Karlsruhe Institute of Technology

HD(CP)²
High definition clouds and precipitation for advancing climate prediction

WAVES TO WEATHER

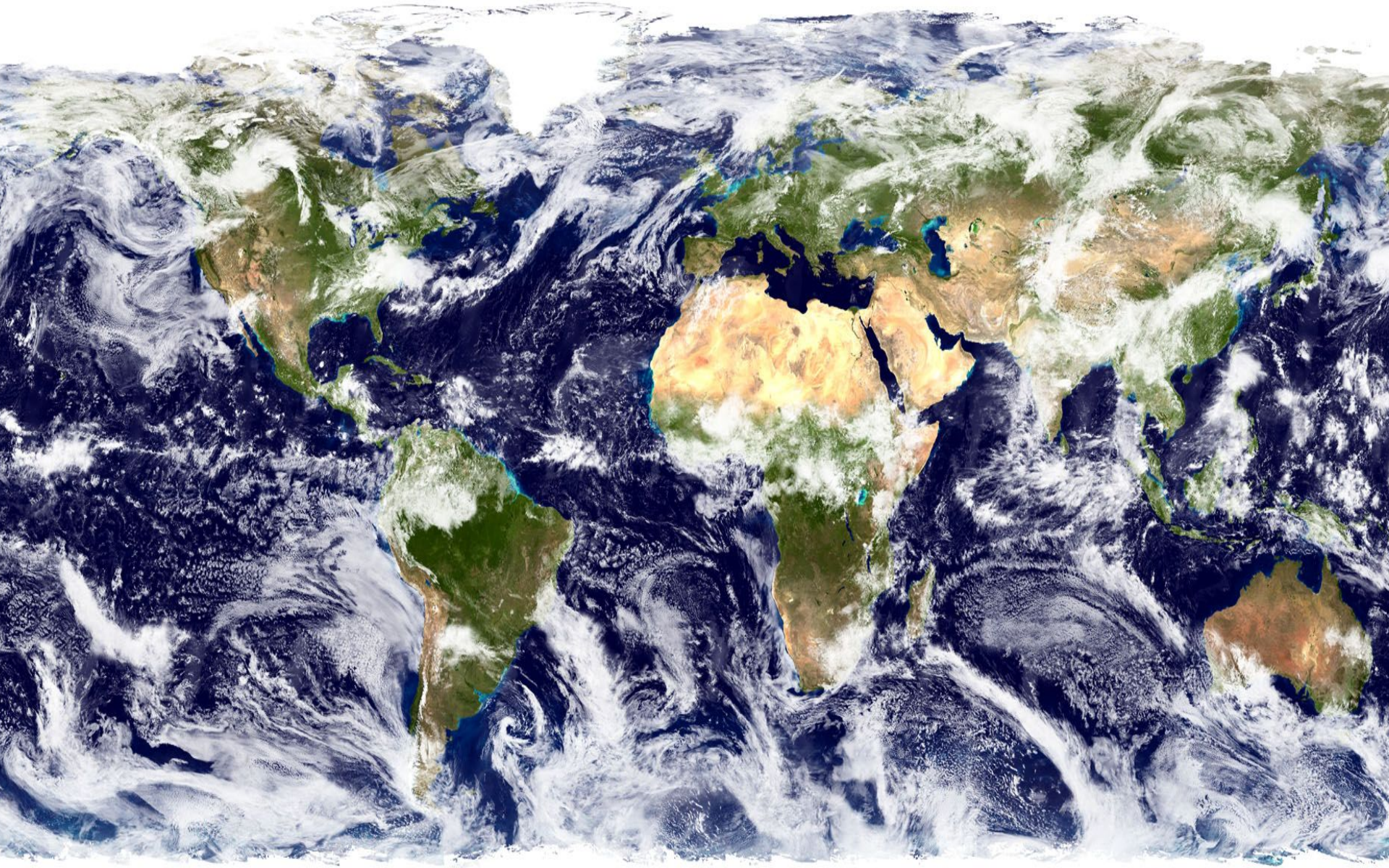
Cloud-radiation-circulation coupling and its impact on regional climate and climate change

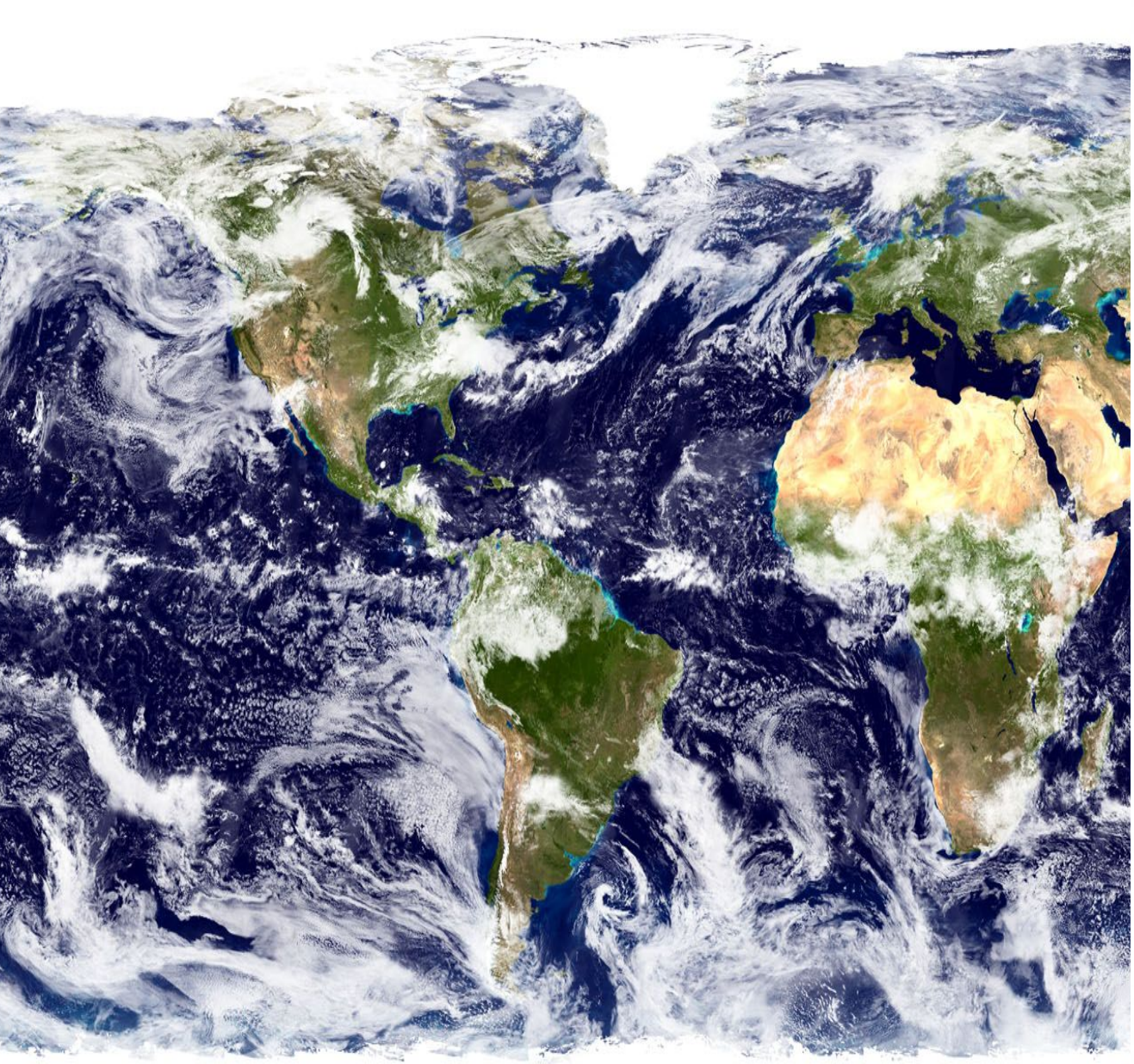
Aiko Voigt

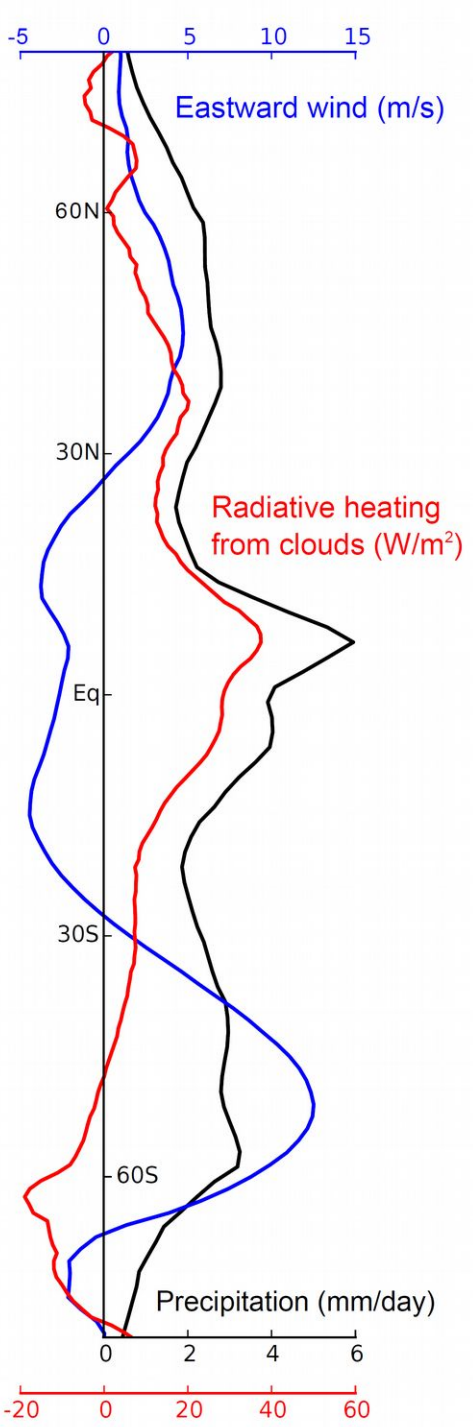
Karlsruhe Institute of Technology
Institute of Meteorology and Climate Research – Department Troposphere Research

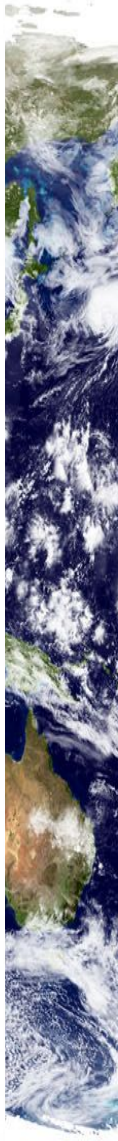
Funded by the German Ministry for Education and Research and FONA: Research for Sustainable Development

Bundesministerium für Bildung und Forschung









GPCP v2.2
ERA-Interim
CERES EBAF v2.6

Three themes of cloud-radiation-circulation coupling

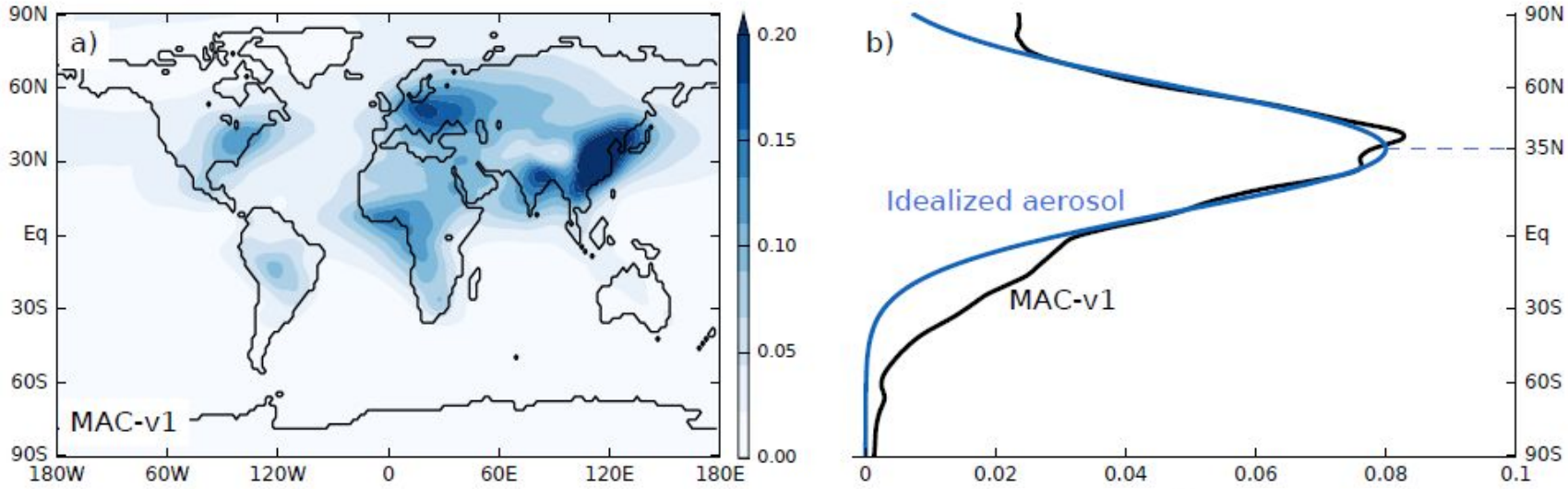
1. Aerosols, clouds, and the position of the intertropical convergence zone

