Climate variability and extremes

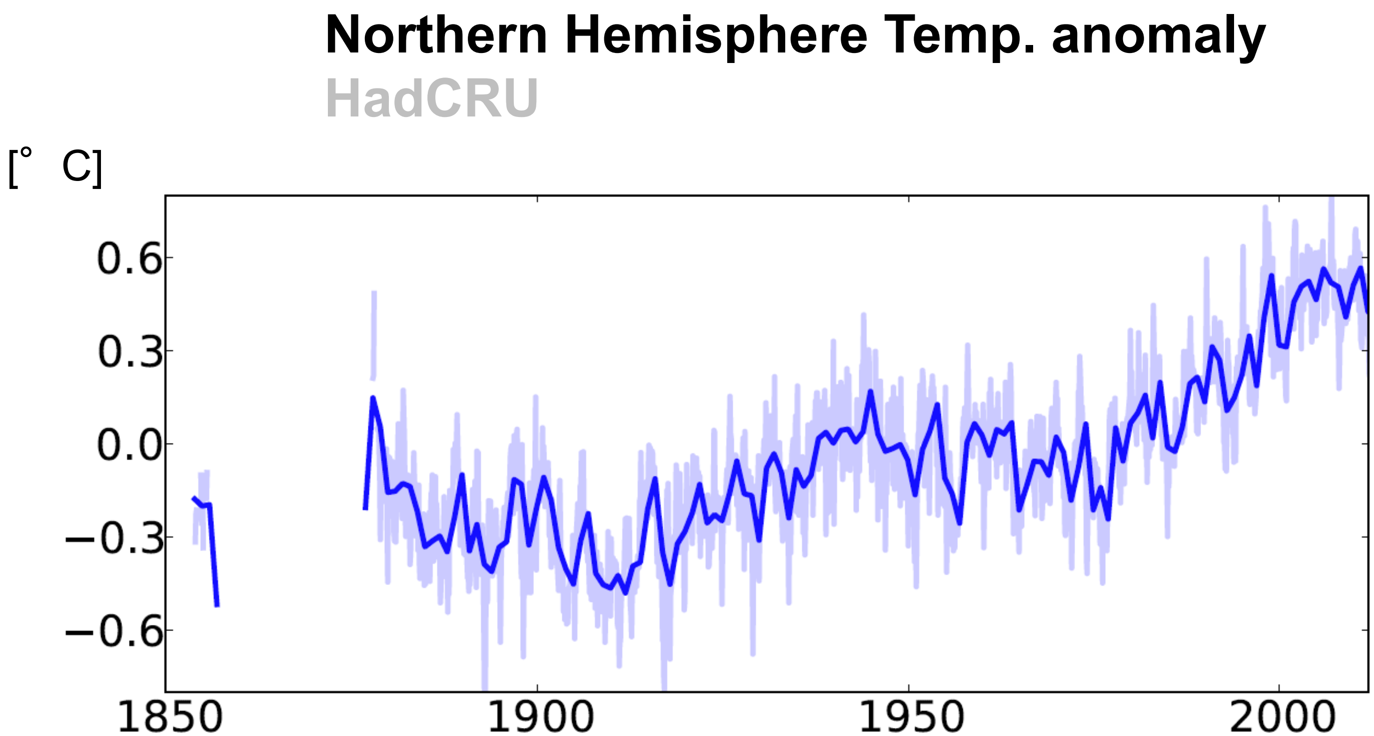
Climate System II (Lohmann/Werner)

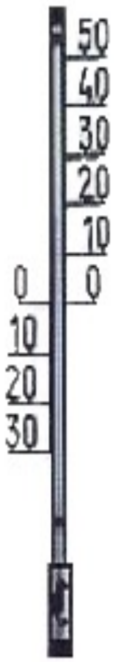
9th lecture 19.12.2023

Gerrit Lohmann

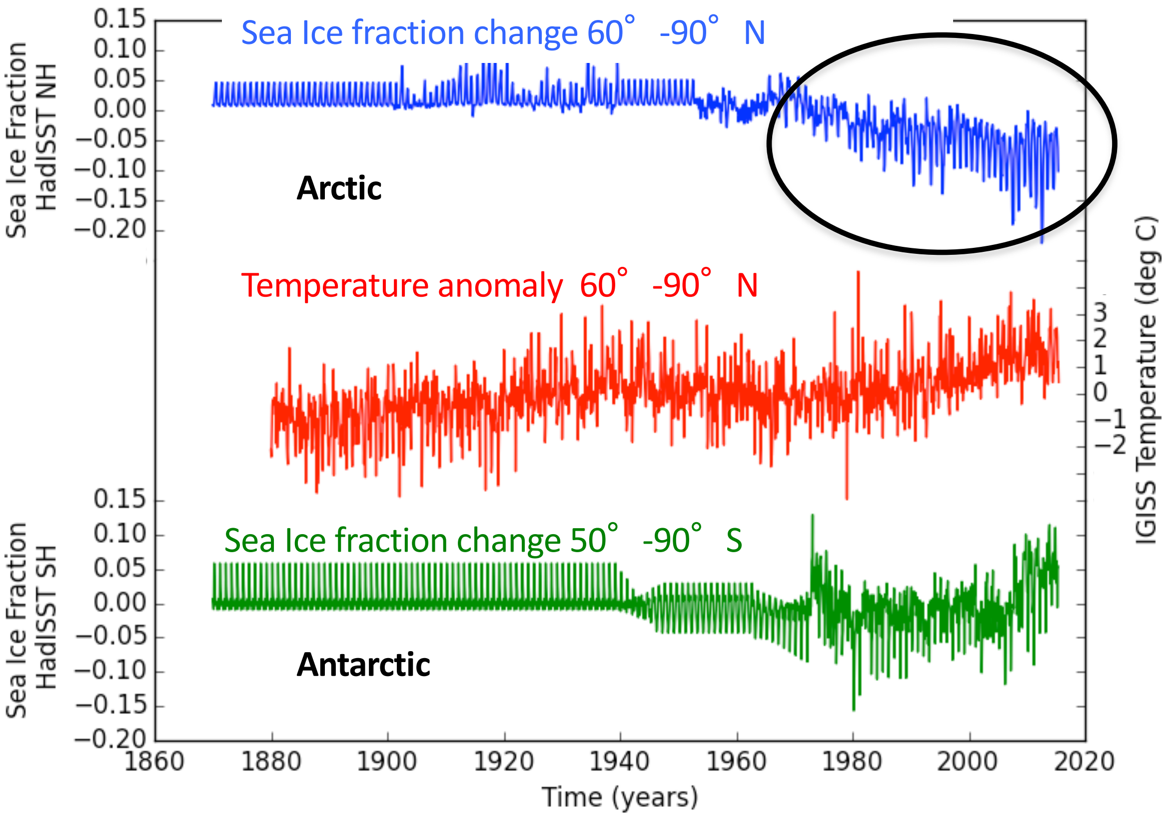
Instrumental record/period

Temperature of the last **150 years** (instrumental data)



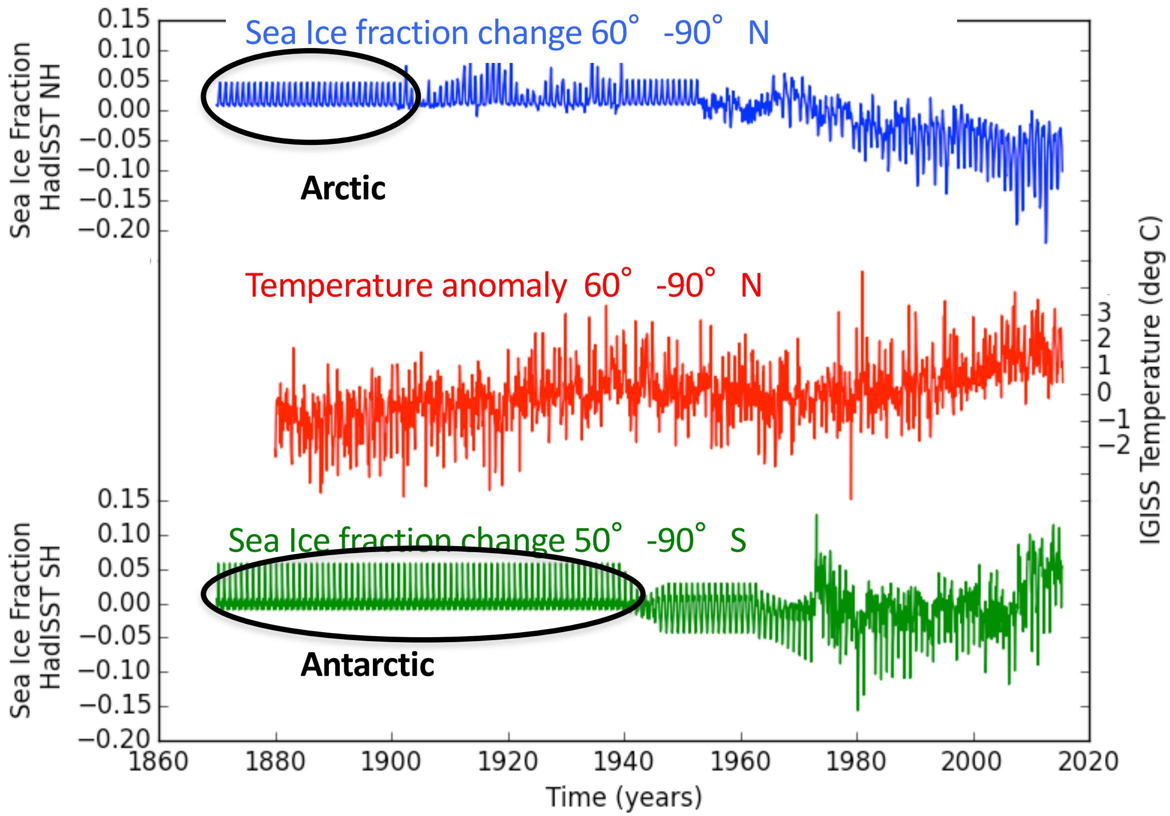


Arctic Sea Ice retreat



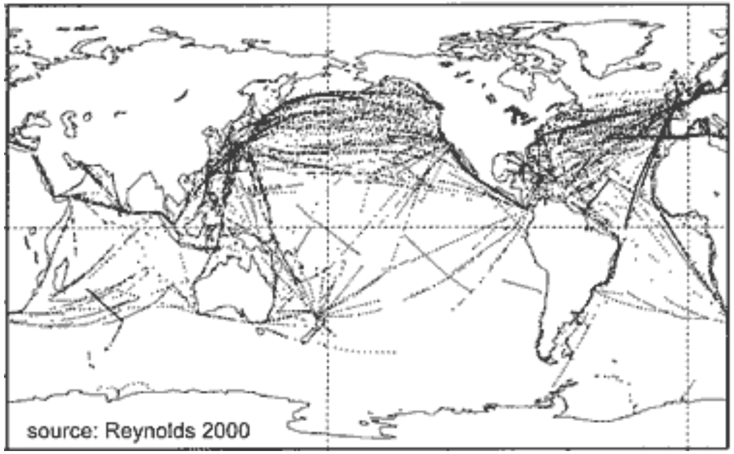
Arctic Sea Ice retreat

Missing Information about Sea Ice



The “Climate dilemma“

- Instrumental data are **sparce**



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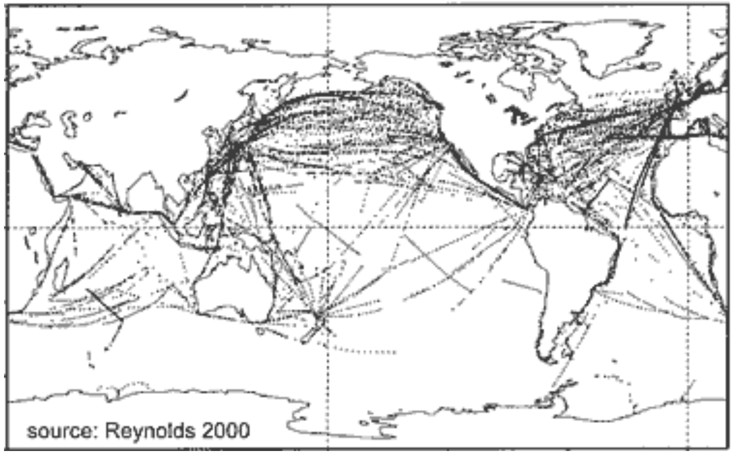

- The records of direct temperature measurements are **short** and already fall in the phase of strong **human influence**.

The "Climate dilemma"

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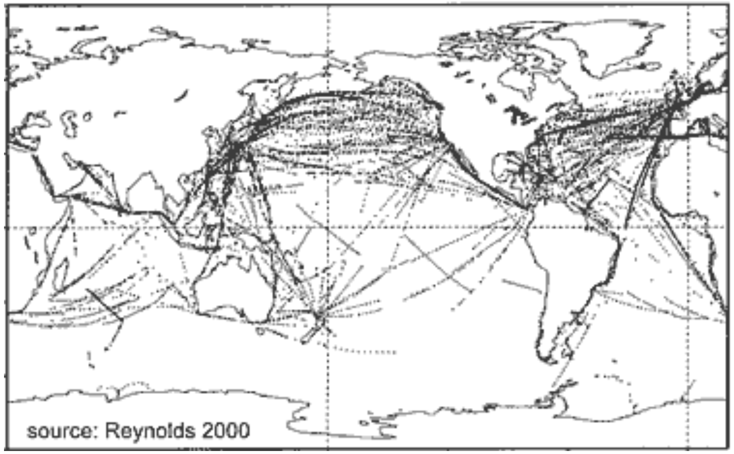
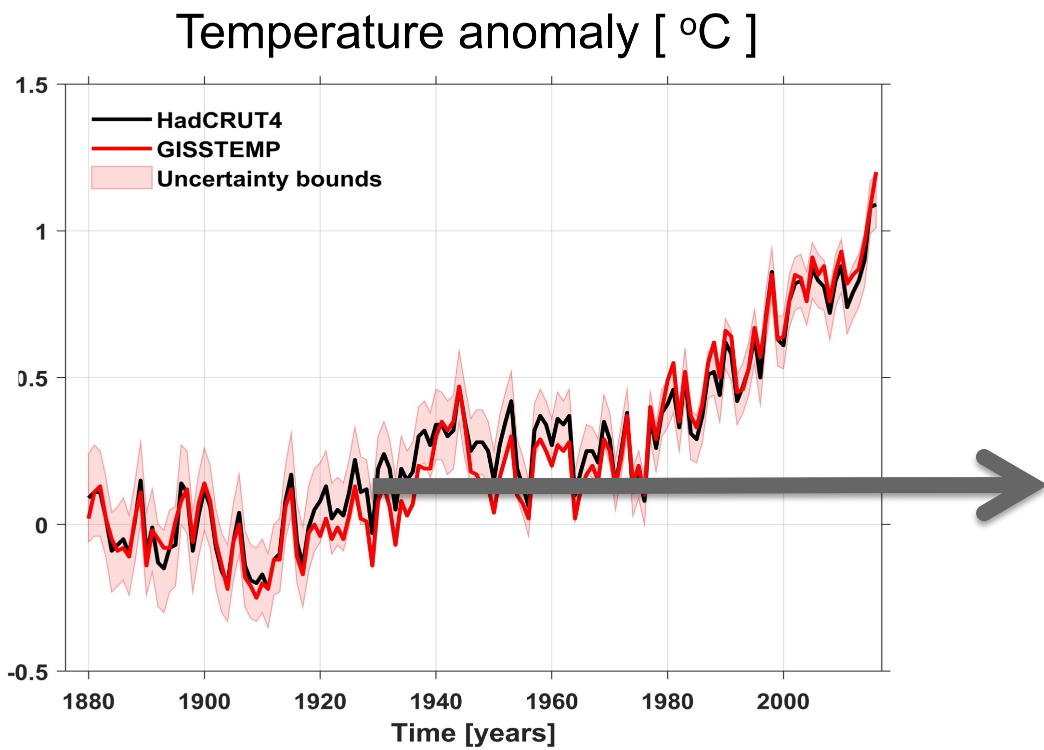


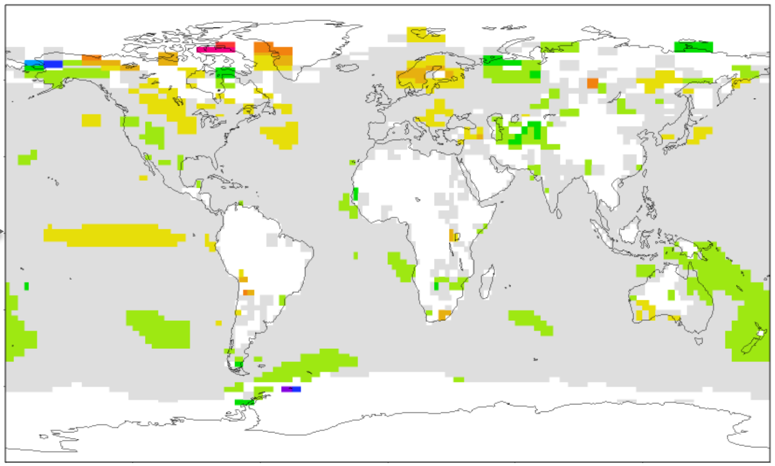
- The records of direct temperature measurements are **short** and already fall in the phase of strong **human influence**.

