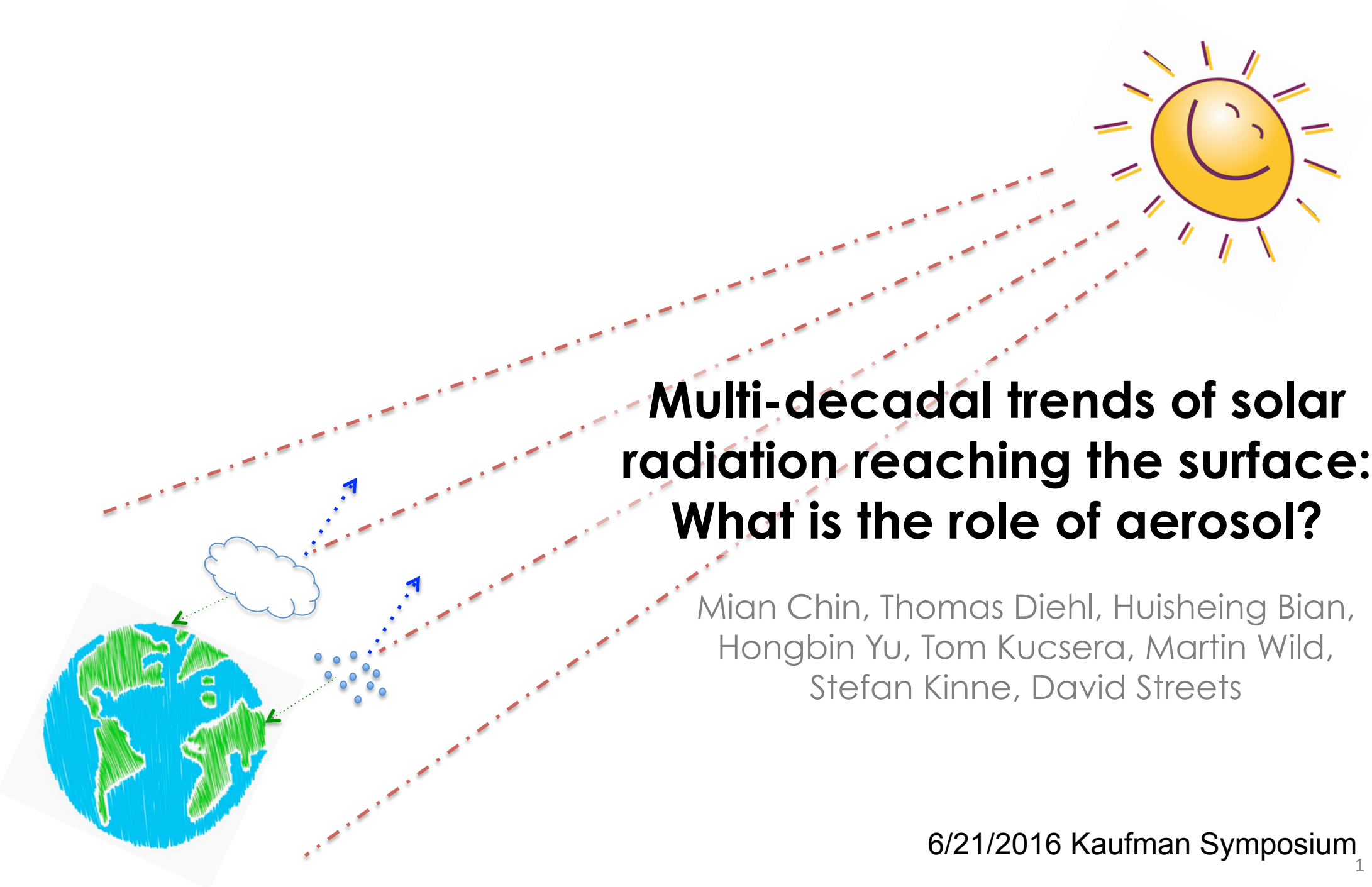


Multi-decadal trends of solar radiation reaching the surface: What is the role of aerosol?

Mian Chin, Thomas Diehl, Huisheing Bian, Hongbin Yu, Tom Kucsera, Martin Wild, Stefan Kinne, David Streets

6/21/2016 Kaufman Symposium

Introduction

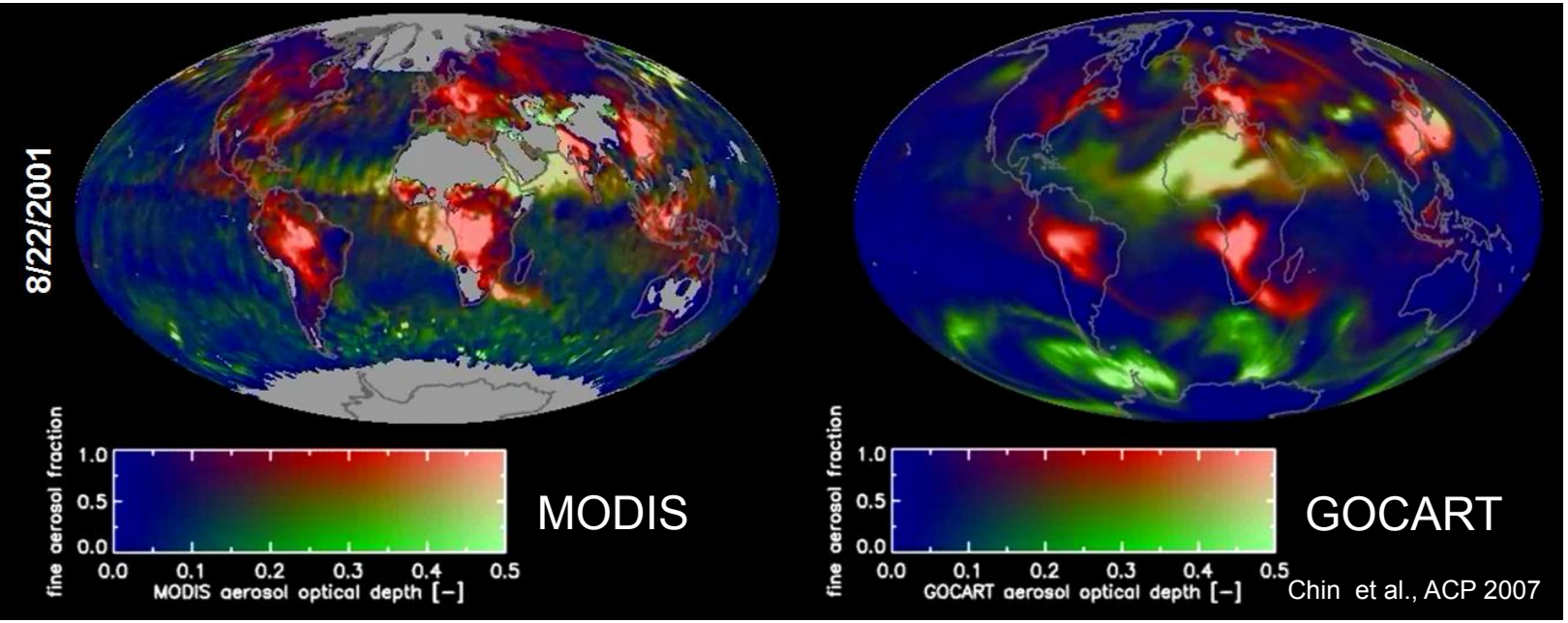
- Incoming solar radiation drives the Earth's climate system
- Globally, about 53-55% of the incoming solar radiation reaches the Earth's surface, the rest being reflected or absorbed by the atmosphere
- Long-term surface observations have shown decrease or increase trends of solar radiation reaching the surface (R_S), aka "dimming" or "brightening", in difference regions
- Several previous studies have suggested that the R_{SFC} trends are determined by the changes of anthropogenic aerosols in those regions
- This work: Using a global model and analyzed meteorological data to assess the role of aerosols in the so-called solar "dimming" and "brightening" in different regions of the world

