Climate, Water and Carbon Cycles: Records Across a Hierarchy of Time Scales

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A COSMIC CONNECTION

Physicists and climate scientists have long argued over whether changes to the Sun affect the Earth’s climate? A cloud chamber could help clear up the dispute, reports Jeff Kanipe.
What is the principal climate driver?

SUN?

BUT...

Solar irradiance $< 1.5 \text{ W m}^{-2}$
($\sim 1/3$ of centennial temperature increase)

An amplifier is required
Solar “constant” = 1368 W m$^{-2}$

1.5 W m$^{-2}$
Solar irradiance

2.5 W m$^{-2}$
Greenhouse gases
Solar “constant” = 1368 W m$^{-2}$

1.5 W m$^{-2}$

Positive water vapour feedback

$\text{CO}_2... \sim 1 \text{ W m}^{-2}$
CLIMATE MODELS

“Atmosphere”, from NASA
WATER CYCLE MODELS

“Atmosphere”, from NASA
Any input of energy into water cycle generates more water vapor and higher temperatures

“Water vapor”, from NASA
NOTE

The uncertainties of planetary energy balance estimates are about $\pm 6 \text{ W m}^{-2}$

Kandel and Viollier (2005), Space Science Reviews
Could cosmic rays be an amplifier to solar irradiance?
What controls the flux of cosmic rays reaching the Earth?
Supernova Remnant where Cosmic Rays (with $E \lesssim 10^{15}\text{eV}$) are generated

"Indirect Picture" of Milky Way

N. Shaviv
What controls the flux of cosmic rays reaching the Earth?

and

shield(s)
Cloud formation, cosmic rays, and solar irradiance

Marsh and Svensmark (2003), Space Science Reviews

X-ray sun, Yohkoh satellite (ISAS)
The Influence of Solar Changes on the Earth’s Climate

L.J. Gray, J.D. Haigh, R.G. Harrison

Hadley Centre technical note 62
January 2005

EXECUTIVE SUMMARY

“Galactic cosmic rays have been shown to be closely correlated with continuous satellite (ISCCP) retrievals of low cloud from 1983 - 1994, and possibly from 2001. Modelling and observations now support atmospheric production of ultra-fine aerosol from cosmic ray produced ions…”

“Theory shows that charged aerosols are preferentially removed by cloud droplets, presenting the possibility of a long-range influence [on climate] through the global atmospheric electrical circuit.”

Harrison and Stephenson (2005), Proceedings of the Royal Society

1% “clouds” ~ 0.2 °C
Experimental evidence for the role of ions in particle nucleation under atmospheric conditions

By Henrik Svensmark\textsuperscript{1,*}, Jens Olaf P. Pedersen\textsuperscript{1}, Nigel D. Marsh\textsuperscript{1}, Martin B. Enghoff\textsuperscript{1} and Ulrik I. Uggerhøj\textsuperscript{1,2}

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Experimental studies of aerosol nucleation in air, containing trace amounts of ozone, sulphur dioxide and water vapour at concentrations relevant for the Earth's atmosphere, are reported. The production of new aerosol particles is found to be proportional to the negative ion density and yields nucleation rates of the order of 0.1–1 cm\textsuperscript{-3} s\textsuperscript{-1}. This suggests that the ions are active in generating an atmospheric reservoir of small thermodynamically stable clusters, which are important for nucleation processes in the atmosphere and ultimately for cloud formation.

Keywords: cosmic rays; aerosol nucleation; clouds
Verdict of geologic record?
Brachiopods

Christoph Korte
Veizer, Godderis, Francois (2000)
Supernova Remnant where Cosmic Rays (with $E \lesssim 10^{15}$ eV) are generated

“Indirect Picture” of Milky Way

N. Shaviv
420,000 Year Vostok CO$_2$ Record
Petit et al. (1999)
Bubbles prompt climate-change rethink

Argon traces hint that carbon dioxide did not lead life out of the freezer, but followed.
14 March 2002

TOM CLARKE

Carbon dioxide certainly warms our planet, but it might not turn on the heat, reveals a new analysis of ancient Antarctic ice.

“Our data suggest that the warming came first, then carbon dioxide increased,” says Jean Jouzel of the Pierre-Simon Laplace Institute in Gif-sur-Yvette, France. Something else probably extraterrestrial got the warming going, his team concludes.

Aside from water vapour, carbon dioxide is the major warming influence on our planet. But it’s hard to work out which comes first: a rise in carbon dioxide levels or a slight temperature hike increases atmospheric carbon dioxide, through its effects on forests and oceans.
Holocene

Marine record
Atlantic borehole off Ireland
Kromer et al. (2001)
Bond et al. (2001)

The graph shows the concentration of $^{14}C$ (14 carbon) and ice rafted debris over time, measured in calendar years (kyrs). The concentration is given in atoms/cm$^2$/sec. The peak around 12 kyrs suggests a significant event or period of increased activity.
Holocene

Terrestrial record
Cave in Oman

Neff et al. (2001)
Cave in the Alps

“Medieval climate optimum”

Adapted from Mangini et al. (2005), EPSL
Norse settlements at “L’Anse aux Meadows” in Newfoundland, ca. 1000 AD
Adapted from Mangini et al. (2005), EPSL

"Little Ice Age"
“Washington Crossing The Delaware”, winter 1776 - 1777

By Emmanuel Leutze
Sun ($\Delta^{14}C$)

Climate

$\text{CO}_2$

Year (AD)
Magnetosphere
Temperature
Sun

Le Mouel et al. (2005)
From Soon (2005)
So what is the sequence?
Solar irradiance

Cosmic rays

Atmospheric water cycle

Aerosols

Climate

Carbon cycle (CO₂)
How are the water and carbon cycles coupled in terrestrial systems?
Gridded data from Global Primary Productivity Data Initiative (GPPDI)
Bow River valley, southern Alberta
South Saskatchewan River watershed
(Annual precipitation = 480 mm)

Transpiration = 247 ± 73 mm
Ok Tedi watershed
(Annual precipitation = 8300 mm)

Transpiration = 1120 ± 160 mm
END
Adapted from Nemani et al. (2002), GRL
Empirical evidence for a nonlinear effect of galactic cosmic rays on clouds

By R. Giles Harrison* and David B. Stephenson

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• “The diffuse radiation changes are, therefore, unambiguously due to cosmic rays.”

• 1 % “clouds” ~ 0.2°C
Earth paleomagnetic intensity

\[ ^{10}\text{Be} \]

age (kyr BP)

Frank (2000)
Frank (2000)
Cosmic Ray Decrease (%) vs. Solar Cycle Length (year)

Δ Irradiance (W/m²)

T (°C)

Year

1900 2000

CO₂ (ppm)

Svensmark, 1998
- Water Cycle
- Carbon Cycle
- Life
- Climate
Geomagnetic Activity Index

$^{10}\text{Be}$

$^{14}\text{C}$

% change cosmic rays from solar flux

1700 1800 1900 2000 Year
“… basin-wide [Amazon] enhanced rainforest activity in the sunnier dry season, suggesting that sunlight may exert more influence than rainfall on rainforest phenology and productivity.”

_Huete et al. (2006), JGR_
Rainforest ecosystems, South America and New Guinea