Effet du CO_2 sur la circulation atmosphérique tropicale et les changements régionaux de précipitation

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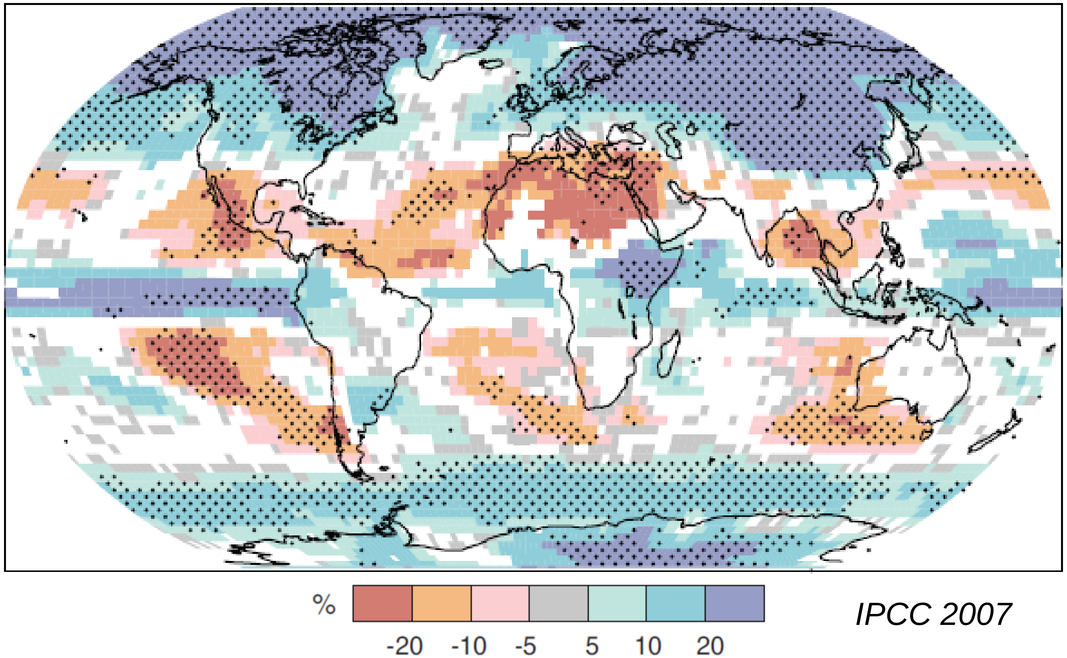
CMIP3 Precipitation projections



IPCC 2007

[How to tackle the problem ??]()

What is robust ? What is not ?

Why ? What implications ?

First step : Unravel the physical mechanisms underlying the change in tropical precipitation pattern...

(Bony et al, in revision)

What controls the regional pattern of precipitation change ?

Increased CO_2 is known to affect the hydrological cycle through :

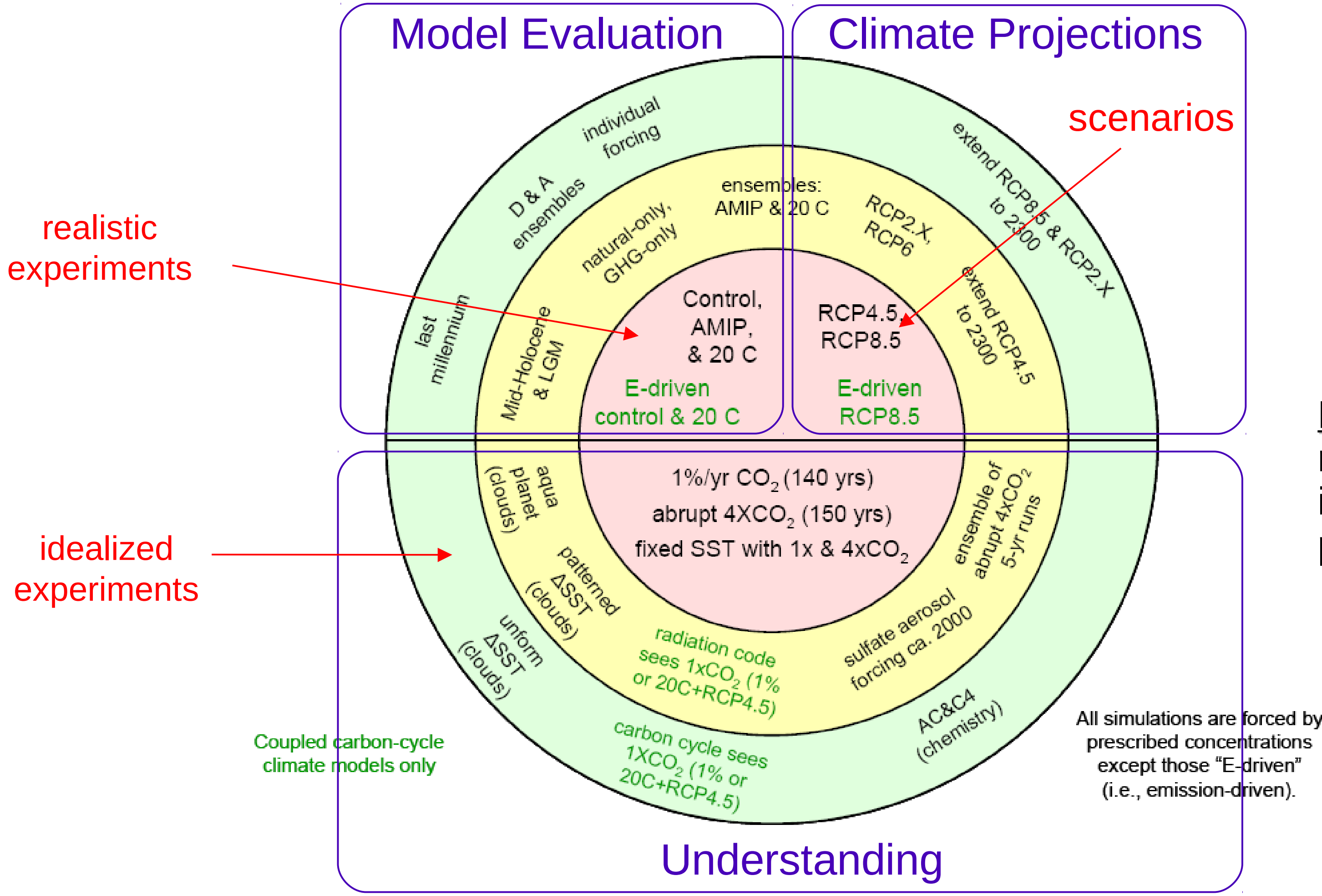
- Surface warming (e.g. Held and Soden 2006)
- Tropospheric adjustments (e.g. Gregory and Webb 2008)

↓

How much do regional precipitation changes depend on surface warming ?

