Approaches to observe the anthropogenic aerosol indirect effect

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Acknowledgements

Ribu **Cherian** (Universität Leipzig) and Karsten **Peters** (Monash University, Melbourne)

Effect of aerosols on clouds

→ Based on theory (Köhler equation)

$$S(r,T,B) \equiv \frac{p_{v,\mathrm{sat,drop}}}{p_{v,\mathrm{sat}}} = \exp\left(\frac{A(T)}{r} - \frac{B}{r^3}\right)$$

curvature effect
(Kelvin term)

solution effect
(Raoult term)

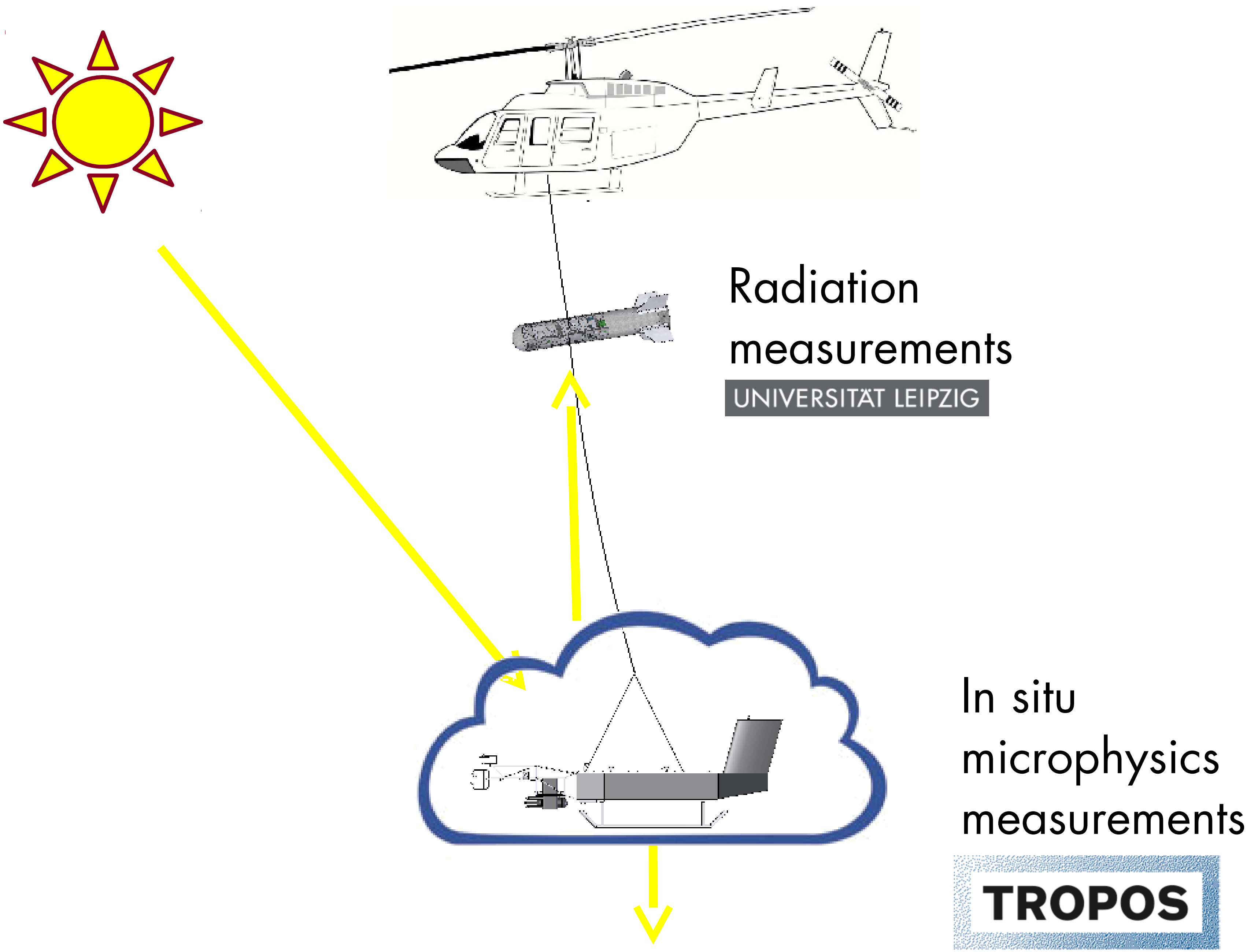
in thermodynamic equilibrium

S – saturation ratio
(saturation vapour pressure above solution droplet vs. saturation vapour pressure over flat water surface)
↔ relative humidity

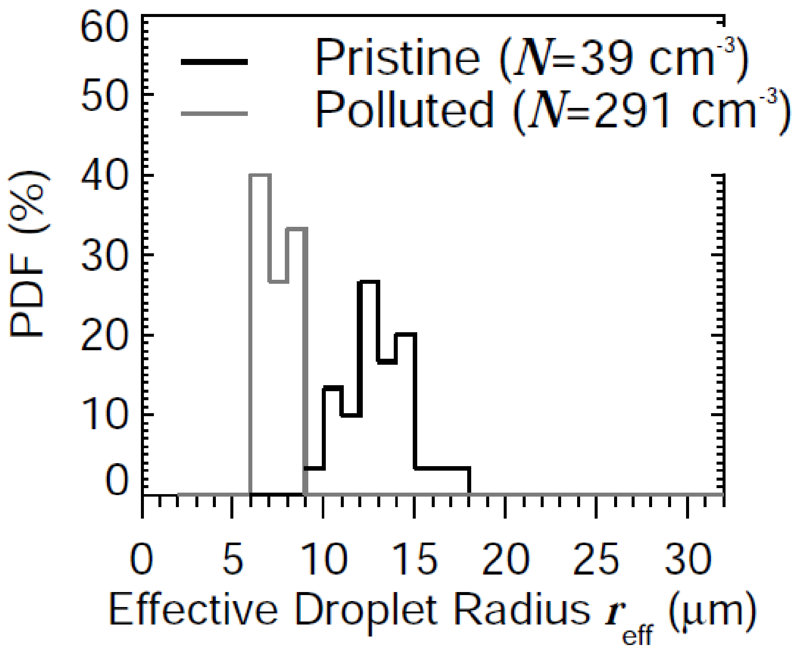
r – haze droplet radius

B – aerosol term
→ dependent on aerosol mass ~ r_a^3
→ dependent on solubility.

Effect of aerosols on clouds: observational evidence



Effect of aerosols on clouds: observational evidence

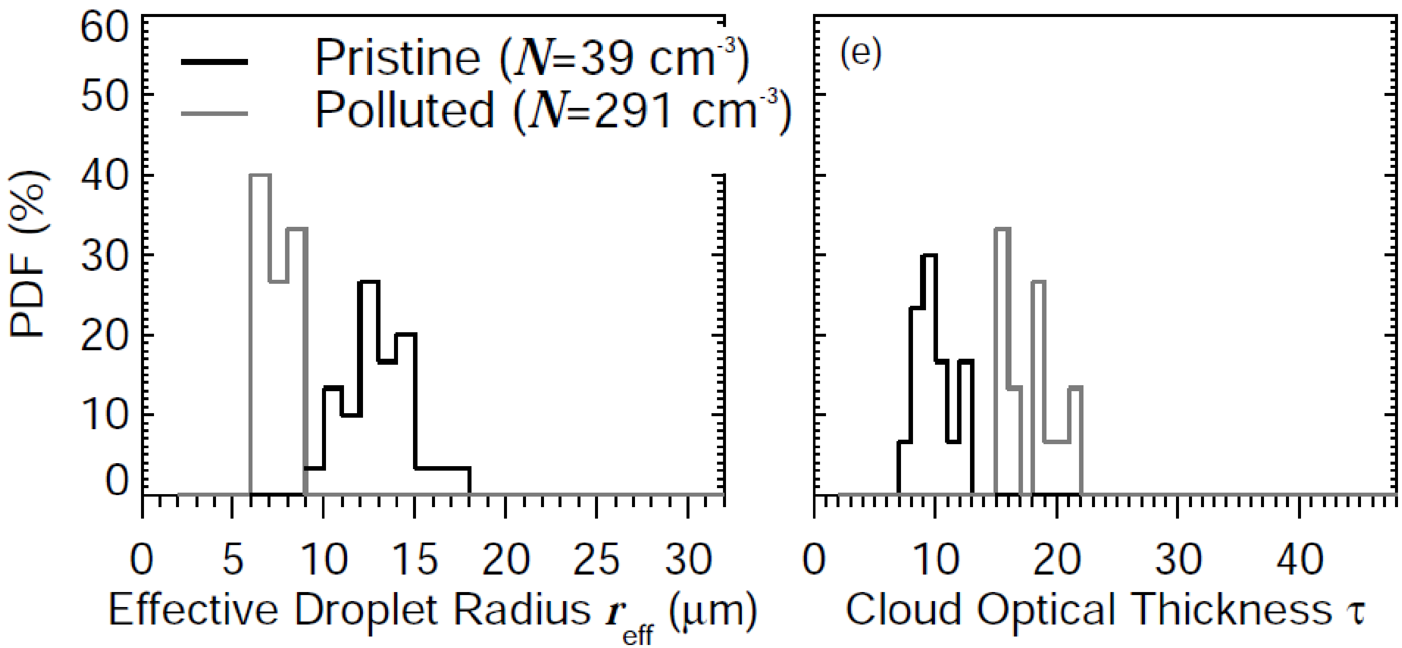


CARRIBA campaign
Barbados island, April 2011
16 April: biomass burning
22 April: pristine marine

LWP selected at 80-90 g m^{-2}

Werner, et al., J. Geophys. Res. revised

Effect of aerosols on clouds: observational evidence



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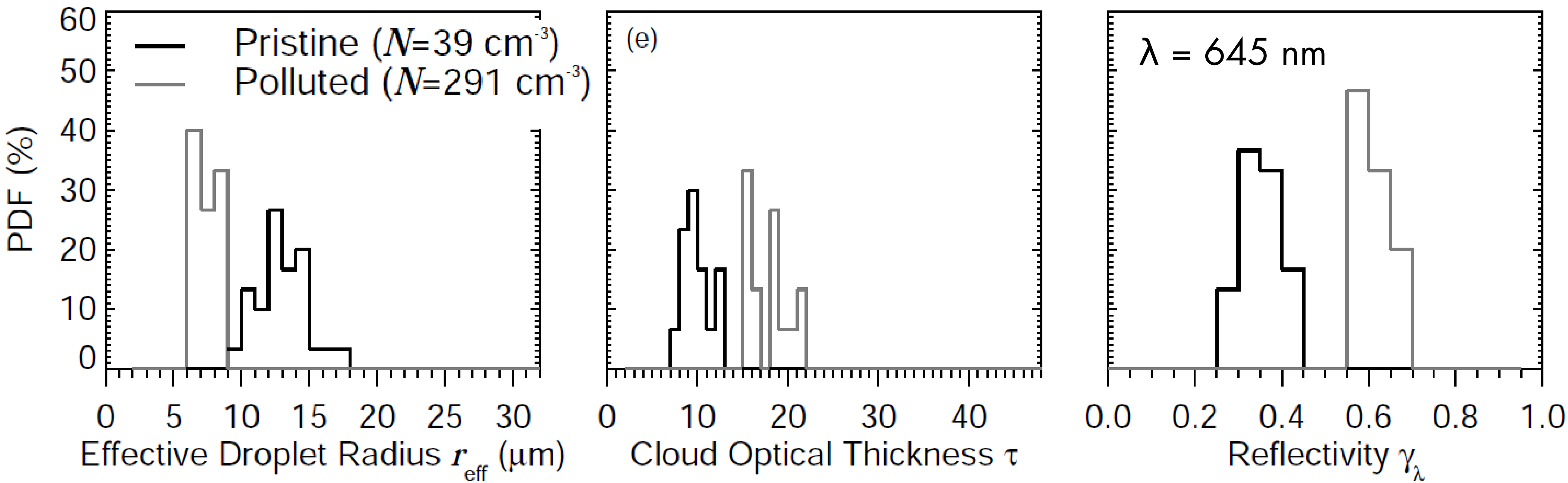

CARRIBA campaign
Barbados island, April 2011
16 April: biomass burning
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but:
anthropogenic component is what counts for climate **forcing.**

	AOD	absorption AOD	Clear-sky radiative perturbation [W m^{-2}]	All-sky radiative forcing [W m^{-2}]
Total	0.180	0.008	-7.3	xxx
Anthropogenic	0.073	0.007	-2.9	-0.7
	41%	88 %	40%	xxx

Data: Monitoring Atmospheric Composition and Climate (MACC)
Aerosol re-analysis

Bellouin, Quaas., Boucher and Morcrette, Atmos. Chem. Phys. 2013

Approaches to observe the anthropogenic aerosol indirect effect

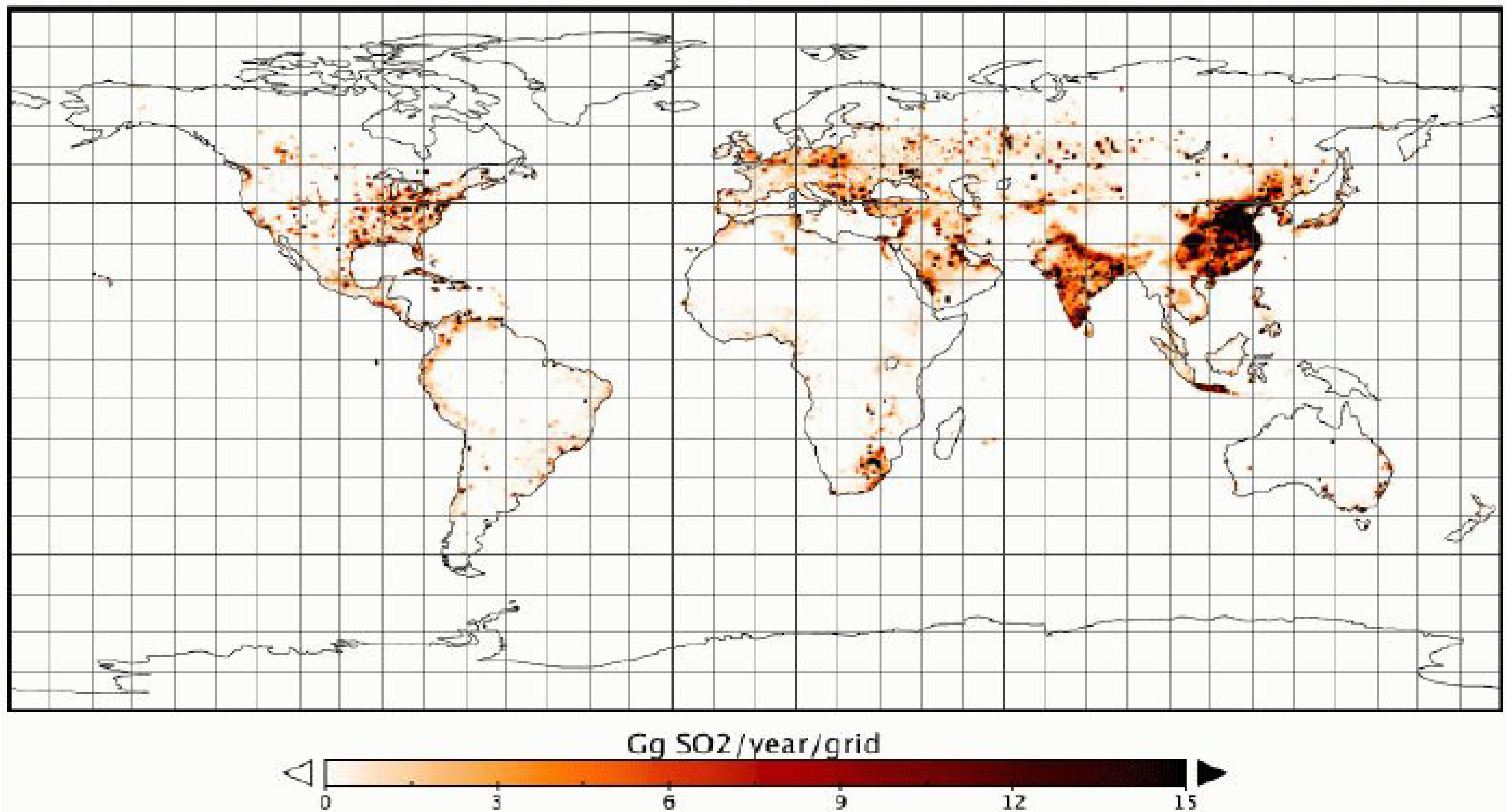
1) **Hemispheric contrast**
   – Anthropogenic emissions in Northern hemisphere vs. pristine Southern hemisphere

