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Baltic Earth
Earth System Science for the Baltic Sea Region

Climate variability and extremes

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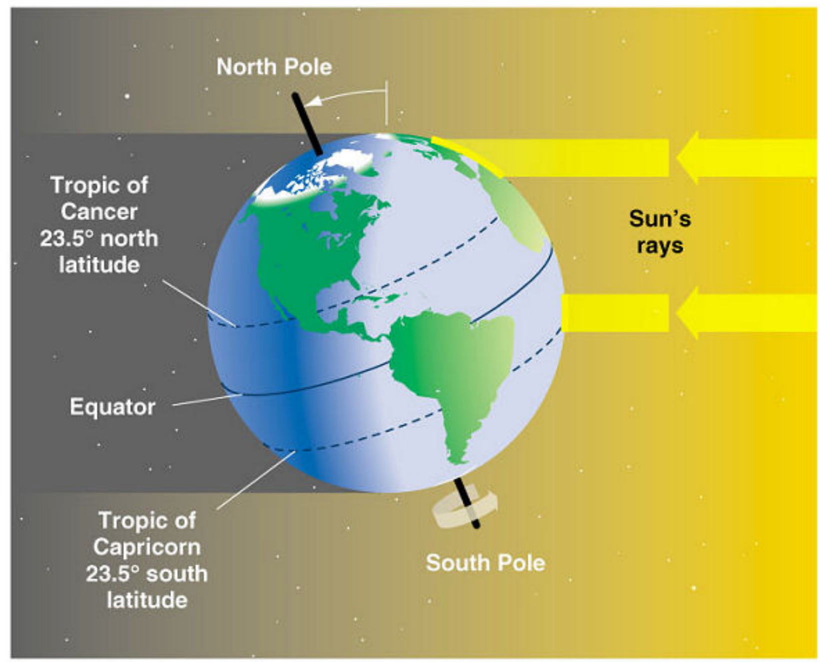
Climate

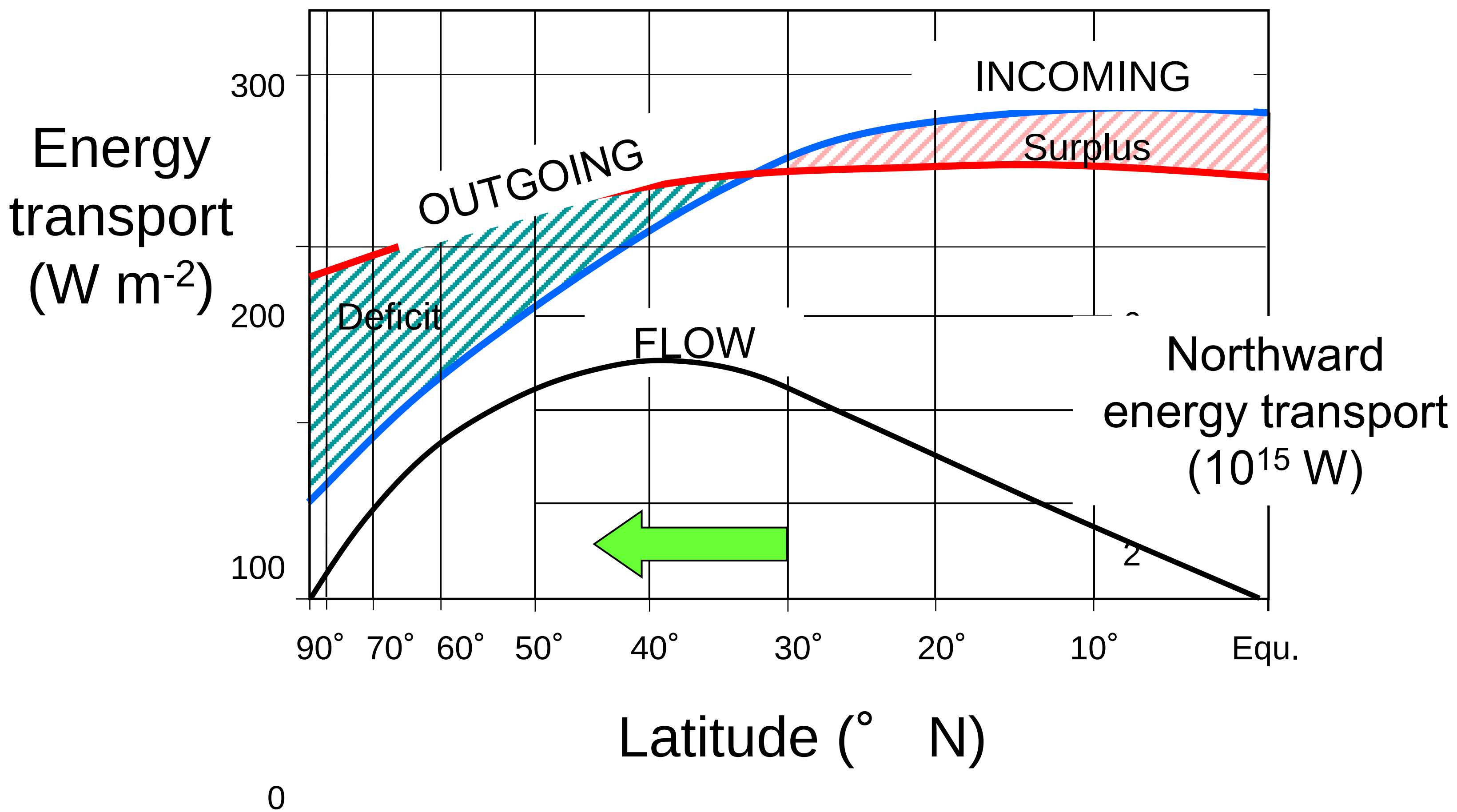
- Uneven heating equator/poles
- Heat transport toward the poles

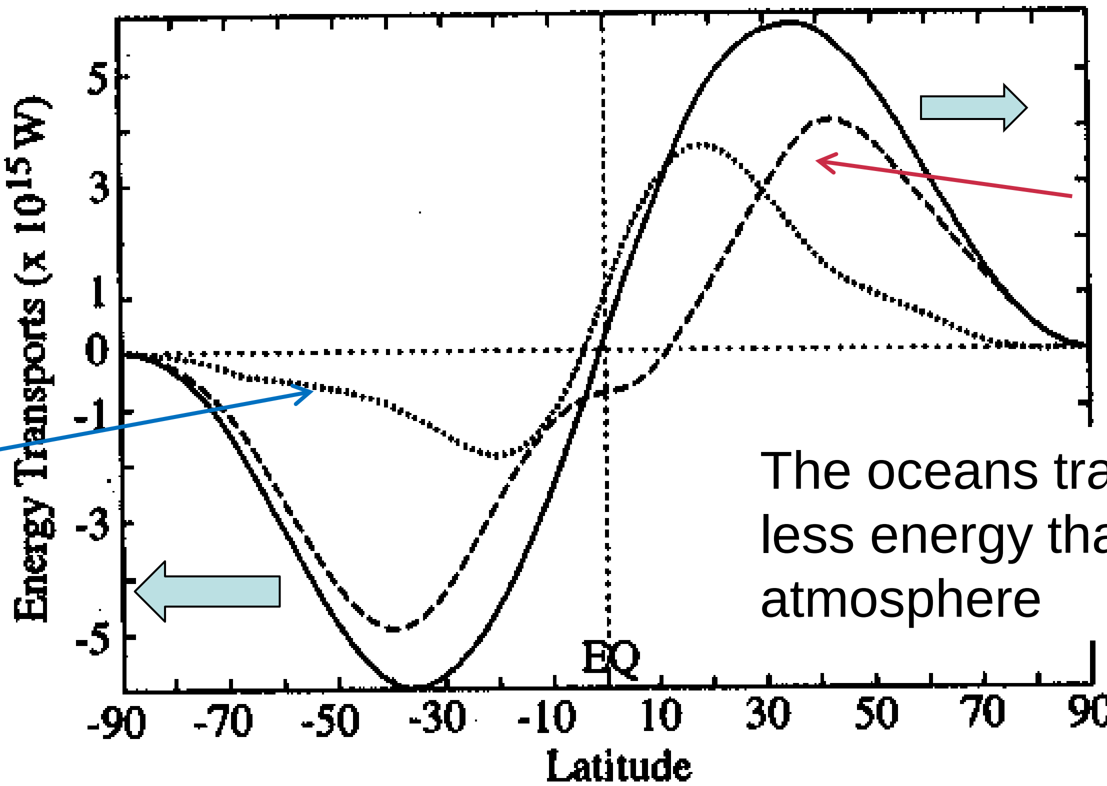


The Earth

- The earth is a sperical rotating body
  - different heating
  - rotating coordinate system
- Chemical components (N_2, O_2 also Ar, CO_2 etc)
  - absorption/emission in constituents
- Fysiography
  - distribution of land/ocean
  - montain ranges
- Water
  - water in different phases, phase changes
- Flow is never at rest, turbulence near the surface

Radiation balance





Atmosphere

Oceans

The oceans transport slightly less energy than the atmosphere

Figure 12.5 Annual mean northward energy transports required to equalize the pole–equator radiative imbalance. The solid line represents the top-of-the-atmosphere radiation budget, the dashed line represents the atmosphere, and the dotted line represents the ocean (From Zhang and Rossow, 1997).

Northward energy transport

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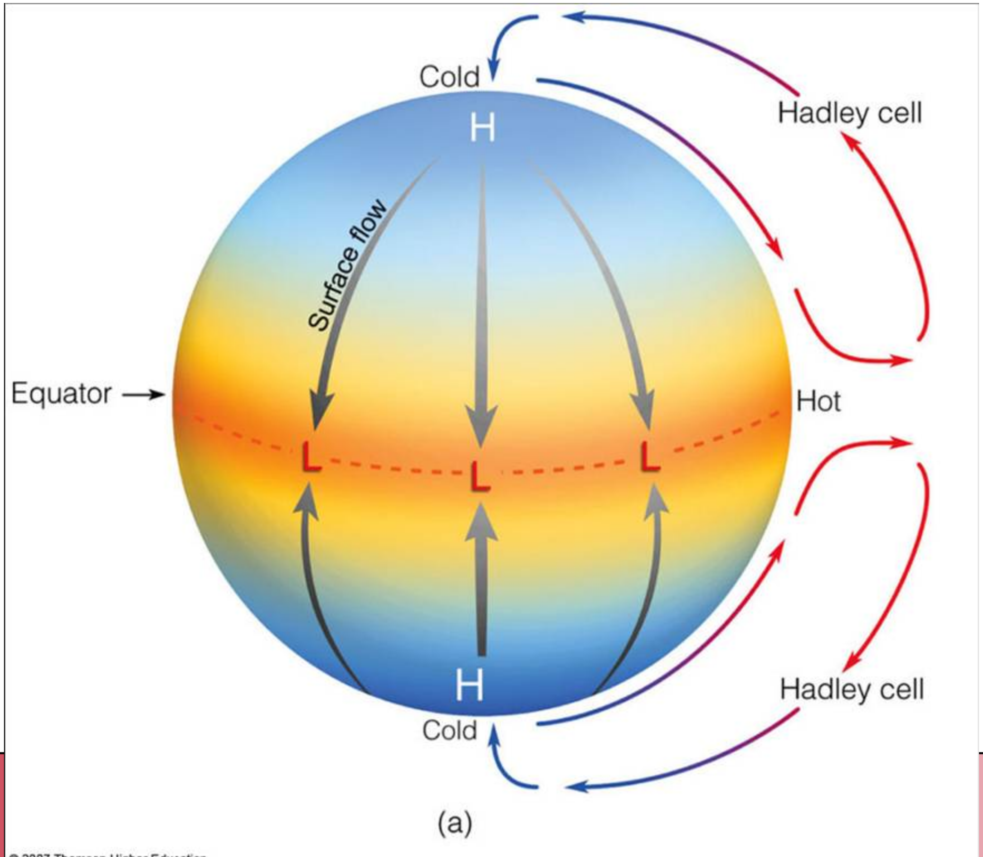
Poleward transport of energy by:

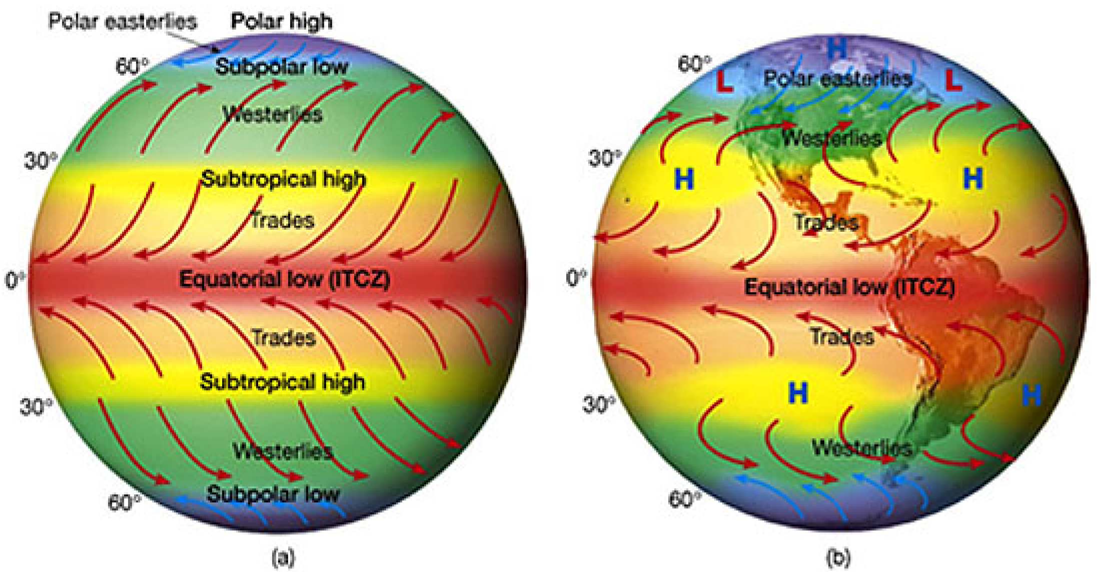
1. Mean meridional circulation (Hadley cell).
2. Stationary eddies (monsoon circulations).
3. Transient eddies (low pressure systems).

