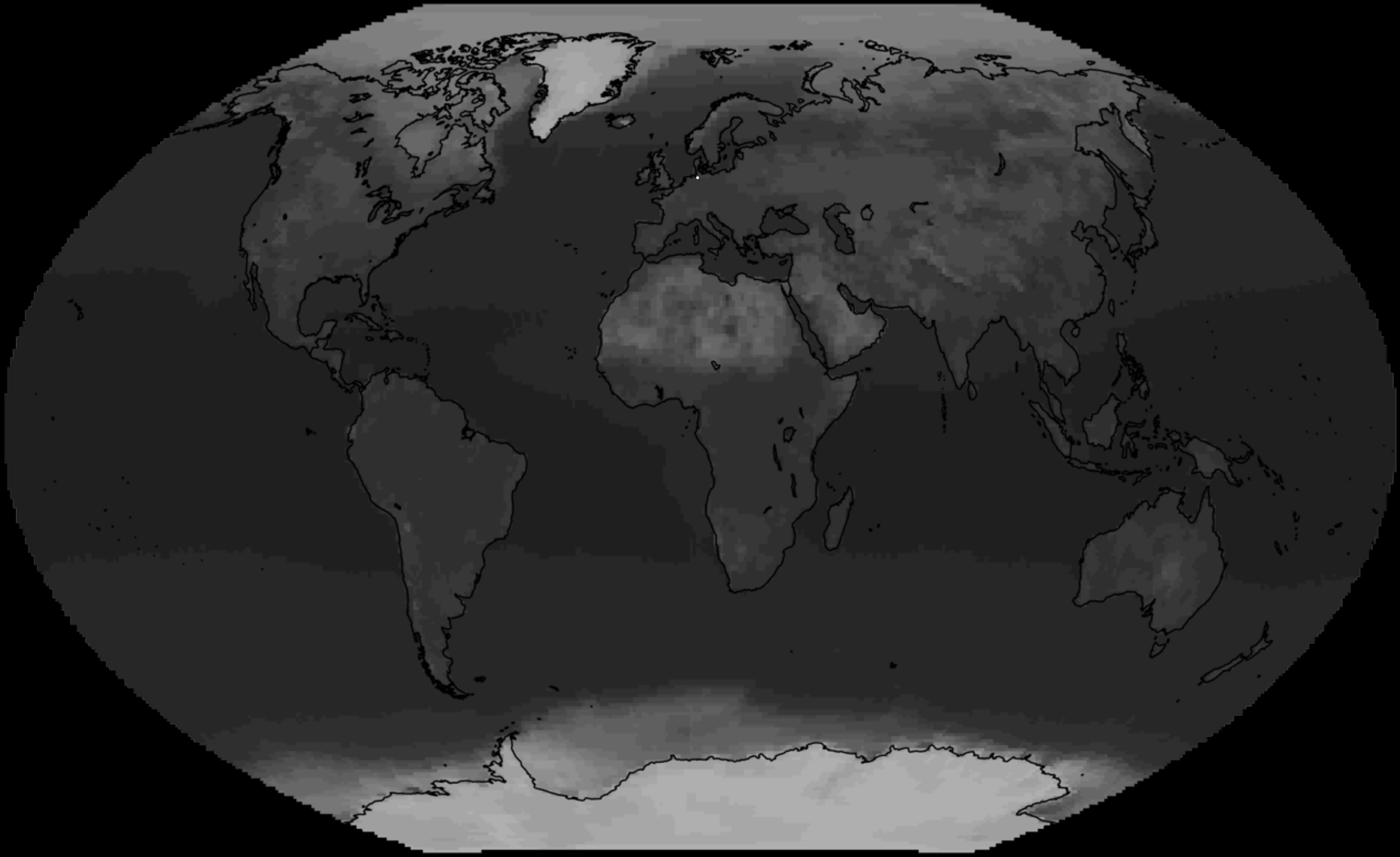


Max-Planck-Institut
für Meteorologie

Earth’s broadband albedo as measured by 13 years of CERES measurements

Lessons from a Scientific Assessment

Bjorn Stevens

MPI for Meteorology, KlimaCampus, Hamburg

Five Main Points

Semantics!
What is the question?
What has been learned?
Understanding!
Future directions?

Semantics

- Direct Aerosol Radiative **Effect**
  - *Difference between cloud-free and pristine cloud-free irradiances at the top of the atmosphere.*
- Direct Aerosol Radiative **Forcing**
  - *That component of DARE associated with the anthropogenic perturbation to the aerosol, usually called the Direct **Effect**.*
- Indirect **Effect**
  - *A radiative **forcing** by anthropogenic perturbations acting to change cloud optical properties, either directly (e.g.,Twomey) or indirectly (e.g., Lifetime) … or maybe a **feedback?**.*
- Semidirect **Effect**
  - *A radiative **forcing** by anthropogenic perturbations to the aerosol acting to change cloud optical properties by changing the thermodynamic environment in which they form.*

Non-evocative, inconsistent.

Perturbations, Adjustment and Forcing

- Compositional Changes to the Atmosphere Cause a Change in the globally averaged surface Temperature, T.

$$\Delta R = F - \lambda \Delta T$$

- A more meaningful definition of F arises by assuming it to be proportional to the initial perturbation to the irradiances at the top of the atmosphere ($\Delta R(t_0)$) and an adjustment, F_{app} which acts relatively quickly but is independent of the surface temperature change.

