Climate sensitivity in a global aqua-planet WRF

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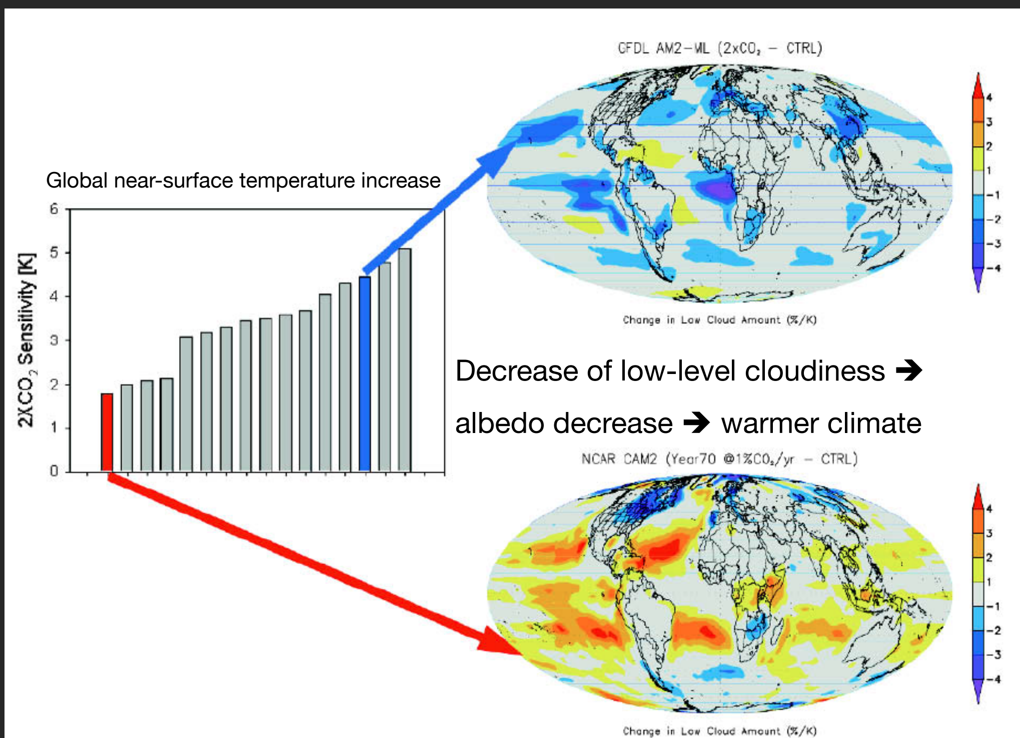
Cloud radiative feedbacks in GCMs

