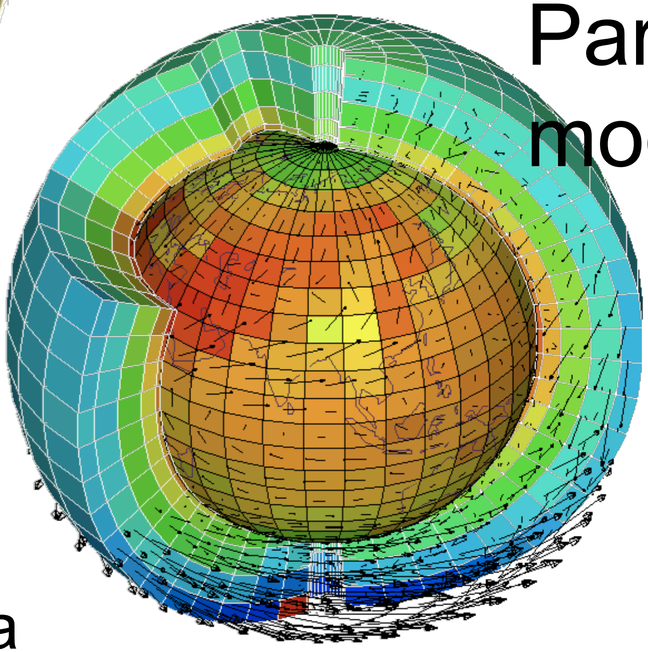
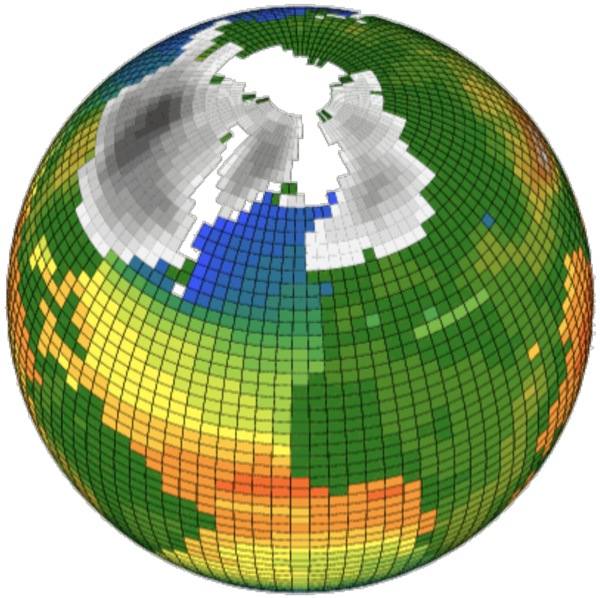
Introduction to palaeoclimate modelling

Part I : climate models





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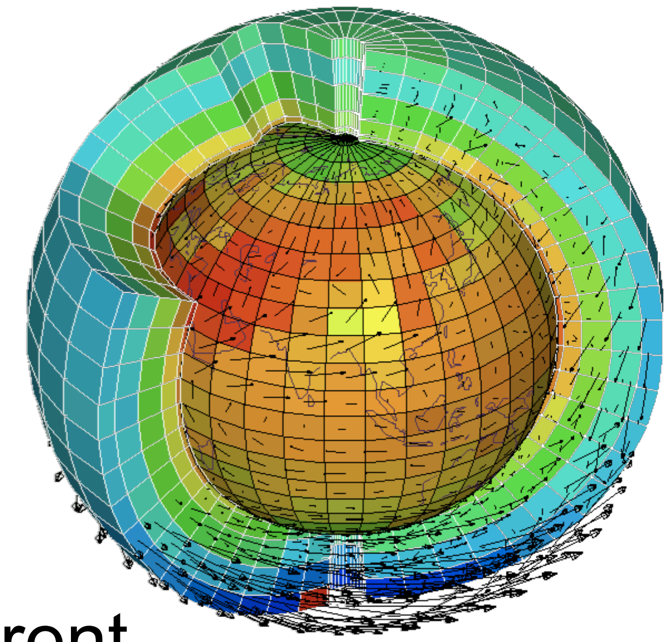
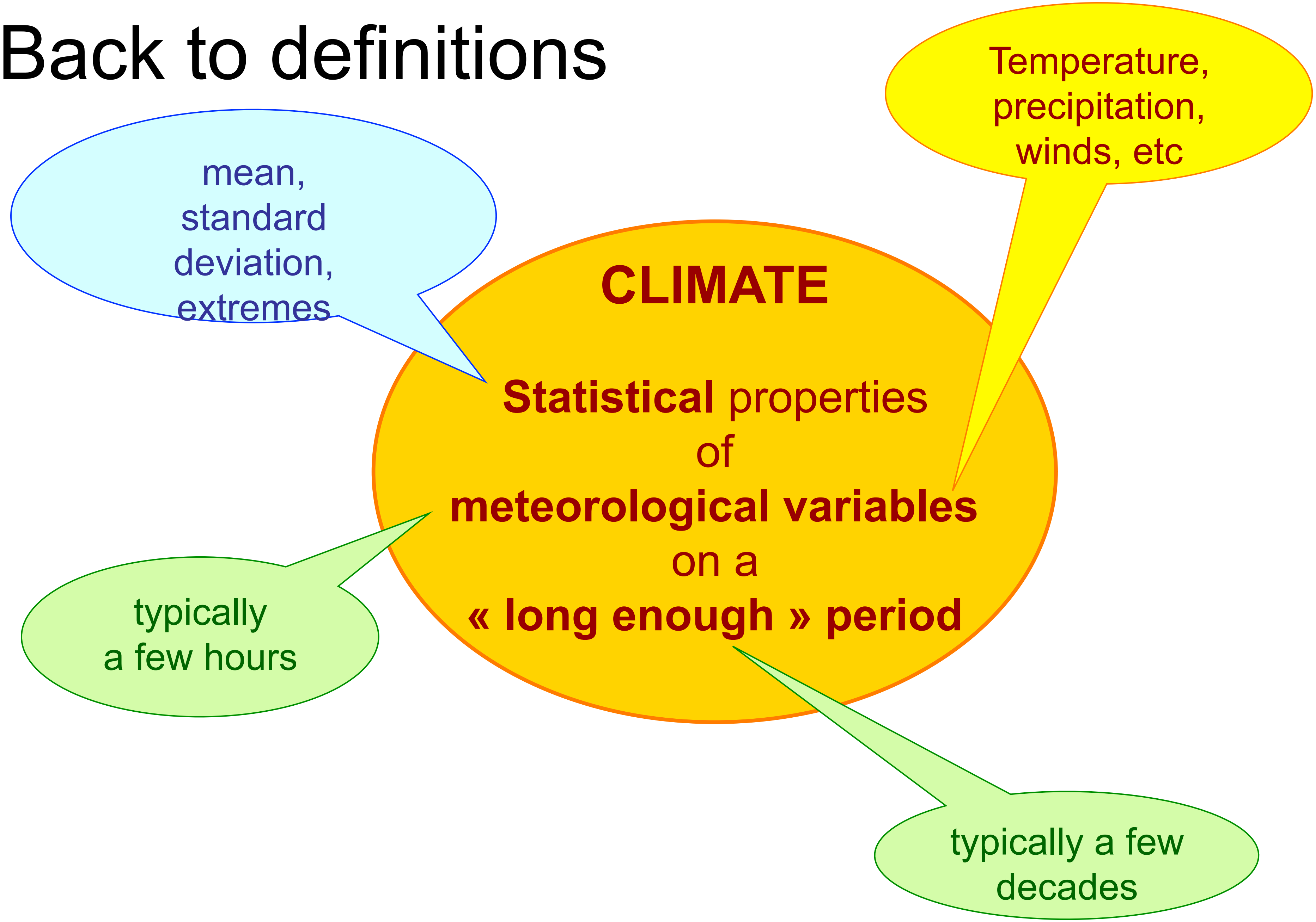
Why climate models?



- For prediction
- For understanding
- Why paleoclimate models?
  - For evaluating models in different climate contexts
  - For testing mechanisms responsible for observed or reconstructed climate changes
  - For prediction?

Back to definitions



What's a model?

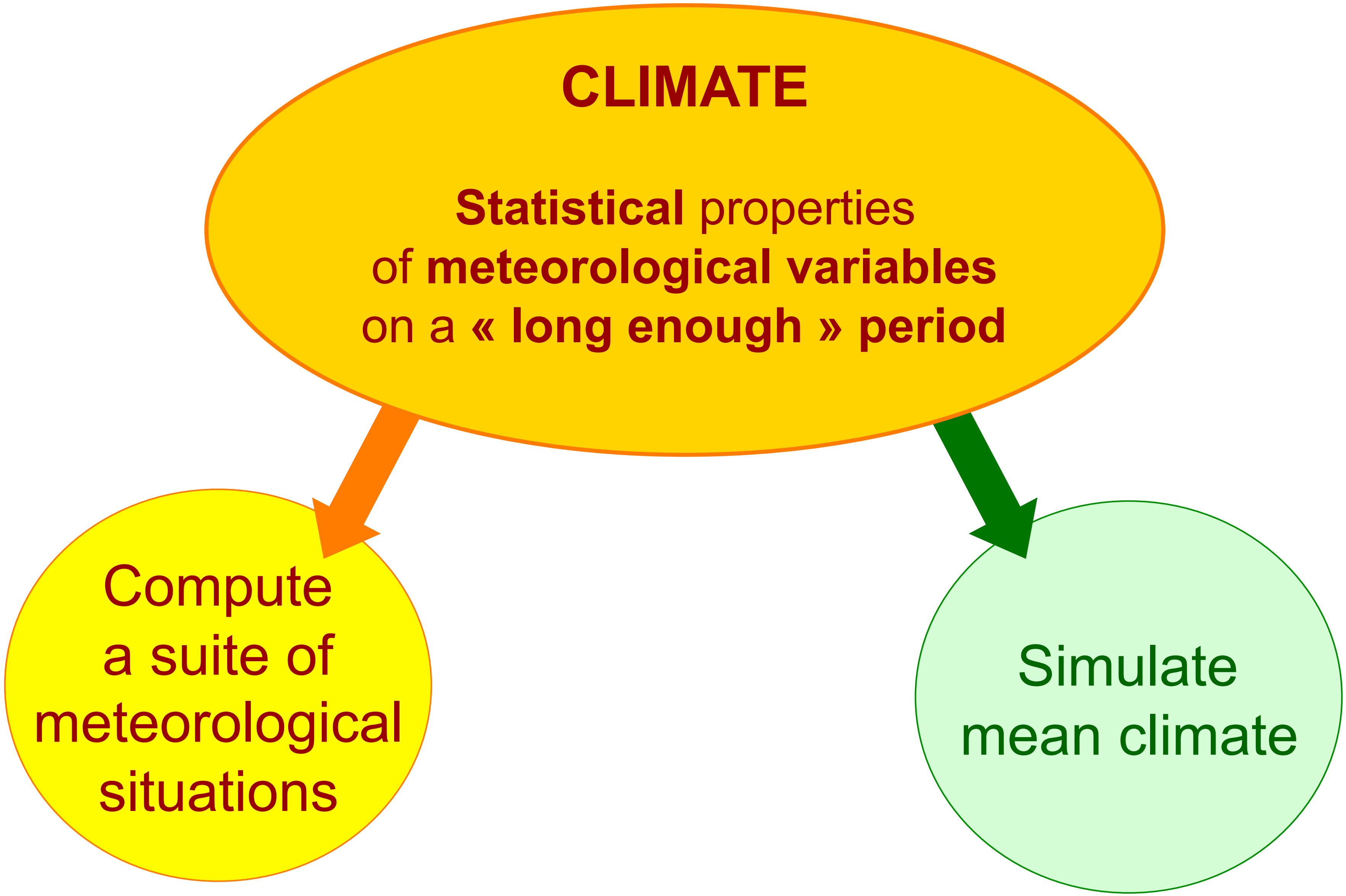
- An ensemble of hypotheses with which a phenomenon can be explained

- The computer program translating these hypotheses

→ Several types of climate models according to

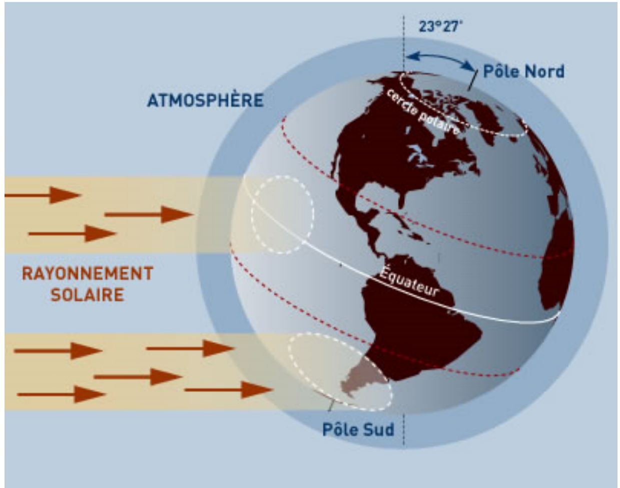
- The hypotheses on which they are based
- The problems we want to solve

Two approaches to climate modelling



What do we need to represent ?

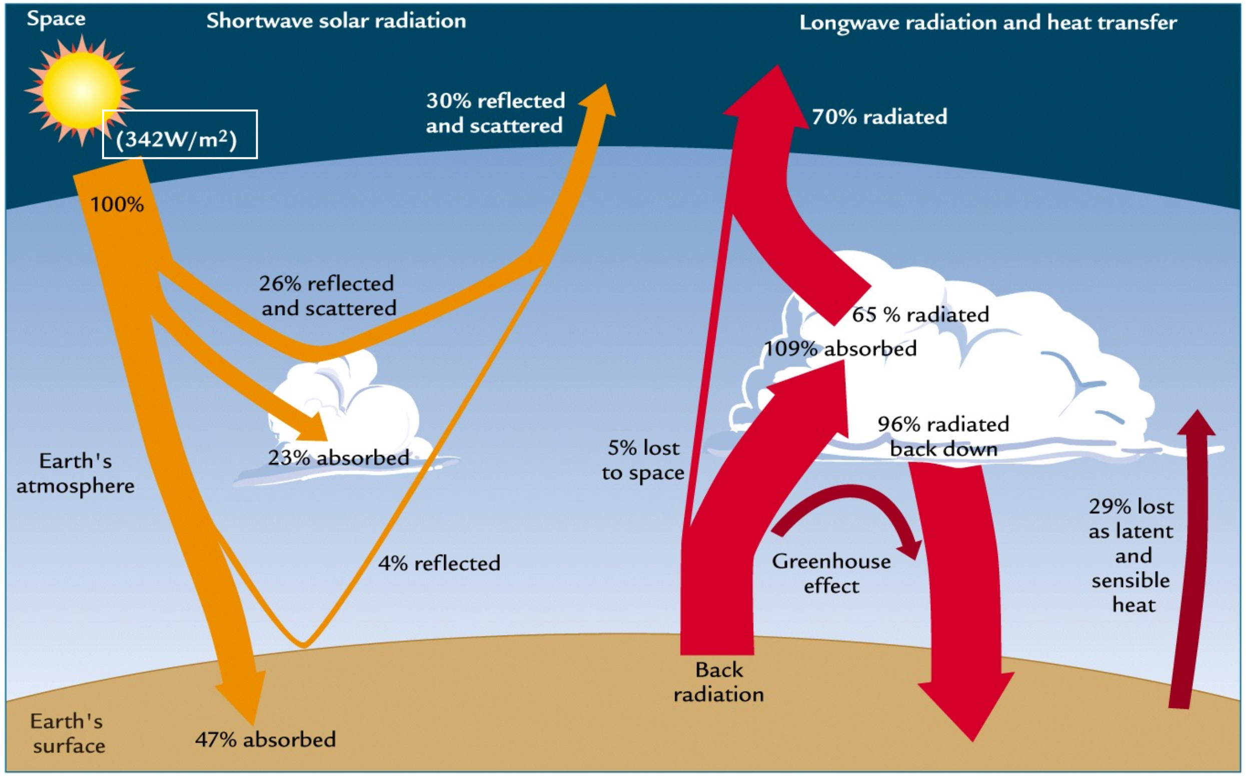
- 1a. atmospheric



Clouds

Greenhouse gases

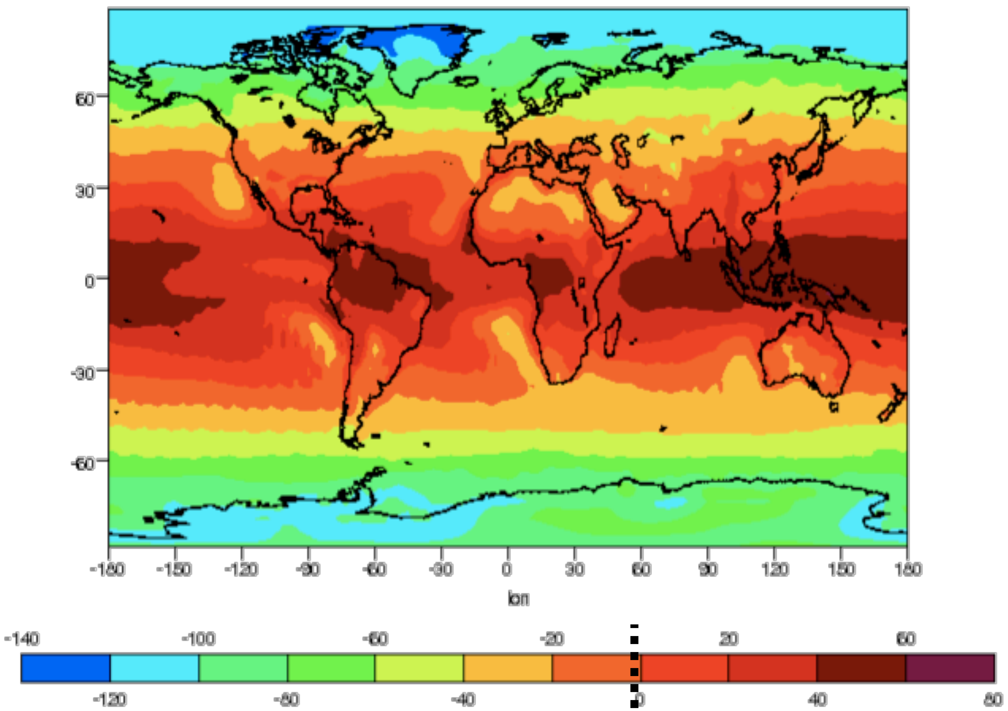
Surface (snow, vegetation…)



What do we need to represent ?

- 1b. atmospheric energetics and dynamics

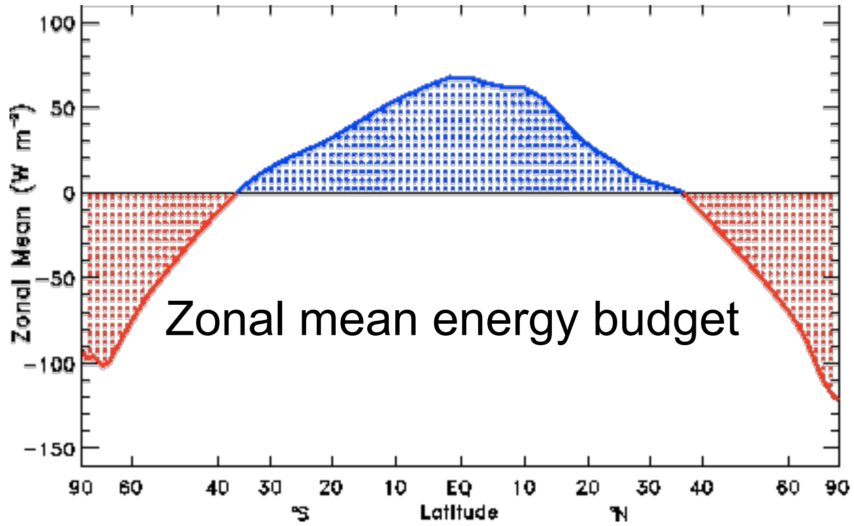
Top of the atmosphere radiative budget

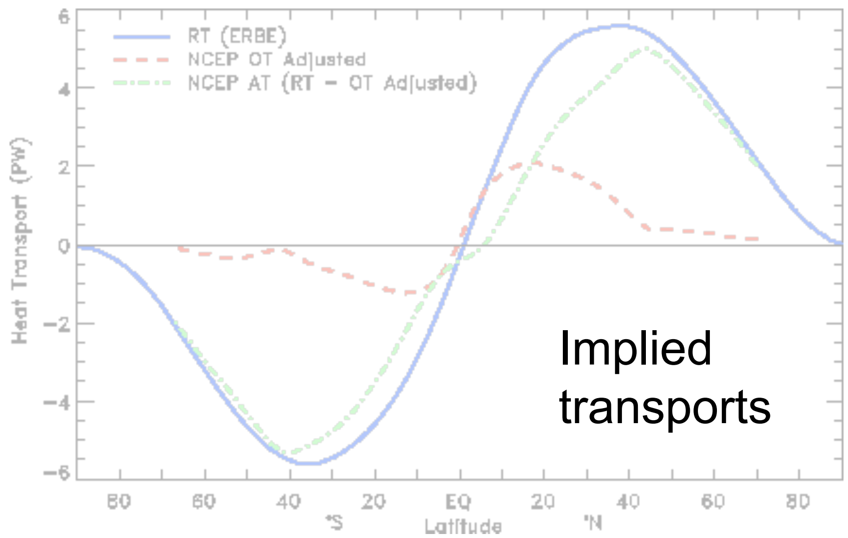


W/m^2

Atmosphere is **losing** energy

gaining energy

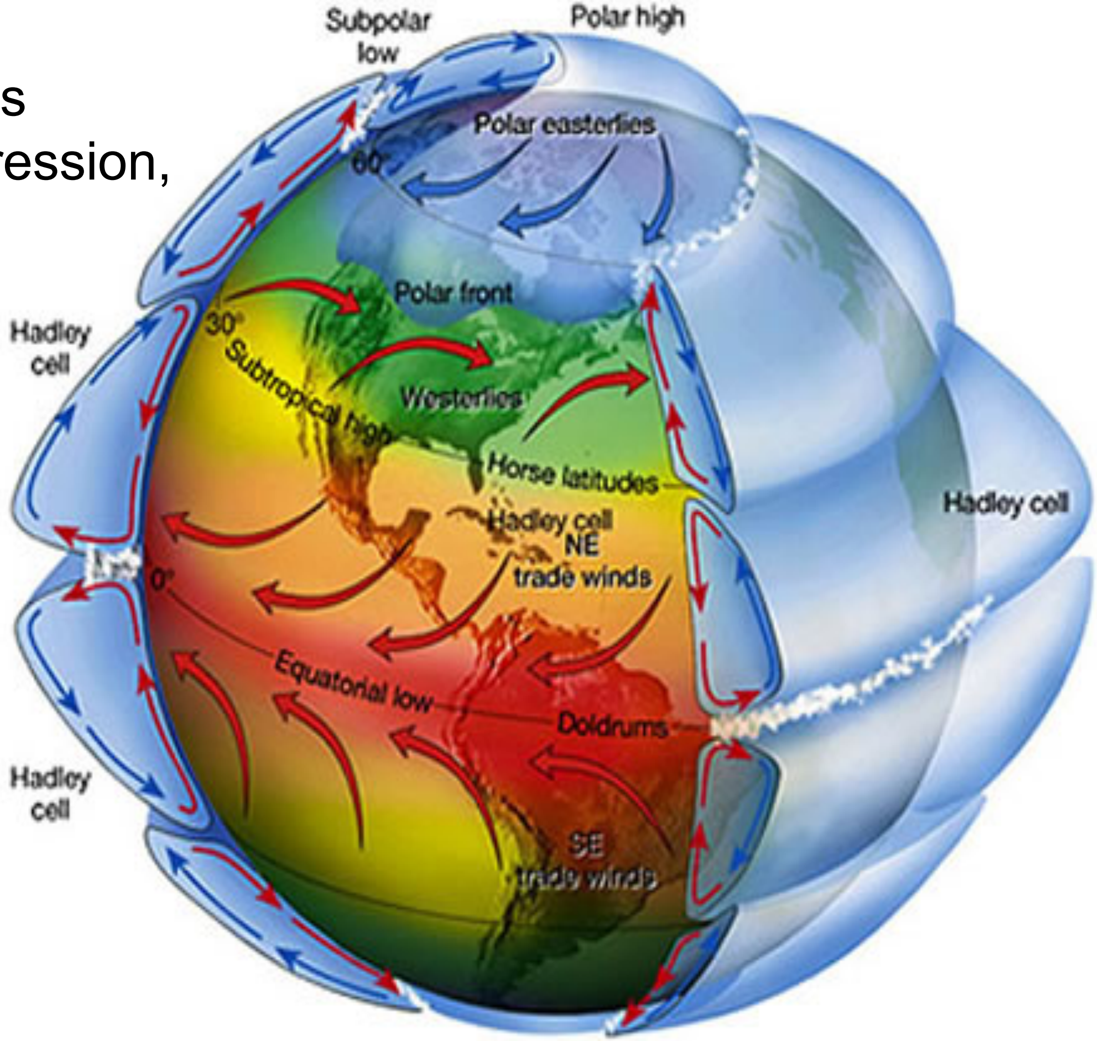




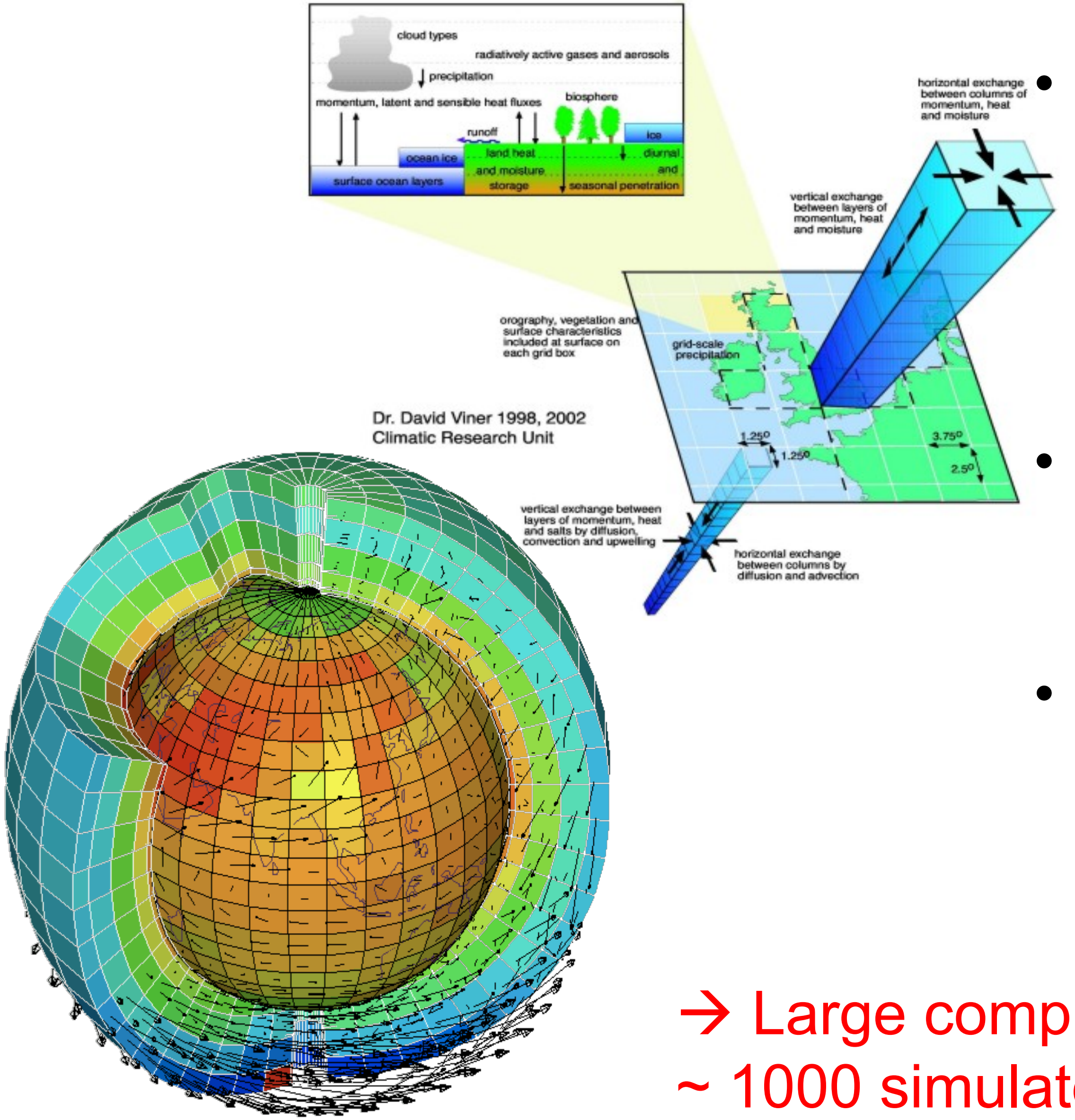
What do we need to represent?