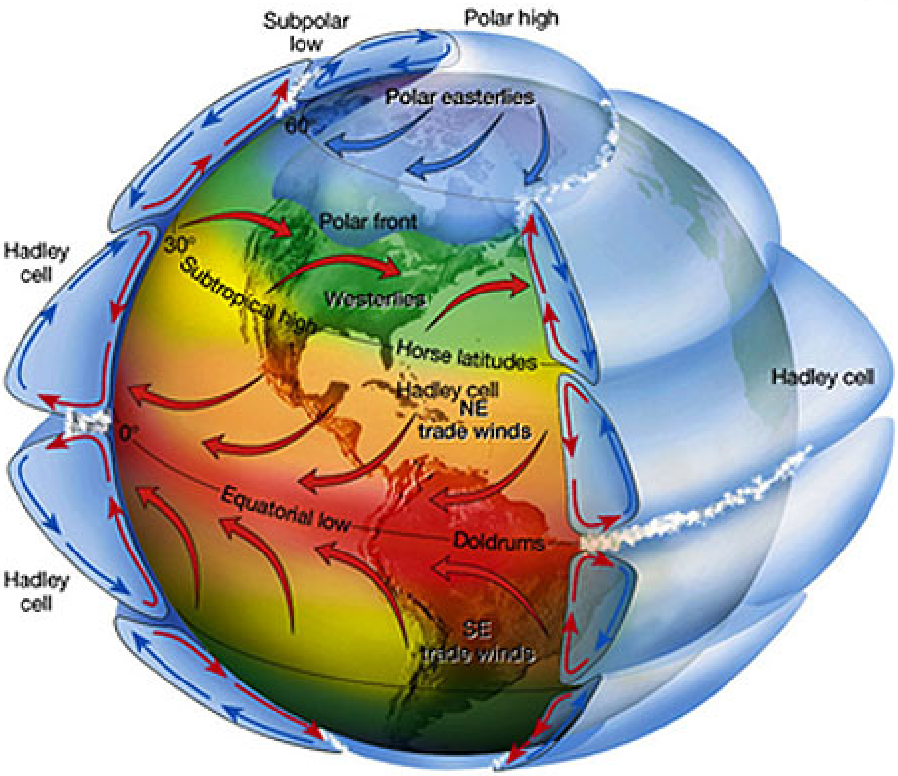
Mean meridional circulation

- More solar heating at the equator, convection and rising air form a closed circulation – the ’Hadley cell’.
- Earth rotation (coriolis force) makes the Hadley cell break down at higher latitudes.



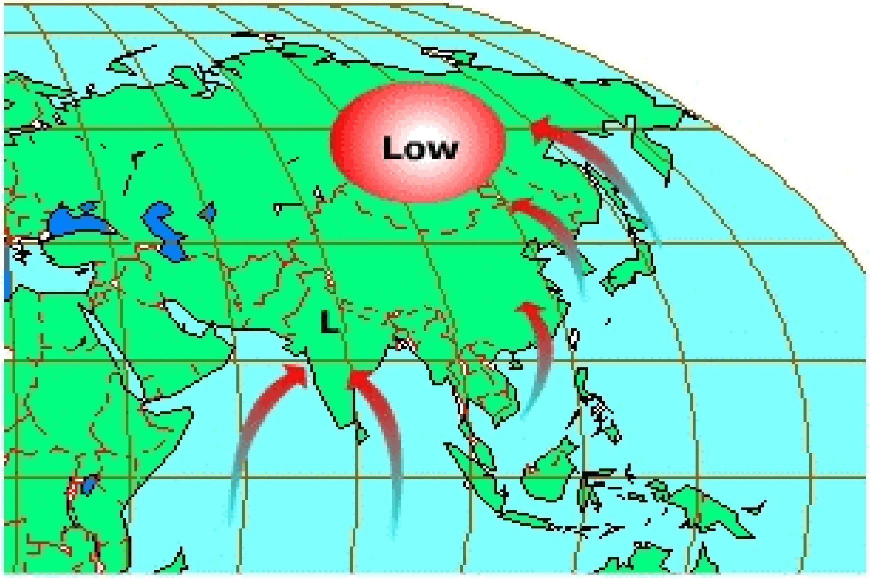
Three cell planet

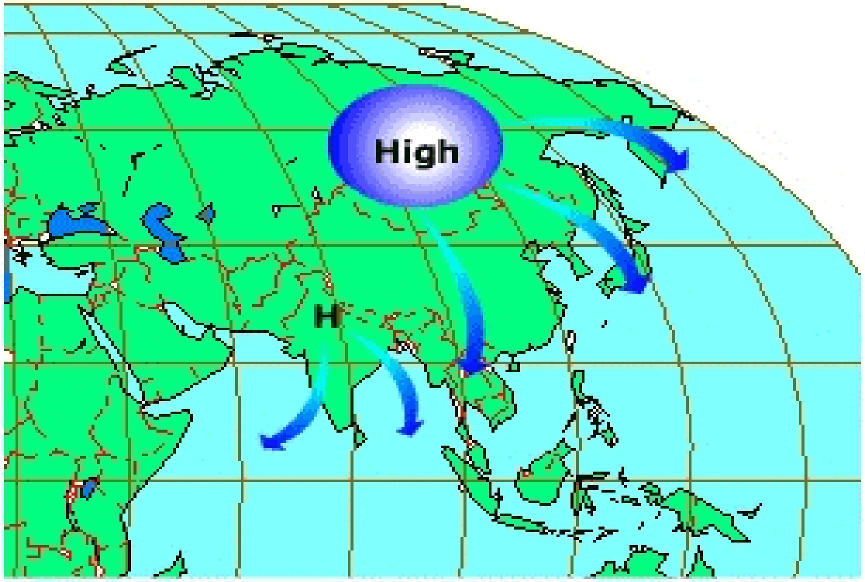




Stationary eddies

Stationary circulation systems (fixed by lans/sea contrast) – transporting energy poleward





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Transient eddies

- Rotation of the earth makes the Hadley cell break down at 30º. The flow then goes west-east instead of north-south.
- Instabilities in this easterly flow generates transient eddies (cyclones).
- These eddies transport heat and water towards the poles along frontal surfaces.
- The cyclones move along the quasi-stationary ’Rossby waves’ in the region 30º- 60º.
- On average they form the ’Ferrel cell’.

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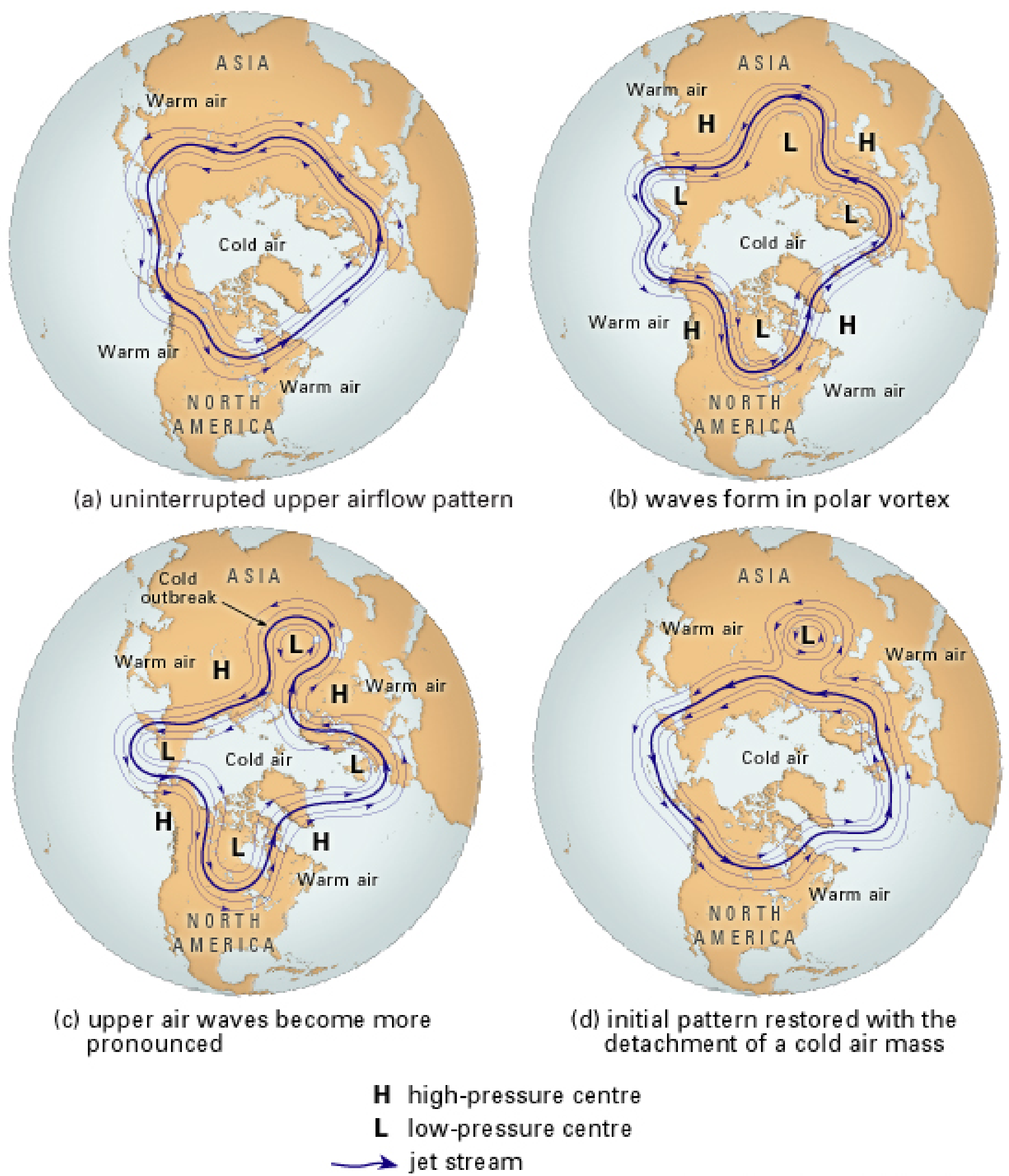
Rossby waves



Northward transport of energy

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Total

Transient eddies

Stationery eddies

Mean meridional circulation

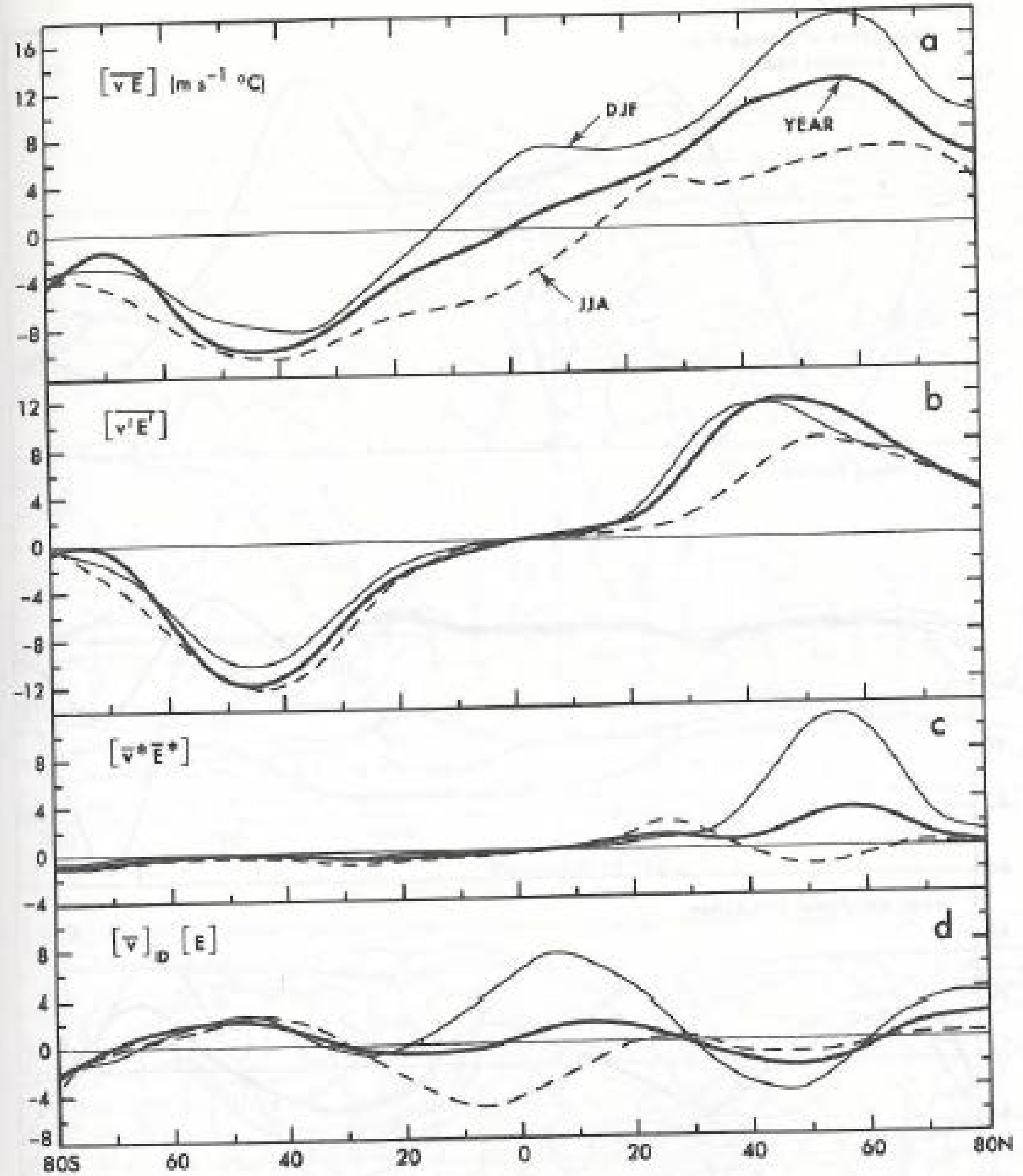

FIGURE 13.11. Meridional profiles of the zonal- and vertical-mean northward transport of energy by all motions (a), transient eddies (b), stationary eddies (c), and mean meridional circulations (d) in °C m s^{-1} [to convert to units of 10^{15} W multiply values by $2\pi R \cos\phi \, c_p (p_0/g) \simeq 0.4 \cos\phi$; from Oort and Peixoto, 1983].

