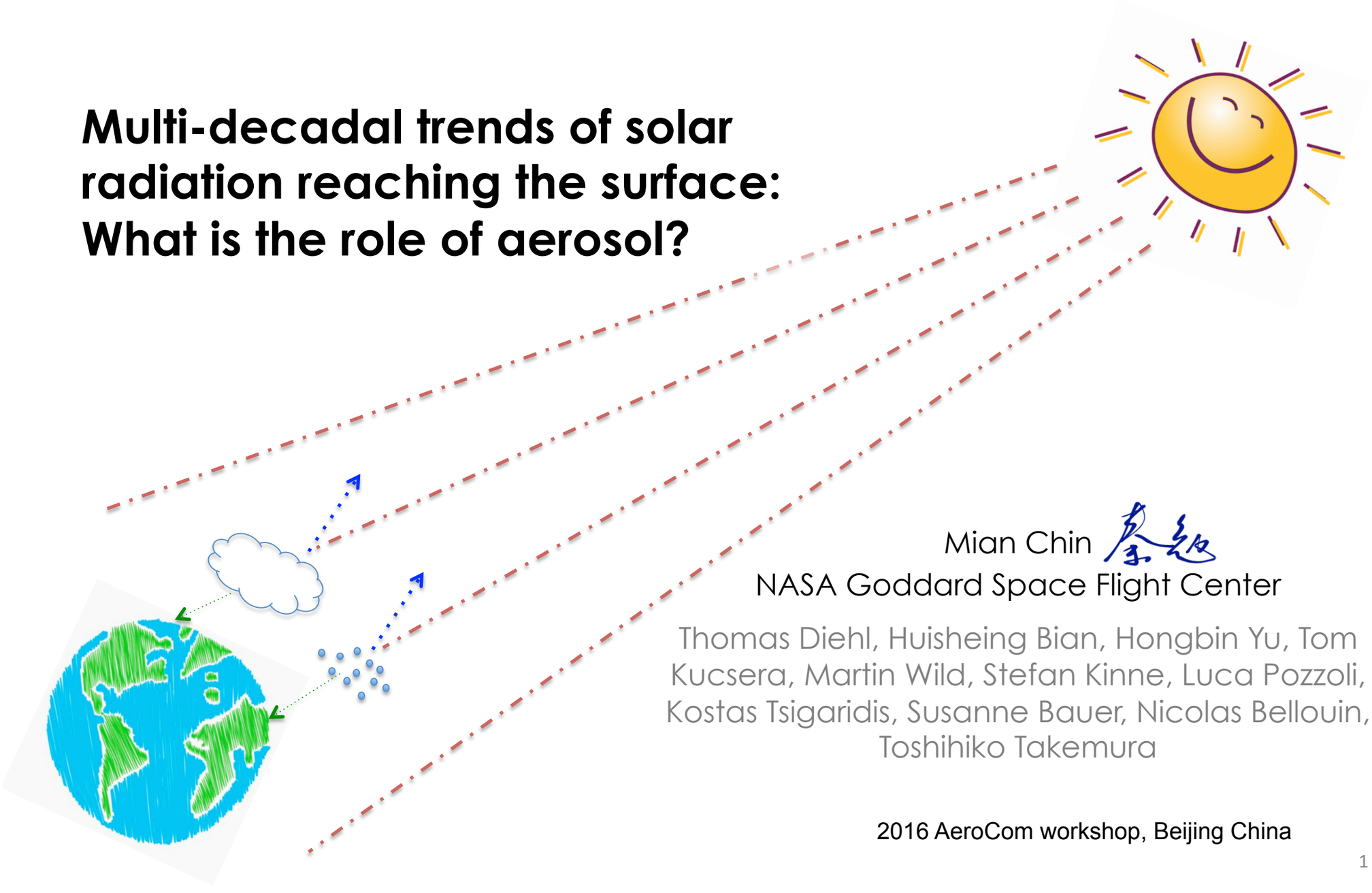
Multi-decadal trends of solar radiation reaching the surface: What is the role of aerosol?



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2016 AeroCom workshop, Beijing China