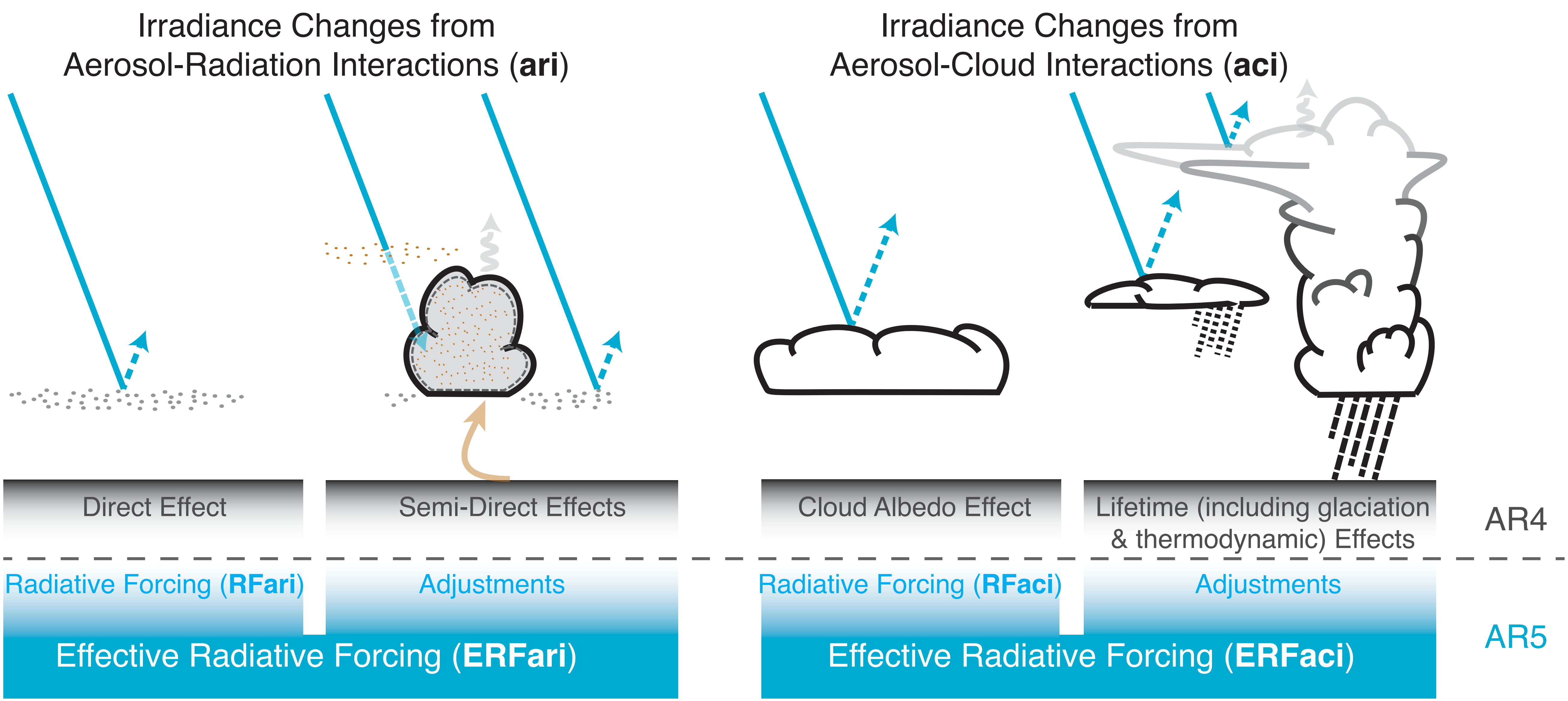
$$\Delta R = F + F_{app} - \lambda \Delta T$$

- In the AR5, $\Delta R(t_0)$ is called the radiative forcing, and F the '***Effective Radiative Forcing***' as it accounts for adjustments.

- Examples of adjustments are the temperature adjustment (reduction) in the stratosphere which accompanies an increase in CO2, or a reduction in stratiform cloudiness in an atmosphere with more CO2 through a reduction of cloud-top cooling. But also what the community used to call aerosol indirect effects.

The concept of adjustment helps clean up a confusing terminology

Fazit: Aerosol Radiation & Aerosol Cloud Interactions



What is the Question?

A long long time ago …

"An increase by a factor of 4 in the equilibrium dust concentration … could decrease the mean surface temperature by as much as 3.5 K …such a temperature decrease could be sufficient to trigger an ice age!"[1]

[1]Rasool & Schneider, *Science*, ***173*** (1971)

A long time ago ...

"Reasonable values of the parameters in Eqs. 1 to 5 (Table 1) which take into account the geographic distribution of cloud cover and surface albedo, place the global mean direct ***radiative forcing due to sulfate aerosol at -1 Wm^{-2}*** ... the resultant forcing is exerted predominantly in the NH, with a magnitude roughly twice the global-average value. … NH perturbation in ***cloud radiative forcing due to anthropogenic sulfates is approximately -2 $W\,m^{-2}$***."

And by the way … they don't include Biomass Burning (-0.6 Wm^{-2}); Nitrates (-0.3 Wm^{-2}); Dust (-0.1 Wm^{-2}) and cloud "lifetime" effects.

Magnitude of NH aerosol forcing > 5 Wm^{-2} about half of which is due to clouds.

Charlson et al., *Science*, ***195*** (1992)

Not that long ago …

"Probability density functions obtained for the direct radiative forcing at the top of the atmosphere ***give a clear-sky, global, annual average of -1.9 Wm^{-2} with standard deviation, ± 0.3 Wm^{-2}***. These results suggest that present-day direct radiative forcing is stronger than present model estimates, implying future atmospheric warming greater than is presently predicted, as aerosol emissions continue to decline. … Using the MODIS cloud fraction, the all-sky DRF is -0.8 ± 0.1 W m^{-2} at the top of the atmosphere …"

… yes, this is a moving target … DR, in all his enthusiasm, is good for an example a year of why the aerosol might be important for cloud, and now SOA and brown and black carbon are increasingly being drawn into focus.

