50 YEARS OF PLATE TECTONICS:

JUNE 25-26, 2018 - COLLÈGE DE FRANCE, AMPHITHÉÂTRE MARGUERITE DE NAVARRE, PARIS, FRANCE

Plate tectonics and climate: what's new since Wegener and Köppen?

Tuesday June 26, 2018

Gilles Ramstein (Research director at CEA – LSCE)

In order of appearance:
Yves Godderis (GET Toulouse), Yannick Donnadieu (CEREGE Aix-Marseille), Guillaume Lehir, (IPG Paris), Jean Besse (IPG Paris), Frédéric Fluteau (IPG Paris), Zhongshi Zhang (IAP Beijing/Bergen university), Camille Contoux (LSCE) , Mathieu Schuster (EOST Strasbourg), Baohuang Su (IAP Beijing), Dabang Jian IAP Beijing), Ran Zhang (IAP Beijing), Pierre Sepulchre (LSCE).

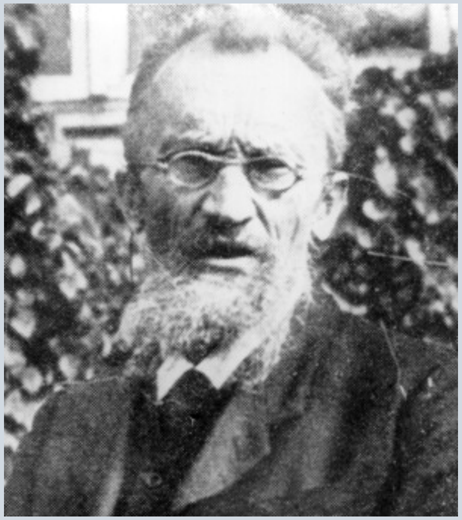
Support of presentation by Sarah Amram

Continental drift & climate change

ALFRED WEGENER
1880-1930

WLADIMIR PETER KÖPPEN
1846-1940

&

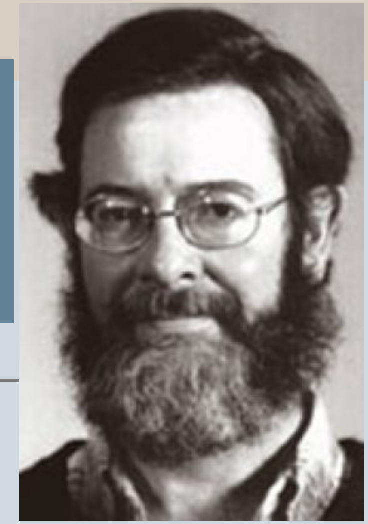


Astronomer and meteorologist

Meteorologist, climatologist, botanist,

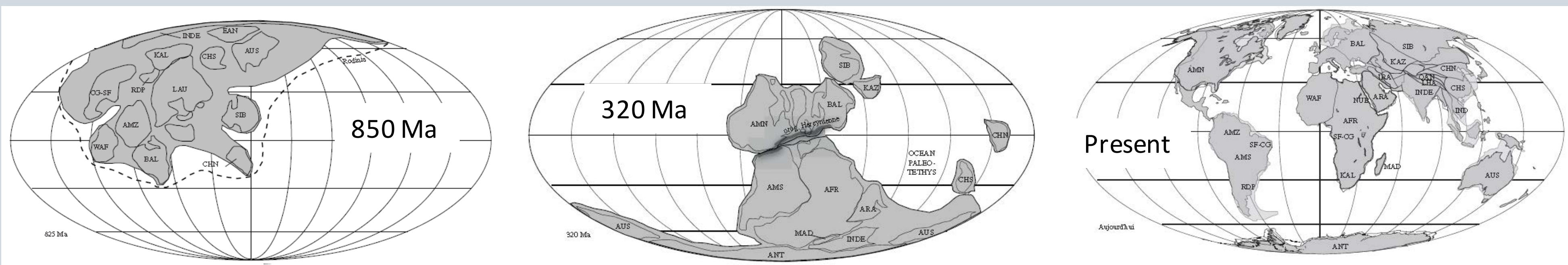
January 1912: A. Wegener first conference in Francfort on continental shift.
1915: First edition of Wegener's book concerning ocean and continent genesis
1924: A. Wegener and W. Köppen: « Die Klimate der Geologischen Vorzeit »
Since 1930: a first correlation between tectonics, climate and glacial-interglacial cycle already existed
1968: A full theory of tectonics

The carbon cycle/climate/tectonics feedback at geological time scale



Regulation of the climate system at million year scale: tectonics, climate and pCO2.

James G. C. Walker
University of Michigan



Continental distribution drives pCO2 and climate on a long term scale

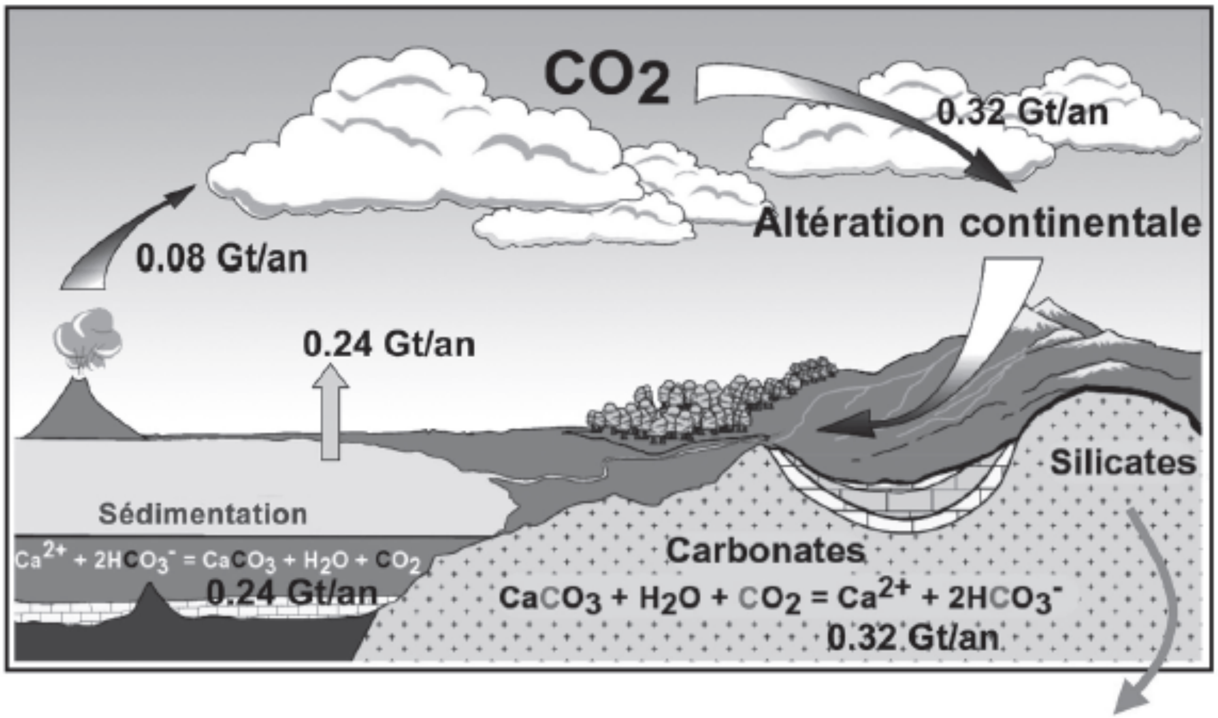
Some illustrations of climate-tectonics interactions:

- The role of continental drift in triggering Neoproterozoic snowball Earth

- The disappearance of an epicontinental sea (Tethys shrinkage)
  – Asian monsoon system
  – African monsoon system

- Uplift of mountain ranges
  – TP-Himalaya uplift
  – African rift uplift

The exospheric cycle of carbon at million -year time scale.



$$CaSiO_3 + 2H_2CO_3 \longrightarrow Ca^{2+} + 2HCO_3^- + SiO_2 + H_2O$$

0.16 Gt/an

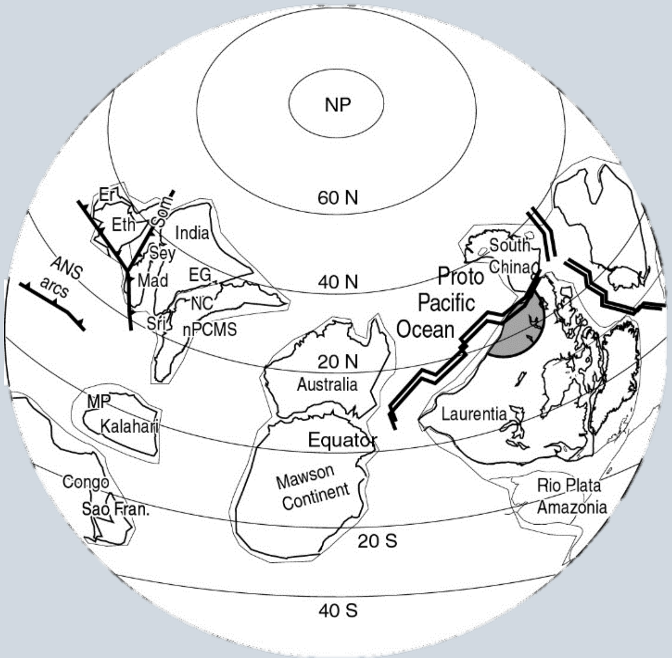
Mechanisms of long time global cooling

1 – Succession of traps events

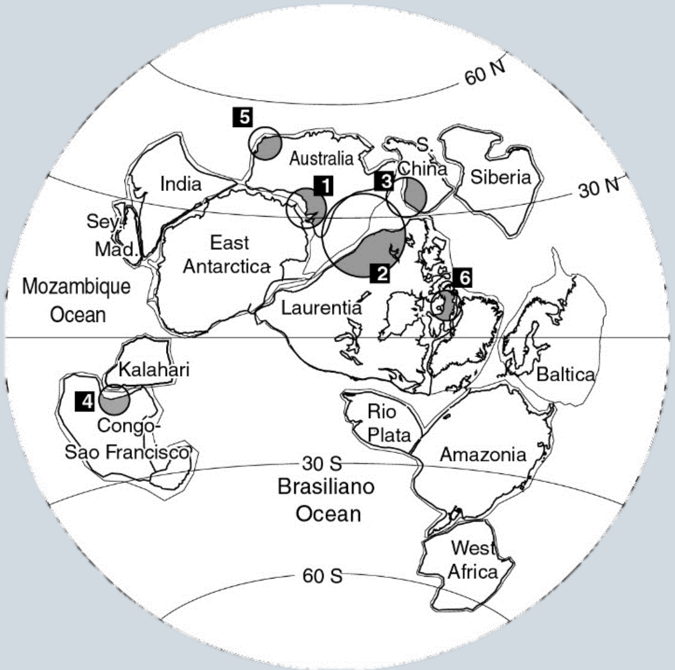
2 – Located at low at mid latitudes

3 – Break up of the Rodinia supercontinent

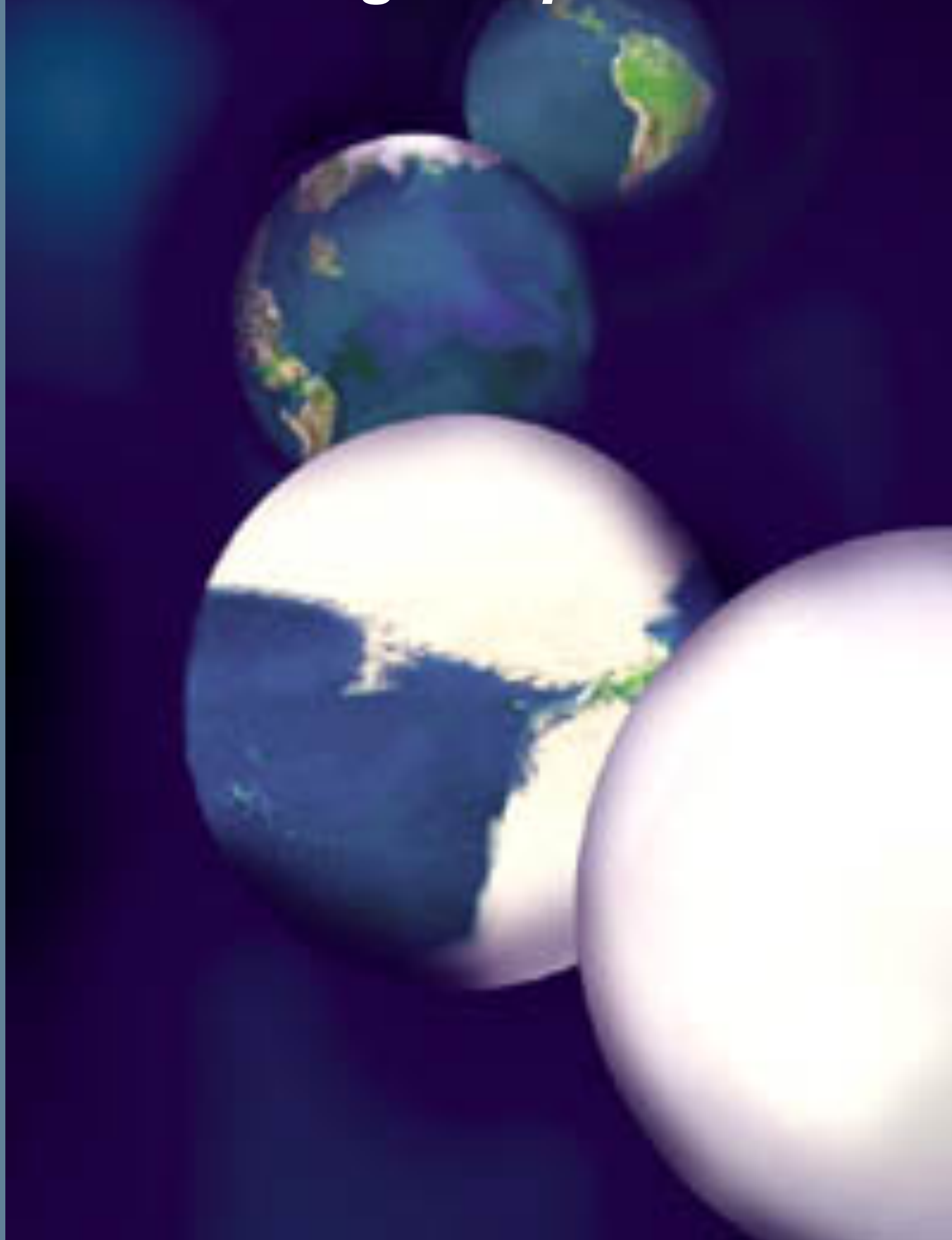
750 Ma

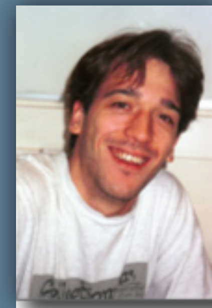


800 Ma



Why did a snowball earth occur during Neoproterozoic ?



