Solar Influence on Climate in Observation and IPCC Models

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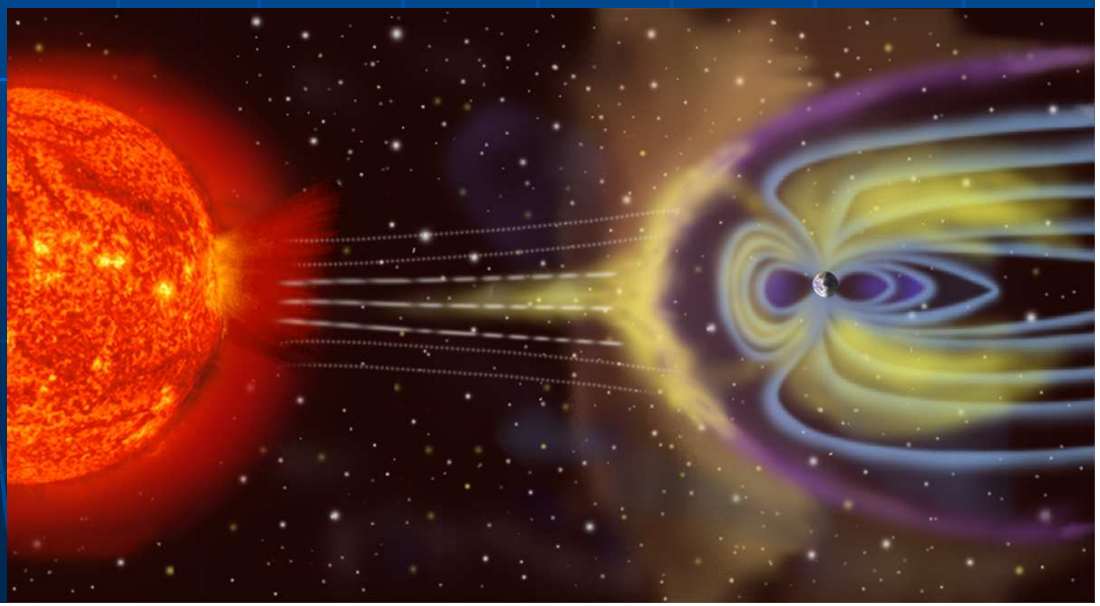
"*Possible changes in the sun's influence on climate remains one of the most commonly raised objections to global warming attribution and projections*."

Gray *et al*, 2005



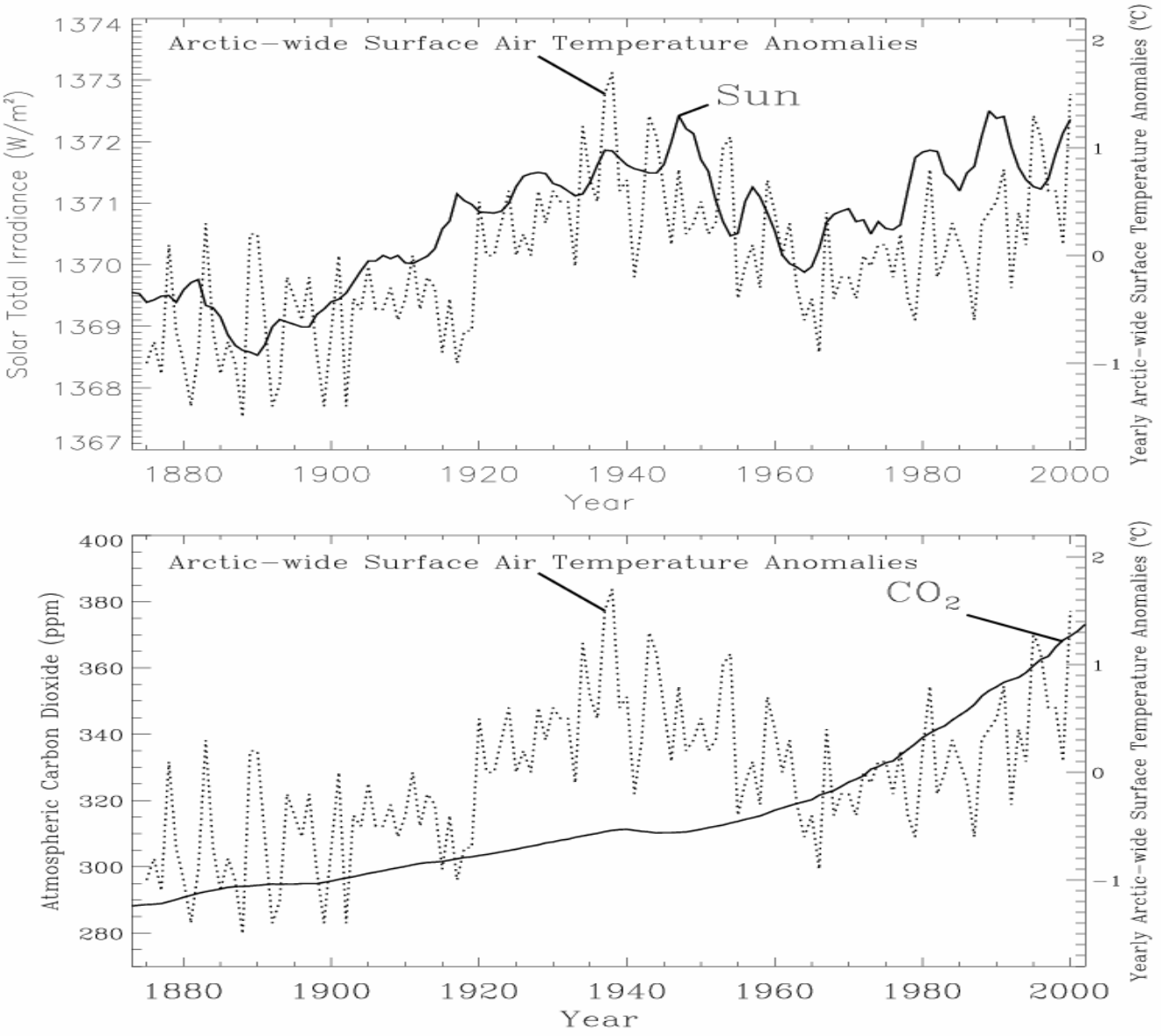
References can be found on my Website:
http://www.amath.washington.edu

The truth about global warming
it's the Sun that's to blame.
The Telegraph, UK

Hoyt and Schatten in *The Role Of the Sun in Climate Change* p84: “We favor the viewpoint that solar activity has been increasing in this century in a way that appears to fit the global temperature record, a fit that is perhaps better than the variation in carbon dioxide.”

Soon (2005):

"Solar forcing explains well over 75% of the variance for the decadally-smoothed Arctic annual-mean or spring SATs."



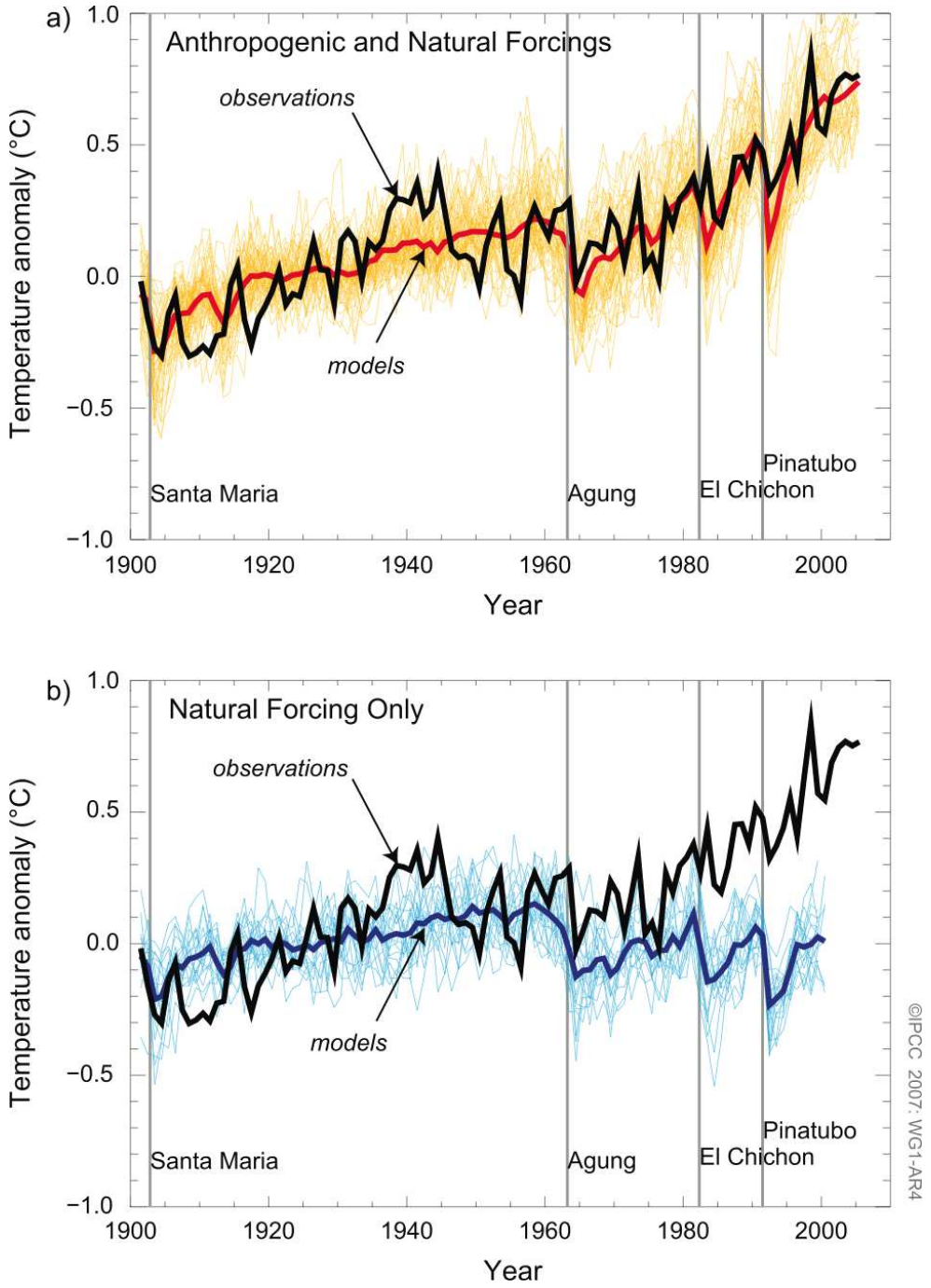

a)
Anthropogenic and Natural Forcings
observations
models
Temperature anomaly (°C)
1.0
0.5
0.0
−0.5
−1.0
Santa Maria
Agung
El Chichon
Pinatubo
1900
1920
1940
1960
1980
2000
Year
b)
Natural Forcing Only
observations
models
Temperature anomaly (°C)
1.0
0.5
0.0
−0.5
−1.0
Santa Maria
Agung
El Chichon
Pinatubo
1900
1920
1940
1960
1980
2000
Year
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Figure TS.23

IPCC AR4 Conclusions (excerpts)

