Clouds and the atmospheric circulation response to warming

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Dennis Hartmann, Ted Shepherd
Model hierarchies workshop, 4 October 2016

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Two questions

- **How will clouds affect the atmospheric circulation response to CO_2 forcing?**

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- **How will clouds affect the atmospheric circulation response to CO_2 forcing?**

- **How much of the uncertainty in circulation response is due to clouds?**

Model hierarchy

- Idealized aquaplanet: GFDL AM2.1

- Realistic GCM: CAM4

- *Feedback-locking* technique: prescribe clouds, water vapor, albedo in radiation code

Two questions

- **How will clouds affect the atmospheric circulation response to CO_2 forcing?**

- **How much of the uncertainty in circulation response is due to clouds?**

Idealized experiments

- GFDL AM2.1 aquaplanet, annual-mean insolation, 50 m slab ocean
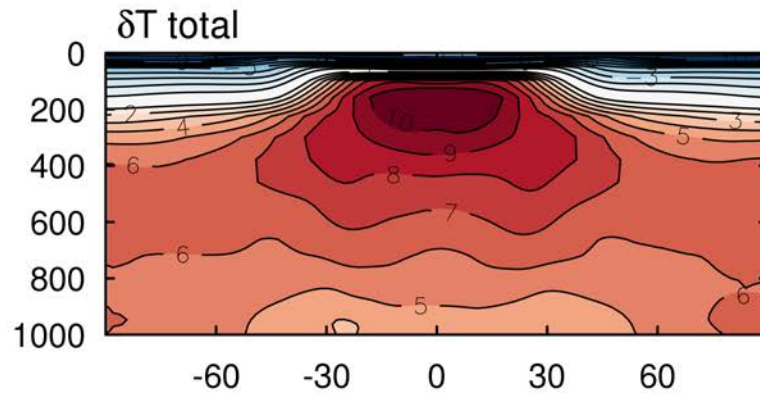
- CTL and 4xCO_2 experiments

Experimental procedure

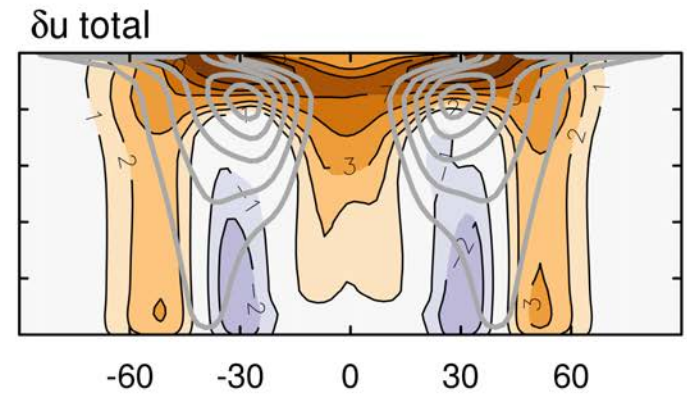- **Prescribe** the clouds to either CTL or 4xCO2 state in radiation code
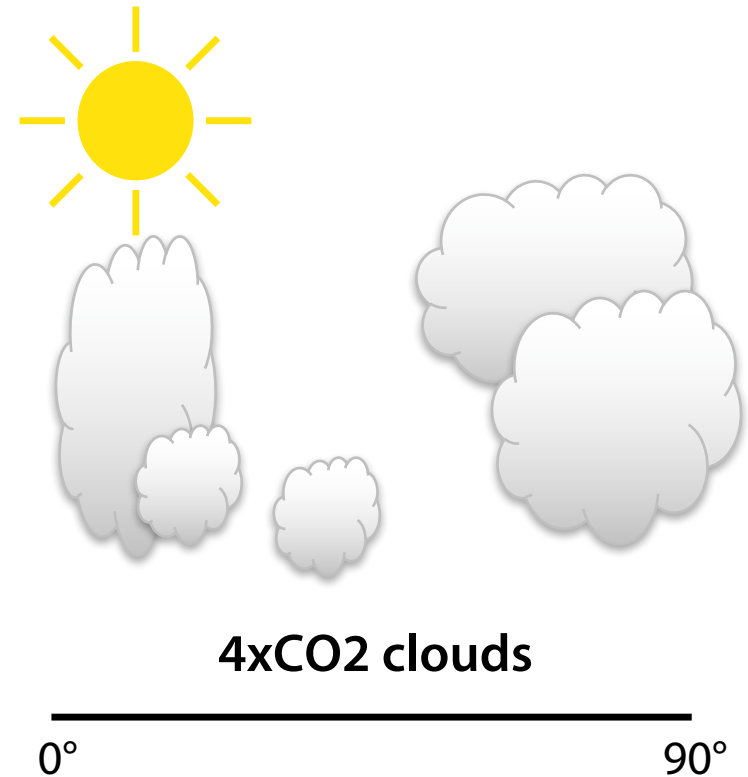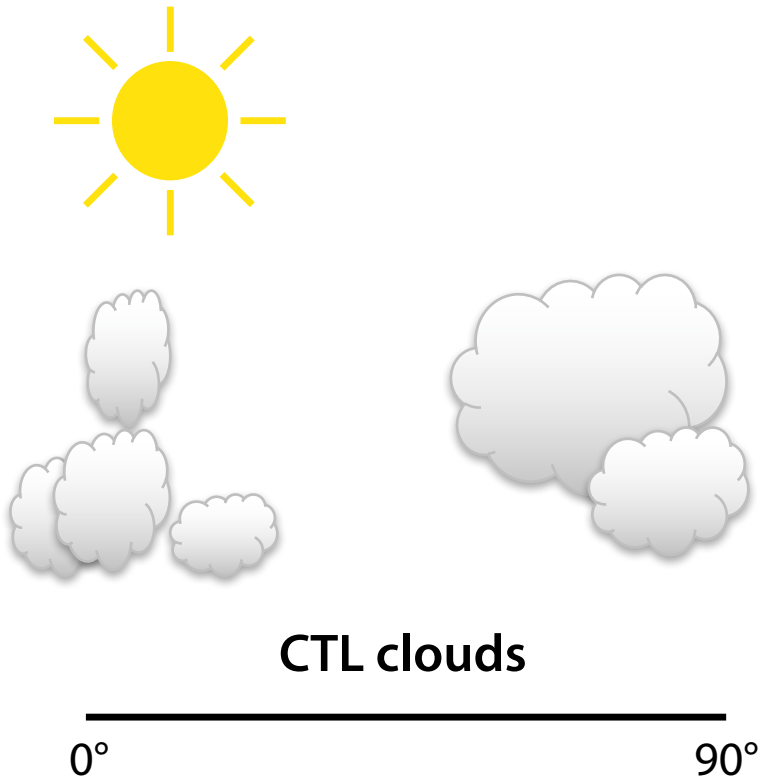
CTL clouds

0°   90°

4xCO2 clouds

0°   90°

temperature (K)

zonal wind (m s^{-1})
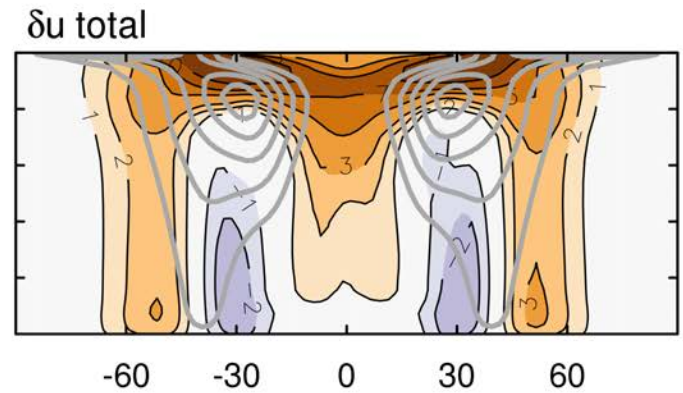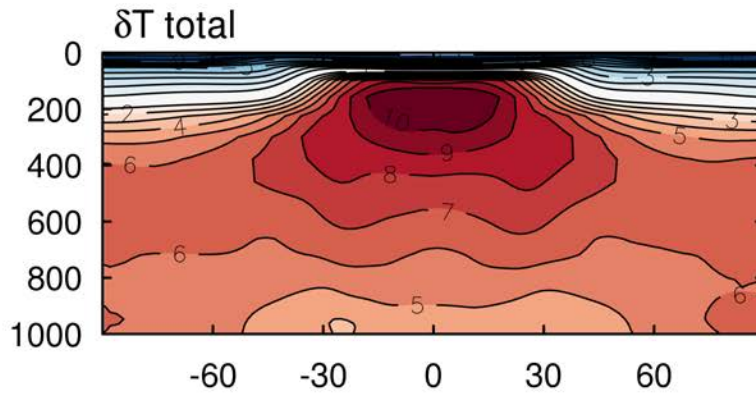
total 4xCO$_2$ response

δT total

δu total

latitude

temperature (K)   **zonal wind (m s⁻¹)**

δT total   δu total

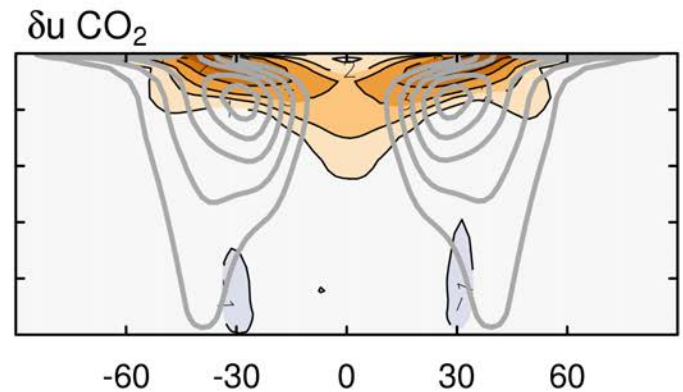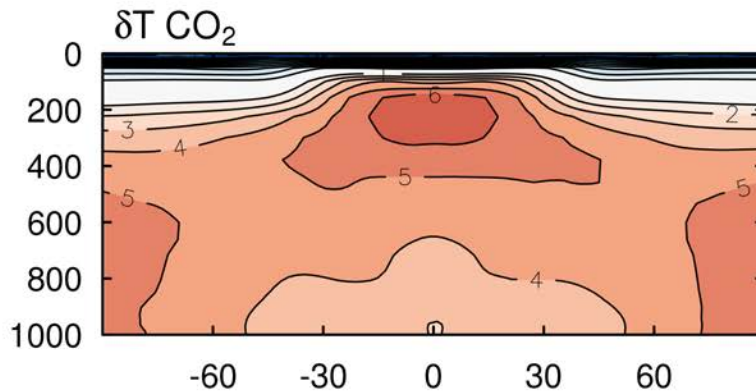**total 4xCO₂ response**

δT CO₂   δu CO₂
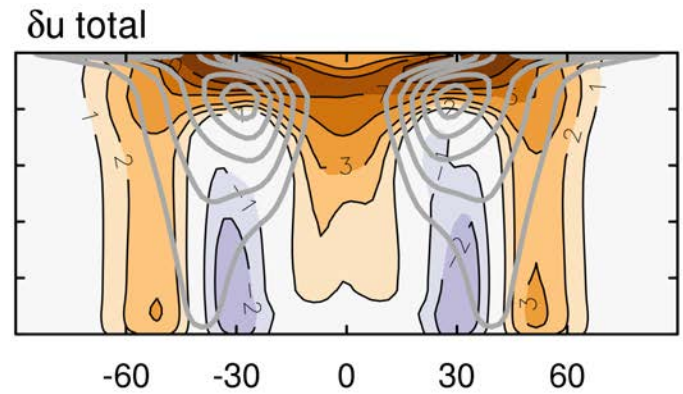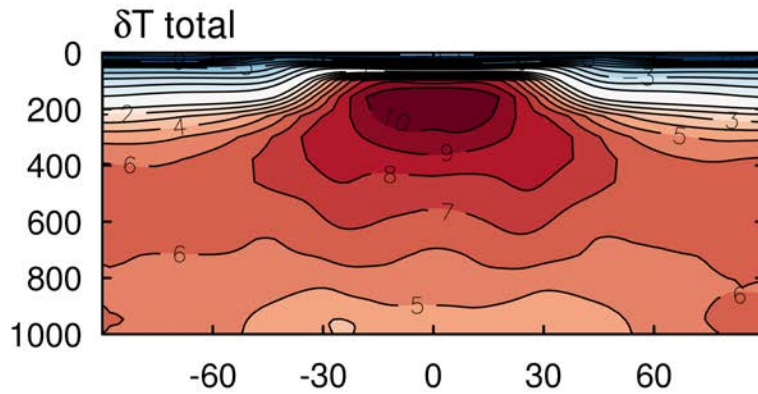
CO₂

