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- Climate
- Climate change
  - Mean parameters
  - Circulation changes
  - Globally/regionally
- Why is it climate changing?
  - Climate factors
  - Feed-back mechanisms
- Climate sensitivity/climate variability
- Methods to understand and describe climate and its changes

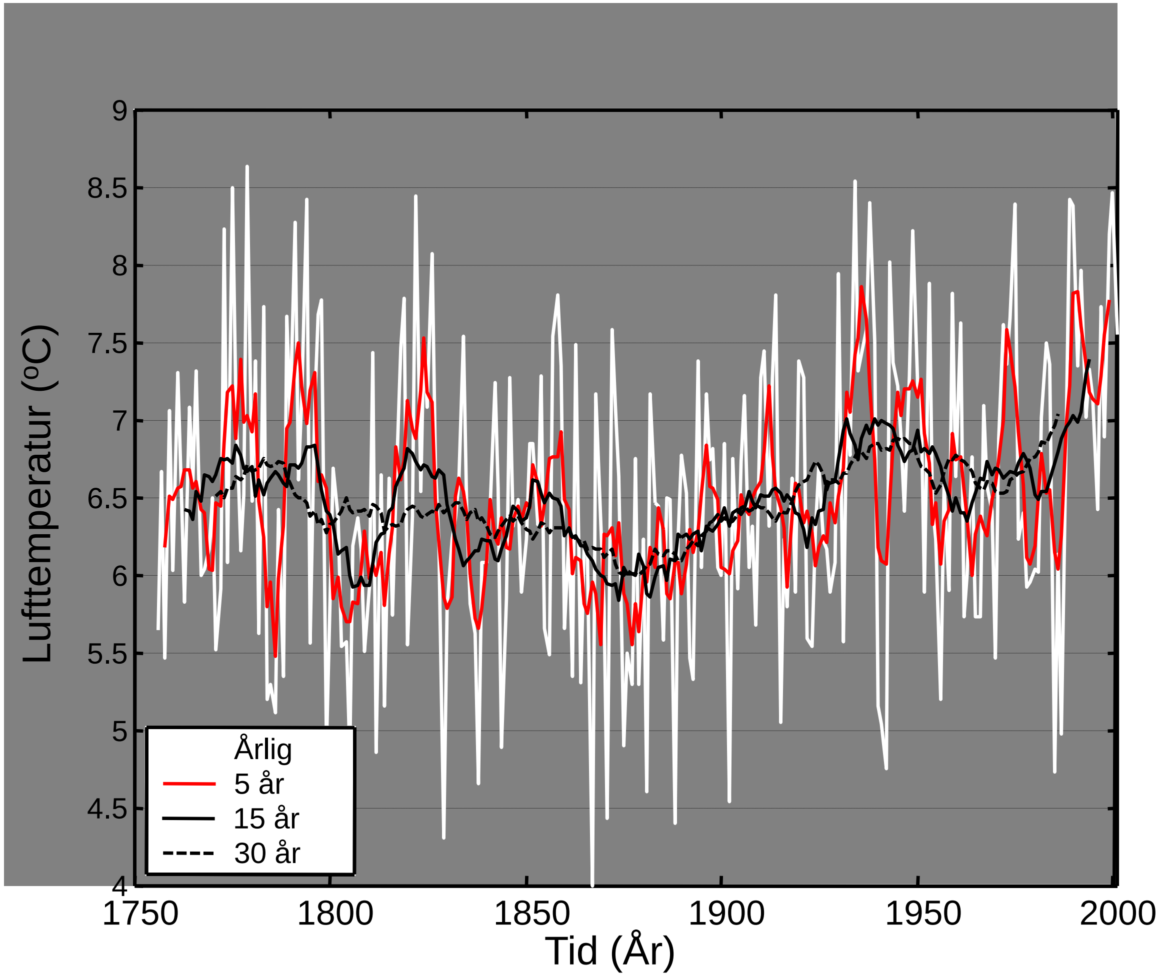
What is climate?

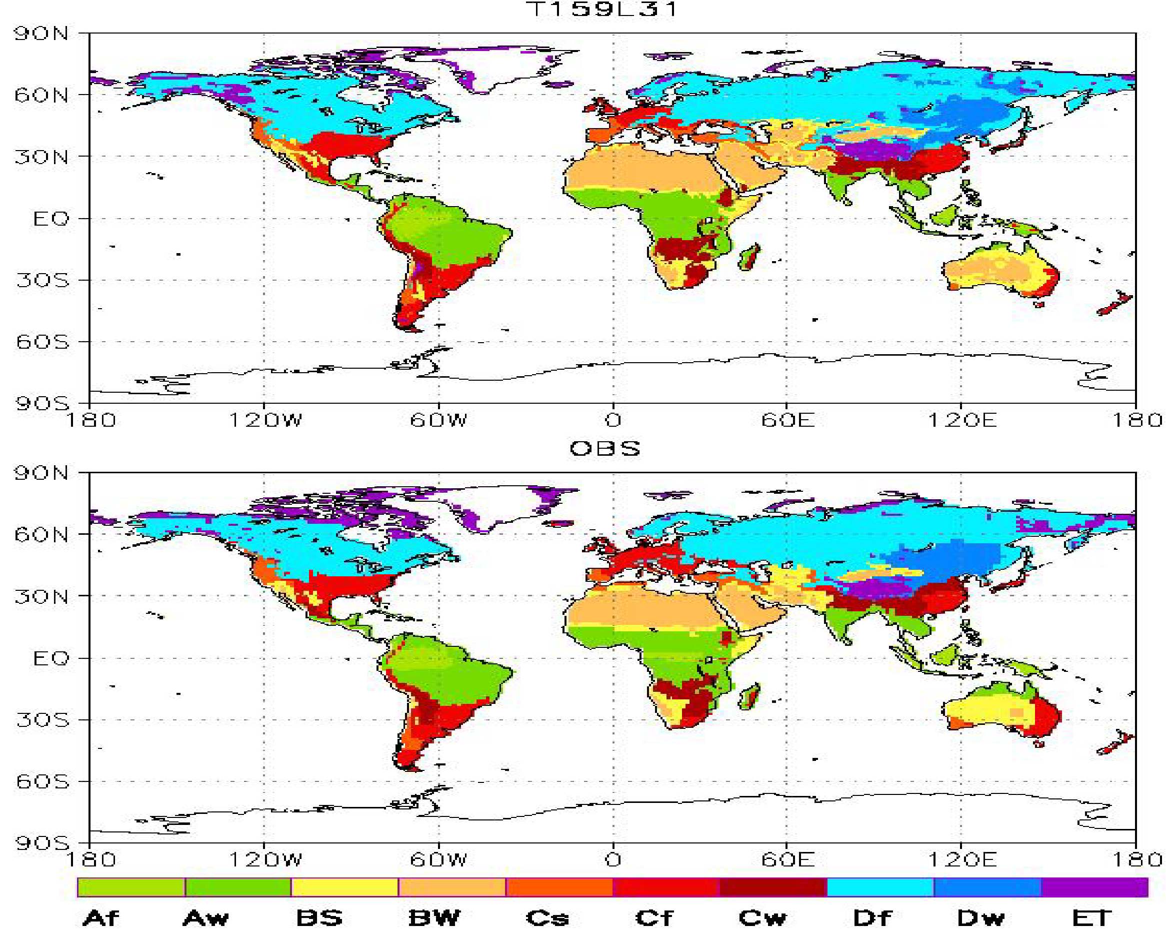
- 1 day (diurnal)
- 10 days (synoptic weather)
- 100 days (season)
- 1000 day (warm/cold years)

- **30 år (standard climate period)**
- 300 år (Little ice age)
- 3000 år (land rise)

- 30 000 år (Glacier retreat)

What is climate?





Köppen climate zones

ECHAM5

GPCP (Prec)
CRU2 (Temp)

T159

Climate stationary concept

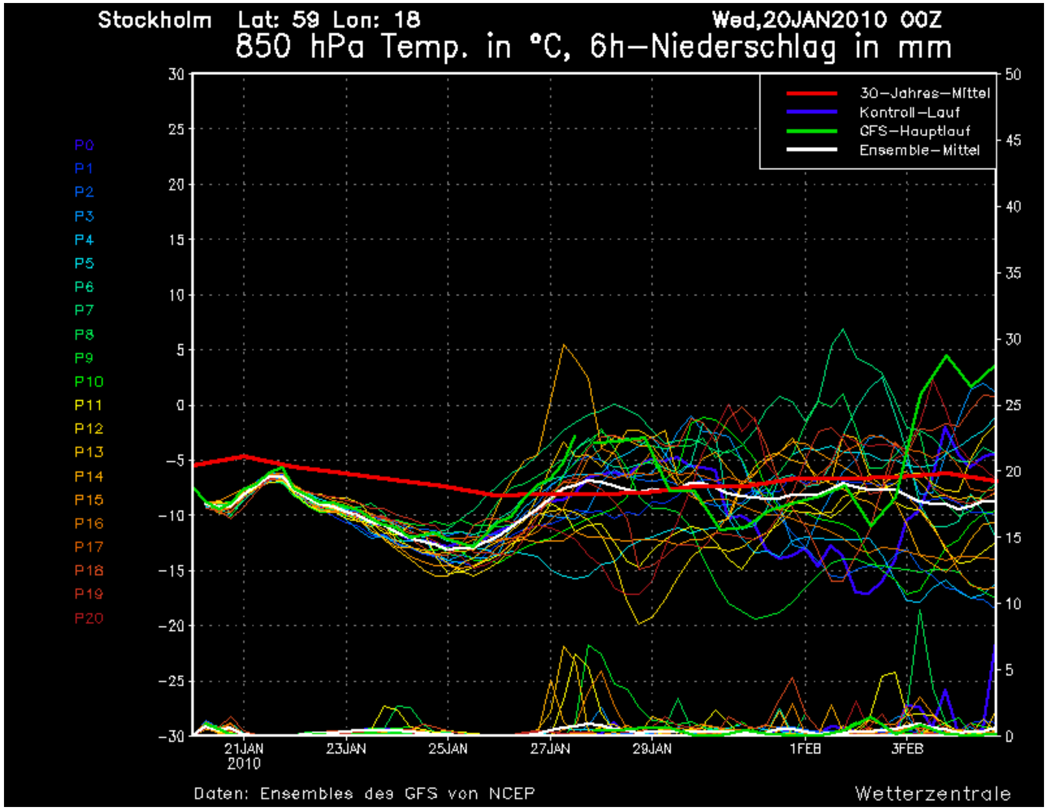
Main groups

- A: Tropical rainy climate, all months > +18 C
- **B**: Dry climate, Evaporation > Precipitation
- **C**: Mild humid climate, coldest month +18 C - -3 C
- **D**: Snowy - forest climate, coldest month < -3C but w
- **E**: Polar climate , warmest month < +10 C
- ET: Tundra climate, warmest month > 0 C

Internal variability of climate

Why do the climate vary – natural variability?

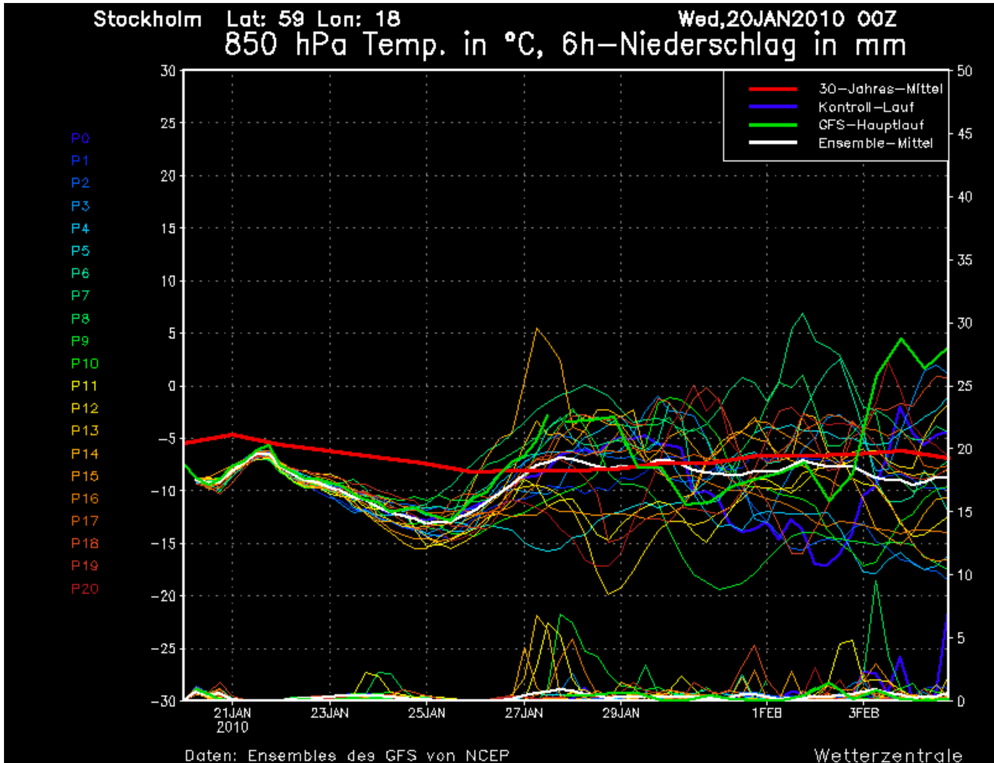
- We know that weather has a natural variability – so also the climate.



