Paleoclimate dynamics- identifying driving mechanisms of climate change

POLMAR course 2017

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Paleoclimate dynamics- identifying driving mechanisms of climate change

- to identify driving mechanisms for climate change
- external forcing and internal variability of the climate system
- to test models of the Earth system

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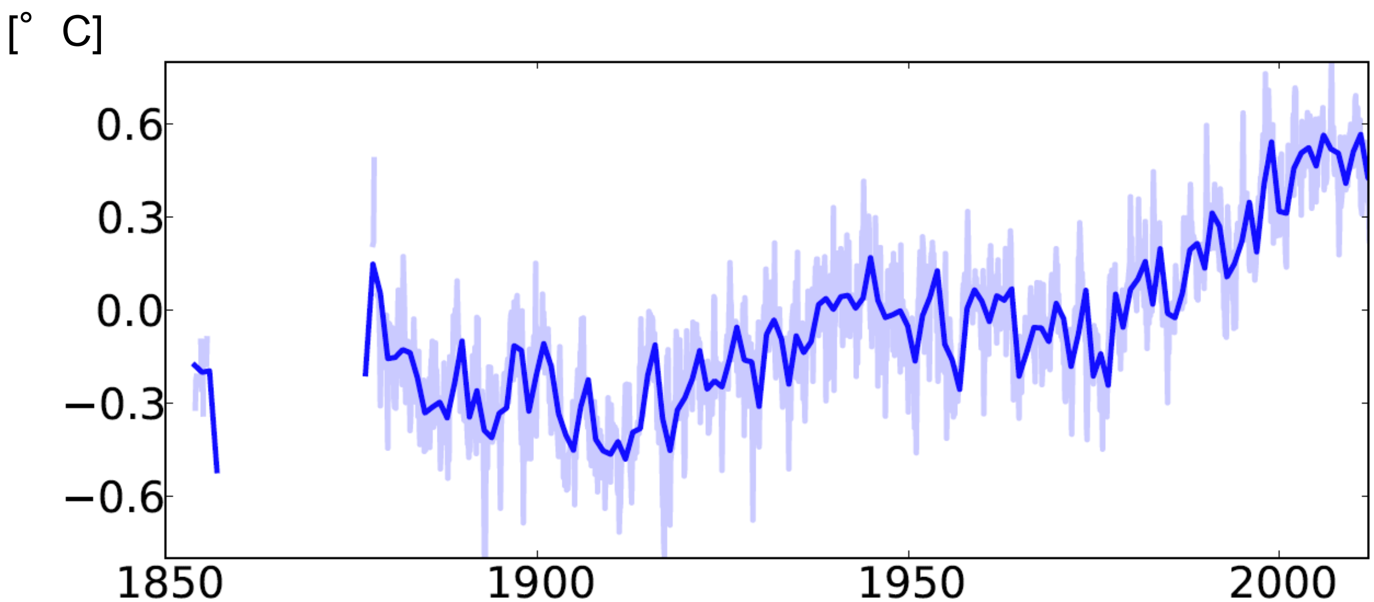
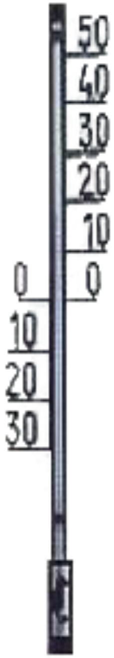
- statistical analysis of instrumental and proxy data.
- Practicals complement the lecture.

Climate Trends at different Timescales

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

Northern Hemisphere Temp. anomaly
HadCRU





History

last **1000 Years**

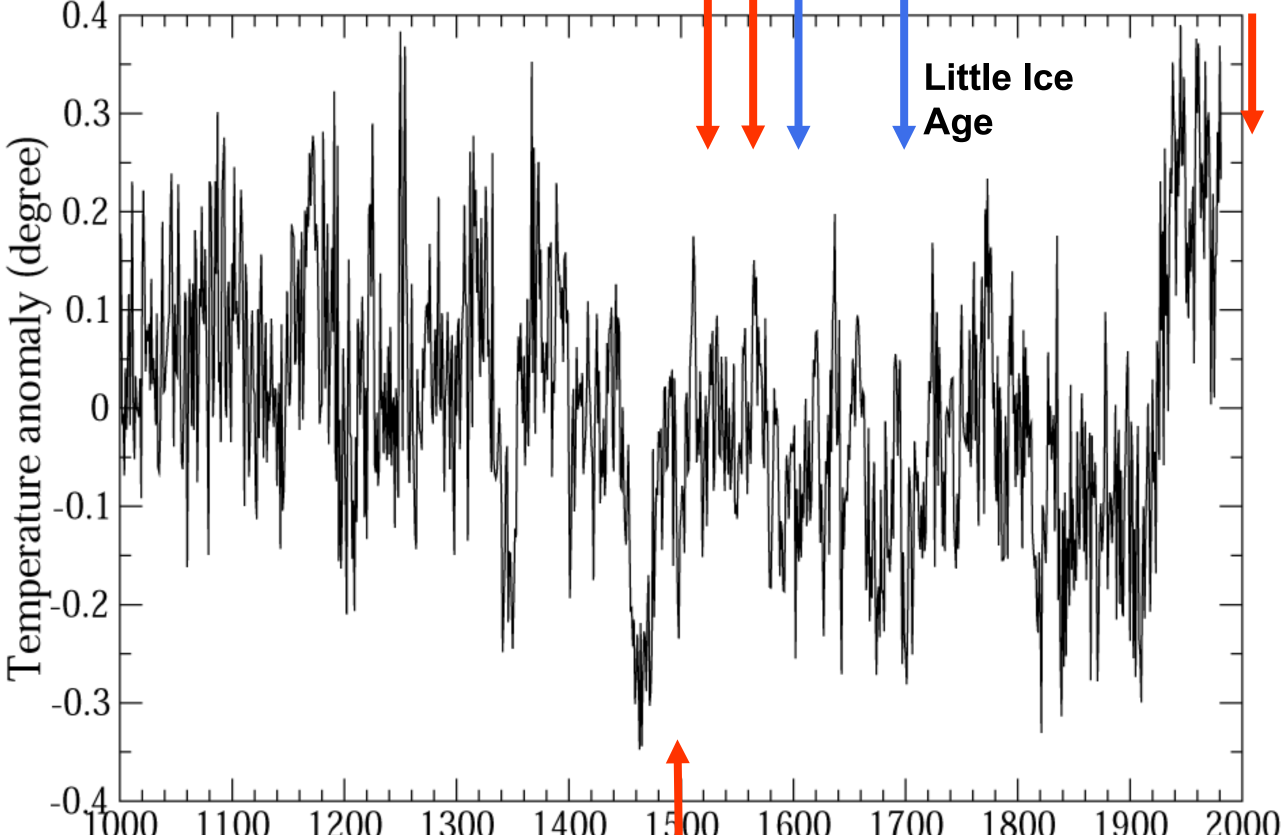
Pieter Breughel d.Ä.

Thermometer

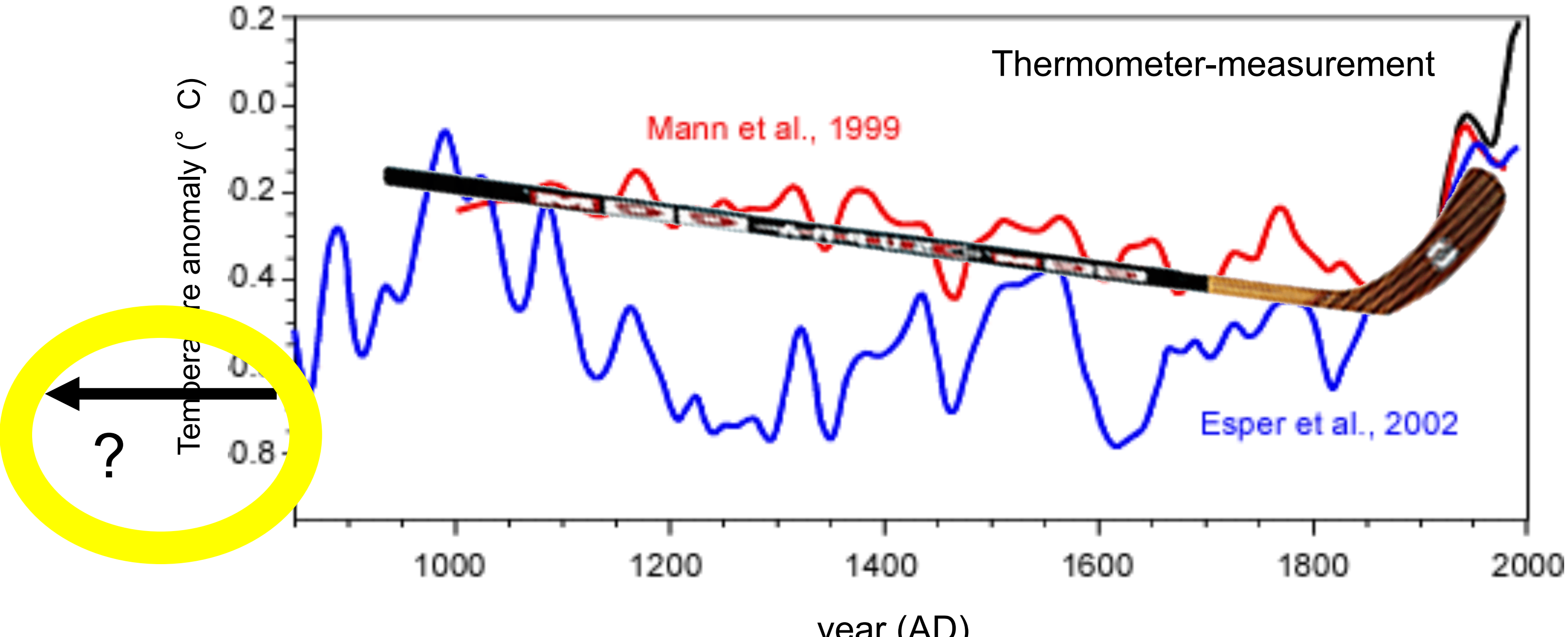
Barometer
(Torricelli)

Little Ice
Age

present



Nicolaus Kopernikus

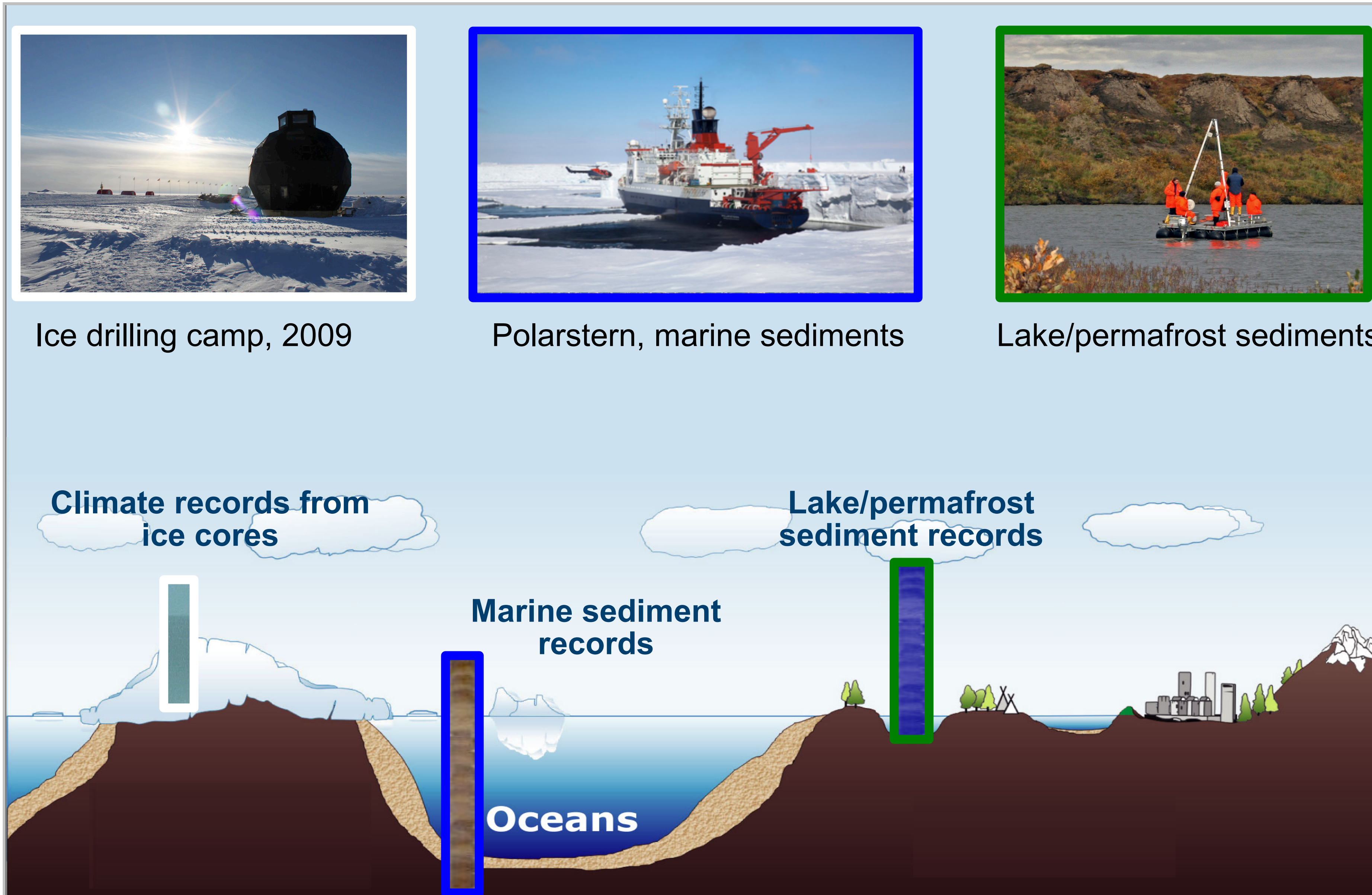


Further back in time?

