宇宙線が気候変動および気象現象に及ぼす影響について

Heliosphere

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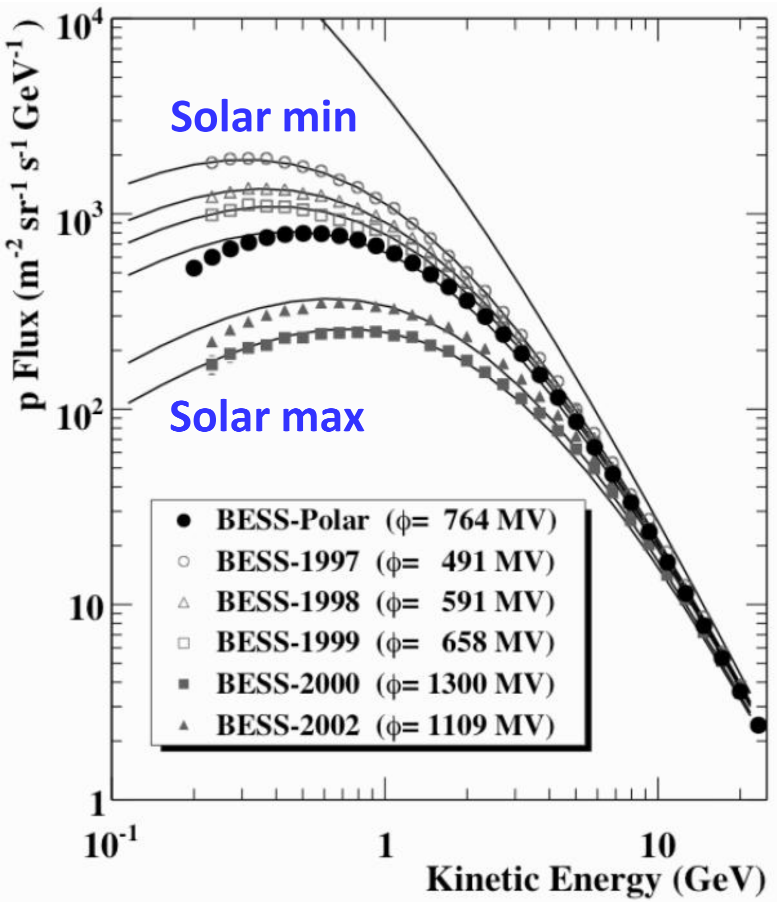
Contents

宇宙線の22年周期変動

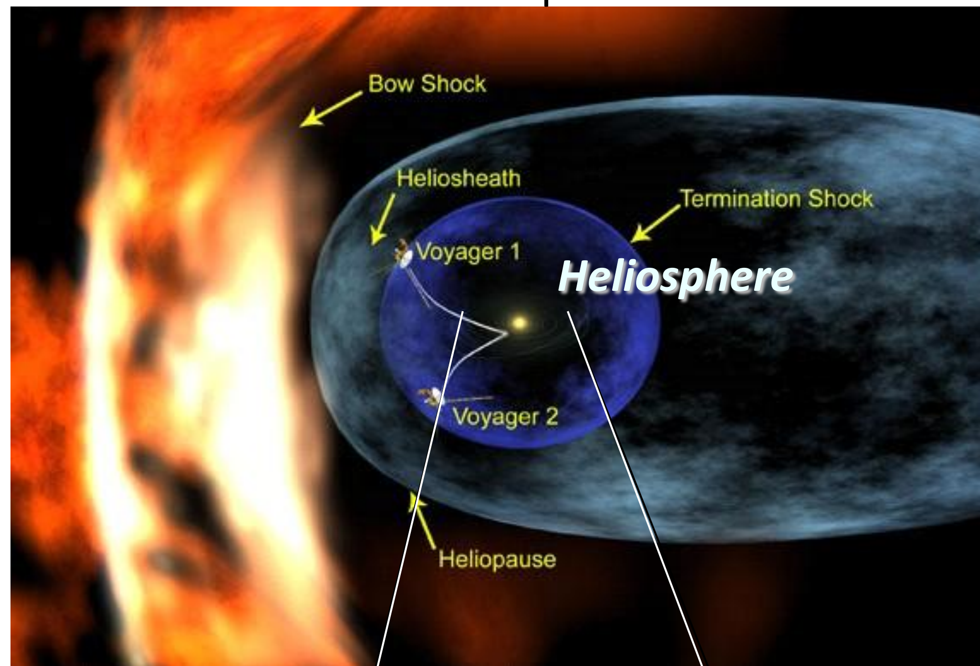
マウンダー極小期における宇宙線変動と気候変動

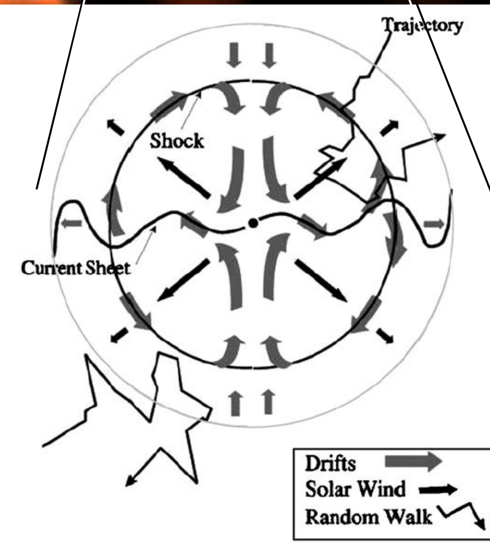
宇宙線の27日周期変動と赤道熱帯域の雲活動の変動
（宇宙線が気候システムに及ぼす変動のトレースの観点、
気象への影響の観点から）

Solar modulation of Galactic Cosmic Rays (GCRs)



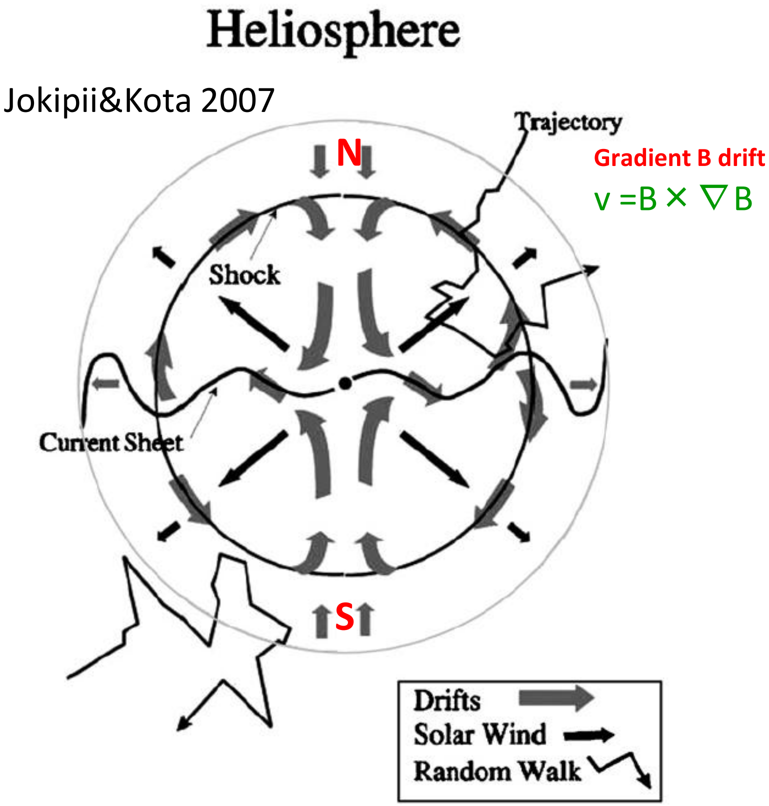
- Charged particles (mainly protons)
- Accelerated at supernova remnant