latitude

temperature (K)

zonal wind (m s⁻¹)

total 4xCO₂ response

δT total

δu total

CO₂

δT CO₂

δu CO₂
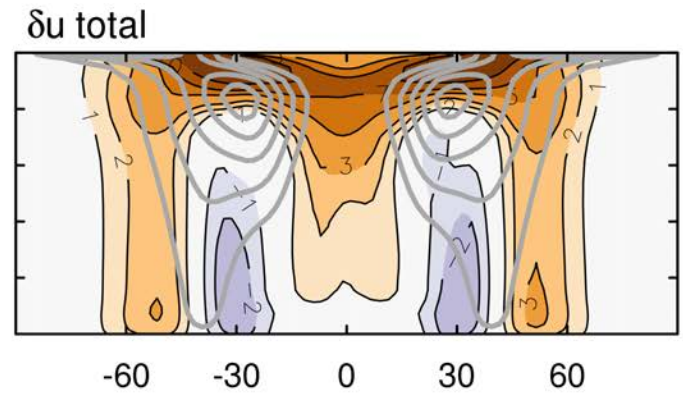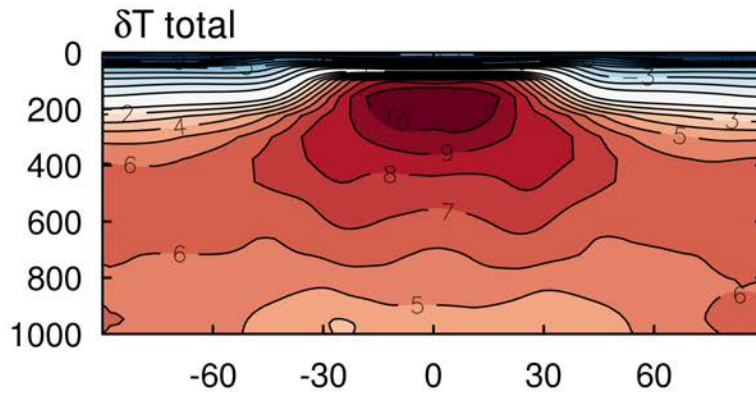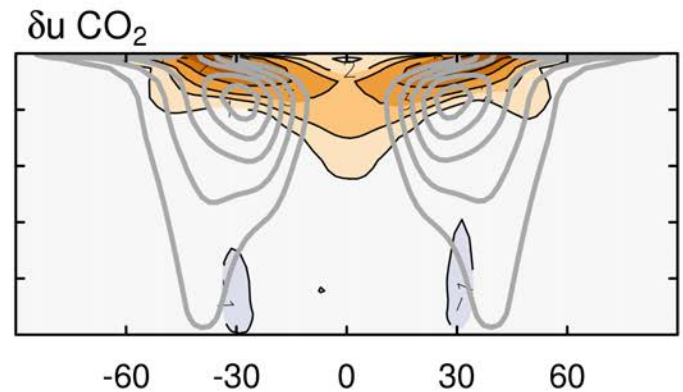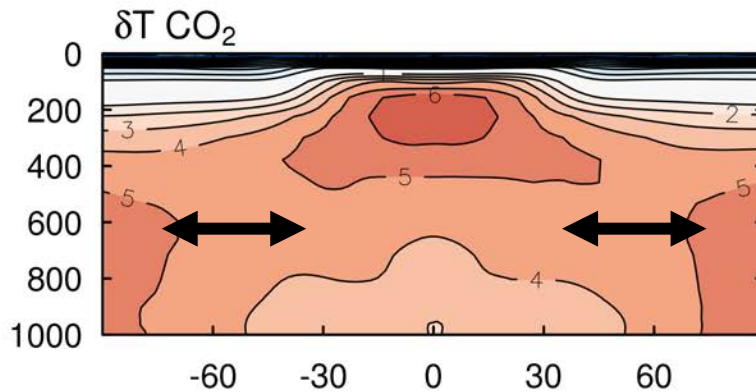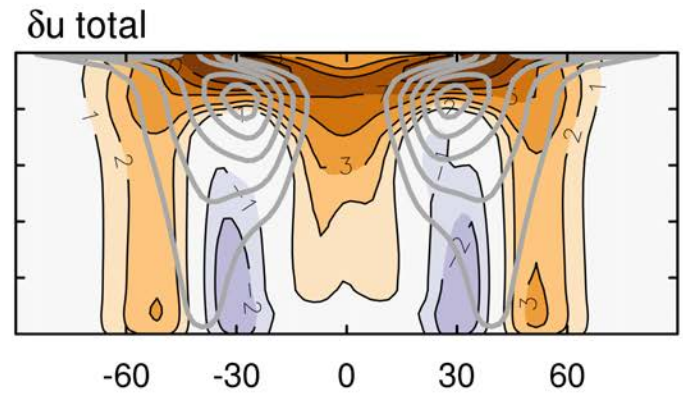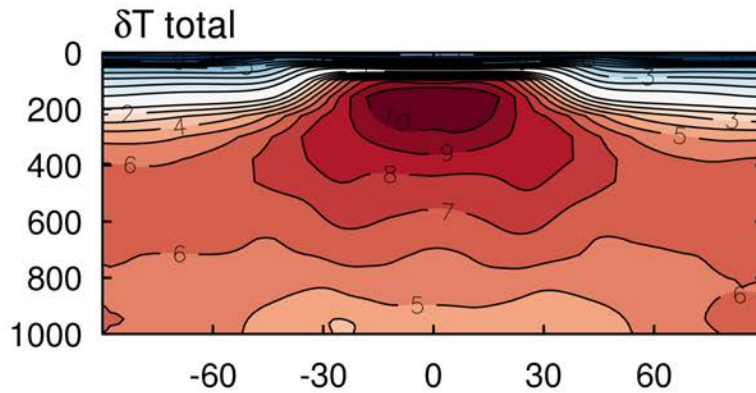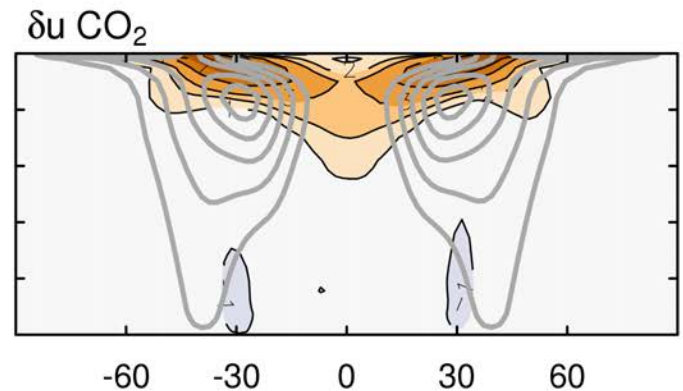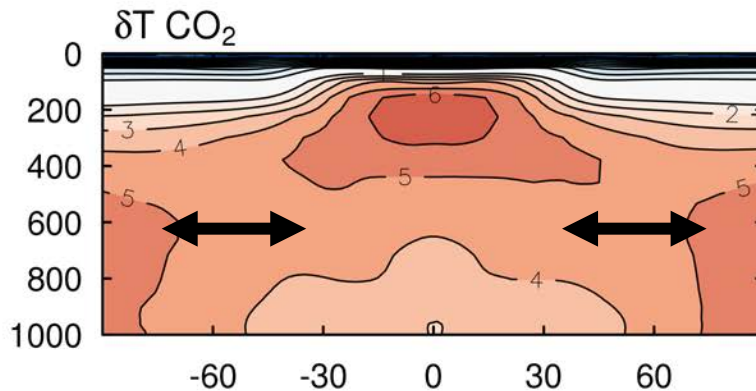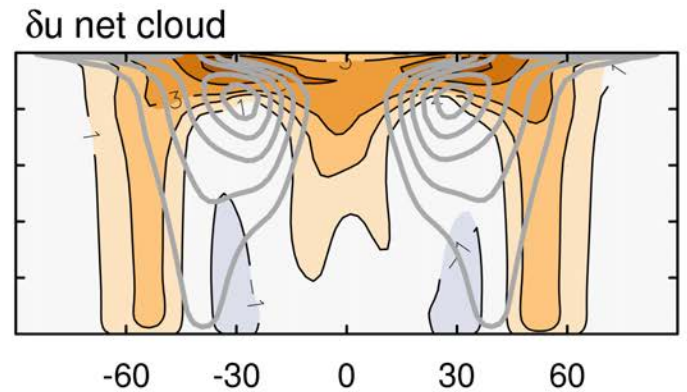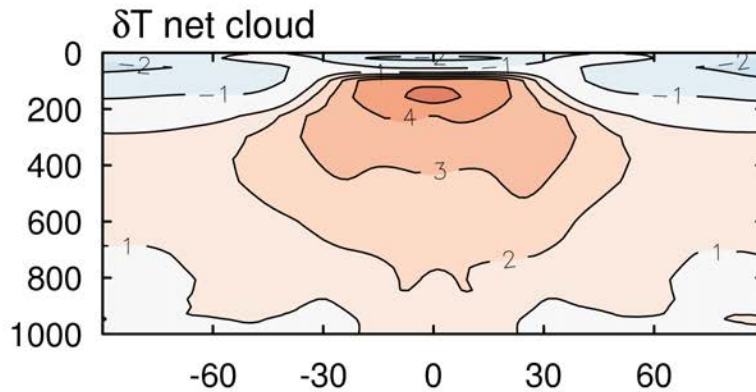
net cloud

δT net cloud
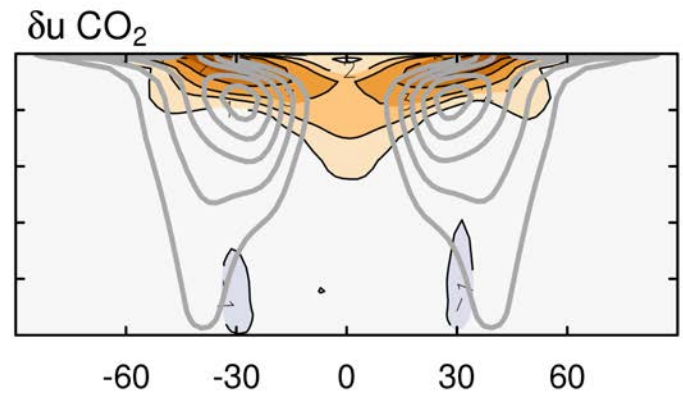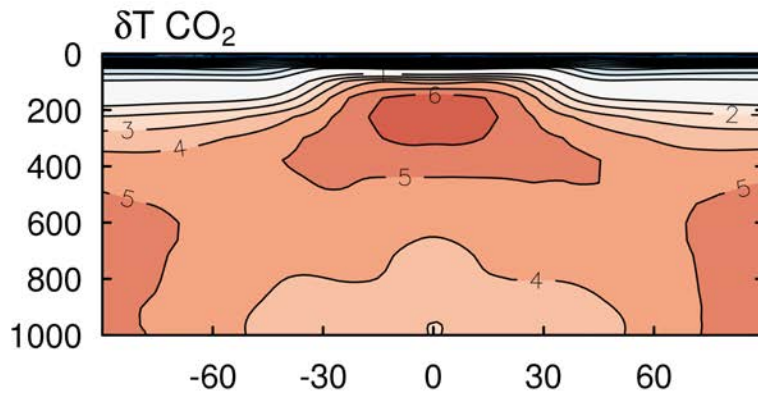
δu net cloud

latitude

temperature (K)

zonal wind (m s⁻¹)

