Disentangling atmospheric biases in the tropical Atlantic in the CNRM climate model

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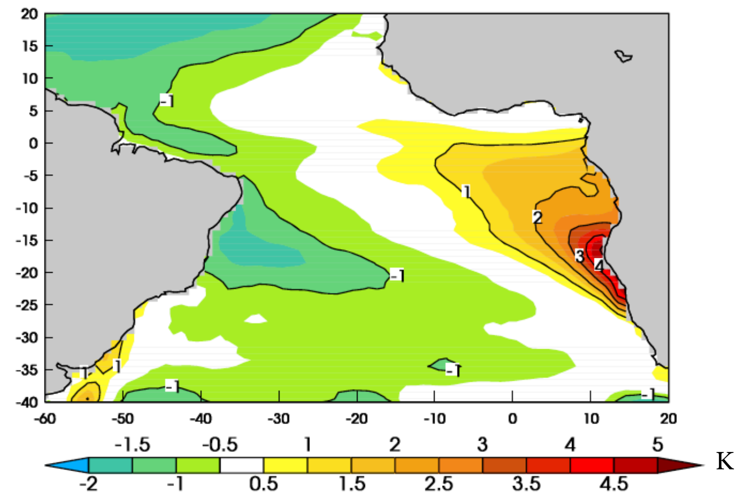
Climate models and the Tropical Atlantic

- Most coupled climate models have a warm SST bias and westerly bias in the tropical Atlantic (eg. Richter et al 2014, Voldoire et al 2014)
- These biases have large impact on the regional atmospheric and oceanic circulation.
- 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 (eg, Voldoire et al 2014)
- CNRM-CM5 exhibits this kind of behavior

SST bias of the CMIP5 ensemble mean



Voldoire et al. (2014)

Objective:

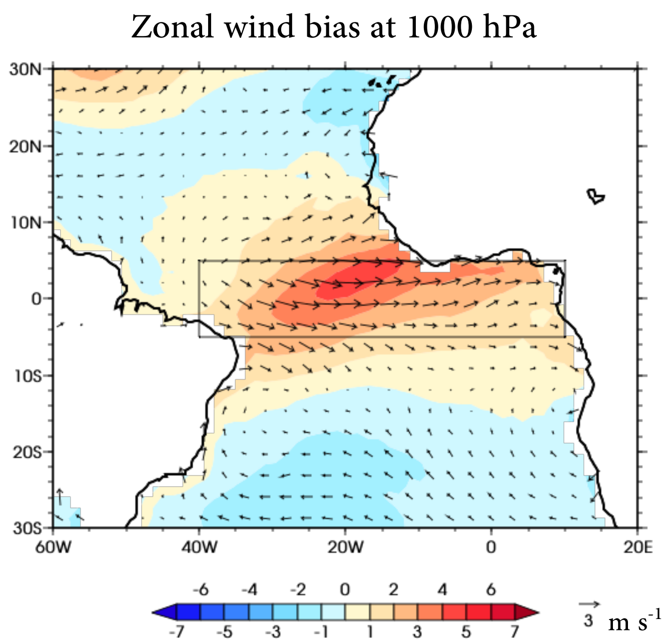
➢ ***Identify the source(s) of wind errors in the Tropical Atlantic for the CNRM-CM5 atmospheric component.***

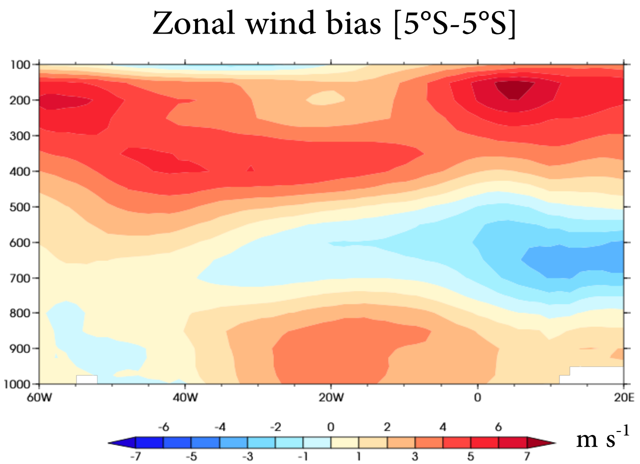
Outline

1. *Context and motivation*
2. *AMIP biases of CNRM-CM5 in the tropical Atlantic*
3. *Cause and effect: use of atmospheric hindcasts*
4. *Conclusions and perspectives*

