Stratospheric implications of climate engineering through solar radiation management

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Budyko, „Climatic Changes“, 1977

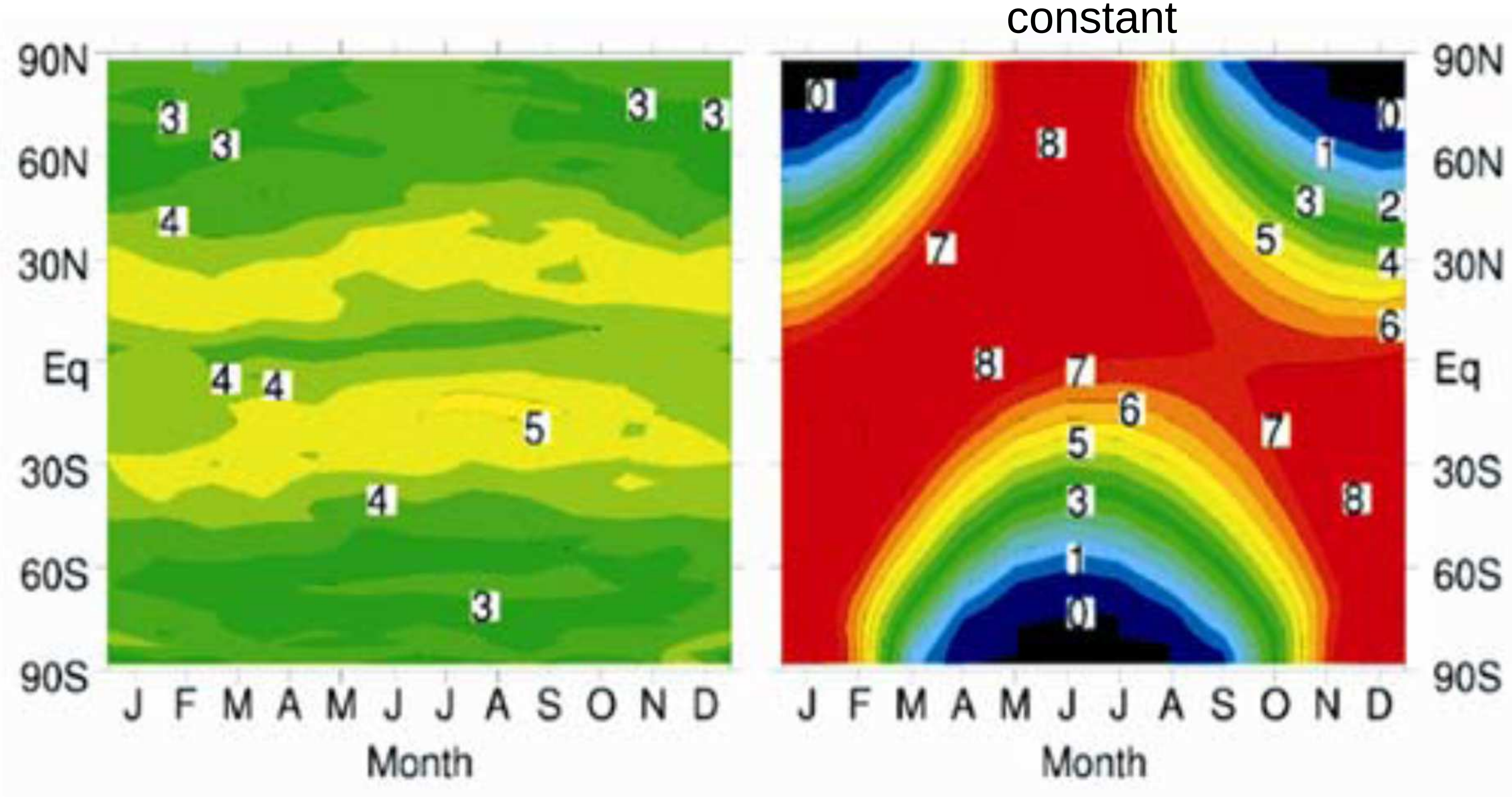
“Let us consider the possibility of changing climatic conditions by increasing the concentration of aerosol particles in the lower stratosphere …”

“… annually … about 40,000 tons of sulphur will be necessary … in order to induce the climatic change observed in the warming period of the 1920s and 1930s, but in the opposite direction …”

“… this mass … can be transported by several aircrafts operating every day …”

Net IR tropopause radiative forcing from CO2 doubling

Net solar tropopause radiative forcing from modifying the solar constant



(Bala et al., Current Science, 2009)

GeoMIP publications

Published/accepted

Experimental design: Kravitz et al. (ASL, 2011), Kravitz et al. (JGR, 2013d)
Project overview: Kravitz et al. (JGR, 2013c)
General climate: Schmidt et al. (ESD, 2012), Kravitz et al. (JGR, 2013a)
Hydrology (monsoons; energy balance): Tilmes et al. (JGR, 2013), Kravitz et al. (JGR, 2013b)
Comparison of different techniques: Niemeier et al. (JGR, 2013)
Cloud brightening: Alterskjaer et al. (JGR, 2013)
Termination effect: Jones et al. (JGR, 2013)
Arctic cryosphere: Berdahl et al. (JGR, 2014)

Submitted

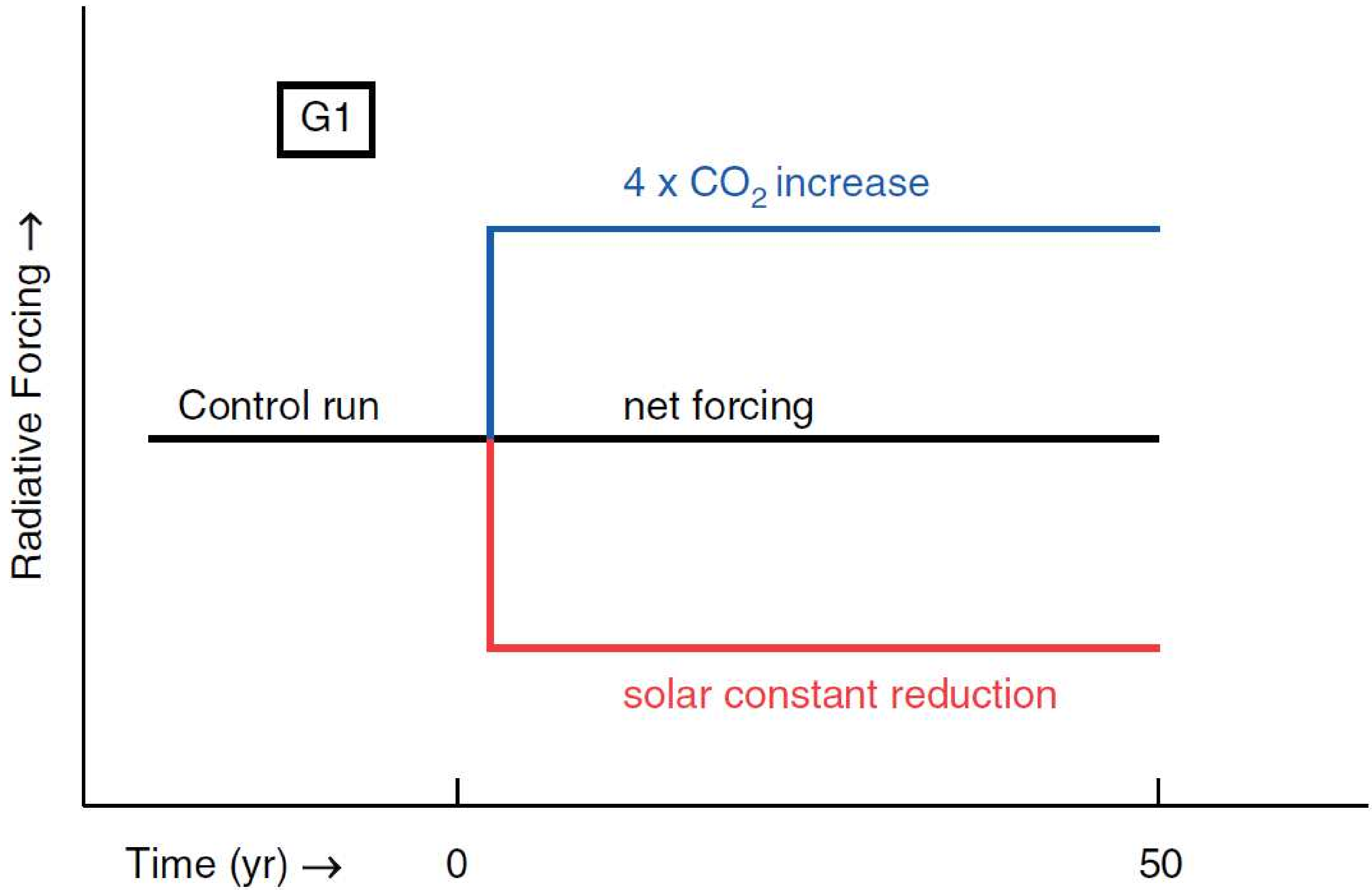
Arctic cryosphere: Moore et al. (JGR, 2013)
Climate Extremes: Curry et al. (JGR, 2013)
Key uncertainties: Irving et al. (JGR, 2013)
Stratospheric ozone: Pitari et al. (JGR, 2013)
Agriculture in China: Xia et al. (JGR, 2013)

