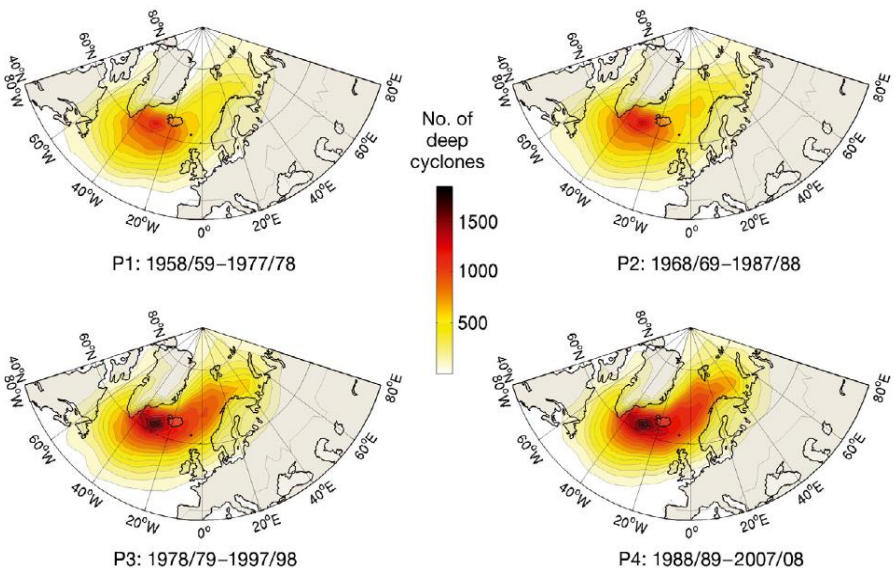
The 500 hPa height field on March 6, 1948, showing a typical blocking situation. From Barriopedro et al. (2006).



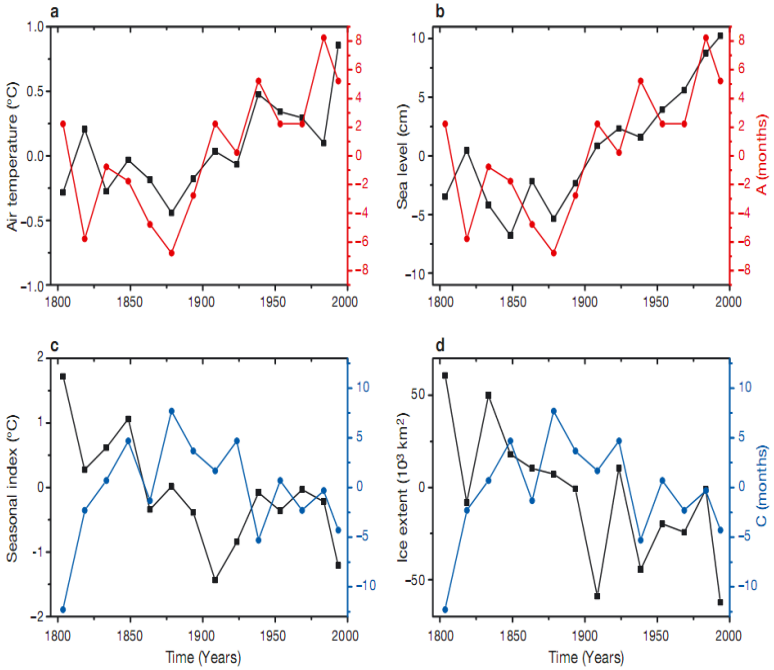
Blocking index (bars) and its decadal variation (seven year running mean; red) for boreal winter (December-February) 1908 to 2005. From Rimbu and Lohmann (2011).

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).

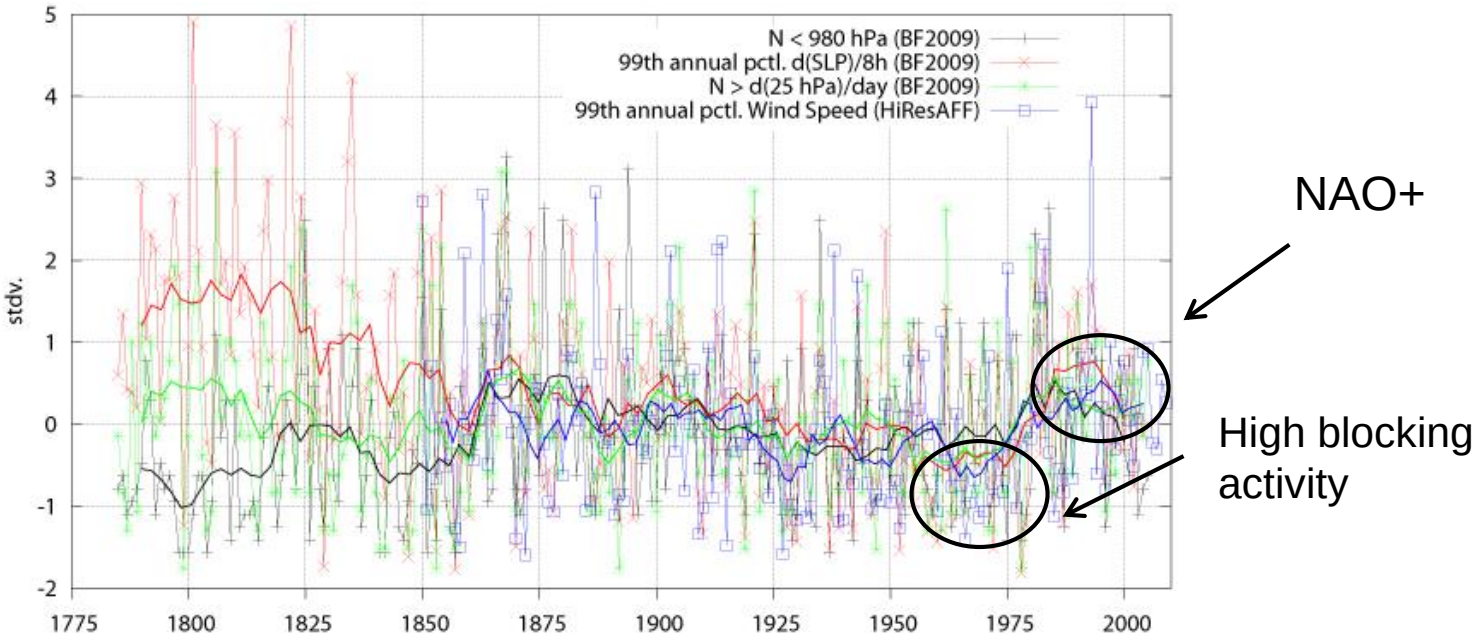


Anomalies and circulation types that describe the vorticity of the atmospheric circulation. Red indicates anticyclonic and blue cyclonic circulation. (a) air temperature, (b) sea level, (c) difference between summer (JJA) and winter (DJF) seasonal temperatures, and (d) ice cover, Omstedt et al. (2004).

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.

