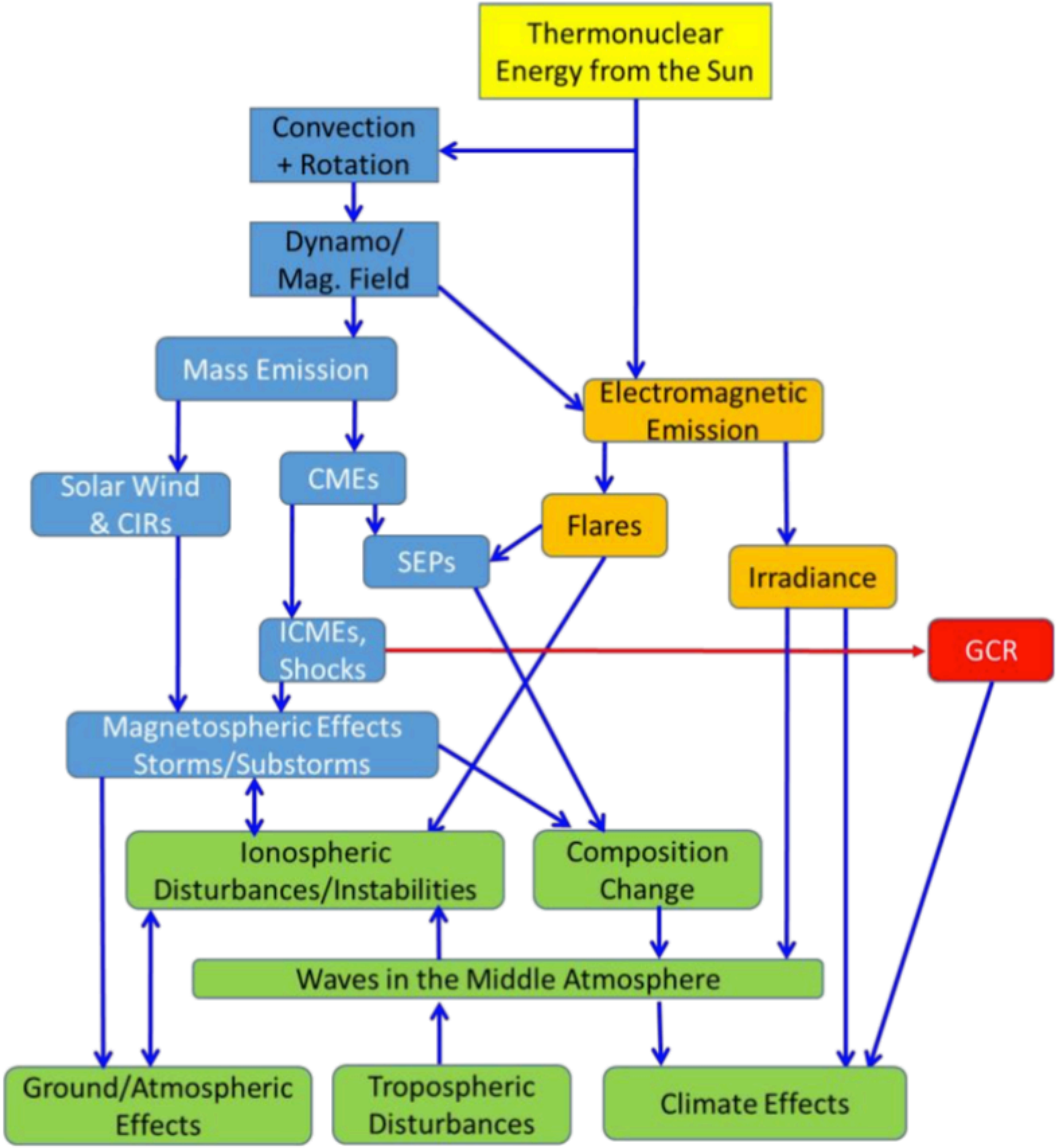
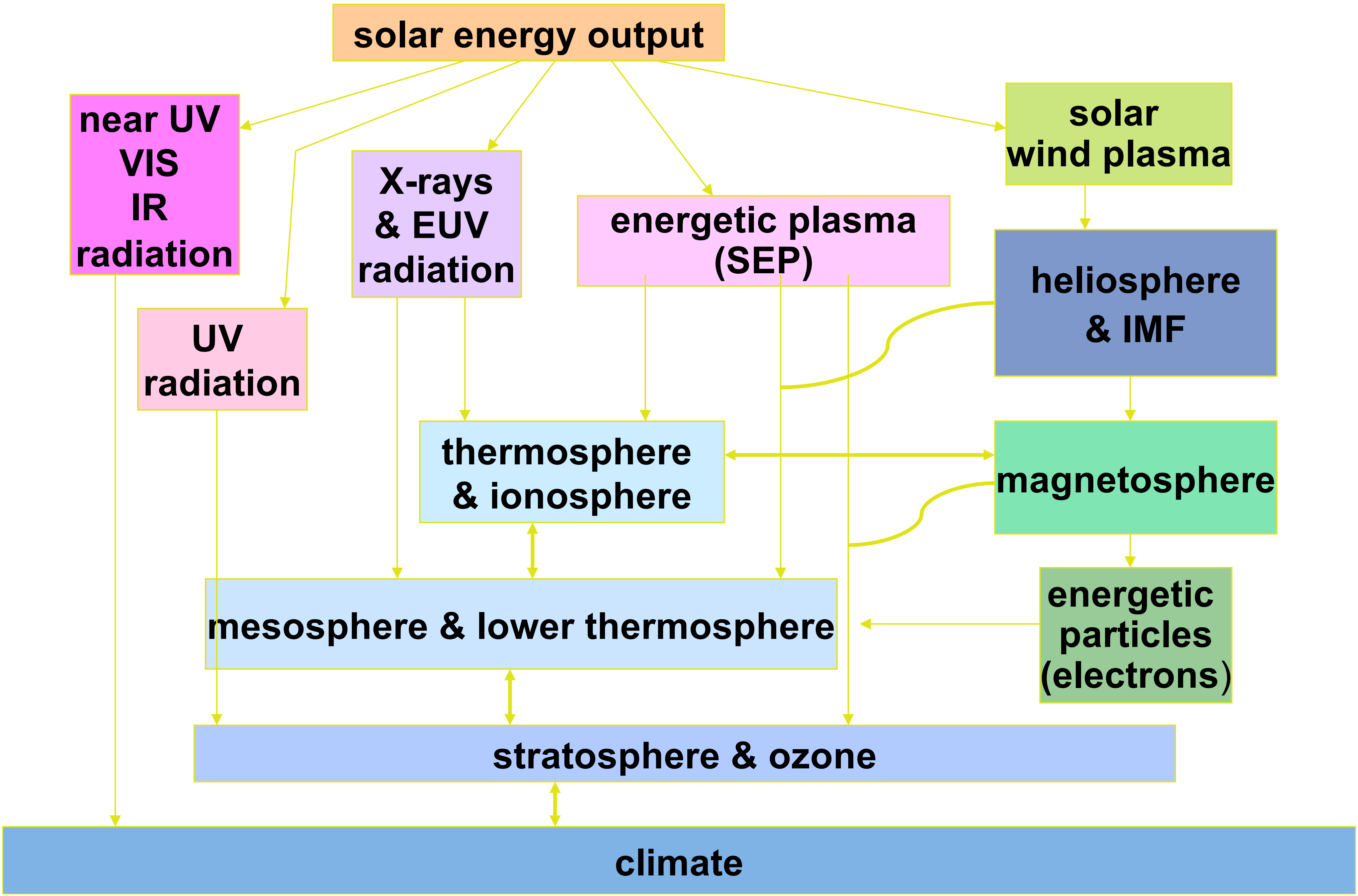
