



Transition of the Schwabe/Hale Solar Cycles Associated with the Long-Term Variation of Solar Activity

+ their effects on climate change during the Maunder Minimum

(1645-1715 AD)

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Motivation

Reconstruct the 11-year/22-year solar cycles by measuring ^{14}C content in tree-rings with annual time resolution to clarify.....

- the characteristics of solar variations during the long-term solar dynamo events; such as **the Maunder Minimum**, **the Spörer Minimum** and the Medieval Maximum Period, as well as their precursors.
- if the “11-year” solar cycle really affects climate over time.
Many climate parameters show ~11-year cycle (Hoyt & Schatten, 1997), but similar cycle could also come from climate system itself.
- what is the possible mechanisms of Sun-Climate connection at the decadal timescales, **TSI**, **UV** and/or **GCRs**?
There is one way to differentiate their effects; which is the 22-year cycle

Cosmic rays and ^{14}C in tree-rings

Galactic Cosmic Rays (proton etc.)



Modulation by Solar Magnetic Field



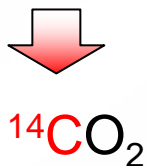
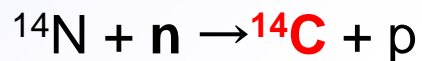
Modulation by Geomagnetic Field



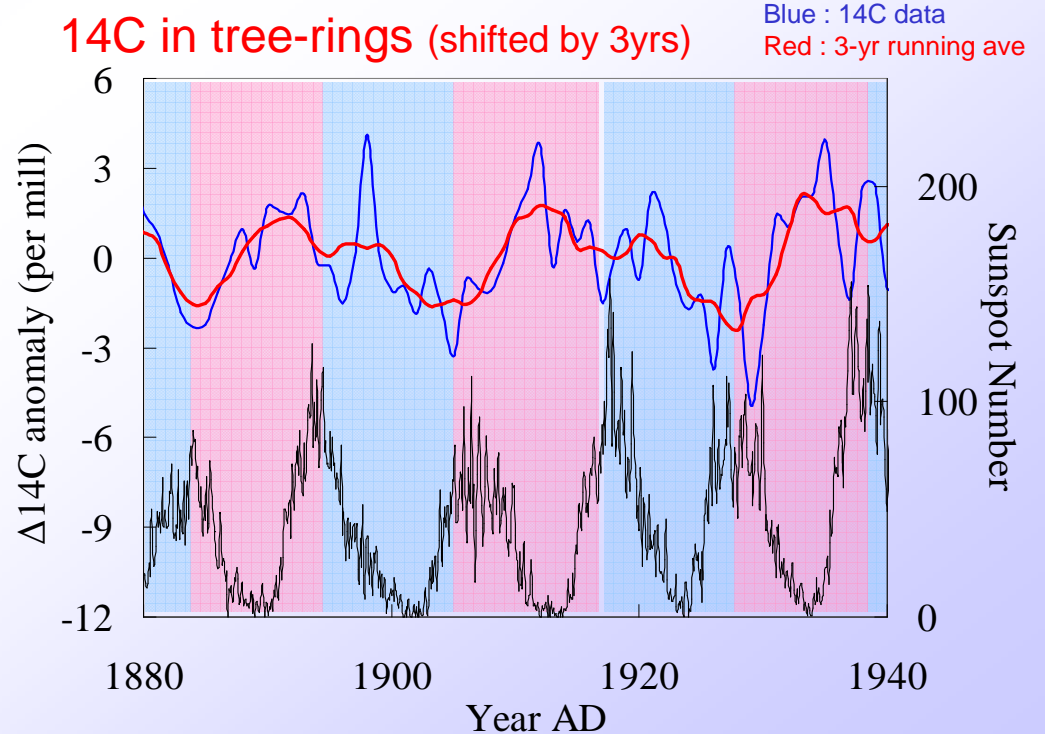
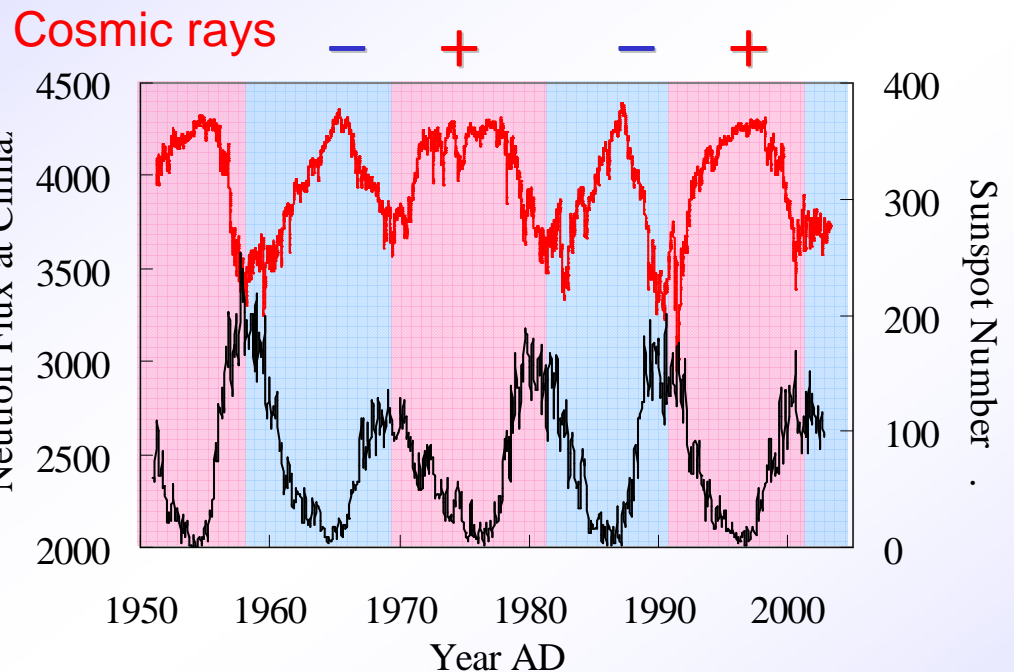
Cosmic Ray Air Shower in the Atmosphere