CMIP5

A hierarchy of models, experiments, configurations
(coupled ocean-atmosphere, atmosphere-only, aqua-planet..)



Models :
ESM
OAGCM
AGCM
Aqua-planet

Experiments :
realistic
idealized
partial forcings

Analysis Method

- Water budget : $P = E - \left[\omega \frac{\partial q}{\partial P}\right] + H_q$
- Let $\overline{\omega}$ be mass-weighted vertical average of ω.
- Then : $P = E + \overline{\omega}\,\Gamma_q + H_q + V_q^{\alpha}$

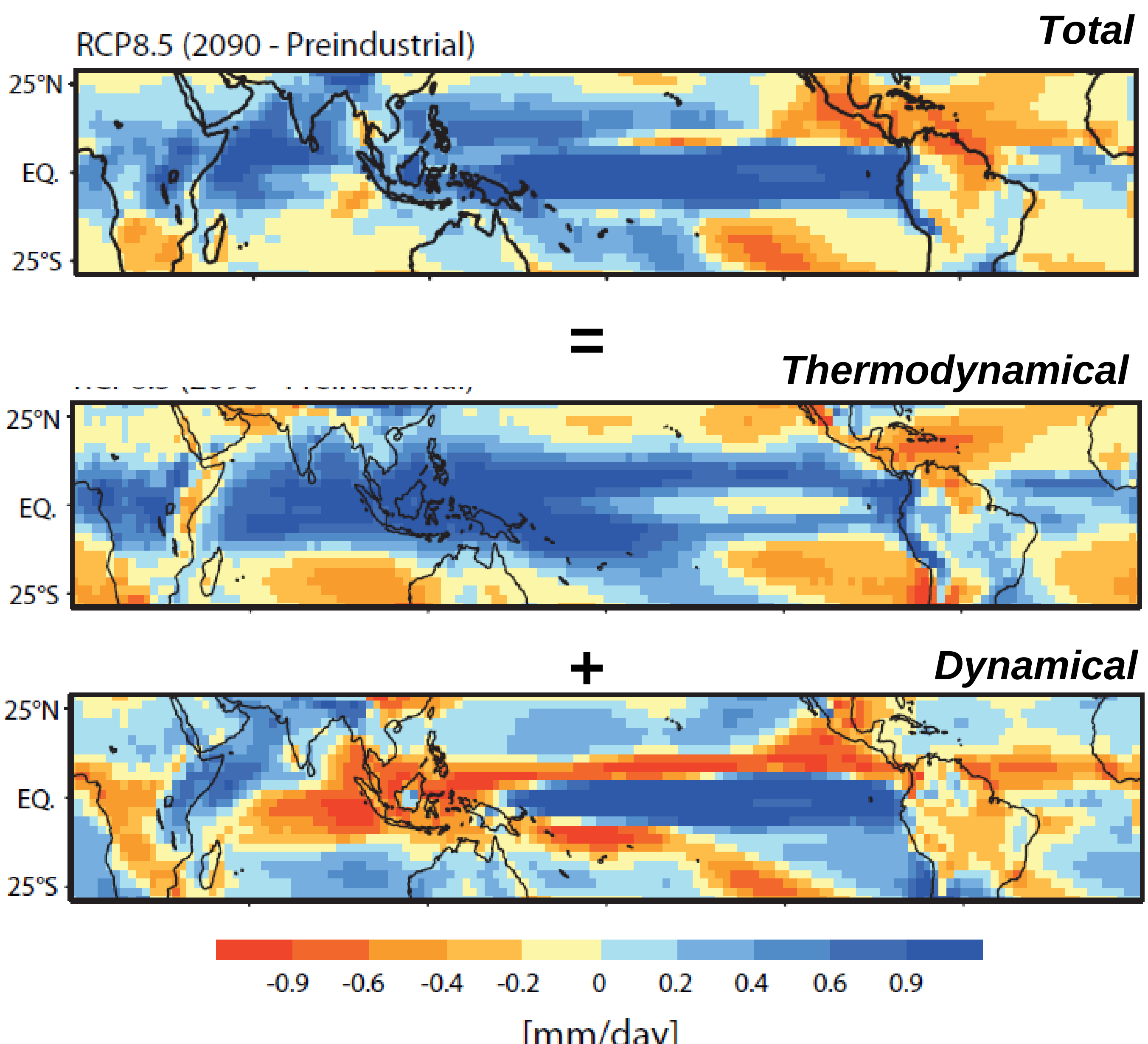
surface evaporation (E) — vertical advection ($\overline{\omega}\,\Gamma_q$) — horizontal advection (H_q) — shape of omega profile (V_q^{α})

$$\Delta P = \boxed{\left(\Delta E + \overline{\omega}\,\Delta\Gamma_q + \Delta H_q + \Delta V_q^{\alpha}\right)} + \boxed{\Gamma_q\,\Delta\overline{\omega}}$$