Today's talk

- Using the GSFC radiative transfer model and GOCART-simulated aerosols from 1980 to 2009 to calculate R_S in all sky and cloud-free sky conditions
- Comparing results with data from surface network measurements on 3-decadal variations/trends
- Attributing the "dimming/brightening" trends to the changes of aerosols

All models are wrong, but some are useful. – George Box

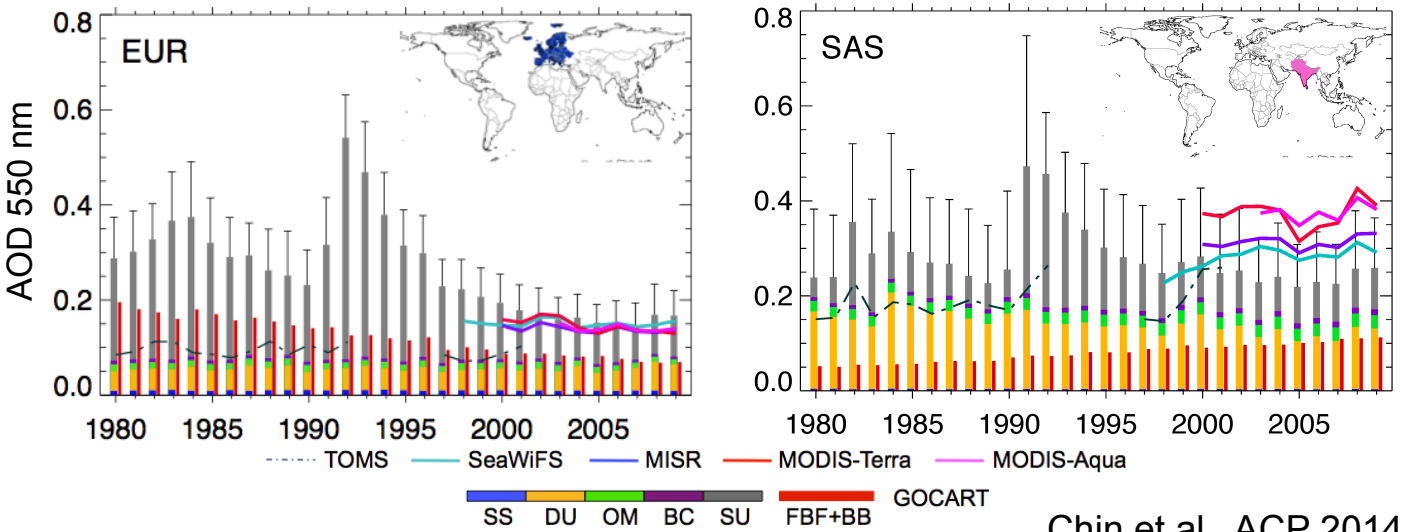
Multi-decadal aerosol variations/trends



Yoram's idea on satellite data-model comparisons

"The aerosol movie is of great importance, far beyond the outreach goal. It may become the highlight of the aerosol research community looking for new ideas…..As a proof, let me mention that I got a full-hearted compliment from Ralph Kahn."

- Yoram Kaufman, Feb 2002



Chin et al., ACP 2014

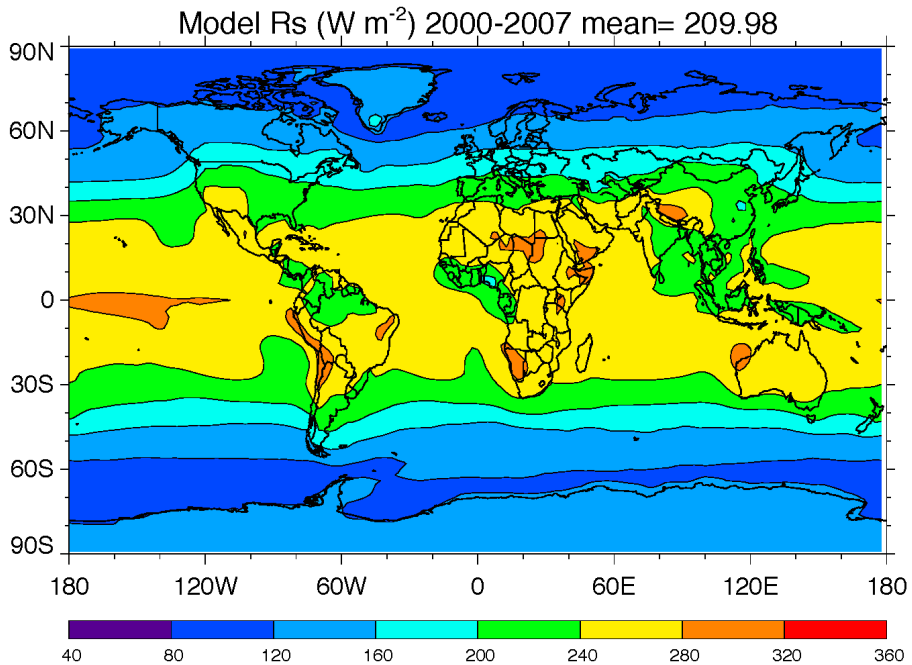
AOD variations/trends, 1980-2009:

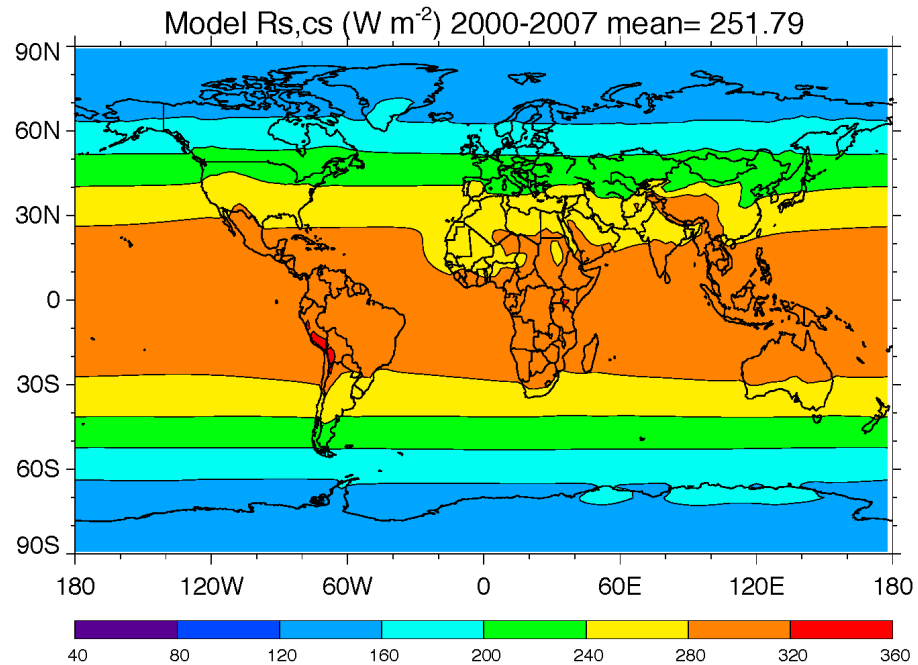
Comparisons between satellite data and GOCART model simulations over Europe (large decrease of anthro AOD) and South Asia (large increase of anthro ADO

