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)

Vostok Ice Core Record - 4 Glacial Cycles

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

- GLOBAL LAND AND OCEAN
  Trend is +0.6°C/Century; +1.0°F/Century

- GLOBAL LAND
  Trend is +0.7°C/Century; +1.3°F/Century

- GLOBAL OCEAN
  Trend is +0.5°C/Century; +0.9°F/Century

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

Trend in Annual TMEAN, 1900 to 2009

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

Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii

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
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

Global Temperature Anomalies
from 1890-1919 average

- Black: Observations
- Blue: Models with natural effects (volcanoes and solar) only
- Red: Models with human and natural effects

IPCC, 2007
Natural versus human forcing on climate

Global and continental temperature change

- North America
- Europe
- Asia
- Africa
- South America
- Australia

- Global
- Global Land
- Global Ocean

models using only natural forcings
models using both natural and anthropogenic forcings
observations
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

- Multivariate ENSO index - weighted average of the main ENSO features contained in sea-level pressure, surface wind, surface sea and air temperature, and cloudiness in the tropical Pacific (Walter and Timlin, 1998)

- Net effect of sunspot darkening and facular brightening - model developed from observations of total solar irradiance (Lean and Rind, 2009)

- Optical thickness at 550 nm - compiled by Sato et al. (1993) since 1850, updated from giss.nasa.gov and extended to the present with zero values

- Hansen et al. (2007) net effect of eight different components

- From Lean and Rind (2009)
Global Surface Temperature Response to Natural and Human Influences: 1980-2008

Lean and Rind (2009)

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

... CRU temperature data, Univ. East Anglia, UK
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)
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
  – Electroscaavenging (circuit current in supercooled clouds)
  – Electroactivation (liquid water clouds)
  – electrocoalescence (liquid water clouds)
Henrik Svensmark

  – 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

Inverse of cosmic rays relative to the global mean surface air temperature anomaly $\Delta T$

Also, that more warming has been occurring at night doesn’t work for an albedo based effect


Kulmala et al., ACP, 2010: find no effects on particles from cosmic rays
What role could the Sun play in the next few decades?
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. ΔT=0.3°C from 2004-2014

Advancing decadal-scale climate prediction in the North Atlantic sector


…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.
Discontinuous Changes in Temperature

GFDL CM2.1 Surface Air Temperature
95W–90W, 40N–45N (Upper Midwest)
(anomalies relative to 2001–2005 average)

- B1 scenario

GFDL CM2.1 Surface Air Temperature
95W–90W, 40N–45N (Upper Midwest)
(anomalies relative to 2001–2005 average)

- A2 scenario
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.
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

Thank You
Future climate and its impacts depends on choices made today

- **HIGHER**
  - A1FI (940 ppm)

- **LOWER**
  - B1 (550 ppm)

**CO2 Emissions**

Source: IPCC 2004
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

Bago and Butler

McMurdo, Antarctica, Neutron Monitor
Bartol Research Institute, University of Delaware
27-Day Averages - data through 1 August 2000
Estimating Long-Term Solar Variability

sub-surface dynamo

surface magnetic fields of opposite polarity

transported by...
differential rotation, meridional flow, diffusion

NRL Flux Transport Model

Total Solar Irradiance

flux transport simulations
Wang et al., 2005

range of cycle+background
Leen, 2000

Galactic Cosmic Ray Flux at Earth
0.0000007 Wm\(^{-2}\)

Irradiance at Earth
1365 Wm\(^{-2}\)
Sun and Anthropogenic Regional Surface Temperature Responses: 1889 – 2003

**SOLAR IRRADIANCE**

**ANTHROPOGENIC**

CRU Empirical Analysis for 1889-2008

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

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

drought
Equatorial East Africa
Verschuren et al., 2000

high rainfall
Oman
Neff et al., 2001

stronger monsoon
Wangxiang cave
Zhang et al., 2008

warming Beijing
Tan et al., 2004

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

streamflow
Parana River
Mauas et al., 2008

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

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)

---

From Muschler 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

United States
Trend is +1.3°F/Century

Global (Land and Ocean)
Trend is +1.3°F/Century
Natural and Anthropogenic Change in Earth’s Atmosphere

Solar increase $\rightarrow$ warming
$CO_2$ increase $\rightarrow$ warming
Volcanoes $\rightarrow$ cooling
Climate Model Response to Radiative Forcing

\[ \Delta T = \kappa F \]

\[ \text{climate sensitivity} \]

IPCC range: 0.2-1°C per Wm\(^{-2}\)
Paleoclimate: 0.75°C per Wm\(^{-2}\)  
Hansen, 2004

Anthropogenic Influence

\[ \Delta T = 0.4^\circ \text{C} \quad (1980-2006) \]
\[ F = 1 \text{ Wm}^{-2} \quad \text{(total, not all radiative)} \]
\[ \therefore \kappa \approx 0.4^\circ \text{C per Wm}^{-2} \]

\[ \text{BUT… response to cyclic decadal forcing is assumed to be attenuated by } \sim 5x \text{ compared with “equilibrium” response} \]

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
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

- ENSO
  - La Nina
  - El Nino

- Volcanic Aerosols
  - El Chichon
  - Pinatubo

- Solar Irradiance
- Anthropogenic Forcing

- ENSO
- Volcanic Aerosols
- Solar Irradiance
- Anthropogenic Forcing
56

- cycle 21 & 22 length was 10.6 years
- cycle 23 length is >12 years
- there were no sunspots from Jan to Sept 2008
- some solar and geomagnetic indices are historically (over decades) low
- polar fields have reversed
- there have been similar long quiet episodes in the past
- recent new-cycle activity

Is a big El Niño coming?

"...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