thermodynamical component — **dynamical component**

Tropical Precipitation Projections

RCP8.5 scenario at the end 21C

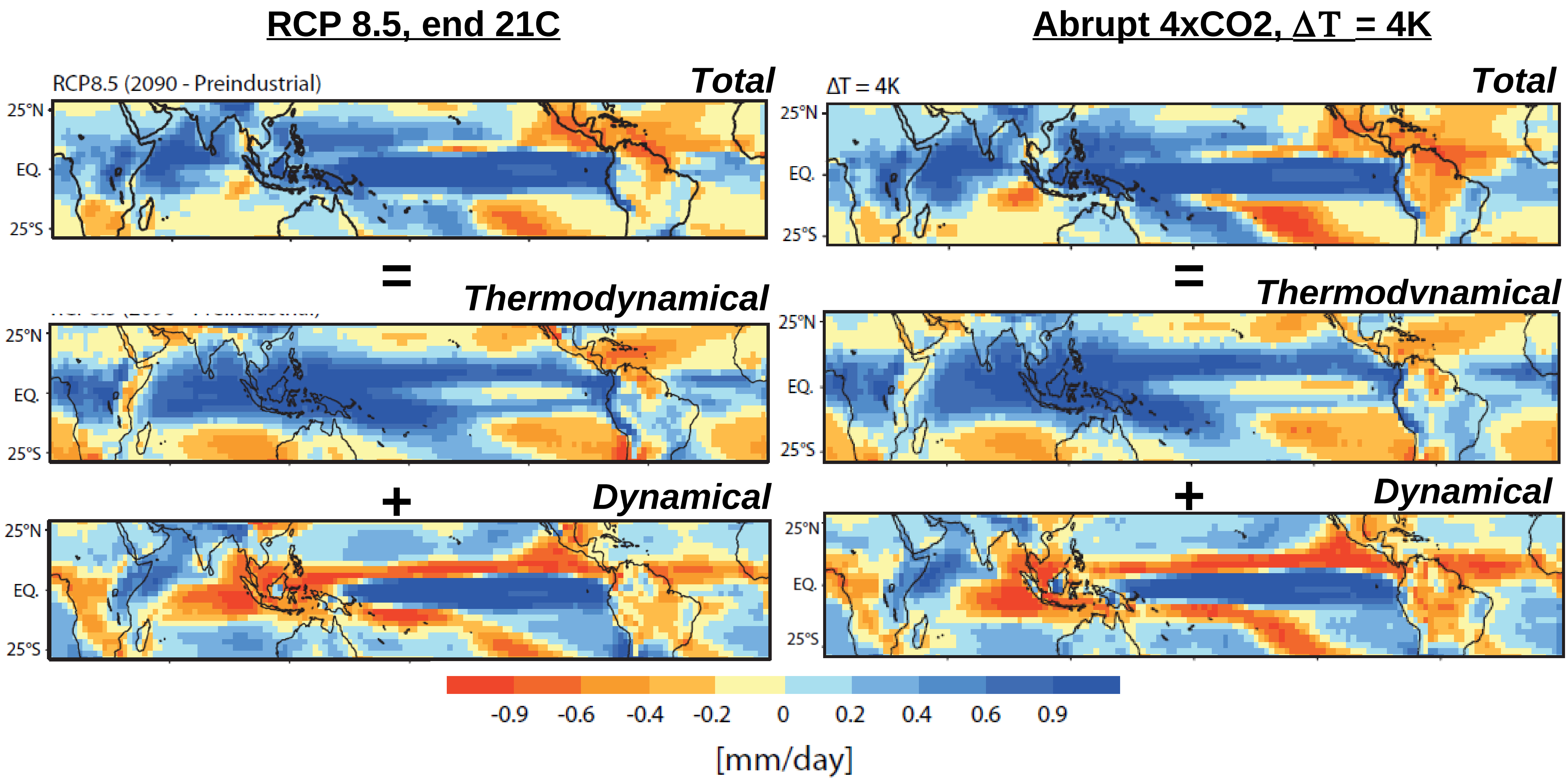


$$\Delta P_{ther} = \Delta P - \Delta P_{dyn}$$

$$\Delta P_{dyn} = \Gamma_q \Delta \overline{\omega}$$

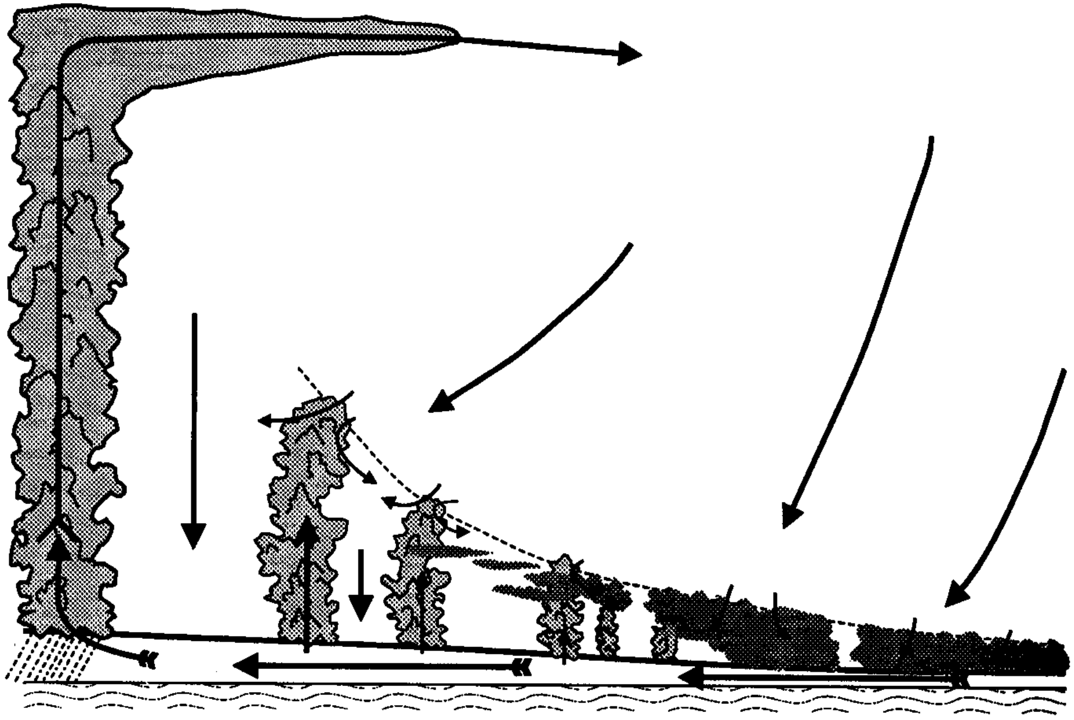
Tropical Precipitation Projections

RCP8.5 scenario vs idealized abrupt 4xCO2 expt



→ an opportunity to understand precipitation changes in RCP scenarios

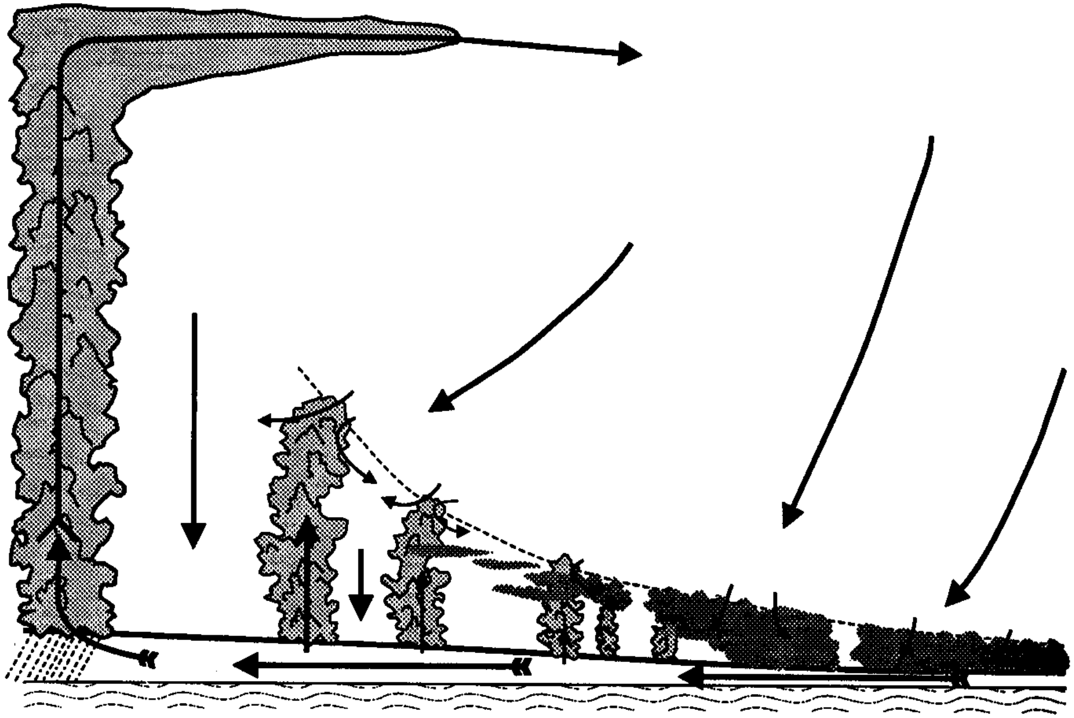
Interpretation of regional precipitation changes



