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Mechanisms of tropospheric cloud adjustment to CO_2 increase in CMIP5 models

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Recent studies on cloud adjustment to increasing CO_2:

- ☐ CMIP3/CFMIP1 models show large uncertainty (in either sign or magnitude) in cloud-related effective radiative forcings

Gregory and Webb 2008; Webb et al. 2013

- ☐ Some CMIP5 models shows **positive ΔSWcld** (using radiative kernel method) associated with **negative ΔC**

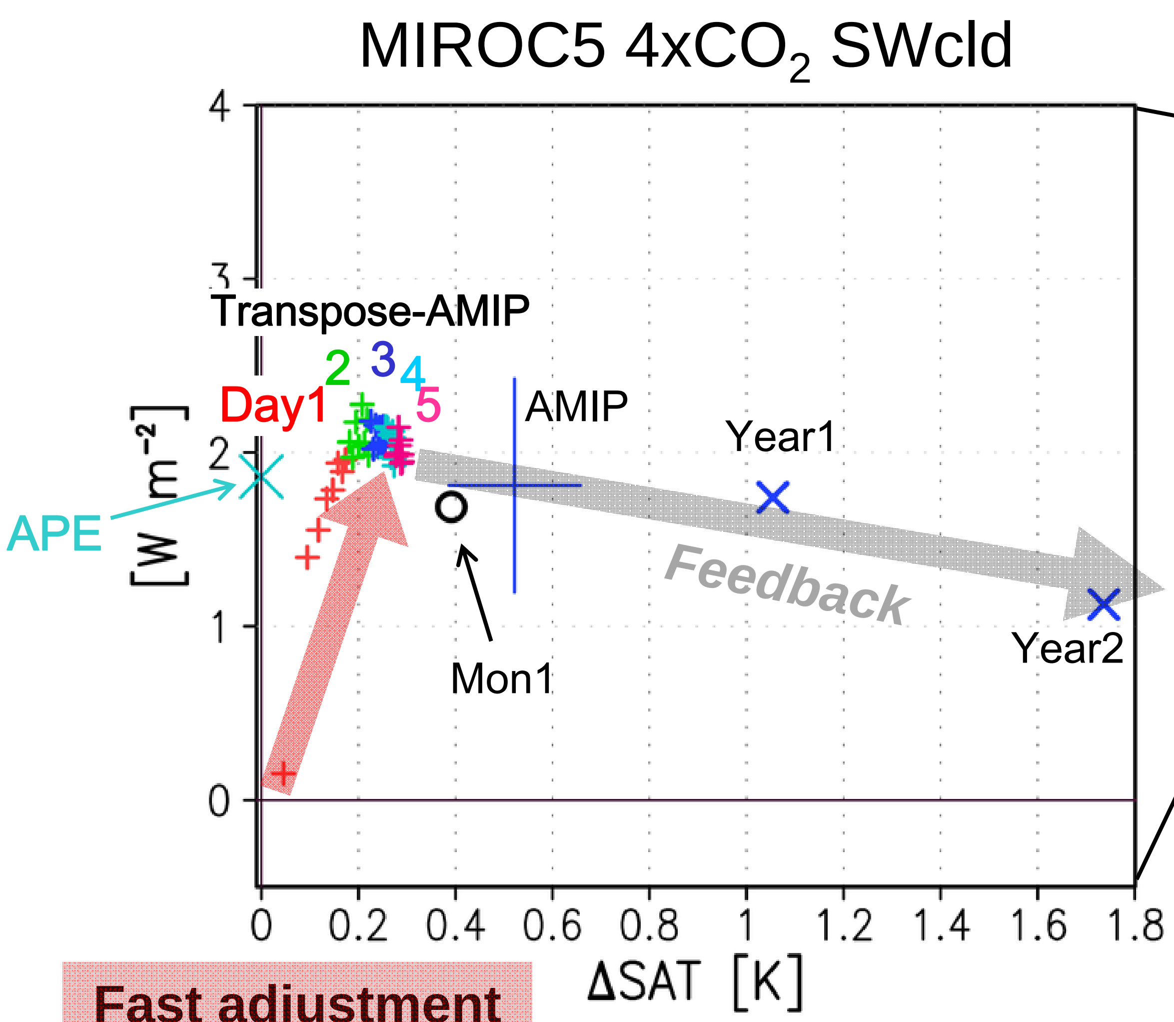
Zelinka et al. 2013; Tomassini et al. 2013

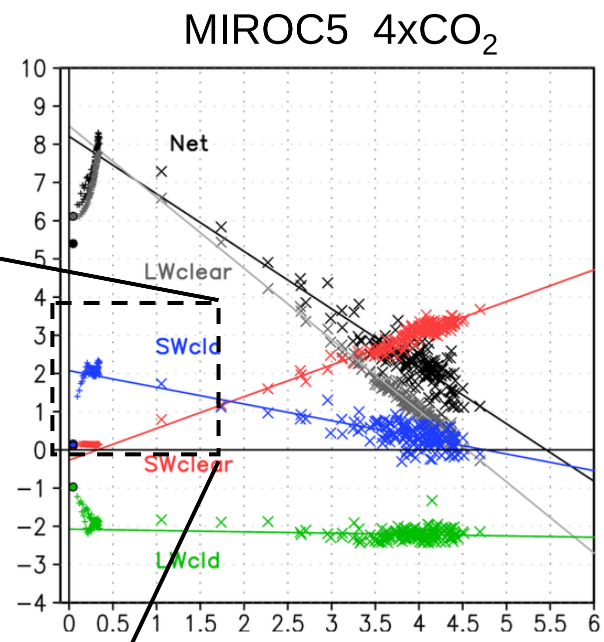
- ☐ A super-parameterized GCM shows **shoaling of PBL** and **positive ΔSWcld**
- ☐ **Reduced radiative destabilization** and **strengthened trade inversion** due to tropospheric warming are important for the shoaling of PBL

Wyant et al. 2012

What's the mechanism?
Is it robust among CMIP5 models?