Content

What climate would result from solar radiation management (SRM)?

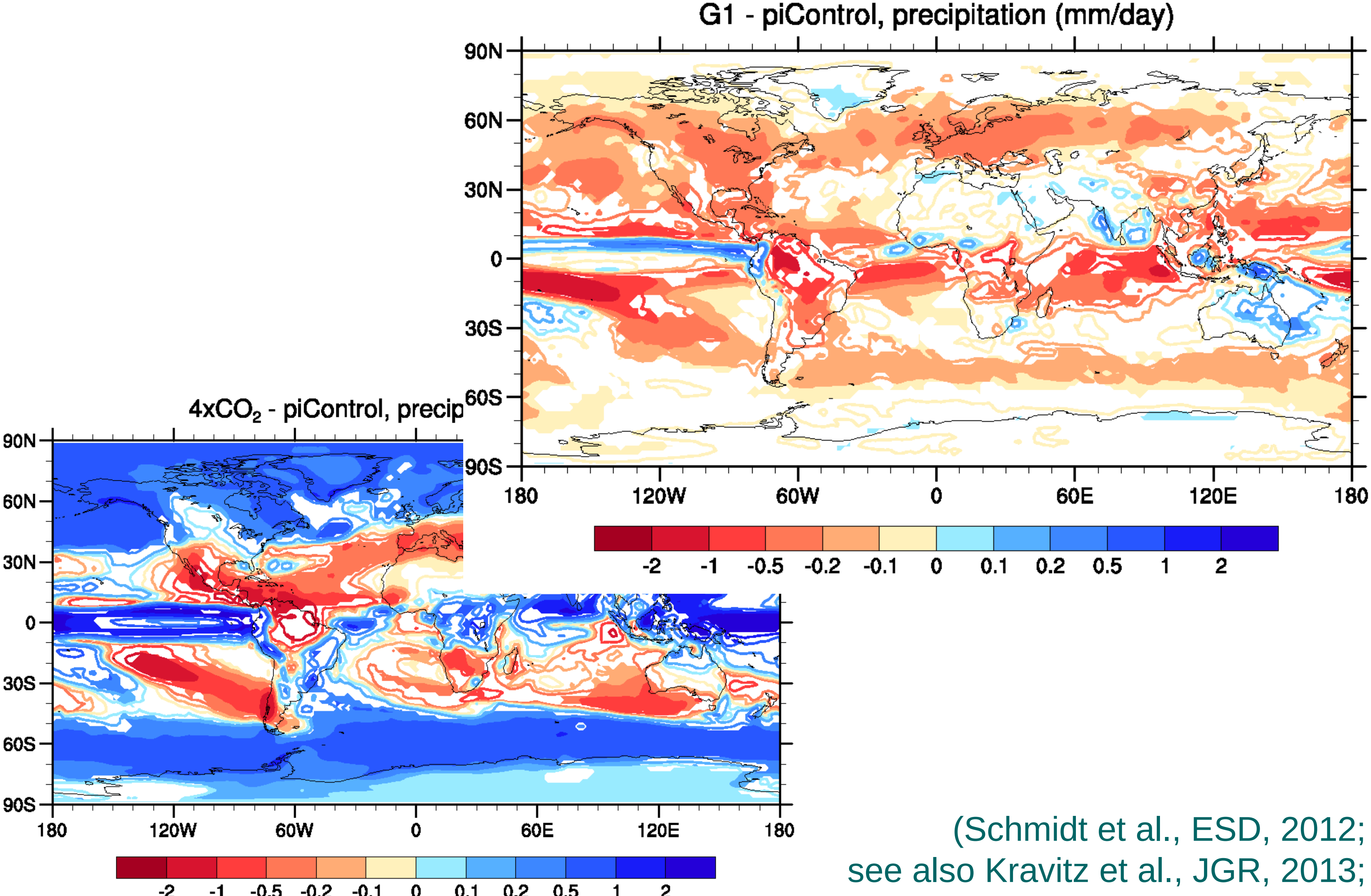
- How would the hydrological cycle be affected by space mirrors, stratospheric sulfate aerosols and cloud brightening?
- How would stratospheric dynamics react to SRM?