Wind/circulation

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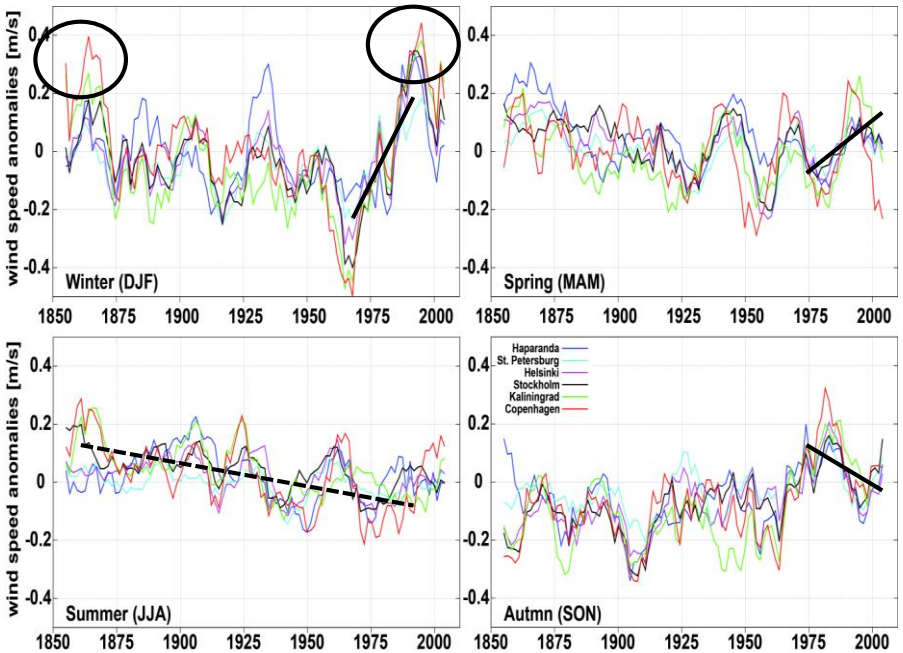
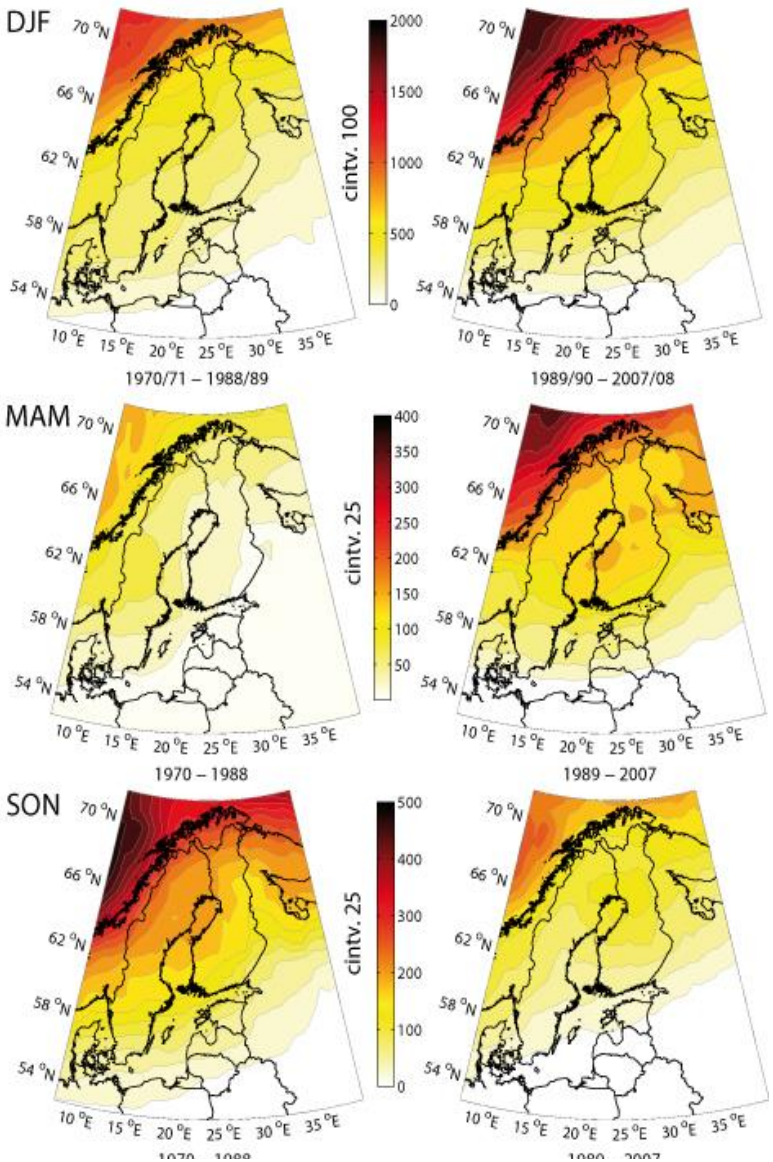
Seasonal differences:

- 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

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).

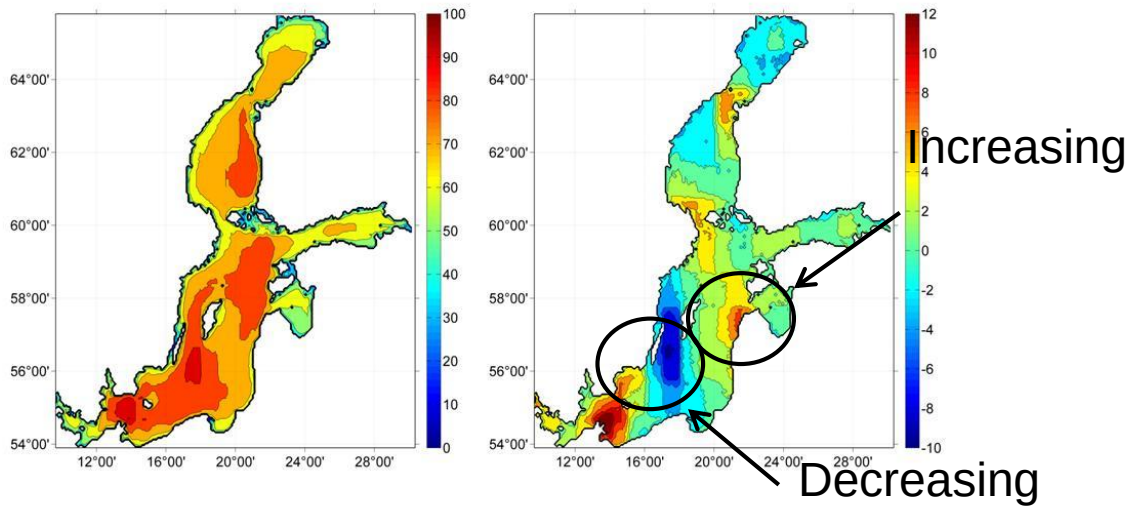
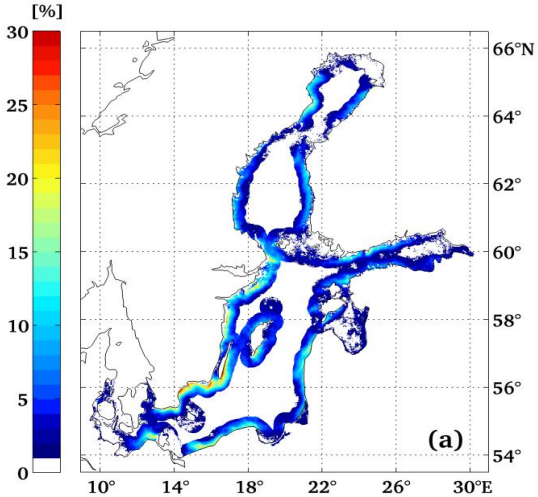


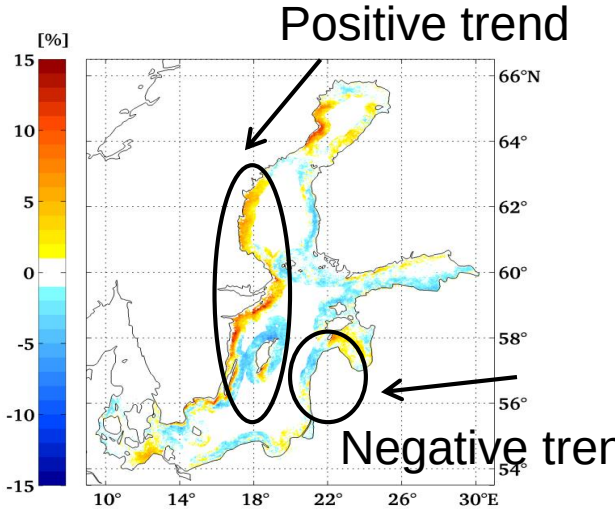
Fig.3.4.3-16 (left) Numerically simulated average significant wave height (colour bar, cm; isolines plotted after each 10 cm) in the Baltic Sea in 1970–2007 (from Räämet and Soomere 2010); (right) Long-term changes in the annual average significant wave height (cm, based on the linear trend, isolines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

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.





