Convective entrainment and large-scale organization of tropical precipitation:

sensitivity of the CNRM-CM5 hierarchy of models

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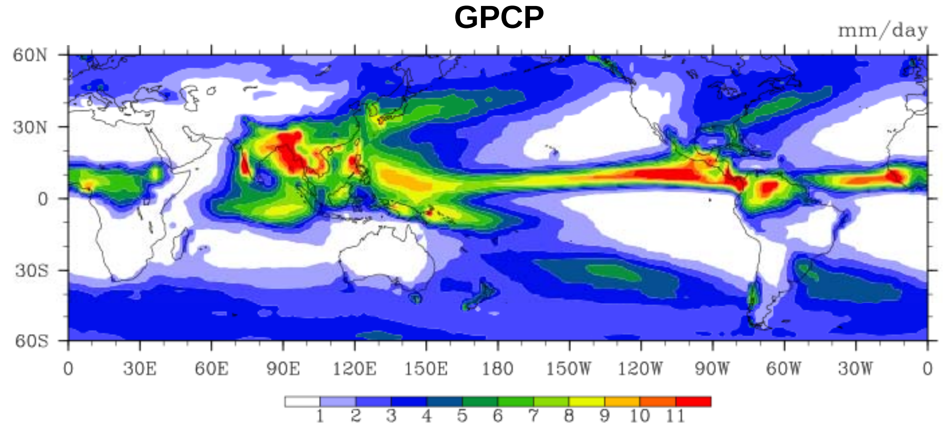
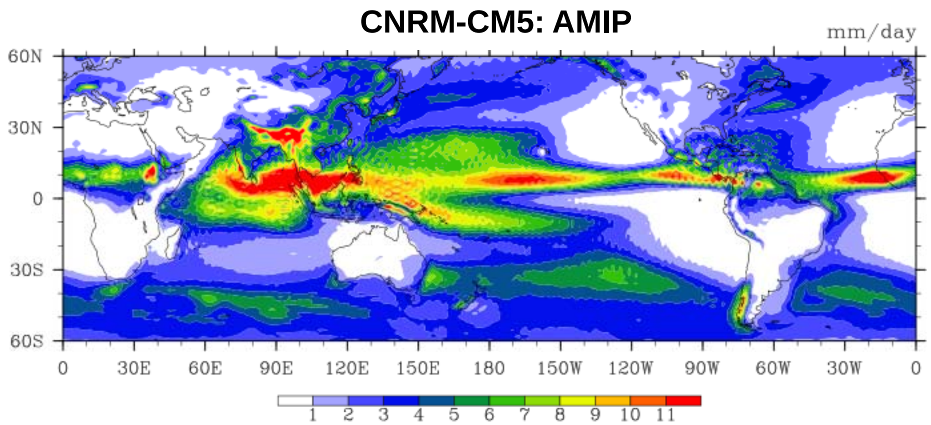
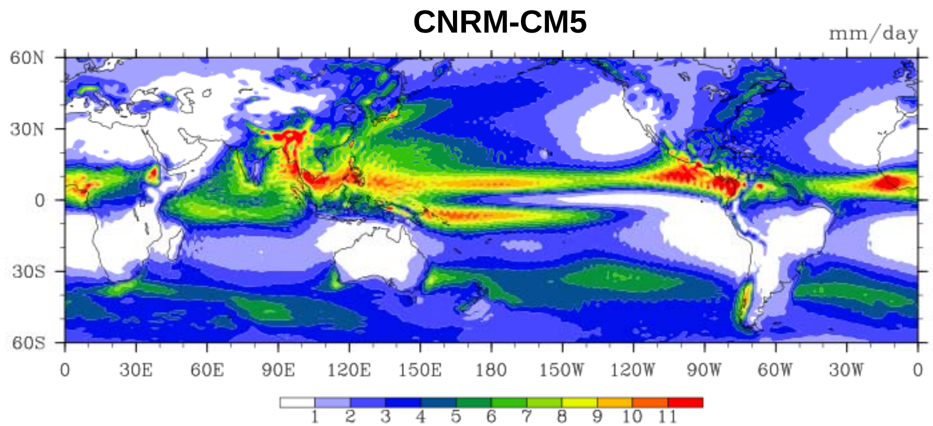
The double ITCZ syndrome