2. Meridional shifts of the extratropical jet stream shift in response to global warming

3. Ongoing and future work within HD(CP)^2

   - Baroclinic lifecycles
   - Internal circulation variability
   - Ultra high-resolution ICON-LEM simulations over the North Atlantic

Impact of anthropogenic aerosol on the zonal-mean ITCZ

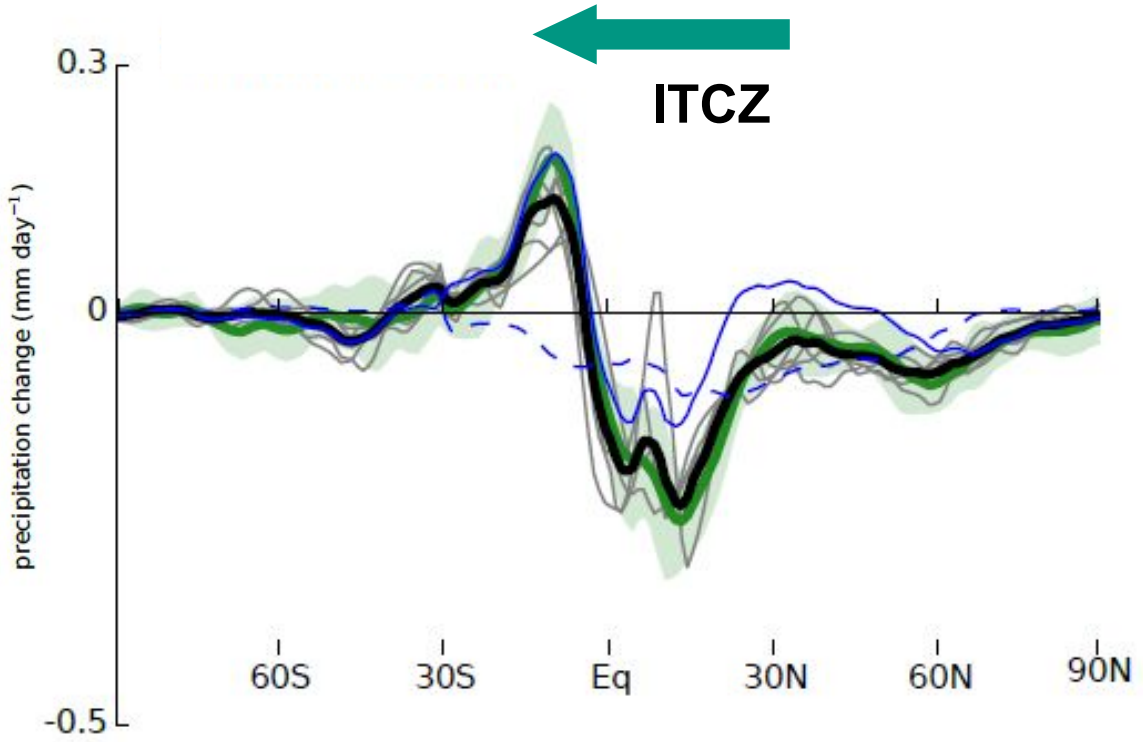


Aerosol optical depth

Easy Aerosol MIP within WCRP Grand Challenge „Clouds, Circulation and Climate Sensitivity“

Voigt et al., 2017, JAMES

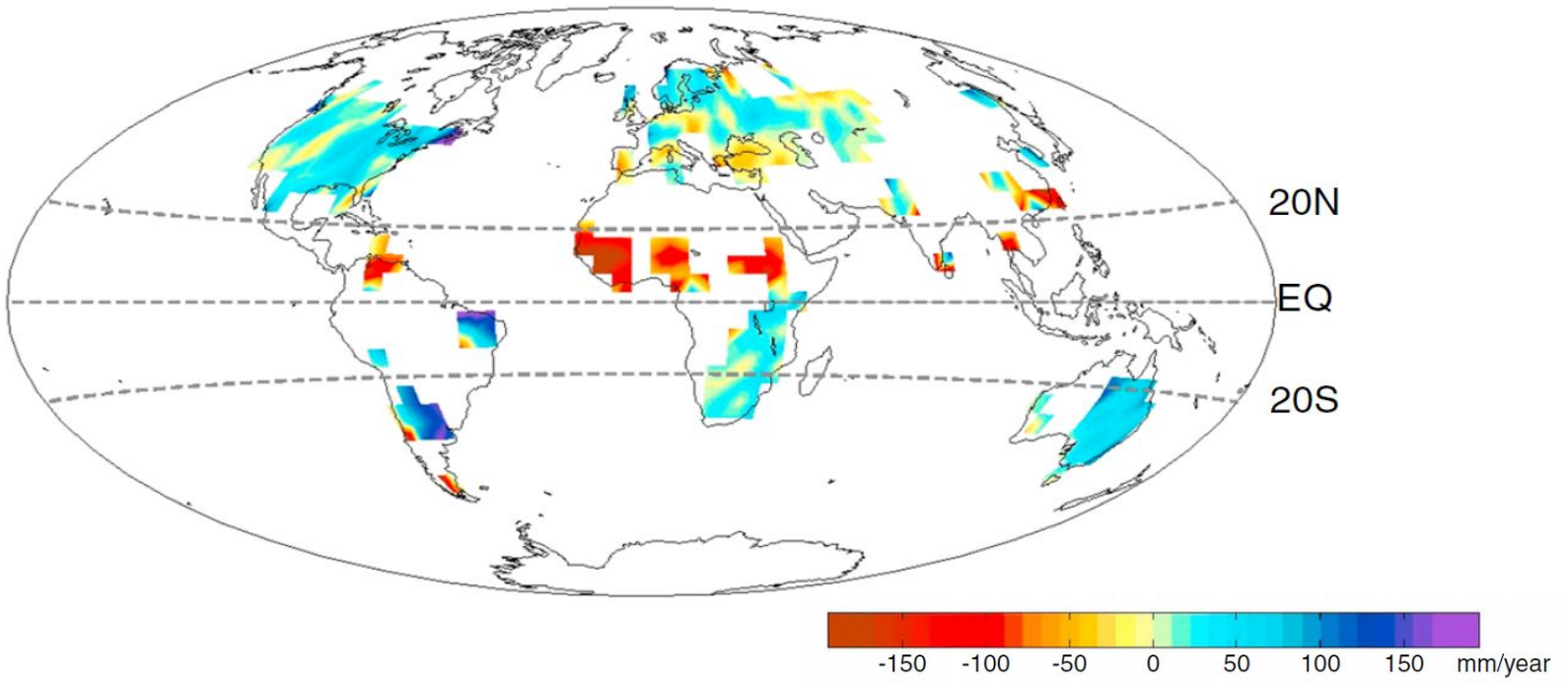
Anthropogenic aerosol causes southward ITCZ shift



Effect of introducing the idealized anthropogenic aerosol into global climate models

Voigt et al., 2017, JAMES

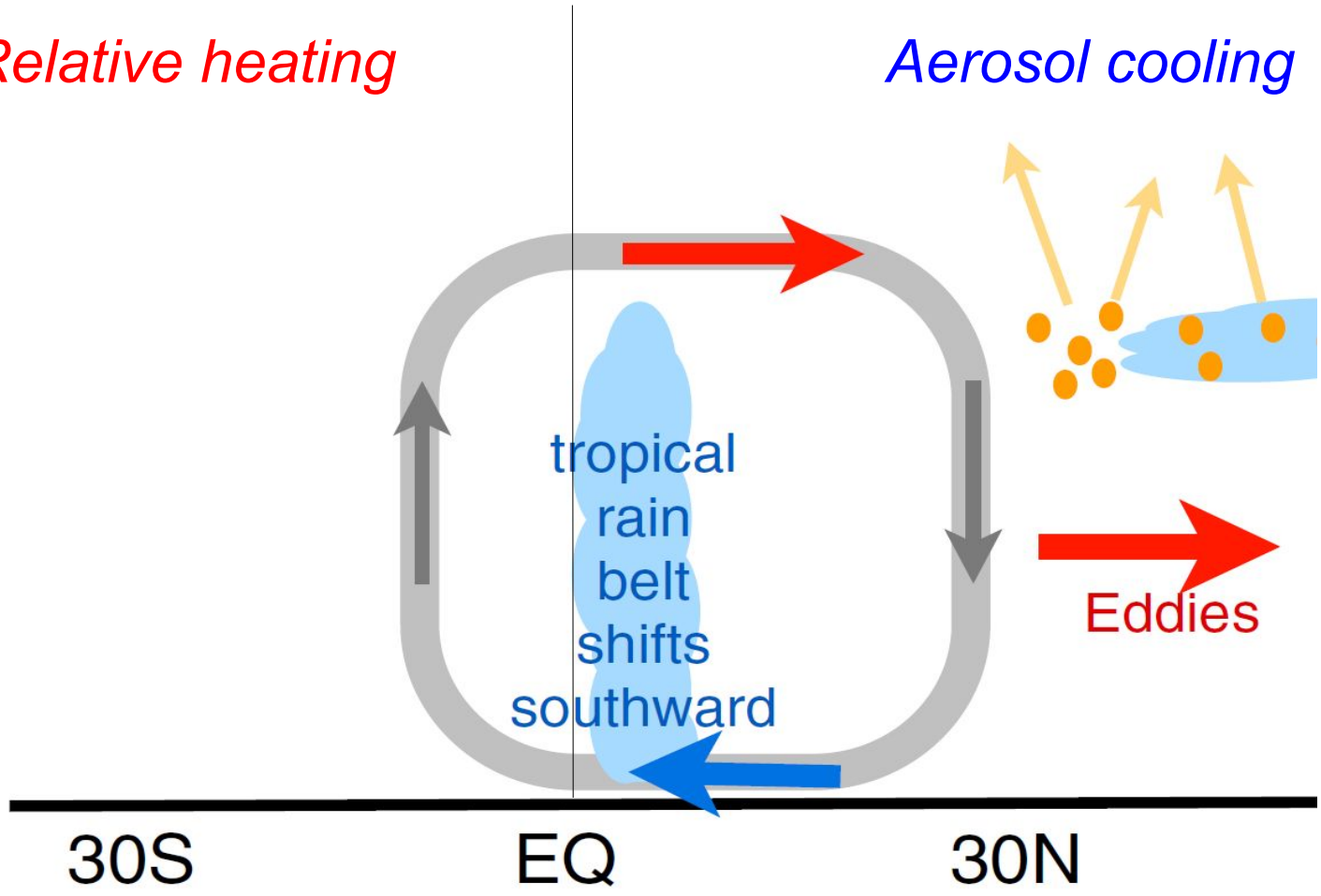
Anthropogenic aerosol might have caused the Sahel drought of the 1970's and 1980's



Precipitation change from 1931-1950 to 1971-1990 from Global Historical Climatology Network

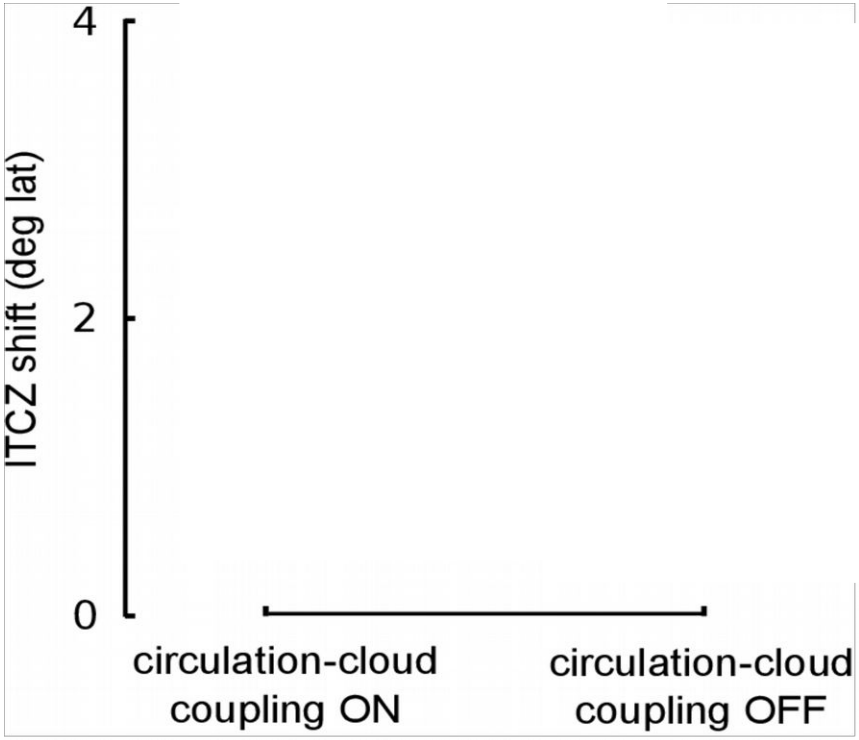
Hwang et al., 2013, GRL

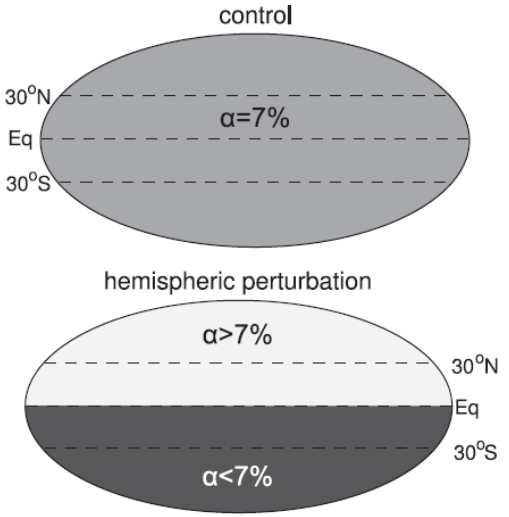
ITCZ shifts into the (relatively) heated hemisphere