Fast cloud adjustment



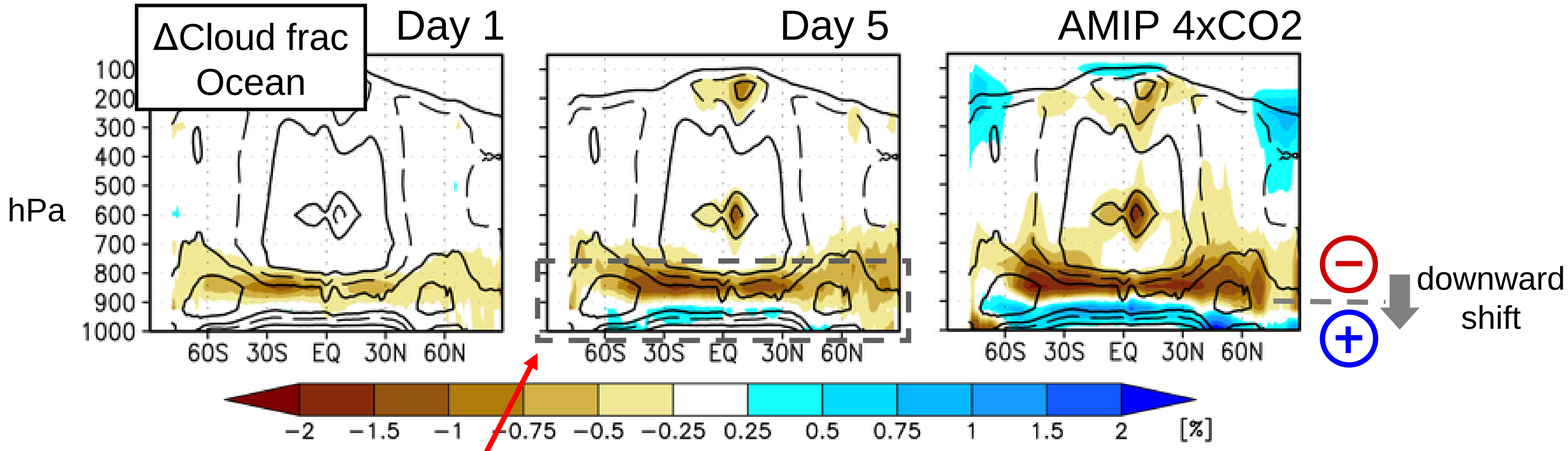


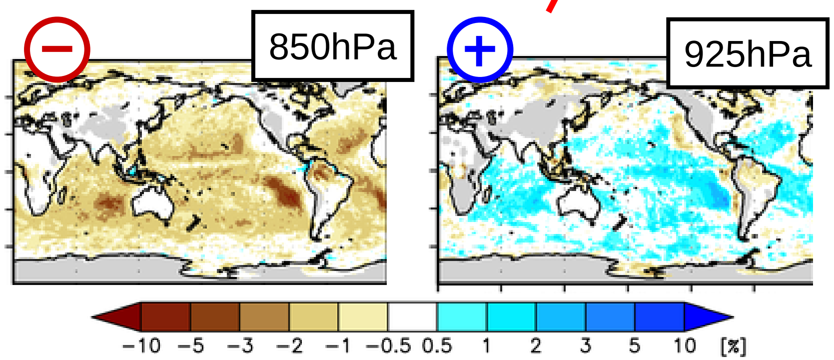
Fast adjustment

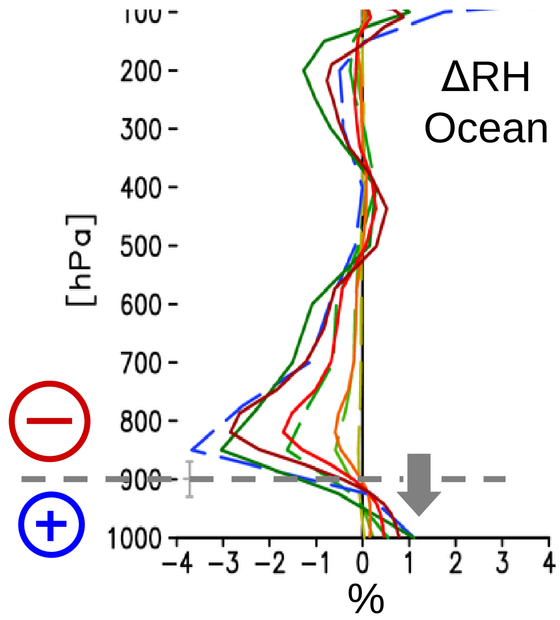
~2 days

Kamae and Watanabe (2012a)