Variability of climate

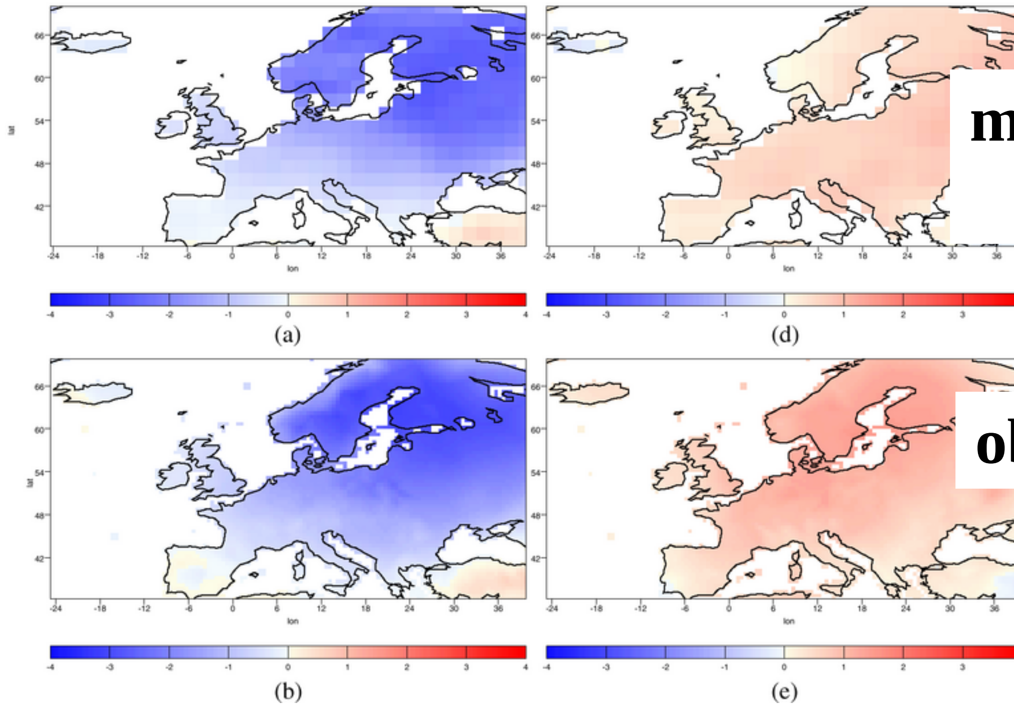
Why does the climate vary ?

- Internal variability
- Changes in forcing
  - Green-house-gases
  - Land-use-change
  - solar forcing



Internal variability of climate

- Model studies indicate that climate variations 1500-1900 is dominated by internal variability (not external forcing)
- 1900-2000 falls besides the internal variability

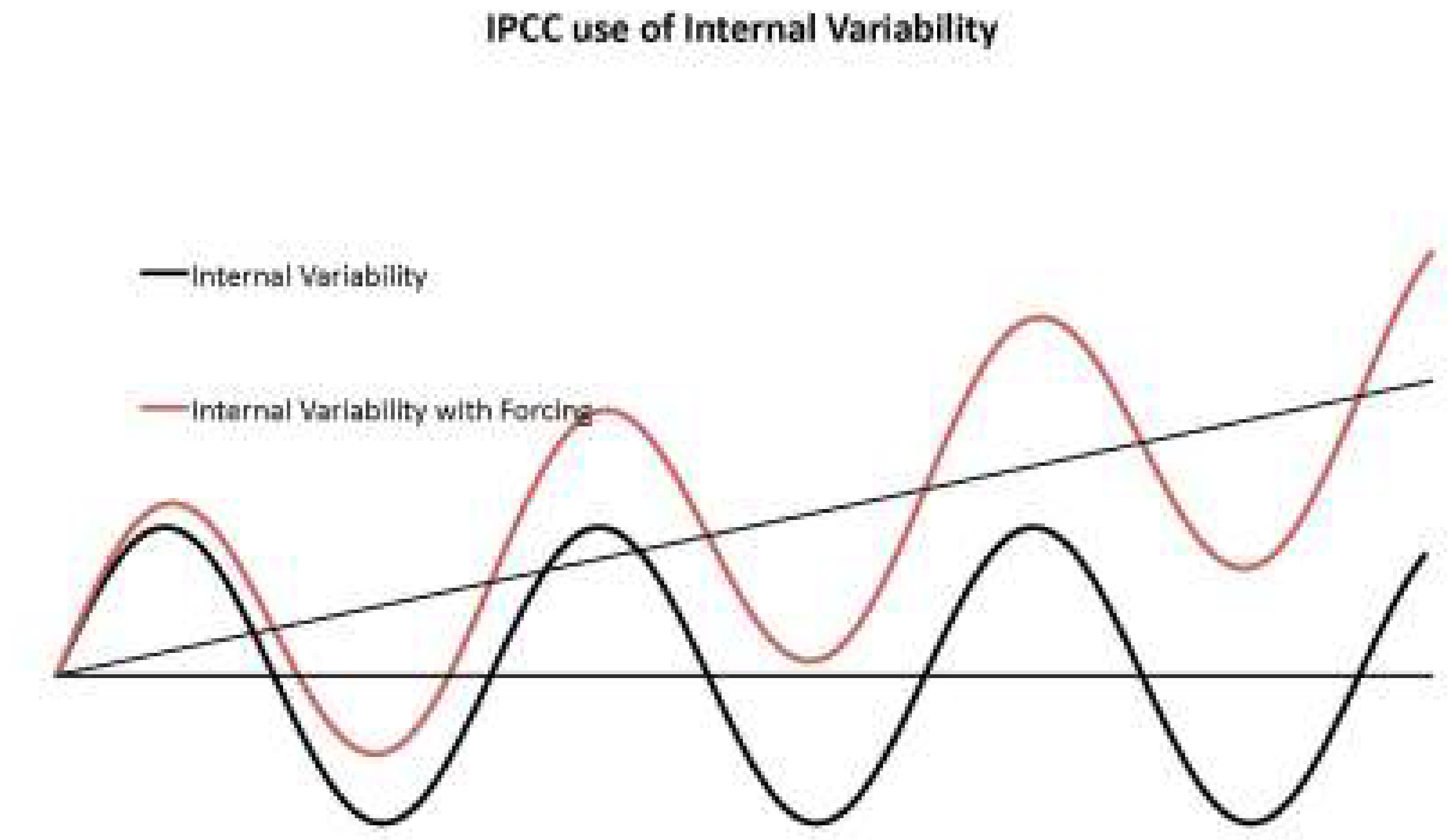


Largest temperature differences between 30 year periods winter (cold-warm) left, summer (warm-cold) right

Bengtsson et al

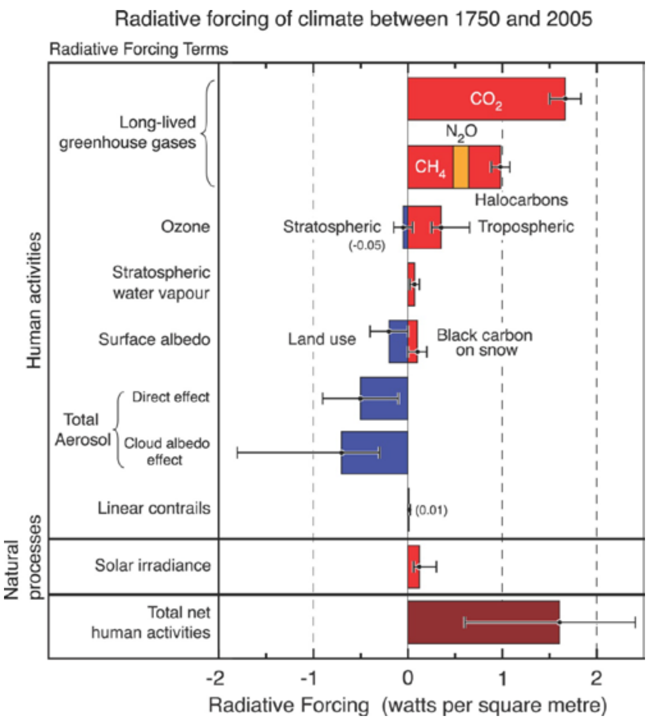
Internal variability of climate

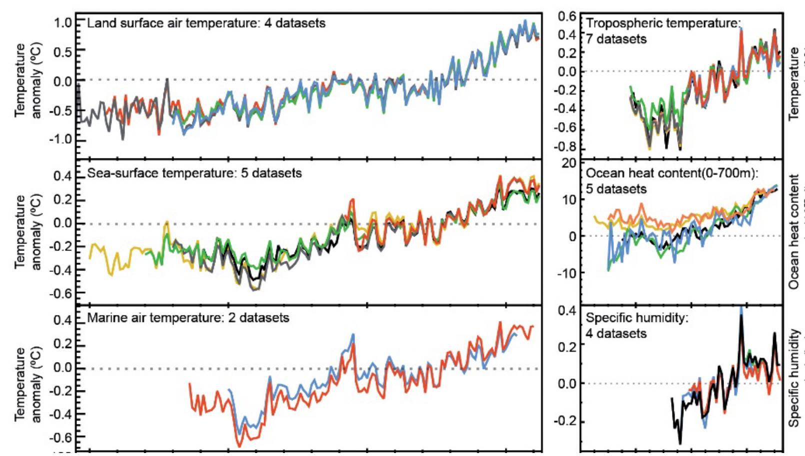
Variation is a combination of internal variability and changed forcing

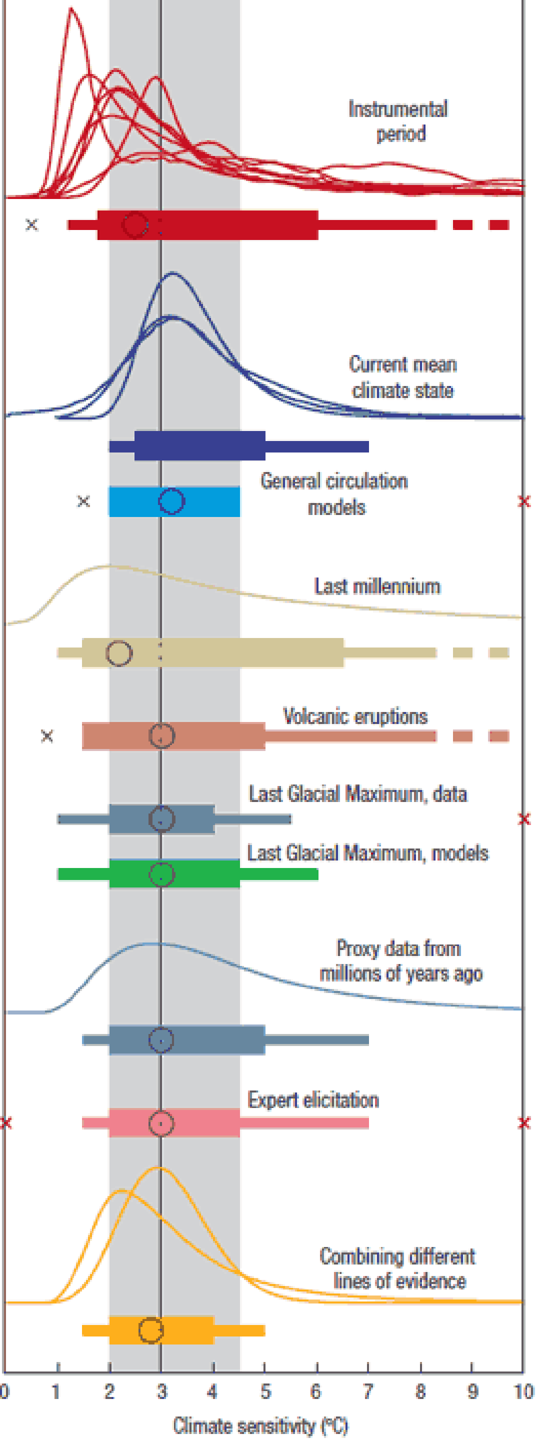


Climate sensitivity:

- **Climate sensitivity** is
  the equilibrium temperature change in response to changes of the radiative forcing.







Climate sensitivity:

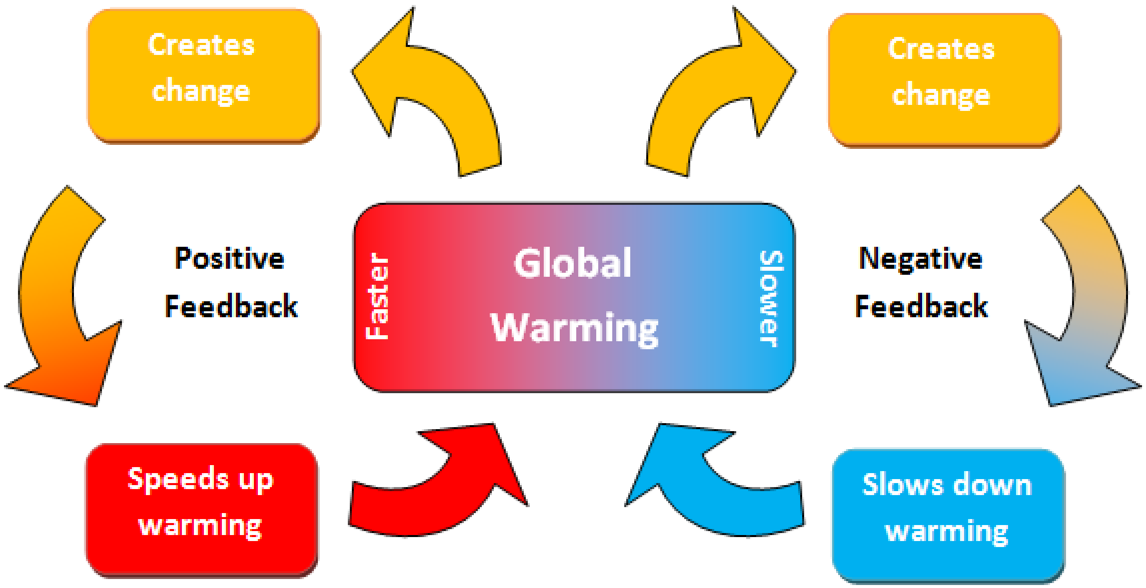
Temperature change for a certain change in radiation balance (K/(Wm[-2]))

$$\Delta T_s = \lambda \cdot RF$$

- Climate sensitivity: λ
- Often use climate sensitivity for a doubling of CO2 concentration
- IPCC: 2-4.5K

- Can be studied for present, past and future climates.