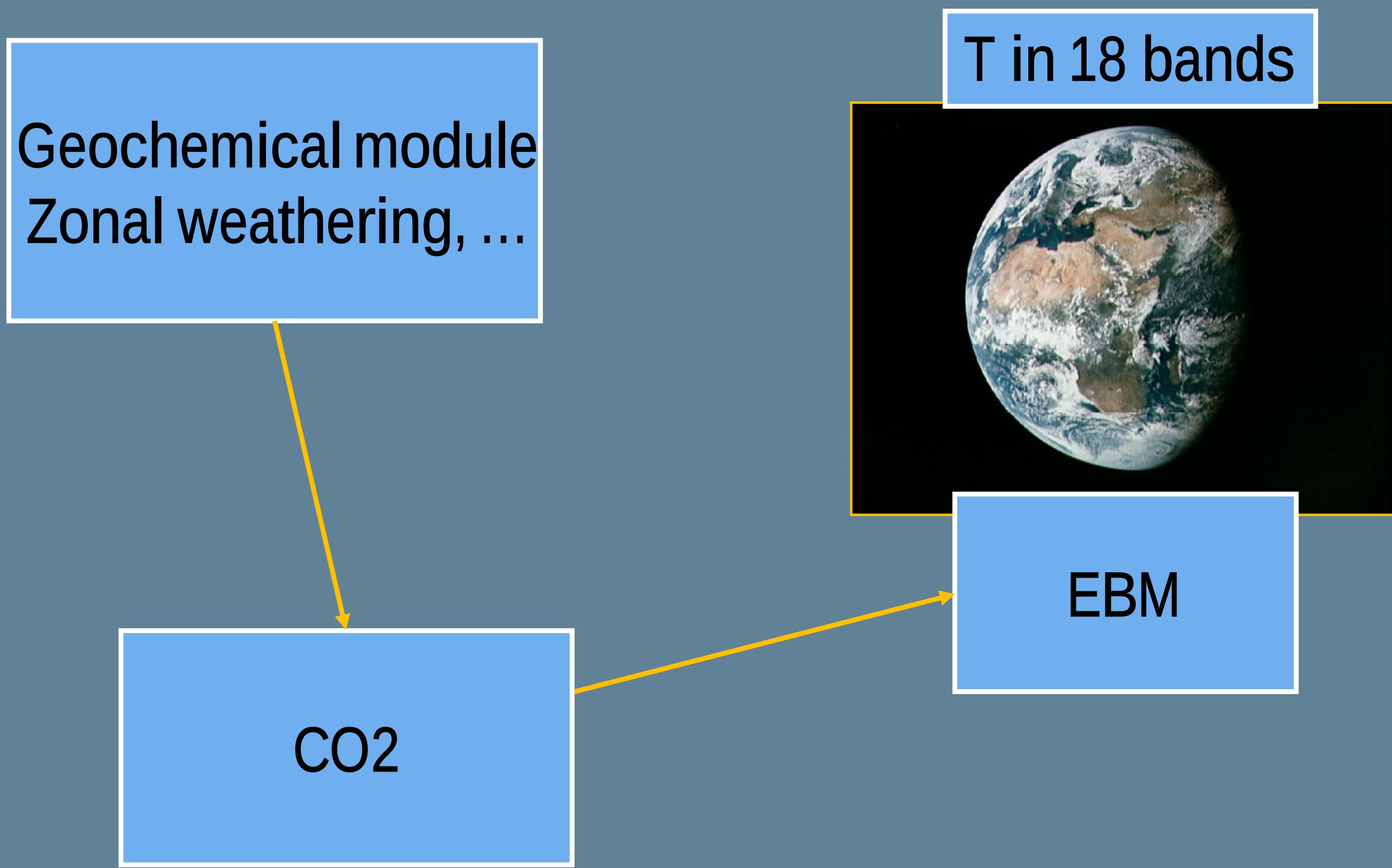


Yannick DONNADIEU
CEREGE, Aix-Marsaille

Guillaume LE HIR
IPG, Paris

Yves GODDERIS
GET, Toulouse

Climate CO2 interactions within Geochemical models of Geochemical (COMBINE) and Climate models (CLIMBER) to test trap impact

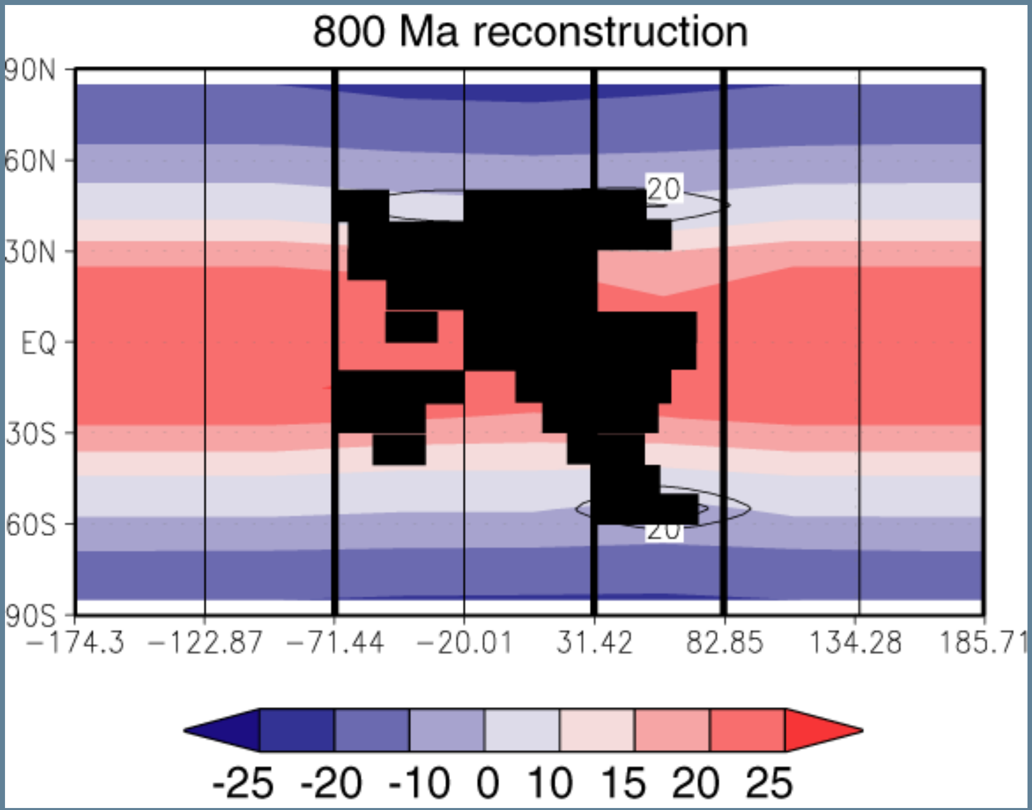


First Results

1 – A 800 Ma

The coupled Carbone-Climate model reaches equilibrium for pCO2 = 1800 ppm

Corresponding to a mean global temperature of 10.2 °C



Tropical location of the continental mass: no large impact on temperature.