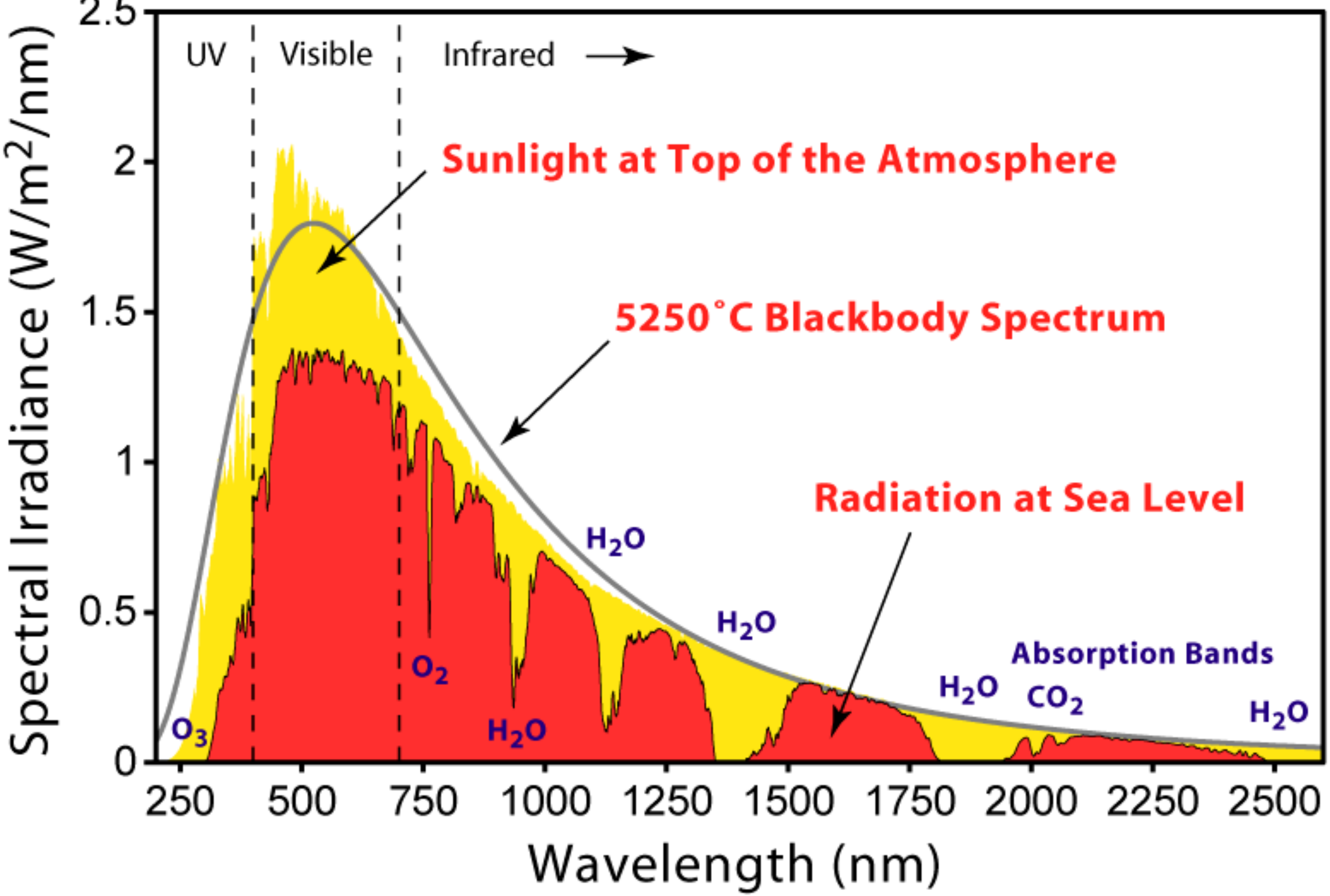