Fast cloud adjustment

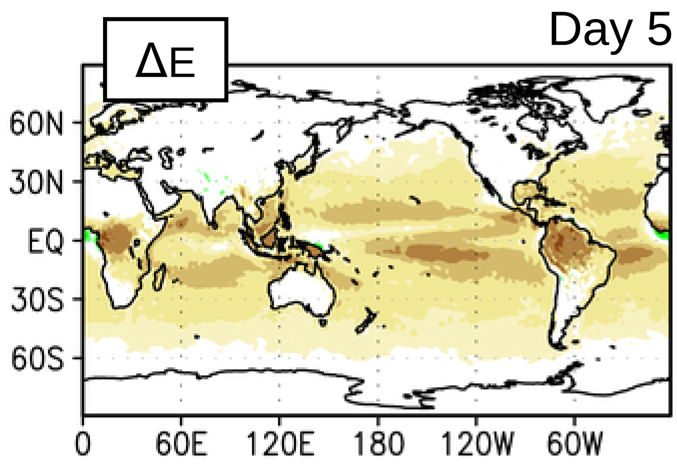


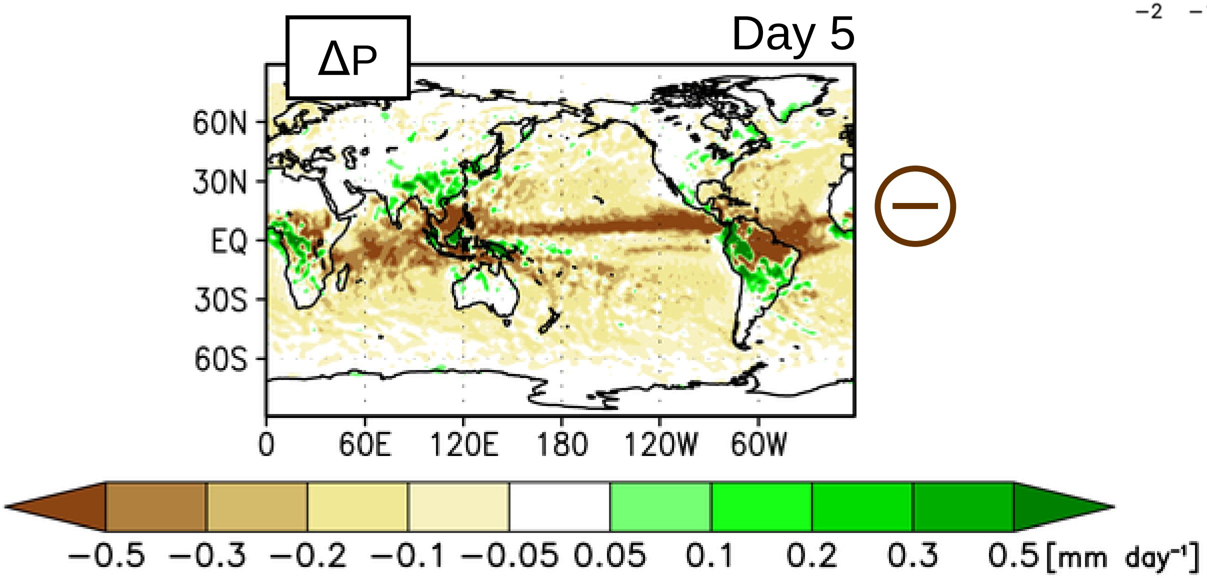


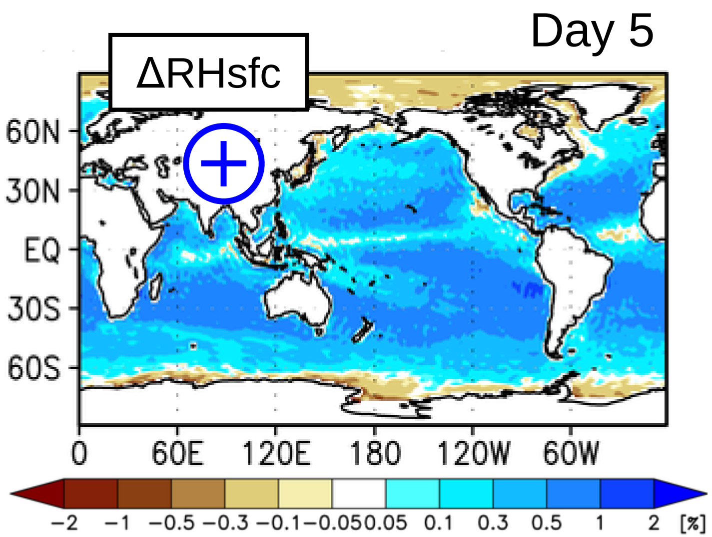


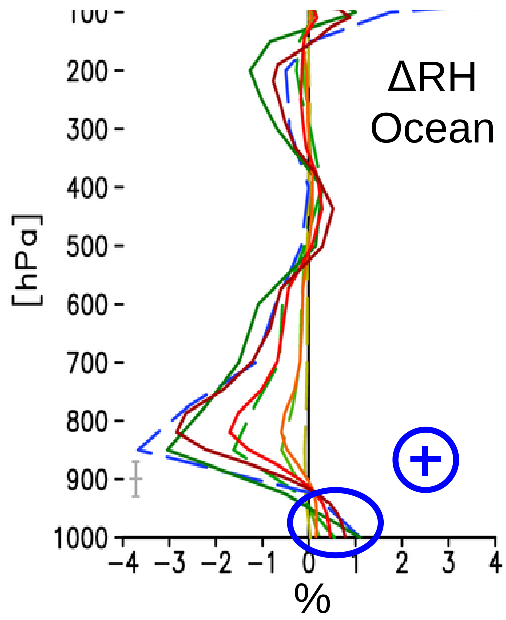
- ✓ Downward shift of cloud layer
- ✓ Lower tropospheric drying and cloud decrease
  → positive ΔSWcld

