The cloud radiative effect on the atmospheric energy budget and global mean precipitation

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July 5, 2014

Outline

Slab model $2\times CO_2$ versus control HadSM3 (3-hourly 15 hour snapshots), QUMP (annual) and MIROC3.2 (3-hourly) experiments.

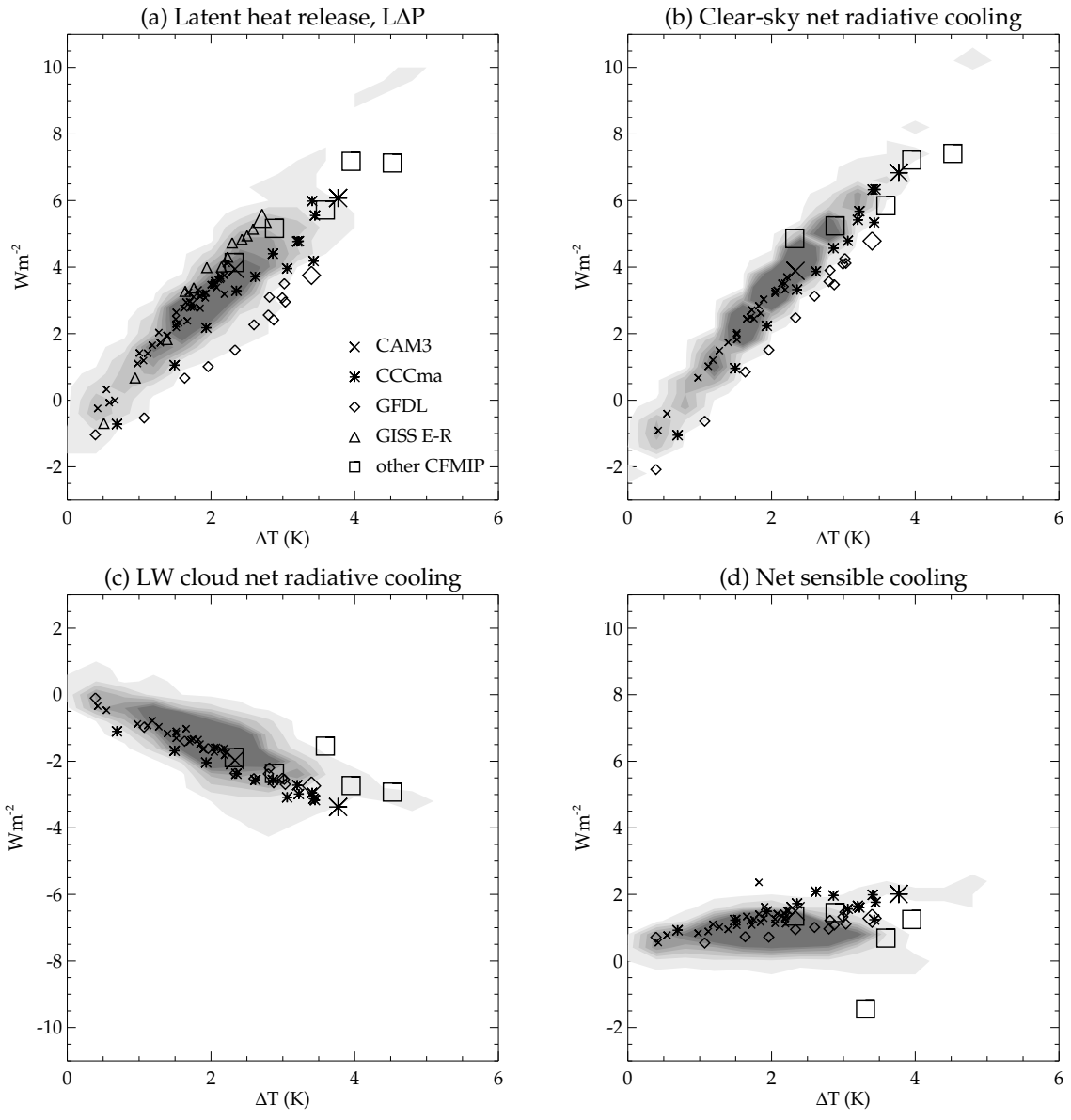
- Introduction and hypotheses
- Selected results
- Discussion

Introduction (1)

Try to understand the relatively robust nature of cloud impacts on atmospheric longwave flux changes during climate change.