Thermonuclear Energy from the Sun
Convection + Rotation
Dynamo/ Mag. Field
Mass Emission
Electromagnetic Emission
Solar Wind & CIRs
CMEs
Flares
SEPs
Irradiance
ICMEs, Shocks
GCR
Magnetospheric Effects Storms/Substorms
Ionospheric Disturbances/Instabilities
Composition Change
Waves in the Middle Atmosphere
Ground/Atmospheric Effects
Tropospheric Disturbances
Climate Effects


solar energy output
near UV
VIS
IR
radiation
X-rays
& EUV
radiation
energetic plasma
(SEP)
solar
wind plasma
heliosphere
& IMF
UV
radiation
thermosphere
& ionosphere
magnetosphere
mesosphere & lower thermosphere
energetic
particles
(electrons)
stratosphere & ozone
climate

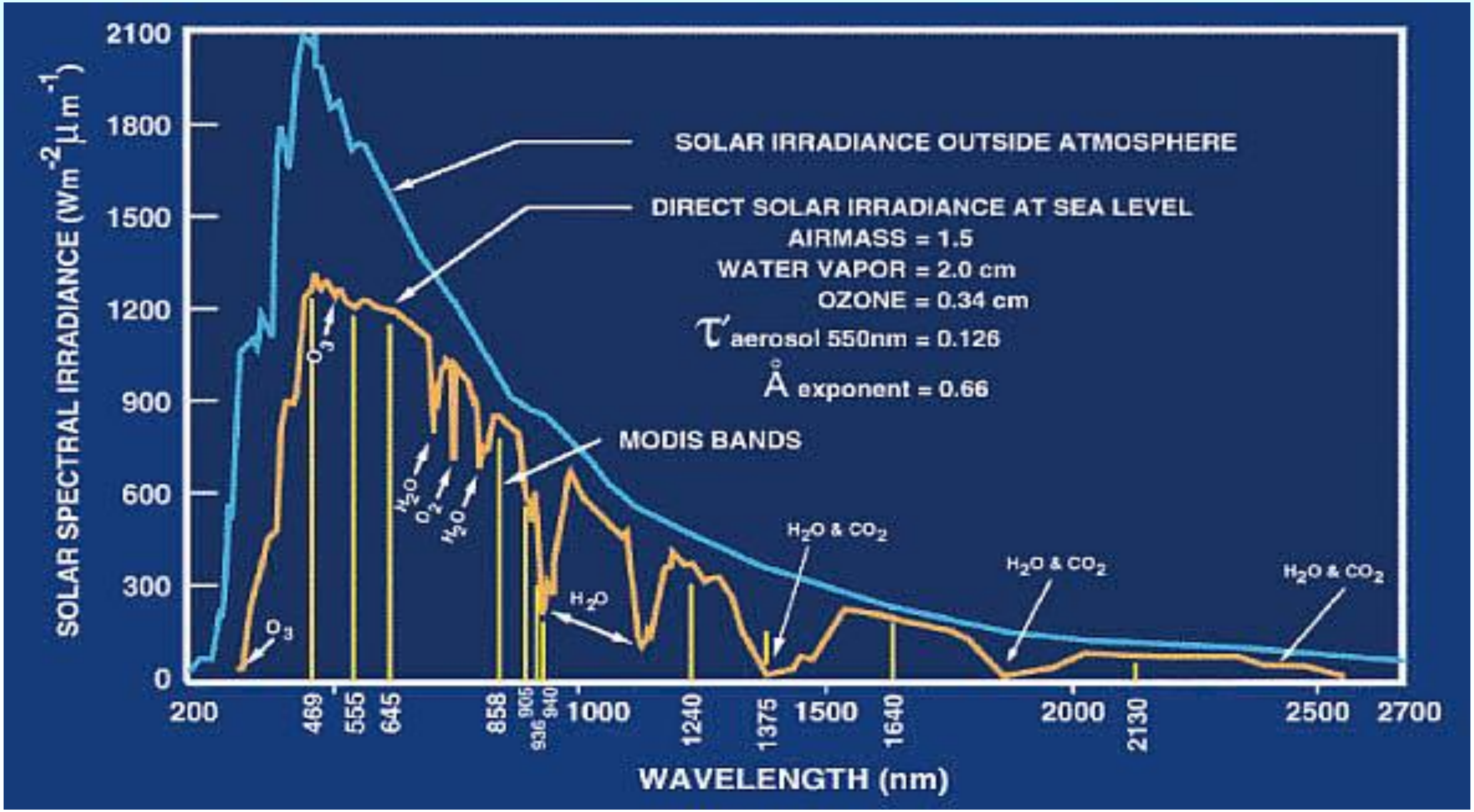
ΗΛΙΑΚΗ ΜΕΤΑΒΛΗΤΟΤΗΤΑ

Η περιοχή του ορατού μέρους του ηλιακού φάσματος (που συνεισφέρει το μεγαλύτερο μέρος ενέργειας που προσπίπτει στη Γη) παρουσιάζει τη μικρότερη μεταβλητότητα (0,1% κατά τη διάρκεια του κύκλου 21, μεταξύ ελάχιστου και μέγιστου).

Solar Radiation Spectrum



Solar spectrum

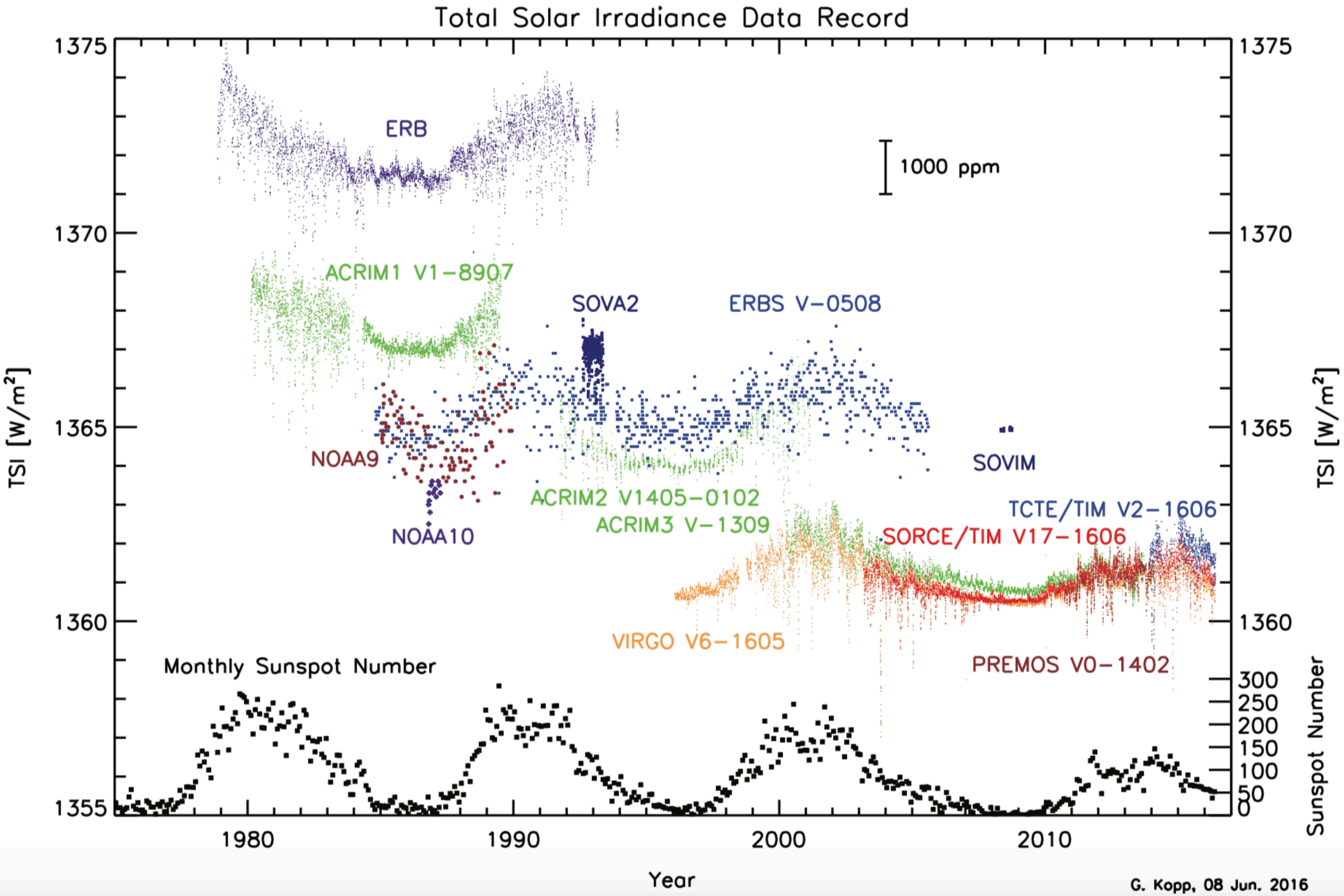


Solar irradiance at Earth's surface:

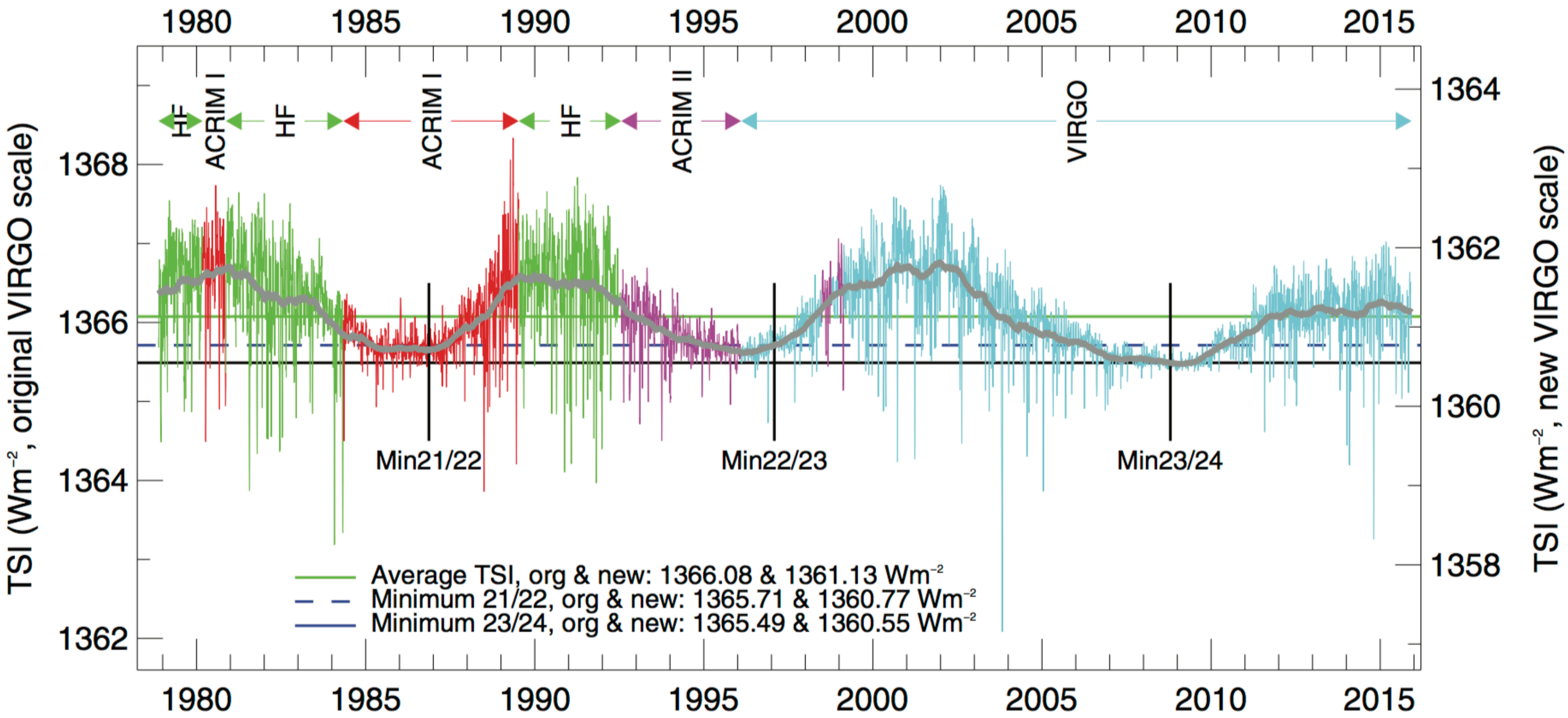
52-55 % infrared (above 700 nm)

42-43 % visible (400 to 700 nm)

3-5% UV (below 400 nm)


Total Solar Irradiance Data Record
1375
1370
1365
1360
1355
TSI [W/m²]
ERB
1000 ppm
ACRIM1 V1−8907
SOVA2
ERBS V−0508
NOAA9
SOVIM
ACRIM2 V1405−0102
TCTE/TIM V2−1606
NOAA10
ACRIM3 V−1309
SORCE/TIM V17−1606
VIRGO V6−1605
PREMOS V0−1402
Monthly Sunspot Number
300
250
200
150
100
50
0
Sunspot Number
1980
1990
2000
2010
Year
G. Kopp, 08 Jun. 2016

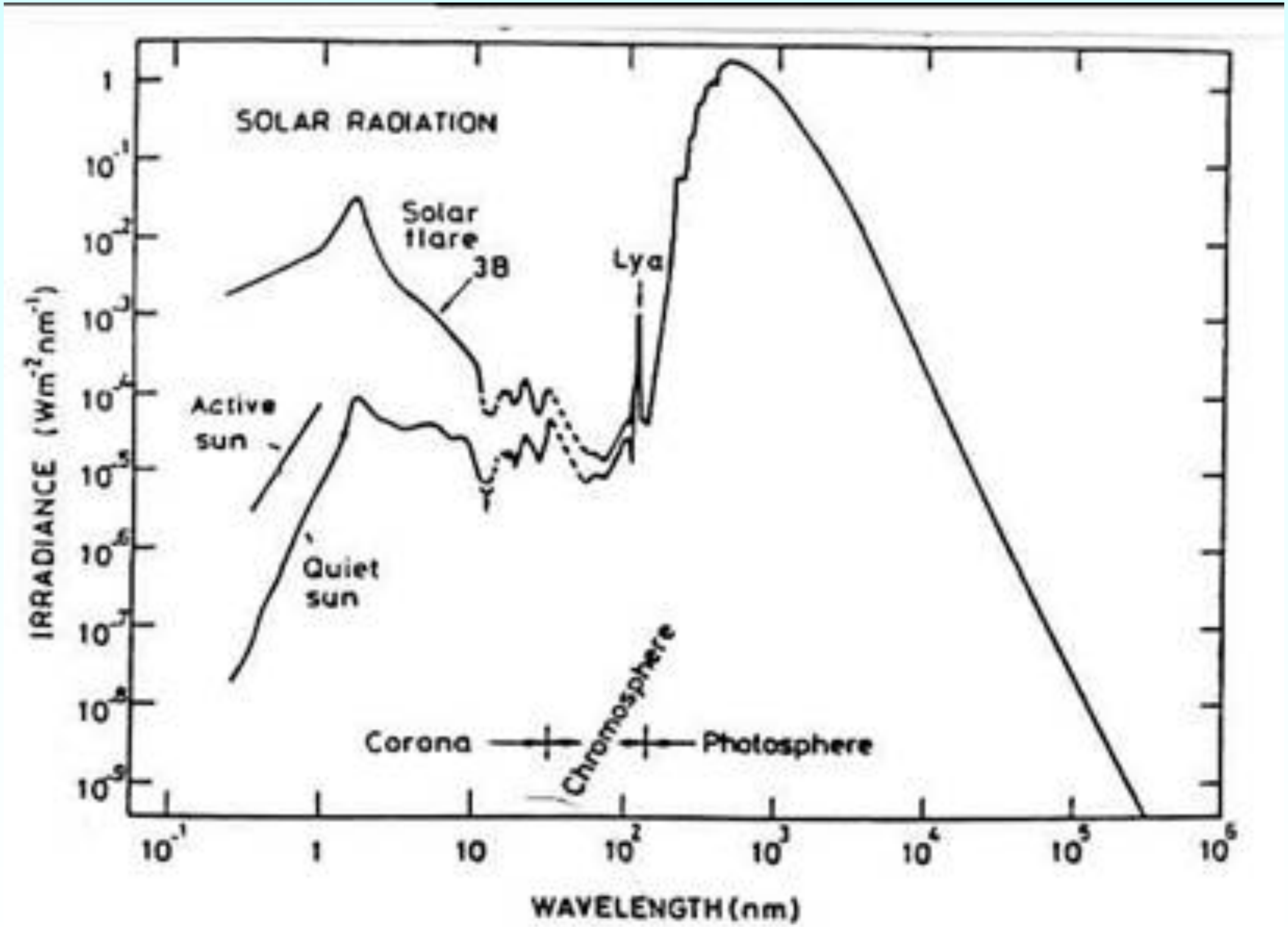
PMOD TSI Composite



ΗΛΙΑΚΗ ΜΕΤΑΒΛΗΤΟΤΗΤΑ

Η περιοχή του ορατού μέρους του ηλιακού φάσματος (που συνεισφέρει το μεγαλύτερο μέρος ενέργειας που προσπίπτει στη Γη) παρουσιάζει τη μικρότερη μεταβλητότητα (0,1% κατά τη διάρκεια του κύκλου 21).