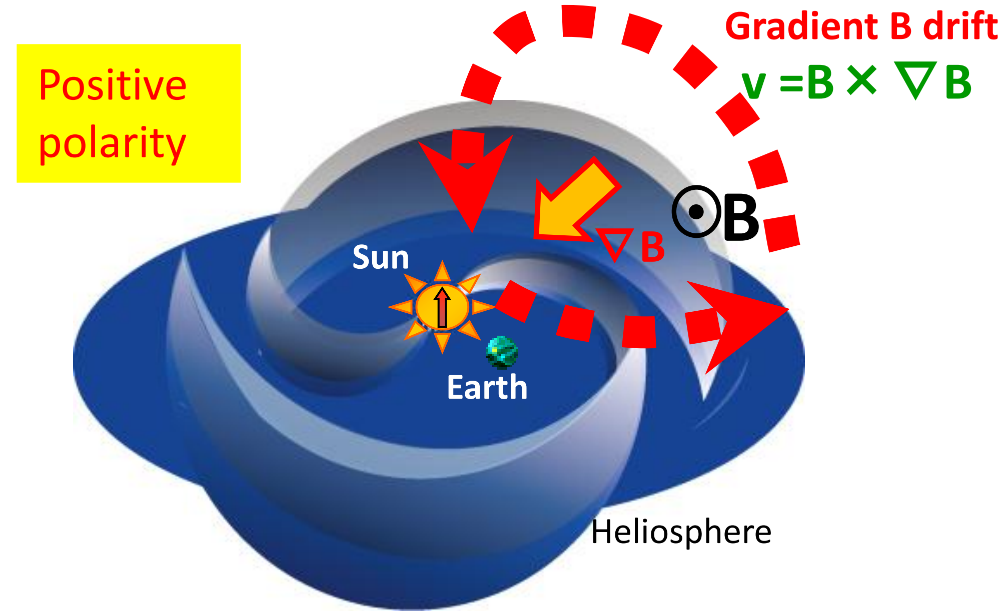




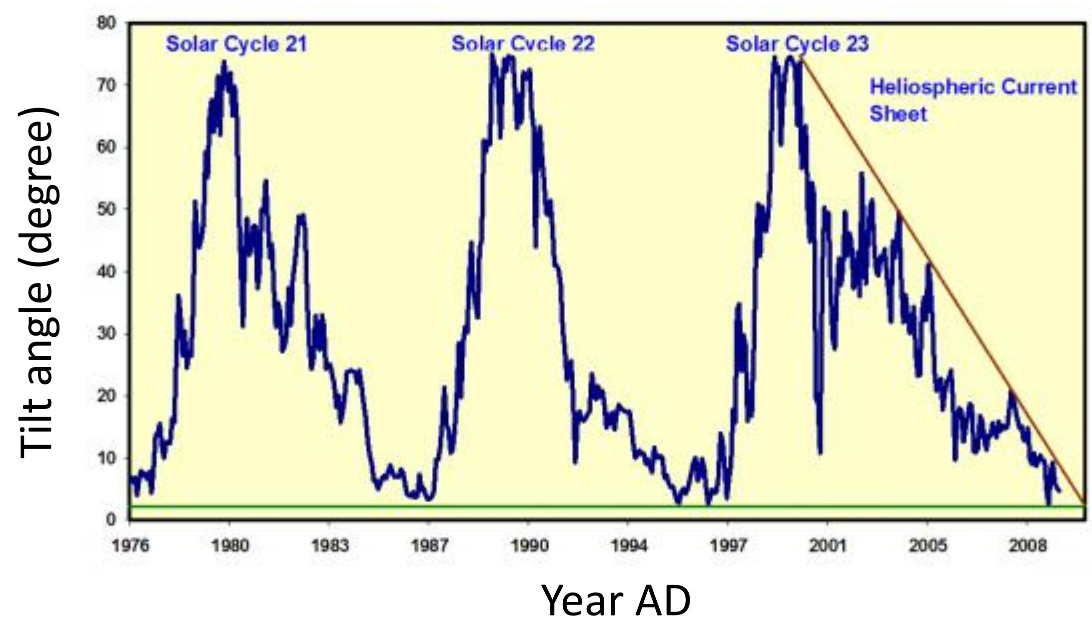
- **diffusion**
- **advection by solar wind**
- **drift　(B × ∇Bドリフト）**

Solar modulation of cosmic rays & Drift effect



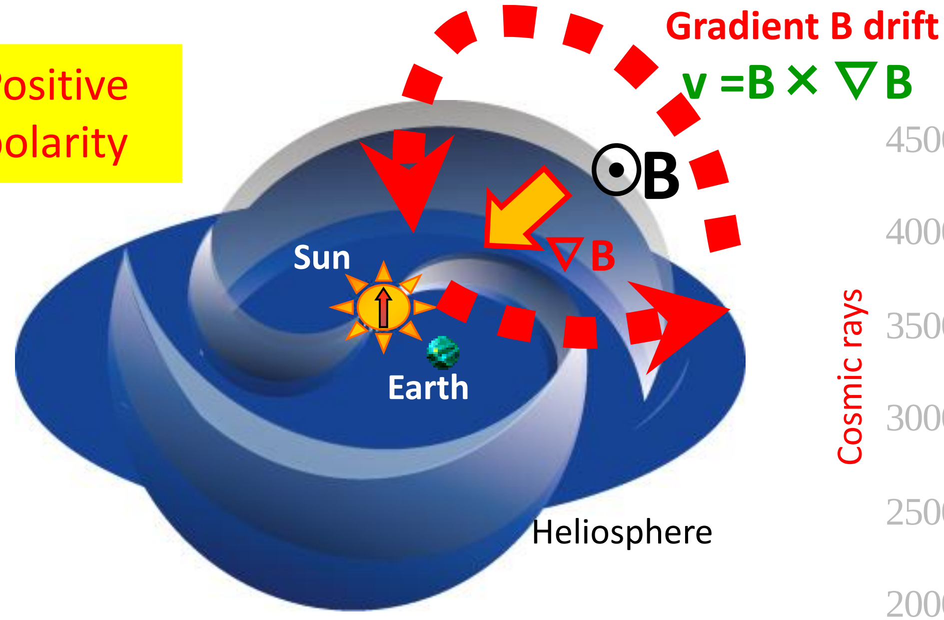


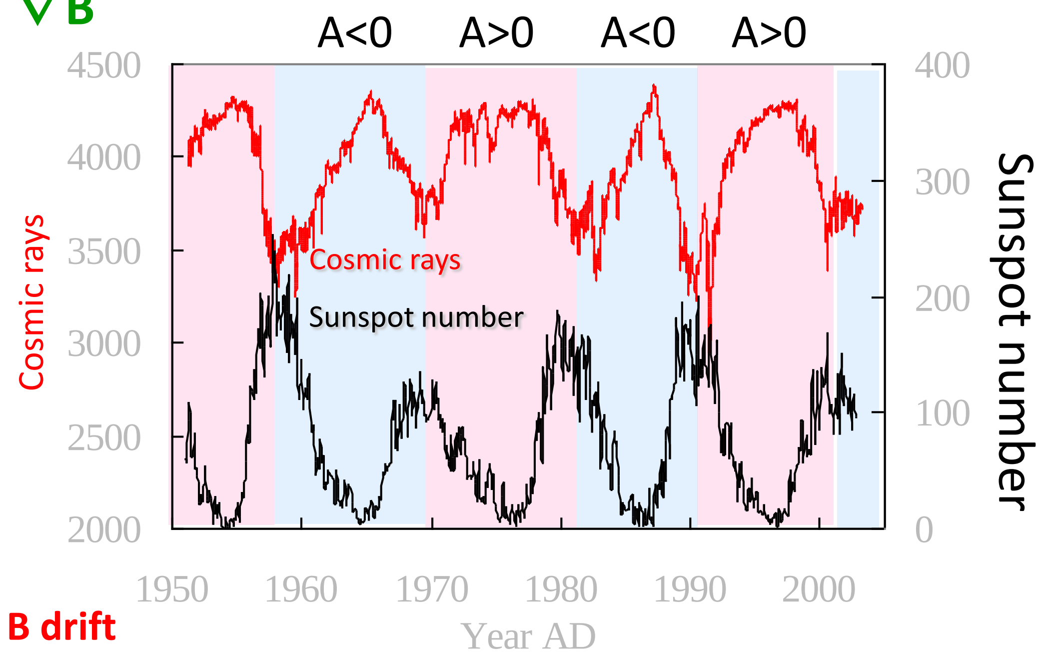
- diffusion
- advection by solar wind
- drift　(B × ∇Bドリフト)



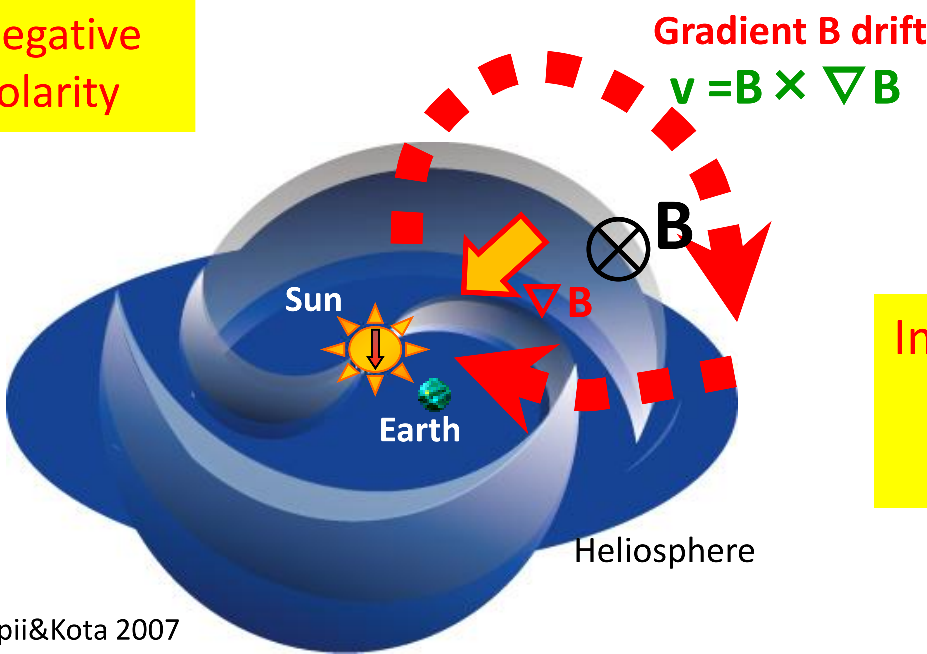
Cosmic ray variation & Solar magnetic polarity

