

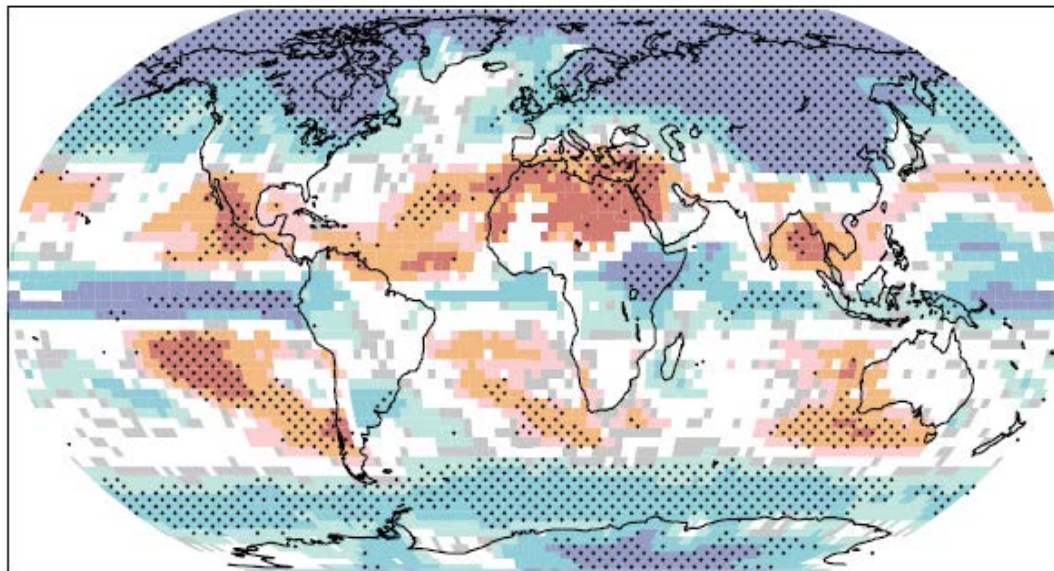
Effet du CO2 sur la circulation atmosphérique tropicale et les changements régionaux de précipitation

Sandrine Bony (LMD, Paris)

En collaboration avec :

Gilles Bellon (CNRM, Toulouse), Daniel Klocke (ECMWF, Reading),
Steve Sherwood (Univ New South Wales, Sydney),
Solange Fermepin (LMD, Paris) et Sébastien Denvil (IPSL, Paris)

CMIP3 Precipitation projections



% -20 -10 -5 5 10 20 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 CO₂ is known to affect the hydrological cycle through :

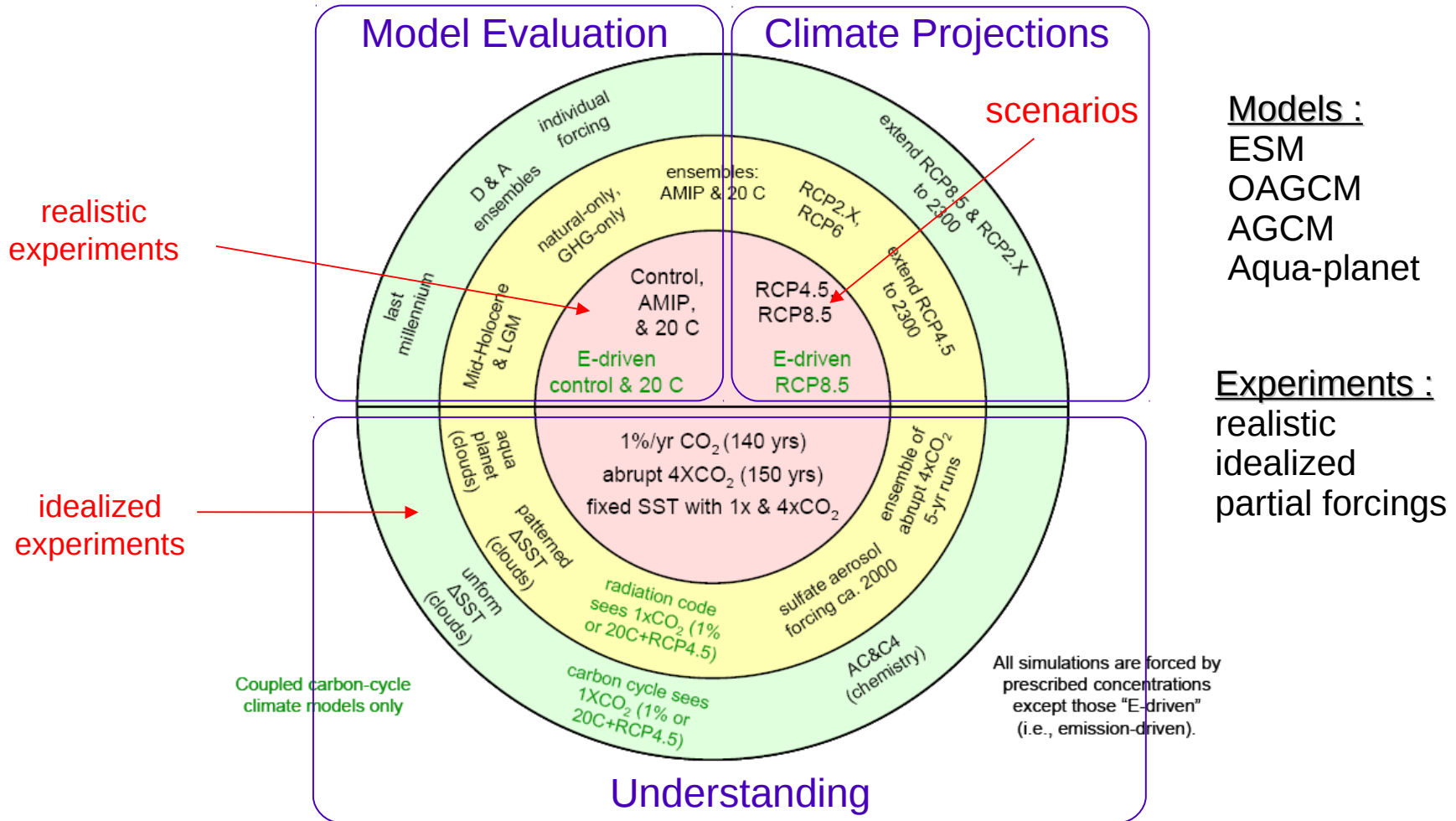
- Surface warming (e.g. Held and Soden 2006)
- Tropospheric adjustments (e.g. Gregory and Webb 2008)



How much do regional precipitation changes depend on surface warming ?

CMIP5

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



Analysis Method

- Water budget : $P = E - \left[\omega \frac{\partial q}{\partial P} \right] + H_q$
- Let $\bar{\omega}$ be mass-weighted vertical average of ω .