Ωστόσο στην περιοχή συχνοτήτων των ακτίνων Χ, η ροή ακτινοβολίας μπορεί να μεταβληθεί κατά αρκετές τάξεις μεγέθους στη διάρκεια εκλάμψεων.



SOLAR RADIATION
Solar flare
3B
Lyα
Active sun
Quiet sun
Corona
Chromosphere
Photosphere
IRRADIANCE (Wm^{-2}nm^{-1})
WAVELENGTH (nm)

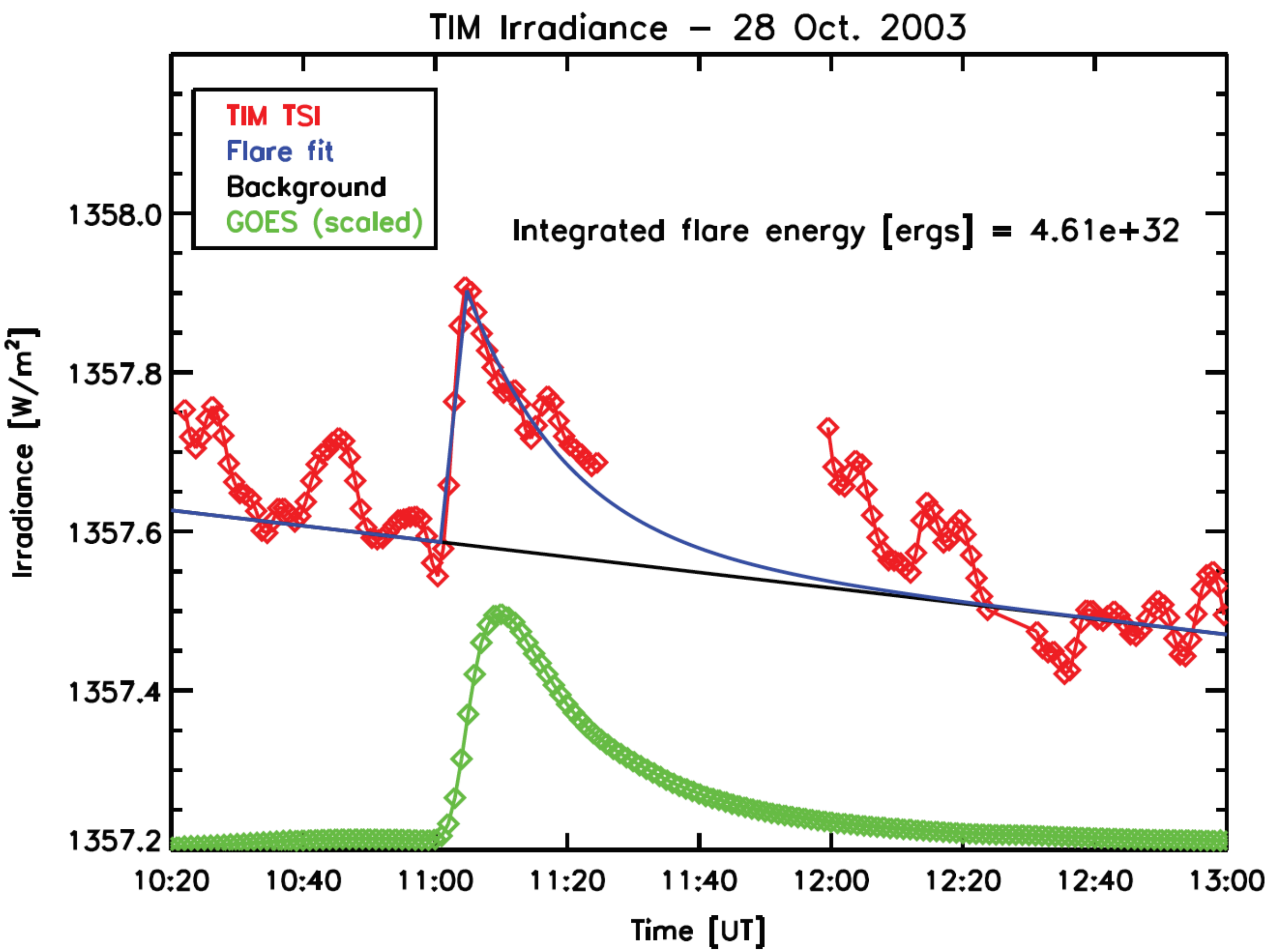
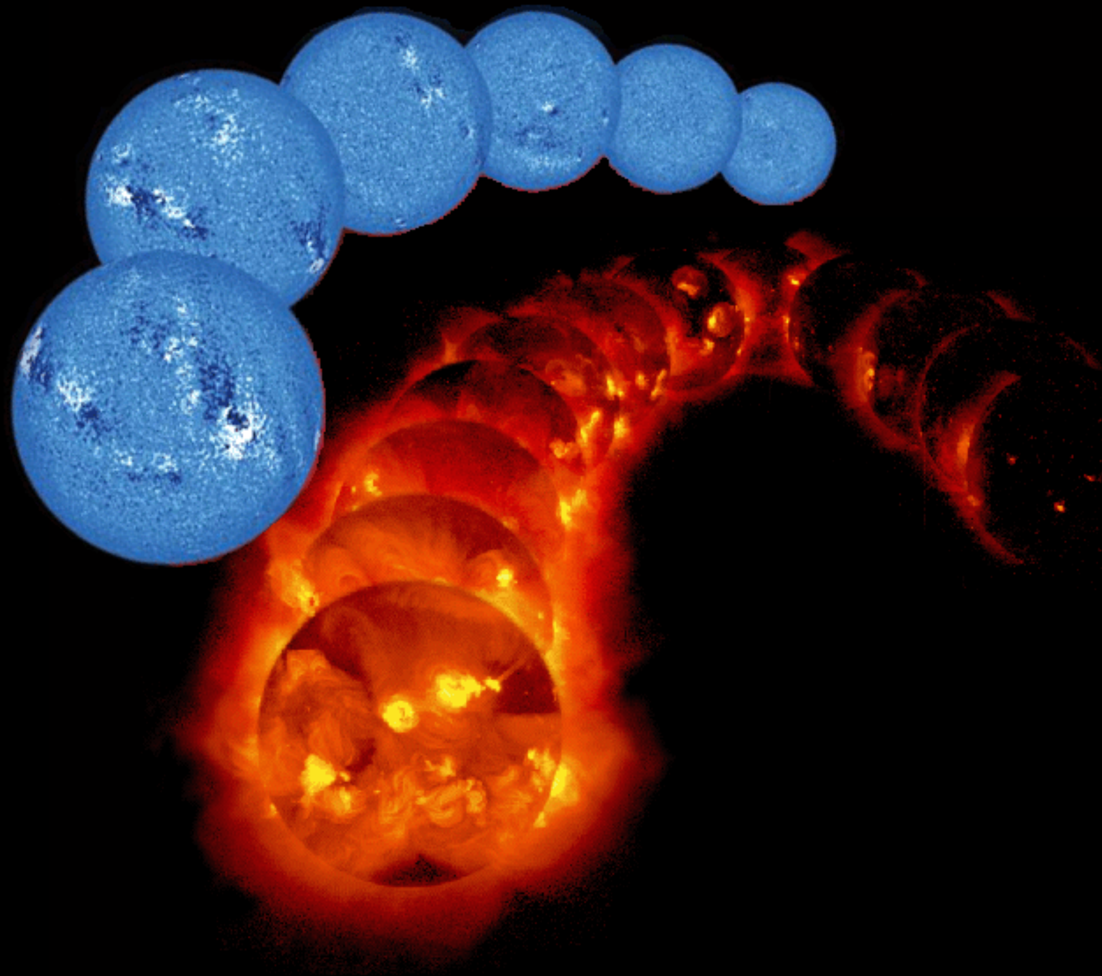


Fig. 4. The X17 flare on 28 October 2003 caused an abrupt, short-duration 0.028% increase in the TSI. A time-integration of a fit of the flare's abrupt increase and subsequent decay (blue) to TSI (red) shows a net radiant-energy release of 4.6×10^{25} J for this flare (from Kopp et al. 2005).