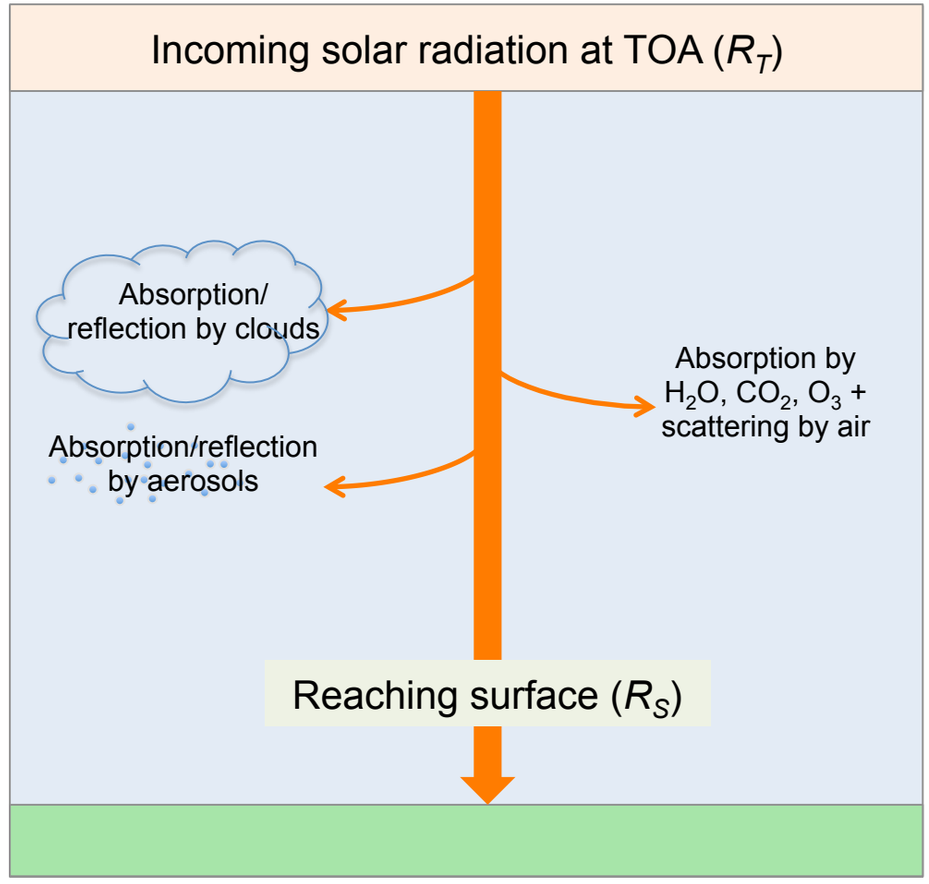
Introduction

- 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_S trends are determined by the changes of anthropogenic aerosols in those regions
- This work is to assess the role of direct radiative effects of aerosols on the so-called solar "dimming" and "brightening" trends in different regions of the world

Today's talk

- The change of R_S from the AeroCom II hindcast model simulations (1980-200x) and compare the results with observations from the surface network
- Using the GOCART model to attribute the "dimming/ brightening" trends to the changes of aerosols through the direct radiative effects

Shortwave (SW) solar radiation budget

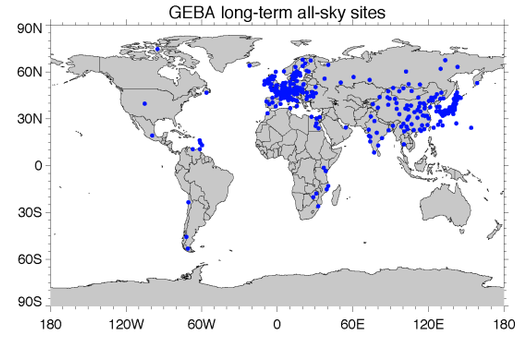


AeroCom II hindcast model simulations

Model	*Abbr.*	*Anthro. emission*	*Volc. emission*	*Period*	*Rs*	*Rs,cs*	*Rs,csdif*
ECHAM5-HAMMOZ.A2.HCA-0	ECH-0	A2-MAP	No	1980-2005	Yes	No	No
HadGEM2-ES.A2.HCA-0	HAD-0	A2-MAP	Yes	1980-2006	Yes	Yes	Yes
GISS-modelE.A2.HCA-IPCC	GIE-i	A2-ACCMIP	No	1980-2008	Yes	Yes	No
GISS-MATRIX.A2.HCA-IPCC	GIM-i	A2-ACCMIP	No	1980-2008	Yes	Yes	No
SPRINTARS-v384.A2.HCA-0	SPR-0	A2-MAP	Yes	1980-2008	Yes	Yes	No
SPRINTARS-v384.A2.HCA-IPCC	SPR-i	A2-ACCMIP	Yes	1980-2008	Yes	Yes	No
GOCART-v4.A2.HCA-0	GO4-0	A2-MAP	Yes	1980-2007	Yes	Yes	Yes
GOCART-v5 (not in AeroCom II)	GO5-i	A2-ACCMIP	Yes	1980-2009	Yes	Yes	Yes