Northward transport of moisture

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Total

Transient eddies

Stationery eddies

Mean meridional circulation

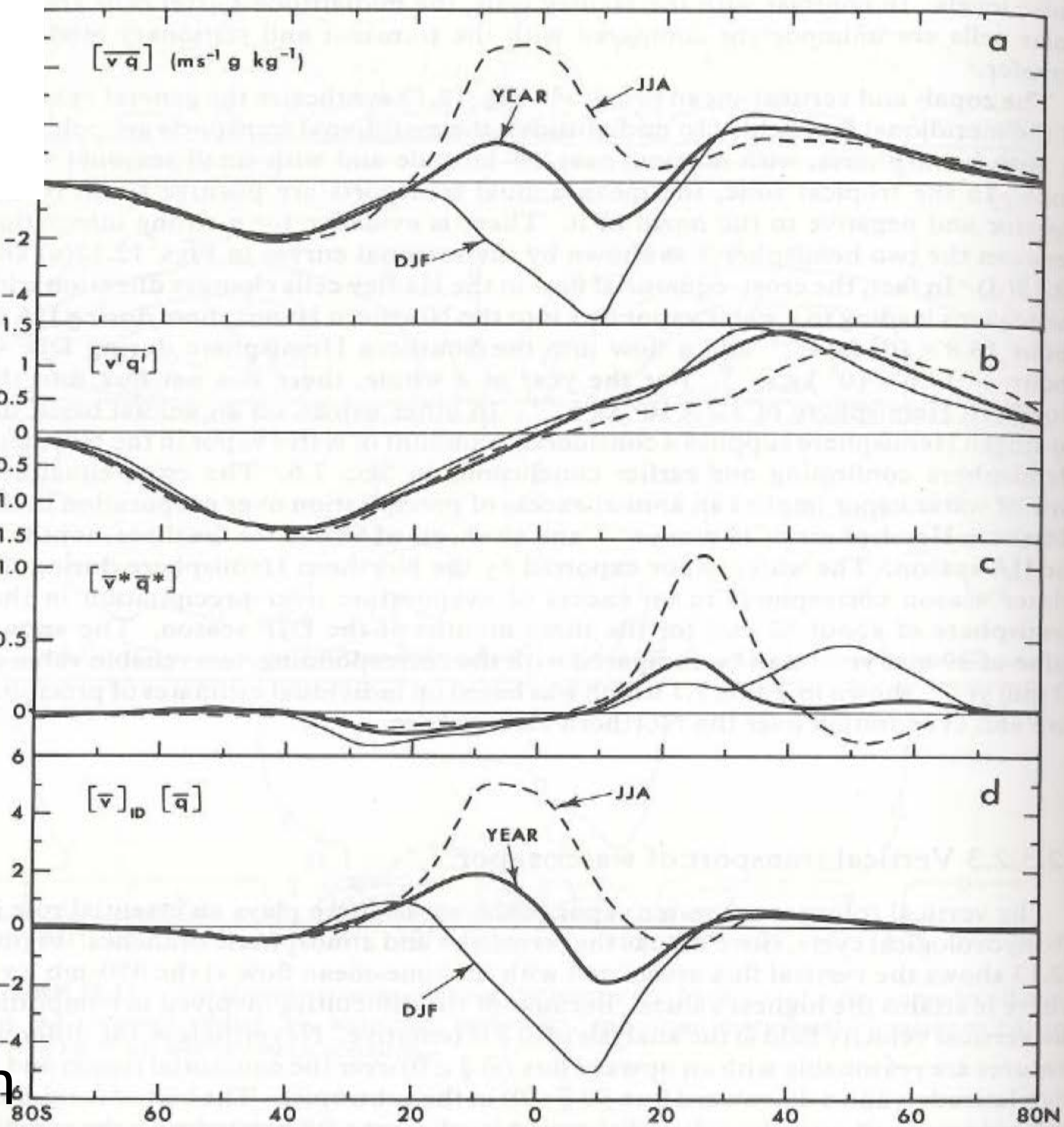


FIGURE 12.12. Meridional profiles of the vertical- and zonal-mean values of the northward transport of water vapor by all motions (a), transient eddies (b), stationary eddies (c), and mean meridional circulations (d) in m s^{-1} g kg^{-1} for annual, DJF, and JJA mean conditions. [To convert to total transport estimates multiply values by $10^{-3} 2\pi R \cos\phi\, p_0/g = 4 \cos\phi$ to find values in units of 10^8 kg s^{-1} or by $12.6 \cos\phi$ to find units in 10^{15} kg yr^{-1}, where $2\pi R \cos\phi$ = length of latitude circle and $p_0/g = 10^4$ kg m^{-2} the total atmospheric mass per unit area.] (After Peixoto and Oort, 1983).

Mid-latitudinal hydrological cycle (North Atlantic – European sector)

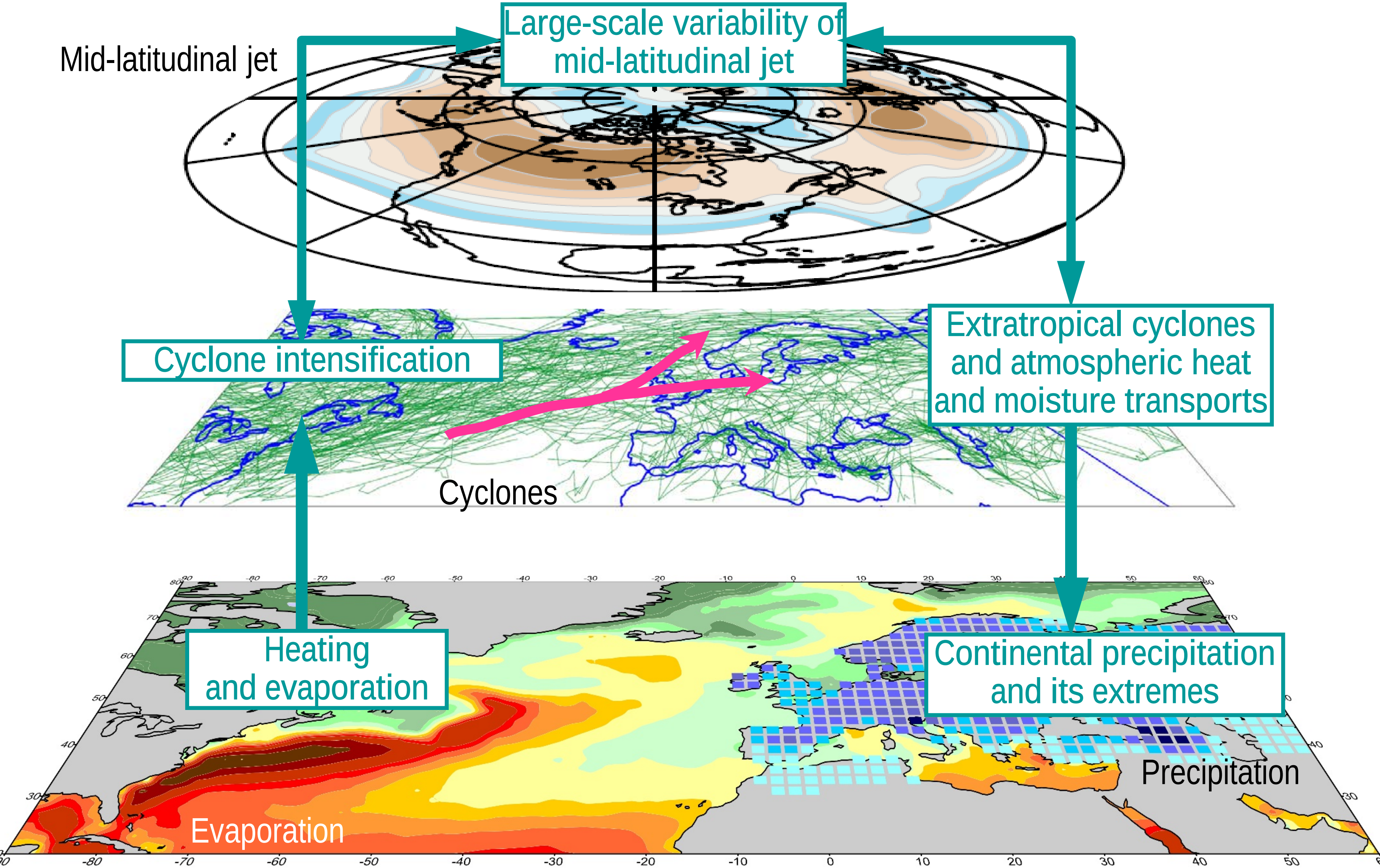
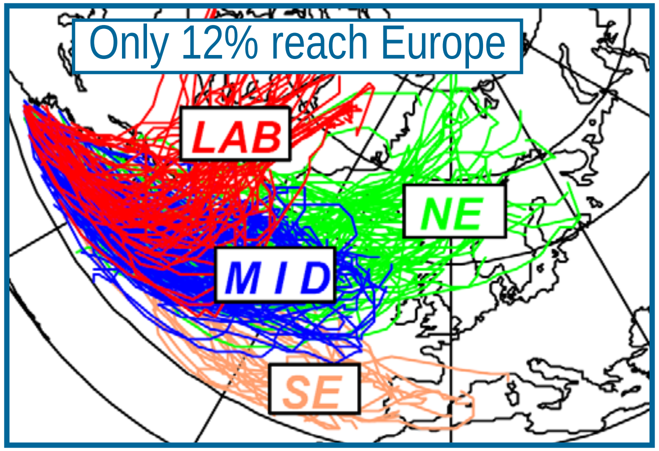
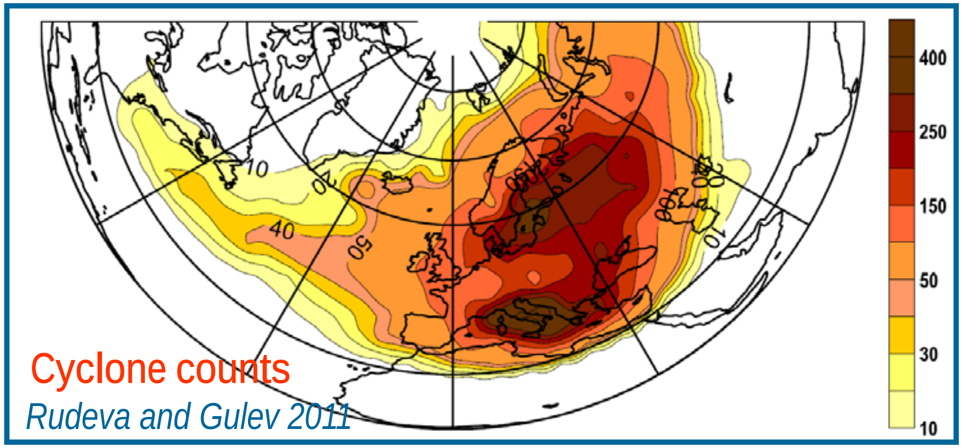


Figure from Sergey Gulev

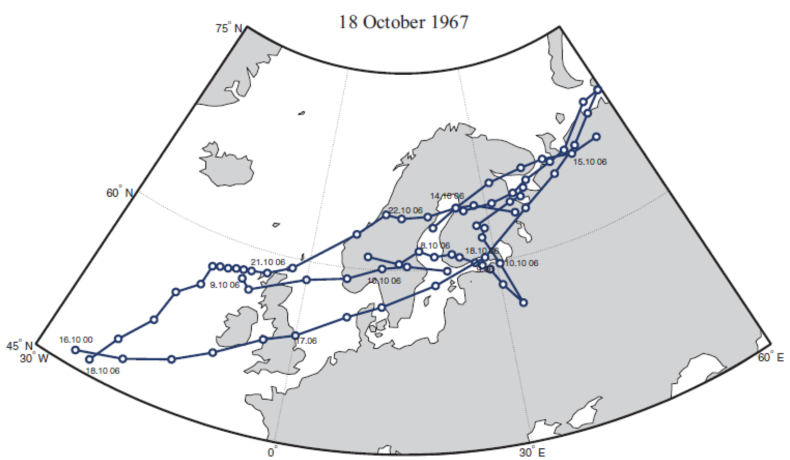
Which cyclones are bringing moisture and heat to Europe?





European weather is to a lesser extent dependent on cyclones generated over GS, but is rather determined by the transients generated in the NE Atlantic

Cyclones causing extreme sea levels in the Baltic Sea – also primarily EA cyclones



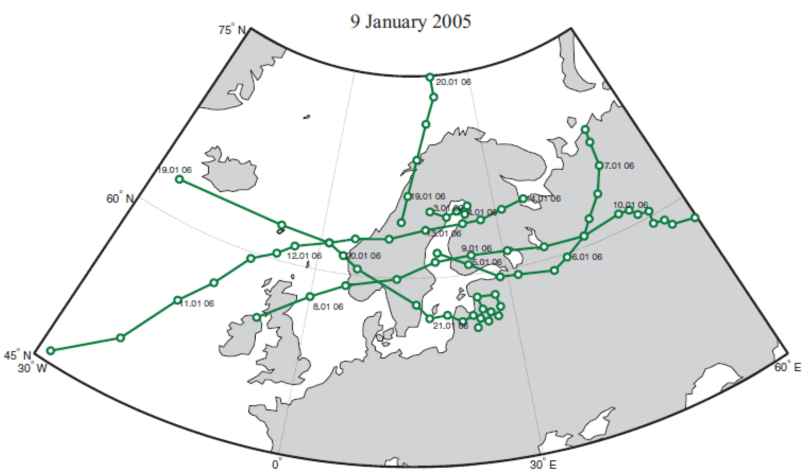
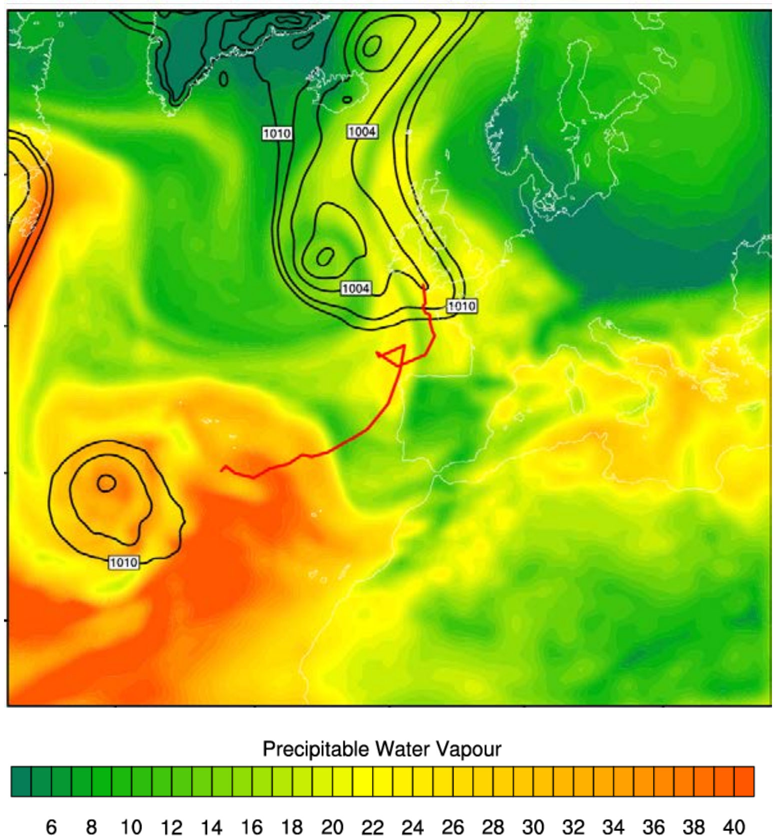


