

気候変動と太陽活動

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3. 気候変動と太陽活動のリンケージ

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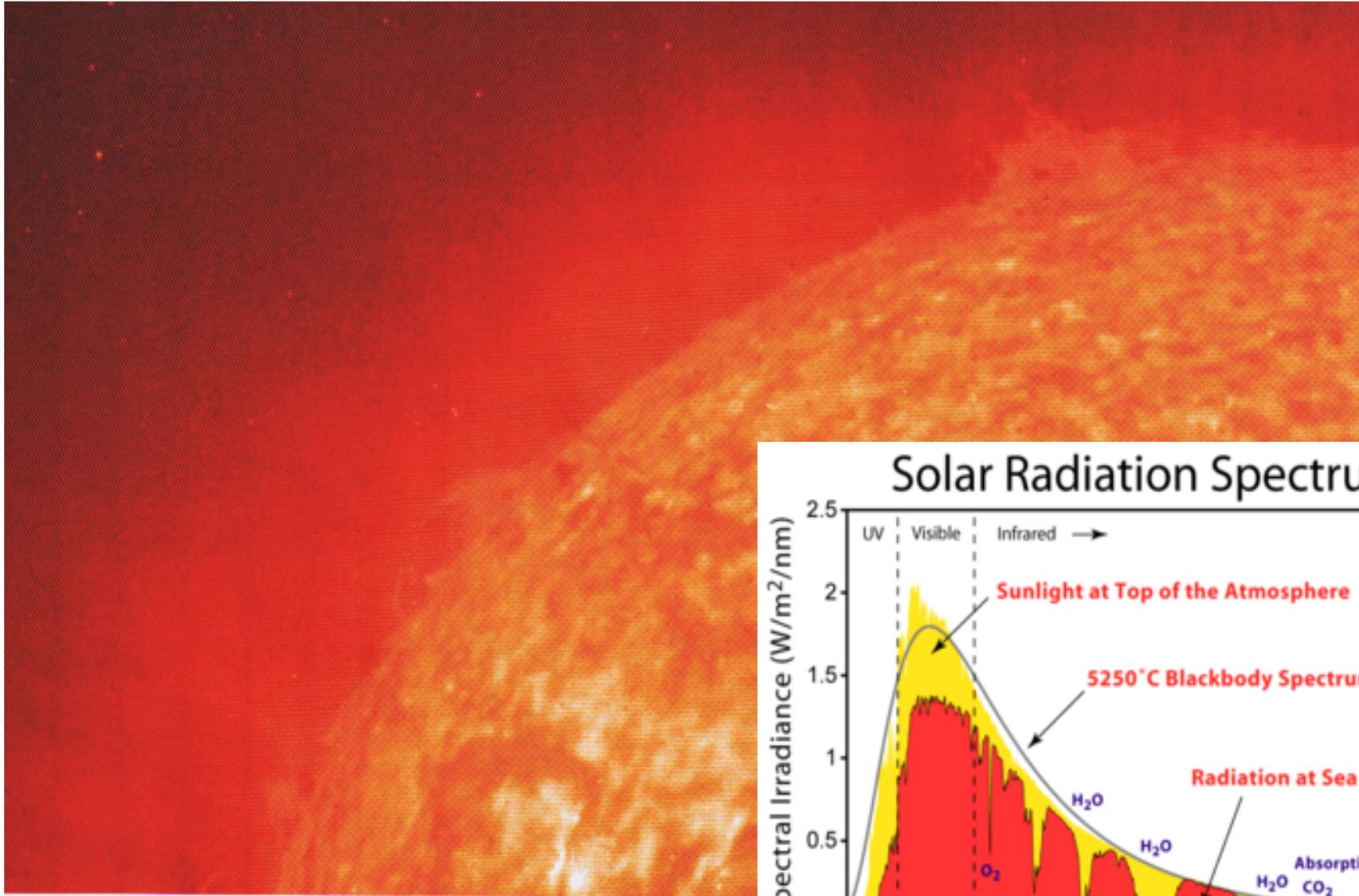
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1.2.3 太陽活動と ^{14}C 濃度変動

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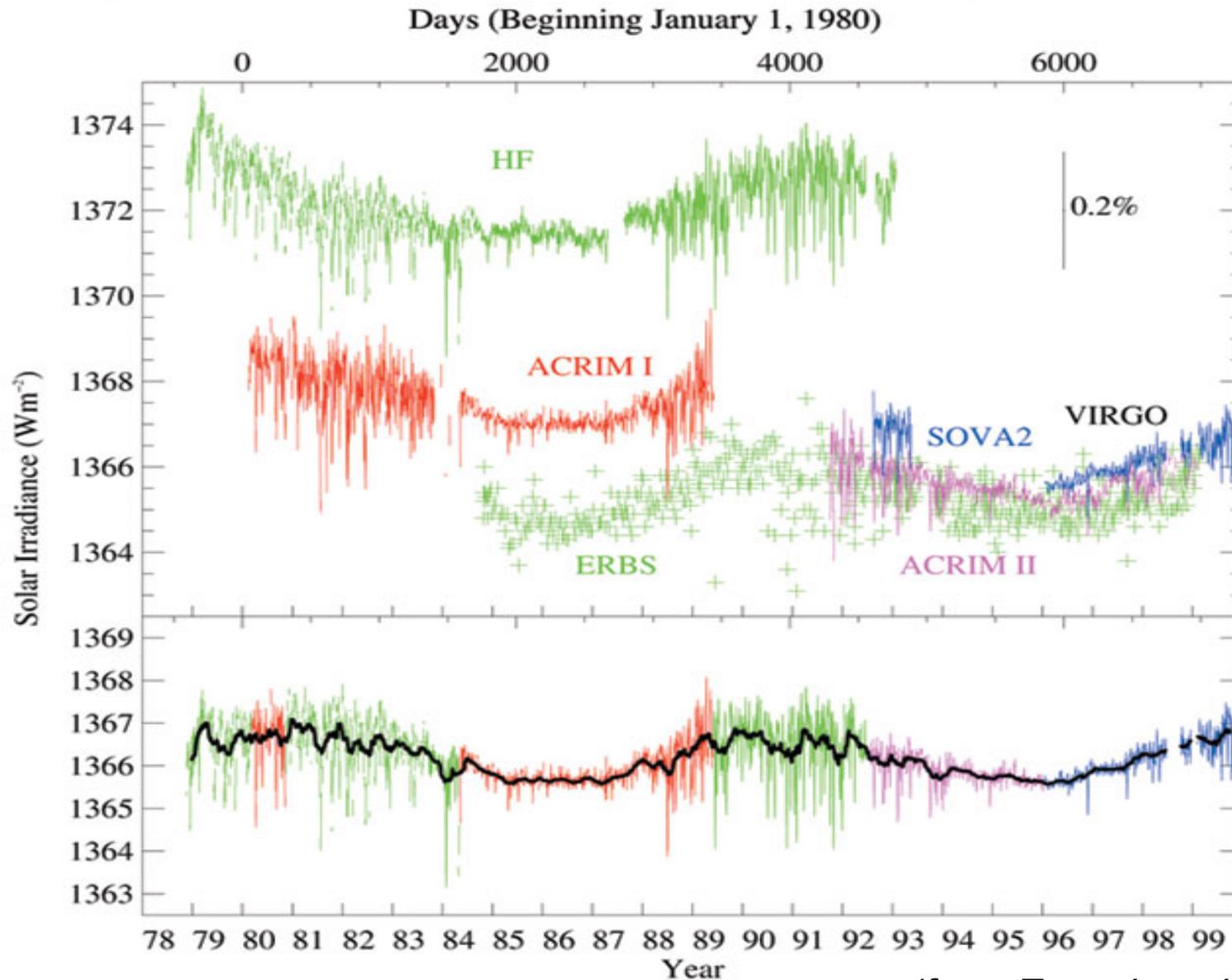
1.2.5 ^{14}C 濃度変動と ^{10}Be 濃度変動の比較

1.1 太陽放射とその変動



1.1.1 太陽放射變動

Total Solar Irradiance: Original Data (top) and Composite (bottom)



(from Encyclopedia of Earth)

可視～紫外線領域の太陽スペクトルとoptical depth

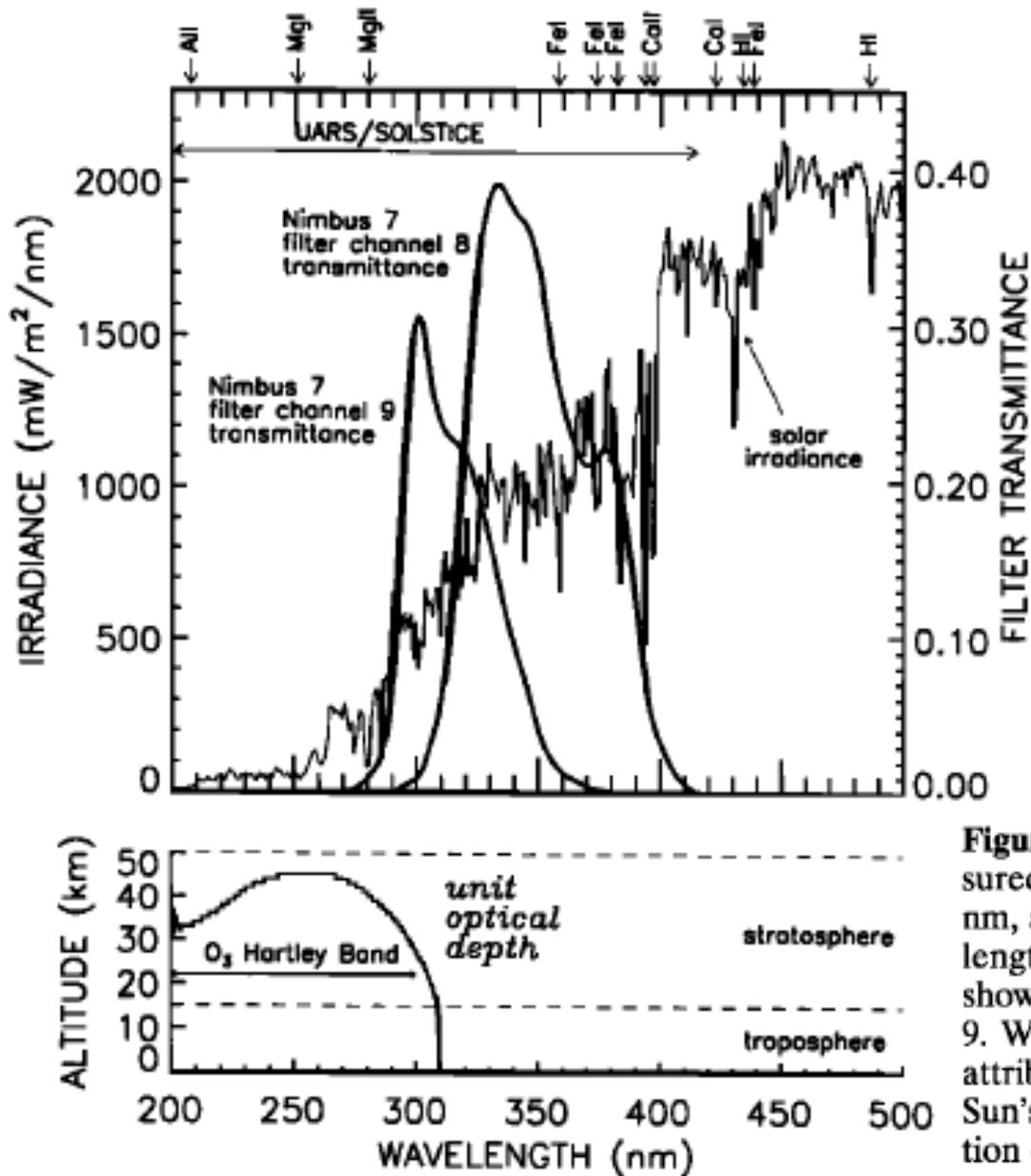


Figure 1. (top) Solar spectrum from 200 to 500 nm, measured by SOLSTICE on UARS at wavelengths less than 415 nm, and by the solar spectrometer on ATLAS at longer wavelengths (G. Thuillier, private communication, 1995). Also shown are the transmittances of Nimbus 7 filter channels 8 and 9. Wavelengths are identified for prominent spectral features attributable to various absorbing and ionizing species in the Sun's atmosphere. (bottom) Unit optical depth for the absorption of the solar spectrum in the Earth's atmosphere.

太陽UV放射変動 振幅の波長による 違い

200-300 nmで 1.1%
300-400 nmで 0.25%

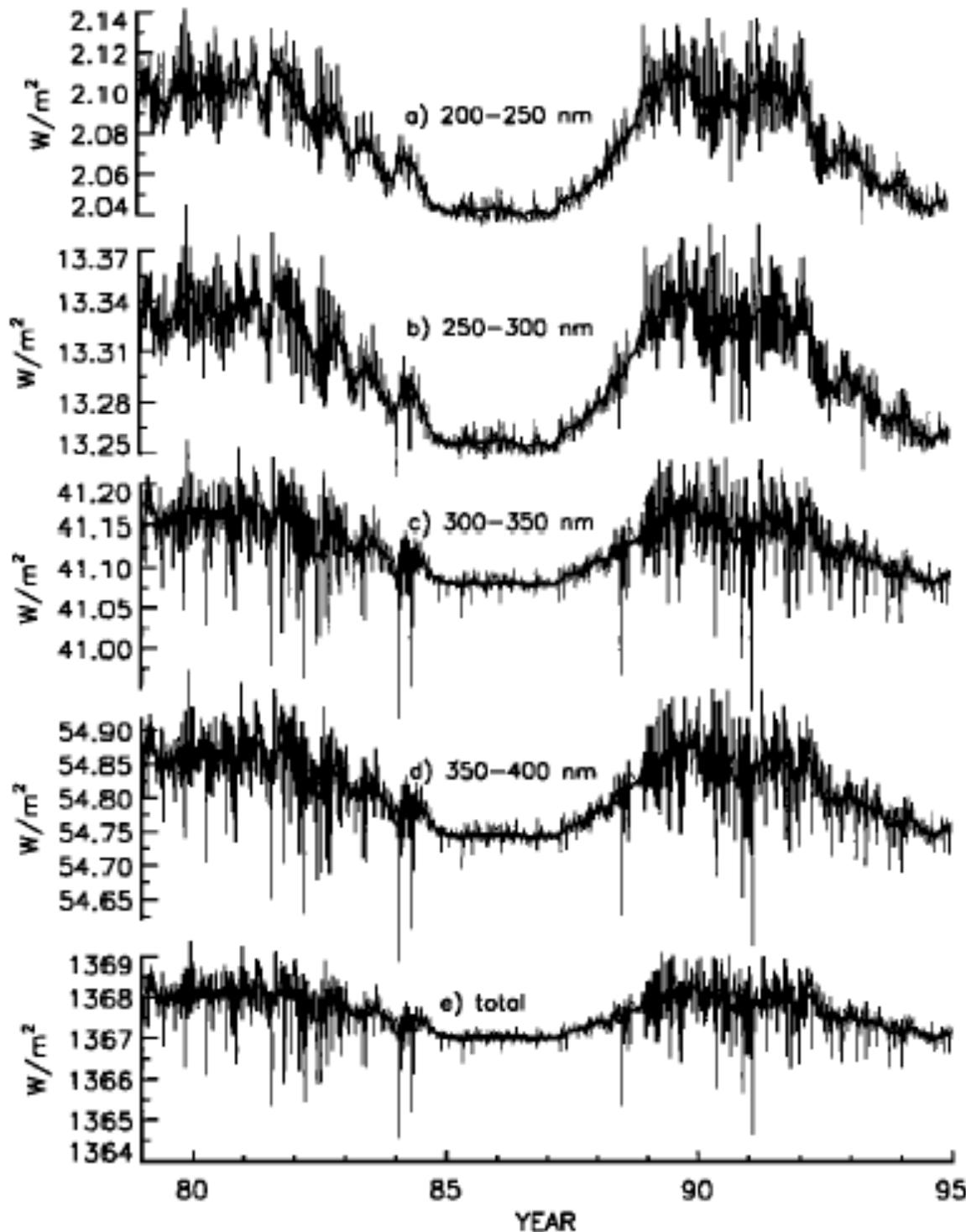
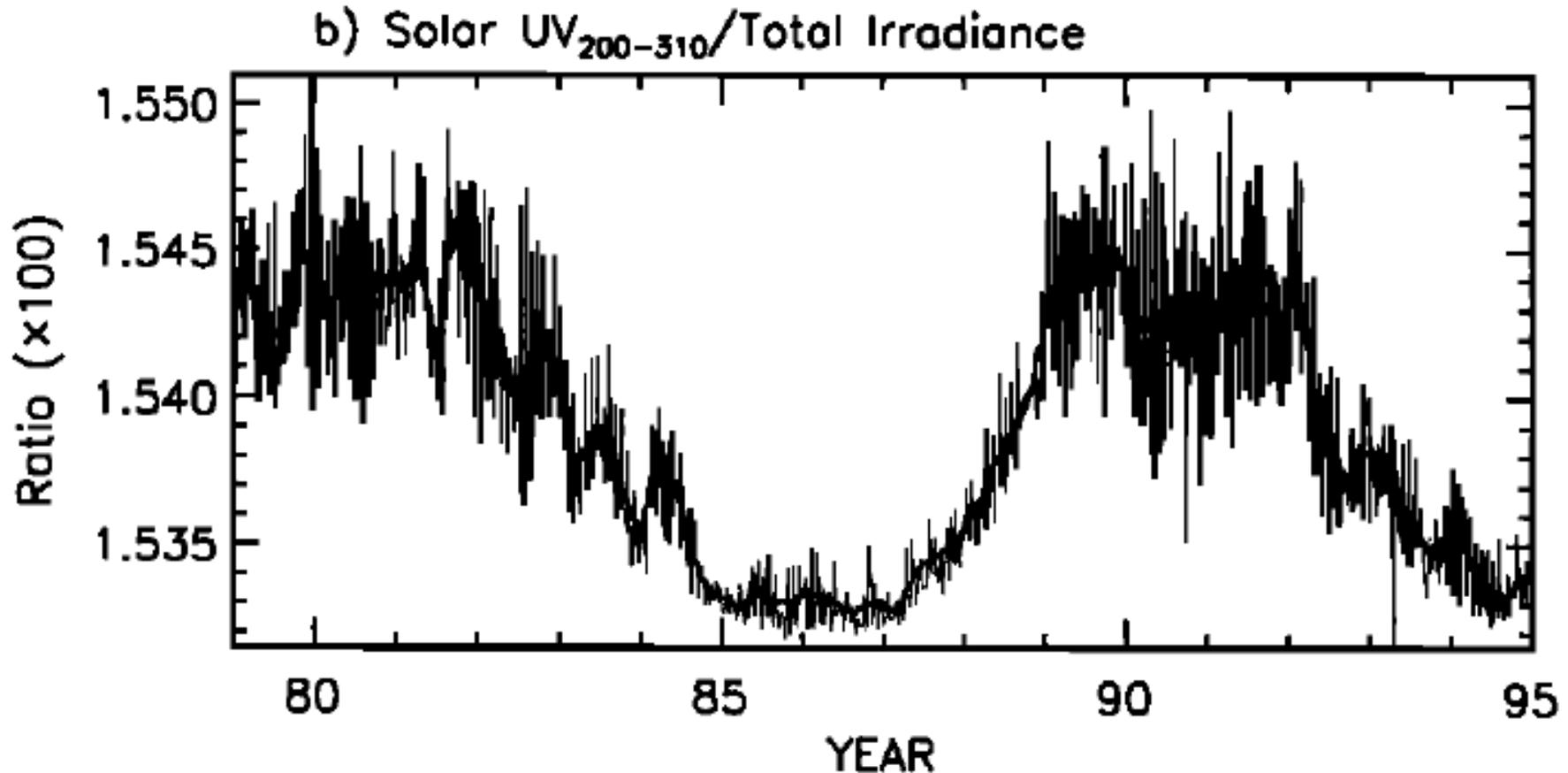


Figure 16. Solar mid- and near-UV irradiance variations reconstructed from 1979 to 1995 by using the sunspot darkening and facular brightening parameterizations deduced by multiple regression of the detrended SOLSTICE 1-nm spectra, summed into wavelength bands (a) 200–250 nm, (b) 250–300 nm, (c) 300–350 nm and (d) 350–400 nm, with (e) variations in total radiative output, estimated from a proxy model of the SMM/ACRIM I measurements from 1980 to 1989 [Lean et al., 1995a], shown for comparison. According to the solar activity proxies, minimum solar activity between solar cycles 21 and 22 occurred in September 1986, while November 1989 was the month of maximum activity in solar cycle 22.

(Lean et al., 1997JGR)

太陽総放射照度に対するUV放射の割合も、太陽活動変動と共に変化する



1.1.2 太陽活動と太陽黒点

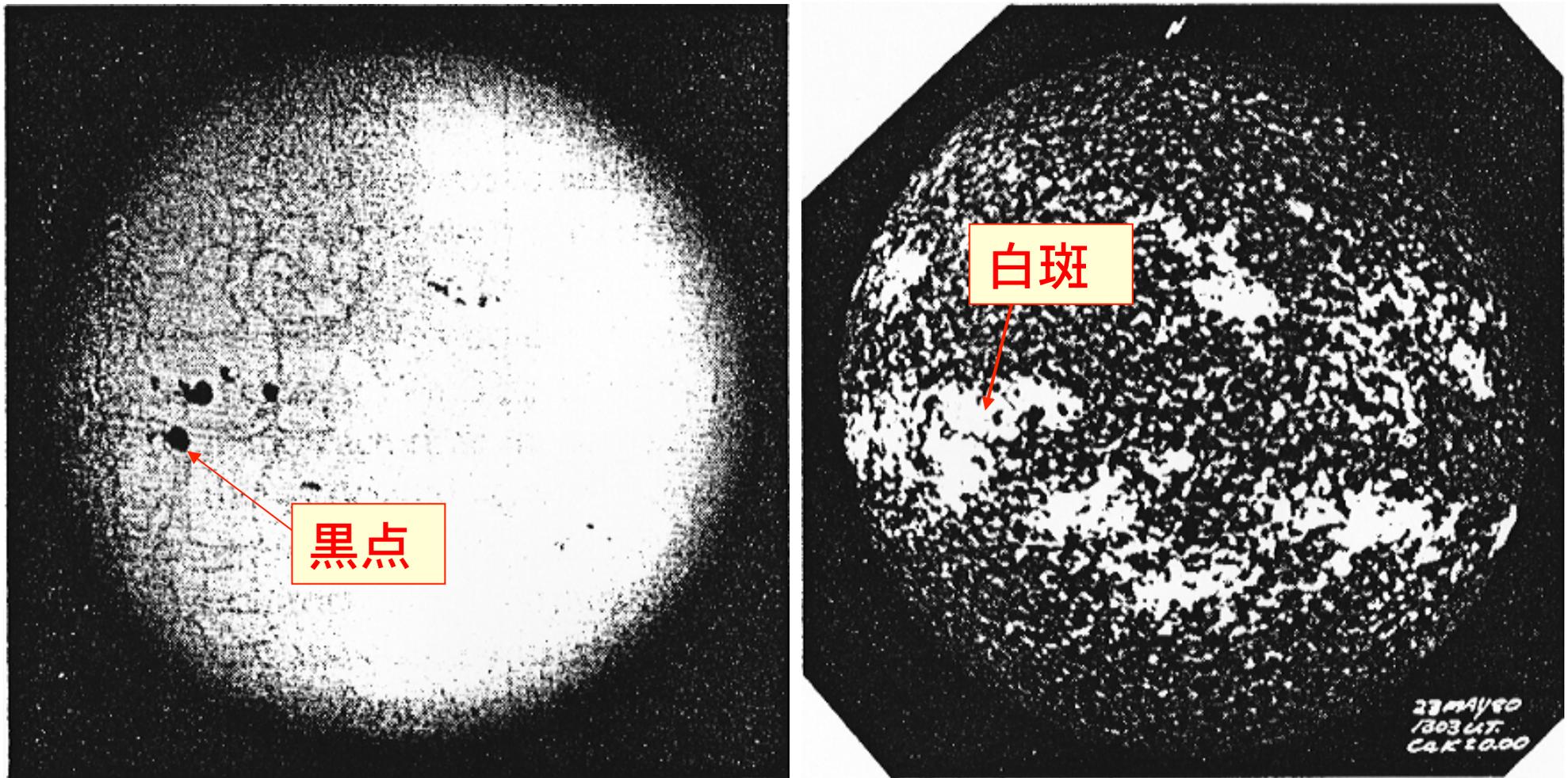


Fig. 1. Faculae and spots seen nearly simultaneously on 23 May 1980 (**top**) in integrated white light and (**bottom**) in the narrow band absorption of the CaII K resonance line. In white light the faculae are visible only near the limb,

where their photometric contrast increases to about 10%. In the CaII absorption line they are seen with good contrast across the whole disk. [Photograph courtesy of the National Solar Observatories, Association of Universities for Research in Astronomy, Inc.]