Hwang et al., 2013, GRL
Kang et al., 2009, J. Climate

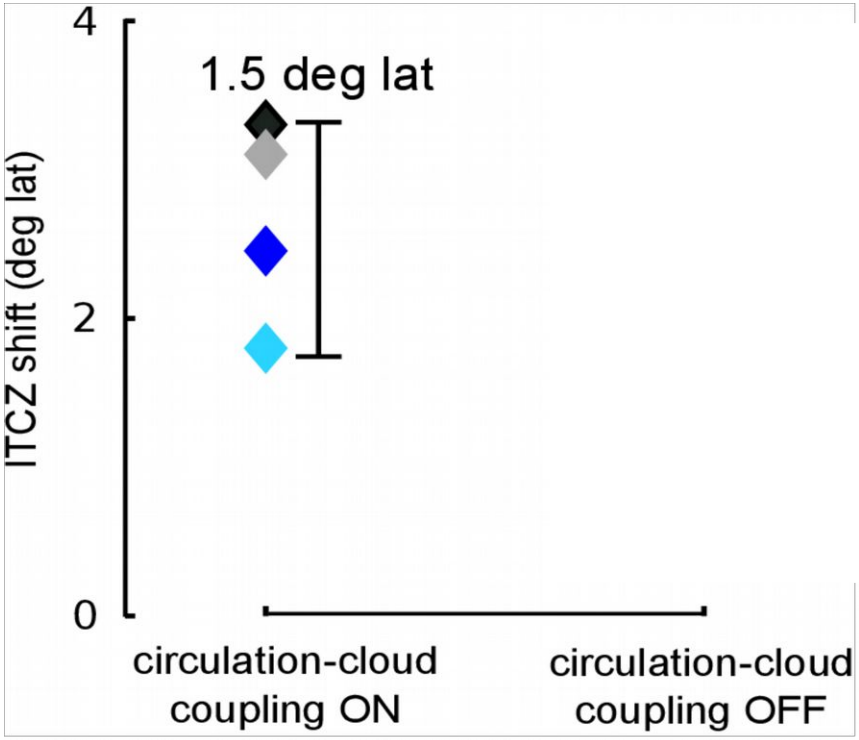
How much does the ITCZ shift in response to a hemispheric perturbation?

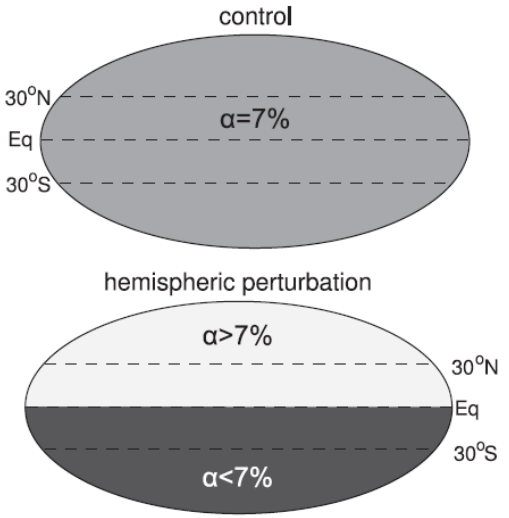




Voigt et al., 2014, GRL

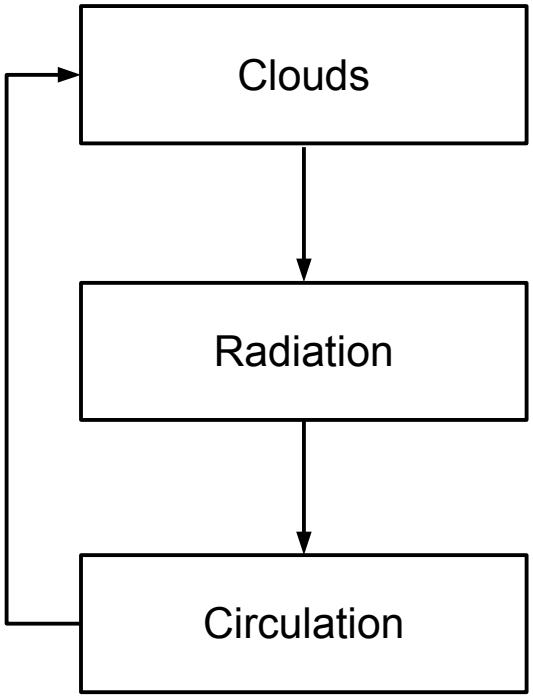
Same perturbation, but large model spread





Voigt et al., 2014, GRL

Digression: cloud-locking to break radiative coupling between clouds and circulation



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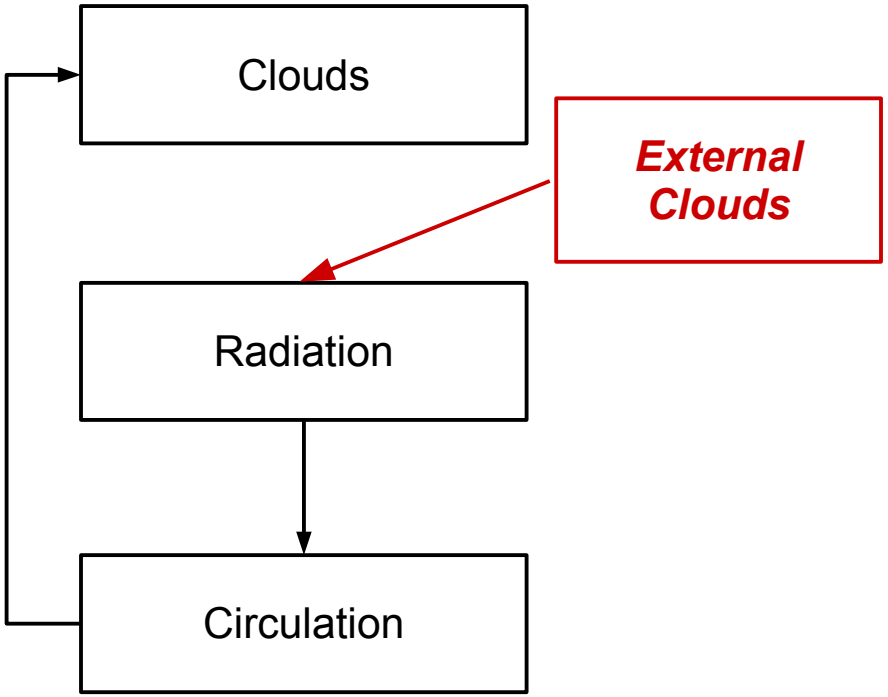
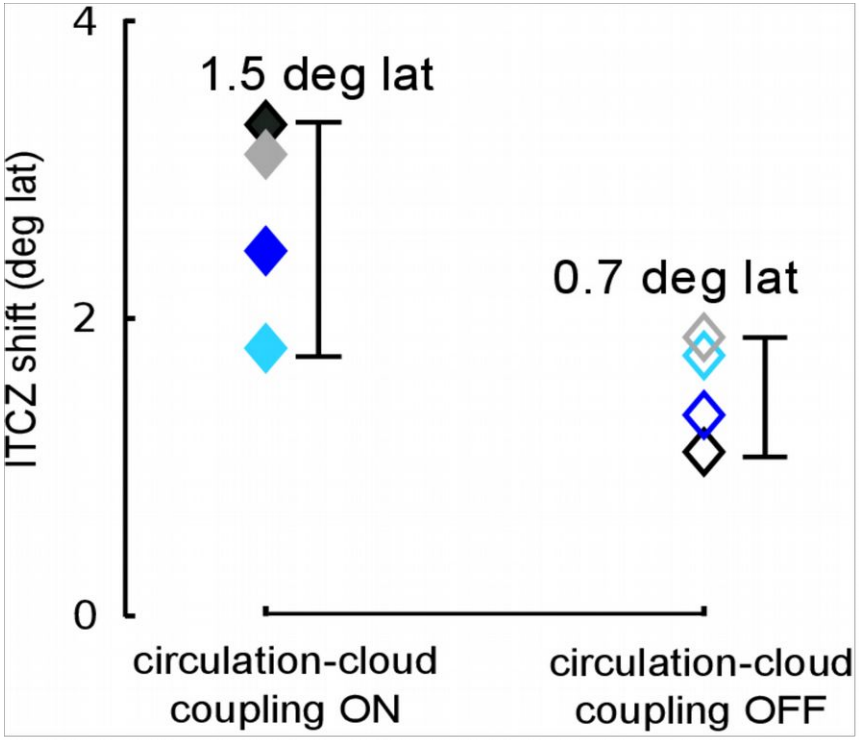
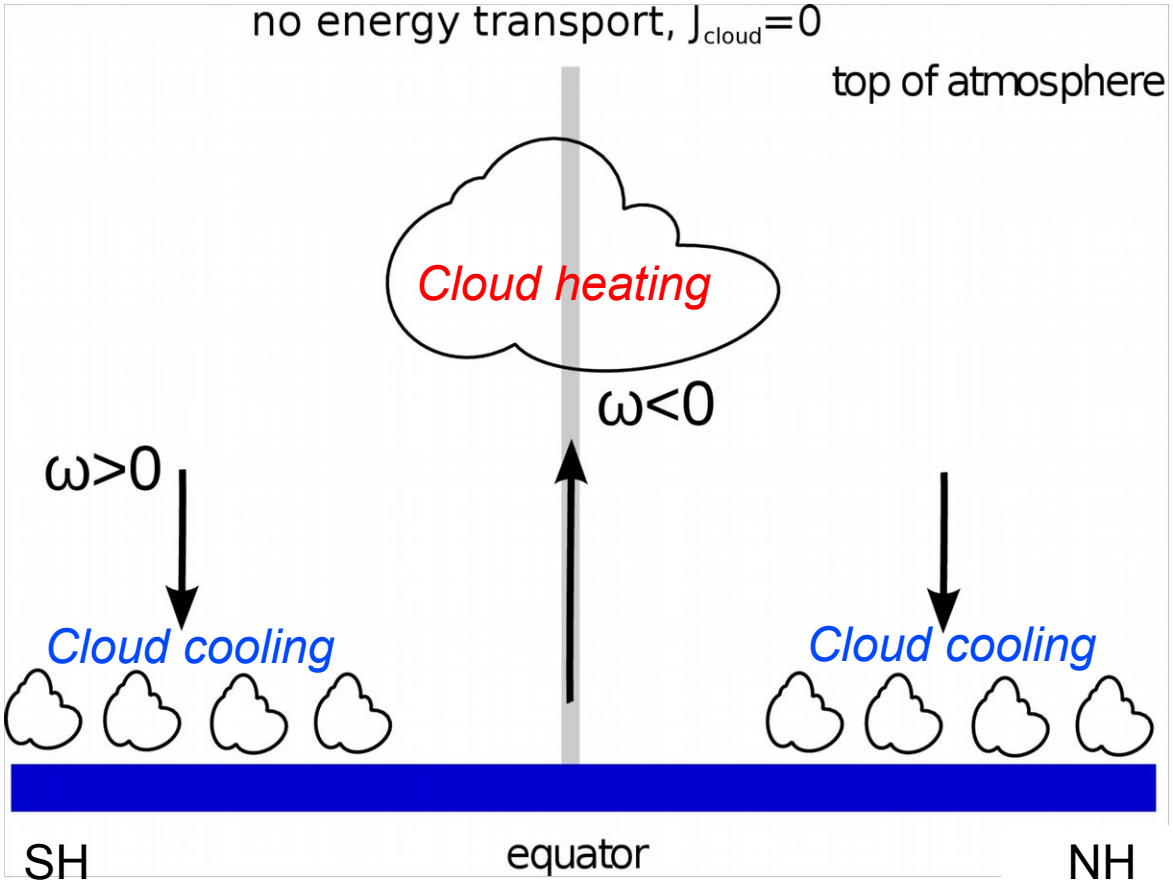