$$\Delta P = \boxed{\left(\Delta E + \overline{\omega}\,\Delta\Gamma_q + \Delta H_q + \Delta V_q^{\alpha}\right)} + \boxed{\Gamma_q\,\Delta\overline{\omega}}$$

thermodynamical component | **dynamical component**

How would precipitation respond to global warming in the absence of change in vertical motion ?



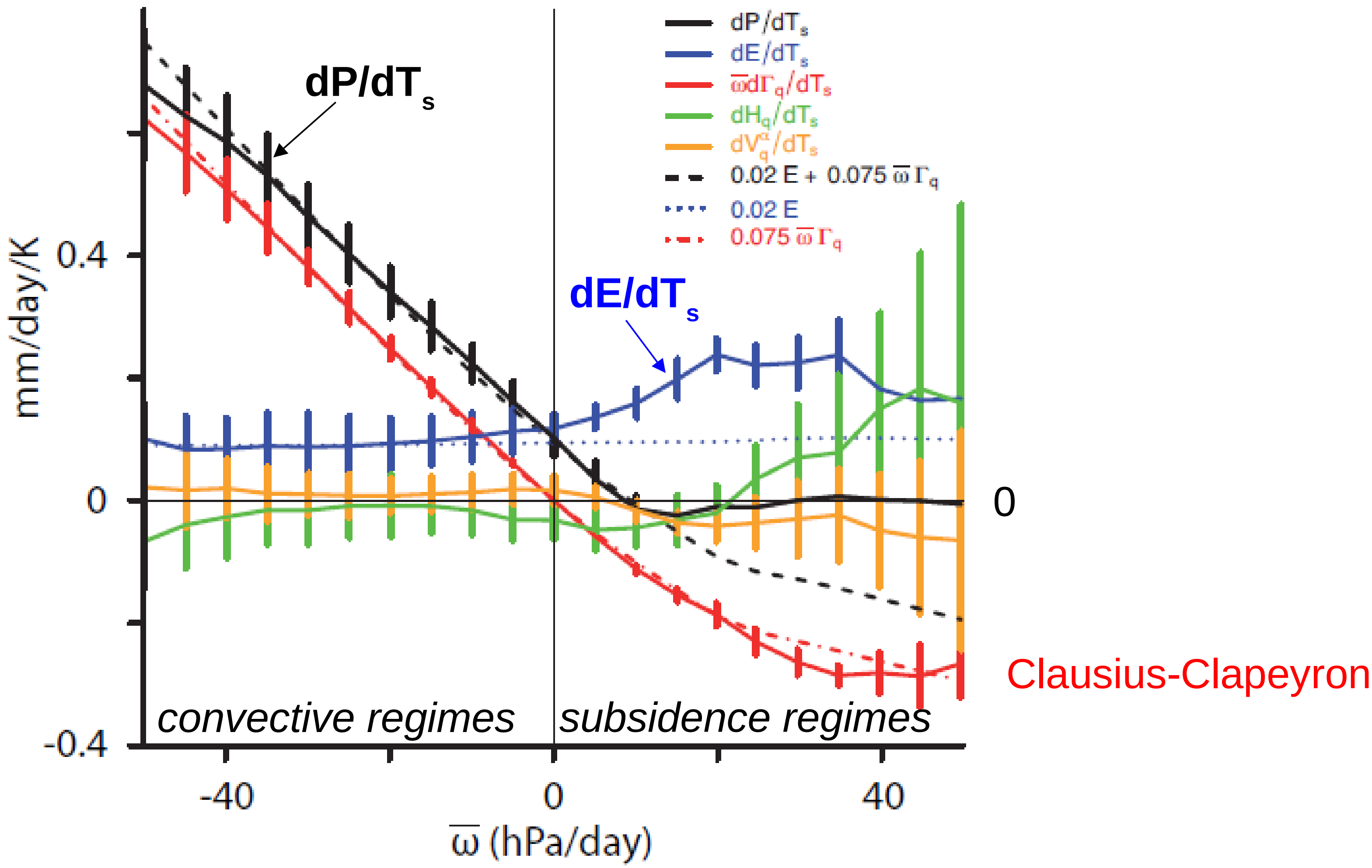
$$\Delta P = \boxed{\left(\Delta E + \overline{\omega}\,\Delta\Gamma_q + \Delta H_q + \Delta V_q^{\alpha}\right)} + \boxed{\Gamma_q\,\Delta\overline{\omega}}$$