CORELATION BETWEEN GCM CLIMATE SENSITIVITY AND DECREASE OF (LOW-LEVEL) CLOUDS

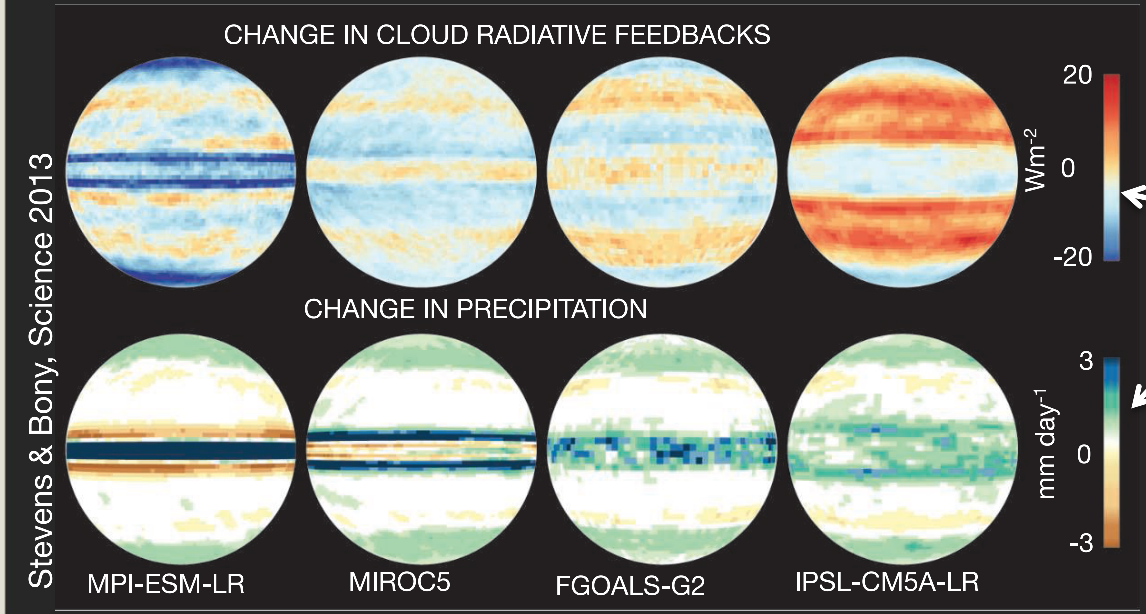


Stephens, J. Clim. 2005

- Clouds - key source of physical uncertainty when predicting climate change
- Little improvement of representation of clouds in GCM over the last decade
- Which processes in GCMs need to be improved for better representation of clouds?

Aqua-planet GCM

RESPONSE OF CMIP5 GCM AQUA-PLANET SIMULATIONS TO 4K INCREASE OF SST



- Similar to uncertainty in complex Earth's GCM simulations
- Key problem seems to be dynamics/physics of the atmosphere
- Understanding differences in aqua-planet simulations – pathway to improve full GCMs
- Which parts of the GCMs (processes) are responsible for these differences?

Aqua-planet GCM simulations:

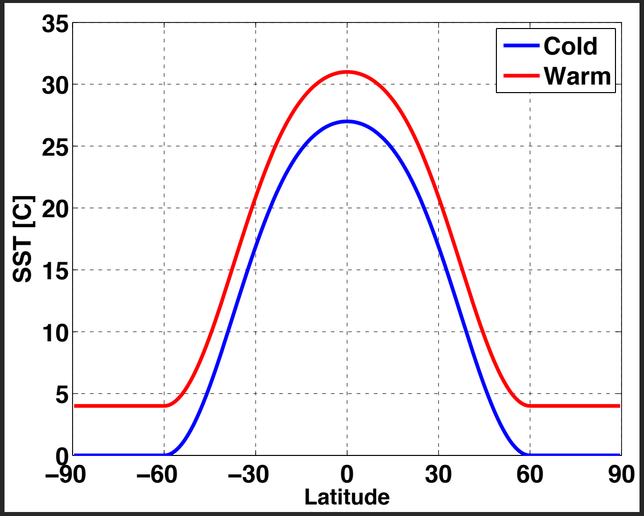
- Earth's atmosphere without land and ice
- Simulation of the atmosphere only (prescribed SST, no land and cryosphere)
- Atmospheric GCMs identical to CMIP5 climate simulation GCMs
- Climate perturbation – change of SST (prescribed)

WRF GCM simulations

SENSITIVITY OF WRF AQUA-PLANET SIMULATIONS TO PHYSICAL PARAMETERIZATIONS

Aqua-planet simulations:

- WRF V3.5
- No land
- No seasons (no axial tilt and eccentricity)
- Mean zonal aerosol and ozone concentration
- Simulation length: 1 year (+ 4 months spin-off)
- Horizontal/Vertical resolution: 1° x 1° / 40 levels
- Prescribed SST: ‘Cold’ and ‘Warm’ (+4K SST) climate
- Sensitivity: difference between warm and clod climate simulation
- 4 sets of simulations

