Disentangling atmospheric biases in the tropical Atlantic in the CNRM climate

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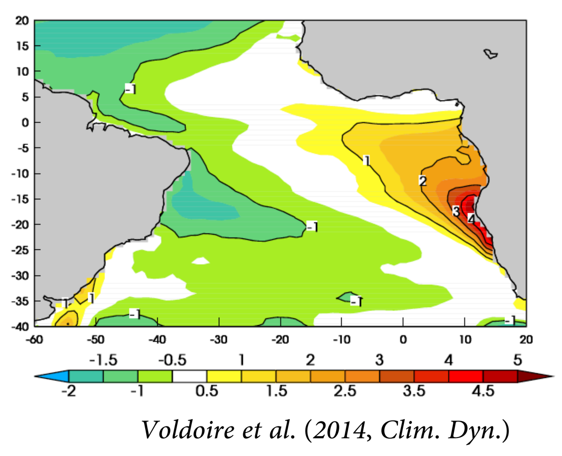
Introduction

- Most coupled climate models have a warm SST bias and westerly bias in the tropical Atlantic (e.g., Richter et al 2014, Voldoire et al 2014)
- These biases have large impact on the regional atmospheric and oceanic circulations.
- Various processes at play, possibly different for the equatorial biases and those in the southeastern part of the basin: *surface cloud radiative effect, regional convective heating sources, boundary layer wind mixing, coastal upwelling, barrier layers…*
- The **westerly wind bias is generally already present in AMIP** simulations and has been shown in some models to be instrumental in the development of the warm SST bias along the Equator (e.g., Voldoire et al 2014)
- CNRM-CM5 exhibits this kind of behavior

CMIP5 SST bias



Voldoire et al. (2014, Clim. Dyn.)

Focus on April, when the westerly wind bias is maximum and strongly impacts on the development of the summer Atlantic cold tongue.

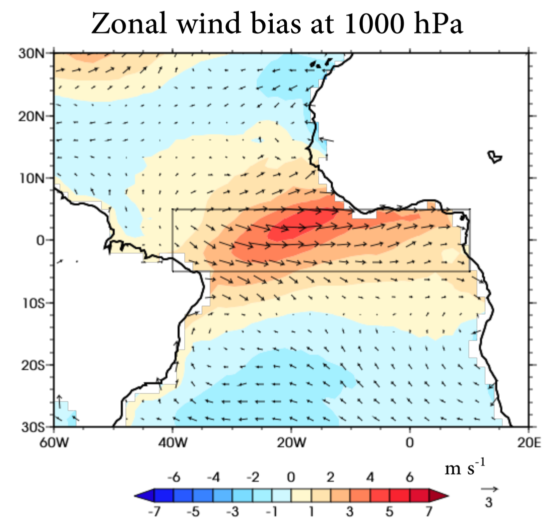
Conclusions

- **CNRM-CM5 AMIP simulation:**
  - Surface zonal wind bias ***in equilibrium with*** errors in the zonal gradients of geopotential, temperature in the free troposphere, precipitation and associated convective sources.
- **Short-term hindcasts:**
  - Reproduce the main features of CNRM-CM5 AMIP biases in the tropical Atlantic and allow for cause and effect identification.
  - Fast adjustment (~5 days) of the regional Walker circulation to the lack of convection in the western part of the basin. This controls the development of other biases in the region.
  - The deficit of precipitation in the western part of the basin is characterized by underestimated surface evaporation (*fast processes to be further investigated*), which does not favor intense convection in a convective parameterization based on moisture convergence closure.
- This last point is partly confirmed by the results of the new CNRM-CM physics, which has a convection parameterization based on a CAPE closure.

