INSTITUTE FOR ATMOSPHERIC AND CLIMATE SCIENCE

Radiative flux analyses using surface observations

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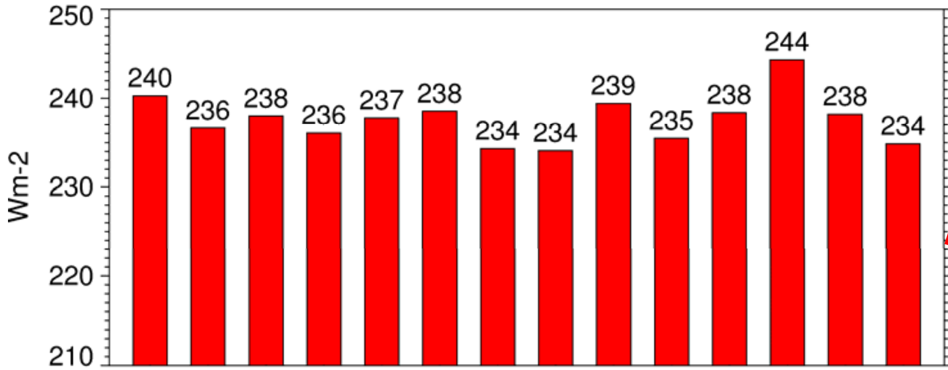
Solar radiation budgets in IPCC AR4 GCMs

Wild 2005, Geophys. Res. Lett. 32
Wild 2008, Tellus (in press)

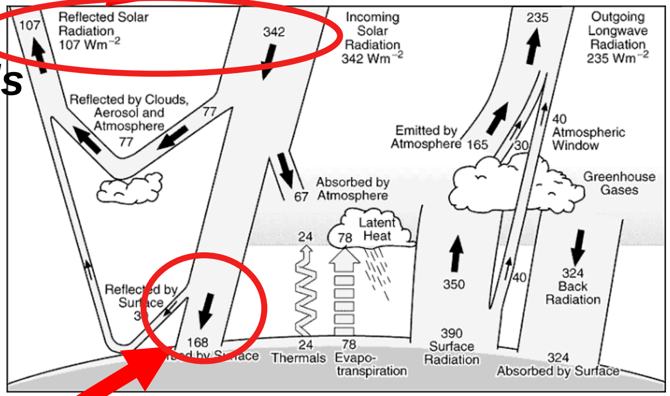
Absorbed solar radiation
top of atmosphere



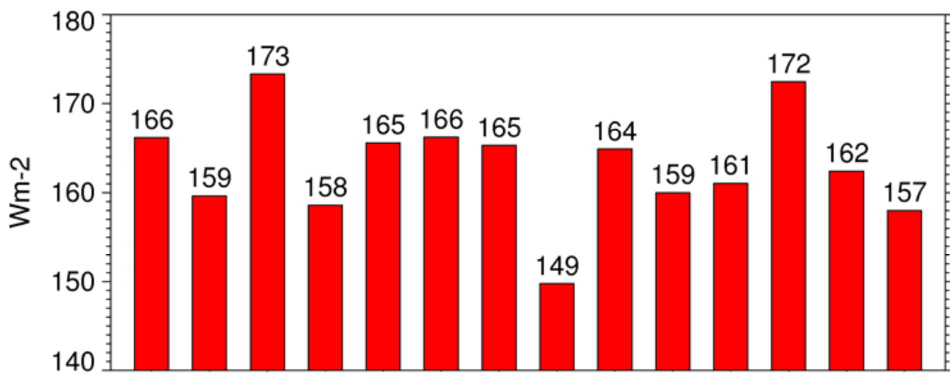
Global means of 14 state-of-the-art climate models

Model range: 10 Wm^{-2}
Standard dev.: 2.8 Wm $^{-2}$

Reference Satellite Value (ERBE/CERES): 240 Wm^{-2}



Absorbed solar radiation
surface



Global means of 14 state-of-the-art climate models

Model Range: 24 Wm^{-2}
Standard dev.: 5.5 Wm $^{-2}$

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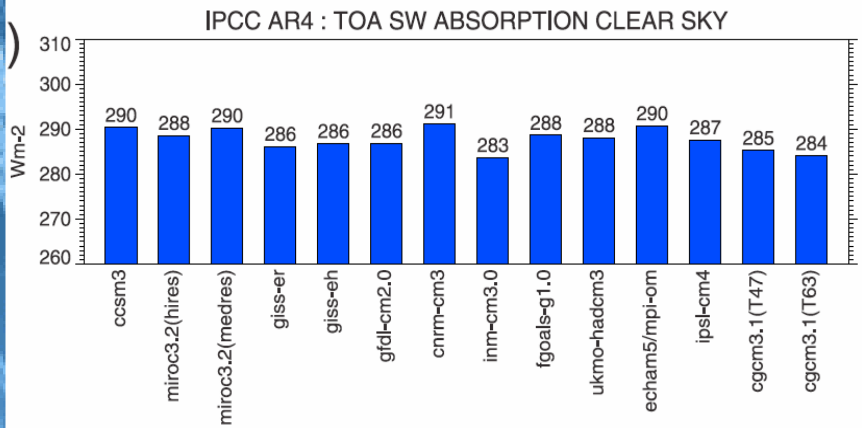
Clear sky solar radiation budgets in IPCC AR4 GCMs



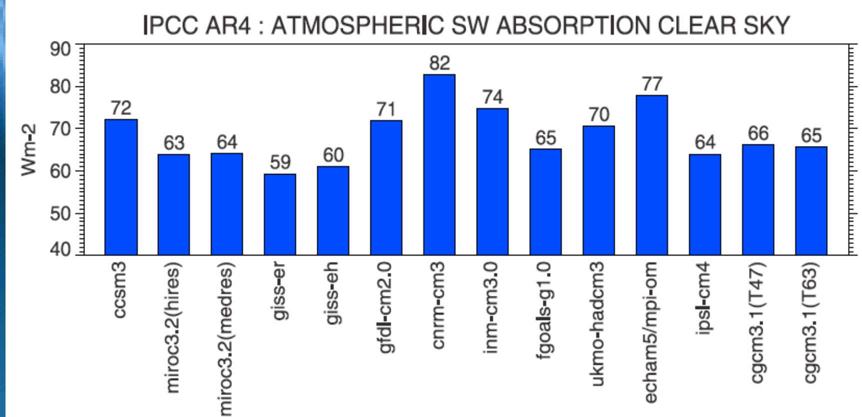
Absorbed SW clear sky

top of atmosphere (global mean)

Range of models: 8 Wm^{-2}

Standard deviation: 2.4 Wm^{-2}

Wild et al. 2006, J. Geophys. Res.

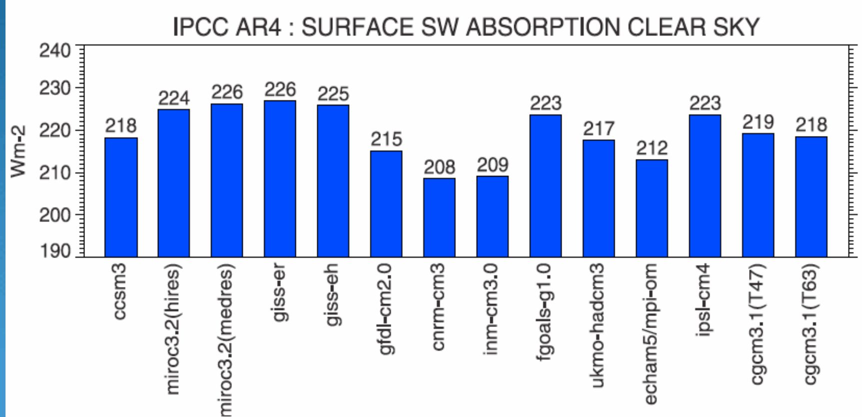


Absorbed SW clear sky

in the atmosphere (global mean)

Range of models: 24 Wm^{-2}

Standard deviation: 6.7 Wm^{-2}



Absorbed SW clear sky

at the surface (global mean)

Range of models: 18 Wm^{-2}

Standard deviation: 6.2 Wm^{-2}

Wild Tellus 2008

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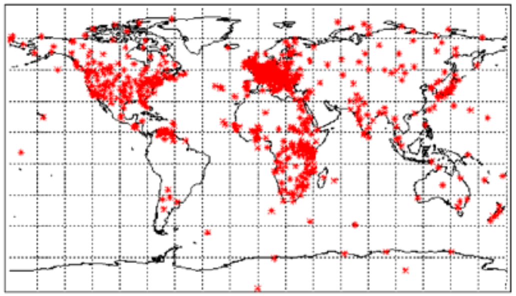
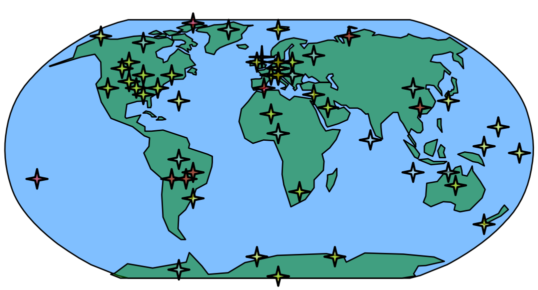
Observational Databases



Ohmura, Gilgen, Wild 1989

GEBA
Global Energy Balance Archive

- Worldwide measurements of energy fluxes at the surface (2500 sites)
- Solar radiation data since 1960s
- Monthly mean values



Ohmura et al. 1998

BSRN
Baseline Surface Radiation Network

- Highest measurement quality at selected sites worldwide (currently 38 anchor sites)
- Starting in 1992
- Minute Values
- Ancillary data for radiation interpretation

Annual cycle SW down clear sky at BSRN sites

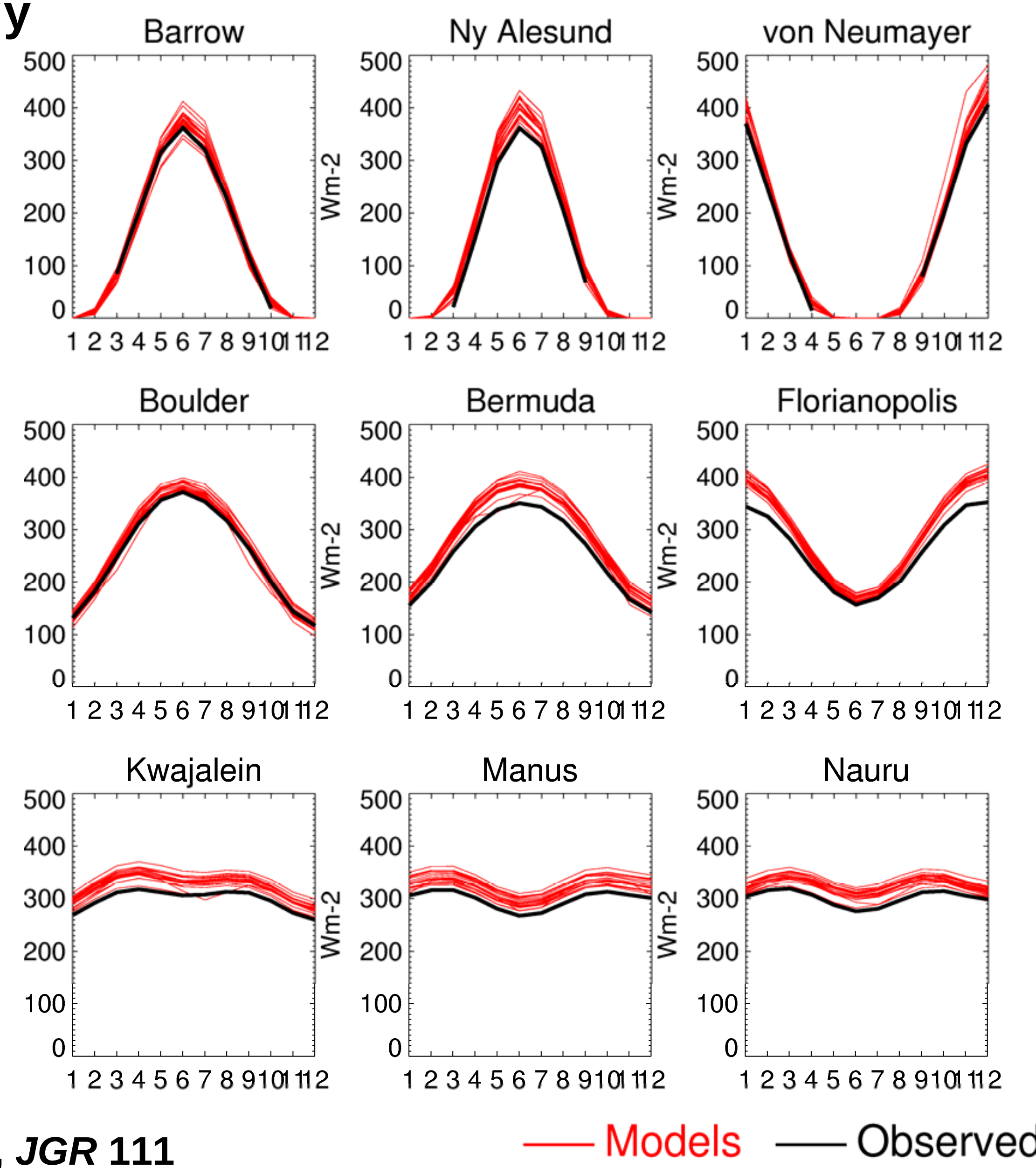
Mean monthly climatology

20 Models

High latitude sites

Mid latitude sites

Tropical sites



Wild et al. 2006, *JGR* 111

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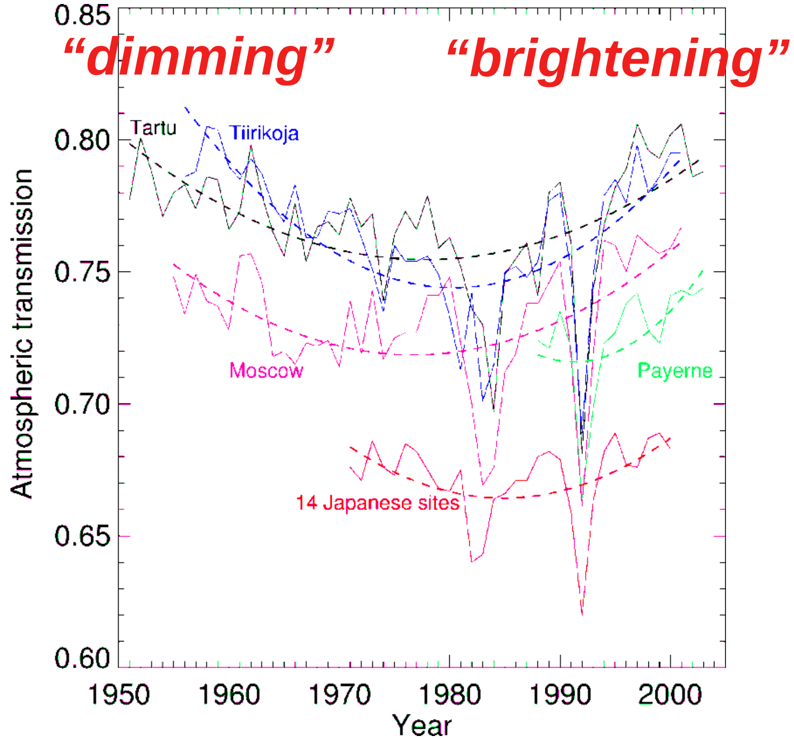
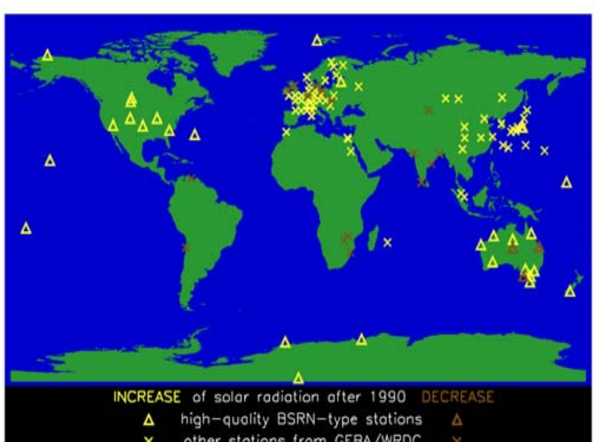
Decadal changes in surface solar radiation

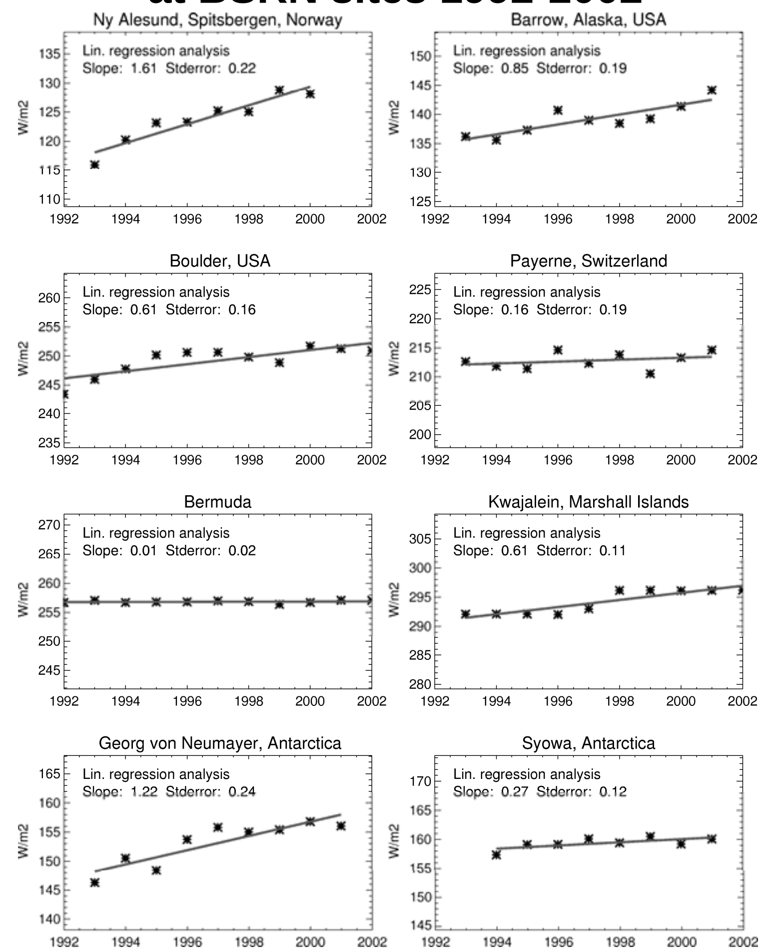


Surface insolation changes in 1990s



Transition from dimming to brightening during 1980s

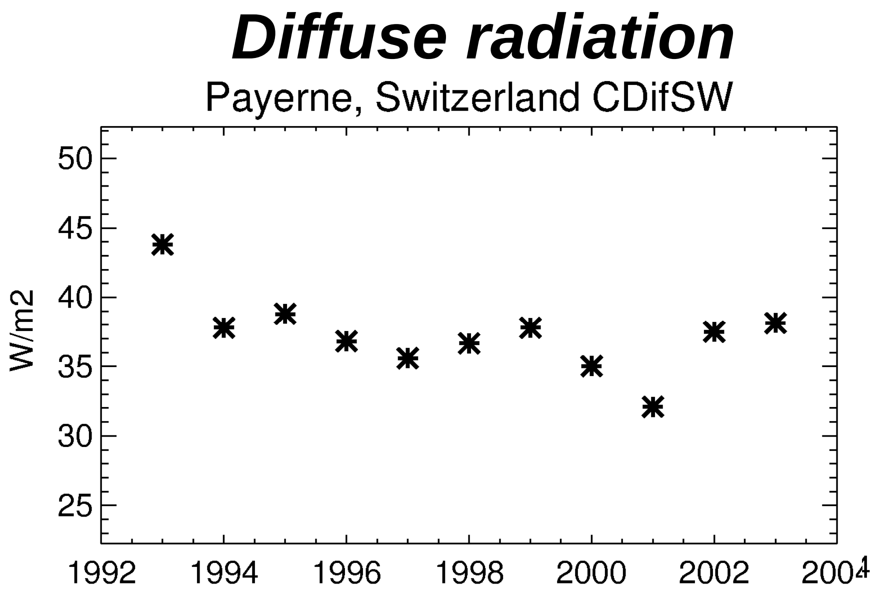
Surface clear sky insolation at BSRN sites 1992-2002

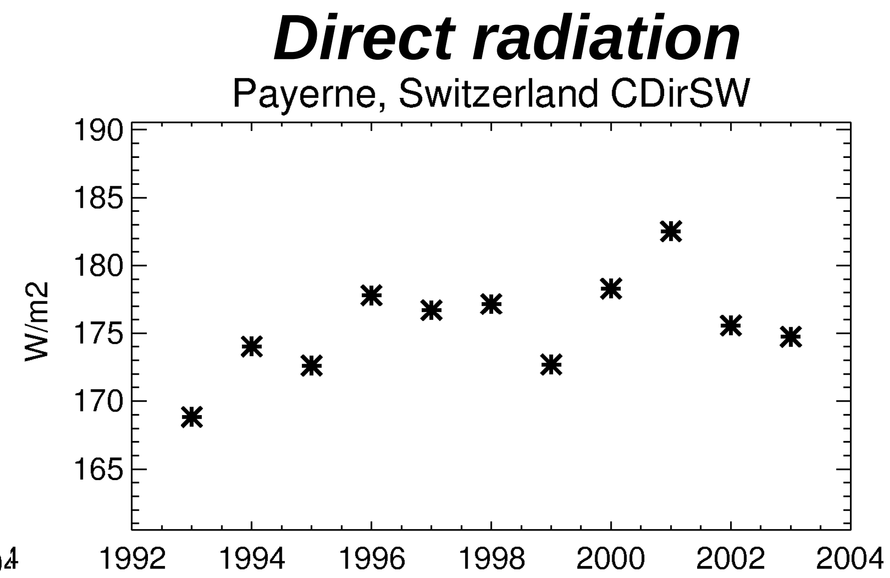


Wild et al. 2005:. Science , 308, 847-850.

Diffuse and direct clear sky radiation timeseries

Changes in diffuse and direct surface SW radiation



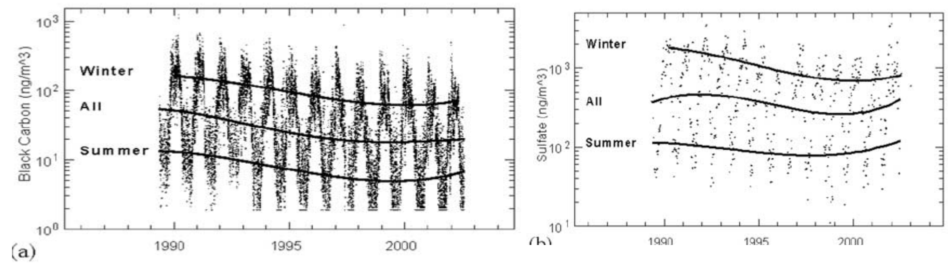


BSRN Station Payerne Switzerland, 1992-2003

GDB transition consistent with aerosol trends

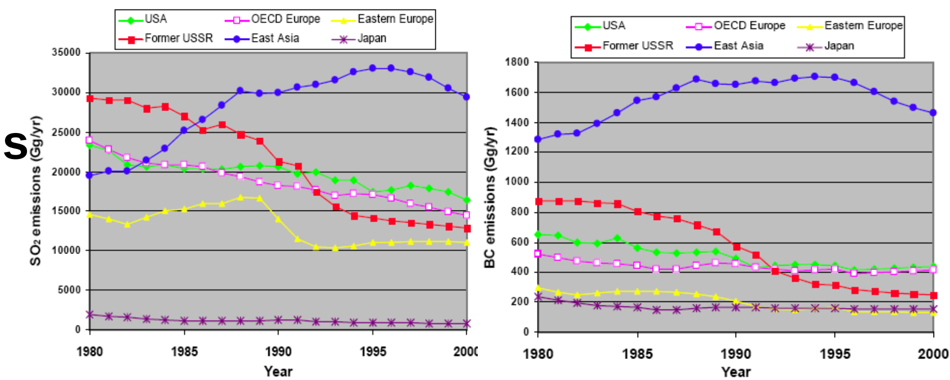
Direct measurements

(Canadian arctic)
BC decrease 1989-2002: 60%
Sulfate decrease 1989-2002: 29%
(Sharma et al. 2004)



Emission histories

Reduction of SO_2 and BC emissions in industrialized regions 1980-2000
(Streets et al. 2006)



Satellite estimates

Decrease of AOD over oceans 1990- 2005
(Mishchenko et al. 2007)

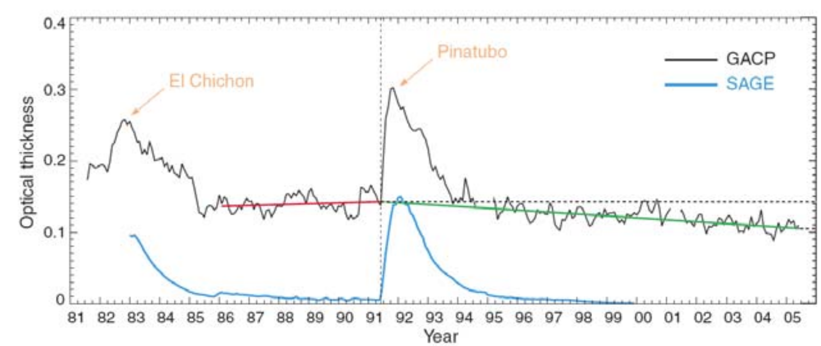


Fig. 1. GACP record of the globally averaged column AOT over the oceans and SAGE record of the globally averaged stratospheric AOT.

