Solar UV flux, DMS and Climate: Is there a connection?

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2007 SOLAS Open Science Meeting
Xiamen, China
March 6-9, 2007

Outline

- Climate science -- Review: Why climate scientists need to pay attention to DMS
- Relationships between solar radiation, cloud properties and DMS emissions
- A simple calculation to evaluate UV-hypothesis
- Conclusions: Future research

Q: What drives Global Climate Change ?

Changes in Atmospheric Composition

greenhouse gases, aerosols, clouds, water vapor

+

Changes in Land Use

deforestation, desertification, ...

+

Changes in Solar Output

=

Sustained Perturbation to Radiative Balance of the "Climate System"

troposphere, land, and ocean

Q: What is Radiative Forcing ?

Solar Heating of the climate system ≈ 235 W m^{-2}

↑ *is balanced by* ↓

Terrestrial InfraRed Cooling ≈ 235 W m^{-2}

A perturbation to the climate system

– either natural or anthropogenic –

Is evaluated by the radiative imbalance that it causes

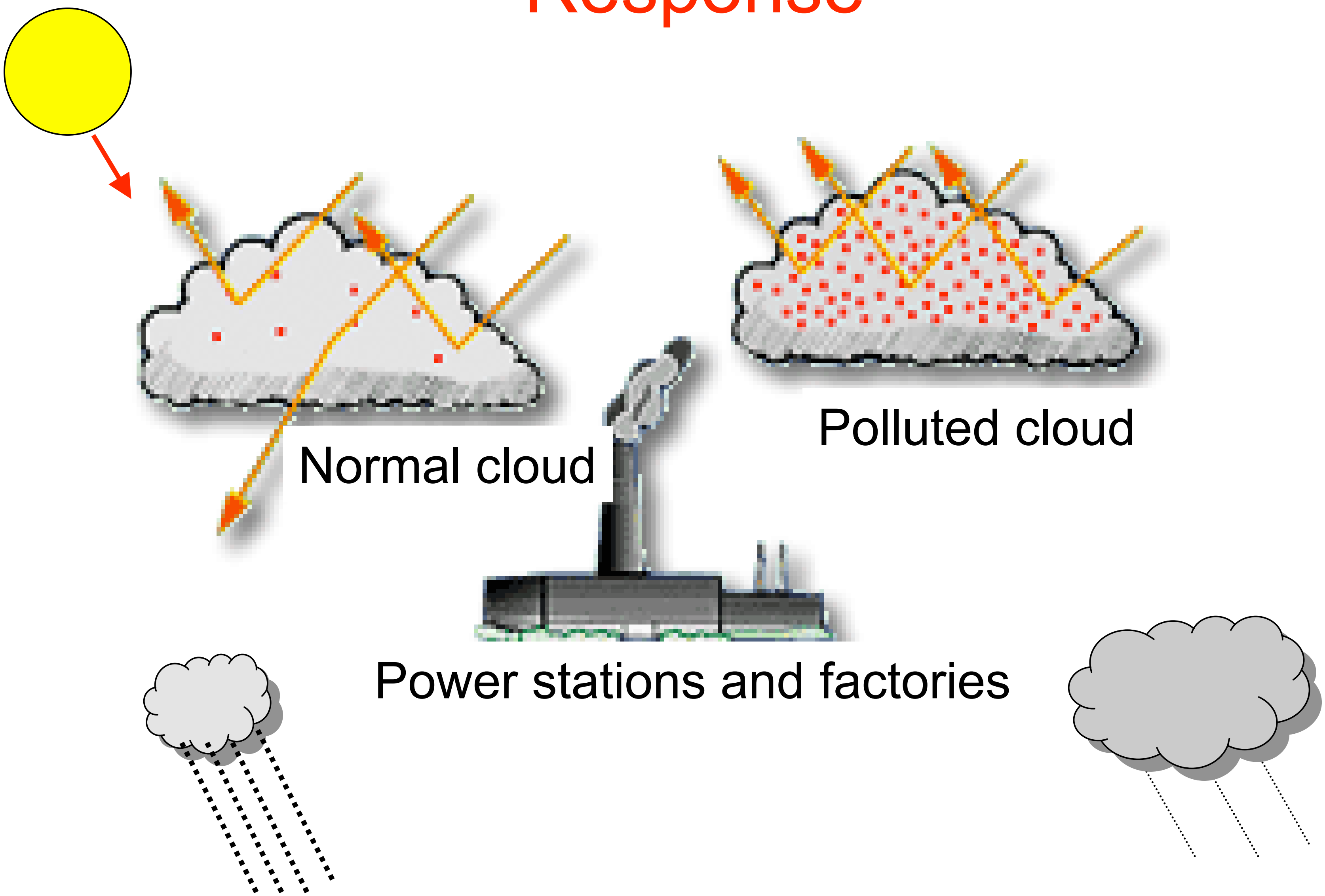
– before the system adjusts –

Is calculated as the global mean Radiative Forcing

– RF in units of W m^{-2} –

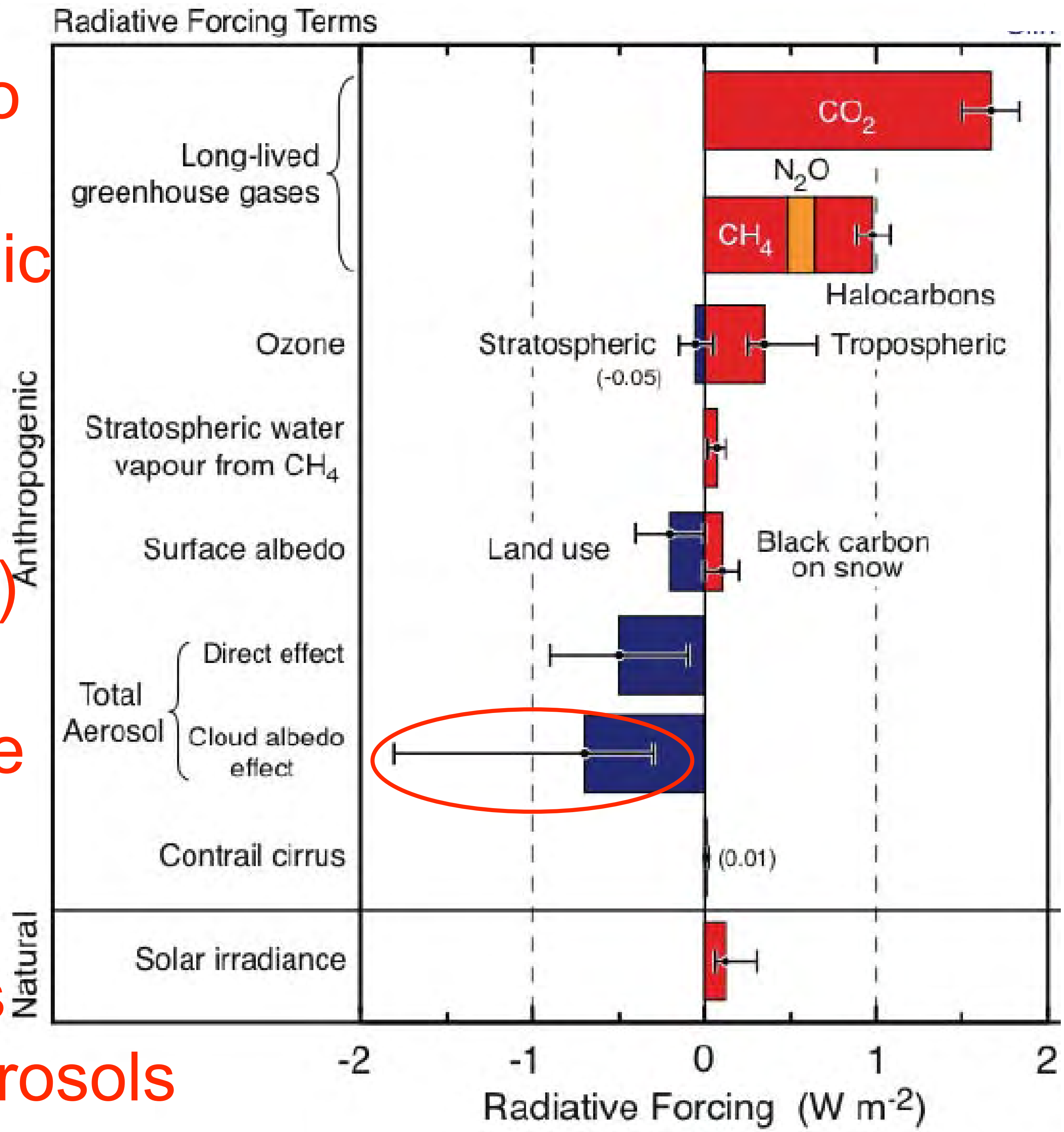
Current anthropogenic RF from greenhouse gases ≈ +3 W m^{-2}

Aerosol 'Albedo' Effect vs Cloud Response



Cloud albedo effect (from anthropogenic aerosols is still highly uncertain (IPCC, 2007)

This estimate does not account for any changes in natural aerosols



Are there significant changes in DMS fluxes over time?

Solar variability, dimethyl sulphide, clouds, and climate

S. H. Larsen
C-Research, Lincoln, New Zealand

Received 7 July 2004; revised 22 December 2004; accepted 3 January 2005; published 19 February 2005.

