The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

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Workshop on Aerosol Impact in the Environment: from Air Pollution to Climate Change

8 - 12 August 2011

Global dimming and role of aerosols

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Global dimming/brightening and role of aerosols

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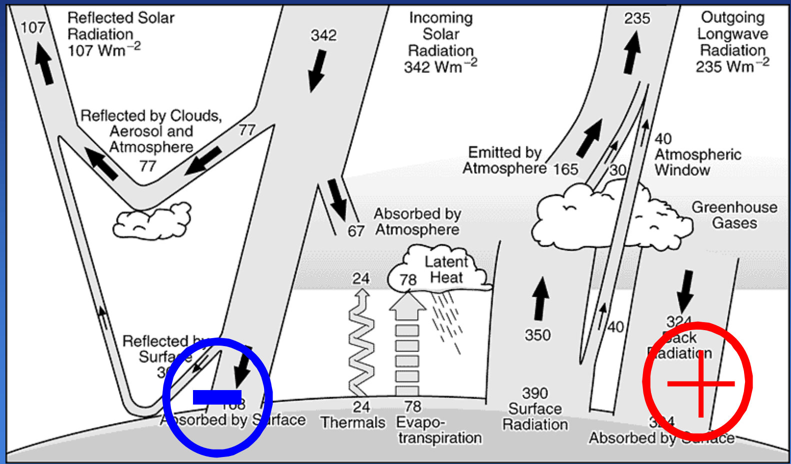
Workshop on Aerosol Impact in the Environment:
from Air Pollution to Climate Change

9 August 2011

Content

- Dimming/ Brightening in Europe
- Update on Global Dimming/Brightening beyond 2000 and around the globe

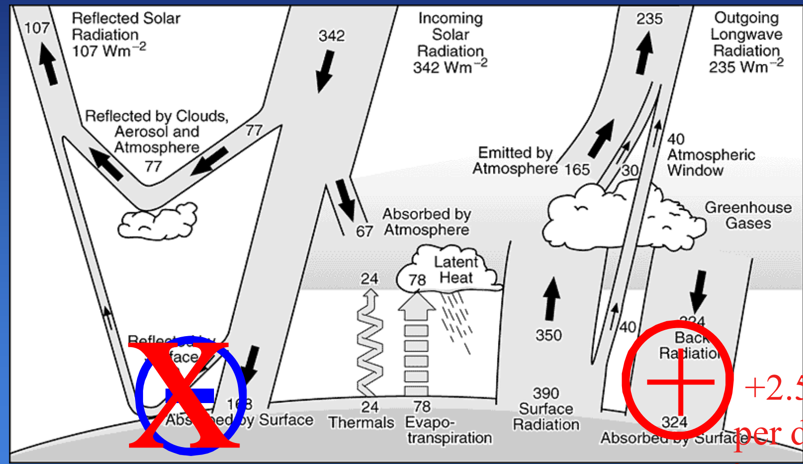
Surface solar versus greenhouse forcings



1960s to 1980s

- **Solar dimming counter-balances increasing longwave downward radiation**
- **Surface radiative heating is not increasing**

Wild et al. (2004) GRL 32



+2.5 Wm^{-2} per decade from BSRN

1980s to present

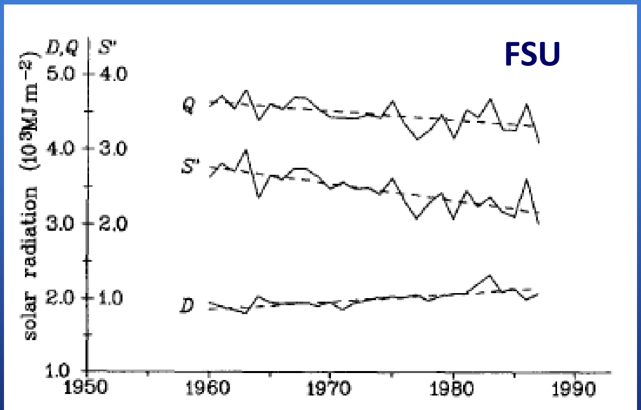
- **Absense of solar dimming no longer maks longwave greenhouse effect**
- **Surface radiative heating increases significantly**

Wild et al. (2005); Wild et al. (2007)

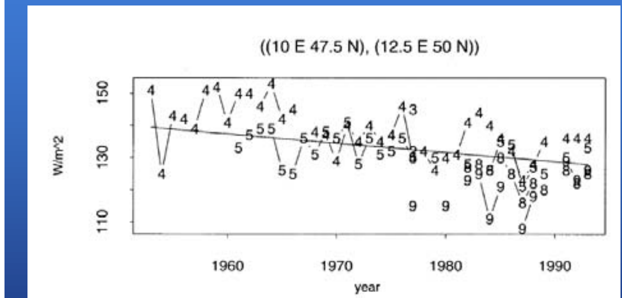
Decadal Variations of SW Radiation

Global dimming

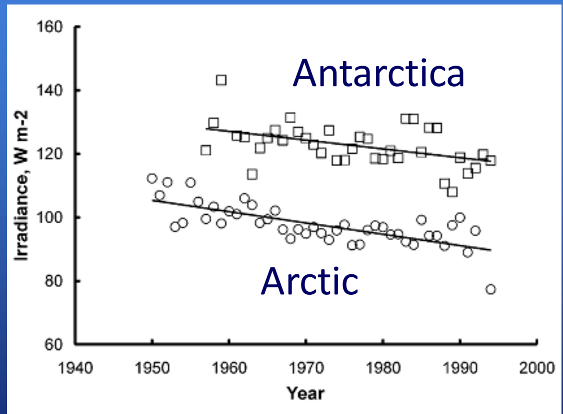
• Late 1980s: first evidences of decrease in surface solar radiation between 1950s-1990s (e.g. Ohmura and Lang, 1989)
• Estimated linear changes between 2% and 10%/decade (Stanhill and Cohen 2001)
• Liepert (2002) estimated a decrease of 7 Wm^{-2} over global land sites during the 1961-1990 period



Abakumova et al. (1995)



Gilgen et al. (1998)



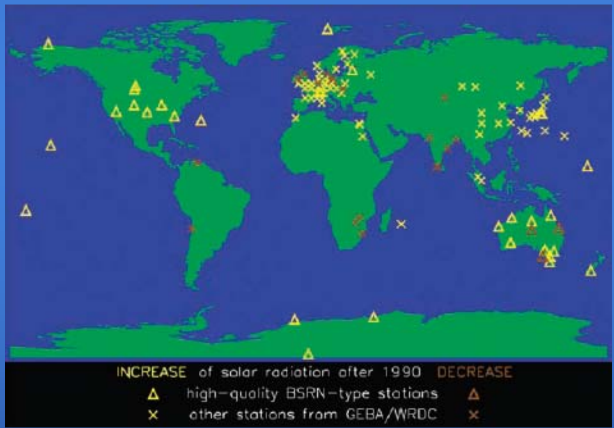
Stanhill and Cohen (2001)

Decadal Variations of SW Radiation

Global brightening

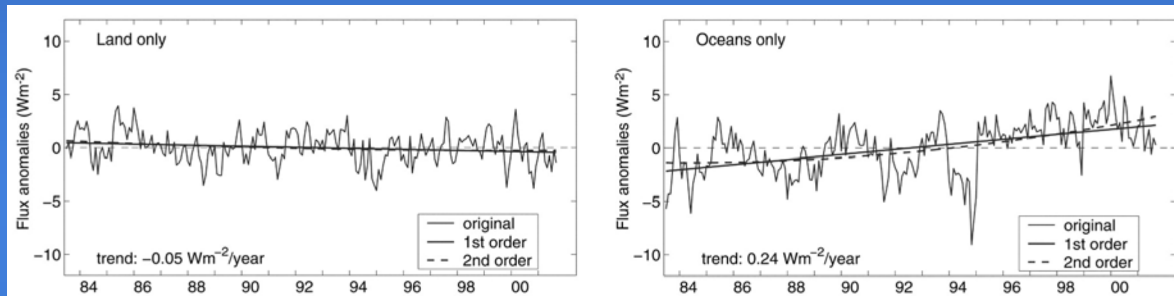
• Since late 1980s a reversal in this trend has been detected in many regions of the world using surface and remote sensing observations

1992-2002

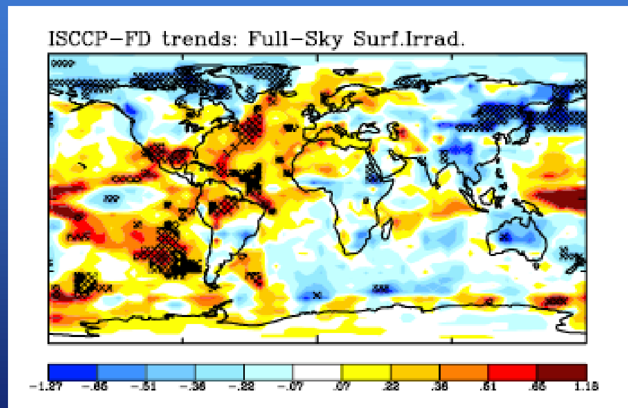


Wild et al. (2005)

Land and Ocean (1983-2001)



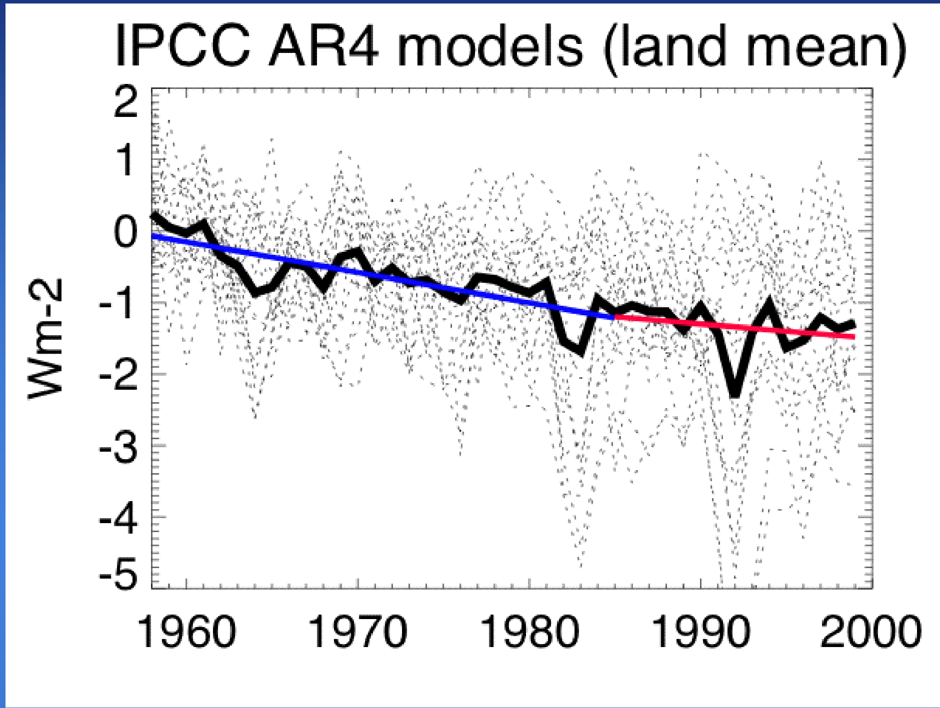
Pinker et al., 2005



Romanou et al. (2007)