total 4xCO₂ response

CO₂

net cloud

latitude

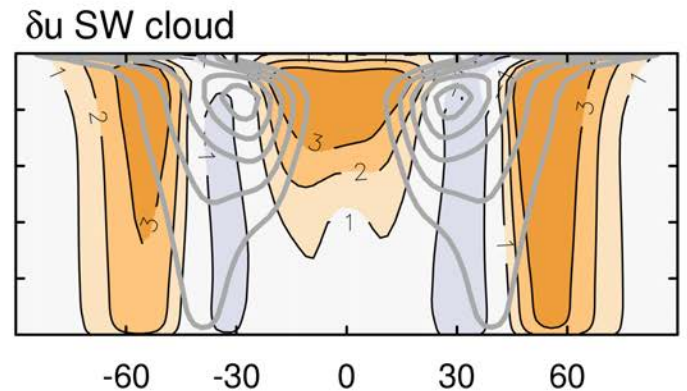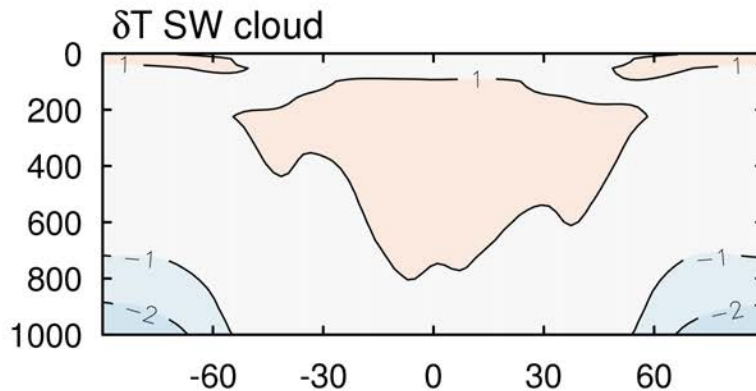|	temperature (K)	zonal wind (m s^{-1})
total 4xCO$_2$ response	δT total	δu total
CO$_2$	δT CO$_2$	δu CO$_2$
net cloud	δT net cloud	δu net cloud
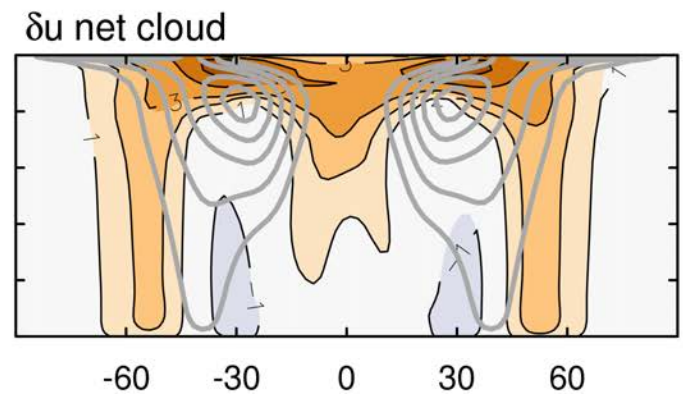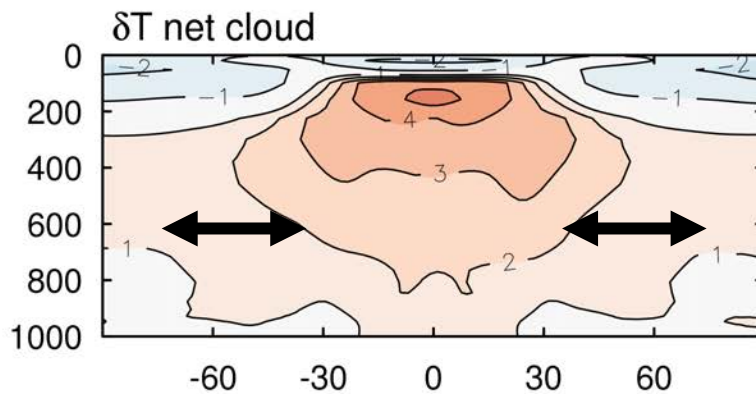
latitude

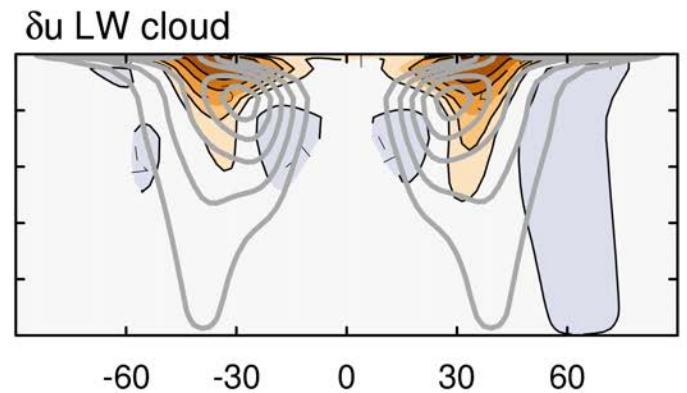**temperature (K)**   **zonal wind (m s⁻¹)**

net cloud

δT net cloud   δu net cloud

SW cloud

δT SW cloud   δu SW cloud

LW cloud

δT LW cloud   δu LW cloud
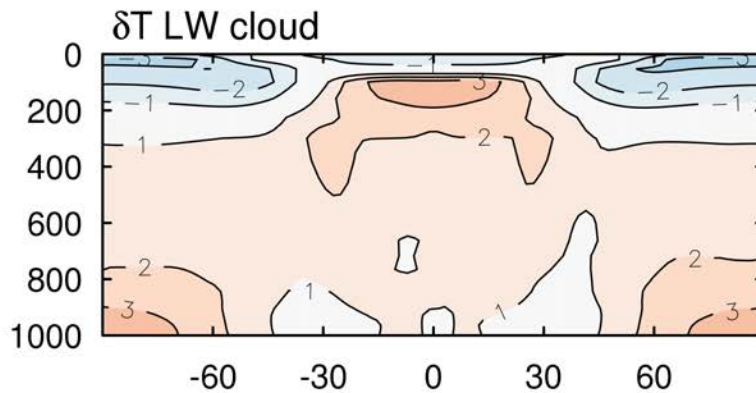
latitude
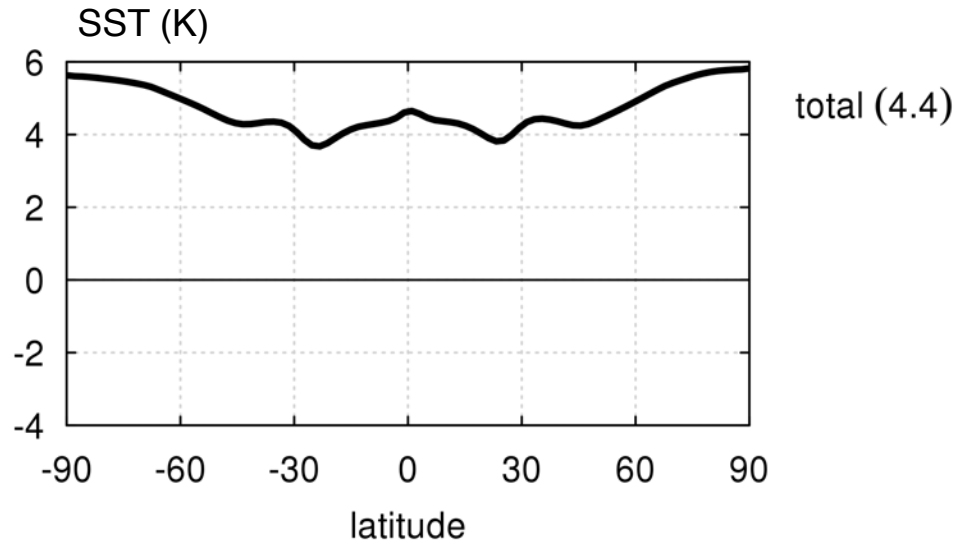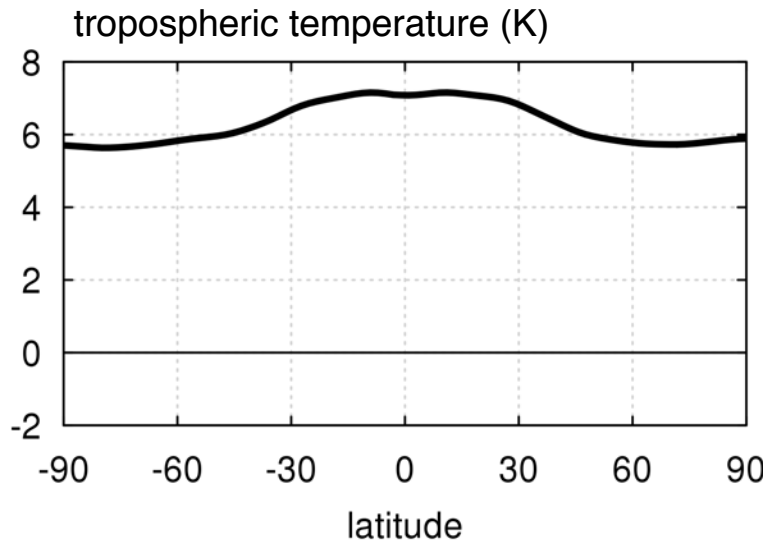
Temperature response

Temperature response

tropospheric temperature (K)

SST (K)

total (4.4)
CO_2 (3.4)
net cloud (1.1)

Temperature response
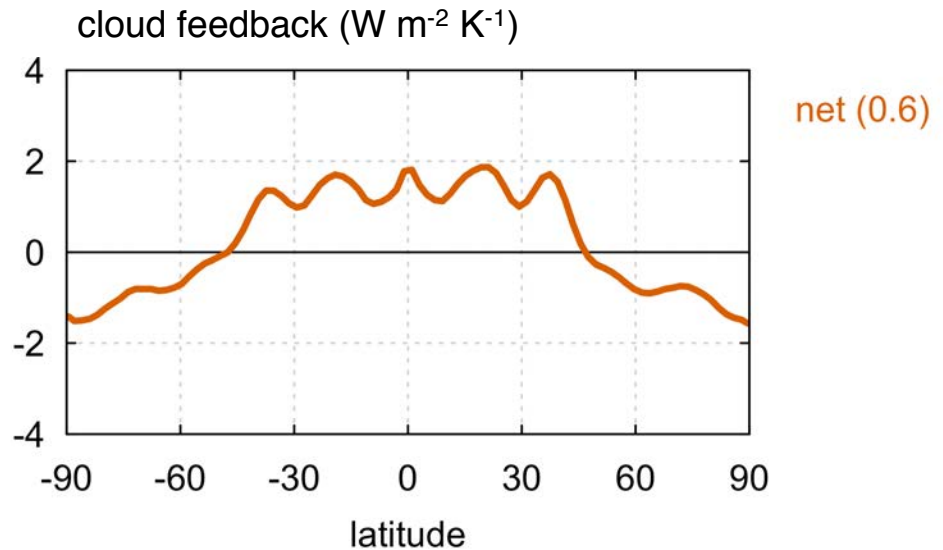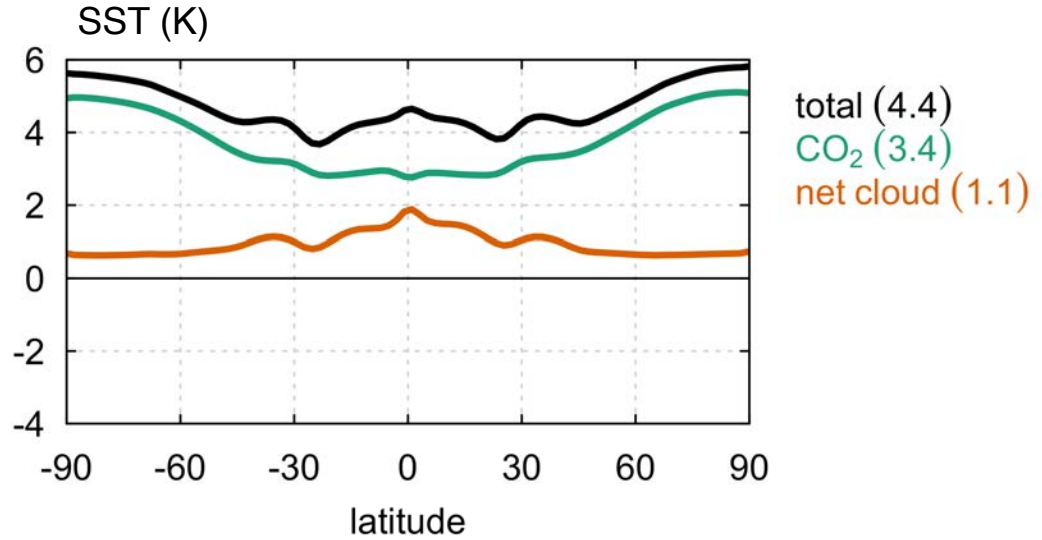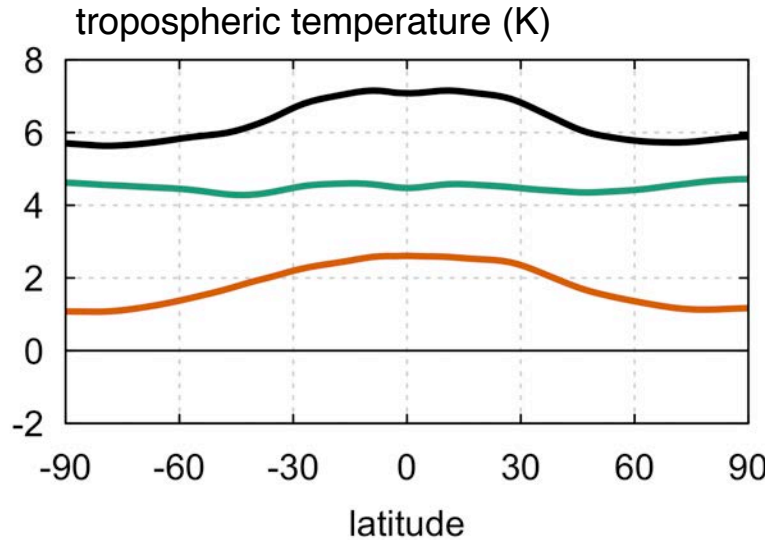
Circulation indices
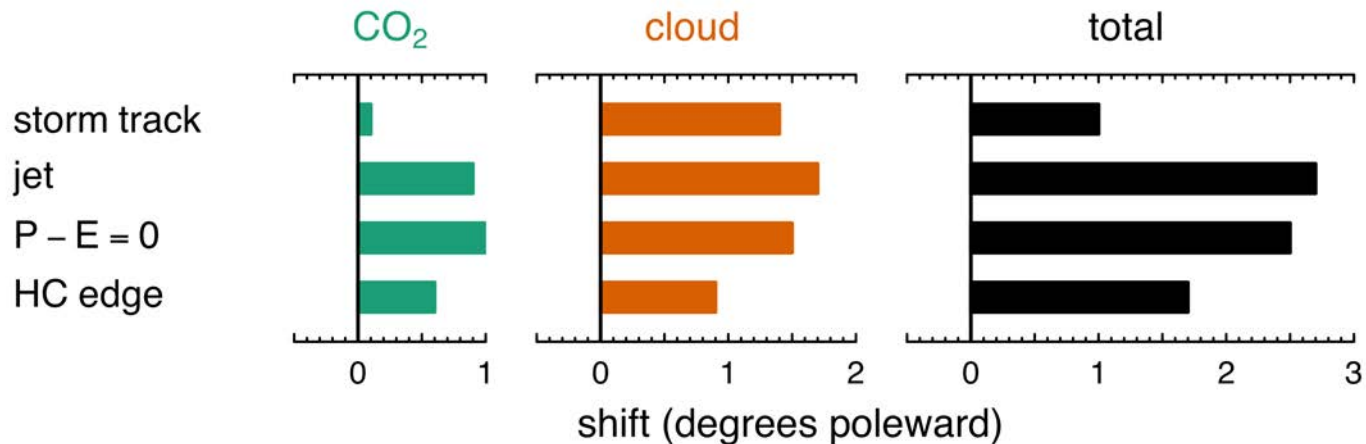
- clouds cause >50% of the total poleward expansion of the circulation