• Then : $P = E + \bar{\omega} \Gamma_q + H_q + V_q^\alpha$

surface
evaporation

vertical
advection

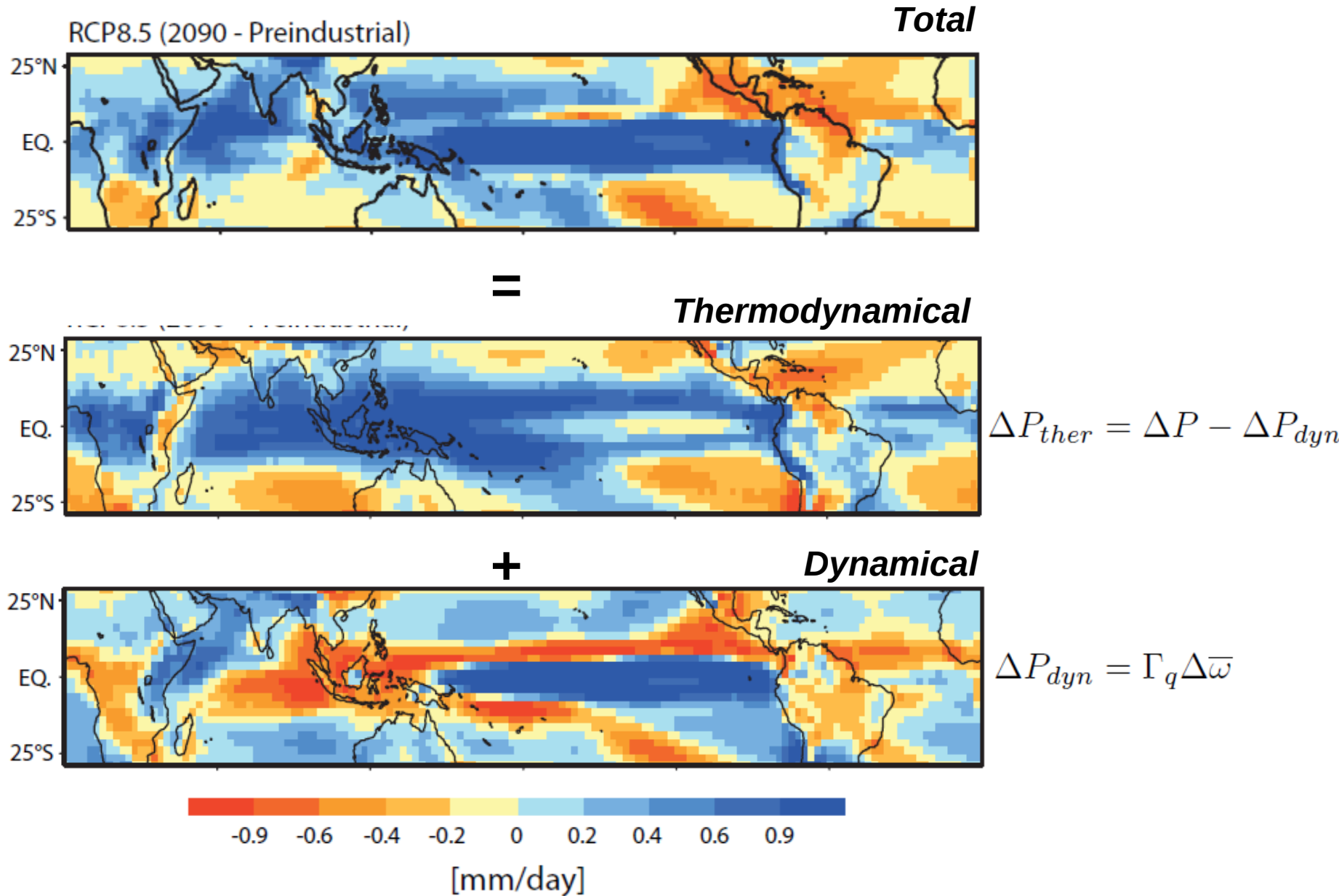
horizontal
advection

shape of
omega profile

$$\Delta P = \underbrace{\left(\Delta E + \bar{\omega} \Delta \Gamma_q + \Delta H_q + \Delta V_q^\alpha \right)}_{\text{thermodynamical component}} + \underbrace{\Gamma_q \Delta \bar{\omega}}_{\text{dynamical component}}$$

Tropical Precipitation Projections

RCP8.5 scenario at the end 21C



Tropical Precipitation Projections

RCP8.5 scenario vs idealized abrupt 4xCO2 expt

RCP 8.5, end 21C

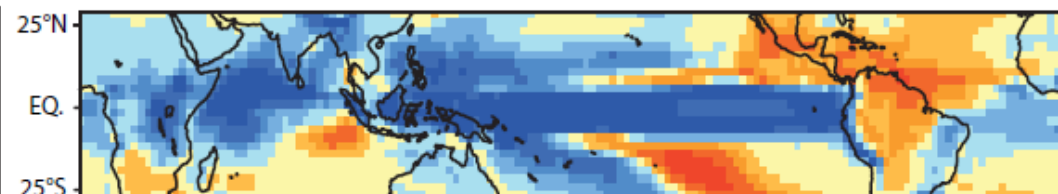
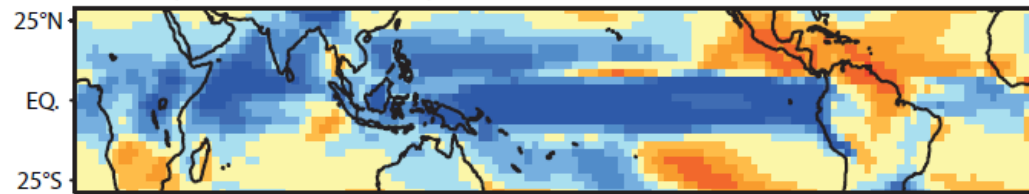
Abrupt 4xCO2, $\Delta T = 4K$

RCP8.5 (2090 - Preindustrial)

Total

$\Delta T = 4K$

Total

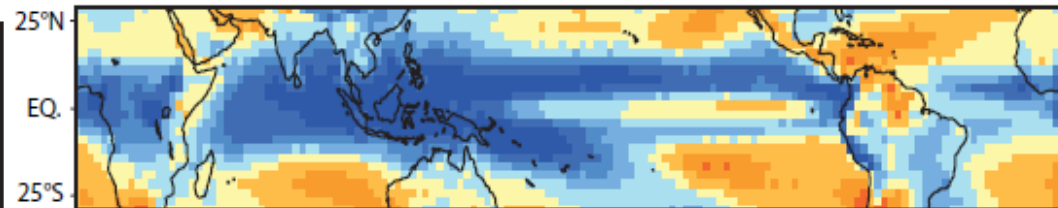
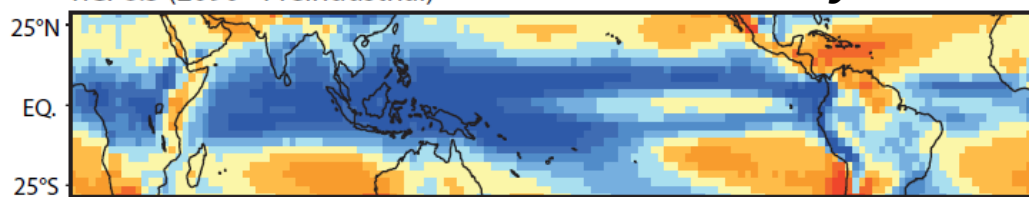