Simulated changes in surface solar radiation

SW down



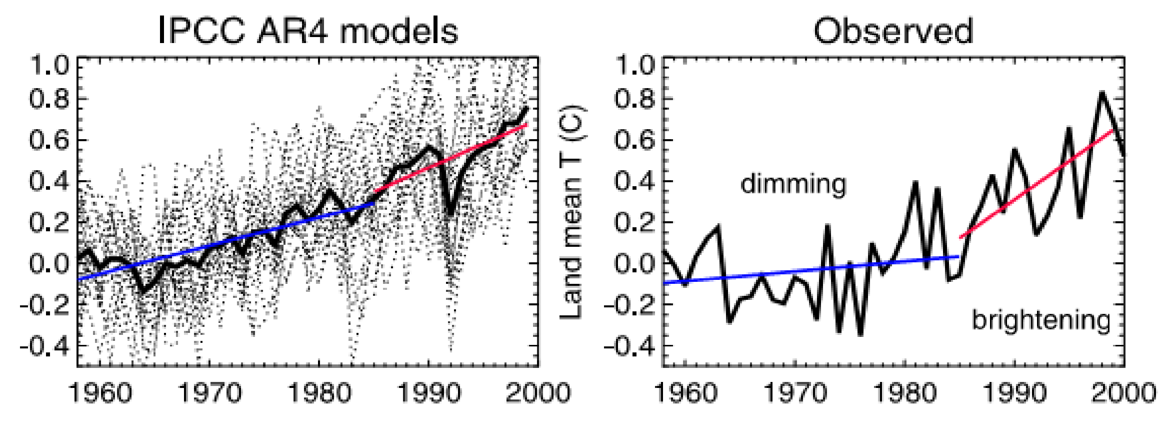
18 Models and multimodel mean

Linear regression slopes land surface solar radiation

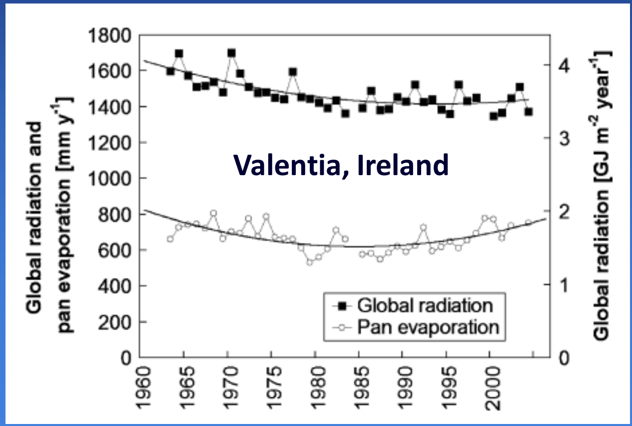
Units Wm^{-2} per decade	Dimming period 1958-85	Brightening period 1985-99	Total period 1958-99
Model mean	-0.42	-0.20	-0.36

Indication that lack of dimming/brightening in GCMs causes underestimated acceleration of global warming

Impact of Dimming/Brightening



Wild (2009)



Stanhill and Möller (2008)

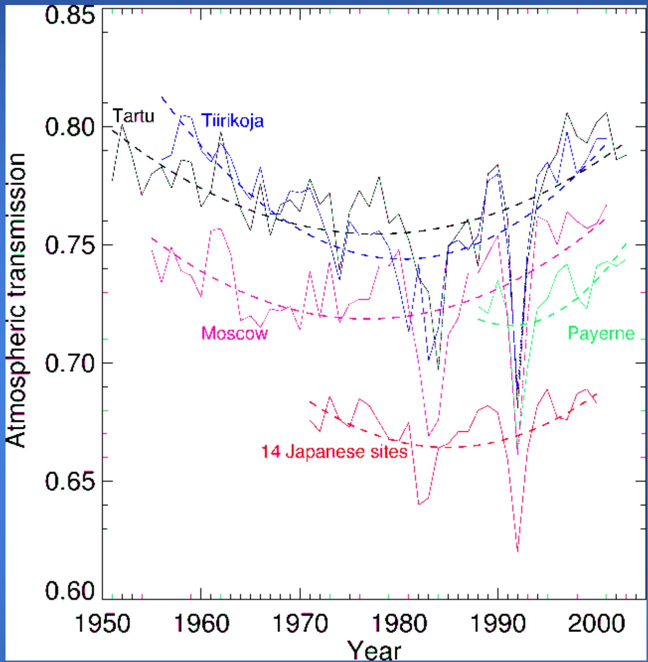
- Impact on **surface temperature** and global warming (e.g. Wild, 2009)

- Impact on components and intensity of the **hydrological Cycle -** evaporation (e.g. Roderick and Farquart, 2002; Stanhill and Möller, 2008; Teuling et al., 2009)

- Impact on the **terrestrial biosphere** and **carbon cycle** (e.g. Mercado et al., 2009)

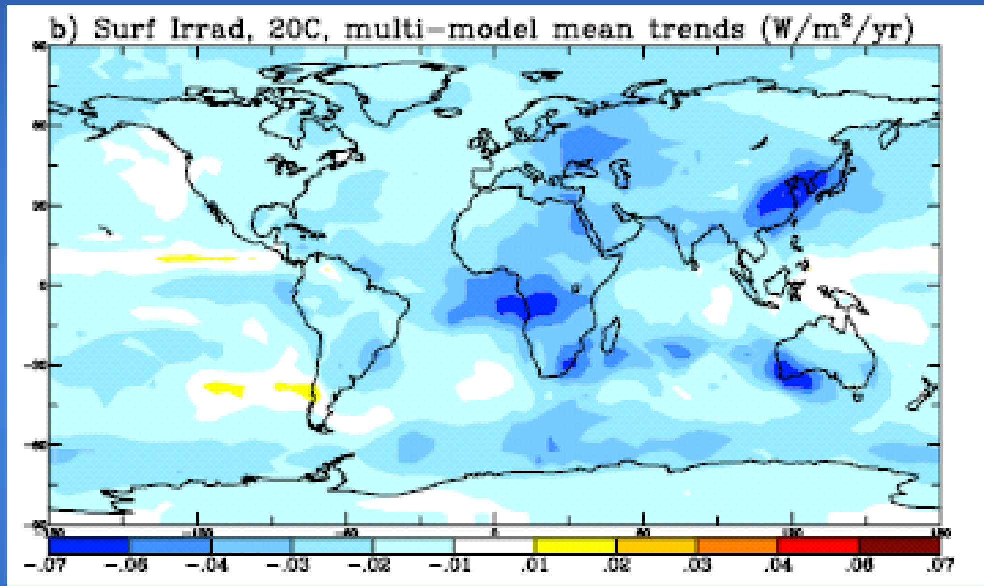
Causes of Dimming/Brightening

Atmospheric transmission
1950-2002



Wild et al. (2005)

IPCC multi-model mean shows decline mostly over land areas (20c)



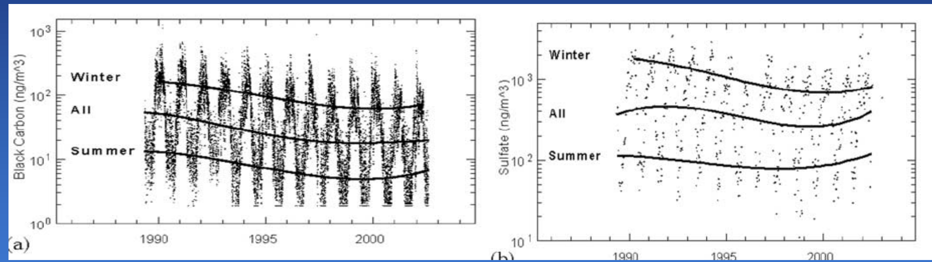
Romanou et al. (2007)

- Transmissivity of the Earth's atmosphere due to changes in concentrations of **aerosols** as a consequence of anthropogenic emissions are considered the most likely cause
- It has also been found that the dimming/brightening periods may be linked to changes in **cloud cover**

GDB transition consistent with aerosol trends

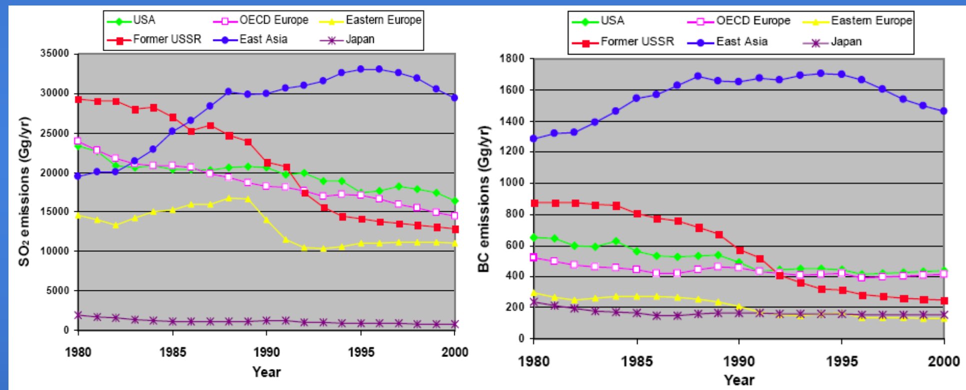
Direct measurements

(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)

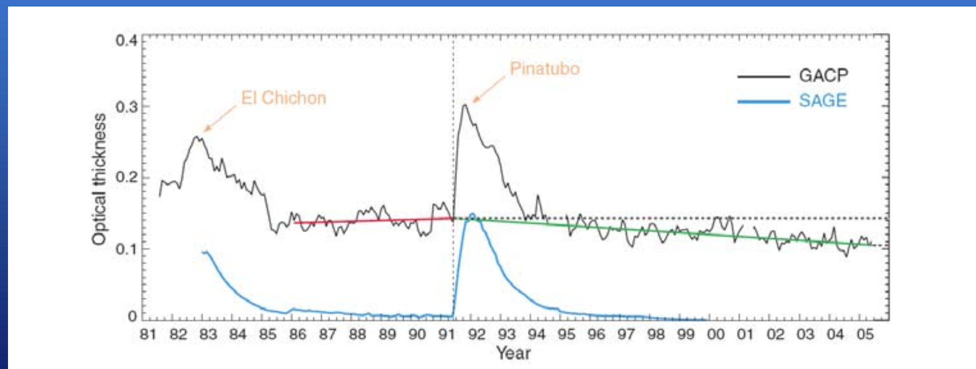


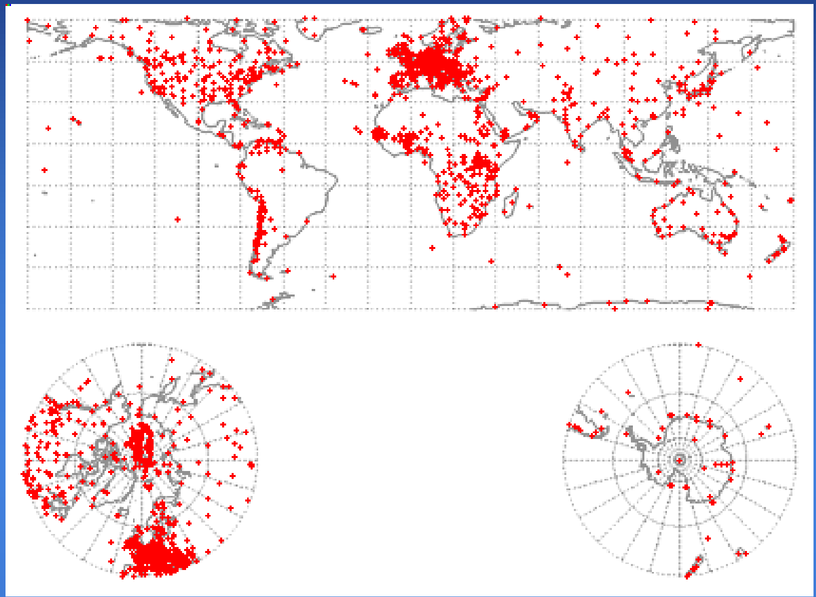
Fig. 1. GACP record of the globally averaged column AOT over the oceans and SAGE record of the globally averaged stratospheric AOT.

