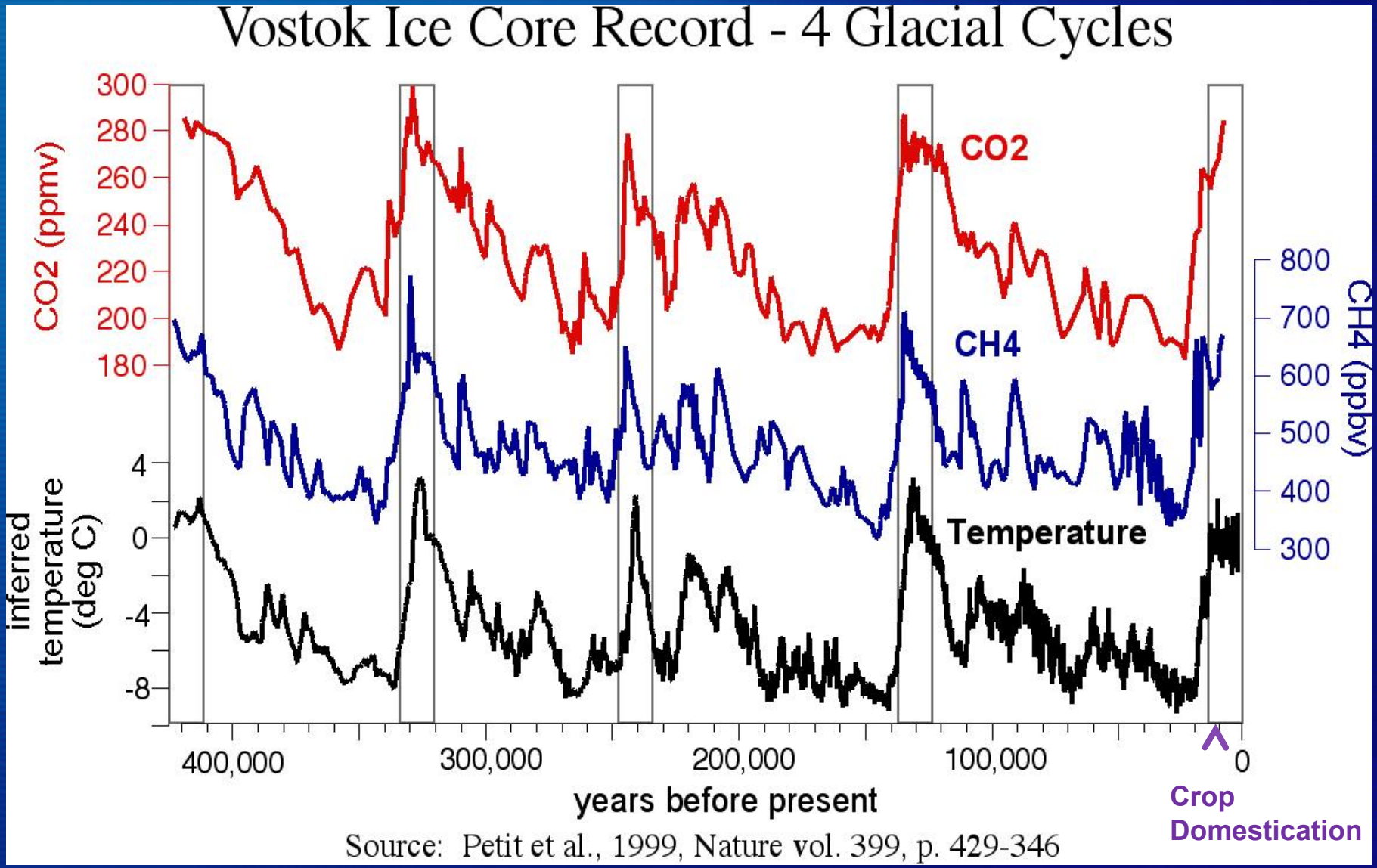
The Role of Solar Influences in Climate Change

Don Wuebbles
Department of Atmospheric Sciences
University of Illinois
Urbana, IL

June 13-17, 2010

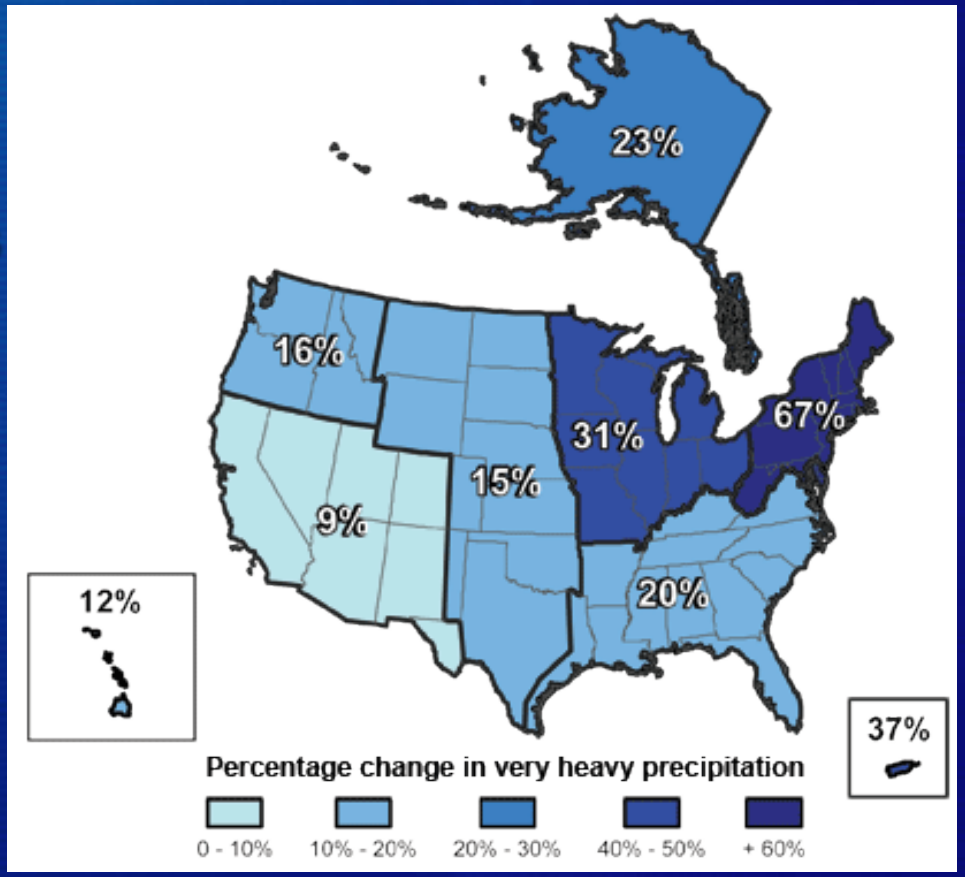
400,000 Years of Climate Change

(Prior to the Industrial Revolution)



The Climate is changing throughout the world, including the U.S.

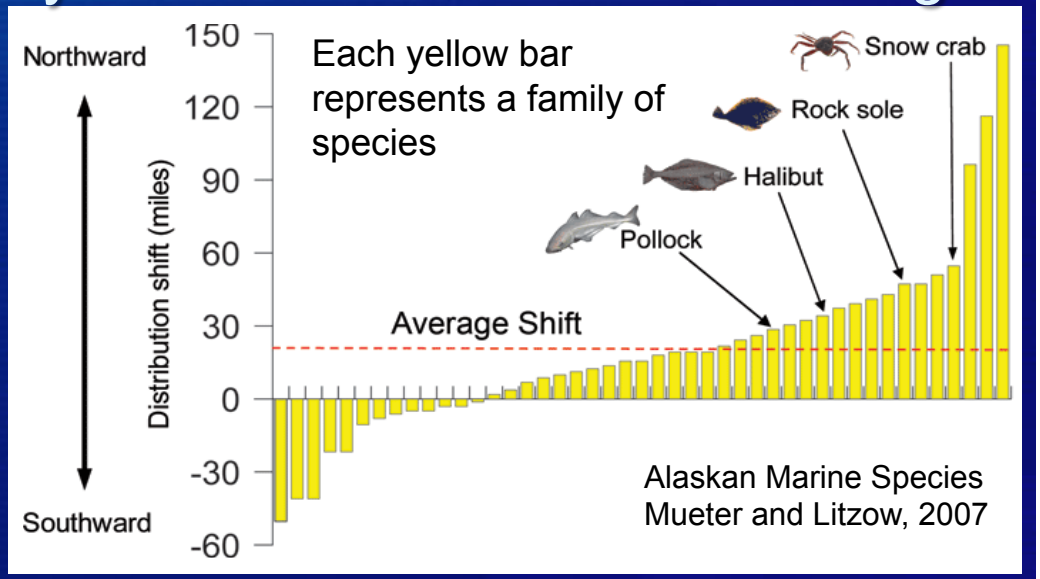
- Temperature rise
- Sea-level rise
- Increase in heavy downpours
- Rapidly retreating glaciers
- Thawing permafrost
- Lengthening growing season
- Lengthening ice-free season in the ocean and on lakes and rivers
- Earlier snowmelt
- Changes in river flows



USGCRP, 2009

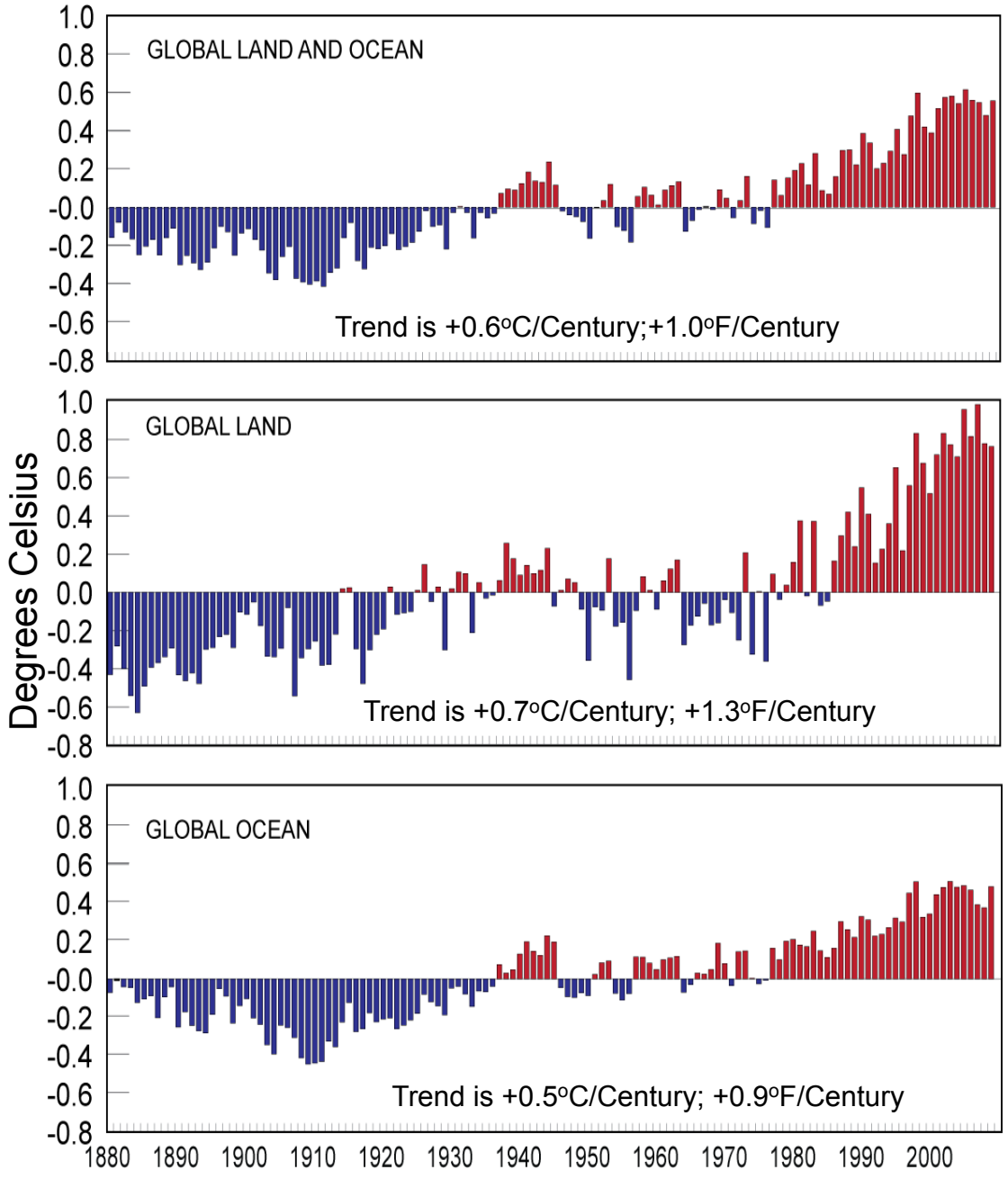
Plants and Animals are a Signature of the Warming

- **Plants are blooming 1-3 days/decade earlier**
  - "Altered timing of spring events has been reported for a broad multitude of species and locations" (IPCC 2007).
- **Animals species are moving poleward**
  - "Many studies of species abundances and distributions corroborate predicted systematic shifts related to changes in climatic regimes" (IPCC 2007)



From GCCI Report, USGCRP, 2009

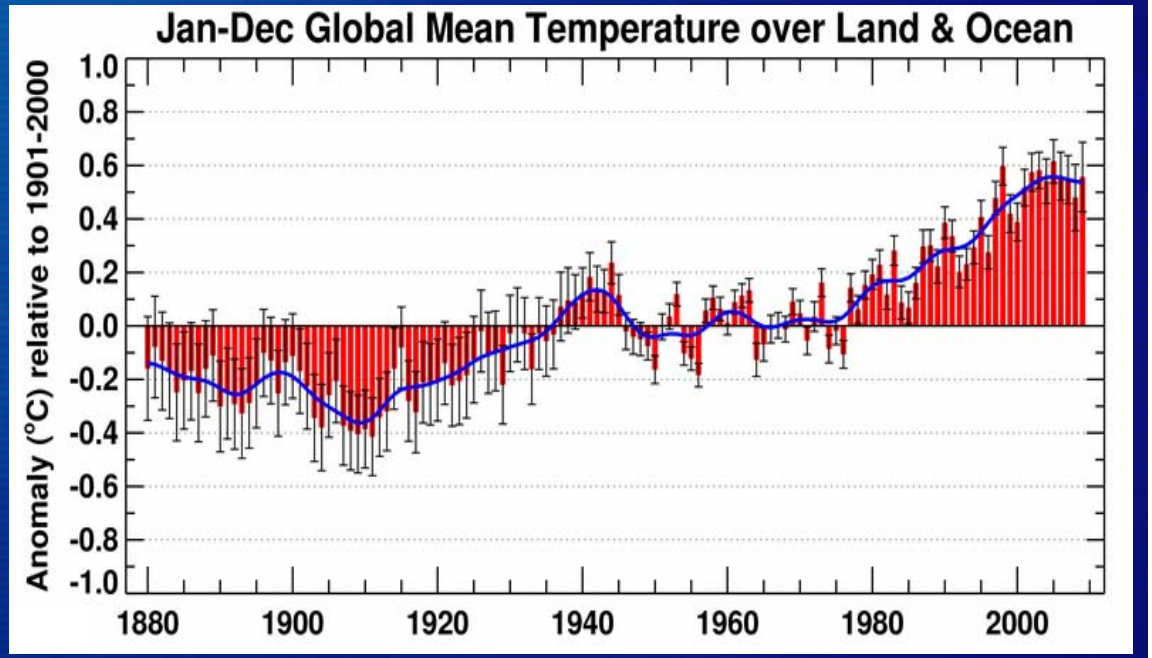
Jan-Dec Global Surface Average Temperature Anomalies



Updated from NCDC/NOAA/NESDIS (Smith *et al.*, 2008)

How Large is the Uncertainty in Global Temperatures?

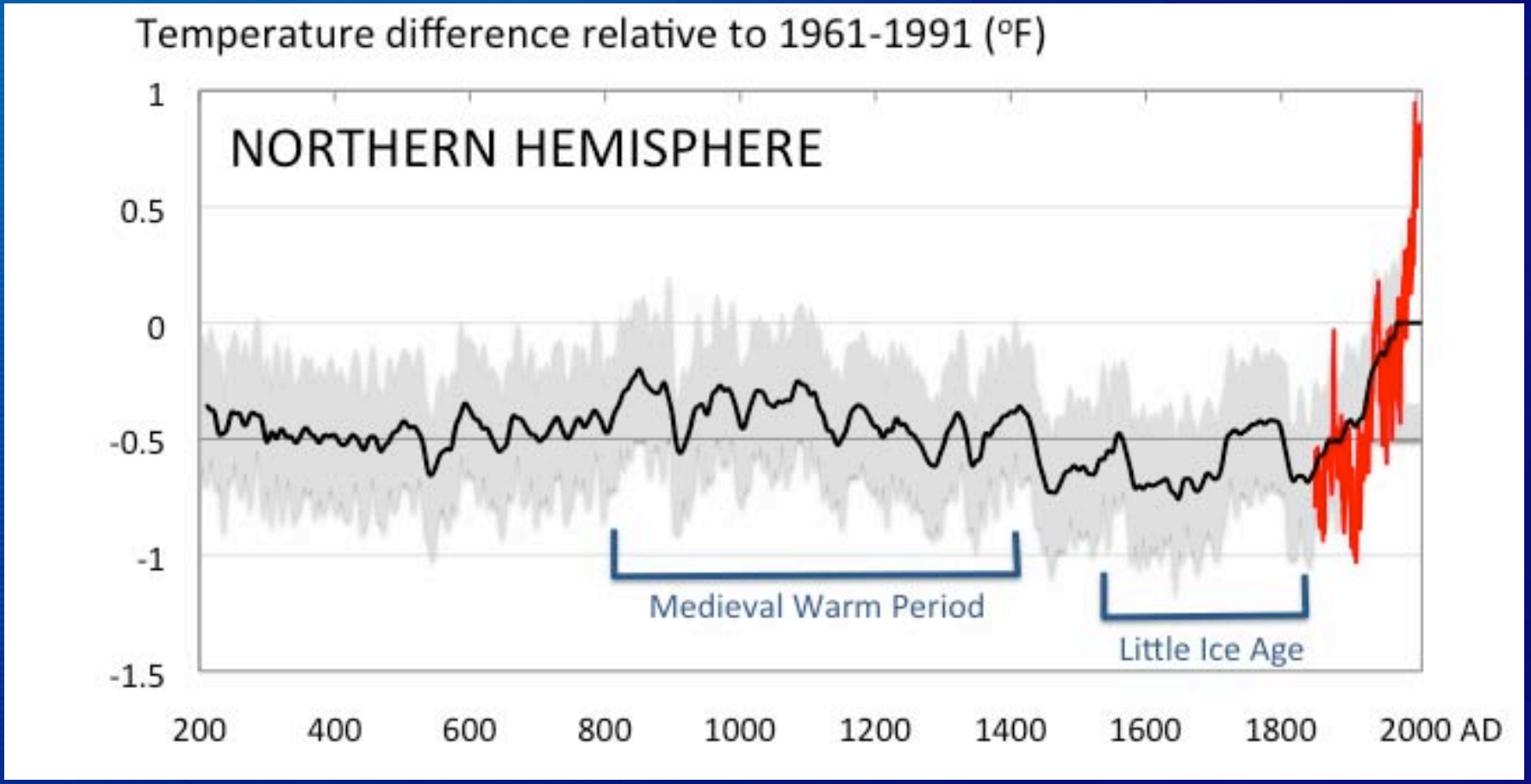
- Uncertainty in the global temperature is due to sampling, instrumental, and platform changes
- Uncertainties make it difficult to say with complete confidence that 2005 was warmer than 1998, for example.



- Uncertainties do not bring into question the century-scale and multi-decadal warming trend observed since 1880.