Clouds double the model spread in ITCZ shift



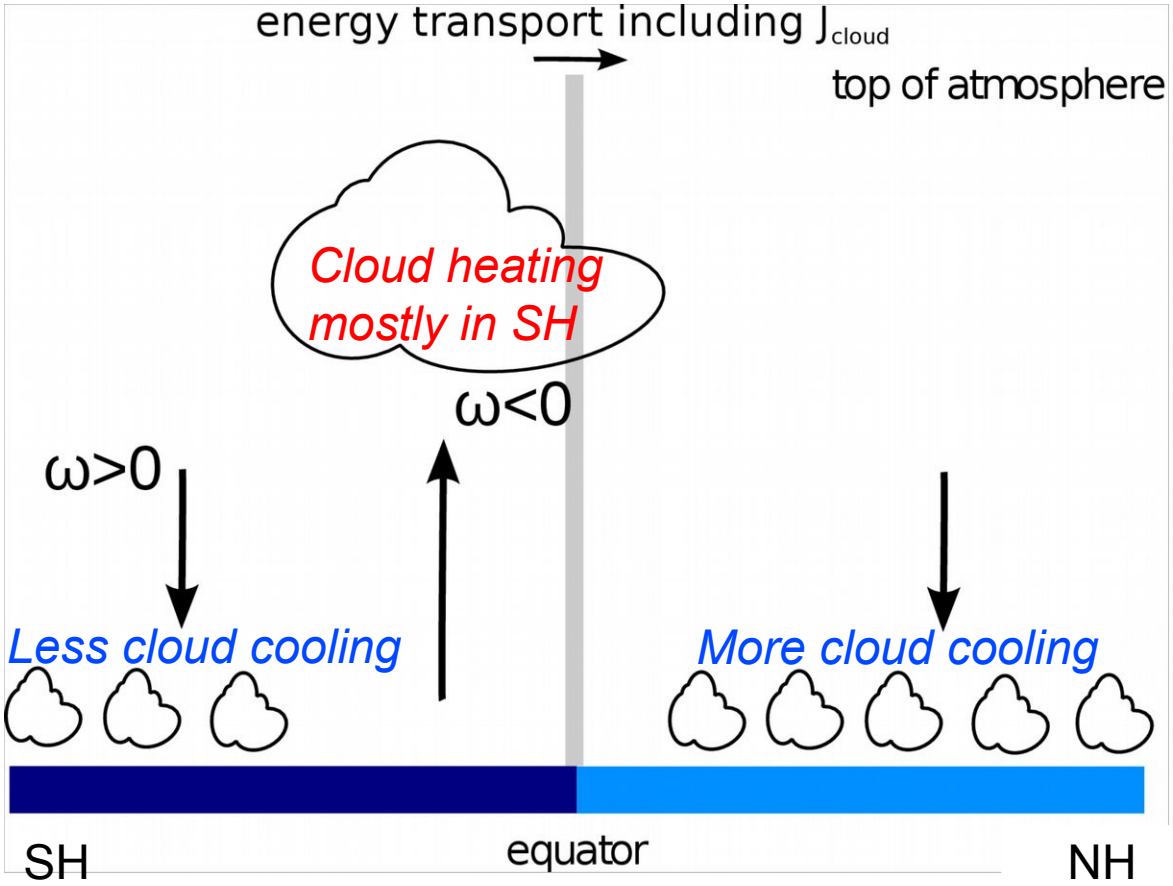
Voigt et al., 2014, GRL

Control climate: tropical clouds heat and cool Northern & Southern hemispheres by same amount



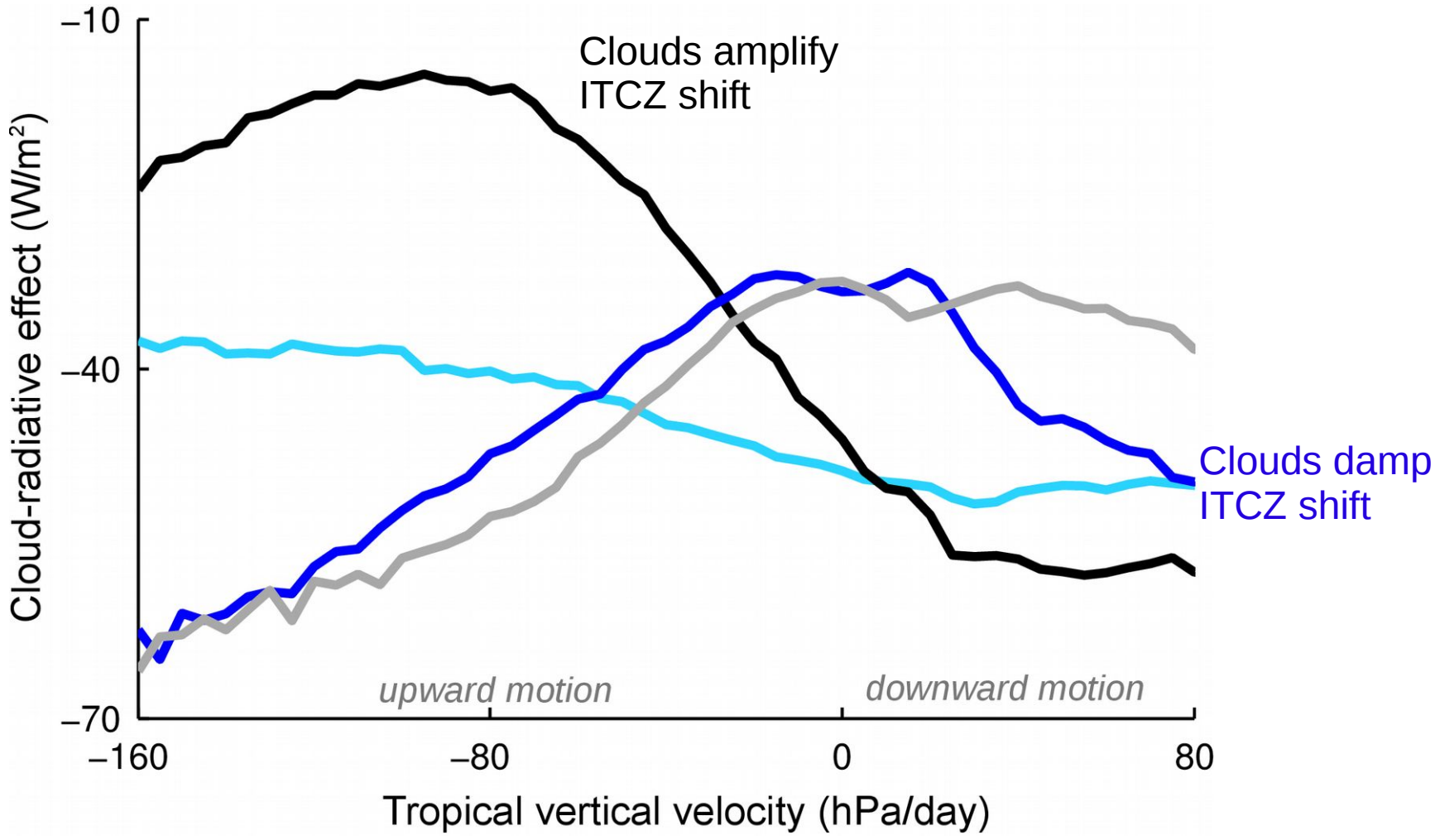
Voigt et al., 2014, GRL

Asymmetric climate: tropical clouds shift with ITCZ → further energy transport and hence ITCZ shift