secondary neutron

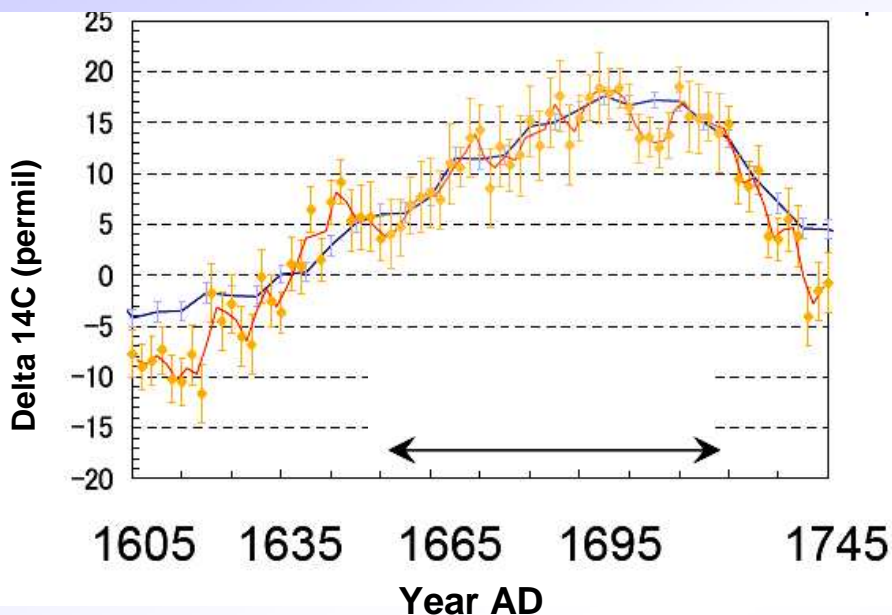


High magnetic activity = Low ^{14}C
 Low magnetic activity = High ^{14}C

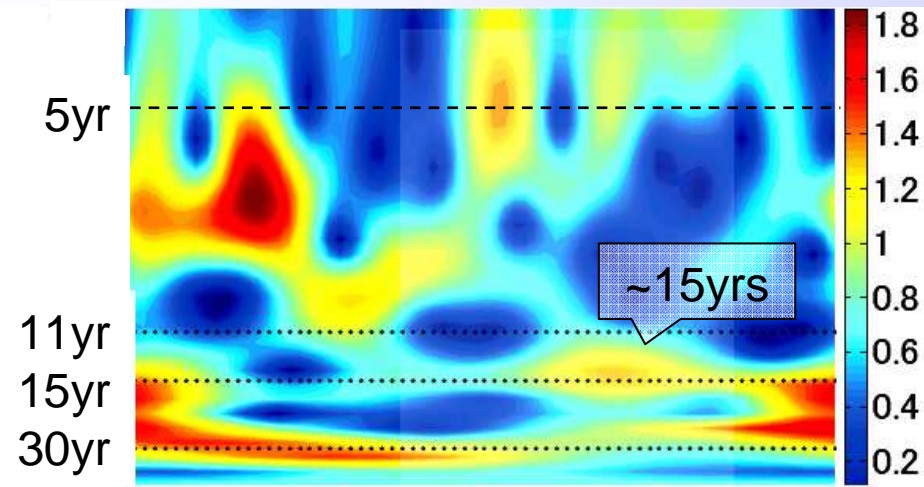
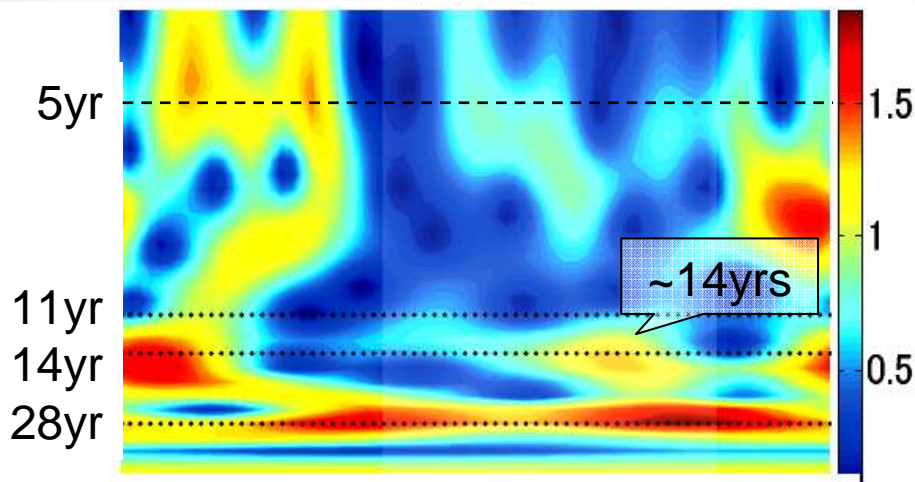
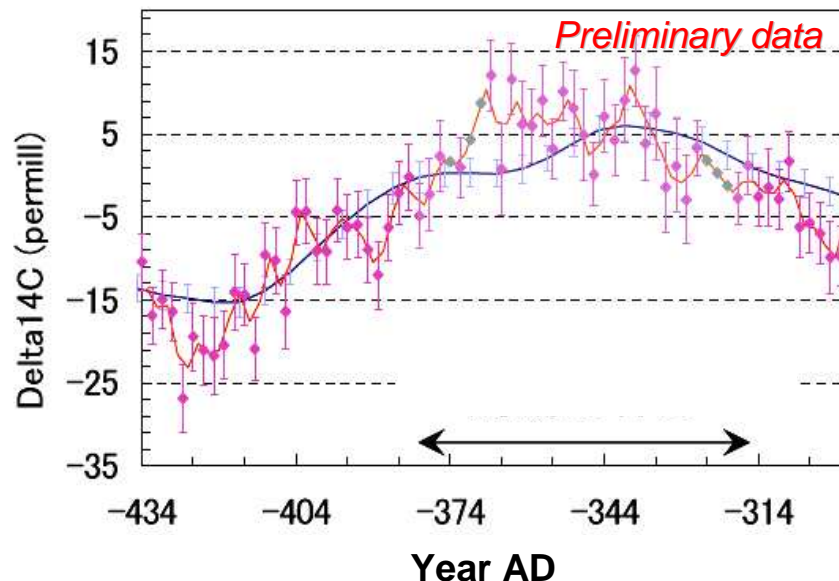


Solar cycle at the Maunder & Maunder-type Grand Solar Minima

The Maunder Minimum (1645-1715 AD)
(Miyahara et al., 2004, 2006)



The Maunder-type Grand Minimum (B.C. 4th century)
(B.C. 4th century)



Different evolution of solar cycle at the Spoerer Minimum (1415-1534 AD)

- During the Maunder Minimum (duration: 70 yrs) solar cycles more or less stably continue with ~14-year period
- During the Spoerer Minimum (duration: 120 yrs) the evolution of solar cycles seems complex

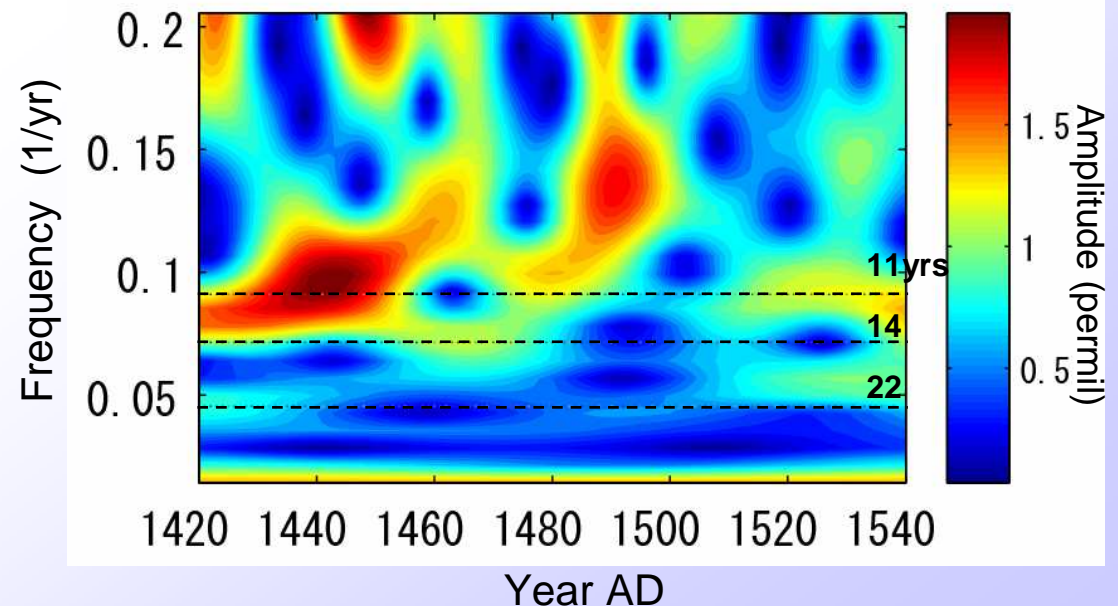
such as...

Intermittent ~11-year cycles

Strongly suppressed signal around 1460-1500 AD

Occasional 13~14 year cycles

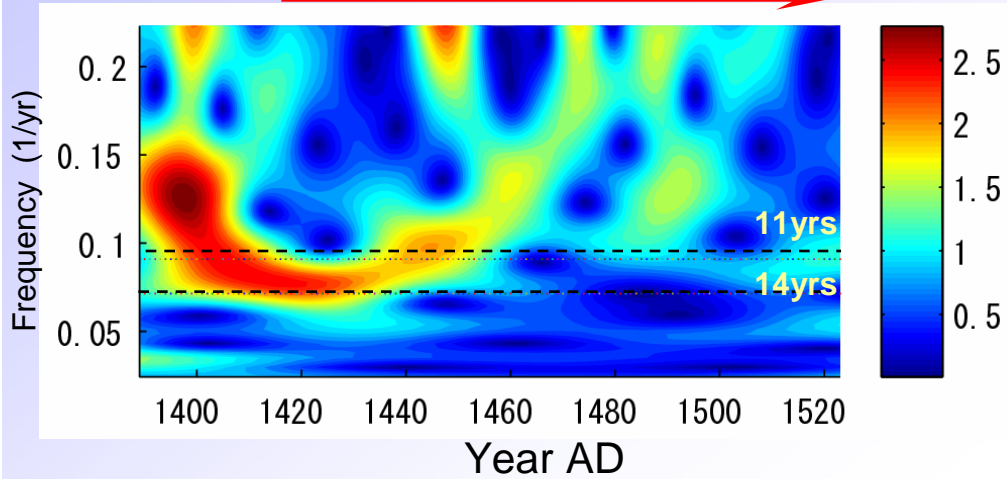
(Miyahara et al., JGR, 2006)



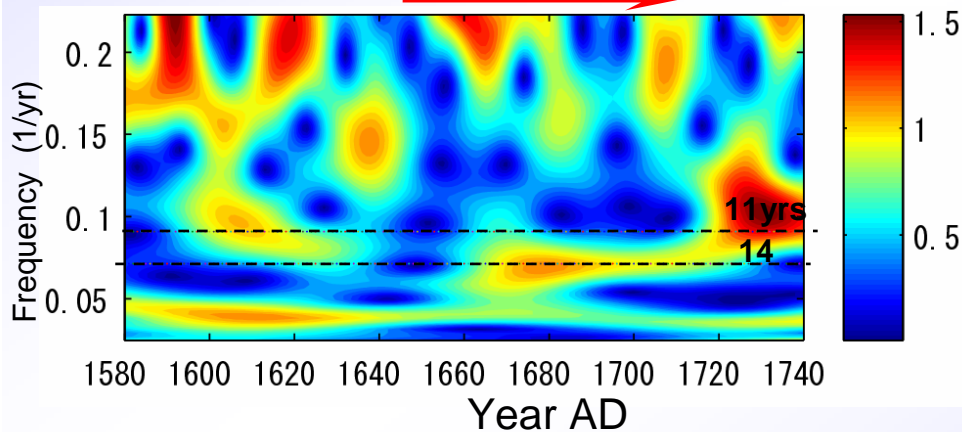
*High precision measurements
are needed to confirm this results*