2) **Ship tracks**
   – Anthropogenic emissions in a very pristine environment

3) **Weekly cycles**
   – Larger anthropogenic emissions on weekdays

4) **Trends**
   – Increasing or decreasing anthropogenic emissions

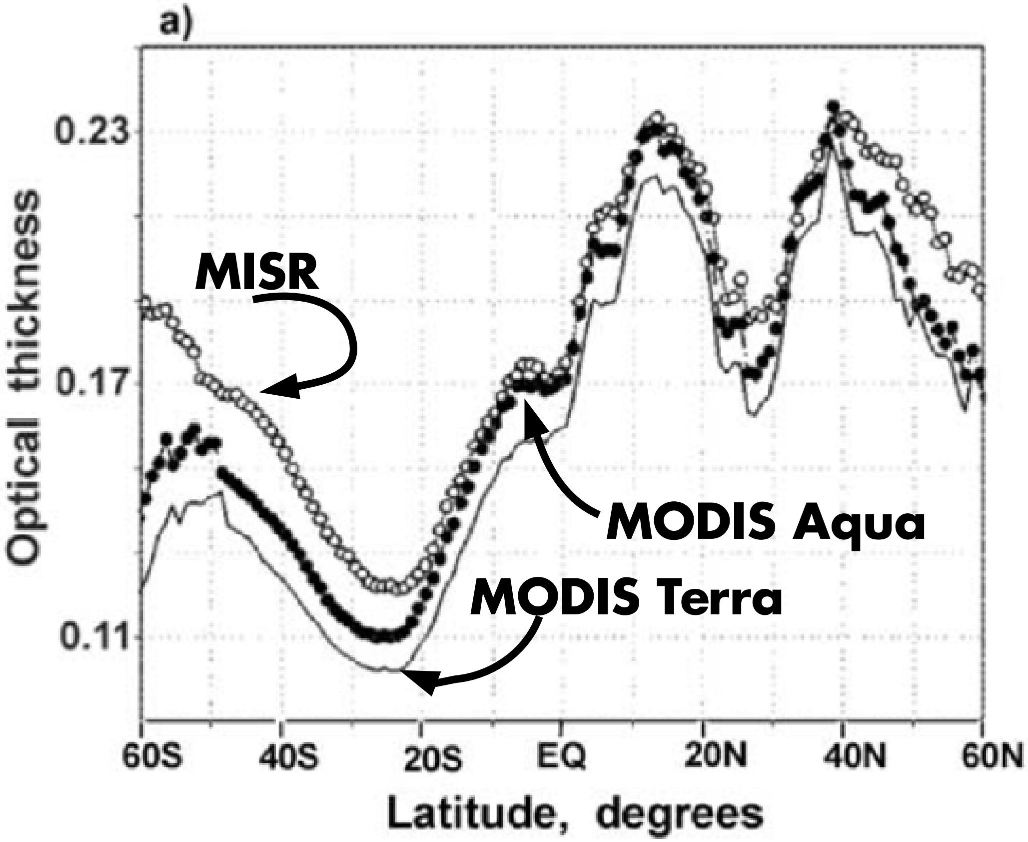
1. Hemispheric contrast



Anthropogenic SO_2 emissions 2010 (0.5° grid)

1. Hemispheric contrast

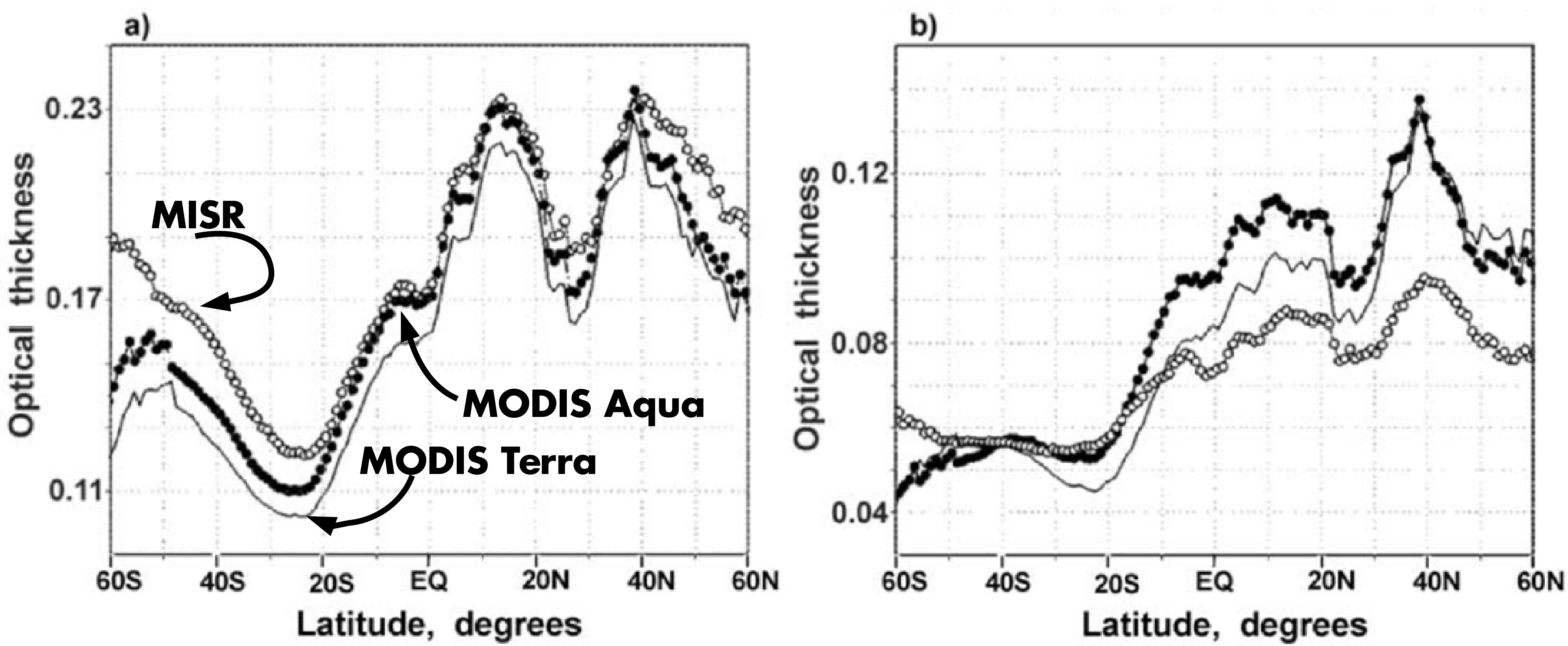
Aerosol optical depth



Kishcha et al., J. Geophys. Res. 2009

1. Hemispheric contrast

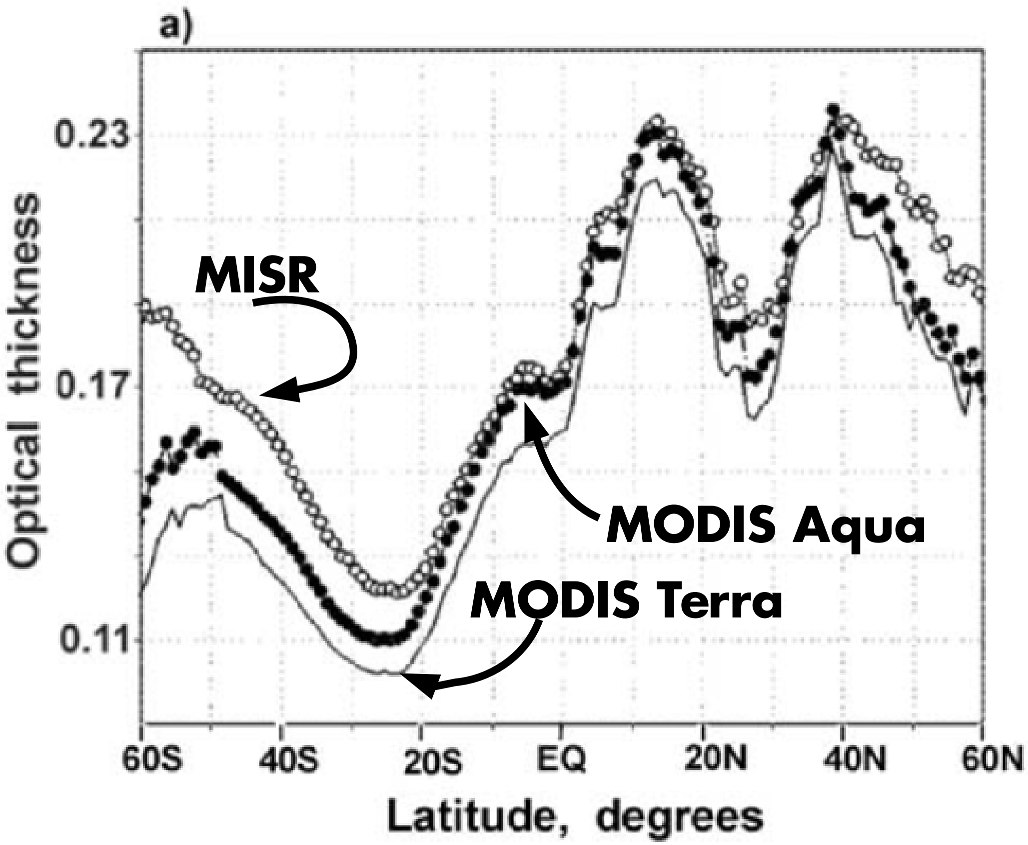
Aerosol optical depth **Fine-mode AOD**



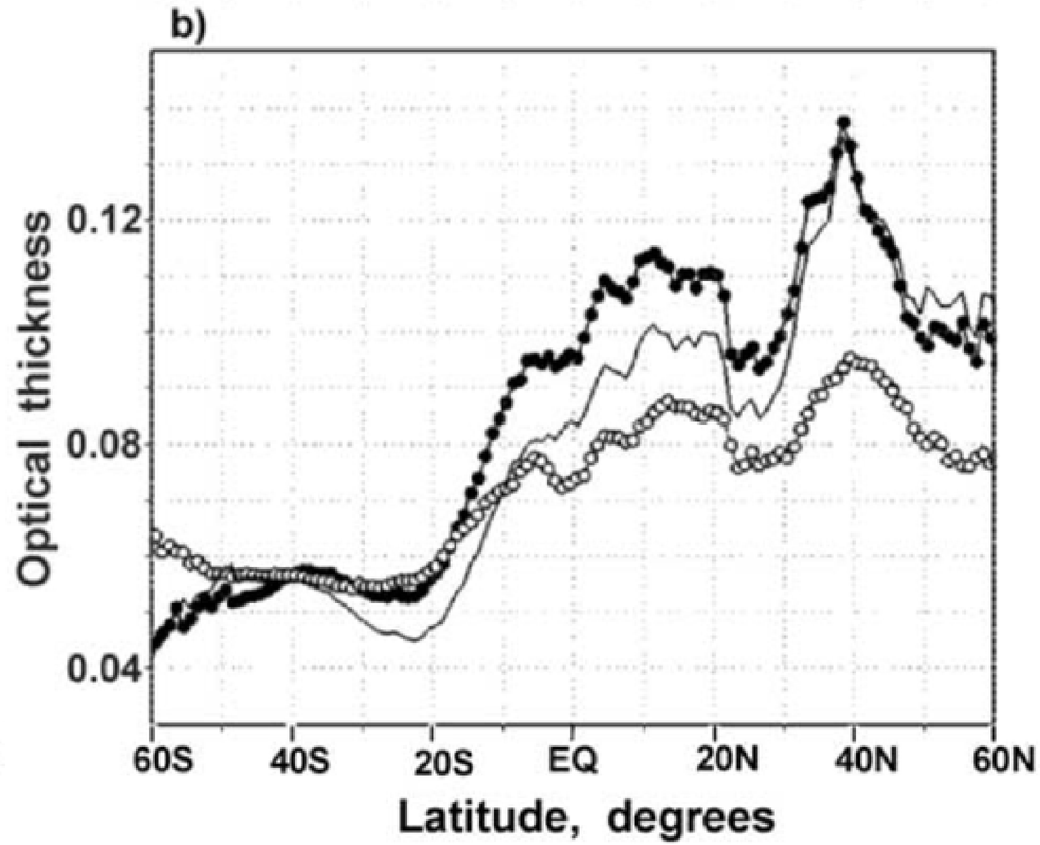
Kishcha et al., J. Geophys. Res. 2009

1. Hemispheric contrast

Aerosol optical depth



Fine-mode AOD



	Ratio NH : SH	
MISR	1.39	1.34
MODIS-Aqua	1.46	1.67
MODIS-Terra	1.51	1.74

Kishcha et al., J. Geophys. Res. 2009

1. Hemispheric contrast

		r_e	τ
Northern Hemisphere	Total	11.0	6.6
	Ocean	11.6	6.4
	Land	8.2	7.8
Southern Hemisphere	Total	11.7	7.4
	Ocean	12.0	7.4
	Land	9.0	8.6

AVHRR NOAA-9 and NOAA-10; January – April – July – October 1987 and 1988

Han et al., J. Climate 1994

1. Hemispheric contrast

	Northern hemisphere	Southern hemisphere
Fine-mode aerosol optical depth	0.091	0.055
Droplet effective radius [μm]	10.4	12.9
Cloud optical depth	14.7	12.1

→ Chemistry-transport model simulation (IMPACT) for year 2001, driven by ERA-40
45° S to 45° N over oceans

Feng and Ramanathan, Tellus 2010

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	0.094	**0.061**
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Feng and Ramanathan, Tellus 2010