AMIP biases of CNRM-CM5 in the tropical Atlantic

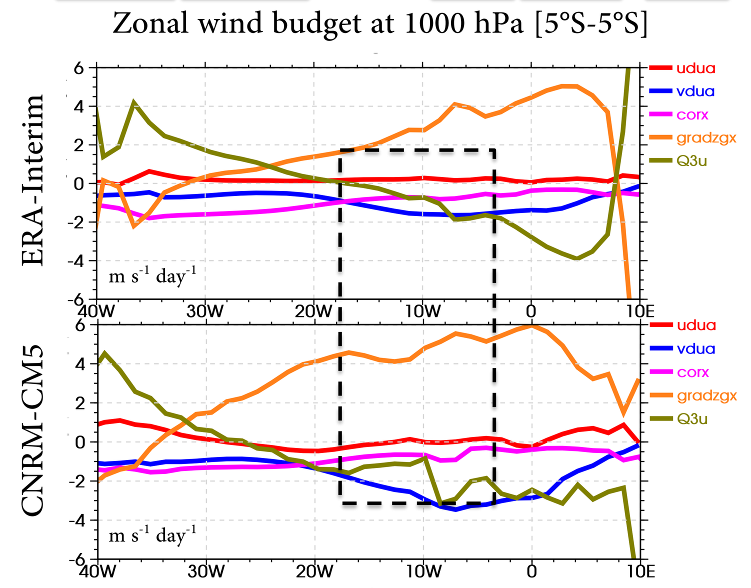
1. Surface wind bias and budget - April

Zonal wind bias at 1000 hPa



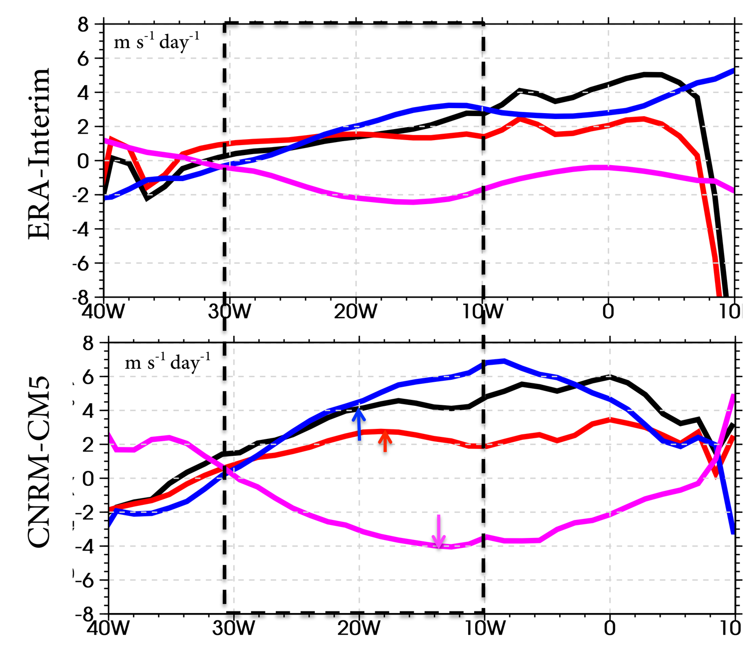
$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - \omega\frac{\partial u}{\partial p} - fv - \frac{\partial \Phi}{\partial x} + Q_{3u}$$

Zonal wind budget at 1000 hPa [5°S-5°S]



- Westerly wind bias along the Equator, maximum near 20°W
- Zonal wind budget: too strong geopotential gradient force, partially cancelled by turbulent mixing (Q3u)

2. Role of convective source



- Hydrostatic balance integrated over the vertical:

$$\partial_x\Phi(1000hPa) = \partial_x\Phi(200hPa) - \int_{1000hPa}^{800hPa} R\partial_x T\frac{dp}{p} - \int_{800hPa}^{200hPa} R\partial_x T\frac{dp}{p}$$