Nevertheless the mean annual temperature is rather cold: 10.2 °C

Donnadieu et al, Nature 2004

First Results

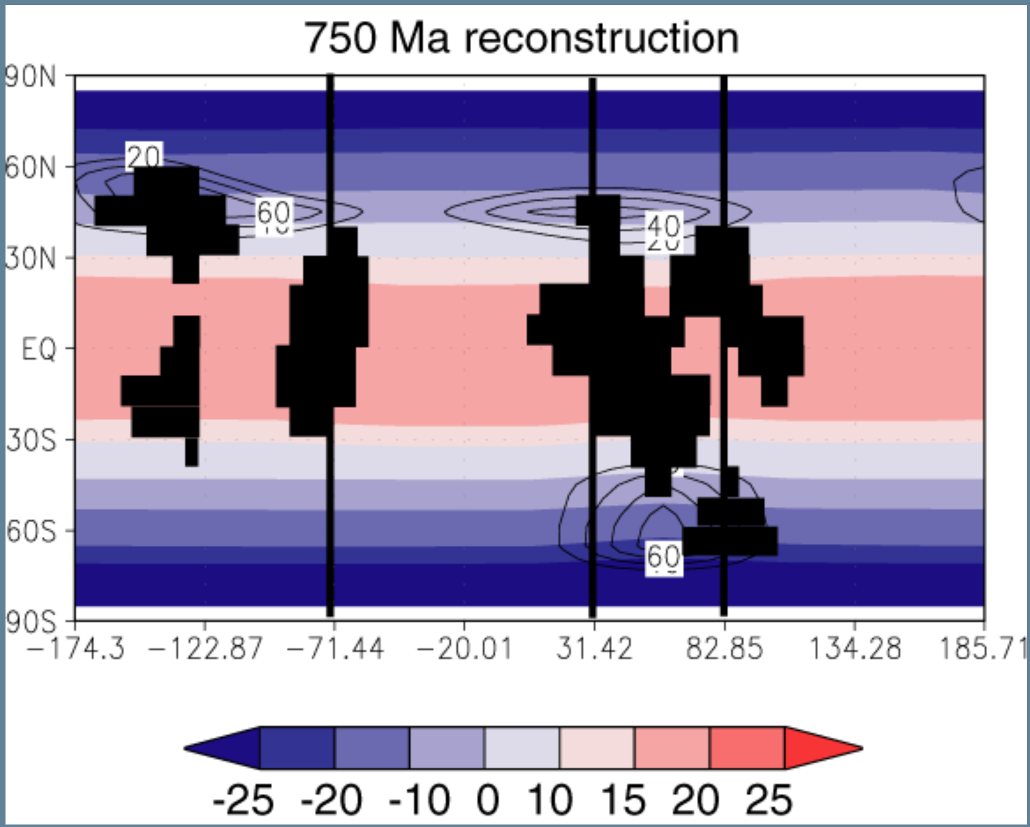
1 – A 750 Ma

The coupled Carbone-Climate model reaches equilibrium for pCO2 = 500 ppm

>> reduction of 1300 ppm

Corresponding to a mean global temperature of 2 °C

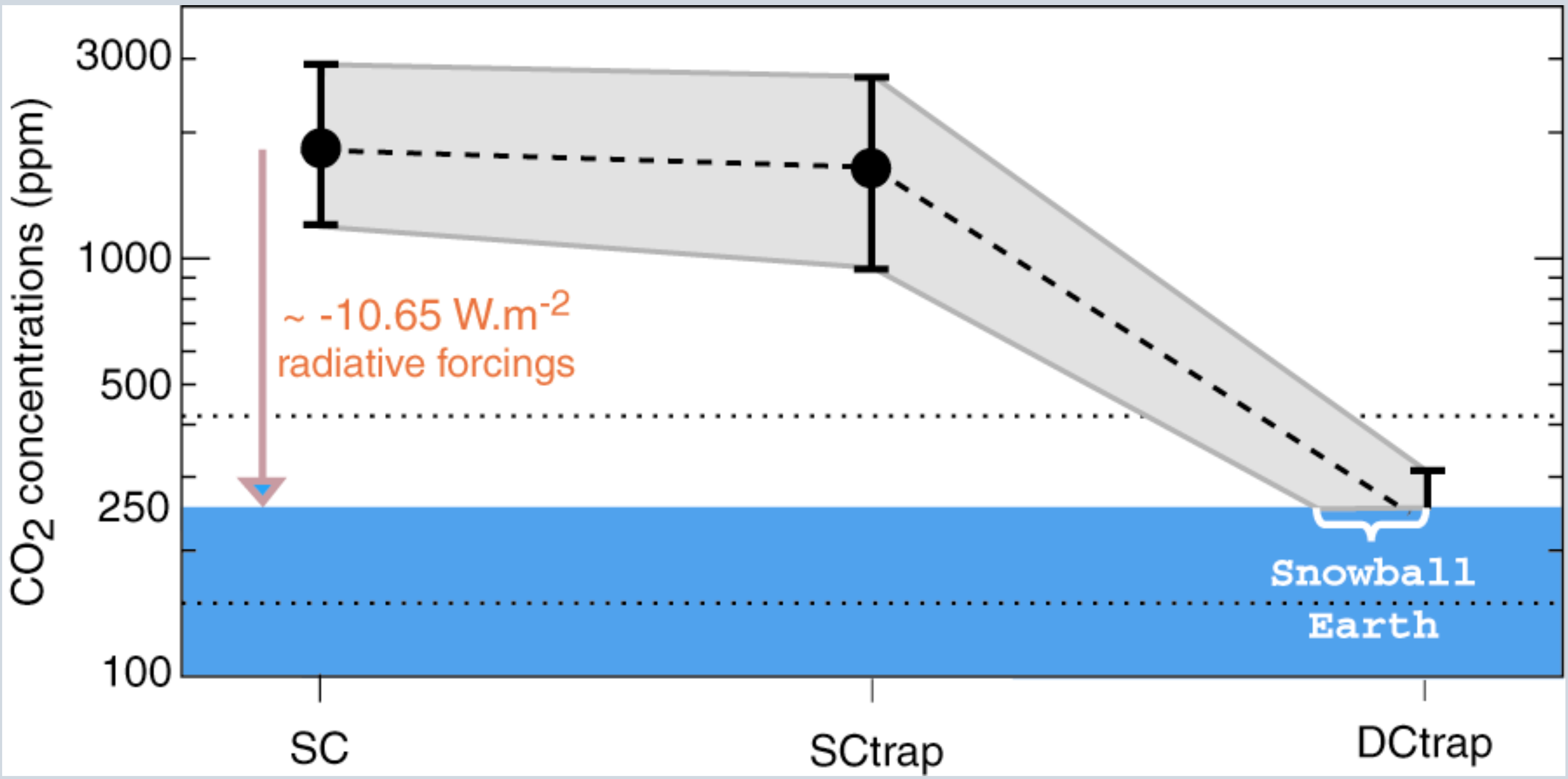
>> reduction of 8.2°C

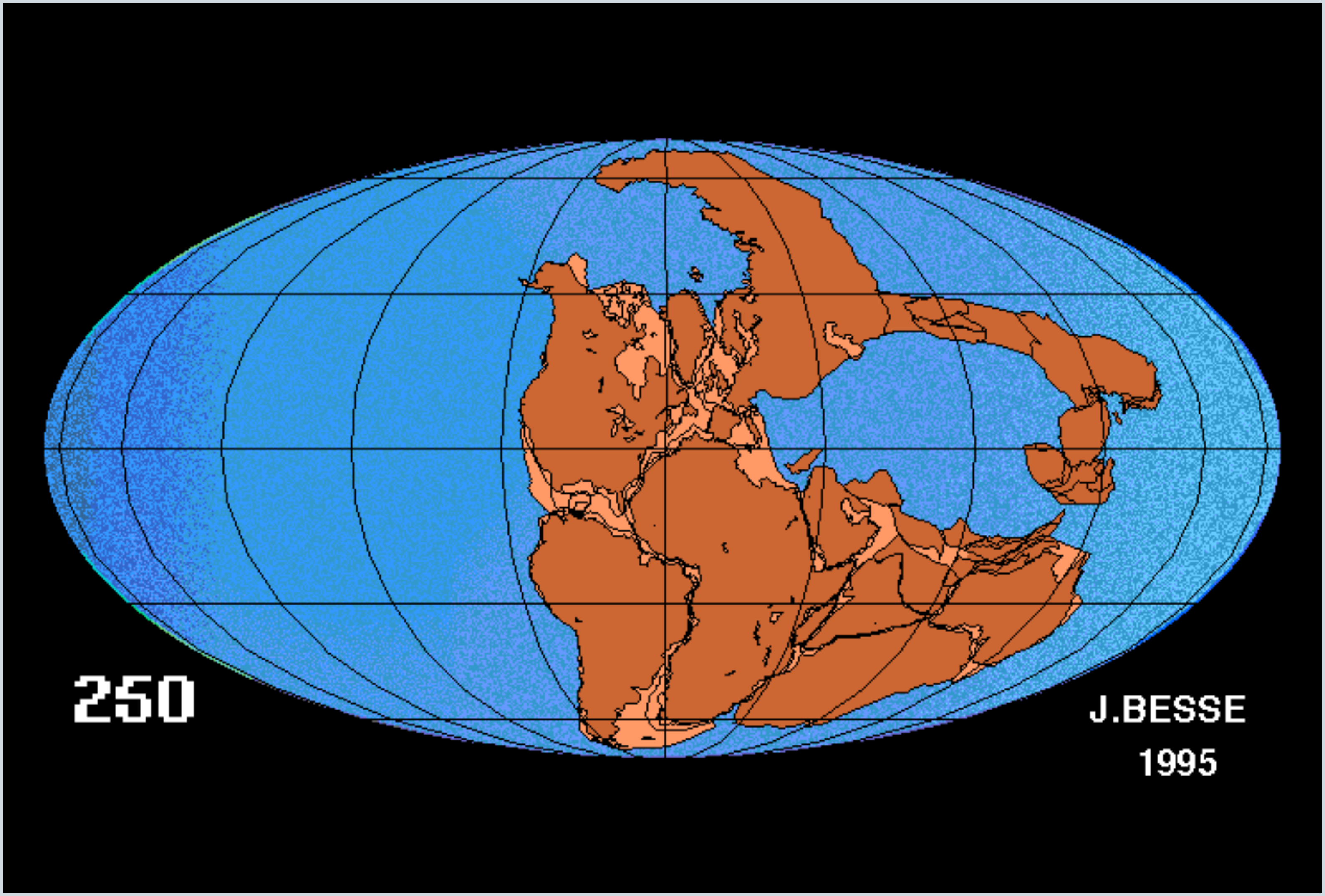


Continental distribution with small continents in equatorial locations: enhance the decrease of CO2 (extensive burial along margins) and leads to global glaciation

Donnadieu et al, Nature 2004

Impact on the CO2




250
J.BESSE
1995

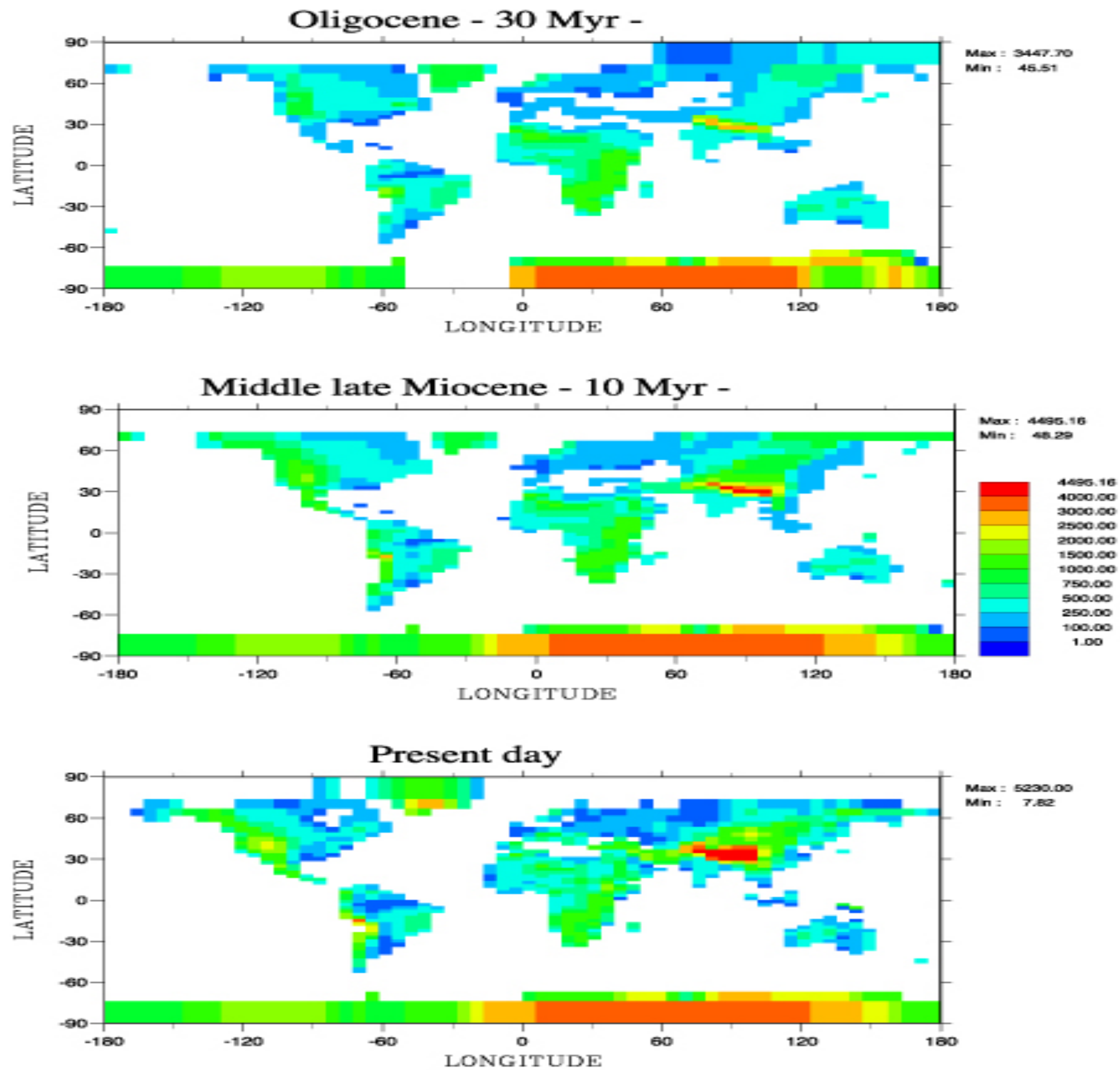
Tethys shrinkage: impact on Asian monsoon (1)

Paleogeography:

30Ma.

10Ma

Present day



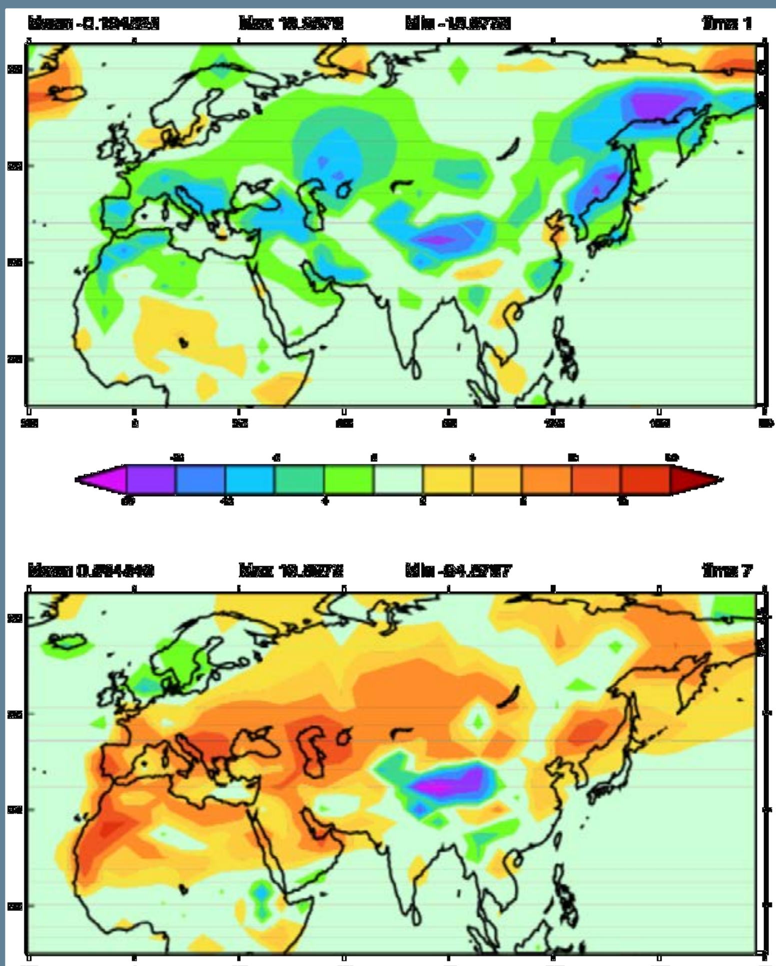
Ramstein et al., Nature, 1997. Fluteau et al., JGR, 1999

Tethys shrinkage: impact on Asian monsoon (2)

