Basics of Environmental Physics and Climate

10:00-11:15 Overview with essential questions

1) Astrid Bracher, Ocean Optics and Ocean Color Remote Sensing
2) Gerrit Lohmann, Dynamics II
3) Christoph Völker, Global Carbon Cycle
4) Gunnar Spreen: Remote Sensing of Ocean and Cryosphere /remote sensing of sea ice, polar regions
5) Mihalis Vrekoussis (Mathematics/Python)
6) Mihalis Vrekoussis Atm. Chemistry together with John P. Burrows,

11:15-11:30 Break with Posters
11:30-12:45 continue with essential questions

7) Atmospheric Modeling
8) Christian Melsheimer: Microwave Remote Sensing
9) Alexandra Klemme: Isotopes in Environmental Physics (elective)
10) John Burrows Atmospheric Physics
12) Gerrit Lohmann, Climate II

12:45-13:30 Break with Posters and food
13:30-14:00 Tour through the building
14:00-15:00 Developing ideas in breakout groups

Aim of meeting, overview of key activities, essence

How does the Earth System evolve in a warming climate ?

Environmental Changes

Drivers, Thresholds, Variability & Extremes, …

Aim of meeting, overview of key activities, essence

How does the Earth System evolve in a warming climate ?

Environmental Changes

Drivers, Thresholds, Variability & Extremes, …

Common understanding & Framework

Suitable diversity for interdisciplinary research & teaching

What can be done together?

Developments and gaps

Dynamics II

Gerrit Lohmann, Monica Ionita

- underlying dynamics of the atmosphere-ocean system
- The fundamental concepts of atmosphere-ocean flow, energetics, vorticity, and waves
- dynamical equations, climate data, basic physical concepts
- Exercises

$$\overbrace{\rho\left(\underbrace{\frac{\partial \mathbf{u}}{\partial t}}_{\substack{\text{Unsteady}\\ \text{acceleration}}} + \underbrace{\mathbf{u}\cdot\nabla\mathbf{u}}_{\substack{\text{Advective}\\ \text{acceleration}}}\right)}^{\text{Inertia (per volume)}} = \overbrace{\underbrace{-\nabla p}_{\substack{\text{Pressure}\\ \text{gradient}}} + \underbrace{\mu\nabla^2\mathbf{u}}_{\text{Viscosity}}}^{\text{Divergence of stress}} + \underbrace{\mathbf{F}}_{\substack{\text{Other}\\ \text{body}\\ \text{forces}}} .$$

Fundamental aspects: Dynamics

Goal: replace physical parameters with dimensionless numbers, which completely determine the dynamical behavior

representative values for velocity (U), time (T), distances (L)

Using these values, the values in the dimensionless-system (written with subscript d) can be defined:

$$u = U \cdot u_d$$

$$t = T \cdot t_d$$

$$x = L \cdot x_d$$

with $U = L/T$.

From these scalings, we can also derive

$$\partial_t = \frac{\partial}{\partial t} = \frac{1}{T} \cdot \frac{\partial}{\partial t_d}$$

$$\partial_x = \frac{\partial}{\partial x} = \frac{1}{L} \cdot \frac{\partial}{\partial x_d}$$

$$\frac{\partial}{\partial t_d}\mathbf{u_d} + (\mathbf{u_d} \cdot \nabla_d)\mathbf{u_d} = -\nabla_d p_d + \frac{1}{Re}\nabla_d^2 \mathbf{u_d} \qquad (1.27)$$

The dimensionless parameter $Re = UL/\nu$ is the Reynolds number and the only parameter left!

CIRCULATION

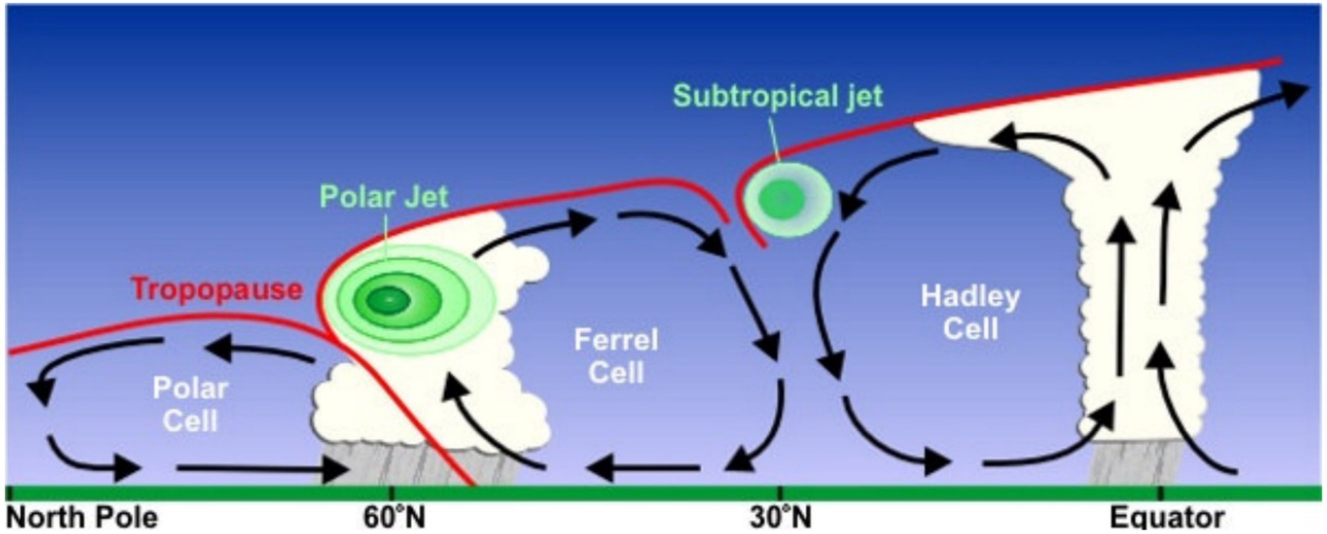


Figure 4.1: Cross section of the subtropical and polar jet streams by latitude.

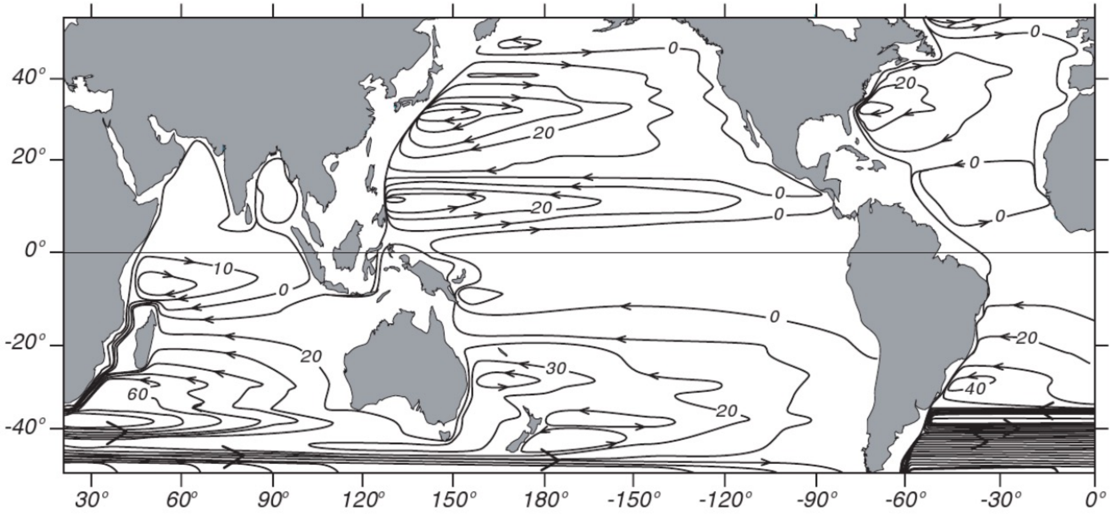


Figure 5.1: Depth-integrated Sverdrup transport applied globally using the wind stress from Hellerman and Rosenstein (1983). Contour interval is 10 Sverdrups (Tomczak and Godfrey, 1994).

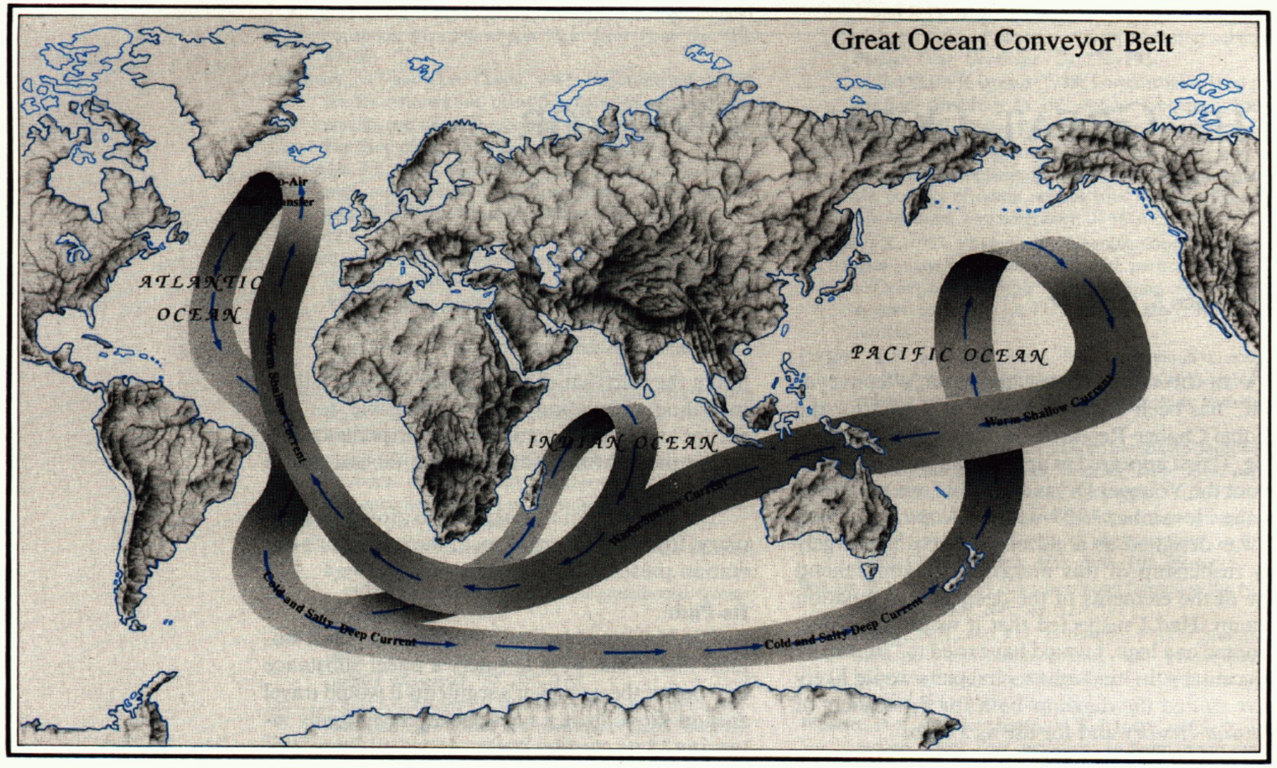
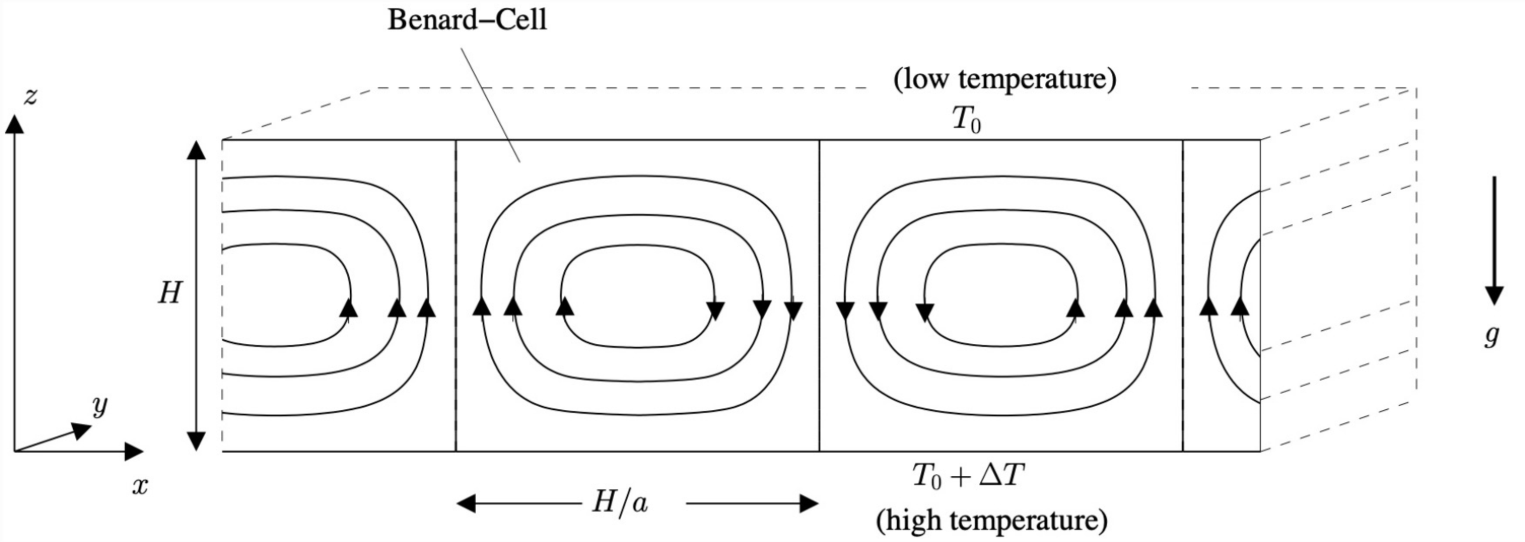


Fig. 1: The great ocean conveyor logo (Broecker, 1987). (Illustration by Joe Le Monnier, Natural History Magazine.)