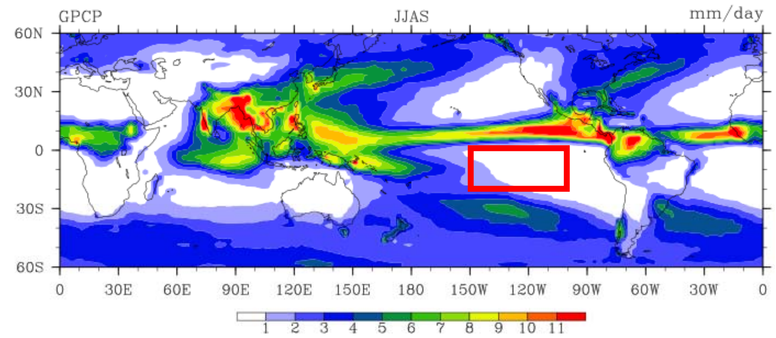
JJAS mean precipitation





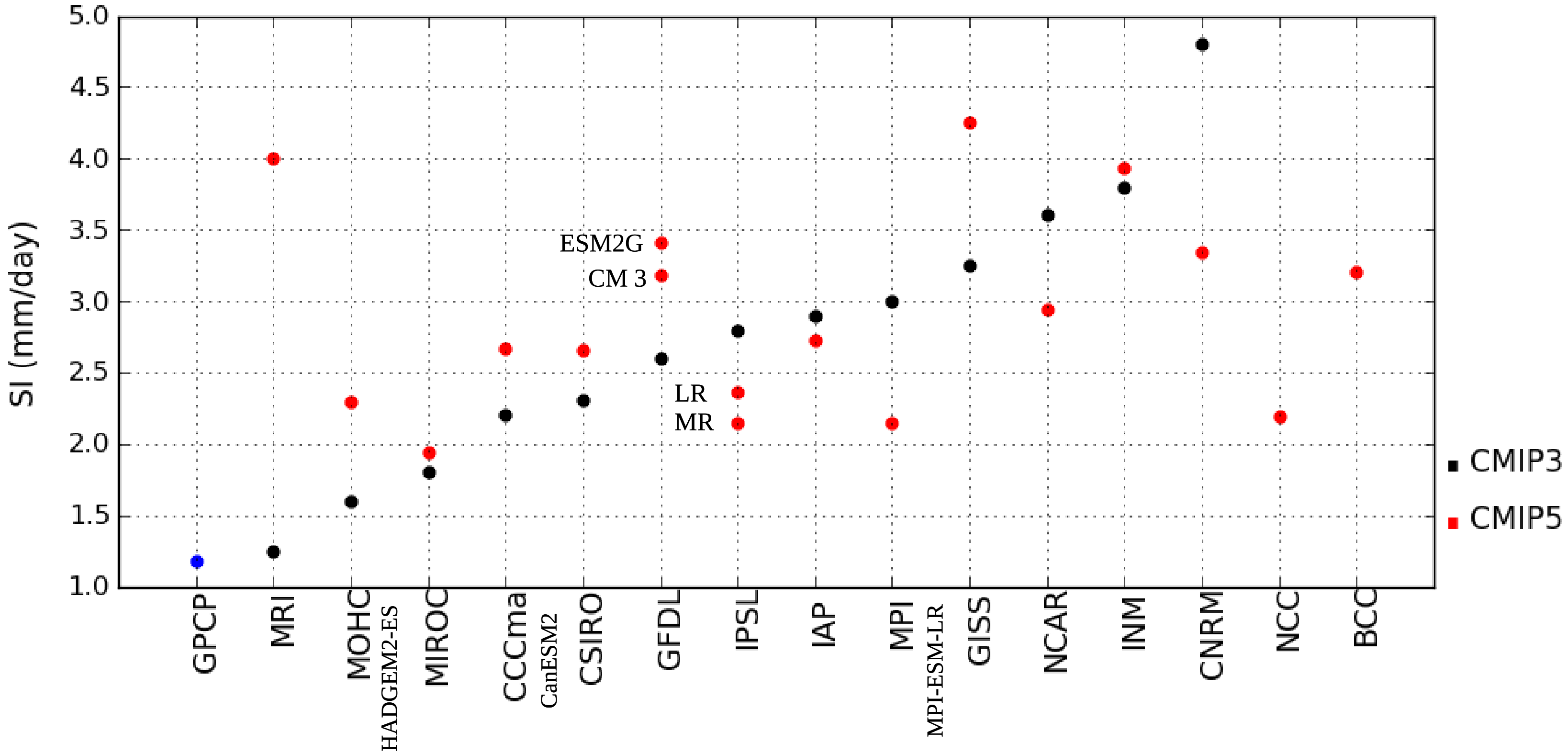


The double ITCZ syndrome: CMIP5 vs CMIP3



The Southern ITCZ index (SI), Bellucci et al. 2010

Annual mean precipitation over the 20S-0, 100W-150W window

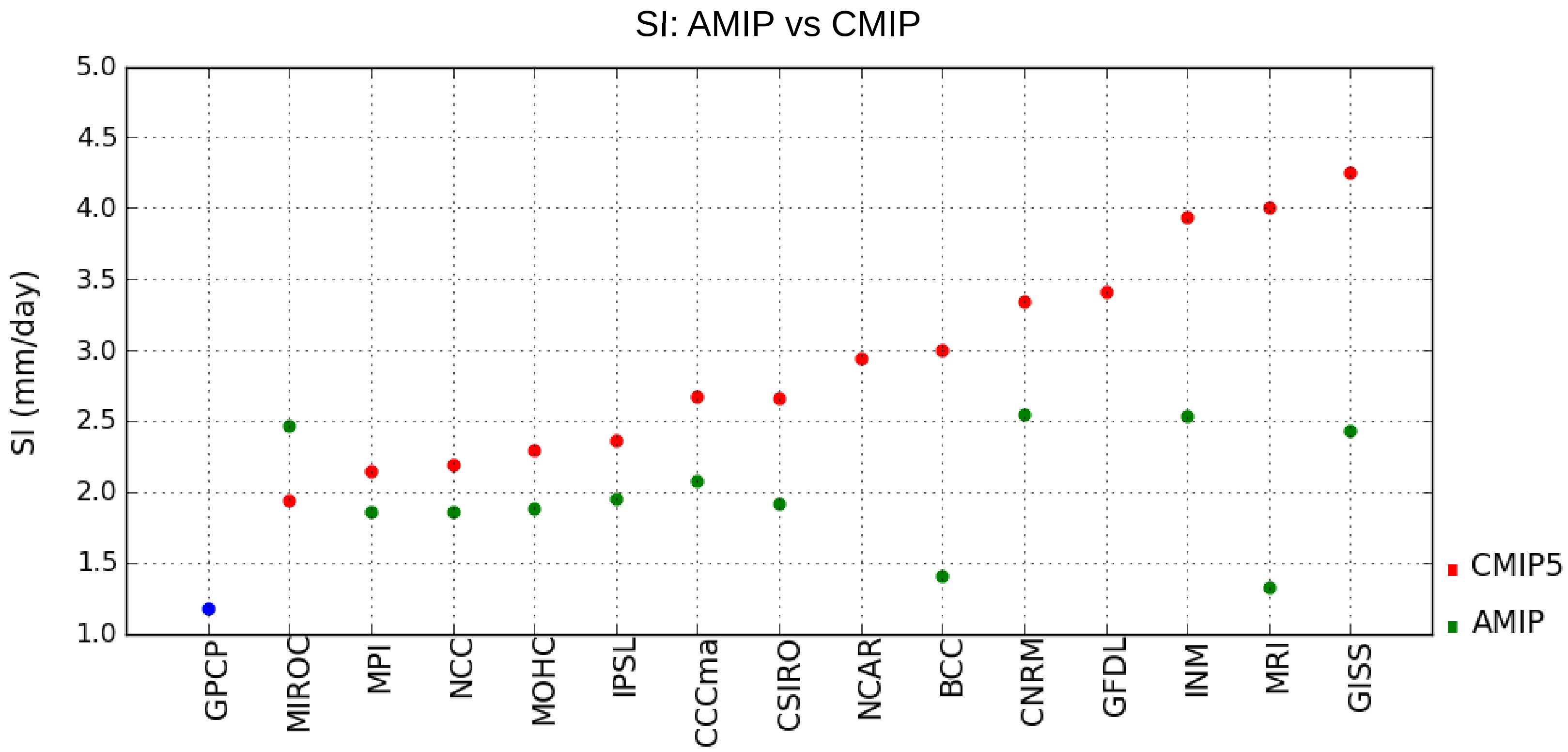


The double ITCZ syndrome: Mechanisms at play

- Role of atmosphere-Ocean feedbacks **(Lin, 2007)**

Erroneous representation of SST distribution in the tropical Pacific ocean, amplified by biases in coupled feedbacks