~ tropopause | Atmospheric boundary layer | Free troposphere

ERA-Interim surface geopotential gradient

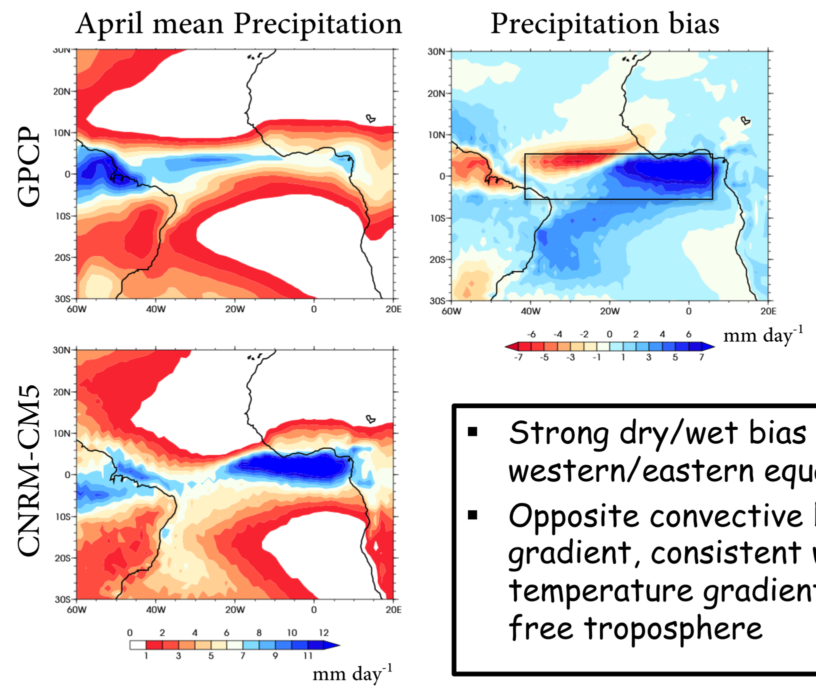
- Equivalent contributions from the boundary layer (SST gradient – Lindzen and Nigam) and the free troposphere (Gill) temperature gradient, partially compensated by the one at the tropopause

CNRM-CM5 (AMIP) bias

- Main contribution from ***temperature gradients within the free troposphere***
  - **Role of convective sources – Gill-type response?**
- Partially compensated by the tropopause contribution increase
- Small contribution from the boundary layer temperature gradients (turbulent mixing)