- **For the time before instrumental records, one has to rely on information from proxy data and modeling.**

Observational Record



Uncertainty largely due to missing information at high latitudes



Temperature Anomaly 1930
White areas: not enough data

History

last **1000 Years**

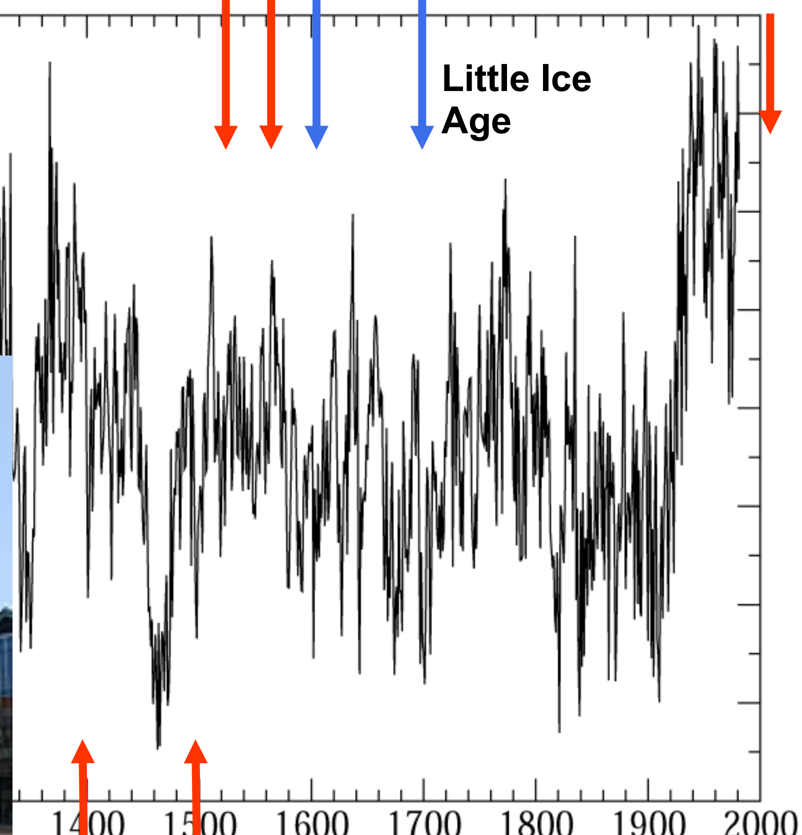
Thermometer

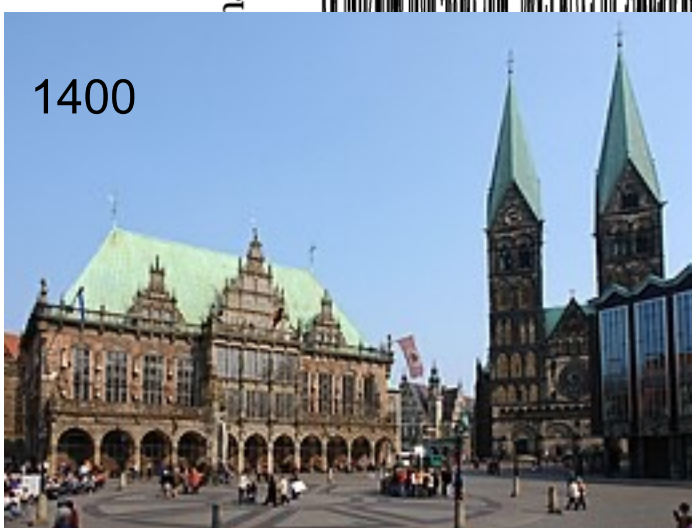
Barometer (Torricelli)

Pieter Breughel d.Ä.

Little Ice Age

present





Bremen townhall

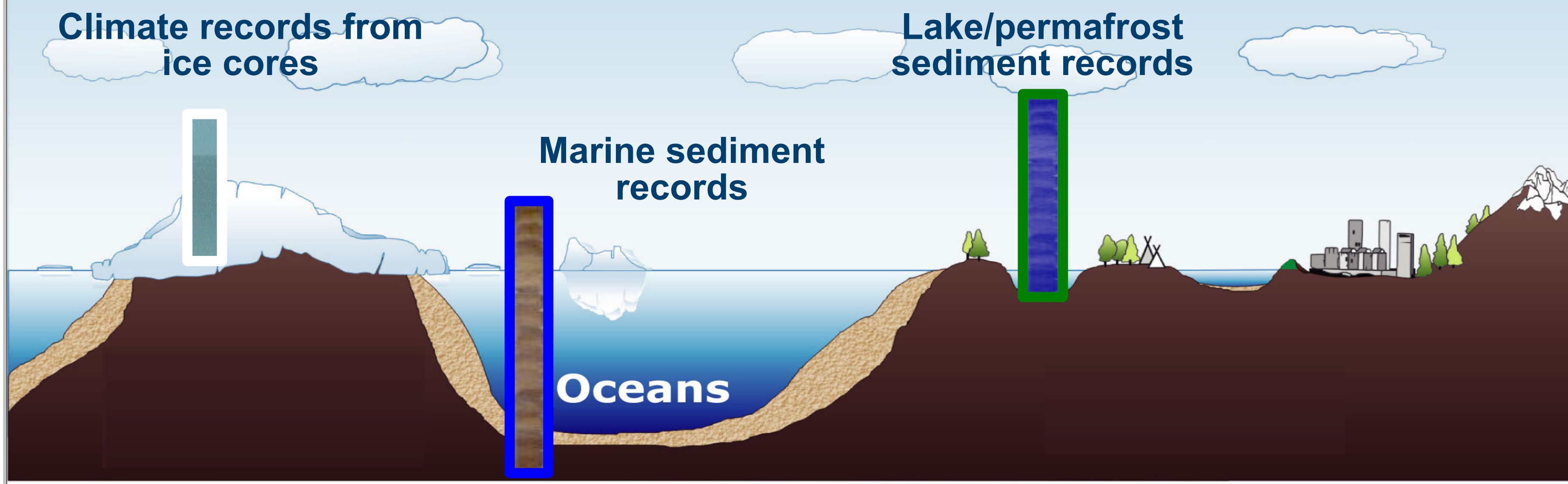
Nicolaus Kopernikus

Earth System: a polar perspective

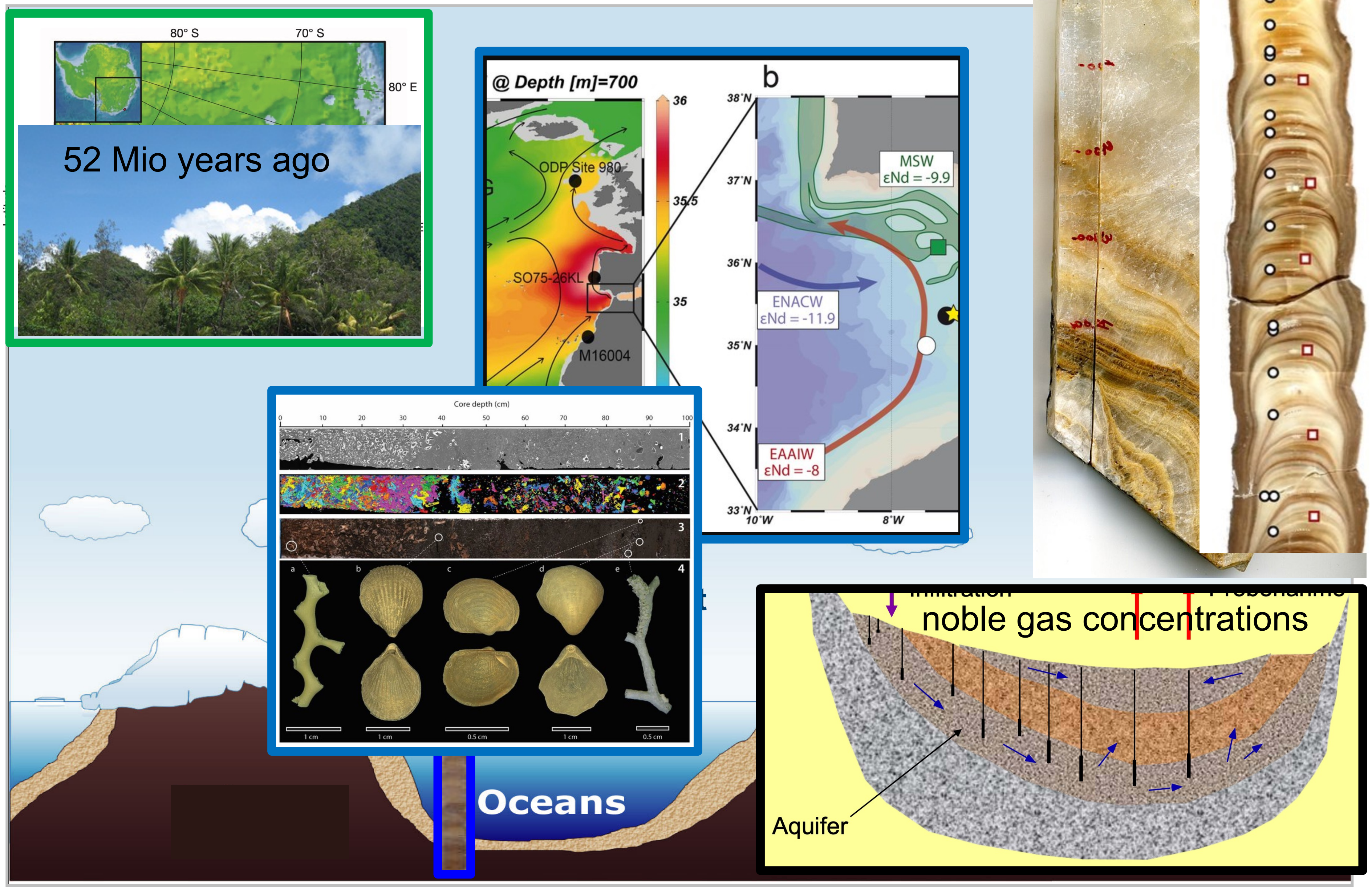
Ice drilling camp, 2009

Polarstern, marine sediments

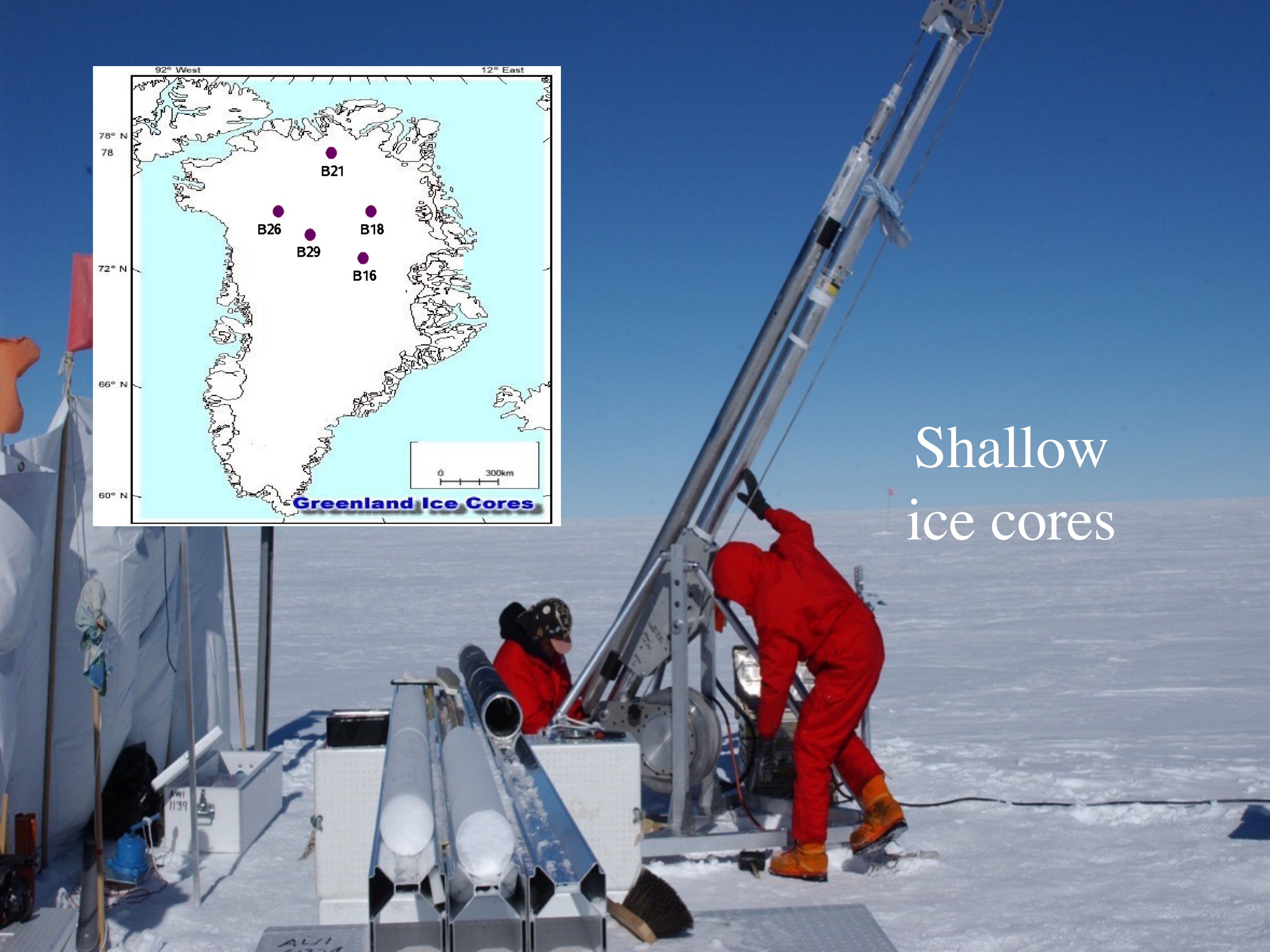
Lake/permafrost sediments



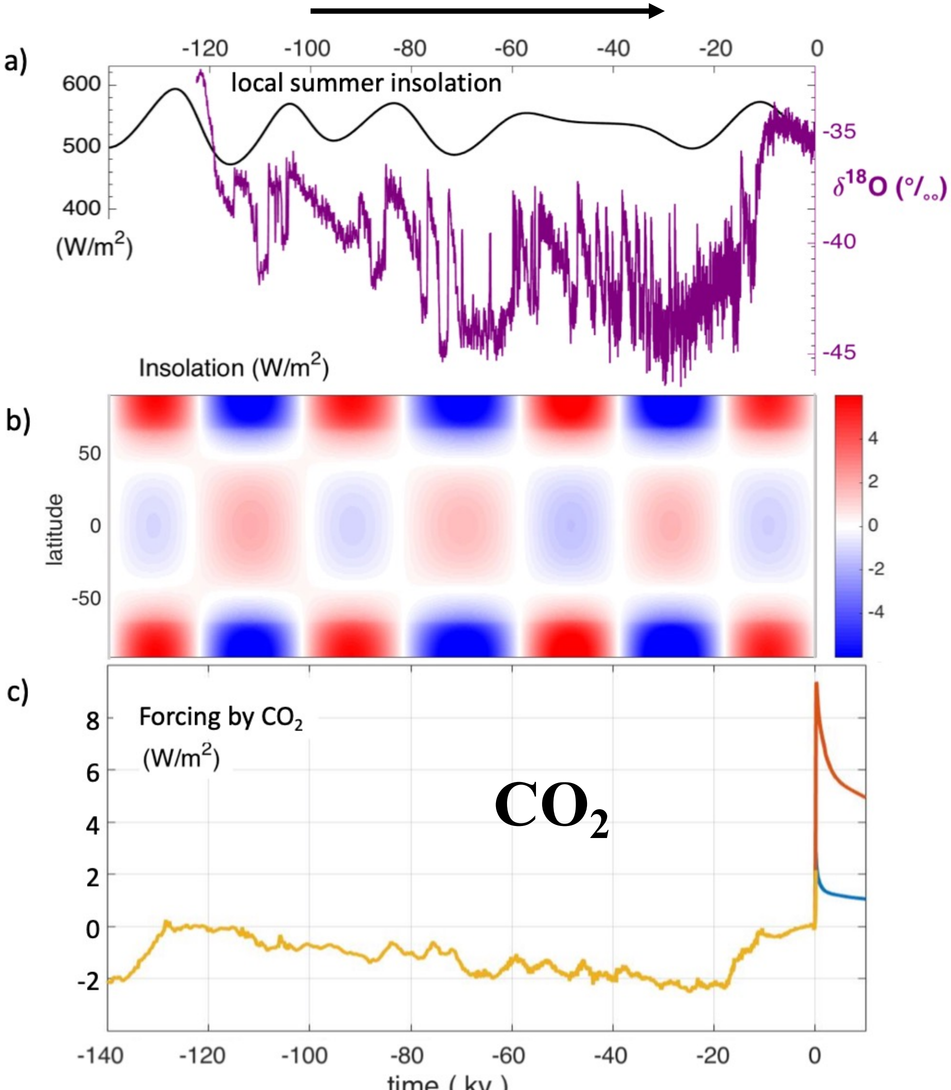
Earth System: Reconstructions

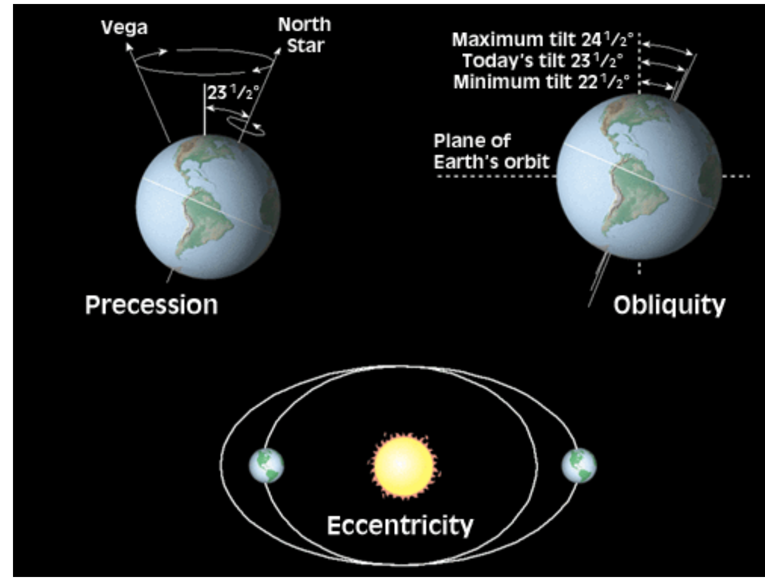


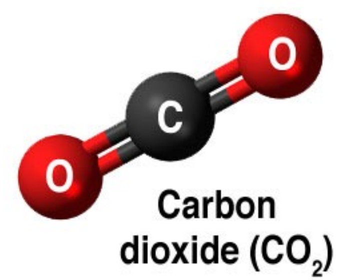
Shallow ice cores



Time (ky)

