Multi-decadal variations of atmospheric aerosols and their effects on surface radiation trends

AeroCom 2010

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Introduction

- Long-term observations of surface downward solar radiation have shown a wide-spread trends from dimming to brightening in the past 50+ years over Europe, North America, China (e.g., Wild et al. 2005; Qian et al., 2006)

- Various explanations have been given, with special attention given to aerosols since the anthropogenic emission trends of aerosol and precursor gases mirror the change of surface radiation (Streets et al., 2006, 2008)

- However, the link of the changes of anthropogenic emission and surface radiation is not straightforward because of the complex atmospheric processes especially the interactions of aerosol and clouds

- This work attempts to investigate the aerosol trends in the modern era (1980 to present) and assess the role of aerosol effects on surface radiation using satellite data, ground-based observations, and a global model

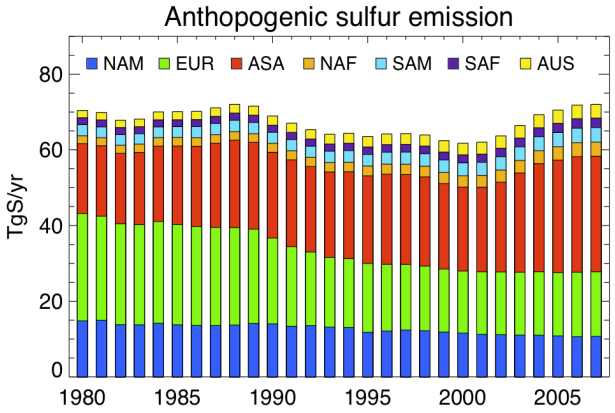
Model and observations

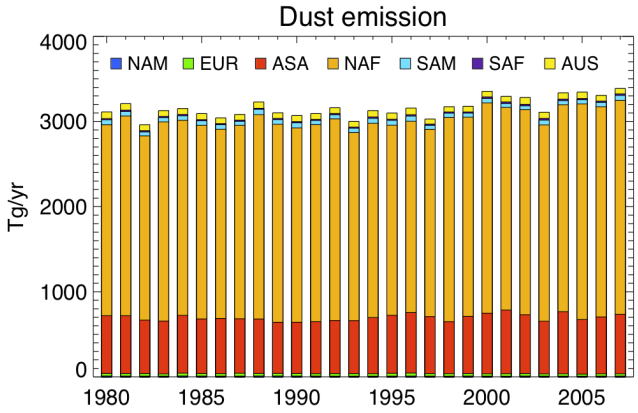
- Model: GOCART – global aerosol chemistry and transport model using the assimilated meteorology from GEOS-DAS, with sulfate, dust, BC, POM, and sea salt simulated
- Satellite observations: AOD from AVHRR (two different retrievals from NOAA and GISS), MODIS, and MISR
  - Limitations: MODIS and MISR only available since 2000
  - AVHRR only covers ocean
- Surface radiation data: ~~Global Energy Balance Archive (GEBA) network (annual average, total SW downward total flux, all sky)~~, Baseline Surface Radiation Network (BSRC, daily, total/diffuse/direct), and China Meteorological Administration (CMA, daily, total/diffuse/direct)

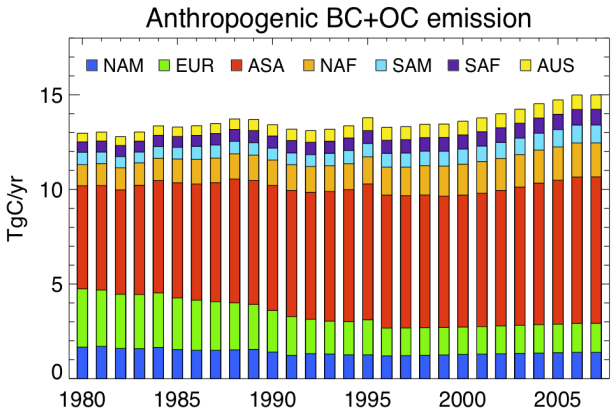
Today's talk:

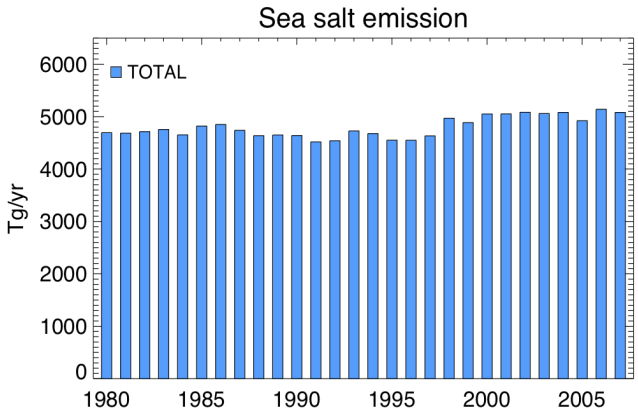
- Showing multi-decadal variations of AOD from 1980 to 2007 from GOCART simulations and satellite data on global and regional scales
- Comparing model simulated short-wave radiative flux at the surface with data from the China Meteorological Administration (CMA, 12 sites) and the Baseline Surface Radiation Network (BSRN, 12 sites)
- Discussing the possible role of aerosols on the multi-decadal variation of surface radiation change – your feedback is appreciated!

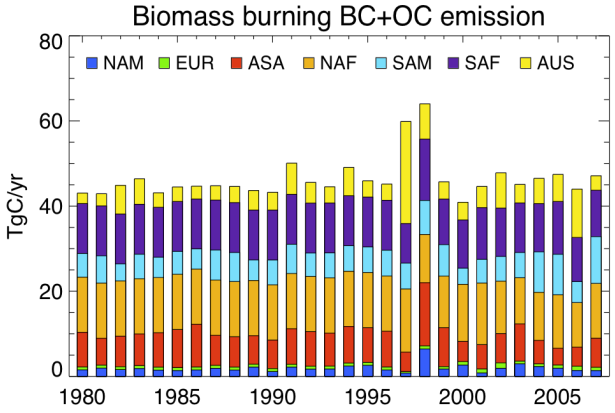
Anthropogenic and natural emissions of aerosols and precursors – 1980 to 2007

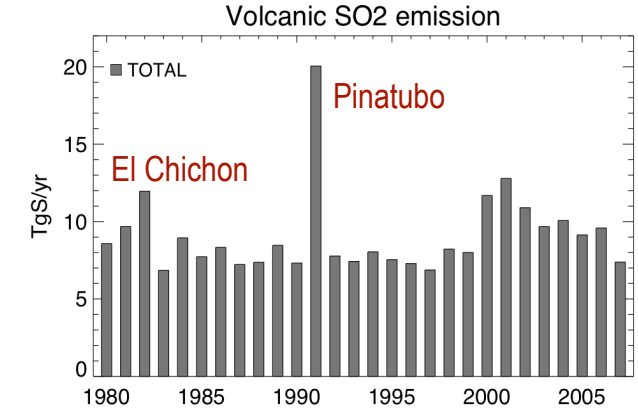


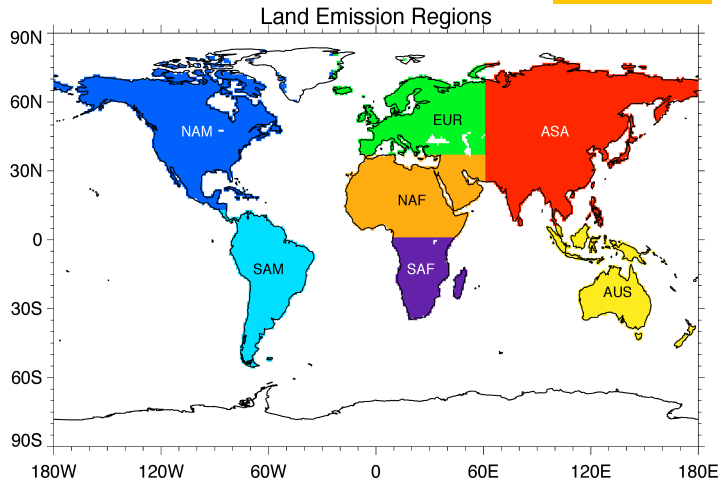












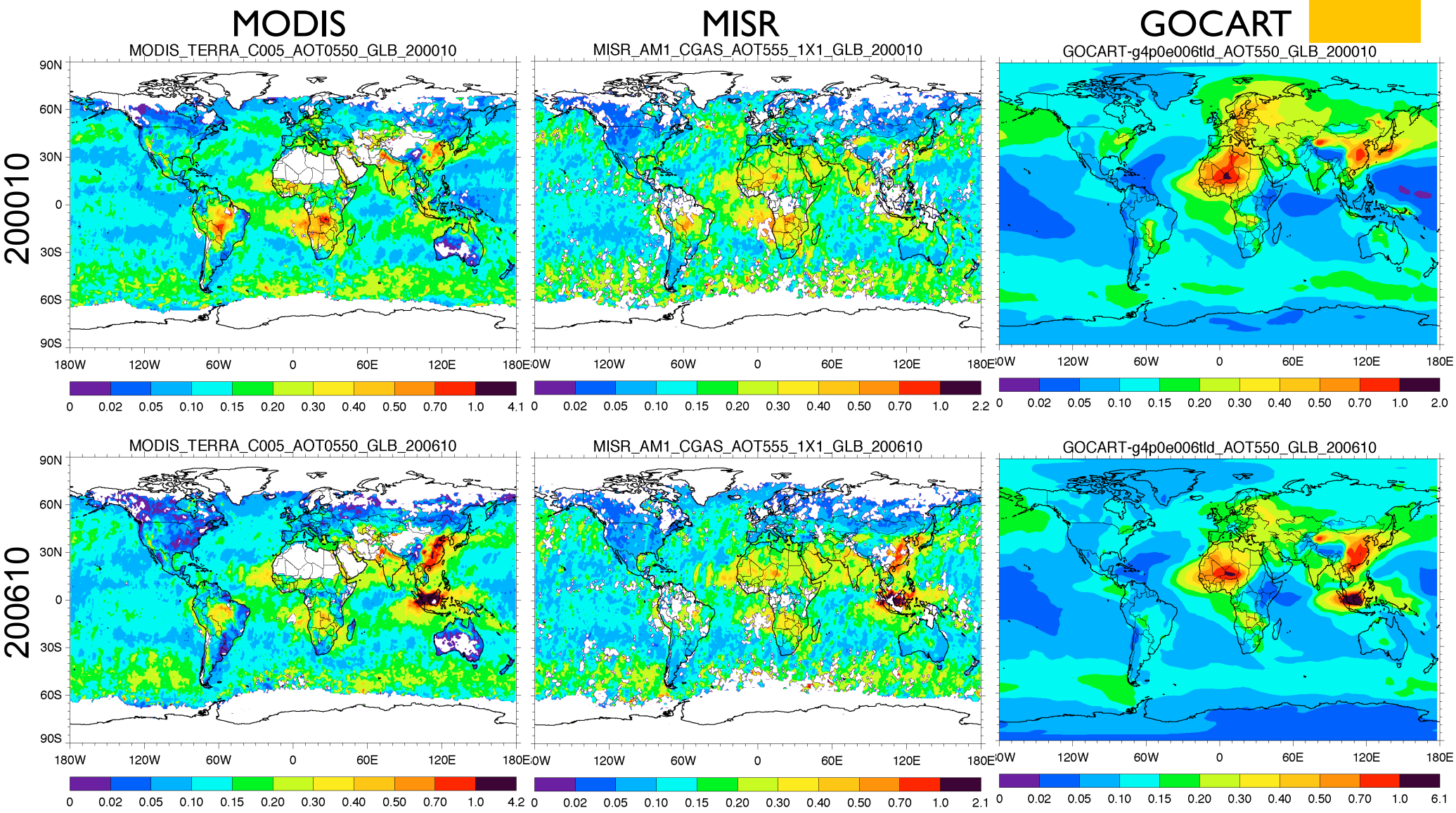
Anthropogenic emissions:

- North America and Europe – decreased
- Asia and other regions – increased

Biomass burning and natural emission:

- Varying from year to year (and place to place)