(Lean and Foukal, 1988)

黒点の総放射照
度に対する寄与

白斑の総放射照
度に対する寄与

両者の合計

太陽活動と黒点

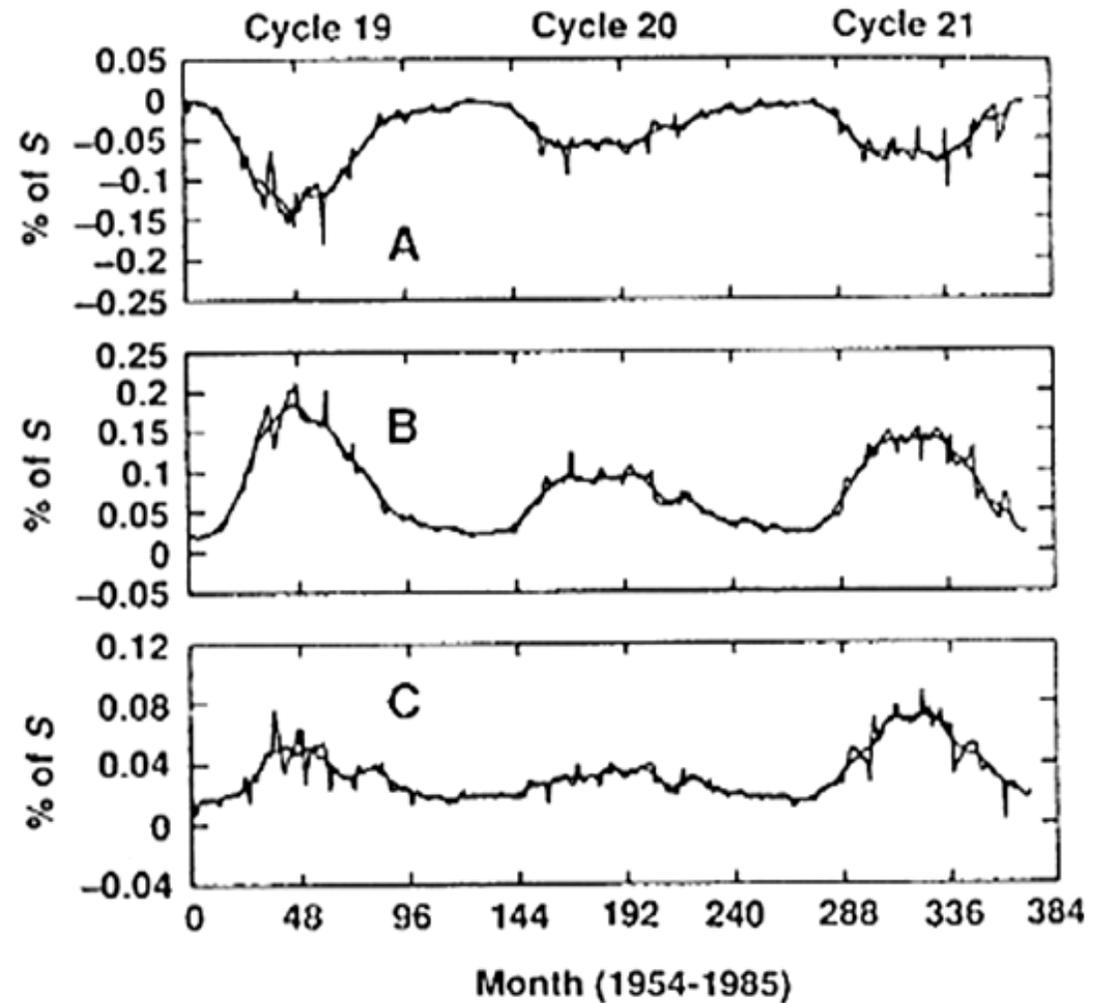


Fig. 4. Plots of (A) the sunspot contribution to total irradiance, (B) the facular contribution obtained from the $F_{10.7}$ regression against the ACRIM data, and (C) their cumulative effect, all shown as a percentage of the total irradiance for the period of 1954–1984.

(Lean and Foukal, 1988)

Wolfの黒点相対数の定義

$$R = k(10g + s)$$

R: 黒点相対数

g: 黒点群の数

s: 個々の黒点数

k: 観測地点や方法に依存する定数

太陽総放射照度と年間平均黒点相対数

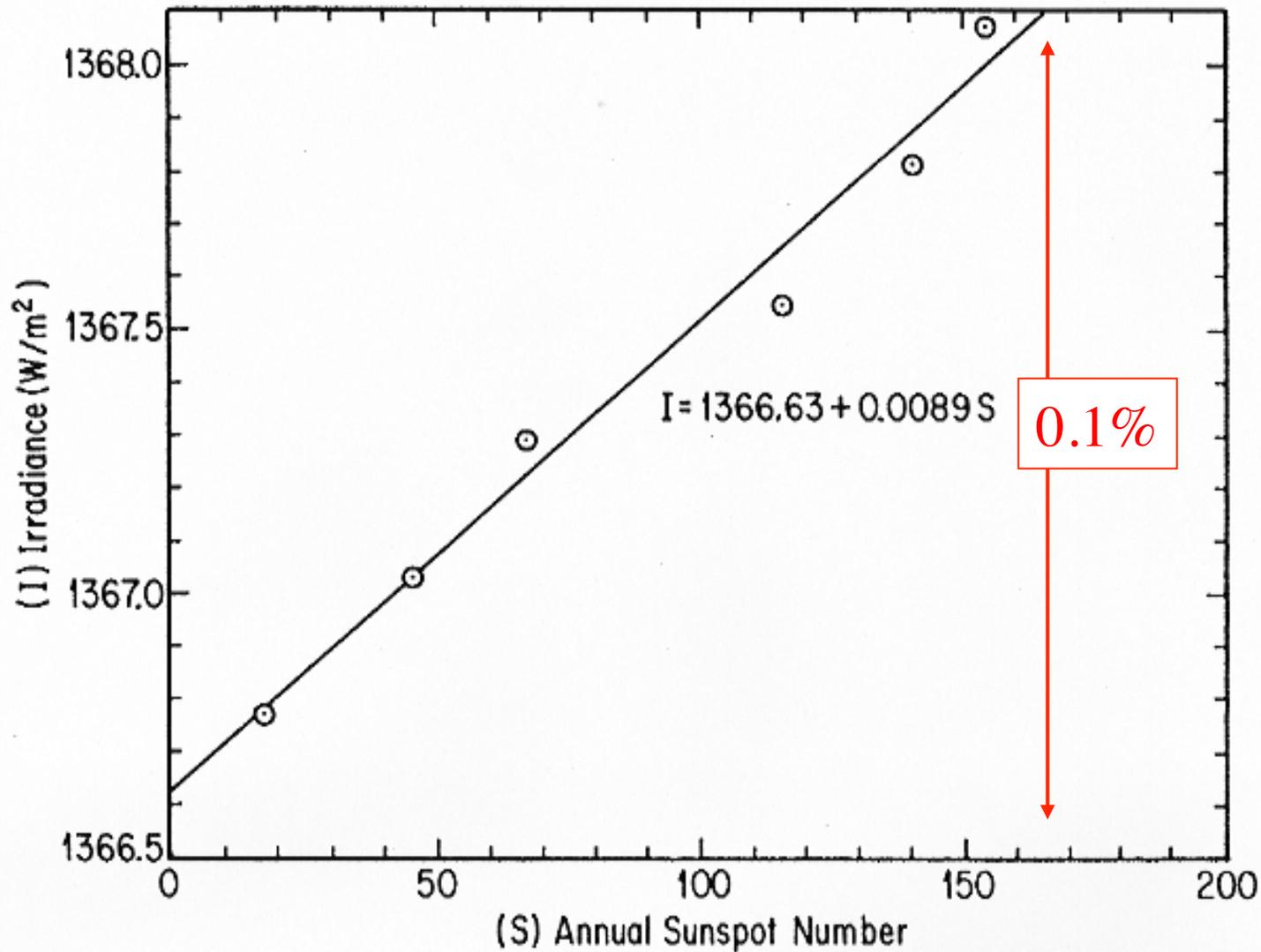
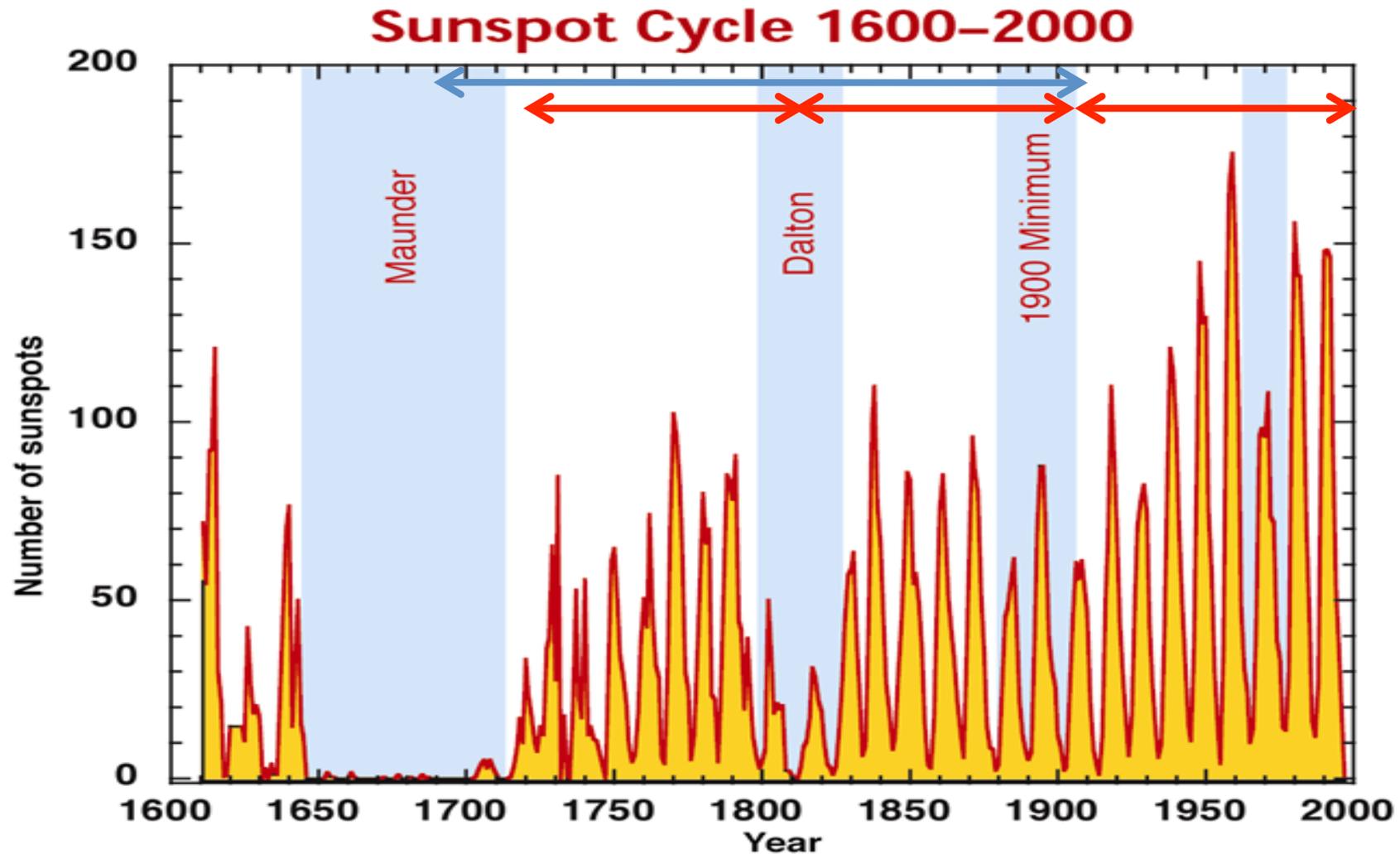


Fig. 11. Total solar irradiance S from the NASA Solar Maximum Mission (Willson et al. 1986) vs annual sunspot number R_x (figure after Damon 1988).

(Damon and Sonett, 1991)

太陽黒点の時代変動と太陽黒点周期

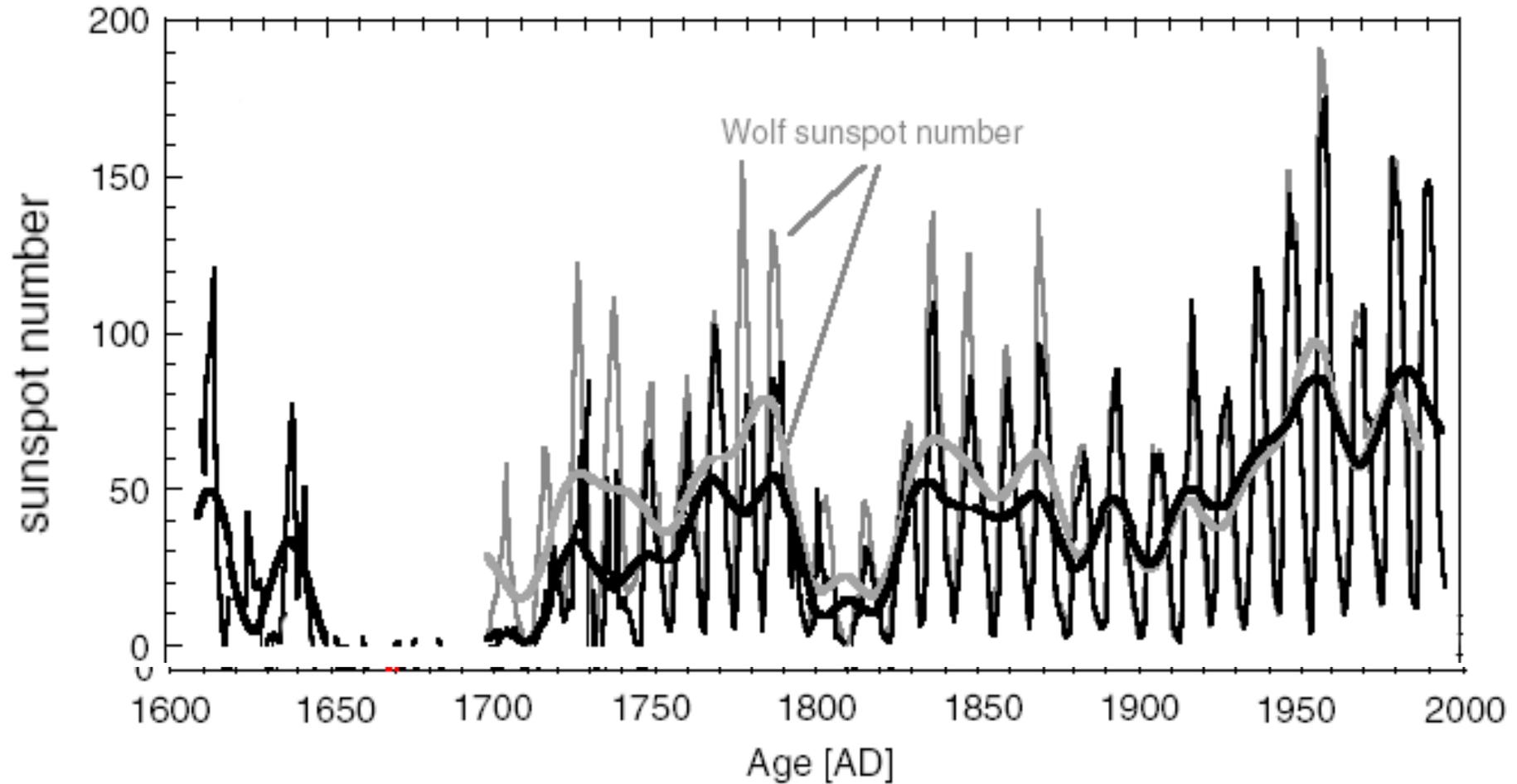


Past Global Changes and Their Significance for the Future
Alverson, Oldfield and Bradley eds.

Beer *et al.* (2000) QSR, 19 403–15.

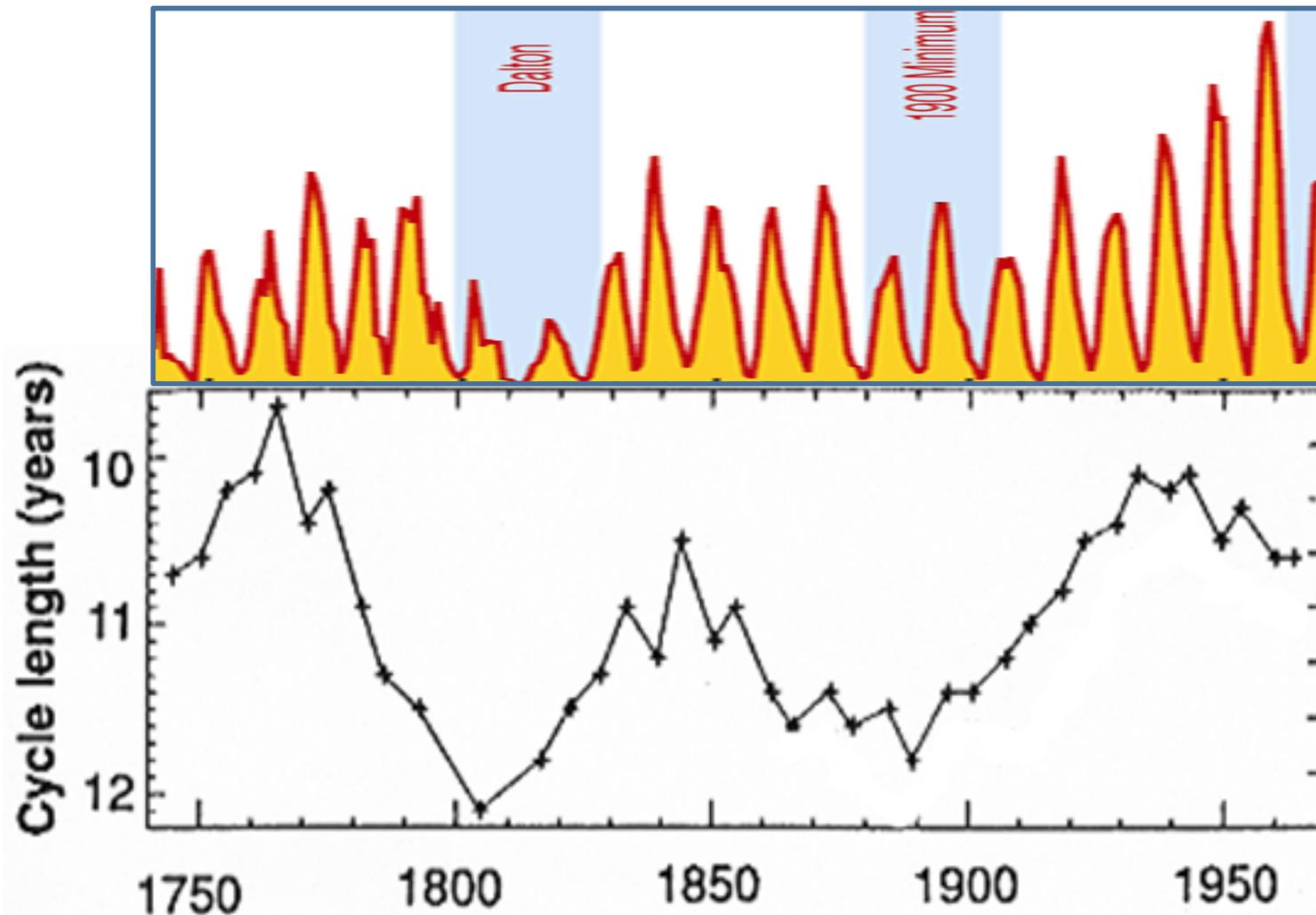
After Hoyt and Schatten (1998) Solar Physics, 179, 189–219.

Wolf sunspot numberとGroup sunspot number



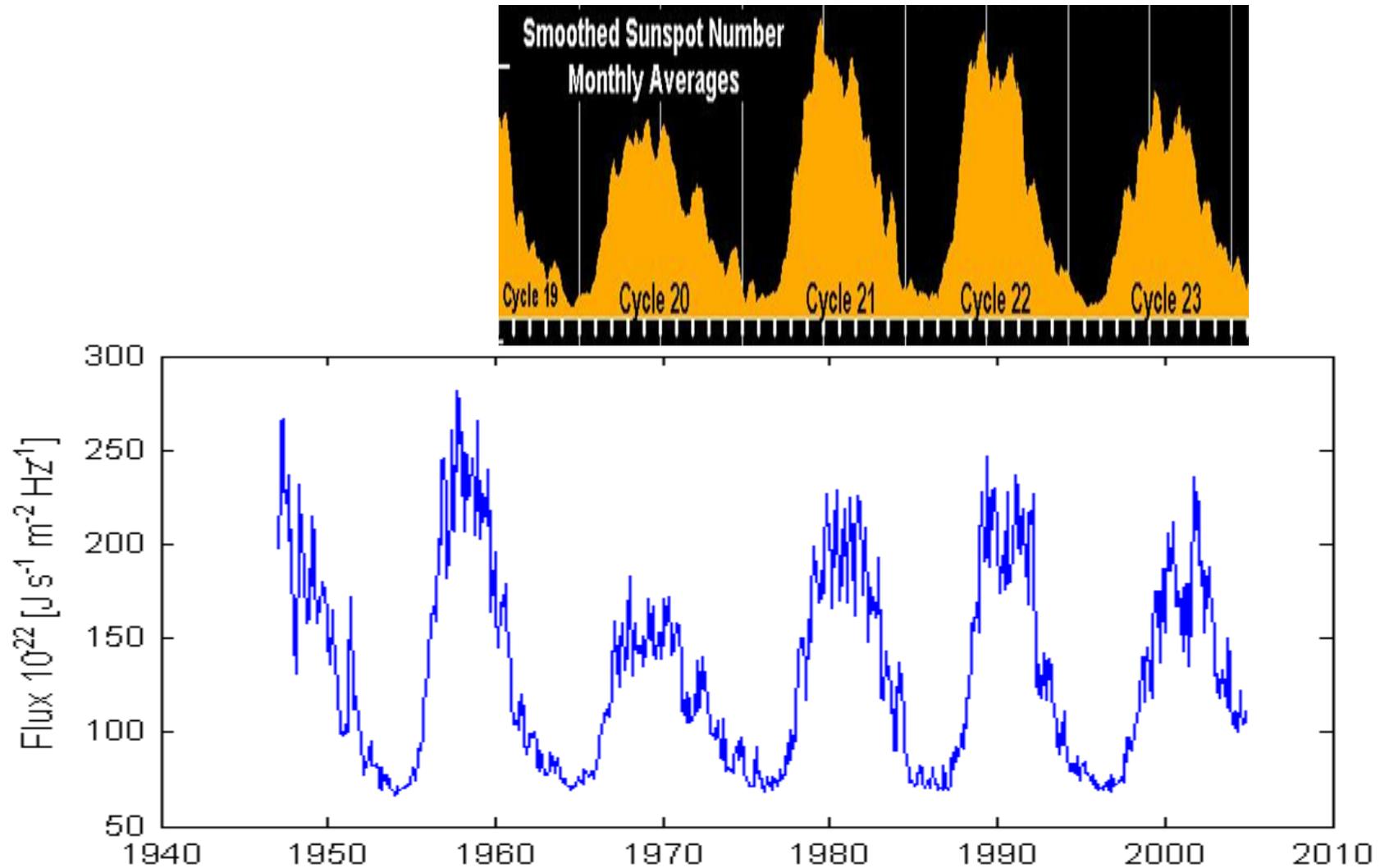
太陽黒点数変動と、太陽黒点周期変動

太陽活動が活発な時期にSchwab cycleの周期が短くなる



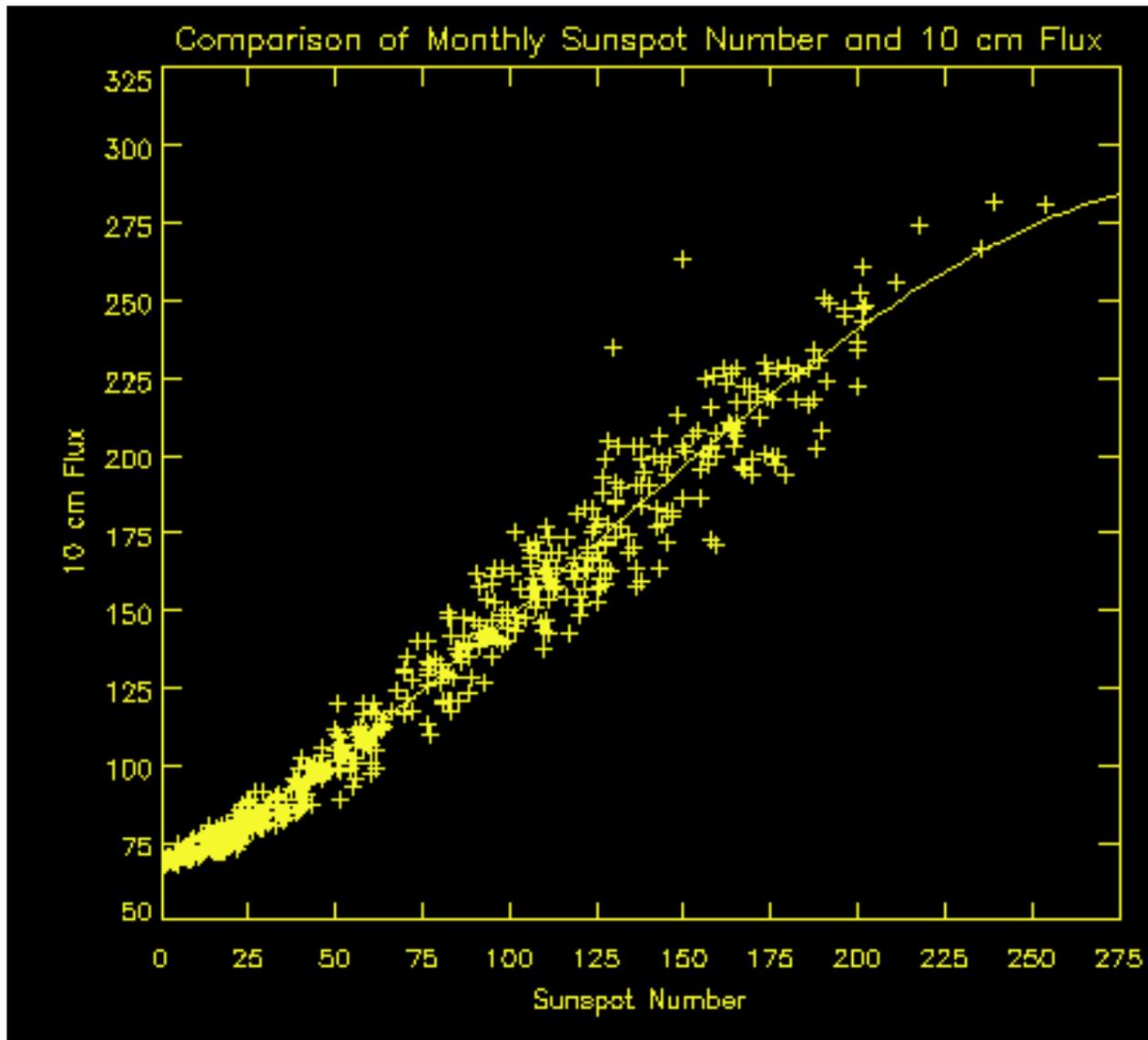
(Friss-Christensen and Lassen, 1991)