=

Thermodynamical

=

Thermodynamical

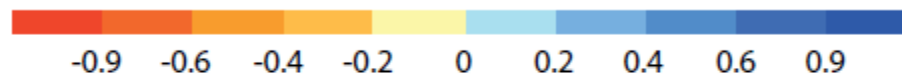
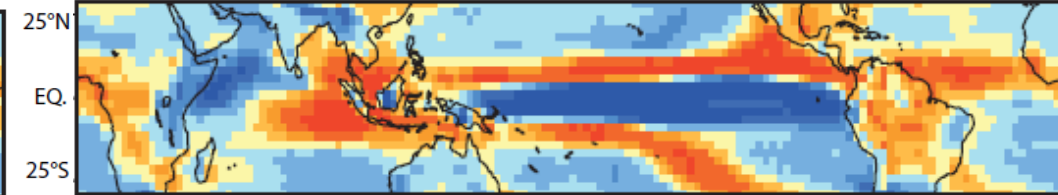
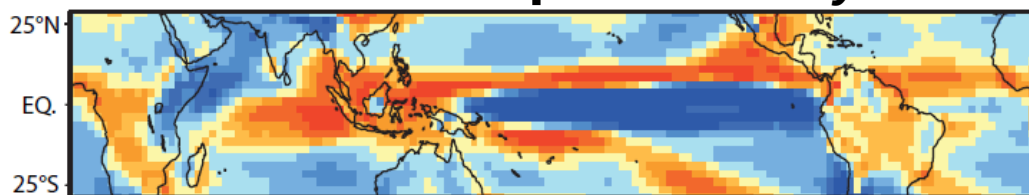


+

Dynamical

+

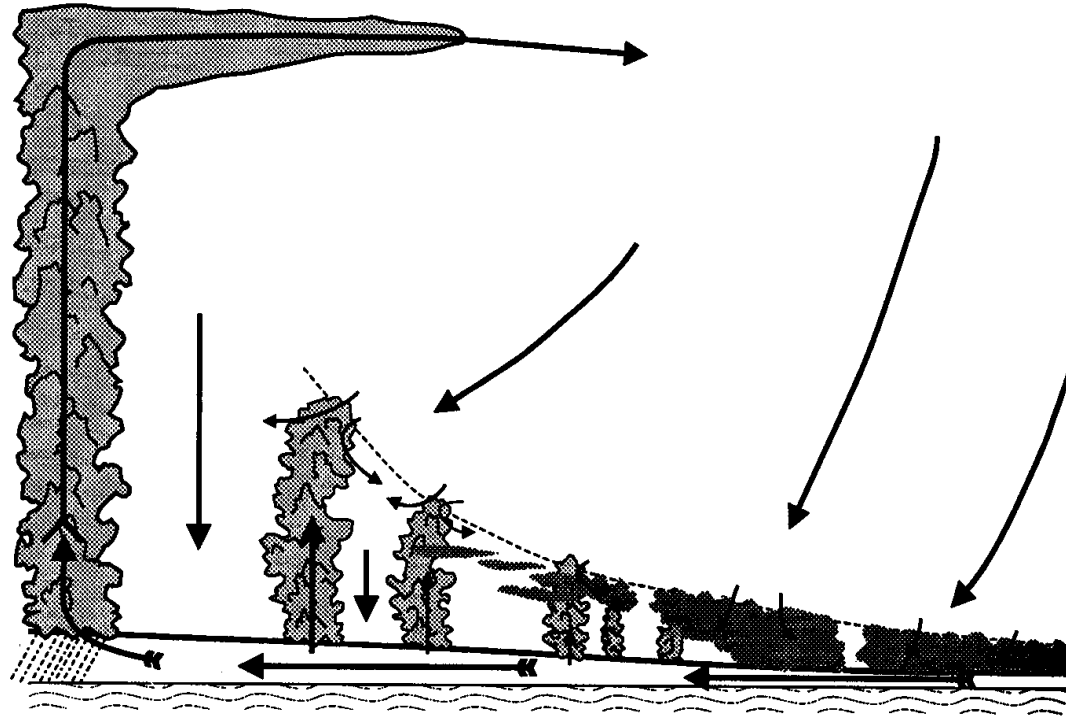
Dynamical



[mm/day]

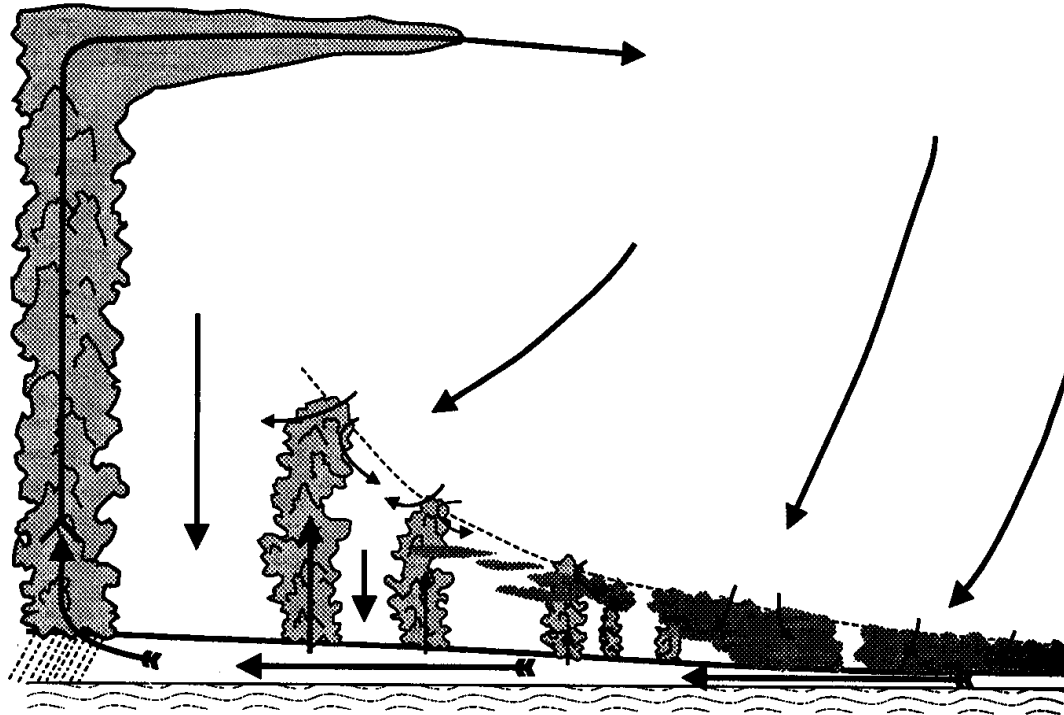
→ an opportunity to understand precipitation changes in RCP scenarios

Interpretation of regional precipitation changes



$$\Delta P = \underbrace{(\Delta E + \bar{\omega} \Delta \Gamma_q + \Delta H_q + \Delta V_q^\alpha)}_{\text{thermodynamical component}} + \underbrace{\Gamma_q \Delta \bar{\omega}}_{\text{dynamical component}}$$