Model calculations of SW radiative fluxes, 1980-2009

- Radiative transfer model:
  - GSFC (Chou and Suarez, 1999), SW spectral region from 0.2 to 4 μm
- Input to the RTM:
  - Aerosol optical properties (τ, ω, g) simulated by the GOCART model with anthropogenic, biomass burning, and natural aerosols
  - Cloud fields from MERRA
  - Water vapor, ozone, CO_2, and air density also from MERRA
- Output including 3-D total, direct, diffuse radiative fluxes in all sky and cloud-free sky conditions and with or without aerosols. Main variables :
  - R_S= total SW downwelling radiation at the surface under all sky condition
  - $R_{S,CS}$ = total SW downwelling radiation at the surface under cloud-free sky condition (no clouds)
  - R_{S,CS_DIF} = diffuse SW downwelling radiation at the surface under cloud-free sky condition
- Remember: Aerosol reduces total and direct radiation but enhances the diffuse radiation (so does clouds)

8-year average of R_S and $R_{S,CS}$



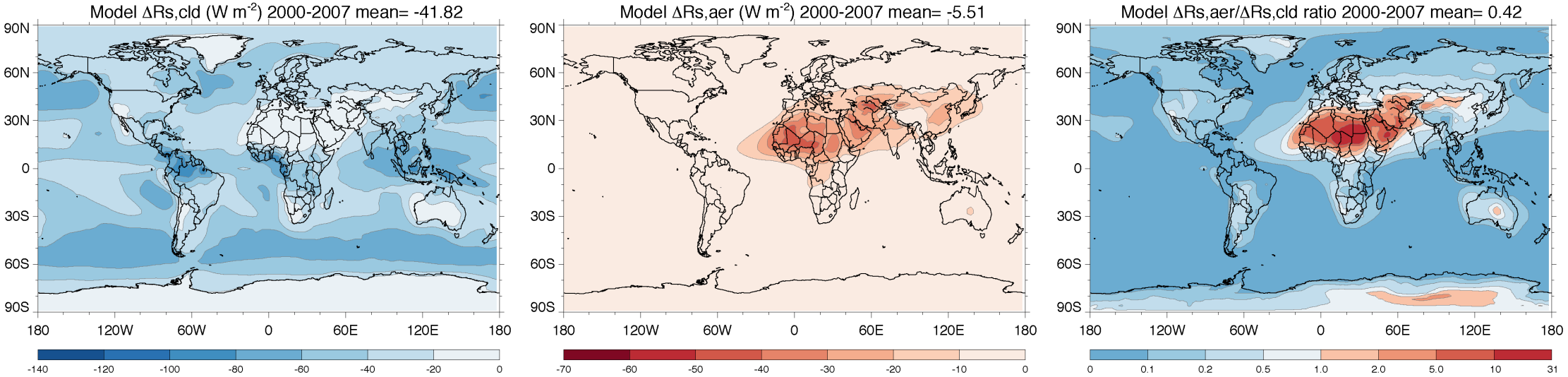


- Incoming solar radiation at TOA: 340-342 W m^{-2}
- Part of it is attenuated by clouds, aerosols, water vapor, and other trace species in the atmosphere; the left reaches the surface

- Less radiation is attenuated in cloud-free sky conditions, thus more solar radiation reaching the surface

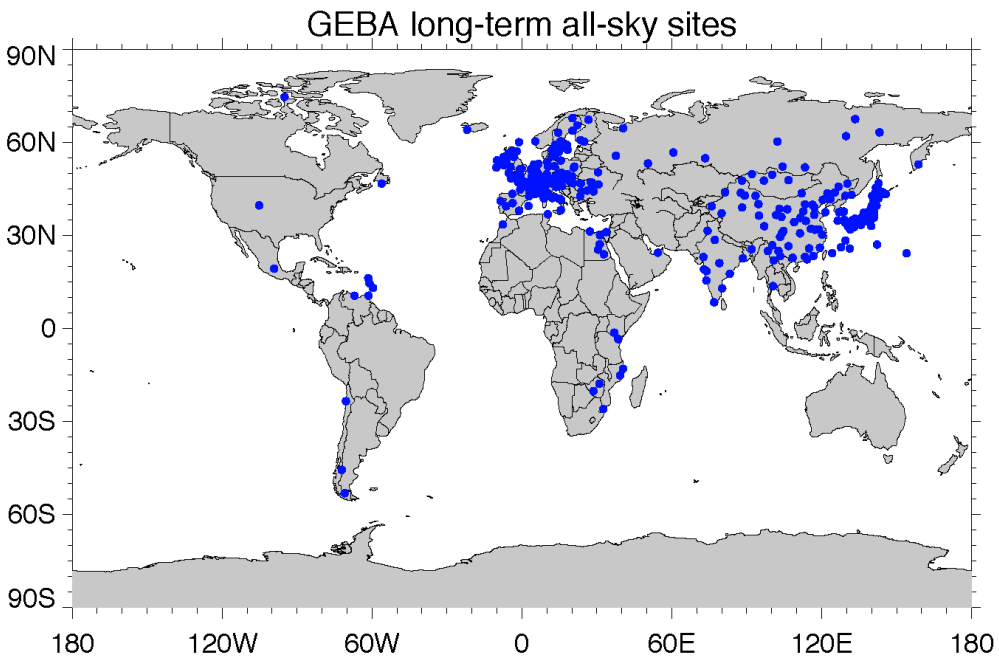
Compared to clouds, aerosol effects on radiation is much smaller…