1.2.3 太陽電波フラックス (F10.7) とその変動



(www oulu.fi/~spaceweb/textbook/f107.html)

F10.7cm fluxと黒点数の相関



F10.7 index とは、波長 10.7 cm (2.8GHz) の太陽電波強度を太陽フラックス ユニットで表したもの (1太陽フラックス ユニット = $10^{-22} \text{ W m}^{-2} \text{ Hz}^{-1}$)。

UVと 10.7 cm 太陽電波は、ともに太陽コロナから放射されていると言われ、その強度の代替指標として使われる。

1.2 銀河宇宙線フラックスとその変動

1.2.1 太陽活動、太陽磁場変動と銀河宇宙線フラックス

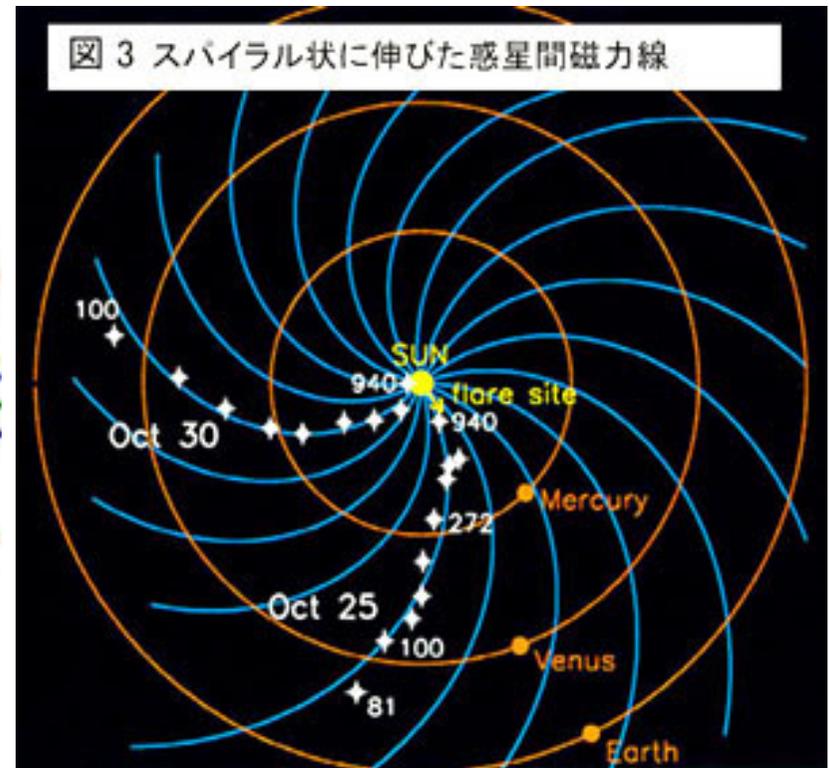
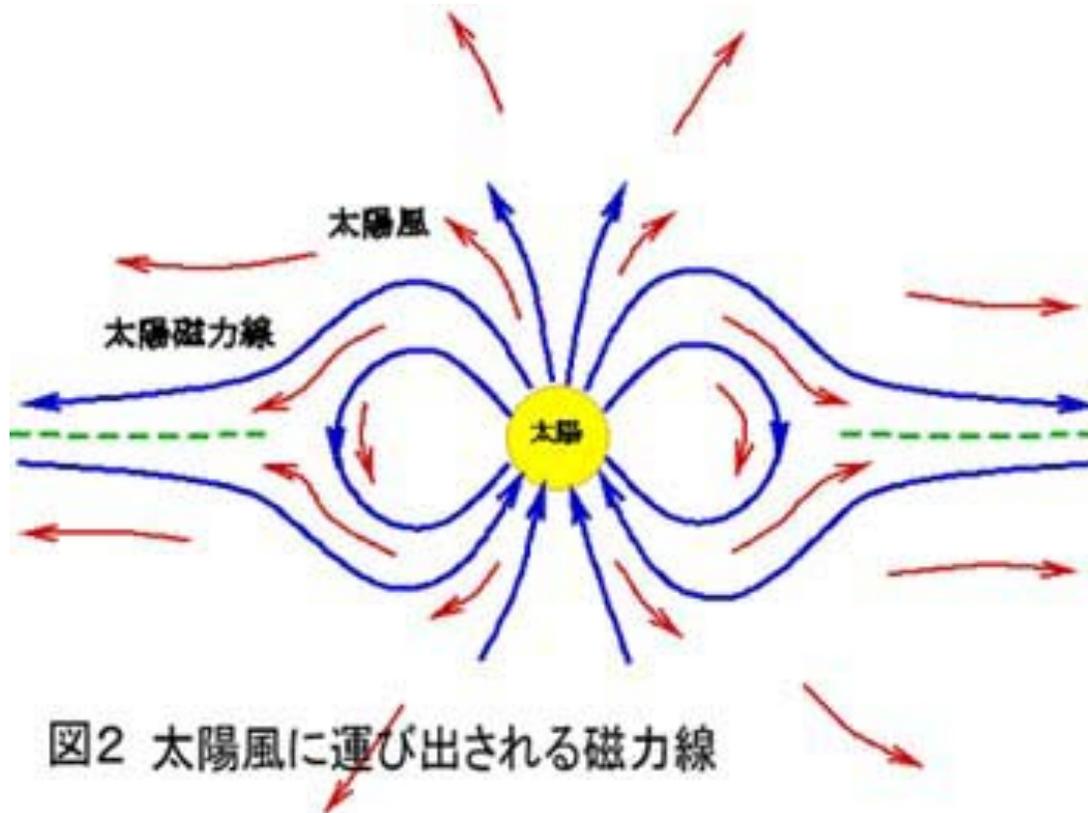
1.2.2 銀河宇宙線フラックスと放射性元素

1.2.3 太陽活動と ^{14}C 濃度変動

1.2.4 太陽活動と ^{10}Be 濃度変動

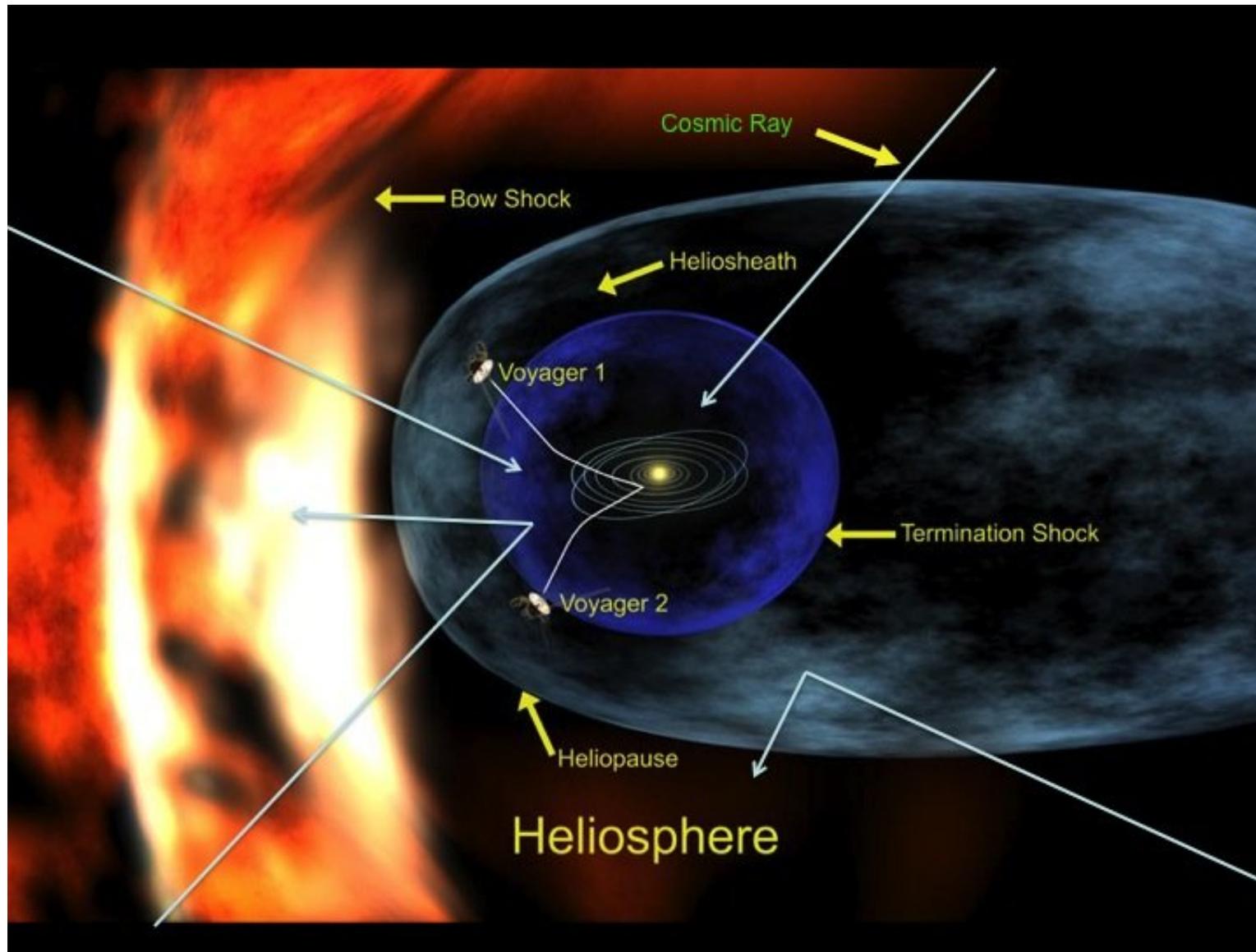
1.2.5 ^{14}C 濃度変動と ^{10}Be 濃度変動の比較

1.2.1 太陽活動、太陽磁場変動 と銀河宇宙線フラックス



www8.ocn.ne.jp/~yohsuke/mag_storm_0.htm

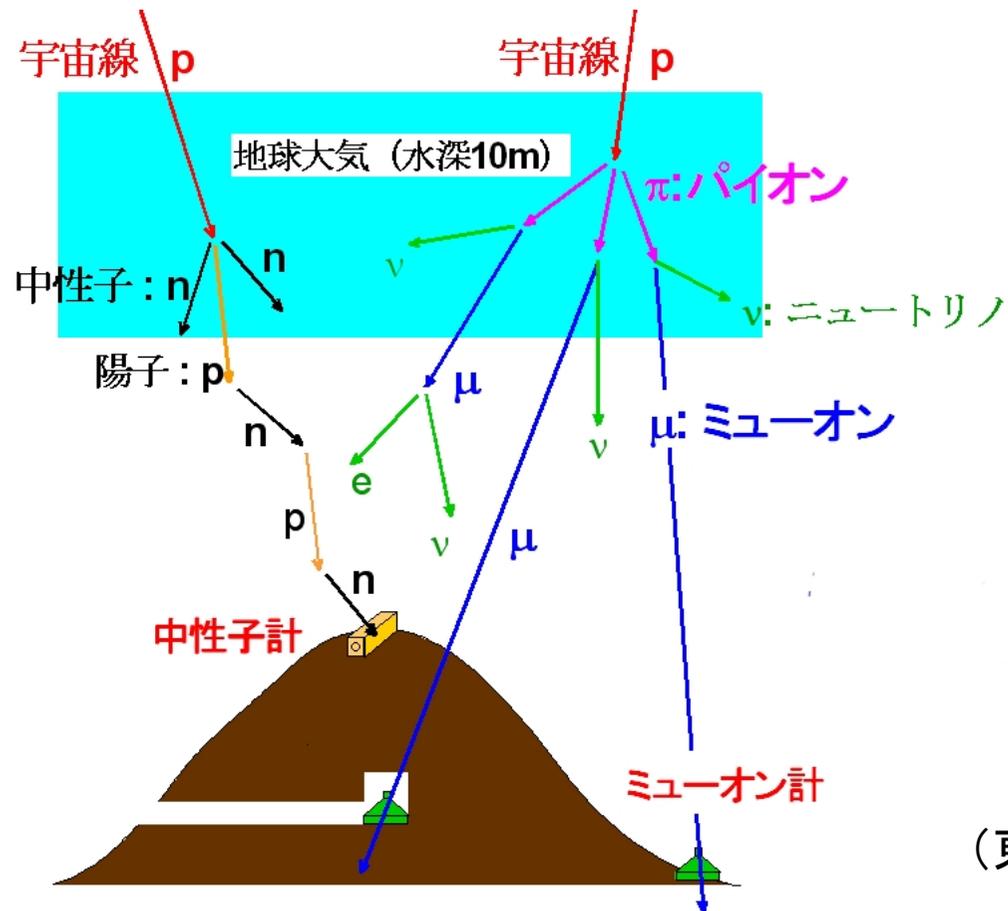
太陽磁場が太陽系への銀河宇宙線の侵入を抑制している



(heliophysics.org/headlines/y2009/29sep_cosmicrays.htm NASA HPより)

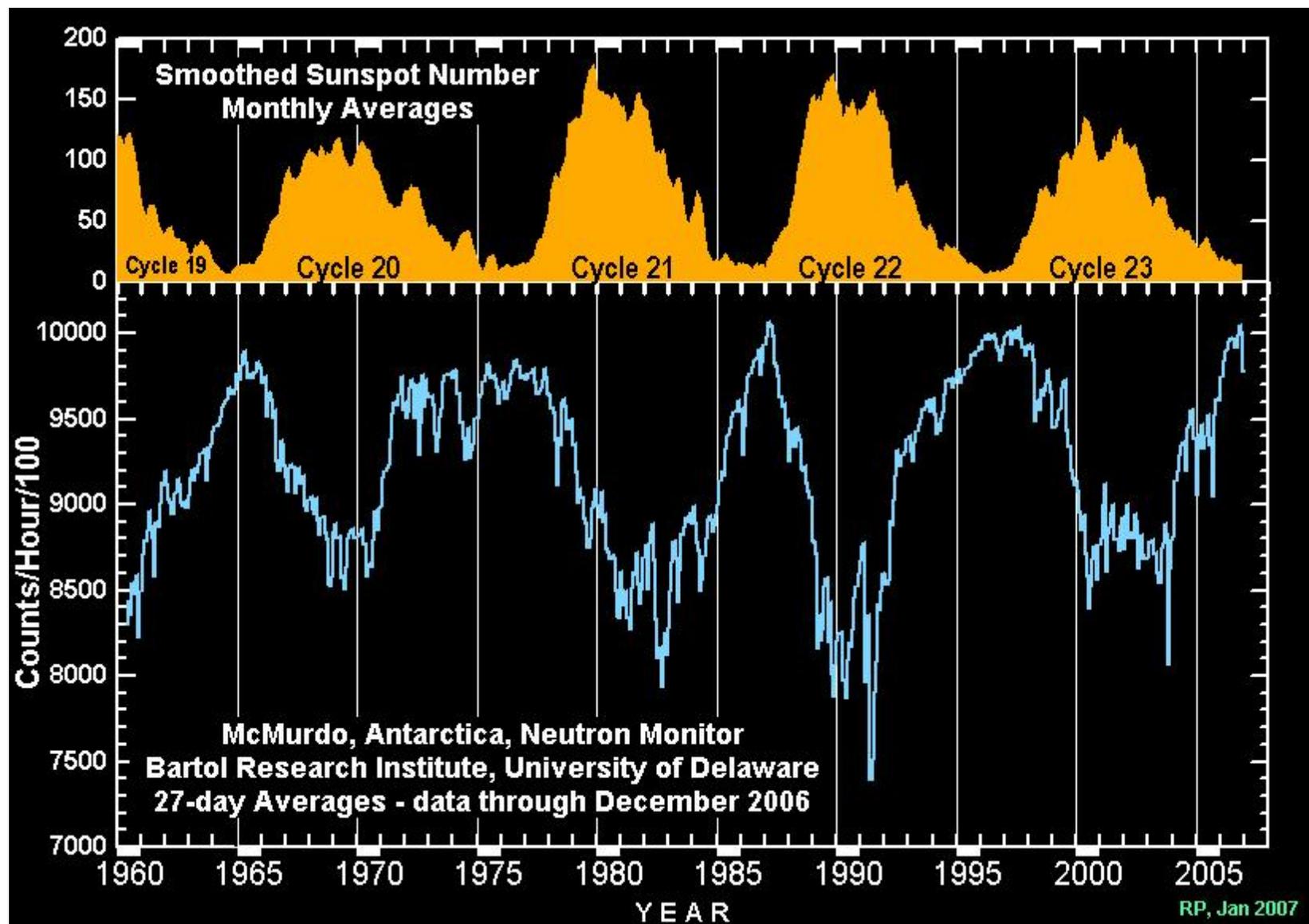
宇宙線

- 90%は陽子(proton)
- 10%弱が α 線(ヘリウム核)
- 1%弱が β 線(高エネルギー電子)や γ 線(波長が10pm以下の電磁波:原子核内のエネルギー準位の遷移による)



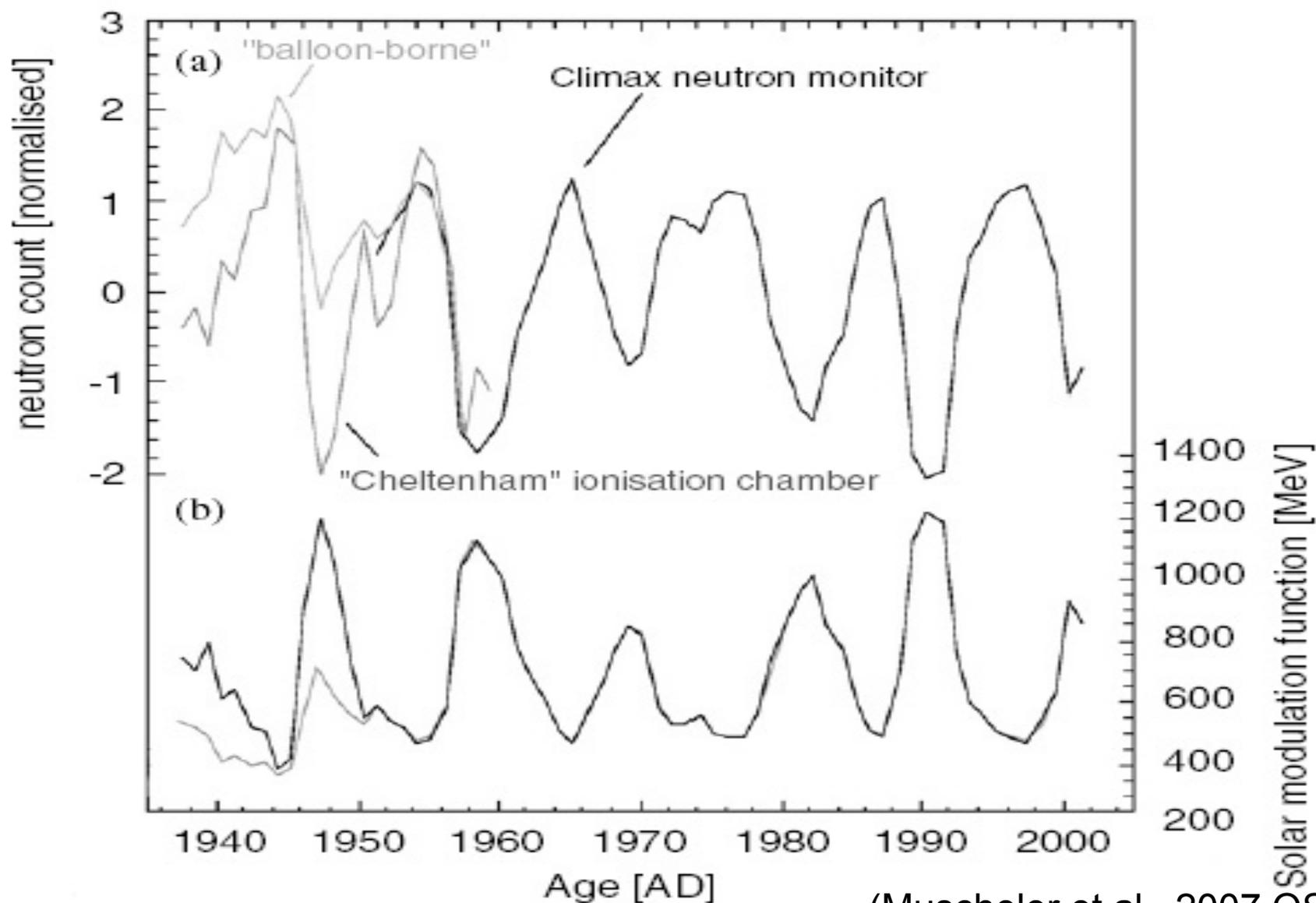
(東大宇宙線研究所HPより)

月平均黒点数変動と南極での中性子計による 宇宙線強度変動の関係



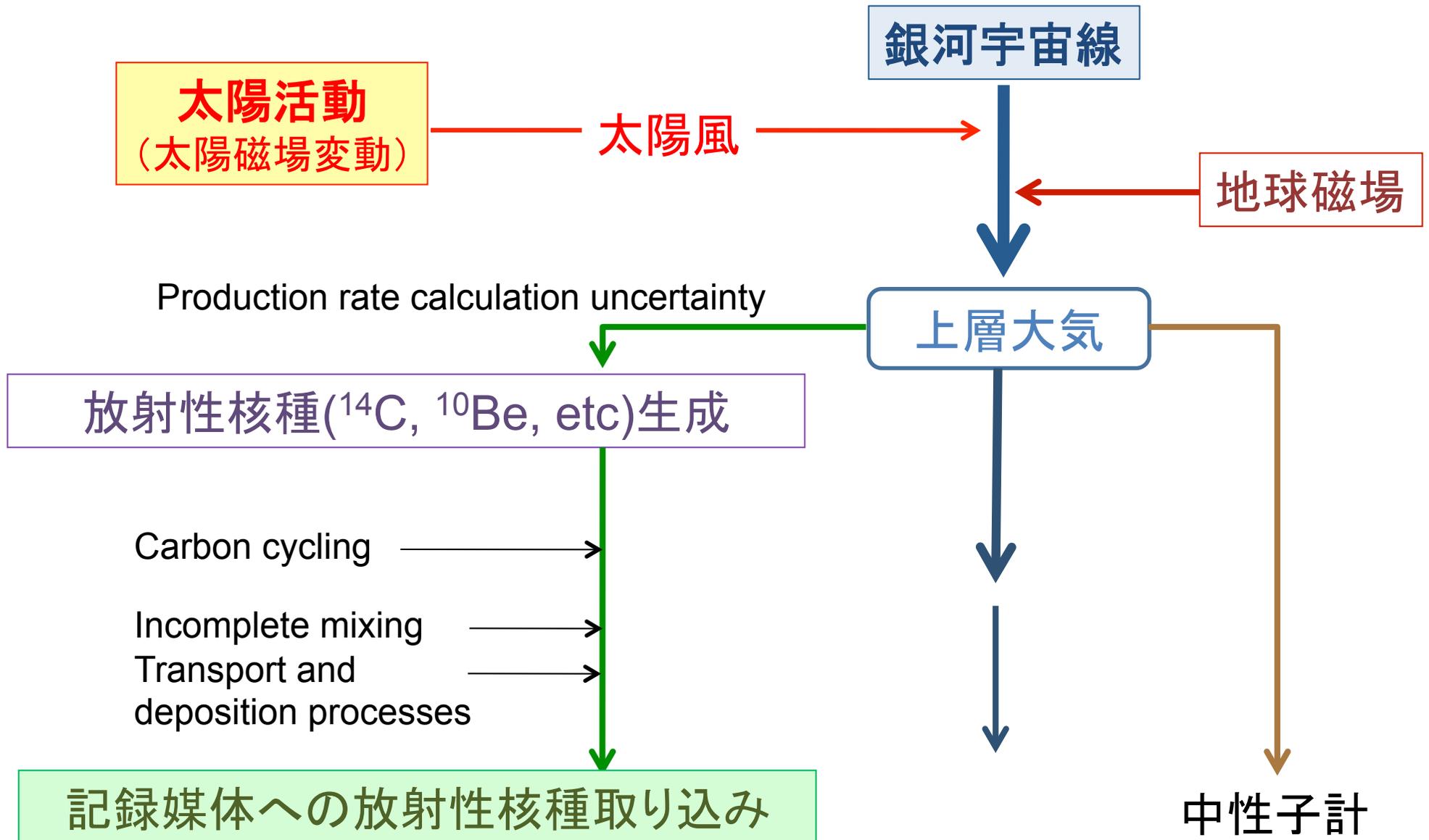
Bartol Res., Uni. of Delawareのページから

中性子計のデータは1950年以降、balloonやionization chamberによる測定で1937年までたどれる



(Muscheler et al., 2007 QSR)