- Role of intrinsic atmospheric processes **(Schneider, 2002)**



The double ITCZ syndrome: Mechanisms at play

The atmospheric processes controlling the ITCZ location: state-of-the-art

- **The CISK-based mechanisms**
  (Charney, 1971; Holton et al., 1971; Hess et al., 1993; Waliser and Sommerville, 1994)

- **The Wind-Evaporation feedback**
  (Numaguti, 1993)

- **Competing roles of frictional convergence and surface fluxes**
  (Chao and Chen, 2004)

- **Role of ABL temperature gradients in forcing the low-level convergence**
  (Oueslati and Bellon, 2012)

- **Role of cumulus parameterization**
  (Numaguti and Hayashi, 1991; Liu et al., 2009; Song and Zhang, 2009…)

The double ITCZ syndrome: Mechanisms at play

- **Role of cumulus parameterization**

  ❖ **Control via the vertical profile of convective heating** (Oueslati and Bellon, 2012; Bacmeister et al., 2006)

  ❖ **Control via the modulation of moisture-convection feedbacks** (Derbyshire et al., 2004; Del Genio, 2011)

The double ITCZ syndrome: Mechanisms at play

- **Role of cumulus parameterization**

❖ **Control via the vertical profile of convective heating** **(Oueslati and Bellon, 2012; Bacmeister et al., 2006)**

❖ **Control via the modulation of moisture-convection feedbacks** **(Derbyshire et al., 2004; Del Genio, 2011)**

Explore the sensitivity of the ITCZ to lateral entrainment (ε) in the CNRM-CM5 hierarchy of models

(Terray, 1998 ; Chikira, 2010)

- **CMIP**
- **AMIP**
- **Aquaplanet**

- Entrainment parameterization in the CNRM-CM5:

$$\varepsilon = \frac{C}{\min(z, z_{ABL})}$$

- Sensitivity studies:

$\varepsilon \times 2$

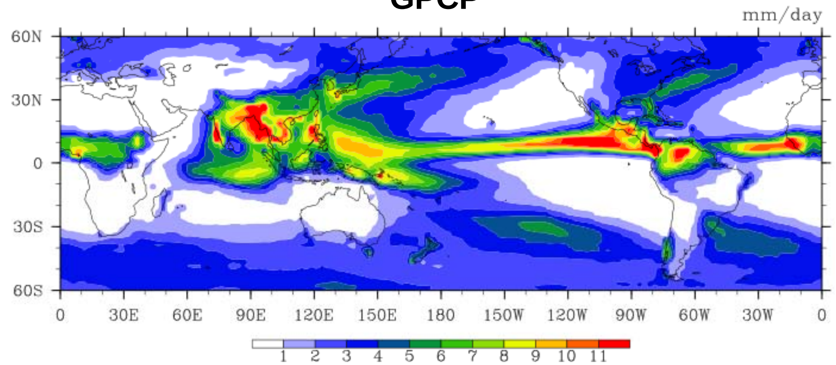
$\varepsilon / 2$

$\varepsilon \times 5$ **(CMIP)**

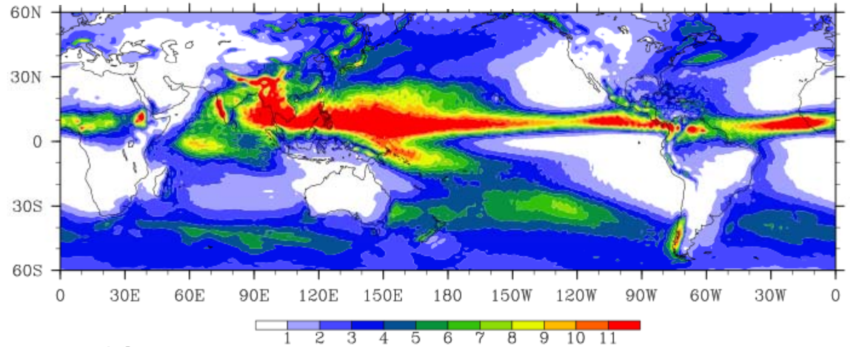
Impact of entrainment on the double ITCZ