- 1b. Atmospheric transports

Mid-latitude planetary waves
(e.g. in winter, oceanic depression,
continental anticyclones)



General Circulation Models



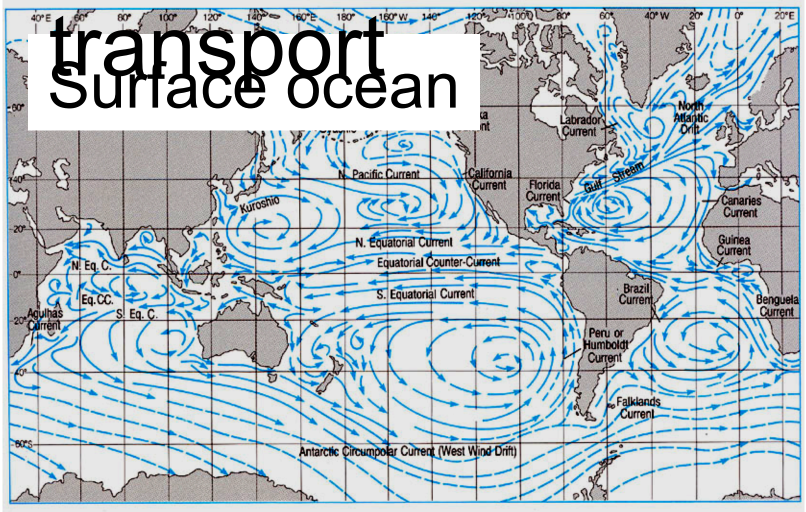
- Compute « meteorological » evolution of the atmosphere on a global grid
- Small time step, smaller for finer grid (otherwise numerical instabilities)
- Parameterisations for fine scale processes or processes whose physics are not well known

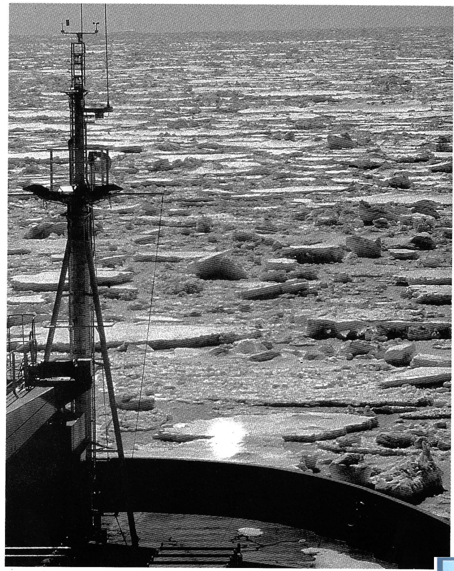
→ Large computing time:
~ 1000 simulated years in ~a few months on a super-computer

What do we need to represent?

- 2. oceanic/sea ice feedbacks, surface + transport

Surface ocean

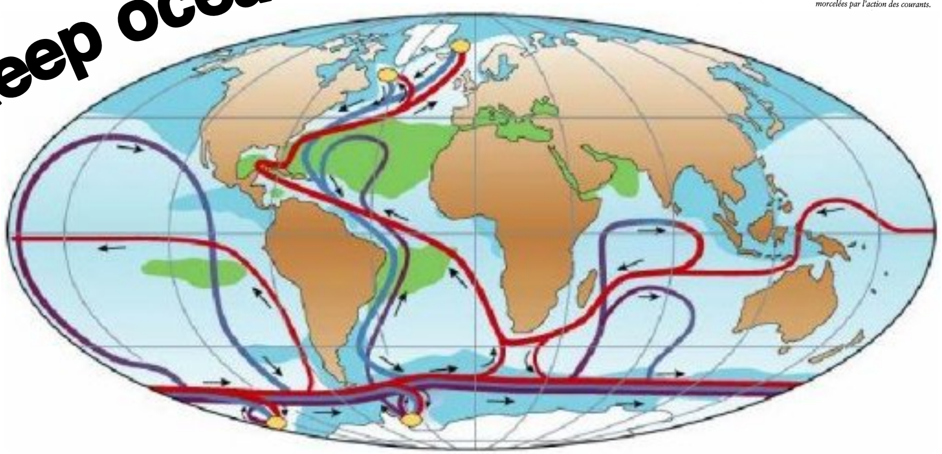




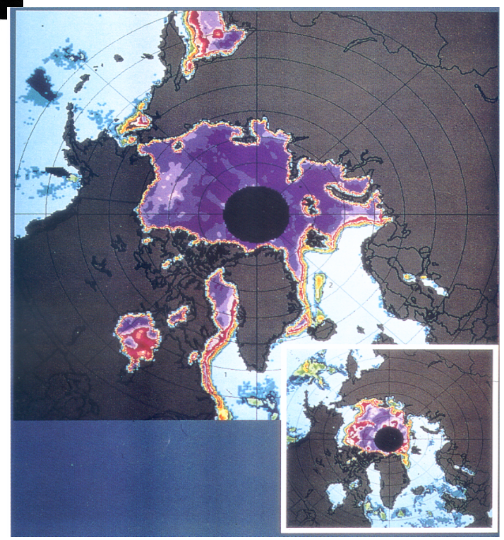
La banquise se présente le plus souvent sous la forme de plaques de glace morcelées par l'action des courants.

Sea ice

deep ocean



(Rahmstorf, Nature 2002)



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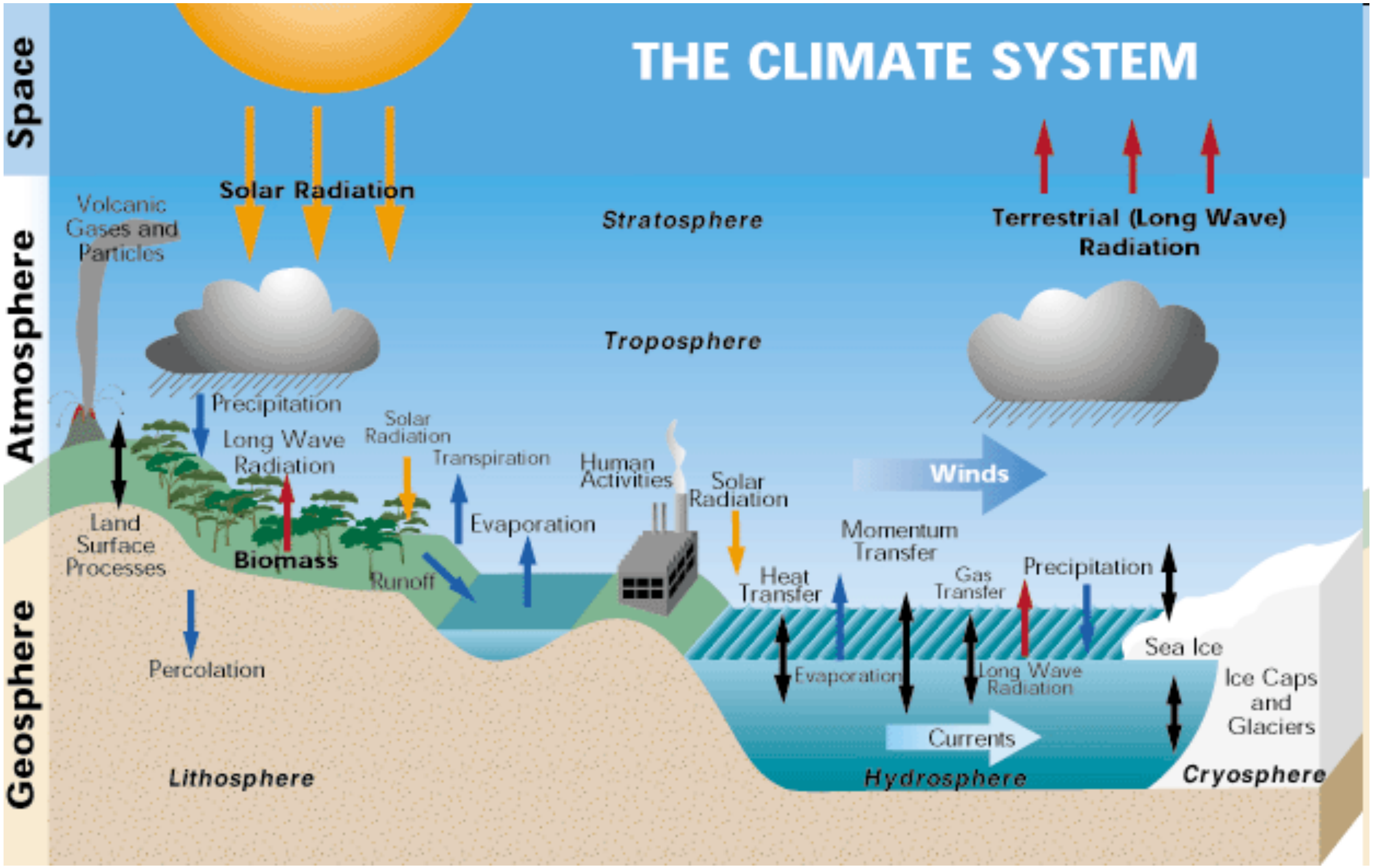
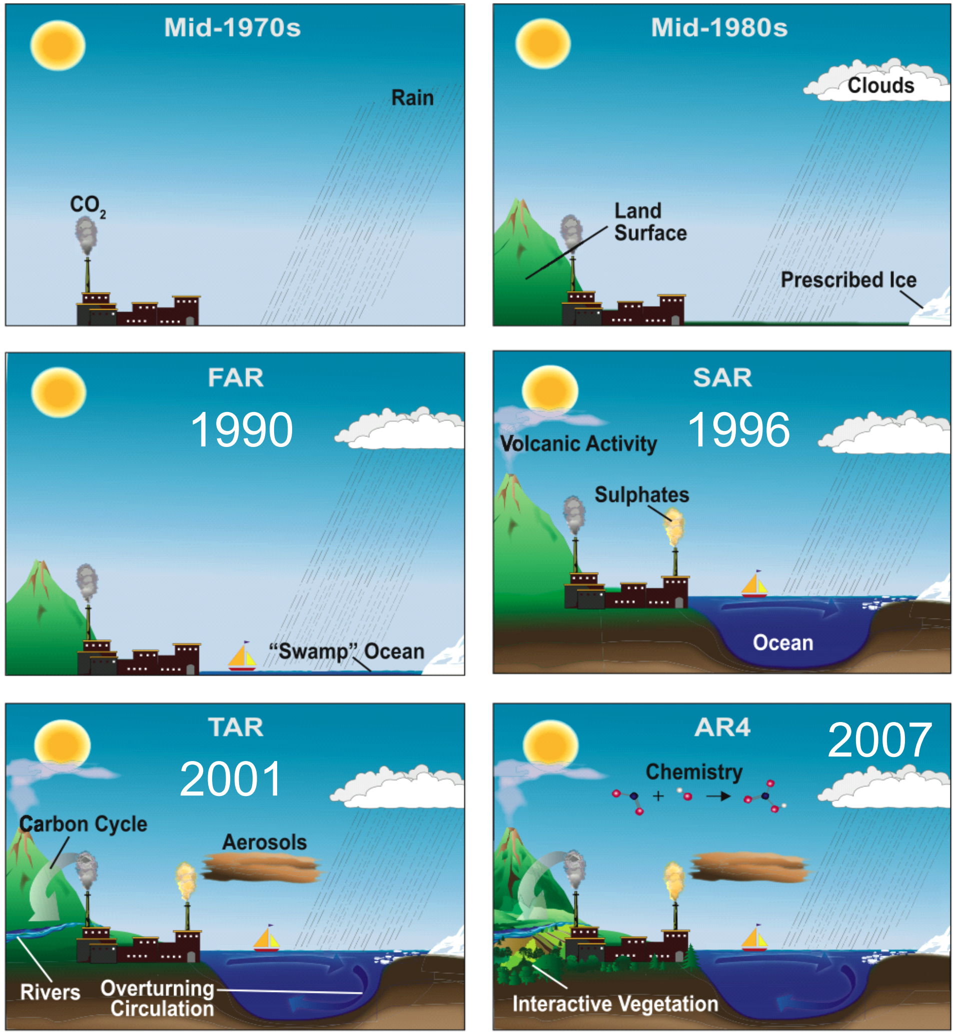
Earth System Models

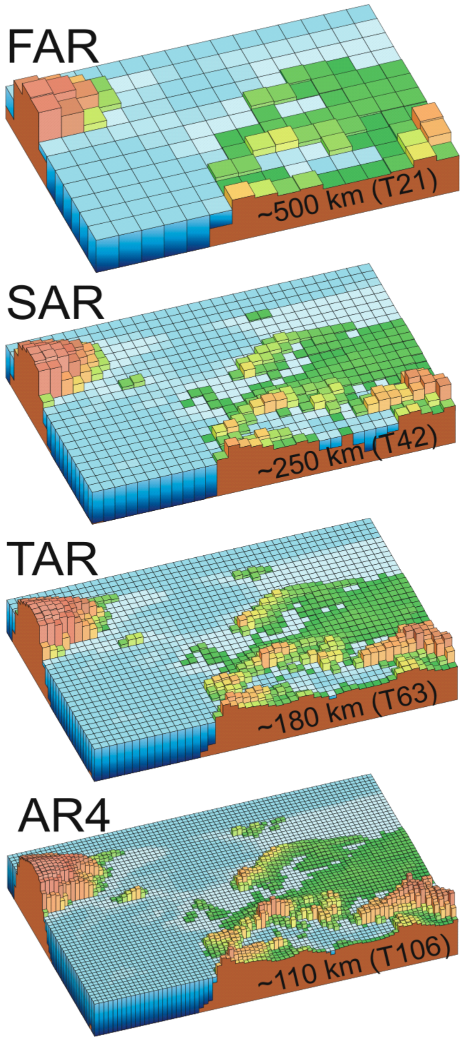


Global (general circulation) climate models

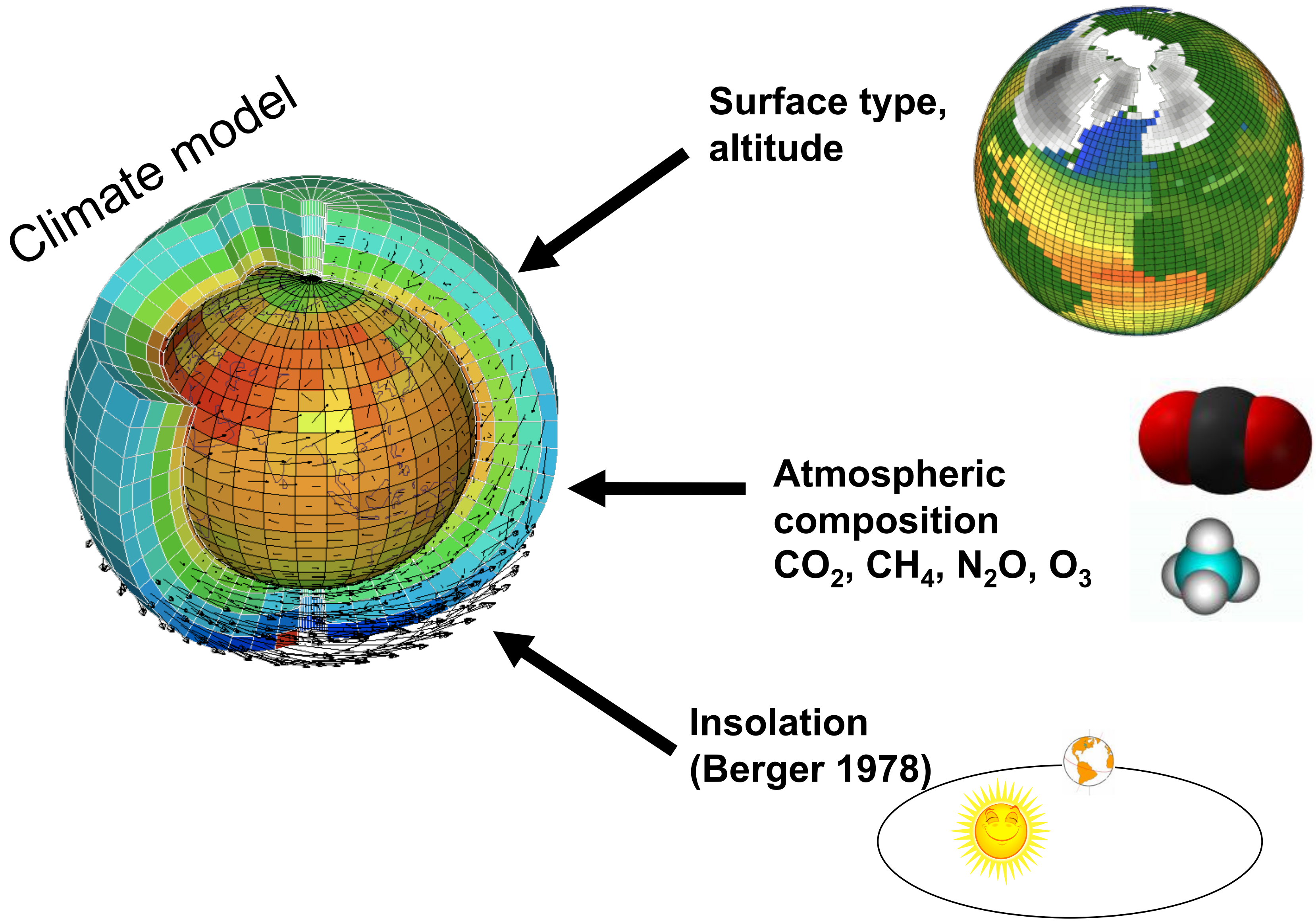
components



resolution



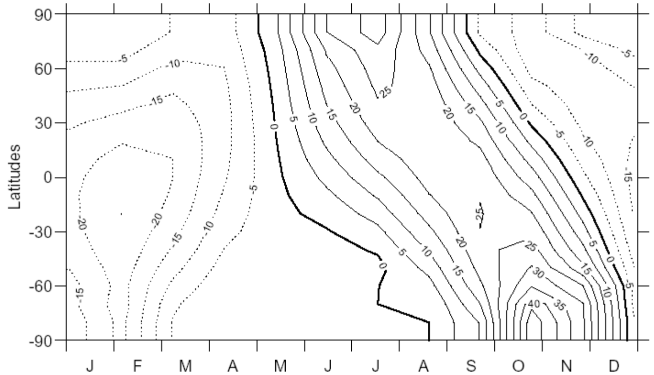
Modelling palaeoclimates



Palaeoclimate Modelling Intercomparison Project (PMIP)

Mid Holocene, 6000 years ago

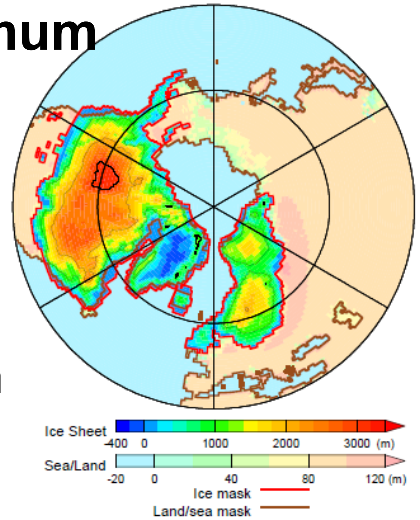
Change in insolation forcing



Last Glacial Maximum

21000 years ago

Changes in
- ice-sheets
- GHG forcings:
  CO2 = 185ppm
- coastlines

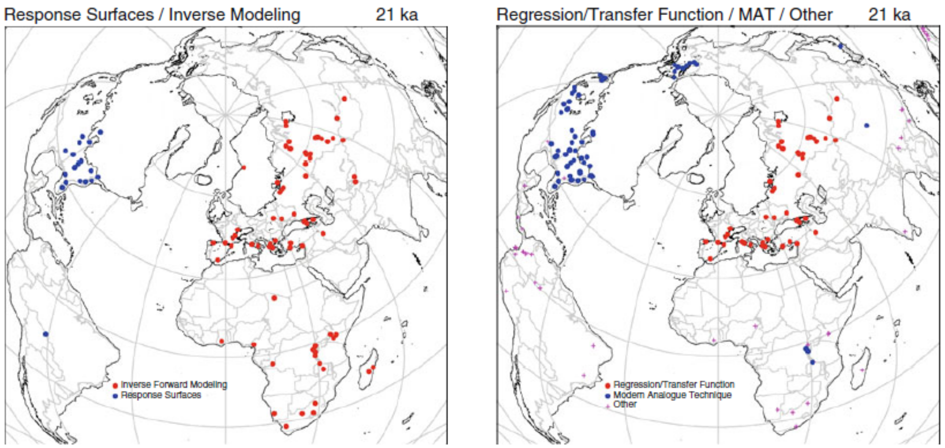


several global circulation models
run with the same boundary conditions

compare
& understand
model results

compare model
results with data

Data bases for the LGM climate

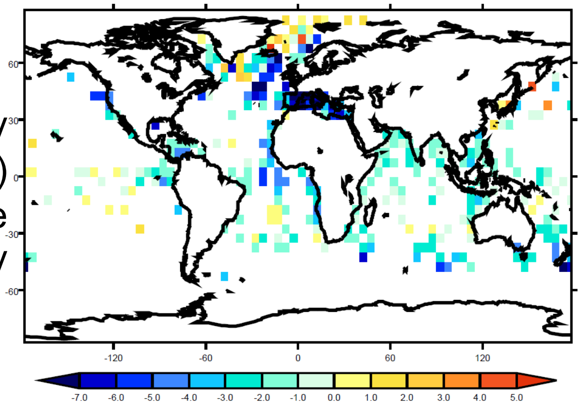


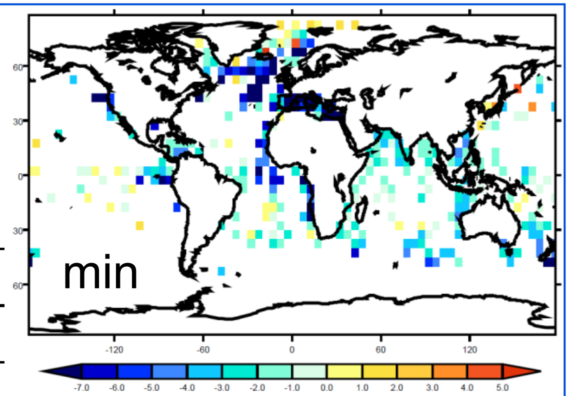
Pollen-based reconstructions
Bartlein et al, 2010

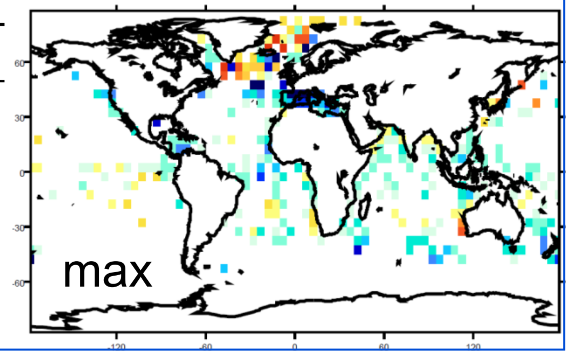
Surface marine data :

compilation from the MARGO project (2009), 696 reconstructions

Mean annual SST anomaly (LGM – present)
Several proxies, unique calibration for each proxy