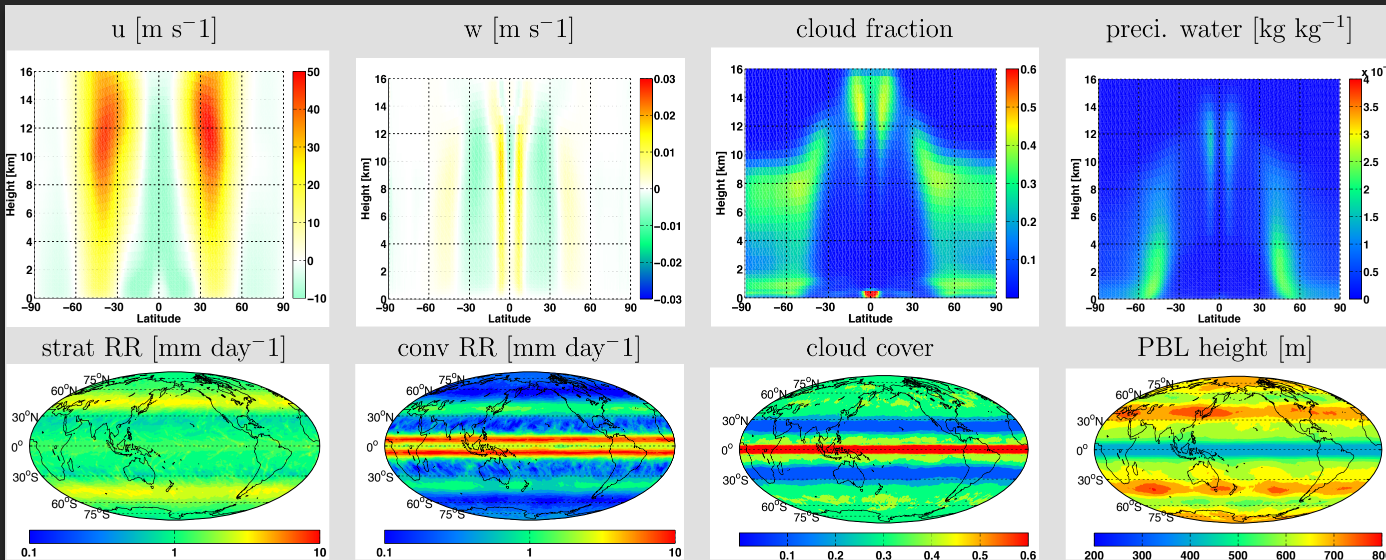


SIMULATIONS / PARAMET.	CTL	ΔPBL	ΔMF	ΔCU
PBL	MYNN	**YSU**	MYNN	MYNN
Cumulus	Kain-Fritsch	Kain-Fritsch	Kain-Fritsch	**Tiedtke**
Microphysics	Morrison	Morrison	**WSM (3 class)**	Morrison
Radiation	CAM			

WRF GCM simulations

CONTROL SIMULATION

COLD CLIMATE



- Realistic representation of mid-latitude jets (max. wind speed around 40 m s^{-1})
- Double ITCZ at latitude of around 10°N/S
- Cumulus precipitation – tropical convection and mid-latitude storm tracks
- Stratiform precipitation - primarily at mid-latitude storm tracks

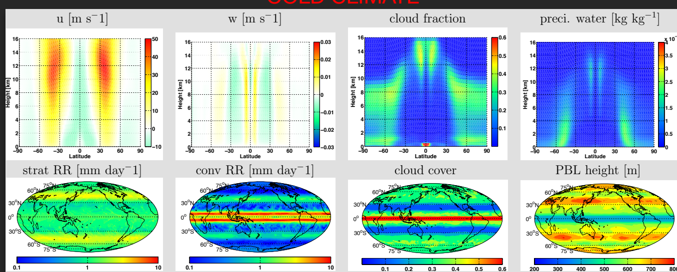
Cloudiness:

- Mid-latitude & polar regions - Bimodal distribution: low (below 2km) and high (around 8 km)
- Tropics – near surface (subtropical stratocumulus type) and above 12 km (convective storm detrainment)