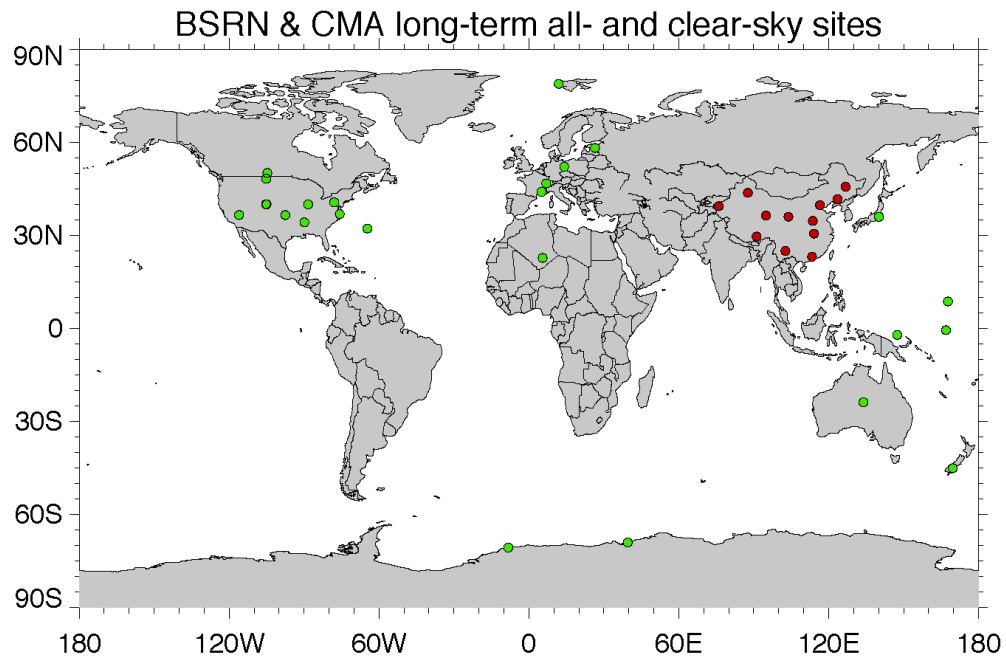
- Under all sky conditions, even with cloud amount from MERRA being too low, aerosol effects on R_S over ocean is <10% of cloud effects
- Aerosol effects only exceeds clouds over the "dust belt" over land where cloud fraction is low and aerosols are overestimated by GOCART. Over polluted NH land, even over East and South Asia, reduction of R_S due to clouds is more than that due to aerosols
- But can we explain the surface radiation changes or trends of the "dimming/brightening" by the changes/trends of aerosols?



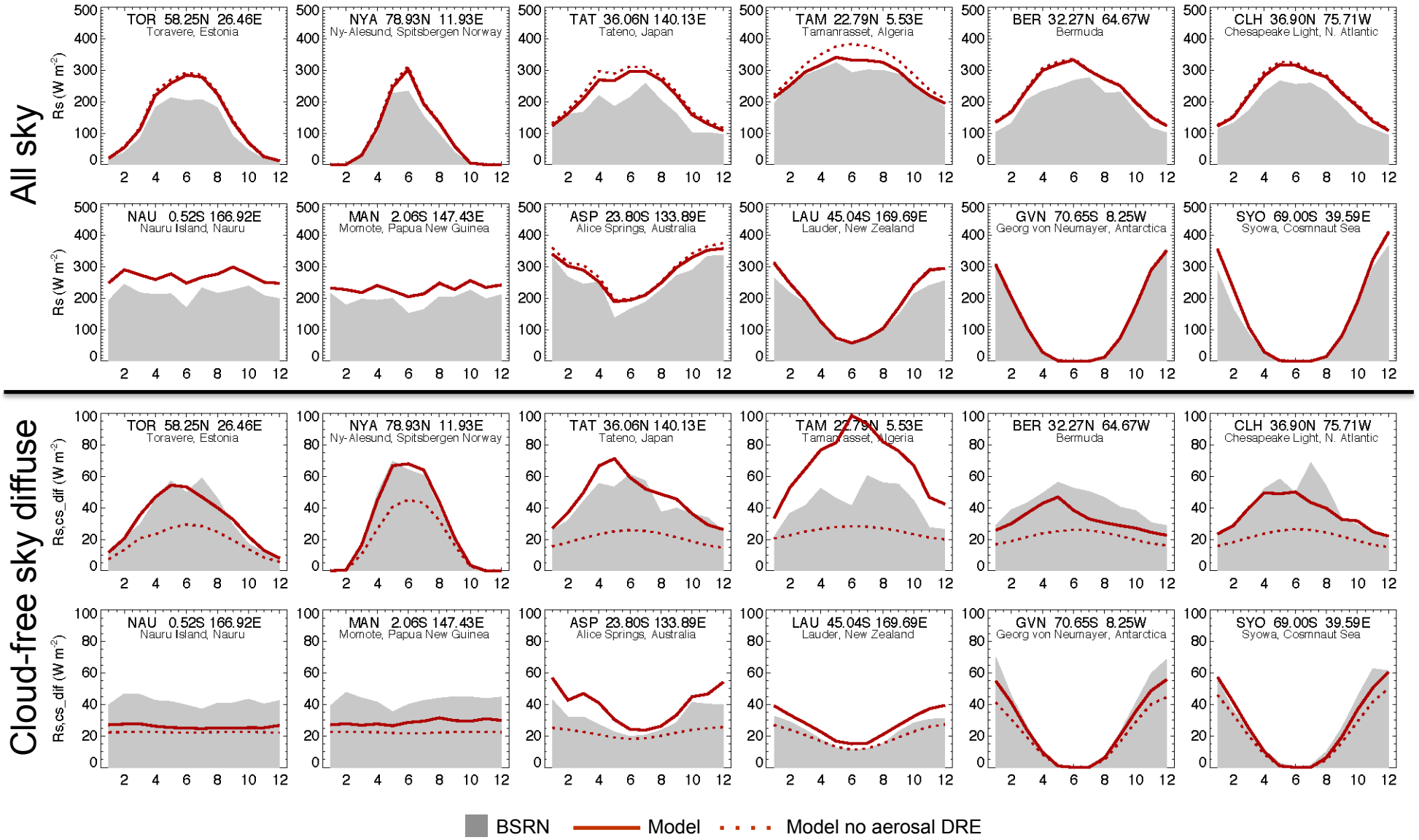
Surface networks

	GEBA	BSRN	CMA
Time period used	1980 – 2009	1992-2009	1980-2009
Products used	R_S	R_S, $R_{S,CS}$, R_{S,CS_DIF}	R_S, $R_{S,CS}$, R_{S,CS_DIF}
Number of sites	323 (>20 yrs of data)	26 (>10 yrs of data)	12 (with both all- and clear sky data)
Reference	Ohmura, Wild, etc.	Ohmura et al. 1998	Wang 2014 (?)