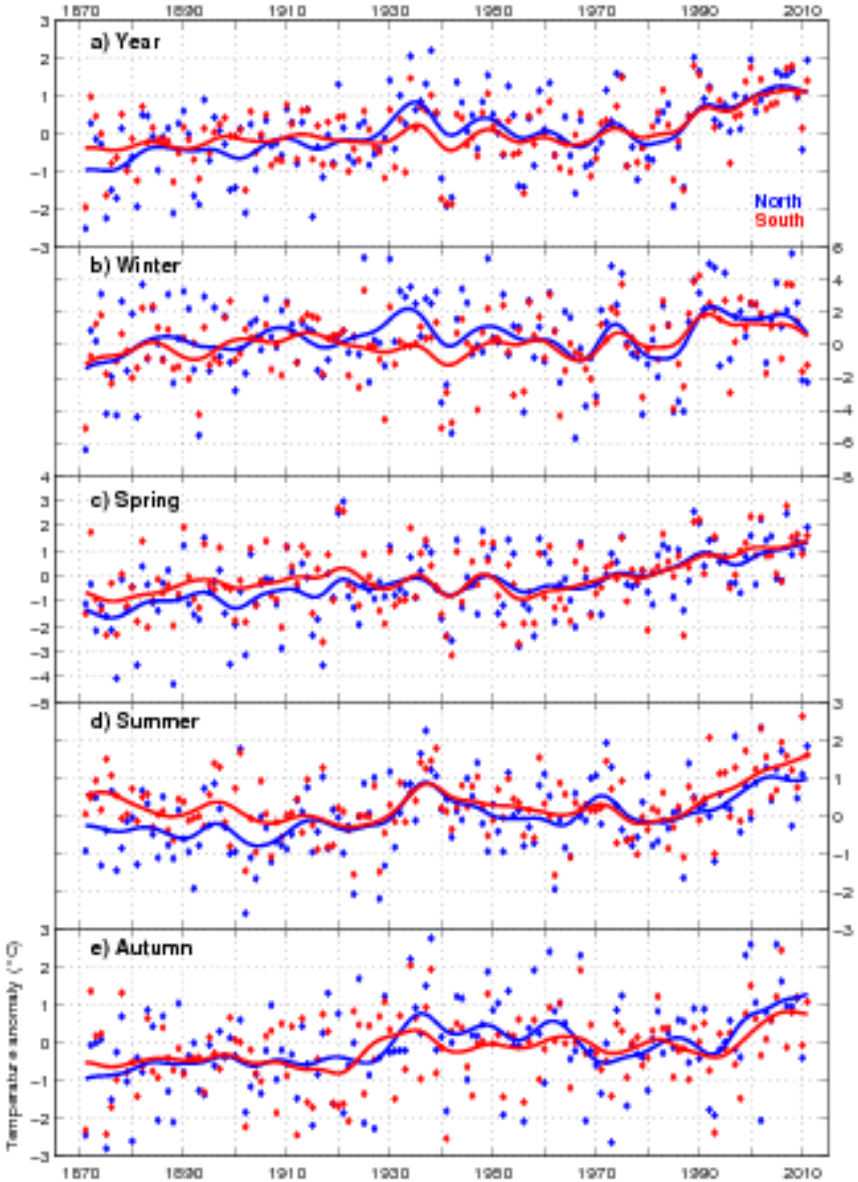
Upwelling frequencies [%] obtained from the automatic detection method for upwelling based on 443 SST maps for the period 1990–2009, May-September (left) and trend for upwelling frequencies May-September, 1990–2009 (right; Lehmann et al., 2012).

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

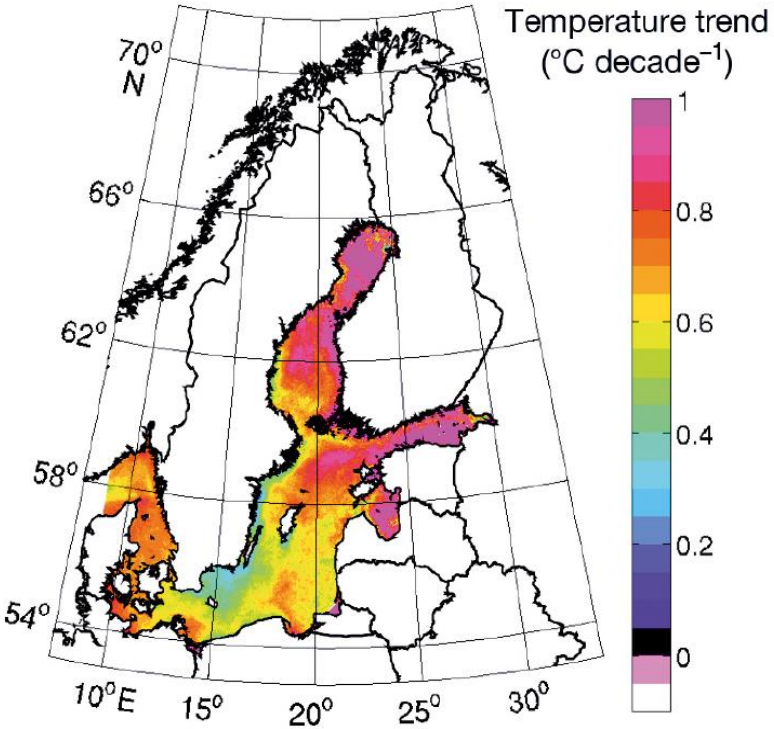
The warming of the water basin is significant during the last decades.

