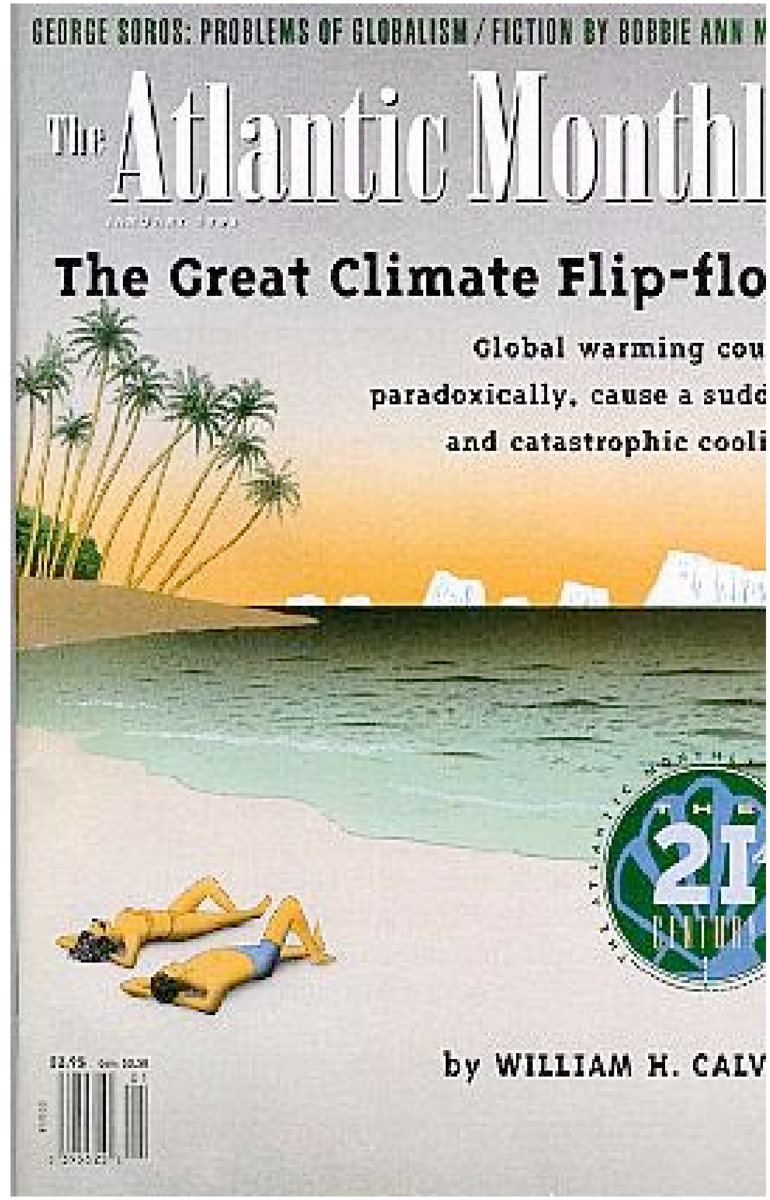
Abrupt climate change: a role for the tropics?

Axel Timmermann,
Uta Krebs
Fei-Fei Jin
Stephan Lorenz

July 9th 2005



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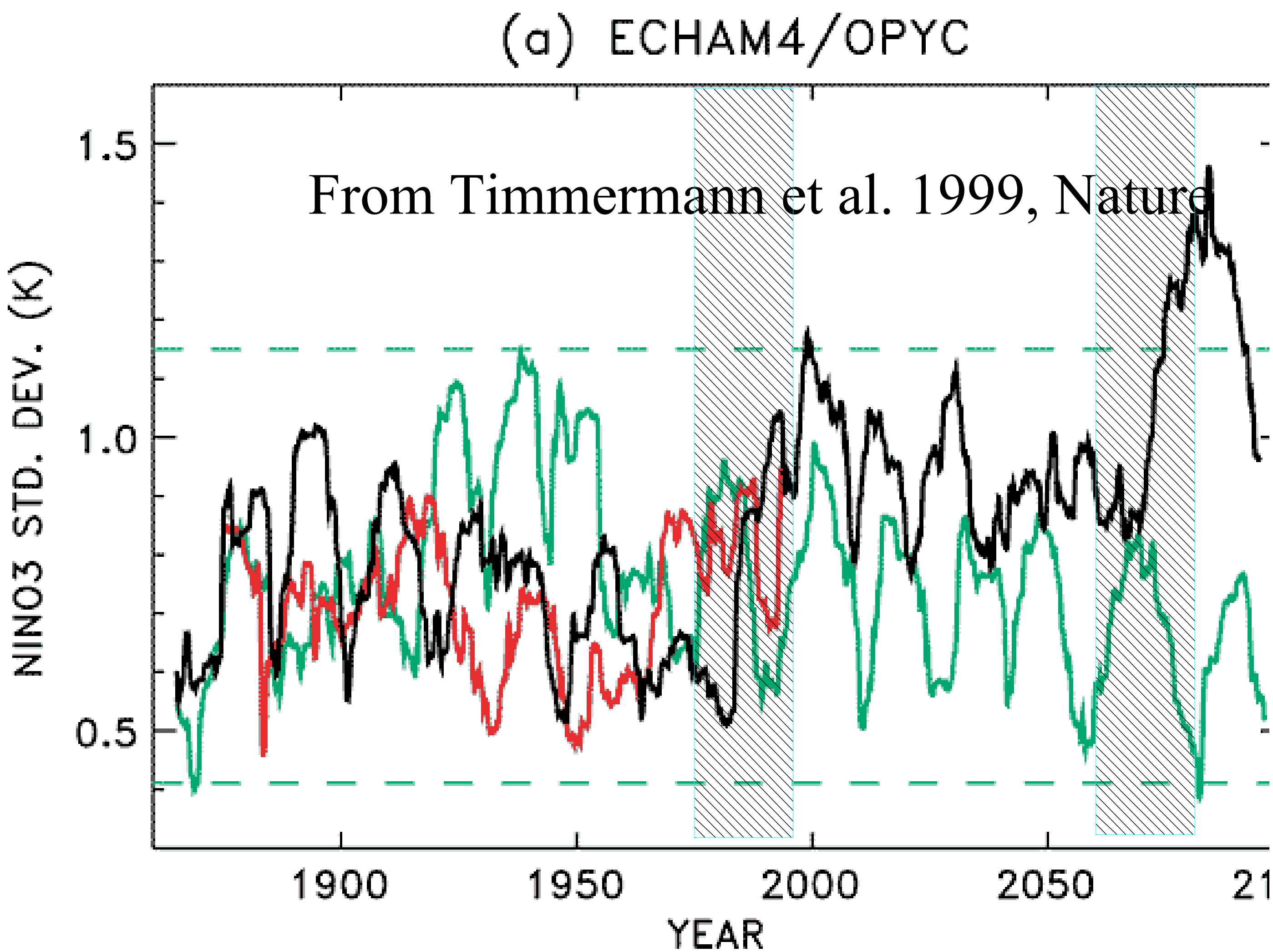
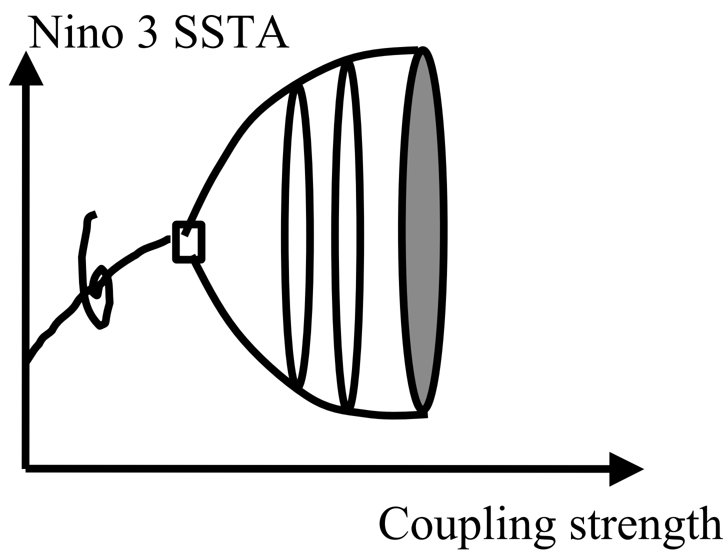
Examples of “abrupt” climate change

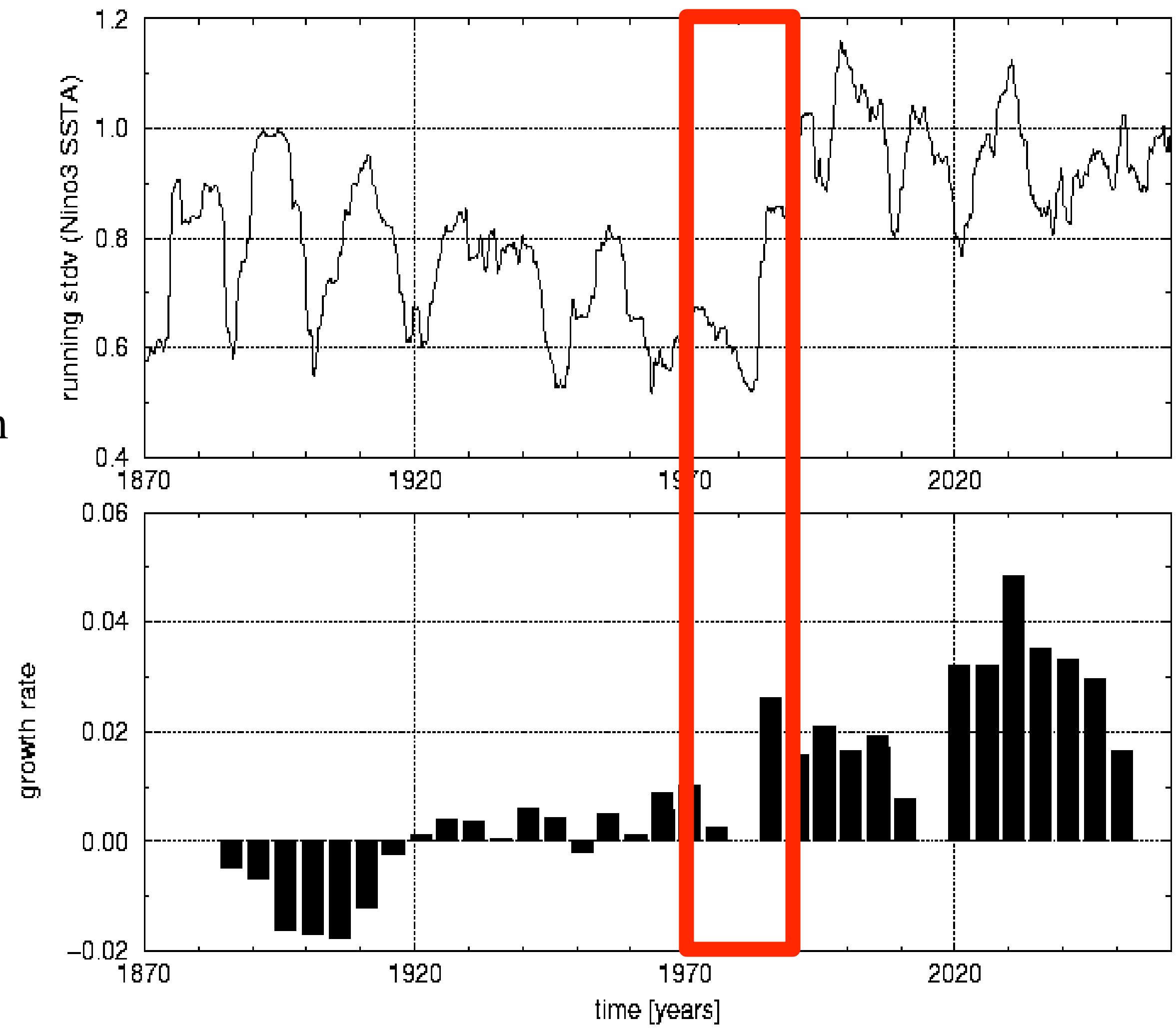
Decadal amplitude modulations and abrupt variance jumps for ENSO



Examples of “abrupt” climate change



Variance jumps are associated with “empirical” Hopf bifurcations



Timmermann 2001

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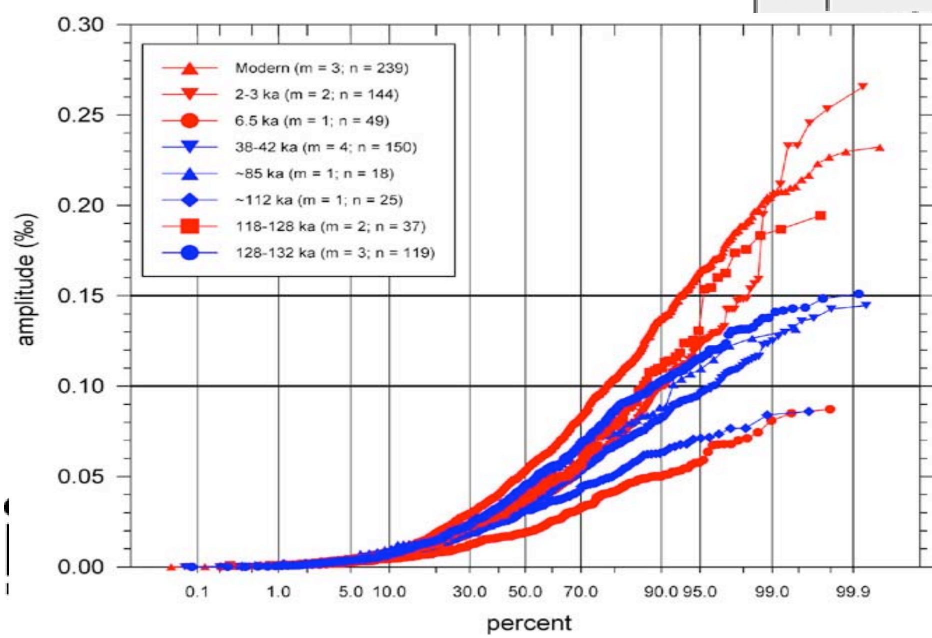
ENSO during the last 130,000 years

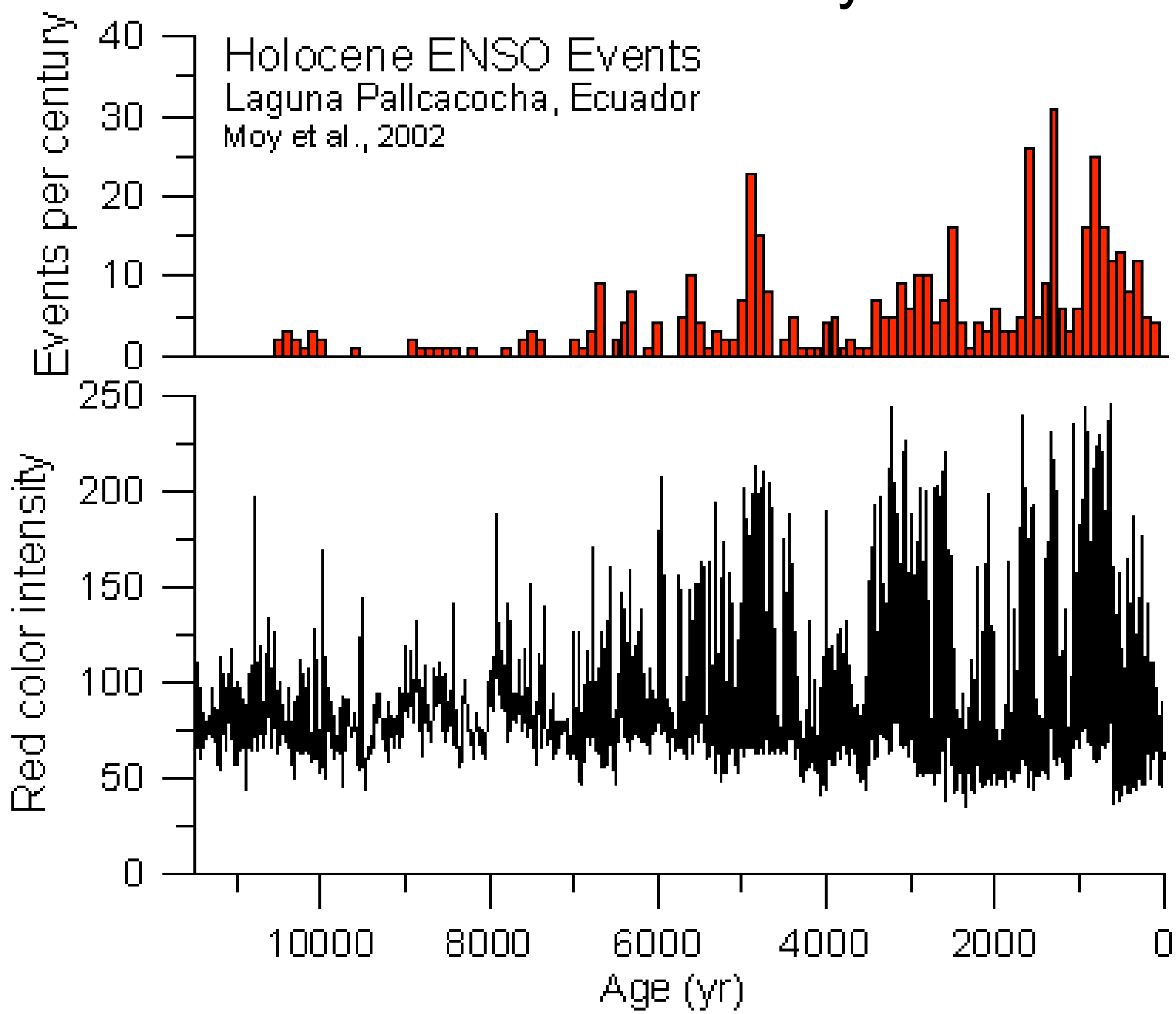
Geochemical ($d^{18}O$ of coral as a paleoproxy for precipitation) analysis of drill cores of fossil Porites corals from Papua New Guinea terraces



Tudhope et al. 2001

ENSO during the last 10,000 years

Moy et al. '03



2000 year cycle of ENSO activity ?