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

Surface wind bias and budget - April

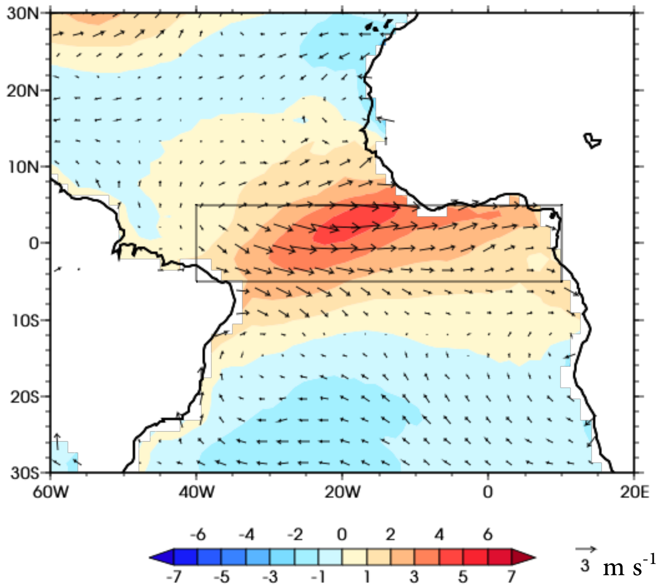




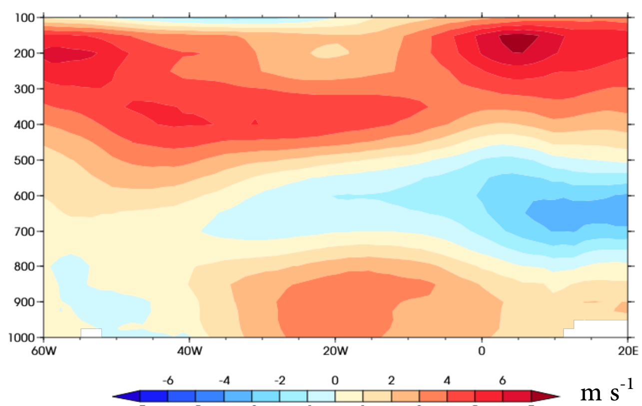
- Westerly wind bias along the Equator, maximum near 20°W, between surface and ~750 hPa.

Surface wind bias and budget - April

Zonal wind bias at 1000 hPa



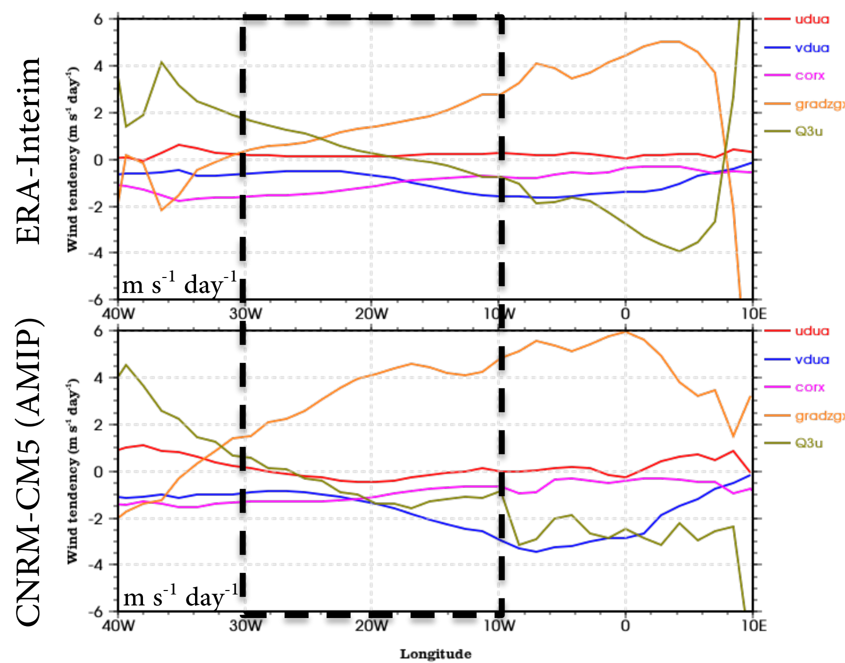
Zonal wind bias [5°S-5°S]



- Westerly wind bias along the Equator, maximum near 20°W, between surface and ~750 hPa.
- Zonal wind budget: too strong geopotential gradient, partially cancelled by turbulent mixing (Q3u)

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

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

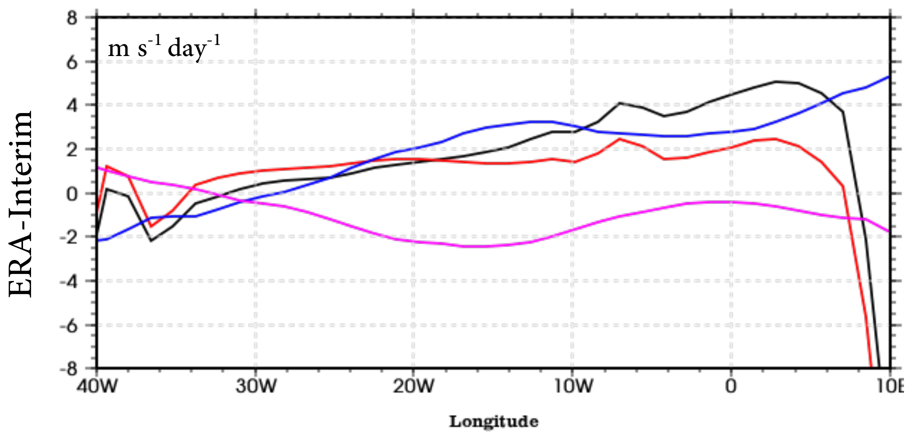


Role of convective source

- Vertical integration of the hydrostatic equation yields:

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

~ 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

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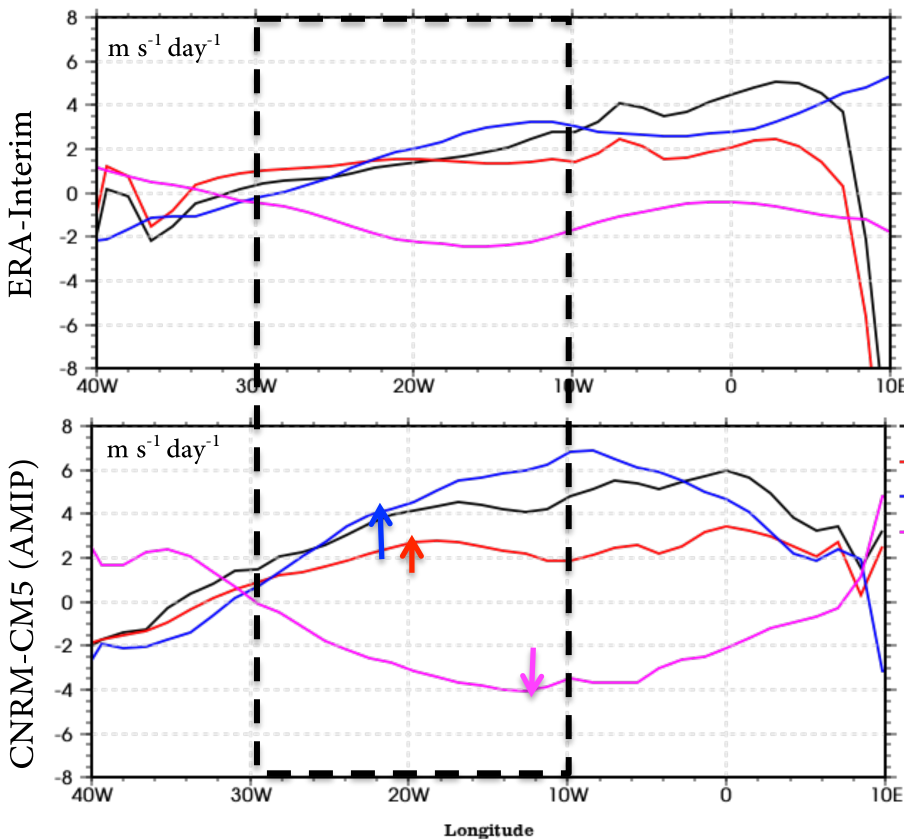

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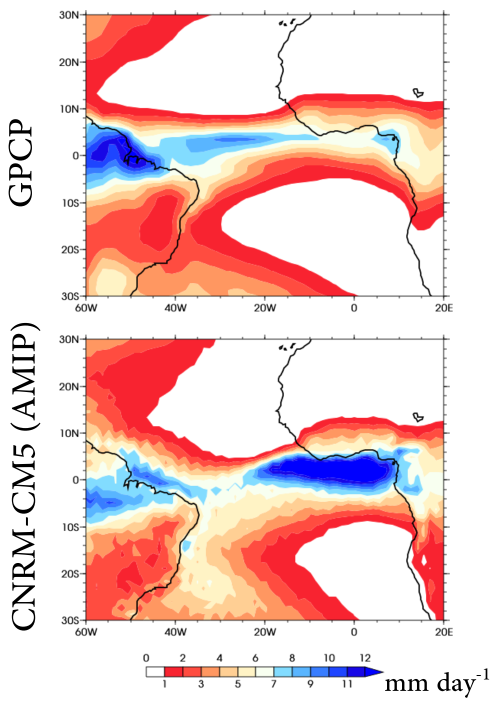
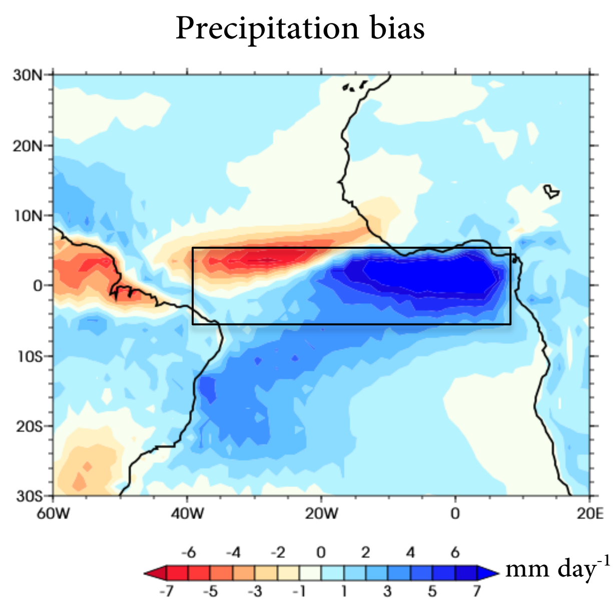
CNRM-CM5 (AMIP) bias

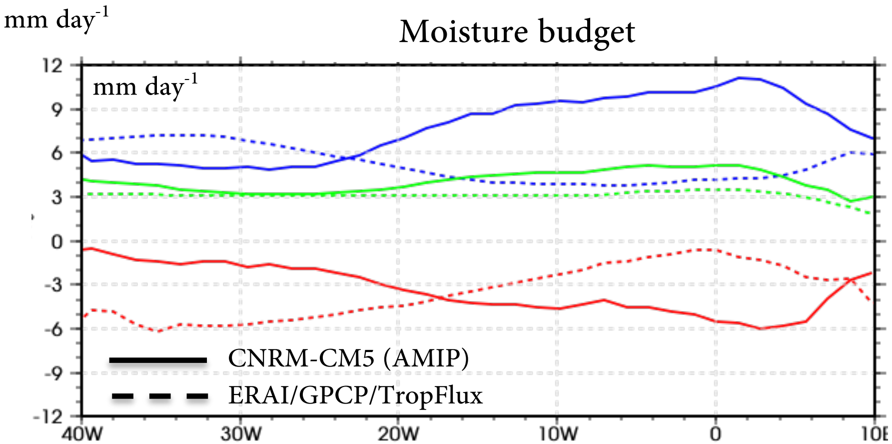
- Main contribution from ***temperature gradients within the free troposphere***
  - **Role of convective sources – Gill-type response?**
- Partially compensated by the tropopause contribution
- Small contribution from the boundary layer temperature gradients (turbulent mixing)