3. Precipitation and moisture budget

April mean Precipitation | Precipitation bias

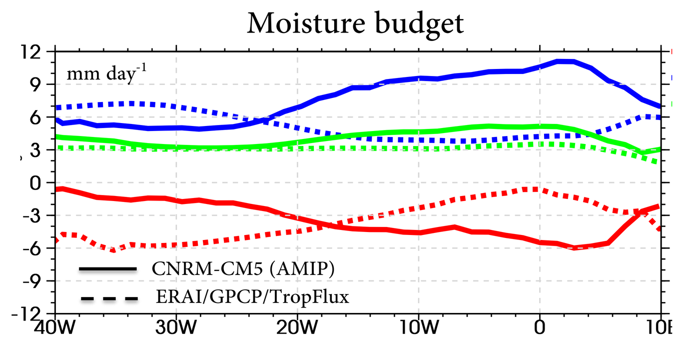


$$Precip \approx -\int_{p_s}^{0} div\left(q_v\vec{V}\right)\frac{dp}{g} + Evap$$

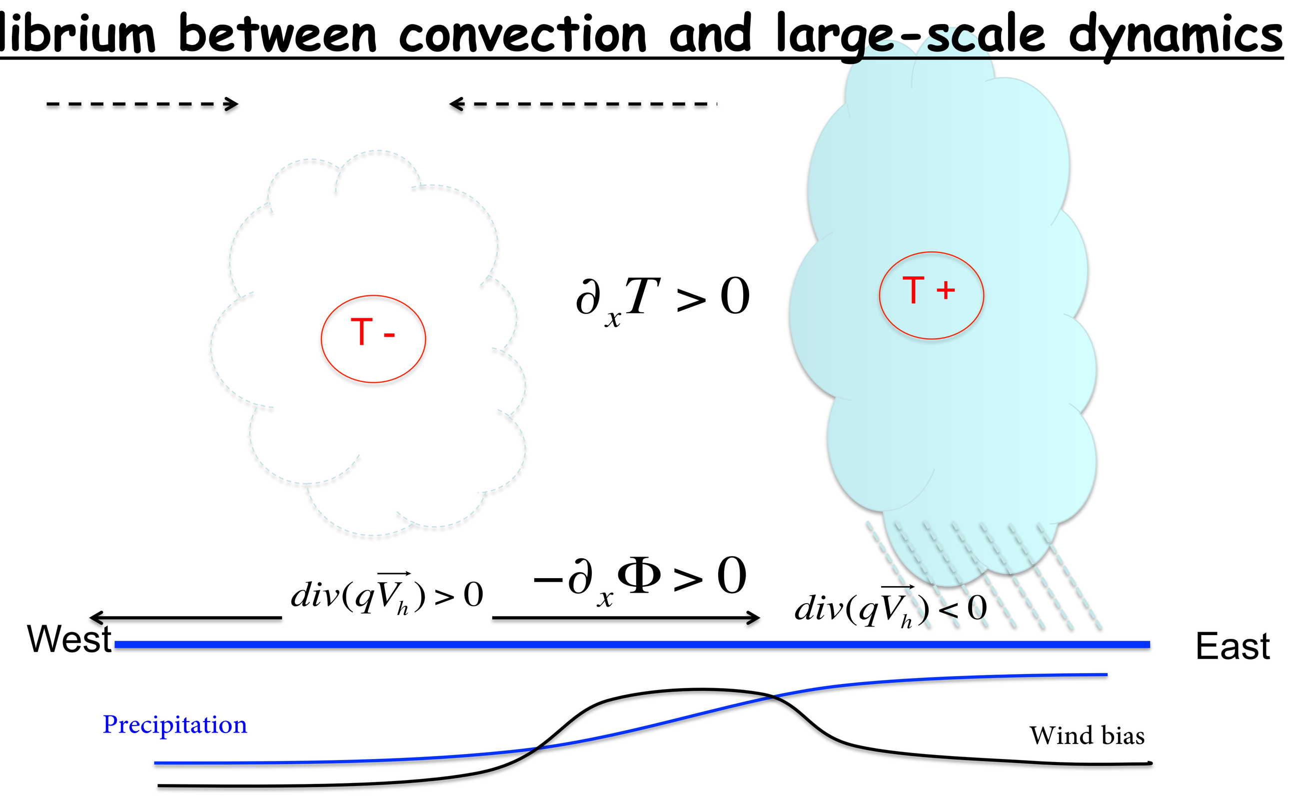
- Precipitation bias in equilibrium with moisture convergence bias.
- Mainly driven by the dynamics (horizontal wind convergence)
- East-West contrast in surface evaporation contributes to a lesser extent

- Strong dry/wet bias in the western/eastern equatorial Atlantic
- Opposite convective heating source gradient, consistent with the temperature gradient bias in the free troposphere

Moisture budget



4. Equilibrium between convection and large-scale dynamics



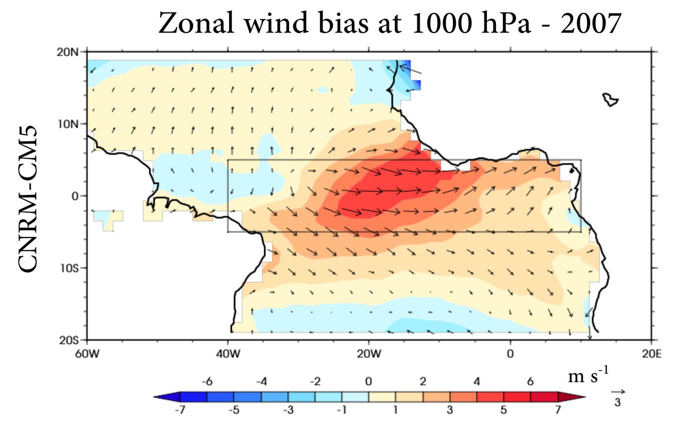
Cause and effect: use of short-term atmospheric hindcasts