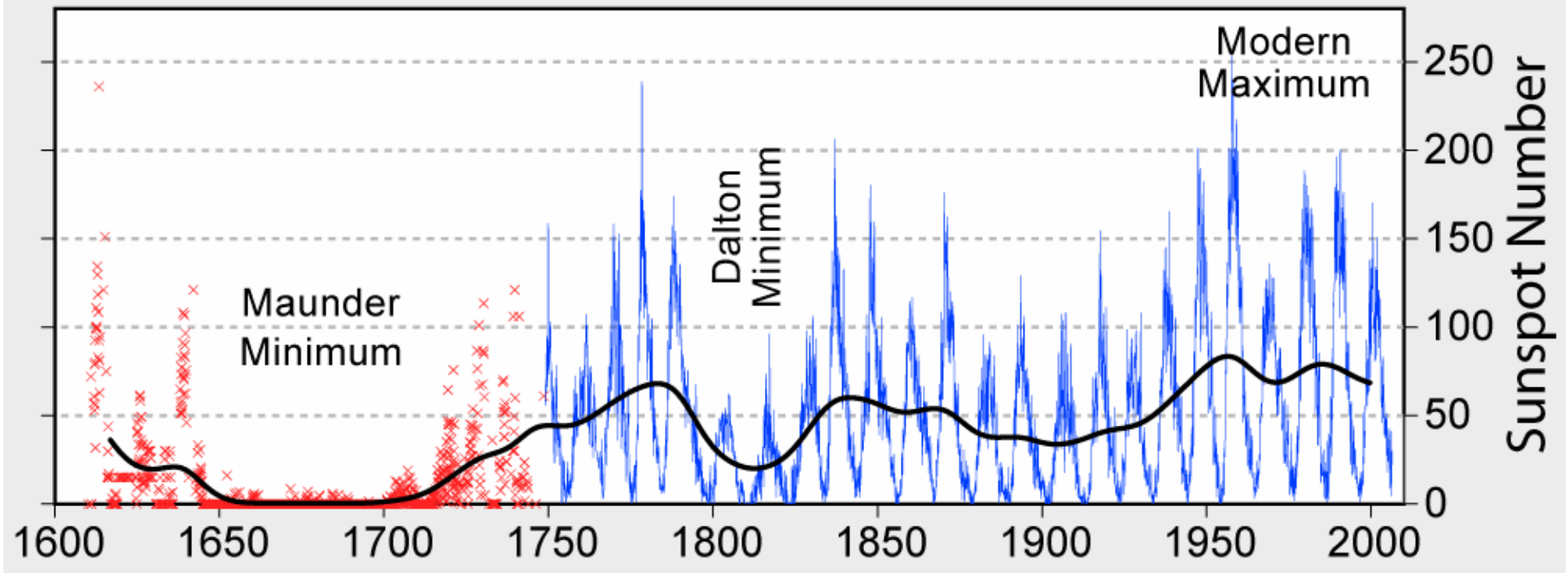
1. "Warming of the climate system is unequivocal."

2. "Most of the observed increased in globally-averaged temperature since the mid 20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations."

3. "Analysis of models together with constraints from observations suggest that the equilibrium climate sensitivity is *likely* to be in the range of 2 C to 4.5 C… It is *very unlikely* to be less than 1.5 C"

4. "The estimated direct radiative forcing due to changes in solar output since 1750 is +0.12[0.06 to 0.3] Wm^{-2}, which is less than half of the estimate given in the TAR, with a low level of scientific understanding."

400 Years of Sunspot Observations



Little Ice Age

Past reports of solar-weather connection

- Pittock (1978) reviewed many such reports. None can be shown to be real.

- 1600s, cold temperatures were associated with sunspots.
- 1676, Robert Hook arrived at opposite conclusion.
- 1801, Sir William Herschel noted that high wheat prices occur when sunspots are few, and concluded that lower solar activity means less light and therefore less wheat….
- 1870s, 20 papers on rainfall: when sunspots are numerous, rainfall is more plentiful, and vice versa.
- 1882, Balfour Stewart noted an 11-year cycle in Nile River flow.
- 1889, D. E. Hutchins claimed an 11-year solar cycle in African droughts
- 1987, Robert Currie examined drought records from China, North America and South America, and found 118 locations (61% of those examined) had 10-11 year cycles….

- Hoyt and Schatten (1997): "…the field nearly died. After this brief hiatus, a steady increase in the number of sun/climate studies has appeared in the twentieth century. Unfortunately, none of these new studies is definitive in either proving or disproving the sun/climate connection."

Reasons for the past difficulties with observational analysis and modeling of solar-cycle response

- Regional vs global response
- Lack of statistical tests
- Using energy-balance models and get weak response (0.03-0.06 K)
- Using General Circulation Models (GCMs) with fixed sea-surface temperature (SST) and get weak response
- Still thinking that the mechanism is through stratosphere ozone-UV interaction, or is more exotic (cosmic rays, atmospheric electricity, etc). This thinking affects the design of model experiments.

Turns out that IPCC AR4 coupled atmosphere-ocean GCMs are adequate for studying solar cycle-climate interaction, even though they do not have much of a stratosphere or interactive ozone. They incorporate climate feedback processes such as water-vapor, albedo and cloud feedbacks.

Mechanisms

- In the most recent review of Gray, Haigh and Harrison (2005), a three-page long table of various mechanisms were listed, involving e.g. ozone UV absorption in the stratosphere affecting the troposphere or cosmic rays affecting clouds or atmospheric electricity and storms.
- None could be shown to work, to yield a detectable signal at the surface, although no one tried putting them all together in a model.
- It nevertheless succeeded in giving the modelers an inferiority complex, since their GCMs do not have a credible stratosphere or cosmic ray forcing, and “so” they couldn’t possibly produce solar-cycle response…..

Aspect	Comments
DIRECT TSI CHANGES	
Spatially inhomogeneous heating of the surface, due to variations in cloud cover, produces horizontal temperature gradients which feedback on cloudiness through changes in circulation.	Contentious. One GCM experiment purports to show this.
DIRECT UV EFFECTS	
Irradiance changes are not uniformly distributed across the EM spectrum. Changes in UV (of a few percent) will lead to a response in stratospheric ozone and hence temperature	Well established. Temp and ozone signals confirmed in in-situ and satellite data analyses. However, disagreement in details of the observed signals needs resolving.
INDIRECT UV EFFFECT THROUGH MIDDLE ATMOSPHERE DYNAMICS	
Both direct TSI changes and indirect UV effects result in temperatures changes in equatorial upper stratosphere and hence corresponding stratospheric zonal wind anomalies. This influences winter hemisphere planetary wave propagation.	Not contentious. Recent analyses have confirmed anomalies in zonal wind and EP-fluxes in both winter hemispheres.
Changes in stratospheric planetary wave propagation in winter influence frequency of stratospheric sudden warmings and thus transfer solar signal from upper equatorial stratosphere to winter polar lower stratosphere.	Not contentious, although there is strong interaction with QBO influence which complicates extraction of solar signal in polar winter latitudes. Recent progress in understanding details of planetary wave sensitivity has enabled models to reproduce the observed solar cycle / QBO interaction.
Changes in planetary wave activity associated with changes in sudden warming frequency also cause changes in global meridional circulation strength. This is a mechanism for solar cycle influence to reach equatorial lower stratosphere and summer hemisphere.	Probable. Changes in lower stratospheric temperature, ozone and zonal winds that are consistent with this hypothesis are observed in the data but models are unable to reproduce the amplitude of these observed changes.
Changes in stratospheric temperature and circulation penetrate downwards into the troposphere.	Possible. Some observational evidence, and models reproduce some features, but details of the mechanism unclear. Possibilities include: affecting propagation of stationary planetary waves; affecting growth of internally generated long waves; modifying baroclinic lifecycles.

ATMOSPHERIC ION PRODUCTION	
Cosmic ray ionisation is ubiquitous throughout the atmosphere and provides a source of ions, modulated by cosmic rays.	Well established. Cosmic rays lead to ionisation and, above the continental boundary layer are the principal source of tropospheric small ions. The cosmic ionisation rate depends on latitude (increasing towards the poles) and increases with altitude.
Variations in the solar wind modulate the cosmic ray flux in antiphase with the sunspot number	Not contentious. Neutron fluxes, ion production rates and air conductivity have been observed to vary inversely with the solar cycle.
Cosmic ray and solar proton ionisation penetrate the troposphere at mid and high latitudes.	Not contentious. Cosmic rays are the major source of ions at the surface in marine air. Solar proton events reach the surface.
ION-AEROSOL-CLOUD PHYSICS	
Ions provide a source of atmospheric condensation nuclei (CN).	Not contentious. Laboratory and atmospheric measurements show ultrafine particles (CN) can be formed from ions. Variations in the trace condensable species and aerosol vapour removal control the efficiency of the conversion, which will lead to spatial changes in the process.
Ions provide a source of Cloud Condensation Nuclei (CCN).	Probable. Detailed microphysical models show that particles large enough to act as cloud condensation nuclei can grow from ion-induced ultrafine aerosol production on the timescale of hours. There will usually, however, be competing effects, so the fraction of new aerosol that ultimately grow to CCN sizes is uncertain, but is likely to be small.
Electrification of aerosol increases its effectiveness as Ice Nuclei (IN)	Possible. Limited laboratory evidence suggests that charging alters the ice nucleation efficiency of aerosol, but there is no atmospheric experimental evidence. Theory, however, shows electrically enhanced aerosol scavenging increases the acquisition of contact ice nuclei by supercooled droplets. Only a small fraction of atmospheric aerosol is able to act as IN, depending on temperature.
Cosmic ray ionisation variations lead to variations in aerosol and water droplet	Probable. Atmospheric aerosol undergoes charge exchange through ion-aerosol

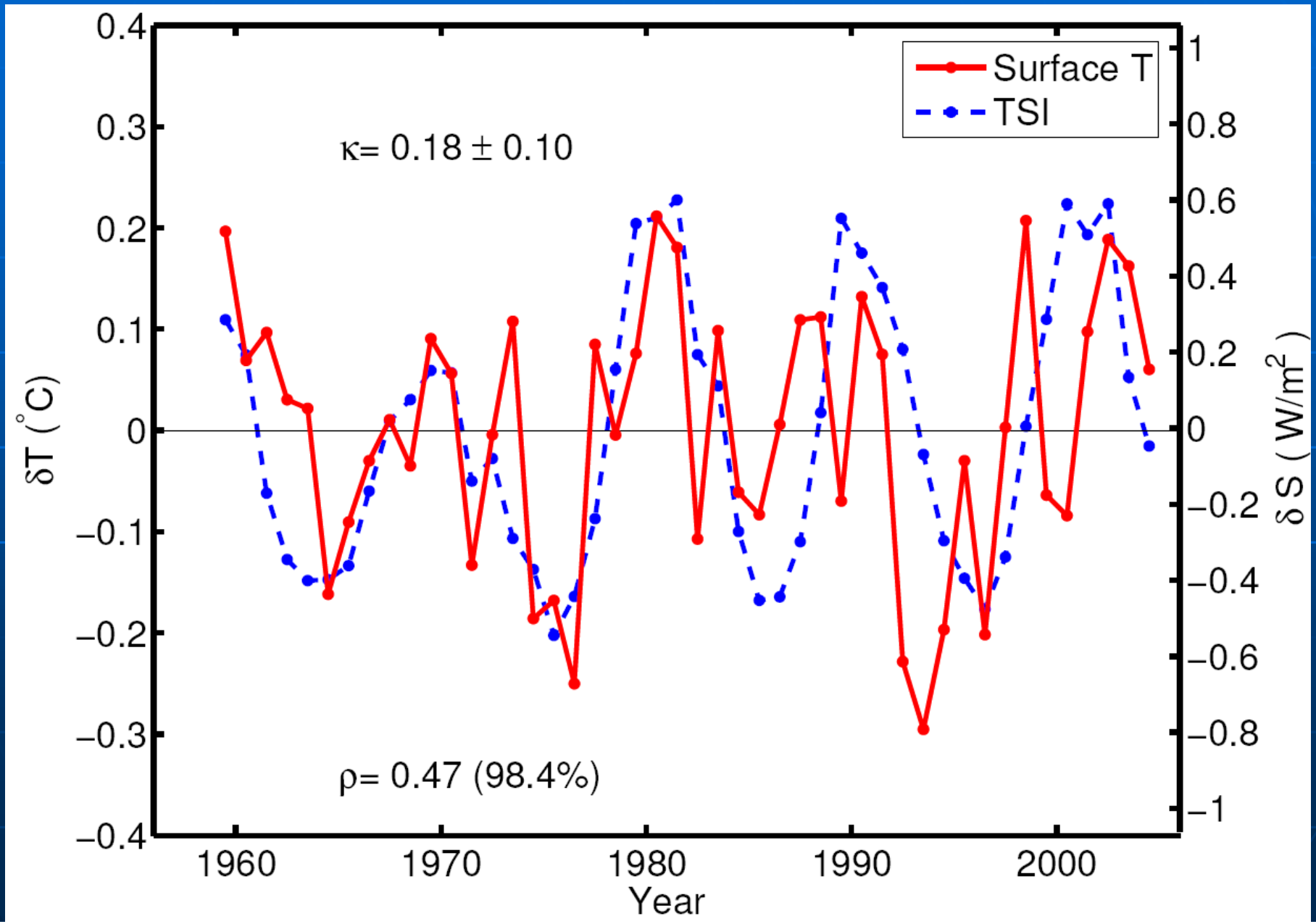
electrification	collisions and charged atmospheric aerosol particles are observed. Variations in the magnitude of aerosol charge on layer boundaries through which the conduction current J_z passes are expected from theory and have been observed.
Aerosol electrification modifies coagulation and scavenging rates.	Not contentious. Theory indicates coagulation rates are modified by charging, but this depends on aerosol charge distributions. Charge distributions depend on ion asymmetry; charging timescales depend on ion concentrations. Theory also shows that aerosol scavenging rates are strongly sensitive to aerosol charge.
CCN changes modify cloud properties, cloud lifetimes and precipitation.	Not contentious. Reducing uncertainties in understanding the effects of aerosol changes on clouds (the *aerosol indirect effect*) is a major area of active climate research.
Cosmic rays significantly modulate liquid water clouds.	Possible. Quantitative evidence is lacking.
SOLAR VARIABILITY EFFECTS ON CLOUDS	
Solar modulation of global clouds, through production of CCN from cosmic ray ionisation, has been observed.	Contentious. A significant positive correlation between cosmic rays and cloud cover has been obtained from ISCCP satellite cloud data over 1983-1994. If a correction is accepted to the satellite data, the correlation continues to 2001. Different suggestions have been made to explain spatial pattern of the correlation, some of which do not require CCN production from cosmic rays.
Solar-induced changes in ionisation will influence freezing in *all* clouds.	Unlikely. The variability in atmospheric clouds and aerosol is such that it cannot be predicted which clouds will be affected by electrofreezing. It seems likely that only a subset will be affected
A solar influence on electrofreezing intensifies cyclone development and modifies storm tracks, through the changes in cloud temperature and latent heat release.	Contentious. Modification of cyclones is highly selective, depending on where and at what stage in the cyclone's development the latent heat is released. The magnitude, and even sign, of any effect must be regarded as very uncertain