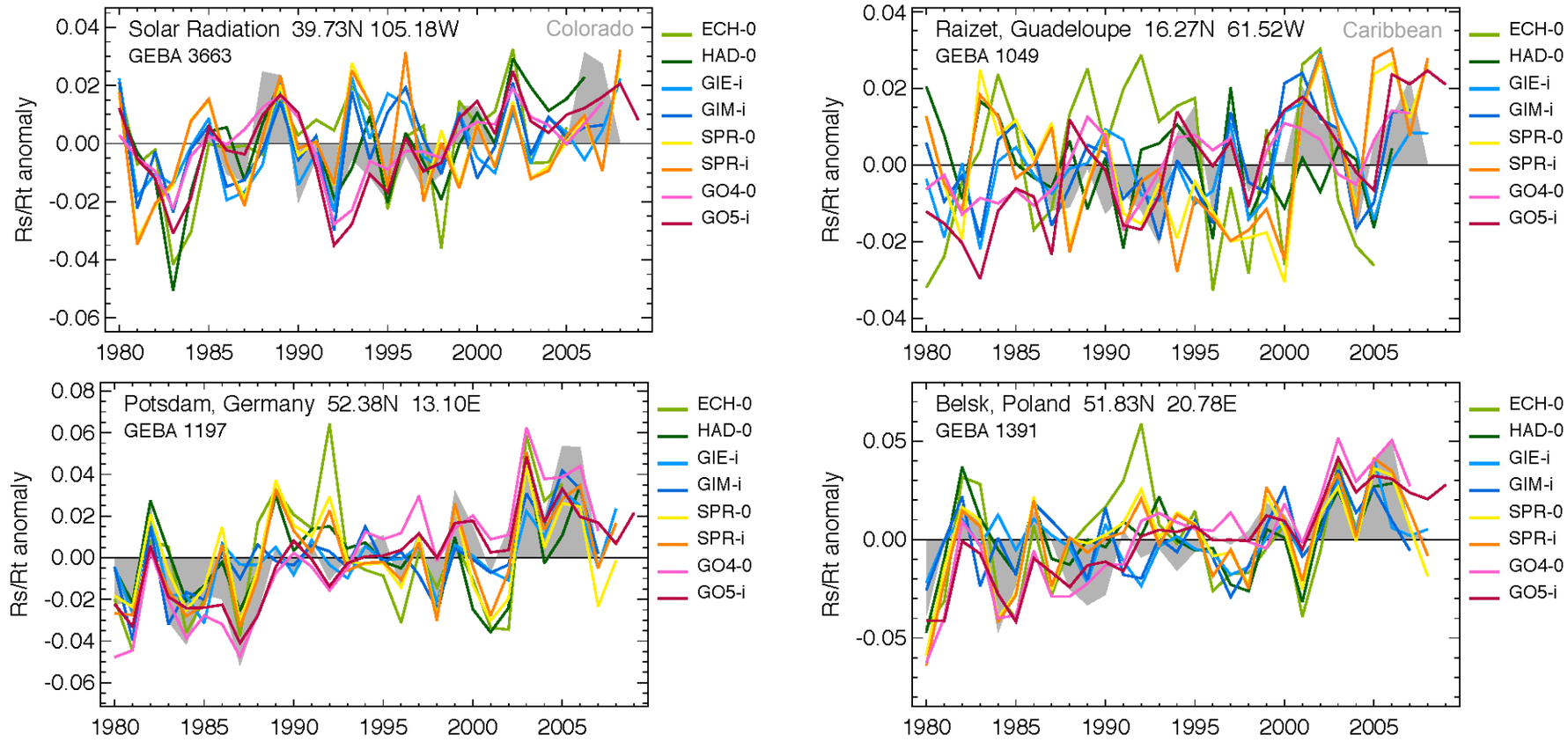
Rs = all sky total SW radiation at the surface. Rs,cs = clear sky, Rs,csdif = clear sky diffuse