Suppressions of E and P





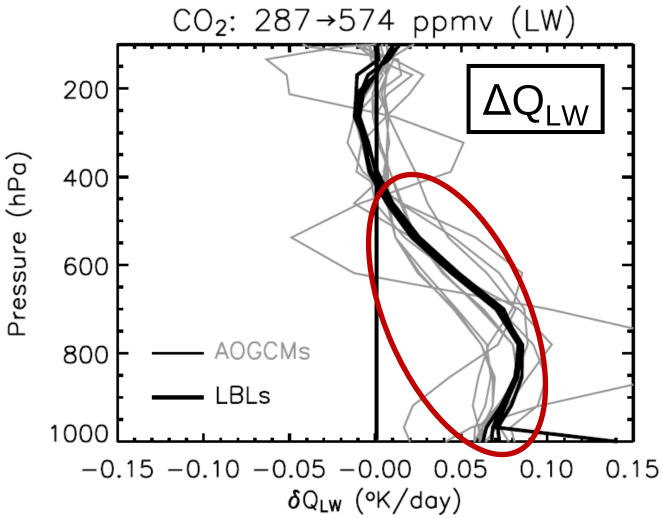




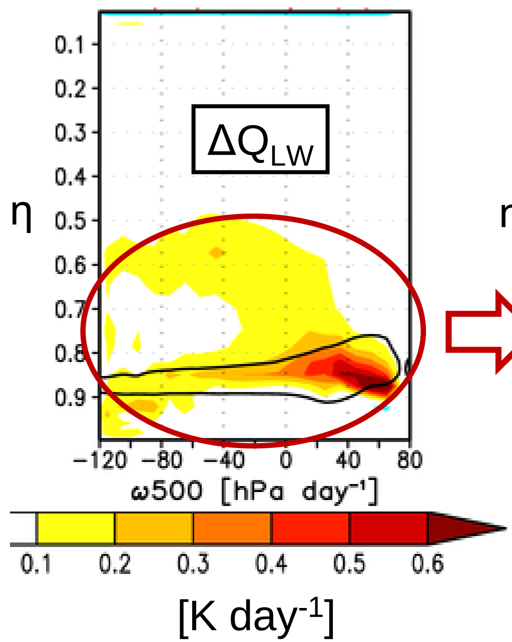
CO_2 increase → RHsfc increase → suppressed E & P

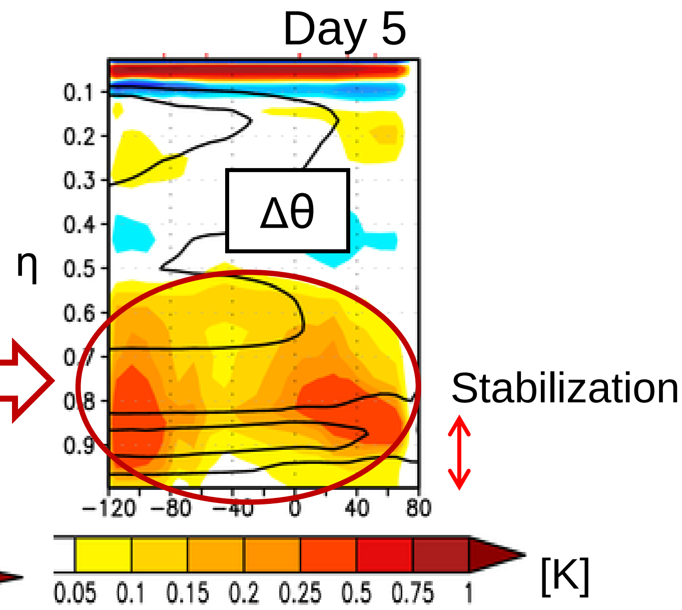
Consistent with Allen and Ingram (2002); Andrews et al. (2009); Cao et al. (2012)

Drying of troposphere



Collins et al. (2006)





Instantaneous CO_2 radiative forcing

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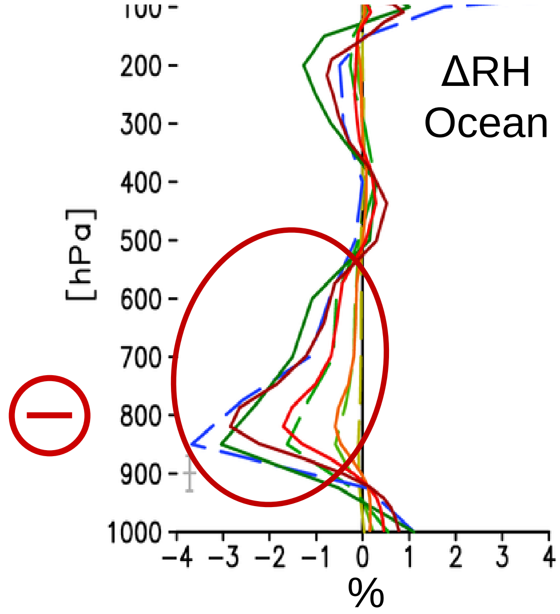
Tropospheric warming