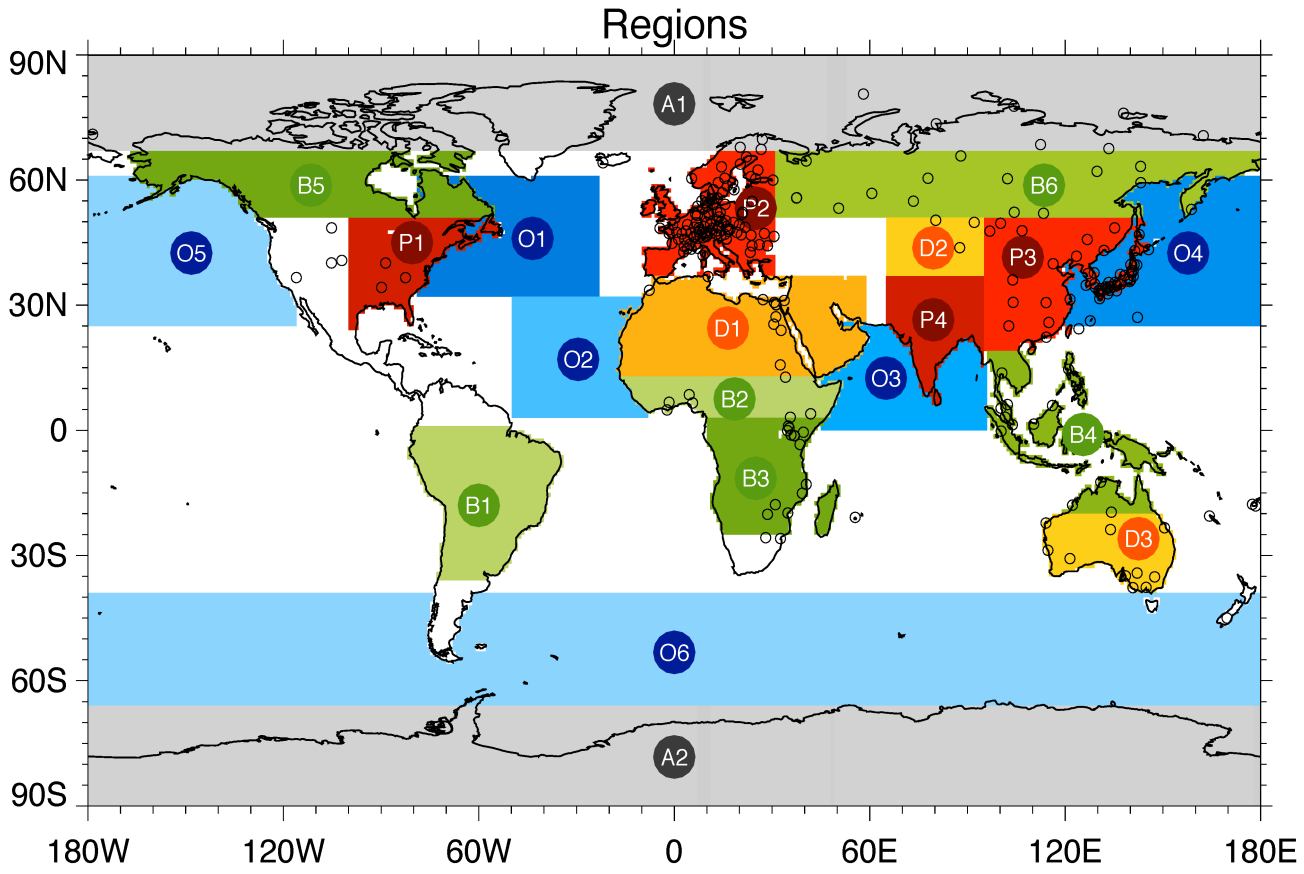
Global distribution of AOD



Comparisons between 200010 and 200610:

- Pollution regions: N. America & Europe decreased, Asia increased
- Biomass burning: Large fire in Indonesia in Oct 2006

Global and regional aerosol trends – comparisons of AOD between model and satellite data



21 regions:

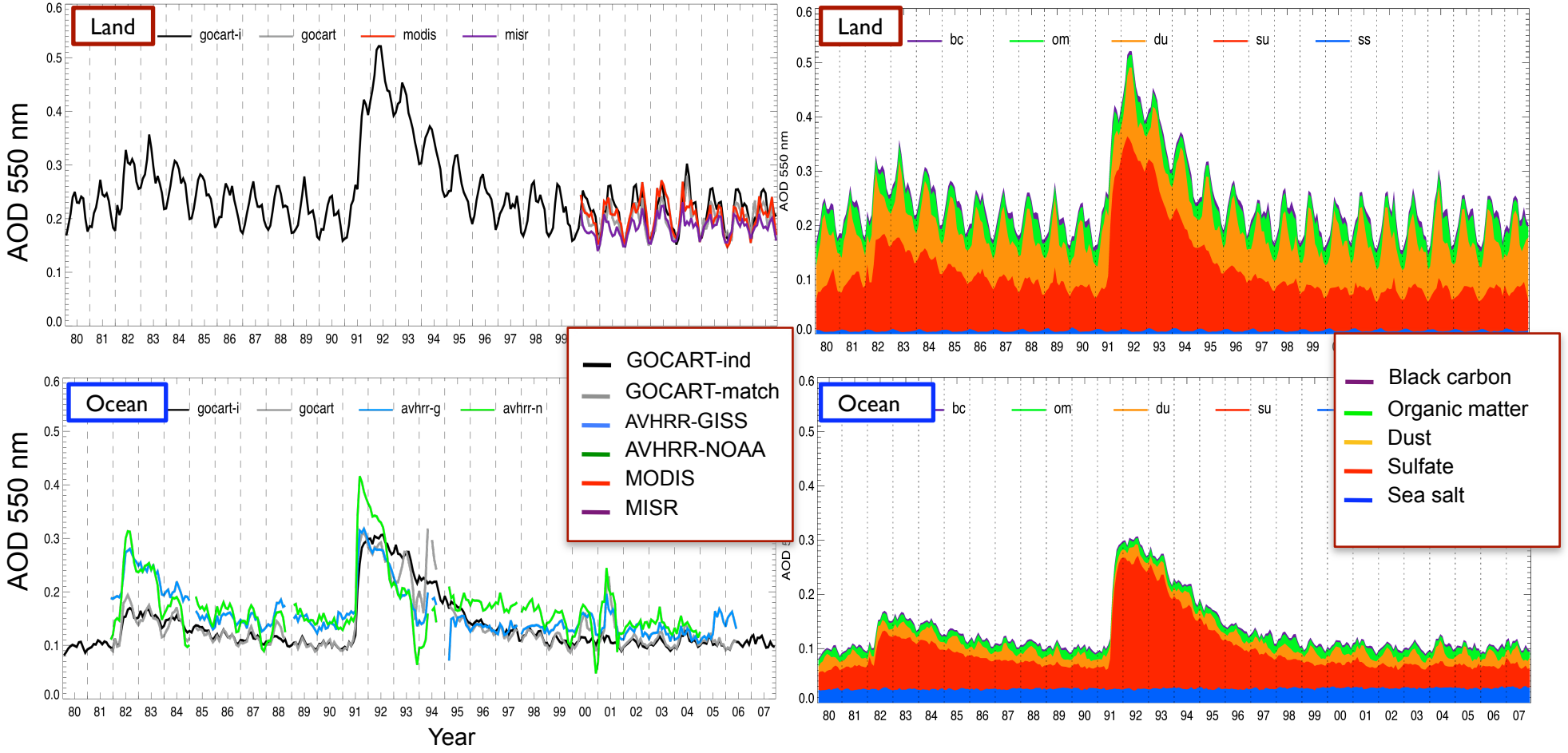
- 4 pollution (P)
- 6 Biomass burning (B)
- 3 Dust/mixed (D)
- 6 Oceanic (O)
- 2 polar (A)

Open circles are locations of 260 GEBA surface radiation sites

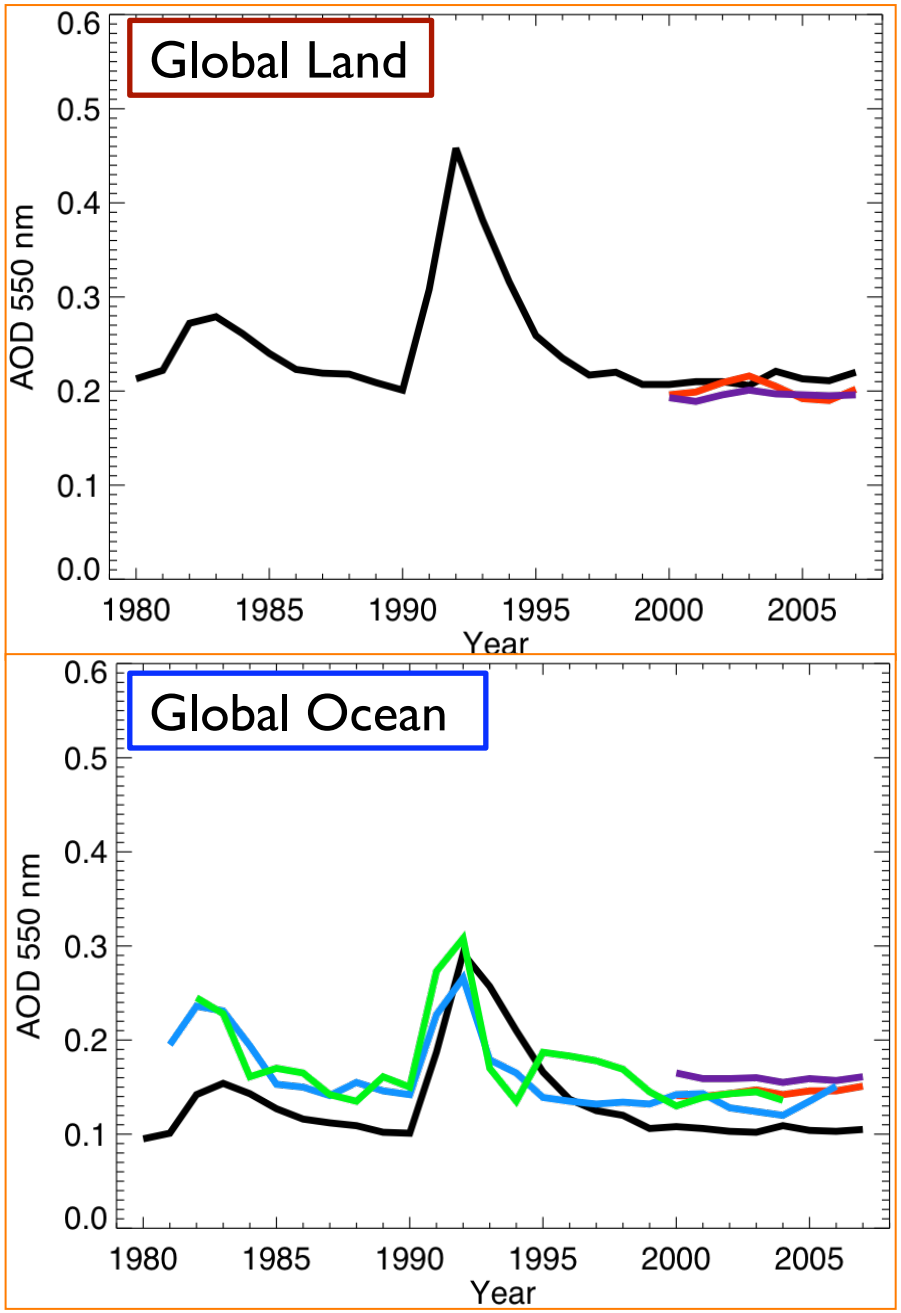
Multi-year variations of AOD – Global land and ocean