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

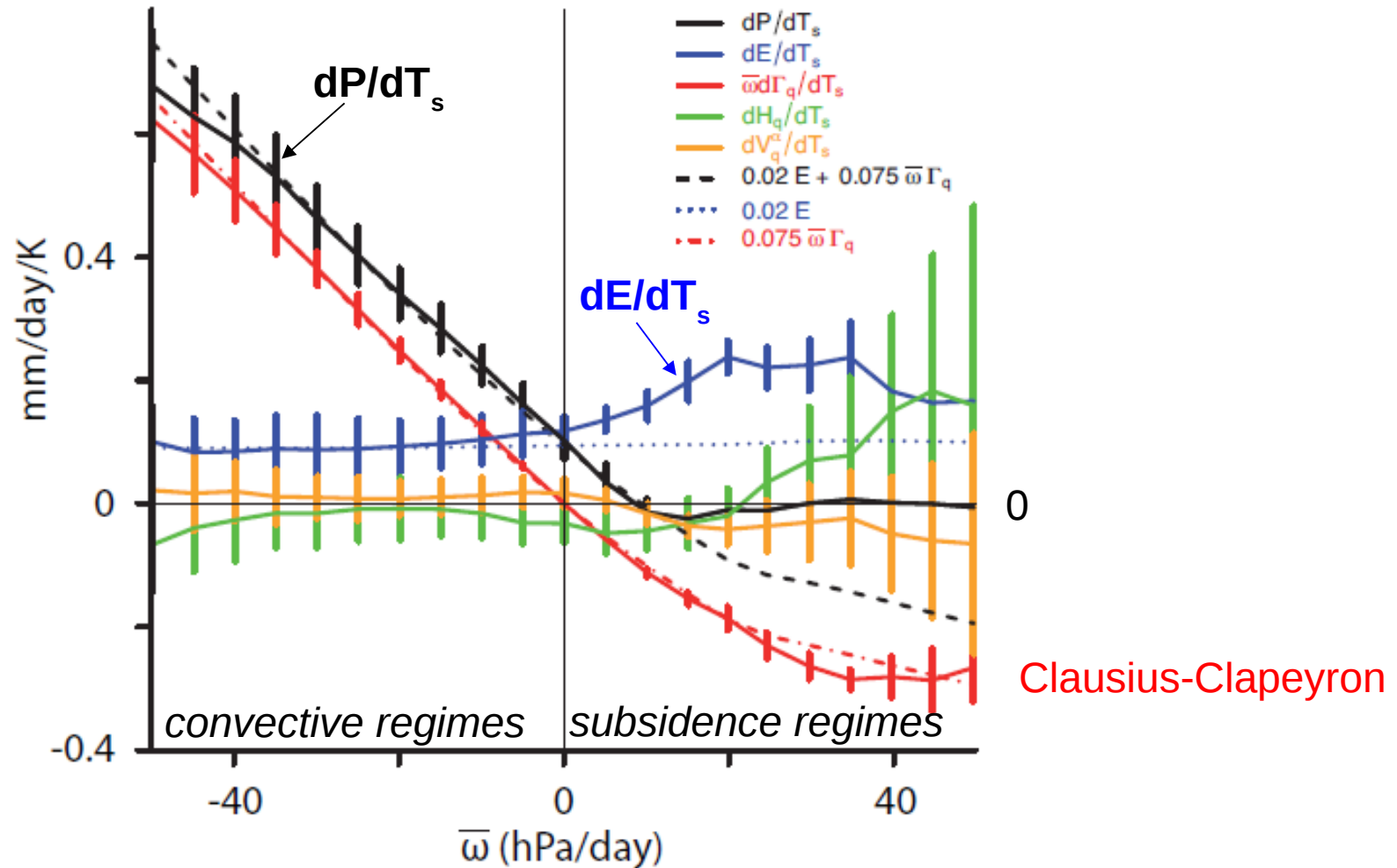


$$\Delta P = (\Delta E + \bar{\omega} \Delta \Gamma_q + \Delta H_q + \Delta V_q^\alpha) + \cancel{\Gamma_q \Delta \bar{\omega}}$$

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*



$$\Delta P = (\Delta E + \bar{\omega} \Delta \Gamma_q + \Delta H_q + \Delta V_q^\alpha) + \cancel{\Gamma_q \Delta \bar{\omega}}$$

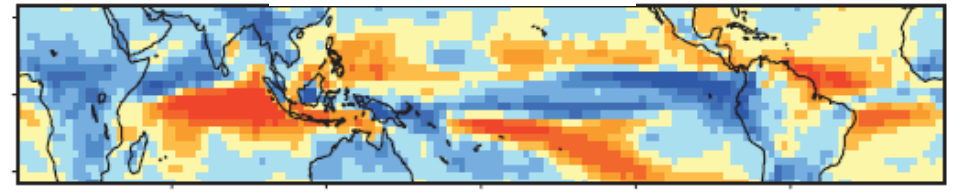
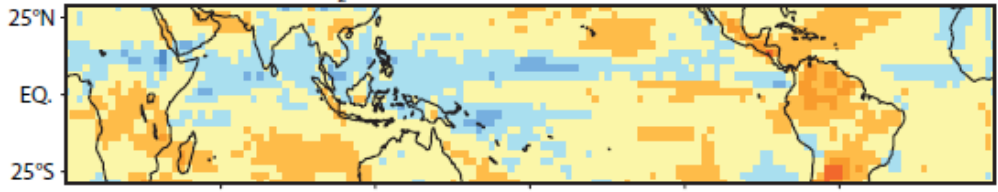
Evolution of regional precipitation changes in abrupt 4xCO₂ experiments

Thermodynamical component

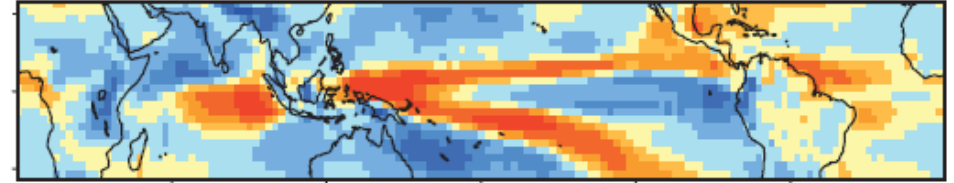
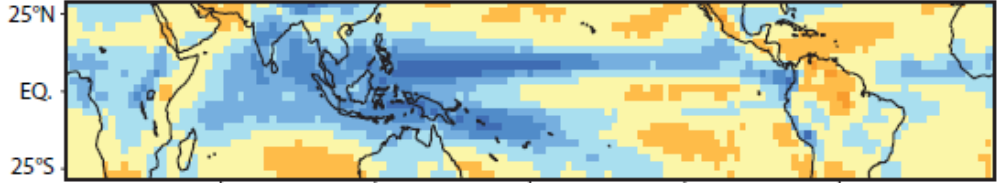
Dynamical component