Precipitation and moisture budget





- 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

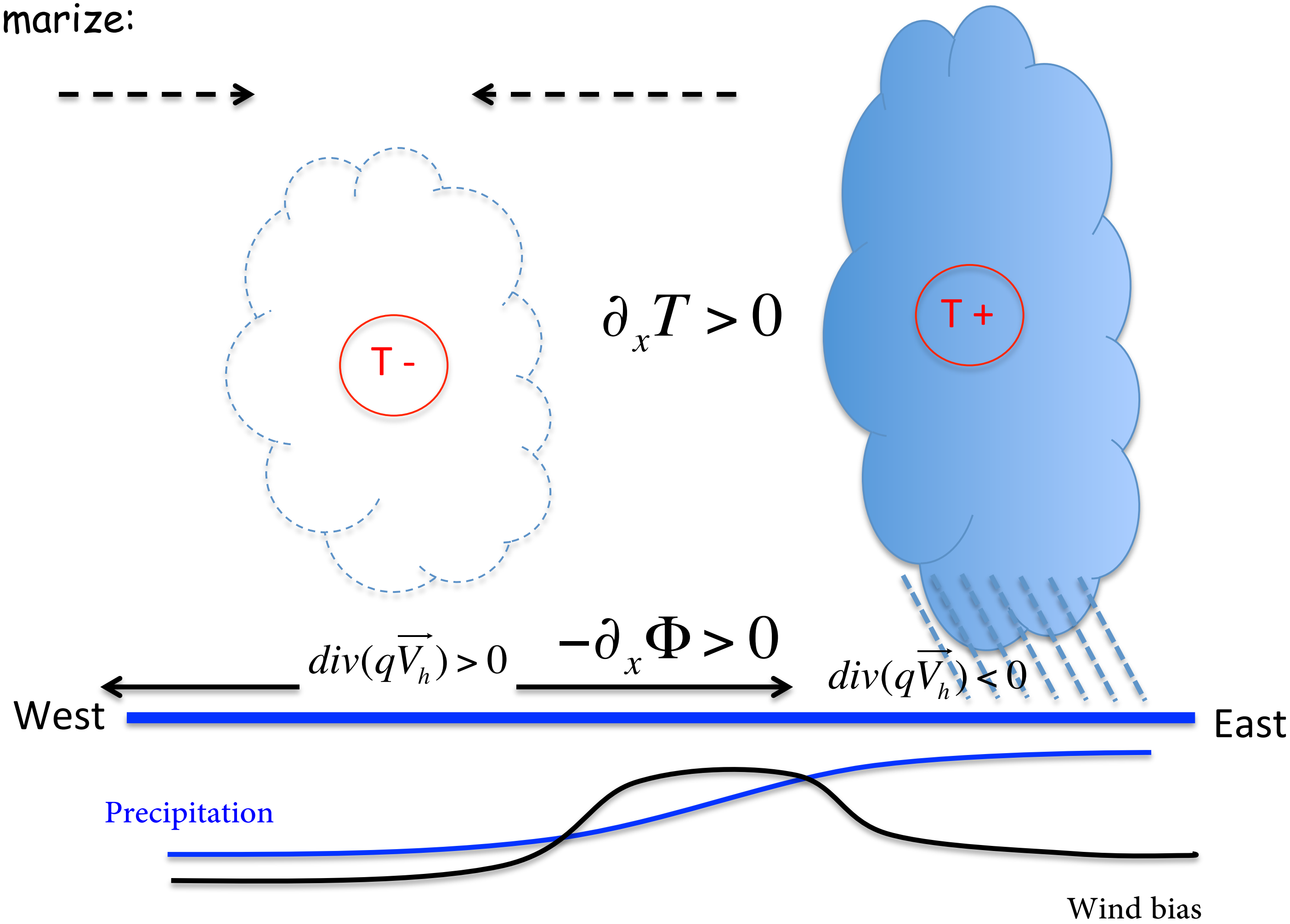


- Precipitation bias in equilibrium with moisture convergence bias
- Mainly driven by the dynamics (horizontal wind convergence)

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

Equilibrium between convection and large-scale dynamics

- To summarize:

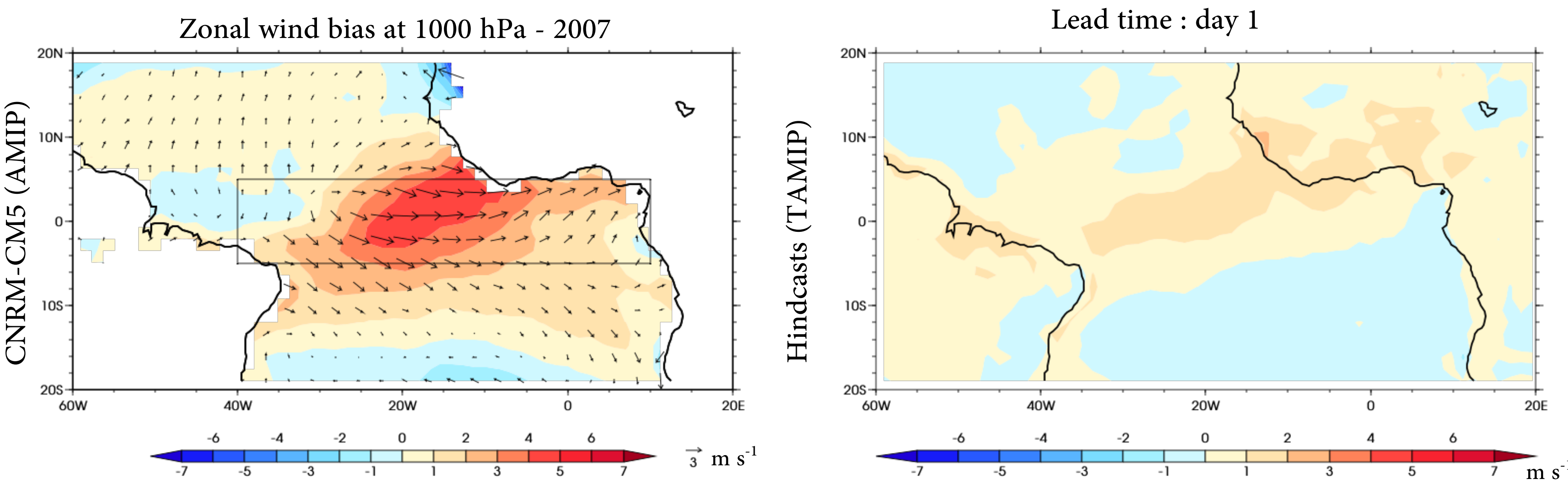


Short-term hindcast setup – Transpose-AMIP

- This Transpose-AMIP framework has been used in several studies to analyse the development of biases associated with „fast" processes such as cloud or tropical precipitation biases (Bodas-Salcedo et al., 2008; Williams and Brooks, 2008; Martin et al., 2010, Ma et al. 2014…)

- 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.

Correspondance between AMIP and TAMIP bias



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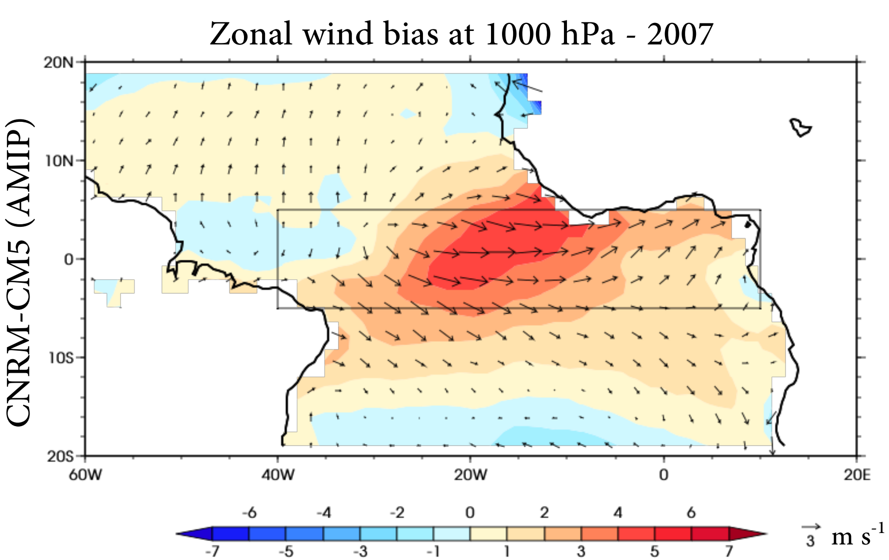