Positive polarity





Negative polarity



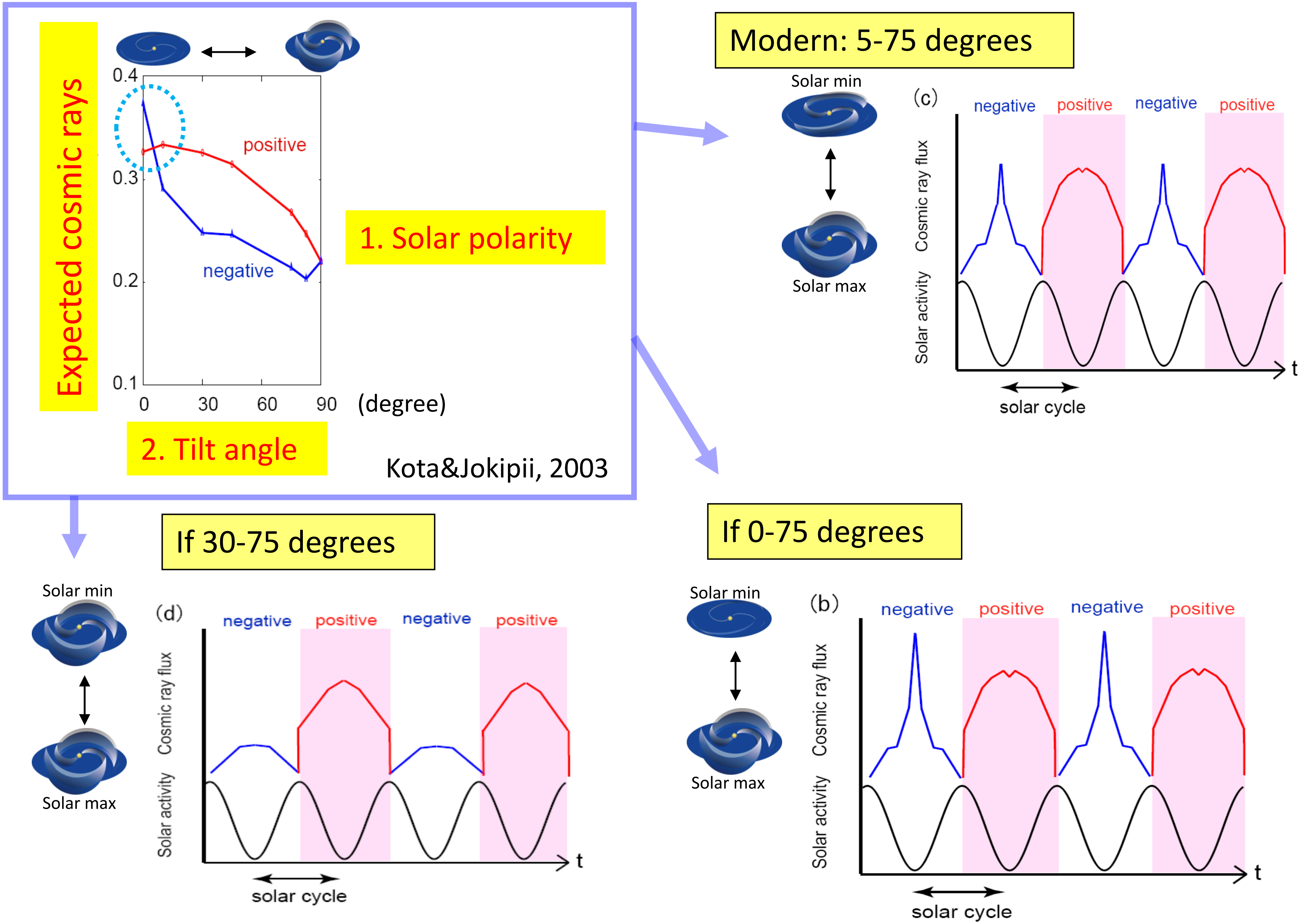
Important parameters for solar modulation

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

Jokipii&Kota 2007

Variable "22-year" variation of cosmic rays

Miyahara et al.,2009



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

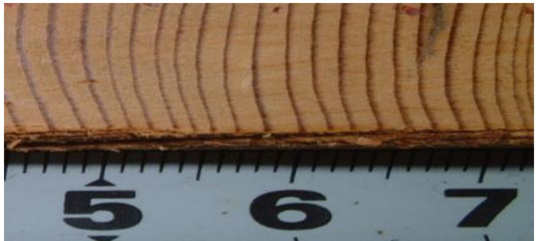
$^{14}N + n \rightarrow {}^{14}C + p$

Atmospheric circulation

$^{14}CO_2$

Photo-synthesis

Tree ring

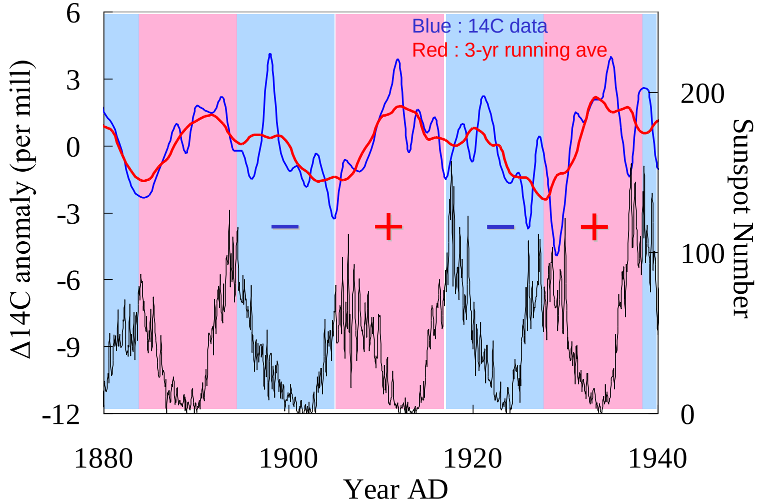


^{10}Be etc.

Precipitation

Antarctic/Greenland
Ice sheets

^{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

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

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

Solar cycle

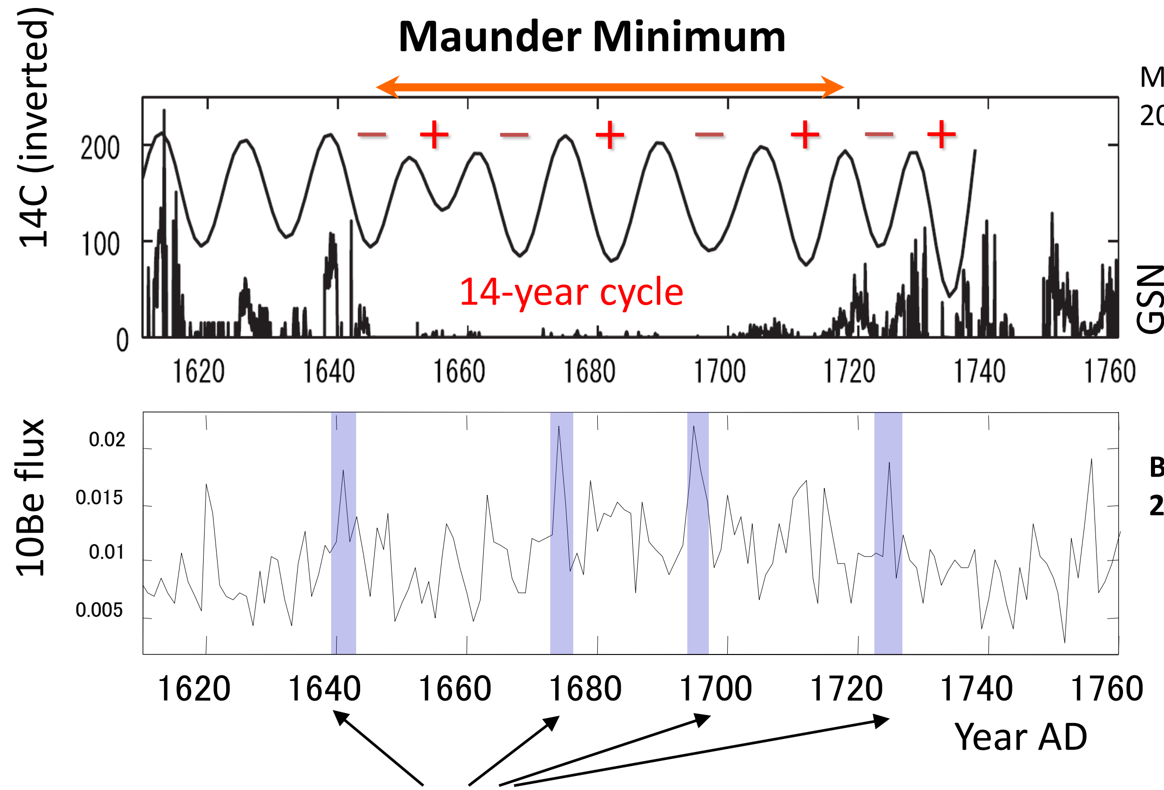
Filtered ^{14}C

Tree ring: No dating error

Cosmic rays

^{10}Be

Ice core:
a few years of dating errors



- 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

Pattern of cosmic ray variation at the Maunder Minimum and present

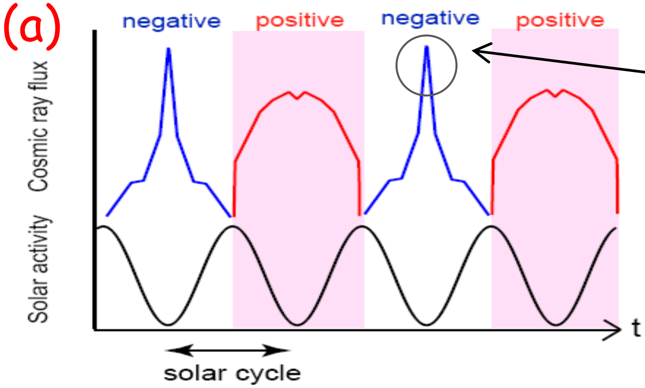
Miyahara et al.,2009

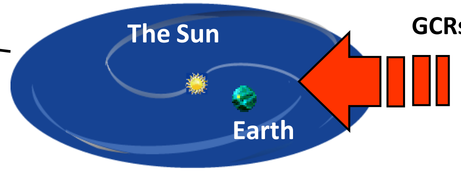
Based on
Kota&Jokipii, 1983; 2003

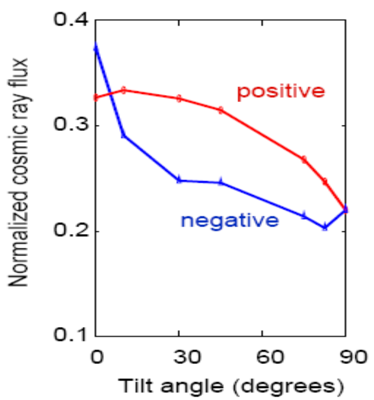
(a) 0 deg. at cycle min

(b) 5 degs. at cycle min

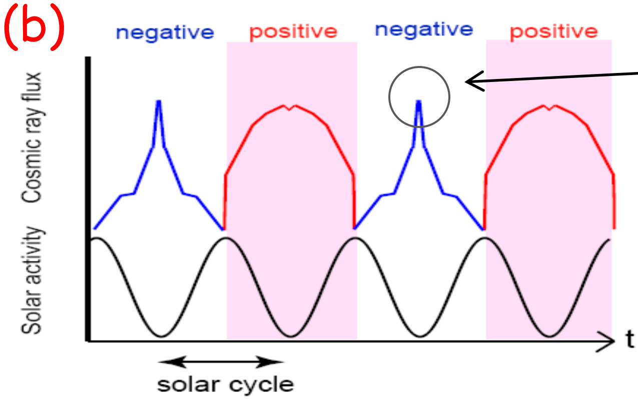
(a)