Idealized vs realistic GCMs

4xCO$_2$ cloud feedback (W m^{-2} K^{-1})

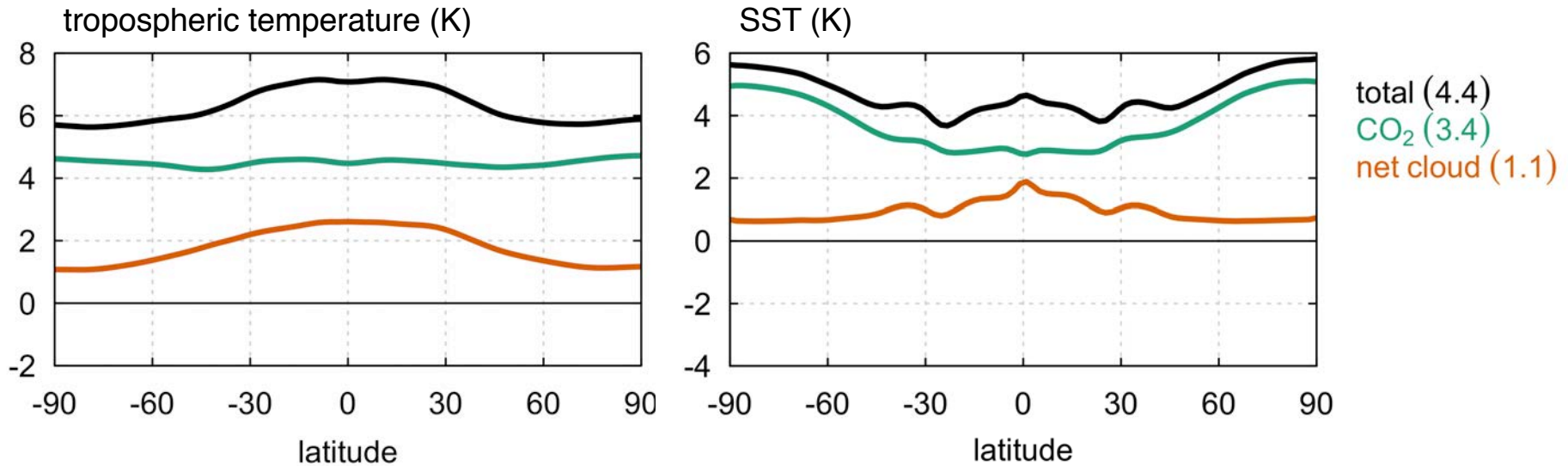AM2.1 aquaplanet
CMIP5

latitude

Idealized vs realistic GCMs

4xCO₂ cloud feedback (W m⁻² K⁻¹)

AM2.1 aquaplanet
CMIP5

latitude
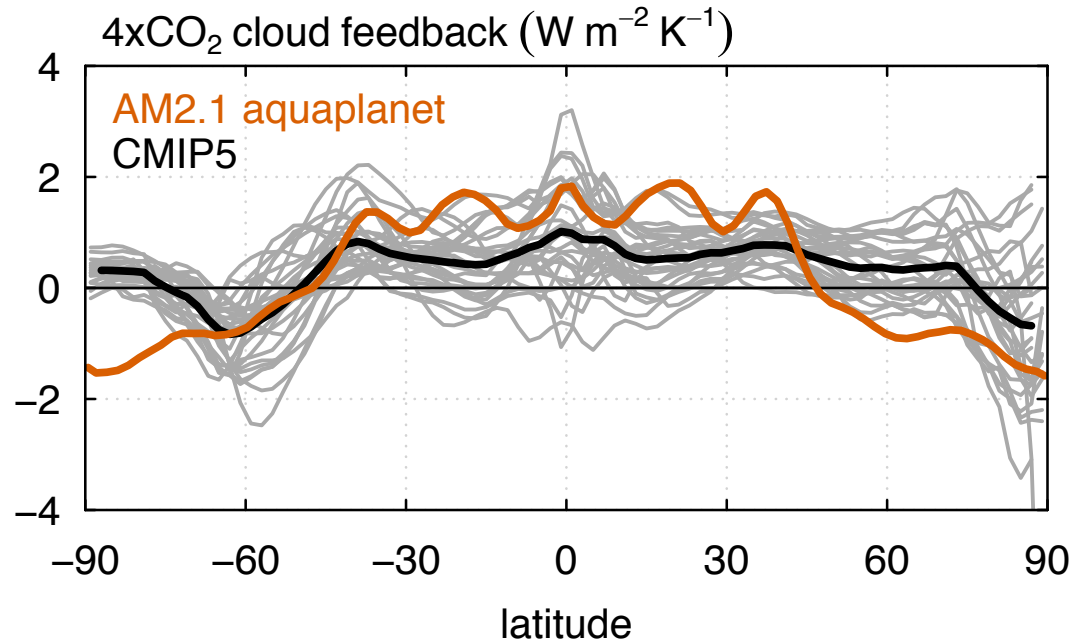
- aquaplanet overall consistent with CMIP5
- large uncertainty in cloud feedback

Two questions

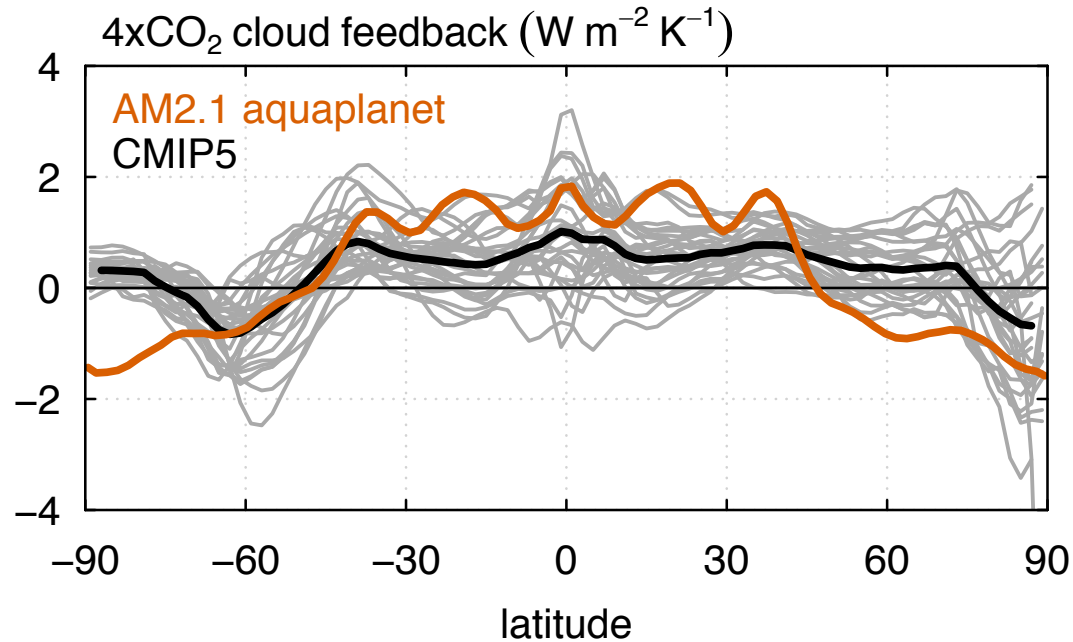- **How will clouds affect the atmospheric circulation response to CO_2 forcing?**

- **How much of the uncertainty in circulation response is due to clouds?**

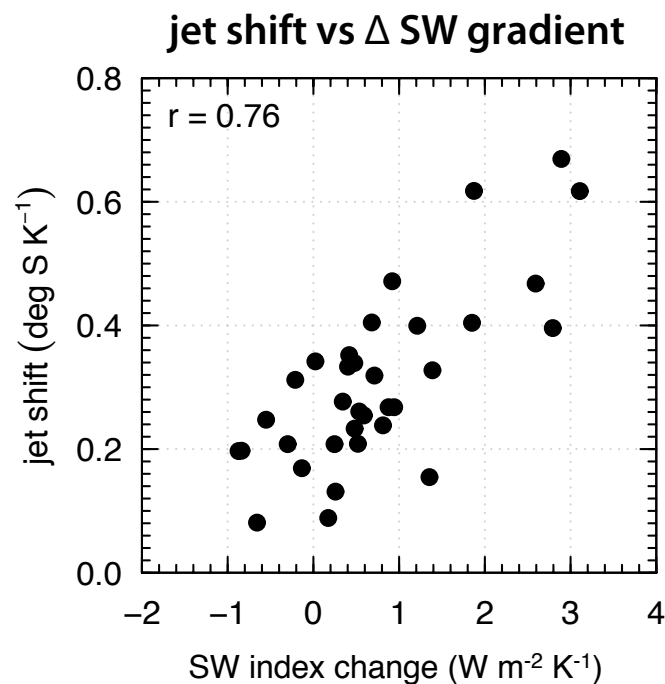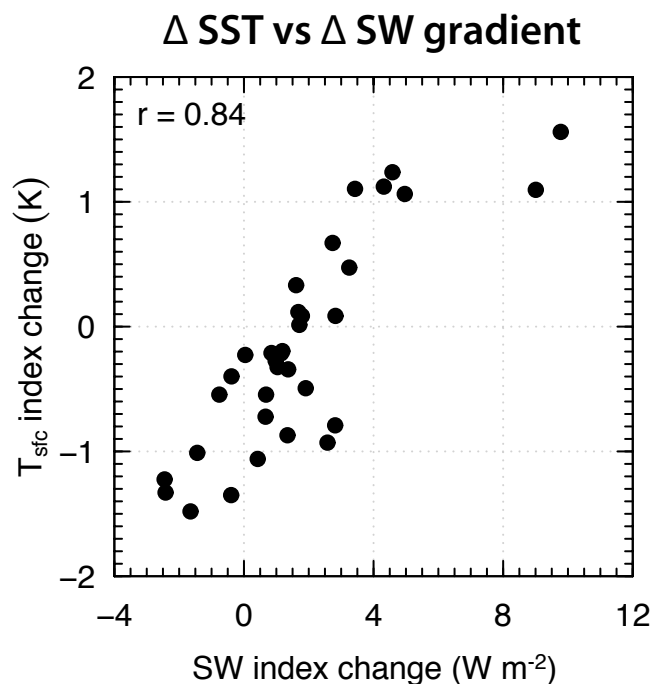### The response of the Southern Hemispheric eddy-driven jet to future changes in shortwave radiation in CMIP5

