太陽圏システムと地球の気候/気象

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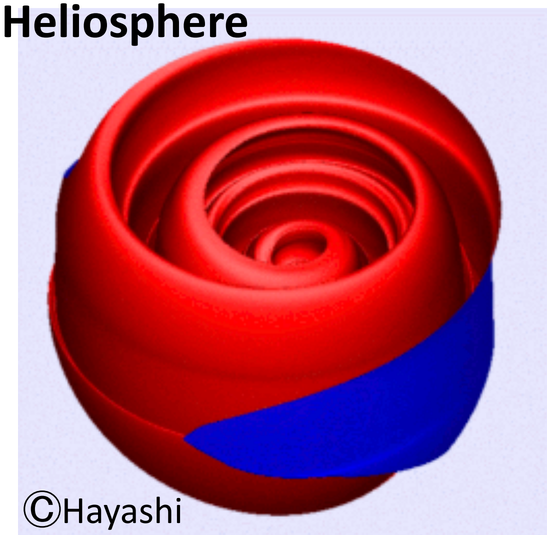

http://sun.stanford.edu/~keiji/gallery11.html

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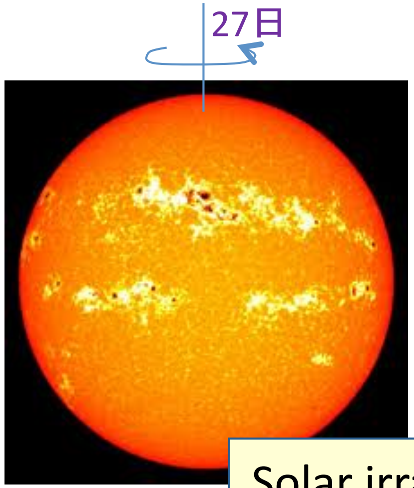
太陽活動と気候をとりまく諸問題

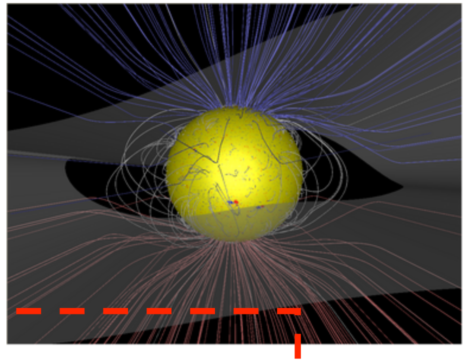
・太陽の放射強制力
太陽活動の長期変動にともなう総放射・スペクトル放射
の絶対値、変動幅（daily～millennial）
（気候モデルのvalidationへの影響）

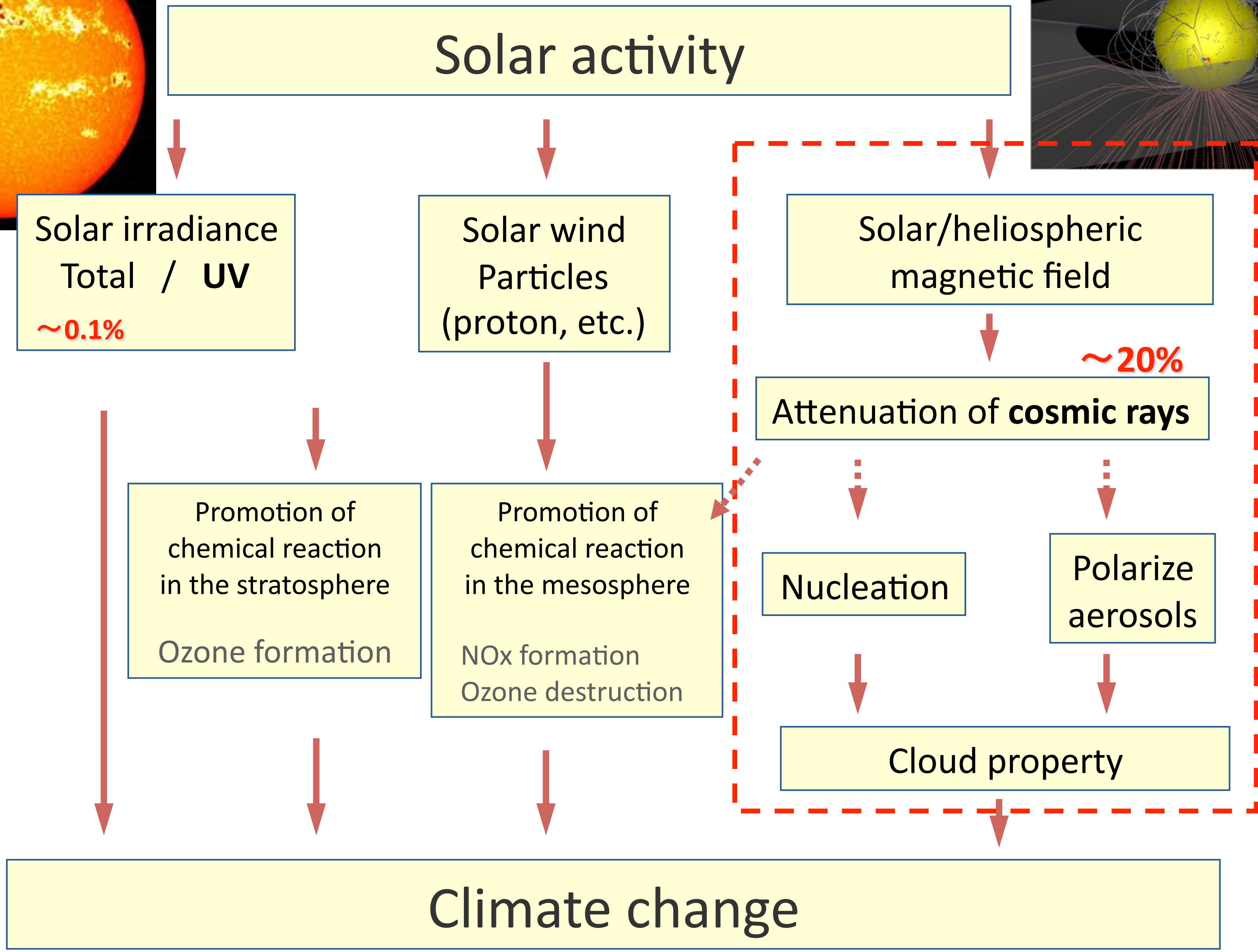
・太陽活動が気候変動に影響するメカニズム
日射、スペクトル放射、太陽風、宇宙線（太陽圏磁場による減衰）
宇宙現象、地磁気強度変動と
古気候との相関からも重要性が示唆されている

・太陽ダイナモ物理
11年変動、長期変動（88年周期、208年周期、1000年周期）
27日周期の黒点・太陽フレア予測
（最終的には、活動予測→気候予測モデルへのインプット）