Feedback mechanisms

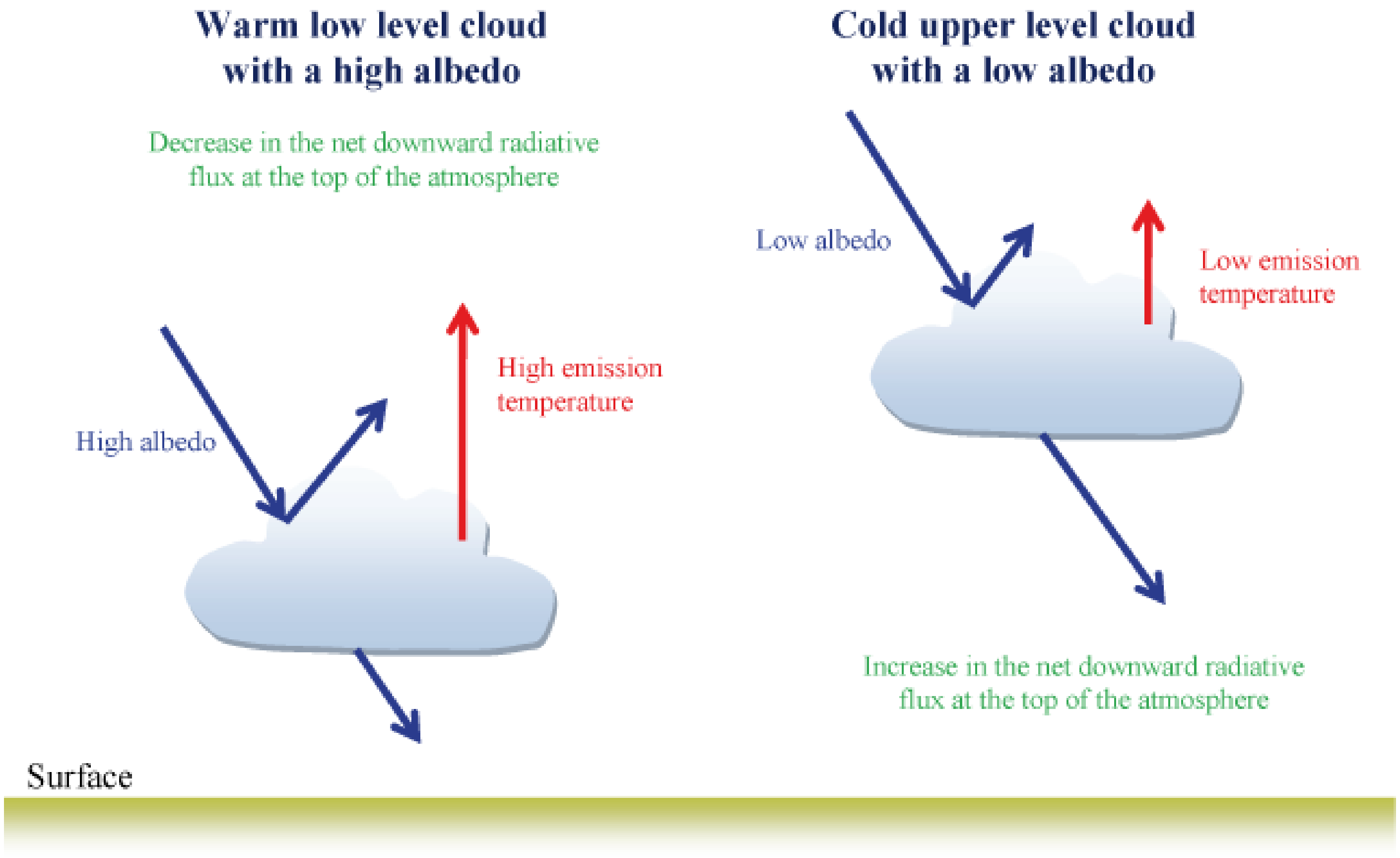


Feedback mechanisms

- Water vapor - positive
  - A warmer atmosphere can hold more water vapor and thus further enhance the greenhouse effect.
  - Water vapour feedback acting alone approximately doubles the warming from what it would be for fixed water vapour
  - Amplifies other feedbacks in models
- Clouds – positive/negative
  - Clouds has increased by 3.4-9.4% since 1900.
  - Increased low clouds probably responsible for a part of the heating (especially the nighttime heating).
  - Increase in clouds increase the reflectivity of the SW and thus leads to a cooling of the atmospehre.
  - Net effect is still very uncertain.
- Albedo – positive
  - Less snow and ice, give smaller reflectivity

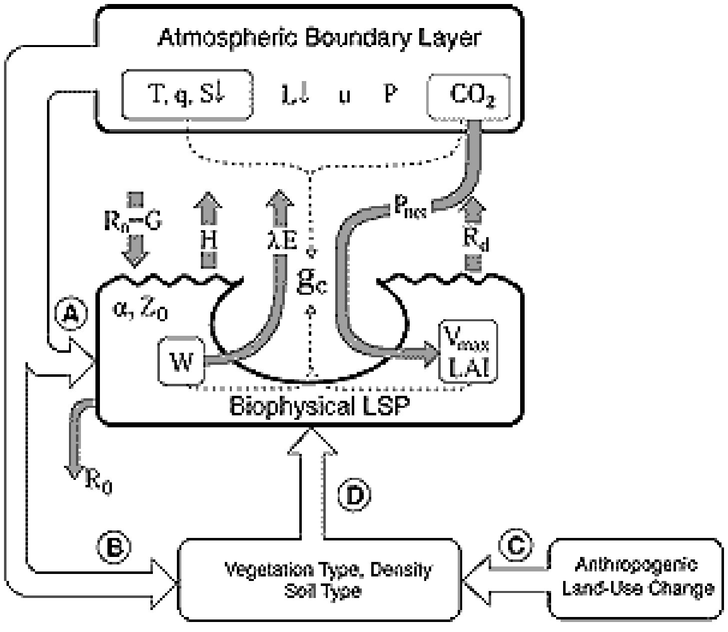
Feedback mechanisms

- Clouds positive/negative



Feedback mechanisms II

- Landuse – positive/negative
  - Uptake of carbon dioxide in plants
  - Surface albedo changes
  - Soil moisture changes (influences turbulent heat fluxes).
- Ocean – positive/negative
  - Change uptake of carbon dioxide
  - Changes in horisontal circulation
  - Changes in vertical structure



Other forcing mechanisms (not feedback mechanisms)

- Sulphate aerosols (dimethylsulphide, sulphur dioxide, natural sulphate, hydrogene sulphide) - negative
  - 1-7 days lifetime in atmosphere
  - Globally human induced of sulphate radiative forcing equals the natural sulphate radiative forcing.
  - Anthropogenic flux of sulphur dioxide to atmosphere is 10-20 times that of volcanoes.
  - Increases cloudiness by increasing cloud nuclei.
  - Makes clouds denser and brighter.
- Dust, positive/negative
  - Source regions are mainly deserts, dry lake beds, and semi-arid desert fringes, but also areas in drier regions where vegetation has been reduced or soil surfaces have been disturbed by human activities
  - 50% of the dust of anthropogenic origin (human disturbed surfaces)
  - Very uncertain effect, but most likely quite small due to cancellation.

Summarising feedback effects

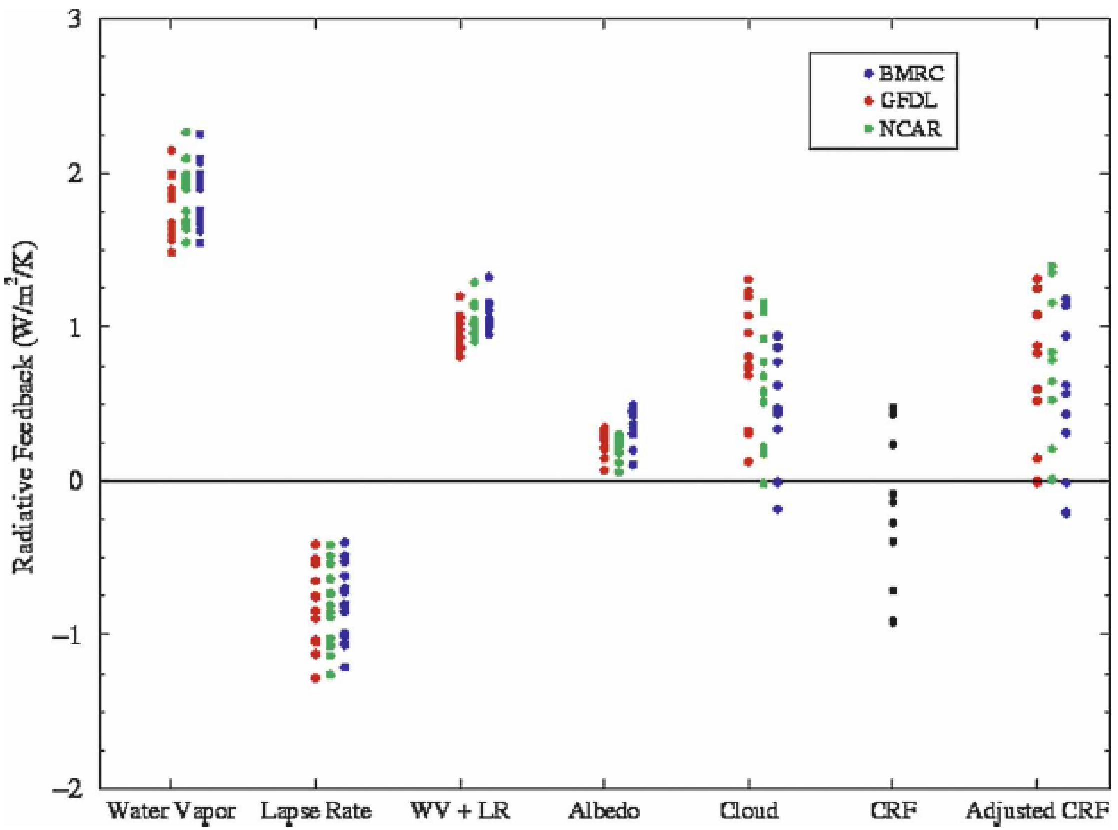


FIG. 7. The global-mean water vapor, lapse rate, water vapor + lapse rate, surface albedo, and cloud feedbacks computed for 14 coupled ocean–atmosphere models (listed in Table 1 of Soden and Held 2006) using the GFDL (red), NCAR (green), CAWCR (blue) kernels. The global-mean change in cloud radiative forcing (CRF) per degree global warming (black dots) and the adjusted change in CRF based on each of the three kernels are also shown. Only 12 of the 14 models archived the necessary data for computing cloud feedbacks, and only 11 of the 14 archived the necessary data for computing the change in CRF.

Soden et al (2008)

Summarising feedback effects

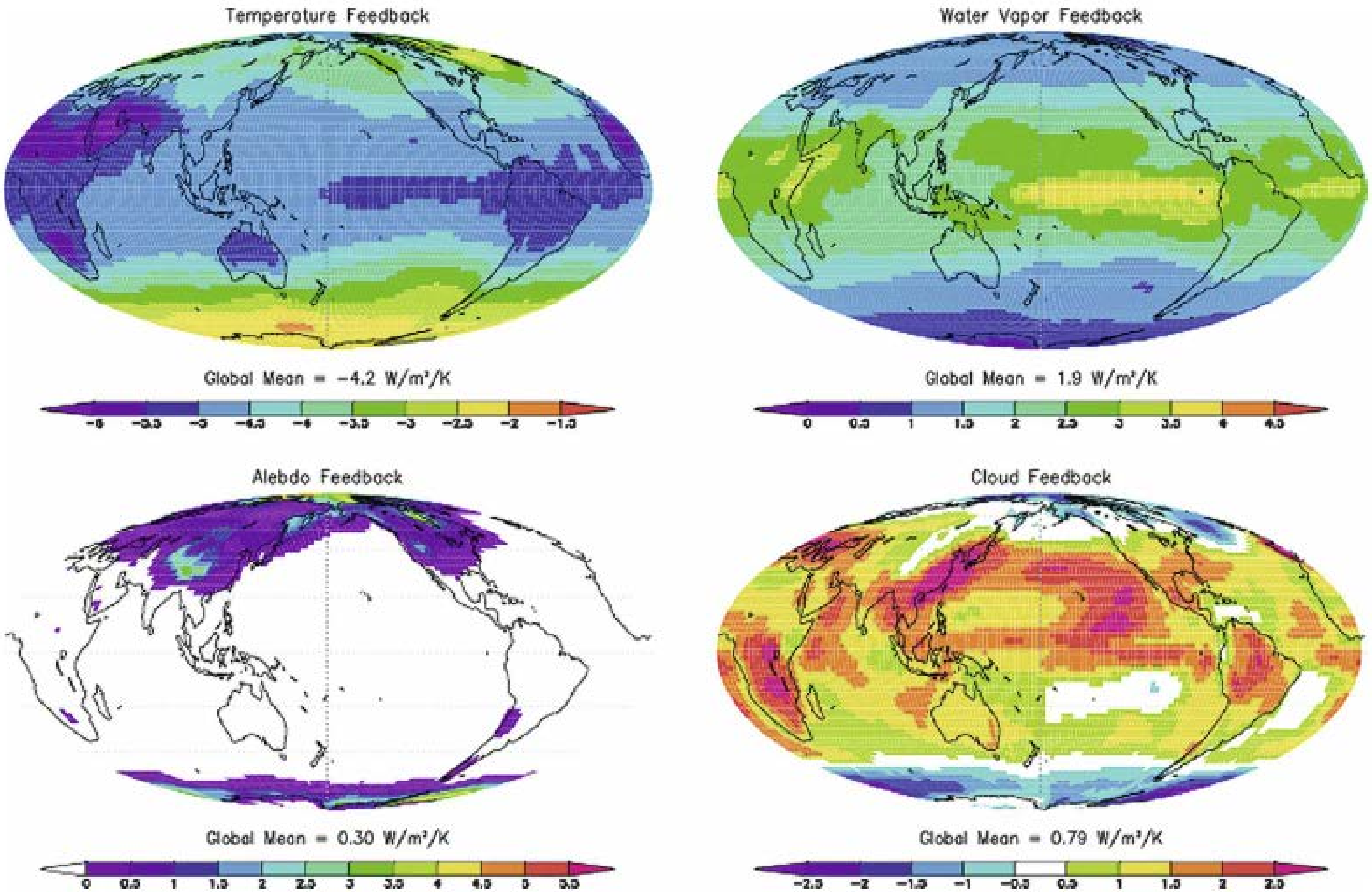


FIG. 8. Multimodel ensemble-mean maps of the temperature, water vapor, albedo, and cloud feedback computed using climate response patterns from the IPCC AR4 models and the GFDL radiative kernels.