Figure from Sergey Gulev

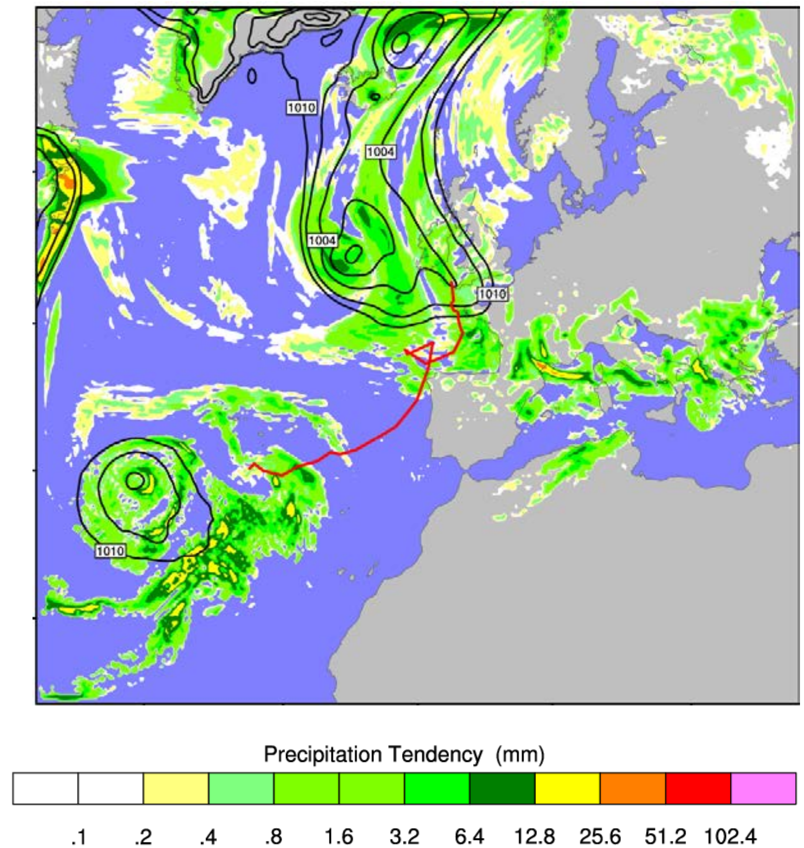
Post and Kouts 2014

The role of cyclones in moisture and energy transports

Precipitable water content



Precipitation



WRF, 12-km resolution, 27.11.2004 – 03.12.2004

Figure from Sergey Gulev

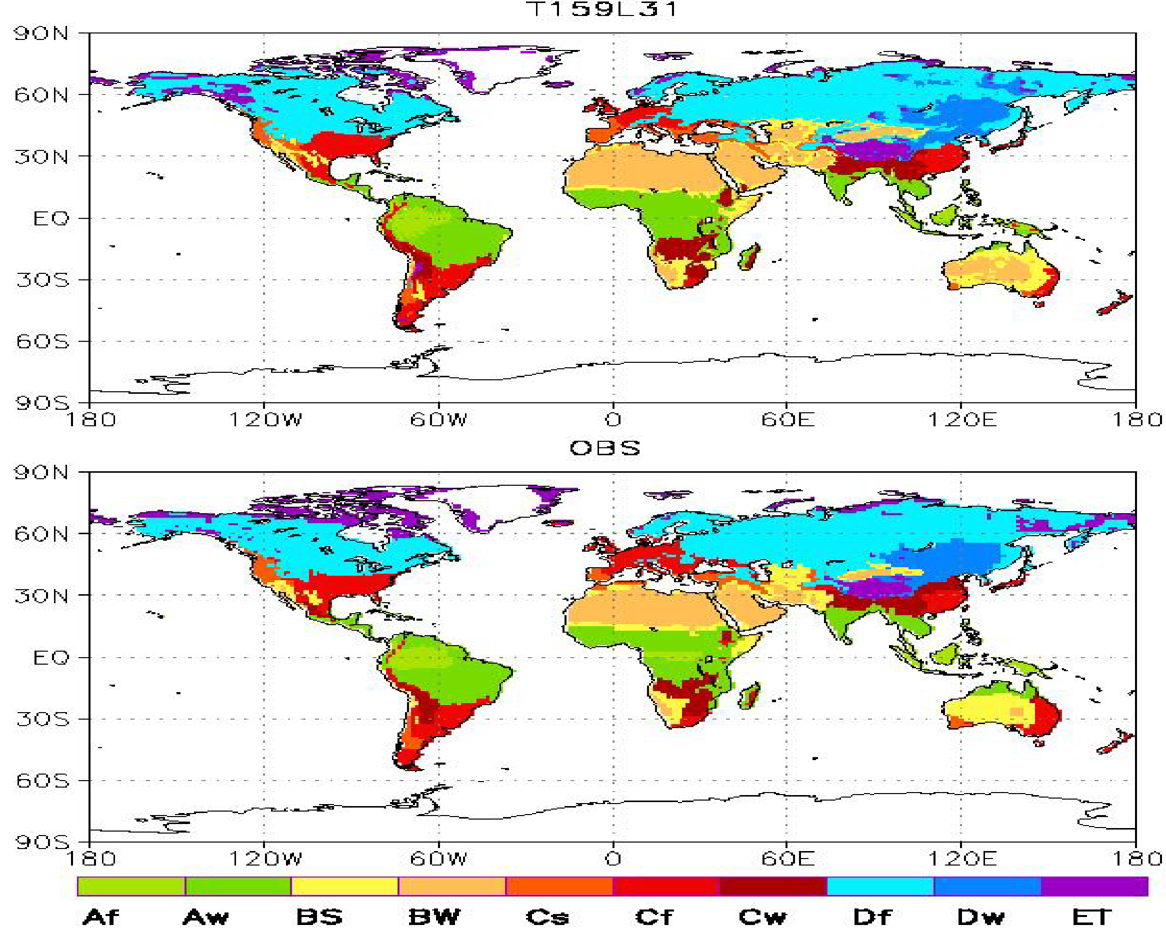
Gavrikov and Gulev 2014

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)



Köppen climate zones

ECHAM5

GPCP (Prec)
CRU2 (Temp)

T159

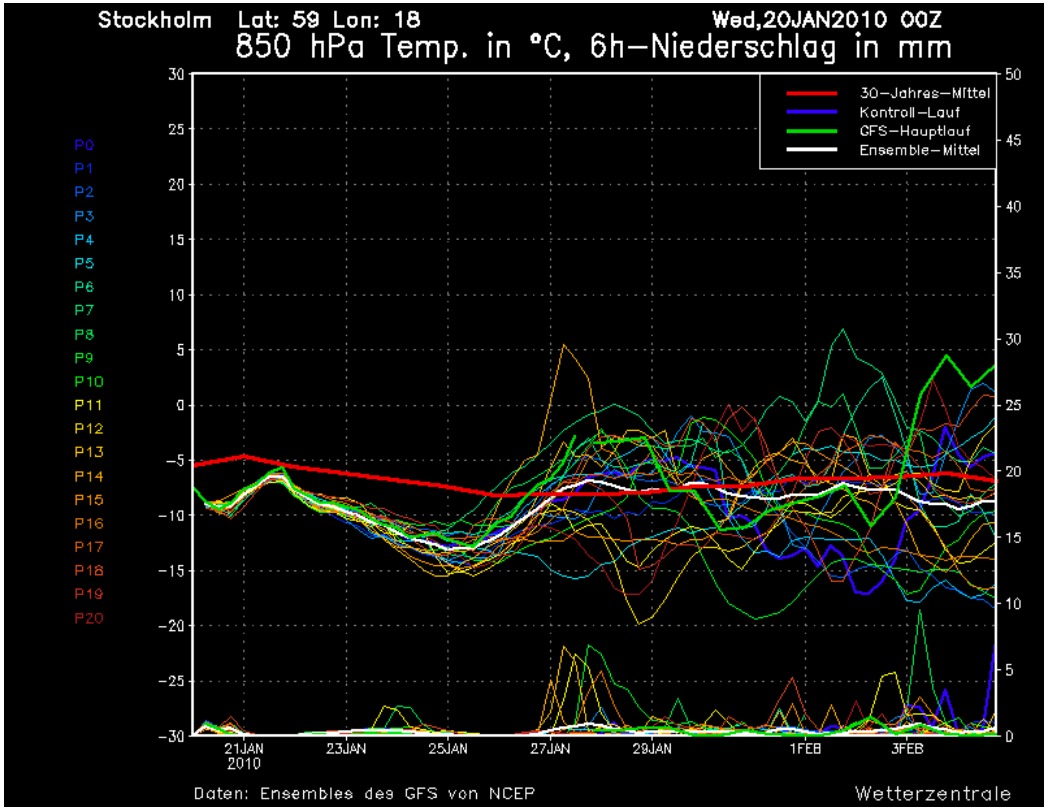
Climate stationary concept

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

Variability of climate

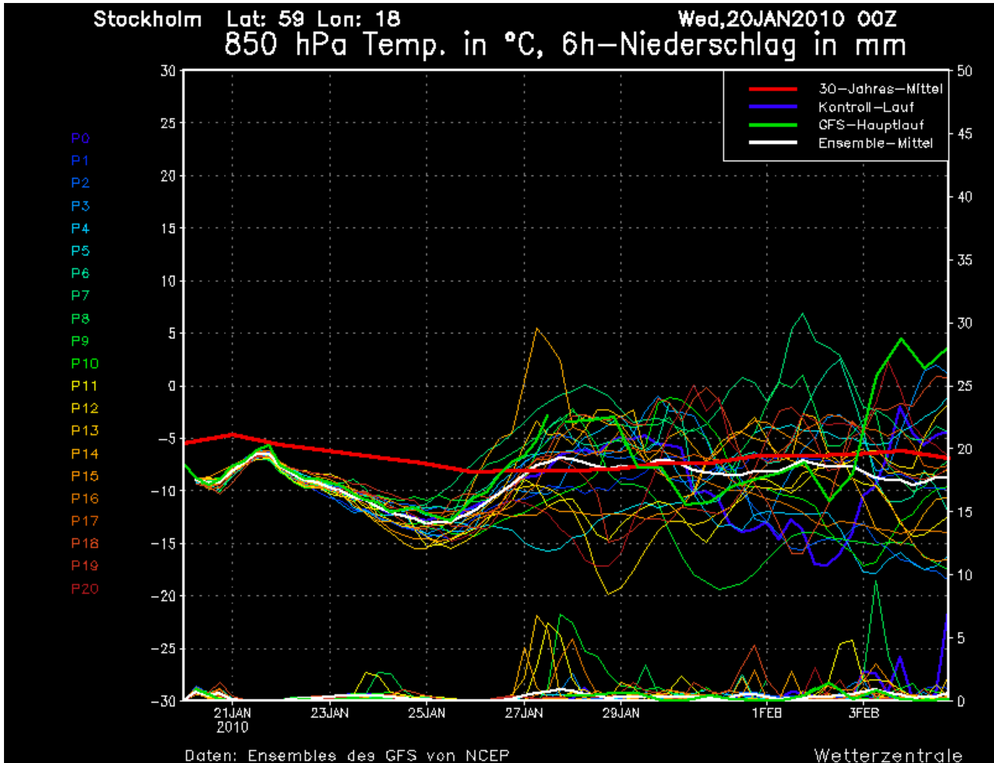
Why do the climate vary ?



Variability of climate

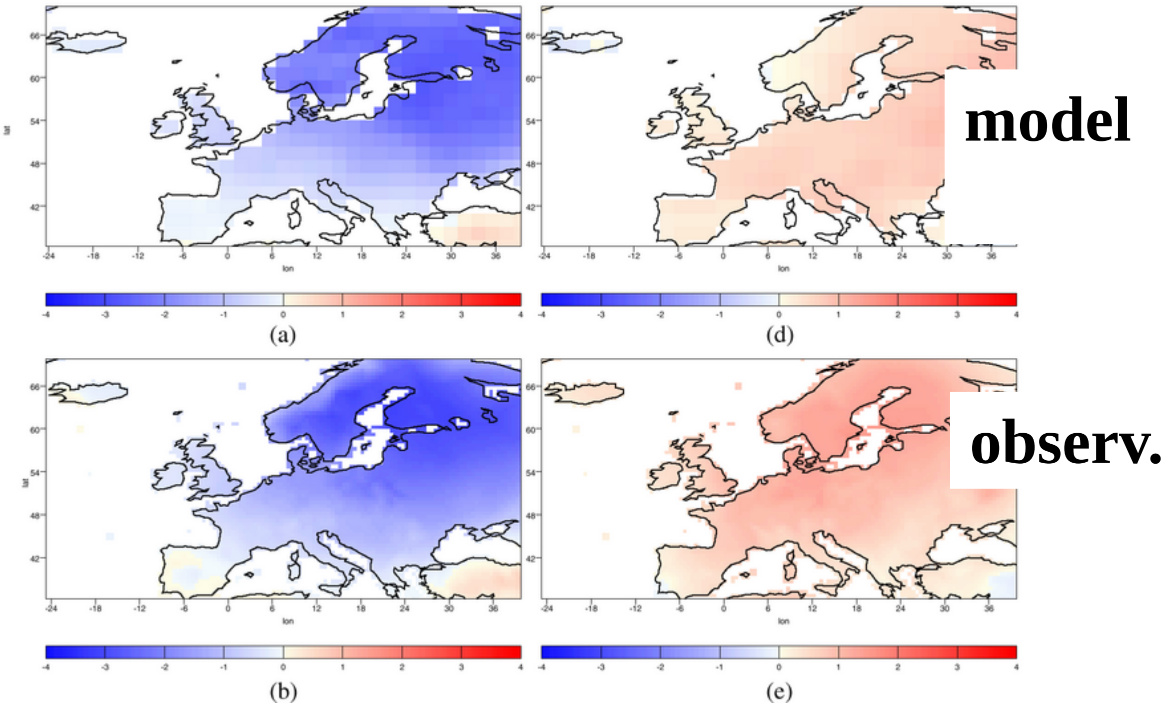
Why does the climate vary ?