The Transpose-AMIP framework

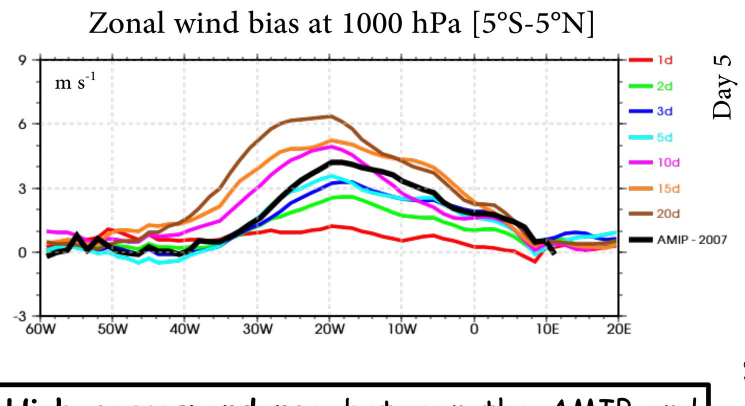
- 20-day hindcasts, initialized every day of April 2007 at 0h UTC (30 members)
- April 2007 is rather neutral in terms of SSTs anomalies and CNRM-CM5 (AMIP) biases in the Tropical Atlantic
- Initialization from ERA-Interim for the atmosphere (so ERA-Interim is our reference for the dynamics and thermodynamics).
- For continental surface, initial state derived from an offline simulation of the land surface model using a forcing based on observations/reanalyses.

1. Correspondance between AMIP and TAMIP bias

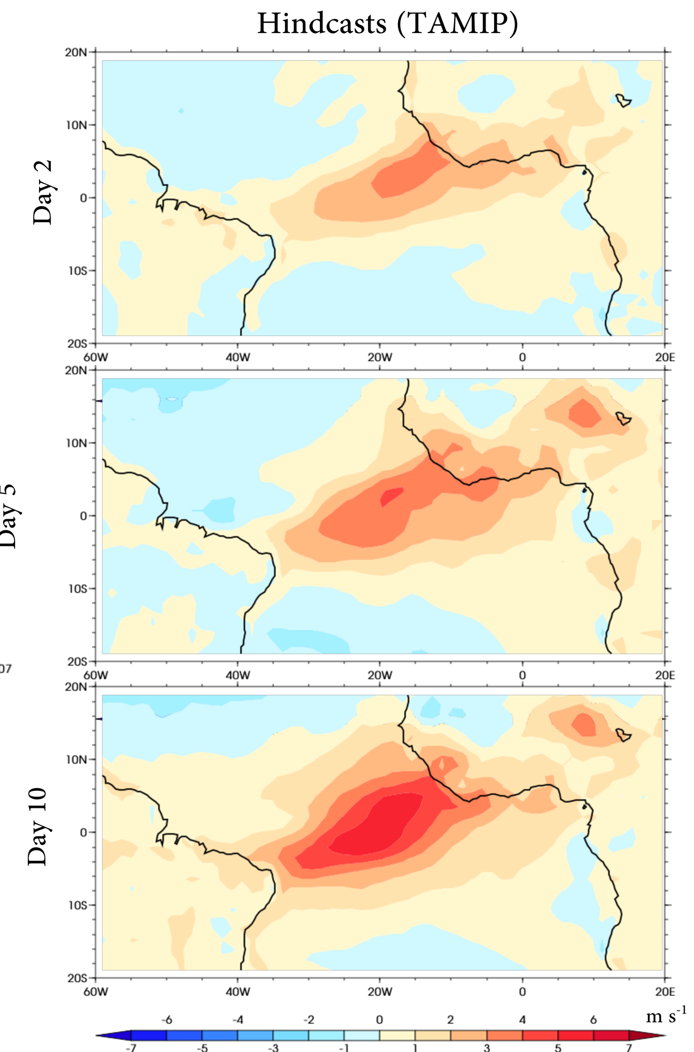
Zonal wind bias at 1000 hPa - 2007



Zonal wind bias at 1000 hPa [5°S-5°N]