JJAS mean precipitation

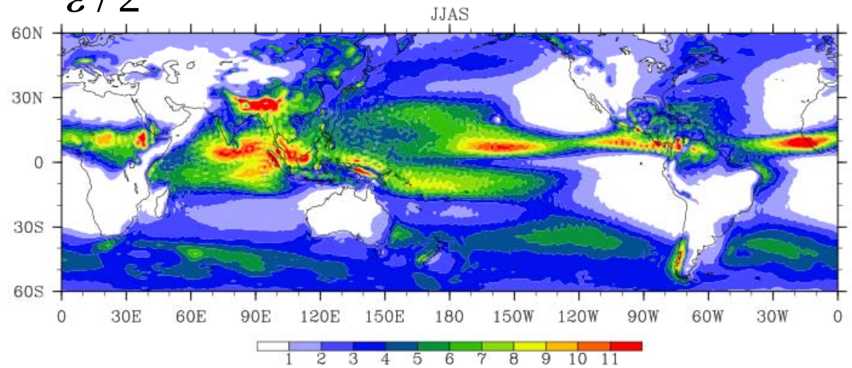
GPCP



$\varepsilon \times 2$ **AMIP**



$\varepsilon / 2$



Impact of entrainment on the double ITCZ

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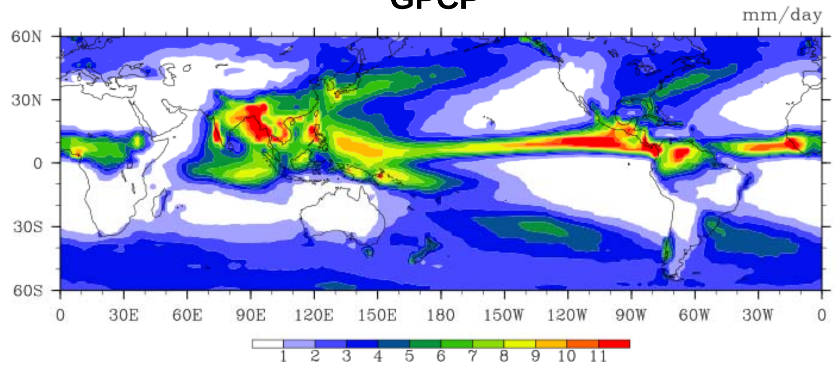
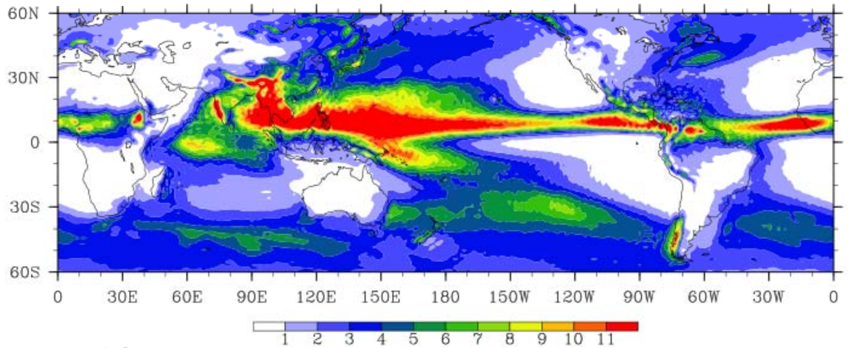
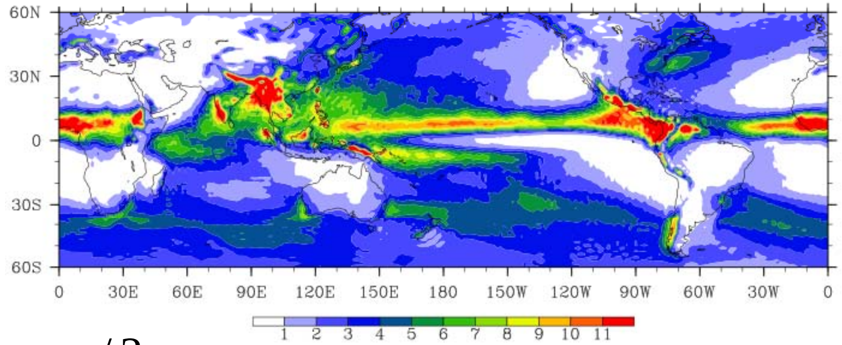


