Simplified ocean basin geometries in CESM: implementation and some science questions

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Motivation

- Simulate a hemispherically symmetric climate
  - Useful to explore perturbations that cause asymmetries.
  - Address fundamental questions:
    - **Why is the ITCZ in the northern hemisphere?**
    - **Why is there an Indo-Pacific warm pool?**
    - **Why is the Atlantic saltier than the Indo-Pac?**

Setup based on CESM1 low res

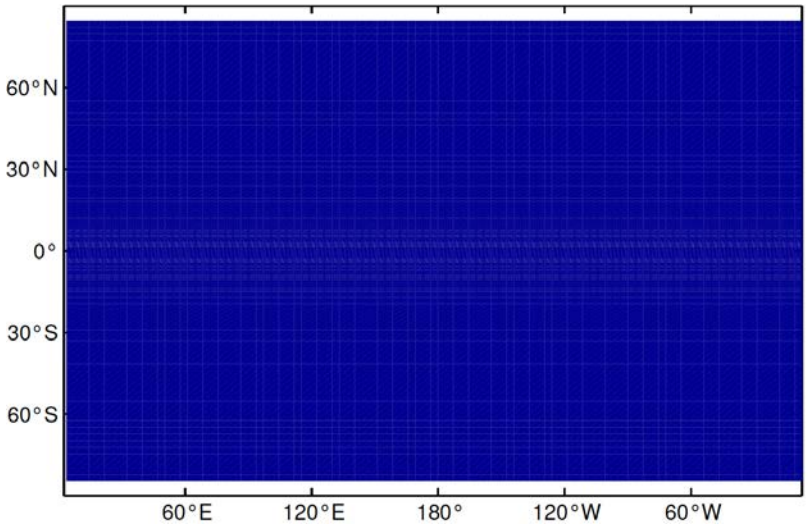
- **CAM**
  - T31 spectral dynamical core
  - CAM4 physics
- **POP**
  - 3° x 3° resolution,
  - 0.5° in latitude towards the equator
  - 60 levels

- **High throughput with small number of processors**
  - 24 pe 40 model years in 24h
  - 8 pe 12 model years in 24h

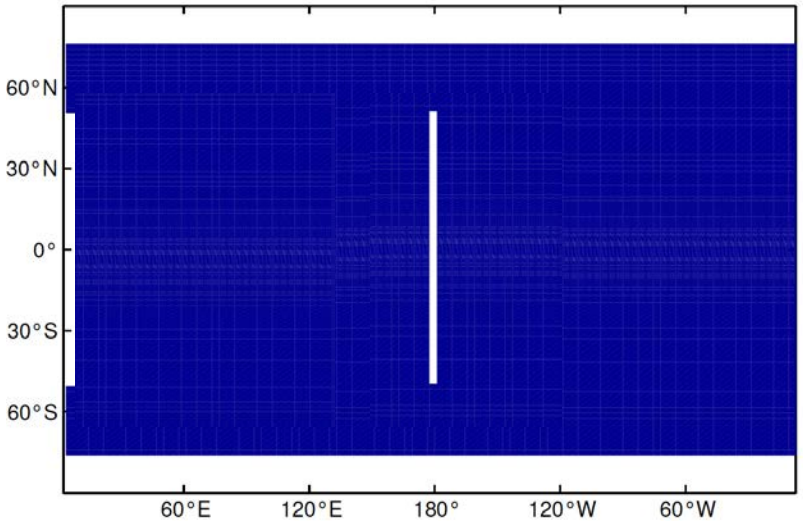
Idealized continents

- **Idealized continents**
  - No mountains.
  - Covered by wetlands.