GeoMIP Experiment G1

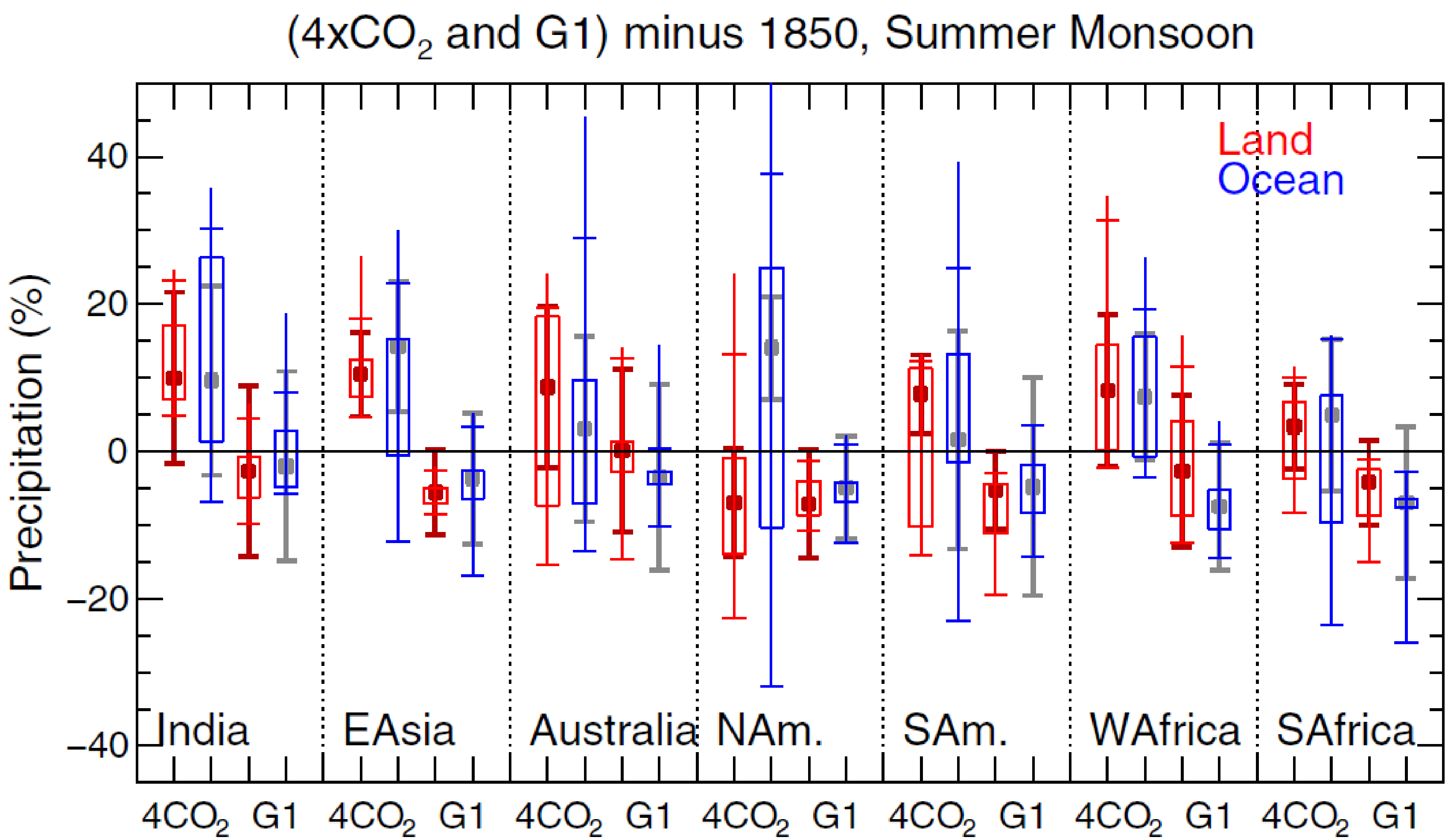


(Kravitz et al., ASL, 2011)

Precip (mm/day), G1 vs. $4xCO_2$, four ESMs

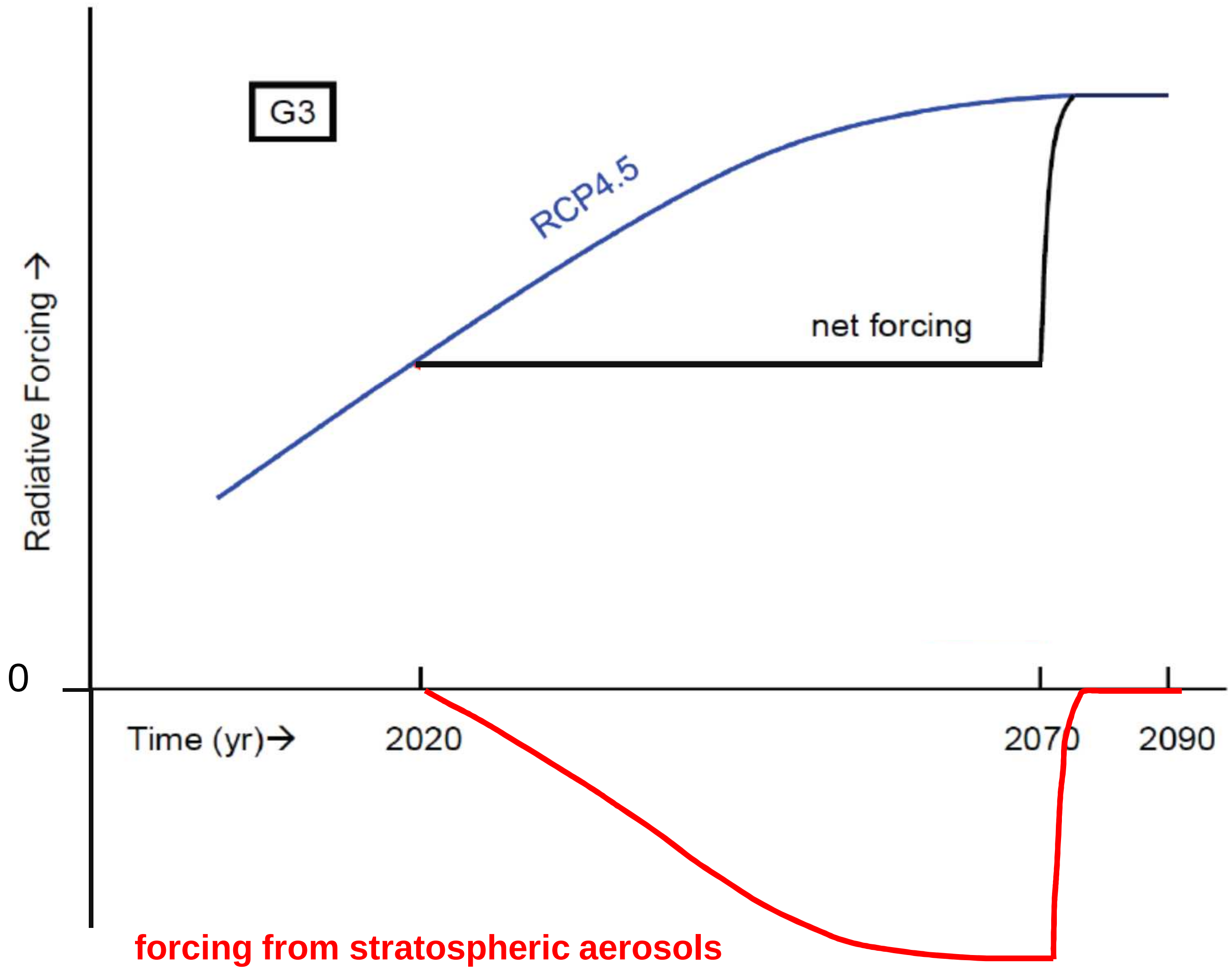


(Schmidt et al., ESD, 2012;
see also Kravitz et al., JGR, 2013;
Bala et al., PNAS, 2008)



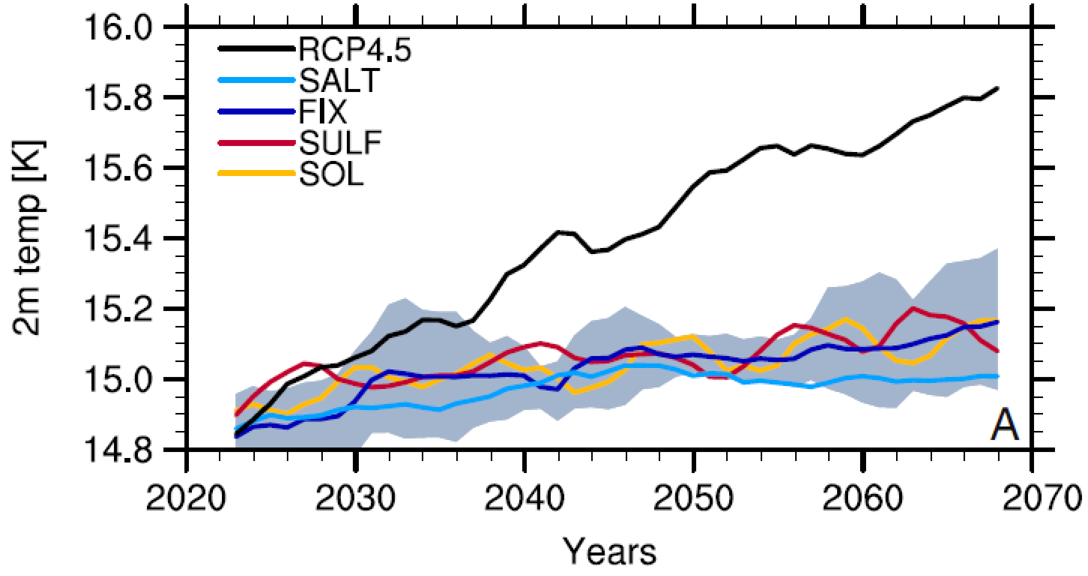
(Tilmes et al., JGR, 2013)