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Climate impacts of global dimming/brightening

Global dimming and brightening may have had an impact on:

- ***Global warming*** (Wild et al. 2007 GRL)
- ***Photosynthesis*** (Mercado/Bellouin 2008)
- ***Pan evaporation*** (Roderick and Farquhar 2002, Science)
- ***Soil moisture*** (Robock et al. 2006 GRL)
- ***Intensity of the global hydrological cycle*** (Wild et al. 2008 GRL)
- ***River basin water budgets*** (Teuling et al.2008 GRL)
- ***Cryosphere and glaciers*** (Ohmura et al. 2007, Paul et al. 2005, GRL)

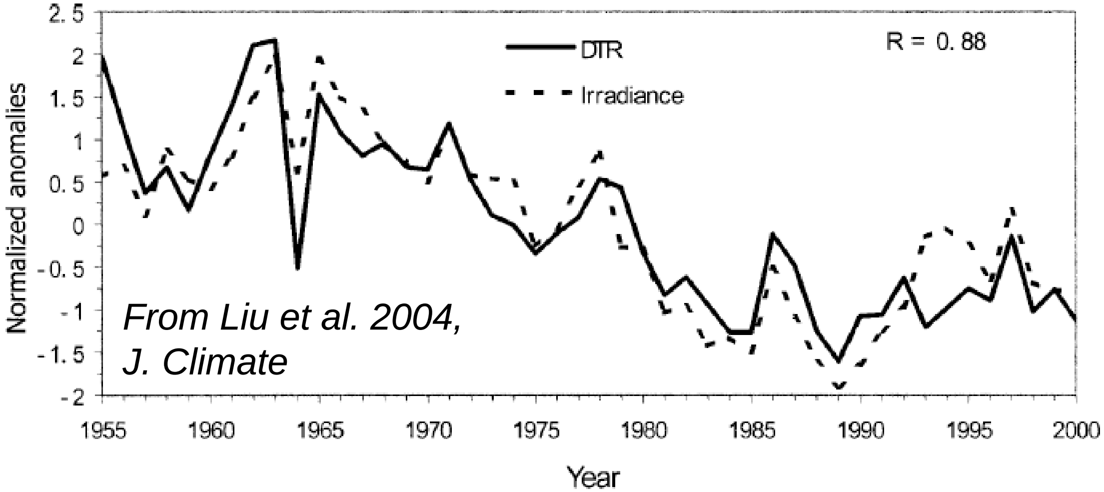
Impact on Diurnal Temperature Range (DTR)

DTR:

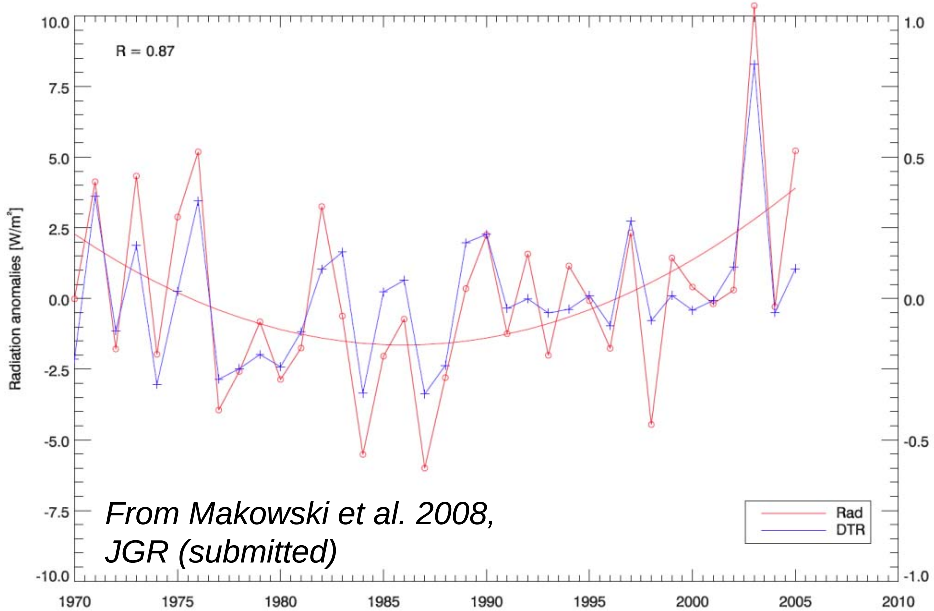
Diurnal Temperature Range

=T max – T min

Correlation of surface insolation and DTR in China



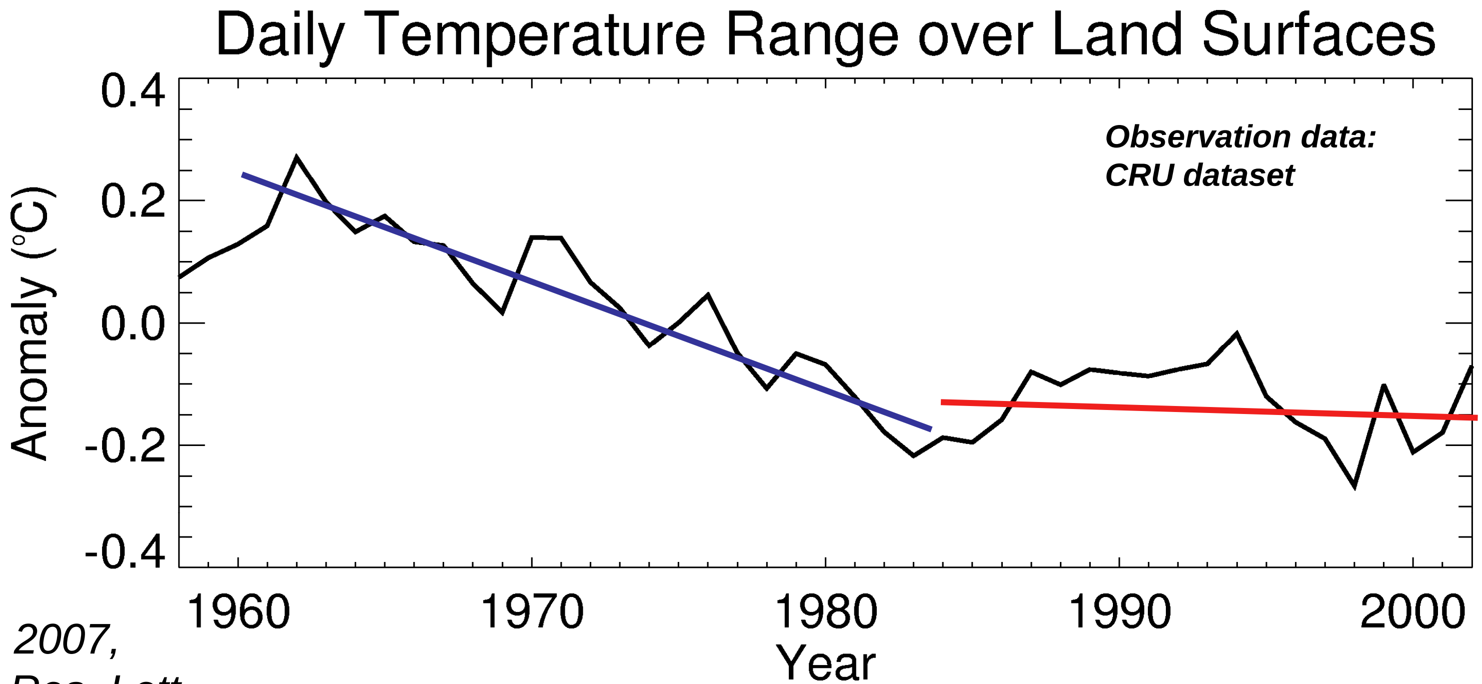
Correlation of surface insolation and DTR in Europe



Daily maximum temperature dominated by surface solar radiation

Daily minimum temperature dominated by thermal radiation

Observed DTR Land Mean 1958-2000



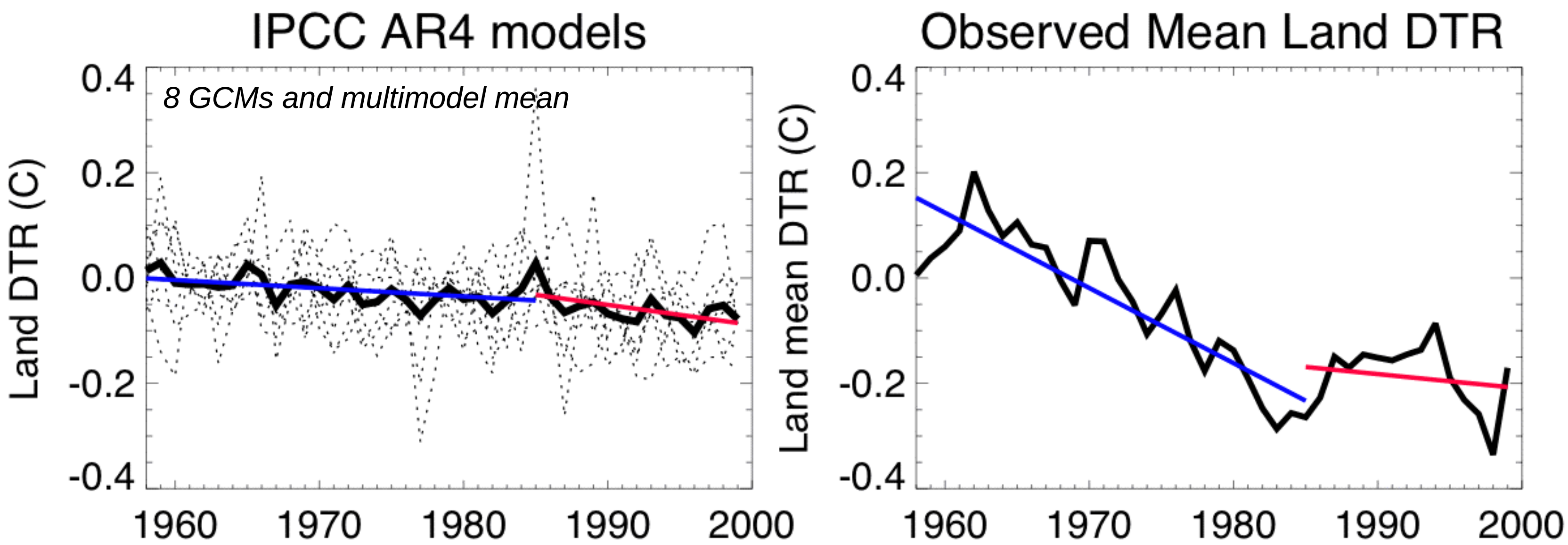
Wild et al. 2007, Geophys. Res. Lett.

Evidence for large scale change in surface radiative forcings

Linear regression slopes land mean DTR

Units °C/decade	**1958-1985 "dimming"**	**1985-2002 "brightening"**
T max	**-0.04**	**+0.37**
T min	**0.11**	**+0.40**
DTR	**-0.15**	**-0.03**

DTR in IPCC-AR4 GCMs

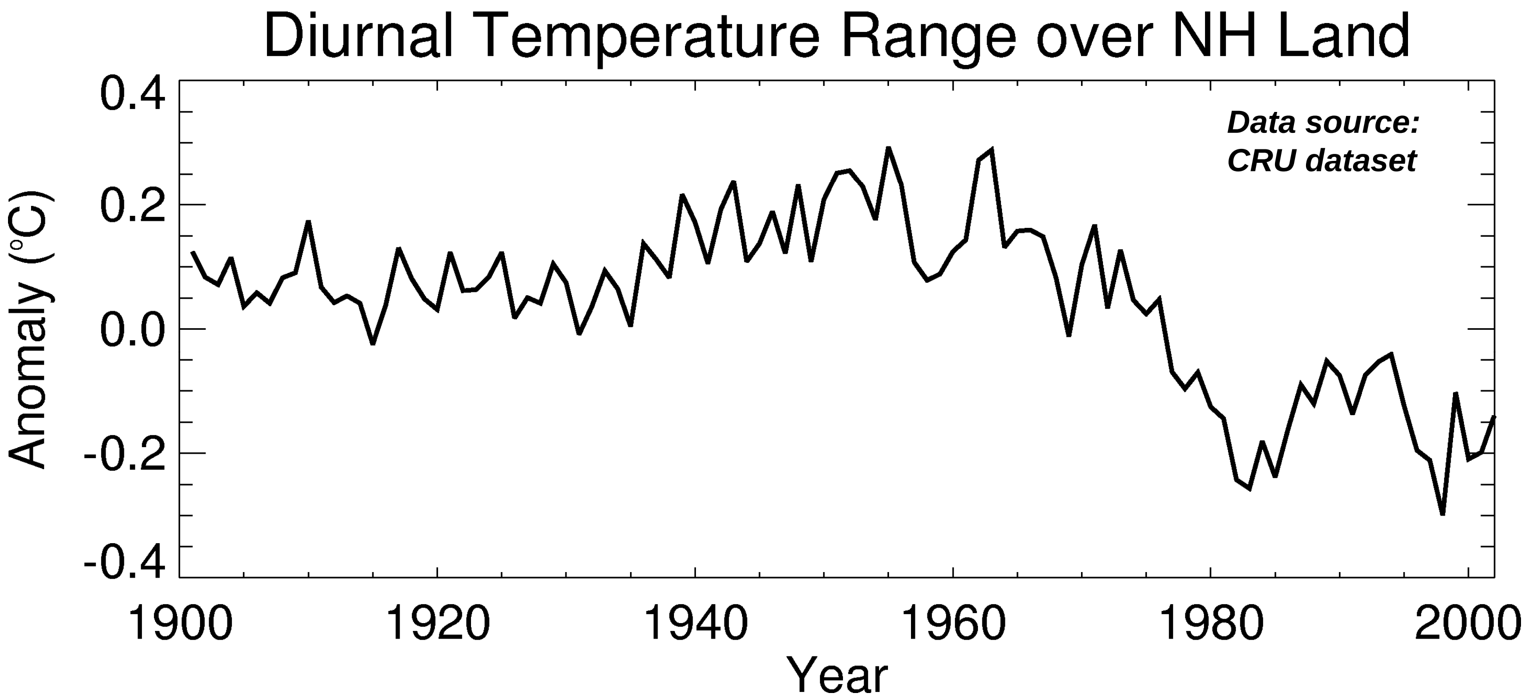


Linear regression slopes land mean DTR

Units °C per decade	dimming phase 1958-85	brightening phase 1985-99	Change dimming > brightening
Model mean (8 GCMs)	**-0.02**	**-0.04**	**-0.02**
Observed	**-0.15**	**-0.03**	**+0.12**

GCMs do not show strong decrease in DTR during dimming phase and leveling off in brightening phase > indication for lack of dimming/brightening in GCMs

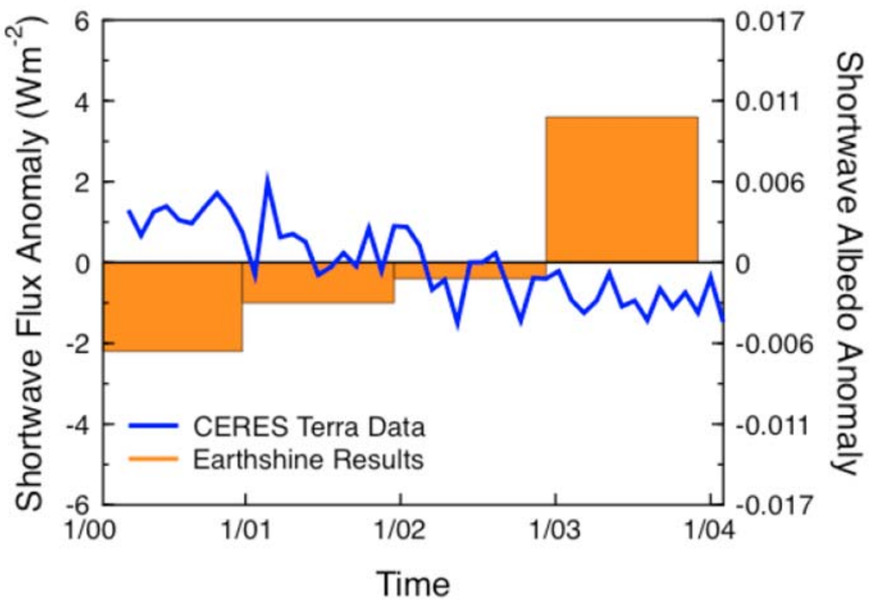
DTR as proxy for surface insolation changes



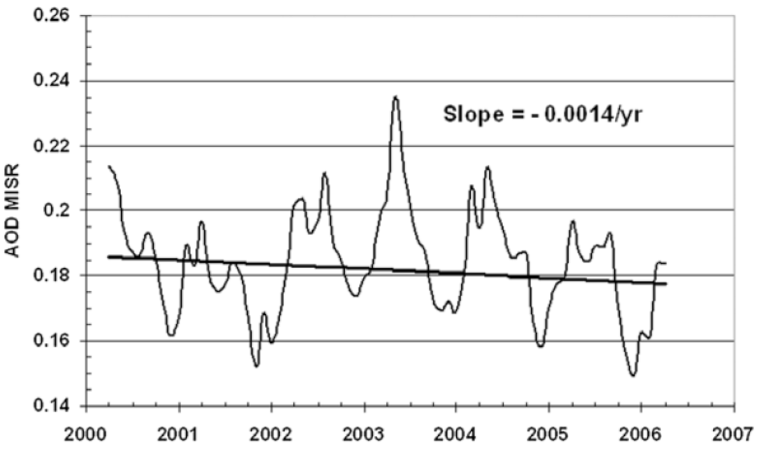
Indication for global dimming mainly in second part of 20th century (1950s-80s), and for two brightening periods in the 1930s and 1980s/90s

Global dimming/brightening beyond 2000

Changes in surface solar radiation 2000-2005



Wielicki et al. 2004

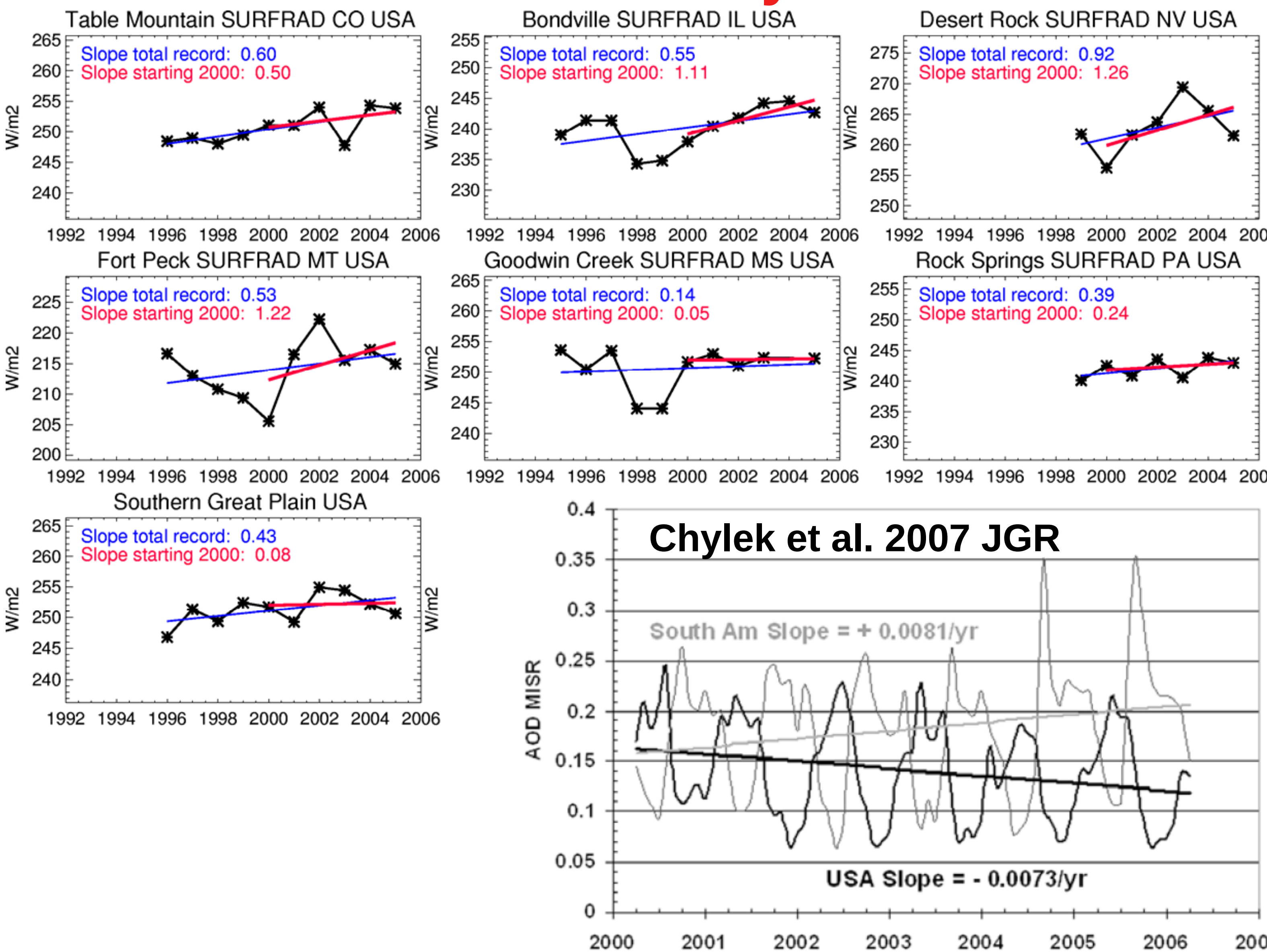


Chylek et al. 2007

Period after 2000 particularly interesting, where comprehensive satellite and AOD information start to become available