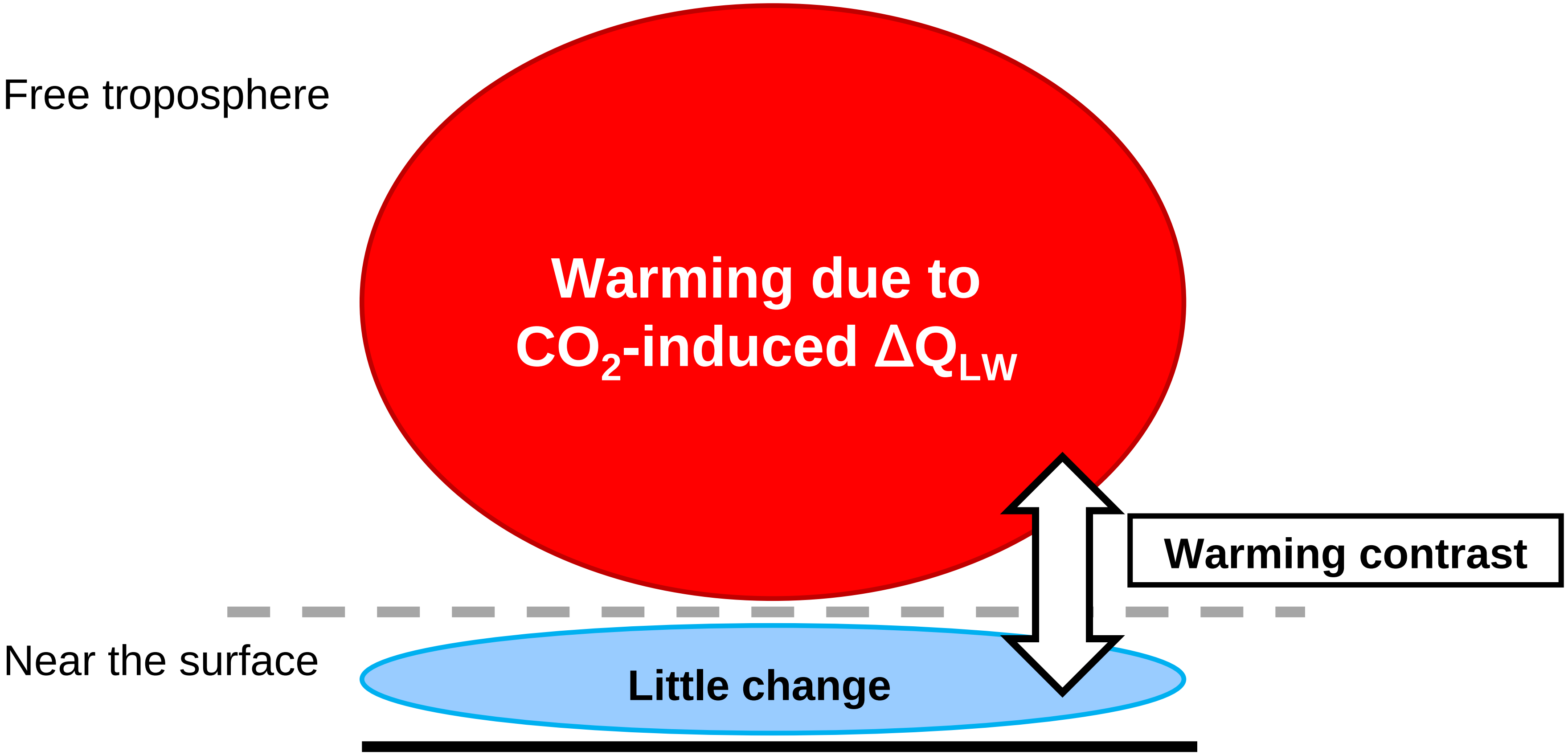
⇩

Drying of troposphere

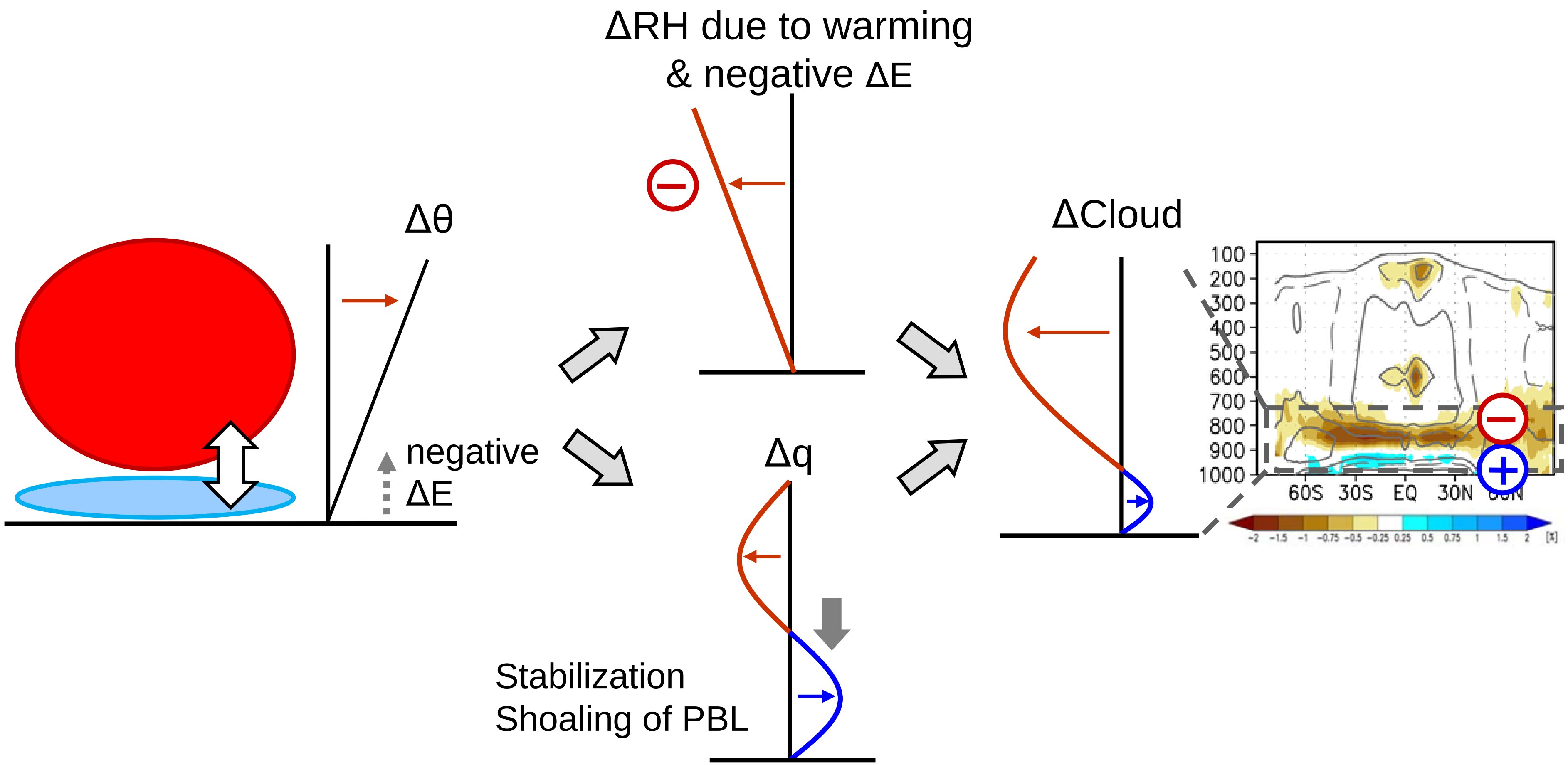


Consistent with Colman and McAvaney (2011)