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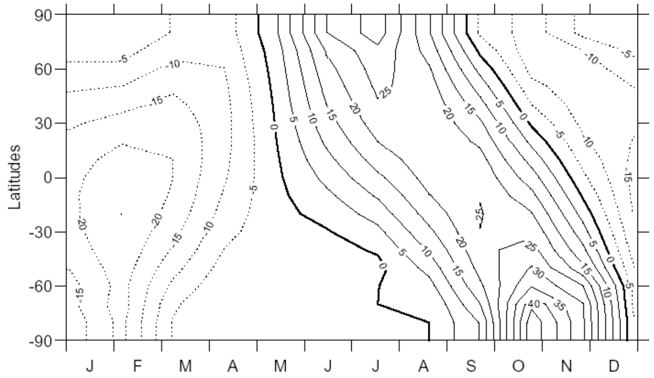

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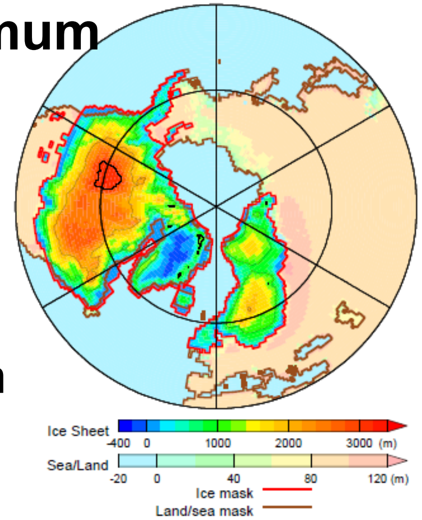
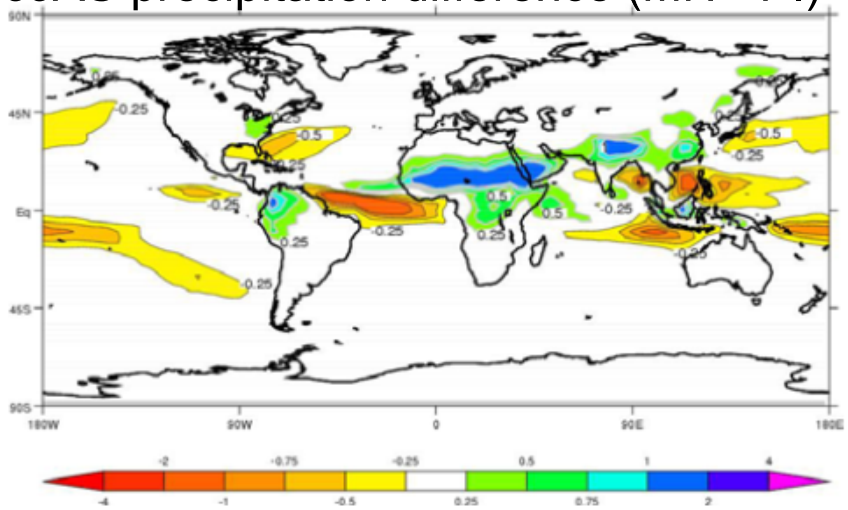
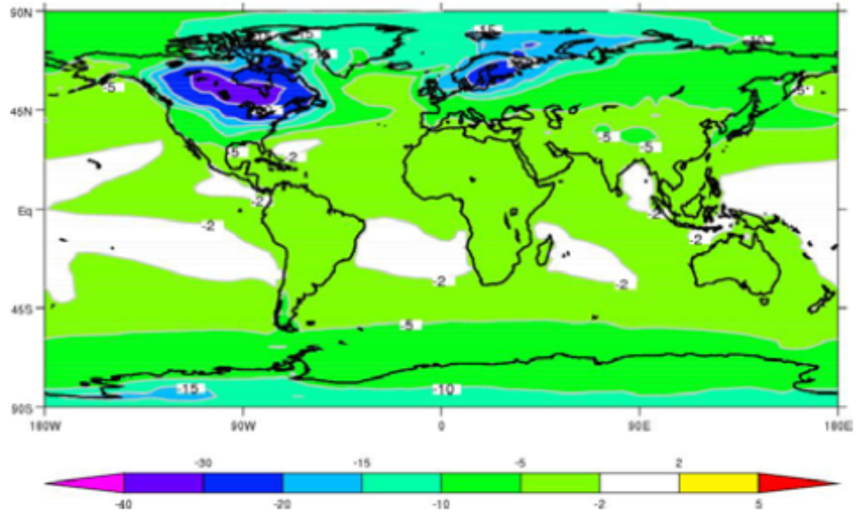


JJAS precipitation difference (MH - PI)

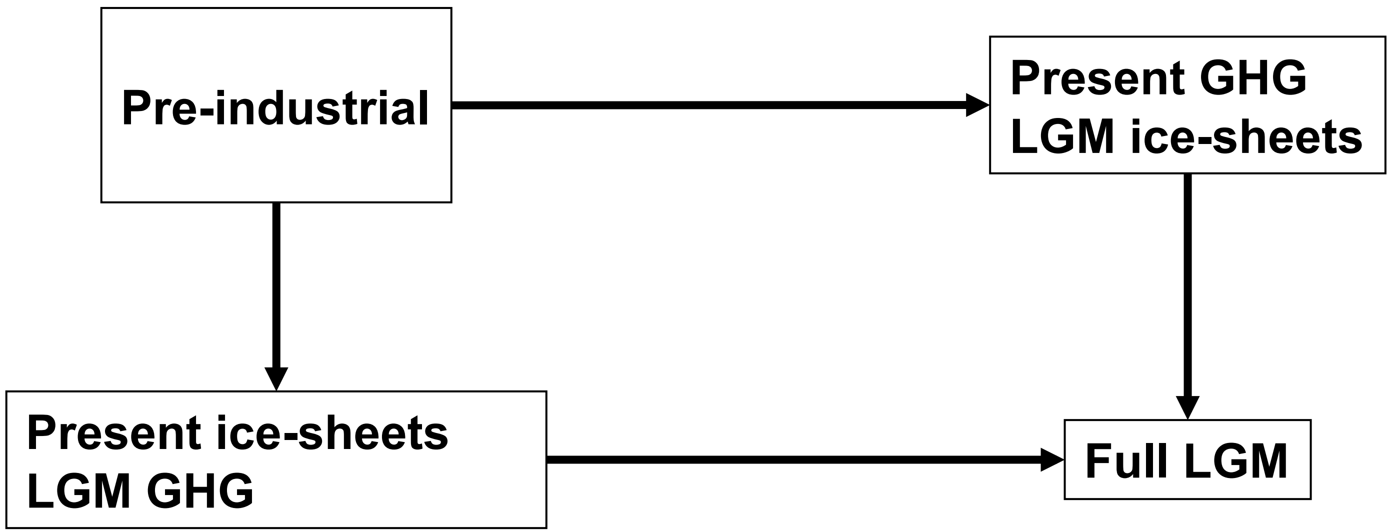


Mean Annual Temperature difference (LGM - PI)



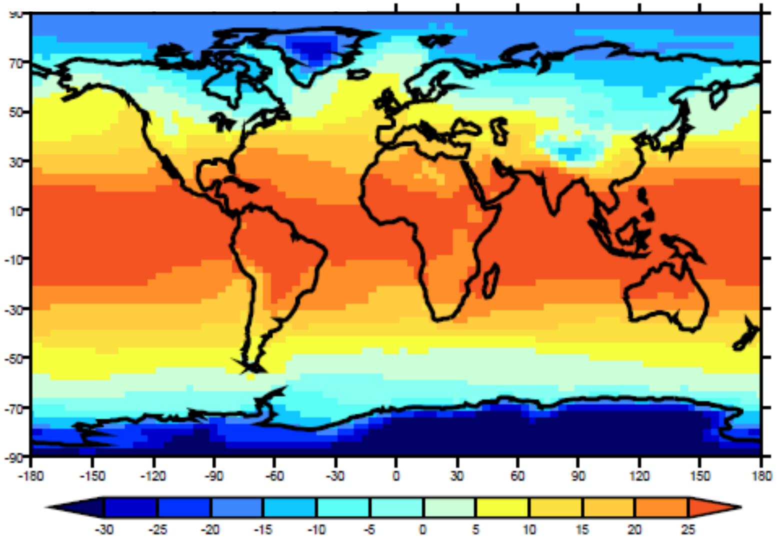
Sensitivity experiments

- Trying to understand the impact of each new boundary condition
- 4 simulations:

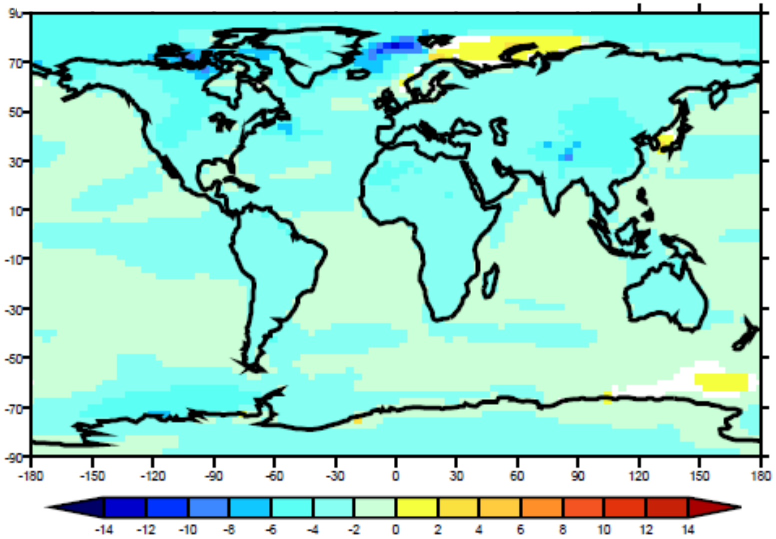


Results for the mean annual temperature

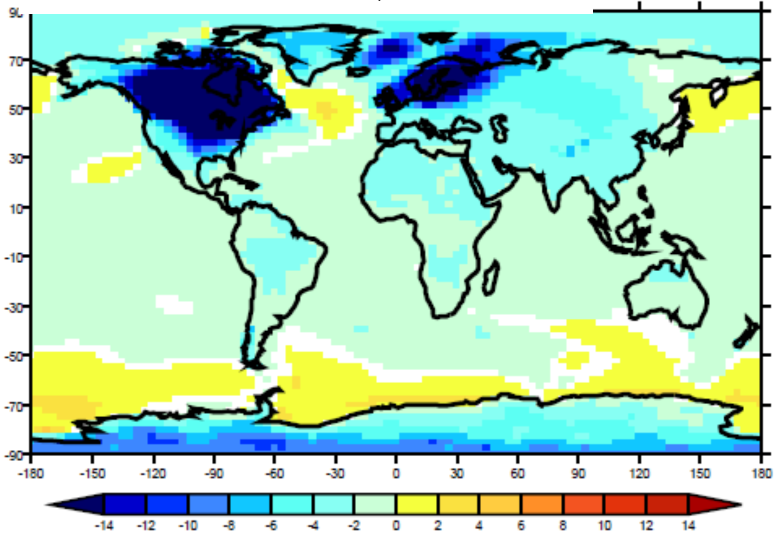
Preindustrial



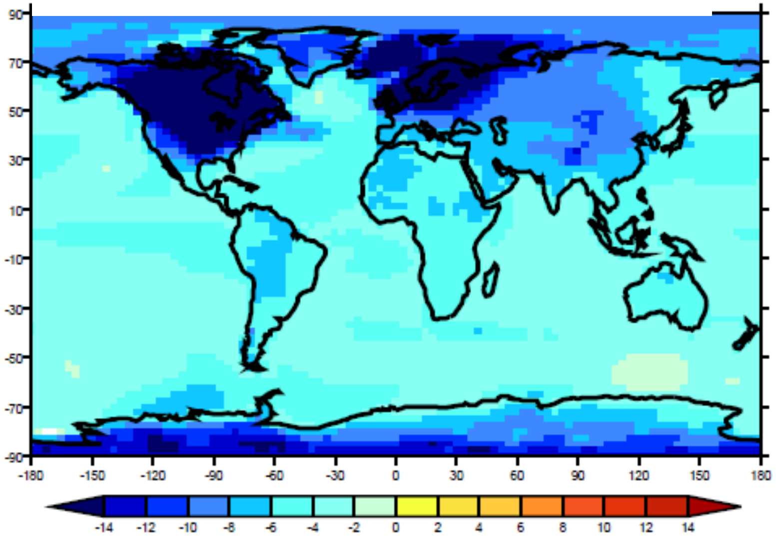
LGM GHG, PI ice-sheets



LGM ice-sheets, PI GHG



LGM GHG and ice-sheets

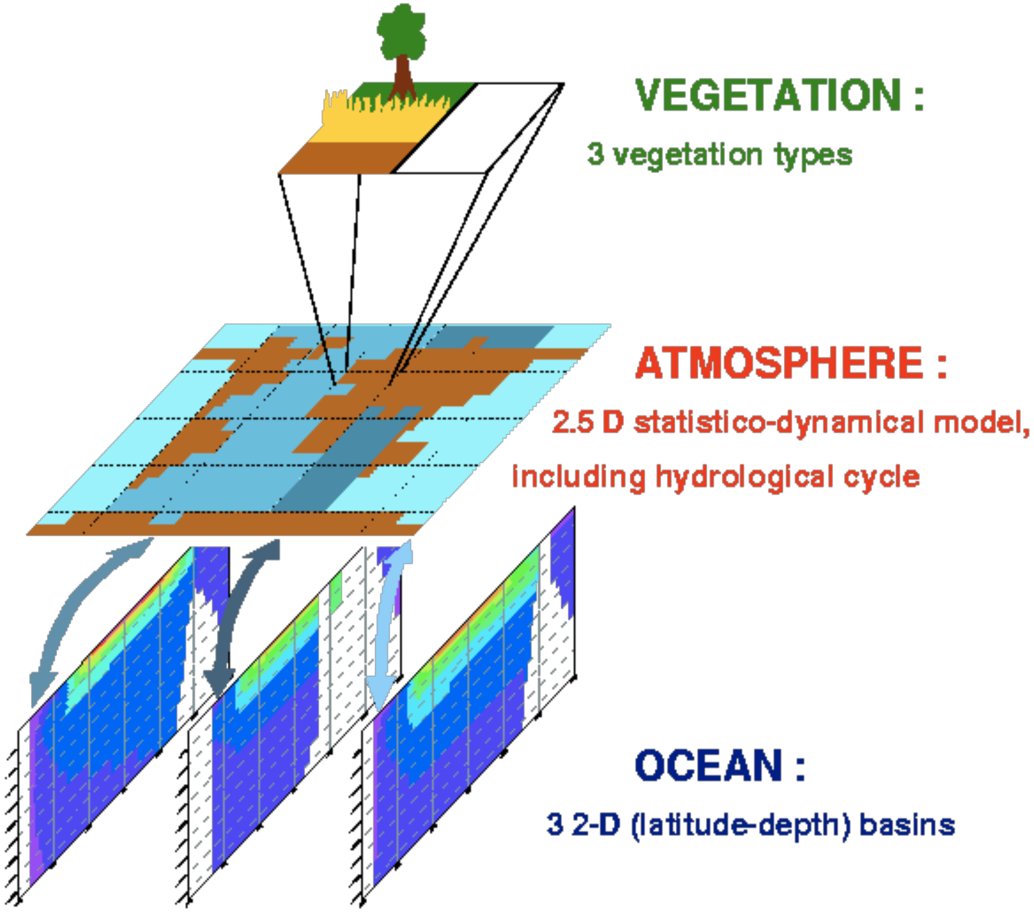


Global Coupled Models in brief

- ~ Weather prediction models run for a long time, long enough to compute the statistical characteristics defining climate
- Heavy to use: on super computers, several real-time months to obtain 1000 years of simulations
- Use for palaeoclimate modelling of restricted periods → « snapshots »
- A few studies with transient forcings

Earth System Models of Intermediate Complexity (EMICS)

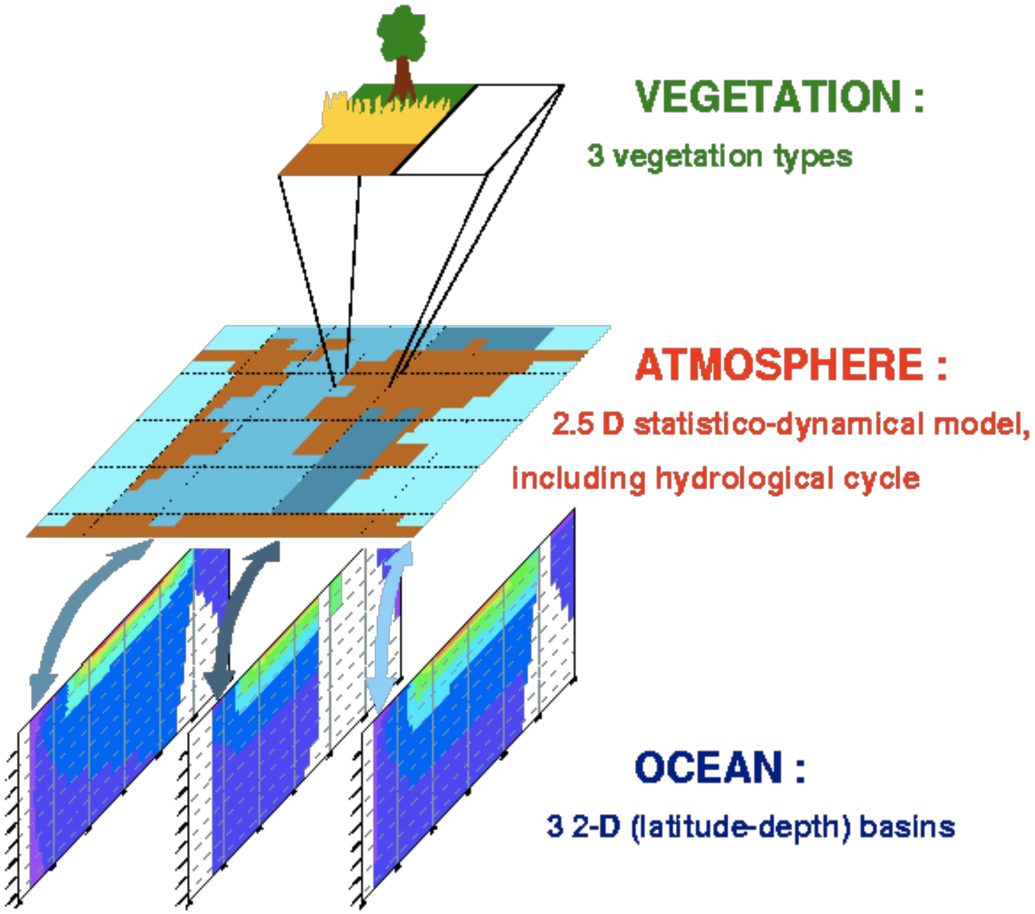
→ Time-consuming processes are parameterised
e.g. mid-latitude weather systems



Climber

Petoukhov et al 2000
(Postdam Institute for Climate Studies)
1000 years in 1 hour on a PC

The CLIMBER EMIC



Petoukhov et al 2000

Simple representation of the vegetation changes

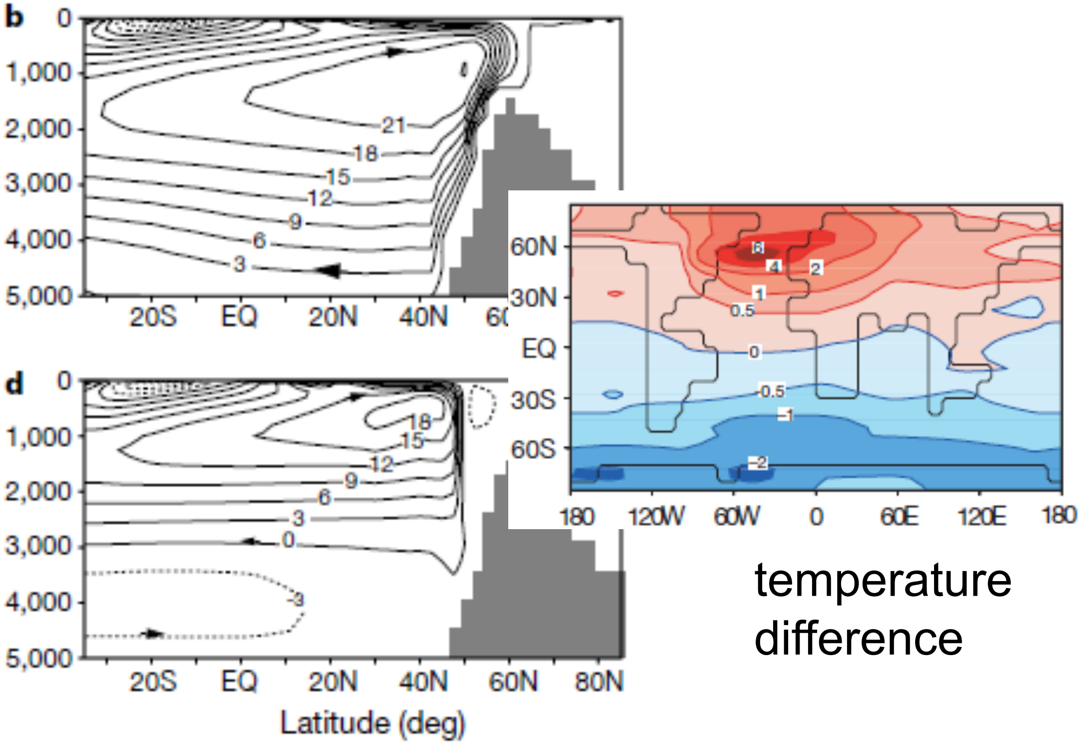
Parameterisation of impacts of fast atmosphere processus (e.g. mid-latitude weather systems)
→ time step = 1 day
→ coarse spatial resolution

3 latitude-depth basins, oceanic variability assumed to be primarily linked to meridional circulation changes

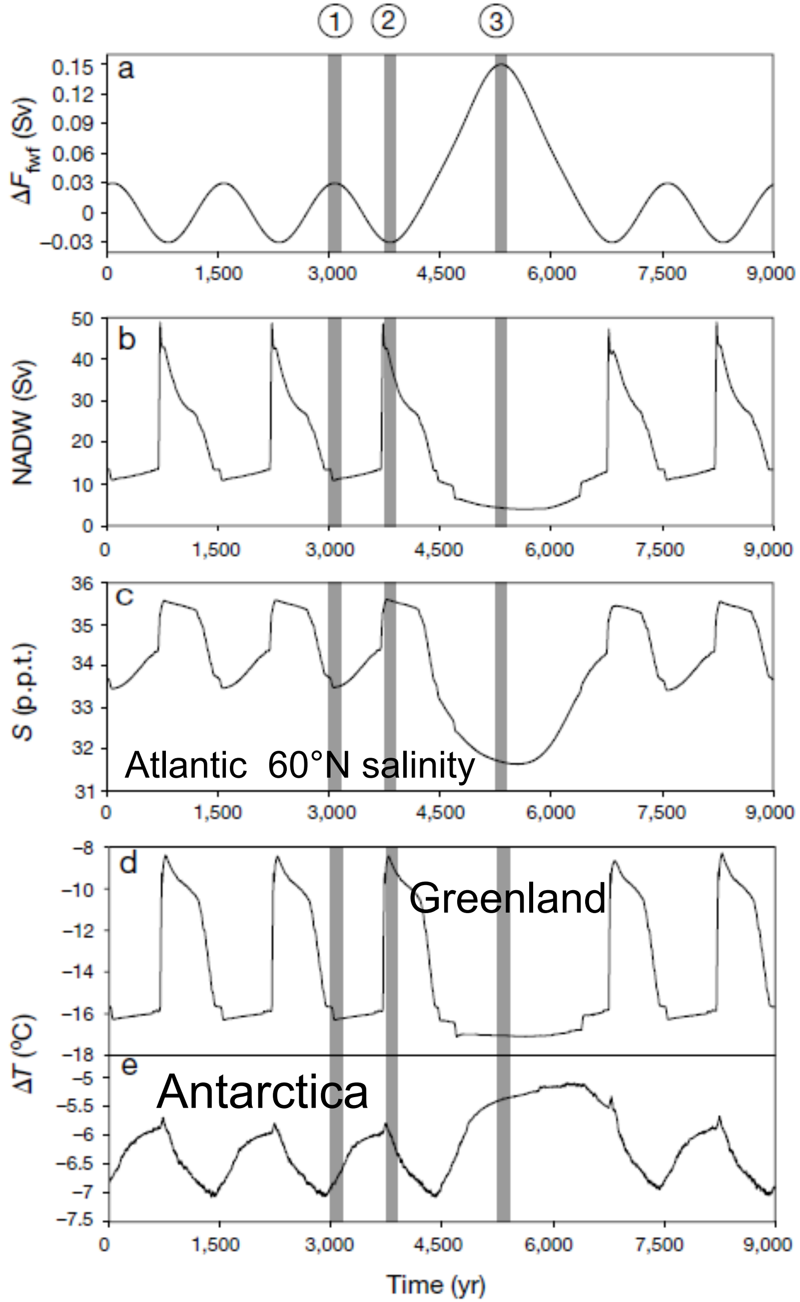
MIS3 example

Ganopolski and Rahmstorf 2001
(CLIMBER2)