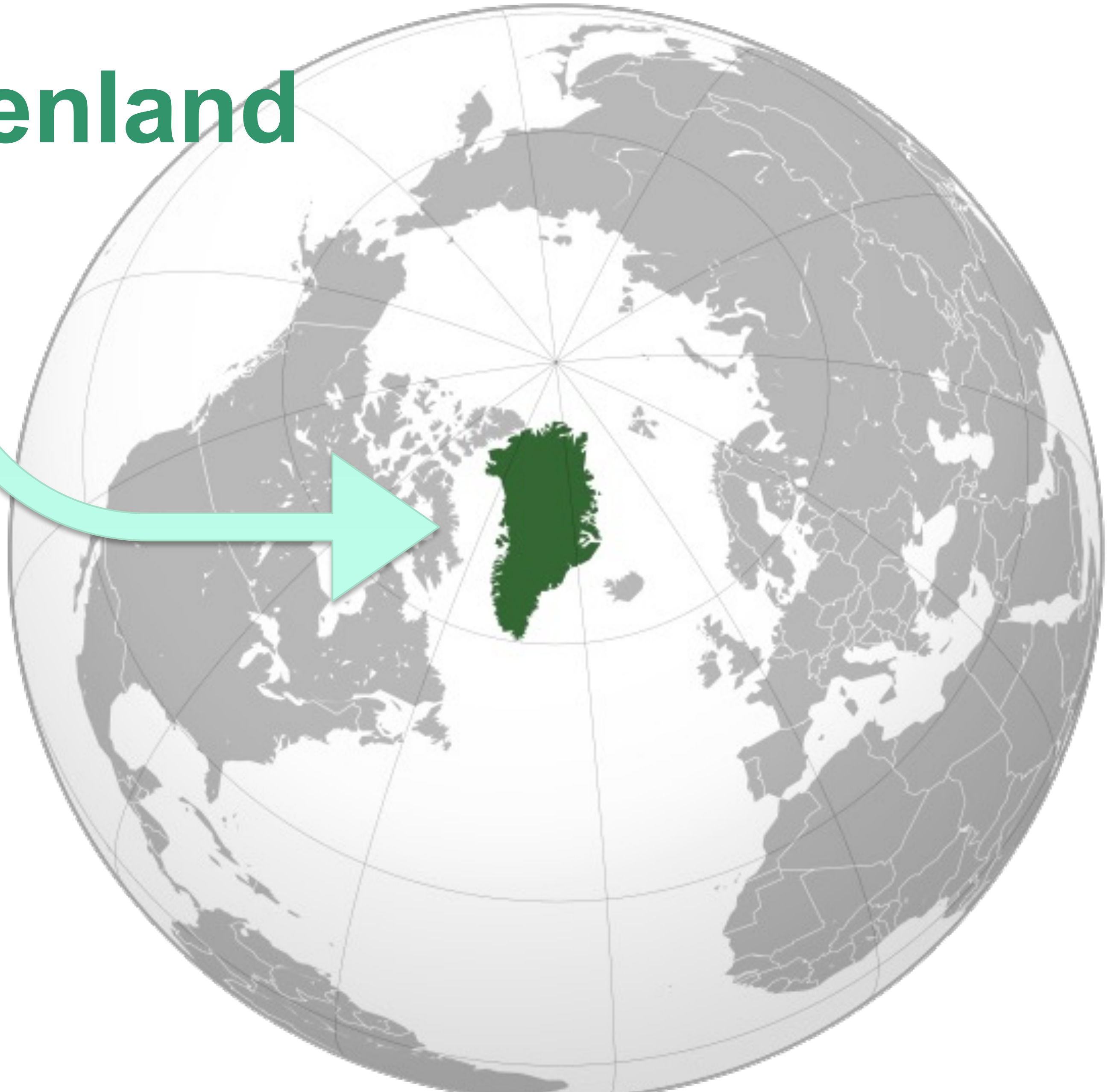






Lohmann et al. (2020) based on NGRIP, 2004; Berger, 1988; Köhler et al., 2017; Archer and Brovkin, 2008

Greenland



The world’s largest island

<u>The Greenland Ice Sheet</u>

Area: 1.7 million km^2

Average thickness: 2.3 km

Greenland's ice melts → 7m sea level rise

Antarctica’s ice melts → 60m sea level rise

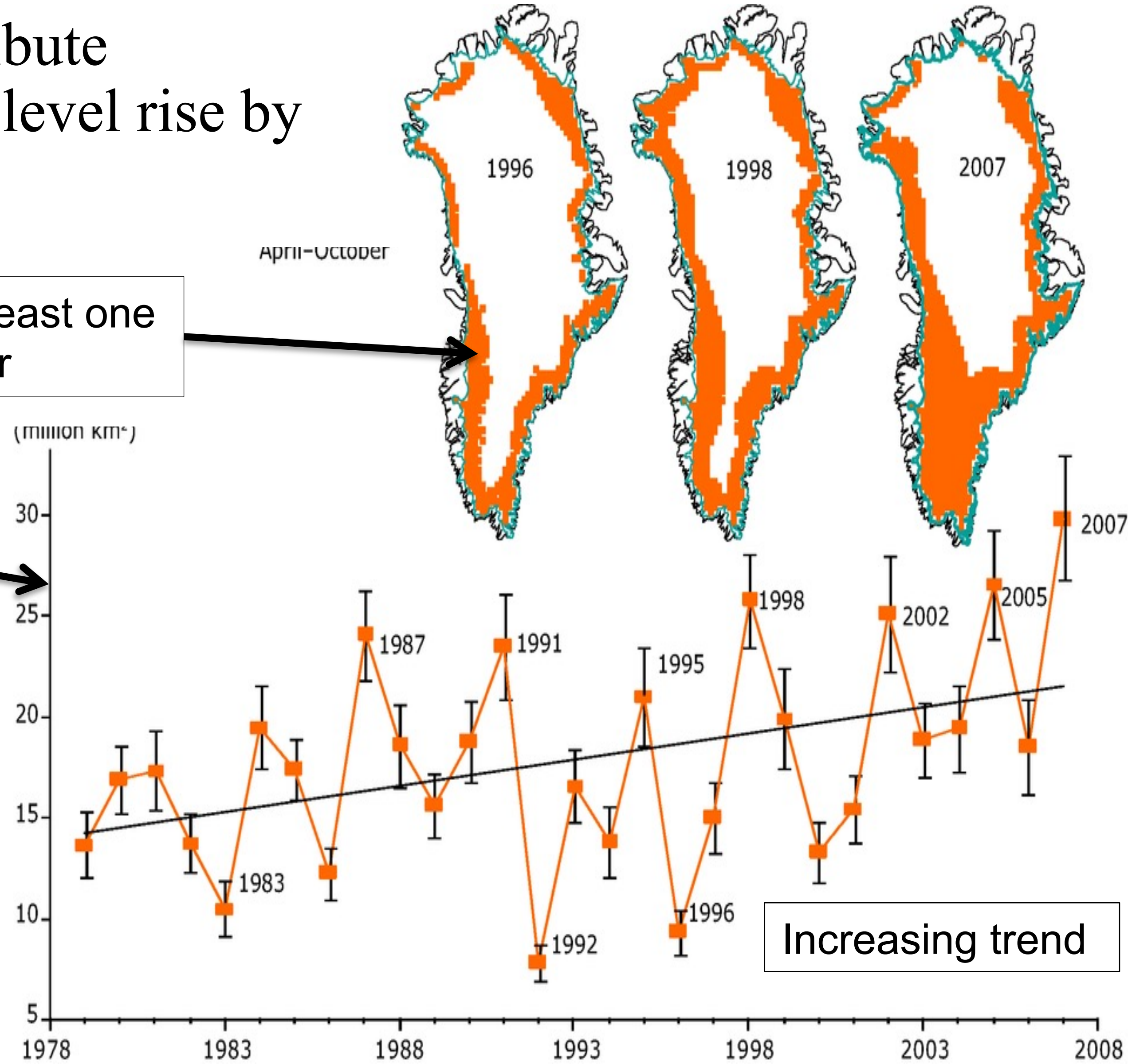
How quickly will Greenland's ice melt?

And will this contribute significantly to sea level rise by 2100?

Ice sheet surface with at least one melt day in April – October

Cumulated melt area days (million km^2)

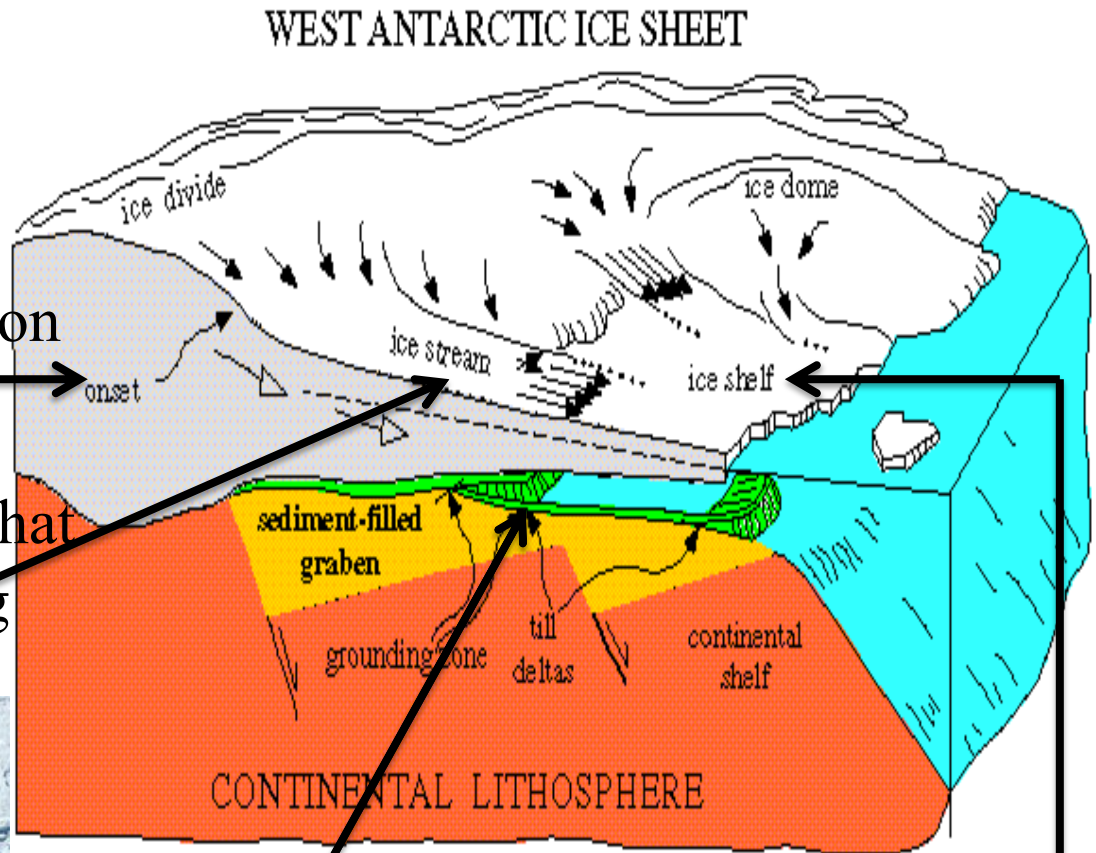
Greenland's surface melt area is increasing!



Ice Terminology

Ice sheet: mass of glacial ice on terrain over 50,000 km^2

Ice stream: part of ice sheet that moves faster than surrounding



Grounding line where ice sheet loses contact with solid ground

Ice shelf: thick, floating platform in ocean that is connected to ice sheet

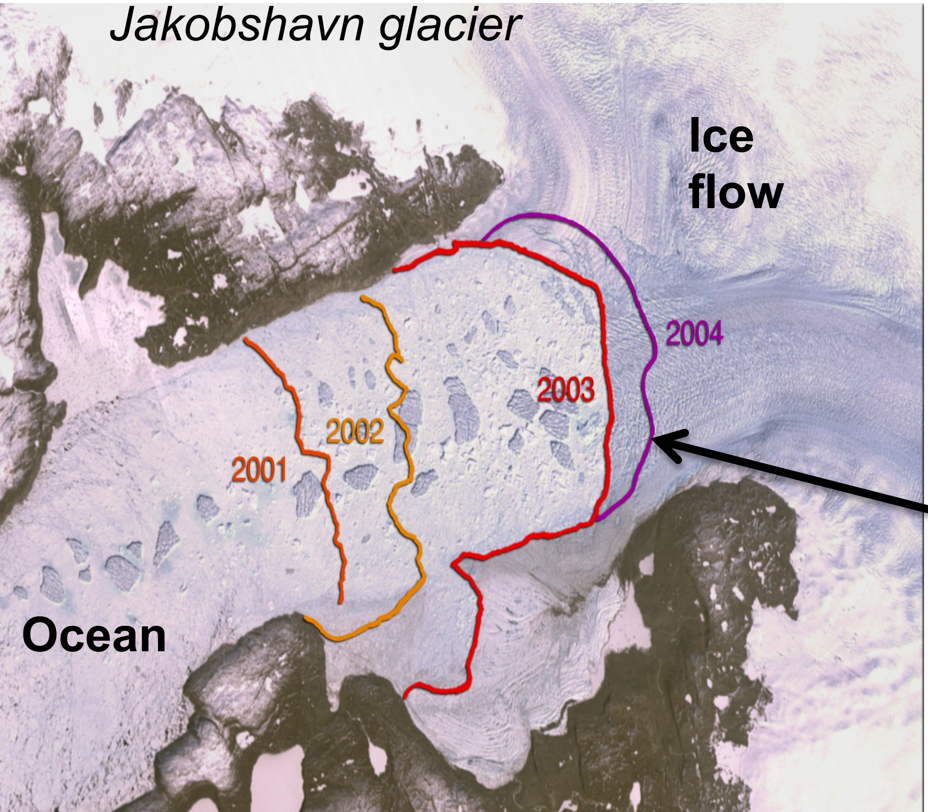
Moulin: well-like opening in glacier where water can flow into

Ice Terminology

Ice sheet mass balance = accumulation – ablation

Two main ways of losing mass:

1. Surface melt
2. Ice flow and calving



Glacier: Body of ice moving by own weight

Mountain glacier: glaciers on slopes of mountains

Terminus: end of glacier

Calving: ice breakoffs at terminus

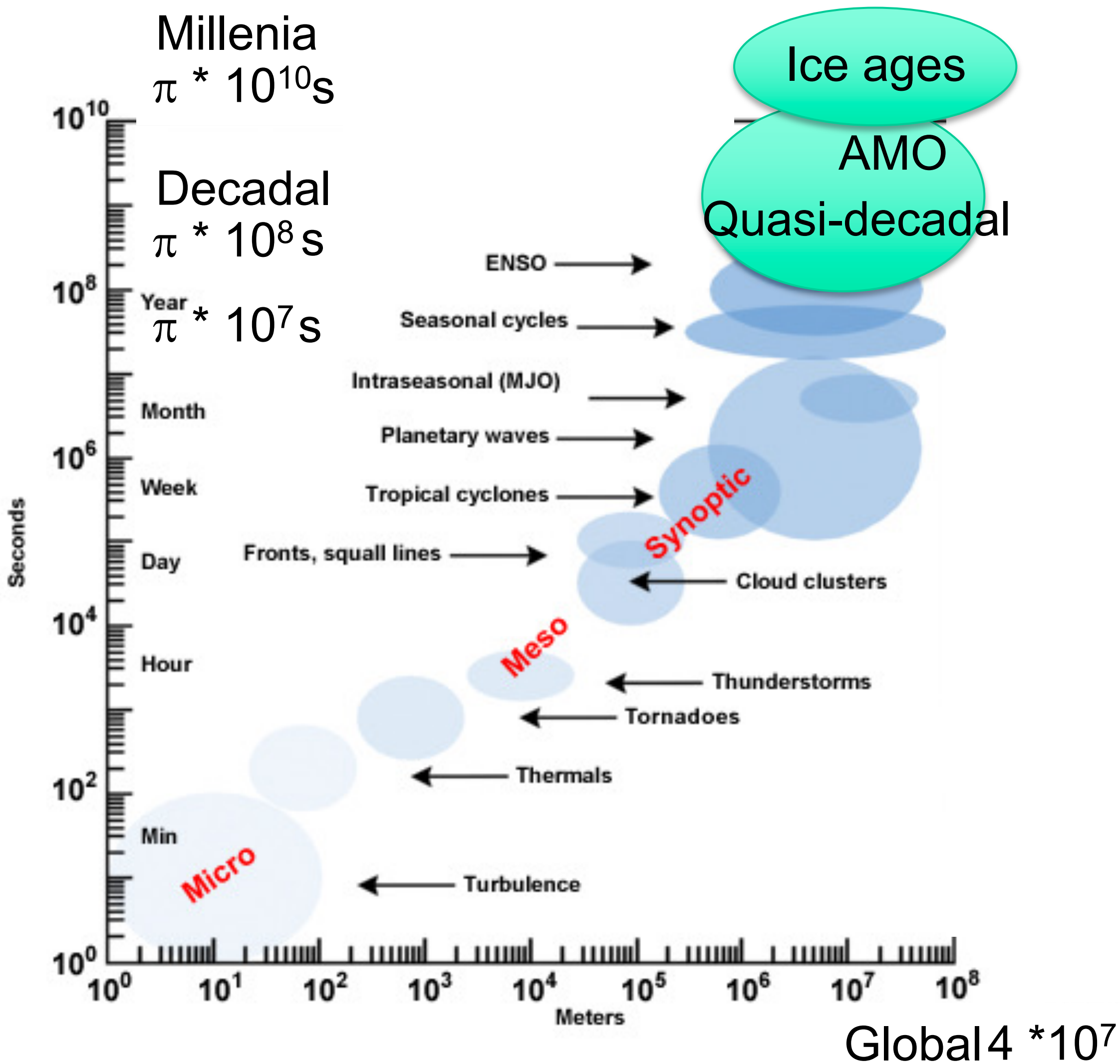

Helicopter
Helheim glacier terminus

Proxy Data

- Indirect data, often qualitative
- Long time series from archives
- Information beyond the instrumental record