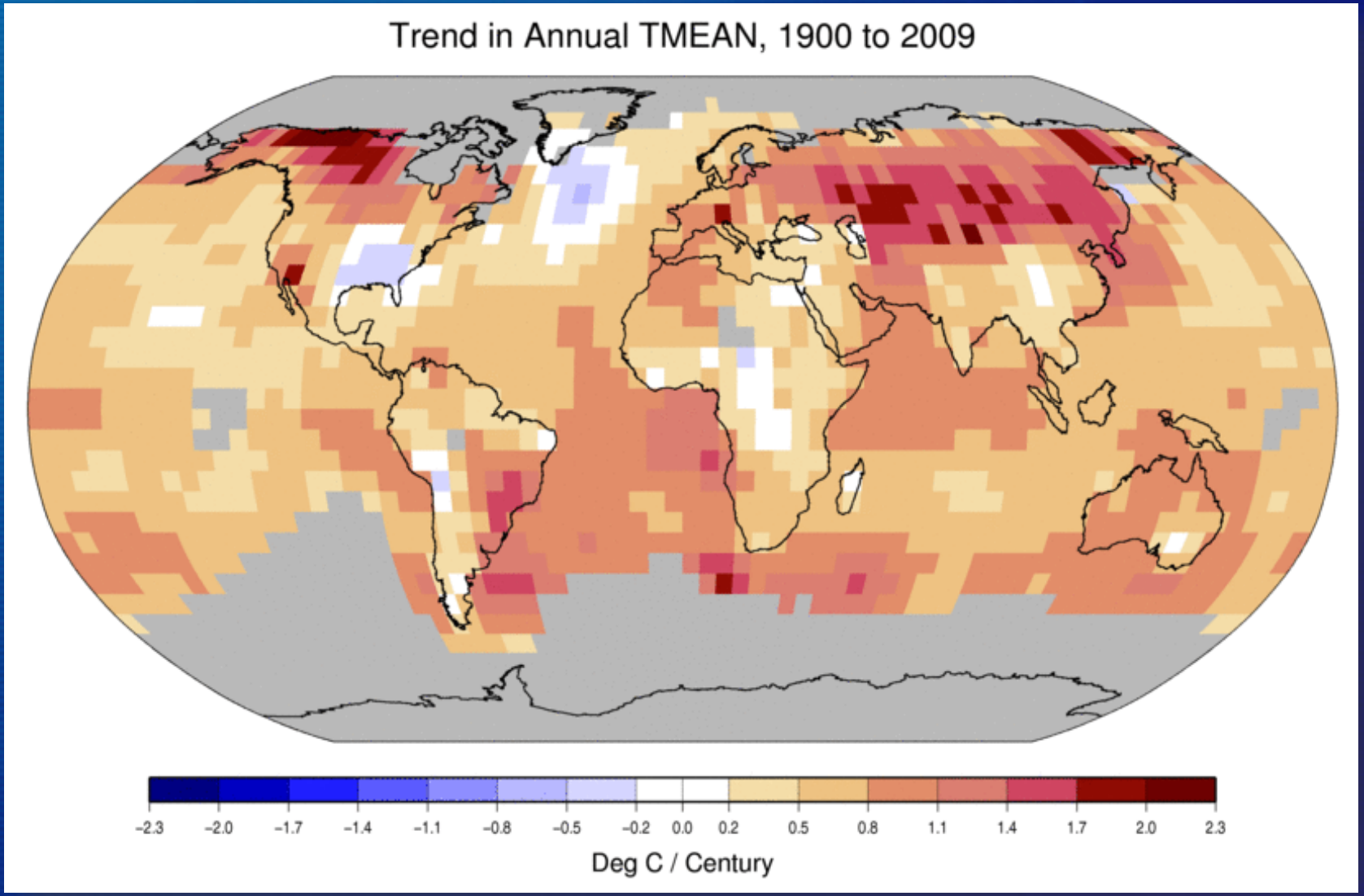
From Tom Karl, NOAA NCDC

Conditions today are unusual in the context of the last 2,000 years …



Updated from Mann et al., 2009

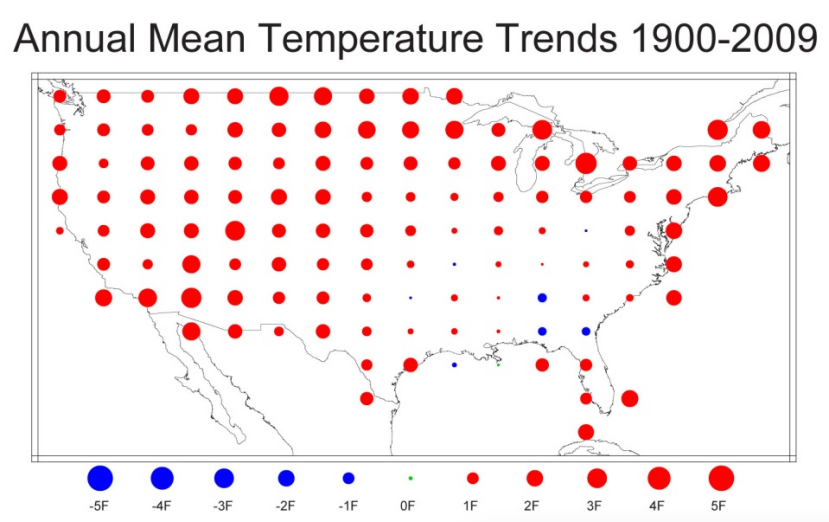
Global Warming is not Uniform Around the Globe

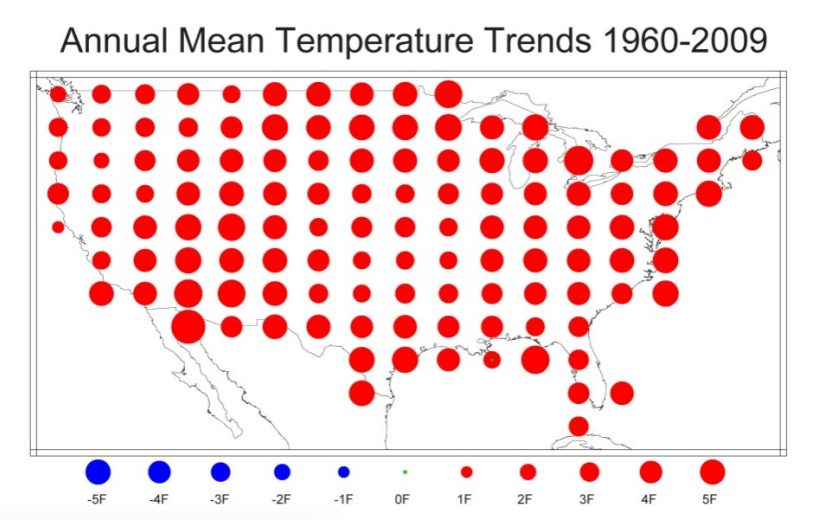


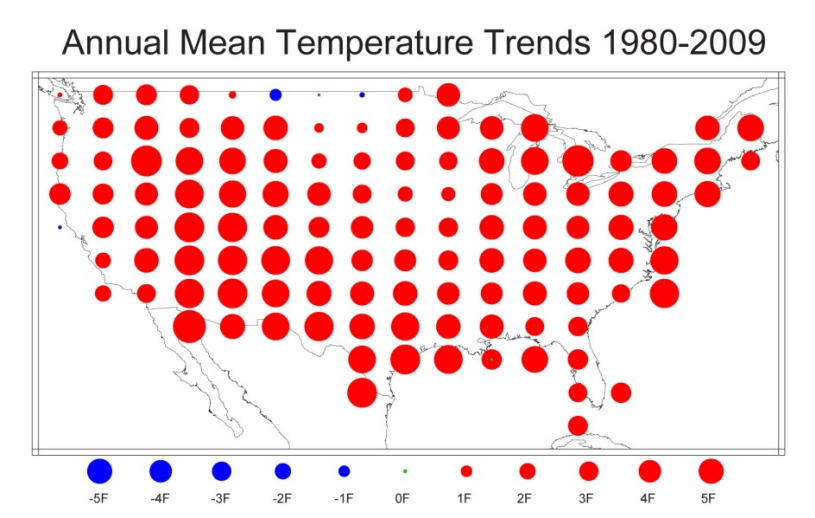
From Tom Karl, NOAA NCDC

Temperature

U.S. average temperature has risen more than 2°F over the past 50 years

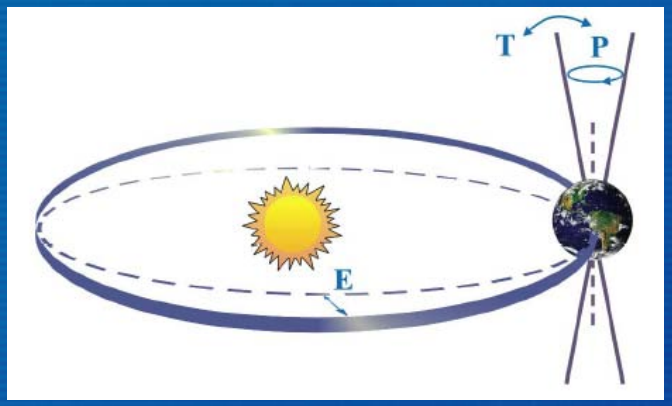




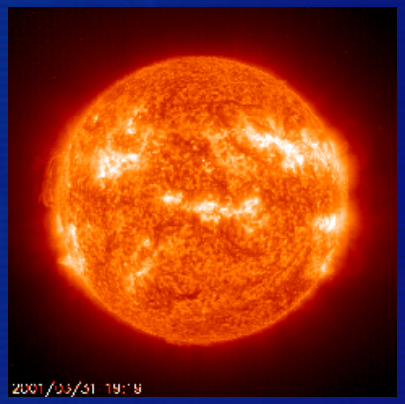


From Tom Karl, NOAA NCDC

Natural factors can affect climate

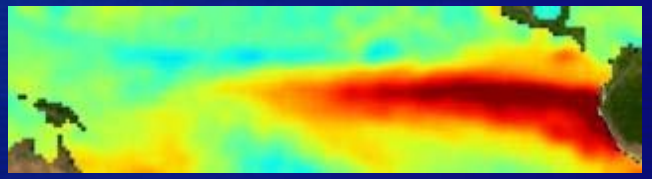


Variations in the Earth's orbit
(Milankovic effect)



Variations in the energy
received from the sun

Stratospheric
aerosols from
energetic
volcanic eruptions

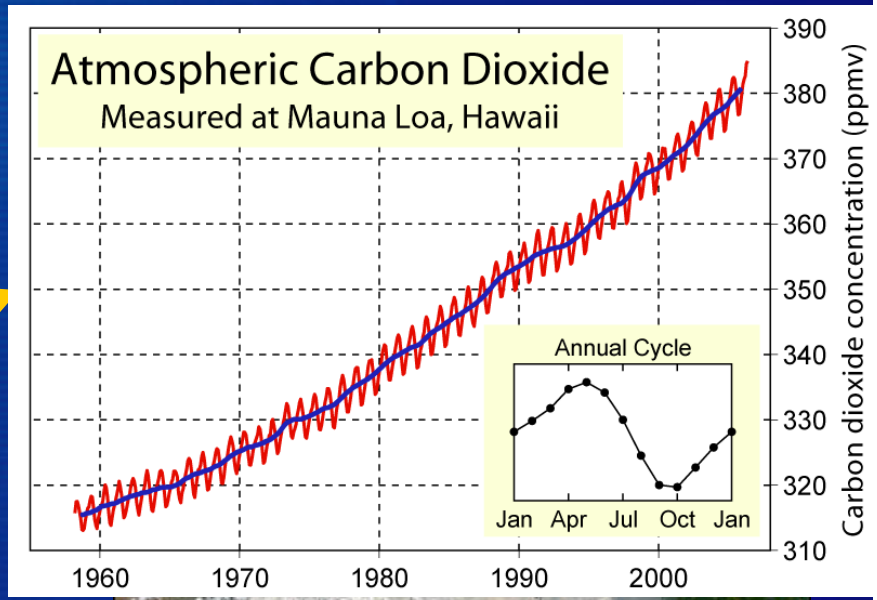


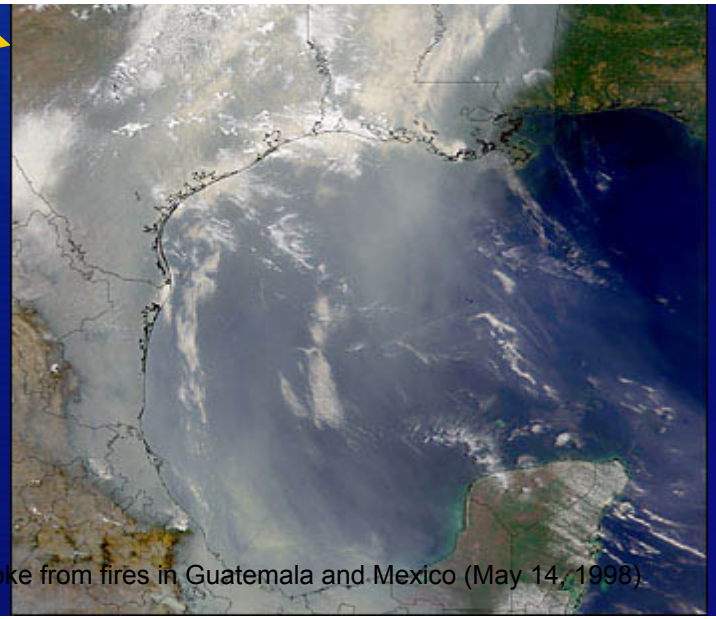
Internal variability of the coupled
atmosphere-ocean system
(for example, El Nino, NAO)

Human factors also influence climate

Non-natural mechanisms

- Changes in atmospheric concentrations of radiatively important gases
- Changes in aerosol particles from burning fossil fuels and biomass
- Changes in the reflectivity (albedo) of the Earth's surface





Smoke from fires in Guatemala and Mexico (May 14, 1998)

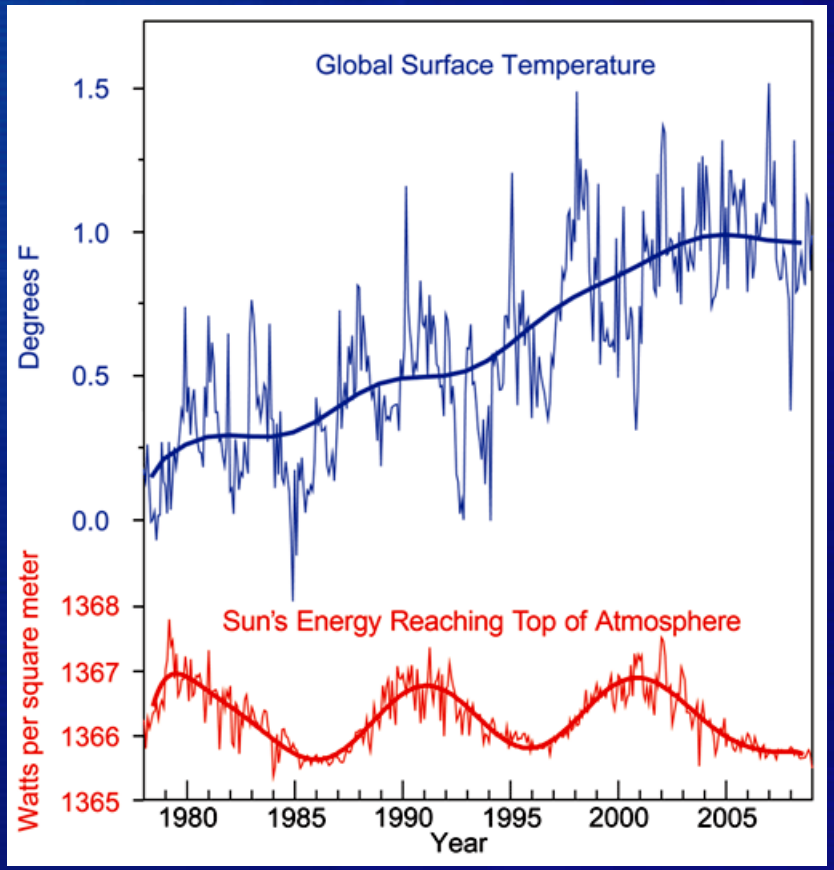
Many lines of evidence for conclusion of a "discernible human influence"

1. **"Basic physics" evidence**
   - Physical understanding of the climate system and the heat-trapping properties of greenhouse gases
2. **Qualitative analysis evidence**
   - Qualitative agreement between observed climate changes and model predictions of human-caused climate changes (warming of oceans, land surface and troposphere, water vapor increases, *etc.*)
3. **Paleoclimate evidence**
   - Temperature reconstructions enable us to place the warming of the 20th century in a longer-term context
4. **Fingerprint evidence**
   - Rigorous statistical comparisons between modeled and observed patterns of climate change

There is strong evidence that the climate change occurring is primarily human induced

Human fingerprints have been identified in many aspects of climate change

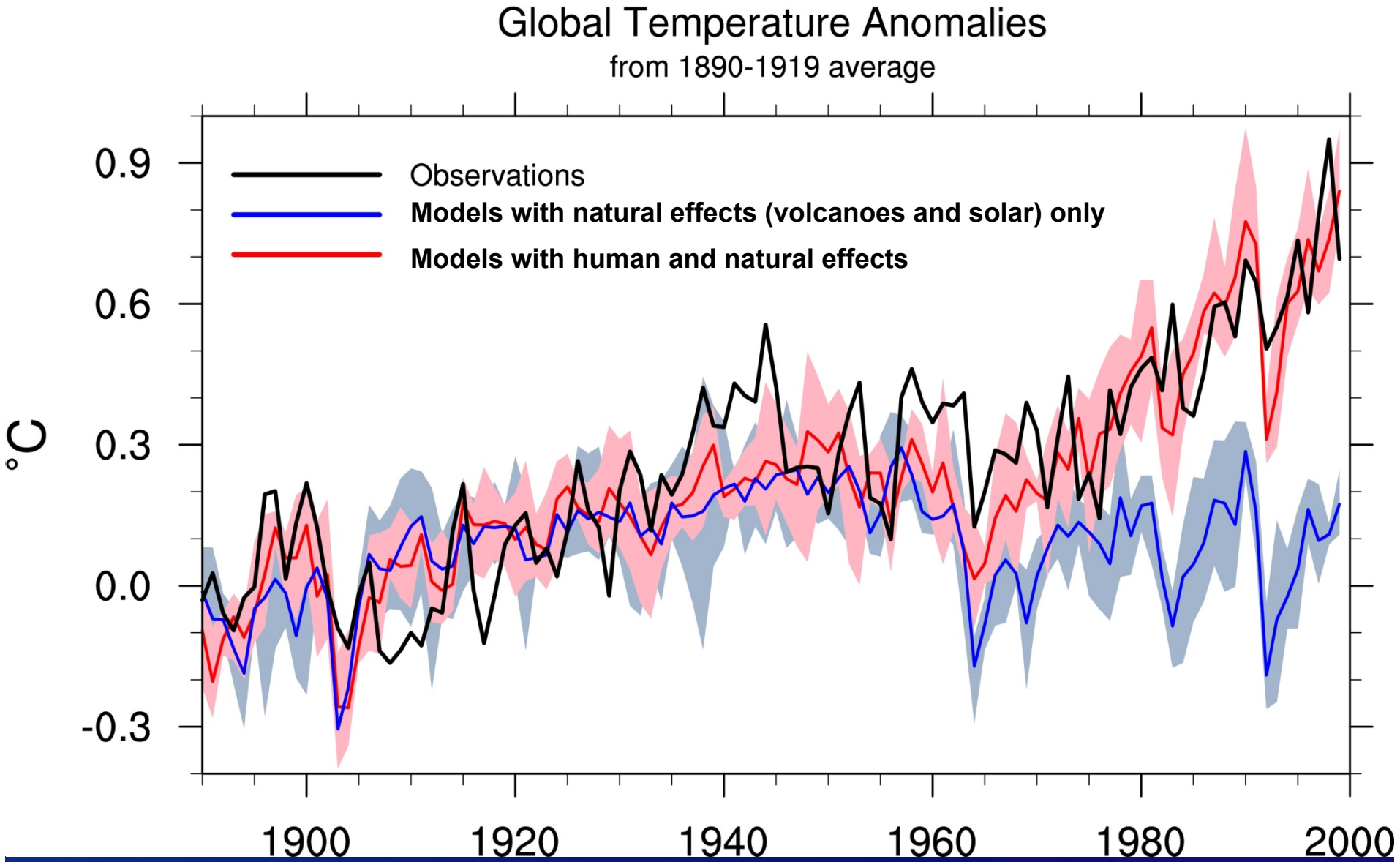
- Surface and vertical temperature
- Stratospheric and tropospheric temperature change
- Height of the tropopause
- Precipitation
- Vertical structure of upper-ocean temperature changes
- Ocean heat content
- Atmospheric moisture
- Arctic sea ice
- Sea-surface temperature changes in hurricane formation regions



USGCRP, 2009

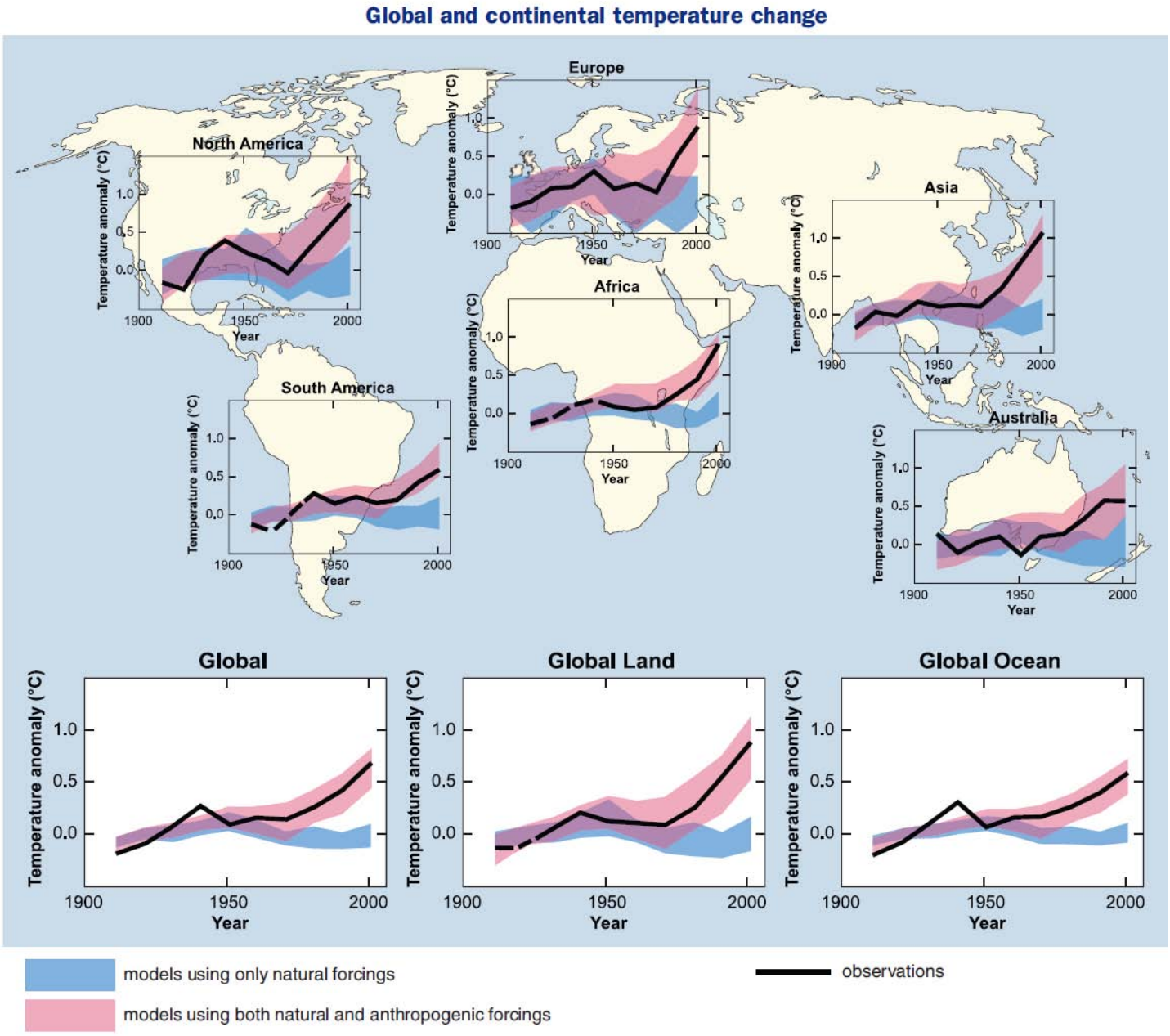
So, how do we know it is not the Sun?