1.1.2 銀河宇宙線フラックスと宇宙線起源放射性元素



宇宙線による ^{14}C の生成

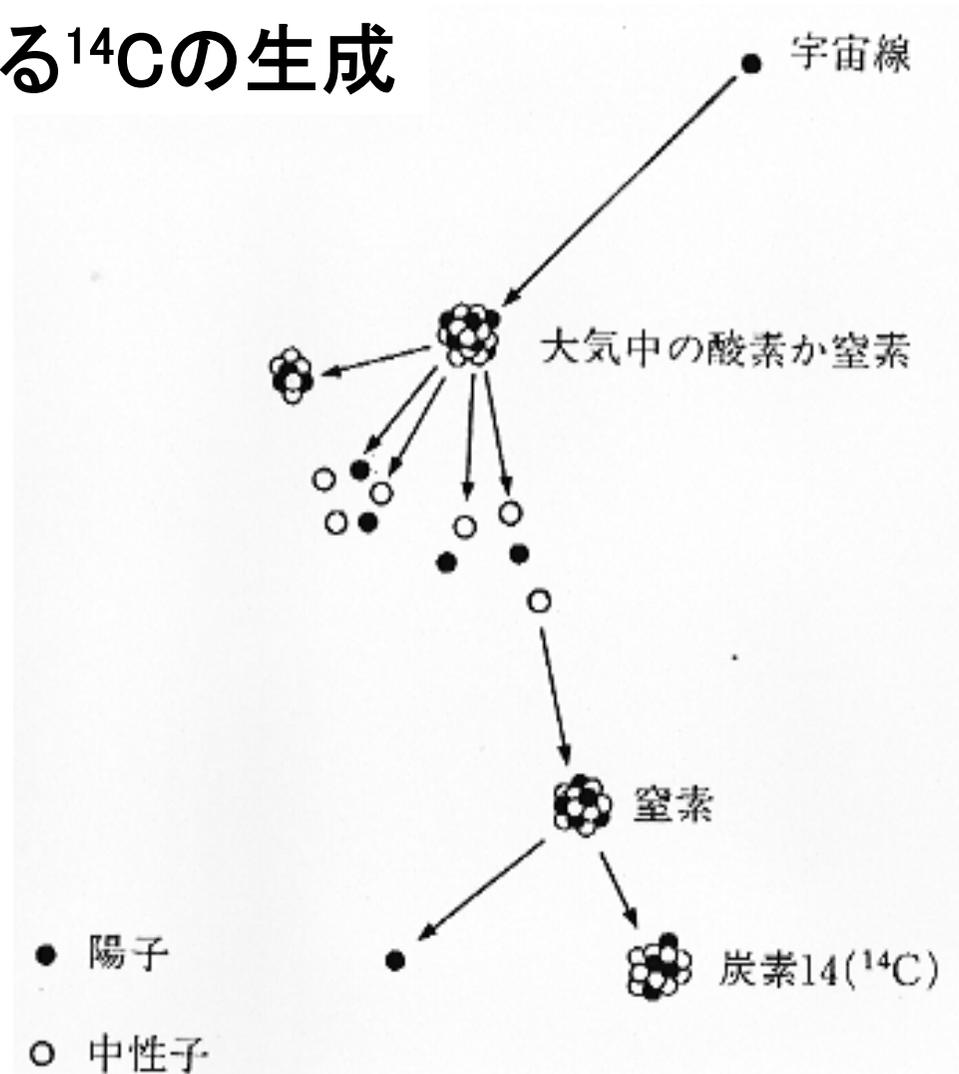
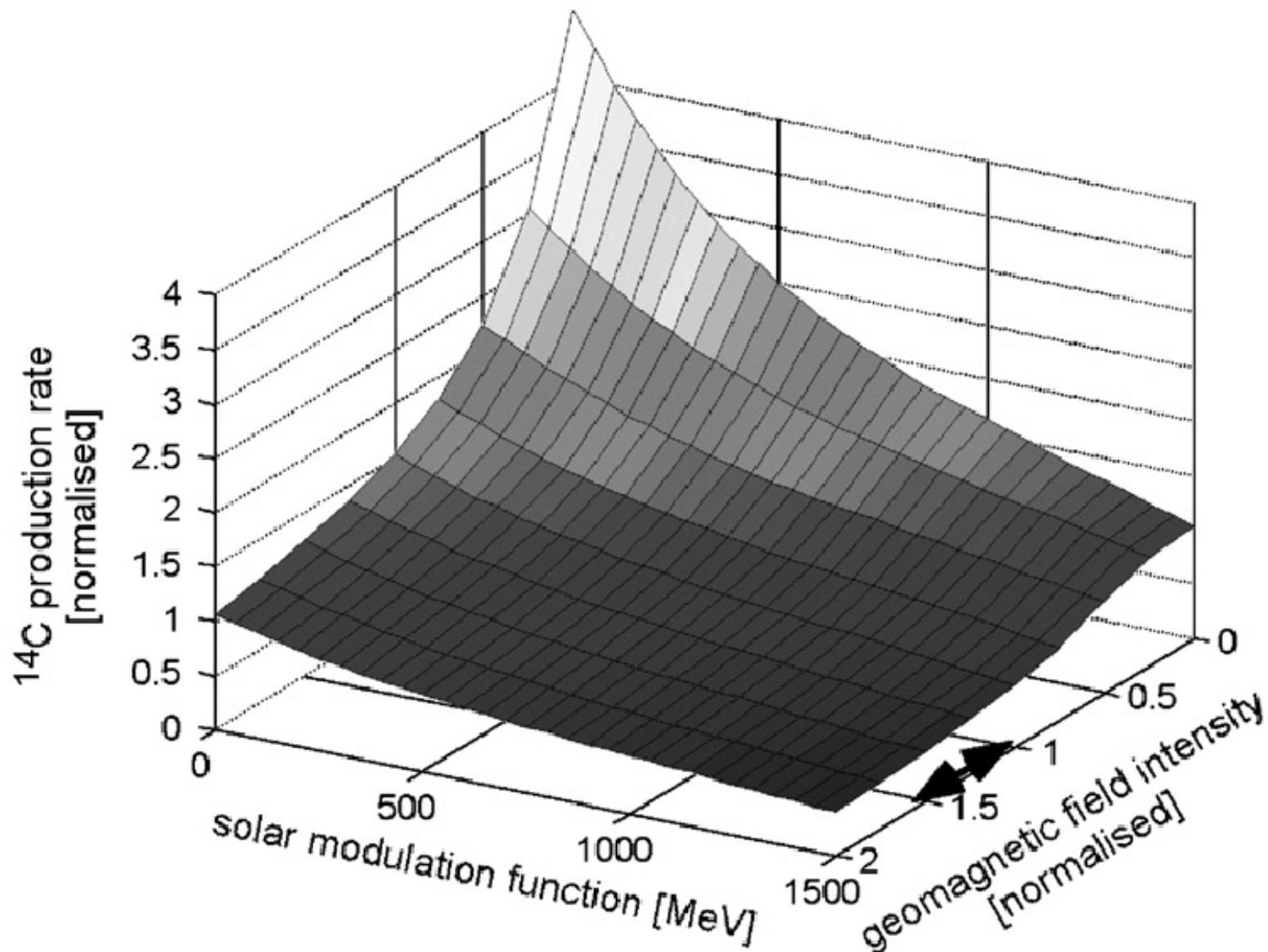


図 4.9 大気中に侵入した宇宙線による炭素の放射性同位体 (^{14}C) の生成過程。

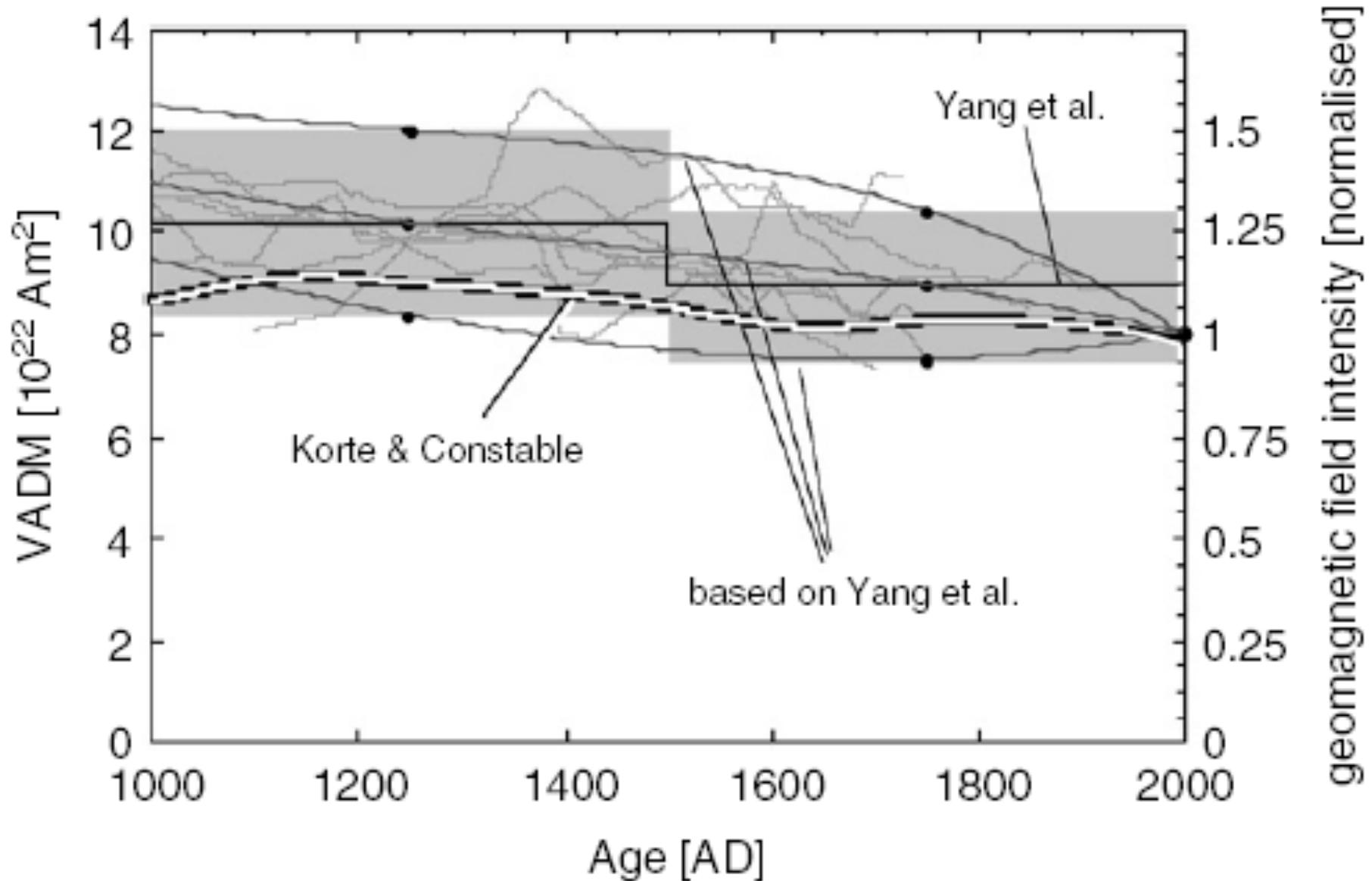
(桜井、1990)

宇宙放射線起源放射性核種生成 を制御する要因



(Muscheler et al., 2007 QSR)

過去1000年間の地球磁場強度変化



地球磁場変動と ^{14}C 初期濃度変動

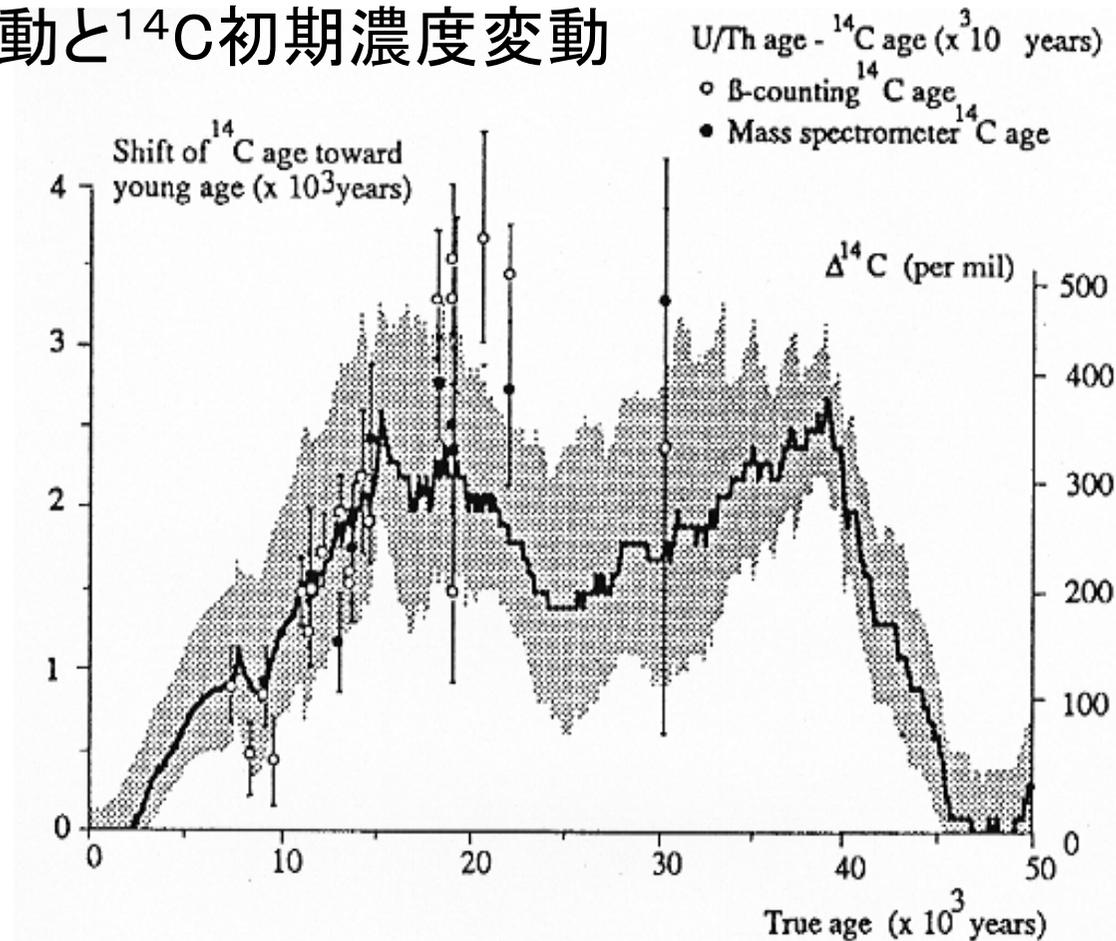


Fig. 4. Calibration of the radiocarbon time scale, together with spot calibrations of ^{14}C ages obtained from U-Th ages determinations. Open symbols show ^{14}C ages determined by β -counting ^{14}C disintegrations [Bard et al., 1990a]. Closed symbols show ^{14}C ages determined by accelerator mass spectrometry [Bard et al., 1990b]. The shaded area corresponds to the uncertainties of the magnetic intensities given by Tric et al (in press). Vertical axis on right gives atmospheric $\Delta^{14}\text{C}$.

(Mazaud et al., 1991)

大気中¹⁴C初期濃度の制御要因

TABLE I
Possible Causes of Radiocarbon Fluctuations^a

I. Variations in the global rate of radiocarbon production

1. Variations in the cosmic ray flux throughout the solar system
 - a. Cosmic ray bursts from supernovae and other stellar phenomena
 - b. Interstellar modulation of the cosmic ray flux
2. Modulation of the cosmic ray flux by solar activity
3. Modulation of the cosmic ray flux by changes in the geomagnetic field
4. Production by antimatter meteorite collisions with the Earth
5. Production by nuclear weapon testing and nuclear technology

II. Variations in the rate of exchange between geochemical reservoirs and CO₂ reservoir inventory

1. Control of CO₂ solubility and dissolution and residence time by temperature variations
2. Effect of sea-level variations on ocean circulation and capacity
3. Assimilation of CO₂ by the terrestrial biosphere
4. Dependence of CO₂ assimilation by marine biosphere

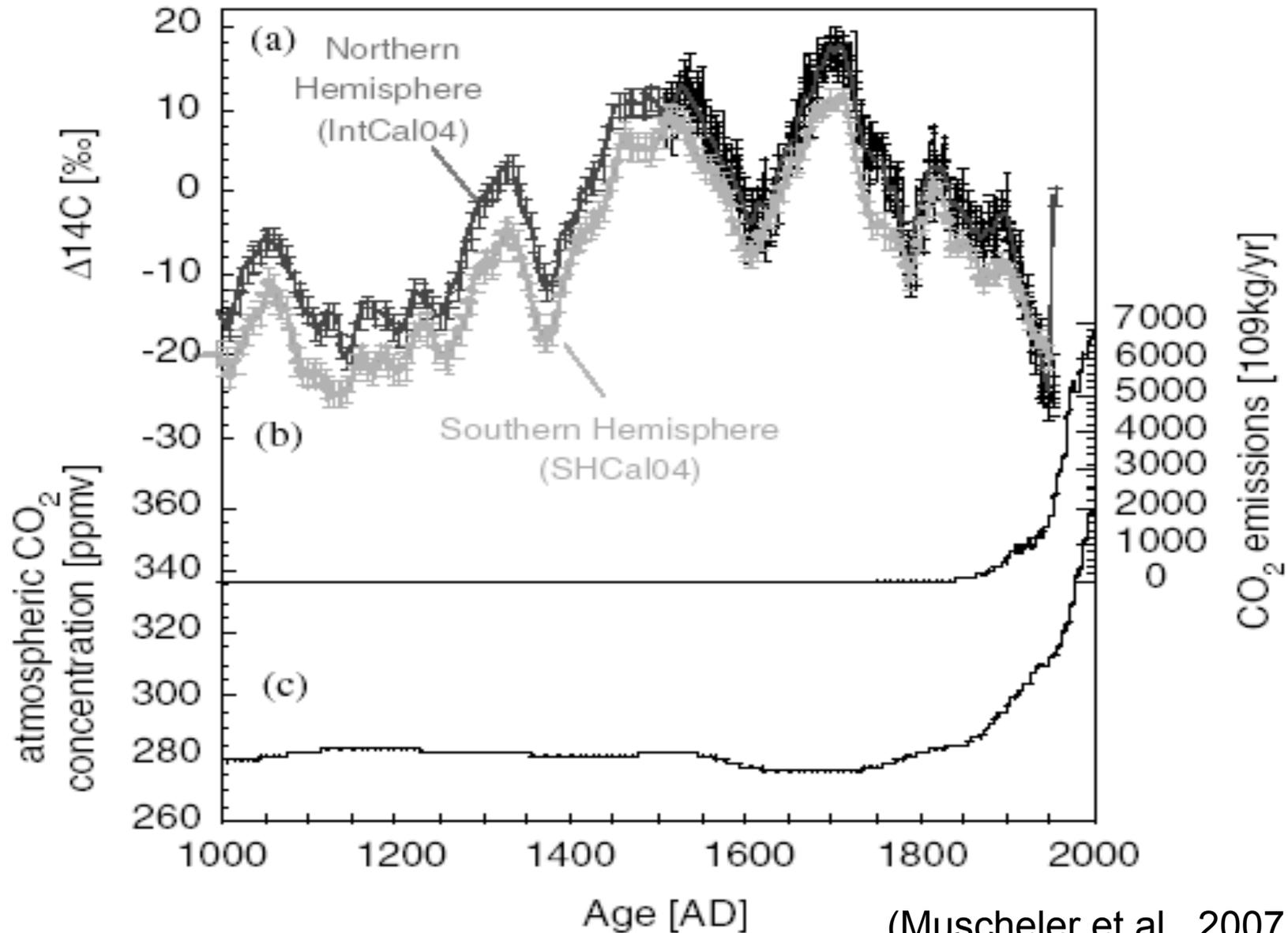
III. Variations in the total CO₂ in atmosphere, biosphere and hydrosphere

1. Changes in input rate of CO₂ by lithospheric degassing, e.g., vulcanism
 2. Combustion of fossil fuels from industrial and domestic activity
 3. Changes in long-term storage in the sedimentary reservoir
-

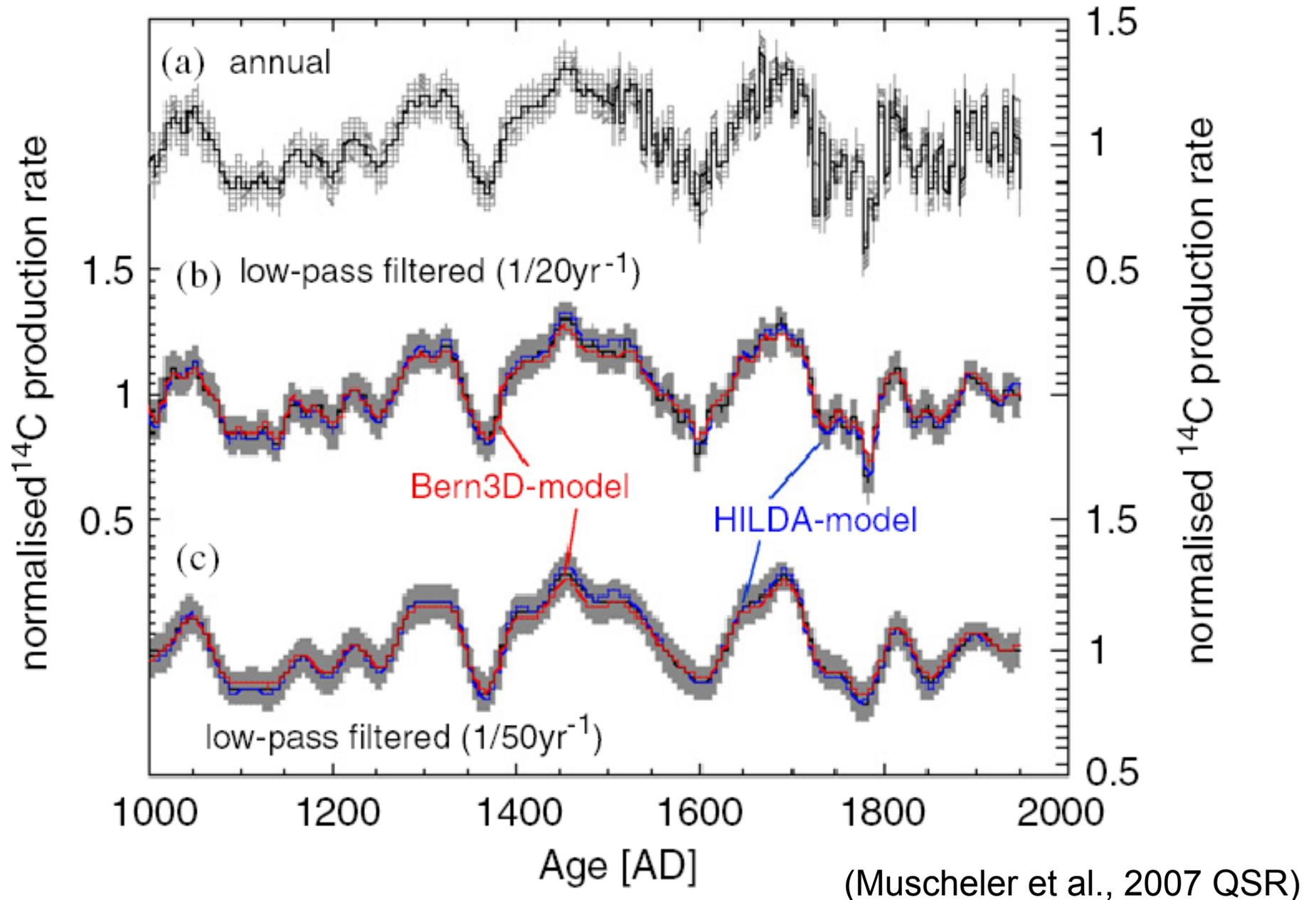
(Damon and Sonett, 1991)

