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Influence of Solar Activity Cycles on Earth's Climate.

ISAC

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ISAC Goals

- How does solar activity influence climate over a solar cycle?

- Assess the likely impact of each of the candidate mechanisms.

- Advise on possible methods for integrating mechanisms into climate simulations.

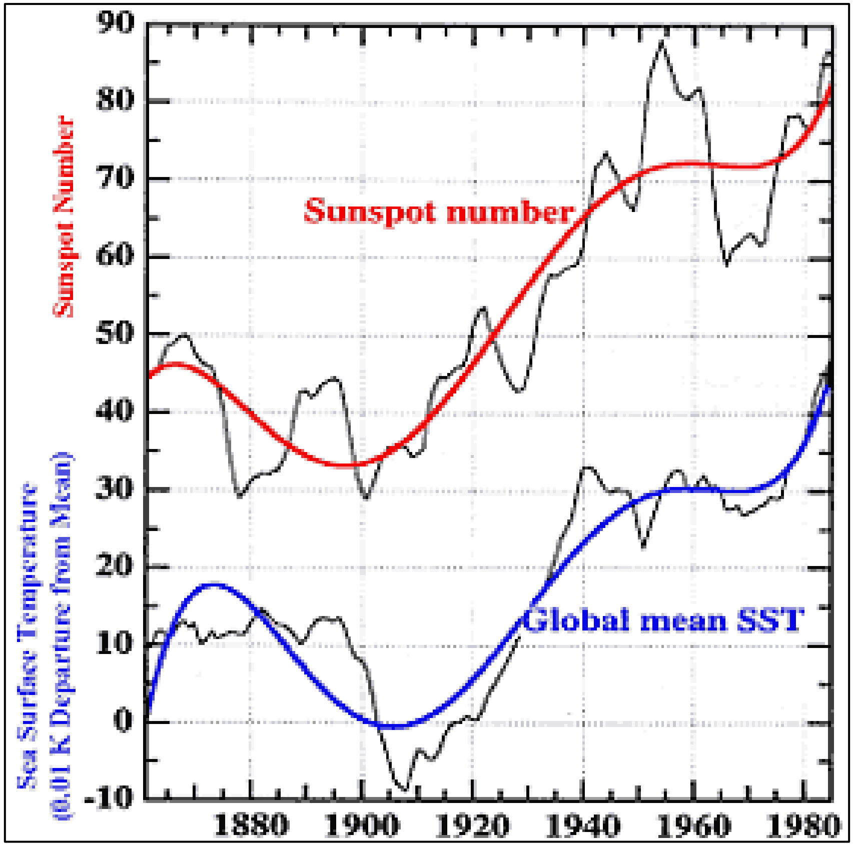
Talk Outline

1) Evidence for solar influence on climate.
    - Ocean Temperatures.
    - Land Temperatures.
    - Tropospheric Temperatures.

2) Amplification required.
    - Models underestimate solar contribution.

3) Amplification Mechanisms.
    - Solar UV – ozone, dynamics
    - Solar Wind – downward wave propagation.
    - GCR – atmospheric ionisation, clouds

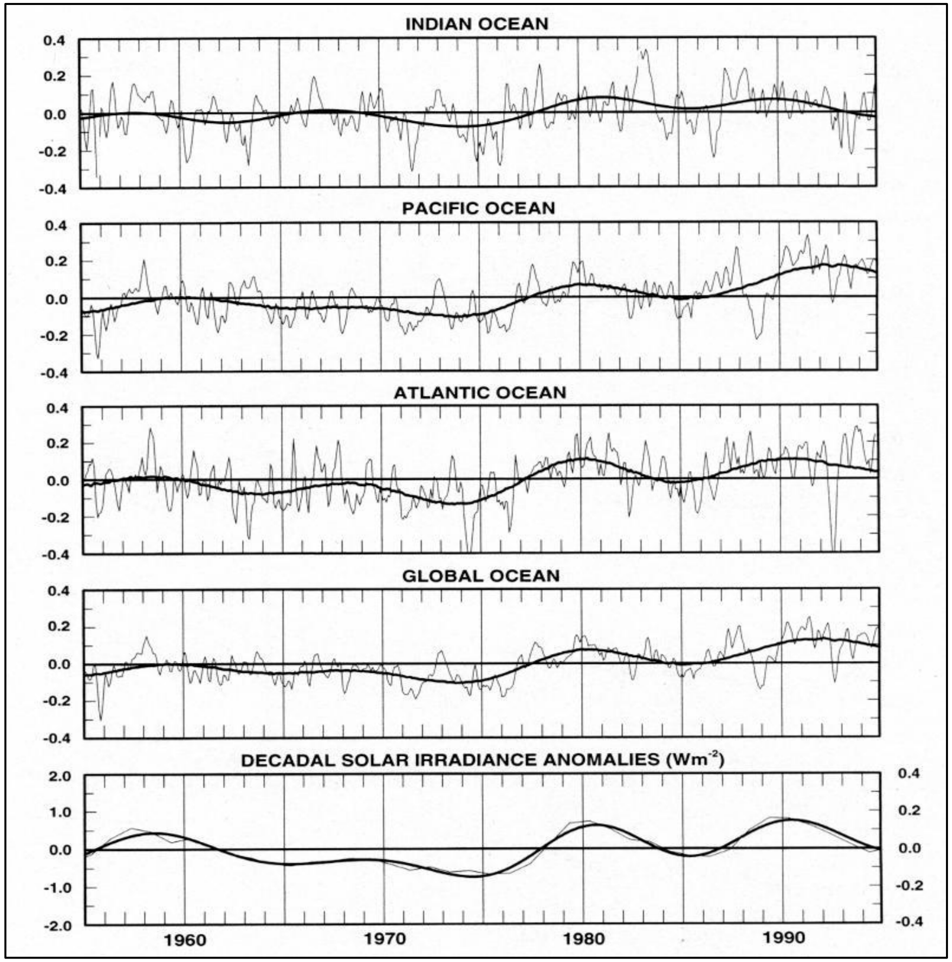
Ocean Temperatures vs Solar Variability



Sea Surface Temperatures (SST's) obtained from ships.

Reid,Nature, 1987.