Climate models: Natural processes do not account for observed 20th century warming after 1965



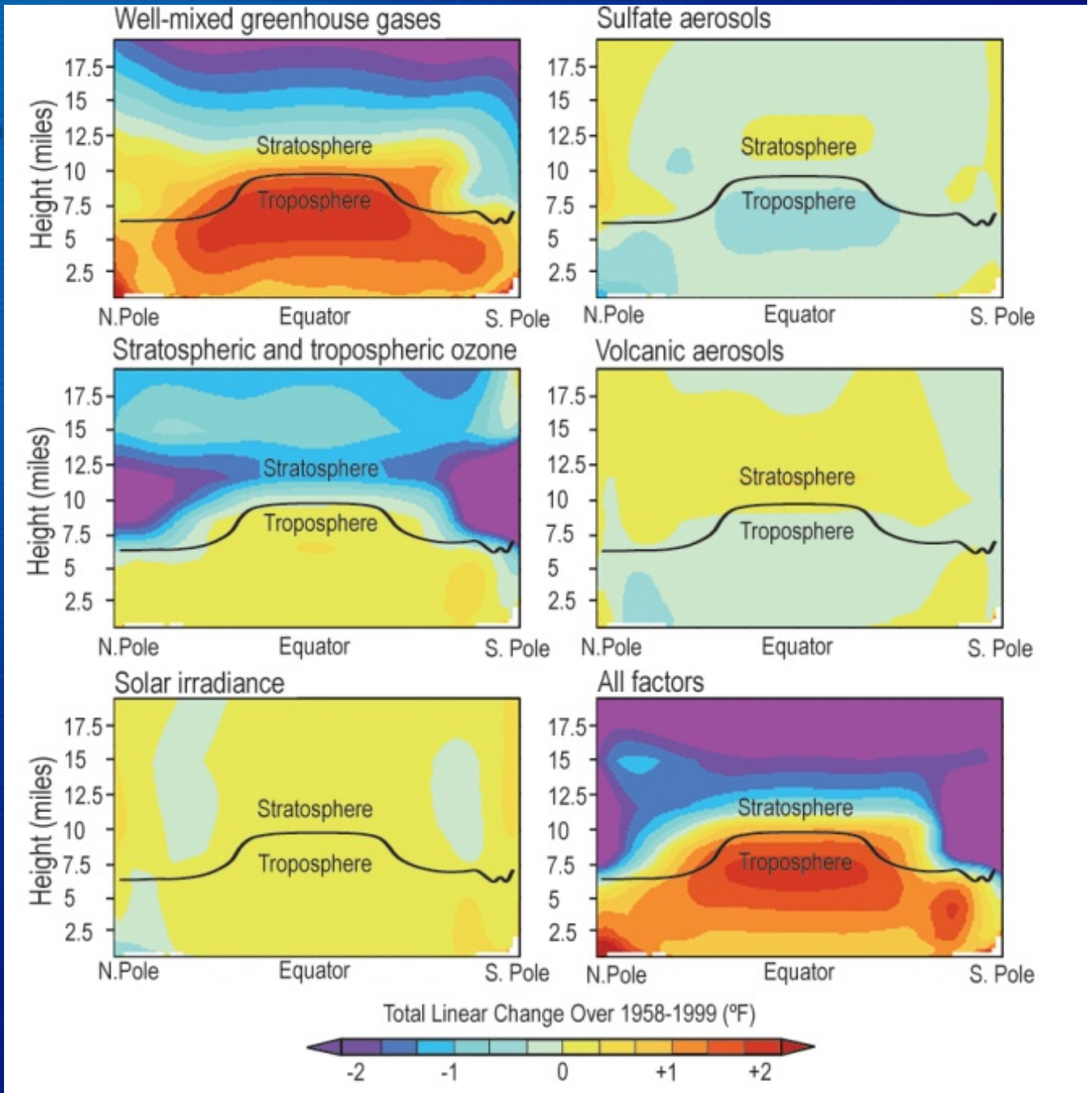
IPCC, 2007

Natural versus human forcing on climate



IPCC, 2007

Fingerprints of 20th century climate forcings

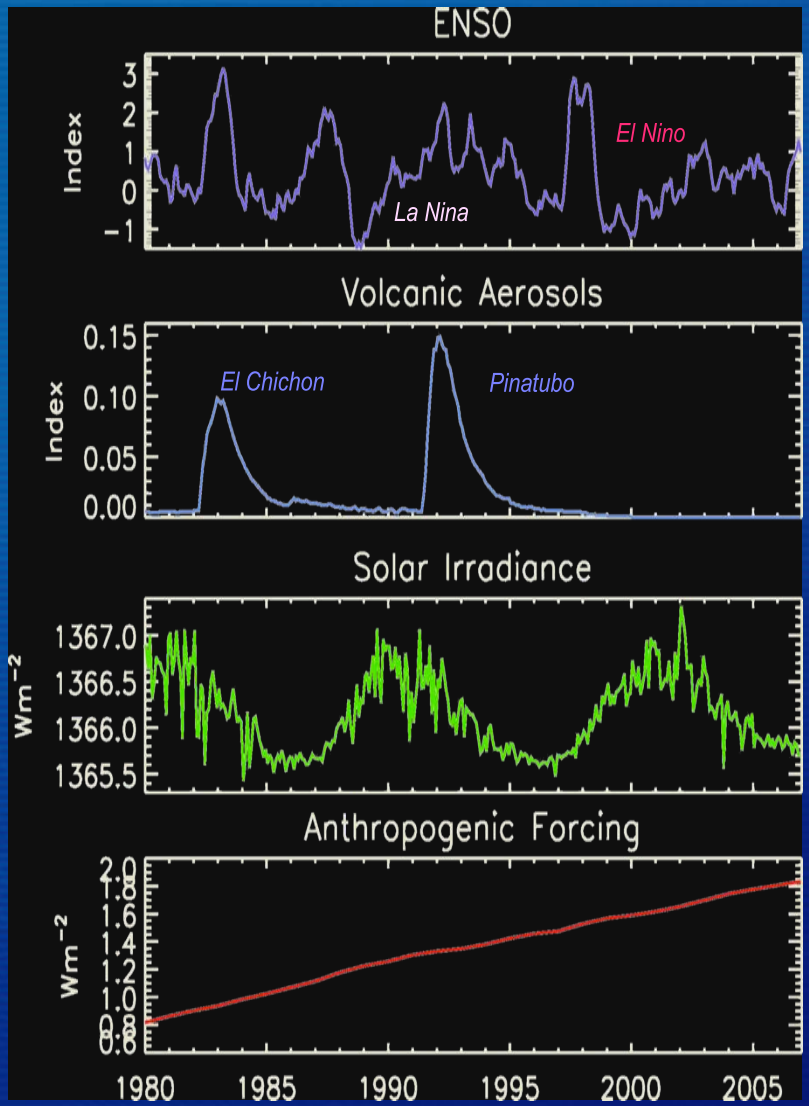


Santer et al.

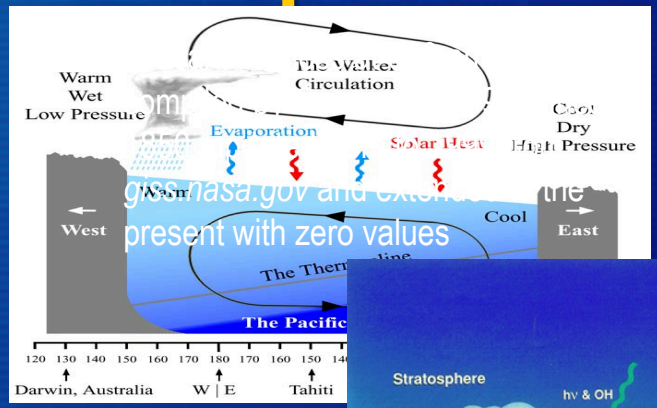
Nonetheless, deniers of human driven "global warming" will still argue that it is the Sun:

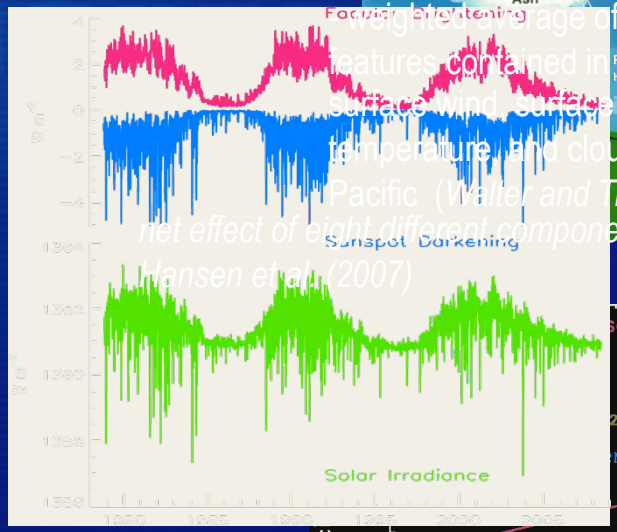
1. **Variations in the solar irradiance ("recovering from the Little Ice Age")**
2. **Solar Cycle Length correlations with temperature**
3. **Galactic Cosmic Rays affecting clouds**

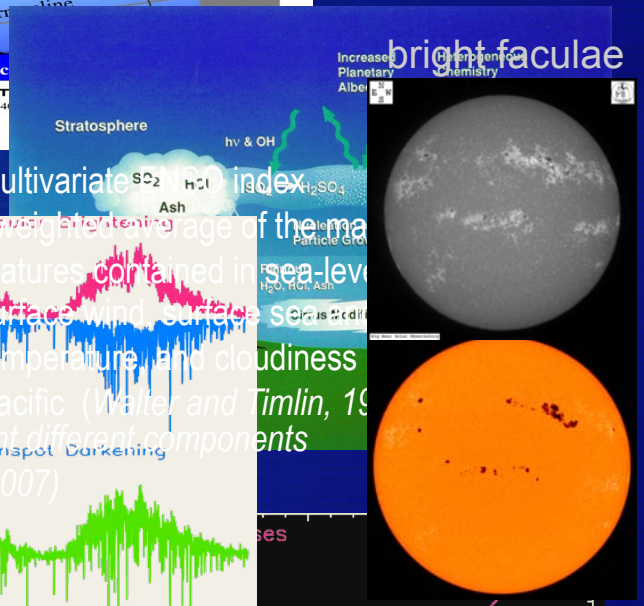
Natural and Anthropogenic Climate Influences in the Space Era



From Lean and Rind (2009)

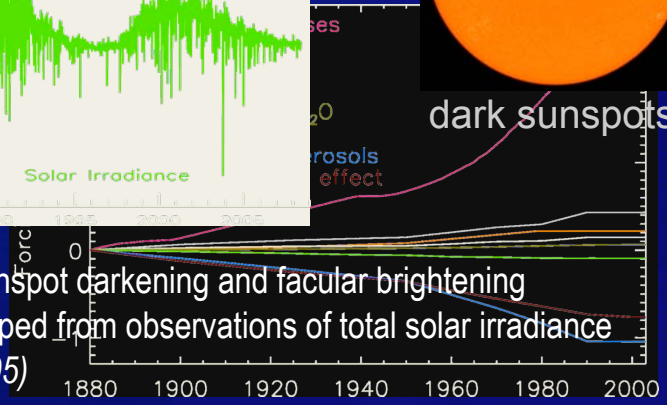






bright faculae

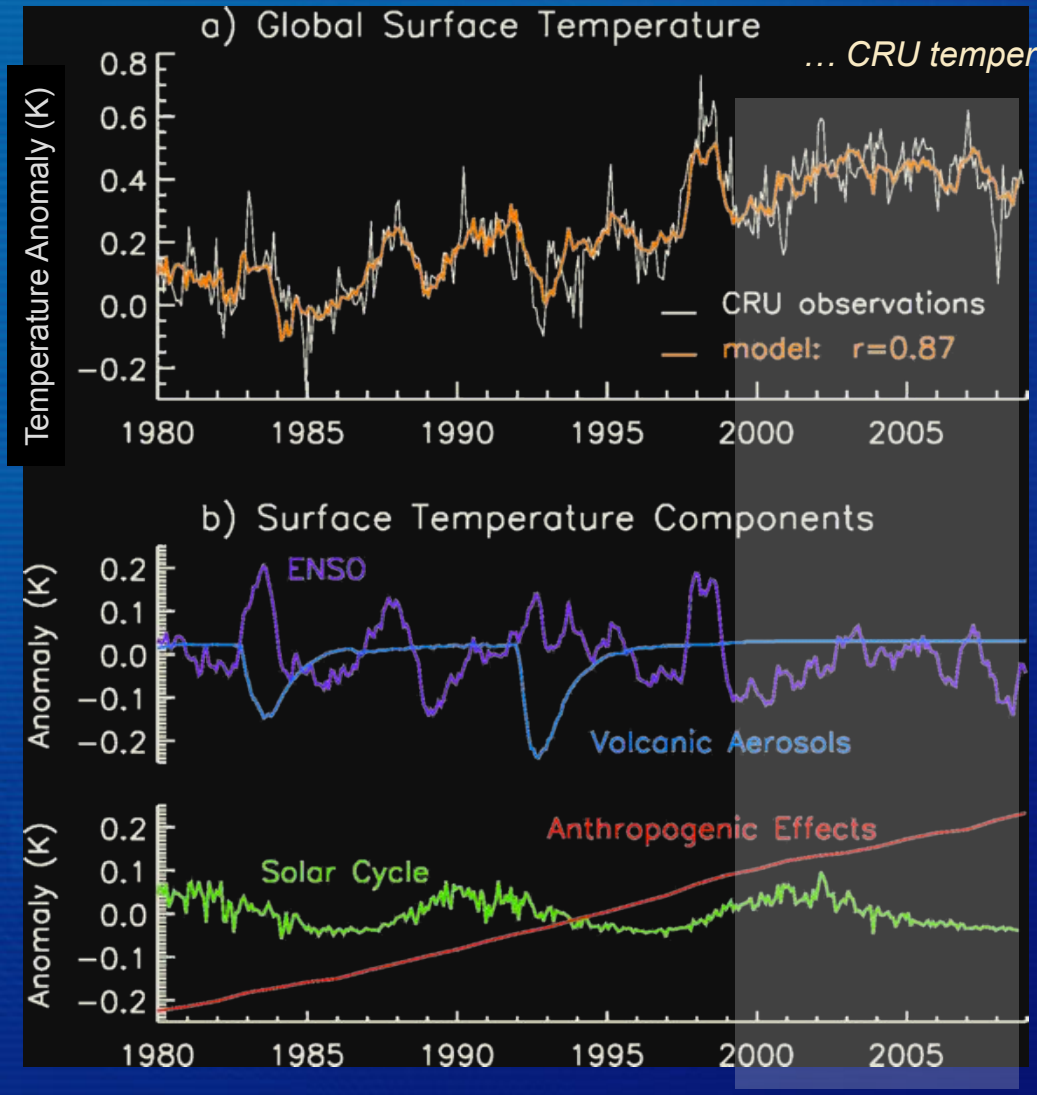
dark sunspots



Net effect of sunspot darkening and facular brightening
- model developed from observations of total solar irradiance
(*Lean et al. 2005*)

Global Surface Temperature Response to Natural and Human Influences: 1980-2008

Lean and Rind (2009)



… CRU temperature data, Univ. East Anglia, UK

Combined ENSO + volcanic aerosols + solar activity + anthropogenic effects explain 76% of observed temperature variance

+0.2°C 1997-98 "super" ENSO

-0.3°C Pinatubo Volcano

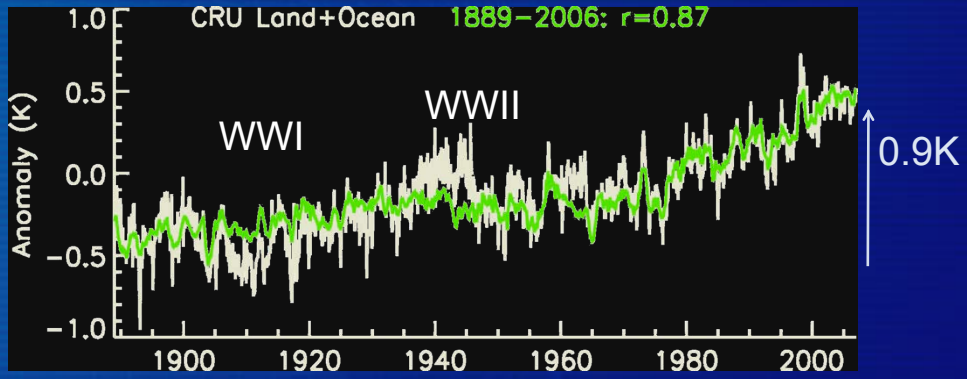
+0.1°C Solar cycle 23

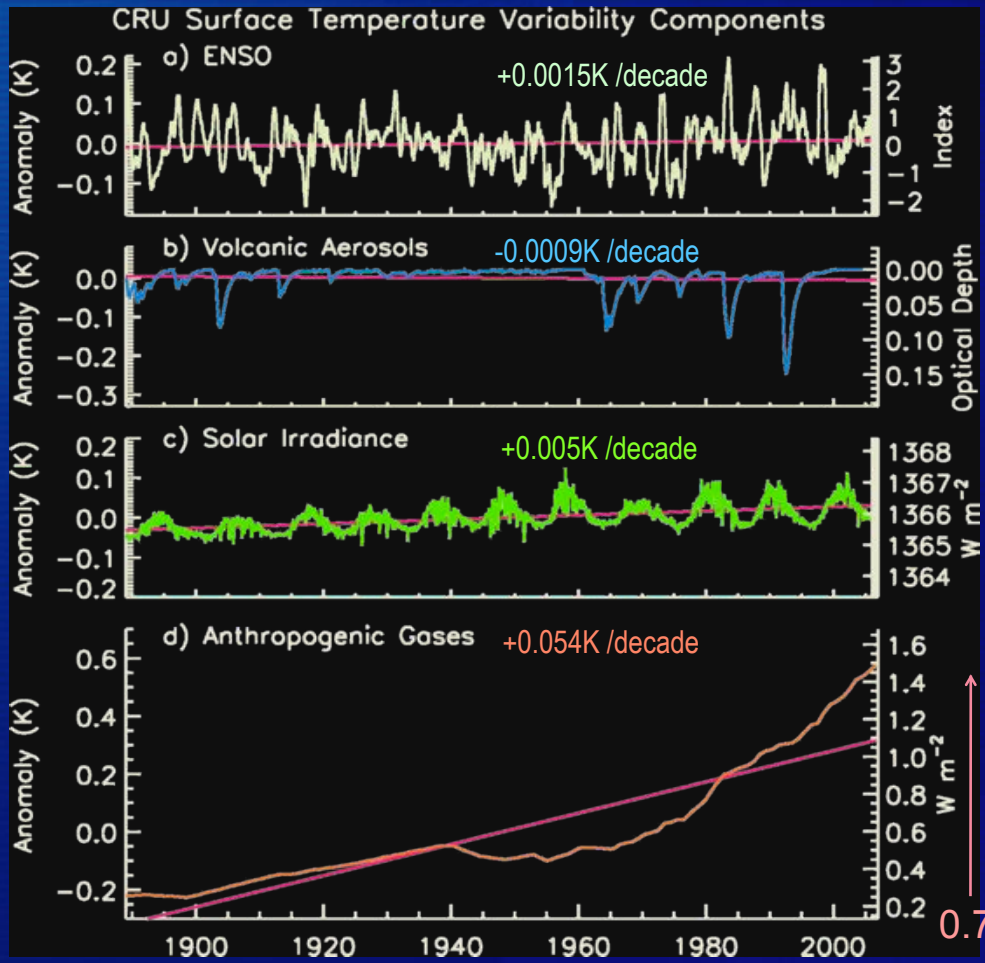
+0.4°C Anthropogenic effects 1980-2006

Earth's Surface Temperature Change Since 1890

Decompositions of *historical* and *recent* global surface temperatures give consistent individual natural and anthropogenic components:

Natural components account for <15% of warming since 1890

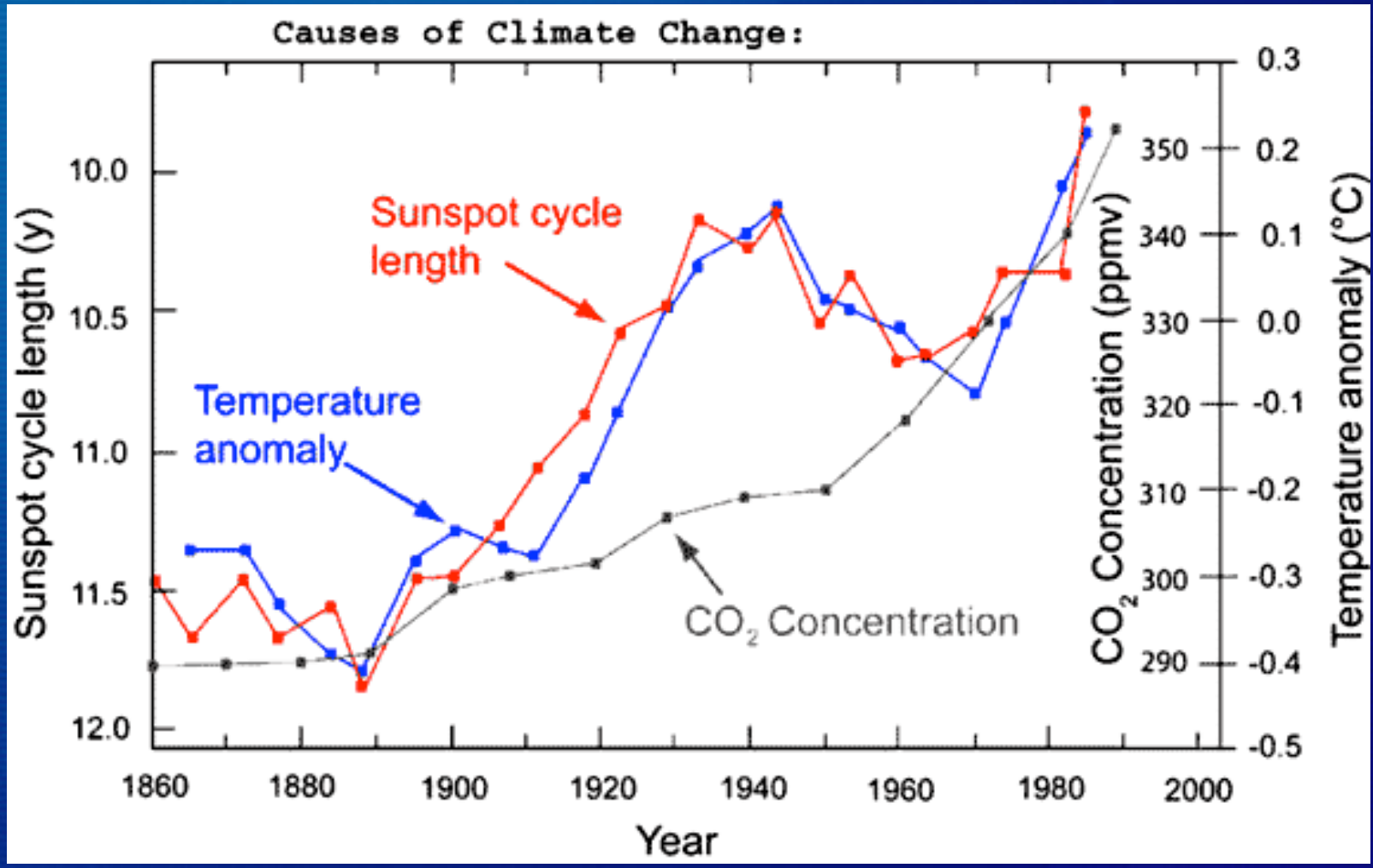




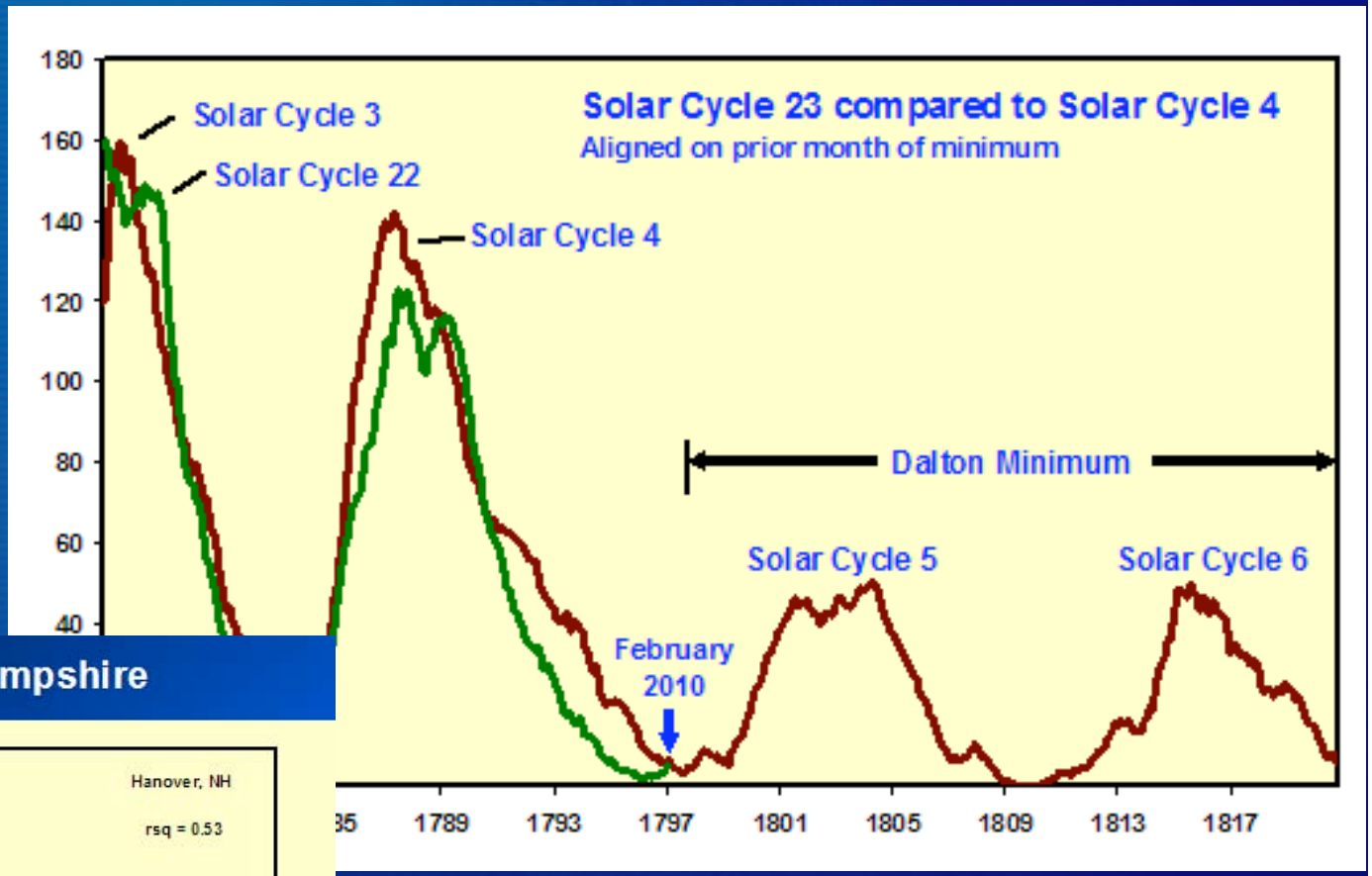
Claims that the Sun has caused as much as 70% (Scafetta and west, 2008) of recent global warming presents fundamental puzzles. It requires that