Soden et al (2008)

Summarising feedback effects

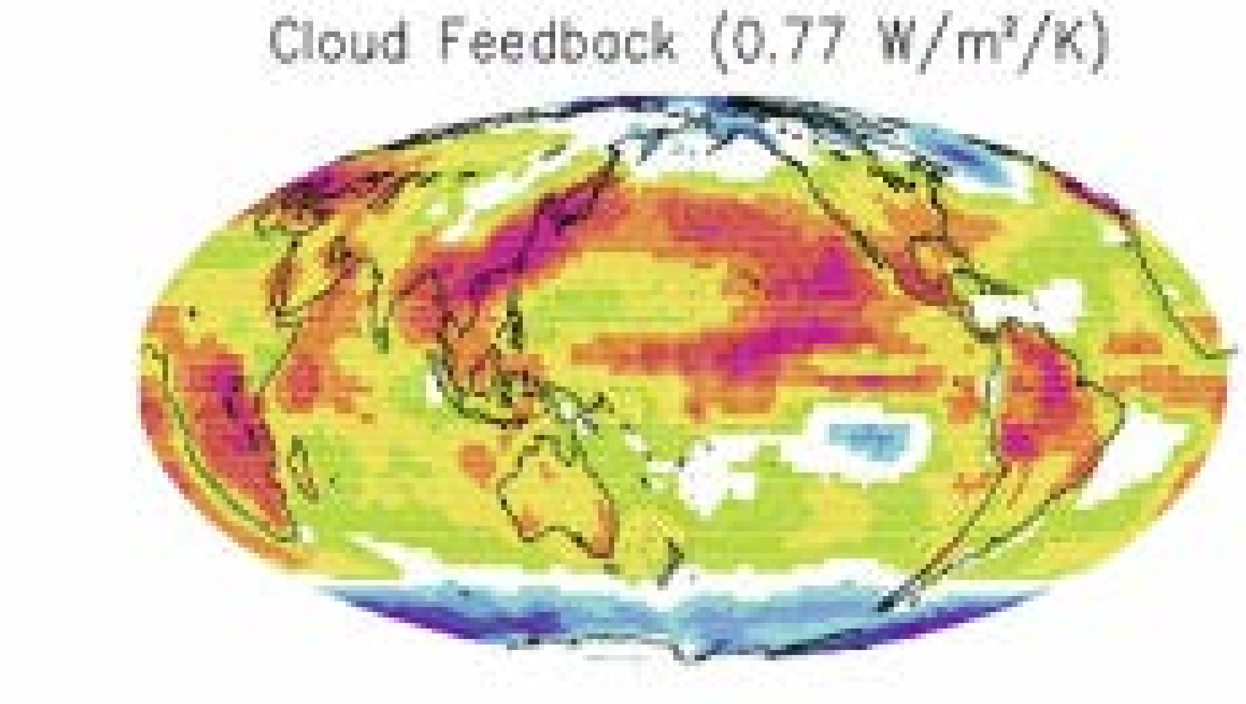
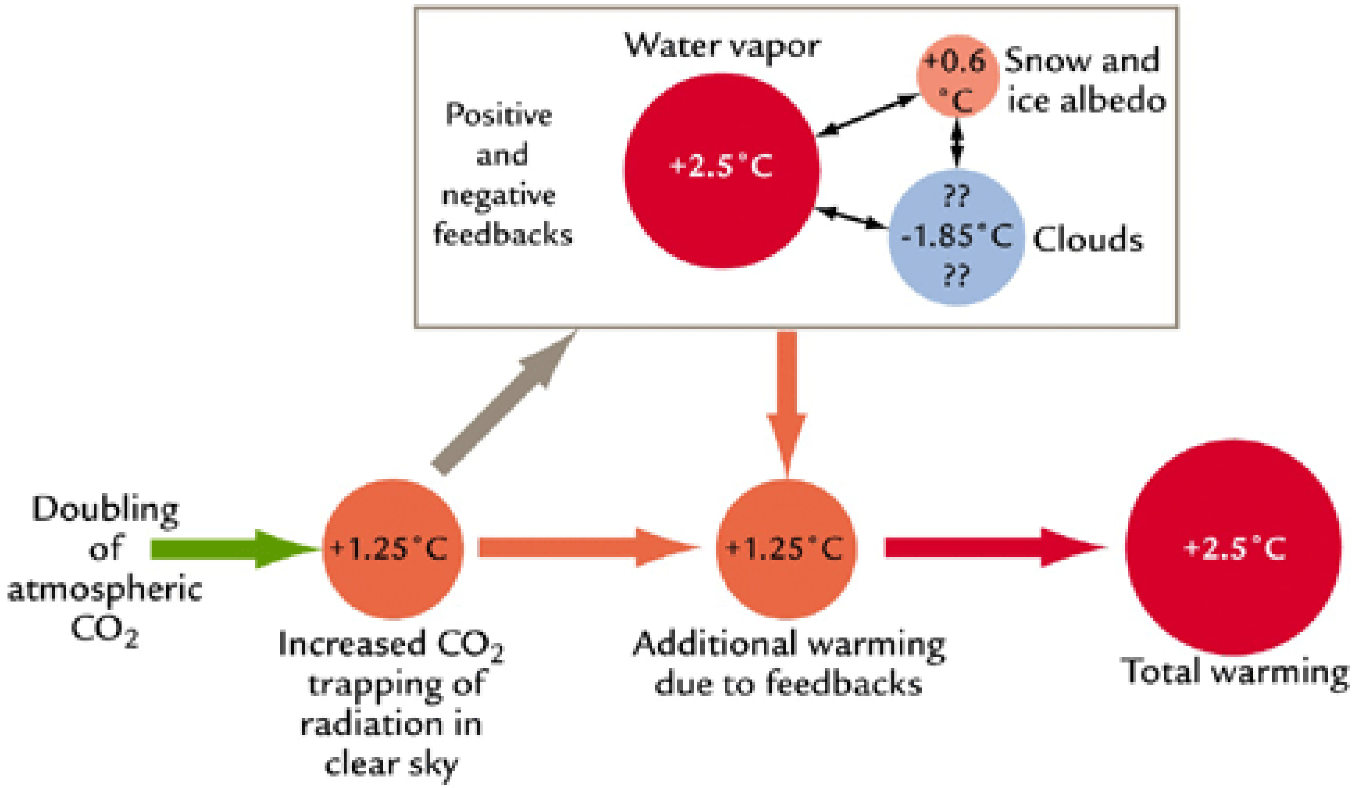


FIG. 11. Multimodel ensemble-mean maps of the cloud feedback estimated as (top) the residual of the kernel calculations, (middle) the change in cloud forcing, and (bottom) the change in cloud forcing after adjusting for the effects of cloud masking on noncloud feedbacks and external radiative forcing. Only those models for which both the cloud feedback and CRF were available are included in the ensemble mean. Both the cloud feedback and cloud-masking adjustments to the change in cloud forcing are estimated using the GFDL kernel.

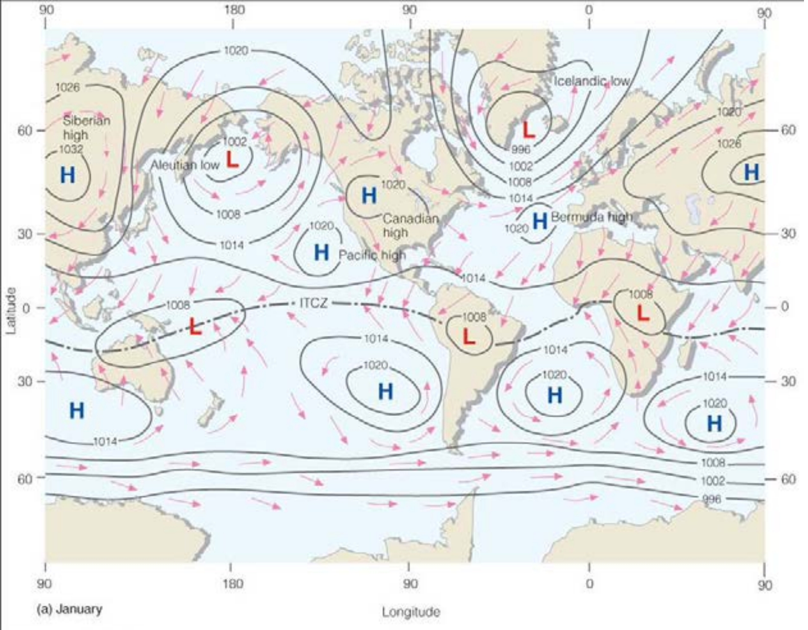
Soden et al (2008)

Feedback mechanisms

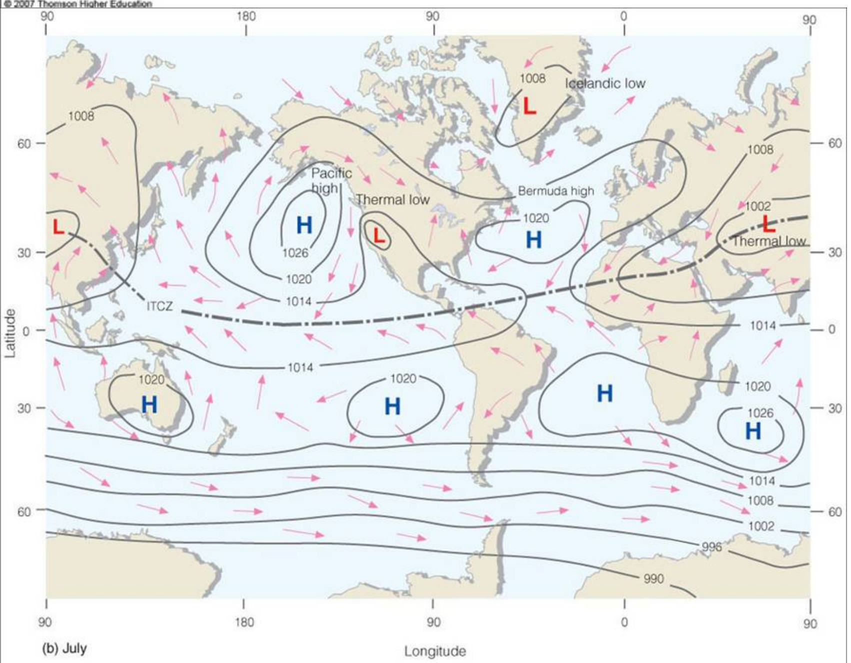
- Water vapor - positive
- Clouds – positive/negative
- Albedo – positive
  - Less snow and ice, give smaller reflectivity



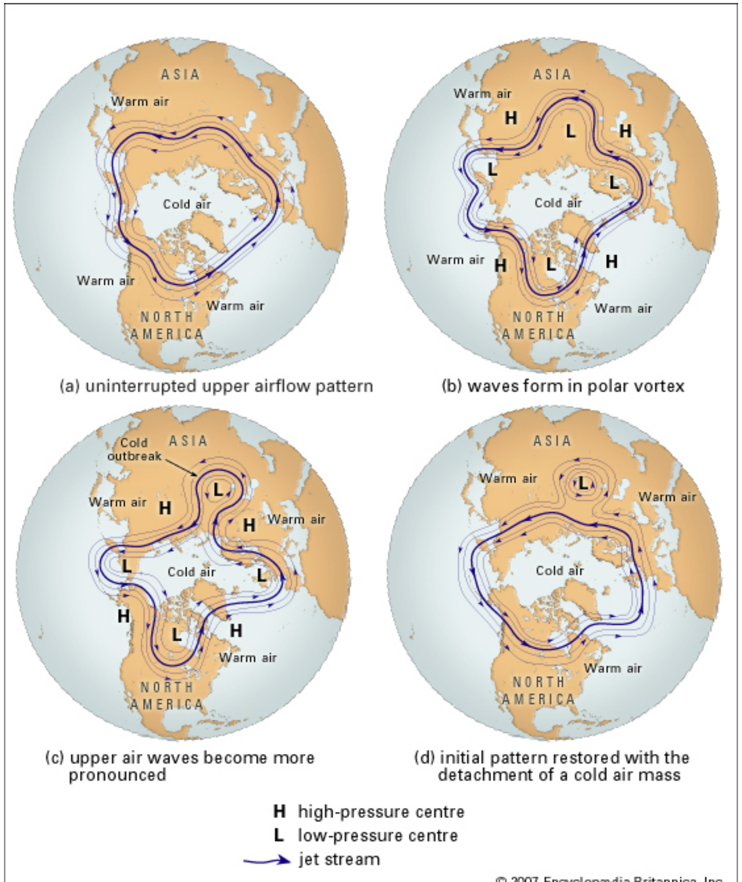
Large scale circulation patterns



(a) January



(b) July



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Global circulation patterns

- NAO/AO; Blocking
- ENSO
- Monsoon

Explain feature, and identify trend…

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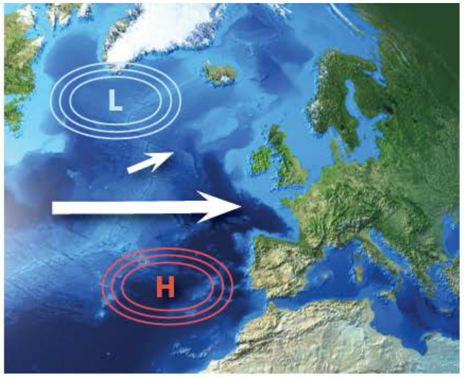
Atmospheric Circulation

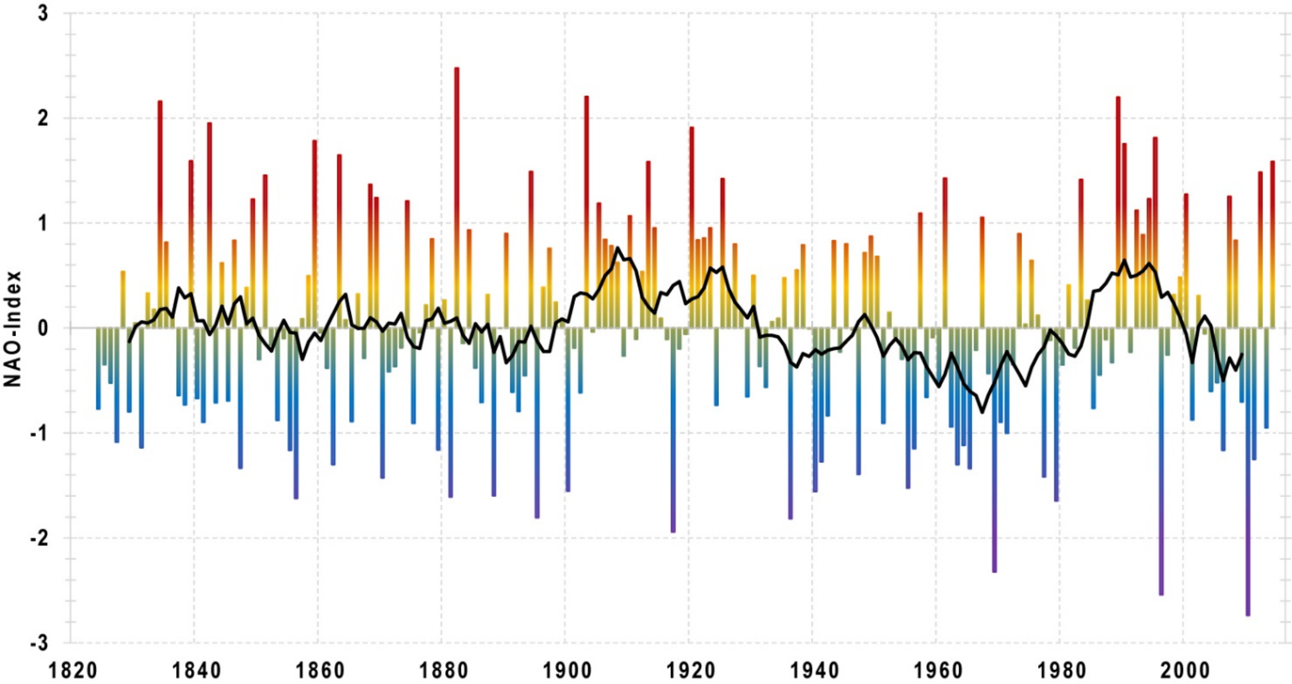
The climate of the Baltic Sea region is to a large extent determined by the circulation.