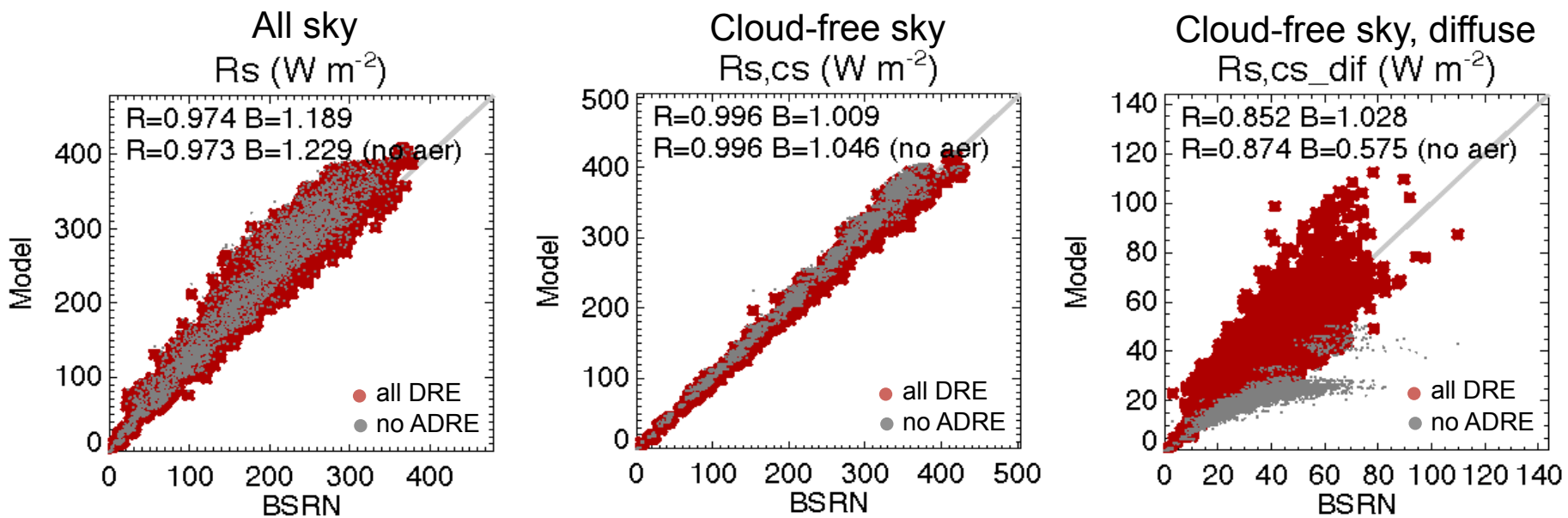




Comparisons of model and satellite R_S *and* R_{S,CS_DIF} with BSRN measurements at 12 sites, 2004 monthly mean



Overall comparisons with BSRN for all sites and entire data record, monthly mean

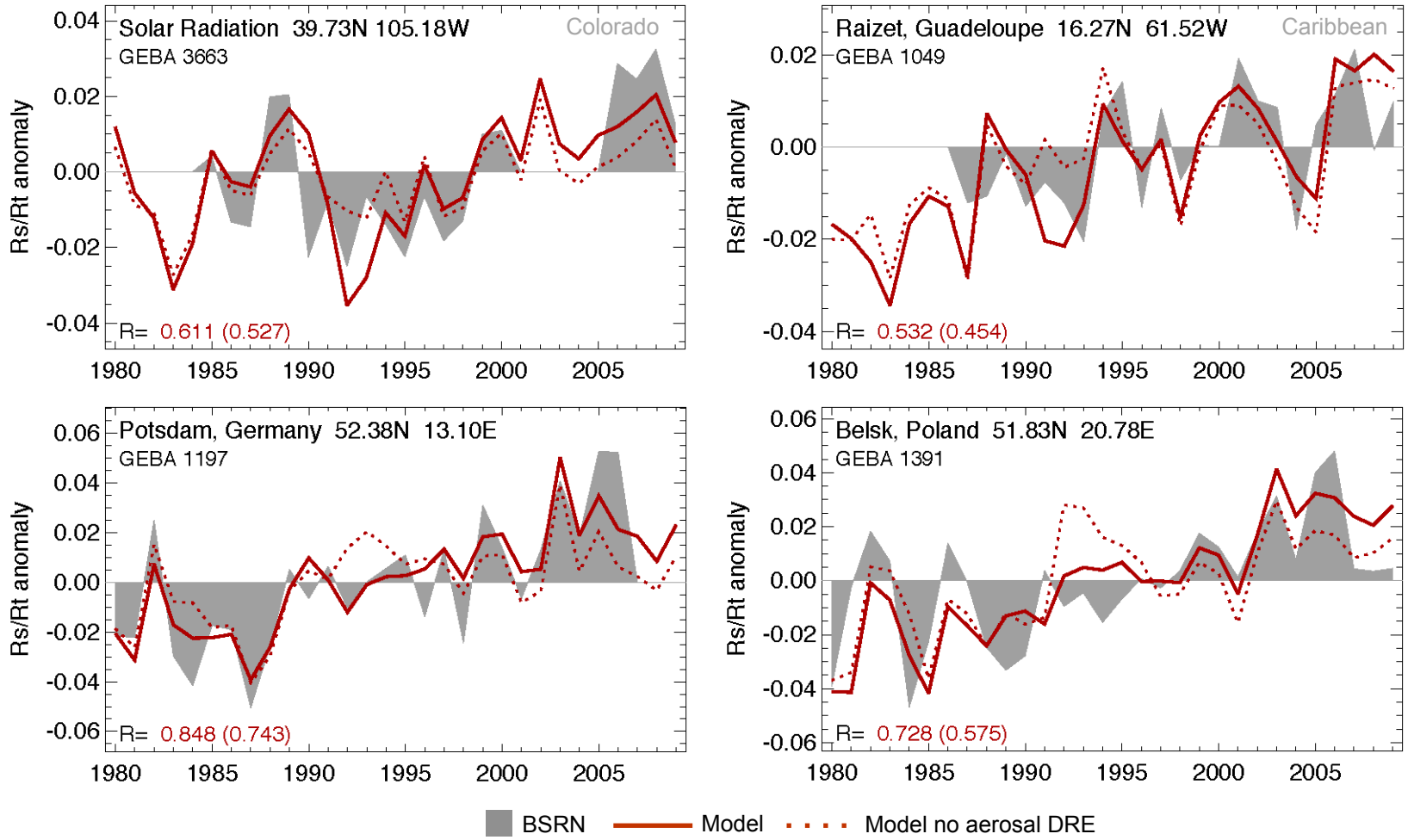


- Model simulated R_S is overall 19% higher than BSRN data. Without considering aerosol DRE it would be 23% higher.
- Model simulated $R_{S,CS}$ agrees with BSRN data. $R_{S,CS}$ would be 4% higher without considering aerosol DRE
- Aerosol effects are most obvious in R_{S,CS_DIF}. Model cannot capture observed R_{S,CS_DIF} without considering aerosol DRE.
- Note: the apparent high correlations are driven by the spatial and temporal variations of incoming solar radiation, not by the existence of aerosols and clouds