Bellouin et al., *Nature*, ***438*** (2005)

Fazit

- *Aerosol radiative forcing is large*
- *It likely exceeds the greenhouse gas forcing in the Northern Hemisphere*
- *It raises the possibility that the climate system is unusually sensitive to CO_2 as the modest rise in global temperatures reflects the masking effect of the aerosol*

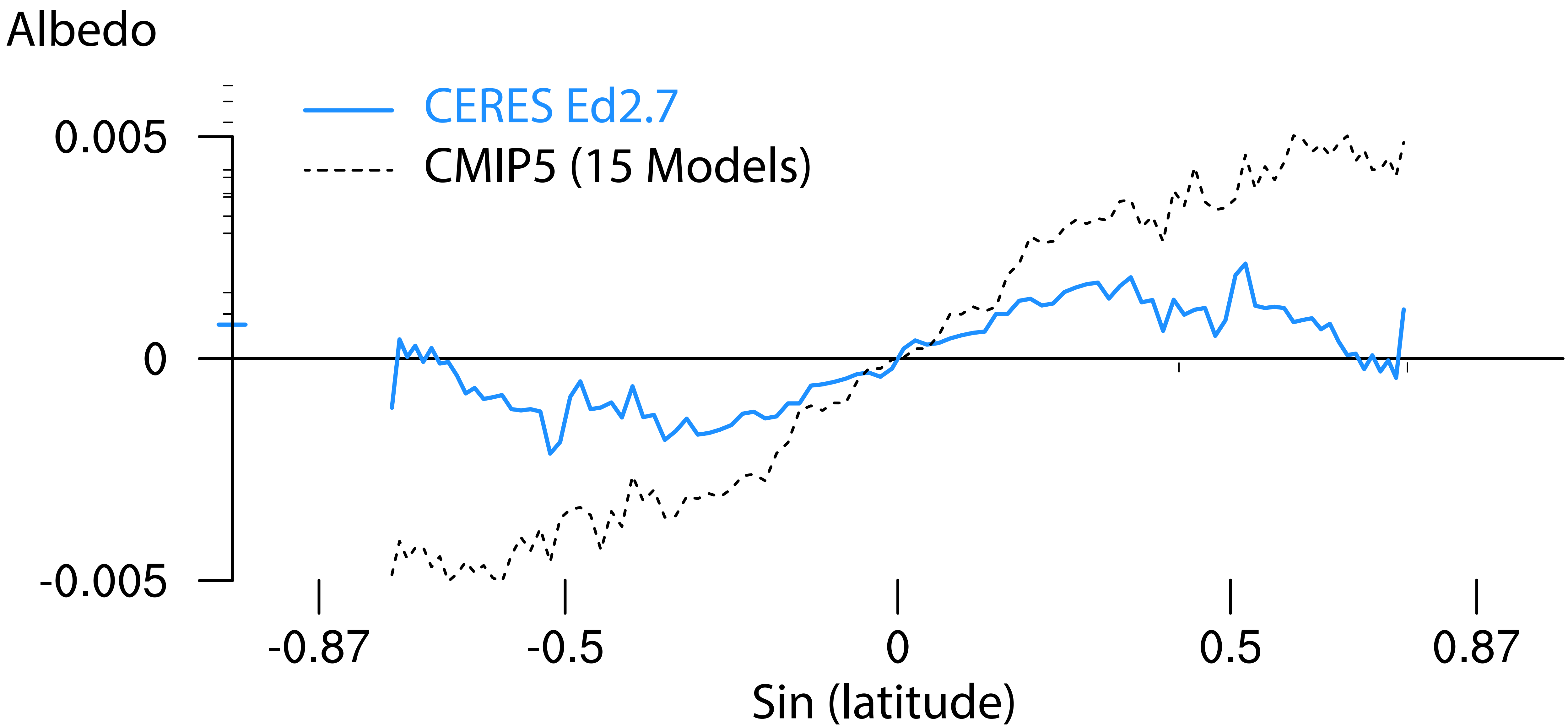
There is reason to be worried …

What have we learned?