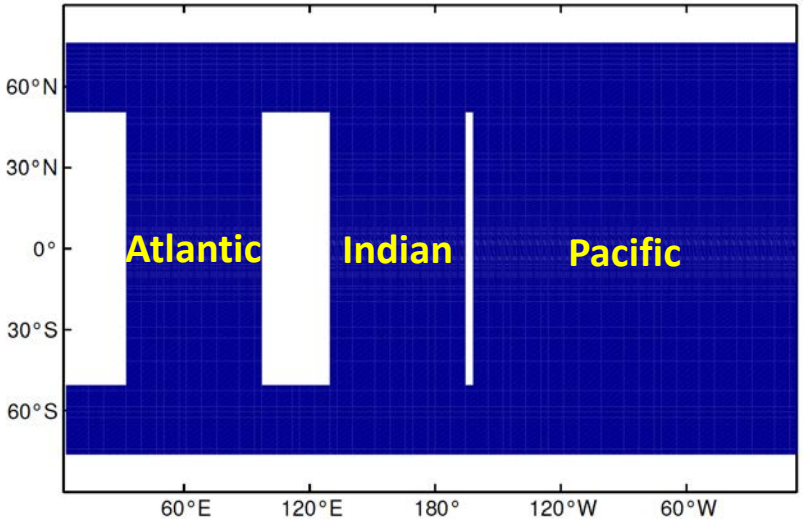
quasi Aqua



2 oceans

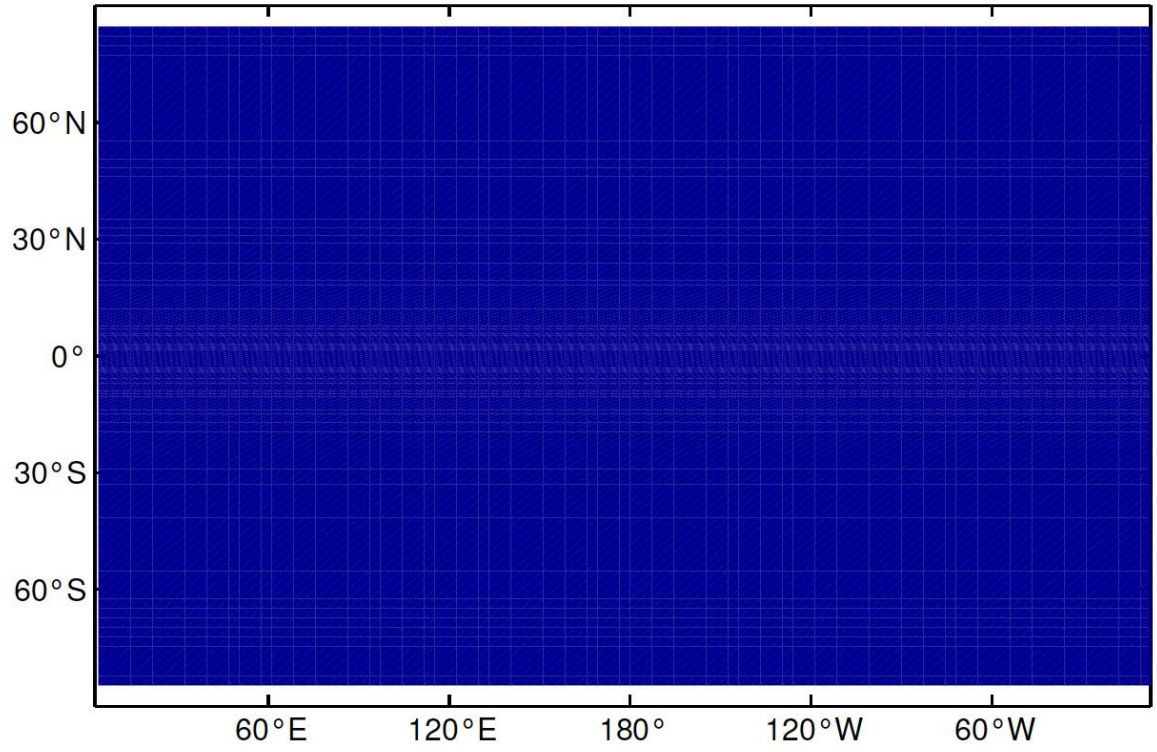


3 oceans



Idealized continents

quasi Aqua

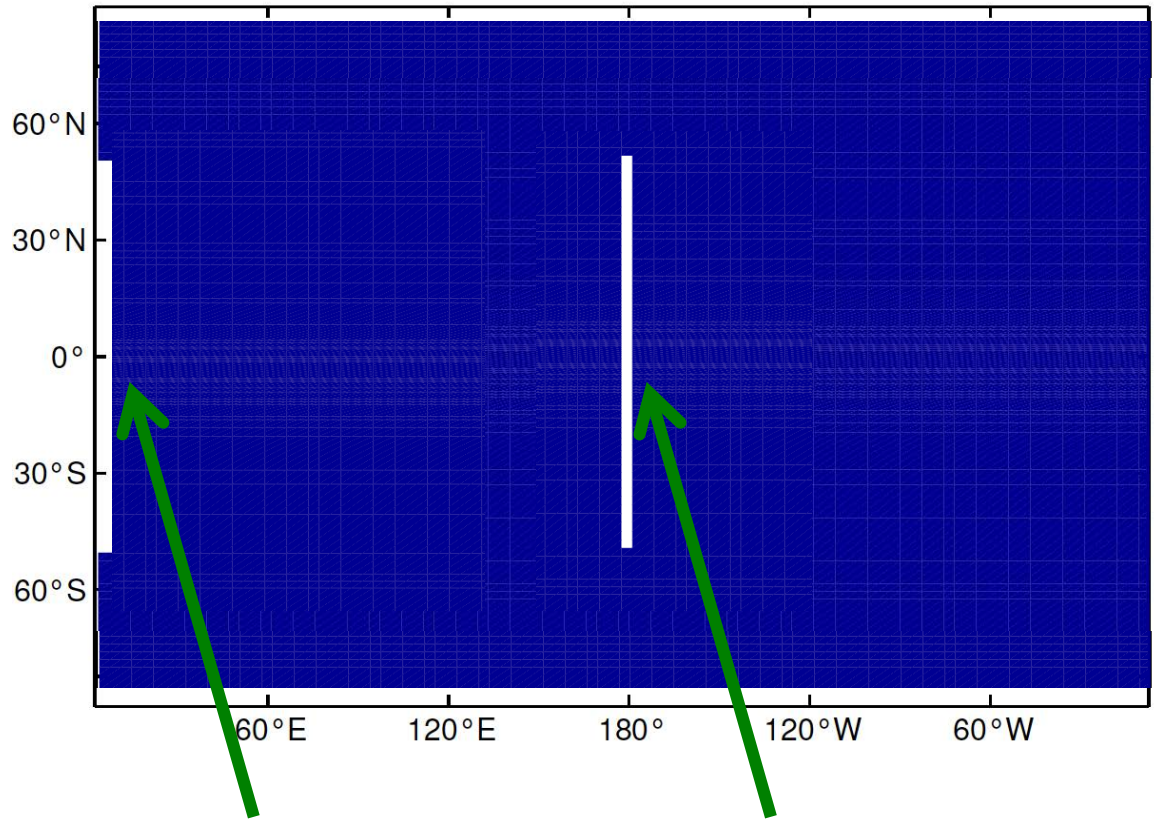


two small polar continents

No walls blocking equatorial currents

Idealized continents

2 tropical oceans

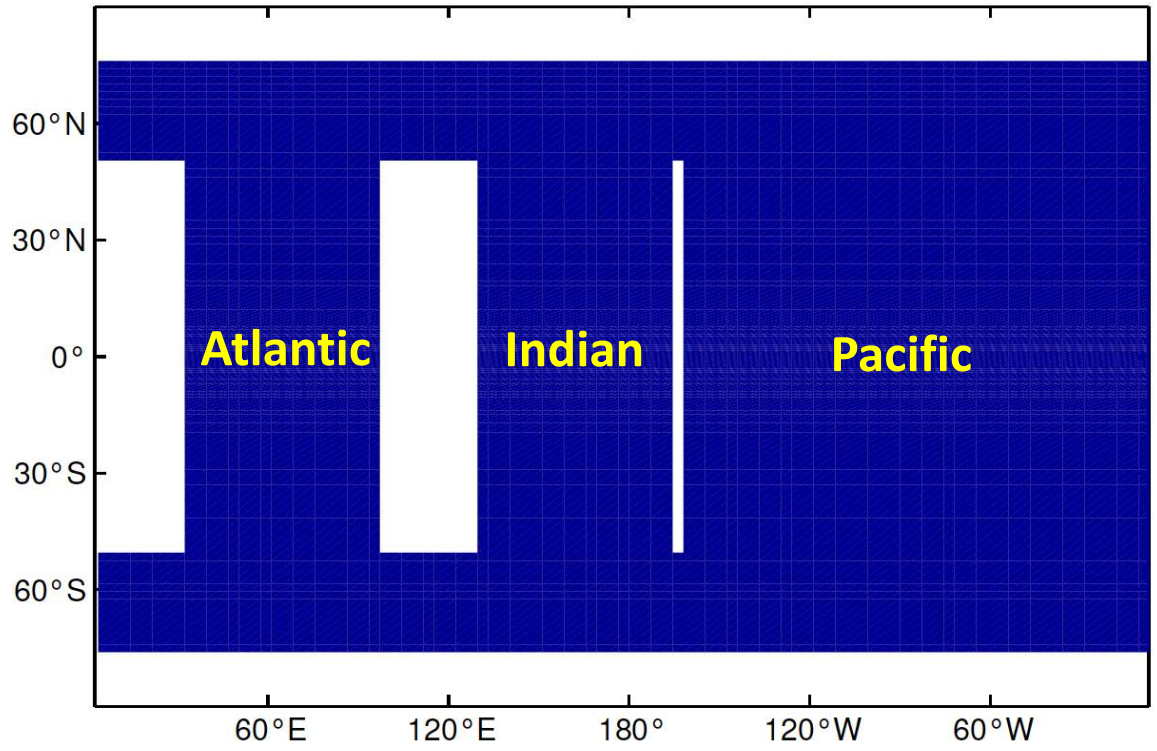


two tropical oceans with the same zonal extent

walls blocking equatorial currents

Idealized continents

3 tropical oceans



Three tropical oceans with the realistic zonal extent

- walls blocking equatorial currents
- continents decoupling Walker circulations

Key modifications – CAM

- **Hemispherically symmetric insolation:**
  - Eccentricity = 0 -> no precession of the equinoxes.
  - Axis tilt = 23.3° (average value)
- **Make all other boundary conditions zonally and hemispherically symmetric:**
  - Salt aerosols and DMS
  - Ozone
    - Using annual-mean zonal-mean values taken from Southern Hemisphere
- **GHGs at pre-industrial levels**
- **Not dust or anthropogenic aerosols**