Temperature evolution

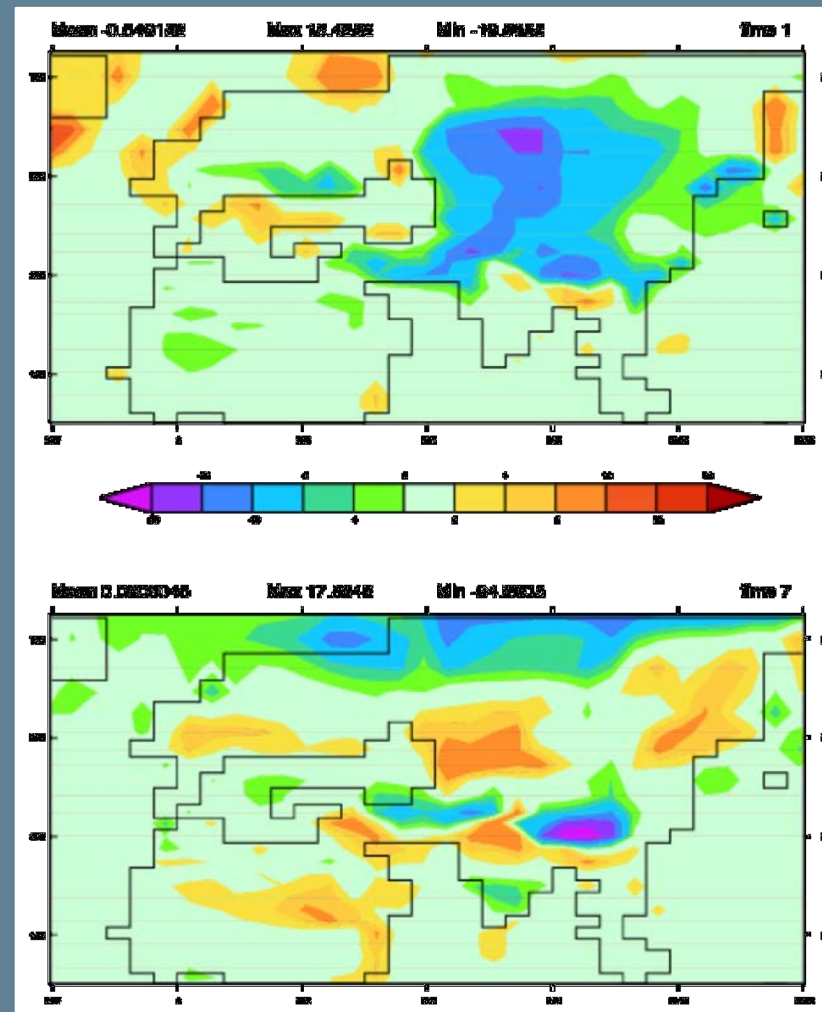
Present - 10 Ma

10 Ma - 30 Ma



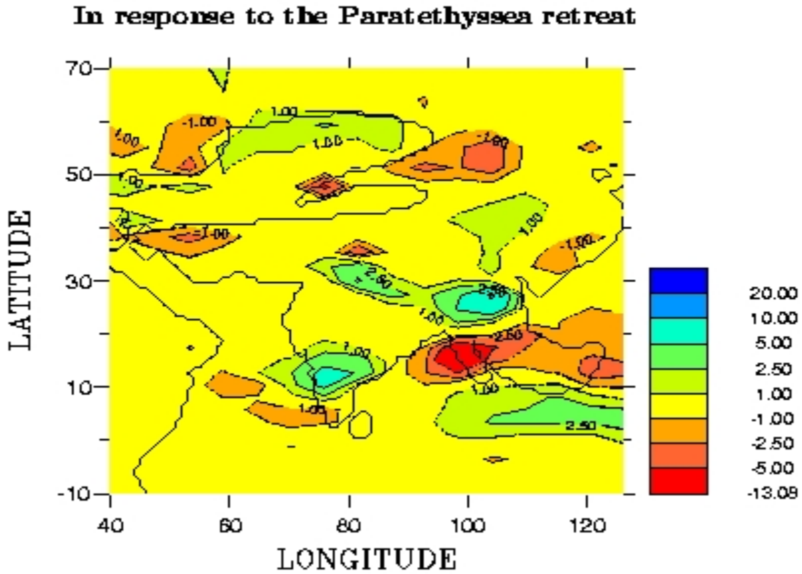
winter ⟷

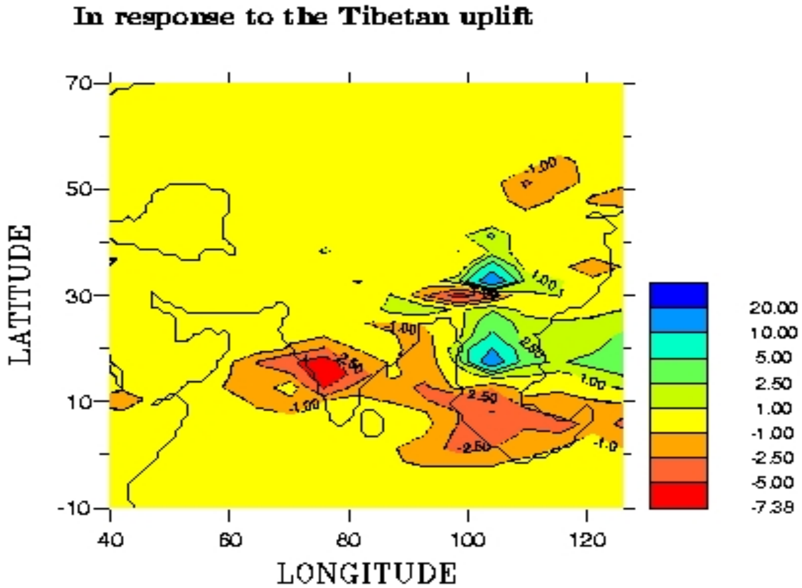
summer ⟷



Ramstein et al., Nature, 1997. Fluteau et al., JGR, 1999

Summer precipitations difference



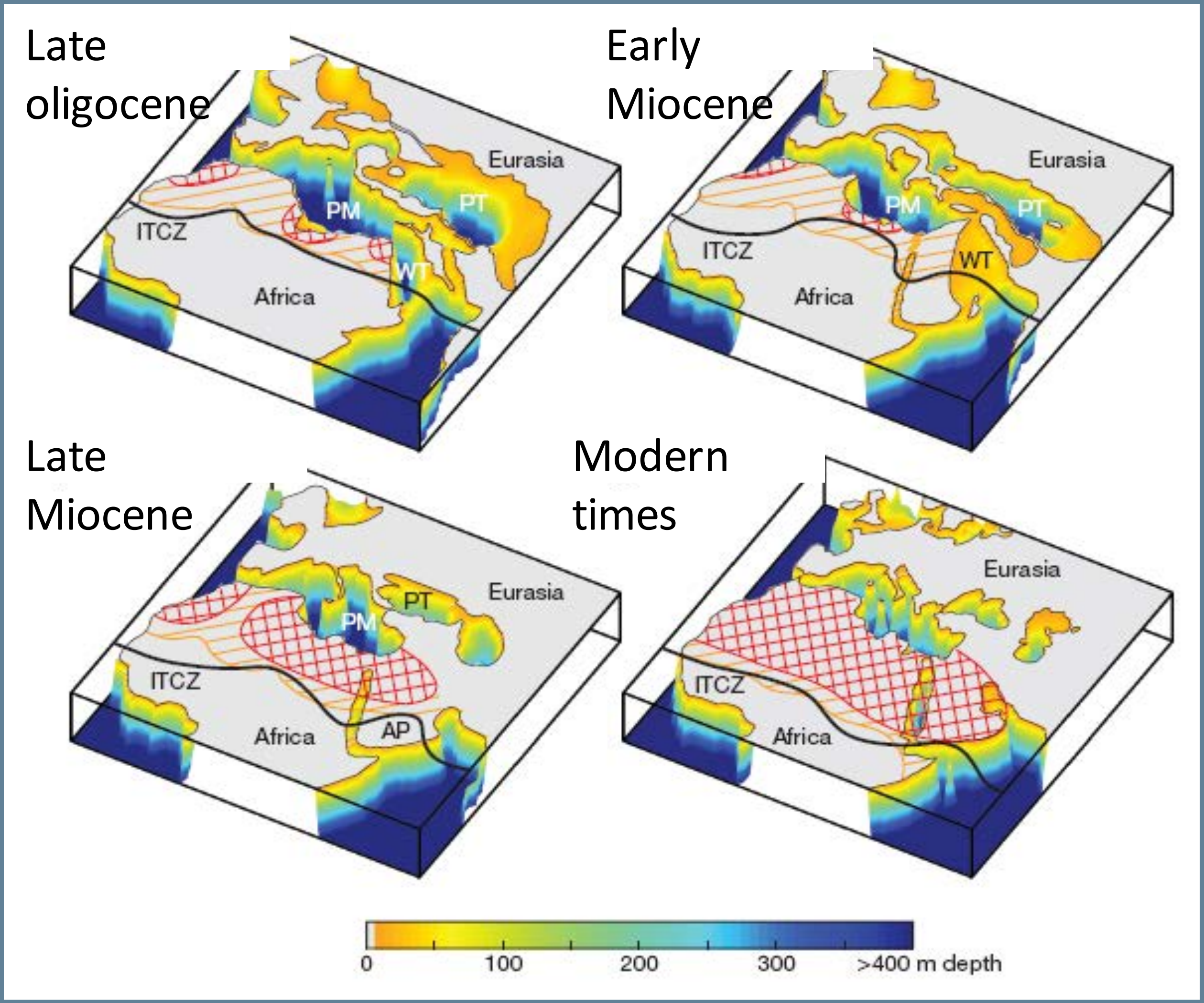


Jean BESSE
IPG, Paris

Frédéric FLUTEAU
IPG, Paris

Ramstein et al., Nature, 1997. Fluteau et al.; JGR, 1999

After a slow shrinkage, since 30 million years, this huge epicontinental Tethys sea, spread from East to Western Asia finally vanishes



Zhang et al, *Nature 2014*

Zhongshi ZHANG
IAP, Biejing
Bergen, Norway

Mathieu SCHUSTER
EOST, Strasbourg

Camille CONTOUX
LSCE, Paris-Saclay

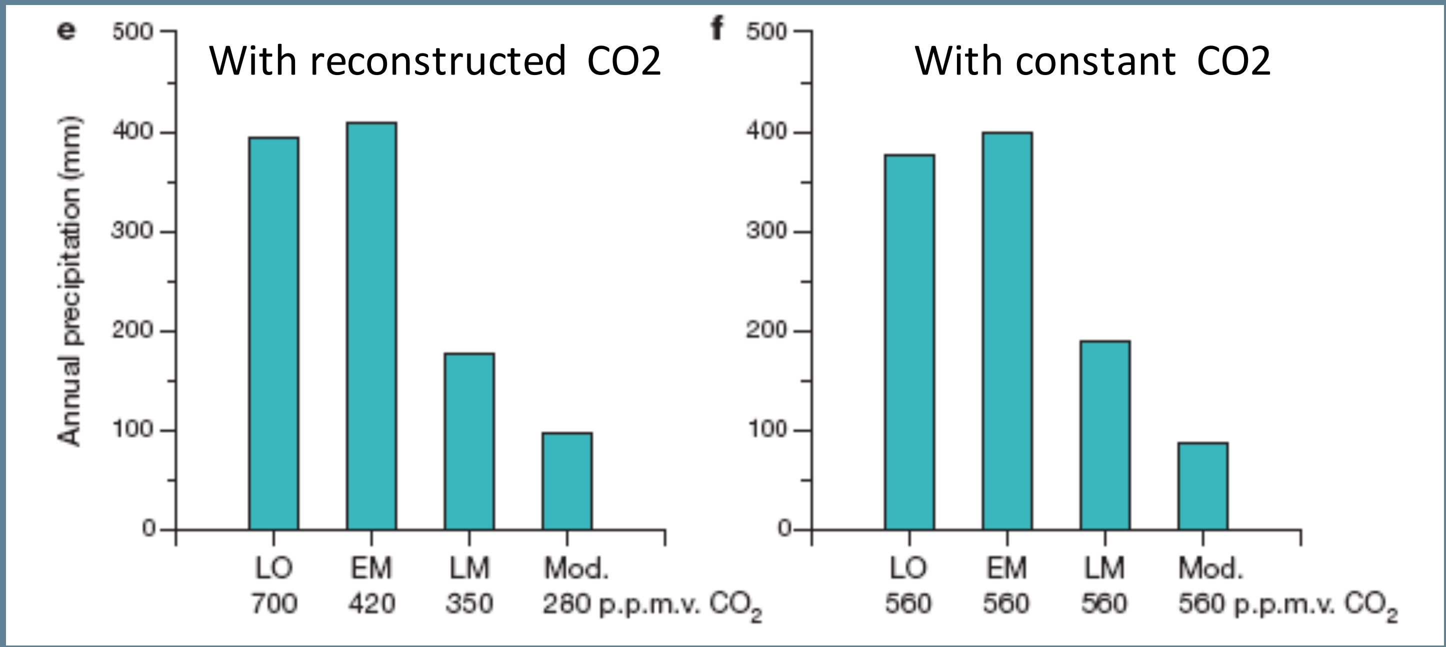
Impact of the Tethys shrinkage over North Africa Sahara Onset

LO: End of Oligocène
[33- 28 Ma]

EM: Beginning of Miocène
[20-17]

LM: End of Miocene
[11-7 Ma]