Motivation

• Lack of information of dimming and brightening on seasonal time scale is essential for determining its causes

• Study of dimming and brightening with respect to surface measurements of surface solar radiation is limited in spatial coverage

Global Energy Balance Archive (GEBA)



total of 2500 stations and 450,000 monthly mean values of different surface energy parameters

station history of these sites are also included in this database

First version was implemented in 1988 (Ohmura et al. 1989)

Uses of the GEBA dataset:
• studying the surface energy balance
• validating satellite radiation algorithms
• validating of energy fluxes simulated from general circulation models
• providing data for industrial applications

Update of GEBA

Radiative Parameters in GEBA:

Global radiation

Direct solar radiation

Diffuse sky radiation

Albedo

Reflected short-wave radiation

Long-wave incoming radiation

Longwave outgoing radiation

Longwave net radiation

Radiation balance

Sensible heat flux

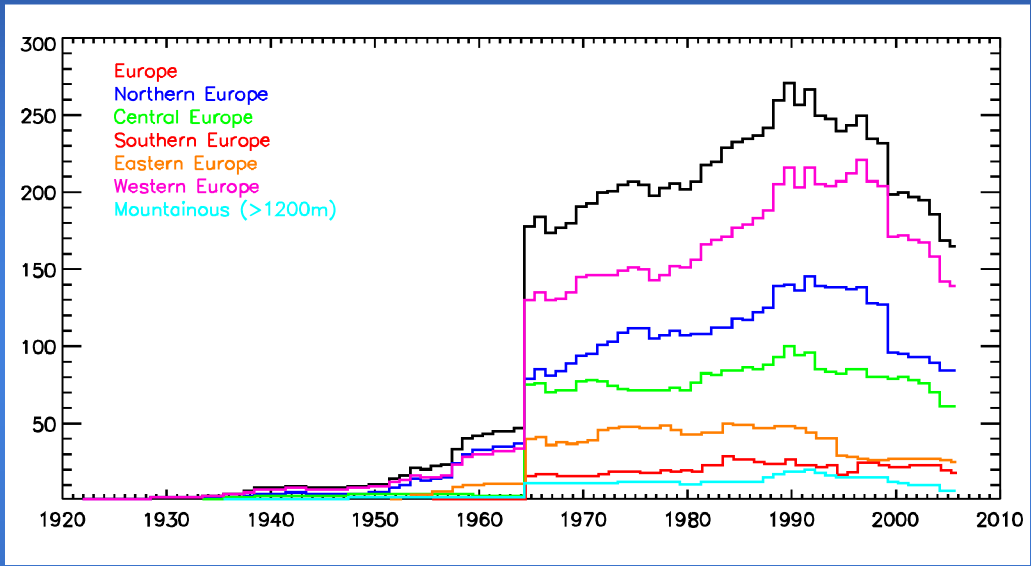
Latent heat of melt

UV radiation

Absorbed short-wave radiation

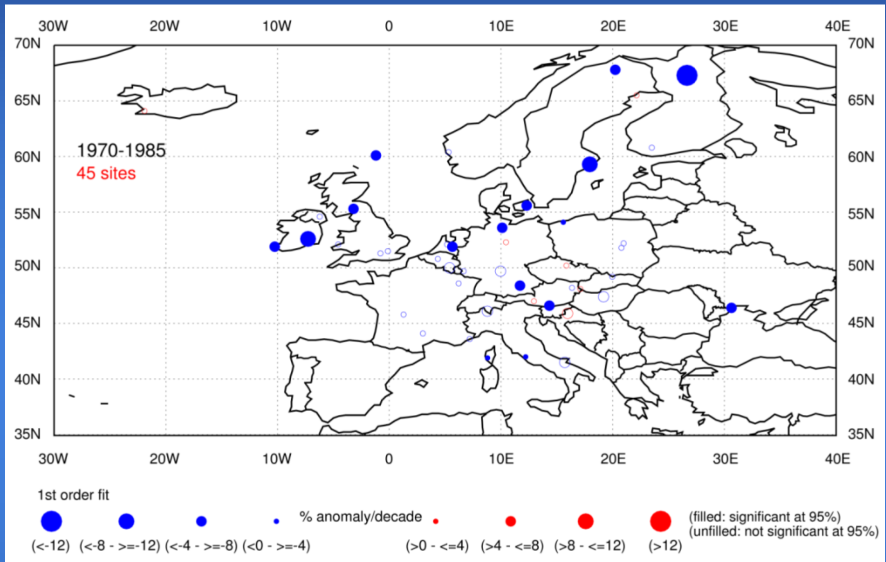
Sum of outgoing short-and long-wave radiation

Sum of latent and sensible heat flux



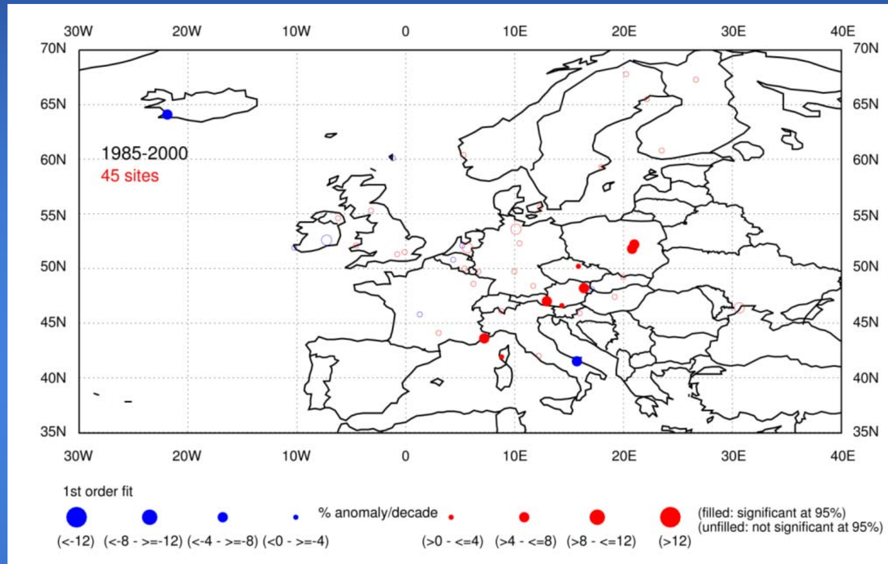
Trends of SW Radiation over Europe

1970-1985



Annual 1970-1985 (% decade^{-1})	**-3.0**

1985-2000

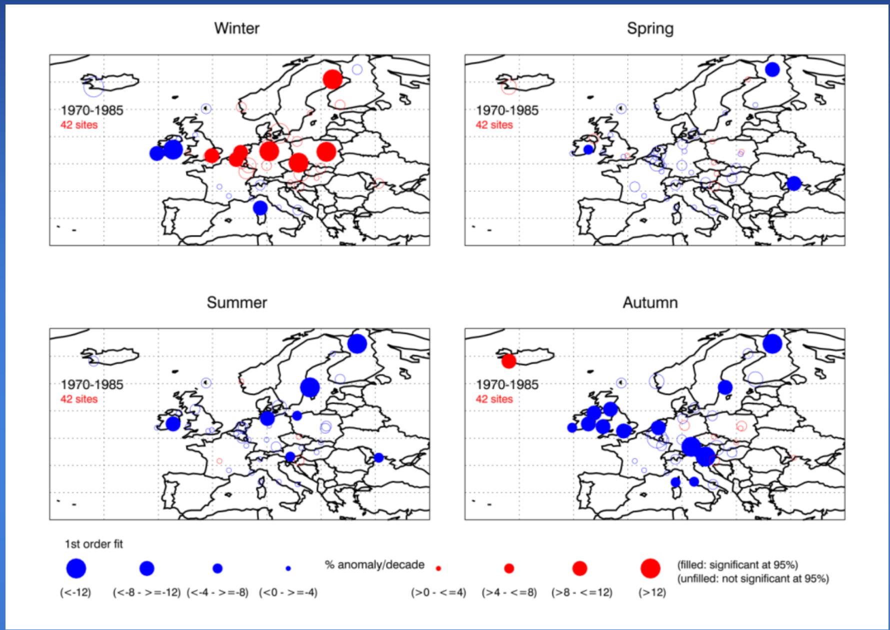


Annual 1985-2000 (% decade^{-1})	+0.3

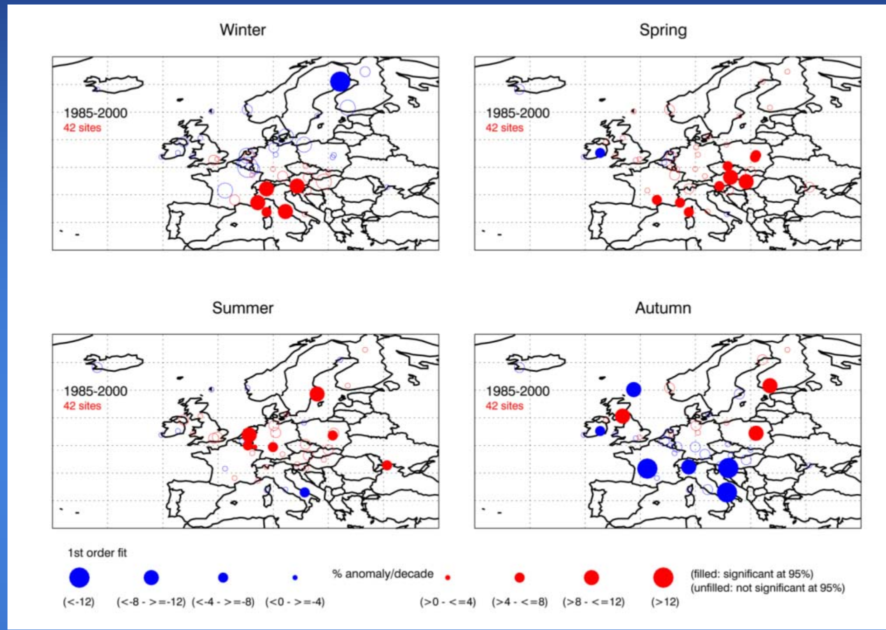
Chiacchio and Wild (2010)

Trends of SW Radiation over Europe

1970-1985



1985-2000



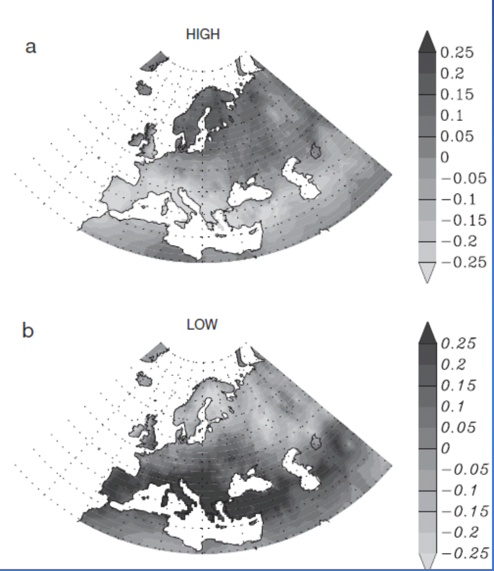
Winter (% dec^{-1})	+0.5
Spring	-2.4
Summer	-3.2
Autumn	**-2.5**

Winter (% dec^{-1})	+0.5
Spring	+1.6
Summer	+0.9
Autumn	**-2.5**

Chiacchio and Wild (2010)