Proxy Data

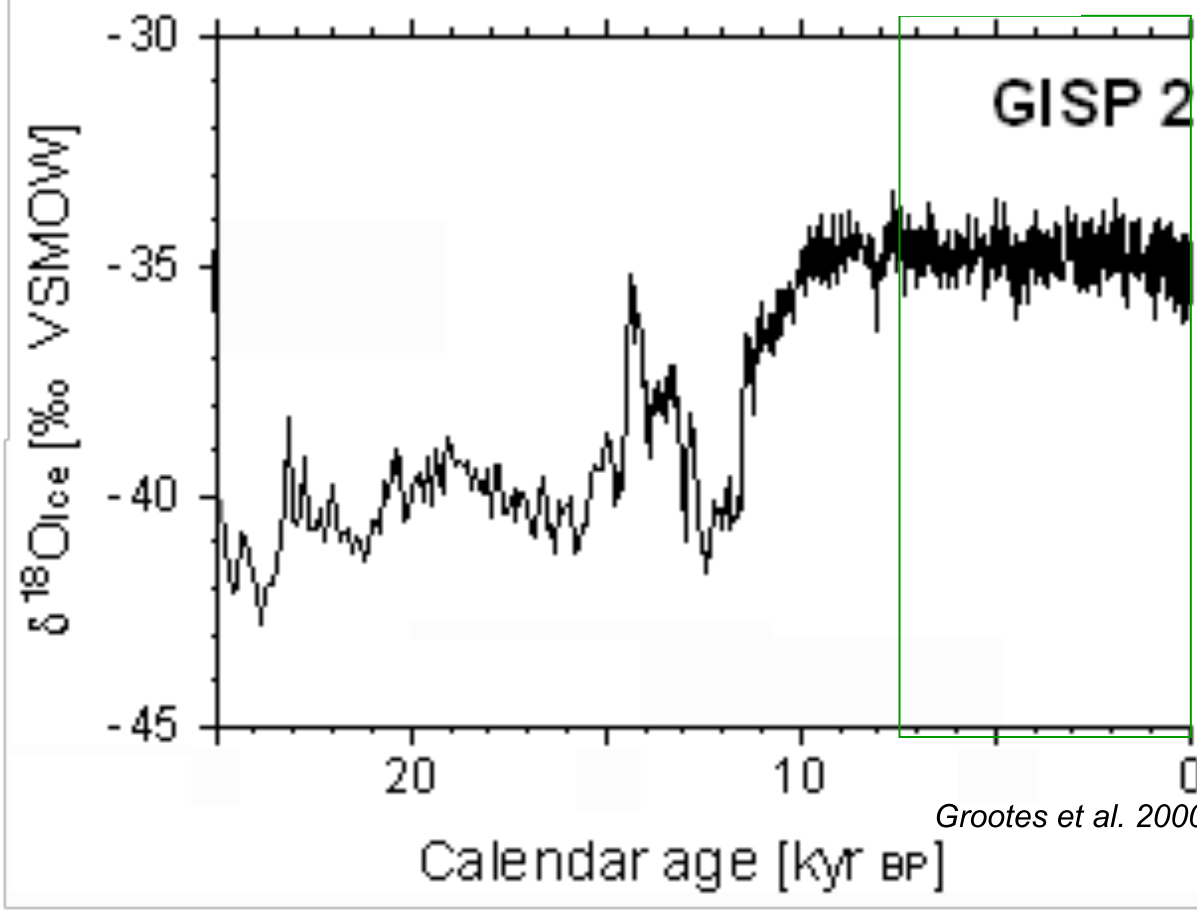
- Indirect data, often qualitative
- Long time series from archives
- Information beyond the instrumental record

Earth System: a polar perspective

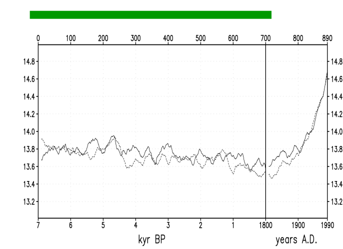


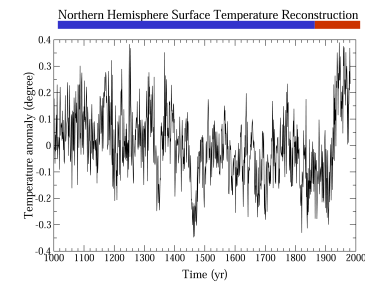
Climate Trends at different Timescales

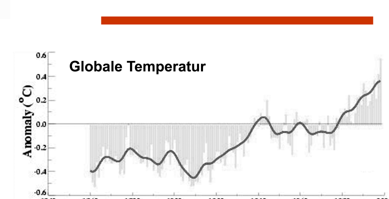
Deglaciation – Greenland ice core

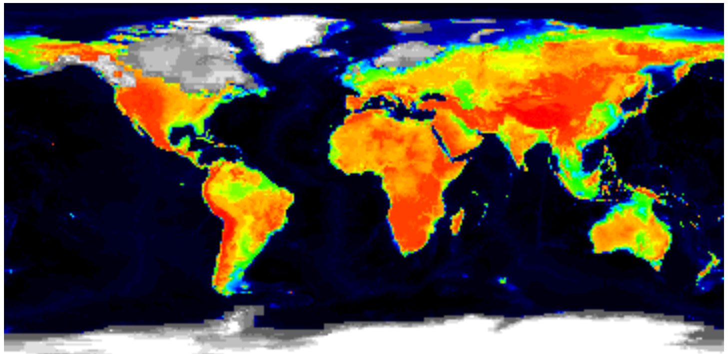


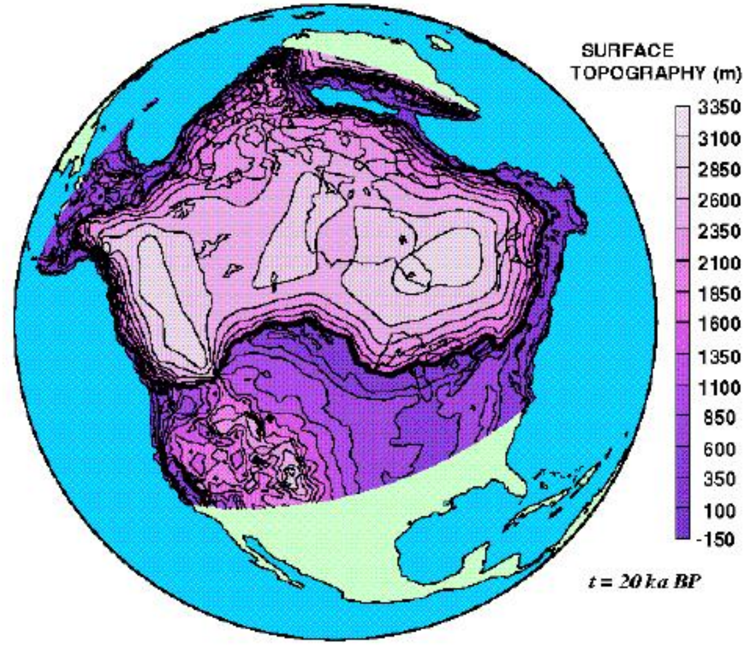
Grootes et al. 2000





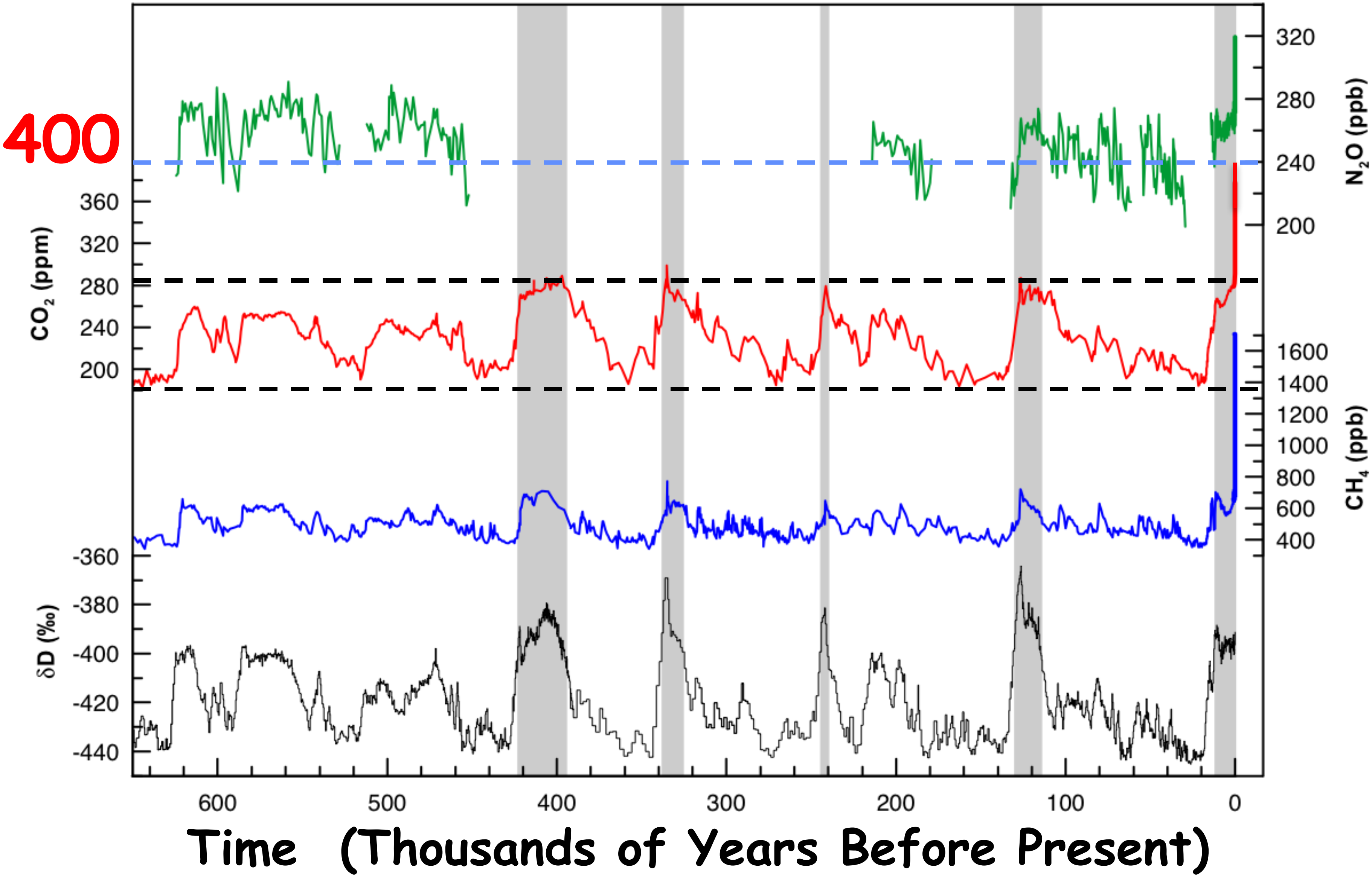




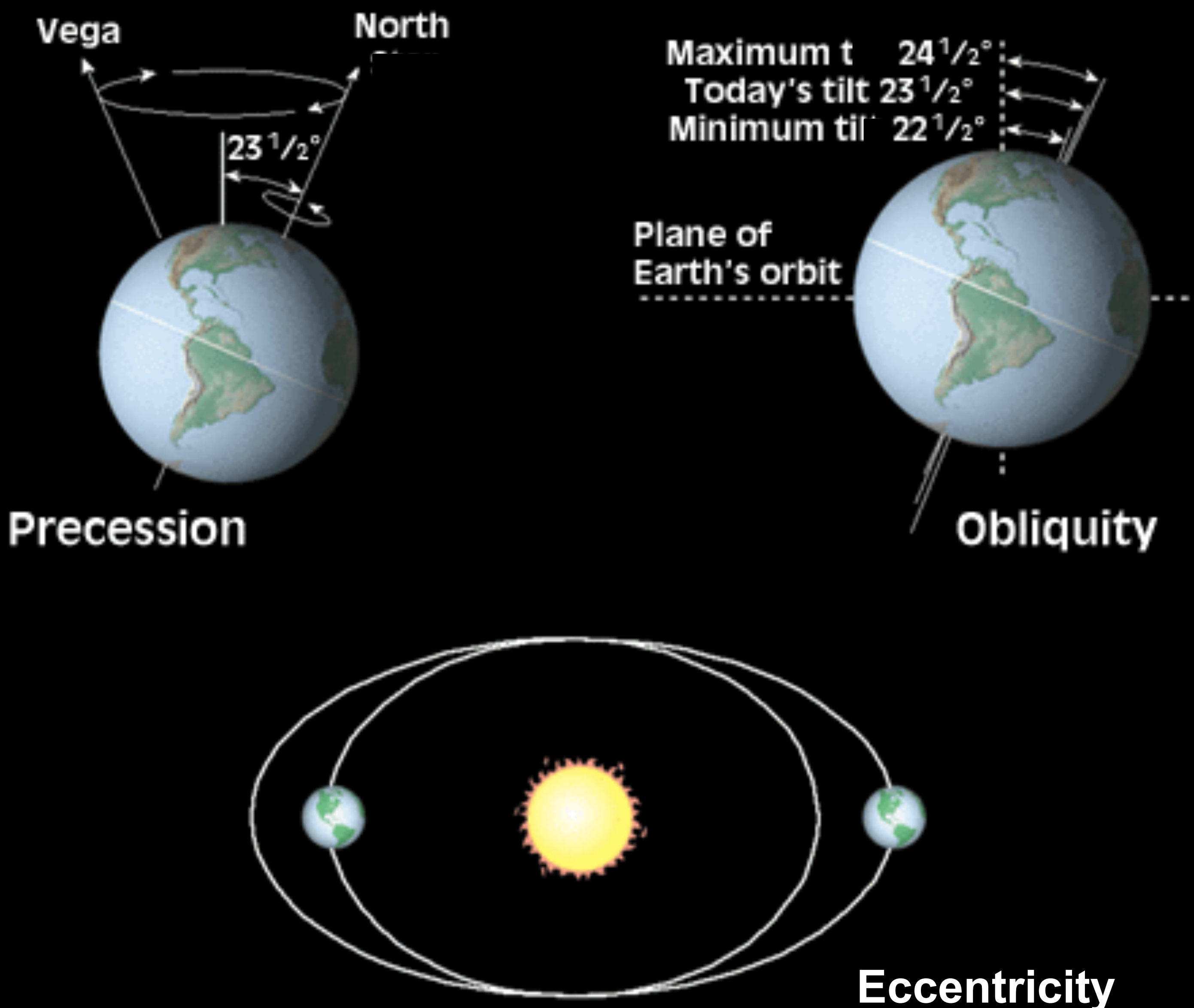


Deglaciation

Atmospheric Gas Concentrations from Ice Cores



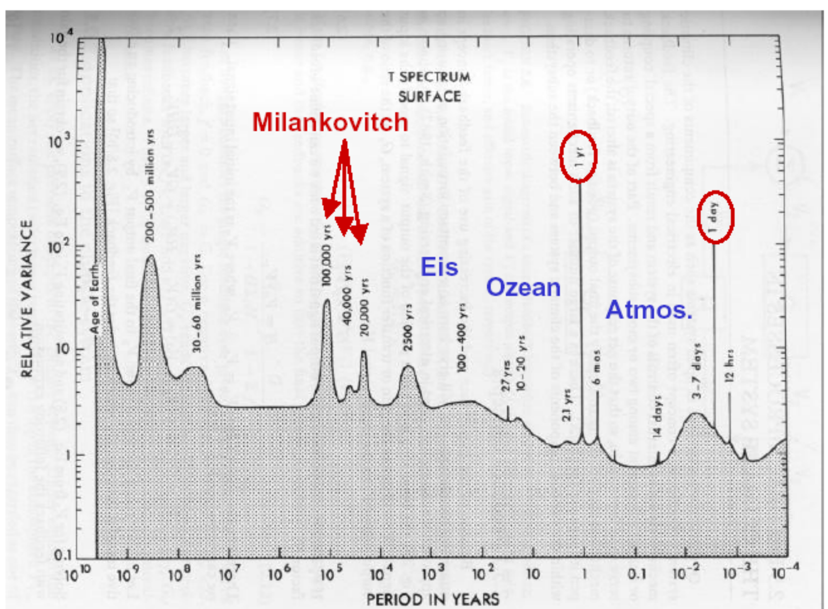
EPICA 2008


Vega
North
23 1/2°
Precession
Maximum t 24 1/2°
Today's tilt 23 1/2°
Minimum til 22 1/2°
Plane of
Earth's orbit
Obliquity
Eccentricity