Fundamental aspects: Dynamics

Convection in the Rayleigh-Benard system



Bild

Rayleigh (1916) temperature difference between the upper- and lower-surfaces

$$T(x, y, z = H) = T_0$$

$$T(x, y, z = 0) = T_0 + \Delta T$$

Rossby waves atmosphere

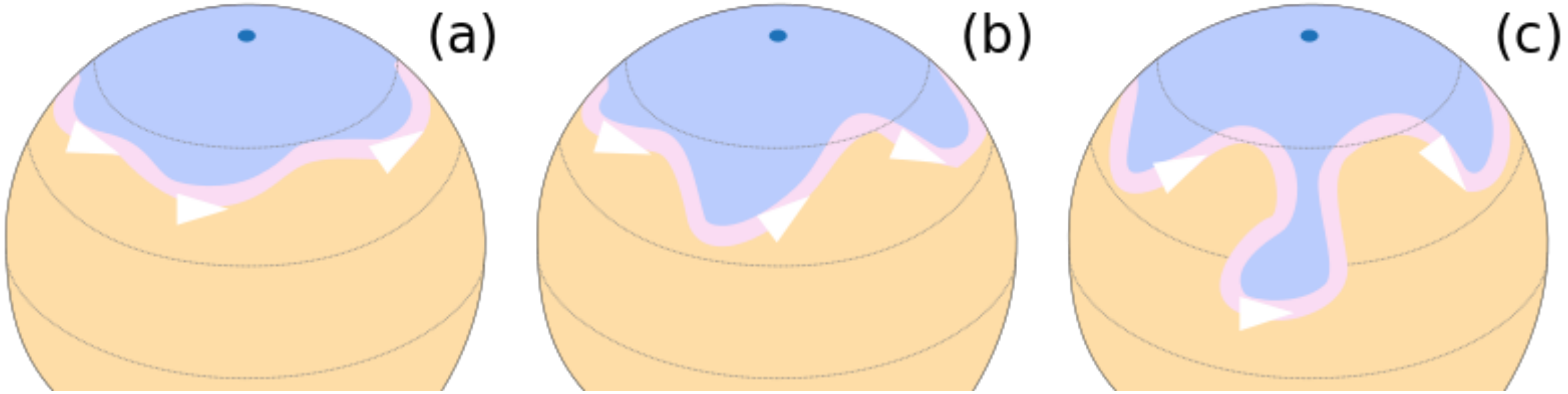


Figure 7.1: Meanders (Rossby Waves) of the Northern Hemisphere's polar jet stream developing (a), (b); then finally detaching a "drop" of cold air (c). Orange: warmer masses of air; pink: jet stream.

$$\begin{aligned}
\partial_t u &= f\, v - g\, \partial_x \eta \\
\partial_t v &= -f\, u - g\, \partial_y \eta \\
\partial_t \eta &= -\partial_x (H u) - \partial_y (H v)
\end{aligned}$$

https://www.youtube.com/watch?v=Lg91eowtfbw&ab_channel=MetOffice-LearnAboutWeather

open shallow2D_rossby.R

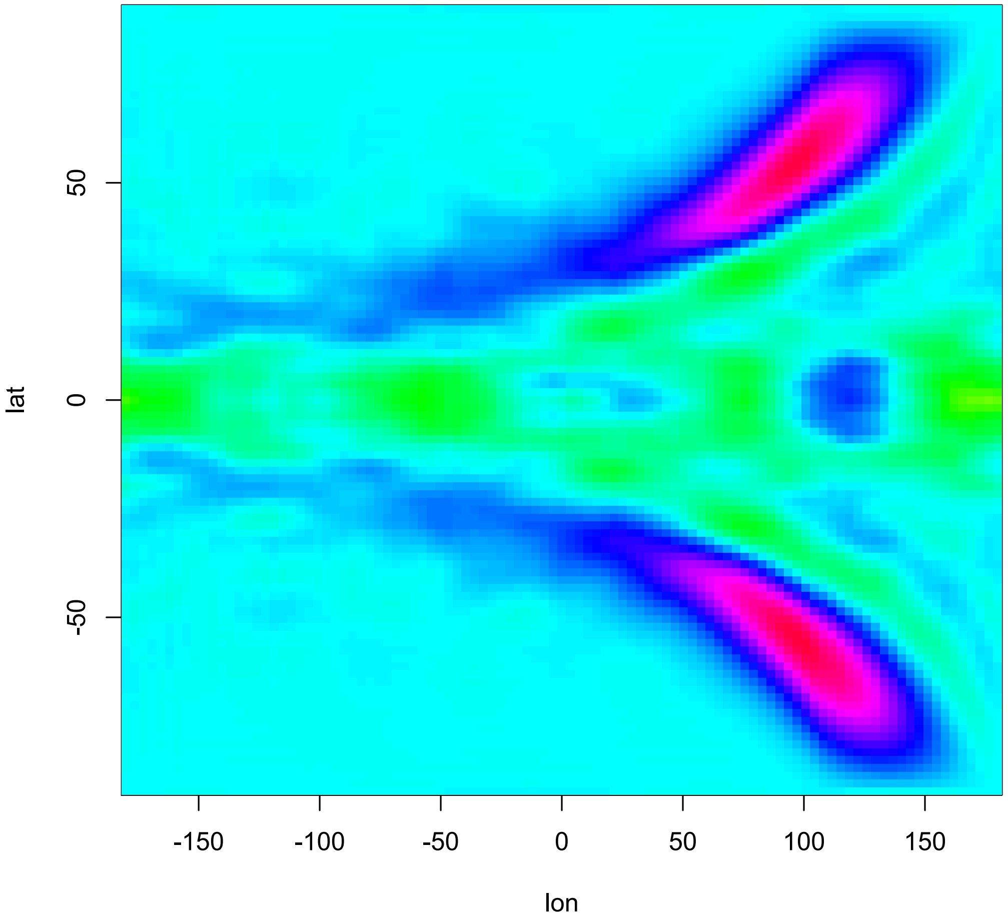
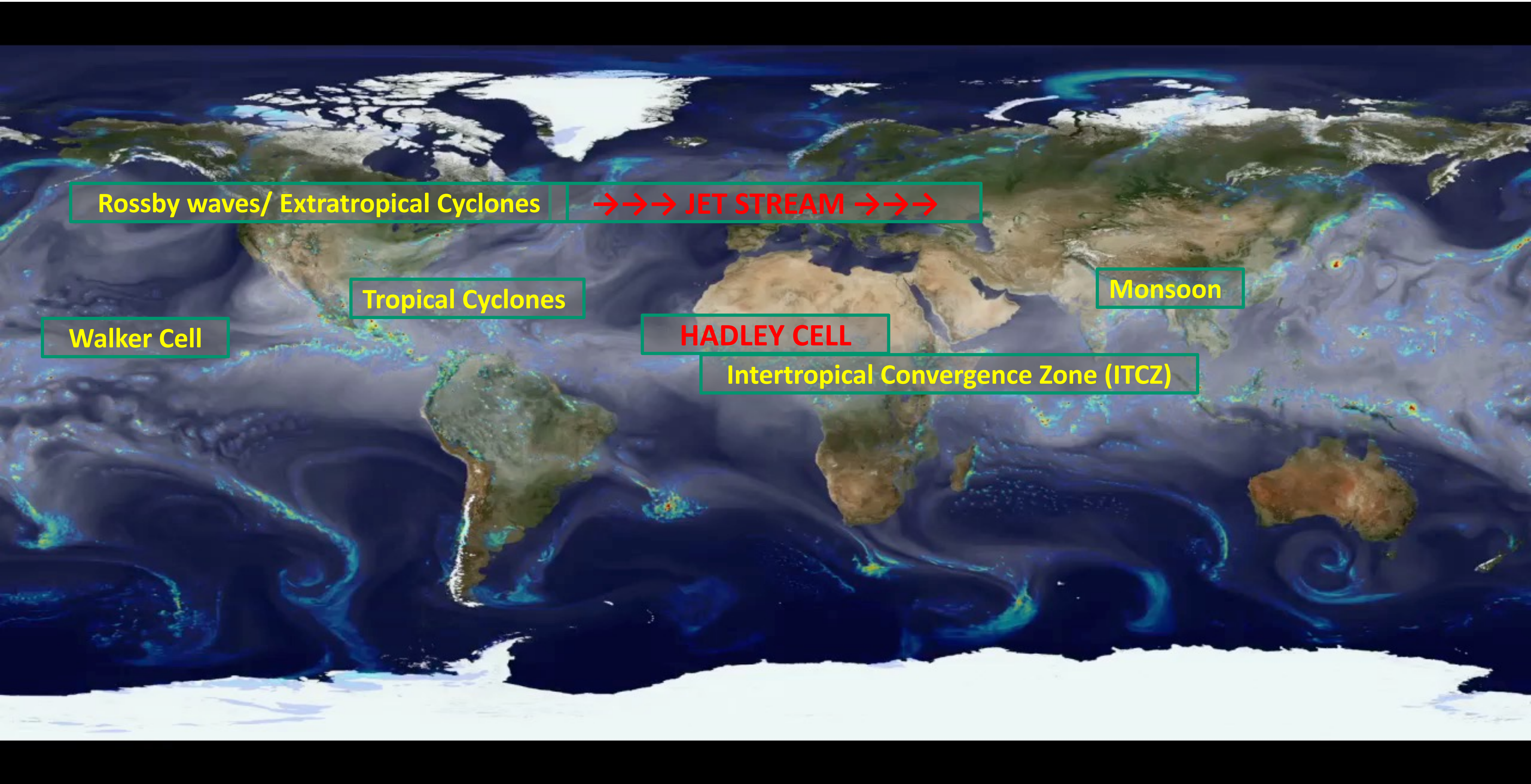
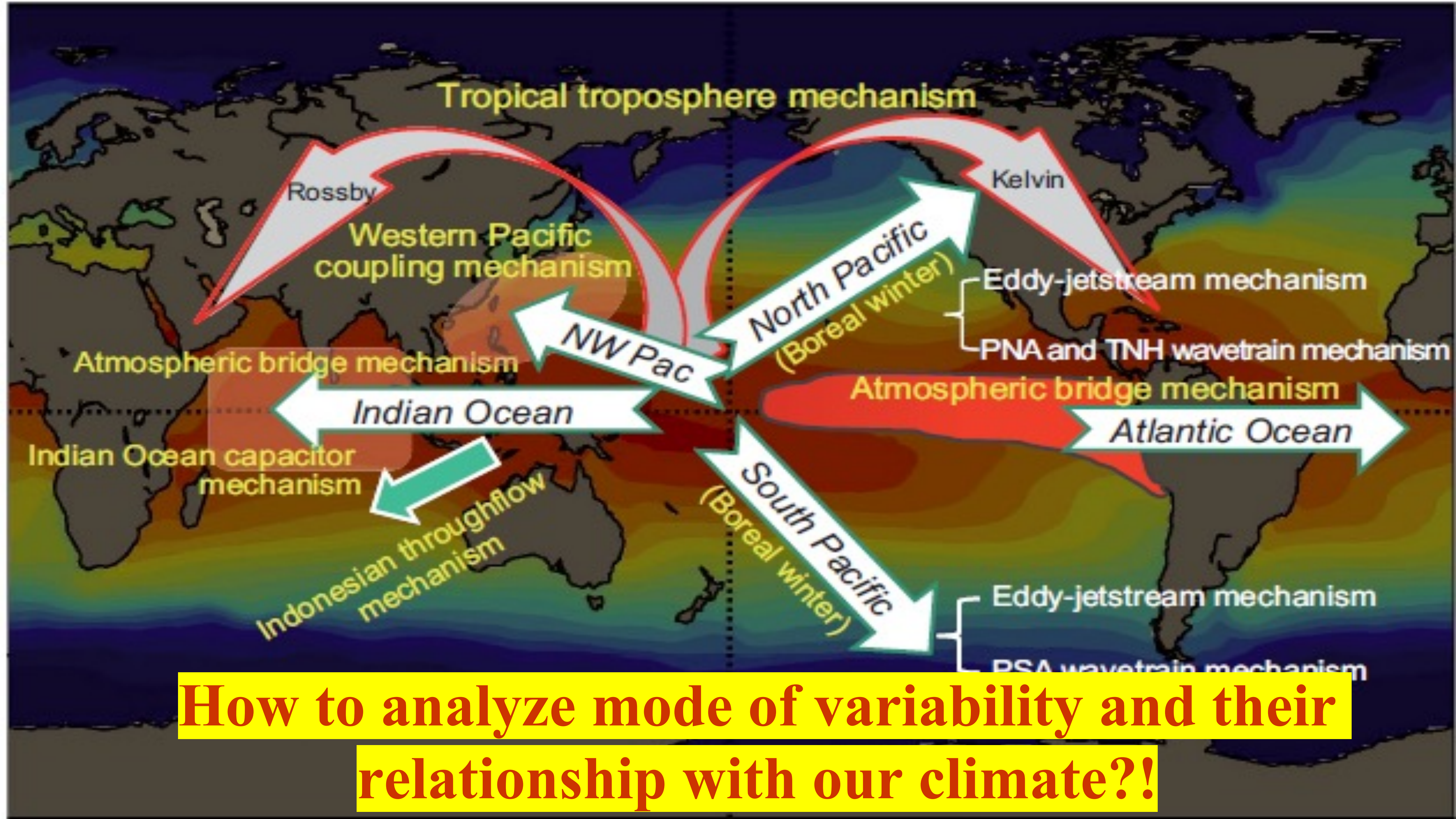


Figure 7.3: Global Rossby and Kelvin wave signatures in the exercise 49.

Large scale atmospheric circulation

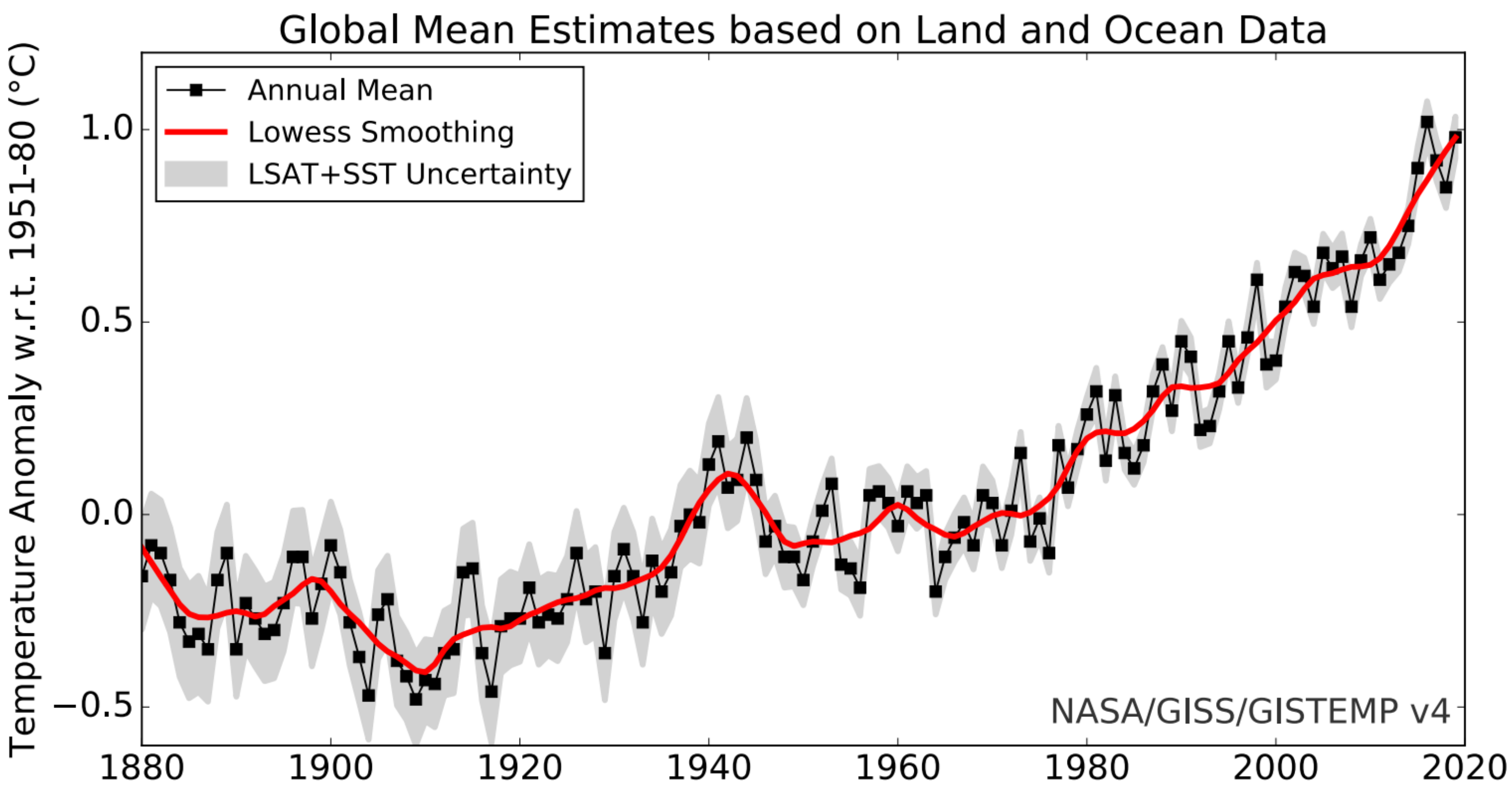




How to analyze mode of variability and their relationship with our climate?!