- NAO (pressure difference between Icelandic low and Azores high)
  - positive (warm, wet winters)
  - negative (cold, dry winters)

a/ NAO +



b/ NAO –



NAO index for boreal winter (DJFM) 1823/1824-2011/2014.

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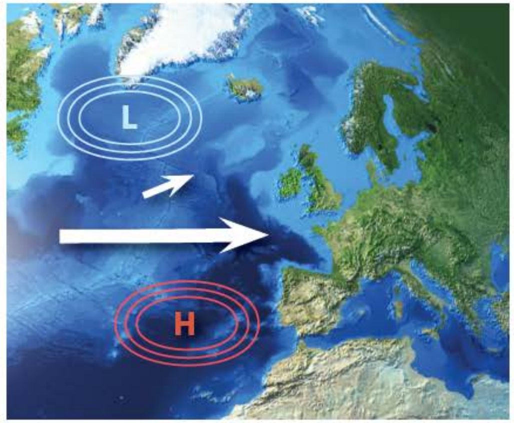
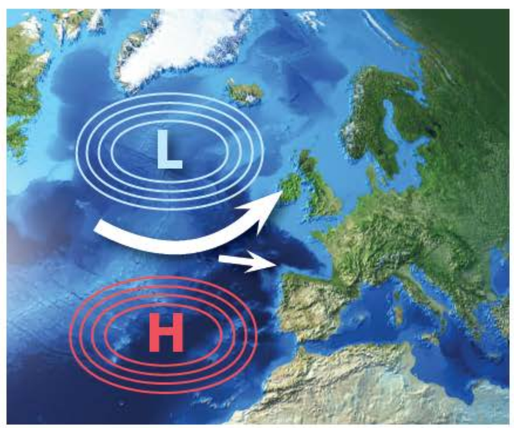
Atmospheric Circulation

a/ NAO +



b/ NAO -

c/ EA +



d/ EA -

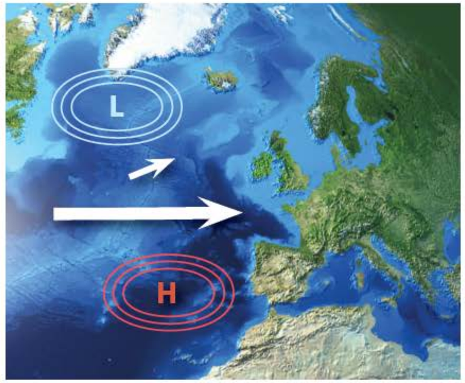
NAO: strength of pressure difference.

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

positive means a northward displacement (more zonal flow)

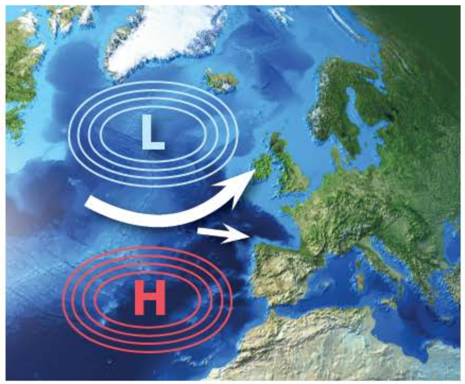
negative means a southward displacement (lower temperatures)

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.

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NAO and climate change

- Strong internal variability (adds uncertainties to climate scenarios (dominated by NAO or not)

- Behavious of NAO might be influenced climate change:

Indicated is a shift to more positive NAO and a northeastward shift in centers of action Deser et al 2017.

- AO have been thought of responsible for cold winters in Northern Europe

Contradicting features – very uncertain link to global warming.

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Forcing of NAO

Are winter temperatures related to ice in the Arctic?

Idea – reduced summer ice in the Arctic give lower winter temperatures in northern Europe.

One suggested mechanism:

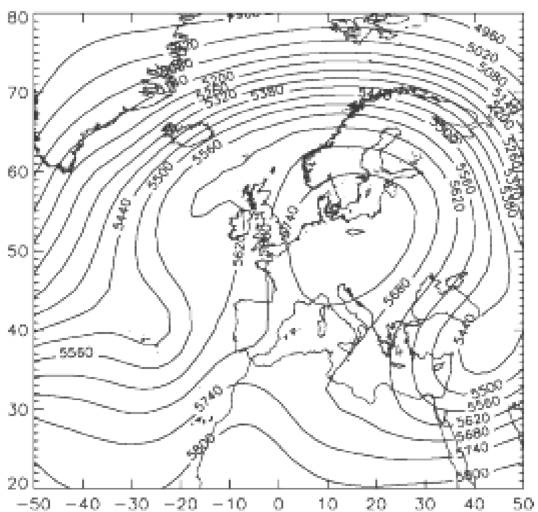
Low ice conc over Arctic Ocean → More heat into the atmosphere

↓

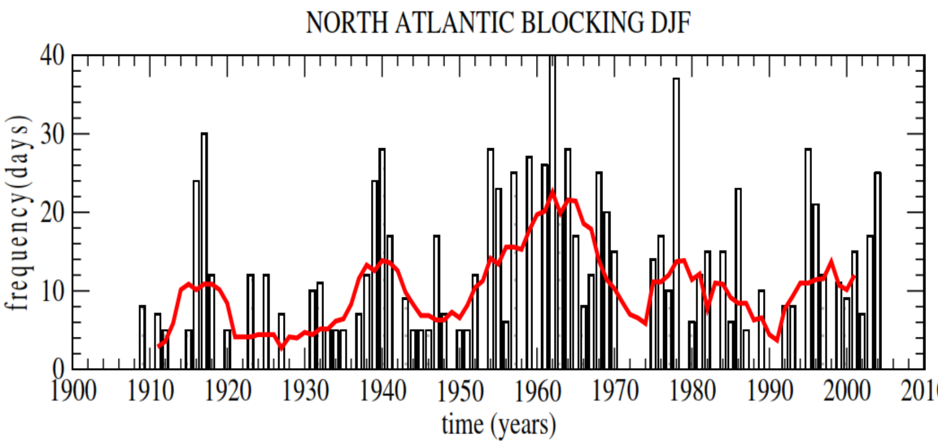
Circulation anomaly resembling of negative NAO ← Reduced vertical static stability

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 in a changing climate

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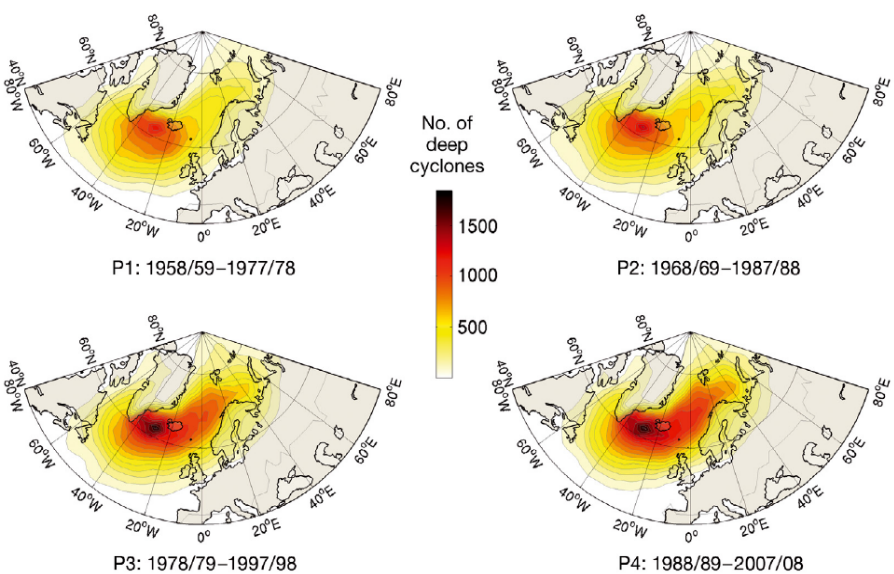
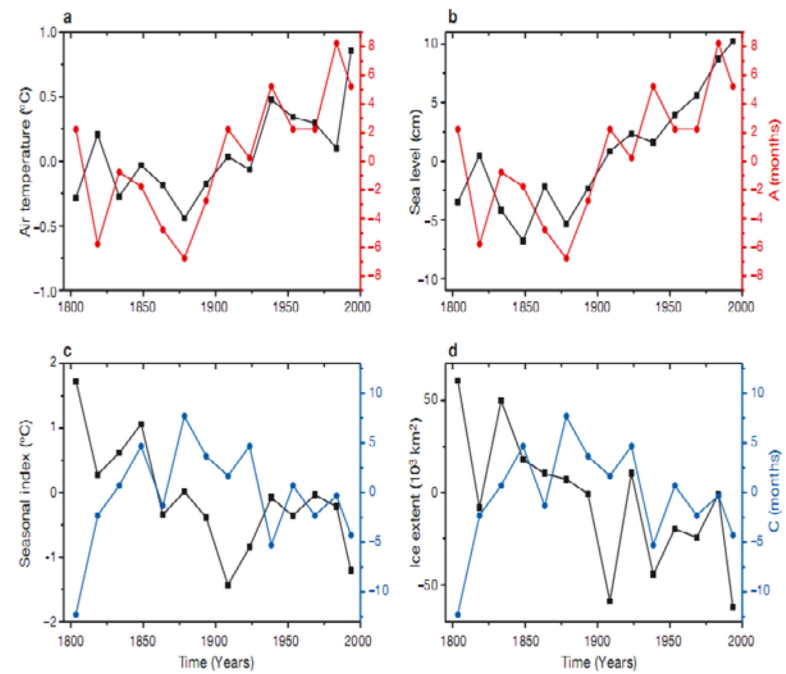
- Northward shift of low pressure tracks agrees with increased frequency of anticyclonic circulation.
- Increased frequency of westerlies.
- Increase in number of **deep** cyclones (not total number of cyclones).



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

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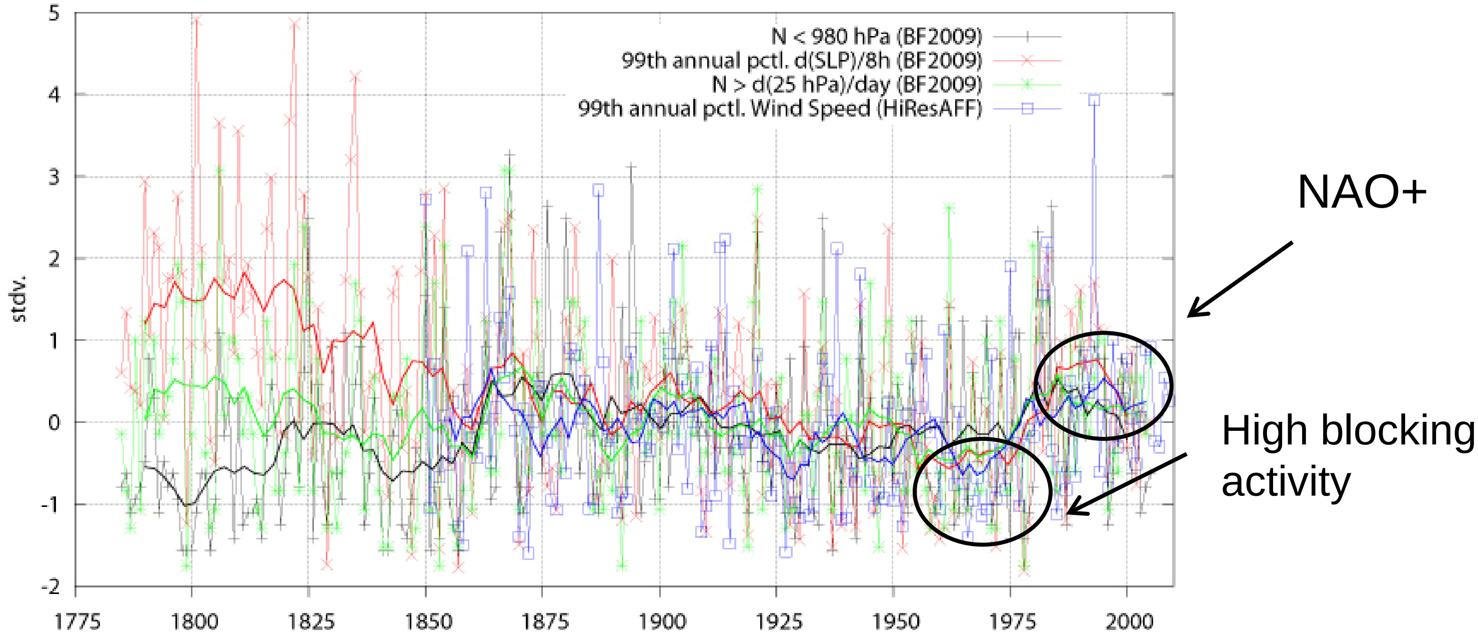
The wind climate is strongly connected with circulation.

