The Science and Politics of Climate Change

J. Srinivasan
Divecha Centre for Climate Change
Indian Institute of Science
CLIMATE OF FEAR

Why We Shouldn't Worry about Global Warming

Thomas Gale Moore
This Book claims that Global warming is a hoax
Michael Crichton’s book refers specifically

- absence of real world data
- lack of model testing and validation
- lack of independent assessments of models
With so much at stake, it is right that climate science is subjected to the most intense scrutiny.

Michael Le Page, New Scientist.
The climate problem is an unprecedented challenge to humanity. It is global in scope, its time-scale is centuries, and the mitigation strategies required are often fraught with risks as large as the problem itself.
How good is the scientific evidence for global warming?

How sure are we that Global warming has been induced by human beings?

What is the impact of aerosols on climate change?
U.S. Temperature Trends: 1901 to 1998

Red circles = warming; Blue circles = cooling
All stations/trends displayed regardless of statistical significance
Global annual temperature versus 1961-1990

HadCRUT3 data

VWO normal period
Before 1970, both natural and human factors could have played a role.
Surface weather stations: Note concentration in US and western Europe. Vast areas of the world with no coverage. Ocean 70% of surface.
Satellite-Based Estimates of Temperature

✓ Difficulties in piecing together a homogeneous temperature record
  ▪ 13 separate satellites 1979-2002 – all have varying degrees of overlap
  ▪ No on-board calibration
  ▪ Orbital drift and decay affects each satellite differently
    From Karl, NOAA, 2002

Local equatorial crossing time for NOAA satellites show the long-term drift

Ascending LECT (Hrs.)

12 14 16 18 20 22 24

Year

NOAA-6
NOAA-8
NOAA-10
NOAA-12

NOAA-7
NOAA-9
NOAA-11
NOAA-14

TIROS-N

Wentz, 2002
CO2 AND GLOBAL MEAN TEMPERATURE [ 1882 - 2004 ]
Air moves freely through ice

Air diffuses slowly through ice

Air sealed in ice
Permission from the British Antarctic Survey (BAS), Eric Wolff (BAS) and Keith Shine at the University of Reading.
4 glacial cycles recorded in the Vostok ice core

The cooling and warming during the ice ages and interglacial periods, however, was far greater than would be expected from the tiny changes in solar energy reaching the Earth.
The change in Solar radiation was amplified many times by positive feedbacks.

POSITIVE FEEDBACK

Solar Rad $\uparrow$

Temperature Increases

POSITIVE FEEDBACK

Ice becomes water Absorbs more solar energy

POSITIVE FEEDBACK

Higher Greenhouse Effect

POSITIVE FEEDBACK

CO2, CH4 and Water Vapor increases
where $X$ is ice mass,

$Y$ is ocean temperature

$Z$ is $\text{CO}_2$, 

where in this particular case $X$, $Y$ and $Z$ are the ice mass, deep ocean temperature and atmospheric carbon dioxide.
CH$_4$ = 1755 ppb in 2004
CO$_2$ = 377 ppm in 2004
LOSU = level of scientific understanding

Radiative Forcing Components

<table>
<thead>
<tr>
<th>RF Terms</th>
<th>RF values (W m²)</th>
<th>Spatial scale</th>
<th>LOSU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-lived greenhouse gases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>1.66 [1.49 to 1.83]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>N₂O</td>
<td>0.48 [0.43 to 0.53]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.16 [0.14 to 0.18]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>Halocarbons</td>
<td>0.34 [0.31 to 0.37]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>Ozone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stratospheric</td>
<td>-0.05 [-0.15 to 0.05]</td>
<td>Continental  to global</td>
<td>Med</td>
</tr>
<tr>
<td>Tropospheric</td>
<td>0.35 [0.25 to 0.65]</td>
<td>Continental  to global</td>
<td>Med</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stratospheric water vapour from CH₄</td>
<td>0.07 [0.02 to 0.12]</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td>Surface albedo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land use</td>
<td>-0.2 [-0.4 to 0.0]</td>
<td>Local to continental</td>
<td>Med - Low</td>
</tr>
<tr>
<td>Black carbon on snow</td>
<td>0.1 [0.0 to 0.2]</td>
<td>Local to continental</td>
<td>Med - Low</td>
</tr>
<tr>
<td>Total Aerosol</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct effect</td>
<td>-0.5 [-0.9 to -0.1]</td>
<td>Continental  to global</td>
<td>Med - Low</td>
</tr>
<tr>
<td>Cloud albedo effect</td>
<td>-0.7 [-1.8 to -0.3]</td>
<td>Continental  to global</td>
<td>Low</td>
</tr>
<tr>
<td>Linear contrails</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar irradiance</td>
<td>0.12 [0.06 to 0.30]</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td>Total net anthropogenic</td>
<td>1.6 [0.6 to 2.4]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 3. Estimates of Earth’s heat balance components ($10^{22}$ J) for the 1955–1998 period.
ARGO floats