Stretching of the preceding solar cycle of the Grand Solar Minima

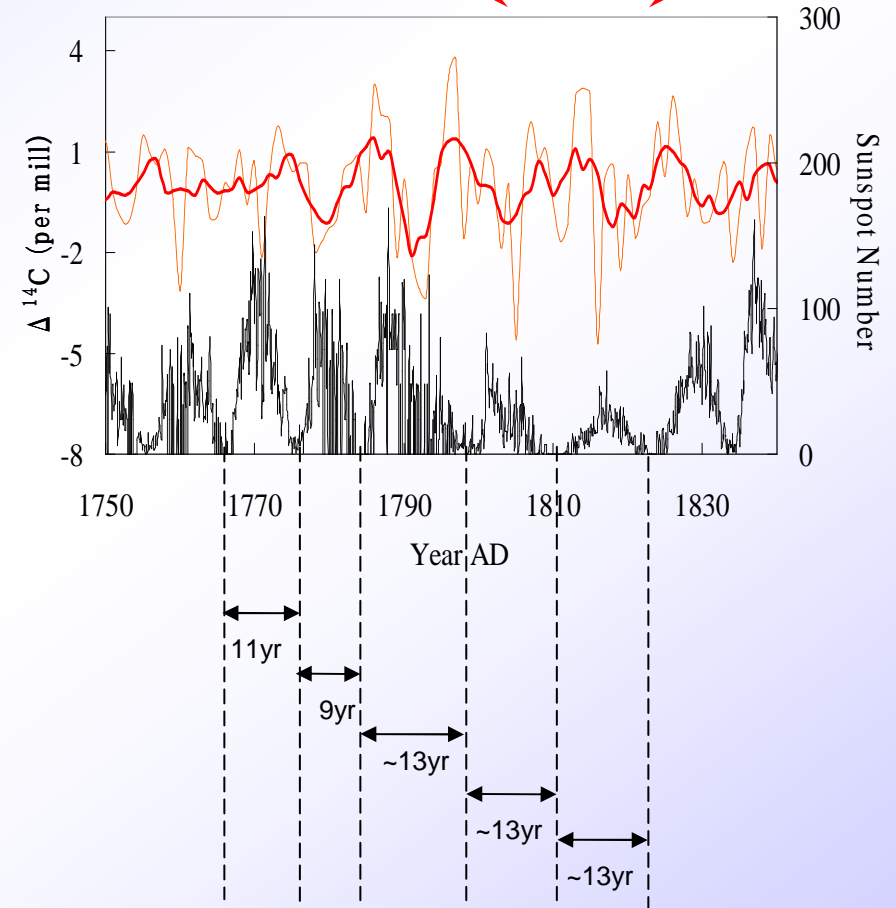
The Spörer Minimum (1415-1534 AD)



The Maunder Minimum (1645-1715 AD)

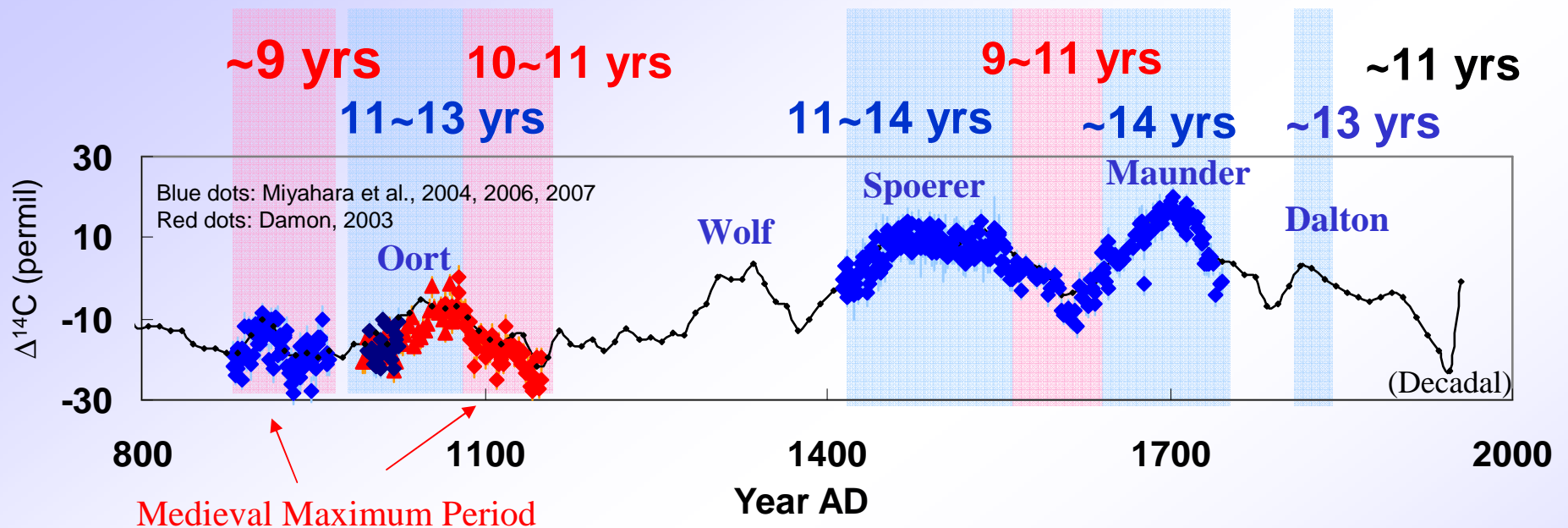


The Dalton Minimum



Preceding cycle of any kind of Grand Solar Minima is stretched to be ~13 years

Actual length of the “11-year” solar cycle during the last 1100 years



- Cycle lengths tend to have **inverse correlation with the activity level**
- If this relationship is confirmed, the record of solar cycle length may help in understanding the long-term change of the absolute solar activity level
- Solar activity at **the Early Medieval Maximum Period (the 9-10th century)** seems **higher than today** (Miyahara, et al., EPSL, in press)

“11-year” solar cycle affects climate?

*Let's look at
the Maunder Minimum !*

Because the length of the “11-year” cycle
changes at the Maunder Minimum

What is the medium of solar forcing?

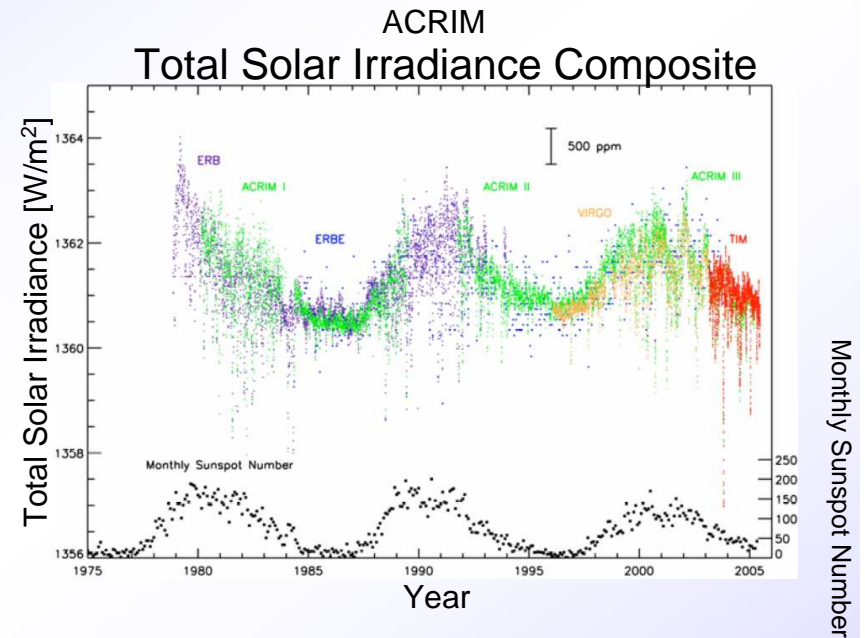
*We can understand the contribution of
GCRs by looking at the 22-year cycle*