thermodynamical component

dynamical component

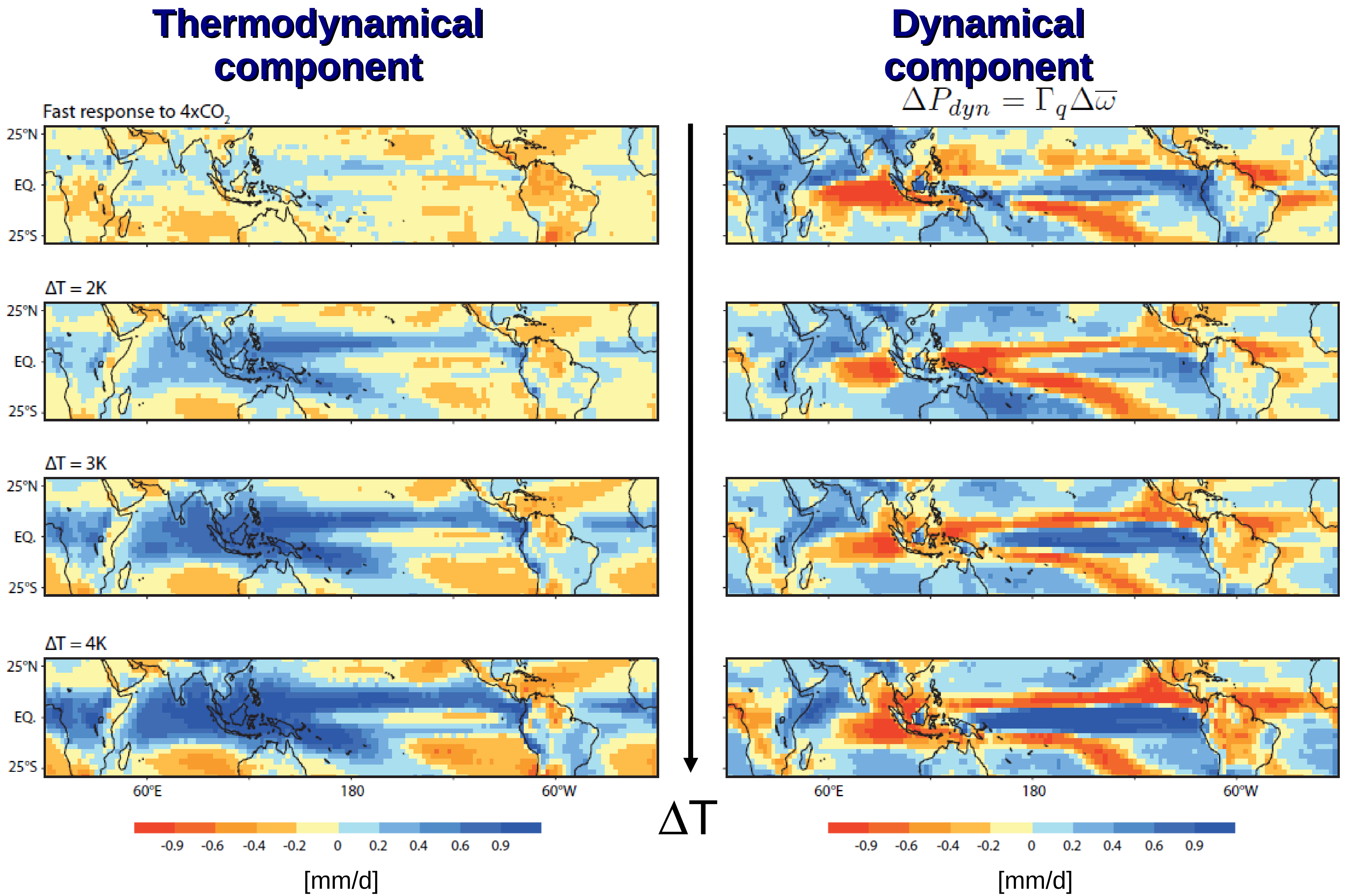
How would precipitation respond to global warming in the absence of change in vertical motion ?

- 16 CMIP5 models (mean and spread)
- *wet get wetter, dry get drier*
- *wet get getter* more robust than *dry get drier*

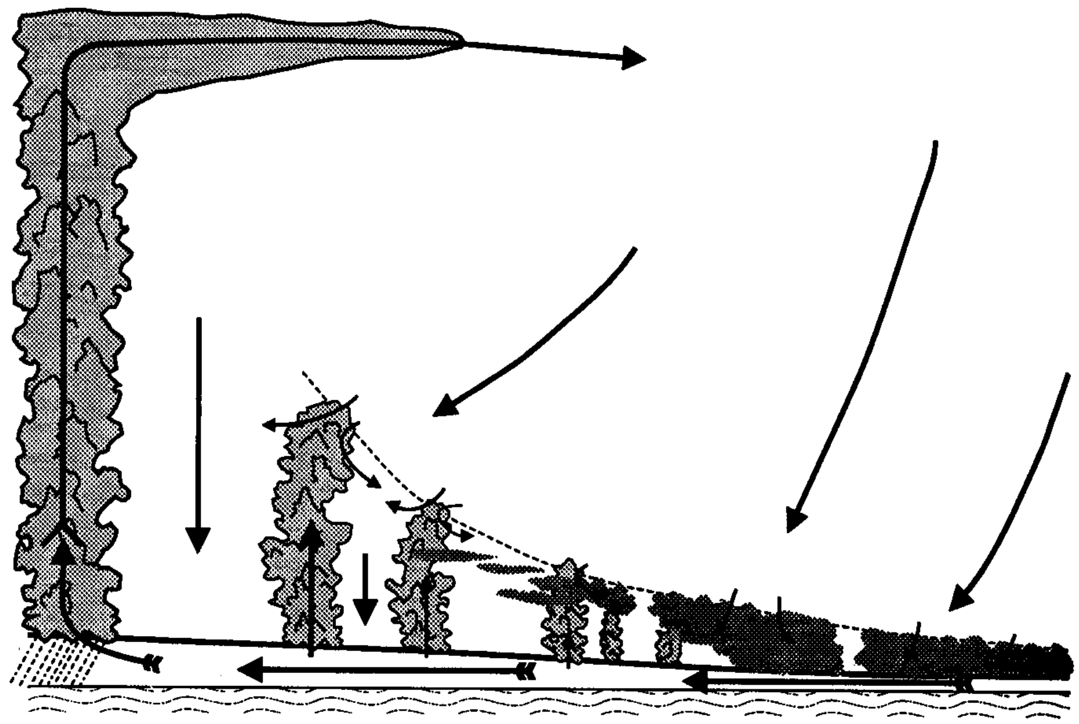


$$\Delta P = \left(\Delta E + \overline{\omega}\,\Delta\Gamma_q + \Delta H_q + \Delta V_q^\alpha\right) + \Gamma_q \Delta\overline{\omega}$$

Evolution of regional precipitation changes in abrupt 4xCO2 experiments



How does the tropical overturning circulation respond to increased CO_2 ?