USA 2000-2005 from Surfrad/BSRN

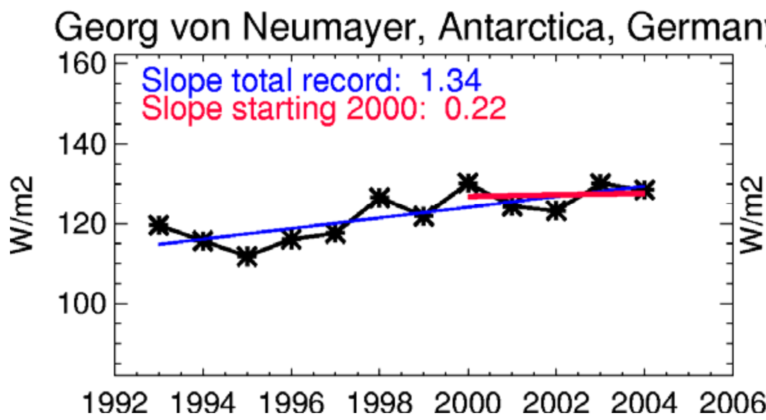
Clear sky

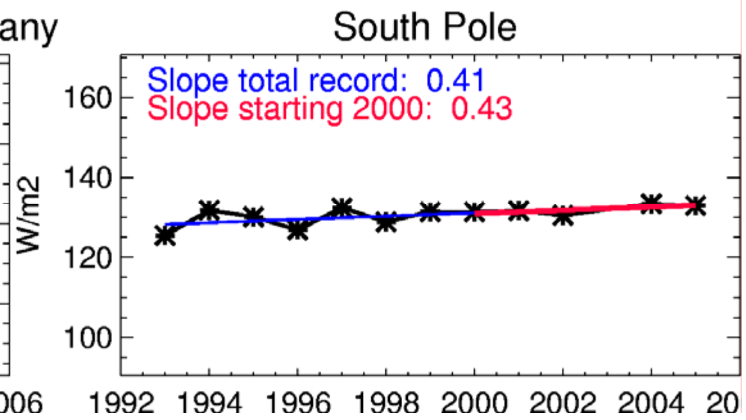


Antarctica 2000-2005 from BSRN

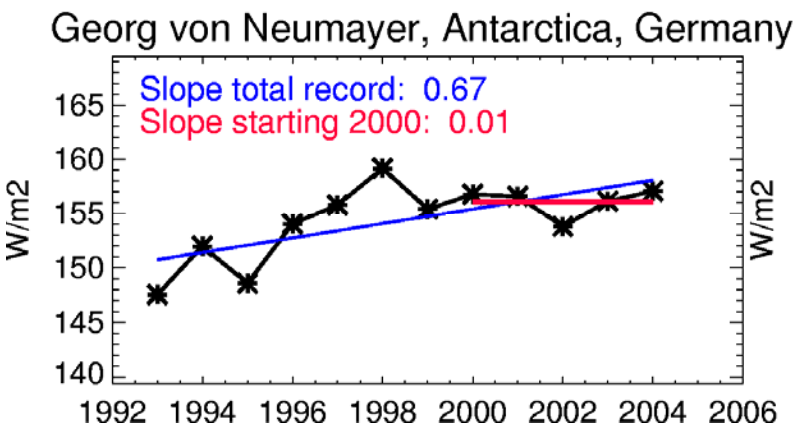
Joint work with Chuck Long

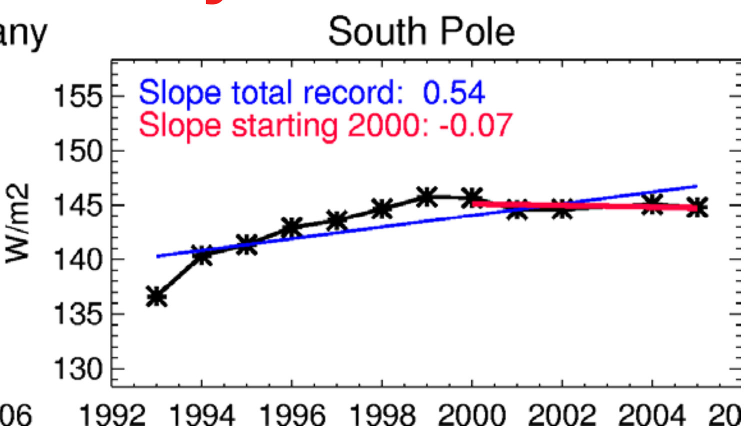
All sky





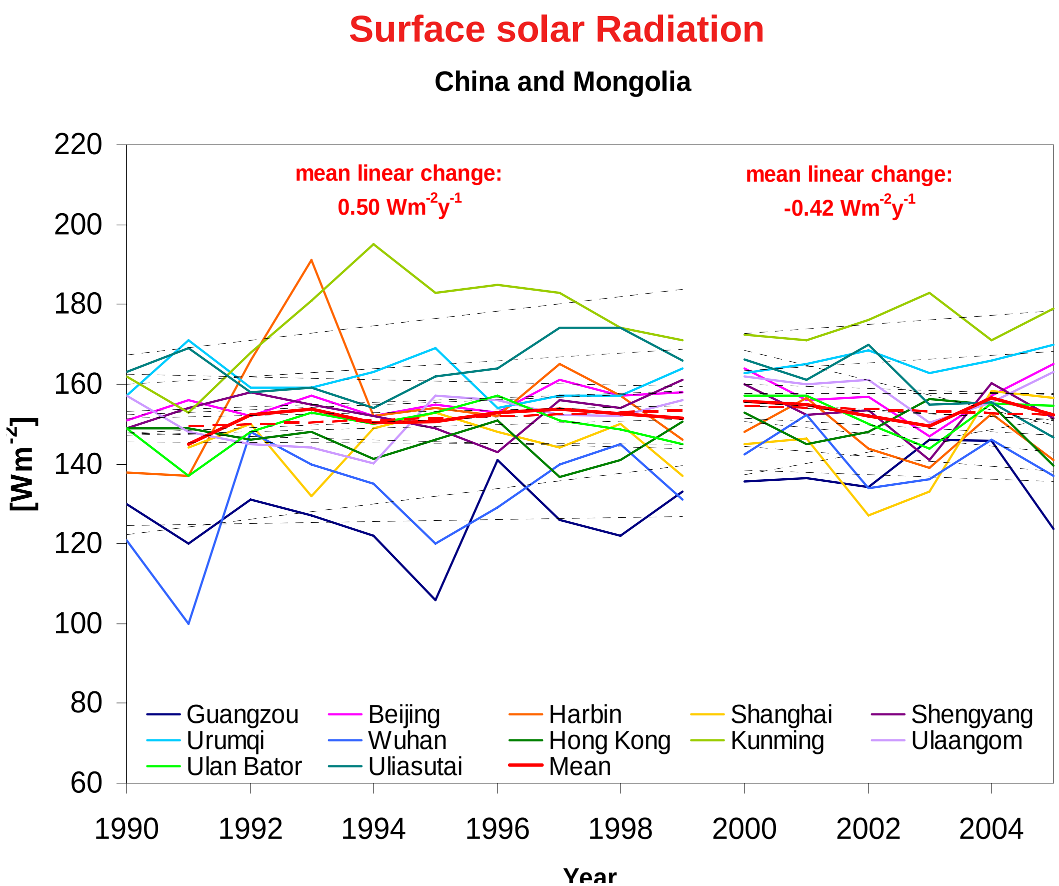
Clear sky





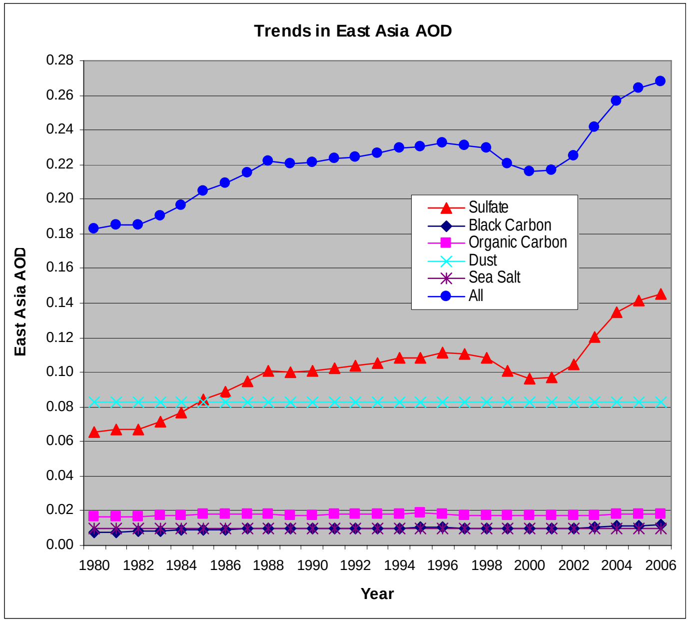
⇒ Brightening in Antarctica levels off in 2000-2005 period

China 1990-2005 from GEBA

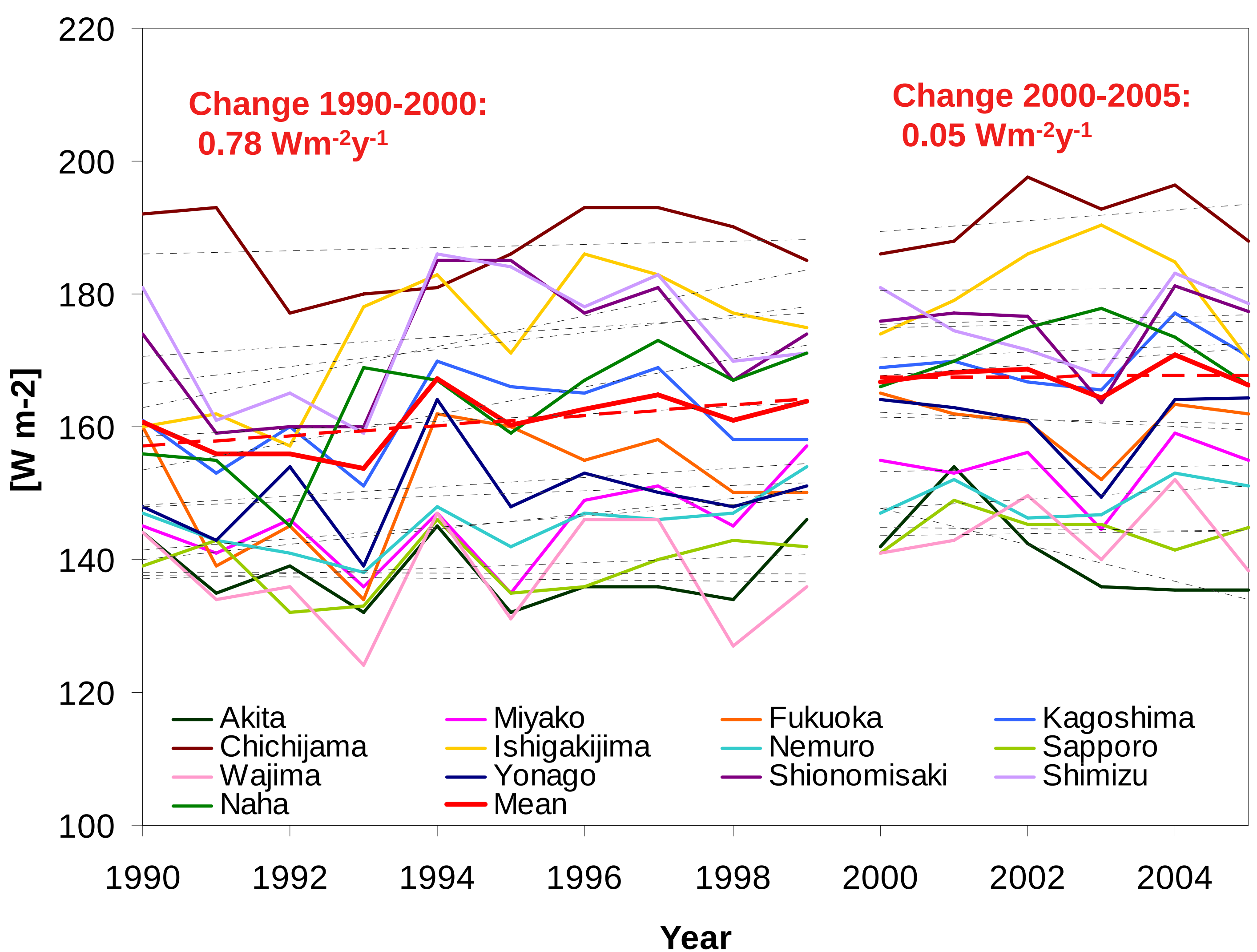


***China returns into slight dimming after 2000,* in line with increasing AOD**

AOD East Asia 1980-2005 From David Streets

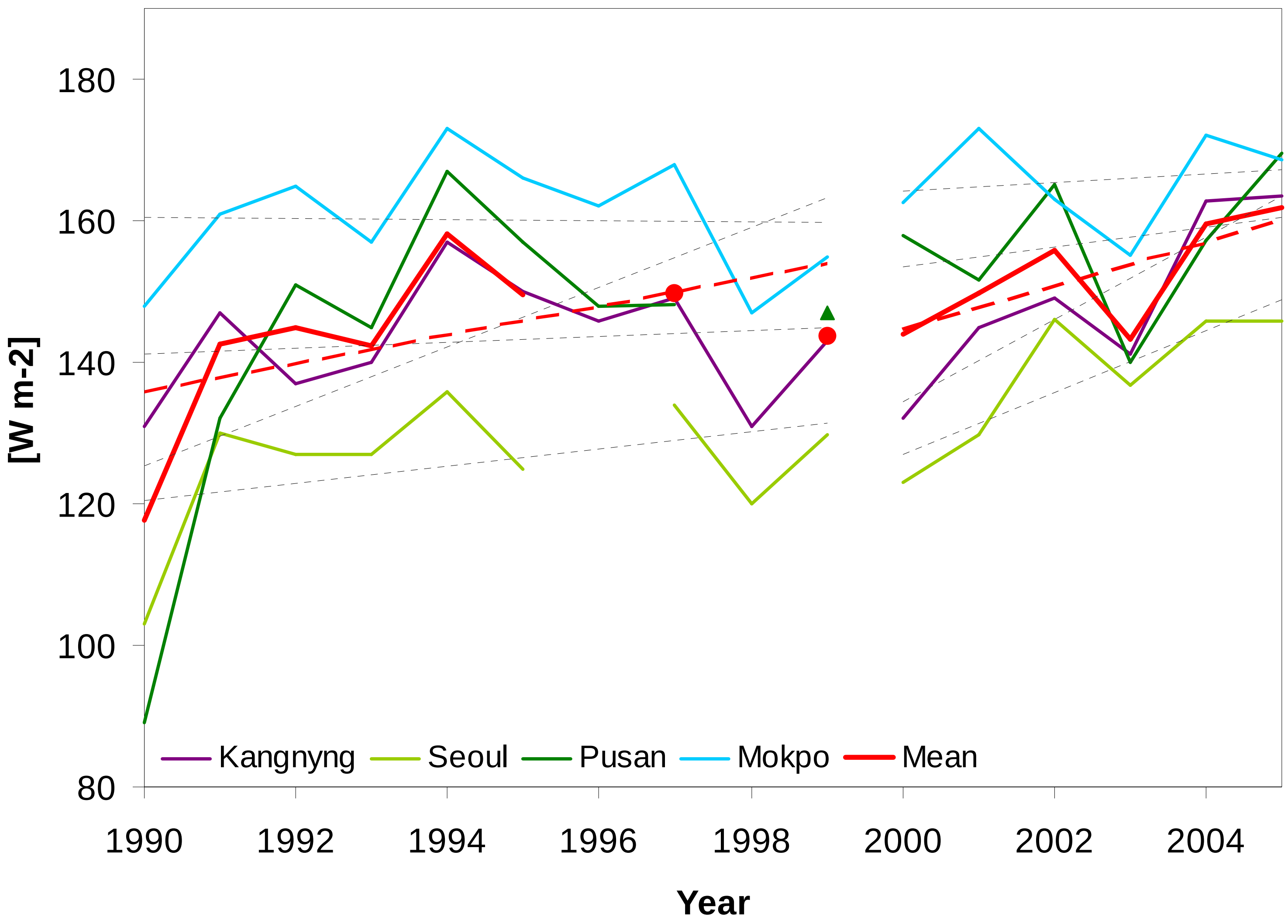


Japan 1990-2005



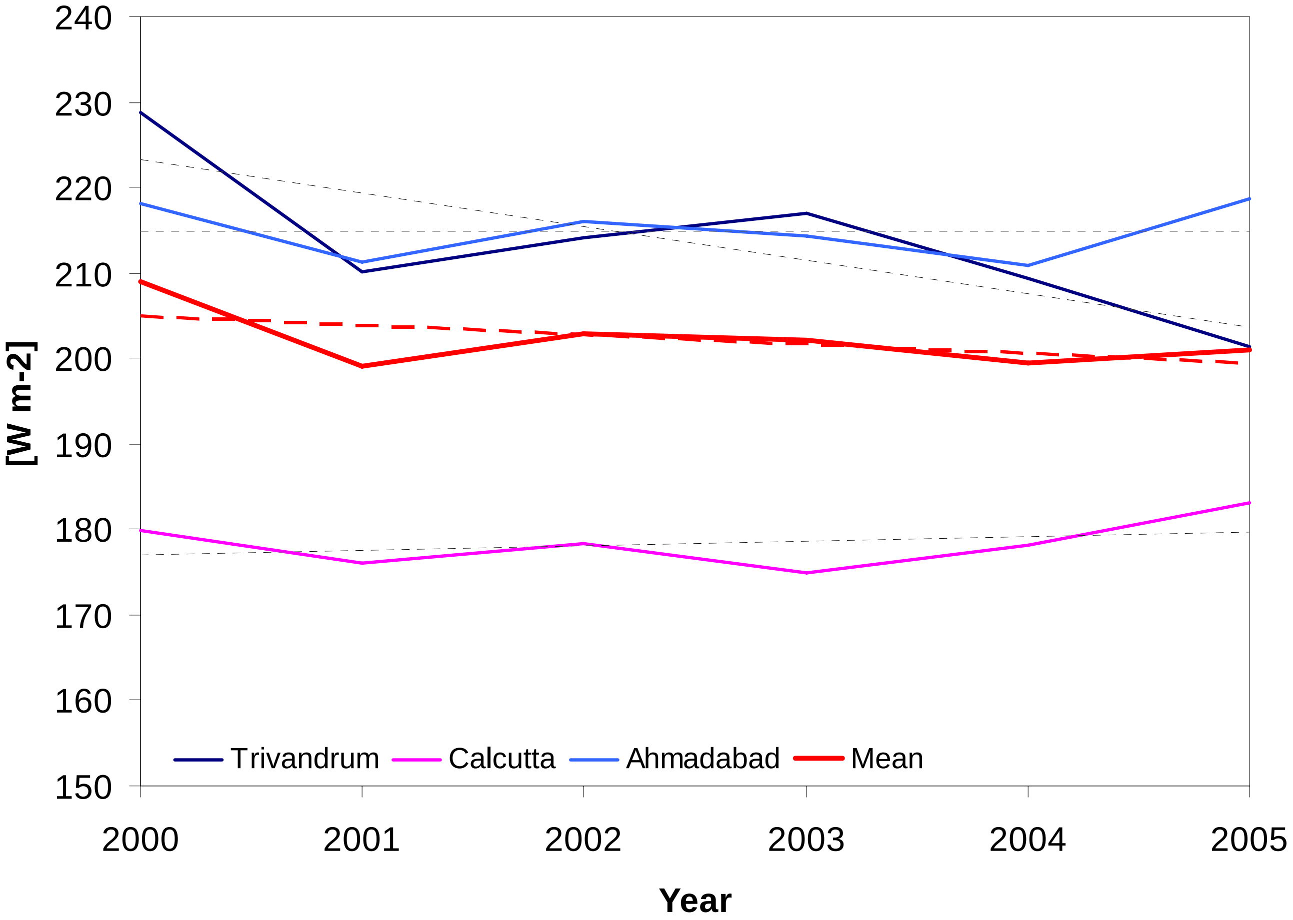
Brightening slows down at Japanese sites after 2000

Korea 2000-2005



Strong brightening continues at Korean sites after 2000

India 2000-2005



Continuation of dimming in India after 2000

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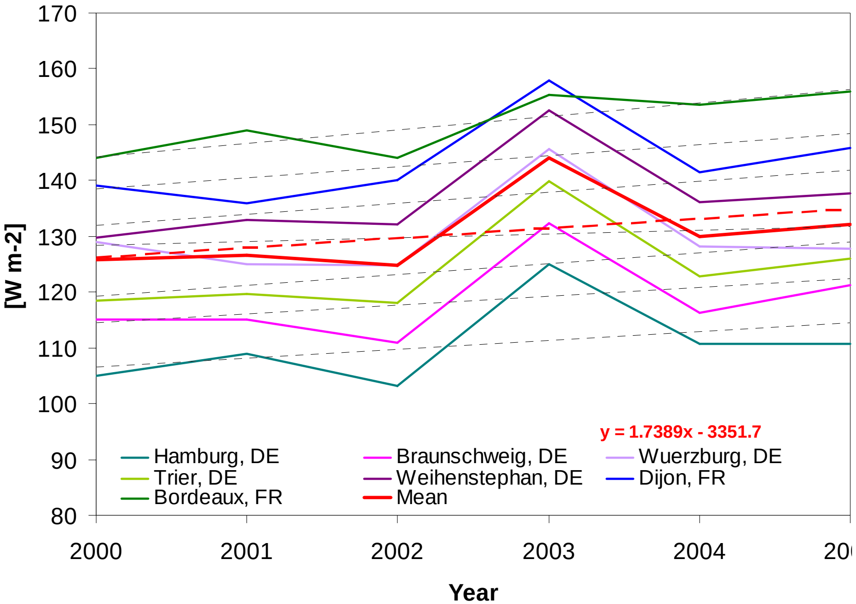
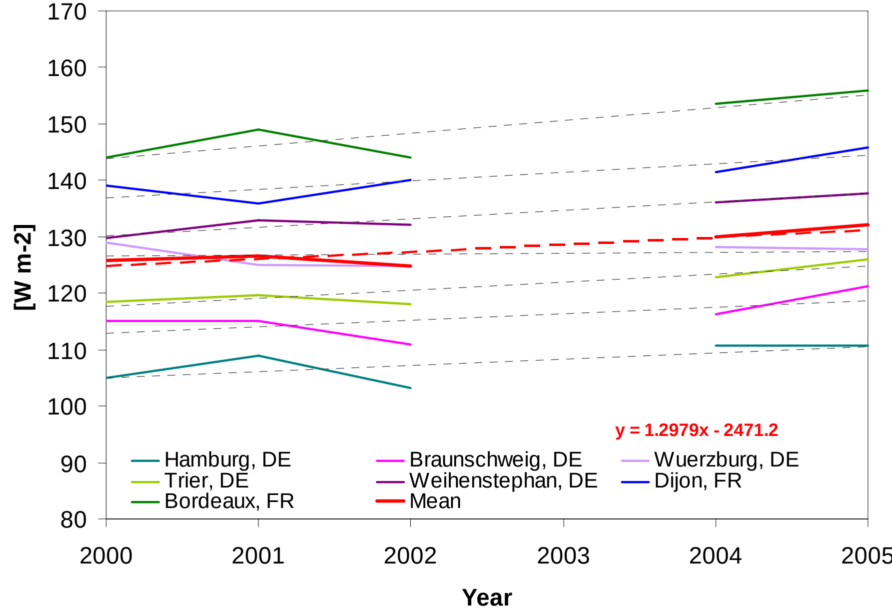
Europe: France/Germany 2000-2005

Surface solar radiation 2000-2005



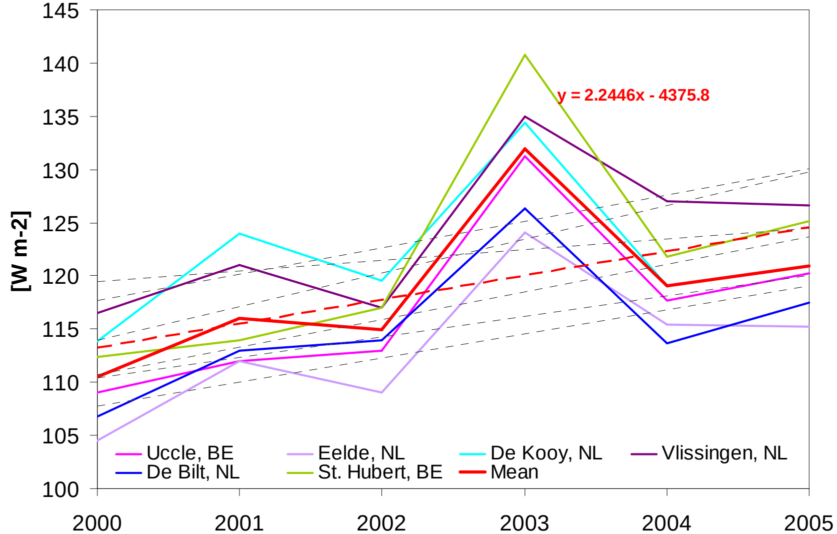
2000-2005, neglecting 2003



Increase in surface solar radiation also after neglecting the extreme year 2003

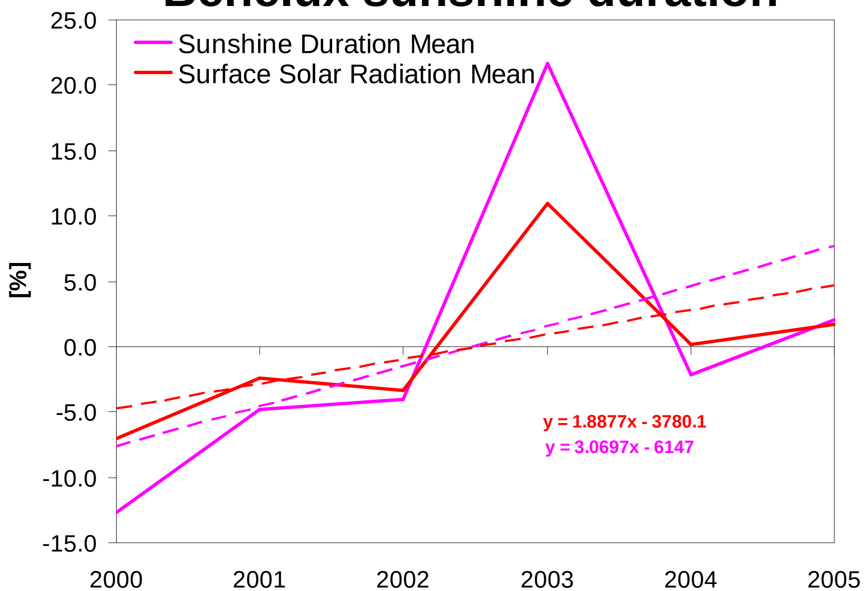
Europe 2000-2005

Benelux surface solar radiation

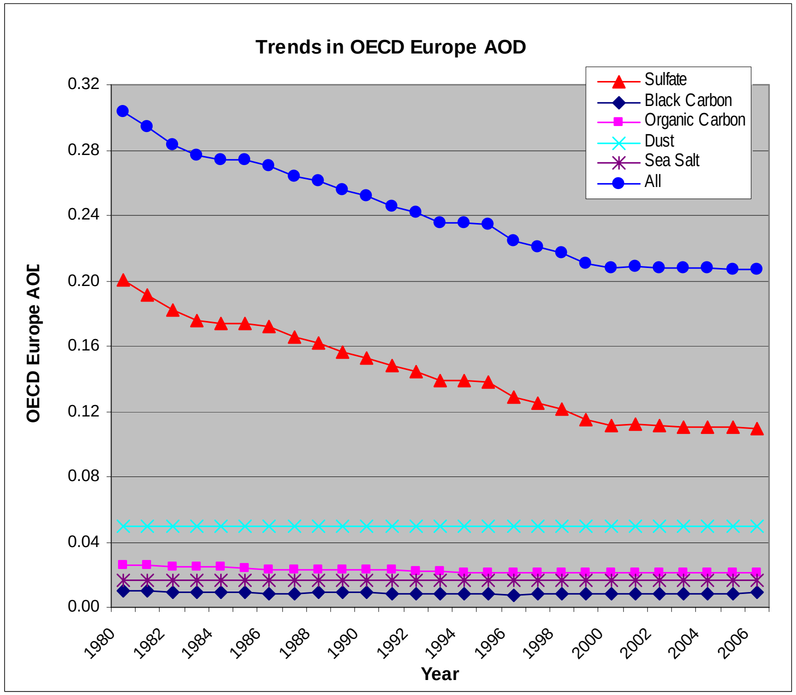


Brightening in Europe after 2000 due to reduced cloud effects while AOD remains constant