Ocean Temperatures vs Solar Variability

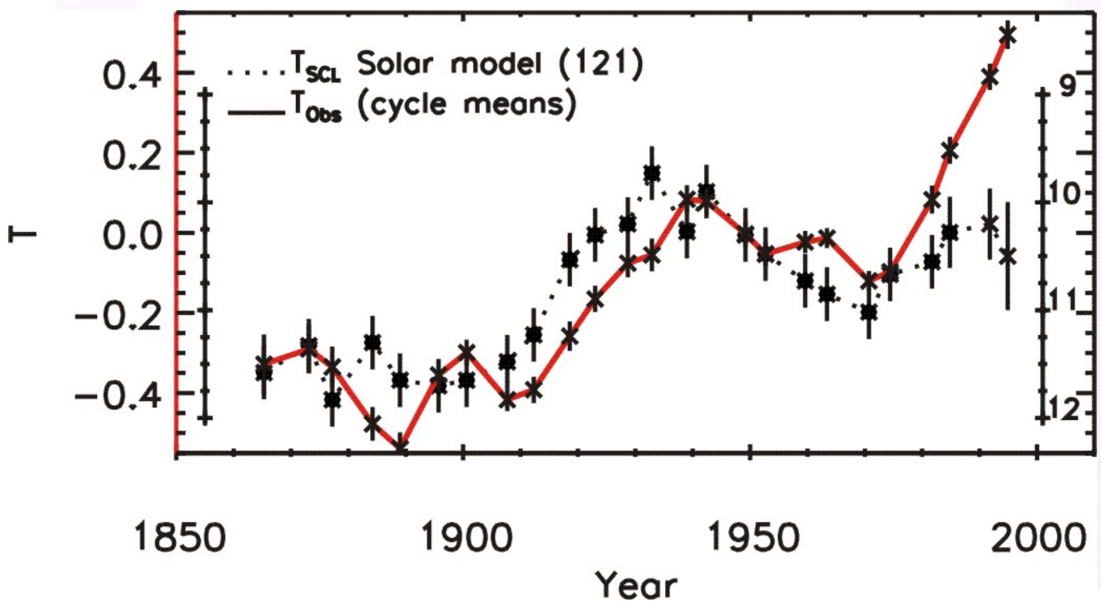


- SST's over different ocean basins consistent with both 11 and 22 year variability in solar activity.
- Observed variations in SST larger than expected from changes in Total Solar Irradiance (amplification?).

White et al, JGR, 1997.

Land Temperatures vs Solar Variability

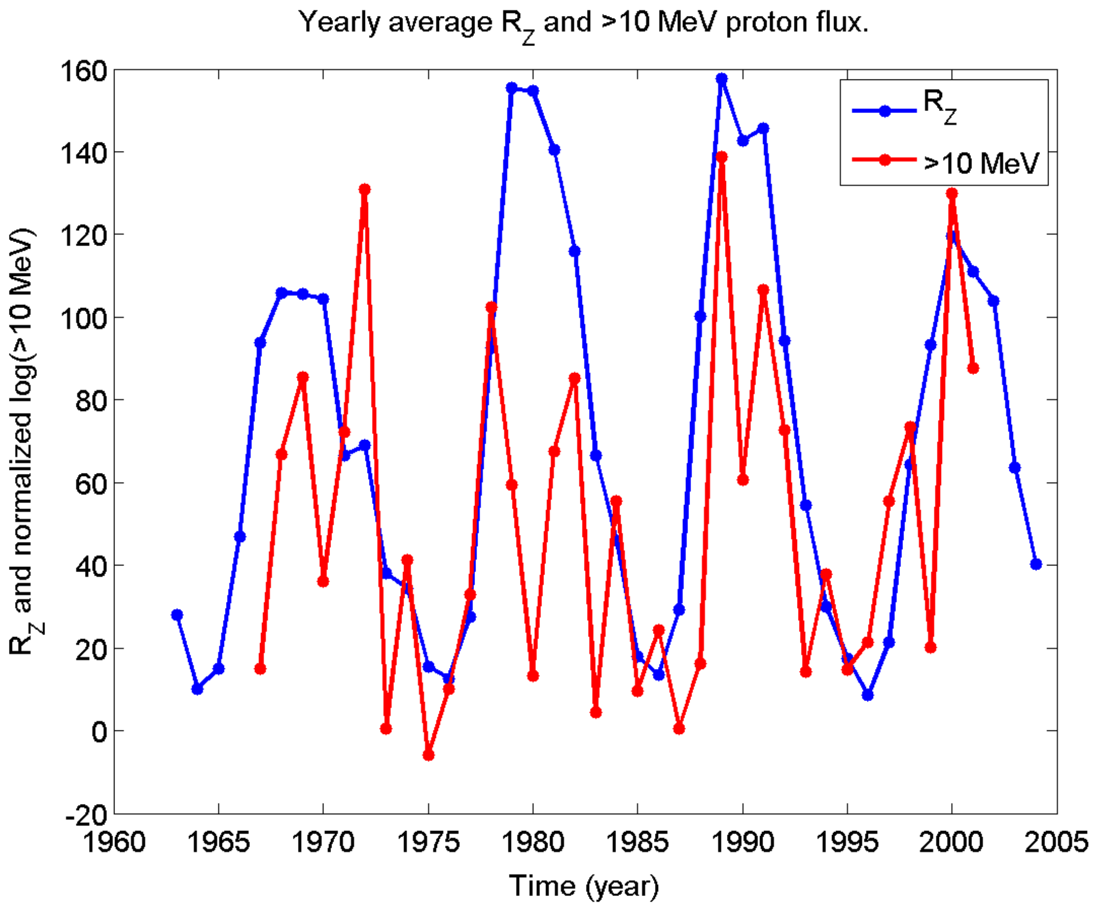
GHG? – Thejll and Lassen, JASTP, 2000.



Solar Cycle Length and NH Land temperature anomalies consistent until 1990.

Friis-Christensen and Larsen, Nature, 1991.

Yearly average Zurich sunspot number R_Z (blue) and proton fluxes (omni) > 10MeV (red).



Tropospheric Temperatures vs Solar Variability

$\Delta T = \lambda\, \Delta F$

$\lambda = 0.6\ KW^{-1}m^2$

$\Delta F = \Delta F_s(1-\alpha)/4$

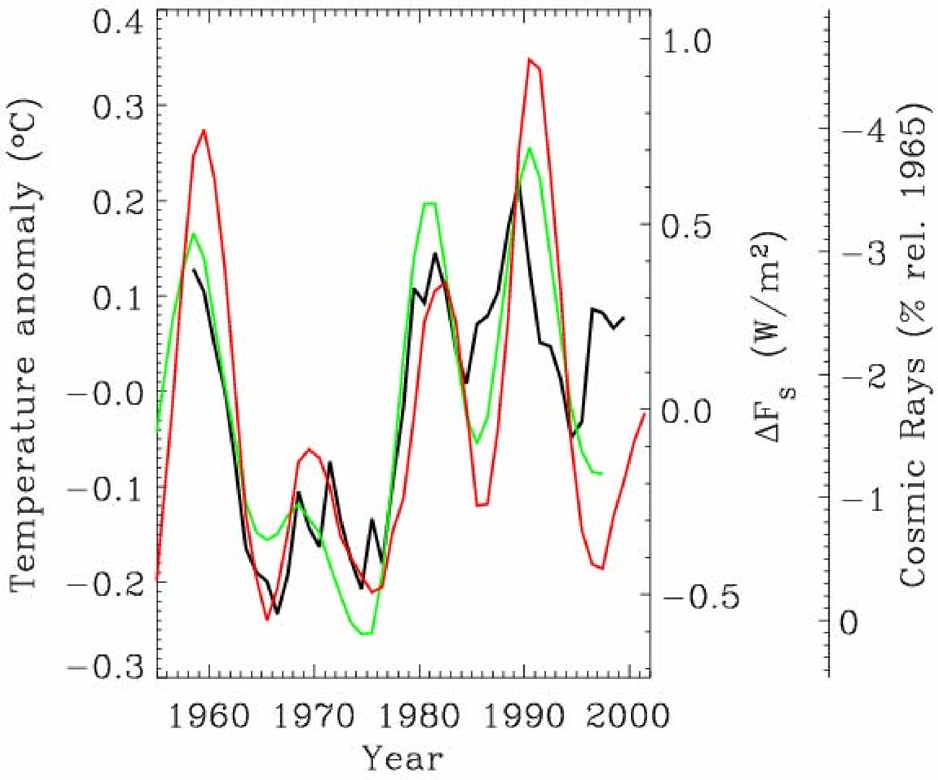
$= 0.2\ Wm^{-2}$

$\Delta T = 0.1$ K

but from figure:

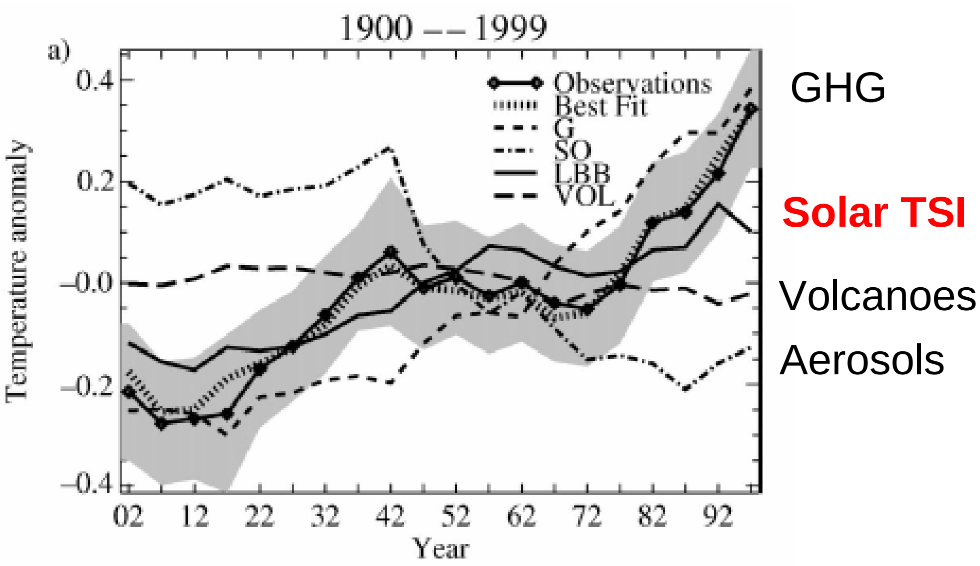
$\Delta T = 0.4$ K

Amplification factor 3-4

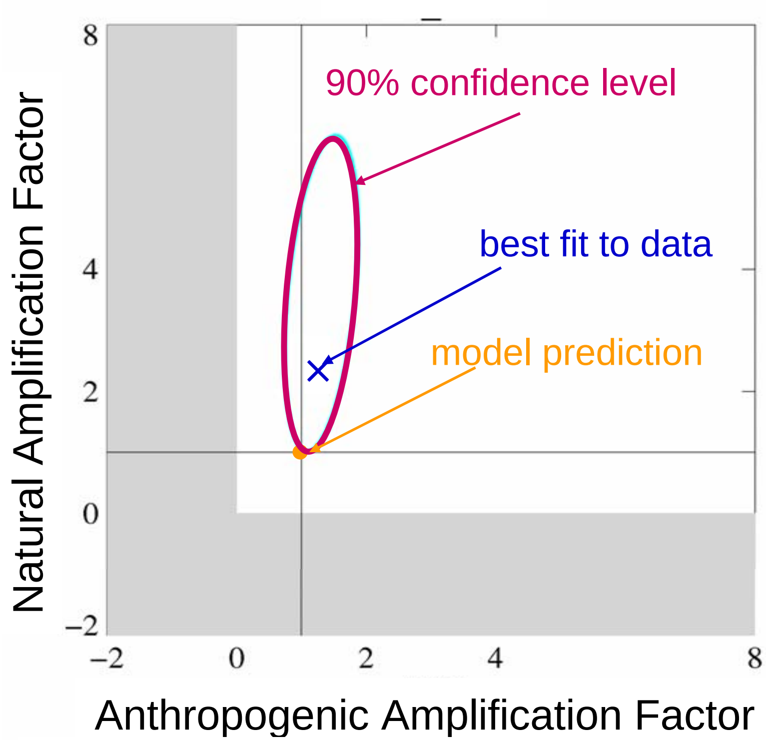


Marsh and Svensmark, SSR, 2003.

Models Underestimate Solar Influence of Surface and Tropospheric Temperatures.



Stott et al, J. Clim., 2003



Hill et al, 2001

Solar Variability requires an Amplification Factor of 3-4

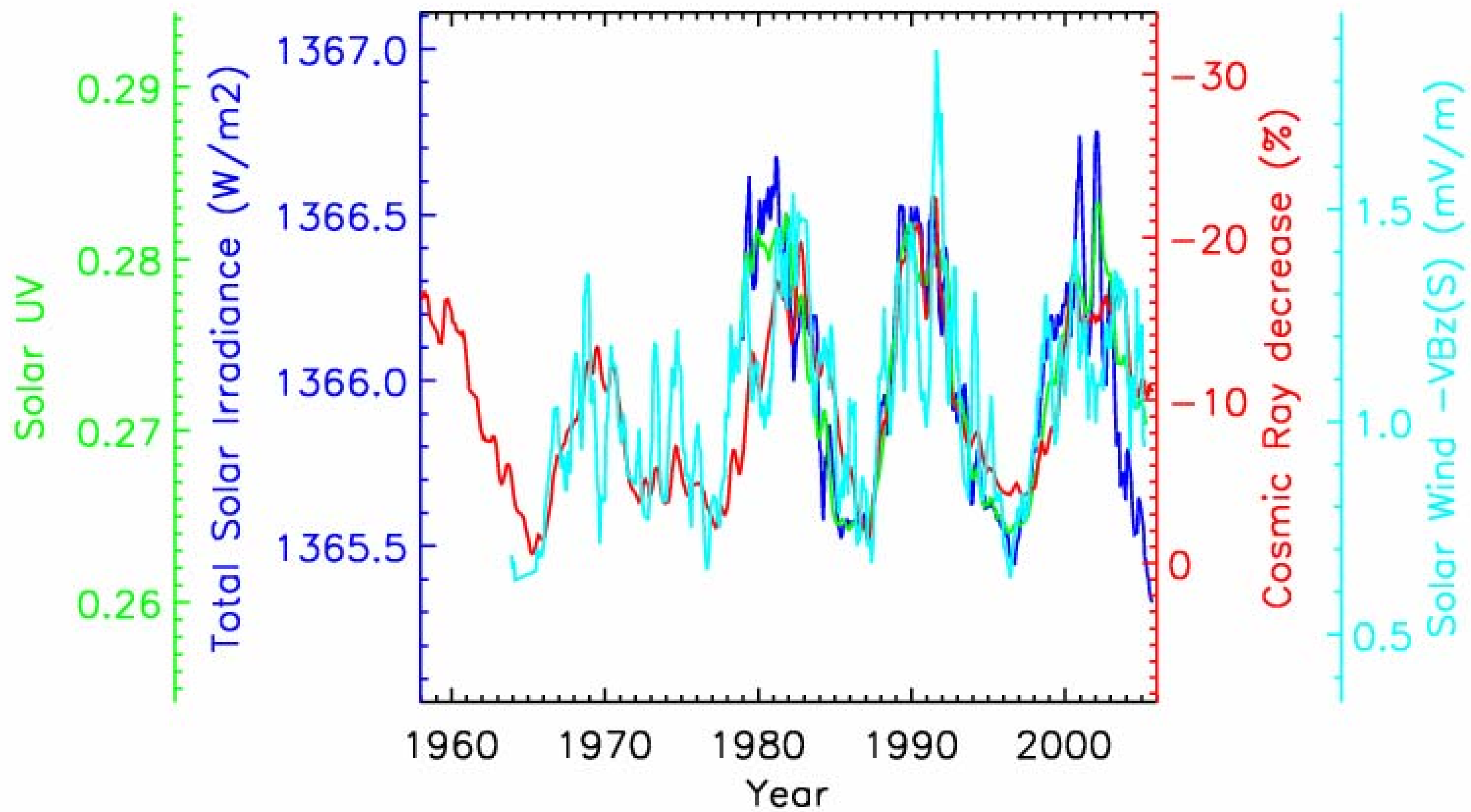
Energy arriving at the top of Earth's Atmosphere.