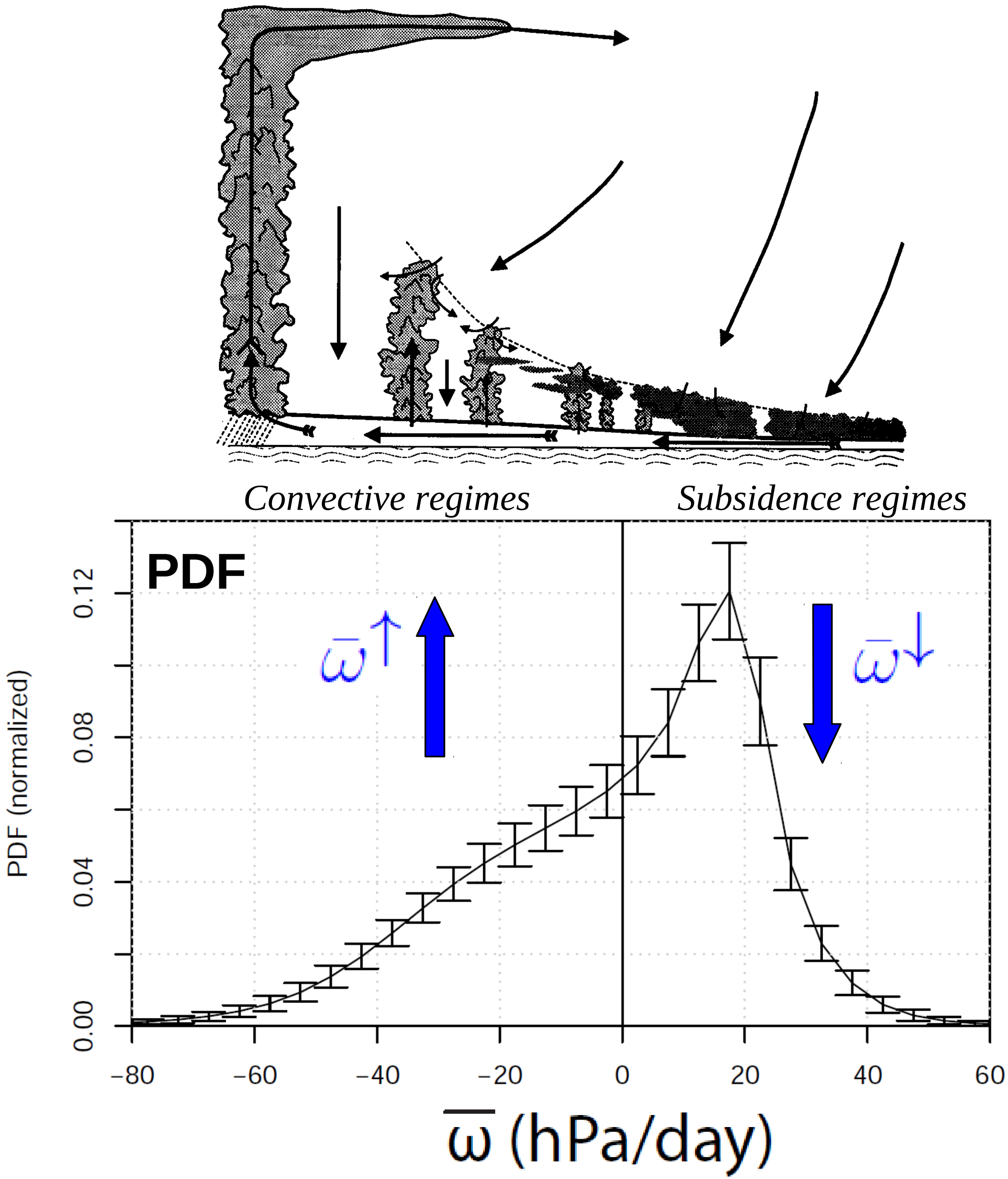


$$\Delta P = \boxed{(\Delta E + \overline{\omega}\, \Delta\Gamma_q + \Delta H_q + \Delta V_q^{\alpha})} + \boxed{\Gamma_q\, \Delta\overline{\omega}}$$