Increase of ENSO variance?

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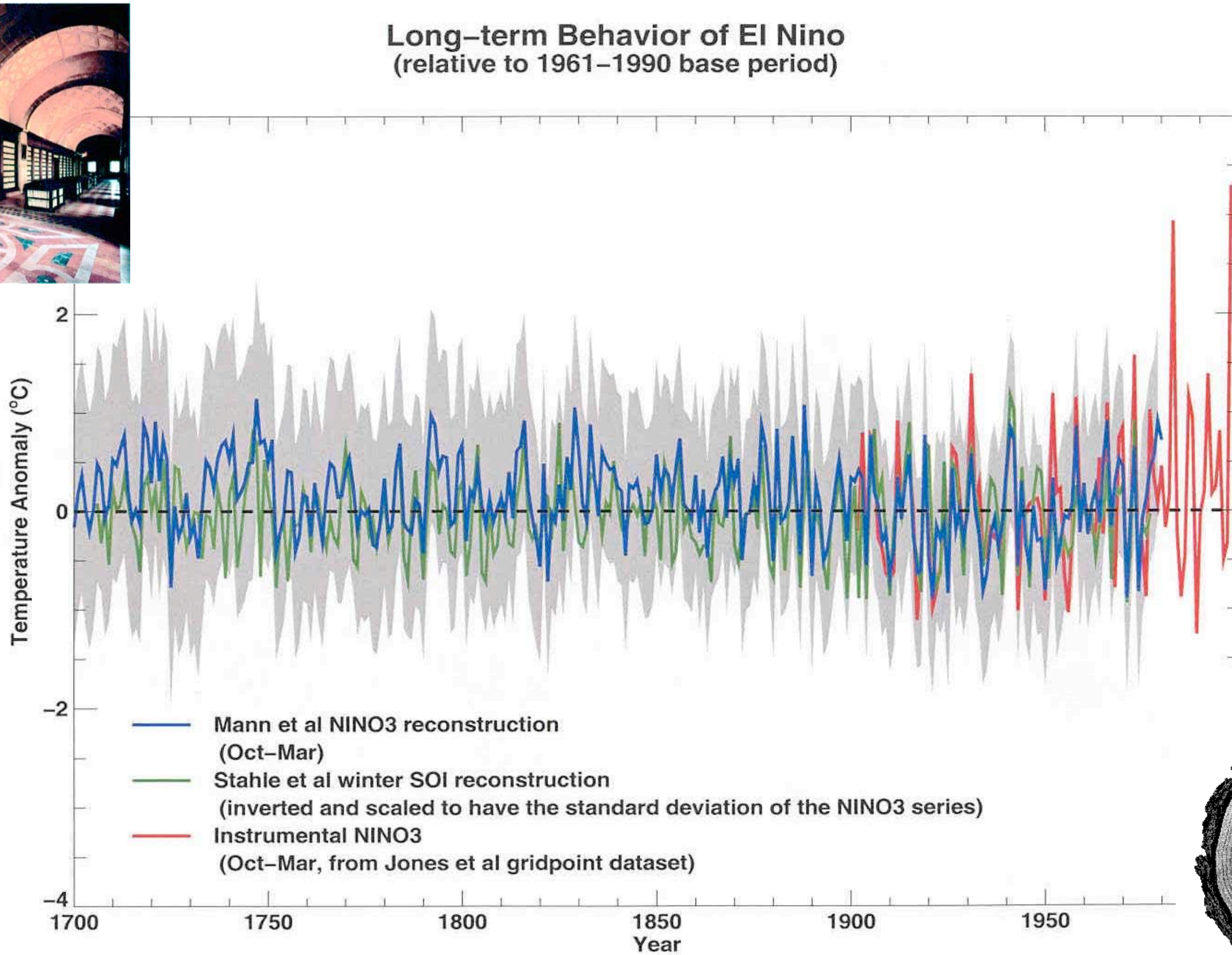
ENSO during the last 400 years



Ian Macadam, 27/9/99.

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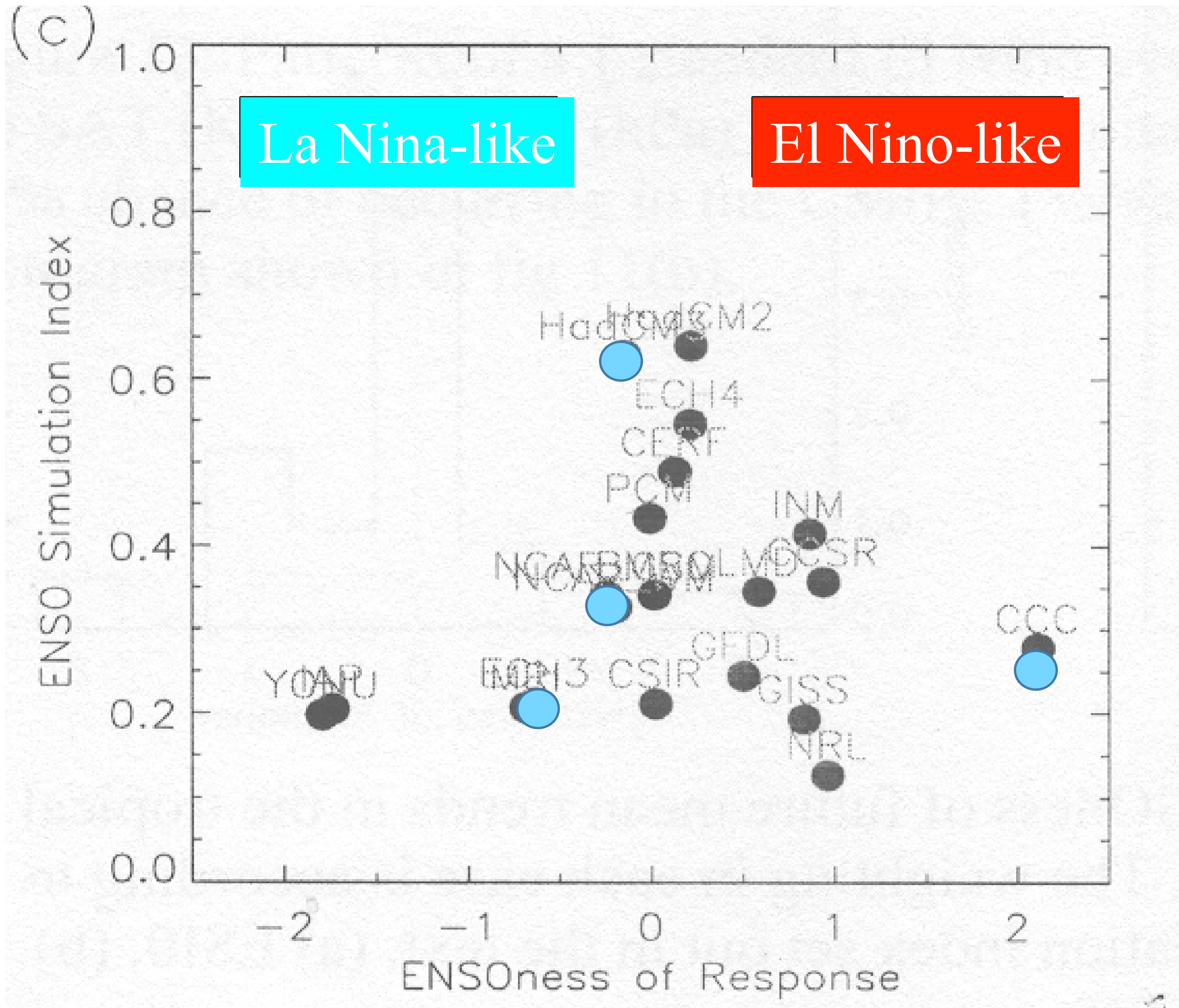
ENSO in the next 100 years?



$2xCO_2$

Collins et al. ‘04

Simulating ENSO during the last glacial maximum (21 ka B.P)

CSM 1.4 climate model (Shin et al. 2003)

- Atmosphere model: spectral model, T31, L18
- Ocean model: primitive equations
- Resolution : ~0.9°x 3.6° Tropics otherwise 1.8x3.6°, L25
- Sea-ice model: thermodynamic-dynamic
- Land model: Dynamic vegetation, Hydrology

Glacial boundary conditions

- Glacial greenhouse gas concentration
- Glacial land albedo
- Glacial topography
- Glacial land-sea distribution

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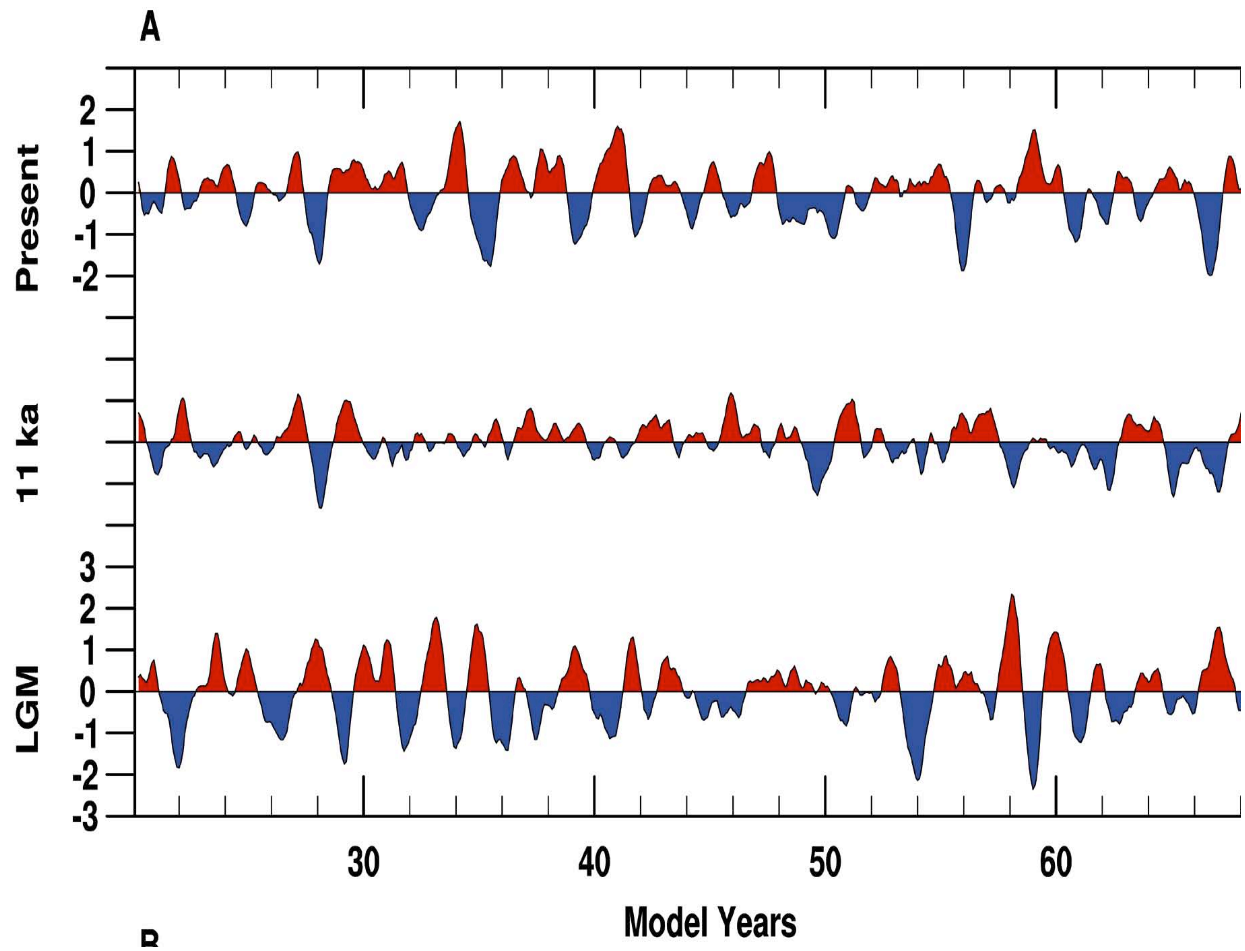
Simulating ENSO during the last glacial maximum (21 ka B.P)

CGCM:Enhanced LGM ENSO variability, weaker east-west teleconnections



Otto-Bliesner 2003

Understanding ENSO during the last glacial maximum (21 ka B.P)

Zebiak-Cane ENSO Anomaly Model

- Atmosphere model:Gill-1982
- Ocean model:1 _ layer reduced gravity β-Model
- Uses fixed climatology
- No extratropical processes

Linearised Zebiak-Cane ENSO Model

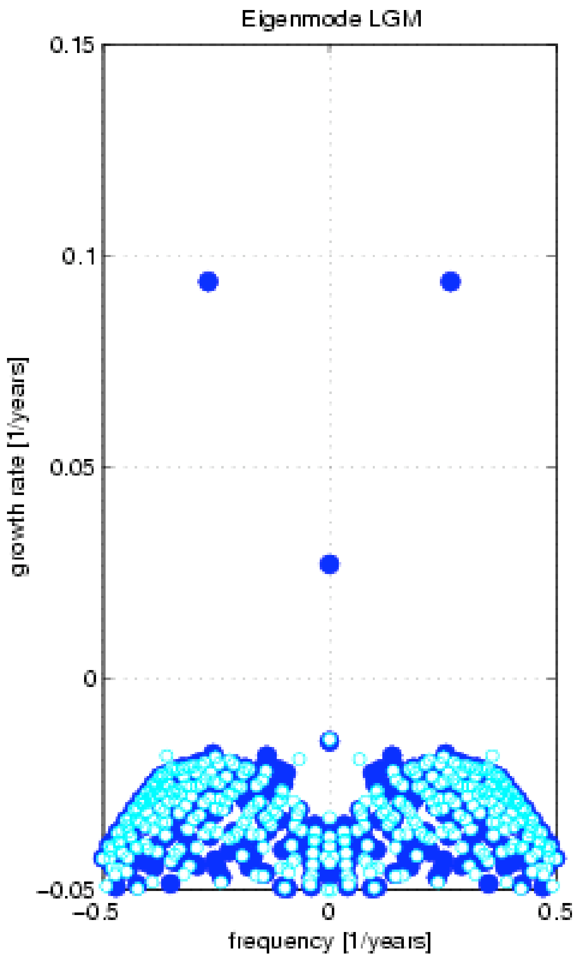
$dX/dt=f(X)$
$X=X_b+x$
$dx/dt= Ax + \text{Residuum}$