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

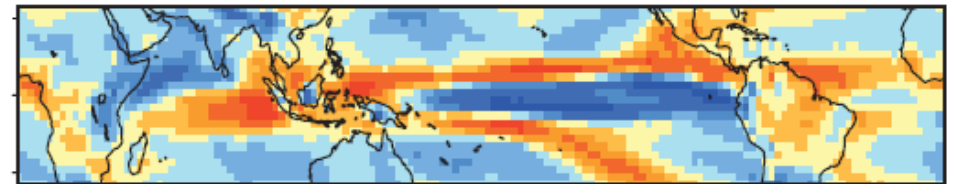
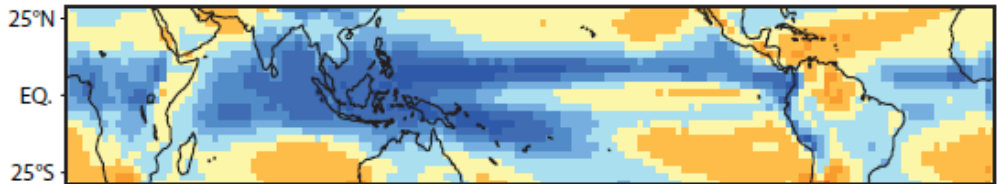
Fast response to 4xCO₂



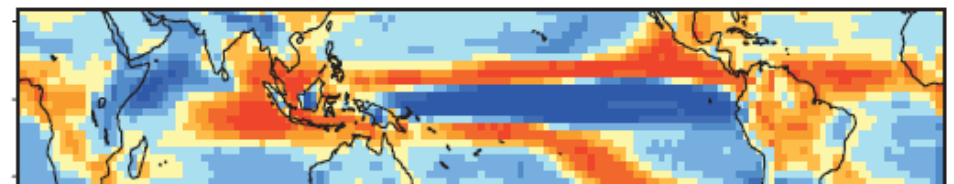
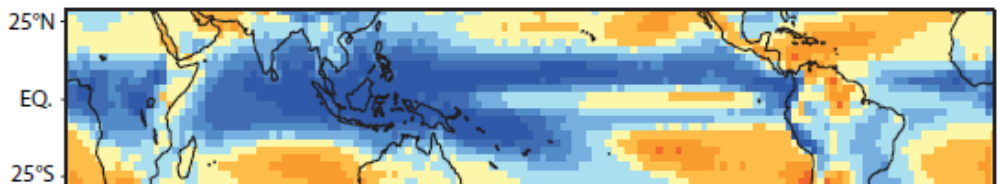
$\Delta T = 2K$



$\Delta T = 3K$

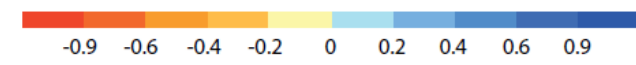
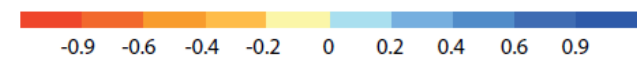


$\Delta T = 4K$



60°E 180 60°W

60°E 180 60°W

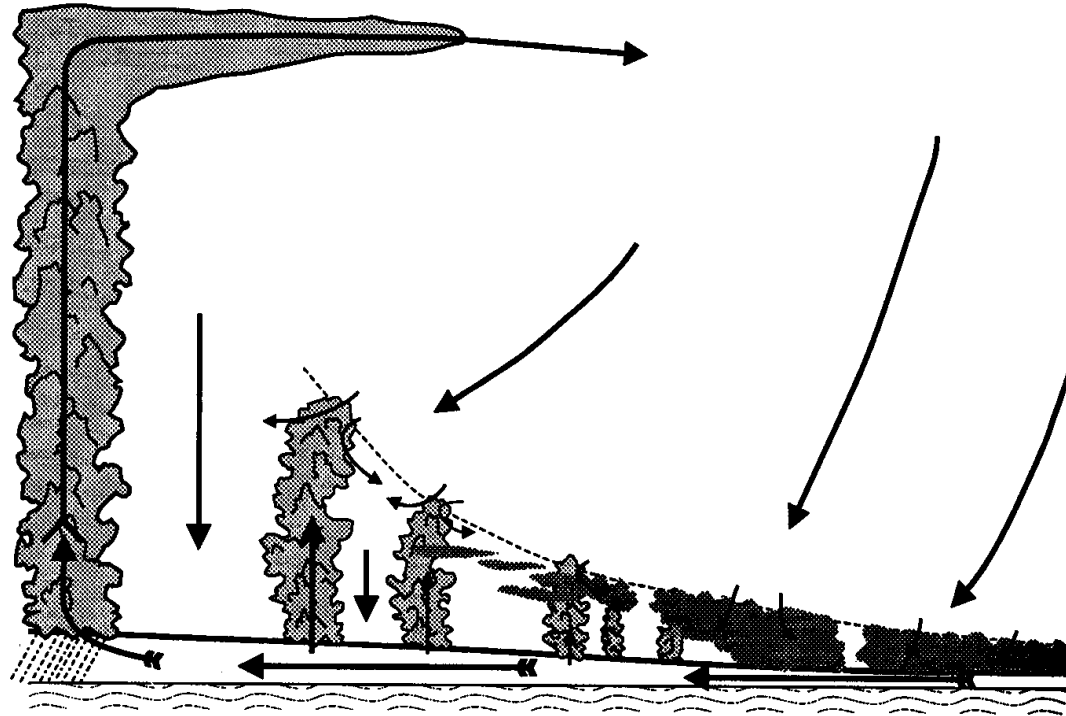


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[mm/d]

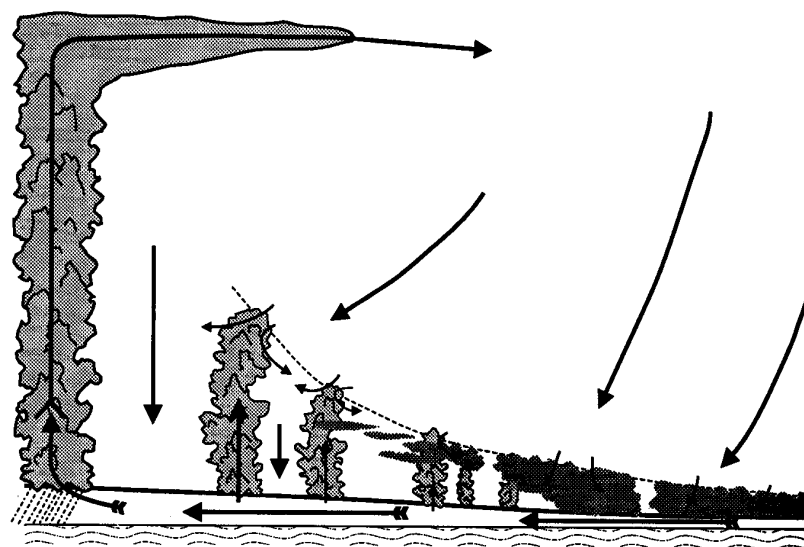
ΔT

How does the tropical overturning circulation respond to increased CO₂ ?