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



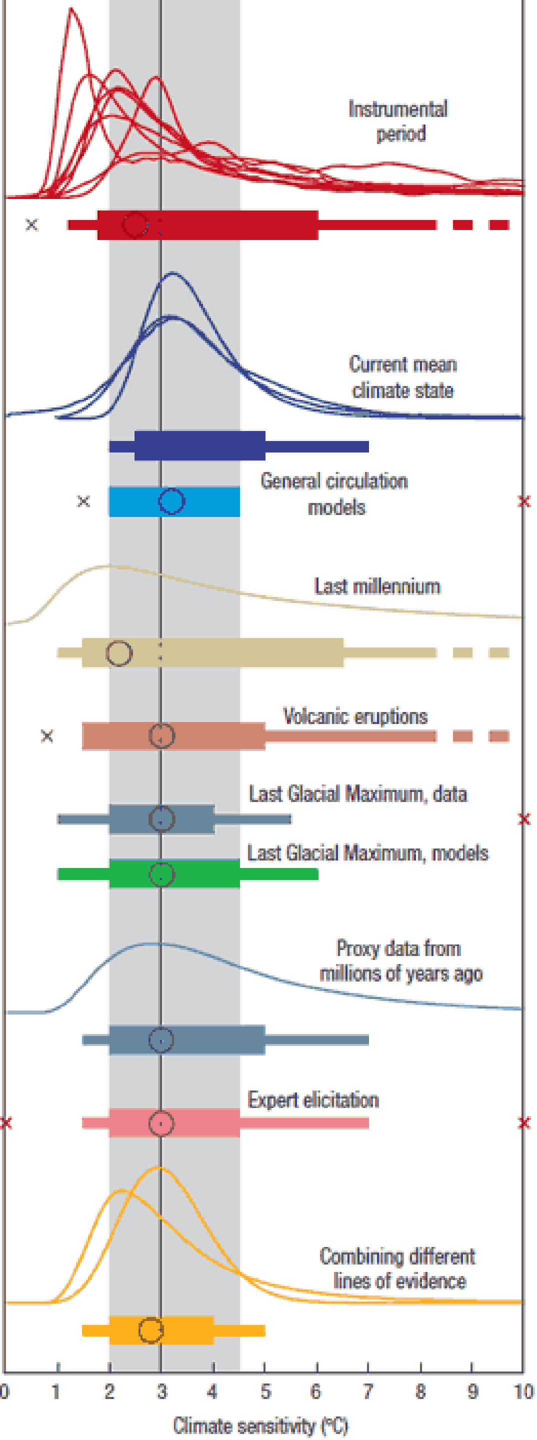
Internal variability of climate

- 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



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

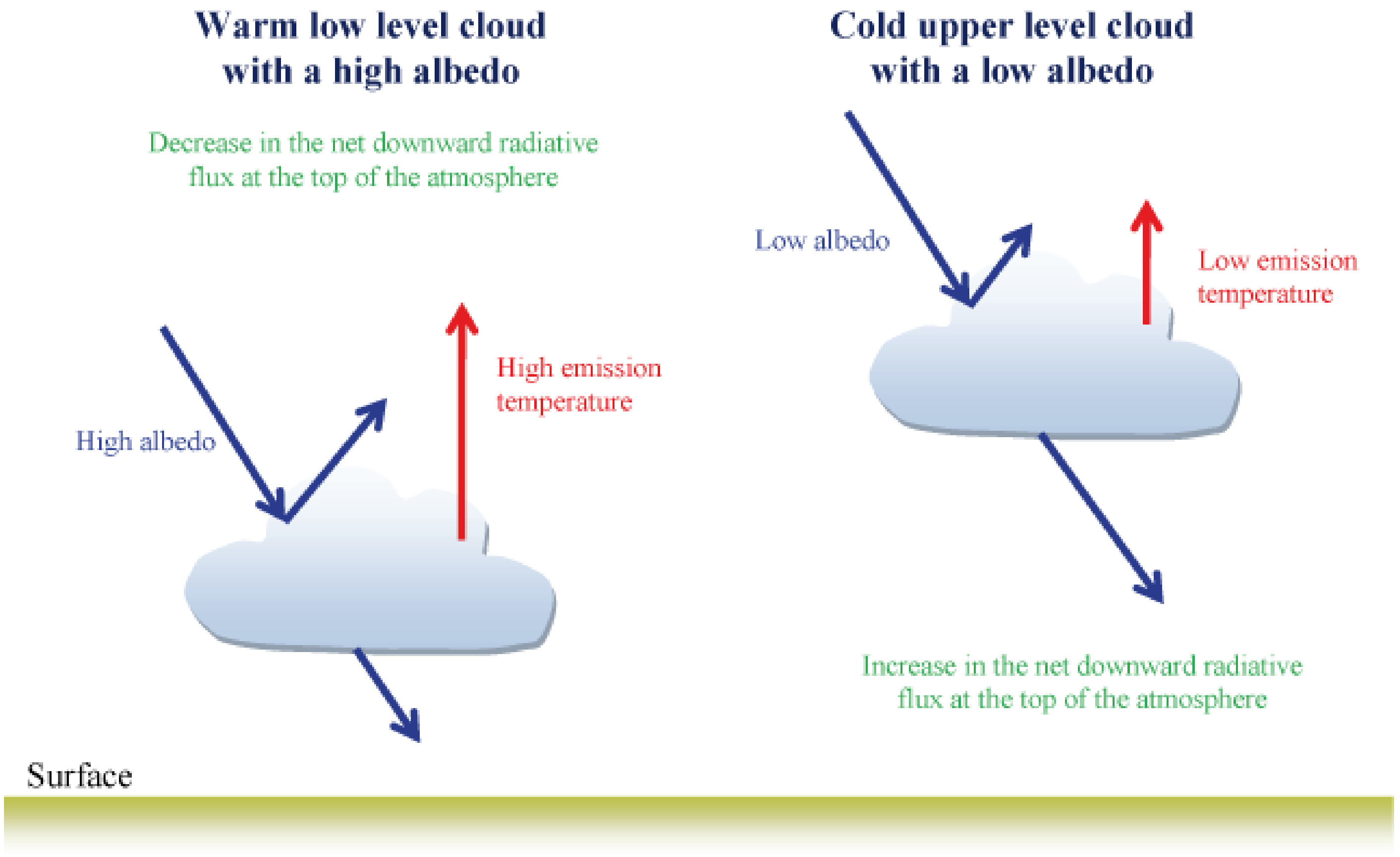
Feedback mechanisms

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



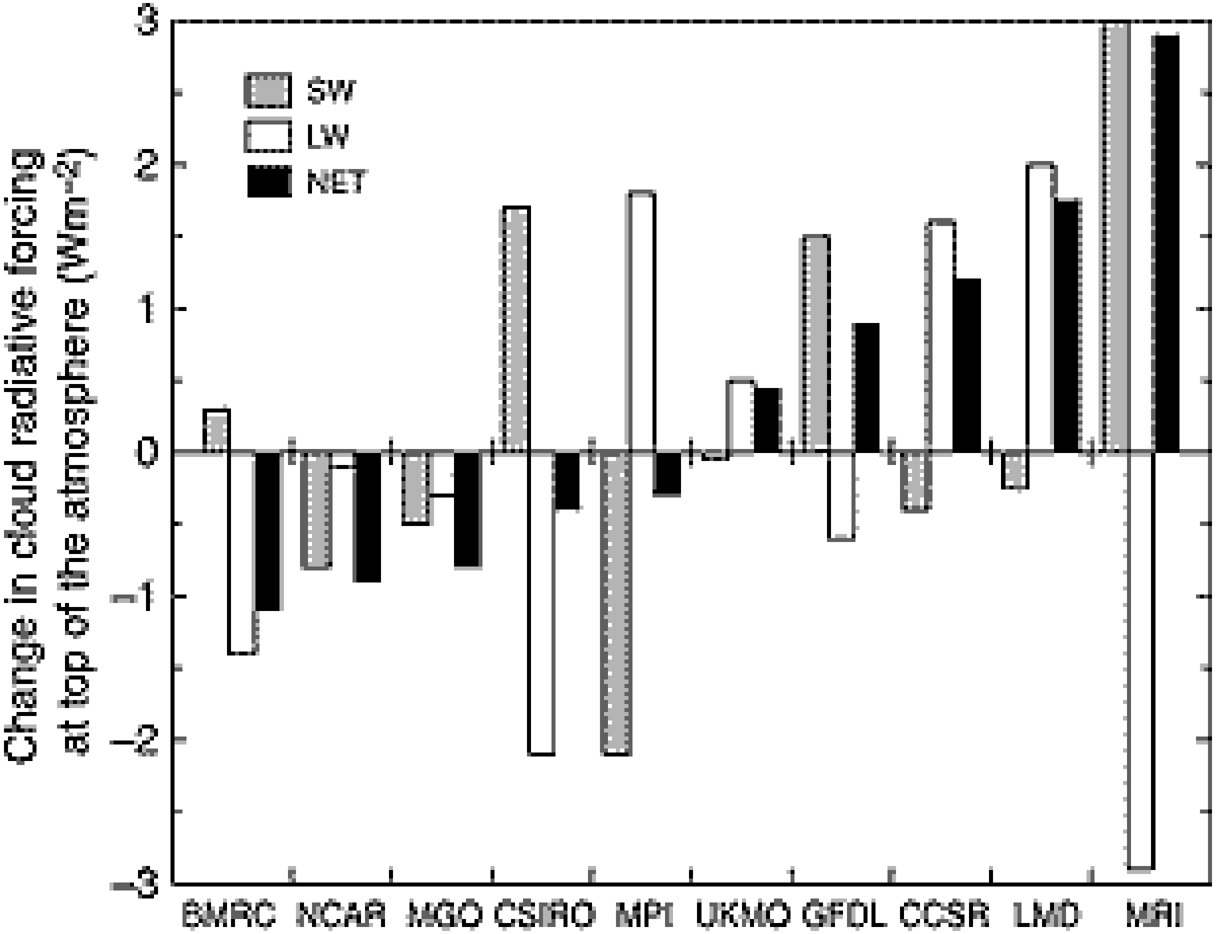
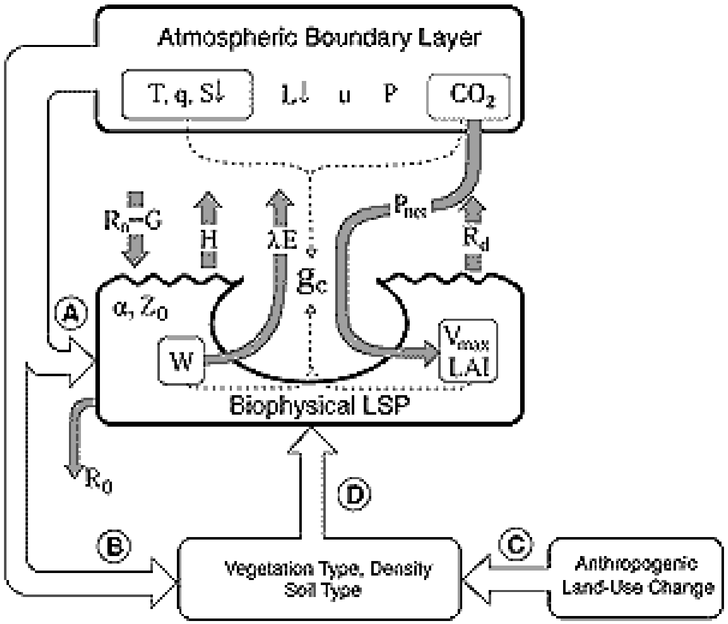


Figure 7.2: *Change in the Top of the Atmosphere (TOA) Cloud Radiative Forcing (CRF) with a CO_2 doubling. The sign is positive when an increase of the CRF (from present to double CO_2 conditions) increases the warming, negative when it reduces it. The contribution of the shortwave (SW, solar) and long-wave (LW, terrestrial) components are first distinguished, and then added to provide a net effect (black bars).*

Feedback mechanisms II

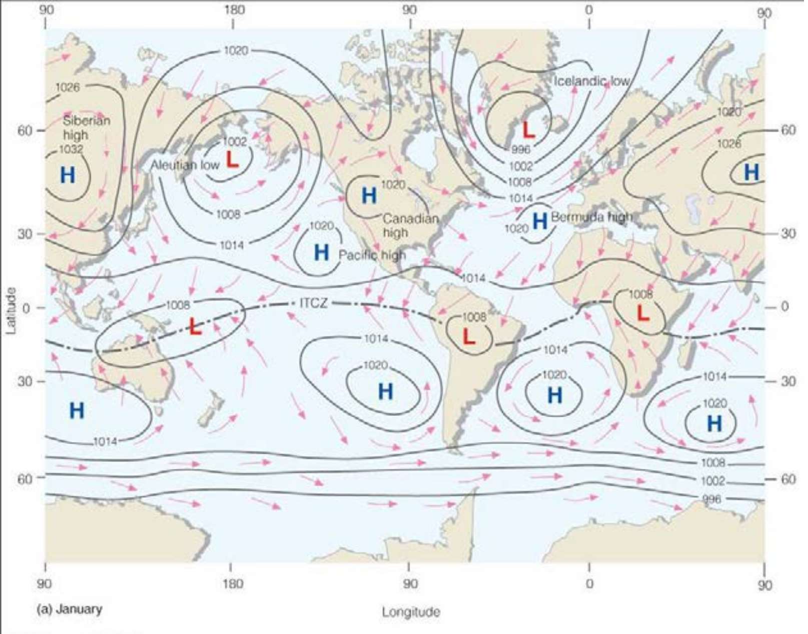
- Landuse – positive/negative
  - Uptake of carbon dioxide in plants
  - Surface albedo changes
  - Soil moisture changes (influences turbulent heat fluxes).
- Ocean – positive/negative
  - Change uptake of carbon dioxide
  - Changes in horisontal circulation
  - Changes in vertical structure