Benelux sunshine duration



AOD in OECD Europe 1980-2005 from David Streets



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Summary tendencies in SWD

Recent tendencies in Surface Solar Radiation

	1990s	After 2000
USA	↗	↗
Central America	↗	↘
Europe	↗	↗
China/Mongolia	↗	→
Japan	↗	→
Korea	↗	↗
India	↘	↘
Antarctica	↗	→

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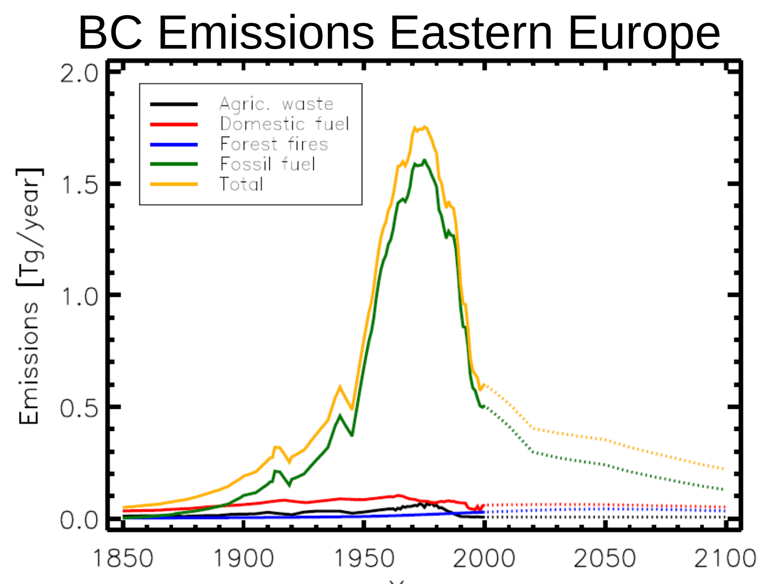
Simulation of observed trends

Cooperation with Max Planck Institute for Meteorology, Hamburg (Group of J. Feichter, E. Roeckner).

- **Model ECHAM5-HAM, research version with sophisticated aerosol scheme and cloud microphysics**, including sulfate, black carbon, particulate organic matter, sea salt and dust, prognostic size distribution, composition, mixing state (Stier, P. et al. 2005, ACP, Lohmann et al. 2007 ACP)
- Transient Simulations with **time dependent emission histories** (currently NIES)

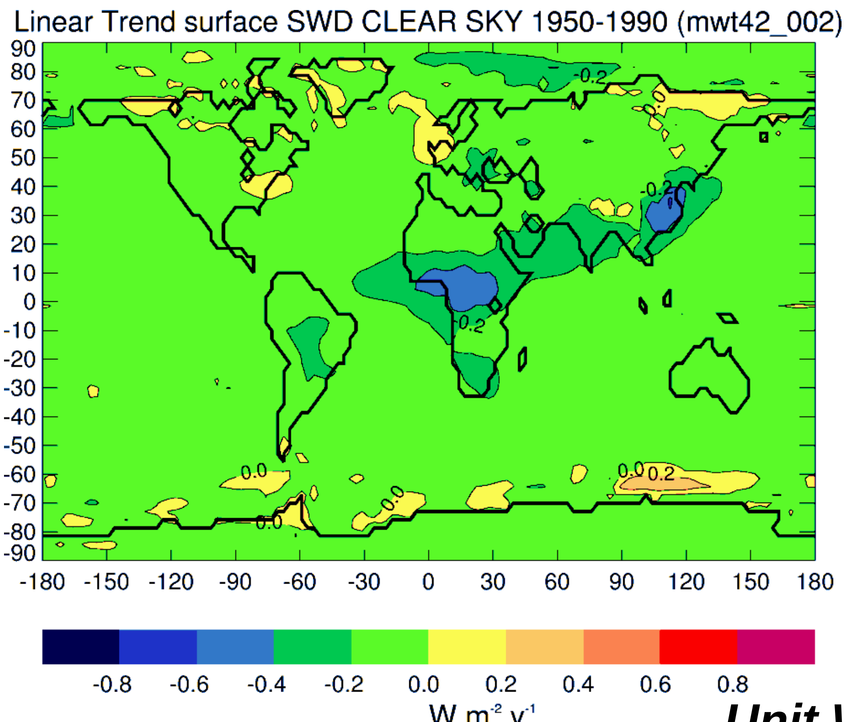
Reduced emissions due to economic breakdown of former communist countries included



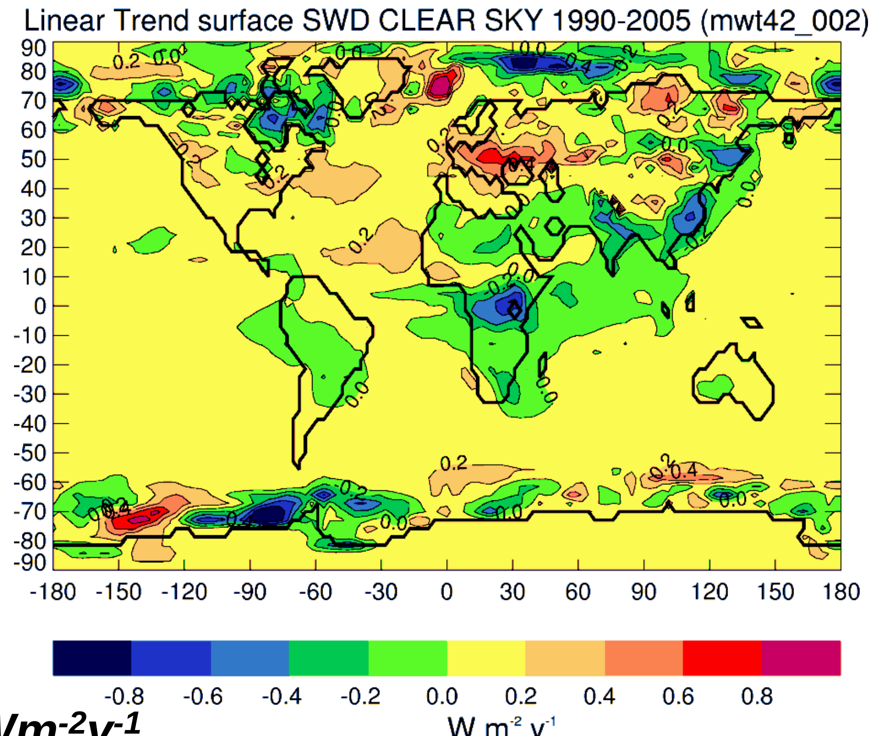
Simulation of global dimming/brightening

Trend in surface clear sky insolation

1950-1990



1990-2005



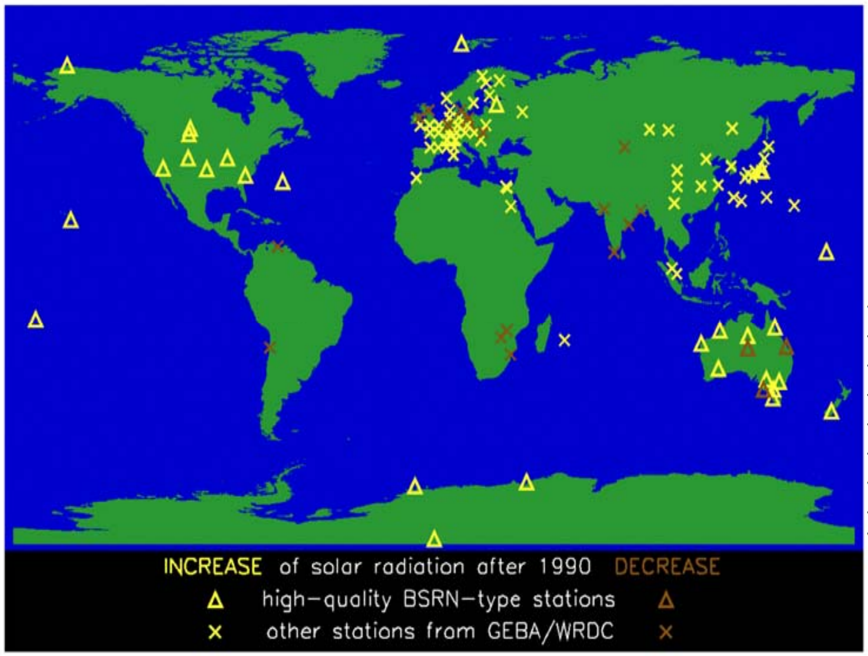
Unit $Wm^{-2}y^{-1}$

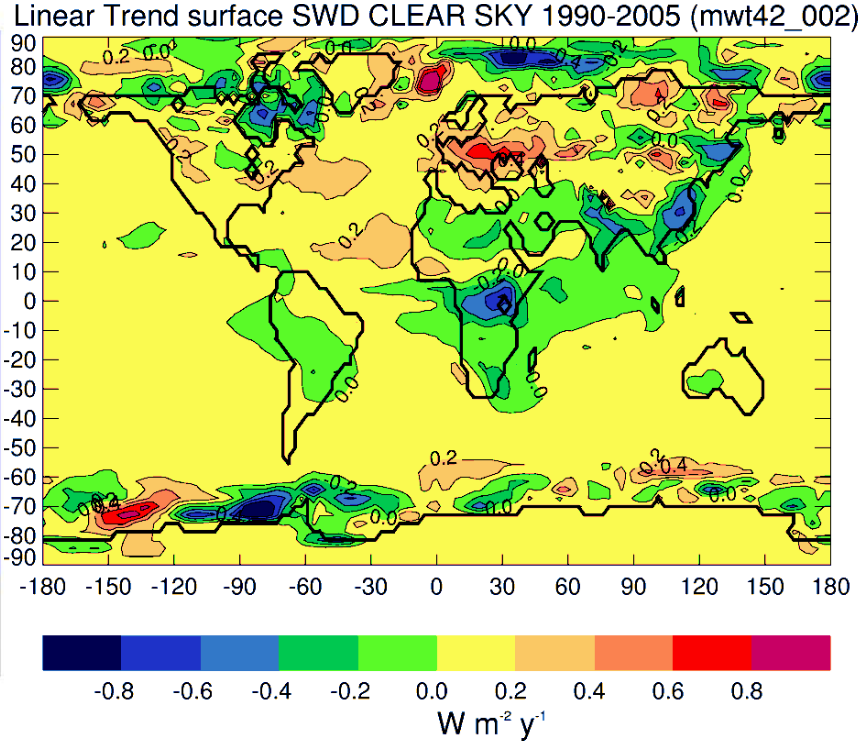
ECHAM5-HAM T42, ENSEMBLE SSTs

Simulation of global dimming/brightening

Trend in surface clear sky insolation

Observations **1990-2005**



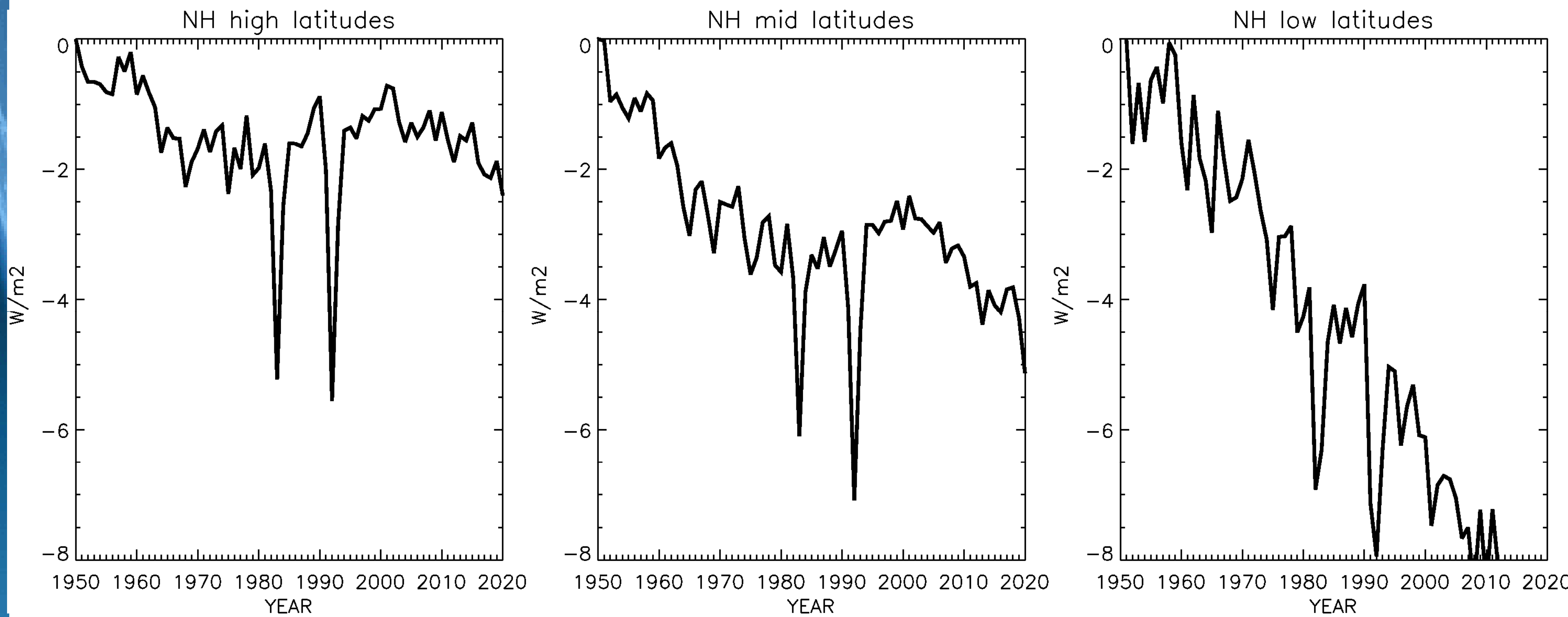


ECHAM5-HAM T42, ENSEMBLE SSTs

Latitudinal dependence of dimming/brightening

1950 - 2020

Surface clear sky insolation in different latitude belts



From model simulations with ECHAM5 HAM

=> Interesting to see coming years in surface observations

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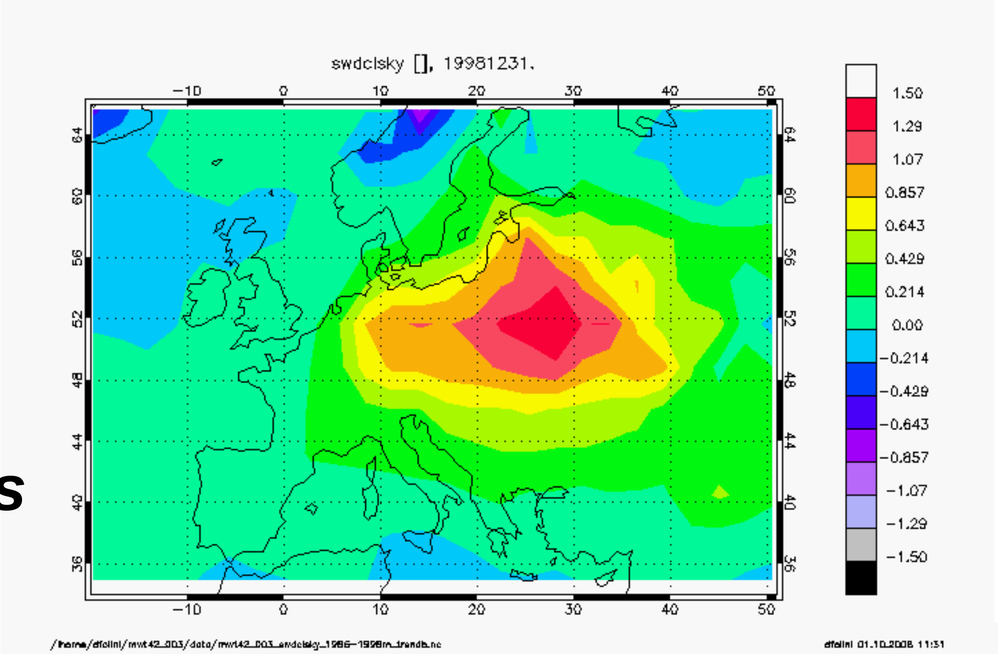
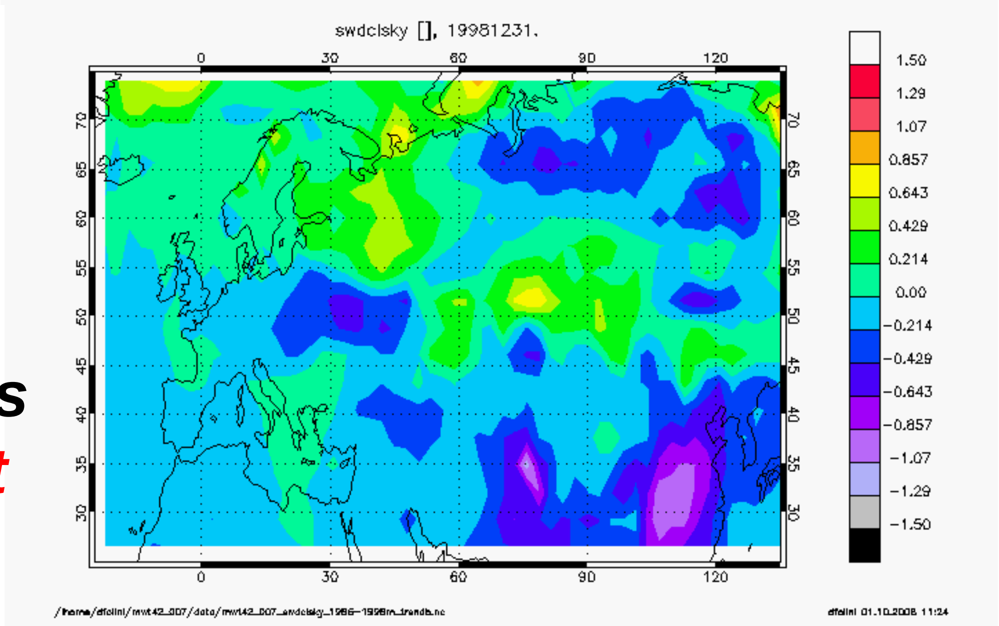
Europe 1986 - 2000

SW down clearsky trends
with NIES emissions



SW down clearsky trends
Emissions kept constant
after 1980



Summary and outlook

Summary

- Both observational and modelling (hindcast) studies are needed to quantify and understand the decadal variations in surface radiative forcings

Outlook (modelling)

- ECHAM5-HAM simulations over entire 20th century
- ECHAM5-HAM with Aerocom emissions 1980-2006

Desirable diagnostics for radiation analyses

Ideally available from hindcast experiments:

- Surface shortwave downward and absorbed (all sky, clear sky)
- SW Diffuse/direct
- Longwave downward and net (all sky, clear sky)

Additional

- TOA radiative fluxes (all sky, clear sky)
- water vapour
- Cloud/aerosol characteristics
- From GCMs: Tmin, Tmax, Evap, Prec

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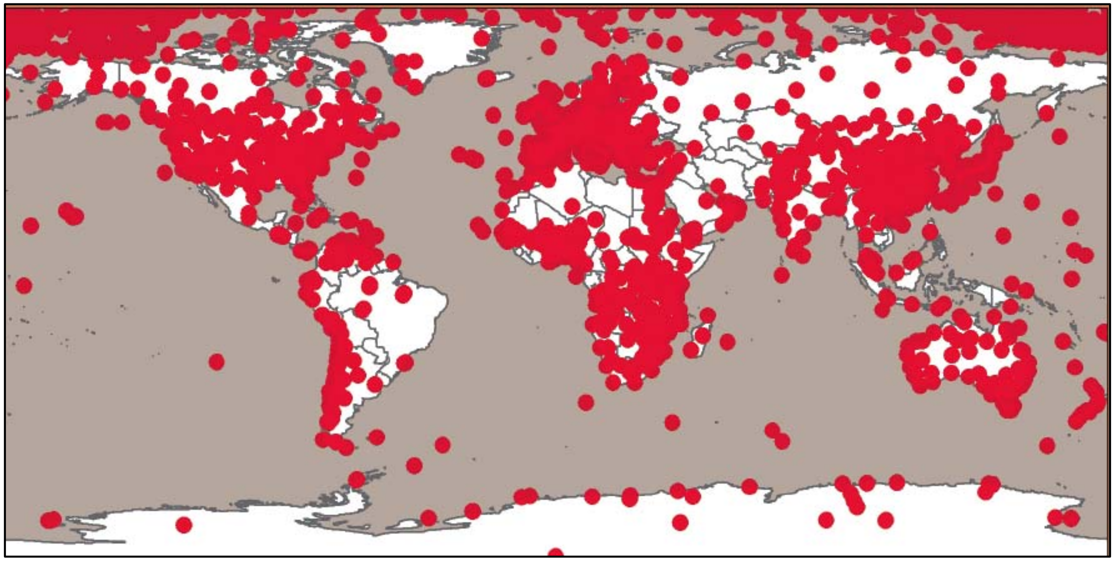
Revision of Global Energy Balance Archive



- **Renewal of technical infrastructure** (dates back to 1990), database upgrade to Oracle 10, new database sever, new web space and web interface
- **Update of time series**, focus on period 2000-2005
- **New data sources** (e.g. BSRN, SURFRAD monthly means, nonradiative energy balance components Euroflux, Ameriflux, Asiaflux)

