Tropical Cloud Response to quadrupling CO_2 in SP-CCSM: Preliminary results

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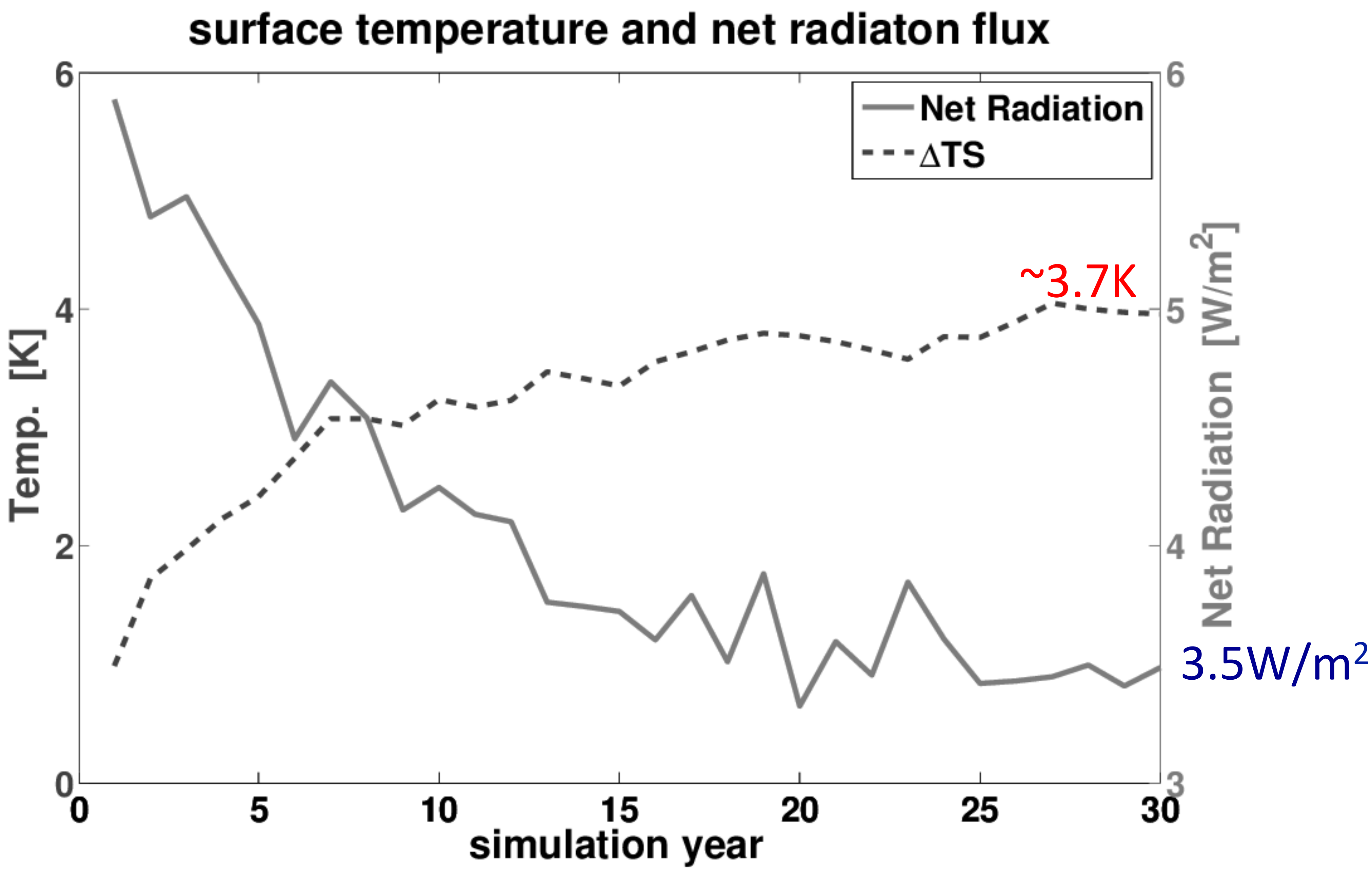
Thanks to Cristiana Stan for sharing SP-CCSM data.

SP-CCSM Response to 4xCO_2

- Cristiana Stan has performed an experiment in which CO_2 is instantaneously quadrupled in SP-CCSM, and the climate system (including a fully coupled ocean) evolves over ~35 years. A similar control run is performed with unchanged CO_2.
- This framework for studying cloud responses to increased CO_2 and warming was developed by Gregory et al (2004) and Gregory & Webb (2008), who identified separate rapid and slow responses to CO_2
    - Rapid cloud responses are caused by the direct effects of CO_2 on cloud, e.g., more downwelling LW radiation on low clouds.
    - Slow responses are related to temperature changes and are intended to identify temperature-dependent feedbacks.
- Wyant et al (2012) looked rapid response to 4xCO_2 in SP-CAM over a fixed SST and found a monsoonal response with precipitation and cloud in the tropics shifting to the warmed land areas.

SP-CCSM Reponse to 4xCO2 (from Cristiana)

- SP-CCSM warms quickly over ~6 years, more gradually later.