Radiation quantity used



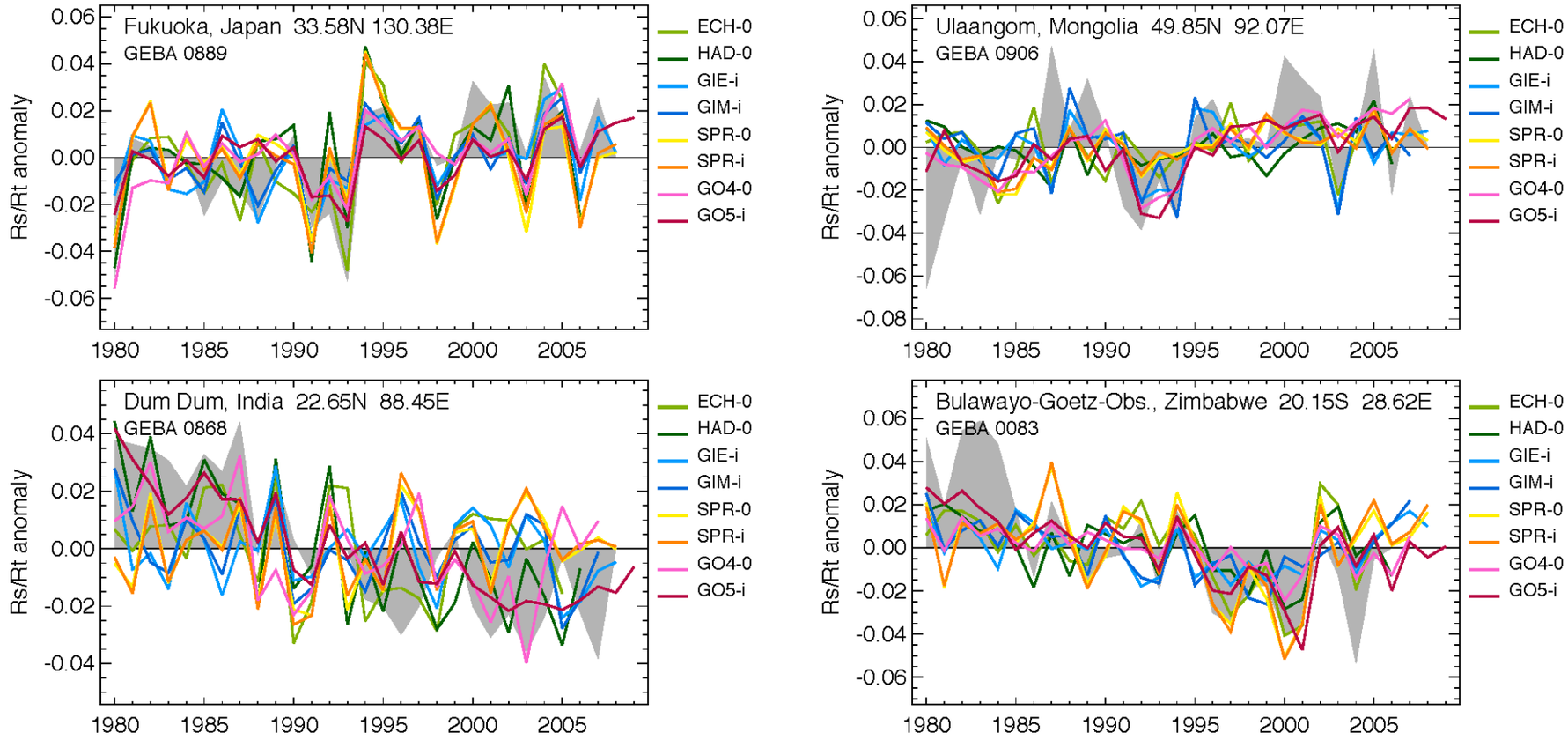
- We will show comparisons only for all sky conditions, because the "clear sky" definition is quite different among models, and only two models submitted clear sky diffuse/direct SW fluxes
- To avoid the temporal and/or spatial sampling bias, we use the "normalized" quantity such that the surface radiation is divided by the incoming solar radiation at TOA, R_T
- The "dimming" or "brightening" is shown as the anomaly, i.e. the deviation of R_S/R_T in any particular year from a "climatological" value
- => **Comparisons of anomaly of R_S/R_T at GEBA sites**

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



- General “brightening” trends over North America and Europe from GEBA data
- Models are more consistent over the continents but show large diversity over the Caribbean site

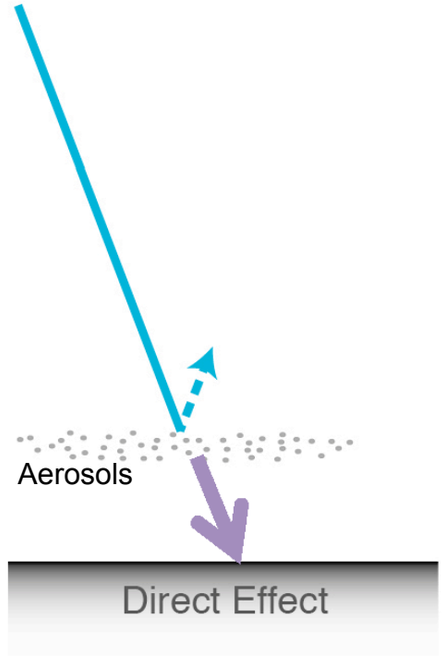
Comparisons of changes of R_S/R_T at 4 GEBA sites over Asia and Africa