Climate II

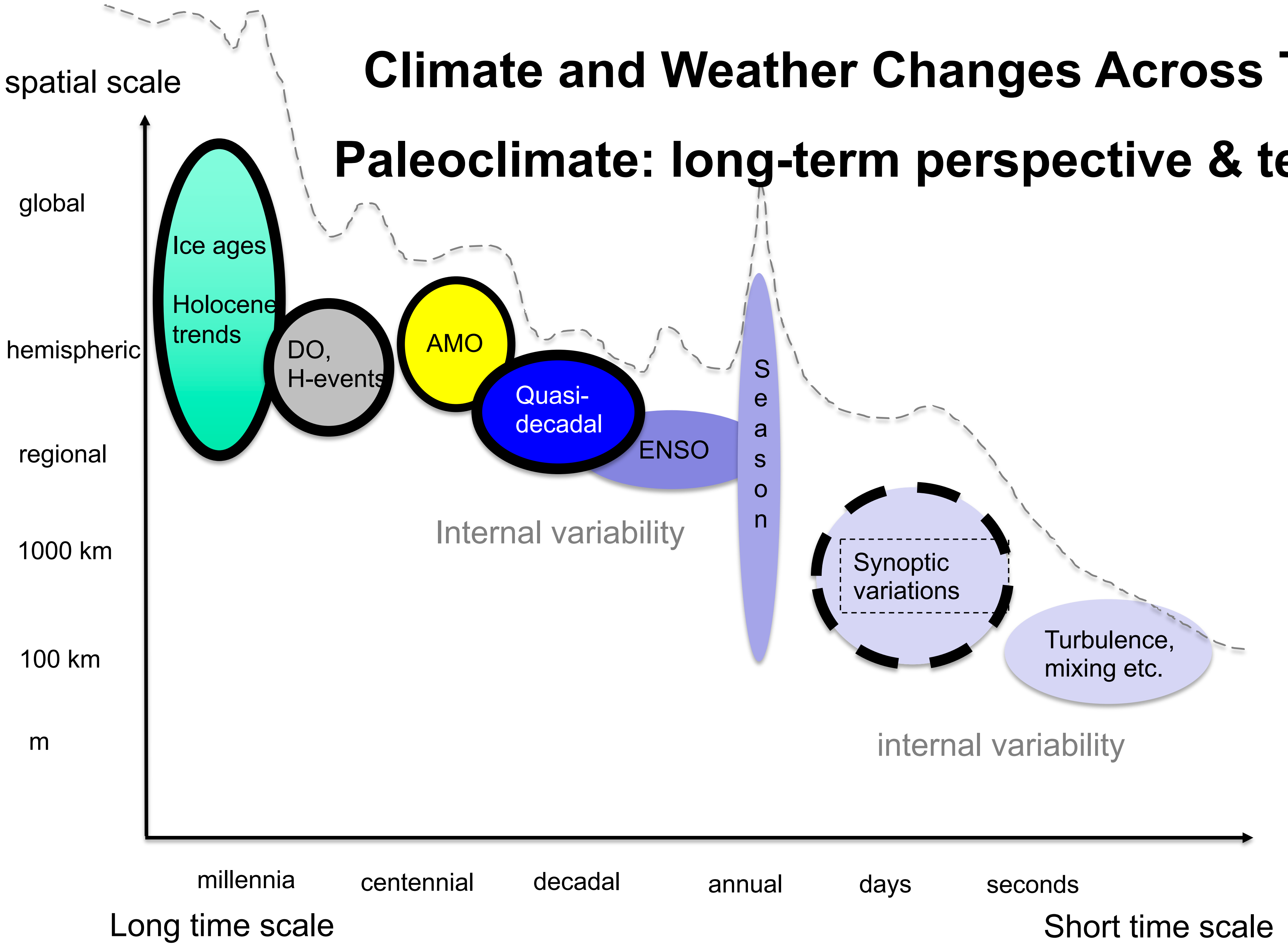
Gerrit Lohmann & Martin Werner



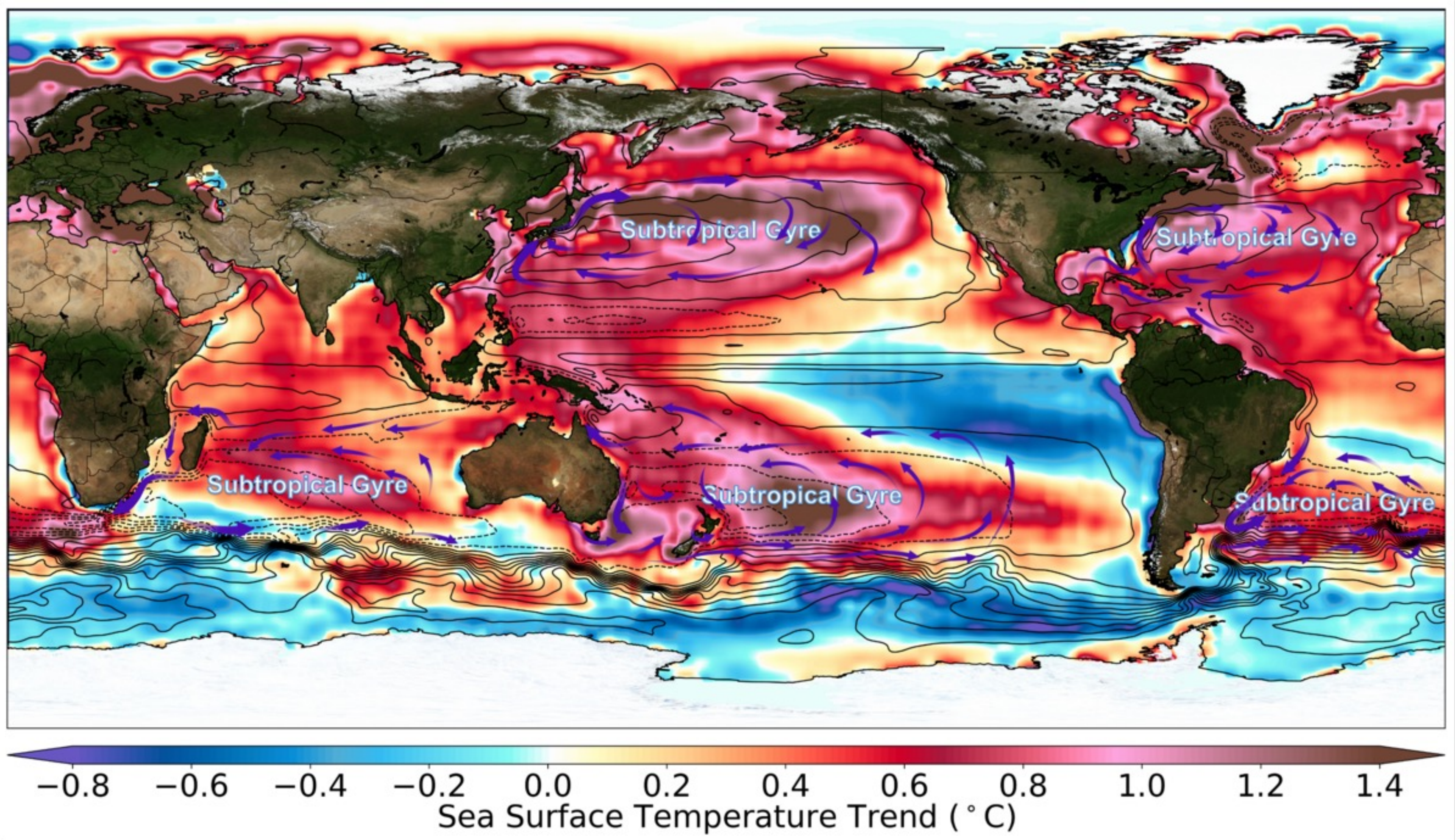
[https://data.giss.nasa.gov/gistemp/graphs_v4/]

Climate and Weather Changes Across Time Scales

Paleoclimate: long-term perspective & test of models



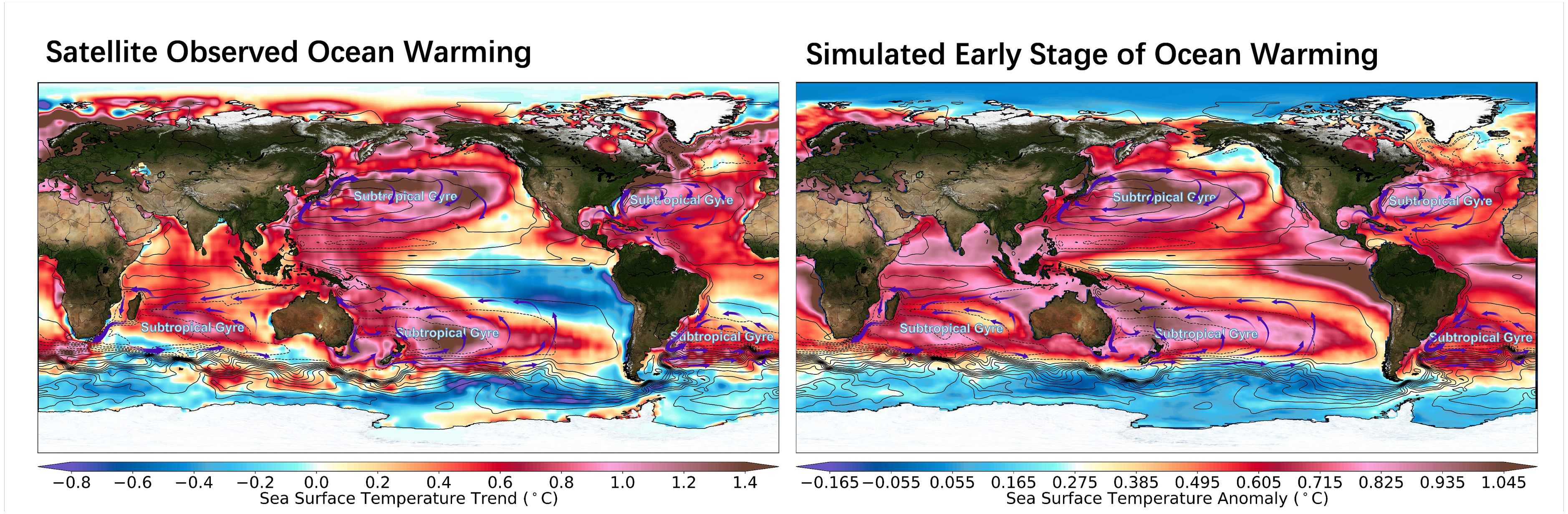
Temperature trend of the last 40 years



Information based on satellites

Yang, G. Lohmann, ... & J. Müller, 2023: The emergent pattern of infant stage ocean warming in satellite measurements. Communications Earth & Environment

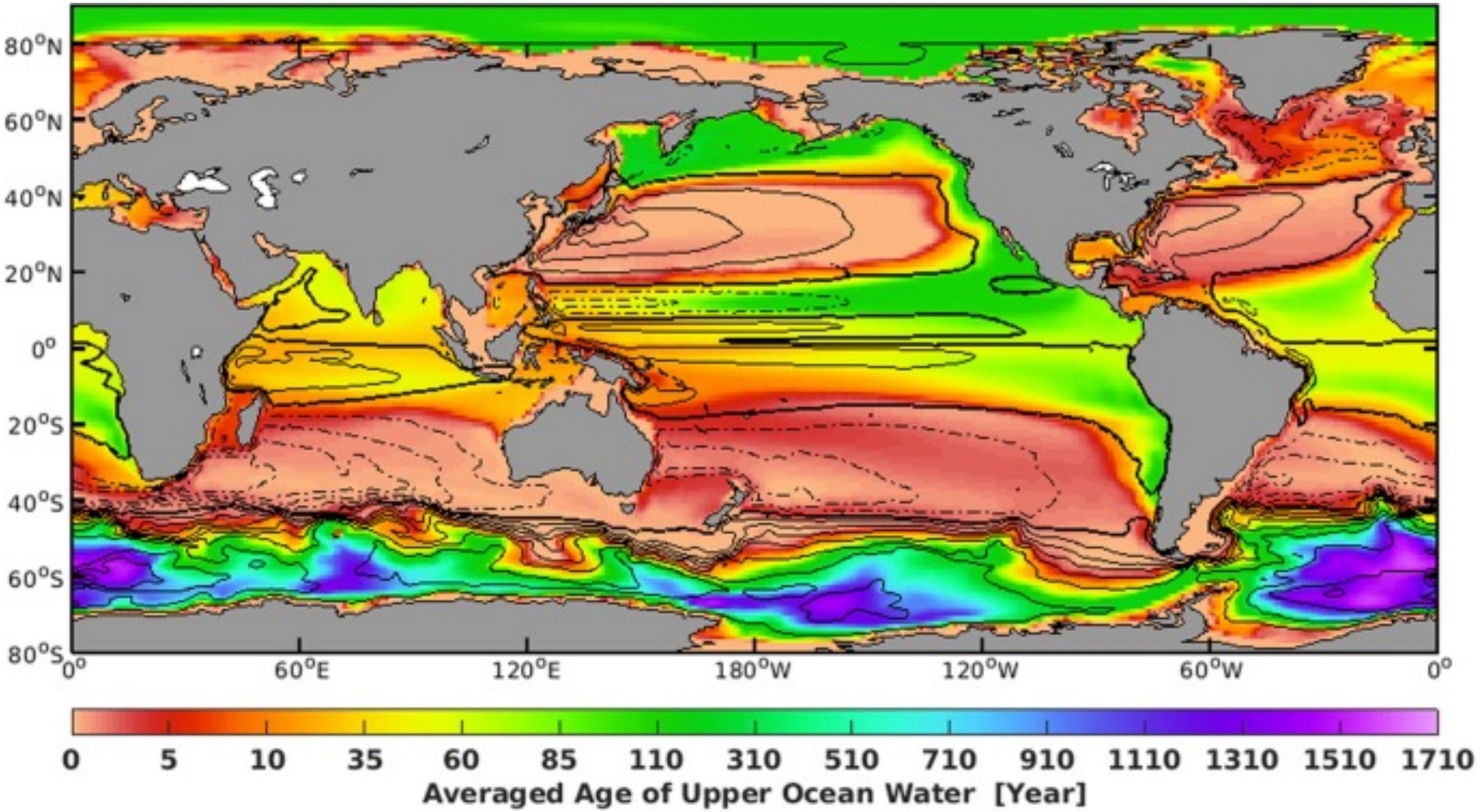
Satellite-observed strong subtropical ocean warming as an early signature of global warming



AWI-ESM:
initial shock

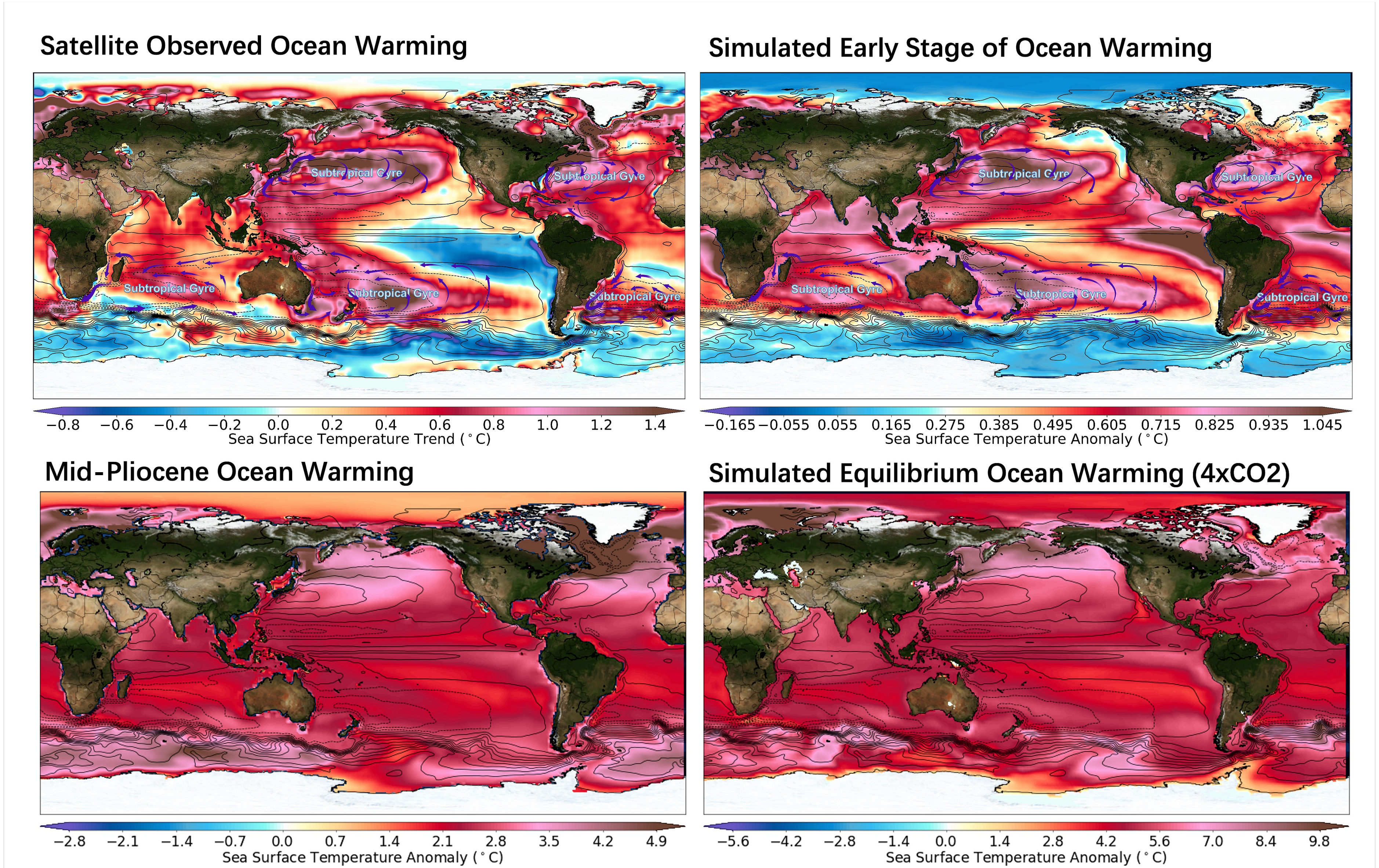
observed warming pattern is likely a short-term transient response to the increased CO_2 forcing, which only emerges during the early stage of anthropogenic warming.