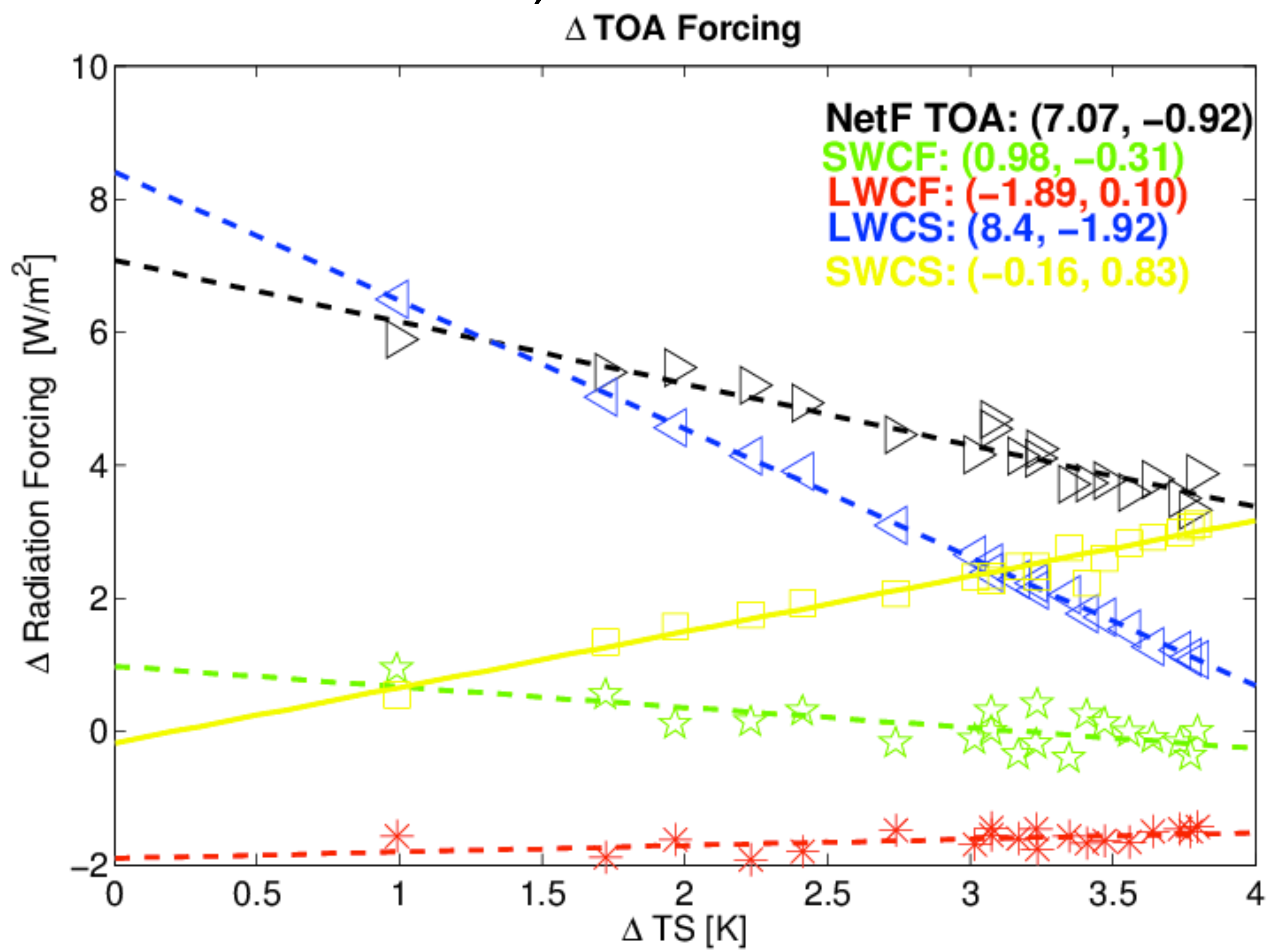


Courtesy Li Xu & C. Stan

- **UW Plan:** Look at (non-Arctic) cloud response to 4xCO_2, try to understand transient adjustment to CO_2.
- **Note:** Preliminary results. We're just getting started...

SP-CCSM Reponse to 4xCO2 (Continued)

- Gregory-Webb diagram shows evolution of radiative quantites (Net TOA flux, SWCF, LWCF, ...) as a function of surface temperature.



Courtesy Li Xu & C. Stan

- Note that SW cloud radiative effect (green) is close to zero so that the rapid response to CO2 (cloud thinning) is apparently cancelled by the temperature-dependent response.
- LW CRE (includes CO2 masking) seems to weaken with time as well.

Breaking down response to $4xCO_2$

	Global	Tropics	Extratropics
TS, K	288 (+3.8)	298 (+3.2)	277 (+4.5)
PRECT, mm/d	3.1 (+0.06)	3.4 (+0.09)	2.8 (+0.04)
CLDTOT, %	54 (-0.5)	48 (-0.5)	59 (-0.3)
SWCF, W/m^2	-55 (+0)	-62 (+1.5)	-47 (-1.7)
LWCF, W/m^2	32 (-1.6)	36 (-2.5)	28 (-0.6)

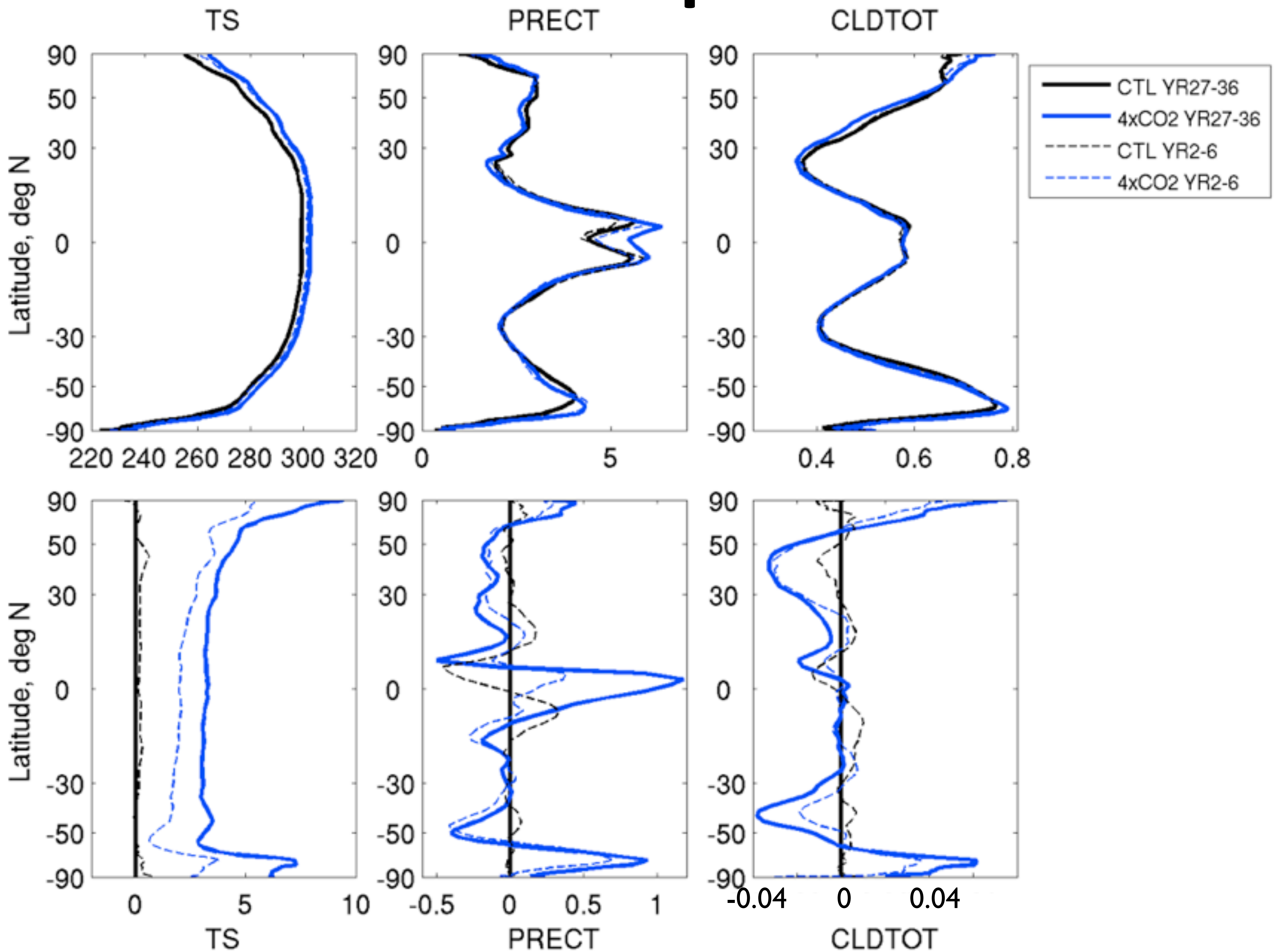
CTL YRS 27-36 → 32

Δ(4x-CTL) YRS 27-36 → (-1.6)