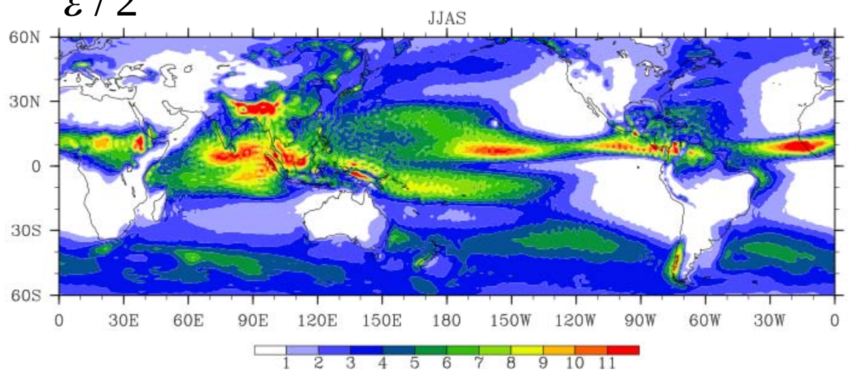
$\varepsilon \times 2$ **AMIP**



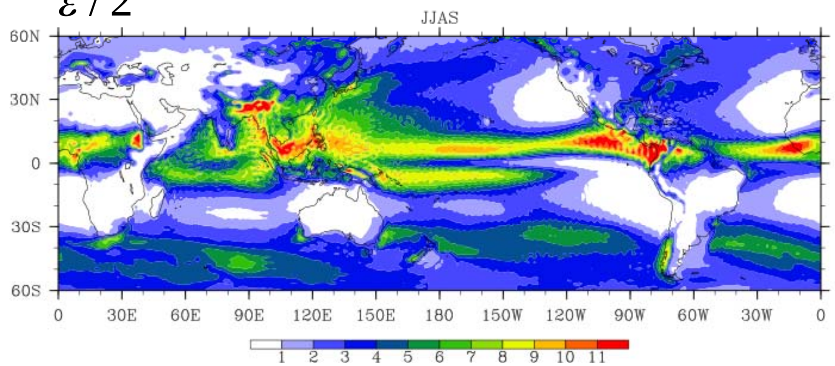
$\varepsilon \times 5$ **CMIP**



$\varepsilon / 2$

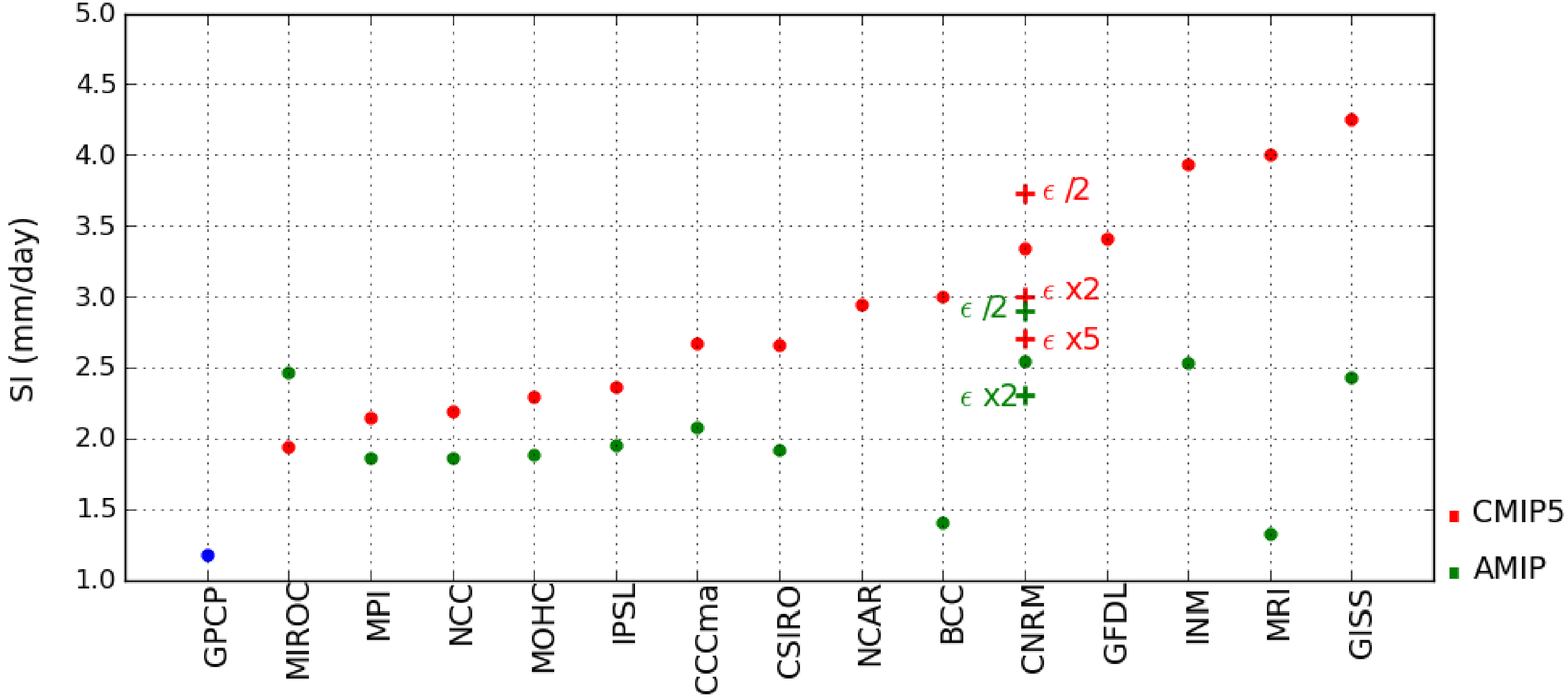


$\varepsilon / 2$



Impact of entrainment on the double ITCZ

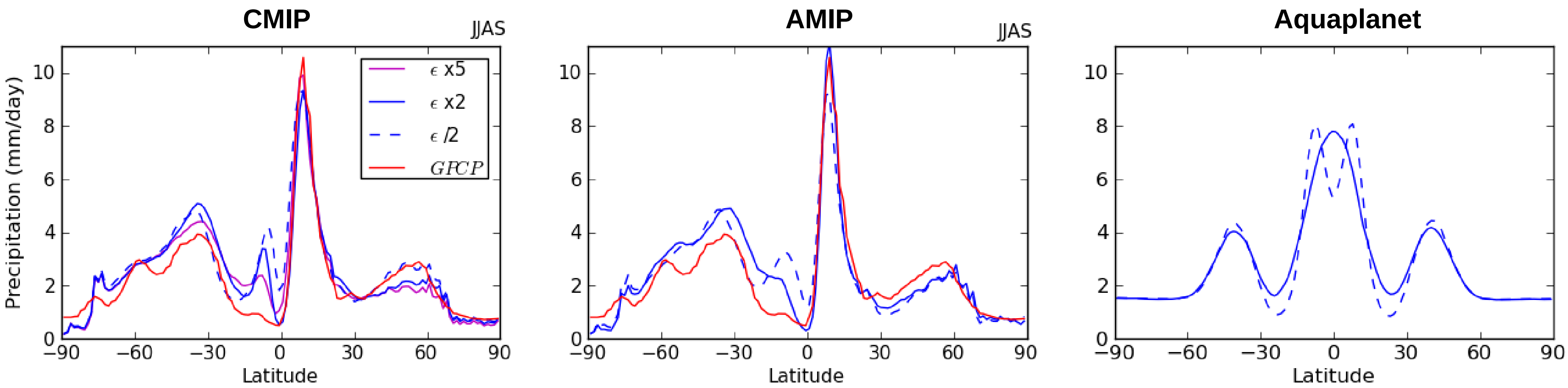
The SI index



Impact of entrainment on the double ITCZ

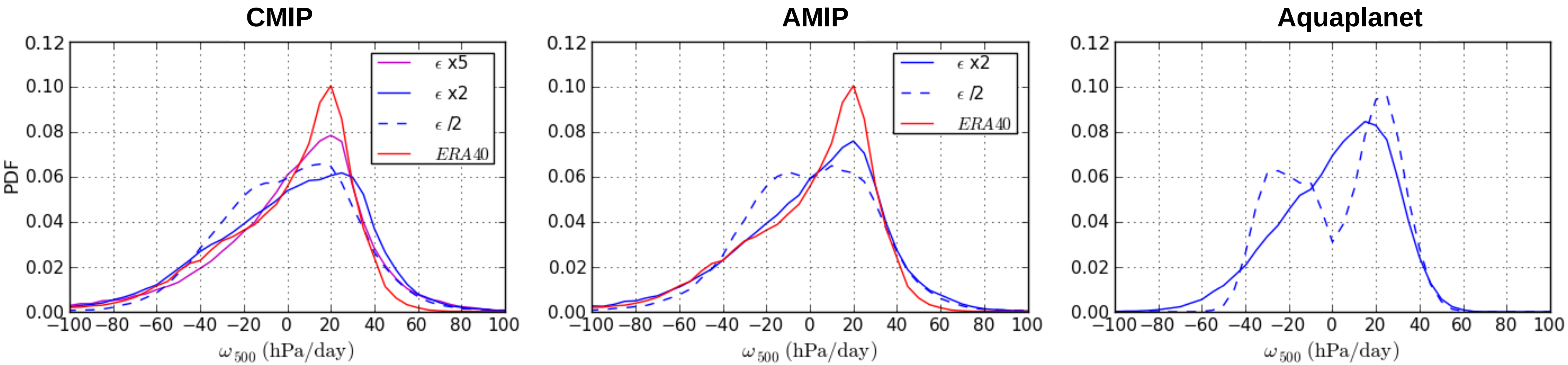
Comparison with the aquaplanet model

CMIP & AMIP: Zonal mean precipitation over central and eastern Pacific
Aquaplanet: Zonal mean precipitation