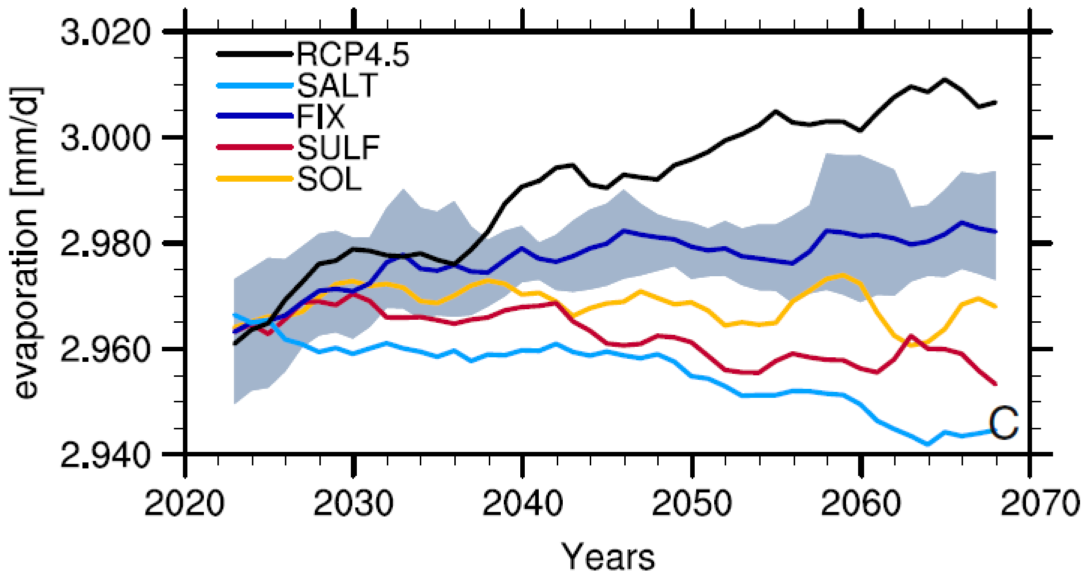
GeoMIP Experiment G3, 2011



(Kravitz et al., ASL, 2011; modified)

Effect of different SRM techniques in the MPI-ESM





(Niemeier et al., JGR, 2013)

Fast responses of the hydrological cycle to different forcings (1)

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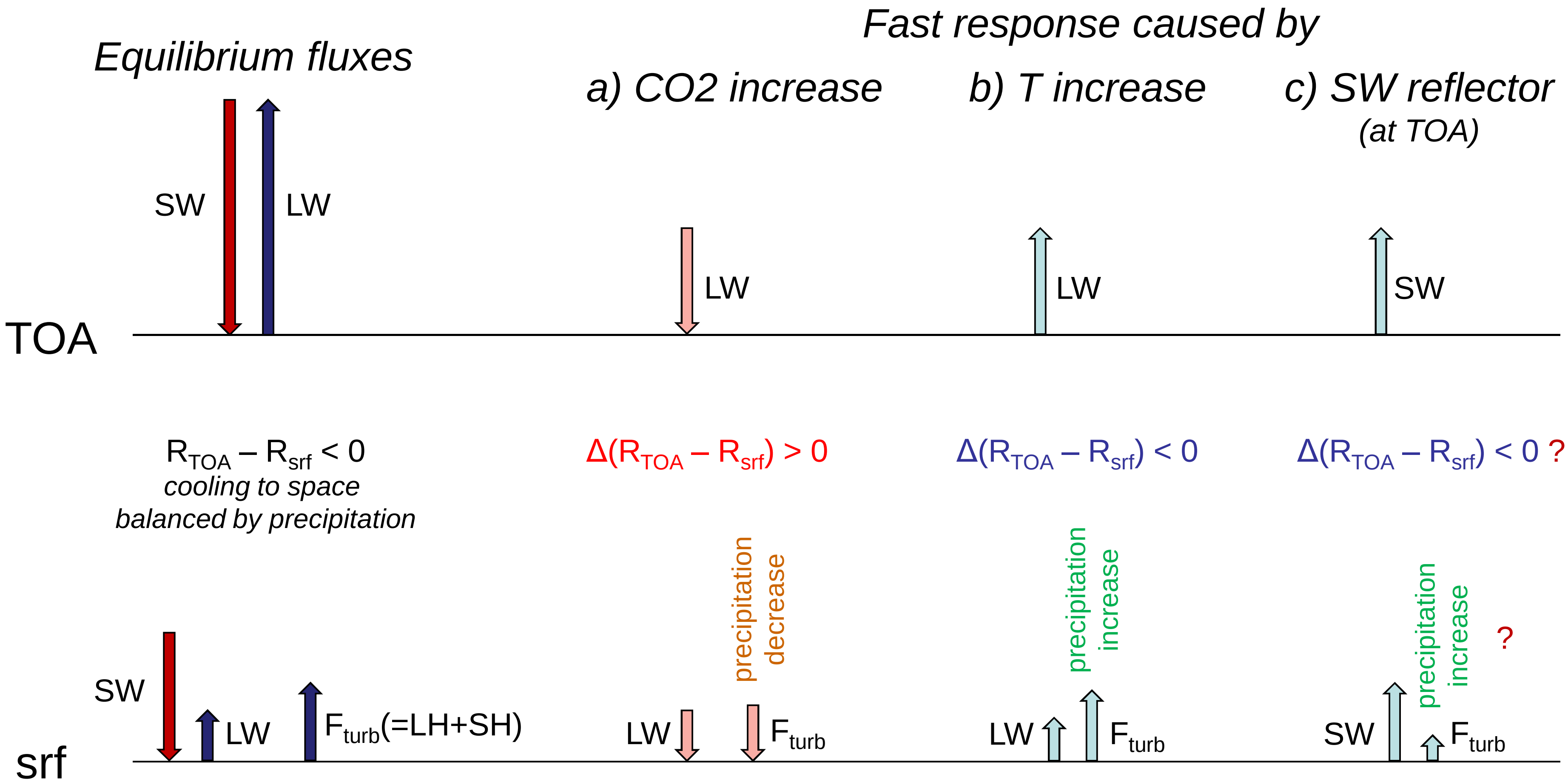
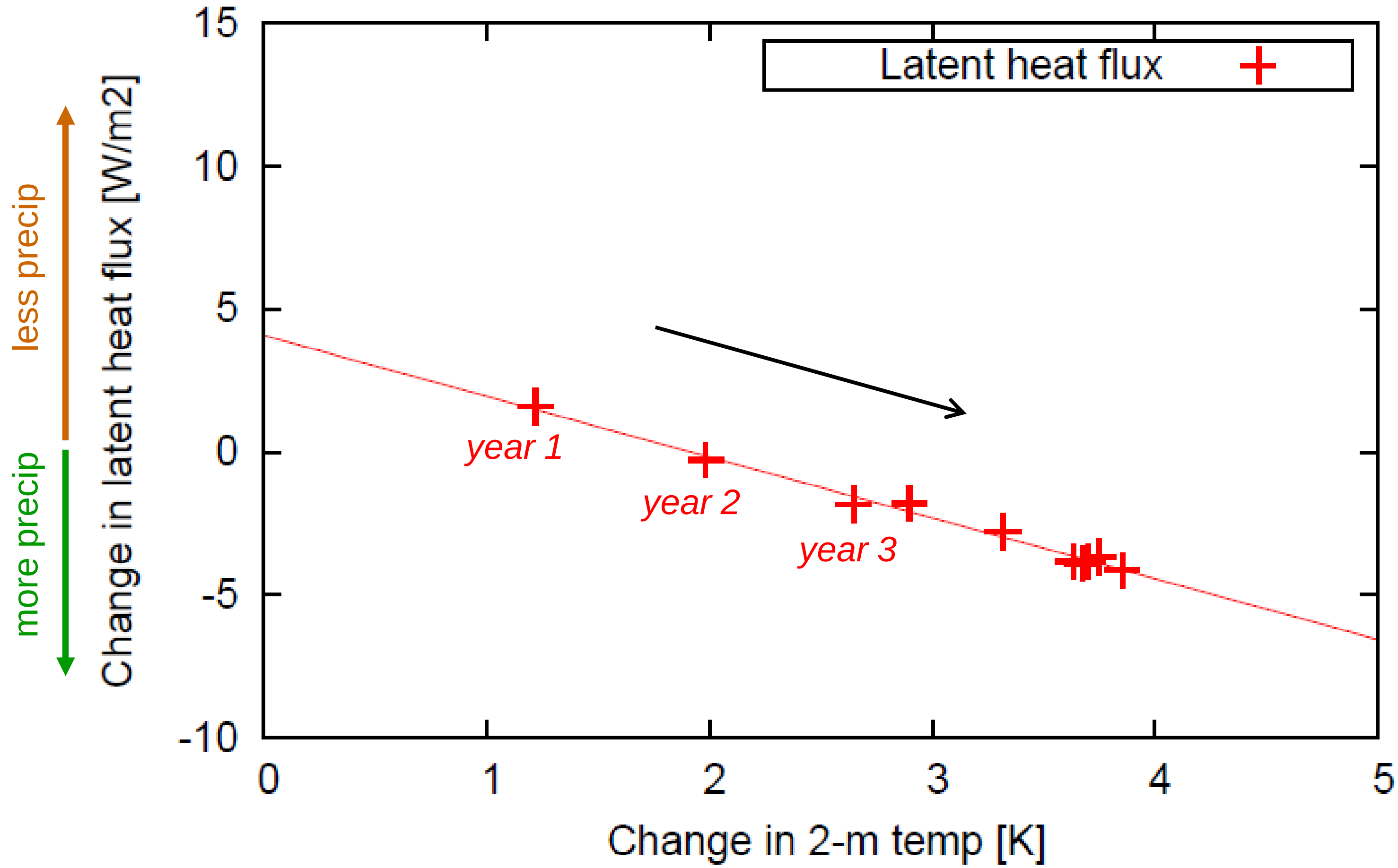