A is determined empirically for given climatology

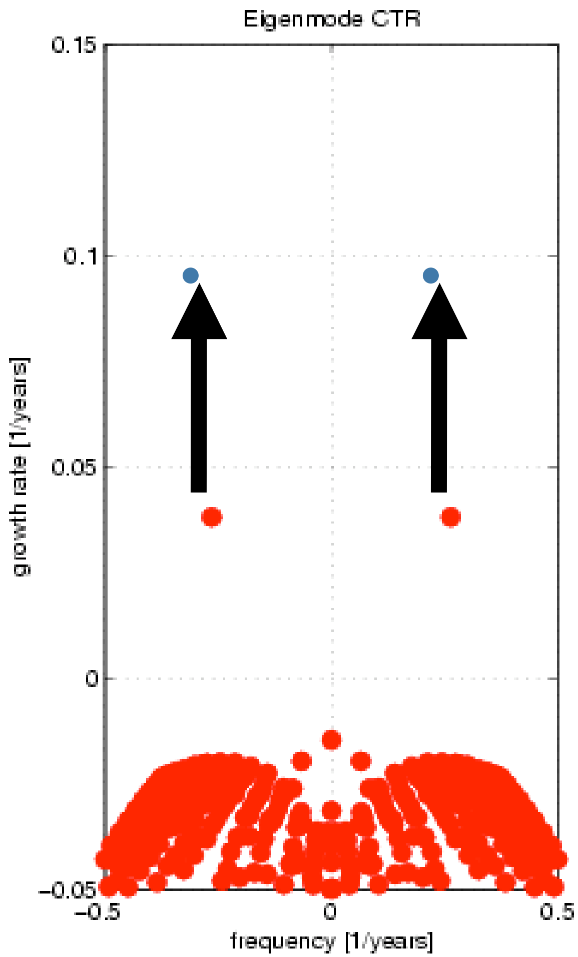
Understanding ENSO during the last glacial maximum (21 ka B.P)

ENSO enhancement due to thermocline shoaling and anomalous meridional SST gradients

LGM



Present-day



An and Timmermann et al. 2004

Enhanced LGM ENSO variability

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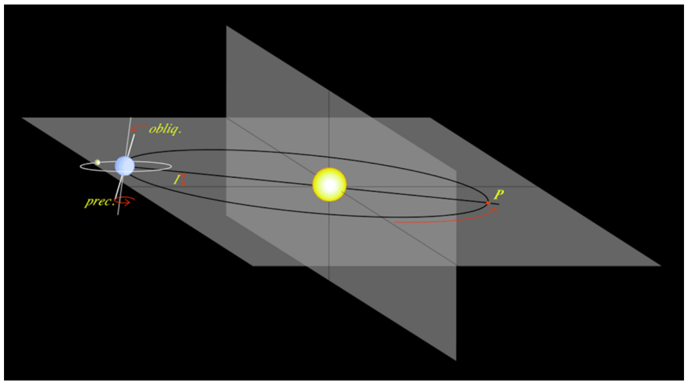
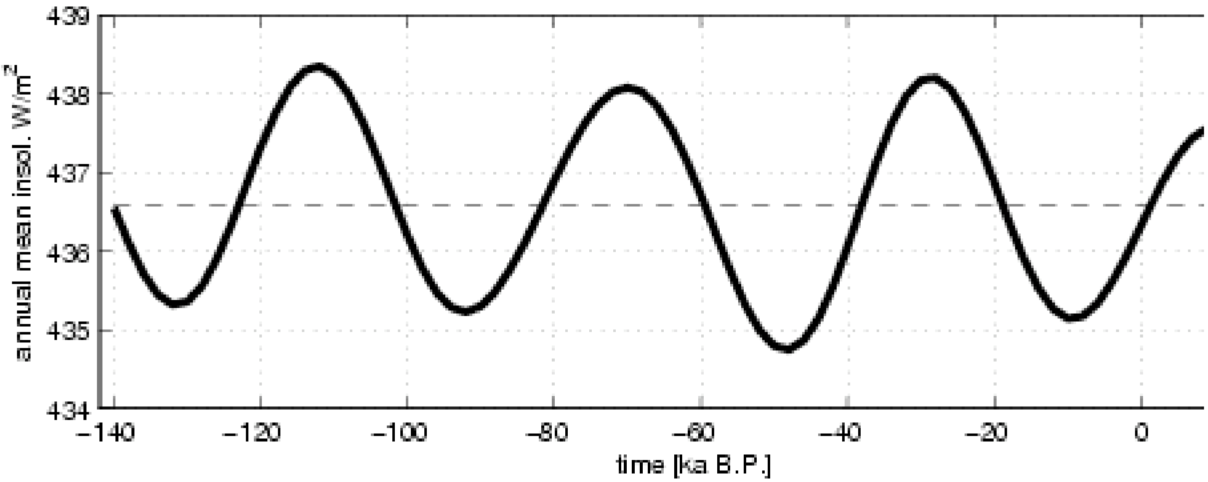
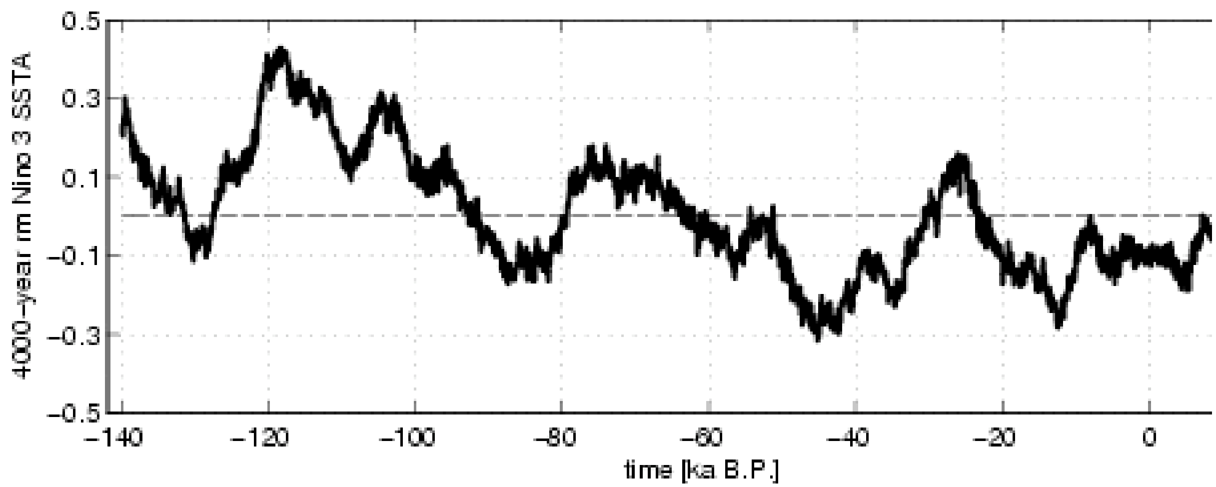
Orbital Pacemaking of ENSO: mean state changes

ECHO-G simulation 165,000 years, orbital accerlation x100





Equatorial annual mean temperature variations driven by obliquity



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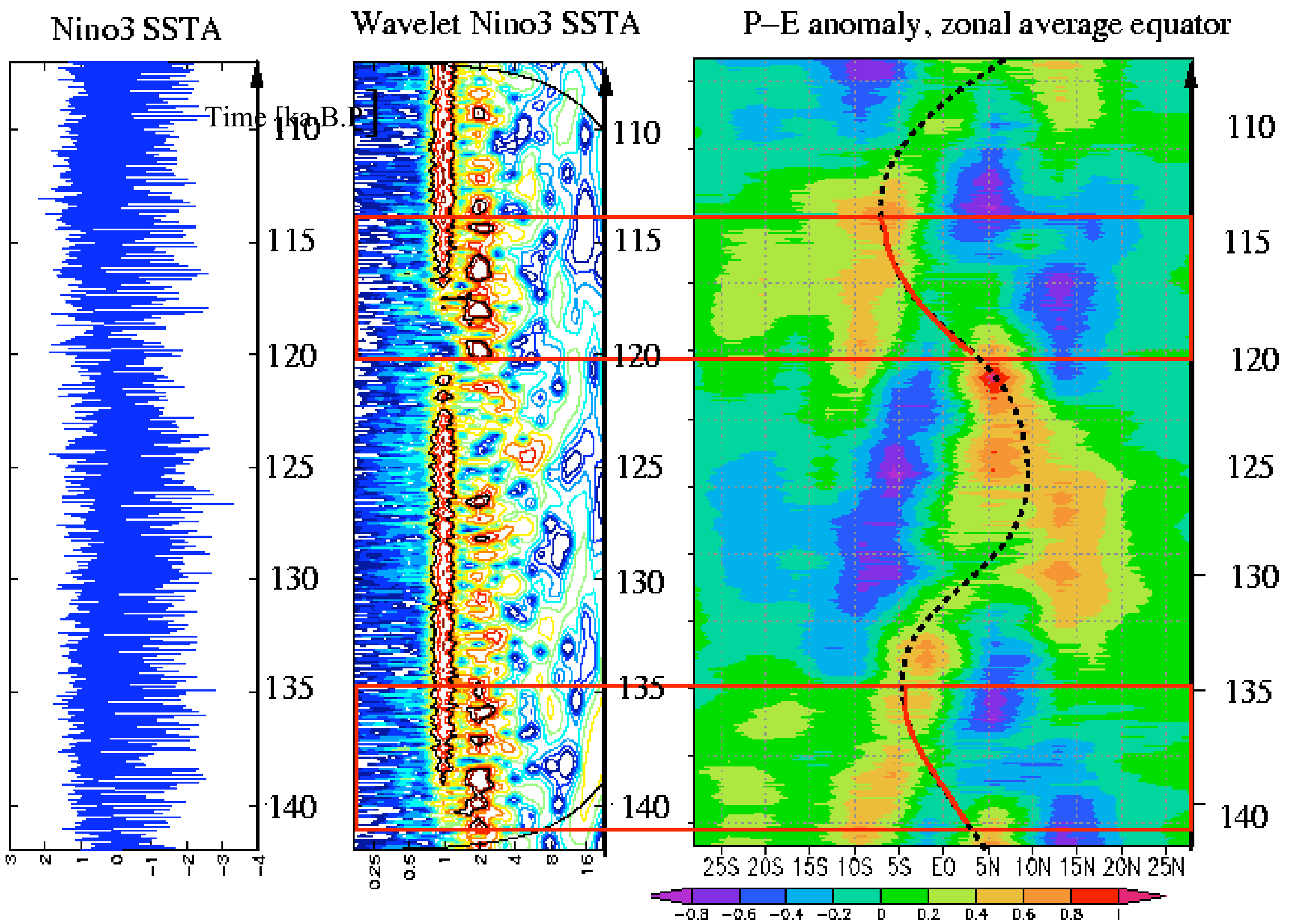
Timmermann et al. 2005, to be submitted

Orbital Pacemaking of ENSO: ENSO modulation

ENSO strong
=>
annual cycle weak
abrupt changes



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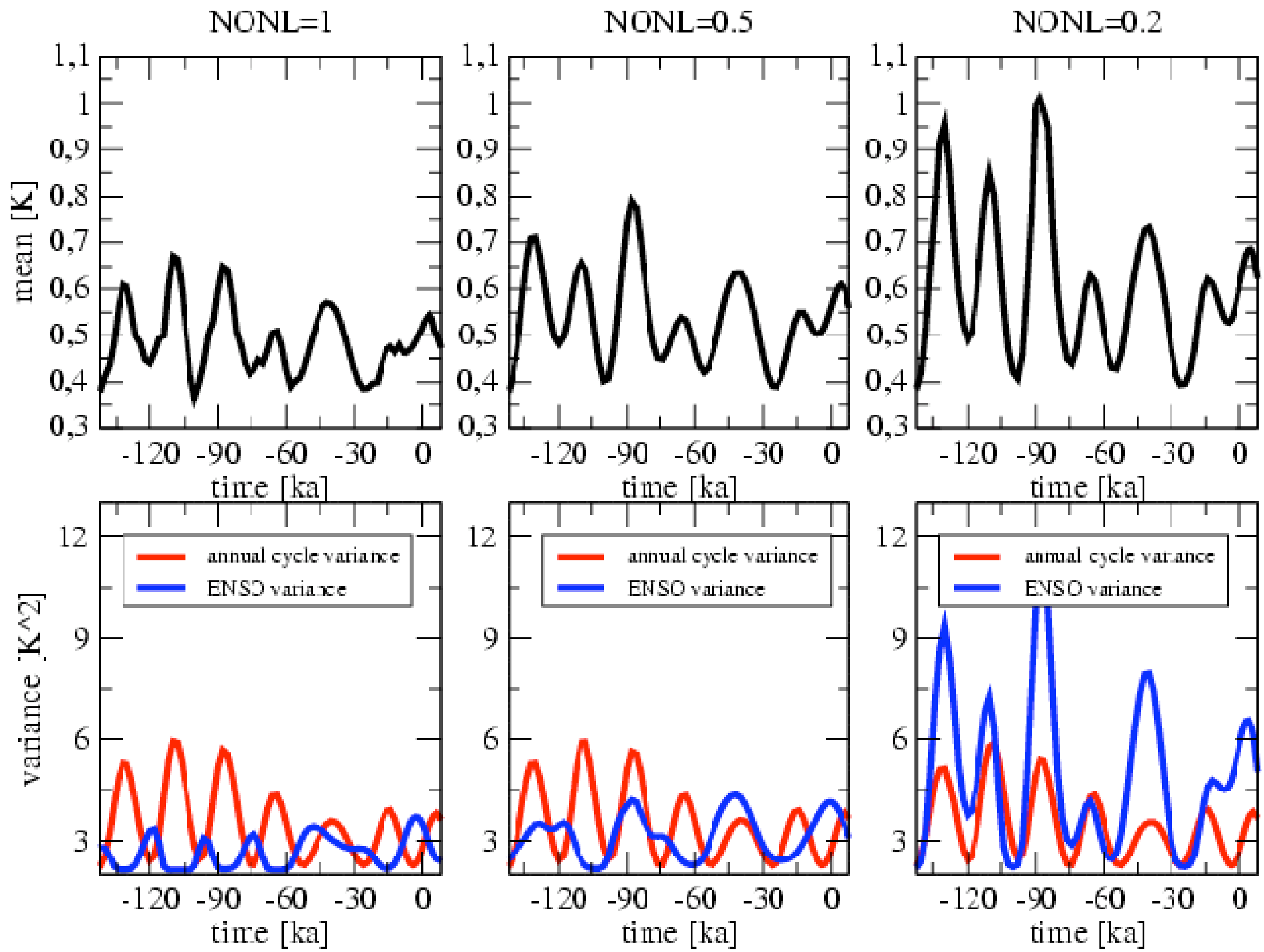
Orbital pacemaking of ENSO: Nonlinearities