Paulo Ceppi[1], Mark D. Zelinka[2], and Dennis L. Hartmann[1]

Δ SST vs Δ SW gradient

jet shift vs Δ SW gradient

The response of the Southern Hemispheric eddy-driven jet to future changes in shortwave radiation in CMIP5

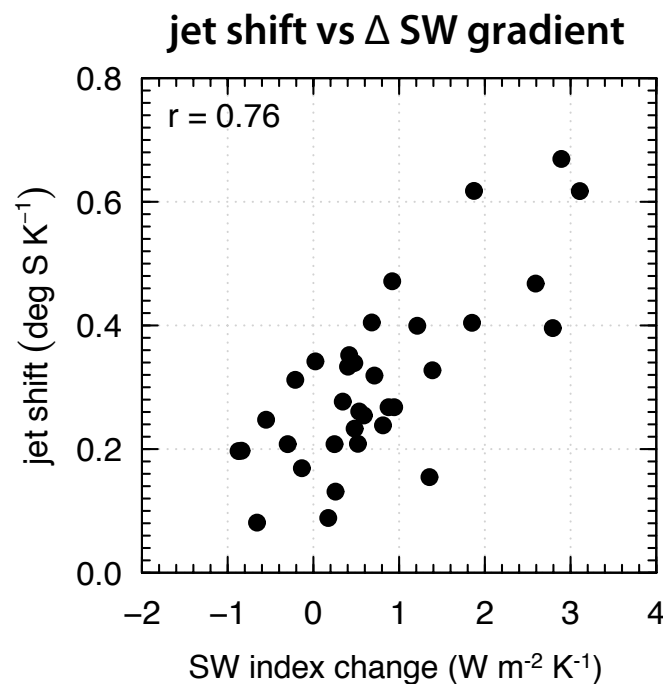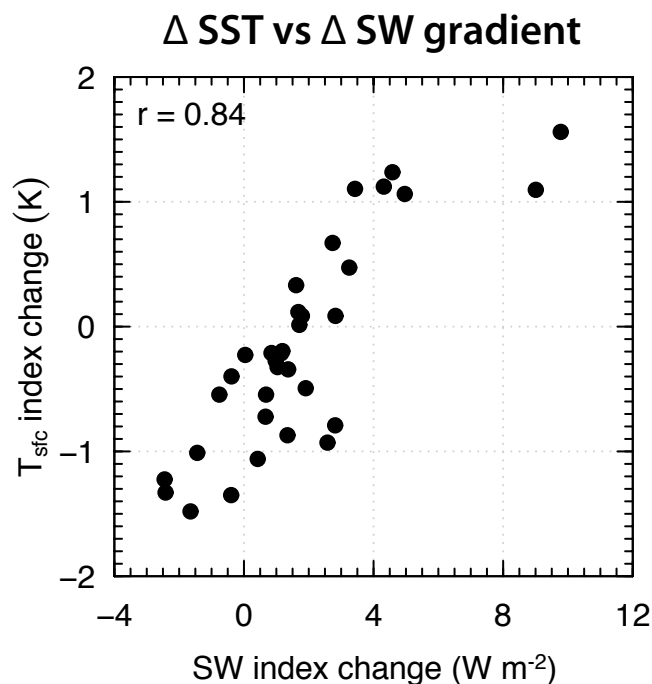Paulo Ceppi[1], Mark D. Zelinka[2], and Dennis L. Hartmann[1]

Δ SST vs Δ SW gradient
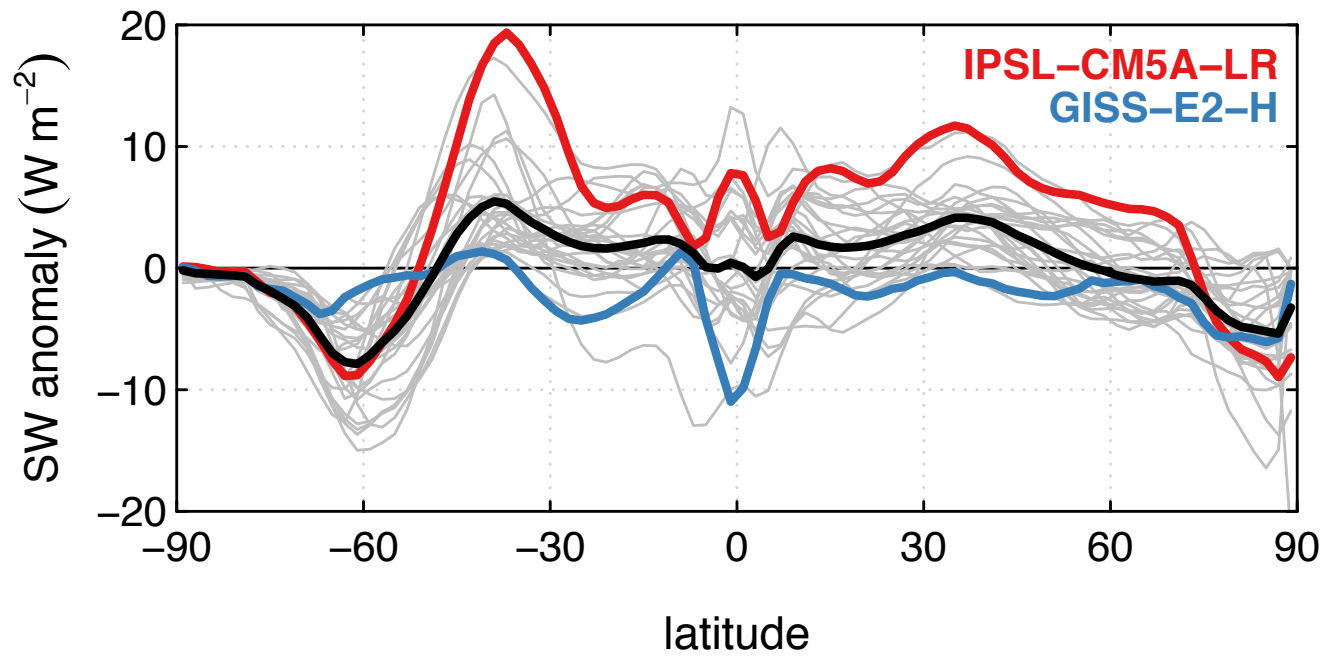
jet shift vs Δ SW gradient

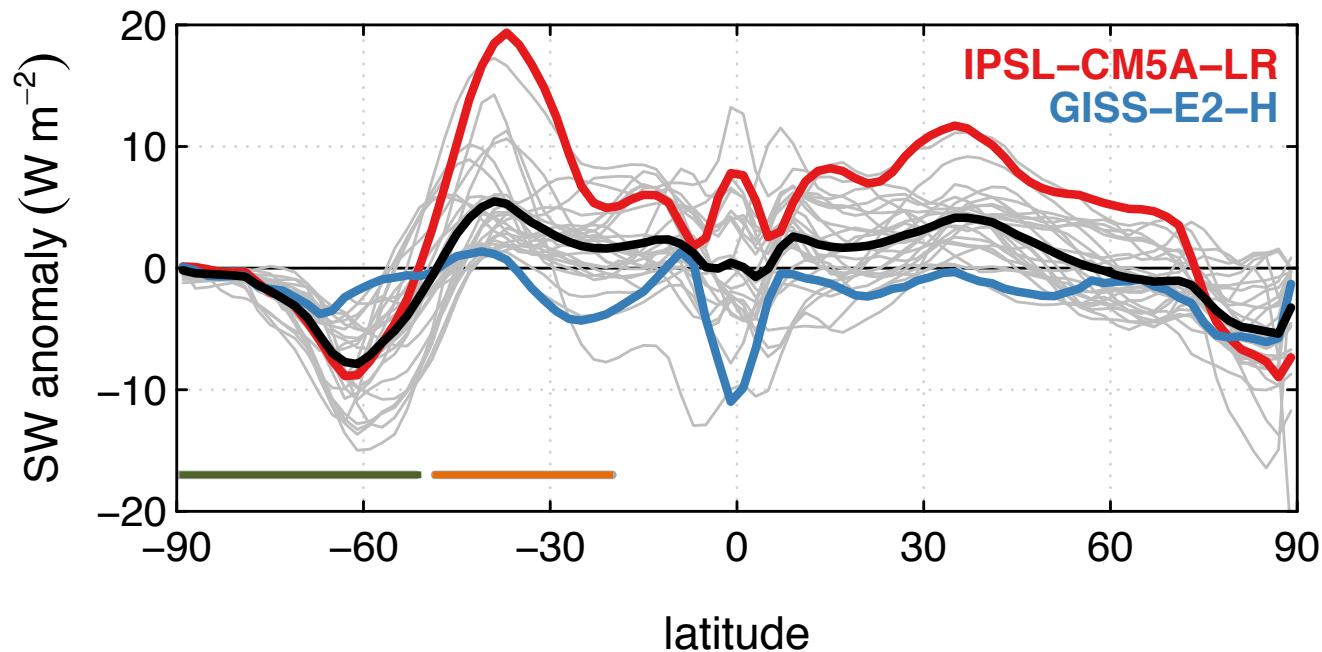SW changes affect the SST gradient and the eddy-driven jet

Experimental procedure

- Run CAM4-SOM with locked feedbacks

- Impose SW cloud anomalies as a forcing
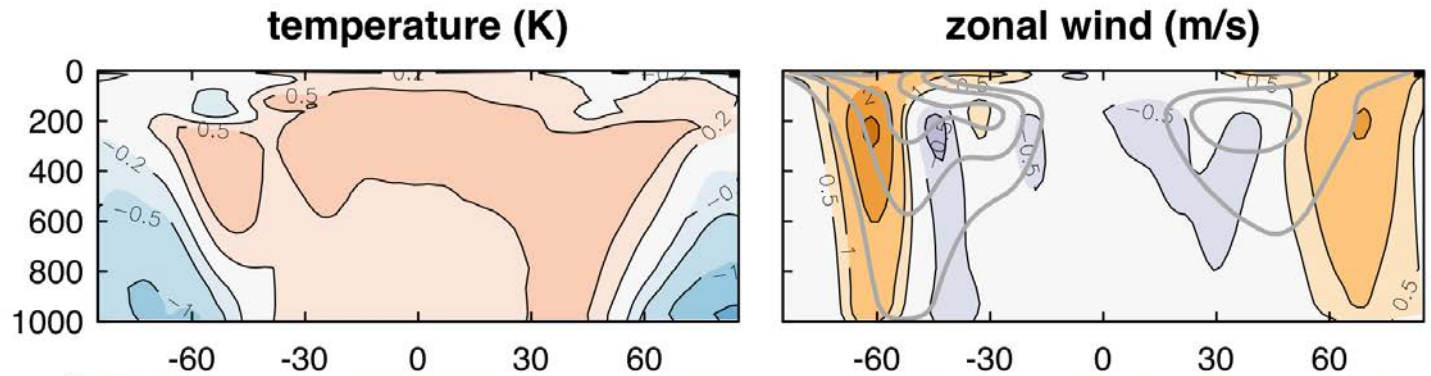
SW cloud feedback in CMIP5 4xCO$_2$
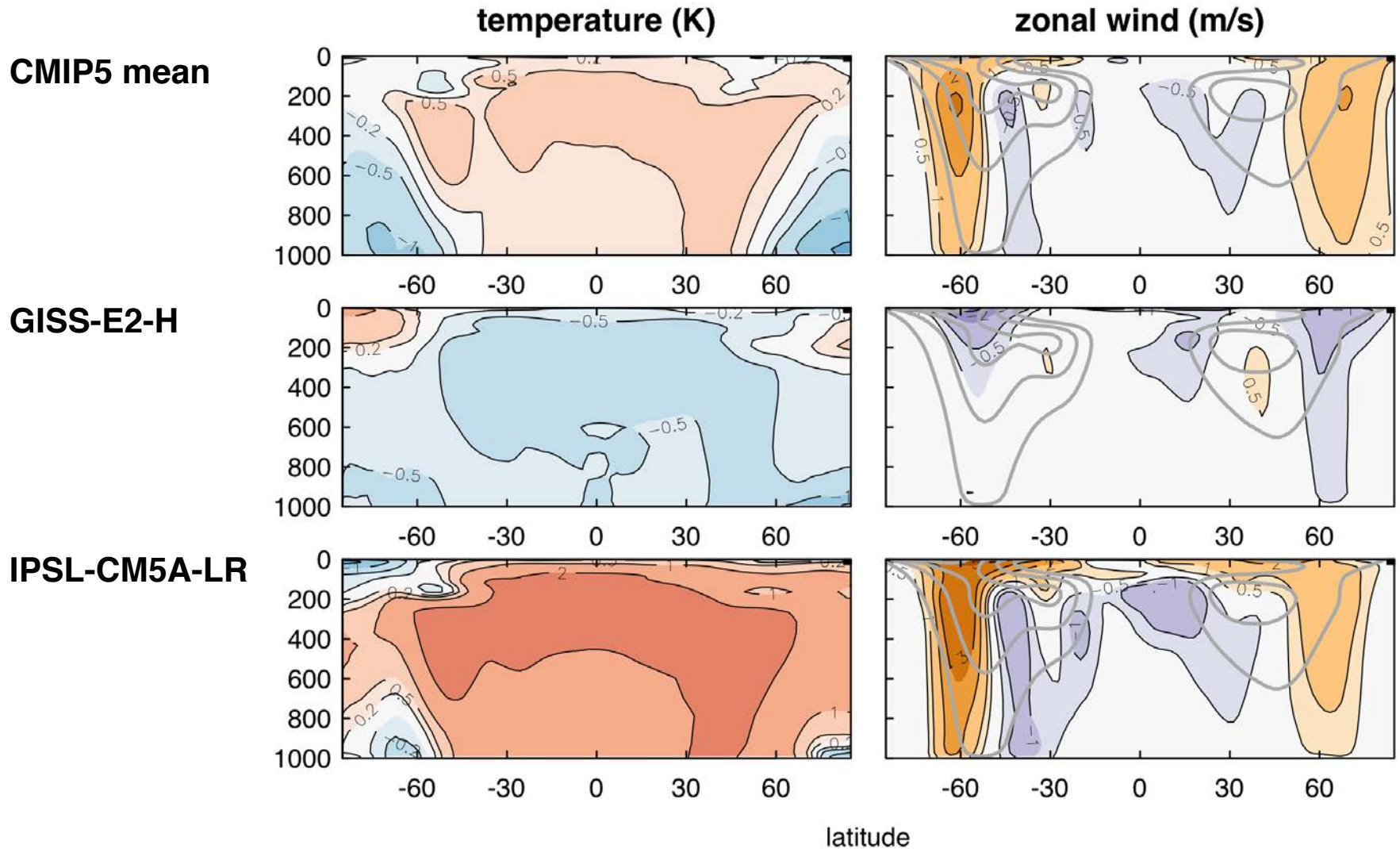
SW cloud feedback in CMIP5 4xCO$_2$