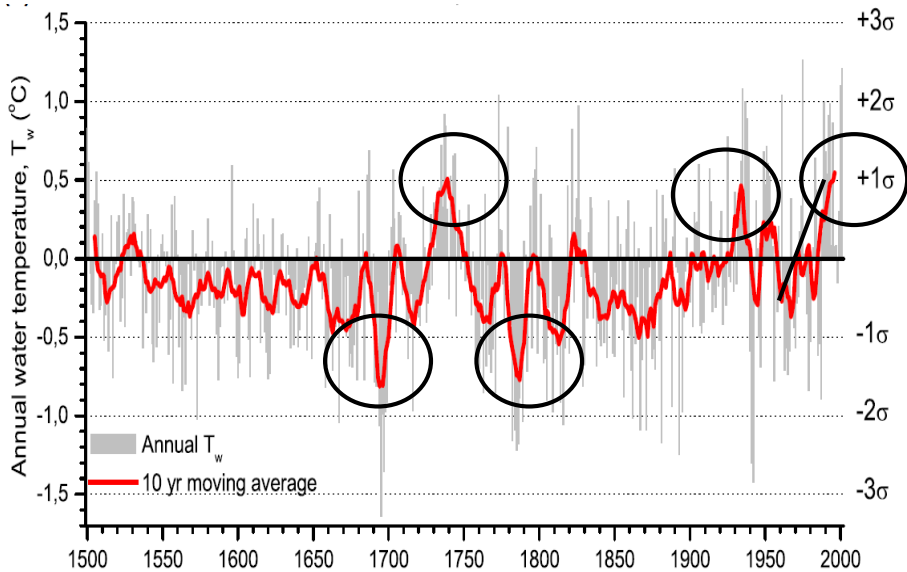
Highest linear trend of in the Bothnian Bay, Gulfs of Finland and Riga and in the Northern Baltic Proper .

Largest warming in August in Bothnian Bay.

Cooling in March.

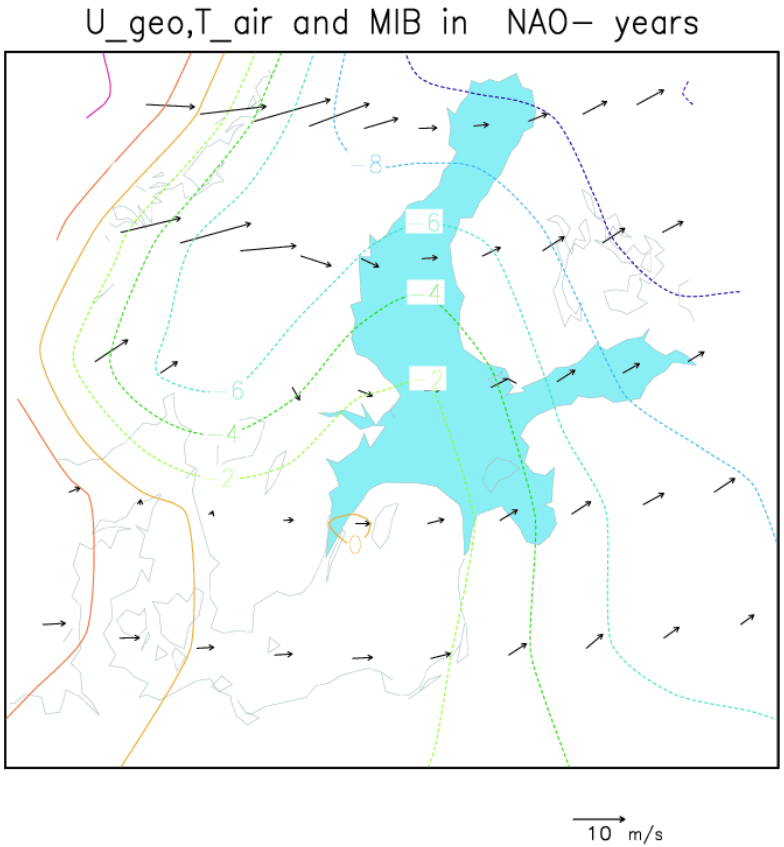
Longer perspective – present strong warming not unique.

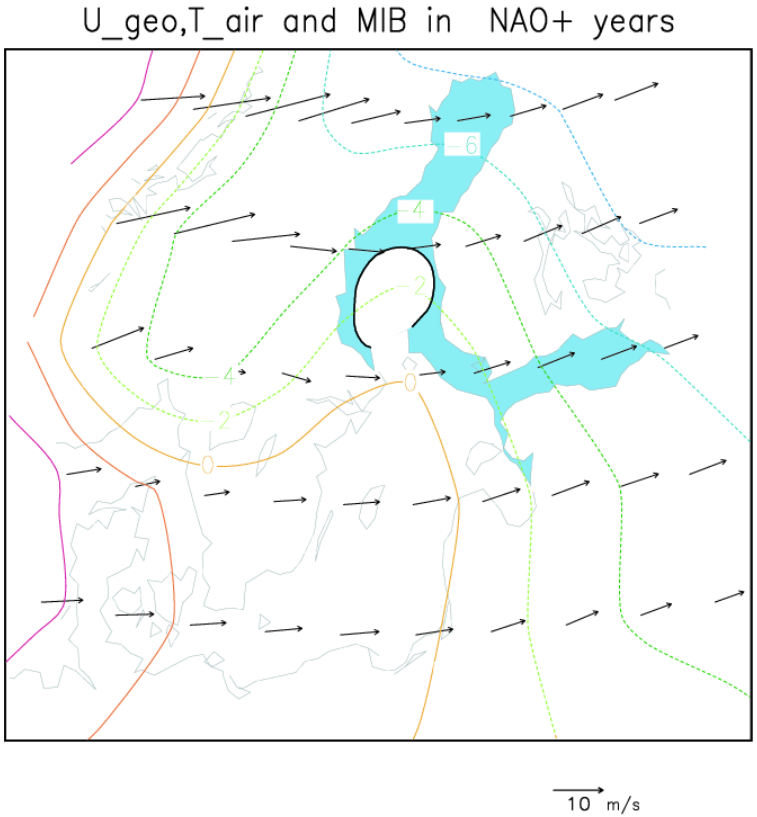




Baltic Sea Ice

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.

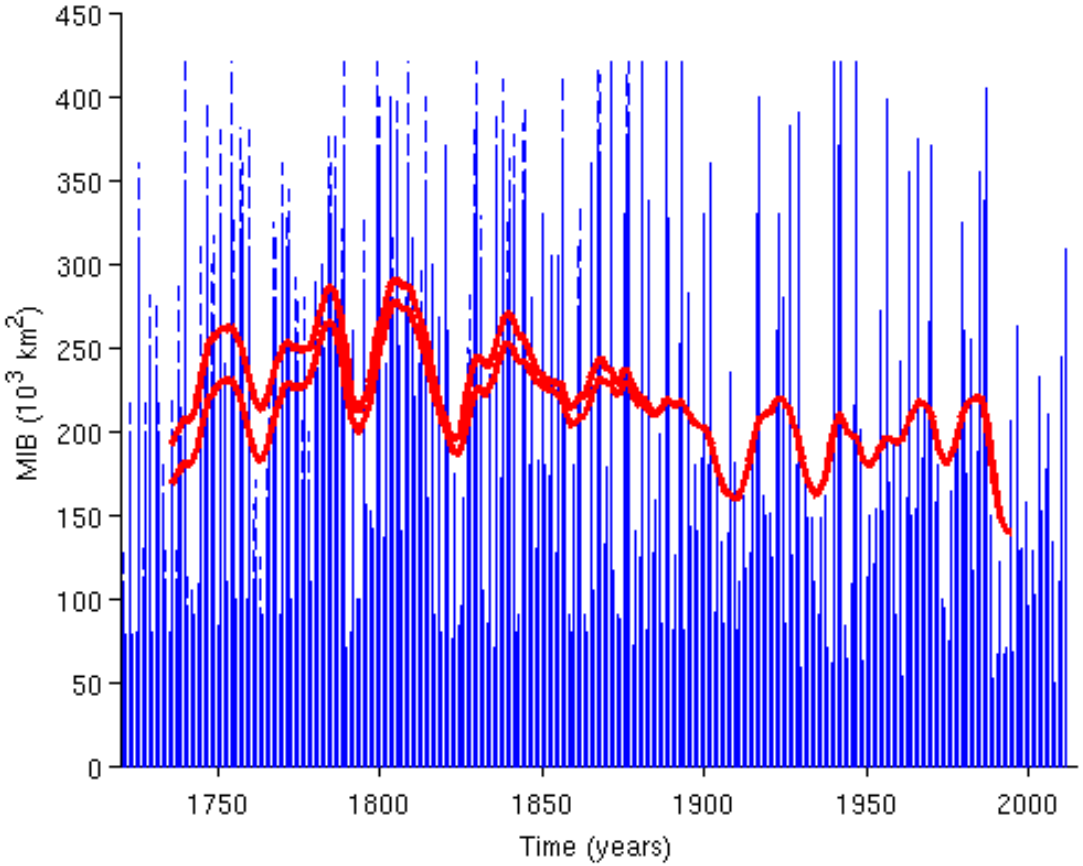




Vihma and Haapala,2009

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

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.