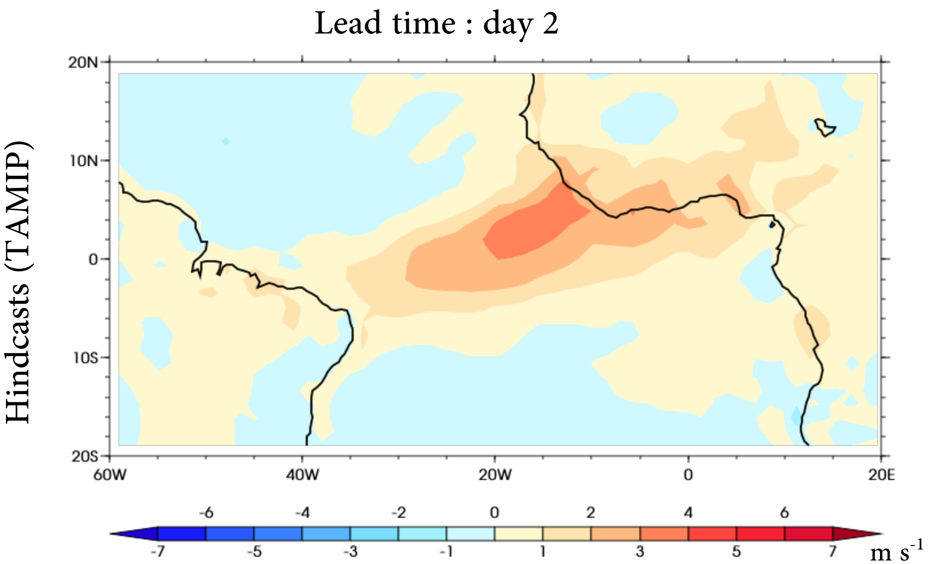

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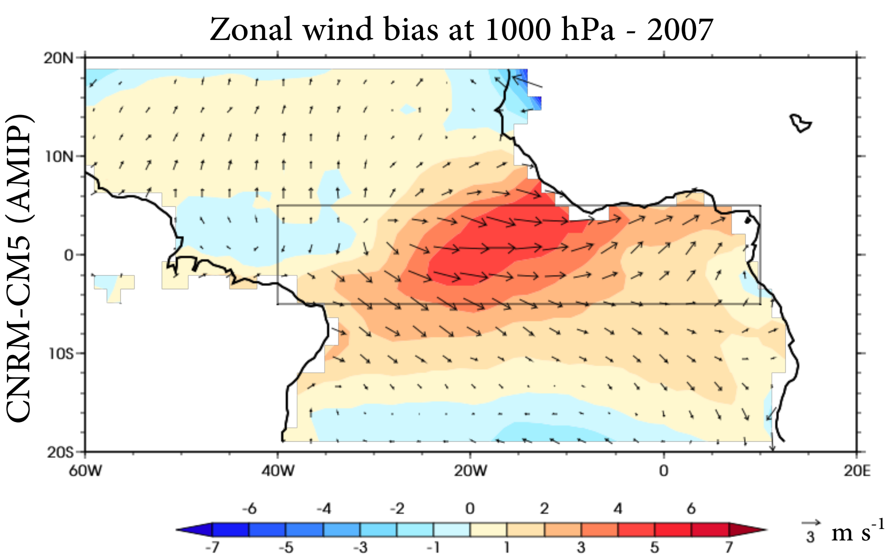
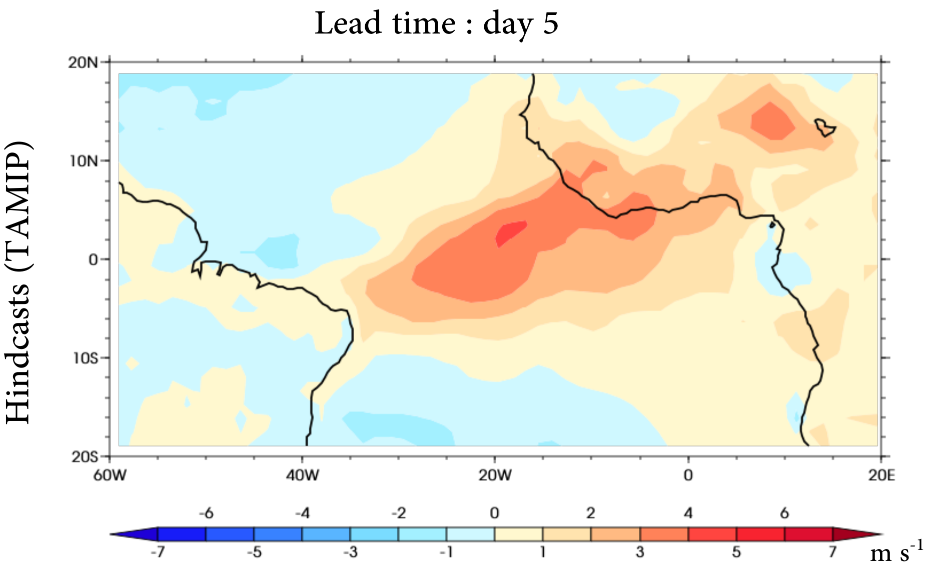
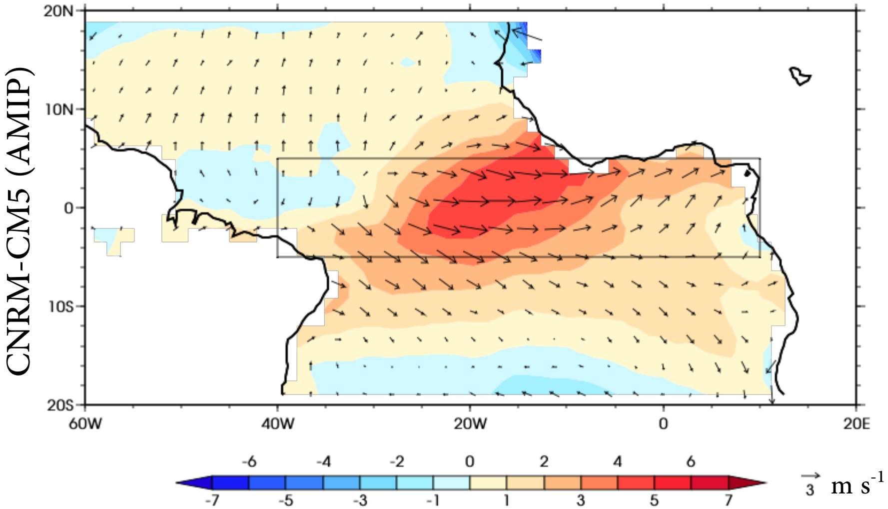