UV ~5-10%

• Total Solar Irradiance	1360 W/m^2
• TSI over Solar Cycle (0.1%)	1.36 W/m^2
• Solar Wind (10^3 eV)	~10^{-4} W/m^2
• Precipitating Particles (10^4 eV)	~10^{-5} W/m^2
• Galactic Cosmic Rays (10^8 eV)	~10^{-5} W/m^2

Solar Variability requires AMPLIFICATION to affect climate.

Solar vectors influencing Earth's Environment: TSI (blue), UV component (green), Cosmic rays (red), Solar wind (light blue).



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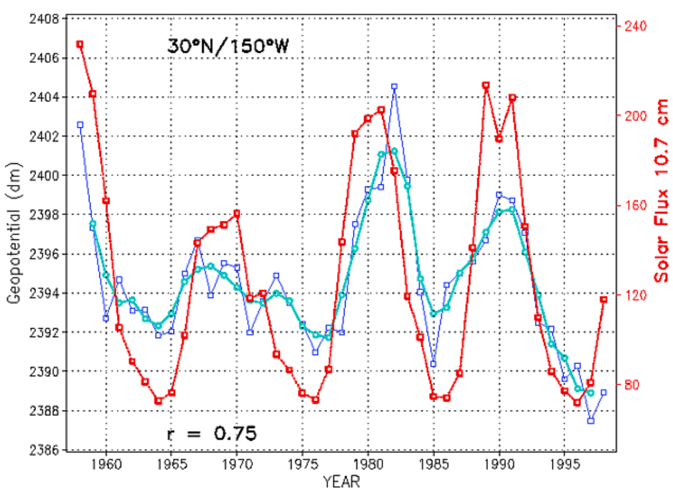
1) Amplification of Solar Variability: Solar UV

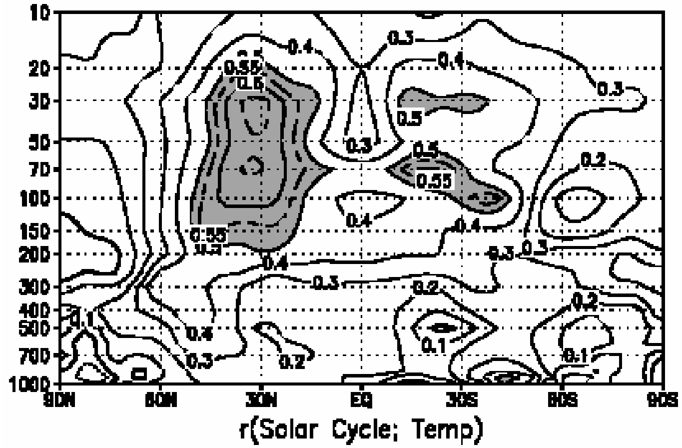
Stratospheric Geopotential Heights and Temperatures correlate with a proxy for Solar UV (10.7cm flux).

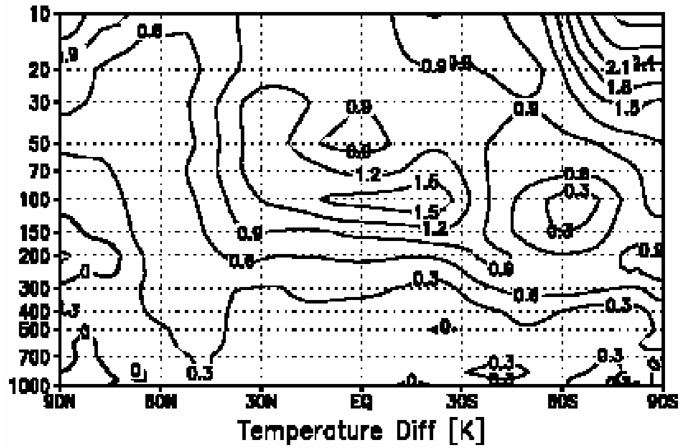
Labitzke and Matthes, 2003

Geopotential Height at 30hPa

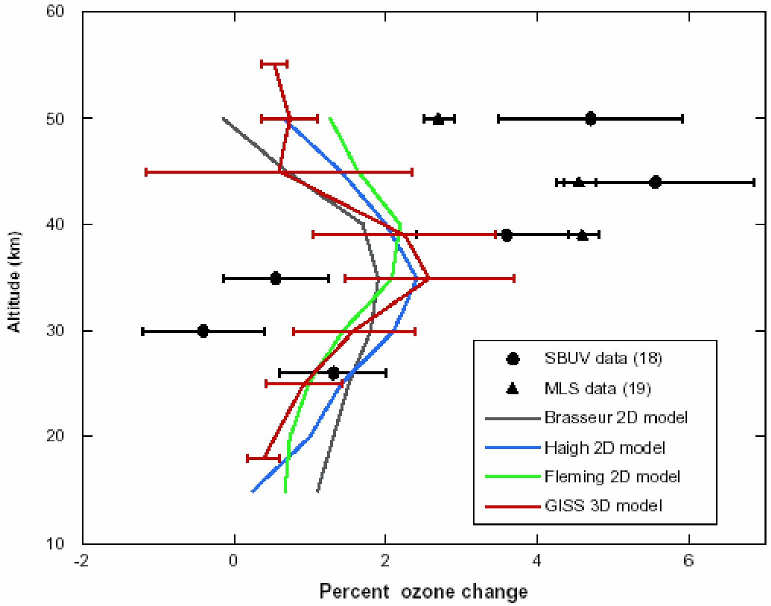


Temperatures

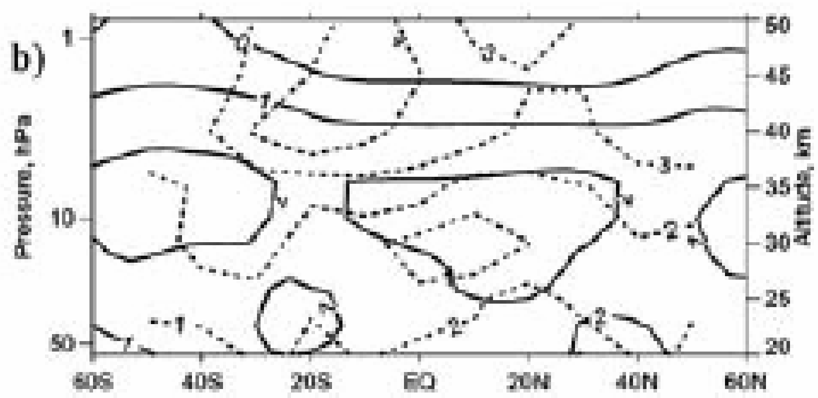




Ozone response to Solar UV Variability in the Stratosphere.