Stronger in 4x
Weaker in 4x

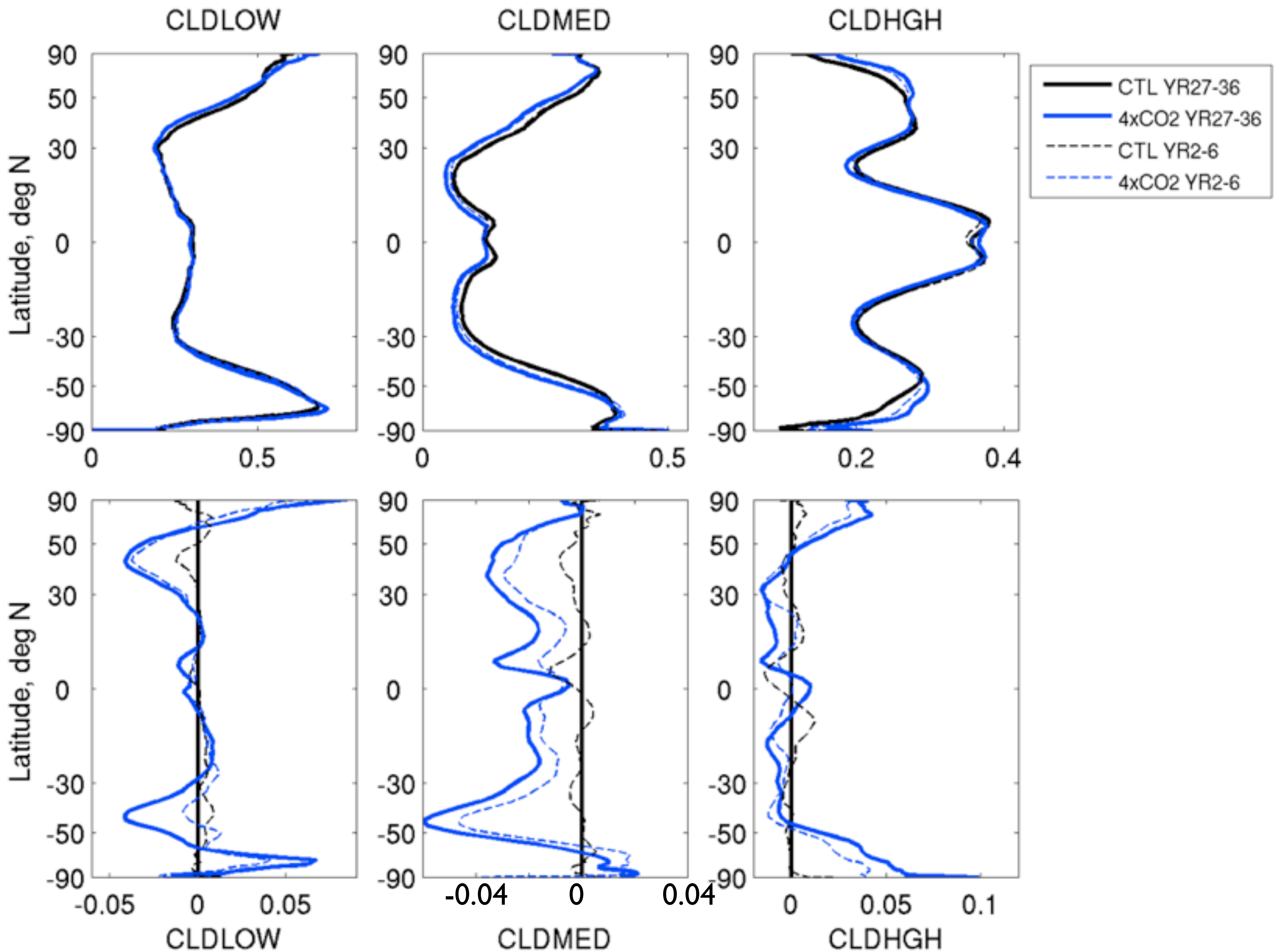
- Substantial warming accompanied by small change in precipitation.
- Slight decreases in cloud matched by weaker cloud forcing, except for SW in polar regions (partly due to ice loss).

SP-CCSM Global Response to 4xCO2



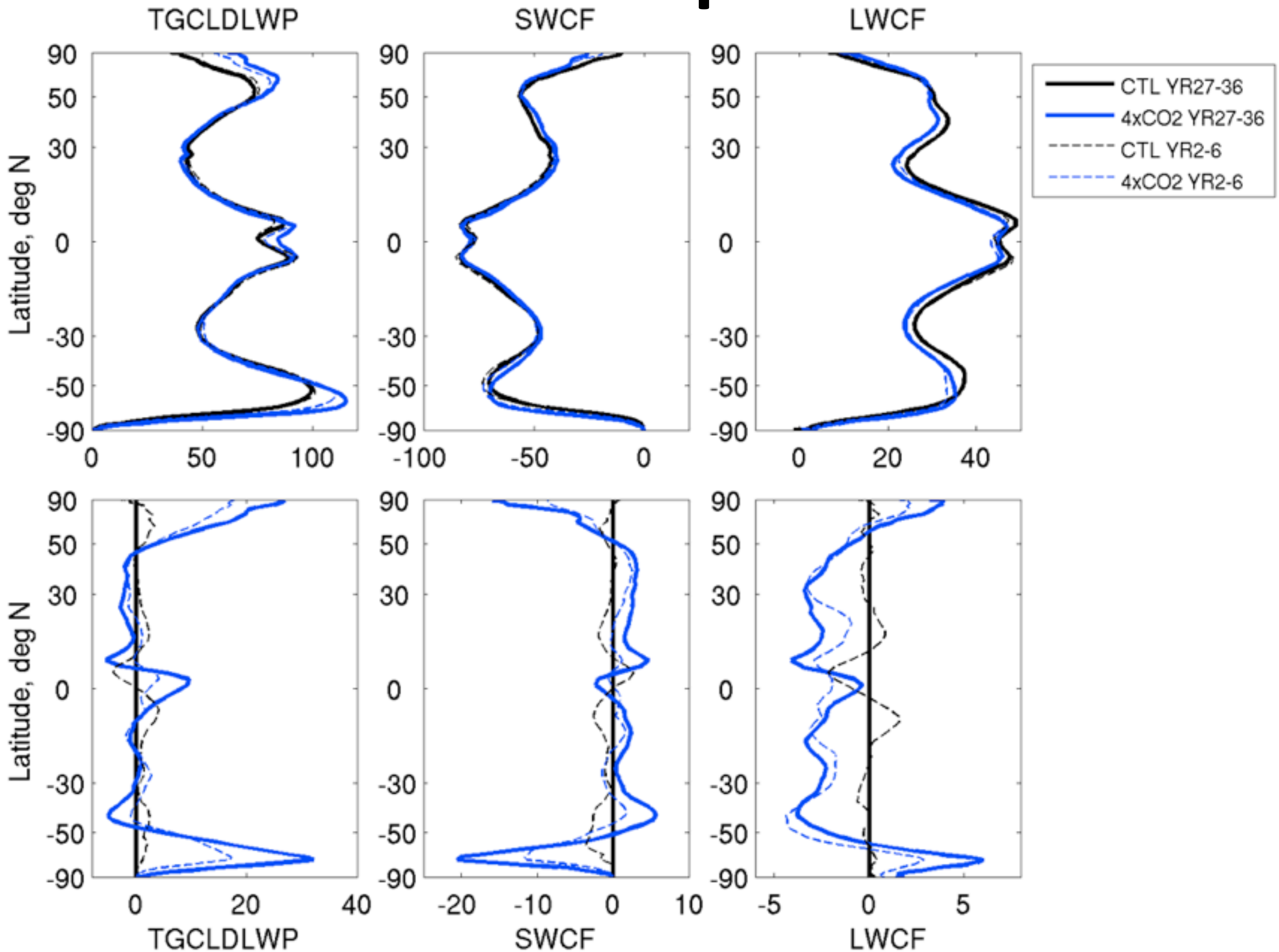
- Biggest precip changes in ITCZ/poles, cloud shifts w/storm tracks