Impact of entrainment on the tropical circulation

Diagnosing the circulation change by a regime-sorting analysis **(Bony et al., 2004)**



- More realistic PDFs in AMIP $\varepsilon \times 2$ and CMIP $\varepsilon \times 5$

Decreased frequency of weak-to-moderate ascending regimes
Enhanced frequency of shallow convective regimes

- A bimodal PDF in $\varepsilon / 2$ experiments

Impact of entrainment on the tropical circulation

Understanding the PDF shape through an energy bugdet analysis

$$\frac{\partial s}{\partial t} = -\left\langle \omega \frac{\partial s}{\partial p} \right\rangle - \left\langle \vec{V}.\vec{\nabla} s \right\rangle + Q_{cond} + Q_{tur} + Q_r = 0$$

$$\left\langle \omega \frac{\partial s}{\partial p} \right\rangle = -\left\langle \vec{V}.\vec{\nabla} s \right\rangle + Q_{cond} + Q_{tur} + Q_r \quad \times \frac{1}{\left\langle \frac{\partial s}{\partial p} \right\rangle}$$

$$\longrightarrow \omega^s = \omega^s_{advH} + \omega^s_{cond} + \omega^s_{tur} + \omega^s_r$$

Note that:

$$s = c_p T + gz$$

$$\langle A \rangle = \int_0^{p_s} A \frac{dP}{g}$$

$$Q_{cond} = L \times P$$

Impact of entrainment on the tropical circulation

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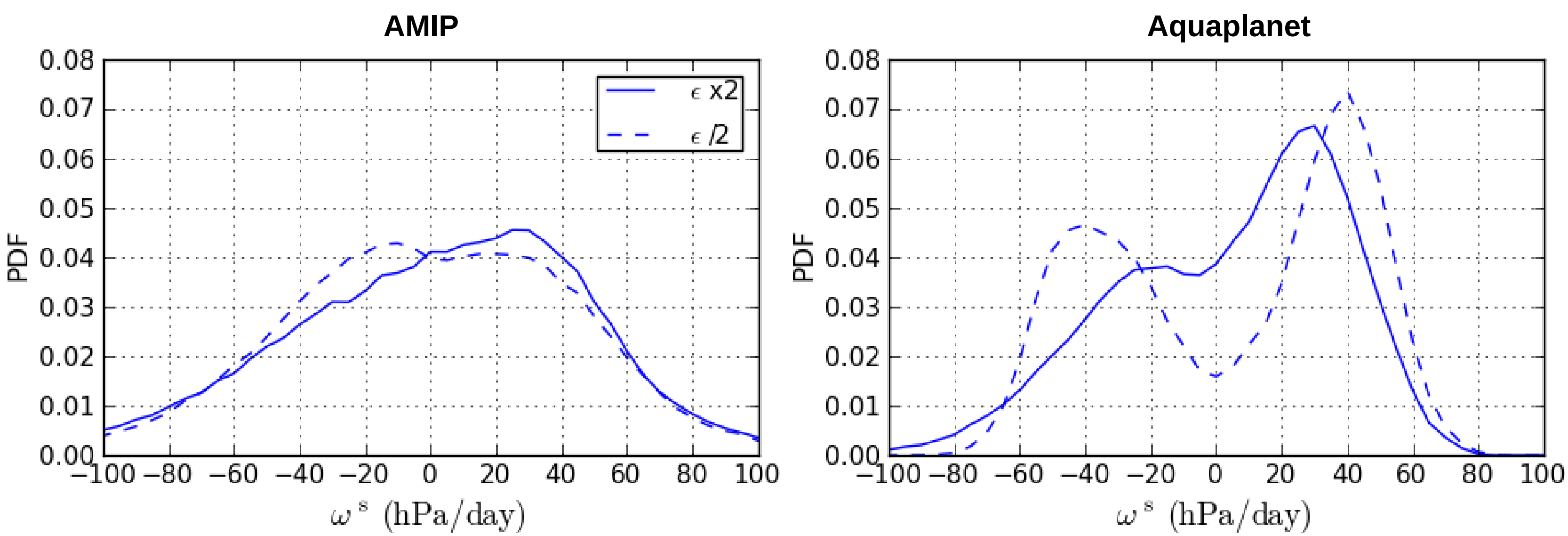