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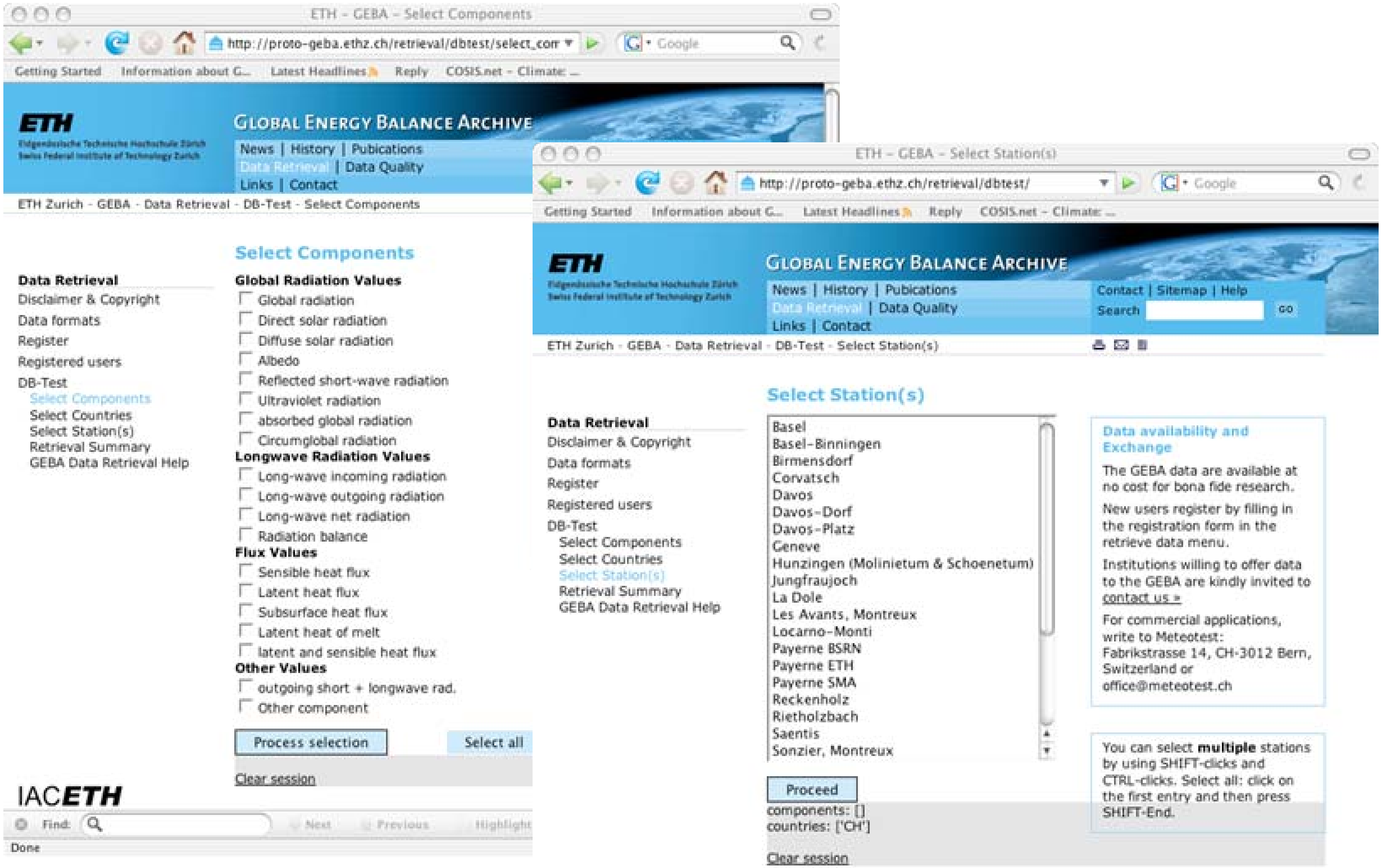
GEBA: new website under construction

Currently: http://proto-geba.ethz.ch/

After official release: http://www.geba.ethz.ch/



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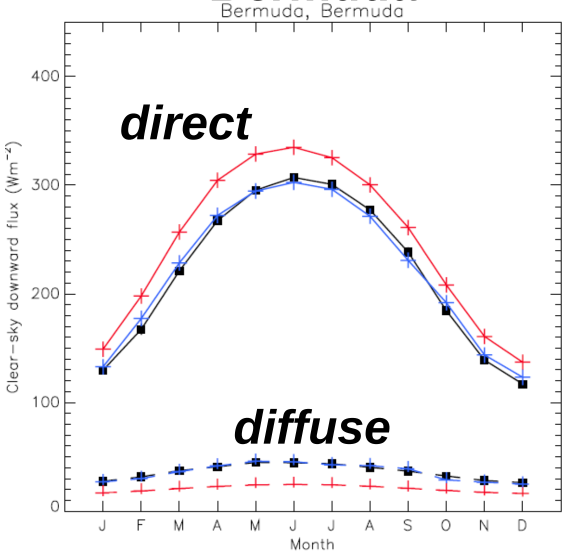
IACETH

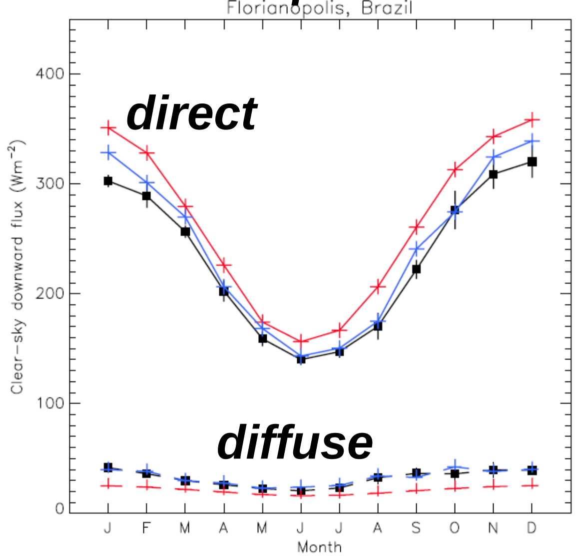
Evaluation of surface SW diffuse/direct radiation

Analysis by N. Bellouin UKMO

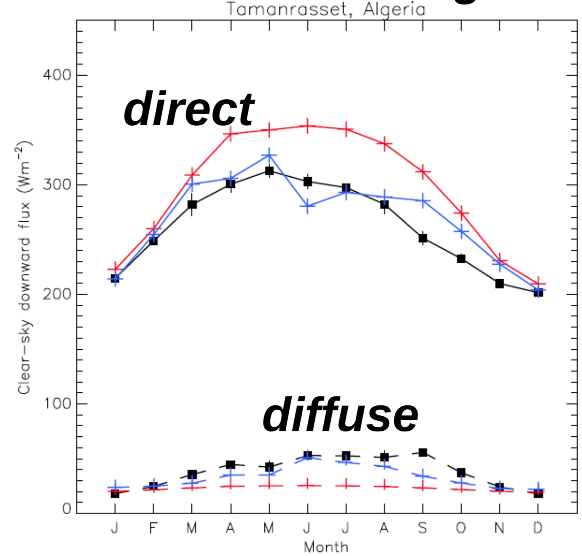
Bermuda



Florianopolis Brazil



Tamanrasset Algeria



BSRN observations

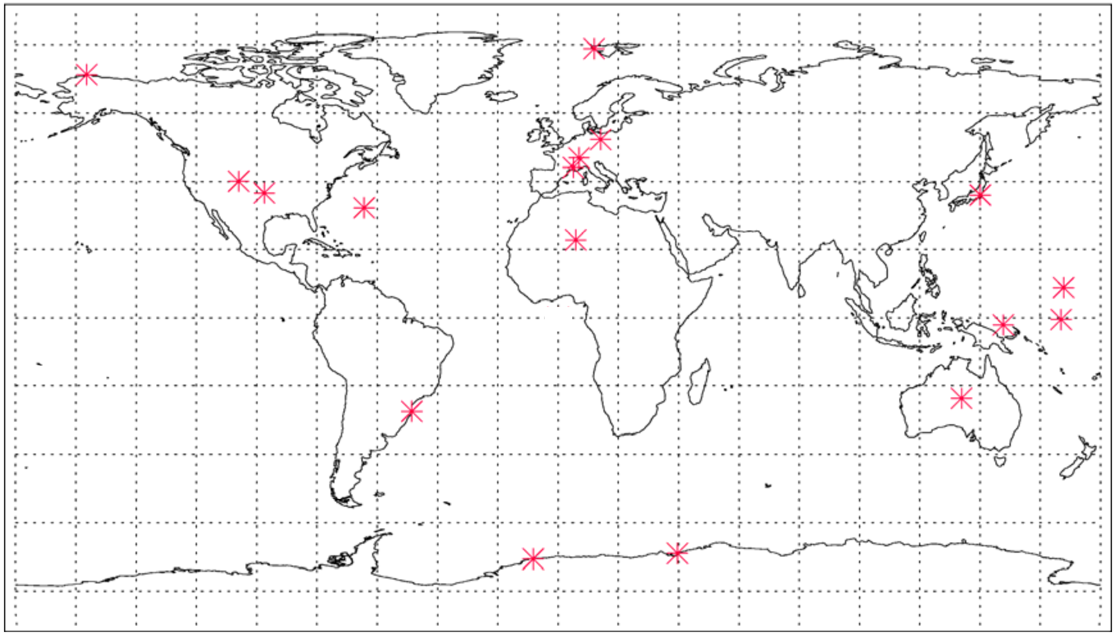
HadGEM GCM, withouth aerosol radiative effects

HadGEM GCM, with aerosol radiative effects

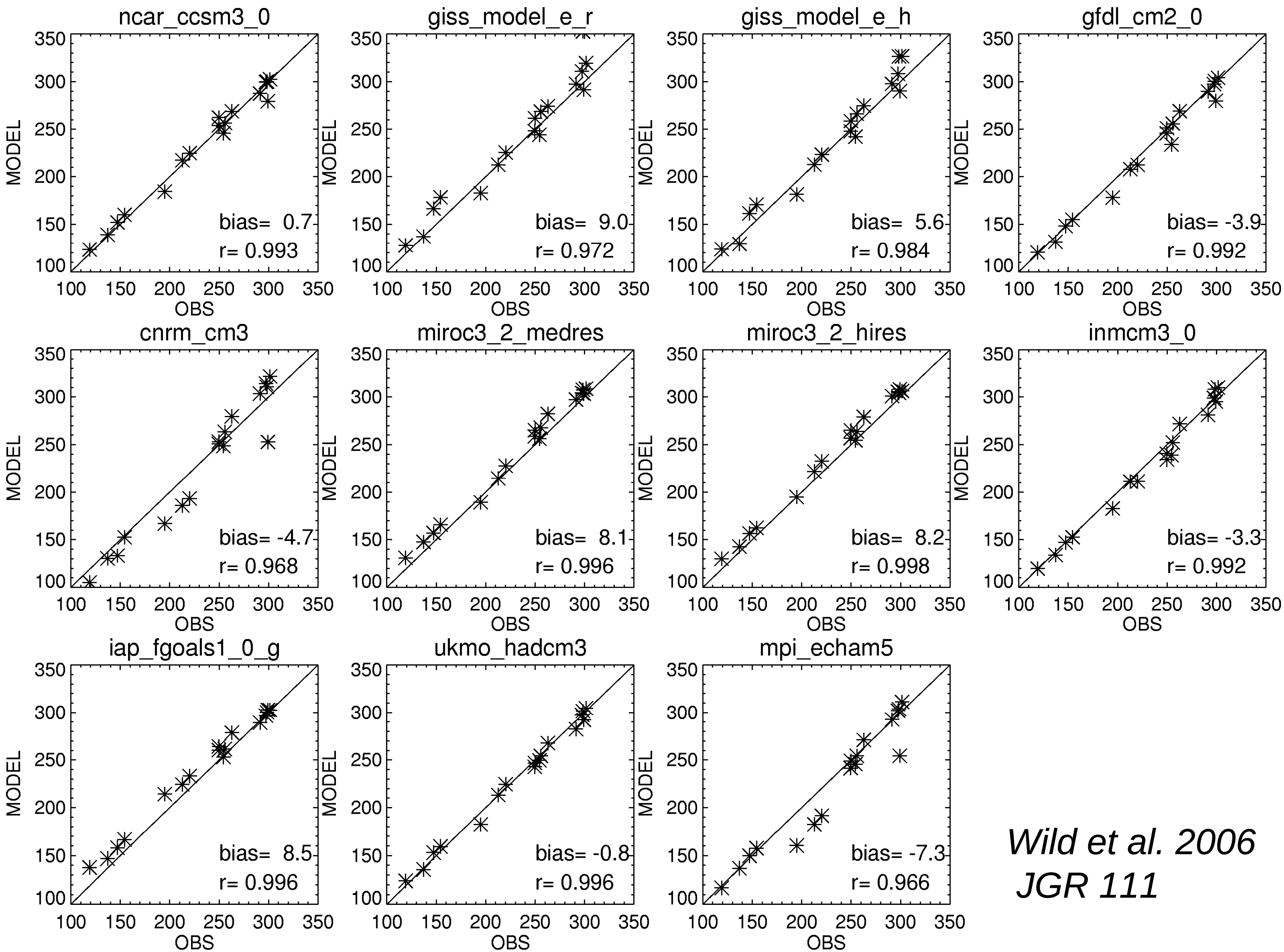
SW clear sky climatologies at BSRN sites

- Evaluation of the IPCC AR4 GCM clear sky SW fluxes with newly obtained observed clear sky climatologies
- Clear sky climatologies constructed from BSRN data using Long and Ackermann (2000) clear sky detection algorithm based on 1 minute data.

BSRN sites with surface SW clear-sky climatologies



SWD clear sky: IPCC AR4 Models versus BSRN



Wild et al. 2006
JGR 111

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Clear sky fluxes in GCMs with/withouth aerosol

Annaul cycles of $SWD_{clearsky}$

BSRN obs. in black

Hadley Centre GCMs:

HadAM2:
- *no aerosol (dashed line)*

HadAM3:
- *no aerosol (dotted line)*
- *with aerosol (solid line)*

WILD ET AL.: CLEAR-SKY SOLAR FLUXES IN GCMs

Wild et al. 2006 JGR

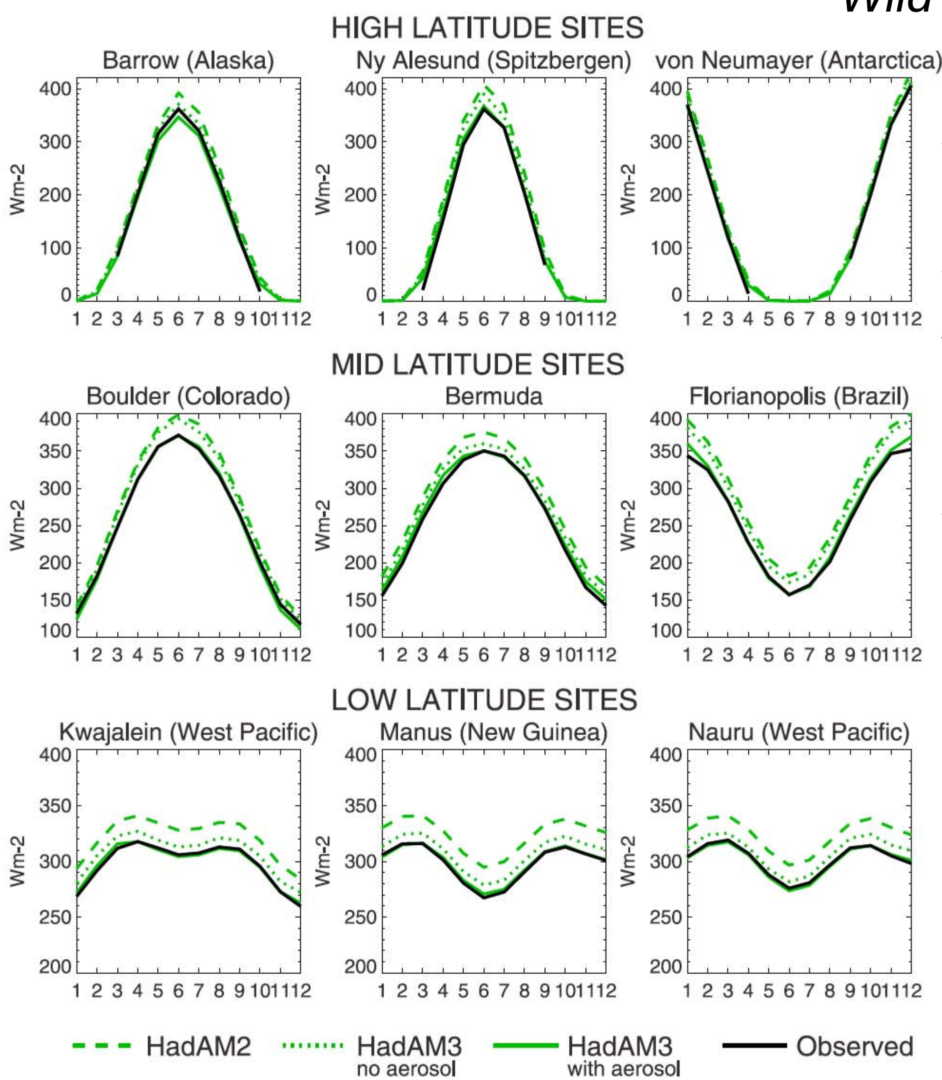

Figure 7. Mean annual cycle of clear-sky insolation at the surface as observed at selected BSRN sites and calculated in the Hadley Centre for Climate Prediction and Research model versions HadAM2 (participating in AMIP I), HadAM3 without aerosols and HadAM3 with aerosols (participating in AMIP II and IPCC AR4) Units are Wm^{-2}.

Mean biases:

HadAM3
no aerosol
+14 Wm^{-2}

HadAM3
with aerosol
+0.4 Wm^{-2}

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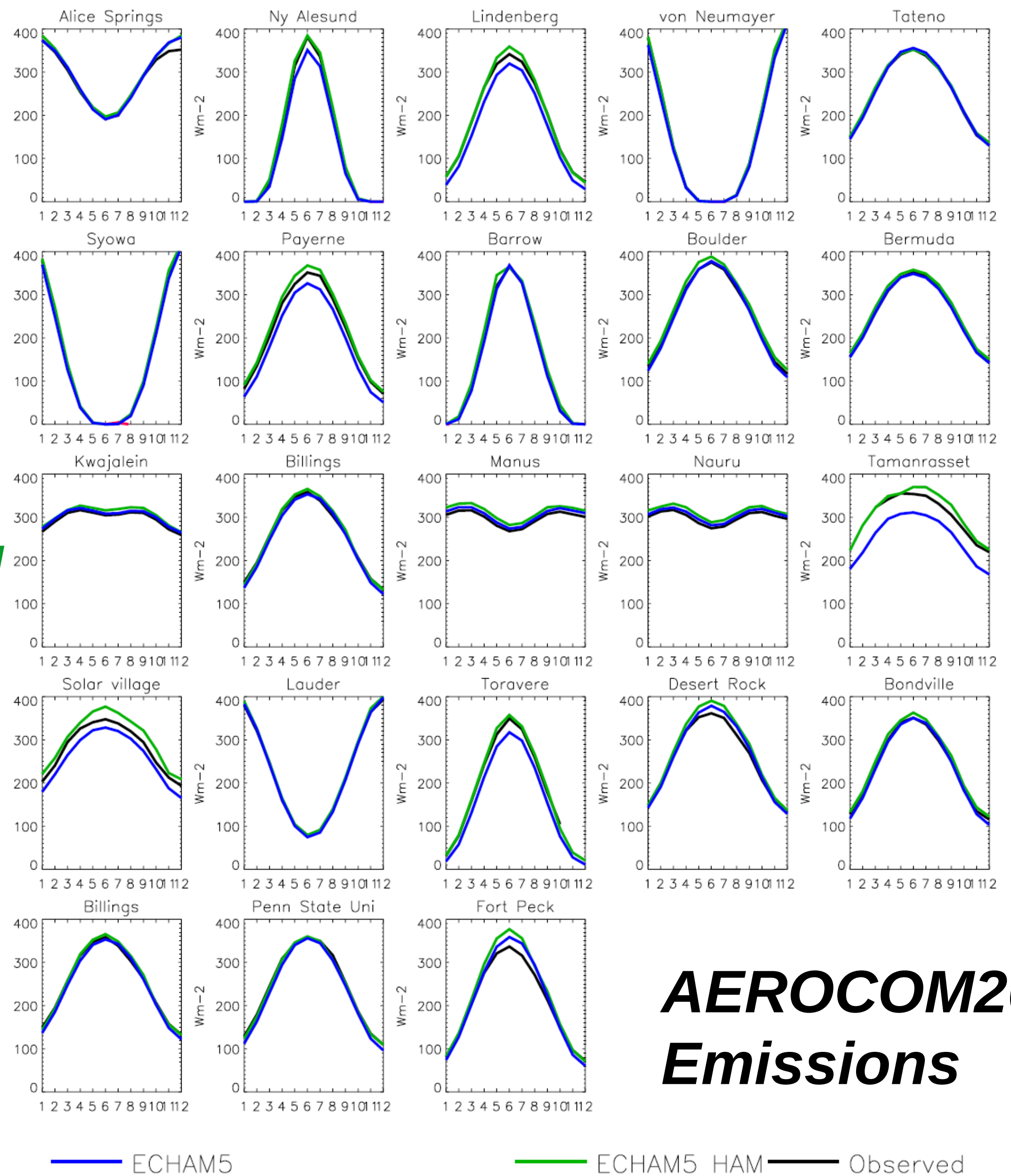
ECHAM5-HAM nudged version year 2000

SWD Clear Sky



ECHAM5-HAM
ECHAM5
BSRN Obs.

Model data courtesy of Philip Stier

AEROCOM2000 Emissions

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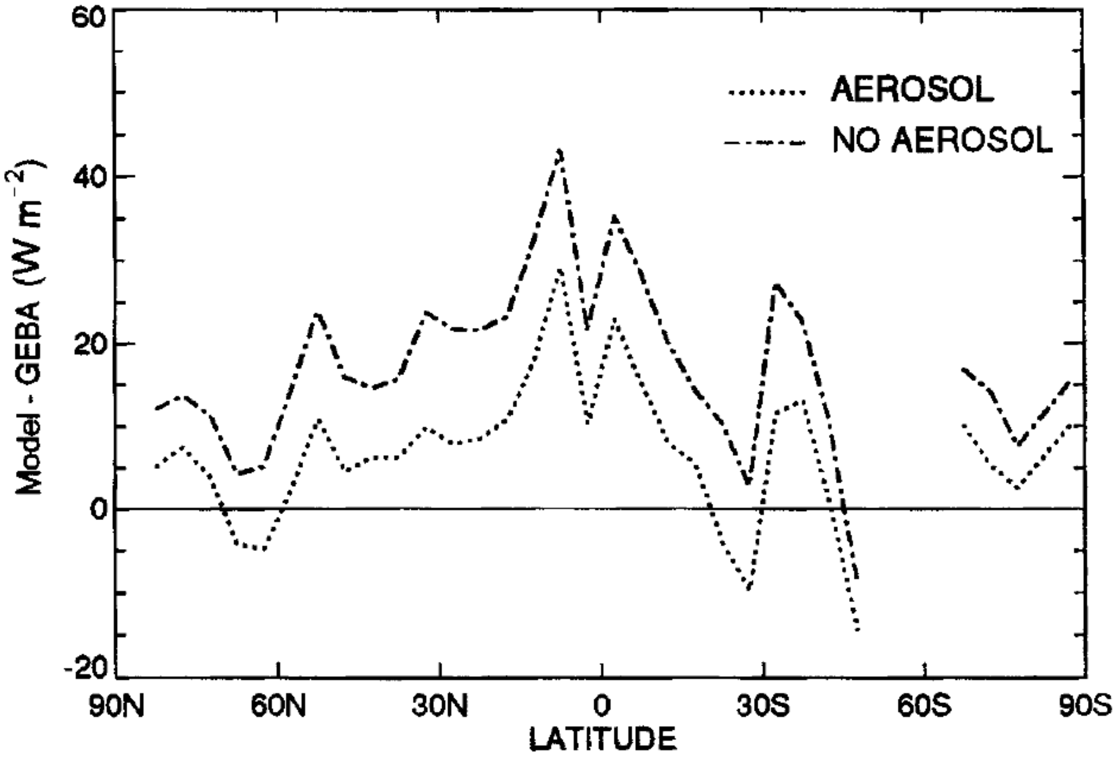
All sky fluxes in GCMs with/withouth aerosol

Surface insolation biases as function of latitude

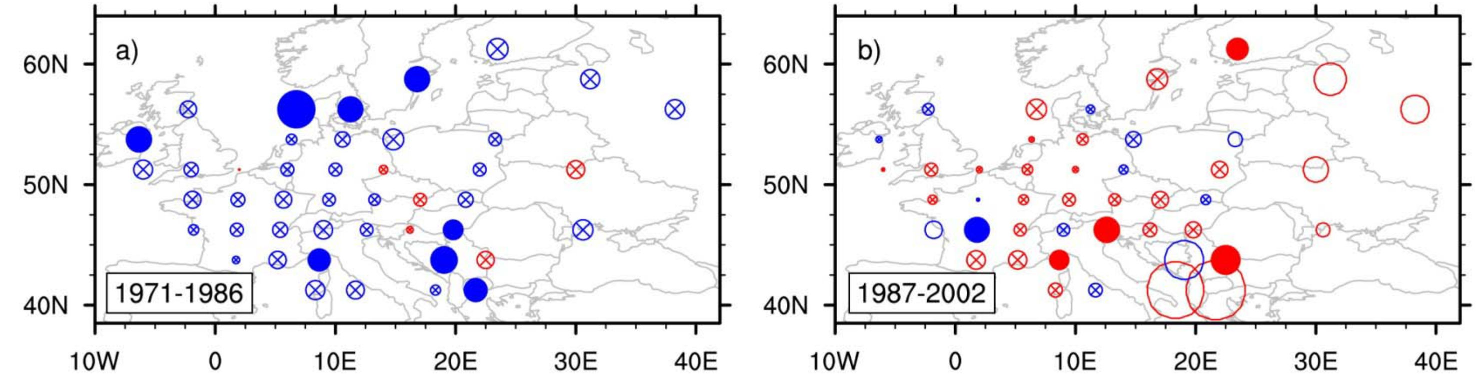
Compared to 760 sites from GEBA



Cusack, Slingo, Edwards, Wild 1998 Q.J.R. Meteorol. Soc.