SP-CCSM Global Response to 4xCO2



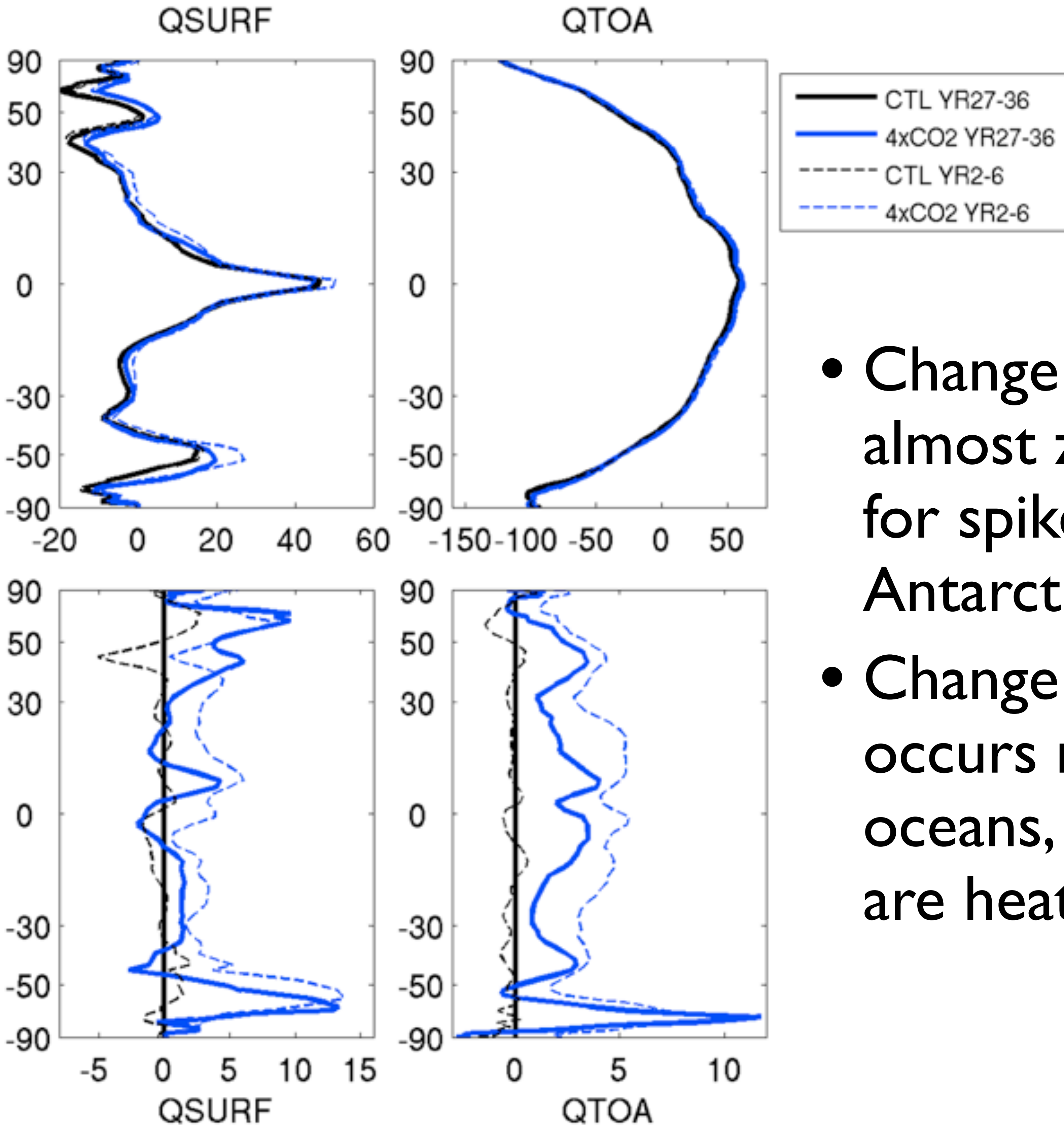
- Small changes in low cloud throughout tropics.
- Mid-level cloud decreases in tropics/mid-lat. High cloud ↓ a bit in tropics.

SP-CCSM Global Response to 4xCO2



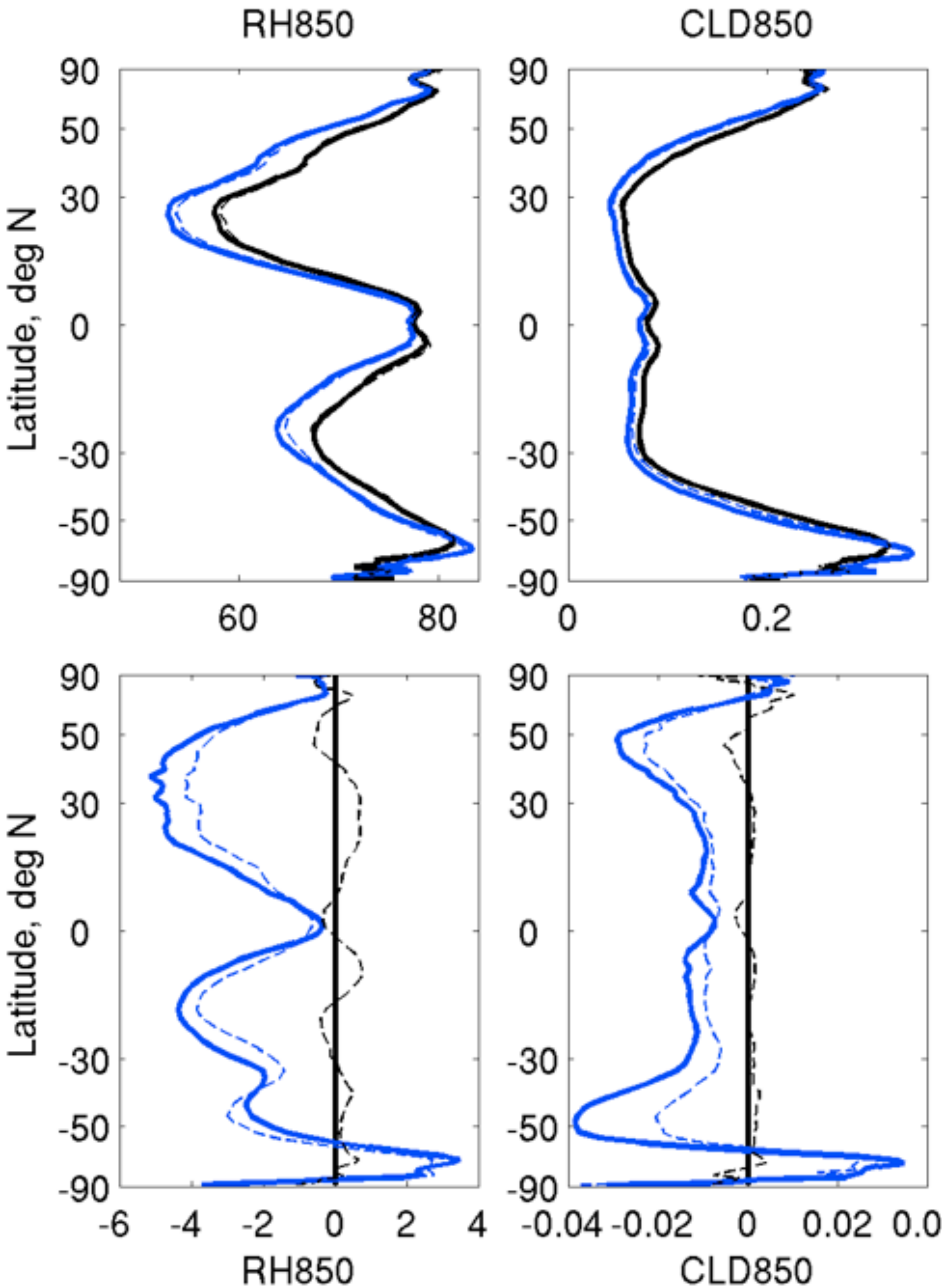
- Big LWP increases in poles. ΔSWCF/ΔLWCF consistent with ΔCLDTOT, with weaker ΔSWCF/ΔLWCF throughout tropics.