Comparisons of monthly mean AOD from co-located satellite data and model

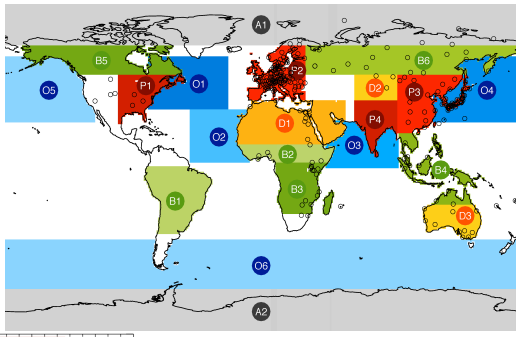
GOCART aerosol composition

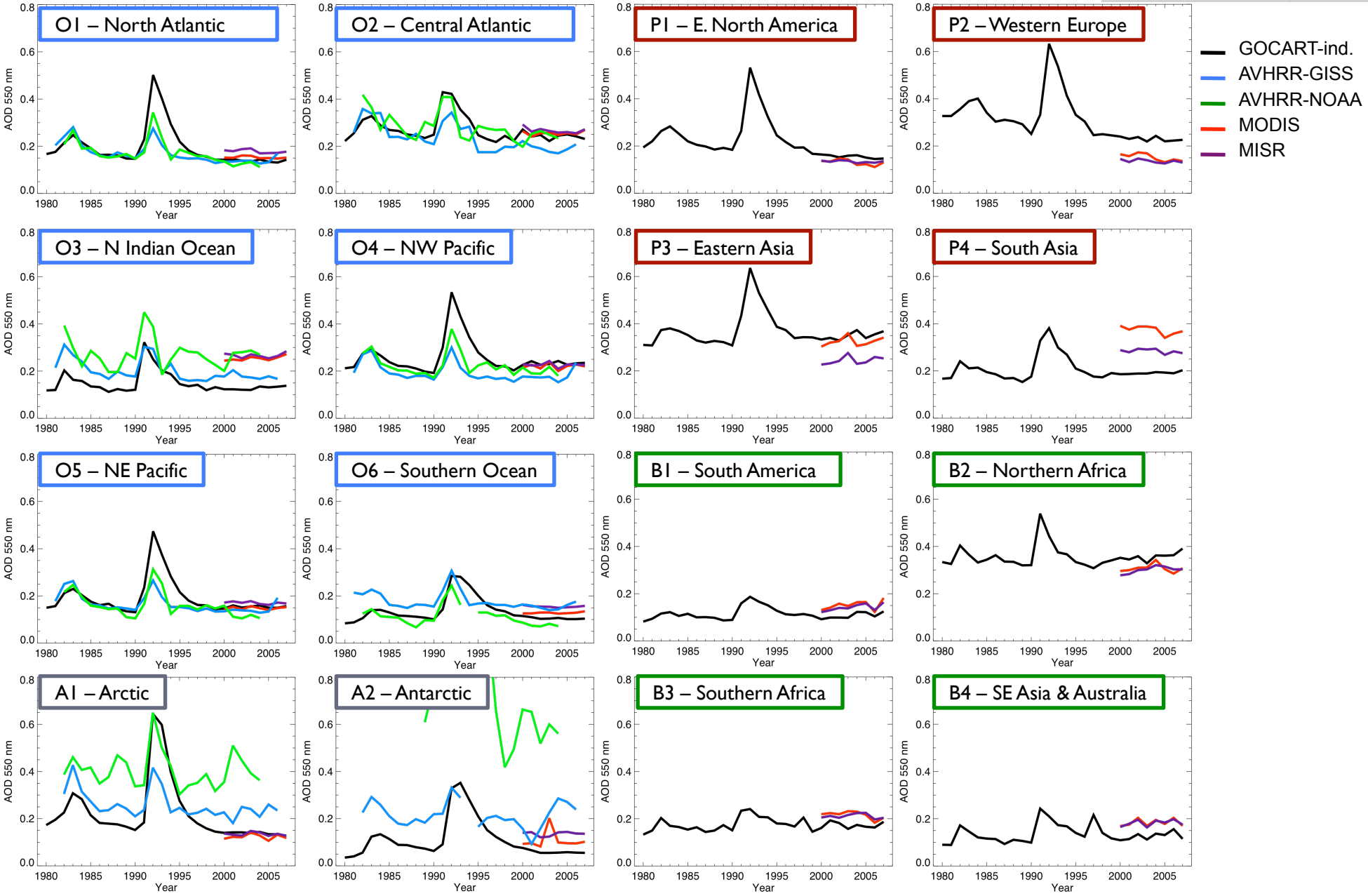


Multi-year variations of AOD – Global land and ocean annual average

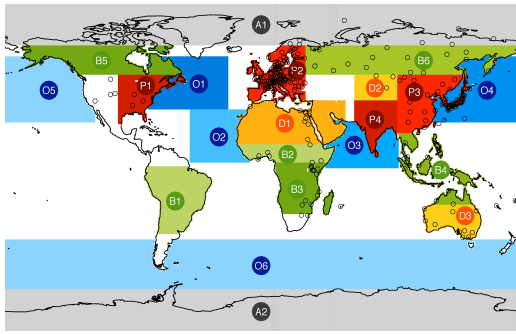


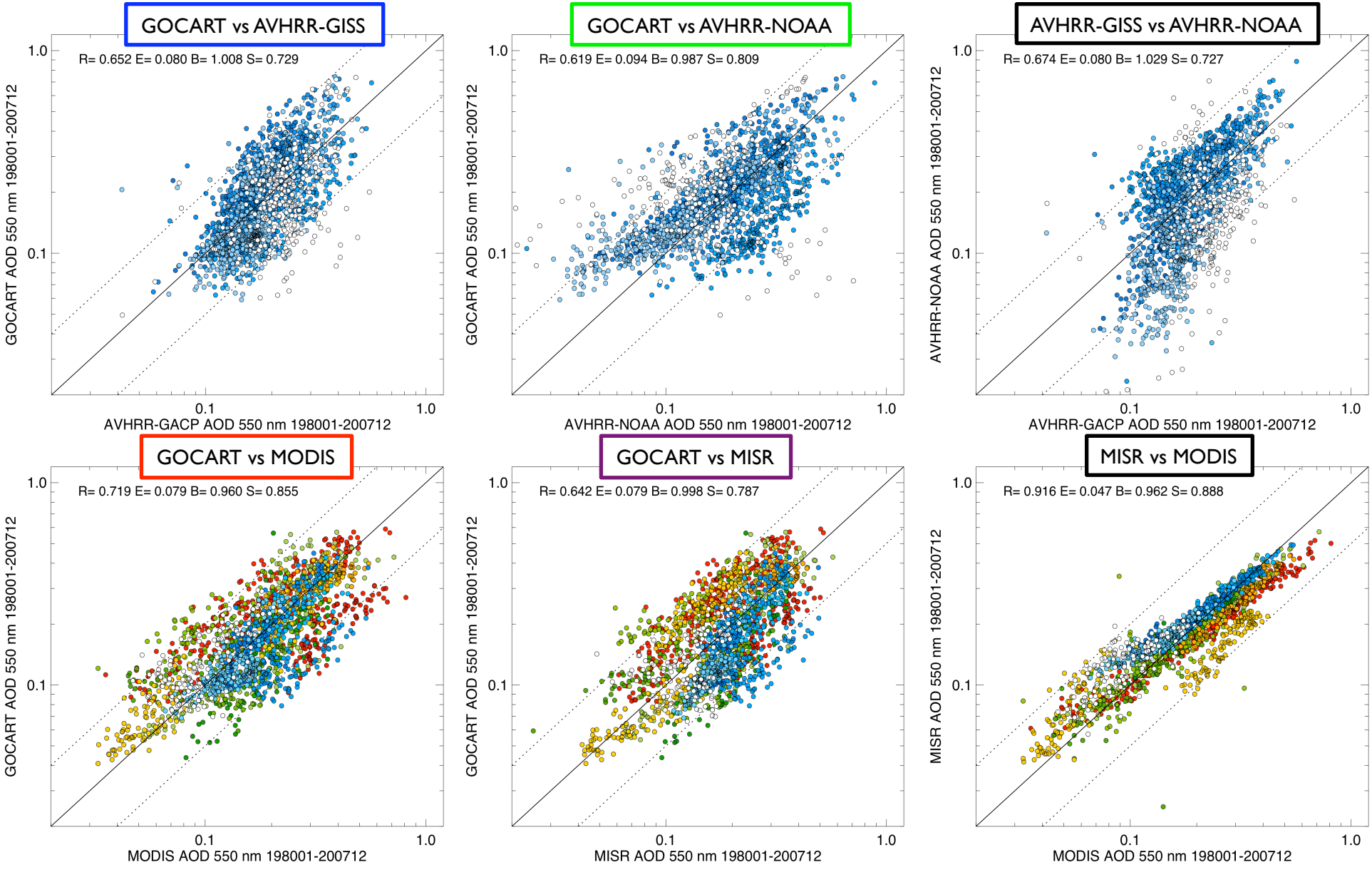
Multi-year variations of AOD – Regional





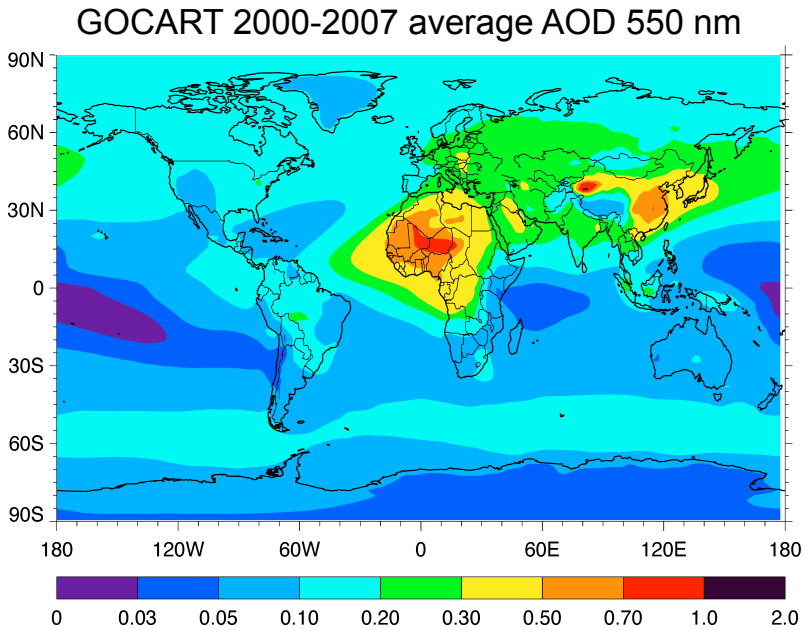
Overall comparisons of AOD (monthly avg, 198001-200712)

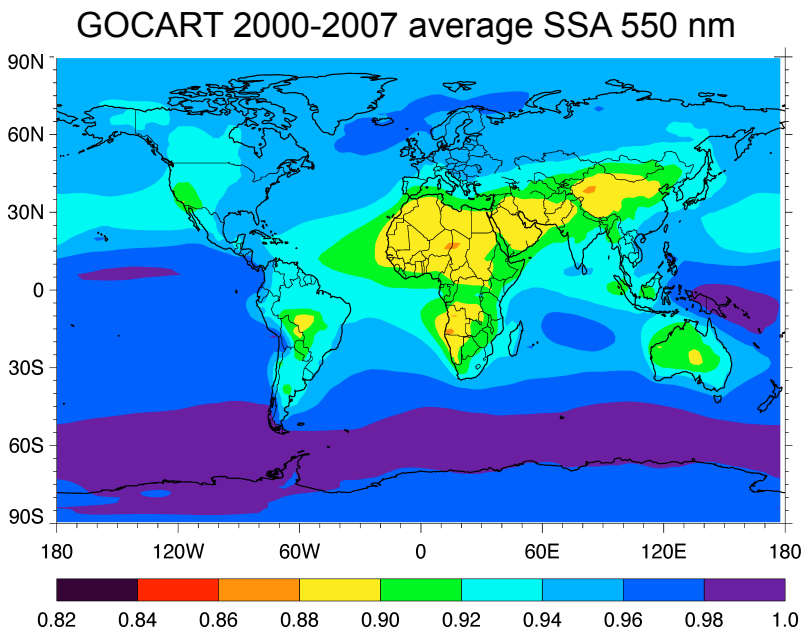




Calculation of surface radiation

- Modeled AOD, single scattering albedo, and asymmetry factor interfaces with the Goddard radiative transfer model
- Climatological CO_2 and ozone from the Goddard models using the same meteorological data as GOCART, and clouds and water vapor from the GEOS-DAS
- We us the all-sky SW downward flux at the surface for comparison with GEBA, BSRN, and CMA data



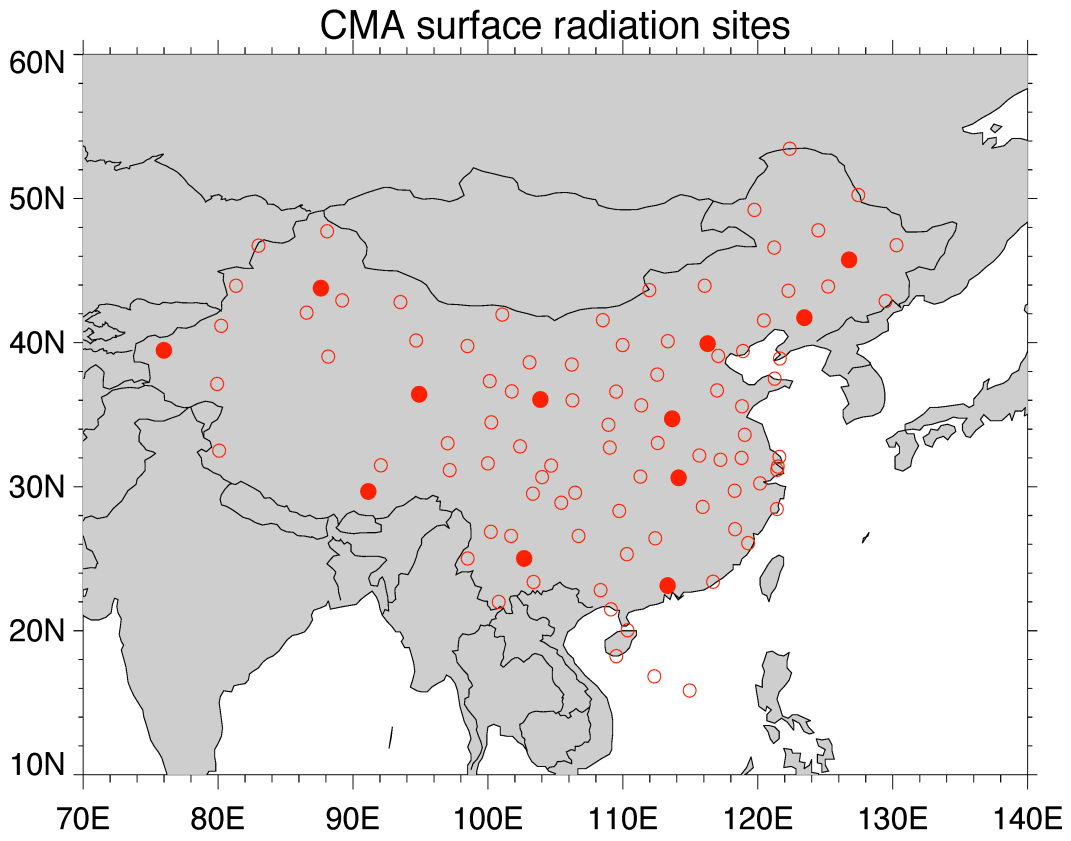


Comparisons with data over China (1980-2005) and BSRN (1992-2004)