- *the Sun's brightness increases more than current understanding allows*
- *Earth's climate be insensitive to well-measured increases in greenhouse gases at the same time that it is excessively sensitive to poorly known solar brightness changes.*

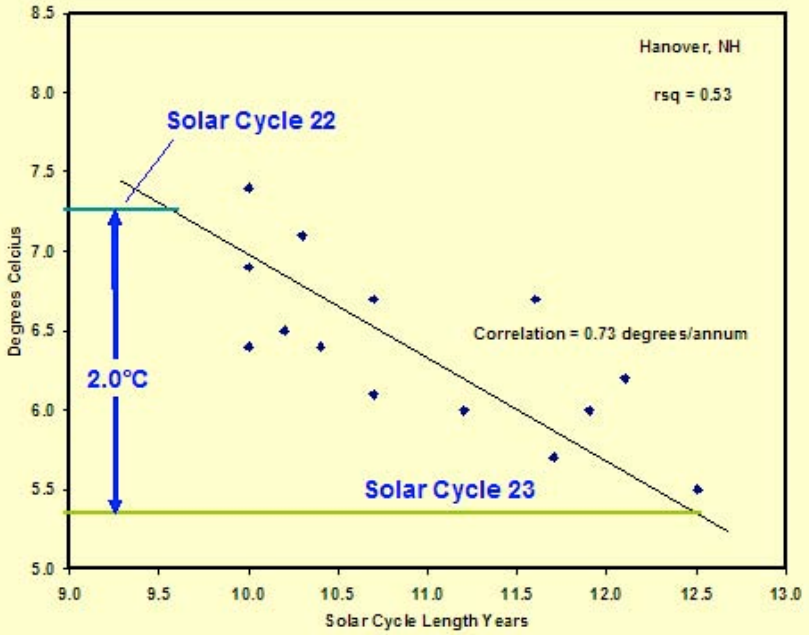
Sunspot Cycle Length
Friis-Christensen and Lassen (Science, 1991)



David Archibald in Watts Up with That? (Anthony Watts)



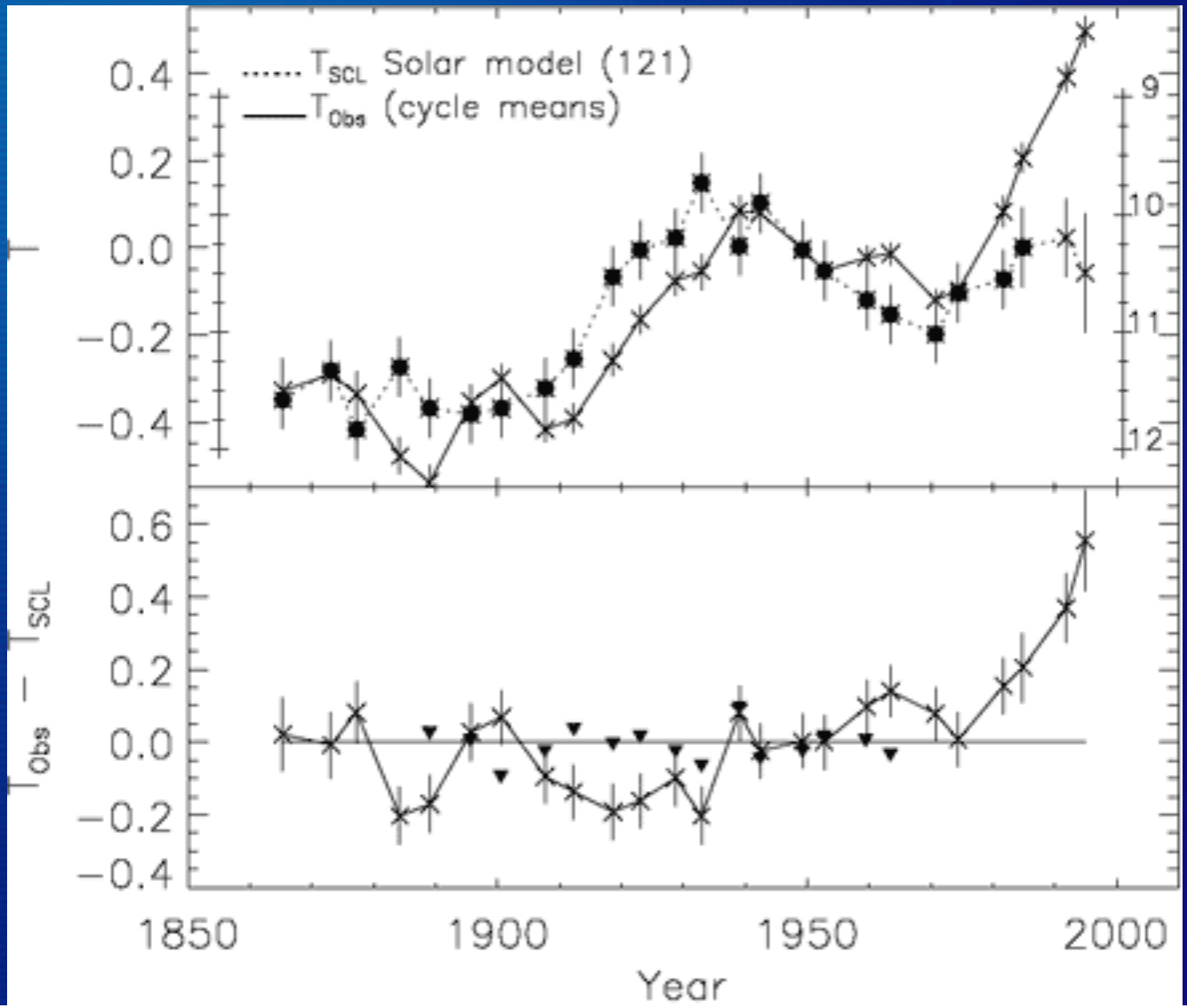
Hanover, New Hampshire



Applying Friis-Christenson and Lassen theory to the temperature record of Hanover, New Hampshire results in a two degree centigrade decline in the annual average temperature at this location over the expected twelve years of Solar Cycle 24,

Top figure compares temperature to solar cycles. Bottom figure plots the difference between temperature and solar cycle length, showing a strong divergence in the mid 1970s

Lassen 1999



Galactic Cosmic Rays

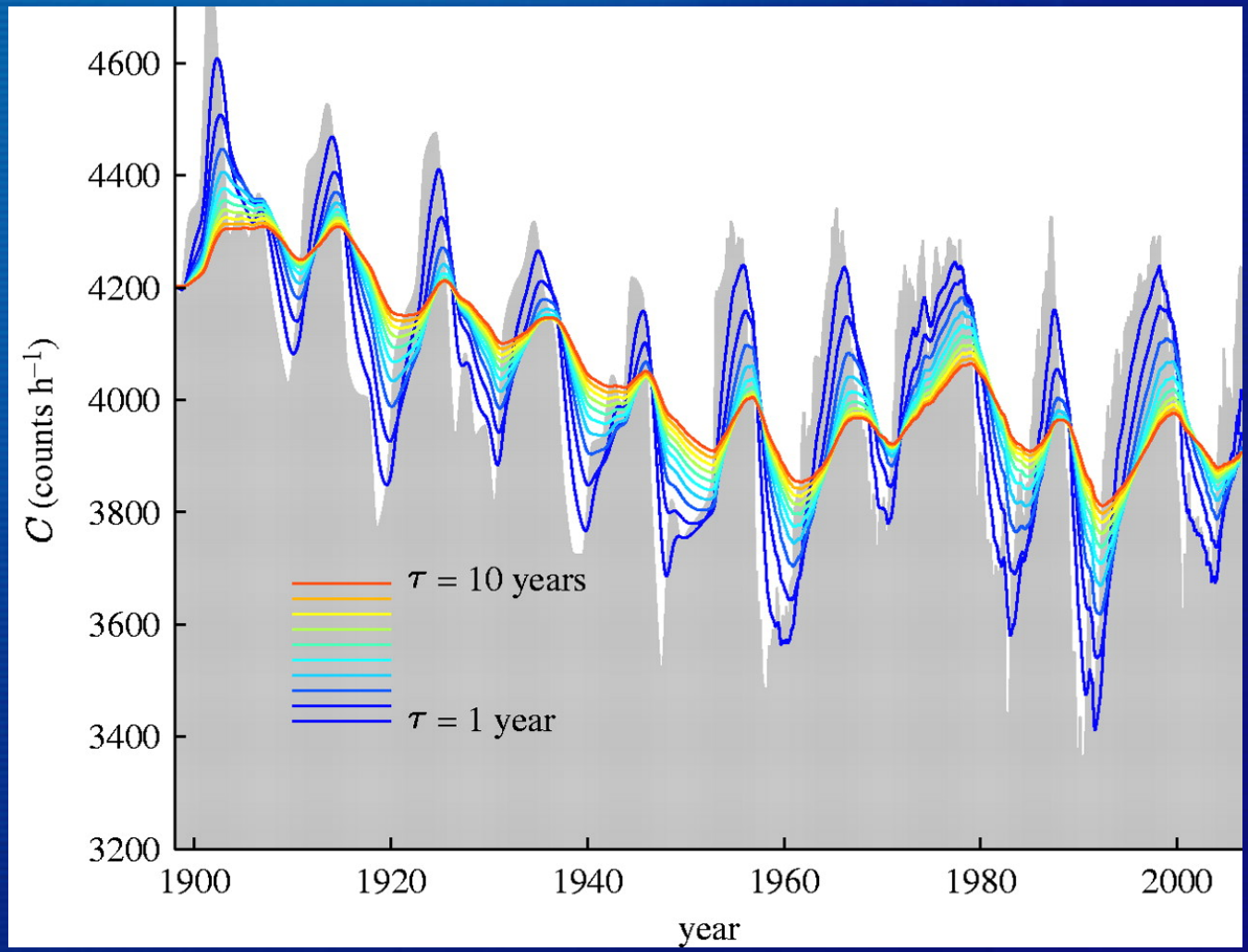
- Primary focus:

  GCR → ions → particles → clouds → climate
- There are other possible effects but poorly understood
  - Electroscavenging (circuit current in supercooled clouds)
  - Electroactivation (liquid water clouds)
  - electrocoalescence (liquid water clouds)

Henrik Svensmark

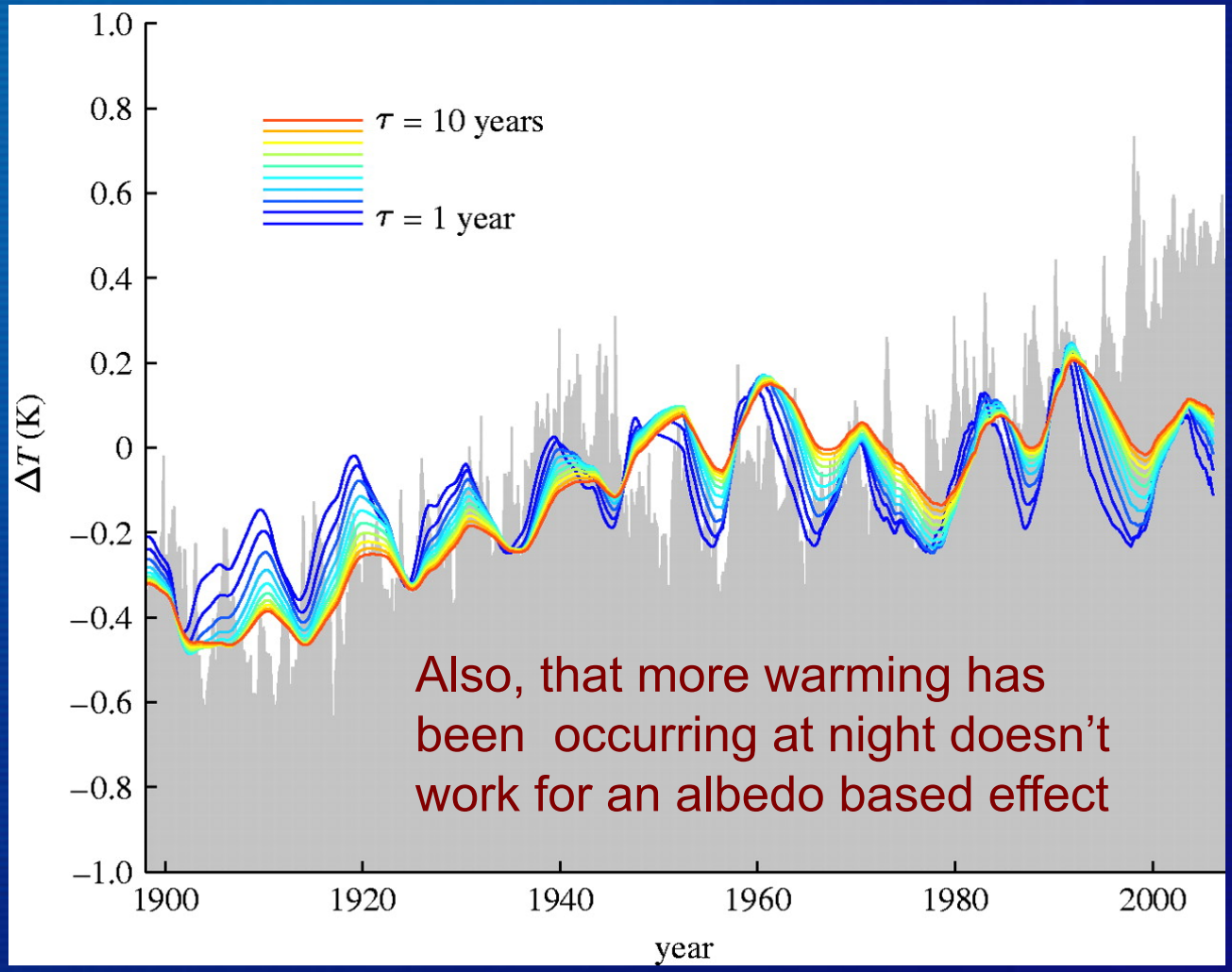
- Svensmark and Friis-Christensen (1996, 1997, 1998)
  - Focus on very limited (mostly 1984-1990) time period
  - *"Our team at the Danish National Space Center has discovered that the relatively few cosmic rays that reach sea-level play a big part in the everyday weather. They help to make low-level clouds, which largely regulate the Earth's surface temperature."*
  - *"The recent discovery by our team … of the chemical mechanism of cosmic-ray action on cloud formation thus brings to a climax a scientific quest that has lasted two centuries."*

Observed cosmic ray counts C at the Climax neutron monitor site



Lockwood M , Fröhlich C Proc. R. Soc. A 2008;464:1367-1385

Inverse of cosmic rays relative to the global mean surface air temperature anomaly ΔT



Lockwood M , Fröhlich C Proc. R. Soc. A 2008;464:1367-1385

Kulmala et al., ACP, 2010: find no effects on particles from cosmic rays

What role could the Sun play in the next few decades?

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Climate change: The next ten years

- 13 August 2008 by **Fred Pearce** and **Michael Le Page**
- Magazine issue 2669. **Subscribe** and get 4 free issues.
- For similar stories, visit the **Climate Change** Topic Guide

WHAT's going to happen to the climate over the next 10 years or so? Is it ti to buy that air conditioner you considered during the last heatwave? Should rip up your garden and replant it with drought-resistant plants, or can you expect more rain - perhaps even floods - in your part of world? The other possibility, of course, is that your local climate will change little in the near future.

On the one hand we have weather predictions for the next few days. On the other we have climate forecasts for the very distant future. But what happens in the middle? Why don't we have forecasts for, say, 2010 or 2018? Knowing how temperature and rainfall will change over the next few years would be invaluable to many people, from farmers to the tourism industry to those in charge of our water supplies. Yet while you might think predicting how the climate will change over the next few years would be a lot easier than saying what it will be like in 2030 or 2050, it's actually harder.

Improved Surface Temperature Prediction for the Coming Decade from a Global Climate Model

Smith et al., Science, 2007

… climate will continue to warm, with at least half of the years after 2009 predicted to exceed the warmest year currently on record…..$\Delta T=0.3^{o}C$ from 2004-2014

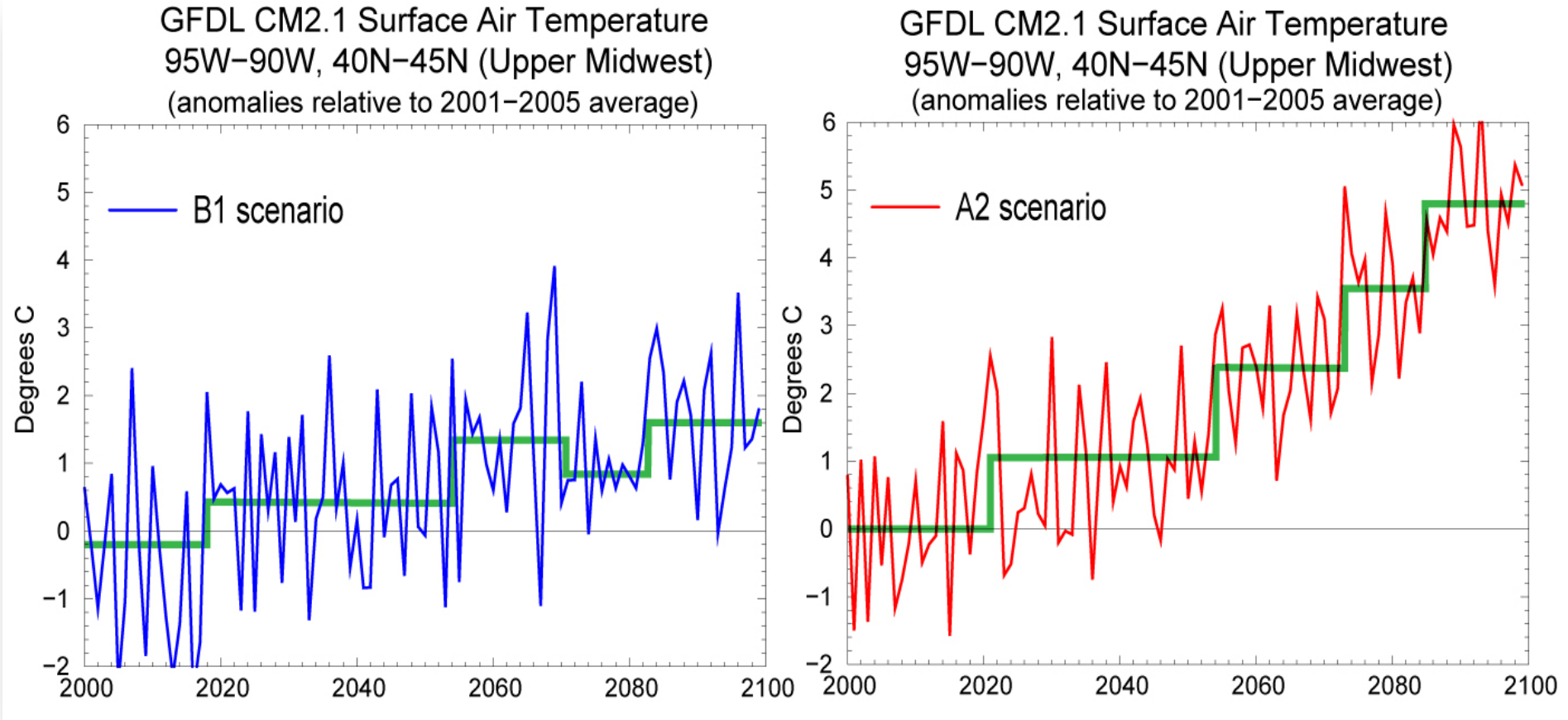
Advancing decadal-scale climate prediction in the North Atlantic sector

Keenlyside et al., Nature, 2008

….global surface temperature may not increase over the next decade, as natural climate variations in the North Atlantic and tropical Pacific temporarily offset the projected anthropogenic warming.