Ice thickness and length of ice season

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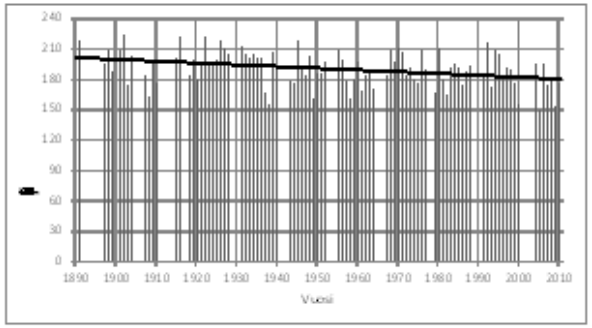
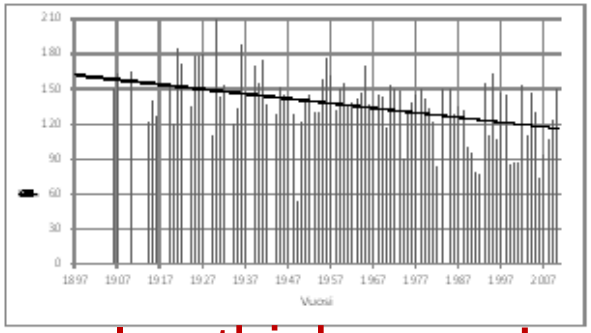
- Length of the ice season has decreased by 14–44 days in a century, mostly due to the earlier ice break-up.