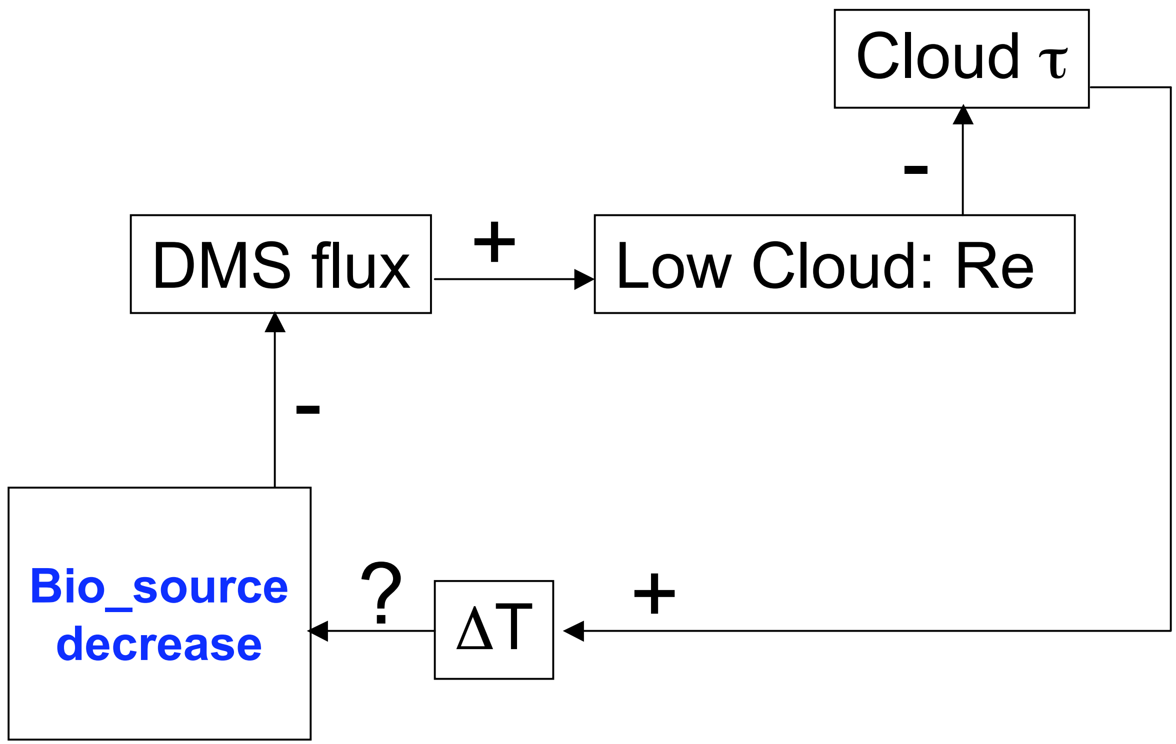
[1] It is proposed that Earth's climate may be modulated, in part, by changes in the flux of ultraviolet/blue light into the oceans. This occurs, at a range of timescales, through solar variability and from damage to the ozone layer. A conceptual model is presented where, through a number of synergistic processes and positive feedbacks, changes in the ultraviolet/blue flux alte
number of cloud condensa
The greatest effects are exp
circulation, in summer.

Strong Relationship Between DMS and the Solar Radiation Dose over the Global Surface Ocean

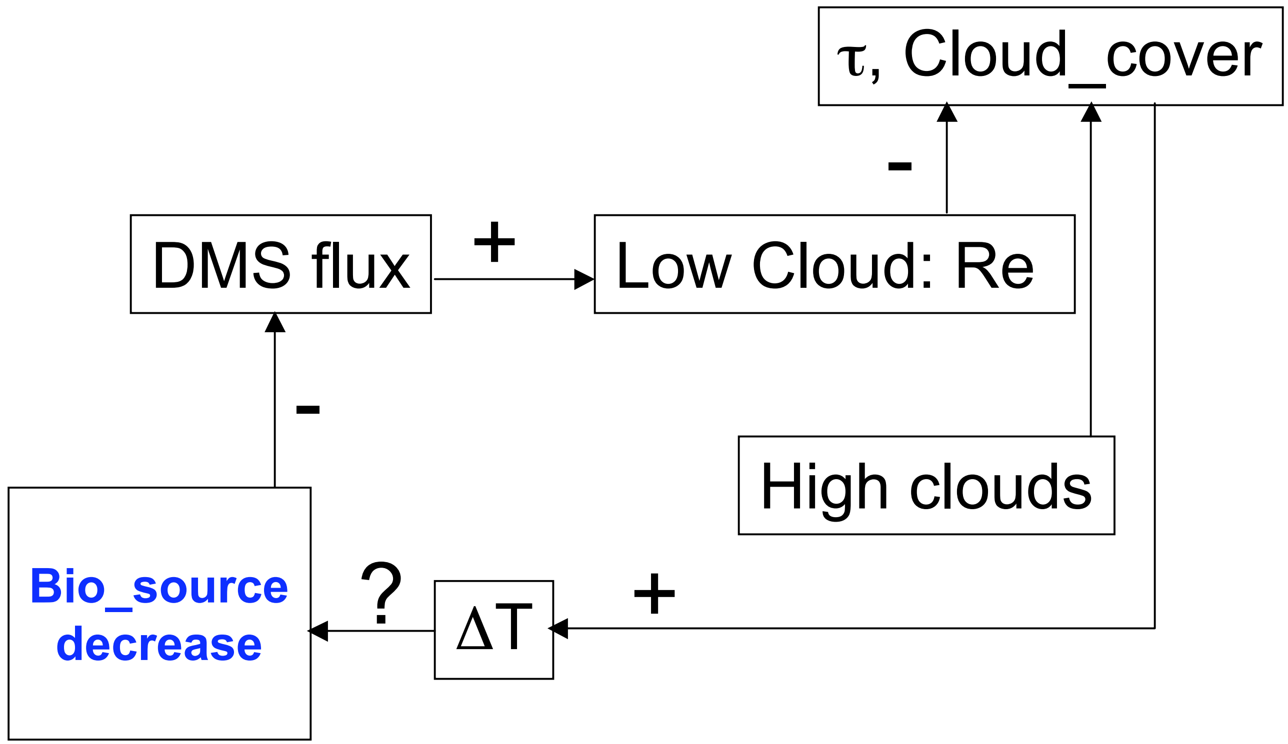
Sergio M. Vallina and Rafel Simó

Marine biogenic dimethylsulfide (DMS) is the main natural source of tropospheric sulfur, which may play a key role in cloud formation and albedo over the remote ocean. Through a global data analysis, we found that DMS concentrations are highly positively correlated with the solar radiation dose in the upper mixed layer of the open ocean, irrespective of latitude, plankton biomass, or temperature. This is a necessary condition for the feasibility of a negative feedback in which light-attenuating DMS emissions are in turn driven by the light dose received by the pelagic ecosystem.

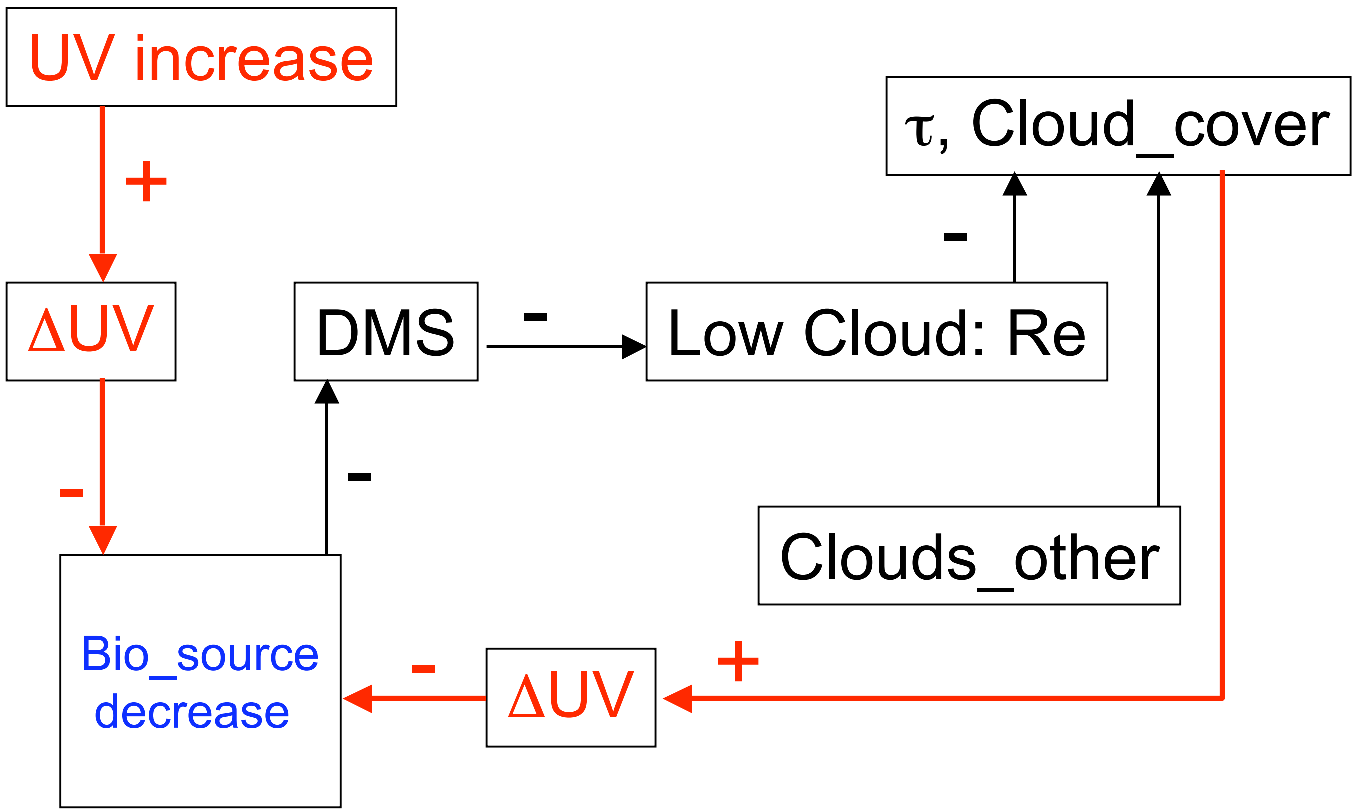
Feedback loop proposed by Charlson, Lovelock, Andrea, Warren:



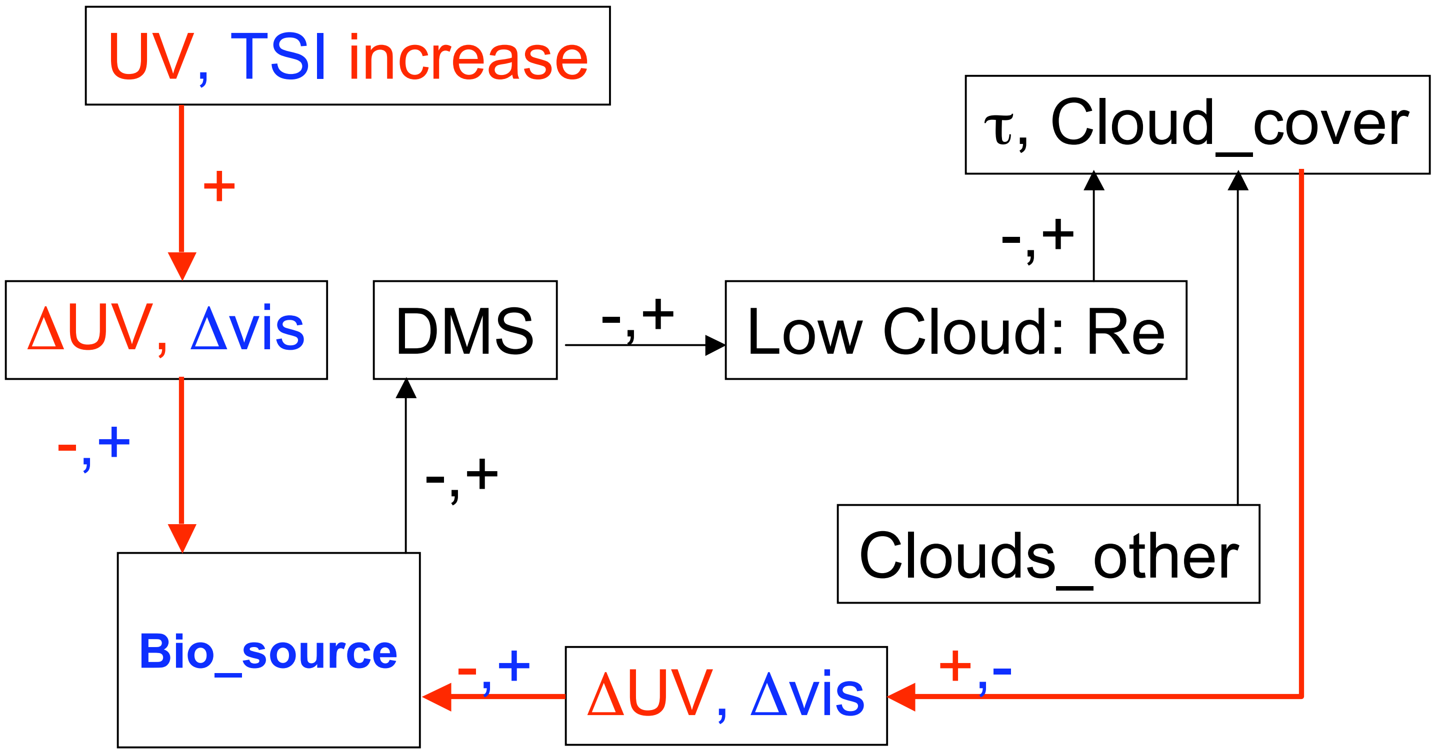
Added complications with addition of cloud feedback (Kaufman et al., 2005):



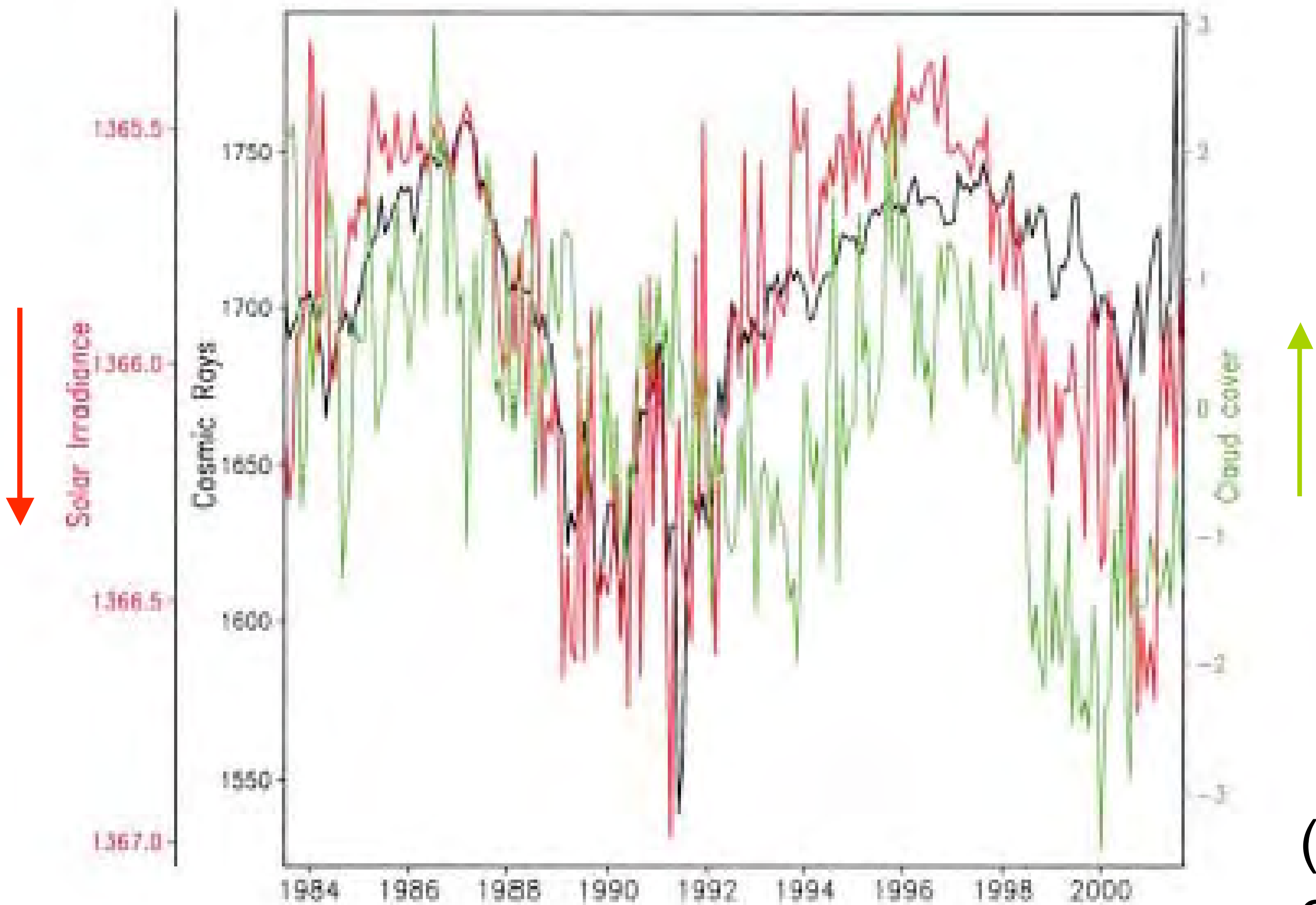
Positive feedback loop (Larson, 2005)



Positive/negative feedback loop (Larson, 2005)/(Vallina and Simó, 2007)



On 11-yr time scale, solar irradiance is inversely proportional to cloud cover (and GCR flux)



(Kristjánsson et al., 2005)

Temperature varies (sort of) with UV, except during period of high GHG growth

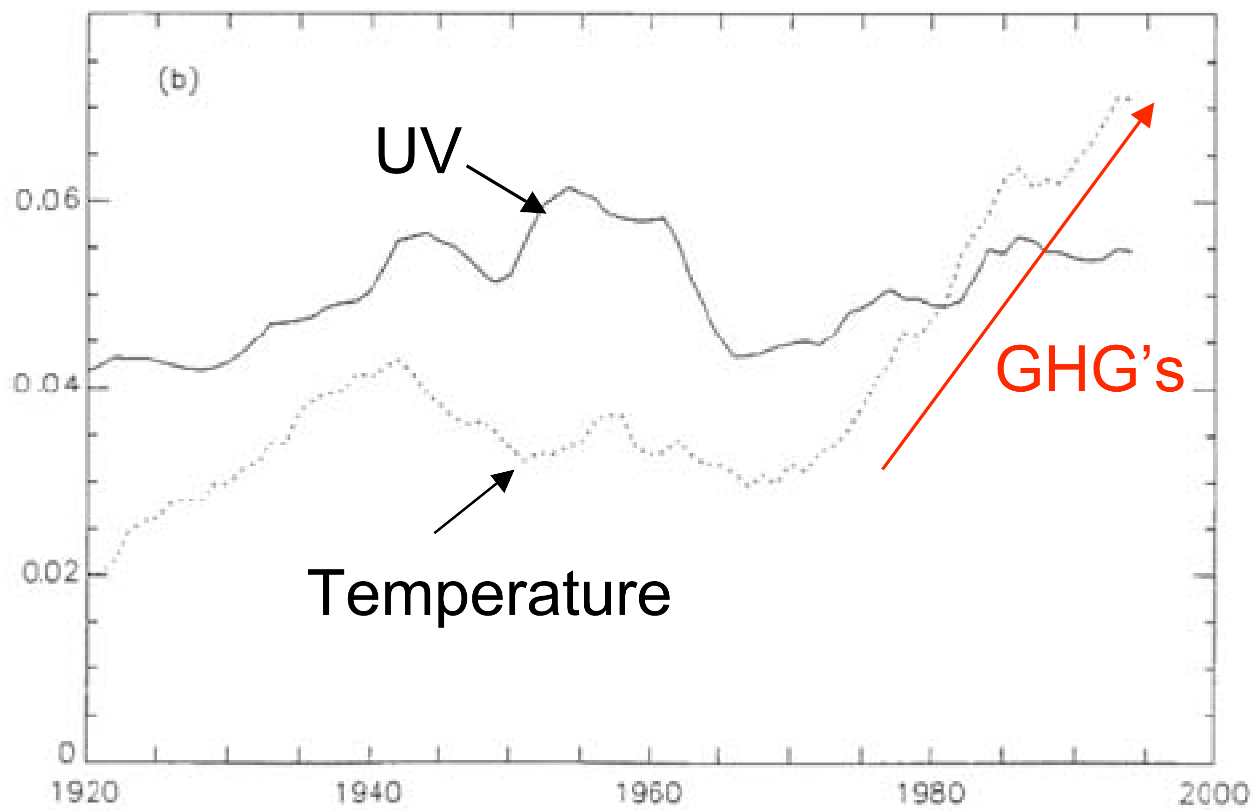
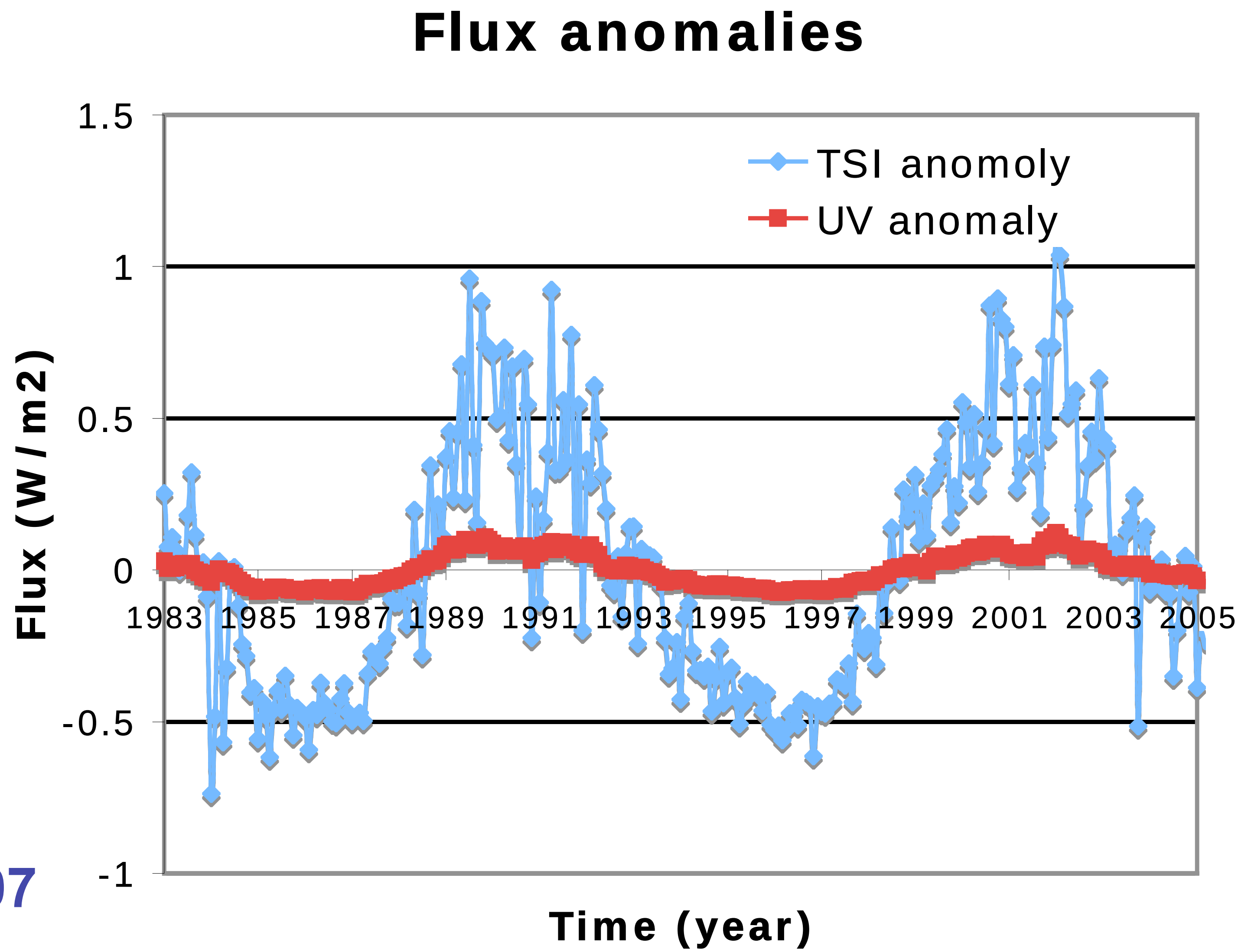