- Show example of comparison at a site of absolute values of surface downward flux of
  - All sky total, diffuse, direct
  - Clear sky total, diffuse, direct
- Show surface/TOA ratio ($R_{sfc/toa}$) for all sites and only for clear sky condition (to remove latitudinal/ seasonal dependence of radiation and to remove cloud effects on radiation) therefore mainly aerosol effects are shown
- Show anomalies of clear sky $R_{sfc/toa}$ to compare "trends" between data and model

Comparison with surface radiation data from China Meteorological Administration (CMA) sites

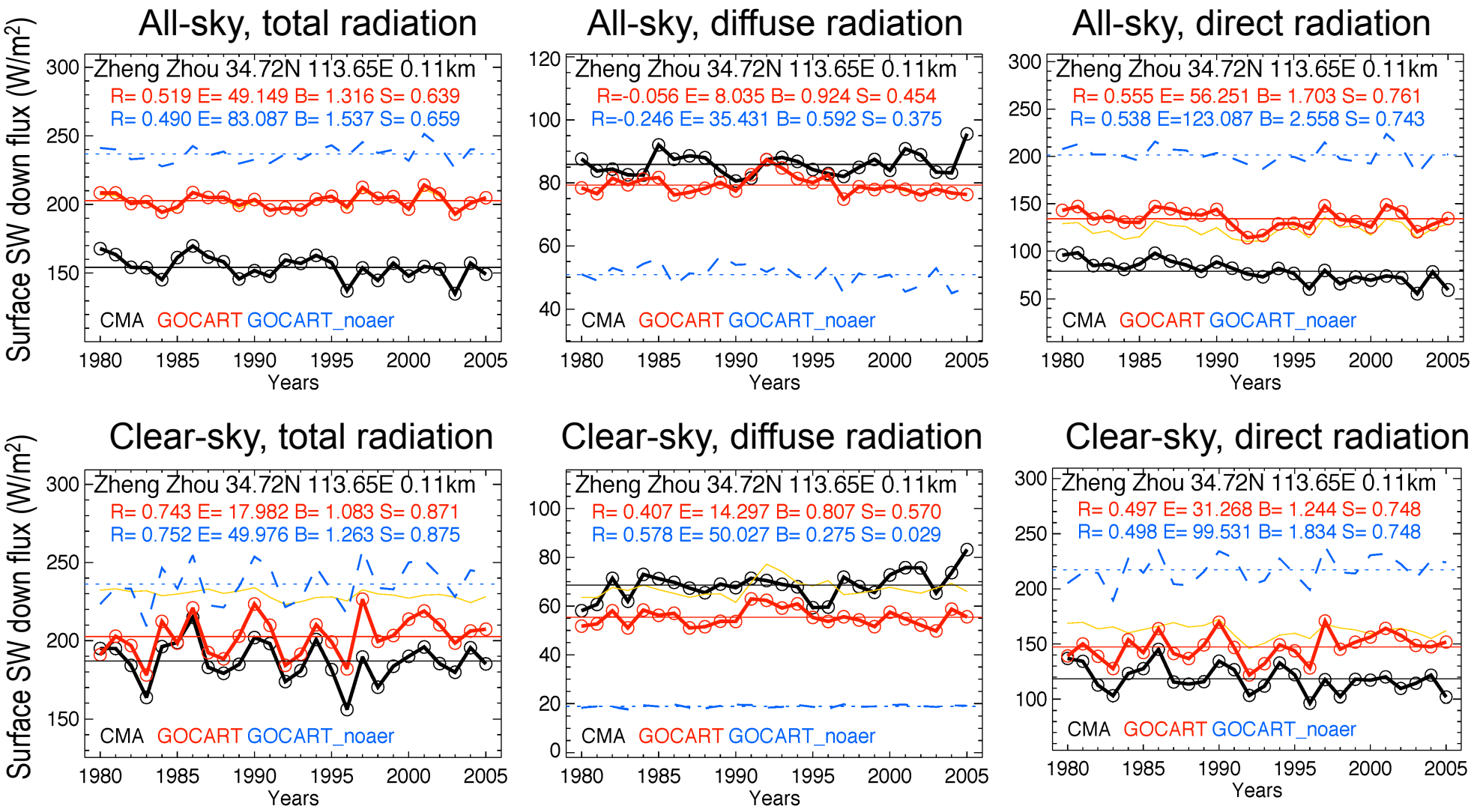
- 122 sites measuring daily total downward SW flux during 1980-2005 timeframe
- Only 12 of them have separate measurements of total, diffuse, and direct radiative flux data nearly continuously from 1980 to 2005 and have cloud fraction information
- We mask "clear sky" with observed cloud fraction less than 10%
- For trend comparisons, we construct "annual average" values by averaging the matching dates when observations are made



1. Example at one site

- Comparison of absolute SW downward flux values

Example of comparison at one site (Zheng Zhou, eastern China)



Overall comparison at all CMA sites:

- Overall, model calculated "all sky" total downward radiation is higher than CMA data, mainly from higher direct radiation from the model
- Under "clear sky" condition the agreement is better (except diffuse)

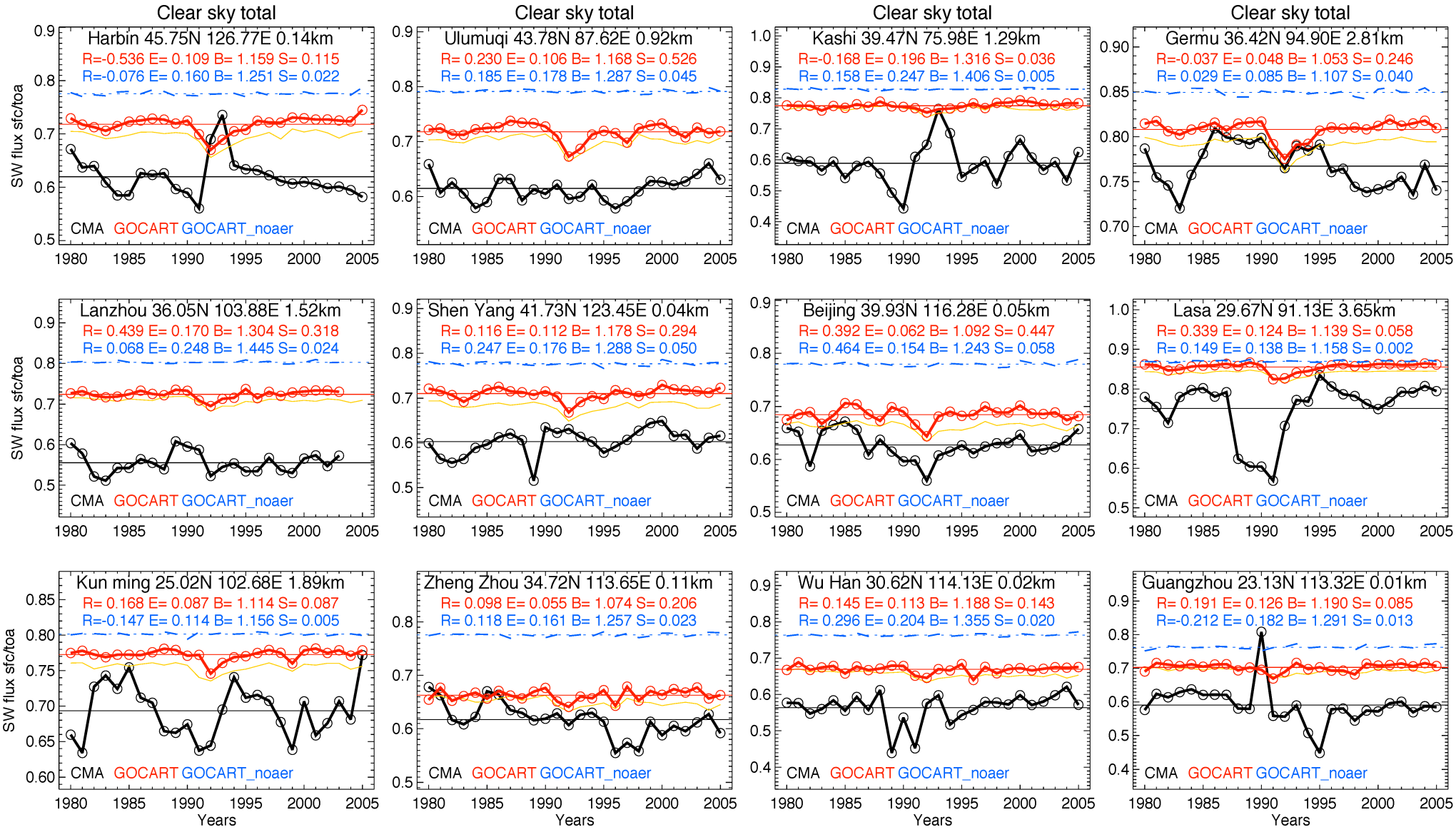
	Total	Diffuse	Direct
All sky	+35%	-4%	+57%
(no aer)	(+49%)	(-32%)	(+103%)
Clear sky	+13%	-20%	+26%
(no aer)	(+24%)	(-68%)	(+60%)

- Without aerosol the agreement would be much worse

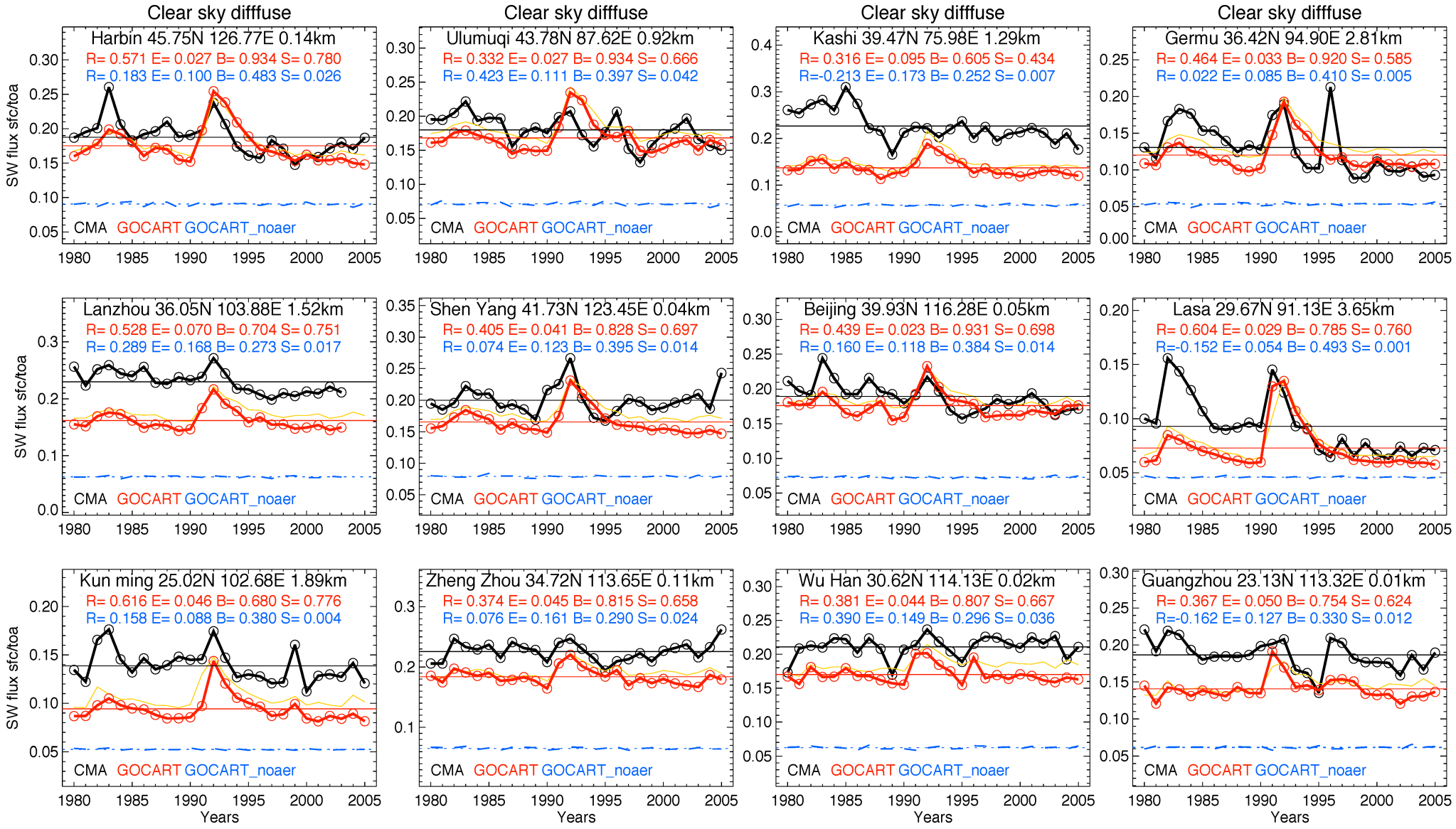
2. Clear sky, surface/TOA ratio ($R_{sfc/toa}$) at all sites