- Satellite antenna
- Temperature/salinity probe
- Circuit boards & satellite transmitter
- Gear motor
- Single stroke pump
- Stability disk
- Battery
- Hydraulic pump (piston)
- Hydraulic fluid
- Bladder
Upper-Ocean “cooling”

2003 to 2005 cooling: 
-1.0 ± 0.33 W/m²

(Averaged over Earth’s surface)

0 – 750m Ocean Heat Content Anomaly

from Lyman et al. (GRL, 2006)
Simulated and observed variability in ocean temperature and heat content by Achuta Rao et al

Proceedings of National Academy of Sciences
Vol. 104, 26 June 2007

We show that the 2003–2005 cooling is largely an artifact of a systematic change in the observing system, with the deployment of Argo floats reducing a warm bias in the original observing system.
Global mean increase in Earth’s atmosphere during the past 100 yrs

- $\text{CO}_2$ increased by 37%
- $\text{CH}_4$ increased by 151%
- $\text{O}_3(\text{trop})$ increased by 31%
- $\text{N}_2\text{O}$ increased by 31%
The Global Carbon Cycle

Atmosphere
- 760 + 3/yr

Ocean
- 38,000
- ~90

Humans
- 7 GtC/yr

Land
- 2000
- ~120
- ~120
Development of $^{14}\text{C}$ in atmospheric CO$_2$ in the Northern Hemisphere in the last 50 years. Data before 1959 have been derived from tree rings (Stuiver and Quay, 1981). From 1959 to 1983 measurements were performed at the Alpine site Vermunt, subsequent data from 1984 onwards are from the Schauinsland station in the Black Forest.
“Suess Effect”

The decline of $^{14}$C after the nuclear tests demonstrates that CO$_2$ entering the atmosphere through fossil fuel use

![Graph showing the decline of $^{14}$C over time in Fruholmen, Norway.](image-url)
\[ \Delta^{14}C \text{ in the troposphere} \]

Observation & models \{from Naegler et al\}
Ralph Keeling's record of atmospheric oxygen, taken in places like Australia's Cape Grim, show a small but steady decline consistent with increased use of fossil fuels.
Climate Change
Natural Vs. Anthropogenic
Is the global warming in the 20th century due to the increase in radiation emitted by the sun?
Graph showing radiative forcing from various sources over time. The x-axis represents years from 1860 to 2000, and the y-axis represents radiative forcing in [W m$^{-2}$]. The lines represent GHGs (red), Sulfates (green), Solar (blue), and Volcanic (black).
CCN are fairly insensitive to the nucleation rate for a simple reason: during the time taken for nuclei to grow to CCN sizes, coagulation depletes particle concentrations.
Frohlich C, Lean J. 1998;
(http://www.pmodwrc.ch/pmod.psi/composite/SolarConstant)
Pattern of Strange Errors Plagues Solar Activity and Terrestrial Climate Data
Damon & Laut, EOS, 2004

E. Friis-Christensen & K. Lassen Science, 1991
Fig. 12: Ion-induced nucleation of new particles from trace condensable vapours and water in the atmosphere.
From Tom Harris, International Climate Science Coalition

**Correlation between sunspot cycle, galactic cosmic rays and global cloudiness**

Solar flux rise $\rightarrow$ GCR influx drop $\rightarrow$ cloud cover drops $\rightarrow$ surface warms

15% variation in cosmic ray penetration between solar max. and min. causes 1.7% variation in low cloud formation.

1.7% variation in low cloud formation causes 1.3 W/m² in surface warming which is $\geq 85\%$ of IPCC estimate for effect of all CO₂ since beginning of industrial revolution = 1.4 W/m².
Kristjansson et al., Advances in Space Research, 2004

One may conclude that neither the coupling between solar irradiance and low clouds suggested by Kristjansson et al. (2002) nor the coupling between cosmic rays and low clouds suggested by Marsh and Svensmark (2000) would have any impact on the global warming over the period 1950–2000.
Krivova & Solanki,
Advances in Space Research, 2004

We have shown that even in the extreme case that solar variability caused all the global climate change prior to 1970 it cannot have been responsible for more than 30% of the strong global temperature rise since 1970.
CLOUD (Cosmics Leaving Outdoor Droplets) experiment is being set up at CERN to investigate GCR-cloud microphysics under controlled conditions in the laboratory.

The experiment involves a 4 m diameter aerosol chamber and a 0.5 m cloud chamber which are exposed to a CERN particle beam, providing an adjustable source of “cosmic rays” that closely simulates GCRs at any altitude or latitude.
INCREASE IN CO2 CAUSES WARMING OF THE TROPOSPHERE AND COOLING OF THE STRATOSPHERE
Climate model results

Weather balloon data
1. Solar

2. Volcanoes

3. Well-mixed greenhouse gases

4. Ozone

5. Sulfate aerosol particles

6. 1st five factors combined

Santer et al., 2007
We Need Climate Models

• To discriminate between natural and anthropogenic causes

• To Predict future climate change
GENERAL CIRCULATION MODELS (GCM) incorporate all known laws of physics and exploit the number crunching power of modern computers.
Source: Jerry Meehl, National Center for Atmospheric Research
Another test: Do coupled models capture the atmospheric temperature changes after major volcanic eruptions?
GISS GCM (Ch8 IPCC AR4)

(b) Surface temperature

- stratospheric aerosols
- + ozone
- + greenhouse gases
- + solar irradiance
- observations

ΔT_s (°C)

Year

[Graph showing temperature changes from 1980 to 1995]
Aerosols and Climate

- Impact of aerosols on climate is complex
- Most aerosols cool the earth (sulphate)
- Some aerosols heat the atmosphere but cool the surface (soot)
- In contrast to $CO_2$, aerosols are not uniformly mixed in the atmosphere
- Life time of aerosols is around one week while that $CO_2$ is of the order of 100 years

[Diagram: A pathway showing aerosol scattering and absorption of solar radiation. The aerosol is shown interacting with cloud droplets (CCN), leading to an unperturbed cloud. Two paths are highlighted: 1. increased cloud albedo and 2. increased cloud lifetime (drizzle suppression). Additionally, a direct effect is noted as “more cloud droplets.”]
Feb-Mar, 1998
Jan-Mar, 1999
“Kyoto also failed to address two major pollutants that have an impact on warming, black soot and tropospheric ozone…”

--President George W. Bush, June 11, 2001

“Climate Effects of Black Carbon Aerosols in China and India”
Menon et al. Science, 297, 2002

Atmospheric brown clouds: Impacts on South Asian climate
Ramanathan et al., PNAS, April 2005
Reducing Black Carbon May Be the Fastest Strategy for Slowing Climate Change

IGSD/INECE Climate Briefing Note June 2009

A drastic reduction of black-carbon emissions could provide near-immediate relief
Grieshop et al., Nature Geoscience, August 2009

Climate trade-off between black carbon and carbon dioxide emissions by Boucher & Reddy, Energy Policy, 36. 2008
YO! AMIGO!!
WE NEED THAT TREE TO PROTECT US FROM THE GREENHOUSE EFFECT!
Petition to the World Heritage Committee:
January 29, 2009
by
Earthjustice, USA & Australian Climate Justice Program

The Role of Black Carbon in Endangering World Heritage Sites Threatened by Glacial Melt and Sea Level Rise
Over the last 25 years, Gangotri glacier has retreated more than 850 meters.
Air pollution control could help to mitigate climate change, buying time until greenhouse gas reductions take effect,

The jury is out on whether air pollution control will accelerate or mitigate climate change

Studies available to date mostly suggest that air pollution control will accelerate warming in the coming decades.
Conclusions

• The global warming in the 20\textsuperscript{th} century was mainly account of increase in greenhouse gases
• The impact of variations in solar radiation and cosmic rays not clearly understood
• The impact of aerosols can cause cooling as well as heating
• We need to act although we do not have a clinching evidence about the adverse impact of global warming
Thank You

I am ready for a barrage of questions!
Solar Radiation (W/m²) at 60°N during the last 400,000 years
Climate Surprises?

• Rapid melting of Greenland
• Break-off of the West Antarctic Ice Sheet
Climate is what you expect but weather is what you get

Mark Twain
The Himalayan Dilemma: Reconciling Development and Conservation by Ives and Messerli 1989

“The impacts of climate change are superimposed on a variety of other environmental and social stresses, many already recognized as severe”
Note the change over the southwestern coasts

Rajendran & Kitoh, 2005
Where does the anthropogenic CO$_2$ go?

- **Atmosphere** - 55%
- **Ocean** - 25% to 30%
- **Biosphere** - 15% to 20%

Ruddiman, 2001
The increase in $CO_2$ will amplified many times by positive feedbacks.

*POSITIVE FEEDBACK*

$CO_2$ rises, temperature increases, water vapor increases, ice becomes water, absorbs more solar energy, higher greenhouse effect, positive feedback.
The planet is committed to a warming over the next 50 years regardless of political decisions.

Mitigation Possible

Adaptation Necessary

Source: National Center for Atmospheric Research
MULTIPLE EQUILIBRIRUM

RADIATION

Temper

T_L

T_U

T_1

T_2

T_3

LW_{out}

SW_{ab}
Oscillation between ice-free and ice-covered earth
Tipping elements
Processes, particularly sensitive to climate change

- Greenland ice sheet
- Arctic sea ice melting
- Deep water formation
- Arctic ozone depletion
- Methane outgasing
- Himalaya snow cover
- Indian monsoon
- Sahara
- El Niño
- Marine carbon cycle
- West Antarctic ice sheet
- Antarctic ozone hole
- Mediterranean

Population density [persons per km²]
Abrupt Climate Change

The graph shows the snow accumulation (mm/yr) over time, with depth in meters (m) on the y-axis and years on the x-axis. The graph highlights the Younger Dryas period between 12,000 and 13,000 years ago, with a significant drop in snow accumulation followed by a rapid increase.

Year:
- 1600
- 1700
- 1800

Depth (m):
- 0.3
- 0.2
- 0.1
- 0.0

Time Periods:
- 10,000 - 11,000
- 12,000 - 13,000
- 13,000 - 14,000
- 15,000 - 16,000
- 17,000
Vecchi and Soden, *Journal of Climate*, 2007
Volcanic aerosols in the high atmosphere block solar radiation and increase cloud cover leading to widespread cooling, especially significant in summer.
Total Column Water Vapor Anomalies (1987-2004)

We have high confidence in the model projections of increased water vapor.

Held and Soden 2006
(a) Water vapor vs. Temperature  
(b) Precipitation vs. Temperature
**IPCC-1990** “The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more.”

**IPCC1995** “The **balance of evidence** suggests a discernible human influence on global climate.”

**IPCC 2000** “Most of the observed warming over the last 50 years is **likely** to have been due to the increase in greenhouse gas concentrations.”

**IPCC 2007** “Most of the observed increase in global temperatures since the mid-20th century is **very likely** due to the observed increase in anthropogenic greenhouse gas concentrations.”
Trends in “Extreme” and “Moderate” Events

- Red line: $R \geq 100$ mm/day
- Blue line: $5 \leq R < 100$ mm/day
Change in Global Water Vapor at 2100

\[ \Delta q \text{ (\%)} = 7.5\%/K \Delta T \text{ (K)} \]

Held and Soden 2006
Change in Global Precipitation at 2100

\[ P = \text{Mc} \times q \]
\[ \frac{dP}{P} = \frac{d\text{Mc}}{\text{Mc}} + \frac{dq}{q} \]

\begin{align*}
2\%/\text{K} & \quad -5\%/\text{K} & \quad 7\%/\text{K}
\end{align*}

Reduction in circulation

Held and Soden 2006
The heart of the Kyoto and post-Kyoto discussion:
Achieve CO2 stabilization at levels that do not pose serious threats to the earth’s climate

From Giorgi, ICTP, Trieste
Natural climate change over the last 18,000 yrs

- Holocene maximum
- Medieval warm period
- Little ice age
- Younger Dryas
- The last Ice Age
- The present interglacial
The Natural Greenhouse Effect: clear sky

Clouds also have a greenhouse effect
Kiehl and Trenberth 1997