1.2.3 太陽活動と ^{14}C 濃度変動

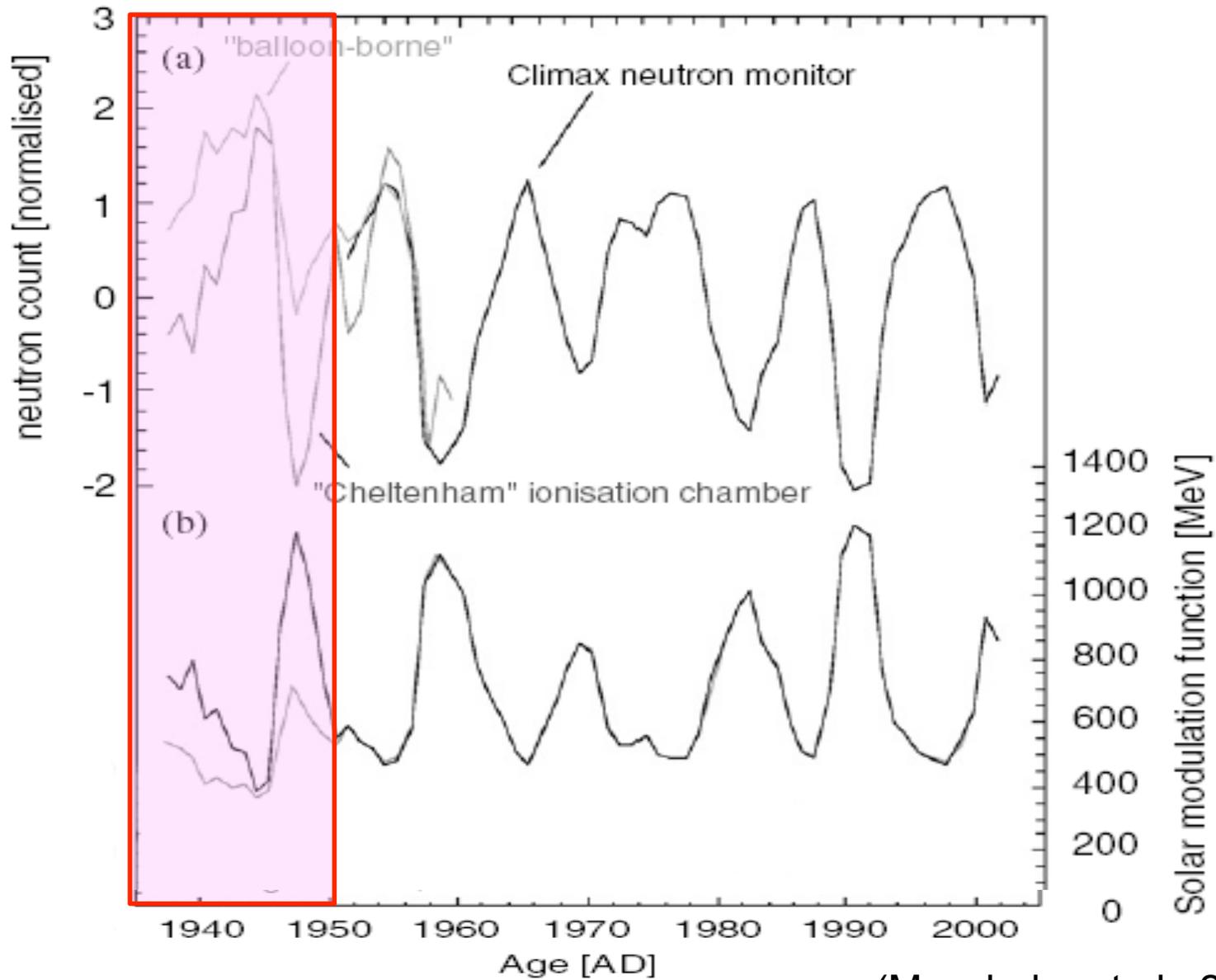
過去1000年間の大気中の ^{14}C 濃度変化



過去1000年間の ^{14}C 生成速度変化

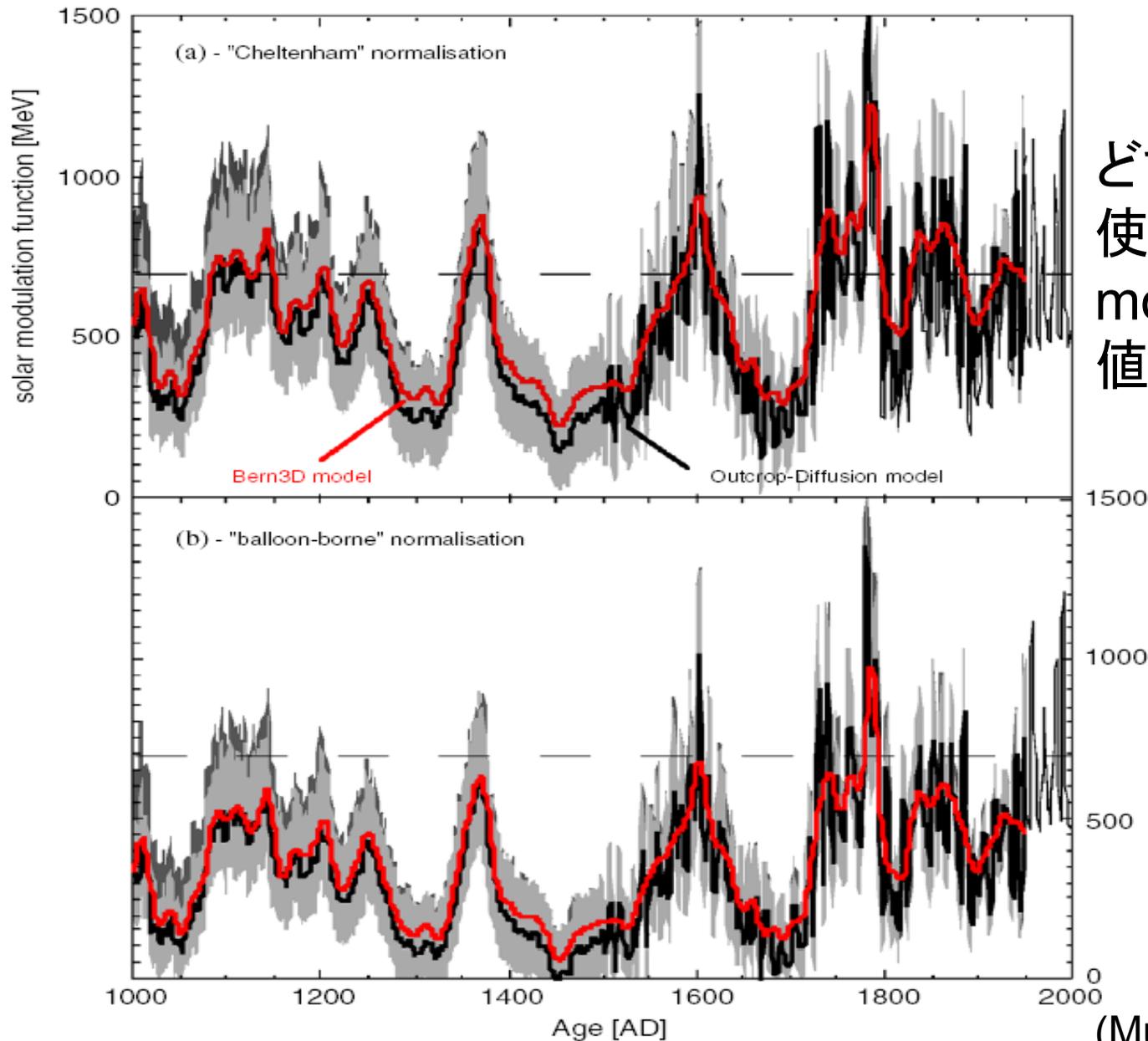


中性子測定記録(1937年より)



(Muscheler et al., 2007 QSR)

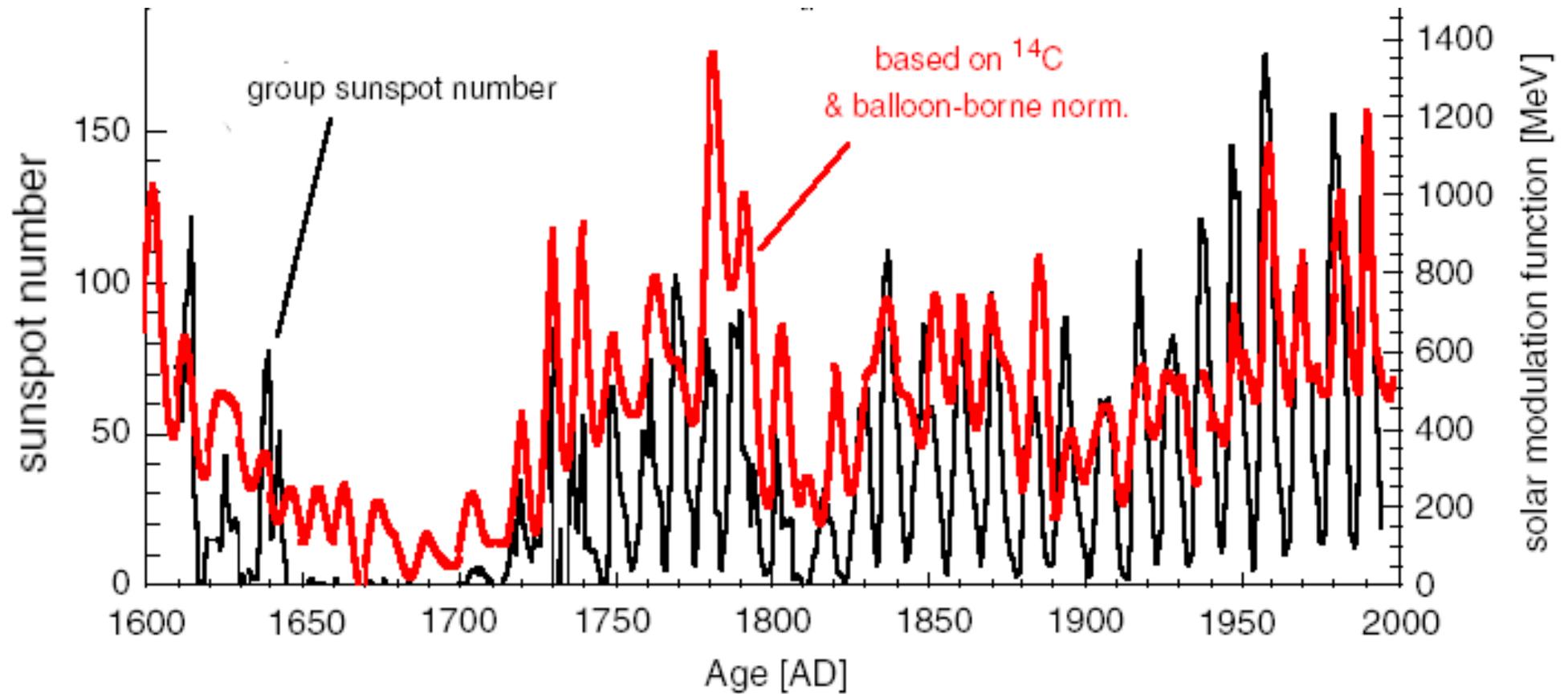
^{14}C に基づく、過去1000年間の solar modulation functionの変化



どちらのcalibrationを
使うかで、solar
modulation functionの
値が2割以上違う

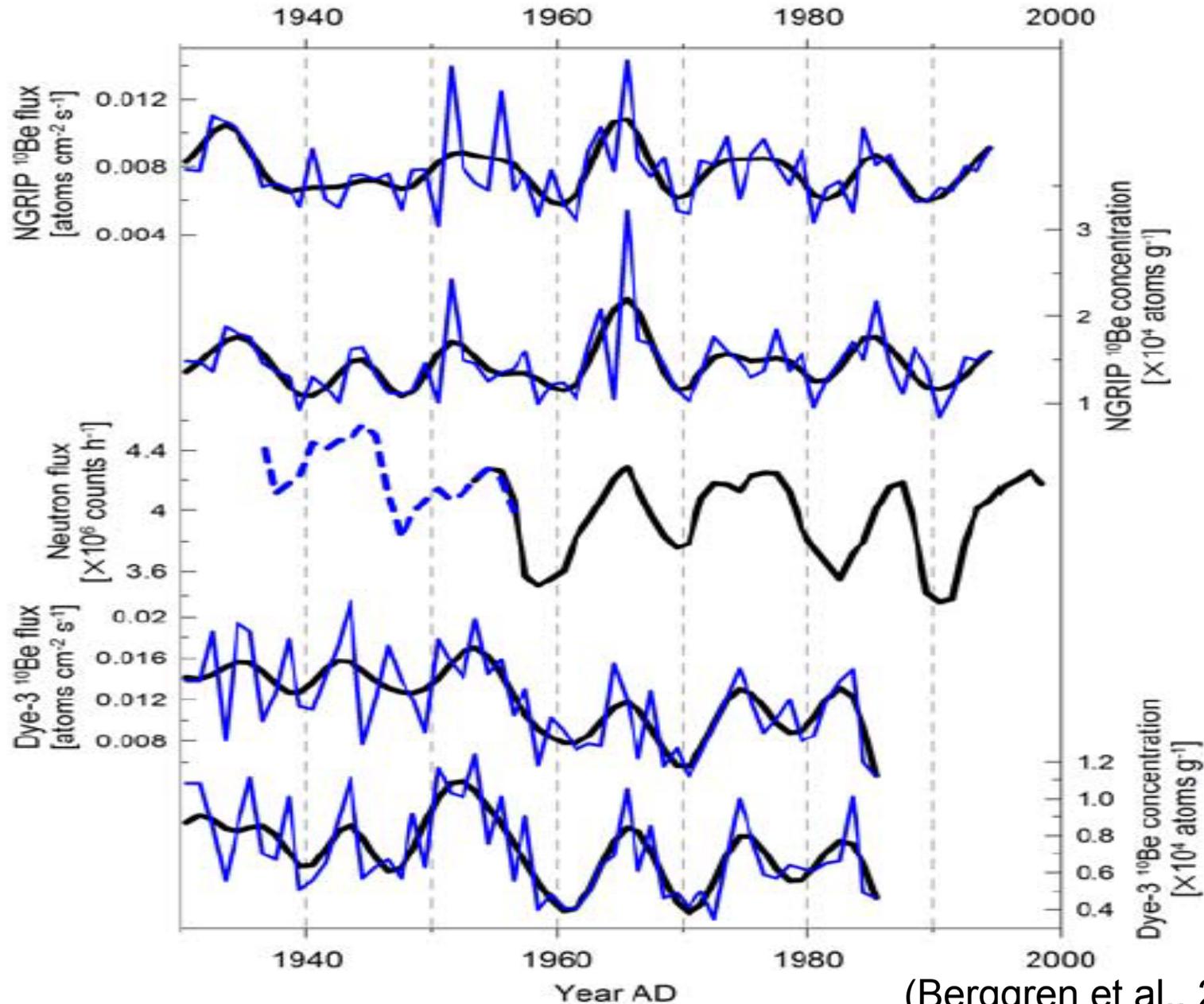
(Muscheler et al., 2007 QSR)

黒点相対数と ^{14}C に基づくSolar modulation functionの比較



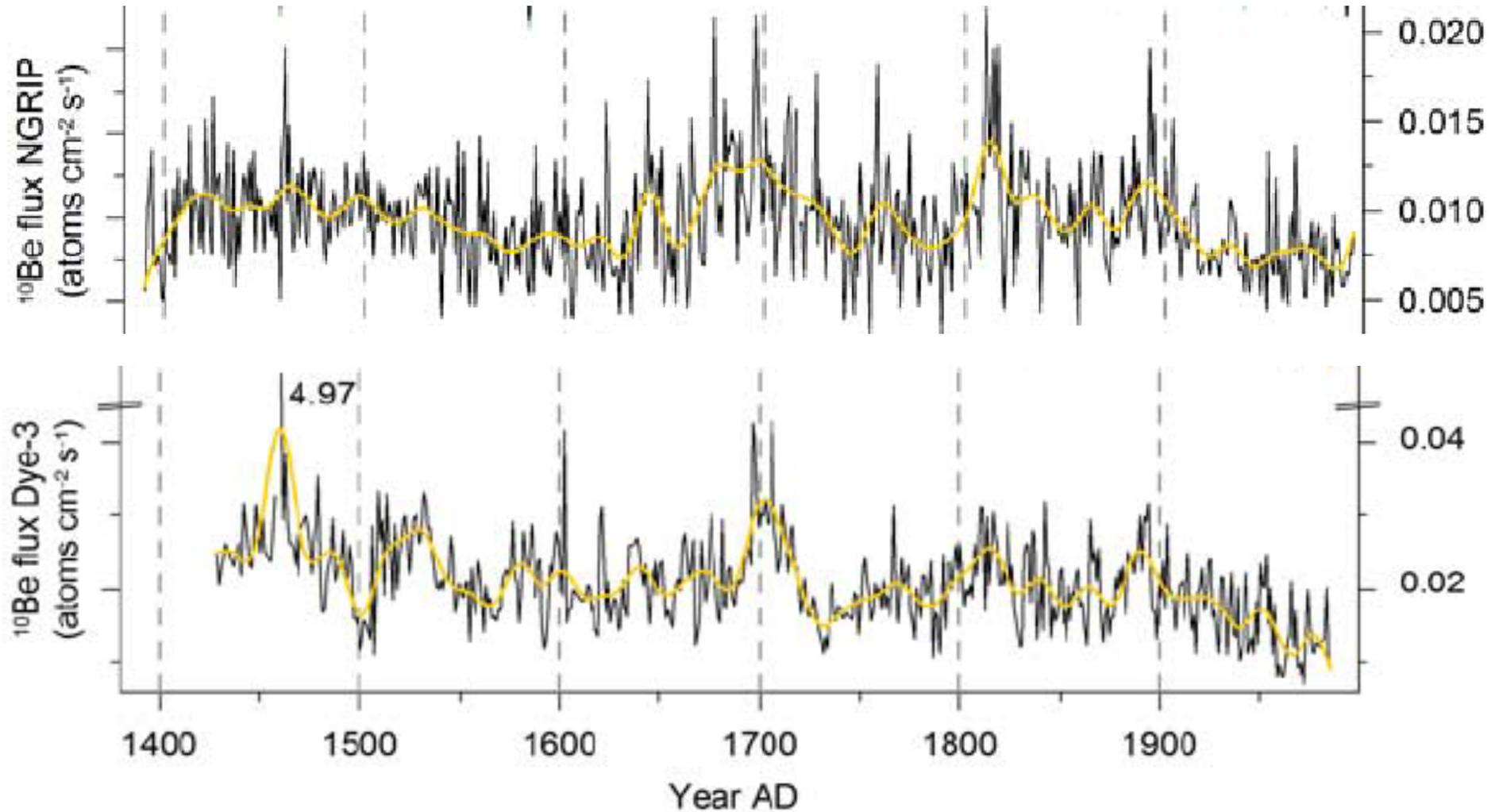
1.2.4 太陽活動と ^{10}Be 濃度変動

中性子フラックスとNGRIP,Dye-3の ^{10}Be 濃度、フラックスの比較

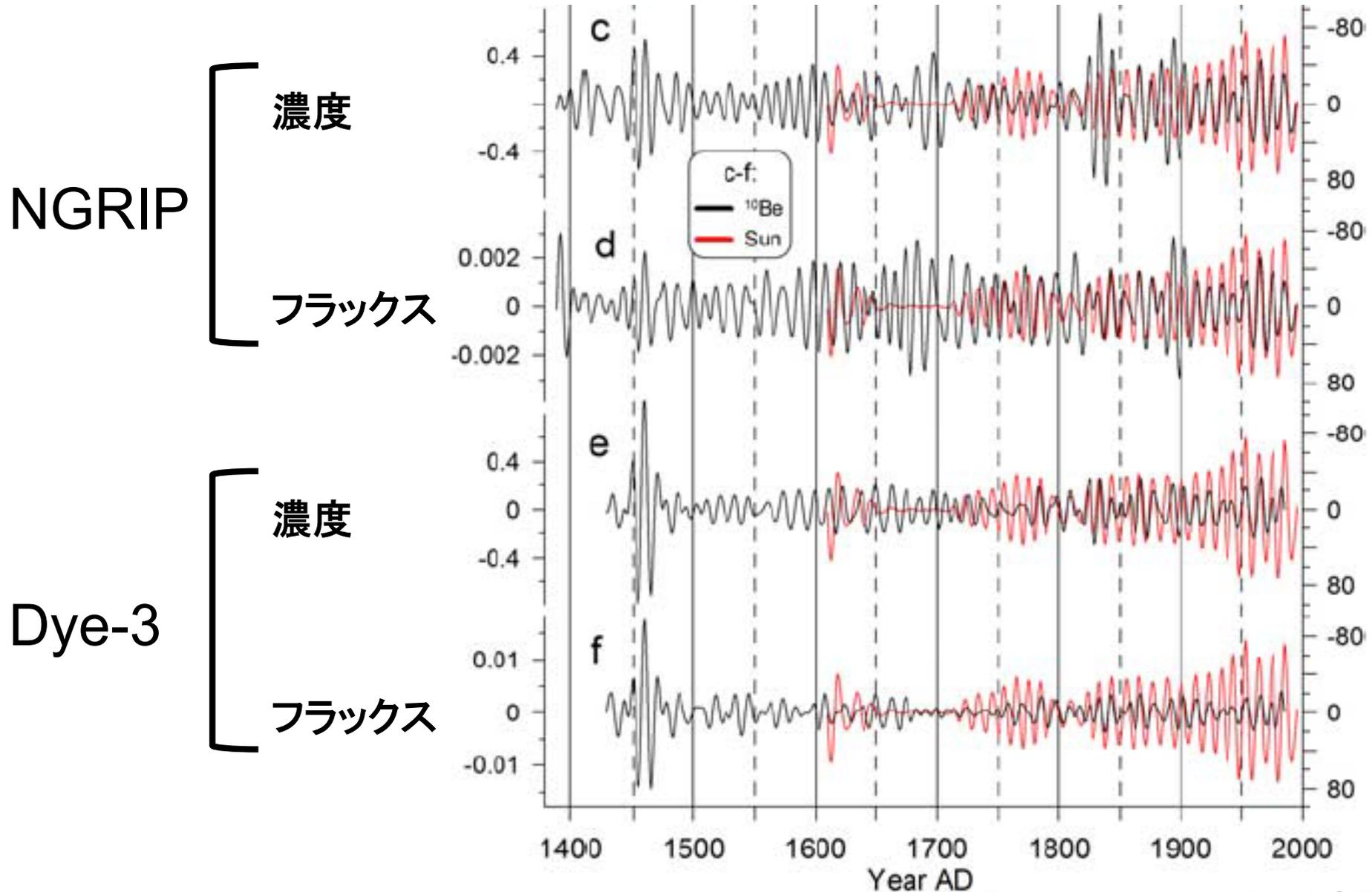


(Berggren et al., 2009GRL)

グリーンランドにおける 過去600年間の ^{10}Be Flux変動

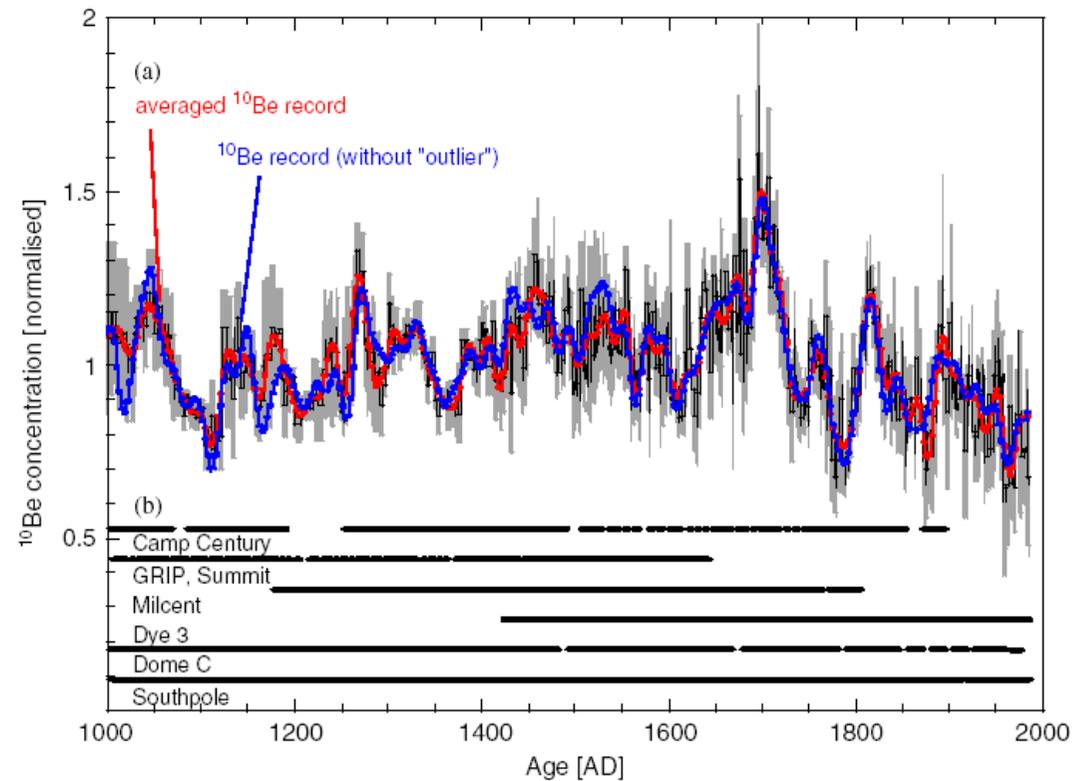
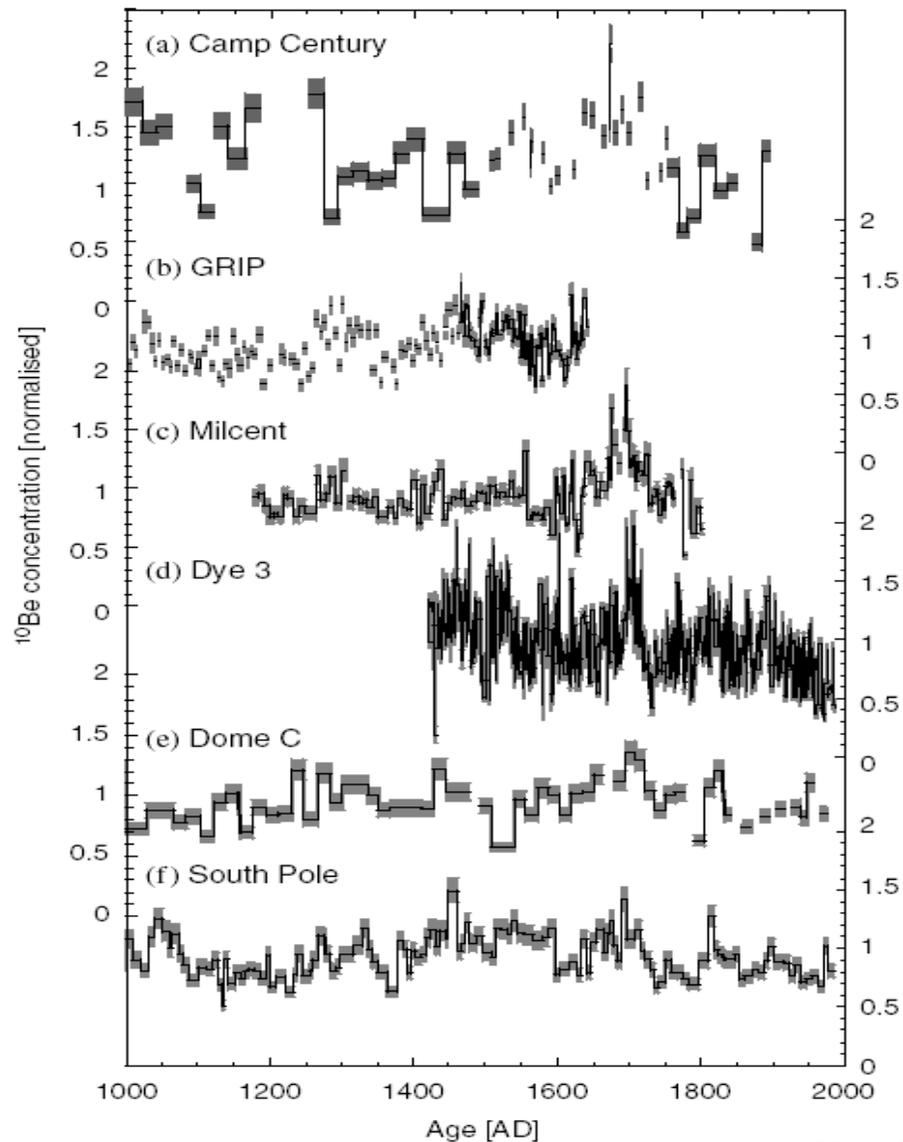