Possible pathway of solar influence on climate change

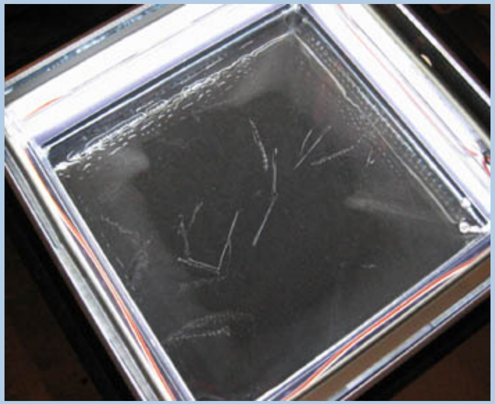






Possible mechanisms

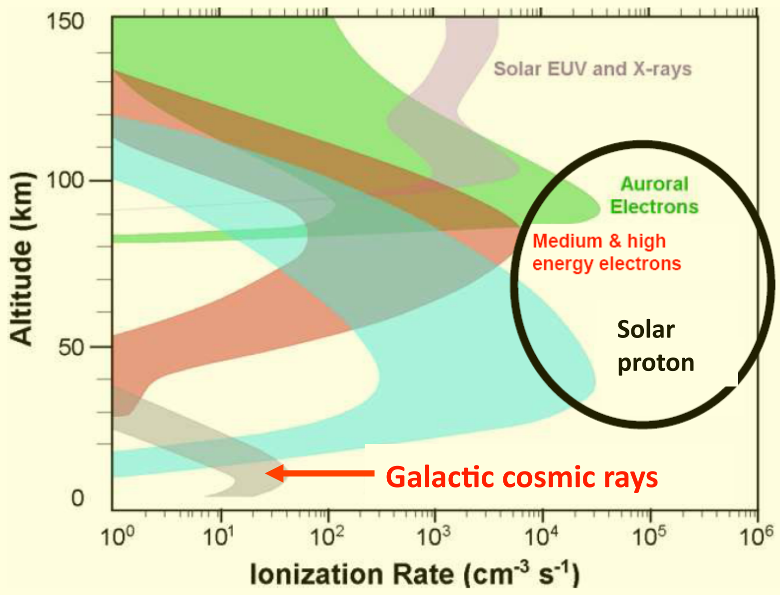
1.Nucleation



Formation of
Cloud Condensation Nuclei

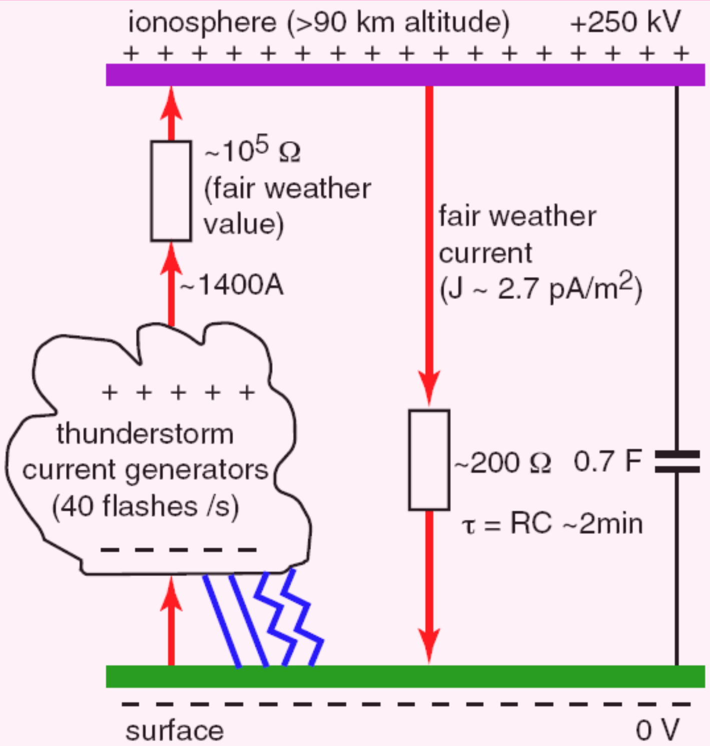
2.NOx formation

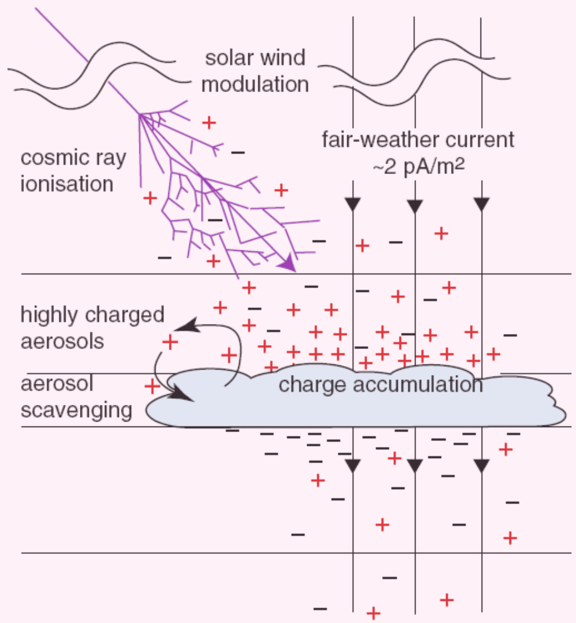
Energetic Particle Precipitation



3.Coagulation

collision efficiency
of aerosol particles





詳細な物理&定量的な議論は今後の課題

Kirkby, Nature, 2011

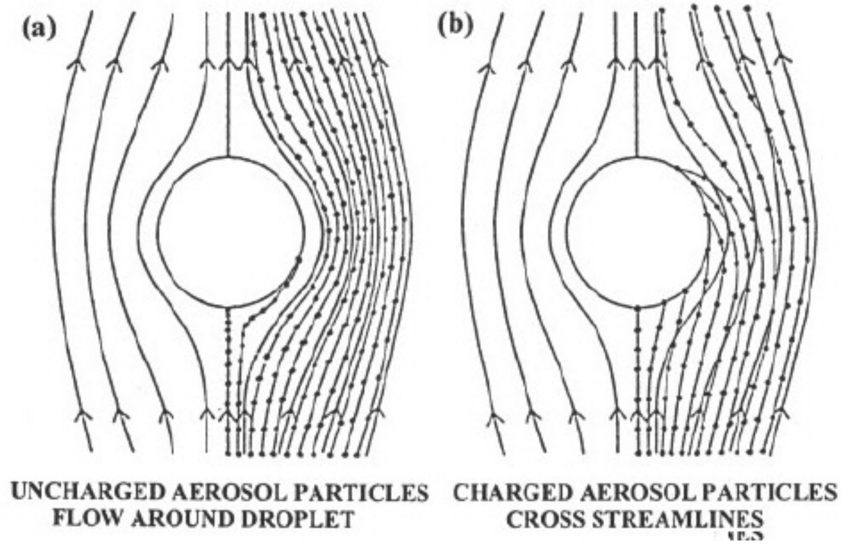


Figure 5.3. (a) Schematic of aerosol flow around a falling droplet in the absence of electrical forces. (b) Schematic of effect of electrical forces in moving aerosol particles across streamlines.

Tinsley 1996

Tinsley & Yu 2006

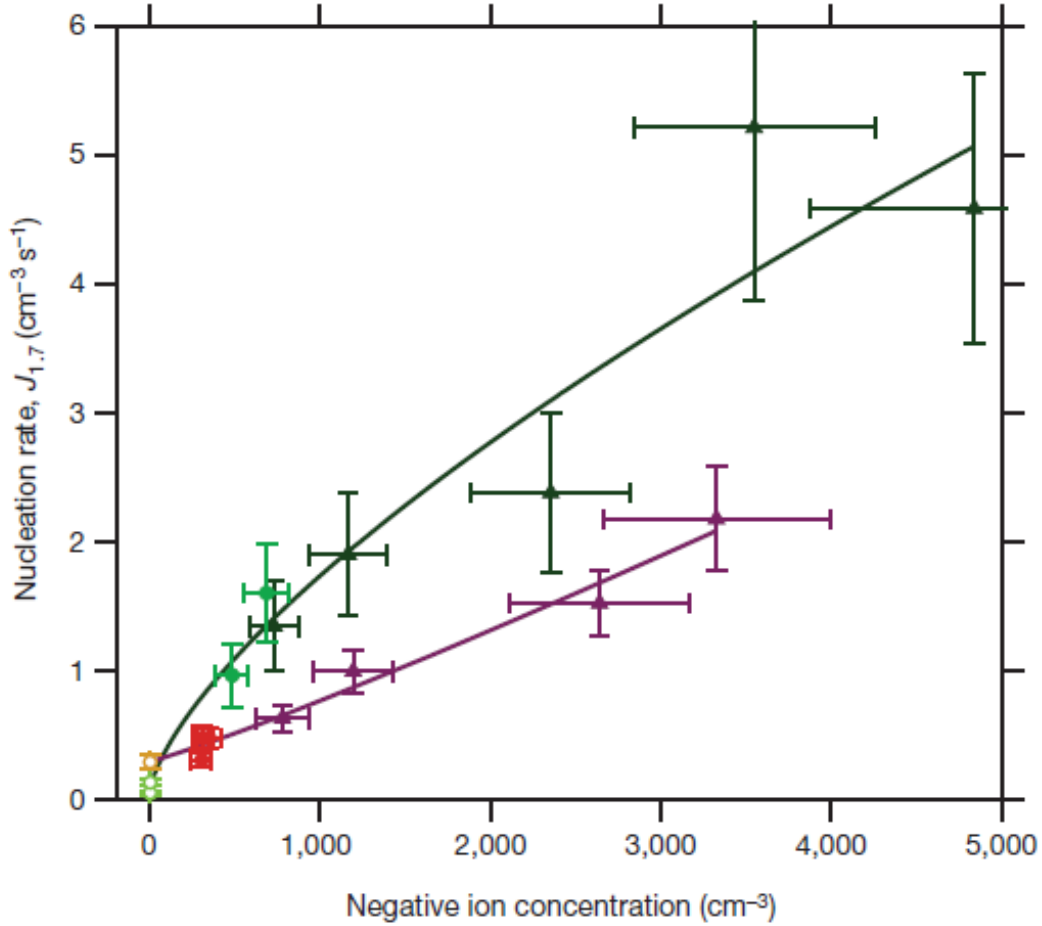
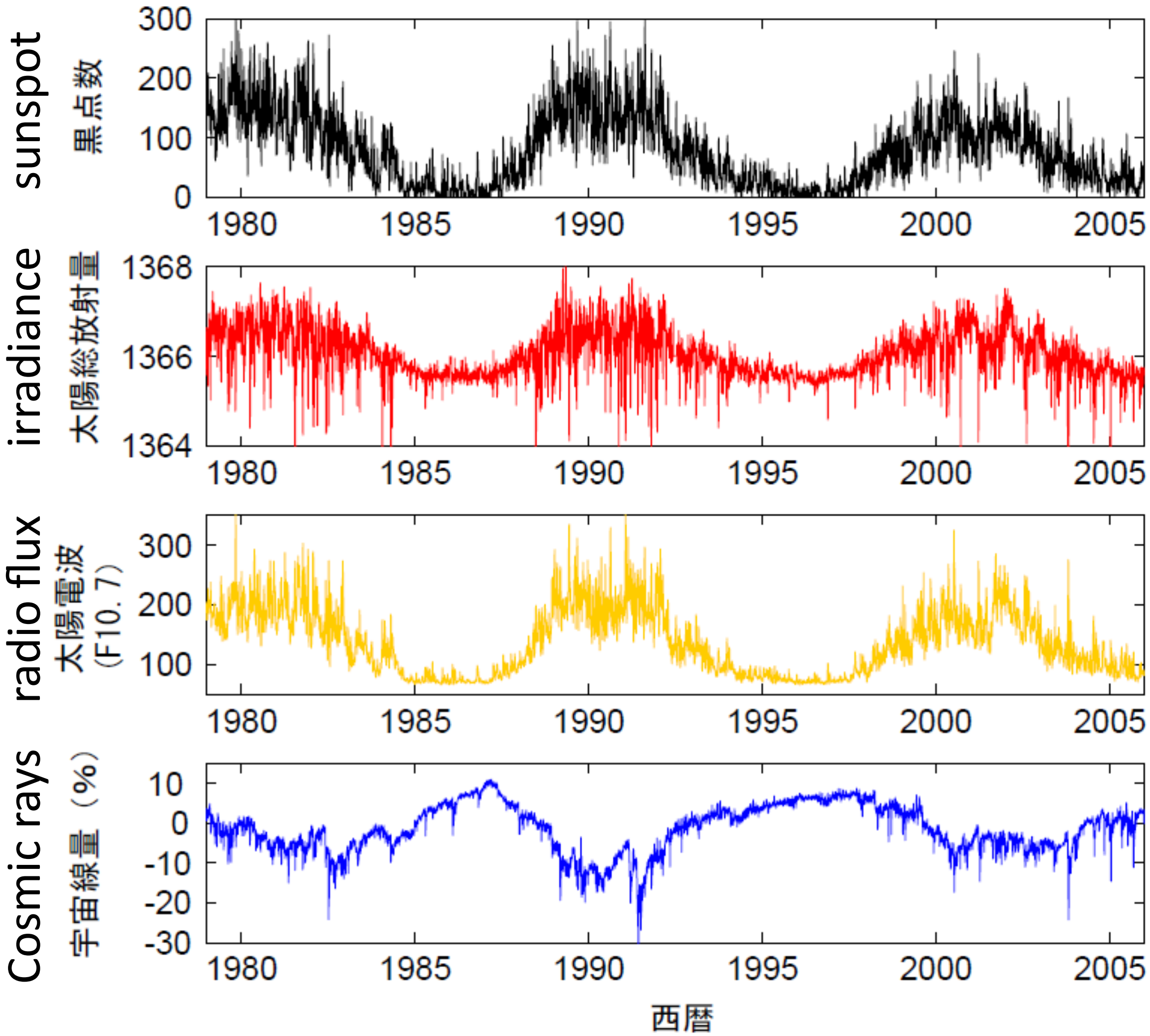
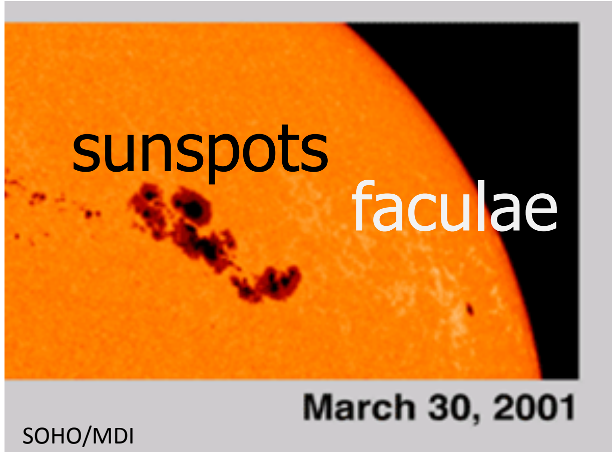