Simplified tropical model 165,000 years



Orbital pacemaking depends on oceanic stratification

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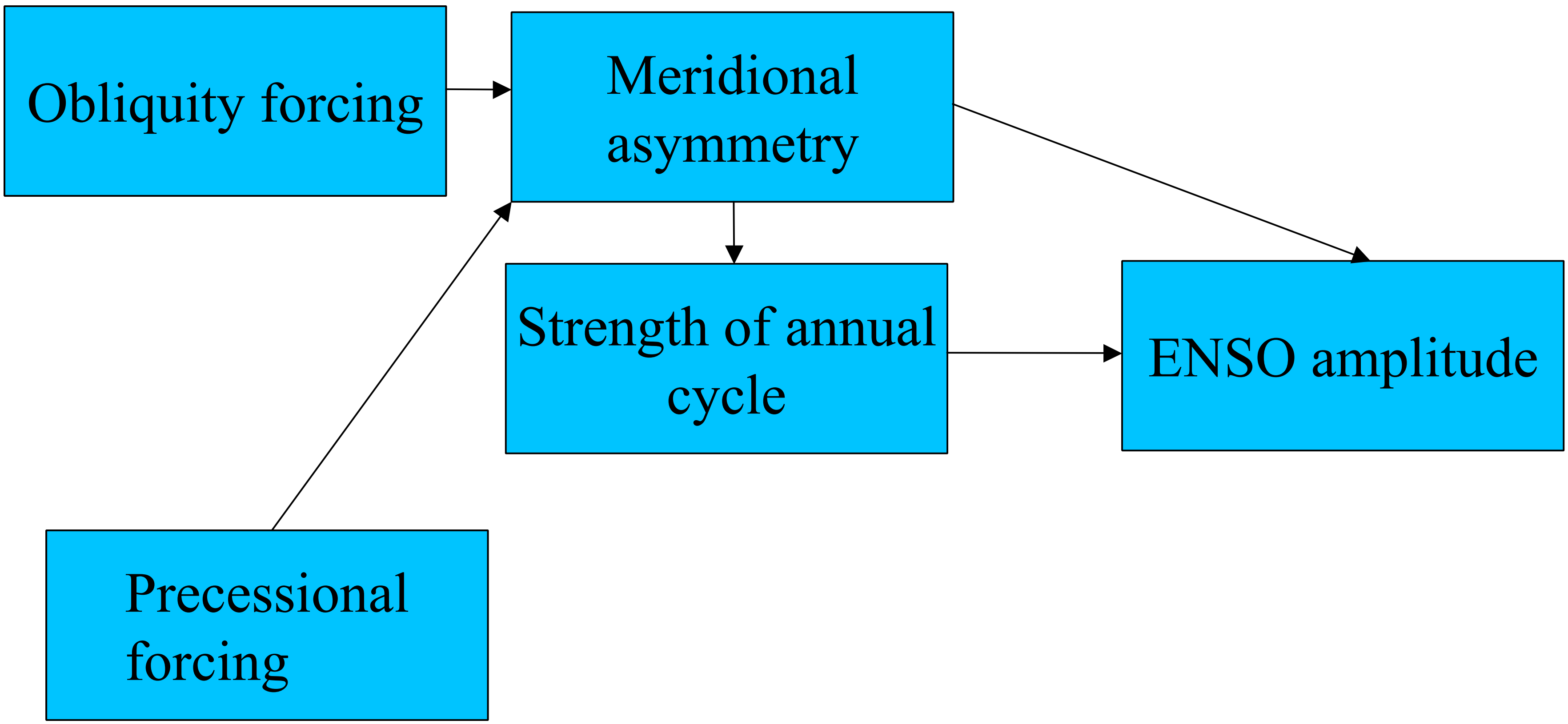
Orbital pacemaking of ENSO: strawman



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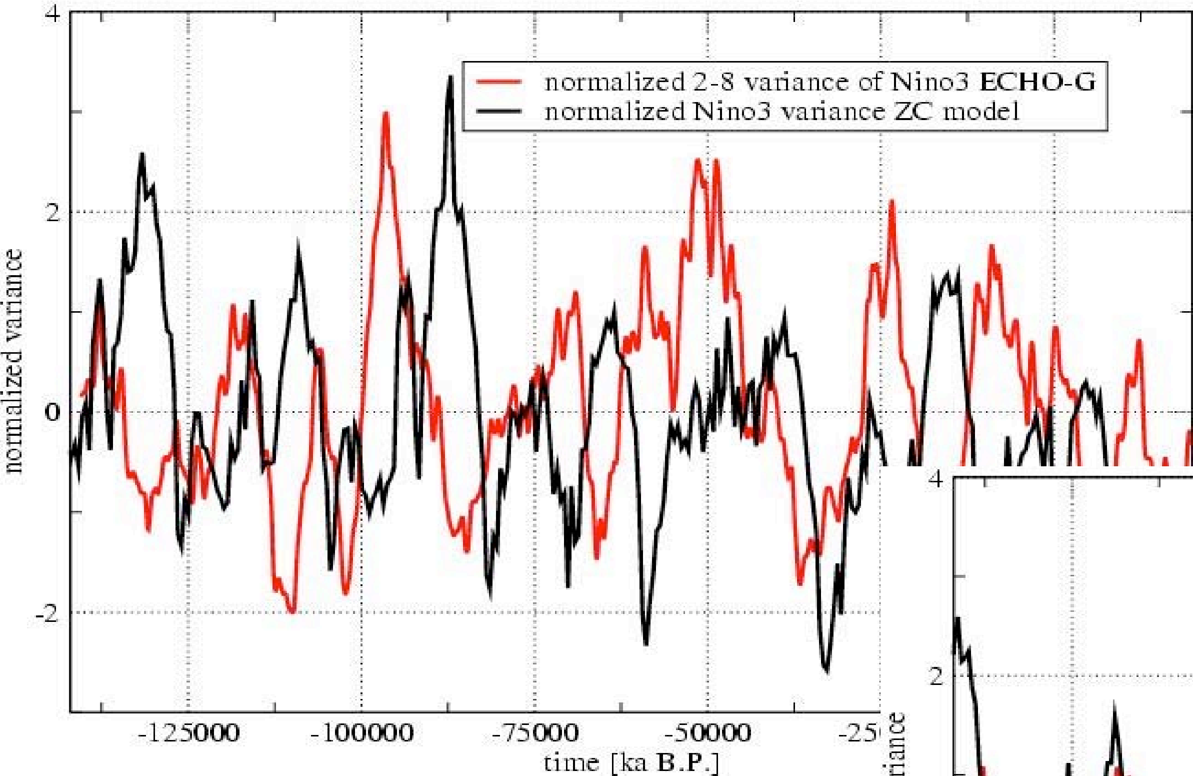
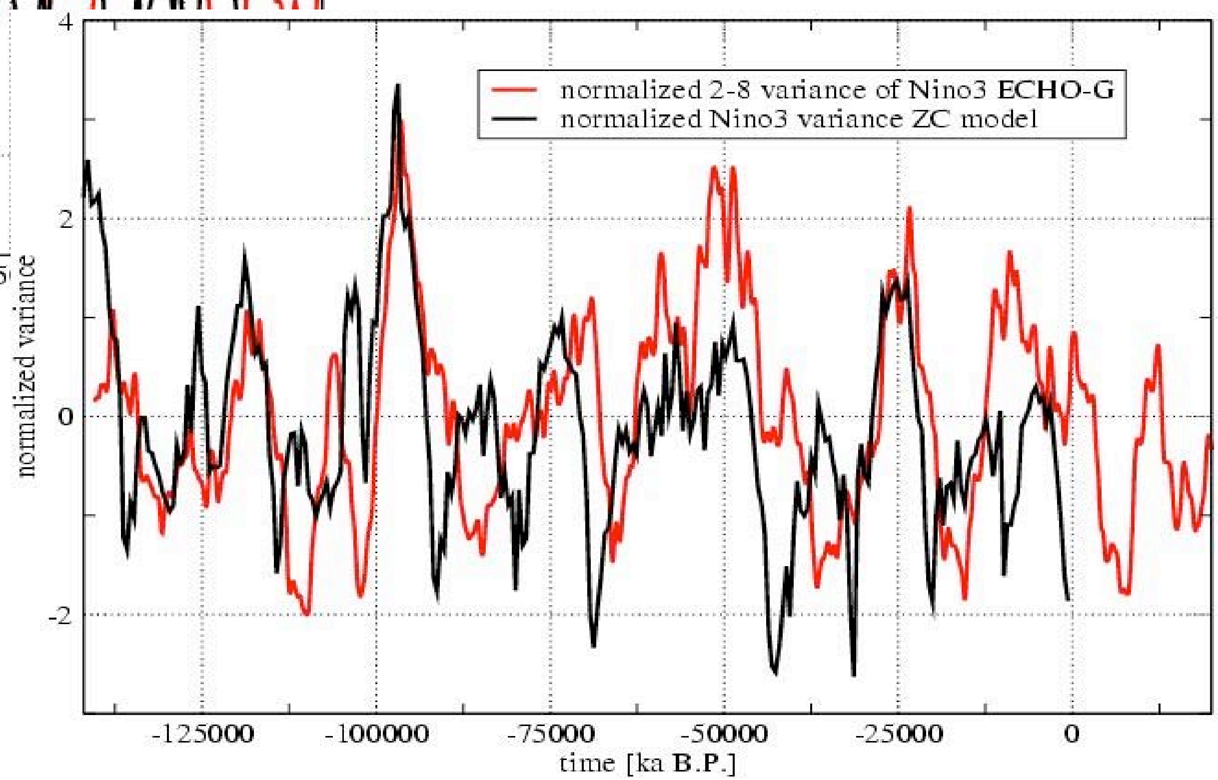
Orbital pacemaking of ENSO: robustness





Comparison with
Amy Clement's results

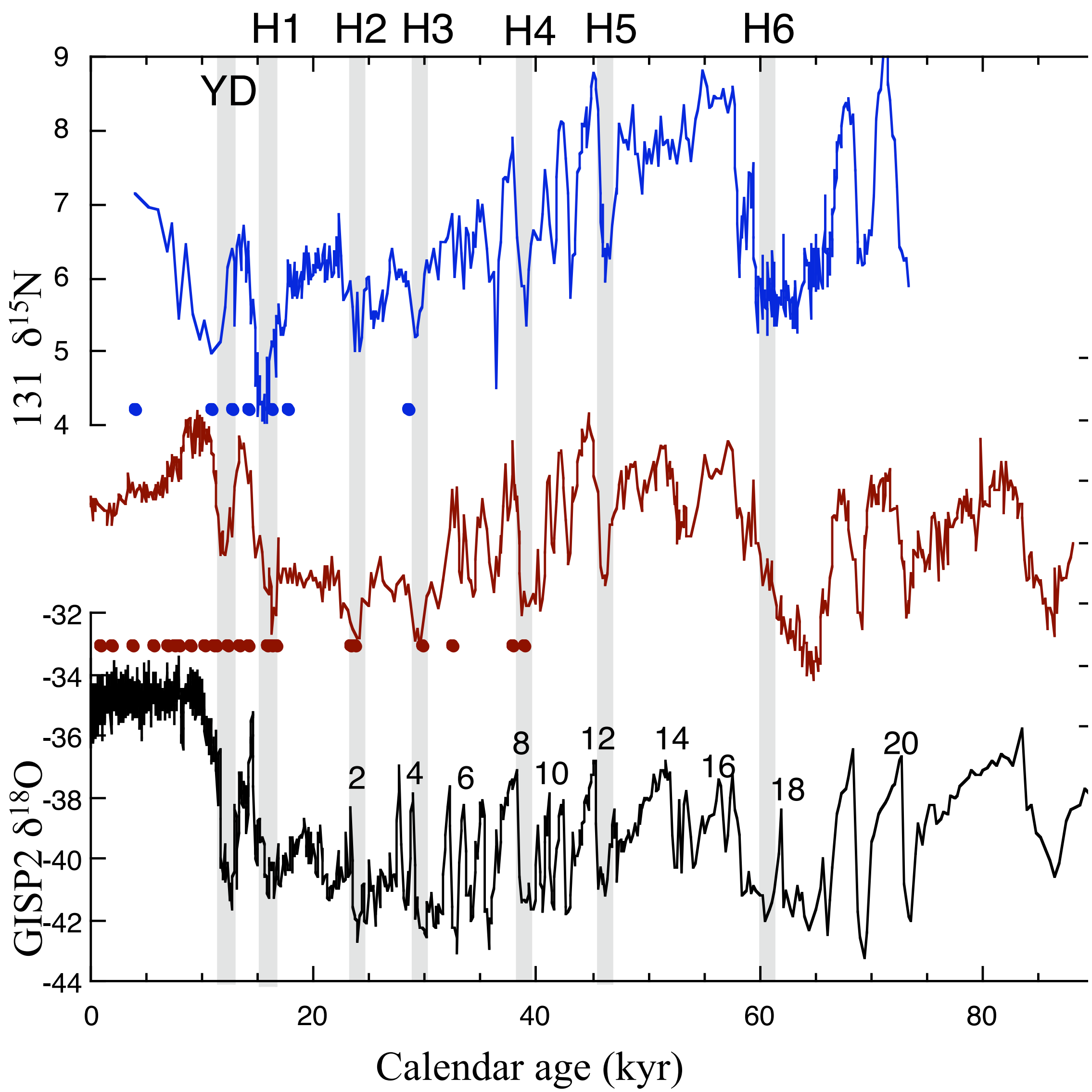
"Abrupt" millennial-scale changes in the tropics: Indian ocean