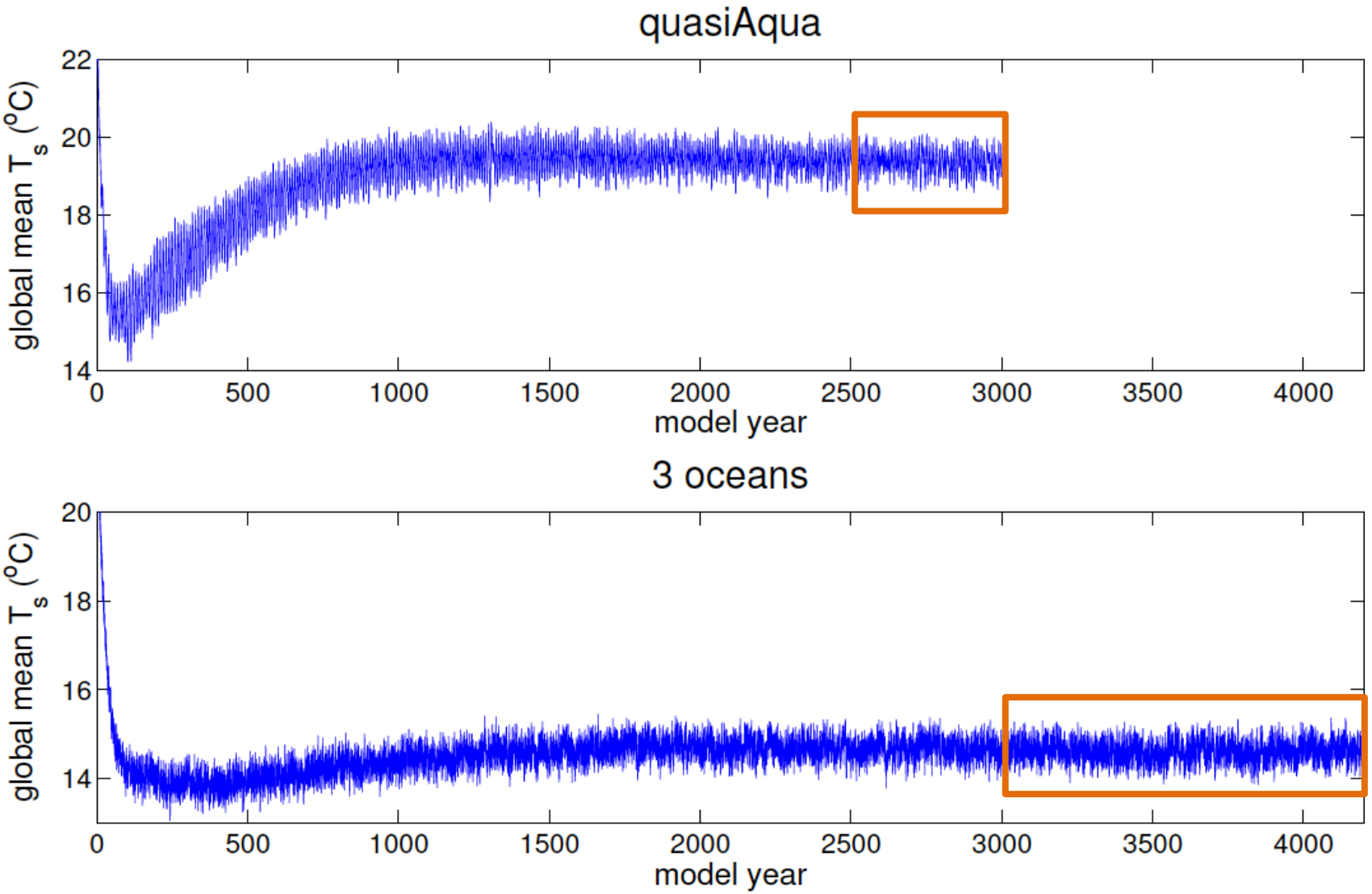
Key modifications – POP/CICE

- **New grid based on gx3 grid** with same number of latitude points in each hemisphere:
  - Grid poles coinciding with geographical poles,
  - Small polar continents over poles,
    - Matt Maltrud's idea, also used by Smith et al. (2006).
- **Flat bathymetry** with 10X increase in bottom drag to compensate for lack of form drag:
  - similar to Marshall et al. 2007,
  - Smoothed out angles against continents to avoid instabilities.
- **SW absorption** based on Jerlov water types.
- **Initialization** from idealized T(lat,z) and S(z) profiles:
  - Extremely long equilibration times.
- **Tidal mixing** disabled.

Key modifications – CLM/RTM

- **Land**
  - Land covered by wetlands.
- **Runoff**
  - Simplified runoff scheme over continents that keeps hemispherically symmetric freshwater forcing.
  - No rivers.