- To isolate signal mostly due to aerosols

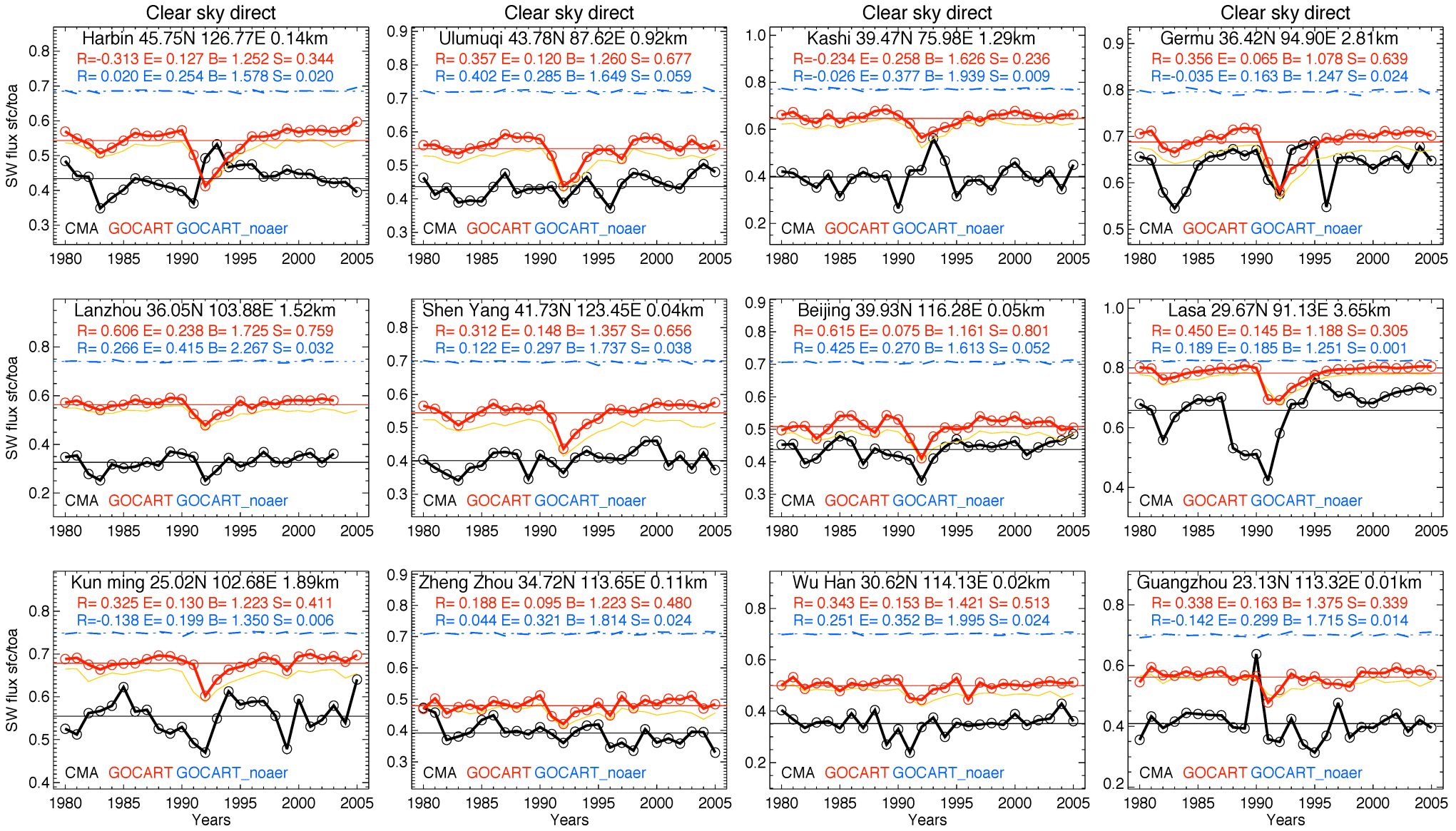
Clear sky, $R_{sfc/toa}$, total rad, 12 CMA sites



Clear sky, $R_{sfc/toa}$, diffuse rad, 12 CMA sites



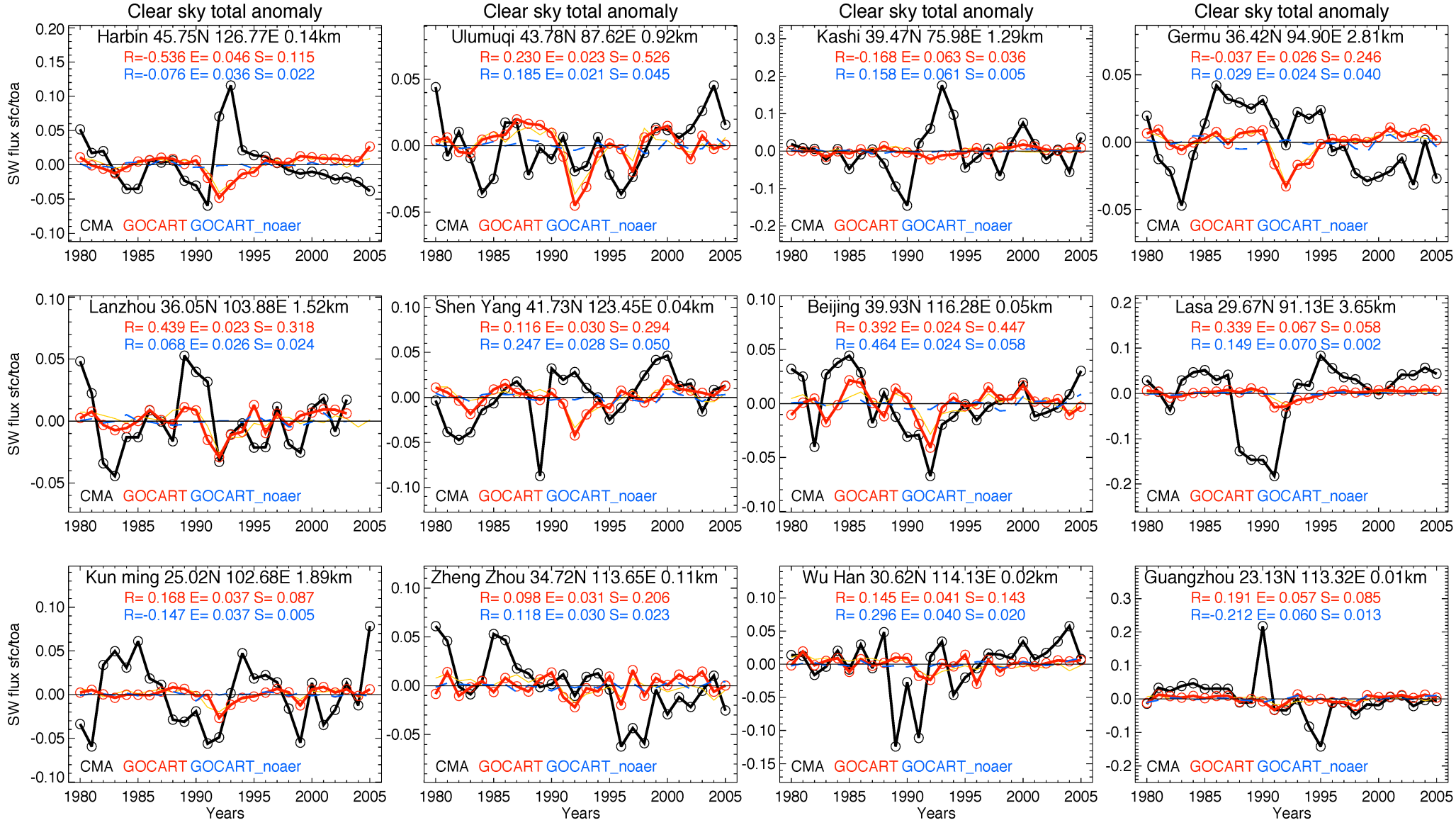
Clear sky, $R_{sfc/toa}$, direct rad, 12 CMA sites



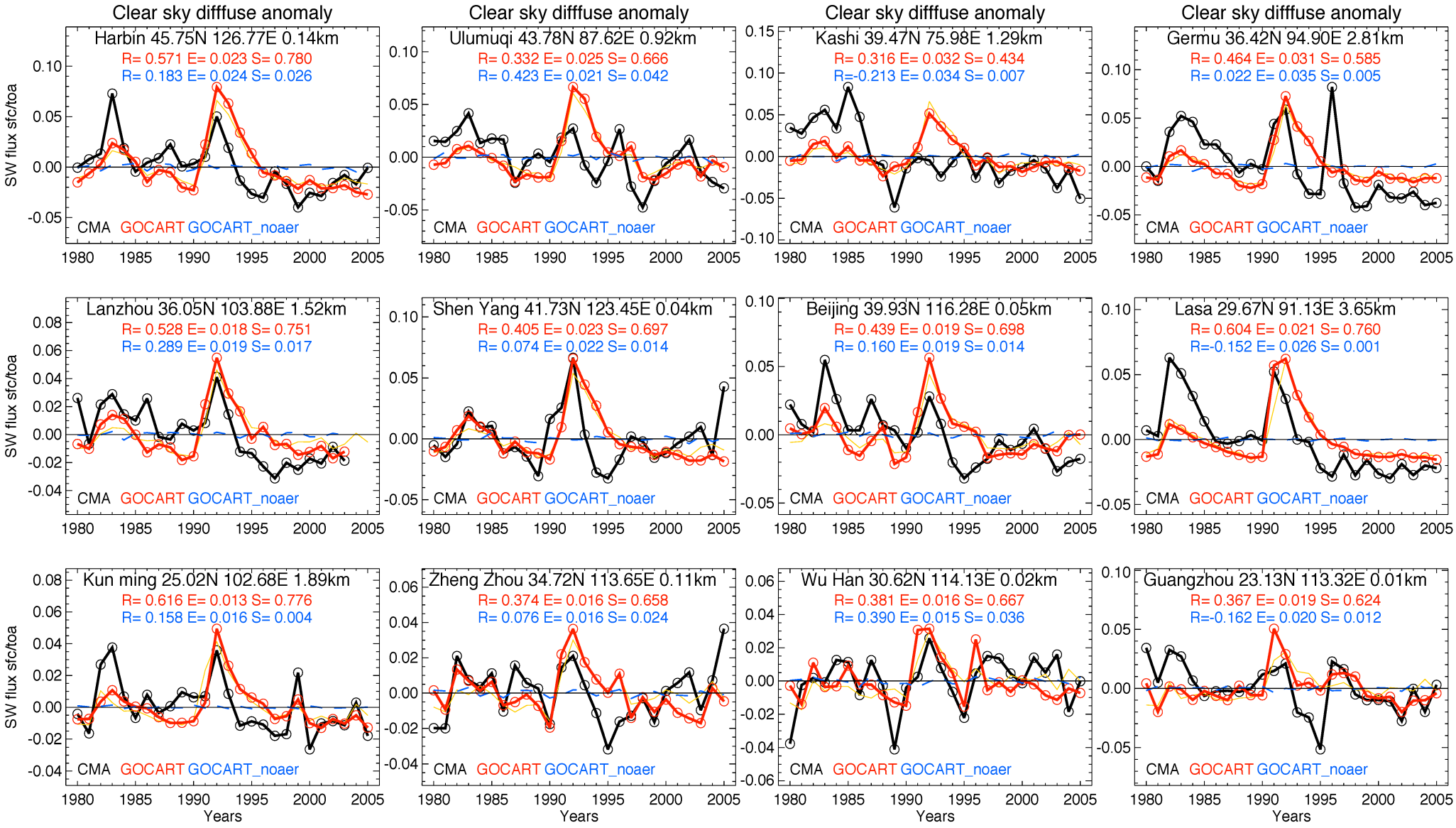
3. Anomaly of clear sky $R_{sfc/toa}$

- To compare "trends" regardless of observation and model differences in absolute radiation or $R_{sfc/toa}$