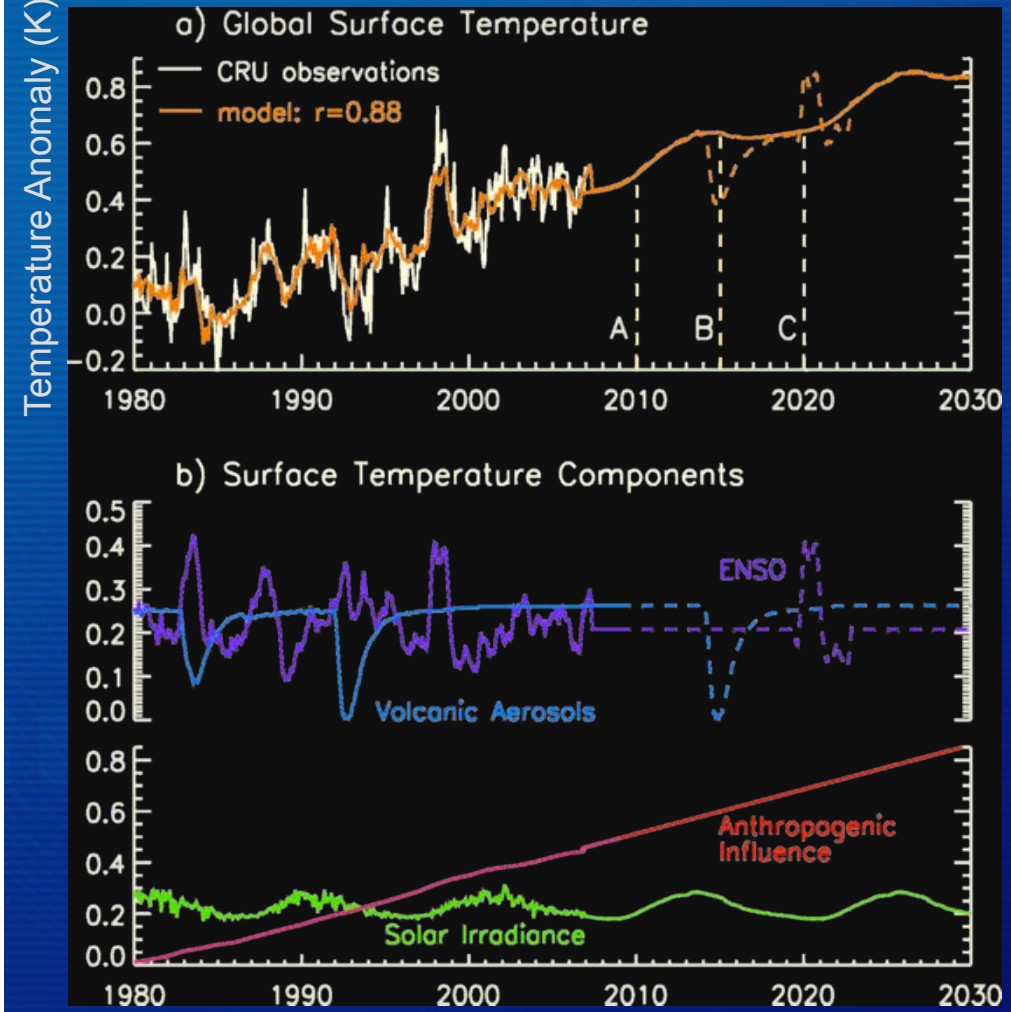
2 more images

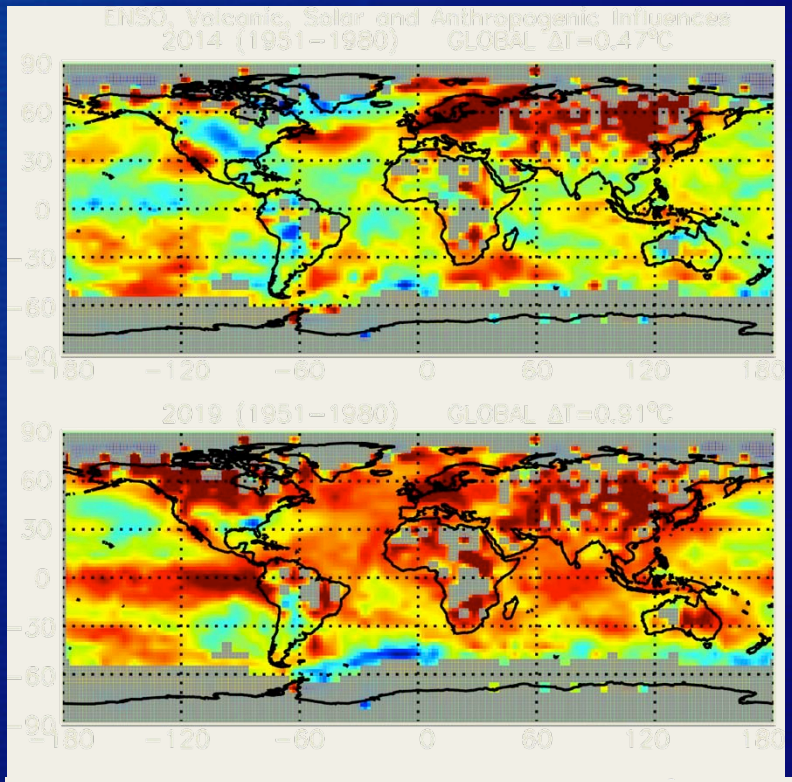
Discontinuous Changes in Temperature



How – and Why - will Climate Change in the next few Decades?

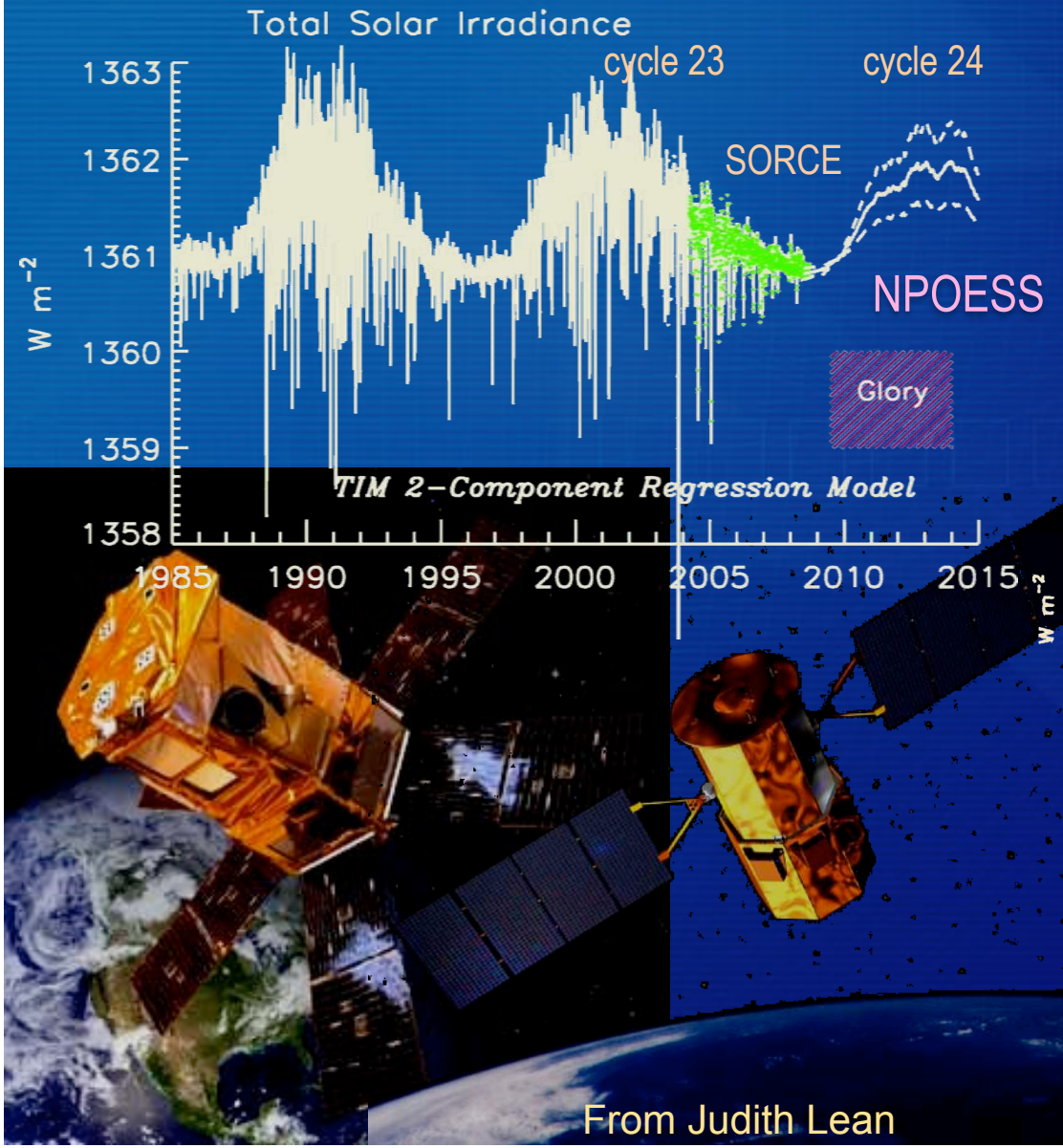
Assuming Past is Prologue.... future near-term climate change will vary because of both natural and anthropogenic influences





There will be both warming and cooling in the next few decades

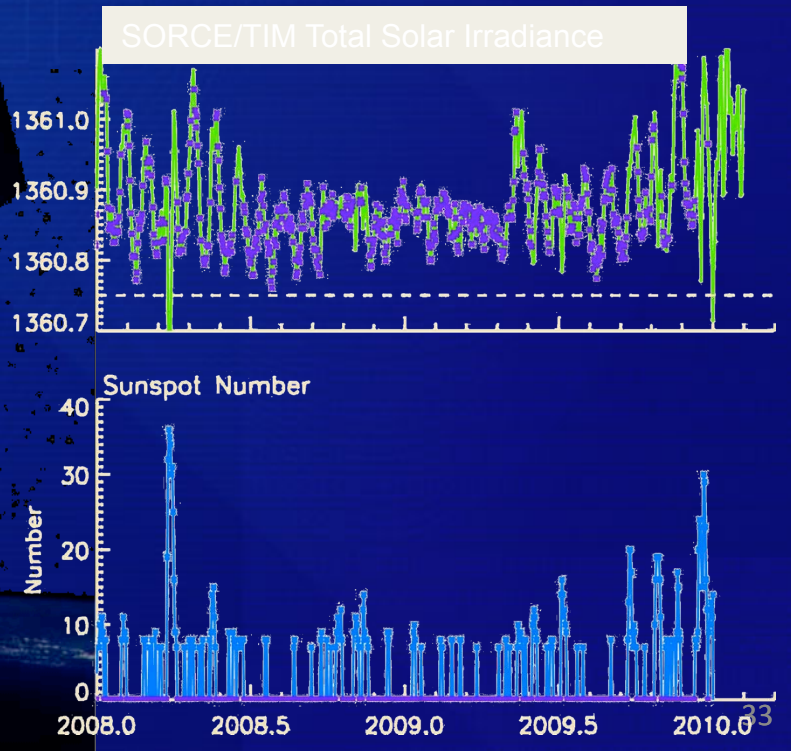
How – and Why - will Solar Irradiance Change in the Future?



How active will solar cycle 24 be?

- *40% higher than cycle 23 (Dikpati et al, 2005)*
- less active than cycle 23

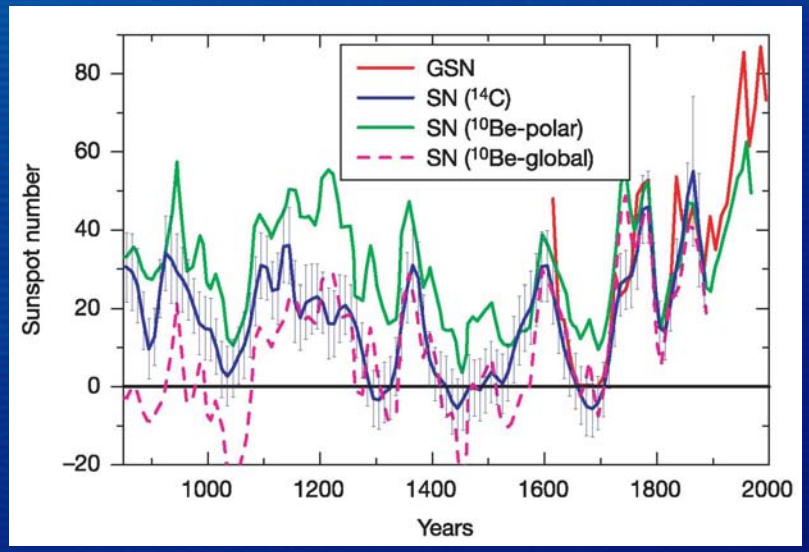
Are we entering a protracted solar minimum? (NO)

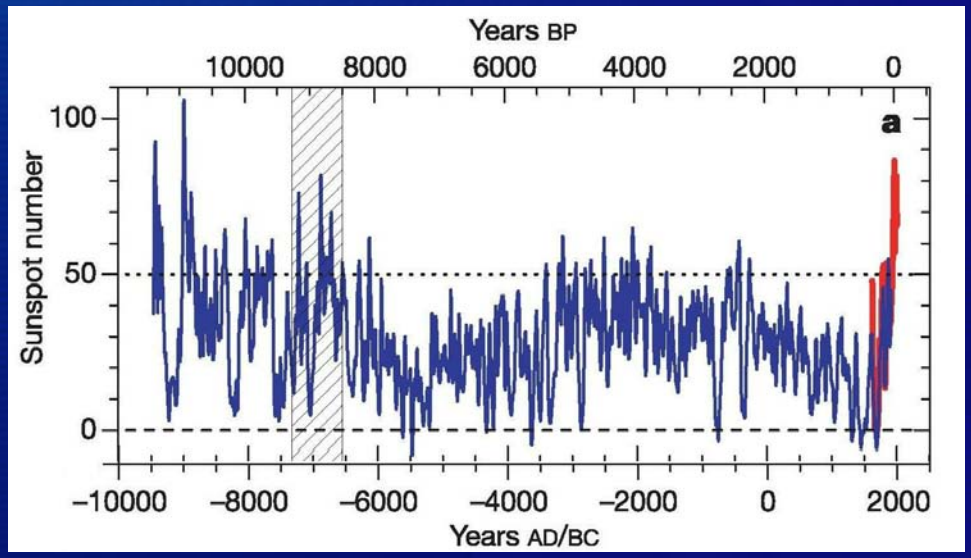


From Judith Lean

Solar Activity over last 11,400 Years

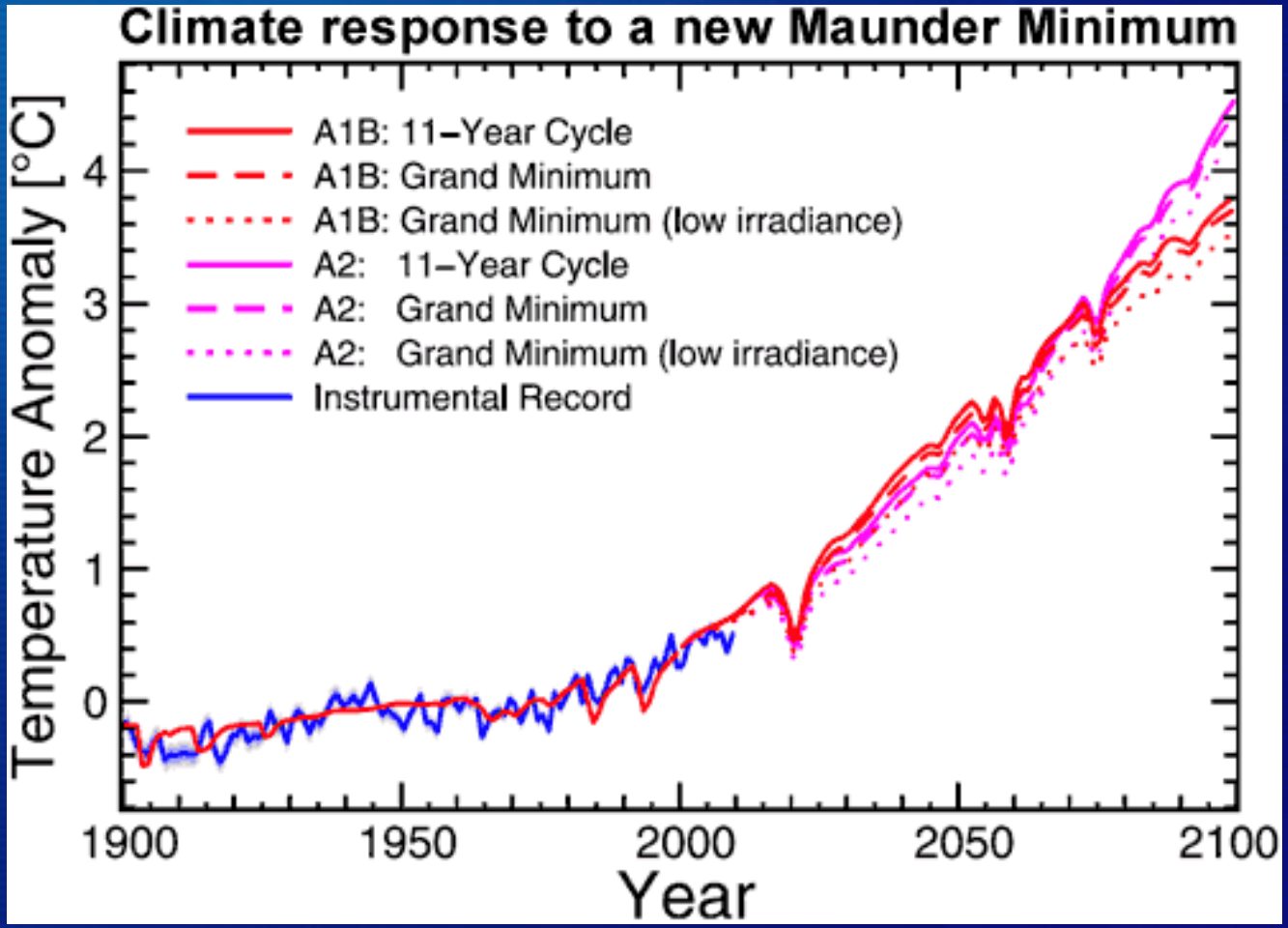
Solanki *et al.*, *Nature* 431 1084-1087 (2004) have reconstructed the sunspot number over the last 11,400 years using ^{14}C data. Comparisons with the observed Group Sunspot Numbers (GSN) and sunspot numbers reconstructed from ^{10}Be ice core data show good agreement. They conclude that the high levels of solar activity seen in the last 60 years have not been seen for 8000 years. (Note, however, that this high level of activity is seen only in actual sunspot number.)





Feulner and Rahmstorf (GRL, 2010)

On the effect of a new grand minimum of solar activity on the future climate on Earth – What if we had another Maunder Minimum?



Widespread climate-related impacts are occurring now and are expected to increase