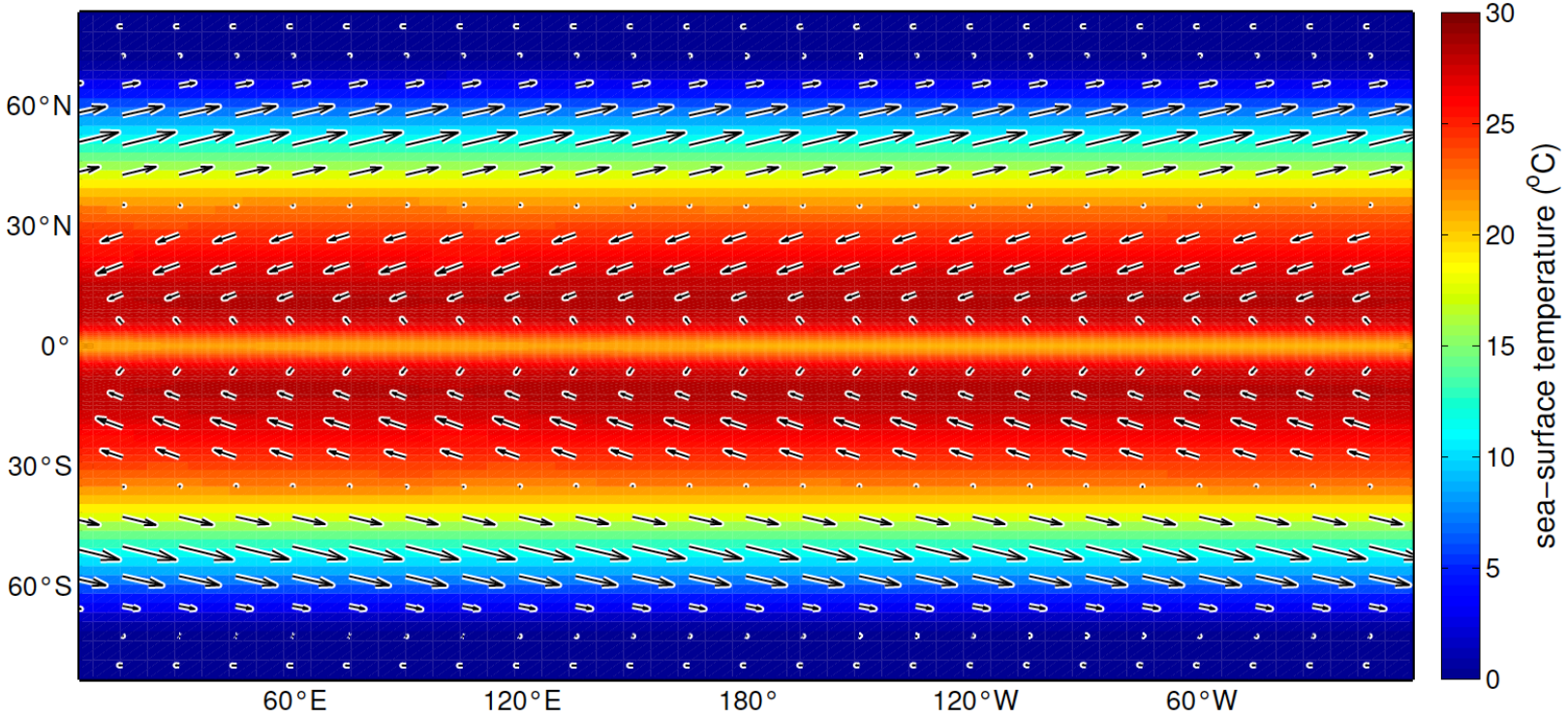
Equilibration



Results

Aqua climate

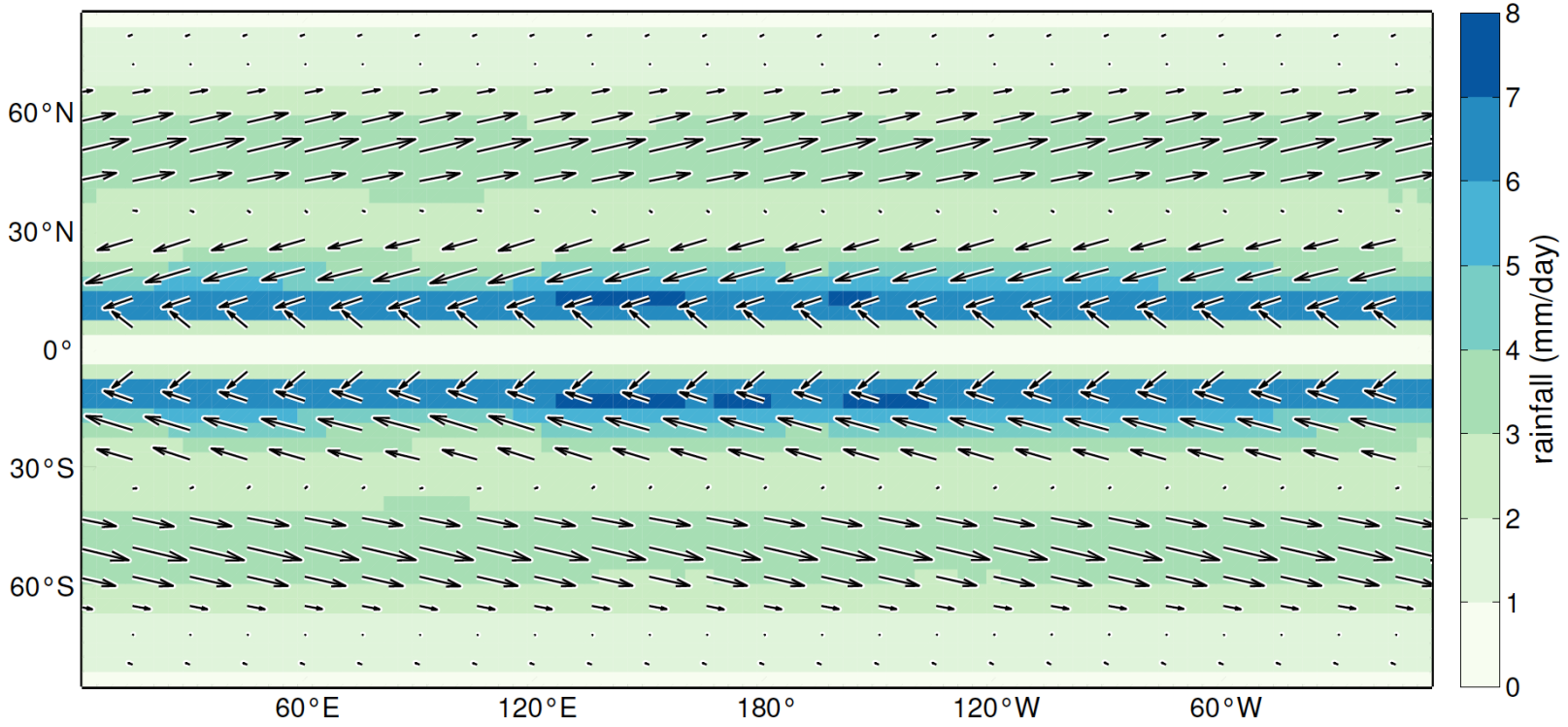
years 2500-3000



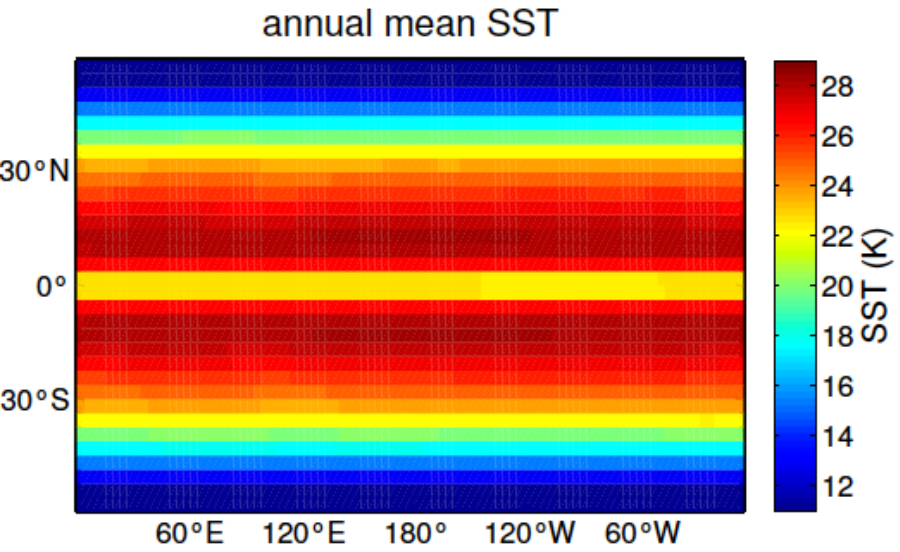
- Equatorial cold tongue,
- Weak equatorial trades,
- Trade winds converging off the equator at about 10°.