Shindell et al, Science, 1999.



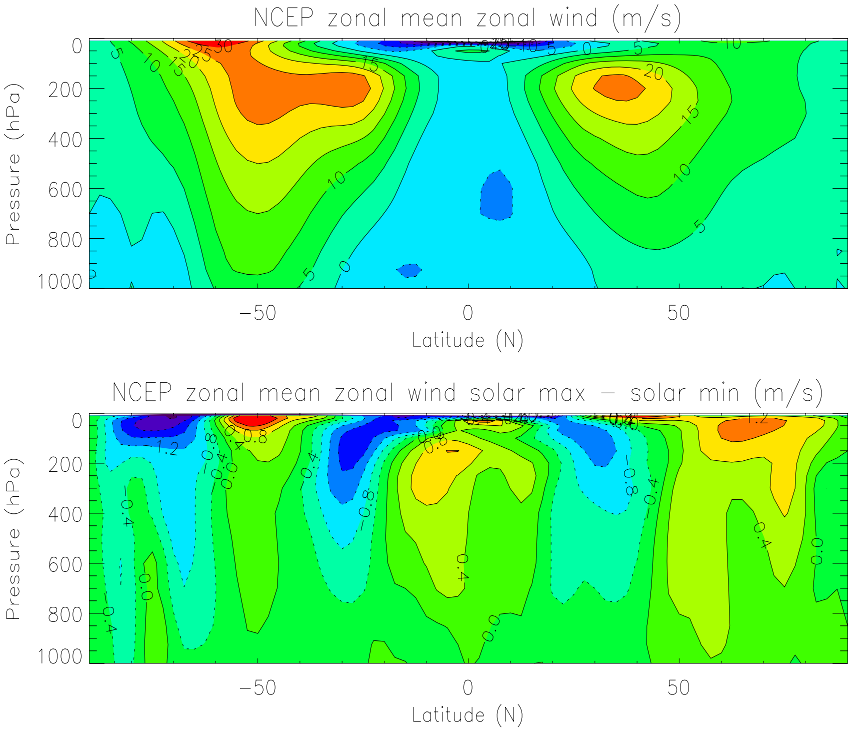
Egorova et al, GRL, 2004

Models suggest UV-ozone interaction origin of stratospheric signal, but currently do not correctly capture ozone variability.

Multiple regression analysis of NCEP data 1979-2002.

Upper panel: Mean
Lower panel: Solar Max-Solar Min

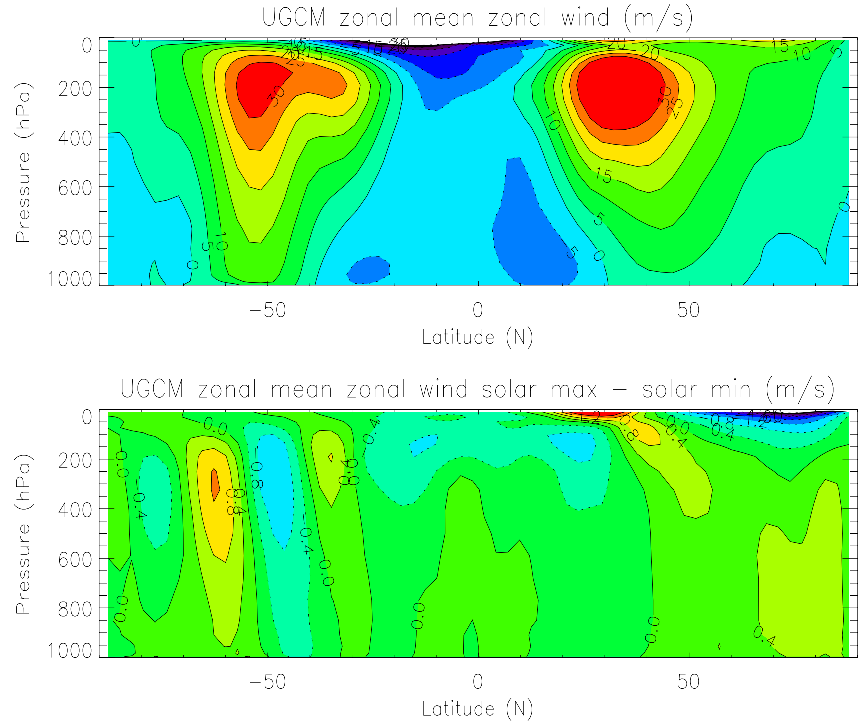
(Haigh, *J. Clim.*, 2005)



GCM simulation including changes in UV and Ozone.

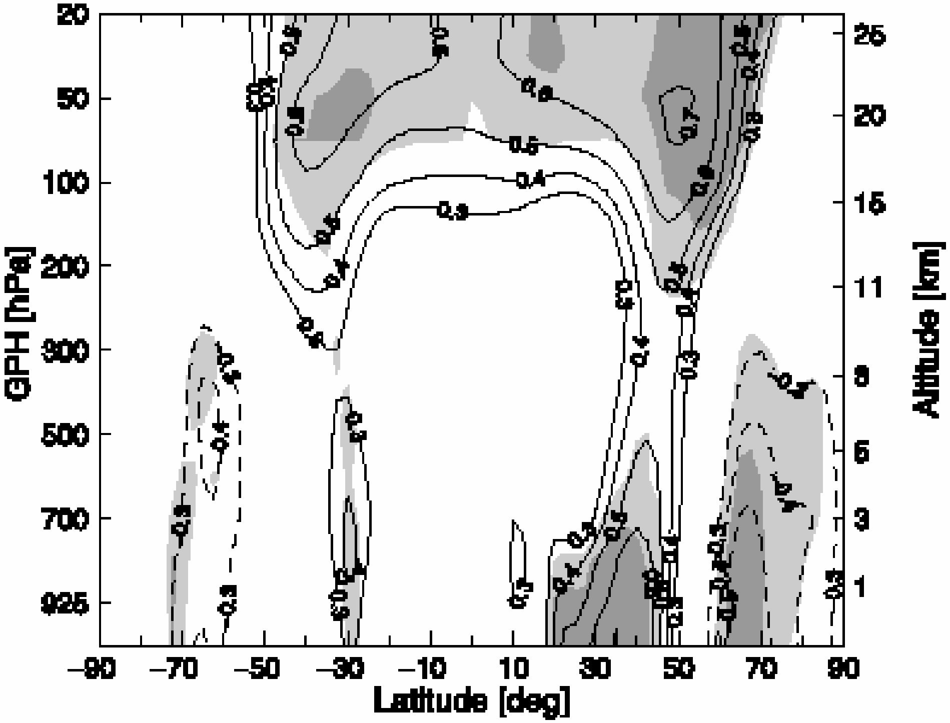
Upper panel: Control run
Lower panel: Solar Max-Solar Min

(Haigh, *Science*, 1996)