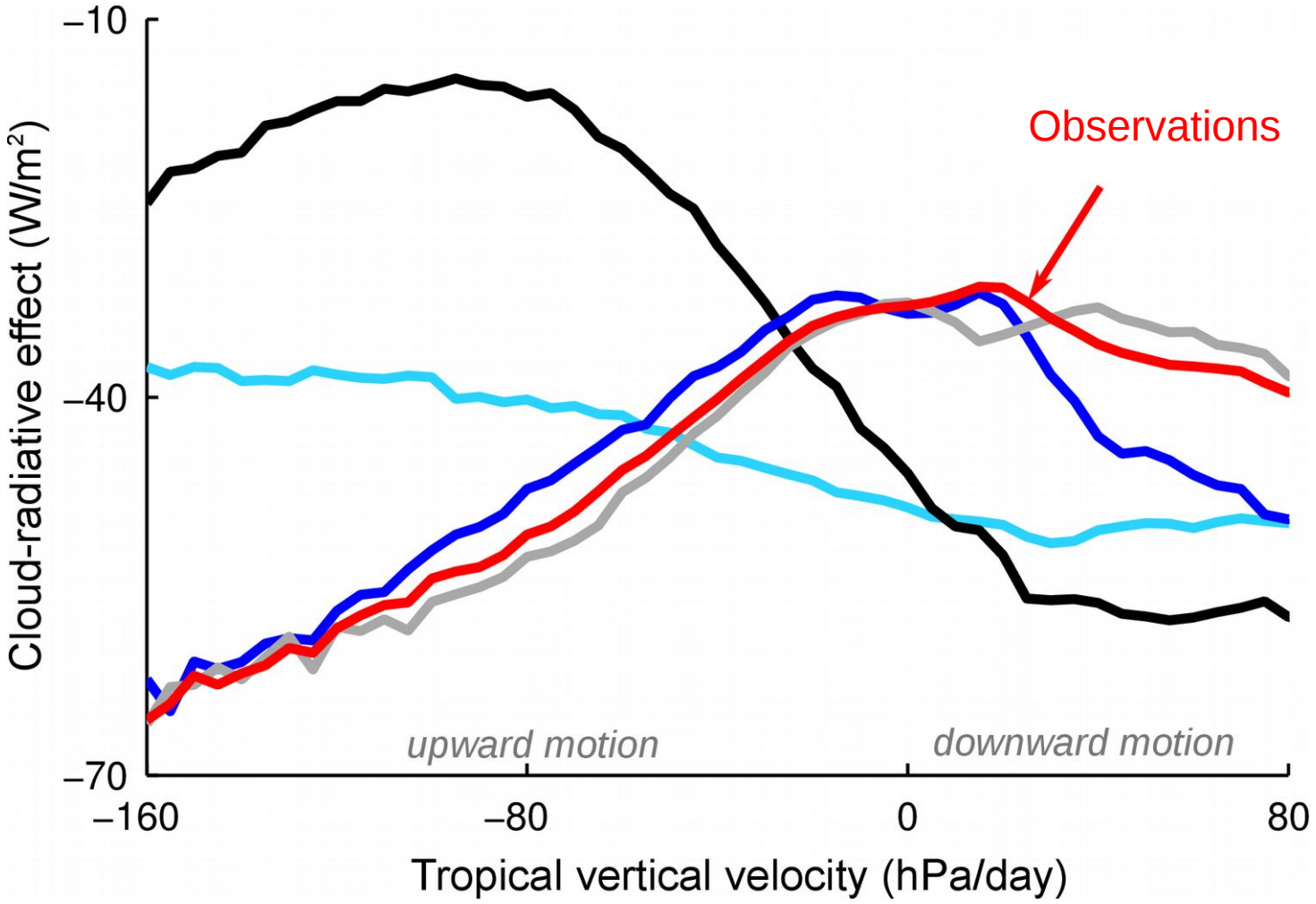
Voigt et al., 2014, GRL

Model-dependent radiative contrast between tropical high- and low-level clouds



Voigt et al., 2014, GRL

Observations suggest that tropical clouds damp ITCZ shift



Voigt et al., 2014, GRL

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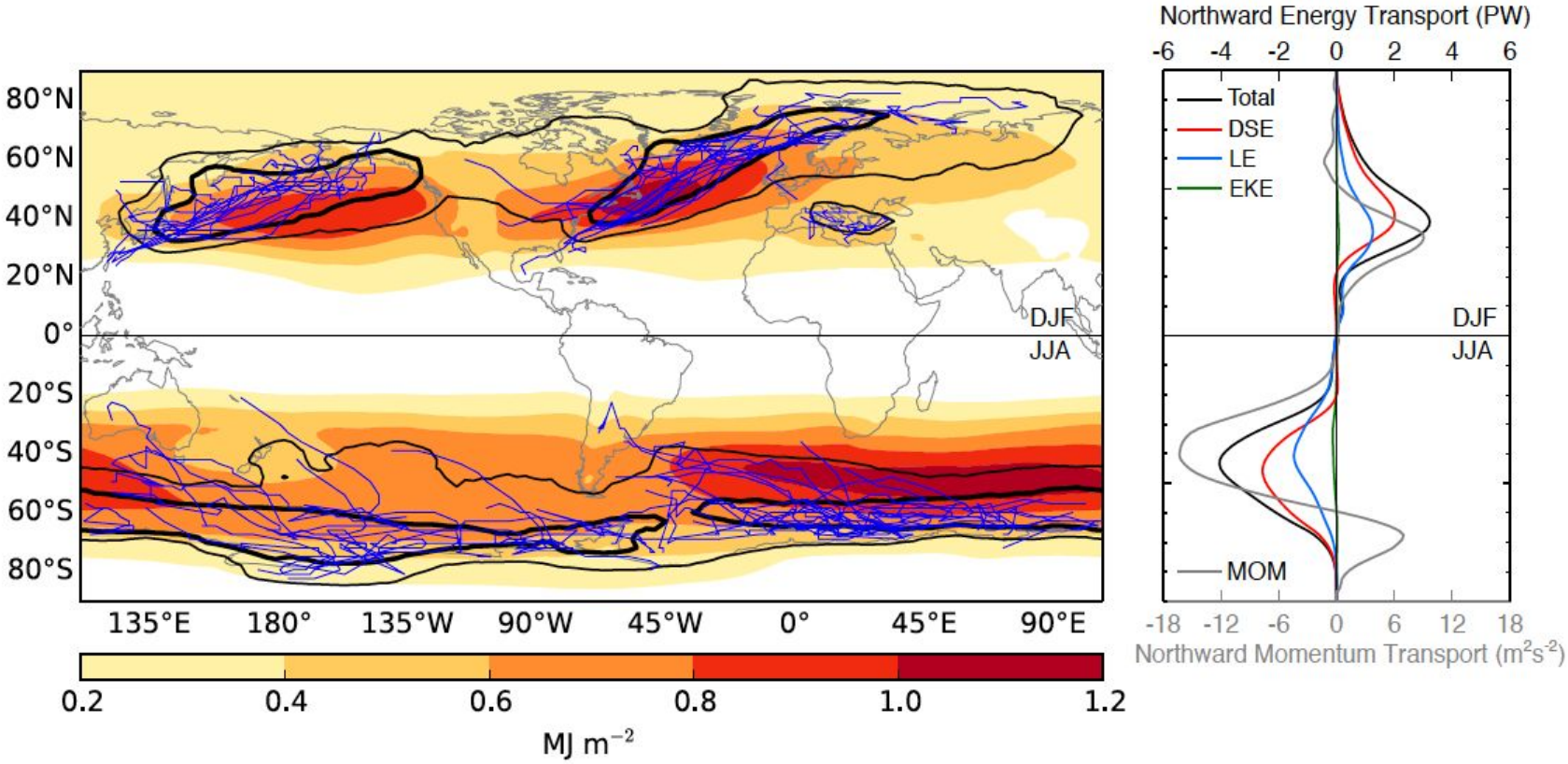
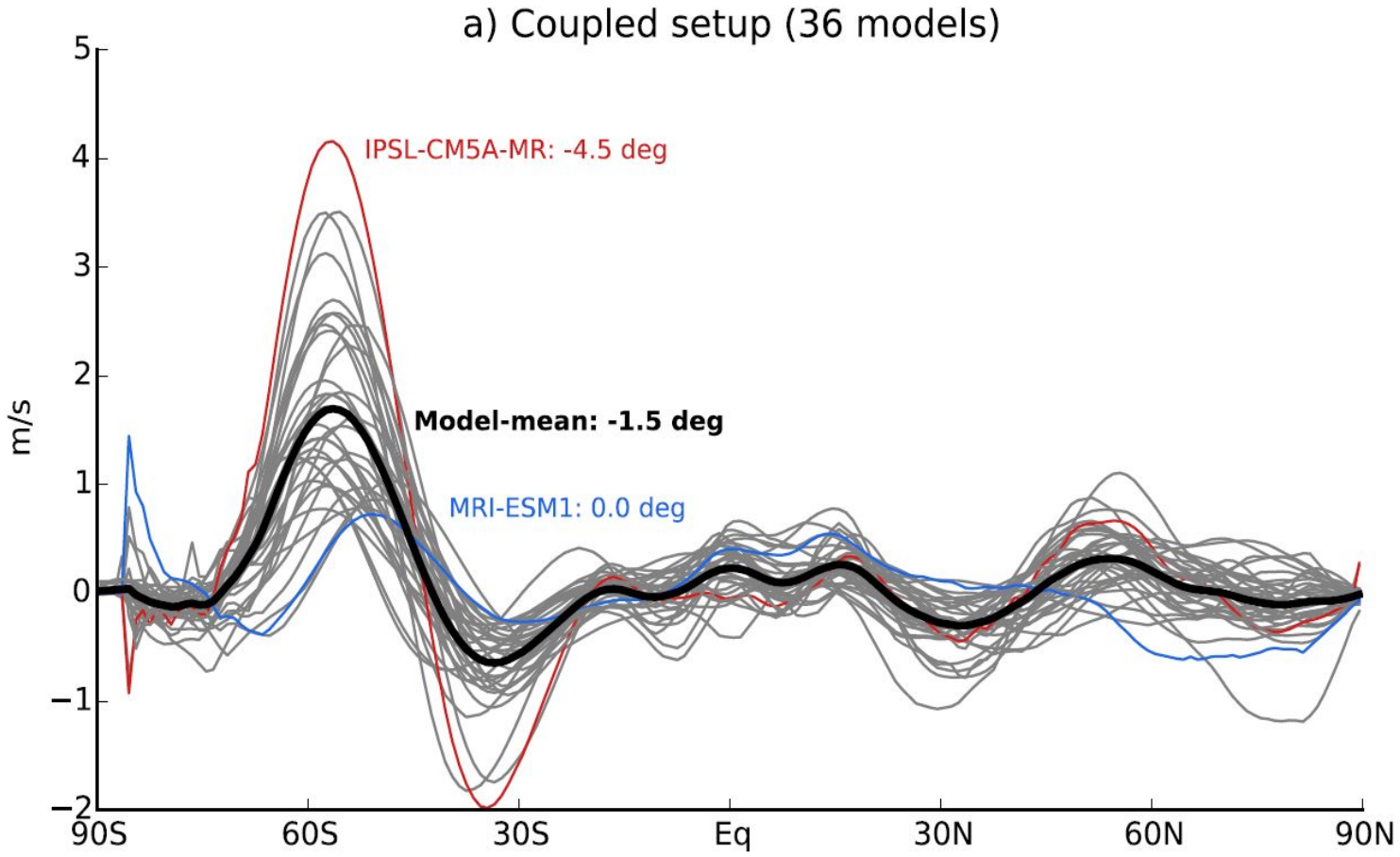
The extratropical circulation is integral component of global weather and climate



Shaw, Baldwin, Barnes, Caballero, Garfinkel, Hwang, Li, O'Gorman, Rivière, Simpson, and Voigt; Nature Geoscience, 2016.

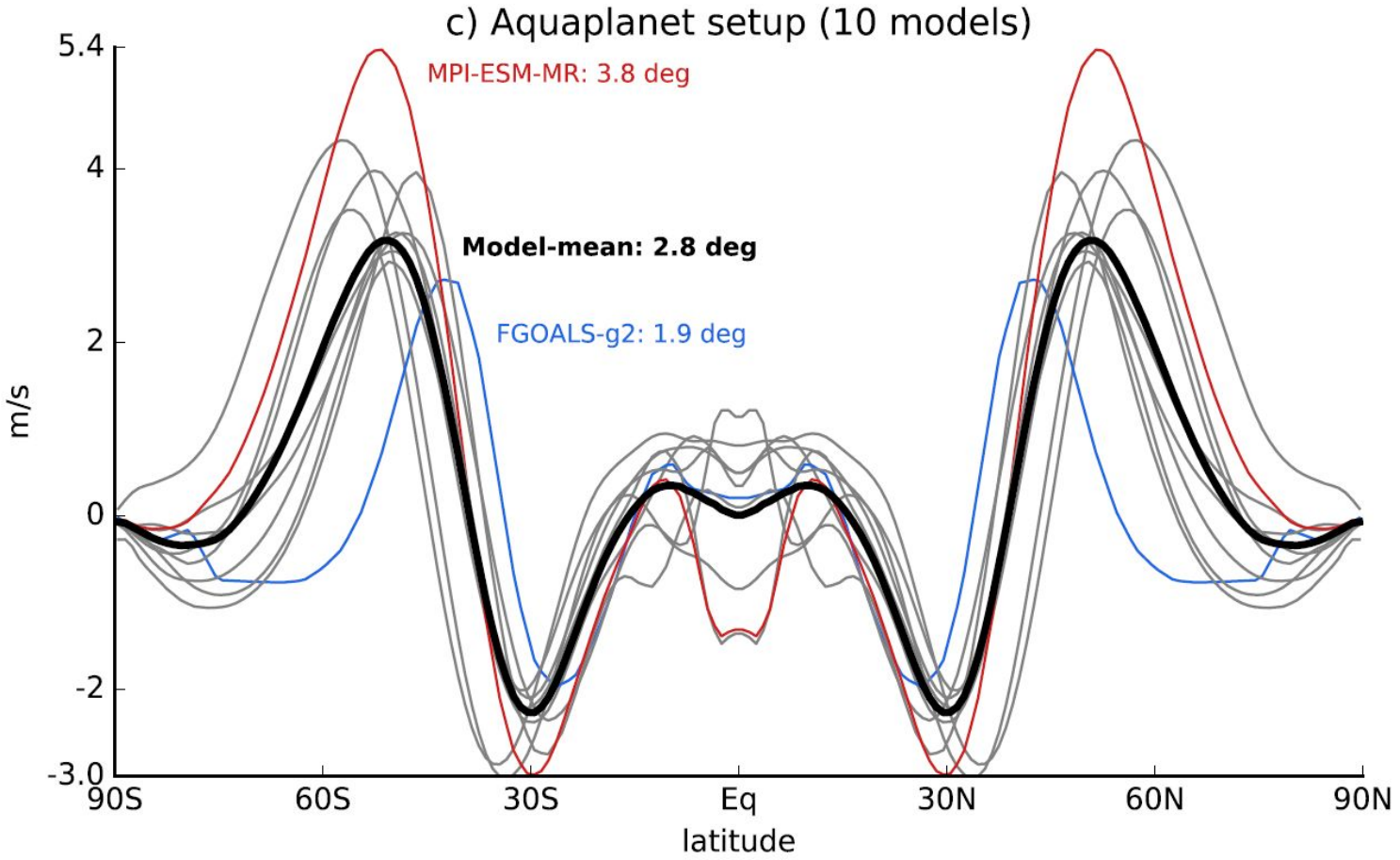
Fundamental aspects of the extratropical circulation response to global climate change remain uncertain



Change of 850hPa zonal wind in CMIP5 models under ~4xCO2

Voigt and Shaw, J. Climate, 2016

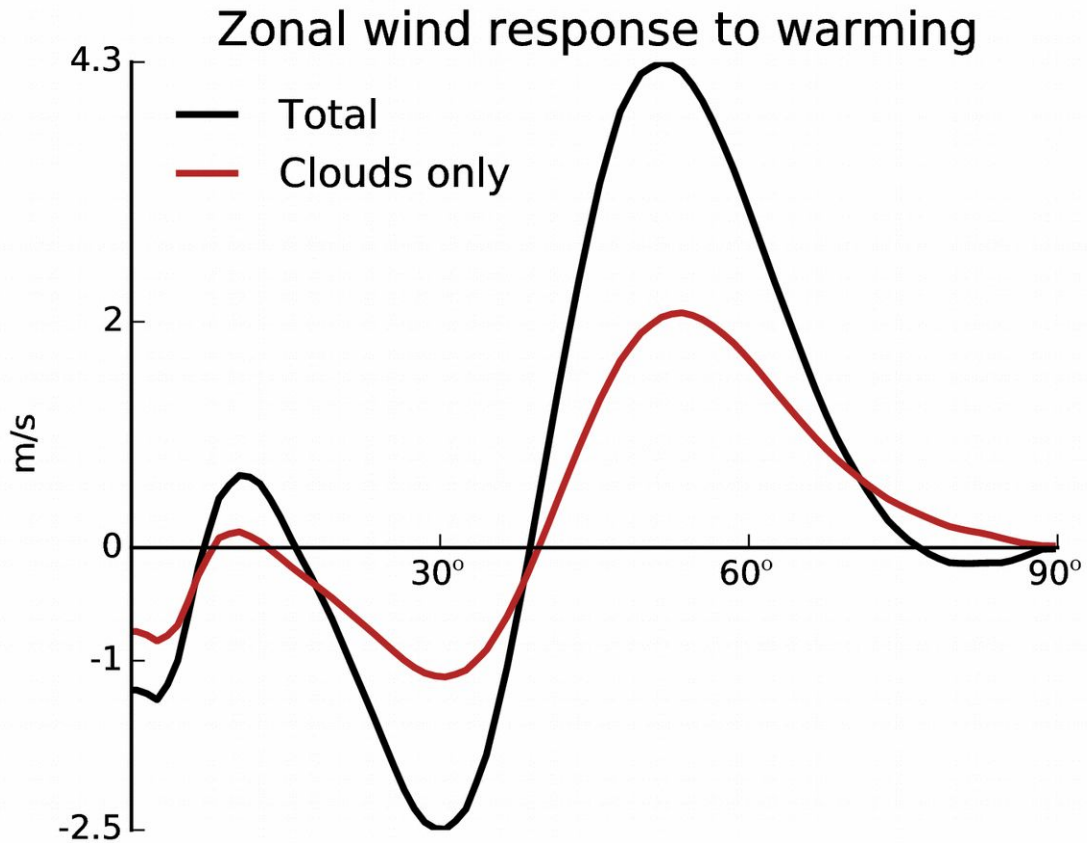
This is even true in aquaplanet setup that highlights the role of clouds

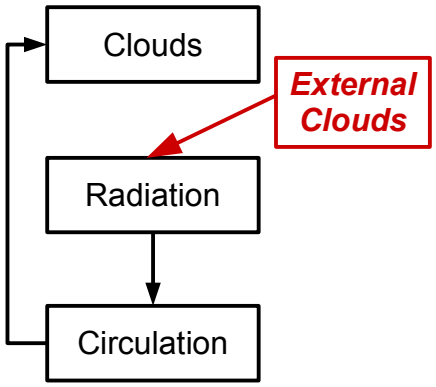


Change of 850hPa zonal wind in CMIP5 aquaplanet models under +4K SST

Voigt and Shaw, J. Climate, 2016

Cloud-radiative interactions may determine much of mid-latitude circulation response to warming