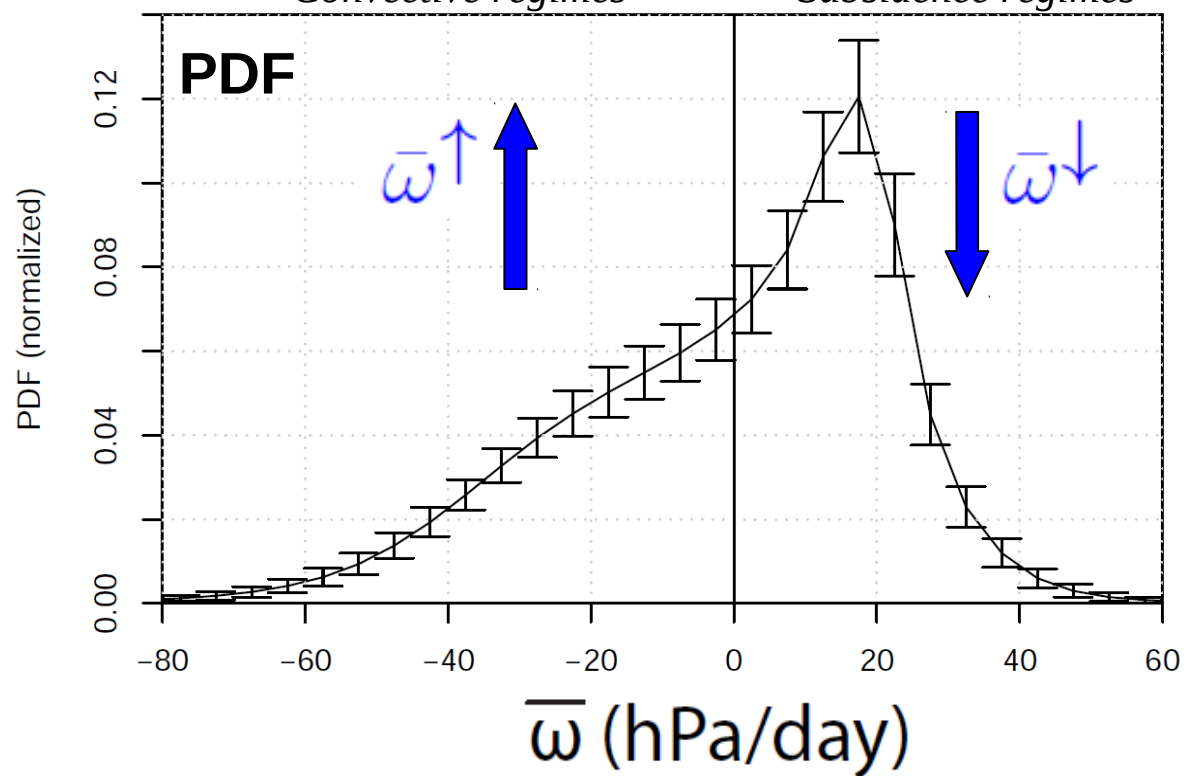
$$\Delta P = \underbrace{(\Delta E + \bar{\omega} \Delta \Gamma_q + \Delta H_q + \Delta V_q^\alpha)}_{\text{thermodynamical component}} + \underbrace{\Gamma_q \Delta \bar{\omega}}_{\text{dynamical component}}$$

Tropical Overturning Circulation



Convective regimes

Subsidence regimes



Change in circulation (%) predicted by CMIP5 models

... in multiple models, experiments and configurations

$$\frac{\Delta \bar{\omega}^{\uparrow}}{\bar{\omega}^{\uparrow}}$$

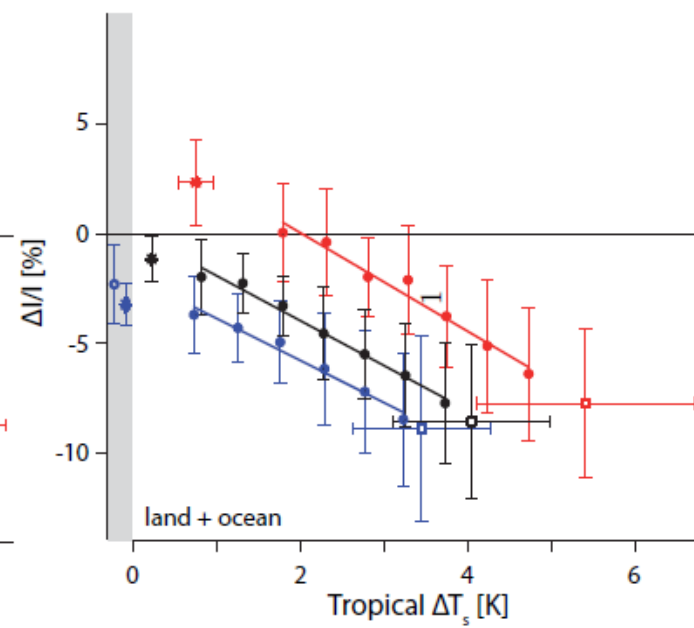
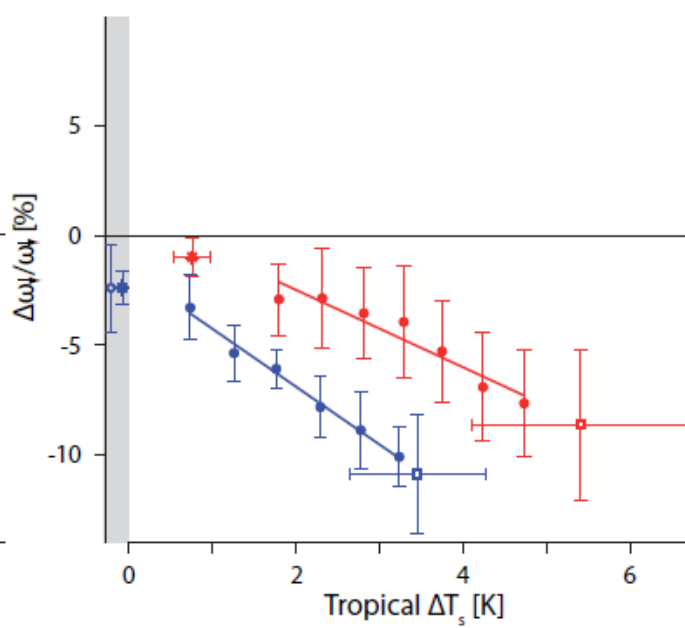
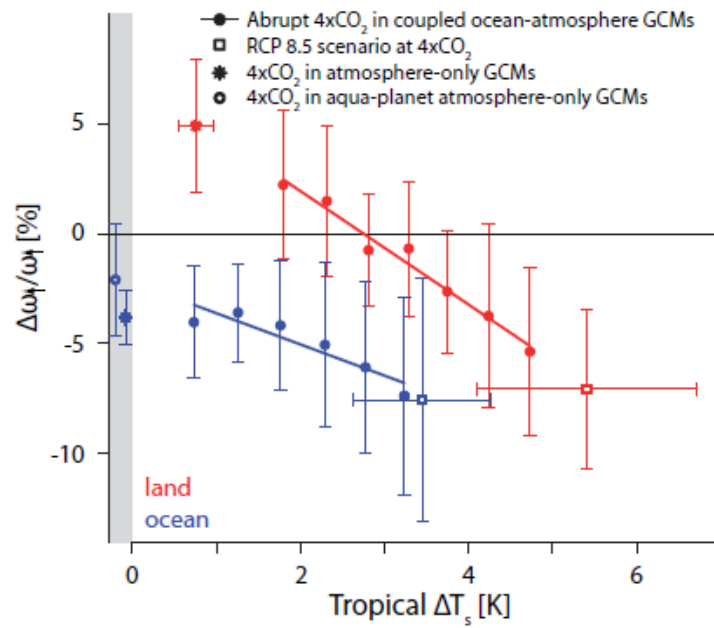
$$\frac{\Delta \bar{\omega}^{\downarrow}}{\bar{\omega}^{\downarrow}}$$