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

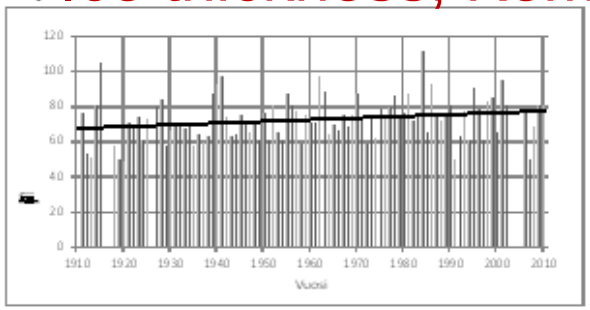
a) Ice season, Kemi



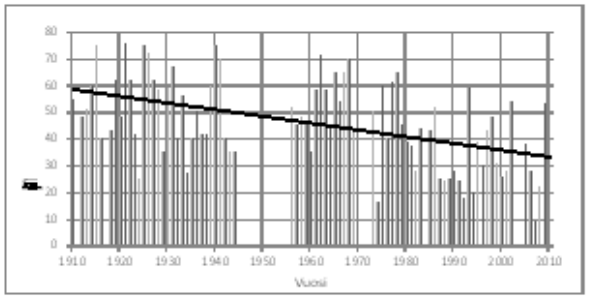
b) Ice season, Loviisa



c) Ice thickness, Kemi



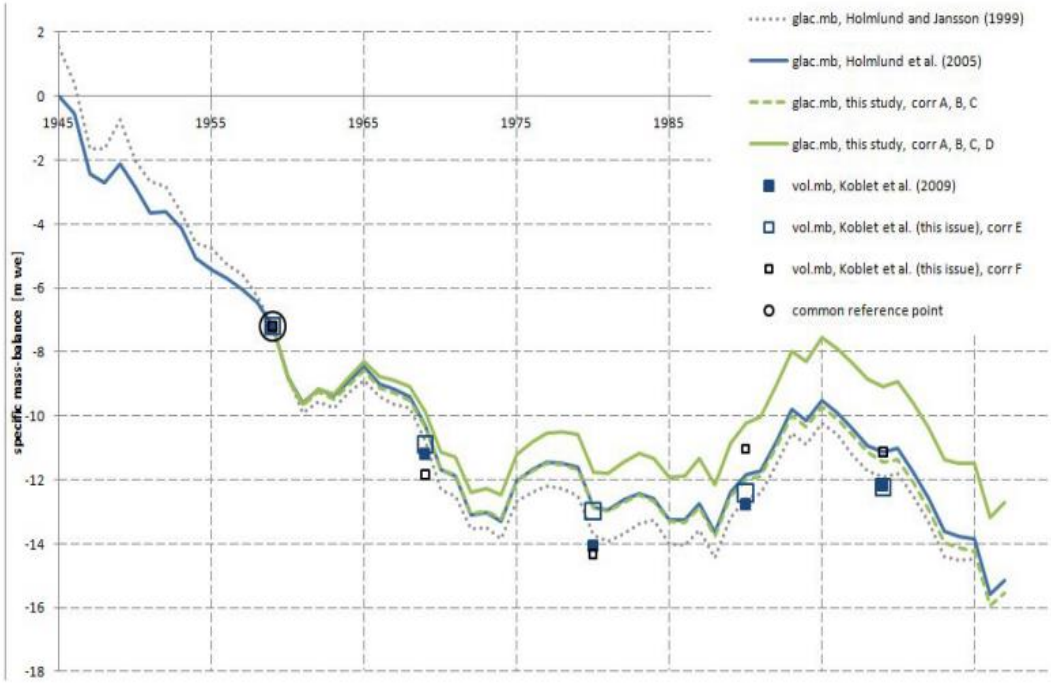
c) Ice thickness, Loviisa



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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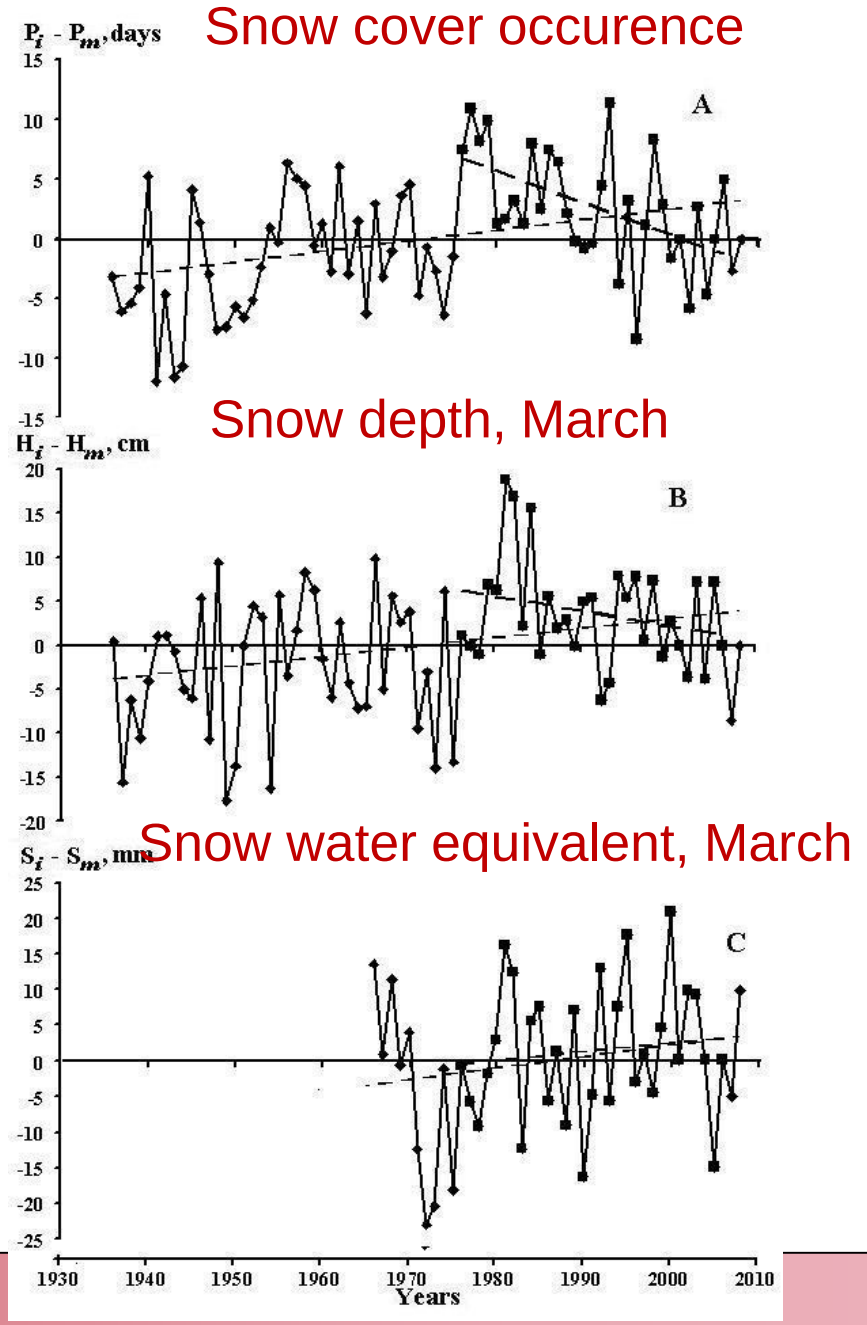
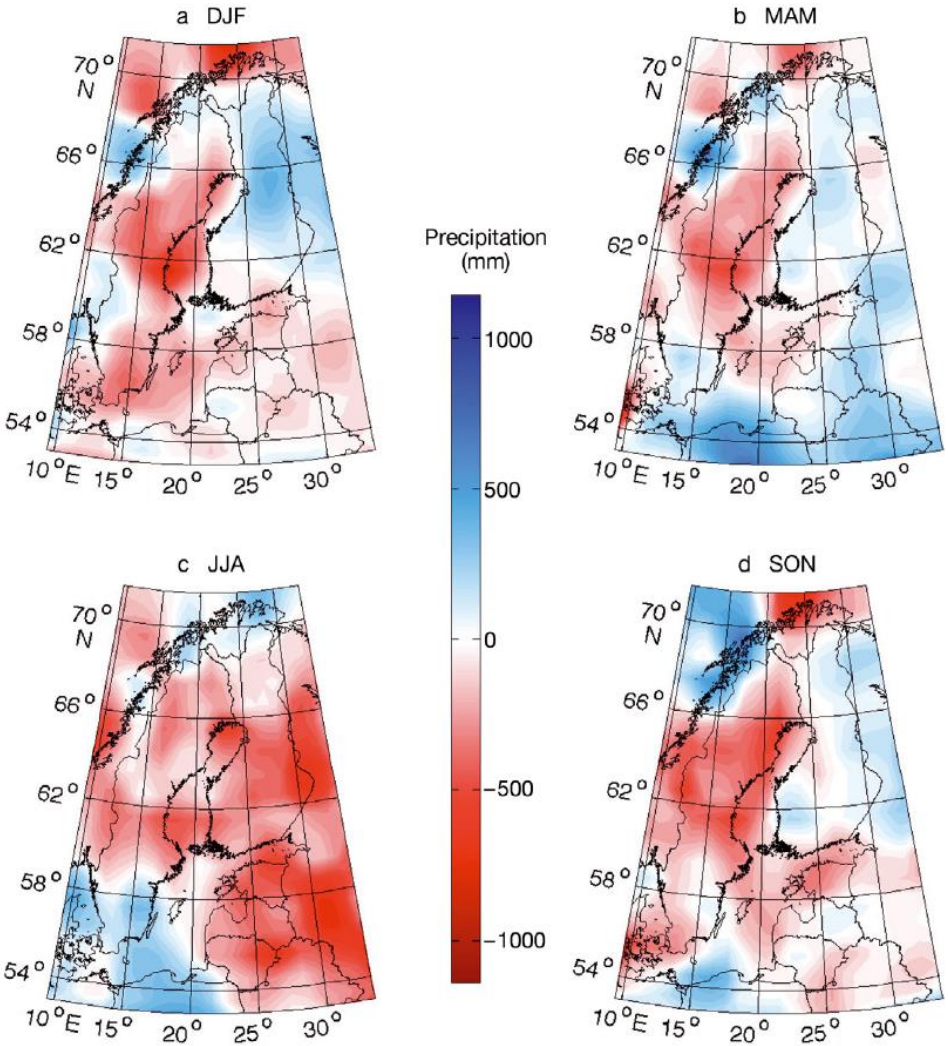
- **Shortening of the annual snow cover period especially during spring**, except in mountainous areas. Most of the negative trends are more pronounced during the last few decades.
- **a general decrease of annual maximum snow amount**
- **Warming trends are observed in soil temperatures, as well as 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

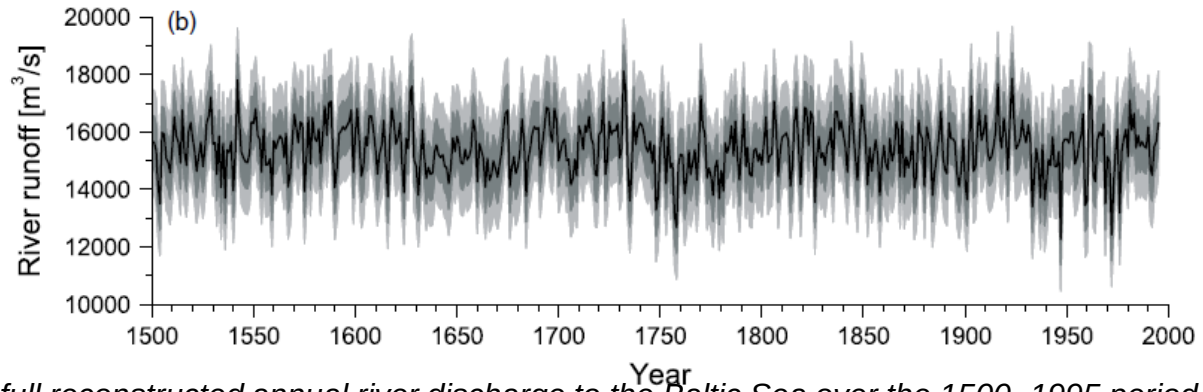
- For the last decades
  - General increase in winter and spring precipitation in northern Europe.
  - Highest increase in Sweden and eastern coast of the Baltic Sea.
- Comparing 1994-2008 to the previous 15 years:
  - Less precipitation in northern and central Baltic Sea.
  - More precipitation in the 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.