- 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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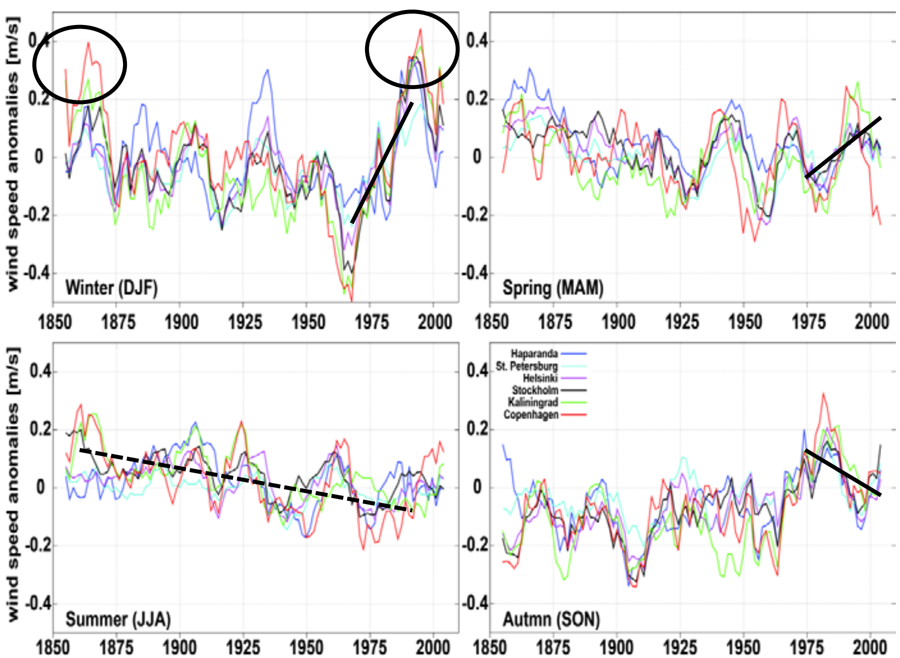
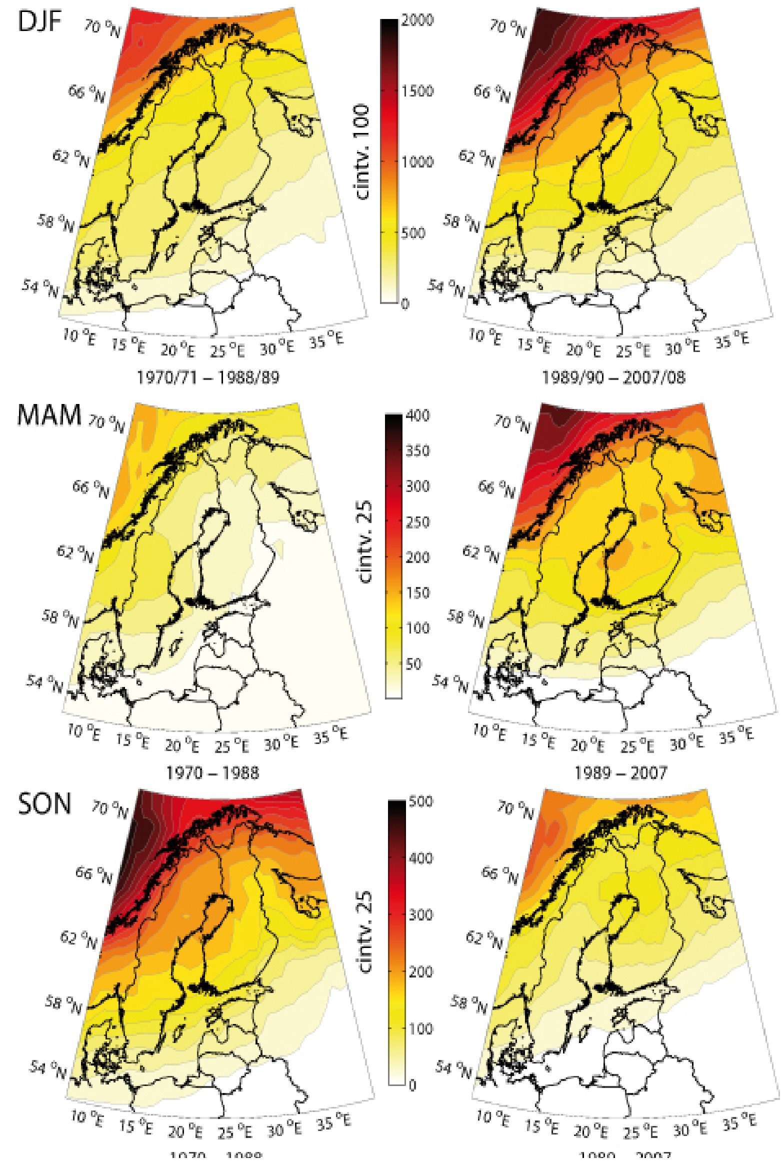
Wind/circulation

Seasonal differences:

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

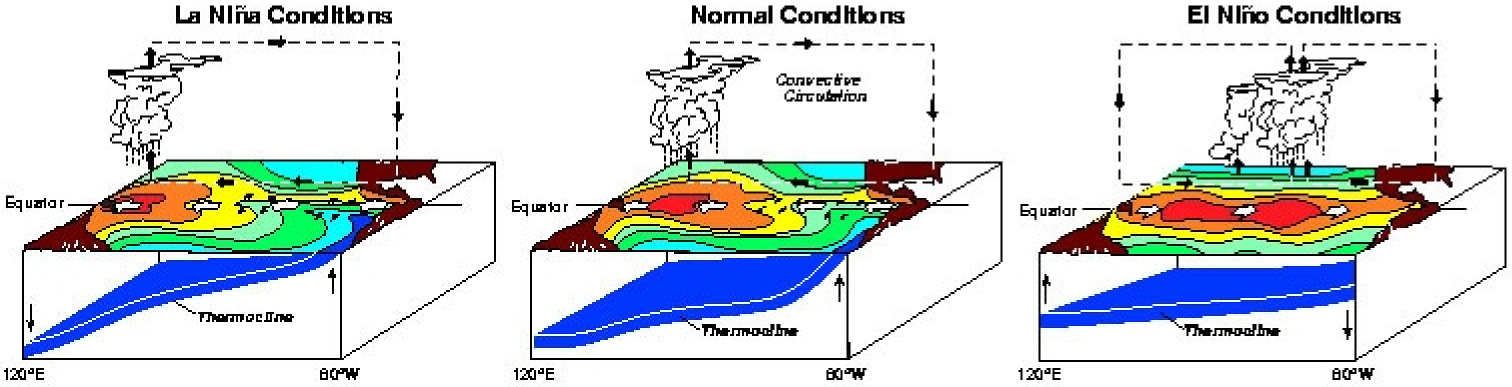


Sliding decadal (11-y) mean seasonal wind speed anomalies for the Baltic Sea regions for 1850-2009 (Schenk and Zorita, 2011, 2012).



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).

What is El Nino.

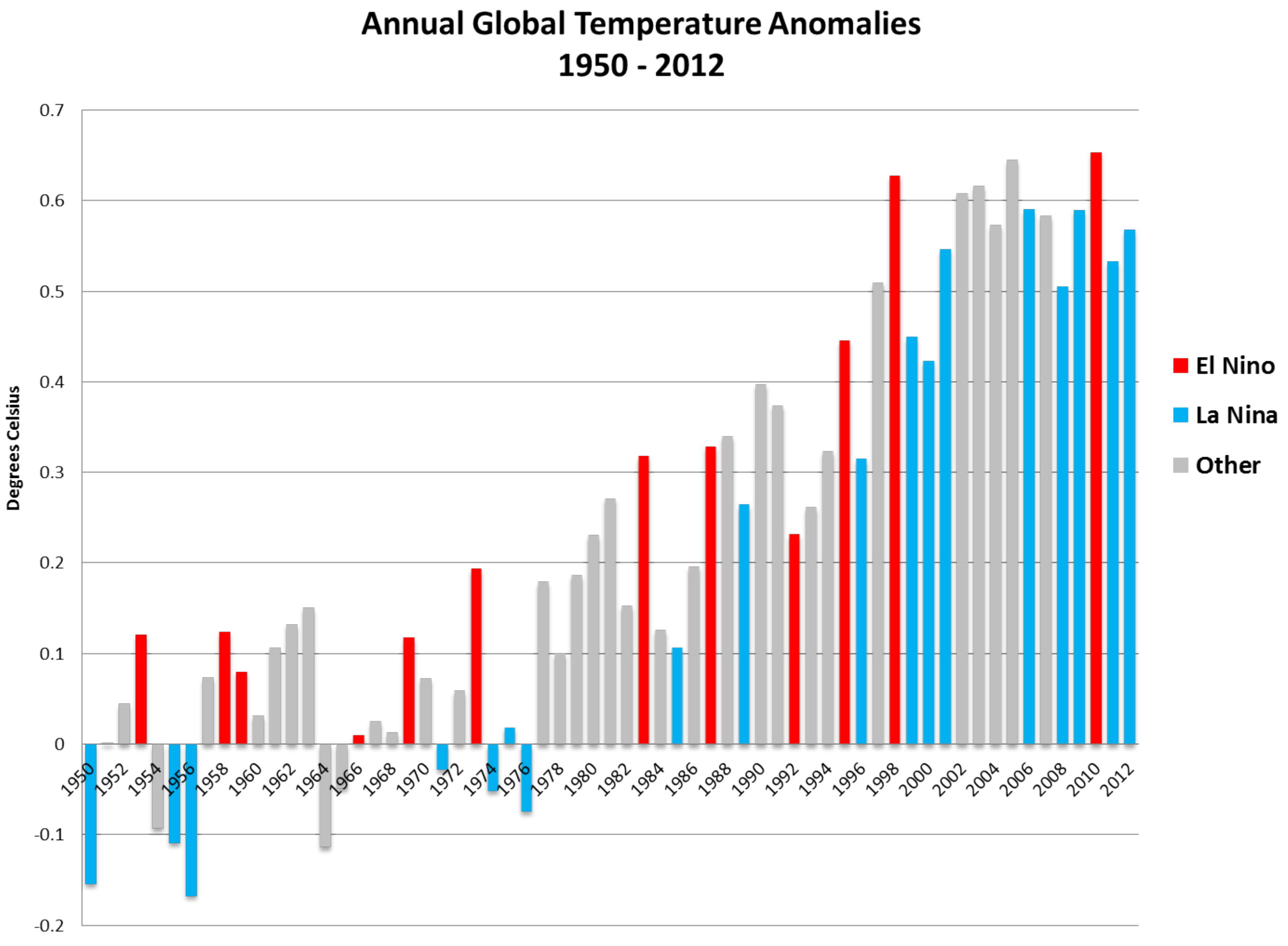


- Increased rainfall across Eastern Pacific Ocean and South American west coast (including flooding).
- Suppress cyclones.
- Drier conditions occur in parts of Southeast Asia and Australia.

Cold phase (La Nina)

- Enhance tropical cyclones
- Heavy rains over Malaysia, Philippines and Indonesia.
- Drought in the coastal regions of Peru and Chile

El Ninjo (Southern Oscillation) events



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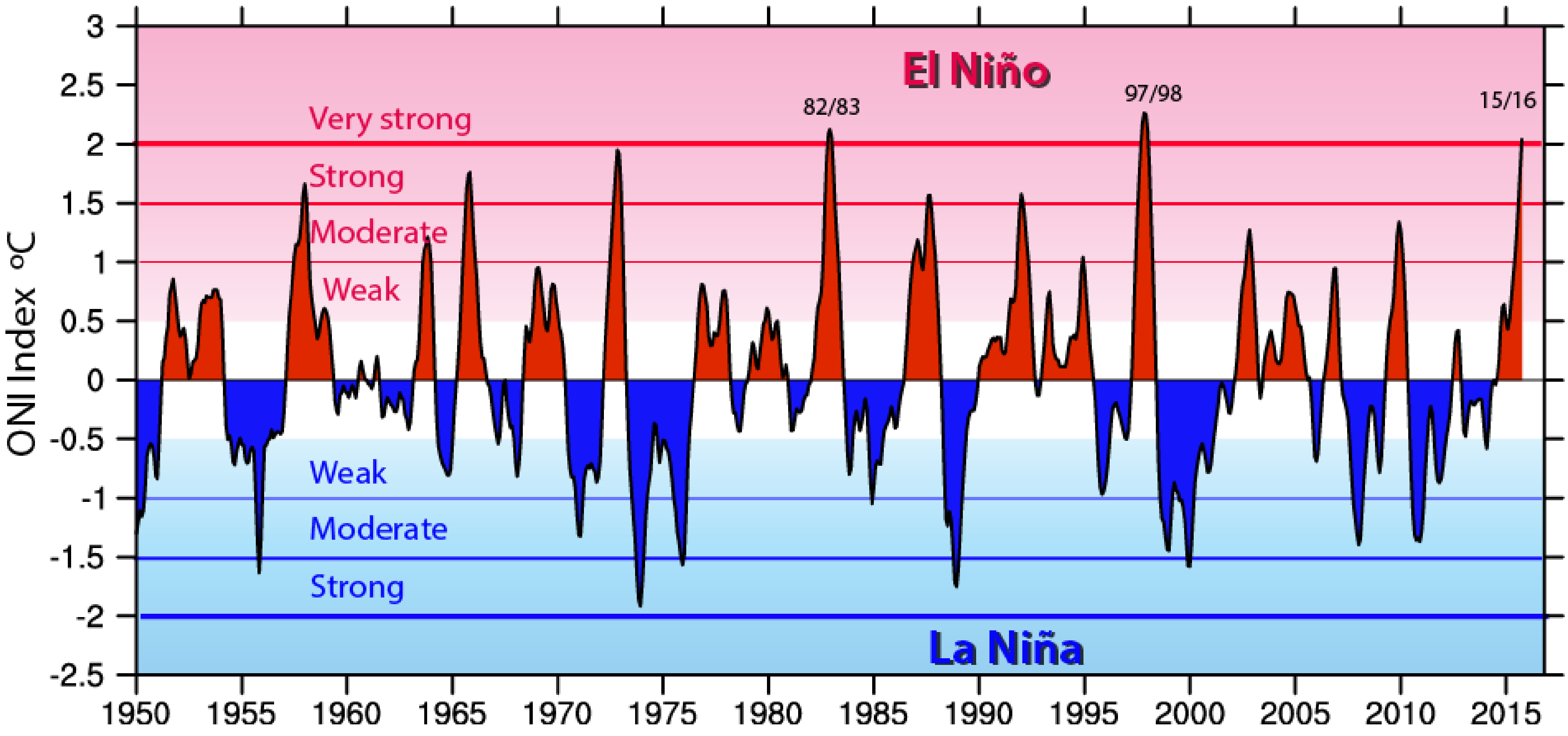
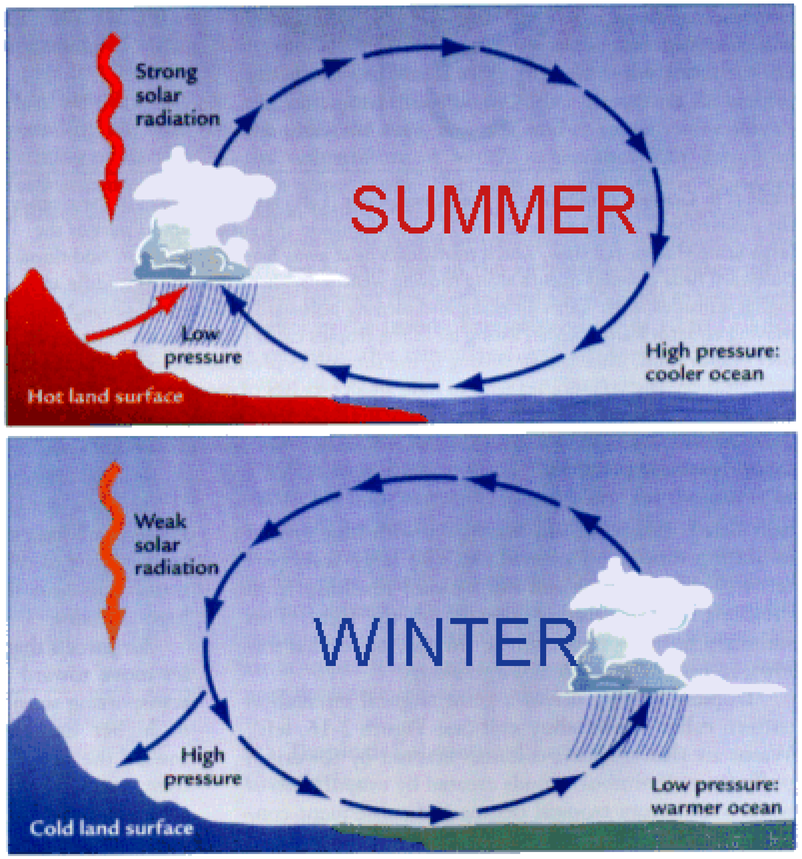
No clear link between climate change and frequency of El Nino.