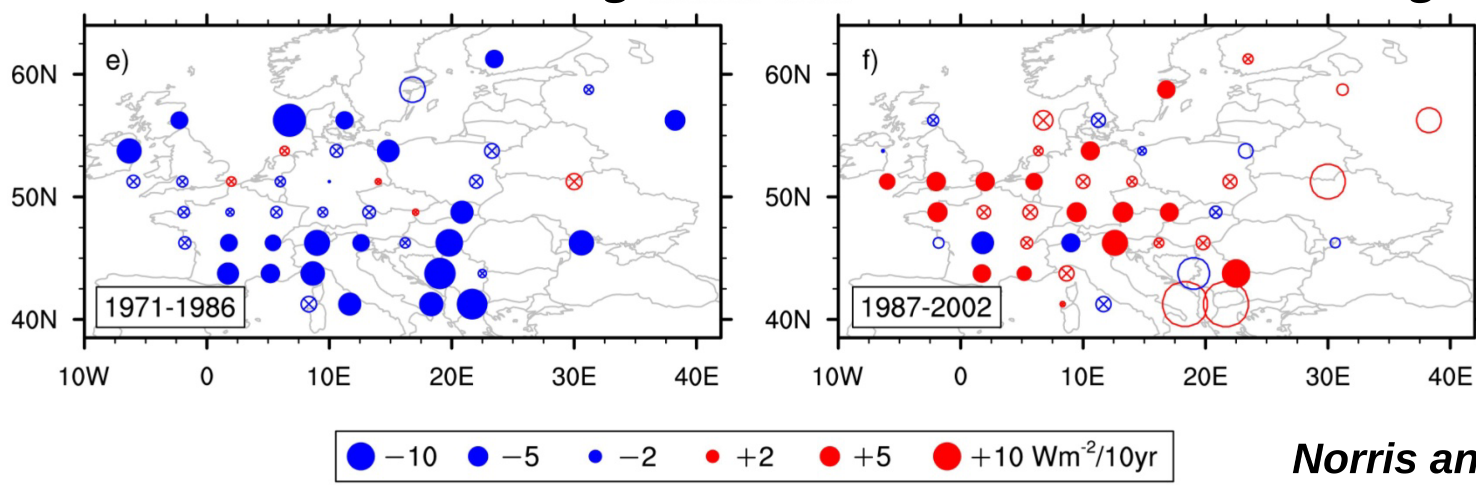
Effects of cloud amount on dimming/brightening in Europe

Original surface SW radiation trends in GEBA (all sky)



1971-1986 ***1987-2002***

Trends after removing effects form cloud cover changes

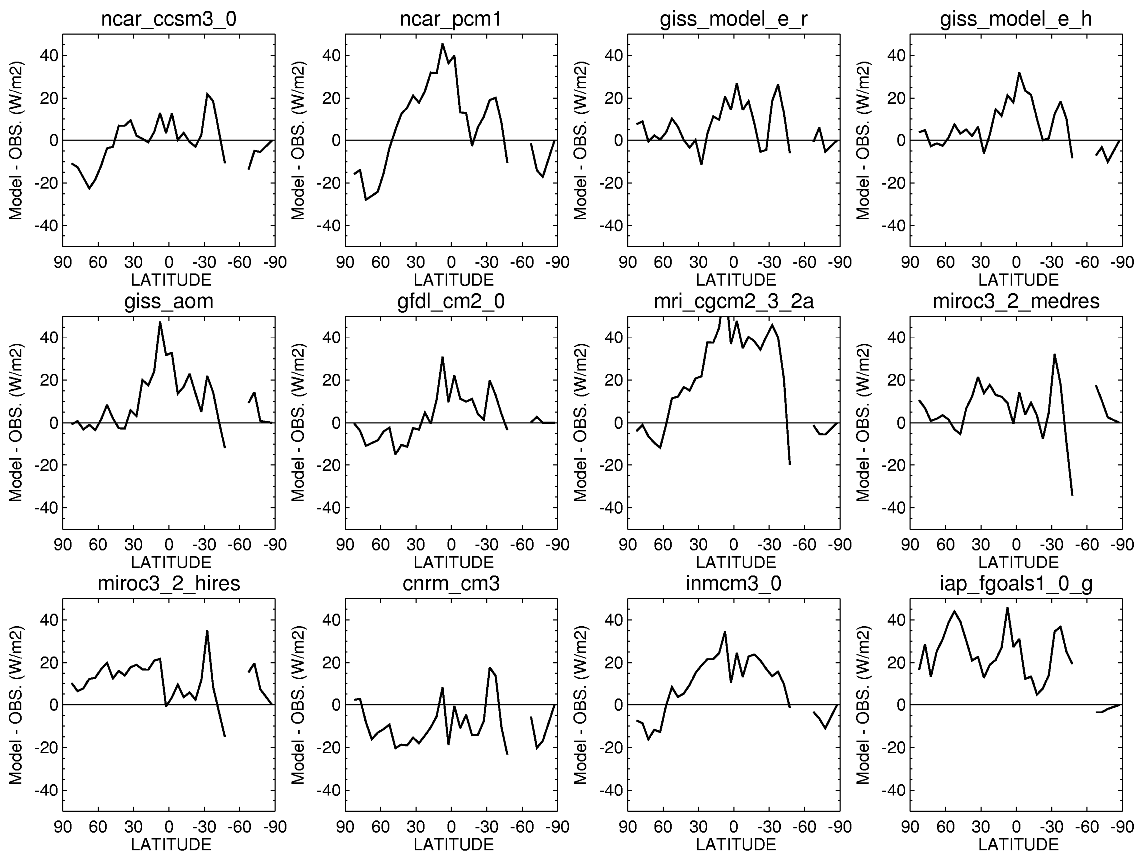


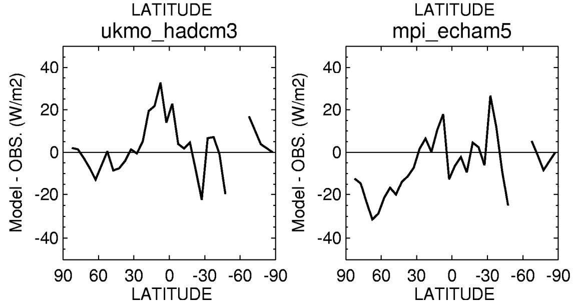
Norris and Wild 2007, JGR

Dimming and brightening trends remain after removal of effects of changing cloud covers

Doward solar radiation at the surface:

IPCC AR4 model biases as function of latitude





Most IPCC AR4 models tend to overestimate SW surface insolation particularly at low latitudes

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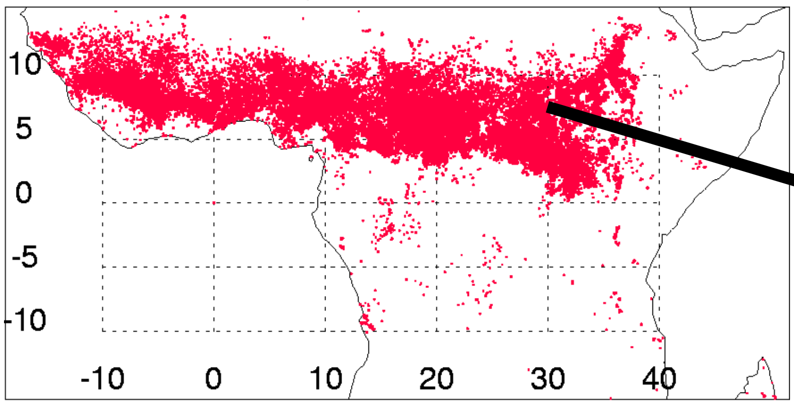
Biomass burning in Equatorial Africa

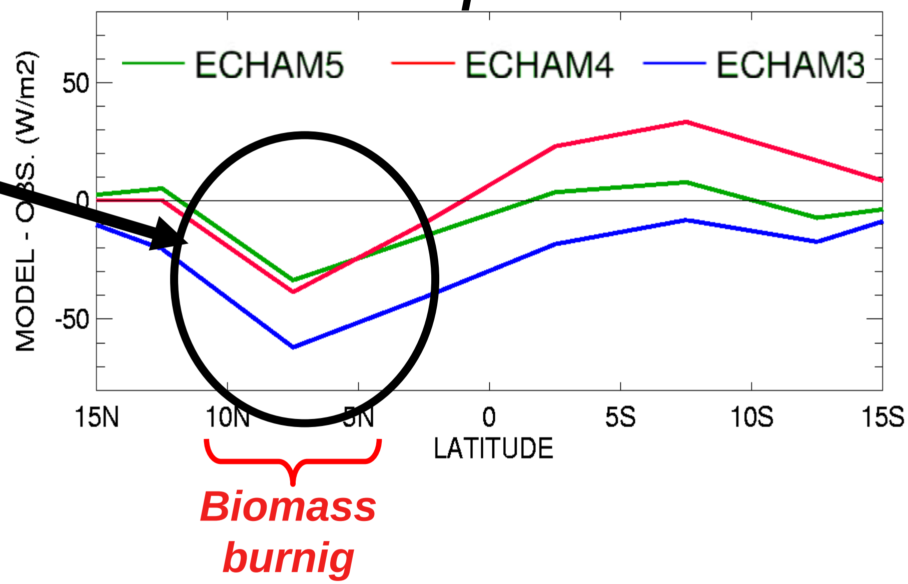
- *Problems in areas with large seasonal aerosol loadings: Example: Equatorial Africa, strong biomass burning in dry season*
- *Estimates for atmospheric SW column absorption from combined surface (GEBA) and satellite (ERBE) measurements.*

Fires counts over Africa January



Wild 1999, J. Geophys. Res.
Wild and Roeckner 2006 J. Climate

Atmospheric SW Absorption: Bias over Equatorial Africa



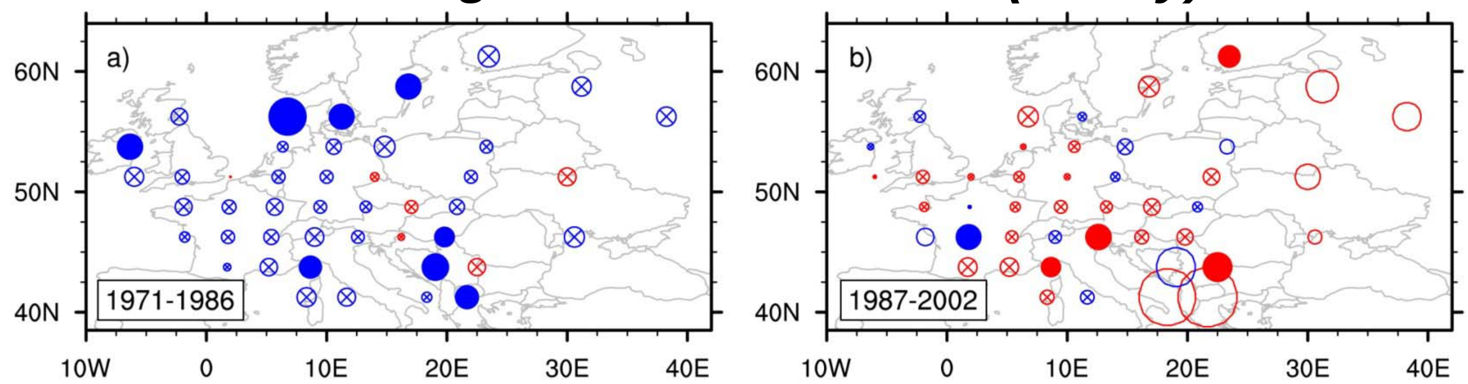
Large atmospheric absorption biases remain in areas with high loadings of absorbing aerosol

Wild and Roeckner 2006 J. Climate
Wild JGR 1999

From dimming to brightening: Europe

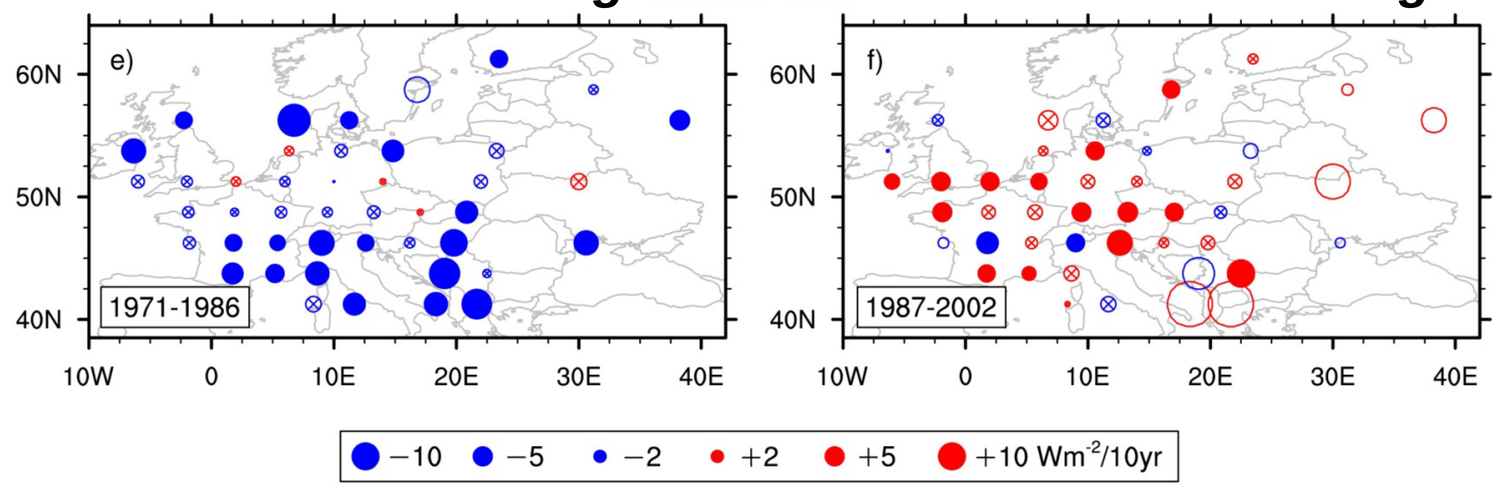
Norris and Wild 2007, JGR

Original trends in GEBA (all sky)



1971-1986 ***1987-2002***

Trends after removing effects form cloud cover changes



Dimming and brightening trends remain after removal of effects of changing cloud covers

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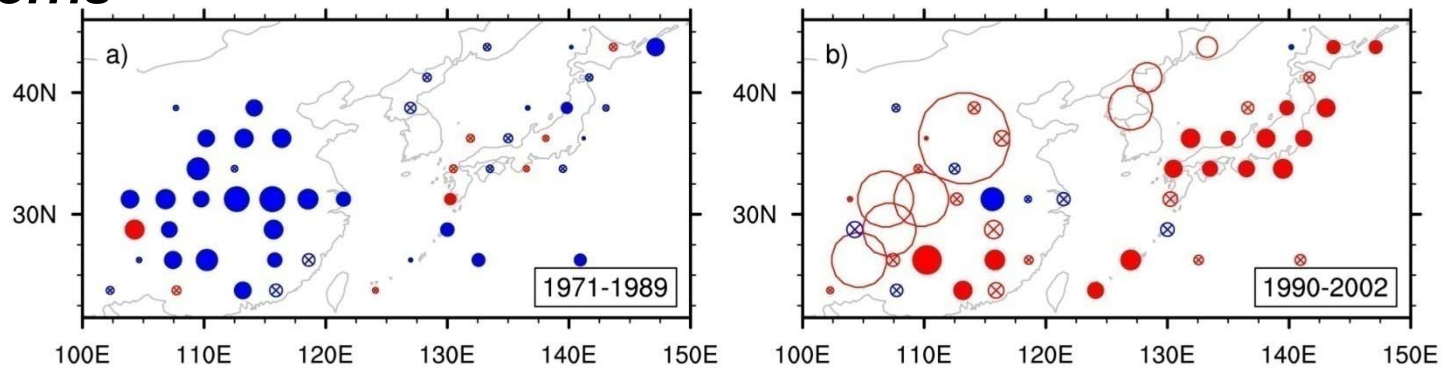
From dimming to brightening: Asia

Work with Joel Norris

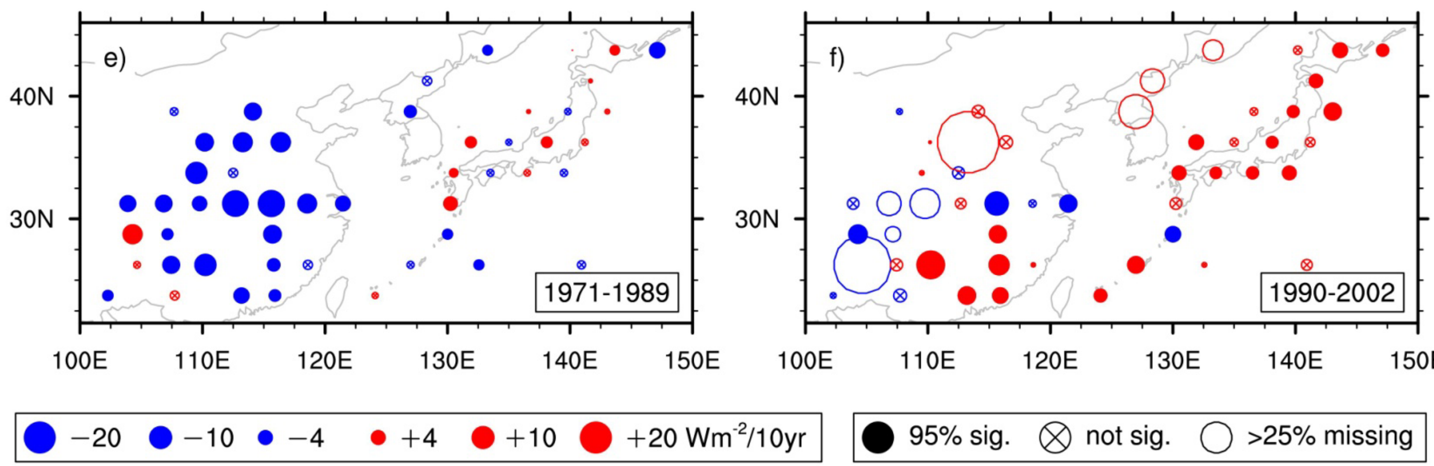
Surface SW radiation trends in GEBA (all sky)



1971-1989

1990-2002

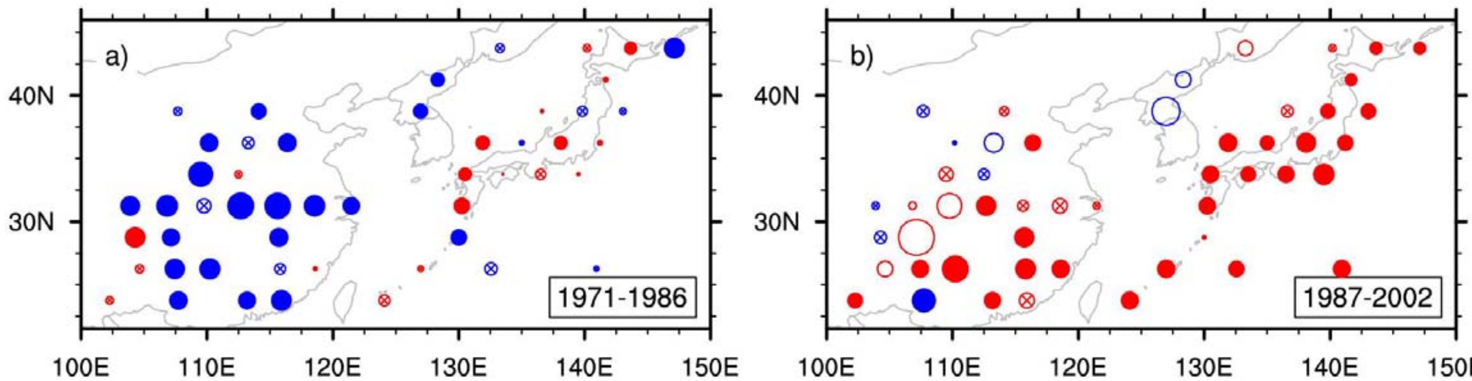
Trends after removing effects form cloud cover changes



Dimming and brightening trends remain after removal of effects of changing cloud covers

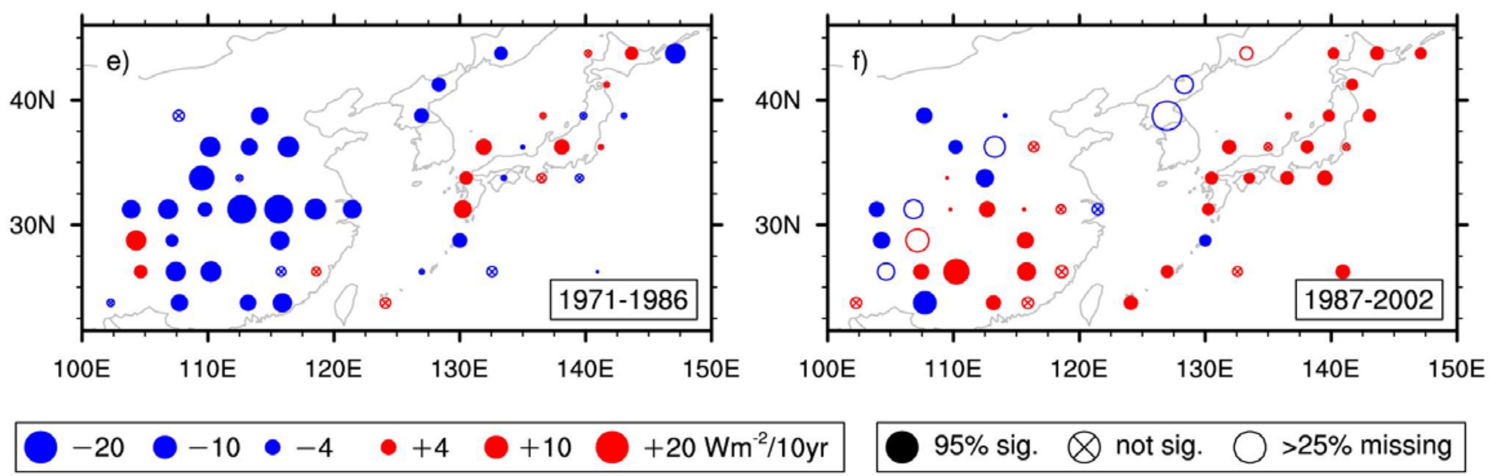
From dimming to brightening: Asia

Original trends in GEBA (all sky)