2) Amplification of Solar Variability: Solar Wind

SW Electric Field vs Geopotential Height



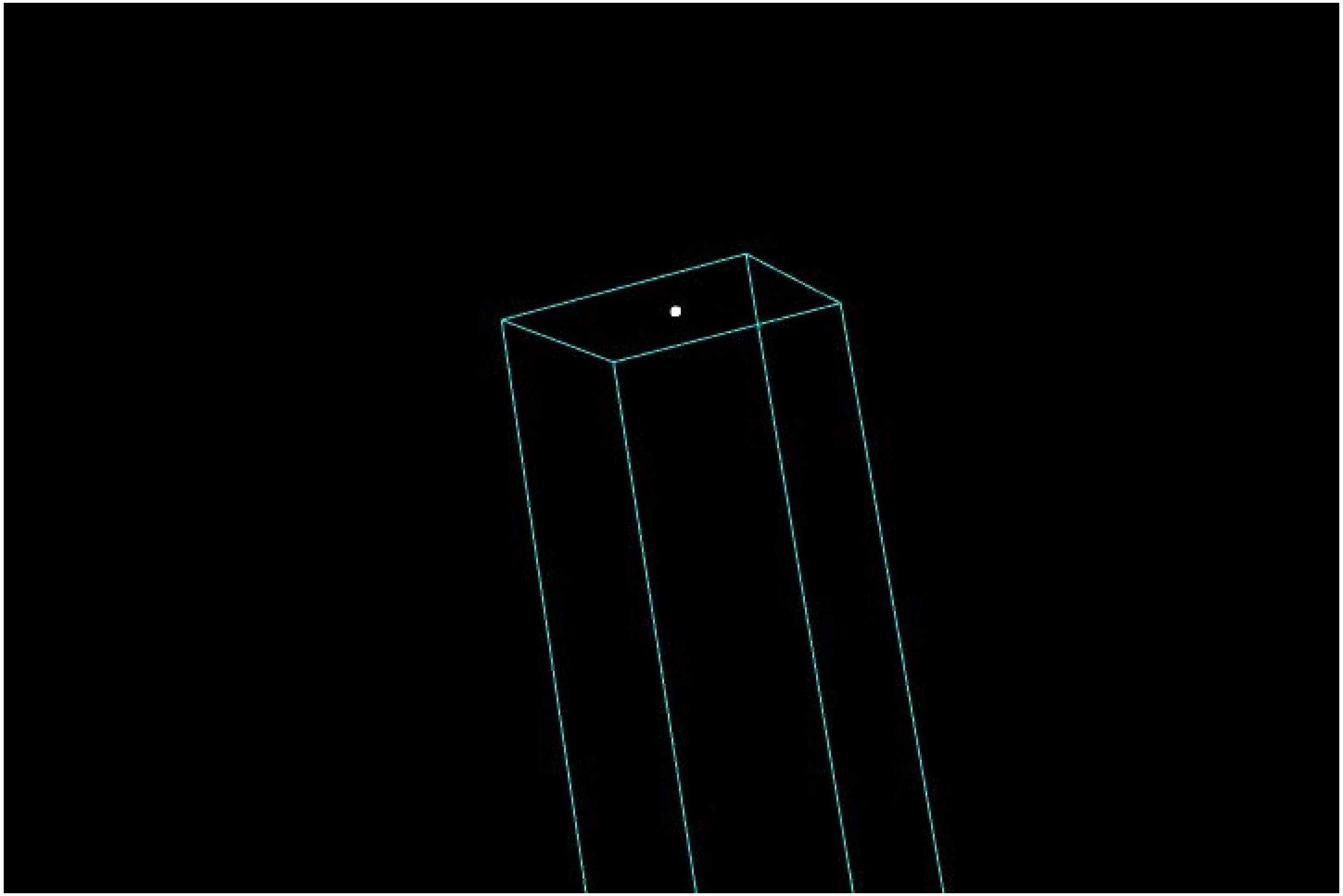
Boberg and Lundstedt, 2003

SW heats lower thermosphere and drives ionospheric currents, and the resulting disturbance dynamically propogates downwards.

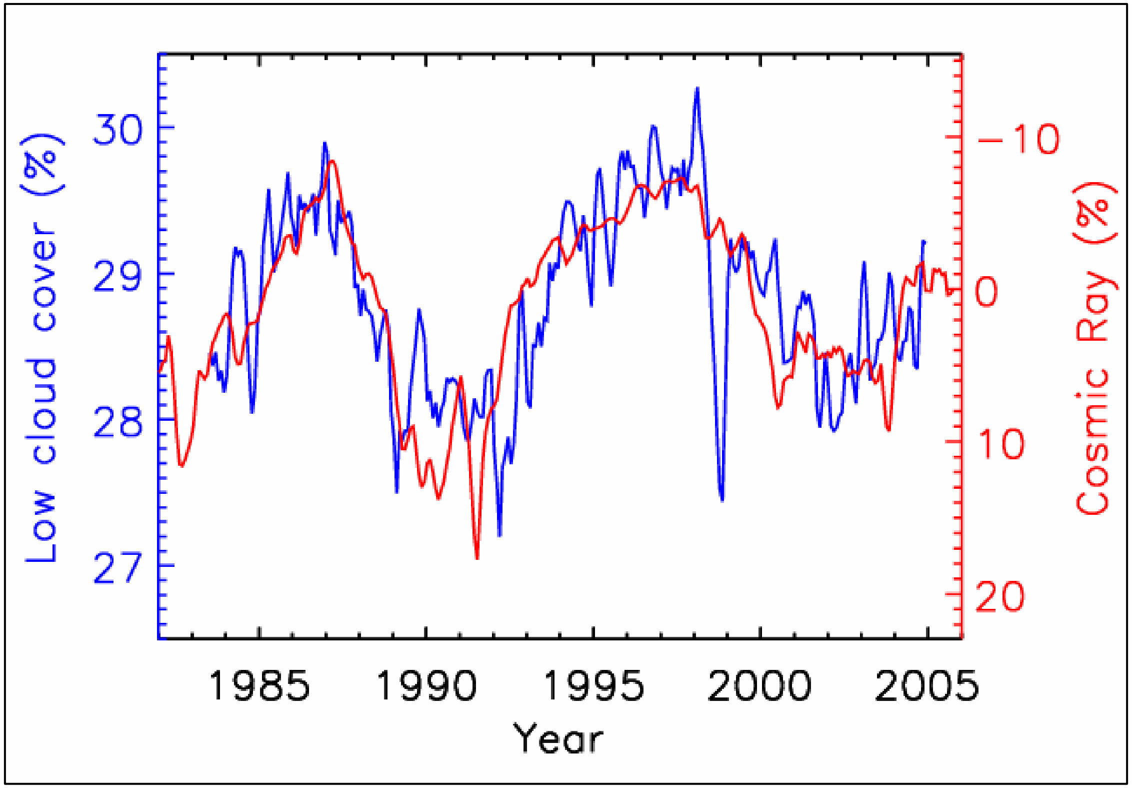
Model studies suggest that the stratospheric response to SW variablity could be comparable to Ultraviolet-ozone responses.

Arnold and Robinson, 1998, 2001.

3) Amplification of Solar Activity: GCR Flux.



Link between Low Cloud Cover and Galactic Cosmic Rays?



Low Cloud Cover vs GCR.
Marsh and Svensmark, PRL, 2000.

How do clouds affect the transparency of the atmosphere?