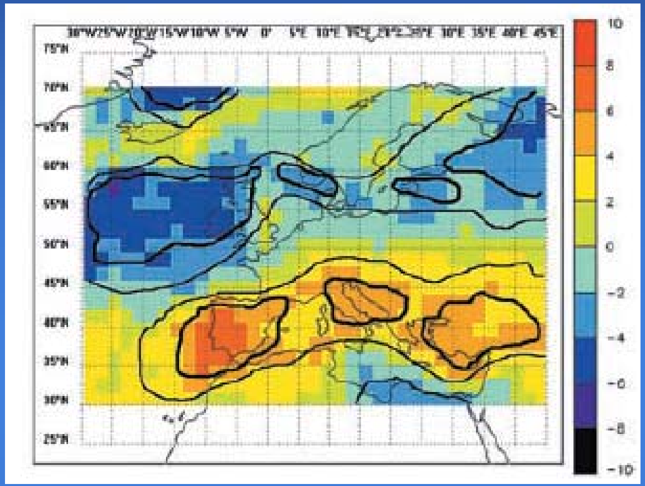
NAO Influence in Europe

Cloud Cover



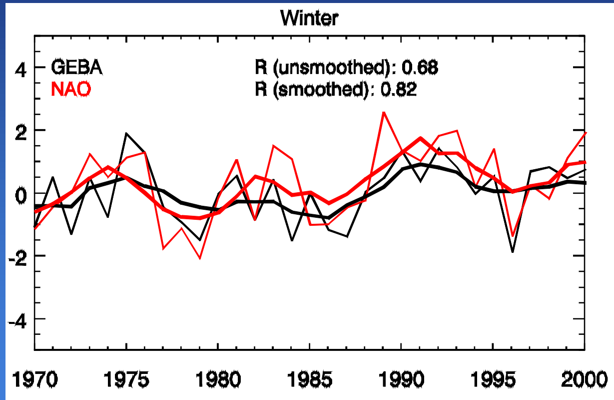
Trigo et al. (2002)

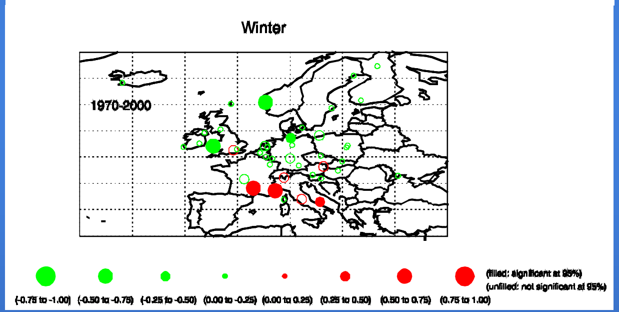
Sunshine duration and NAO



Pozo-Vazquez et al. (2004)

SW Radiation and NAO





Chiacchio and Wild (2010)

- Important to analyze SW radiation and their relationship to circulation patterns
- Previous studies found a strong influence of the NAO on winter radiation (Pozo-Vazquez et al., 2004; Chiaccio and Wild, 2010) and cloud cover (Trigo et al., 2002) variability over the European region

Correlation of Solar Radiation and NAO

	1970-2000	1970-2000 (running avg)	1970-1985	1970-1985 (running avg)	1985-2000	1985-2000 (running avg)
Europe						
winter	0.26	0.34	0.29	0.23	0.09	0.16
spring	**0.37**	0.29	0.45	0.36	0.34	0.44
summer	**0.62**	**0.62**	0.56	0.61	**0.75**	0.45
autumn	0.32	**0.42**	0.07	**-0.60**	0.42	**0.57**
S. Europe						
winter	**0.68**	**0.82**	0.56	0.60	**0.74**	**0.95**
spring	0.29	0.10	0.31	0.42	0.27	-0.30
summer	-0.15	-0.07	-0.06	0.08	-0.36	-0.47
autumn	0.30	**0.58**	0.28	-0.26	0.09	0.47
N. Europe						
winter	-0.34	**-0.52**	-0.11	-0.15	-0.57	-0.59
spring	0.29	0.30	0.36	0.28	0.27	0.59
summer	**0.66**	**0.72**	0.59	**0.65**	**0.79**	**0.66**
autumn	0.21	0.06	0.11	**-0.66**	**0.55**	**0.63**

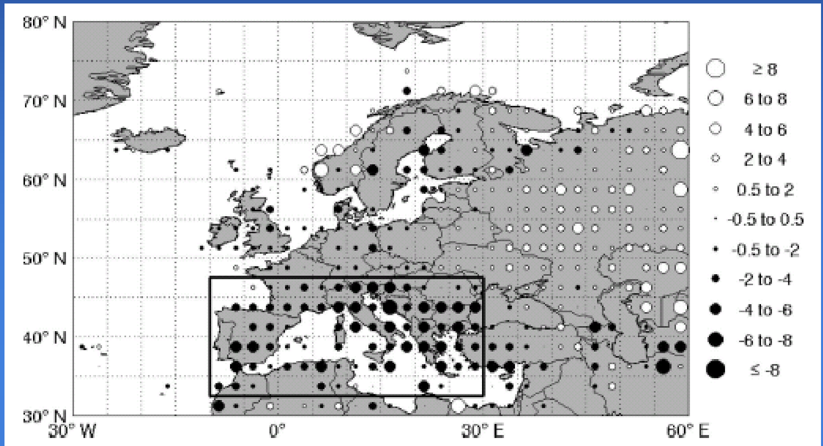
Chiacchio and Wild (2010)

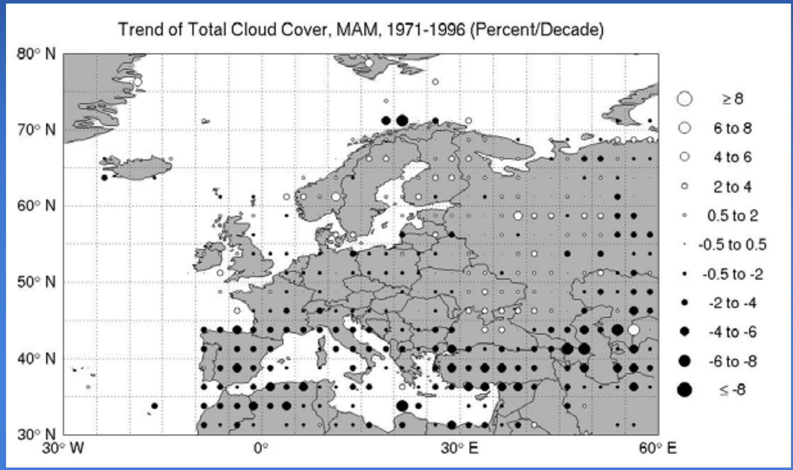
Correlation becomes stronger in low-frequency variability with a maximum in winter and autumn in Southern Europe

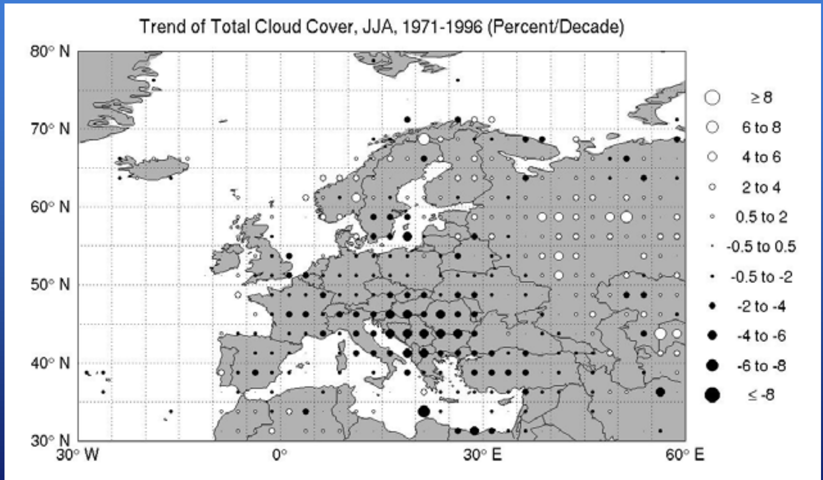
Decadal Variations in Seasonal Cloud Cover

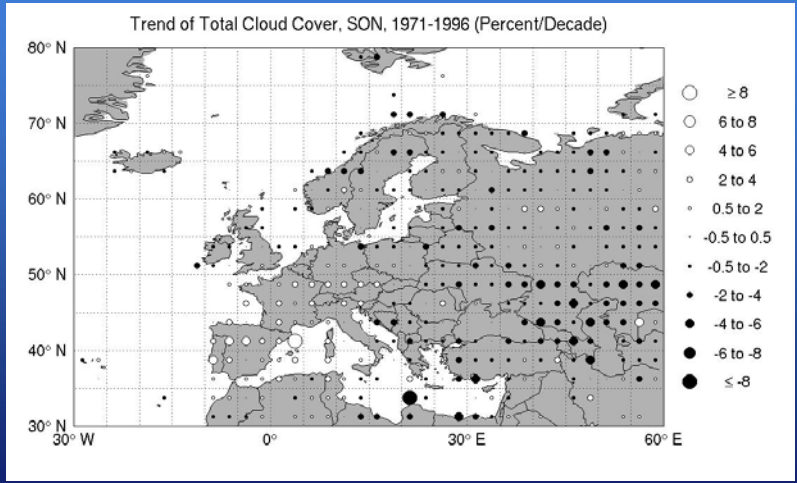
Decreases are strongest over Mediterranean in winter

Stephen Warren (personal comm.)









Solar Radiation and Cloud Cover

1971-1996

Season	Europe	Europe (running avg)	S. Europe	S. Europe (running avg)	N. Europe	N. Europe (running avg)
DJF	**-0.55**	-0.15	**-0.80**	**-0.75**	**-0.37**	0.12
MAM	**-0.81**	**-0.56**	**-0.57**	-0.27	**-0.88**	**-0.77**
JJA	**-0.85**	**-0.65**	**-0.57**	0.07	**-0.93**	**-0.81**
SON	**-0.70**	**-0.55**	**-0.80**	**-0.66**	**-0.63**	**-0.48**

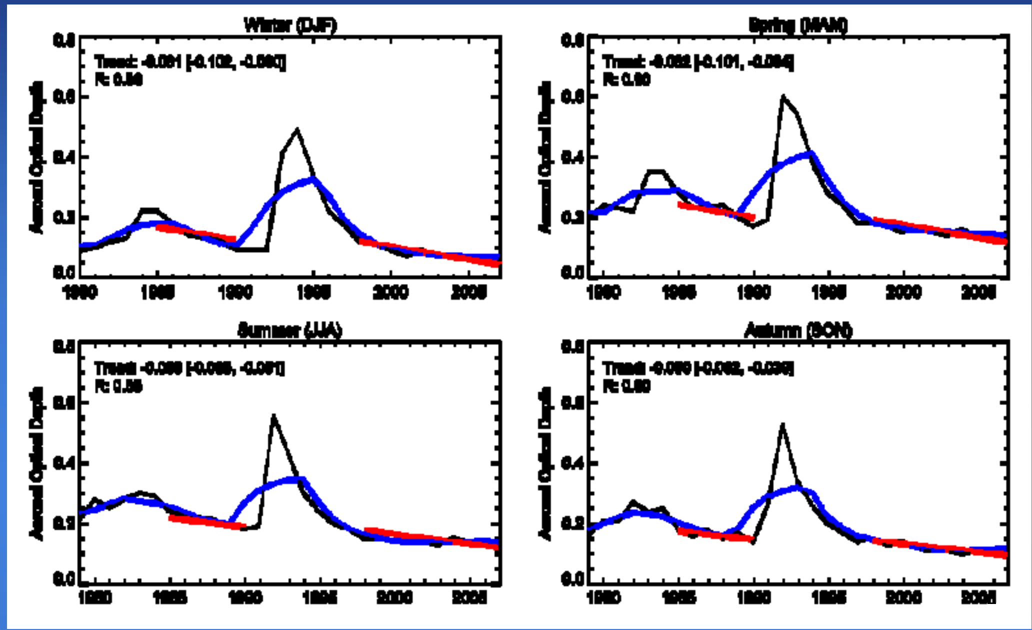
Chiacchio and Wild (2010)