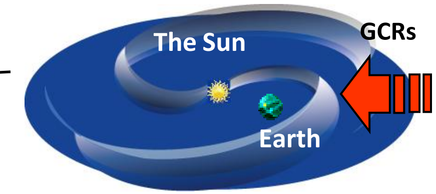


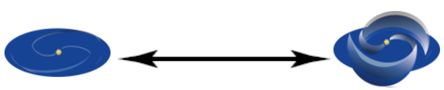




(b)



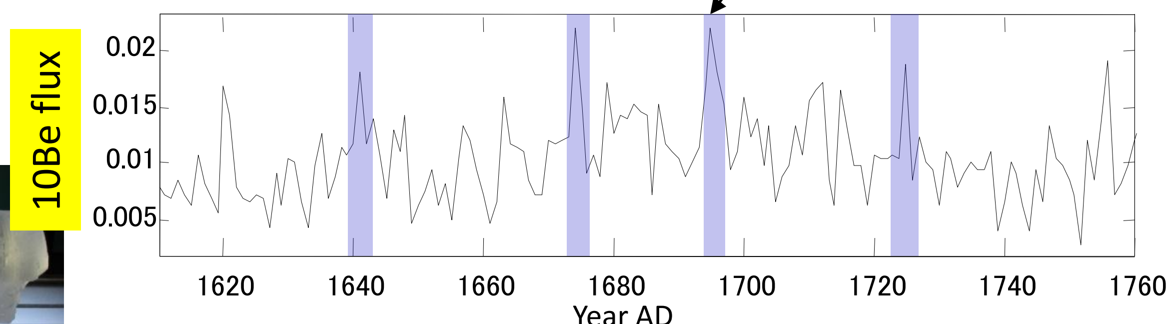




Heliospheric
Magnetic field

"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

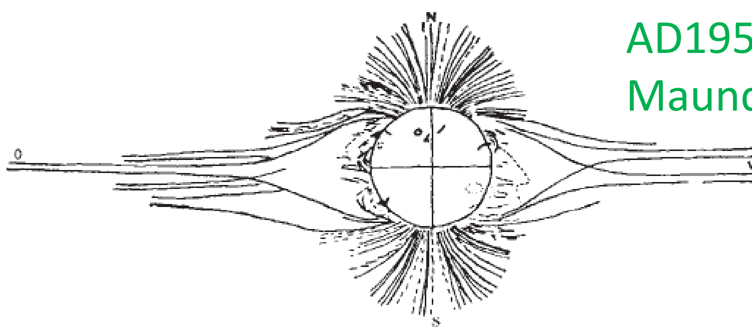


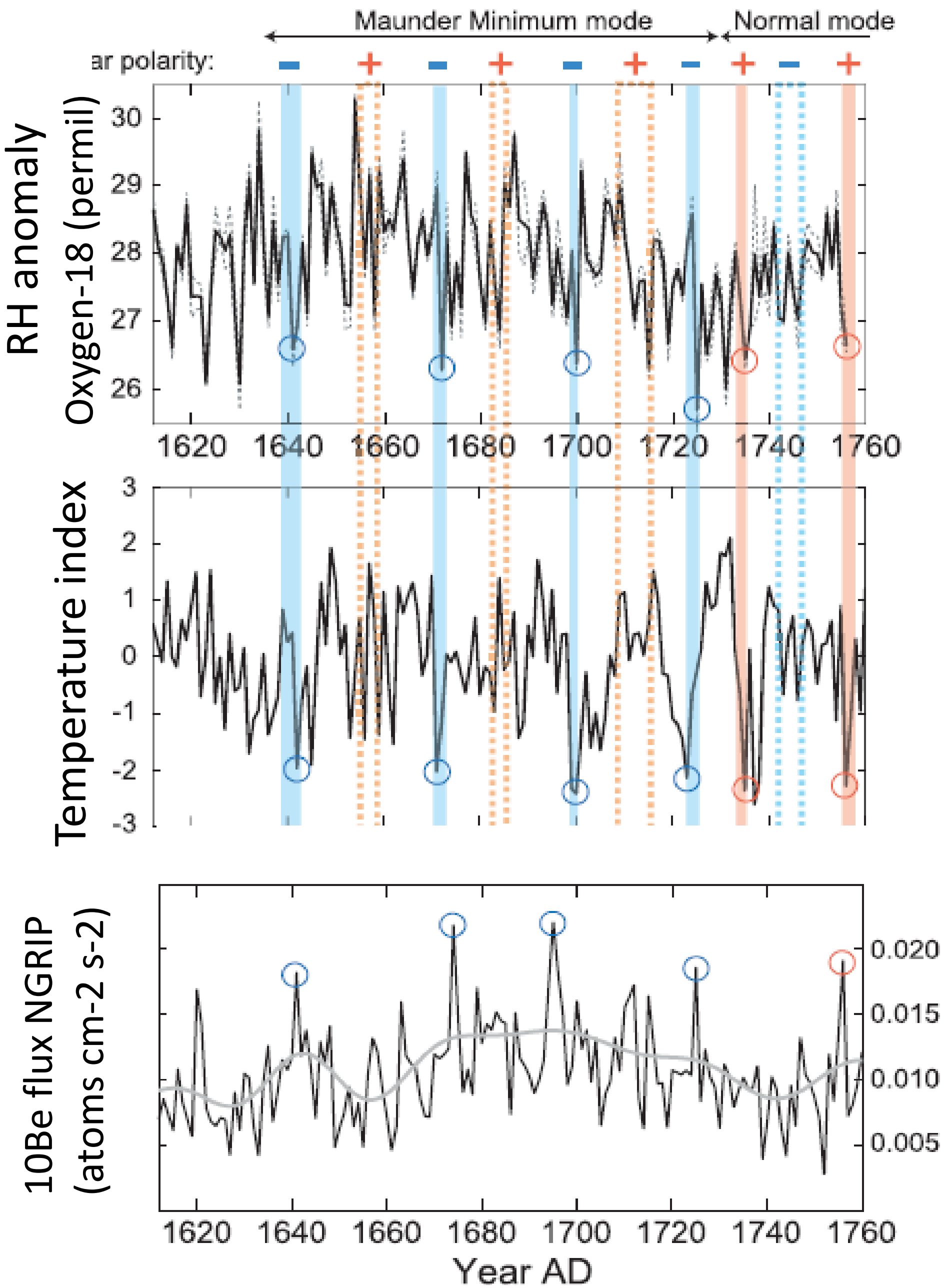
Fig. 2 The structure of a sunspot minimum solar corona drawn from eclipse photographs[11] (June 30, 1954) obtained in Kozeletsk.

AD1954 case: stronger polar field
Maunder Min: weaker equatorial field

Any impact on climate? : GCR spikes can be the tracer

Climate response to cosmic-ray spikes during the Maunder Minimum

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



Dry

Humid

Humidity in Japan around June

Warm

Cold

Greenland winter temperature

High

Low

GCR flux

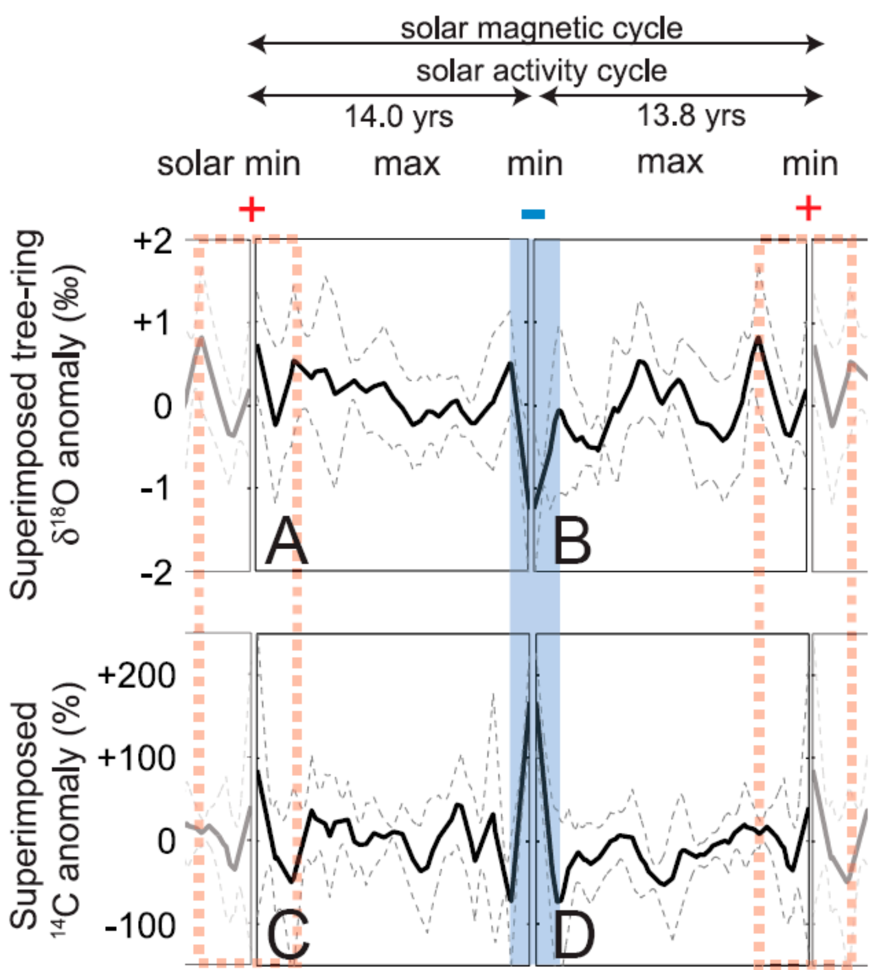
(Berggren et al., 2009)

Ice core:
a few years of dating errors

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

Relative Humidity anomaly

^{14}C anomaly



~4 sigma

No time lag!