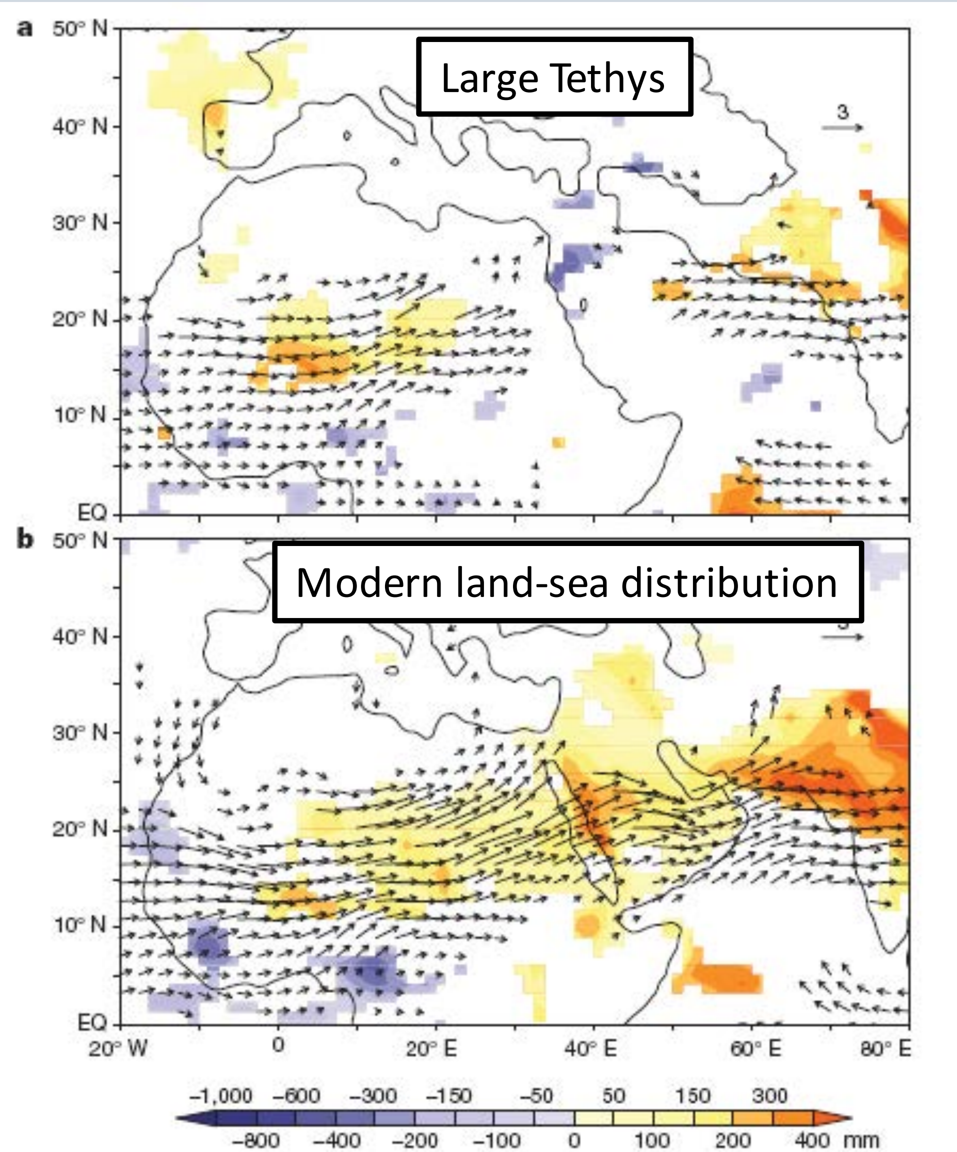
d. MOD: Present



Zhang et al; Nature 2014

Annual precipitation (mm) averaged over north Africa (between 25°N and 35°N, 12°W and 38° E, in the Late Oligocene (LO), Early Miocene (EM), Late Miocene (LM) and modern experiments (Mod.)

An increased response to orbital forcing



- Climate response to increased summer insolation in the Northern Hemisphere before and after Tethys shrinkage

- Change between today and 6 kyr ago.

Shading: annual precipitation (mm)
Arrows: 850-hPa summer winds ($m.s^{-1}$)

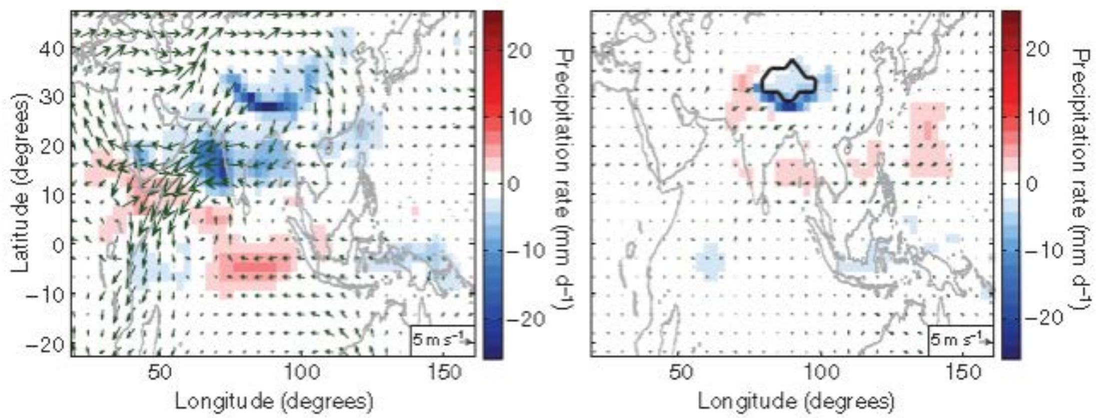
Zhang et al, *Nature 2014*

Results from model runs with modified topography and surface albedo

Precipitation and 850 hPa horizontal winds: anomalies relative to Ctrl

No topography, standard albedo

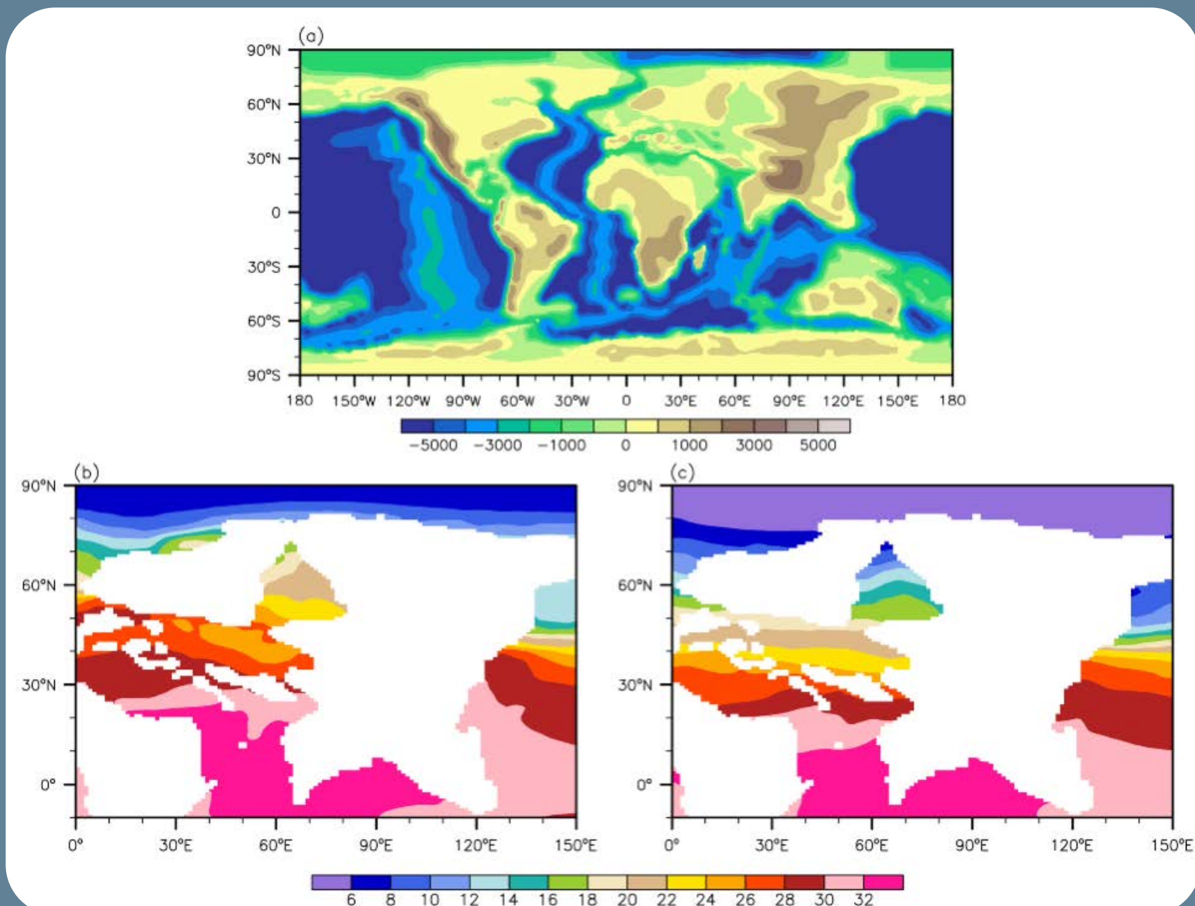
Full topography, plateau albedo =1



Boos and Kuang, Nature 2013.

Northward shift of the TP from Indian-Asian collision to present day

Topography and bathymetry (units: m) used in the ~40 Ma experiments by NorESM-L.



Summer (left) and annual (right) SSTs used in the ~40 Ma experiments by CAM4.

Ran Zhang
IAP Beijing

Dabang Jiang
IAP, Beijing

R. Zhang et al. EPSL, 2018

Interaction between hydrology and mountain range location

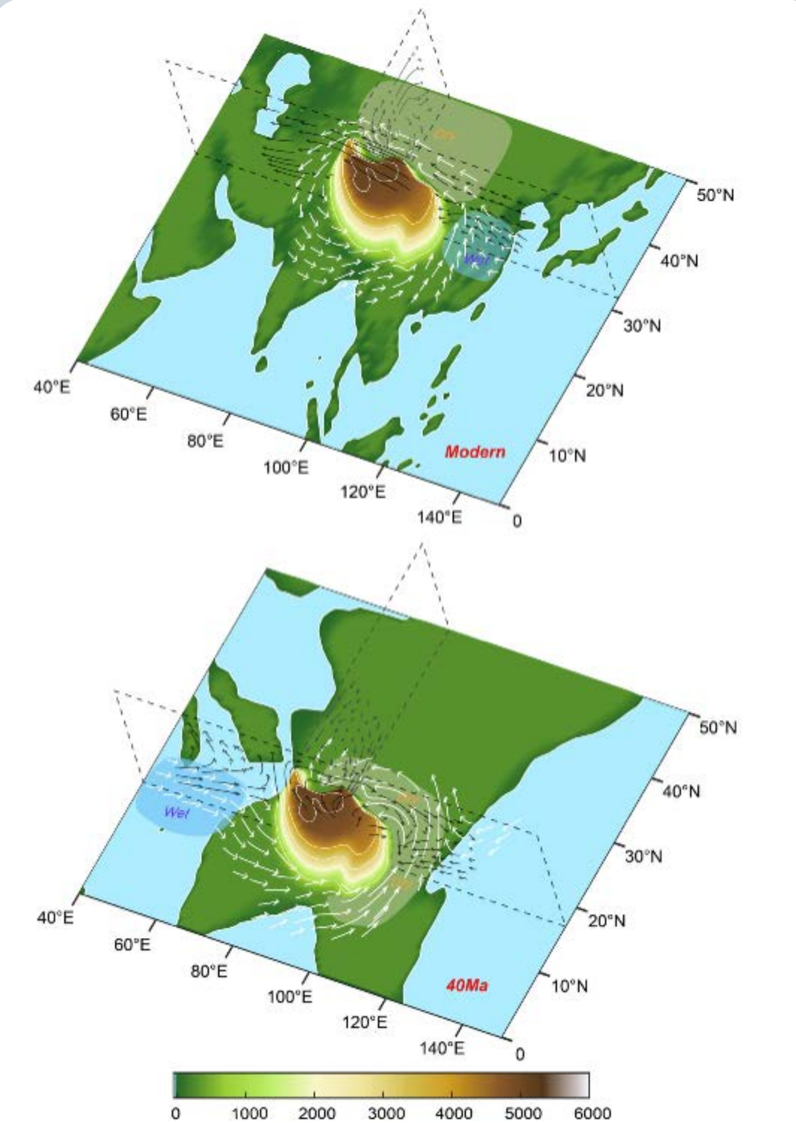
Rise of the Himalaya–TP in the subtropics

🎭 intensifies aridity throughout inland Asia north of ~40◦N and enhances precipitation over East Asia.

