Sensitivity of deep convection to free-tropospheric humidity in a hierarchy of models

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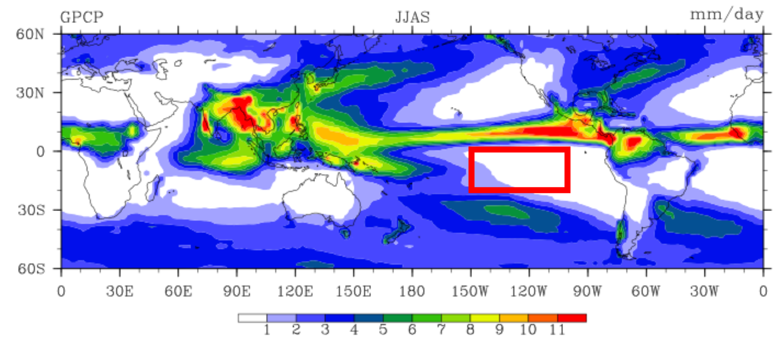
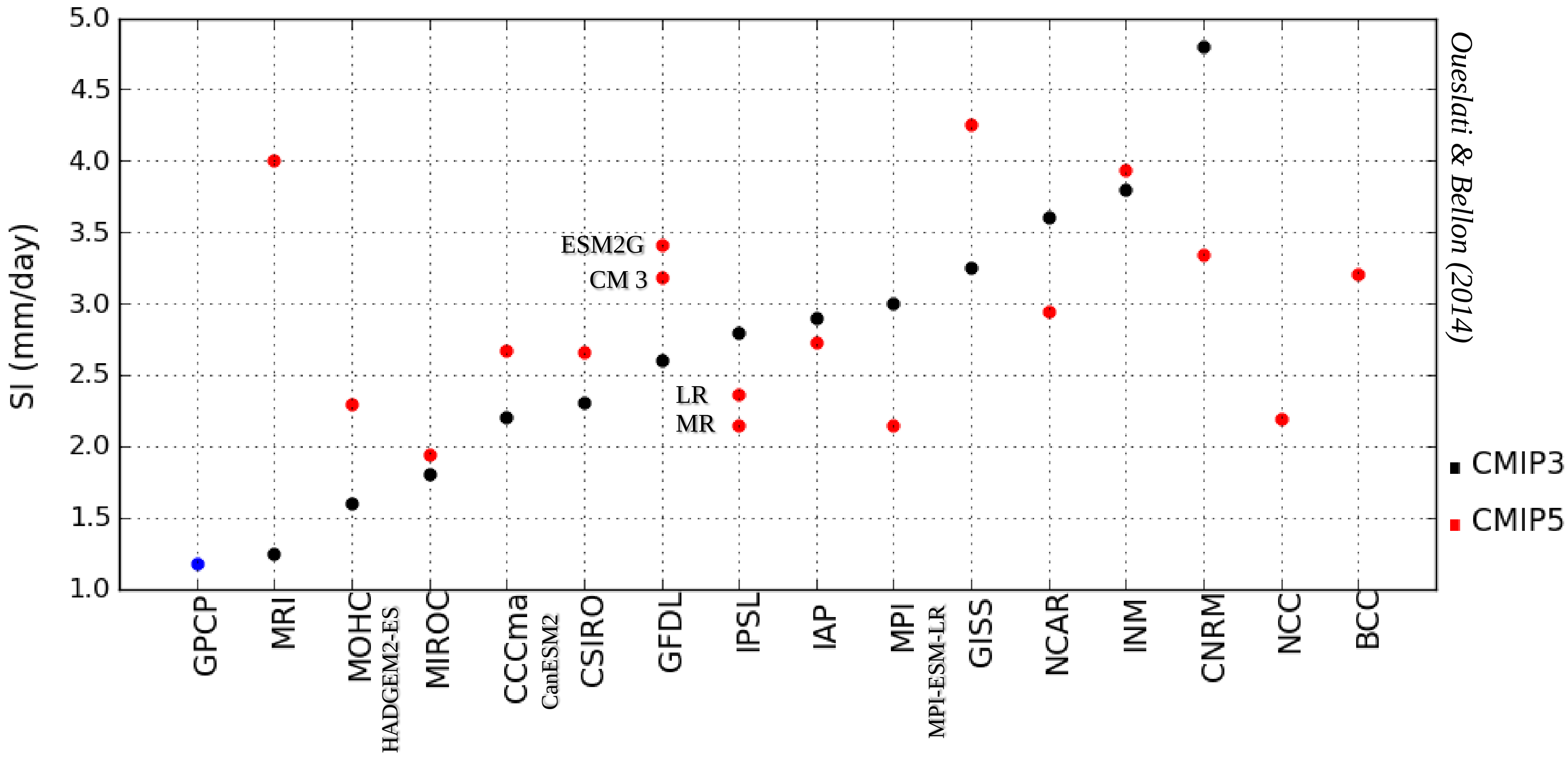
Thanks to Boutheina Oueslati

>Initial motivation: the double ITCZ « syndrome »



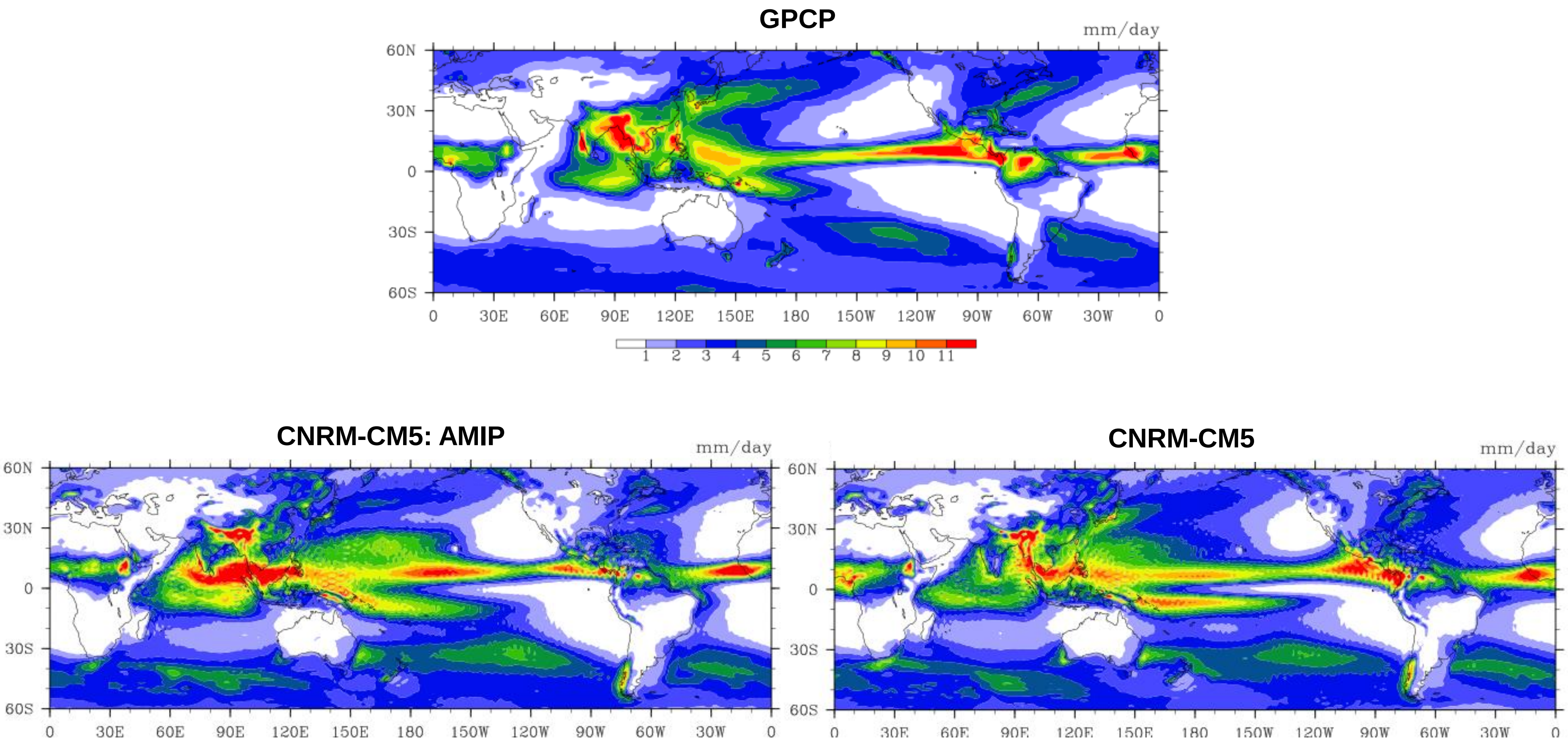
The Southern ITCZ index (SI) *(Bellucci et al. 2010)*

Annual mean precipitation in a box between 20S-0, 100W-150W



The double ITCZ in the CNRM-CM5

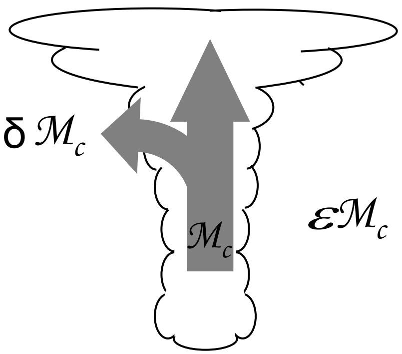
JJAS mean precipitation :



Oueslati & Bellon (2013)

Convective scheme: mass-flux scheme with a closure on the humidity budget (Bougeault, 1985).