With applications to why modelled global mean precipitation changes are in the range 1–3 $\%K^{-1}$.

Introduction (2): Radiative and turbulent flux changes



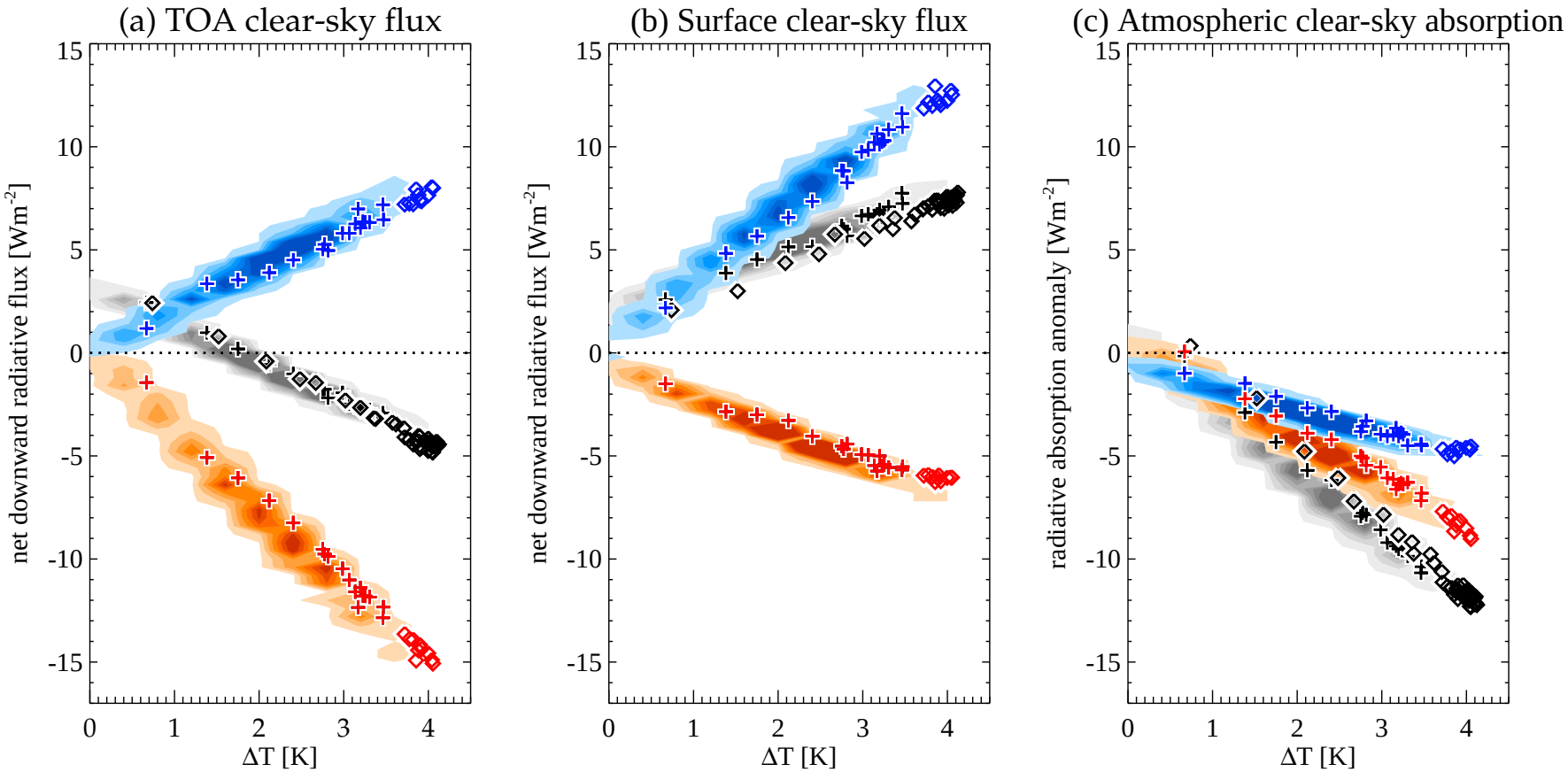
Clear-sky radiative cooling. (We think we understand that quite well?)

Turbulent fluxes. Sensible versus latent.

Cloud radiative cooling. (LW only.)

Source: (3).