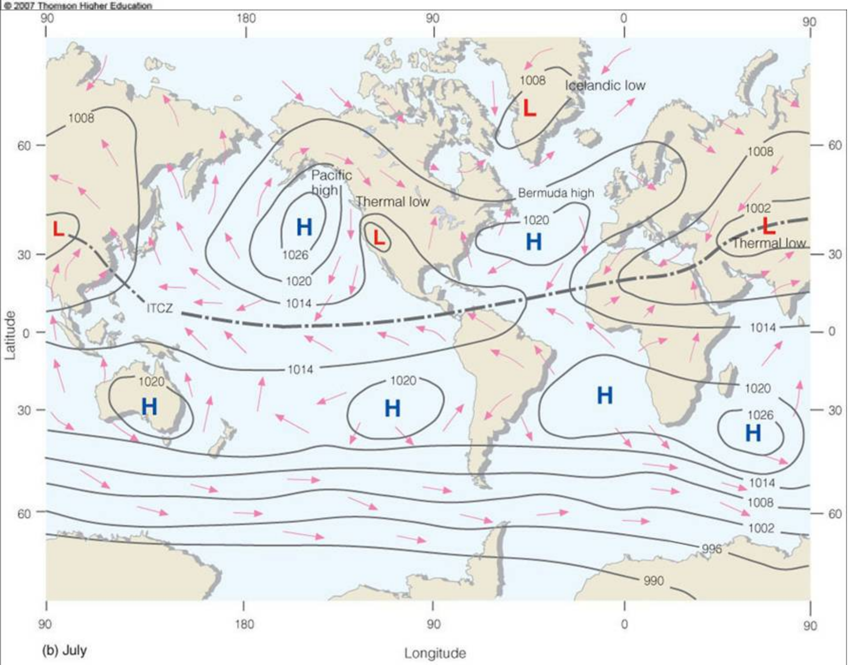


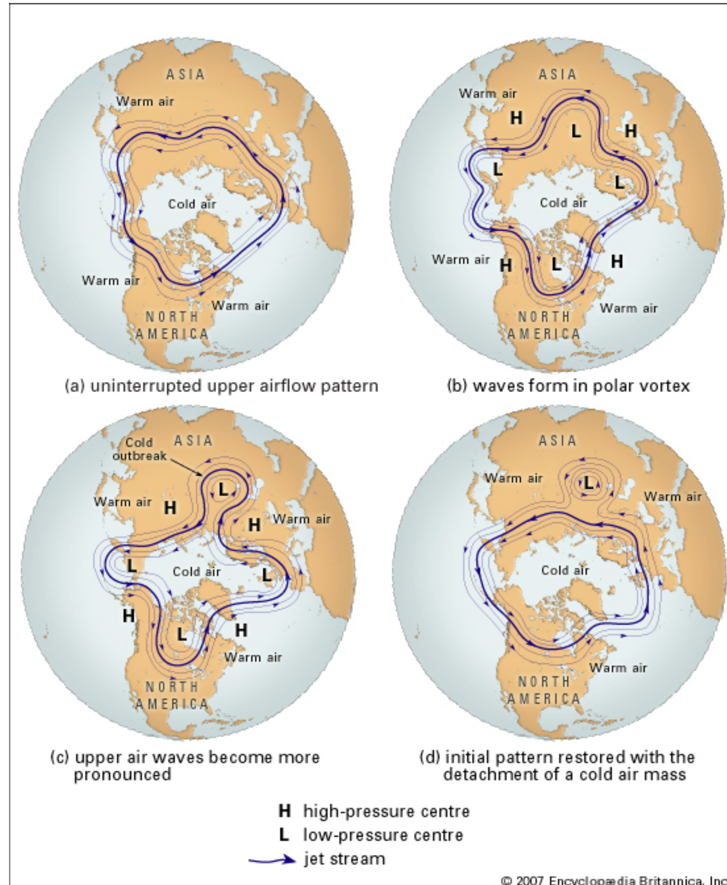
Other forcing mechanisms (not feedback mechanisms)

- 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.

Large scale circulation patterns







(a) uninterrupted upper airflow pattern

(b) waves form in polar vortex

(c) upper air waves become more pronounced

(d) initial pattern restored with the detachment of a cold air mass

H high-pressure centre

L low-pressure centre

jet stream

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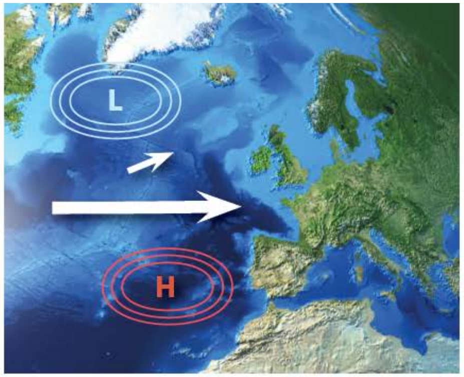
Atmospheric Circulation

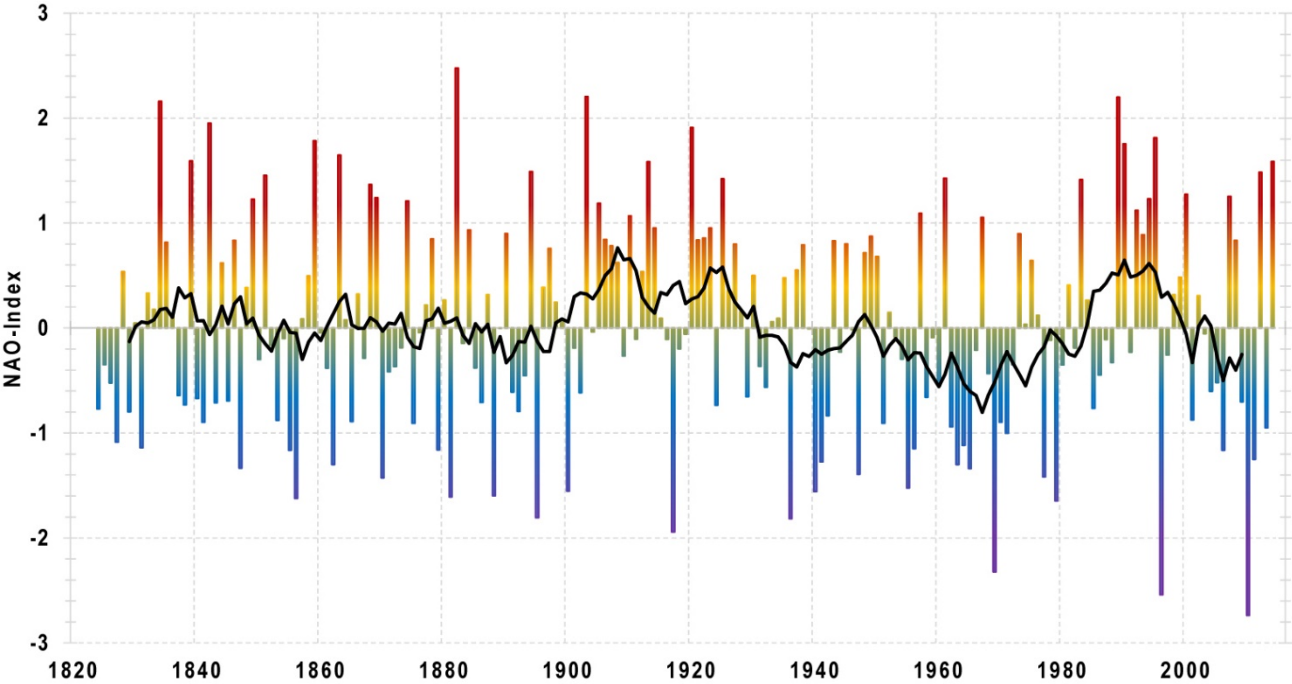
The climate of the Baltic Sea region is to a large extent determined by the circulation.

- 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.

Atmospheric Circulation

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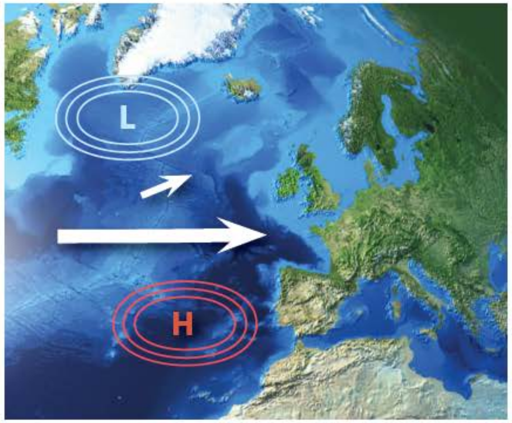
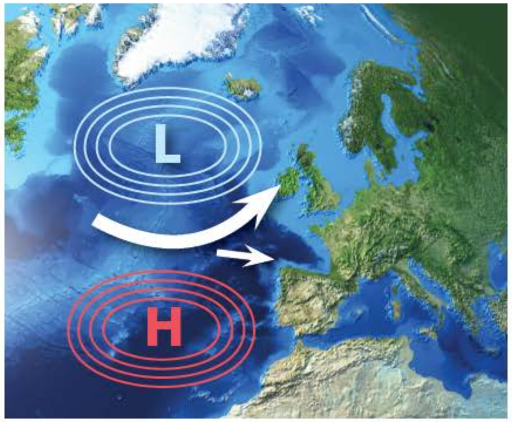
a/ NAO +



b/ NAO -

c/ EA +



d/ EA -

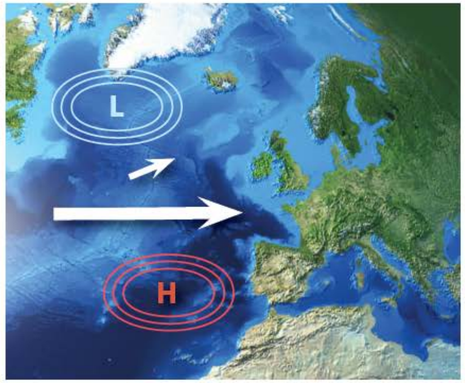
NAO: strength of pressure difference.

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

positive means a northward displacement (more zonal flow)

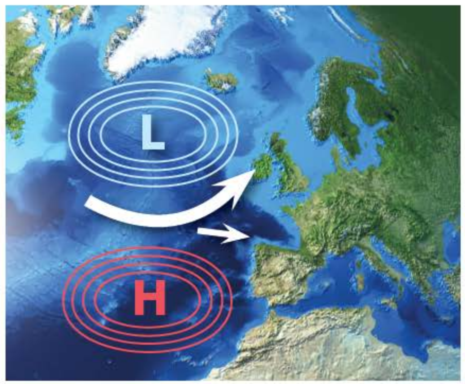
negative means a southward displacement (lower temperatures)

a/ NAO +



b/ NAO -

c/ EA +



d/ EA -

e/ Scandinavian Pattern

f/ Sc Atlantic Ridge

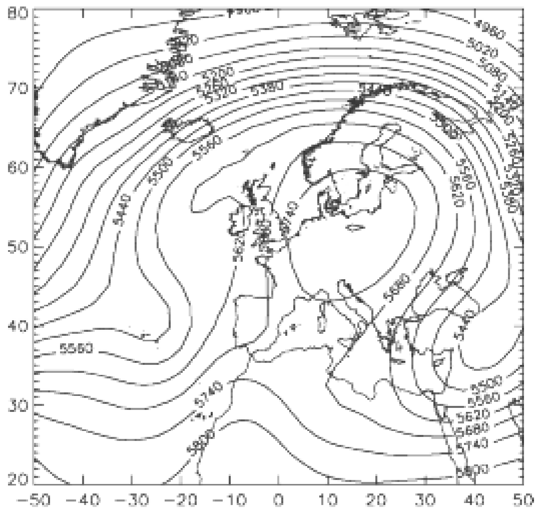
NAO: strength of pressure difference.

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

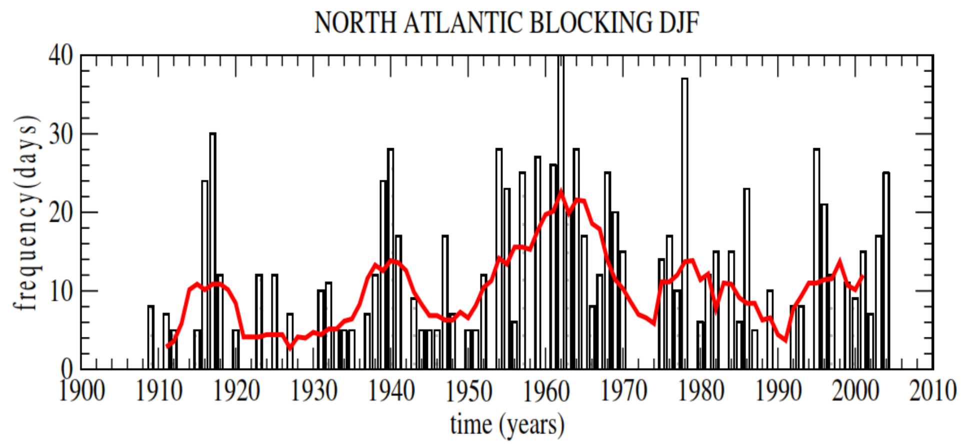
Scandinavian pattern: blocking, represents an east-west shift of the centres of variability.

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).