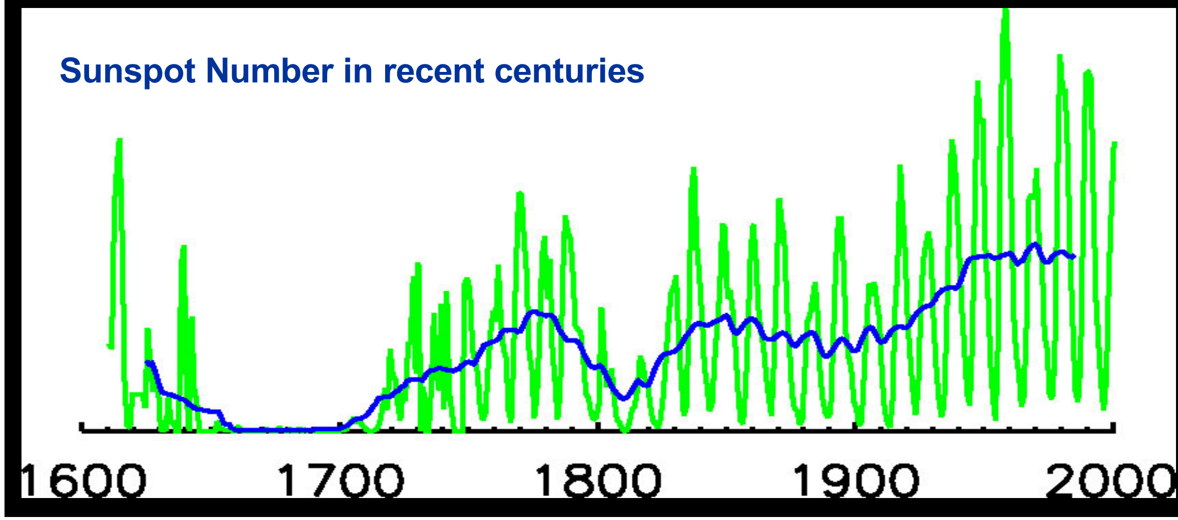
ΗΛΙΑΚΗ ΜΕΤΑΒΛΗΤΟΤΗΤΑ

Η μεταβλητότητα στη ροή UV και ακτίνων Χ σχετίζεται με τις μεταβολές του μαγνητικού πεδίου του Ήλιου, που με τη σειρά του οφείλεται στο ηλιακό δυναμό.

The solar dynamo is responsible for the 11-year solar cycle (also called the 22-year solar cycle, the sunspot cycle, magnetic cycle)

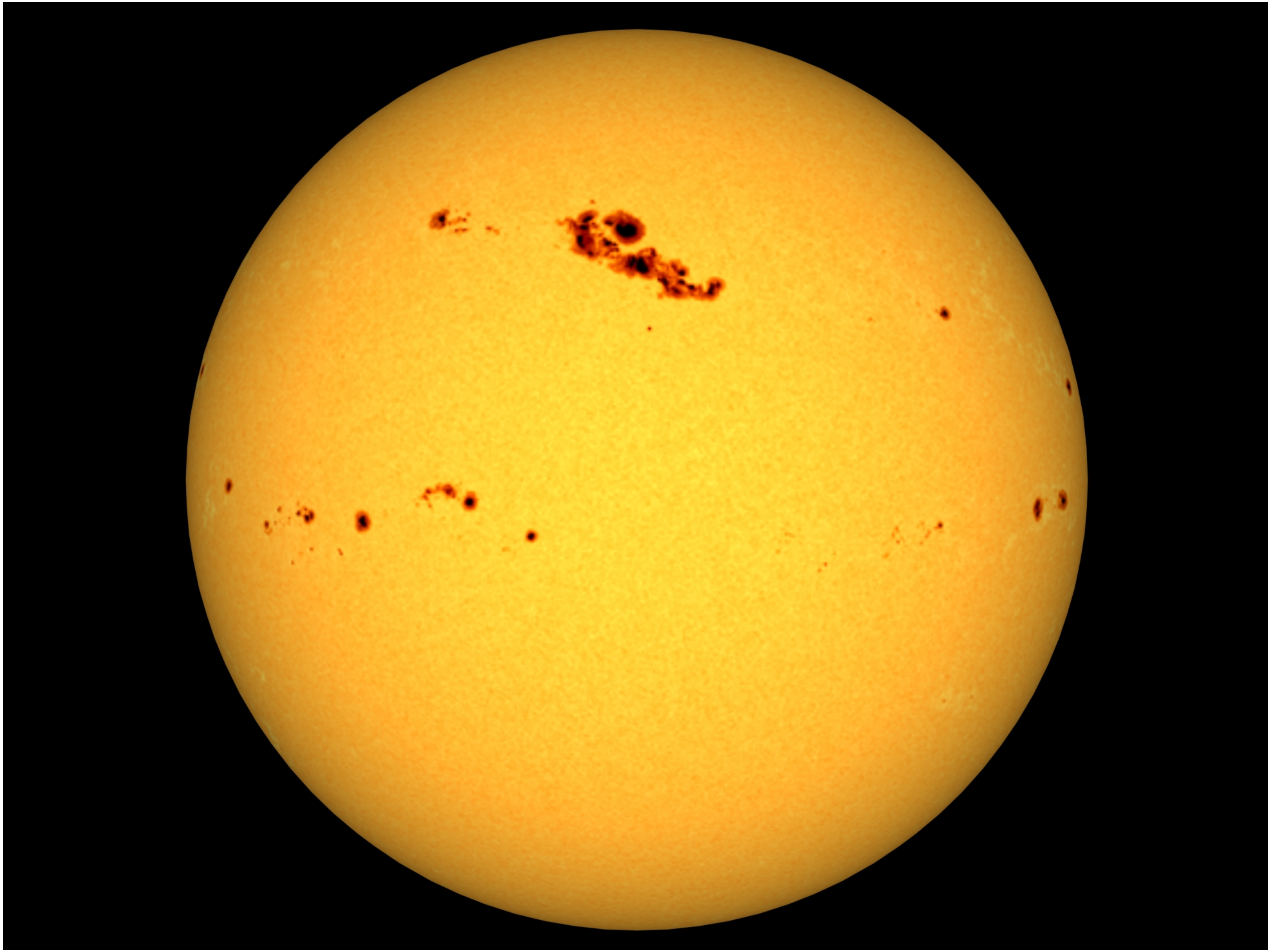


No matter how you view the Sun, it exhibits significant changes over the 11-year solar cycle. All types of solar energy output are modulated by this cycle. *In some respects*, the Sun can appear dramatically different within minutes.