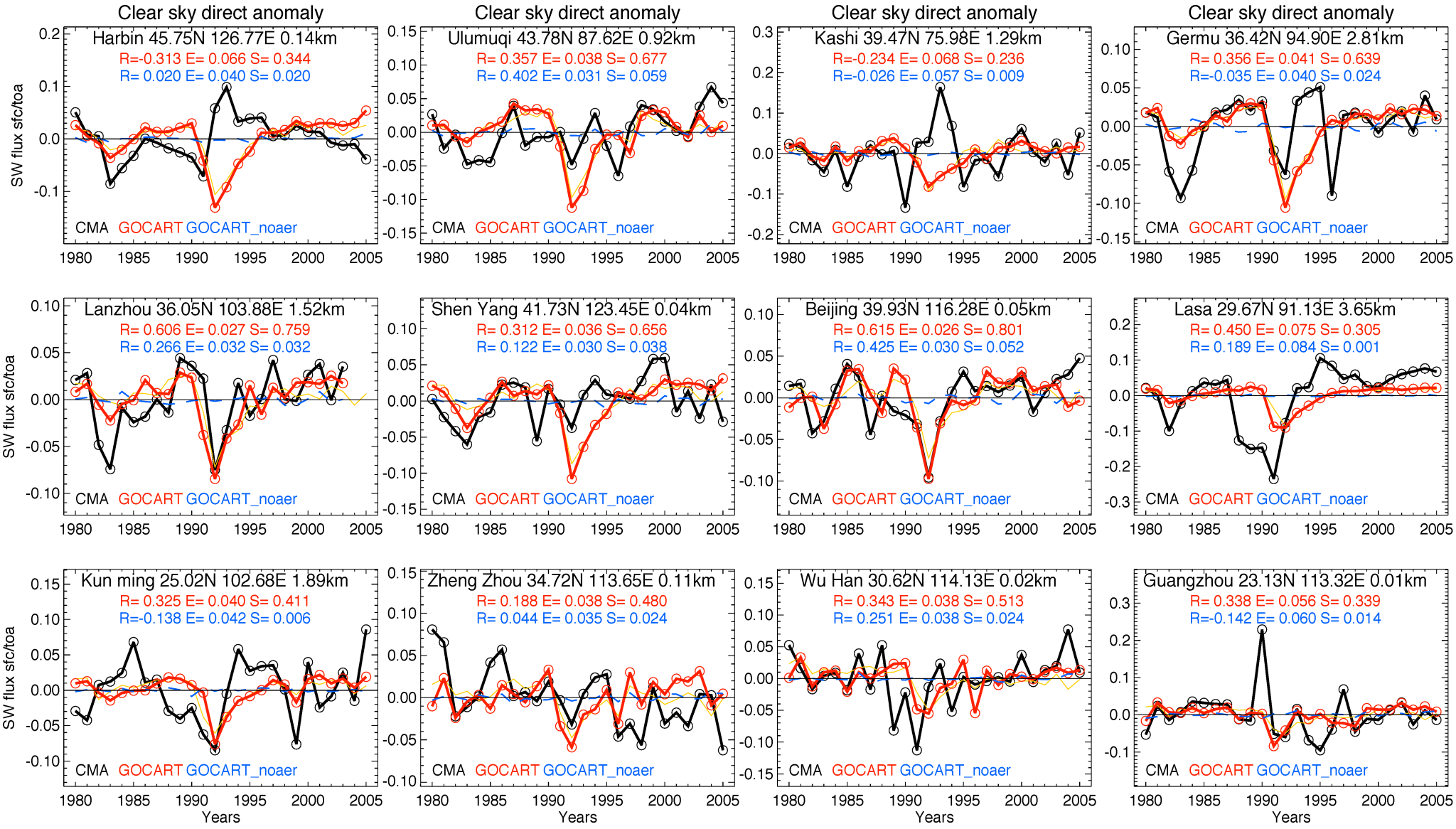
Anomaly, Clear sky, $R_{sfc/toa}$, total rad,12 CMA sites



Anomaly, clear sky, $R_{sfc/toa}$, diffuse rad, 12 CMA sites

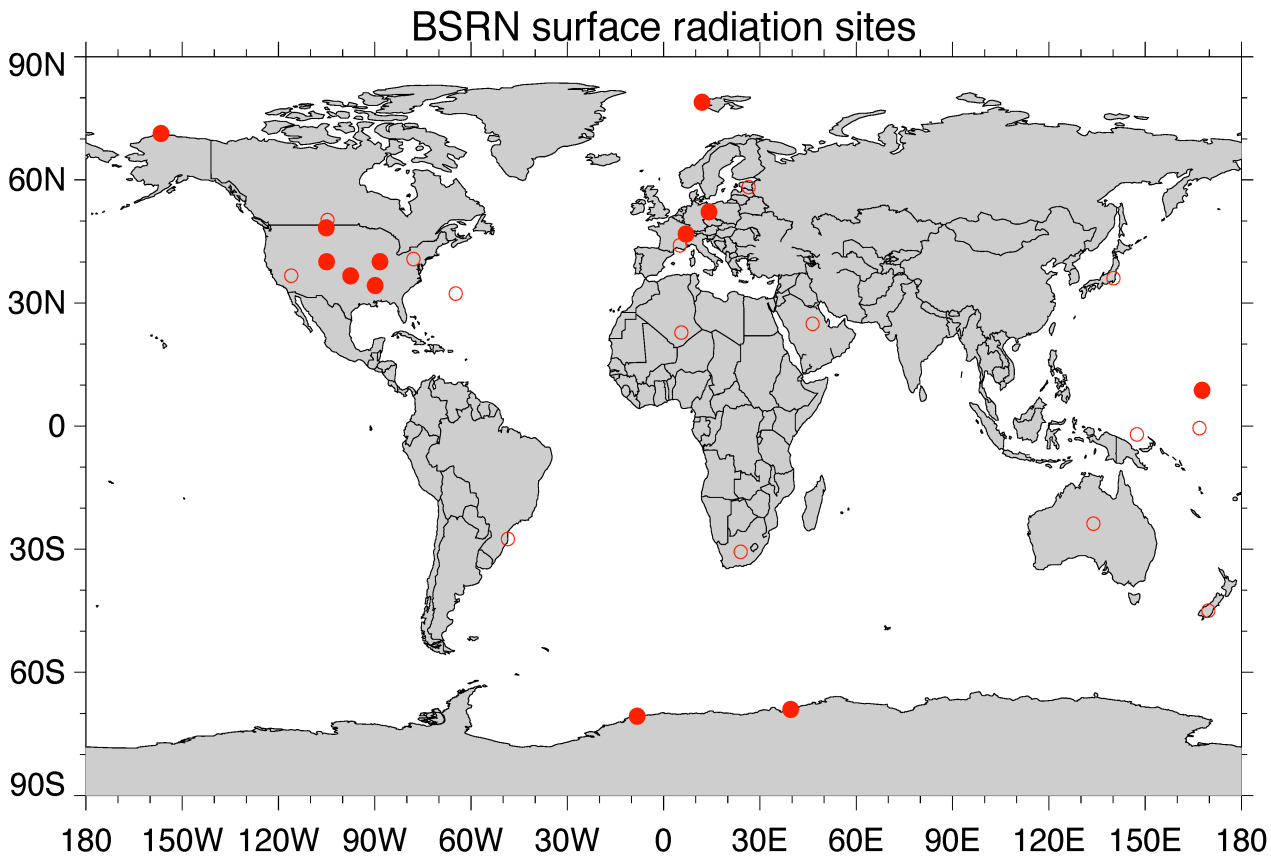


Anomaly, clear sky, $R_{sfc/toa}$, direct rad, 12 CMA sites



Comparison with surface radiation data from Baseline Surface Radiation Network (BSRN) sites

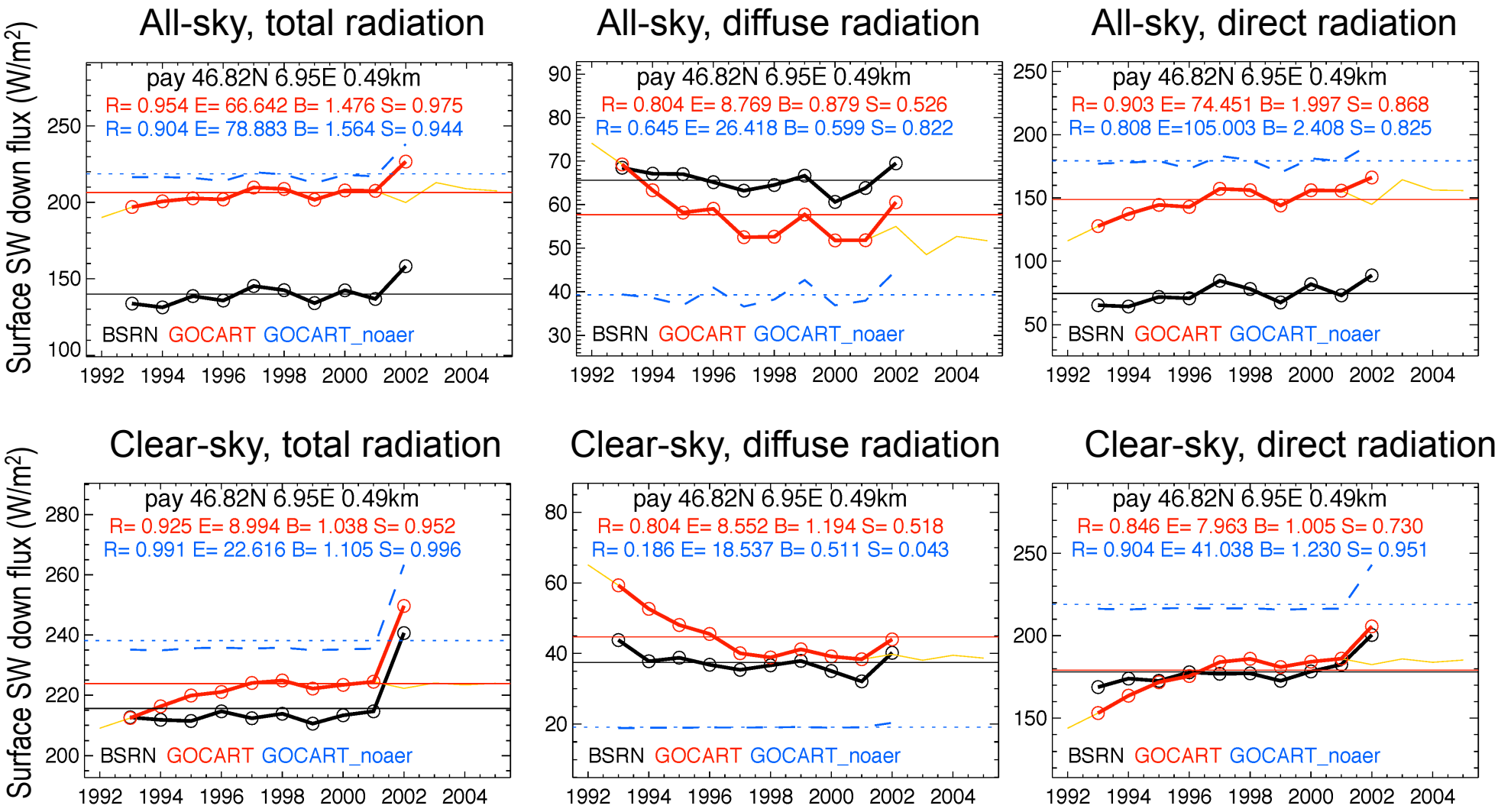
- 28 high frequency measurement sites recording total, diffuse, and direct radiative flux data under all sky and clear sky conditions starting late 1992
- Compare with 12 sites that have the most continuous and longest data records
- We use monthly average data (from Stefan Kinne)
- For trend comparisons, we construct "annual average" values by averaging the matching months when observations are made



1. Example at one site

- Comparison of absolute SW downward flux values

Example of comparison at one site (Payerne, Switzerland)



Overall comparison at all BSRN sites:

- Overall, model calculated "all sky" total downward radiation is higher than BSRN data, mainly from higher direct radiation from the model. Diffuse is lower than BSRN data
- Under "clear sky" condition the agreement is much better for total and direct, but diffuse is higher