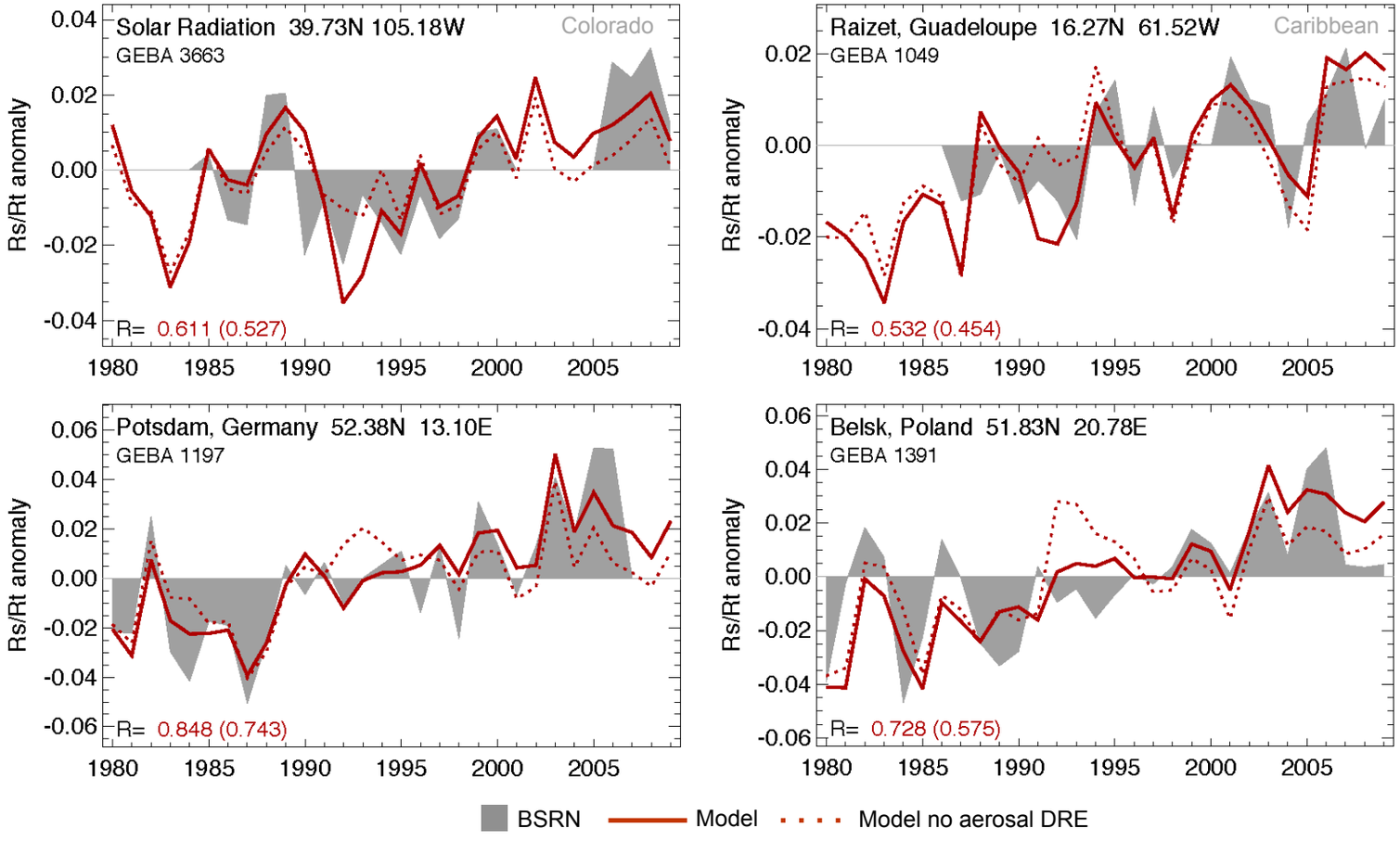
- General “brightening” trends over Japan and Mongolia, “dimming” over Inida and Zimbabwe
- Models show large diversity over India, with trends from dimming to no change even with the same emissions

The question: How much can we attribute the dimming/ brightening R_s trends to the change of aerosols?

- We use the NASA MERRA system (for clouds, H_2O, CO_2, and O_3) and GOCART model simulated aerosols to answer the above question by the model experiments:
  - Calculating R_s with all aerosols, clouds, and other atmospheric constituents
  - Same as above but without aerosols