Ivanochko et al. 2005 EPSL

Arabian Sea

Somalia Basin

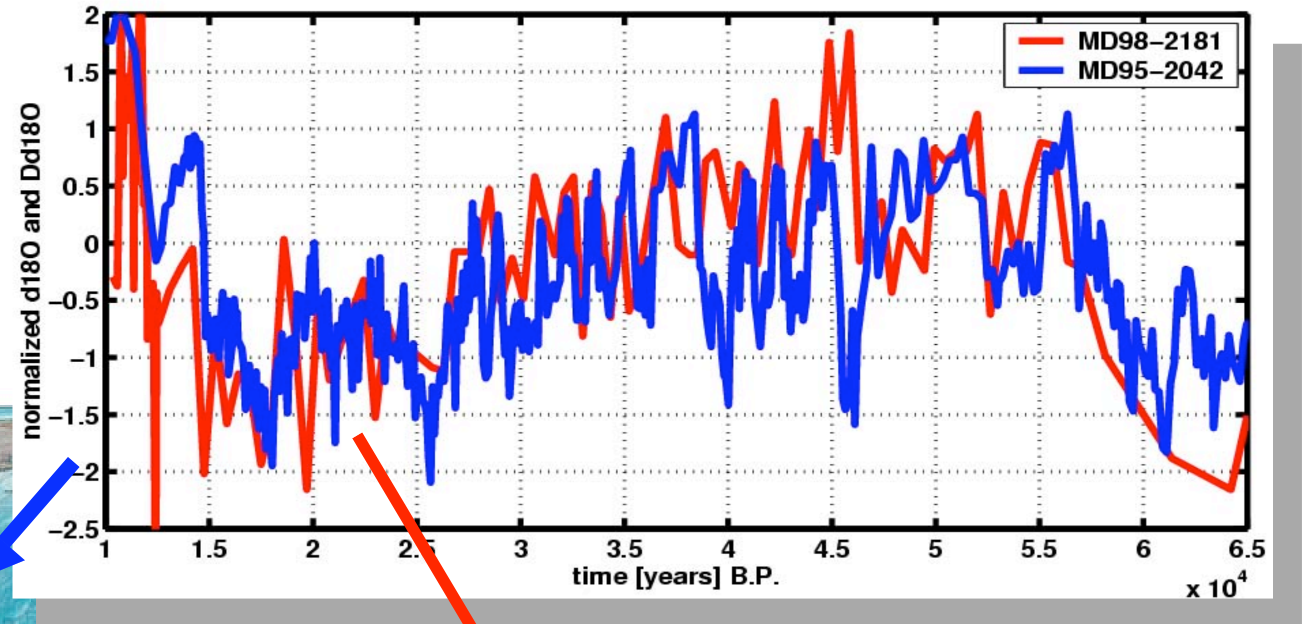
Greenland

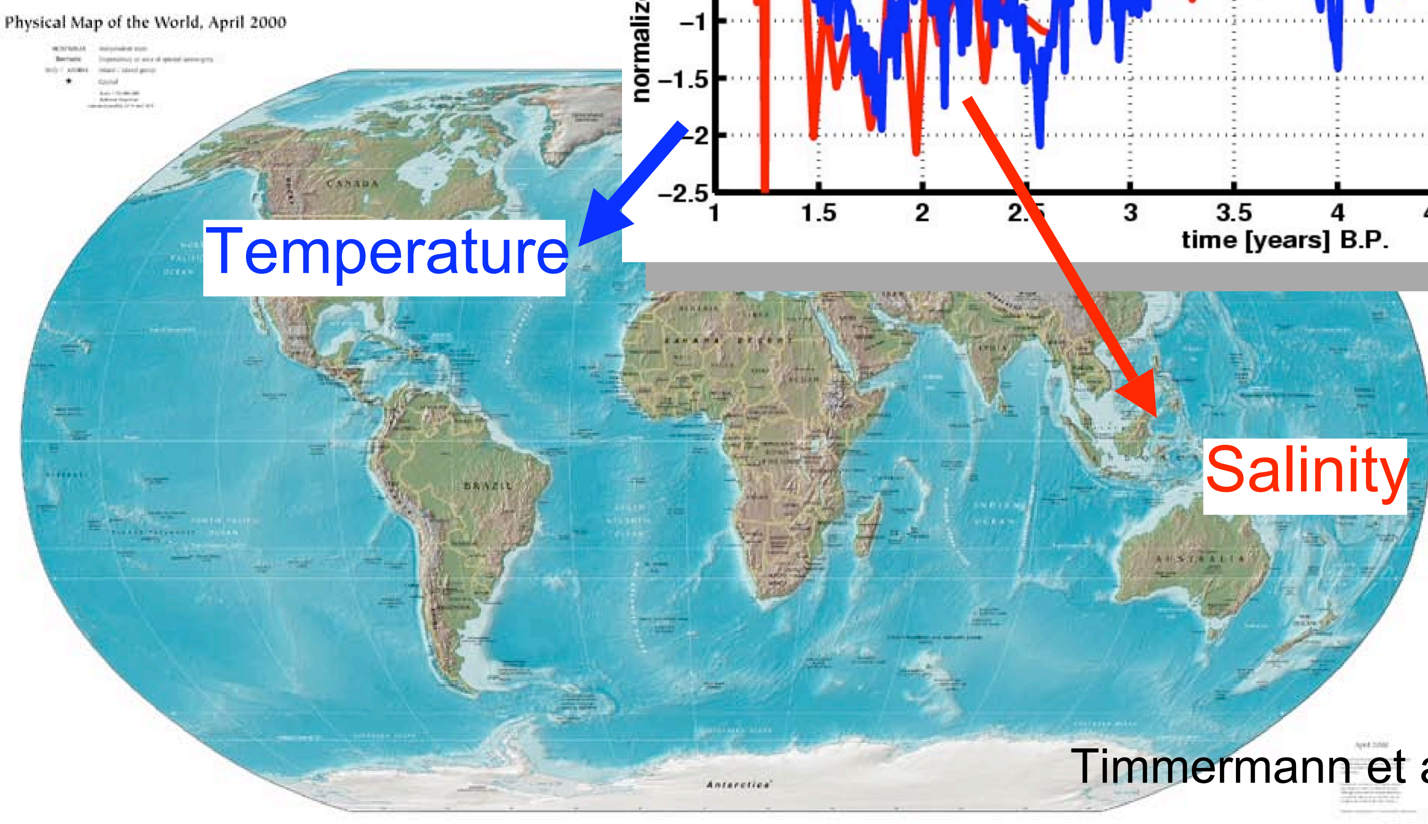


Timmermann et al. 2005 Paleoceanography, in press

“Abrupt” millennial-scale changes in the tropics: Pacific ocean

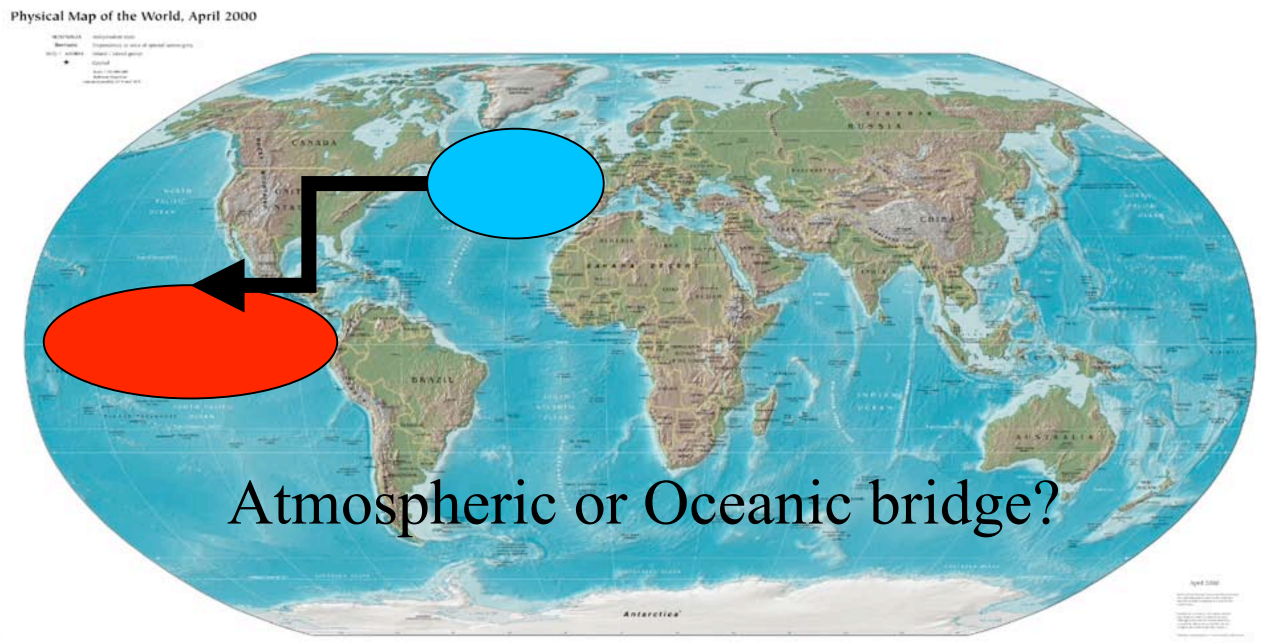
Data from Stott et al. 2003

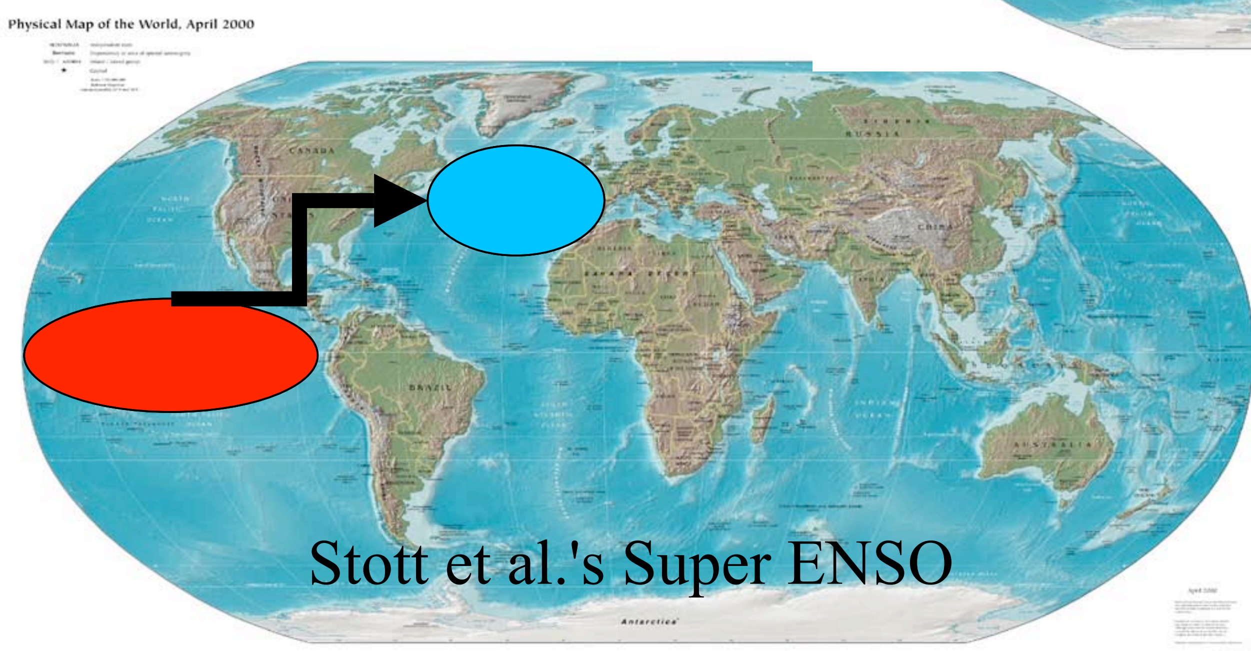




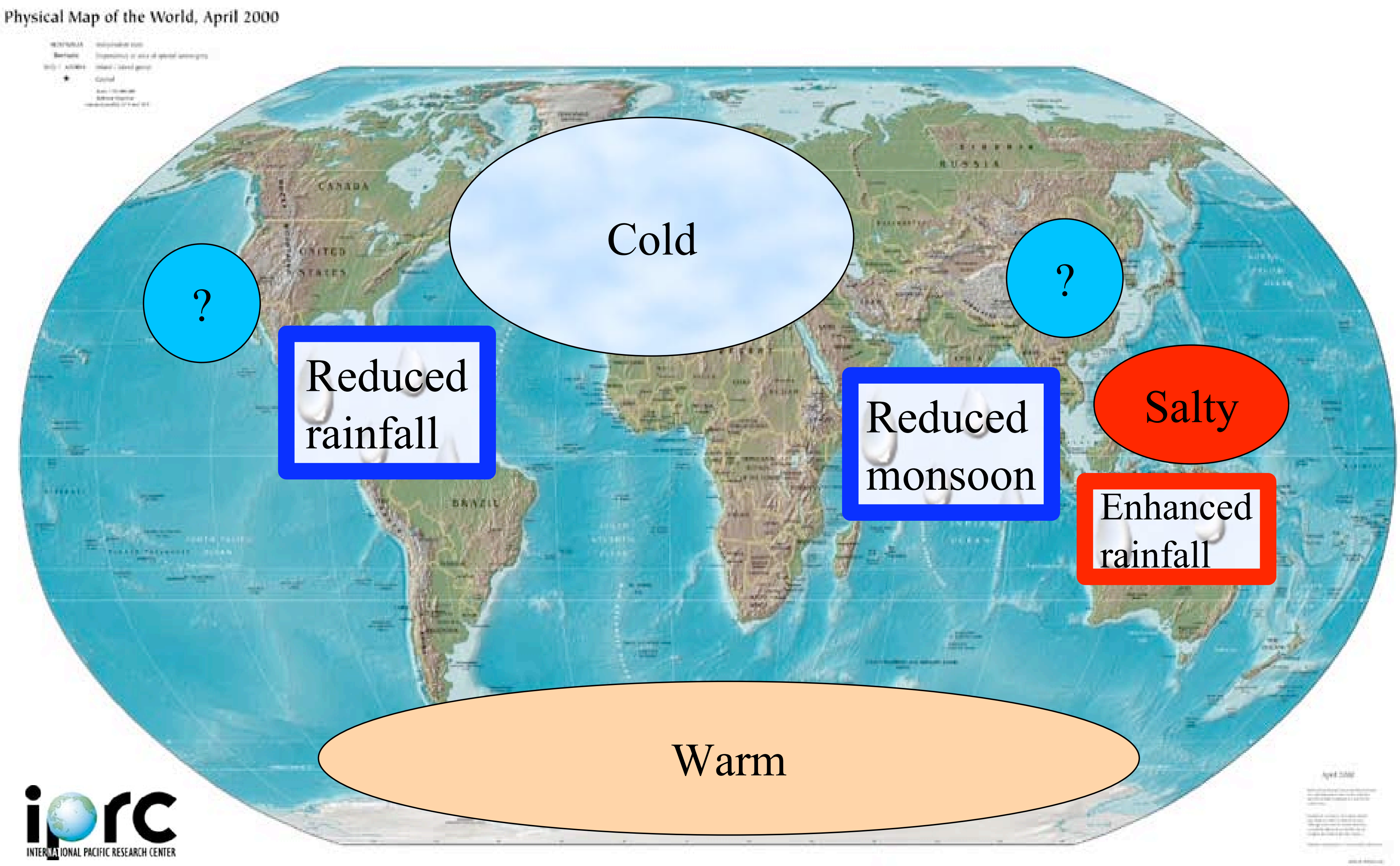
Timmermann et al., Paleoceanography 2005

Tropical variations: Cause or effect ?