Spatio-Temporal Scales

Dissipative Systems (as atmosphere & ocean) cannot maintain large gradients on long time scales



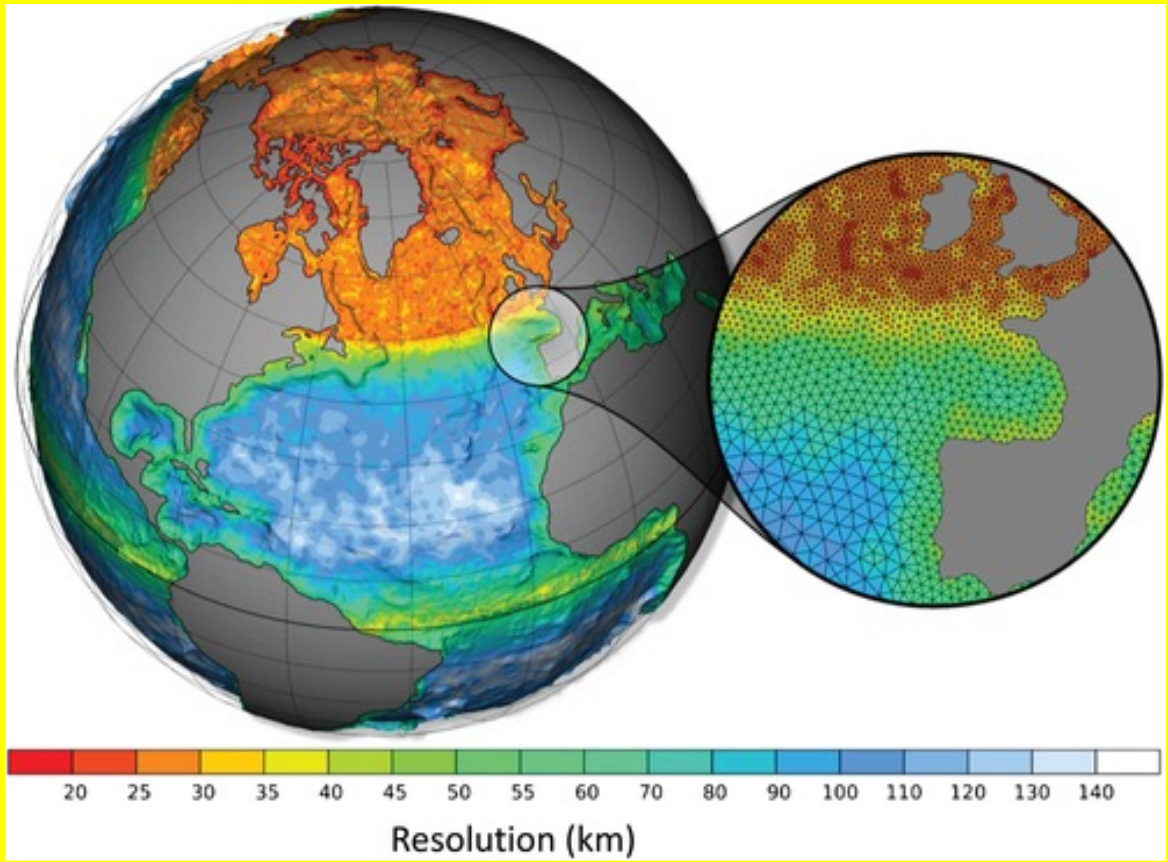
Spatial || temporal Scales

Earth System Analysis: Models

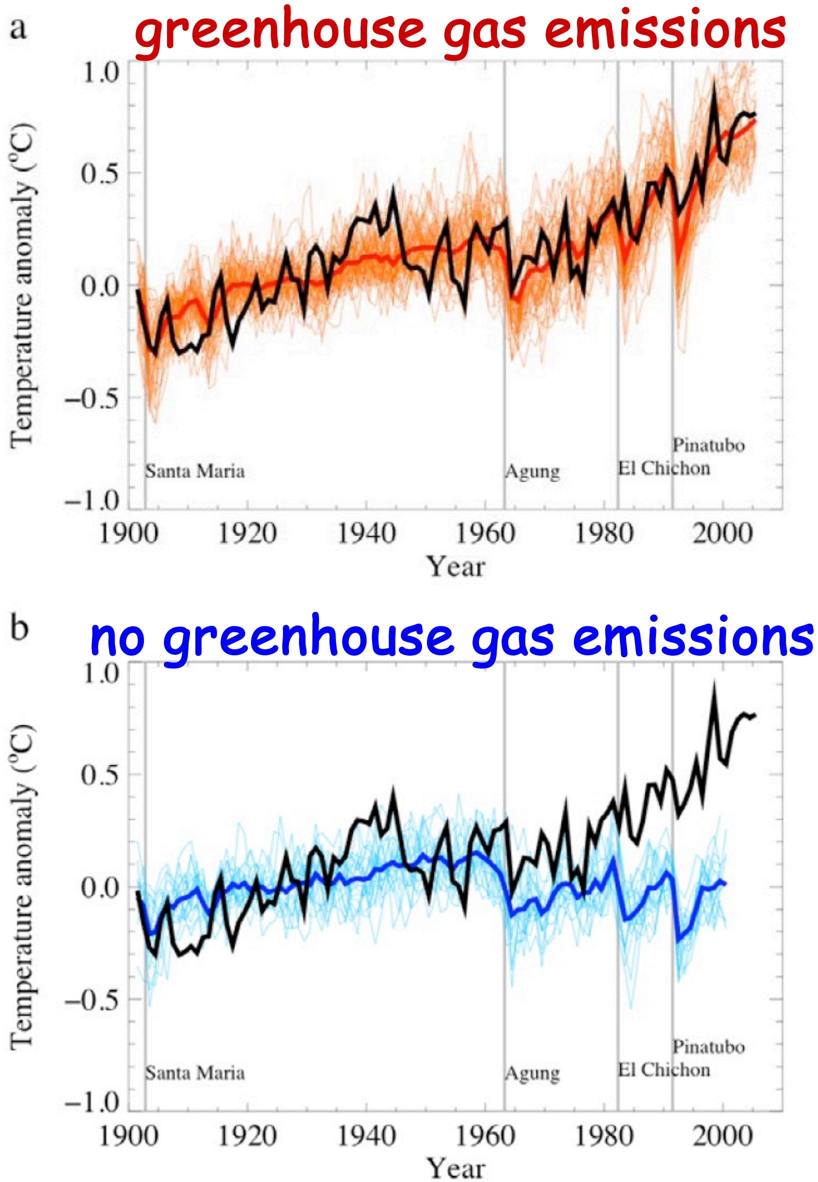
$$\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} = -2\Omega \times \mathbf{v} - \frac{1}{\rho}\nabla p + \mathbf{g} + \mathbf{F}$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{v} = 0$$

$$\frac{\partial T}{\partial t} + \mathbf{v} \cdot \nabla T - \frac{p}{\rho^2}\frac{d\rho}{dt} = Q$$



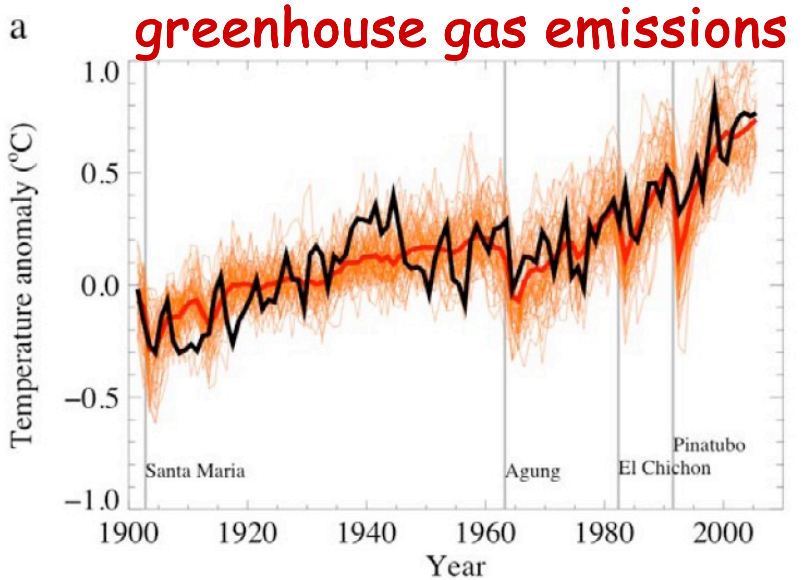
Attribution (model world)



observed changes are consistent with modeled response to external forcing, inconsistent with alternative explanations

Nobel Price, 2021

Attribution (model world)



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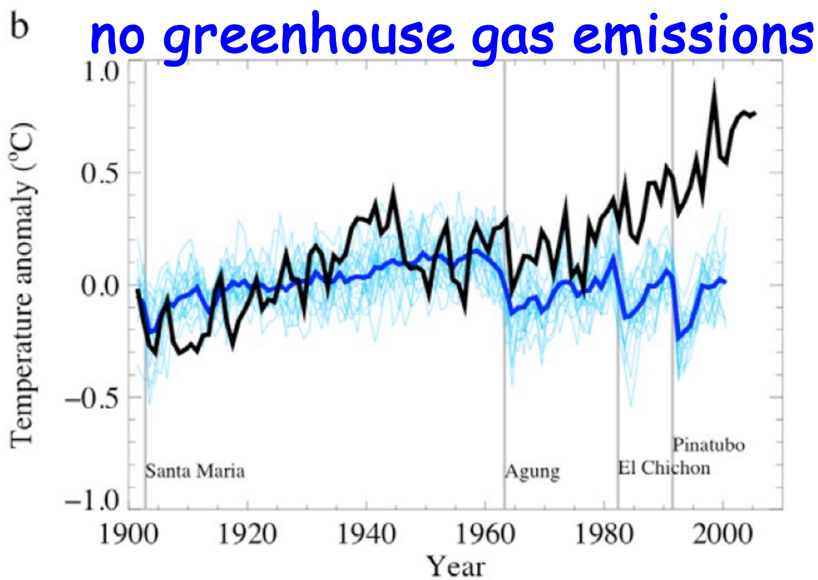
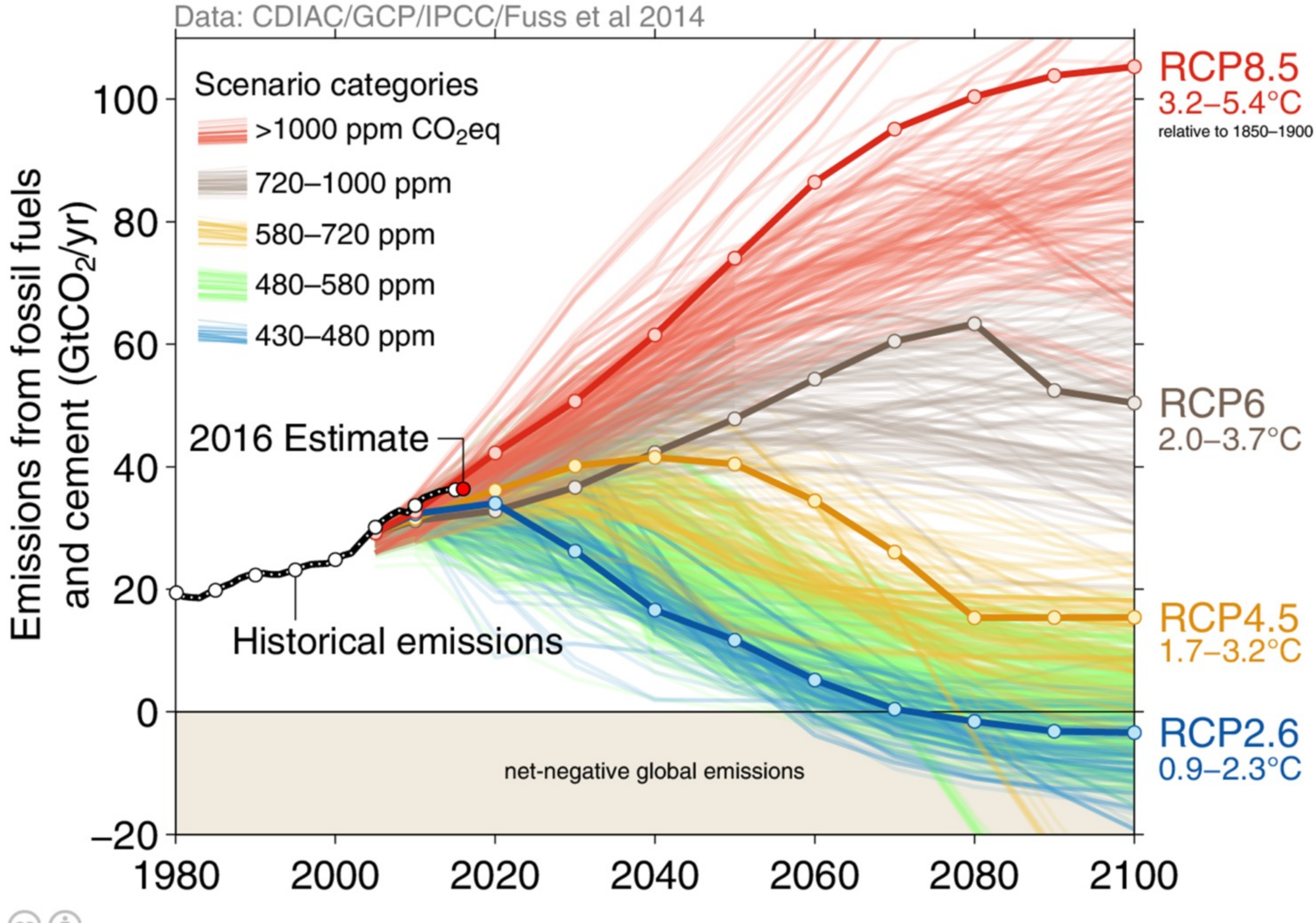
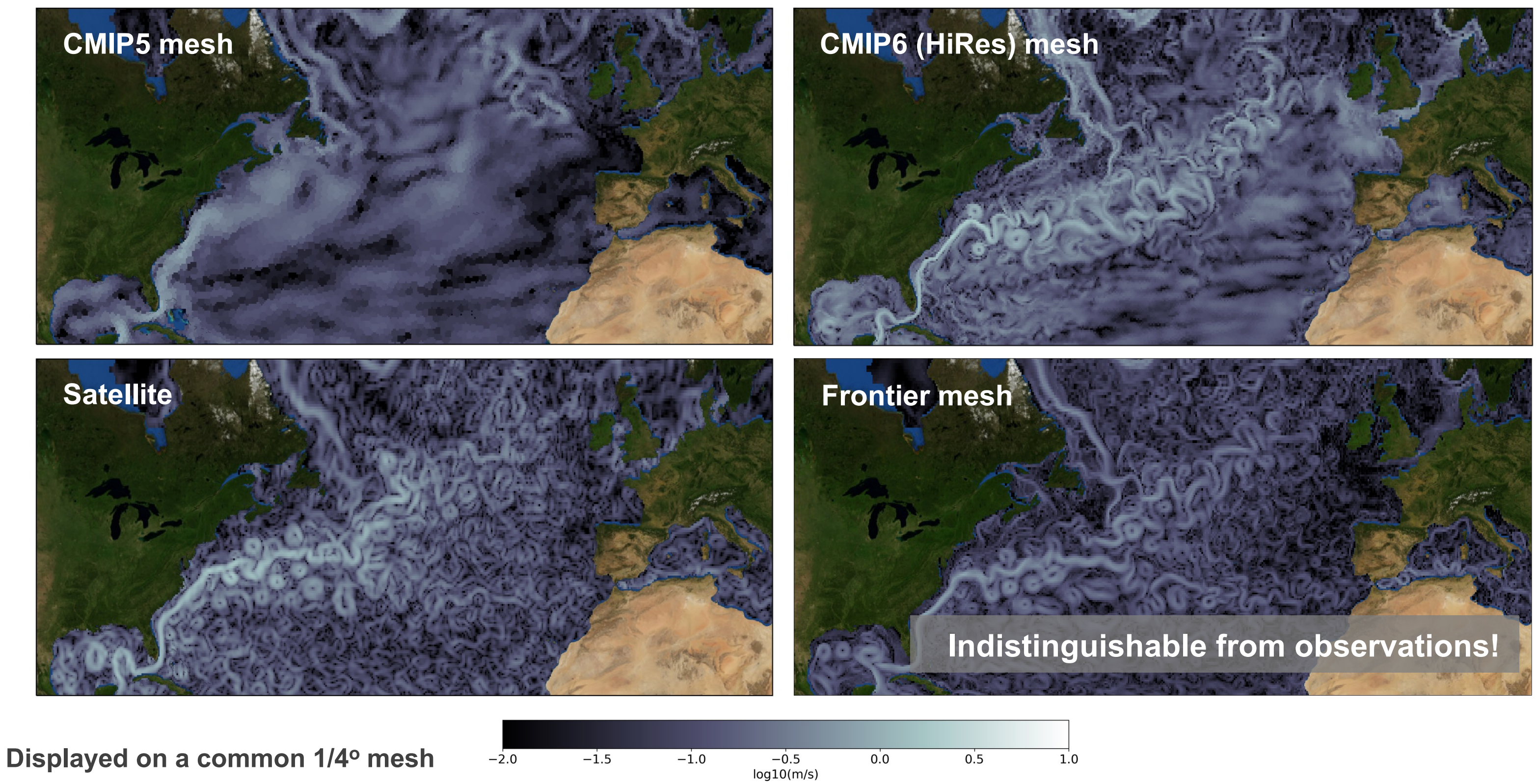


Critics:

- **Time series too short**
- **Estimates of natural variability based only on models**