Figure 2. Panel (a): The 11-year smoothed time series of S based on A_{PN} (solid), and the global mean temperature, T, (dots) between 1915–1999. Panel (b): Comparison of the 11-year smoothed time series of A_{PN} (solid) and of T(dots). Ordinates are in percent variation.

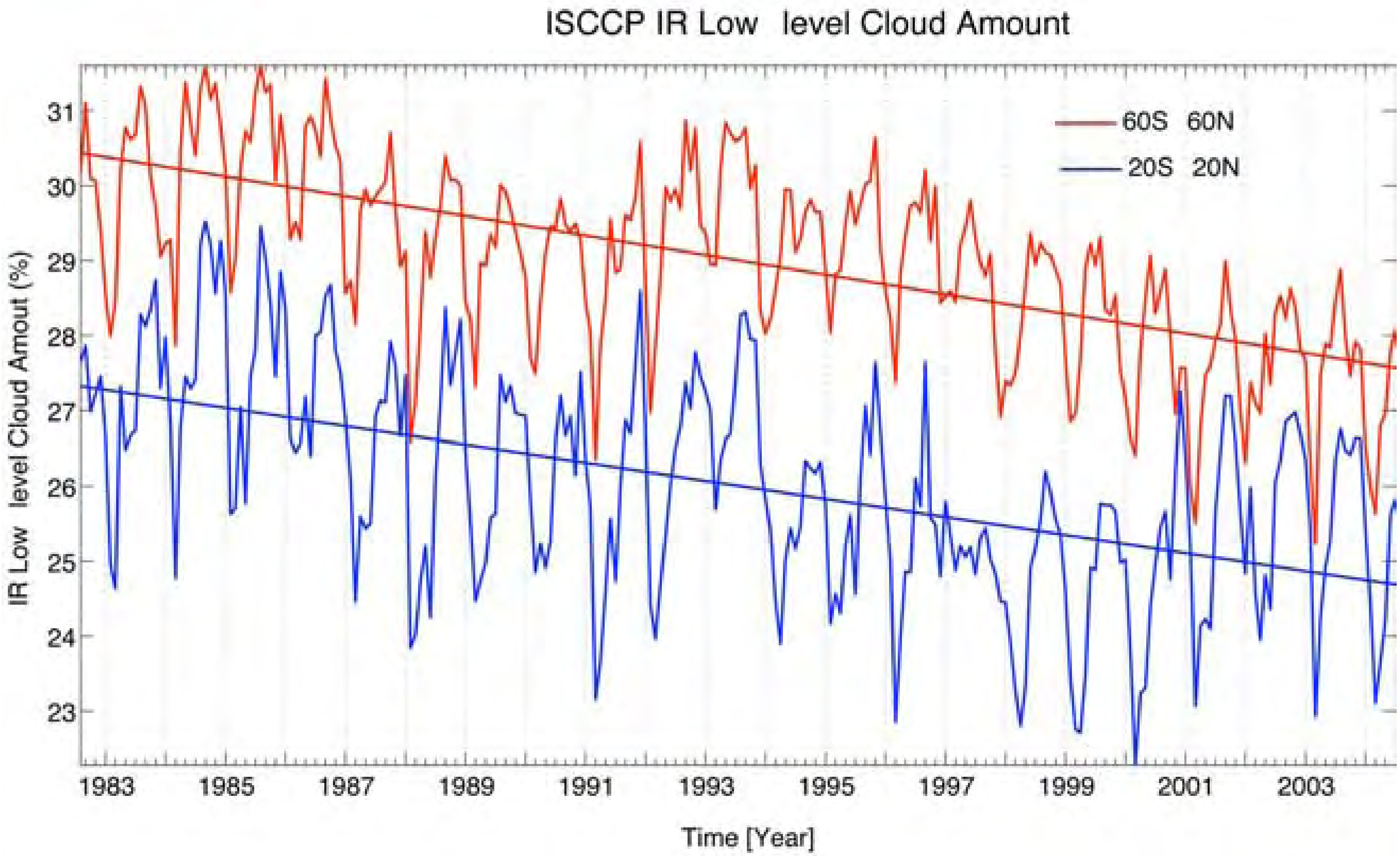
Foukal, 2002

Since the satellite era there has been a small increase in TSI and UV flux, but largest variations occur on 11-year time scale:

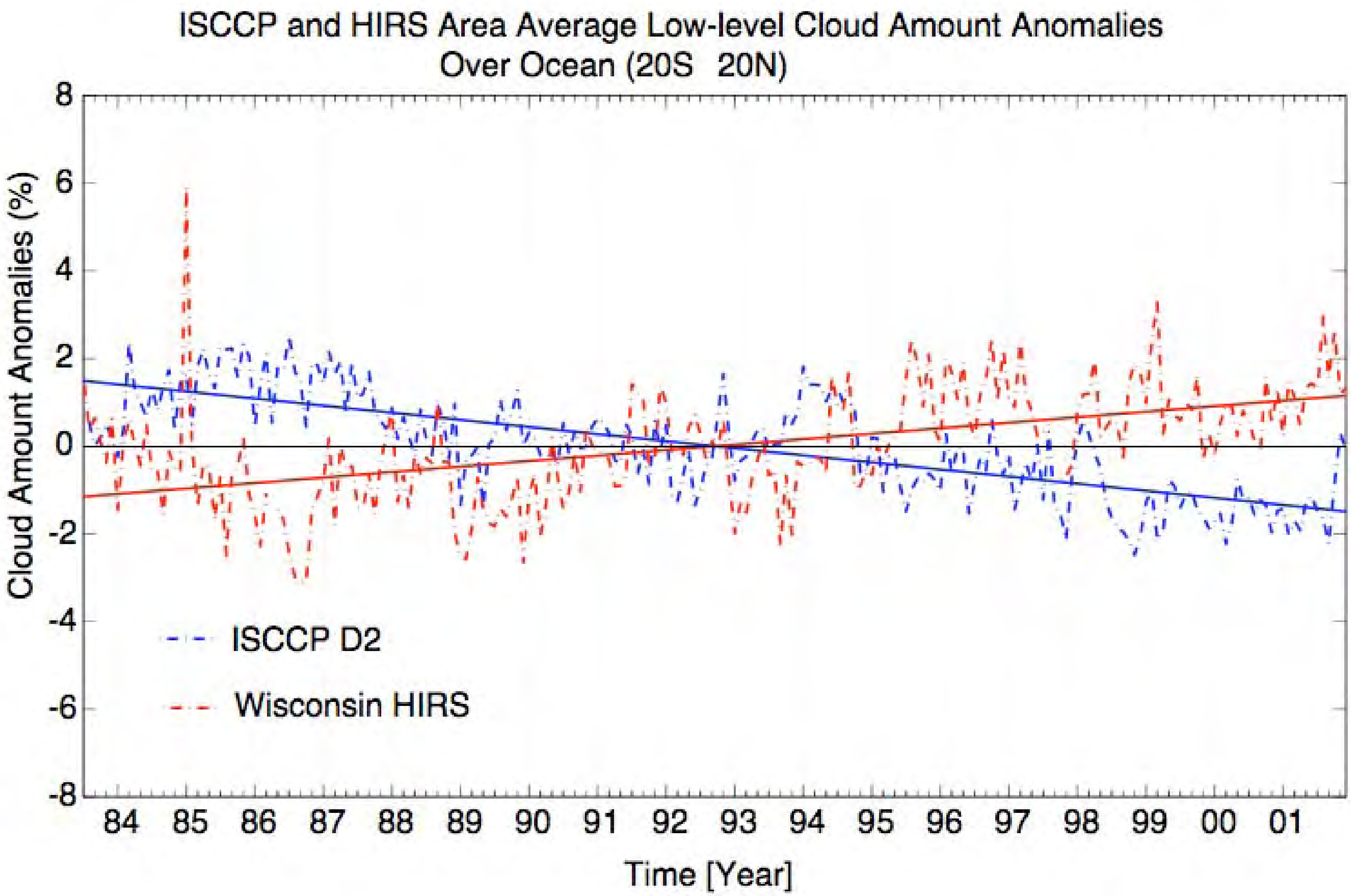


Lean, 2007

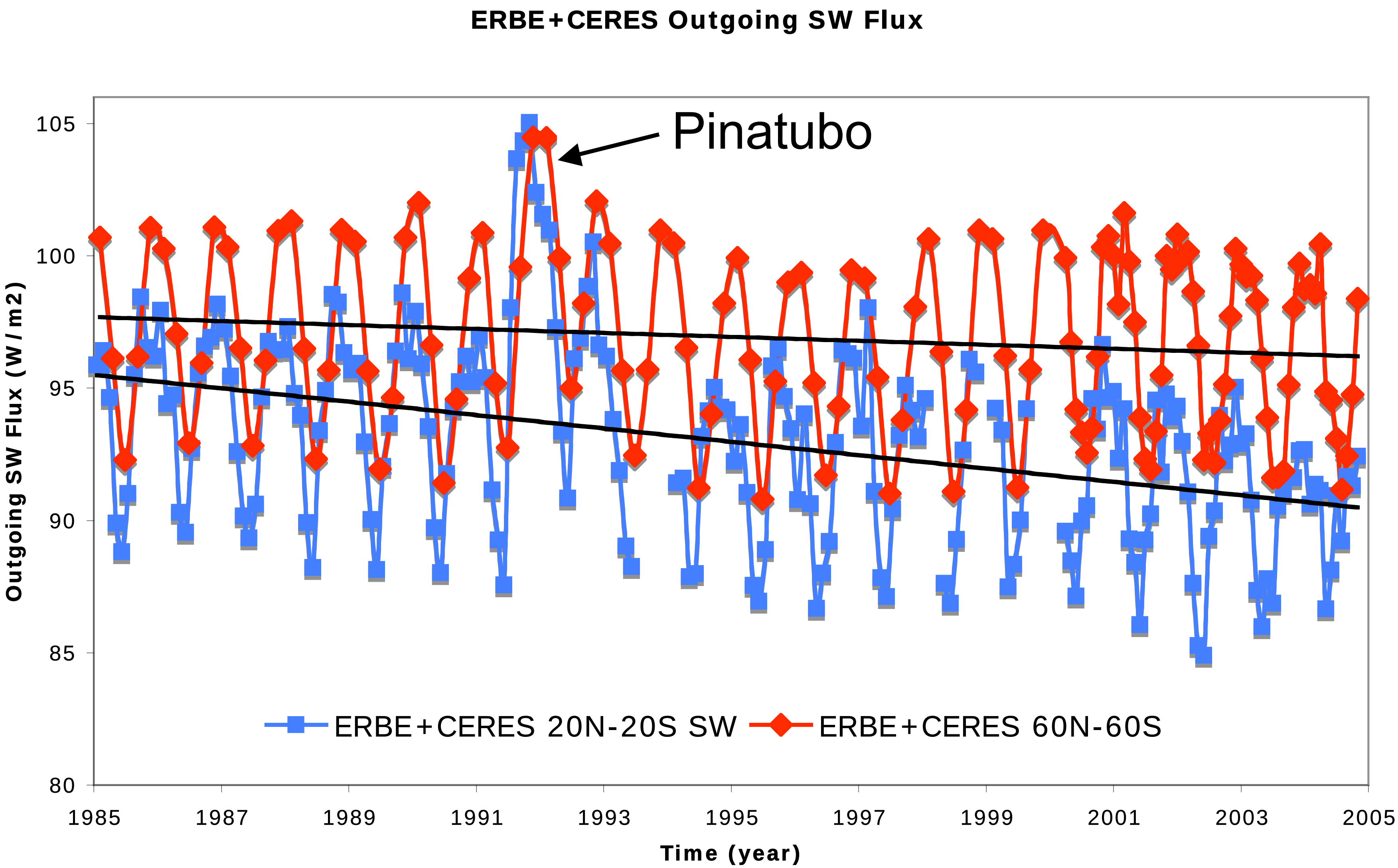
There is a continuing large decrease in cloud cover:



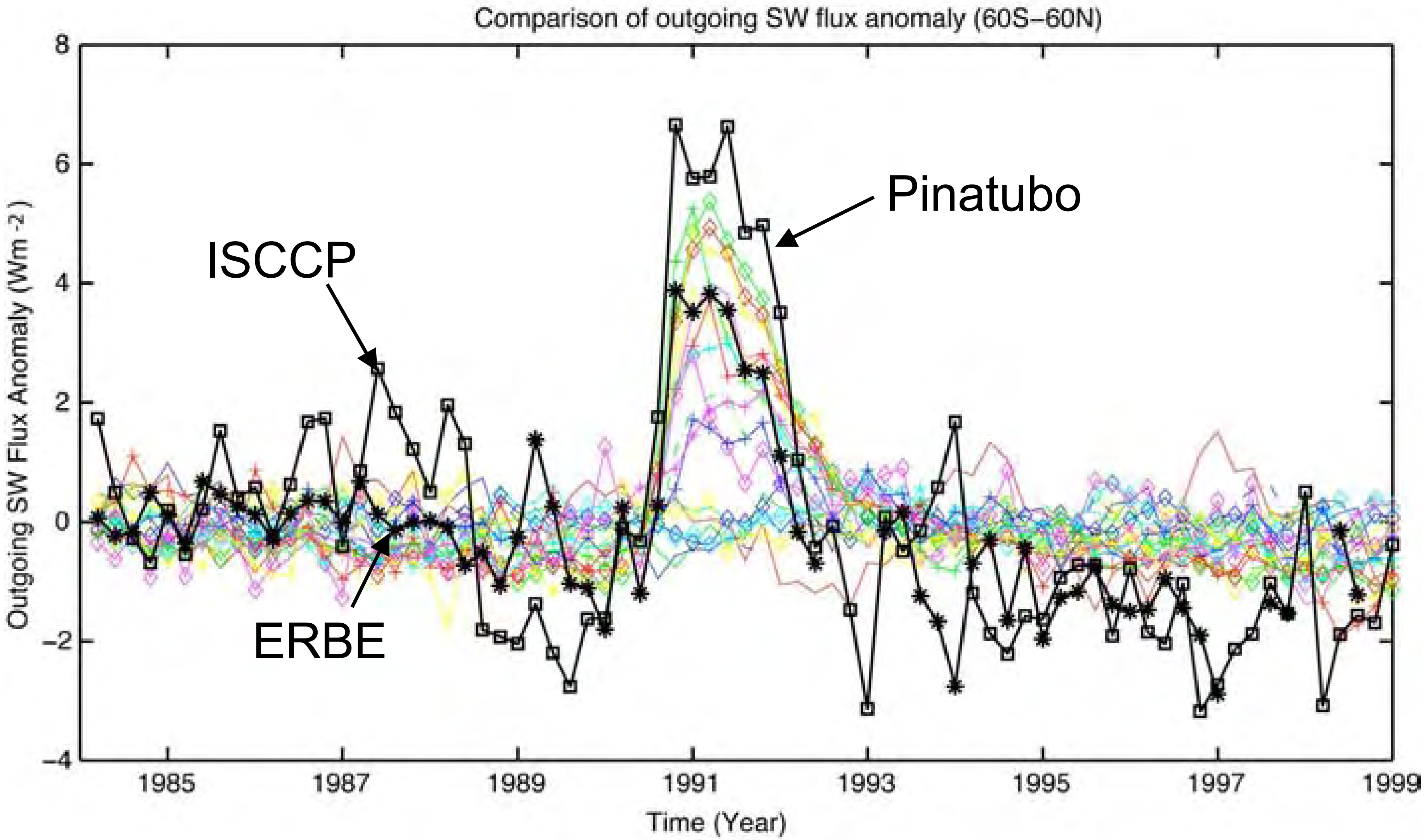
Caution: some satellite records show an increase in low cloud cover:



There is confirmation for the ISCCP trend from the ERBE and CERES satellite instruments for a decrease in cloud amount