Simulated averaged age of the upper 300-m ocean water column



Yang et al. 2023

Satellite-observed strong subtropical ocean warming as an early signature of global warming

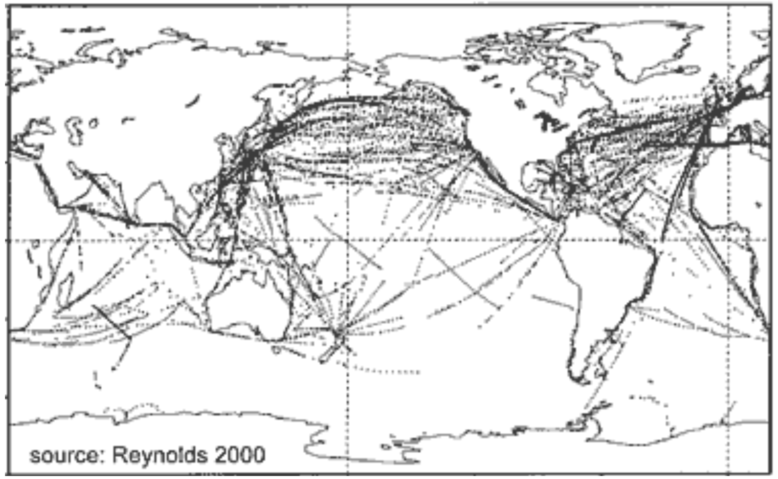


Early stage

equiliibrated stage

The “Climate dilemma“

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

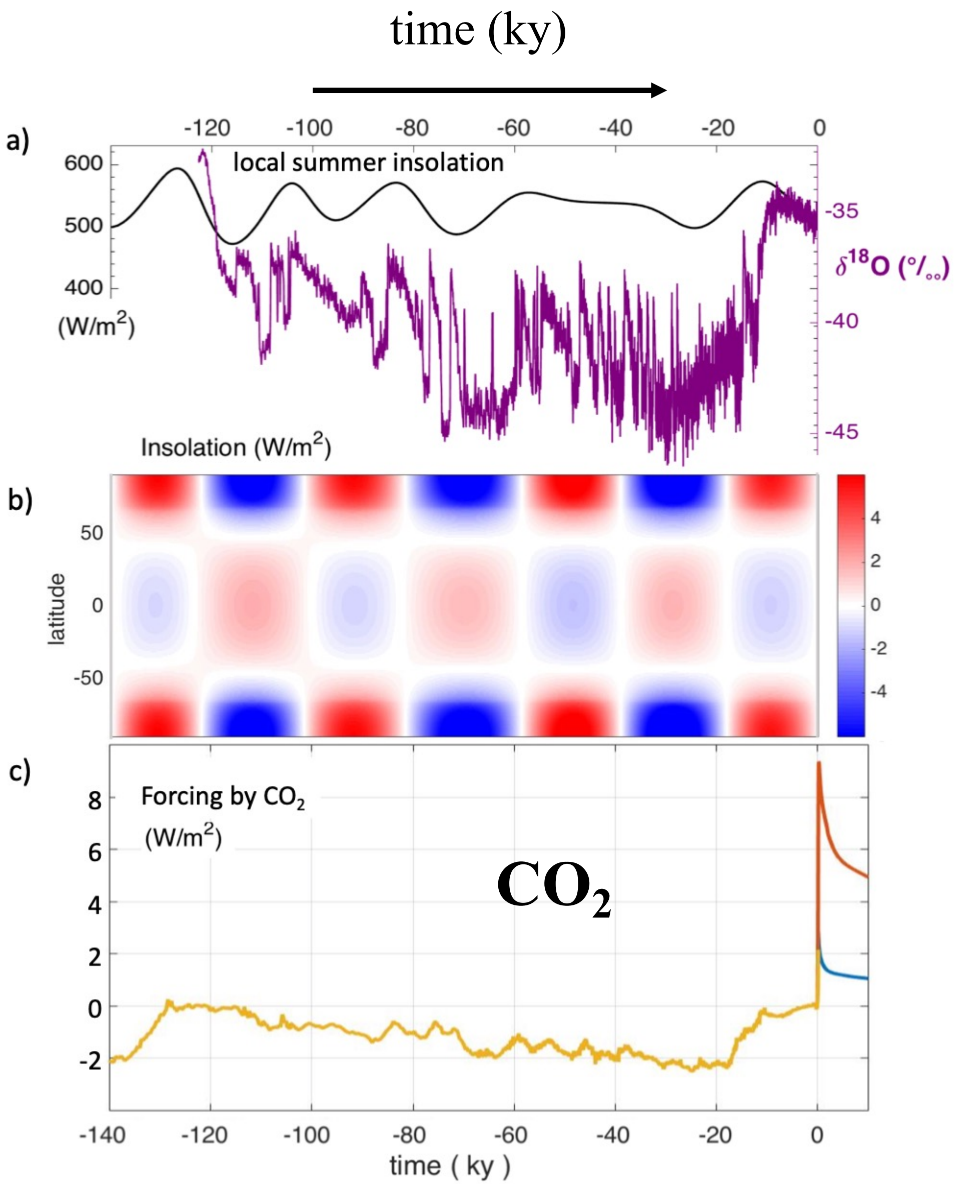


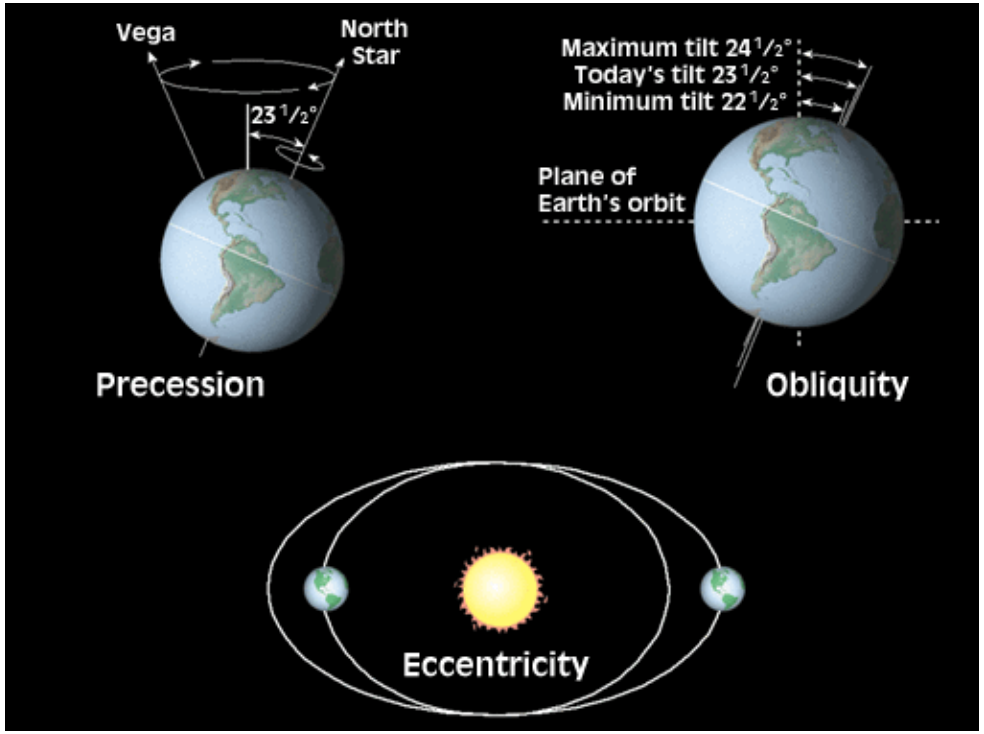
- For the time before instrumental records, one has to rely on information from **long-term data and modeling**.

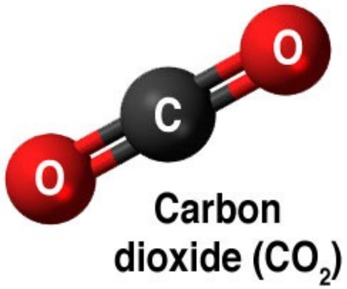
Abrupt climate change

Short wave radiation

Long wave radiation







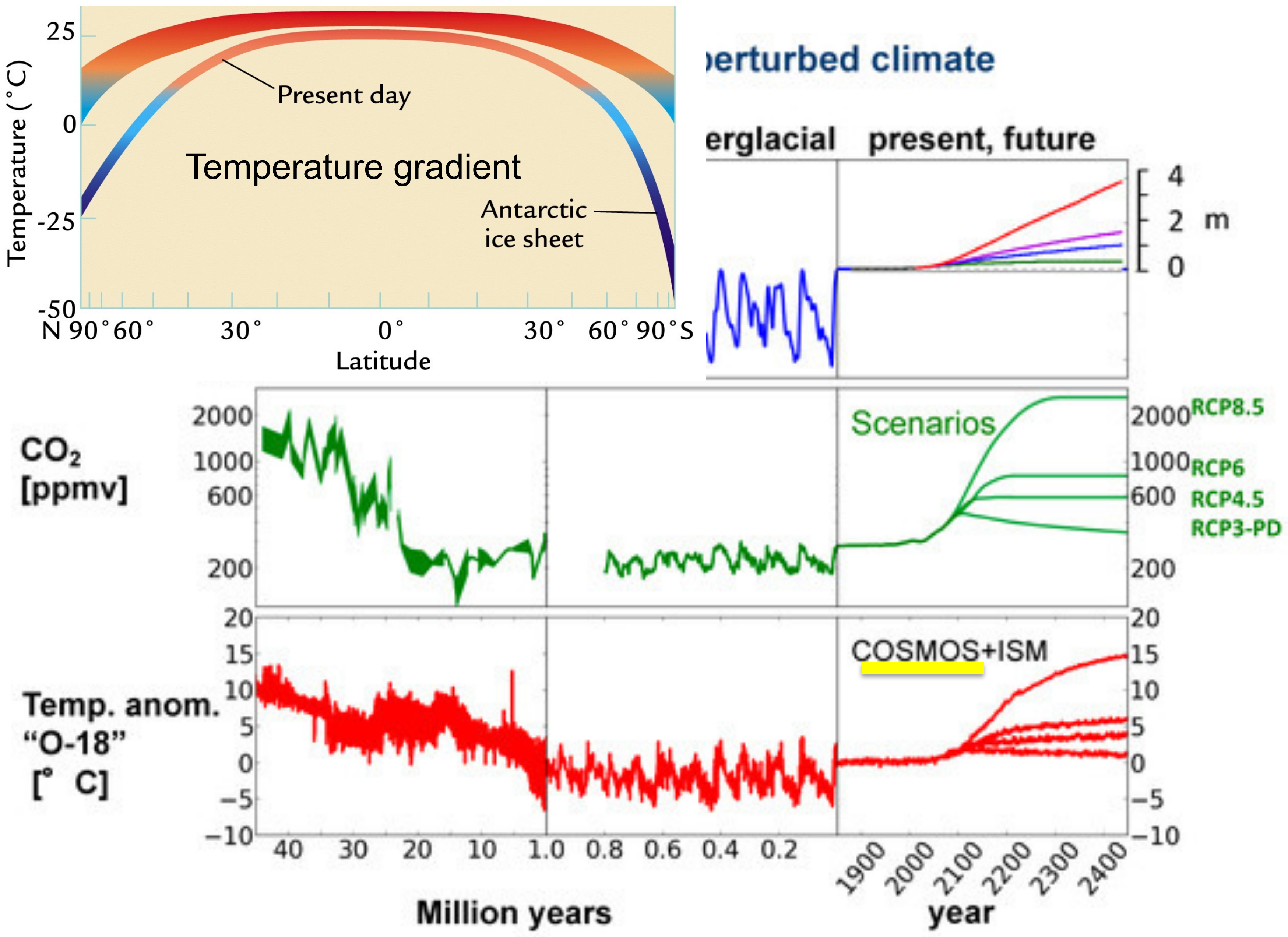
based on NGRIP, 2004; Berger, 1988; Köhler et al., 2017; Archer and Brovkin, 2008

Effect of **obliquity** on the **position Tropic of Cancer**

Highway in Mexico

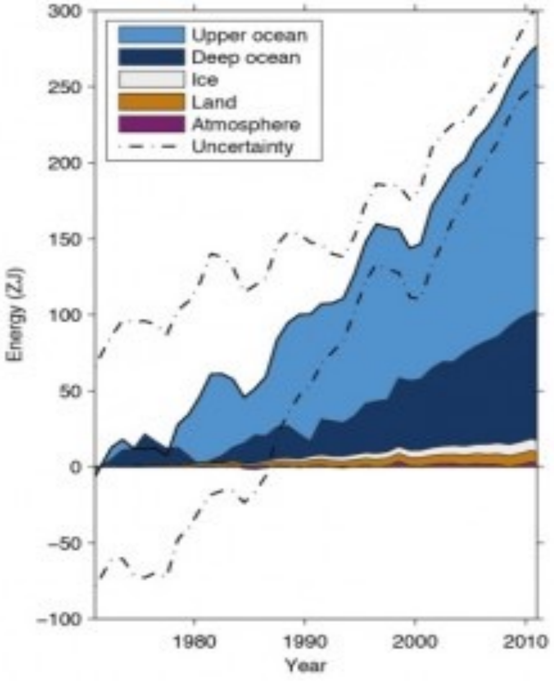
How many meters per year?

Earth's obliquity oscillates between 22.1° and 24.5° on a 41,000-year cycle.
The Earth radius a=6371 km



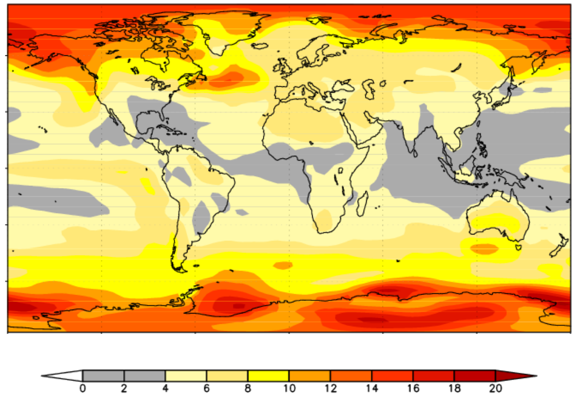
PACES program = our last 10 years

Lohmann et al., 2020b

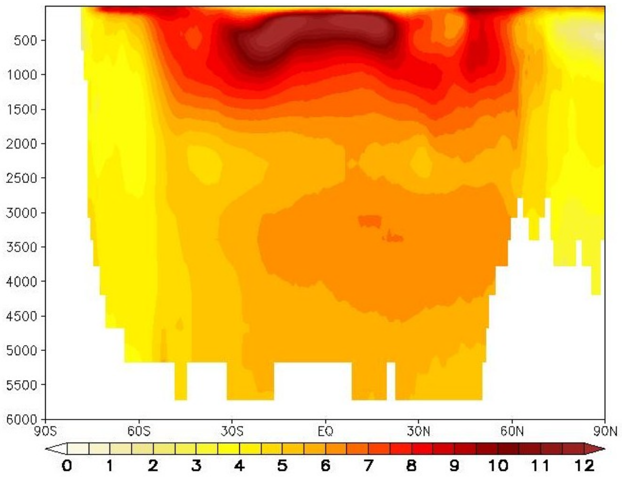


"old" IPCC report

a)



b)



Effective heat capacity/heat uptake

$$C_p^o \partial_t T = \partial_z (k^o \partial_z T)$$

Increased k leads to high latitude warming

& pronounced warming at the thermocline.