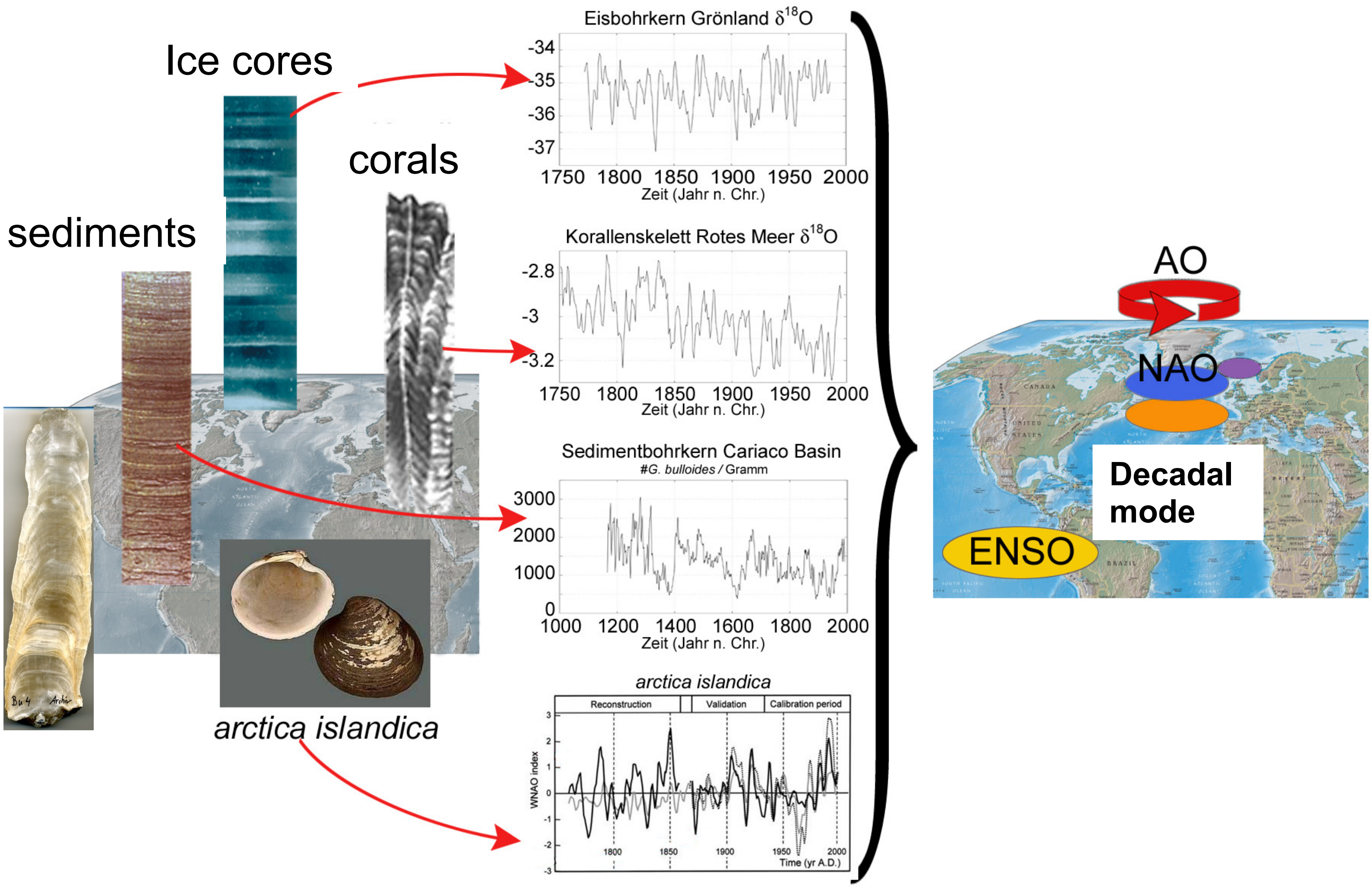

Data: CDIAC/GCP/IPCC/Fuss et al 2014
Scenario categories
>1000 ppm CO_2eq
720–1000 ppm
580–720 ppm
480–580 ppm
430–480 ppm
Emissions from fossil fuels and cement ($GtCO_2$/yr)
2016 Estimate
Historical emissions
net-negative global emissions
RCP8.5
3.2–5.4°C
relative to 1850–1900
RCP6
2.0–3.7°C
RCP4.5
1.7–3.2°C
RCP2.6
0.9–2.3°C
100
80
60
40
20
0
–20
1980
2000
2020
2040
2060
2080
2100

How realistic is the model?



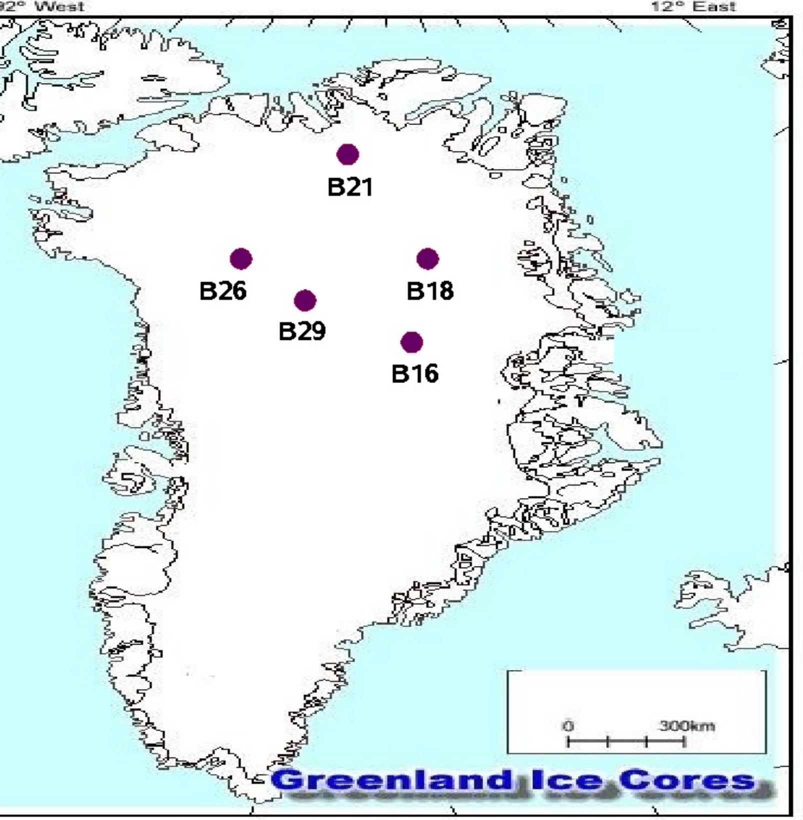
Ocean velocity

Upscaling concept



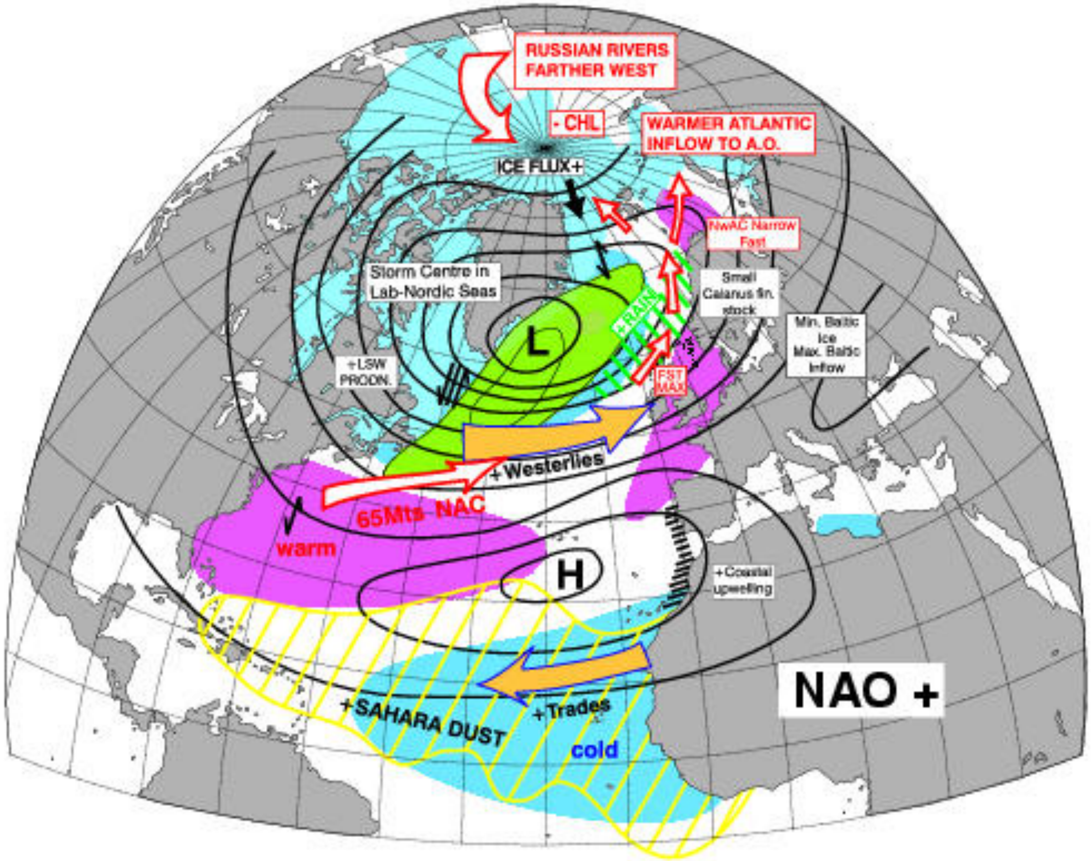
Climate archives **Climate variabiliy**

Lohmann, 2007



Shallow ice cores

The Phases of the North Atlantic Oscillation



During the high phase of the NAO westerlies in the North Atlantic are enhanced, resulting in mild and wet winter conditions over Northern Europe. (Courtesy of CEFAS, UK)

AV/D1/99-1

Statistics

covariance is a measure of how much two random variables change together

Covariance (cross, auto)

$$\gamma(\Delta) = E\Big((x(t) - \overline{x})\,(y(t+\Delta) - \overline{y}) \Big)$$

e.g. coral   e.g. meteorol. data

$$\mathrm{cov}(X,Y) = \frac{1}{n}\sum_{i=1}^{n}(x_i - E(X))(y_i - E(Y)).$$

Correlation (cross, auto)

$$\rho_{xy} = \frac{\gamma(\Delta)}{\text{normalized}}$$

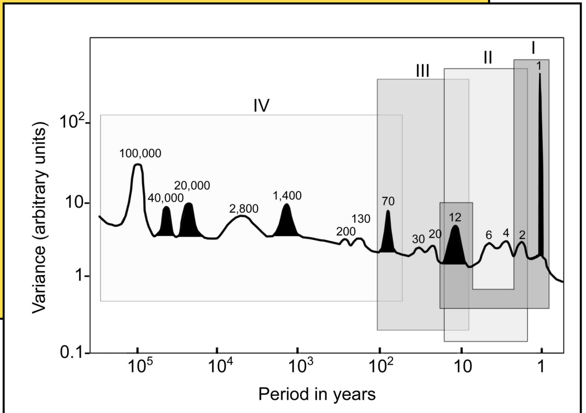
measures the tendency of x (t) and y (t) to covary, between -1 and 1

Spectrum (cross, auto)

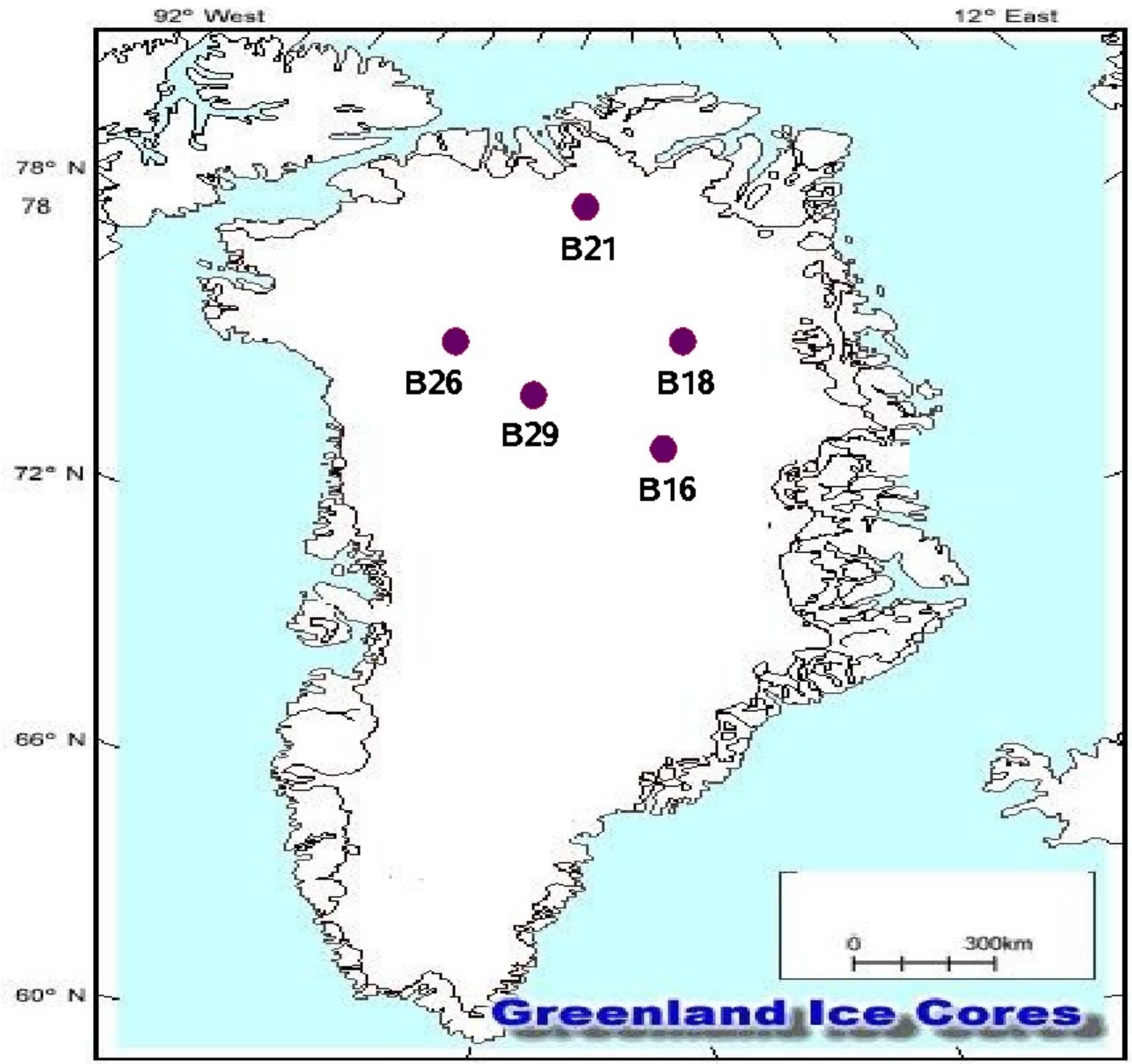
(spectral density)

$$\Gamma(\omega) = \sum_{\Delta=-\infty}^{\infty} \gamma(\Delta)\, e^{-2\pi i \Delta}$$

measures variance



SNOW ACCUMULATION ICE CORE



Greenland Traverse AWI (1993-1995)

- Shallow ice core (depths up to 150 m)

- Mean accumulation rates vary between:

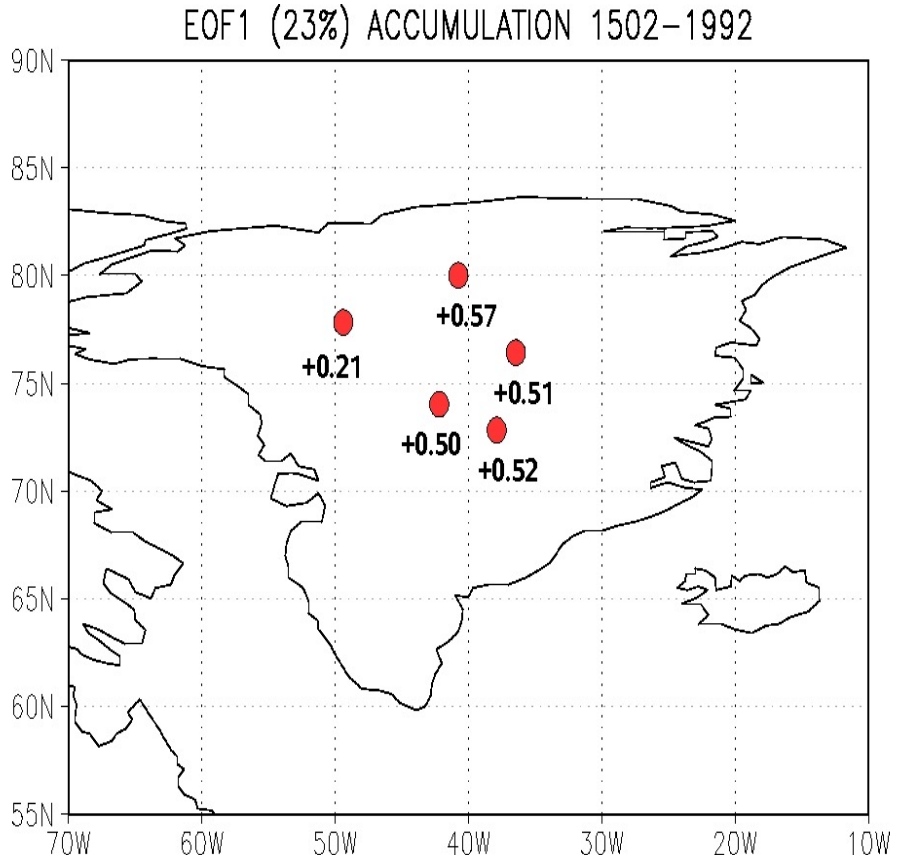
$$104 \pm 32\, mm_{w.e.}\, a^{-1}$$

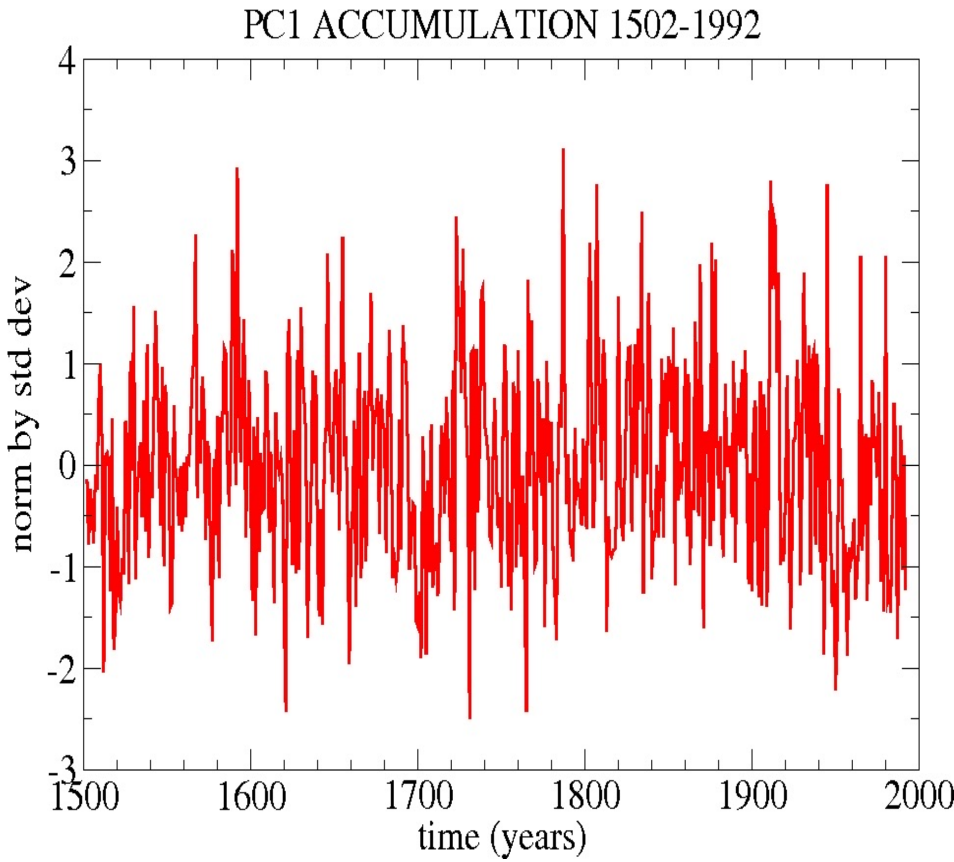
and:

$$179 \pm 49\, mm_{w.e.}\, a^{-1}$$

Description: Schwager, AWI report, 2000

Accumulation variability



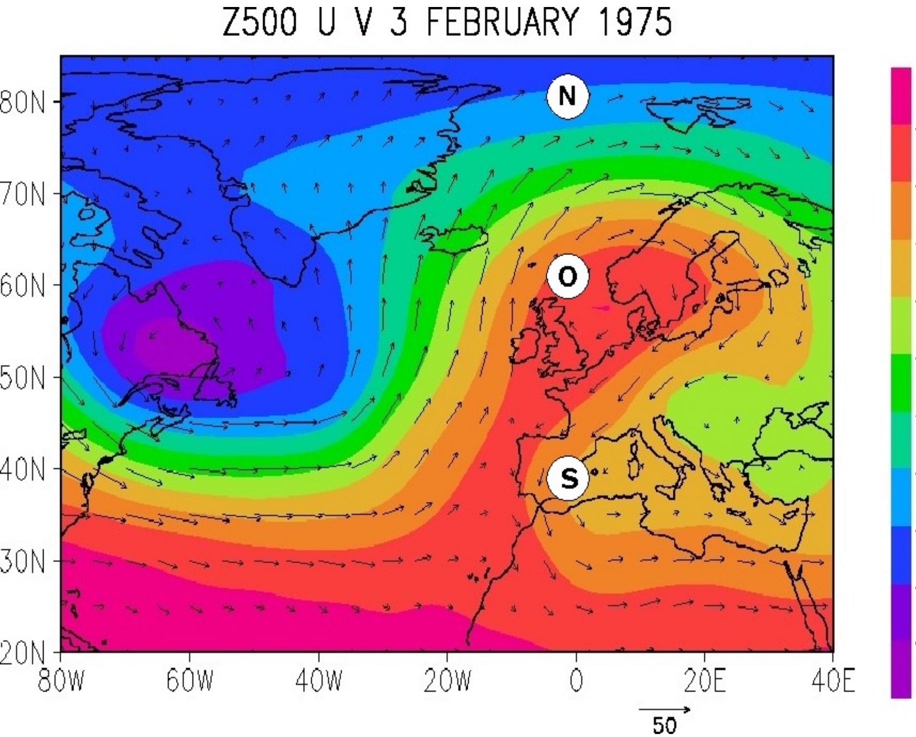


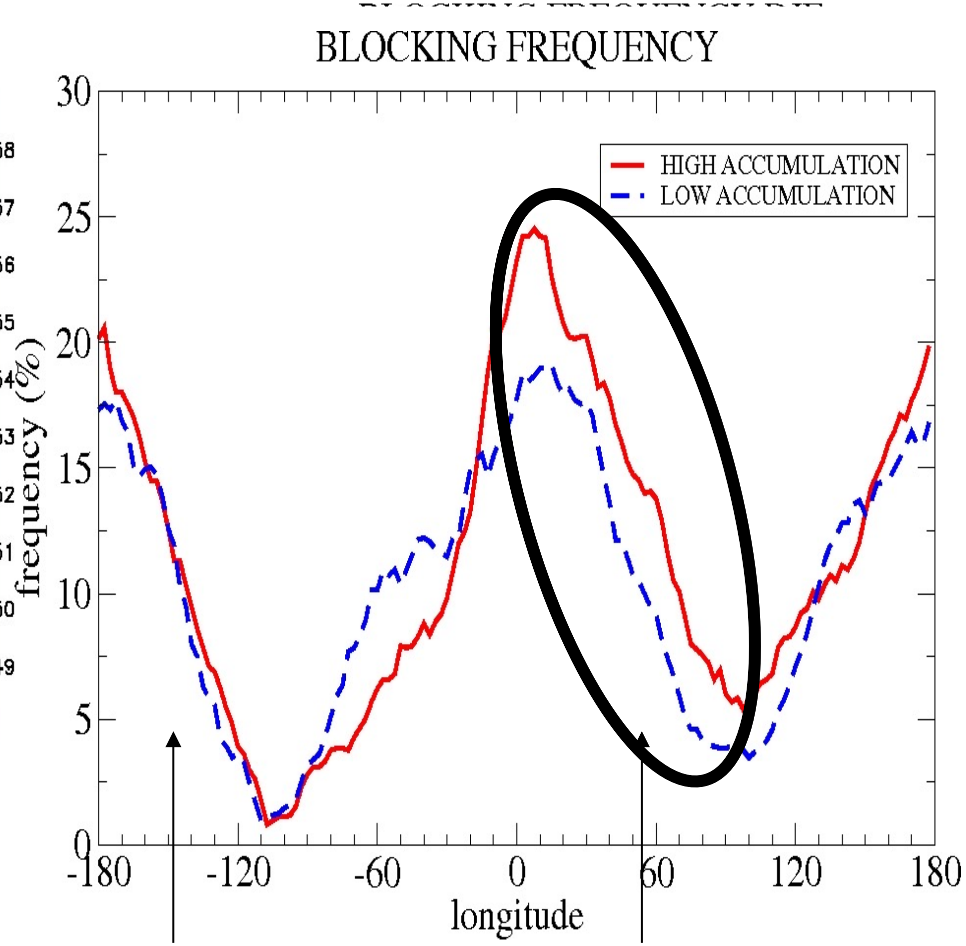
EOF1- MONOPOLAR STRUCTURE POSSIBLE RELATED TO LARGE-SCALE ATMOSPHERIC CIRCULATION

PC1 – INTERANNUAL AND DECADAL VARIATIONS

Rimbu, Lohmann, Grosfeld, GRL, 2007

Atmospheric Blocking

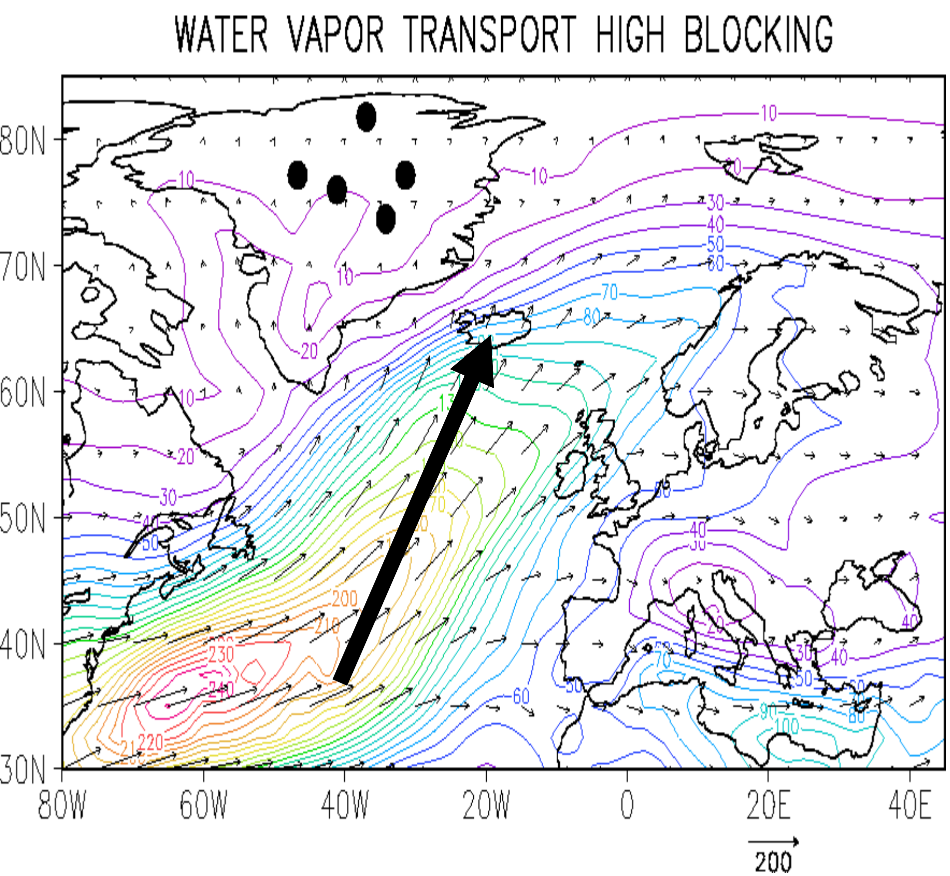


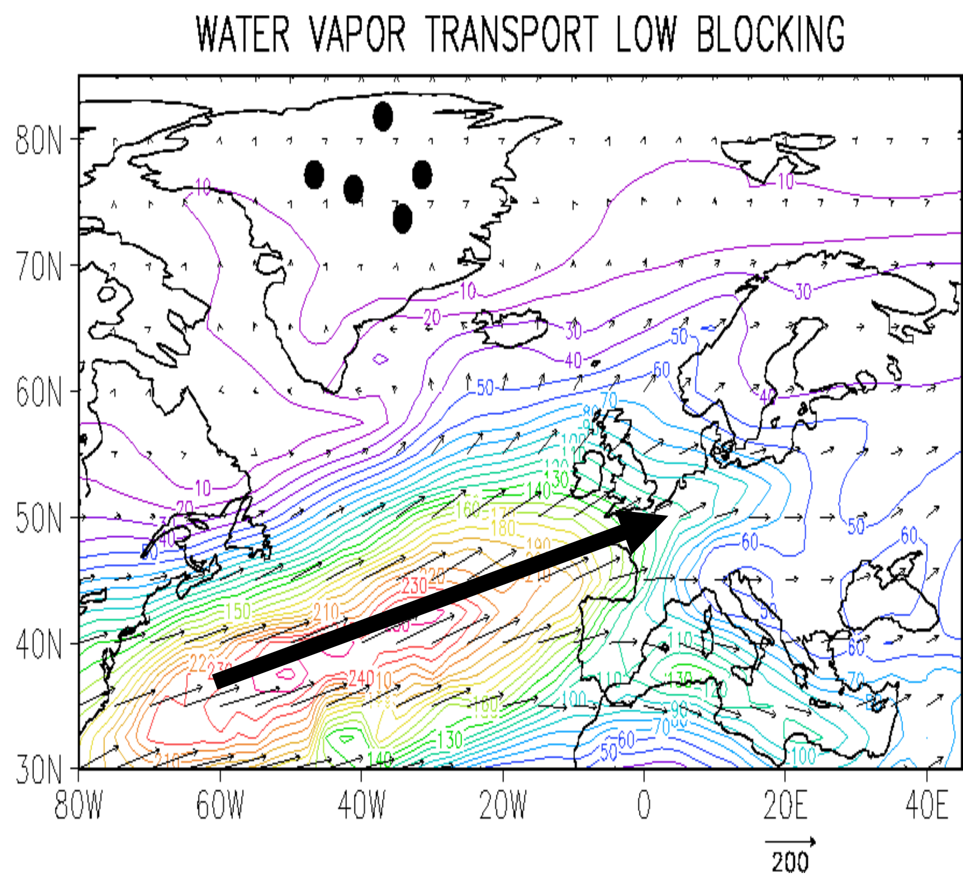


Z500 (NCEP): 1948-2005 (57 winters)
TM index (Tibaldi and Molteni,1990)

Pacific **Euro-Atlantic sectors**

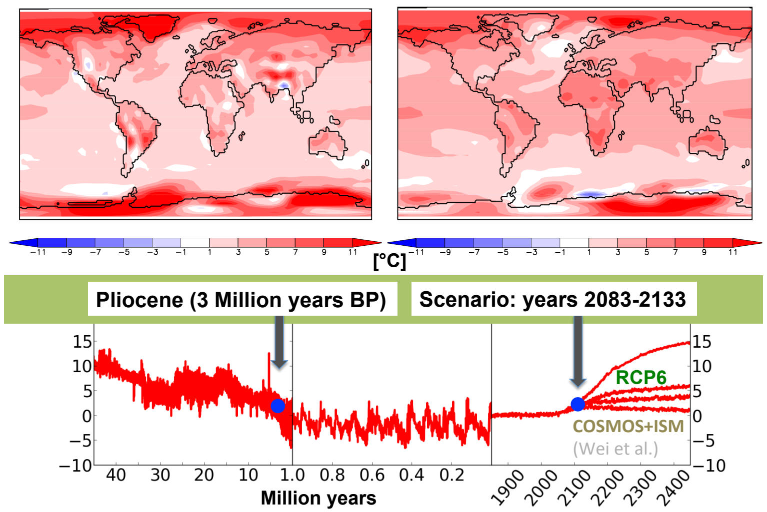
WATER VAPOR TRANSPORT



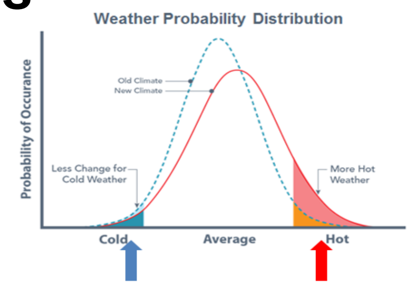


ENHANCED MOISTURE TRANSPORT TOWARD GREENLAND DURING HIGH BLOCKING ACTIVITY IN 20ºW - 20ºE SECTOR

Until now: Climate science concentrates on the mean changes („climate sensitivity“)



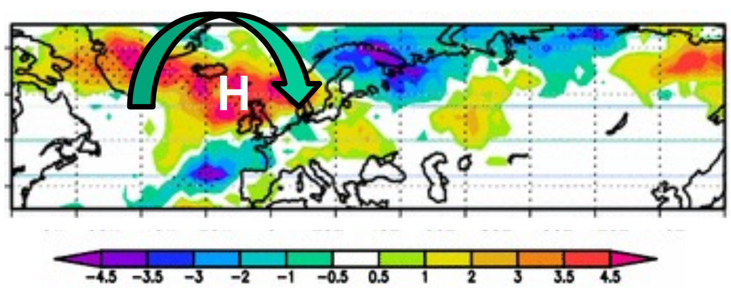
climate variability and extremes



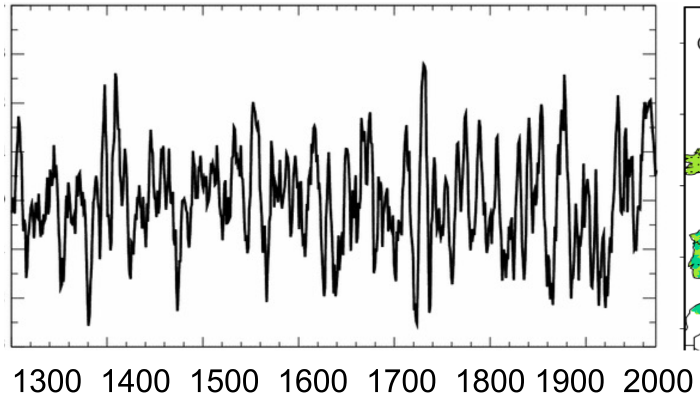
OBSERVATIONS MODELS PROXY DATA

High-resolution modelling of the jet stream and associated extreme events in Europe

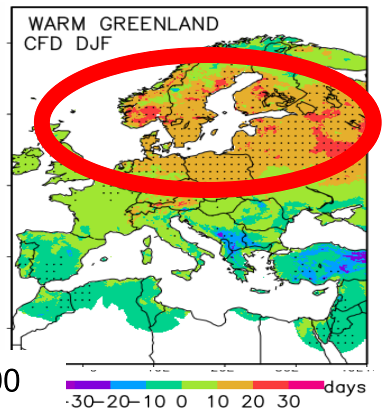
Assessment of resolution impact on the jet stream in the Euro-Atlantic region