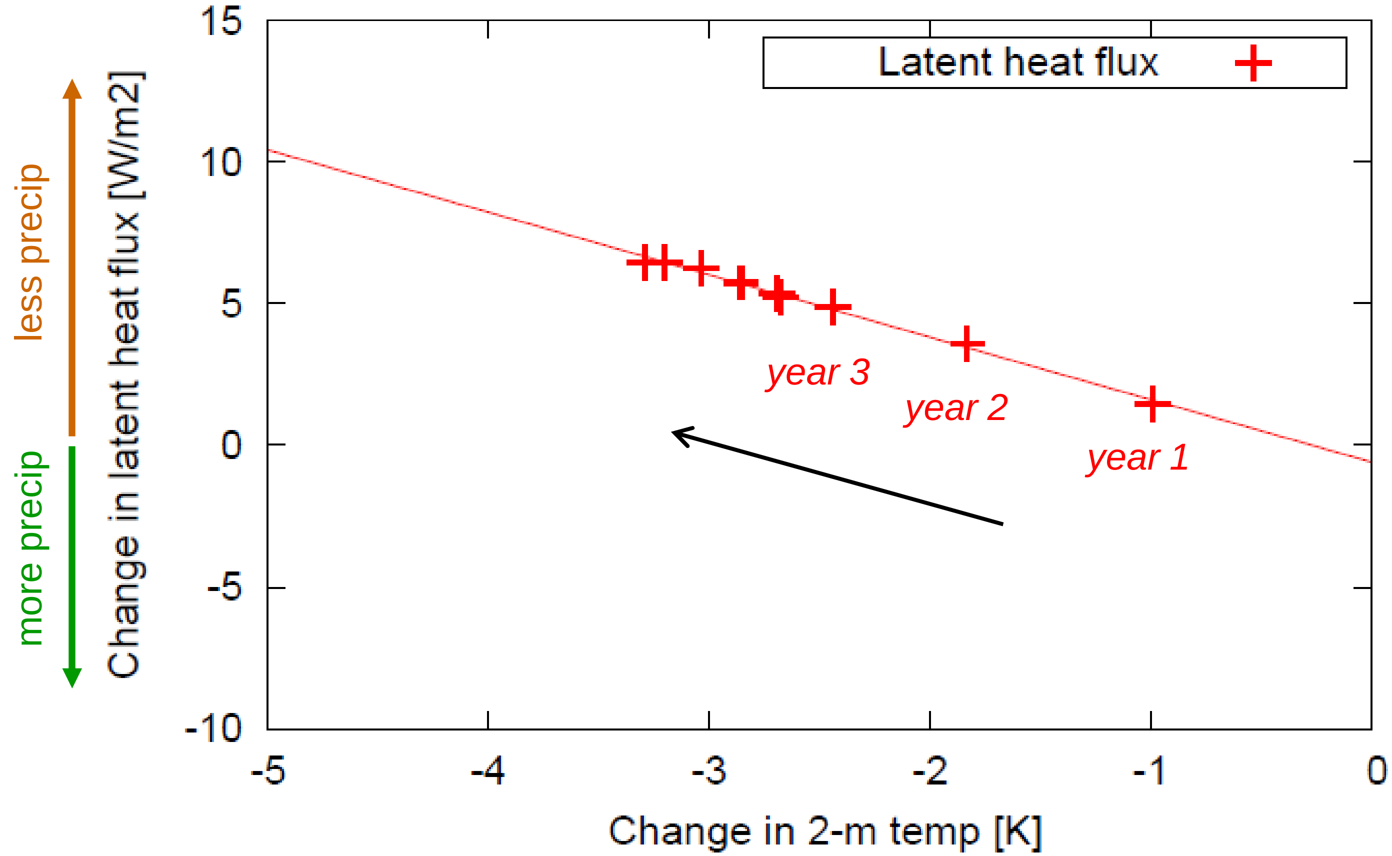
- Cloud effects, changes of the Bowen ratio and stratospheric adjustment are ignored.
- In general, the CO2 effect dominates the reflector effect.
- Aerosols in general have an additional greenhouse effect. → precipitation decrease.
- The effect of a SW reflector depends on its altitude.

(Allen & Ingram, 2002; Andrews et al., 2009; Liepert and Previdi, 2009; Kravitz et al., 2013b, Niemeier et al., 2013)