→ apply fresh water flux in North Atlantic to trigger abrupt events



temperature difference

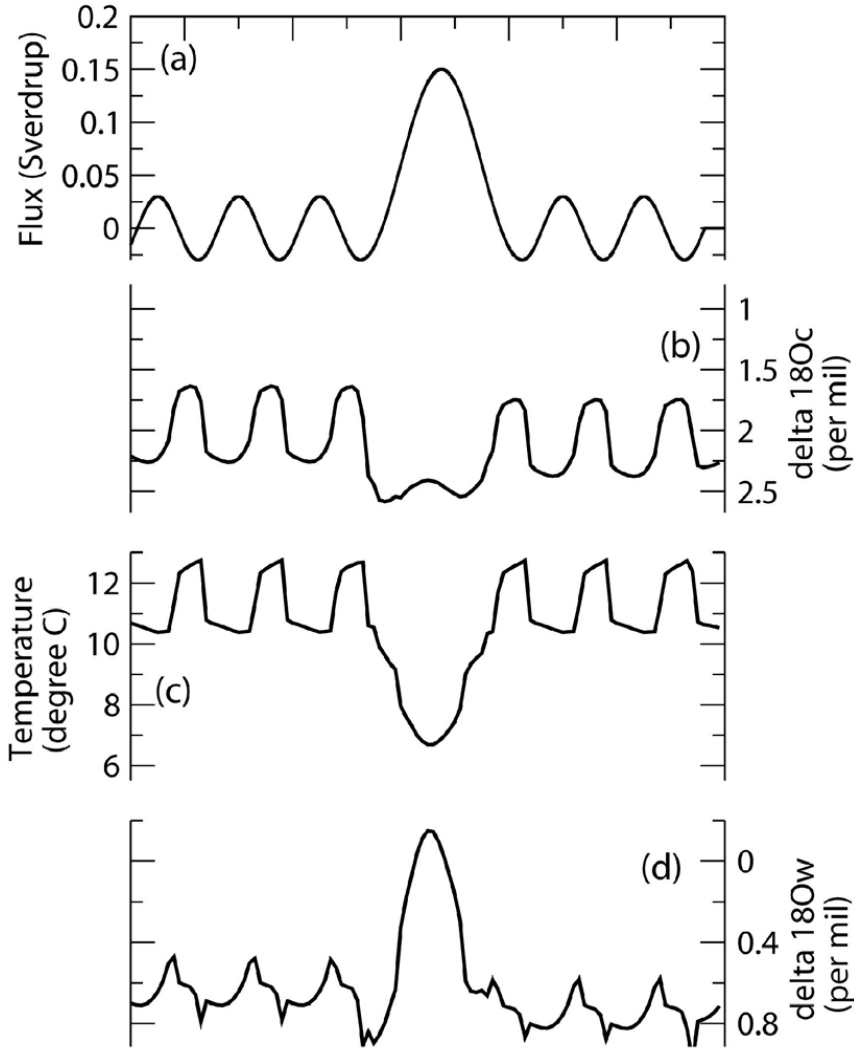


Additional information a model can bring

- « ^{18}O enabled model »

fresh water forcing

surface waters

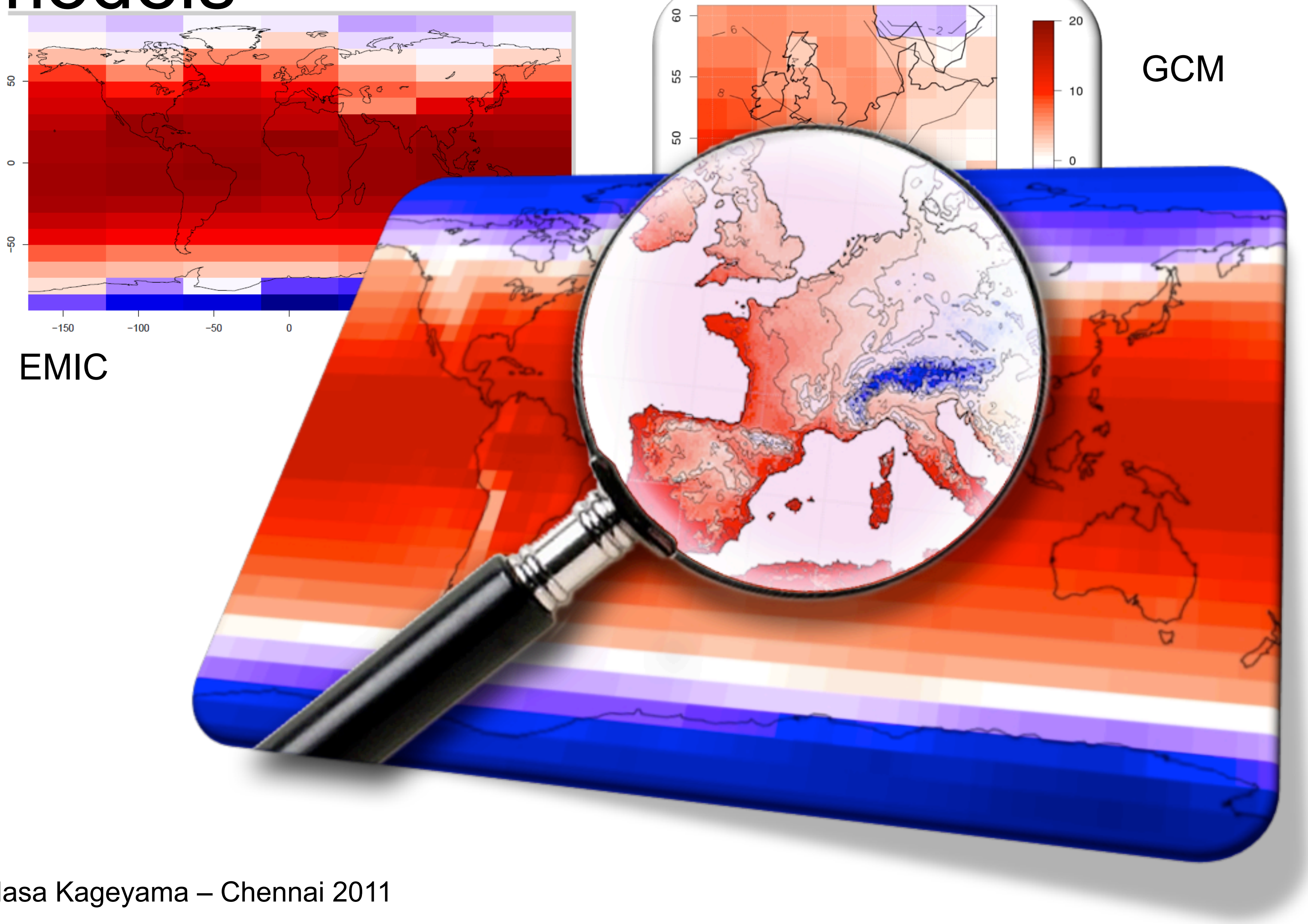


Roche et Paillard 2005

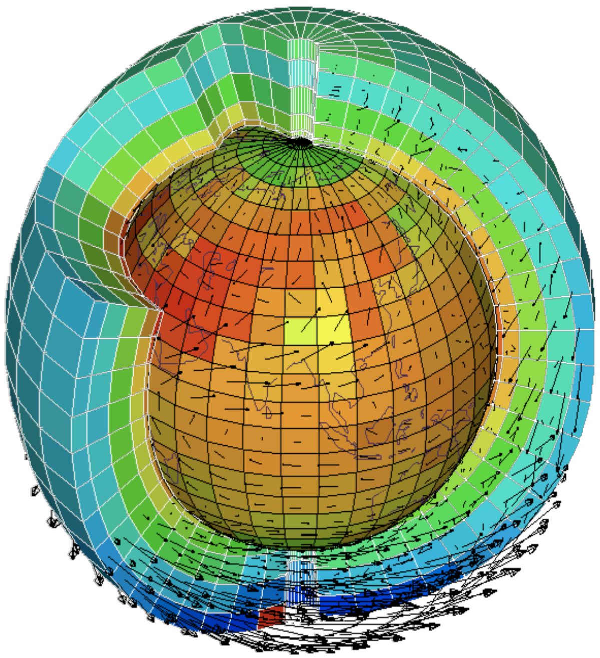
Other EMICS: a diversity of models

- Zonal models: LLN (e.g. Gallée et al)
- « 2.5D »: CLIMBER
- 3D models with energy balance models for the atmosphere: UVic
- 3D models with simplified dynamics for the atmosphere: ECBILT-CLIO, LOVECLIM

Resolution of typical global climate models

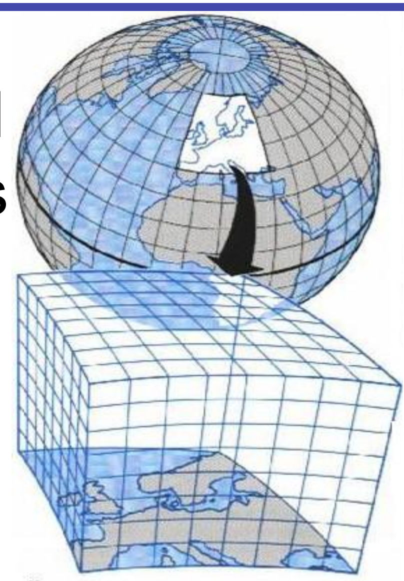


Getting regional

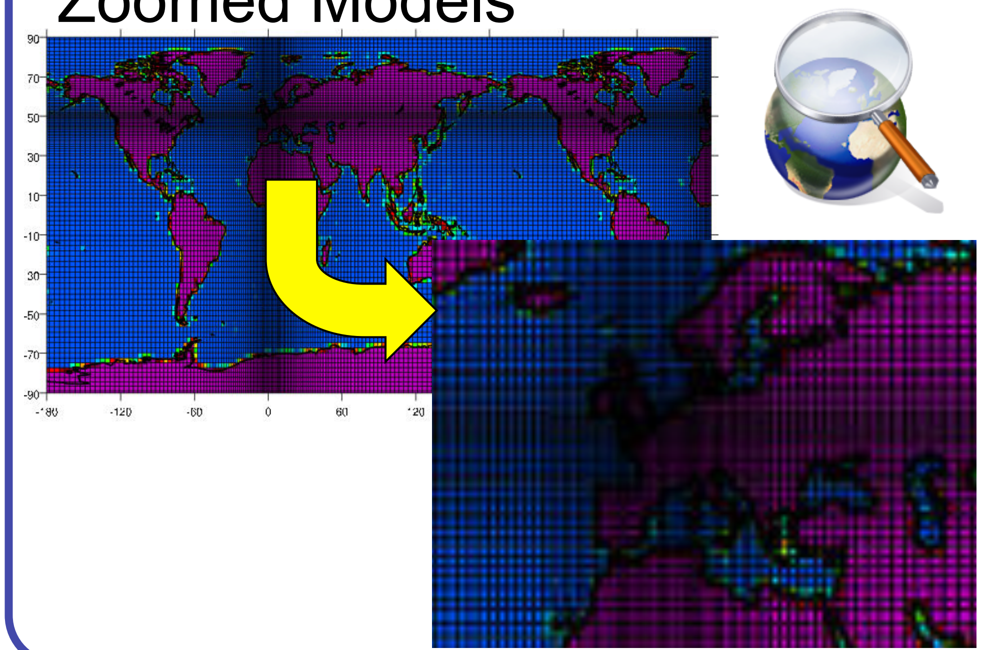


Atmospheric Dynamical Models

Nested Models



Zoomed Models

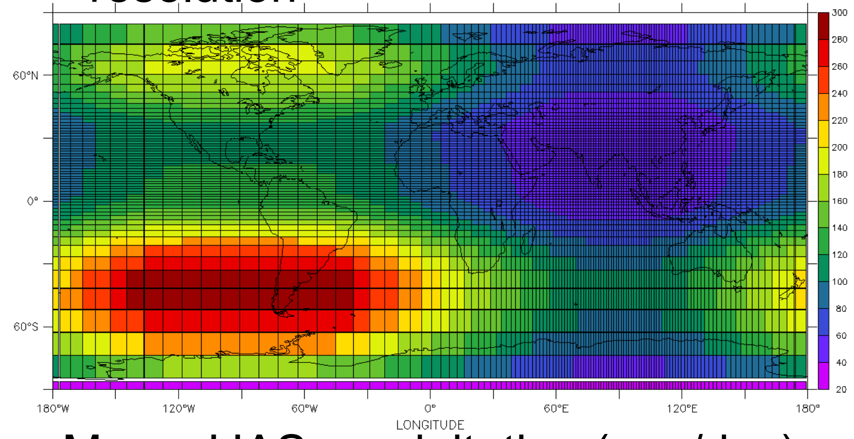


Statistical Downscaling

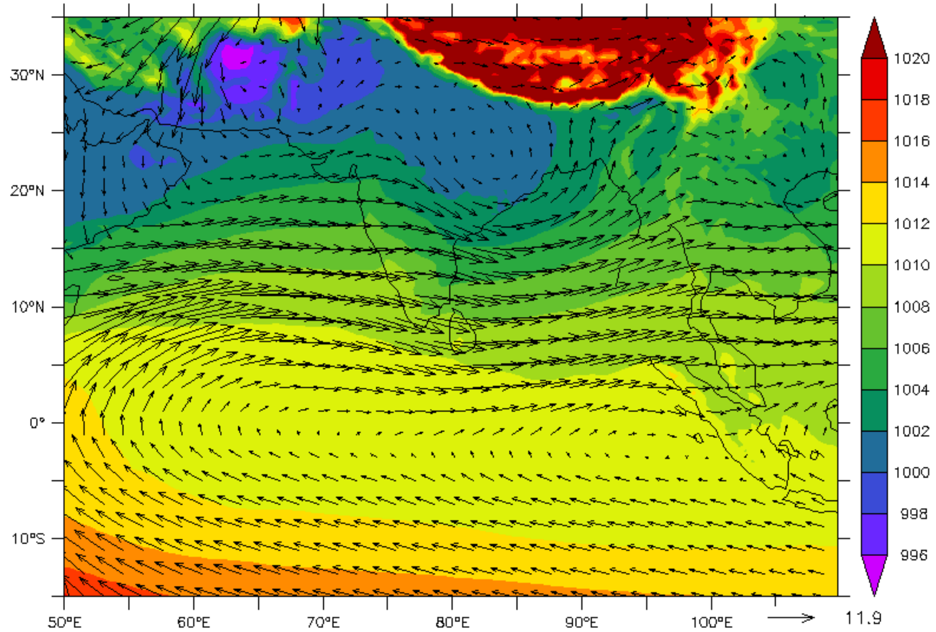
Streched grid global models

LMDZ model
run at Indian Institut of Tropical Meterology
35 km resolution over India

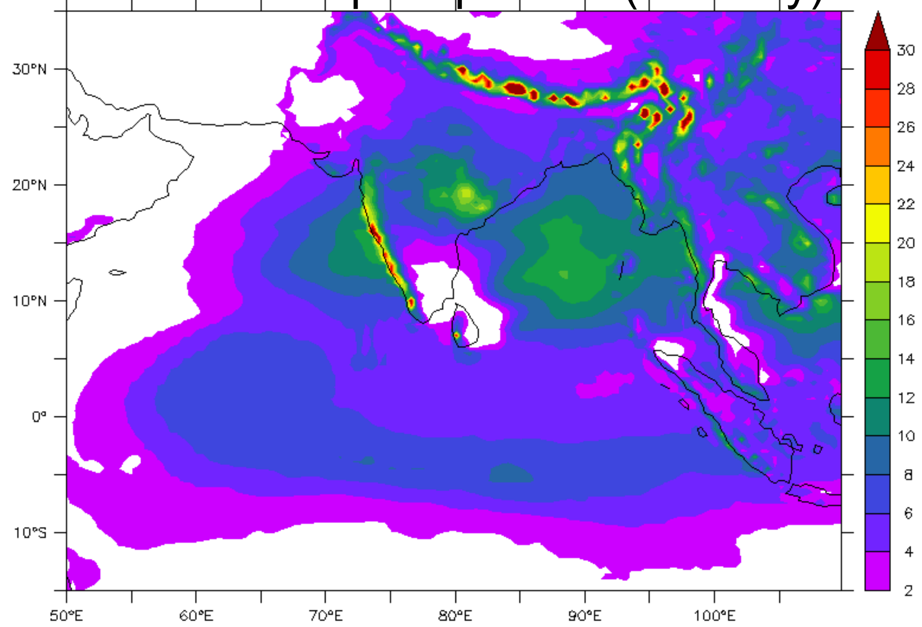
resolution



Mean JJAS SLP and 850 hPa winds



Mean JJAS precipitation (mm/day)



Statistical downscaling techniques

- Weather generators (e.g. Wilby 1998, Wilks,1999)
- Transfer functions (e.g. Huth 2002, Vrac 2007)
- Clustering (Zorita and von Storch 1998, Vrac and Naveau 2007)
- …

One example using GAM

Predictors (Vrac et al. 2007)***:***
low resolution from climate model
- Air temperature at the surface,
- Specific humidity

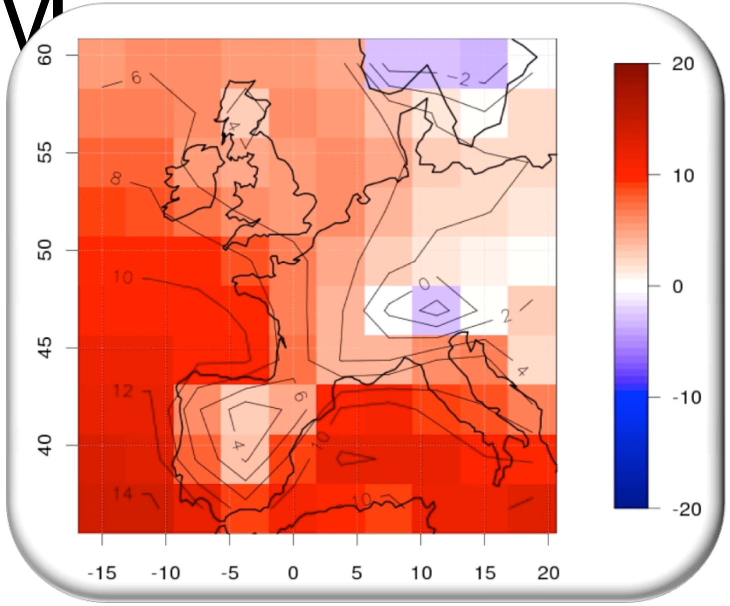
high resolution geographical information
- Diffusive continentality,
- Advective continentality,
- Local-scale topography

Predictand:
Local-scale temperature & precipitation (CRU)

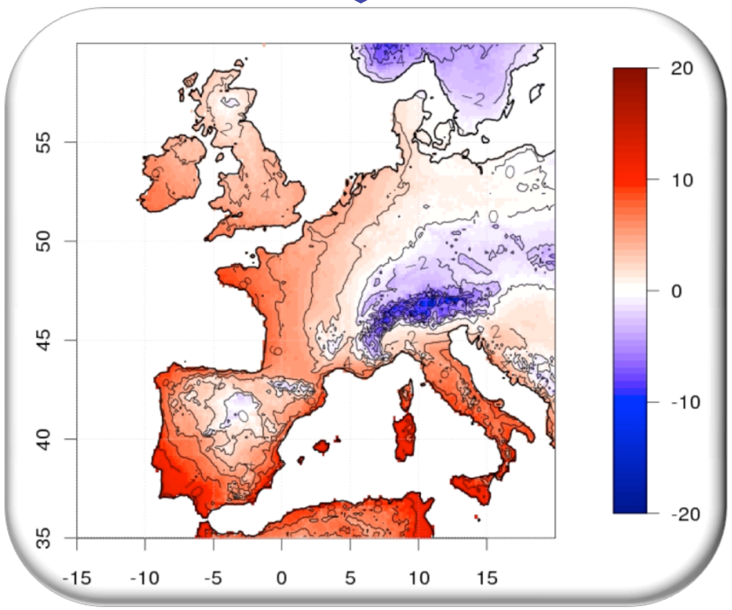
Generalized Additive Model
(GAM)

Downscaled temperatures & precipitation

GCM output

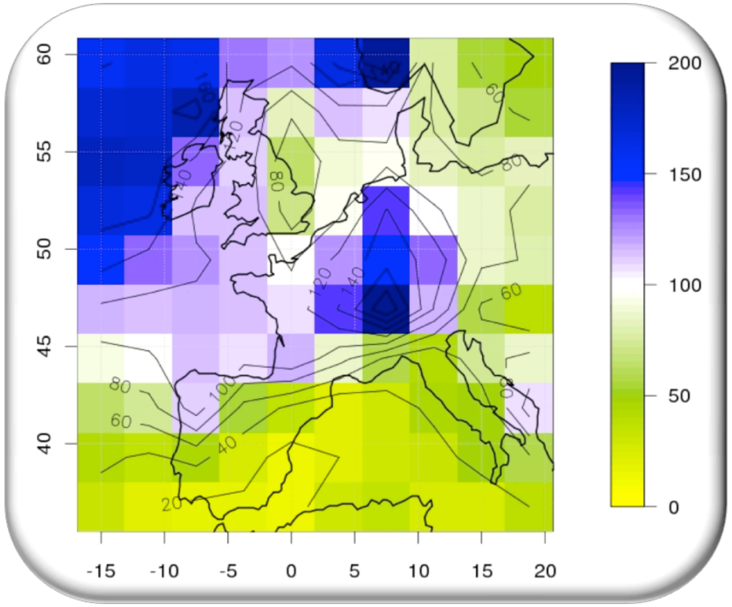


GCM downscaled

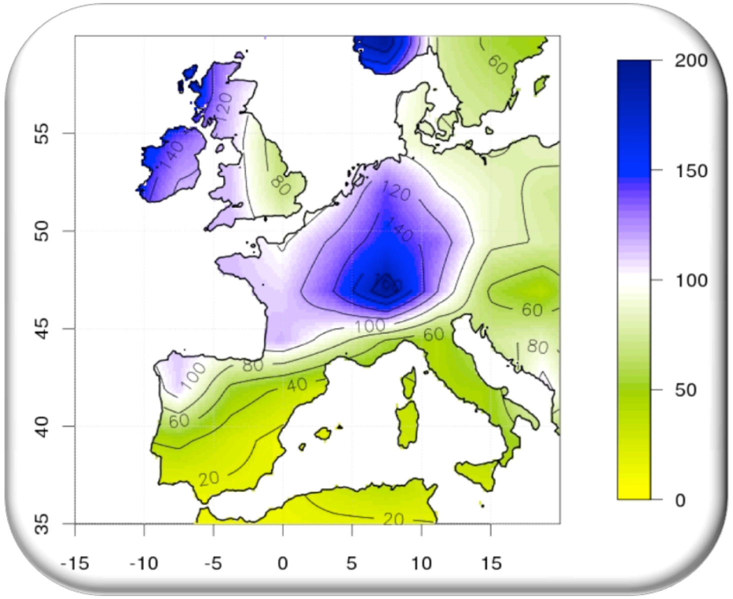


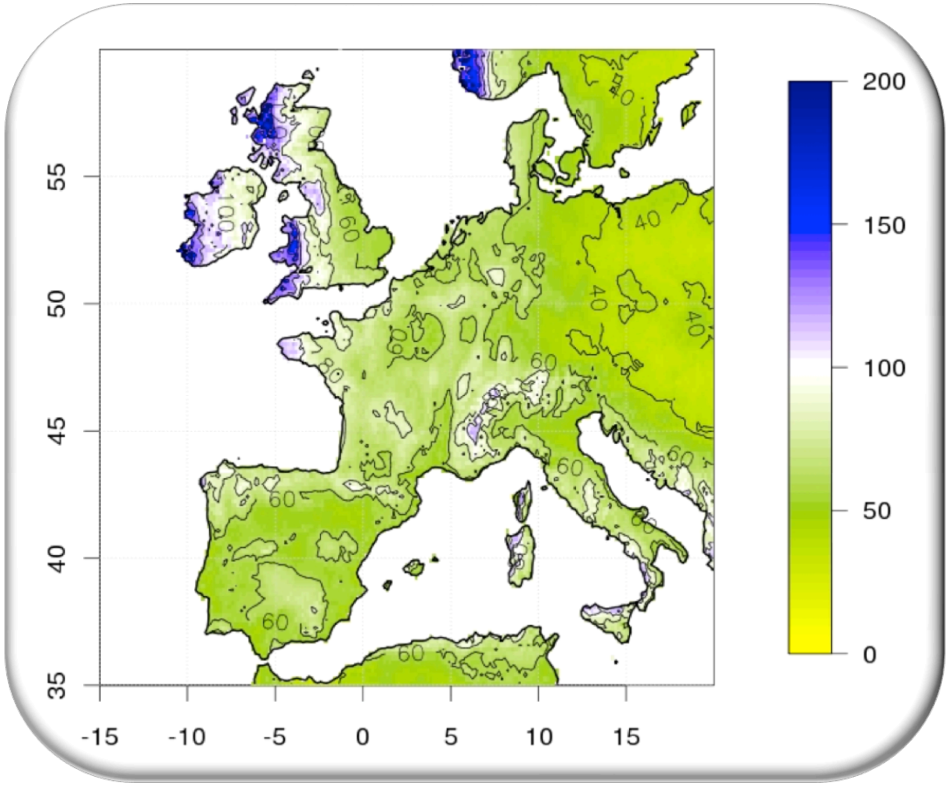
IPSL-LMDZ Precipitations (CTRL, January, in mm)