Direct TSI Changes	Comments
Spatially inhomogeneous heating of the surface, due to variations in cloud cover, produces horizontal temperature gradients which feedback on cloudiness through changes in circulation.	Contentious. One GCM experiment purports to show this
Direct UV Effects	
Changes in UV (of a few percent) will lead to a response in stratospheric ozone and hence temperature.	Well established.
Indirect UV Effect through Middle Atmosphere Dynamics	
Both direct TSI changes and indirect UV effects result in temperature changes in equatorial upper stratospheric zonal wind anomalies. This influences winter planetary wave propagation. Changes in stratospheric planetary wave propagation in winter influence frequency of stratospheric sudden warmings and thus transfer solar signal from upper equatorial stratosphere to winter polar lower stratosphere. Changes in planetary wave activity associated with changes in sudden warming frequency also cause changes in global meridional circulation strength. This is a mechanism for solar cycle influence to reach equatorial lower stratosphere and summer hemisphere.	Not contentious. Recent analyses have confirmed anomalies in zonal wind and EP-fluxes in both winter hemispheres
Changes in stratospheric temperature and circulation penetrate downwards into the troposphere.	Possible.

Find clues from observation

- Coughlin and Tung (2004): EMD on NCEP data
- Camp and Tung (2007):CMD on NCEP data
- Tung and Camp (2008): LDA on NCEP and ERA-40 data
- Tung, Zhou and Camp (2008): CMD and LDA on NCEP, ERA-40, GISS, HadCRUT3, NCDC.

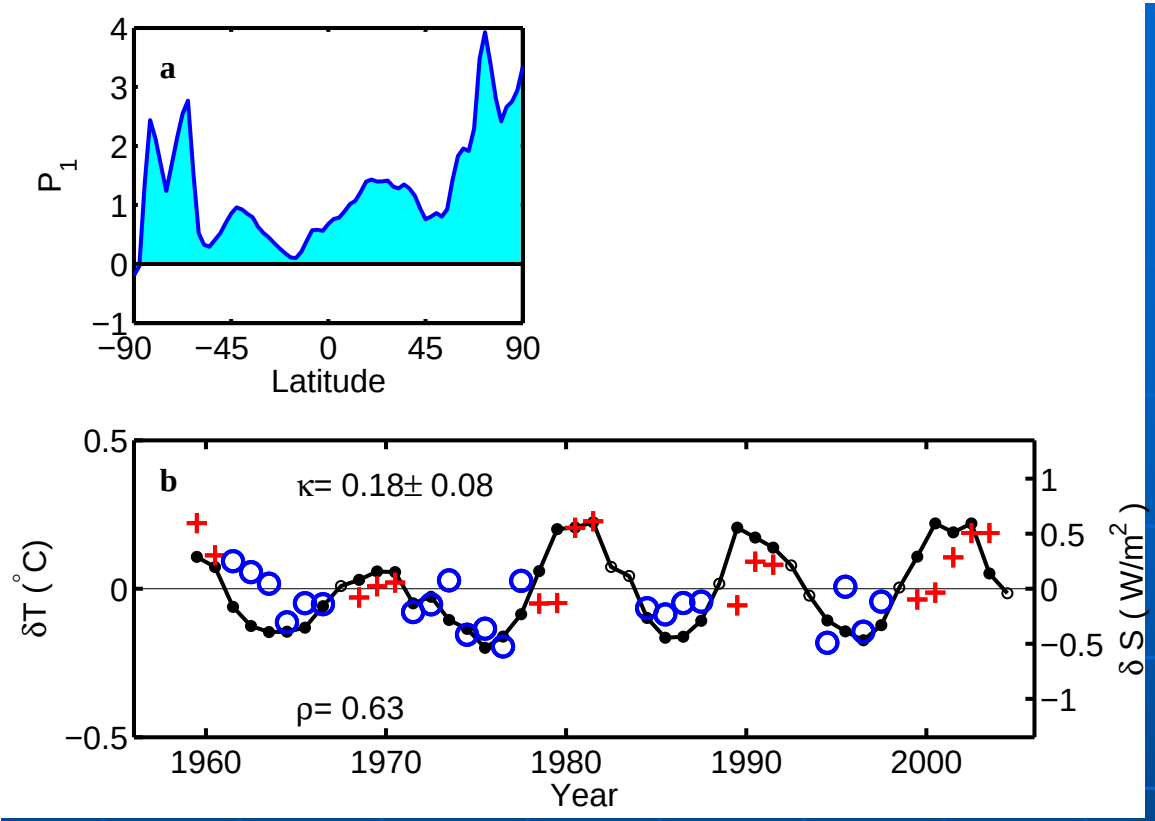
---:global mean, annual mean surface temp



Spatial-time analysis—taking advantage of the spatial pattern associated with the solar cycle response

- CMD Projection method; Camp and Tung (2007, GRL): Objectively determine the spatial pattern by composite mean difference of the solar max years and solar min years; then project the original data onto this spatial pattern to obtain a time series. The resulting correlation coefficient is tested with Monte-Carlo simulation.

- LDA analysis; Schneider and Held (2001, J. Climate), Tung and Camp (2008, JGR). Find the optimal spatial weights that best separate the solar max years from solar min years, as measured by the separation index *R*, which is the ratio of variance between solar groups vs variance within each solar group. More difficult to understand but yields almost the same spatial pattern. The signal is much cleaner, with less than half the error bars.

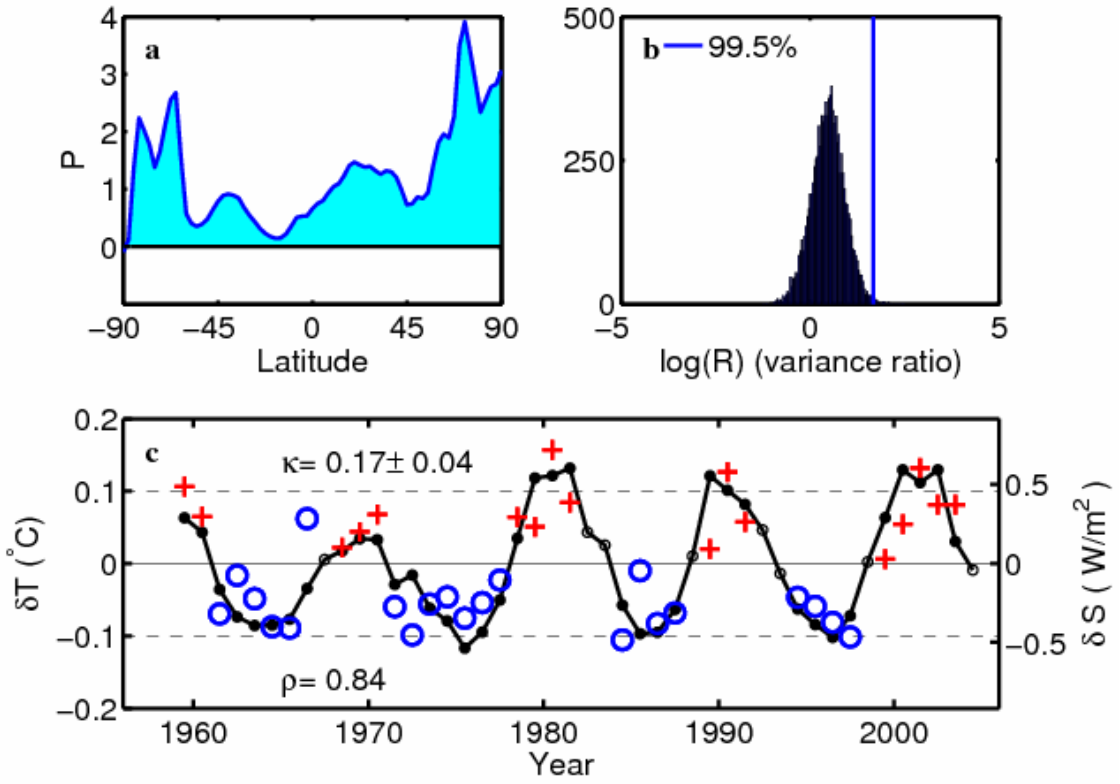


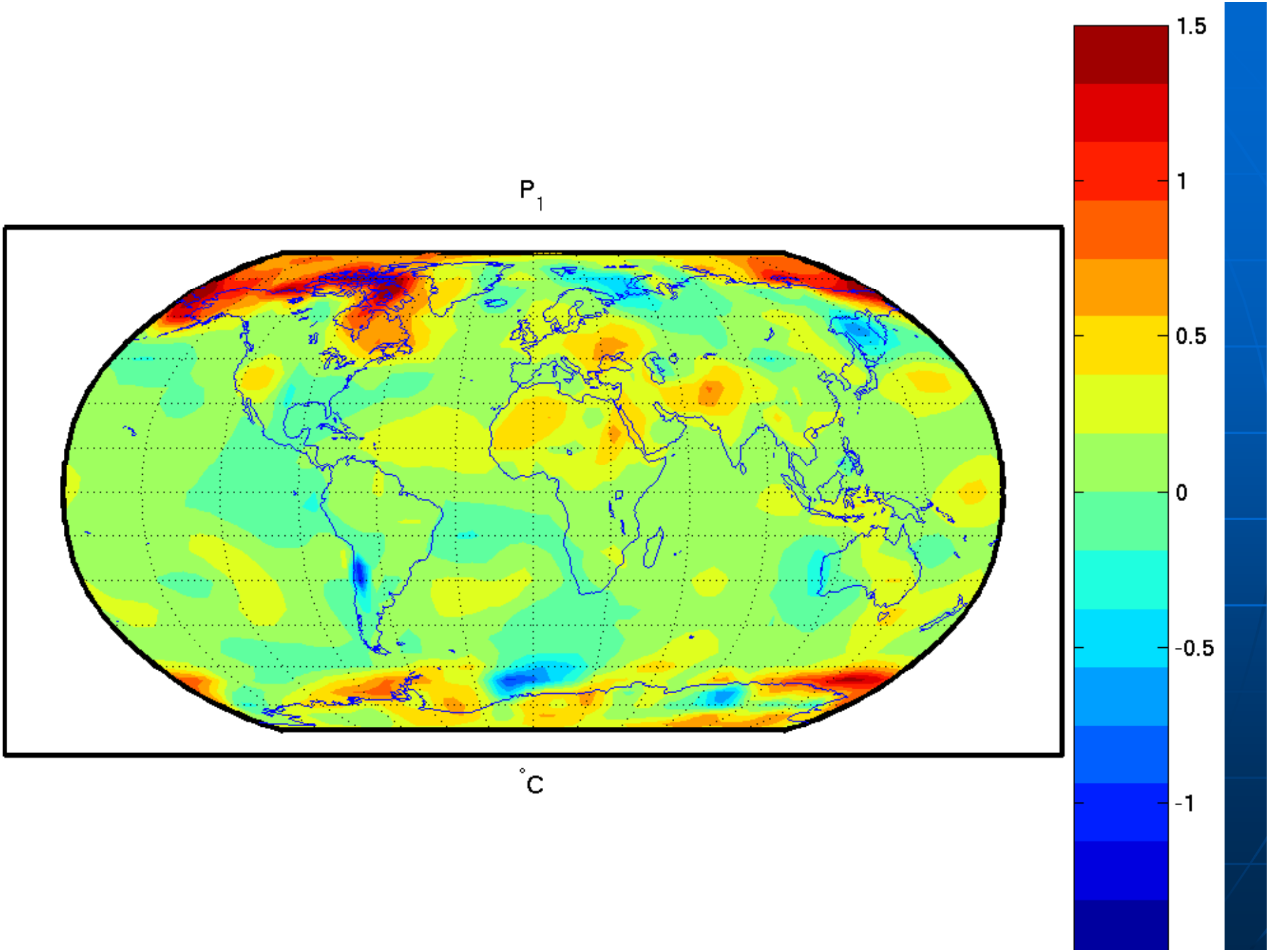
(a) The zonal mean, annual mean spatial pattern obtained by subtracting the mean of the solar min years from the solar max years. Projecting the original time series onto the spatial pattern yields the time-dependent index shown in (b).

LDA method (due to Schneider and Held (2001) in its present form) finds the best spatial pattern that separates solar max years from solar min years

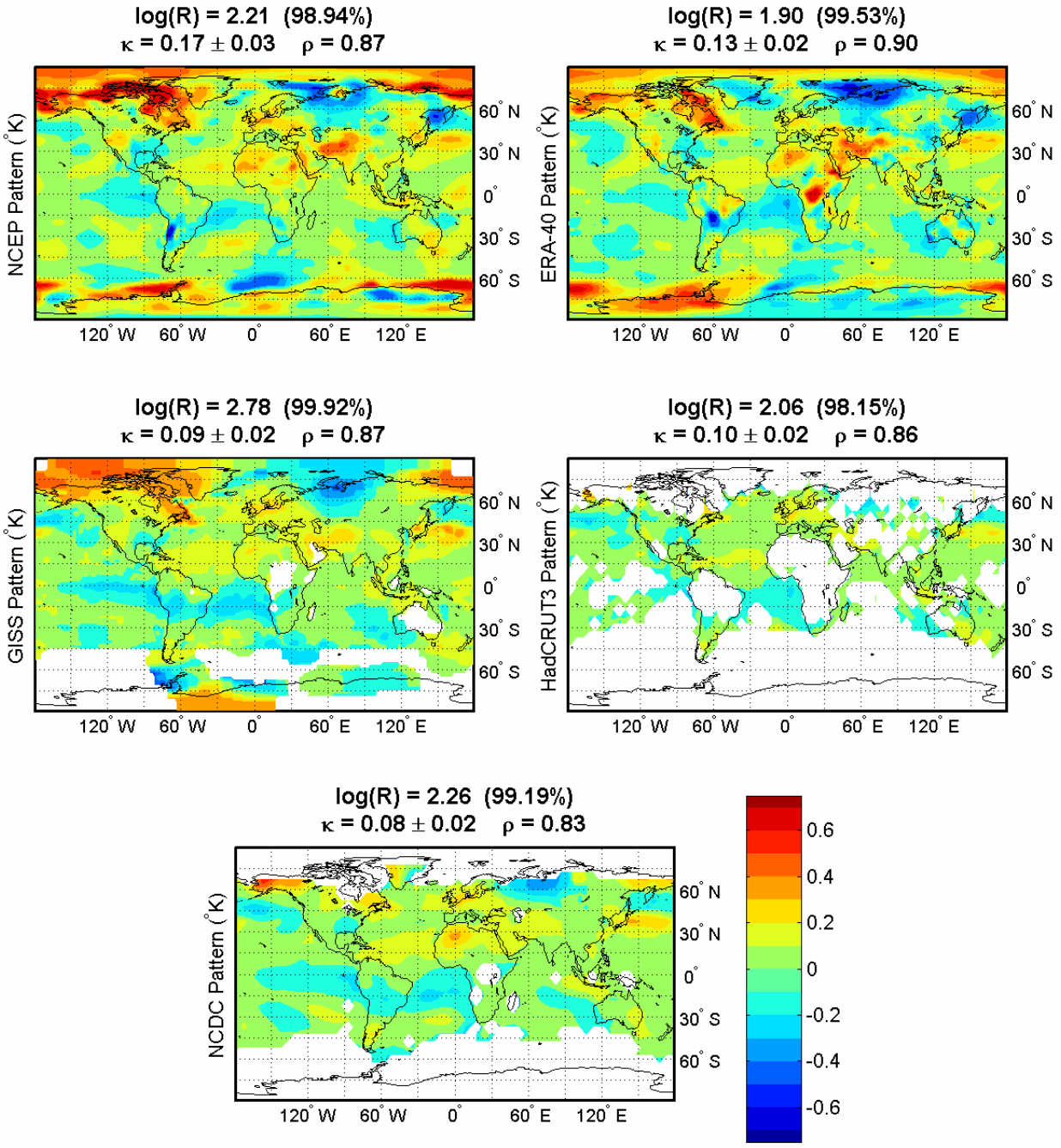
Polar amplification of warming → Surface air temp.

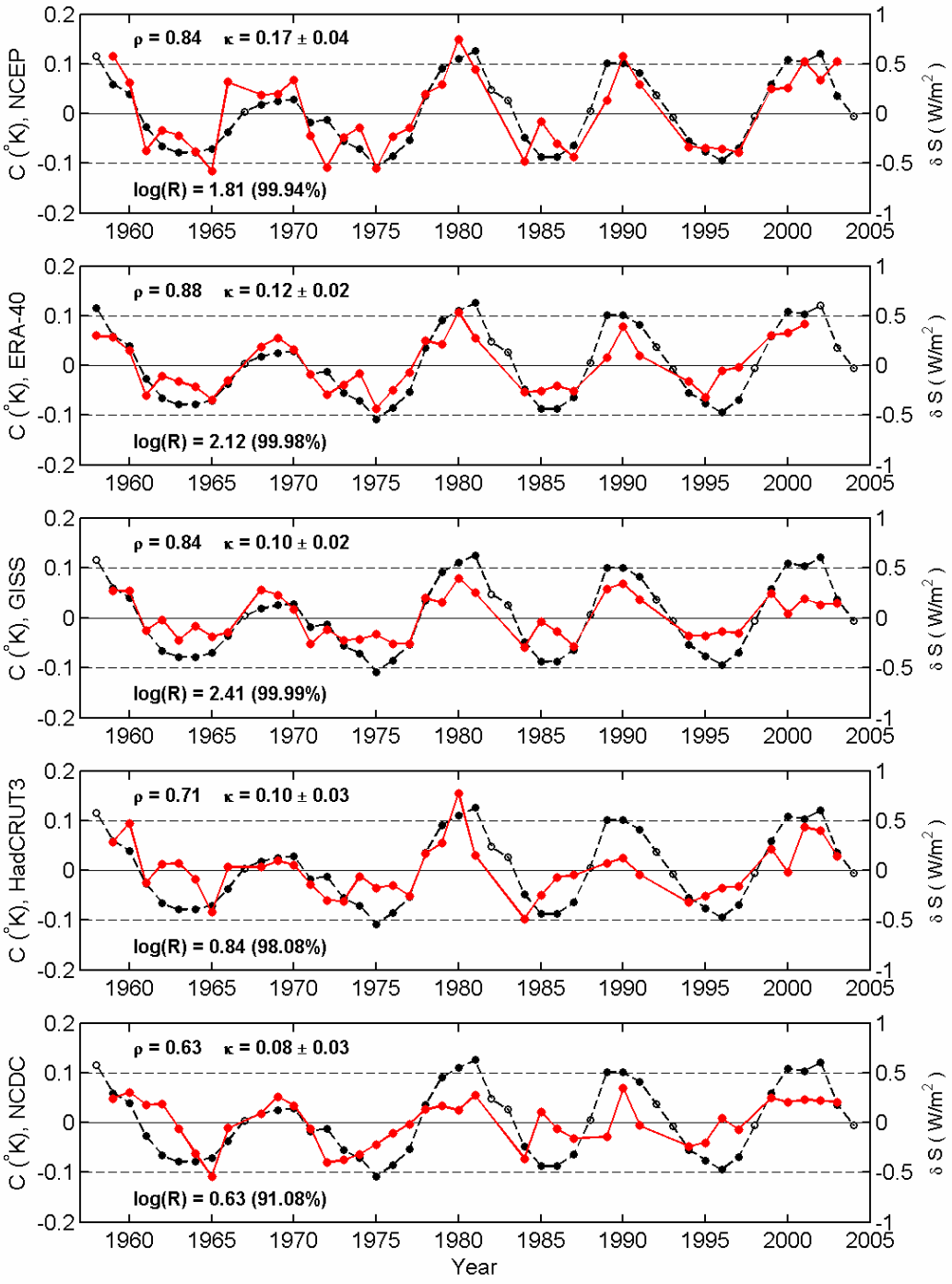
Global mean warming δT~0.2 K →
Correlation coef: 0.84



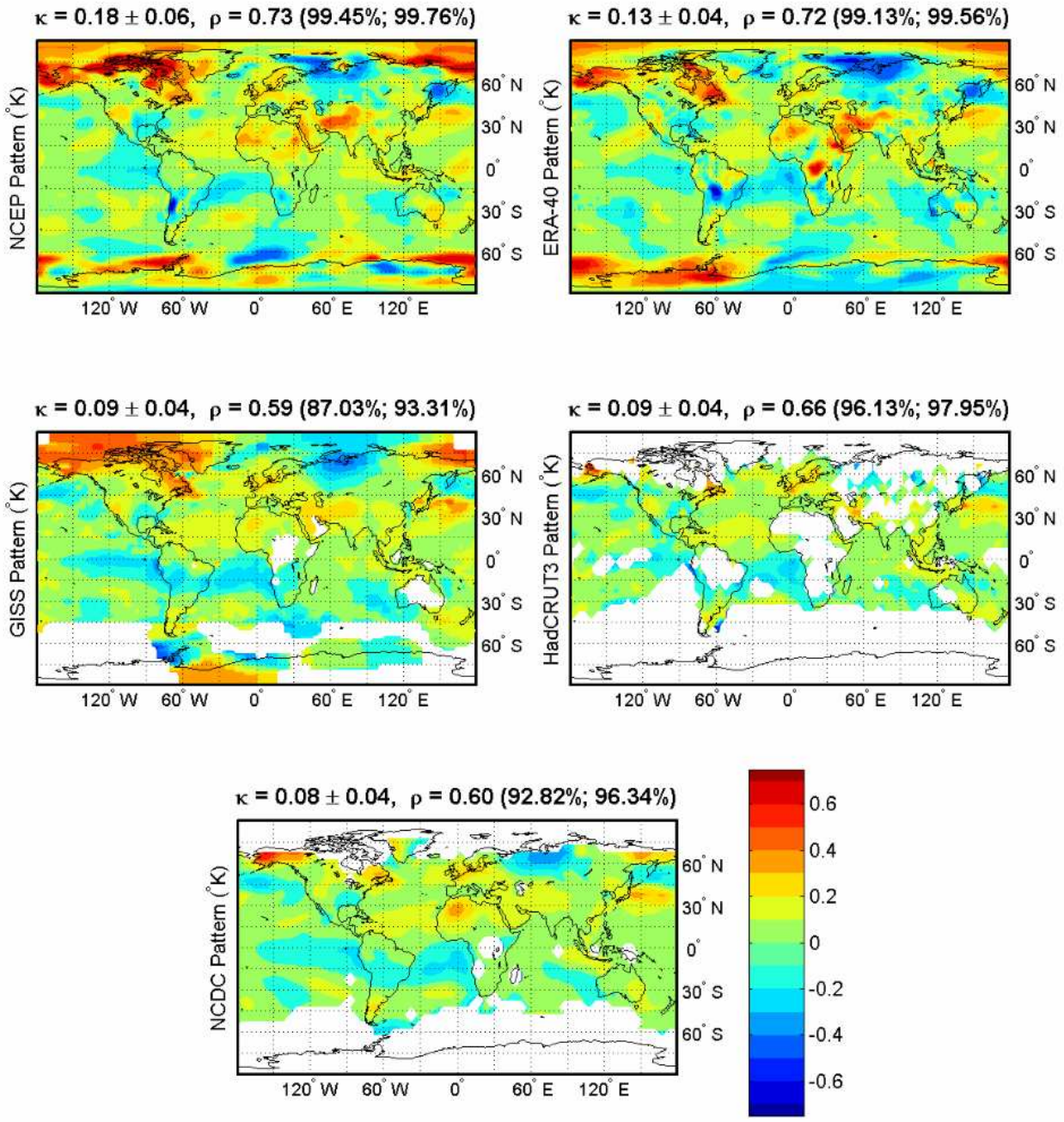

P1
1.5
1
0.5
0
-0.5
-1
°C

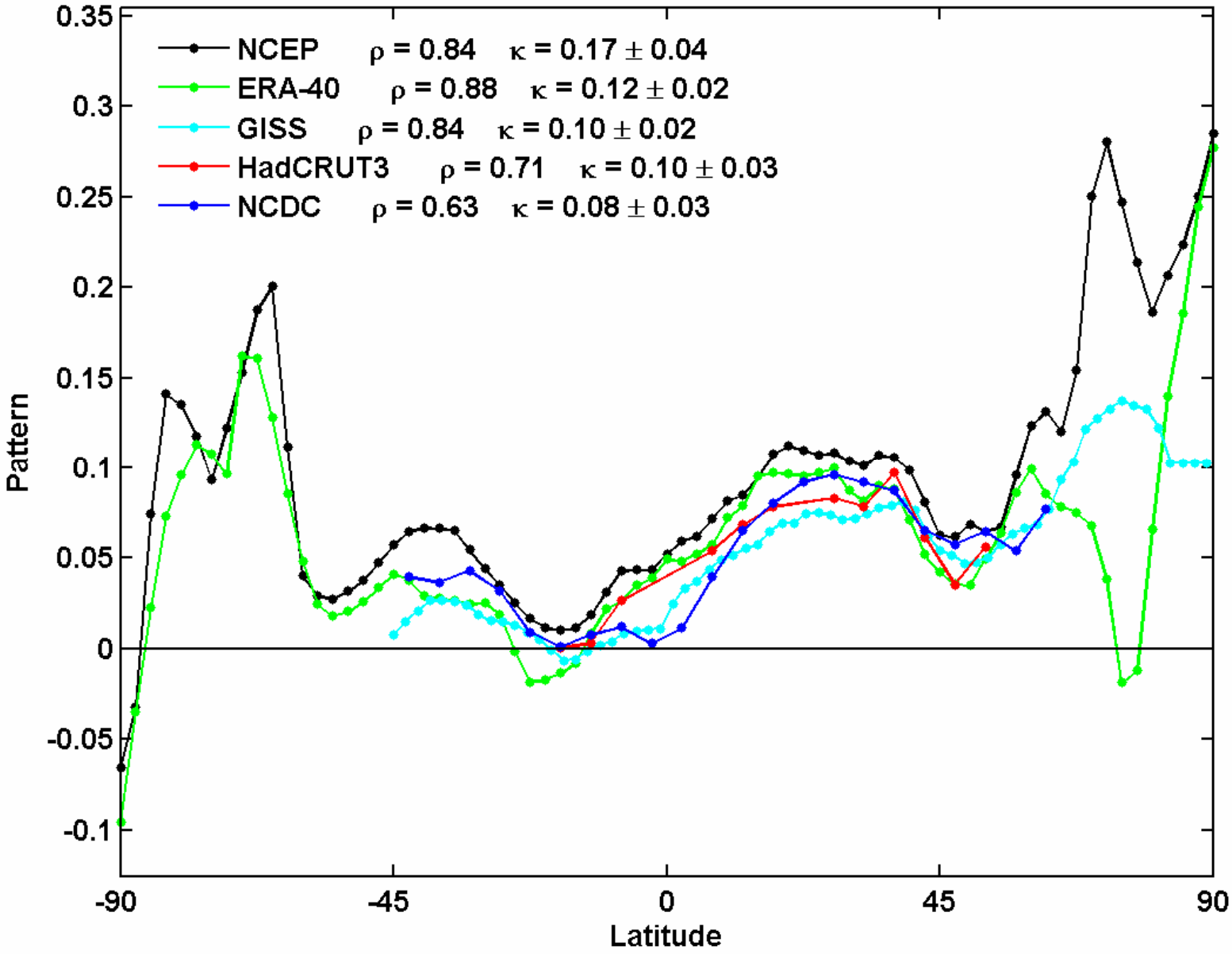
LDA Spatial Pattern




ρ = 0.84 κ = 0.17 ± 0.04
log(R) = 1.81 (99.94%)
C (°K), NCEP
ρ = 0.88 κ = 0.12 ± 0.02
log(R) = 2.12 (99.98%)
C (°K), ERA-40
ρ = 0.84 κ = 0.10 ± 0.02
log(R) = 2.41 (99.99%)
C (°K), GISS
ρ = 0.71 κ = 0.10 ± 0.03
log(R) = 0.84 (98.08%)
C (°K), HadCRUT3
ρ = 0.63 κ = 0.08 ± 0.03
log(R) = 0.63 (91.08%)
C (°K), NCDC
δ S (W/m2)
Year
1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
0.2 0.1 0 -0.1 -0.2
1 0.5 0 -0.5 -1

Composite Mean Difference between solar max years and solar min years for NCEP, ERA-40, GISS, HadCRUT3, NCDC




NCEP ρ = 0.84 κ = 0.17 ± 0.04
ERA-40 ρ = 0.88 κ = 0.12 ± 0.02
GISS ρ = 0.84 κ = 0.10 ± 0.02
HadCRUT3 ρ = 0.71 κ = 0.10 ± 0.03
NCDC ρ = 0.63 κ = 0.08 ± 0.03
Pattern
Latitude
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-90
-45
0
45
90

Some numbers:

Total solar radiation varies by 0.08% from solar min to solar max, as detected by satellite at the top of the atmosphere. More at UV, uncertain at longer wavelengths.

A variation of the solar “constant” S
On 11-year time scale of about $\delta S \sim 1$ watts m^{-2} .
$\delta Q = \delta S/4 \sim 0.25$ watts m^{-2}.
30% of that is reflected back to space by clouds and snow and surface. Ozone in the stratosphere absorbs 15%, the remaining absorbed near the surface. Stratospheric warming due to ozone absorption also warms the troposphere through downward long-wave flux.

Net radiative forcing is ~0.18 watts m^{-2} (Larkin et al, 2000). Response is expected to be small. Can we detect it?

Hoyt and Schatten p99: “From an energy standpoint, a factor of at least 10 is missing in known solar variations that would produce the observed climate fluctuations. Many meteorologists and climatologists remain skeptical about whether solar activity variations are significant at all.”

"Back of envelope calculation"

for solar cycle forcing of RF=0.18 Wm^{-2} balancing RF by radiative cooling~$B\delta T$

$$\delta T : [\delta Q \cdot (1-\overline{\alpha}) / B] = RF / B : \ 0.18/1.9 : \ 0.1K$$

"Phenomenological Model":

$$\delta T : \ f[\delta Q \cdot (1-\overline{\alpha}) / B] : \ f\,0.1K.$$

Where does the climate gain factor f come from?

Time-dependent Held & Suares climate model with dynamical transport (annually averaged)

$$C\frac{\partial}{\partial t}T = Qs(y)(1-\alpha(y)) - (A+BT) + \nabla \bullet (Heat\ Fluxes)$$

where

C = heat capacity of the lower atmosphere and upper few meters of ocean

$\equiv B\tau$.

Global Average (overbar denotes global average except for α):

$$C\frac{\partial}{\partial t}\overline{T} = Q(1-\overline{\alpha}) - (A+B\overline{T}) - \frac{\partial}{\partial z}\overline{F_z},$$

$$where: \overline{\alpha} = \int_0^1 \alpha(y)s(y)dy.$$

Perturbation Equation

small perturbation, linear response

$Q = Q_0 + \delta Q.$

First variation

(Taylor expansion, B and α depend on T):

$$C \frac{\partial}{\partial t} \delta T = \delta Q (1 - \overline{\alpha}) - B \delta T (1 - g) - \frac{\partial}{\partial z} \delta F_z$$

$$g = ((- \frac{\partial A}{\partial T} - T \frac{\partial B}{\partial T} - Q \frac{\partial \overline{\alpha}}{\partial T}) / B)_0 = g_1 + g_2.$$

Climate gain factor: $f = 1/(1-g)$.

$$B \delta T = f \delta Q (1 - \overline{\alpha}) - fC \frac{\partial}{\partial t} \delta T - f \frac{\partial}{\partial z} \delta F_z.$$

At equilibrium, last two terms drop out, and

$$\delta T = f \frac{\delta Q (1 - \overline{\alpha})}{B}.$$

For doubling CO_2: $\delta T : f \frac{3.7}{1.9} \sim f\, 2.0$ K.

Feedback processes

- g_1: water-vapor feedback: more water vapor in the upper troposphere more greenhouse effect.
- $g_{2.}$ ice-snow albedo feedback: less ice/snow cover, lower albedo, earth absorbs more heat.
- cloud feedback: more convection more clouds, traps more heat or reflects more to space. Has effect in both *g*'s.
- These feedback processes are well-known and intensely studied in global warming research, but often neglected in solar response research.

For the 11-year solar cycle, the heat flux into the ocean is diffusive and does not reach the main thermocline (White et al, 1997);the mixed layer thus appears to be semi-infinite. Ocean response to solar cycle :

$\delta T(z) = \delta T(0)\exp\{-\mu z\}$, z increasing with ocean depth.

$$\delta F_z = CD\frac{\partial}{\partial z}\delta T,$$

where D~1.0 cm^2 / s, typical ocean diffusivity.

So the energy balance is (dropping overbars):

$$B\tau f\frac{\partial}{\partial t}\delta T = f\delta Q\cdot(1-\alpha) - B\delta T(1+fD\mu^2).$$

$\delta Q(t) = a\cos(\omega t)$:

$$\delta T = \left(\frac{a(1-\overline{\alpha})}{B}\right)\frac{\cos\omega(t-\Delta)}{\sqrt{1+\varepsilon^2}}\,\tilde{f},\quad \tilde{f} = \frac{f}{1+D\mu^2 f\tau}$$

$$= [\delta Q(t-\Delta)\cdot(1-\overline{\alpha})/B]\frac{\tilde{f}}{\sqrt{1+\varepsilon^2}} \approx [0.1K]\frac{\tilde{f}}{\sqrt{1+\varepsilon^2}},$$

$where: \varepsilon = \tilde{f}\omega\tau; \omega\Delta = \tan^{-1}(\varepsilon); \omega = 2\pi/11yr.$

Δ known from measured lag; this then yields ε.

$\Rightarrow$ $f \sim 3$ for a lag of one year.

Solar cycle and Global Warming

- Radiative forcing from solar-min to solar-max:

  ~0.18 watts m^{-2}.
- periodic warming ~0.18K
- Transient (periodic) climate sensitivity:

  $\lambda = \delta T/\delta RF \sim 1$ K/(Wm^{-2})

  Equilibrium:

  $\lambda = \delta T/\delta RF \sim 1.5$ K/(Wm^{-2})
- Radiative forcing for 2x CO_2~3.7 watts m^{-2},

20 times larger.

- Transient Climate Response (TCR) and Equi. Climate Sensitivity (ECS)

My estimate: ~3.7 K for TCR and ~6 K for ECS

Current model range:

2 K-4.5 K for ECS;

1.2 K-2.6 K for TCR.

Solar influence of climate change: Is it in the IPCC AR4 models?

Solar-cycle warming in IPCC models

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¶ Department of Physics, The Chinese University of Hong Kong, Shatin, Hong Kong
† Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA, USA
£ Science Team, NASA's Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

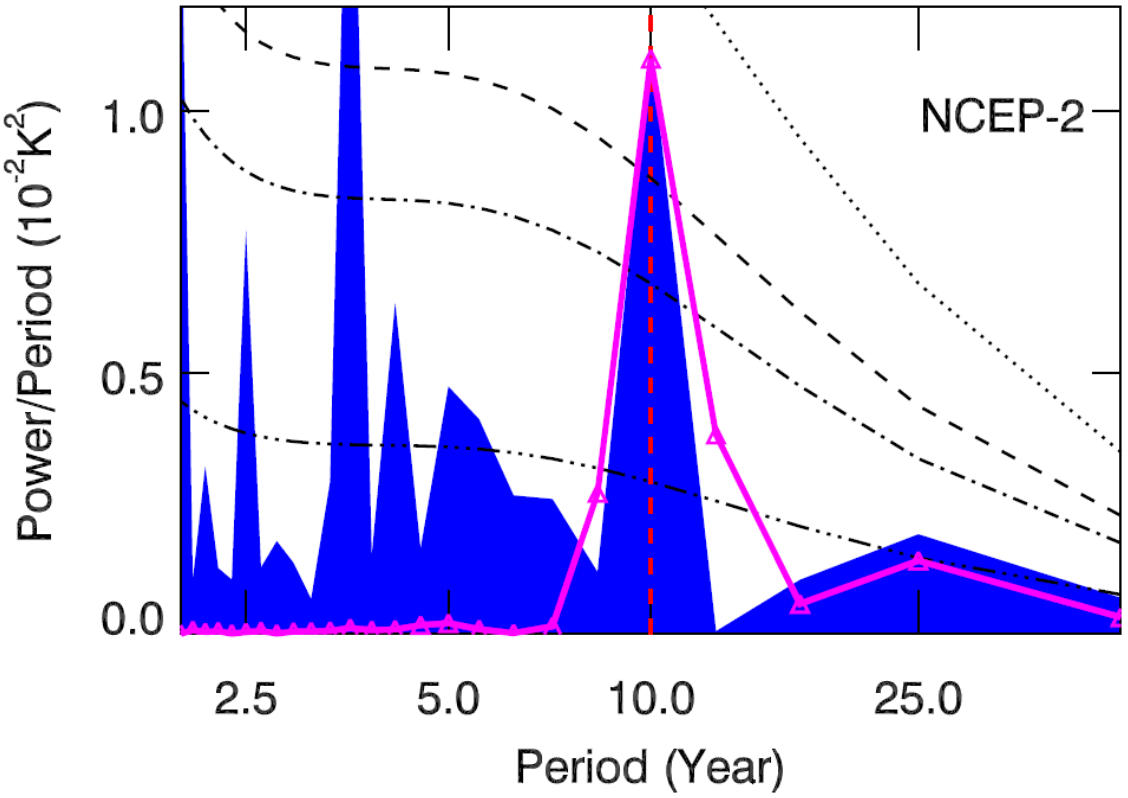
22 IPCC AR4 GCMs, 11 with solar forcing, 11 without solar forcing

	Model	G	O	SD	SI	BC	OC	MD	SS	LU	SO	VL	Members
1	CCSM3	O	O	O	--	O	O	--	--	--	O	O	8
2	GFDL-CM2.0	O	O	O	--	O	O	--	--	O	O	O	3
3	GFDL-CM2.1	O	O	O	--	O	O	--	--	O	O	O	3
4	GISS-EH	O	O	O	O	O	O	O	O	O	O	O	5
5	GISS-ER	O	O	O	O	O	O	O	O	O	O	O	9
6	INM-CM3.0	O	--	O	--	--	--	--	--	--	O	--	1
7	MIROC3.2(medres)	O	O	O	?	O	O	O	O	O	O	O	3
8	MIROC3.2(hires)	O	O	O	?	O	O	O	O	O	O	O	1
9	MIUB/ECHO-G	O	--	O	O	--	--	--	--	--	O	O	5
10	MRI-CGCM2.3.2	O	--	O	--	--	--	--	--	--	O	O	5
11	PCM	O	O	O	--	--	--	--	--	--	O	O	4
1	BCCR-BCM2.0	O	--	O	--	--	--	--	--	--	--	--	1
2	CCCma-CGCM3.1(T47)	O	--	O	--	--	--	--	--	--	--	--	5
3	CCCma-CGCM3.1(T63)	O	--	O	--	--	--	--	--	--	--	--	1
4	CNRM-CM3	O	O	O	--	O	--	--	--	--	--	--	1
5	CSIRO-Mk3.0	O	--	O	--	?	?	?	?	?	--	--	3
6	ECHAM5/MPI-OM	O	O	O	O	--	--	--	--	--	--	--	4
7	FGOALS-g1.0	O	--	O	?	--	--	--	--	--	--	--	3
8	GISS-AOM	O	--	O	--	--	--	--	O	--	--	--	2
9	IPSL-CM4	O	--	O	O	--	--	--	--	--	--	--	2
10	UKMO-HadGEM1	O	O	O	O	O	O	--	--	O	--	O	1
11	UKMO-HadCM3	O	O	O	O	--	--	--	--	--	--	--	2

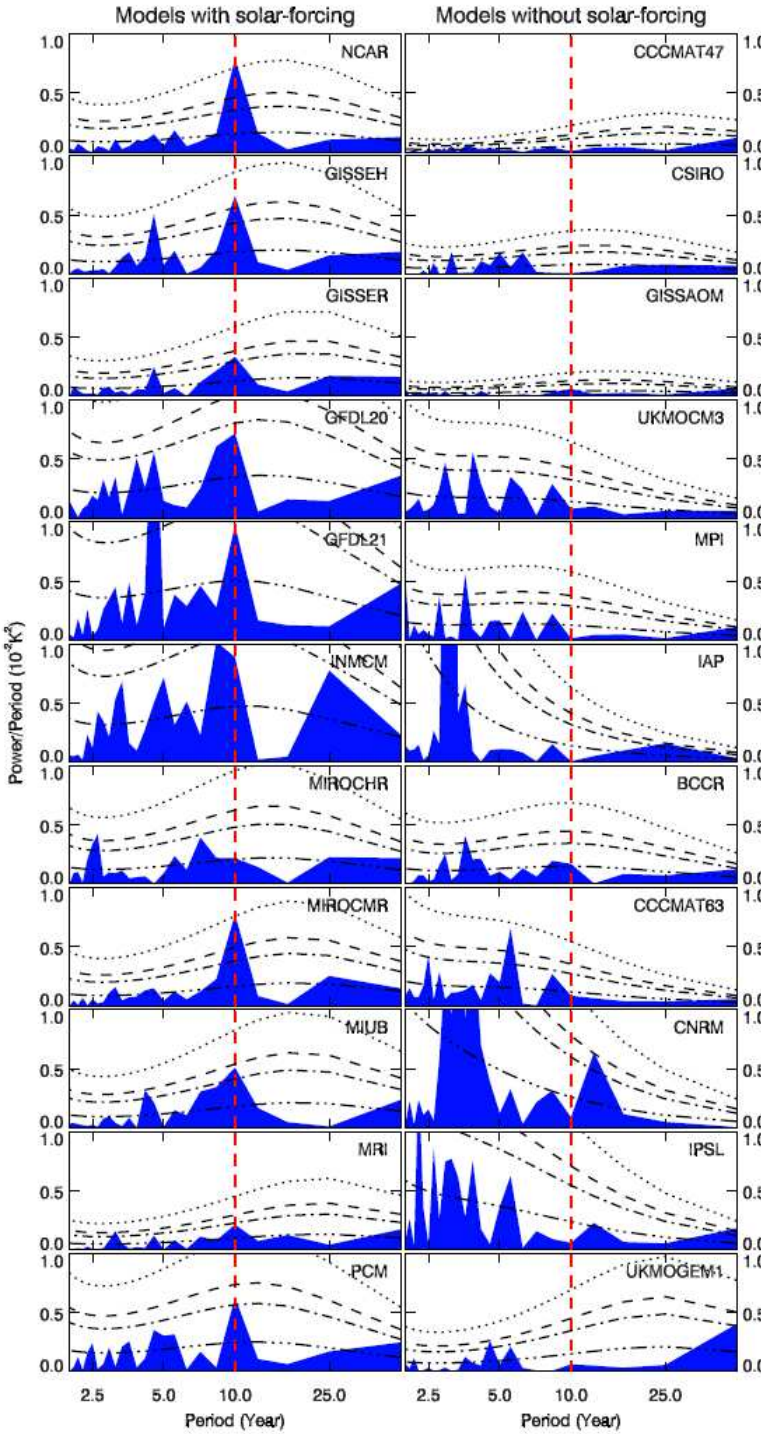
G = Well-mixed greenhouse gases
O = Tropospheric and stratospheric ozone
SD = Sulfate aerosol direct effects
SI = Sulfate aerosol indirect effects
BC = Black carbon
MD = Mineral dust
LU = Land use change
VL = Volcanic aerosols
OC = Organic carbon
SS = Sea salt
SO = Solar irradiance

GCM spectrum→

Observed Fourier spectrum

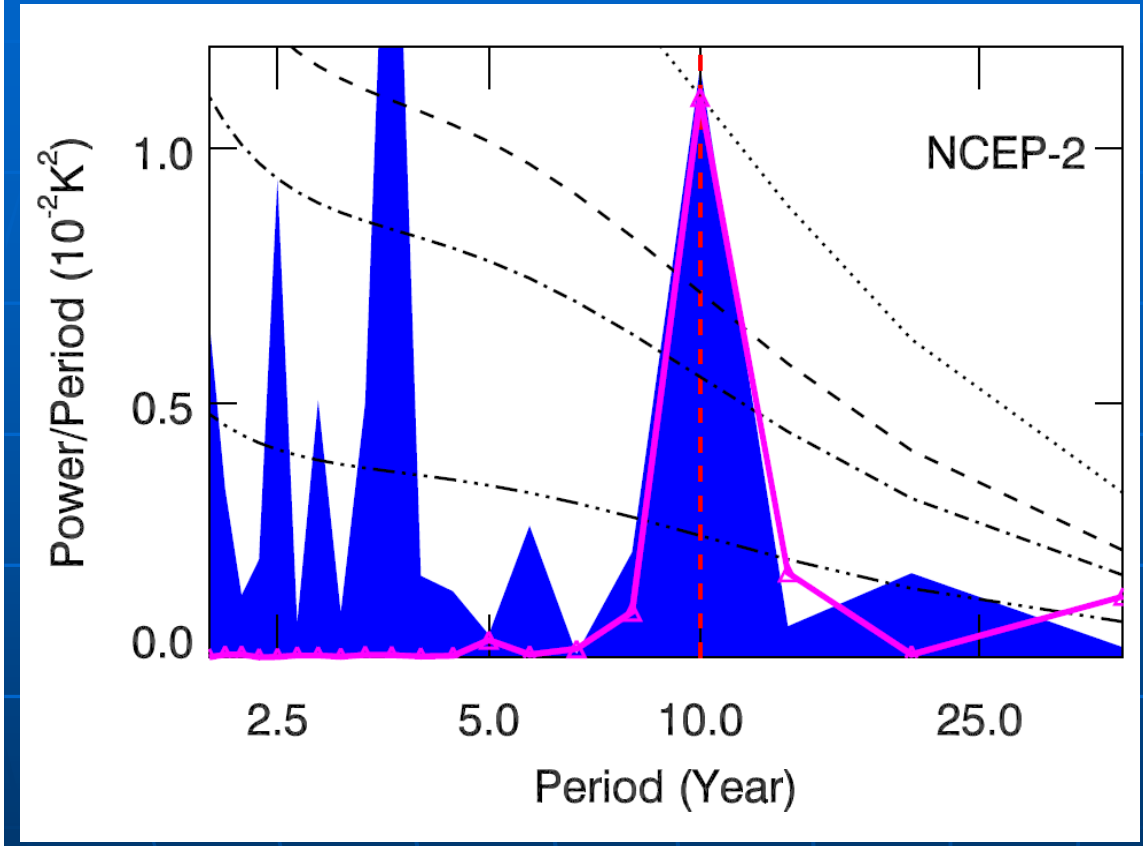


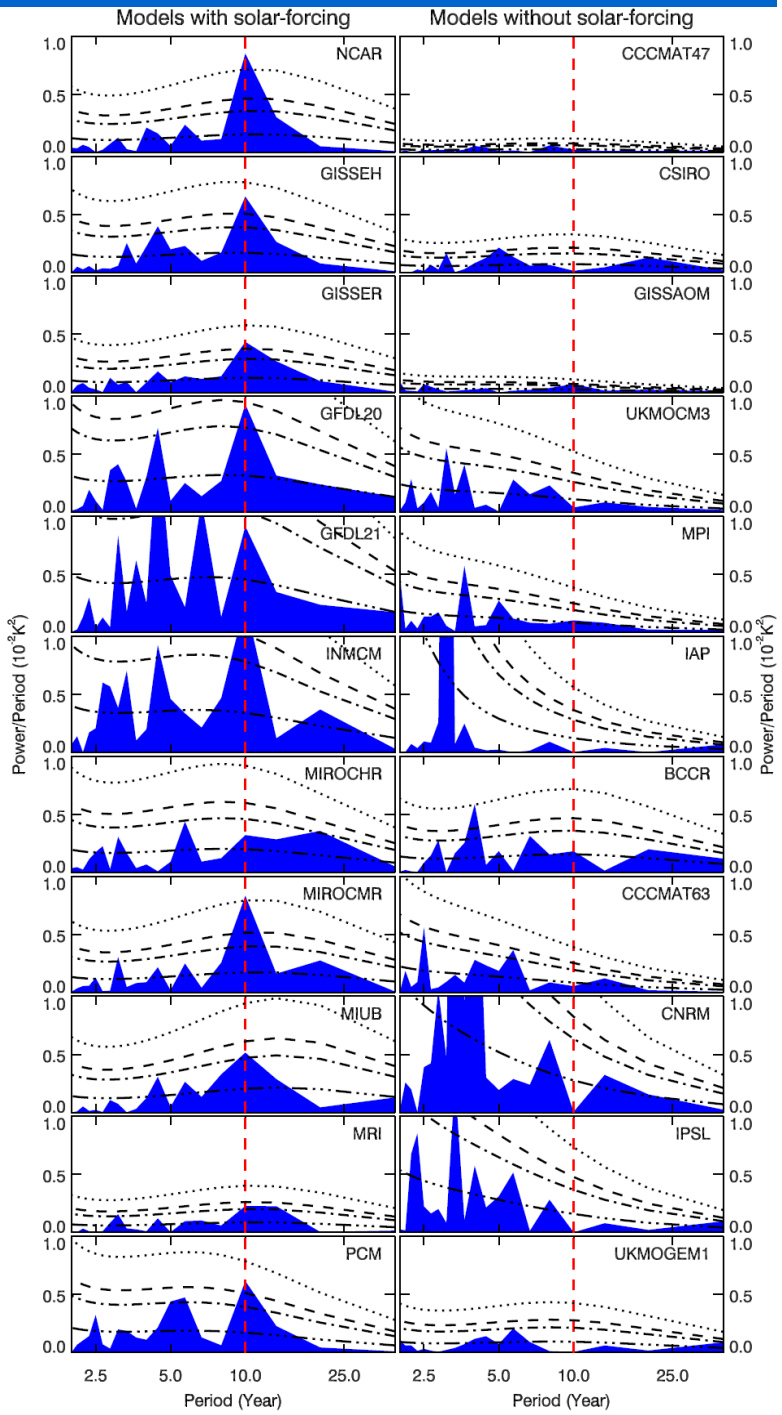
FFT of global mean annual mean surface temperature
1950-1999
vs the FFT of solar index (TSI) in magenta.



GCM spectrum→

Observed Fourier spectrum





FFT of global mean annual mean surface temperature 1960-1999
vs the FFT of TSI for the same period (in magenta)

Solar induced warming

4."The estimated direct radiative forcing due to changes in solar output since 1750 is +0.12[0.06 to 0.3] Wm^{-2}, which is less than half of the estimate given in the TAR, with a low level of scientific understanding."

If calibrated against response to solar cycle, the longer-term (equilibrium response) to

RF=0.12 Wm^{-2} is approximately $\delta T \sim 0.18$ K globally averaged.

while the upper bound RF=0.3 Wm^{-2} should yield $\delta T \sim 0.45$ K globally averaged. Arctic warming is ~3x higher.

Not negligible, but is probably what is needed to explain the warming prior to mid 20th century.

More research is needed to narrow the solar RF range.

Solar forcing cannot explain the peak in warming in 1940, because the solar forcing peaked a decade later.

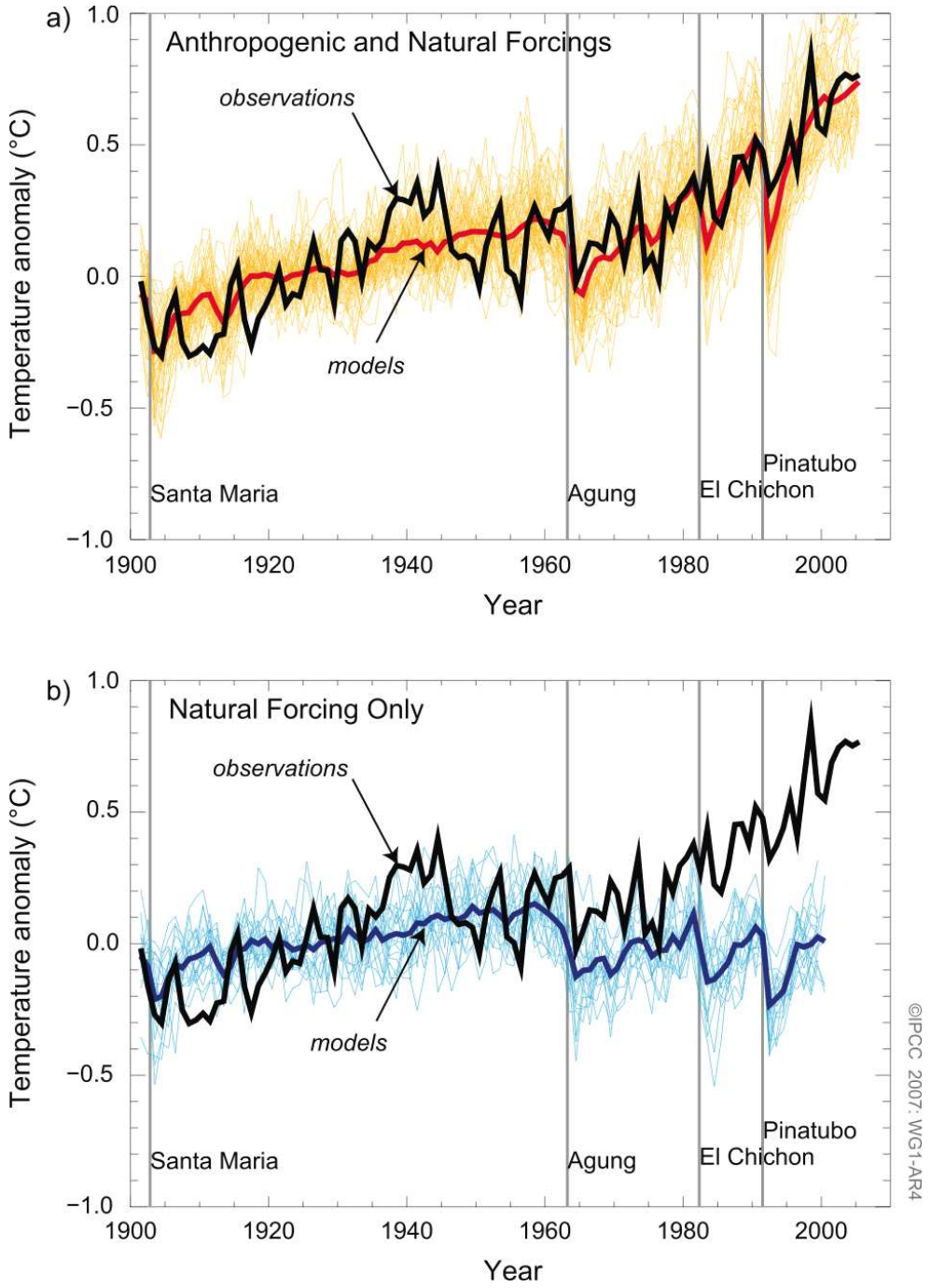
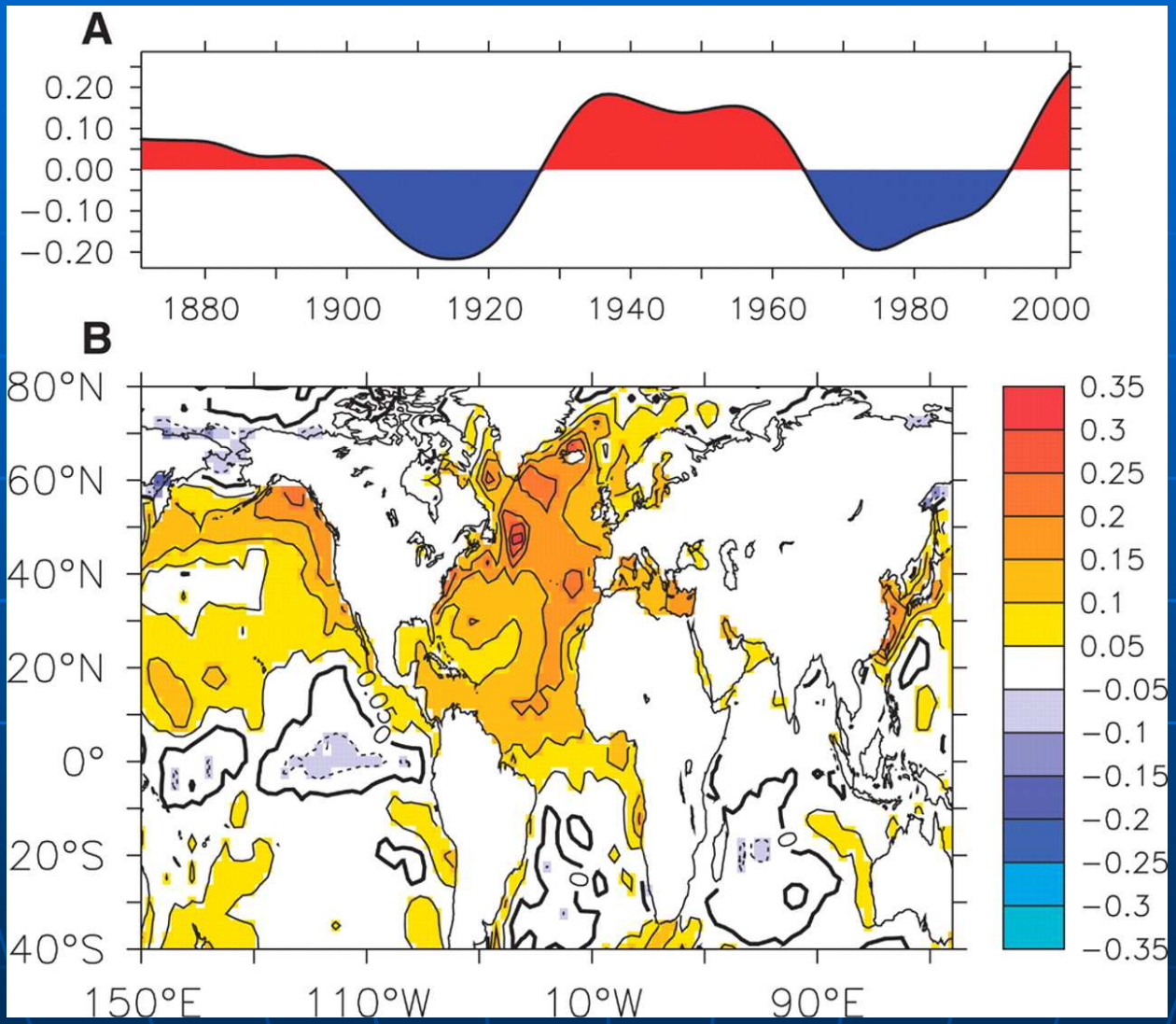

a)
Anthropogenic and Natural Forcings
observations
models
Temperature anomaly (°C)
1.0
0.5
0.0
−0.5
−1.0
Santa Maria
Agung
El Chichon
Pinatubo
1900
1920
1940
1960
1980
2000
Year
b)
Natural Forcing Only
observations
models
Temperature anomaly (°C)
1.0
0.5
0.0
−0.5
−1.0
Santa Maria
Agung
El Chichon
Pinatubo
1900
1920
1940
1960
1980
2000
Year
©IPCC 2007: WG1-AR4

Figure TS.23

(A) Index of the AMO, 1871 to 2003



R. T. Sutton et al., Science 309, 115 -118 (2005)

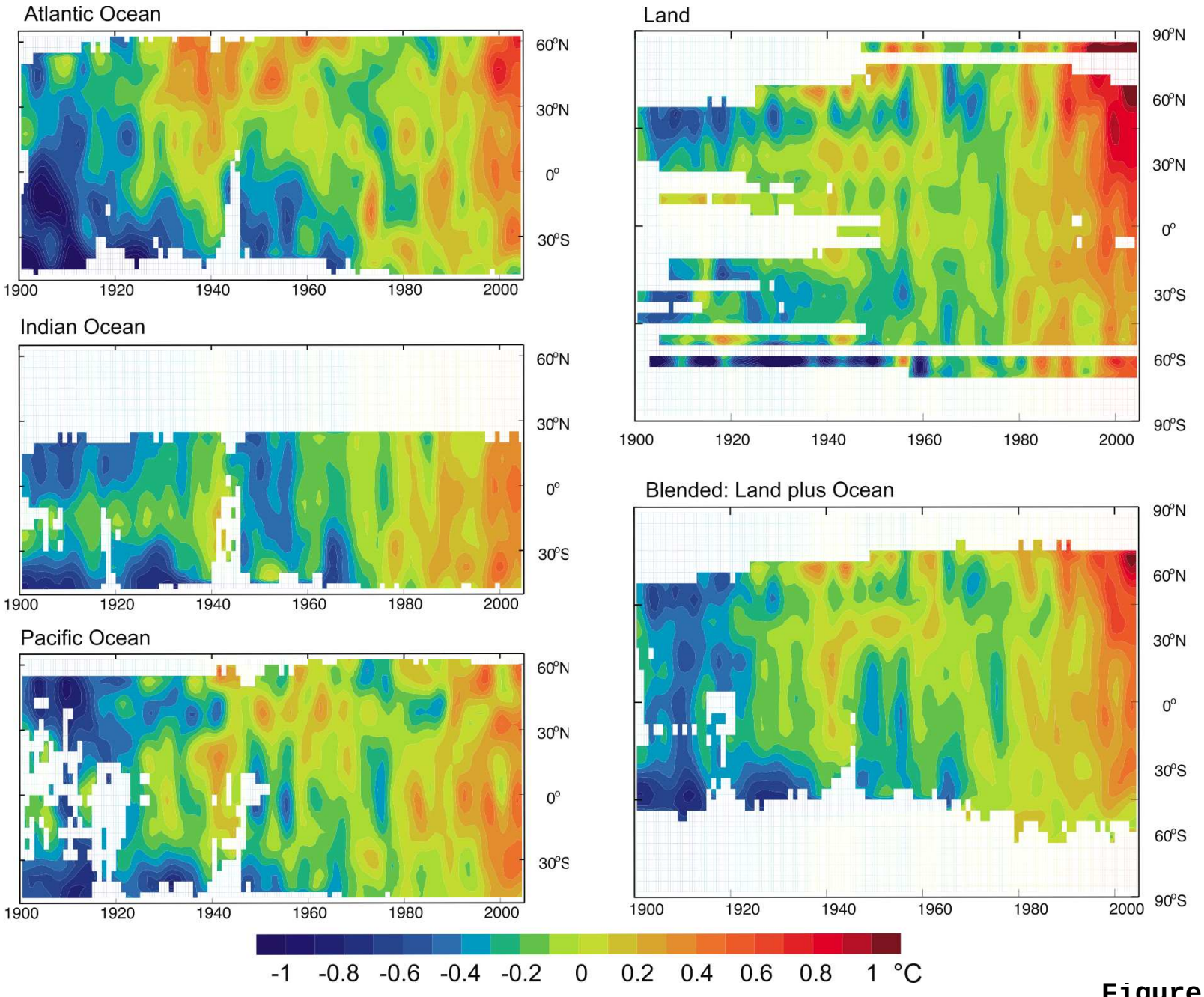

Atlantic Ocean
Indian Ocean
Pacific Ocean
Land
Blended: Land plus Ocean
60°N
30°N
0°
30°S
90°N
60°N
30°N
0°
30°S
60°S
90°S
1900
1920
1940
1960
1980
2000
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
°C

Figure 3.5

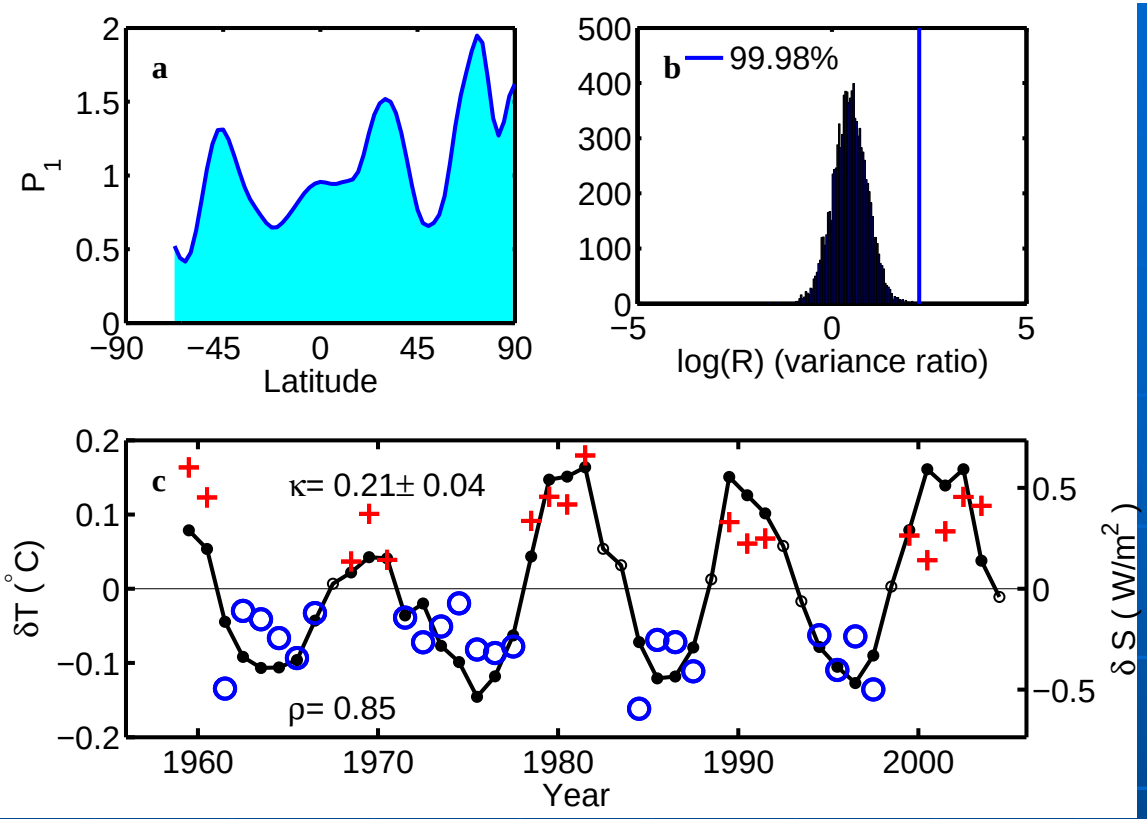
Summary

- Observational analysis, theory, model analysis all point to the existence of a solar cycle response at the surface. Established statistical significance for the first time and offered an energetically consistent explanation.
- This response can be understood as arising from the direct radiative heating of the sun amplified by positive feedback processes well studied in GHG warming problems.
- The similarity of the solar and GHG responses implies that one can be used to constrain the other, thus reducing model uncertainty.

  IPCC models need to be validated against this observational data. Better than calibrating against volcano-induced cooling…
- In arguing the case for anthropogenic origin of global warming, some scientists in recent publications tended to dismiss solar forcing as being negligible. Perhaps not such a good tactic.

P. Foukal, C. Frohlich, H. Spruit & M. L. Wigley, 2006, *Nature Reviews*: used Energy Balance Model:

"Overall, we can find no evidence for solar luminosity variations of sufficient amplitude to drive significant climate variations on centennial, millenial and even million-year timescales….Less direct Sun-climate couplings driven by the Sun's well-known variability in ultraviolet flux and in outputs of magnetized plasma might yet account for Sun-climate correlations that defy explanation by the direct influence of TSI variation considered here…"



850–500 hPa average