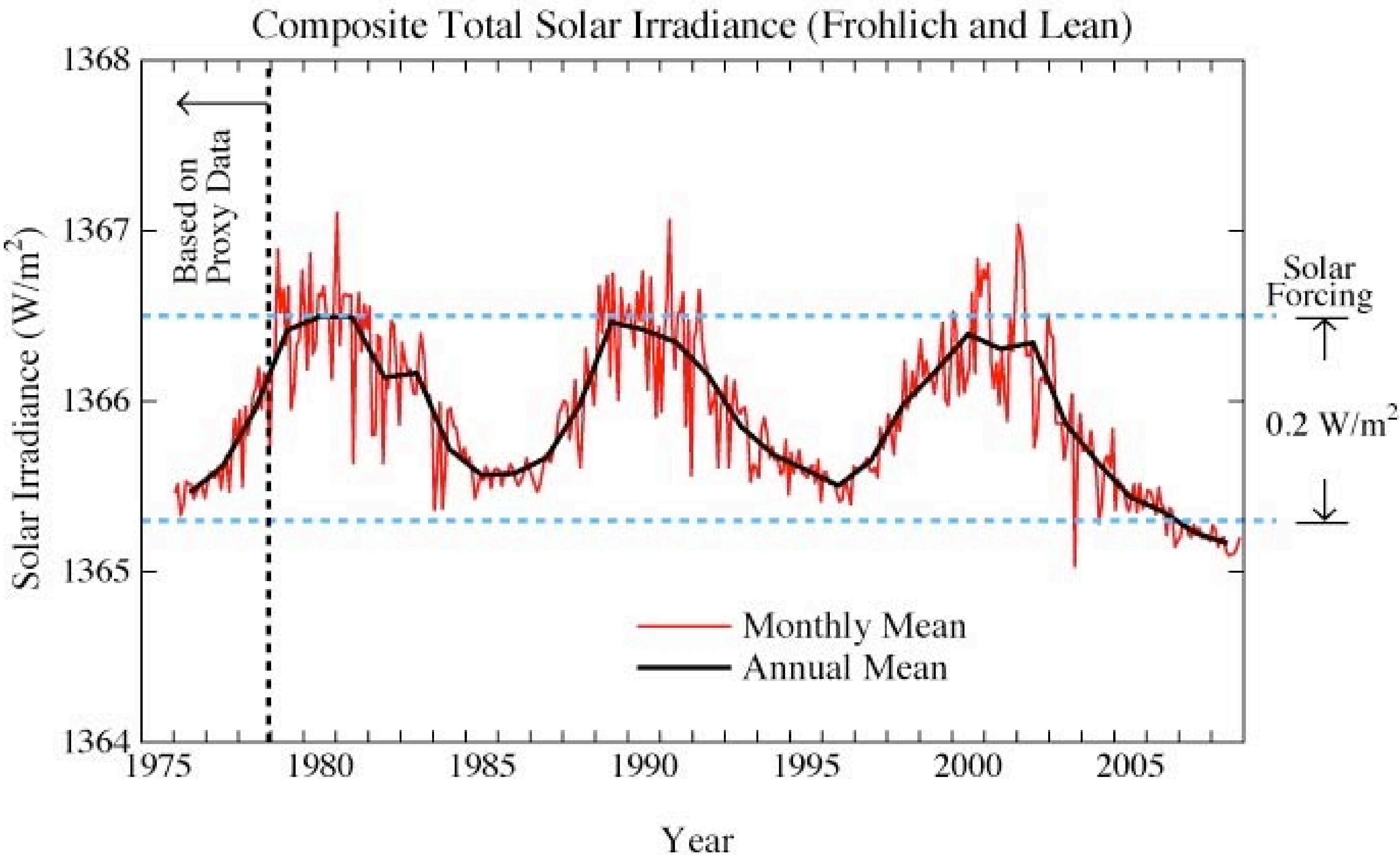
Solar Variability and Climate Change over the Late Holocene

D. Rind

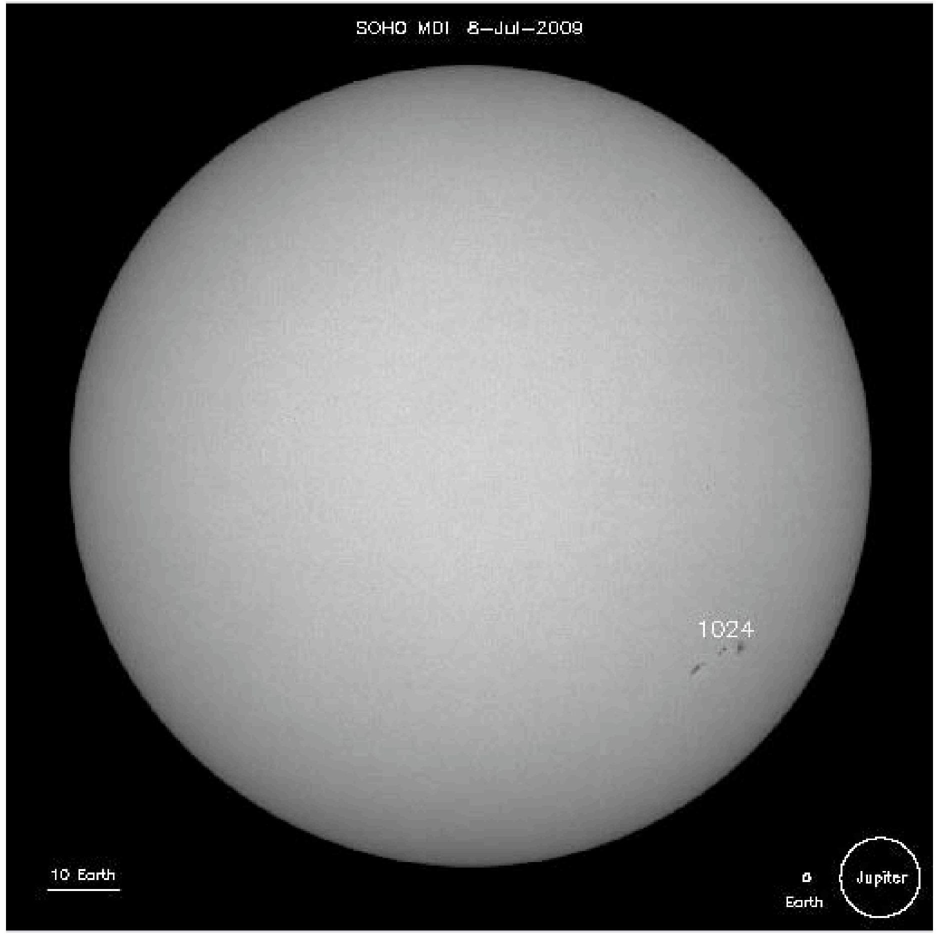
NASA/GISS

NOAA Program:

Abrupt Change in a Warming World

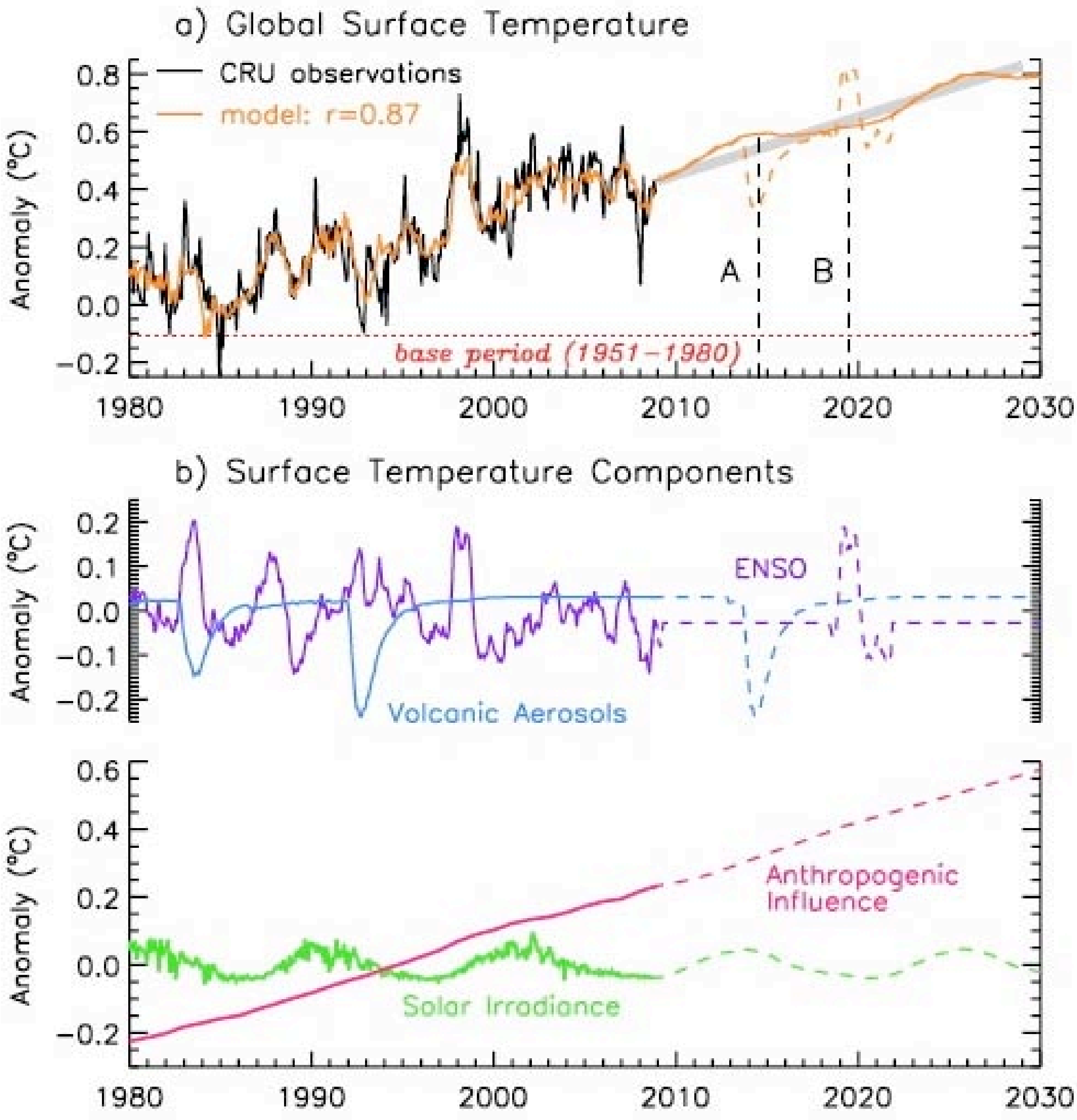


Composite Total Solar Irradiance (Frohlich and Lean)
Solar Irradiance (W/m2)
1368
1367
1366
1365
1364
Based on Proxy Data
Solar Forcing
0.2 W/m2
Monthly Mean
Annual Mean
1975
1980
1985
1990
1995
2000
2005
Year



http://sohowww.nascom.nasa.gov/

It looks like the solar minimum may have been in Aug 2008 -other indicators of coronal brightness suggest the same thing-and so I think cycle 24 has started. Also we do have a decent amount of polar field strength-which is the seed magnetic flux for the cycle and if we were going into a Maunder Minimum we would not likely have polar fields -since they are a consequence of the dynamo that drives the cycle. {Judith Lean, personal communication}



Lean and Rind, GRL, 2009

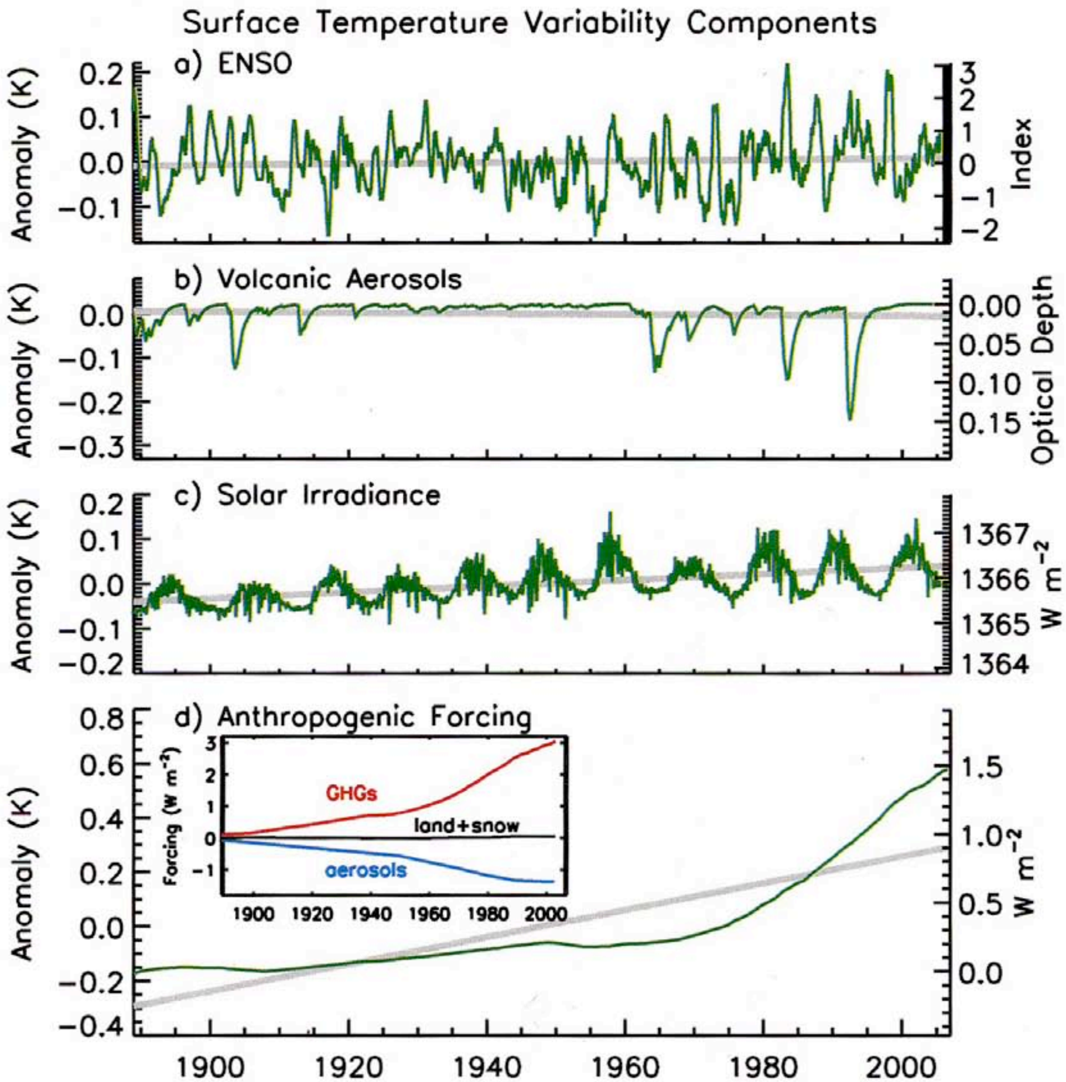


Figure 2. Reconstructions of the contributions to monthly mean global surface temperatures by individual natural and anthropogenic influences (at appropriate lags) are shown. The right hand ordinates give the native scales of each influence and the left hand ordinates give the corresponding temperature change determined from the multiple regression analysis. The grey lines are trends for the whole interval. The inset in Figure 2d shows the individual greenhouse gases, tropospheric aerosols and the land surface plus snow albedo components that combine to give the net anthropogenic forcing.

Lean and Rind 2008

Lean and Rind 2008

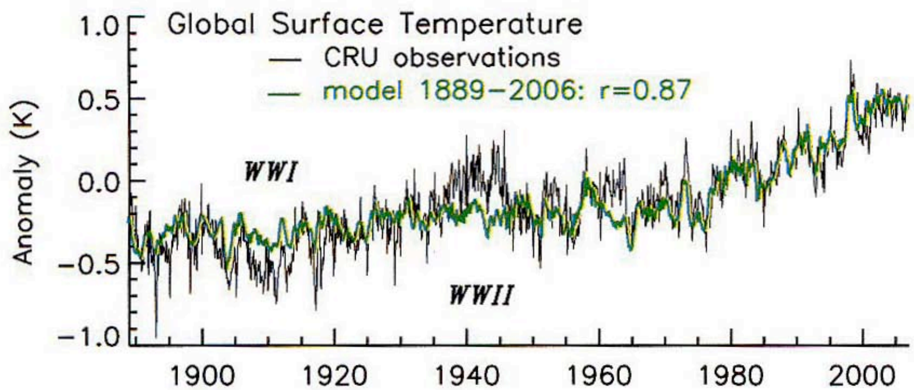
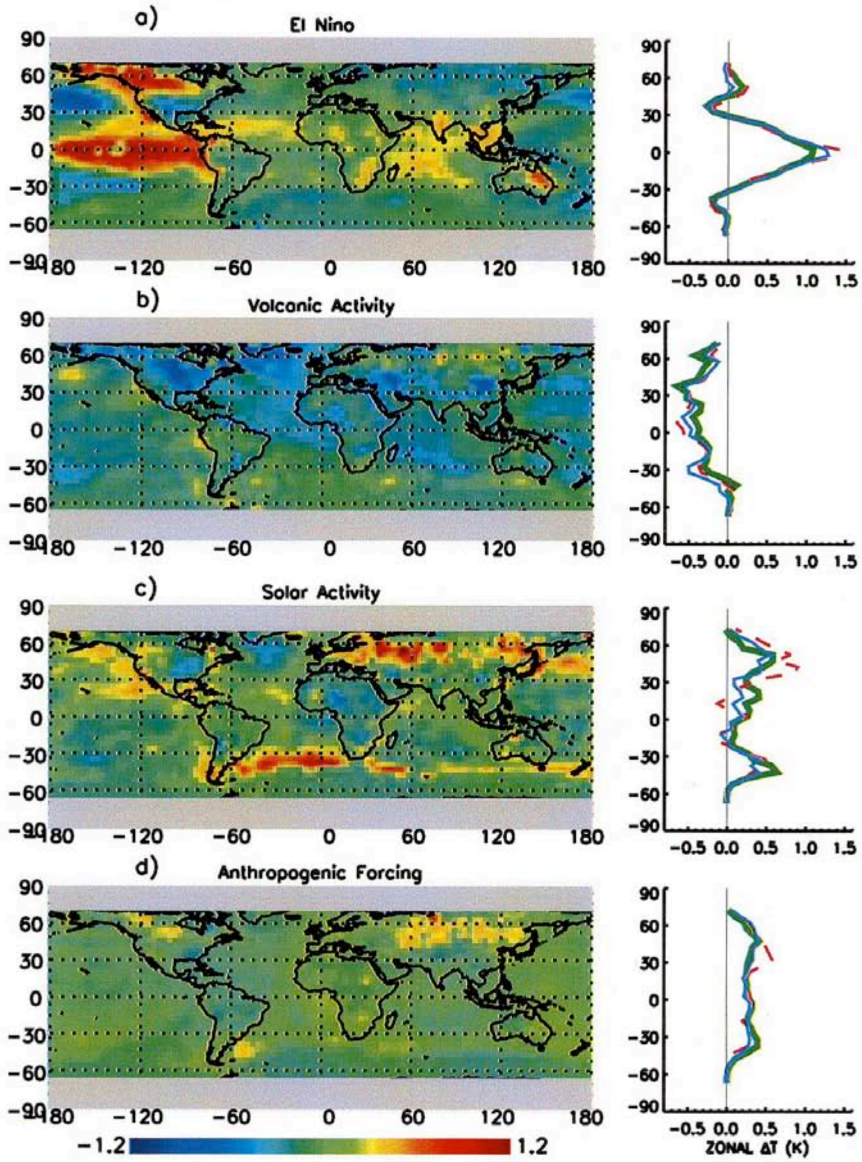


Figure 1. Compared with the CRU monthly mean global temperature time series (hadcrut3vcgl) is an empirical model obtained from multiple regression for the period from 1889 to 2006, inclusive. The value of *r* is the correlation coefficient for the global temperature observations and empirical model. Largest differences occur at the times of the two World Wars when observations were sparse.

Table 1. Amplitudes of Global Temperature Trends Arising From Individual Natural and Anthropogenic Influences Determined As the Slopes of the Time Series in Figure 2 Over Different Epochs[a]

Period	ENSO	Volcanic Activity	Solar Activity	Anthropogenic Forcing	*IPCC* [2007] Temperature
1889–2006	0.0015 ± 0.0005	−0.0009 ± 0.0003	0.007 ± 0.001	0.050 ± 0.001	
100 yrs: 1905–2005	0.0028 ± 0.0006	−0.0029 ± 0.0004	0.007 ± 0.001	0.059 ± 0.001	0.074 ± 0.018
50 yrs: 1955–2005	0.015 ± 0.002	0.001 ± 0.001	0.002 ± 0.001	0.136 ± 0.003	0.128 ± 0.026
25 yrs: 1979–2005	−0.007 ± 0.005	0.018 ± 0.004	−0.004 ± 0.004	0.199 ± 0.005	0.177 ± 0.052

[a]The given uncertainties are the combined statistical uncertainties of the multiple regression and the fitted trend and do not include uncertainties in either the temperature observations or the forcings. *IPCC* [2007] net global temperature trends are included for comparison. Trends are in K per decade.



Lean and Rind 2008

Figure 3. (left) Compared are geographical response patterns, each normalized to a 0.1 K global temperature change, due to ENSO, volcanic, solar and anthropogenic influences, derived from the monthly historical surface temperature records (1889–2006). (right) Also shown are zonal means of the geographical responses from the regression of data in three different epochs. The thick (green) curve is for the entire period from 1889 to 2006, the thin (blue) curve is for the NCEP period from 1960 to 2006 and the dashed (pink) curve is for the satellite era from 1980 to 2006.

IPCC 2007

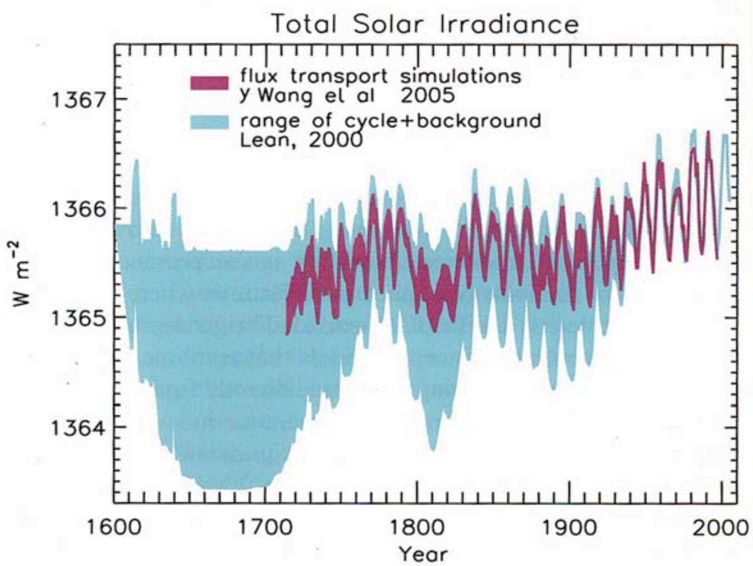
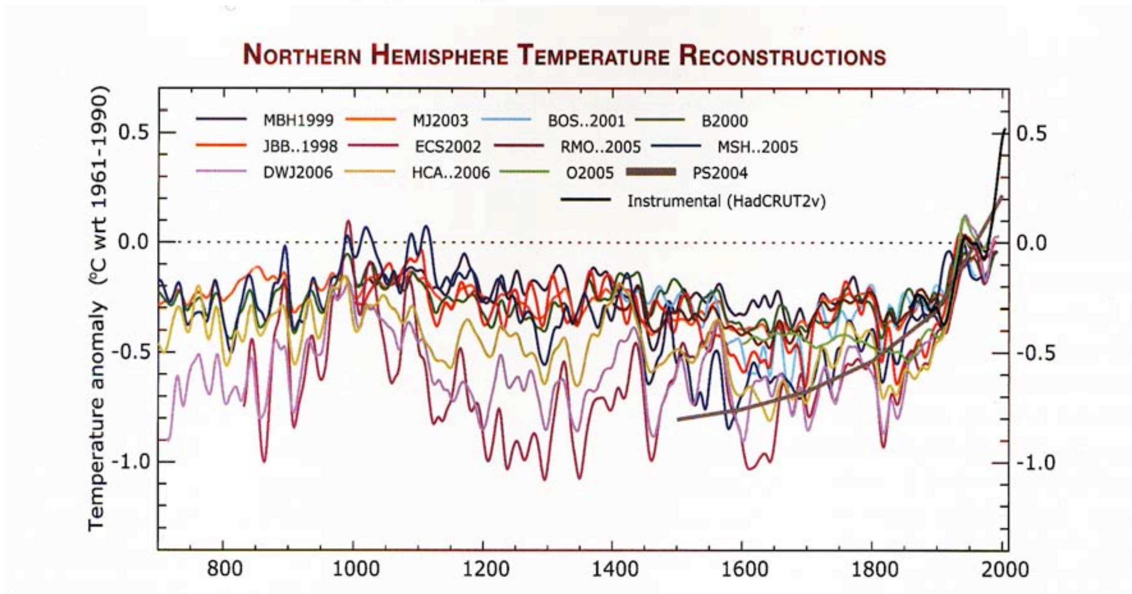


Figure 2.17. *Reconstructions of the total solar irradiance time series starting as early as 1600. The upper envelope of the shaded regions shows irradiance variations arising from the 11-year activity cycle. The lower envelope is the total irradiance reconstructed by Lean (2000), in which the long-term trend was inferred from brightness changes in Sun-like stars. In comparison, the recent reconstruction of Y. Wang et al. (2005) is based on solar considerations alone, using a flux transport model to simulate the long-term evolution of the closed flux that generates bright faculae.*



IPCC 2007

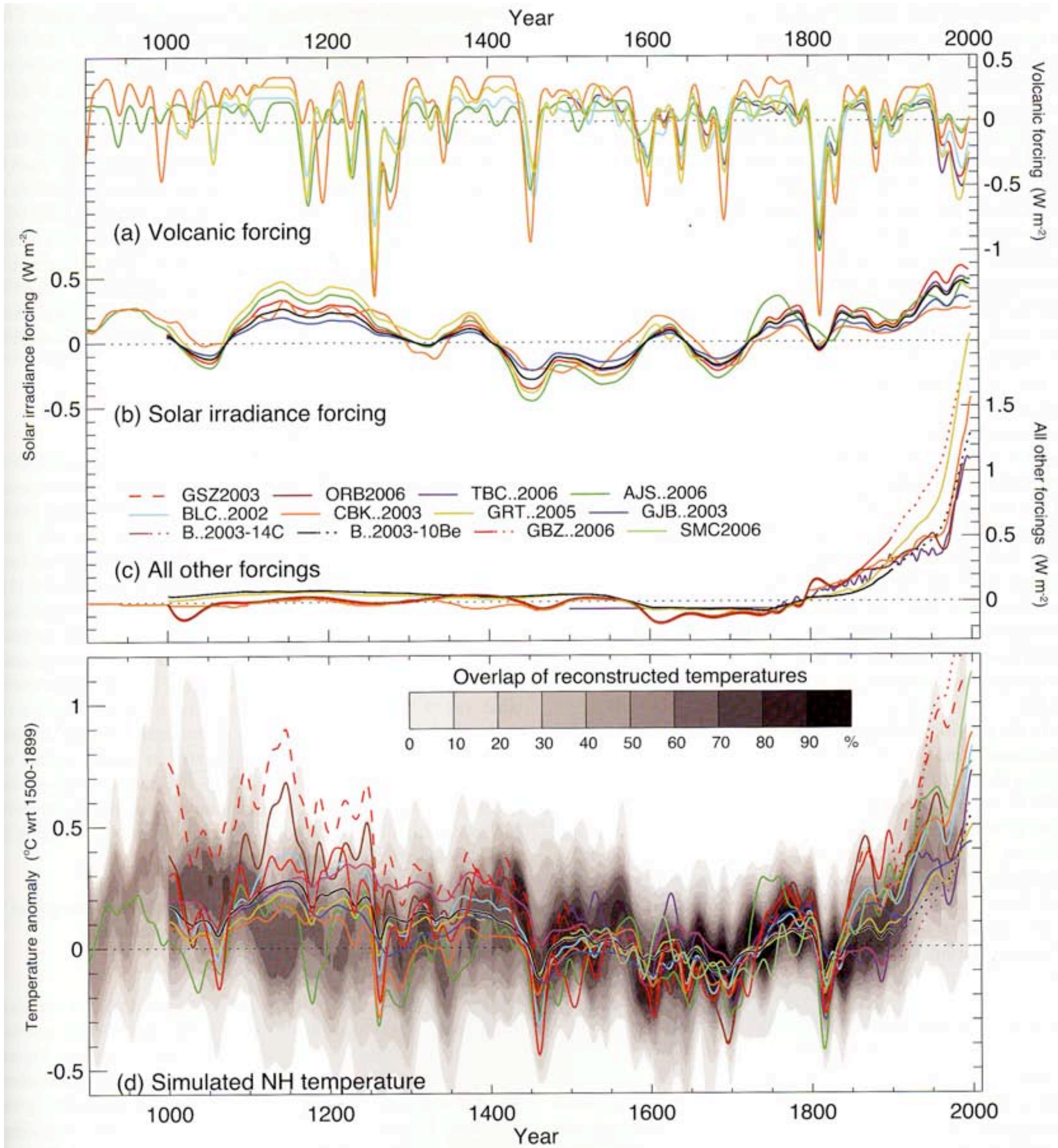


Figure 6.13. Radiative forcings and simulated temperatures during the last 1.1 kyr. Global mean radiative forcing (W m^{-2}) used to drive climate model simulations due to (a) volcanic activity, (b) solar irradiance variations and (c) all other forcings (which vary between models, but always include greenhouse gases, and, except for those with dotted lines after 1900, tropospheric sulphate aerosols). (d) Annual mean NH temperature (°C) simulated under the range of forcings shown in (a) to (c), compared with the concentration of overlapping NH temperature reconstructions (shown by grey shading, modified from Figure 6.10c to account for the 1500 to 1899 reference period used here). All forcings and temperatures are expressed as anomalies from their 1500 to 1899 means and then smoothed with a Gaussian-weighted filter to remove fluctuations on time scales less than 30 years; smoothed values are obtained up to both ends of each record by extending the records with the mean of the adjacent existing values. The individual series are identified in Table 6.2.

Model Simulations

The most consistently occurring solar peaks are at periods of ~120 and ~56 years. Peaks at ~200 and ~120 yr. support previous findings[8, 16]; peaks at ~420 and ~56 yrs appear to represent new findings. Although solar spectra can be found in some of these climate records, in most cases there are a number of significant differences between the solar peaks

SOLAR SPECTRA IN CLIMATE RECORDS

		Suess		Gleissberg			
PERIOD	~420	~200	~120	~87	~56	r	r_{max}
GLACIERS	x		**X**	**X**		-0.11	.15 (330)
SIERRA TR			**X**		**X***	-0.10	.22 (70)
CHINA TR		**X***	x	x	x	-0.54	-54 (0)
GRN O18	**X**		**X**		**X***	-0.01	.39 (45)
PERU O18			x	x	**X**	0.05	.08 (15)
SPOLE O18		**X***	x	x	x	0.37	.42 (-20)

Table 1. Correlations between solar spectra in climate records. A small "x" indicates that solar periods occur but not consistently (as defined by variations in the amount of record smoothing). Bold X's refer to a more consistent occurrence, and bold X*s refers to records that have coherences >0.6. Parentheses after r_{max} refers to number of years the climate time series leads or lags at maximum correlation (minus sign indicates climate leads ^{14}C).

after Crowley and Howard
1990

Mechanisms for Solar Influence on Tropospheric Temperatures

- Variations in total solar irradiance (TSI)
  - Influence on subtropical surface temperatures (land and sea), with subsequent atmospheric dynamic and moisture effects; influence on Hadley circulation
- Impact of solar irradiance variations on ocean/atm dynamics
  - ENSO
  - NAM/NAO
  - NADW
- Variations in solar UV affecting stratosphere and stratospheric ozone
- Impact of stratospheric changes on tropospheric dynamics
  - Hadley circulation
  - Planetary waves

TSI EFFECTS

Rind et al, 2004

ΔTSI=-0.2%

ΔSpec Irrad+ Ozone

ΔTSI+ Anthro trace gases+ aerosols

Anthro trace gases+ aerosols

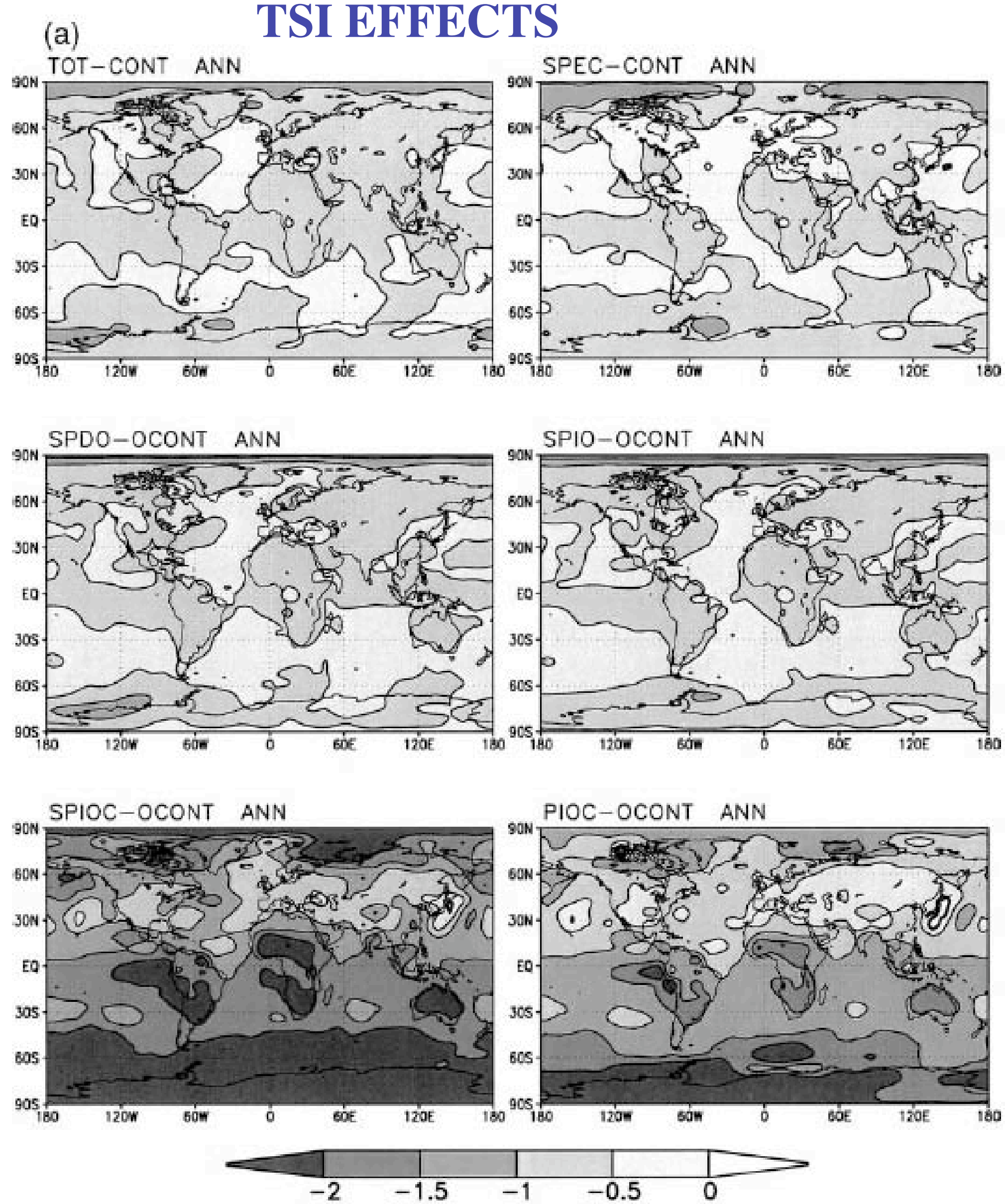
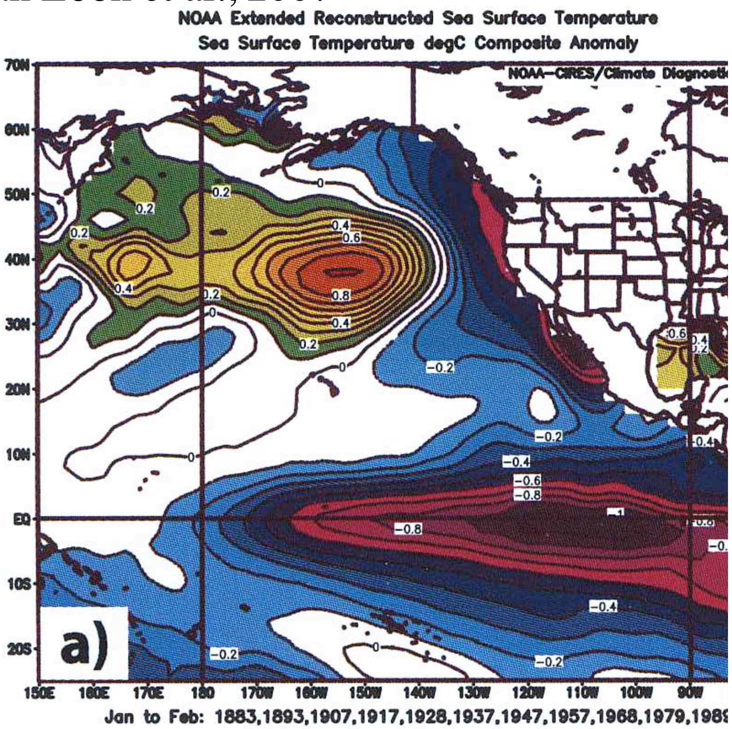


FIG. 3. Surface air temperature change for the (a) annual average and (b), (c) solstice seasons in the different experiments. For this and the other figures, results are given for the period 1651–1700 of the ensemble of simulations for each experiment compared to the mean of their respective control runs. All the changes are significant at the 95% level, except for the occasional small warming regions at high latitudes.

ΔAnnual surf temp, 1651-700 minus present

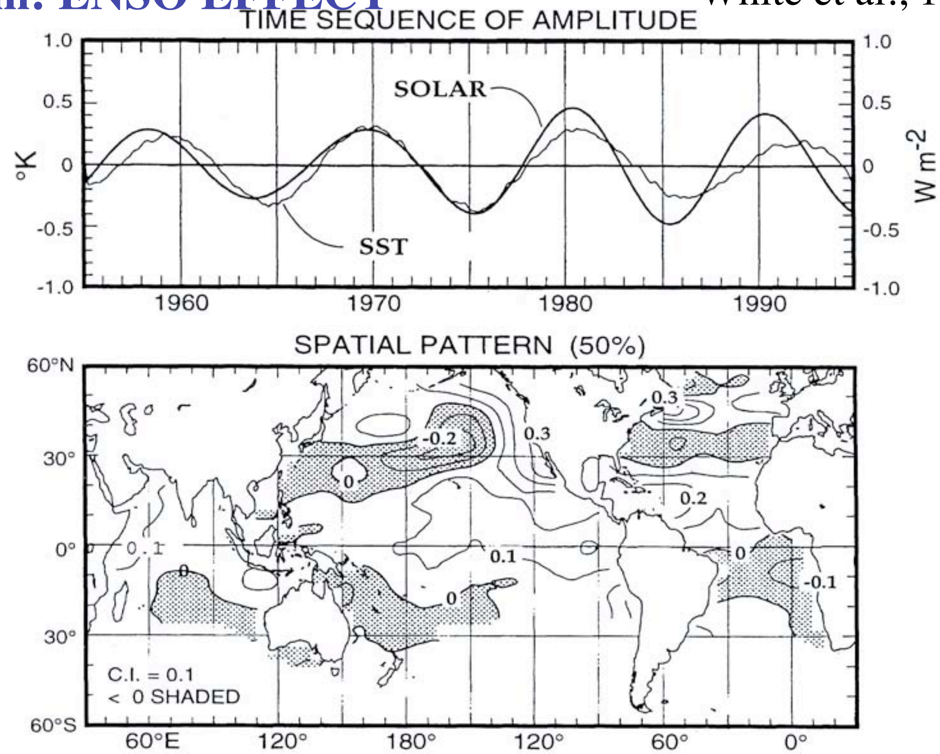
Solar Max - Min: ENSO EFFECT

Van Loon et al., 2007



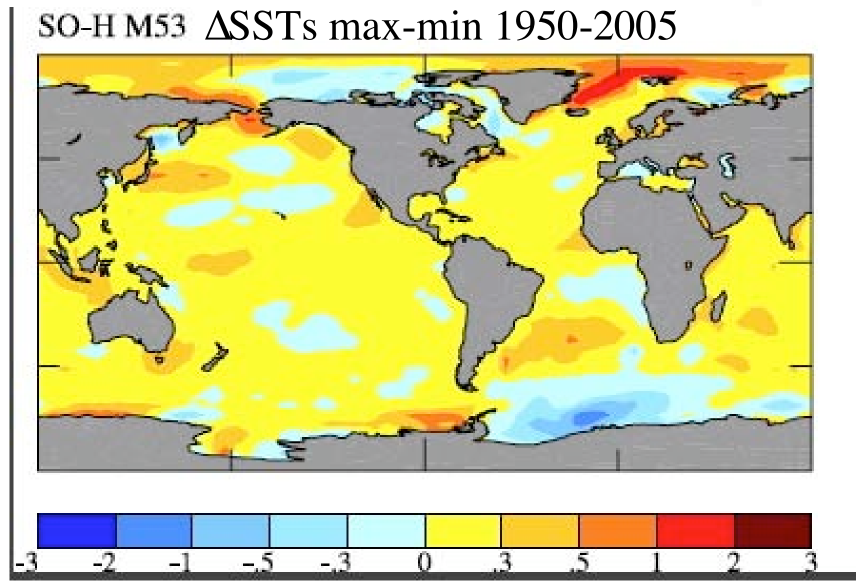
January-February data

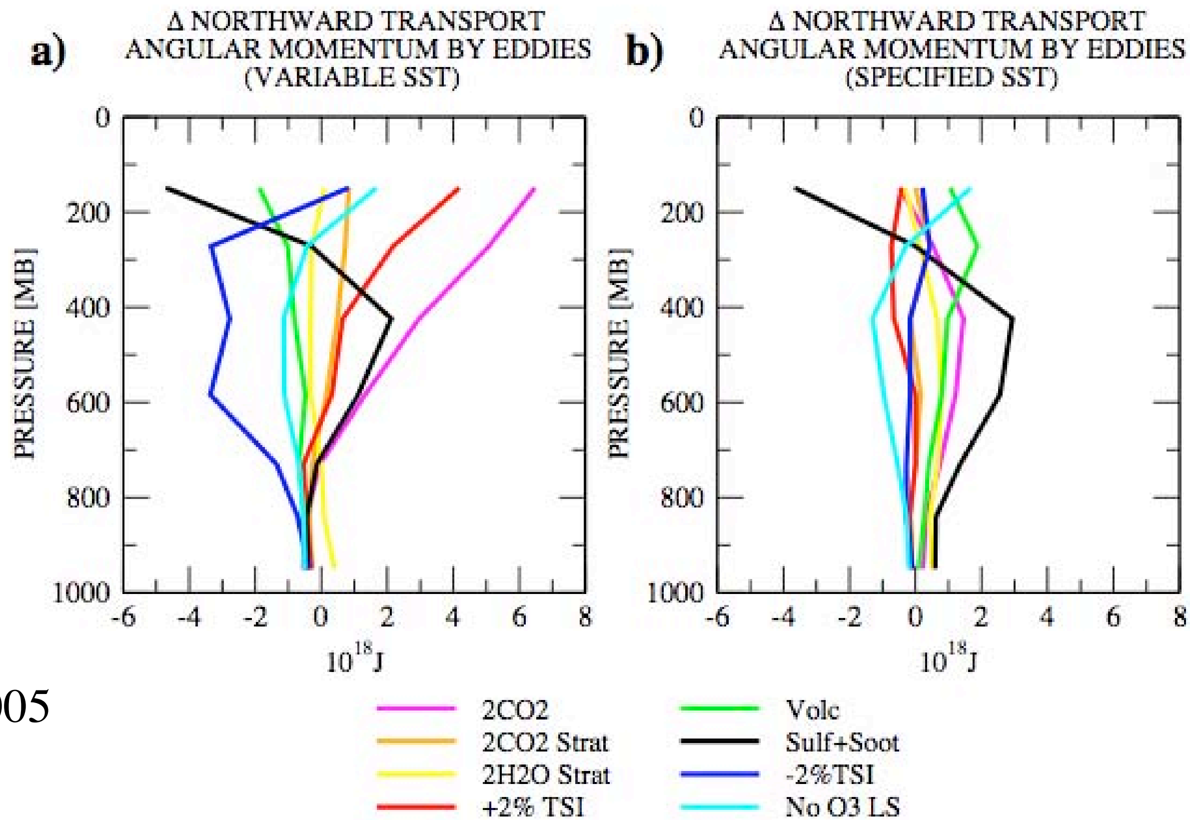
White et al., 1997



Also: Geay et al. 2007: Moderate -to--large positive solar forcing increases E-W temp gradient in the Pacific (upwelling thermostat effect) leading to enhanced La Nina conditions.

Rind et al., 2008->





Rind et al., 2005

Table 2. Change in AO-index (30-50°N minus 60-80°N) and NAO during Dec-Feb

ΔTs	EXPERIMENTS	VARIABLE SSTS				SPECIFIED SSTS				ΔT 68mb
	Equilibrium Results	SLP/ AO (MB)	NAO (MB)	100 MB (M)	10 MB (M)	SLP/ AO (MB)	NAO (MB)	100 MB (M)	10 MB (M)	
5.15	2CO2	***4.47***	***5.77***	***231***	***224***	0.51	***4.95***	***131***	222	-1.5
0.54	2CO2 Strat	***1.84***	-1.64	46	53	0.90	1.00	***82***	***259***	-0.4
0.46	2H2O Strat	1.33	-0.10	19	-55	0.76	***3.50***	33	57	-0.8
4.73	+2% TSI	***4.44***	1.84	***180***	***193***	-0.95	-1.16	-21	***326***	0.5
-3.39	Volc	***-3.39***	***-3.44***	-11	***189***	***1.79***	***3.00***	14	-45	1.2
-0.3	Sulf+Soot	-0.30	-1.66	***533***	***1962***	***3.8***	***3.55***	***589***	***1937***	36.3
-3.84	-2% TSI	***-3.84***	***-5.99***	***-74***	66	0.02	0.84	-46	***196***	-0.4
-1.36	NO O3 LS	-1.36	***-2.25***	***-94***	79	0.89	0.17	-66	***318***	-8.8

Solar Cycle -Ozone Response

Observed

Modeled

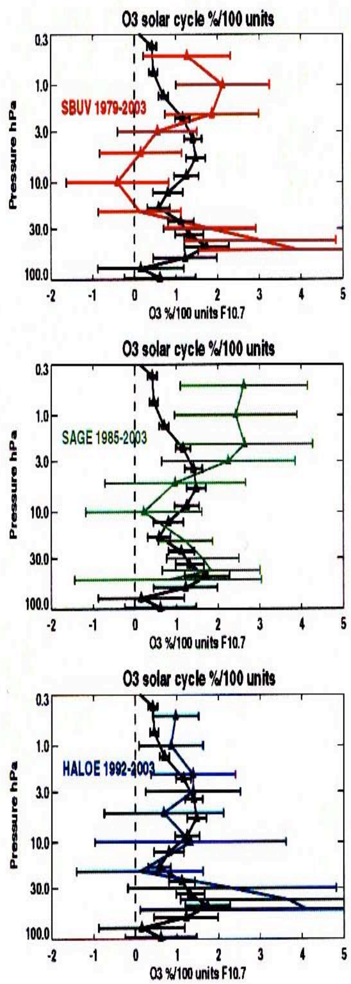
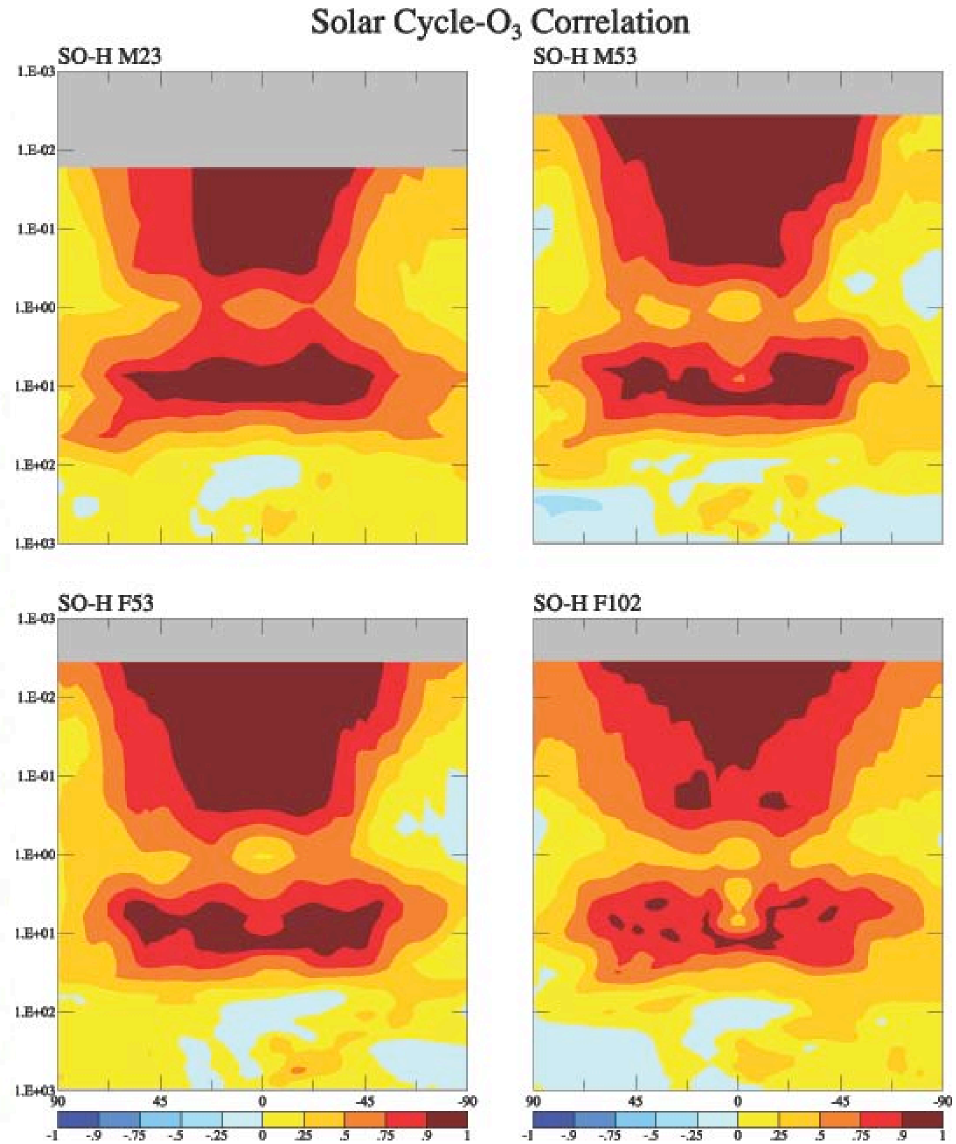
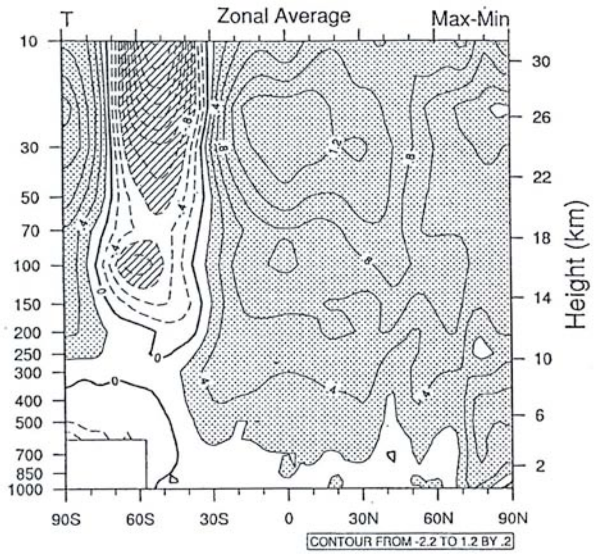


Fig. 7. Annual mean ozone solar response in % per 100 units of 10.7 cm flux in comparison with satellite measurements. The results have been averaged over the latitude range 25° S to 25° N and over all three ensemble members. The error bars indicate 95% confidence intervals from the linear regression analysis. Black lines: model results; coloured lines: satellite results as indicated, from Soukharev and Hood (2006).



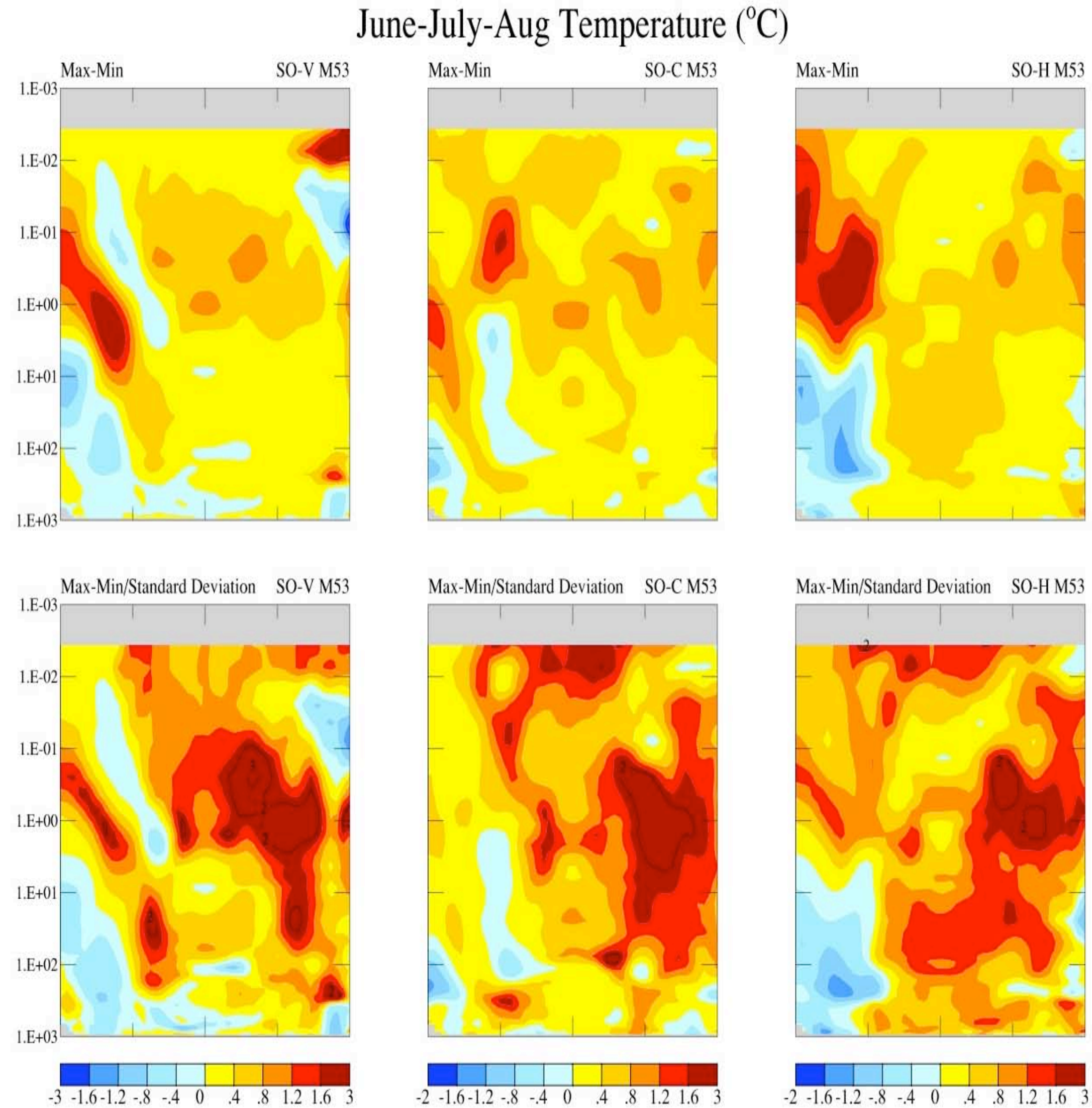
Rind et al., 2008



June-August

Van Loon and Shea 1999

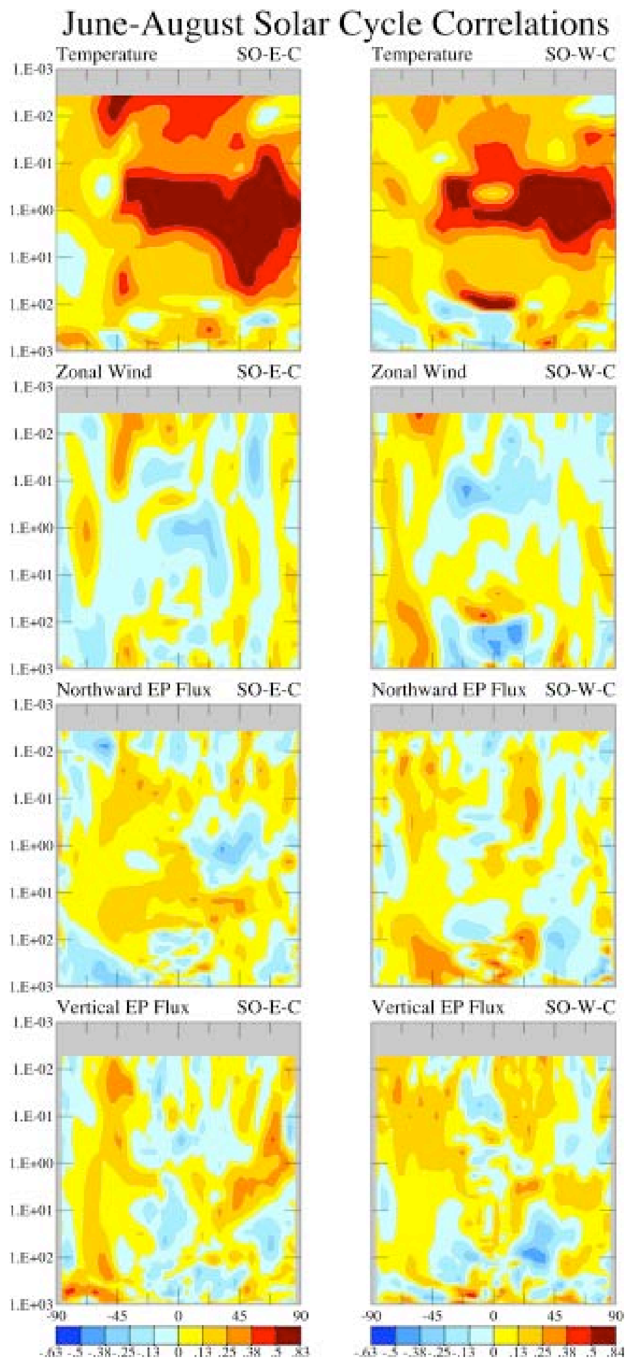
Observed



Modeled

Rind et al., 2008

Rind et al., 2008



Influence on monsoon precipitation

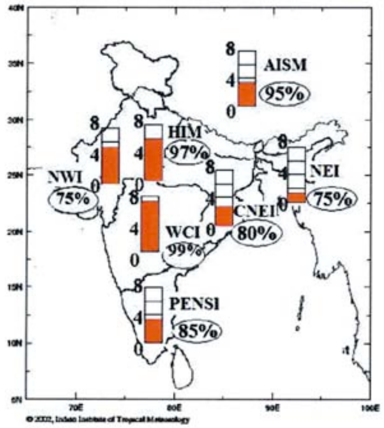


Figure 4. Map showing homogeneous monsoon regions of India. Marked in bars are the % difference of rainfall means over test periods with respect to the annual means and encircled numbers next to them indicate the confidence level at which the differences are significant.

Bhattacharyya and Narsimha, 2005)

{from below}

{from above}

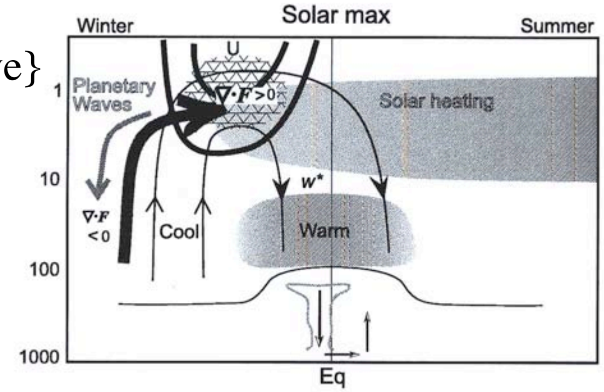
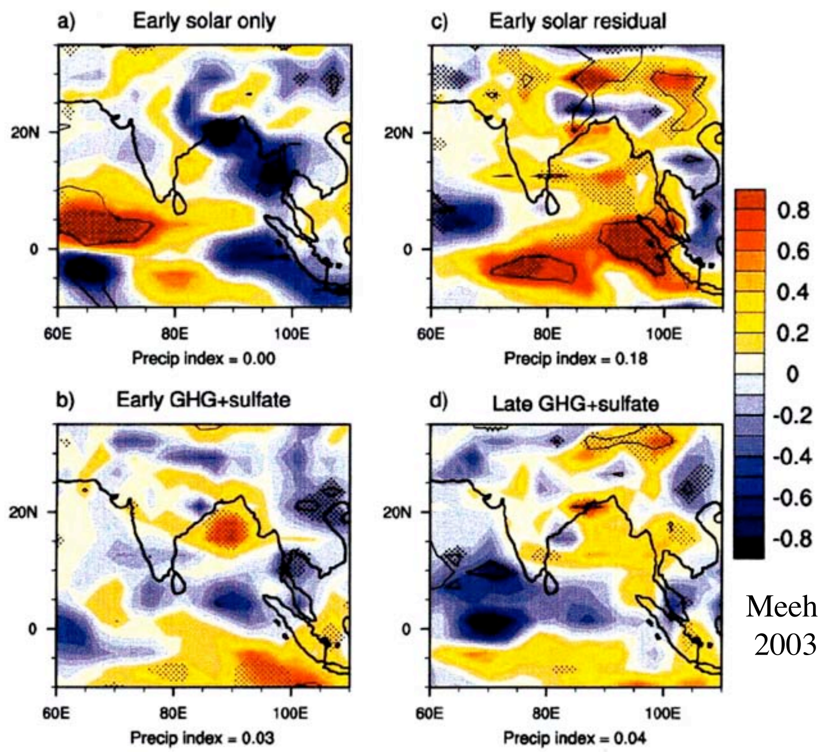


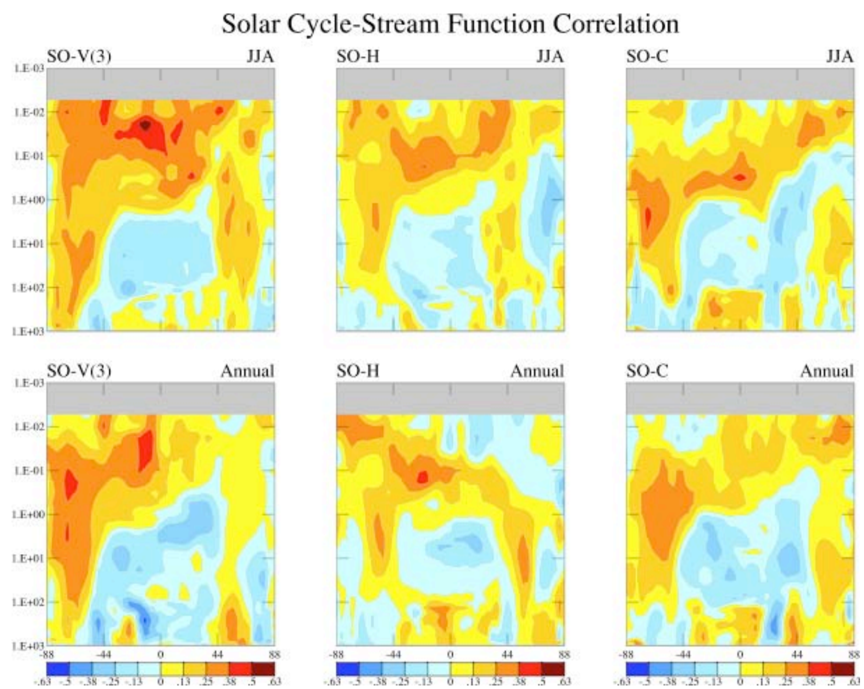
Figure 1. Schematic presentation of a possible mechanism of solar influence on the tropical troposphere through dynamical processes (see text).

Kodera and Shiabata 2006

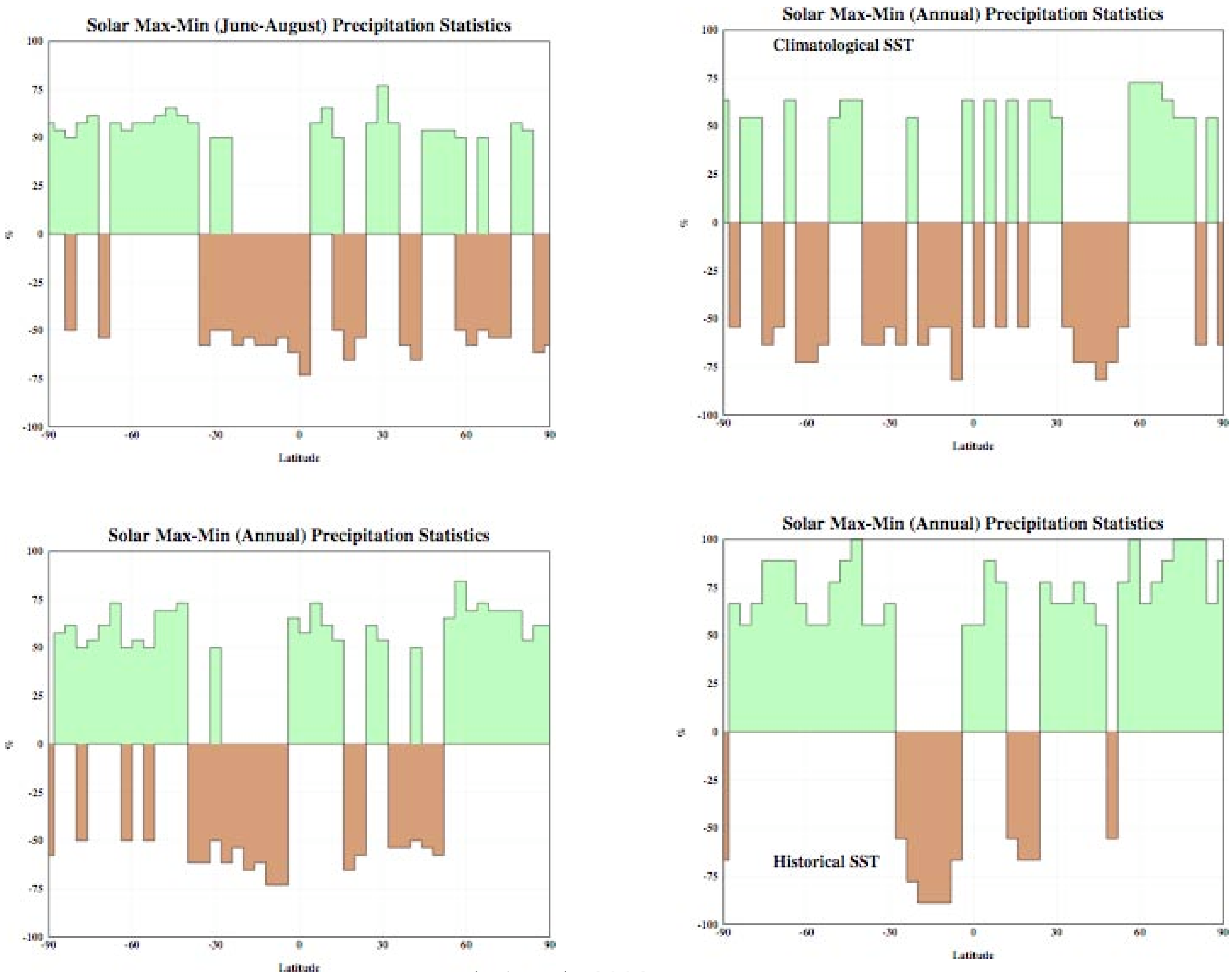


Meeh et al., 2003

FIG. 7. Same as Fig. 6 except for the South Asian monsoon region; the precipitation index is the area-averaged precipitation for 10°S–35°N, 60°–110°E.



Rind et al., 2008



Rind et al., 2008

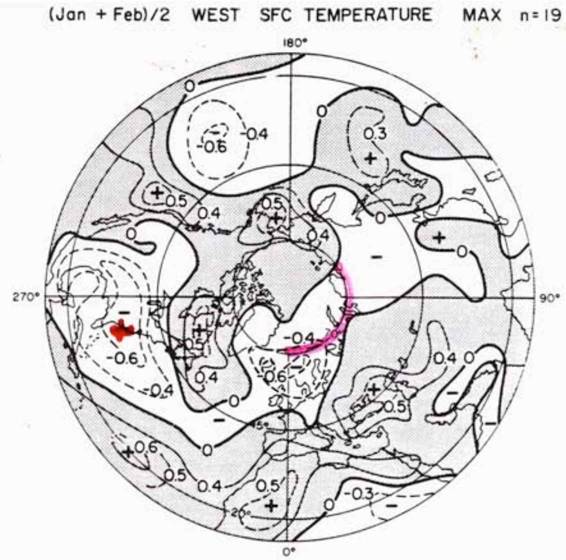


FIG. 8. Lines of equal correlation coefficient: surface air temperature in January–February in west years at stations and in COADS blocks correlated with the 10.7 cm solar flux. Largest possible sample for land stations is 19 years, and for COADS blocks 16 years.

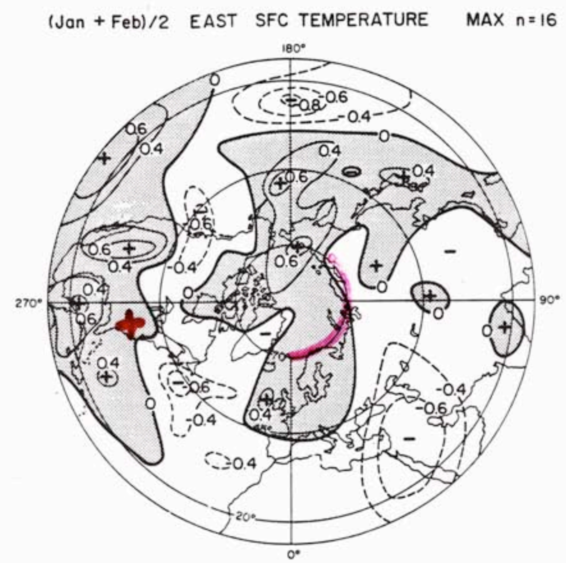


FIG. 10. As in Fig. 8 except for years when the QBO was easterly. Maximum number in a sample is 16 years.

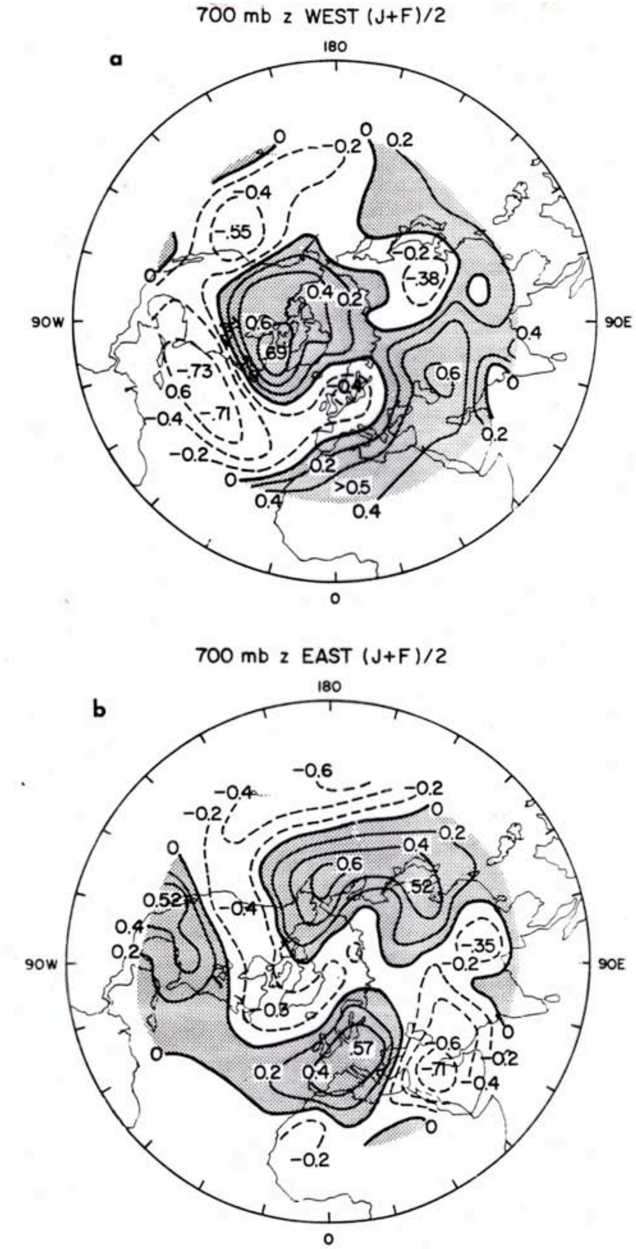


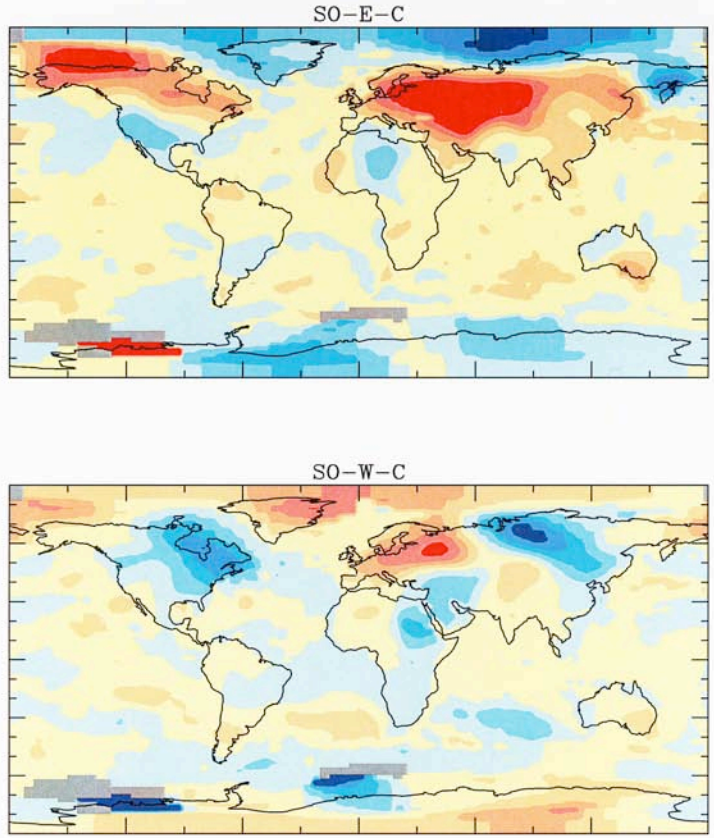
FIG. 12. Lines of equal correlation between 700-mb geopotential height at grid points and the 10.7 cm solar flux, in January–February and for years of (a) westerly and (b) easterly QBO.

Van Loon and Labitzke 1988

GISTEMP Anomalies
1950 -> 2002

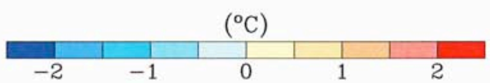
Surface Temperature

Max–Min DJF



Scenario A
E/W Break at 9mb

	Min	Max
E	5	7
W	5	4



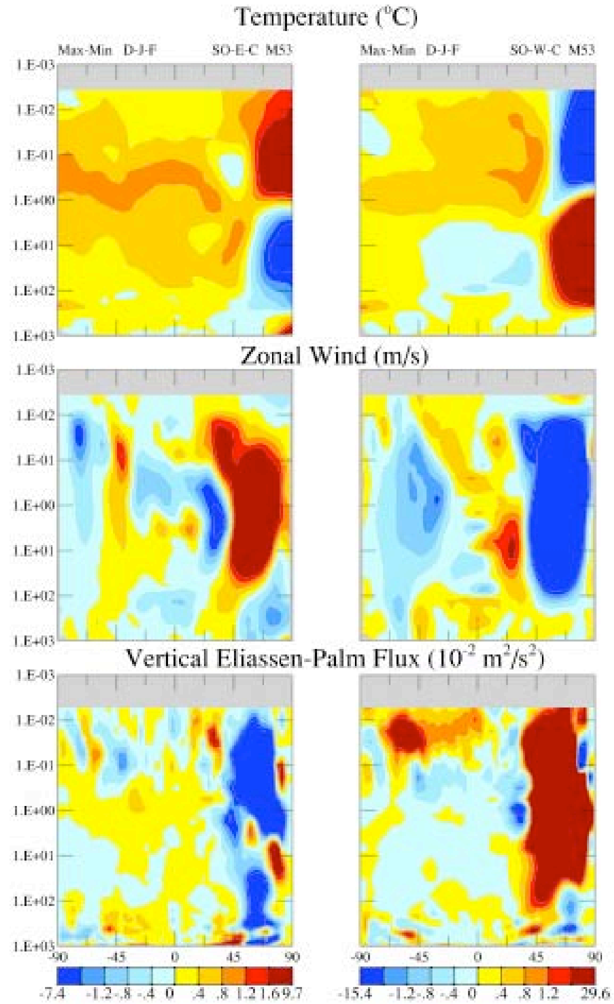
NASA/GISS

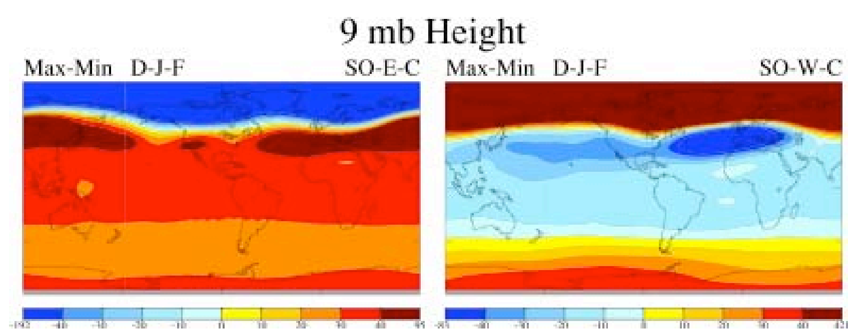
Effect on planetary waves

December-February

Solar max-min with East QBO

Solar max-min with West QBO





Rind et al., 2008

The Near Future…

Lean and Rind 2009

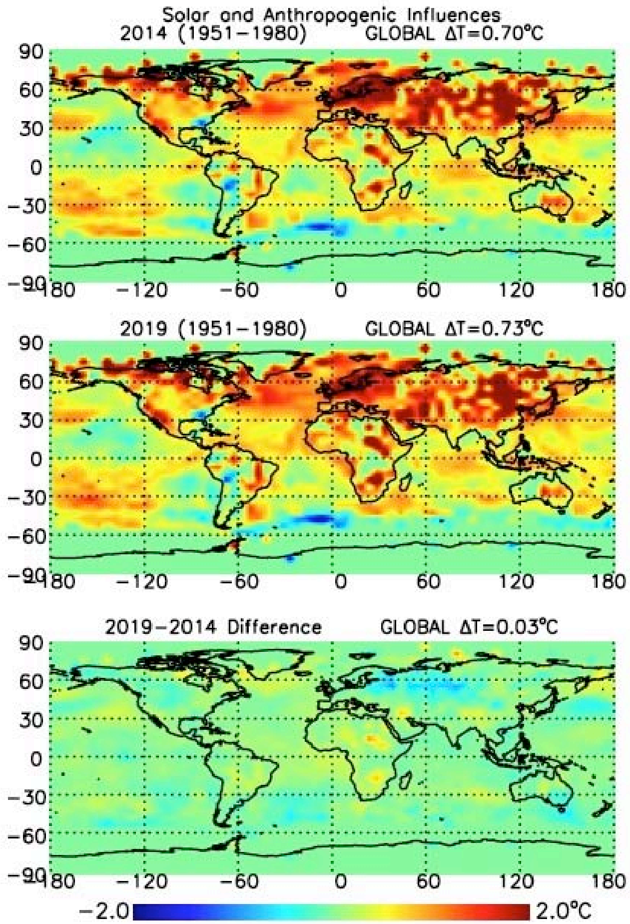


Figure 3. Compared are the regional changes in annual surface temperature forecast for 2014 and 2019, relative to the base period of 1951-1980, corresponding to the global changes in Figure 1. The patterns are derived by using the parameterizations of CRU monthly historical surface temperature records from 1980 to 2008 with ENSO, volcanic and solar activity and anthropogenic forcing on a 5°×5° latitude-longitude grid, together with the forecast anthropogenic and solar time series in Figure 1b.

Conclusions

- Solar variability has likely affected recent decadal temperature trends and will probably continue to do so for the next decade - the overall warming for the past century is almost certainly due to greenhouse gas emissions.
- Solar variability may have contributed to cooler conditions during the last 500 years, although the magnitude of its effect is highly uncertain.
- It's unclear how solar variability relates to ENSO variations.
- Solar variability may affect NAM/NAO phase and NADW production, although it's not obvious that it has any special influence compared to other climate forcings.
- Solar influence on the troposphere appears to be the result of both

  1)"top-down" forcing from solar UV variability, stratospheric ozone changes, and stratospheric temperatures affecting tropospheric stability

  2) "bottom-up" through TSI influence on the surface, perhaps especially in the subtropics
- These effects seem capable of influencing the Hadley circulation and tropical (monsoon) precipitation, as recorded in some modern and paleo-records.
- They may also affect planetary waves and extratropical winter phenomena, perhaps in association with the QBO, although this has yet to be proven.
- With current estimates of future climate forcing, solar variability may produce a period of little global temperature change during the 2014-2020 time period, similar to what has been observed over the last 10 years.

$$\overline{v'q'} = -\partial \frac{\overline{u'v'}}{\partial y} + \frac{f_0}{\rho_0} \frac{\partial}{\partial z} \left(\frac{\rho_0}{N^2} \overline{v' \frac{\partial \Phi'}{\partial z}} \right)$$

2 terms: 1)change of eddy angular momentum transport with latitude
2)change of eddy heat transport with altitude

MORE POLAR COOLING ->MORE NEGATIVE NAO

Table 3. Northern Hemisphere changes in SST gradient experiments. Results for the experiments using an increased latitudinal SST gradient are shaded.

	EXP I	EXP D	EXP CI	EXP WD
ΔSURF TEMP	0.24	-0.06	***-4.94***	***6.17***
ΔSURF TEMP 4N	***2.7***	***-2.6***	***-1.8***	***1.9***
ΔSURF TEMP 74N	***-2.0***	***2.2***	***-13.4***	***22.1***
Δ320MB	***2.9***	***-2.5***	***-2.7***	***3.3***
Δ 26MB TEMP	***-0.7***	***0.5***	***-0.5***	***1.0***
ΔAO INDEX SLP	-1.16	1.16	***-6.20***	***5.58***
ΔNAO (MB)	***-4.67***	-1.33	***-5.90***	***3.34***
ΔAO INDEX 100MB (M)	***111***	-38	-29	49
ΔAO INDEX 30MB (M)	***267***	24	21	***185***
ΔTROP EKE (%)	***10.9***	-2.2	***9.2***	***-9.4***
ΔTROP WAVE#1-4 (%)	***7.6***	1.0	3.1	***-6.0***
ΔEDDY NT ANG MOM(%)	12.7	***-20.9***	-1.5	-6.0
ΔEDDY NT QGPV (%)	-9.4	3.6	***-28.6***	***35.1***

NAM/NAO Effect

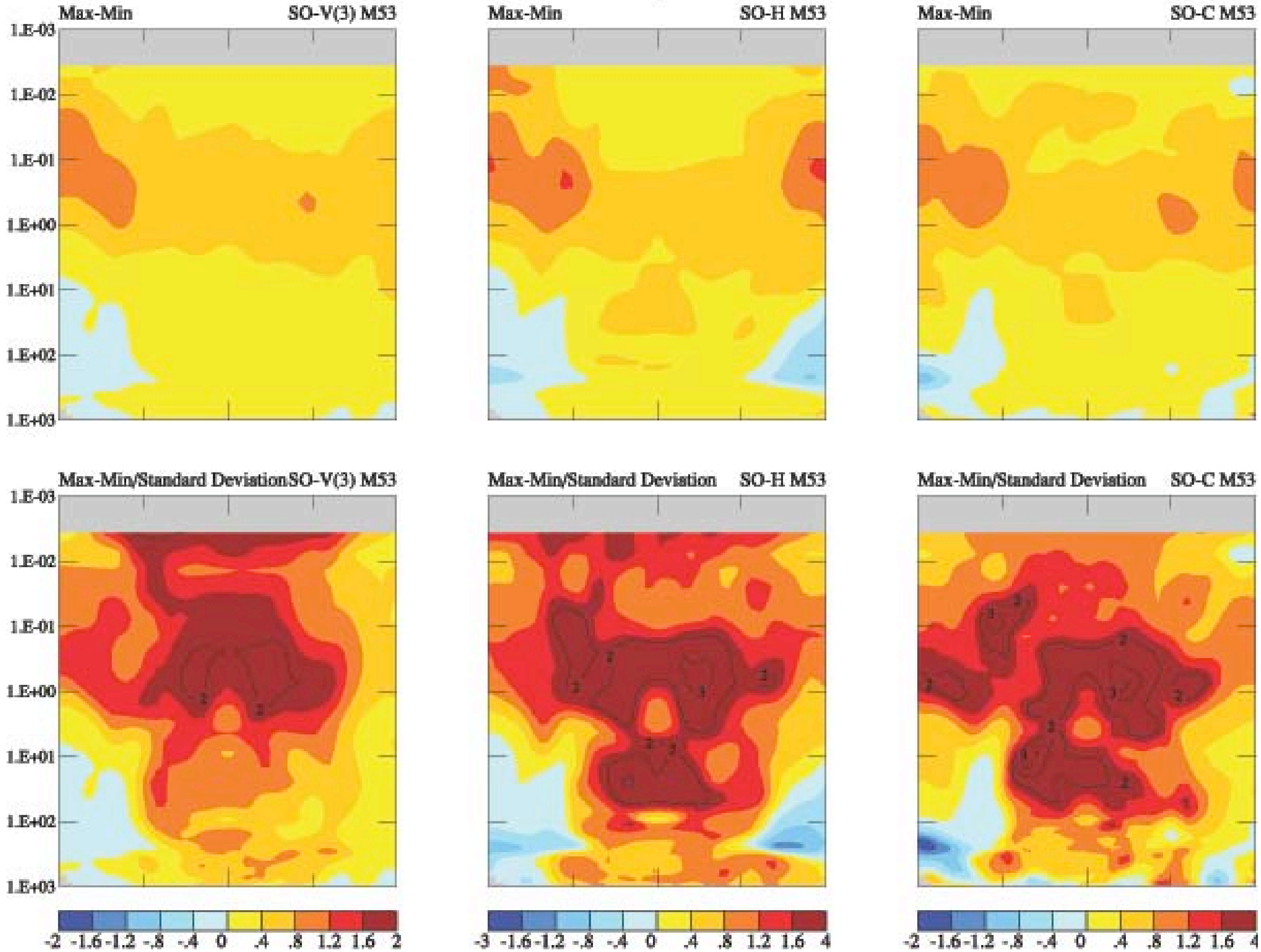
Table 1a. Annual temperature changes in the variable SST experiments. The experiments in which the temperature changes in the troposphere and stratosphere are of the same sign are shaded. Values in parenthesis refer to the latitudinal slices listed in the column heading. Significant results at the 95% confidence level are in bold italics.

Experiment	**SURF**	**346-203MB (D-F 50°-90°N)**	**Trop**	**68Mb (16N-16S)**	**1.5 MB**	**Strat**
2CO2	***5.15***	***7.9 (3.4)***	***6.13***	***1.7 (3)***	***-8.6***	***-0.71***
2CO2 Strat	***0.54***	***1.1*** (1.0)	***0.77***	0.5 ***(1)***	***-8.7***	***-1.32***
2H20 Strat	***0.46***	***0.8*** (0.4)	***0.45***	-0.6 (0)	***-1.7***	***-1.8***
+2% TSI	***4.73***	***7.8 (3.0)***	***5.94***	***3.6 (4)***	***1.4***	***2.78***
Volc	***-2.55***	***-3.6 (-1.6)***	***-2.91***	0.10 ***(2.3)***	-0.10	-0.01
Sulf+Soot	***-4.59***	***-1.7 (-1.6)***	***-1.51***	***34.8 (42)***	***6.6***	***31.28***
-2% TSI	***-4.09***	***-5.6 (-1.6)***	***-4.68***	***-1.8*** (0)	***-1.4***	***-1.91***
No O3 LS	***-1.15***	***-2.4 (-1.2)***	***-2.04***	***-8.8 (-12)***	0.1	***-5.71***

Table 1b. As in Table 1a but for the specified SST experiments.

Experiment	**SURF**	**346-203MB (D-F 50°-90°N)**	**Trop**	**68MB (16N-16S)**	**1.5 MB**	**Strat**
2CO2	***0.36***	***0.26*** (-0.7)	***0.23***	***-1.5 (-1.5)***	***-8.6***	***-3.1***
2CO2 Strat	0.0	***0.30*** (0.4)	0.08	-0.4 (1)	***-8.3***	***-1.4***
2H20 Strat	0	-0.1 (0.0)	0.03	***-0.8*** (-1)	***-1.7***	***-1.3***
+2% TSI	***0.16***	***0.4*** (0.0)	***0.25***	0.5 (0)	***1.1***	***0.58***
Volc	***-0.10***	0.1 (0.0)	0	***1.2 (2.2)***	0.0	***0.8***
Sulf+Soot	-0.04	***3.8*** (-0.2)	***1.06***	***36.3 (41)***	***5.9***	***32.0***
-2% TSI	***-0.15***	***-0.3*** (0.8)	***-0.25***	-0.4 (-1)	***-1.1***	***-0.54***
No O3 LS	-0.03	***-0.5*** (-0.6)	-0.06	***-8.8 (-11)***	-0.1	***-4.36***

Annual Temperature (ºC)



Rind et al., 2008