$$\text{SW index} = [\text{SW}]_{20-50} - [\text{SW}]_{50-90}$$
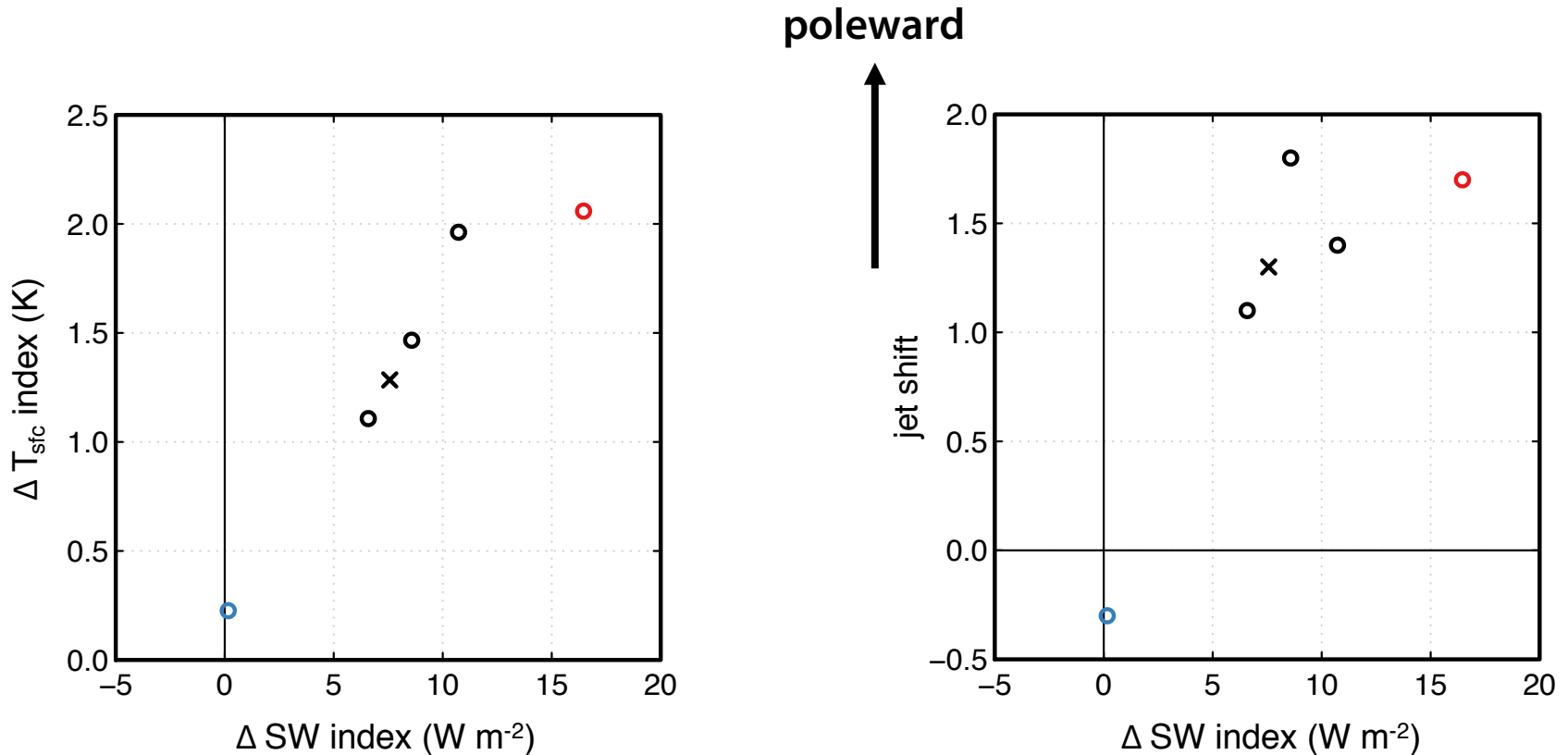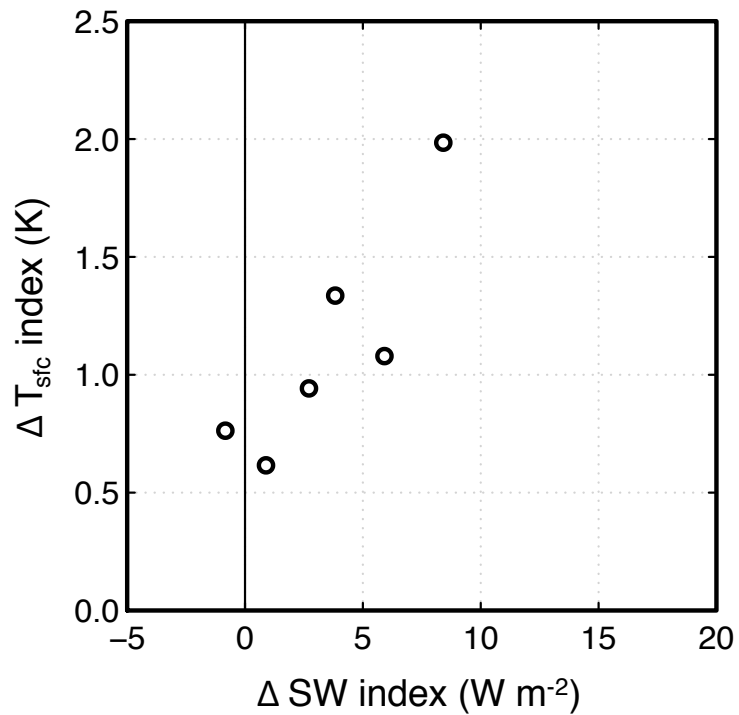
SW cloud forcing in CAM4
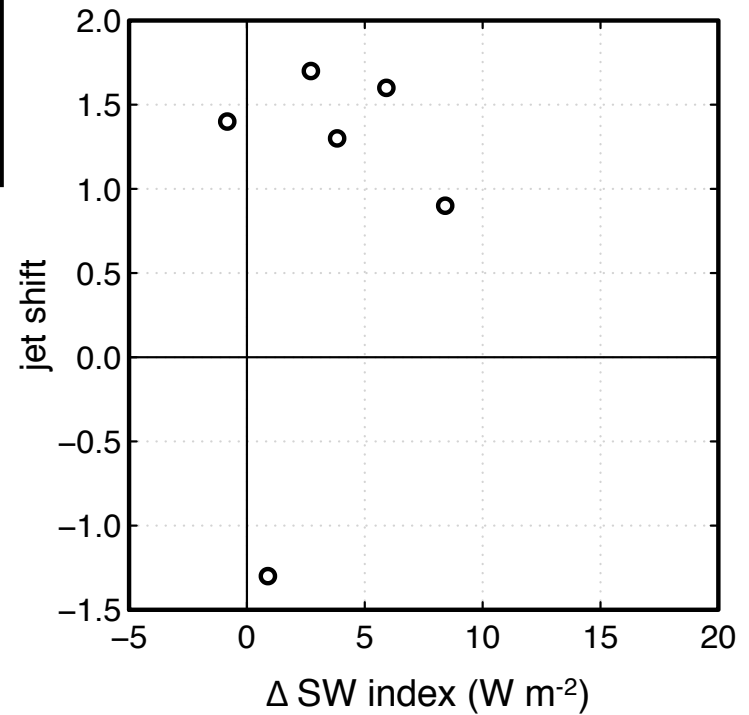
CMIP5 mean

SW cloud forcing in CAM4

SW cloud forcing and SH jet shift

NH jet shift

Conclusions

- Clouds play a very important role in atmospheric circulation response

- Cloud forcing particularly favorable for poleward expansion of circulation

- Cloud feedbacks can account for large inter-model differences in circulation response to warming

Thanks!

References:

Ceppi and Hartmann (2016)

Clouds and the atmospheric circulation response to warming

Journal of Climate, doi: 10.1175/JCLI-D-15-0394

Ceppi, Zelinka, and Hartmann (2014)