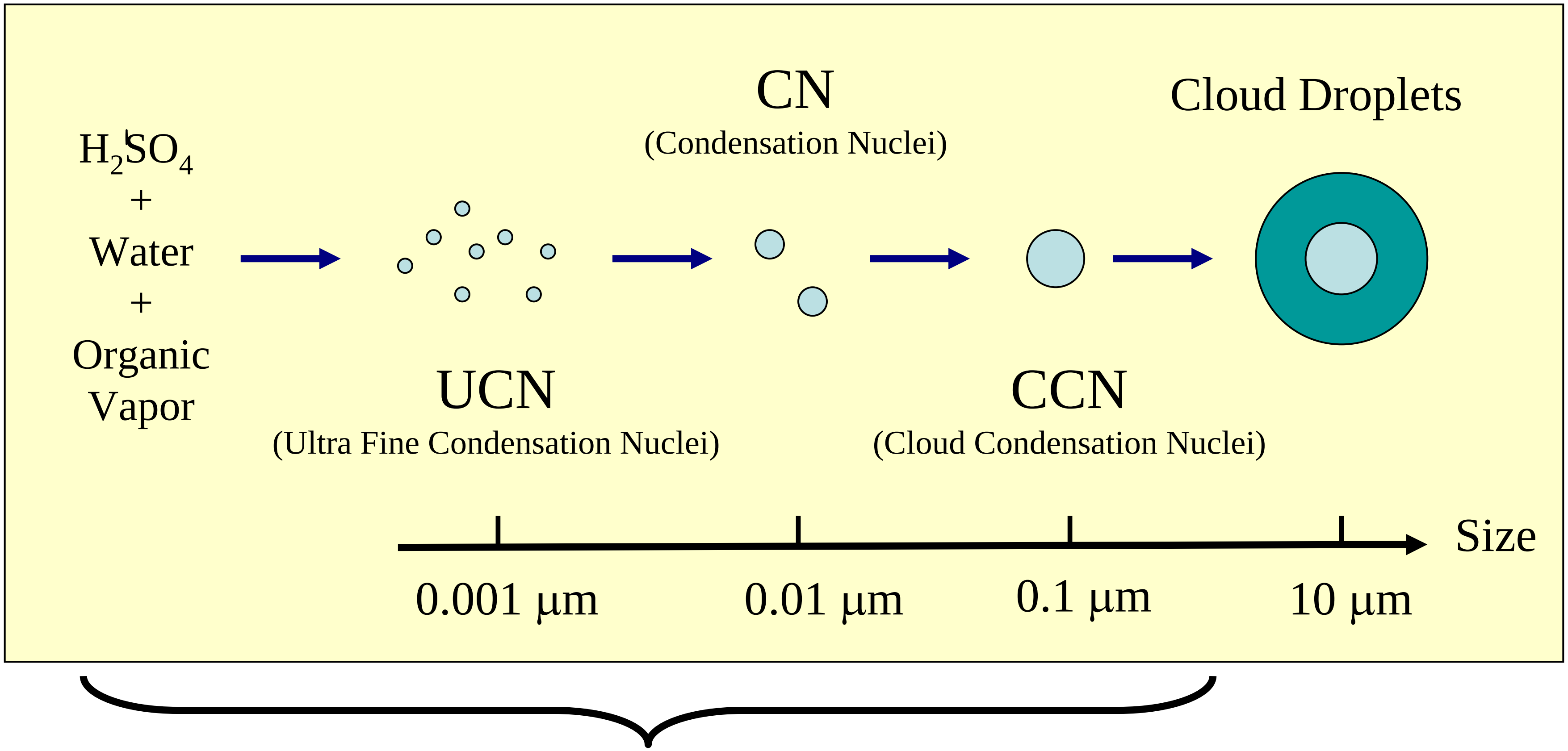
- Trap outgoing Long Wave radiation
- Reflect incoming Short Wave radiation.

More CR=More low clouds
Less CR=Less low clouds

Radiative Properties of Clouds

	High Clouds		Middle Clouds		Low Clouds	Total
	Thin	Thick	Thin	Thick	All	
Global Fraction %	10.1	8.6	10.7	7.3	26.6	**63.3**
Net Cloud Forcing Wm^{-2}	2.4	-7.0	1.1	-7.5	-16.7	**-27.7**

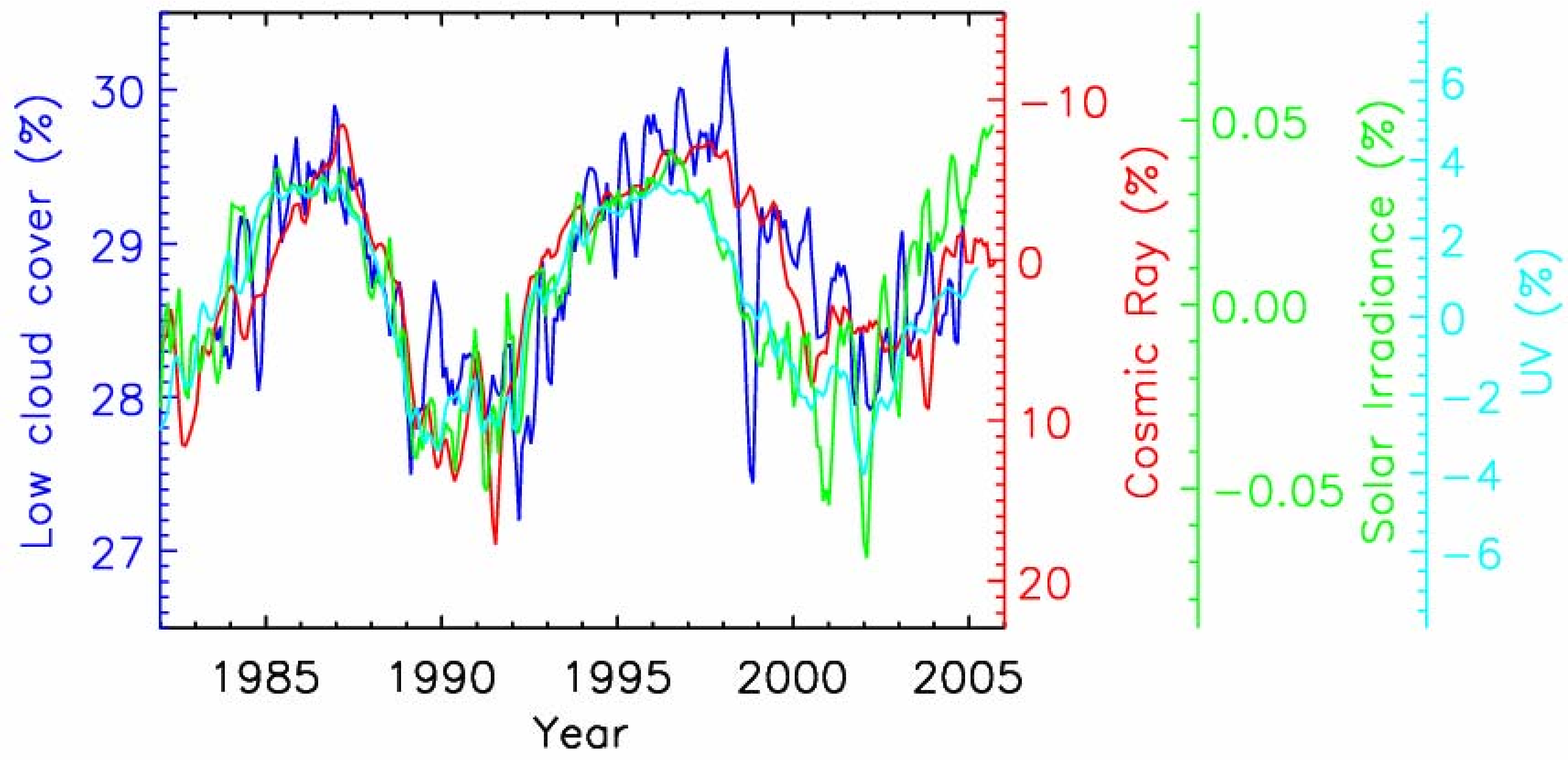
Aerosol formation and growth



Role of Ionisation?