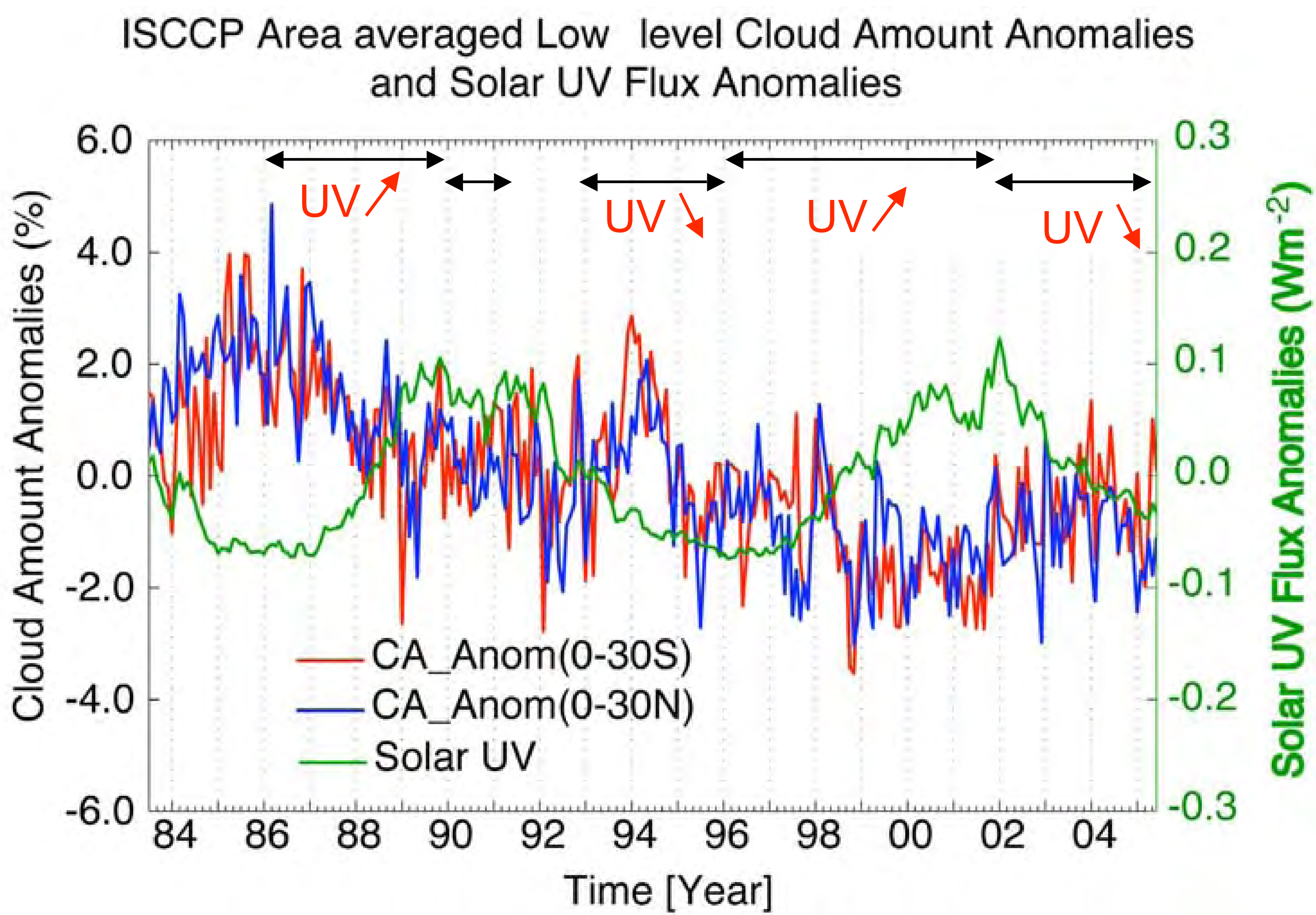


Erbe trends agree with ISCCP trends, but models are not able to reproduce the decrease in outgoing SW flux



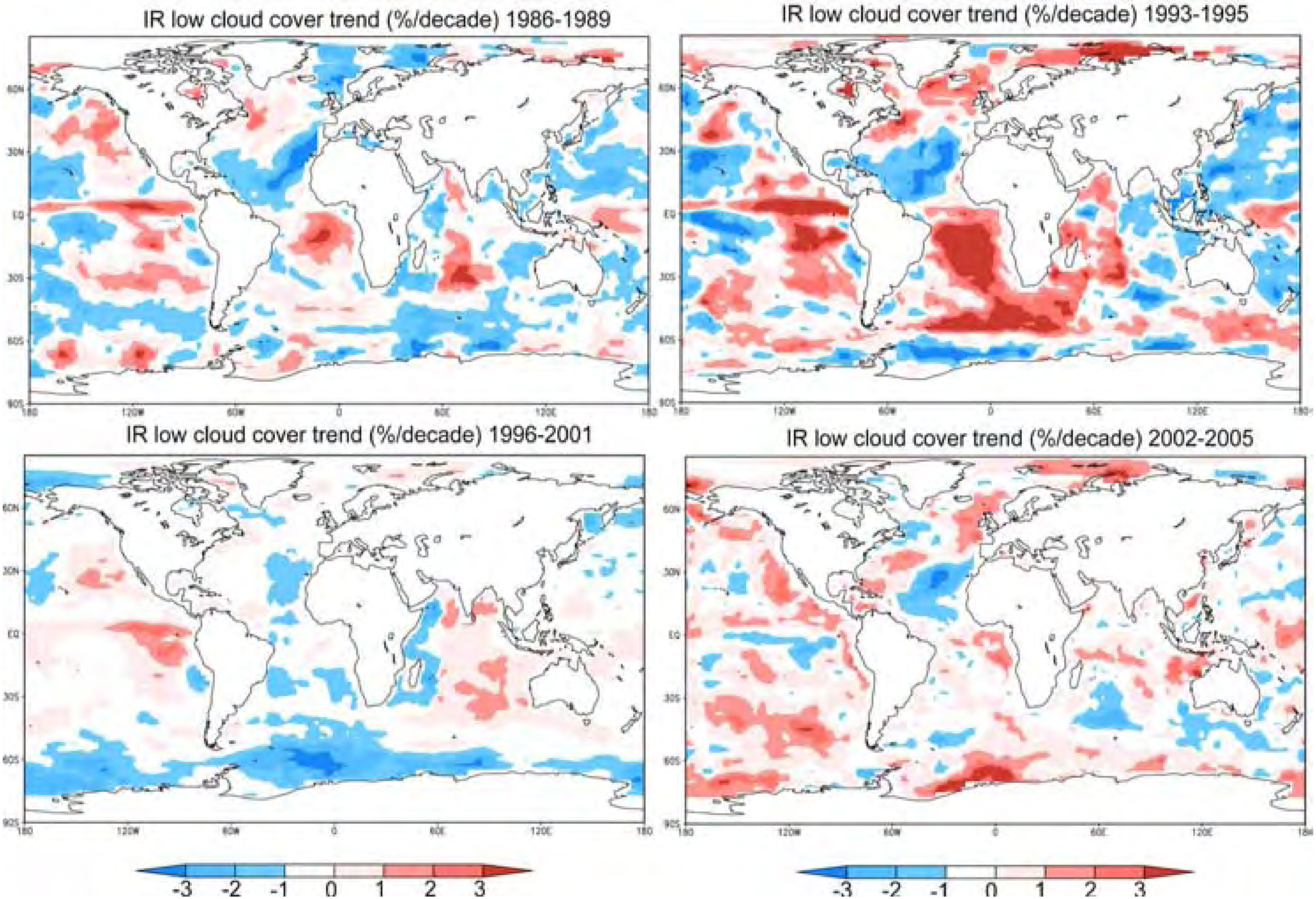
Re-examine DMS-UV-CC hypothesis

- Data analysis:
  - Concentrate on tropical areas (0 - 30S; 0 - 30N)
  - Look at trends in CC for periods of increasing and decreasing UV flux: 1986-89; 1990-91; 1993-95(skip Pinatubo); 1996-01; 2002-05
  - Examine spatial correlations between trends in CC and DMS flux during periods of increasing and decreasing UV flux
- Model analysis:
  - Determine the change in UVA and UVB intensity and flux for a typical change in CC
  - Determine the change in DMS needed to change CC
  - Determine the magnitude of the response of DMS to UVA and UVB needed to explain the change in CC

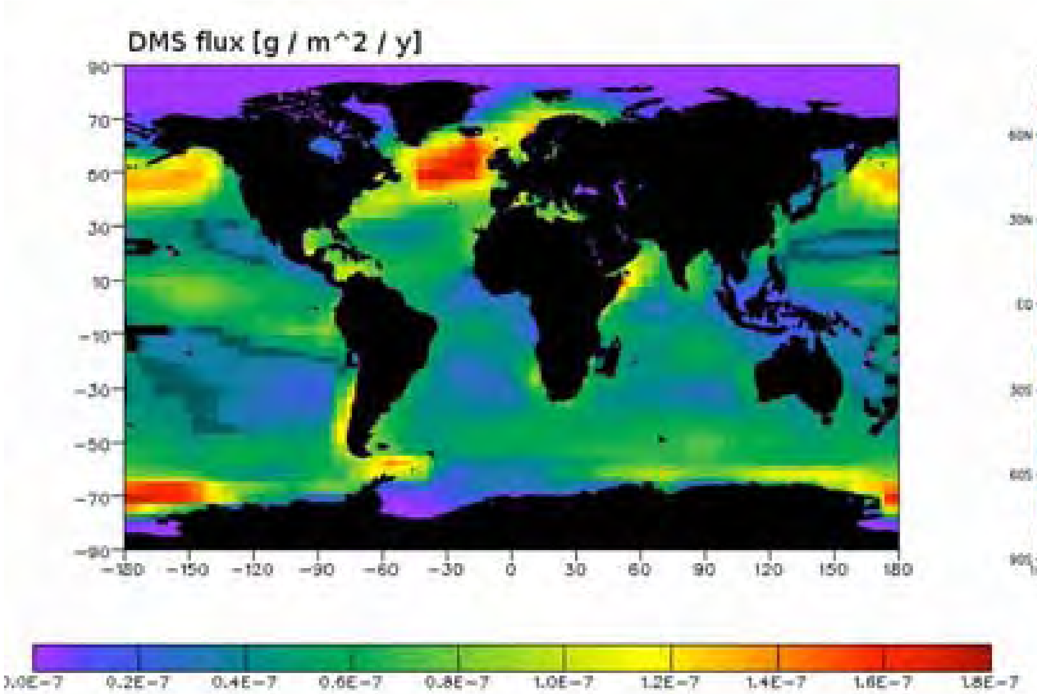


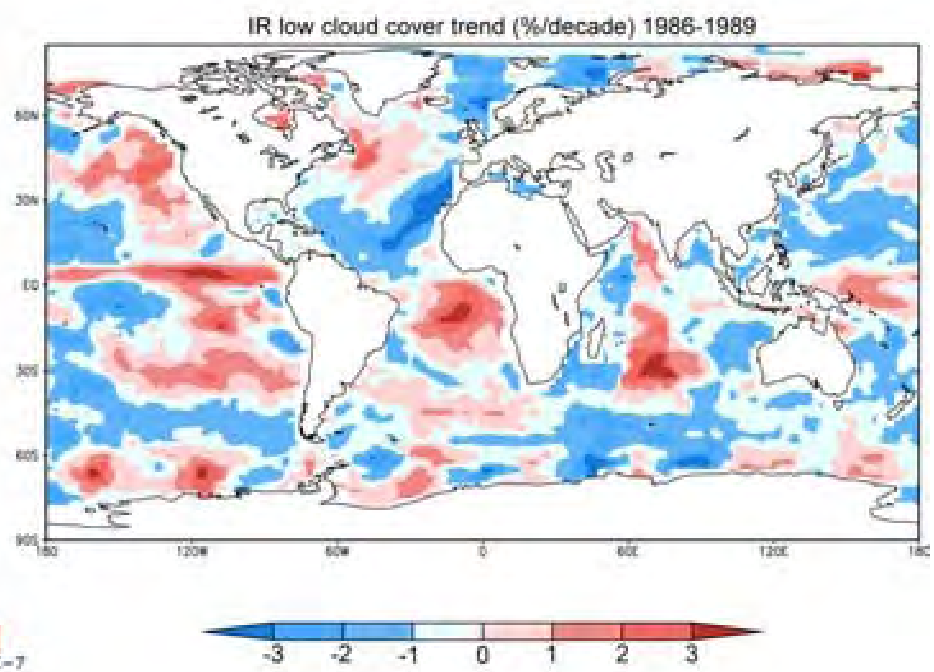
ISCCP Area averaged Low level Cloud Amount Anomalies
and Solar UV Flux Anomalies
Cloud Amount Anomalies (%)
Solar UV Flux Anomalies (Wm-2)
Time [Year]
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
84
86
88
90
92
94
96
98
00
02
04
UV
UV
UV
UV
CA_Anom(0-30S)
CA_Anom(0-30N)
Solar UV

Increasing UV: Decreasing UV:



Is flux of DMS spatially correlated with CC trends during periods of increasing and decreasing UV?