WRF GCM simulations

CONTROL SIMULATION

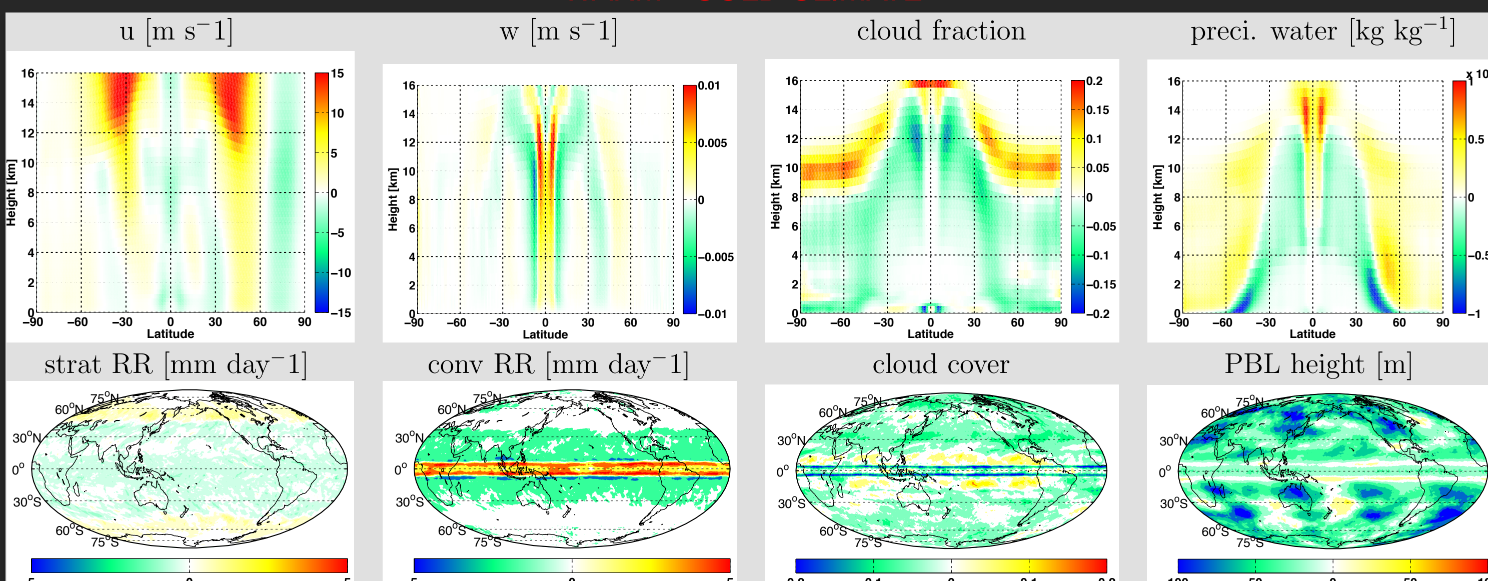
COLD CLIMATE



WARM – COLD CLIMATE

- Increase of strength and depth of tropical convection, significant increase of convective precipitation
- Strengthening of mid-latitude jets, shifting poleward
- Mid-latitude and polar cloudiness: decrease, shifting to higher elevation
- Decrease of tropical near-surface cloudiness (strong effect on radiation)

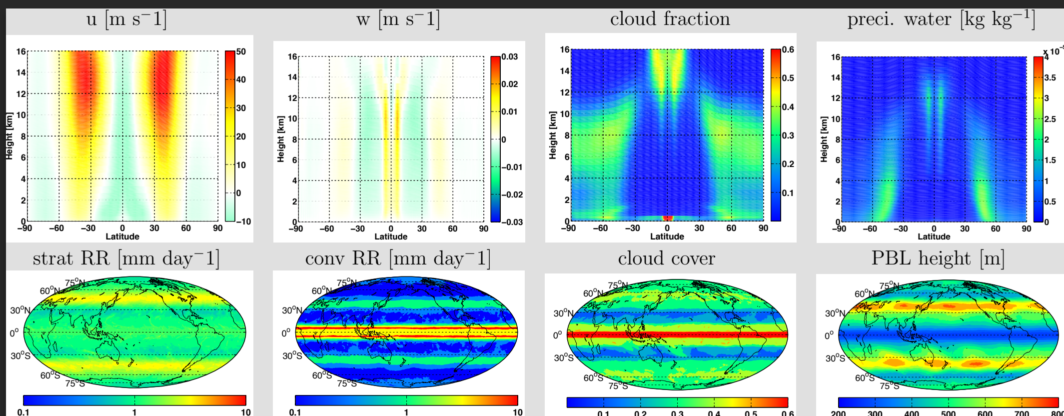
WARM - COLD CLIMATE



WRF GCM simulations

ΔPBL SIMULATION

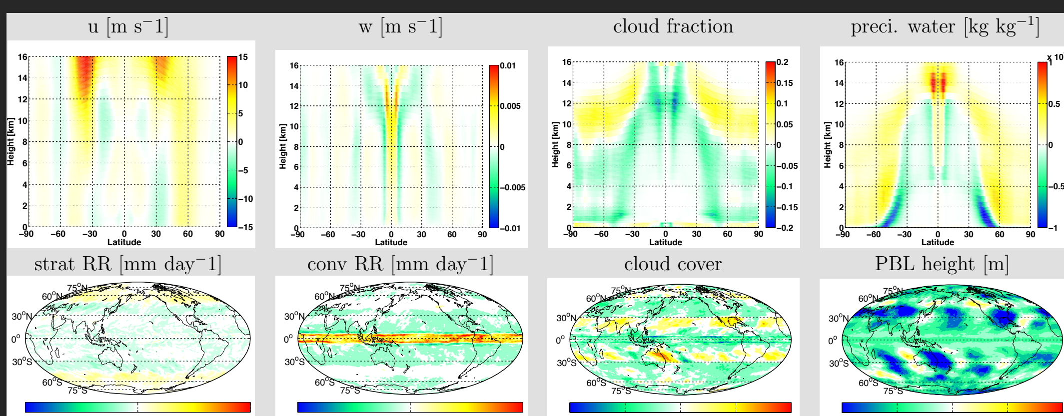
COLD CLIMATE



COLD climate

- Similar to Control
- More subtropical low-level clouds

WARM - COLD CLIMATE



WARM-COLD climate

- Less significant decrease of tropical low-level cloudiness compared to Control
- Increase of subtropical mid-level cloudiness