TSI , Ultra Violet

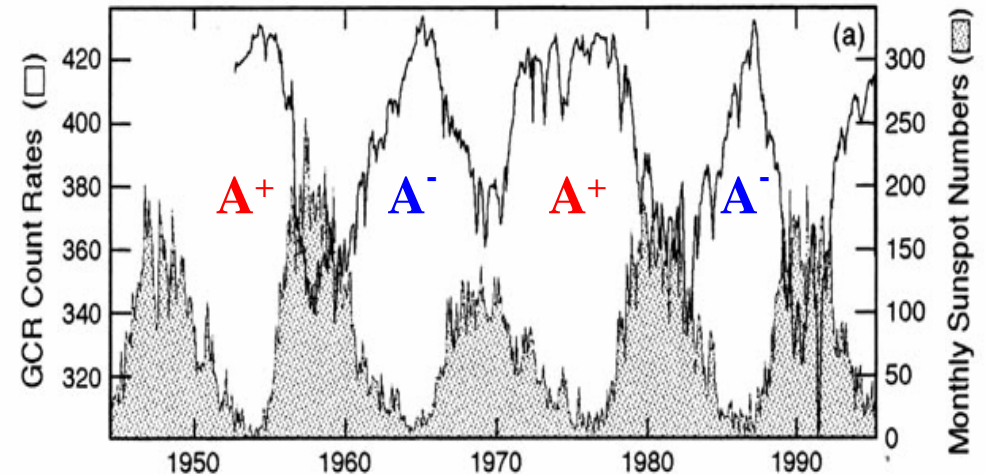
“11-year” variation

Galactic Cosmic Rays

“11-year” / “22-year” cycles



Polarity of the Sun
positive negative positive negative



Cosmic ray modulation in the heliosphere

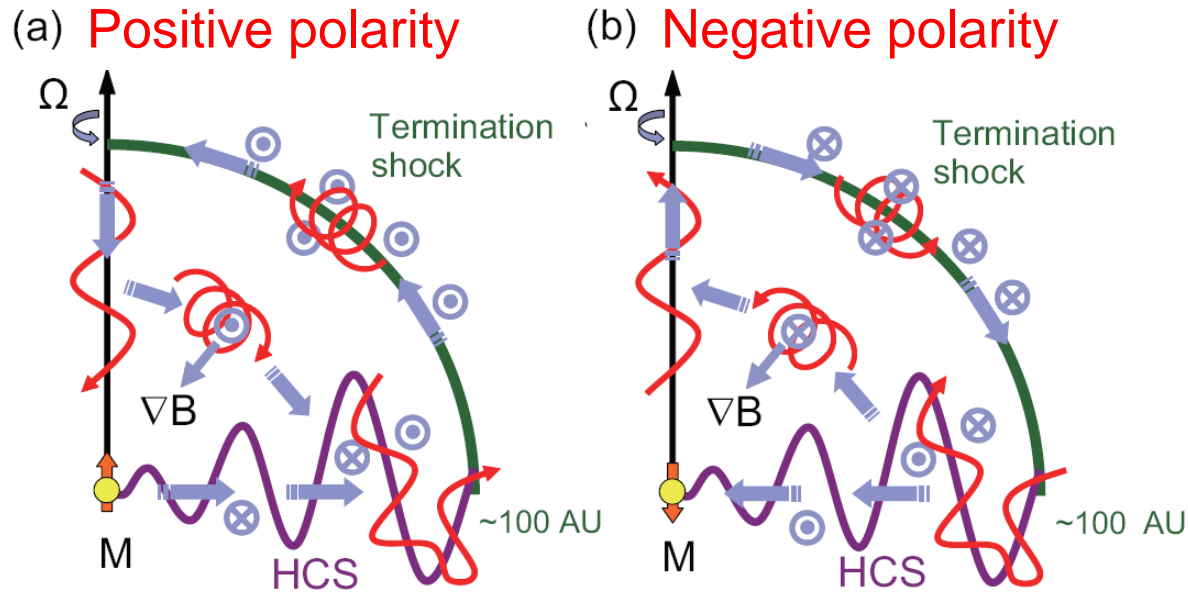
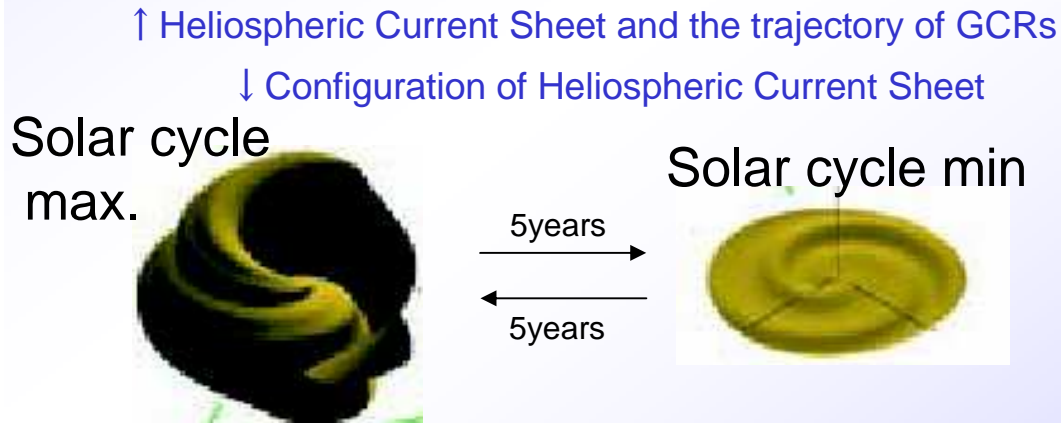
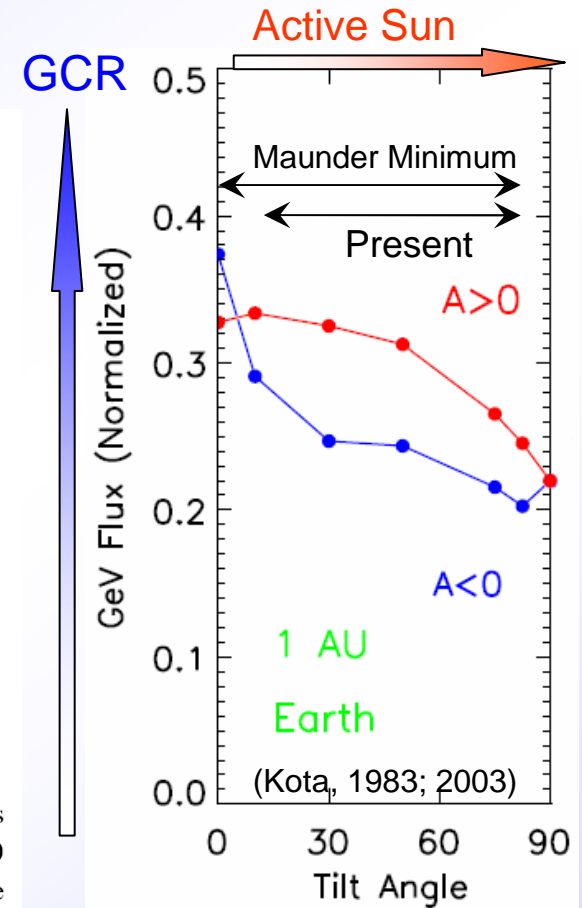
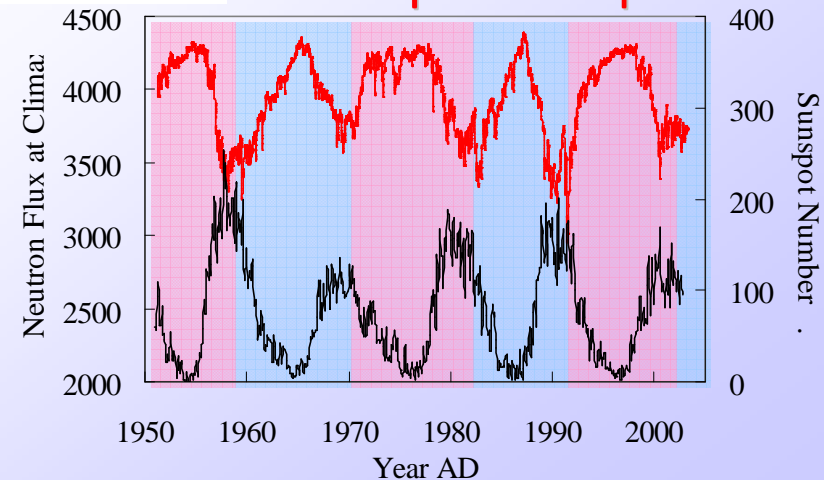