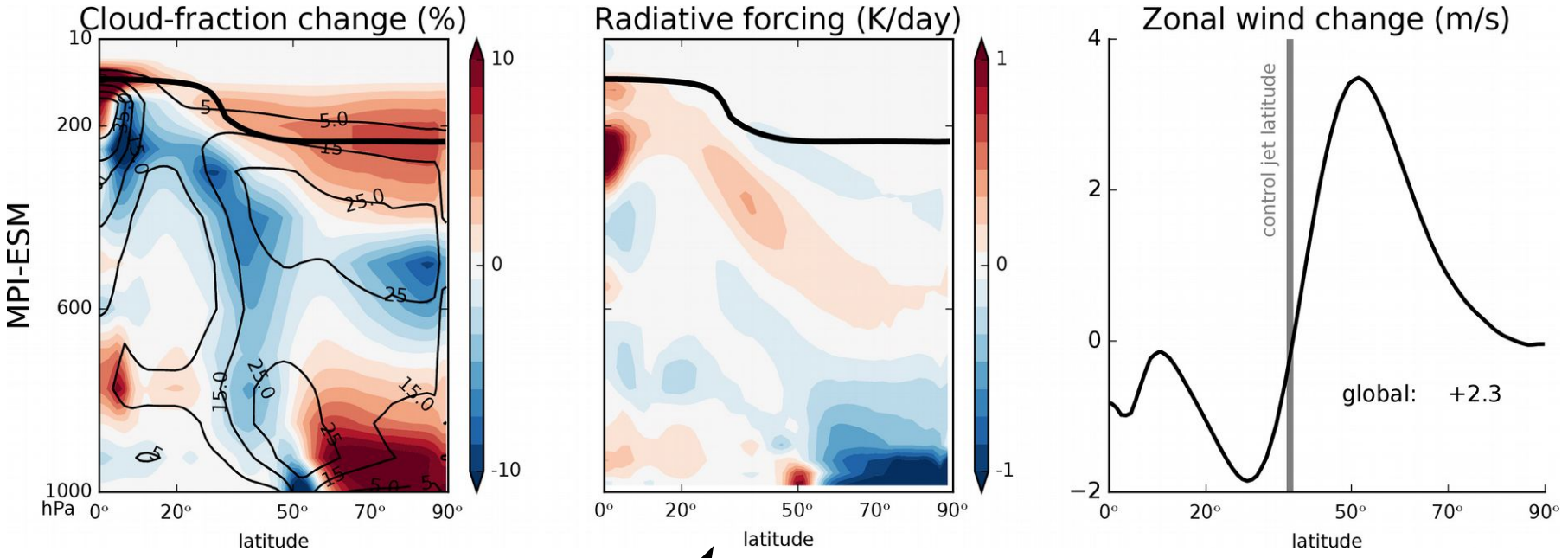




Change of 850hPa zonal wind in MPI-ESM aquaplanet model

Voigt and Shaw, Nat. Geosci., 2015
Ceppi and Hartmann, J. Climate, 2016

Jet impact of *regional* cloud changes

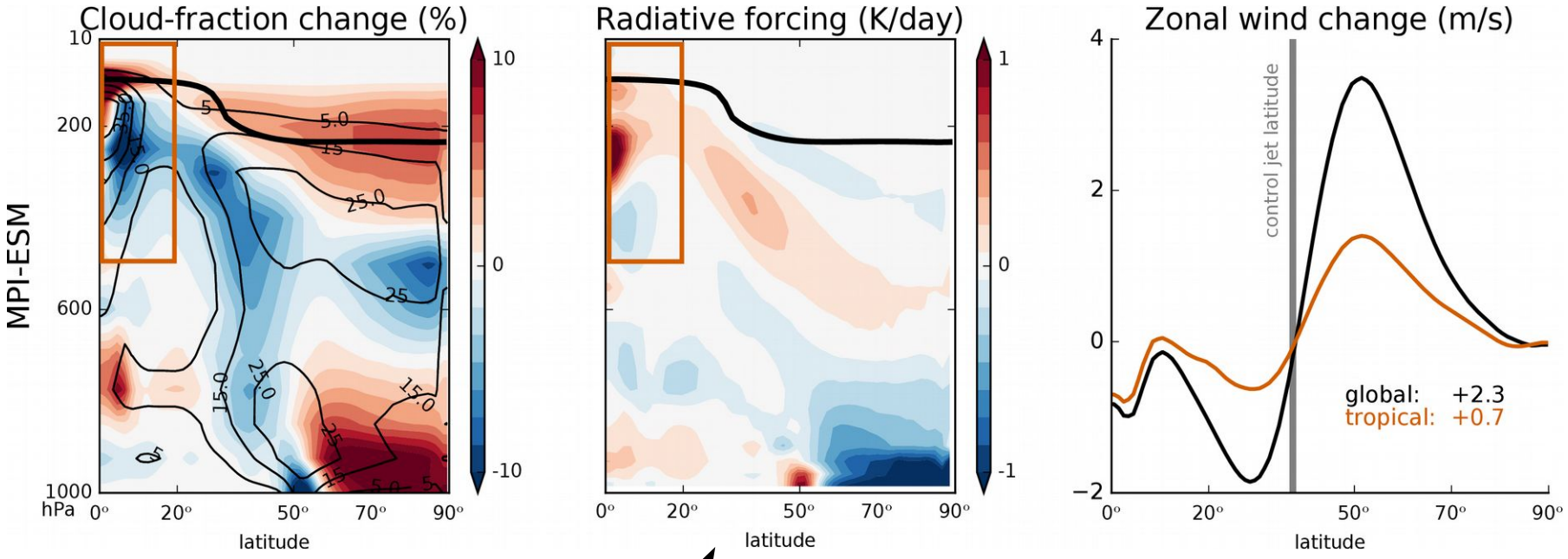


$$\left.\frac{\partial T(\phi,p)}{\partial t}\right|_{\mathrm{PRP}} = R(T_{\mathrm{Ctrl}}, q_{\mathrm{Ctrl}}, c_{\mathrm{4K}}) - R(T_{\mathrm{Ctrl}}, q_{\mathrm{Ctrl}}, c_{\mathrm{Ctrl}})$$

Partial-radiative perturbation calculation

Voigt and Shaw, J. Climate, 2016

The rise of tropical high-level clouds shifts the jet poleward



$$\left.\frac{\partial T(\phi,p)}{\partial t}\right|_{\mathrm{PRP}} = R(T_{\mathrm{Ctrl}}, q_{\mathrm{Ctrl}}, c_{\mathrm{4K}}) - R(T_{\mathrm{Ctrl}}, q_{\mathrm{Ctrl}}, c_{\mathrm{Ctrl}})$$

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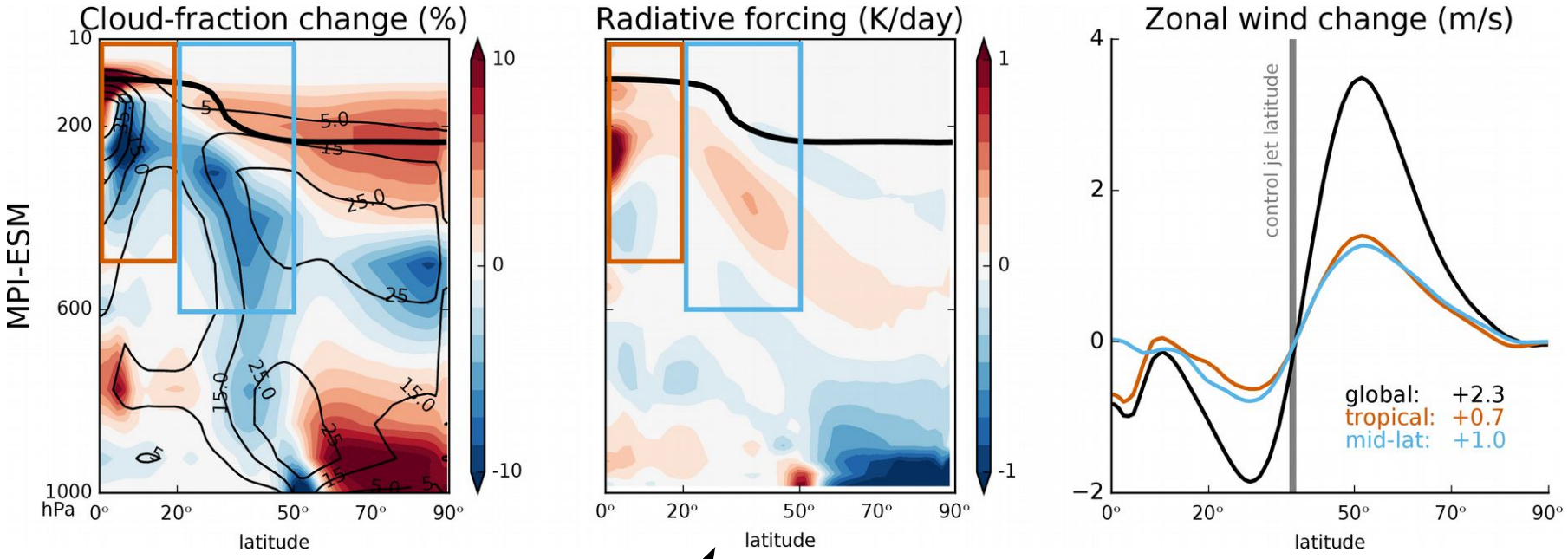
Voigt and Shaw, J. Climate, 2016

Mid-latitude high-level cloud changes shift the jet poleward

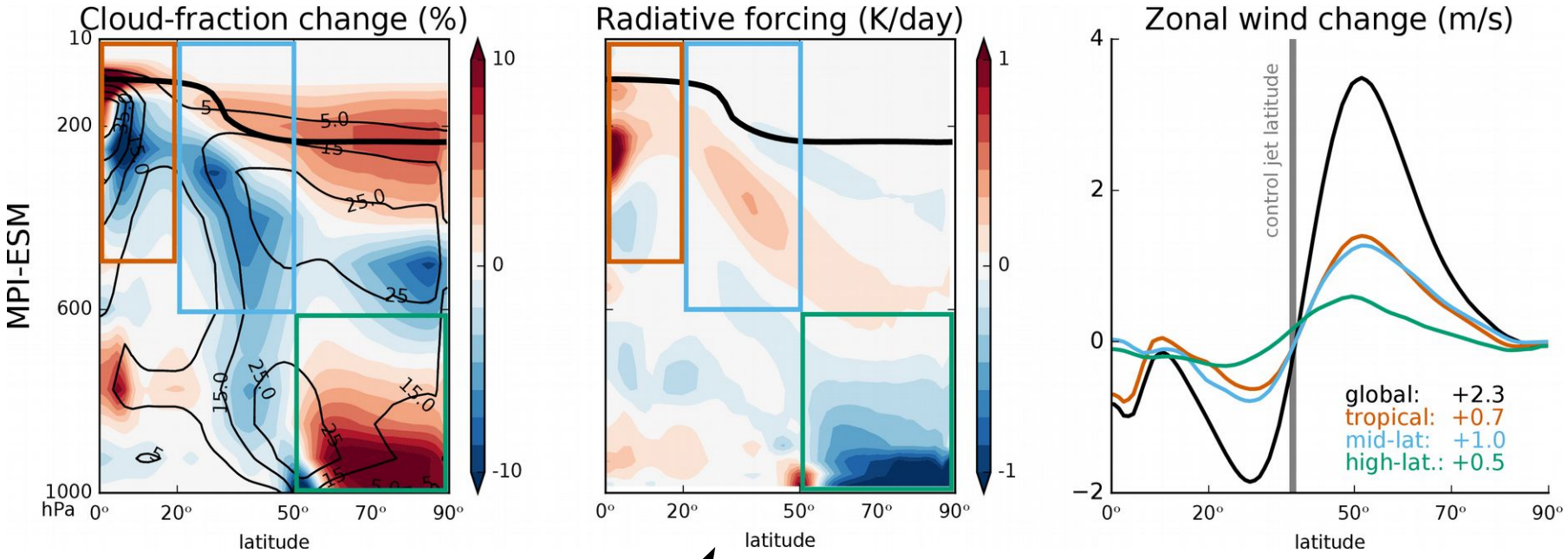


$$\left.\frac{\partial T(\phi,p)}{\partial t}\right|_{\mathrm{PRP}} = R(T_{\mathrm{Ctrl}}, q_{\mathrm{Ctrl}}, c_{4\mathrm{K}}) - R(T_{\mathrm{Ctrl}}, q_{\mathrm{Ctrl}}, c_{\mathrm{Ctrl}})$$

Partial-radiative perturbation calculation

Voigt and Shaw, J. Climate, 2016

Increase in high-latitude low-level clouds shifts the jet poleward



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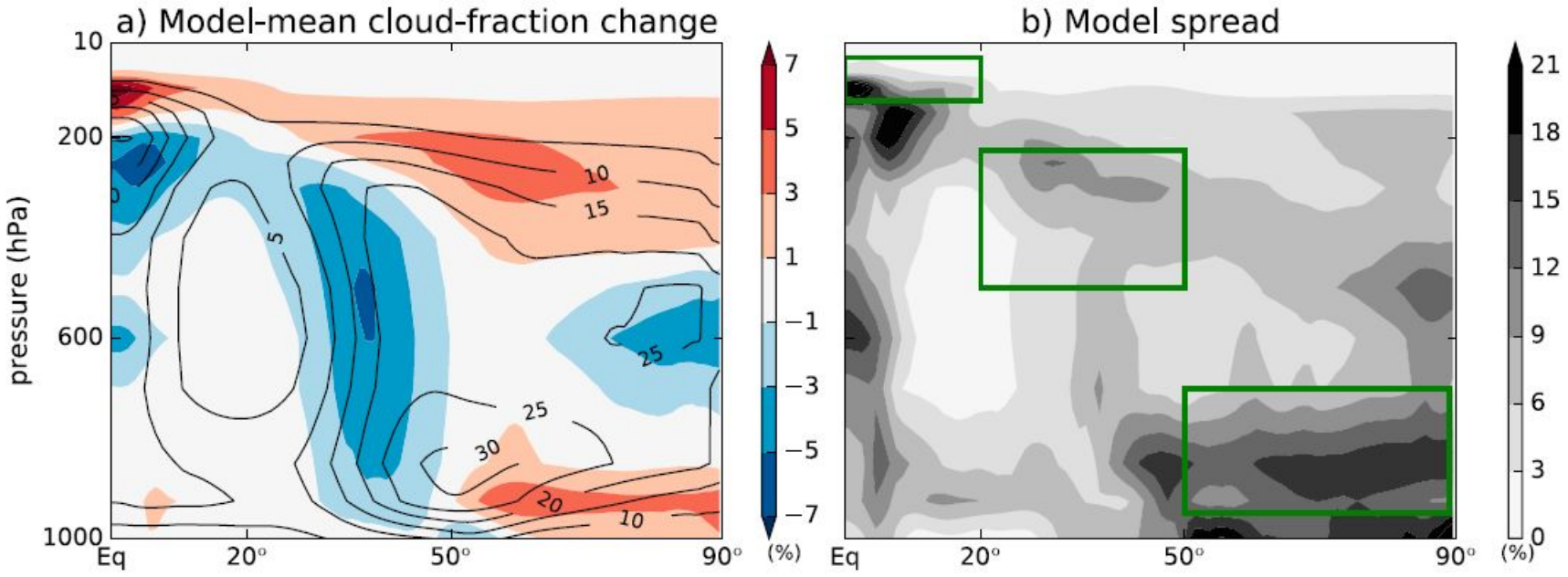
Partial-radiative perturbation calculation