DMS flux and CC trend are negatively correlated, especially during periods of increasing UV

0 - 30 N:

	Corr(low_ca, dms_flux)					
	UV up	UV const	UV down	UV up	UV down	UV down (w/ Pinatubo)
	86/01-89/12	90/01-91/06	93/01-95/12	96/01-01/12	02/01-05/06	90/01-95/12 (w/ Pinatubo)
Correlation coefficient (R)	-0.1491	0.12325	-0.076576	-0.22525	-0.28433	-0.063703
R (- 95% CIs)	-0.20235	0.068815	-0.13092	-0.27671	-0.334	-0.11819
R (+ 95% CIs)	-0.094983	0.17695	-0.021768	-0.1725	-0.23309	-0.0088347
P-value	8.8534e-008	1.0177e-005	0.0062261	3.8513e-016	3.7186e-025	0.022922
R is Significant? (Y/N)	Y	Y	Y	Y	Y	Y

0 - 30 S:

	Corr(low_ca, dms_flux)					
	UV up	UV const	UV down	UV up	UV down	UV down (w/ Pinatubo)
	86/01-89/12	90/01-91/06	93/01-95/12	96/01-01/12	02/01-05/06	90/01-95/12 (w/ Pinatubo)
Correlation coefficient (R)	-0.10194	0.15701	-0.062876	-0.26678	-0.037299	0.098874
R (- 95% CIs)	-0.15304	0.10596	-0.11441	-0.31434	-0.089037	0.047206
R (+ 95% CIs)	-0.050294	0.20723	-0.011001	-0.21789	0.01464	0.15001
P-value	0.00011521	2.5103e-009	0.017568	1.1626e-024	0.1592	0.00018429
R is Significant? (Y/N)	Y	Y	Y	Y	N	Y

UV-DMS facts (Larson, 2005)

- Total TSI varies by 1.36 Wm^{-2} (0.1%)
- UVR (200-400 nm) accounts for 32% of total
- Variation in 300 - 400 nm is 0.24 W/m2 (gets to surface) (larger in tropics)
- Variation is 0.12 W/m2 in summer subtropics (300 - 550 nm, most 400-410)
- Most DMS production in regions of shallow ocean mixing depth in summer -- exposed to UV
- 48% of production of DMS is from 20N to 20S

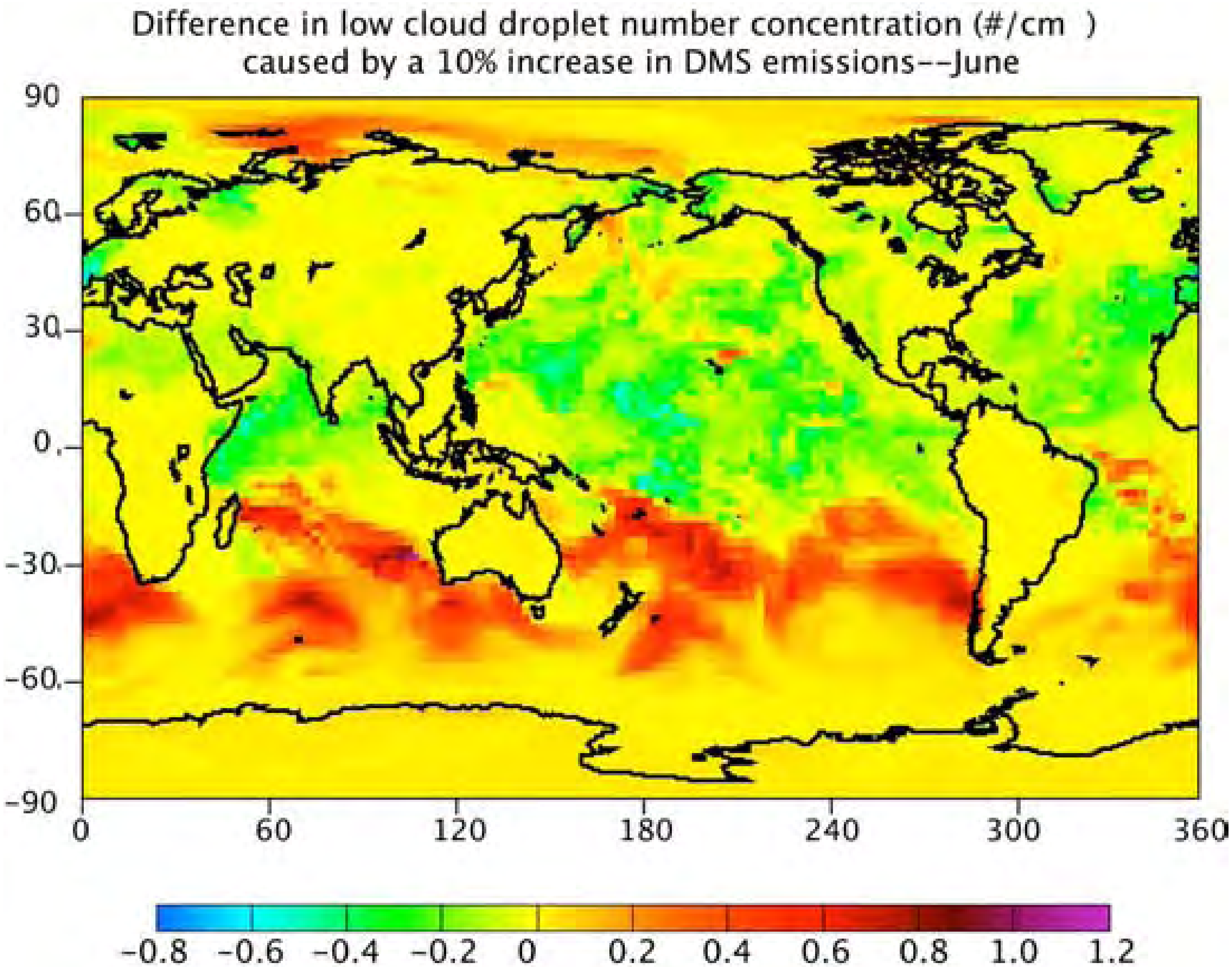
UV-DMS facts (Larson)

- UVA and UVB increases cause a decrease in phytoplankton (UVA: 320 - 400 most important)
- UVA decreased photosynthesis by 40-50% (Cullen et al., 1992; Holm-Hansen et al., and others)
- UVB causes DNA damage, which may repair if cells move below mixing depth (Euphotic zone larger than mixing depth)
- Summer (winter) mixing depth in SH > 40 - 50S varies from 50 (>300)m but less variation in subtropics
- Bacterial removal of DMS dominant below surface; photolysis important near surface, but bacteria stimulated by UV photolysis of DOM but produce CDOM which absorbs UV

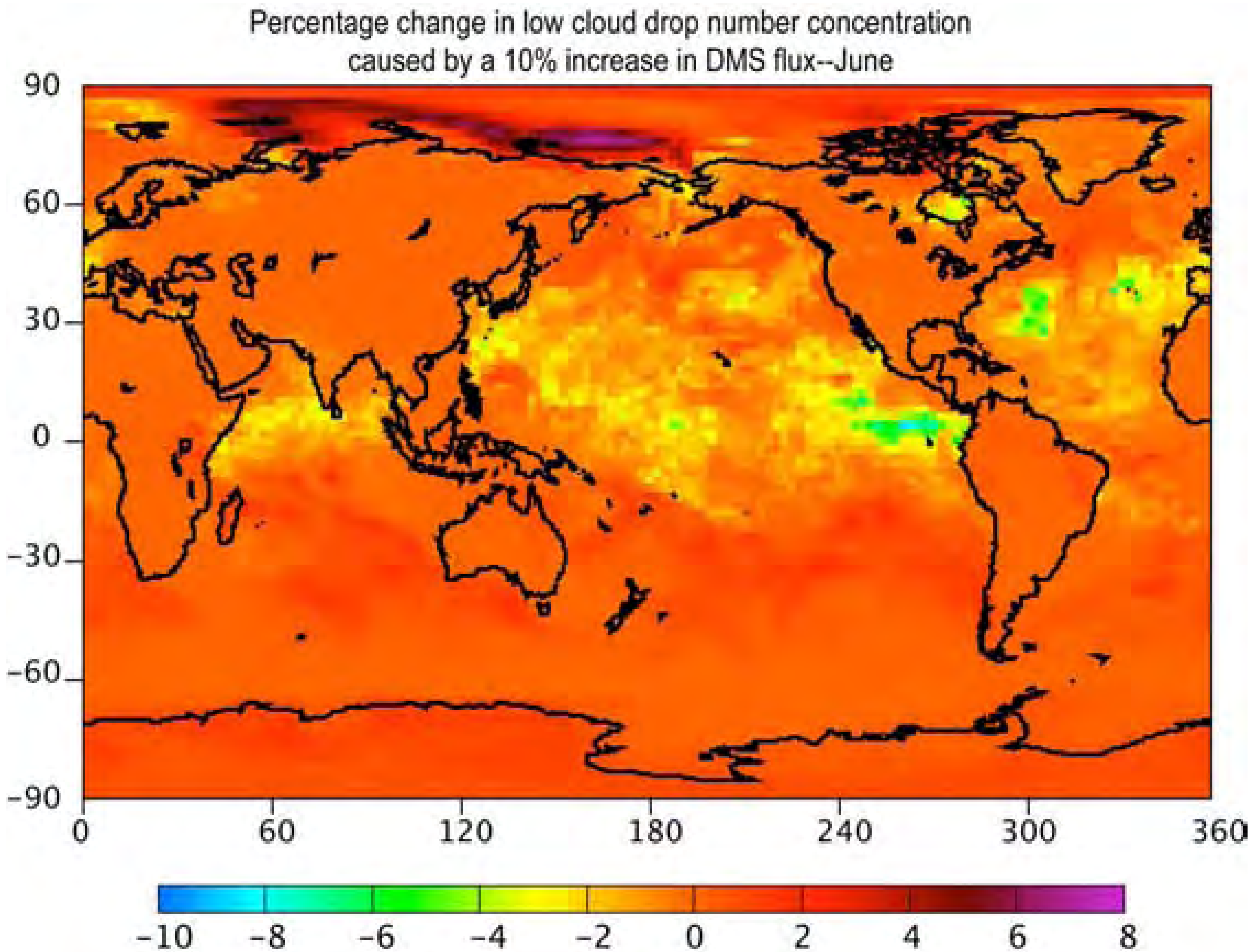
Could regions with high cloud cover and high correlation between UV flux and low cloud trends be due to a feedback between DMS production and UV?