SP-CCSM Global Response to 4xCO2



- Change in TOA net heat flux is almost zonally uniform (except for spike over southern ocean/ Antarctica).
- Change in surface net heat flux occurs mostly in high latitude oceans, though tropical oceans are heated early in simulation.

SP-CCSM Tropical Response to 4xCO2



- Wyant et al (2012) suggested that increased CO2 tends to shallow the marine boundary layer, through its effect on radiative cooling and entrainment by MBL clouds
- Here, 850 hPa RH and cloud fraction decrease in subtropics with little change in CLDLOW, suggesting (though not proving) a shallower MBL in the subtropics.

SP-CCSM Tropical Response to 4xCO2

	Tropics	Trop Land	Trop Ocean
TS, K	+3.2 (+1.9)	+4.6 (+2.9)	+2.7 (+1.5)
PRECT, mm/d	+0.09 (-0.03)	+0.0 (+0.08)	+0.12 (-0.06)
W500, Pa/s	-2e-4 (-2e-4)	-4e-4 (-25e-4)	-2e-4 (+6e-4)
CLDTOT, %	-0.5 (-0.3)	-2.7 (-1.4)	+0.3 (+0.0)
SWCF, W/m^2	+1.5 (+1.0)	+3.8 (+1.6)	+0.7 (+0.9)
LWCF, W/m^2	-2.5 (-2.2)	-2.2 (-0.7)	-2.6 (-2.7)
LTS, K	+1.4 (+0.8)	+0.3 (+0.0)	+1.7 (+1.1)

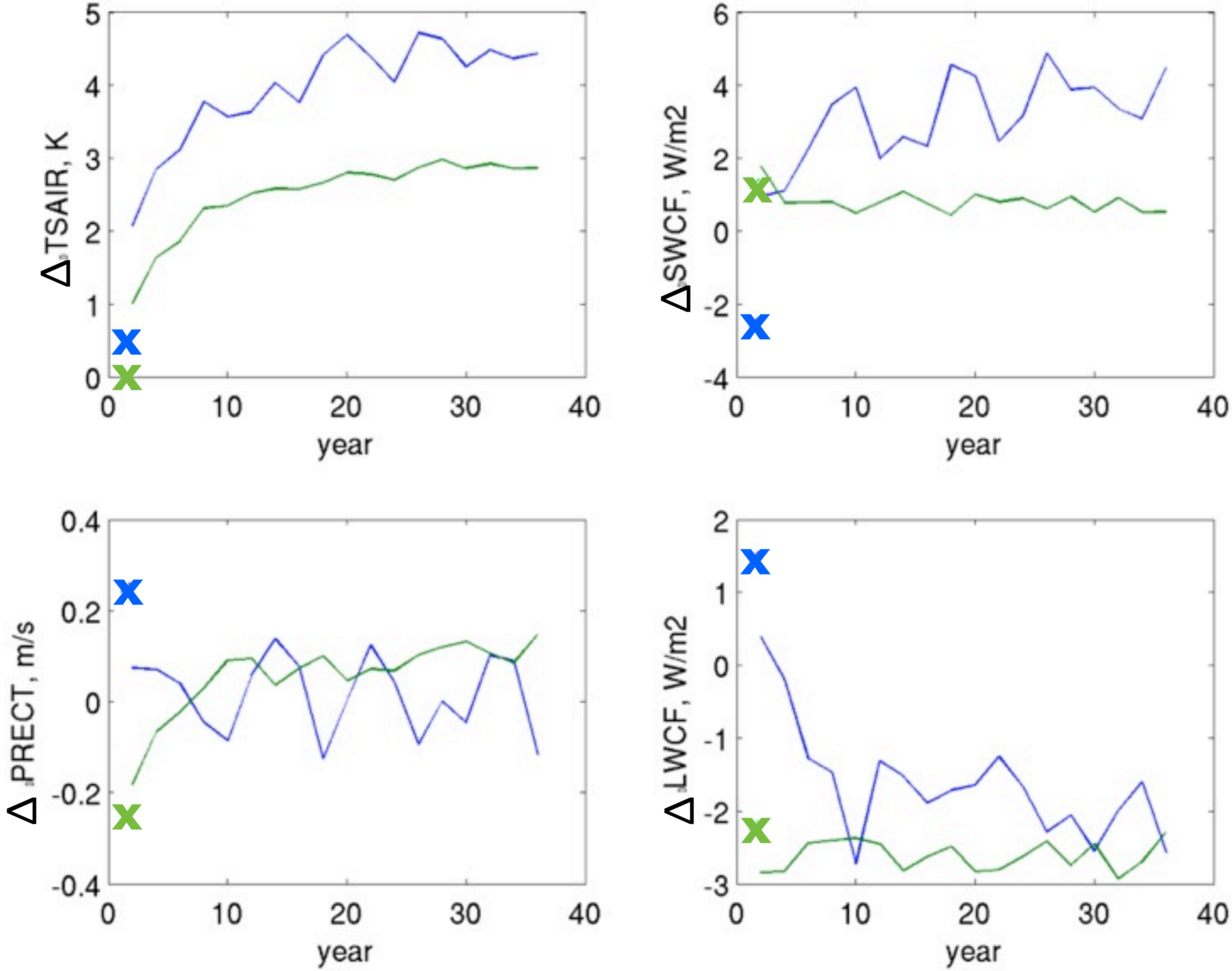
Δ(4x-CTL) YRS 27-36 → first value

Δ(4x-CTL) YRS 2-6 → value in parentheses

Stronger in 4x
Weaker in 4x

- Monsoonal shift in upward motion and precipitation towards land in years 2-6, reverses in longer term w/precip ↑ over ocean
- Ocean cloud response steady, land cloud thins over time.