thermodynamical component

dynamical component

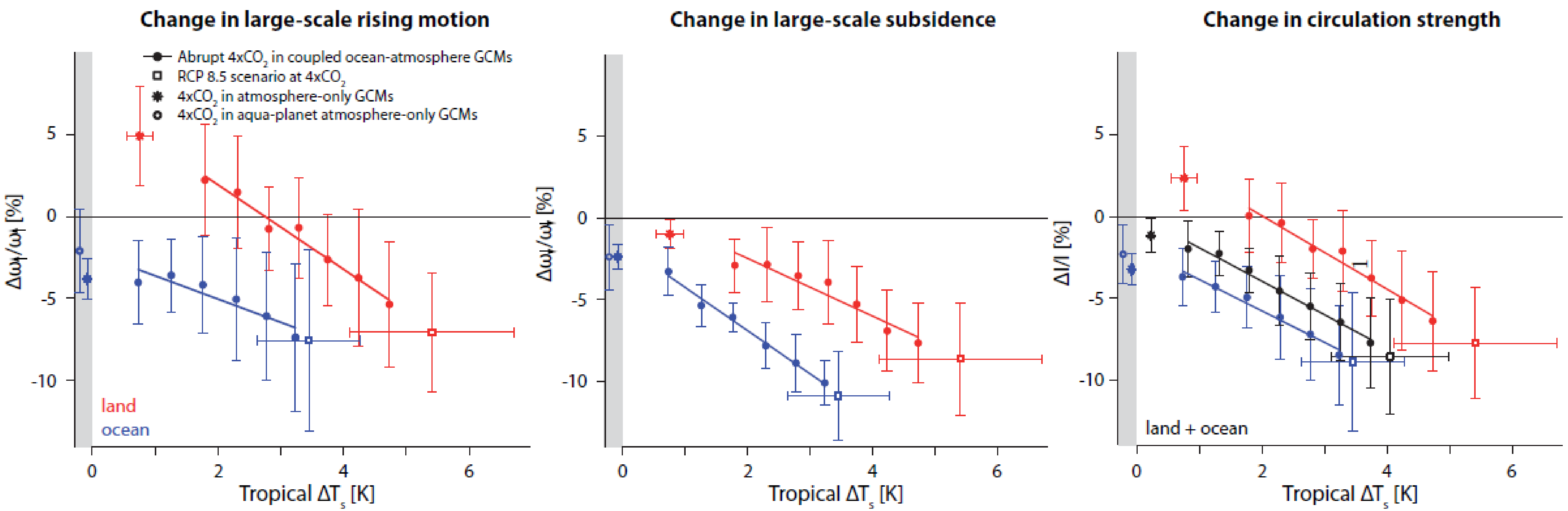
Tropical Overturning Circulation



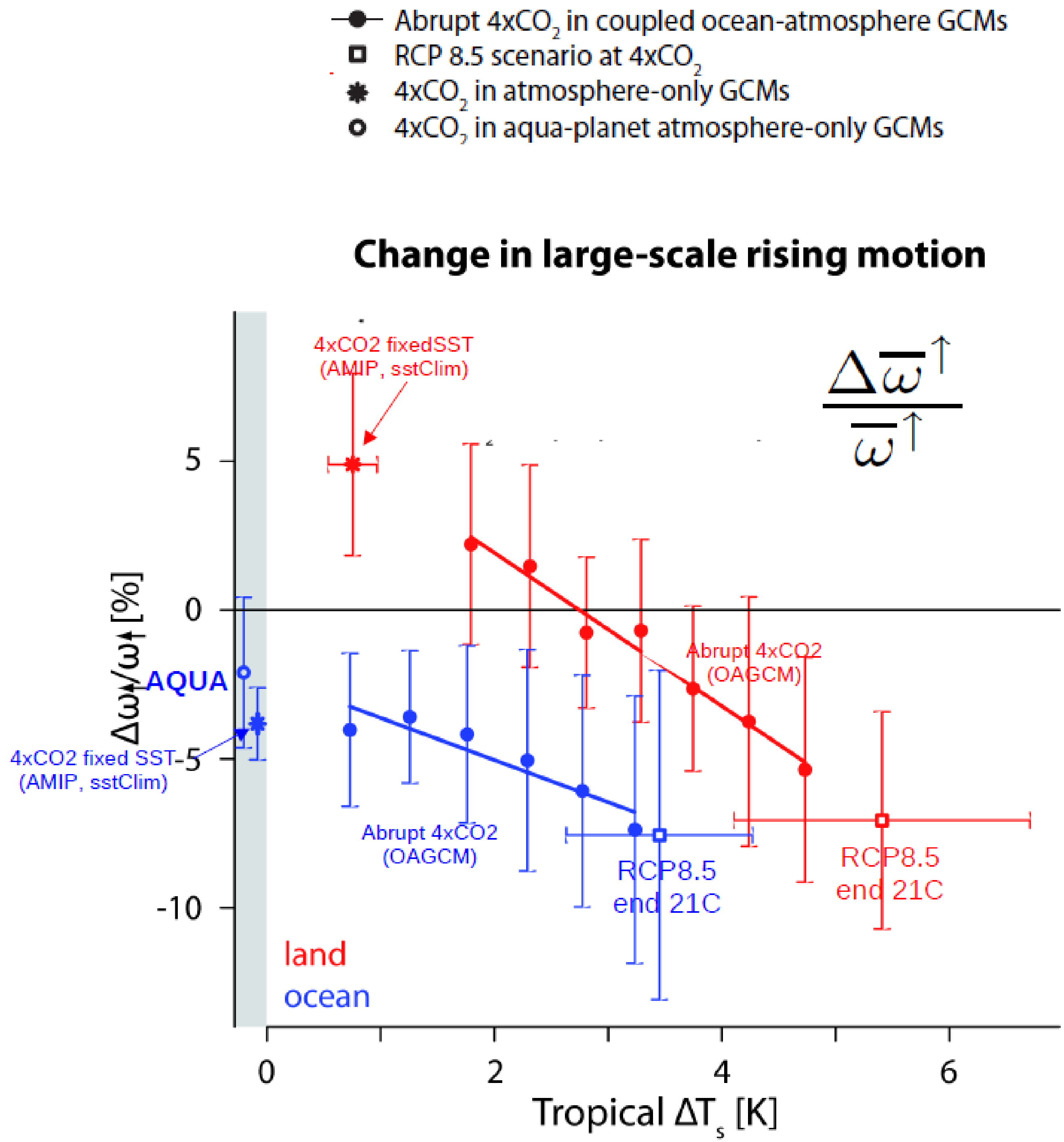
Change in circulation (%) predicted by CMIP5 models

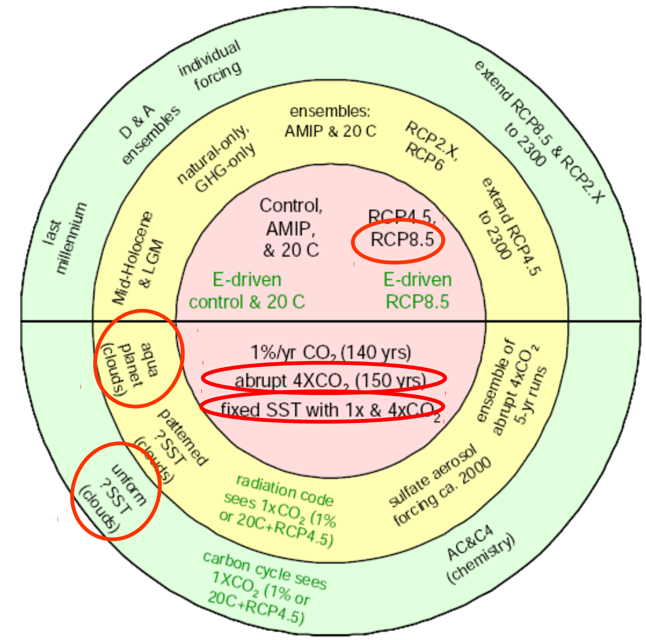
... in multiple models, experiments and configurations

$$\frac{\Delta\overline{\omega}^{\uparrow}}{\overline{\omega}^{\uparrow}} \qquad \frac{\Delta\overline{\omega}^{\downarrow}}{\overline{\omega}^{\downarrow}} \qquad \frac{\Delta I}{I}$$

