Dynamics and feedbacks controlling the intertropical convergence zone location and sensitivity to cumulus parameterization

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Introduction

The purpose of this study is to better understand the complex behavior of climate models and assess the importance of atmospheric internal dynamics and the convective scheme in defining the ITCZ location. In the first part, we investigate the response of two AGCMs (ARPEGE-Climat-CM5 and LMDz-CM5a) in an aquaplanet configuration, to a range of Sea Surface Temperature (SST) latitudinal distributions. In the second part, we show the importance of the choice of the lateral entrainment rate in improving the ITCZ representation in climate models.

Dynamics and feedbacks controlling the ITCZ location in ARPEGE-CM5 and LMDz-CM5a

SST forcing

We impose zonally-symmetric SST distributions that are also symmetric about the equator, similar to those used in the Aqua-Planet Experiment Project (Neale and Hoskins, 2000) :

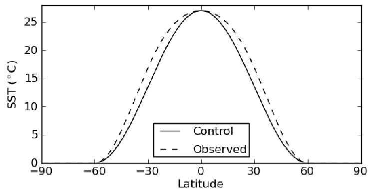


Fig. 1 SST latitudinal distributions for the Control (Peaked SST at the equator) and the Observed (flat SST at the equator) experiments.

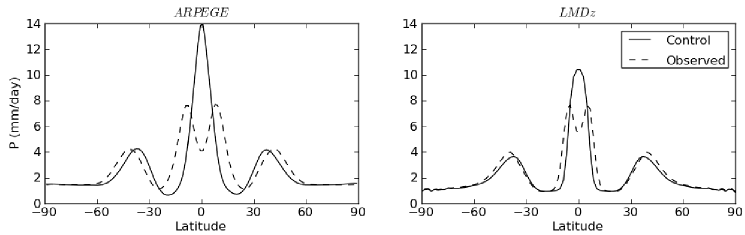


Fig 2. Zonal mean precipitation for the single ITCZ regime (Control) and the double ITCZ regime (Observed)

Changes in the low-level flow drive the transition

Changes in low-level moisture convergence drive the transition from the Double to the Single ITCZ. Changes in moisture convergence are dominated by changes in low-level flow (Fig. 3), mostly through changes in the horizontal wind. The ABL winds are almost linearly forced by the horizontal geopotential gradients.

ABL Temperature (ABLT) gradients versus upper-level forcing

The ABL geopotential gradients can be expressed as the sum of the ABL-top geopotential gradients (convective heating (Gill, 1980) and stratospheric cooling (cold top)) and the ABL Temperature (ABLT) gradients that are partly explained by SST gradients (Lindzen and Nigam, 1987) :

$$\underbrace{\Delta\,\partial_\phi \Phi_{1000\ hPa}}_{Low\ level\ pressure\ gradients} = \underbrace{\Delta\,\partial_\phi \Phi_{800\ hPa}}_{Upper-level\ forcing} - \underbrace{\int_{800}^{1000} R\,\Delta\,\partial_\phi T\,\frac{dP}{P}}_{\substack{ABLT\ gradients \\ (\Delta\partial_\phi\Phi_{ABLT},\ \Delta\partial_\phi\Phi_{SST})}}$$

- In ARPEGE, the ABL flow in the equatorial band is controlled by the ABLT gradients (Fig.4).
- In LMDz, ABLT contribution is weakened by moist thermodynamics. Deep convection acts, through the associated cold top, as a negative feedback on the low-level convergence.

ABL temperature changes

ARPEGE	LMDz	
ABLT gradients off the equator	ABLT gradients off the equator	
+	+	-
Horizontal advection of cooler air off the equator	Off-equatorial surface fluxes	Off-equatorial downdraft cooling

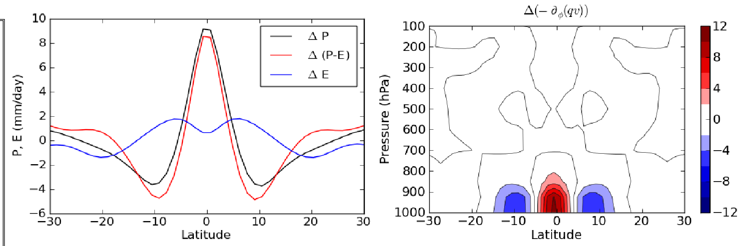


Fig. 3 Difference between the single and double regimes in zonal mean precipitation (P), vertically-integrated moisture convergence (P-E) and evaporation (E) (left) and zonal-mean horizontal moisture convergence flux (right, q is the specific humidity and v the horizontal velocity).