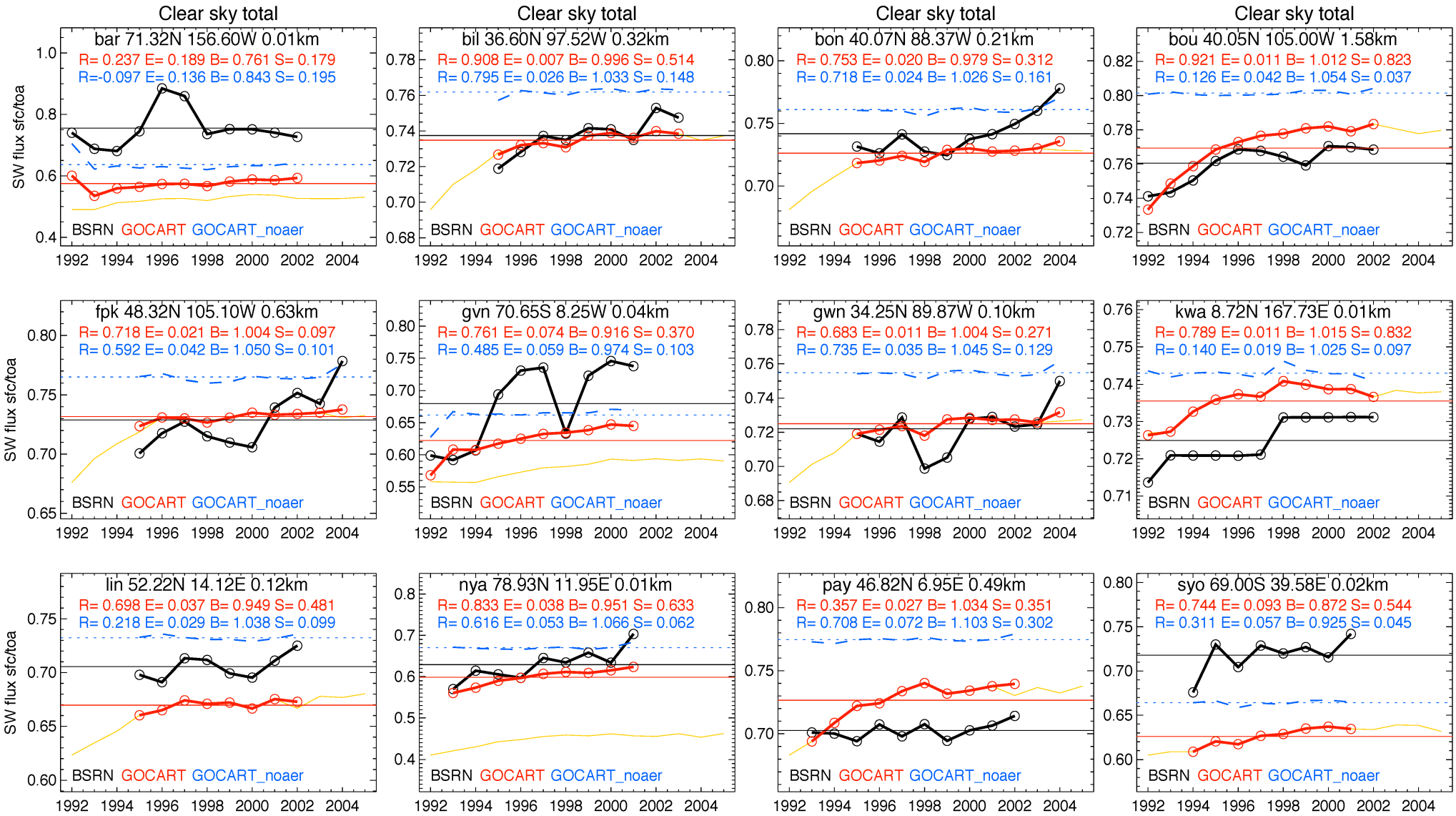
	Total	Diffuse	Direct
All sky	+23%	-17%	+51%
(no aer)	(+28%)	(-34%)	(+72%)
Clear sky	+0.2%	+16%	-3%
(no aer)	(+5%)	(-40%)	(+12%)

- Without aerosol the agreement would be much worse

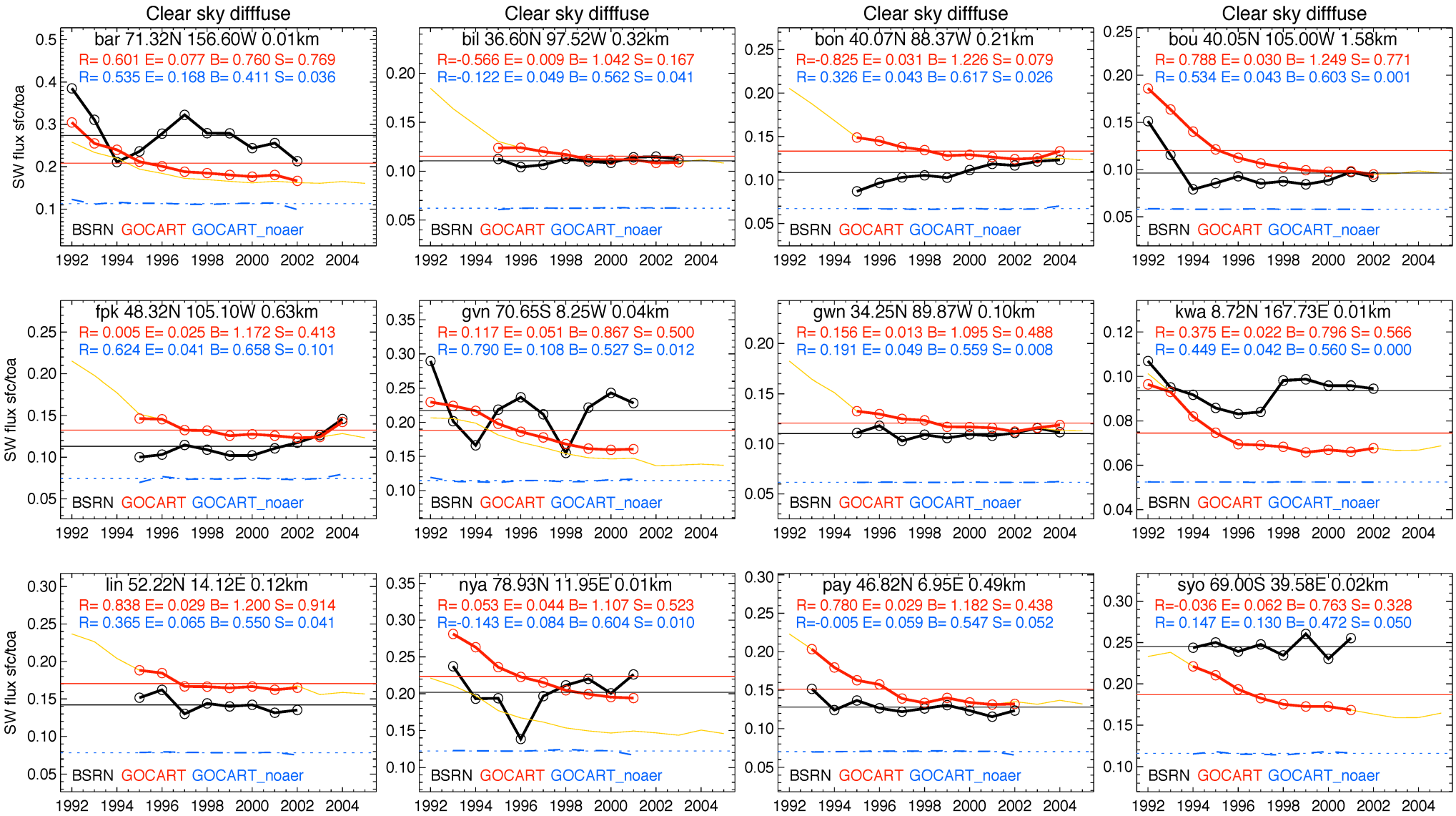
2. Clear sky, surface/TOA ratio ($R_{sfc/toa}$) at all sites

- To isolate signal mostly due to aerosols

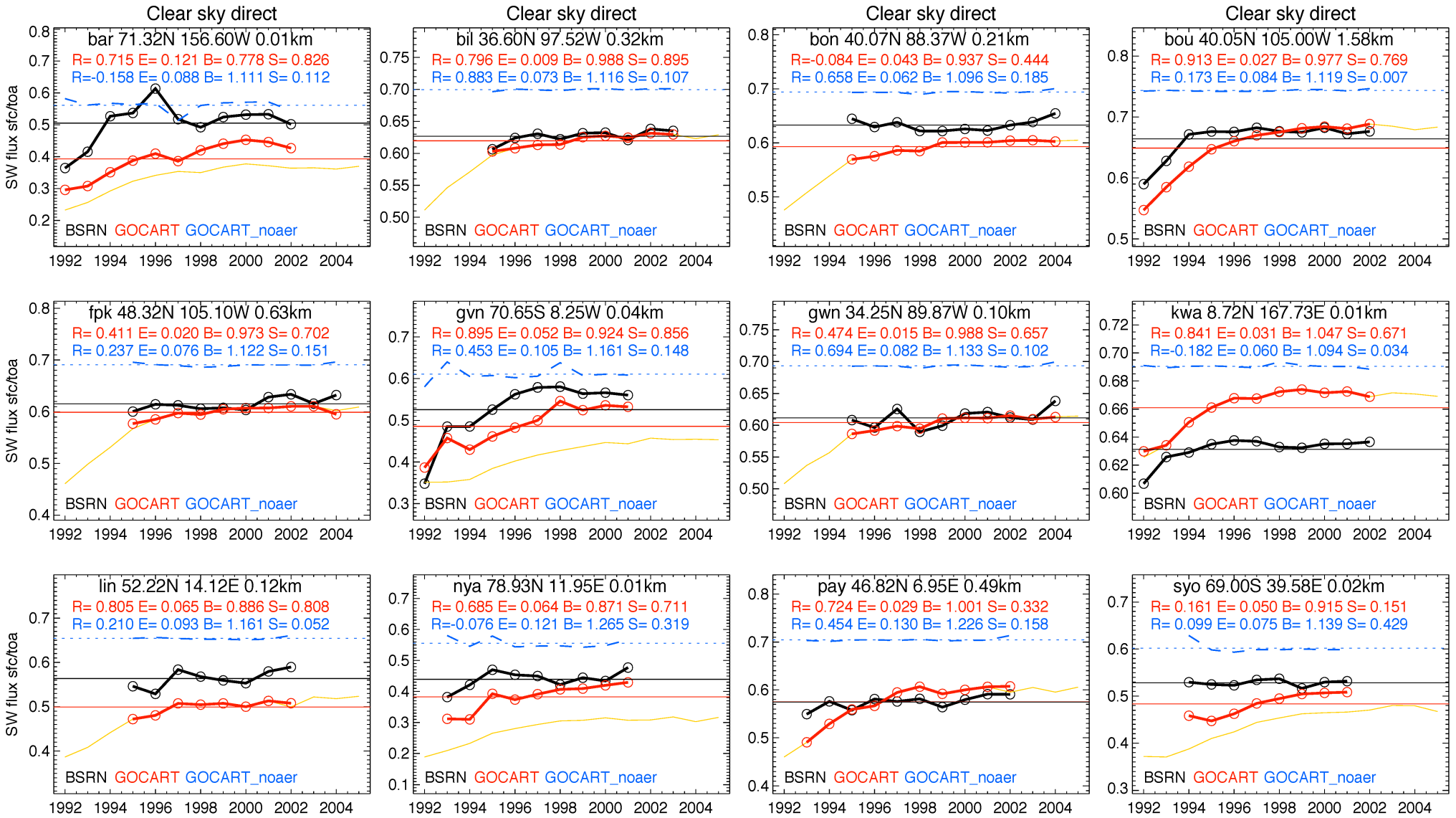
Clear sky, $R_{sfc/toa}$, total rad, 12 BSRN sites



Clear sky, $R_{sfc/toa}$, diffuse rad, 12 BSRN sites



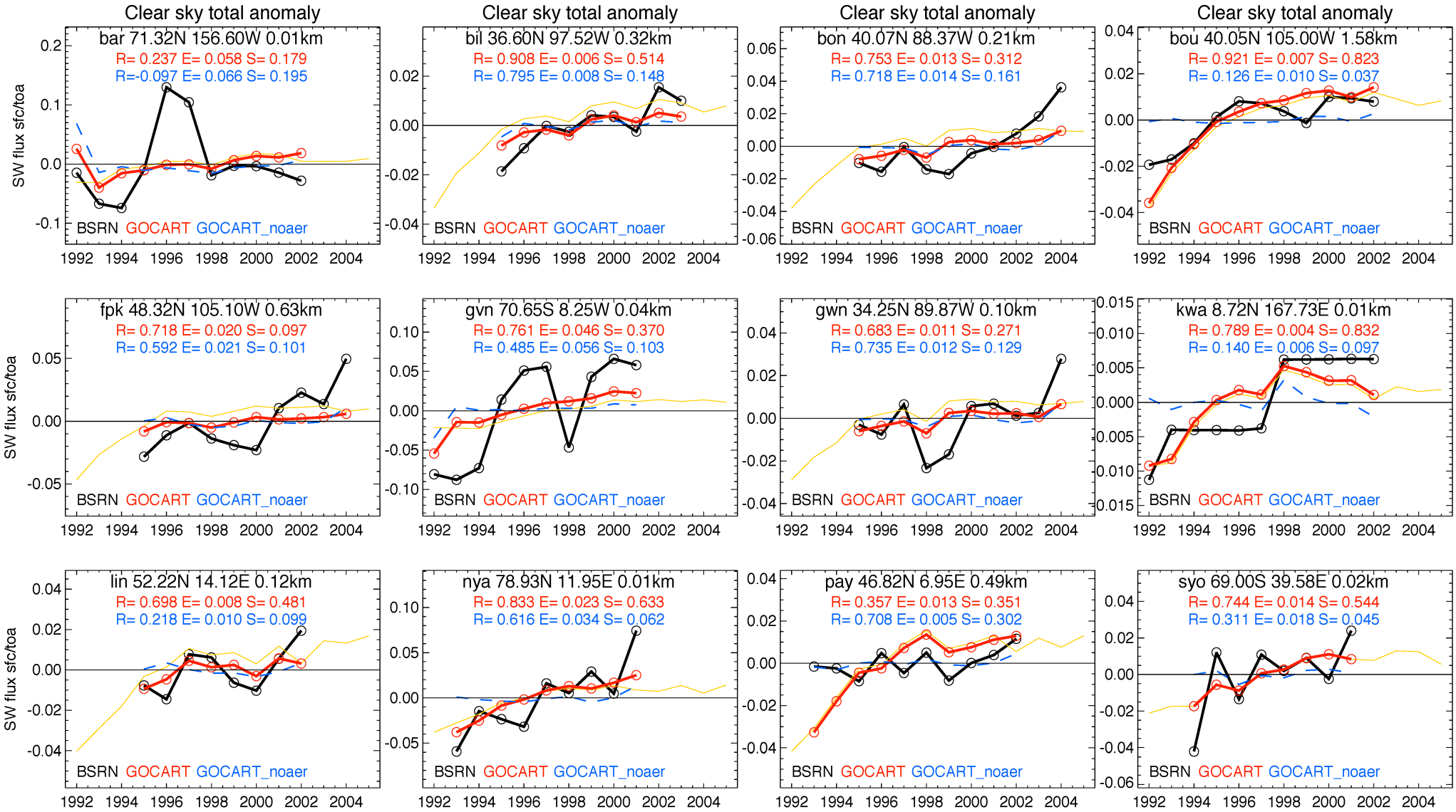
Clear sky, $R_{sfc/toa}$, direct rad, 12 BSRN sites