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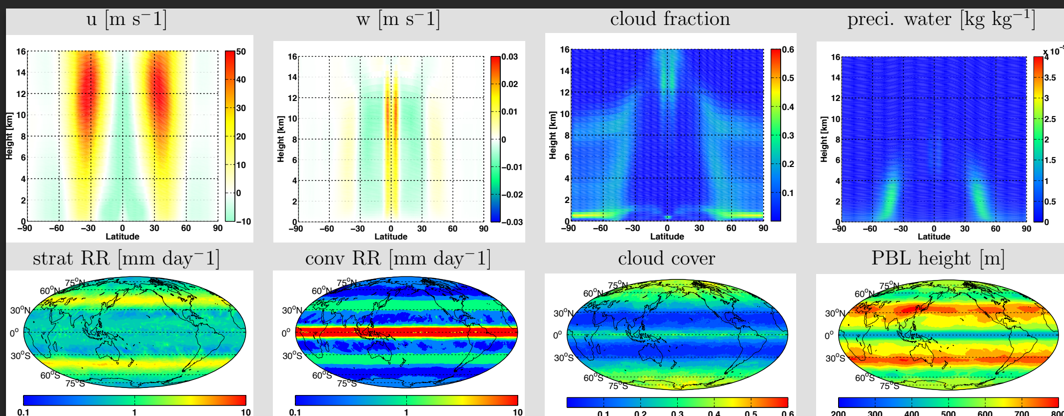
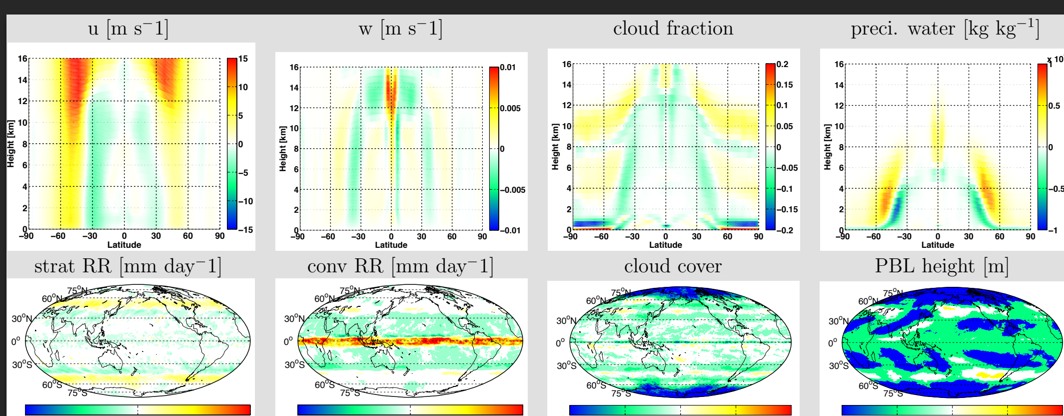
WRF GCM simulations

ΔMF SIMULATION

COLD CLIMATE



WARM - COLD CLIMATE



COLD climate

- Significant less precipitable water and cloudiness than Control
- Tropical convection closer to equator (almost single ITCZ)
- More stratiform precipitation than Control

WARM-COLD climate

- More significant decreases of cloudiness, some increase of near surface cloudiness in mid-latitudes
- PBL height decrease more pronounced

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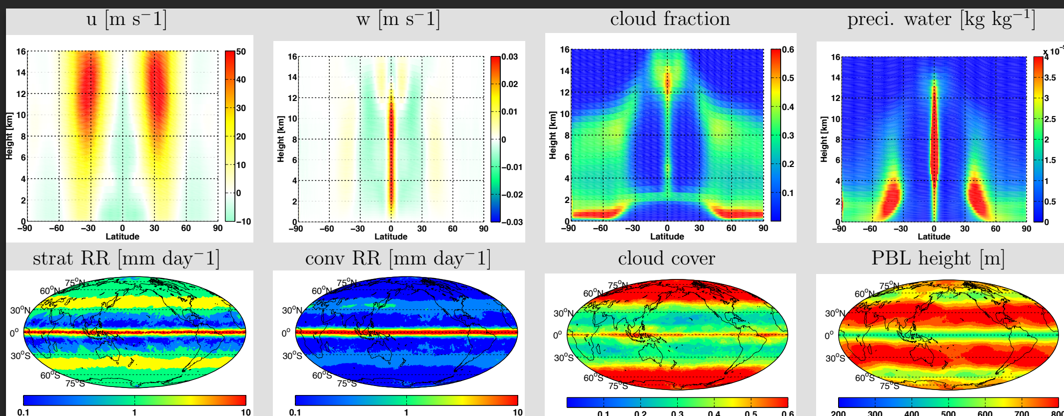
WRF GCM simulations