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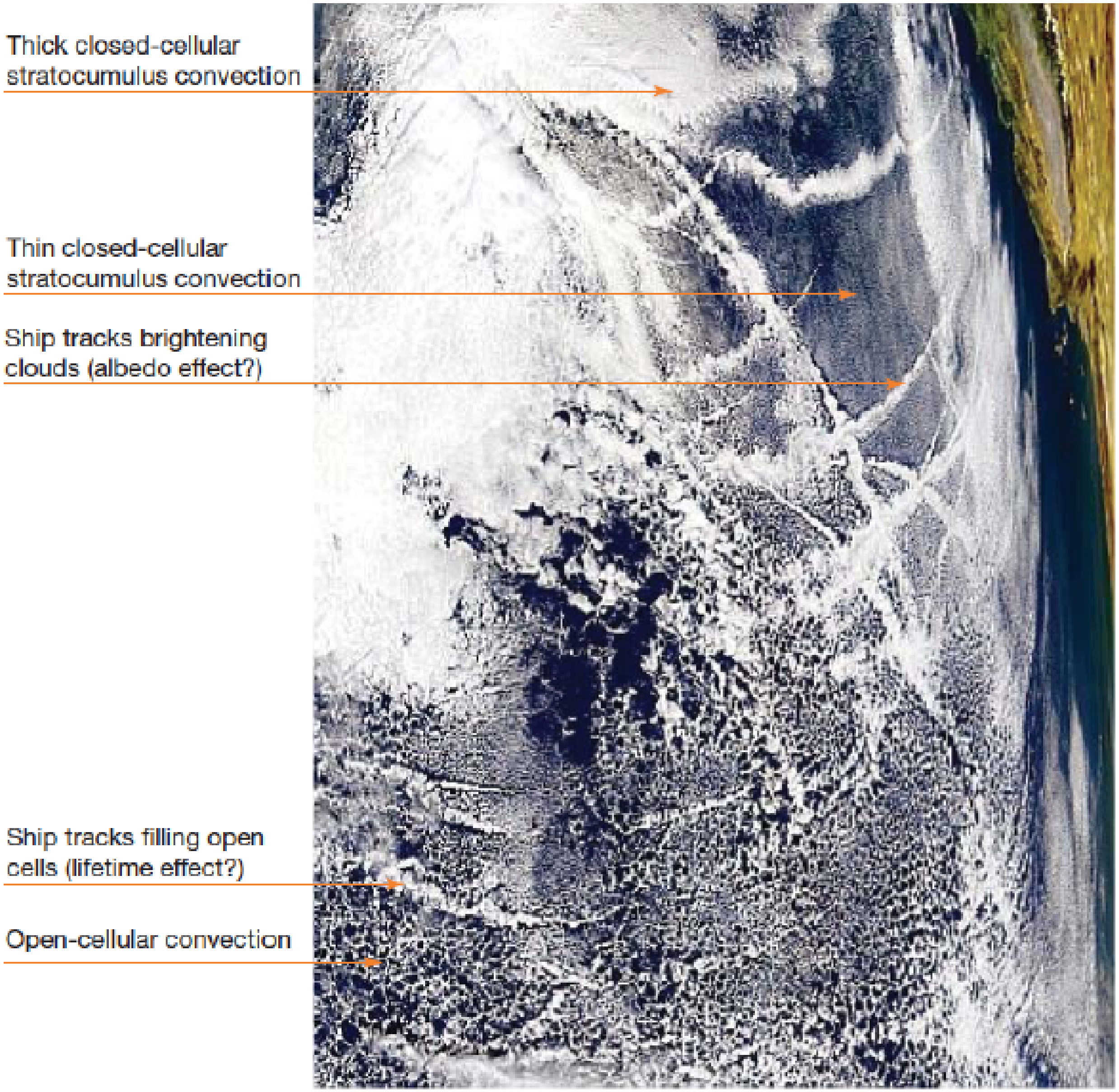
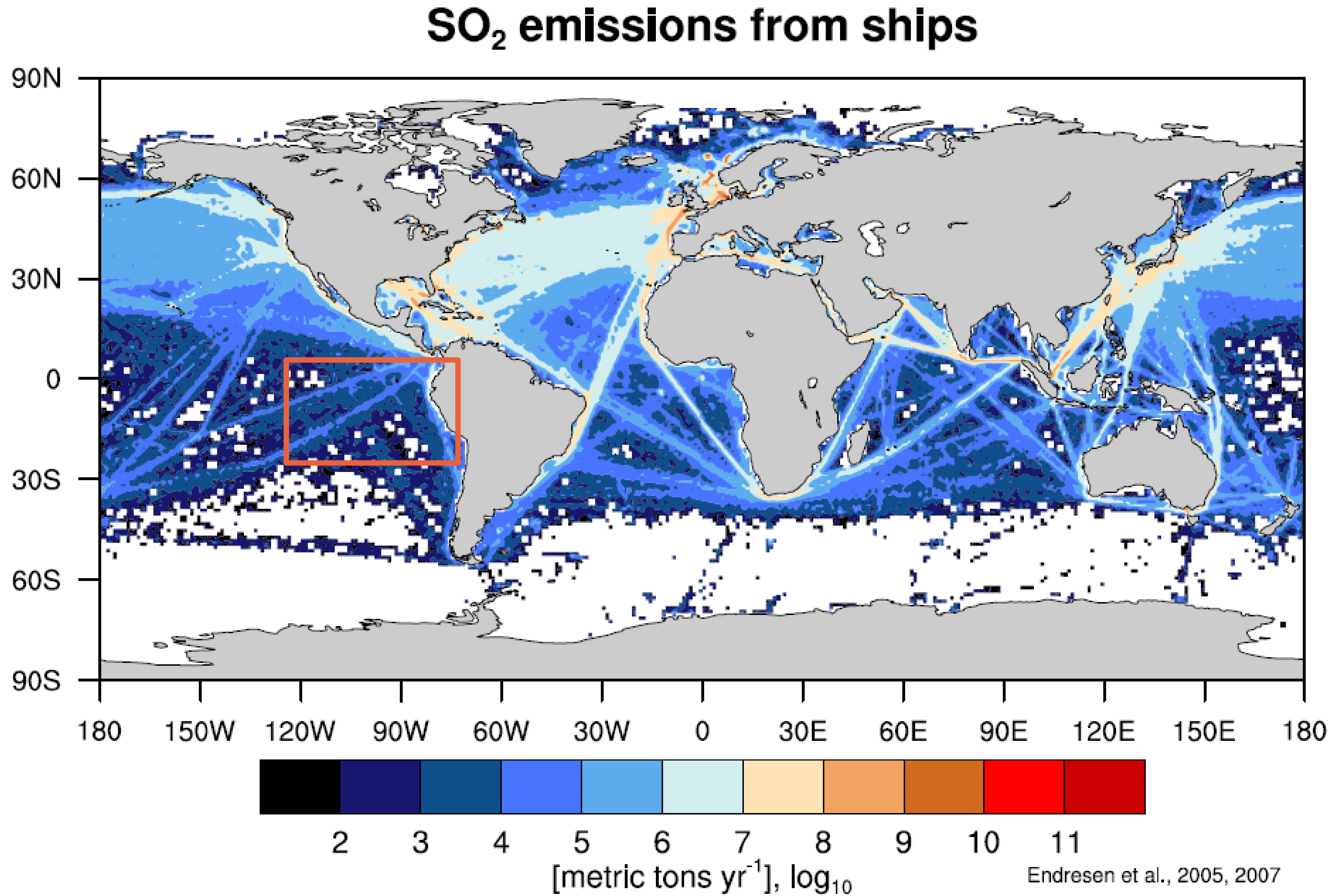
2. Ship tracks



Stevens and Feingold, Nature 2009; Goren and Rosenfeld, J. Geophys. Res., 2012

2. Ship tracks at a large scale



Peters, Quaas and Graßl, J. Geophys. Res. 2011

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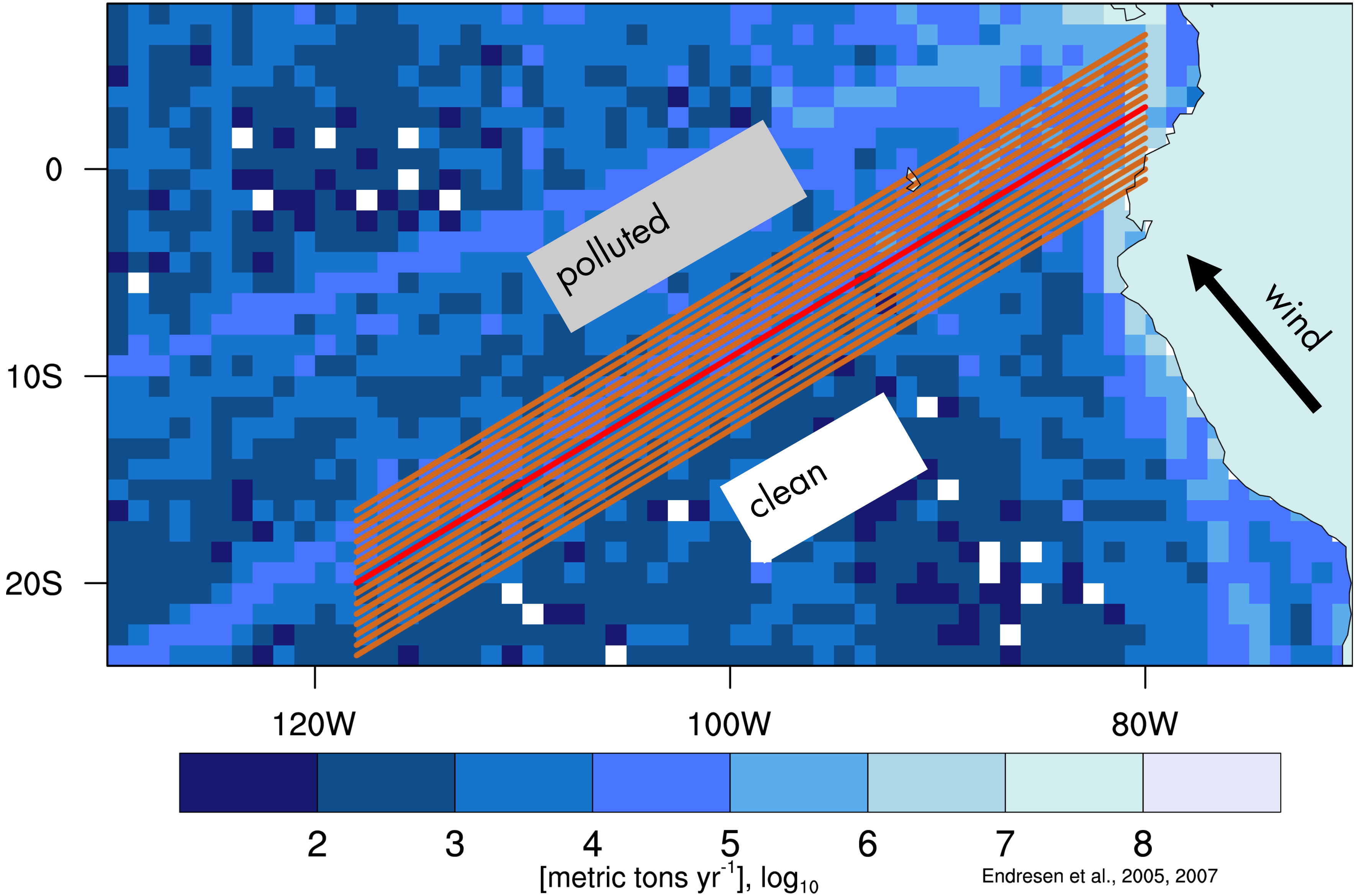
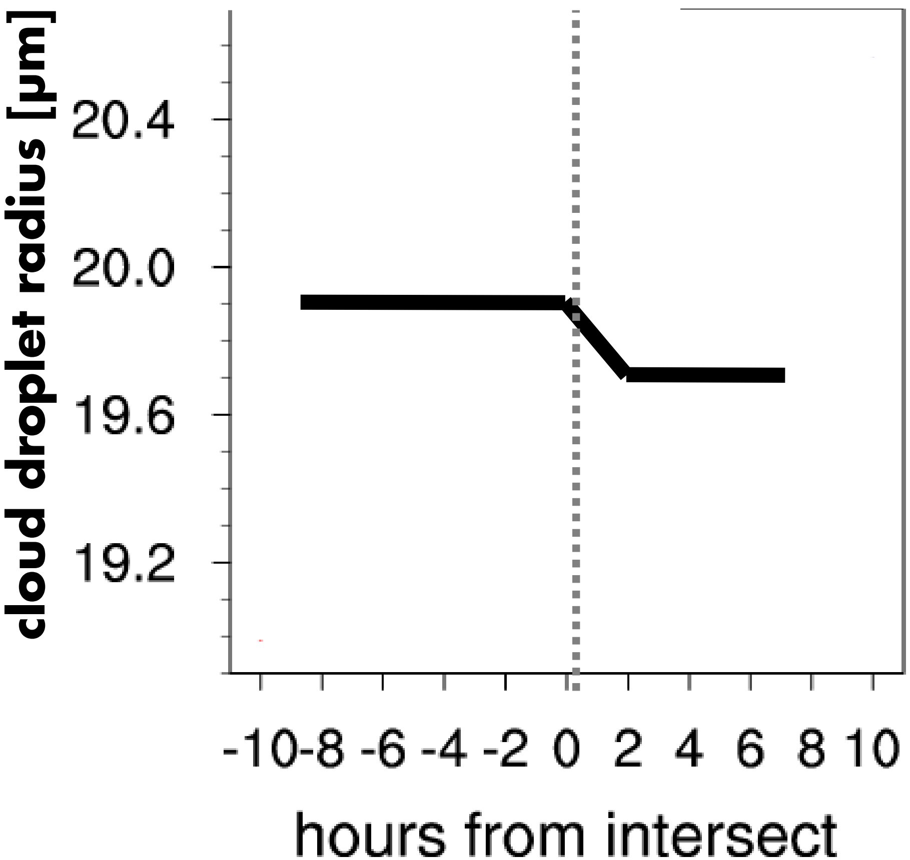


colour code: SO2 ship emissions (log scale)

2. Ship tracks at a large scale

Indirect effect: **cloud droplet radius decrease?**

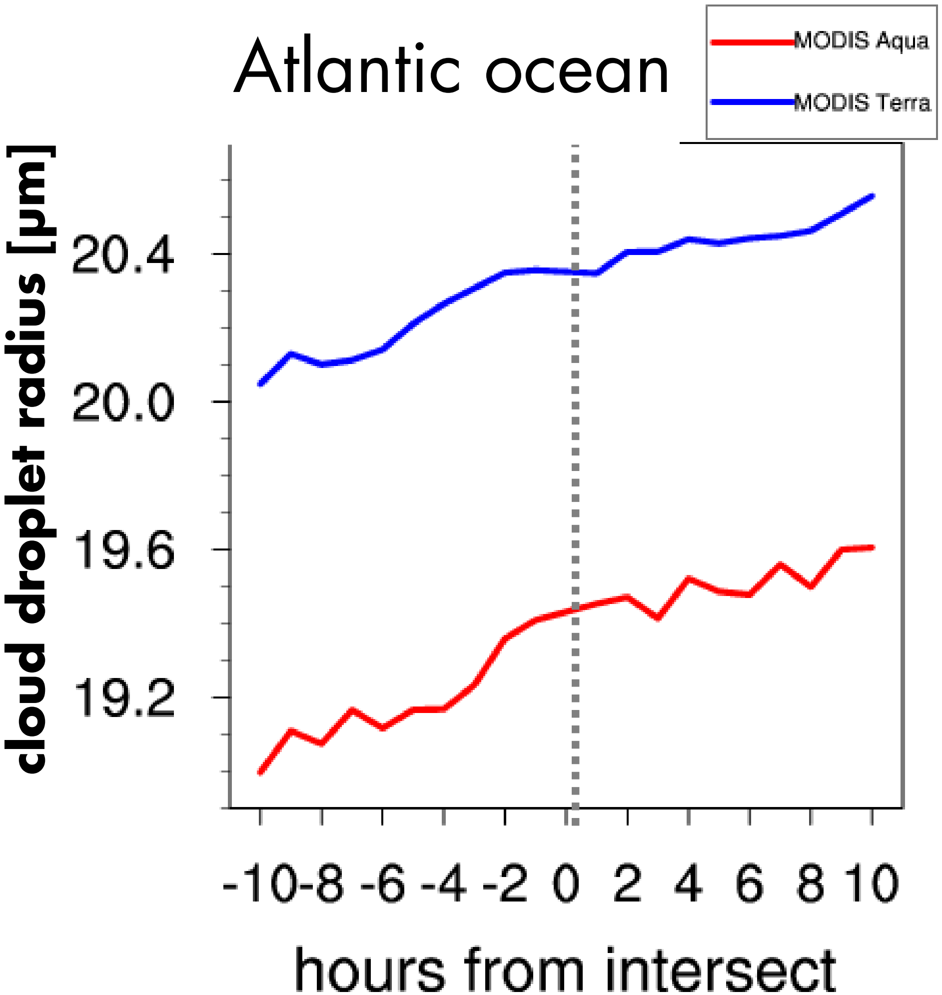


Expected idealised indirect effect result:

→ Cloud droplet radius decreases due to pollution

2. Ship tracks at a large scale

Indirect effect: **cloud droplet radius decrease?**



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Peters, Quaas and Graßl, J. Geophys. Res. 2011

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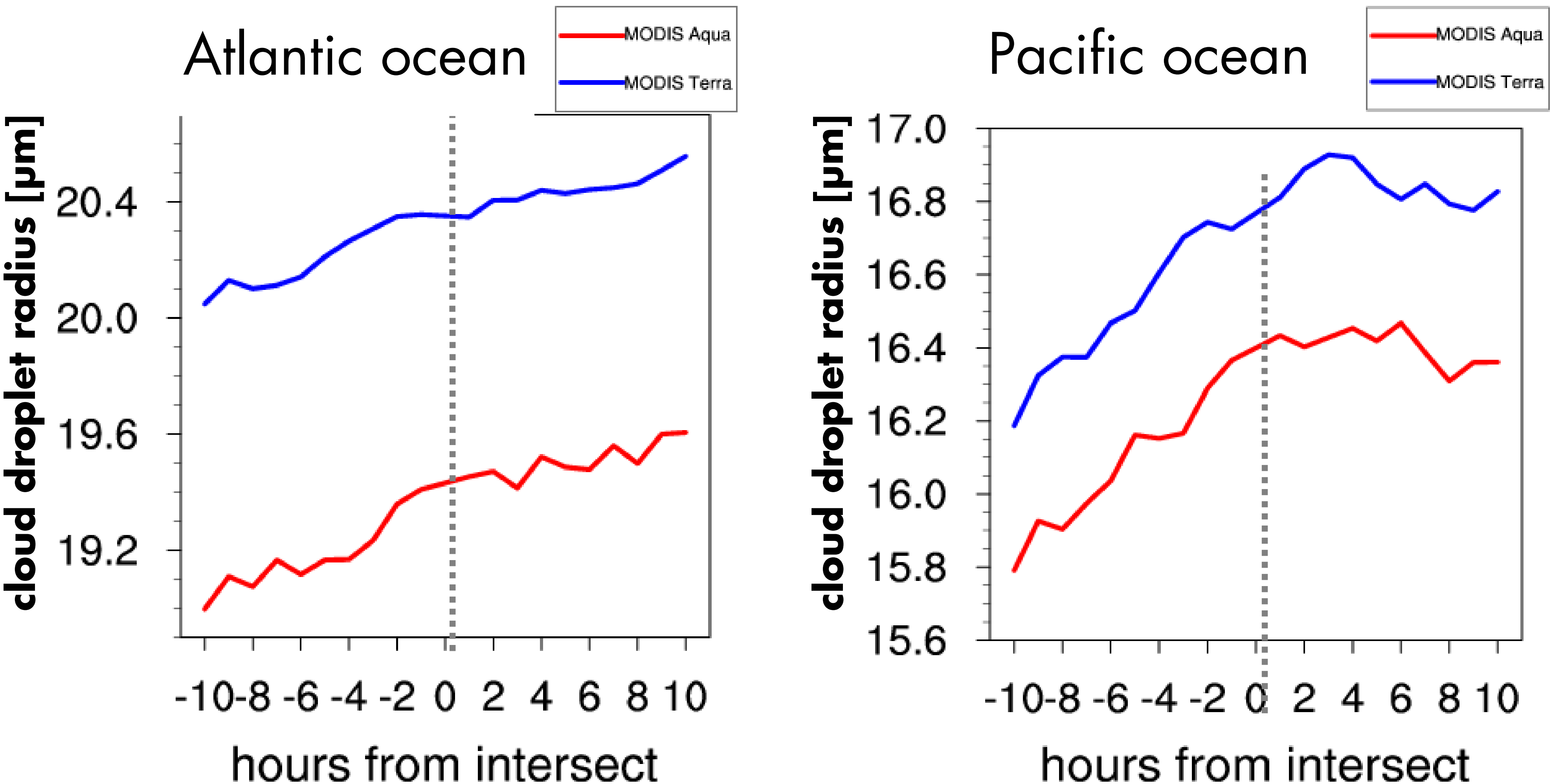
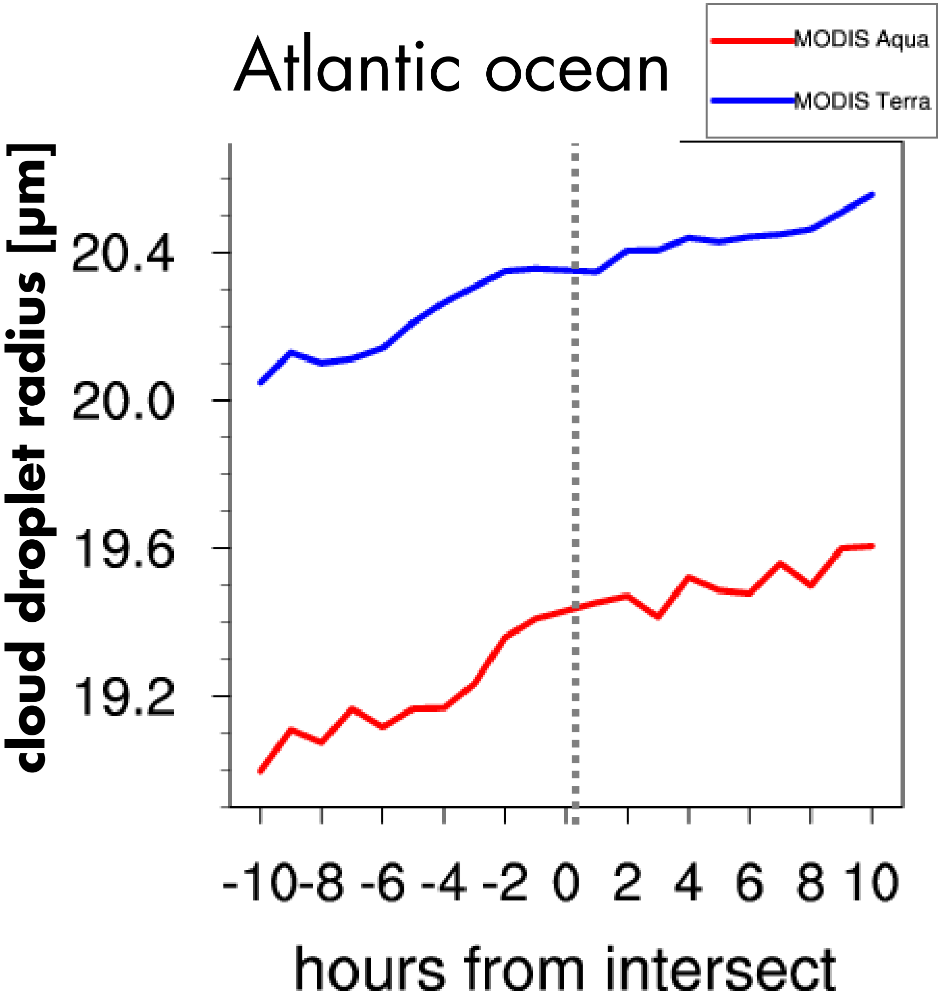
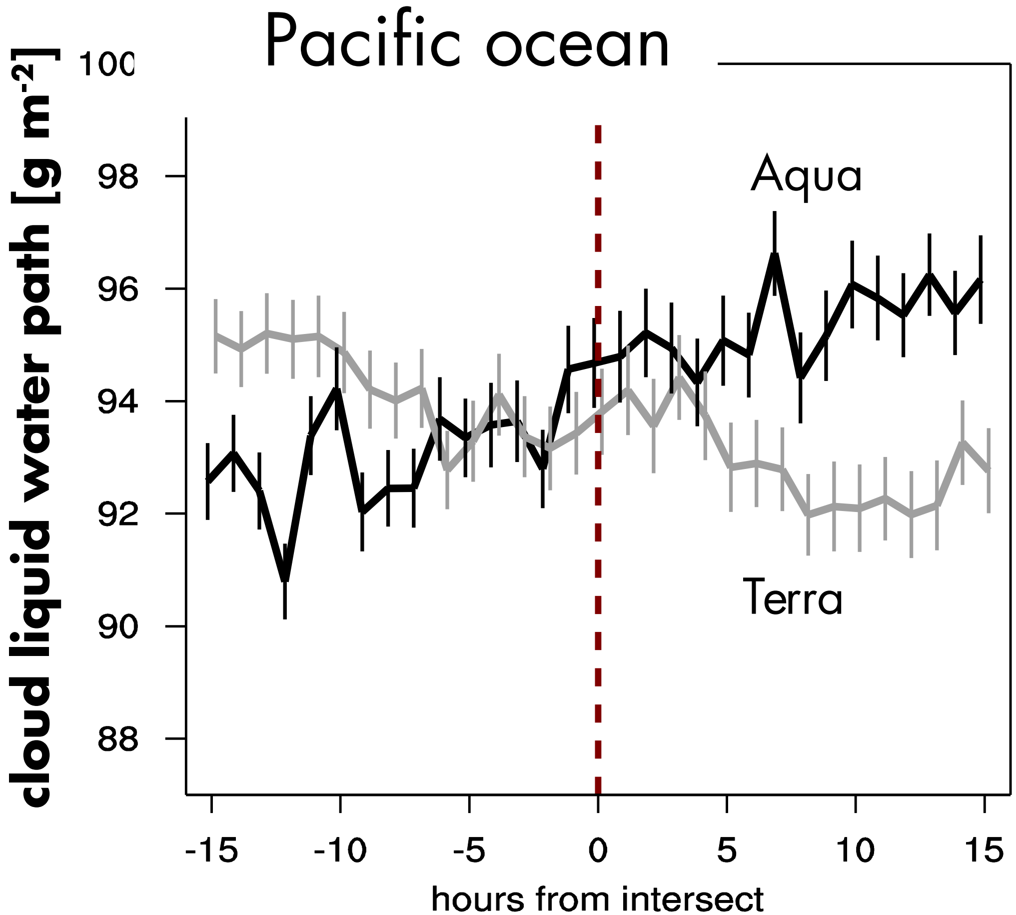


Peters, Quaas and Graßl, J. Geophys. Res. 2011

2. Ship tracks at a large scale

Indirect effect: **cloud droplet radius decrease?** **cloud liquid water path increase?**

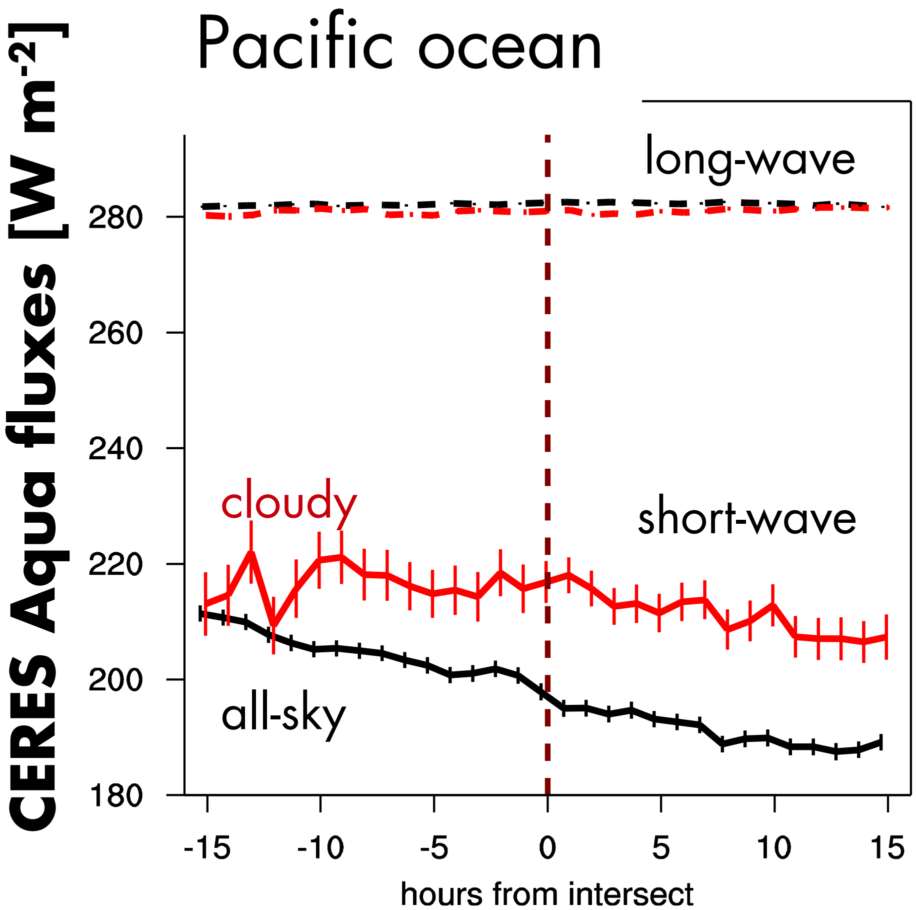




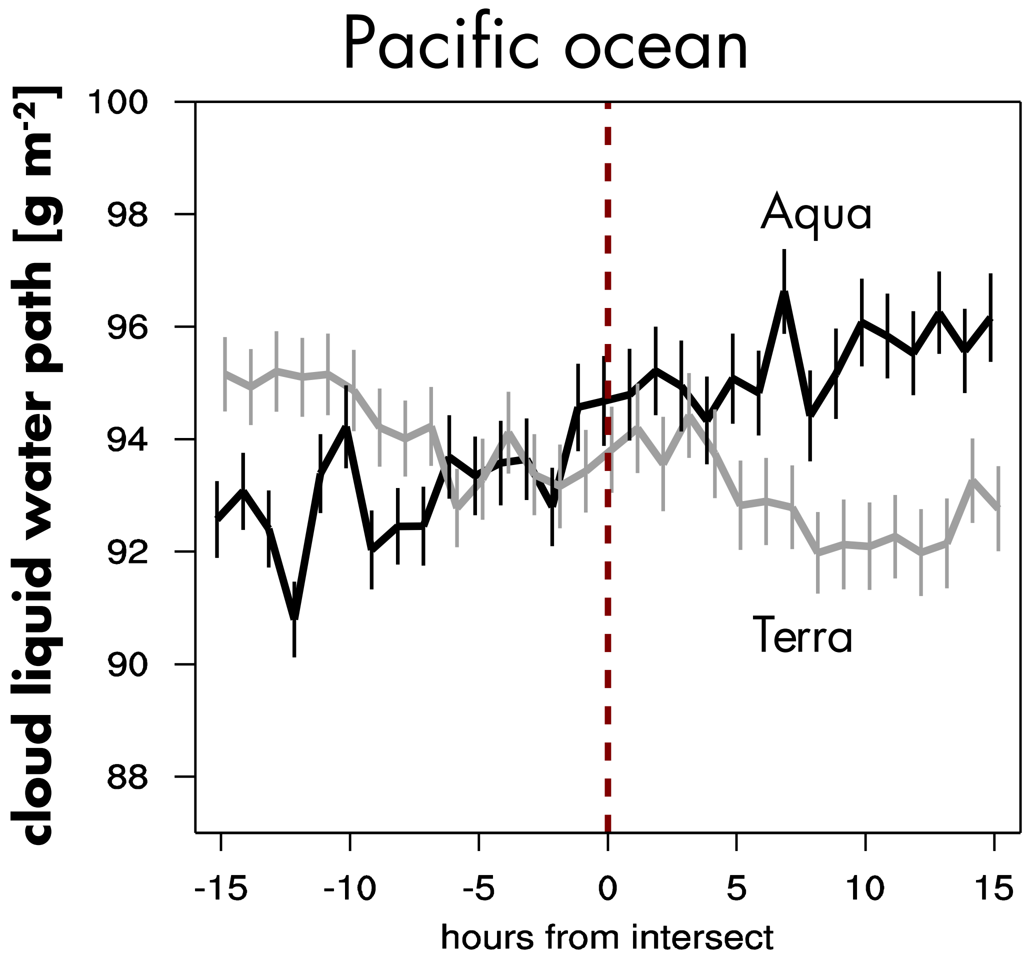
Peters, Quaas and Graßl, J. Geophys. Res. 2011

2. Ship tracks at a large scale

Radiation flux changes?



cloud liquid water path increase?