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

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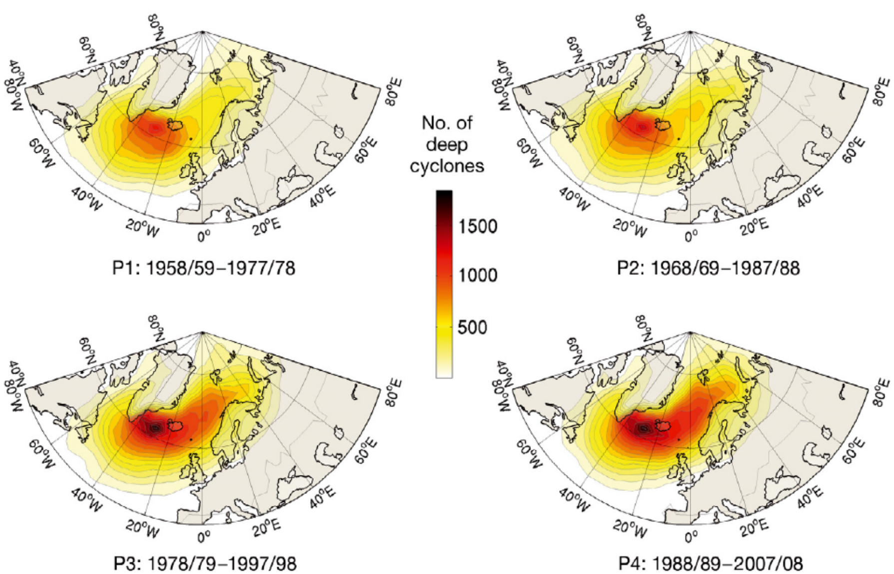
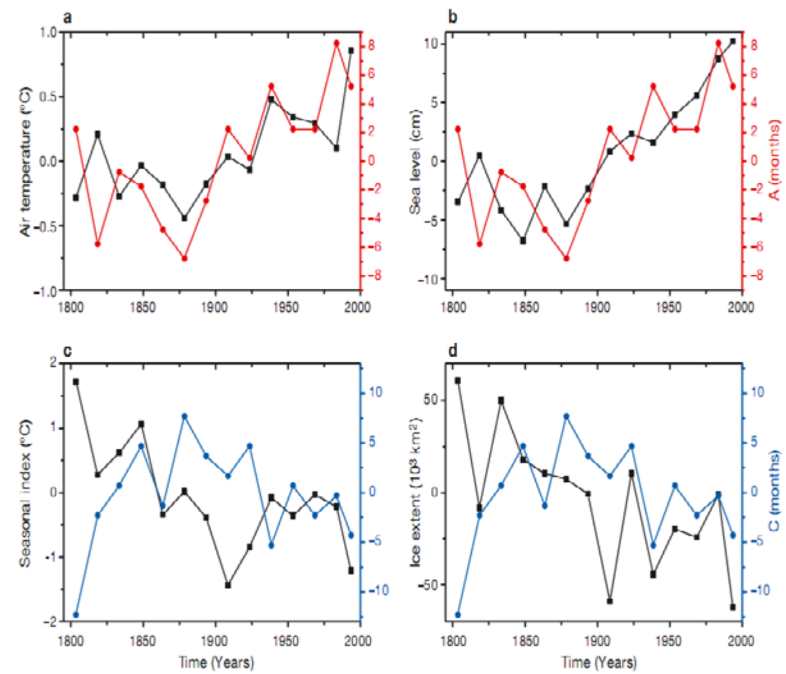
Atmospheric Circulation in a changing climate

- 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).

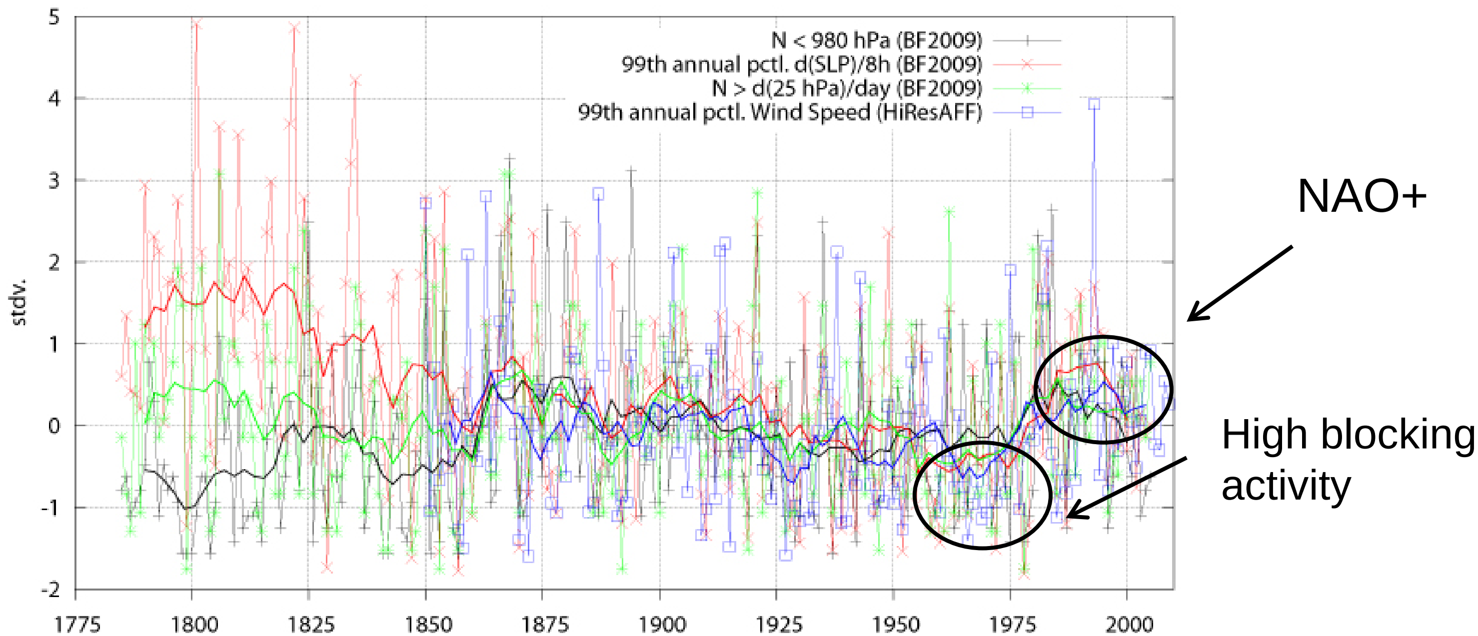


Anomalies and circulation types that describe the vorticity of the atmospheric circulation. Red indicates anticyclonic and blue cyclonic circulation. (a) air temperature, (b) sea level, (c) difference between summer (JJA) and winter (DJF) seasonal temperatures, and (d) ice cover, Omstedt et al. (2004).

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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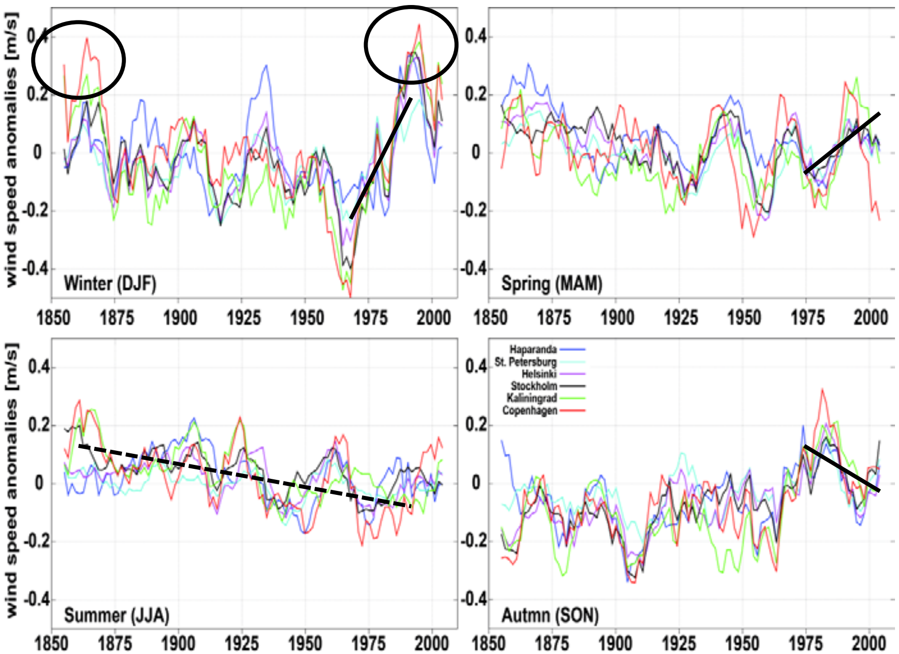
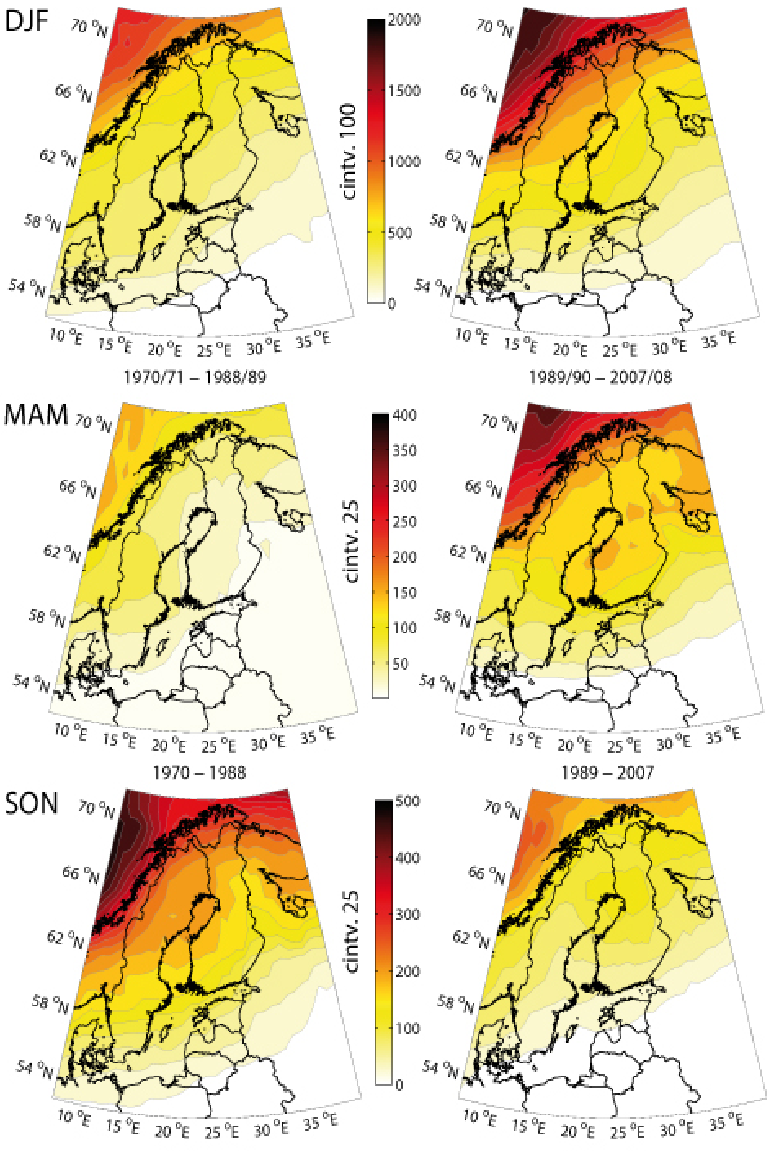
Seasonal differences:

- 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).

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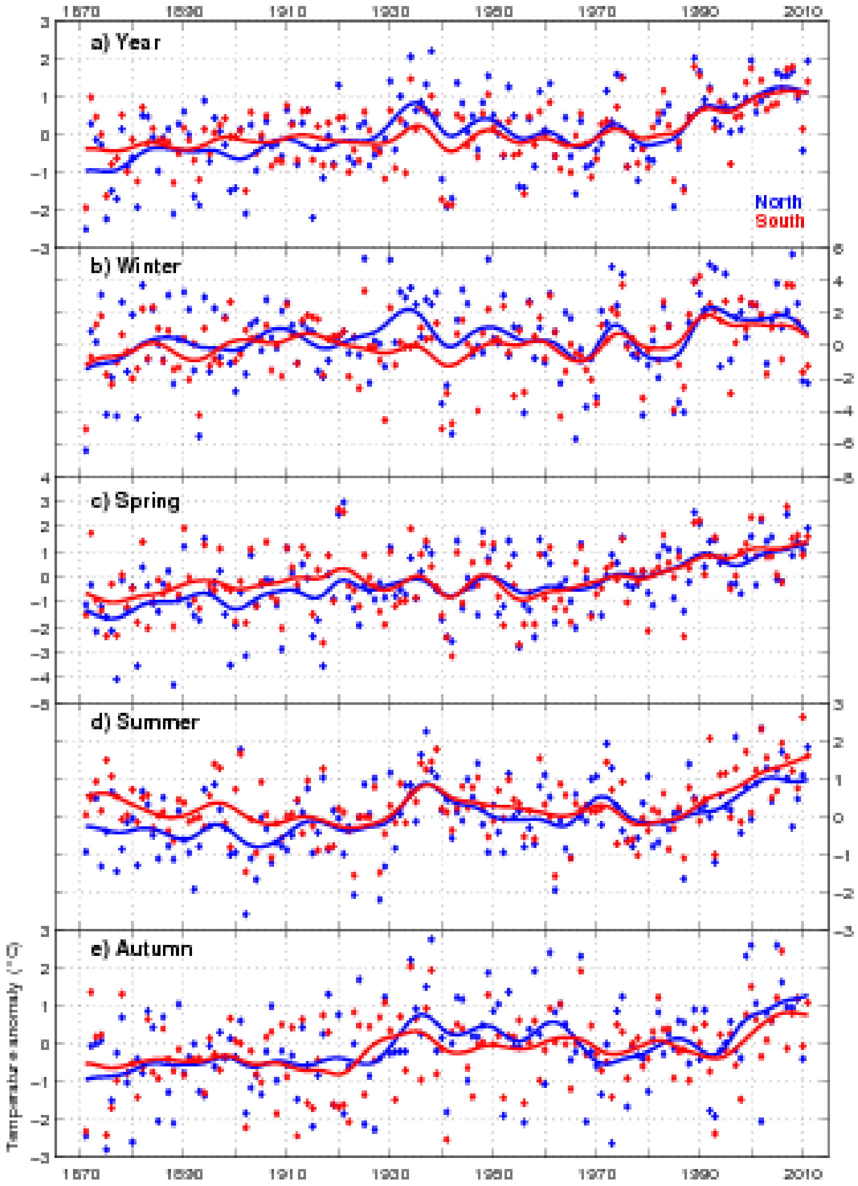
Temperature: Air

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.