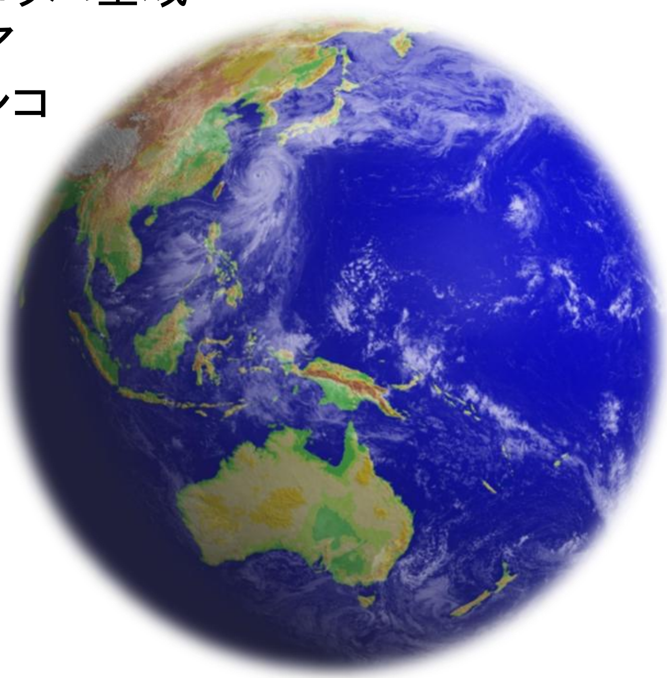
Yamaguchi, Yokoyama, Miyahara et al., PNAS, 2010

現在進行中の計画　:　宇宙線スパイクをトレーサーとした 全球気候マッピング
（計4イベント）

炭素14の超高精度分析も山形大学で実施中　（従来の1/3の統計誤差）

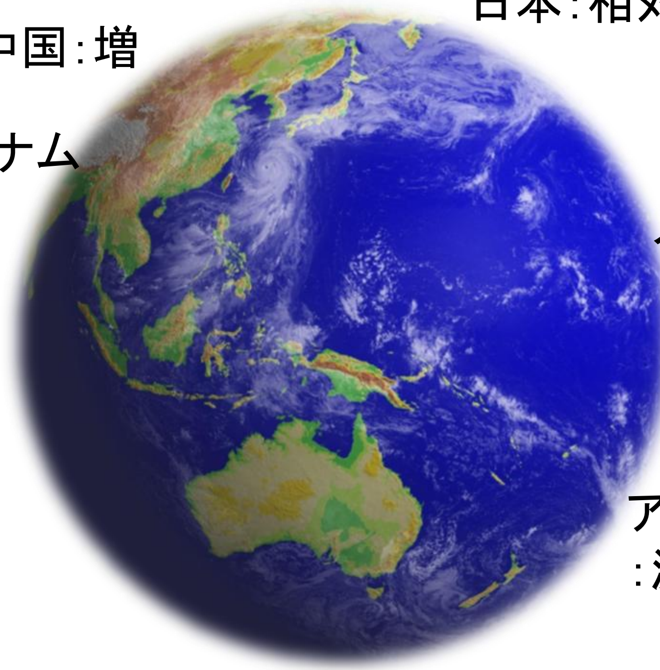
気温: 全球で寒冷傾向

ヨーロッパ全域
ロシア
メキシコ
日本
など



降水:　強い地域性?（モンスーンを介した影響？）

モンゴル:減
日本:相対湿度増
中国:増
ベトナム
:減
メキシコ:減
アルゼンチン
:減



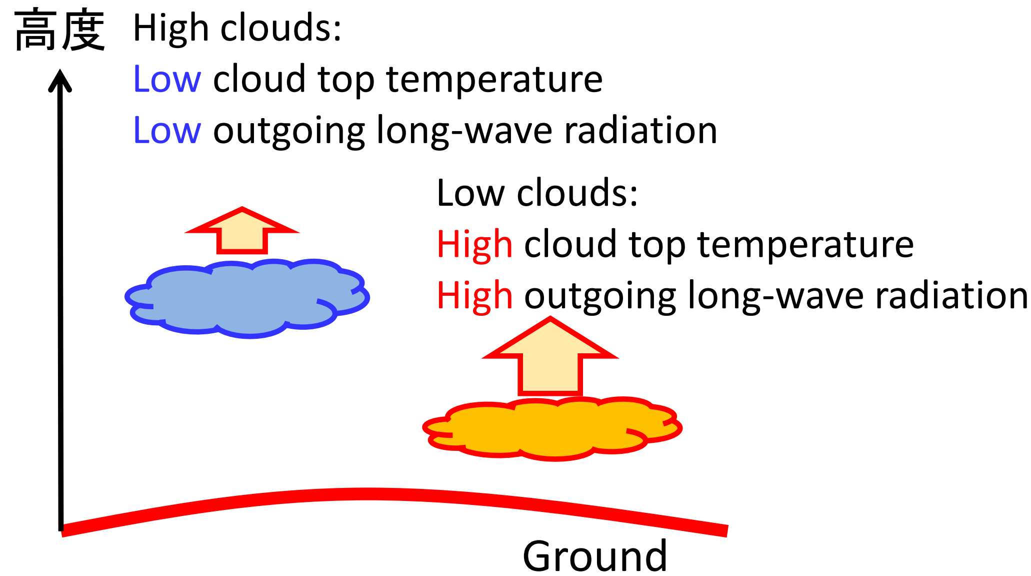
宇宙線に対する地球気候システムの複雑な応答解明

宇宙線はどのように気候を変えるのか？
日日スケールからの検証

Data :

1. Daily Outgoing Long-wave Radiation
   Duration : 1979/Jan – 2004/Dec
   10 x 10 degrees grid

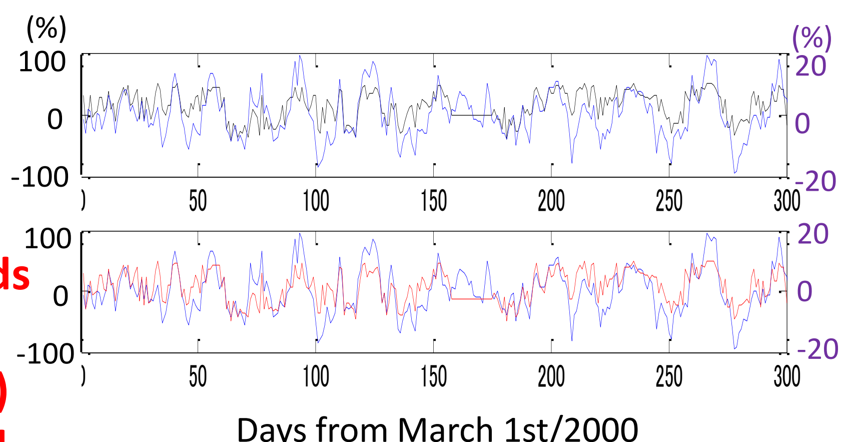
2. MODIS terra/aqua cloud fraction
   Duration : 2000/March –



OLR (inverted) vs MODIS cloud fraction

Total Cloud

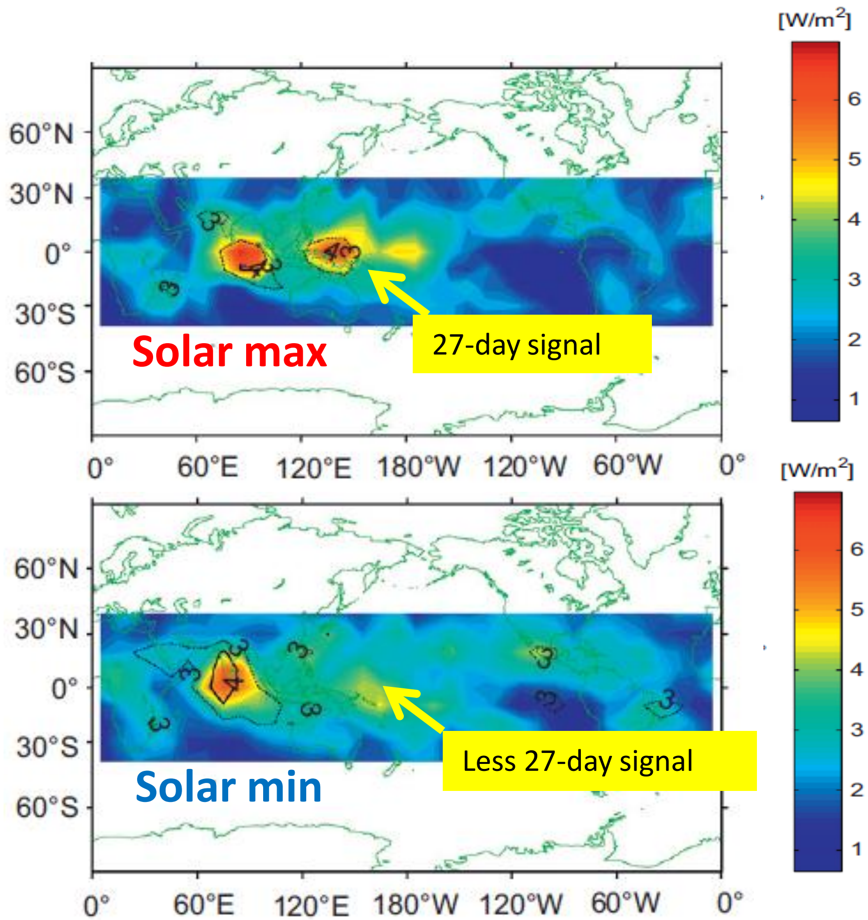
High Clouds fraction (<440 mb) > 7km a.s.l.