Trenberth, Kevin & National Center for Atmospheric Research Staff (Eds). Last modified 02 Feb 2016. **"The Climate Data Guide: Nino SST Indices (Nino 1+2, 3, 3.4, 4; ONI and TNI)."** Retrieved from https://climatedataguide.ucar.edu/climate-data/nino-sst-indices-nino-12-3-34-4-oni-and-tni.

Monsoon

- Different heating land/sea over the major continents
- Pressure difference generates circulations
- Generates seasonal dry/moist periods

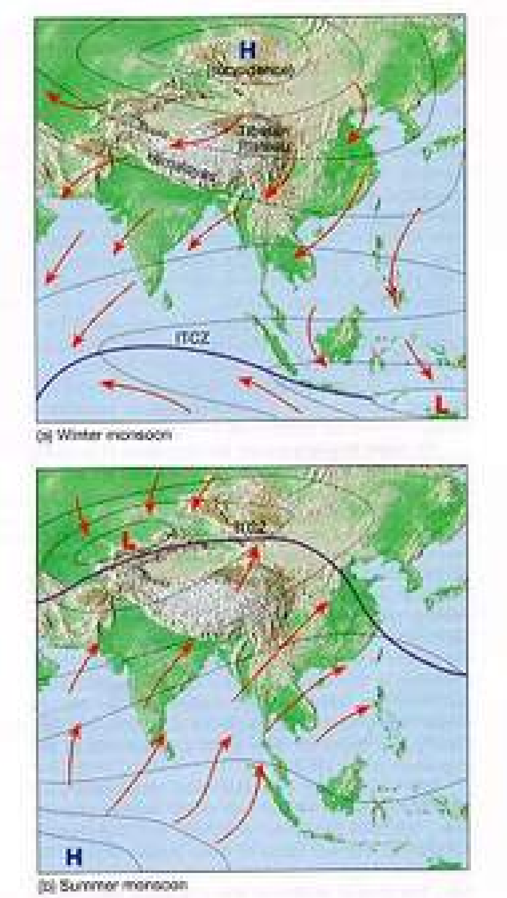


Monsoon and climate change

Results relatively uncertain relation and varying between different monsoon systems

* General decrease of monsoonal flow

* Increase in monsoon related precipitation



Other changes of the climate

- Temp, precipitation

- Extreme events

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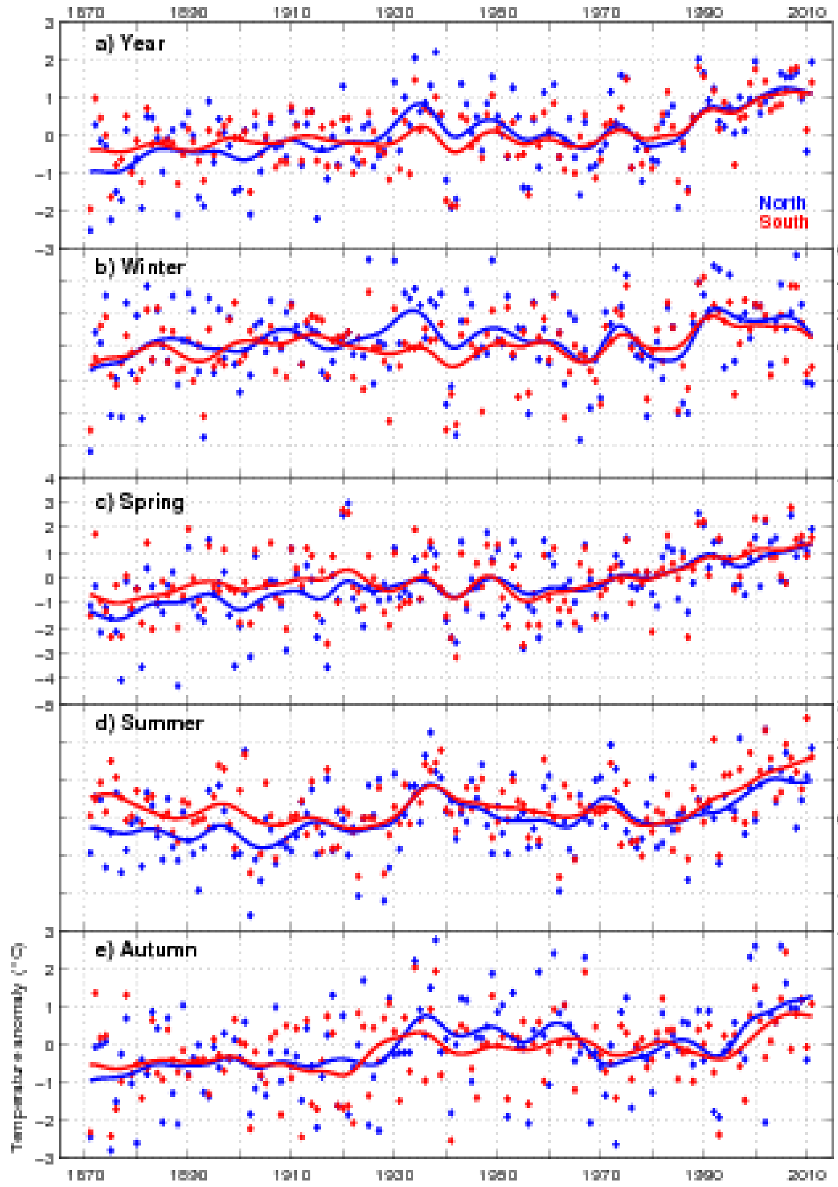
Temperature: Air

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.