Rise of the Himalaya–TP in the tropics

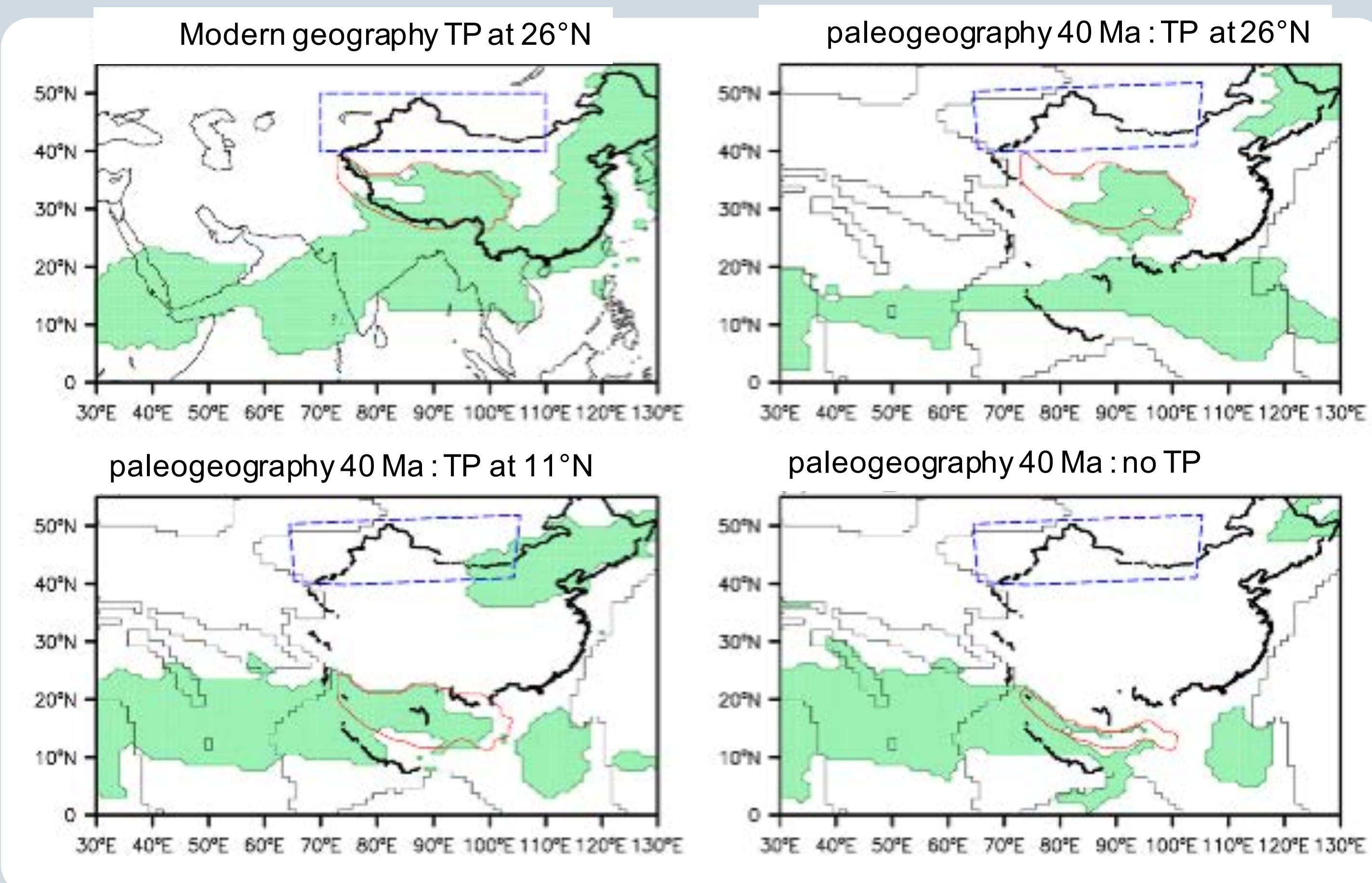
🎭 only slightly intensifies aridity in inland Asia north of ~40◦N and slightly increases precipitation in East Asia.

R. Zhang et al. EPSL, 2018



Distribution of the monsoon domain

R. Zhang et al. EPSL, 2018

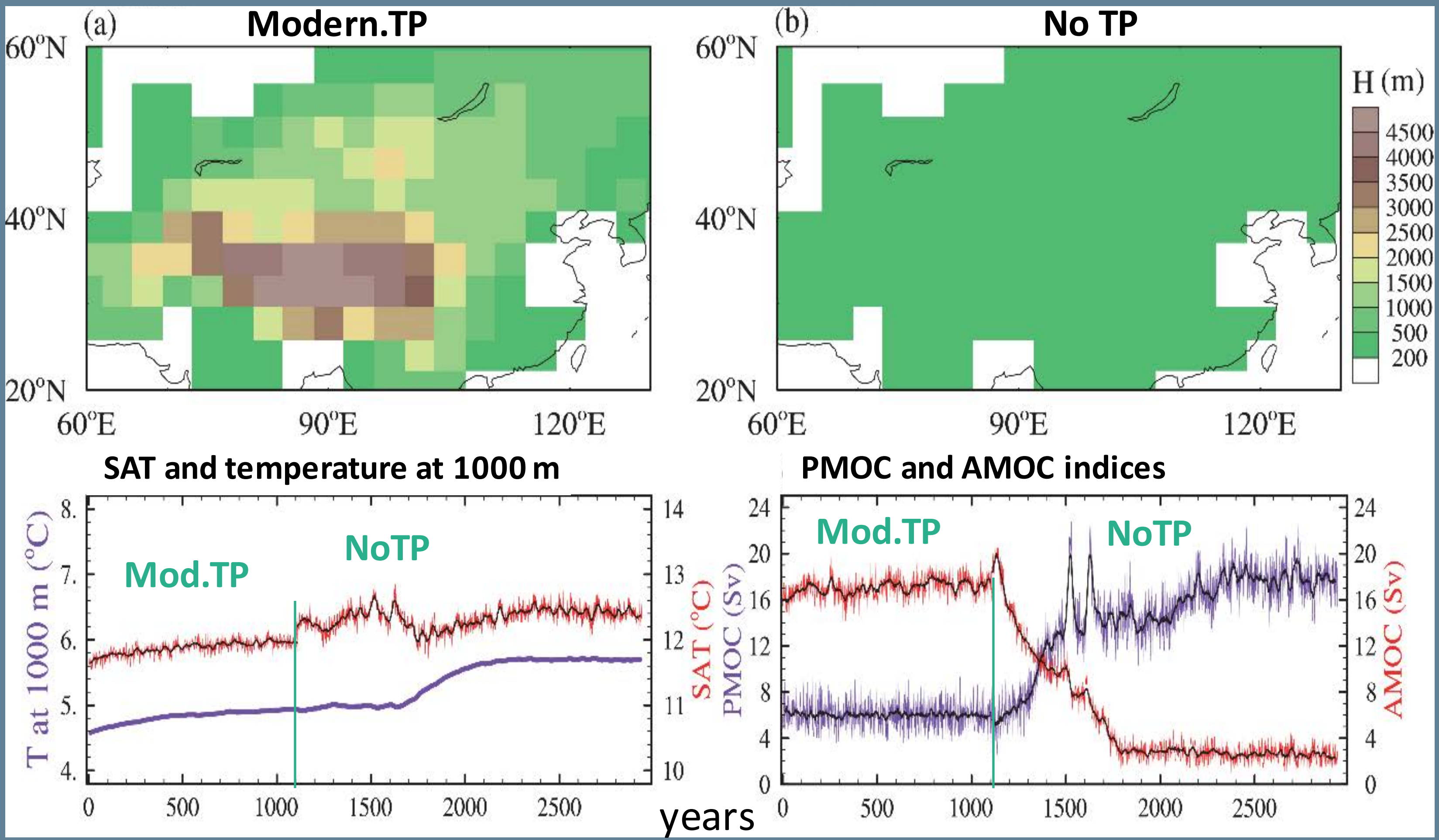


Distribution of the monsoon domain, with the definition by Wang et al. (2012), with the summer-minus-winter precipitation exceeding 2.0 mm day−1 and the local summer precipitation exceeding 55% of the annual total precipitation. The summer (winter) here is from May to September (November to March).

Consequence of uplifts of TP and Himalaya on global ocean circulation PMOC/AMOC

B. Su et al., Clim Past, 2018

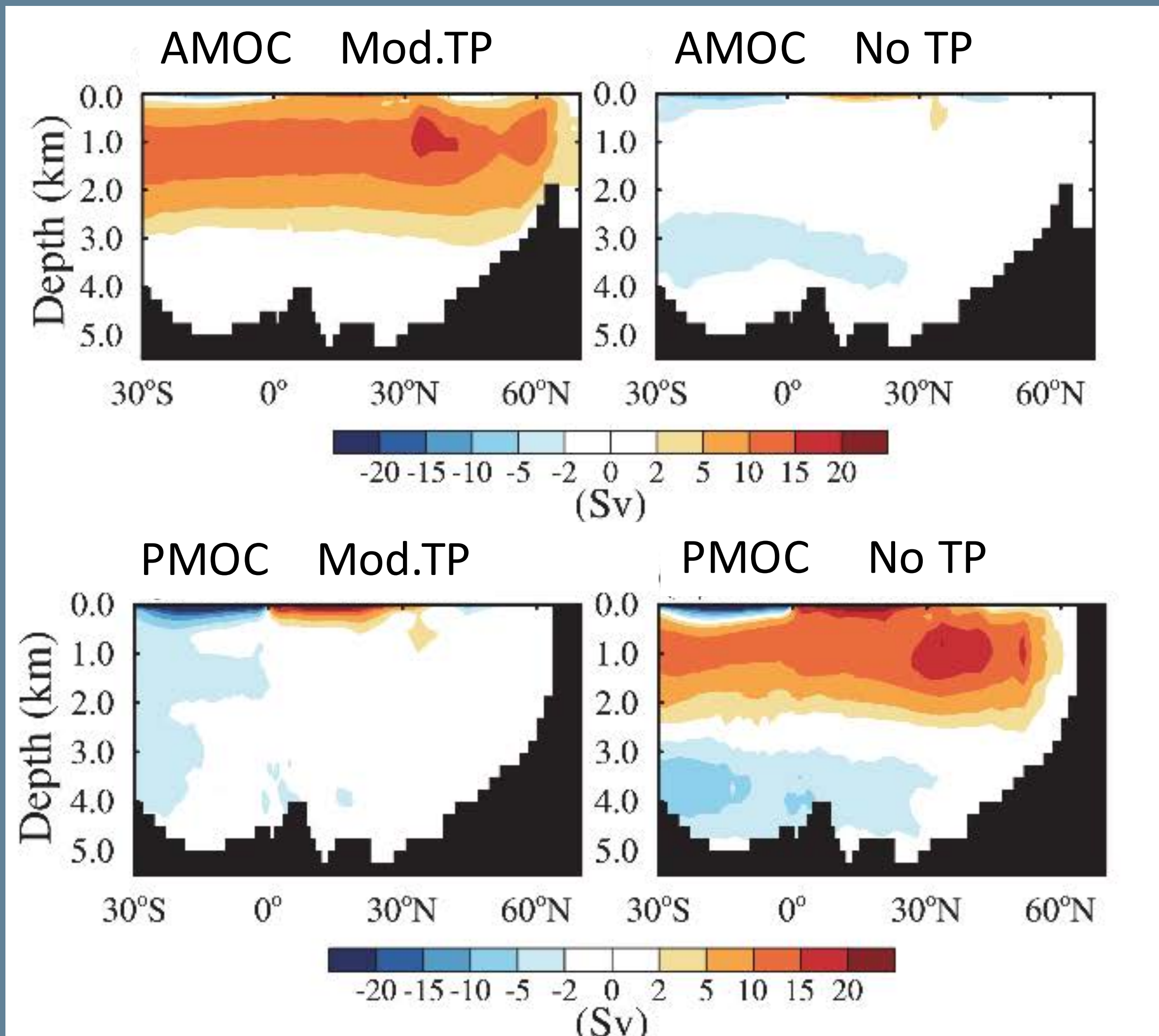
Model used: CESM version 1.05
Low resolution (T31) atmosphere ocean coupled model
Including dynamical and thermal sea ice model



Impact of Tibetan Plateau Uplift ()

Climatological annual mean overturning stream function

B. Su et al., Clim Past, 2018



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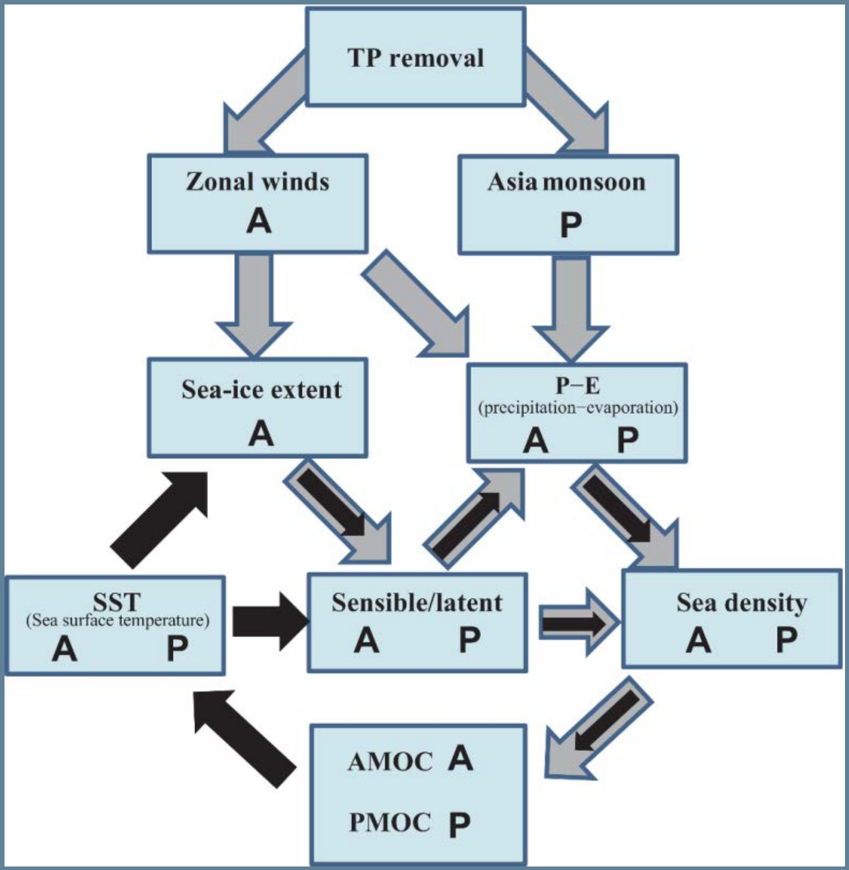
positive shading : clockwise circulations.
negative shading : counterclockwise circulations.