8-16年のband passフィルターをかけた¹⁰Be濃度、フラックス変動と太陽黒点数変動



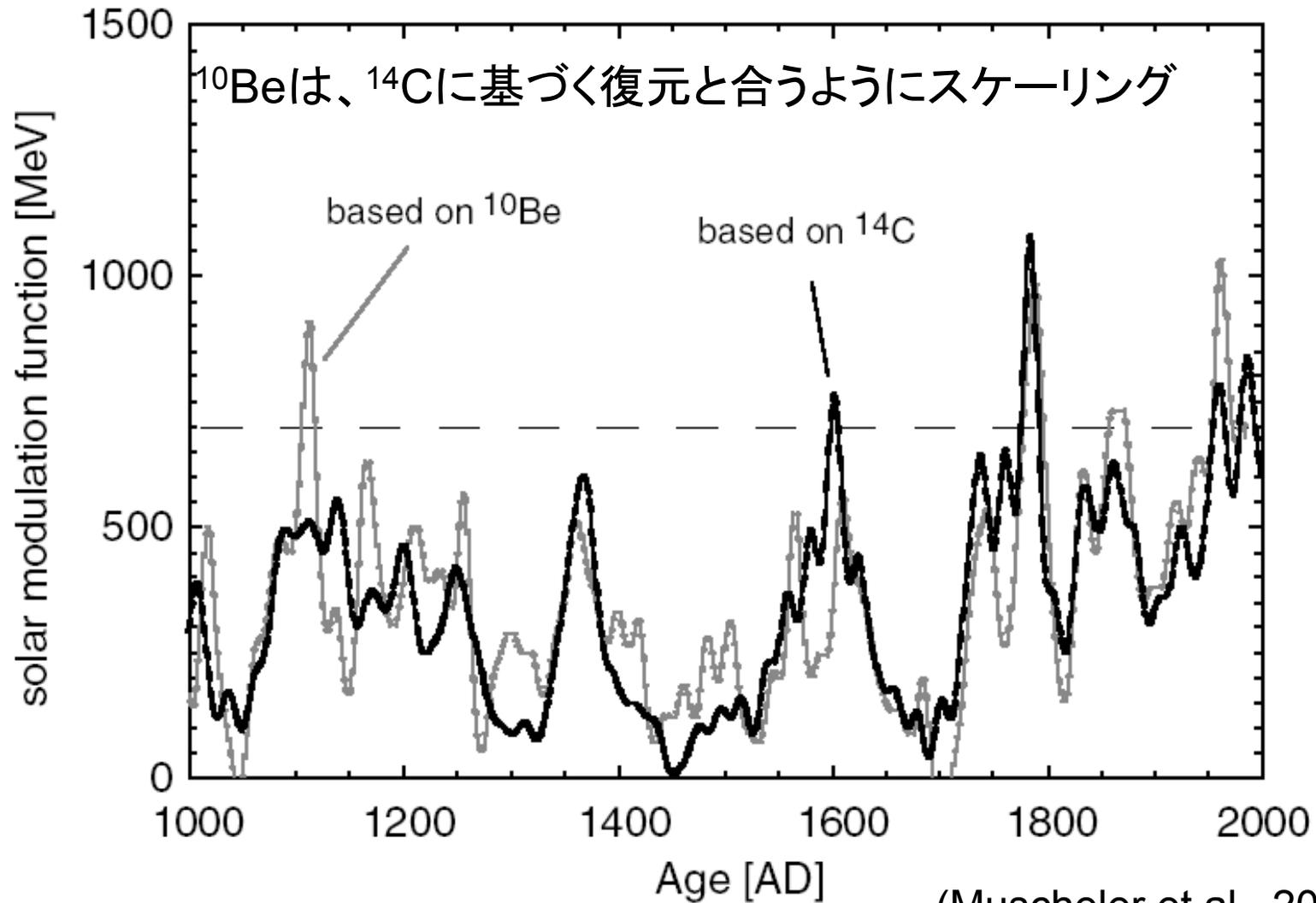
(Berggren et al., 2009GRL)

両極のアイスコアから得られた過去1000年間の ^{10}B e時代変動データを合わせて1つの記録に(図右)

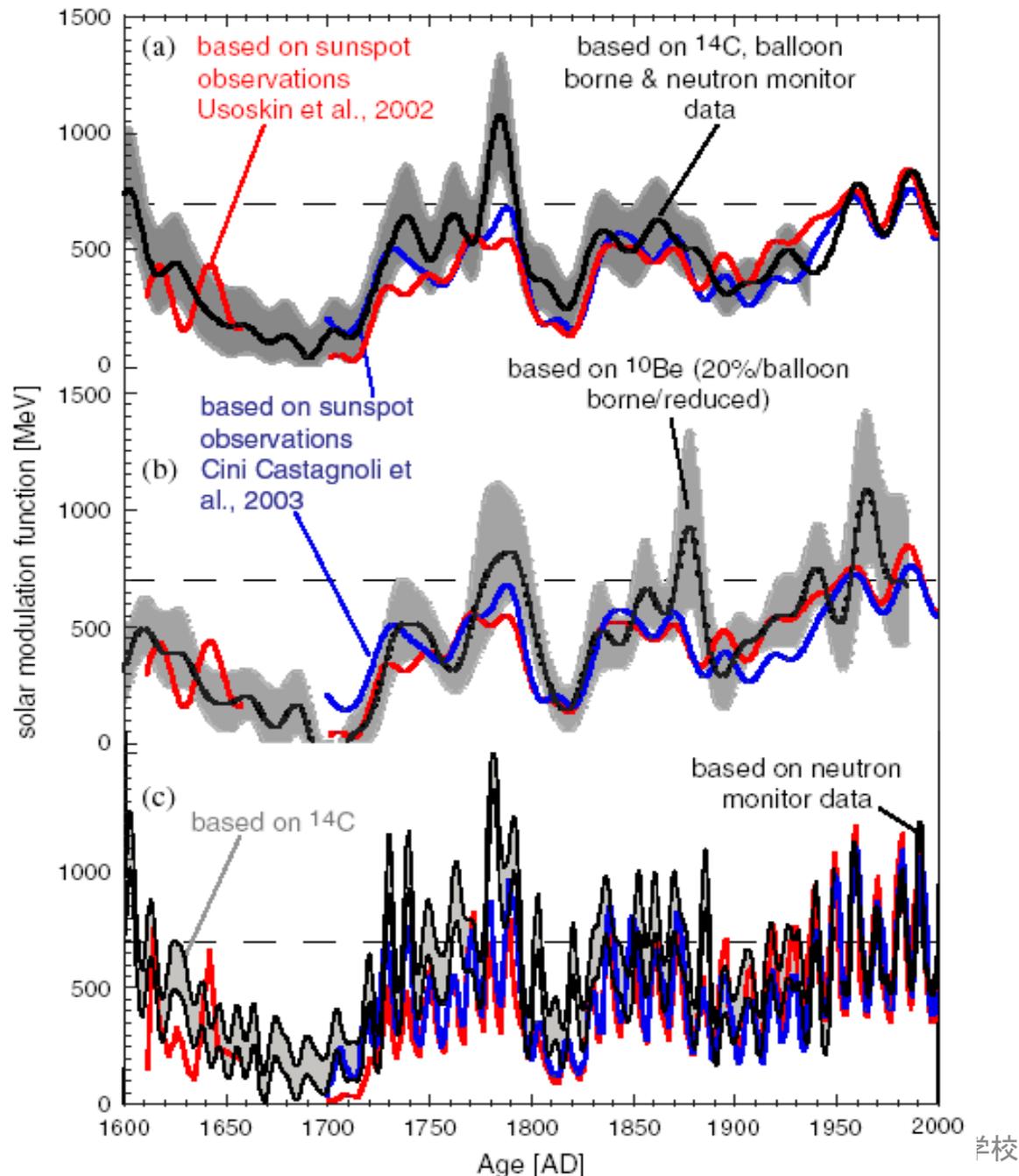


1.2.5 ^{14}C 濃度変動と ^{10}Be 濃度変動の比較

^{14}C および ^{10}Be に基づく、過去1000年間のsolar modulation functionの比較



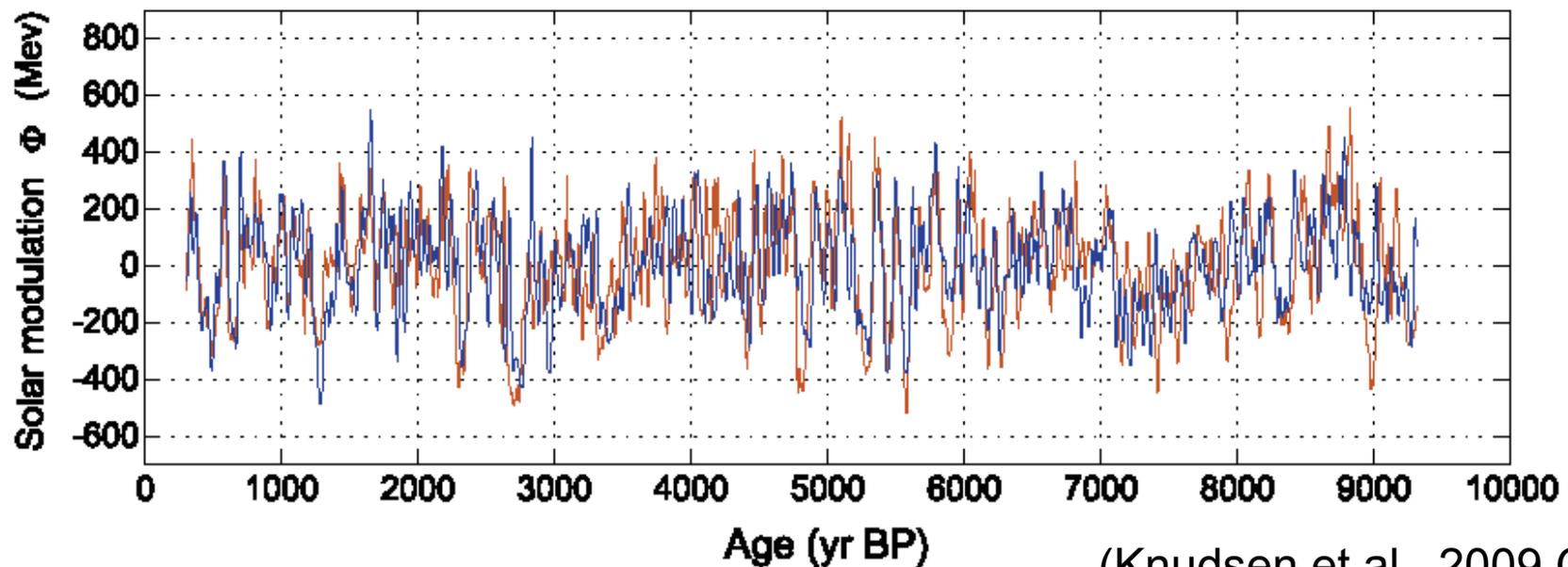
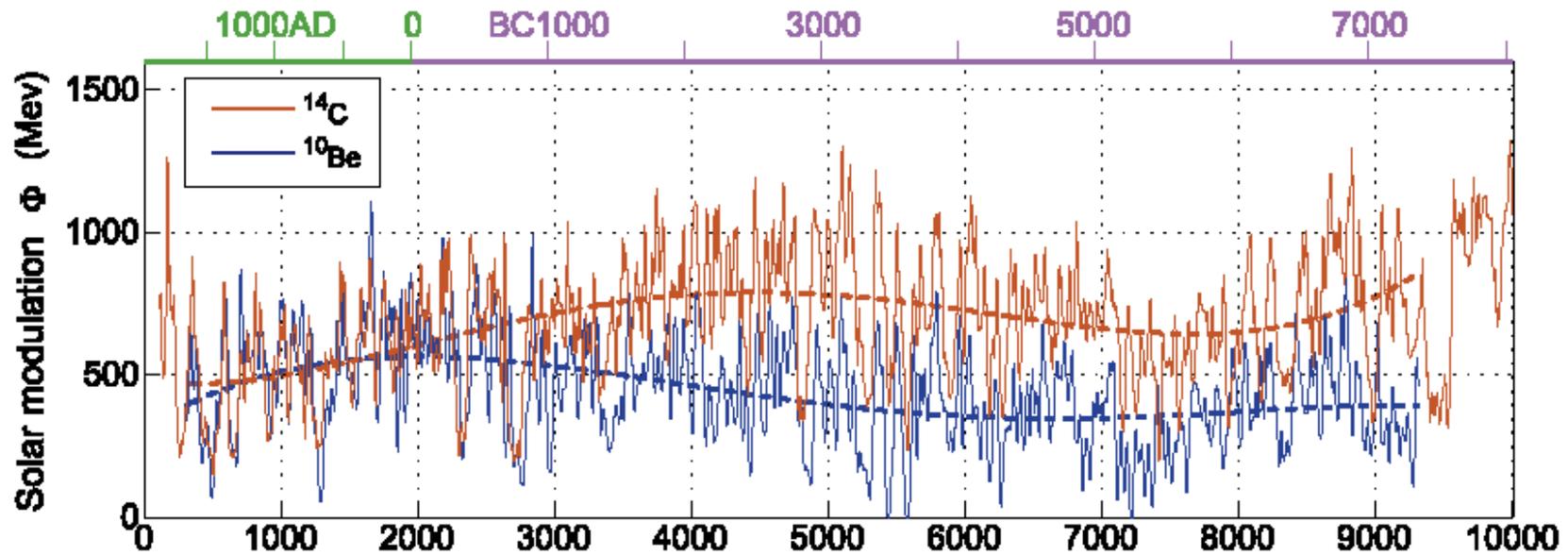
(Muscheler et al., 2007 QSR)



太陽黒点数、 ^{14}C , ^{10}Be の変動記録 に基づいて復元した Solar Modulation Functionの比較

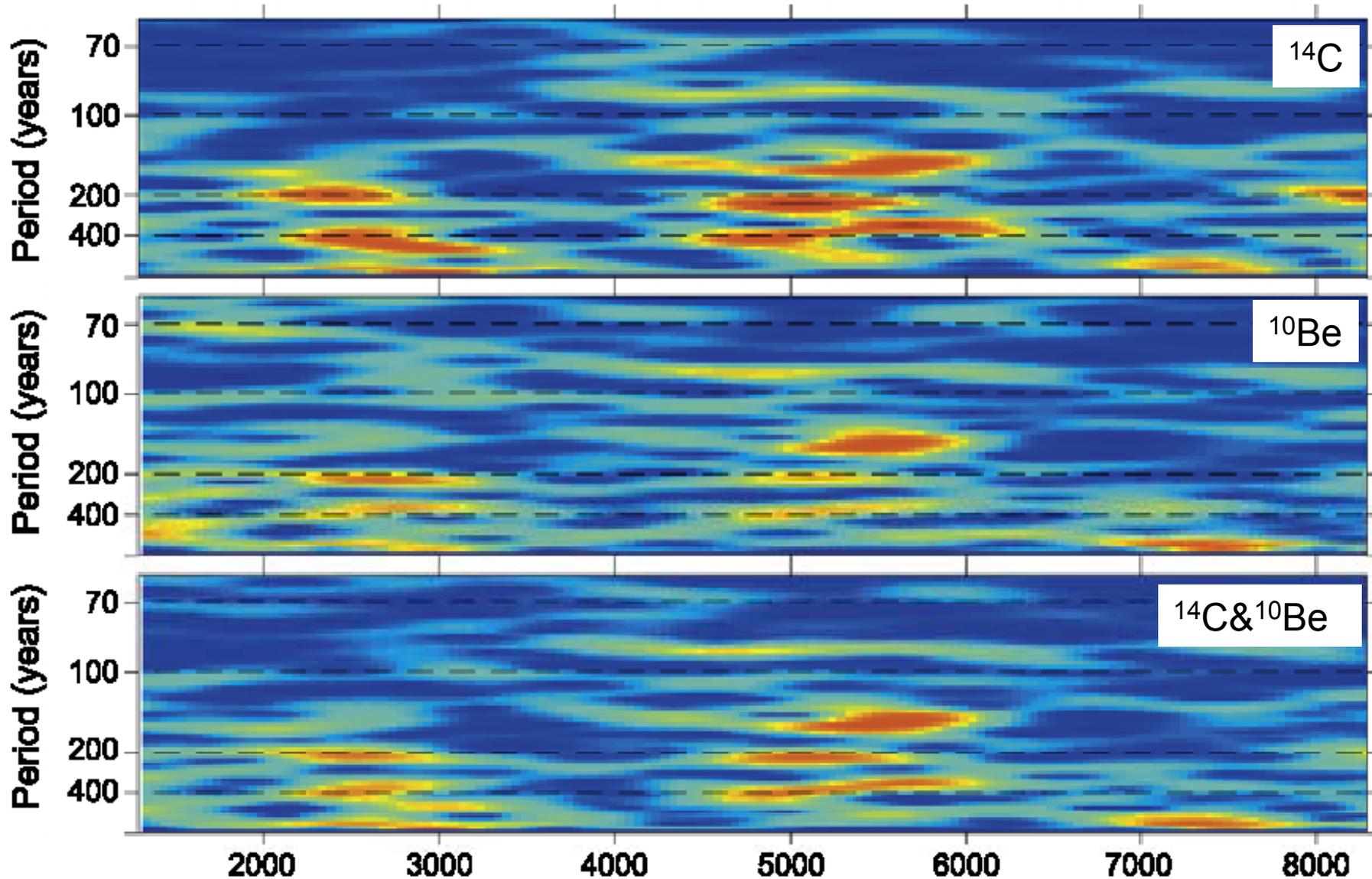
(Muscheler et al., 2007 QSR)

^{14}C , ^{10}Be に基づくHoloceneの銀河宇宙線変動



(Knudsen et al., 2009 GRL)

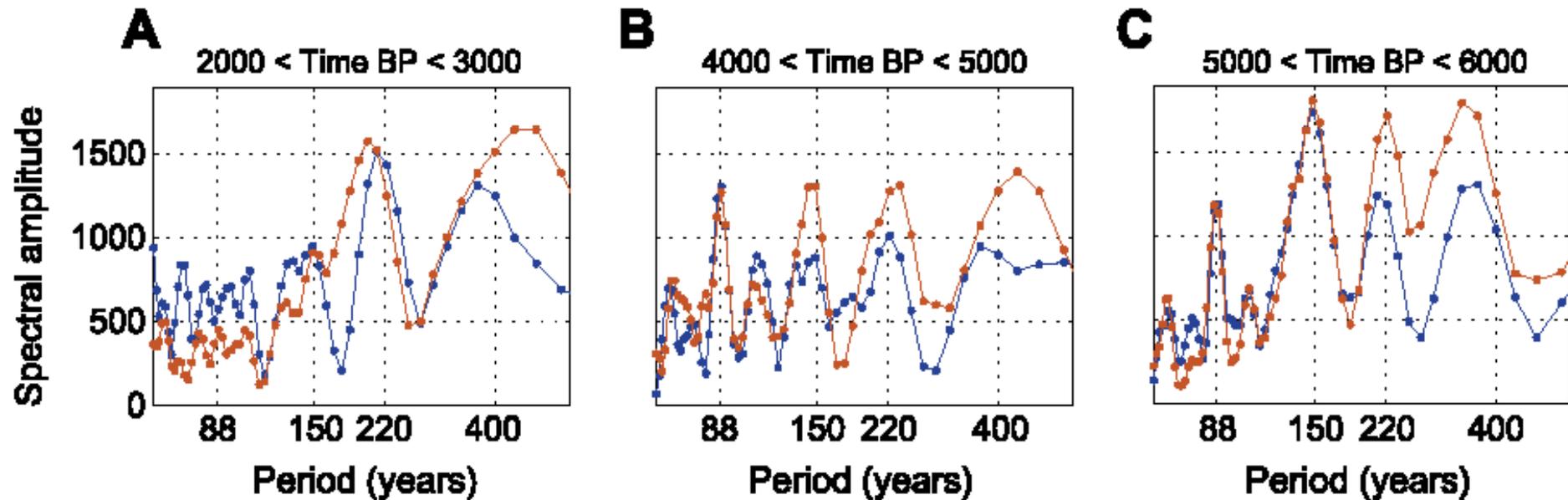
Holoceneを通じたGCR変動周期の変化



Age (yr BP)

(Knudsen et al., 2009 GRL)