Tropospheric adjustment

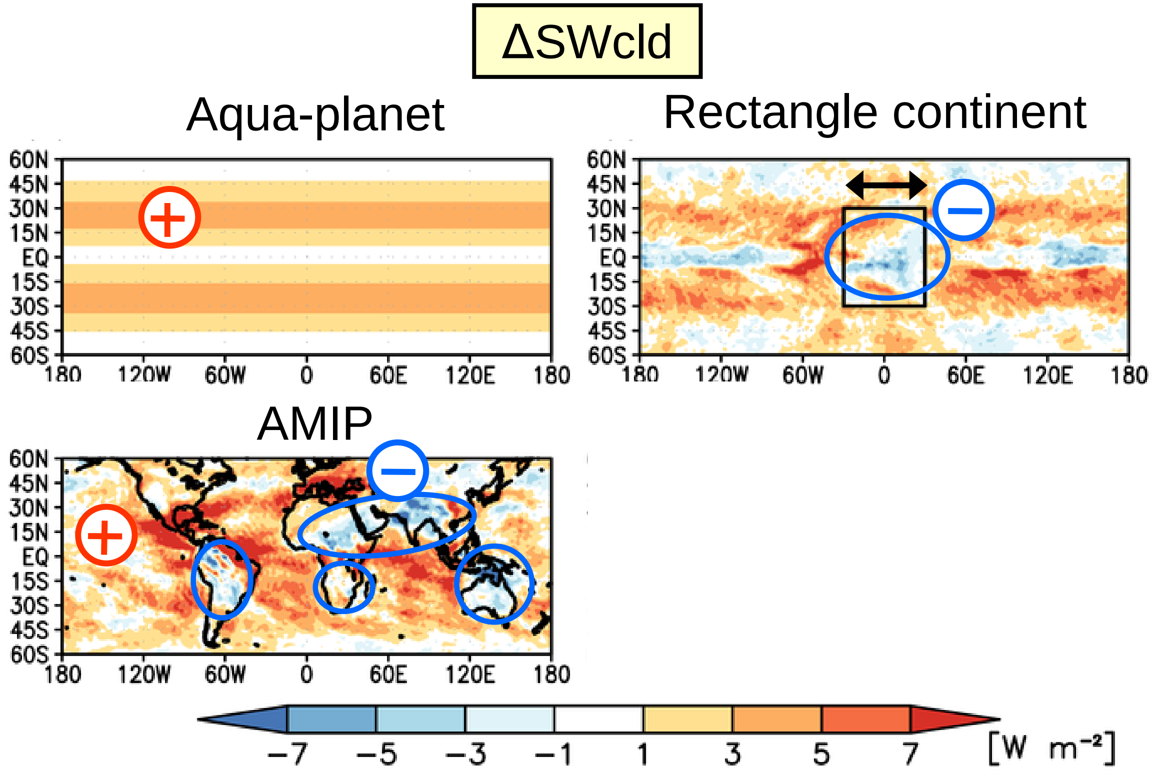


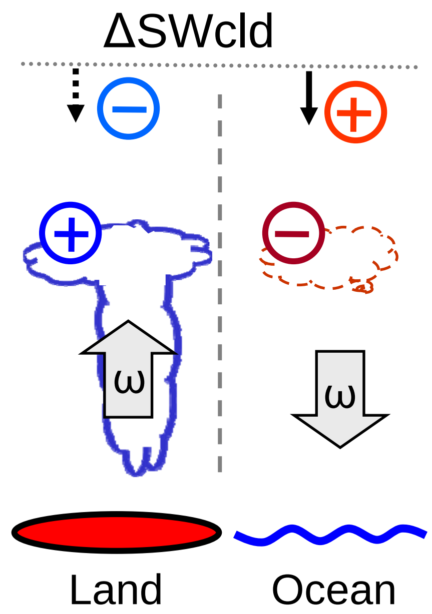
Mechanism of tropospheric cloud adjustment