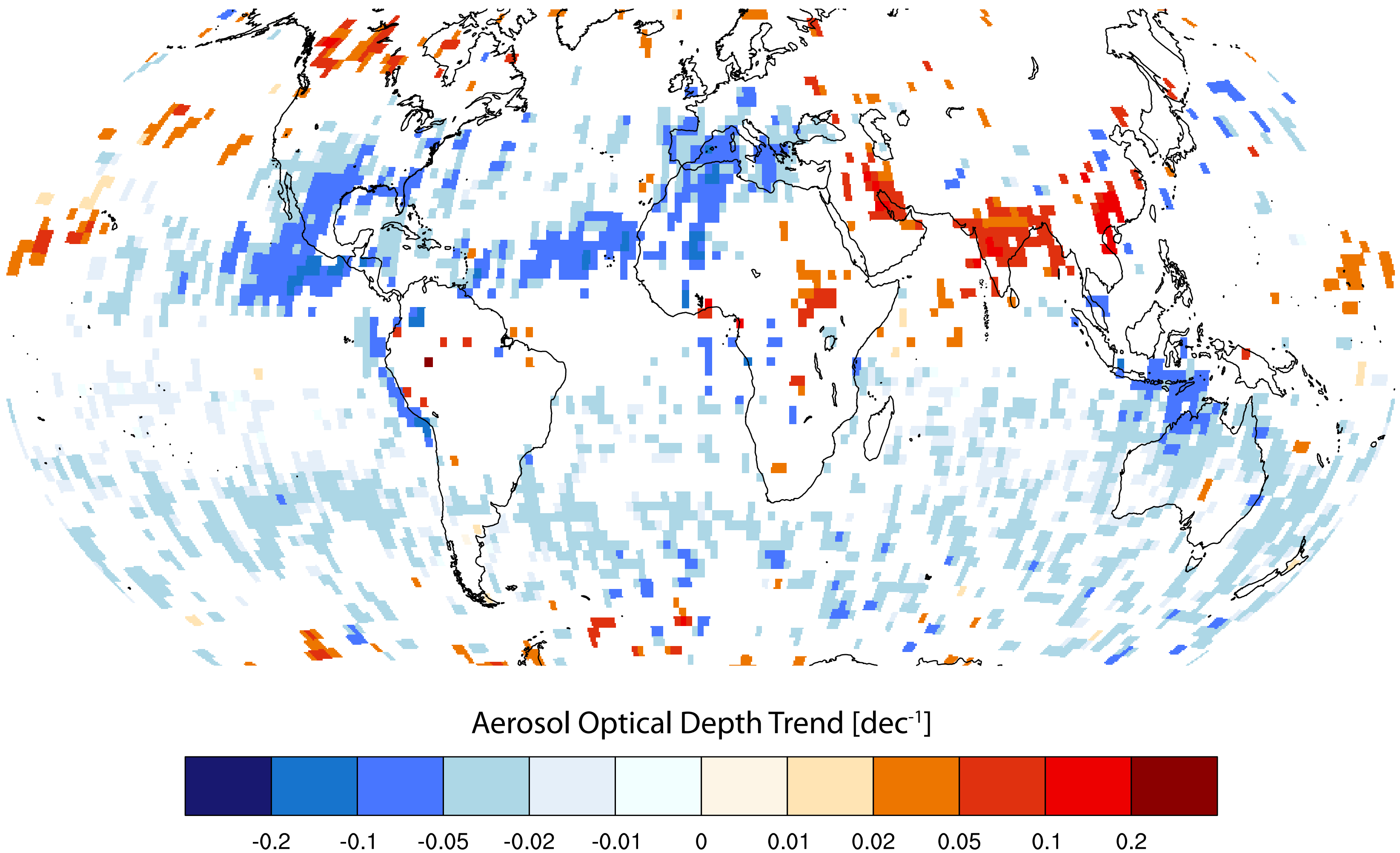
A starting point

- *The pathway from emissions to concentrations becomes increasingly inefficent as concentrations increase (e.g., Schmidt et al., 2012).*
- *The pathway from concentrations to forcing becomes increasingly in-efficient as concentrations increase (Hoose et al., 2009).*
- *Early studies insufficiently considered compensating effects such as absorption, or changes in the longwave budget, or processes that reduce aerosol lifetime (Harris et al., 2013) or cause clouds to respond differently than expected (Stevens and Feingold, 2009).*

Hemispheric asymmetry in clearsky albedo over the oceans



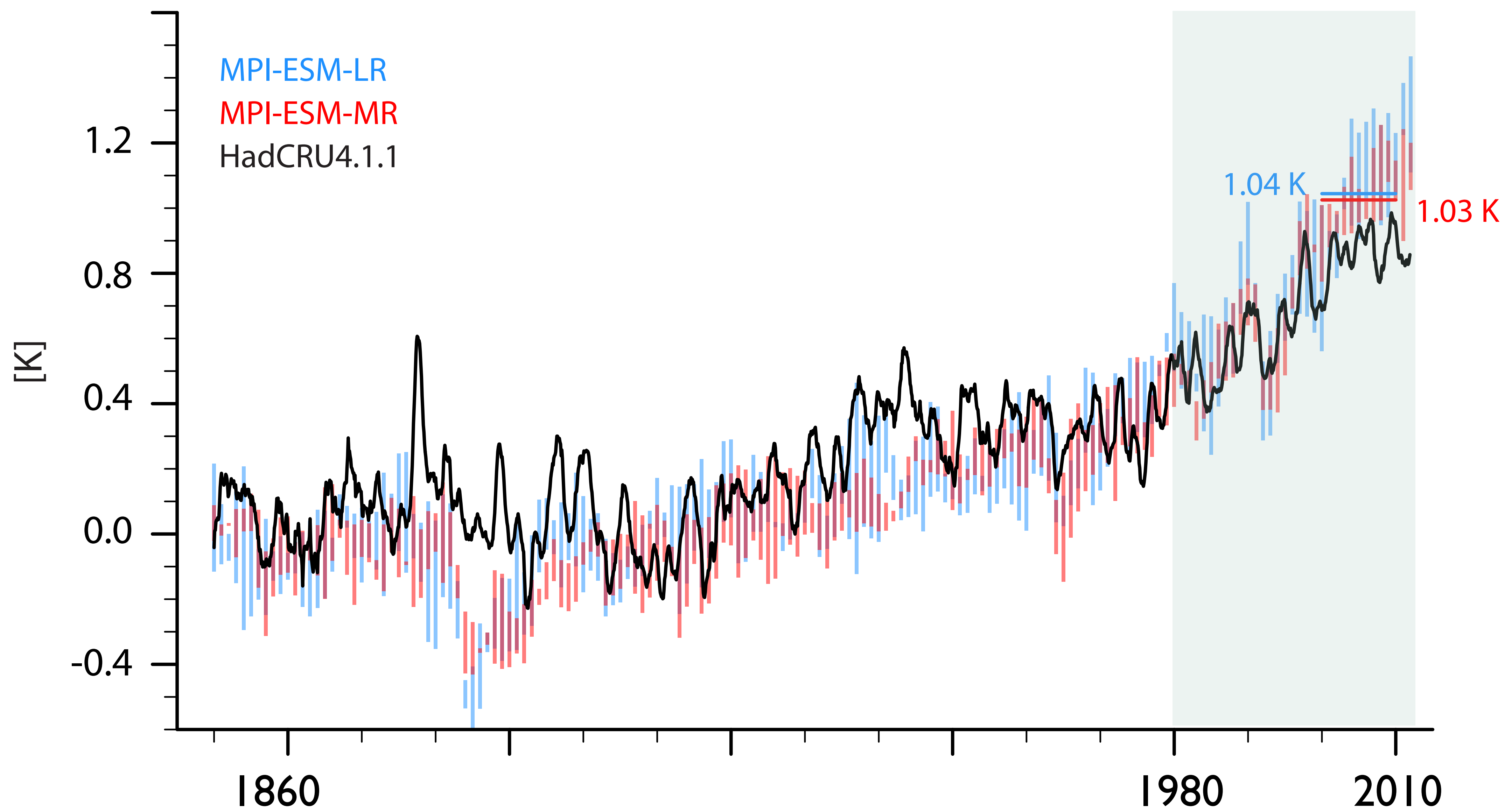
δ_{AOD} over the last decade (from MISR)



- AVHRR data show a negative or no trend since 1983 (Mishchenko et al., 2012).
- A data assimilation approach (Zhang and Reid, 2010) show no aerosol trend in the present century.
- The MAC (Kinne et al., 2013) show that AOD has increased less than 20% over the past 30 years.