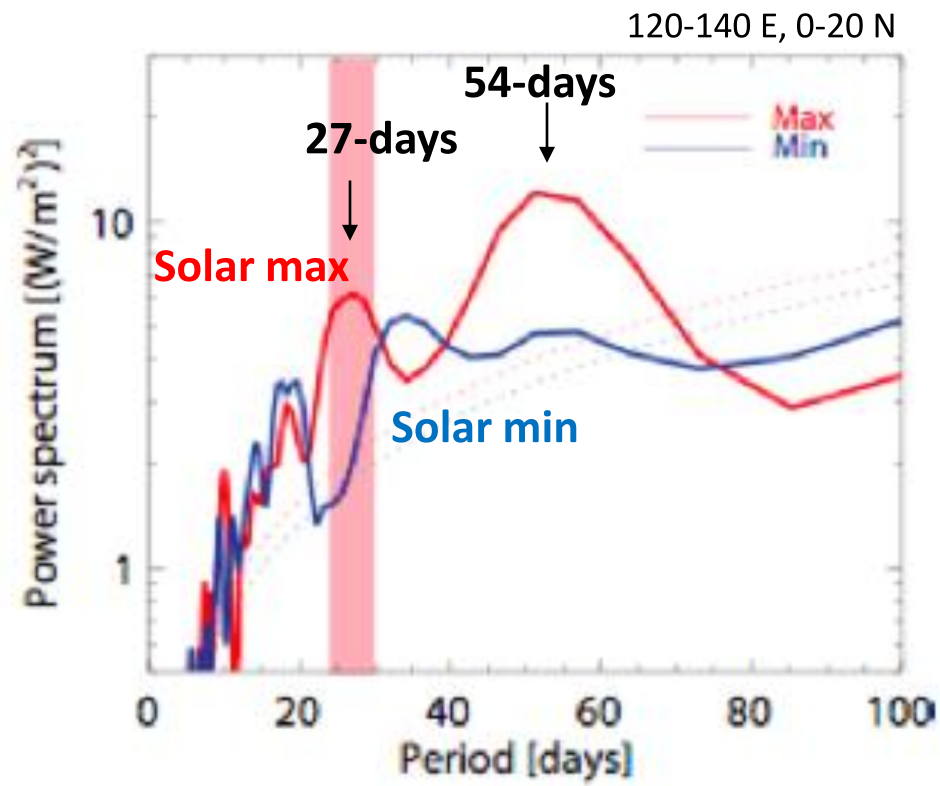
Outgoing Longwave Radiation(OLR)
> monitoring high-altitude clouds

赤道熱帯域の高層雲の27日周期

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



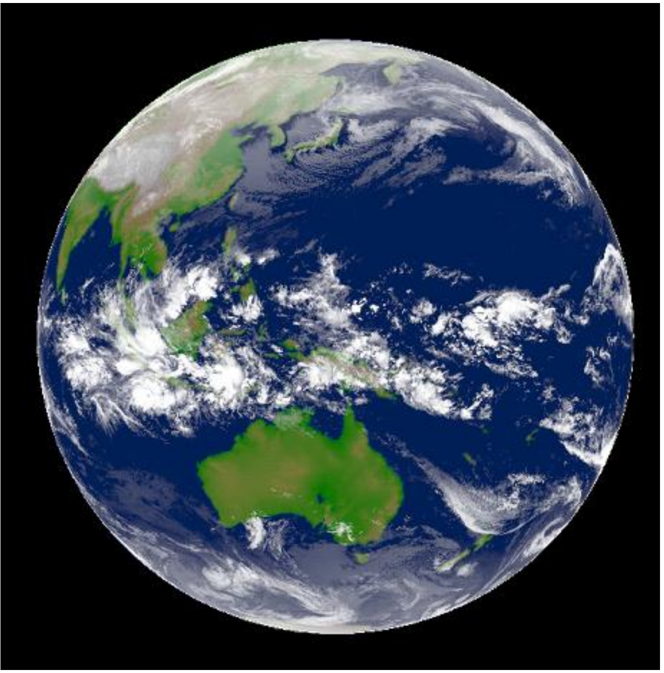
Frequency spectrum of **OLR**



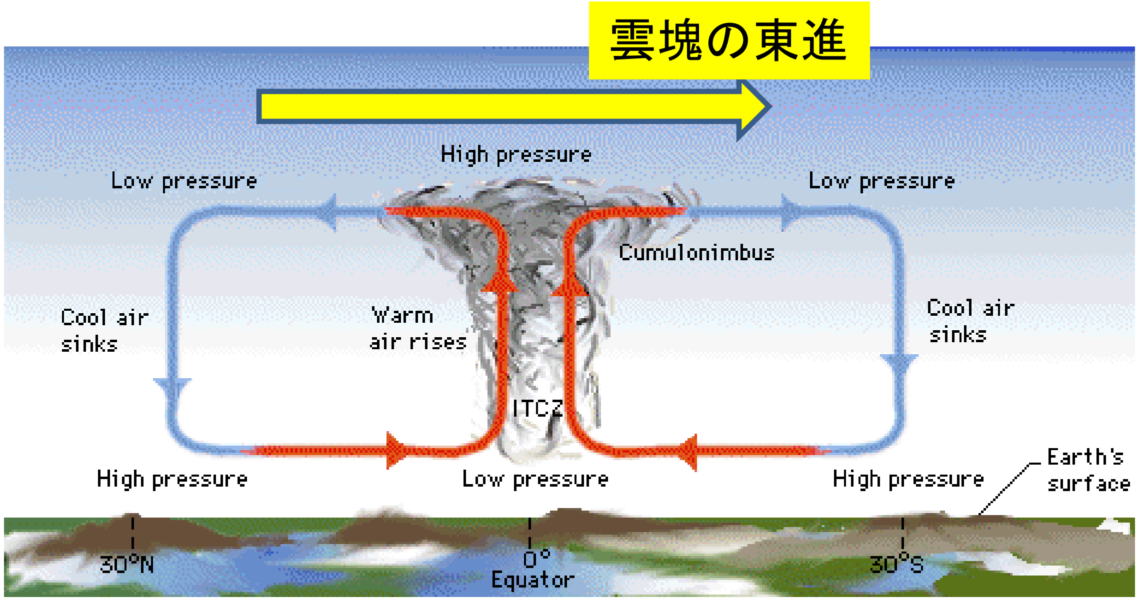
※27日周期は、11年変動の極大のみで顕著

Dynamic cloud activity at equatorial region (Madden-Julian Oscillation) has 30-60 day periodicity.
Intrinsic period (30-50 day period) is modulated to be 27-day and 54-day periods at solar max

マッデン・ジュリアン振動とは



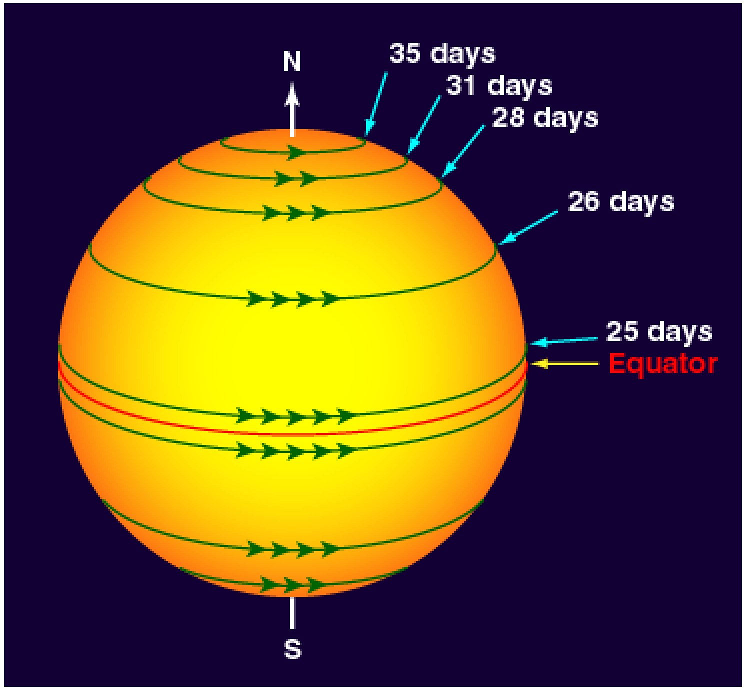
http://www.ccsr.u-tokyo.ac.jp/~satoh/nicam/index.html