Lohmann, 2020

RESEARCH ARTICLE
10.1029/2020PA003953

Special Section:
The Miocene: The Future of the Past

Effects of CO_2 and Ocean Mixing on Miocene and Pliocene Temperature Gradients

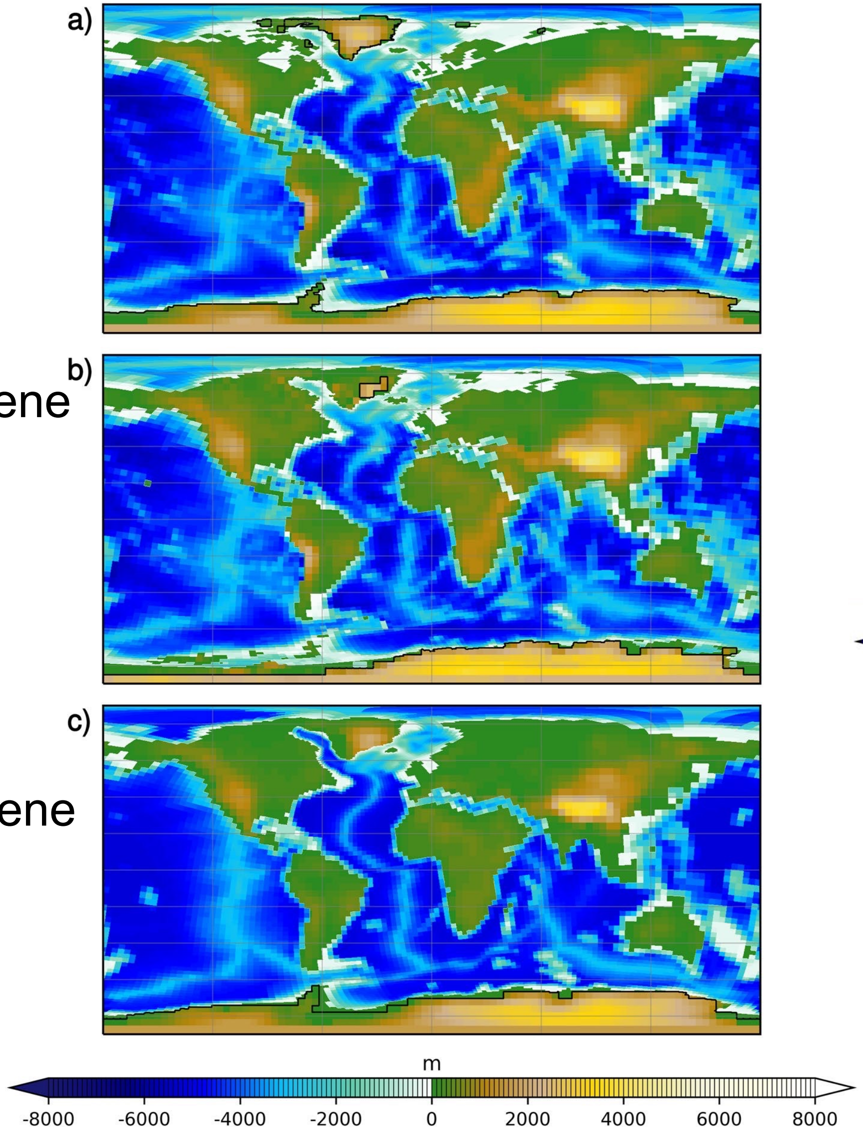
Gerrit Lohmann[1,2], Gregor Knorr[1], Akil Hossain[1], and Christian Stepanek[1]

[1]Alfred Wegener Institute (AWI) Helmholtz Center for Polar and Marine Research, Bremerhaven, Germany, [2]Department of Environmental Physics and MARUM, University of Bremen, Bremen, Germany

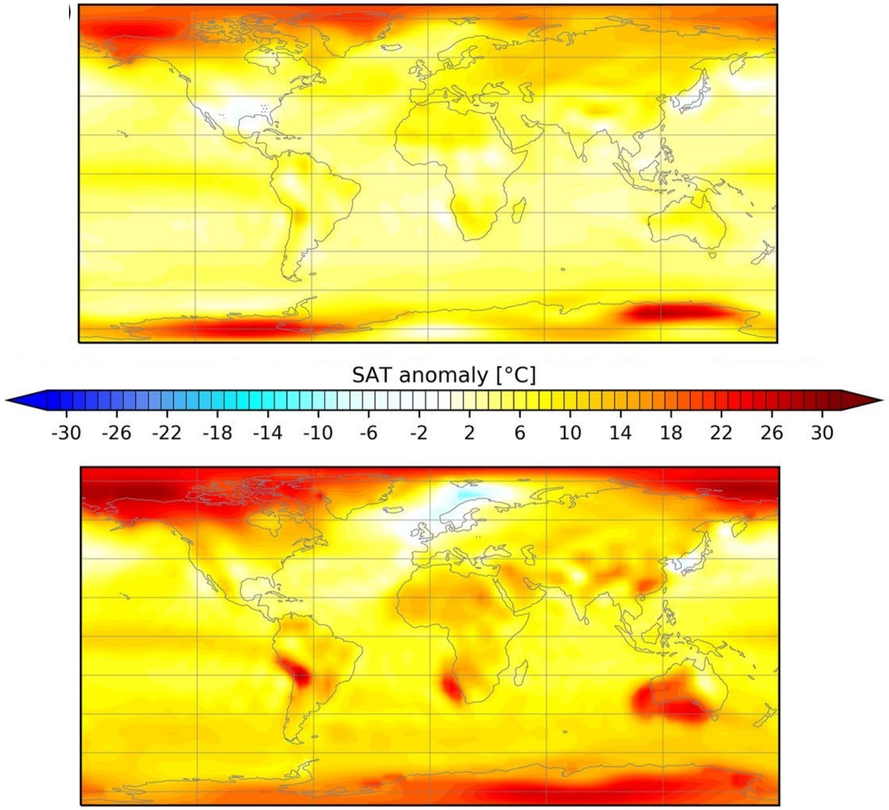
PI

Pliocene

Miocene



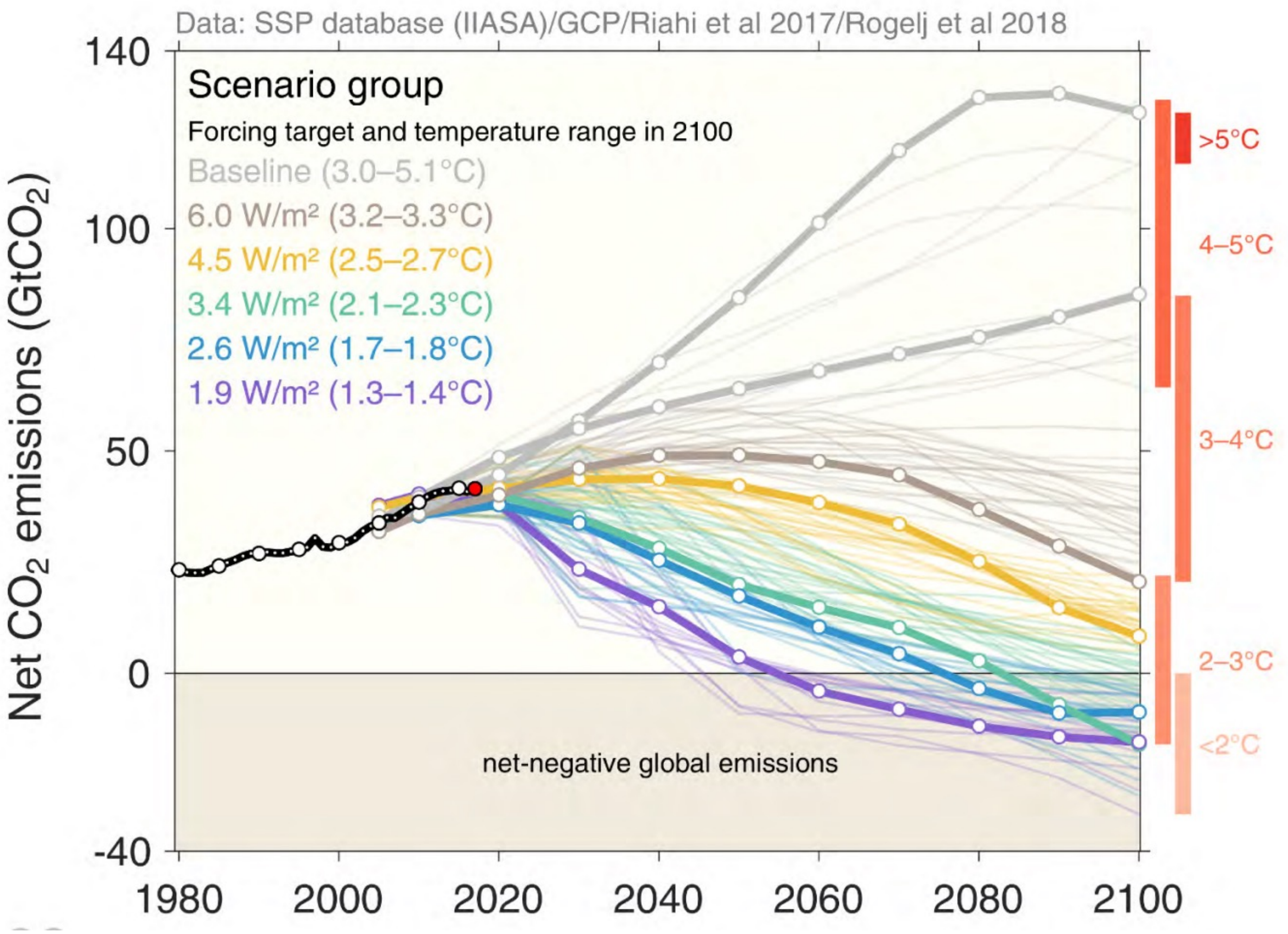
Temperature anomalies



Lohmann et al. 2022, Paleoceanogr.

Scenarios

Global temperatures and CO_2 of the future?



Modelling of the Earth System

Gerrit Lohmann / Silke Thoms / Thomas Jung / Mihalis Vrekoussis

1) 13.4. INTRODUCTION:
Earth system model components, definitions, processes. (MV)

2) 27.4. NUMERICAL APPROXIMATIONS I:
Finite differences: Ordinary differential equations (Runge-Kutta etc) (ST)

3) 4.5. NUMERICAL APPROXIMATIONS II:
Finite differences: Partial differential equations (Arakawa Grids etc) (ST)

4) 11.5. EXAMPLES: waves, diffusion, boundaries (ST)

5) 25.5. NUMERICAL APPROXIMATIONS III:
Finite Volume and Finite Elements and spectral methods (atmosphere and ocean) (TJ)

6) 14.7. HIGH-PERFORMANCE COMPUTING (scalability, Moore's law) (TJ)

7) 8.6. ATMOSPHERIC CHEMISTRY I:
Chemistry Transport Models (chemical processes including types of models, box models, grids, coordinates) (MV)

8) 15.6. ATMOSPHERIC CHEMISTRY II:
Inverse methods (MV)

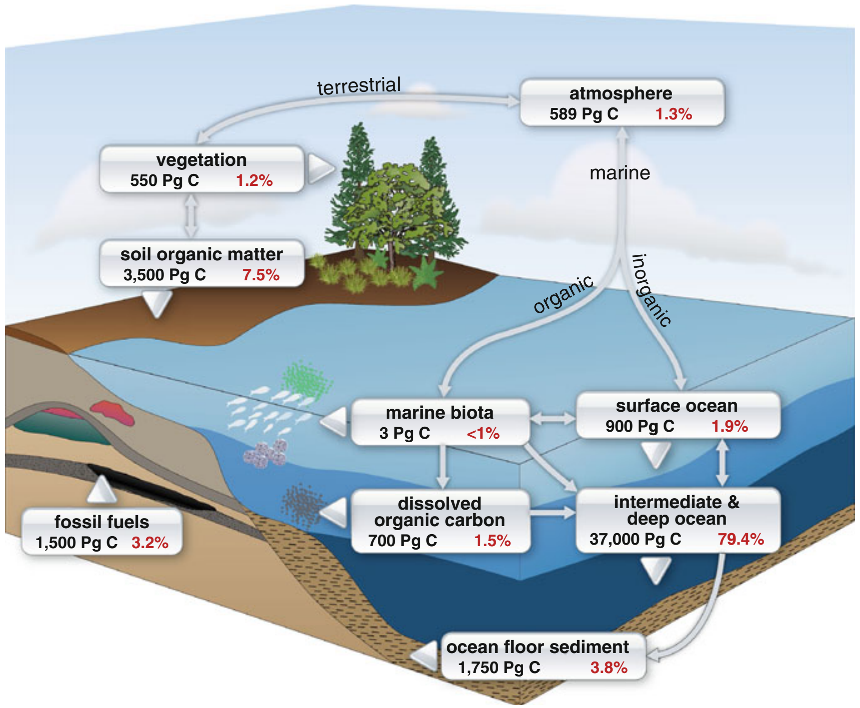
9) 22.6. Earth system models including TRACERS and DYNAMICAL VEGETATION (GL)

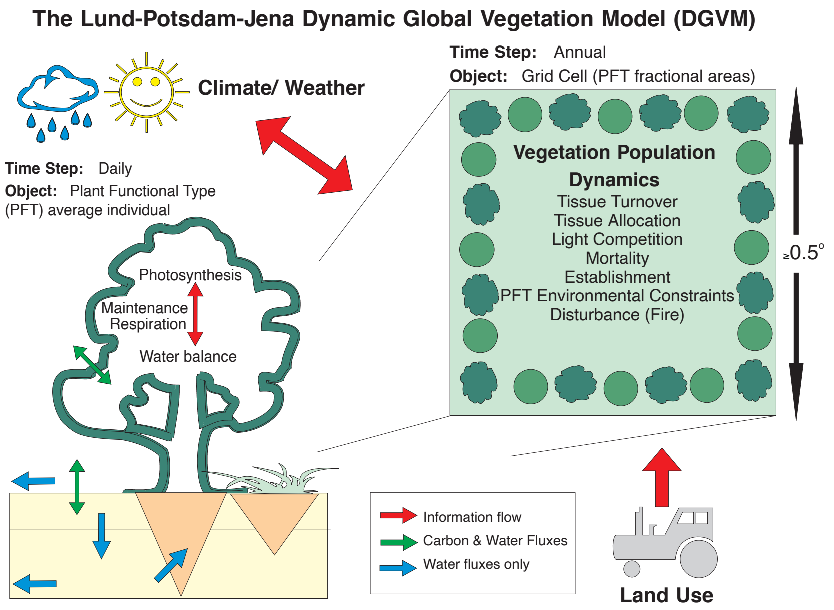
10) 29.6. DATA ASSIMILATION (Kalman filters etc) (TJ)

11) 6.7. RANDOM SYSTEMS (Stochastic differential equations, Lattice Gases) (GL)

12) 13.7. CRYOSPHERE (Sea ice, ice sheets, and permafrost) (GL)