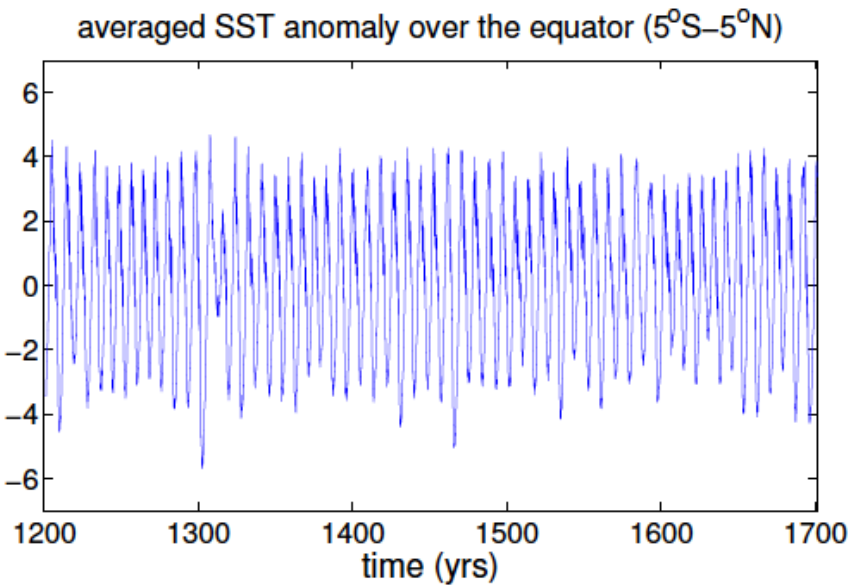
Aqua climate

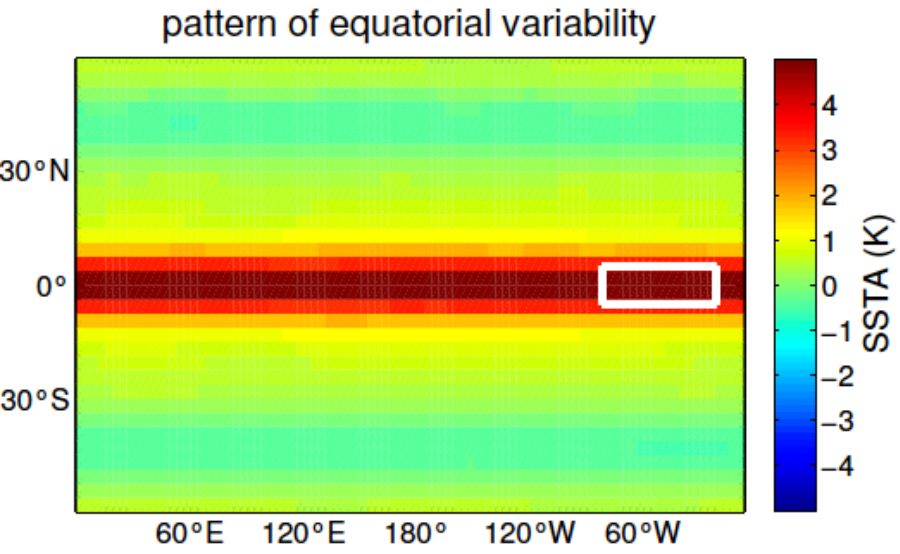
years 2500-3000

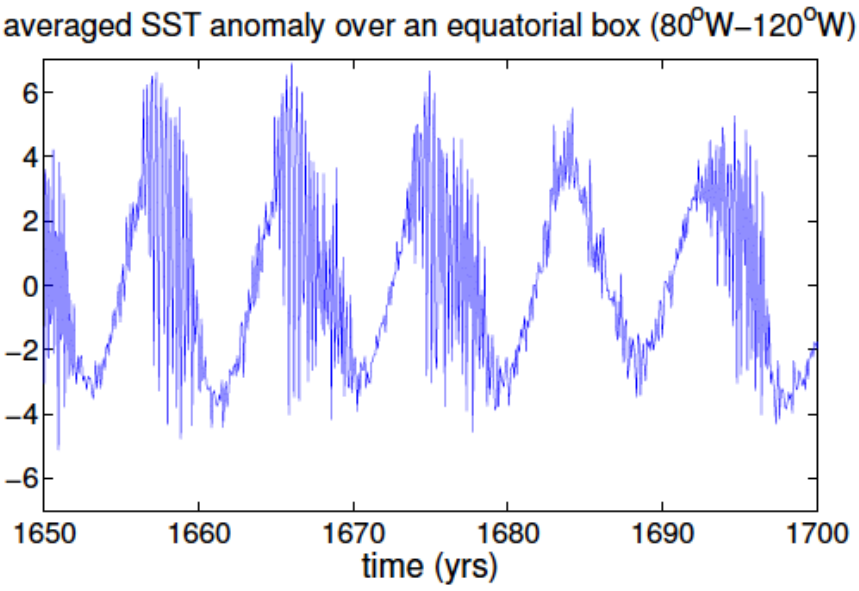


- Very dry equatorial climate (> drier than in Marshall et al. 2007),
- Double ITCZ,
- Strong tropical variability.

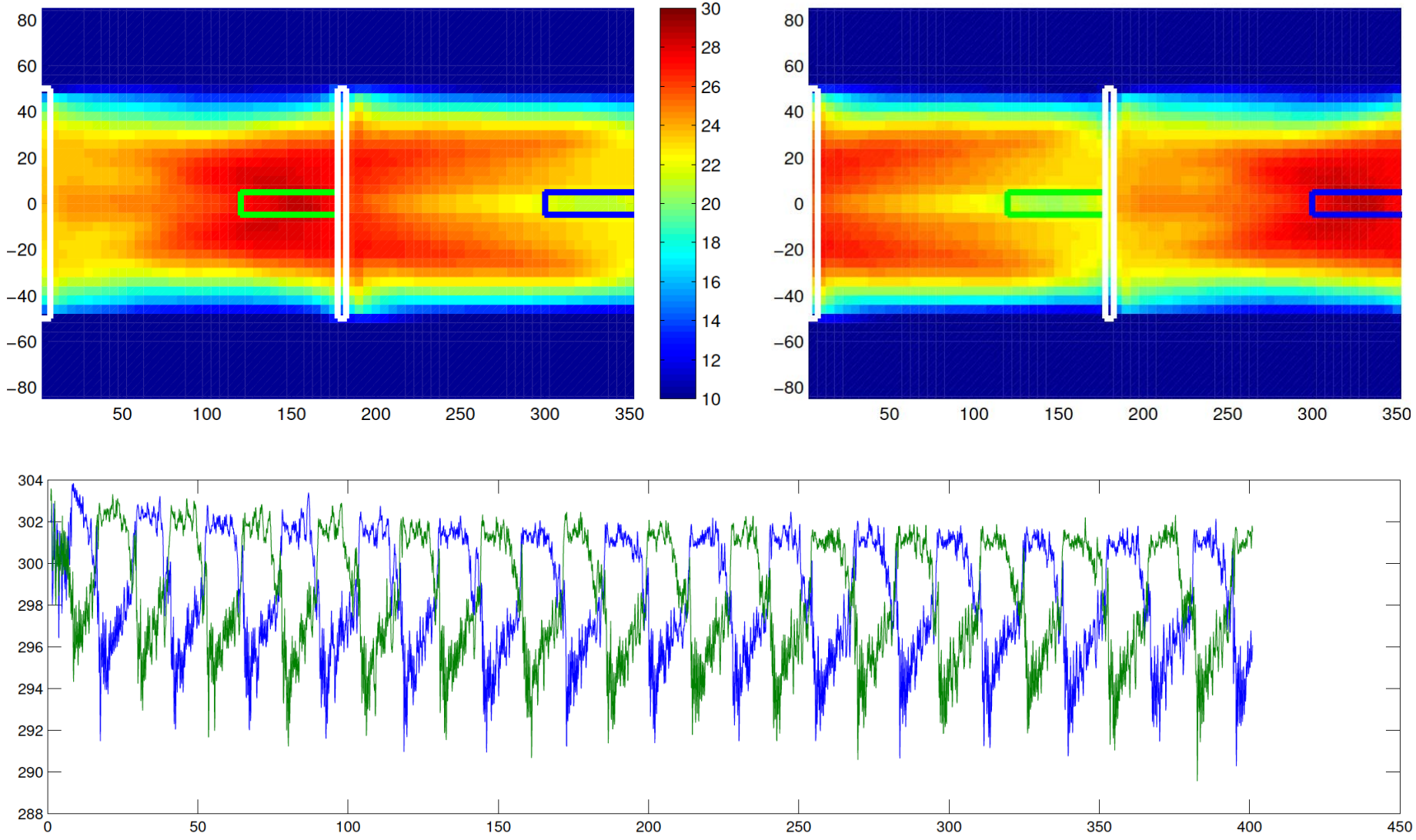

annual mean SST
30°N
0°
30°S
60°E
120°E
180°
120°W
60°W
28
26
24
22
20
18
16
14
12
SST (K)


averaged SST anomaly over the equator (5°S–5°N)
6
4
2
0
−2
−4
−6
1200
1300
1400
1500
1600
1700
time (yrs)


pattern of equatorial variability
30°N
0°
30°S
60°E
120°E
180°
120°W
60°W
4
3
2
1
0
−1
−2
−3
−4
SSTA (K)