Peters, Quaas and Graßl, J. Geophys. Res. 2011

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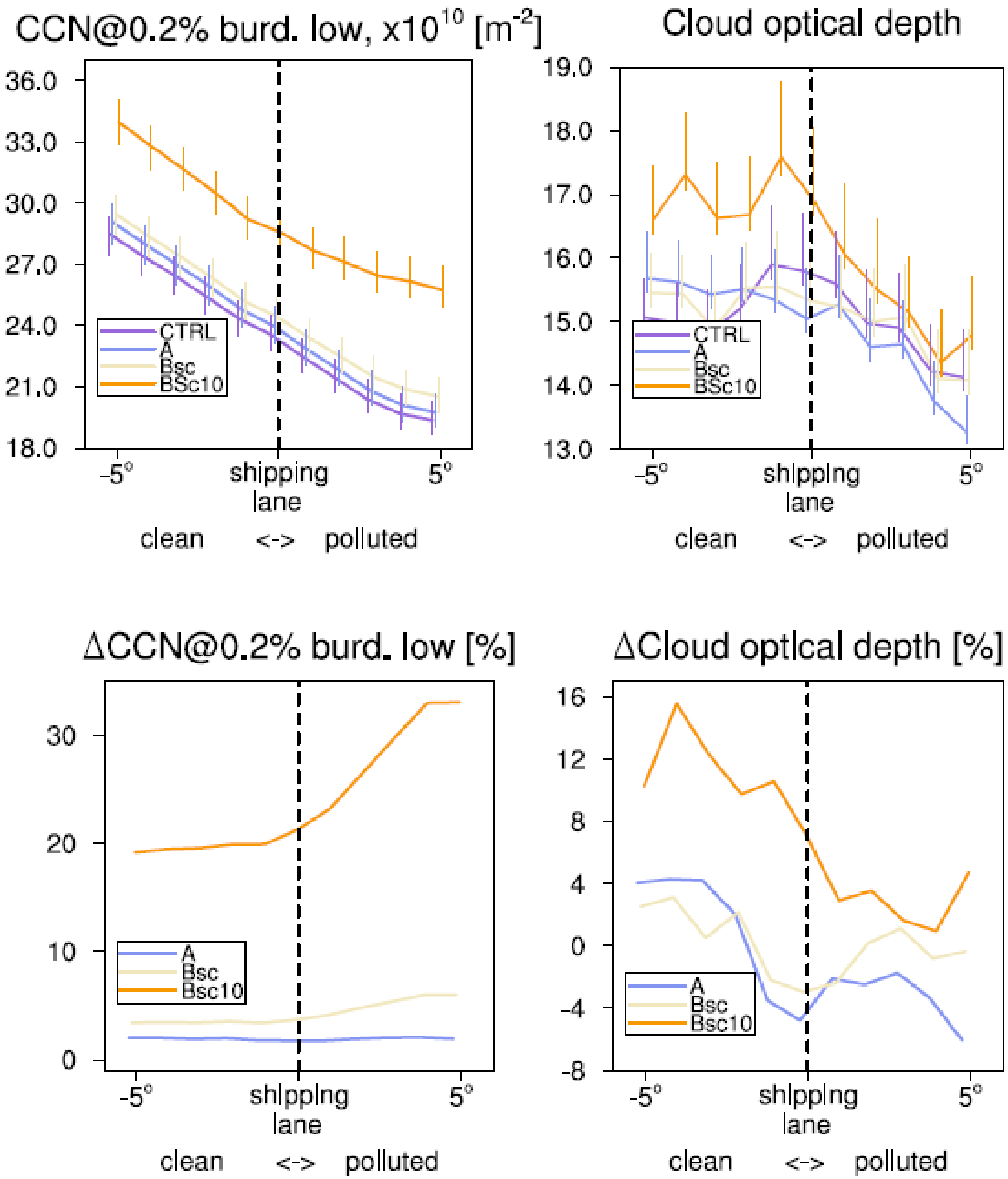
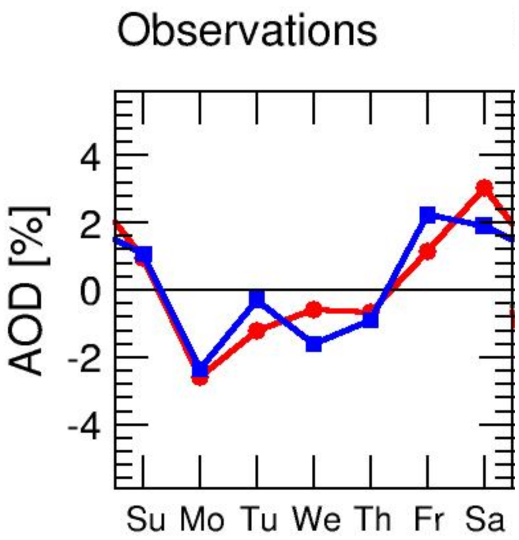


→ **Caveat:**
in model simulations no clear signal either
(despite global mean forcing up to -1.9 Wm^{-2} due to ship emissions alone)

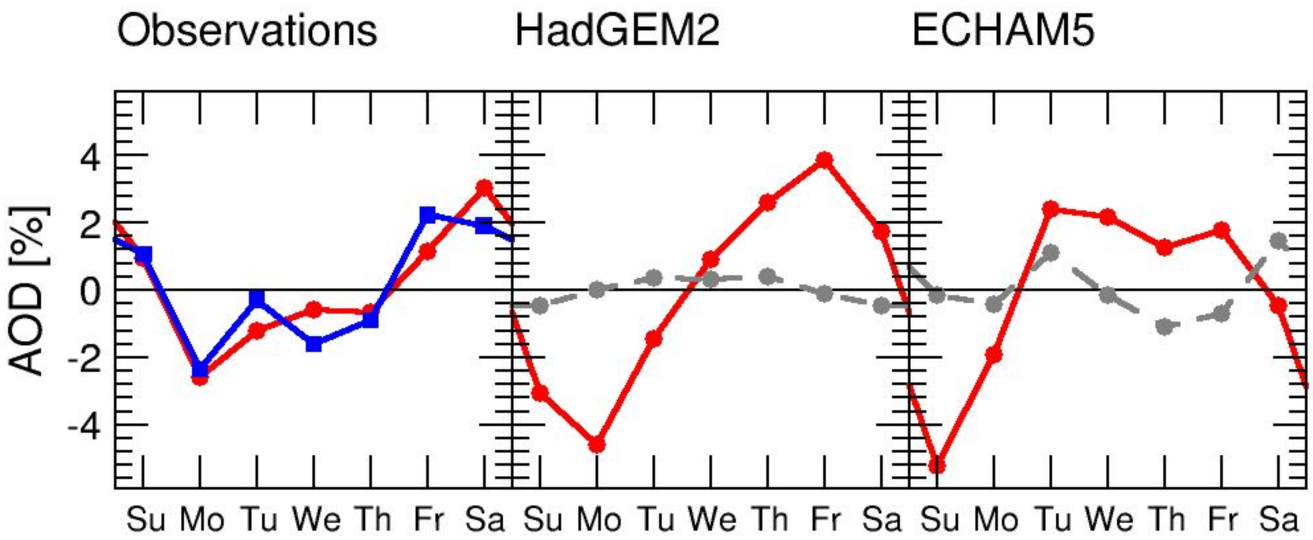
Peters, Quaas, Stier and Graßl, submited to Tellus

3. Weekly cycle



MODIS Terra
MODIS Aqua

3. Weekly cycle

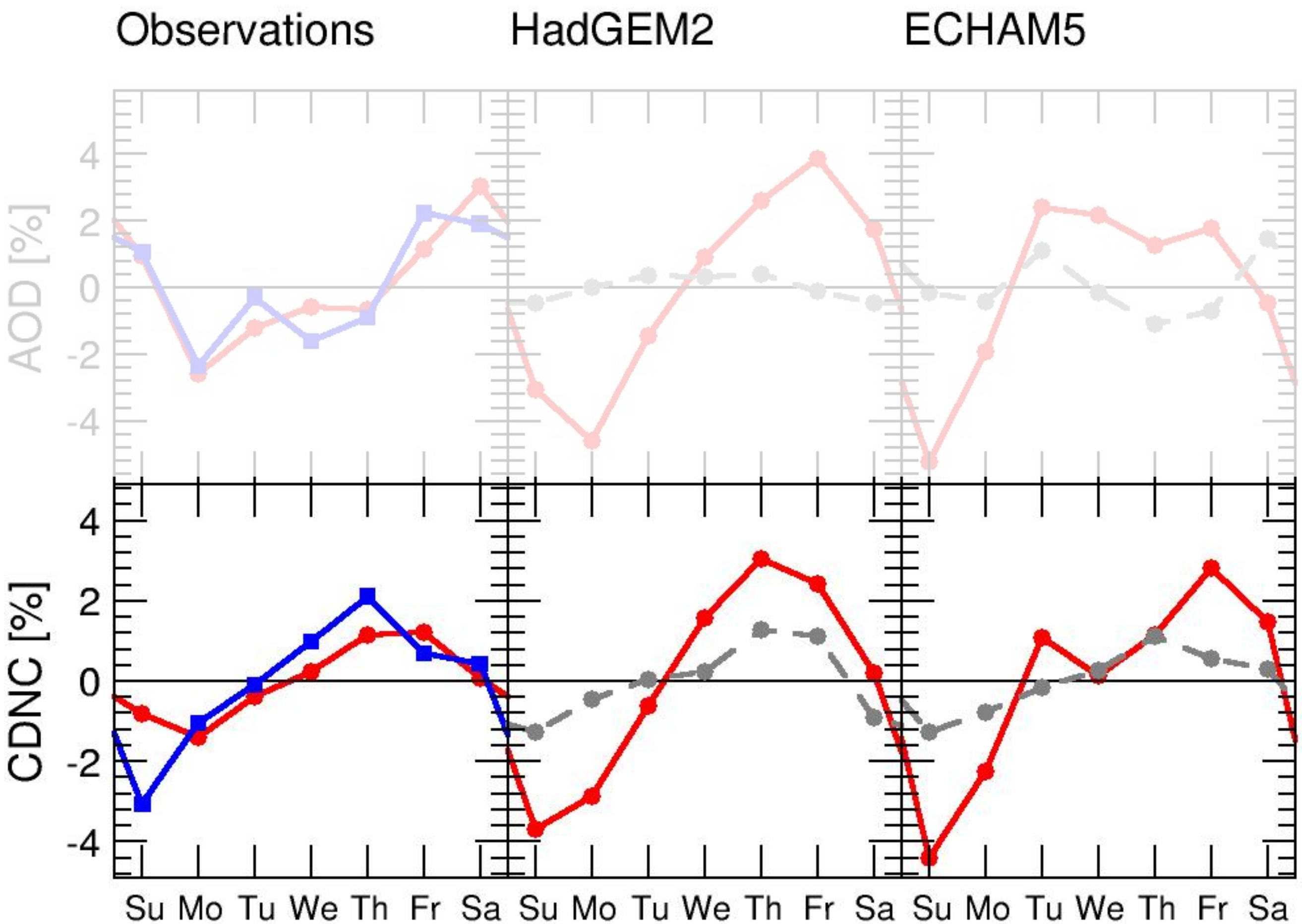


MODIS Terra
MODIS Aqua

Model experiment
Model control

Aerosol optical depth

3. Weekly cycle



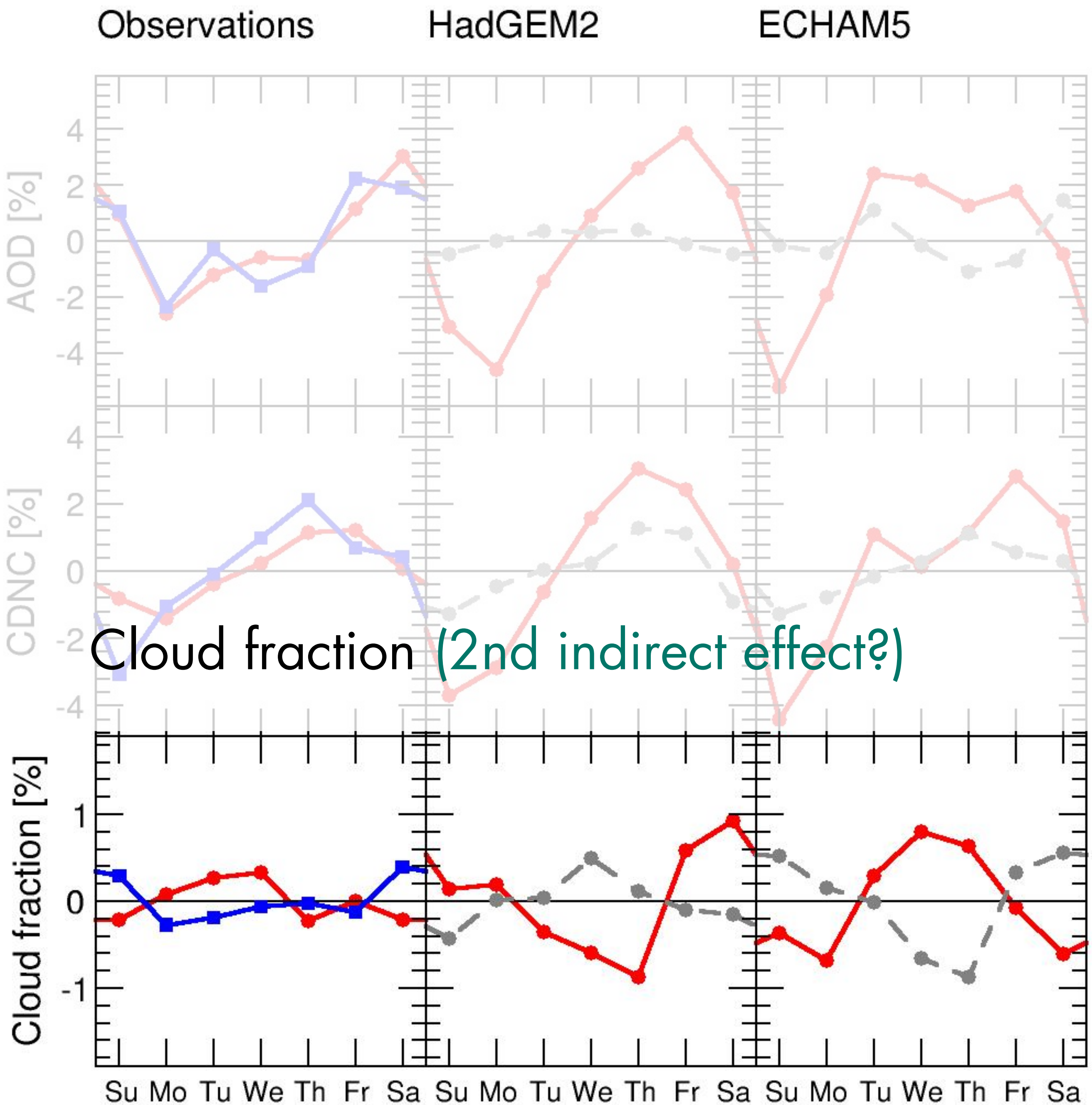
MODIS Terra
MODIS Aqua

Model experiment
Model control

Cloud droplet number concentration
(1st indirect aerosol effect)

