Variations of Solar and Cosmic Ray Cycles at the Maunder Minimum



Hiroko MIYAHARA,

Institute for Cosmic Ray Research, The University of Tokyo, Japan hmiya@icrr.u-tokyo.ac.jp

Collaborators

Yusuke Yokoyama (ORI, The Univ. of Tokyo) Yasuhiko T. Yamaguchi (ORI, The Univ. of Tokyo) Takeshi Nakatsuka (Nagoya University) Hong K. Peng (The Univ. of Tokyo) Yukihiro Takahashi (Hokkaido University) Mitsuteru Sato (Hokkaido University) Hiroyuki Matsuzaki (MALT, The Univ. of Tokyo) What ¹⁴C and ¹⁰Be tell about the Maunder Minimum

Cosmic ray variations Solar Cycle length Magnetic polarity reversal Heliospheric current sheet Precursory features

Any similarity to the last solar cycle minimum? Any information on rotation? Any impact on climate?

¹⁴C and ¹⁰Be : Proxy of past cosmic ray variations



Changes in the solar cycle lengths



Onset of the Maunder Minimum



Onset of the Spoerer Minimum

Miyahara et al., 2010



Two lengthened cycles

before the onset of the Maunder Minimum



Vaquero et al., 2011

First lengthened cycle

> weaker polar field

Second lengthened cycle

both weakened polar field
& slower meridional circulation



Cosmic ray variation at the Maunder Minimum

Miyahara et al., IAU proc., 2009, Yamaguchi et al., PNAS, 2010







Flattened current sheet and cosmic-ray spikes

Miyahara et al.,2009 Based on Kota&Jokipii, 1983; 2003

0.02

0.015

0.01

0.005

1620

10Be flux



Any similarity to the last solar cycle minimum?

Closer to AD1954....





Fig. 9. Observation of the solar eclipse of 30 June 1954 (Vsekhsvjatsky, 1963) showing the alignment of streamers with the solar equator.

Cliver, Svalgaard, Ling, 2004



Dashed=Radial Rs=3

Solid=Classic PFSS Model (preferred)

Rotation rate at the Maunder Minimum (equatorial)

Modern:

26.24 days (Synodical) (Sidereal : 24.47days)

Maunder Minimum: 25.3~26.1 days (@1642-1644, Eddy1976) 27 days (@1642-1644, Abarbanell1980) 27.5 days (@1684+1686, Ribes1993) 27.5 days (@1684, Sidereal:25.5days, Flamsteed1684) 28.5±0.5days (@1684, Vaquero2002)



Historical records of lightening

Modern

• 26.7 day solar rotational period (Muraki+2004; Sato+2005) (GCR / solar wind / UV ...)

Weather records around the Maunder Minimum

Myou-hou-in Nikki (diary) AD1695-1786 AD1695-1766 Mujou-hou-in Nikki (diary) AD1668-1694



AD1991-2002





Reflecting the altitude of active region??

Lightening "27-day" cycle (very preliminary)

Maunder Minimum (cycle minima)



Duration between events

If the altitude of Active region is known > Estimation of rotation rate at known latitude

If not known, solar cycle variation of active regions (larger variation)



Modern

After the Maunder Minimum (AD1723-1727)



Possible pathways for solar influence on climate change



Most unknown part



Response of climate to cosmic-ray spikes at the Maunder Minimum



Superposition of four 1-year spikes for ¹⁴C (GCR) and ¹⁸O (climate)



Yamaguchi, Yokoyama, Miyahara et al., PNAS, 2010

Summary :

What ¹⁴C and ¹⁰Be suggests for the Maunder Minimum Solar Cycle length : \sim 14 years Magnetic polarity reversal : YES (\sim 28-year period) Onset : two preceding 12-13 year cycles Cosmic ray variations : Strong 28-year component Heliospheric current sheet : More flattened Any impact on climate? : YES! (possibly through GCR) Any similarity to the last solar cycle minimum? : More extreme situation at the Maunder Minimum Any information on rotation? : Lightening data as well as sunspot record may help

Possible influence of solar rotation on clouds

Takahashi et al., ACP, 2010 Hong, Miyahara et al., JASTP, 2011



Outgoing Longwave Radiation = high clouds analyzed for each 10 x 10 degree grid Solar rotational signals are detected around the tropics (only at solar cycle maxima) Comparison between cosmic rays, solar radio flux with OLR



High-pass filtered (bandwidth: 80days)



AD 2000 (solar max)



Response to GCRs is local, but localized to the areas that can control Hadley cell, monsoonal activity, and cyclone activity etc.



Comparison between cosmic rays, solar radio flux with OLR



High-pass filtered (bandwidth: 80days)

Solar differential rotation





Red : F10.7 solar radio flux Blue : galactic cosmic rays





AD 2000 (solar max)



Influence of QBO on 27-day signal in OLR?



Influence of QBO on tropospheric cloud?





> QBO influence on tropospheric cloud activity

Stronger Stratosphere-Troposphere interaction at solar max? (which might contribute to 2-9yr short-term climate variability)



Solar modulation of cosmic rays & Drift effect

Heliosphere



Important parameters for the pattern of cosmic-ray variation

- 1. Solar polarity
- 2. Tilt angle of heliospheric current sheet



Solar modulation of Galactic Cosmic Rays (GCRs)