Introduction (3): The clear-sky environment



All components **Temperature** **Water vapour**

See also (5; 1; 4)...

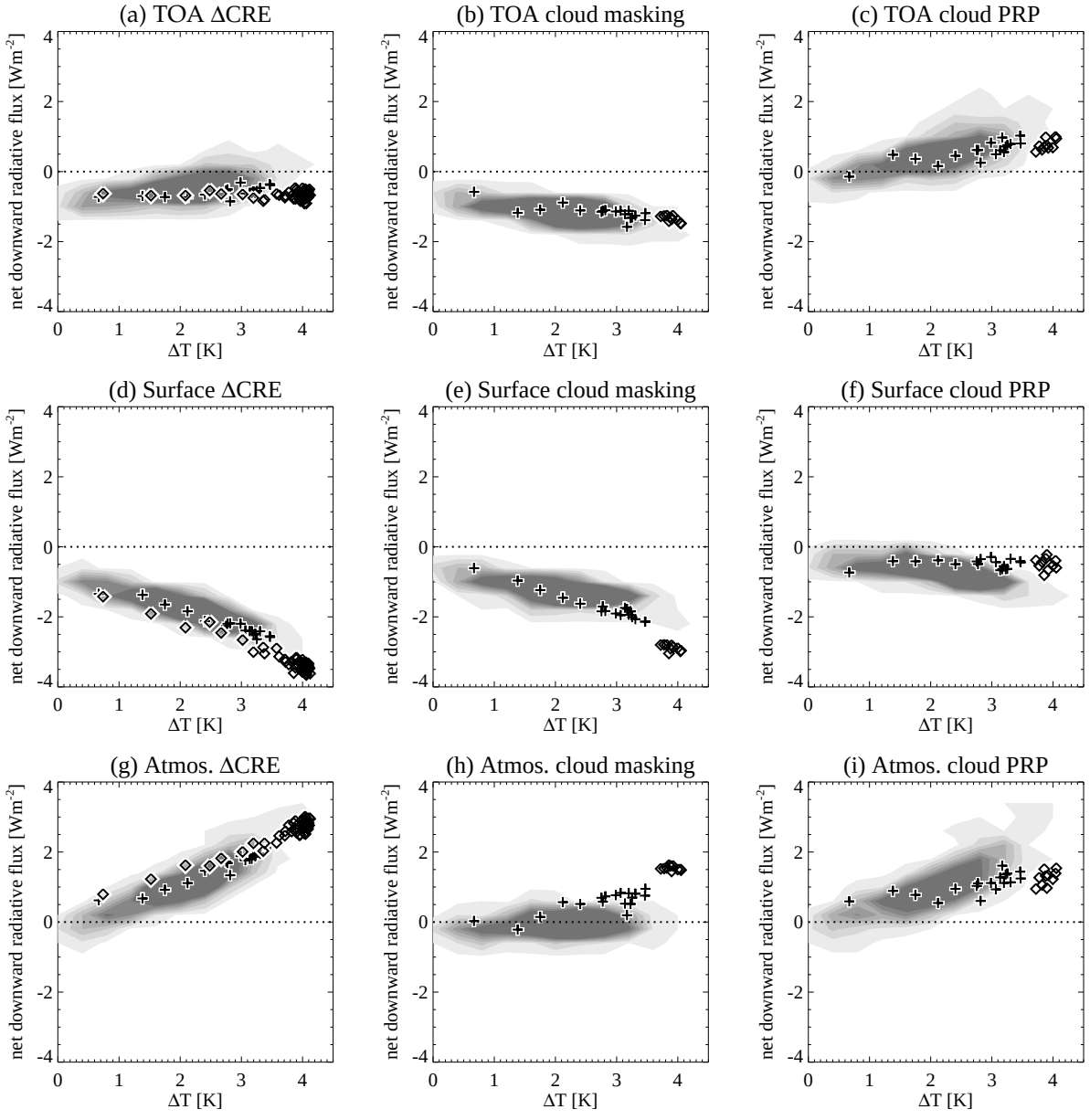
With a focus on the tropics, we ask...

Why are changes in cloud radiative effect robust across models?

Hypotheses and ideas:

1. The cloud masking effect.
2. FAT
3. Subtropical low cloud fraction changes are unimportant to LW?
4. Cloud bases to stay at the same pressure.
5. Geographical changes in ITCZ unimportant?