Earth system models
including tracers and dynamical vegetation





Gerrit Lohmann
MES, 22.6.2023

Todays lecture

- Earth System Models

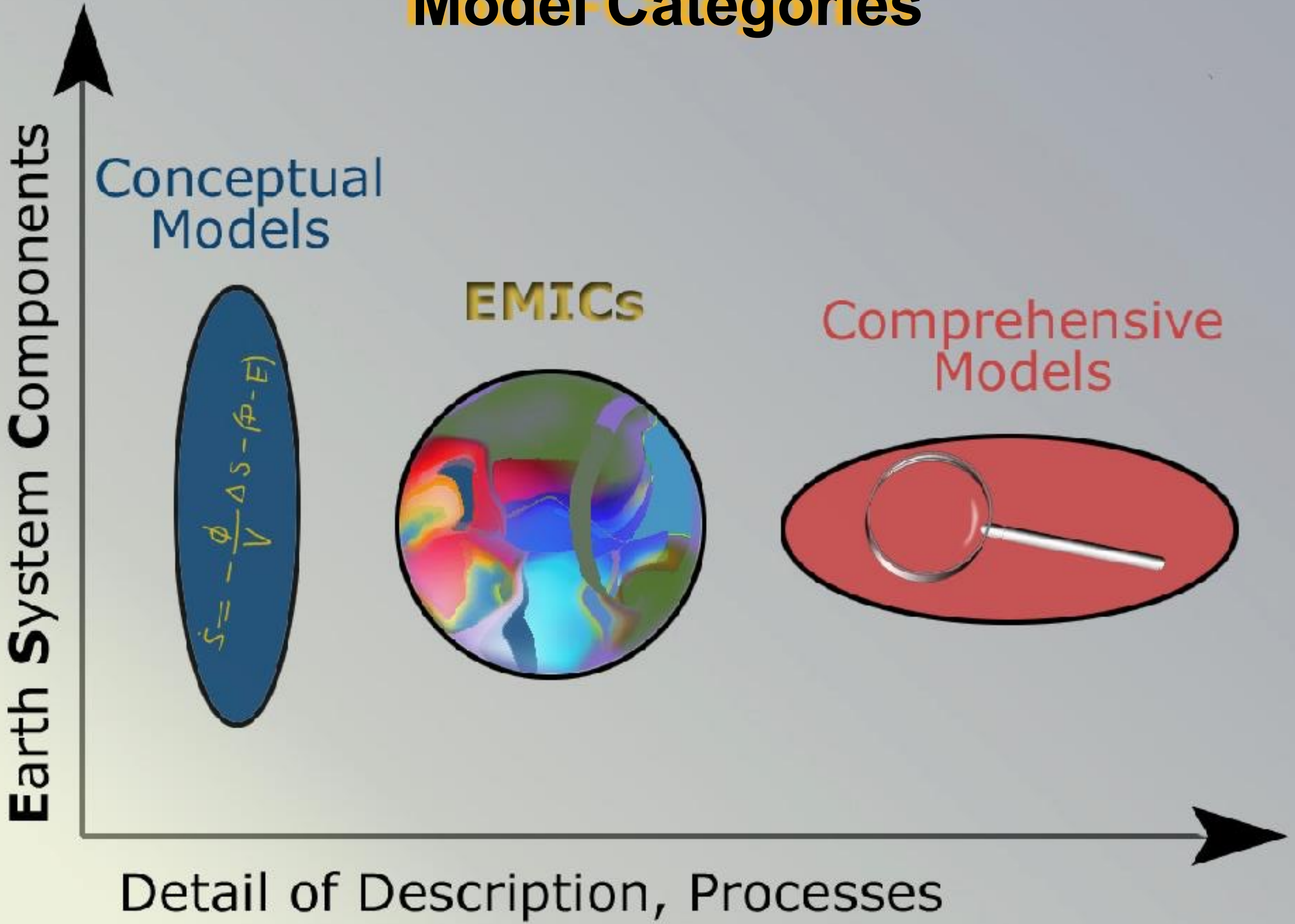
- Vegetation & Ecosystem models

- Practicals: Daisy World, vegetation dynamics

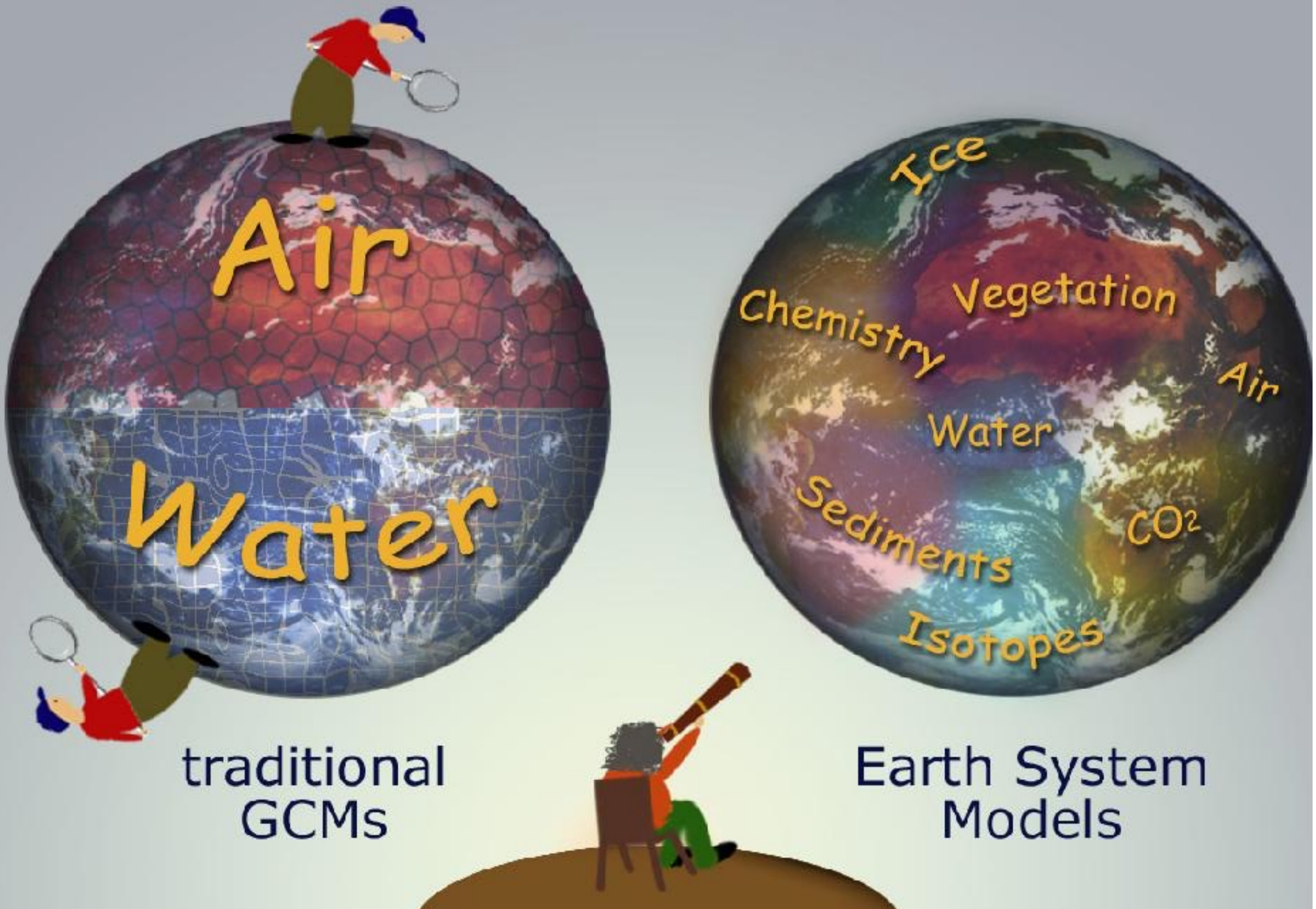
https://paleodyn.uni-bremen.de/study/MES/daisy/

- Tracers in the Sea (Carbon, Radiocarbon)

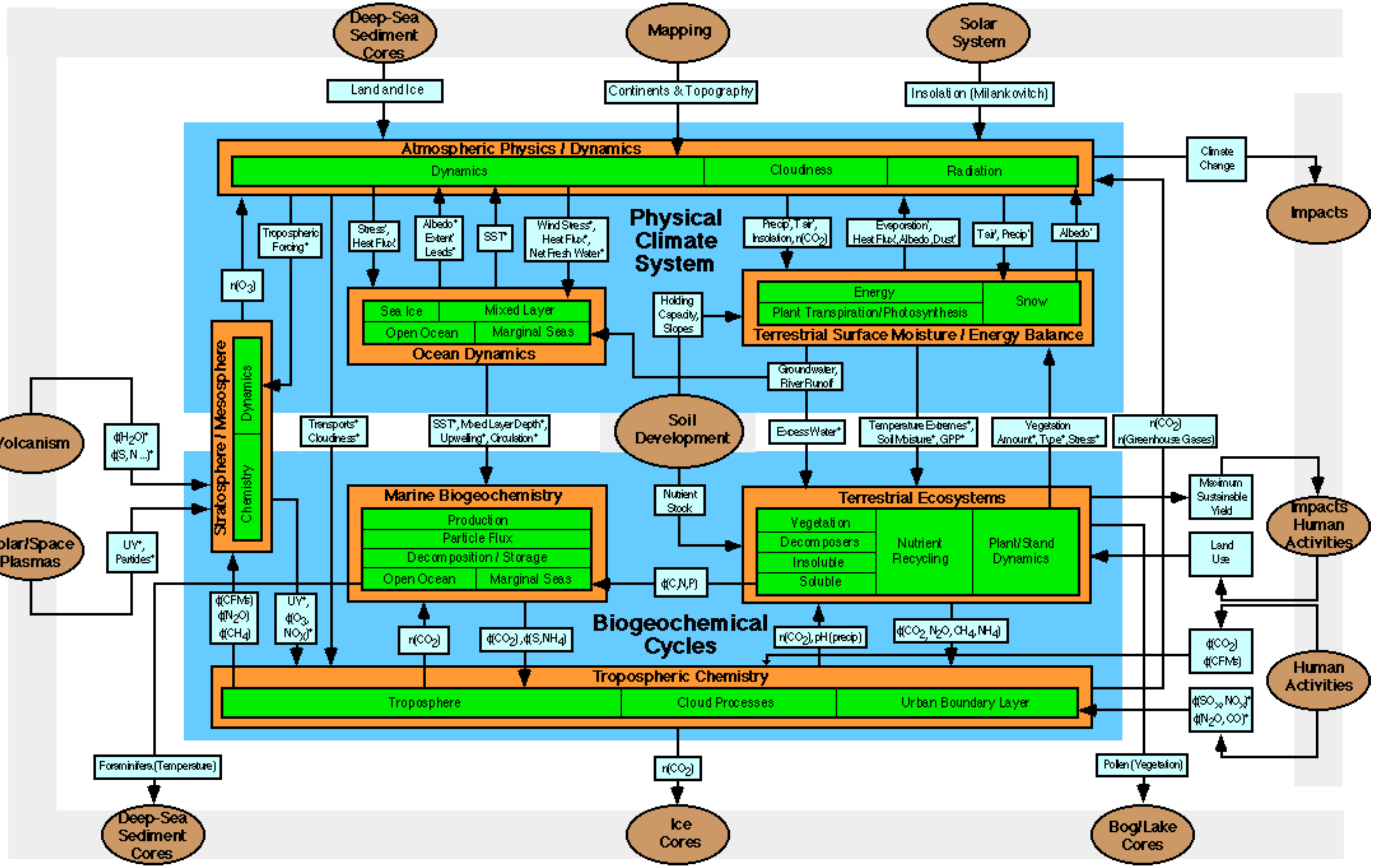
Model Categories



Different Point of View

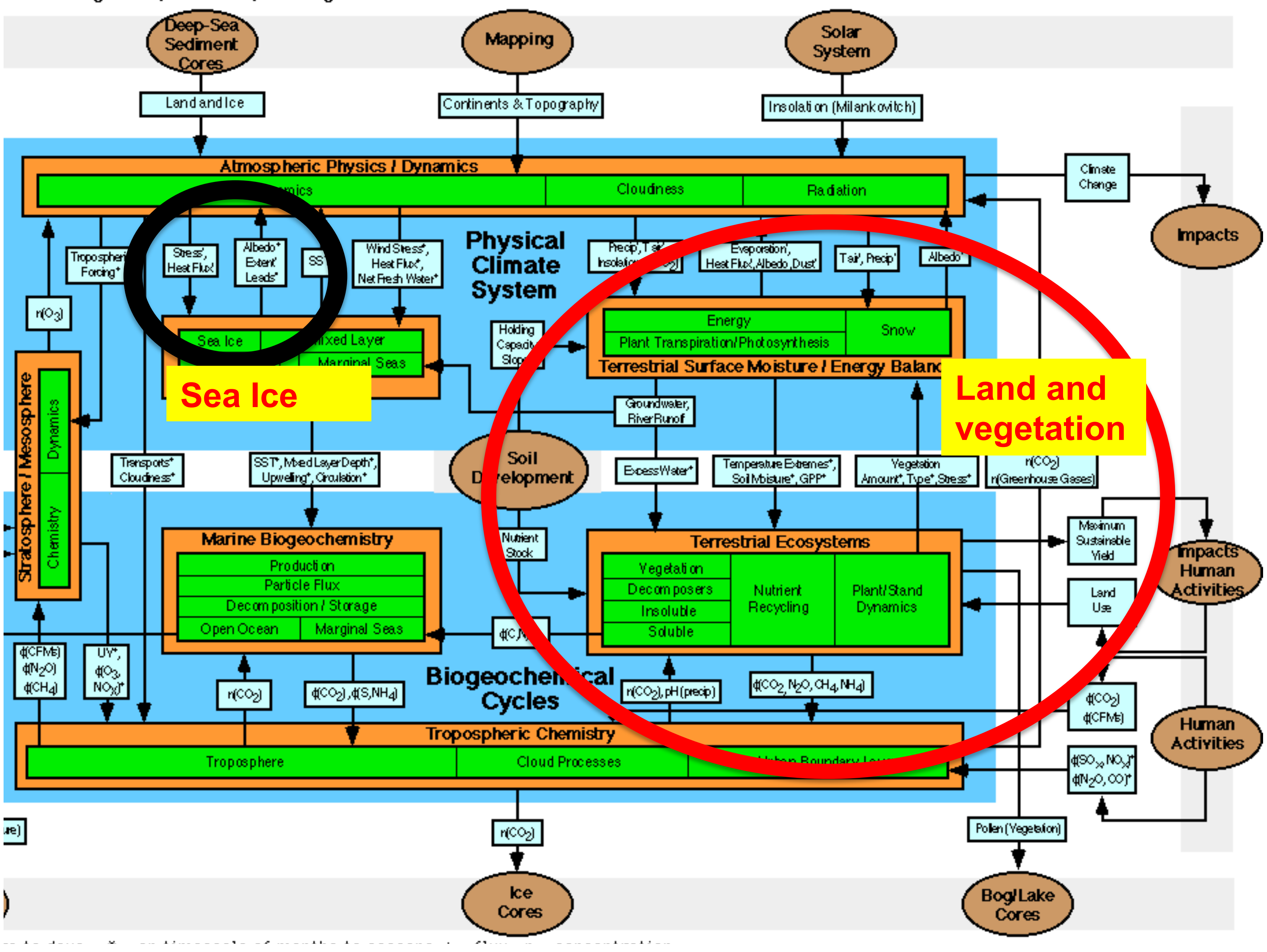


CONCEPTUAL MODEL of Earth System process operating on timescales of decades to centuries



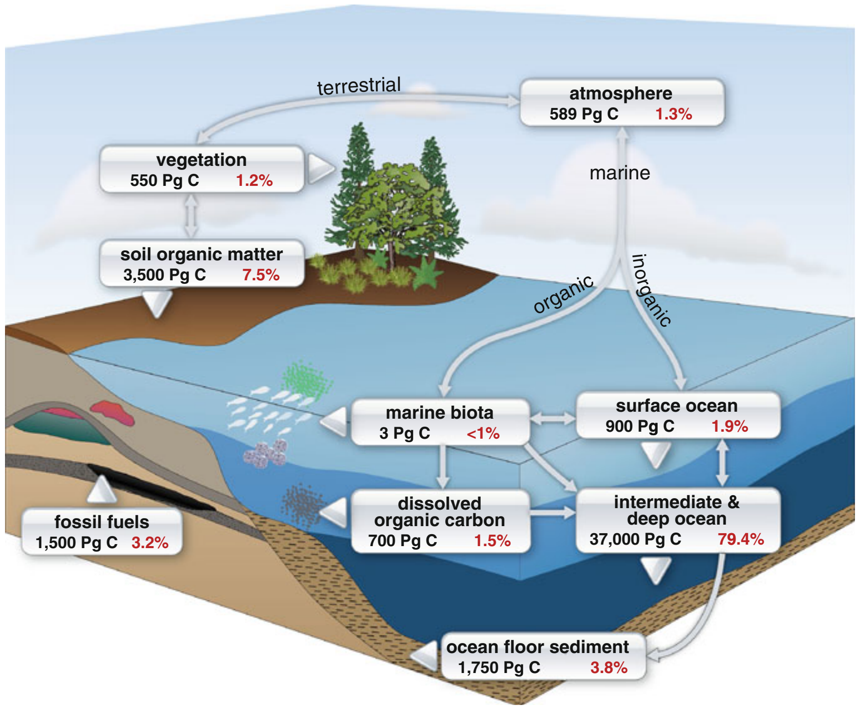
' = on timescale of hours to days * = on timescale of months to seasons ϕ = flux n = concentration