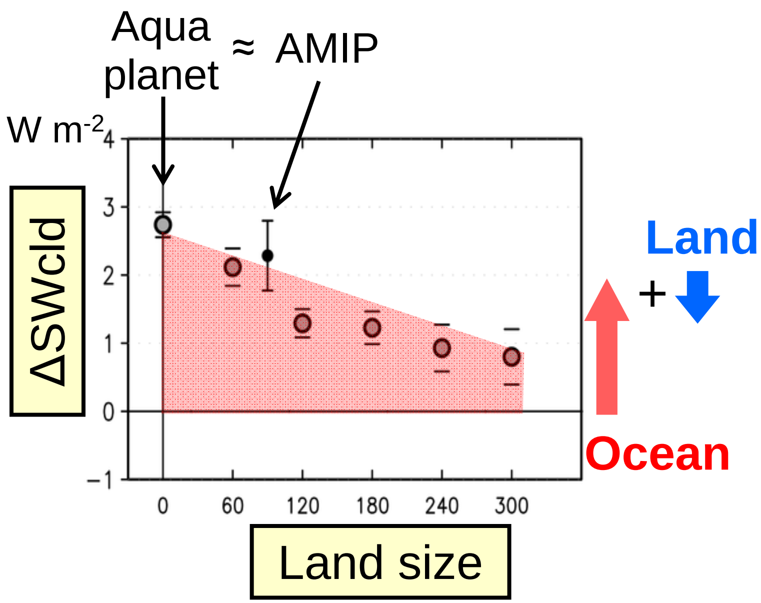


- ✓ Downward shift of low cloud layer
- ✓ Cloud decrease & positive ΔSWcld

Land adjustment

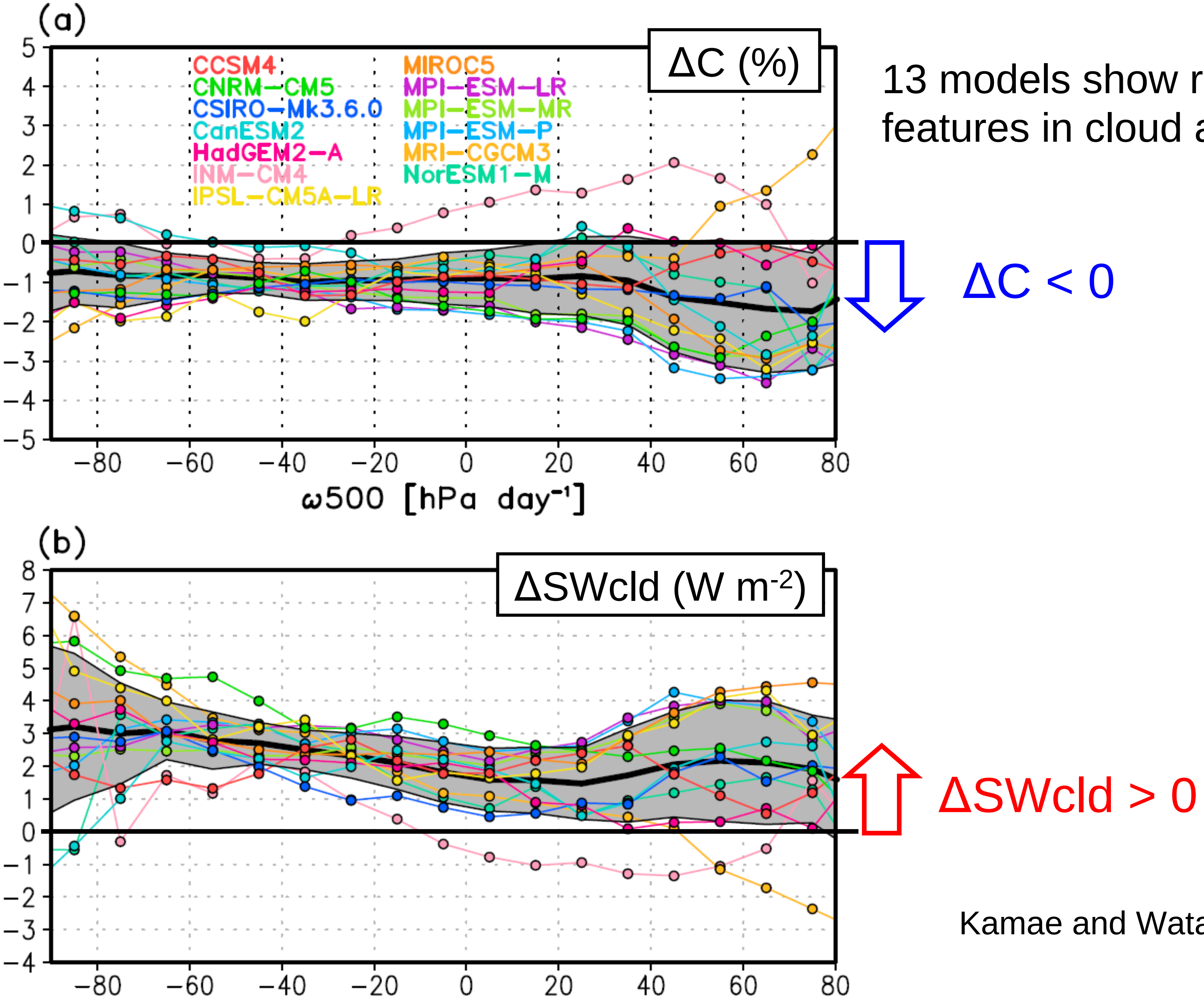






Cloud adjustment = "Pure" cloud adjustment + Land-warming effect (*minor*)