$$\frac{\Delta I}{I}$$

Change in large-scale rising motion

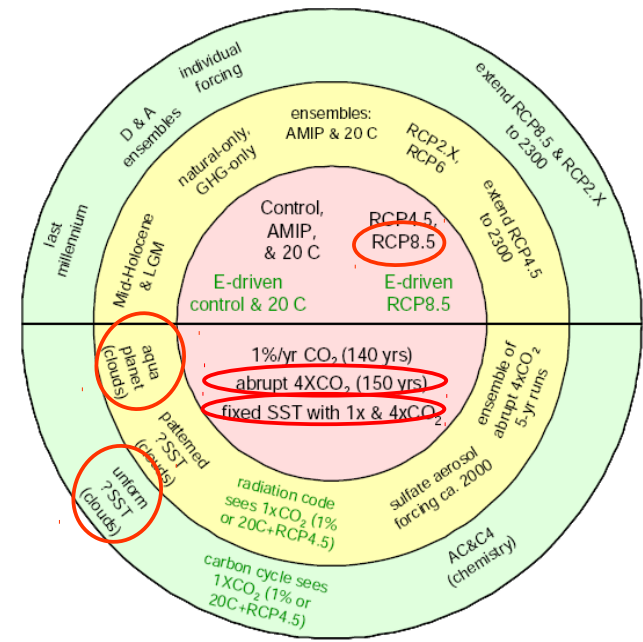
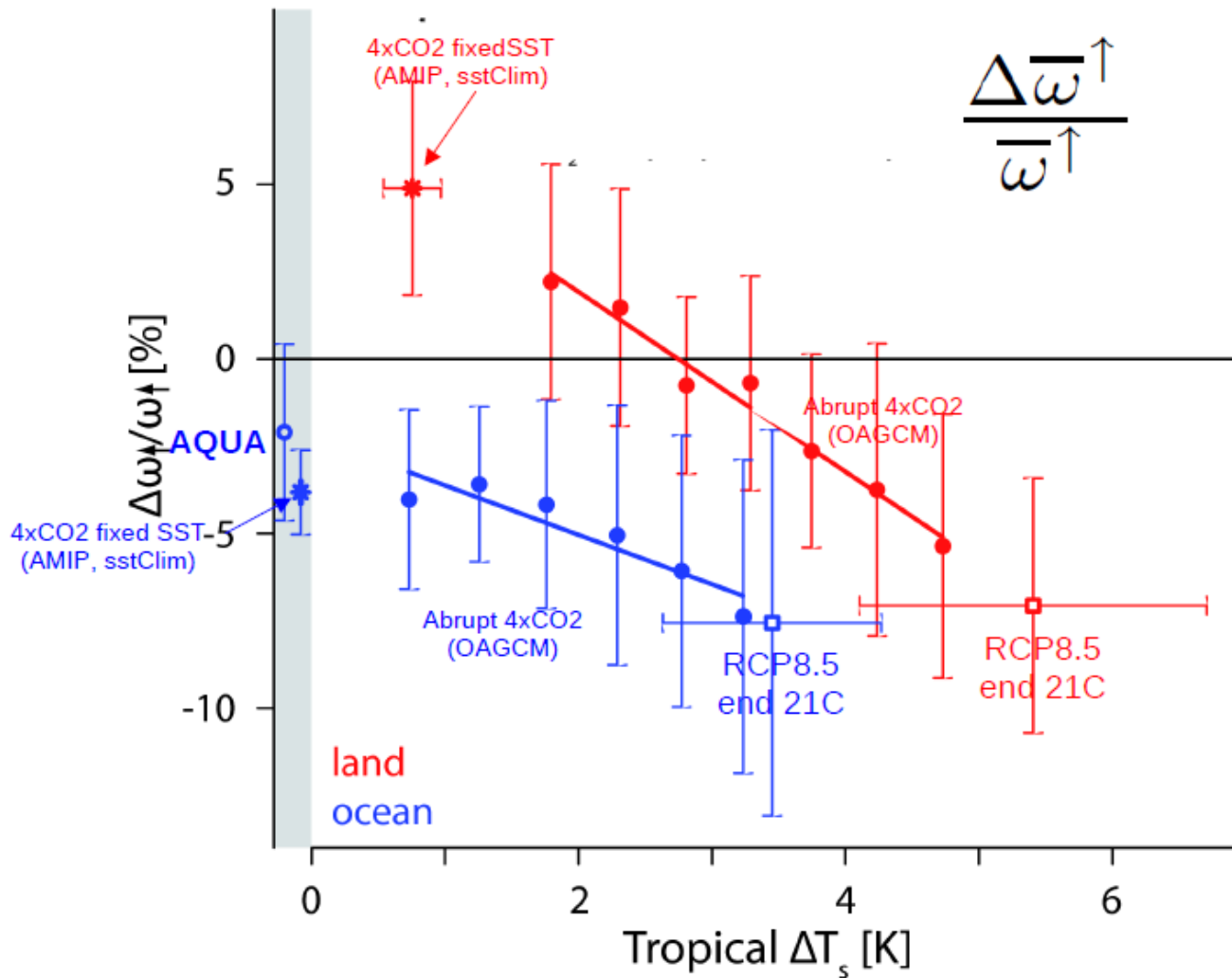
Change in large-scale subsidence