Figure 2 | Plots of nucleation rate against negative ion concentration. Nucleation rates as a function of negative ion concentration at 292 K and $[H_2SO_4] = 4.5 \times 10^8\ cm^{-3}$ (purple line), and at 278 K and $[H_2SO_4] = 1.5 \times 10^8\ cm^{-3}$ (green line). Triangles, J_{ch}; filled circles, J_{gcr}; open circles, J_n. All measurements were made at 38% relative humidity and 35 p.p.t.v. NH_3. Neutral nucleation rates, J_n, were effectively measured at zero ion pair concentration (ion or charged-cluster lifetime <1 s). The curves are fits of the form $J = j_0 + k[\text{ion}^-]^p$, where j_0, k and p are free parameters. The error bars indicate only the point-to-point 1σ errors; the nucleation rates and ion concentrations each have estimated overall scale uncertainties of $\pm$30%.

Eleven-year variation in solar related parameters





現代においては、いずれも同期しており影響の区別をつけにくい　→　より長期的な変動の理解、古気候との比較

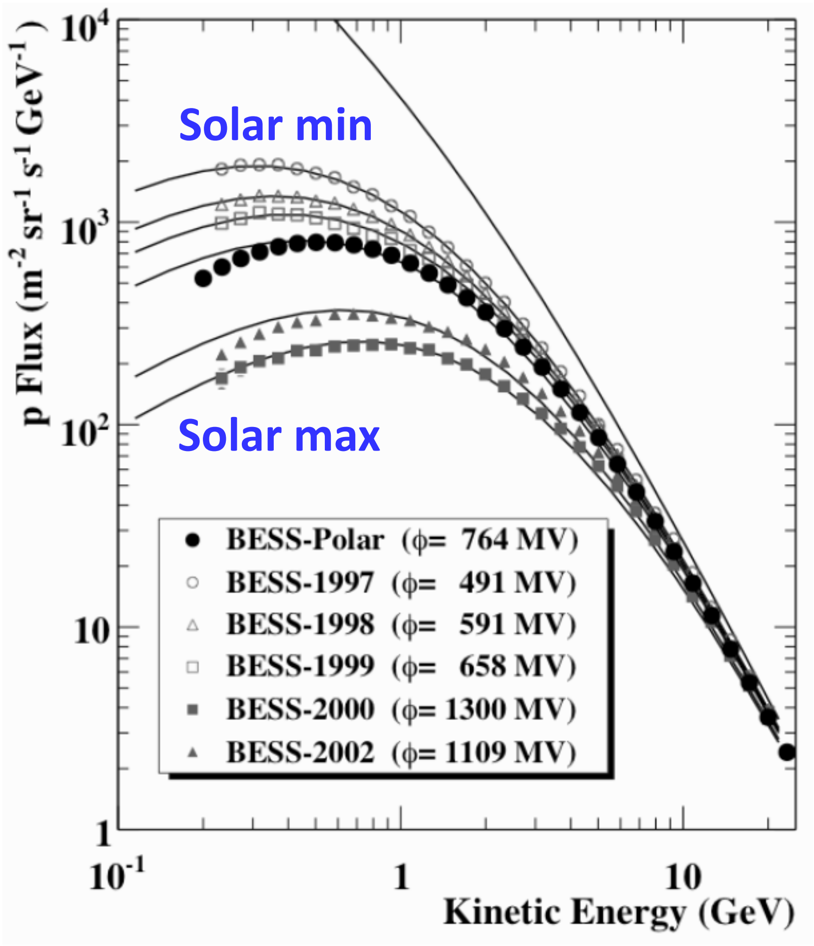
Contents

太陽圏の磁場構造と宇宙線の22年周期変動

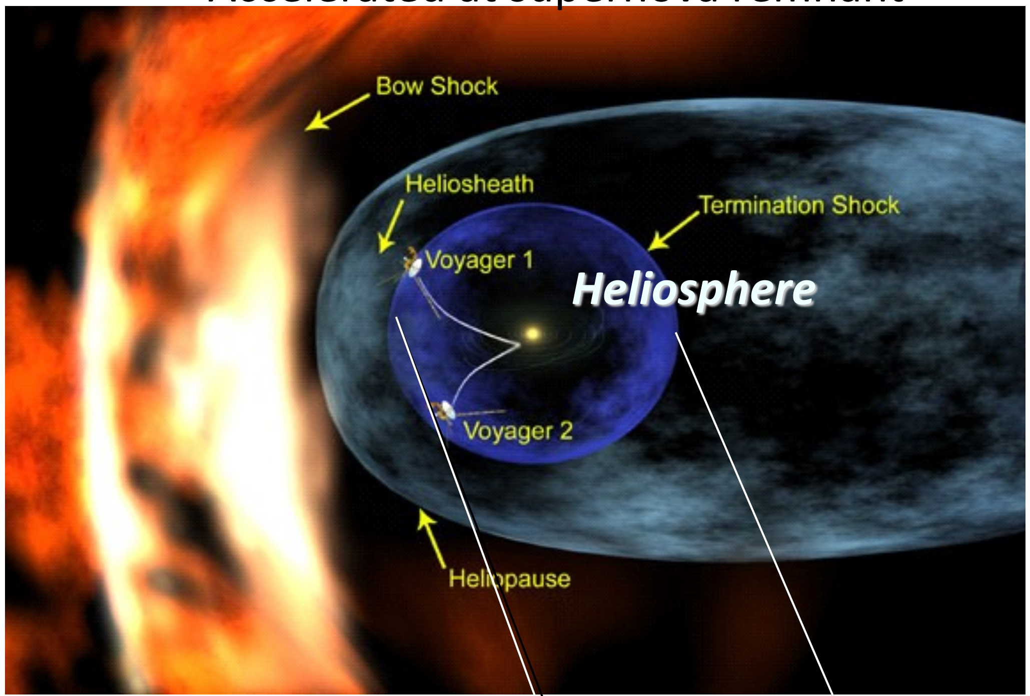
マウンダー極小期（西暦1645-1715年）における
宇宙線変動と気候変動

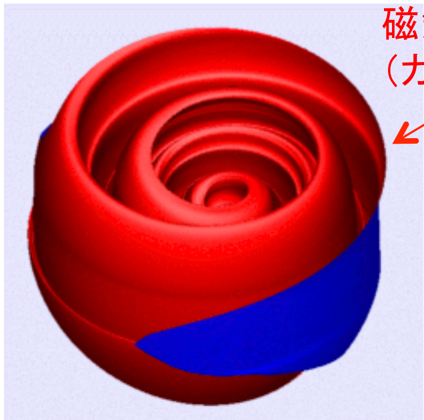
宇宙線の27日周期変動と赤道熱帯域の雲活動
（・宇宙線が気候システムに及ぼす変動のトレース
・気象への影響
の両観点から）

Solar modulation of Galactic Cosmic Rays (GCRs)