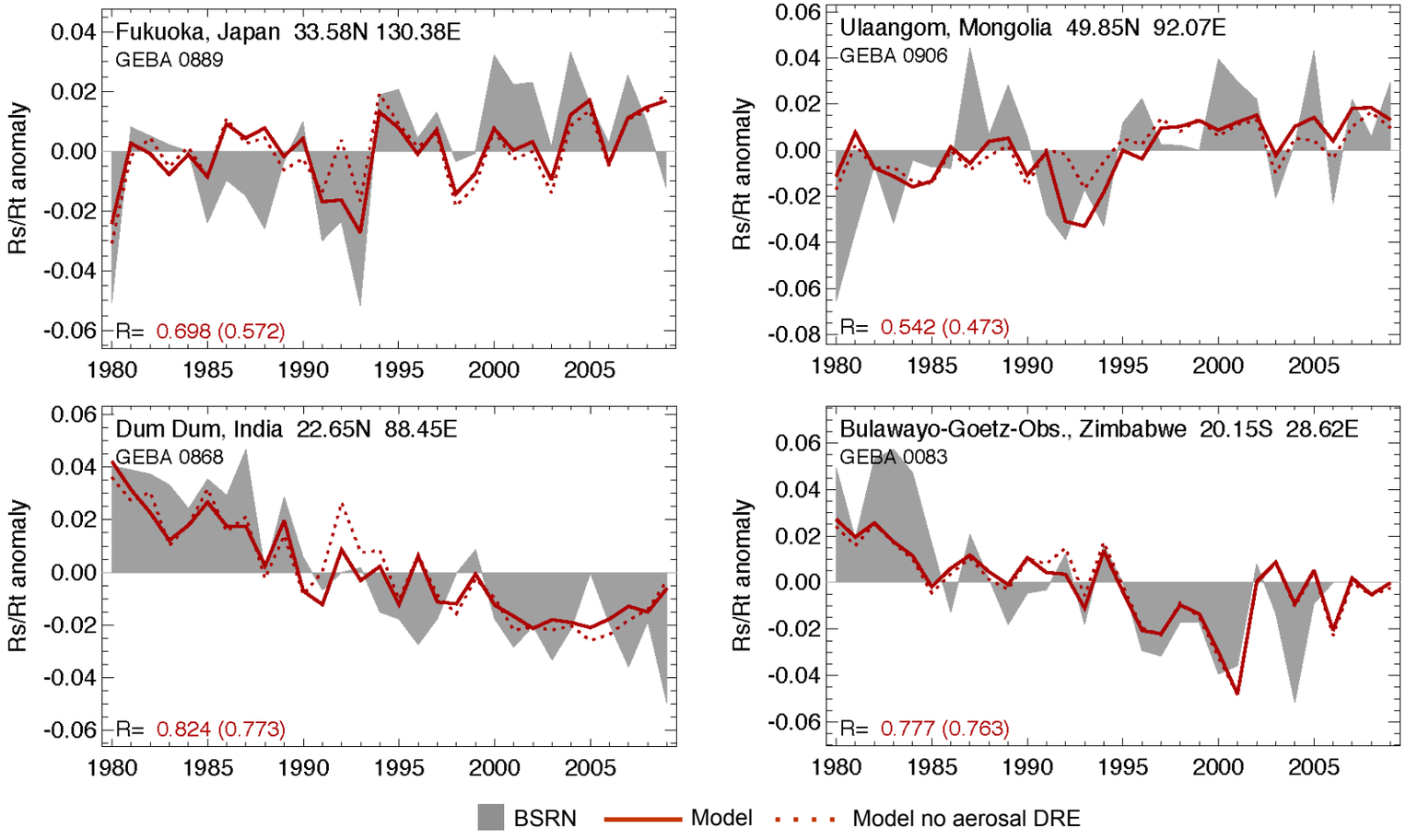


Comparisons of changes of R_S/R_T at 4 GEBA sites over Americas and Europe



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

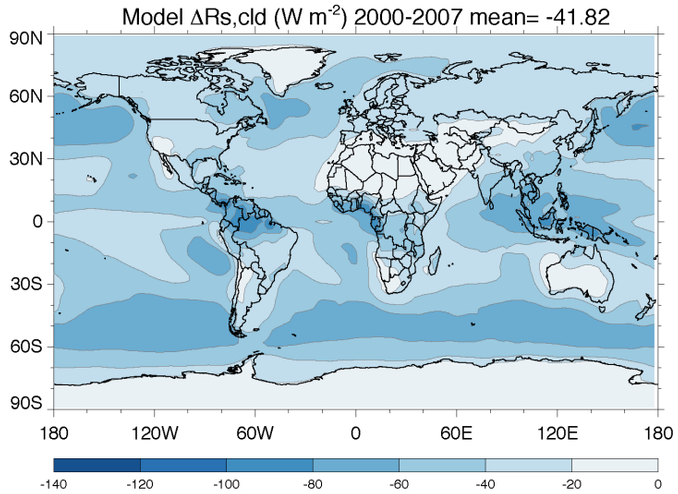
Comparisons of changes of R_S/R_T at 4 GEBA sites over Asia and Africa