ΔCU SIMULATION

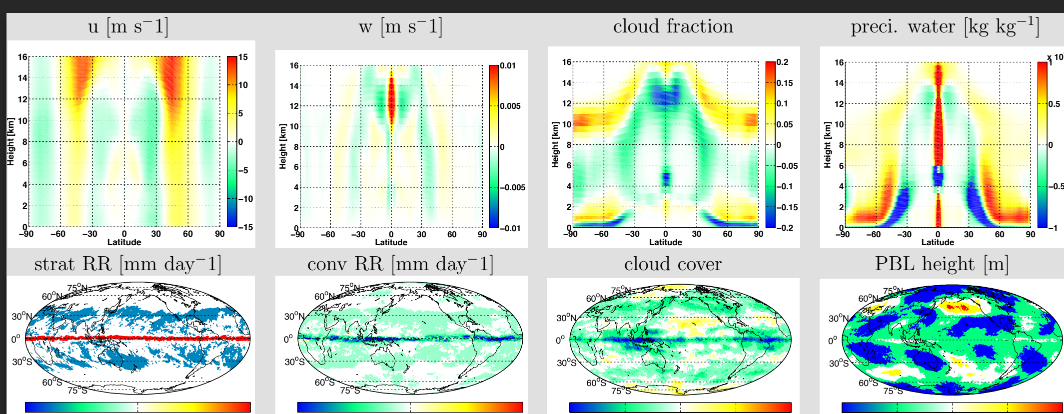
COLD CLIMATE



COLD climate:

- Single and stronger ITCZ than Control
- Stronger mid-latitude storm track
- No near-surface cloudiness in tropics/ subtropics
- More low-level clouds in mid latitude/ polar regions