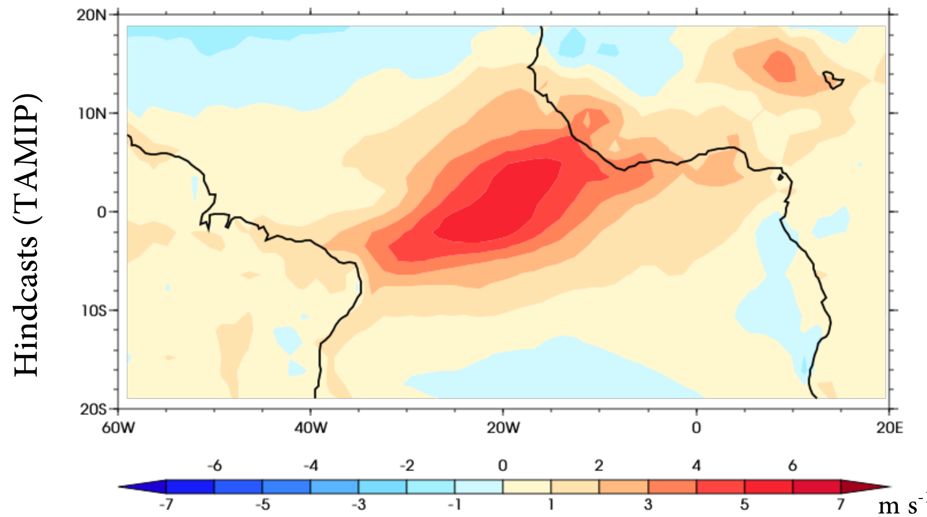


Correspondance between AMIP and TAMIP bias

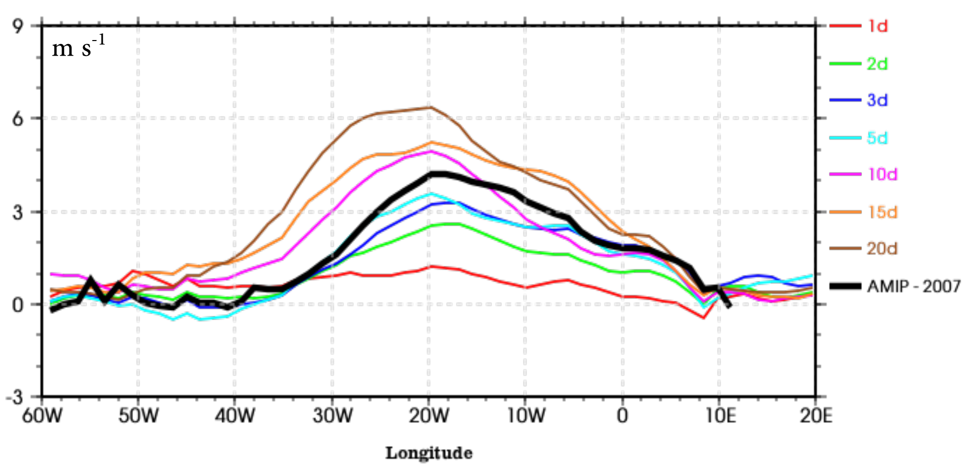
Zonal wind bias at 1000 hPa - 2007



Lead time : day 10



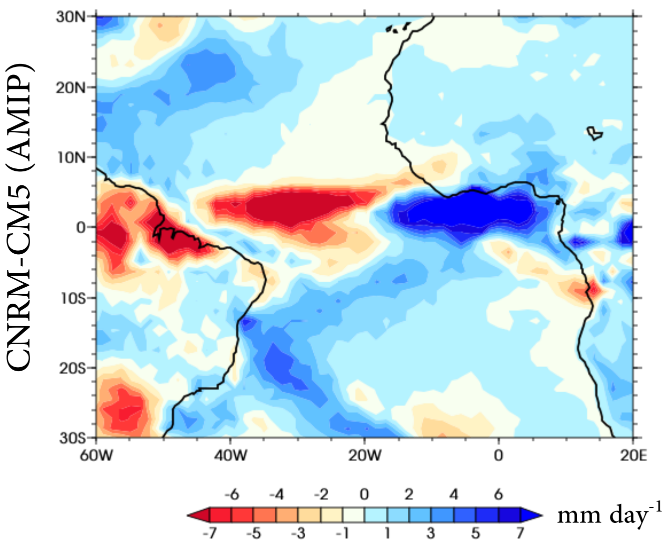
Zonal wind bias at 1000 hPa [5°S-5°N]



- High correspondance between th AMIP and TAMIP surface zonal wind bias after only ~5 days, both in terms of structure and intensity
- Geopotential and temperature gradients biases develop even faster.

Precipitation biases

Precipitation bias – AMIP 2007



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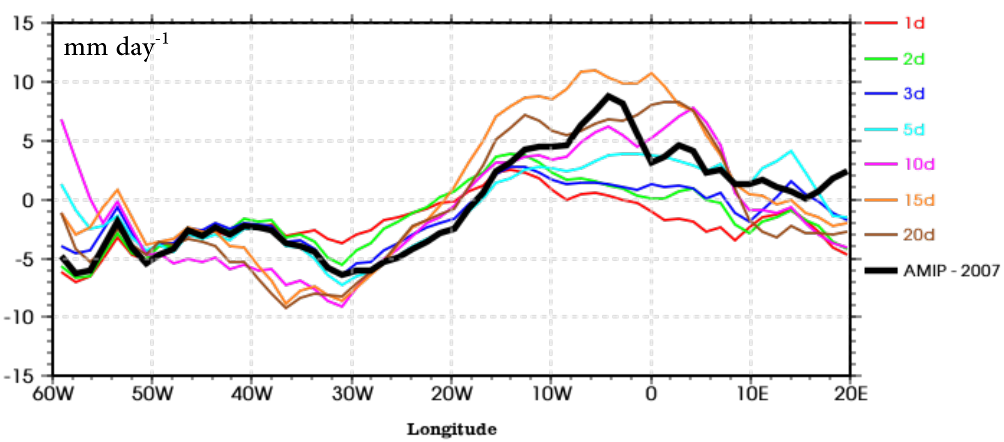
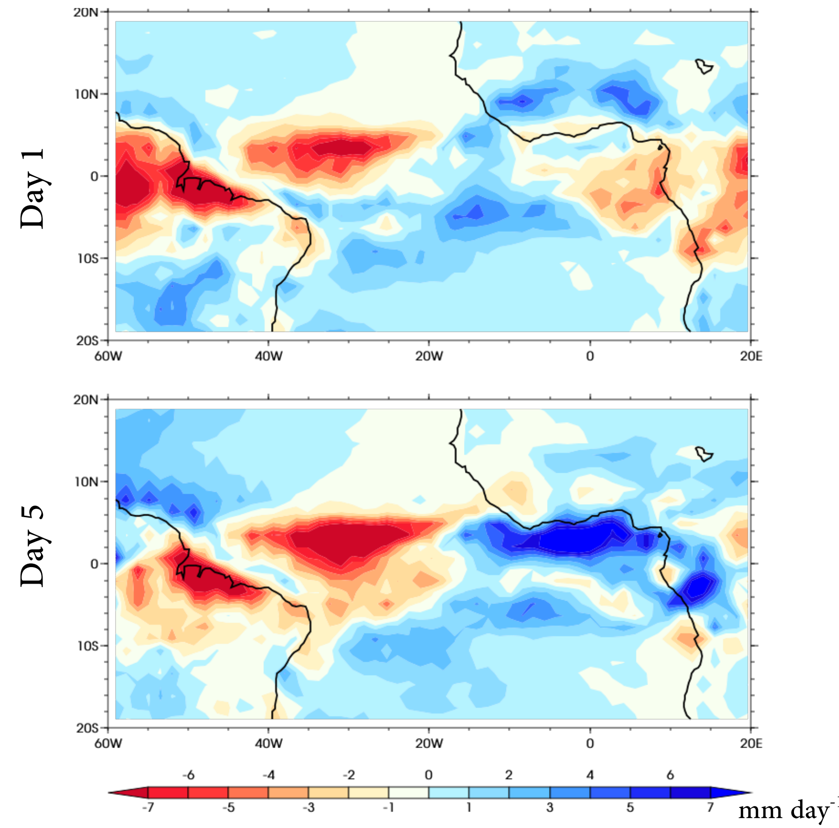