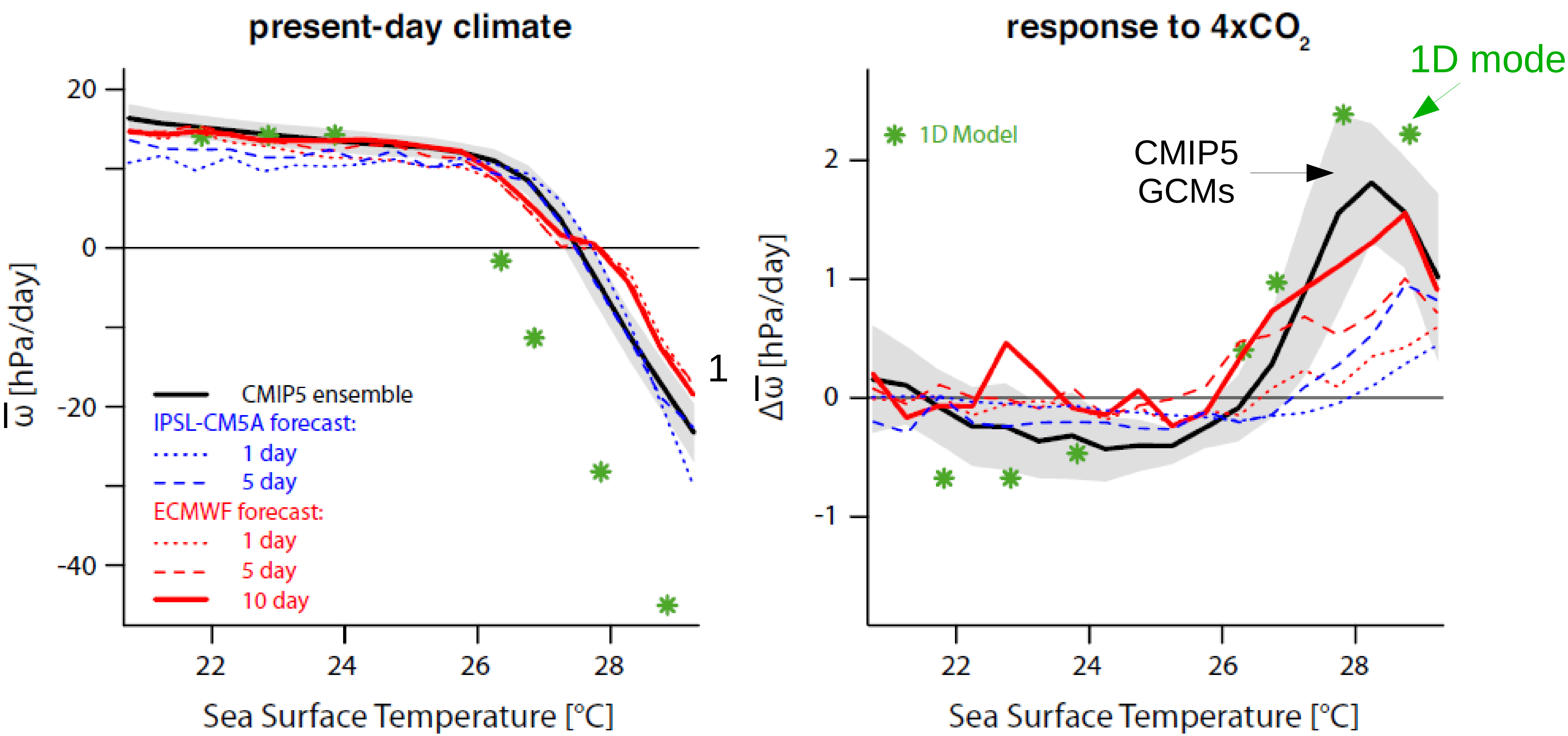


Change in large-scale rising motion





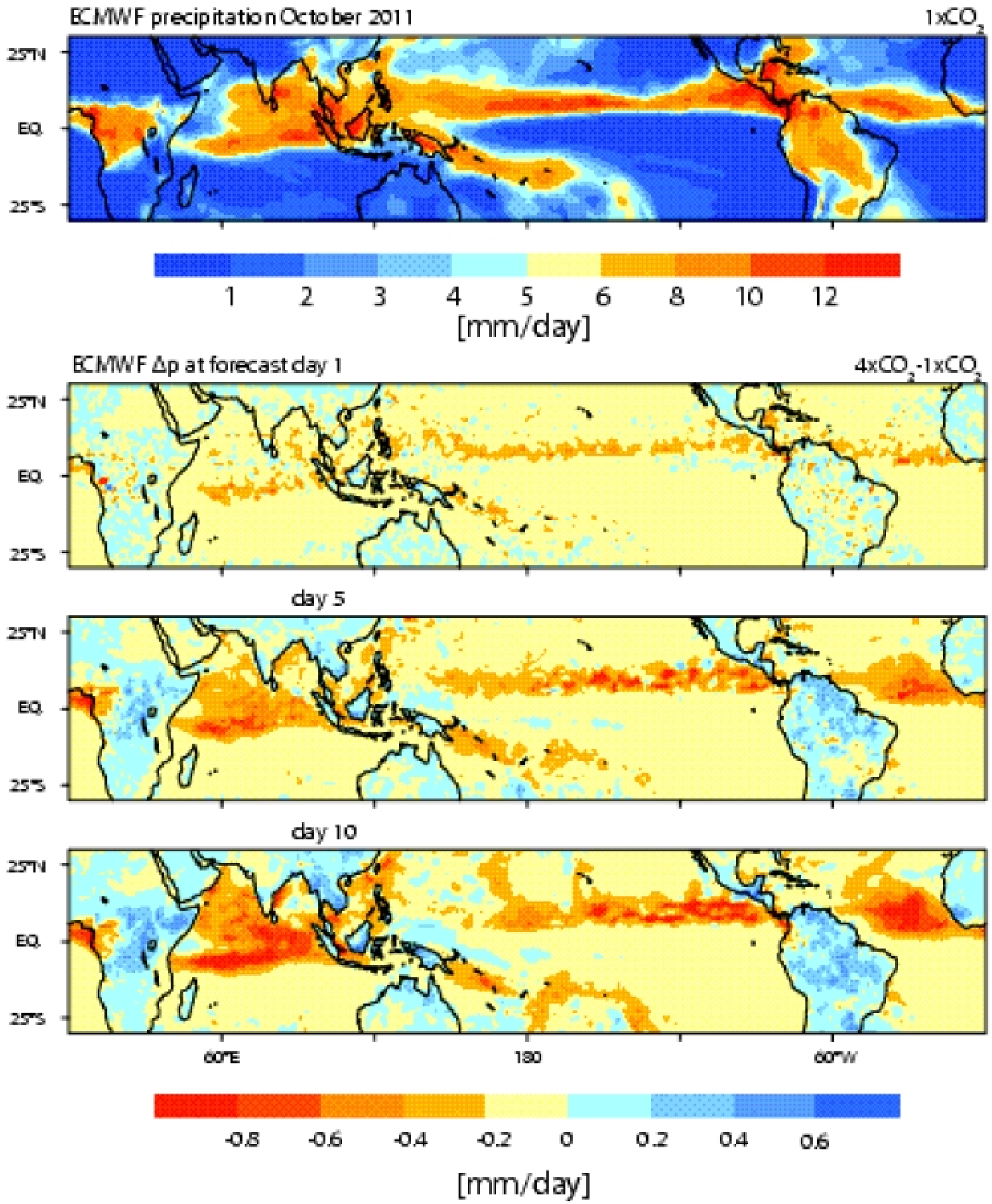
Physical Interpretation and Time Scale of the Dynamical Response to CO2 Radiative Forcing



Direct CO2 effect on the tropical overturning circulation :

- Robust result (CMIP5 AGCMs, 1D model (in WTG mode), ECMWF IFS operational model, SP-CAM)
- Physical interpretation
- Controlled by (ultra) fast physical processes in convective regimes (half the eq response within ~ 5 days)

ECMWF-IFS Operational Model



Monthly-mean precipitation (October 2011)

1xCO2

4xCO2 – 1xCO2 Forecasts :

Day 1

Day 5

Day 10

CONCLUSIONS

- Weakening of the circulation by global warming
- **Direct effect of CO_2 forcing on large-scale vertical motions**
- The direct effect is :
  - fast
  - robust
  - not primarily mediated by sfce warming or land-sea contrasts
- Explains most of the fast precipitation response to CO_2 forcing
- **Substantially contributes to the regional pattern of long-term precipitation changes !**
- Implications regarding geo-engineering strategies
- **Next :**
  - use this analysis framework to interpret inter-model differences in precipitation projections (including IPSL-CM5A vs IPSL-CM5B, paleo changes, etc)
  - further understand inter-model differences in the circulation sensitivity to greenhouse gases and temperature changes
  - explore implications for climate variability and predictability