Orbital focing

- ~20.000, ~40.000, ~100.000 years
- 0.5, 1 year

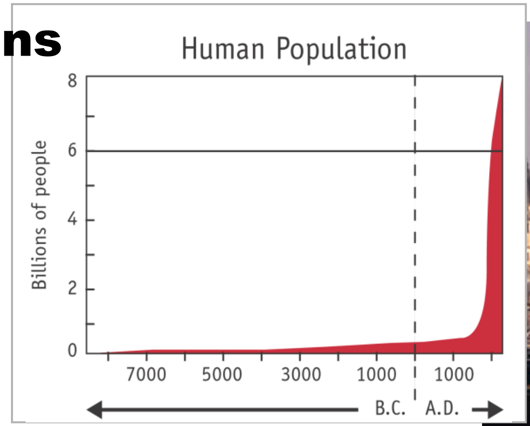
- Geometry of the Sun-Earth configuration



Quelle: Peixoto & Oort

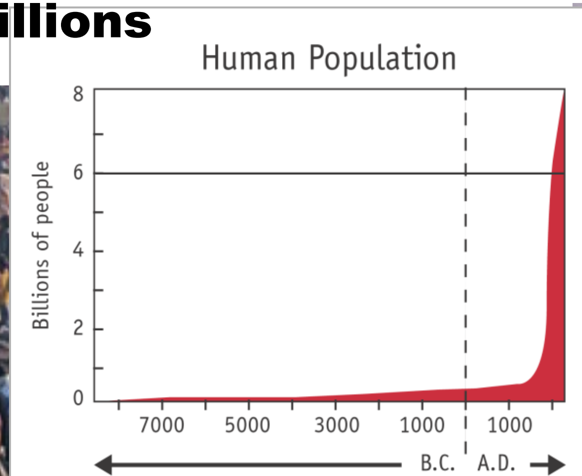
Sunspots Photo: Nasa

Human Population: 7 billions



The Challenge: Sustainable Management and Energy

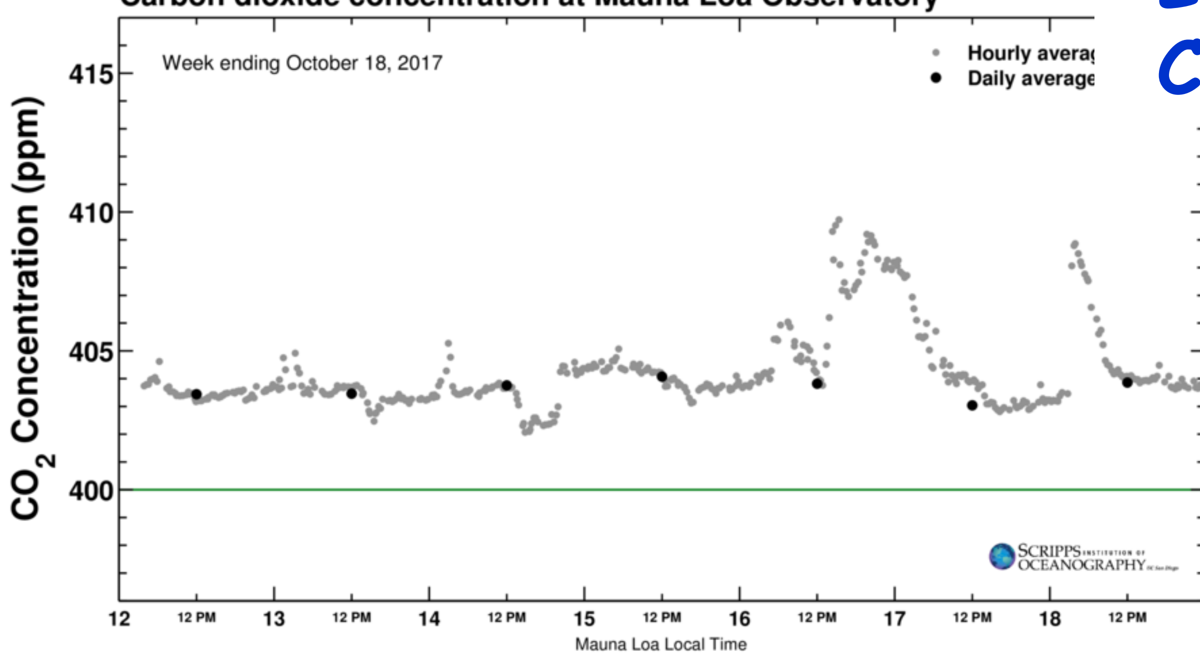
Human Population: 7 billions



Latest CO_2 reading
October 18, 2017

403.86 ppm

Carbon dioxide concentration at Mauna Loa Observatory



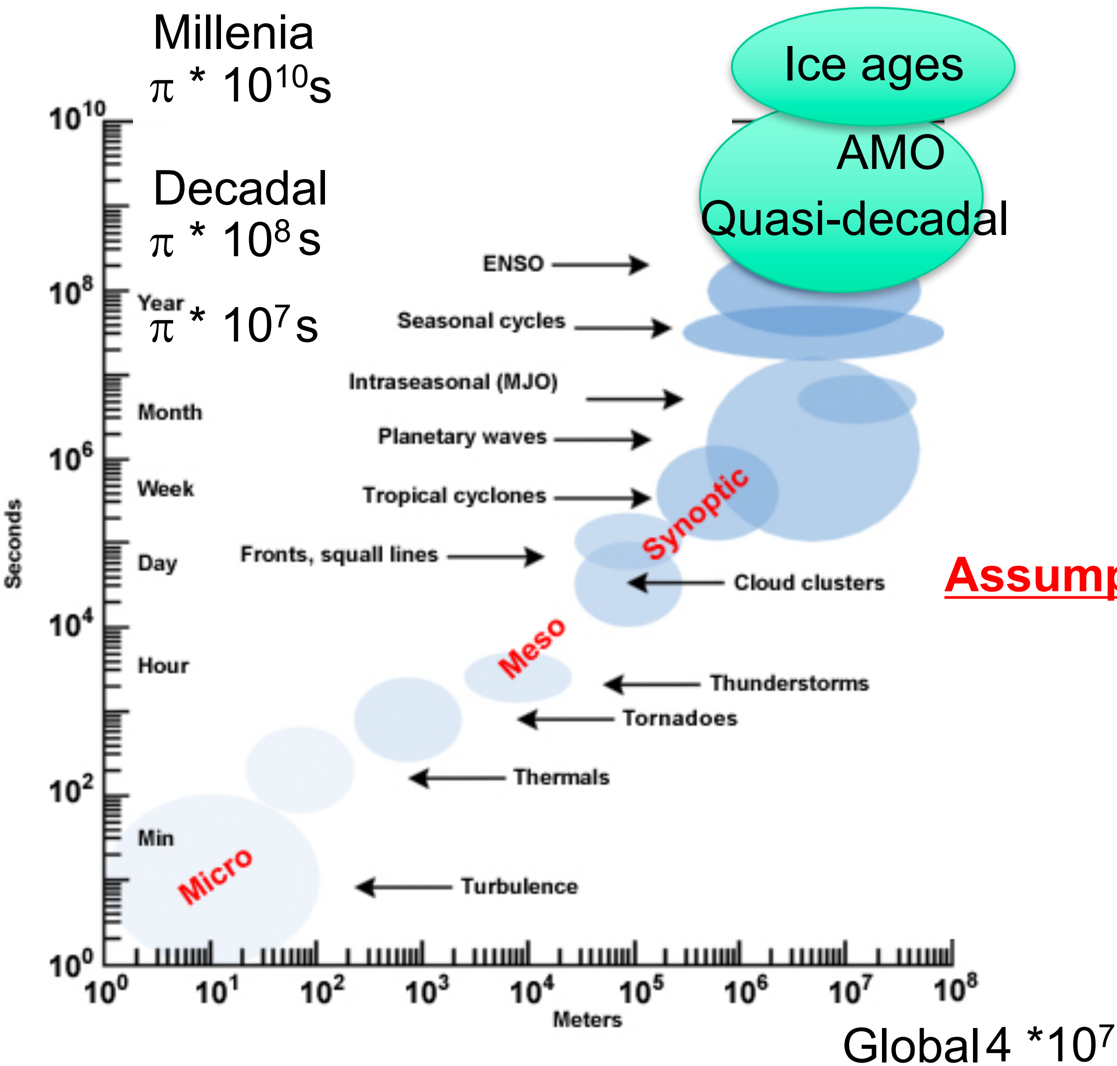
CO_2 Increase:

Land cover: 22%

CO_2-Emissions: 78%

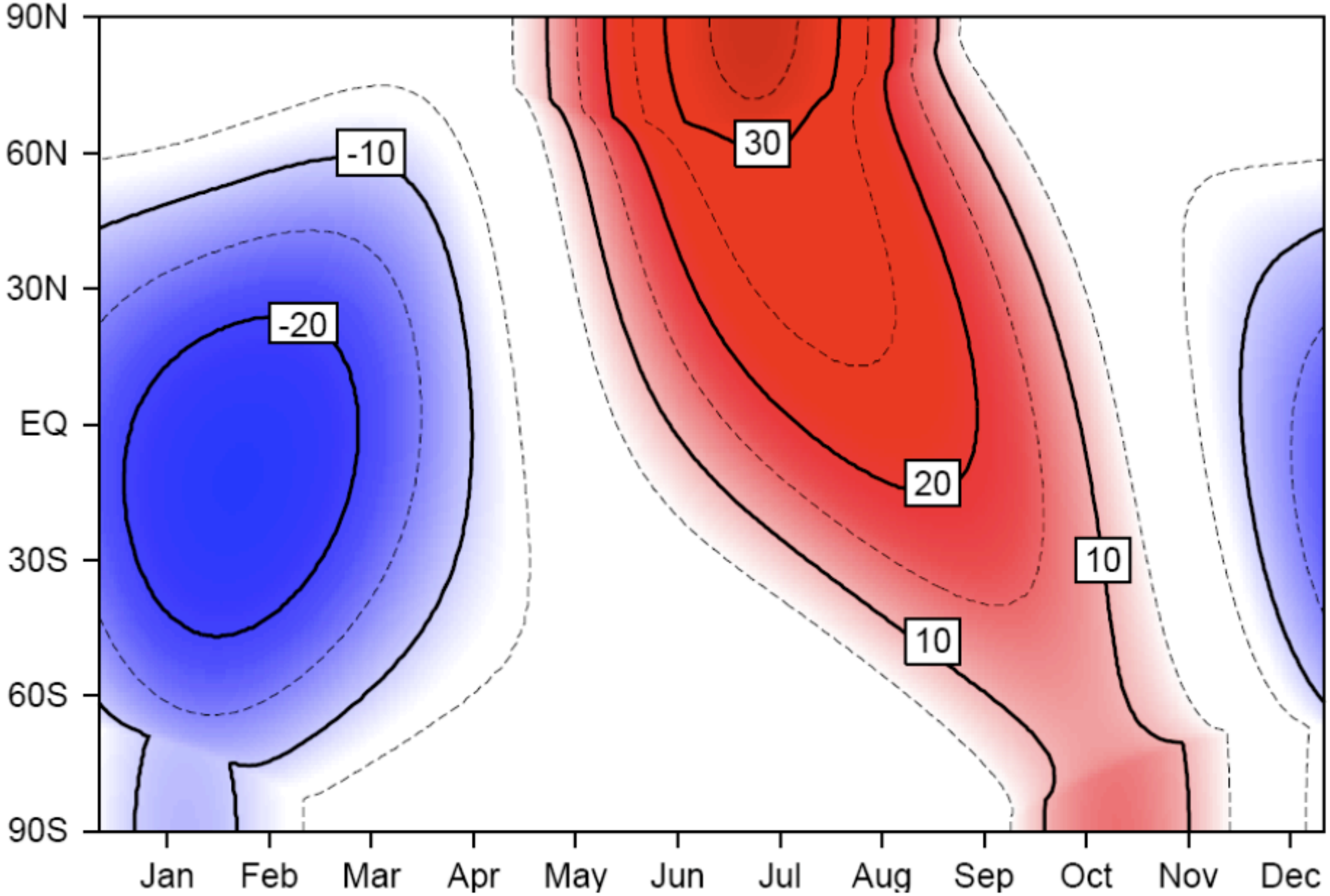
Spatio-Temporal Scales

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

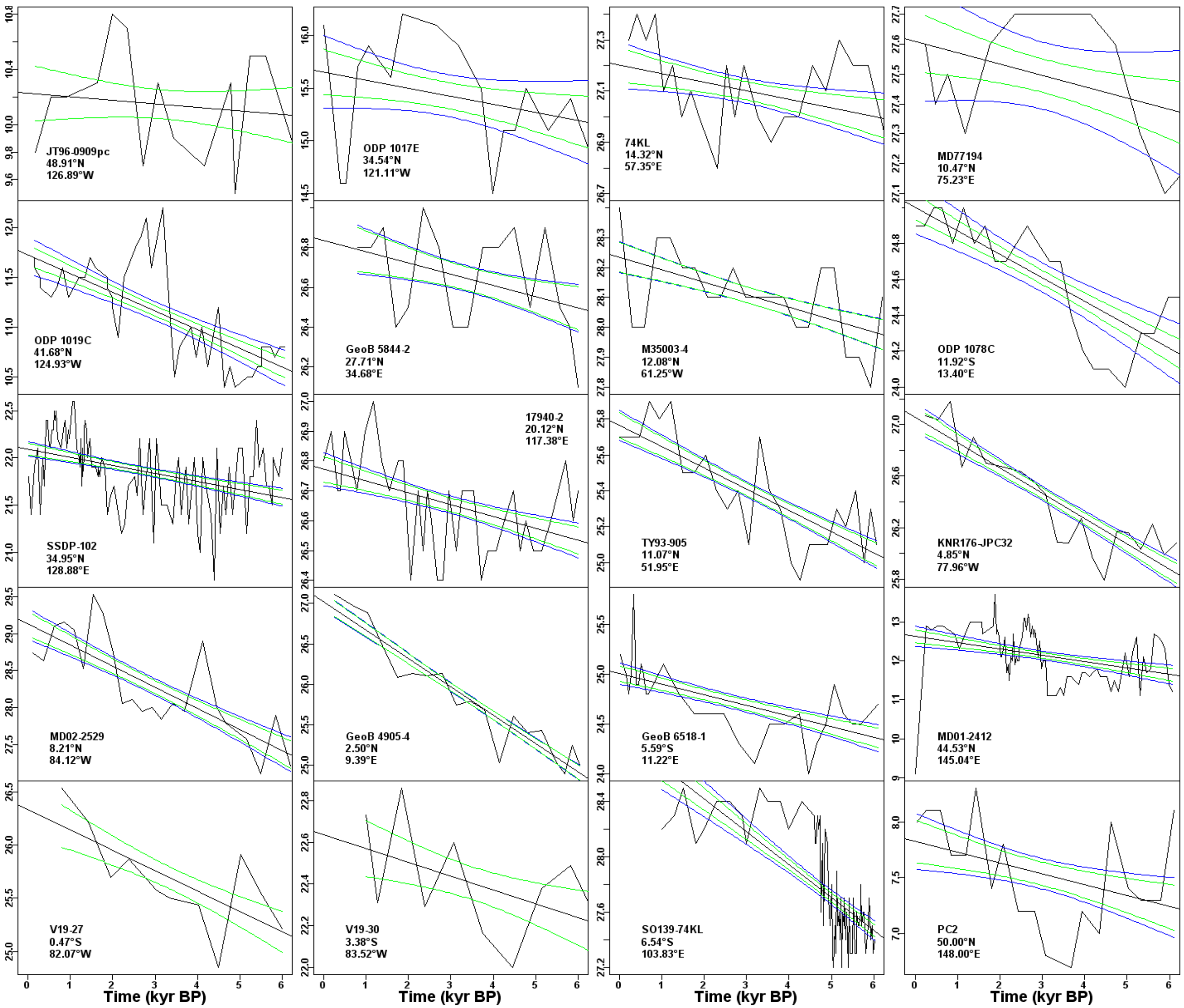


Assumption: Spatial || temporal Scales

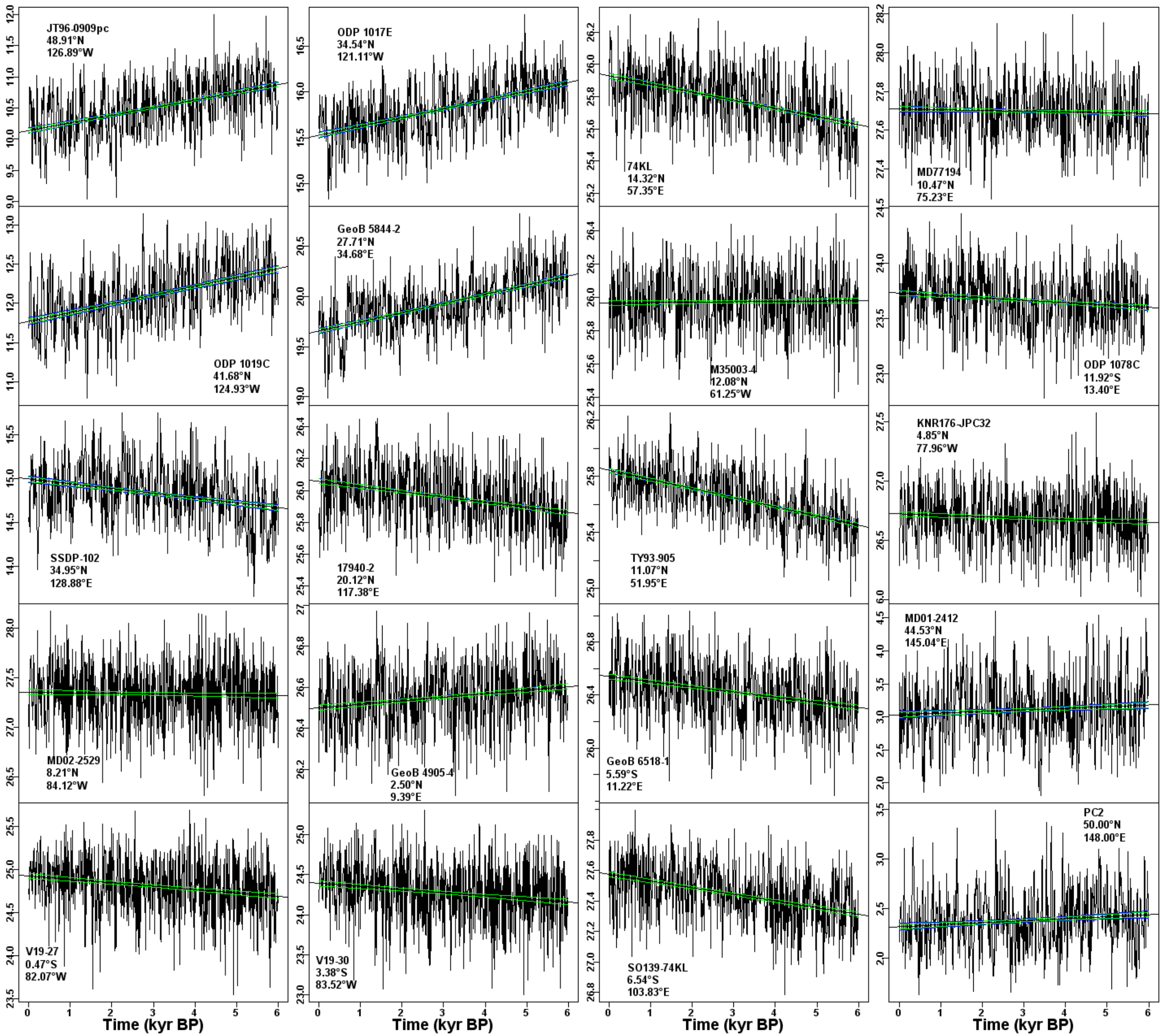
Insolation (6k minus present)



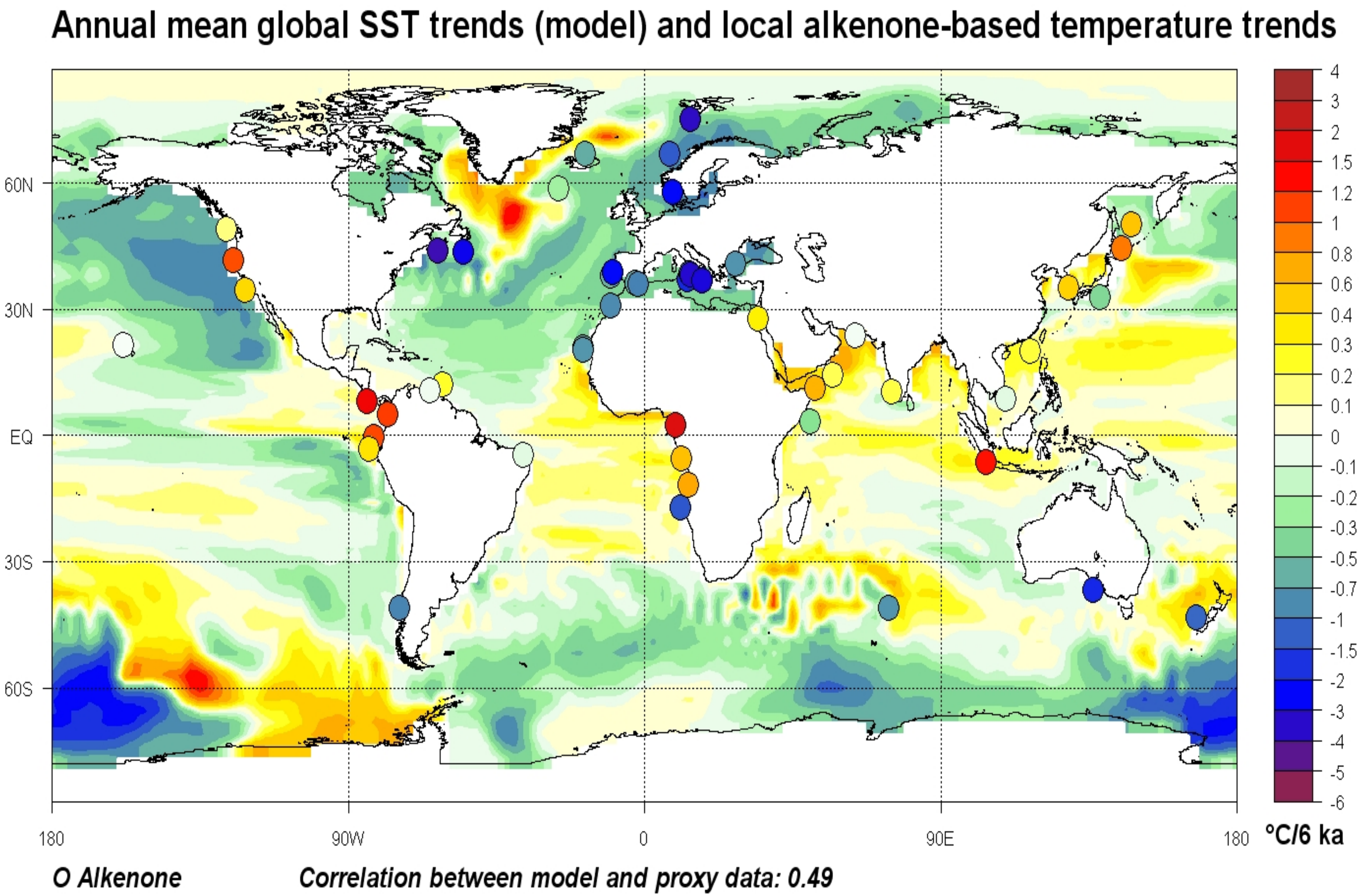
Alkenone Records + Trends



Model SST at core locations

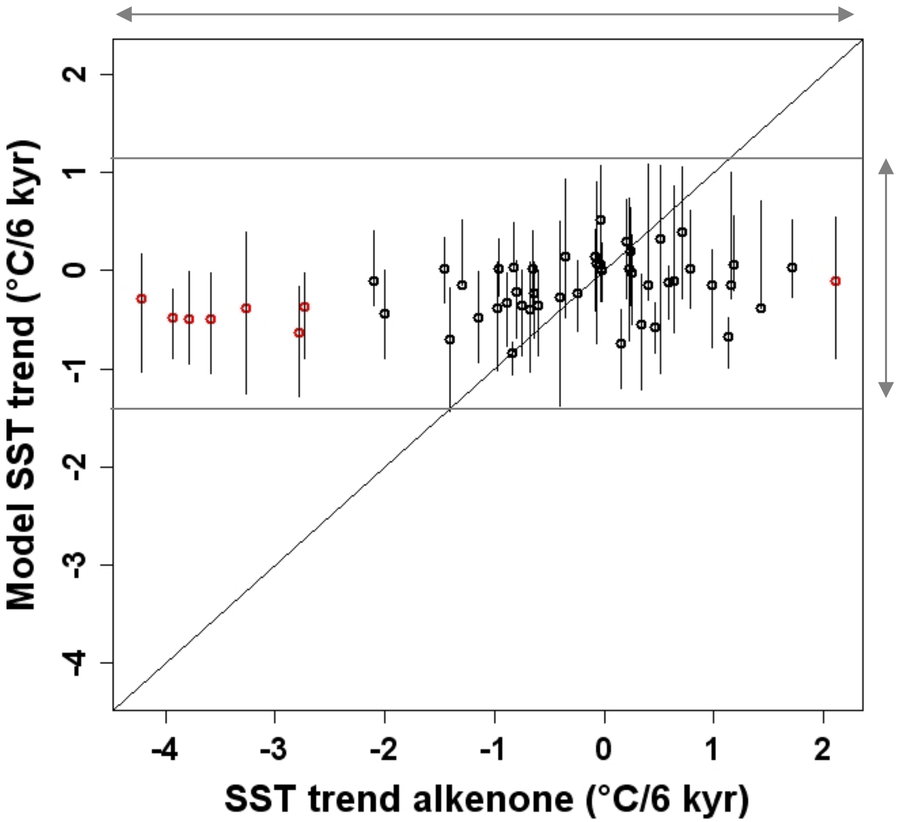


Model-Data Comparison (ECHO-G Model)



Model-Data Comparison SST Trends

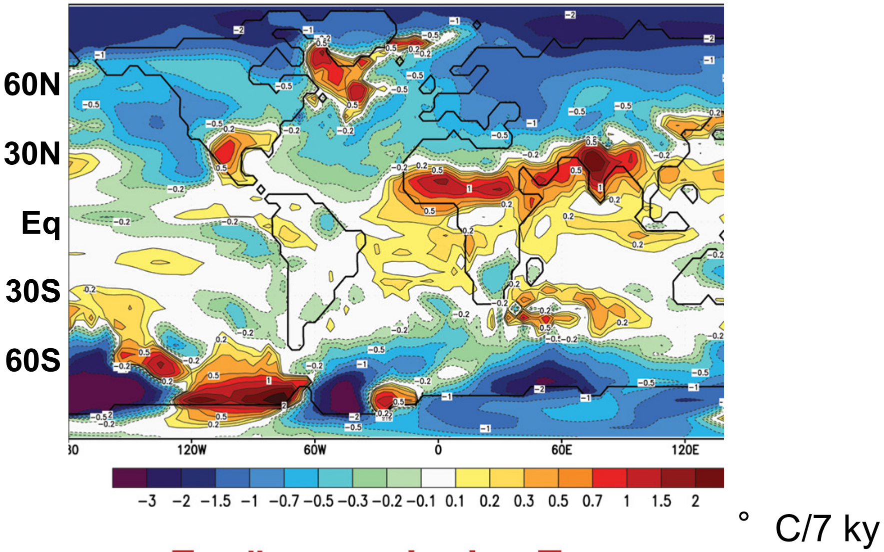
Alkenone-Based vs. Model



| seasonal range

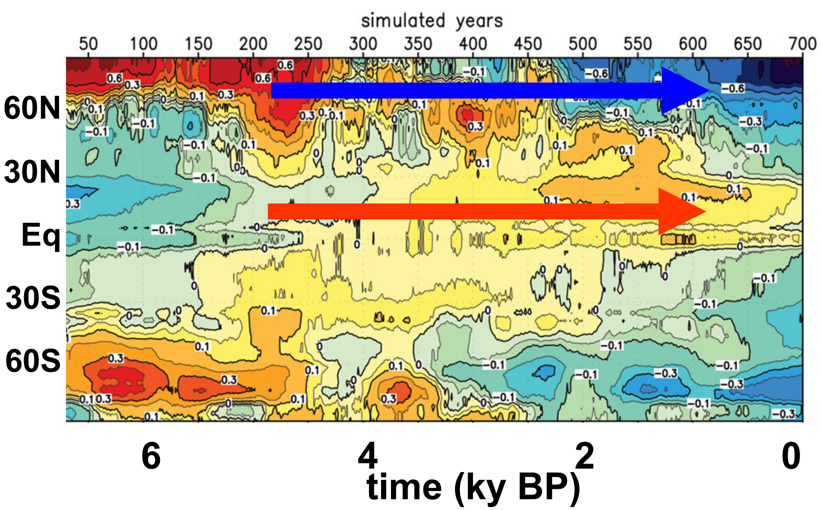
(Lohmann et al., 2013 CP)