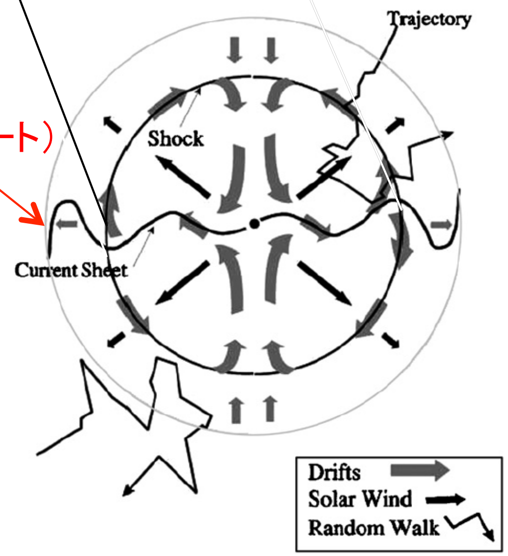


- Charged particles (mainly protons)
- Accelerated at supernova remnant



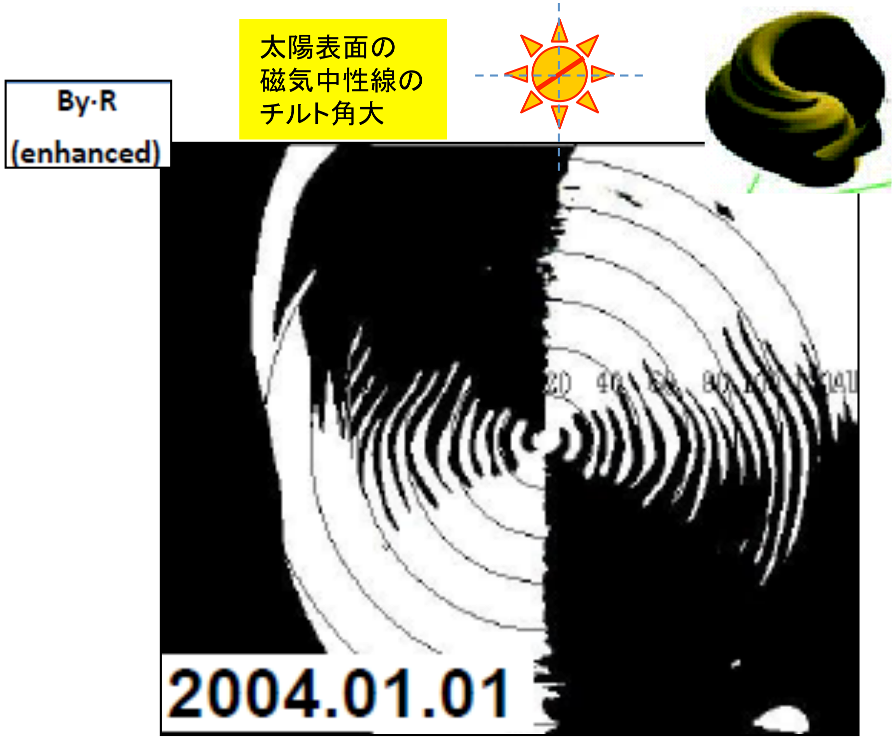


磁気中性面
（カレントシート）

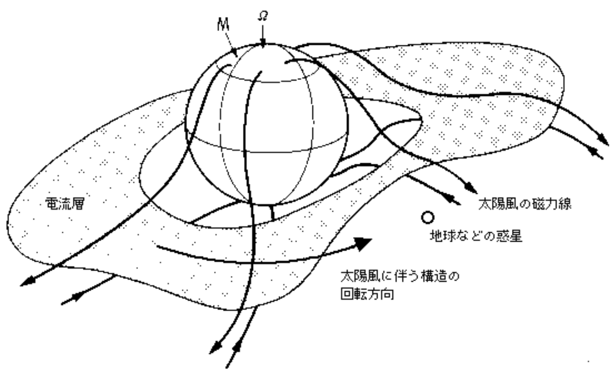


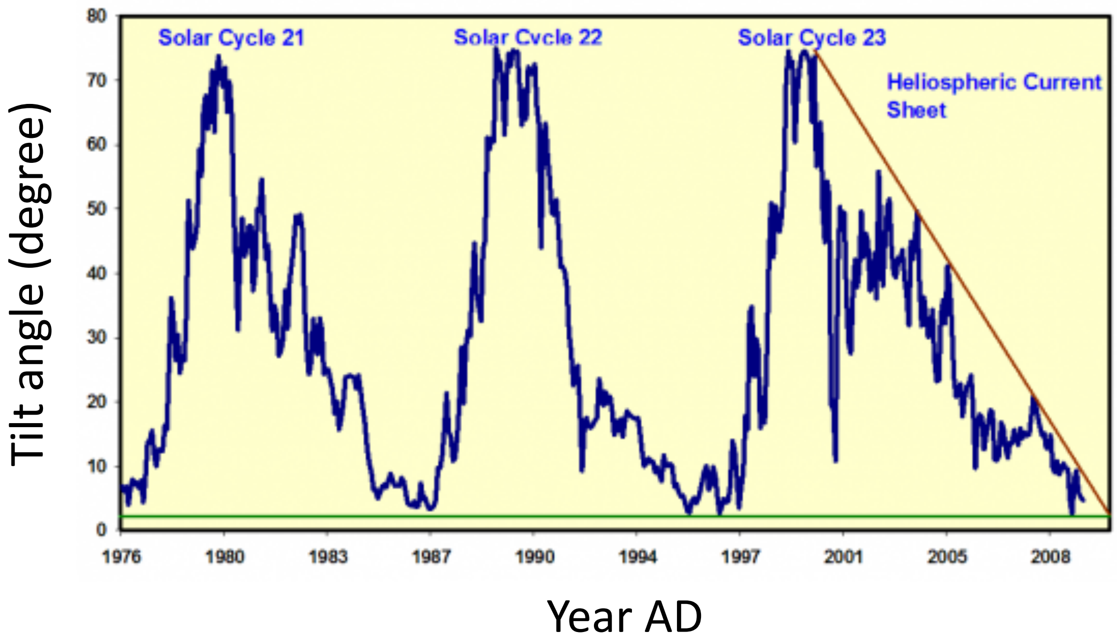
- **diffusion**
- **advection by solar wind**
- **drift （B×∇Bドリフト）**

Large scale structure of Heliospheric magnetic field



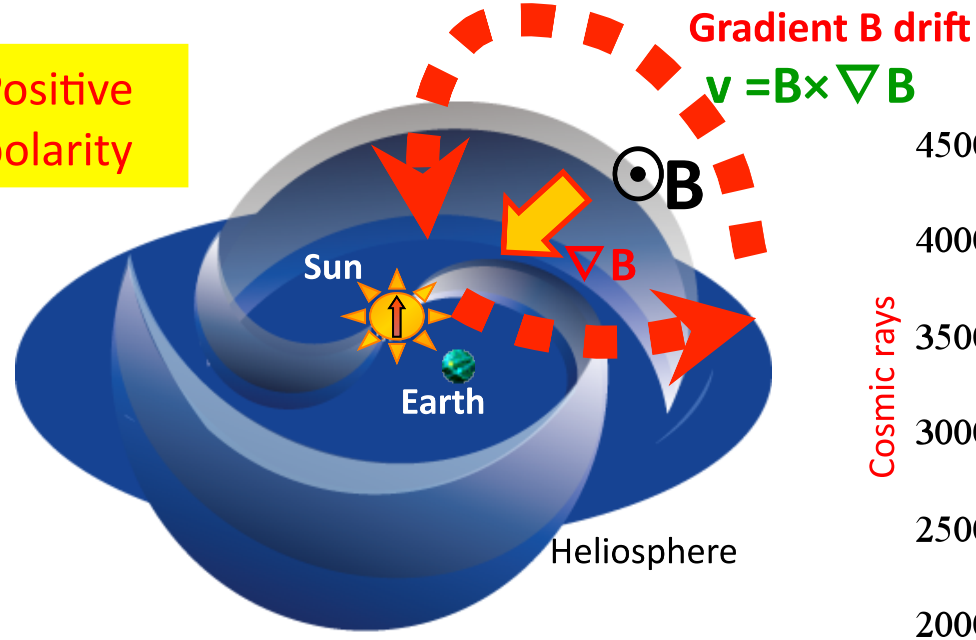
(based on Washimi et al)