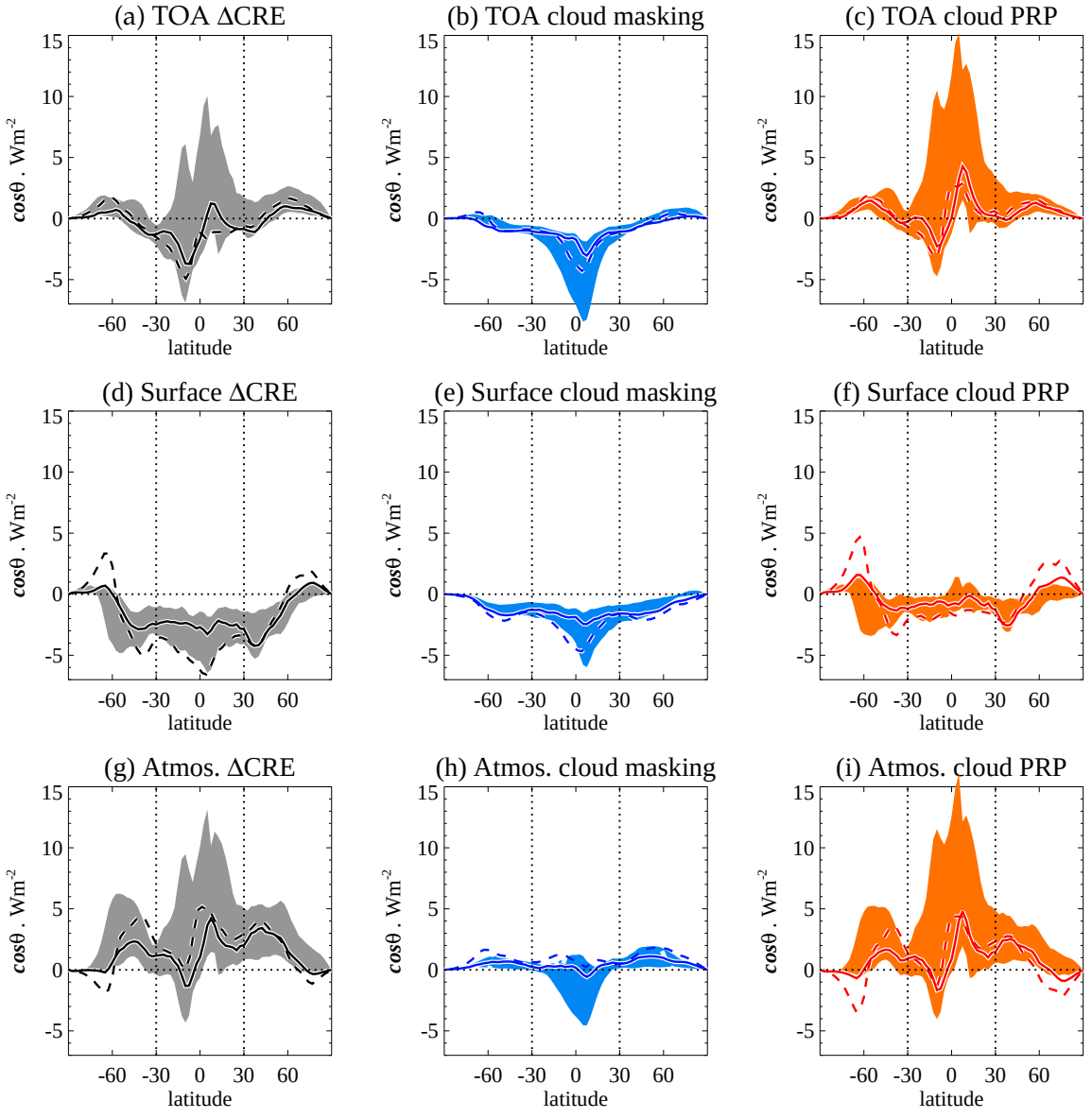
Results: global means



1. The cloud masking effect is indeed robust – but it doesn't explain everything.

The results are similar in the tropics.