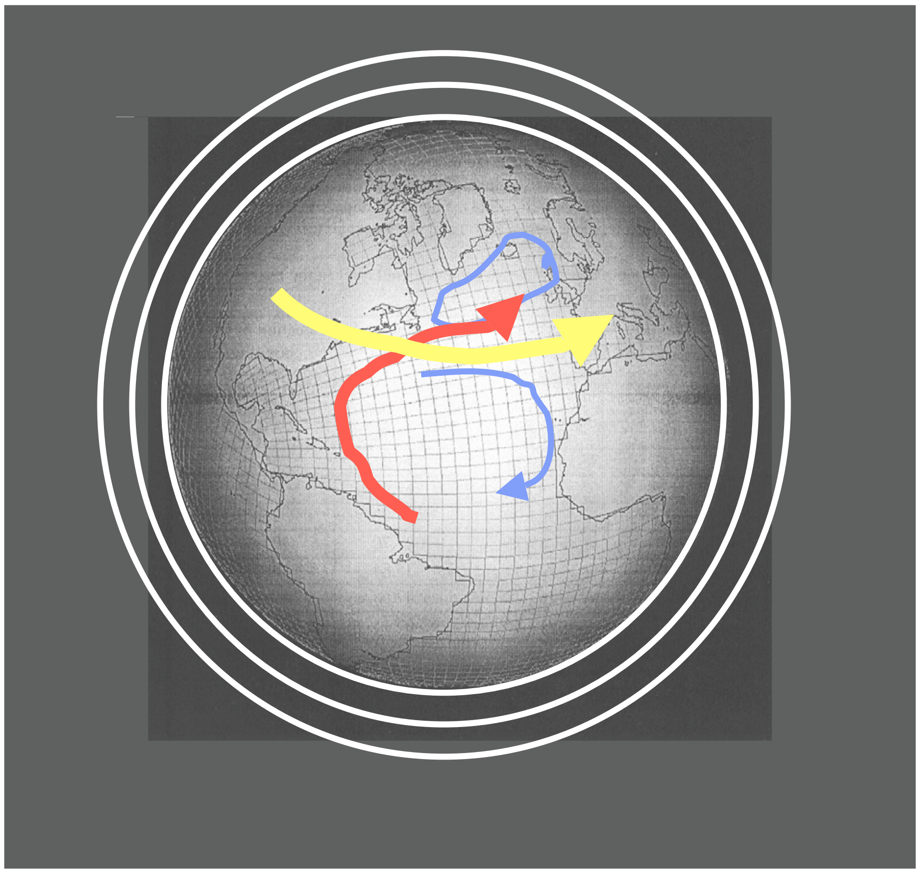
Global impacts of Heinrich events

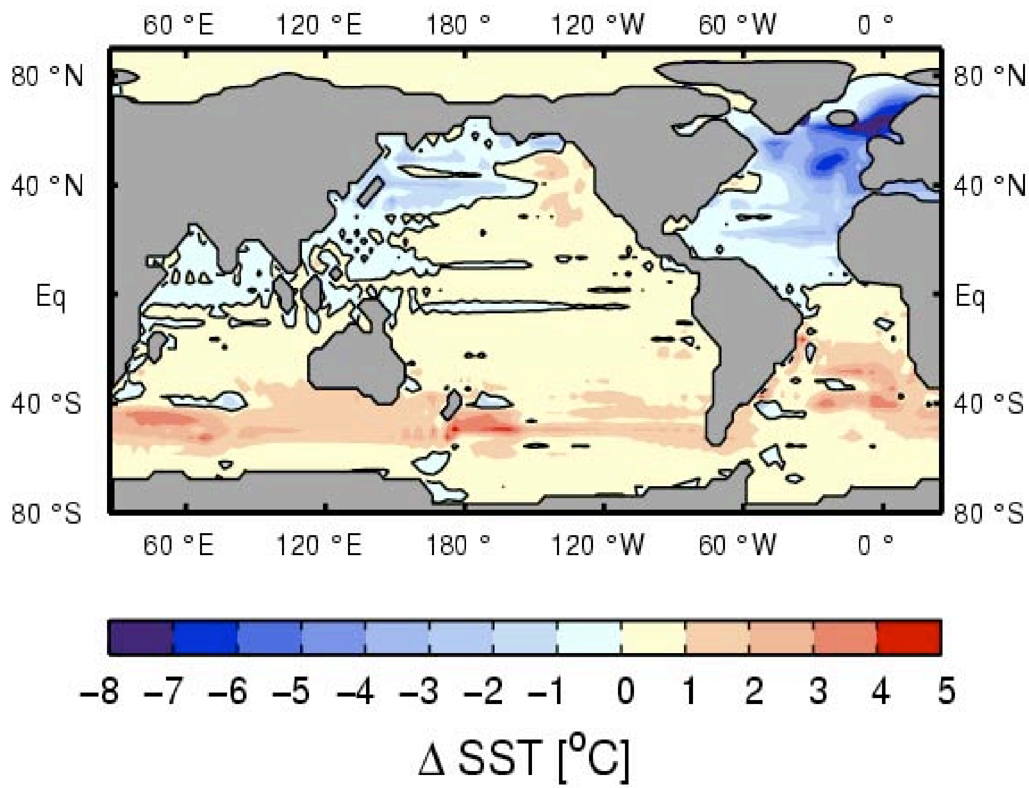


Simulating Global impacts of Heinrich events using ECBilt-Clio

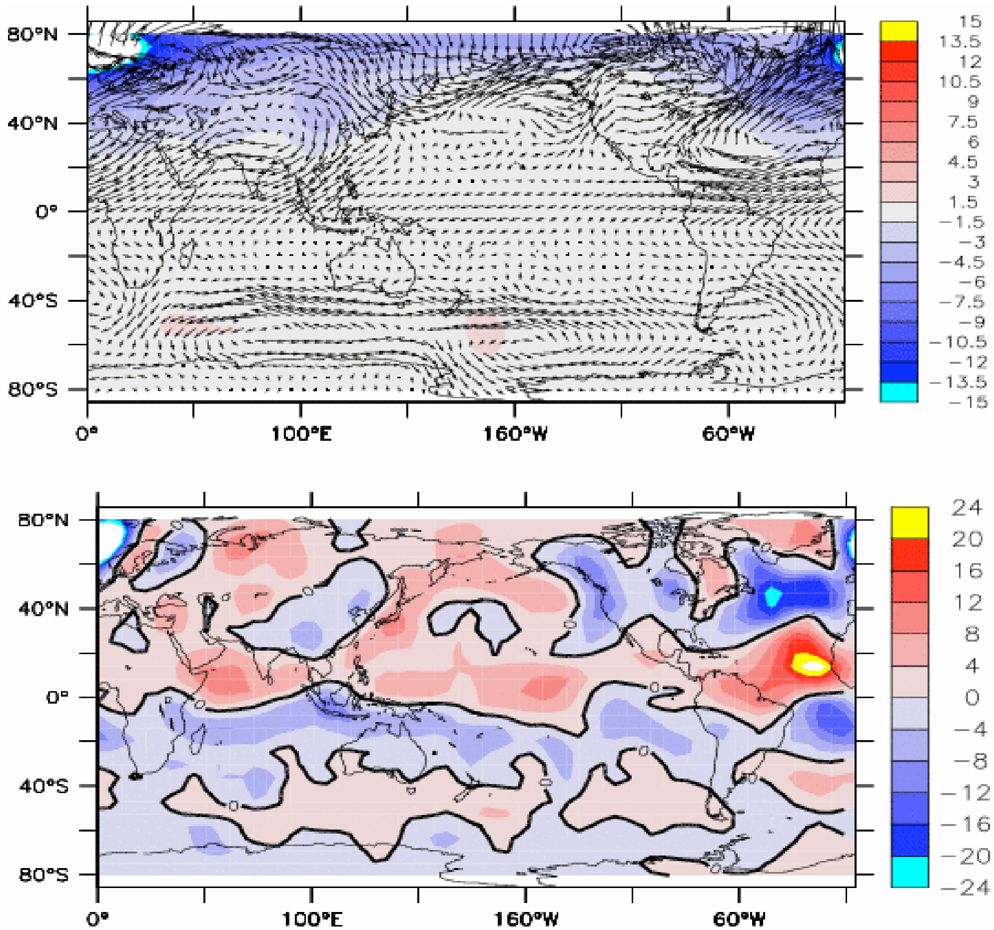
ECBilt: Quasigeostrophic 3 layer atmosphere,
T21 + physical parameterizations

CLIO: Primitive equation ocean, 20 layer, 3x3 degree resolution
viscous-elastic and thermodynamical seaice model

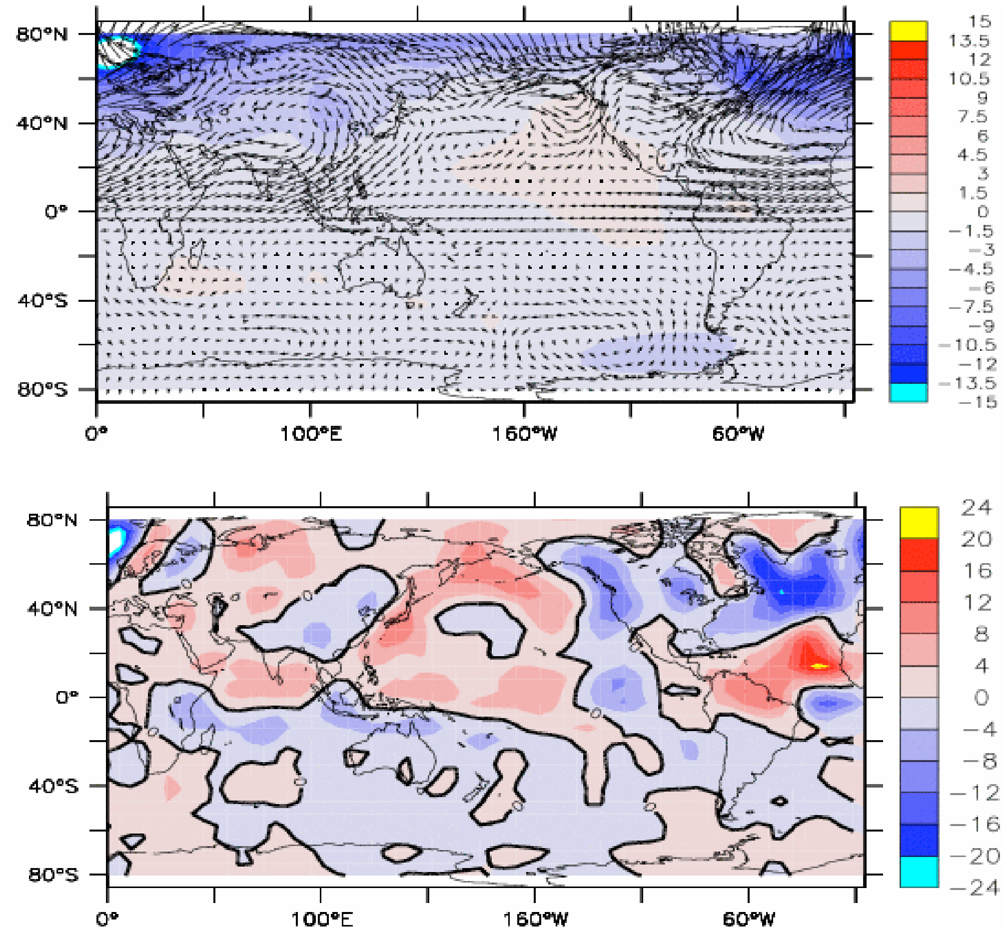




Atmospheric connections



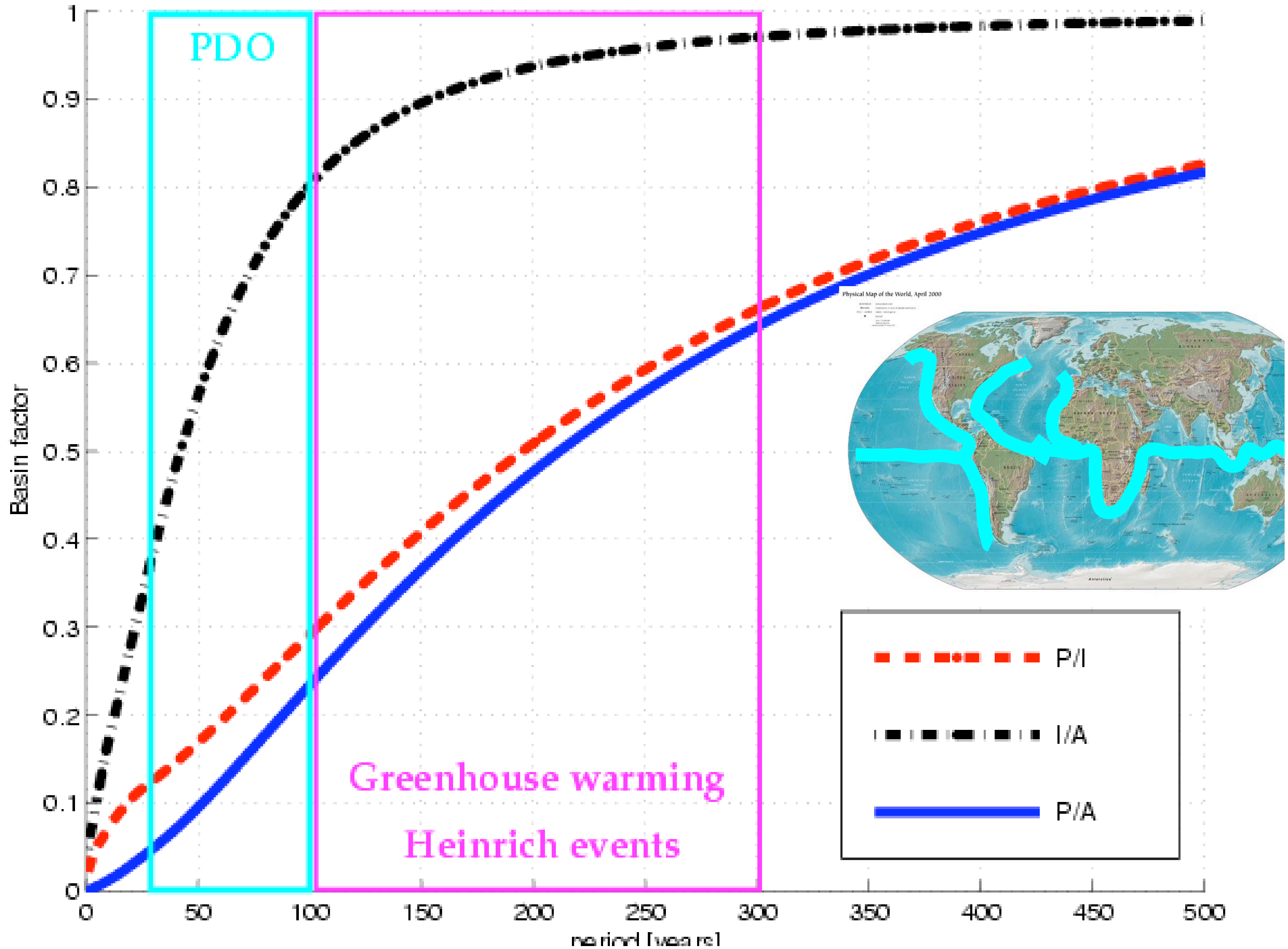
Response of wind and E-P
on Heinrich event
Timmermann et al, Paleoceanography 2005



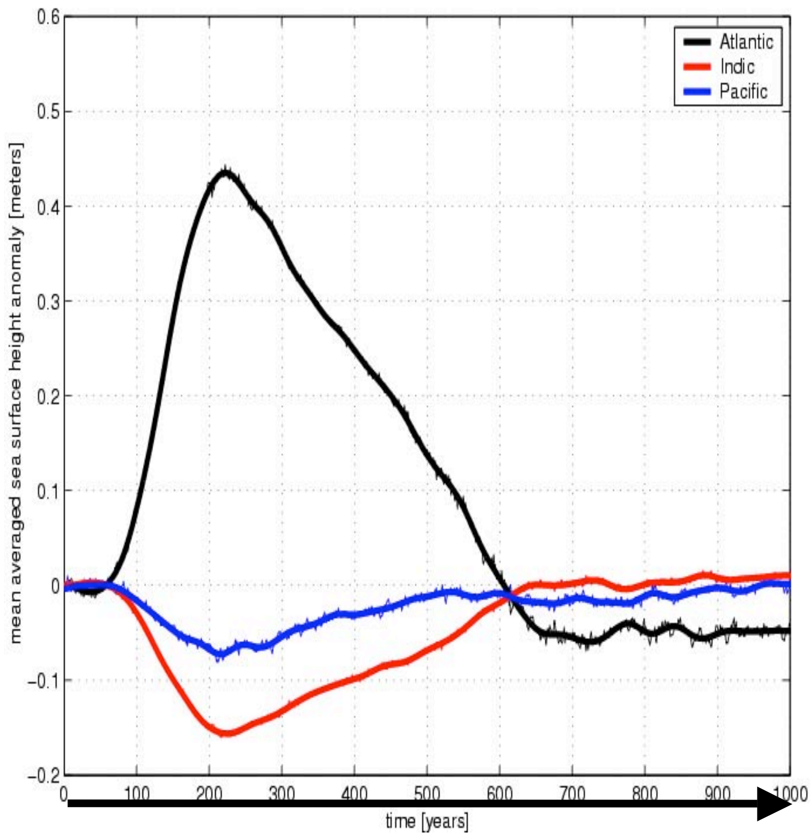
Response of wind and E-P
on Heinrich event, coupling only
North Atlantic