Blocking frequency
Greenland Ice cores



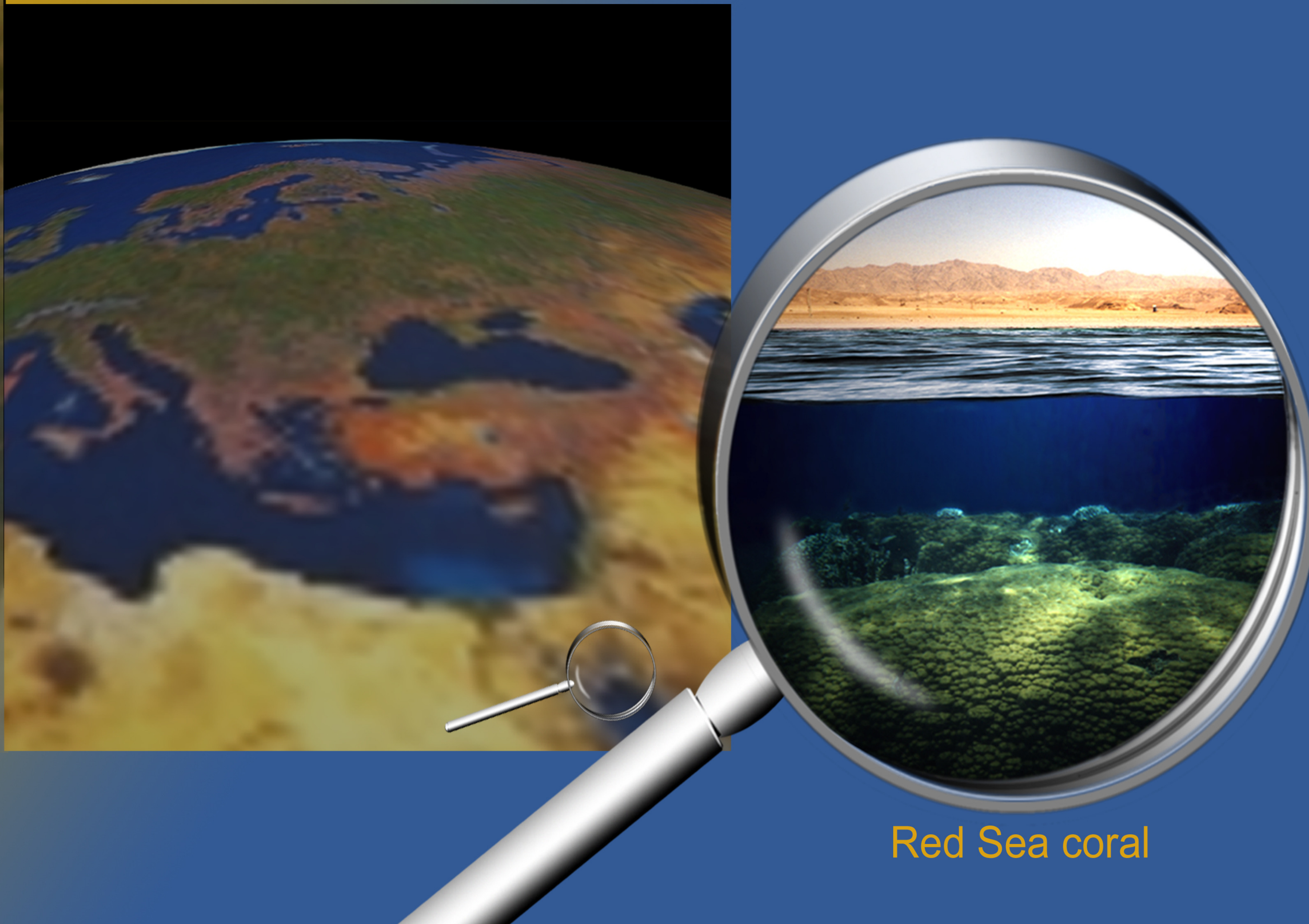
Decadal-centennial variability



Continous Frost days

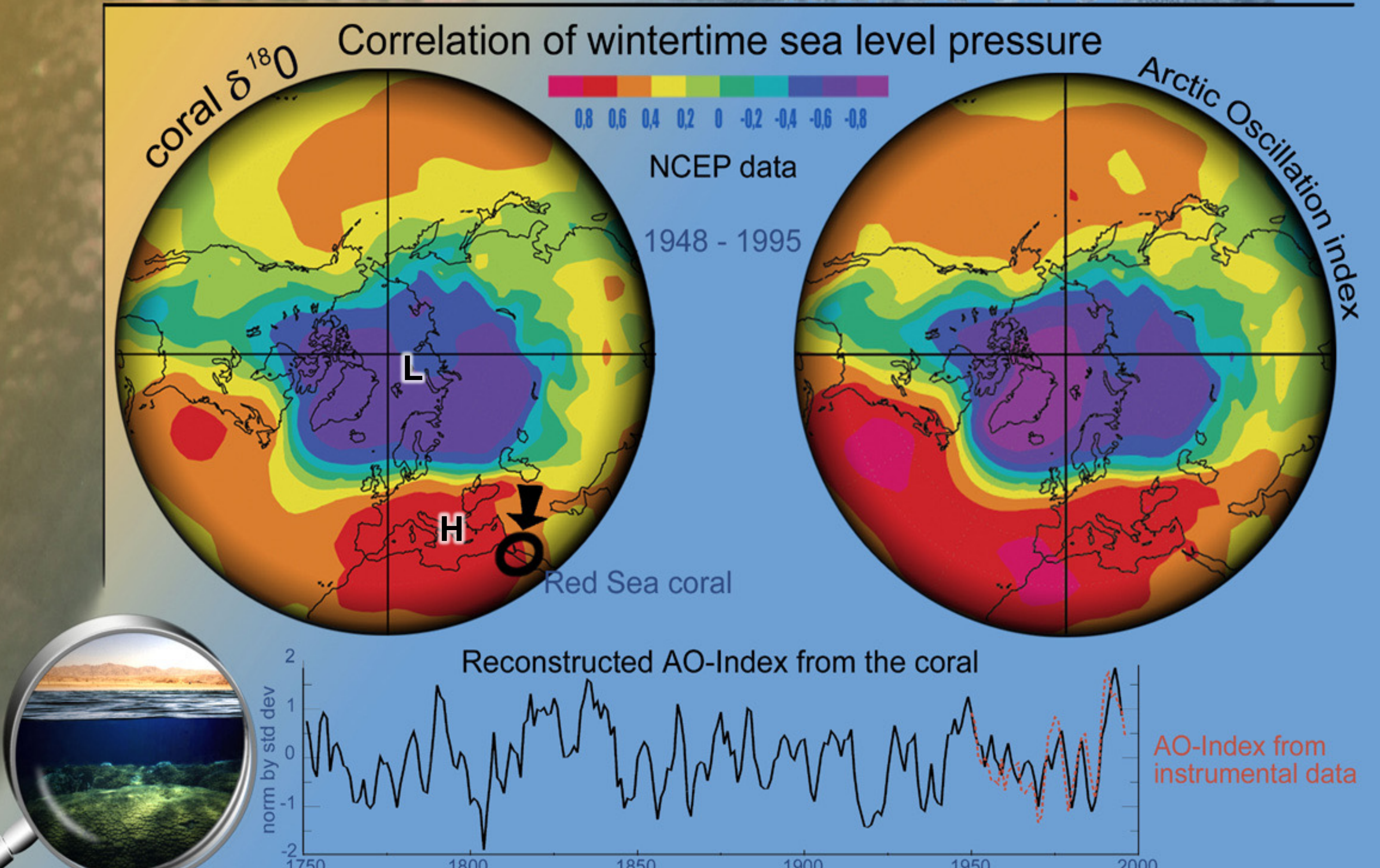
Rimbu and Lohmann, 2011

Climate Modes from Proxy Data



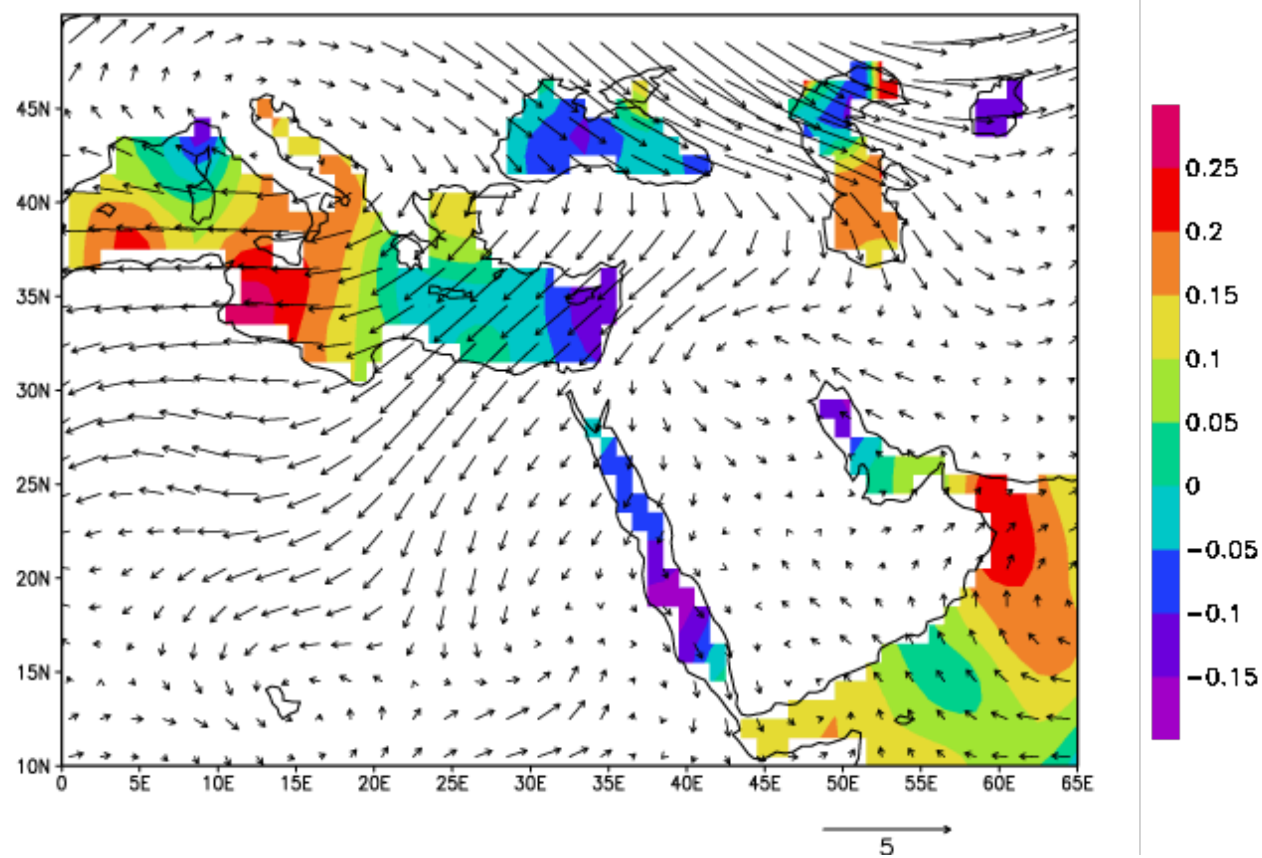
Red Sea coral

ARCTIC OSCILLATION SIGNATURE IN A RED SEA CORAL



Rimbu, Lohmann, Felis, Pätzold; GRL 2001

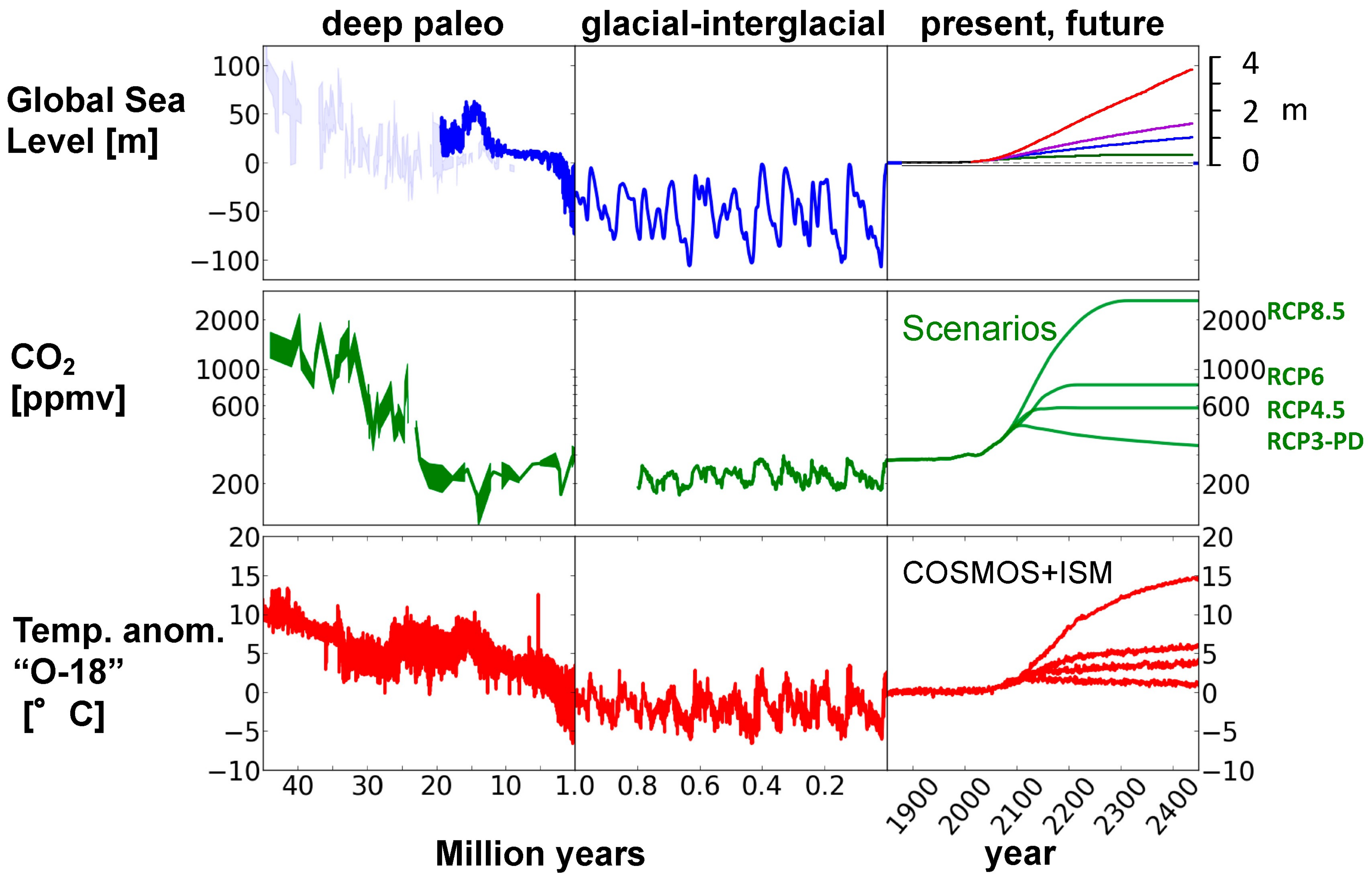
ARCTIC OSCILLATION SIGNATURE IN A RED SEA CORAL



Composite Map of SST [°C] and 925 hPa wind [m/s]
for 1948 -1995, January - February

mechanistic understanding

Natural variability and perturbed climate



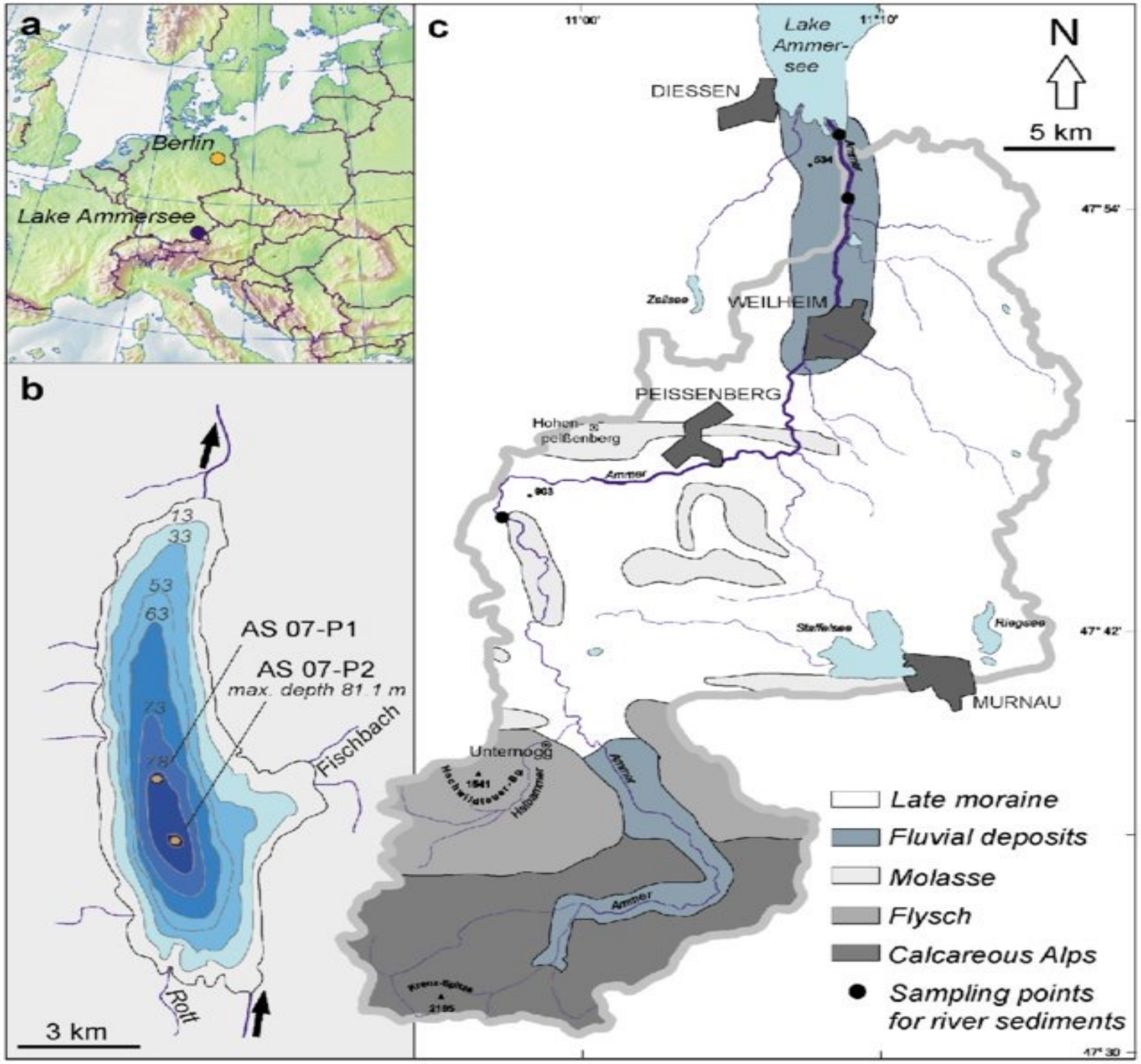
LAKE SEDIMENTS AS CLIMATE ARCHIVES

River Ammer floods

catchement 700 km^2
length 84 km
q =$18 m^3/s$
-river floods (discharge higher than 125 m^3/s) are detected as flood layers in lake Ammer sediments
-summer floods are dominant