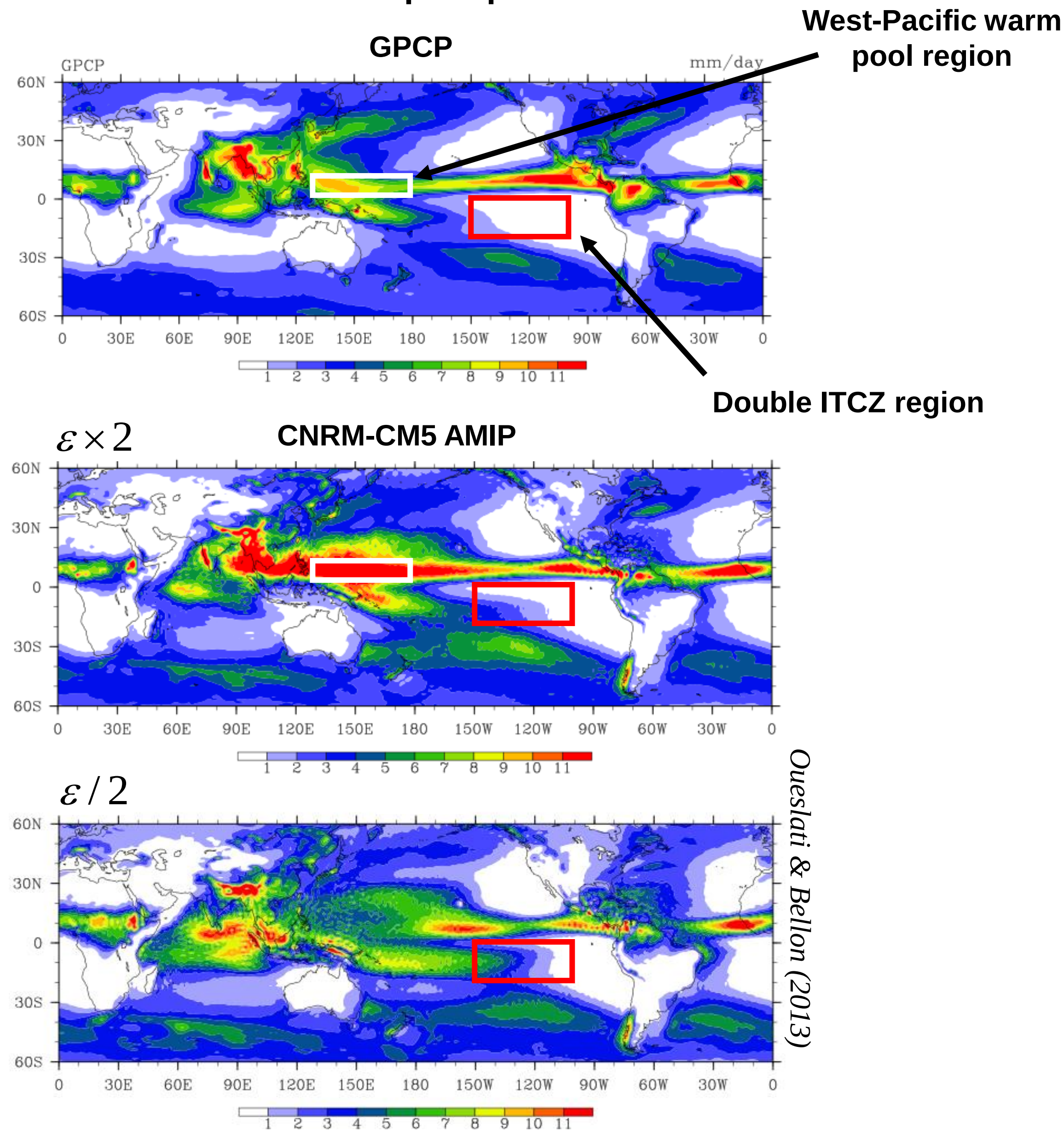
Sensitivity to convective entrainment



$\mathcal{M}_c$ **convective mass flux**

ε fractional entrainment

JJAS mean precipitation:

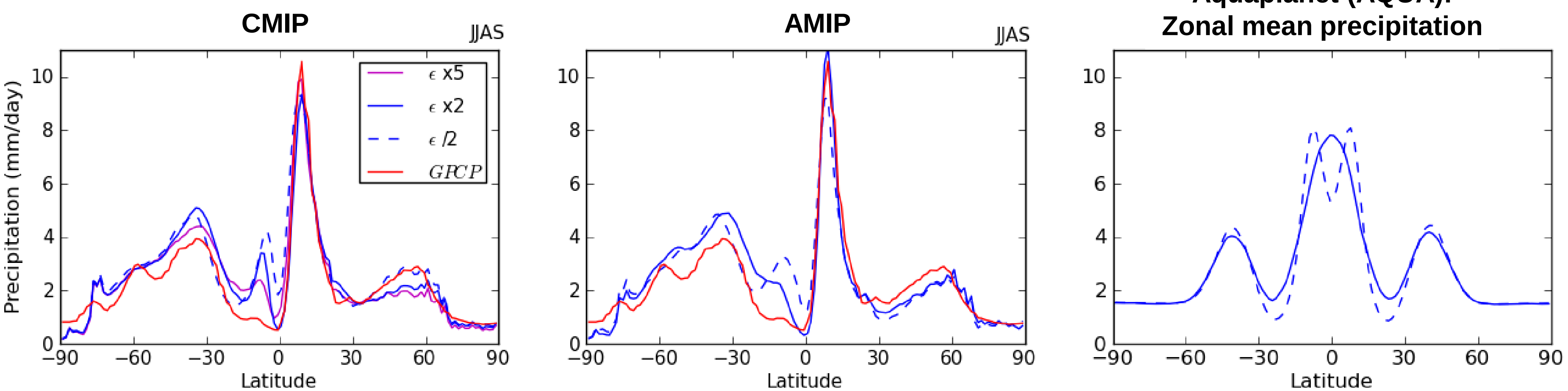


Sensitivity to convective entrainment

Similar sensitivity from coupled ocean-atmosphere to aquaplanet simulations:

Zonal mean precipitation over central and eastern Pacific :

Aquaplanet (AQUA):
Zonal mean precipitation

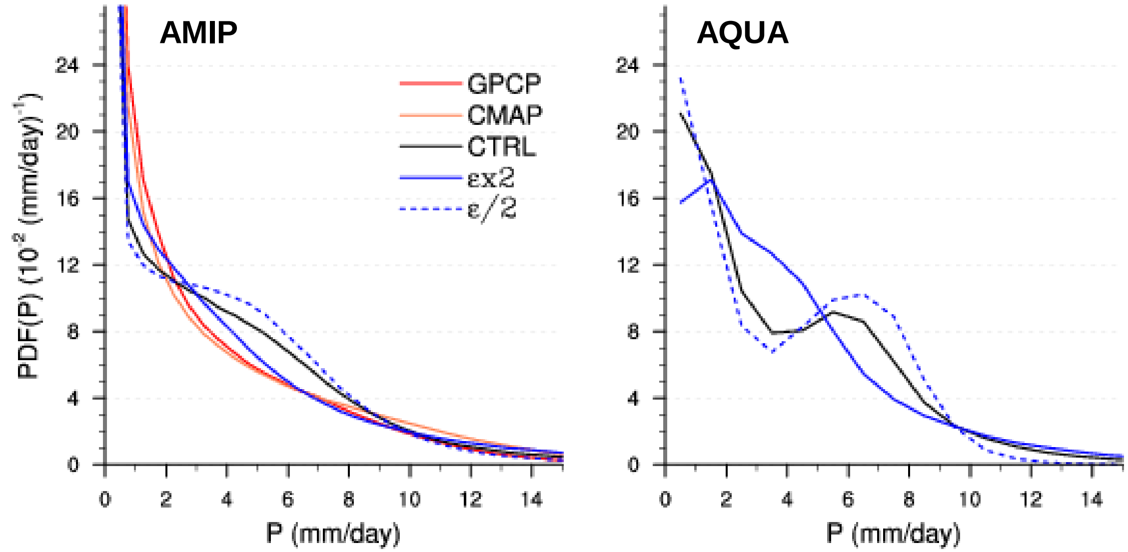


Oueslati & Bellon (2013)

Change in PDFs of precipitation and vertical motion

The change in geographical patterns of precipitation is associated to a change in the distribution of precipitation intensity …