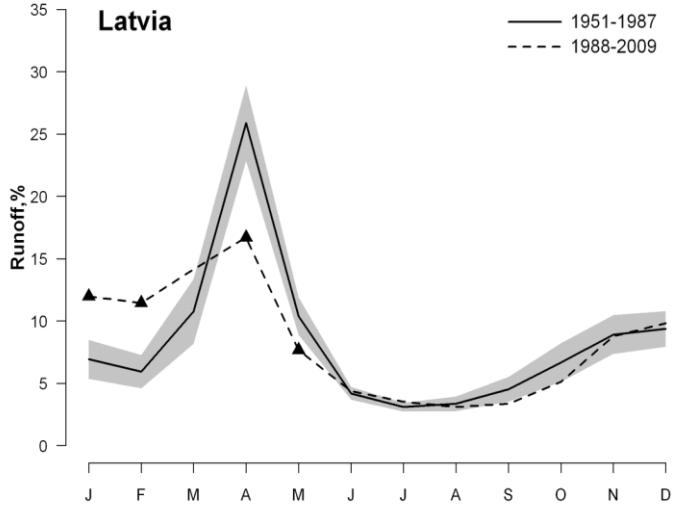
The full reconstructed annual river discharge to the Baltic Sea over the 1500–1995 period (Hansson et al. 2011).

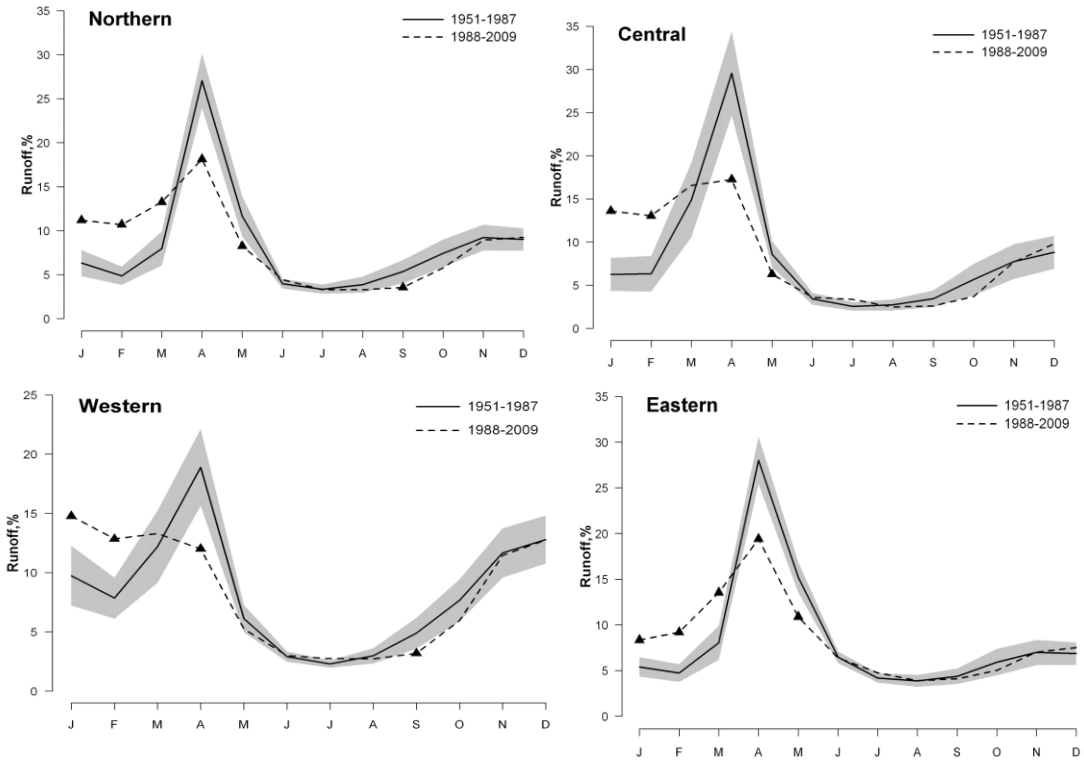
North: runoff linked to temperature, wind, rotational circulation.

South: runoff linked to rotational and deformational circulation components

Runoff

Seasonal variability:



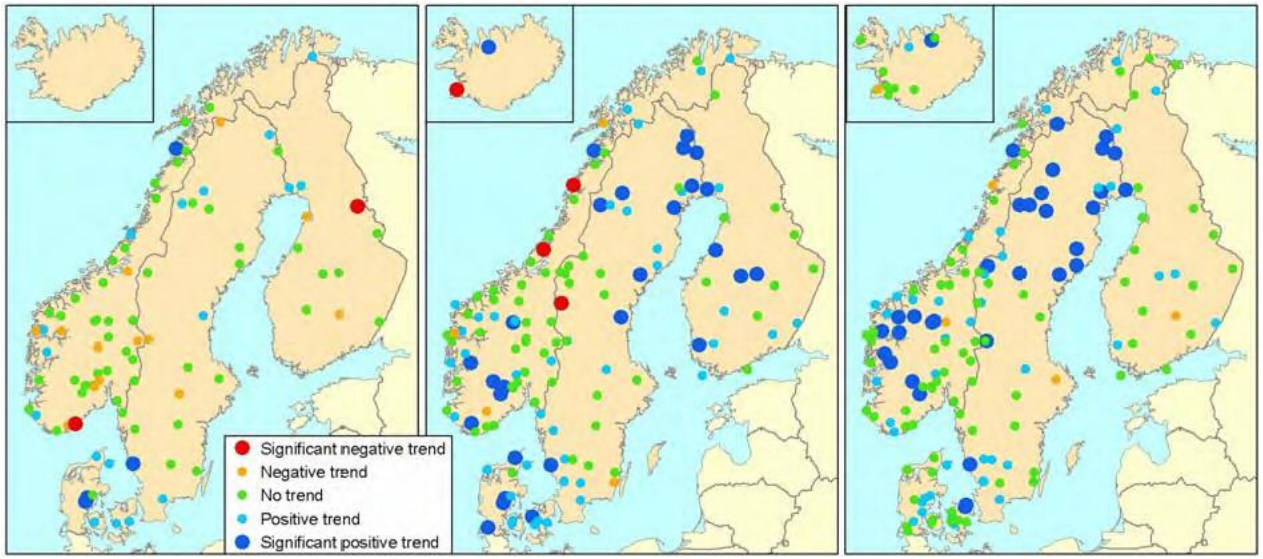


Changes in river hydrographs between two study periods in hydrological districts and whole Latvia. (Apsite et al. 2012 [in press]).

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

Runoff

Decadal variability:



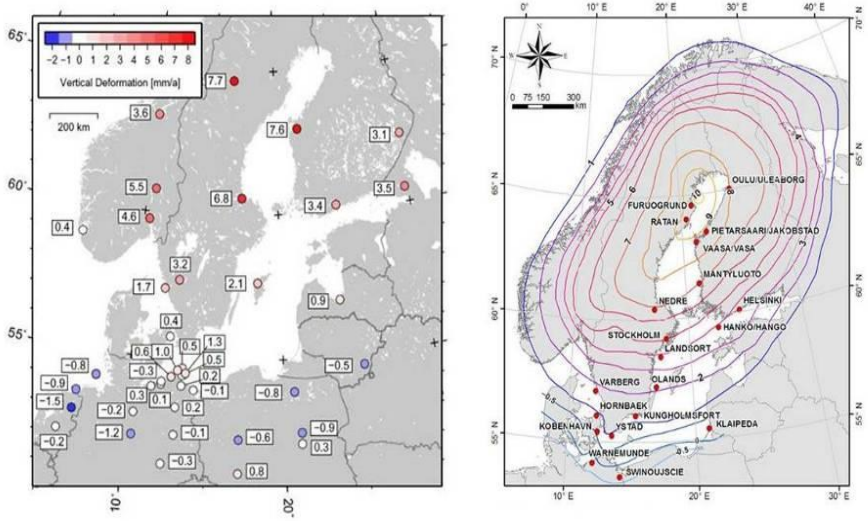
Trends in annual stream flow for the periods 1920-2002 (left), 1941-2002 (middle) and 1961-2000 (right). (Hisdal et al. 2010).