Quaas et al., Atmos. Chem. Phys. 2009

3. Weekly cycle



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MODIS Aqua

Model experiment
Model control

Quaas et al., Atmos. Chem. Phys. 2009

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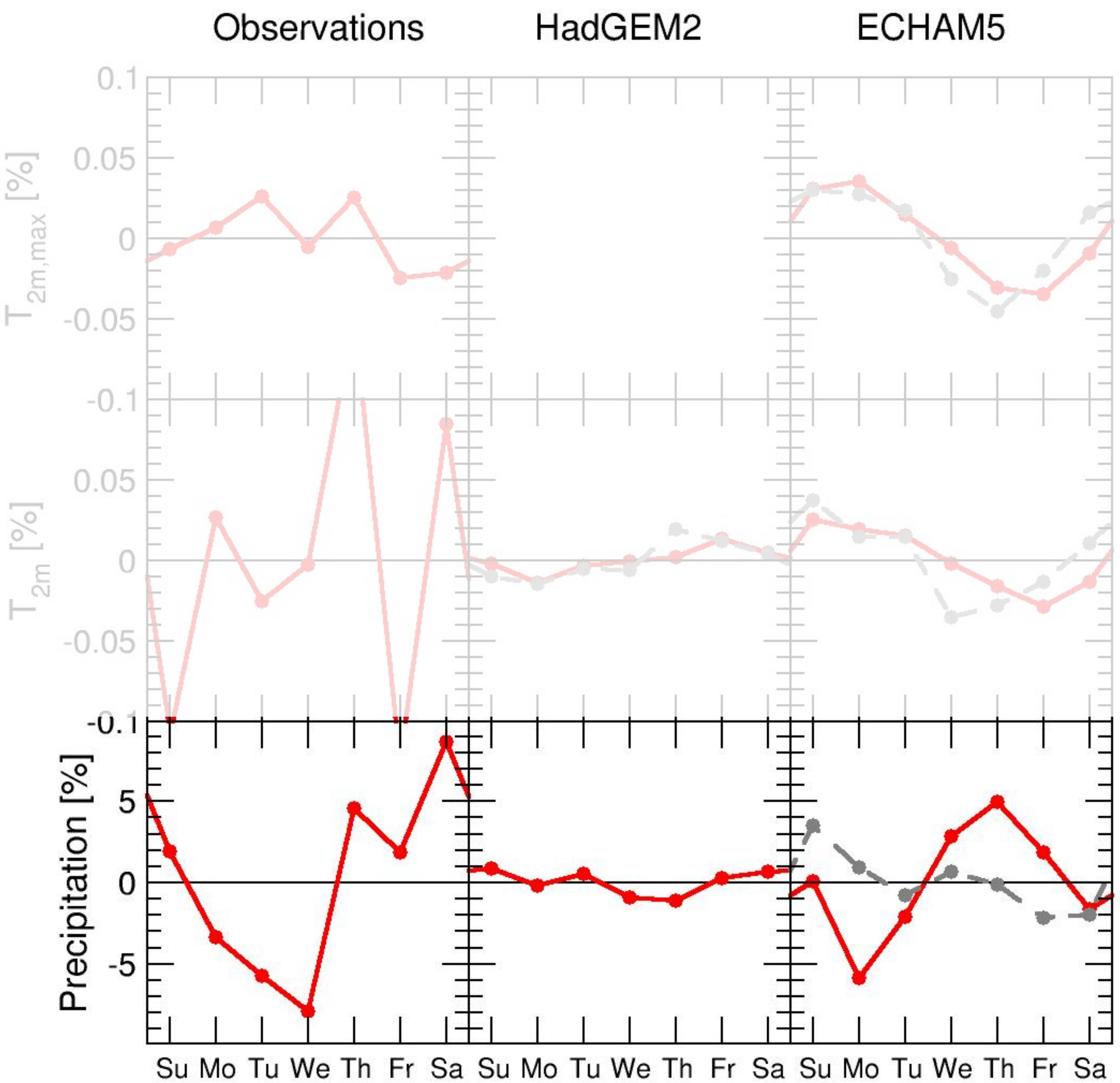


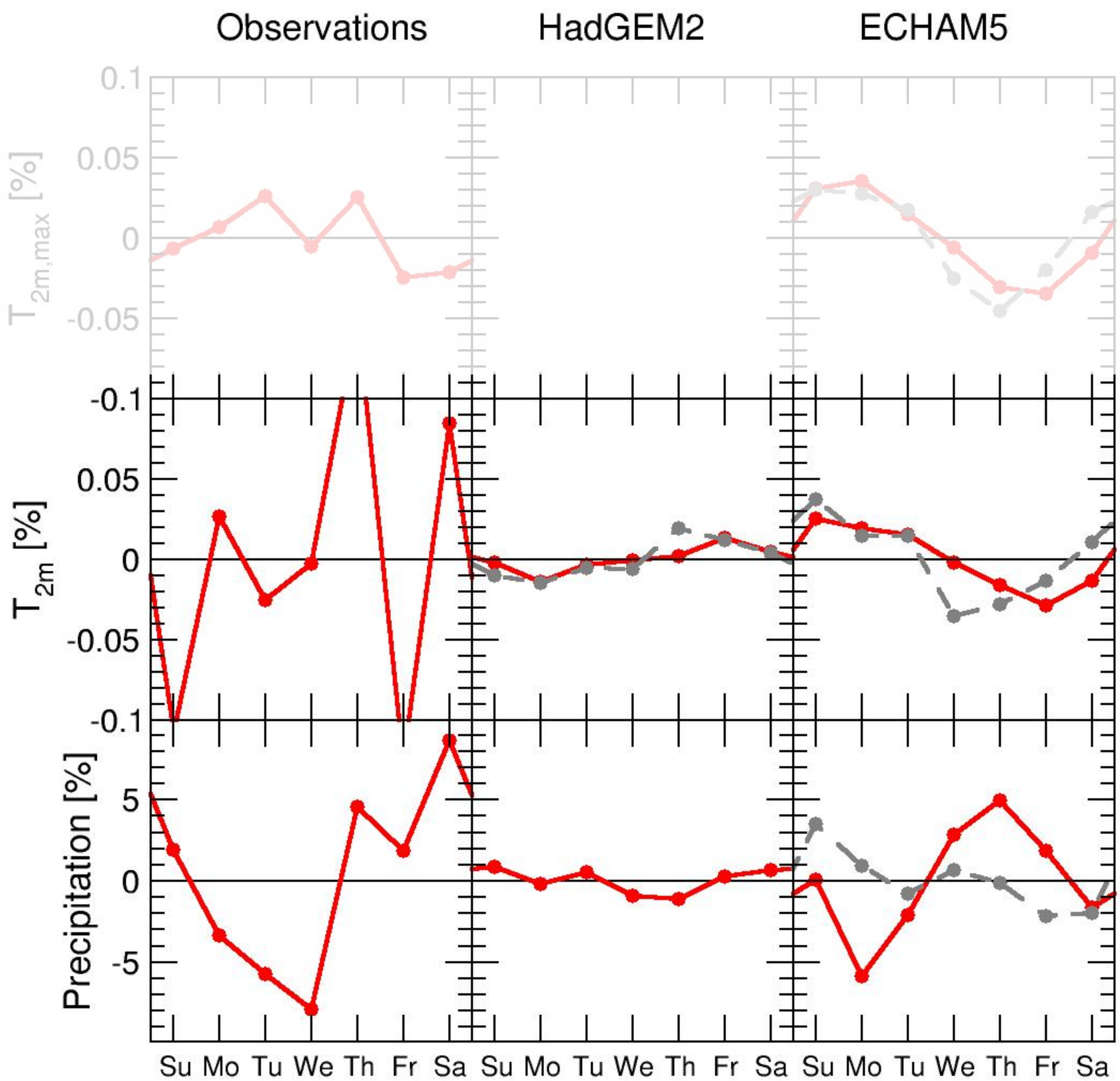
MODIS Terra
MODIS Aqua

Model experiment
Model control

Precipitation

Quaas et al., Atmos. Chem. Phys. 2009

3. Weekly cycle



MODIS Terra
MODIS Aqua

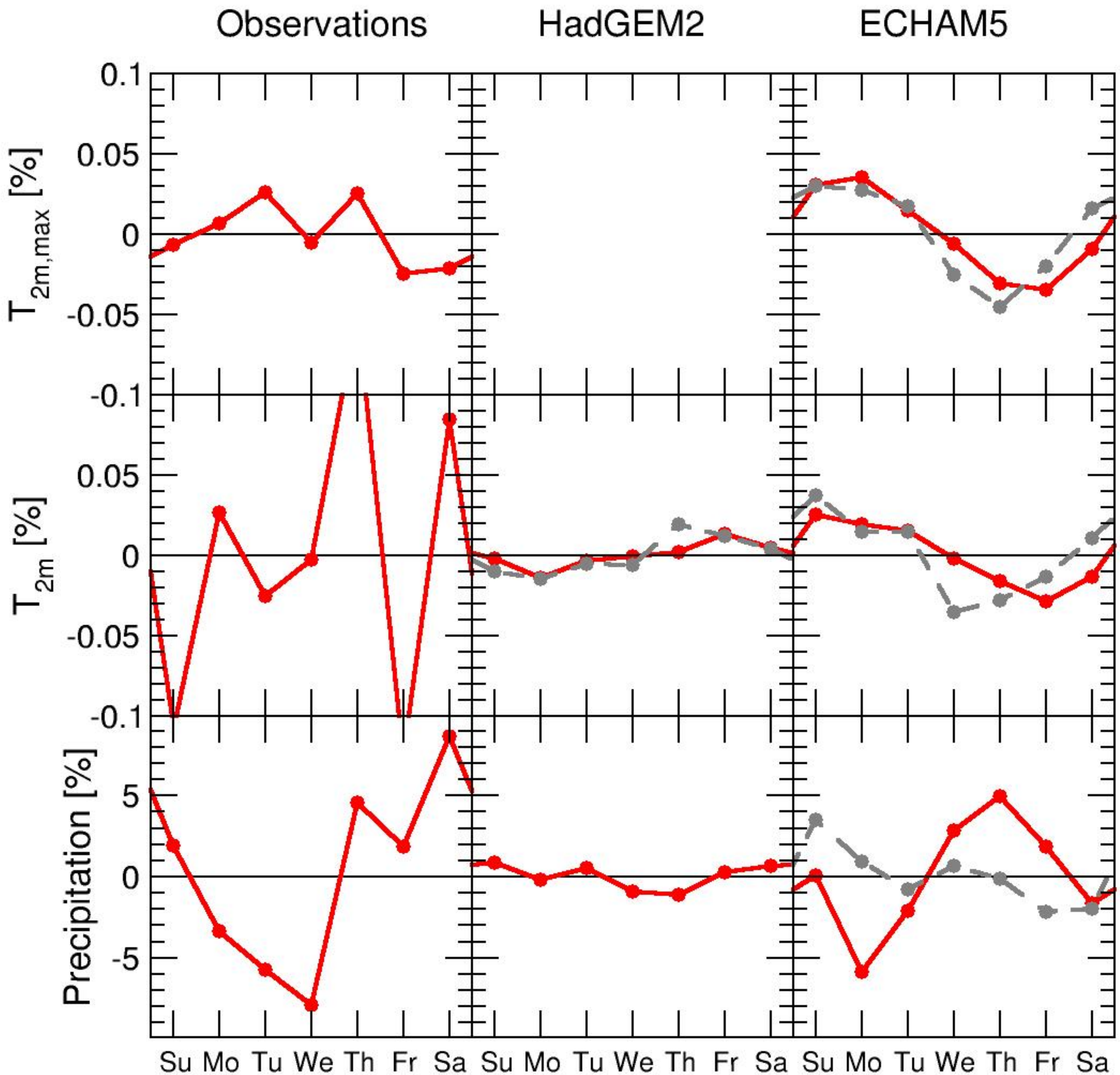
Model experiment
Model control

Temperature

Precipitation

Quaas et al., Atmos. Chem. Phys. 2009

3. Weekly cycle



MODIS Terra
MODIS Aqua

Model experiment
Model control

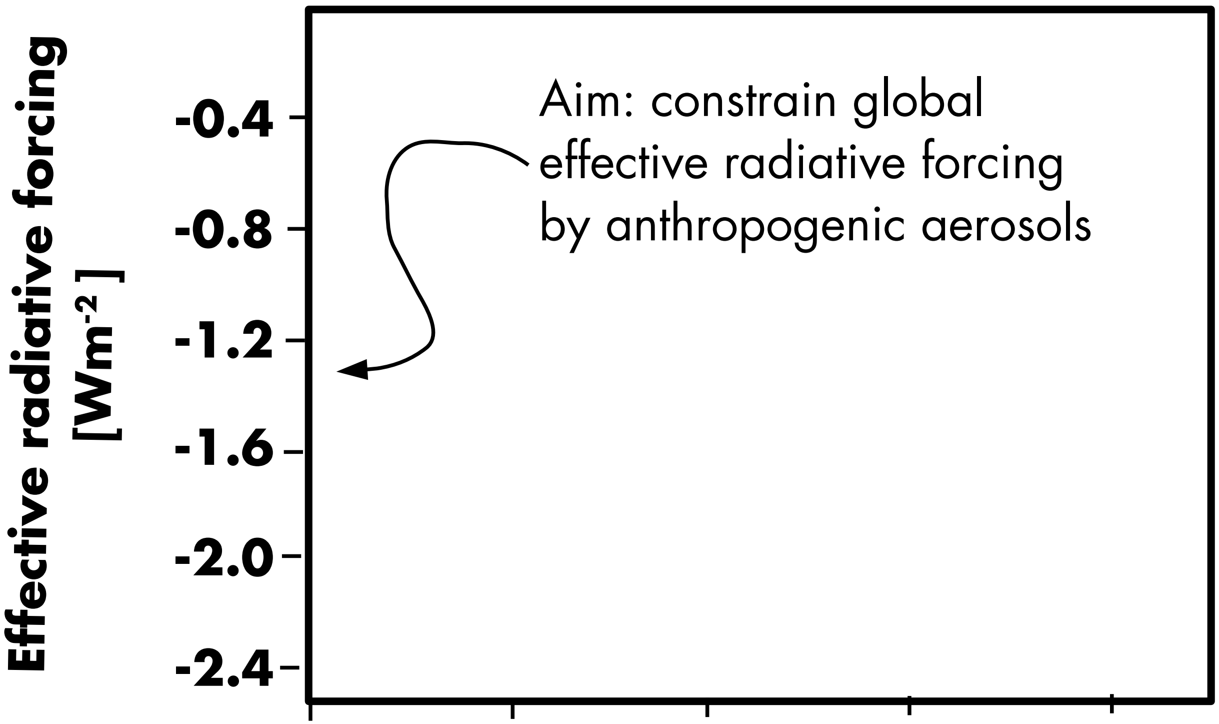
Max. Temperature

Temperature

Precipitation

Quaas et al., Atmos. Chem. Phys. 2009

4. Solar dimming and brightening



Cherian, Quaas, Salzmann and Wild, submitted to Geophys. Res. Lett.