Water Resources

Energy Supply and Use

Transportation

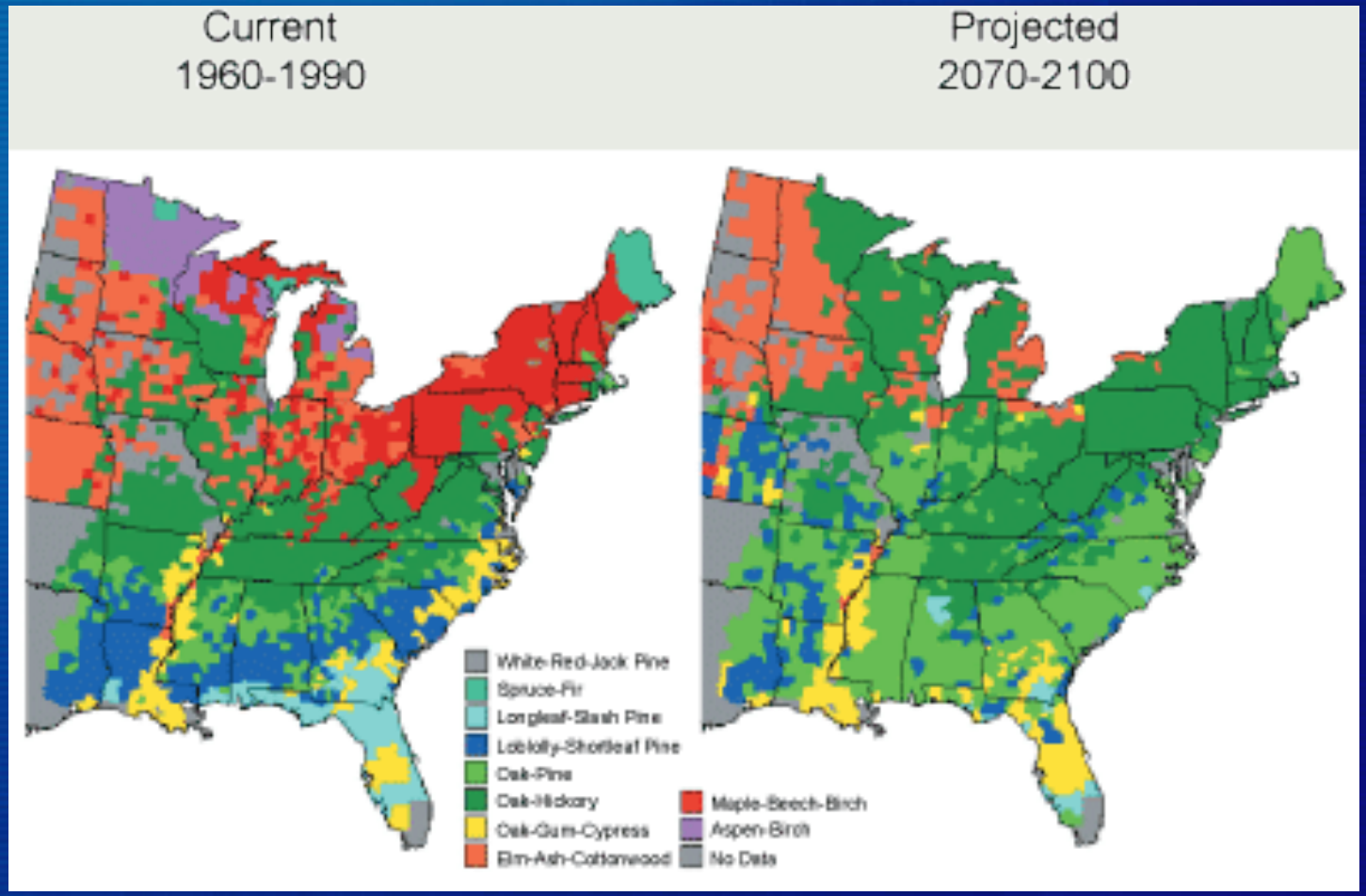
Agriculture

Ecosystems

Human Health

Society

Projected Shifts in Forest Types

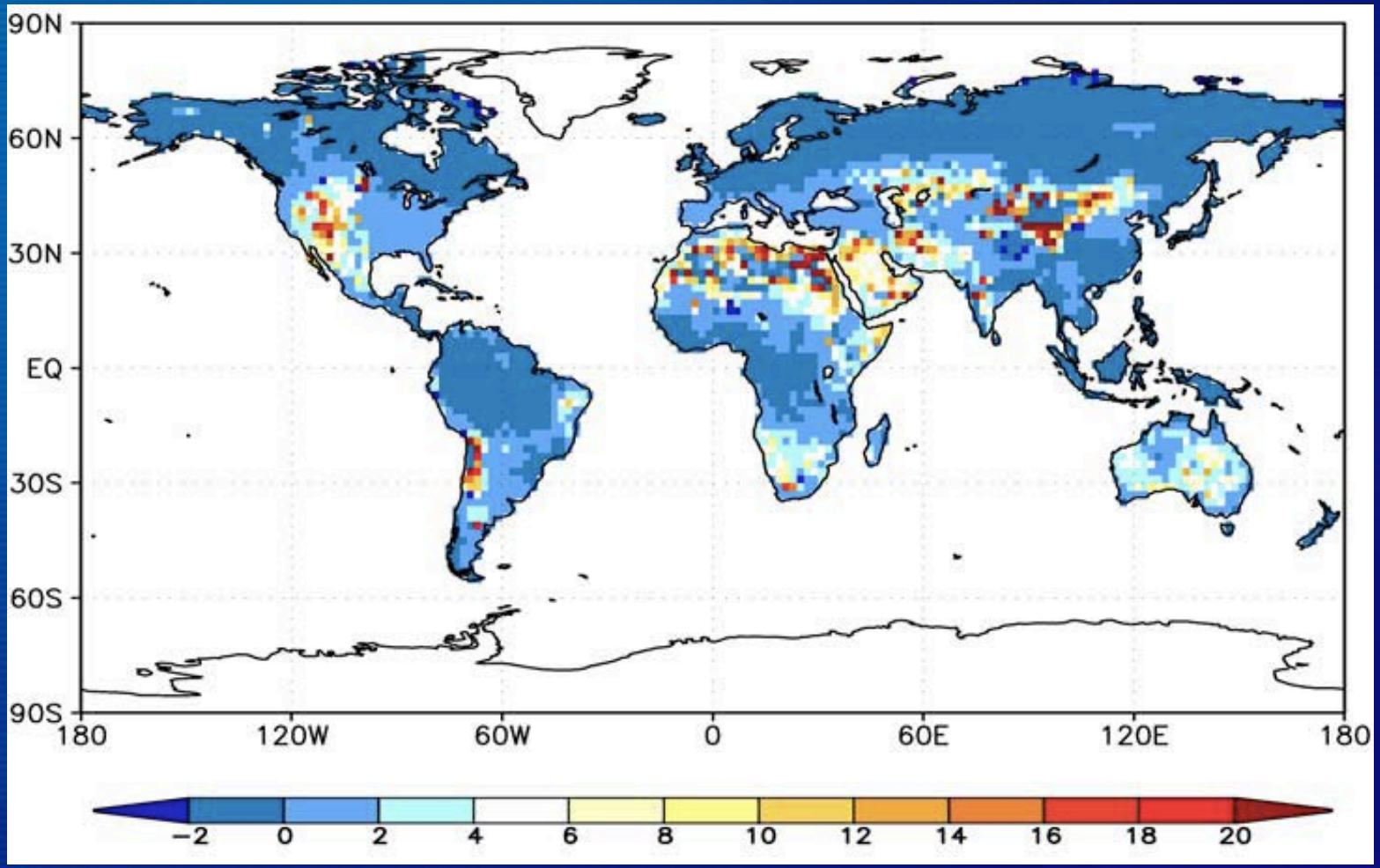


The maps show current and projected forest types. Major changes are projected for many regions. For example, in the Northeast, maple-beech-birch forest type, which is currently dominant in the region, is projected to be completely displaced by other forest types in a warmer future.

USGCRP, 2009

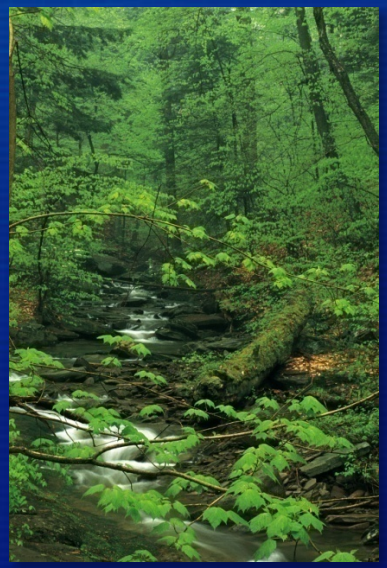
Agriculture faces increasing challenges from heat stress, water stress, pests, diseases, and weather extremes

% change in Net Primary Productivity for 1.8% reduction in solar flux in 2XCO2 scenario

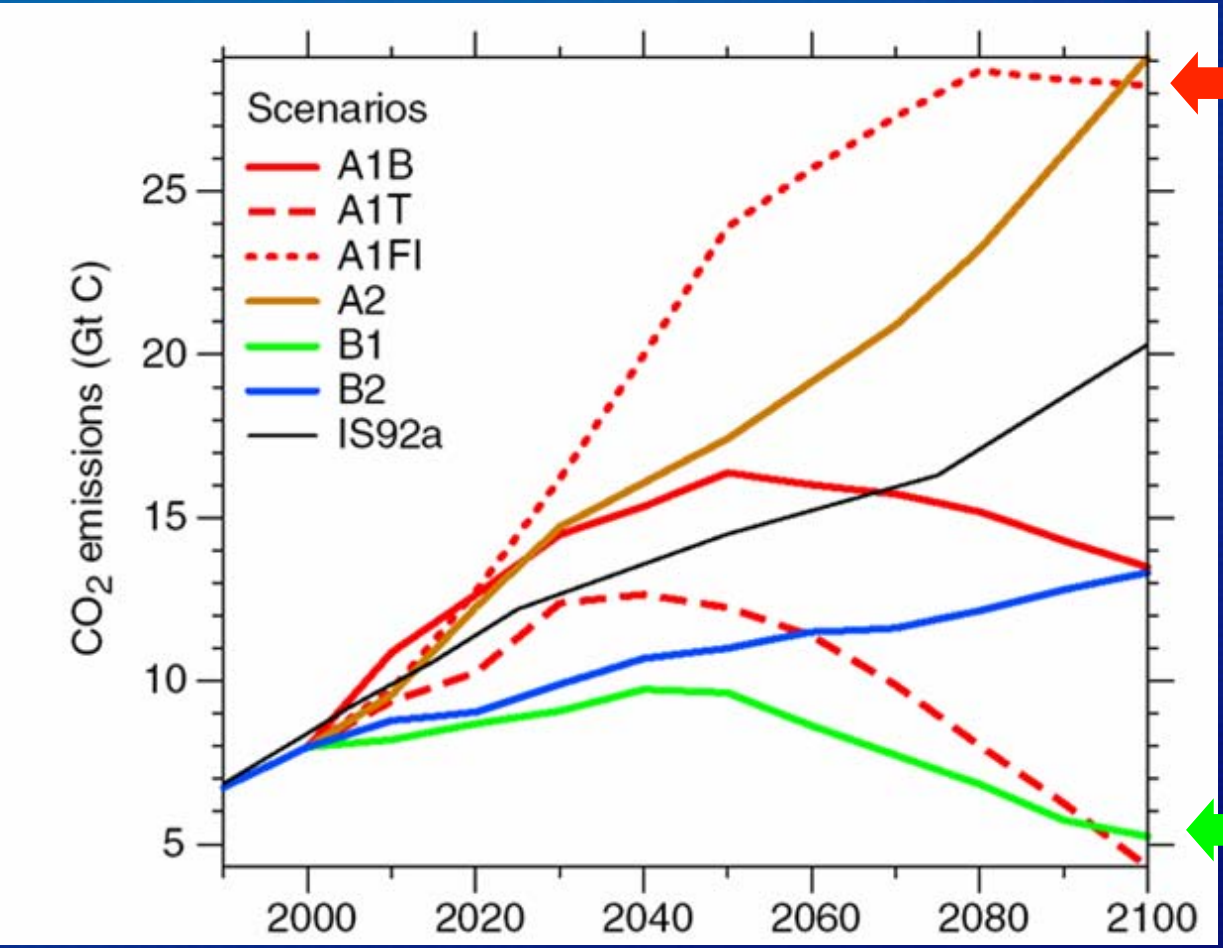


Naik et al. (2003) – first presented at AGCI in 2000

Thank You



Future climate and its impacts depends on choices made today



HIGHER

A1FI (940 ppm)

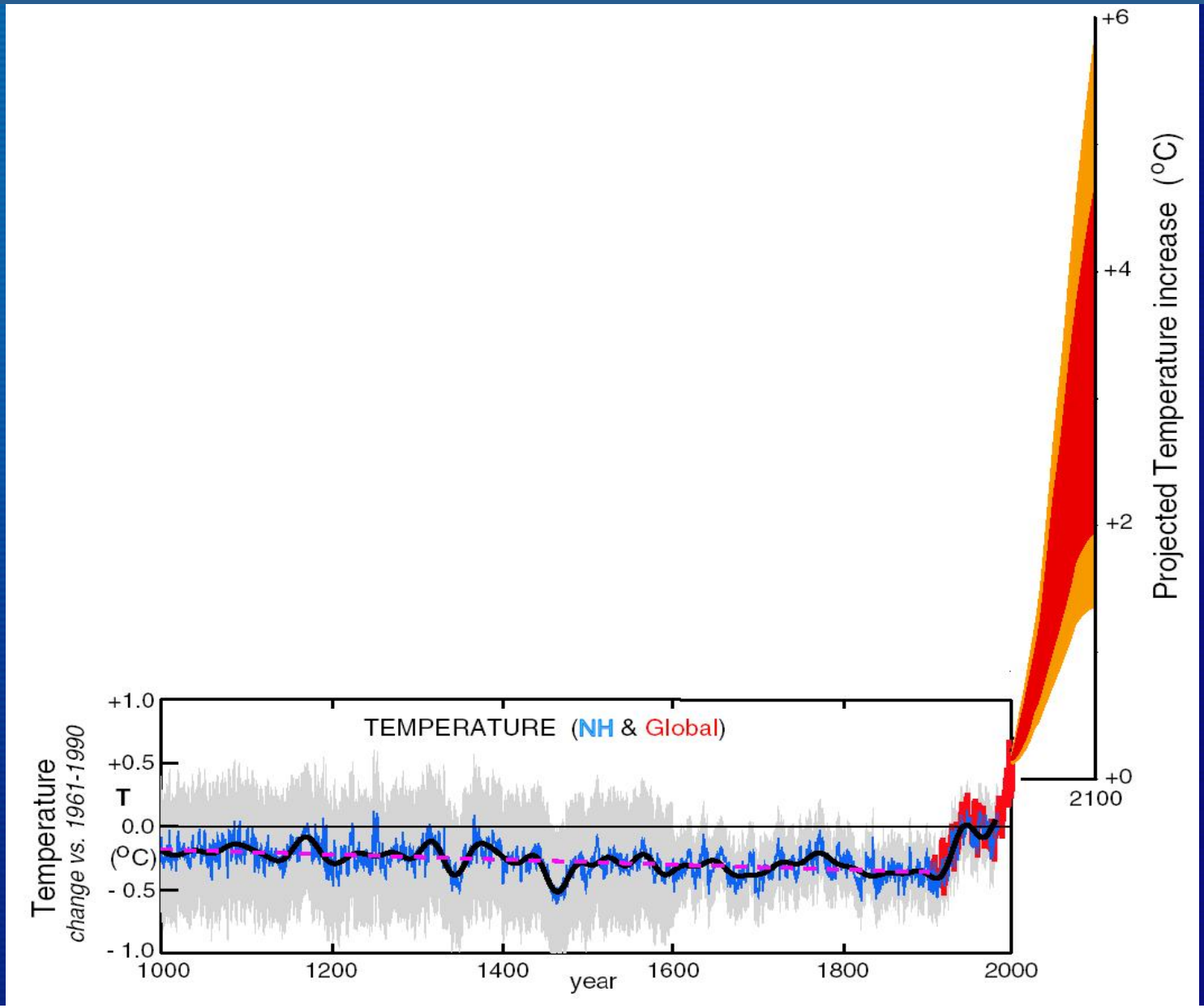
CO2 Emissions

LOWER

B1 (550 ppm)

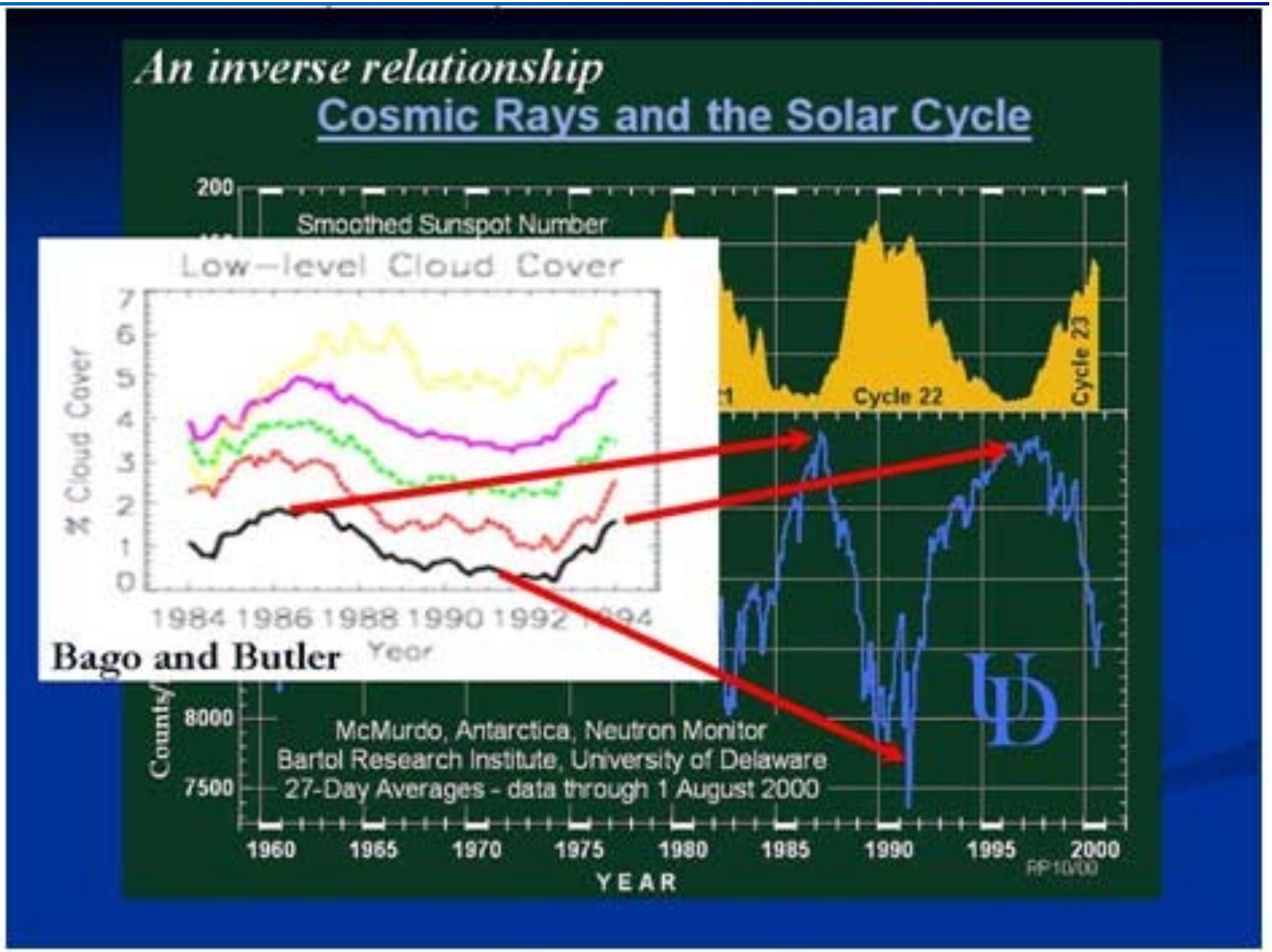
Source: IPCC 2001

What can we expect in the future?



Climate models are routinely tested relative to observations

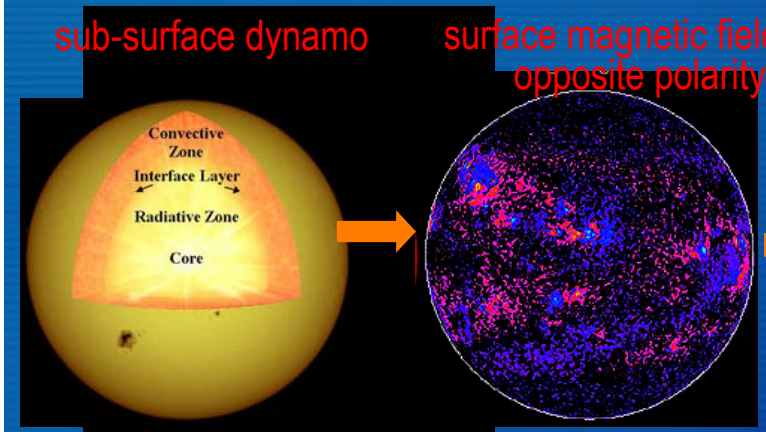
- Today's annual average climate
- The daily cycle
- The seasonal cycle
- The response to massive volcanic eruptions
- Ocean uptake of products of atmospheric tests of nuclear weapons
- The climate changes of the past 30 to 150 years
- Climates of the "deep past" (*e.g.*, the last Ice Age)
- Weather patterns
- Modes of natural climate variability (like El Niño)


An inverse relationship
Cosmic Rays and the Solar Cycle
Smoothed Sunspot Number
200
Cycle 22
Cycle 23
Low-level Cloud Cover
% Cloud Cover
0
1
2
3
4
5
6
7
1984 1986 1988 1990 1992
Year
Bago and Butler
Counts/
8000
7500
McMurdo, Antarctica, Neutron Monitor
Bartol Research Institute, University of Delaware
27-Day Averages - data through 1 August 2000
1960
1965
1970
1975
1980
1985
1990
1995
2000
YEAR

Estimating Long-Term Solar Variability

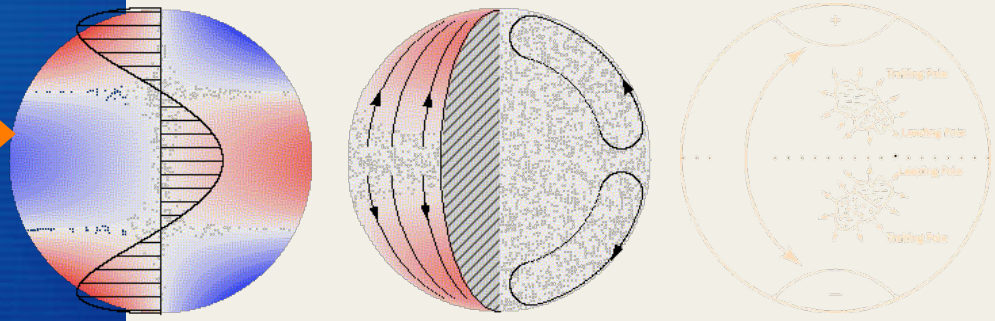
sub-surface dynamo

surface magnetic fields of opposite polarity



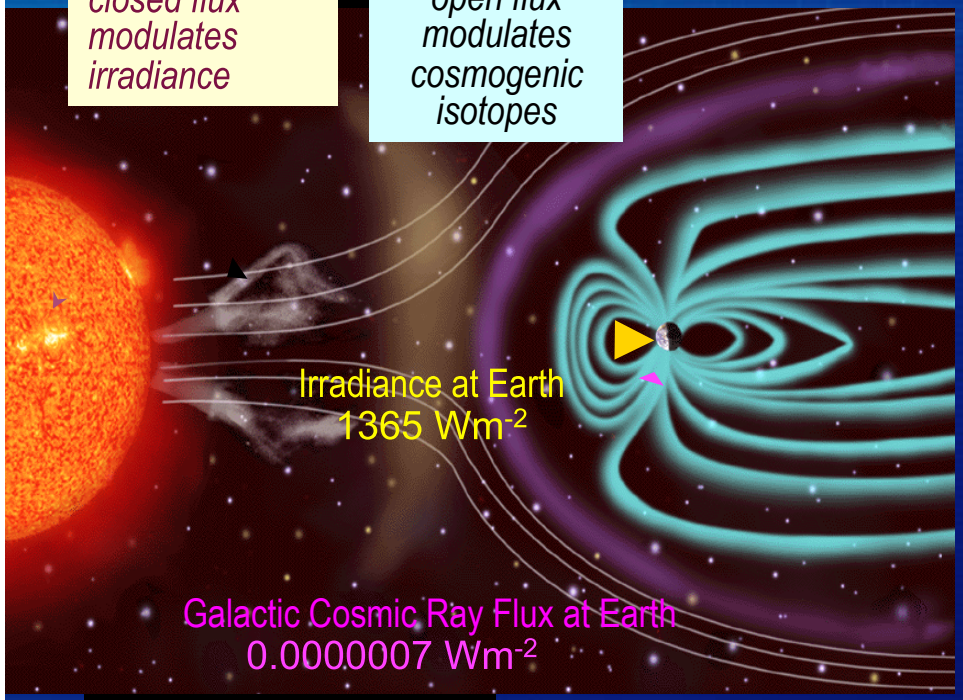
transported by…

differential rotation, meridional flow, diffusion

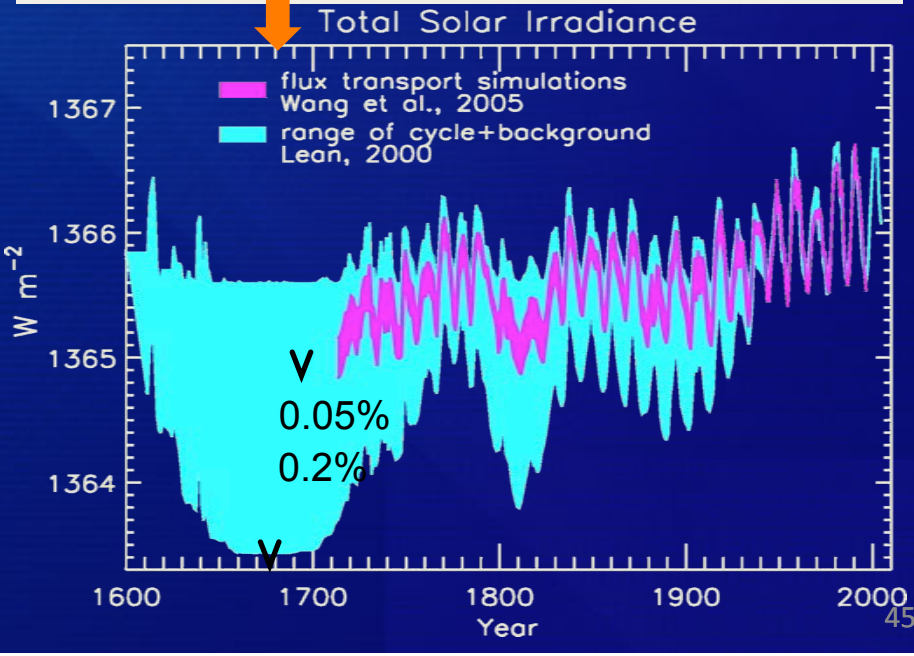


closed flux modulates irradiance

open flux modulates cosmogenic isotopes

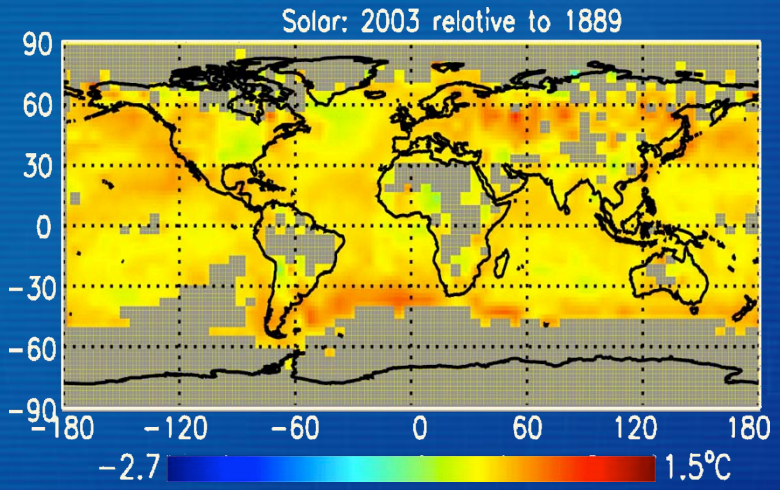


NRL Flux Transport Model



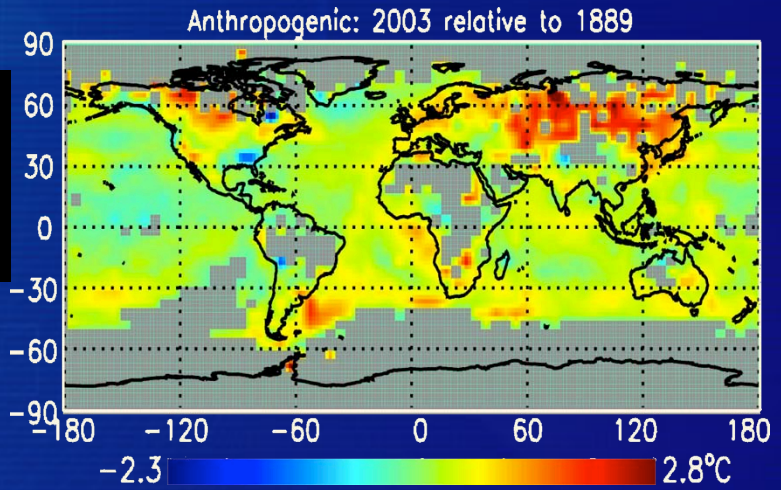
Sun and Anthropogenic Regional Surface Temperature Responses: 1889 – 2003