Summary scheme of TP removal impact on meridional ocean circulations

B. Su et al., Clim Past, 2018



Vectors in gray : climate responses in relation to the increased wind-induced and decreased monsoonal-driven net precipitation-evaporation and wind-driven sea-ice processes.

Black color vectors: feedback processes related to the AMOC weakening.

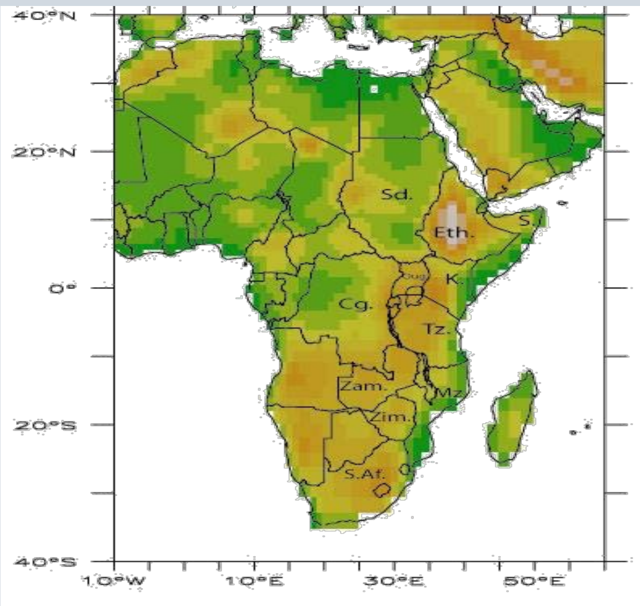
Climatic impact of the African Rift Uplift

Pierre SEPULCHRE
LSCE, Paris-Saclay

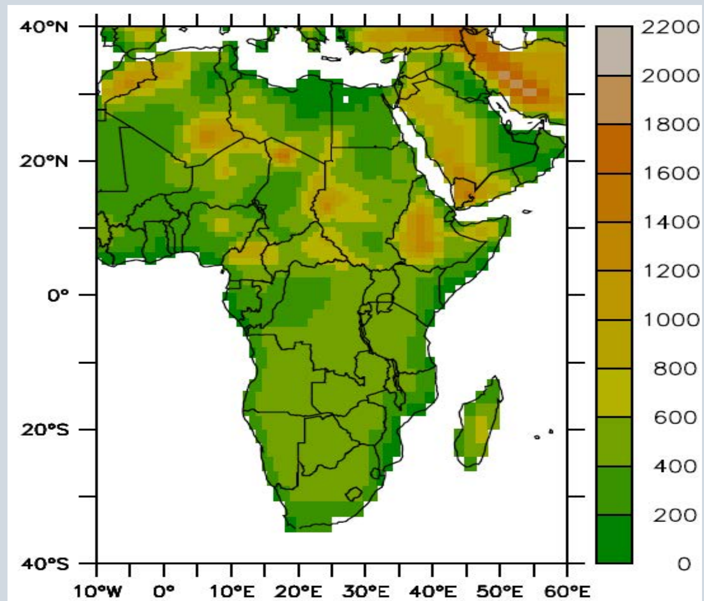
Impact of African Rift Uplift (2)

Different topographic scenarios

Present



Traps



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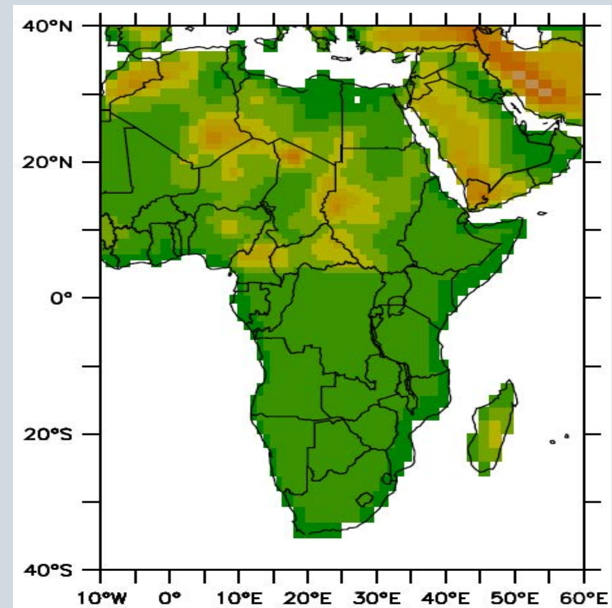
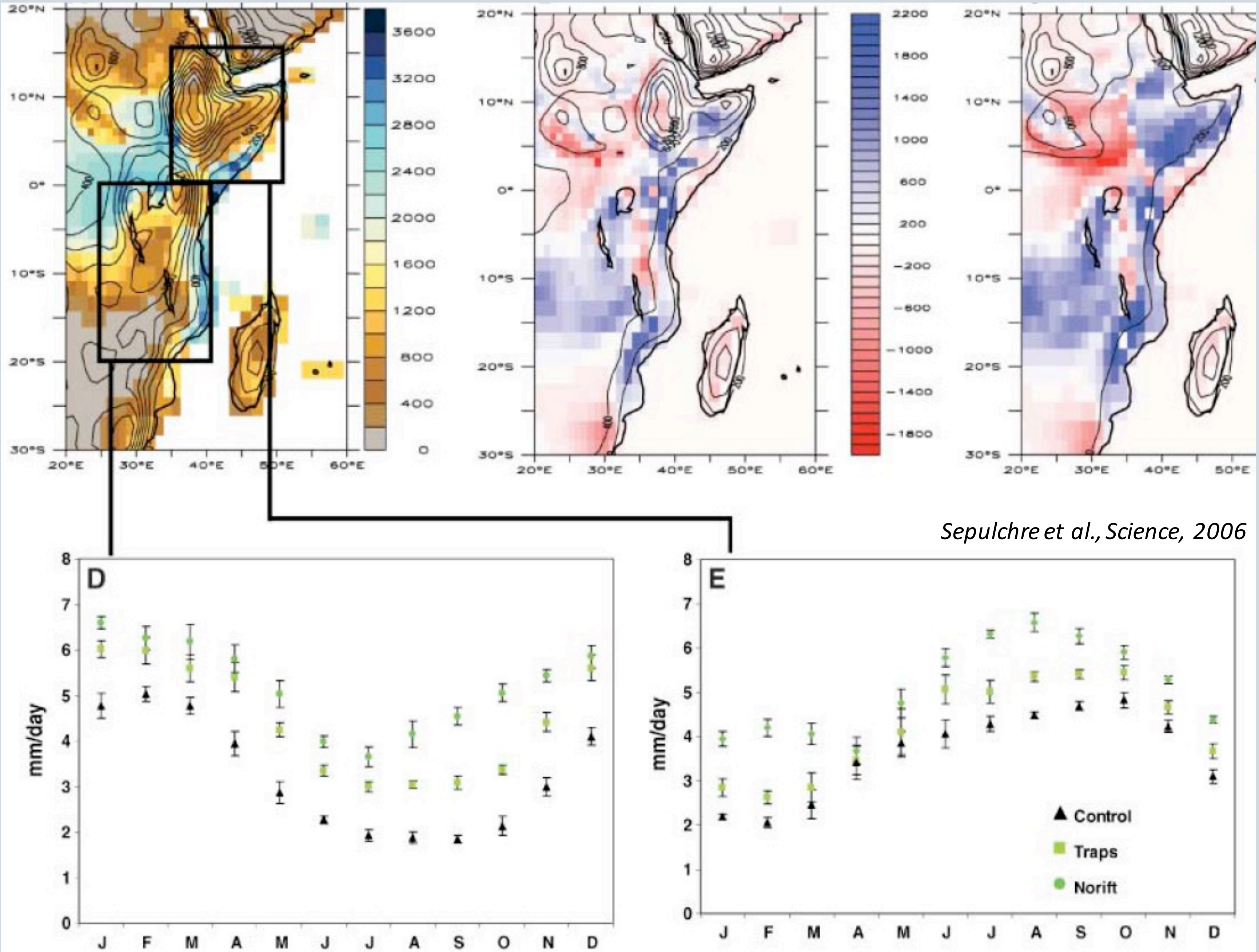