GCM output



GCM interpolated

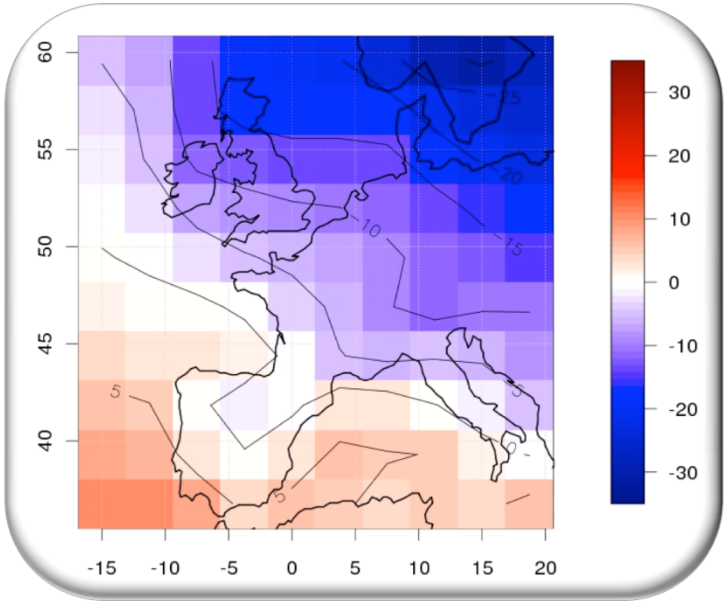




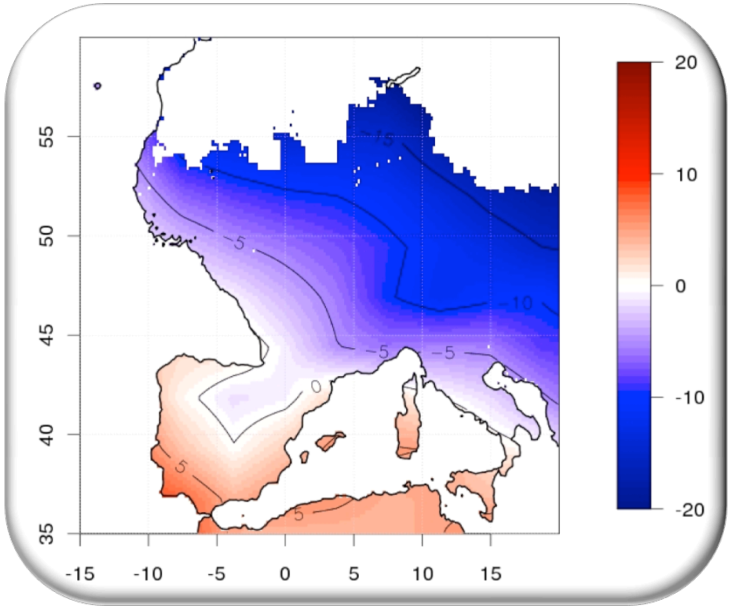
GCM downscaled

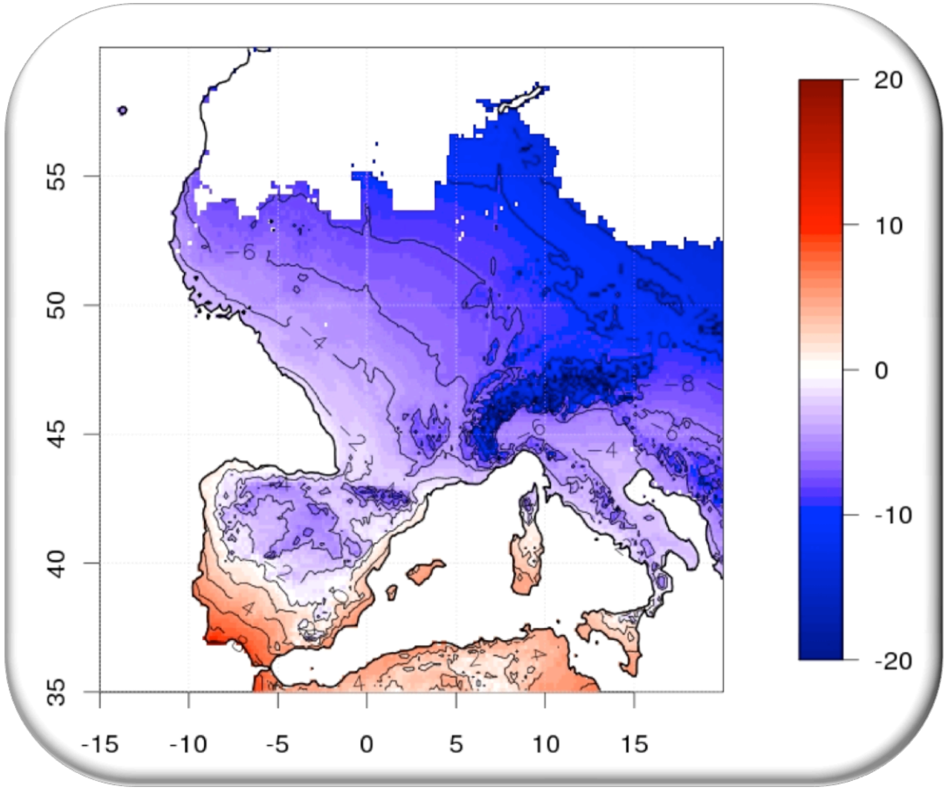
IPSL-LMDZ Temperatures (LGM, January, in °C)

GCM output



GCM interpolated

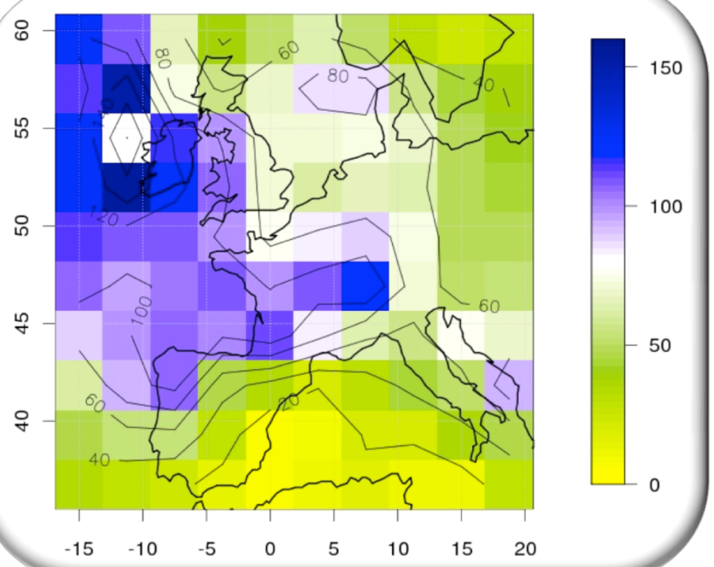




GCM downscaled

IPSL-LMDZ Precipitations (LGM, January, in mm)

GCM output



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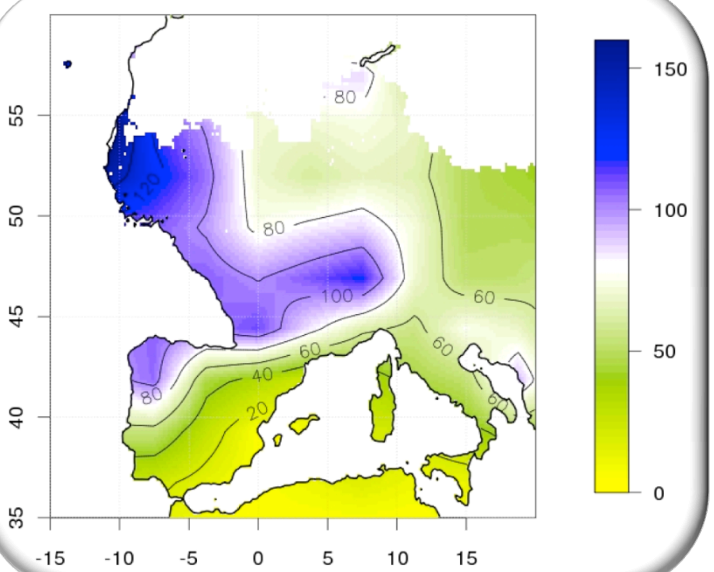
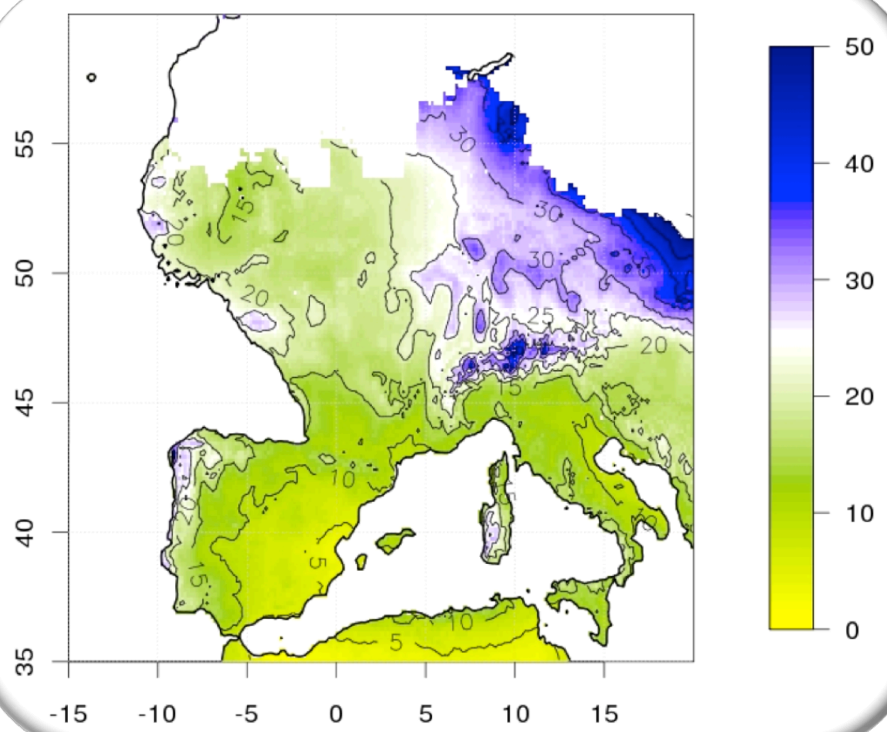




GCM downscaled

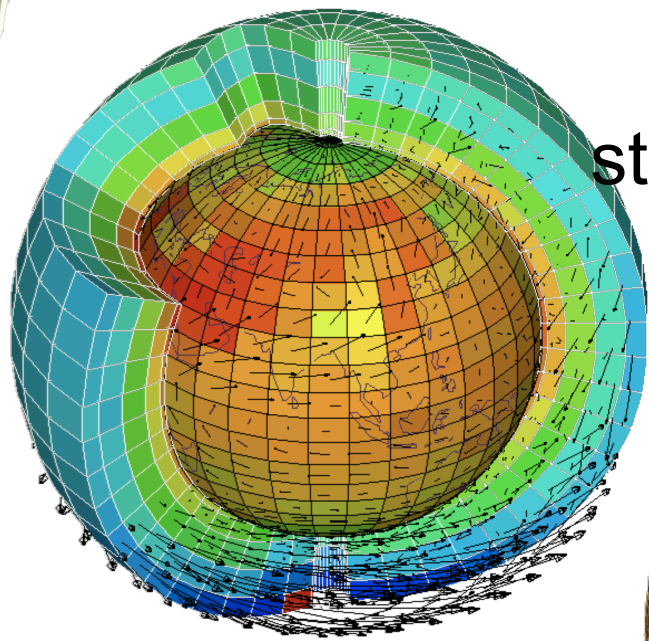
Masa Kageyama – Chennai 2011

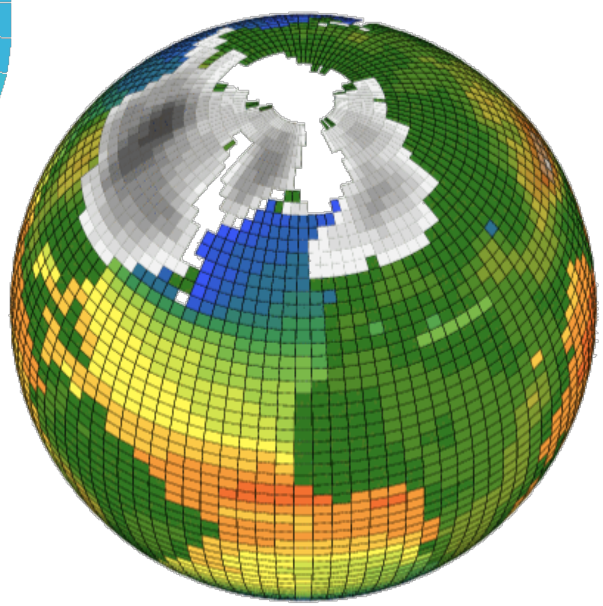
Take home message

- many climate models, including different processes, at different resolution, to tackle questions about climate changes on time scales from 100 to several 100000 years
- downscaling is possible but need global results first!
- each model has its limitations, multi-model studies best (but take more time!)

Introduction to palaeoclimate modelling

Part II : modelling stage 3 – type abrupt variability





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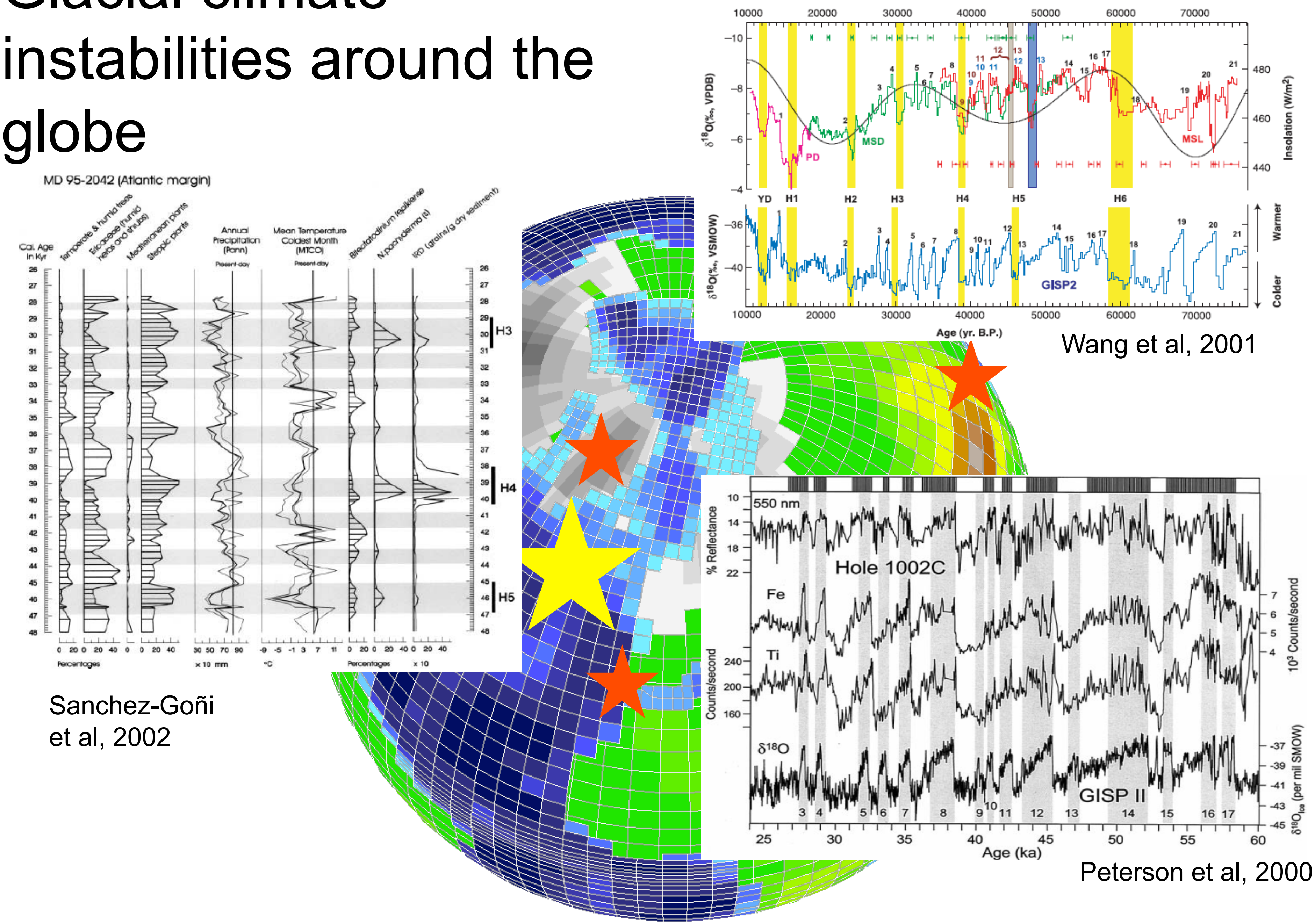
Charline Marzin, Pascale Braconnot, Didier Swingedouw, Juliette Mignot

Glacial climate instabilities around the globe



Sanchez-Goñi et al, 2002

Wang et al, 2001

Peterson et al, 2000

Objectives

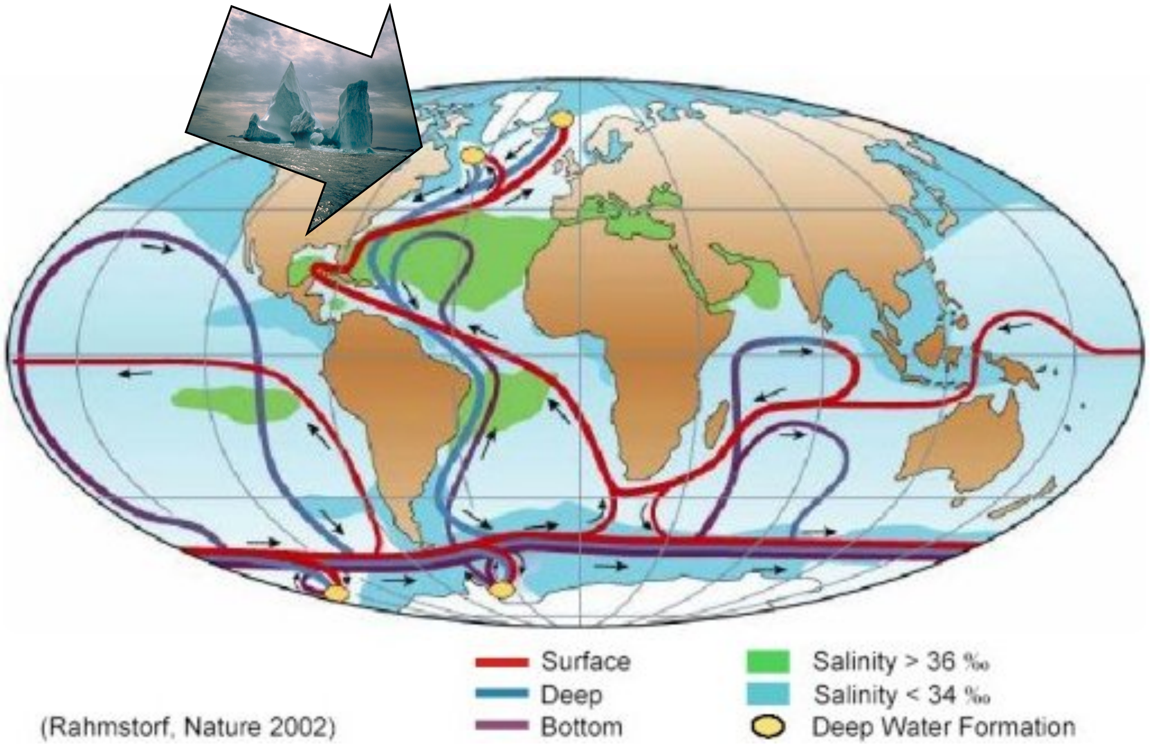
- Finding mechanisms for climatic teleconnections during glacial abrupt events:
  - Can we model them ?
  - If yes, can we understand them ?
- Focus of this talk:
  - North Atlantic/Europe
  - ITCZ shifts
  - Indian monsoon variations

Modelling the climatic impacts of a Heinrich event

Assume that these impacts are related to near collapse of Atlantic Meridional Overturning Circulation

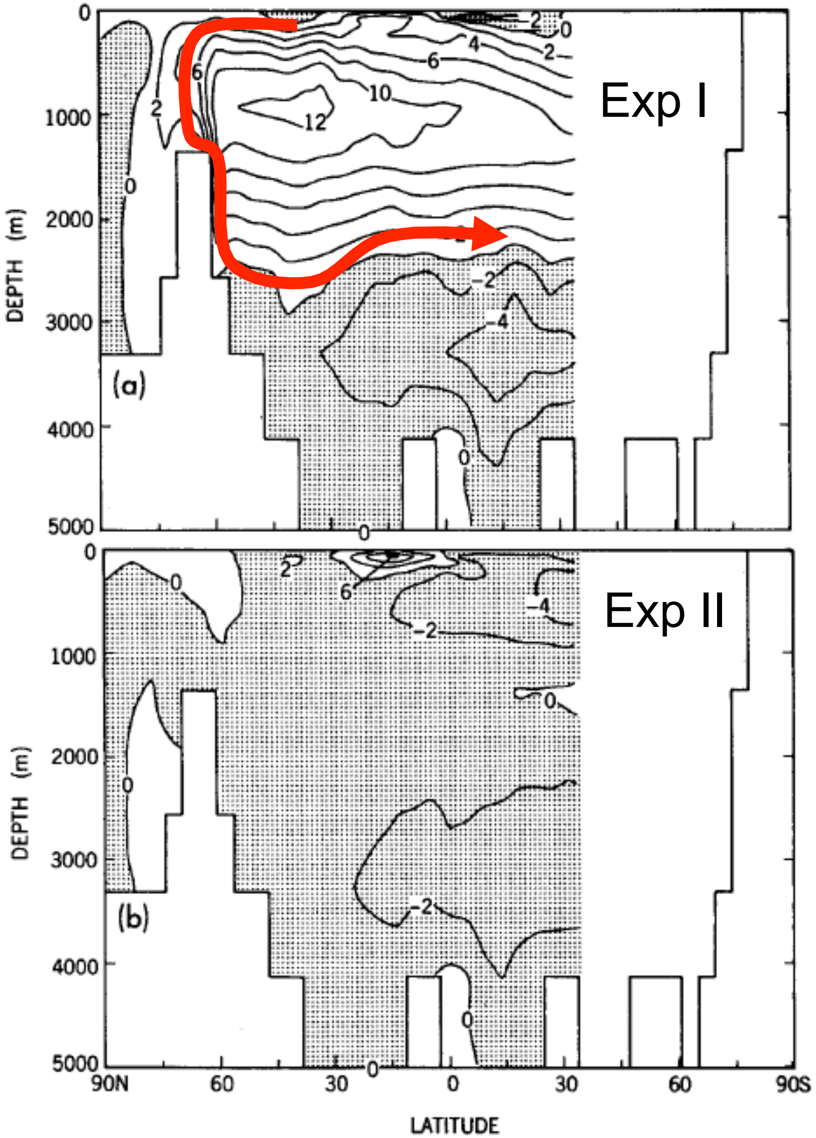
→ Study teleconnections for such a collapse, triggered by a fresh water flux imposed in the North Atlantic

→ Extend results to resumption of AMOC



(Rahmstorf, Nature 2002)

Previous studies. 1. GCMs



S. MANABE AND R. J. STOUFFER

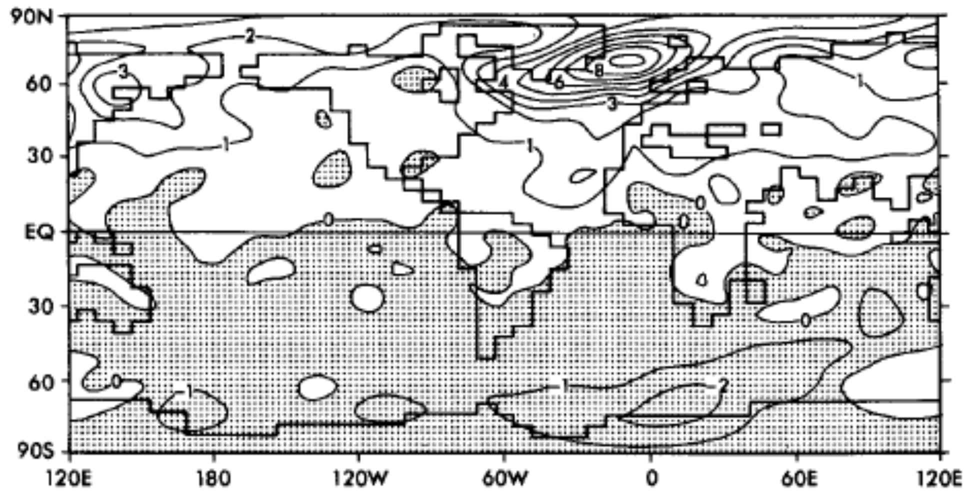
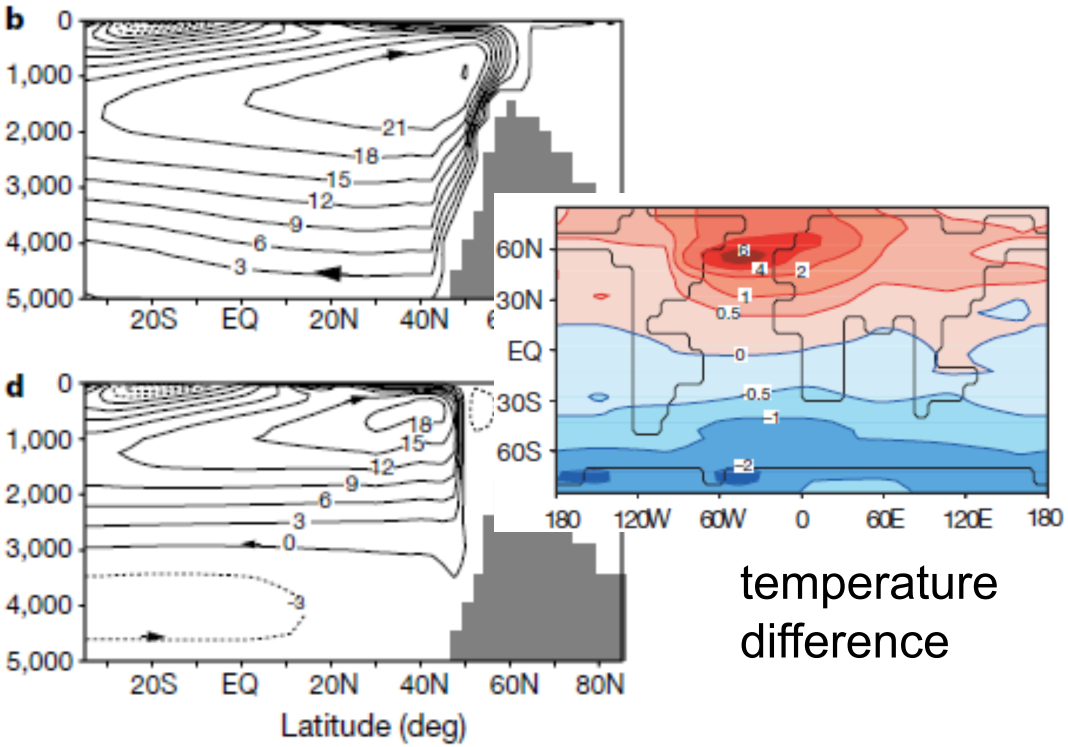


FIG. 22. Difference in surface air temperature (degrees Celsius) between experiments I and II.