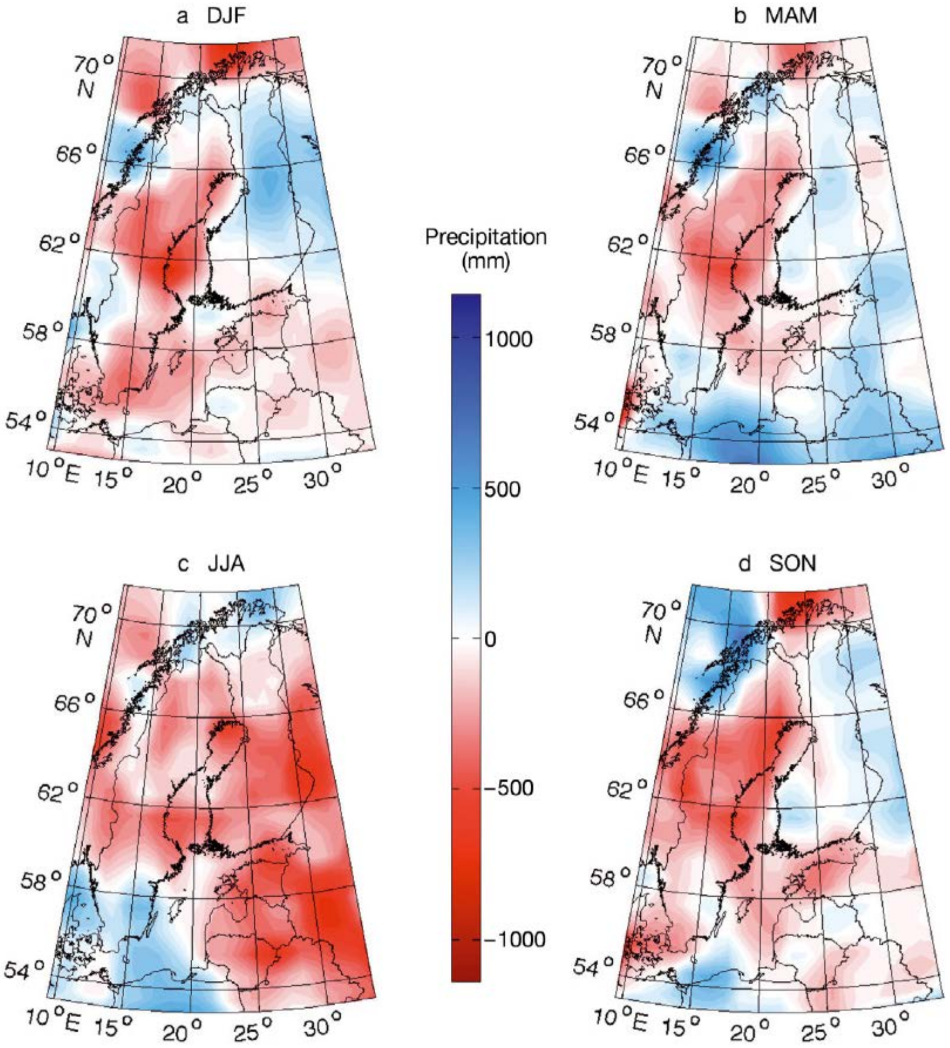
Precipitation

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

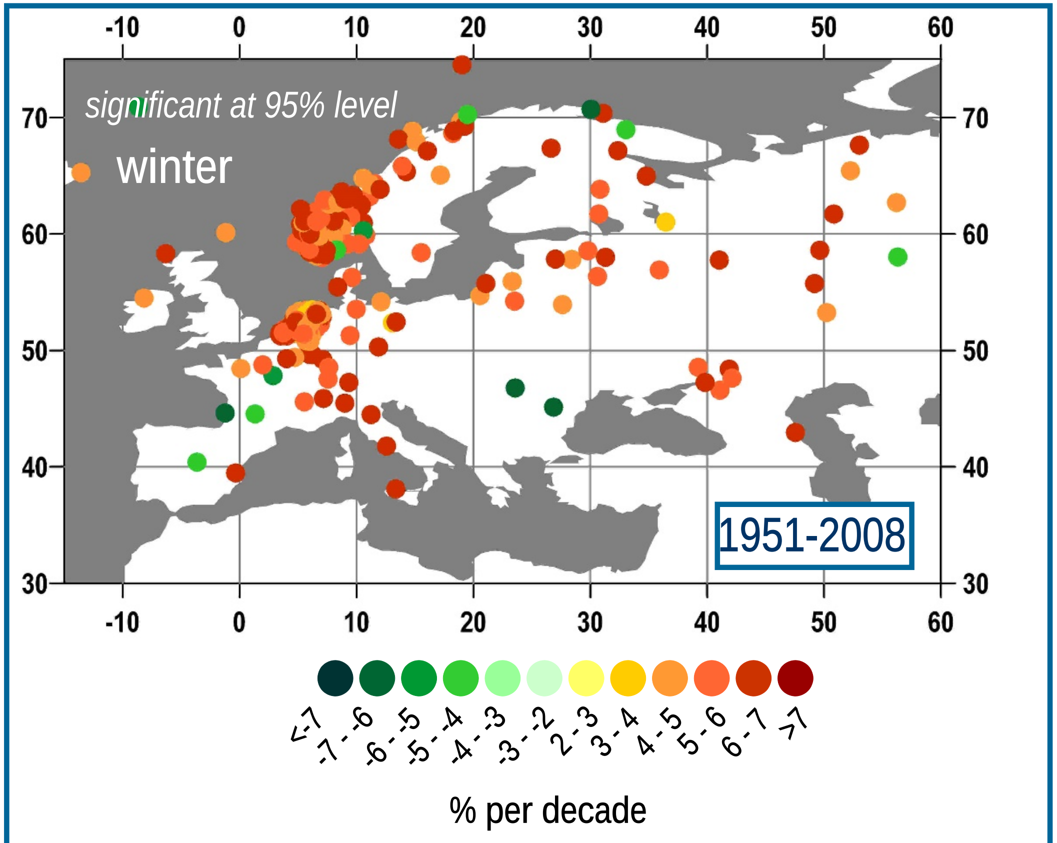
Precipitation

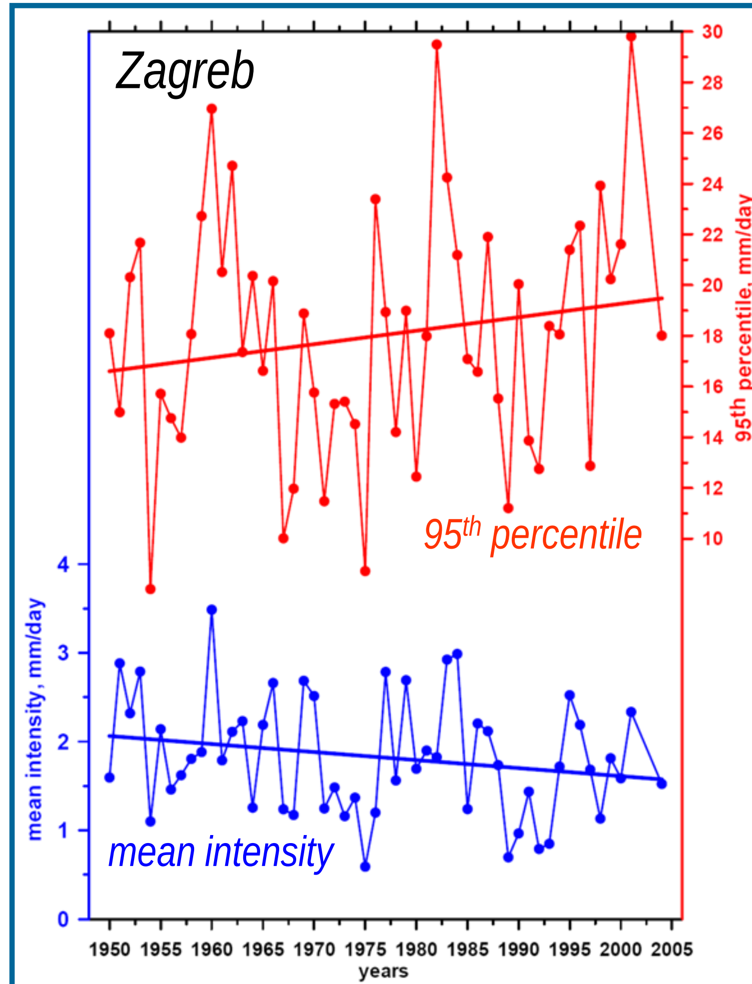
- For the last decades
  - General increase in winter and spring precipitation in northern Europe.
  - Highest increase in Sweden and eastern coast of the Baltic Sea.
- Comparing 1994-2008 to the previous 15 years:
  - Less precipitation in northern and central Baltic Sea.
  - More precipitation in the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

Absolute precipitation extremes: observed changes in 95% percentile of precipitation





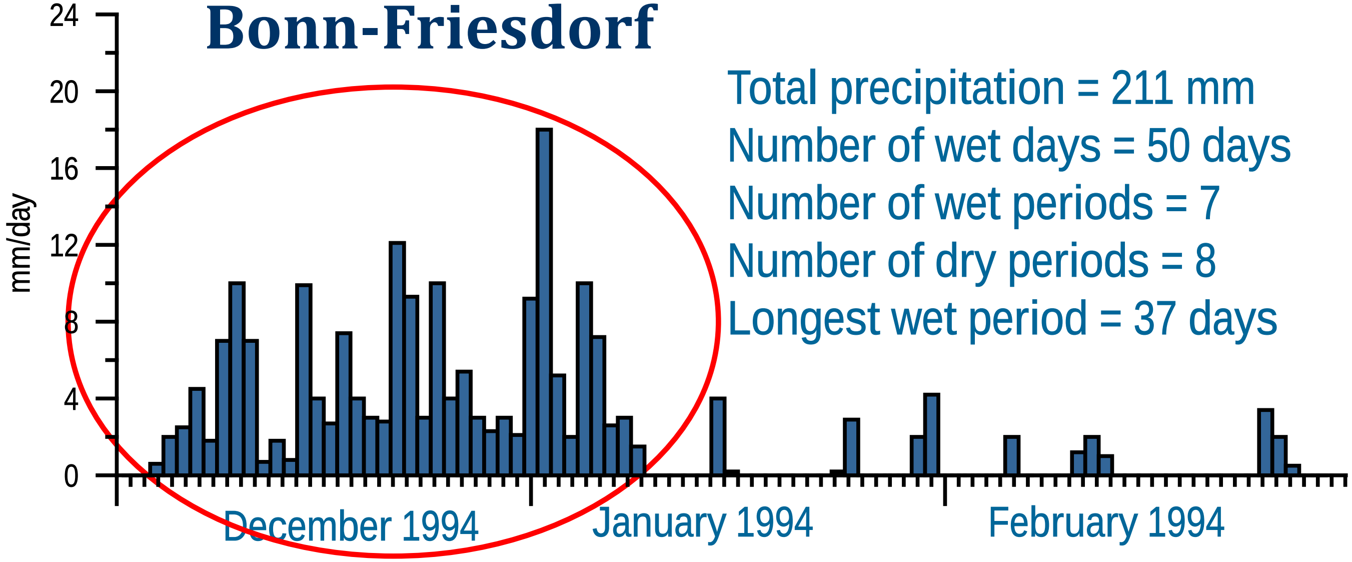
➢ **Changes in absolute extremes differ from those in totals**

Figure from Sergey Gulev

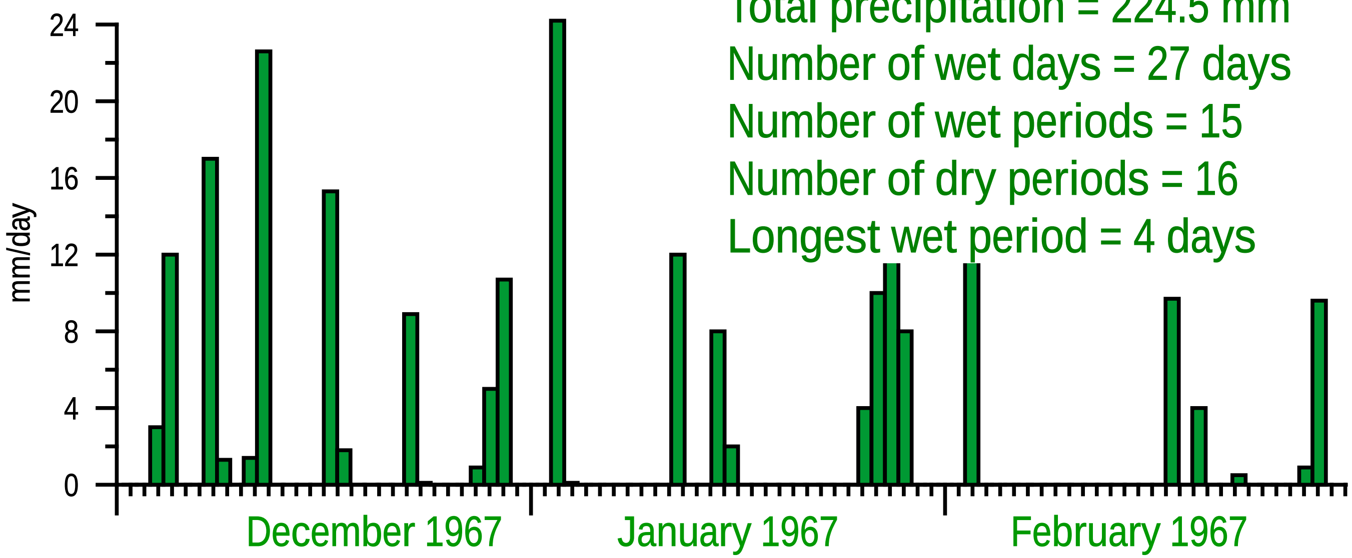
Zolina et al. 2005, Geophys. Res. Lett.

Persistence

Bonn-Friesdorf



Total precipitation = 211 mm
Number of wet days = 50 days
Number of wet periods = 7
Number of dry periods = 8
Longest wet period = 37 days



Total precipitation = 224.5 mm
Number of wet days = 27 days
Number of wet periods = 15
Number of dry periods = 16
Longest wet period = 4 days

Figure from Sergey Gulev

Natural hazards and extreme events in the Baltic Sea region

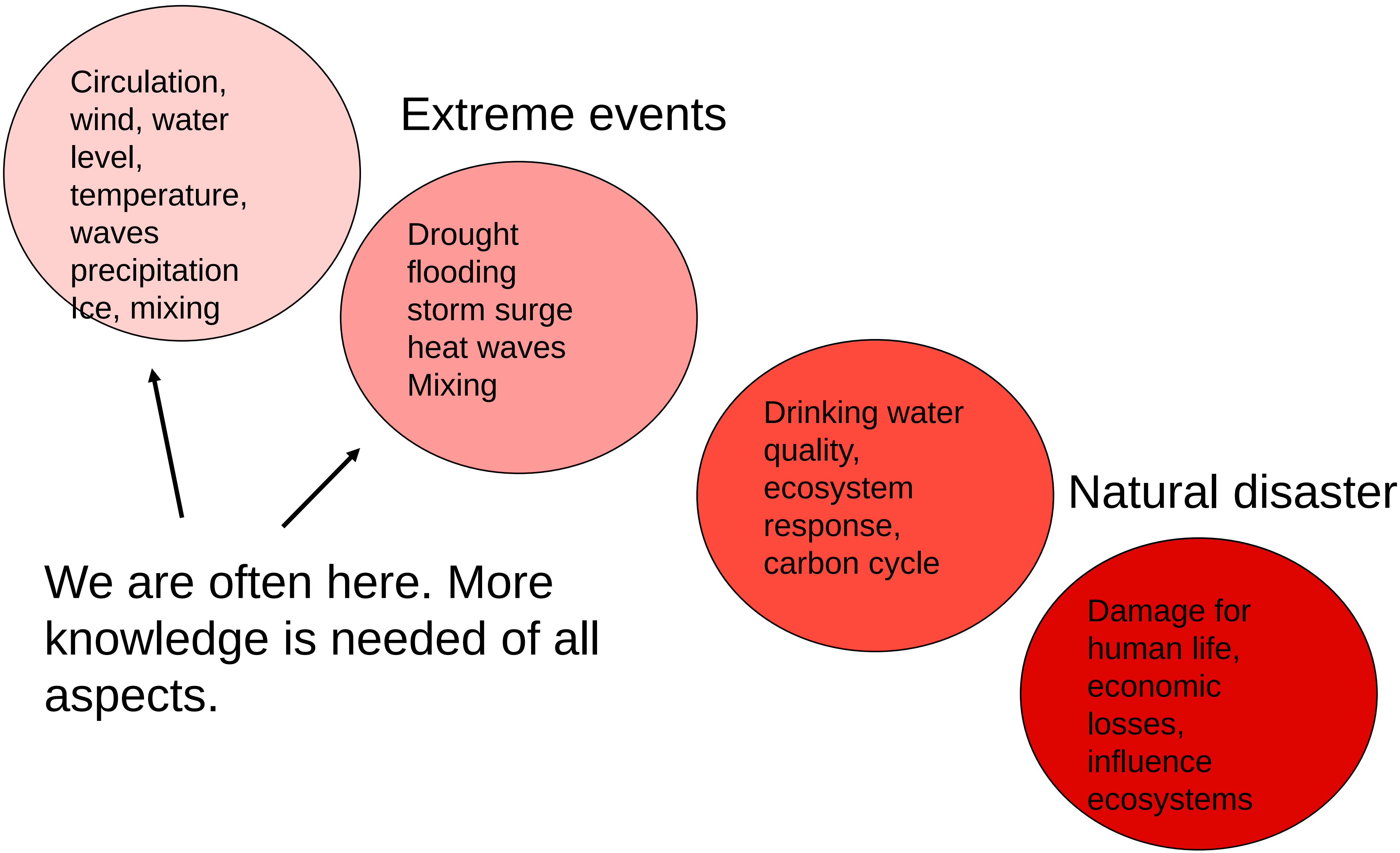
Background:

- Society is very sensitive to extreme geophysical events with severe implications (for human life, generate economic losses and influence ecosystems).
- A natural disaster links extreme geophysical events to ecosystems and society (in particular weaknesses in ecosystems and society).
- Understanding the underlying causes of natural disasters increases the ability to predict the occurrence and severity and may save human lives as well as mitigate economic losses.

Flooding at DMI

Photos: Martin Stendel and Finn Majlergaard

Linking Research



Extreme events: last decades

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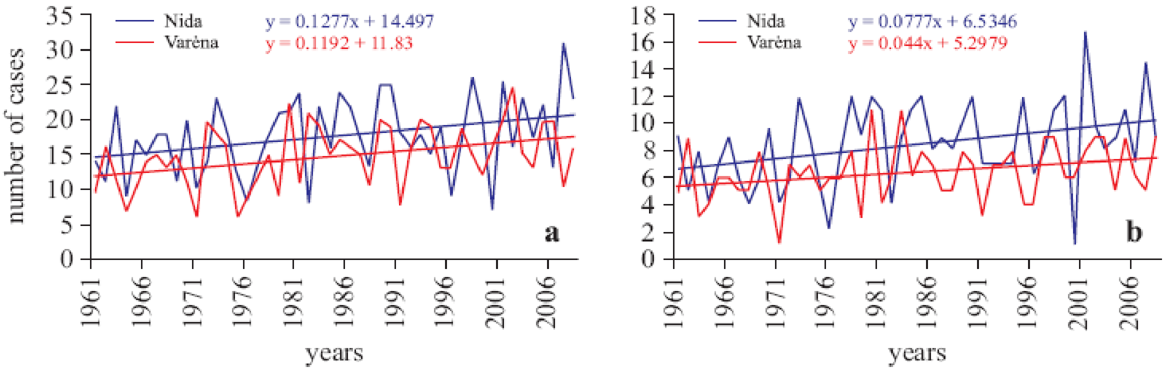
Often extreme events and changes in extreme situations are of more important than changes in mean climate.

- 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).

Extreme events: long term

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- 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.

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Variable	Long term trend	Last decades
Air temperature	positive	positive
Water temperature	positive	positive
Precipitation	no trend	Mainly positive
Wind	no trend	Mainly positive
Heavy precip	x	positive

Conclusions

- Variability in general dominating over trends:

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

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Summary BACC II

- 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).
  - Trends in extreme events.
  - Lack of data for some parameters for example clouds and radiation.

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Climate variability and extremes

- Climate system is highly varaible

- We need to understand atmospheric circulation and moisture transport

- Knowledge about changing extremes in a changing climate is still very limited

Literature

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