Sepulchre et al., Science, 2006

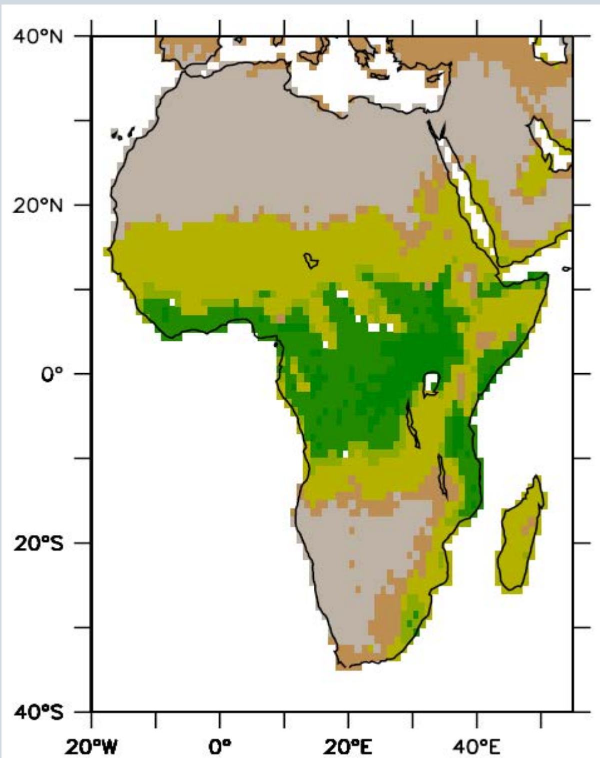
Increase in rainfall



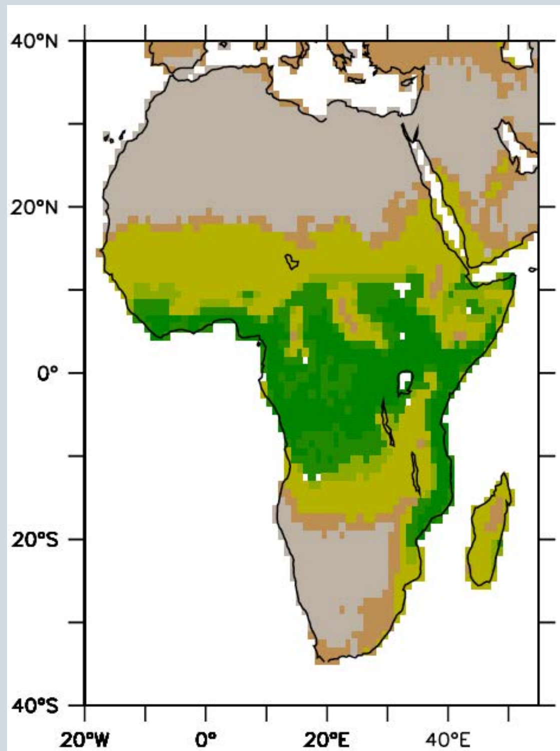
Sepulchre et al., Science, 2006

Changes in vegetation cover

Present



Traps



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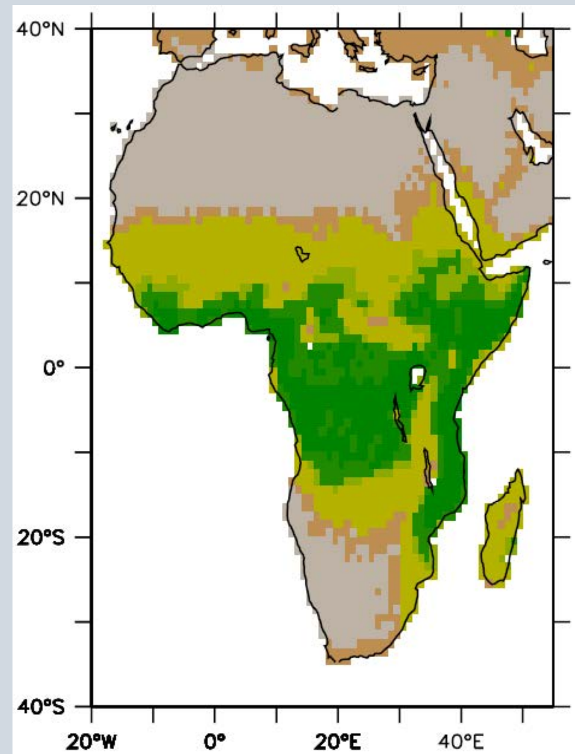
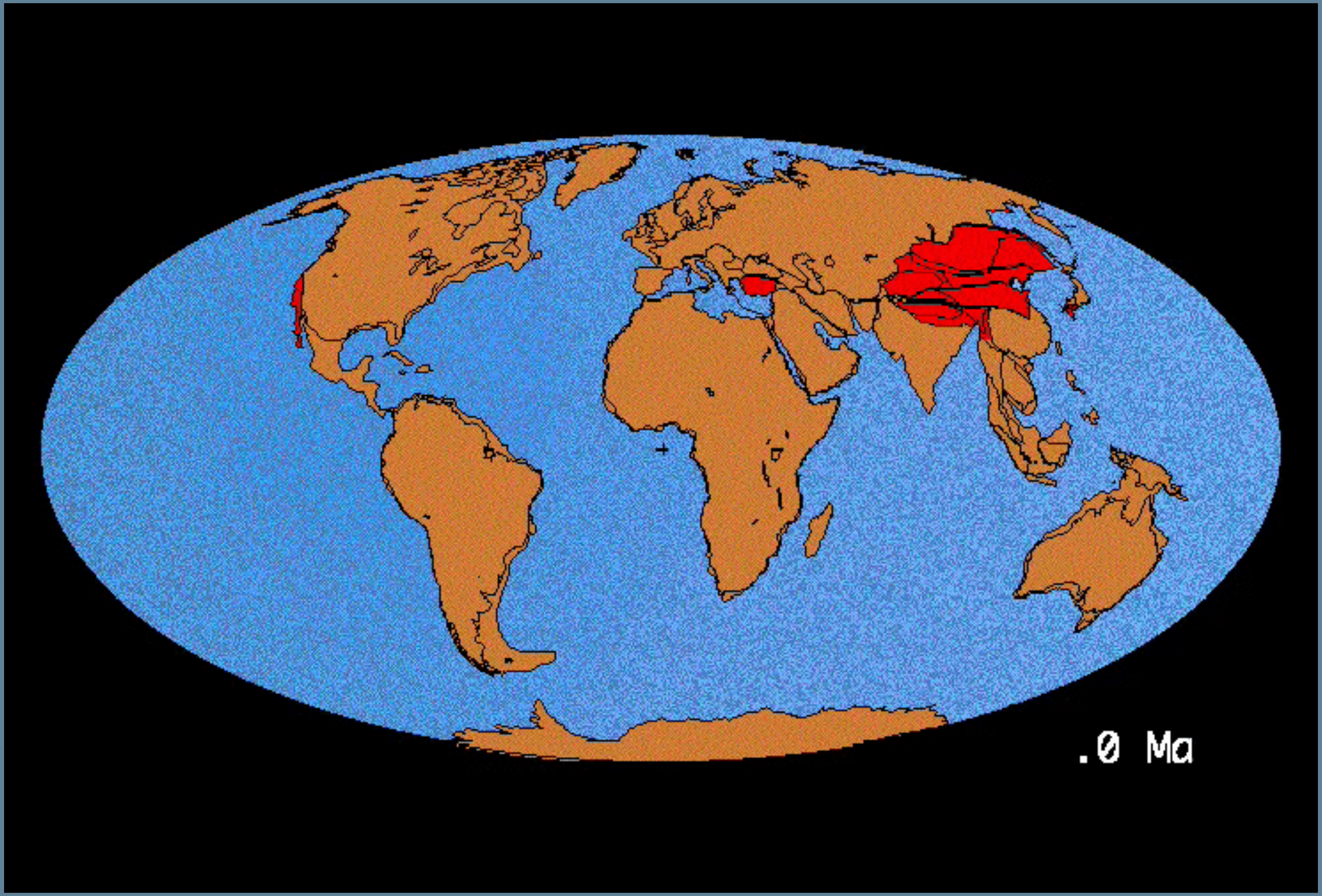


Sepulchre et al., Science, 2006

What's next ?

In the long term (million of years), the relationship between tectonics, pCO2 and climate, will still be appropriate



At short term scale, the perturbation we produce will modify drastically the climate

ACKNOWLEDGEMENTS:

- ECLIPSE/CNRS/INSU
- AURORA project (Norway(Bergen)-France (LSCE))
- Cai YuanPei(IAP-IGG(Beijing))/LSCE(France)

Short-term fundings and jobs endanger French scientific research

Thanks

Anthropocene experiment: 1

A big firework

Moreover, the context is cold, with ice cap in each hemisphere

Anthropocene experiment: 2

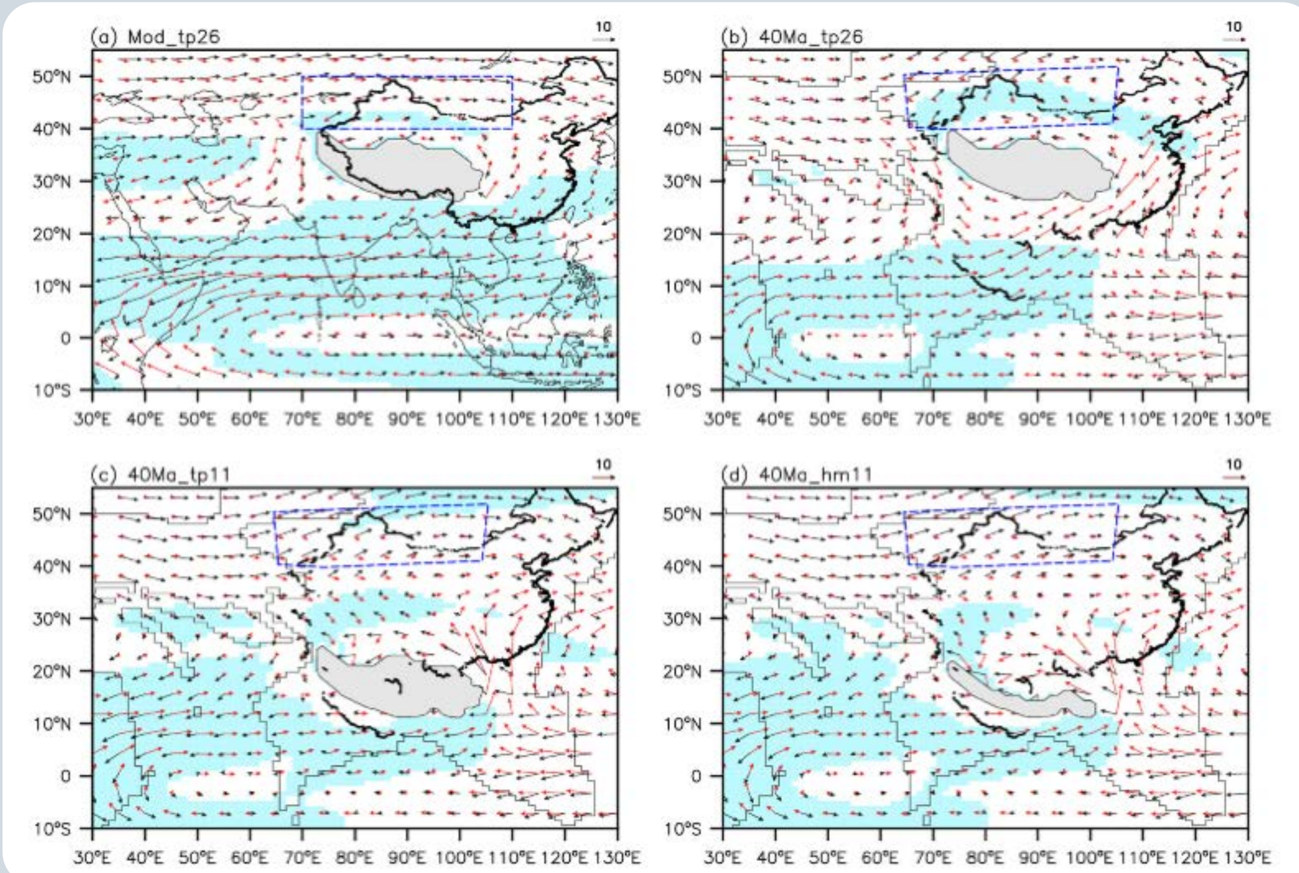
The population is approximately 7.3 billion in 2015 and will reach approximately 9,3 billion in 2050.
An important part of the world population lives close to costal regions.

World population in 2000

World population in 2050

Atmospheric circulation changes in different contexts

R. Zhang et al. EPSL, 2018



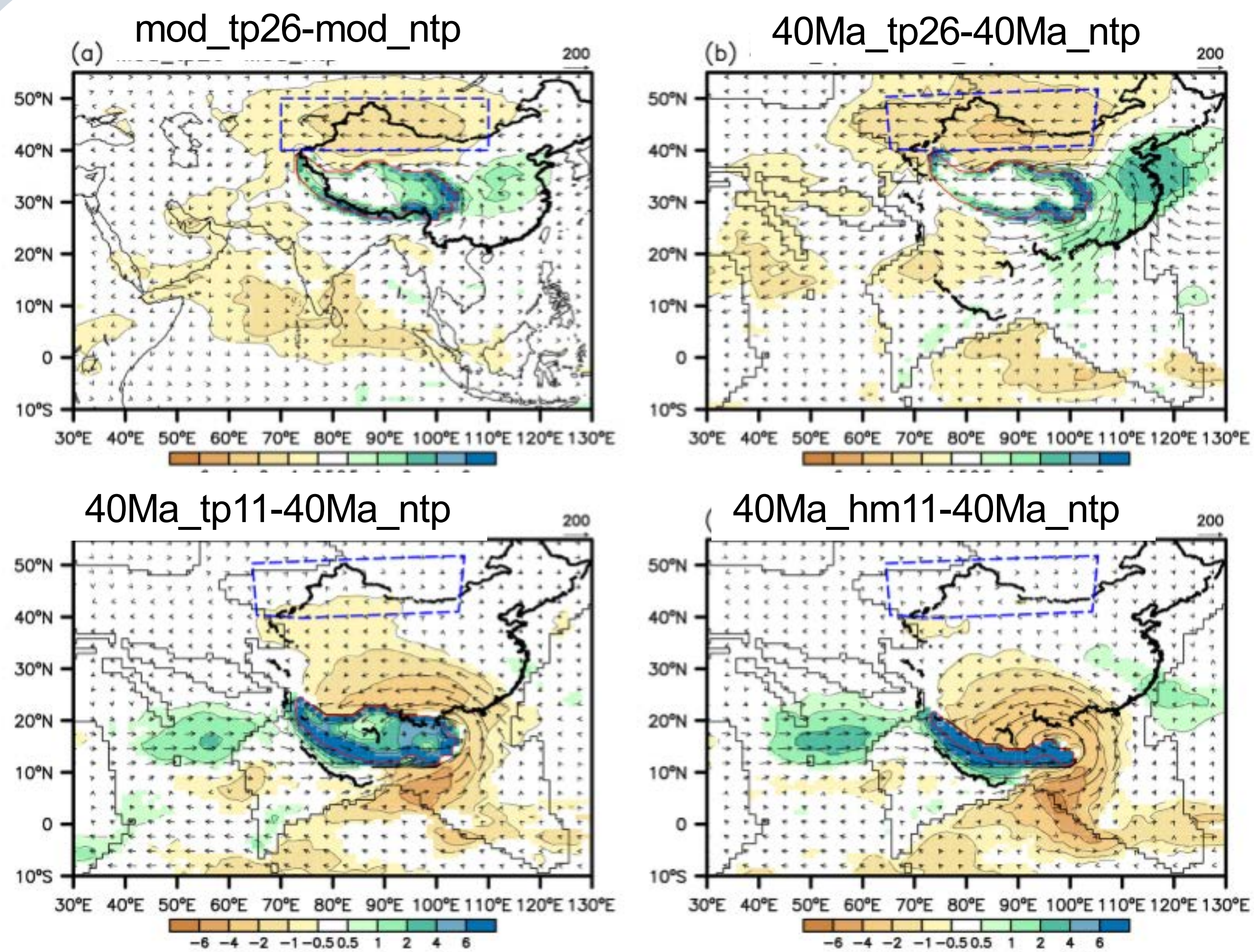
Comparison of wind seasonality due to the surface uplift of the Himalaya–TP.

Red arrows : summer 850hPa (low atmospheric level)

Black arrows : winter 850hPa winds (units: ms−1).

Blue areas: angles between summer and winter winds are greater than 100◦

Pattern of annual precipitation anomalies in the different sensitivity experiments



Changes in annual precipitation and vertically integrated water vapor transport due to the surface uplift of the Himalaya–TP.

R. Zhang et al. EPSL, 2018

AUSTRALOPITHECUS
(plus de 3 millions d'années)
Volume cérébral : ~ 400 cm^3

HOMO SAPIENS
L'Homme moderne
Volume cérébral :
de 1230 à 2 000 cm^3