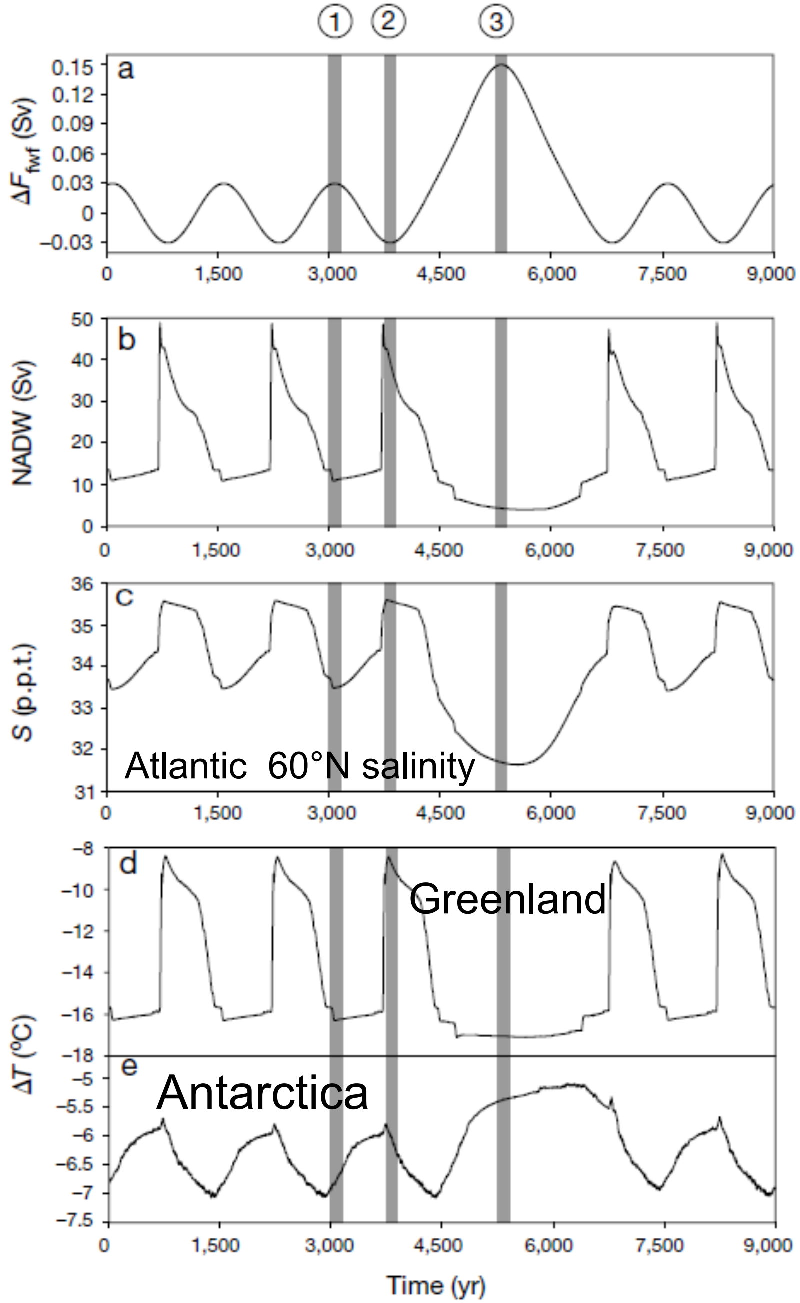
Previous studies. 2. EMICS

Ganopolski and Rahmstorf 2001
(CLIMBER2)

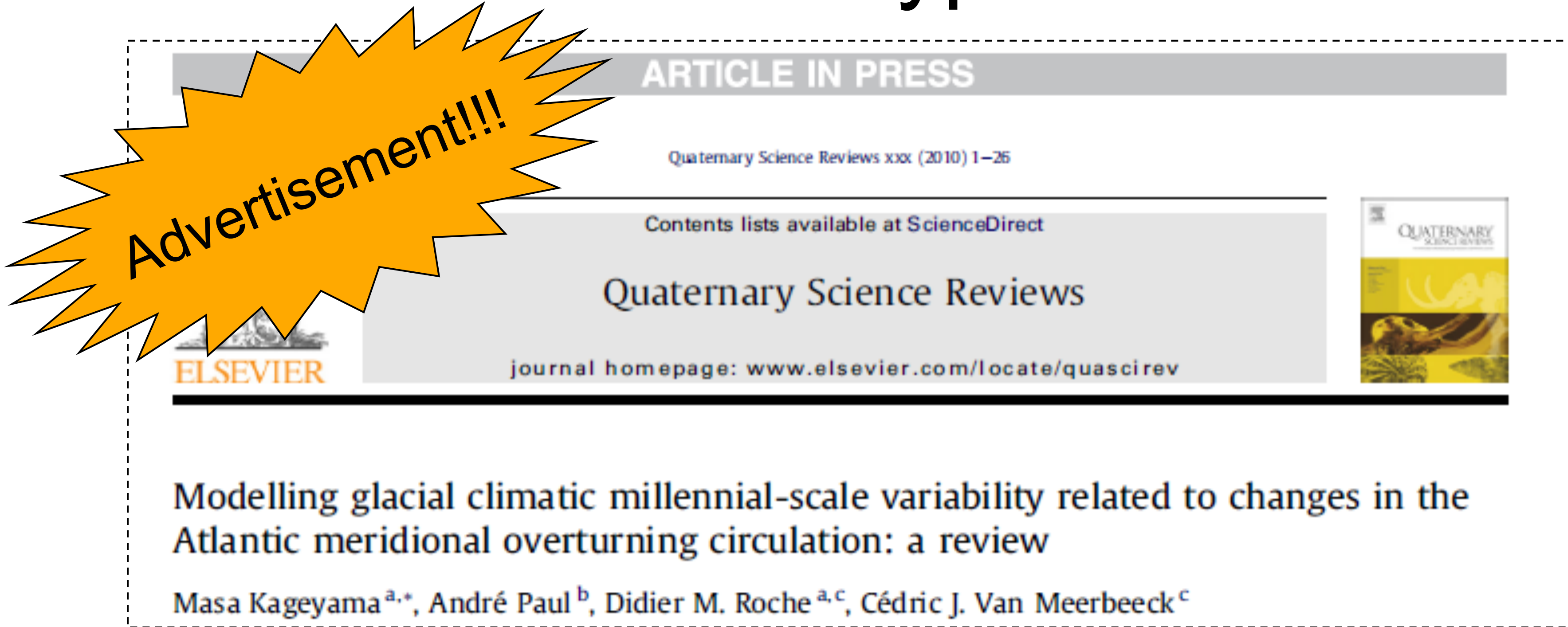
→ apply fresh water flux in North Atlantic to trigger abrupt events



temperature difference



Many studies since, with different models and different types of models



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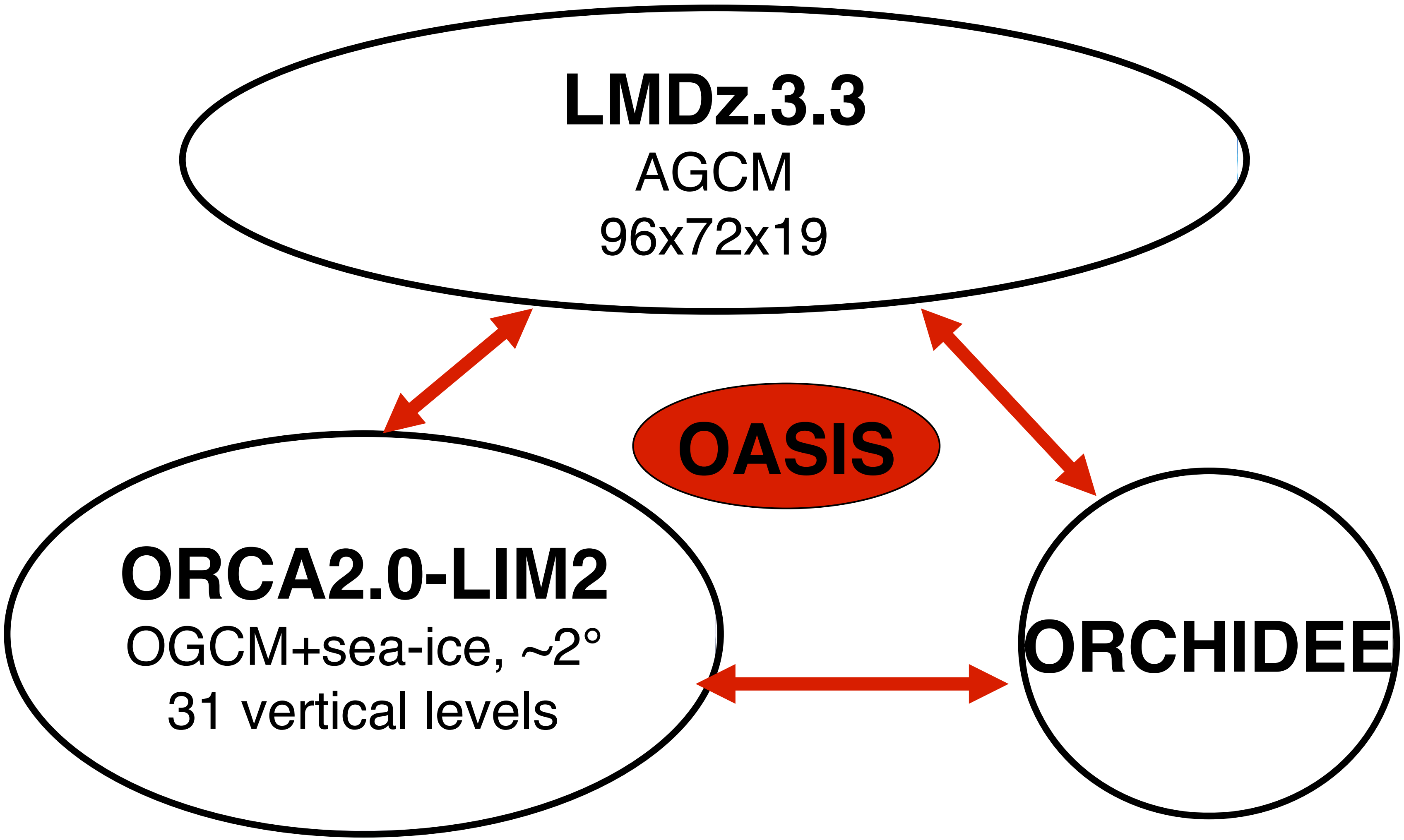
ELSEVIER

Modelling glacial climatic millennial-scale variability related to changes in the Atlantic meridional overturning circulation: a review

Masa Kageyama [a,*], André Paul [b], Didier M. Roche [a,c], Cédric J. Van Meerbeeck [c]

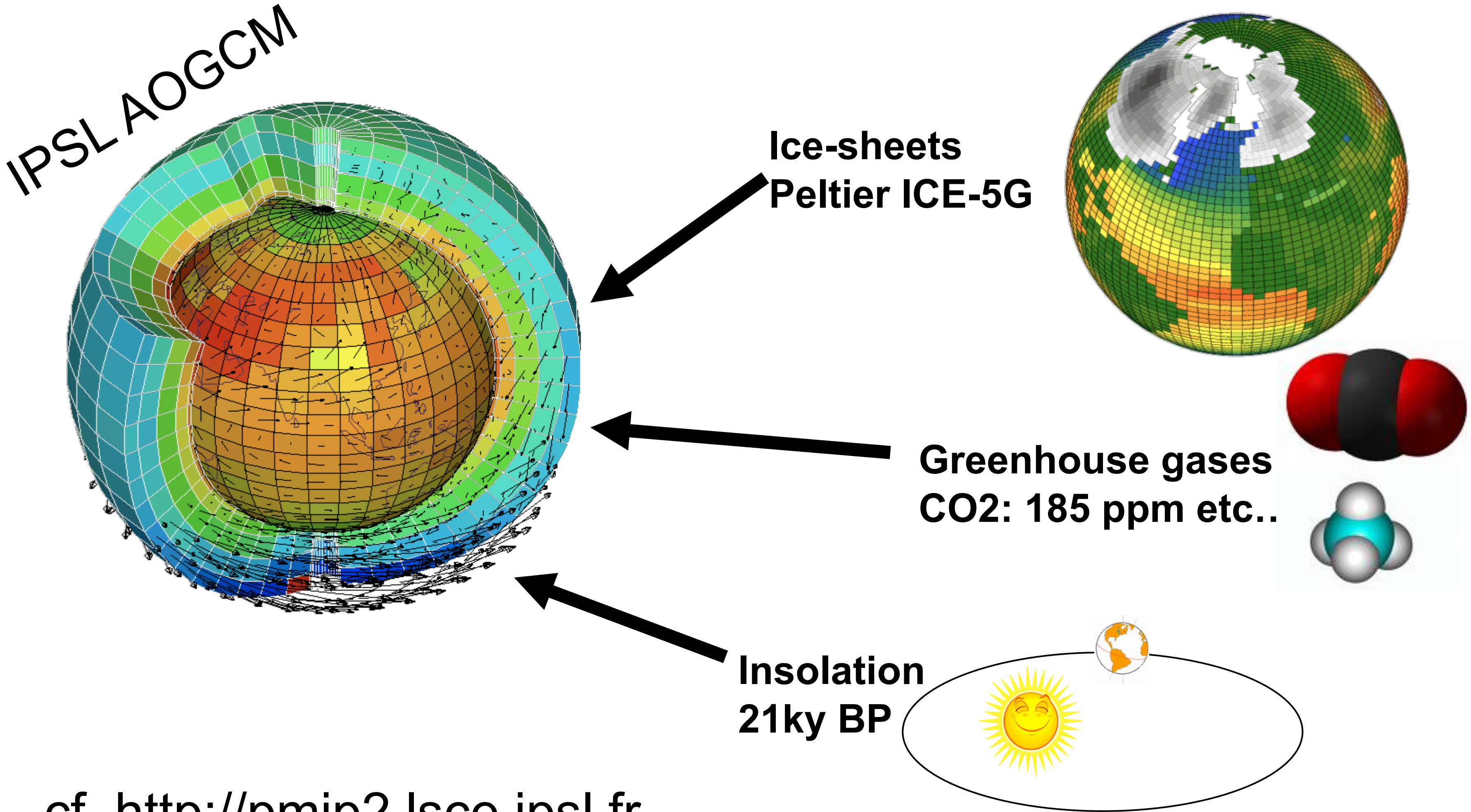
- 2 models: UVic and LOVECLIM
- Comparing climate response to FW forcing for different boundary conditions

The IPSL_CM4 model



Marti et al, 2010

Modelling the reference state : the LGM climate

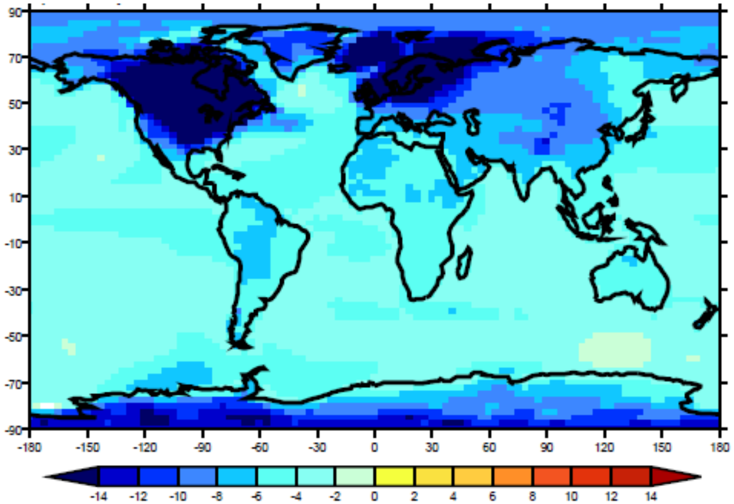


cf. http://pmip2.lsce.ipsl.fr

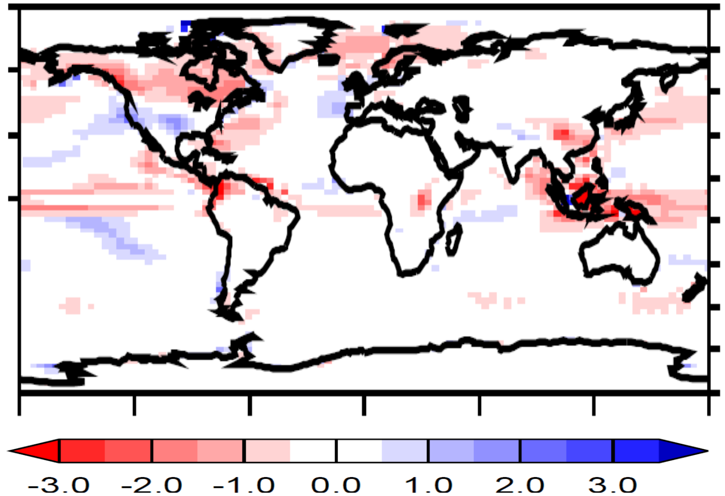
Paleoclimate Modelling Intercomparison Project Phase II

The reference LGM climate: run LGMc

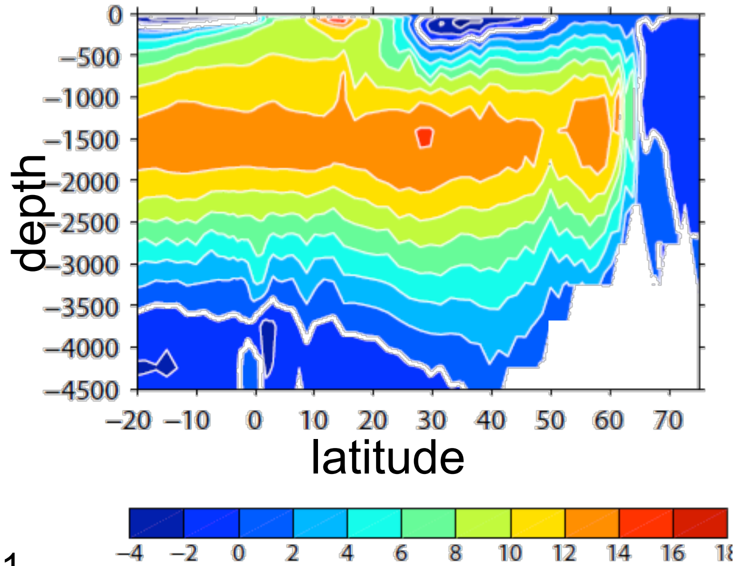
Mean annual temperature (°C)
(anomaly % PI)



Mean annual precipitation (mm/d)
(anomaly % PI)



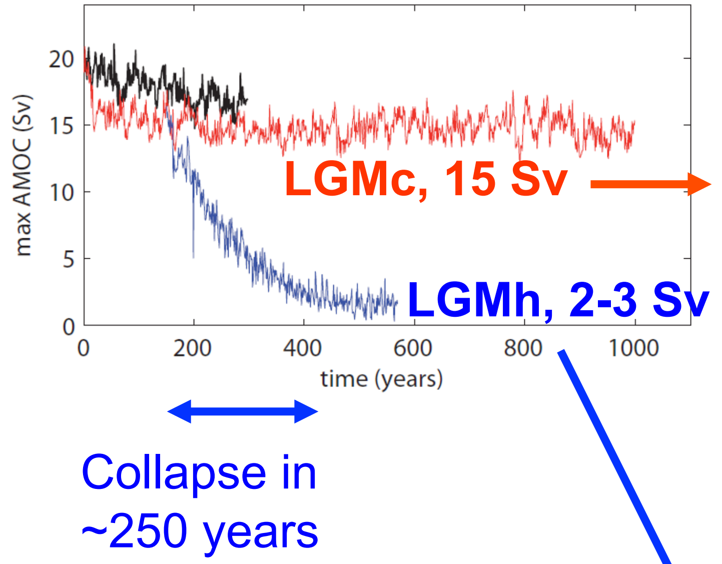
AMOC (Sv)

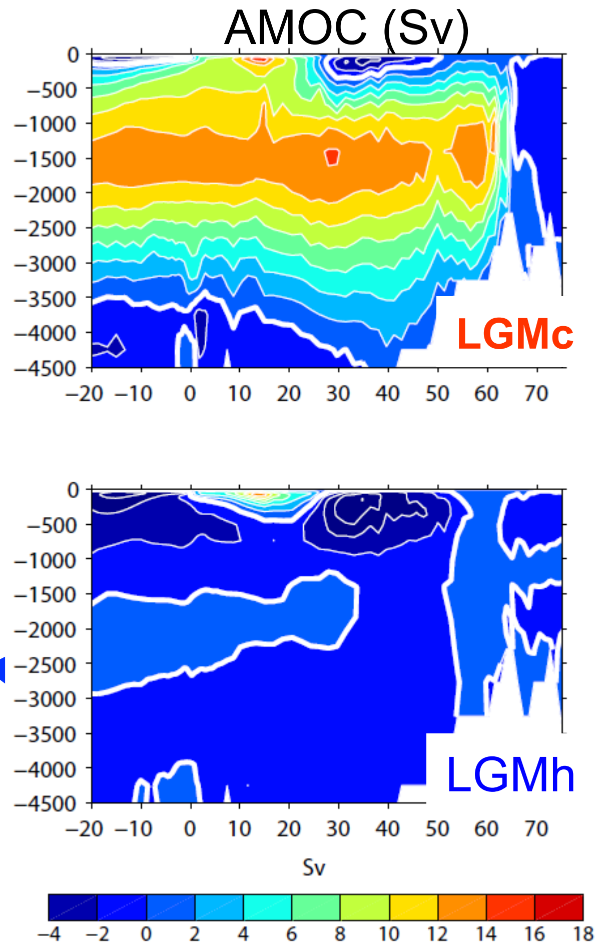


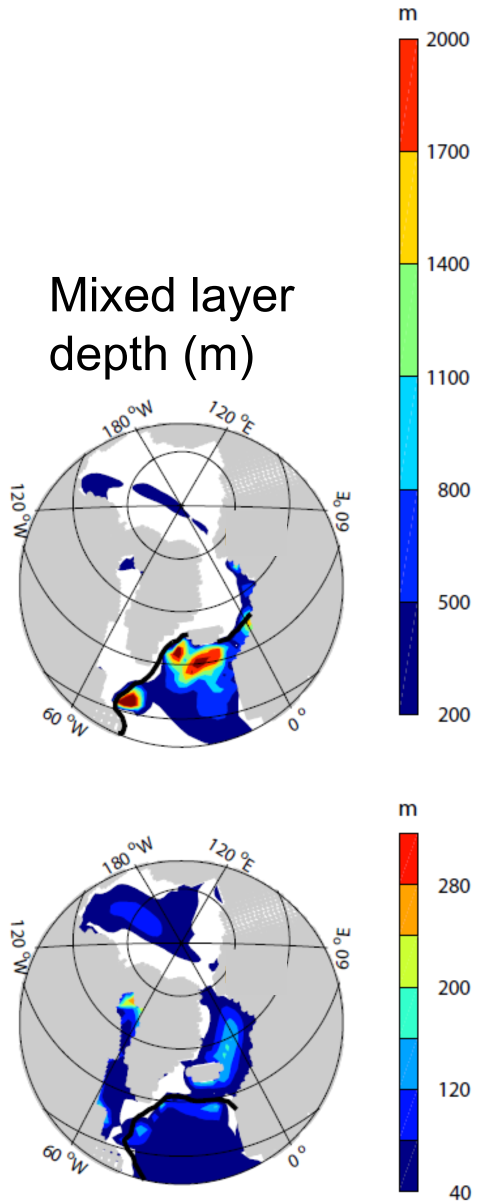
Masa Kageyama – Chennai 2011

Hosing experiment: LGMh

+0.1 Sv in the North Atlantic and the Arctic for 420 years,
Starting at year 150 of reference run LGMc