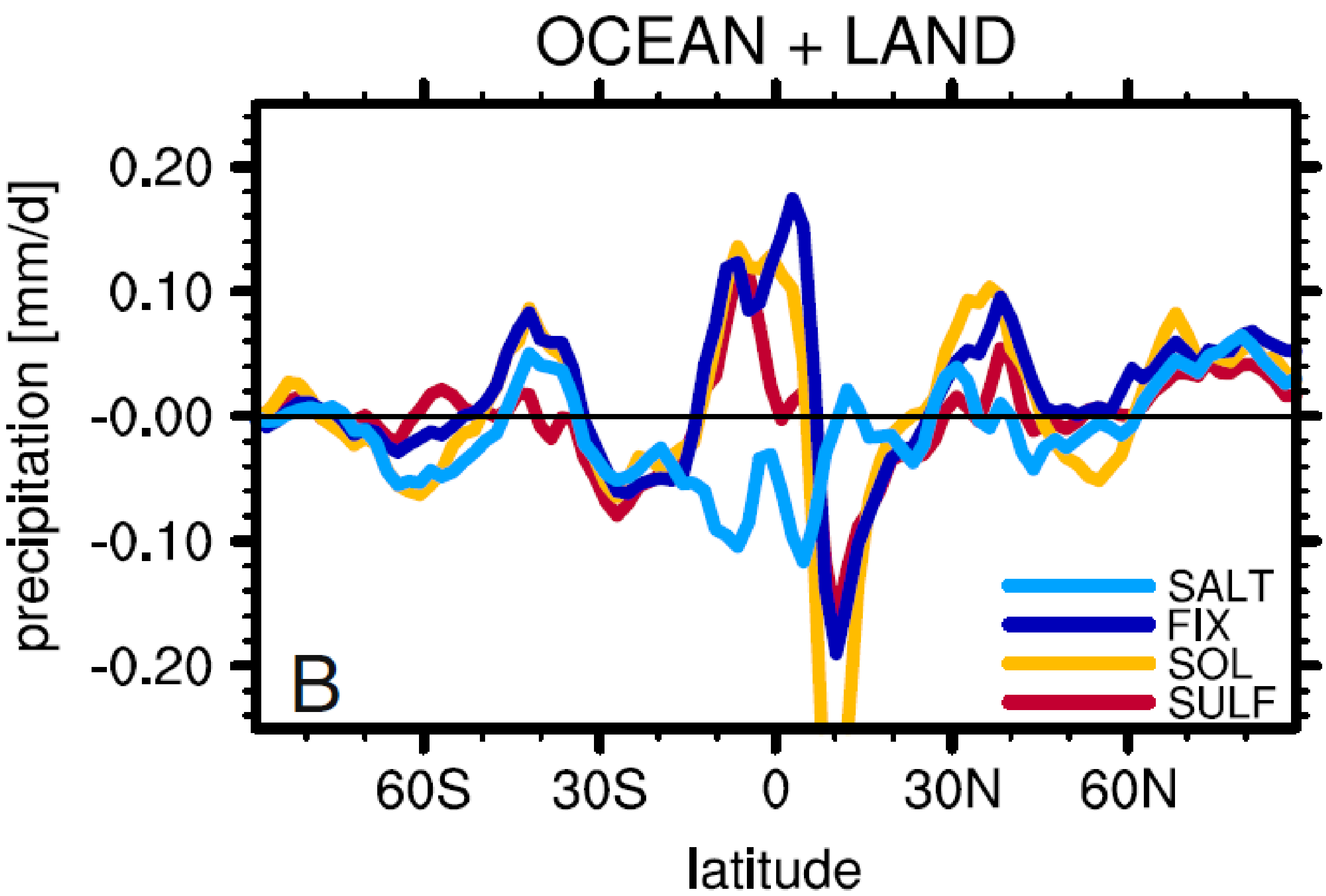
Annual mean responses to an instantaneous quadrupling of CO2 (in the MPI-ESM)



Annual mean responses to an instantaneous decrease of TSI (in the MPI-ESM)

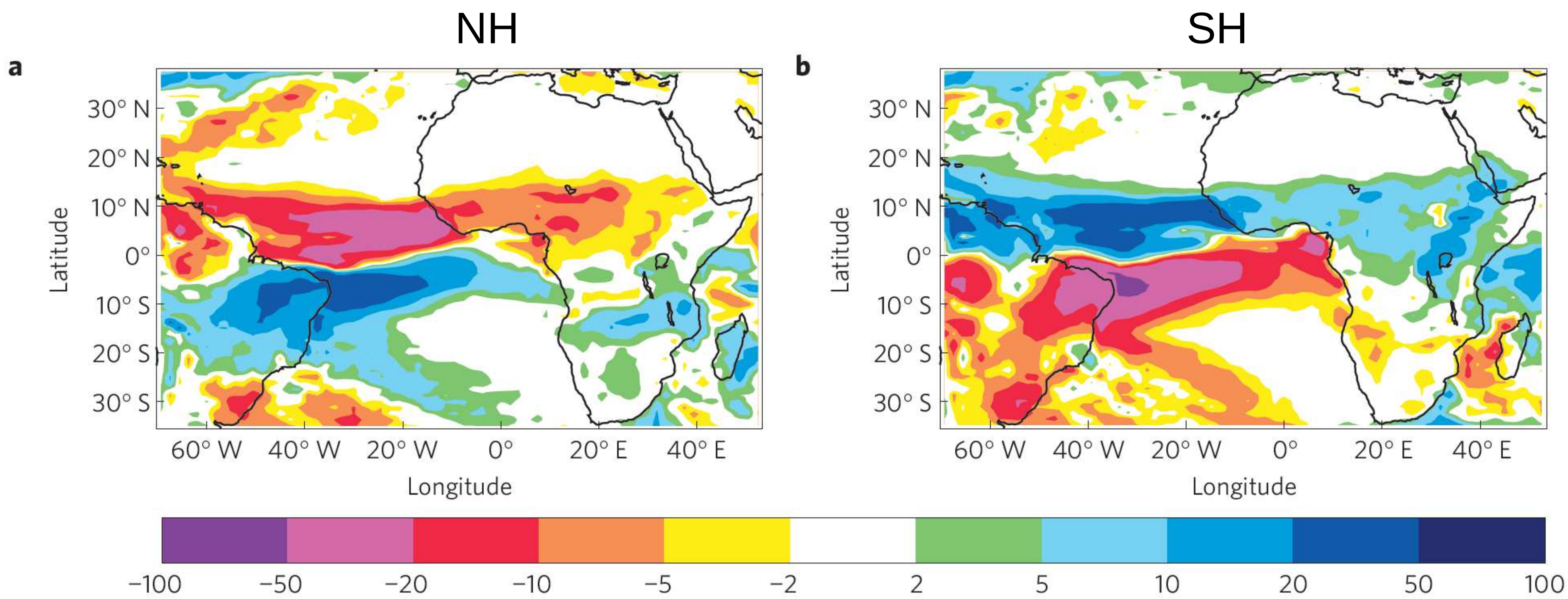


Effect of different SRM techniques in the MPI-ESM on precipitation (2065 - 2020)



(Niemeier et al., JGR, 2013)

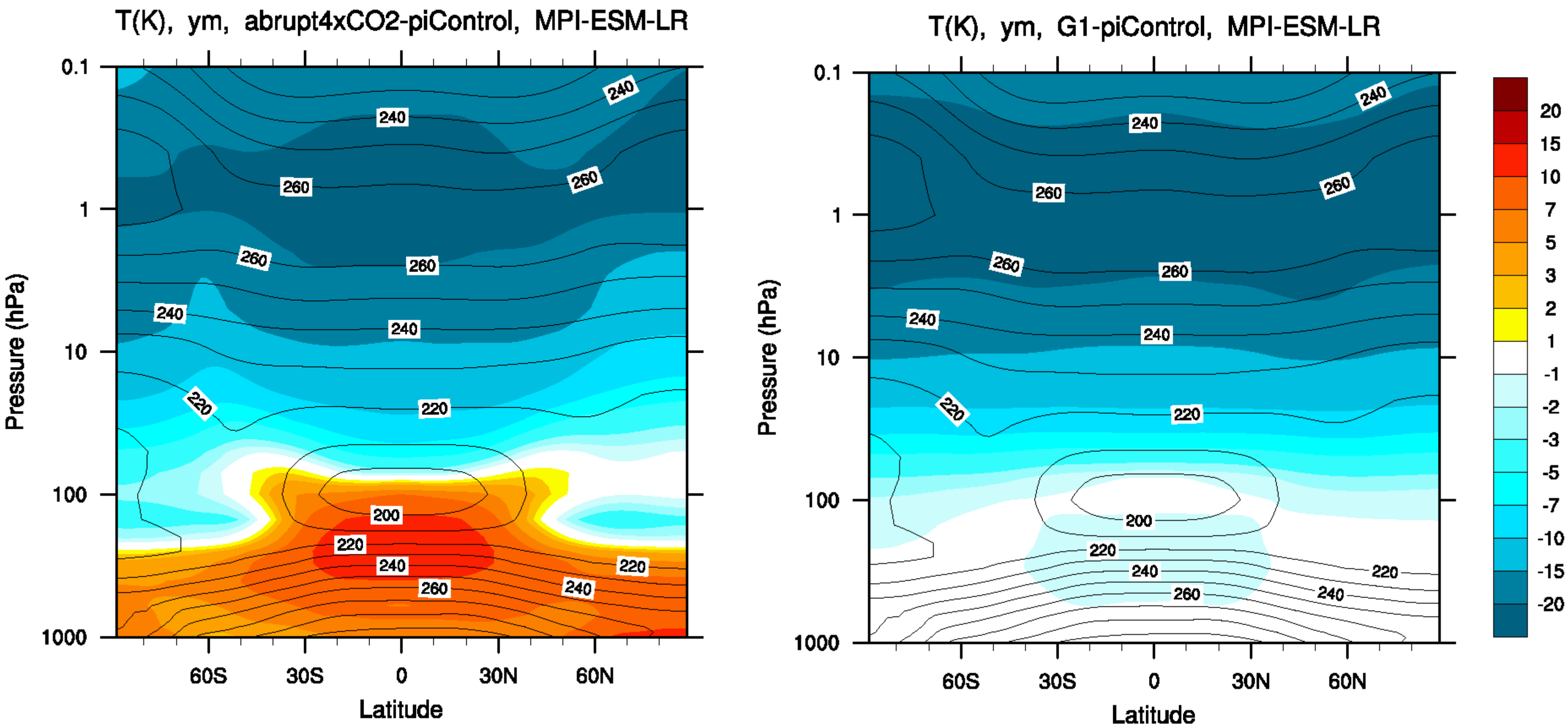
Precipitation change (%) in hemispheric G4 experiments with HadGEM2-ES