Flood layer records

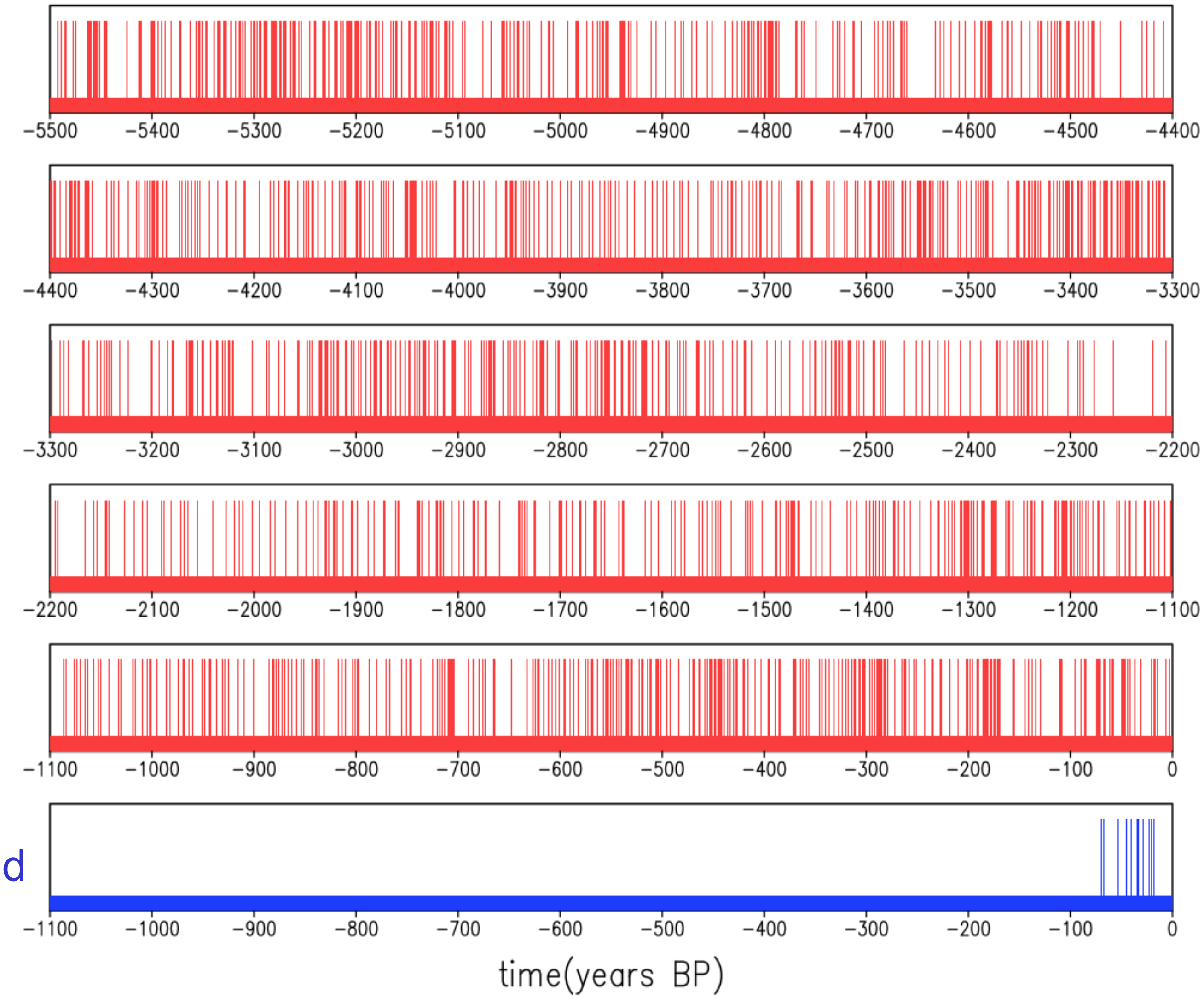
-annual resolution
-cover instrumental period
-go back to mid-Holocene



Czymzik et al., 2010

OBSERVED AND PROXY FLOODS

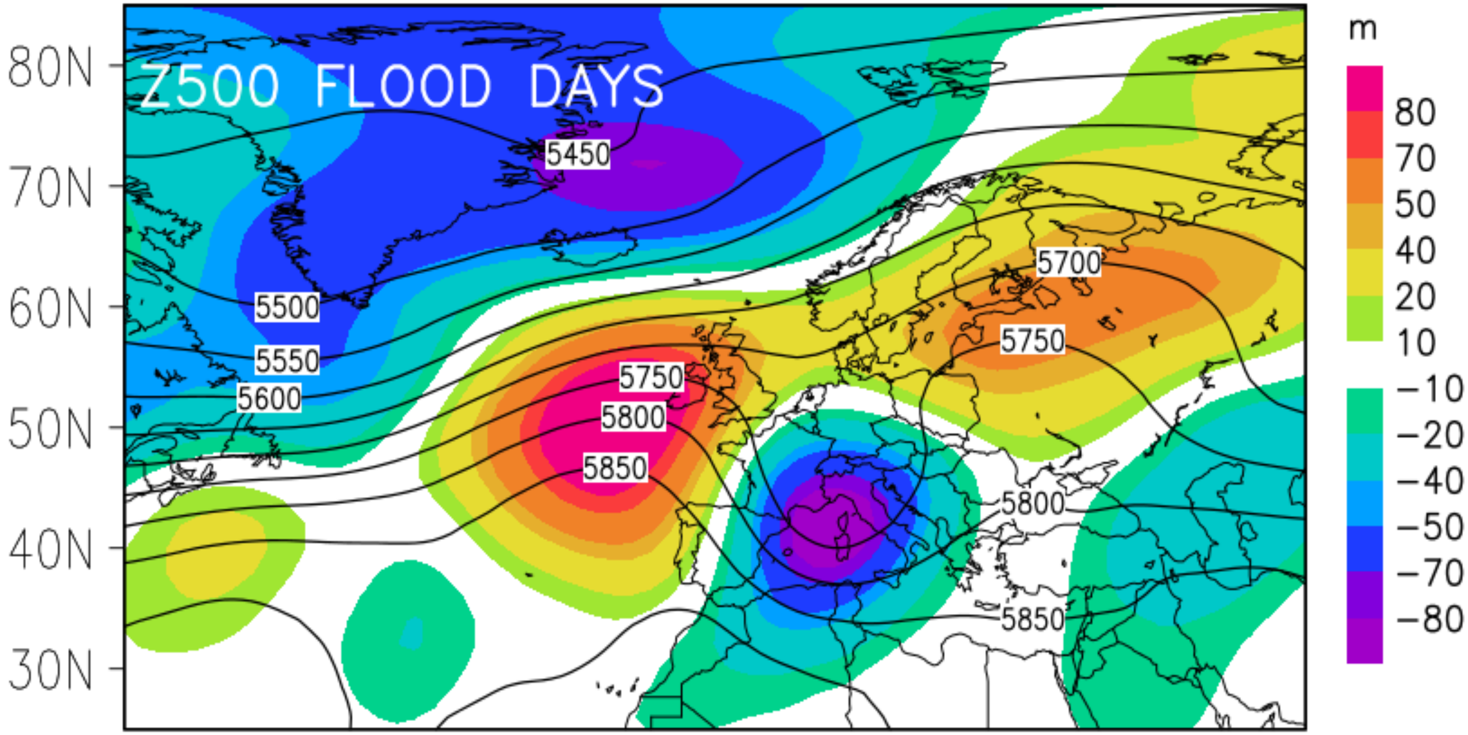
annual flood years: pronounced millennial variations last ~5500 y



observed river Ammer flood years: similar distribution

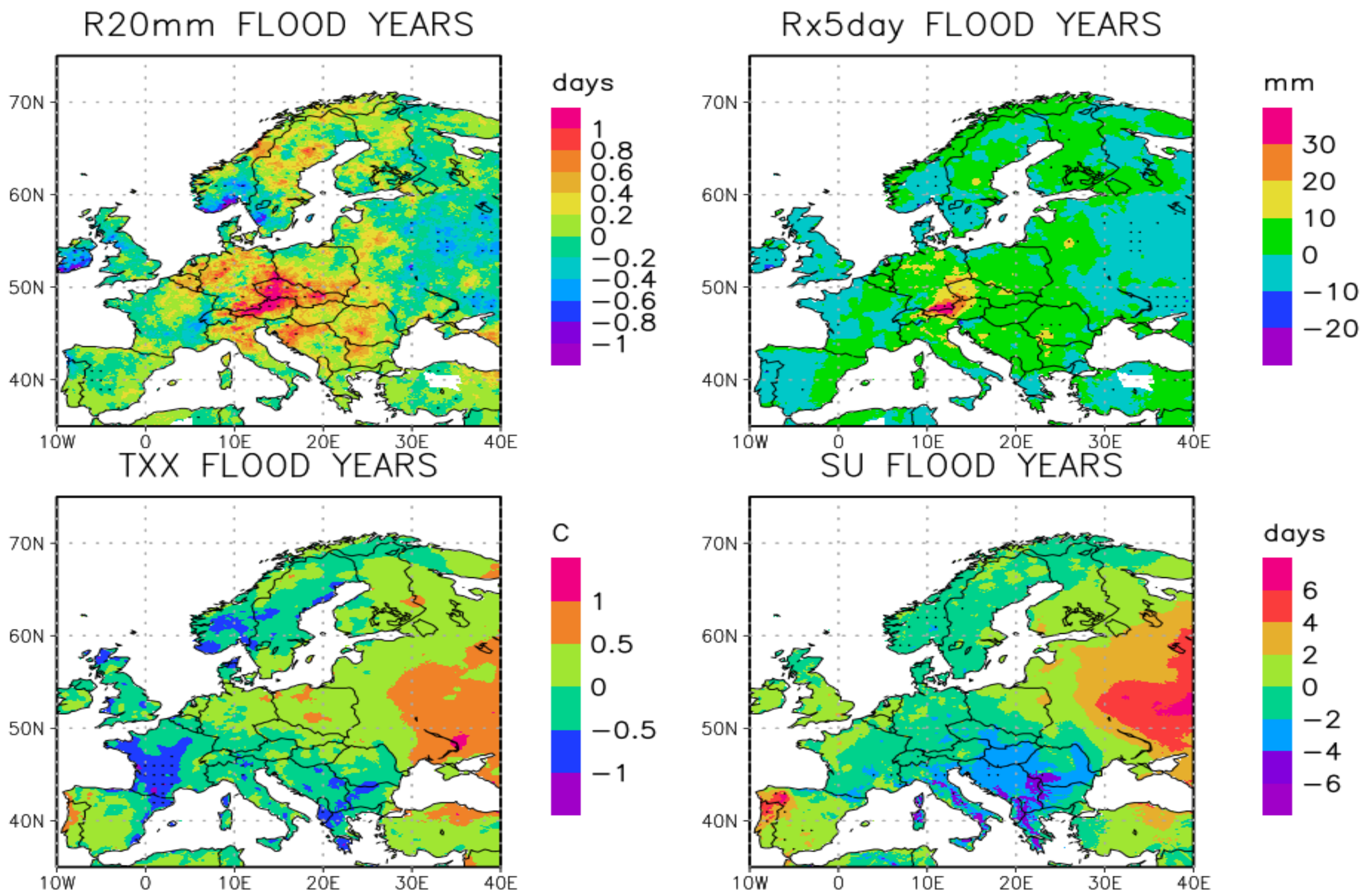
ATMOSPHERIC CIRCULATION

Wave-train pattern with a pronounced trough over western Europe is associated with flood days



LAKE SEDIMENTS

EXTREME PATTERNS ASSOCIATED WITH FLOODS



Exercise teleconnections
using http://climexp.knmi.nl

1) **Monthly climate indices** (temp, precip, ...)
a) Select one pre-defined index
b) Correlation with temperature, precipiation, SLP
c) Explain the teleconnections for different seasons

2) Home town climate
a) Calculate different regions on the world
(home town, Bremen has 53° N, 8° E)
b) Correlation with temperature, precipiation, SLP
c) Explain the teleconnections for different seasons
d) Exlain related modes of climate variability
(ENSO, PDO, NAO, Monsoon)

Help News About Contact World weather Effects of El Niño Seasonal forecasts Climate Change Atlas

Select a monthly time series

Climate indices

Select a time series by clicking on the name		
ENSO	absolute NINO12, NINO3, NINO3.4, NINO4, relative NINO12, NINO3, NINO3.4, NINO4 (1880-now, ERSST v4, relative is relative to 20S-20N, i.e., without global warming, recommended)	i
	NINO12, NINO3, NINO3.4, NINO4 (1870-now, HadISST1)	i
	NINO12, NINO3, NINO3.4, NINO4 (1856-1981 Kaplan, 1982-now NCEP OISSTv2)	i
	SOI (1866-now, Jones)	

Select a time series
- Daily station data
- Daily climate indices
- Monthly station data
- Monthly climate indices
- Annual climate indices
- View, upload your time series

Select a field
- Daily fields
- Monthly observations

KNMI Climate Explorer

Climate Explorer European Climate Assessment & Data KNMI search in the Climate Explorer

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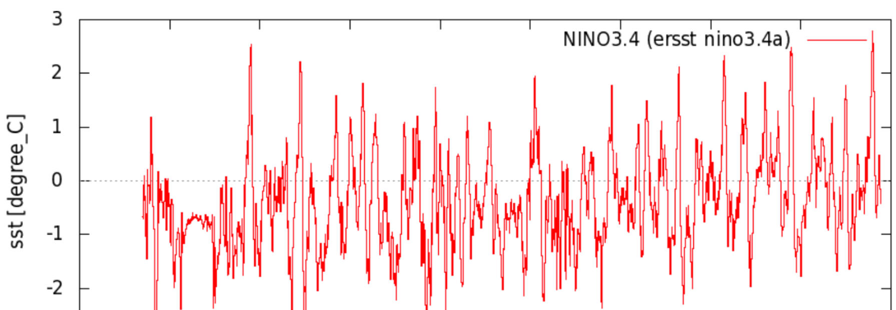
Time series

monthly NINO3.4

cutting out region defined by mask ersstv5 nino3.4 mask.nc, sst [degree C] from NOAA ERSSTAv5 (in situ only), SSTA normalized to 1981-2010, plotdat anomal 1981 2010 ersst nino3.4.dat, cutting out region defined by mask ersstv5 nino3.4 mask.nc, sst [degree C] from NOAA ERSSTv5 (in situ only), (eps, pdf, raw data, netcdf)



Select a time series
- Daily station data
- Daily climate indices
- Monthly station data
- Monthly climate indices
- Annual climate indices
- View, upload your time series

Select a field
- Daily fields
- Monthly observations
- Monthly reanalysis fields
- Monthly and seasonal historical reconstructions
- Monthly seasonal hindcasts
- Monthly decadal hindcasts
- Monthly CMIP3+ scenario runs
- Monthly CMIP5 scenario runs
- Annual CMIP5 extremes
- Monthly CORDEX scenario runs
- Attribution runs
- External data (ensembles, ncep, enact, soda, ecmwf, ...)
- View, upload your field

Investigate this time series
- View per month, season, half year or full year (Jan-Dec or Jul-Jun)
- View last 1, 5, 10, N years

KNMI Climate Explorer

Climate Explorer European Climate Assessment & Data KNMI search in the Climate Explorer

Help News About Contact World weather Effects of El Niño Seasonal forecasts Climate Change Atlas

Correlate time series with an observation field

NINO3.4

Observations		
Temperature	1850-now anomalies: HadCRUT4 median,	i
	1880-now anomalies: GISS 250km, 1200km	i
	1880-now anomalies: NCDC v3.2.1	i
	1850-now anomalies: HadCRUT4 filled-in by Cowtan and Way	i
Land	1850-2010 anomalies: CRUTEM4	i
	1880-now anomalies: GISS 250km, 1200km	i
	1880-now anomalies: NCDC v3.2.1	i

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.... Or select a position

Field
HadCRUT4.5 SST/T2m anom

HadCRUT4 near-surface temperature ensemble data - ensemble ...
X axis: whole world in 72 5.00° steps, first point at 177.50° W, last point at 177.50° E
Y axis: regular grid with 36 5.00° steps, first point at 87.50° S, last point at 87.50° N

Monthly data available from Jan1850 to Jul2017 (2011 months)
Variable temperature_anomaly (near_surface_temperature_anomaly) in K
The associated land/sea mask is available for some operations

Get grid points, average area or generate subset

Mask: no mask — add a mask to the list
Latitude: 53 °N - 54 °N
Longitude: 8 °E - 9 °E
Boundaries: halfway grid points
Make: average / max / min / set of grid points / subset of the field

Field correlations
HadCRUT4.5 SST/T2m anom 8-9E 53-54N mean with Trenberth SLP

Computing correlations... (this may take a minute or so)

If it takes too long you can abort the job here (using the [back] button of the browser does not kill the correlation job)

Requiring at least 50% valid points

Plotting with GrADS 2.0...

corr Jan HadCRUT4.5 SST/T2m anom 8-9E 53-54N mean with Jan Trenberth SLP 1899:2017 p<10% (eps, pdf)

corr Jan HadCRUT4.5 SST/T2m anom 8–9E 53–54N mean with Jan Trenberth SLP 1899:2017 p<10%