1971-1986 ***1987-2002***

Trends after removing effects form cloud cover changes



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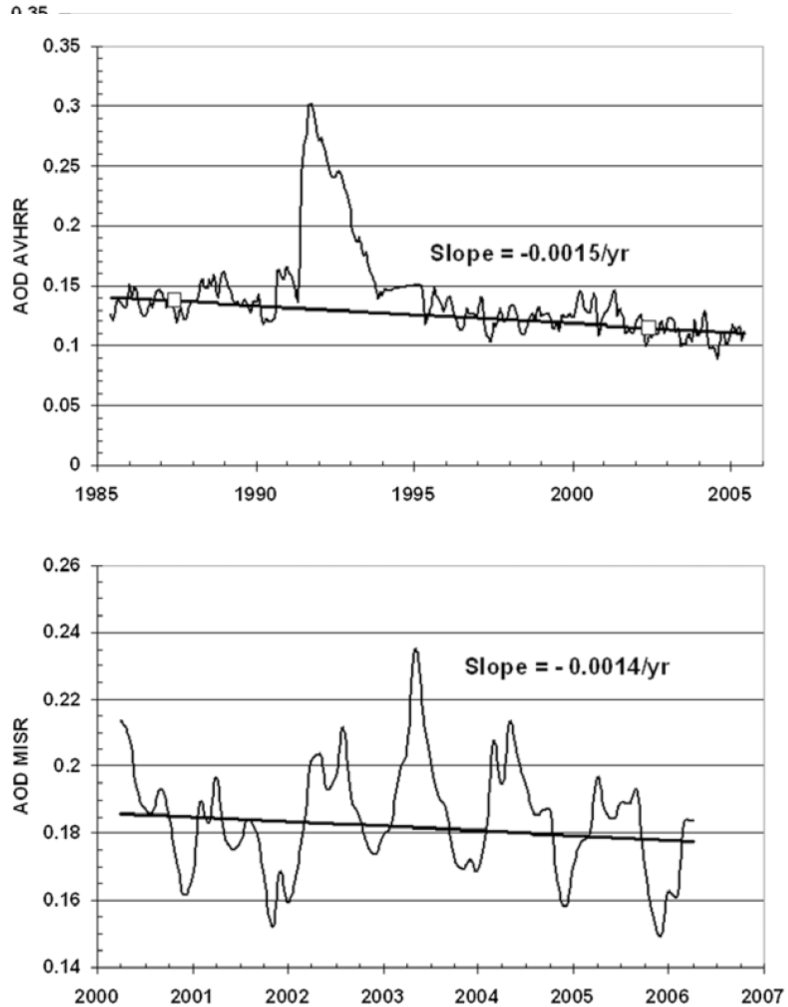
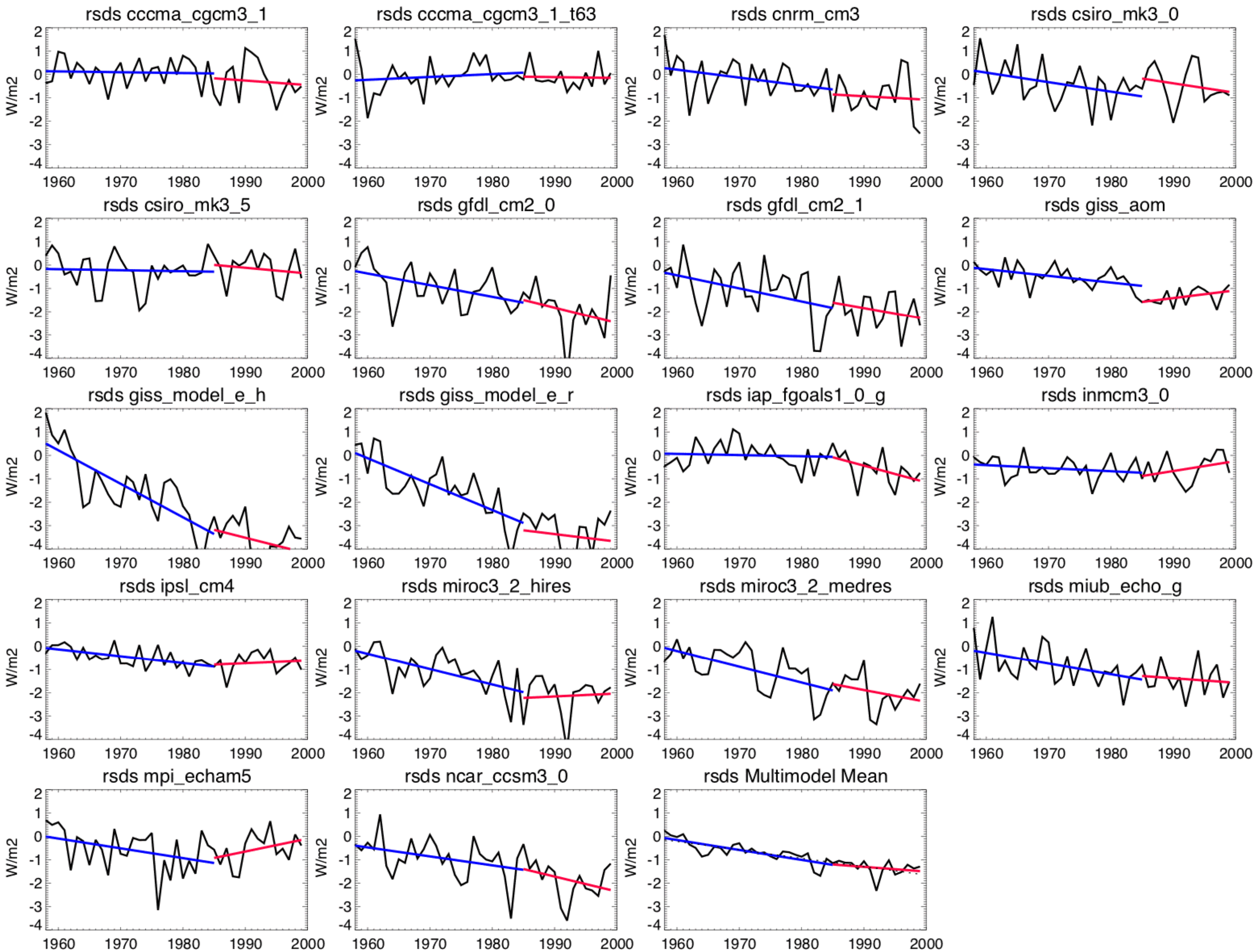
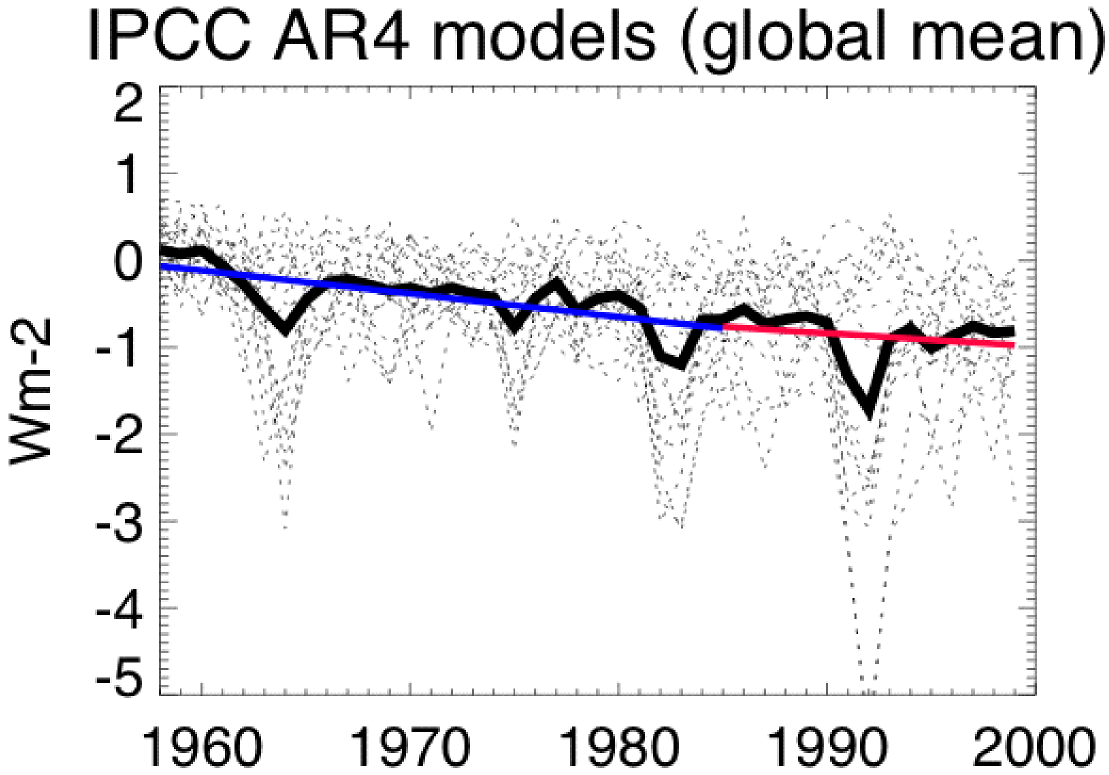


Figure 2. (top) The AVHRR data since 1985 suggests a declining global average of the AOD at the rate of −0.0015/a, while (bottom) the MISR data, available since early 2000, show a declining trend of −0.0014/a. To eliminate the Mt. Pinatubo effect on the AVHRR data, we have calculated an average AOD for years 1985–1990 and 2000–2005 (squares) and interpolated a linear trend through these two points. The AVHRR data are for AOD over the ocean, while the MISR data are for combined ocean and land.

Global radiation IPCC AR4 models



SWD IPCC AR4 models (global mean)

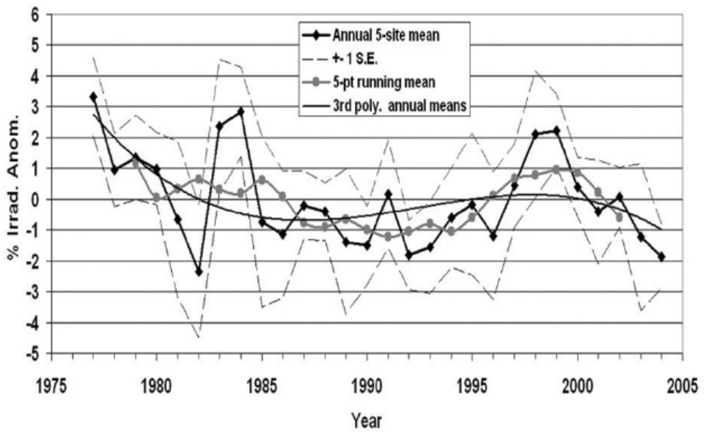


slope 1958-85 multimodel mean -0.027 $Wm^{-2}y^{-1}$

slope 1985-2000 multimodel mean -0.015 $Wm^{-2}y^{-1}$

slope 1958-1999 multimodel mean -0.023 $Wm^{-2}y^{-1}$

Dutton et al. (2006)



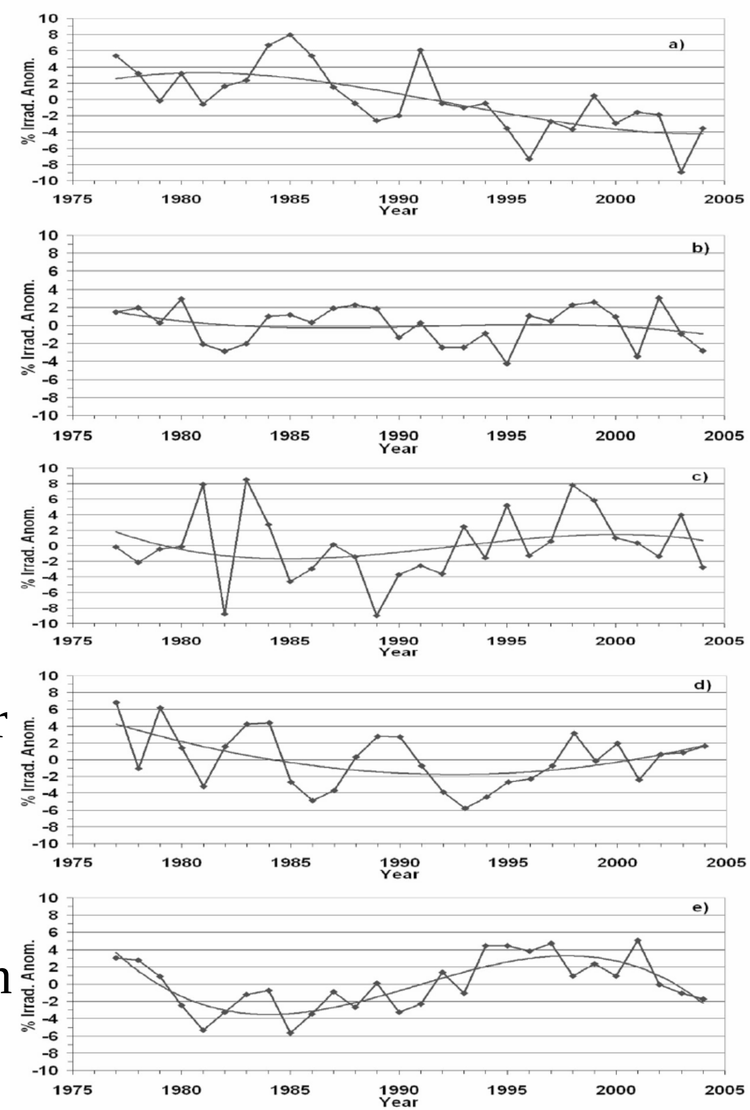


Figure 2. Annual average surface solar irradiance observed at the five sites of the NOAA/GMD baseline monitoring network: (a) Barrow; (b) Boulder; (c) Mauna Loa; (d) American Samoa; and (e) South Pole.

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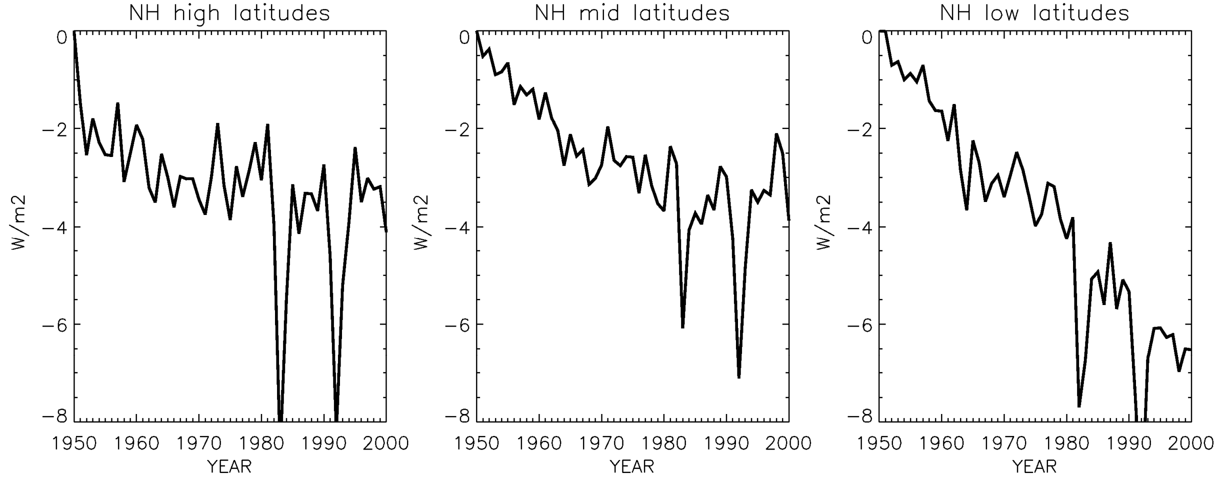
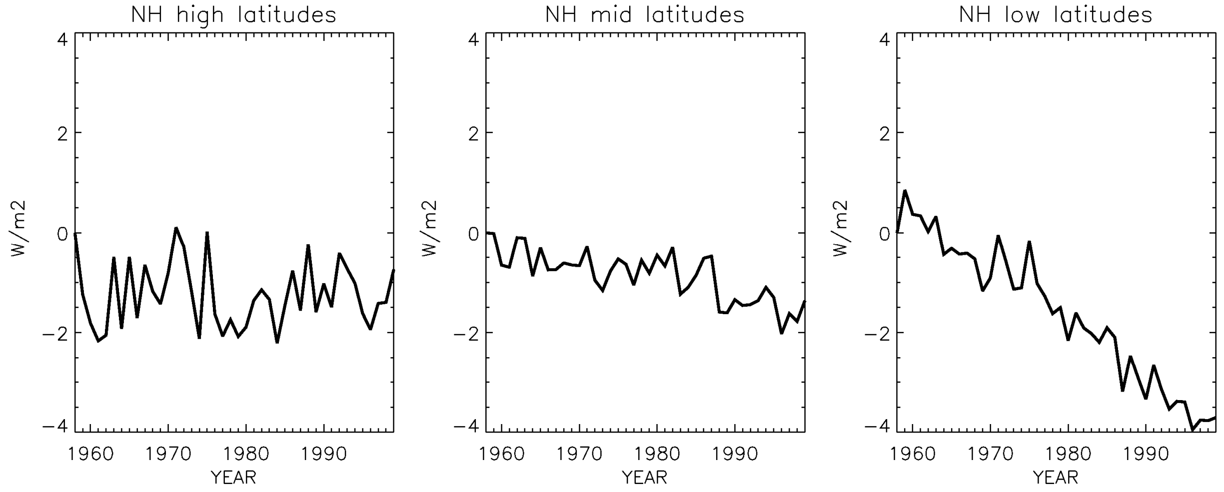
Zonal means SW down clear sky 1950-2000