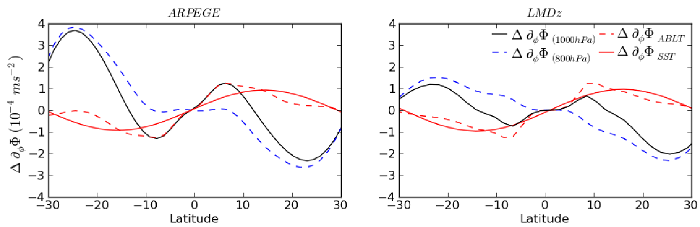
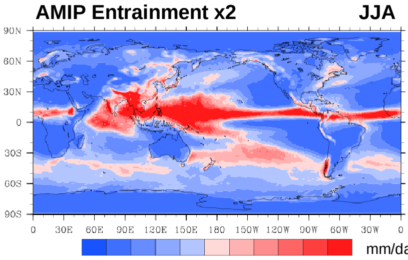
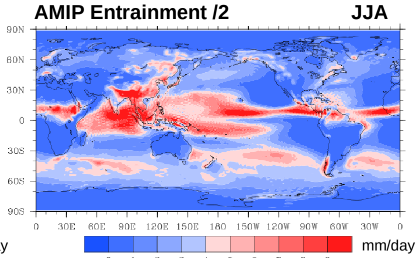
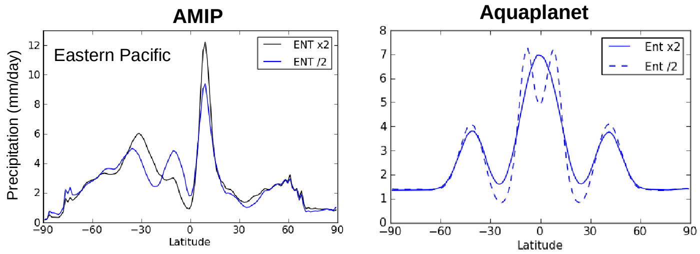


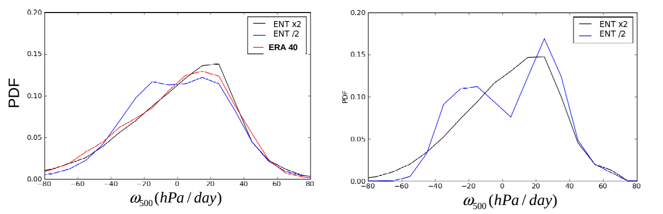
Fig. 4 Difference between the single and double regimes in zonal-mean 1000hPa geopotential gradients, 800hPa geopotential gradients, ABLT gradients and SST gradients.

Sensitivity to the lateral entrainment in ARPEGE









Probability density function of ω_{500} in the tropics (30°S-30°N)

Results

- The double ITCZ problem is removed when the lateral entrainment is doubled.

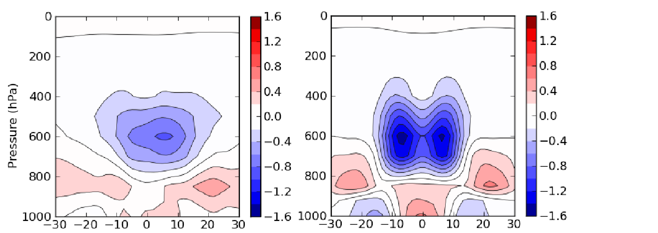
- A change in the dynamical regimes (diagnosed by the midtropospheric vertical velocity) is observed. With doubled entrainment, the frequency of occurrence of subsidence regimes increases, while that of convective ones decreases.

- A deepening of the subtropical ABL is observed when the entrainment is doubled, in response to increased surface turbulent mixing (increased shallow convection and boundary layer clouds).

- Similar responses are observed in the AMIP and Aquaplanet simulations.

General conclusion

The key of a better representation of the ITCZ location is a more constrained convection, either by the inclusion of downdrafts, or by a well defined free tropospheric-stratospheric heating profile associated with convection (Oueslati and Bellon, 2012), or by an appropriate choice of the lateral entrainment…



Difference between the two simulations in zonal-mean specific humidity (g/kg)

References

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