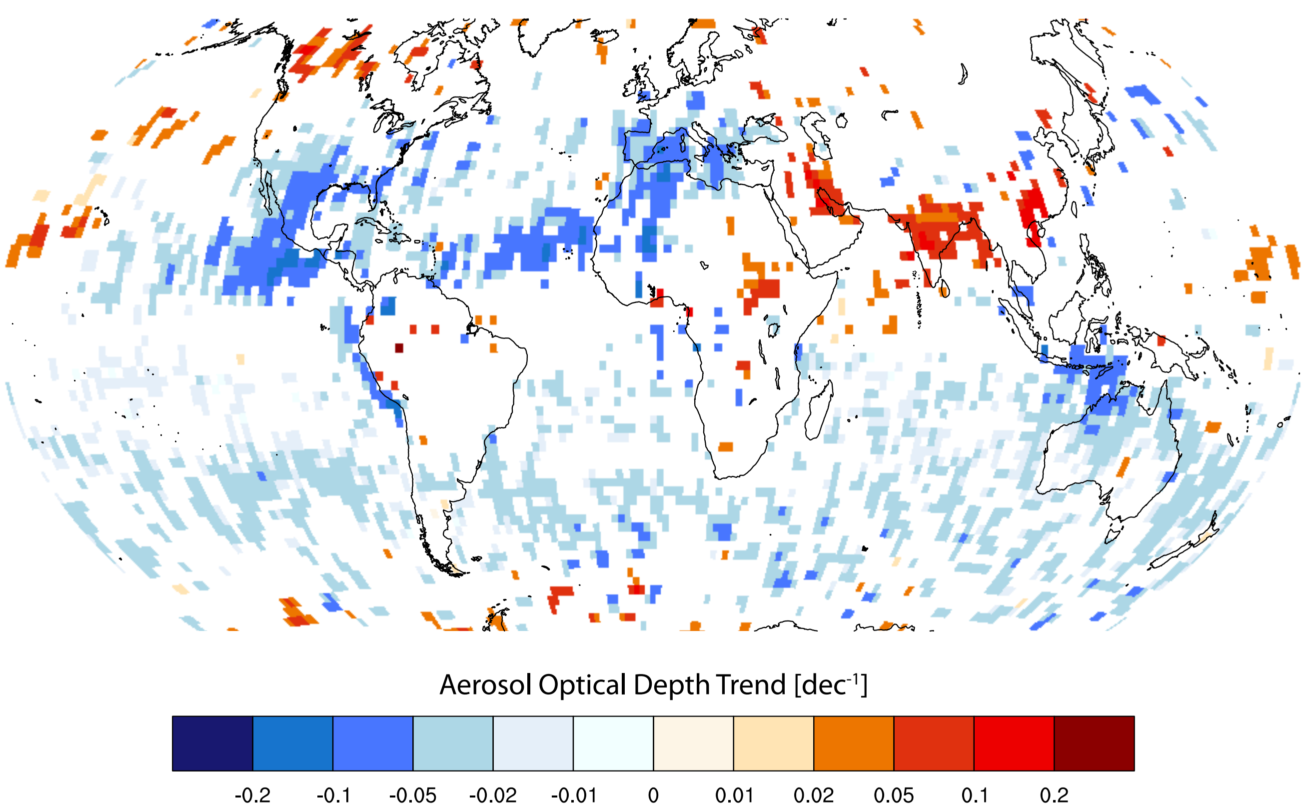
Stevens & Schwartz, *Surveys in Geophys*, (2012)