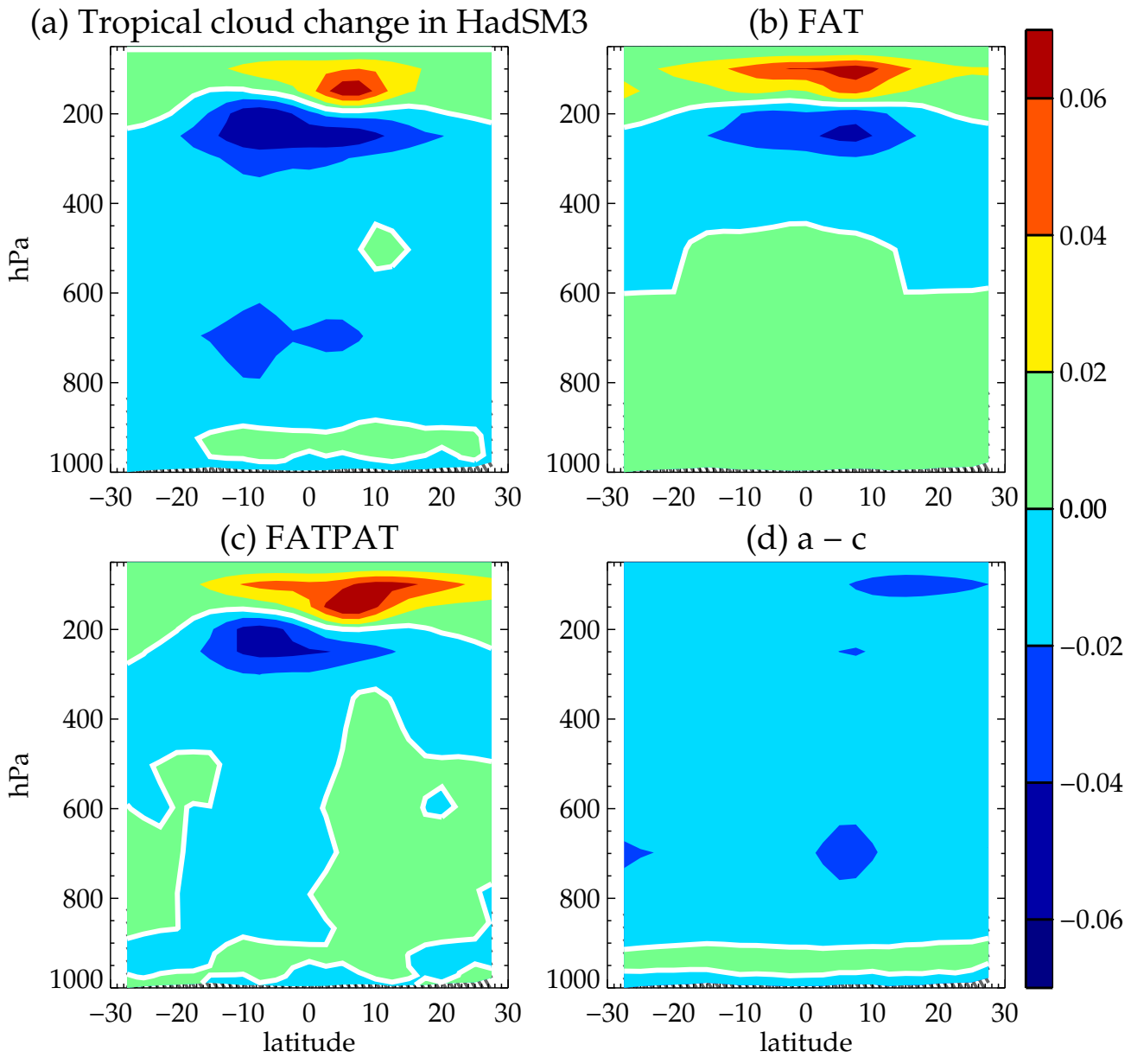
Now focus on the tropics



HadSM3 (solid)
MIROC (dash)
QUMP (shade)

These series are weighted by $\cos\theta$, so you can see how each region contributes to global mean ΔCRE.