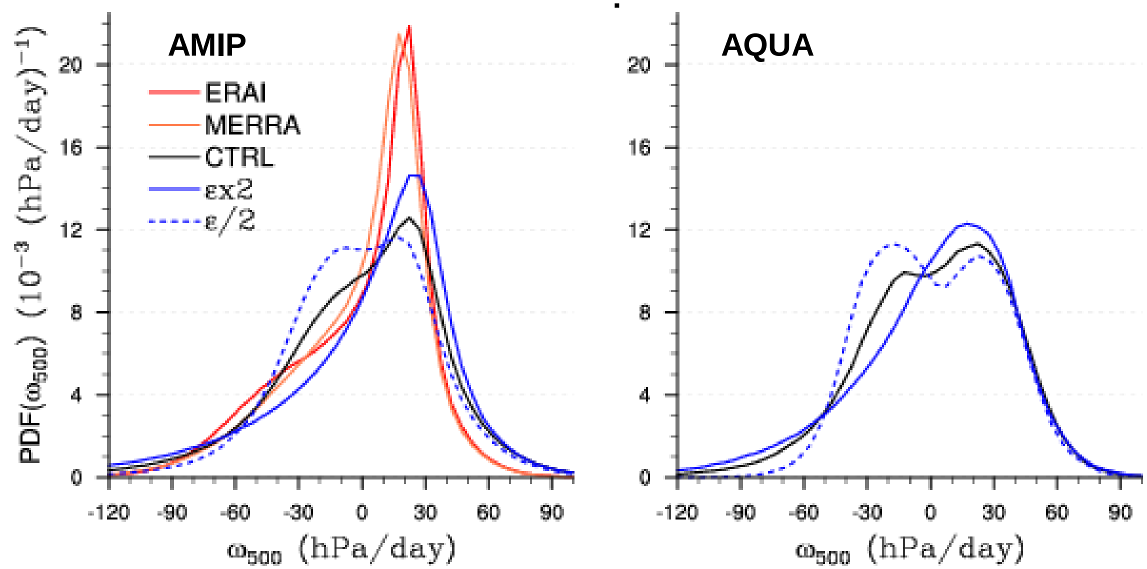
Global PDF of monthly-mean precipitation:



… and in the circulation

as shown by a regime-sorting analysis *(Bony et al., 1998)*

Global PDF of monthly-mean pressure velocity ω_{500} at 500 hPa :

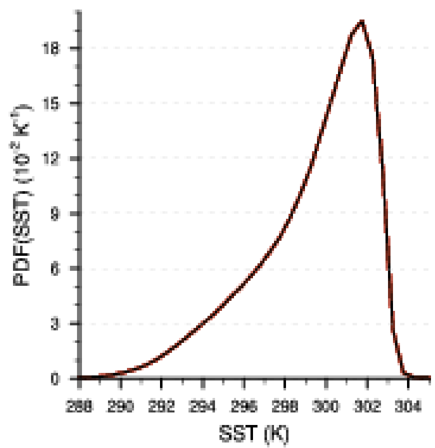


Remark on bimodal PDF

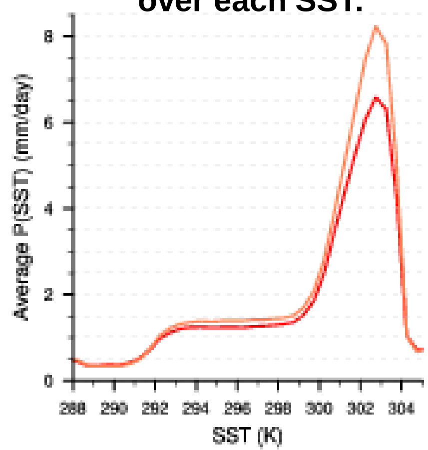
Hypothesizing that the precipitation (or vertical motion) is exclusively a function of SST yields a bimodal PDF of precipitation (or vertical speed) over the ocean.

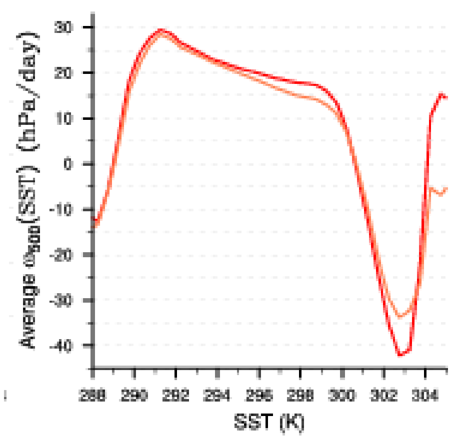
$$P = \mathrm{P}(T_S) \Rightarrow PDF(\mathrm{P}(T_S)) = \frac{PDF(T_S)}{\left| {d\mathrm{P}}/{dT_S} \right|} \qquad \textbf{(H0)}$$

PDF of SST:

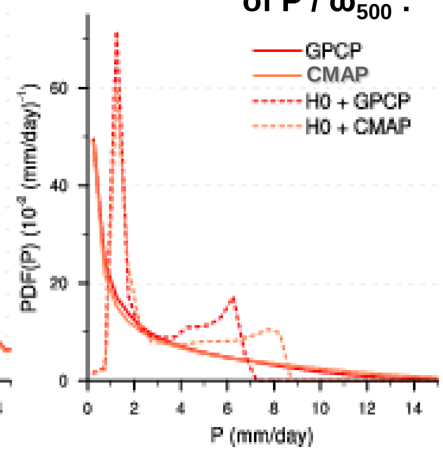


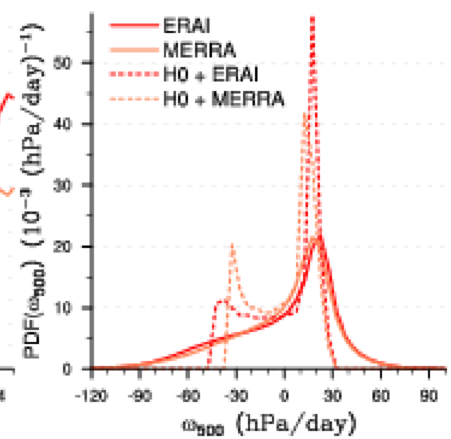
Average P / ω_{500} over each SST:





Reconstructed PDF of P / ω_{500} :



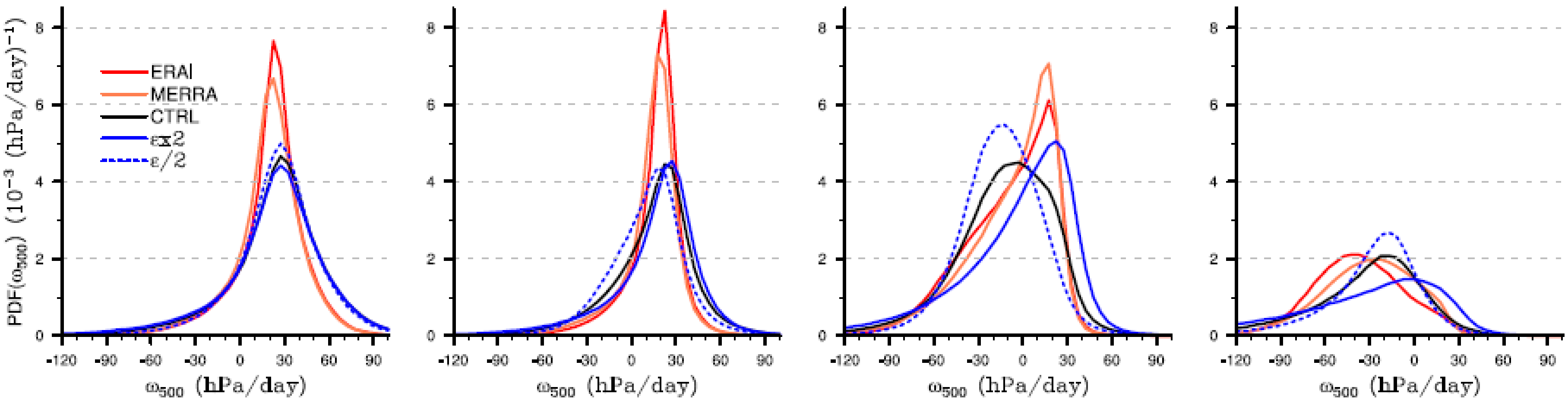


Unimodal PDF and contribution from warm and cool waters

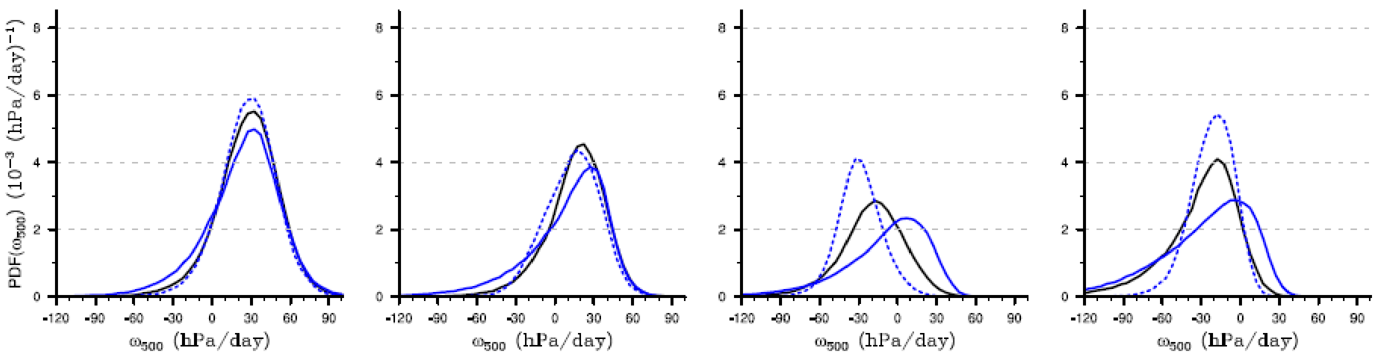
The unimodality results from the transition to ascent for a warm SST threshold and the spread of vertical motion (or precipitation) over warm SSTs

Contributions of SST intervals to the PDF of ω_{500} (AMIP):