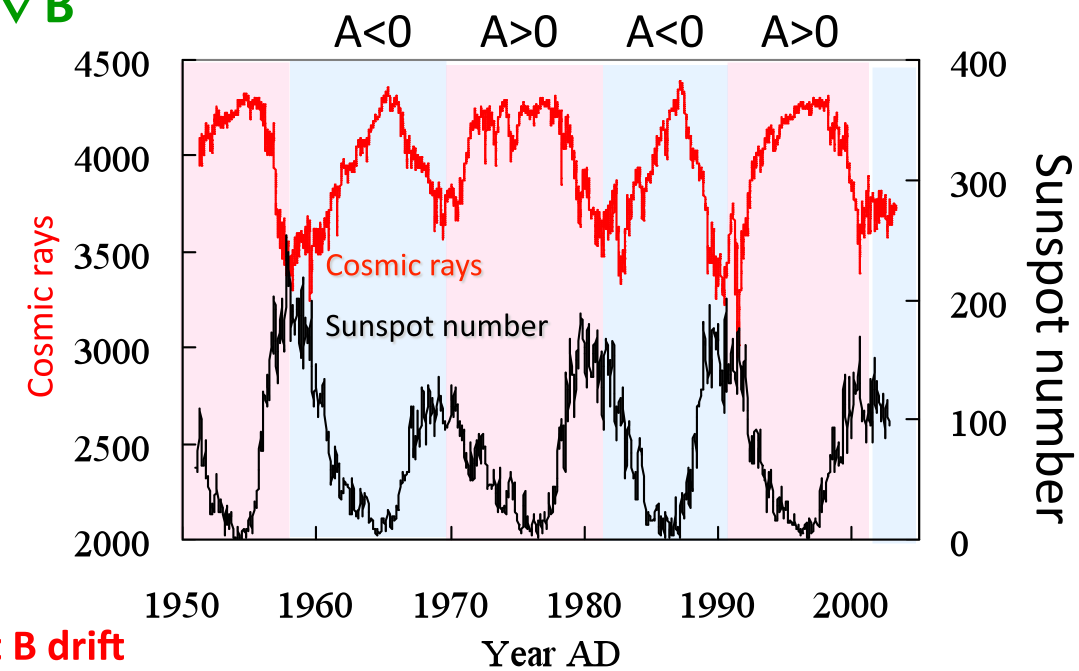




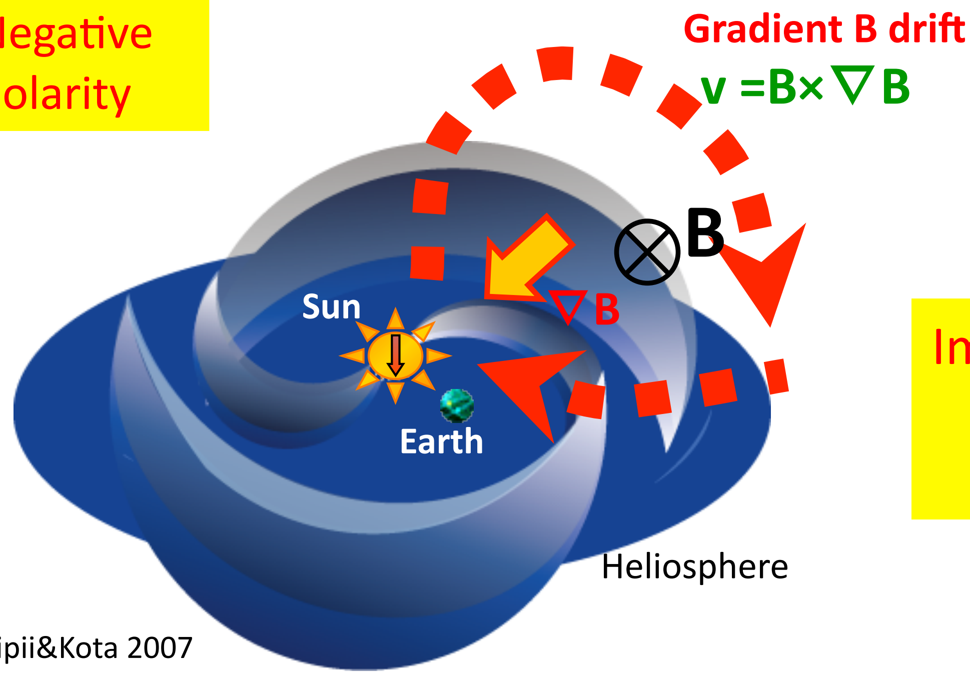
Cosmic ray variation & Solar magnetic polarity

Positive polarity





Negative polarity



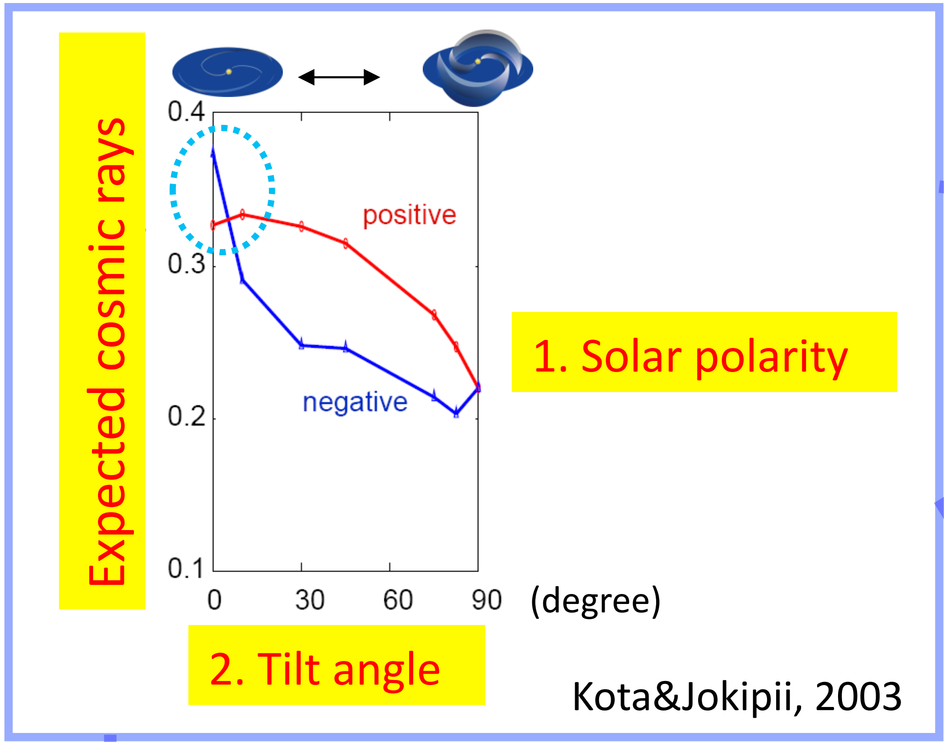
Important parameters for solar modulation

- solar dipole magnetic polarity
- tilt angle of heliospheric current sheet

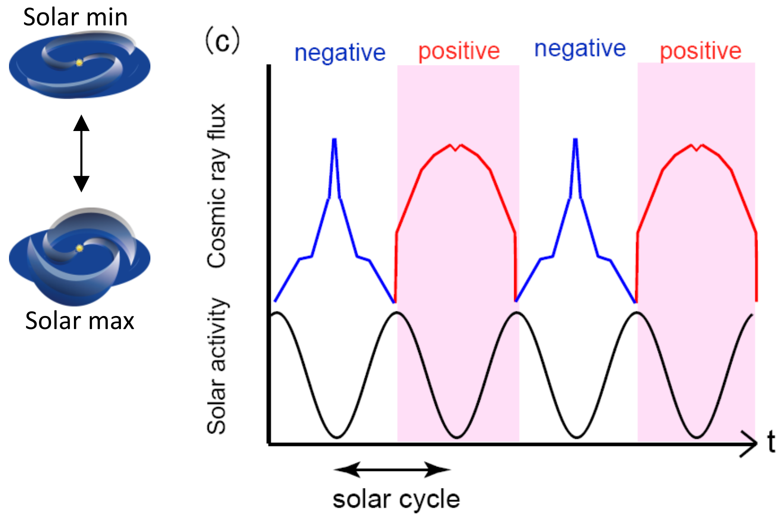
Jokipii&Kota 2007

Variable "22-year" variation of cosmic rays

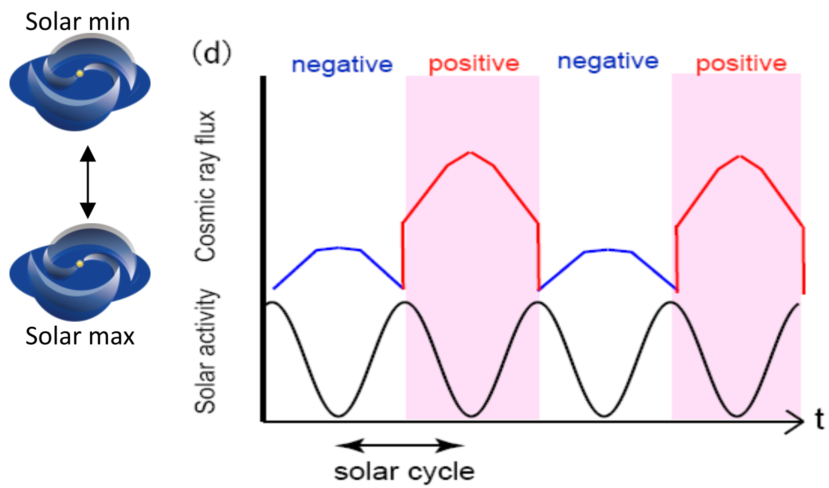
Miyahara et al.,2009



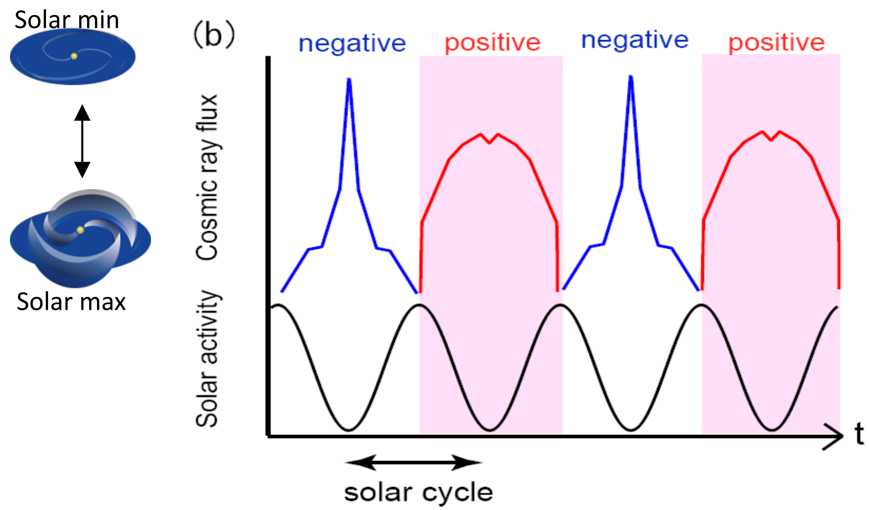
Modern: 5-75 degrees



If 30-75 degrees



If 0-75 degrees



Production of cosmogenic nuclides: ^{14}C and ^{10}Be

Galactic cosmic rays

Attenuation by solar/geo-magnetic field

Air shower in the atmosphere

Secondary neutron

Spallation

^{10}Be etc.