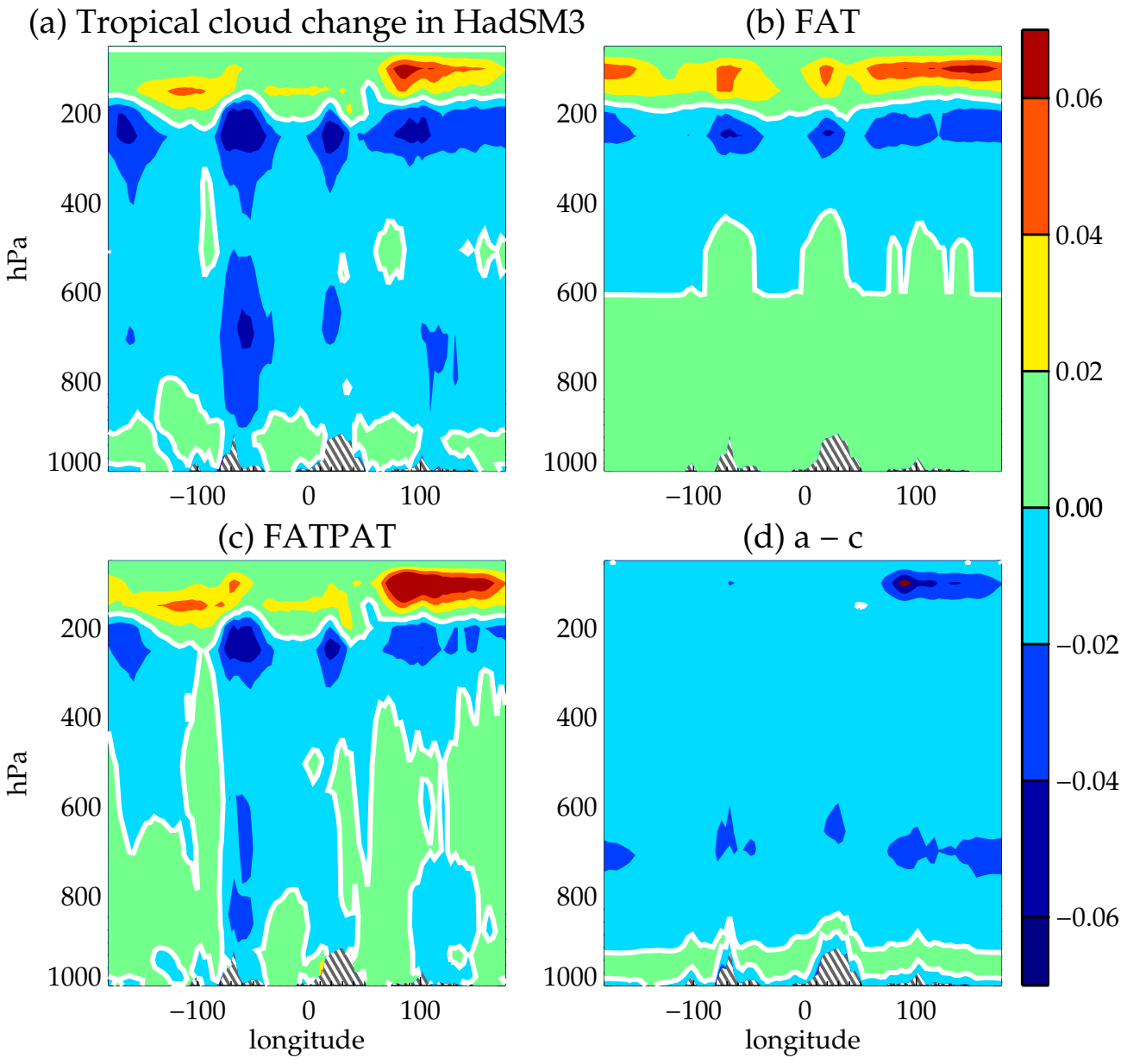
Tropical cloud changes (as a function of latitude)



FAT: FAT hypothesis of (2).

FATPAT: FAT vertical cloud means, but rearranged horizontally to mimic $2\times CO_2$.