Reconciling the temporal record

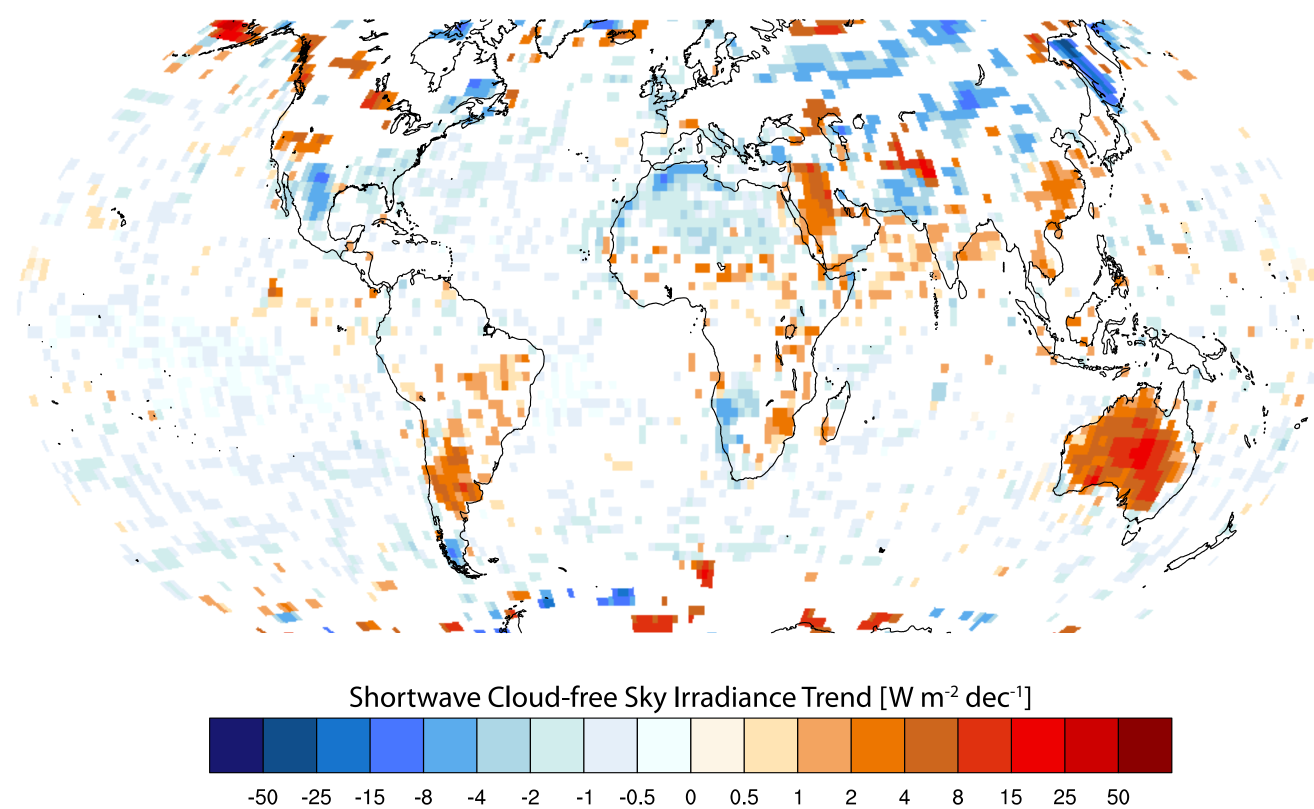


Changes in reflected clear sky radiation

Optical Depth Trend

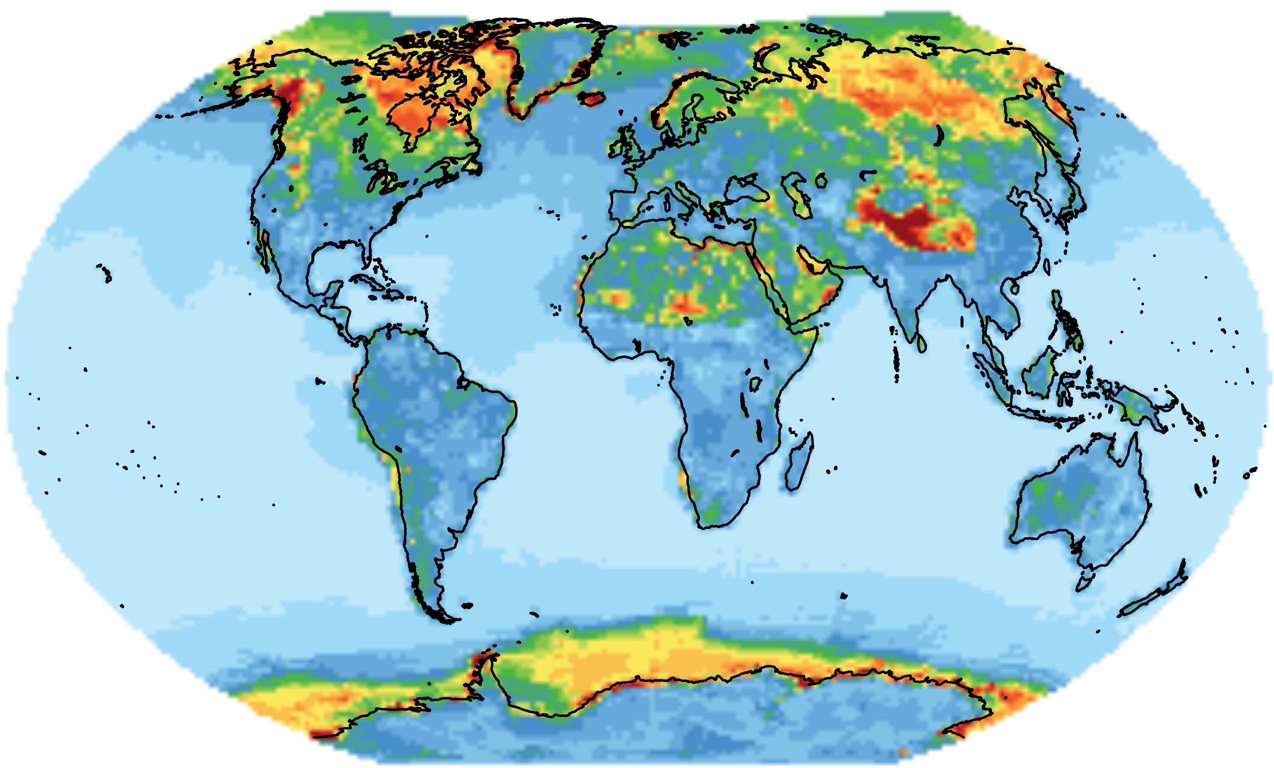


CERES Clearsky trend

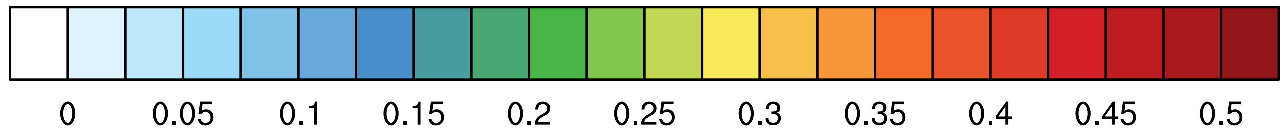


- Only in a few places (western Canada, Middle East, southeast Asia) do regional trends in the CERES clear sky record correspond with the AOD changes
- Largest changes in CERES clear sky are correlated with observed changes in soil moisture.