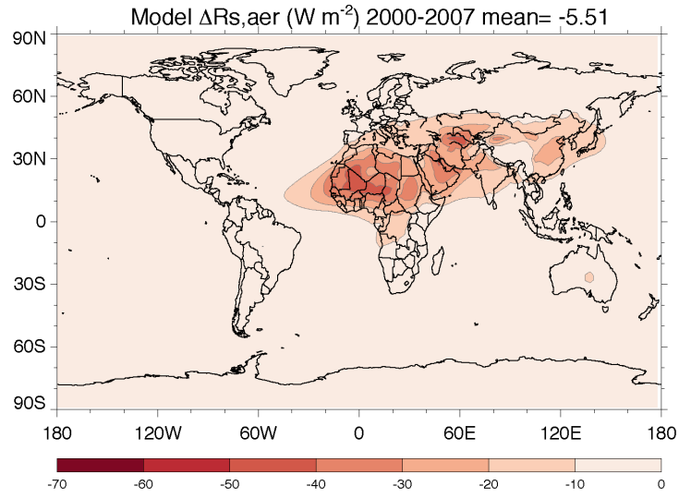


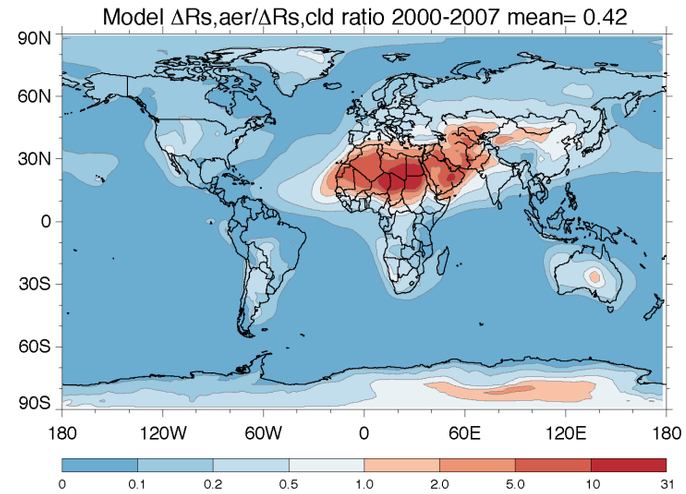
- General “brightening” trends over Japan and Mongolia, “dimming” over India and Zimbabwe
- However, the trends is statistically the same without aerosols DRE

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

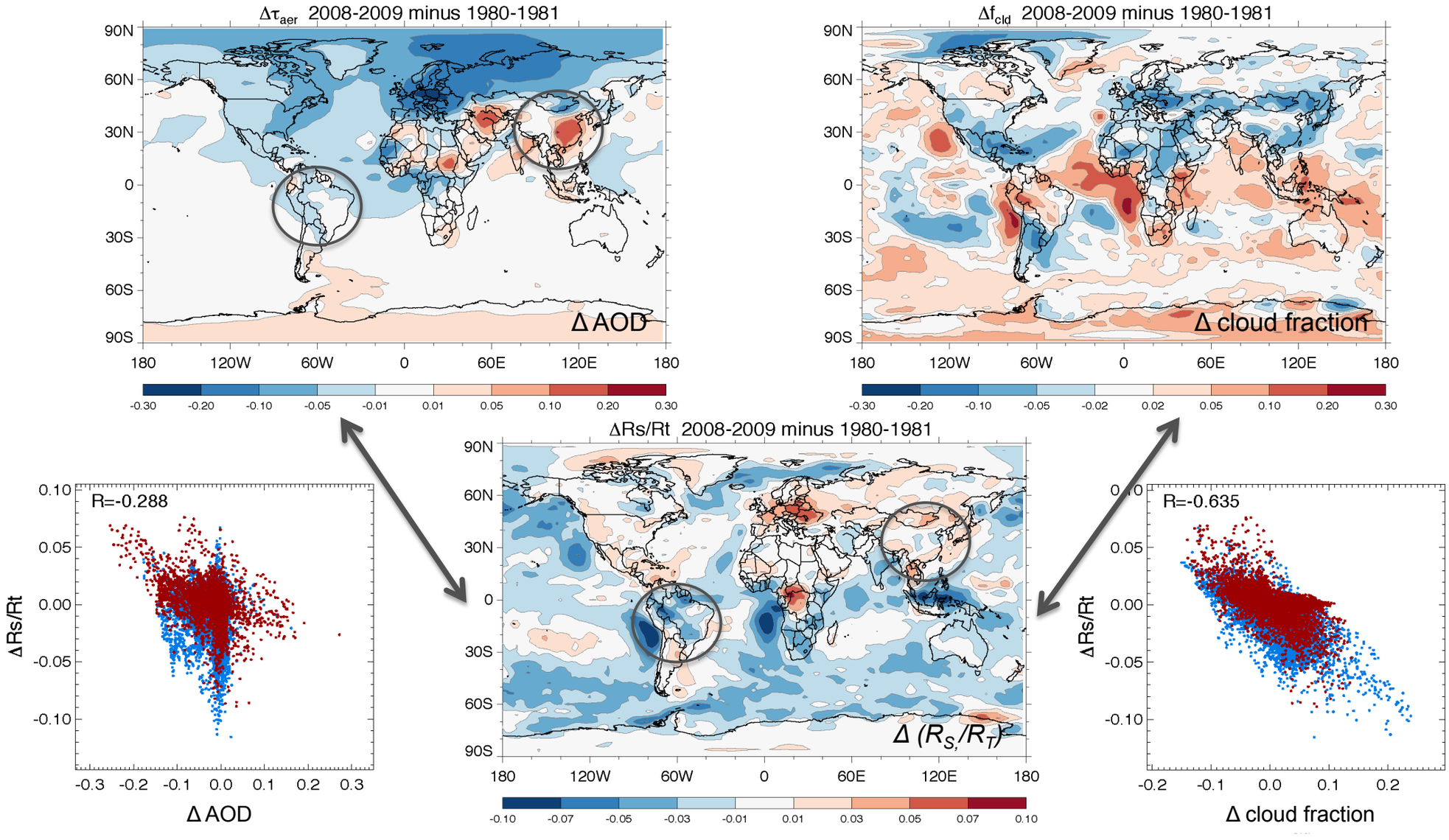
- Under all sky conditions, even with cloud amount from MERRA being too low, aerosol effects on R_S over ocean is <10% of cloud effects
- Aerosol effects only exceeds clouds over the "dust belt" over land where cloud fraction is low. Over polluted NH land, even over East and South Asia, reduction of R_S due to clouds is more than that due to aerosols