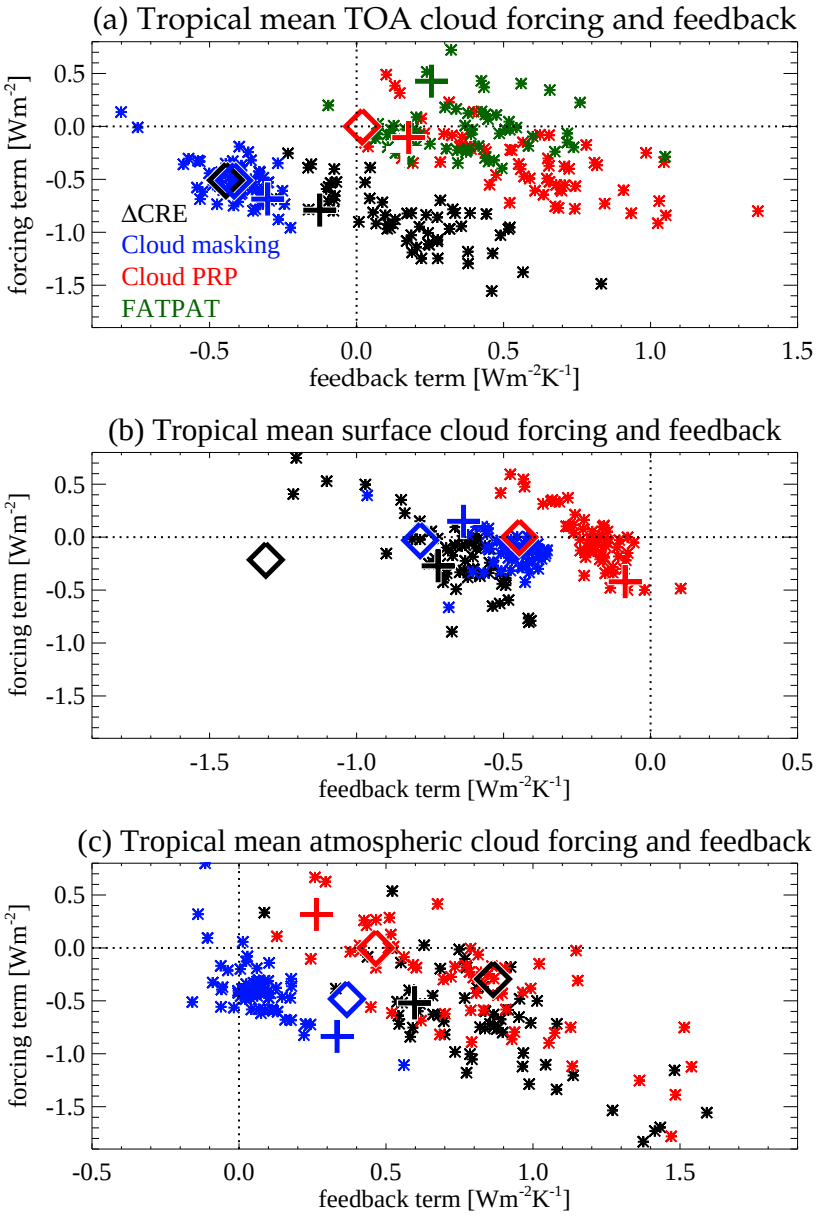
Tropical cloud changes (as a function of longitude)



FAT: FAT hypothesis of (2).

FATPAT: FAT vertical cloud means, but rearranged horizontally to mimic $2\times CO_2$.

Does FAT predict tropical PRP?