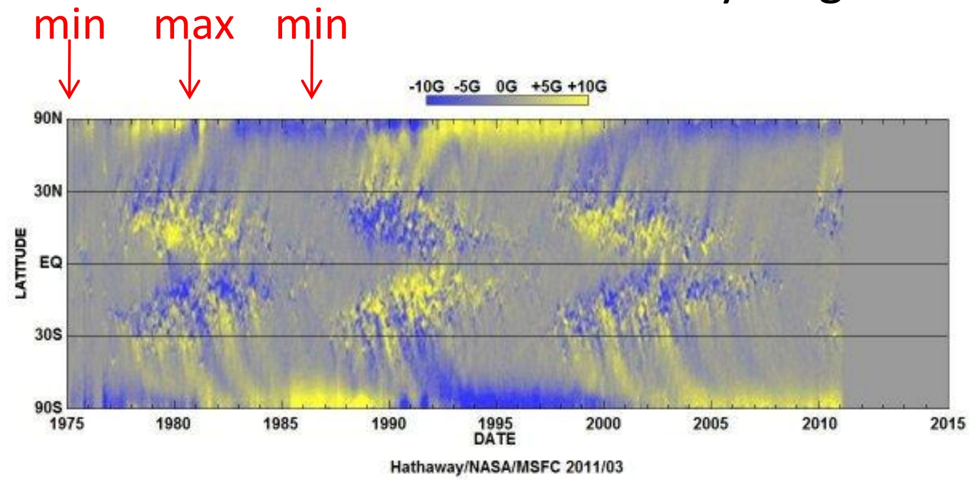
- 赤道熱帯域の雲活動の30－60日周期（周期性の決定因子は未解明）
- エルニーニョの開始、終焉をコントロール
- 南北半球のモンスーンを介して、中高緯度の気候にも影響

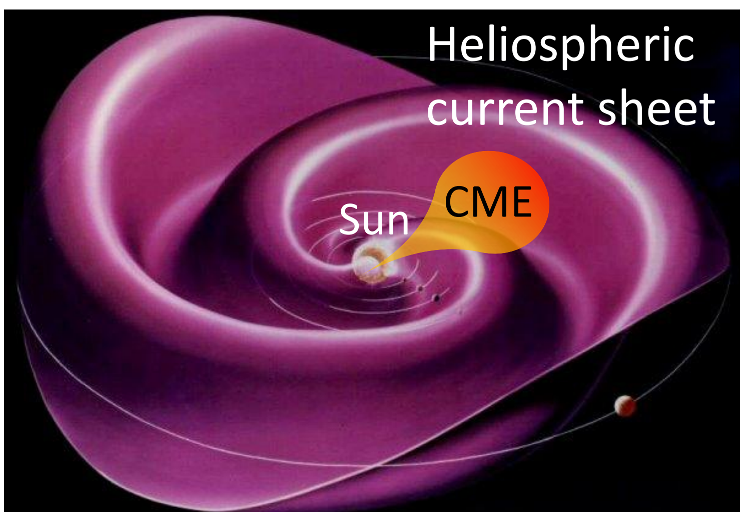
Solar differential rotation

Differential Rotation



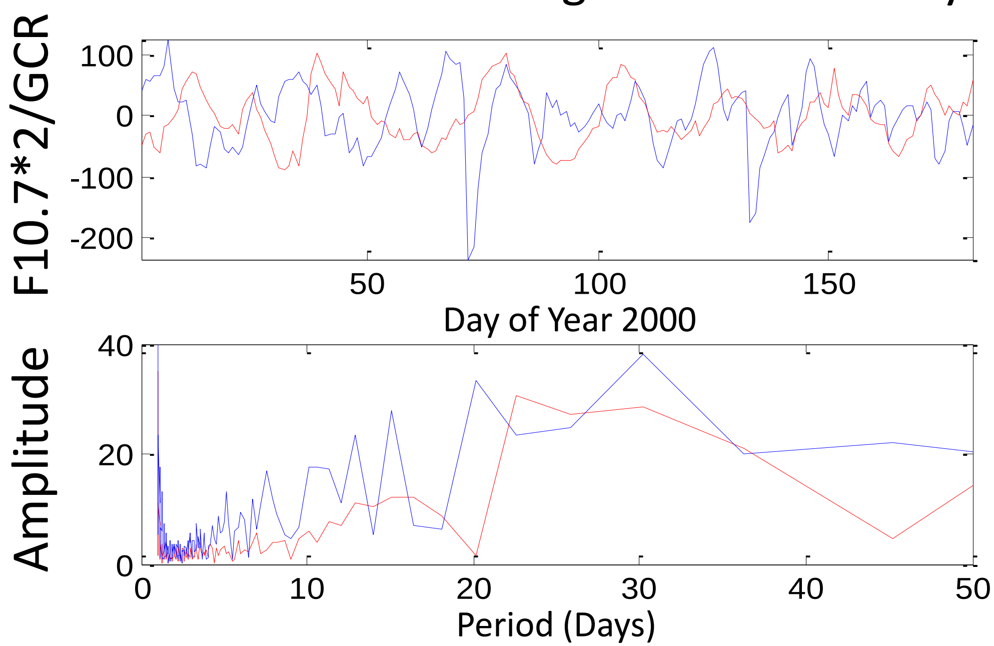
Butterfly diagram



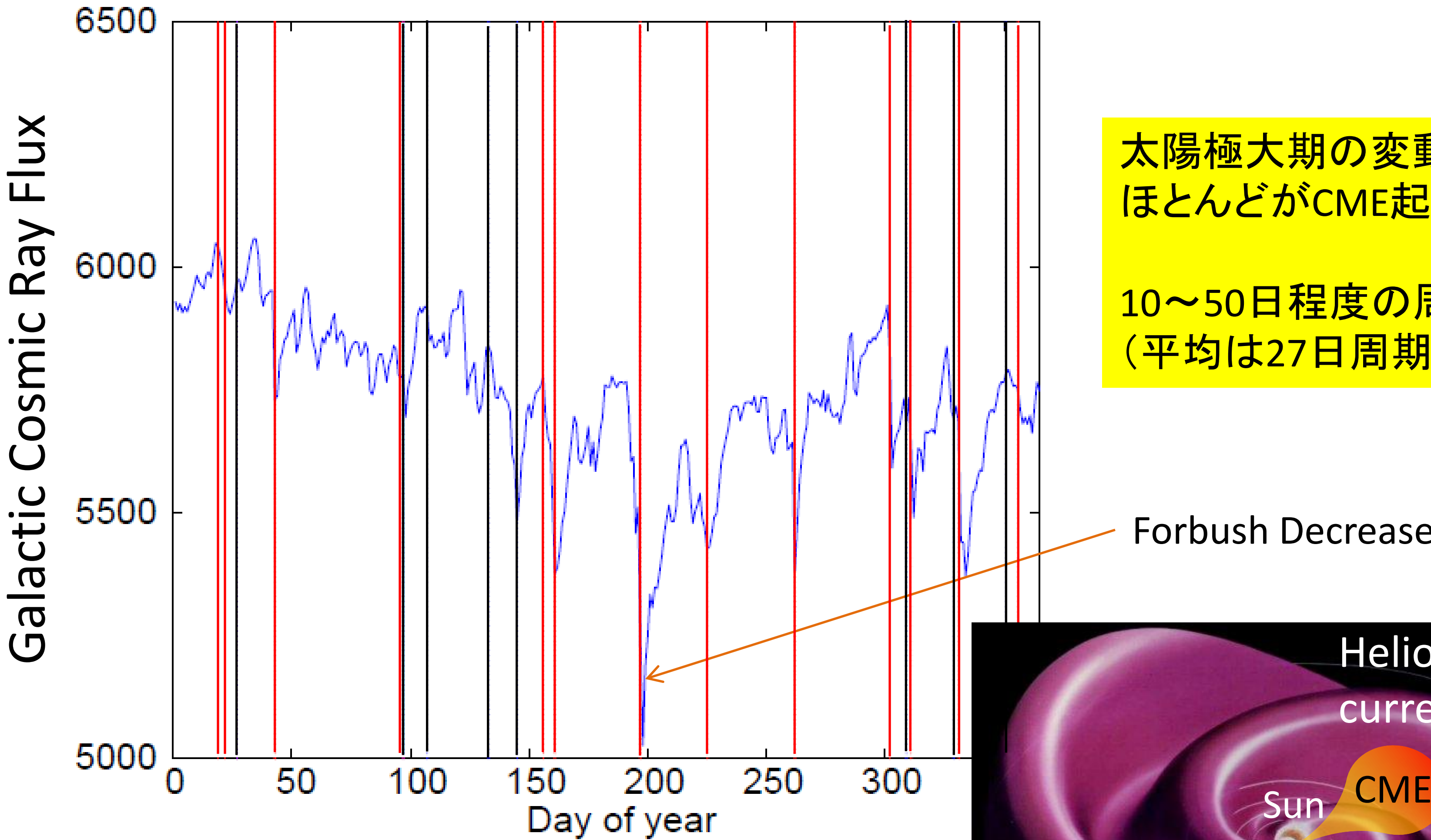


Red : F10.7 solar radio flux

Blue : galactic cosmic rays



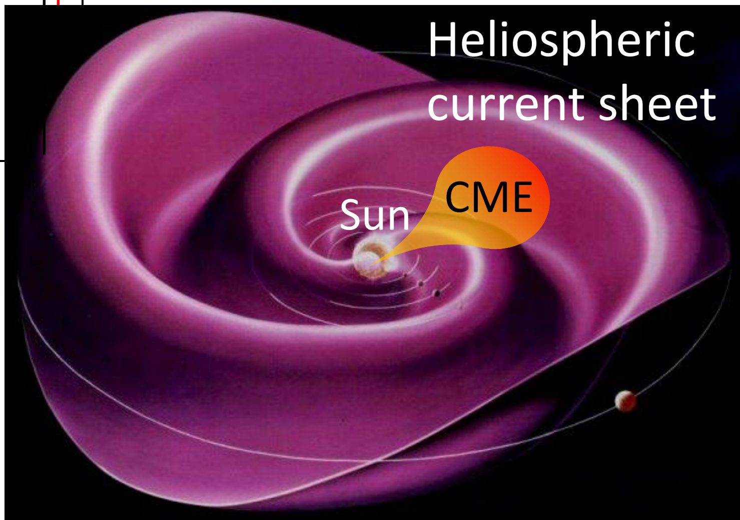
Red: Solar flares (Coronal Mass Ejections (CMEs))
Black: Current sheet passage