Voigt and Shaw, J. Climate, 2016

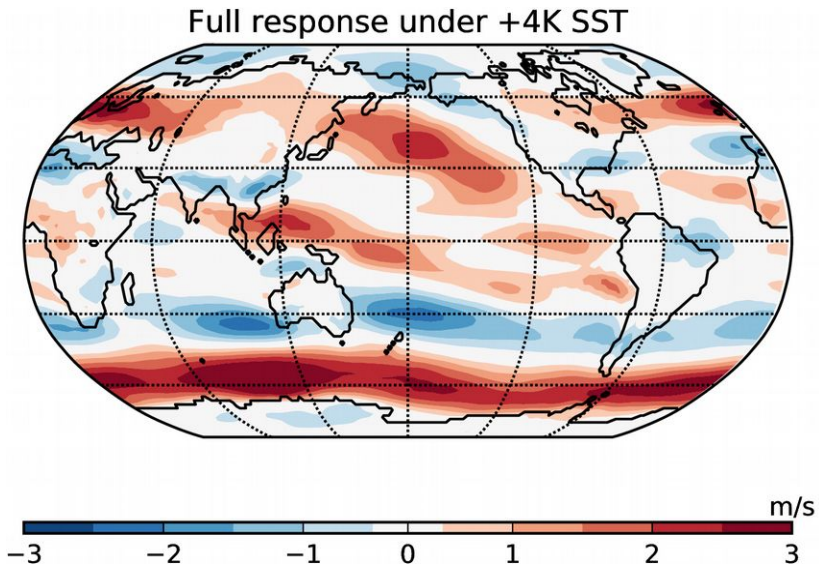
Model spread in clouds appears to contribute to model spread in jet shift

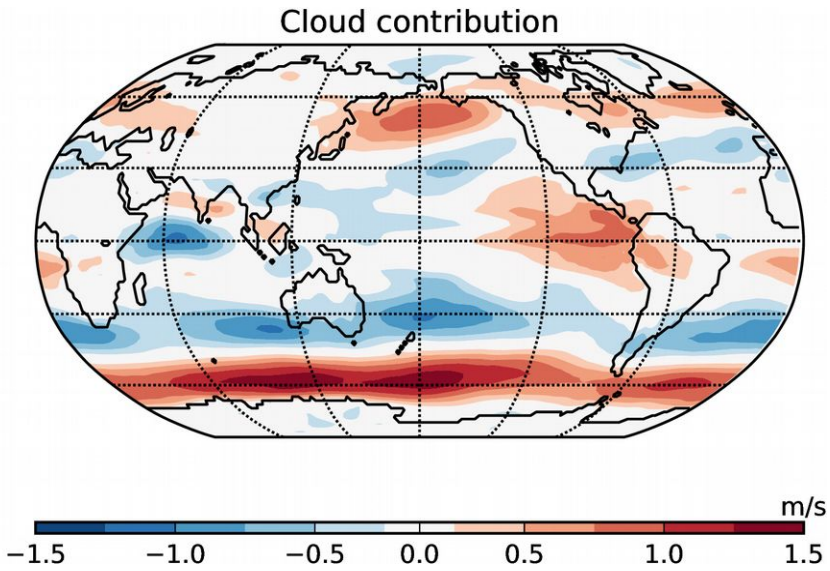


Ensemble of 10 CMIP5 aquaplanet models forced with +4K SST

Voigt and Shaw, J. Climate, 2016

Cloud impact on jet shift also holds in a realistic model setup

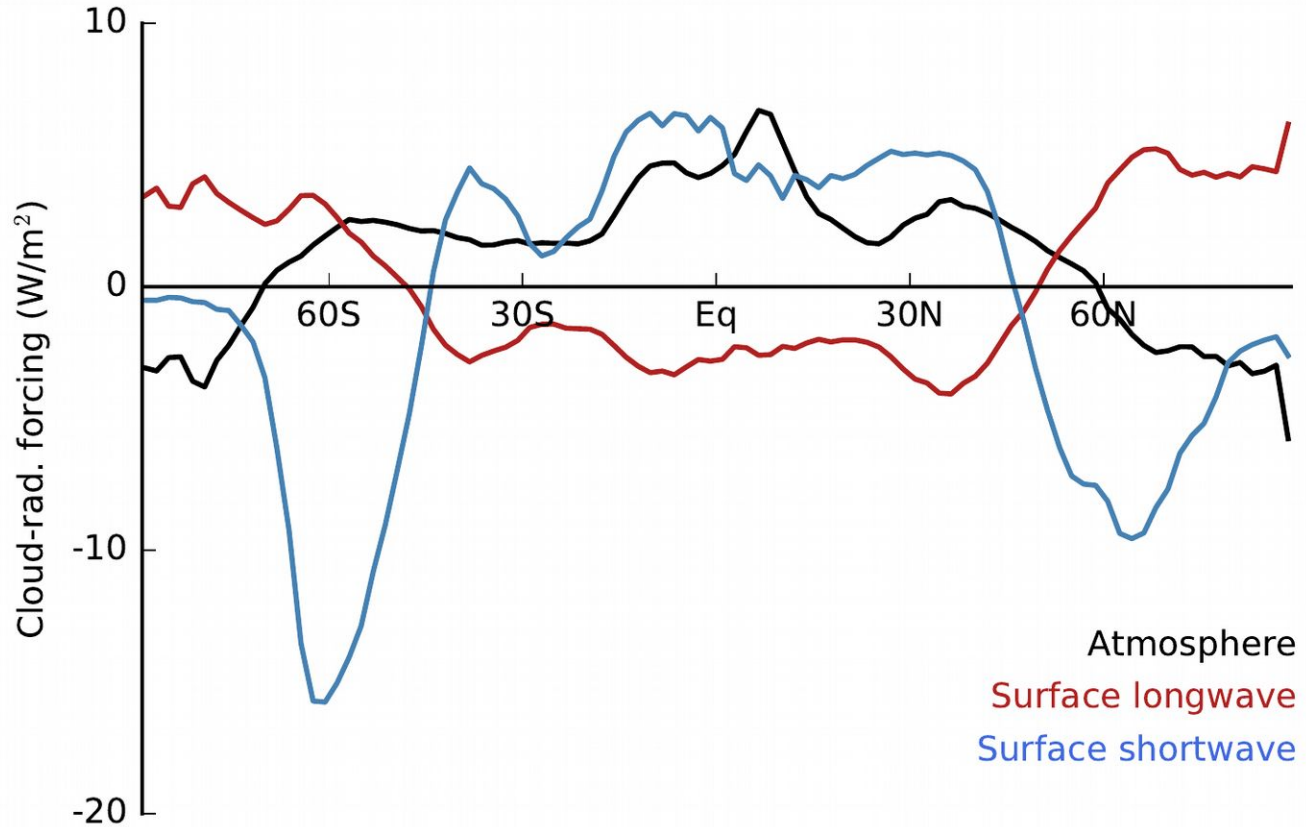




Change in 850 hPa zonal wind in ECHAM6 under +4K SST

Voigt, Shaw and Polvani, in prep.

Impact of surface cloud-radiative forcing via SST changes?



Cloud-radiative forcing in ECHAM6 under +4K SST

Voigt, Shaw and Polvani, in prep
cf. Ceppi and Hartmann, J. Climate, 2016

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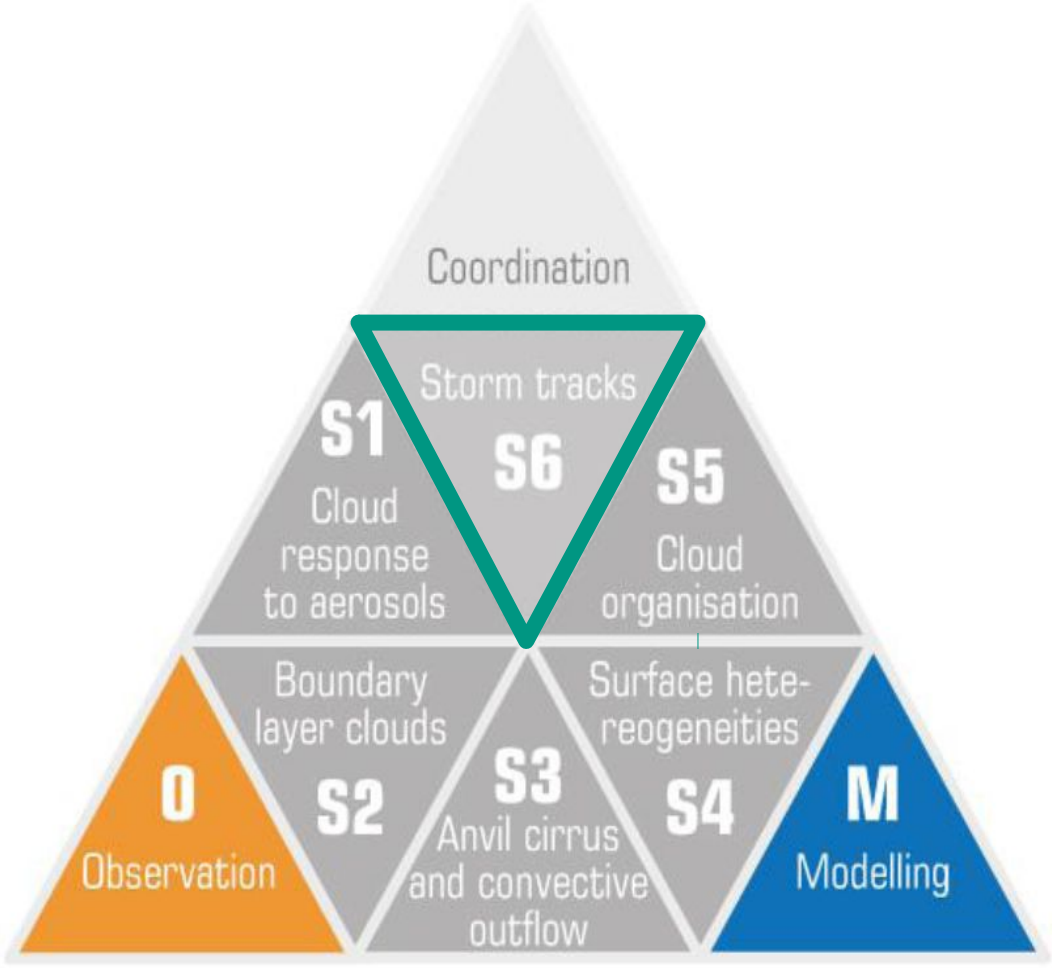
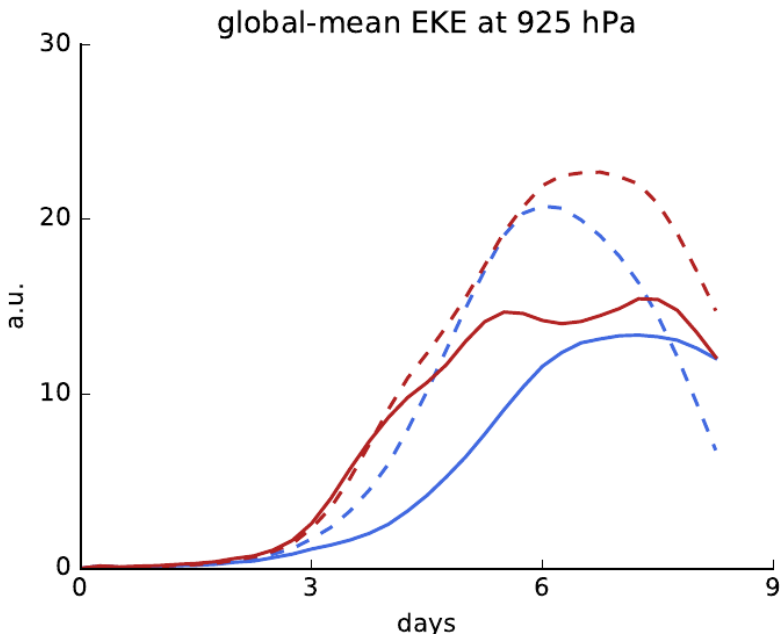
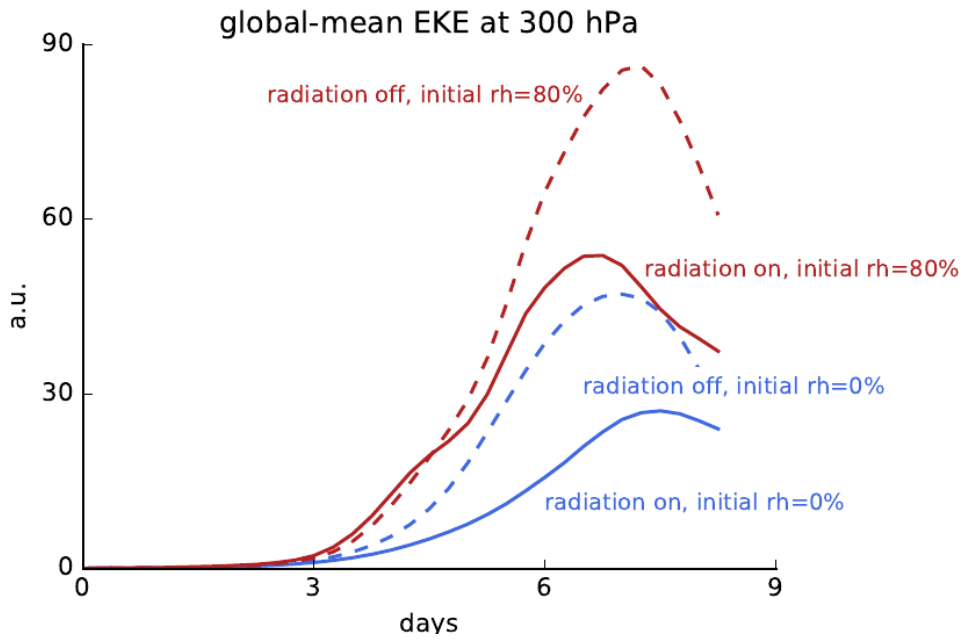
HD(CP)^2 Phase II: High-Definition Clouds and Precipitation for Advancing Climate Prediction