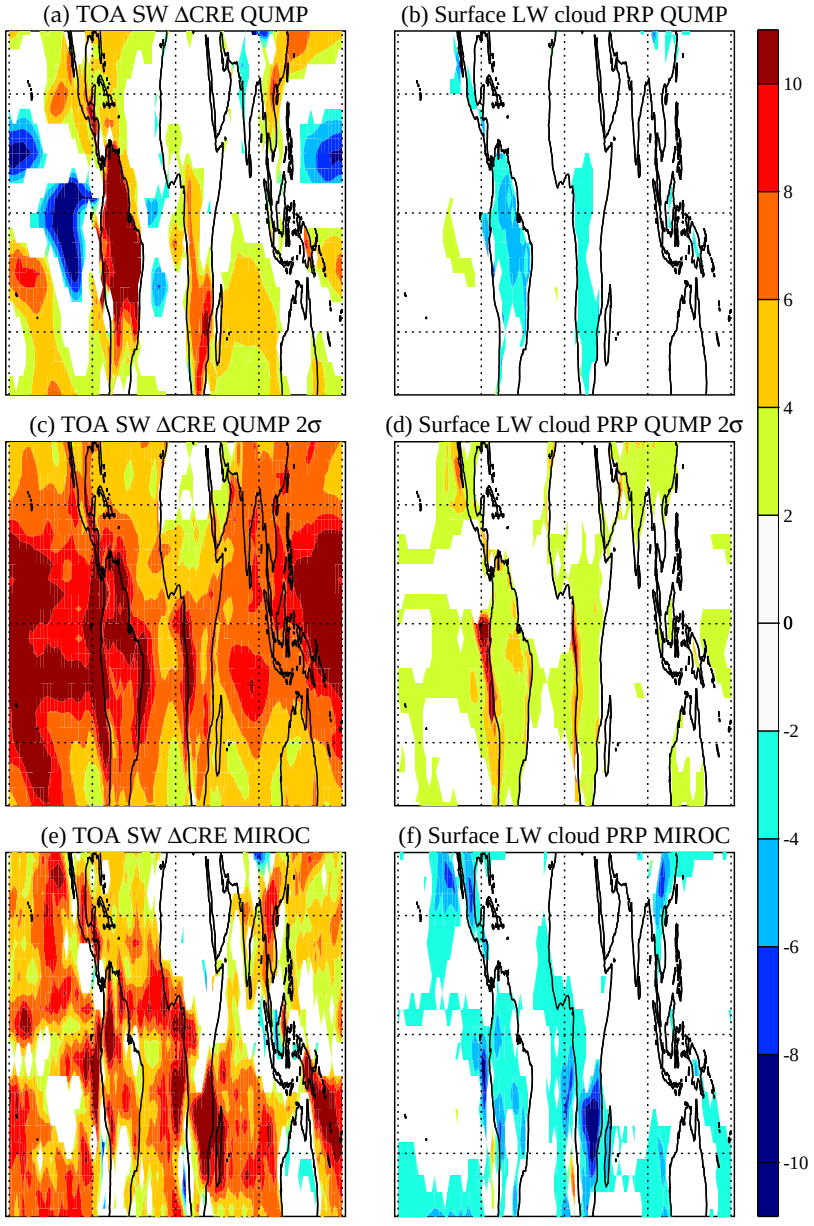


HadSM3 (big cross)
MIROC (big diamond)
QUMP (stars)

2 Not bad, but not as well as it predicts cloud cover above 500 hPa. Not always the right sign.

(Notice also the other panels and the correlations between forcings and feedbacks.)

Are changes in subtropical low cloud important?



Surface LW vs Surface SW (data available)

3. Differences in SW flux changes are very large – both in their magnitude and differences between regions. LW fluxes considerably less so outside of specific regions.

Evaluate the hypotheses and ideas...

1. The cloud masking effect. Yes it's quite robust. No, it doesn't dominate ΔCRE.
2. FAT Controls relevant mid-high cloud amount. Doesn't always match PRP satisfactorily (but our treatment is a little approximate.
3. Subtropical low cloud fraction changes are unimportant to LW? It appears that way. Supported by idealised work, but more probably needed.
4. Cloud bases to stay at the same pressure. ✓
5. Geographical changes in ITCZ unimportant? ✓ We've done some extra simulations.

$\Rightarrow$ **It is difficult to imagine GCMs that produce much larger precipitation increases per degree warming within our current understanding.**

Perspective

- I have presented the "forcings and feedbacks" perspective. It's a helpful but arbitrary breakdown.

- An alternative "dynamical perspective" might be useful at TOA:
  - FAT maintains cloud tops at almost the same temperature. Cloud OLR stays almost the same.
  - Surface and atmospheric temperatures increase, increasing OLR.
  - Weak positive ΔCRE *should* be generated as clouds mask the increasing OLR.
  - In our GCMs, TOA ΔCRE is quite close to zero, but it's negative! FAT's slight overestimate of high cloud increase may be important or further unresolved issues for mid and low level cloud.

[1] R. A. Colman and B. J. McAvaney. On tropospheric adjustment to forcing and climate feedbacks. *Clim. Dyn.*, 36:1649–1658, 2011.

[2] D. L. Hartmann and K. Larson. An important constraint on tropical cloud-climate feedback. *Geophys. Res. Lett.*, 29:1951–1954, 2002.

[3] F. H. Lambert and M. J. Webb. Dependency of global mean precipitation on surface temperature. *Geophys. Res. Lett.*, 35:doi:10.1029/2008GL034838, 2008.

[4] A. G. Pendergrass and D. L. Hartmann. The atmospheric energy constraint on global-mean precipitation change. *J. Clim.*, 27:757–768, 2014.

[5] M. Previdi. Radiative feedbacks on global precipitation. *Environ. Res. Lett.*, 5:doi:10.1088/1748–9326/5/2/025211, 2010.