SP-CCSM Tropical Response to 4xCO2

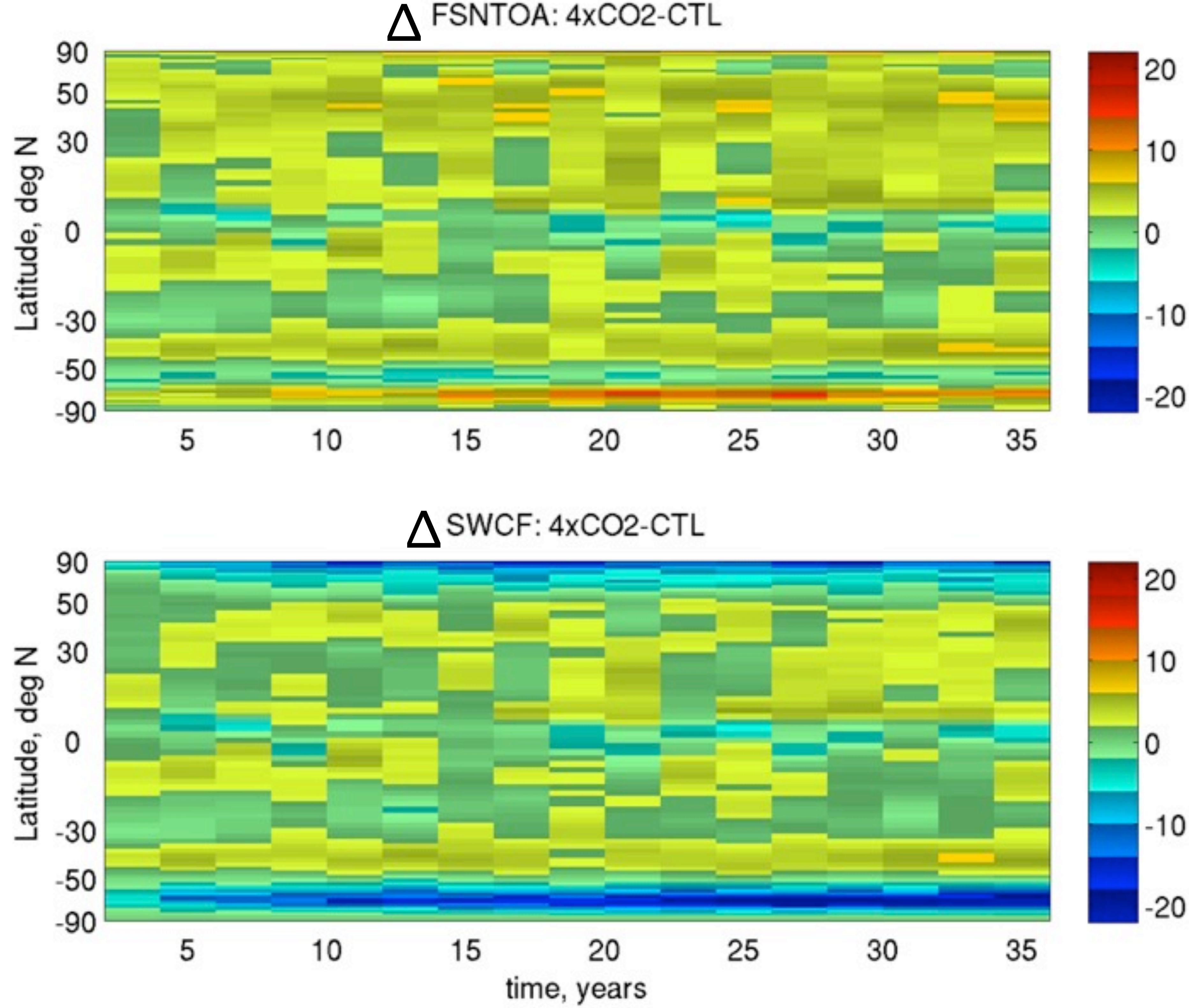


Land
Ocean

x =
SP-CAM
Fixed SST
(Wyant et al 2012)

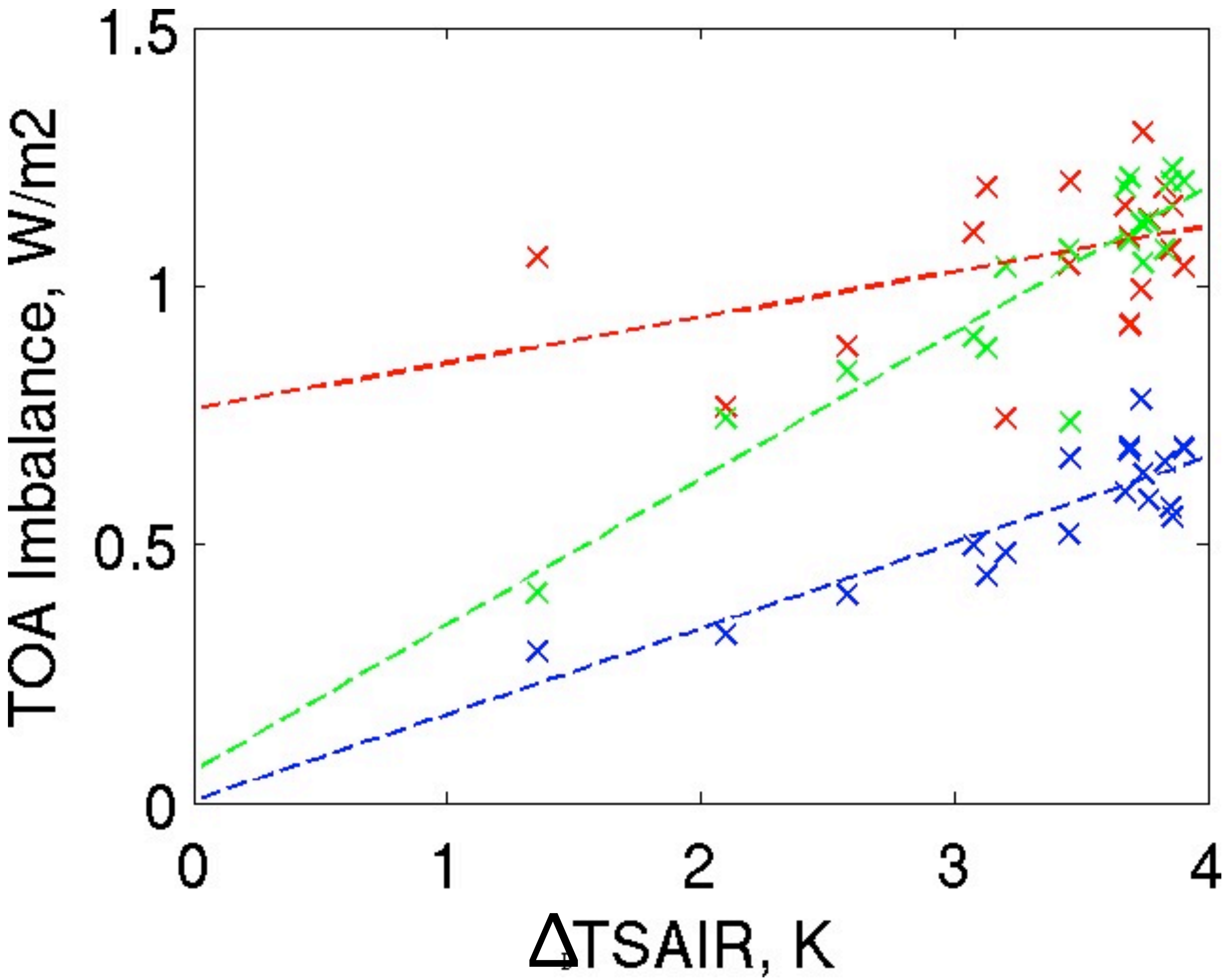
- Some shift of clouds and precip to land early in run, but not as strong as in the fixed SST runs in Wyant et al (2012).
- Note that tropics-avg SWCF seems positive throughout run...