The Response of the Southern Hemispheric Eddy-Driven Jet to Future Changes in Shortwave Radiation in CMIP5
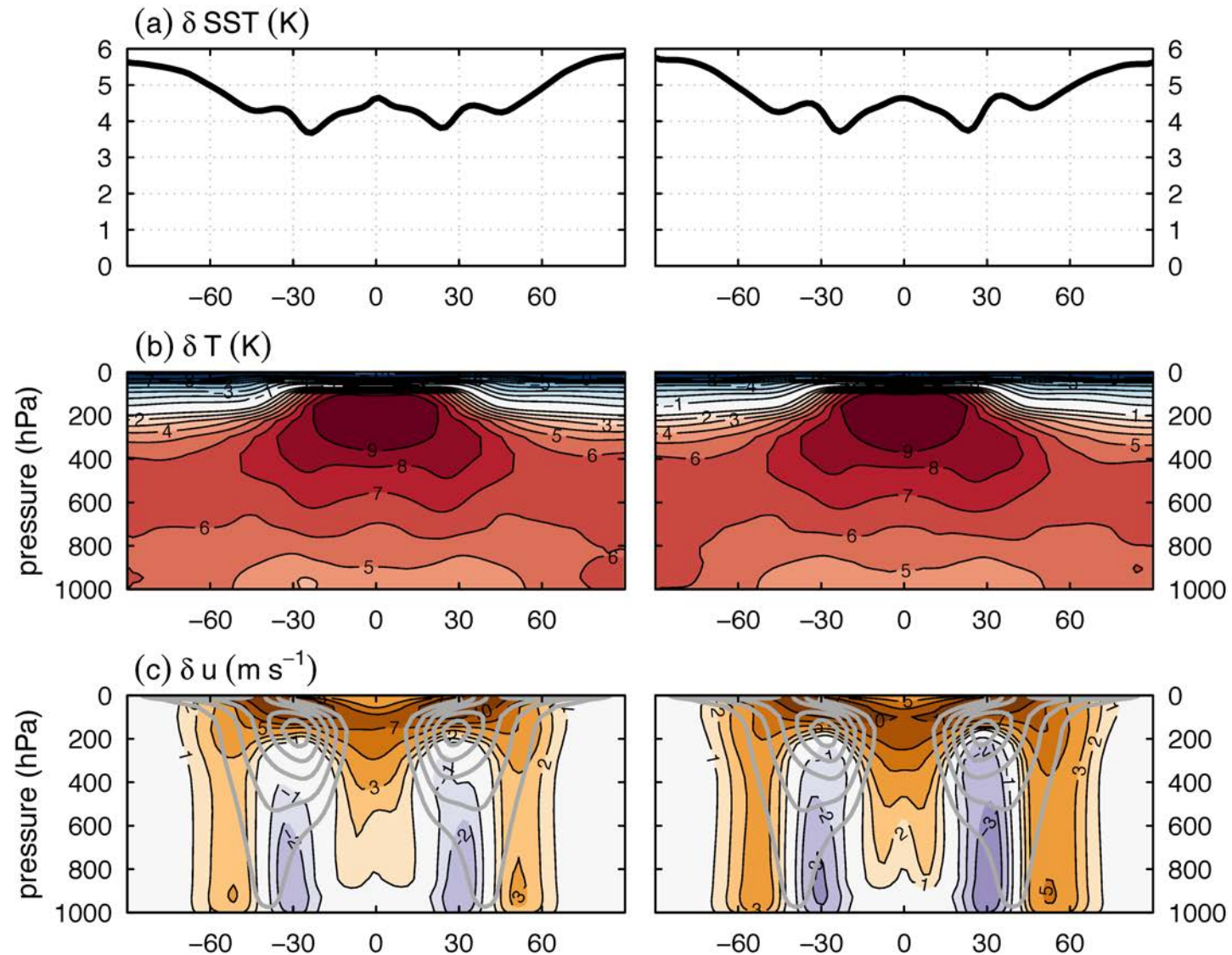
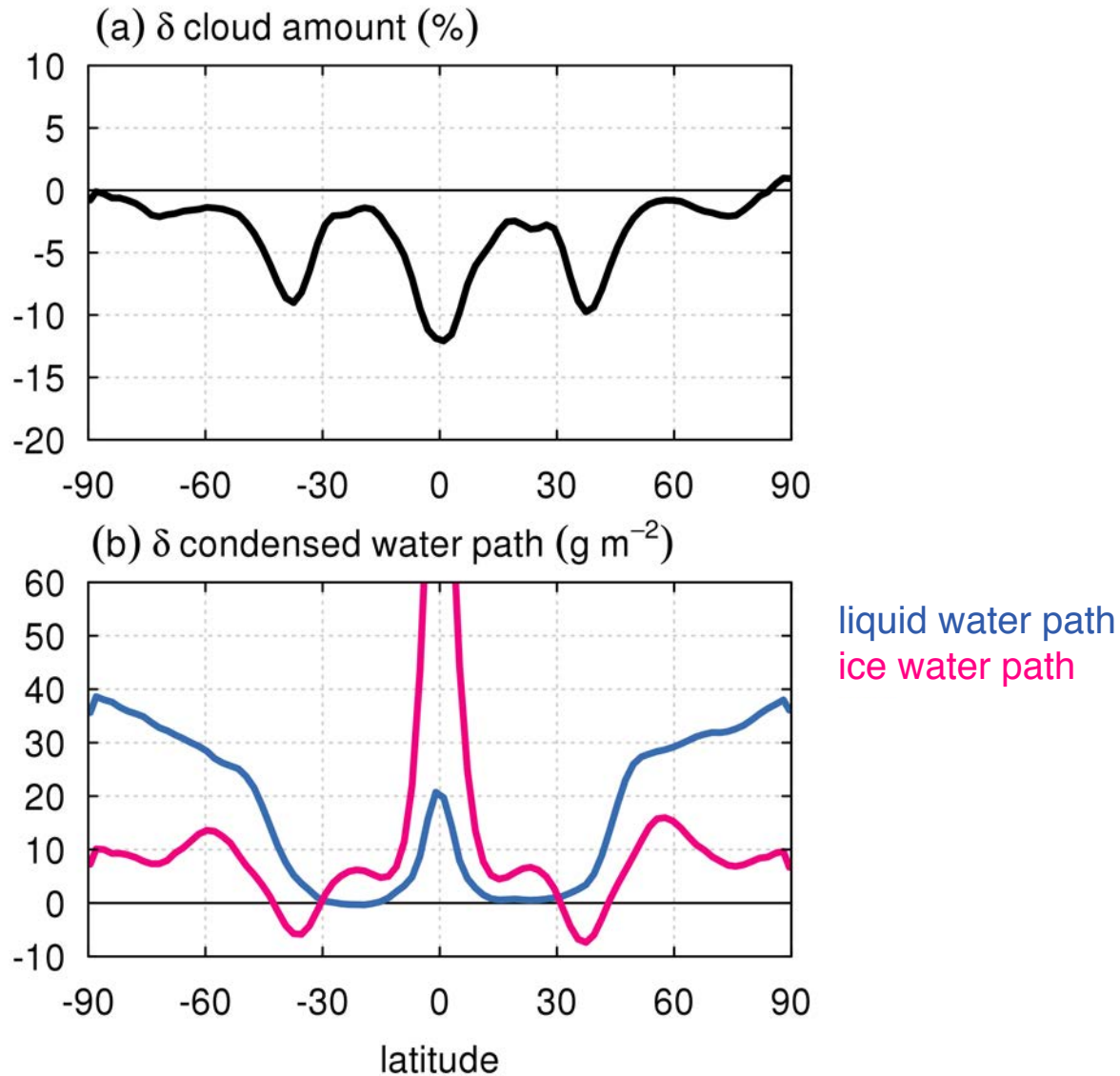GRL, doi: 10.1002/2014GL060043

Extra slides

4xCO2 response

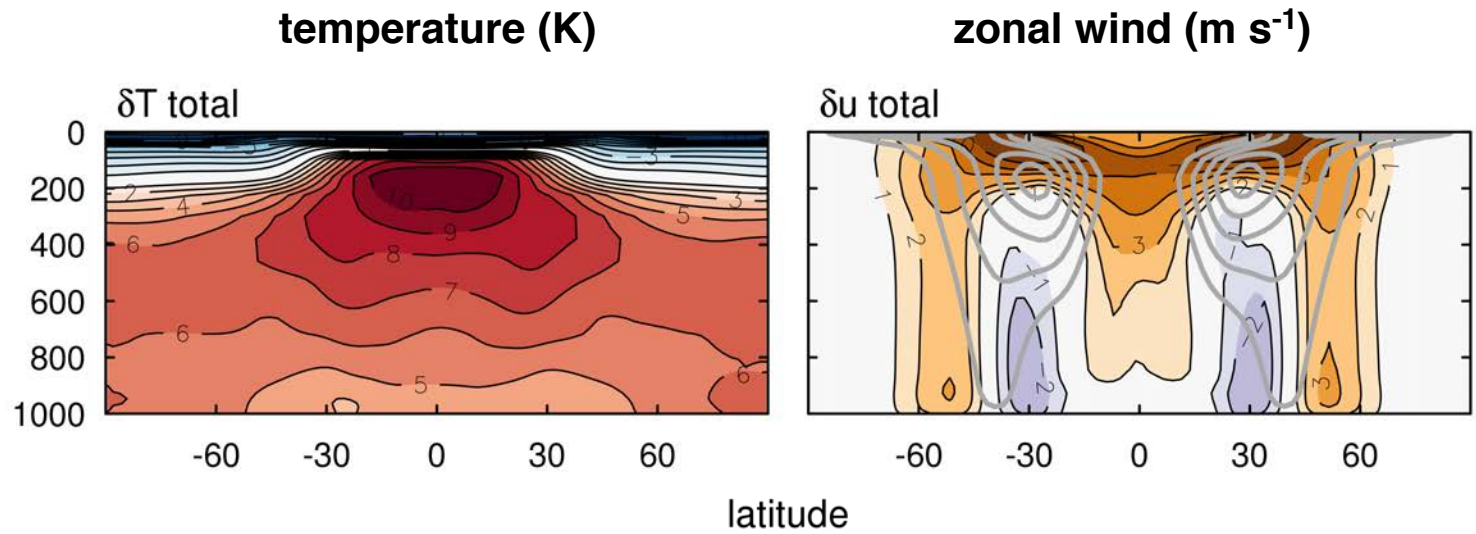prescribed clouds

interactive clouds

Cloud changes in 4xCO2

(a) δ cloud amount (%)

(b) δ condensed water path (g m^{-2})

latitude

liquid water path
ice water path

$$\delta X = X_{\text{G2S2L2}} - X_{\text{G1S1L1}}$$

$$\delta X_{\text{G}} = \frac{1}{2}[(X_{\text{G2S1L1}} - X_{\text{G1S1L1}}) + (X_{\text{G2S2L2}} - X_{\text{G1S2L2}})]$$

$$\delta X_{\text{S}} = \frac{1}{4}[(X_{\text{G1S2L1}} - X_{\text{G1S1L1}}) + (X_{\text{G2S2L1}} - X_{\text{G2S1L1}}) + (X_{\text{G1S2L2}} - X_{\text{G1S1L2}}) + (X_{\text{G2S2L2}} - X_{\text{G2S1L2}})]$$

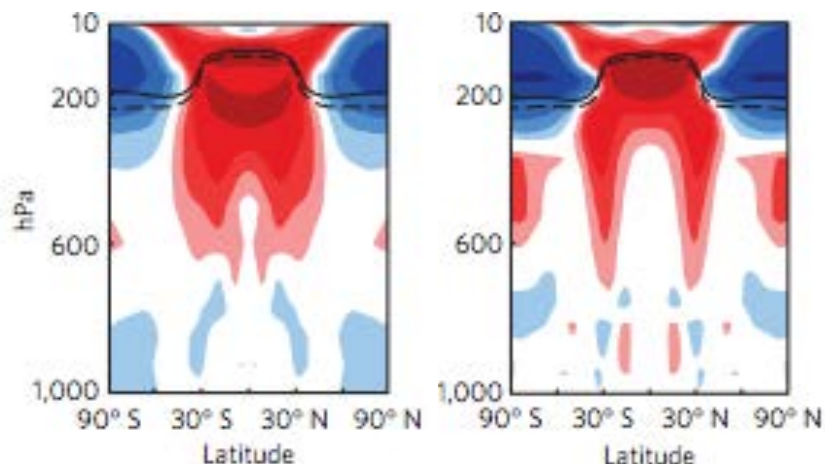# temperature (K)   # zonal wind (m s⁻¹)
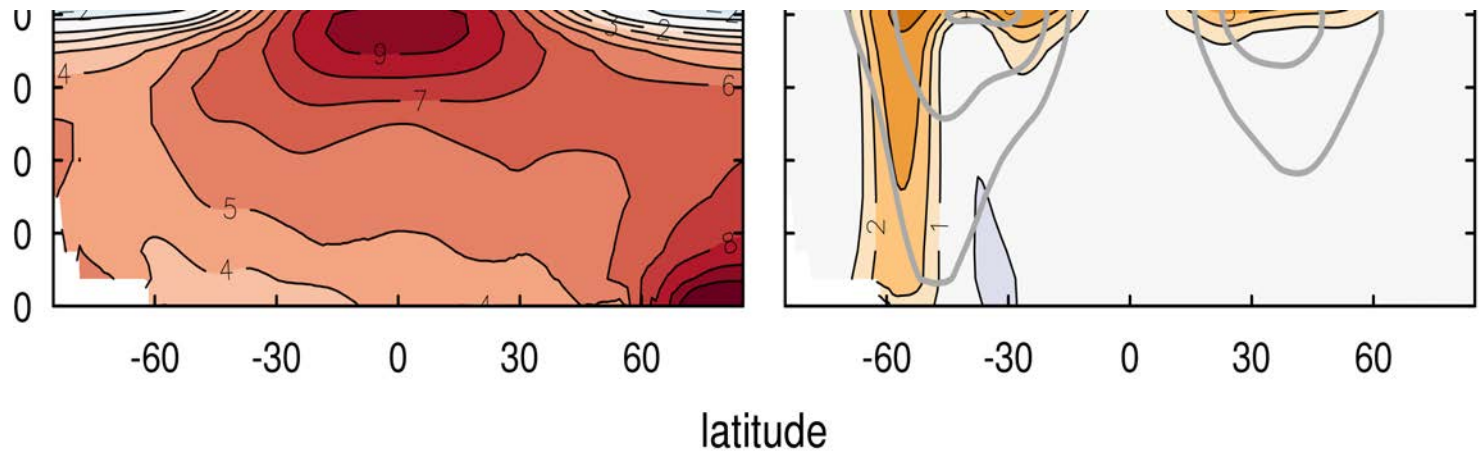
Circulation response to warming shaped by radiative changes of clouds and water vapour