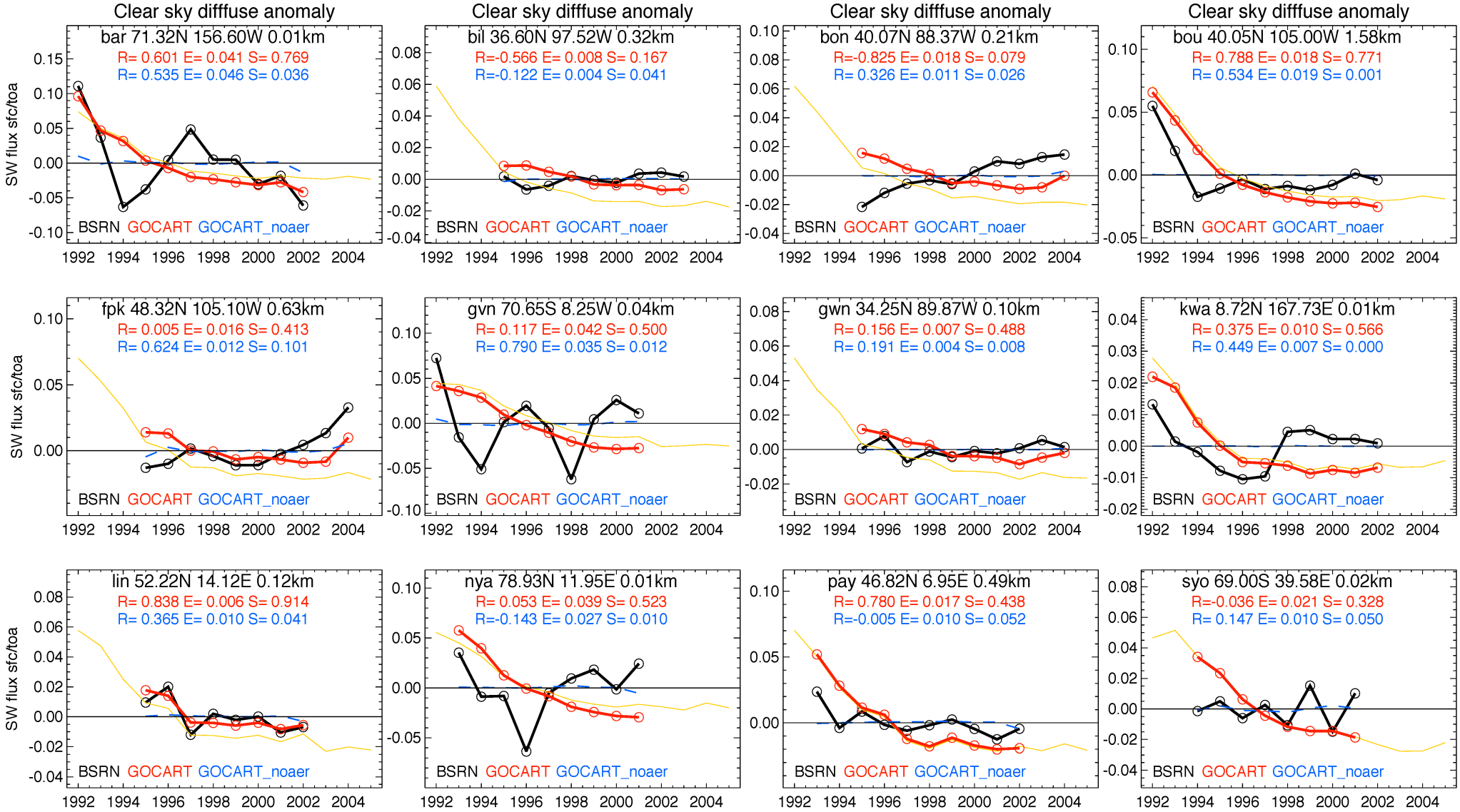
3. Anomaly of clear sky $R_{sfc/toa}$

- To compare "trends" regardless of observation and model differences in absolute radiation or $R_{sfc/toa}$

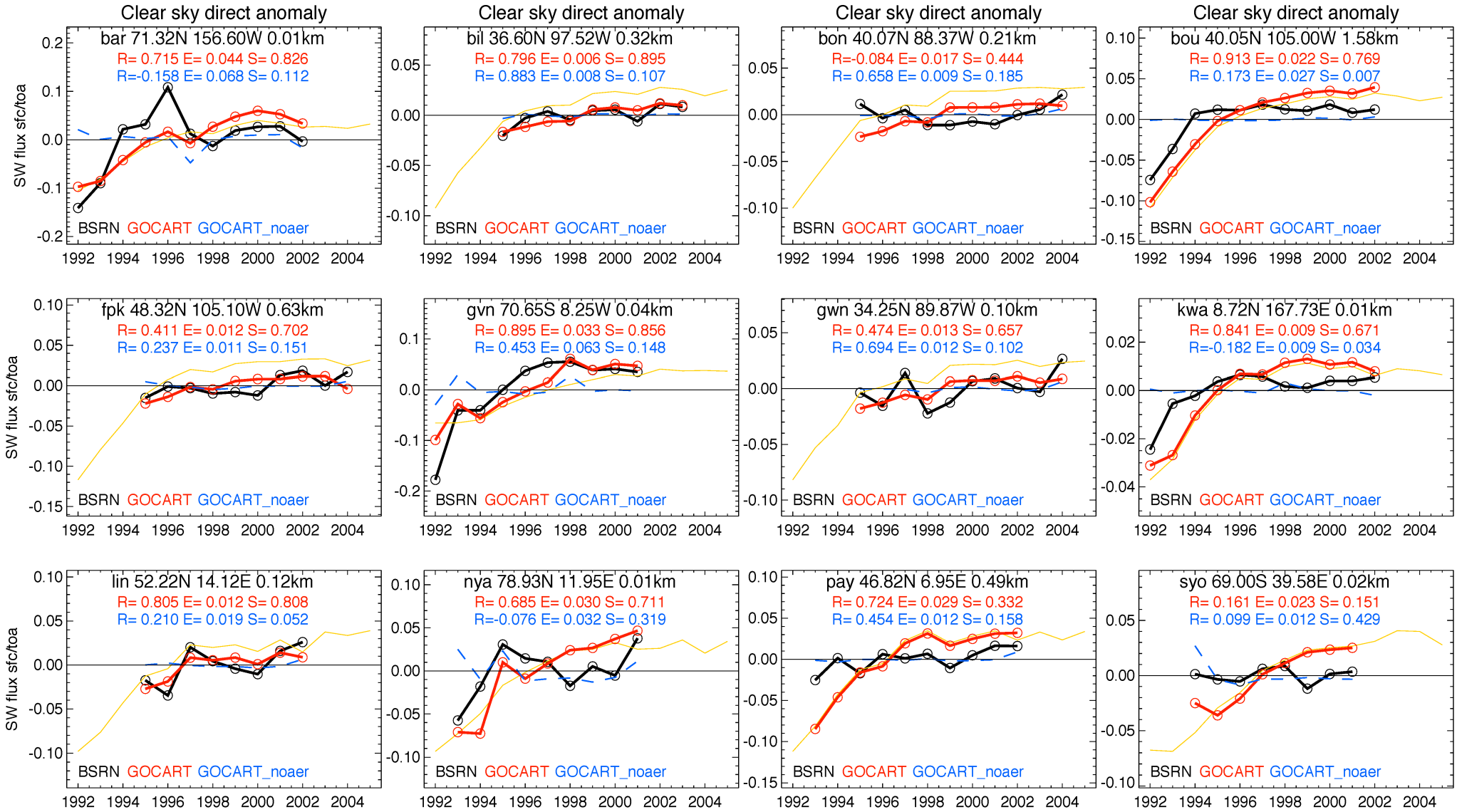
Anomaly, clear sky, $R_{sfc/toa}$, total rad, 12 BSRN sites



Anomaly, clear sky, $R_{sfc/toa}$, diffuse rad, 12 BSRN sites



Anomaly, clear sky, $R_{sfc/toa}$, direct rad, 12 BSRN sites



Remarks

- With seasonal and interannual variation of anthropogenic, biomass burning, and natural emissions, the model simulated global distributions of AOD and its multi-decadal variations agree with different satellite observations within a factor of 2
- Comparison with surface downward radiation data over China and BSRN sites shows
  - Total SW downward flux at surface is too high from the model, especially under all-sky condition
  - This overestimate is mainly due to the overestimate of direct radiation
- Aerosol attenuates the direct radiation but amplifies the diffuse radiation. Aerosol has to be accounted for on simulating surface radiation.
- The best way to extract aerosol effects on surface radiation is to look the clear sky surface to TOA ratio with direct and diffuse radiation separately
- The clearer way to assess the aerosol effects on radiation trends is to look the anomaly with and without aerosols

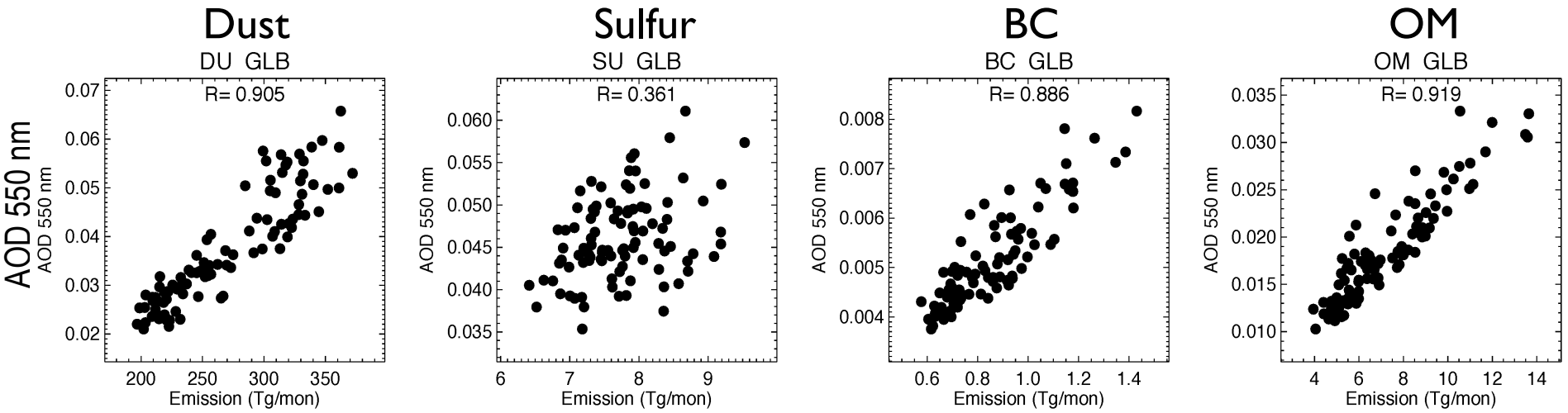
Remarks (cont'd)

- Over the BSRN sites (non-Asia), there is a general trends of increasing surface total and direct radiation but decreasing of diffuse radiation in clear sky from 1992 to 2004, reflecting the decreasing of aerosol over North America and Europe
- Over China the trends from 1980 to 2005 are not clear despite the large increase of anthropogenic emissions over China during the same period

Next steps

- Understand the relationships between emission, AOD, and surface radiation on global and regional scales
- Understand the bias of clear sky direct and diffuse radiation (e.g., non-spherical dust effects, mixing state effects)
- Trends in China in non-Pinatubo period

Relationship between emission and AOD – by species, global monthly average



- For primary aerosols, emission and AOD are linearly related on global bases, but the relationship changes with regions and size of regional domains
- For secondary aerosols (e.g. sulfate) the relationship is less clear