Radiation weakens idealized mid-latitude storms

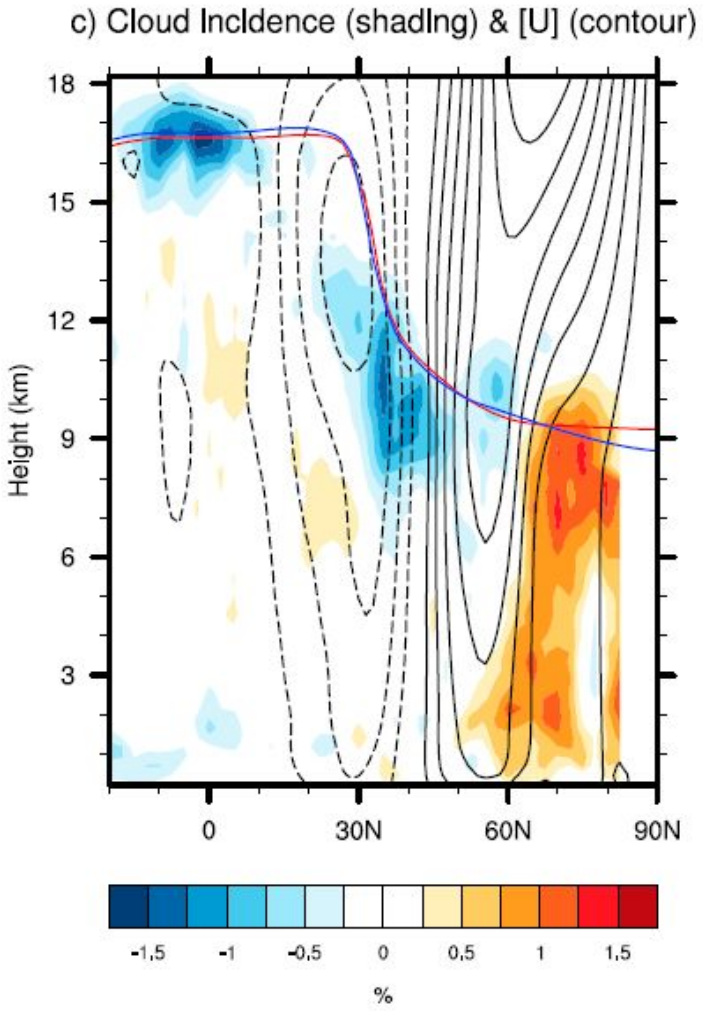




Baroclinic LC1 lifecycle simulations with global ICON R2B05

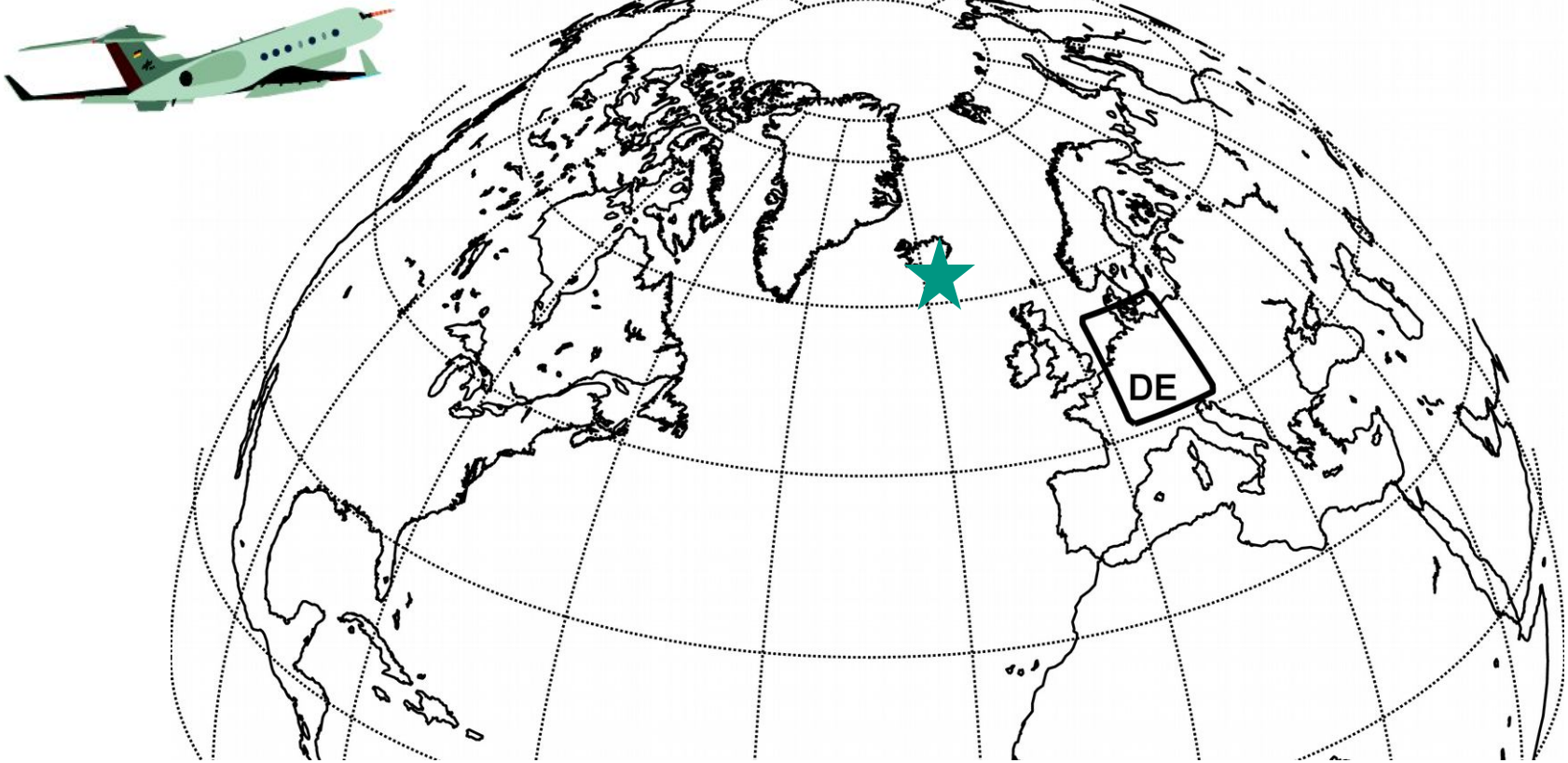
Schäfer and Voigt, in prep.

Cloud impact on circulation variability from days to months



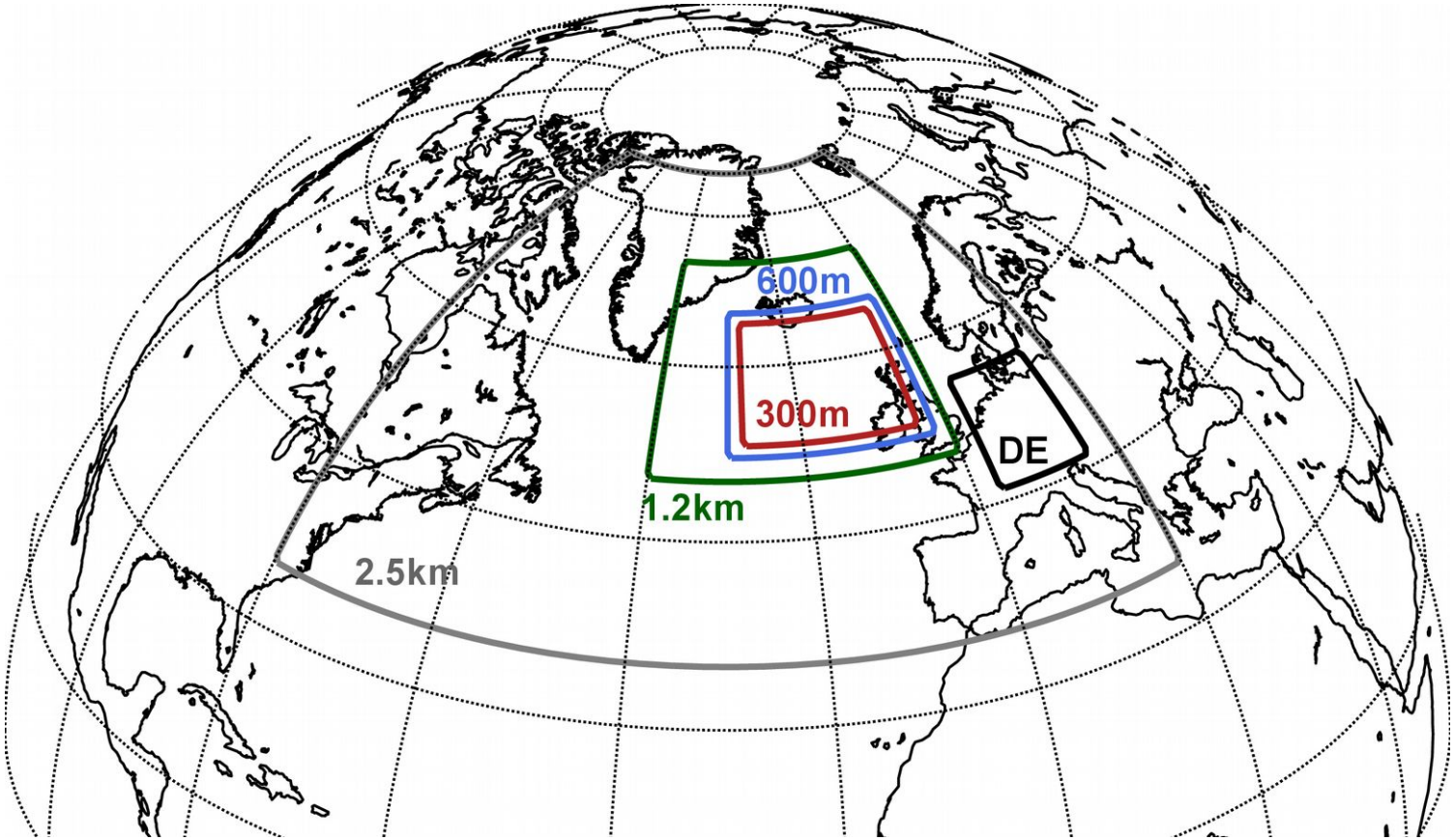
Li et al., GRL, 2014

ICON-LEM simulations in coordination with the NAWDEX field campaign



NAWDEX: North Atlantic Waveguide and Downstream Impact Experiment, Sep-Oct 2016

ICON-LEM simulations in coordination with the NAWDEX field campaign



NAWDEX IOP3: 23 September 2016, cyclone Vladiana

ICON-LEM simulations in coordination with the NAWDEX field campaign

Karlsruher Institut für Technologie

(movie)

Summary

- A *quantitatively* meaningful understanding of the large-scale atmospheric circulation requires us to take into account cloud-radiative interactions.
- In the tropics, the strong dependence of tropical clouds on the circulation proposes a strategy to improve model estimates of ITCZ shifts.
- In the extratropics, cloud-radiative interactions amplify the expected poleward shift of the extratropical jet streams in response to global warming.
- The combination of limited-area ultra-high regional resolution simulations, global model simulations and observations provides an exciting new opportunity to understand, and constrain, the cloud impact on the extratropical circulation.