Aiko Voigt[1]* and Tiffany A. Shaw[1,2,3]
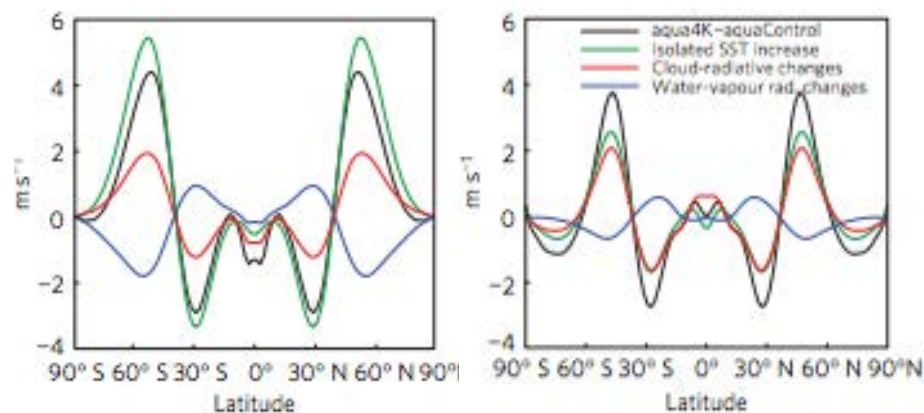
temperature response to cloud-radiative changes
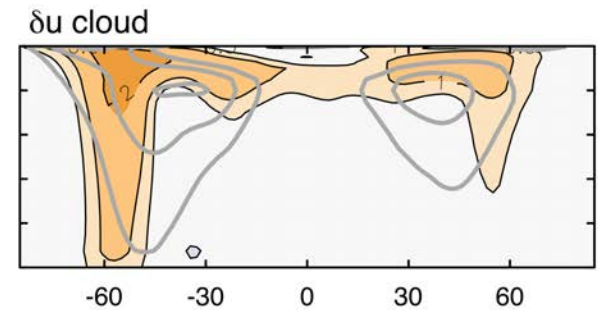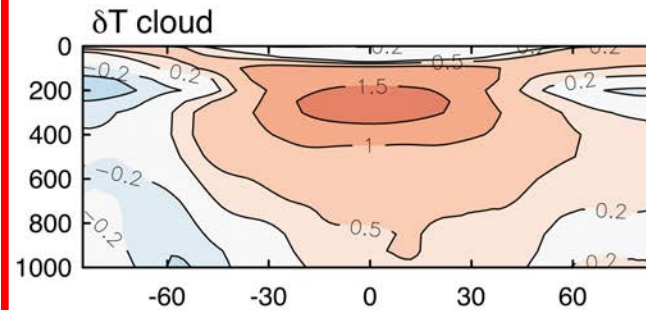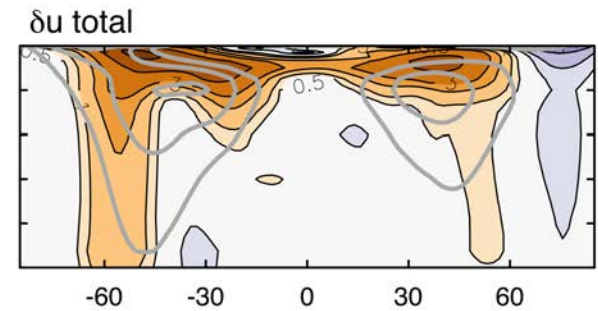
925 hPa zonal wind response

Realistic GCM experiments

- ECHAM6 and CAM4

- Real-world geography, coupled to slab ocean

- Full seasonal cycle

- 2xCO_2 experiment

ECHAM6

ECHAM6

CAM4
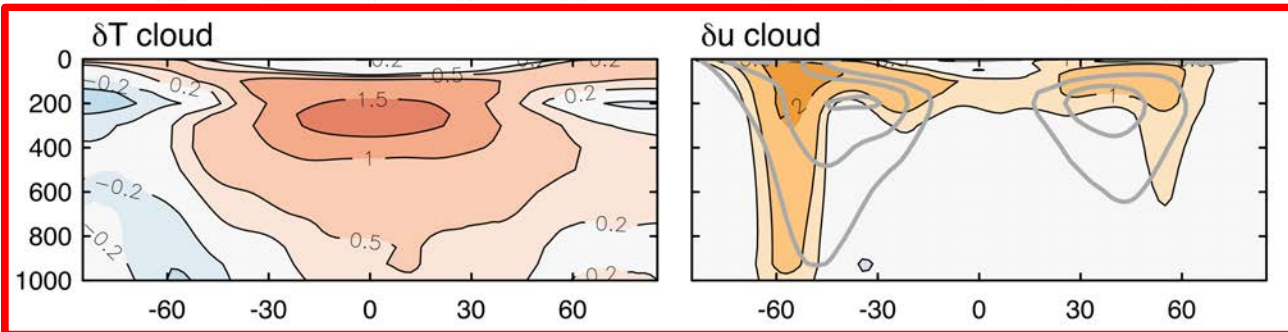
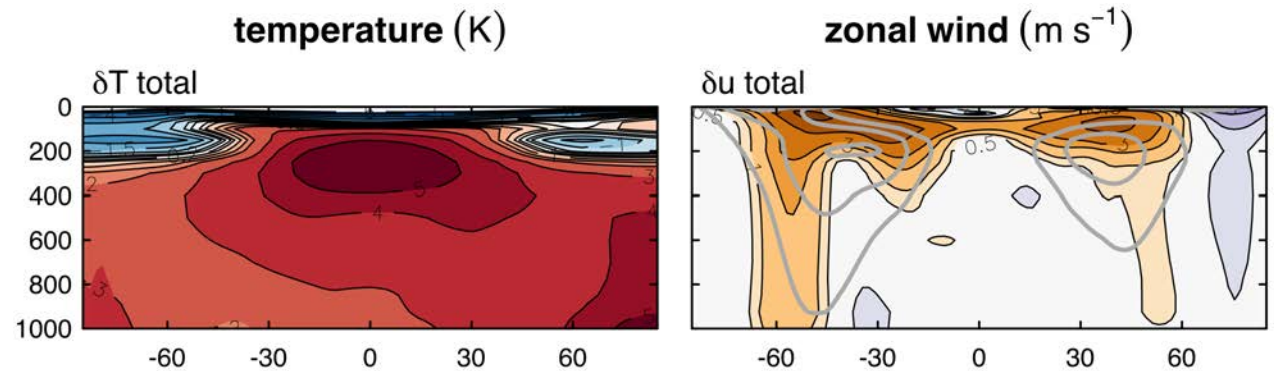temperature (K)

zonal wind (m s^{-1})

δT total

δu total

δT cloud

δu cloud

δT total
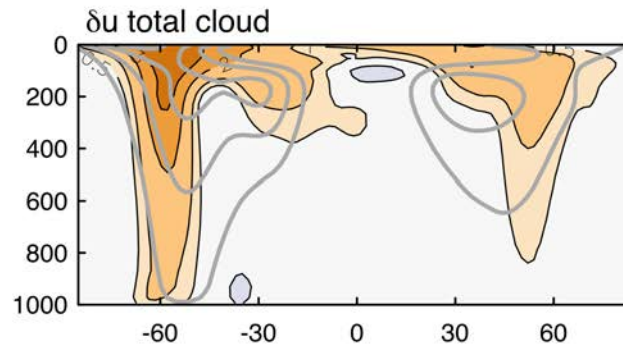
δu total

δT cloud

δu cloud
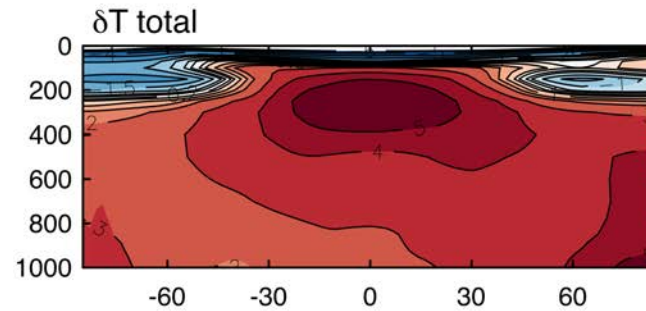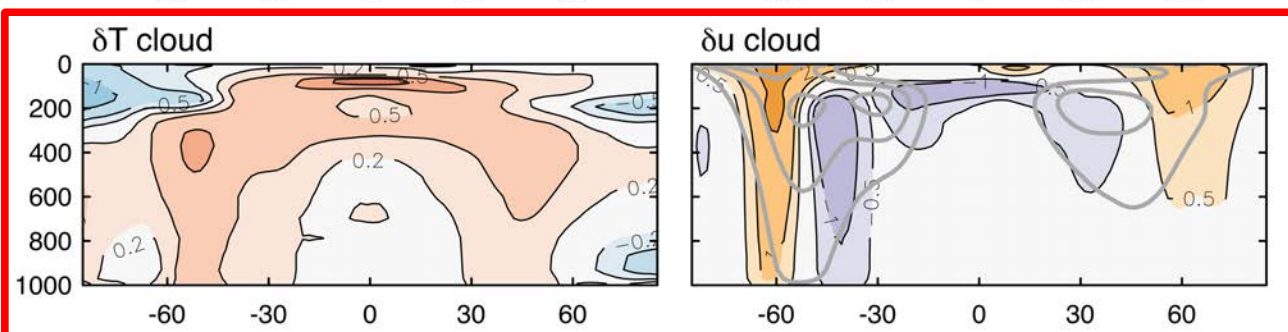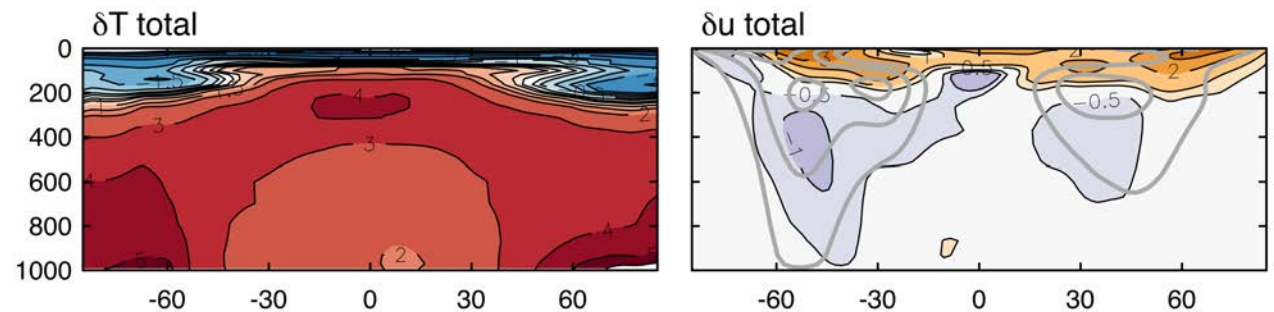
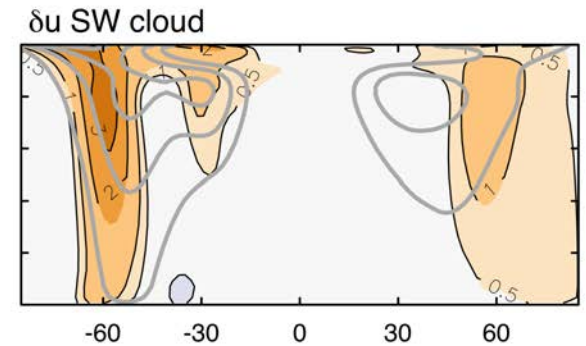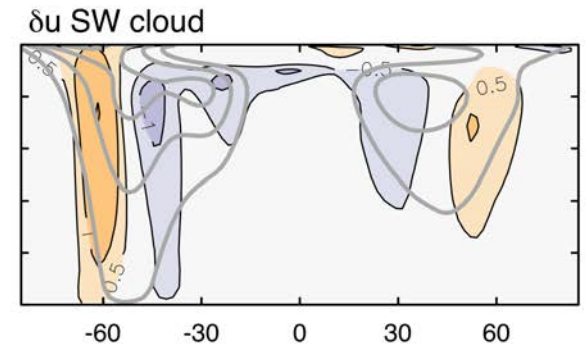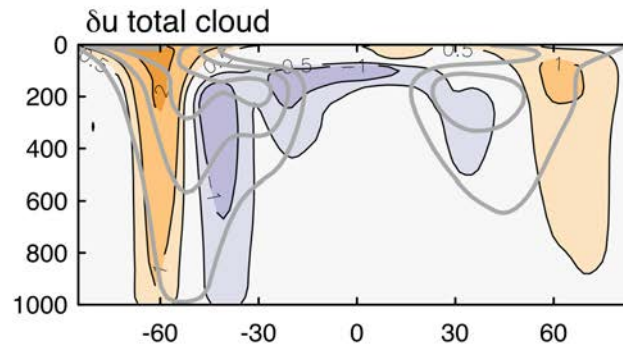# Importance of SW forcing

ECHAM6

CAM4

u response to
total cloud forcing

u response to
SW cloud forcing