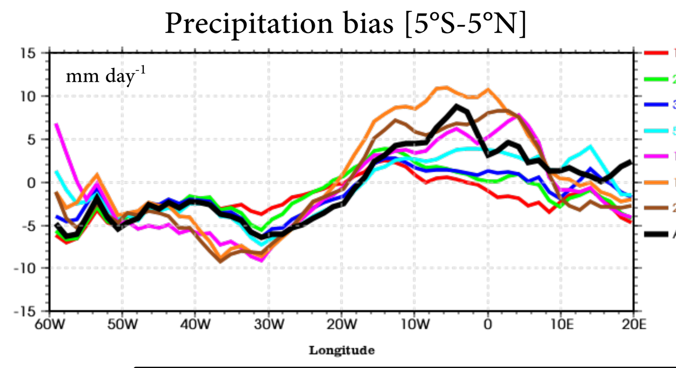
Hindcasts (TAMIP)



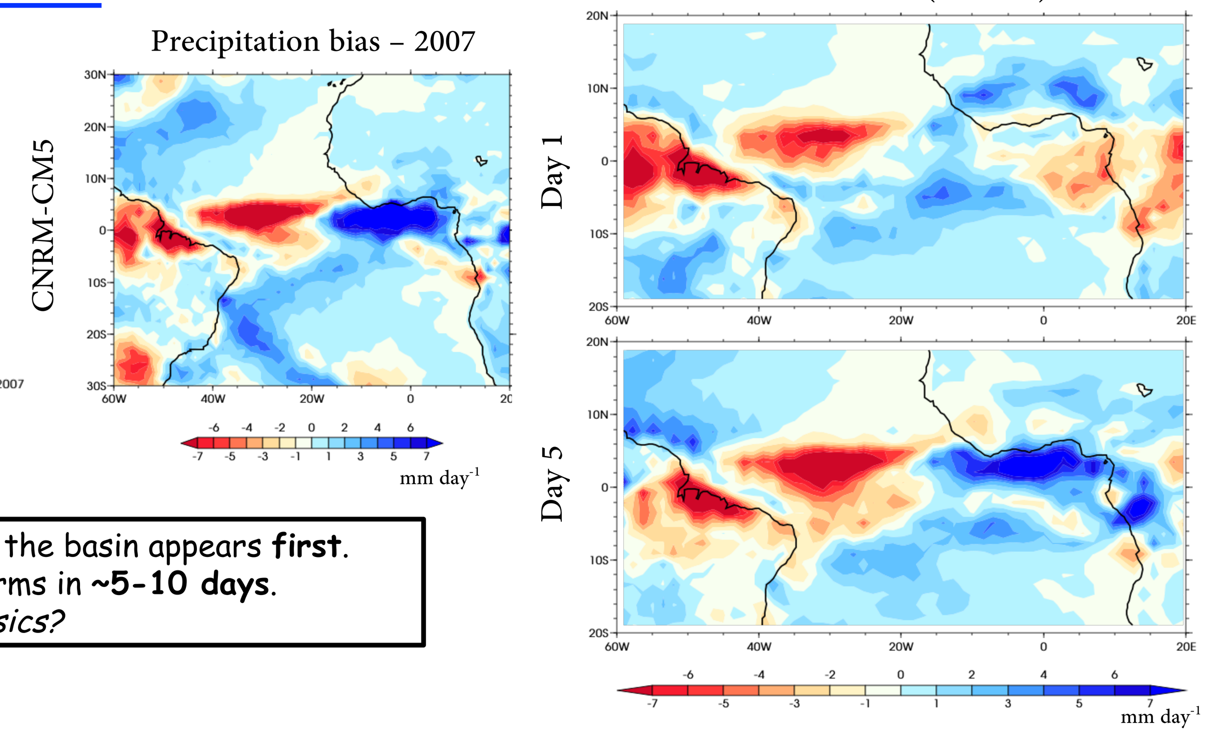
- **High correspondance** between the AMIP and TAMIP surface zonal wind biases after only **~5 days**, both in terms of structure and intensity
- Geopotential and temperature gradients biases develop even faster (not shown).