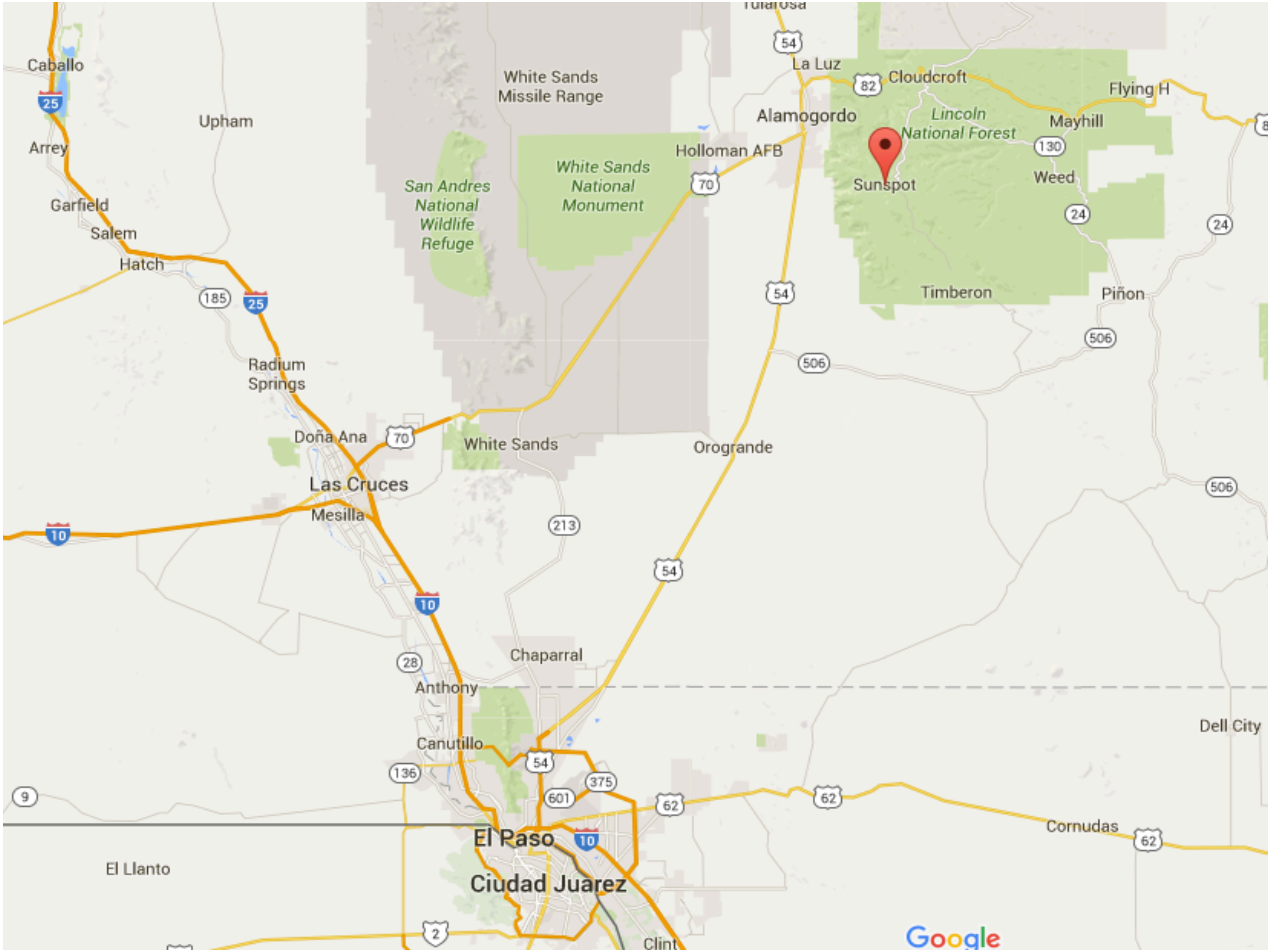


Two important points:

- The sunspot cycle itself varies, and there is evidence of significantly different behavior
- All of the types of energy input to Earth exhibit greater fluctuations on shorter timescales (flares, CMEs)

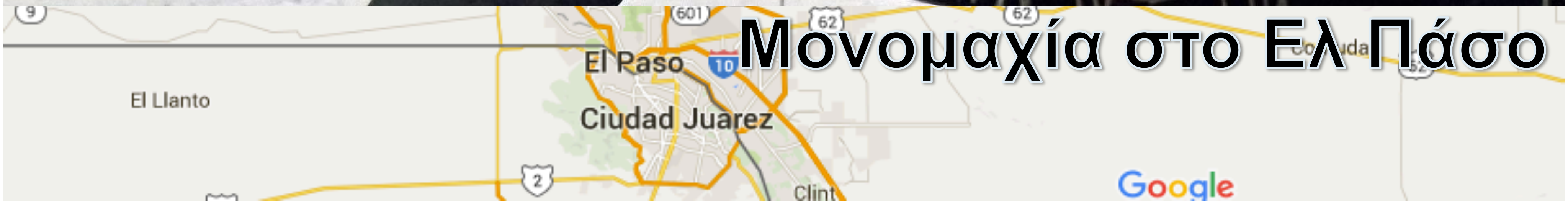



US Post Office
Sunspot
Sunspot Astronomy
& Visitor Center
Apache Point Rd



Caballo
Upham
Arrey
Garfield
Salem
Hatch
Radium Springs
Doña Ana
Las Cruces
Mesilla
White Sands Missile Range
San Andres National Wildlife Refuge
White Sands National Monument
White Sands
Holloman AFB
Alamogordo
La Luz
Cloudcroft
Lincoln National Forest
Flying H
Mayhill
Weed
Sunspot
Timberon
Piñon
Orogrande
Chaparral
Anthony
Canutillo
El Paso
Ciudad Juarez
El Llanto
Clint
Cornudas
Dell City
25
185
70
10
213
54
82
130
24
506
28
136
9
601
375
62
2
Google