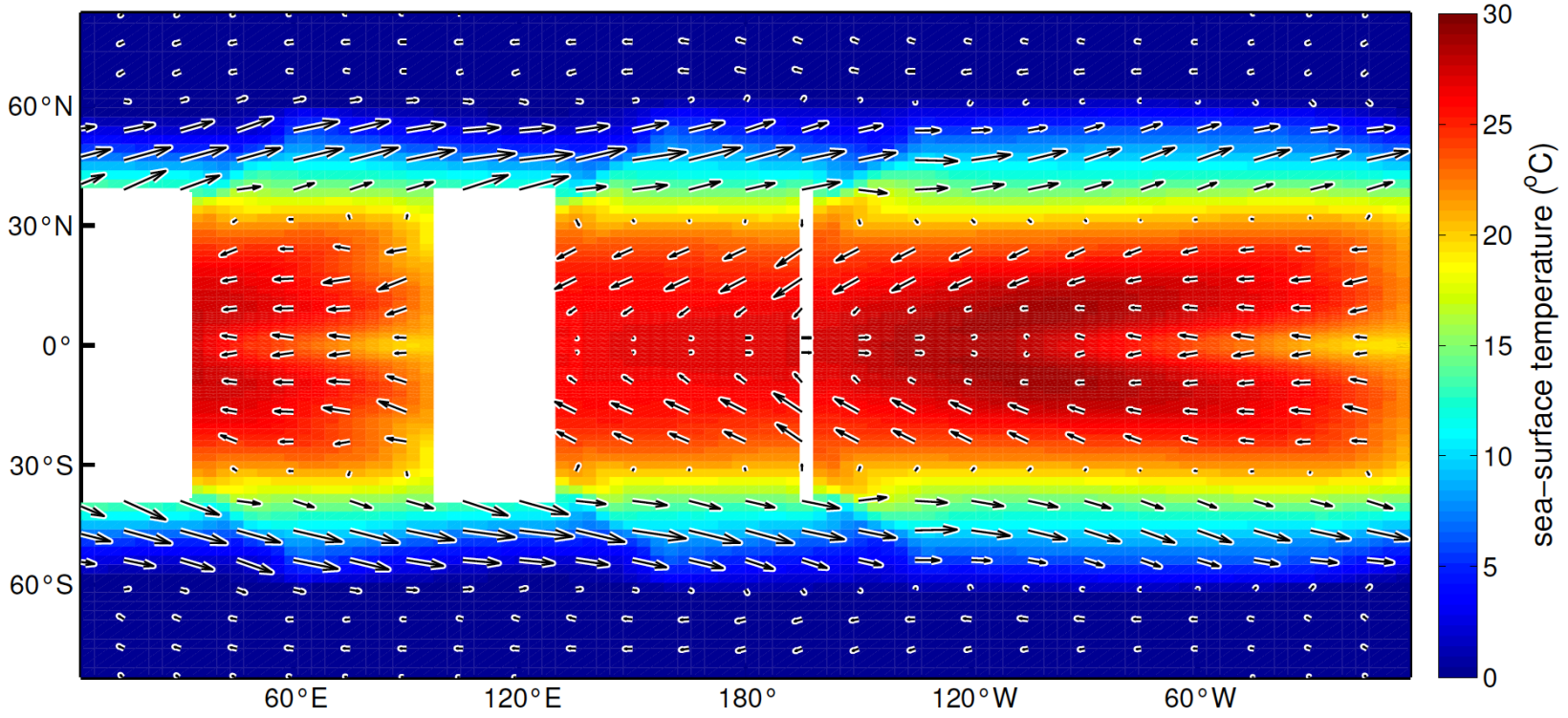

averaged SST anomaly over an equatorial box (80°W–120°W)
6
4
2
0
−2
−4
−6
1650
1660
1670
1680
1690
1700
time (yrs)

two oceans/ two ridges:



3 oceans climate

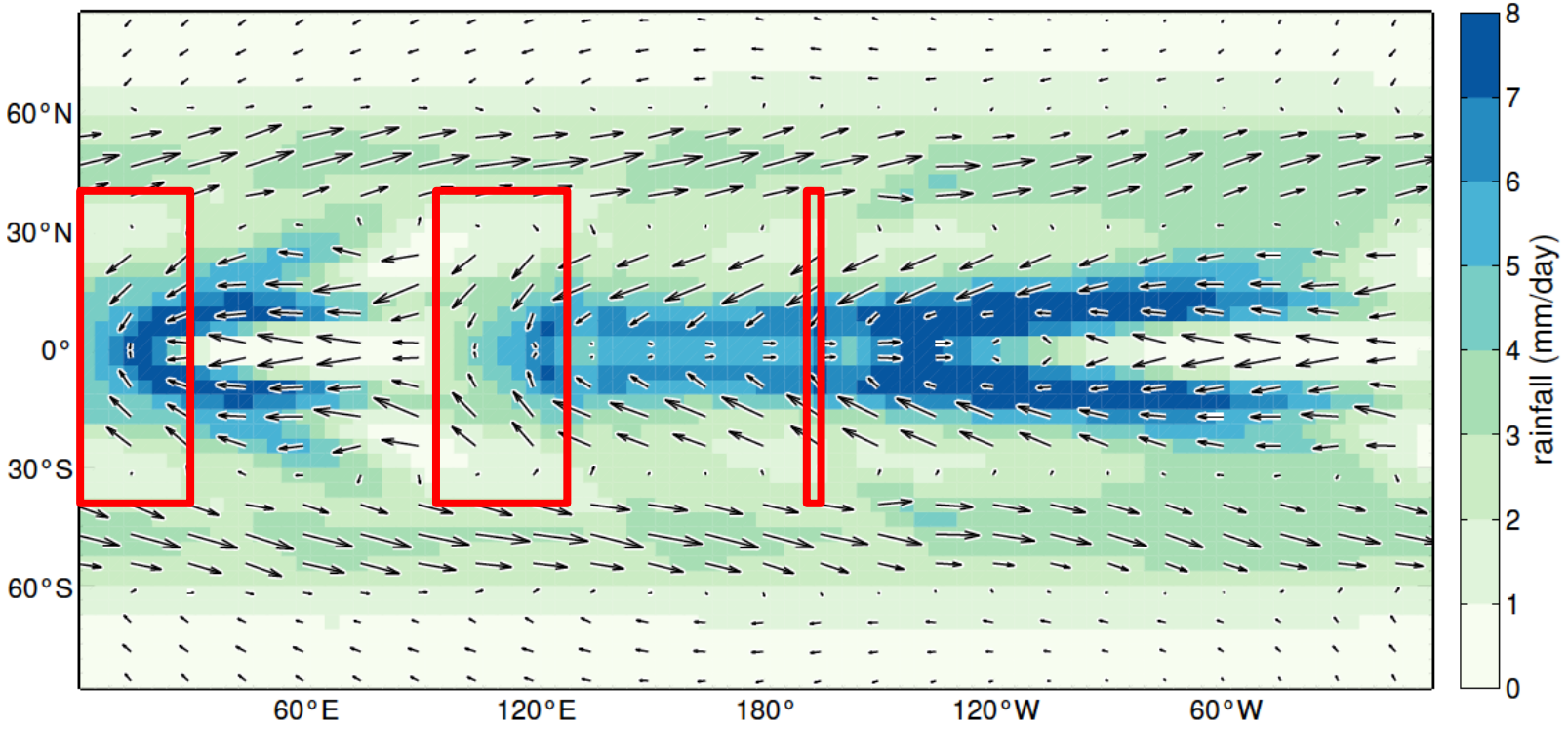
years 3500-4200



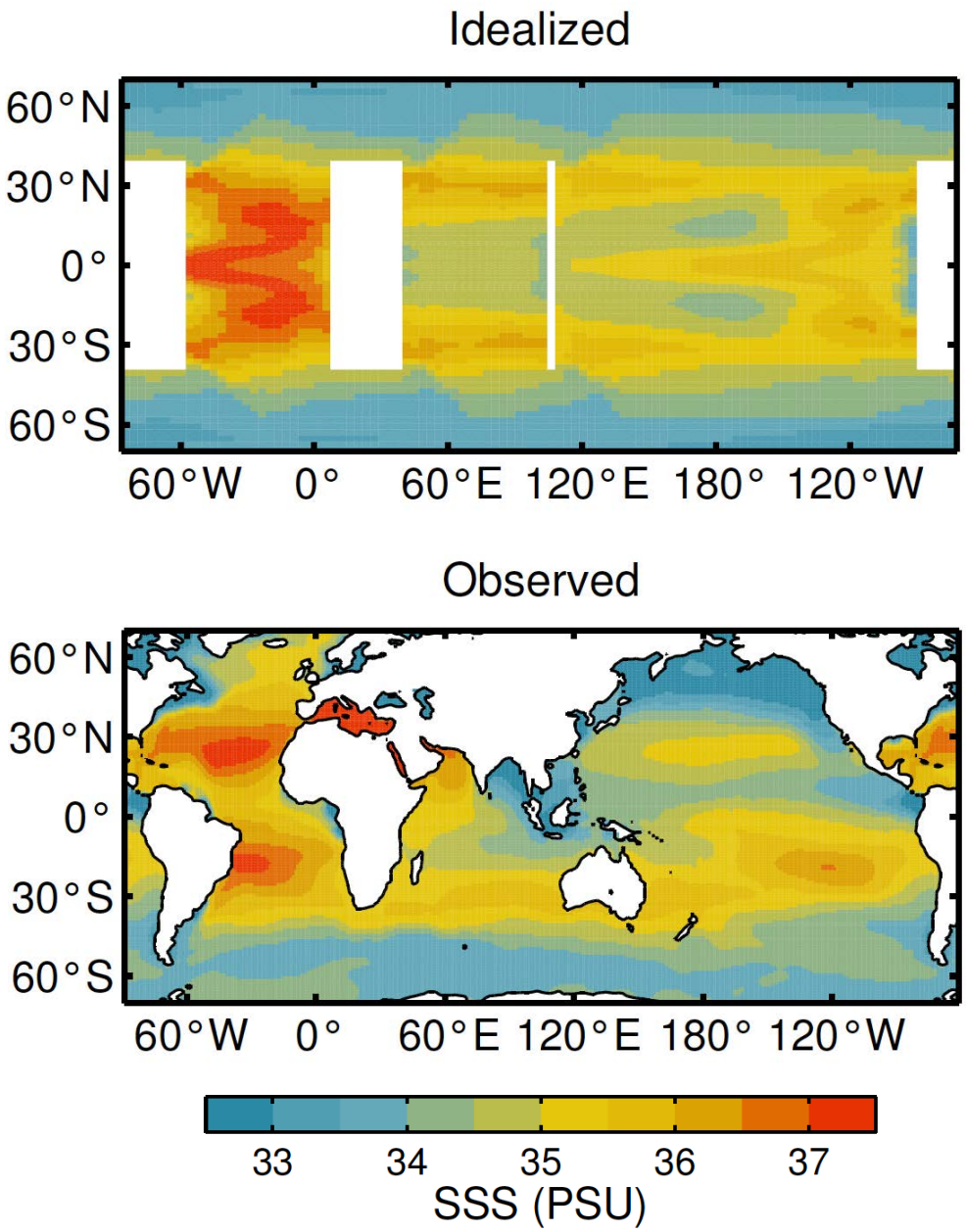
- **western Pacific warm pool**
  - Related to cold tongue to the east.
  - – No cold tongue in the Indian Ocean because of absolute westerlies
- **Independent Atlantic**

3 oceans climate

years 3500-4200



Annual–mean sea–surface salinity



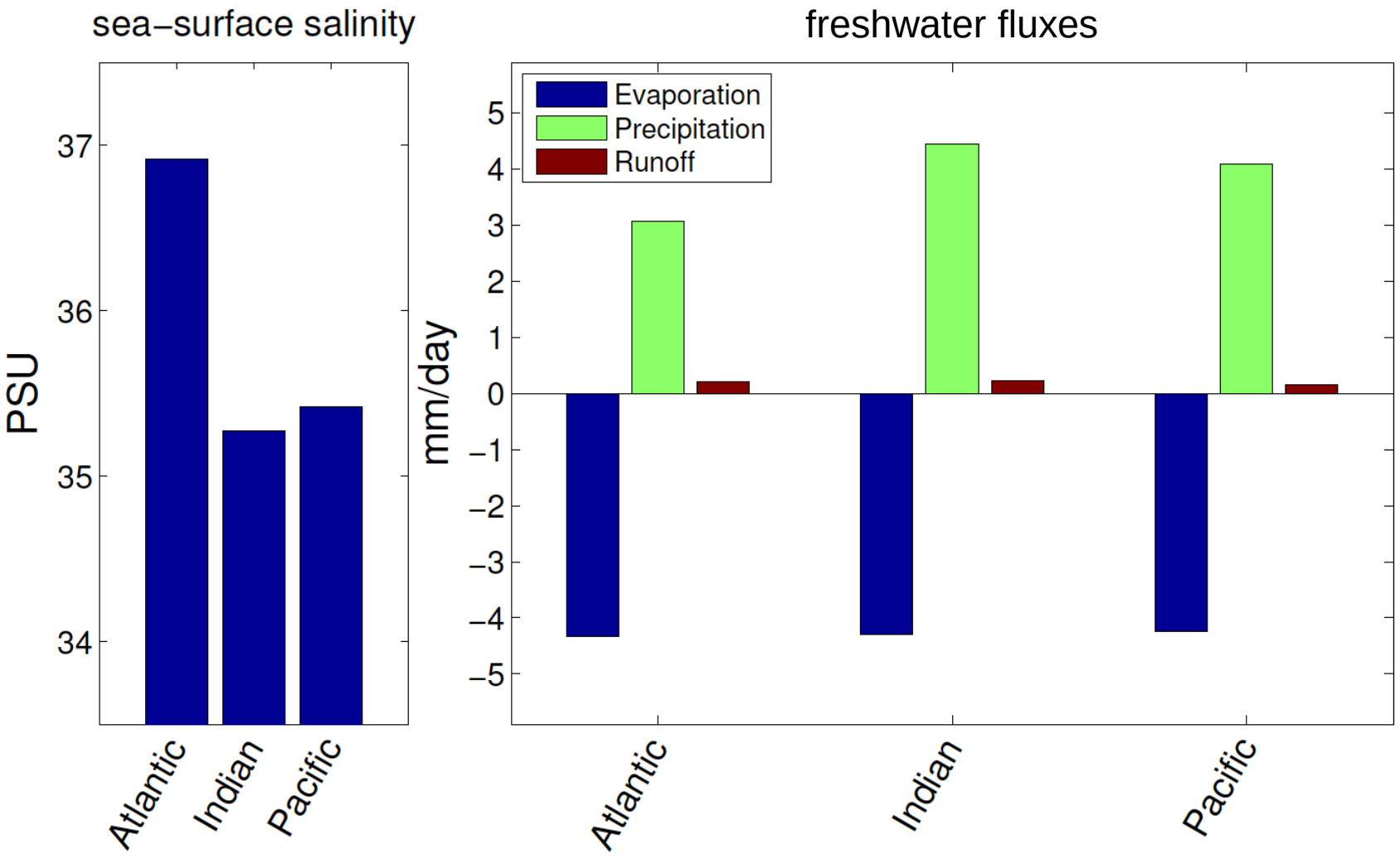
Despite their simplicity and lack of topographic constraints, our simulation represent many of the large-scale features in the annual-mean SSS:

- **saltier Atlantic,**
- maxima in the subtropics in all oceans, coinciding with regions of high evaporation (trade winds) and low precip,
- **fresher conditions in the Indo-Pacific warm pool,**
- fresher conditions over the high latitude oceans, uniformly mixed around the world.

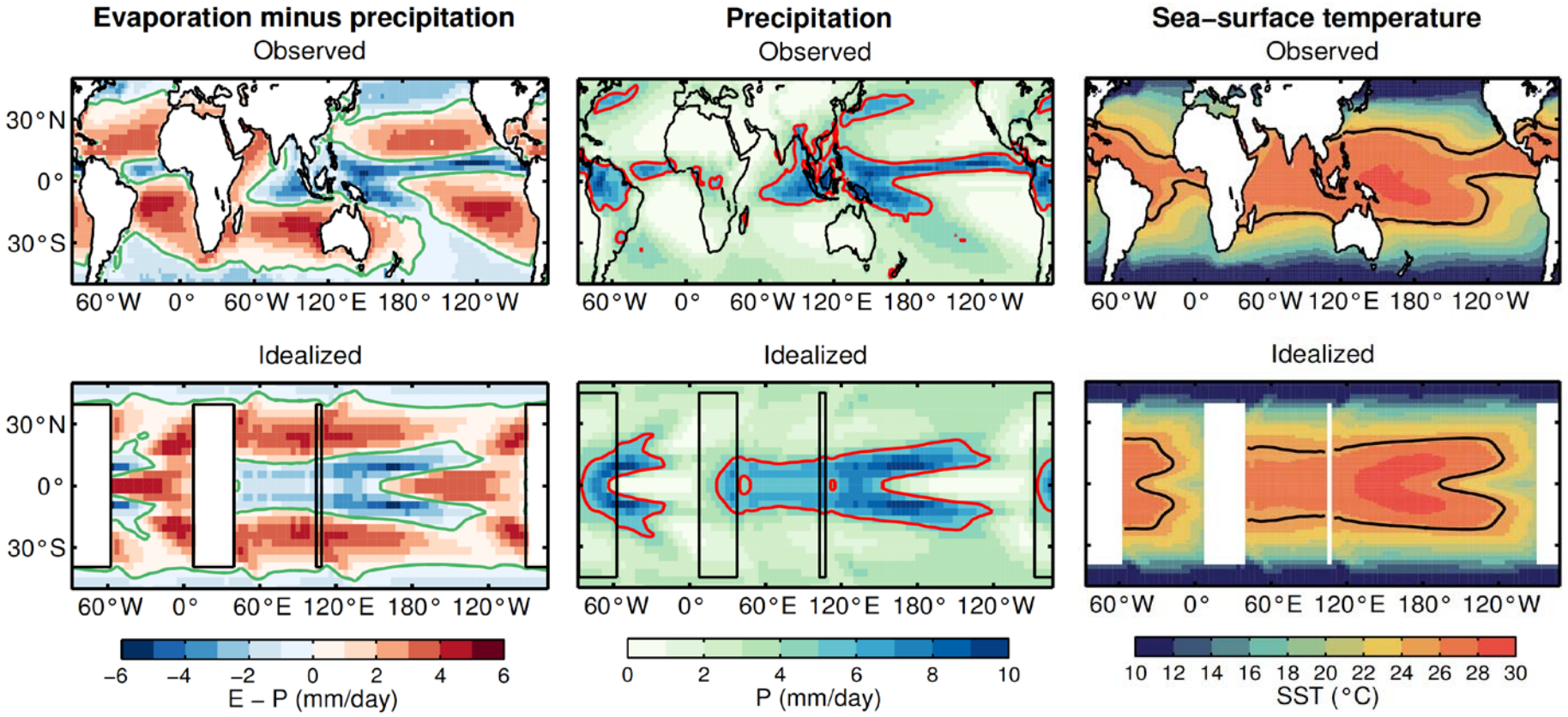
Introduction

- **Several mechanisms have been proposed to explain the salinity contrast between the Atlantic and the Pacific:**
  - Moisture (freshwater) transport (by winds) across Panama isthmus, making Caribbean saltier (Weyl, Broecker et al. 1990, Zaucker and Broecker 1992),
  - Moisture (freshwater) transport by westerlies (Warren 1983, Ferreira et al. 2010),
  - Effect of the the Mediterranean outflow,
  - Behring strait,
  - Rocky mountains and its effect on the storm tracks (Sinha et al. 2012),
  - Asian Monsoon – making the North Pacific fresher (Emile-Geay et al. 2003),
  - Salt transport by Agulhas current from Indian to Atlantic (Beal et al. 2011).
  - …
- **Our simulations excluded all these mechanisms, yet we get a salty Atlantic.**

SSS difference explained by inter-basin rainfall contrast



Impact of the Indo-Pacific warm pool on inter-basin salinity contrast



In both model and obs the Indo-Pacific has a much larger area with SSTs above the tropical mean, thus explaining why it's rainier and hence fresher

Conclusions

- **Idealized simulations with dynamical ocean in CESM1 are possible.**
- **Climates with zonal and/or inter-hemispheric symmetry:**
  - Quasi aqua:
    - Stable climate, but strong equatorial decadal variability.
    - Dry equator, parameter dependent.
  - Two ridge/two ocean:
    - Inter-basin oscillation,
  - 2 continents/1 ridge/3 oceans:
    - Realistic zonal asymmetries, but inter-hemispheric symmetry.
- **Useful to study fundamental features of the Earth's climate via simplification:**
  - Why is the Atlantic saltier?