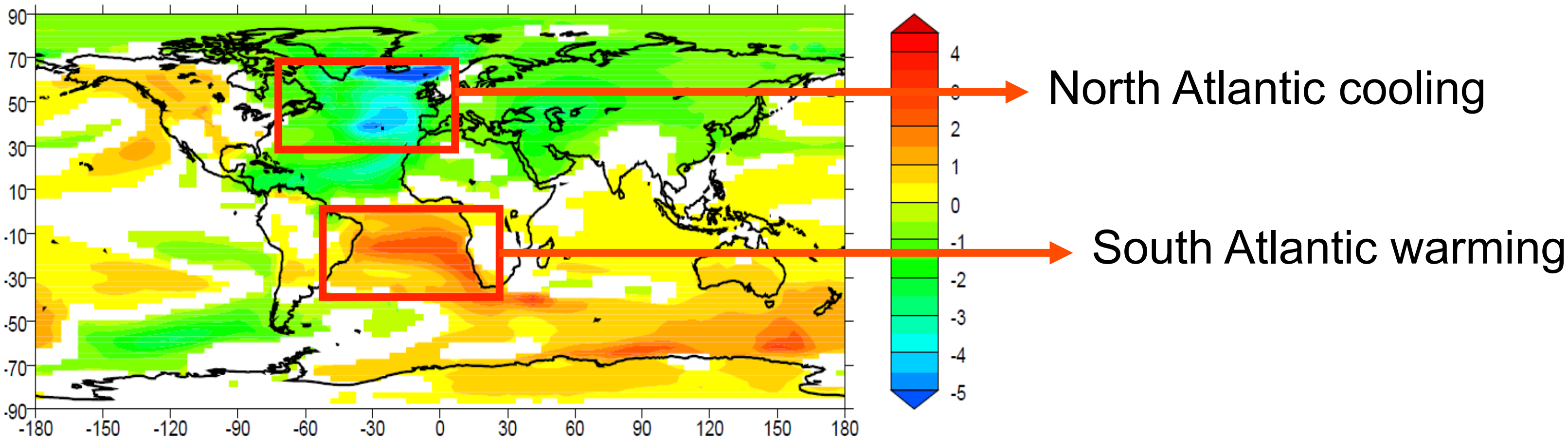




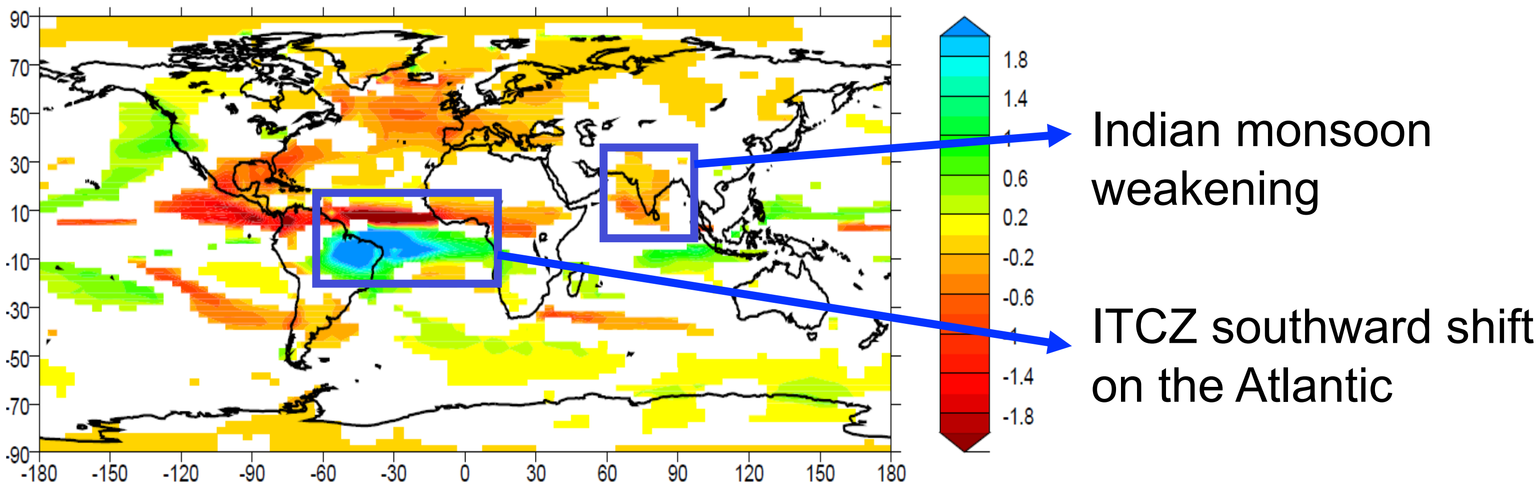
Kageyama et al, CP, 2009

Climatic impacts

LGMh – LGMc mean annual temperature



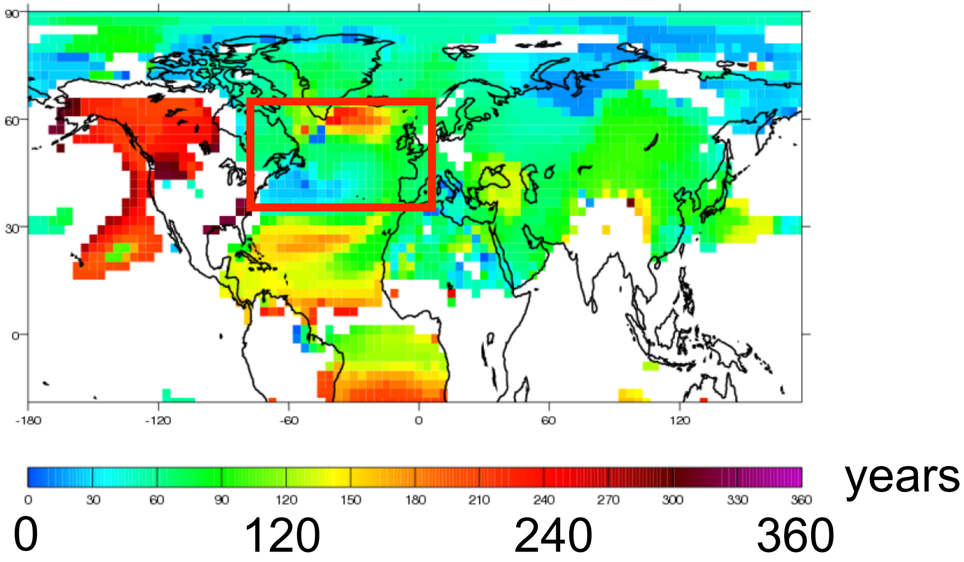
LGMh – LGMc mean annual precipitation



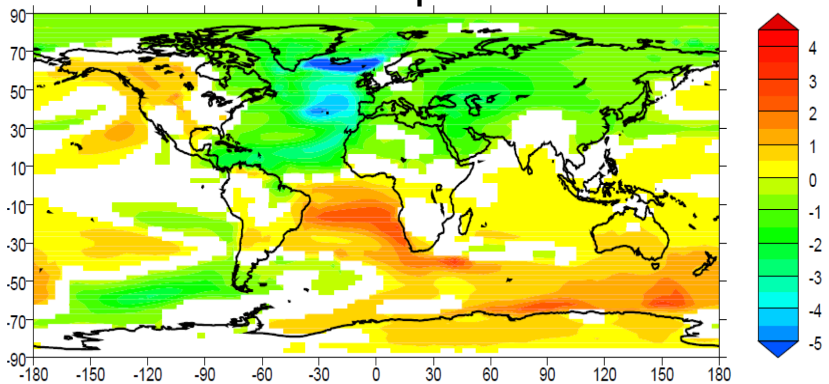
Kageyama et al, CP, 2009

timing of climate changes

year after which 50% of the response is reached for at least 50 years



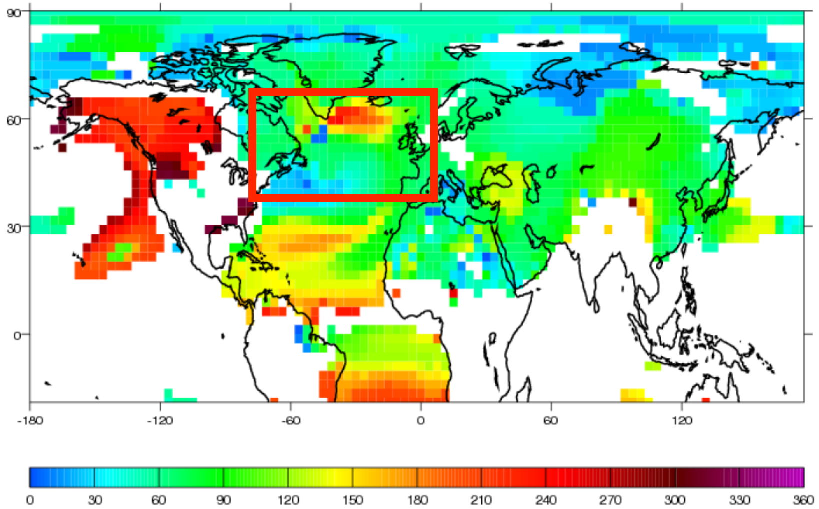
mean annual temperature



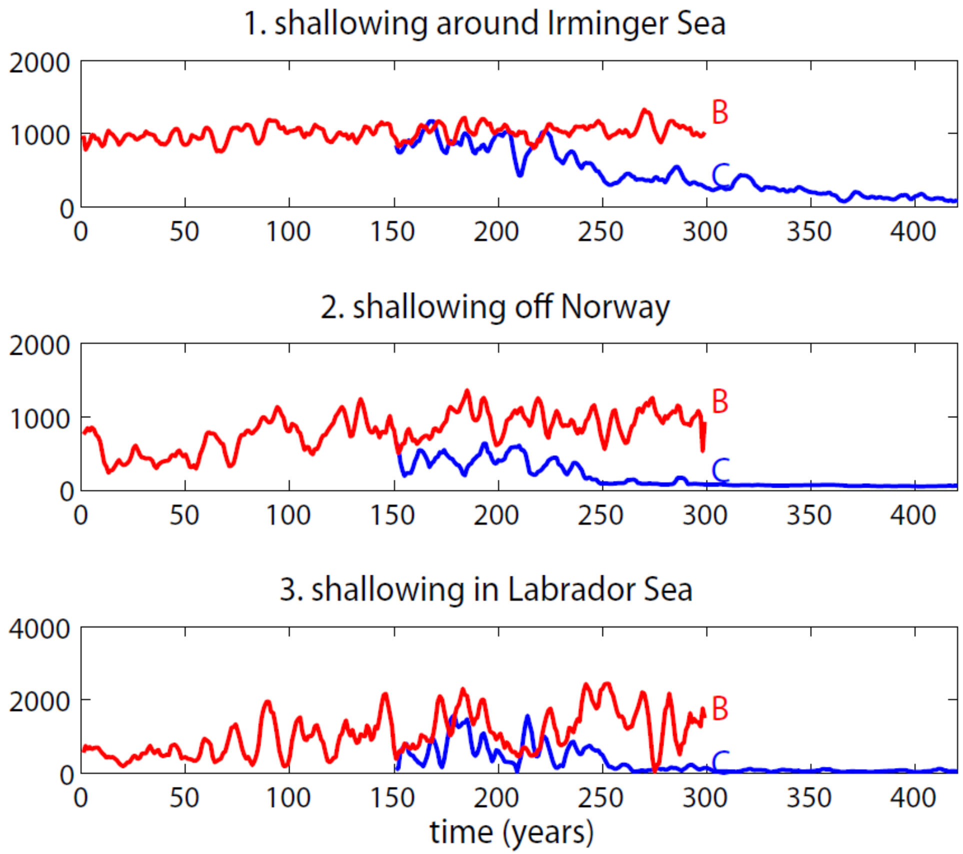
Kageyama et al, CP, 2009

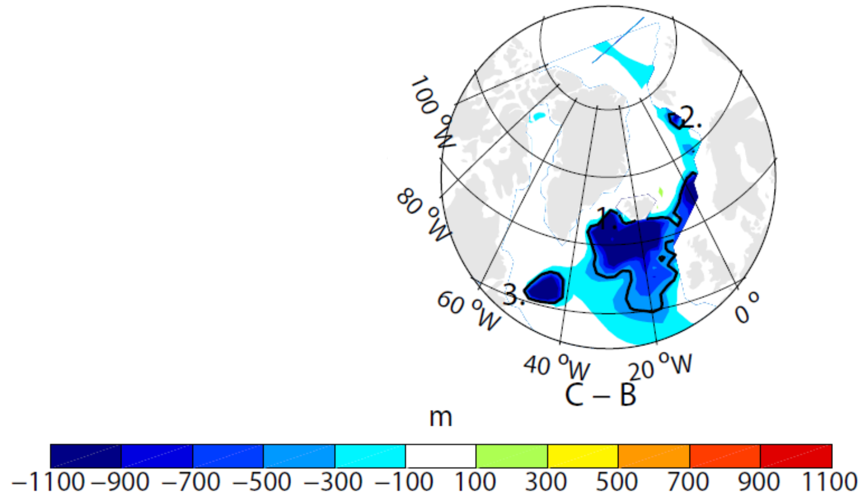
North Atlantic: timing of shallowing of each convection site

timing of temperature response



Kageyama et al, CP, 2009

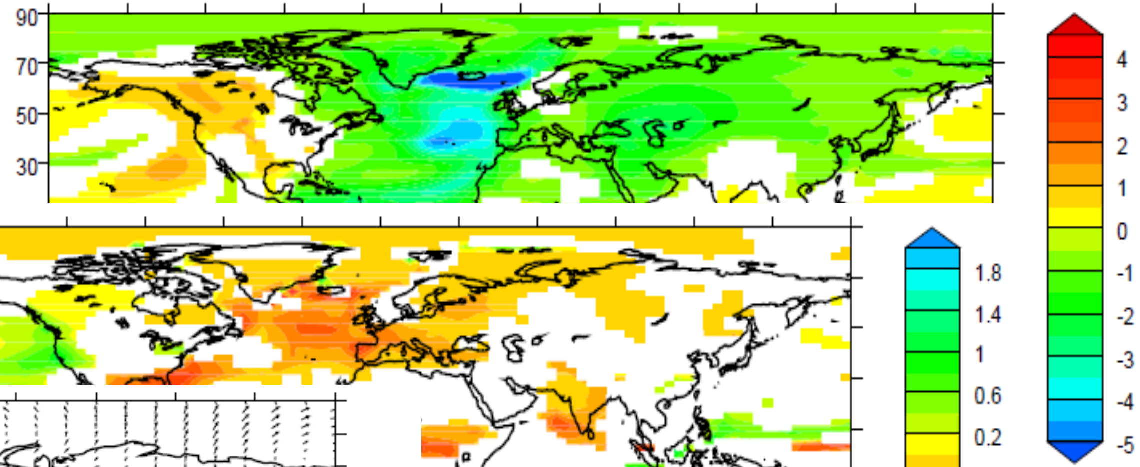




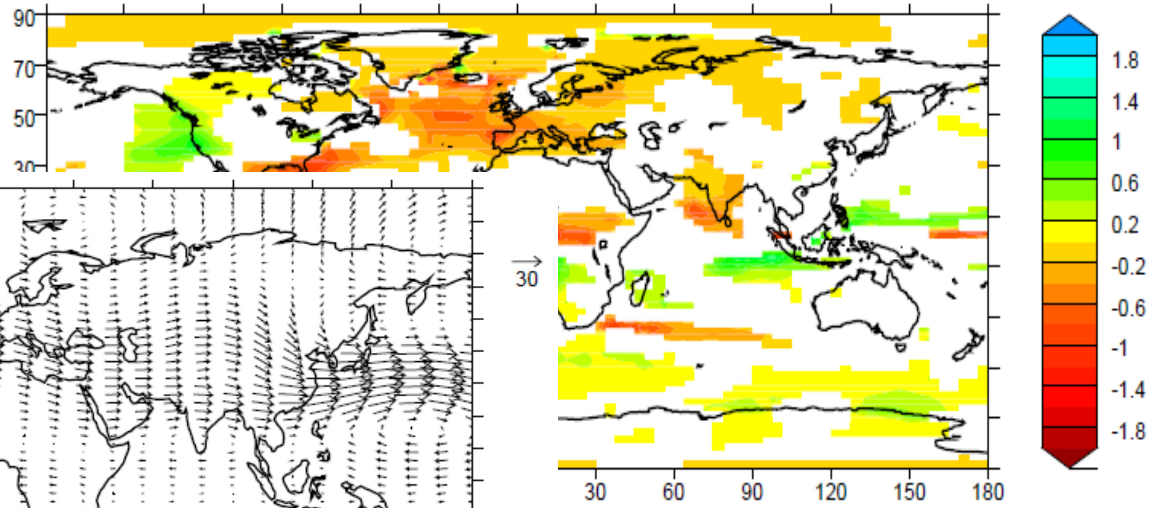
Masa Kageyama – Chennai 2011

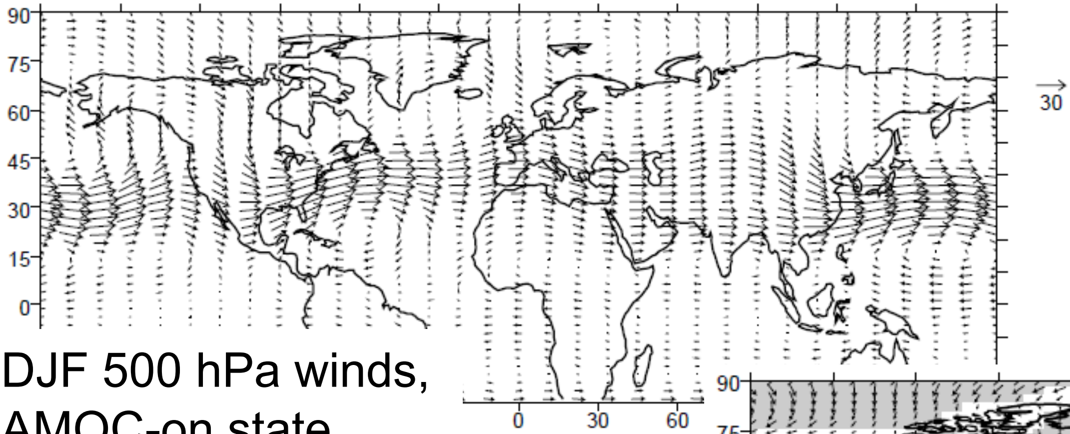
North Atlantic/Europe

Δ(MAT)

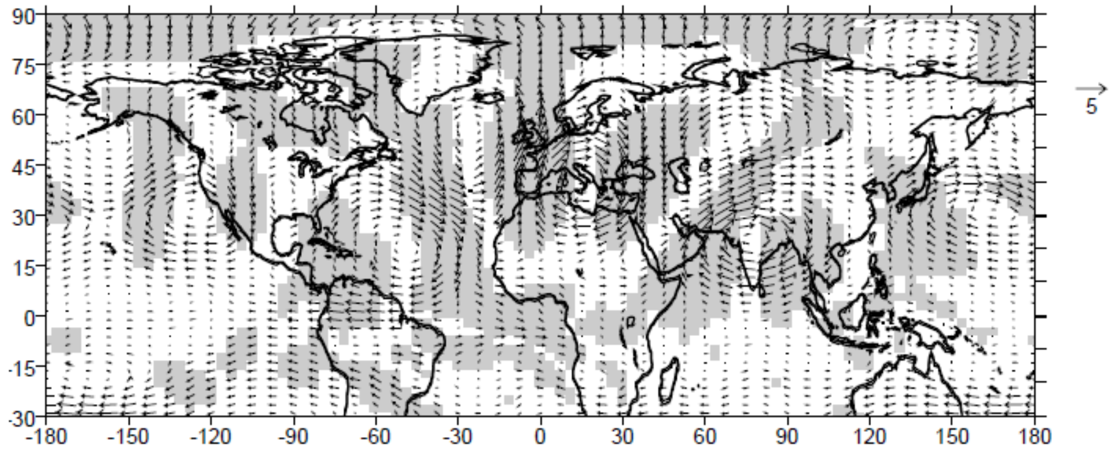


Δ(Annual Precipitation)





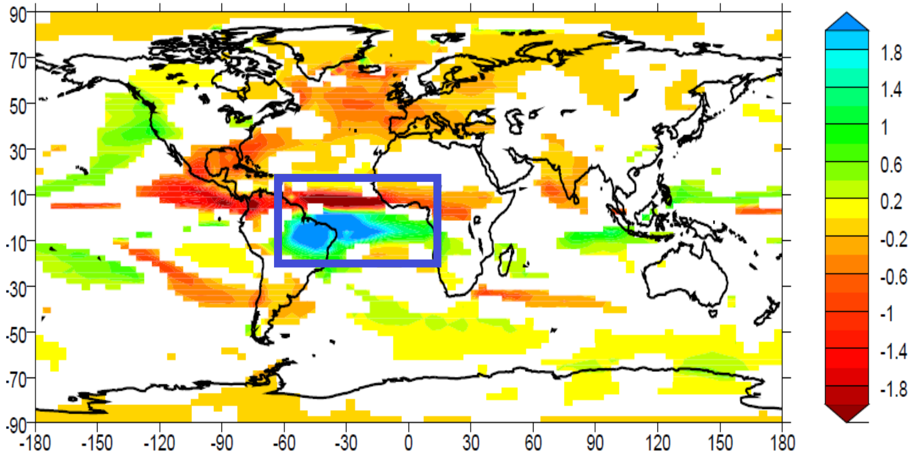
DJF 500 hPa winds,
AMOC-on state



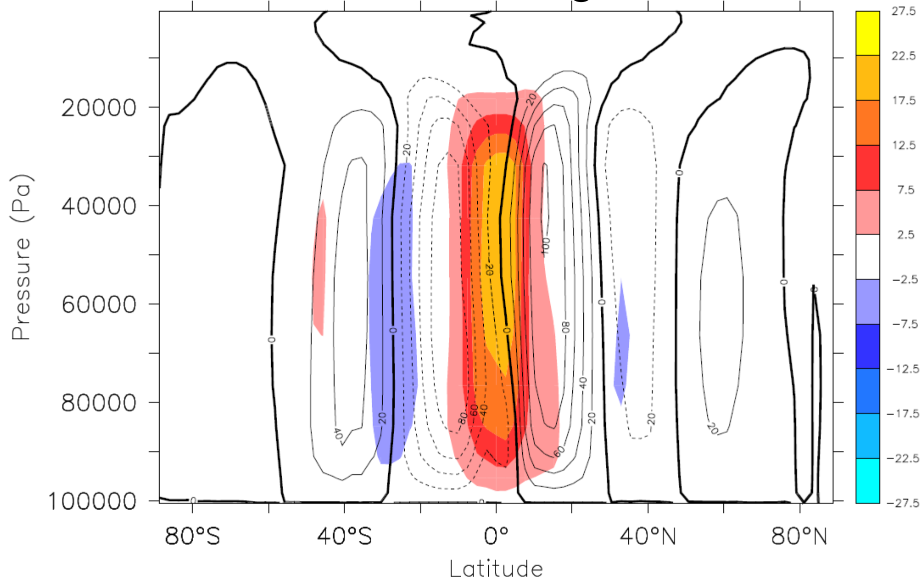
DJF 500 hPa winds,
AMOC-off – AMOC-on

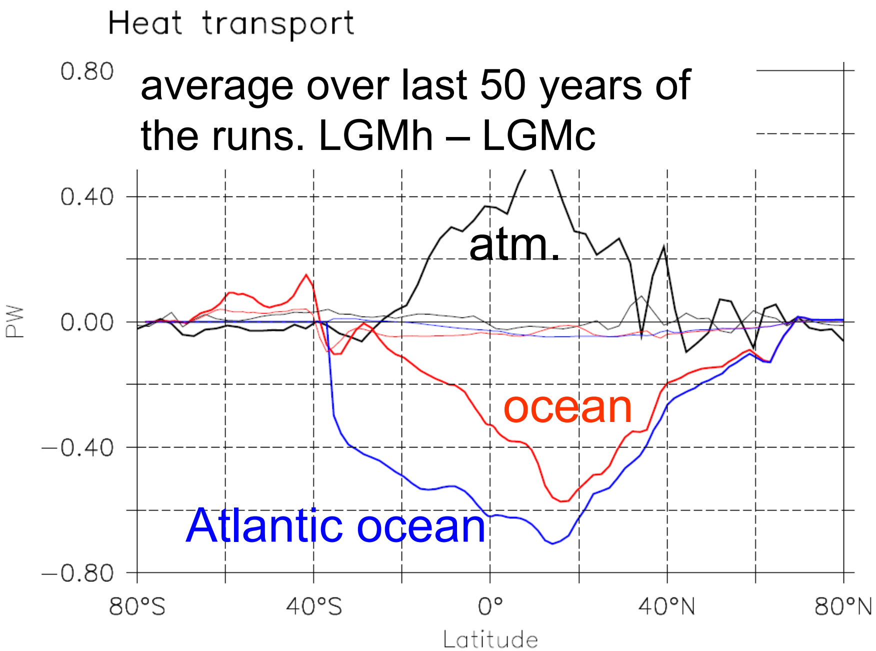
Atlantic tropical response: ITCZ shift

LGMh – LGMc mean annual precipitation

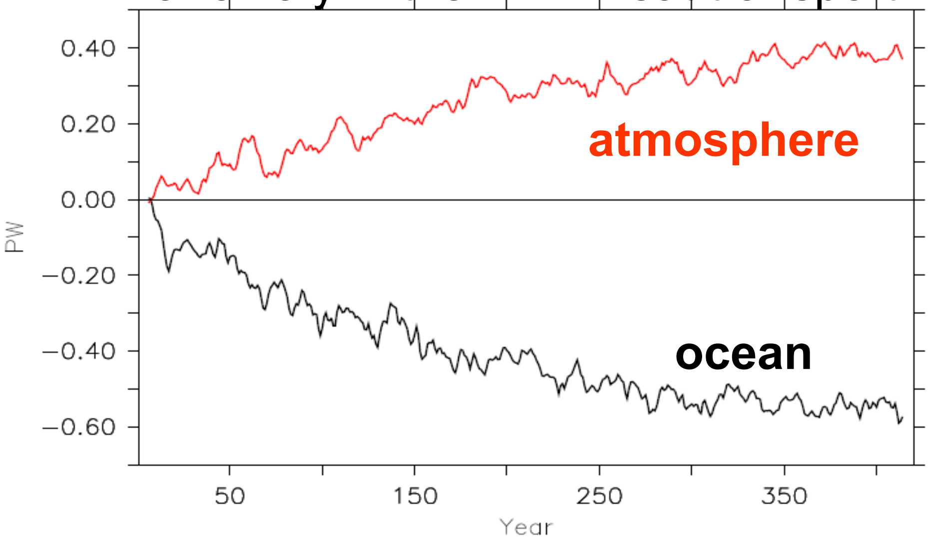


atm. meridional streamfunction
Contours: LGMb, shading: LGMh - LGMc



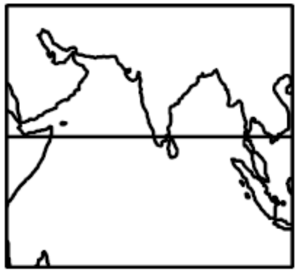


anomaly in the 17°N heat transport



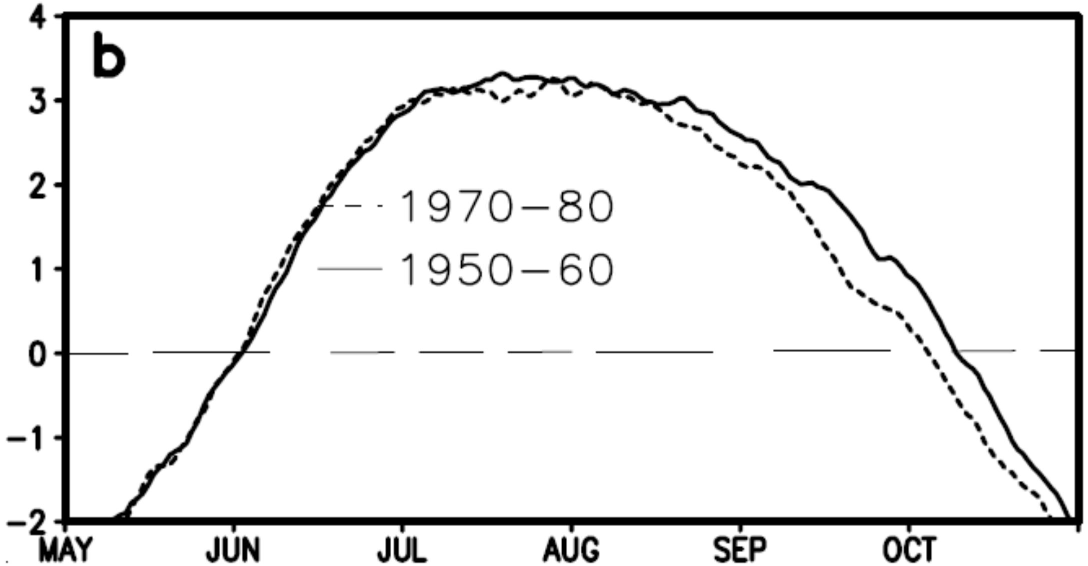
Indian monsoon diagnostic:

- Upper troposphere temperature gradient (ΔTT)



northern box (30-110°E, 10-35°N)

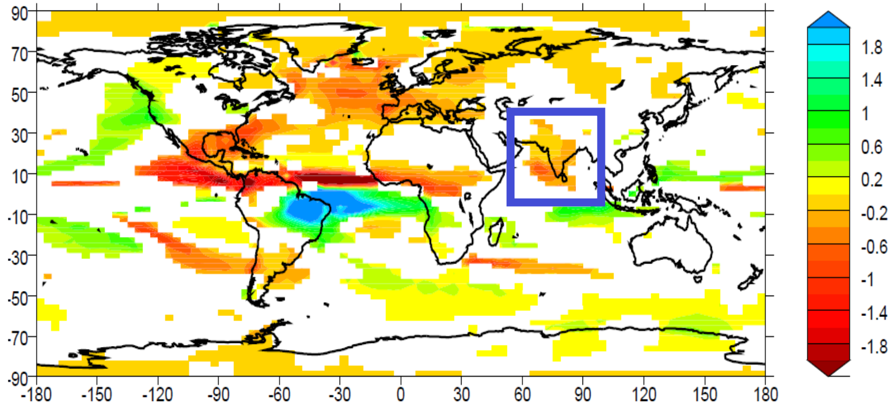
southern box (30-110°E, 15°S-10°N)



Goswami and Xavier 2005, Goswami et al 2006)

Indian monsoon

LGMh – LGMc mean annual precipitation

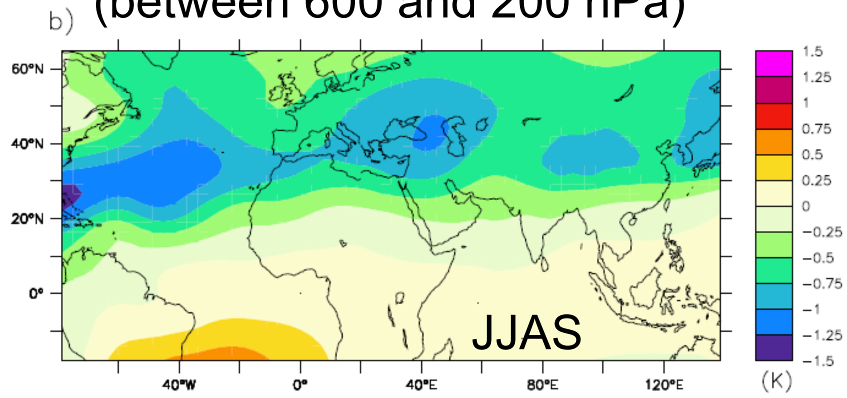


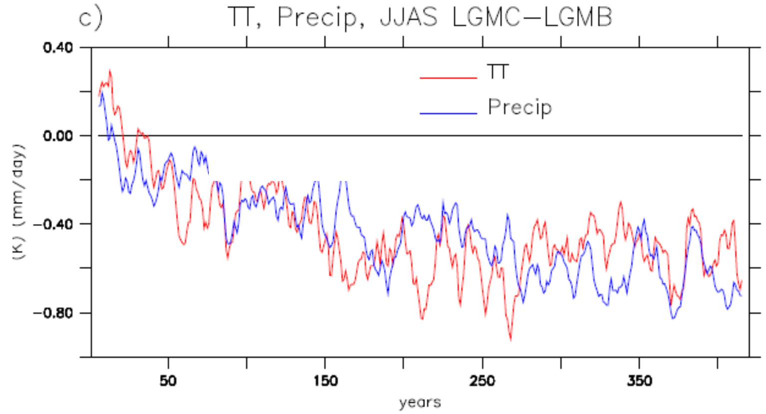
1st hypothesis:
(in Kageyama et al, CP, 2009)

North Atlantic cooling
→ Siberian cooling of upper tropospheric temperature
→ Indian monsoon decrease

→ Test with AGCM

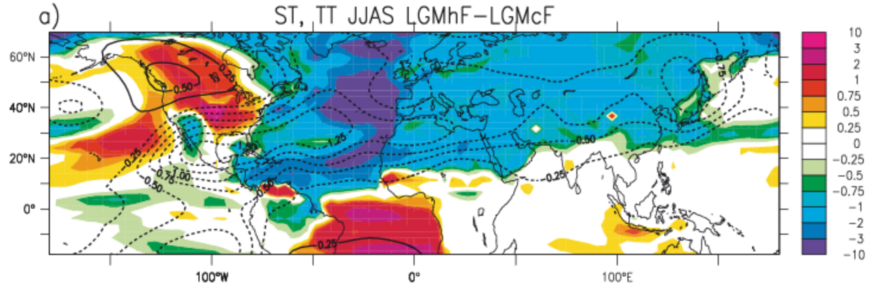
Upper tropospheric temperature (between 600 and 200 hPa)





Anomalies (LGMh – LGMc) in ΔTT between a northern (30–100°E, 10–35°N) and a southern box (30–100°E, 15°S–10°N) and in precipitation over India

Impact of SST changes in different regions



Tests with Atmospheric GCM

- **LGMcF**: forced by SSTs from LGMc

- **LGMhF**: forced by SSTs from LGMh

- **LGMhNA**: forced by SSTs from LGMh over the North Atlantic only:

→ Impact of **North Atlantic cooling**

- **LGMhTA**: forced by SSTs from LGMh over the **tropical Atlantic** only:

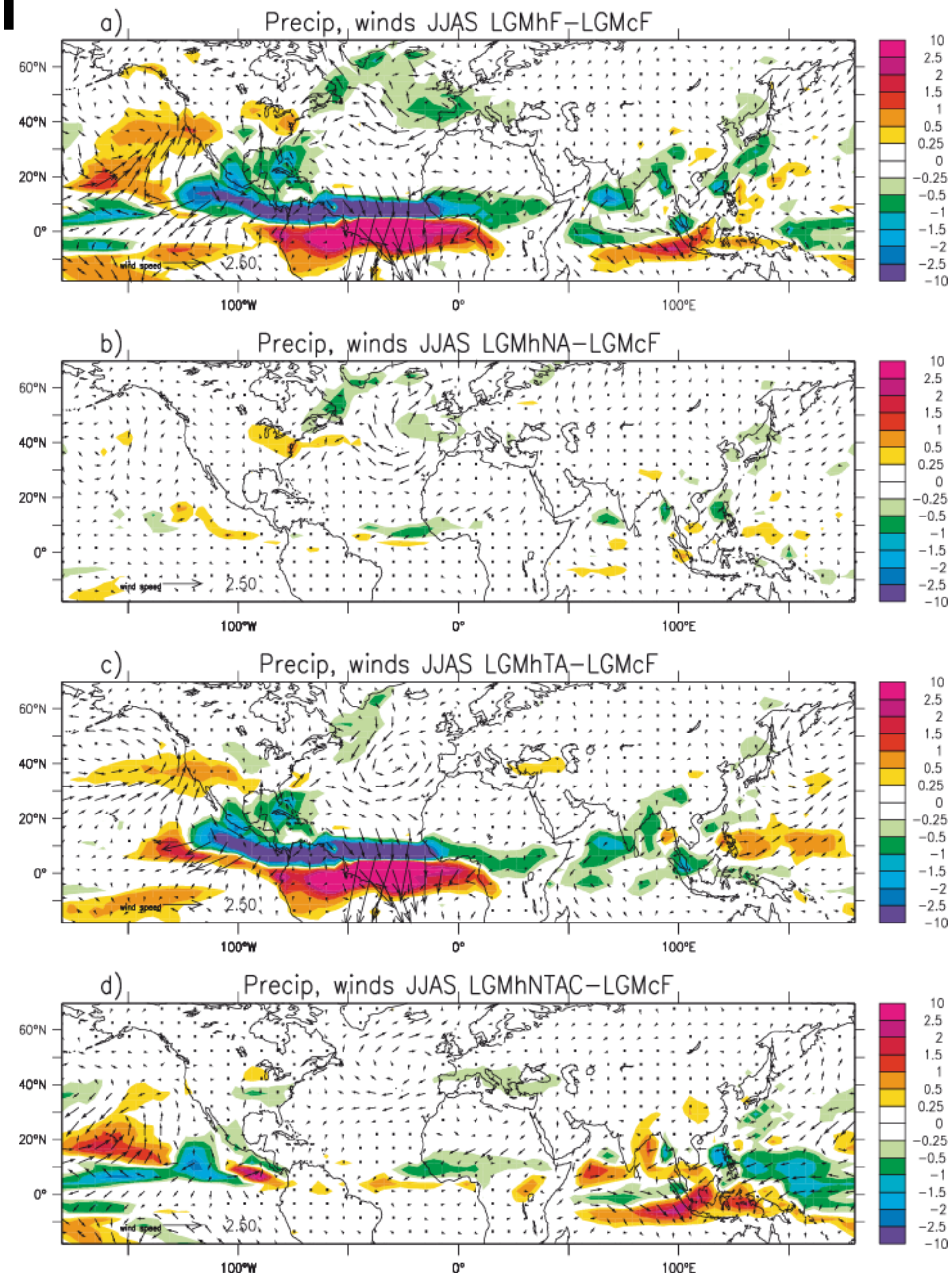
→ Impact of **SST dipole anomaly**

- **LGMhNTAC:** Complementary of the 2 experiments above:

→ Impact of Indian and Pacific Ocean SST changes

Strongest **reduction of TT** for LGMhTA

Impact on winds and precipitation



North Atlantic only

Tropical Atlantic only

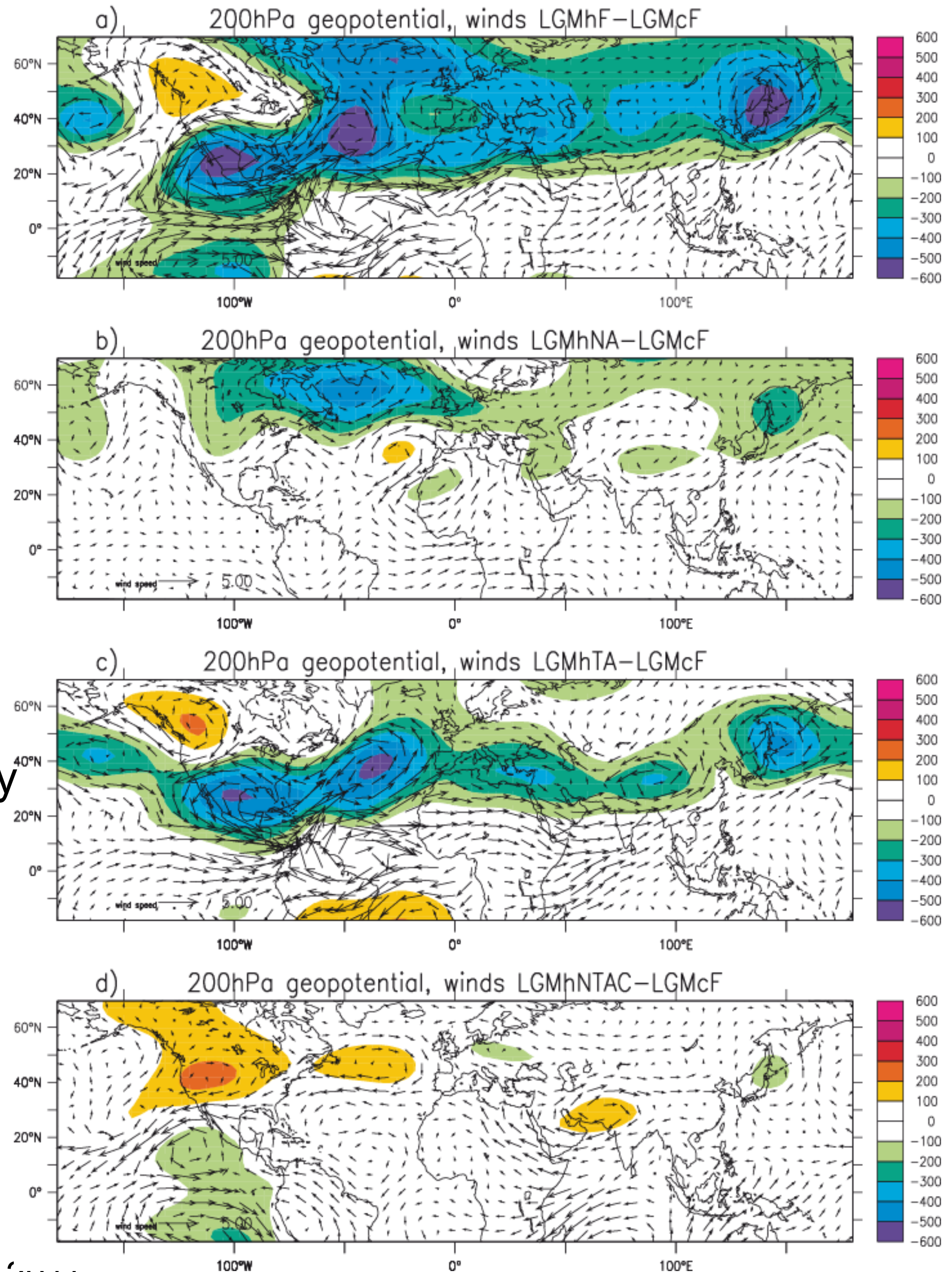
Everywhere except North and tropical Atlantic

Pathway?

North Atlantic only

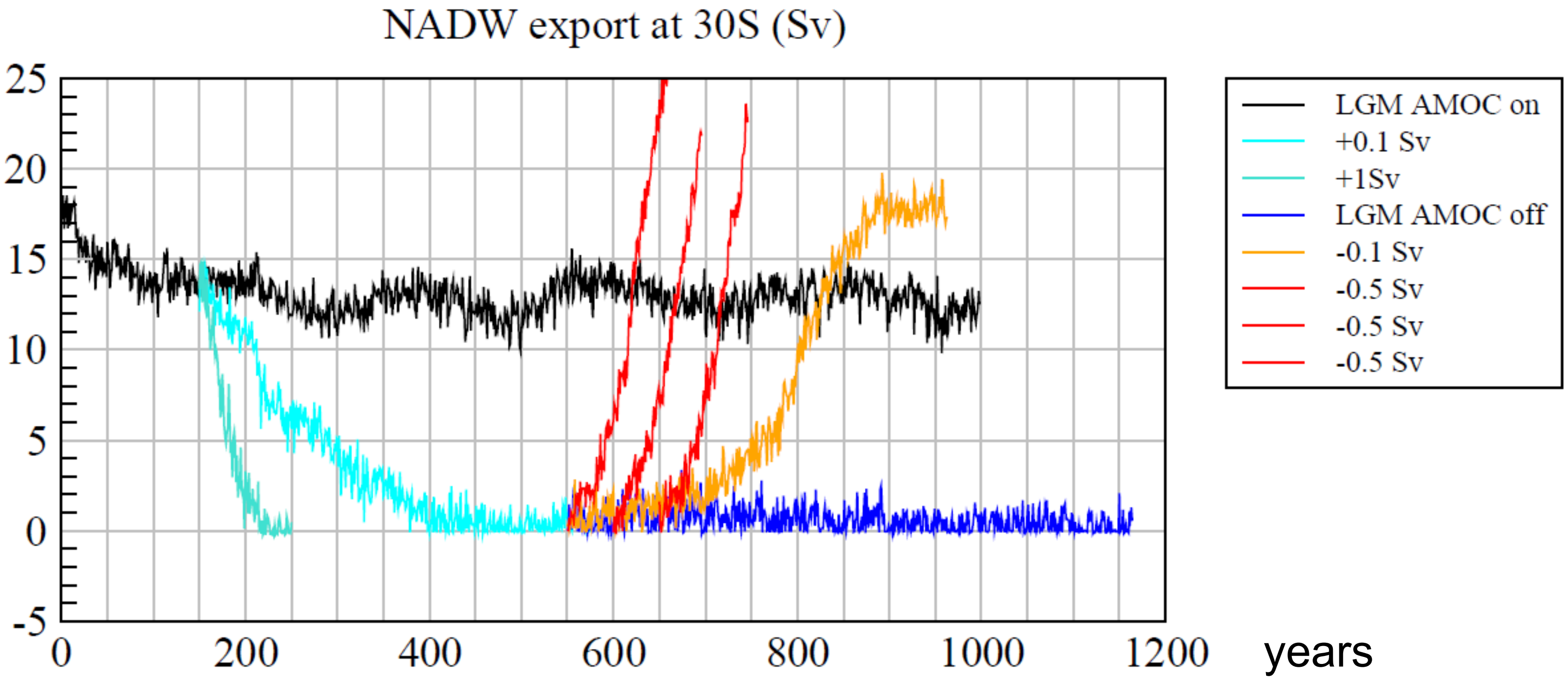
Tropical Atlantic only

Everywhere except North and tropical Atlantic

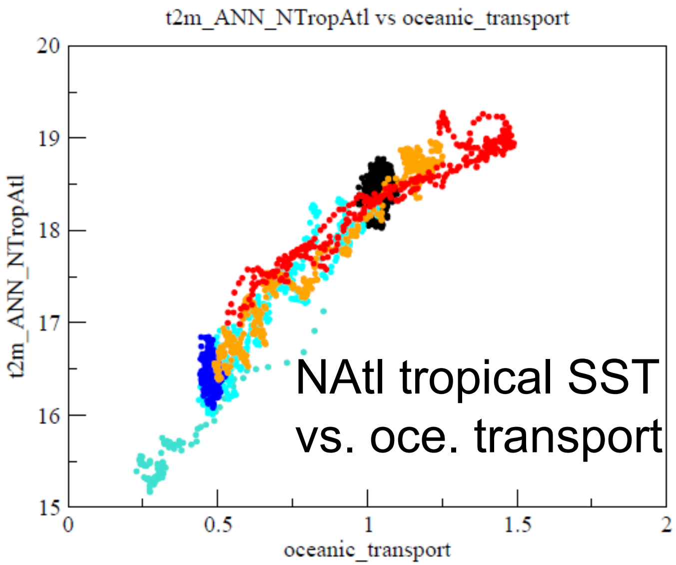


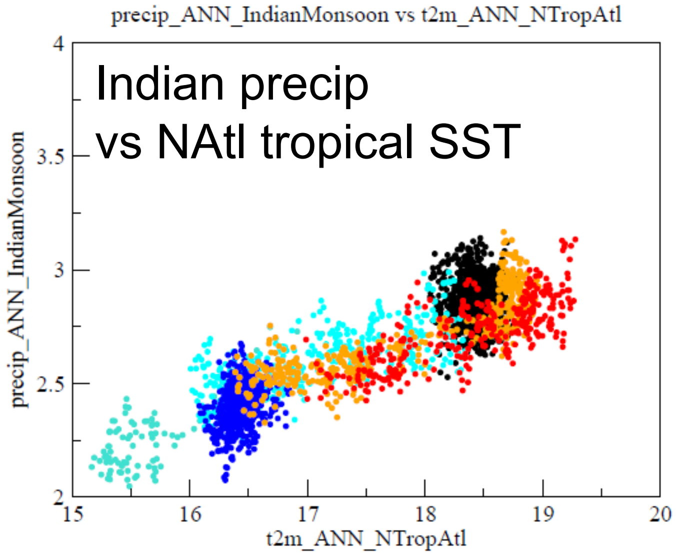
Strong southward shift of the jet stream

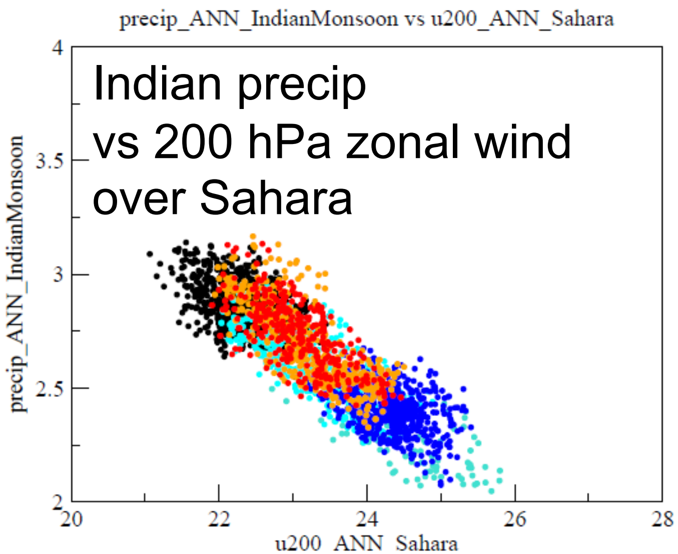
More experiments

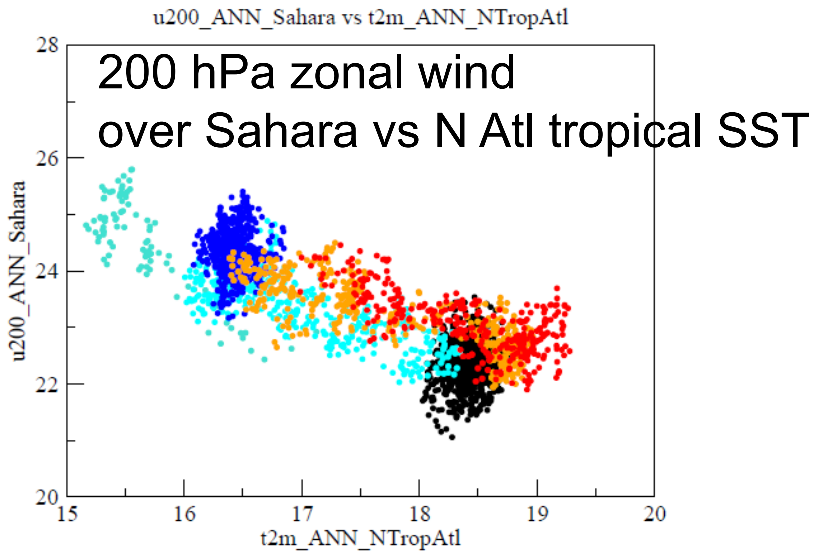


Does our mechanism work for other transitions?

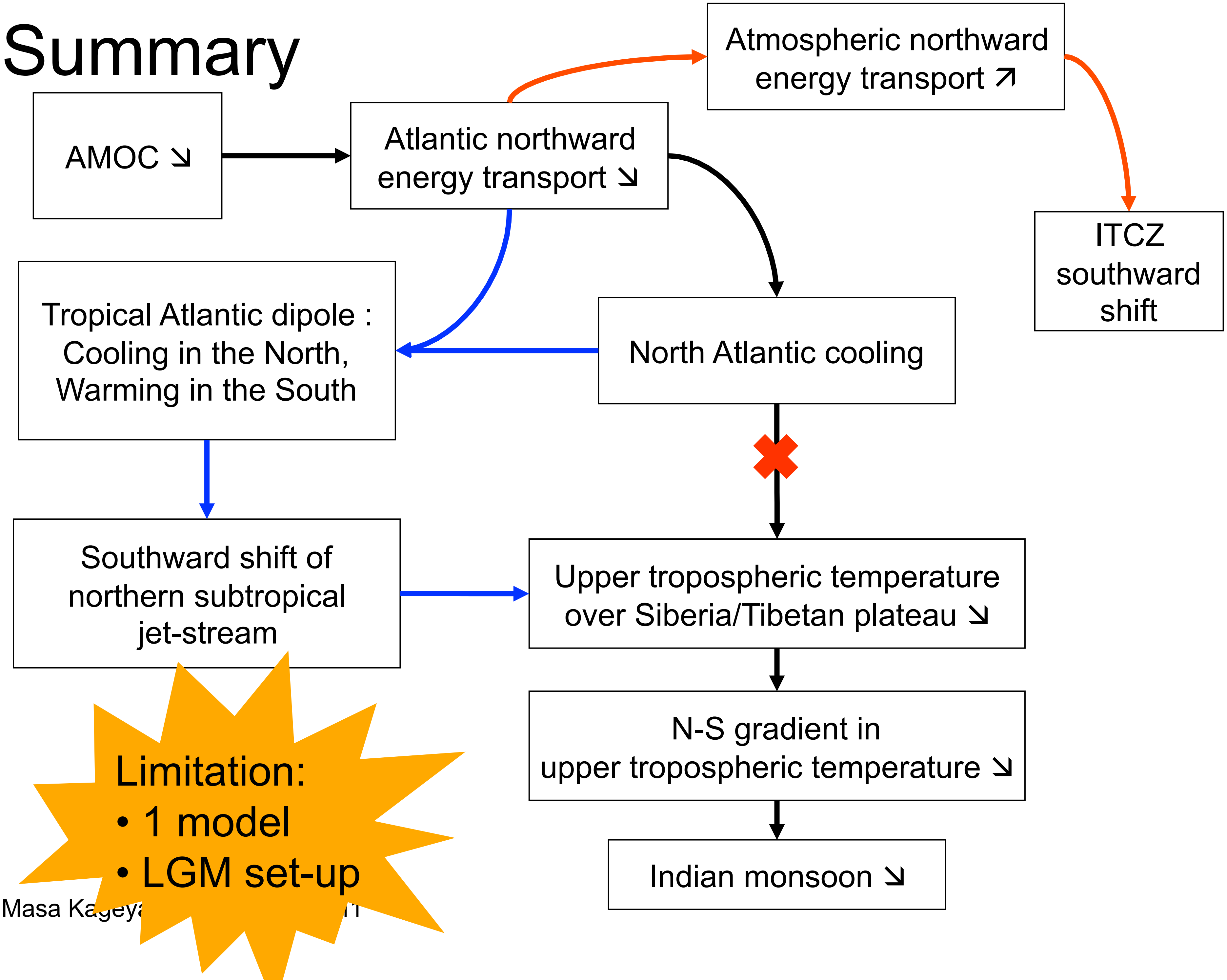








Summary


AMOC ↘
Atlantic northward energy transport ↘
Atmospheric northward energy transport ↗
ITCZ southward shift
Tropical Atlantic dipole : Cooling in the North, Warming in the South
North Atlantic cooling
Southward shift of northern subtropical jet-stream
Upper tropospheric temperature over Siberia/Tibetan plateau ↘
N-S gradient in upper tropospheric temperature ↘
Indian monsoon ↘
Limitation:
• 1 model
• LGM set-up