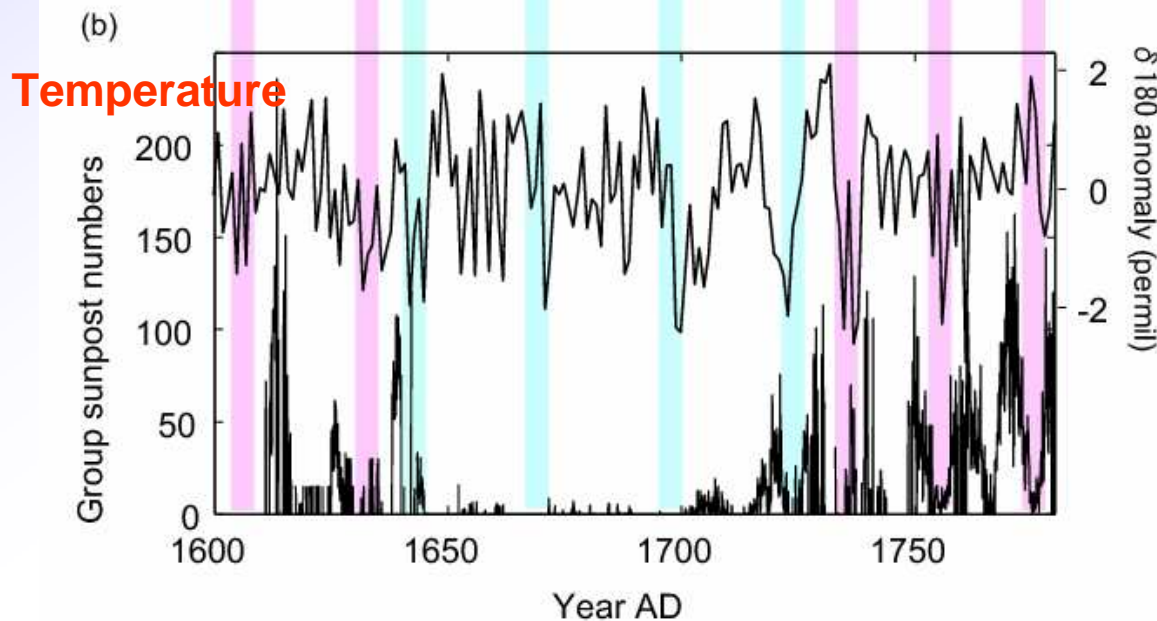
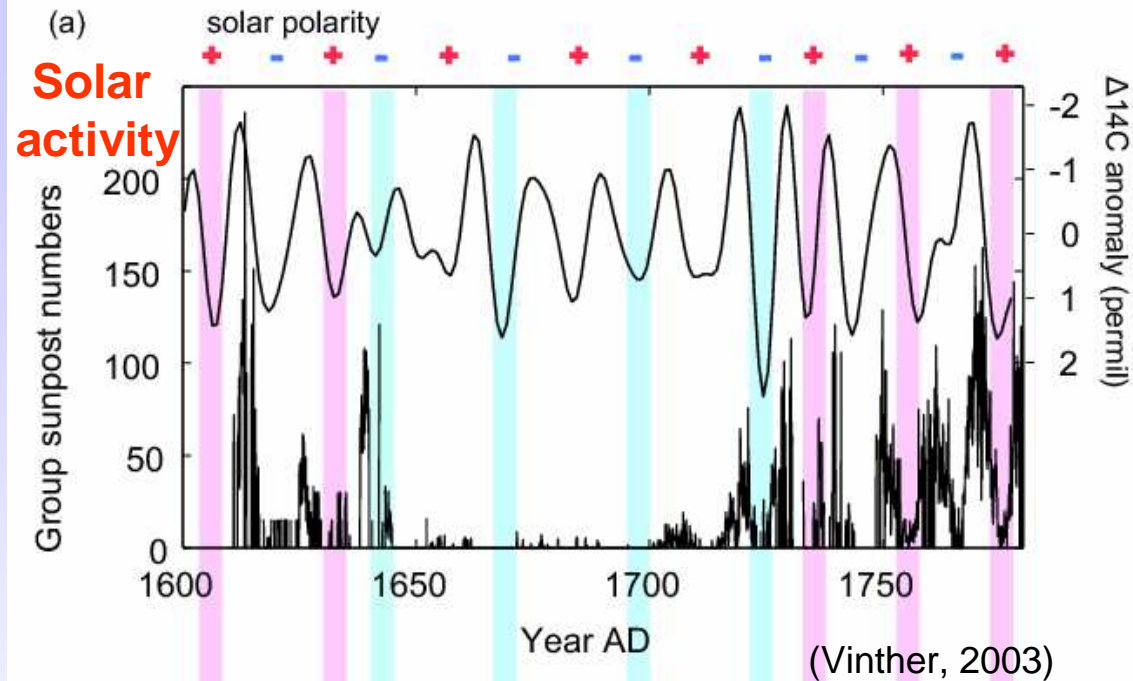
Fig. 1.6: Schematics of the drift trajectories of GCRs in the meridional plane for **a.** $A > 0$ and **b.** $A < 0$ epochs [after Jokipii et al., 1977]. GCRs would enter the heliosphere along the HCS and exit via the poles in $A < 0$ epochs. In $A > 0$ epochs the flow would be reversed with particles entering over the poles and exiting along the HCS. (From Okazaki, 2008)



From P. Riley et al., JGR 2002



Solar forcing of climate during the Maunder Minimum (Miyahara, et al., EPSL, in press)



max
↑
min

Cooling events occur at solar minima but seem to have dependency on the polarity of solar dipole magnetic field

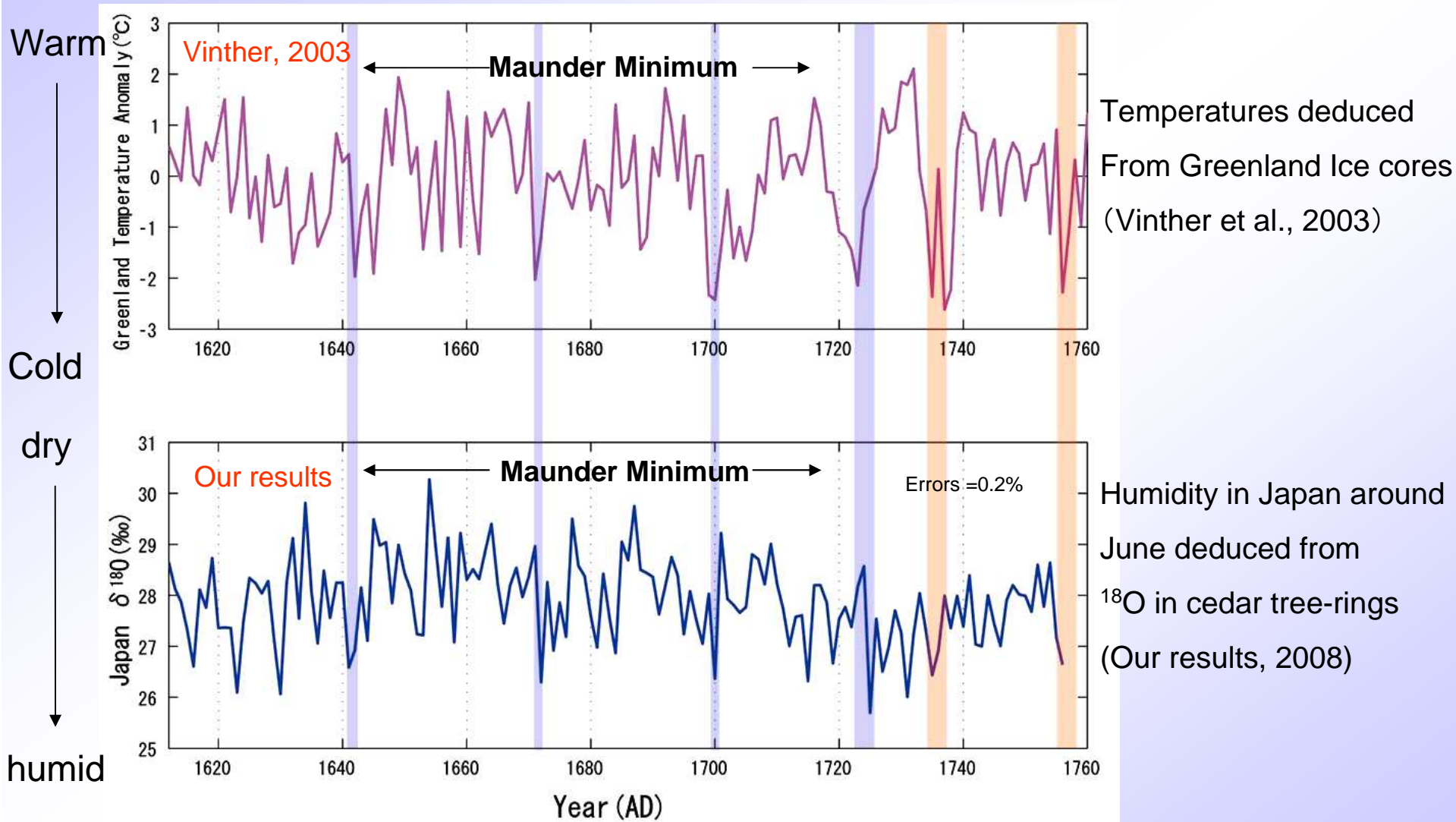
Cooling events @ negative during the Maunder M.

Cooling events @ positive before/after the Maunder M.

-> 14/28-year climate cycle during the Maunder M.

-> 11/22-year climate cycle before/after the Maunder M.