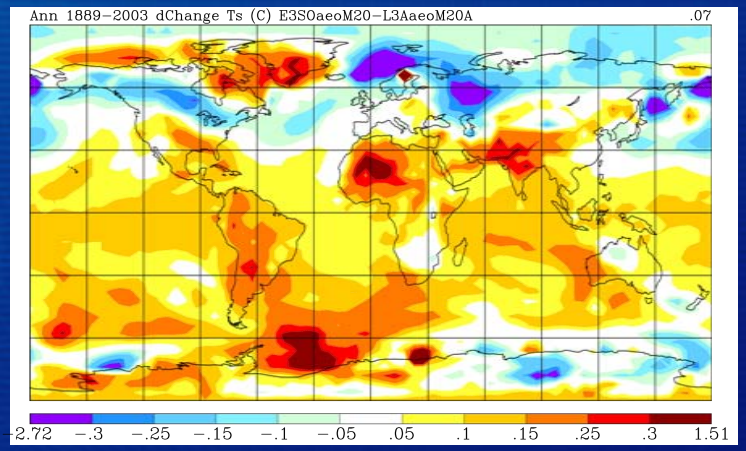
SOLAR IRRADIANCE



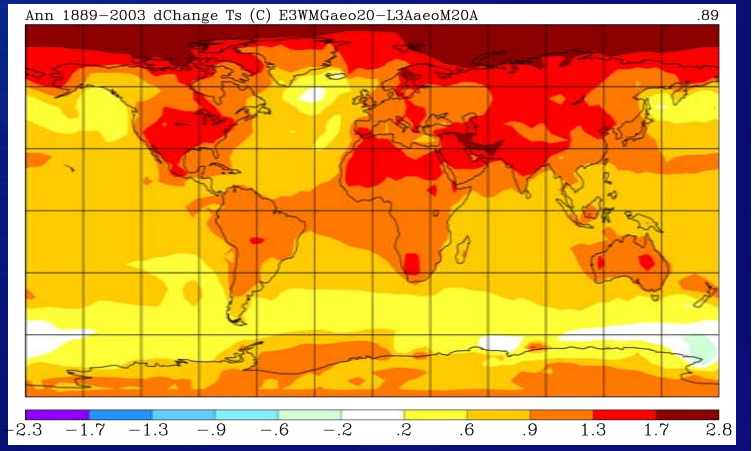
CRU Empirical Analysis for 1889-2008

ANTHROPOGENIC





GISS ModelE



4° (lat) × 5° (long) M20 *Schmidt et al., 2006* *http://www.giss.nasa.gov*

Paleo Sun–Climate Synopsis

…when solar activity is high….

increased temperature & moisture SW Alaska
Sheng et al., 2003

drought Western US
Cookl et al., 2001

warming North Atlantic
Bond et al., 2000

stronger monsoon Wangxiang cave
Zhang et al., 2008

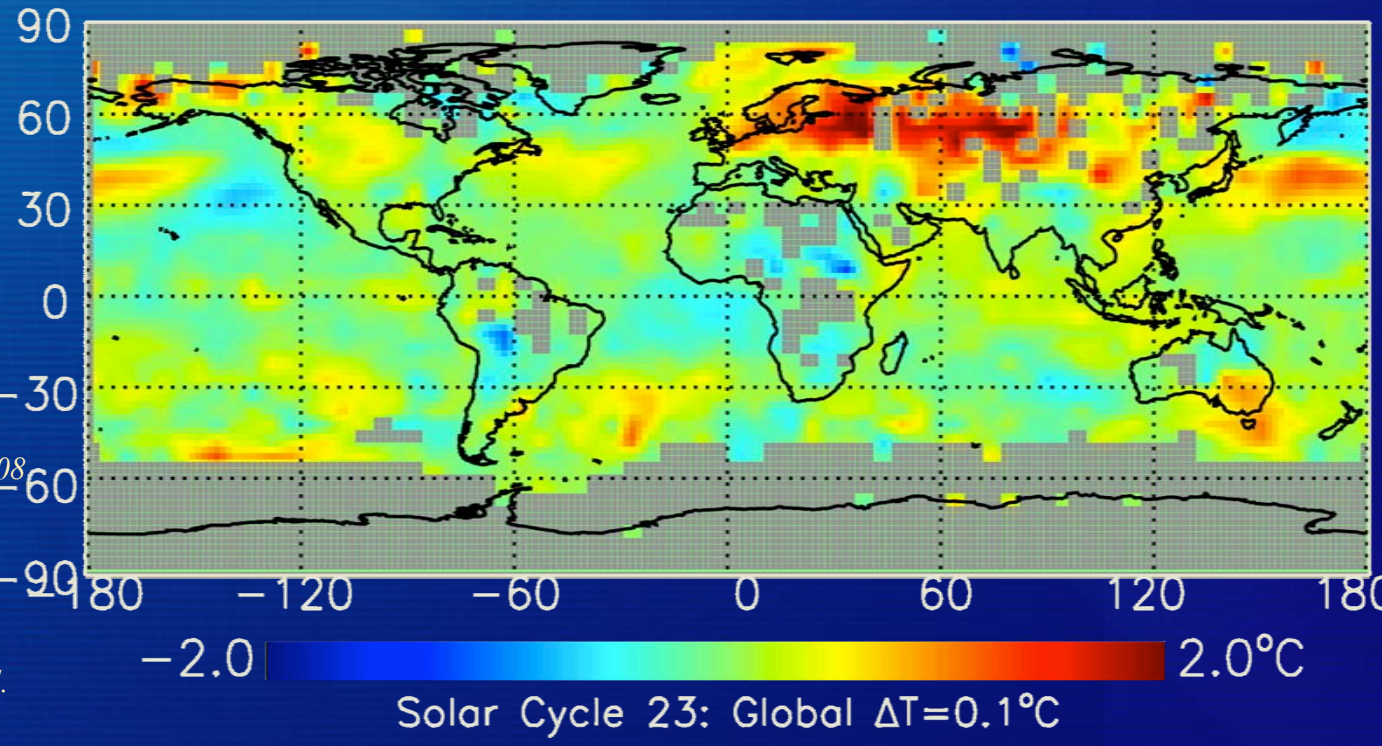
high rainfall Oman
Neff et al., 2001

warming Beijing
Tan et al., 2004

Mayan drought Cariaco Basin
Hodell et al., 2001
Haug et al., 2003

weakened upwelling and trade winds (warmer SSTs) Cariaco Basin
Black et al., 1999

drought Equatorial East Africa
Verschuren et al., 2000



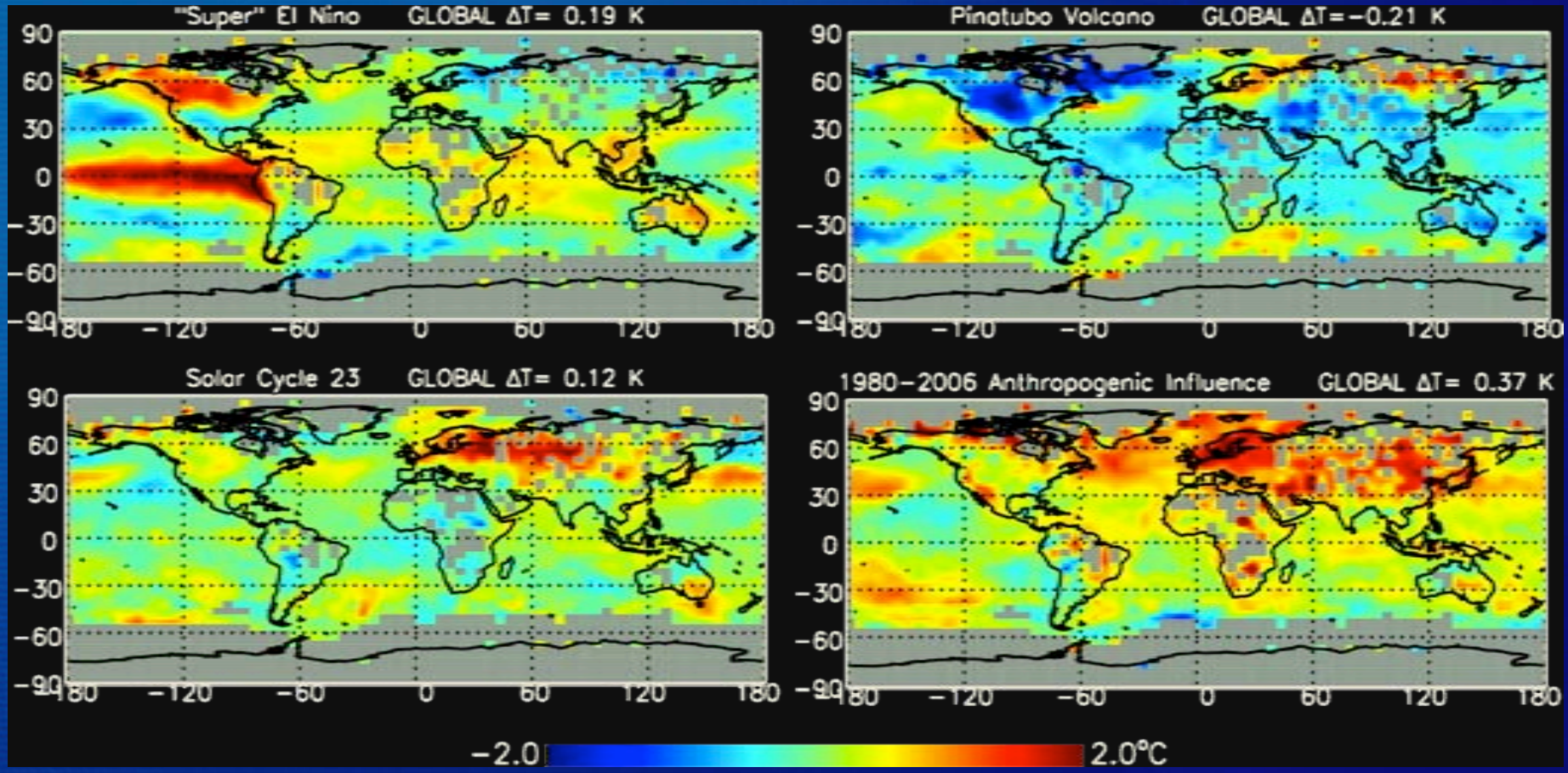
streamflow Parana River
Mauas et al., 2008

tree-rings Chile
Roig et al., 2001
Nordemann et al.

warming Tasmania
Hill et al., 2007

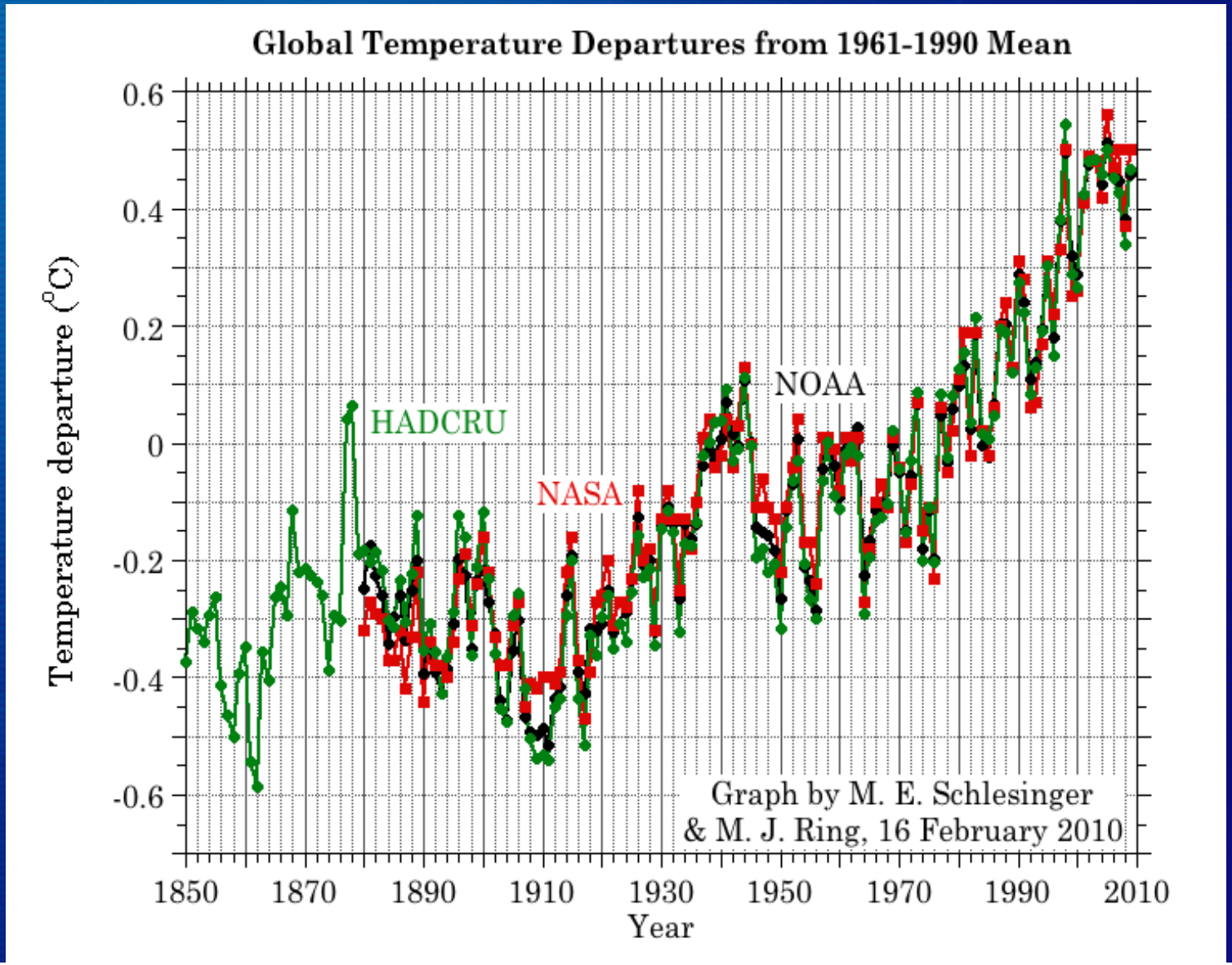
significant local changes do not imply global changes of equal magnitude

Surface Temperature Regional Annual Response Patterns (5°×5° lat-long)



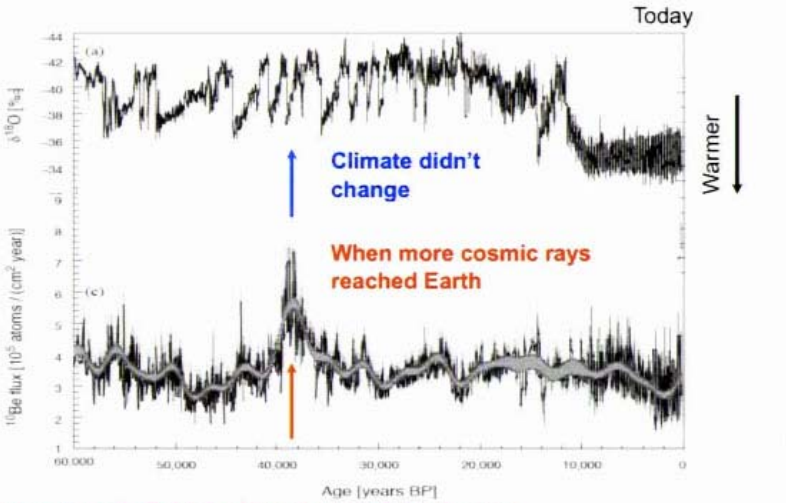
no observations

Three different analyses of the temperature record – Trends in agreement



Svensmark et al. (2009) claim effects on clouds in special GCR events

Others don't find a meaningful connection between GCR, particles, clouds, or climate
e.g., Calogovic et al. (GRL, 2010)

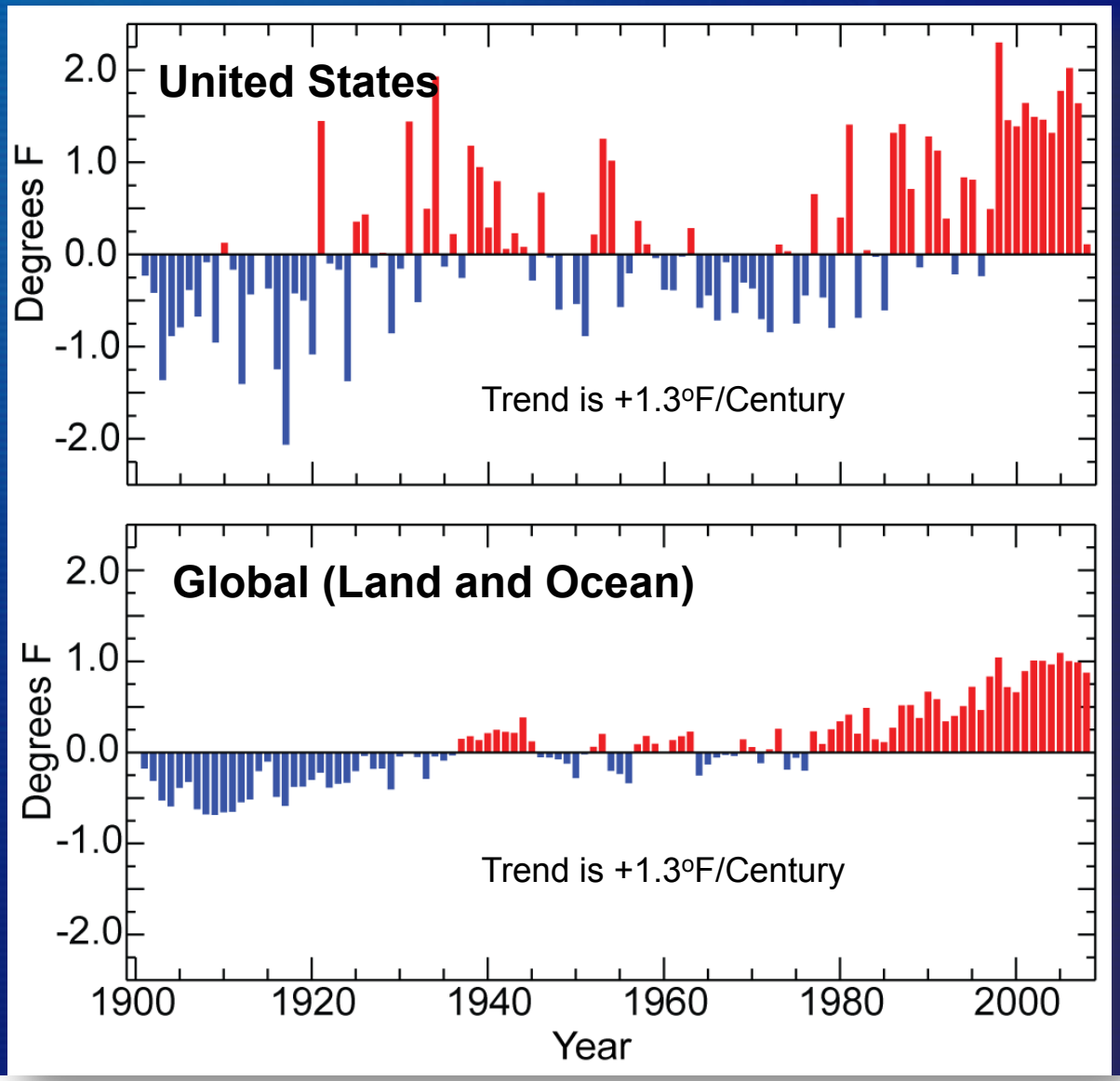


Cosmic rays, magnetic field don't matter much to climate.