WARM - COLD CLIMATE

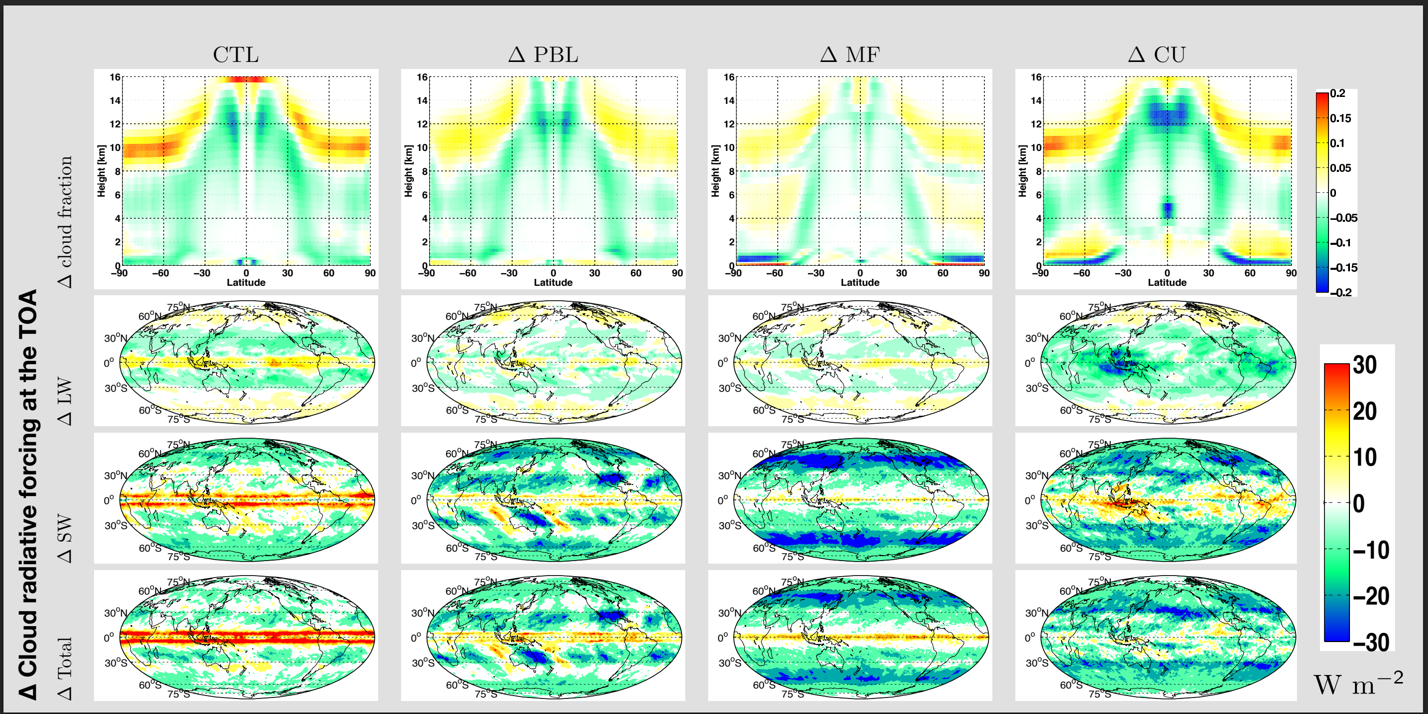


WARM-COLD climate:

- Decrease of tropical cloudiness
- Low-level clouds in mid-latitude/polar regions move to higher elevation

WRF cloud radiative forcing

CHANGE OF CLOUD RADIATIVE FORCING AT THE TOA (WARM-COLD)



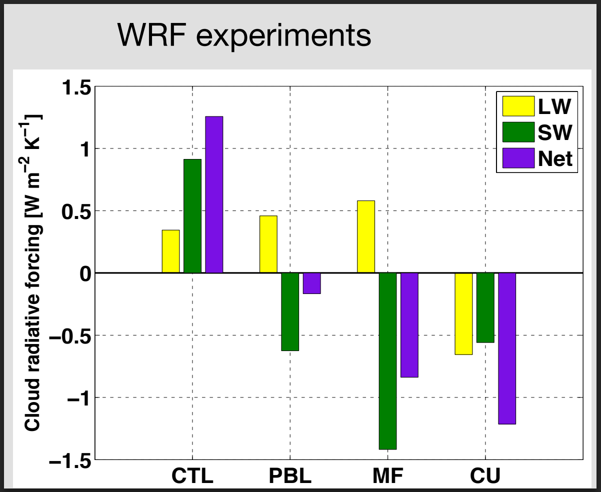
Key responses:

- Tropical near-surface clouds decrease - positive SW feedback – (CTL, ΔPBL, ΔMF)
- Increase of high-level tropical cloudiness – positive LW feedback - (CTL, ΔMF)
- Increase of sub-tropical low-level clouds- negative SW feedback (ΔPBL)
- Increase of mid-latitude/polar near-surface clouds – negative SW (ΔMF)
- Shifting mid-latitude/polar clouds to higher altitudes – negative LW feedback (ΔMF, ΔCU)

WRF cloud radiative forcing, comparison to CMIP5 models

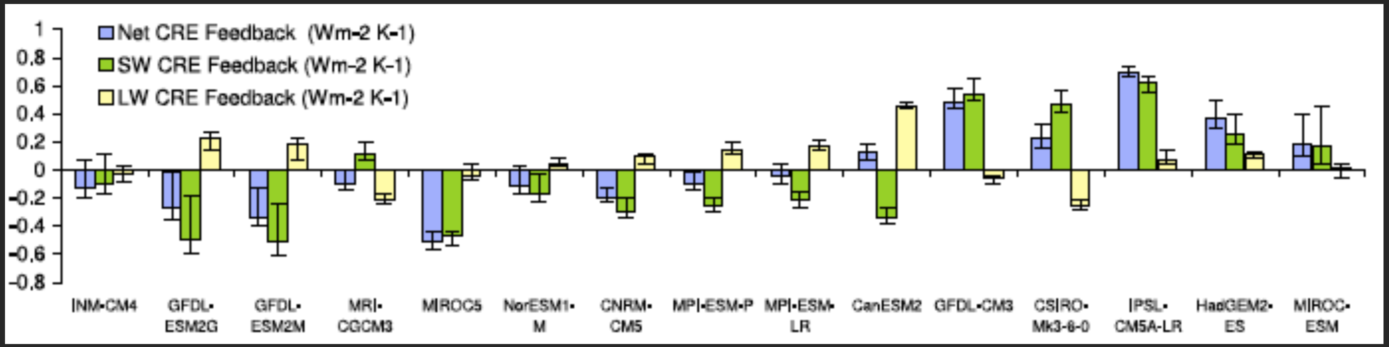
SENSITIVITY OF CLOUD RADIATIVE FORCING TO CHANGE OF NEAR SURFACE TEMPERATURE

Mean global difference of cloud radiative forcing (Warm-Cold) per change of near surface temperature/SST



- Sensitivity of cloud radiative forcing highly depend on physical parameterizations
- Some of WRF simulations seem to have stronger sensitivity than CMIP5 models (different model setup and forcing!)