Precipitation

Antarctic/Greenland Ice sheets

$^{14}N + n \rightarrow {}^{14}C + p$

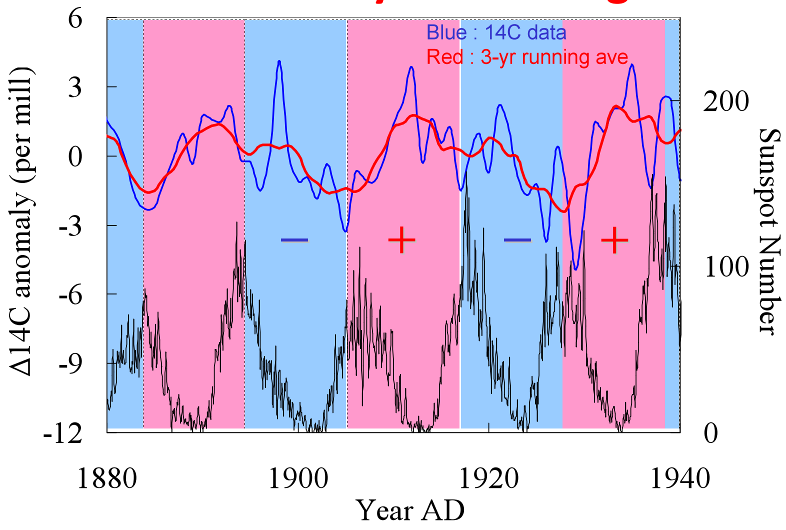
Atmospheric circulation

$^{14}CO_2$

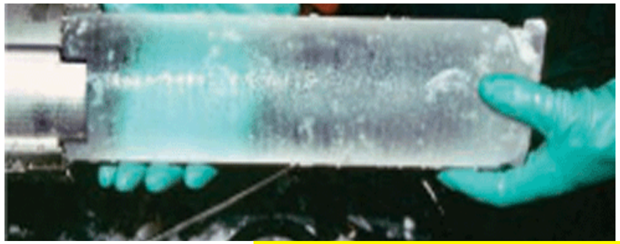
Photo-synthesis

Tree ring

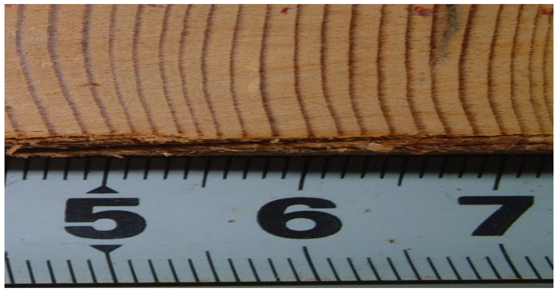
^{14}C anomaly in tree rings



3-yrs of lag in carbon cycle is corrected



Clear signal
A few years of dating error

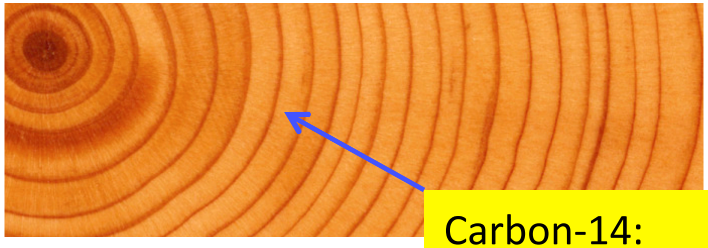


Absolute age
Strongly attenuated signal

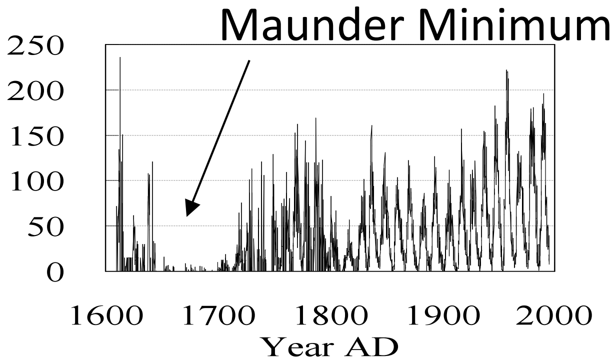
Accelerator Mass Spectrometer

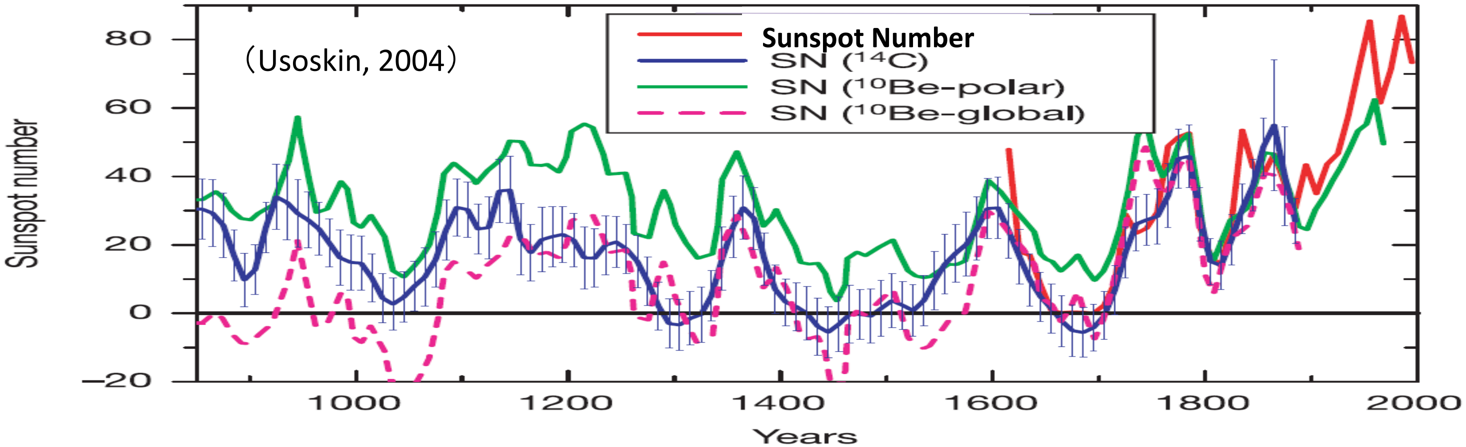
山形大学ホームページより

Reconstructed solar decadal cycles in the past

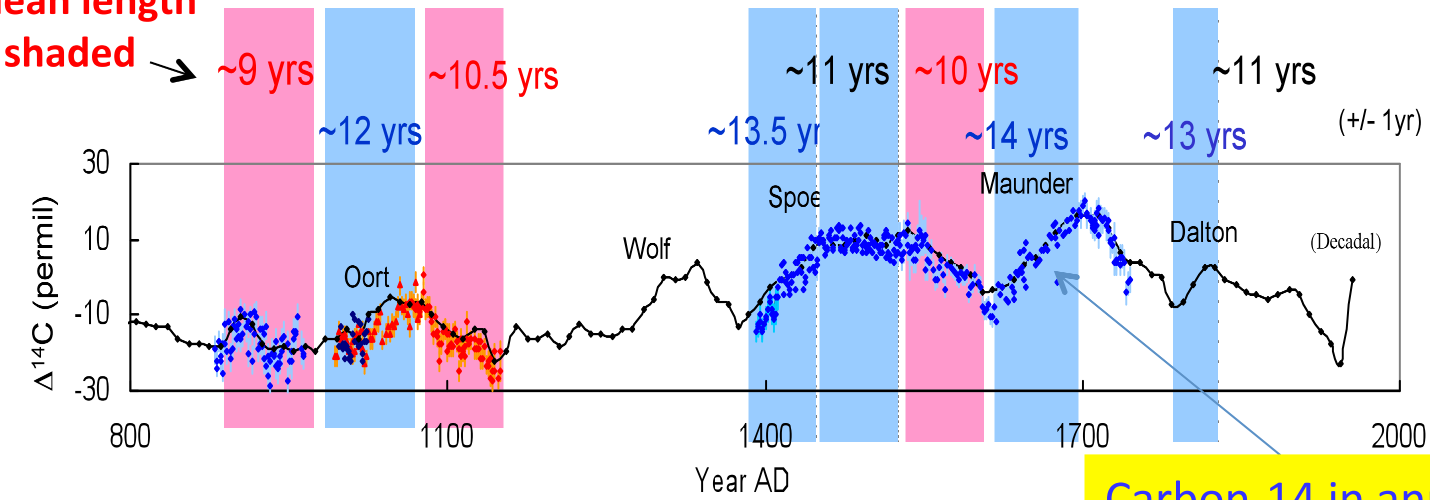


Carbon-14:
(Cosmogenic nuclide)