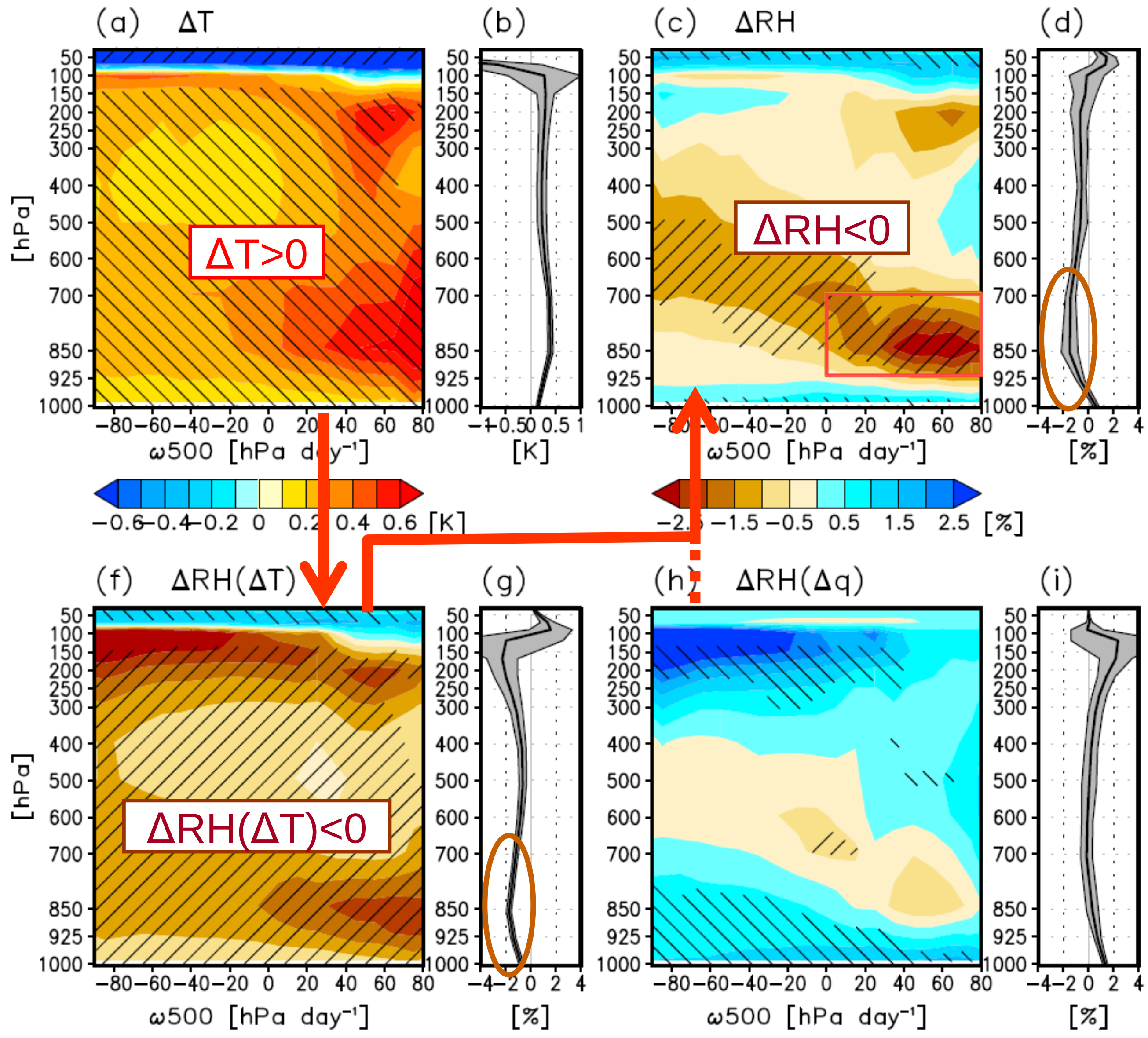
Robustness among CMIP5 models



13 models show robust features in cloud adjustment

Kamae and Watanabe (2012b)

Robustness among CMIP5 models



13 models mean (shade) and consistency (hatch)

4xCO_2-induced heating in the troposphere

↓

ΔT>0

↓

ΔRH(ΔT)<0

↓

ΔRH<0

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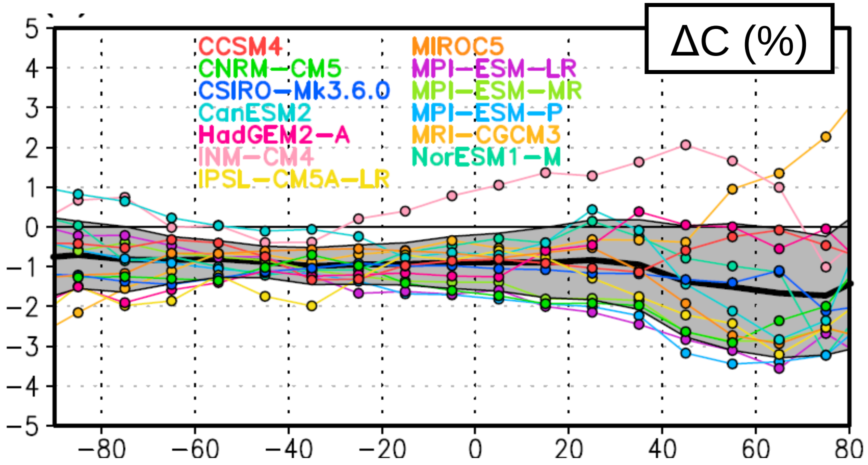
ΔC < 0 and ΔSWcld > 0

Possible sources of inter-model spread



Inter-model spread is NOT negligible

Δq (and resultant ΔRH(Δq)) in the lower troposphere

Kamae and Watanabe 2012b

4xCO_2-induced instantaneous radiative forcing

(Next presentation by T. Ogura)

Further investigations are needed with particular attentions on:

- ✓ Radiation codes
- ✓ Reproducibilities in the control runs (cloud water content, PBL depth, q, …)

in the individual models

Conclusions

Fast cloud adjustment (~2 days) to CO_2 increase

- Warming & drying of troposphere due to ΔQ_{LW}
- Downward shift of low cloud layer
- Cloud decrease & positive ΔSWcld

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"warming contrast" between the free tropos and near the surface

Land surface warming also contributes to the cloud adjustment, but its contribution is **minor**

Kamae, Y., and M. Watanabe, 2012a: Tropospheric adjustment to increasing CO_2: its timescale and the role of land-sea contrast. *Clim. Dyn.*, doi:10.1007/s00382-012-1555-1.

Kamae, Y., and M. Watanabe, 2012b: On the robustness of tropospheric adjustment in CMIP5 models. *Geophys. Res. Lett.*, **39**, L23808, doi:10.1029/2012GL054275.