Cloud feedbacks from CMIP5 models (4×CO2-Control)

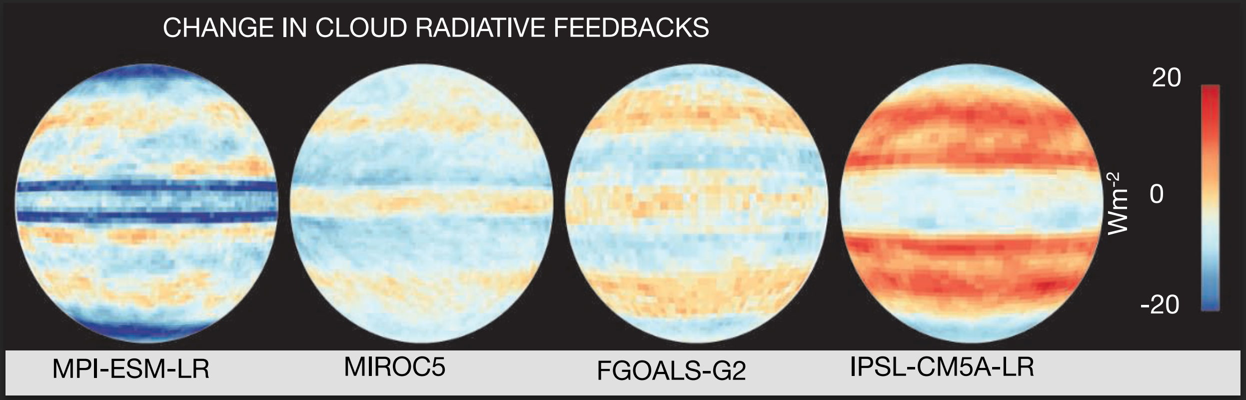


Andrews et al., 2012

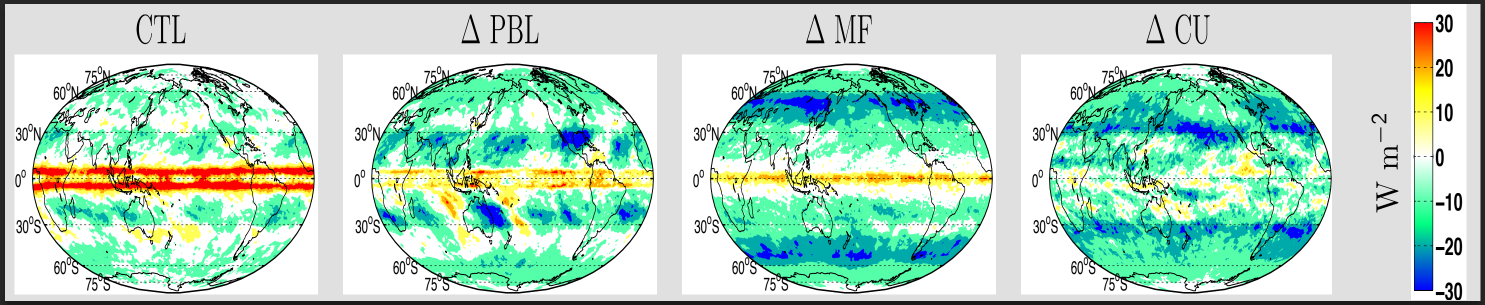
WRF cloud radiative forcing, comparison to Stevens & Bony

CHANGE OF CLOUD RADIATIVE FORCING AT THE TOA (WARM-COLD)

Stevens & Bony, Science 2013



WRF simulations



Summary & Conclusions

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Questions/Problems to be answered:

- Simulated cloud radiative feedbacks – largest source of physical uncertainty when simulating future climate change
- Aqua-planet GCMs – uncertainty similar to complex Earth's system simulations

WRF can:

- Reasonable simulations of aqua-planet's climate
- Identification of parameterized processes/model options that play crucial role for the cloud-climate uncertainty