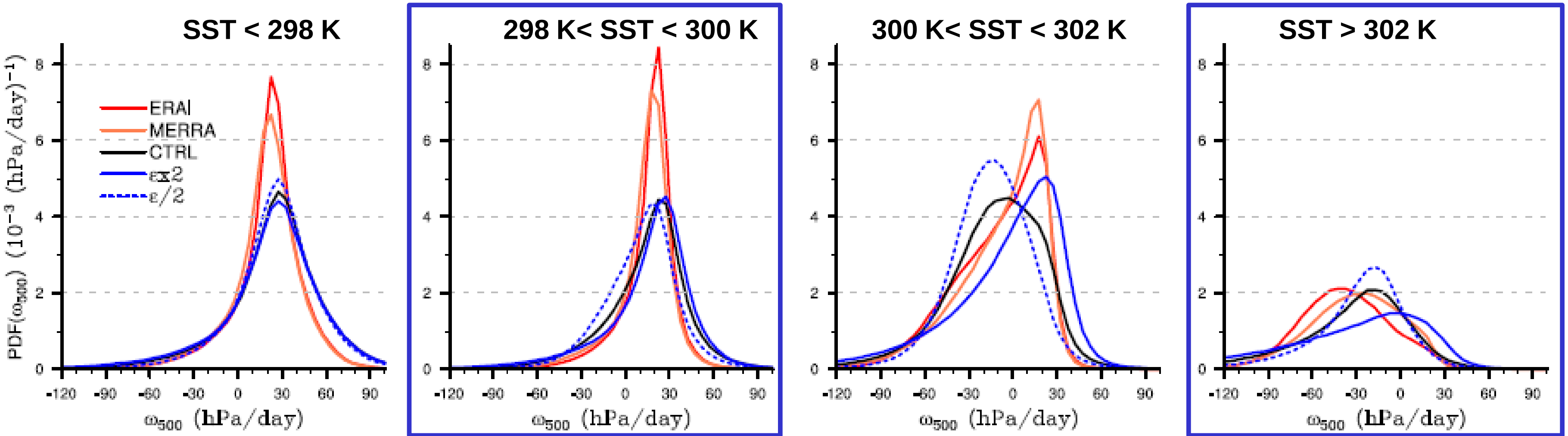
SST < 298 K | **298 K< SST < 300 K** | **300 K< SST < 302 K** | **SST > 302 K**



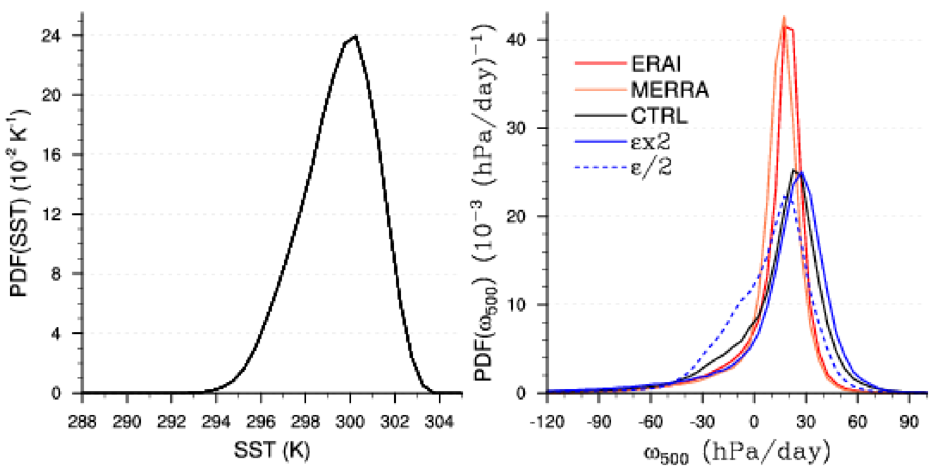
Similar behavior in aquaplanet simulations:



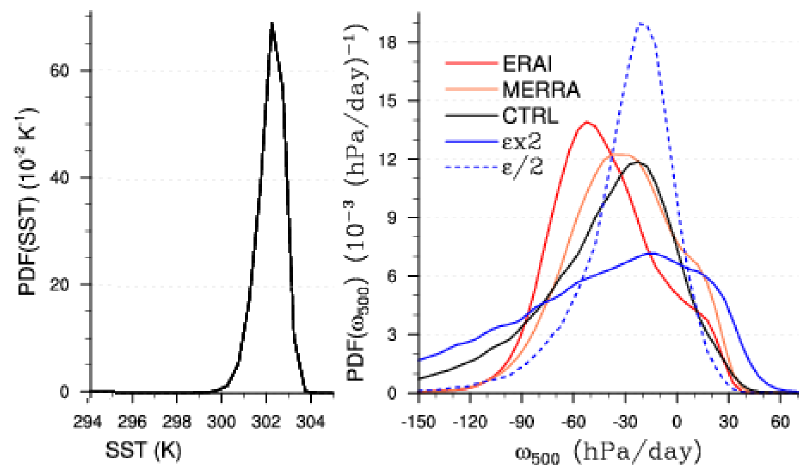
Regional PDFs



Double ITCZ region:

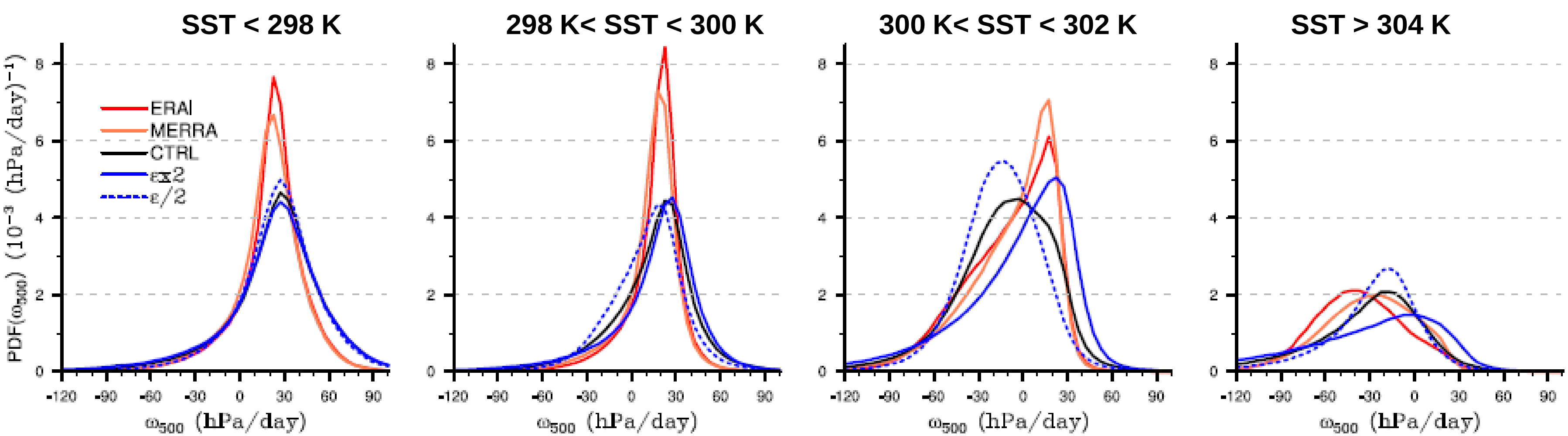


West-Pacific warm pool region:

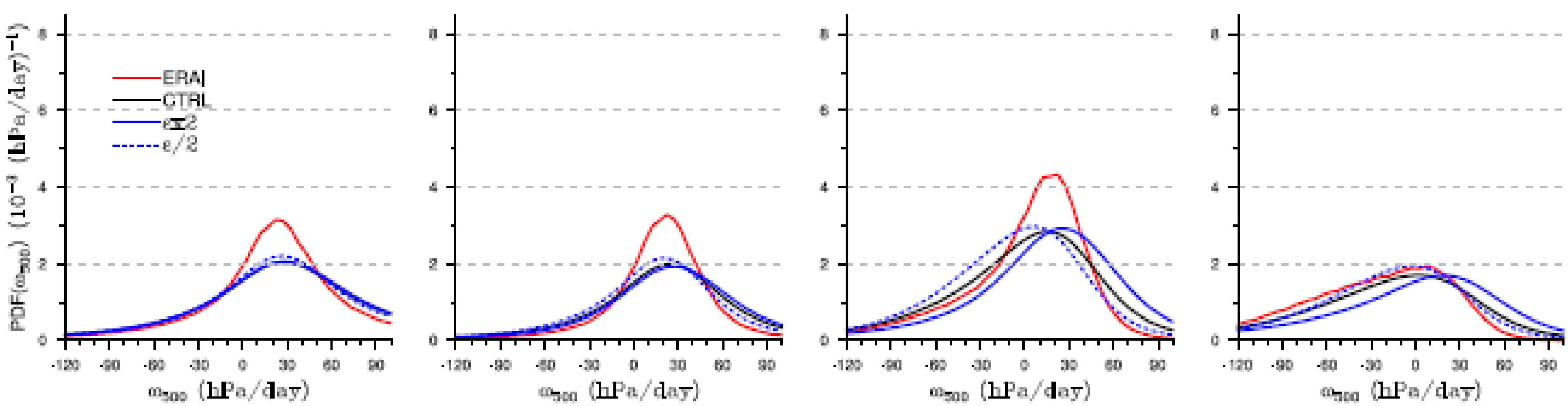


Sensitivity of the PDF to the averaging time scale

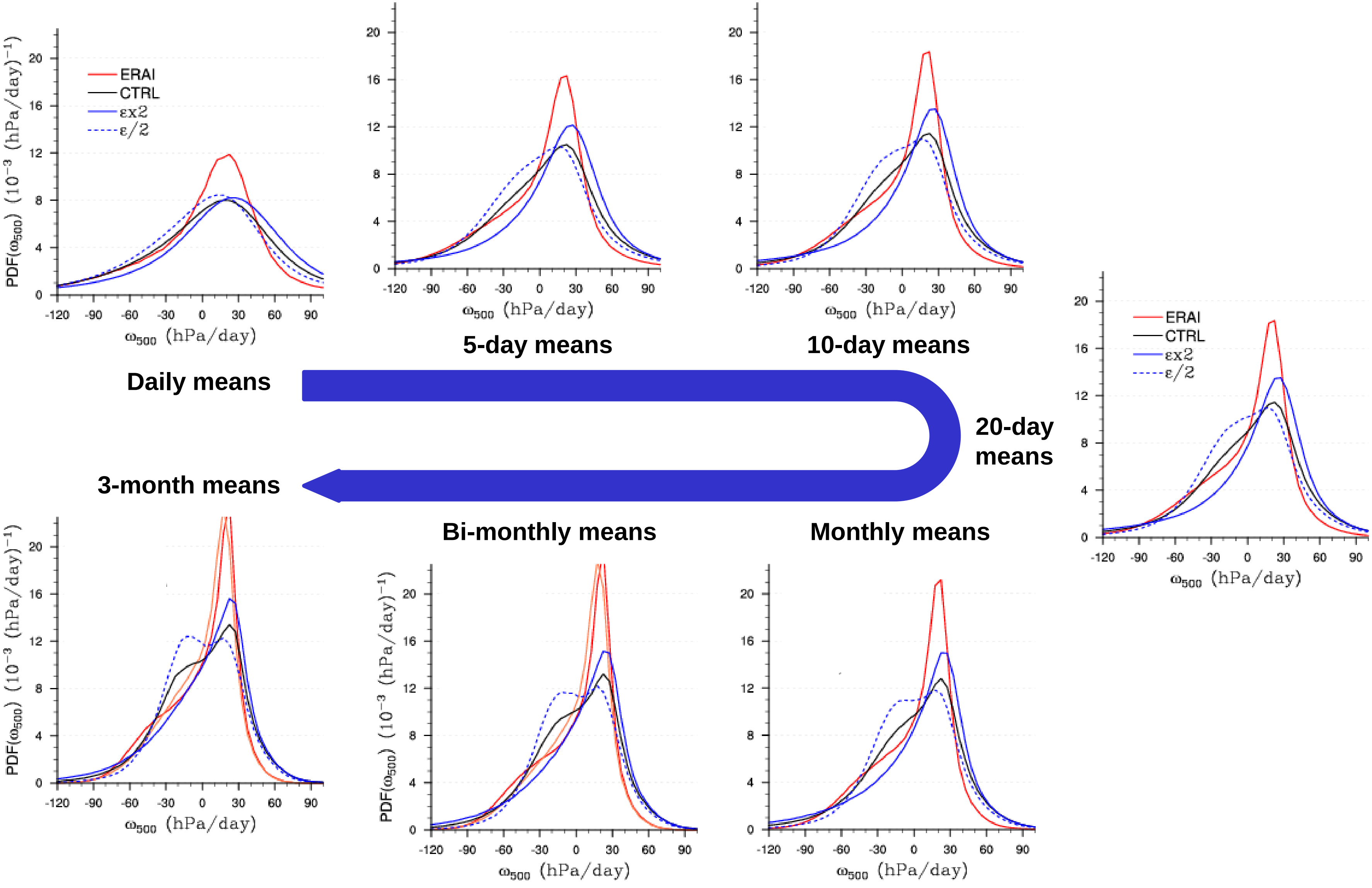
Monthly means:



Daily means:



Sensitivity of the PDF to the averaging time scale



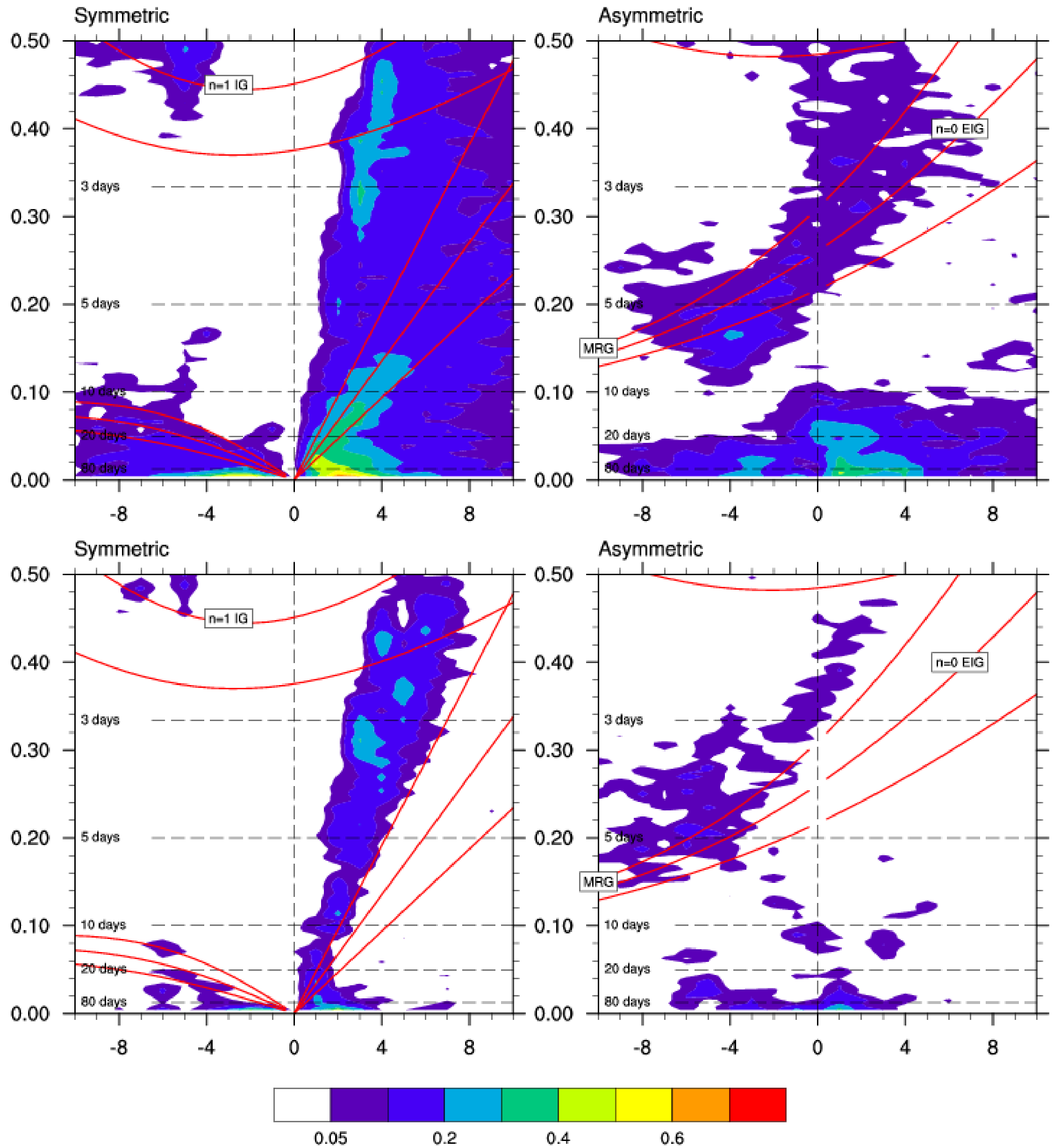
The bimodality arises when averaging over synoptic and intraseasonal scales

Subseasonal variability at the equator

Coherence spectra:

$\varepsilon \times 2$

$\varepsilon / 2$



Summary

- In the reanalysis, the model transitions from subsidence to ascent at a warm SST threshold, and it has a most-likely moderately-ascending regime for SSTs warmer than this threshold.

- In the case with small entrainment, the model transitions from subsidence to ascent at a low SST threshold, and it has a markedly-preferred, weakly-ascending regime not very sensitive to SST for SSTs warmer than this threshold.

- In the case with large entrainment, the PDF of ω_{500} is maximum for subsidence for all SSTs; the PDF has a long tail for warm SSTs, including very fast ascent.

- Energy budgets and equivalent results using precipitation instead of vertical speed suggest that the uni/bimodality results from an interaction between convection and vertical transport.