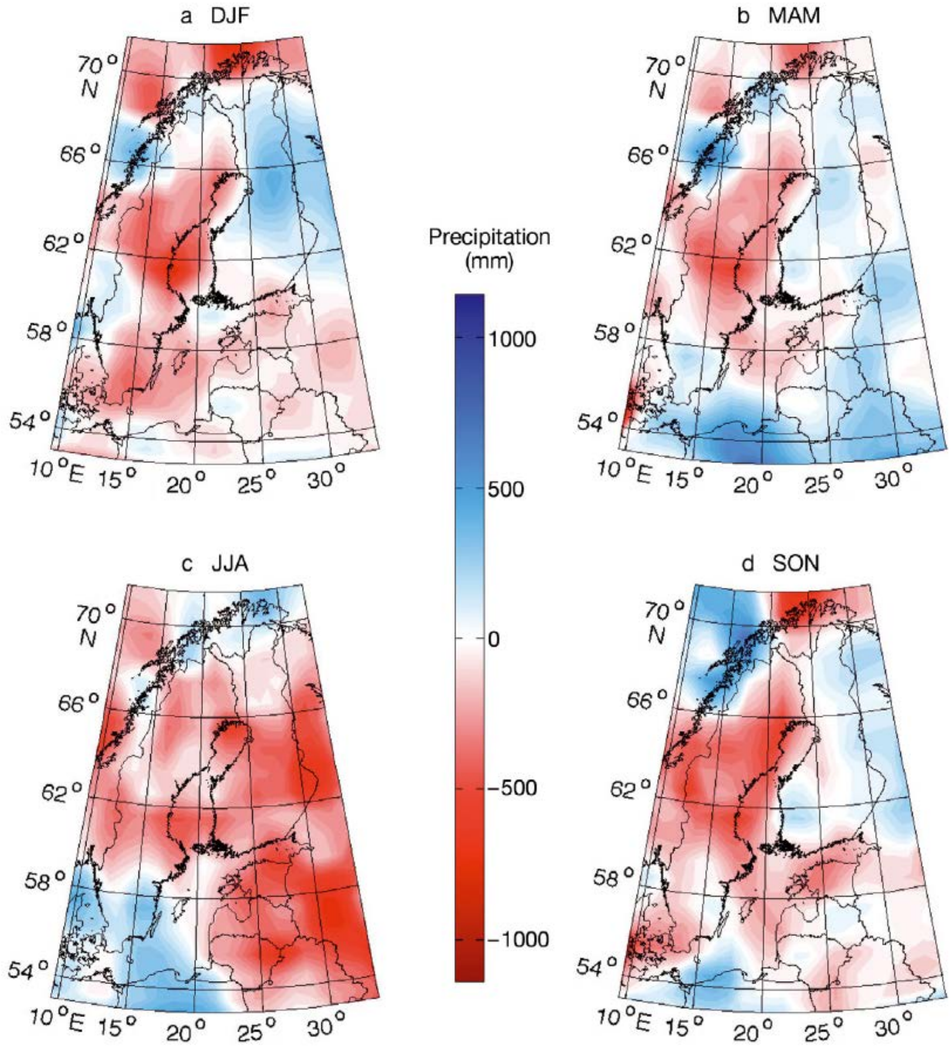
Precipitation

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

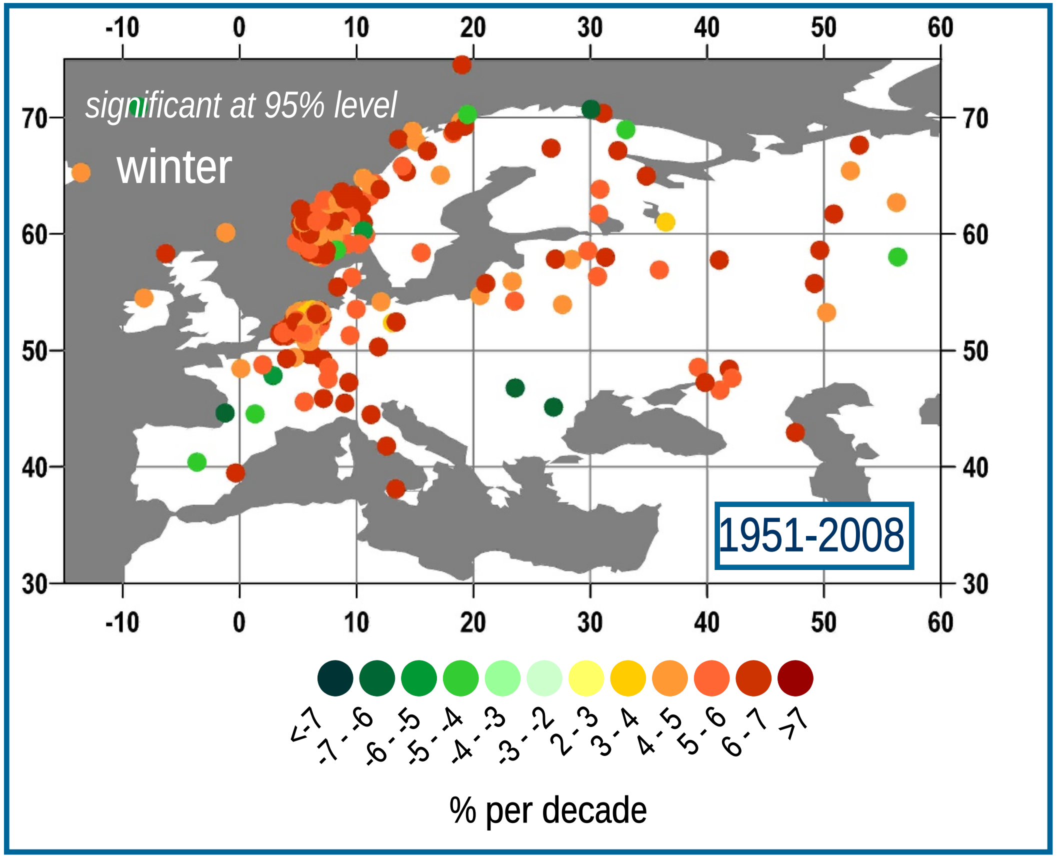
Precipitation

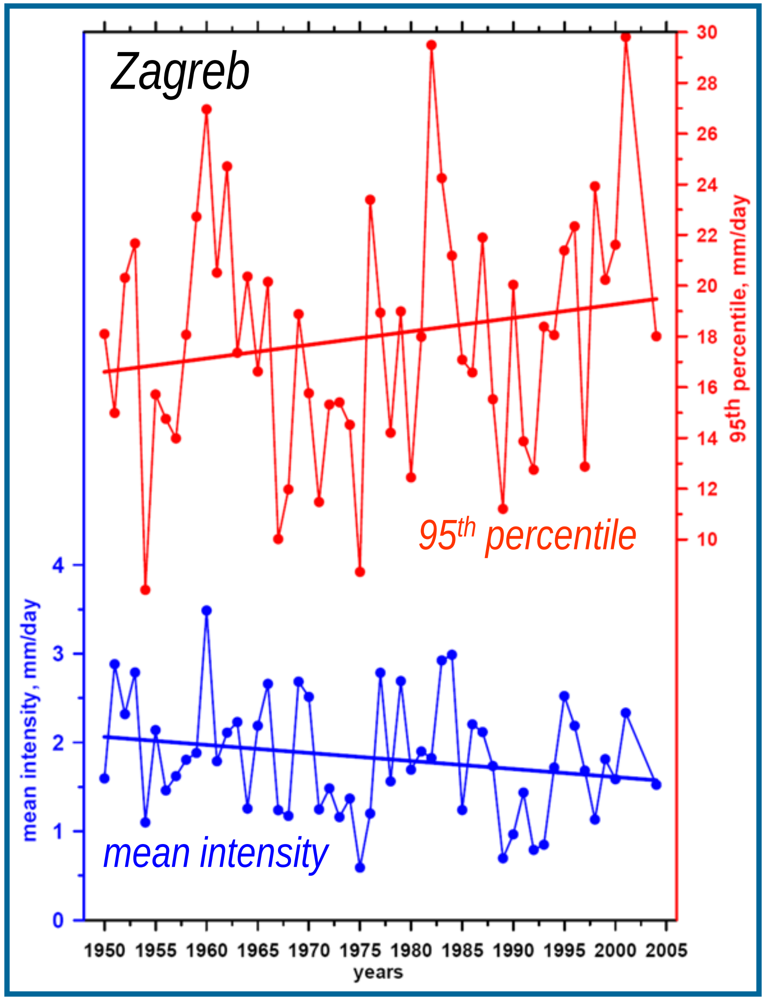
- For the last decades
  - General increase in winter and spring precipitation in northern Europe.
  - Highest increase in Sweden and eastern coast of the Baltic Sea.
- Comparing 1994-2008 to the previous 15 years:
  - Less precipitation in northern and central Baltic Sea.
  - More precipitation in the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

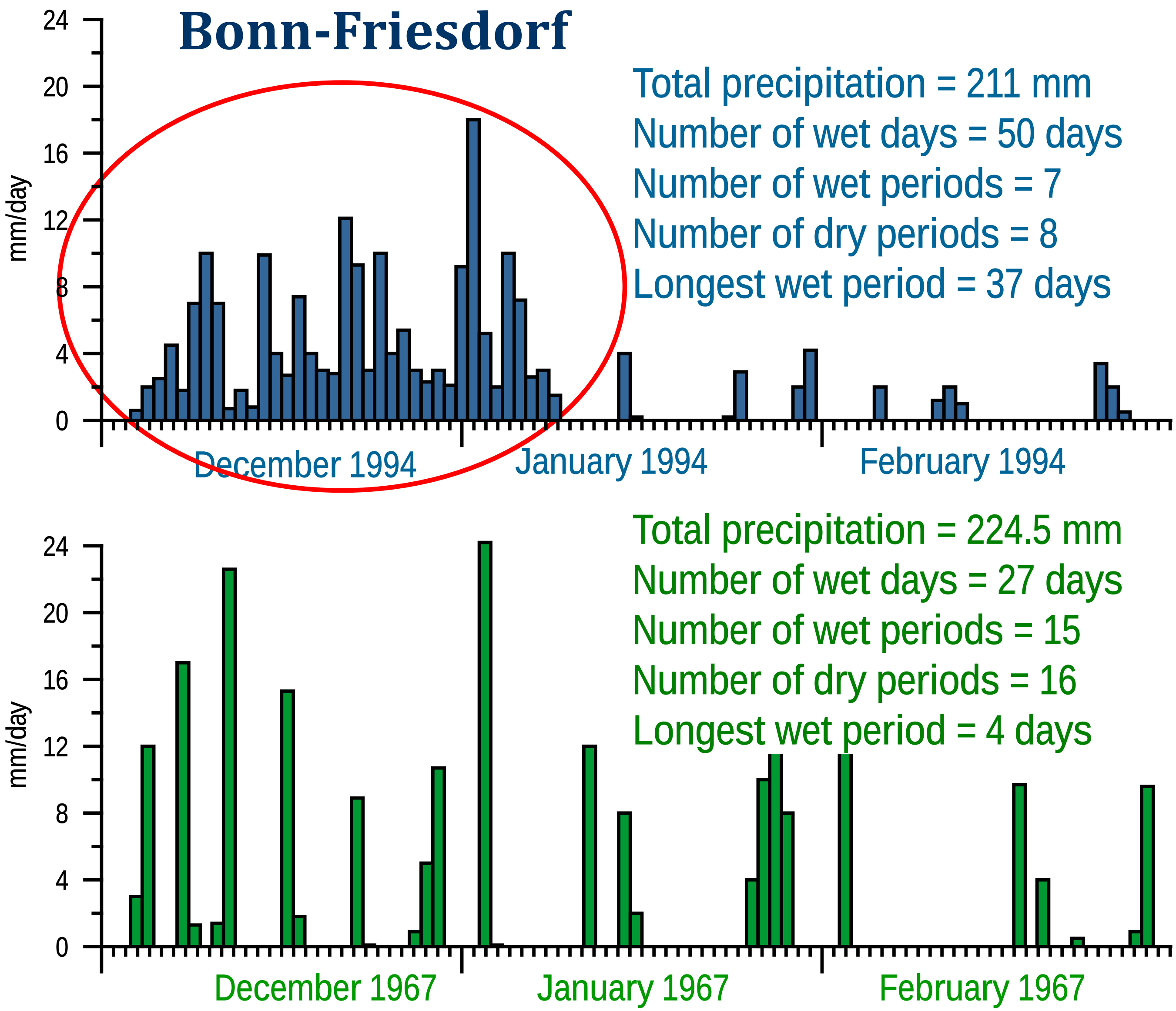


Figure from Sergey Gulev

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

Circulation,
wind, water
level,
temperature,
waves
precipitation
Ice, mixing

Extreme events

Drought
flooding
storm surge
heat waves
Mixing

Drinking water
quality,
ecosystem
response,
carbon cycle

Natural disaster

Damage for
human life,
economic
losses,
influence
ecosystems

We are often here. More knowledge is needed of all aspects.

Extreme events: last decades

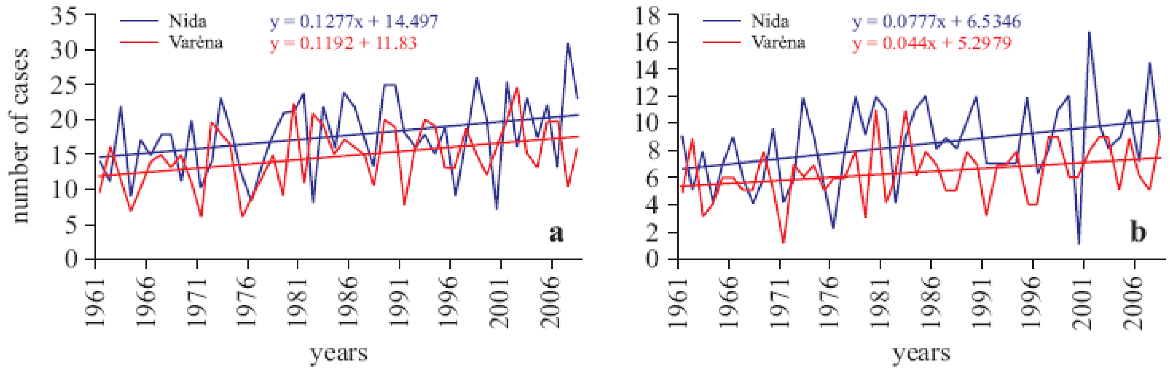
Often extreme events and changes in extreme situations are of more important than changes in mean climate.

- 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).

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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.

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Conclusions

- 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
Heavy precip	x	positive

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

Summary BACC II

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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).
  - 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

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Literature

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