- Model analysis:
  - Determine the change in UVA and UVB intensity and flux for a typical change in CC
  - Determine the change in DMS needed to change CC
  - Determine the response of DMS to changes in UVA and UVB needed to explain the cloud cover changes

A 10% decrease in DMS flux can only cause a droplet number concentration change of less than 1/cm³

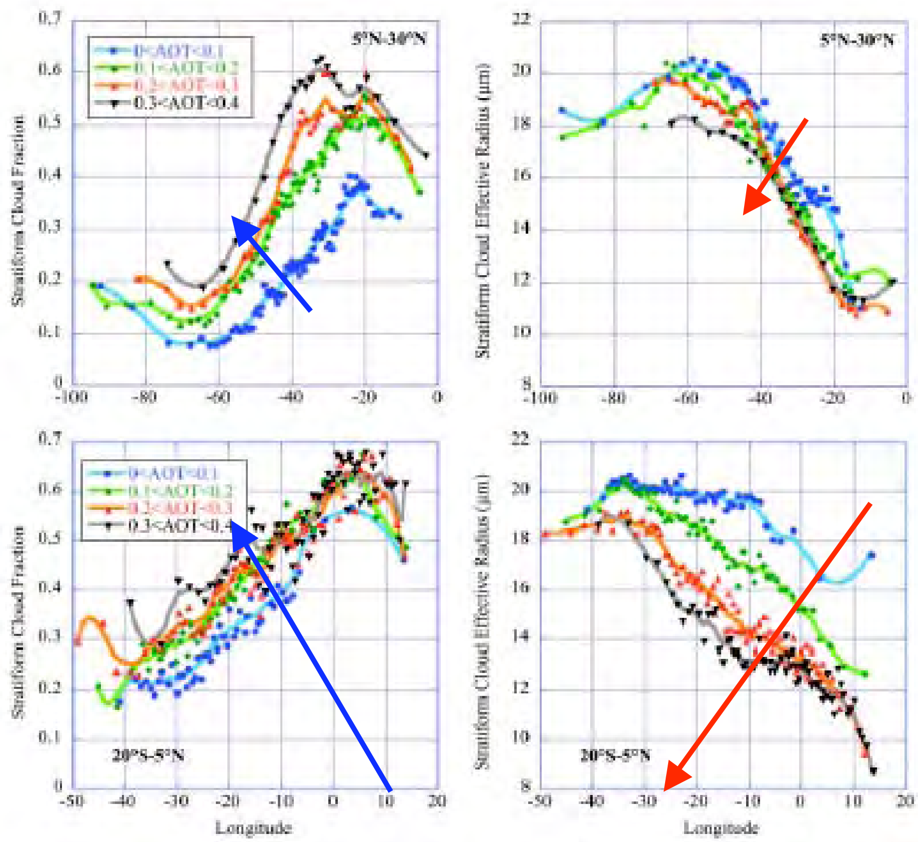


Or a percentage change of 2%



Satellite observations of show that cloud cover increases with aerosol concentration:

Kaufman et al., PNAS, 2005



Increases in aerosol optical depth cause a decrease in cloud drop radius

Increases in aerosol optical depth cause an increase in cloud cover

Kaufman et al.,PNAS, 2005:

Region	Dominant aerosol	Fraction of region	Shallow cloud cover	Range of AOT	Mean AOT	Δcl-aer	δcl-aer	% change in Reff	% change in LWP	Change in CLTP, hPa
30°N-60°N	Pollution	0.17	0.07	0.03-0.19	0.102	0.2±0.06	0.19±0.03	-12±10	6±34	-39±20
5°N-30°N	Saharan dust	0.26	0.11	0.03-0.46	0.174	0.36±0.12	0.25±0.04	-12±13	9±34	-66±13
20°S-5°N	Biomass burning	0.53	0.29	0.03-0.43	0.152	0.31±0.07	0.31±0.04	-32±3	-21±8	-55±11
30°S-20°S	Marine	0.47	0.27	0.02-0.24	0.085	0.45±0.10	0.45±0.04	-19±7	35±22	-72±18

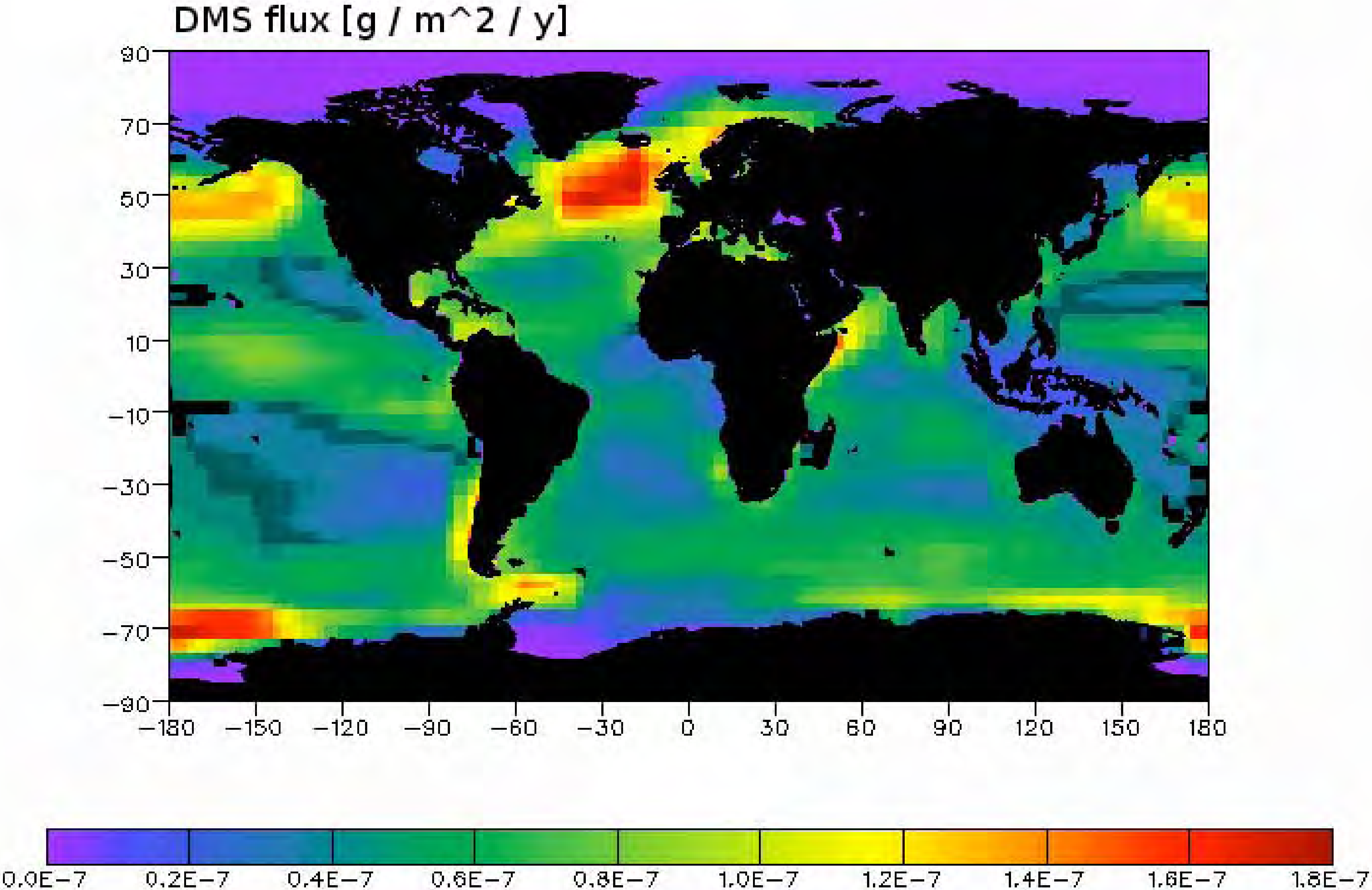
$$\Delta(CC)/\Delta(AOT) = 0.45/0.22$$

Can changes in UV flux explain the change in cloud cover?

- Δ(AOT) for decrease in CC of 0.025 = -0.012
- Δ(UVB) for decrease in CC of 0.025 = +0.5%
- Δ(UVA) for decrease in CC of 0.025 = 0.35%
- $\Delta(DMS) = \Delta(AOT)/k_e = \Delta(AOT)/[8 m^2 g^{-1} (S)] = \Delta(AOT)/ [4 m^2 g^{-1} (DMS)]$

- Δ(DMS)/Δ(UVB,observed) = -0.034 g DMS / m^2-yr
- Δ(DMS)/Δ(UVA,observed) = -0.018 g DMS / m^2-yr

Far too large a change in DMS flux required!



Summary

- Intriguing correspondence between DMS fluxes and changes in cloud cover
- Changes in cloud cover are not reproduced by current climate models
- Changes in cloud cover appear to be real: independent confirmation by ERBE

- There remains to find an explanation that fits!