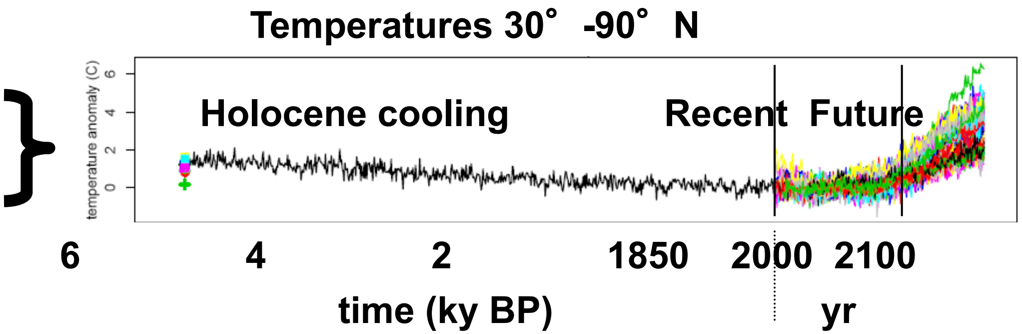
last 7000 years: Models & Data



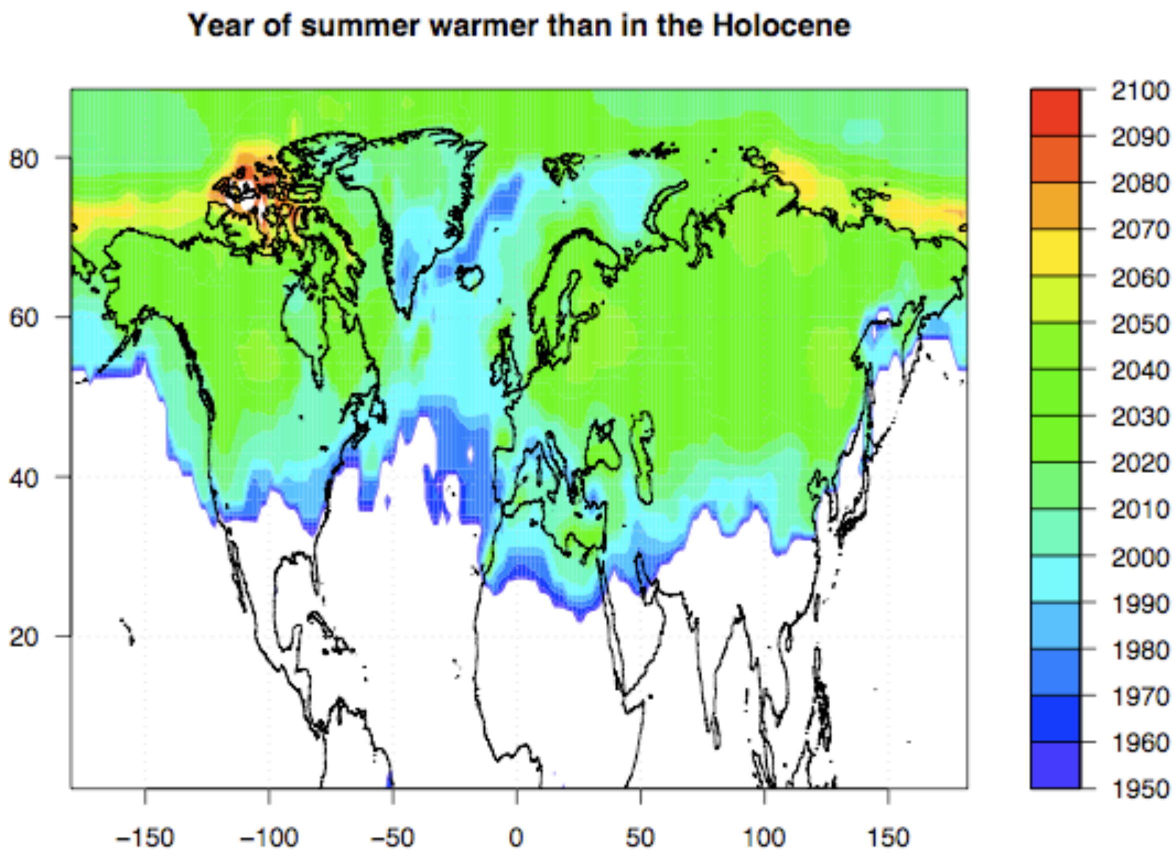
Holocene temperature trend

Erwärmung in den Tropen
Abkühlung in hohen Breiten



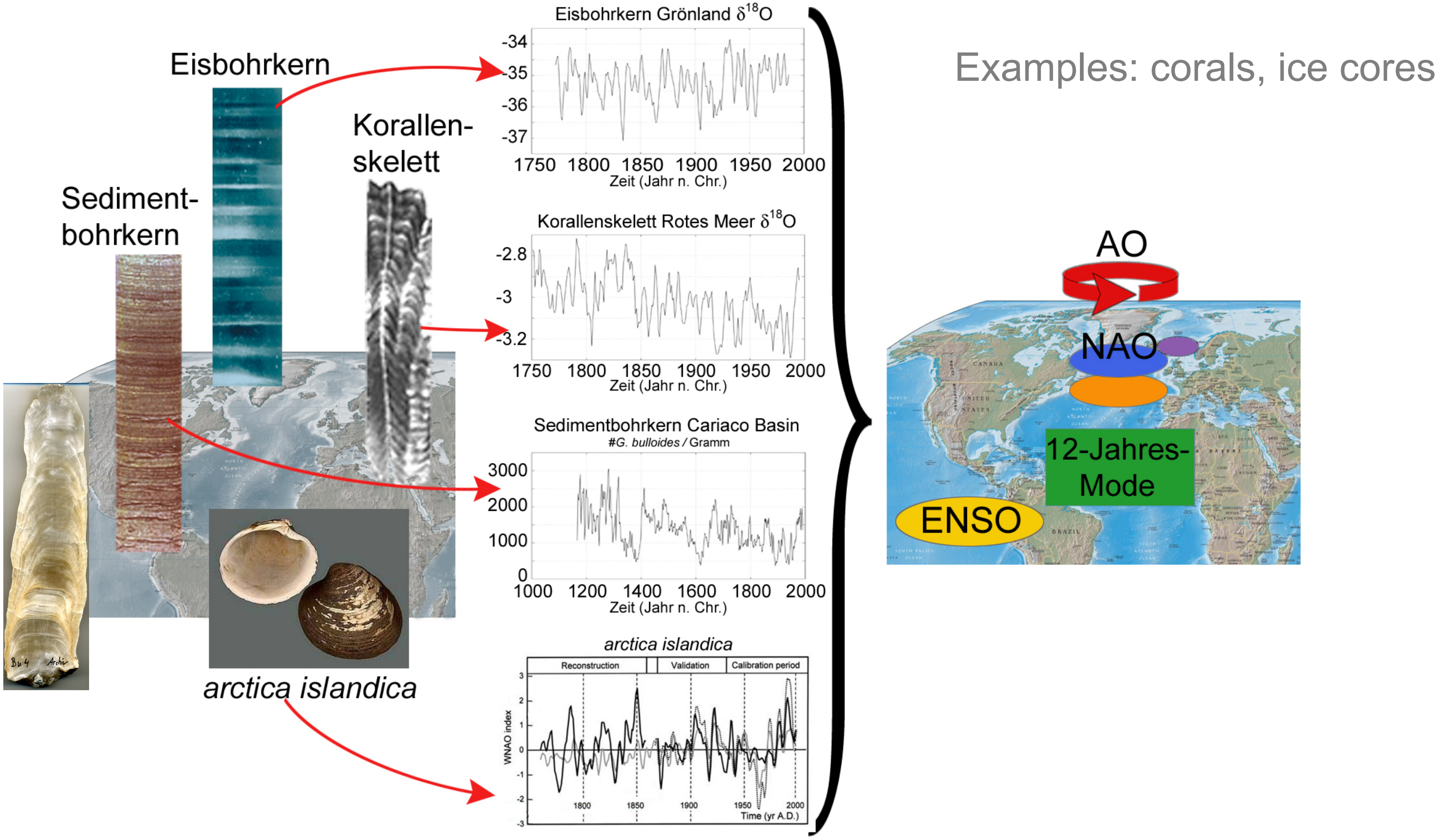


When do we reach the temperature level of 6000 years before present (climate optimum)?



5300 year old man
Ötztaler Alpen 3210m H

Upscaling concept

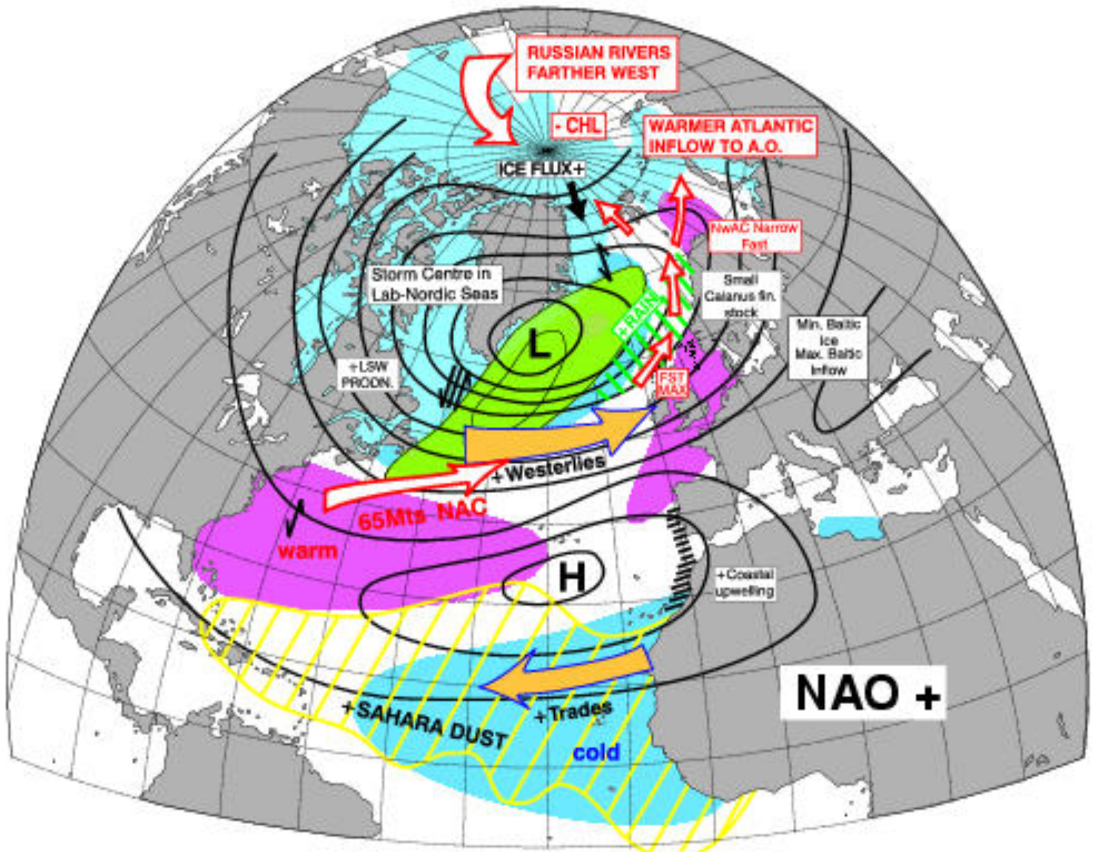


Climate archives

Climate variabiliy

Lohmann, 2007

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)

$$\gamma(\Delta) = E\left((\,x\,(t) - \bar{x}\,)\,(\,y\,(t+\Delta) - \bar{y}\,)\right)$$

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)

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

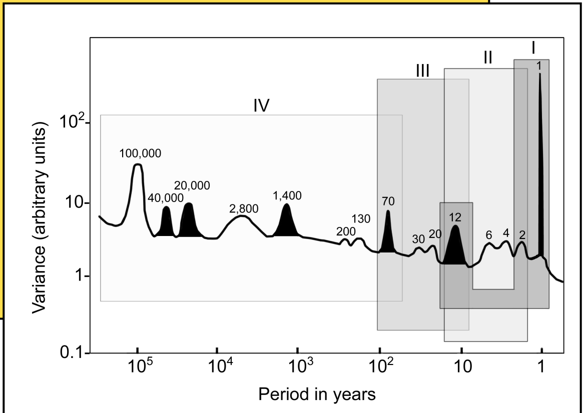
measures the tendency of x (t) and y (t) to covary, between -1 and 1

Spectrum (cross, auto)

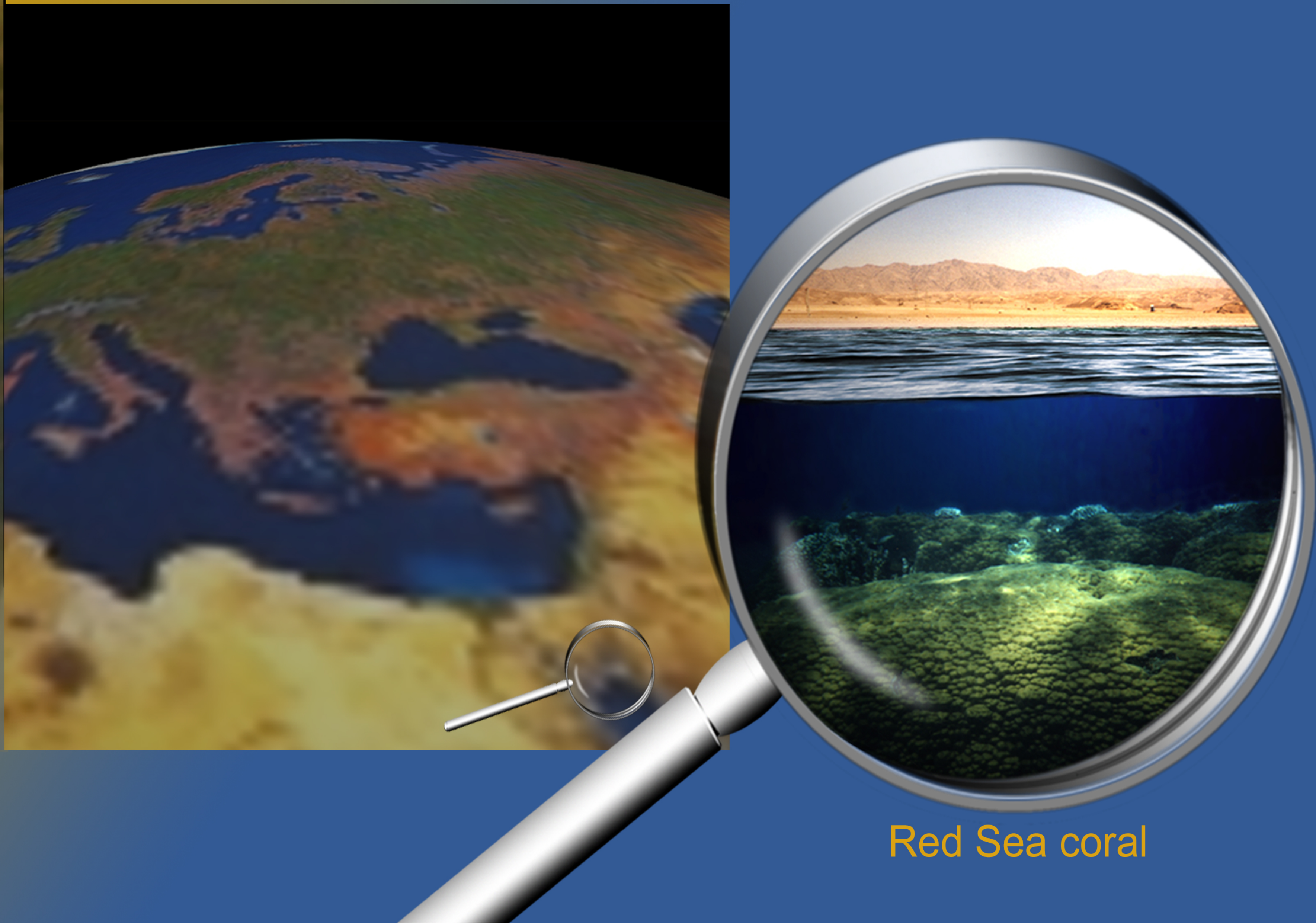
(spectral density)