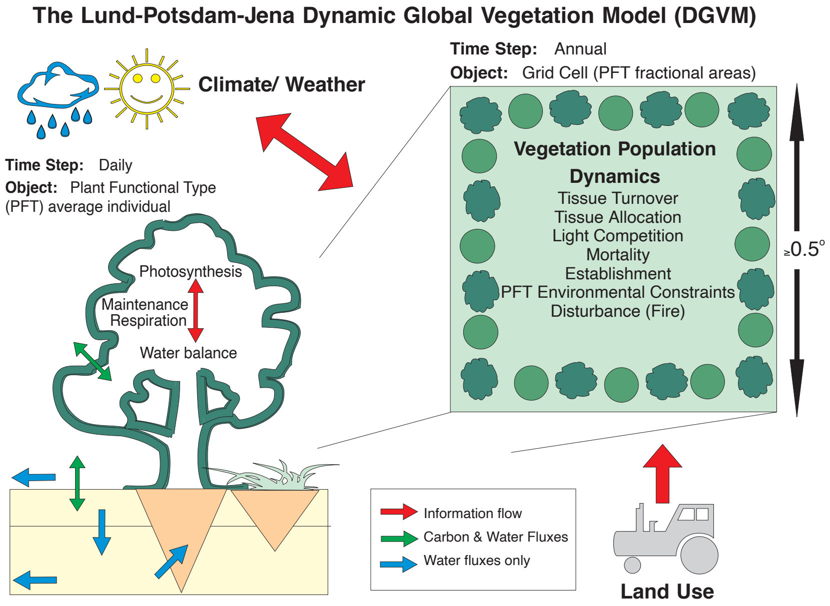
Bretherton



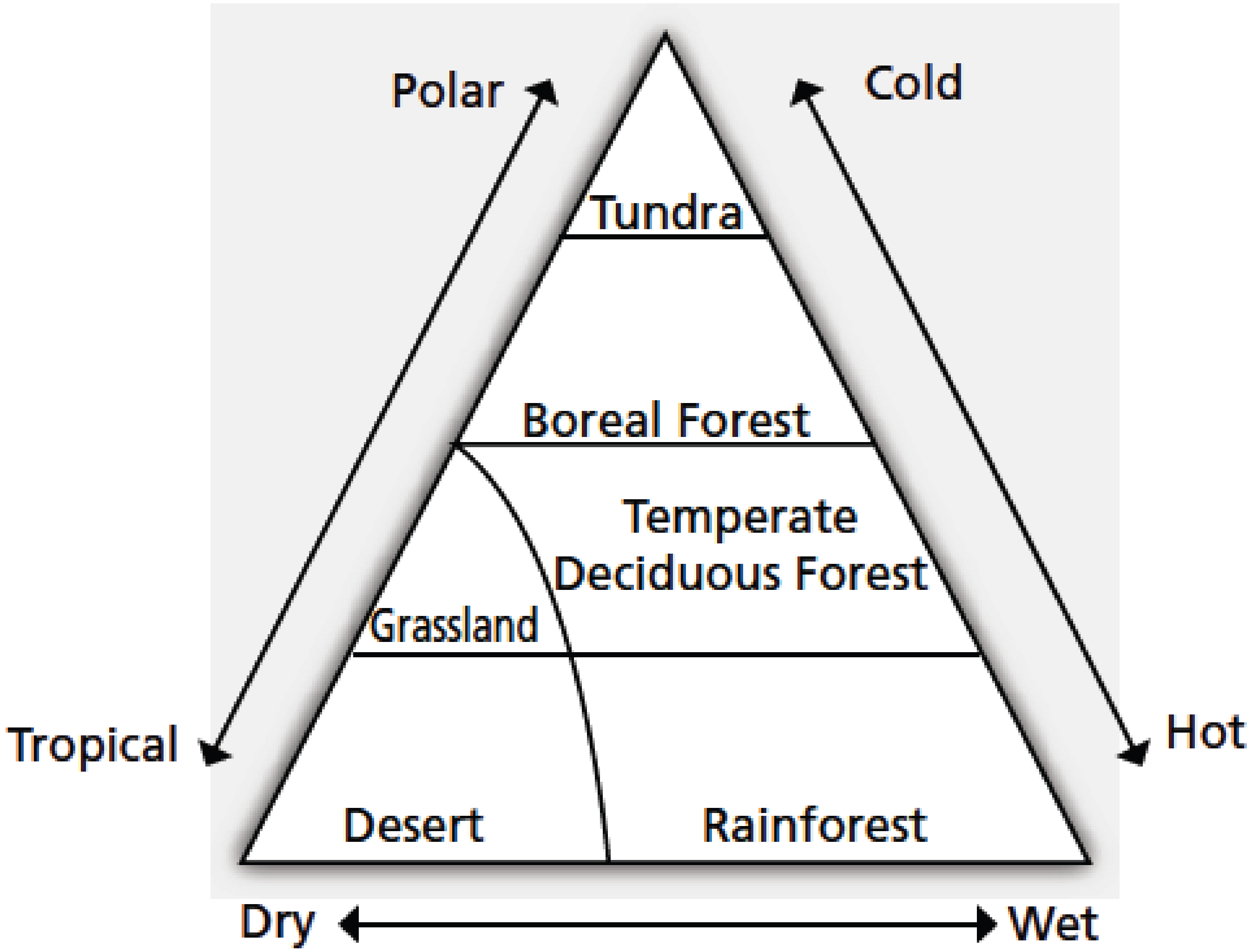
Deep-Sea Sediment Cores
Mapping
Solar System
Land and Ice
Continents & Topography
Insolation (Milankovitch)
Atmospheric Physics / Dynamics
Cloudiness
Radiation
Climate Change
Impacts
Tropospheric Forcing*
Stress*, Heat Flux*
Albedo*, Extent*, Leads*
Wind Stress*, Heat Flux*, Net Fresh Water*
Physical Climate System
Evaporation*, Heat Flux*, Albedo*, Dust*
Tair*, Precip*
Albedo*
Sea Ice
Mixed Layer
Marginal Seas
Energy
Plant Transpiration/Photosynthesis
Snow
Terrestrial Surface Moisture / Energy Balance
Stratosphere / Mesosphere
Dynamics
Chemistry
Groundwater, River Runoff
Transports*, Cloudiness*
SST*, Mixed Layer Depth*, Upwelling*, Circulation*
Soil Development
Excess Water*
Temperature Extremes*, Soil Moisture*, GPP*
Vegetation Amount*, Type*, Stress*
Land and vegetation
Marine Biogeochemistry
Production
Particle Flux
Decomposition / Storage
Open Ocean
Marginal Seas
Nutrient Stock
Terrestrial Ecosystems
Vegetation
Decomposers
Insoluble
Soluble
Nutrient Recycling
Plant/Stand Dynamics
Maximum Sustainable Yield
Impacts Human Activities
Land Use
Biogeochemical Cycles
Tropospheric Chemistry
Troposphere
Cloud Processes
Human Activities
Pollen (Vegetation)
Ice Cores
Bog/Lake Cores

Earth system models
including tracers and dynamical vegetation



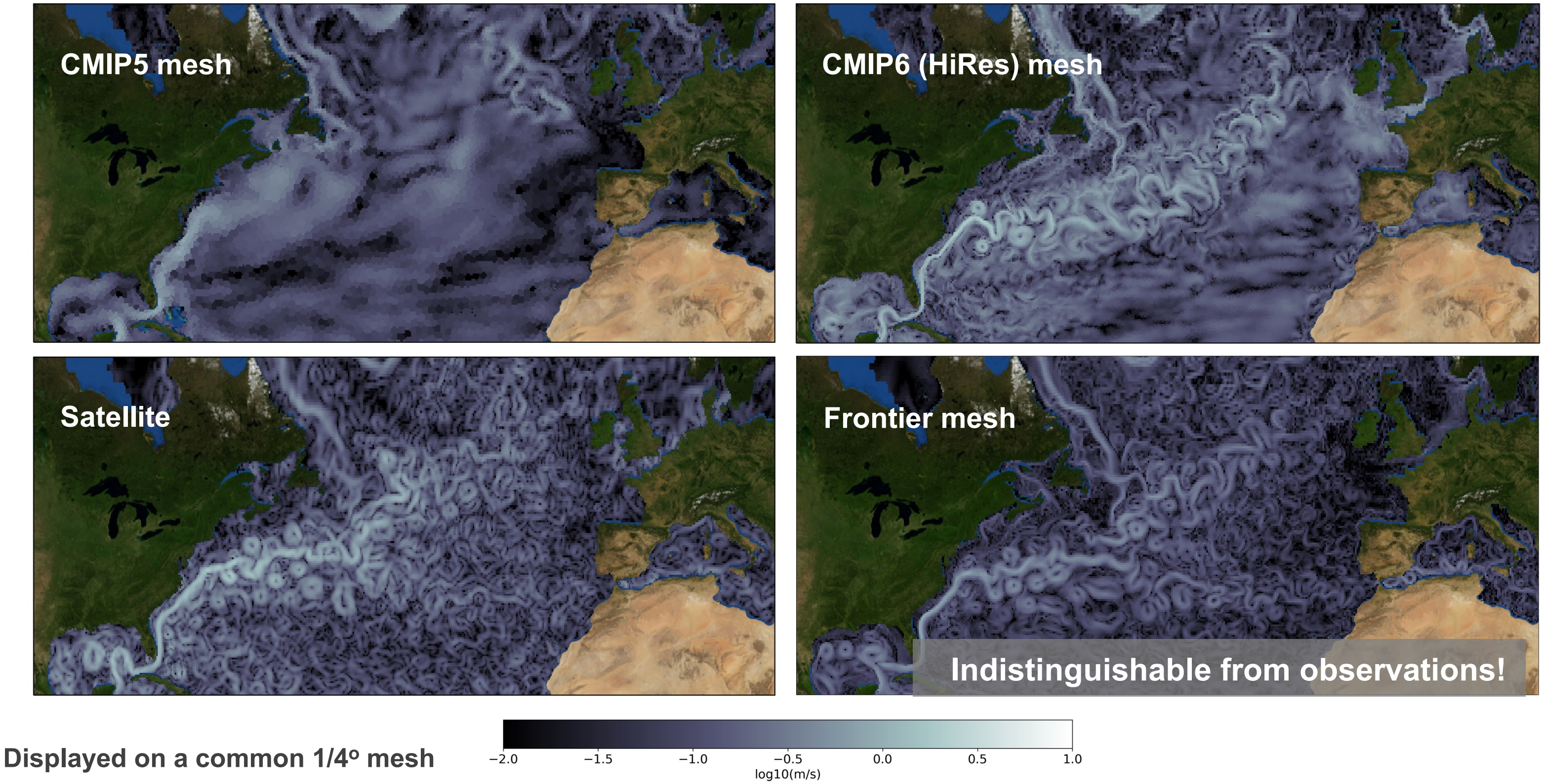


Vegetation & Ecosystem



How realistic are climate models ?

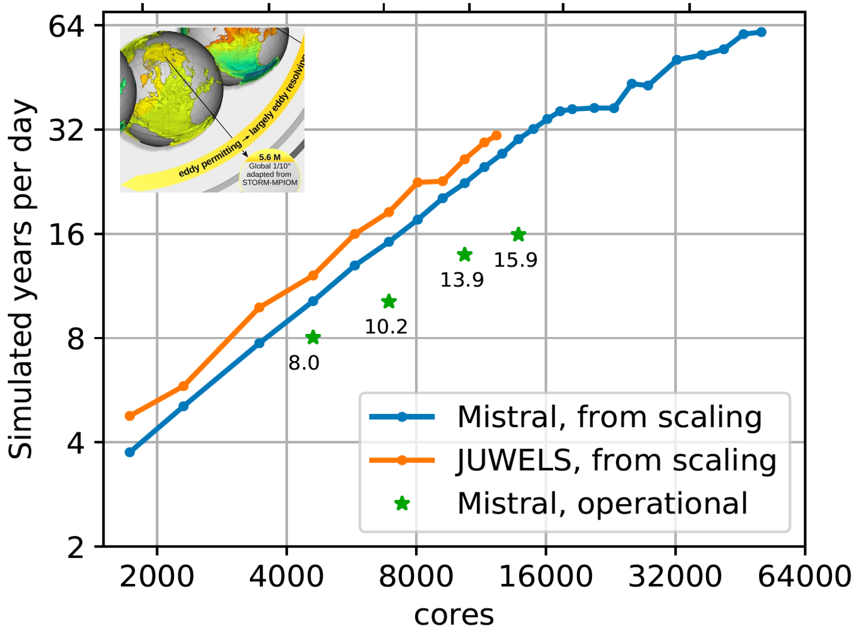
Ocean velocity

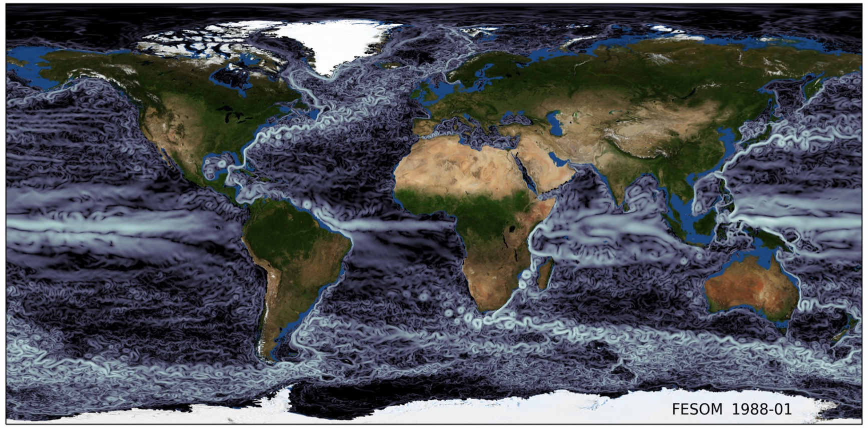


➔ **Large uncertainties in regional changes**

➔ **Limitations for extreme events**

Scalability





Koldunov et al (2019)

Limited by available HPC capabilities (today)

Limited by our ability to use future HPC systems (tomorrow)

Parameterizations

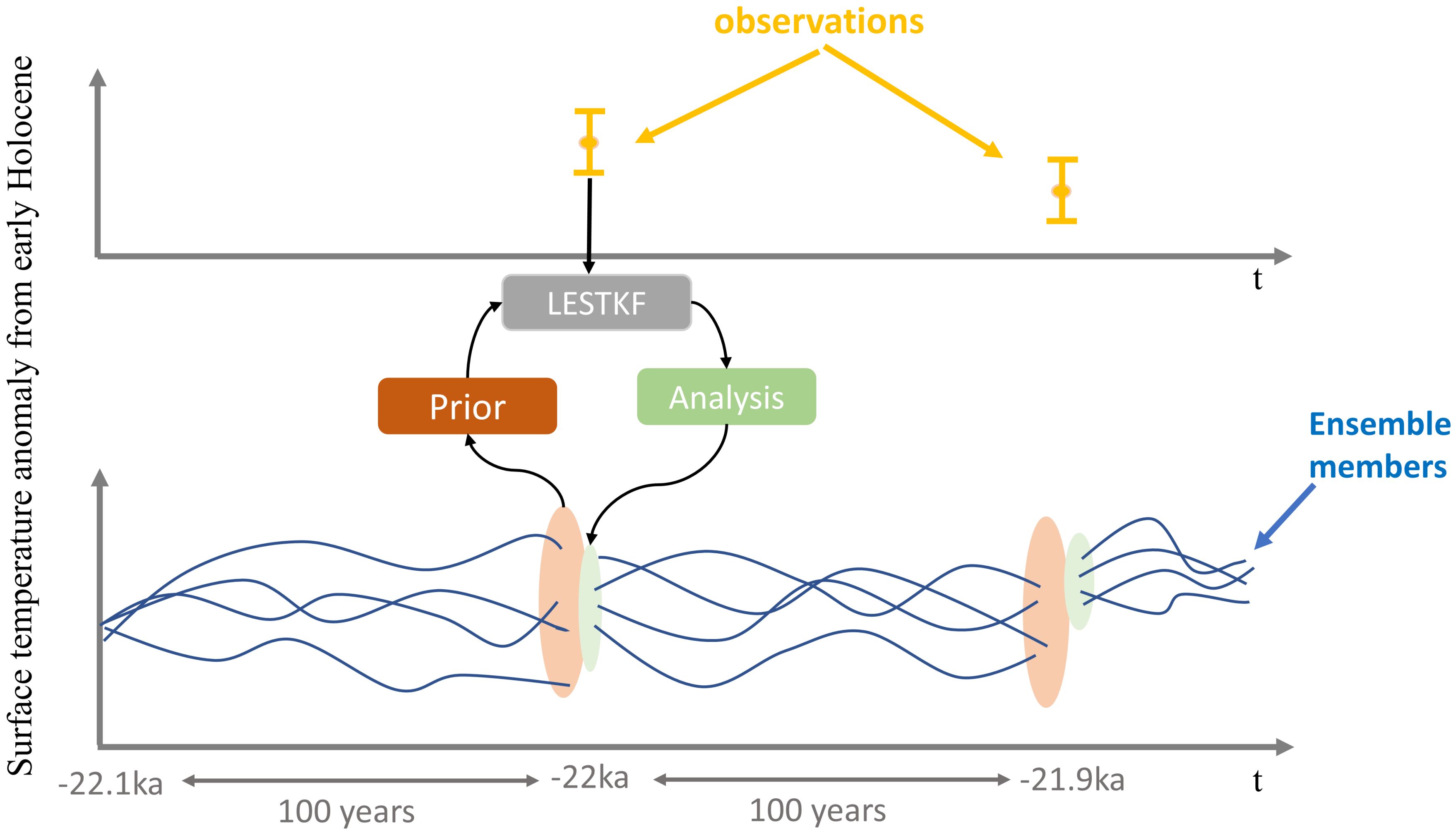
Some critical small-scale processes are *not* represented by the laws of physics, but by physically motivated rules of thumb (parametrizations)