T42 newer model, with volcanoes

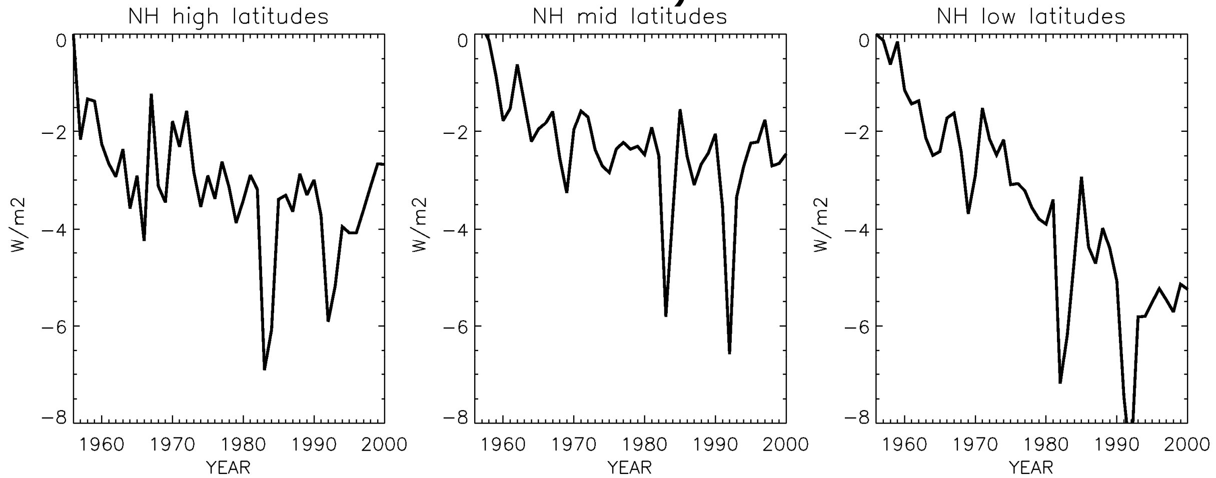


T63 older model, without volcanoes

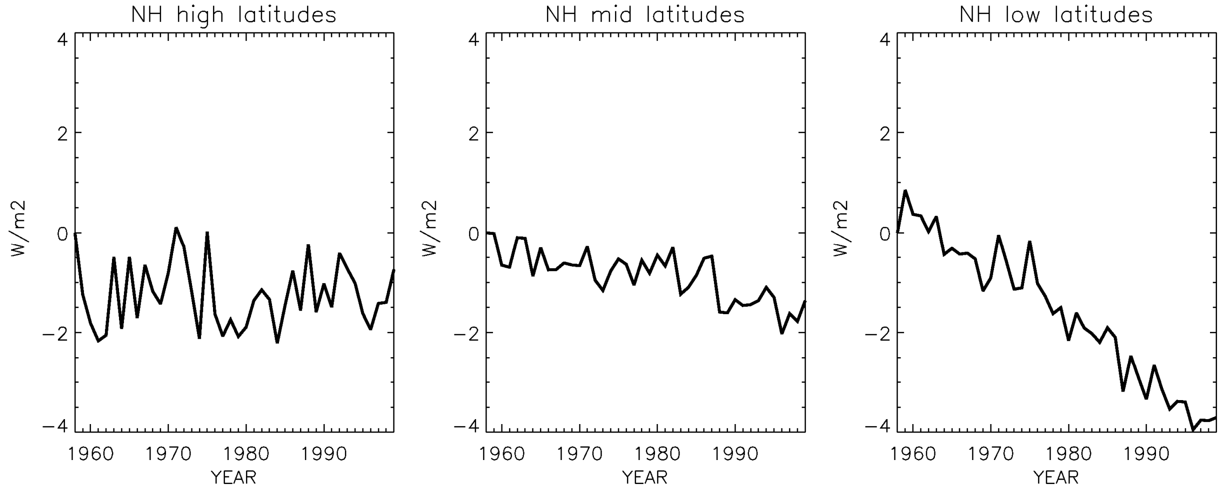


Zonal means SW down clear sky 1956-2000

T42 newer model, with volcanes

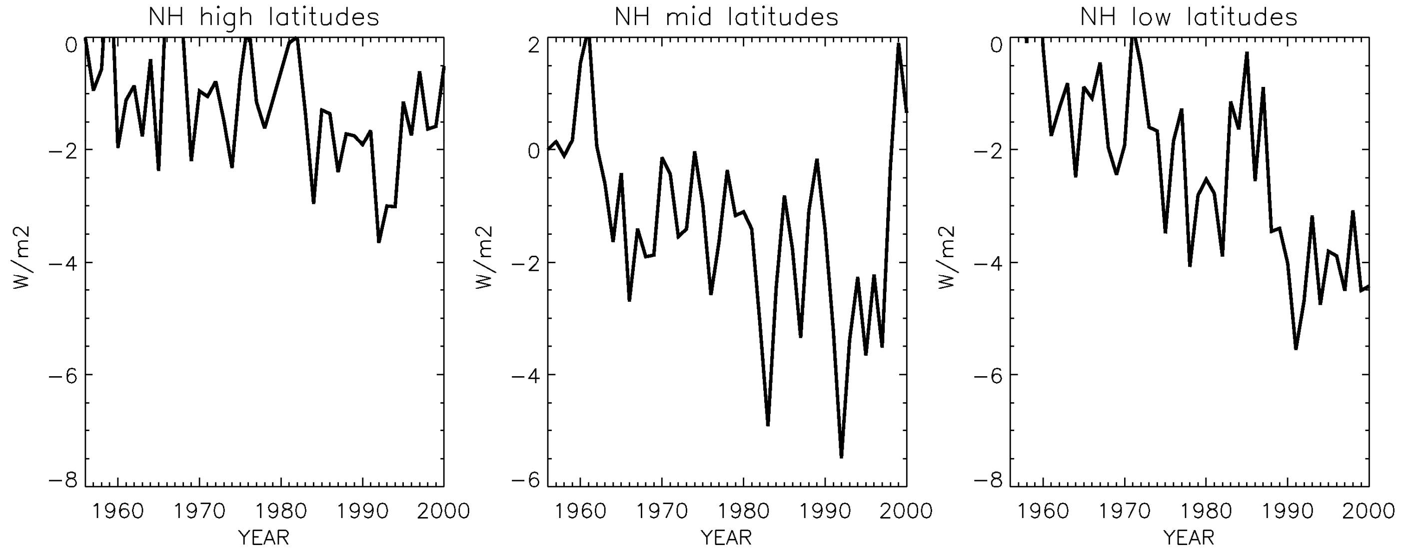


T63 older model, without volcanes

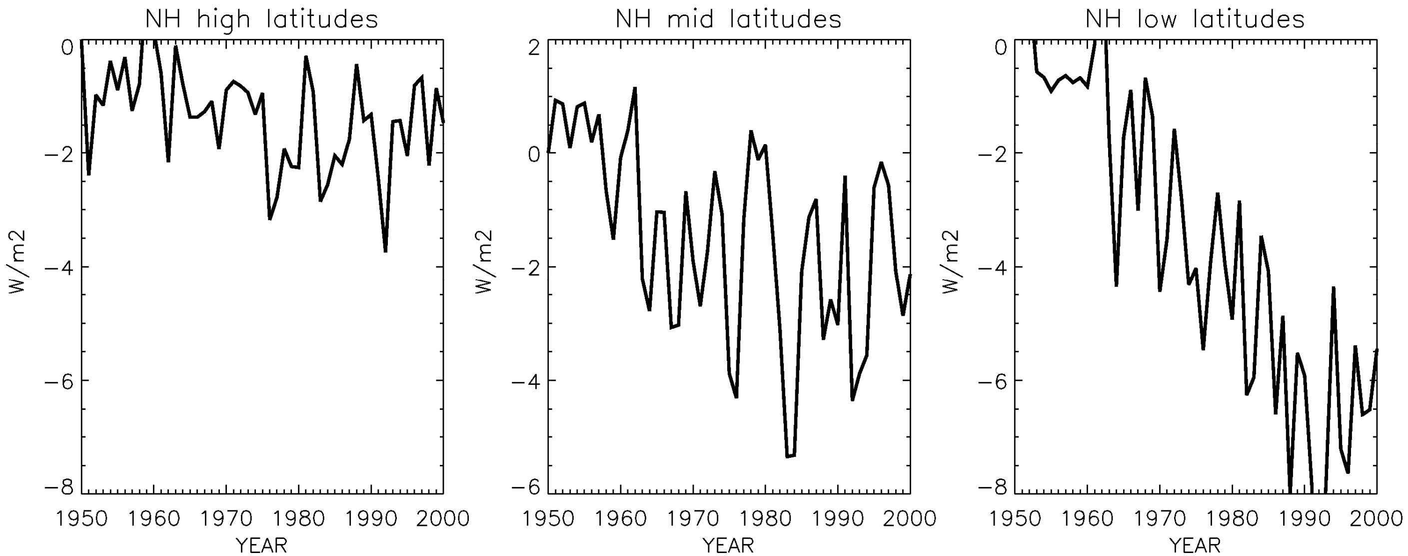


Zonal means SW down all sky, different SSTs

T42 AMIP SSTs



T42 ENSEMBLE SSTs



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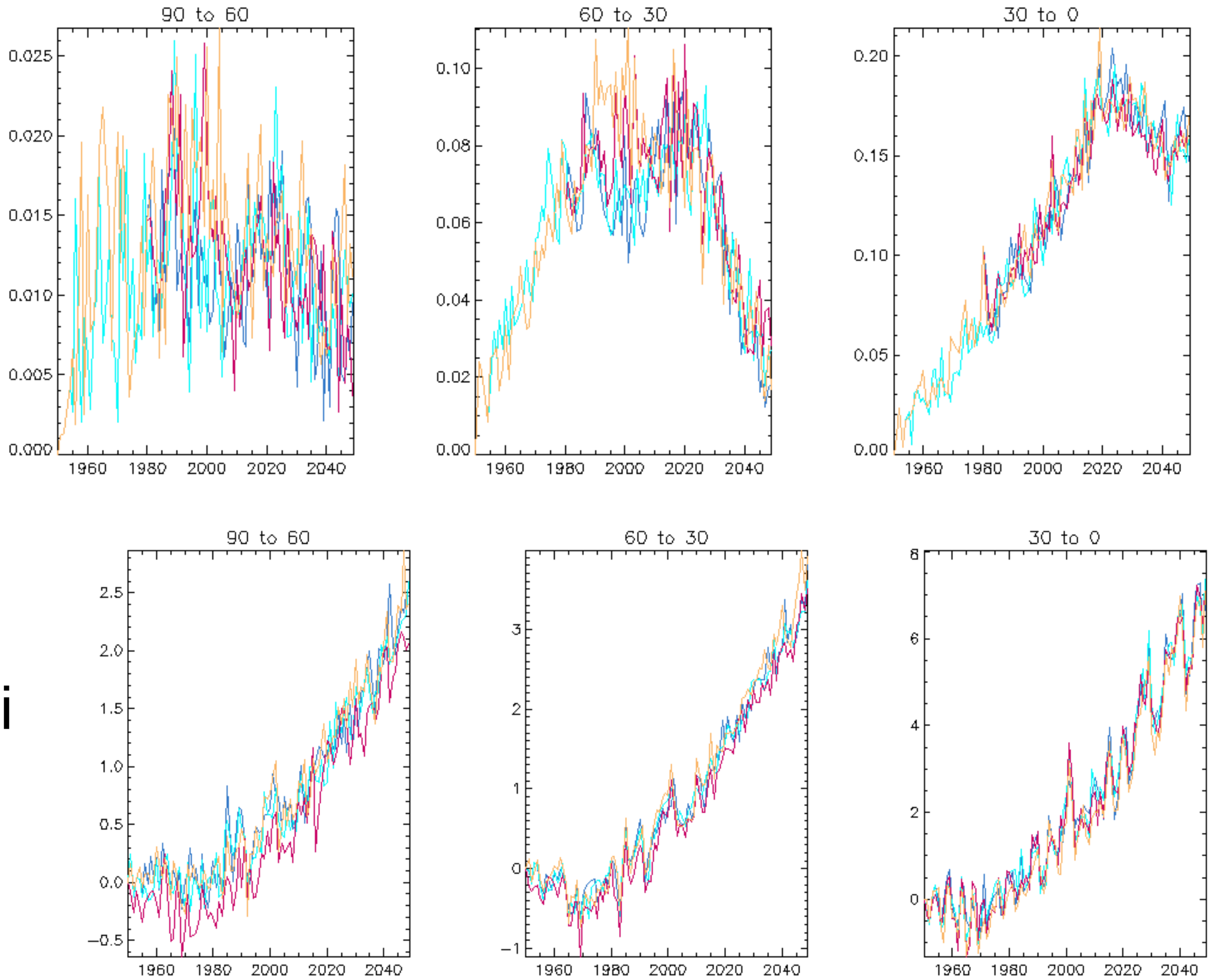
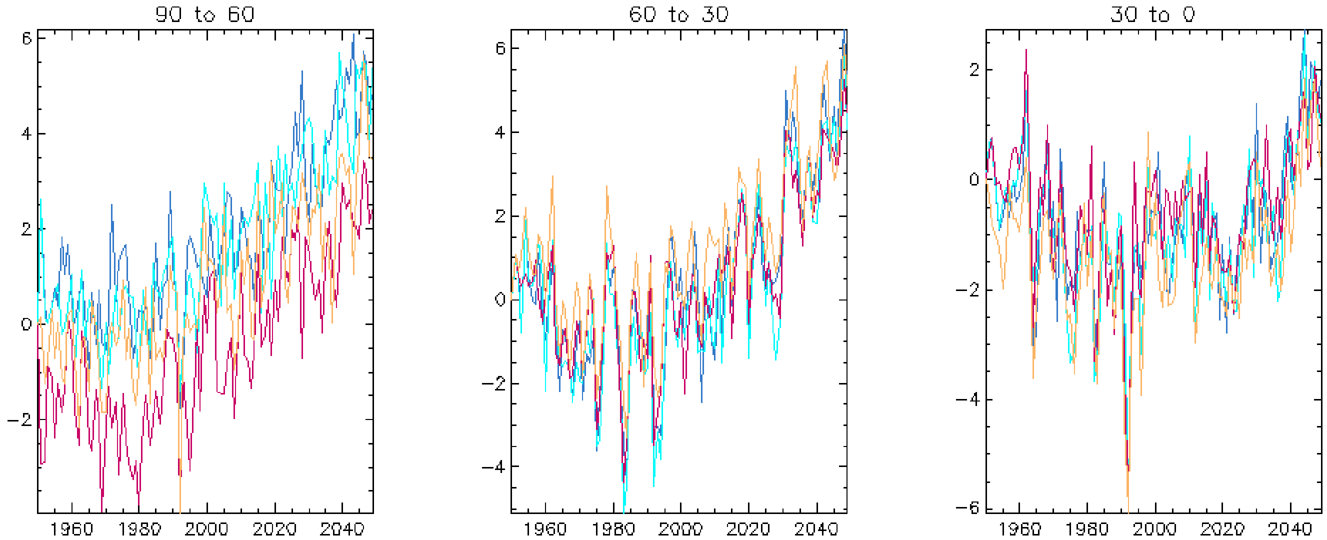
Tau mit mod russland

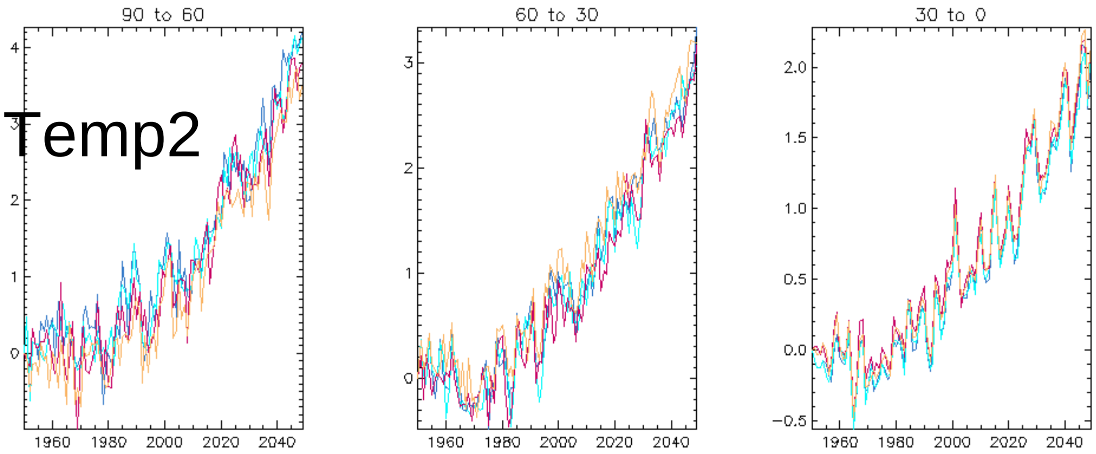


qvi

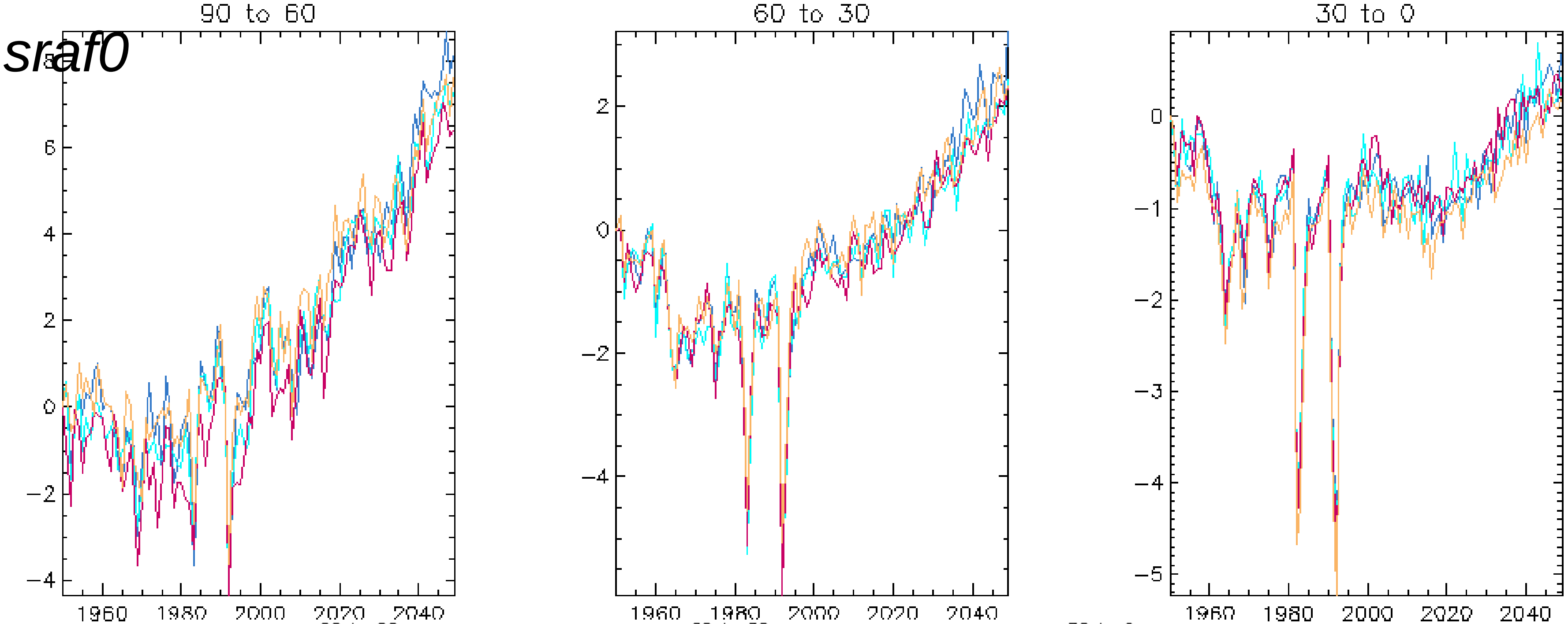
srad0



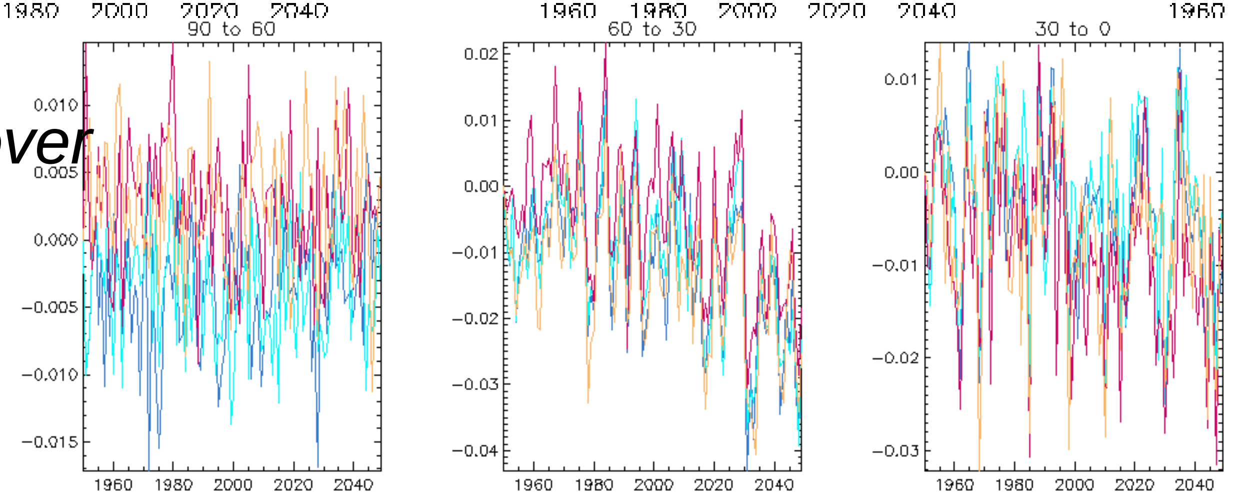
Temp2



sraf0

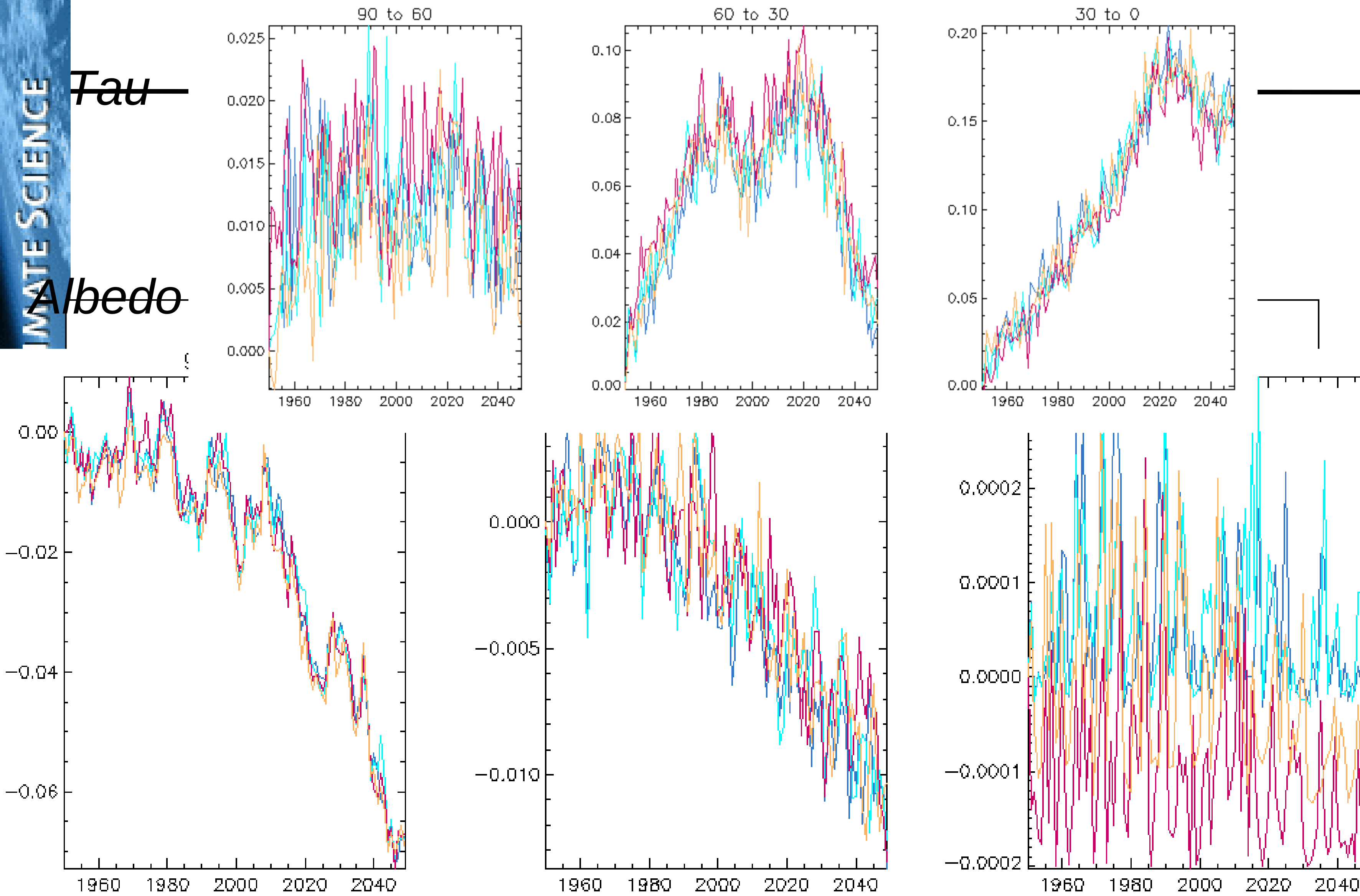


coudcover



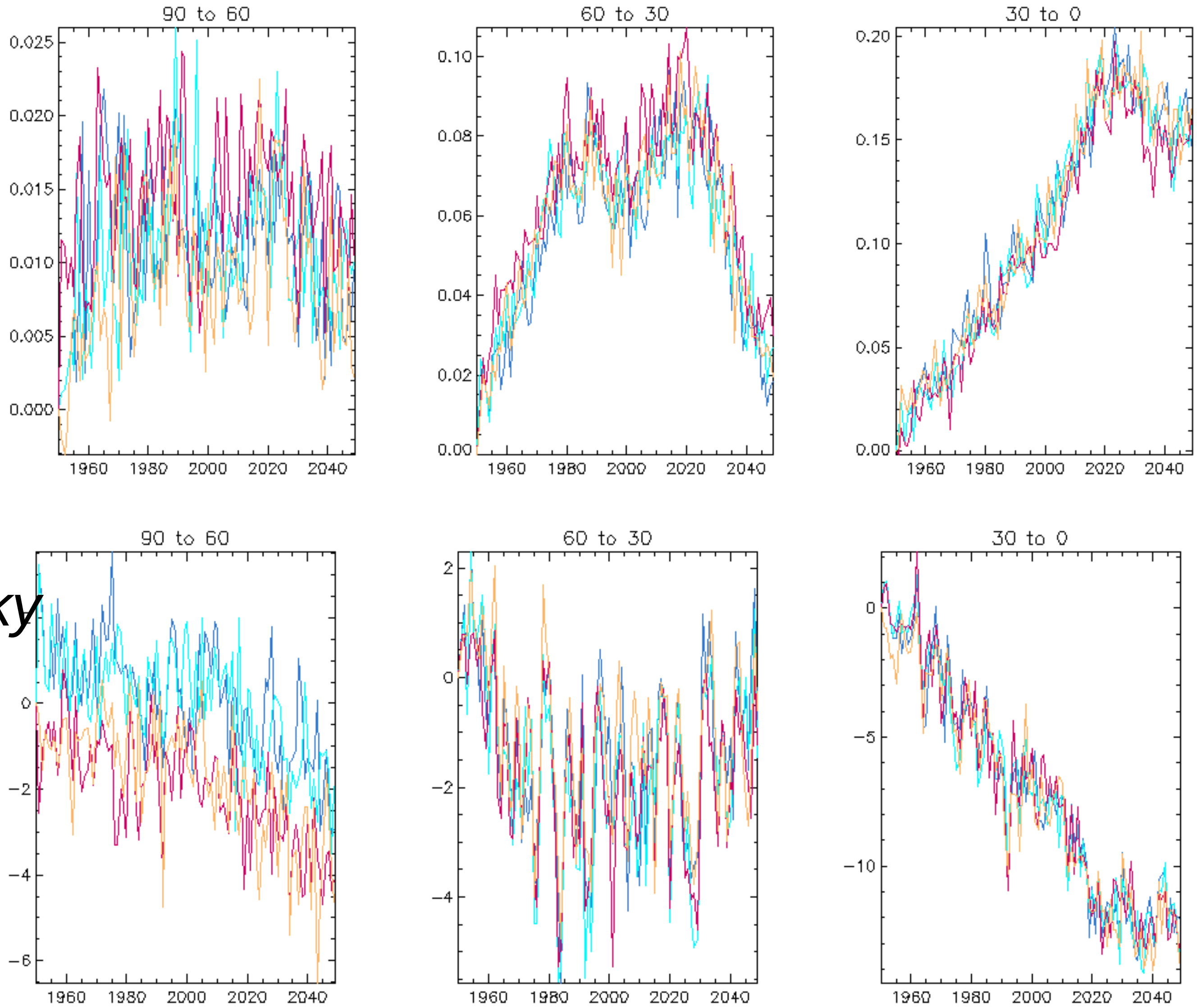
Tau

Albedo


90 to 60
60 to 30
30 to 0
0.025
0.020
0.015
0.010
0.005
0.000
0.10
0.08
0.06
0.04
0.02
0.00
0.20
0.15
0.10
0.05
0.00
0.00
−0.02
−0.04
−0.06
0.000
−0.005
−0.010
0.0002
0.0001
0.0000
−0.0001
−0.0002
1960
1980
2000
2020
2040

Tau

Clear sky SWD



BSRN Measurement Accuracy Target

- **Direct SW radiation: 1% or 2 Wm-2 (normal incidence pyrheliometer)**
- **Diffuse radiation: 4 % or 5 Wm-2 (ventilated pyranometer)**
- **Global Radiation 2% or 5 Wm-2 (ventilated pyranometer)**
- **Reflected SW radiation: 5% (ventilated pyranometer)**
- **Downwelling longwave radiation +/ - 2 Wm-2 (pyrgeometer)**

Measurement uncertainty: single measurement

Kurzwellig:

- Pyranometer:

  2% (Ohmura and Gilgen 1993)

  4 Wm^{-2} bei guter Wartung der Instrumente (Konzelmann und Ohmura 1995)

Langwellig:

- Pyrgeometer: +/- 2 Wm^{-2} (R. Phillipona, Pers. Mitteilung)
- Pyrradiometer:

  Belüftet, mit Schattenscheibe: +/- 10 Wm^{-2}

Fehleranalyse Globalstrahlung (SW down)

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Representativität eines einzelnen Jahresmittelwertes für mittlere Klimatiologie einer 2.5° Gitterbox:

Mittlerer Fehler: 7 %

zusammengesetzt aus:

- Zufälliger Messfehler (2%)

- Vernachlässigung Trends (3%)

- Vernachlässigung interanuelle Variabilität (4%)

- Subgrid Variabiltät (5%)

GCM Analysen:

- **zufällige Messfehler, Trend, interannuelle Variabilität: minimiert, da nur langjährige Messreihen**
- **Subgrid Variabilität reduziert bei T106 (1.1°) Analysen**

Mittlerer Fehler der Obswerte in GCM Vergleichen << 7 %

Identification of clear sky periods

Long and Ackerman (2002), JGR 105 (D12), 15609-15626

- Based on 1 minute data of downwelling total and diffuse shortwave irradiance
- 4 tests applied:

A) **Normalized total shortwave magnitude test** Normalized with solar zenit angle, nominal range of values for clear sky

B) **Maximum diffuse shortwave test**
clear sky diffuse irradiance below a certain threshold

C) **Change in magnitude with time test**
compares temporal change in total irradiance, small for clear periods compared to cloudy periods over short timescales

D) **Normalized diffuse ratio vatiability test**
diffuse divided by total irradiance,smooth timeseries for clear skies, variability below threshold