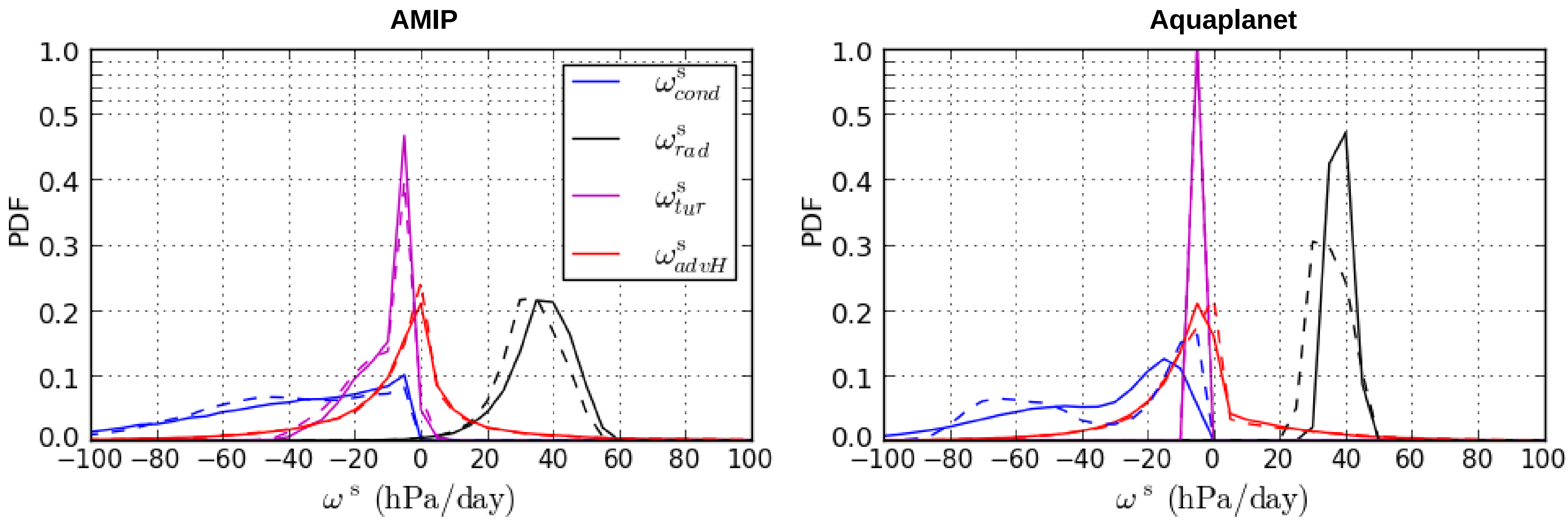
Impact of entrainment on the tropical circulation

Understanding the PDF shape through an energy bugdet analysis

$$\omega^s = \boxed{\omega^s_{advH}} + \boxed{\omega^s_{cond}} + \boxed{\omega^s_{tur}} + \boxed{\omega^s_r}$$

— $\varepsilon \times 2$

-- $\varepsilon / 2$



The bimodality of the PDF results from the bimodality of $\boxed{\omega^s_{cond}}$

The shape of the PDF results from the interaction between Large-scale circulation and Precipitation

Impact of entrainment on the tropical circulation

Convective vs Stratiform contributions

$$\omega^s_{cond} = \boxed{\omega^s_{condC}} + \boxed{\omega^s_{condS}}$$

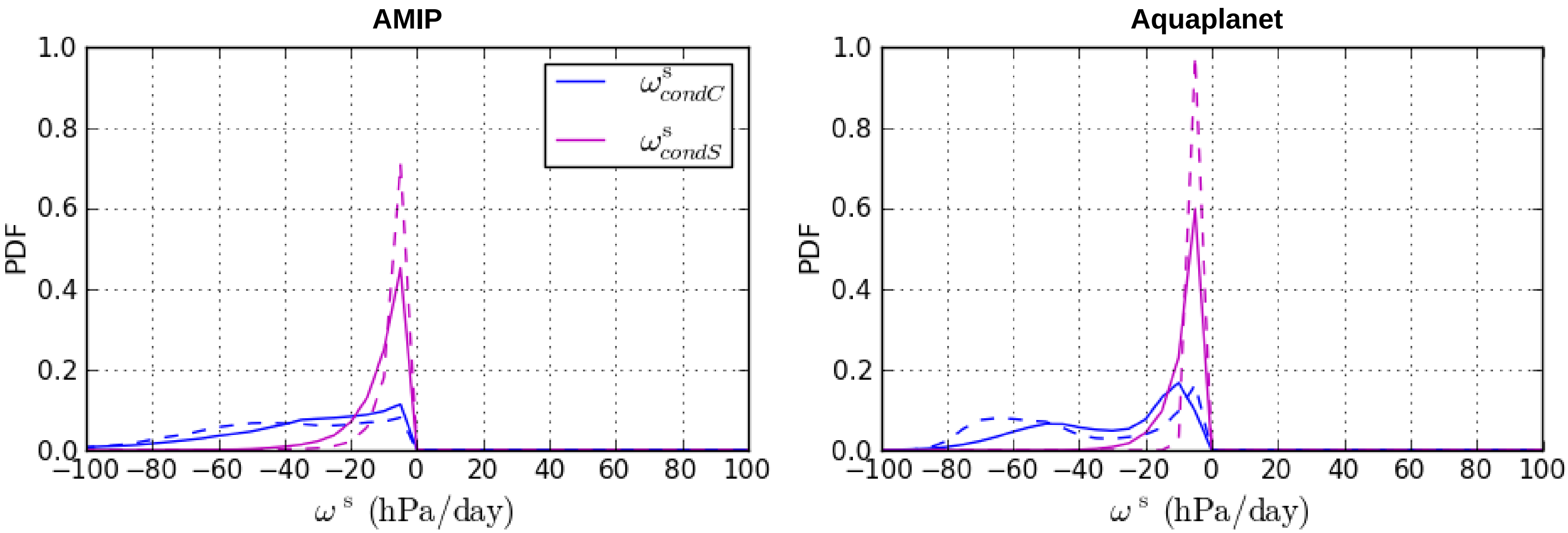
, with

$$\omega^s_{condC} = \frac{L \times P_C}{\left\langle \frac{\partial s}{\partial p} \right\rangle}$$

$$\omega^s_{condS} = \frac{L \times P_S}{\left\langle \frac{\partial s}{\partial p} \right\rangle}$$