Correlation weakens in low-frequency variability

Solar radiation variability is governed by cloud cover in Southern Europe in winter and autumn and in Northern Europe during spring and summer

Decadal Variations of Aerosols in Europe

Simulated from chemistry transport GOCART model (1979-2007)

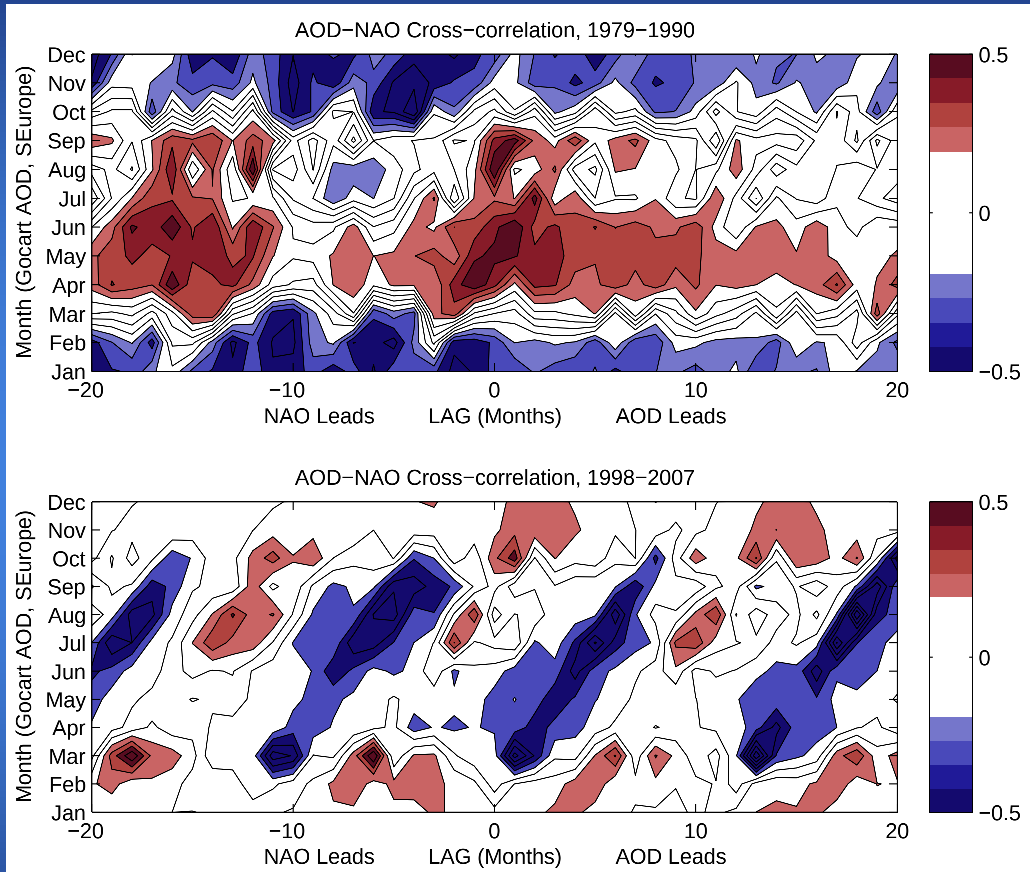


Chiacchio et al. (2011)

AOD changes (%) (1985-2007)

Region	Annual Sulfate/Total	Winter (DJF) Sulfate/Total	Spring (MAM) Sulfate/Total	Summer (JJA) Sulfate/Total	Autumn (SON) Sulfate/Total
Europe	**-69/-41**	**-115/-69**	**-69/-39**	**-60/-39**	**-59/-37**
Northern Europe	**-73/-46**	**-132/-77**	**-76/-46**	**-57/-42**	**-64/-44**
Southern Europe	**-63/-35**	**-99/-54**	**-61/-30**	**-60/-33**	**-57/-34**
Western Europe	**-65/-33**	**-129/-70**	**-67/-34**	**-48/-26**	**-60/-35**
Eastern Europe	**-75/-50**	**-111/-70**	**-76/-49**	**-71/-53**	**-64/-42**

Cross Correlation: Sulfate AOD and NAO



Chiacchio et al. (2011)

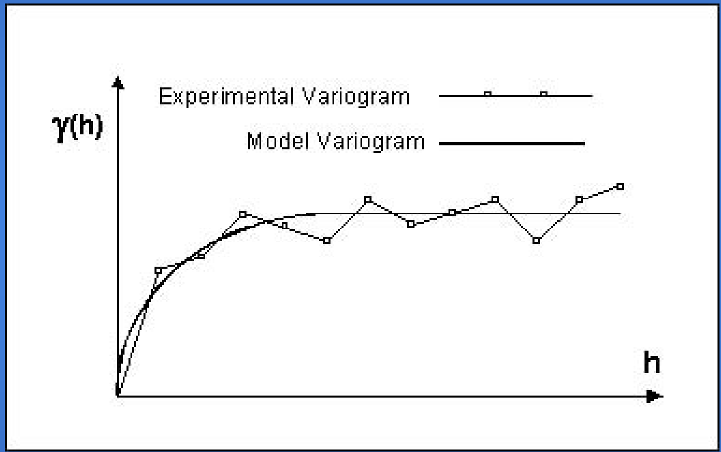
No major lead or lag by AOD or NAO. However, a seasonal relationship exists between AOD and NAO with a negative correlation in winter and positive in summer.

Gridding Methods

Kriging (Ordinary)

• Interpolation algorithm that uses a linear combination of weights at known points to estimate values at unknown points (Krige, 1966; Matheron, 1970)

$$F(x,z) = \Sigma\, w_i f_i$$



• Assigned weights are based on the model variogram (spherical) which is found first from an experimental variogram by computing the variance of each known point with respect to other points and their relative distances between each other $\gamma(h) = [1/2N(h)]\, \Sigma[Z(s_i) - Z(s_i+h)]$

Gridding Methods

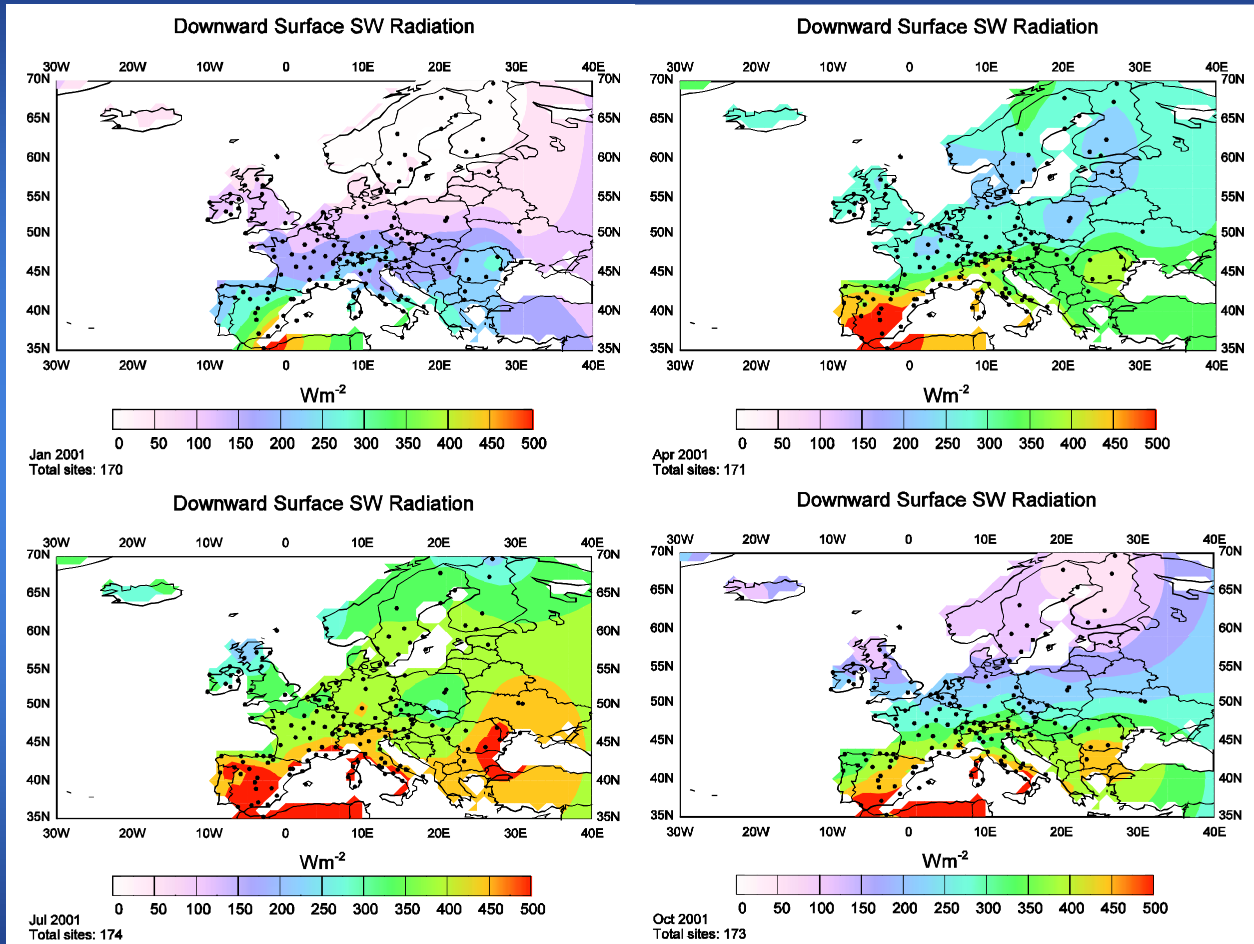
Inverse Distance

• interpolated points will have much less influence from observed points that are farther away (Thiessen, 1911)