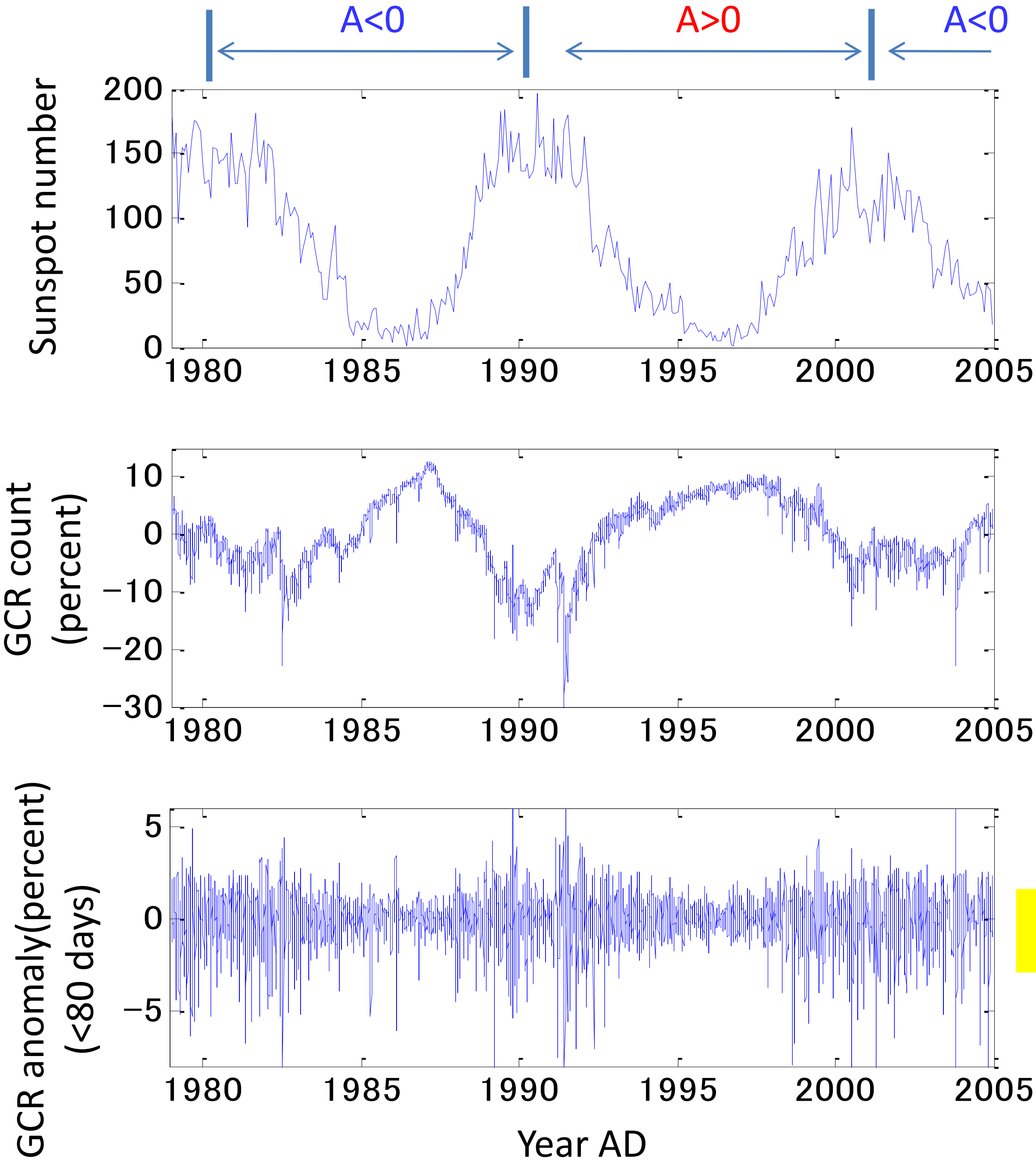
太陽極大期の変動は
ほとんどがCME起源

10〜50日程度の周期性
（平均は27日周期）

AD 2000



(Solar Max)



← short-term variability

Larger at 11-year **max**

（※　未発表分は削除いたしました）

宇宙線に由来する何がどう効いているのかの物理は今後の課題

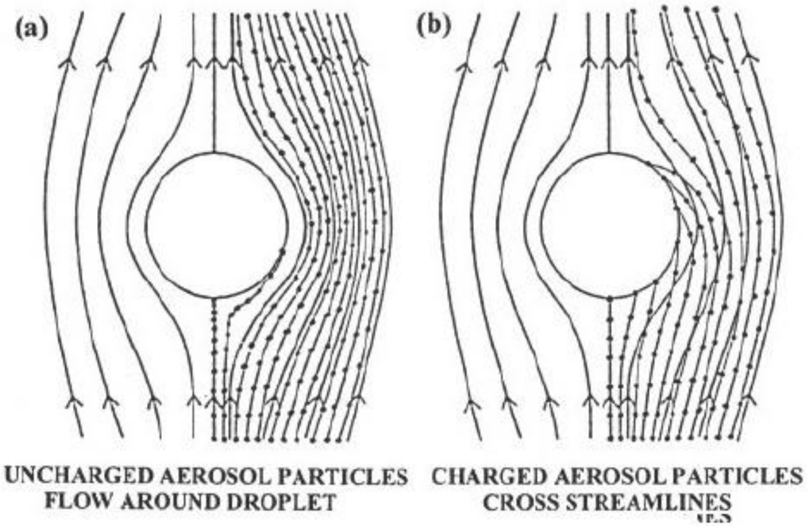


Figure 5.3. (a) Schematic of aerosol flow around a falling droplet in the absence of electrical forces. (b) Schematic of effect of electrical forces in moving aerosol particles across streamlines.

Tinsley & Yu 2006

Kirkby, Nature, 2011

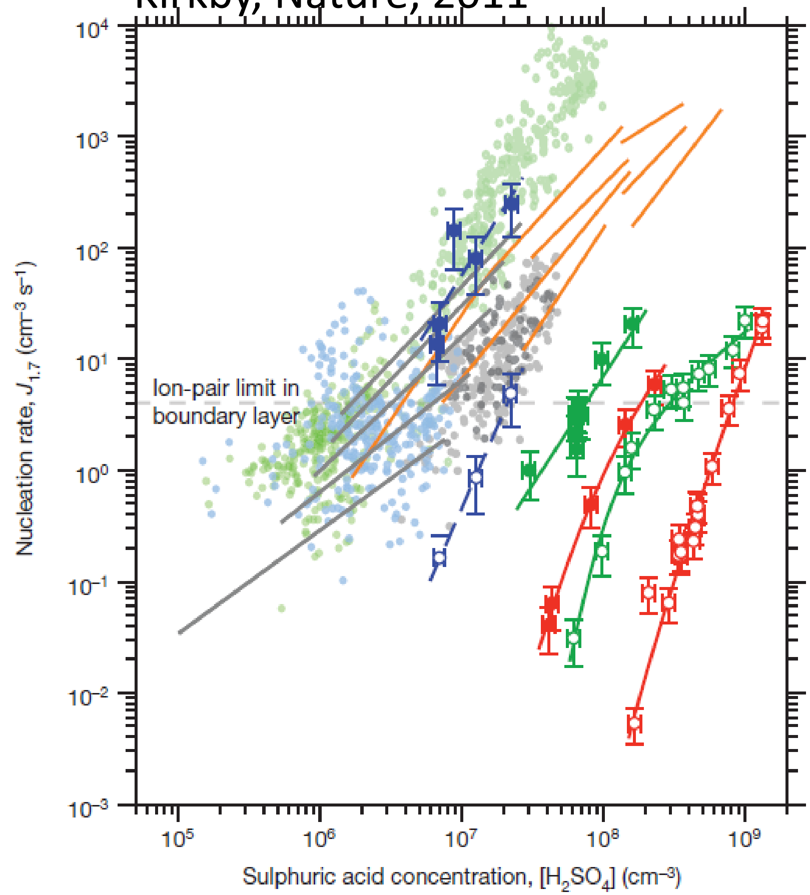
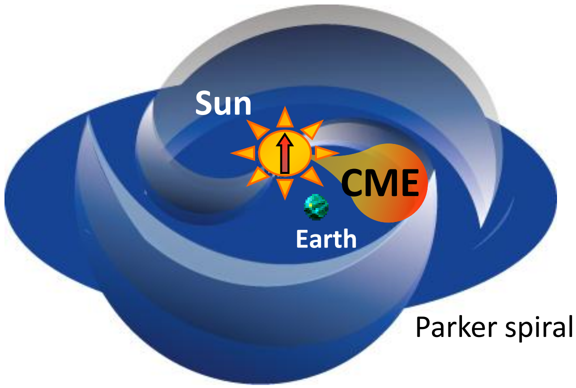


Figure 5 | Nucleation rate comparison. Comparison of CLOUD data with measurements of the nucleation rate of new particles as a function of [H_2SO_4] in the atmospheric boundary layer (pale filled circles[8,33] and pale open circles[32]) and with recent laboratory experiments at room temperature (grey[19] and orange[29] lines). The CLOUD data (large, darker symbols and lines) show the galactic cosmic ray nucleation rates, J_{gcr}, measured at 248 K (blue), 278 K (green) and 292 K (red) and at NH_3 mixing ratios of <35 p.p.t.v. (open green and red circles), <50 p.p.t.v. (open blue circles), 150 p.p.t.v. (filled blue and green circles) and 190 p.p.t.v. (filled red circles). The bars indicate 1σ total errors, although the overall factor 2 scale uncertainty on [H_2SO_4] is not shown. The measurements at 278 and 292 K bracket the typical range of boundary-layer temperatures, whereas those at 248 K reflect exceptionally cold conditions. Ion-induced nucleation in the boundary layer is limited by the ion-pair production rate to a maximum of about 4 cm^{-3} s^{-1}.

まとめ

・太陽圏システムとして地球気候、気象を捉えなおす必要がある



（※　未発表分は削除いたしました）