— $\varepsilon \times 2$

- - $\varepsilon / 2$



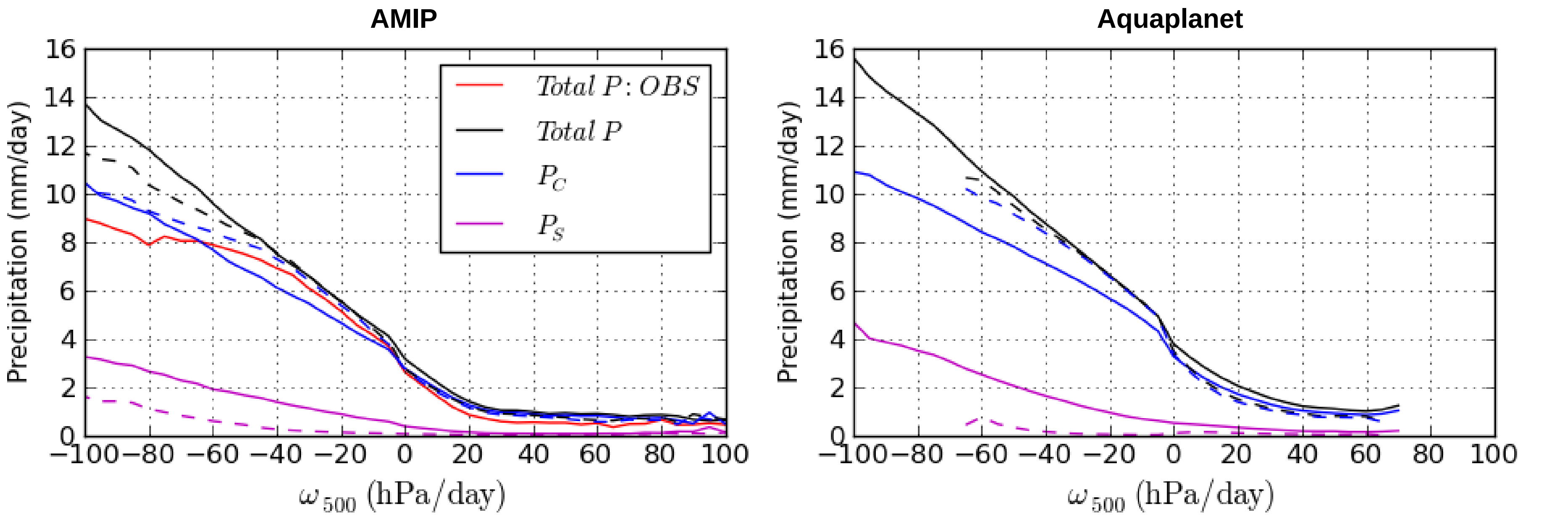
The bimodality of ω^s_{cond} results from the bimodality of ω^s_{condC}

Impact of entrainment on the tropical circulation

Relationship between precipitation and large-scale circulation

— $\varepsilon \times 2$

-- $\varepsilon / 2$

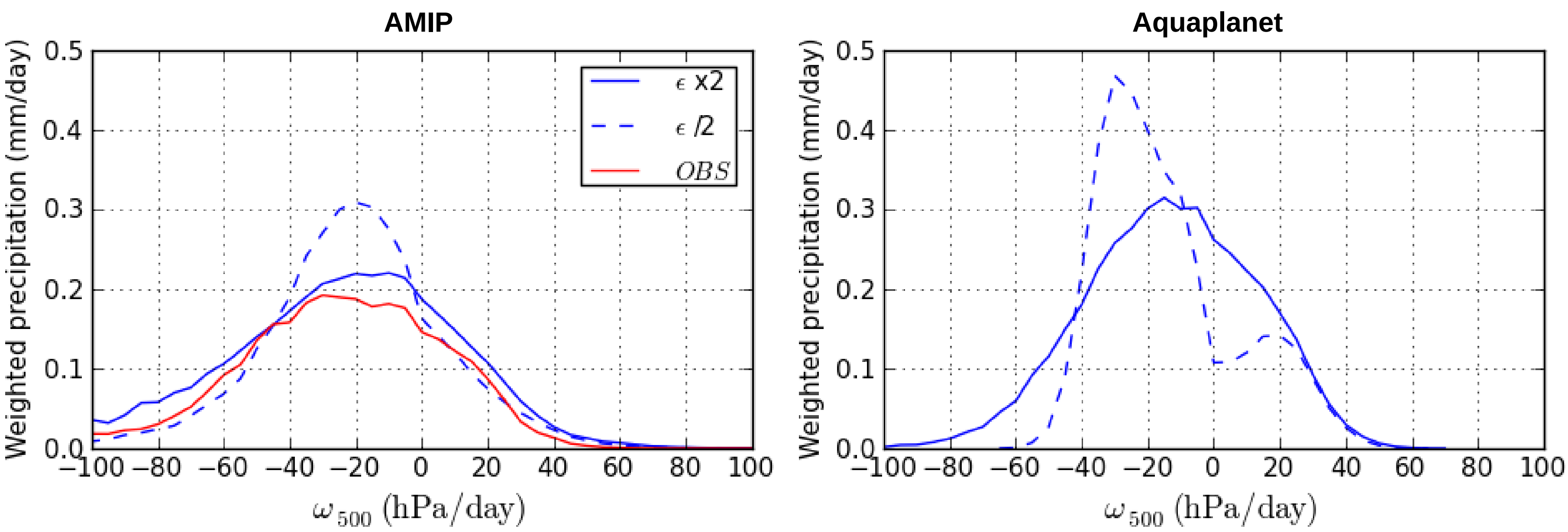


$\omega_{500} < -60hPa/day$ & $0 < \omega_{500} < 20hPa/day$: Overestimated Total P compared to OBS; Total P in $\varepsilon \times 2$ > Total P in $\varepsilon / 2$ — The PDF sets the double ITCZ bias

$\omega_{500} < 0$: Different Pc-Ps partitioning in $\varepsilon \times 2$ and $\varepsilon / 2$

Impact of entrainment on the tropical circulation

Relationship between precipitation and large-scale circulation



$\varepsilon \times 2$ { A more realistic representation of weak-to-moderate ascending regimes
An overestimation of the contribution of strong ascending regimes and subsiding regimes to precipitation

Conclusions

- The sensitivity of the ITCZ structure to entrainment is robust across the hierarchy of models

- The double ITCZ is associated with:

  - A bimodal PDF resulting from feedbacks from large-scale circulation and convective precipitation

    → An enhanced entrainment rate alleviates this bias

  - An error in precipitation magnitude under strong ascending regimes and subsiding regimes

- Ocean-Atmosphere GCM vs Atmosphere-only GCM

Convection inhibition through entrainment needs to be stronger in the coupled model to counteract the amplifying effect of coupled processes on the double ITCZ

Thank you for your attention