GCR強度変動の周期



~88年のGleisberg周期
~150年の周期
~220年のSuess周期
~400年の周期

1000年スケールの周期も存在

220および400年周期において、
 ^{14}C 記録に基づく周期(赤)の方が、 ^{10}Be に基づく周期より顕著

太陽活動の周期性

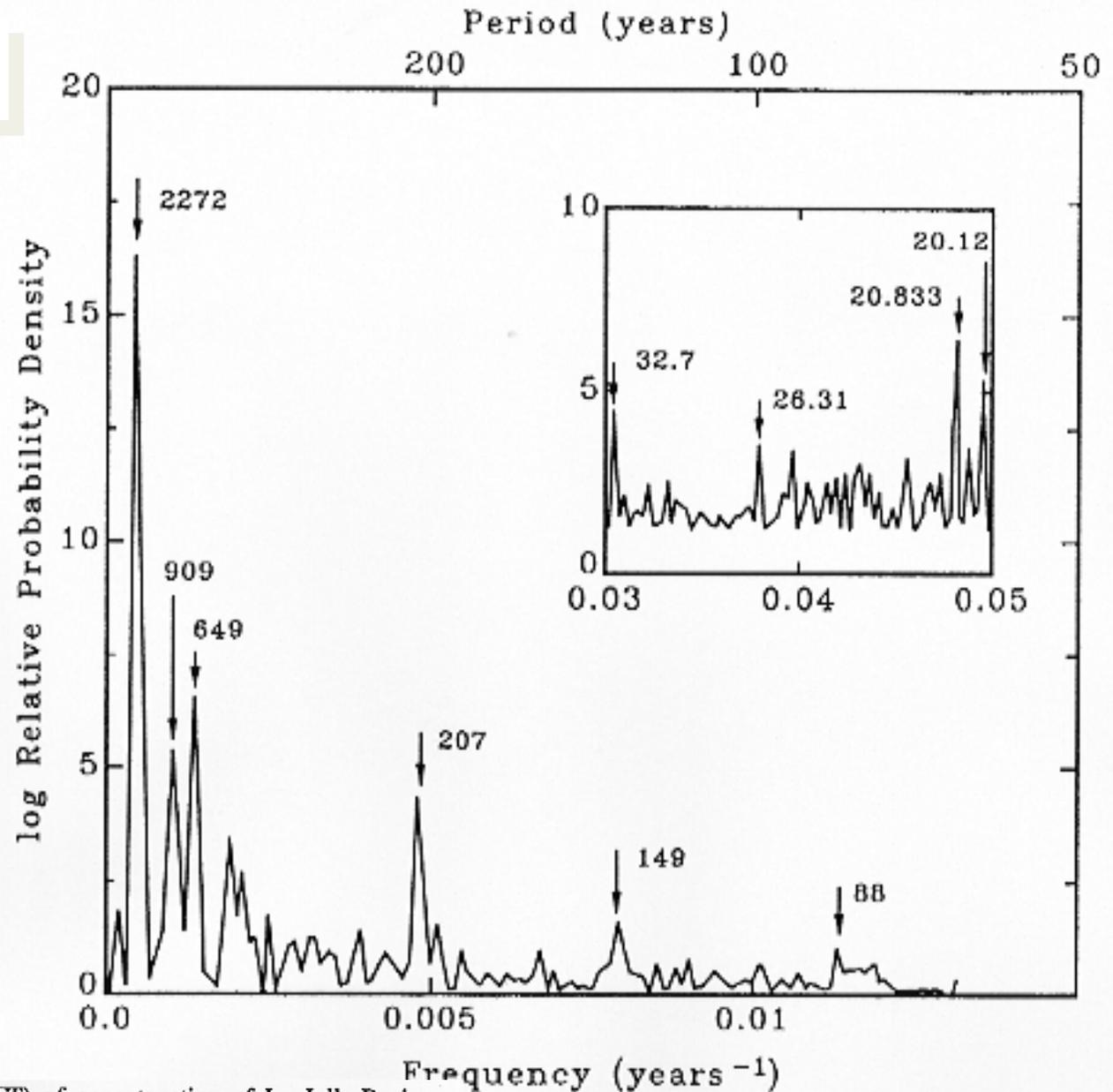
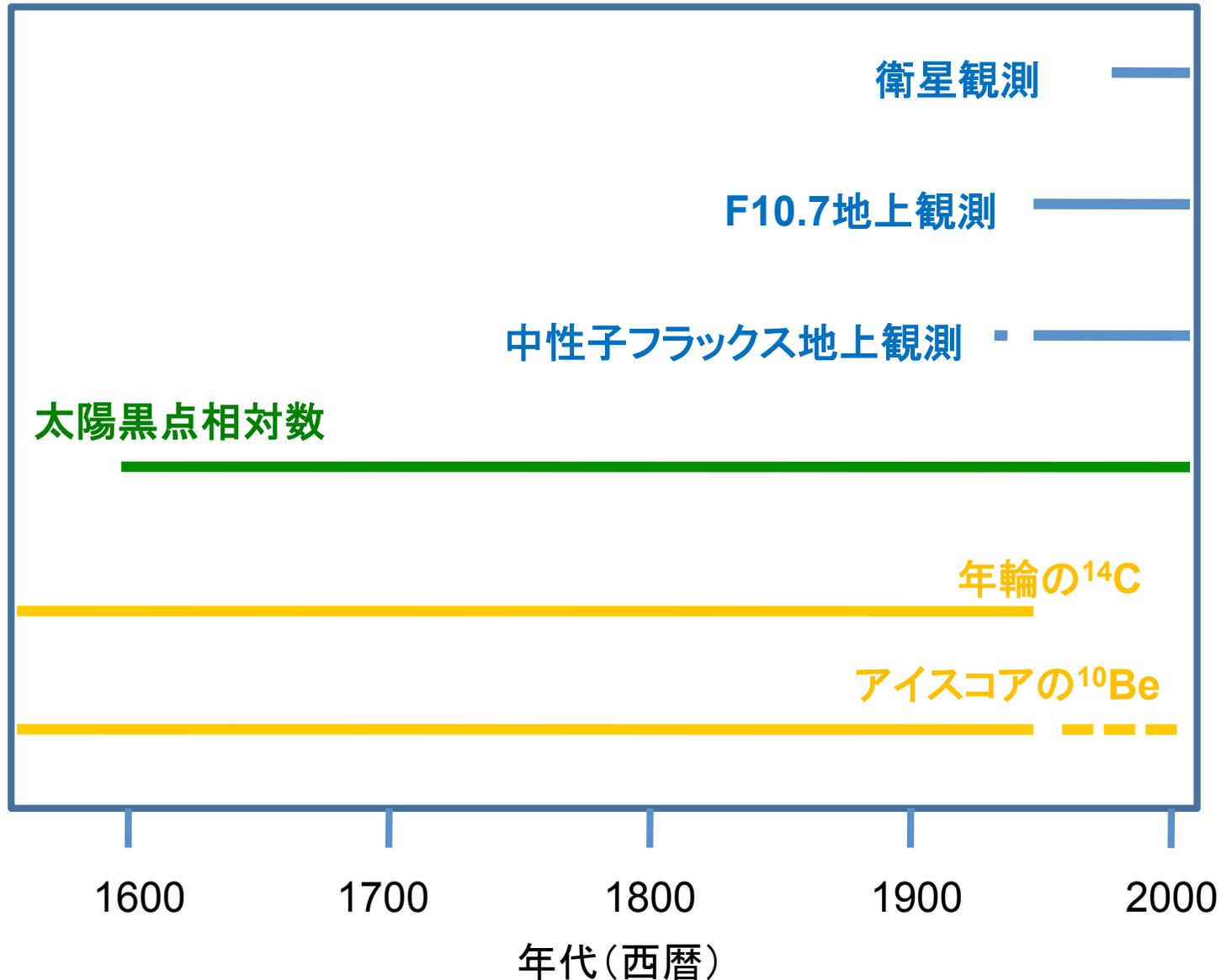


Fig. 4. Amplitude of discrete Fourier transform (DFT) of concatenation of La Jolla-Becker-Stuiver-Pearson ¹⁴C sequences. Detrended using least squares fit to 5th-order polynomial, data is interpolated using cubic spline. Major features are demarked by period in years. Some periods of lesser amplitude are unmarked. Insert is from high-frequency segment periodogram of (BSP) Becker-Stuiver-Pearson sequence extended to 20 yr to emphasize higher frequencies. Major high-frequency lines are present at 20.12, 20.833, 26.31 and 32.7 yr. These high-frequency lines may be aliased contributions.

From Damon and Sonett (1991)

太陽活動放射、宇宙線フラックスの観測記録と代替指標の記録



まとめ

1. 衛星観測によると黒点周期に伴う太陽総放射照度の変動幅は0.1%程度で、F10.7フラックスや黒点相対数と良い相関を示す。
2. UV領域での放射照度の変動幅は、総放射照度より大きく、200-250nmで4%に及ぶ。
3. 銀河宇宙線を反映する中性子フラックスも太陽総放射照度変動と比較的良好な相関を示す。
4. これらの記録を400年以上前まで延ばすには、 ^{14}C や ^{10}Be などの宇宙線起源放射線核種を使う必要があるが、中性子やF10.7フラックスとの間でのキャリブレーションが、精度良くなされていない。
5. ^{14}C 濃度の時系列記録などから、88, 150, 220, 400年などの周期が見出されている。

宇宙入射量と太陽黒点数

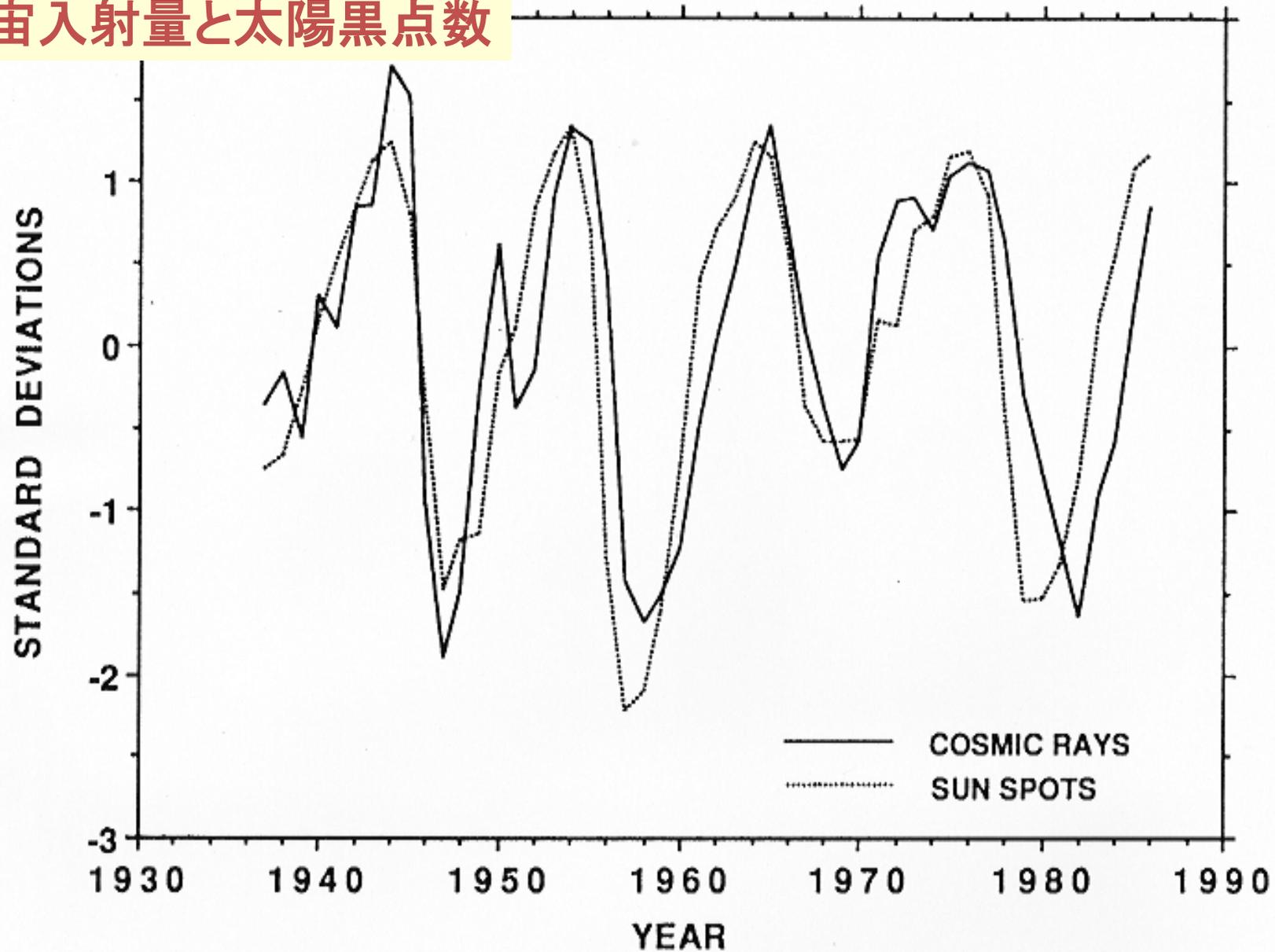


Fig. 3. Comparison of groundlevel cosmic-ray secondary-particle fluxes with sunspot number over the past 150 yr. Sunspot number has been plotted on an inverse scale. The amplitudes are given in units of standard deviations (see text). (Beer et al., 1991)

数十年スケールでの太陽活動と ^{14}C 生成率の相関

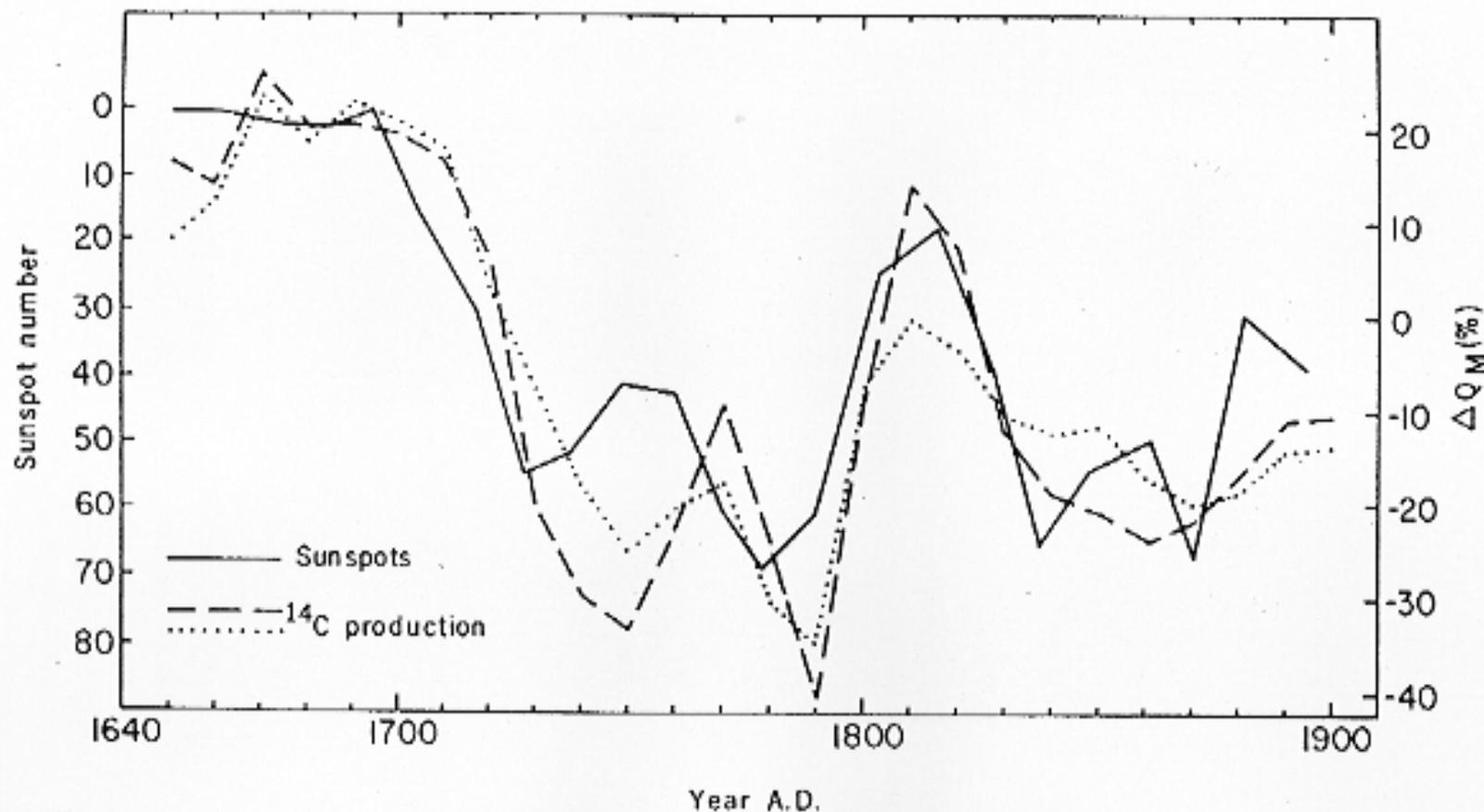


Fig. 7. Changes in ^{14}C production rate (ΔQ_M) calculated from the reservoir model, relative to the average 1000–1860 production rate, and inverse sunspot number record. The calculated ΔQ_M curves are for biospheric residence times of 20 years (dashed line) and 60 years (dotted line).

(Stuiver and Quay, 1980)

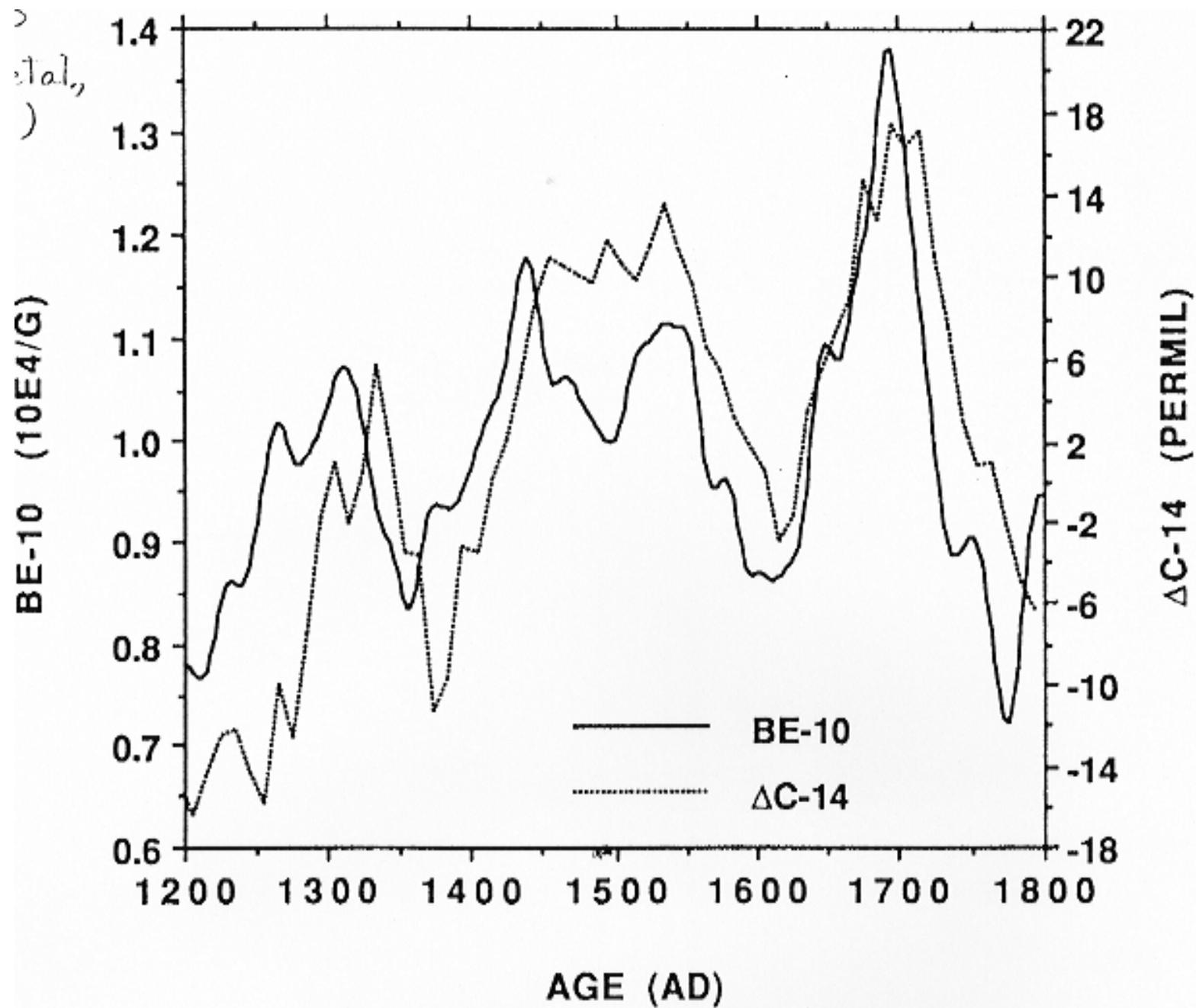


Fig. 9. Comparison of smoothed ^{10}Be composite concentration curve from Milcent and South Pole with tree-ring $\Delta^{14}\text{C}$ record. $\Delta^{14}\text{C}$ expresses the relative deviation in per mil of the atmospheric ^{14}C concentration from the one of 1850 AD. (Beer et al., 1991)

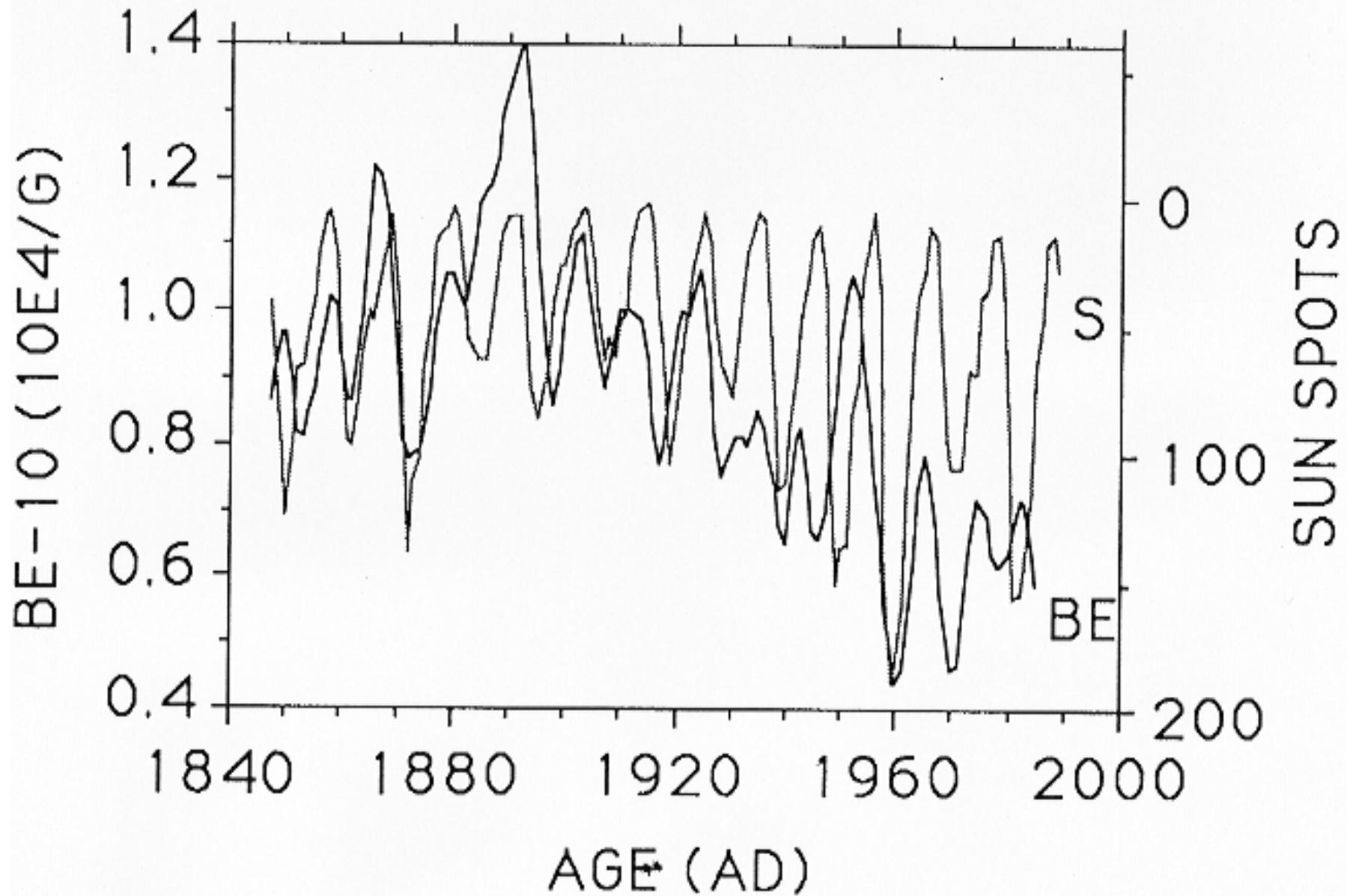


Fig. 6. Comparison of smoothed ^{10}Be concentration from Fig. 4 with sunspot number. The ^{10}Be data have been shifted by 2 yr for easier comparison (see text).