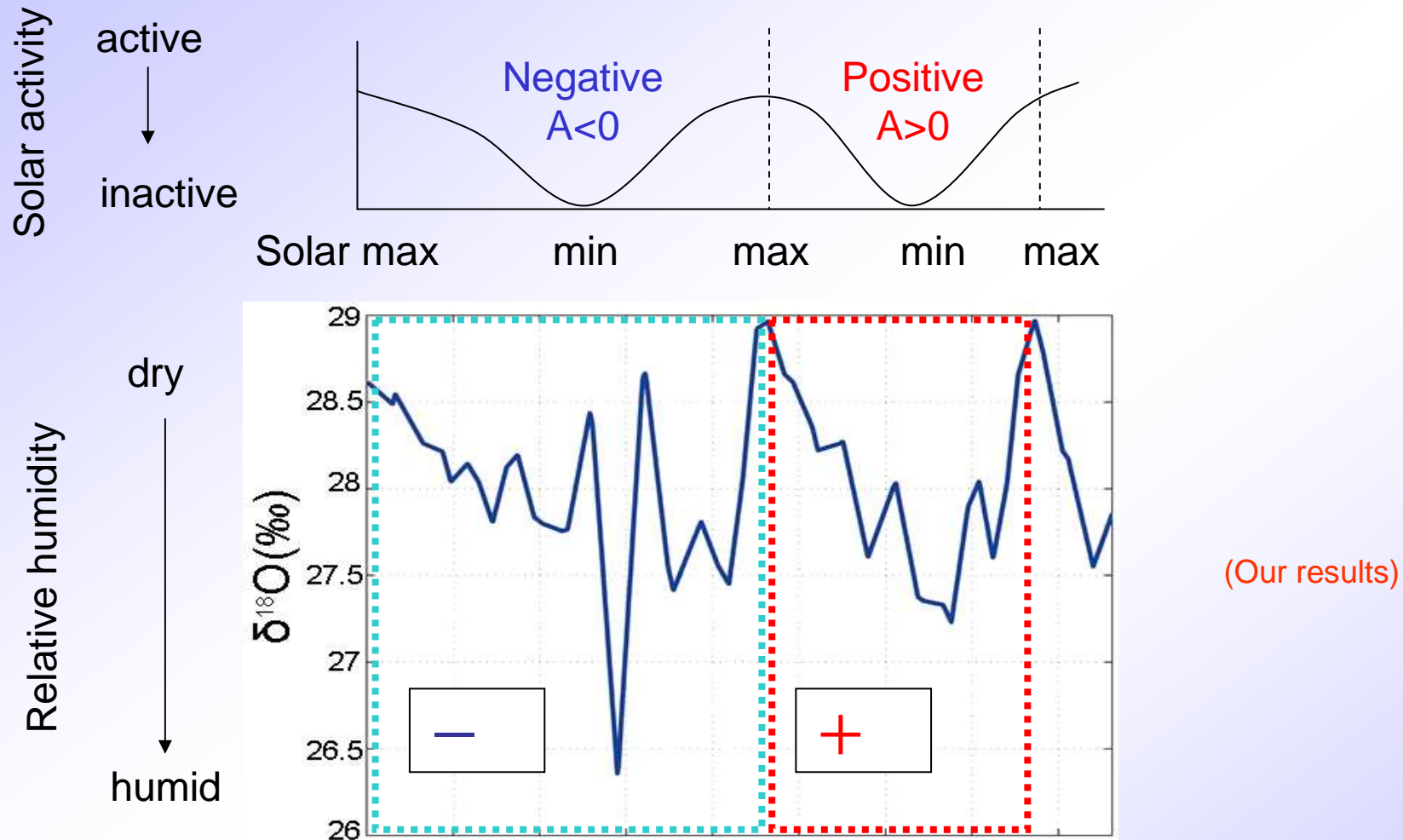
Humidity in Japan increases at solar minima @ polarity negative



Not a regional event!

Blue shade : solar minima @ polarity negative
Red shade : solar minima @ polarity positive

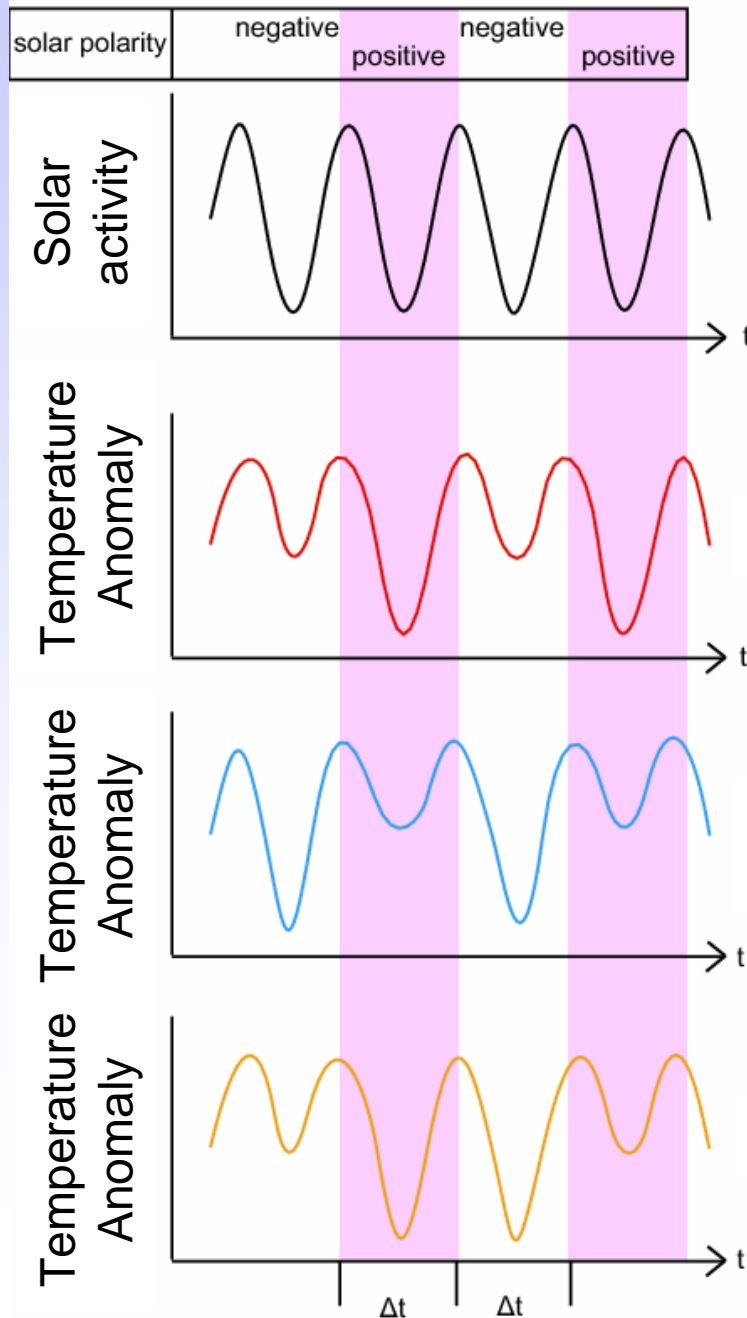
Superposition of Humidity change over “22-years” during the Maunder Minimum



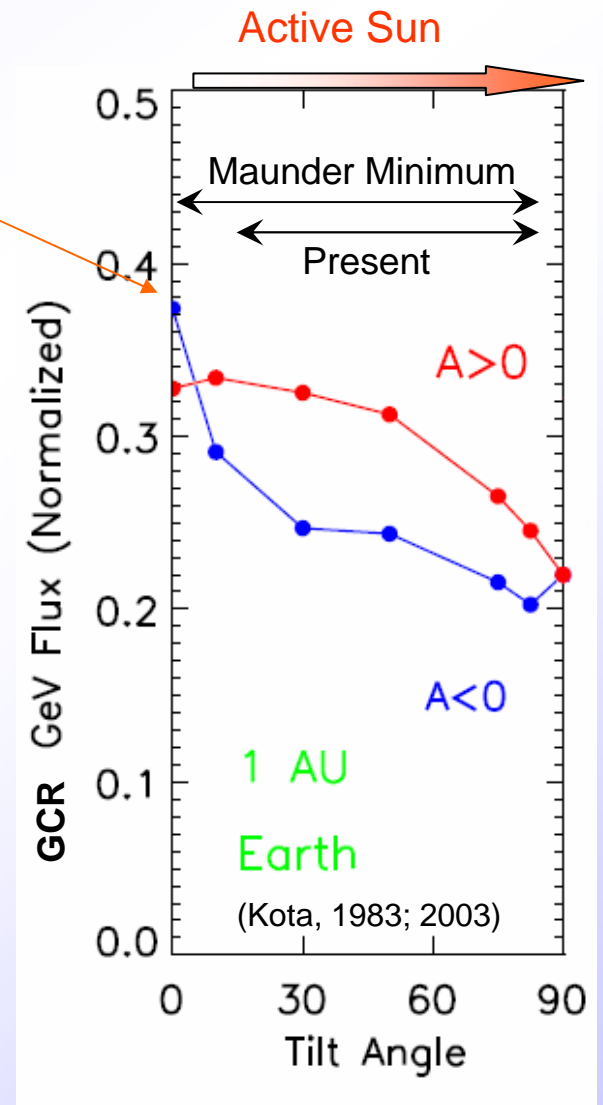
- Superposition of **humidity** in Japan over “22-years” (28 years) shows solar cycle variation + **humidity increase** when the polarity of the Sun is negative (?)