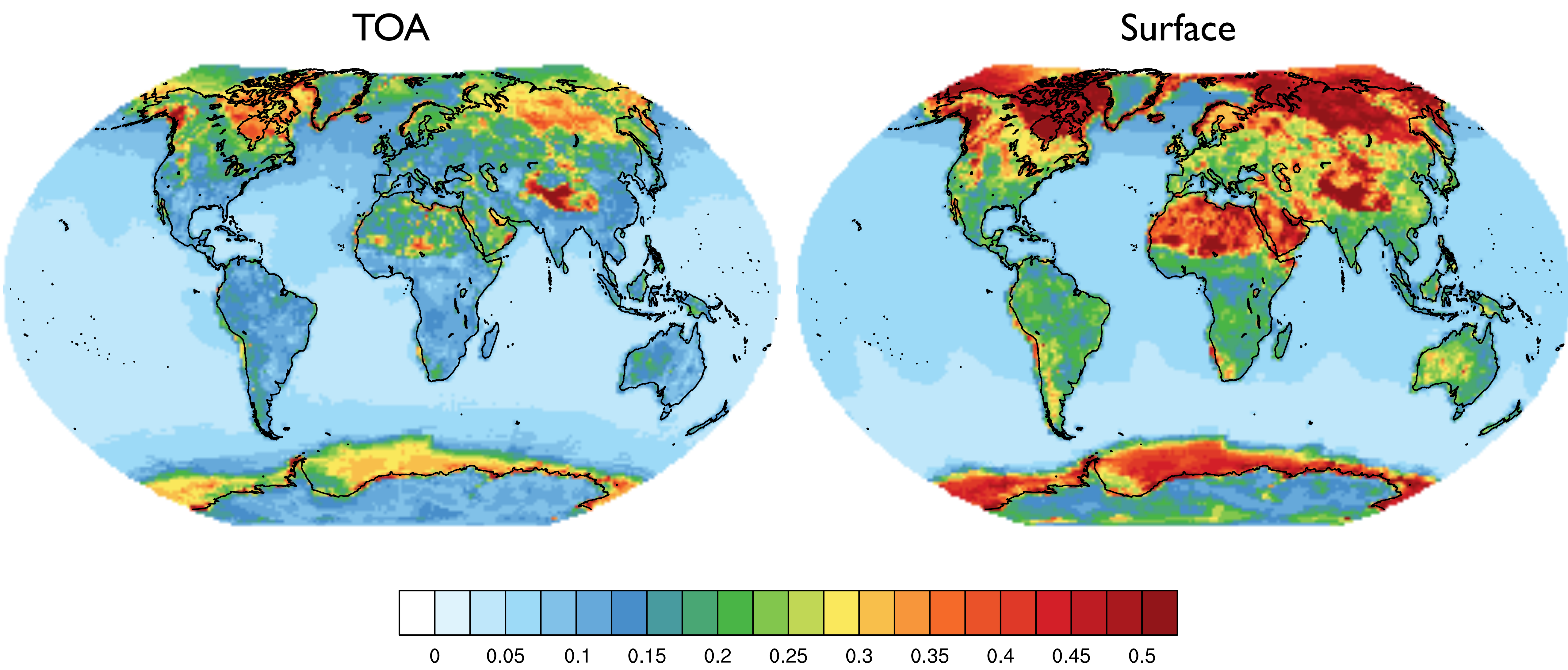
RMS Difference between CMIP5 and CERES



- 16 CMIP5 Models
- Annually averaged clear sky albedo at TOA
- Global average about 0.17
- RMS difference of models compared to CERES



Models biggest challenge is getting the surface right



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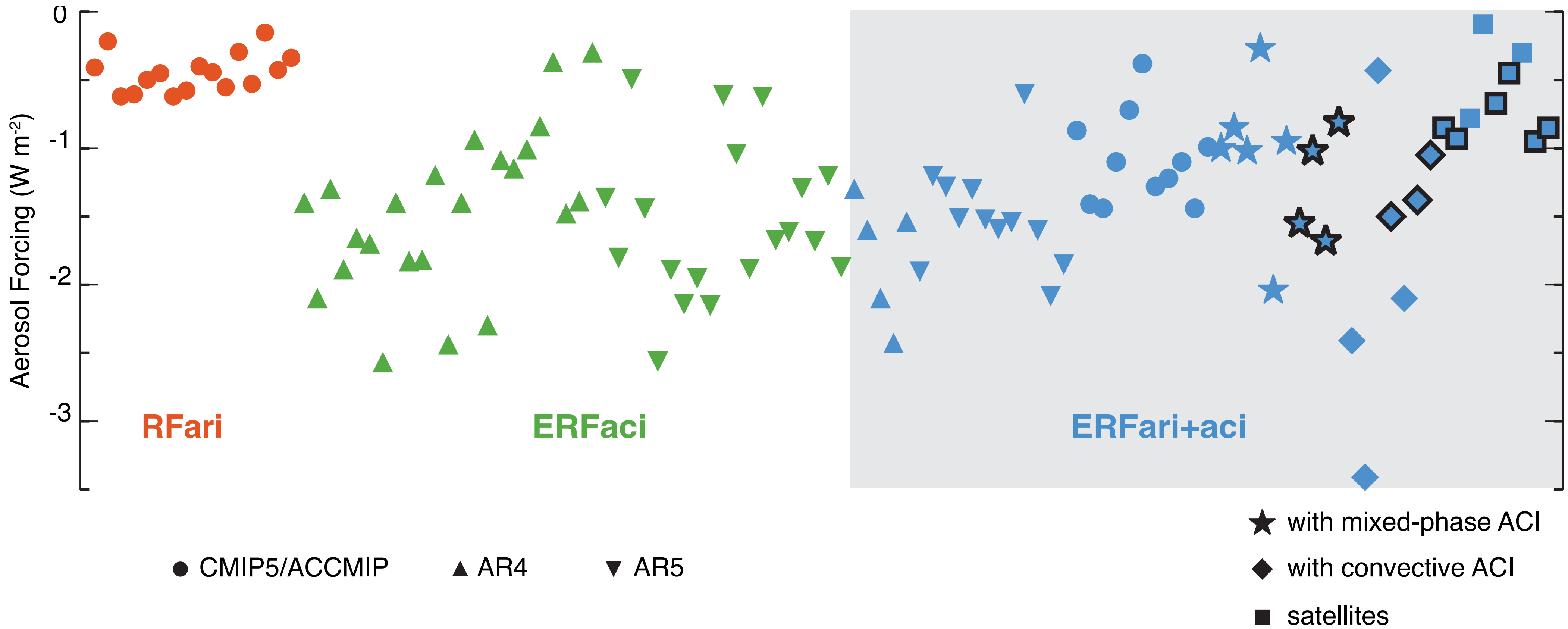
- Aerosol forcing increasingly saturates as the atmosphere ceases to be pristine, meaning that aerosol forcing may have been more important in the pre- rather than the post-industrial period.
- Myriad pathways have emerged which damp initial adjustments to aerosol changes.
- Observations are beginning to rule out a strong aerosol forcing.
- Aerosol forcing has likely not changed in the last fifteen years, and perhaps has changed very little in the last 30 years

The Importance of Understanding

An Assessment



◆ **Menon and Rotstayn, 2006 (2x); Menon and Del Genio, 2007, Unger et al. ,2009, Koch et al., 2009**, Lohmann et al., 2008, Wang et al., 2011.