Change in circulation strength

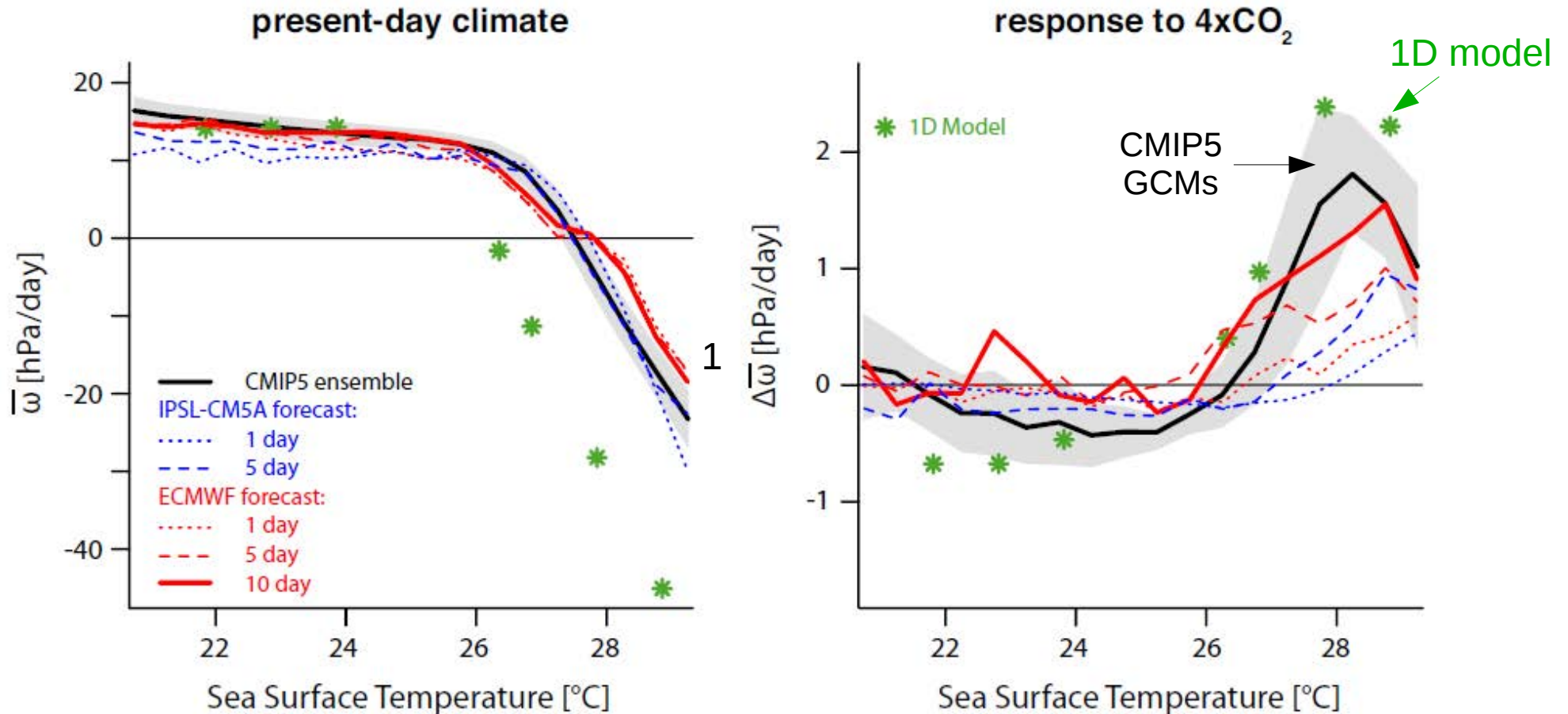


- Abrupt 4xCO₂ in coupled ocean-atmosphere GCMs
- RCP 8.5 scenario at 4xCO₂
- ★ 4xCO₂ in atmosphere-only GCMs
- 4xCO₂ in aqua-planet atmosphere-only GCMs

Change in large-scale rising motion



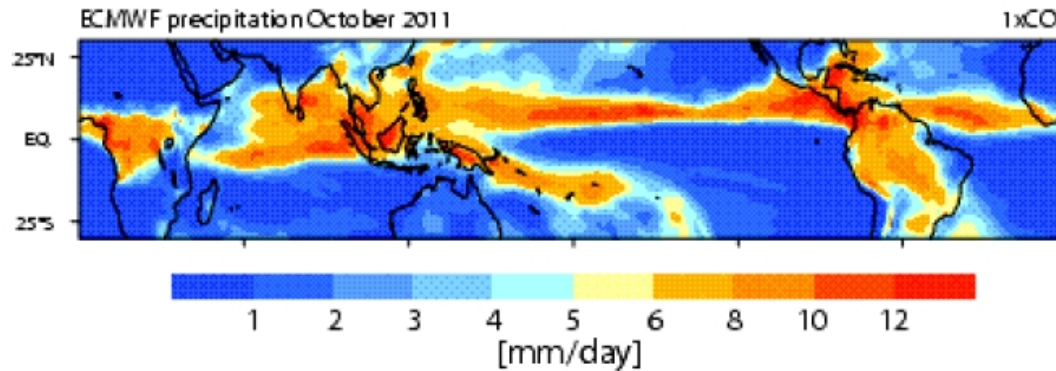
Physical Interpretation and Time Scale of the Dynamical Response to CO2 Radiative Forcing



Direct CO₂ effect on the tropical overturning circulation :

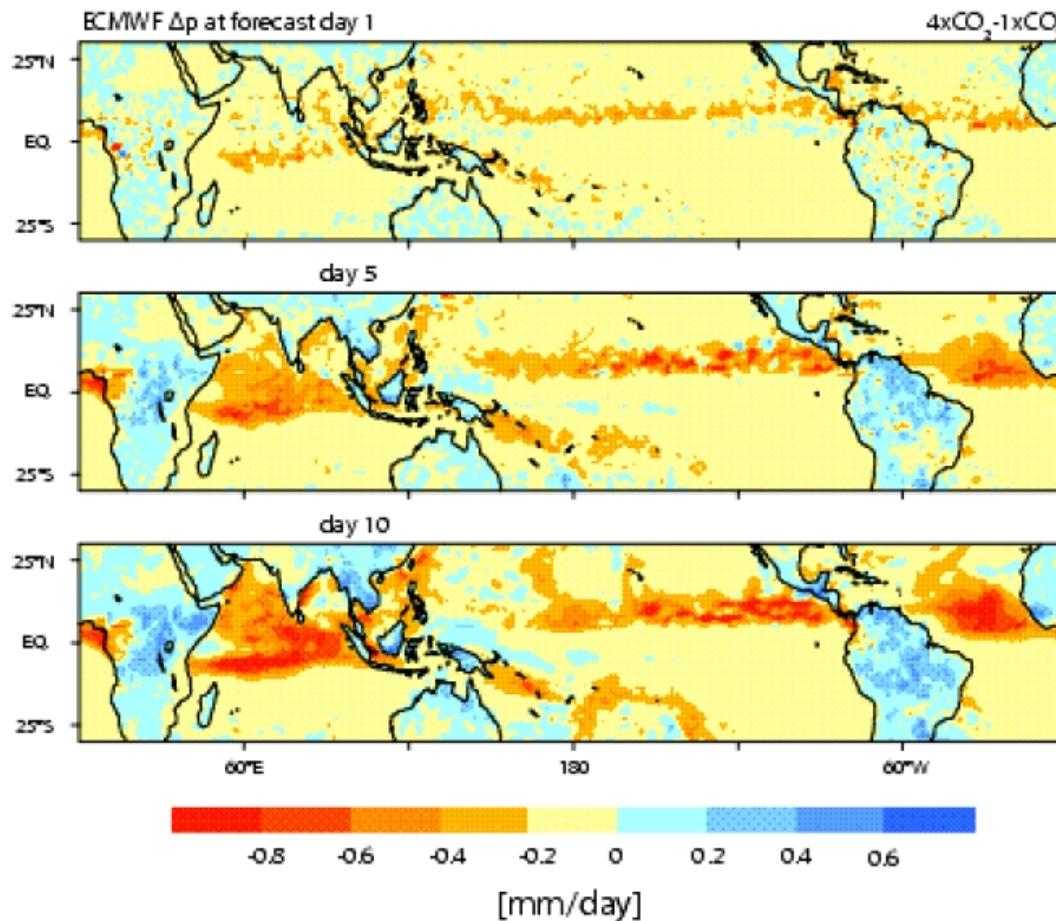
- Robust result (CMIP5 AGCMs, 1D model (in WTG mode), ECMWF IFS operational model, SP-CAM)
- Physical interpretation
- Controlled by (ultra) fast physical processes in convective regimes (half the eq response within ~ 5 days)

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 CO₂ 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 CO₂ 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