Two modes of Climate 22-year cycle

Miyahara, EPSL, 2008 (in press)



Very flat heliospheric current sheet



(Δt depends on long-term solar activity level)

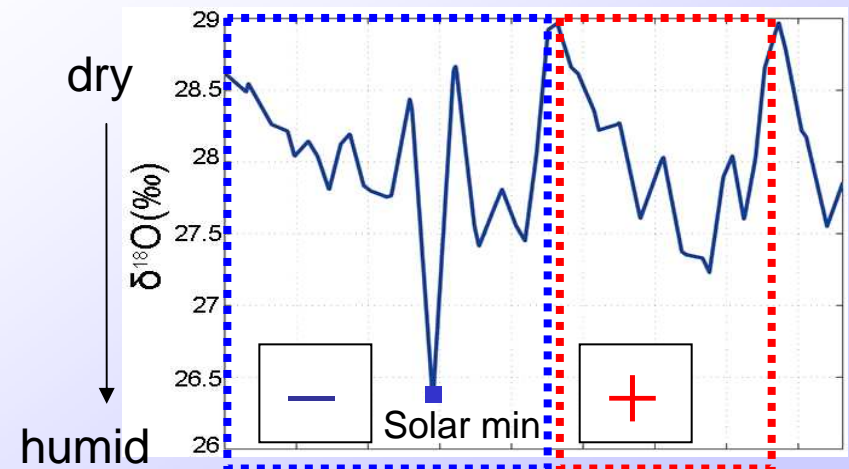
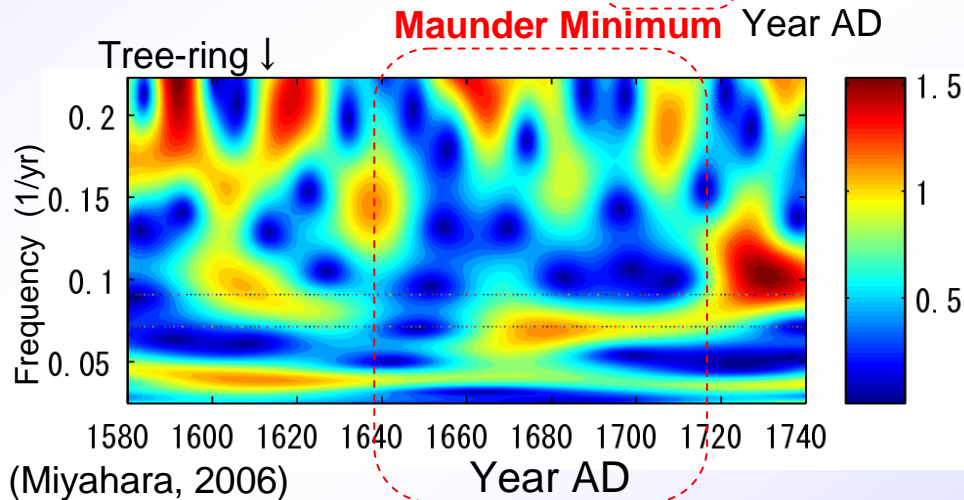
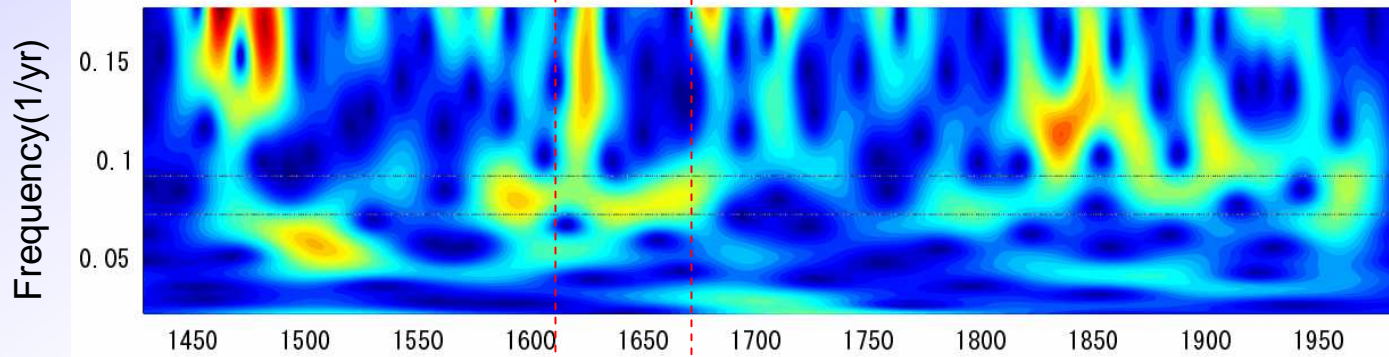
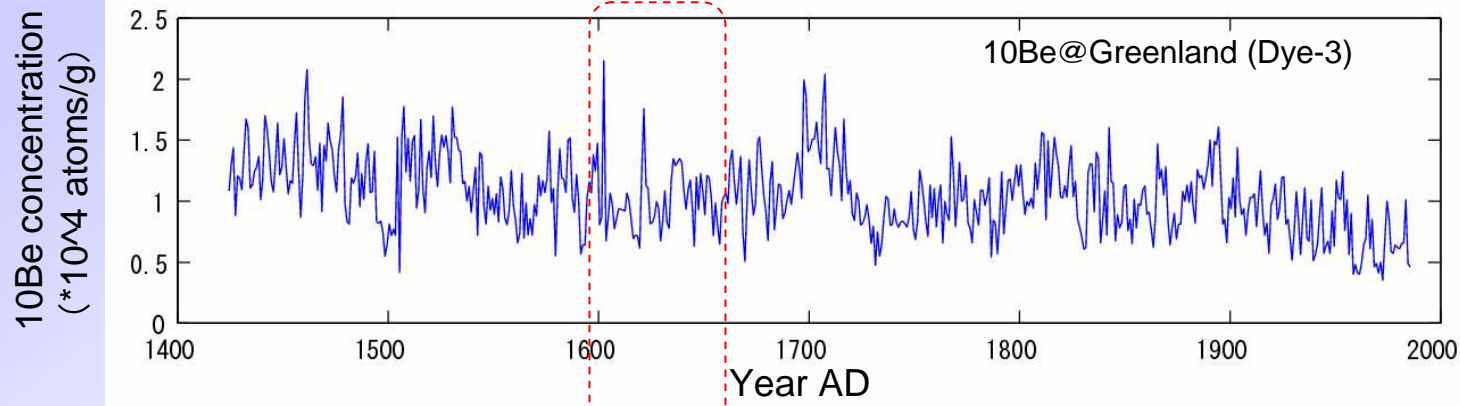
Conclusions

- ☀ Actual length of the “11-year” solar cycle changes ranging over 9-15 years
- ☀ Climate cycles change as solar cycles change
- ☀ Dependence of climate change on solar dipole polarity + phase transition of polarity dependence were observed around the Maunder Minimum

The mechanisms how GCRs affect cloud formation is not yet well known, but climate variations during the Maunder Minimum seem to be suggesting that GCRs could be very important

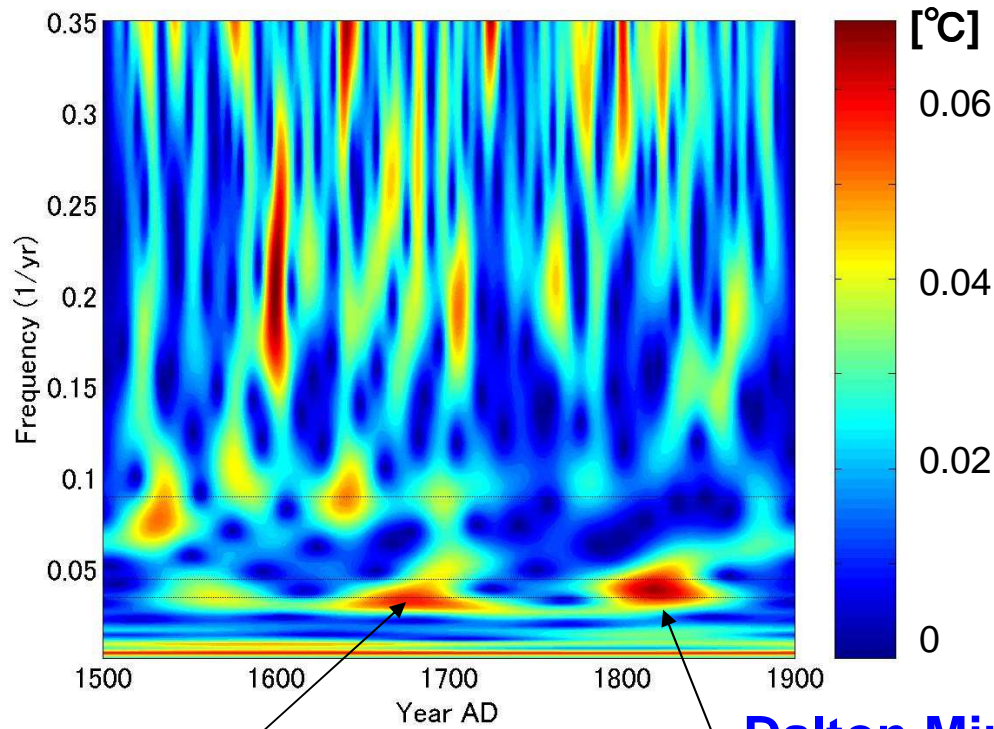
If so, configuration of solar and heliospheric magnetic field & dipole polarity changes could be very important to climate