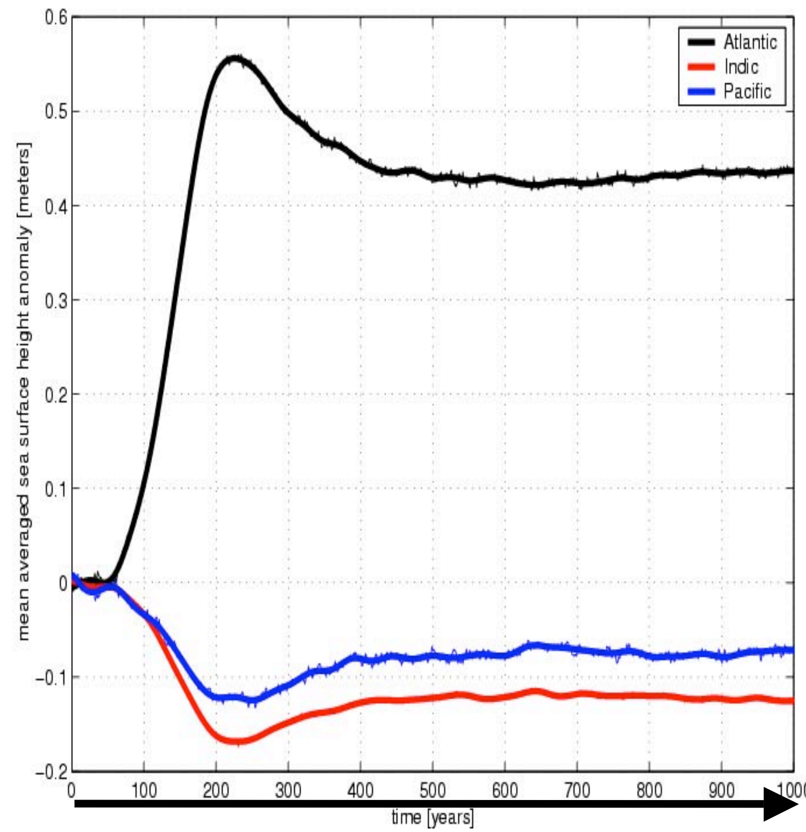
Oceanic teleconnections

Timmermann et al, Paleoceanography 2005



Oceanic connections

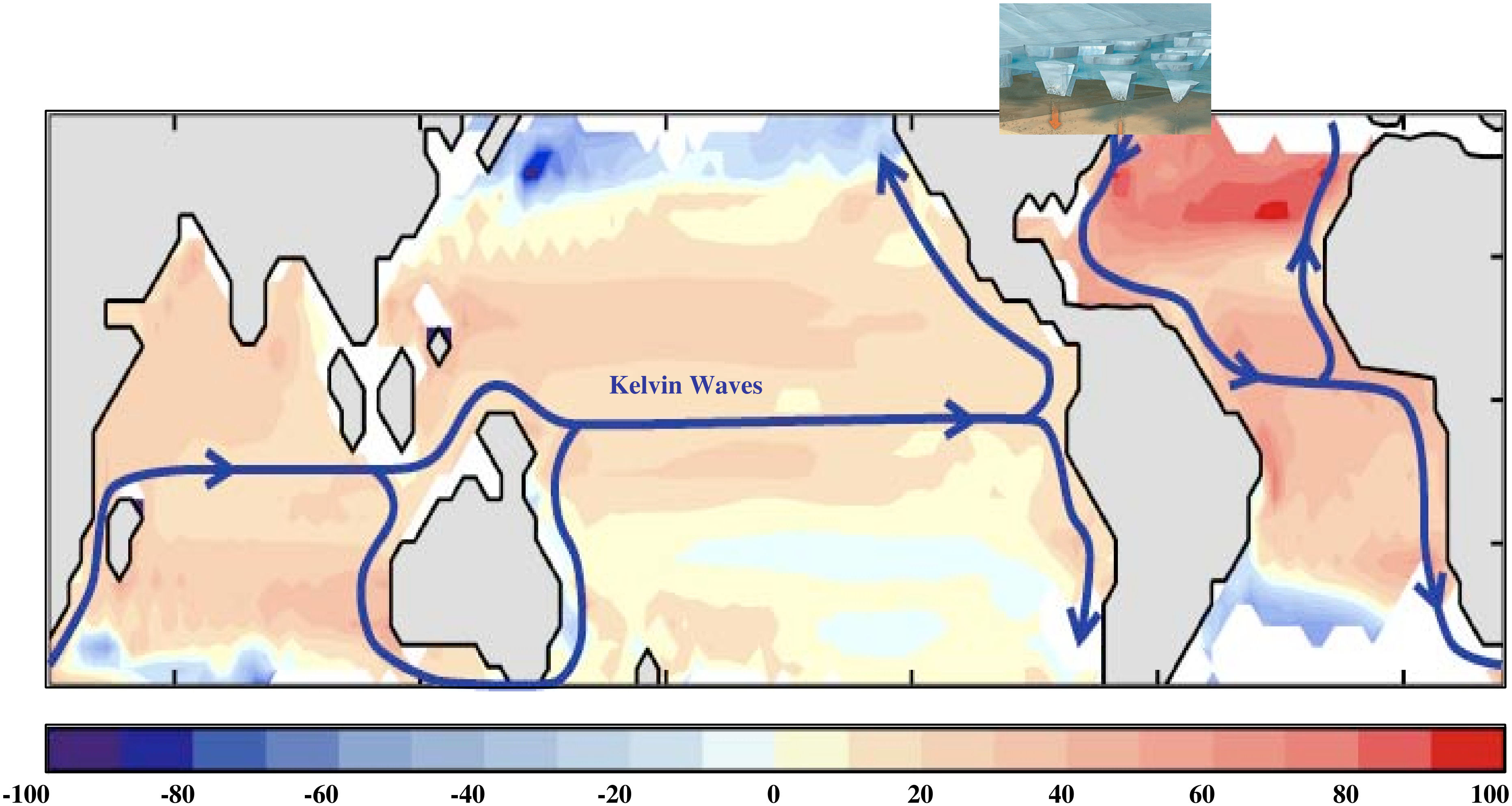




Global forced seiches in coupled model:
-hardly any hysteresis
-atmosphere provides important feedbacks
- sea level gradients drive currents

Global forced seiches in uncoupled model:
-THC does not recover
-new equilibrium state
-important negative feedbacks missing

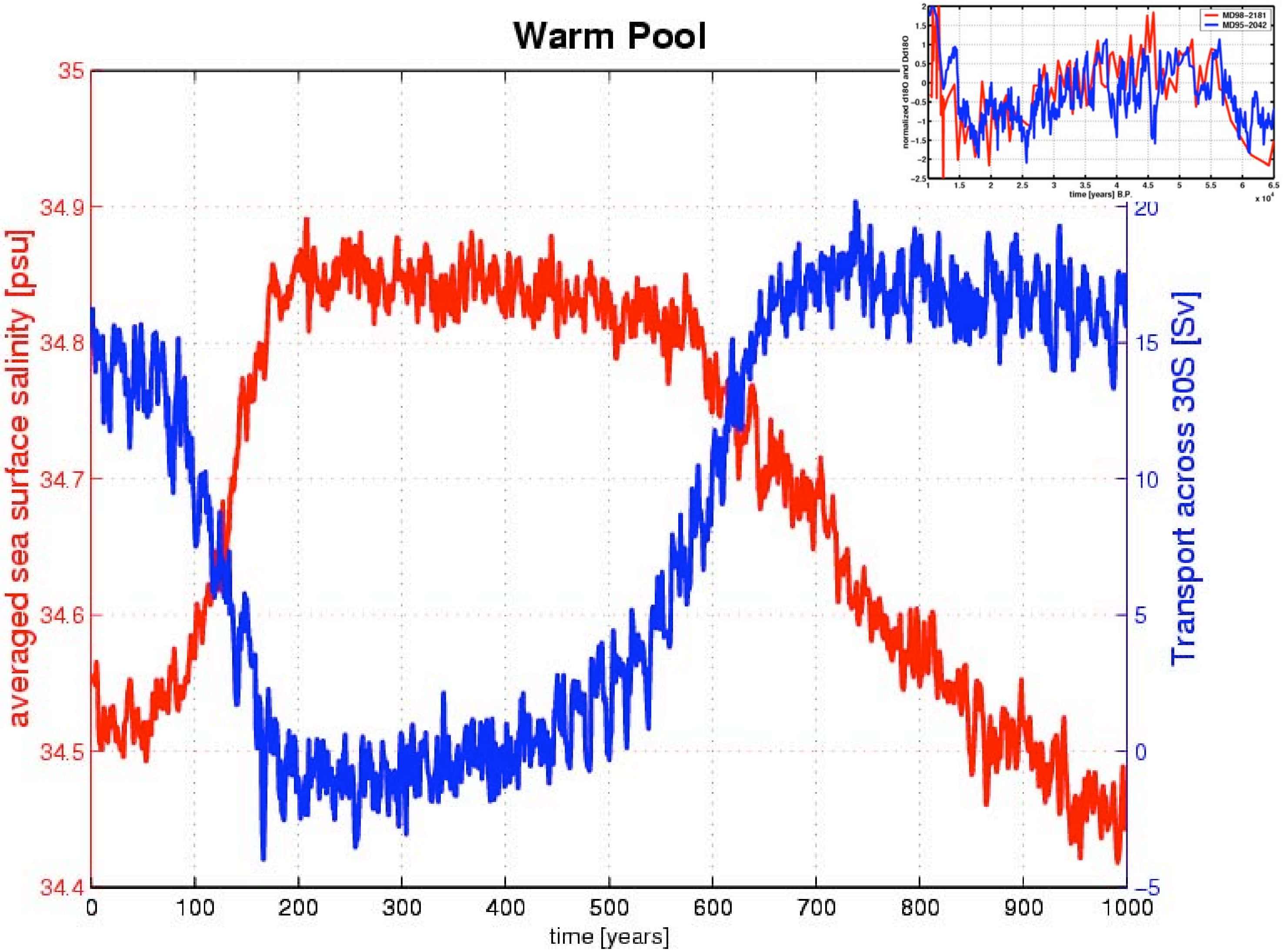
Oceanic connections



Change in thermocline depth $\Delta h_{\sigma=26}$ (m)

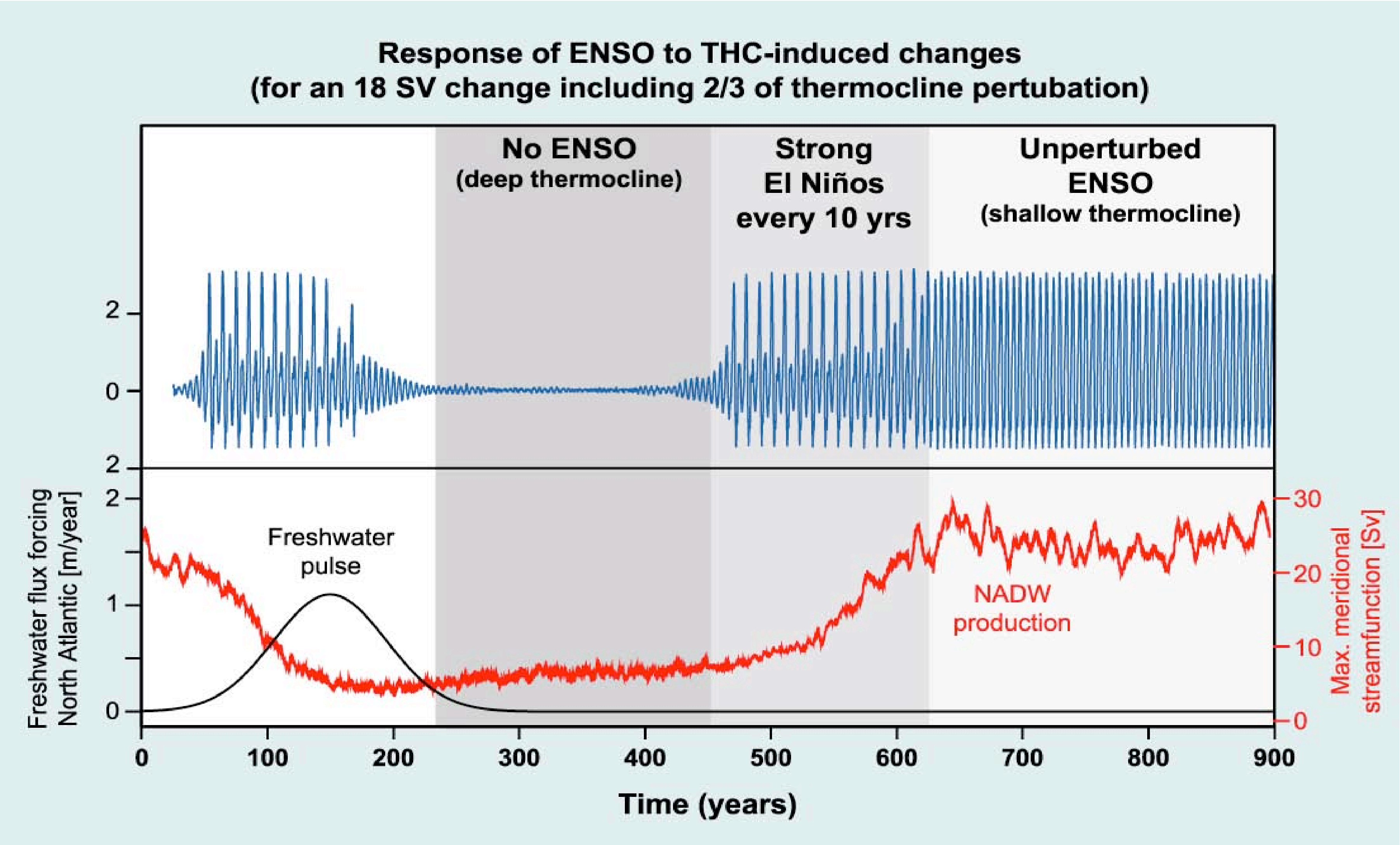
Timmermann et al, Paleoceanography 2005

Oceanic connections



Timmermann et al, Paleoceanography 2005

Collapse of ENSO during Heinrich events



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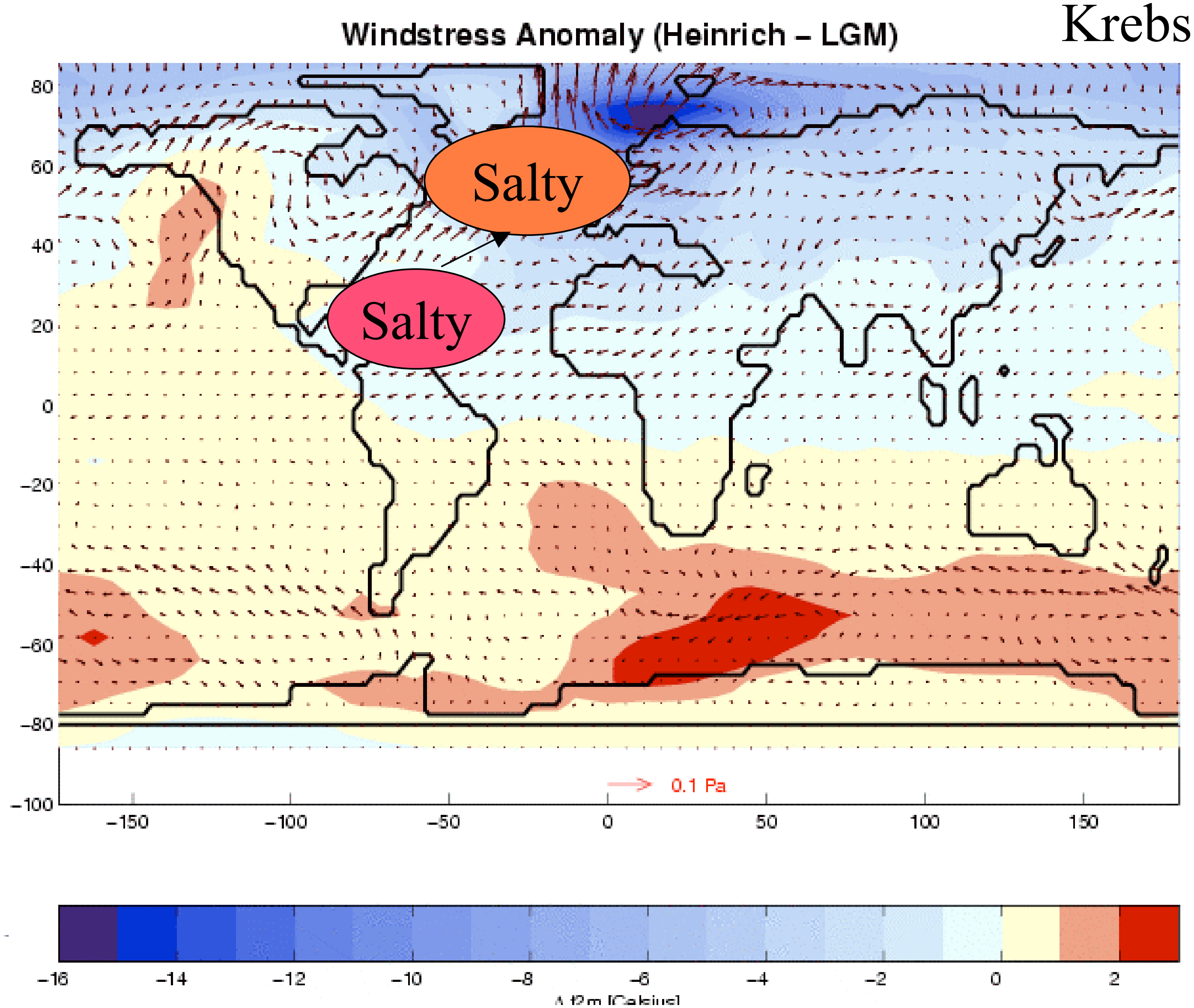
Timmermann et al, J. Climate 2005