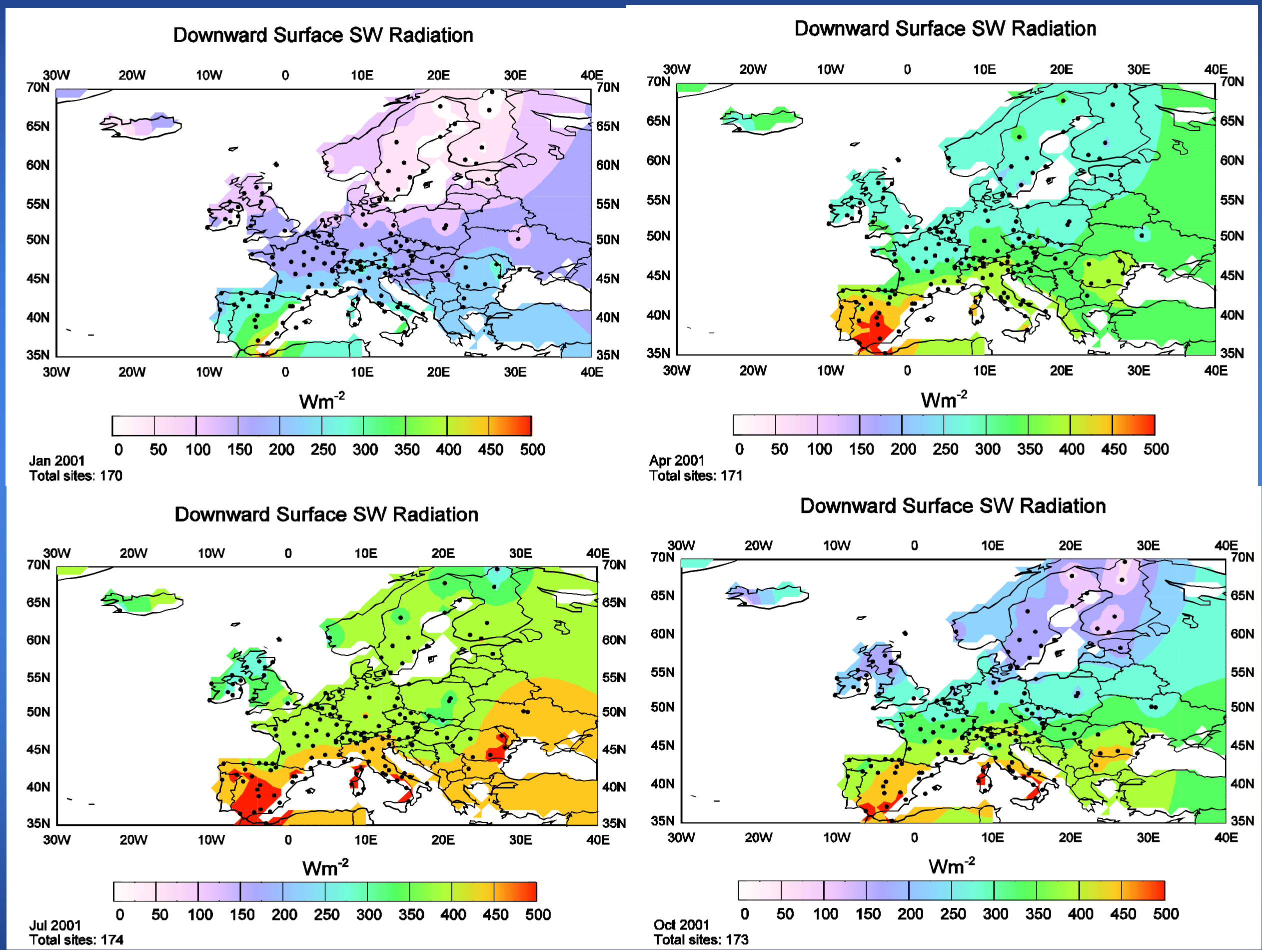
• more weight is given to stations that are closest to predicted values

$$f_p = \Sigma\, w(d_i)\, f_i \;/\; \Sigma\, w(d_i)$$

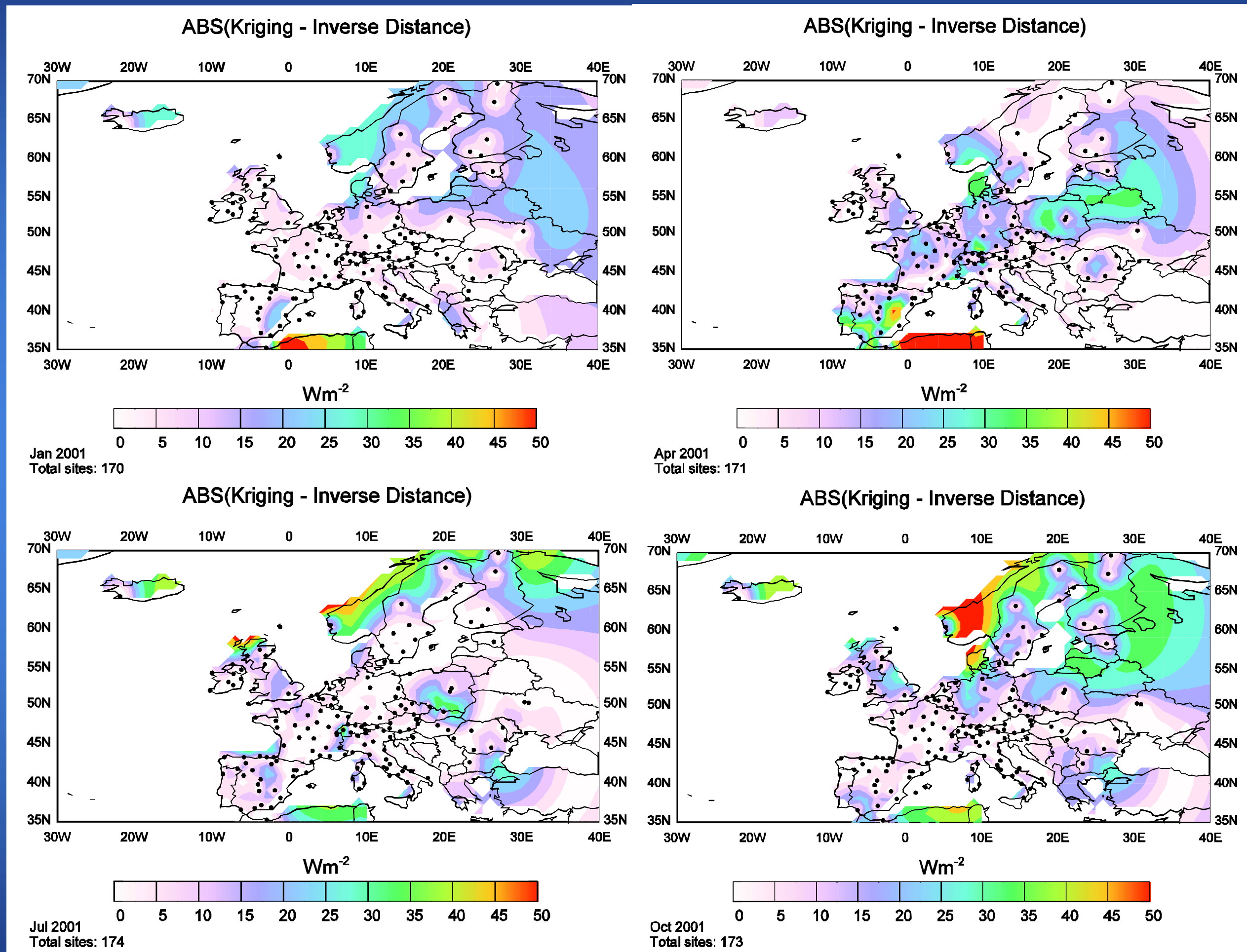
Kriging 2001 (Jan, Apr, Jul, Oct)



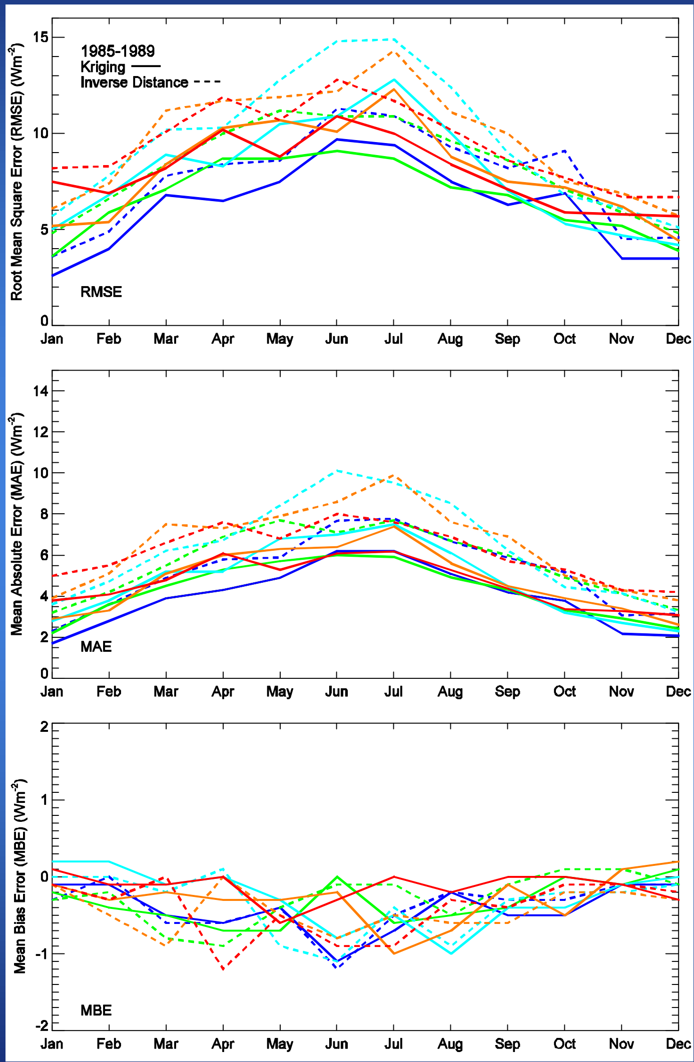
Inverse Distance 2001 (Jan, Apr, Jul, Oct)



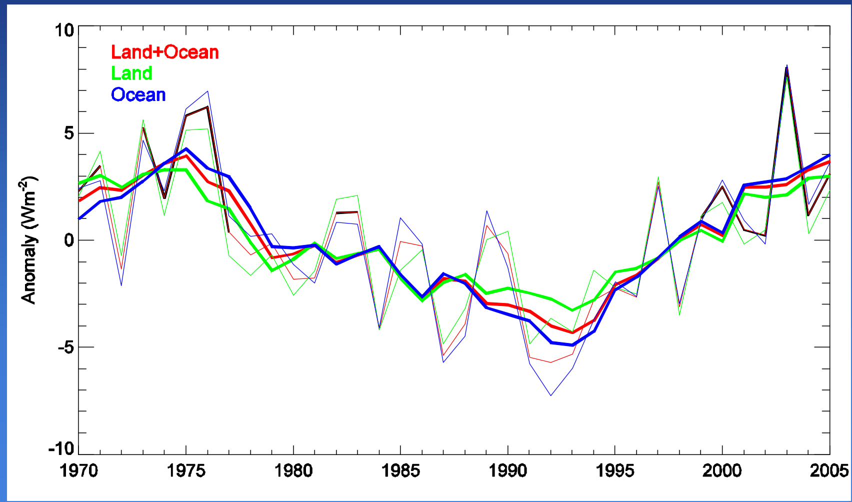
Kriging – Inverse Distance

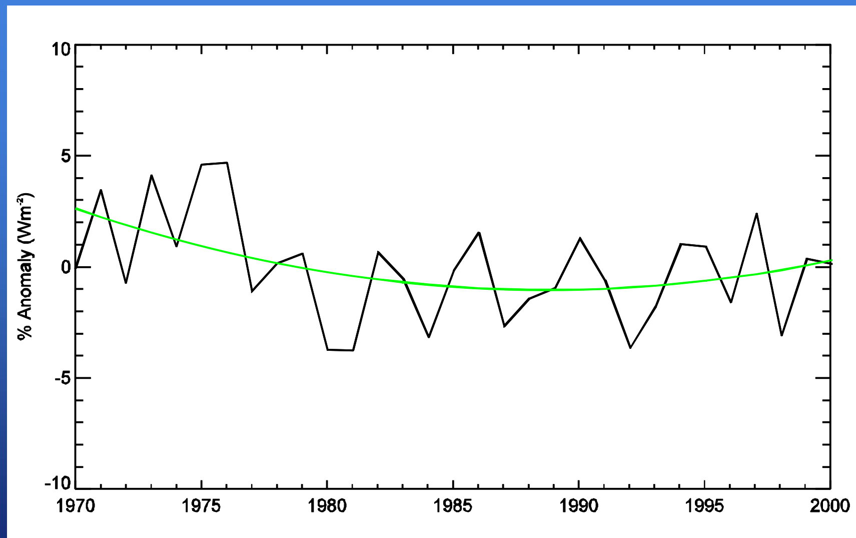


Cross-Validation (1985-1989)