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



Remarks

- 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

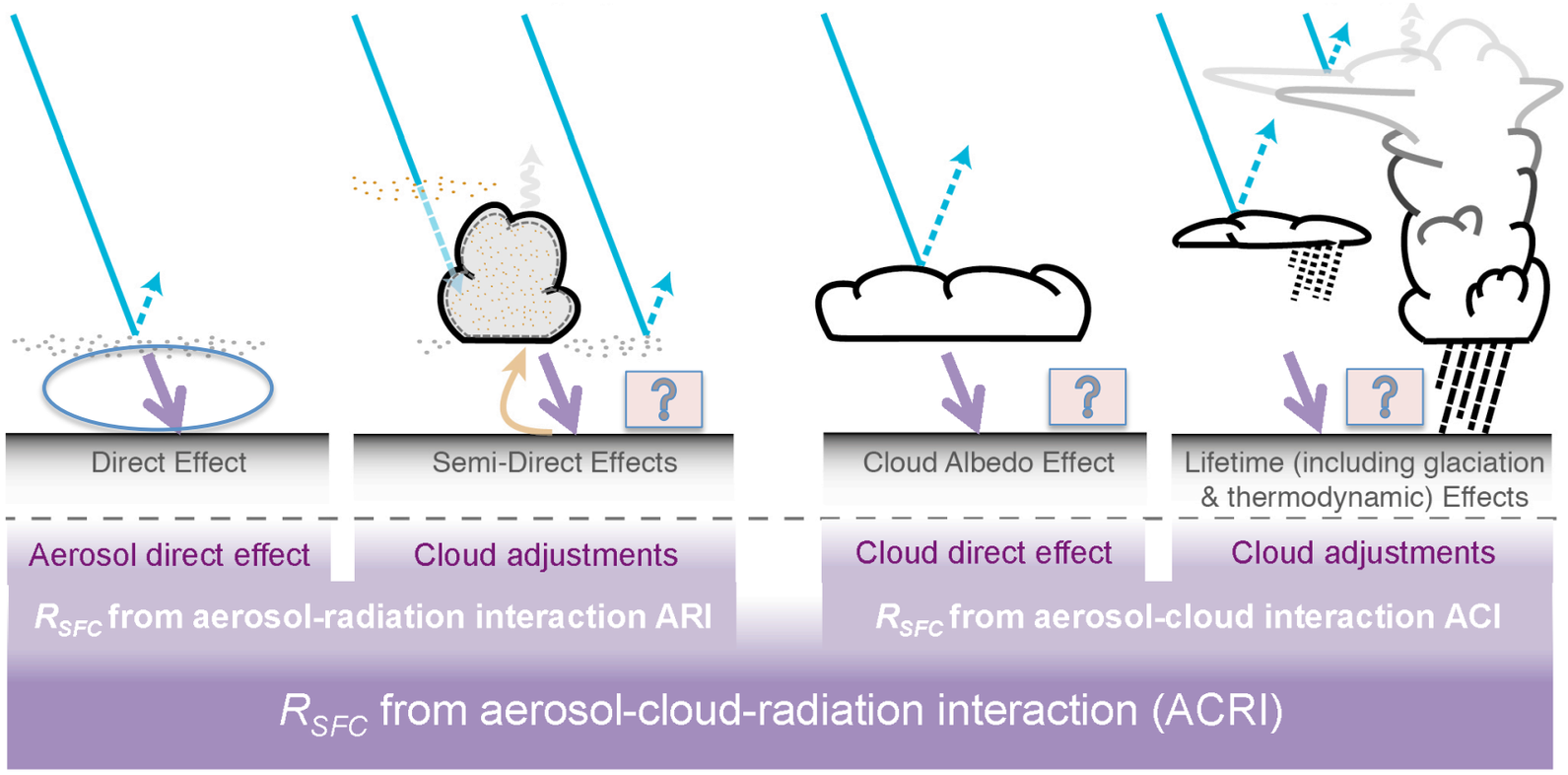


Figure adapted from Boucher et al., 2013 with modifications

More AeroCom model experiment?

- GCM simulation of aerosol-cloud-radiation interactions
  - BASE
  - FIXSST
  - FIXAER
  - FIXARI
  - FIXACI
- These simulations will allow attributing the effect forcing of global warming or aerosol on cloud change
- Could have a side discussion on specifications if there is enough interest