Possibility of spiky cosmic ray increase at every 28 yrs during the Maunder Minimum



End

22-year cycle detected in tree-ring width (proxy of temperature)

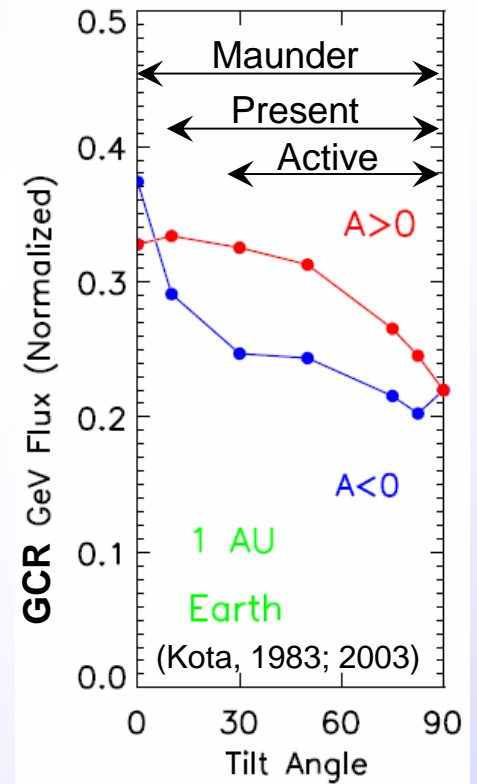


Dalton Minimum

Climate cycle = ~26 years

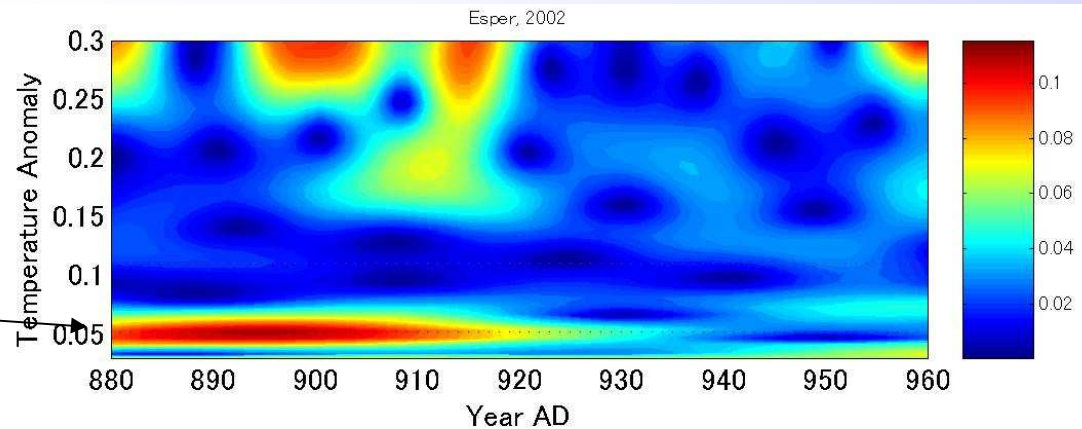
Maunder Minimum

Climate cycle = ~28 years



Medieval Maximum

Climate cycle = ~19 years



Possibility to use the cycle length as a proxy of the absolute solar activity level

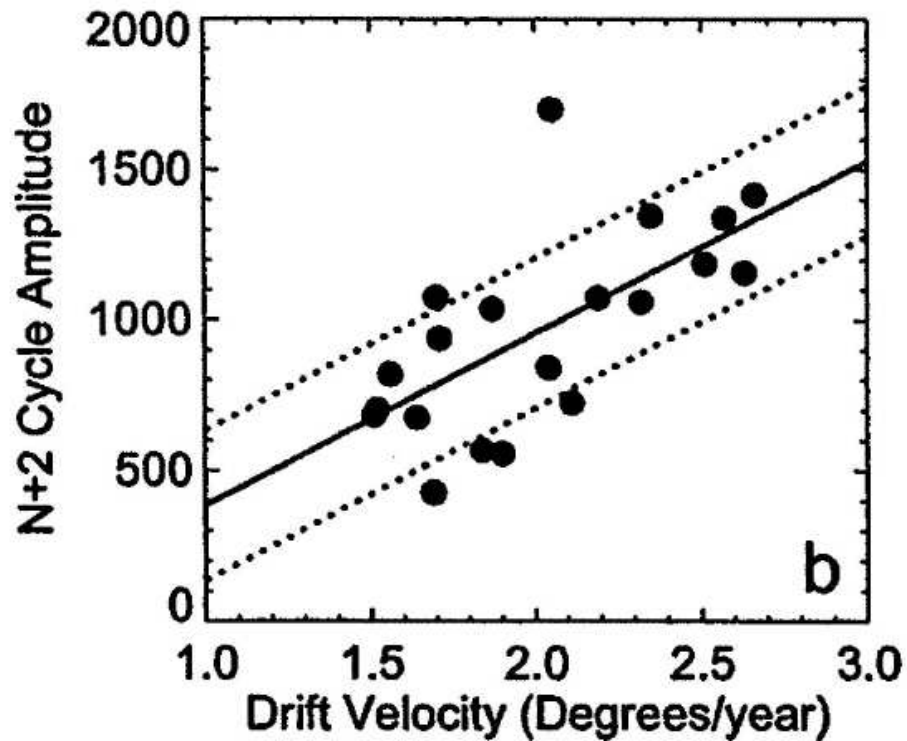


Figure 5. Cycle period and $N + 2$ cycle amplitude as functions of the drift rate of the sunspot area centroid at cycle maximum. The cycle period (panel a) has a significant anti-correlation (-0.5) with the drift velocity at maximum. The amplitude (in sunspot area) of the $N + 2$ (second following) cycle (panel b) has a significant positive correlation (0.7) with the drift velocity at maximum.

Hathaway, Solar Physics, 2004

Hathaway, ApJ, 2003

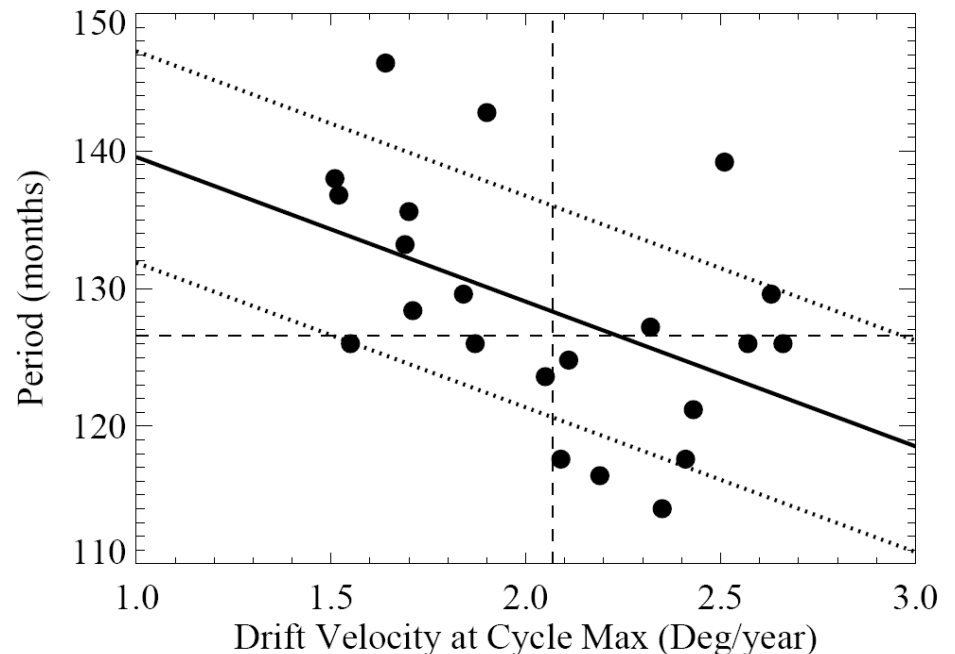


FIG. 4.—Cycle period vs. drift velocity toward the equator at sunspot maximum for each hemisphere cycle. The cycle periods are anticorrelated with the drift velocities. The solid line shows the best linear fit through the points while the dotted lines show the 1σ limits. The dashed lines give the median values of the two plotted quantities. The probability of getting this distribution, or one even more suggestive of a departure from independence, from two independent quantities is less than 5%. Hemisphere cycles with fast drift rates have short periods. This relationship is characteristic of dynamo models that employ a deep meridional flow to transport magnetic flux toward the equator.

Inverse correlation between the cycle length and the cycle amplitude is likely to exist, however, there may be lags of a few cycles between them (Solanki, 2002)