(Haywood et al., NCC, 2013)

How would stratospheric dynamics react to SRM?

4xCO2 vs. G1 T (K), annual mean



(Schmidt et al., in preparation, 2014)

4xCO2 vs. G1 u (m/s), annual mean

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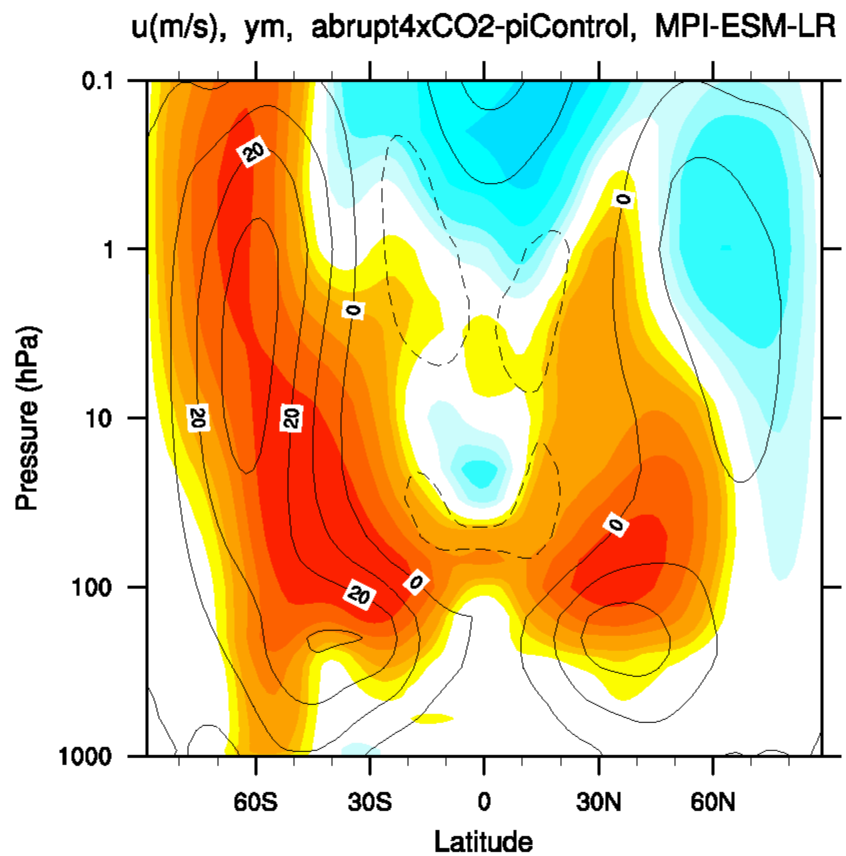
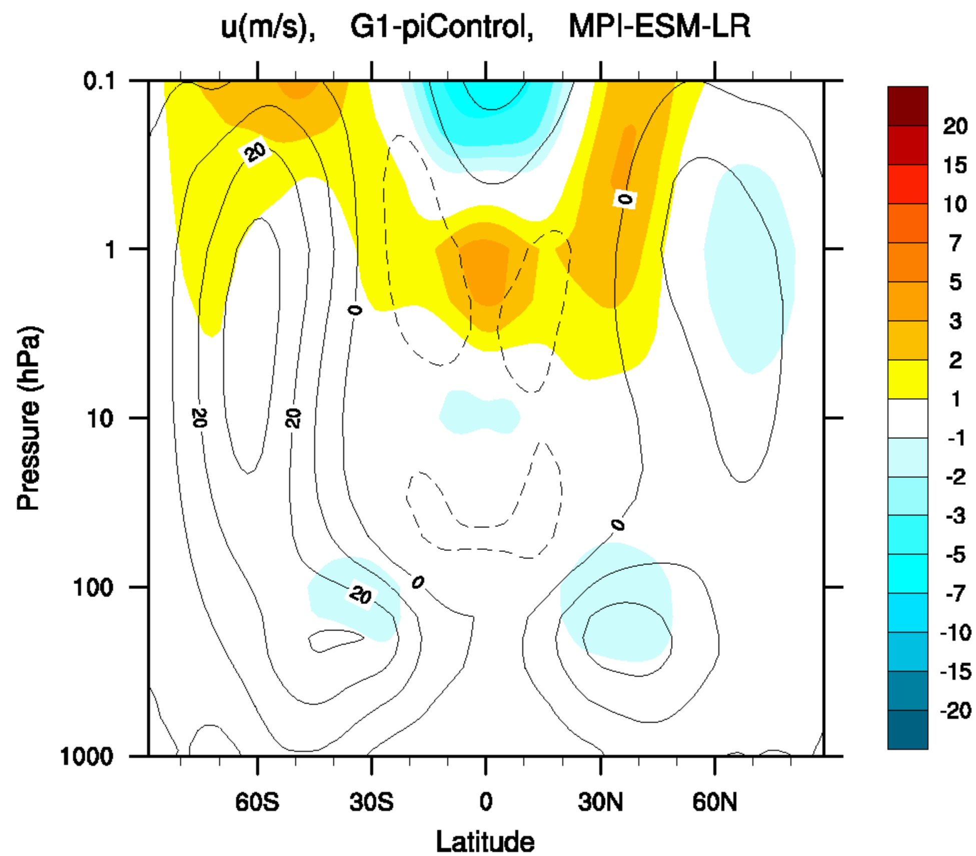
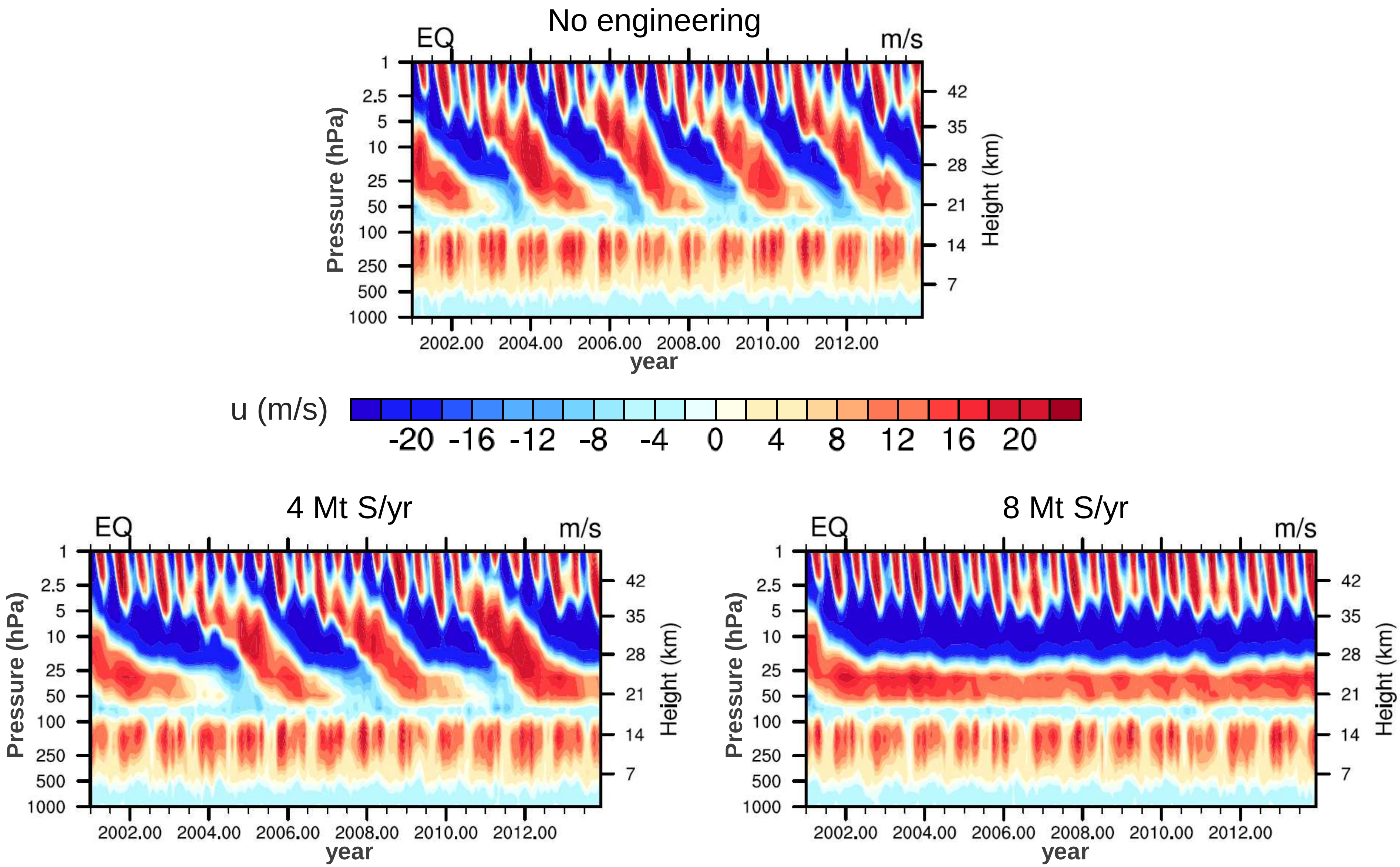