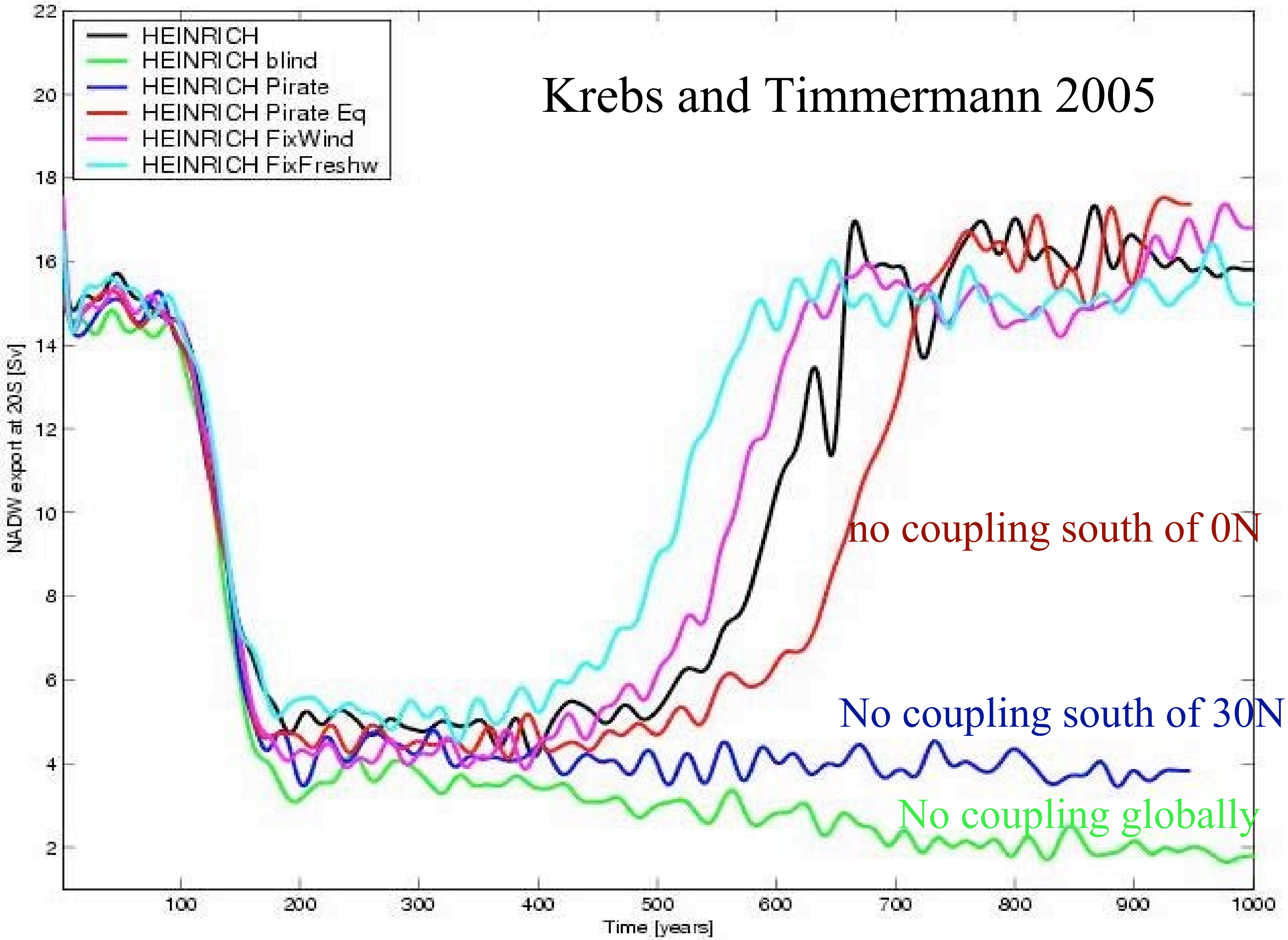
Recovery of the THC: Role of the tropics

Krebs and Timmermann 2005

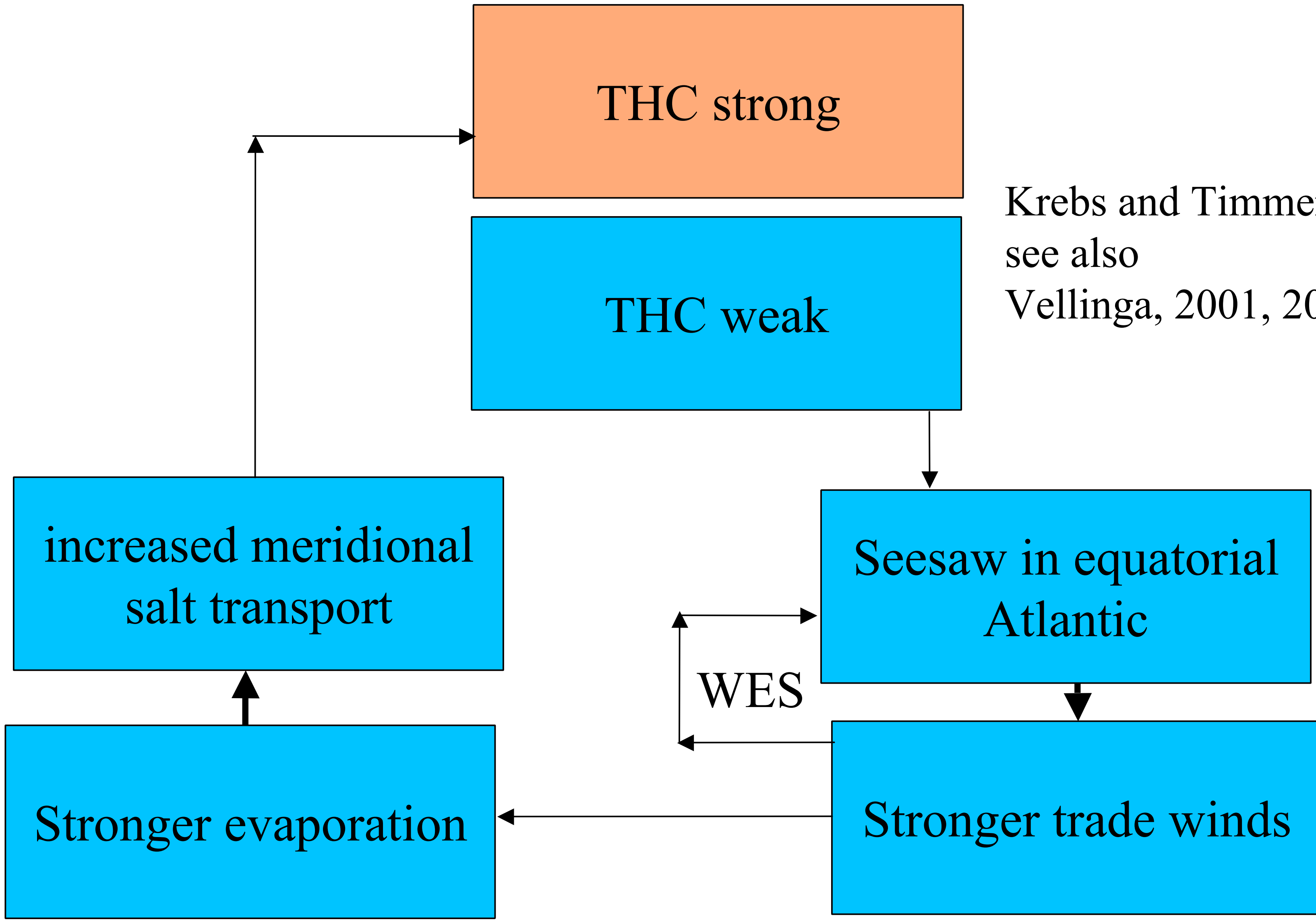


Wind-evaporation feedback is a 1st order tropical stabilizer for the THC

Recovery of the THC: Role of the tropics

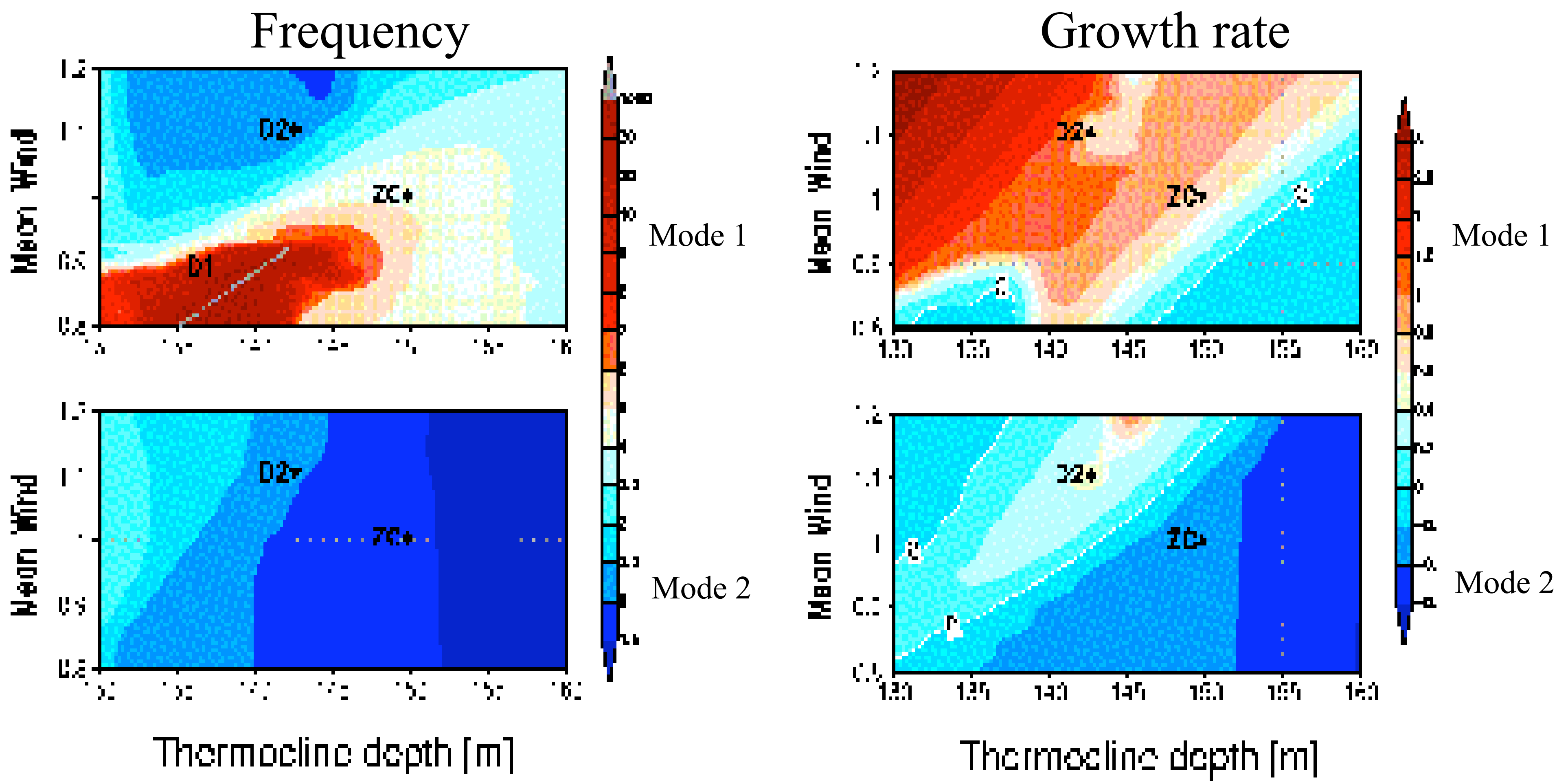


Recovery of the THC: Role of the tropics



Krebs and Timmermann 2005
see also
Vellinga, 2001, 2004

Future climate change: a complex problem: ENSO regimes and mean state changes

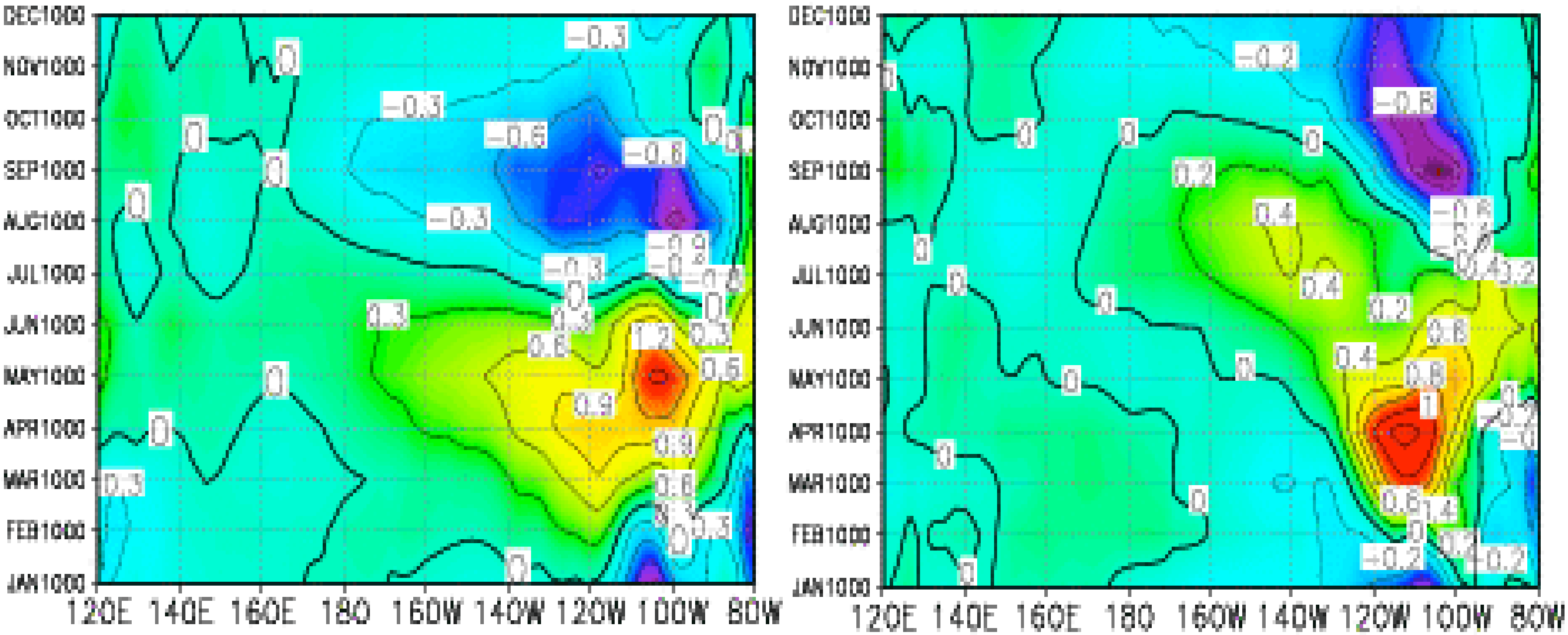


courtesy of Jin and Bejerano 2005

Future climate change: a complex problem: ENSO regimes and annual cycle changes

Scenario A, ECHAM4/ OPYC3

annual cycle eq. CTR anoma. annual cycle eq. 2xCO2-CTR



Timmermann and Jin GRL, (2004)

Discussion and Conclusions

- Annual cycle strength and ENSO amplitude are tightly linked
- Sensitivity of ENSO to climate change depends on the prevailing ENSO regime
- LGM ENSO stronger due to shallower thermocline and meridional temperature gradient (model result)
- THC collapse can induce ENSO collapse (depends also on ENSO regime)
- Pan-oceanic connections due to global seiches and thermocline adjustment
- **We are far away from a realistic assessment of the ENSO response to future greenhouse warming**

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Thank you for your attention