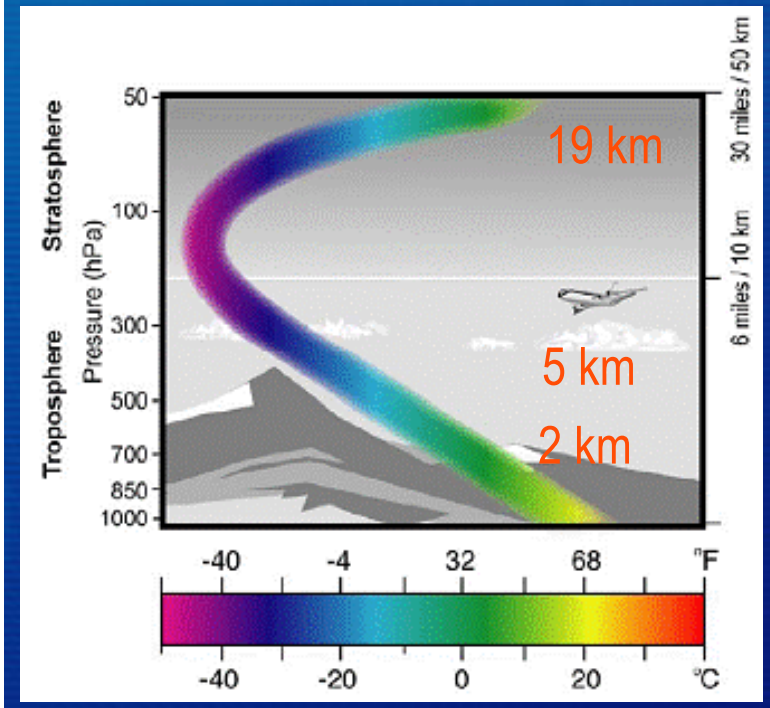
From Musch ler et al., 2005, QSR. $\delta^{18}O$ (proxy for temperature) from GRIP core (top), the concentration of ^{10}Be (middle), and the flux of ^{10}Be (bottom). The Laschamp event of near-zero magnetic field (red arrow) allowed increased cosmic-ray flux producing more ^{10}Be, but with no apparent effect on climate.

Annual Average Temperature
(Departure from the 1901-2000 Average)

NOAA NCDC Analyses

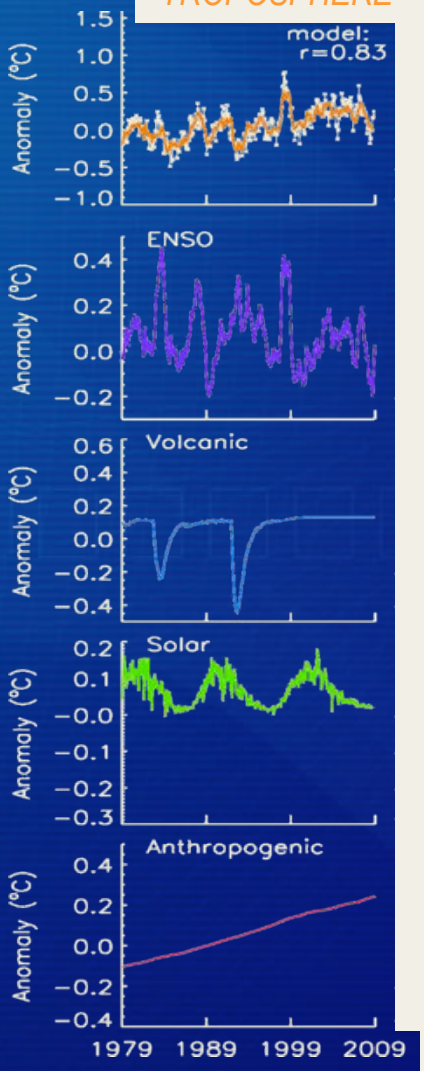


Natural and Anthropogenic Change in Earth's Atmosphere



2 km

LOWER TROPOSPHERE



solar increase → warming
CO_2 increase → warming
volcanoes → cooling

solar increase → warming
CO_2 & CFC increase → cooling
volcanoes → warming

Climate Model Response to Radiative Forcing

surface temperature change ΔT = κ F *forcing*

climate sensitivity κ

IPCC range: 0.2-1°C per Wm^{-2}
paleoclimate: 0.75°C per Wm^{-2}
Hansen, 2004

current understanding assumes that climate response to solar radiative forcing is thermodynamic --
BUT empirical evidence suggests it is
…. dynamic, rather than (or as well as) thermodynamic
… engages existing circulation patterns (Hadley, Ferrel, and Walker cells) and atmosphere- ocean interactions (ENSO)
… involves both direct (surface heating) and indirect (stratospheric influence) components.

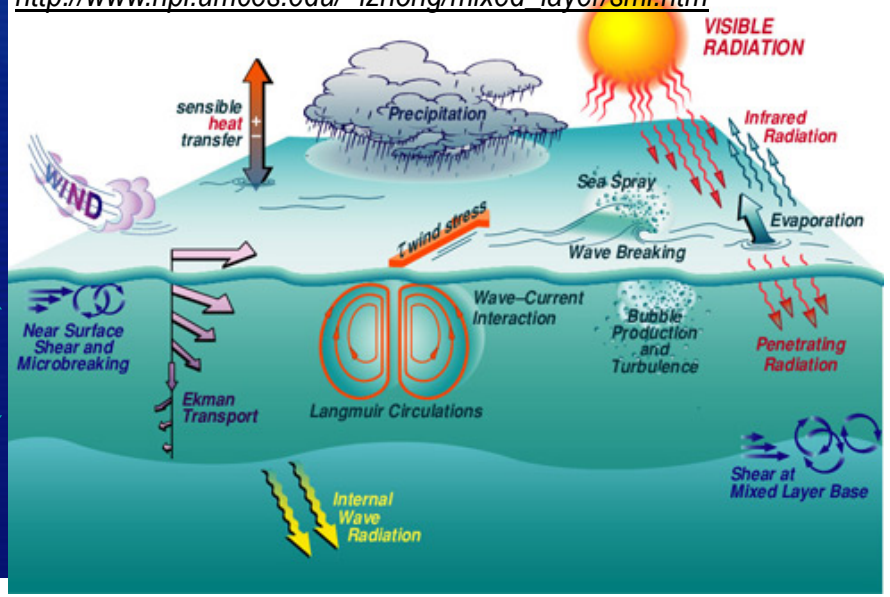
solar irradiance provides a well specified external climate forcing for testing models and understanding

Anthropogenic Influence

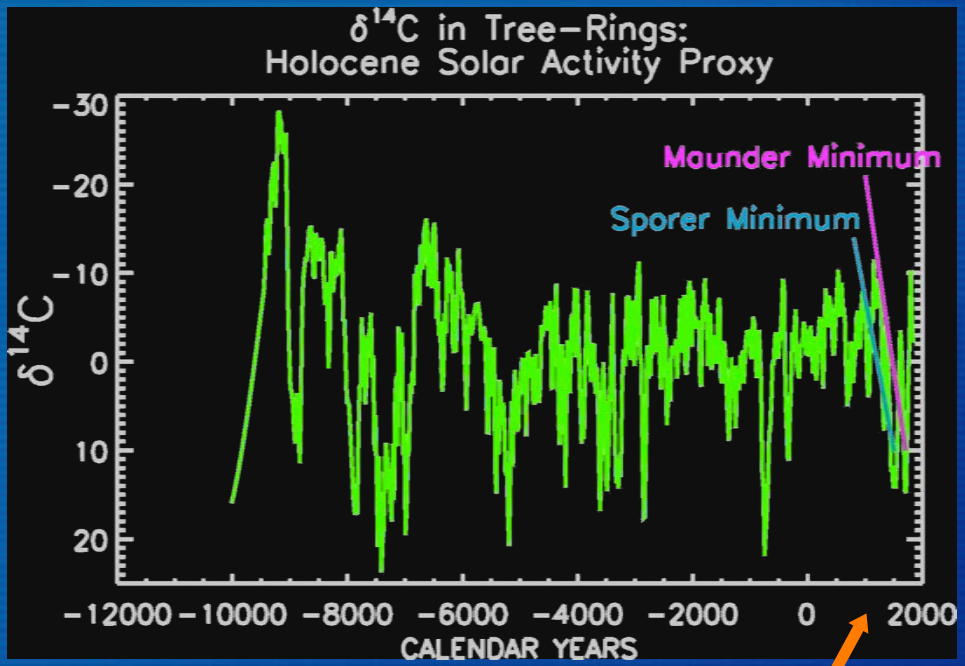
ΔT = 0.4°C (1980-2006)
F = 1 Wm^{-2} (total, not all radiative)
$\therefore \kappa \approx$ 0.4°C per Wm^{-2}

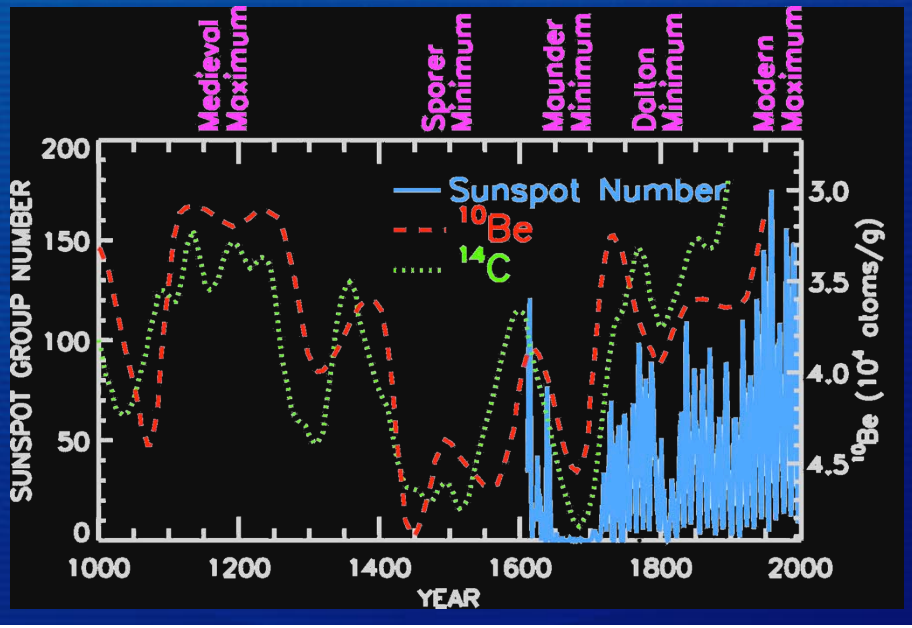
BUT…. response to cyclic decadal forcing is assumed to be attenuated by ~5× compared with "equilibrium" response

http://www.hpl.umces.edu/~lzhong/mixed_layer/sml.htm



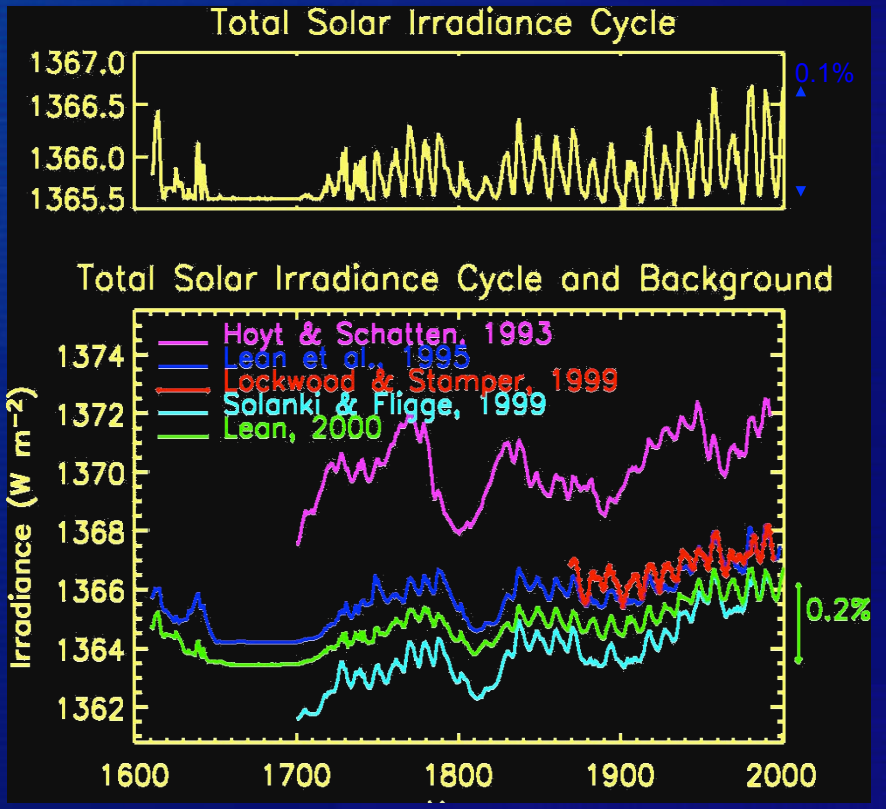
Centennial-Millennial Solar Variability



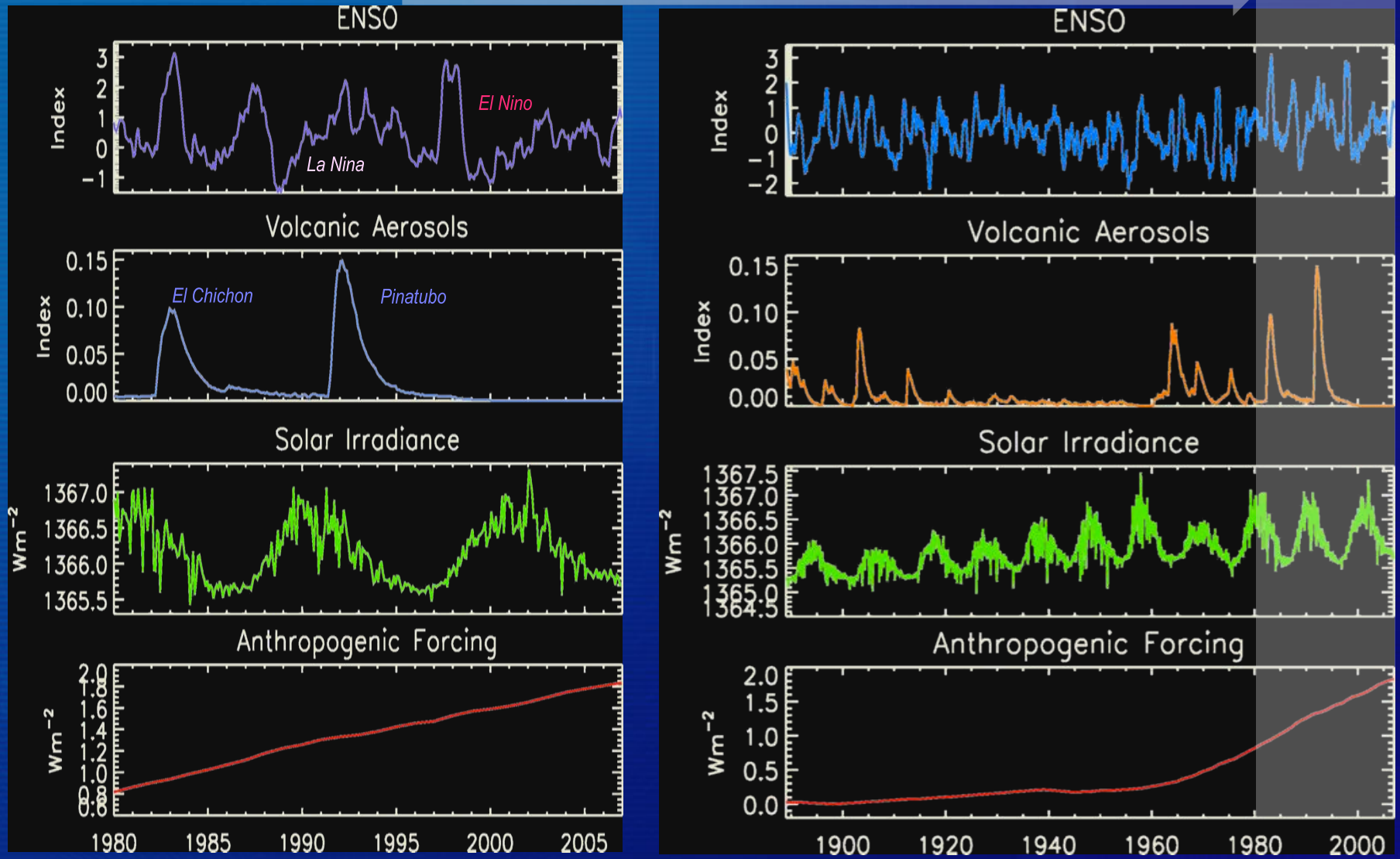


cosmogenic isotope changes - ^{14}C in tree-rings, ^{10}Be in icecores - imply long-term solar activity

… do they also imply long-term solar irradiance variations?



Natural and Anthropogenic Climate Influences since 1890



Is a big El Niño coming?

Climate Prediction Center – Outlooks

http://www.cpc.noaa.gov/products/CDB/Tropics/figt18.shtml

is a big El Nino coming

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National Weather Service

Climate Prediction Center

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Climate Diagnostics Bulletin

CDB Home

Tropics

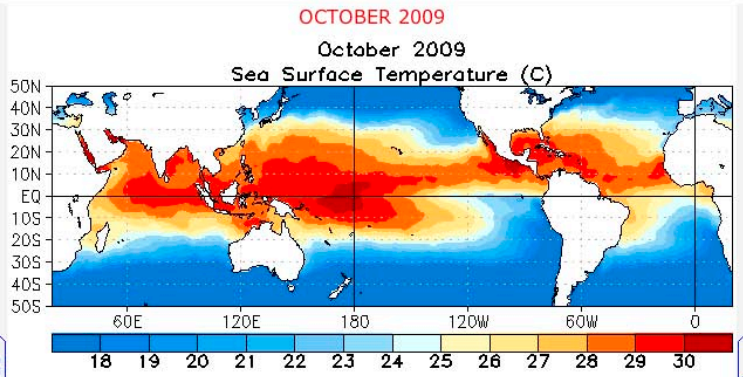
- Tropical Highlights
- Table of Atmospheric Indices (Table 1)
- Table of Oceanic Indices (Table 2)
- Time Series
- Time-Longitude Sections
- Mean & Anomaly Fields
  - Depth of the 20C Isotherm T16
  - Subsurface Eq. Pacific Temp T17
  - Sea Surface Temperature T18
  - Sea Level Pressure T19
  - 850-hPa Vector Wind T20
  - 200-hPa Vector Wind T21
  - 200-hPa Streamfunction T22
  - 200-hPa Divergence T23
  - 200-hPa VPOT & Div Wind T24
  - OLR T25
  - SSM/I Tropical Precipitation T26
  - Cloud Liquid Water T27
  - Precipitable Water T28
  - E-W Divergent Circulation T29
  - W-E Divergent Circulation T30
  - Pacific Zonal Wind (a) T31
  - Pacific Zonal Wind (b) T32

Forecast

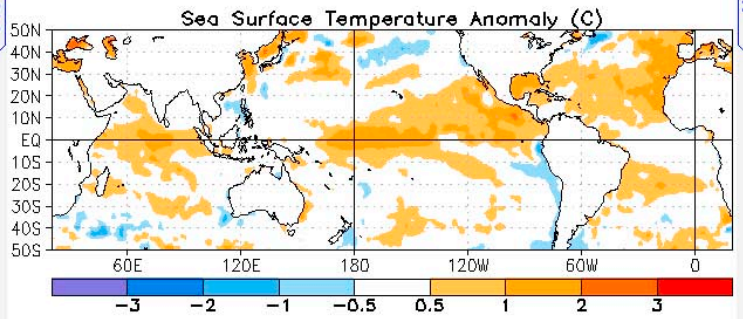
Extratropics

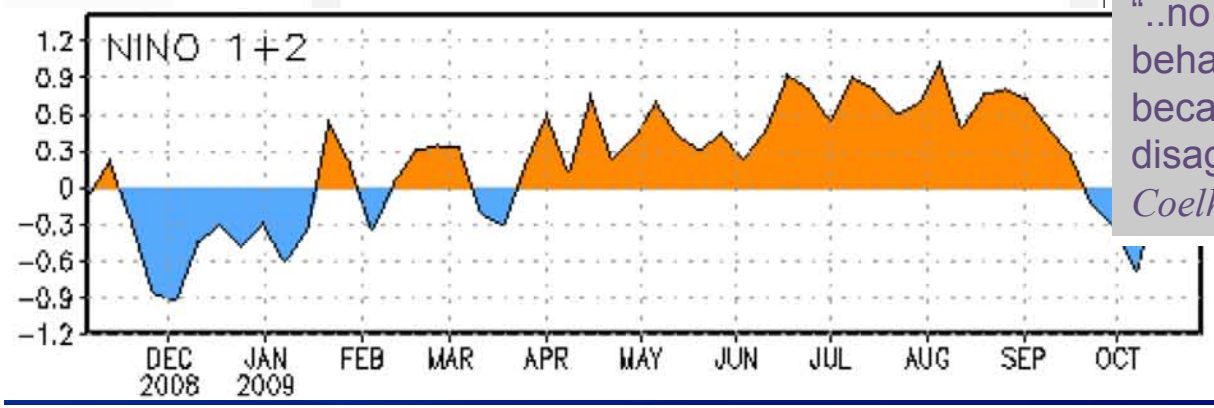
Appendix 1: Outside Contributions

OCTOBER 2009



Previous Next



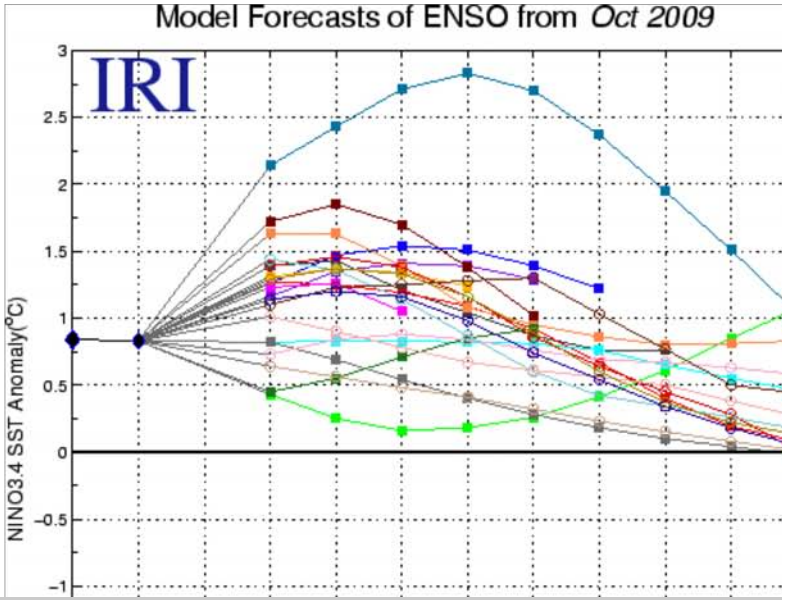


EL NIÑO/SOUTHERN OSCILLATION (ENSO) DIAGNOSTIC DISCUSSION

issued by

CLIMATE PREDICTION CENTER/NCEP/NWS

5 November 2009



"..no firm projection about about the future behavior of El Niño variability can be made because the (IPCC 2007/CMIP3) models disagree"

Coelho & Goddard, J. Clim., 2009