Application – Dimming and Brightening



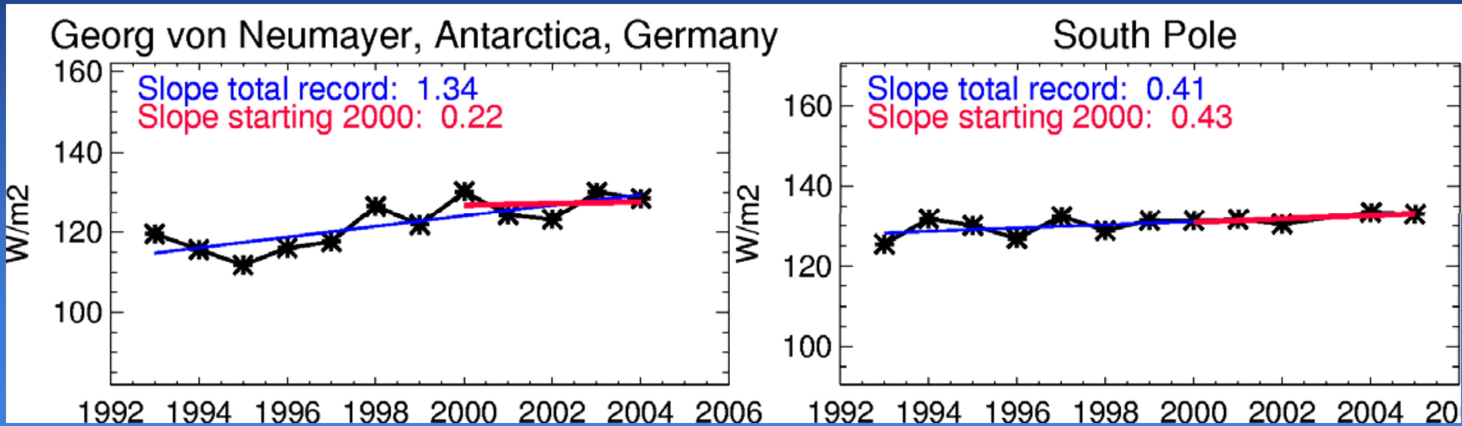


Chiacchio and Wild (2010)

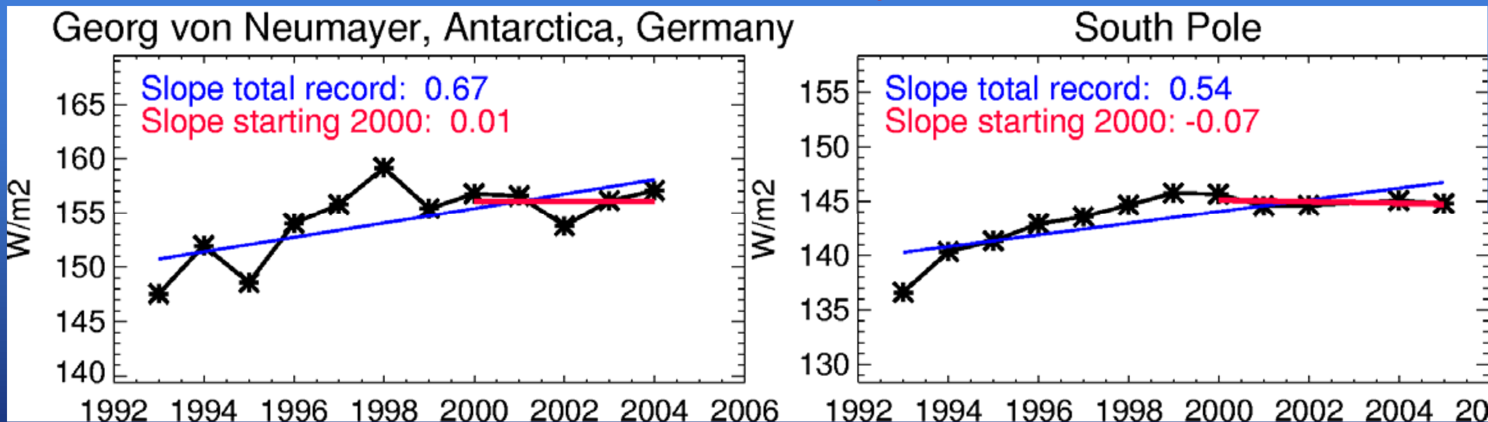
Update on Global Dimming/Brightening beyond 2000

Antarctica 1993-2005 from BSRN

All sky



Clear sky

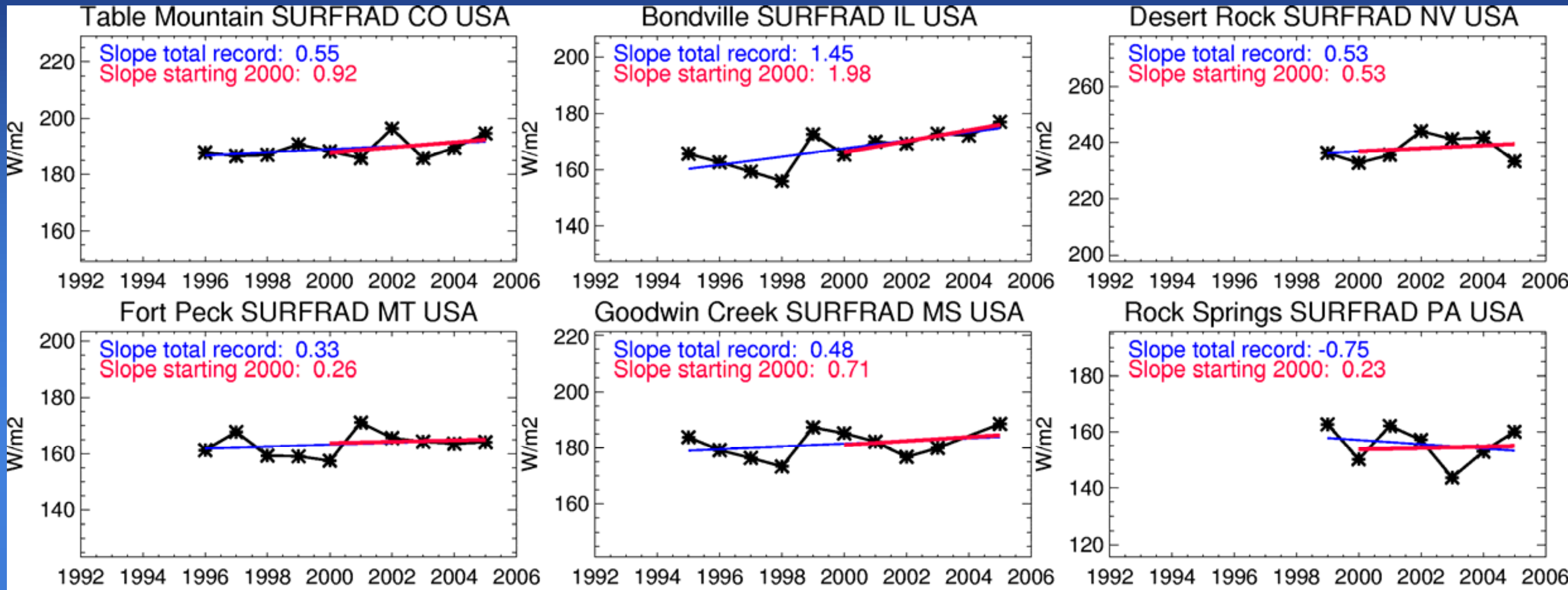


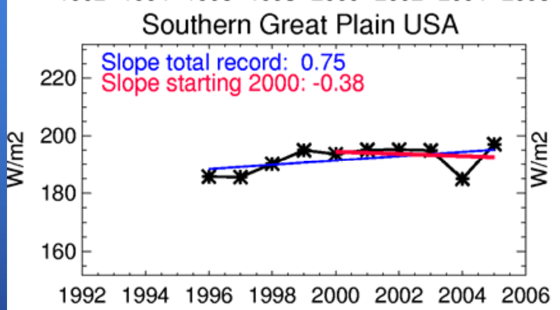
Wild et al. (2009)

⇒ Brightening in Antarctica levels off in 2000-2005 period

USA 1995-2005 from BSRN/surfrad

Brightening in the US





6 sites positive change
1 site negative change

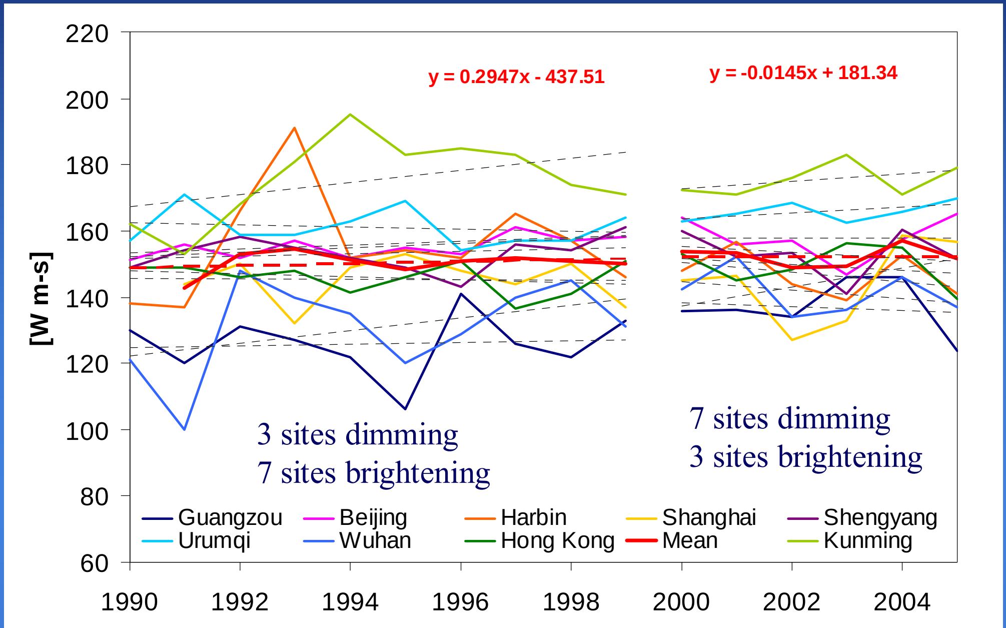
Mean change all sites period 2000-2005:
0.61 $Wm^{-2}y^{-1}$

Wild et al. (2009)

China 1990-2005 from GEBA

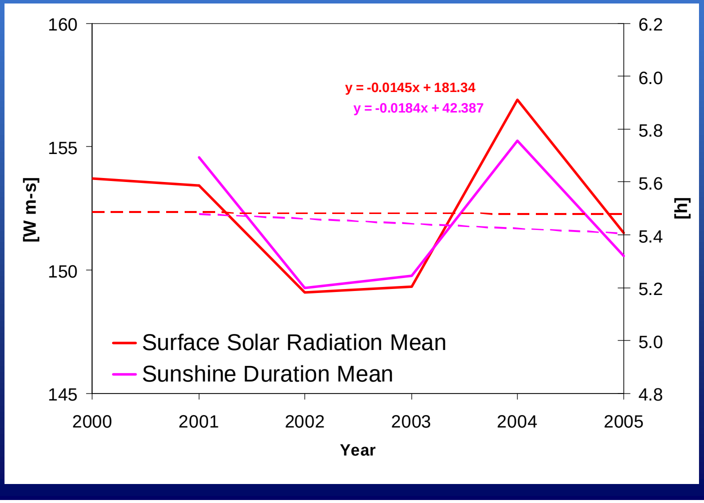
Wild et al. (2009)