Method of investigating the changes/trends of surface radiation

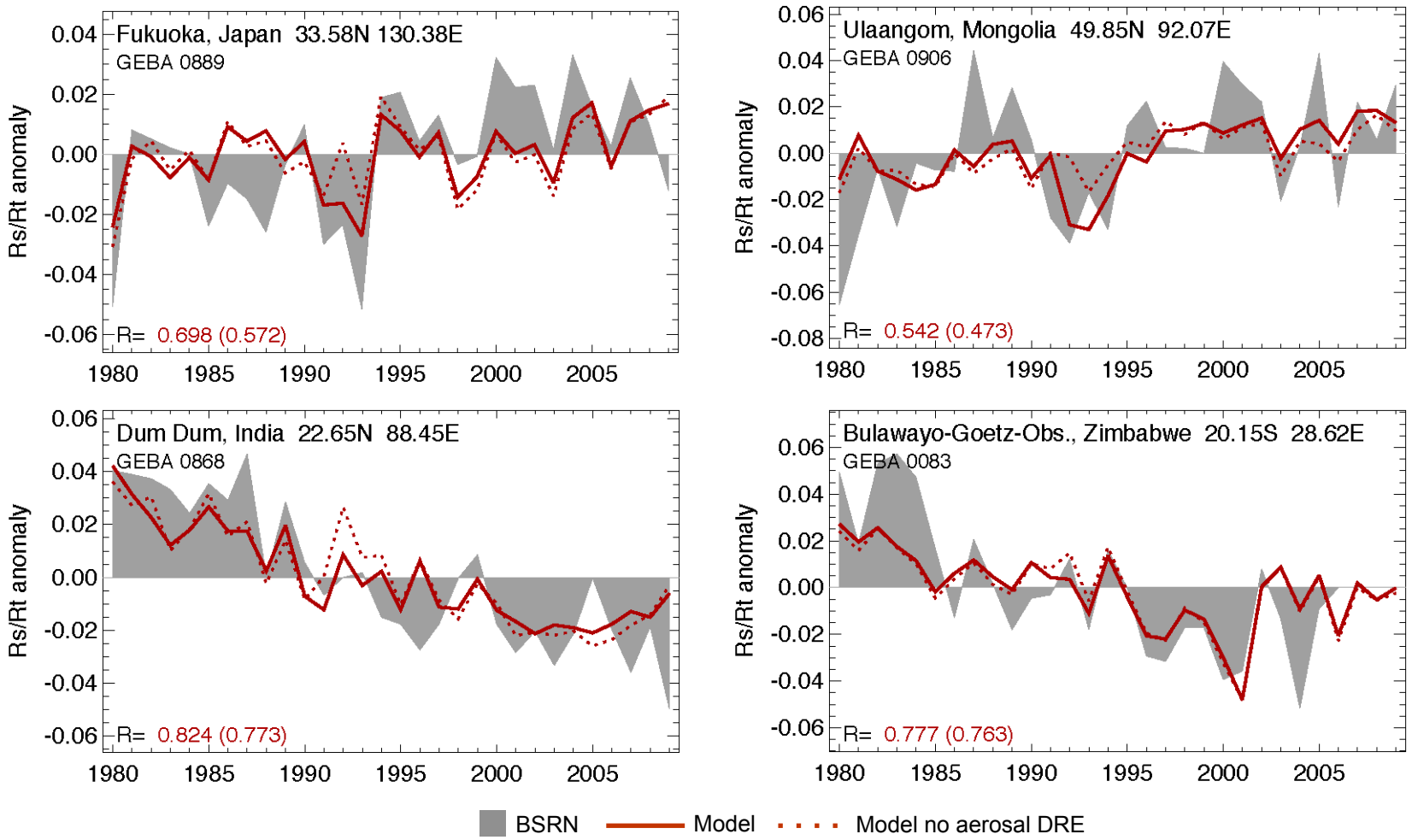
- To avoid the temporal and/or spatial sampling bias (e.g., most measurements taken in a particular season or network locations concentrated in a particular climate zone), we use the "normalized" quantity such that the surface radiation is divided by the incoming solar radiation at TOA, R_T
- The "dimming" or "brightening" is shown as the difference between the R_S/R_T in any particular year to a "climatological" value from the average over a certain period of time
- => **Comparisons of anomaly of R_S/R_T**

Comparisons of changes of R_S/R_T at 4 GEBA sites over Americas and Europe



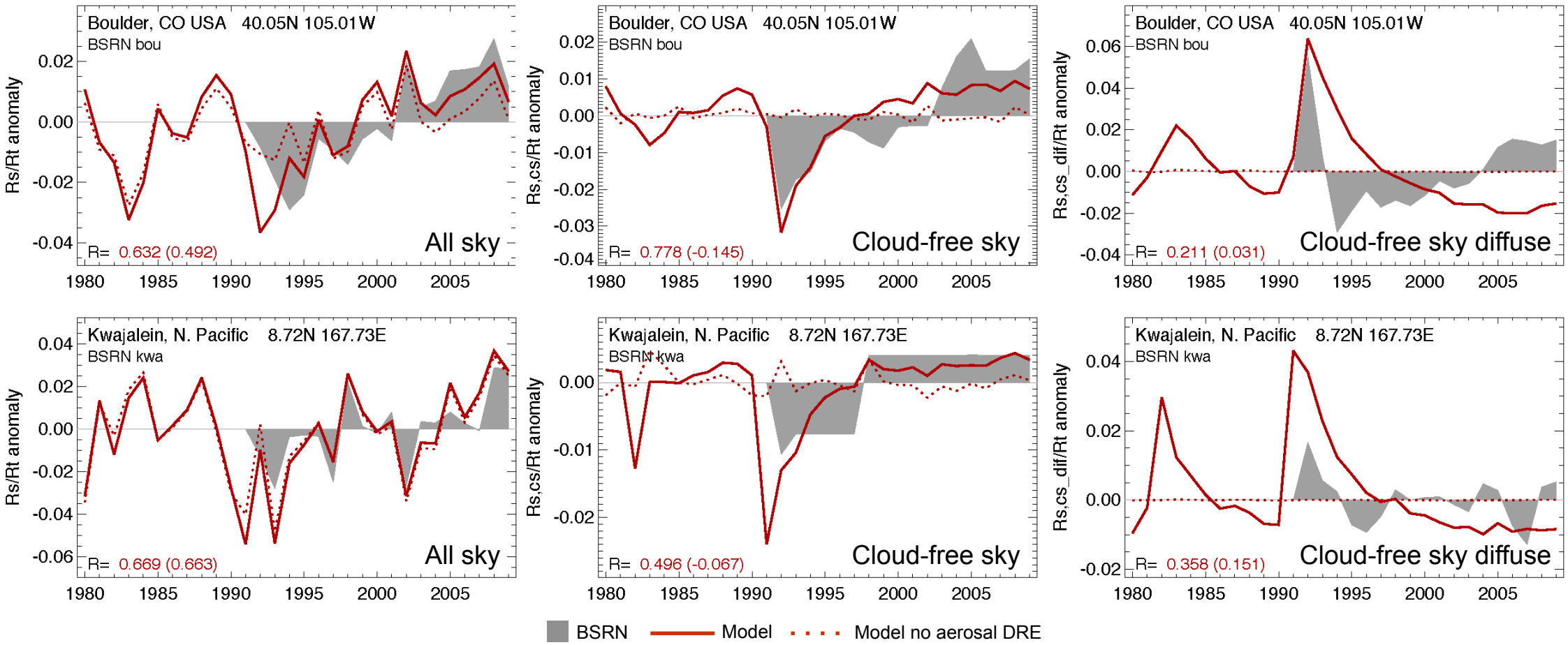
- General "brightening" trends over North America and Europe
- However, the trends is statistically the same without aerosols DRE

Comparisons of changes of R_S/R_T at 4 GEBA sites over Asia and Africa



- General “brightening” trends over Japan and Mongolia, “dimming” over India and Zimbabwe
- However, the trends is statistically the same without aerosols DRE

Comparisons of changes of R_S/R_T, $R_{S,CS}/R_T$, and $R_{S,CS_DIF}/R_T$ at 2 BSRN sites