2. Precipitation biases

Precipitation bias [5°S-5°N]



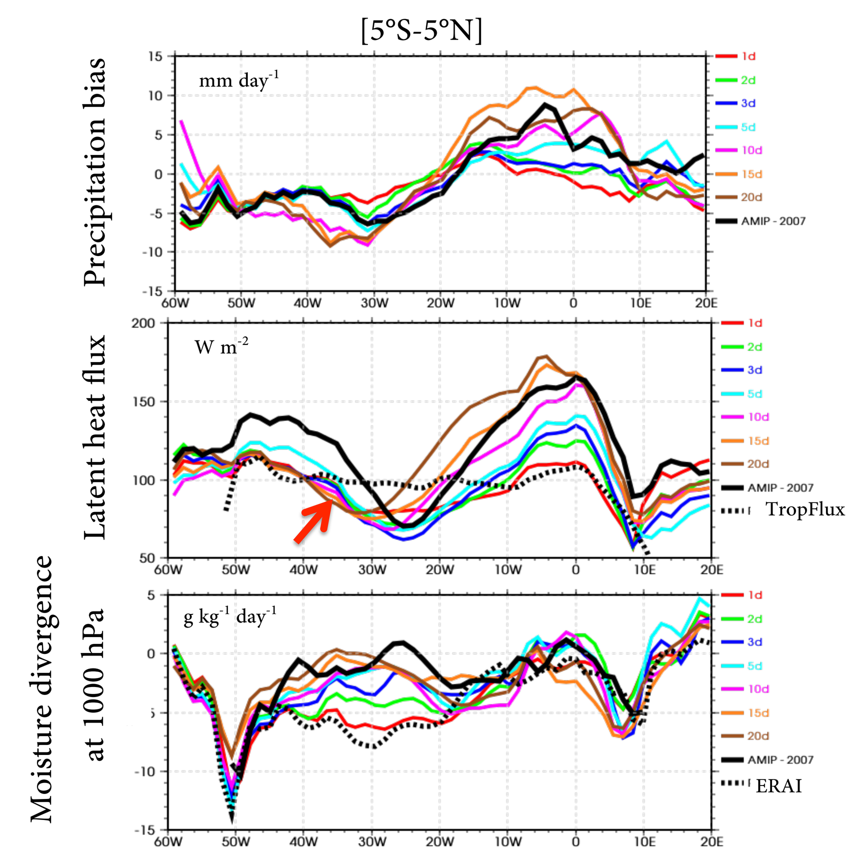
Precipitation bias – 2007 | Hindcasts (TAMIP)



- The **dry bias** in the western part of the basin appears **first**.
- The **wet bias** in the eastern part forms in **~5-10 days**.
- *Can we relate that to the model physics?*

3. Surface evaporation, convective parameterization closure?

[5°S-5°N]



In the West:

- Surface latent heat fluxes underestimated by the model, from the first days of the hindcasts, while moisture convergence is realistic and significant.
- The convective parameterization (Bougeault 1985) has a moisture convergence (MC) closure (Kuo-type): ***resolved MC + subgrid (turbulent) MC = rainfall + detrainement***
  - Weaker evaporation does not favor convection there.

In the East:

- The increase of precipitation mostly responds to the increase of surface fluxes.