Global Radiation

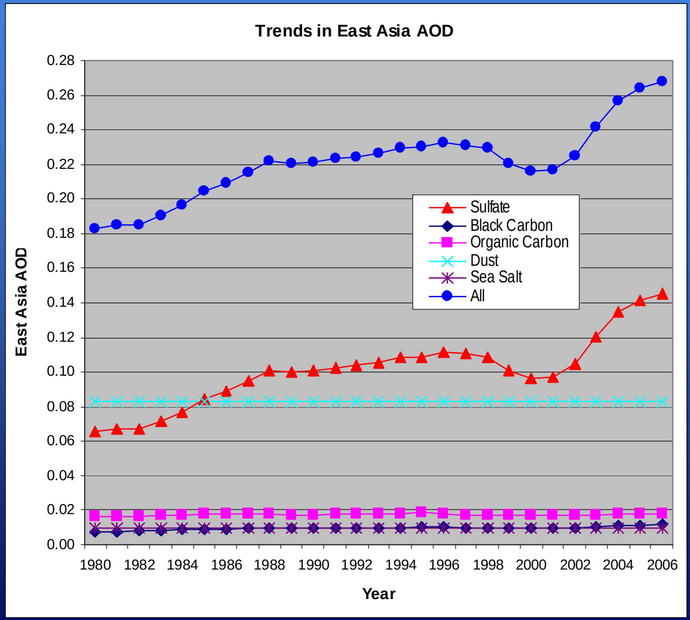


China returns into slight dimming after 2000, in line with increasing AOD and decreasing sunshine duration

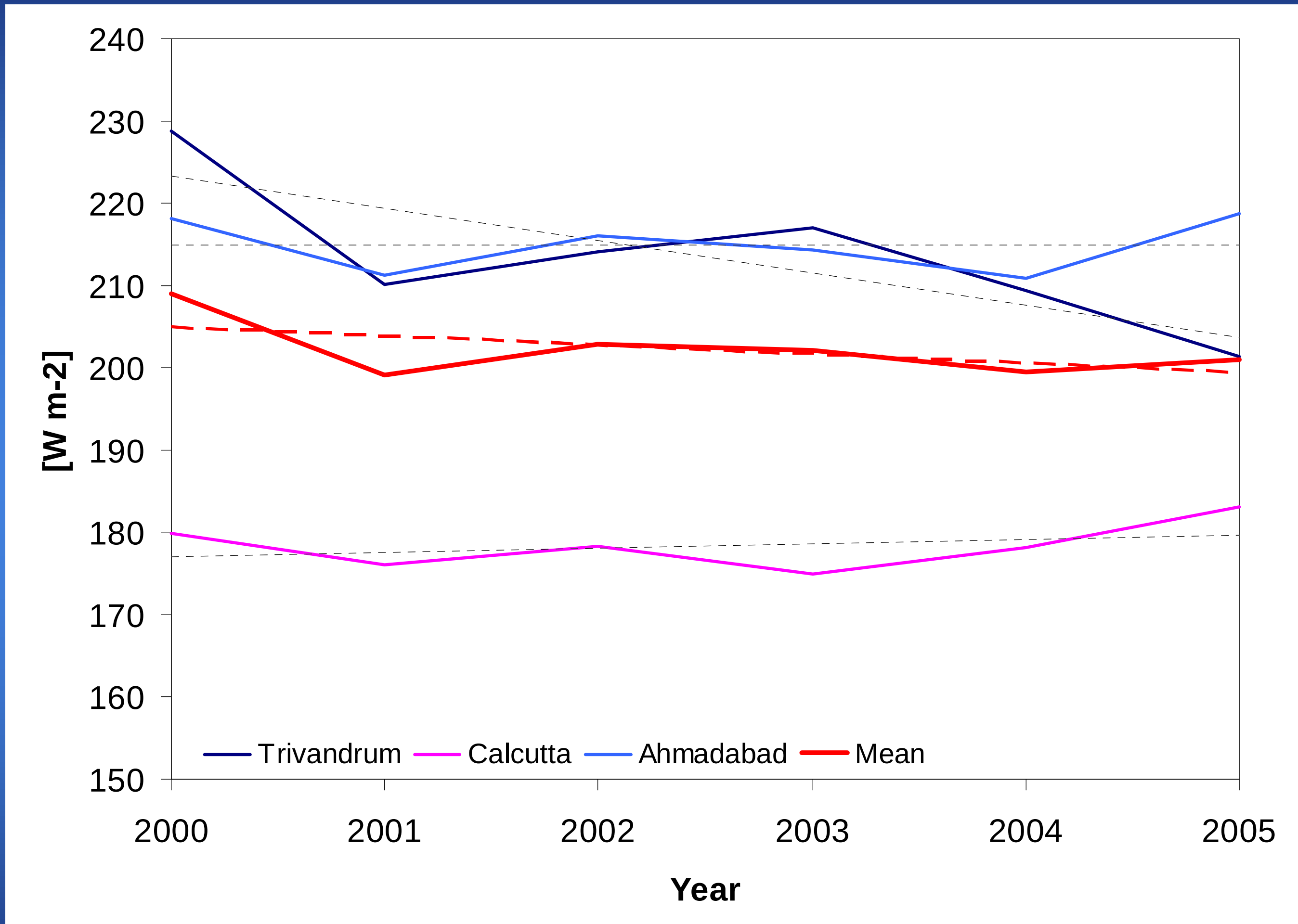
Sunshine Duration and Global Radiation



AOD East Asia 1980-2005
From David Streets



India 2000-2005



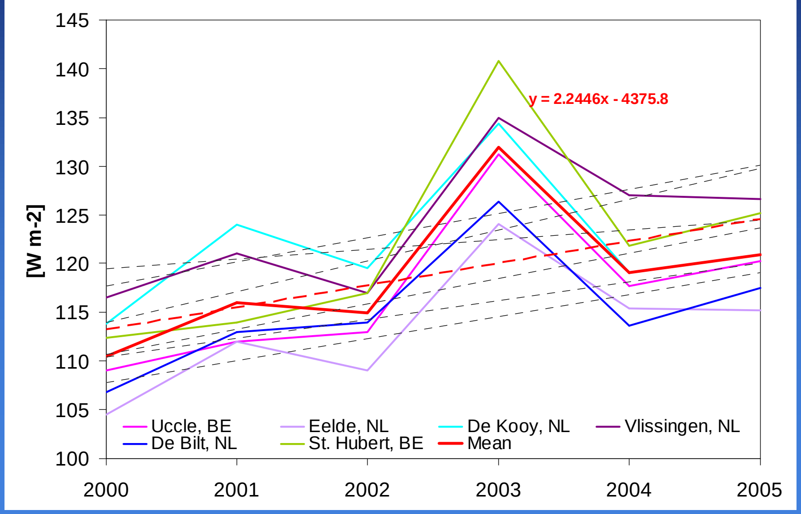
Wild et al. (2009)

Continuation of dimming in India after 2000

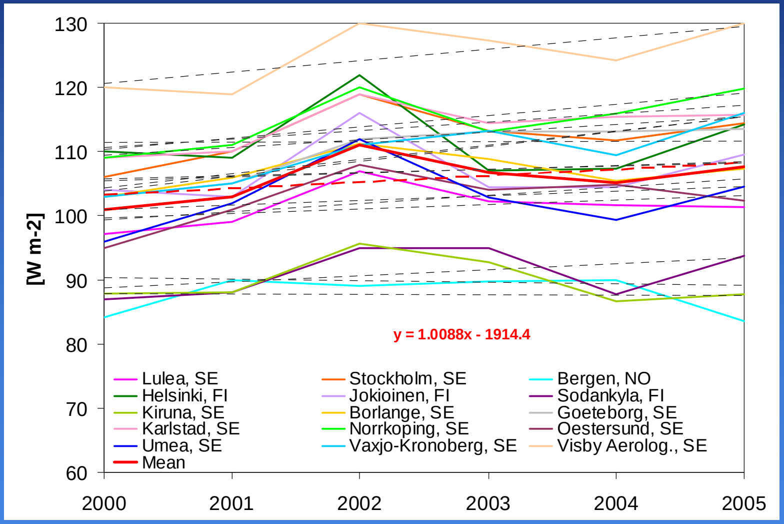
Europe 2000-2005

Wild et al. (2009)

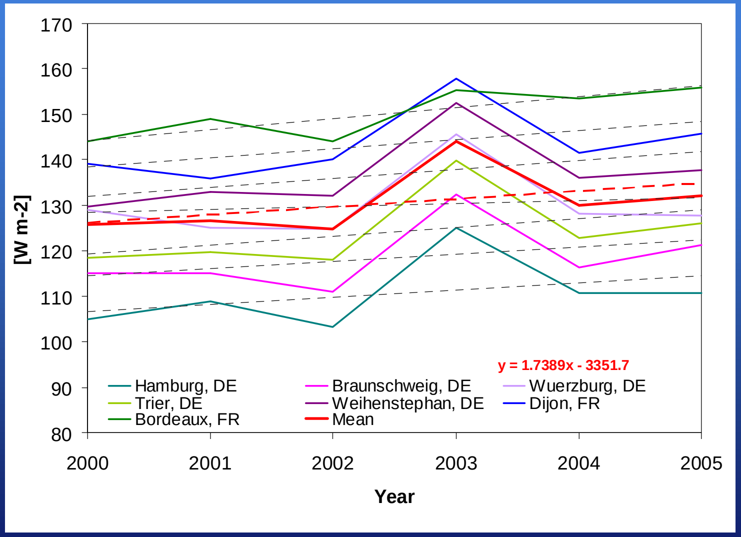
Benelux



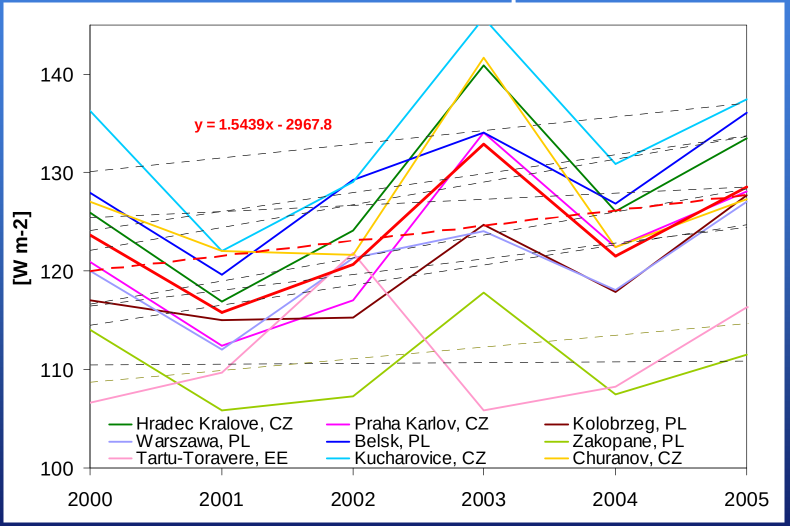
Scandinavia



France / Germany



Eastern Europe



Overall still brightening in Europe after 2000

Summary: GDB update 2000-2005

Wild et al. (2009)

Recent tendencies in Surface Solar Radiation

	1990s	2000-2005
USA	↗	↗
Central America	↗	↘
Europe	↗	↗
China/Mongolia	↗	→
Japan	↗	→
Korea	↗	↗
India	↘	↘
Antarctica	↗	→