Actual mean length over the shaded period →

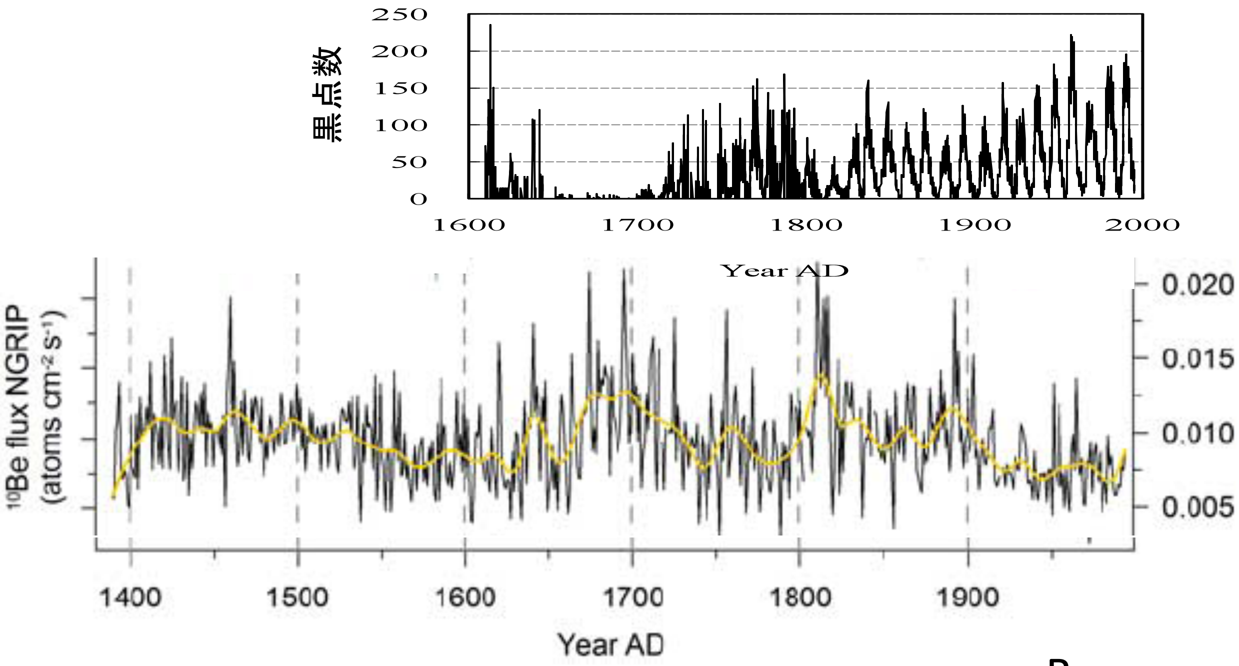


Dacadal:
Stuiver et al., 1998

Annual:
Miyahara et al.,
2004, 2006,
2007, 2008

Carbon-14 in annual tree rings

グリーンランド氷床コア中のベリリウム10（宇宙線生成核種）から読み取るマウンダー極小期の宇宙線フラックス変動



Berggren et al., 2009

シュペーラー
極小期
（無黒点期）

マウンダー
極小期

ダルトン
極小期

Cosmic-ray "22-year (28-year)" variation at the Maunder Minimum

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

Solar cycle

Filtered ^{14}C

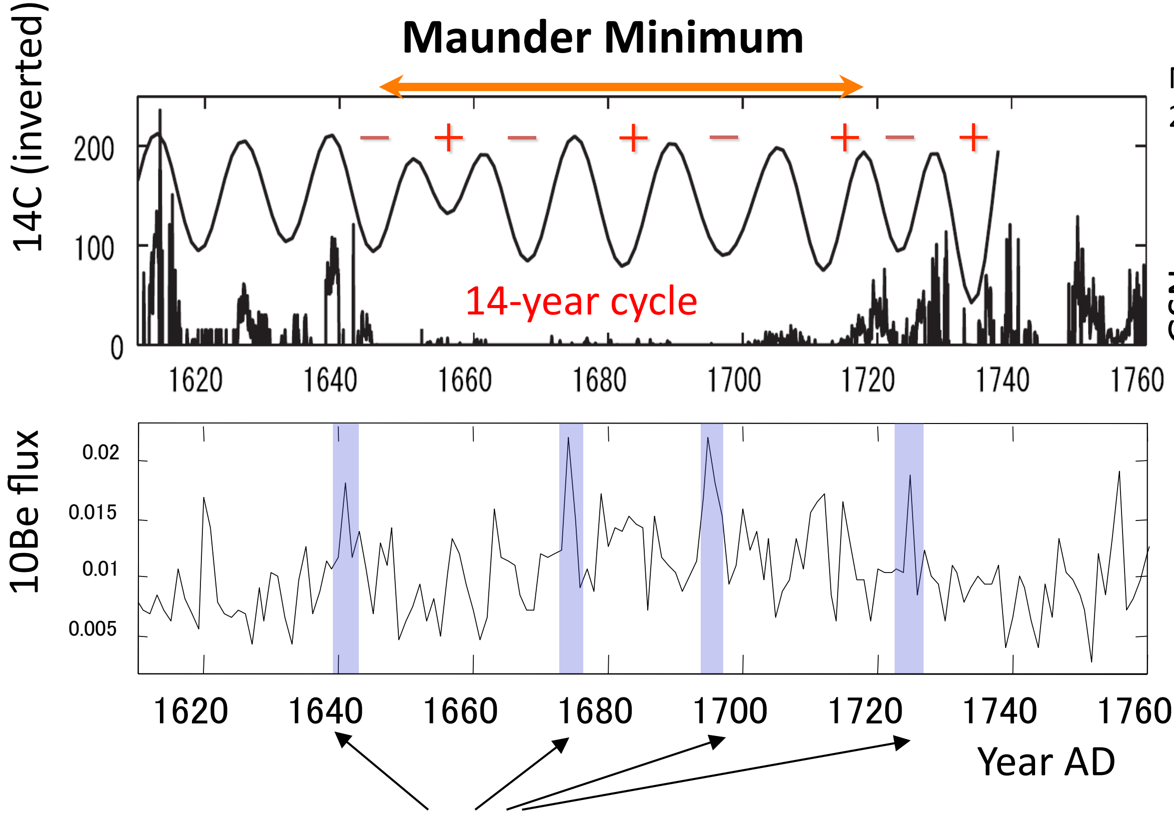
Tree ring: No dating error

Cosmic rays

^{10}Be

Ice core:

<u>a few years of dating errors</u>



Miyahara et al., 2004; 2008

Berggren et al., 2009

- Periodic cosmic ray enhancements, only for negative polarity (~28-year period)
- **1-year scale enhancement, 30-50% higher than the peak for positive polarity**
- Significant manifestation of drift effect of cosmic rays in the heliosphere

Pattern of cosmic ray variation at the Maunder Minimum and present

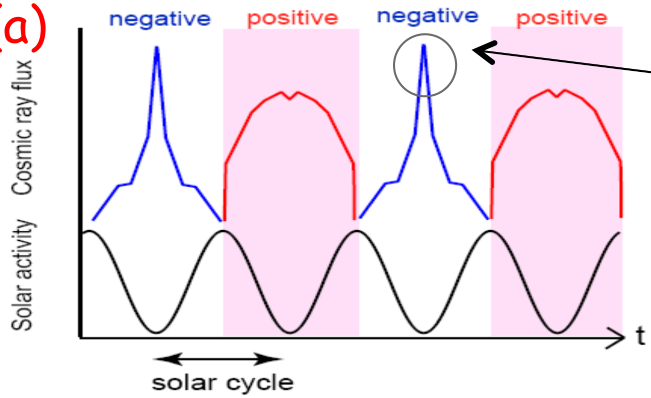
Miyahara et al.,2009

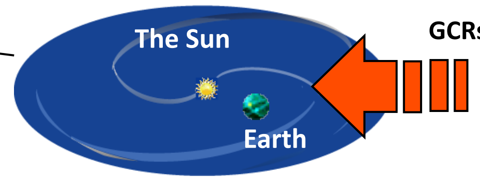
Based on
Kota&Jokipii, 1983; 2003

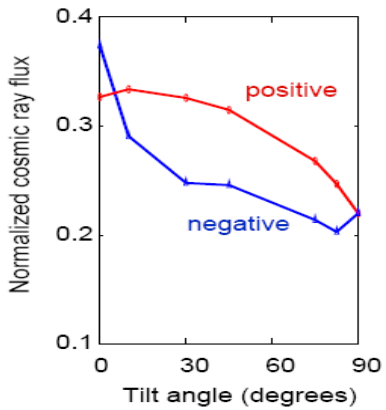
(a) 0 deg. at cycle min

(b) 5 degs. at cycle min

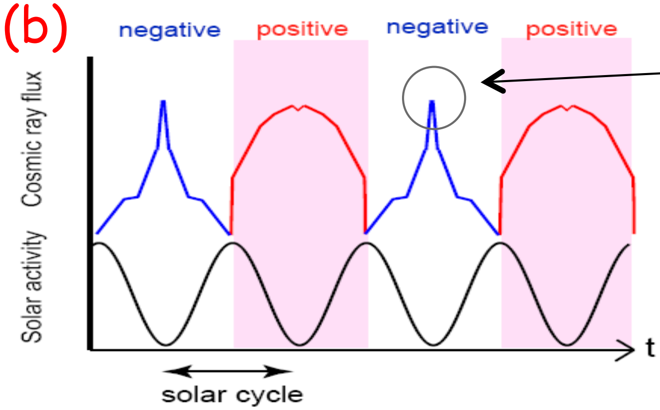
(a)

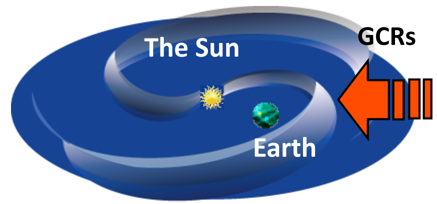


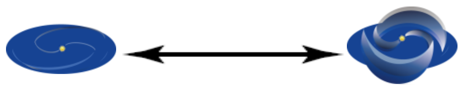




(b)



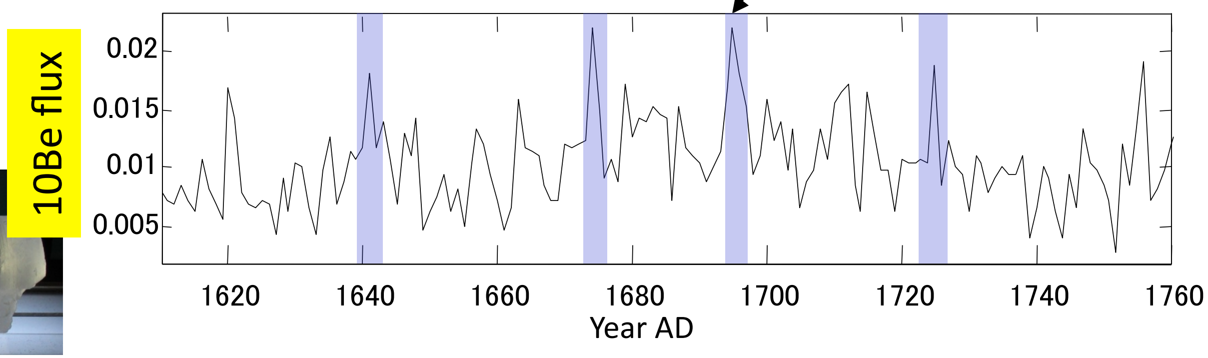


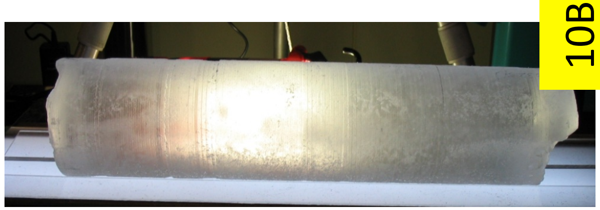


Heliospheric
Magnetic field

"Flattened current sheet model" reproduces 10Be variation

Berggren et al., 2009





What ^{14}C and ^{10}Be suggests for the Maunder Minimum

Solar Cycle length : ～14 years

Magnetic polarity reversal : YES (～28-year period)

Onset : two preceding 12-13 year cycles

Cosmic ray variations : Strong 22-year component

Heliospheric current sheet : More flattened

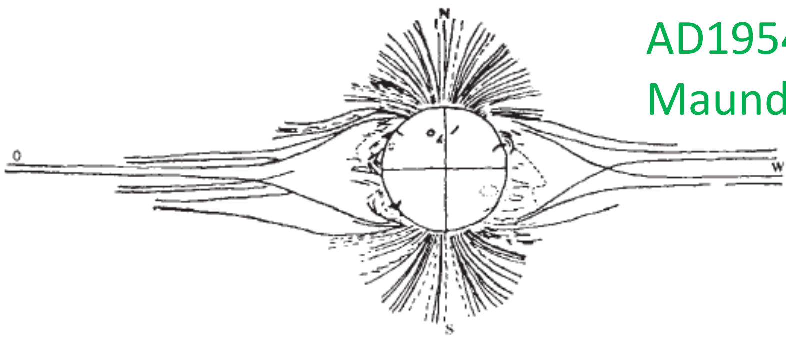


Fig. 2 The structure of a sunspot minimum solar corona drawn from eclipse photographs[11] (June 30, 1954) obtained in Kozeletsk.