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

measures variance

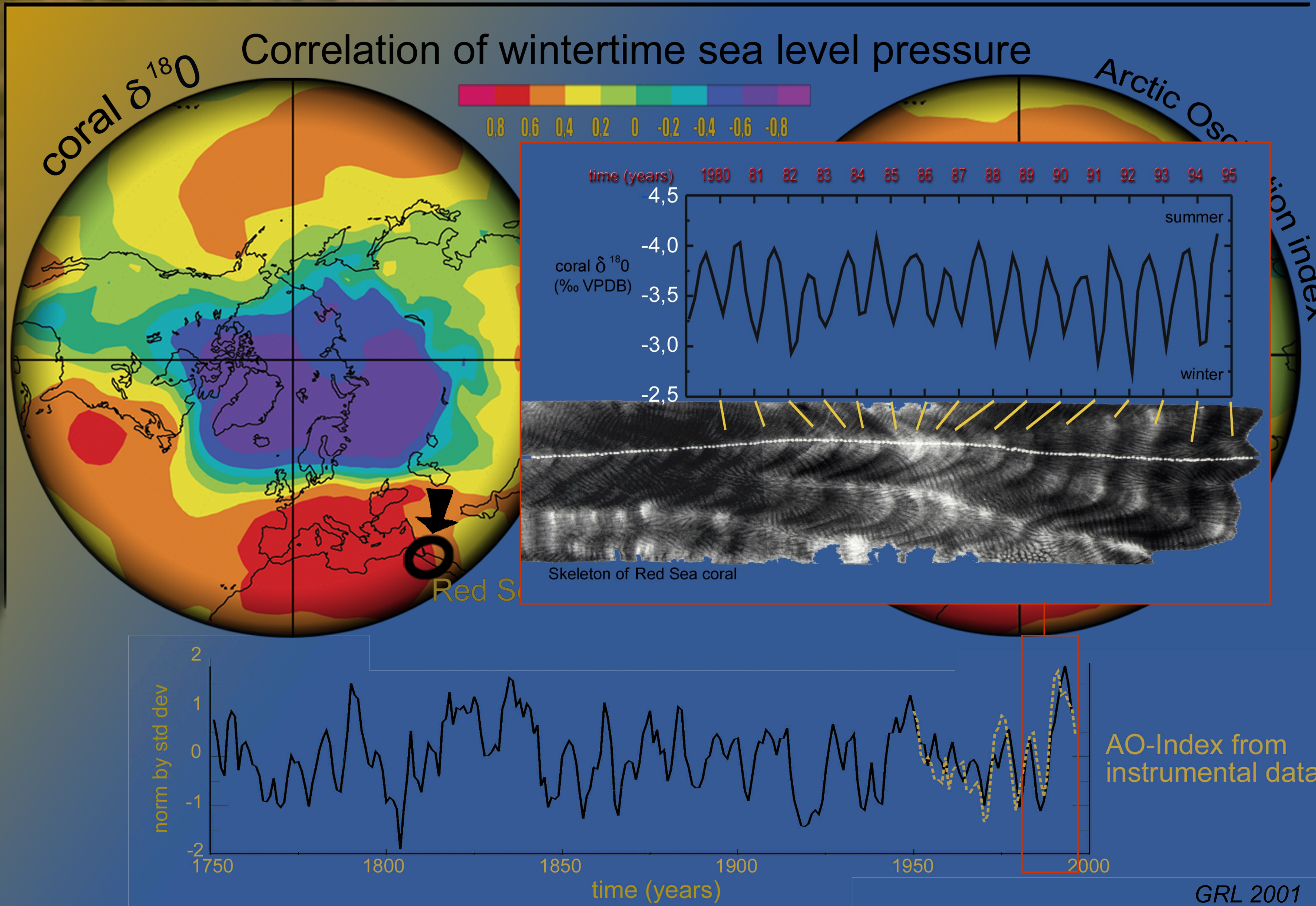


Climate Modes from Proxy Data



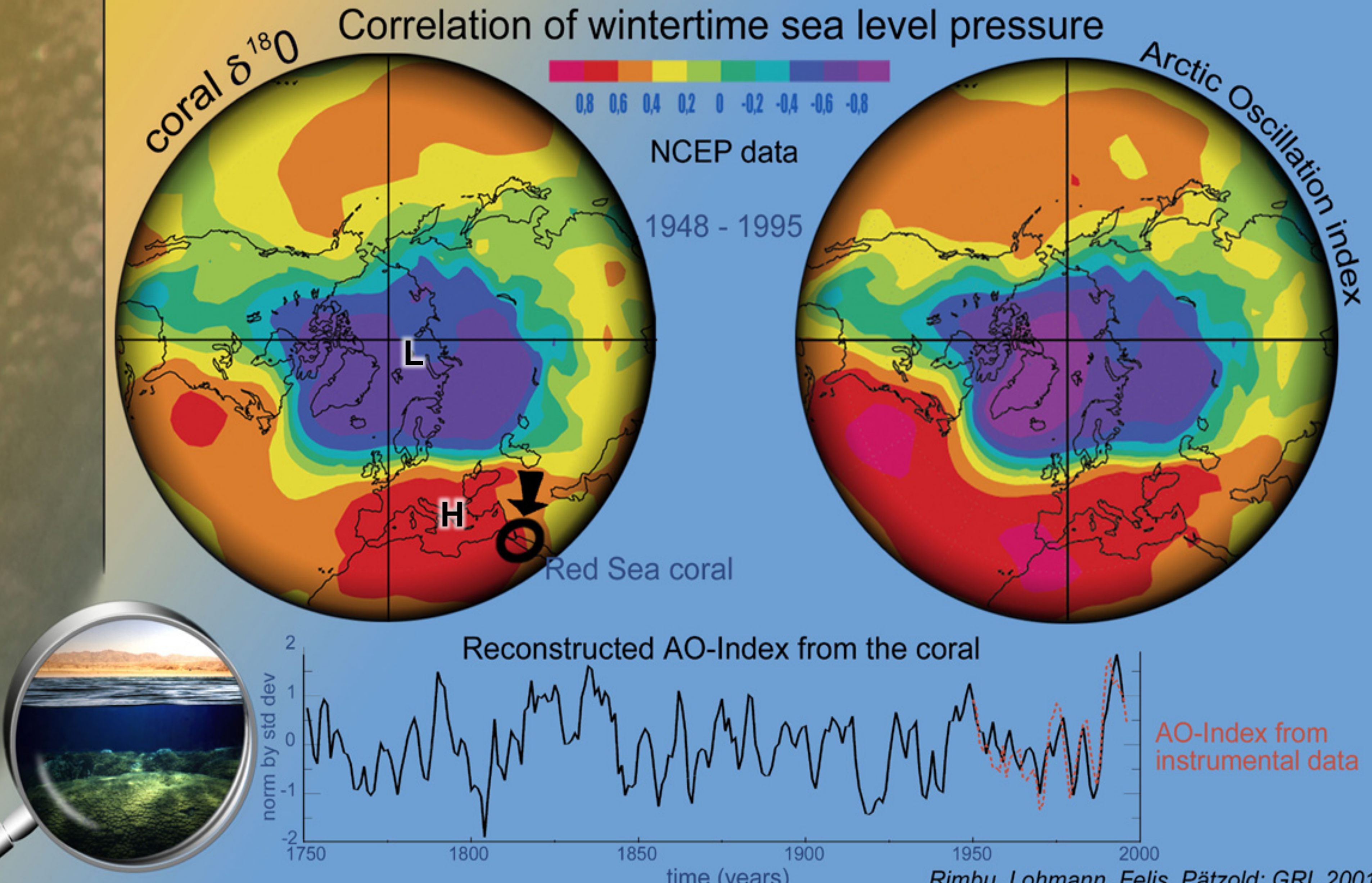
Red Sea coral

Climate Modes from Proxy Data



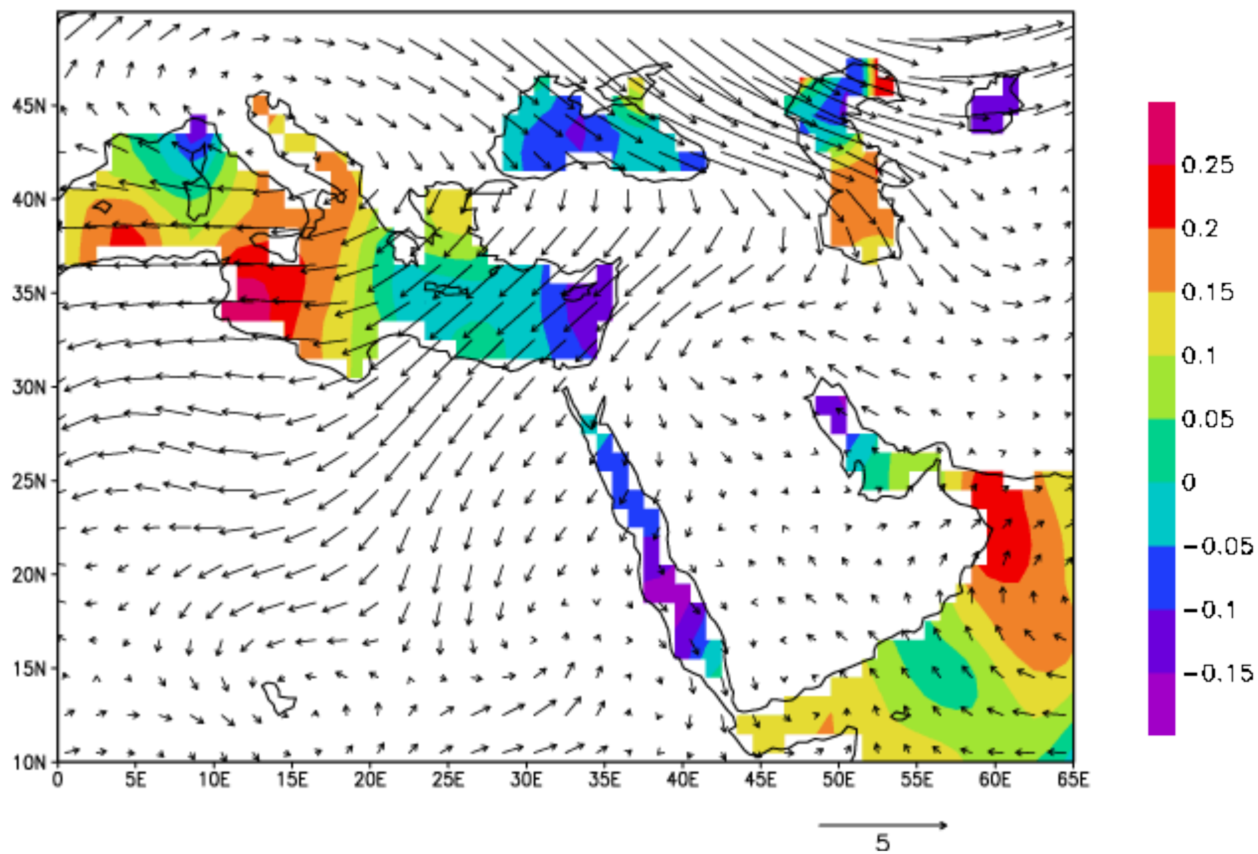
GRL 2001

ARCTIC OSCILLATION SIGNATURE IN A RED SEA CORAL



Rimbu, Lohmann, Felis, Pätzold; GRL 2001

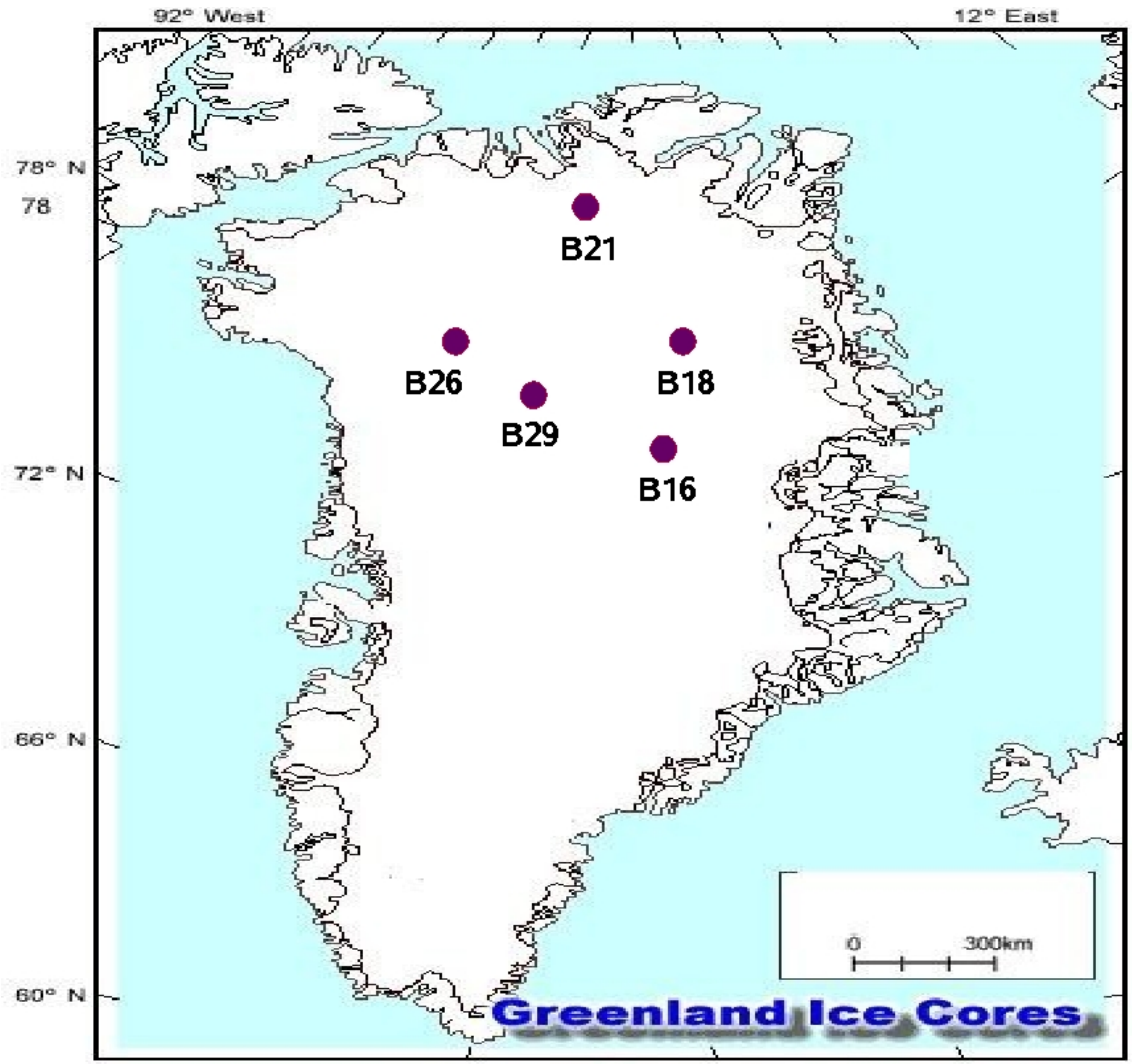
ARCTIC OSCILLATION SIGNATURE IN A RED SEA CORAL



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

mechanistic understanding

SNOW ACCUMULATION ICE CORE



Greenland Traverse AWI (1993-1995)

- Shallow ice core (depths up to 150 m)

- Mean accumulation rates vary between:

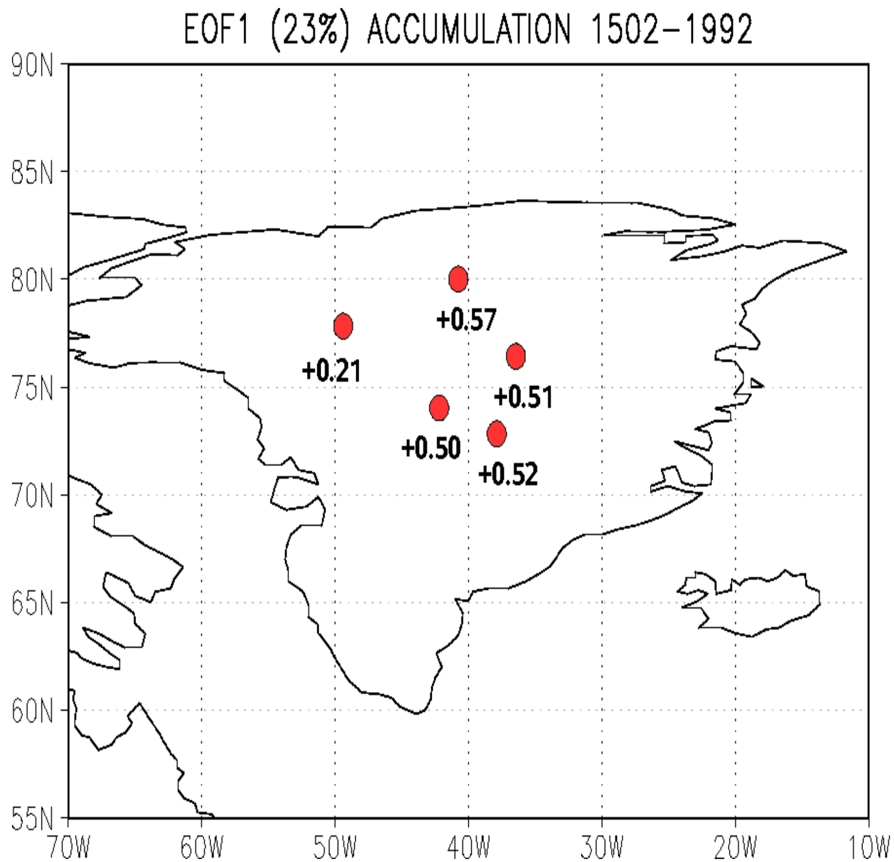
$$104 \pm 32\, mm_{w.e.}\, a^{-1}$$

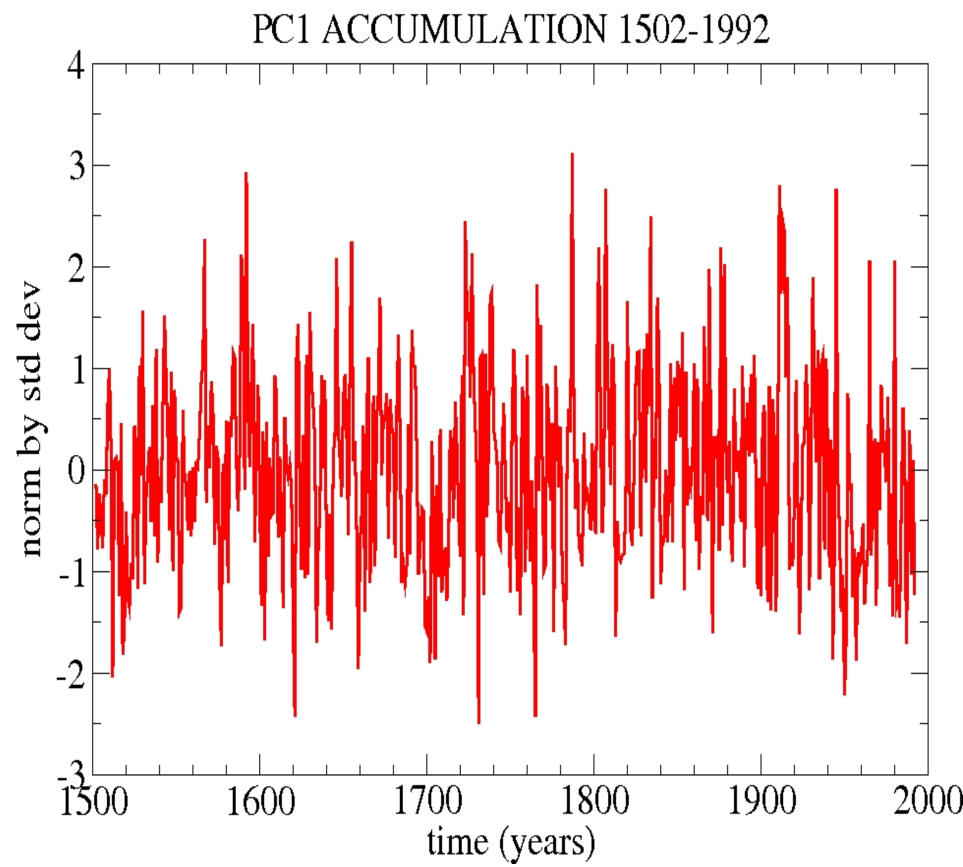
and:

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

Description: Schwager, AWI report, 2000

Accumulation variability



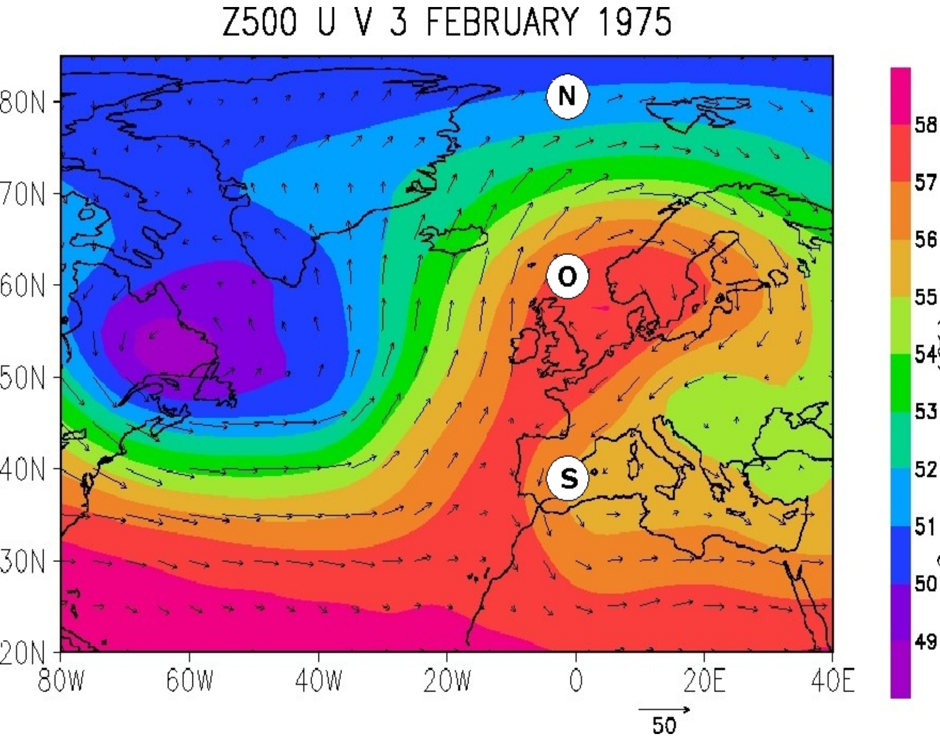


EOF1- MONOPOLAR STRUCTURE POSSIBLE RELATED TO LARGE-SCALE ATMOSPHERIC CIRCULATION

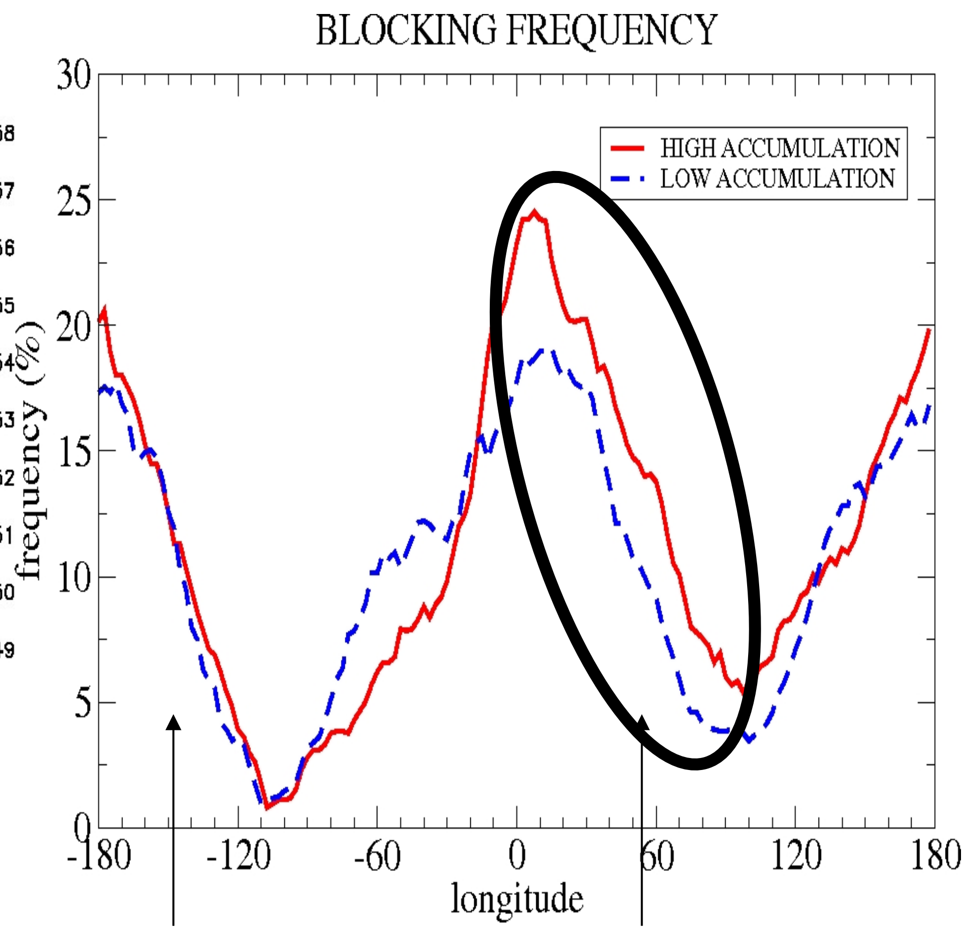
PC1 – INTERANNUAL AND DECADAL VARIATIONS

Rimbu, Lohmann, Grosfeld, GRL, 2007

Atmospheric Blocking



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

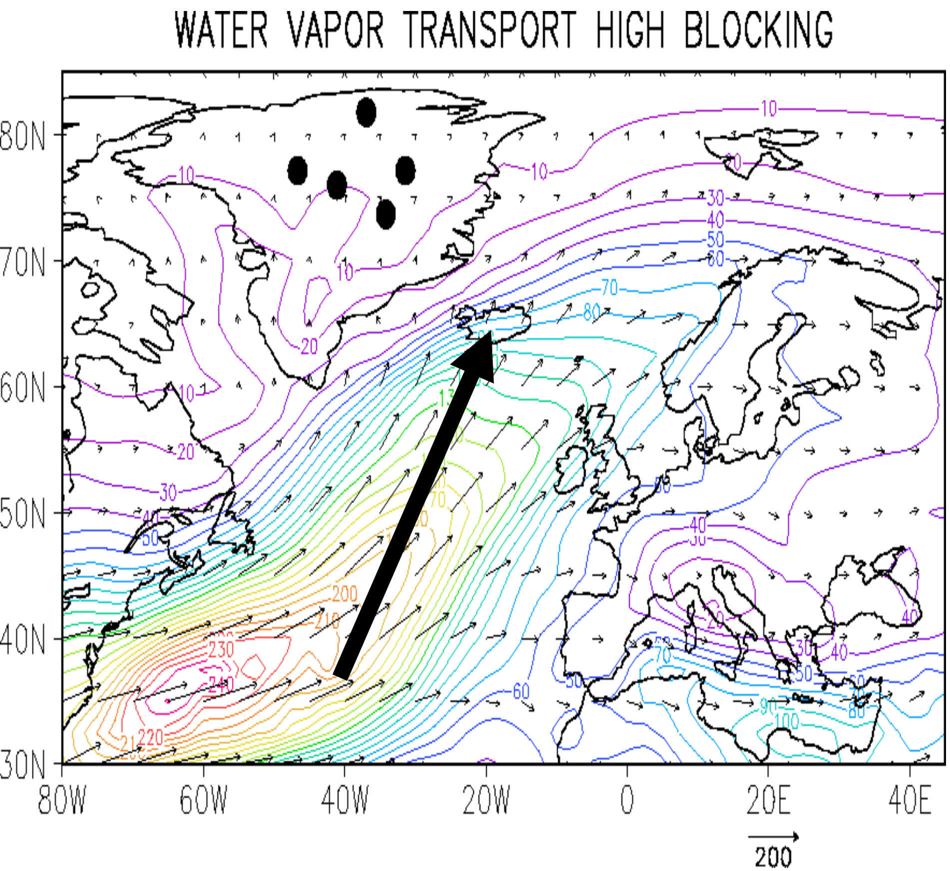


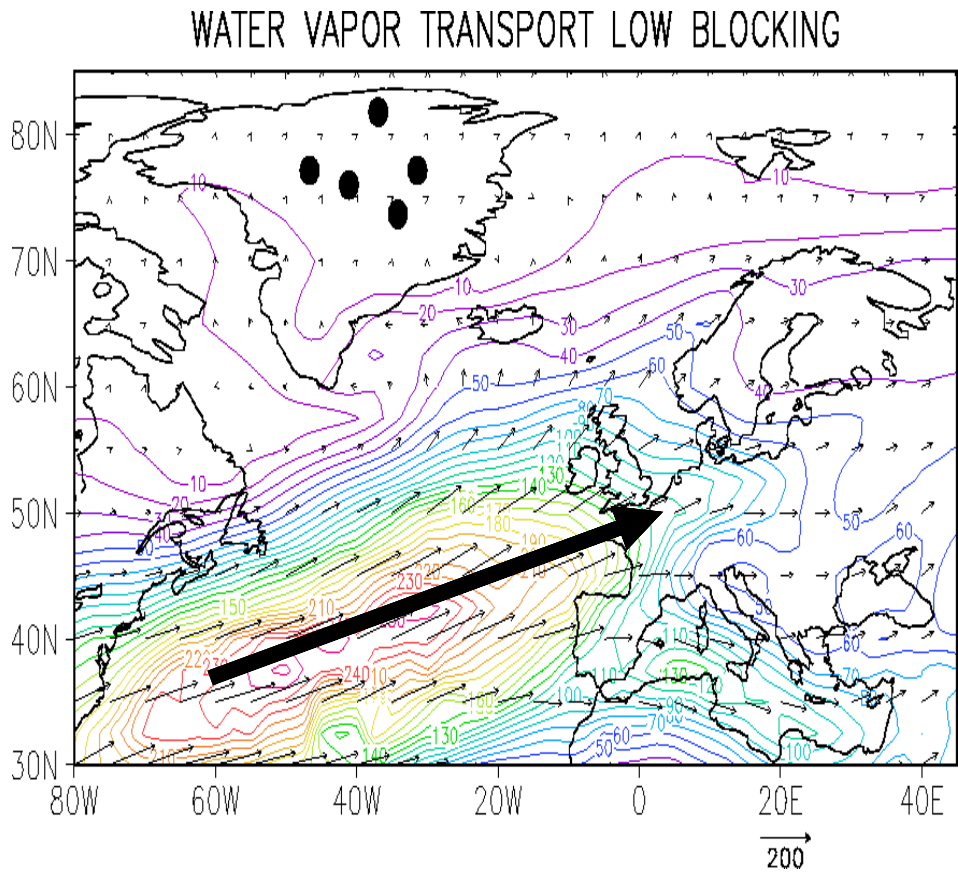
Pacific

Euro-Atlantic

sectors

WATER VAPOR TRANSPORT





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

http://climexp.knmi.nl

1) Monthly climate indices (temp, precip, ...)