SW Cloud Radiative Effect: Polar trend



- SW cloud radiative effect (SWCF) trends weak away from poles.
- Polar trends in ΔSWCF and ΔSW down at TOA (full sky) have opposite signs. ~-1 W/m^2 of global ΔSWCF from >60 deg lat.

SW response to 4xCO2



ΔSWCF, |λ|<60
ΔSWClrSky, |λ|<60
ΔSWFullSky, |λ|>60
λ=latitude, deg

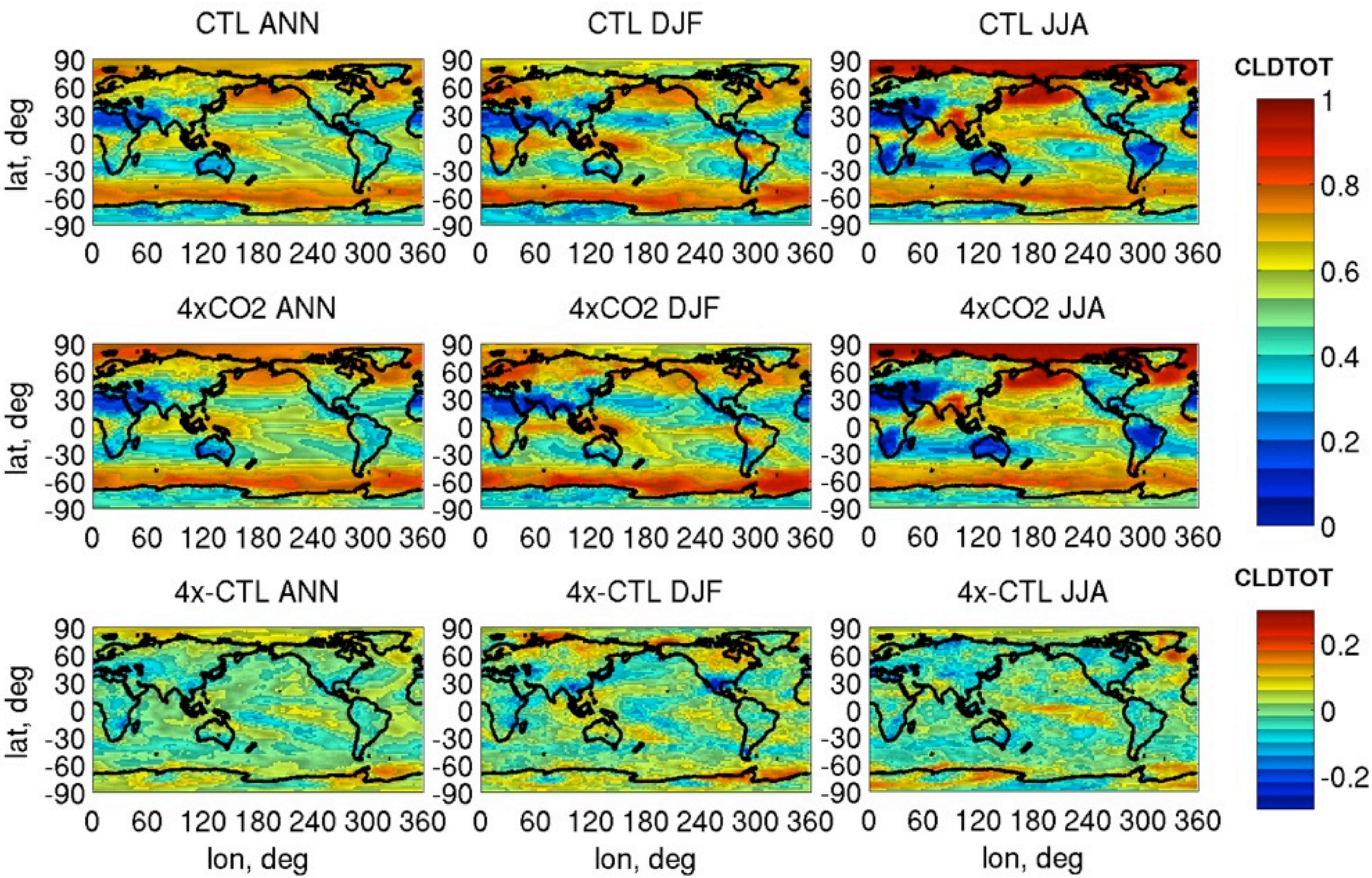
- Away from poles, SW cloud feedbacks seem weak.
- Polar response is complicated in SW with cancellation between ice albedo and cloud changes.
- Separating it can remove these from near-global signal.

Conclusions

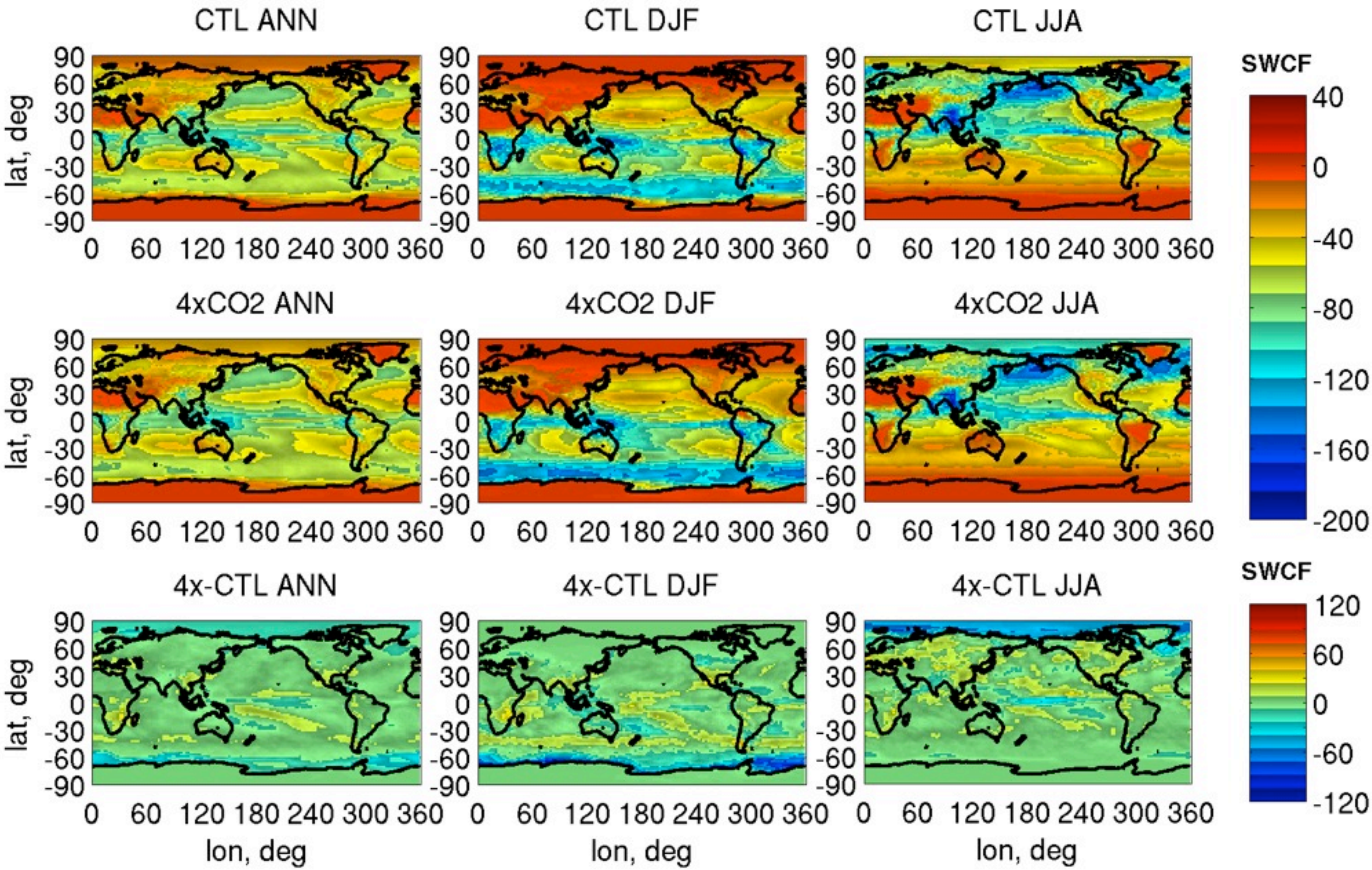
- We've started looking at the cloud response to increased CO2 in SP-CCSM.
- Cloud feedbacks appear weak outside of polar regions, with direct effect of CO2 playing largest role equatorward of 60 deg S/N.
- Some aspects of monsoonal response seen in SP-CAM 4xCO_2 fixed SST experiments can be seen in the early evolution of SP-CCSM.