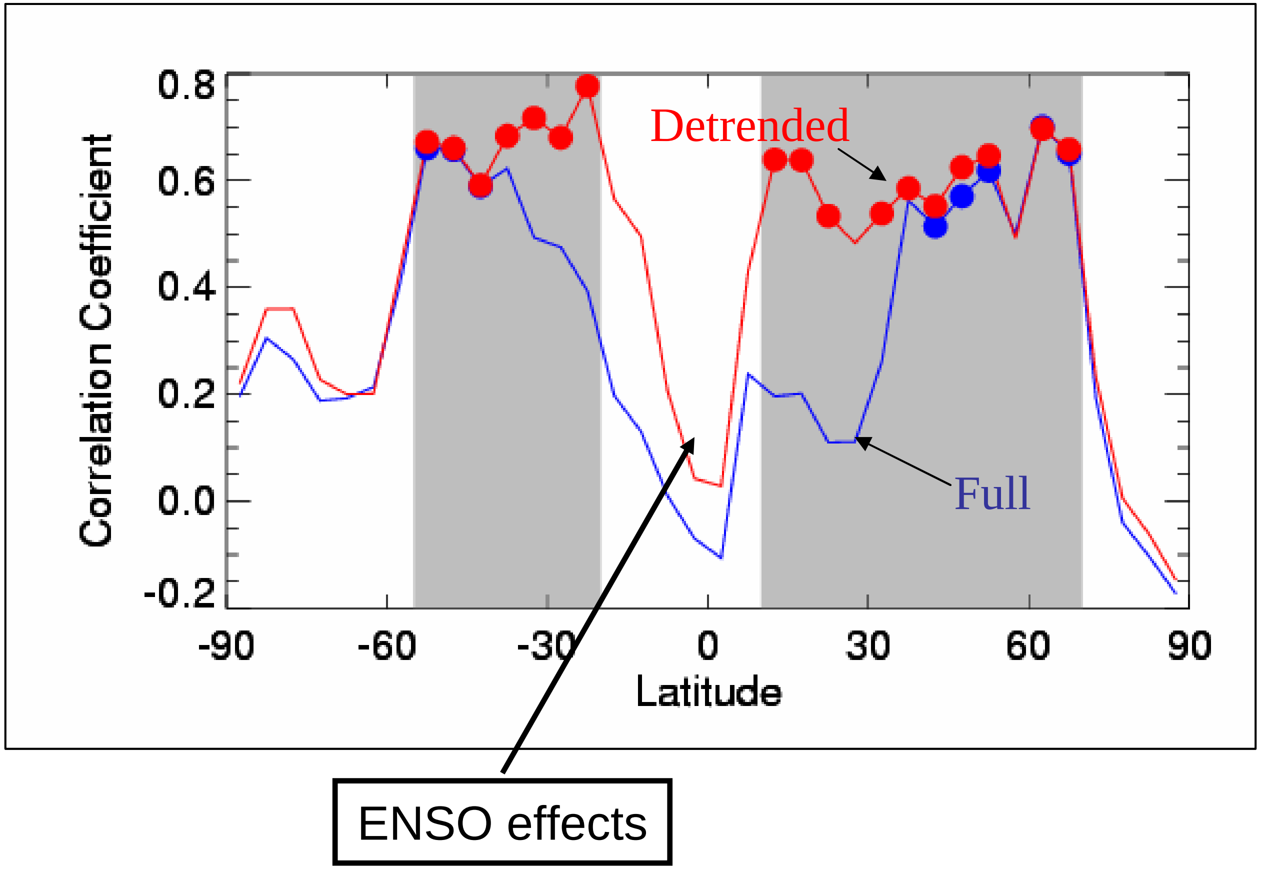
Experiments currently in progress at DNSC!

Low cloud cover vs cosmic rays



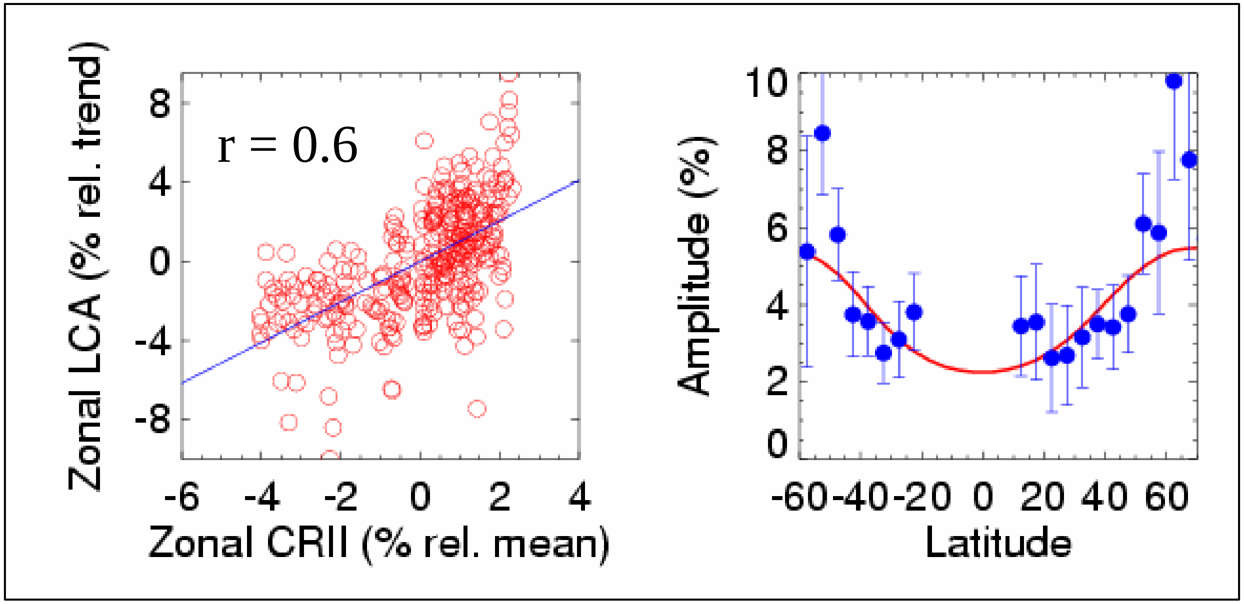
Marsh and Svensmark, JGR, 2003 (update 2005)

Correlation coefficients between zonal averages of Low cloud cover and Ion concentrations for 1984-2000.



Latitudinal dependence between Low cloud cover (LCC) and Cosmic Ray Induce Ion concentration (CRII).

Scatter of zonal ave.



Amplitude of 10yr sinusoid

Linear Model:

$$\Delta LCC = (1.02 \pm 0.08)\Delta CRII$$

Usoskin, Marsh, Kovaltsov, Mursula, and Gladysheva, GRL, 2004.

Summary

- Observations indicate solar variability influences Tropospheric climate.
- Amplification of solar variability required.
- Amplification mechanisms have been proposed involving Solar UV, Solar Wind, and Cosmic Rays.
- No one mechanism has been identified as dominant, it is possible that more than one mechanism operates simultaneously.