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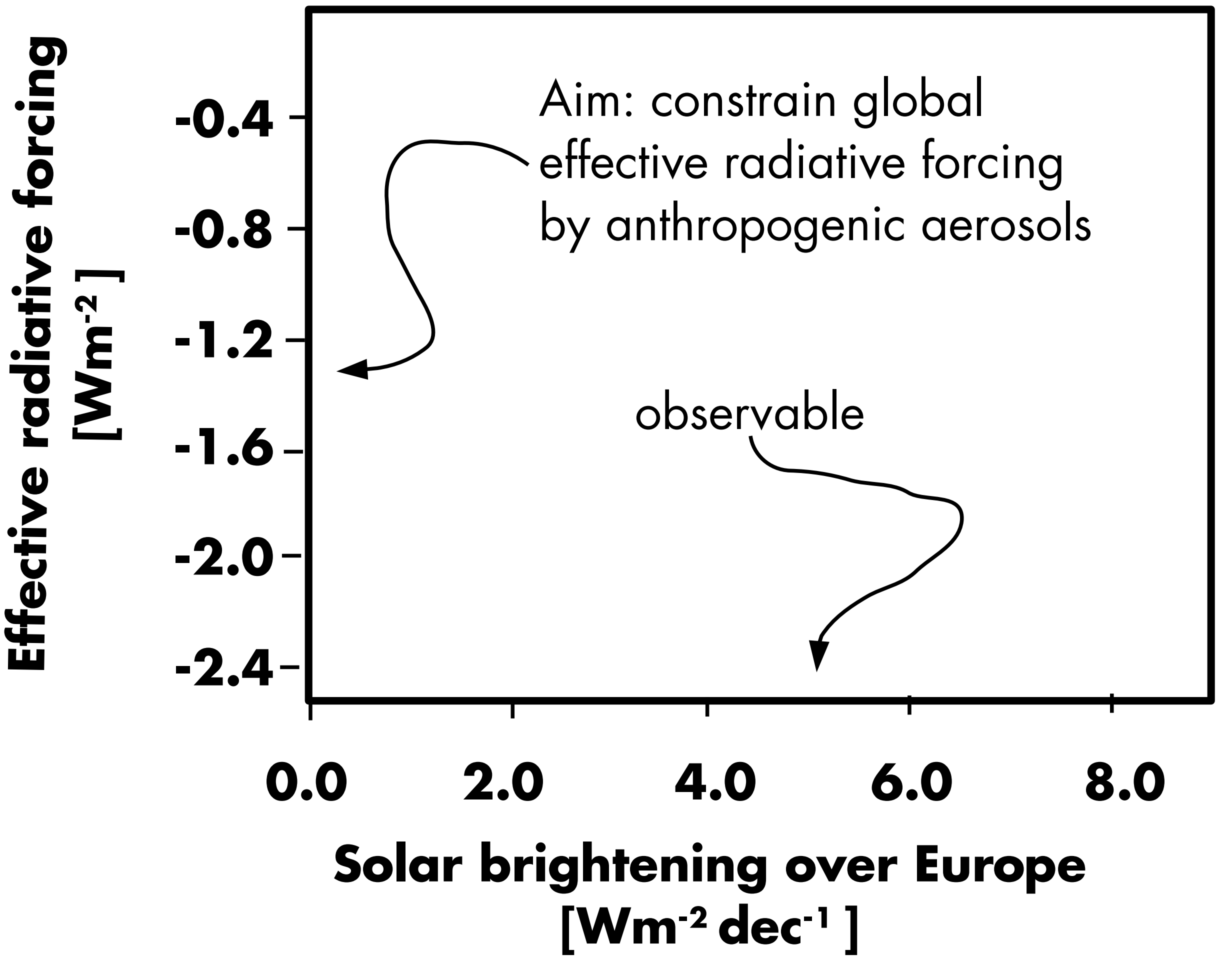


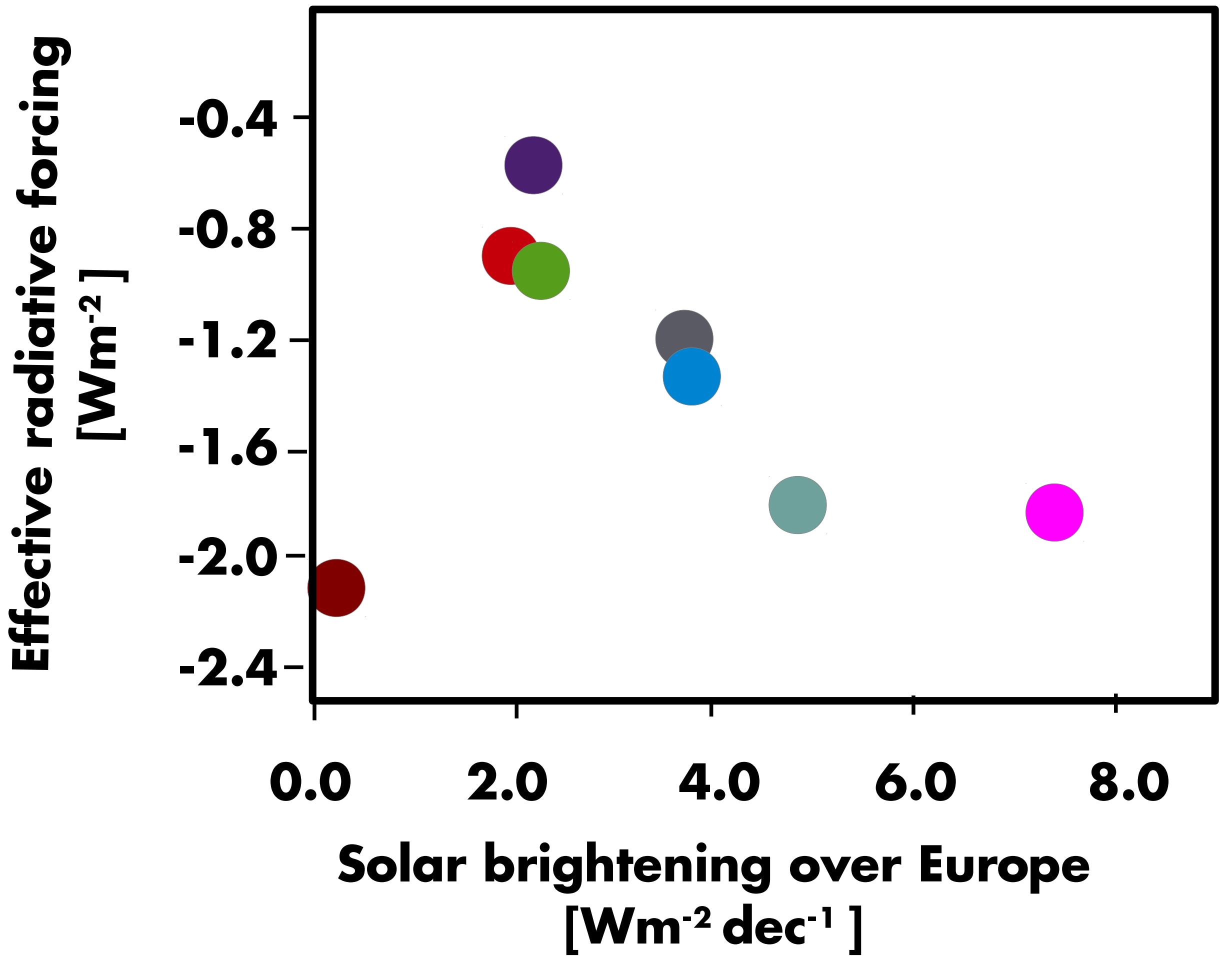
Economic transformation in Eastern Europe after 1990

Pollution control over Western Europe

→ Increase in all-sky surface solar radiation

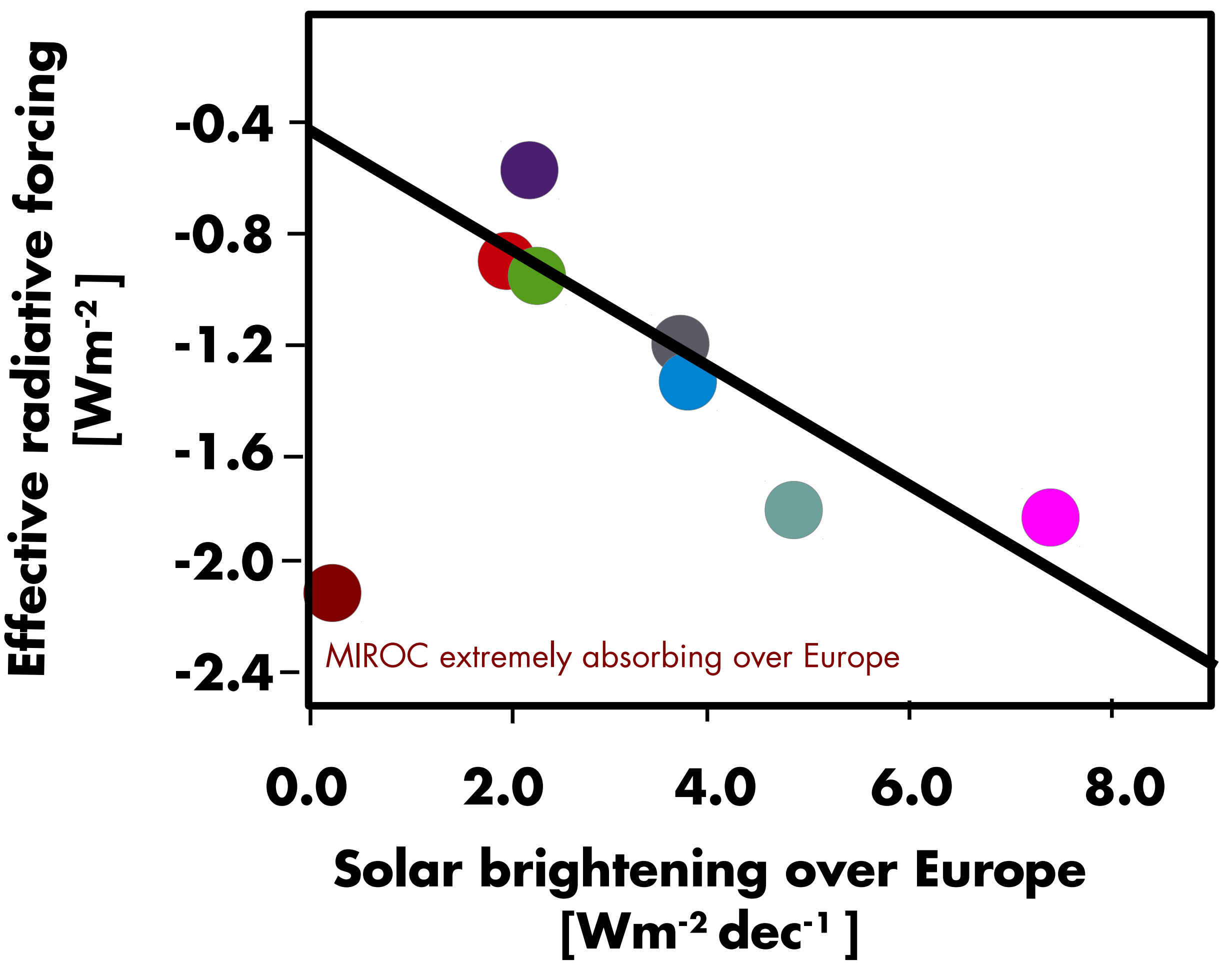
Cherian, Quaas, Salzmann and Wild, submitted to Geophys. Res. Lett.

4. Solar dimming and brightening



CMIP5
Climate model results
historical run 1990 – 2005
SSTClim and SSTClimAer
for adjusted forcing

Cherian, Quaas, Salzmann and Wild, submitted to Geophys. Res. Lett.



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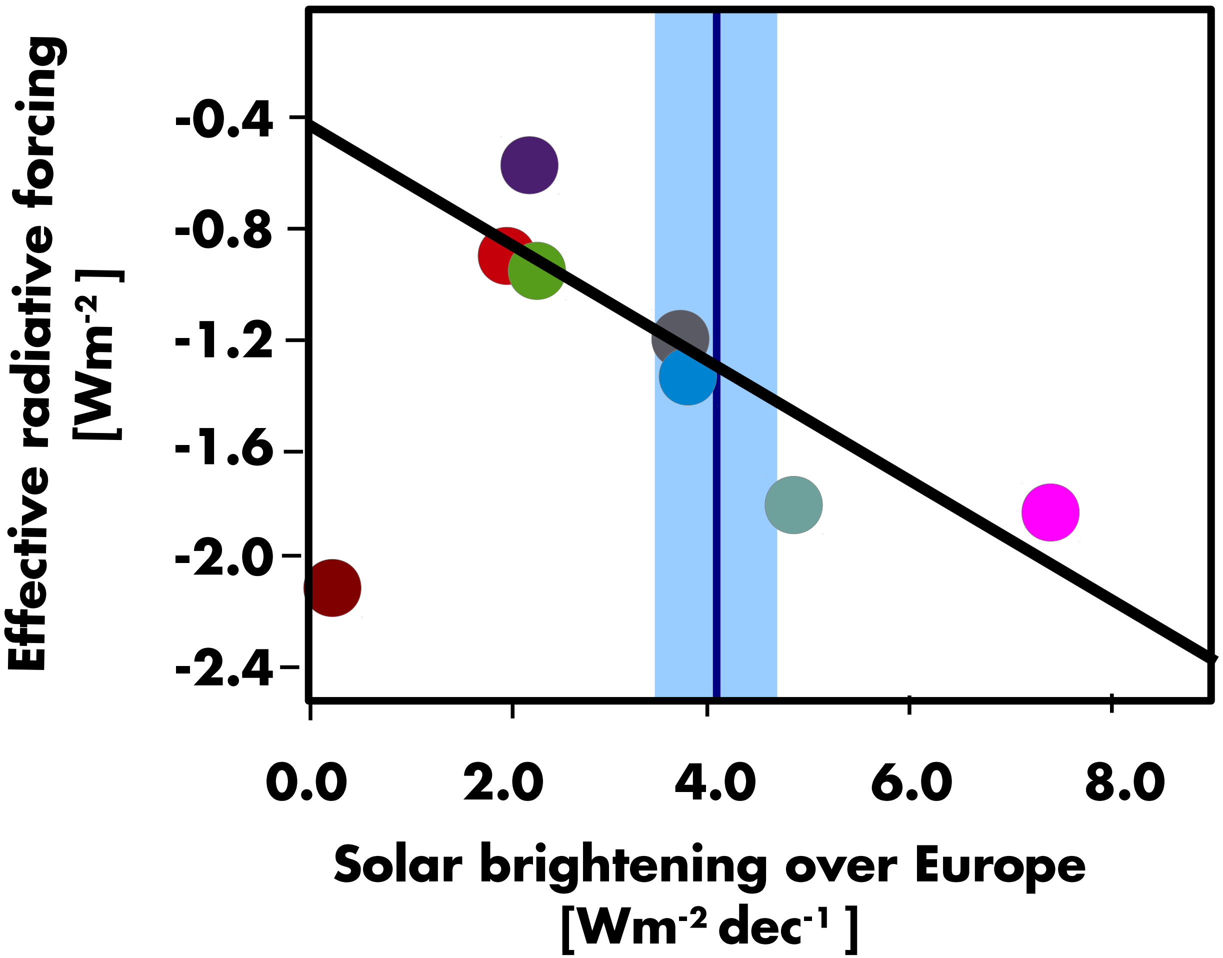

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Observations from the Global Energy Balance Archive (all-sky; range: statistical trend uncertainty)

Cherian, Quaas, Salzmann and Wild, submitted to Geophys. Res. Lett.