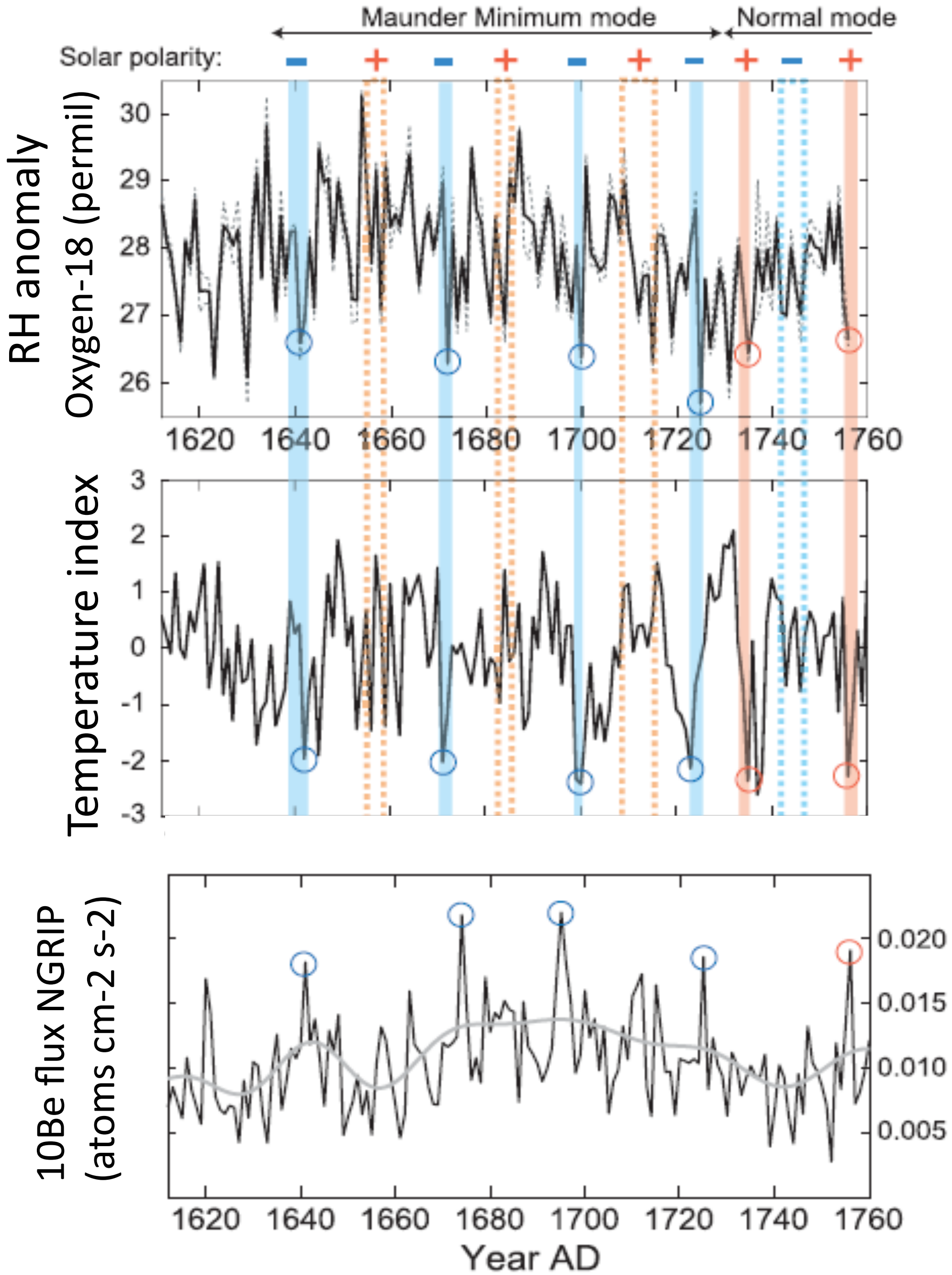
AD1954 case: stronger polar field

Maunder Min: weaker equatorial field

Any impact on climate?

Climate response to cosmic-ray spikes during the Maunder Minimum

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



Dry

Humidity in Japan around June

Humid

Warm

Greenland winter temperature

Cold

High

GCR flux

(Berggren et al., 2009)

Ice core:

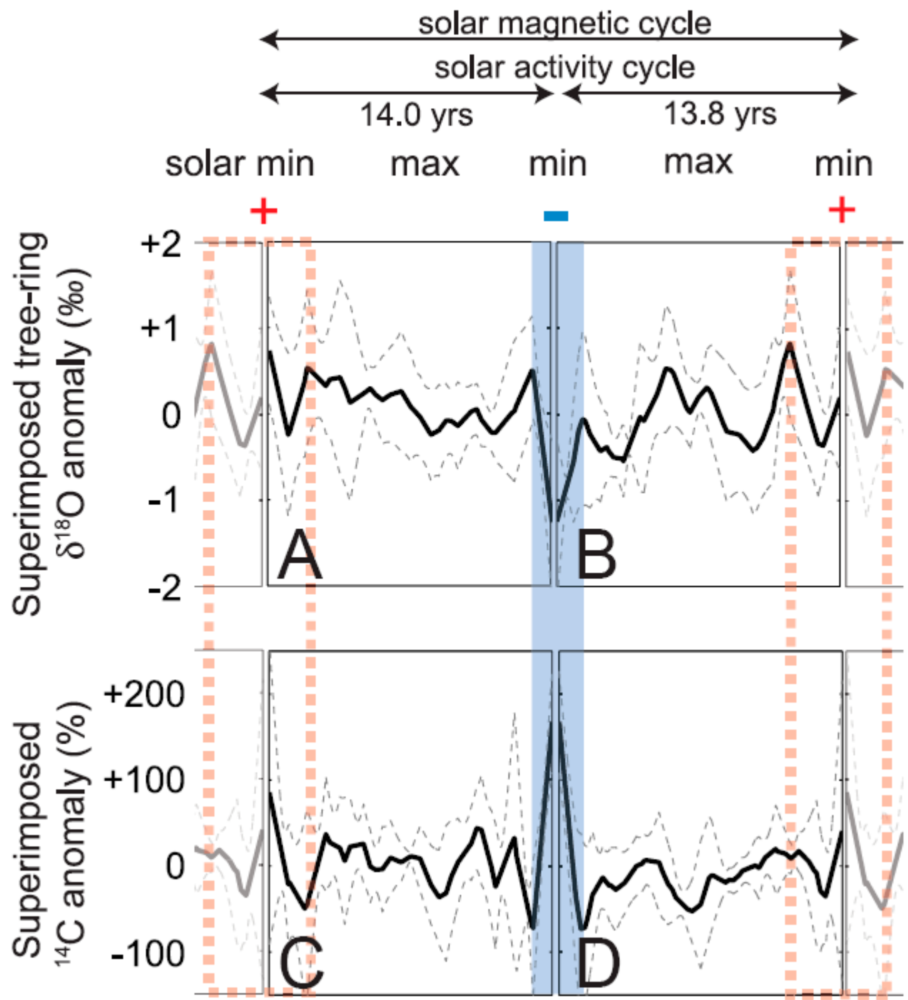
a few years of dating errors

Low

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

Relative Humidity anomaly reconstructed from tree rings

Tree ring ^{14}C anomaly



~4 sigma

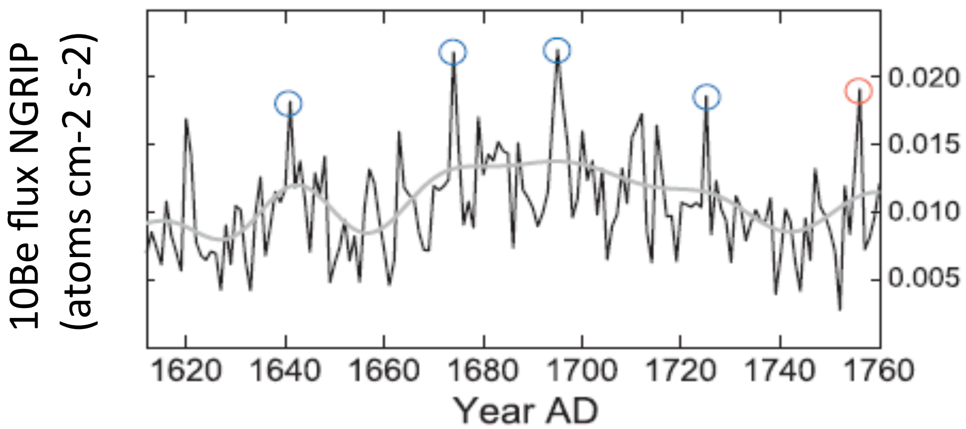
No time lag!

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

課題　：　宇宙線スパイクをトレーサーとした全球気候応答マッピング

（1642年付近、1671年付近、1700年付近、1724年付近の計4イベント）
→　樹木年輪中炭素14濃度の超高精度分析で絶対年代決定

気温と降水の両方のマッピングにより、
宇宙線に対する気候システムの複雑な応答の理解につなげたい



・降水の増減の地域性
・北半球（グリーンランド、日本）の気候変動の同期

まとめ

・太陽圏システムとして地球気候、気象を捉えなおすことで
気候の未解明の振動に関する理解が深まる可能性

・太陽活動、磁場極性、太陽圏磁場構造、周期性などの変化について
理解をより一層深め予測手法を確立する必要性

詳細な雲物理の解明については、雲の高度分布・粒径分布観測
や室内実験に期待