★ **Lohmann et al., 2004; Lohmann and Diehl 2006; Hoose et al., 2008; Lohmann and Ferrachat 2010 (100x); Storelvmo, 2008; Storelvmo, 2010; Hoose et al., 2010;** Salzmann et al., 2011.

■ Lohmann and Lesins, 2002; **Quaas et al., 2006; Quaas et al., 2008; Quaas et al., 2009; Bellouin et al., 2013;** Sekiguchi et al., 2003, Lebsock et al., 2008.

Aerosol Effects on Convective Clouds

Reference	GCM	ERF
Menon and DelGenio 2007	GISS	-0.4
Menon and Rotstayn 2006	"	-2.4
Unger et al., 2009	"	-2.9
Koch et al., 2009	"	**-1.4**
Lohmann 2008	ECHAM	**-1.5**
Menon and Rotstayn 2006	CSIRO	-3.4
Wang et al., 2011	CAM-SP	**-1.1**

Aerosol Effects on Convective Clouds

Now we compare our IE forcing with some other recent studies. Our ACF_{DI} value without increasing GHG, -0.62 W m^{-2}, is very similar to that obtained by Menon and Del Genio (2007) (-0.65 W m^{-2}) with a similar model version. Takemura et al. (2005) estimated -0.94 W m^{-2} for first and second IE (using net flux change at TOA). Solomon et al. (2007) made a central estimate of -0.7 W m^{-2} for the albedo (first) IE only. All of these are larger than the estimates of Quaas et al. (2005) (-0.53 Wm^{-2}), for simulations constrained with satellite data.

enic AOD.

Our estimated total aerosol effect on the shortwave radiative fluxes at the top of the atmosphere is -1.31 W m^{-2}, which falls well within the model results of Quaas et al. (2009) that range from -0.50 to -2.56 W m^{-2}, with a mean value of -1.57 W m^{-2}. The estimated total aerosol effect on the net radiative fluxes at the top of the atmosphere is -1.05 W m^{-2}, which is close to the inverse estimate of -1.1 ± 0.4 W m^{-2} (1σ) based on the examination of the Earth's energy balance in Murphy et al. (2009).

An Assessment

Relationship		Terra	Aqua	ORAC	CAM-NCAR	CAM-Oslo	CAM-PNNL	CAM-Umich	ECHAM5	GFDL	GISS	HADLEY	LMDZ-INCA	SPRINTARS
N_d–τ_a	land	**0.083**	**0.078**		0.180	0.640	0.531	0.340	0.266	0.375	0.168	0.260	0.175	0.154
	ocean	**0.256**	**0.251**		0.408	0.787	0.471	0.348	0.111	0.155	0.162	0.483	0.198	0.213
L–τ_a	land	**0.074**	0.100	0.148	3.064	0.389	0.218	0.313	0.363	1.557	0.192	0.333	0.896	0.690
	ocean	**0.134**	0.093	**0.136**	3.615	0.309	0.466	0.315	0.572	1.422	0.000	1.340	0.339	0.308
f_{cld}–τ_a	land	**0.51**	**0.48**	0.27		0.34	−0.05	0.20	0.11	**0.52**	−0.04	0.11	0.09	0.13
	ocean	**0.31**	**0.29**	0.09		0.59	−0.00	**0.26**	0.00	1.09	0.15	**0.23**	0.14	0.21
T_{top}–τ_a	land	**−0.0064**	**−0.0083**	**−0.0064**	−0.0013	−0.0154	0.0161	−0.0103	**−0.0054**	−0.0116	0.0083	0.0009	−0.0044	0.0003
	ocean	**−0.0150**	**−0.0141**	−0.0082	0.0046	0.0007	0.0195	0.0082	−0.0013	−0.0284	−0.0072	0.0097	−0.0049	0.0200
α–τ_a	land	**0.17**	**0.16**			**0.14**	−0.01	**0.13**	0.02			0.00	−0.04	0.02
	ocean	**0.26**	**0.25**			0.41	0.05	**0.27**	0.12			0.19	0.00	0.08
OLR–τ_a	land	**−0.028**	−0.040		−0.070	−0.052	0.053	**−0.034**	−0.010	−0.060		0.014		0.006
	ocean	**−0.050**	**−0.054**		−0.109	−0.084	0.027	**−0.042**	0.025	−0.140		−0.017		0.034

Everyone agrees on the sign in the first row; but none of the models capture the observed land sea contrast, and only two of ten models get close

Models grossly overestimate second row as compared to observations, by as much as a factor of ten.

Half the models get the wrong sign in the cloud top temperature relationship.

And so on….

Fazit

- *Some great strides have been made (see previous section) but insufficient stock is made of these in light of original questions … the victory dance is missing.*
- *Modeling is not at the point where it usefully constrains estimates of aerosol cloud interactions, whether it is useful for identifying robust regional responses to aerosol-radiation interactions is an open question.*
- *Given past results the challenge is to simplify the problem and hopefully understand something.*

Refine the question(s)

What was the aerosol concentration in the pre-industrial, how has it evolved in time, and what can we explain with this knowledge?

Can we identify robust responses in the complex models, and understand these through a hierarchy of studies using simpler models, thereby helping us to parse the information from the noise of complex models studies.

Summary

Semantics: Adjustments

What is the question: How large is the aerosol forcing?

What has been learned: It is likely (by historical standards) not large, and is (and may well remain) in relative stasis.

Understanding: A great deal has been learned, but this is at times poorly communicated, but overall there is insufficient emphasis on understanding.

Conclusion

The Aerosol Problem is (as it used to be understood) is largely solved; something for which many of the people in this room can, and should, take credit for. Important new and related questions continue to emerge, but risk being forsaken in an effort to be 'useful'.