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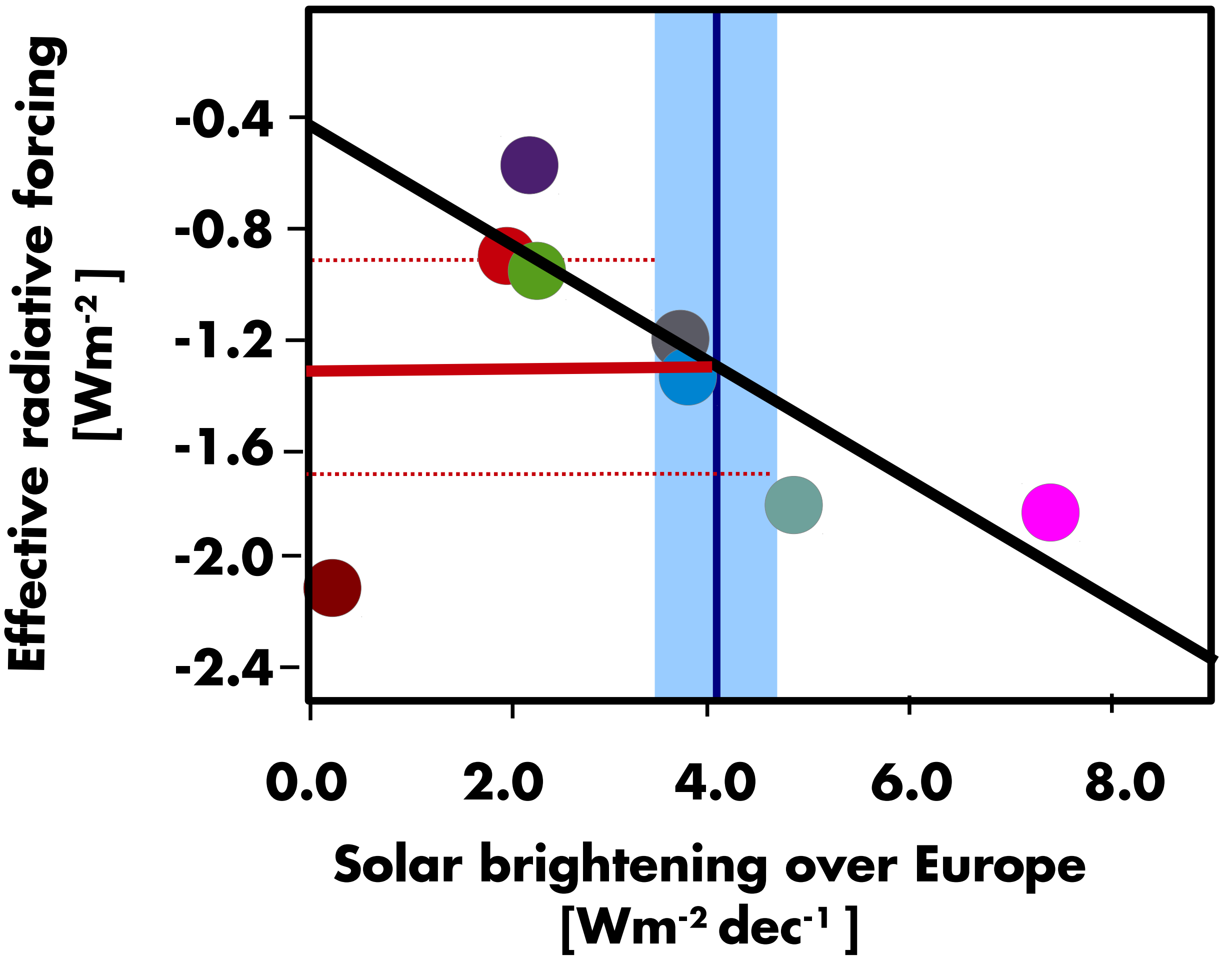

CMIP5
Climate model results
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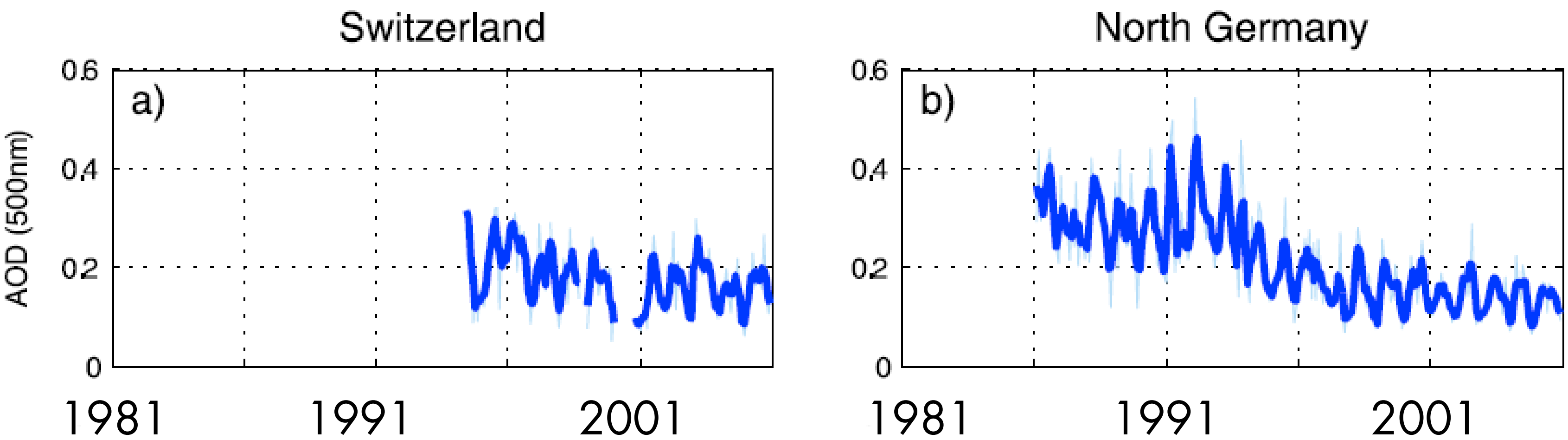
SSTClim and SSTClimAer
for adjusted forcing

Observations from the Global Energy Balance Archive (all-sky; range: statistical trend uncertainty)

Inferred **effective forcing**
-1.3 ± 0.4 Wm^{-2}
(same as AR4,
stronger than AR5)

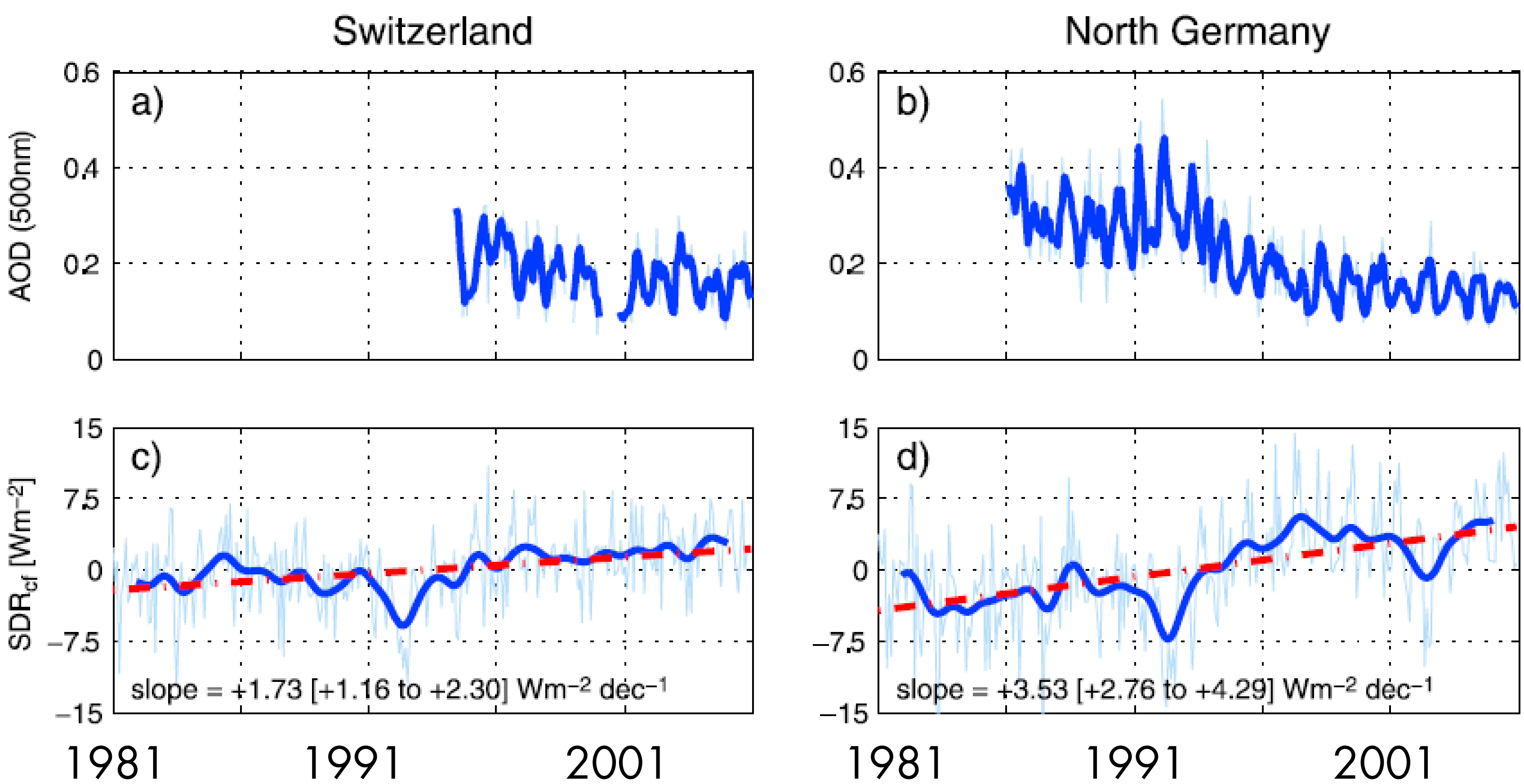
Cherian, Quaas, Salzmann and Wild, submitted to Geophys. Res. Lett.

4. Solar dimming and brightening



Aerosol optical depth

4. Solar dimming and brightening



Aerosol optical depth

Clear-sky surface solar radiation

Ruckstuhl, Norris, Philipona, J. Geophys. Res. 2010
see also Norris and Wild, J. Geophys. Res. 2007

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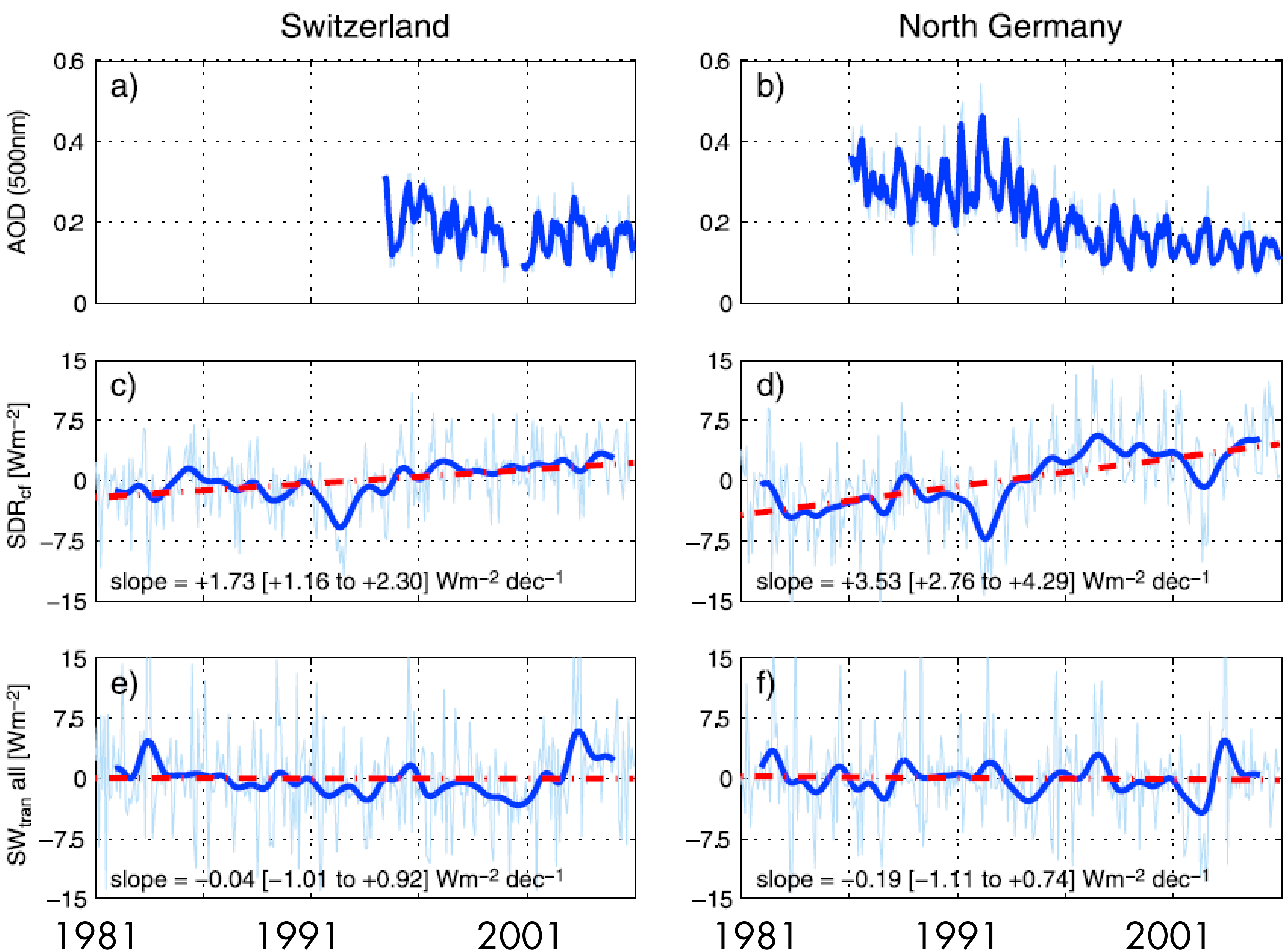

Aerosol optical depth

Clear-sky surface solar radiation

All-sky surface solar radiation

Ruckstuhl, Norris, Philipona, J. Geophys. Res. 2010
see also Norris and Wild, J. Geophys. Res. 2007

Weather modification?

Cotton, FIAS 2009

Aerosol forcing – cloud radiative effect

Global-mean cloud radiative effect (solar) ~ 50 Wm^{-2}

Global-mean aerosol indirect radiative forcing (solar) ~ -2 to 0 Wm^{-2}

→ search for maximum 4% effect

Conclusions

- **Clear observational evidence for aerosol-cloud interactions**
  → from aircraft statistics, but also from satellite
- Strong **anthropogenic** contribution to **aerosol** loading and (direct) forcing
- **Hemispheric contrast** in cloud optical depth small
  → despite strong aerosol contrast
  → despite evident effective radius contrast
- **Ship tracks** not distinguishable at large scale
  → despite clear visibility in certain cases
  → but: small signal-to-noise ratio also in simulations
- **Weekly cycle** in cloud and radiation invisible
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