Future Plans

- Continue to interrogate data to understand interesting features of cloud changes.
- Break down cloud response by circulation (ω500) or stability (LTS/EIS).
- Look at vertical structure of circulation, stability and cloud changes.



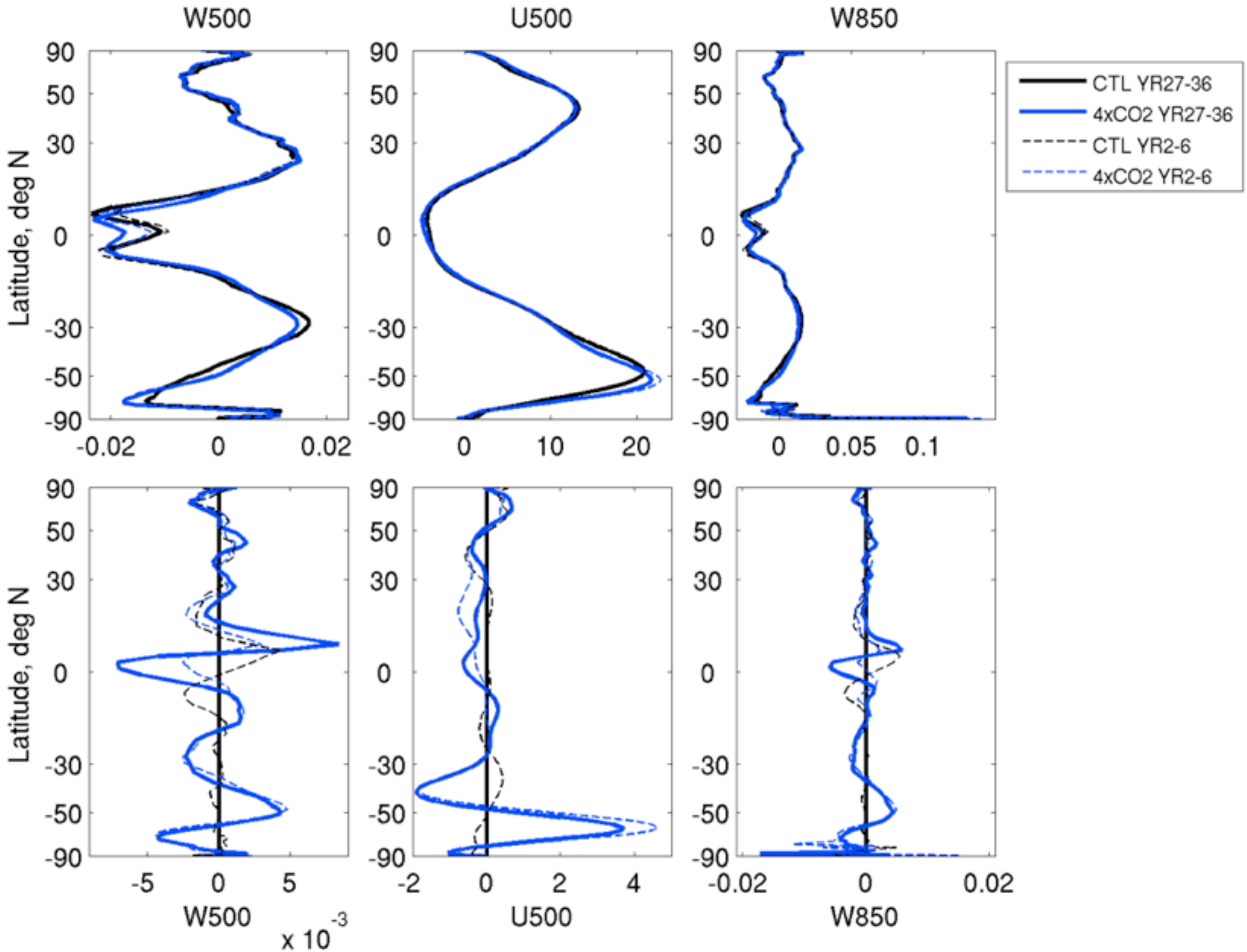
CTL ANN
CTL DJF
CTL JJA
4xCO2 ANN
4xCO2 DJF
4xCO2 JJA
4x-CTL ANN
4x-CTL DJF
4x-CTL JJA
CLDTOT
1
0.8
0.6
0.4
0.2
0
CLDTOT
0.2
0
-0.2
lat, deg
lon, deg
90
60
30
0
-30
-60
-90
0
60
120
180
240
300
360


CTL ANN
CTL DJF
CTL JJA
4xCO2 ANN
4xCO2 DJF
4xCO2 JJA
4x-CTL ANN
4x-CTL DJF
4x-CTL JJA
lat, deg
lon, deg
90 60 30 0 -30 -60 -90
0 60 120 180 240 300 360
SWCF
40 0 -40 -80 -120 -160 -200
SWCF
120 60 0 -60 -120

SP-CCSM Global Response to $4xCO_2$

- Southern hemisphere storm track shifts poleward.
- LWP increases in both storm tracks/polar regions.
- Precipitation increase globally by ~2%, with most of the increase in the tropics and over oceans.
- Land cloud fraction decreases by ~1.5%.
- SWCF: Small global change, stronger over extratropical oceans, weaker over tropical land.
- Climate system not in balance at end of run (~3 W/m2 flux at TOA, surface), still heating deep ocean...

SP-CCSM Global Response to 4xCO2



- Large-scale W at 500 hPa suggests a slight southward shift of the ITCZ.
- Poleward movement of mid-trop jets (U at 500 hPa) strongest in SH.