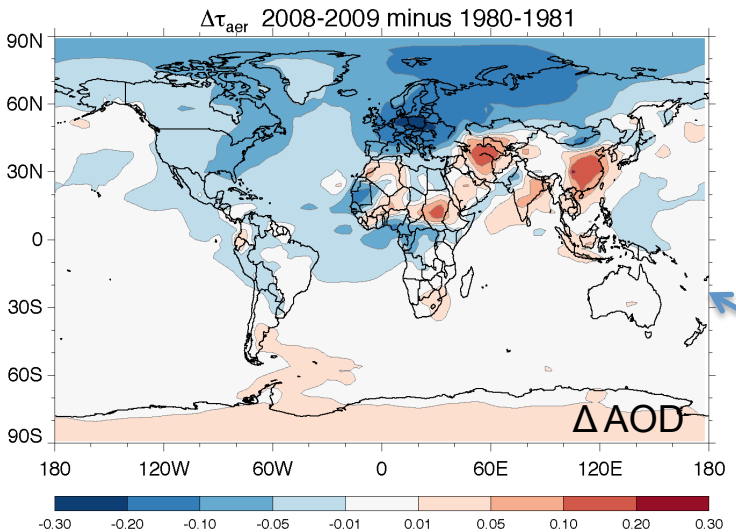


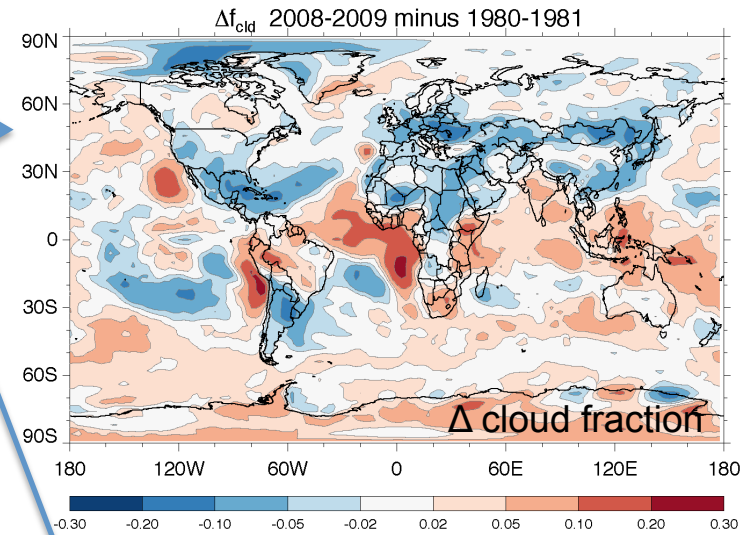
- Aerosol direct radiative effects are only discernable in cloud-free sky conditions, especially cloud-free sky diffuse radiation

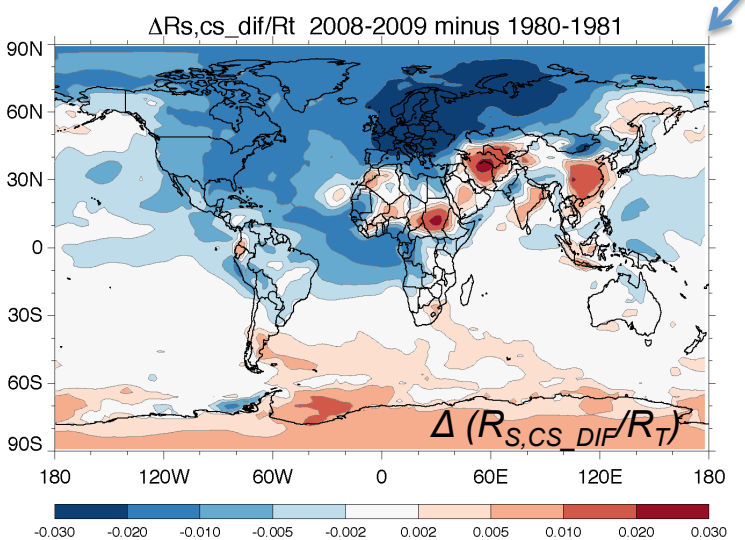
Global maps of changes between 2008-09 and 1980-81

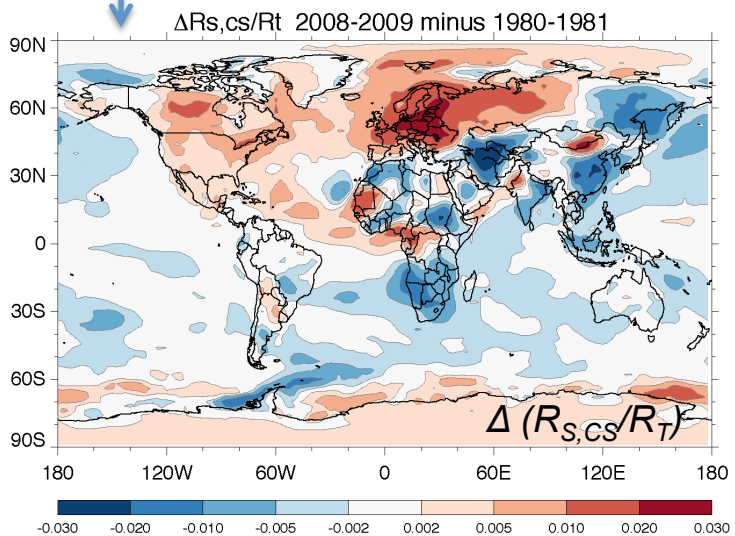
The change of cloud fraction is anti-correlated with the change of R_S

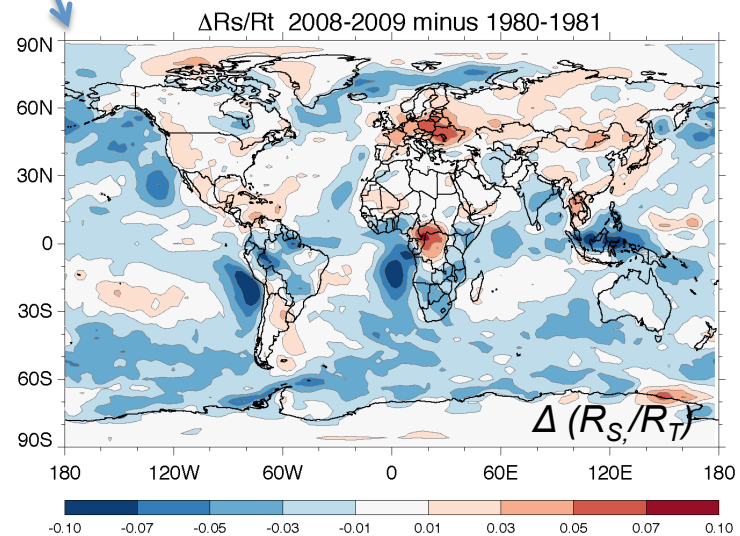
The change of AOD is anti-correlated with the change of $R_{S,CS}$ and R_{S,CS_DIF}