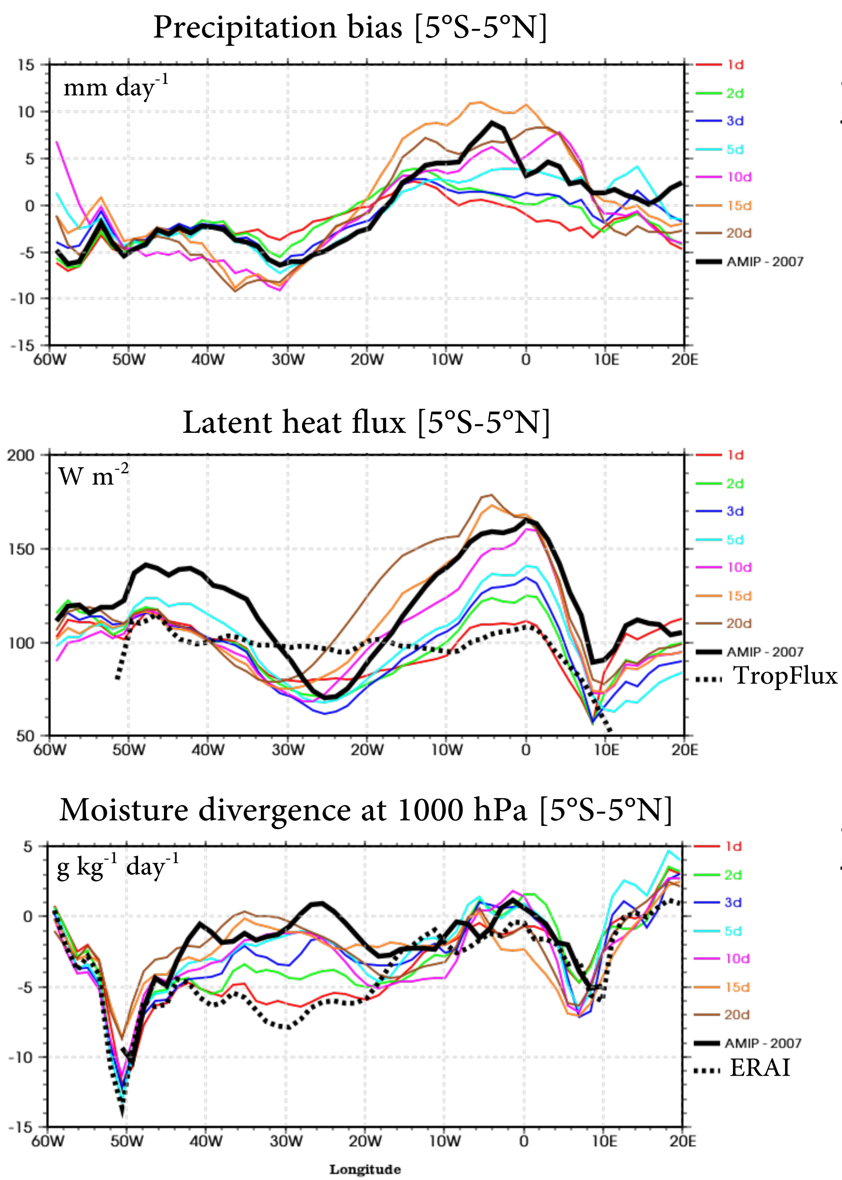
Precipitation bias – Hindcasts (TAMIP)



- 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. Cause and effect: use of atmospheric hindcasts

Surface evaporation, convective parameterization closure?



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 closure (Kuo-type):

  resolved MC + subgrid (turbulent) MC
  = rainfall + detrainement

➢ Weaker evaporation does not favour convection there.

In the East:

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

Conclusions and future work

- **<u>Conclusions</u>** :
  - In the **AMIP** CNRM-CM5 simulation, the surface zonal wind bias is associated 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 biases in the Tropical Atlantic. They indicate fast adjustment (~5 days) of the dynamics to the lack of convection in the western part of the basin. This appears to have some control on the other biases in the Tropical Atlantic.
  - The western part of the basin is characterized by underestimated surface evaporation, that do not favour intense convection in a parameterization based on moisture convergence closure.
  - This is partly confirmed by the results of the new CNRM-CM physics, which has a convection parameterization based on a CAPE closure (cf Florent Brient's poster).

- **<u>Future work</u>** :
  - Further validate and understand the role of surface fluxes and of the convective closure.
  - The tropical Atlantic mean state is significantly improved CNRM model, but part of the westerly wind bias remains. Need to further analyse its origin and to find the other processes at play, using also short-term hindcasts.