SCM with the Damped gravity wave approximation *Kuang(2008)*

Linearized, non-rotating primitive equations:

$$\begin{cases} \partial_t u = -\partial_x \Phi - \varepsilon u \\ \partial_x u + \partial_p \omega = 0 \\ \partial_p \Phi = -\dfrac{RT_v}{p} \end{cases}$$

In steady state, with a base state of rest with temperature profile T_{vr} **:**

$$\boxed{\varepsilon\, \partial_p^2 \omega = \frac{R}{p} k^2 (T_v - T_{vr})}$$

ω is used to compute :

- **vertical transport in the budgets of energy, humidity, and momentum.**
- **horizontal divergent advection for humidity from reference profile** q_{vr} **.**

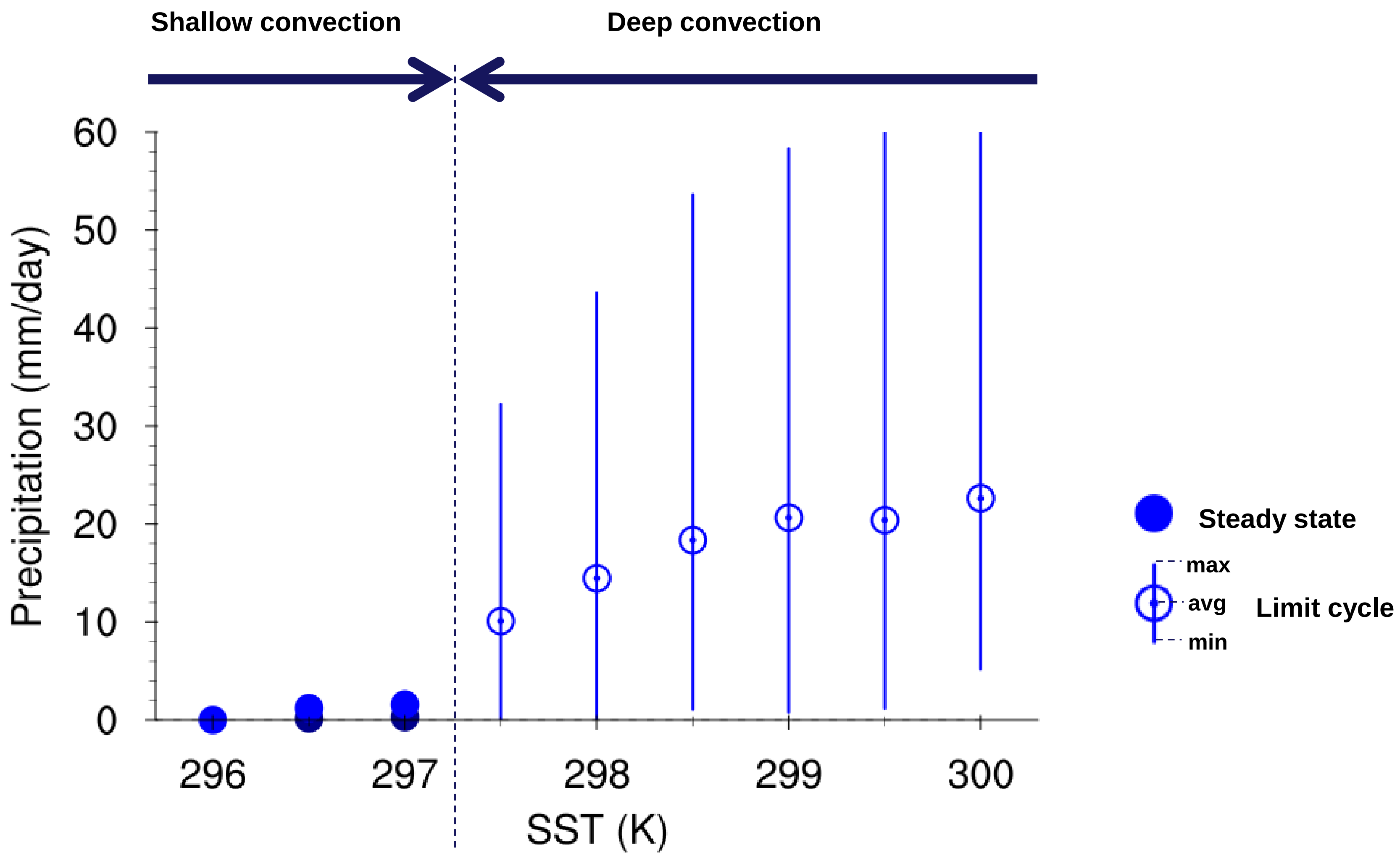
T_{vr}, q_{vr} **: mean tropical (30S-30N) profiles from aquaplanet simulation.**