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

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.

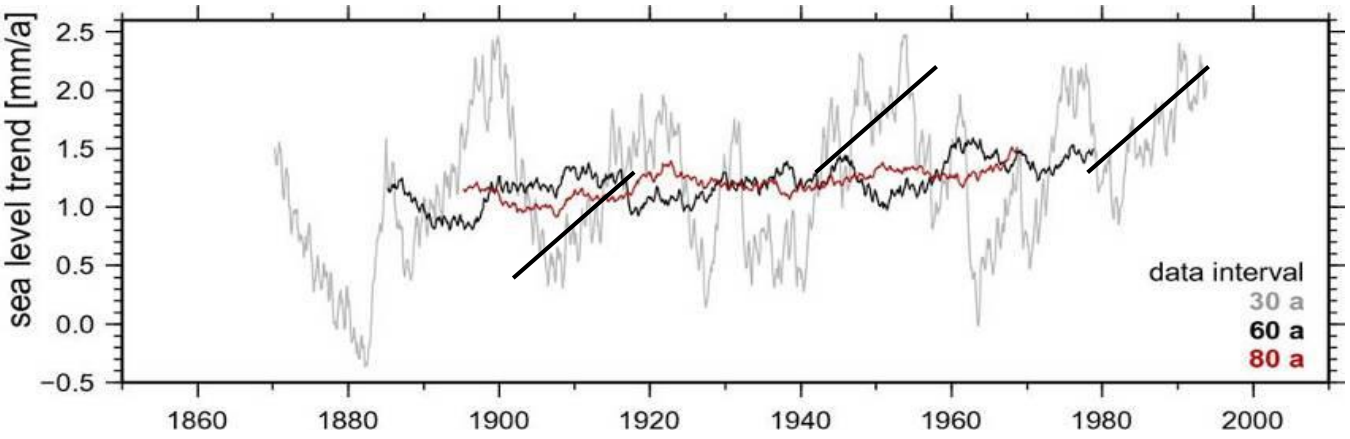
- Changes due to isostatic dynamics following the last glaciation, relative sea-level:
  - falling in the northern Baltic (crust is uplifting at roughly 10mm/yr)
  - rising in parts of the Southern Baltic (crust sinking at 1mm/yr).
  - recent studies: a more easterly peak uplift placed in the middle 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

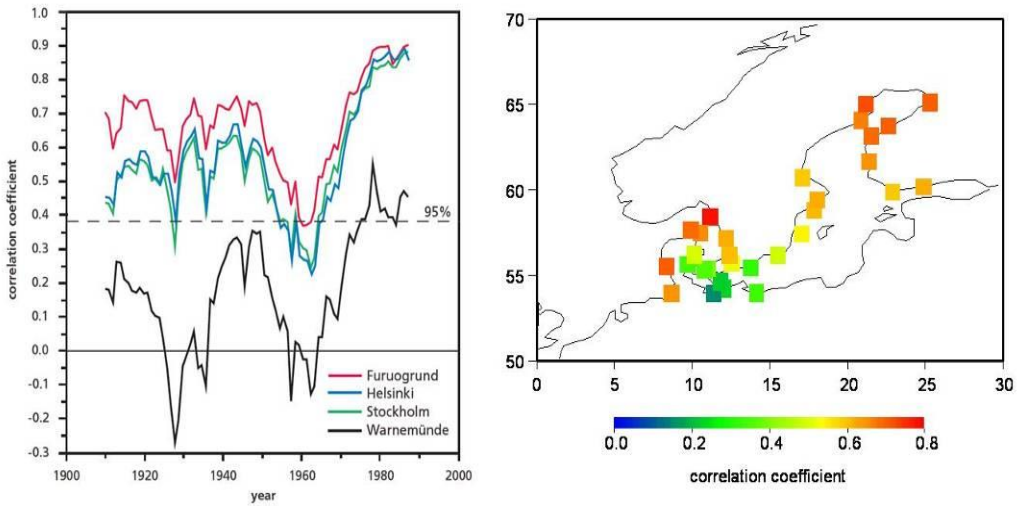
- Gauge records show an upward trend:
  - Absolute sea level increase (1800-2000): 1.3 mm/yr to 1.8 mm/yr. Lies within error bars of global mean (1.7 ±0.5mm/yr).
  - Present rates of Baltic sea level rise are not unprecedented in the observational record.



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)

Extreme events: last decades

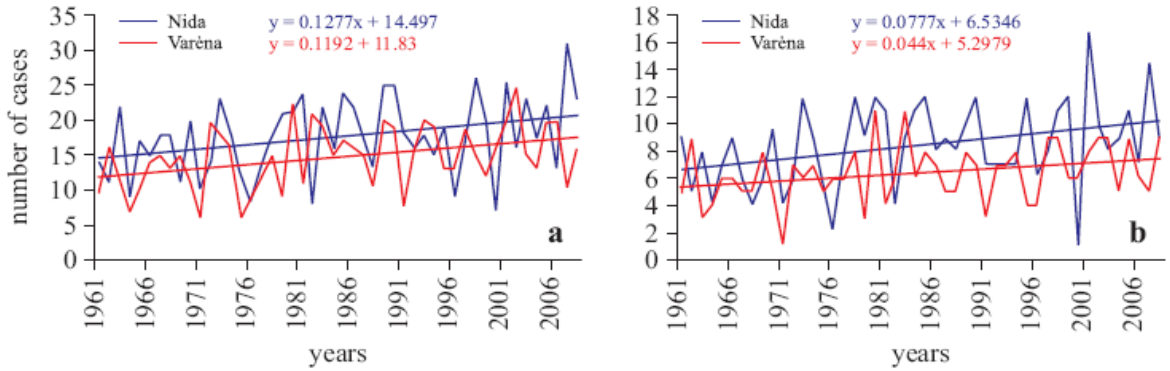
Often extreme events and changes in extreme situations are of more important than changes in mean climate.

- 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.

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)

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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.
  - Runoff explained by temperature, warmer means less runoff in southern regions and more runoff in northern regions.

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Summary

- General comments.
  - 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.

- Specifically:
  - Persistence of weather types has increased.
  - Runoff explained by temperature, warmer means less runoff in southern regions and more runoff in northern regions.

Summary

- 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.

Summary

Variable	Long term trend	Last decades
Air temperature	positive	positive
Precipitation	no trend	Mainly positive
Wind	no trend	Mainly positive
Run off	no trend	positive
Ice extent	negative	negative
Snow cover	negative	negative
Heavy precip	x	positive
Clouds	x	Mainly negative
Radiation	x	Positive and negative
Diurnal temperature amplitude	negative	negative
Length of growing season	positive	positive

Final comment:

- Variability in general dominating over trends: