Decadal Variations of Solar Magnetic Field, Heliosphere and the Cosmic Rays, and their Impact on Climate Change

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Solar modulation of Galactic Cosmic Rays (GCRs)

- Charged particles (mainly protons)
- Accelerated at supernova remnant

@ ~ edge of the heliosphere

- diffusion
- advection by solar wind
- drift

Webber & Higbie 2010
Cosmic ray variation & Solar magnetic polarity

1. Magnetic polarity

2. Tilt angle

Sun
Earth

Positive polarity

Negative polarity

Gradient B drift

\( \mathbf{v} = \mathbf{B} \times \nabla \mathbf{B} \)

Jokipii & Kota 2007
Variable “22-year” variation of cosmic rays

1. Solar polarity

2. Tilt angle

Kota & Jokipii, 2003

Miyahara et al., 2009

Modern: 5-75 degrees

If 30-75 degrees

If 0-75 degrees
Reconstructed solar decadal cycles in the past

Usoskin, 2004

Year AD

1600 1700 1800 1900 2000

Maunder Minimum

Maunder

Spoerer

Wolf

Dalton

Oort

~9 yrs

~12 yrs

~10.5 yrs

~10 yrs

~13.5 yrs

~14 yrs

~13 yrs

14C (permil)

~11 yrs

(+/- 1yr)

~11 yrs

-30

-10

10

30

800 1100 1400 1700 2000

Year AD

Actual mean length over the shaded period

~9 yrs

~10.5 yrs

~11 yrs

~10 yrs

~13 yrs

(Dcadal)

Dcadal:

Stuiver et al., 1998

Annual:

Variable “22-year” variation of cosmic rays

1. Solar polarity

2. Tilt angle

Kota & Jokipii, 2003

Modern: 5-75 degrees

If 30-75 degrees

If 0-75 degrees

Kota & Jokipii, 2003

Miyahara et al., 2009

Expected cosmic rays

Solar min

Solar max

Solar activity

Cosmic ray flux

Solar cycle

t

Solar min

Solar max

Solar activity

Cosmic ray flux

Solar cycle

t
Pattern of cosmic ray variation at the Maunder Minimum and present

(a) 0 deg. at cycle min
(b) 5 degs. at cycle min

“Flattened current sheet model” reproduces 10Be variation

Based on Kota & Jokipii, 1983; 2003

Year AD

Berggren et al., 2009
Cosmic-ray “22-year (28-year)” variation at the Maunder Minimum

Features of cosmic-ray variation

- Periodic cosmic ray enhancements, but only at the negative polarity (~28-year periodicity)
- 1-year scale enhancement, 30-50% higher than those for positive polarity
- Significant manifestation of drift effect

Miyahara et al., IAU proc., 2009, Yamaguchi et al., PNAS, 2010
Climate response to cosmic-ray spikes during the Maunder Minimum

- Temperature index in Greenland
  (Vinther et al., 2003)

- Humidity index in Japan around June
  (Yamaguchi, Miyahara et al., 2010)

Temperature spikes can be utilized to trace GCR effect on climate system.
No time lag!

Yamaguchi, Miyahara et al., PNAS, 2010
Possible influence of solar rotation on clouds? (OLR)  

Takahashi et al., ACP, 2010  
Hong, Miyahara et al., JASTP, 2010

Unsolved periods with 30-60 days in tropical clouds (Madden-Julian Oscillation) may be under the influence of solar rotation
Possible influence of solar rotation on clouds?

Hong, Miyahara et al., JASTP, 2010

Solar rotational signals are imprinted on to Madden-Julian Oscillation (only at solar cycle maxima)
Influence of QBO on 27-day signal at solar max

Hong, Miyahara et al., JASTP, 2010

> QBO influence on tropospheric cloud activity

> Stronger Stratosphere-Troposphere interaction at solar max?
Summary

• Solar magnetic properties (polarity, structure, cycle lengths) are also important in understanding climate patterns.

• Madden-Julian Oscillation might be the key for understanding solar influence.