Calculate different regions on the world
(home town, Bremerhaven 53° N, 8° E)

2) Correlation with temperature, precipiation, SLP

3) Explain the teleconnections for different seasons

---

4) Modes of climate variability (global temperature)

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)	i
	SOI (1882-now, NCEP)	i
	Precipitation Niño indices: GPCC land , CMORPH satellite	i
	MEI (1950-now, NOAA/ESRL/PSD)	i
	Warm Water Volume (5°S-5°N, 120°E-80°W, 1980-now, PMEL/TAO)	i
	WWV (5°S-5°N, 120°E-80°W, 1960-now, POAMA/PEODAS)	i
	temperature averaged to 300m (130°E-80°W, 1979-now, GODAS)	i
NAO	NAO Gibraltar-Stykkisholmur (1821-now, Jones)	i
	NAO Azores-Stykkisholmur (1865-2002, data from Jones)	i
	NAO (pattern-based, 1950-now, CPC)	i
	NAO reconstruction (1658-2001, Luterbacher)	i
SNAO	Summer NAO from NCEP/NCAR (1948-now), UCAR (1899-now), 20C (1871-2008) SLP	i
AO	Arctic Oscillation derived from SLP (1899-2002) and derived from SAT (1851-1997, Thompson, Colorado State)	i
	Arctic Oscillation (1950-now, NCEP/CPC)	i
AMO	Atlantic Multidecadal Oscillation derived from HadSST (1850-now) and derived from ERSST (1880-now) SST 25°-60°N, 7°-75°W minus regression on Tglobal	i
	Atlantic Multidecadal Oscillation derived from HadSST (1850-now) and derived from ERSST (1880-now) SST EQ-60°N, 0°-80°W minus SST 60°S-60°N	i
AMOC	Atlantic Meridional Overturning Circulation: ECMWF S3 (1961-2005)	
Teleconnection patterns	East Atlantic, East Atlantic/Western Russia, Scandinavia and Polar/Eurasia patterns (1950-now, CPC)	i

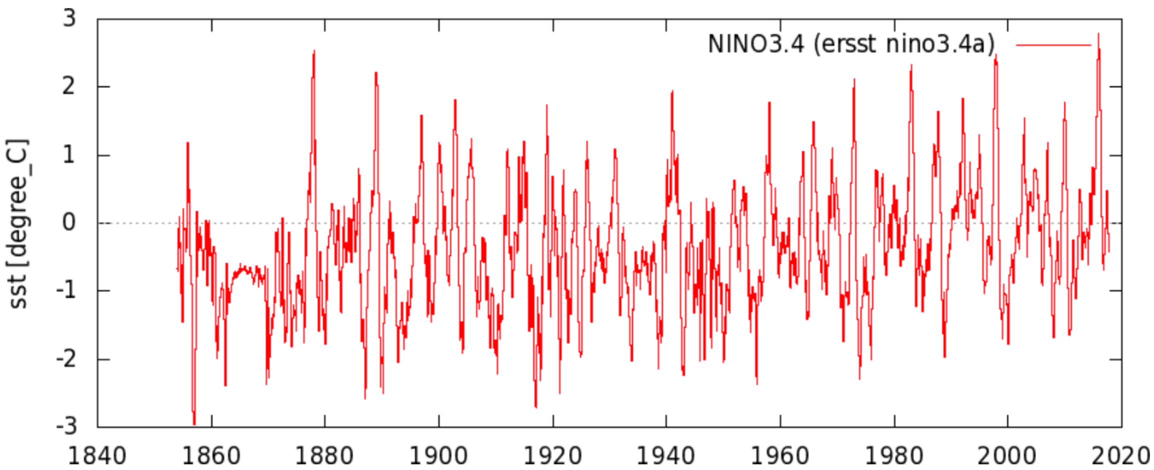
Select a time series
- Daily station data
- Daily climate indices
- Monthly station data
- Monthly climate indices
- Annual climate indices
- View, upload your time series

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

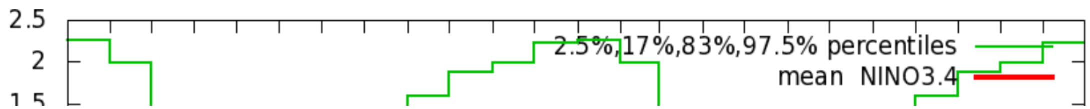
Time series

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)



Two annual cycles, computed with all data available (eps, pdf, raw data)



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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
- Correlate with other time series
- Correlate with a field (correlation, regression, composite)
  - only observations
  - only reanalyses
  - only seasonal forecasts
  - only scenario runs
  - only user-defined fields
- Verify against another time series
- Spectrum, autocorrelation function
- Wavelet
- Running mean/s.d./skew/curtosis
- Trends in return times of extremes

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
	1948-now: CPC GHCN/CAMS t2m analysis (land) 0.5°, 1.0°, 2.5°	i
	1901-2016: CRU TS 4.01 (land) 0.5°, 1.0°, 2.5°, #/value	i
	1901-2016: CRU TS3.25 (land) 0.5°, 1.0°, 2.5°, #/cell, #/value	i
	1750-now: Berkeley 1°	i
	0.25° 1950-now: E-OBS v15.0 Tg, 0.5° 1901-now with CRU TS (Europe)	i
	1895-now: PRISM 4km, PRISM 0.25°, (Contiguous US only)	i
Tmax	1901-2016: CRU TS 4.01 (land) 0.5°, 1.0°, 2.5°, #/value	i
Tmax	1901-2016: CRU TS3.25 (land) 0.5°, 1.0°, 2.5°, #/cell, #/value	i
	1833-now: Berkeley 1°	i
	0.25° 1950-now: E-OBS v15.0 Tx, 0.5° 1901-now with CRU TS (Europe)	i
	1895-now: PRISM 4km, PRISM 0.25°, (Contiguous US only)	i
	HadEX2 1901-2010 2.5° monthly: TXx, TXn, TX10p, TX90p, annual: TXx, TXn, TX10p, TX90p	i

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- Verify against another time series
- Spectrum, autocorrelation function
- Wavelet
- Running mean/s.d./skew/curtosis
- Trends in return times of extremes
- Plot and fit distribution

Field correlations

NINO3.4 with HadCRUT4.5 SST/T2m anom

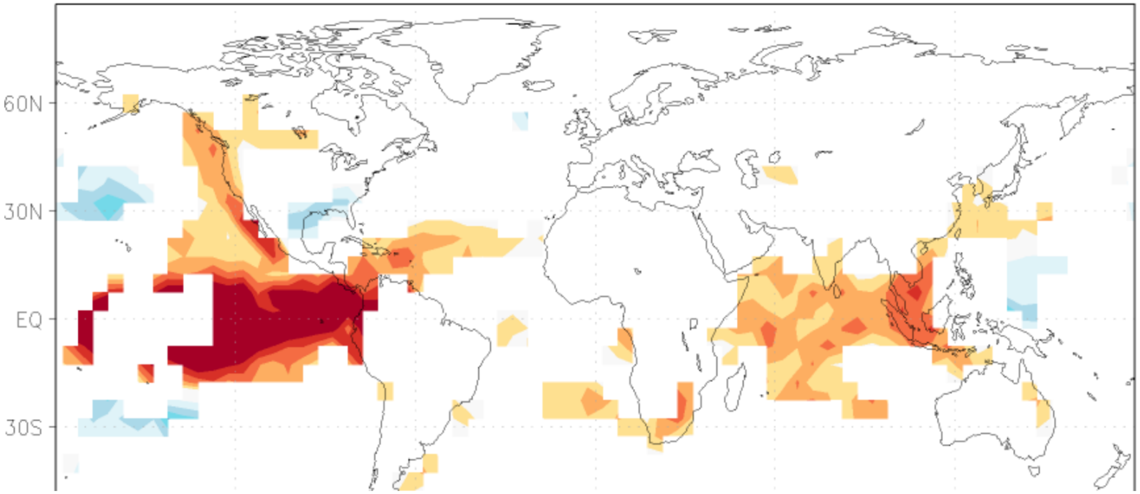
Computing correlations... (this may take a minute or so)

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 NINO3.4 with Jan HadCRUT4.5 SST/T2m anom 1854:2017 p<10% (eps, pdf)



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

Select a field
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- Monthly seasonal hindcasts
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- Monthly CMIP3+ scenario runs
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- Attribution runs
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Investigate this time series
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.... Or select a position

Field

HadCRUT4.5 SST/T2m anom

HadCRUT4 near-surface temperature ensemble data - ensemble median
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
Demand at least: 30 % valid points in this region
Considering: (•) everything ( ) land points ( ) sea points show/hide more
Units: ( ) convert to Celsius (•) leave in K

Make time series

Apply monthly high/low-pass filter

high-pass | running-mean filter
cut-off value 1 months
requiring at least 75 % valid data

Filter consecutive months

Apply year-on-year high/low-pass filter

high-pass | running-mean filter
cut-off value 1 years

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Investigate this field
- Plot this field
- Plot difference with a field
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- Correlate with a time series
- Pointwise correlations with a field
  - only observations
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  - only decadal hindcasts
  - only CMIP5 scenario runs
  - only user-defined fields
- Spatial correlations with a field

Field

HadCRUT4.5 SST/T2m anom

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	1850-2006: Hadley Centre HadSST3.1.1.0 5°	
	1800-2007: 2° ICOADS v2.5 SST, number of obs	
	1982-now: 1° NOAA ("Reynolds") OI v2 SST	
	1982-now: 1/4° NOAA OI v2 SST	
	1980-now: TAO buoys SST, Air Temperature	
Air Temperature	1880-2010: HadNMAT2, anomalies, large-scale uncertainties, (1856-2002 HadMAT1)	
	1800-2007: 2° ICOADS v2.5 Tair, number of obs	
Lower Troposphere	1979-now: Spencer & Christy MSU anomalies v6.0 (v5.6)	
	1978-now: RSS MSU 3.3 TLT, anomalies (3.2, anomalies)	
Precipitation	1901-2016: CRU TS 4.01 (land) 0.5°, 1.0°, 2.5°, #/value	
	1901-2016: CRU TS3.25 (land) 0.5°, 1.0°, 2.5°, #/cell, #/value	
	0.25° 1950-now: E-OBS v15.0 precip, 0.5° 1901-now with CRU TS (Europe)	
	1900-now anomalies: NCDC analysis (land)	
	1901-2013: GPCC V7 analysis (land) 2.5°, 1.0°, 0.5°, only observations: 2.5°, 1.0°, 0.5°, number of gauges 0.5°, 1.0°, 2.5°	
	1986-now: 1° GPCC monitoring product + first guess (land); only observations, number of gauges	
	1900-now: home-merged 1° GPCC V7 + monitoring product + first guess (land); 1°, 2.5°, only observations: 1°, 2.5°	
	1979-now: GPCP v2.3 analysis, v2.2	
	1979-now: CPC Merged Analysis of Precipitation, with model	
	1998-now: 0.5° 1° TRMM, 0.25° 1° TRMM+GPCC	
	1998-now: CMORPH 0.25° precipitation	
	1983-now: CAMSOPI, percentage	
	1895-now: PRISM 4km, PRISM 0.25°, (Contiguous US only)	
	0.1° 1900-2014: CenTrends v1 (Greater Horn of Africa), 0.25° 1900-now: extended with CHIRPS	
	HadEX2 1901-2010 2.5° monthly: Rx1day, Rx5day, annual: Rx1day, Rx5day, R95p, R99p	
OLR	1979-now: UMD/NCEI OLR	
	1974-2013: NOAA Interpolated OLR	
Sea-level Pressure	1899-now: Trenberth's NH	

Field correlations

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

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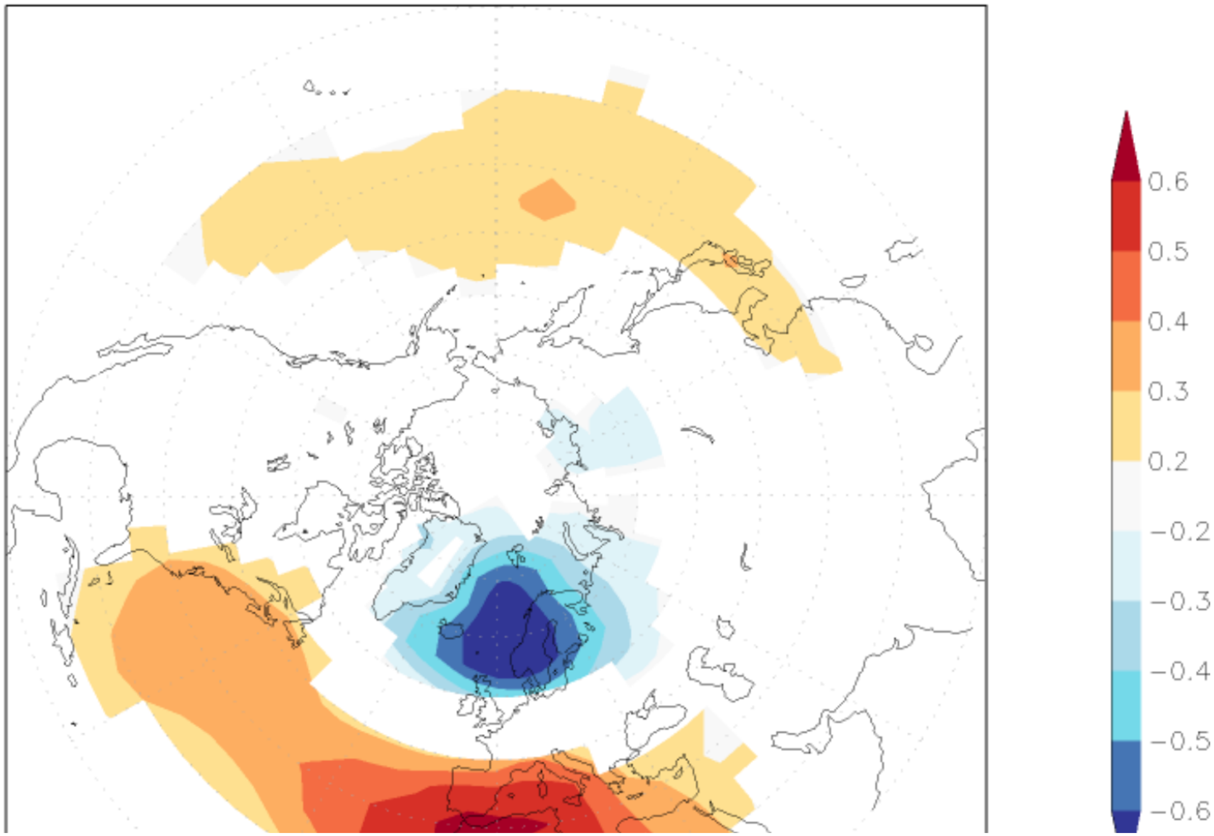
Requiring at least 50% valid points

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%



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  - only observations
  - only reanalyses
  - only seasonal hindcasts
  - only decadal hindcasts
  - only CMIP5 scenario runs
  - only user-defined fields
- SVD
  - only observations
  - only reanalyses
  - only seasonal hindcasts
  - only CMIP5 scenario runs
  - only user-defined fields
- Verify field against observations