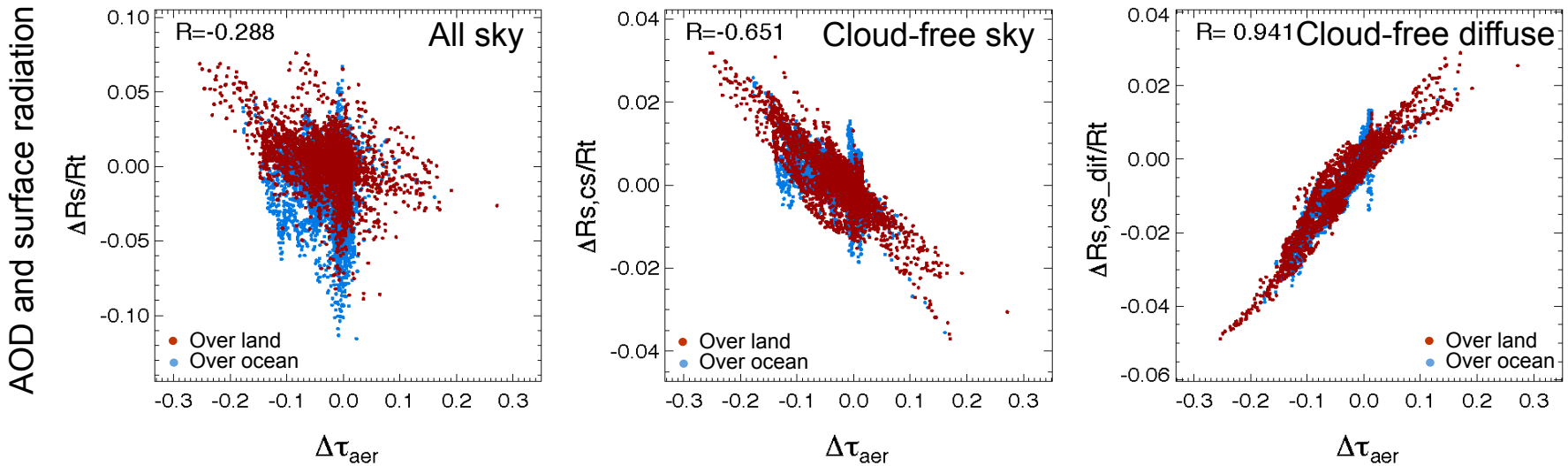


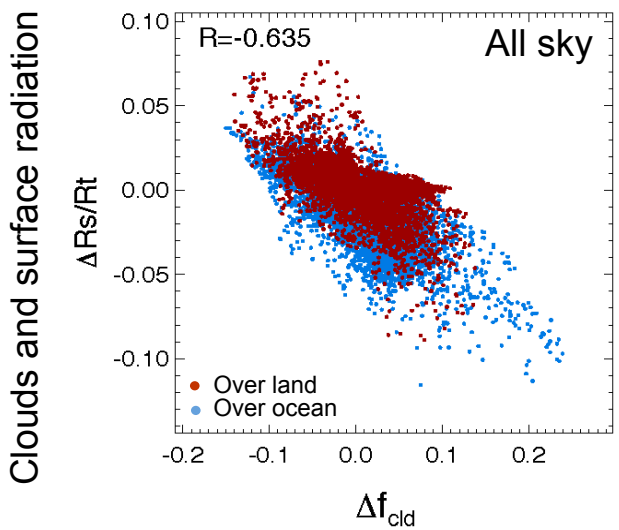






Relationship between AOD, clouds, and SW downwelling fluxes at surface





- The change of aerosols and change of R_S are not correlated
- The change of aerosols and changes of $R_{S,CS}$ and R_{S,CS_DIF} are correlated, especially aerosol and R_{S,CS_DIF}
- The change of cloud fraction is anti-correlated with the change of R_S

Conclusions

- Under all sky condition: Clouds plays much important role in regulating the solar radiation reaching the surface
- Under cloud-free sky condition: Aerosol direct radiative effects are more clear, especially in diffuse radiation
- **Big questions unanswered:**
  - What causes the cloud trend?
  - How much is the change of cloud mediated by aerosols through aerosol-radiation interaction and aerosol-cloud interaction?
  - How does climate change affect the cloud and aerosol trends and their interactions?
- Next model experiments should include realistic aerosol-cloud-radiation interactions in a climate changing environment

Aerosol-cloud-radiation interactions

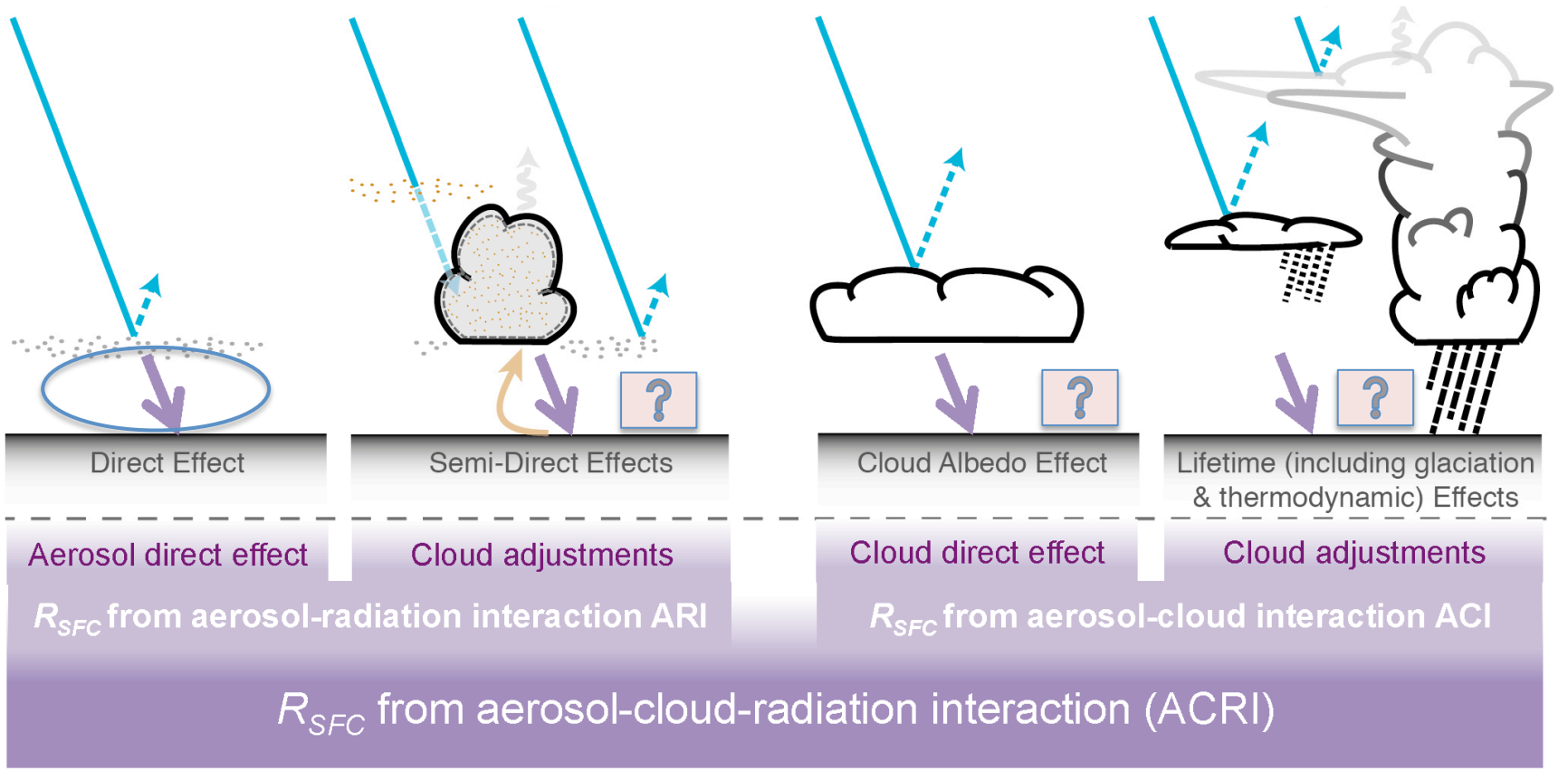


Figure adapted from Boucher et al., 2013 with modifications

2nd AeroCom workshop, Ispra, Italy 2004