➔ Large uncertainties in regional (global) climate change projections

➔ Limitations in predicting extreme events, major feedbacks (ice)

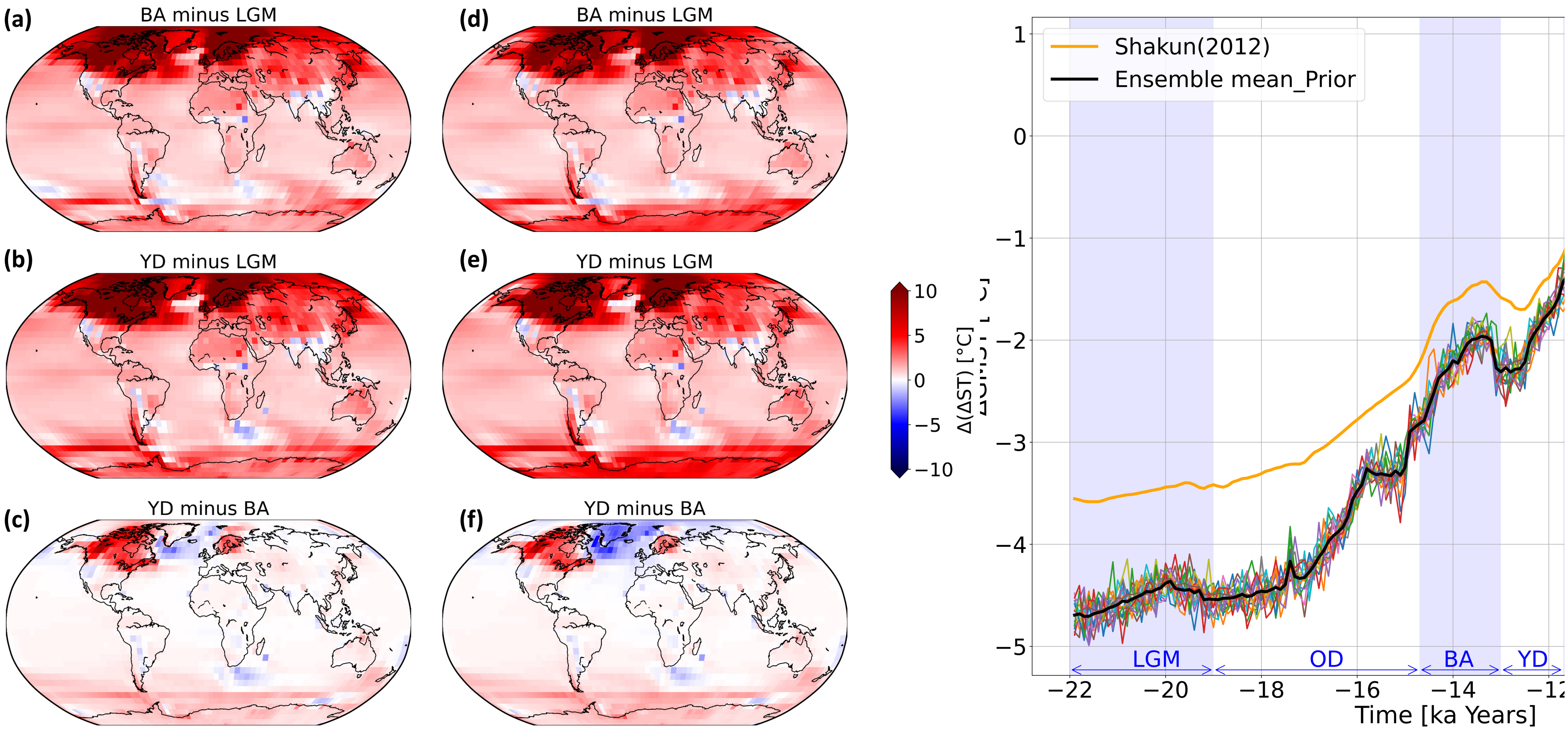
Data assimilation (Ensemble Kalman Filter)

To make use out of data and models



Parallel Data Assimilation Framework

Prior vs DA



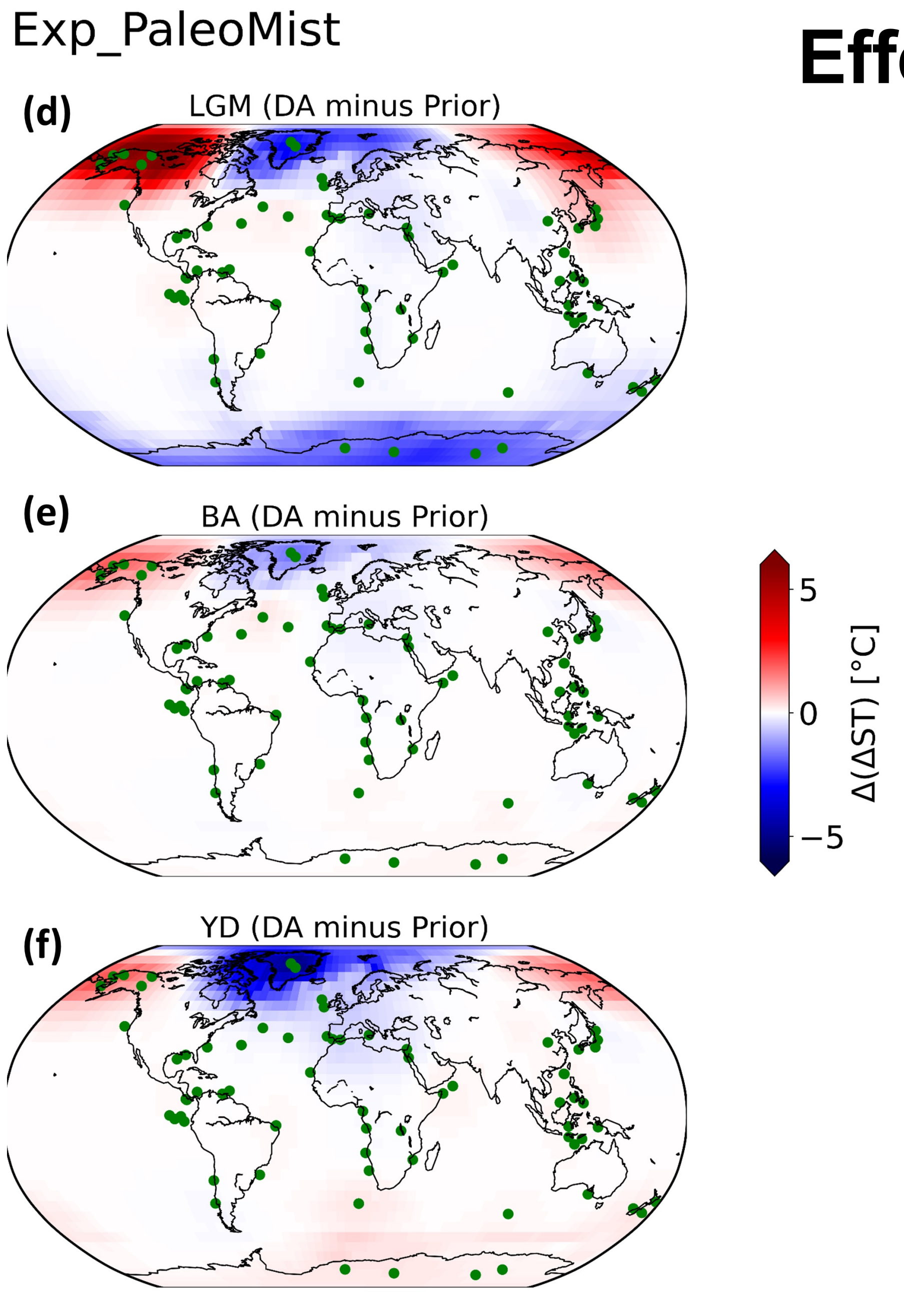
Ahmadreza Masoun, PhD

Effect of Data assimilation

LGM

Boelling/
Alleroed

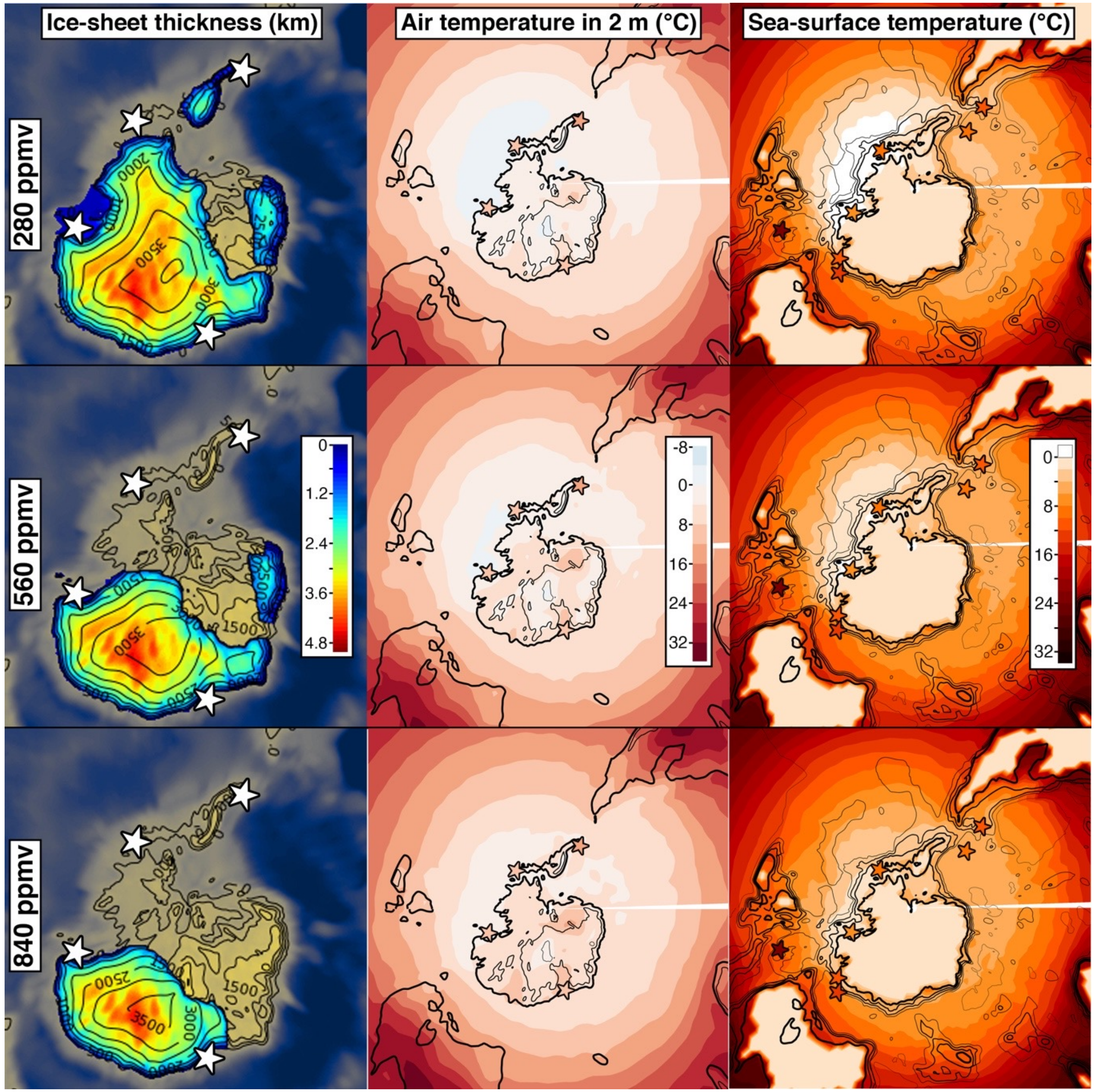
Younger
Dryas



What can learned:

- **Data-model (mis-)fit**
- **Where do we need more data?**
- **Problem in the model**

Absent West Antarctic Ice Sheet during the early Oligocene glacial maximum



$1xCO_2$

$2xCO_2$

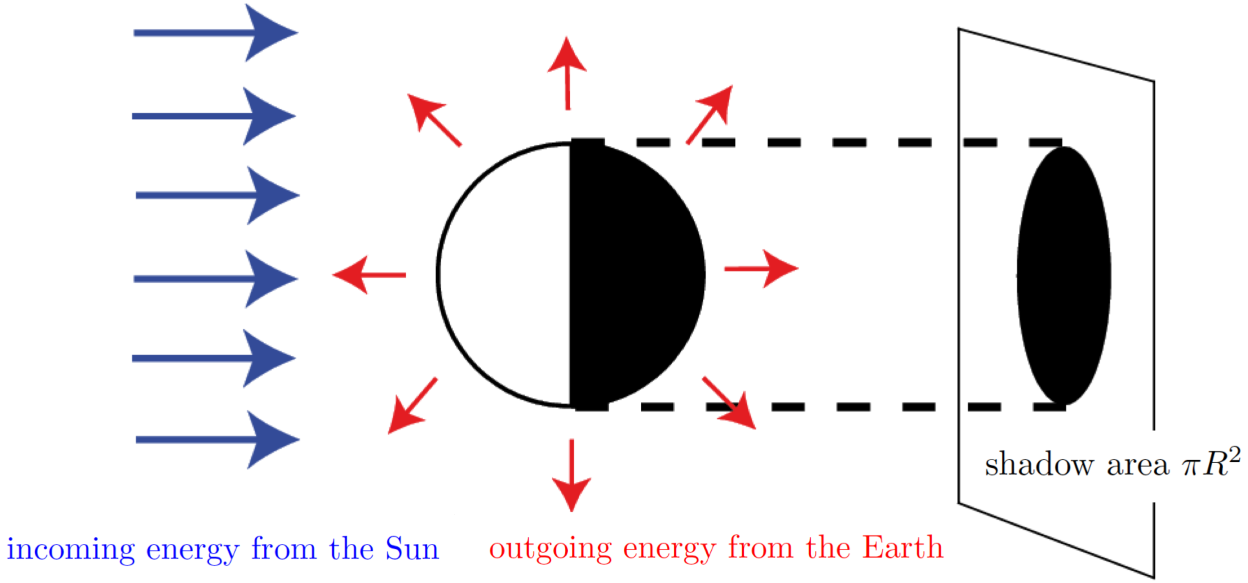
$3xCO_2$

Klages et al.,

Energy balance model: Concepts of climate

$$(1 - \alpha) S \pi R^2 = 4 \pi R^2 \epsilon \sigma T^4$$

$$T = \sqrt[4]{\frac{(1-\alpha)S}{4\epsilon\sigma}}$$



Heat capacity of the climate system

Fast rotation

Lohmann, 2020