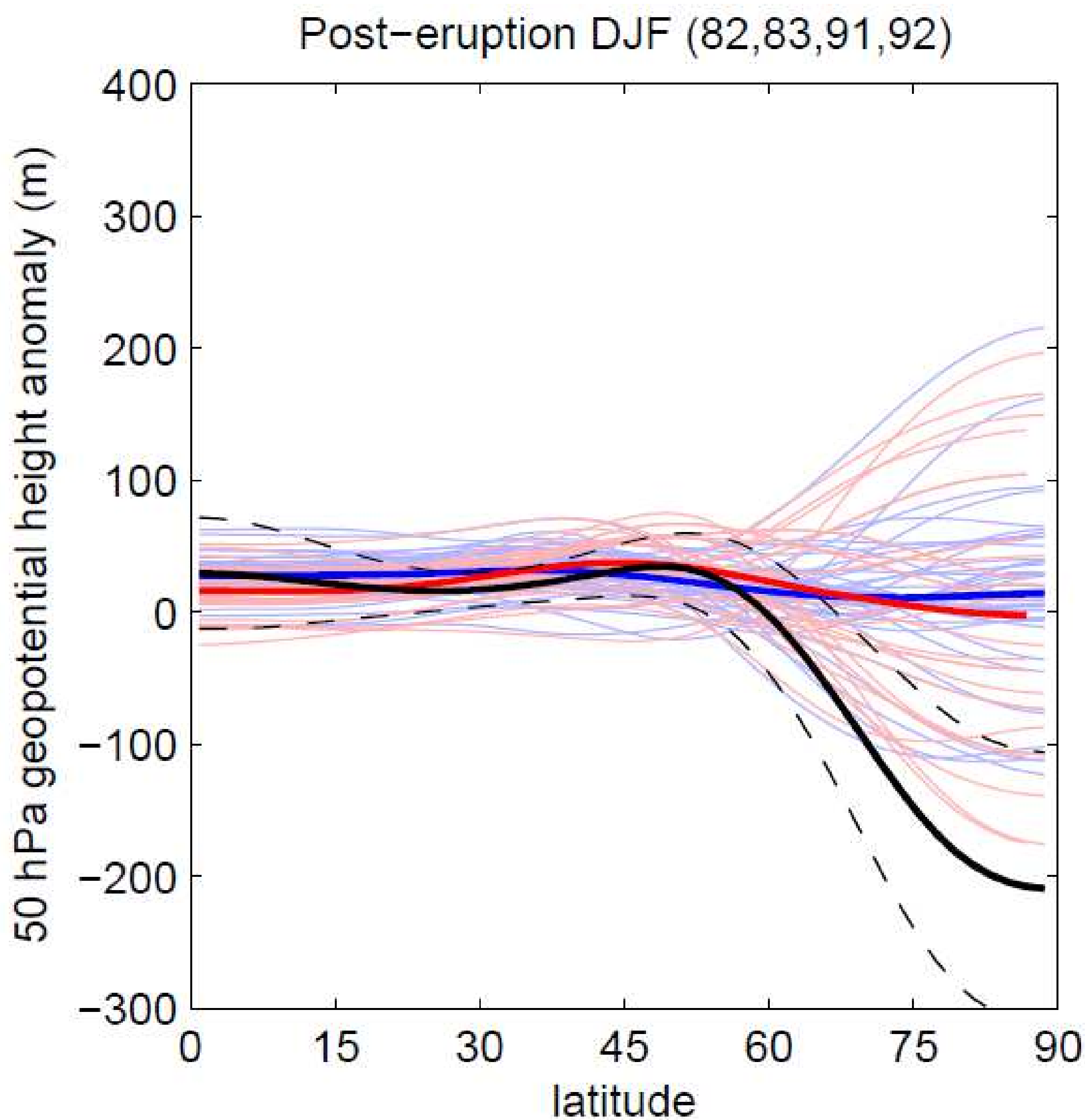
(Schmidt et al., in preparation, 2014)

The QBO depending on emission rate (in ECHAM5/HAM)



(Niemeier et al., in preparation, 2014)

The dynamical response to volcanic eruptions: CMIP5 vs. ERA-Interim



(Charlton-Perez et al., JGR, 2013; see also Driscoll et al., JGR, 2012)

Conclusions

- SRM overcompensates for the precipitation increase caused by CO_2. This is mainly related to the fast response to a CO_2 change.
- The reduction is stronger for aerosol based methods (stratospheric sulfate) than for a pure TSI reduction.
- Inhomogeneous forcing may cause regionally effects very different to homogeneous forcing.

- A TSI reduction would reduce wind changes but not temperature changes in the stratosphere.
- The QBO might be affected (destroyed?) by stratospheric sulfate aerosols.
- Dynamical effects of volcanos seem to be not well reproduced in models.

Budyko, „Climatic Changes“, 1977

“.. current simplified theories are inadequate to determine all the possible changes in weather conditions … that may result from modifications of the aerosol layer of the stratosphere. Obviously, any modifications would be premature before all the consequences can be exactly precalculated.”

Thank you!