(Beer et al., 1991)

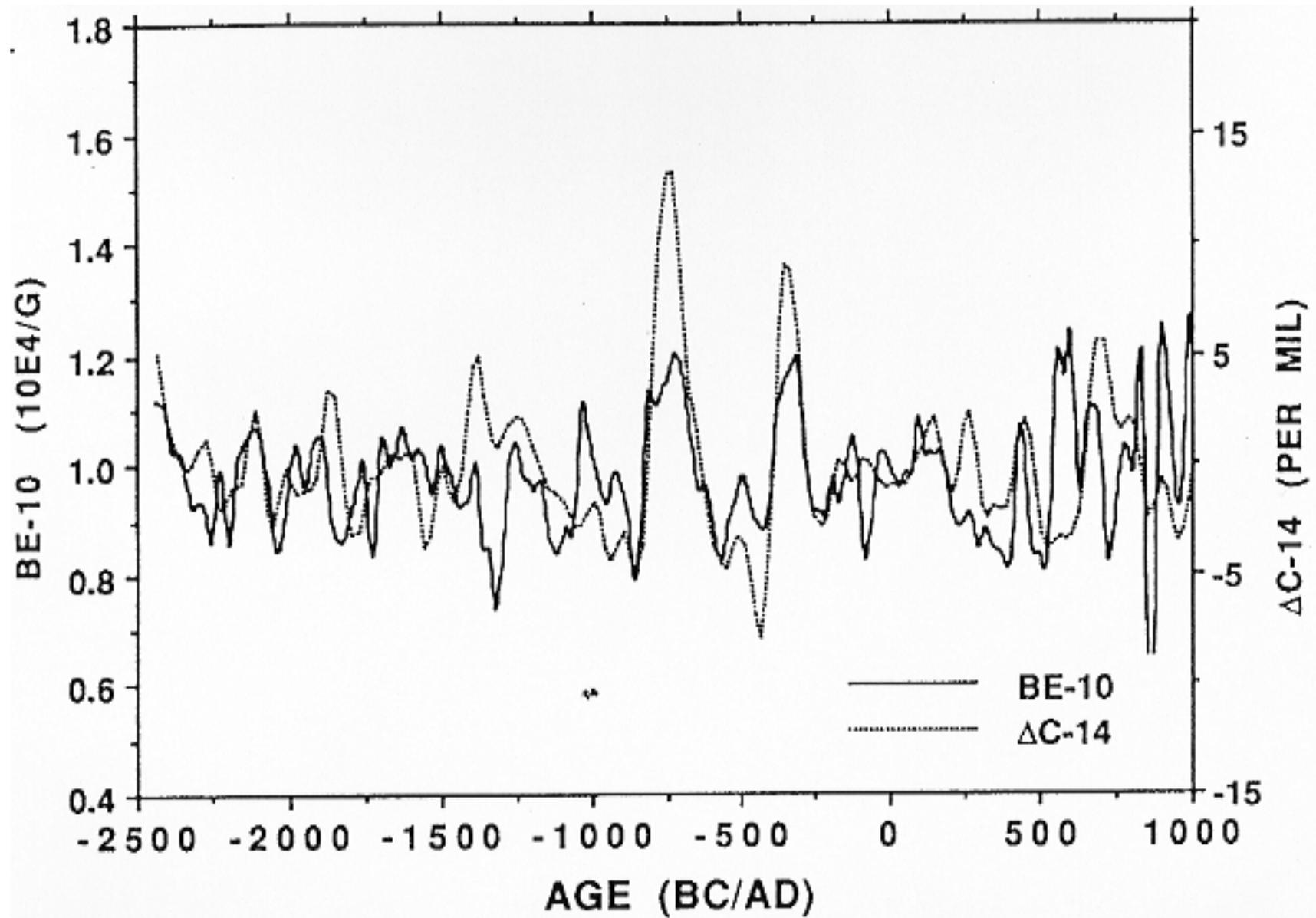
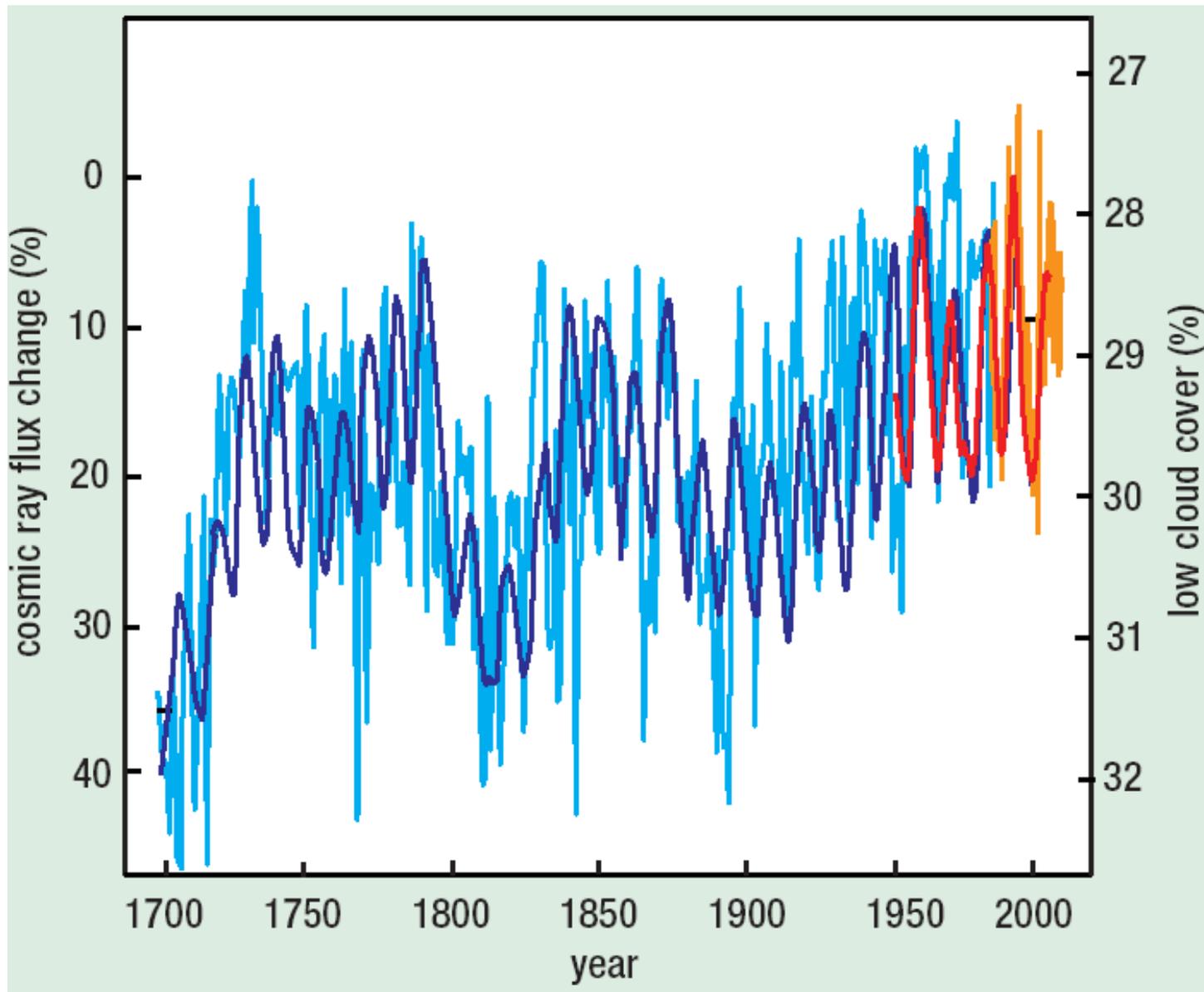
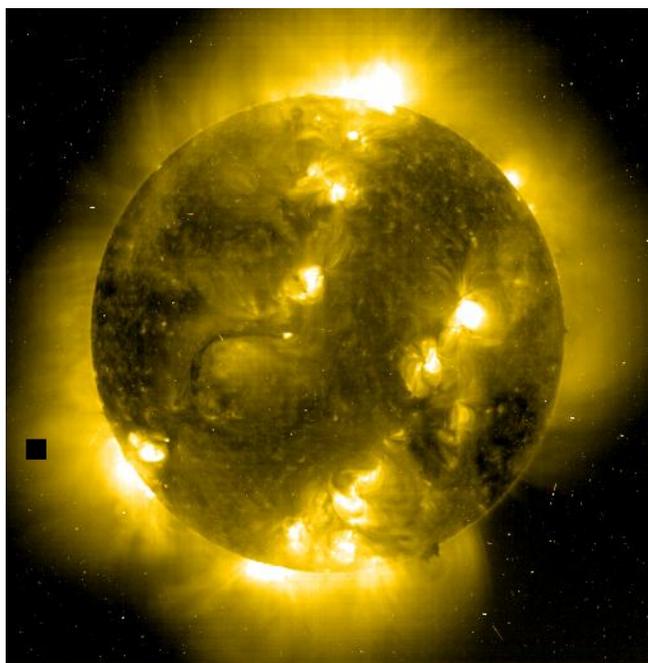
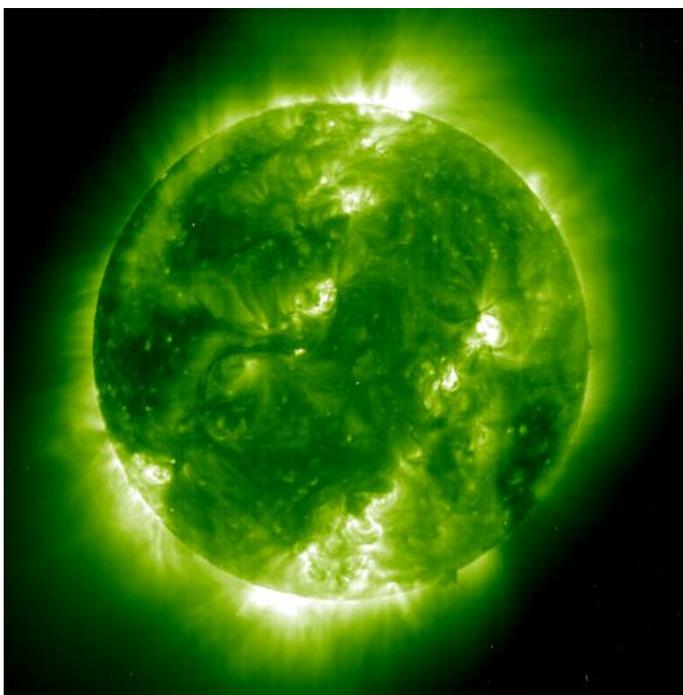
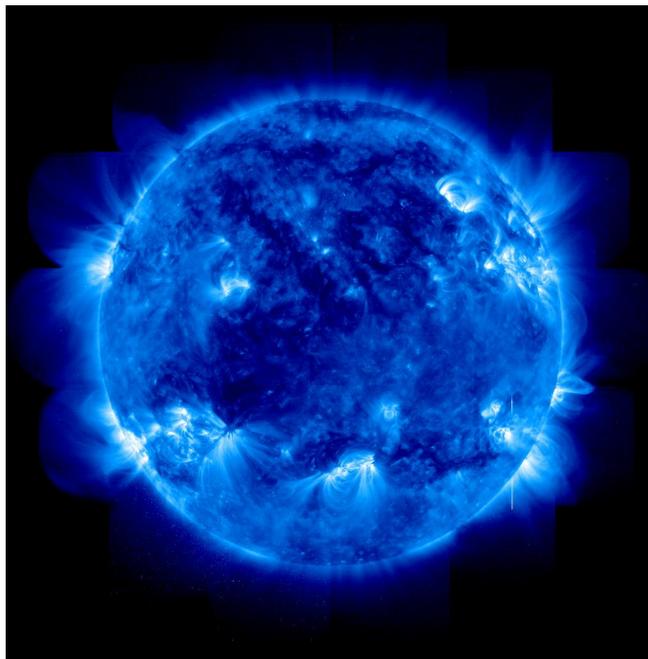
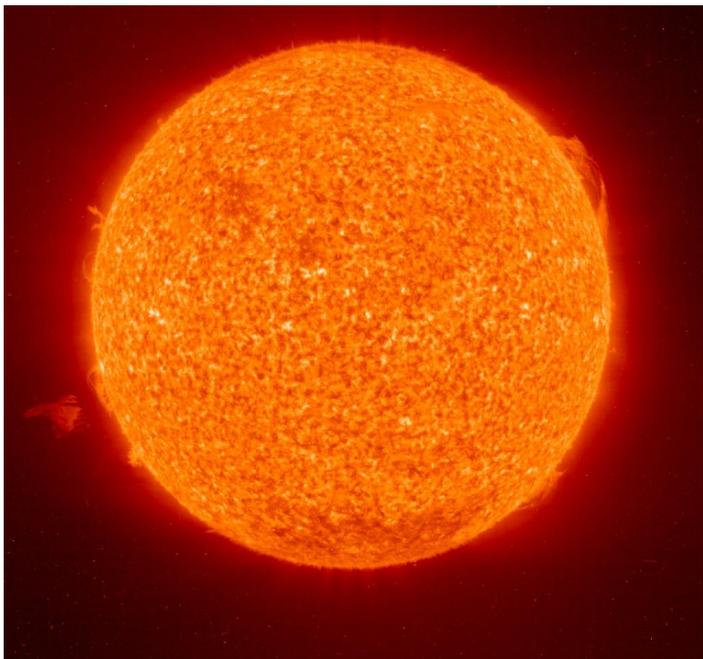


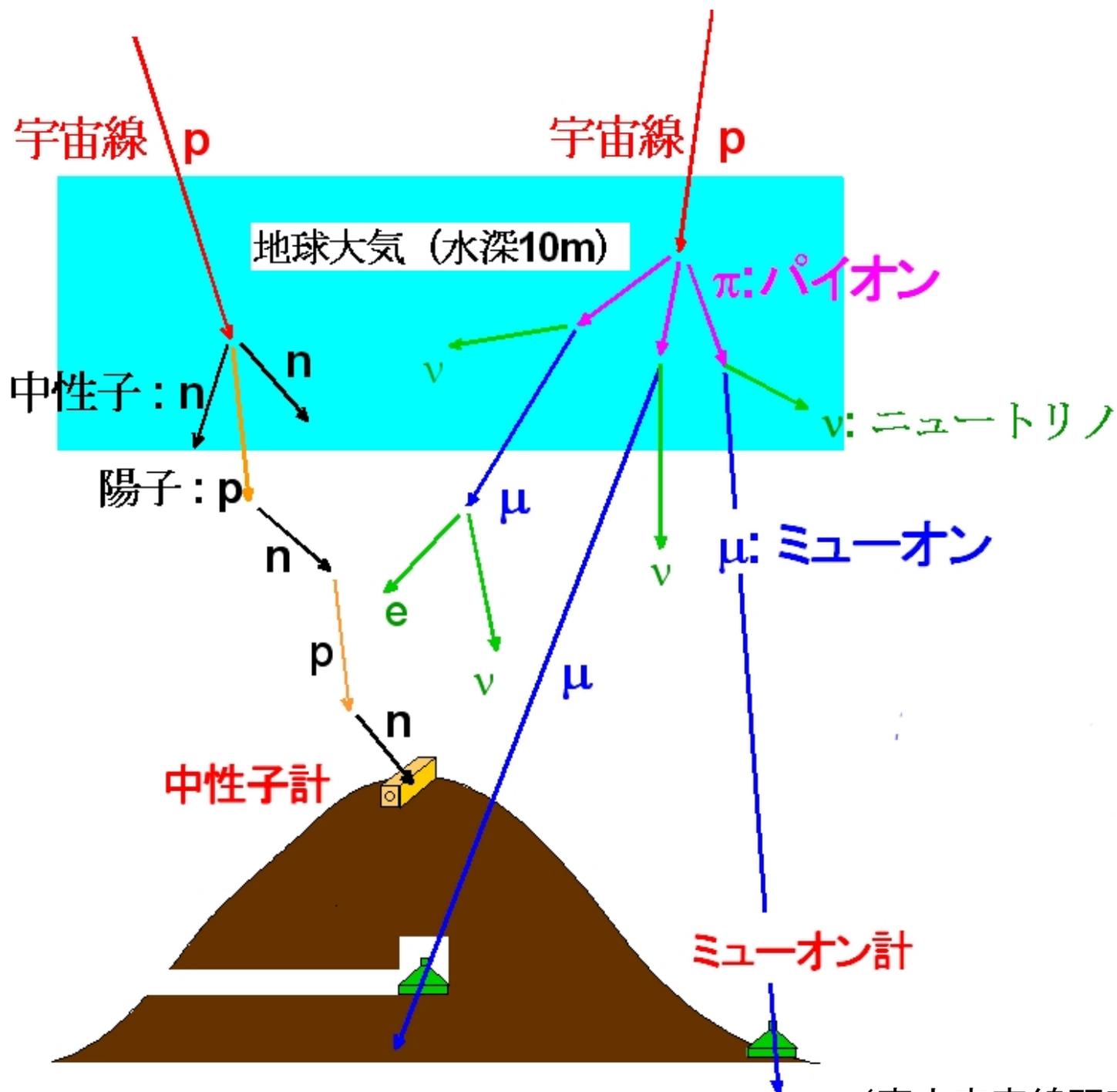
Fig. 10. Comparison of smoothed ^{10}Be composite concentration curve from Camp Century and

(Beer et al., 1991)

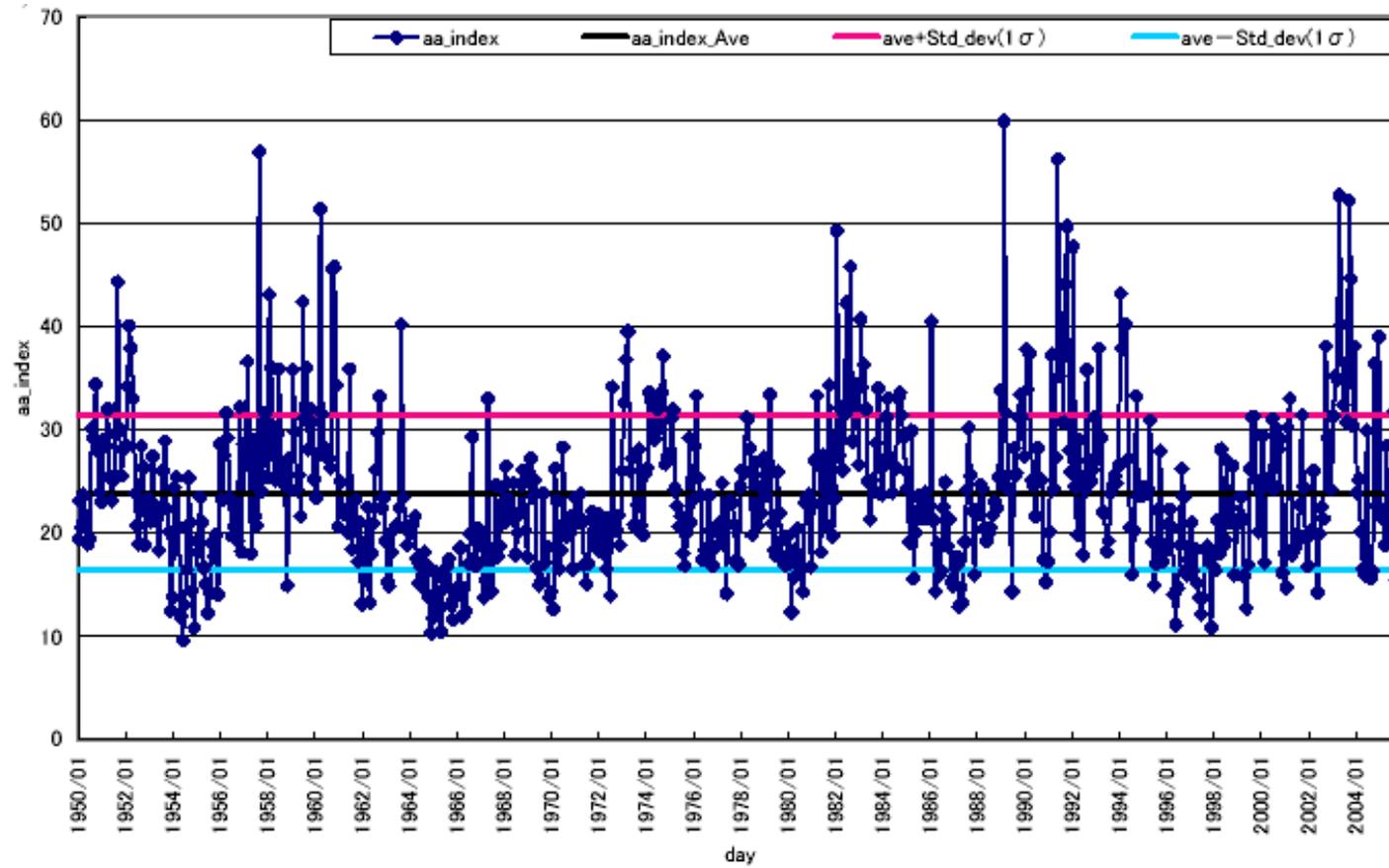
銀河宇宙線フラックスの変化

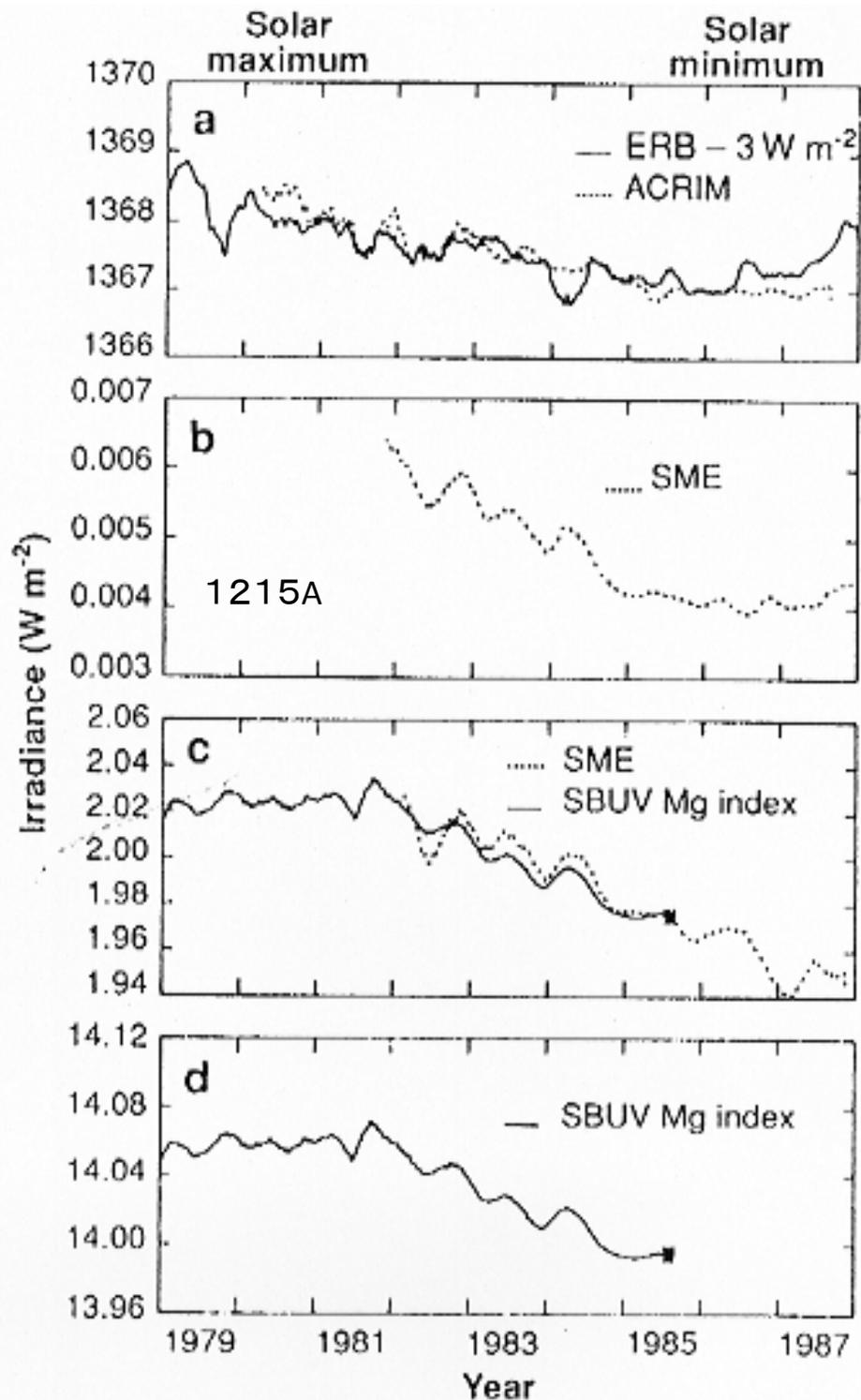






(東大宇宙線研究所HPより)



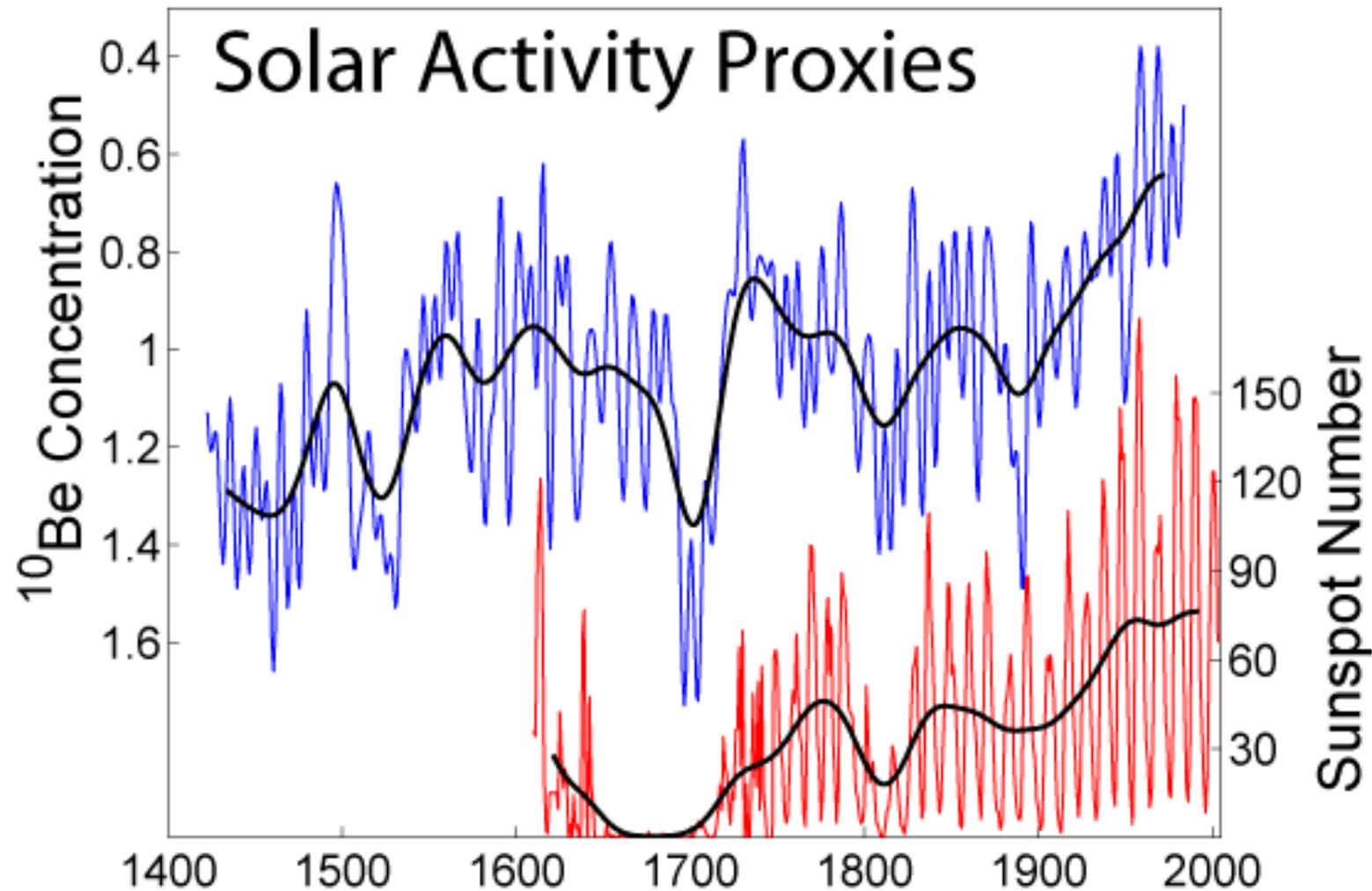


太陽活動に伴う、放射量変動は、可視領域より、紫外、近赤外領域における変動割合のほうが大きい

Fig. 1. Variations in the sun's emission during the declining phase of solar cycle 21, as evidenced by 81-day running means of (a) the total irradiance (4, 5) and the UV irradiance at (b) Lyman α and in the wavelength intervals (c) 200 to 250 nm and (d) 250 to 300 nm (6, 13). The asterisks are the SUSIM measurements (10).

(Lean, 1989)

過去600年間の ^{10}Be 濃度変動と 黒点相対数変動



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