ε **= 1 day^{-1}**

k **= 10^{-6} m^{-1}**

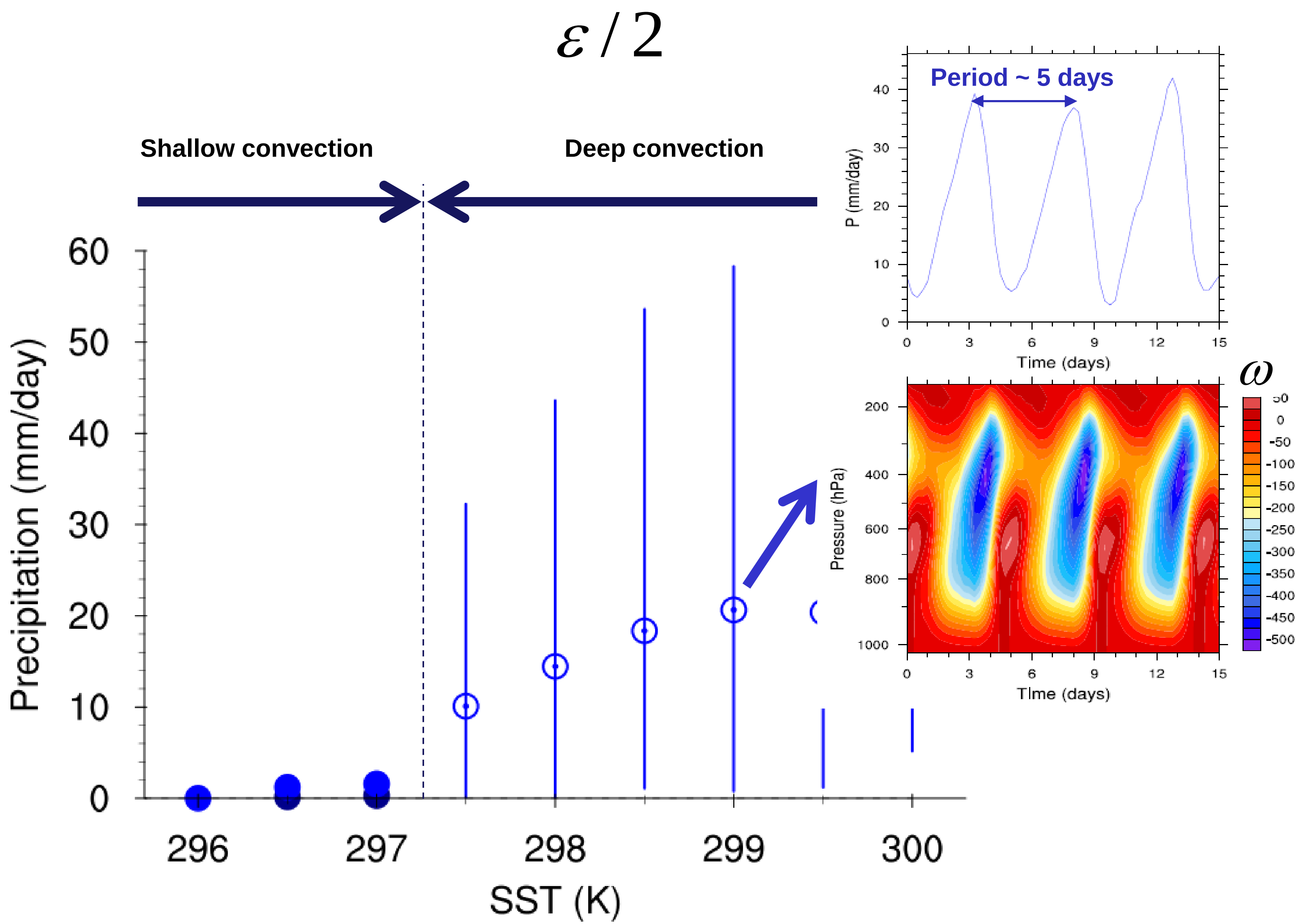
DGW-SCM with weak entrainment

$$\varepsilon / 2$$

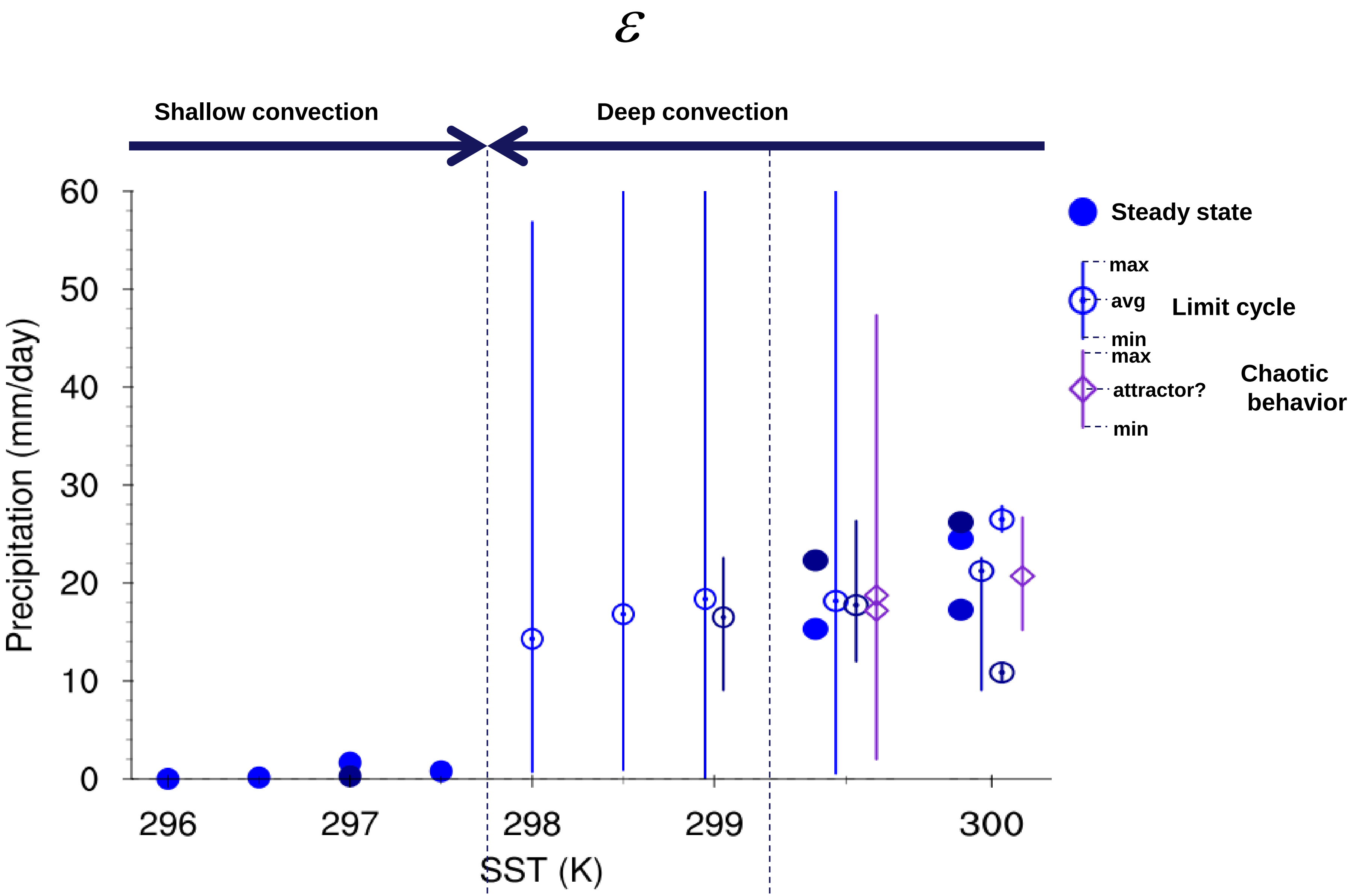


297 K< T_C< 297.5 K

DGW-SCM with weak entrainment



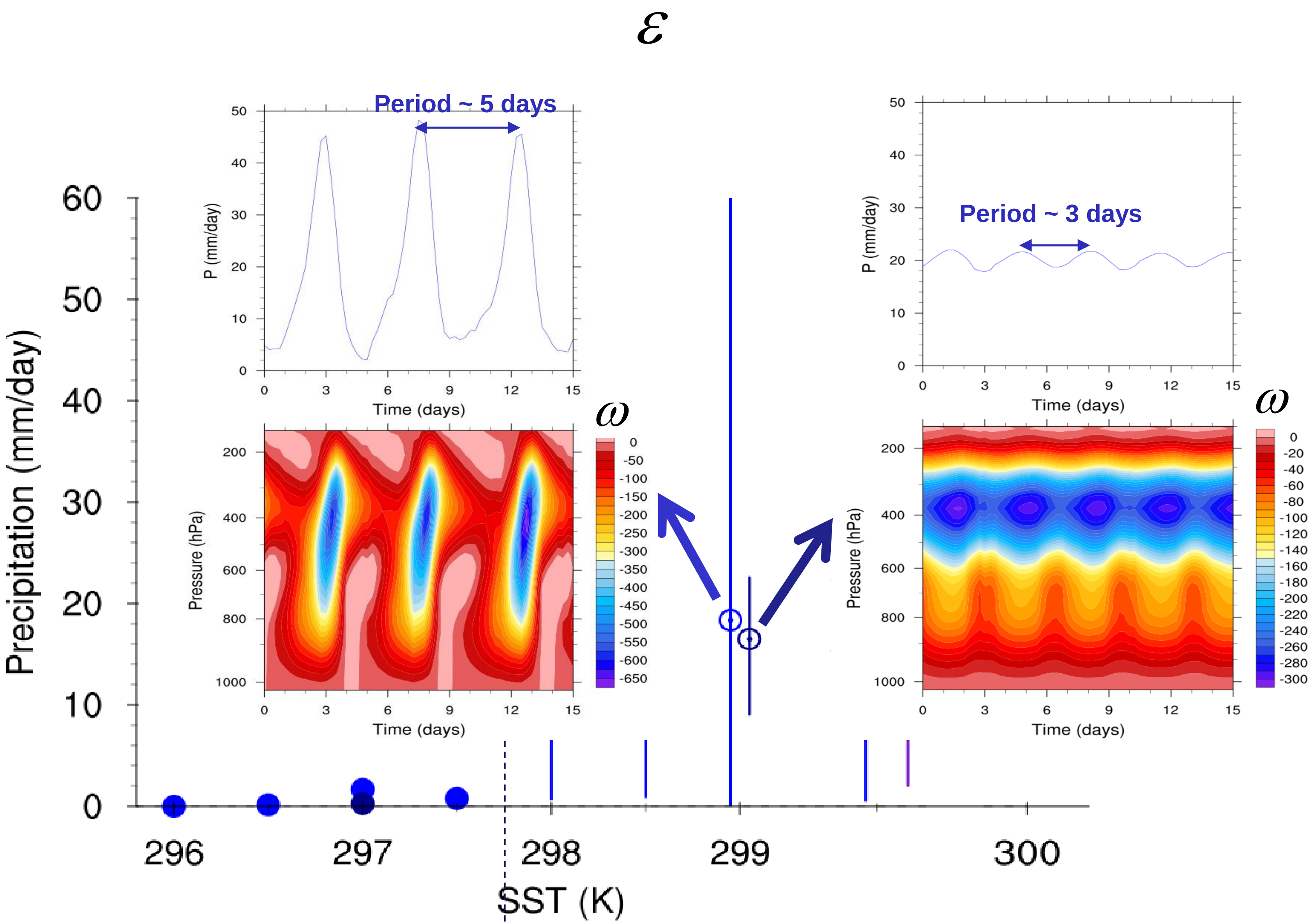
DGW-SCM with control entrainment



297.5 K< T_C< 298 K

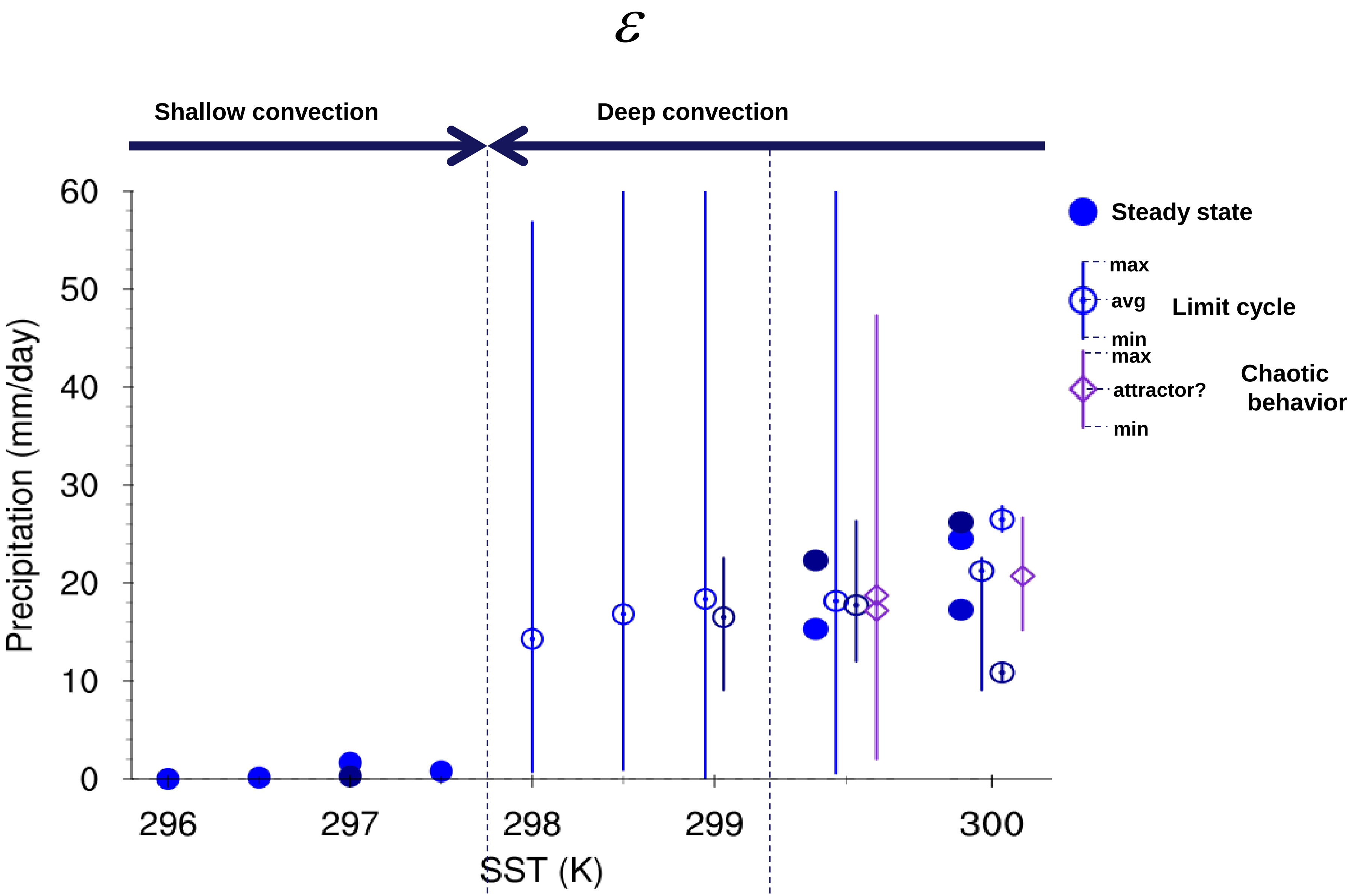
299 K< T_{C2}< 299.5 K

DGW-SCM with control entrainment



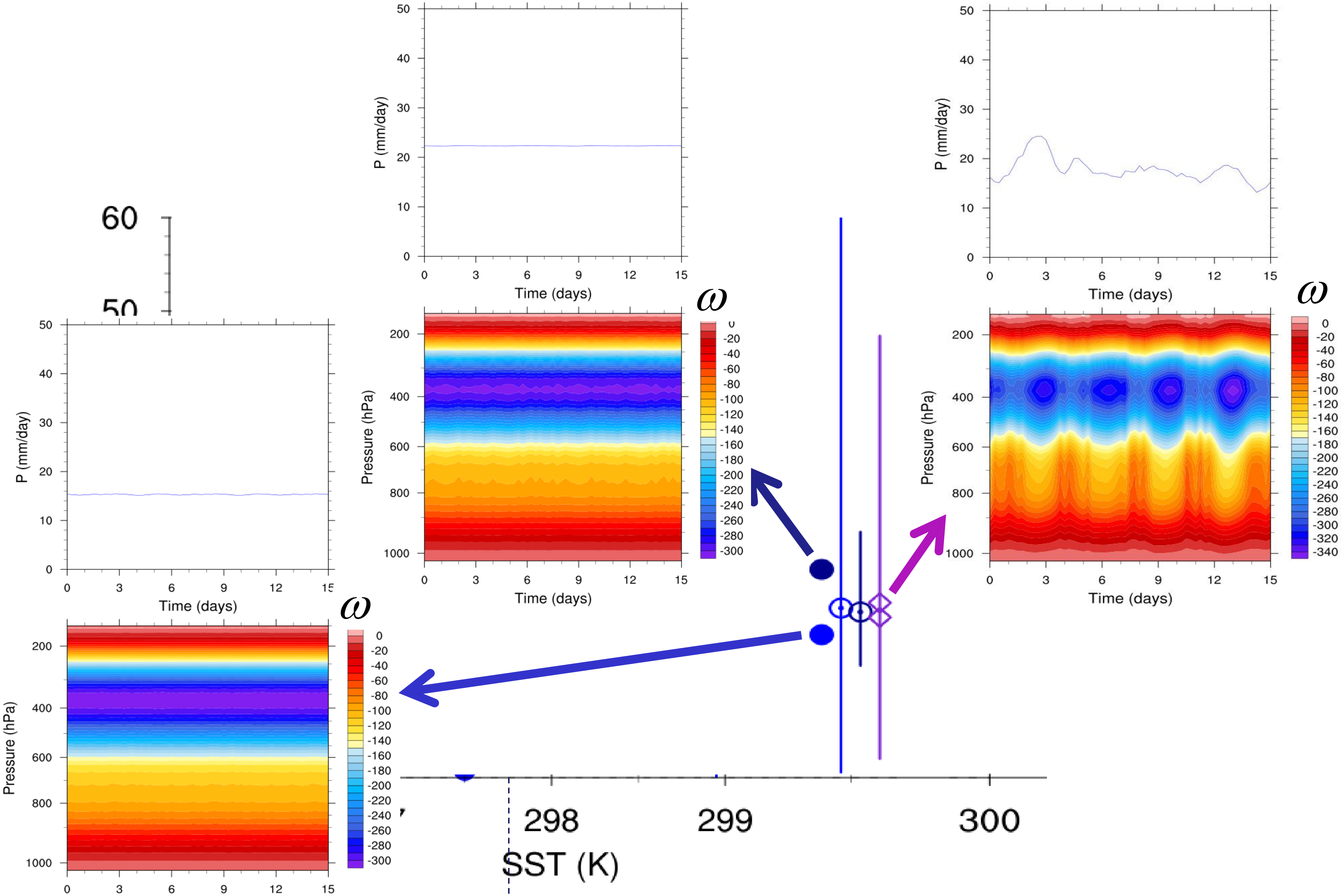
297.5 K< T_C< 298 K

DGW-SCM with control entrainment



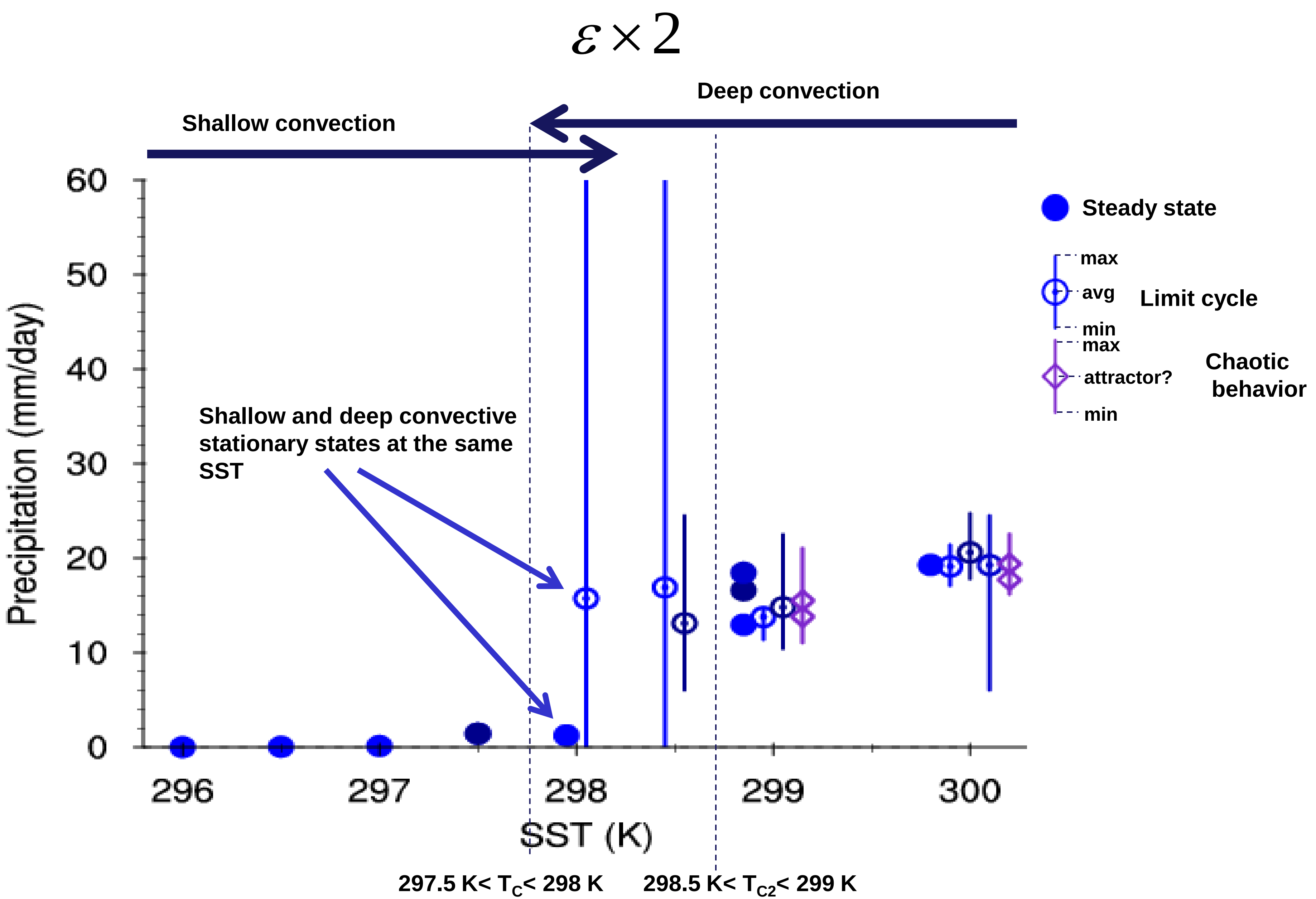
297.5 K< T_C< 298 K   299 K< T_{C2}< 299.5 K

DGW-SCM with control entrainment



297.5 K< T_C< 298 K

DGW-SCM with large entrainment



Conclusions and perspectives

- The SST threshold for transition between shallow and deep convection increases with increasing entrainment, for both the GCM and the DGW-SCM.

- For small entrainment, the model locks into a regime with little (GCM) or no (DGW-SCM) variability beyond the synoptic scale.

- For larger entrainment, the DGW-SCM is able to sustain subsidence for an SST above the threshold of transition from shallow to deep convection, and can sustain multiple stationary states and transition towards chaos for large SST. The GCM exhibits a neutral preferred ascending regime, and its intraseasonal variability is larger than for small entrainment.

- What could be the relationship between the chaotic behavior of the DGW-SCM and the intraseasonal variability in the GCM? Stochastic forcing?

- How chaotic should a DGW-SCM be ? (GASS-WTG / EMBRACE might help understand this)

- How can we understand parameter sensitivity in a chaotic system?

- What do we know about the sensitivity of deep convection to free-tropospheric humidity when convection occurs?

Thank you