Μονομαχία στο Ελ Πάσο

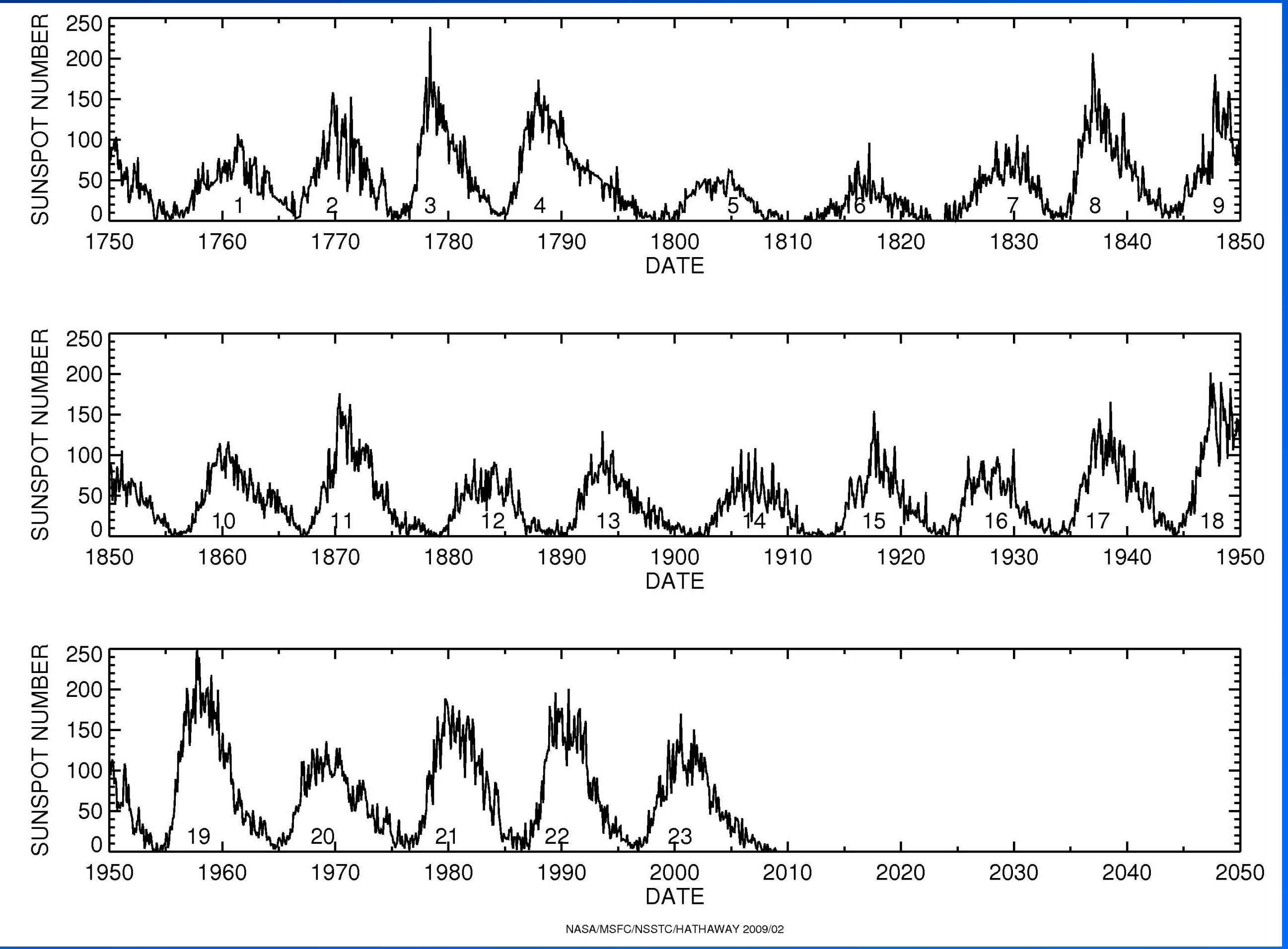


Staring at the Sun Since 1947

Holiday Hours: Dunn Solar Telescope will be closed Dec 25th-30th and Jan 1st. The Visitors Center will be closed Dec 24th & 25th.

Sunspot Cycle or Wolf Cycle

[Schwabe 1843]



The average cycle lasts about 11 years, but with a range of 9 to 14.
The average amplitude is about 100, but with a range of 50 to 200.

Sunspot Cycle or Wolf Cycle

[Schwabe 1843]

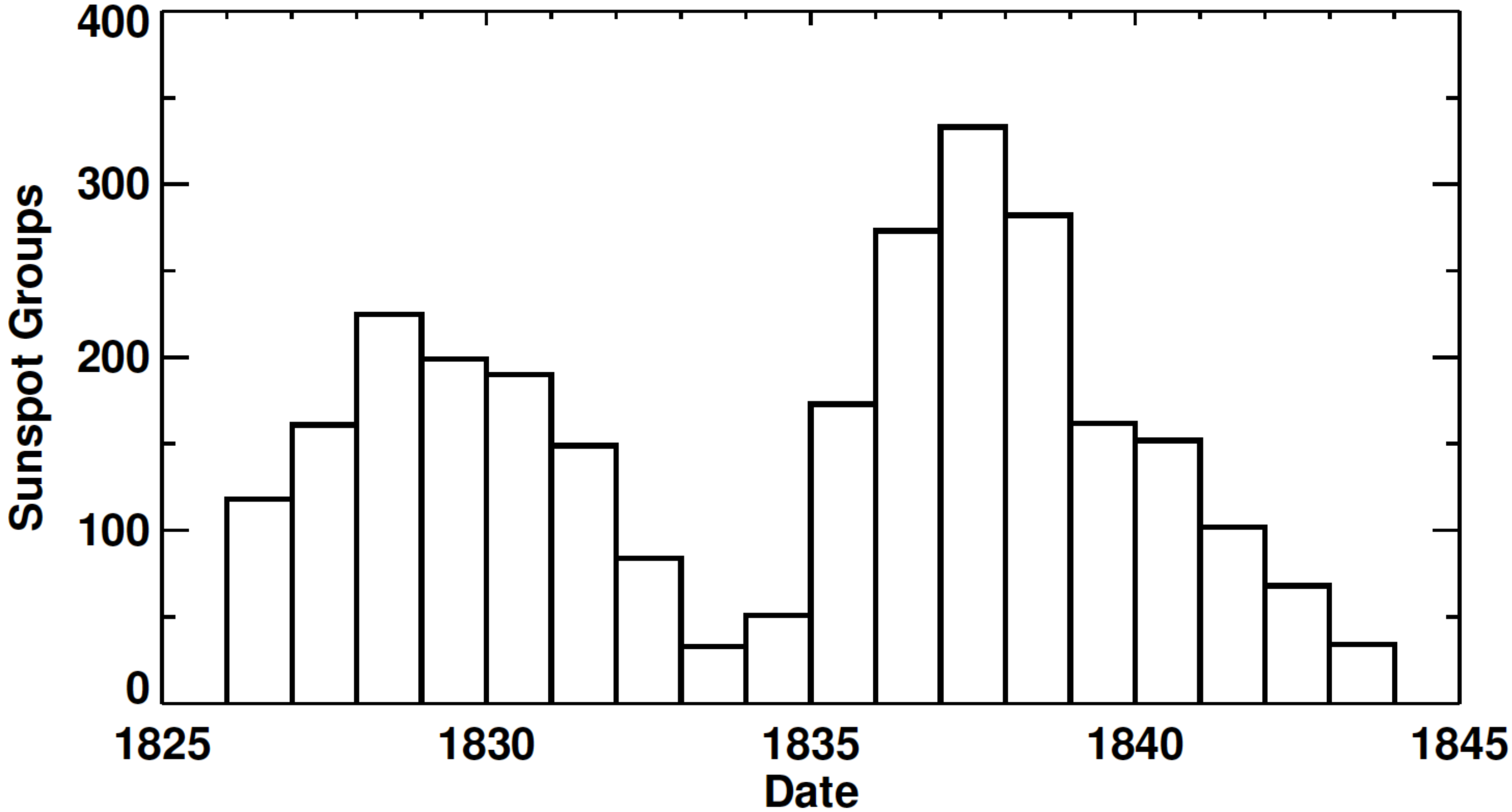


Figure 1: Sunspot groups observed each year from 1826 to 1843 by Heinrich Schwabe (1844). These data led Schwabe to his discovery of the sunspot cycle.

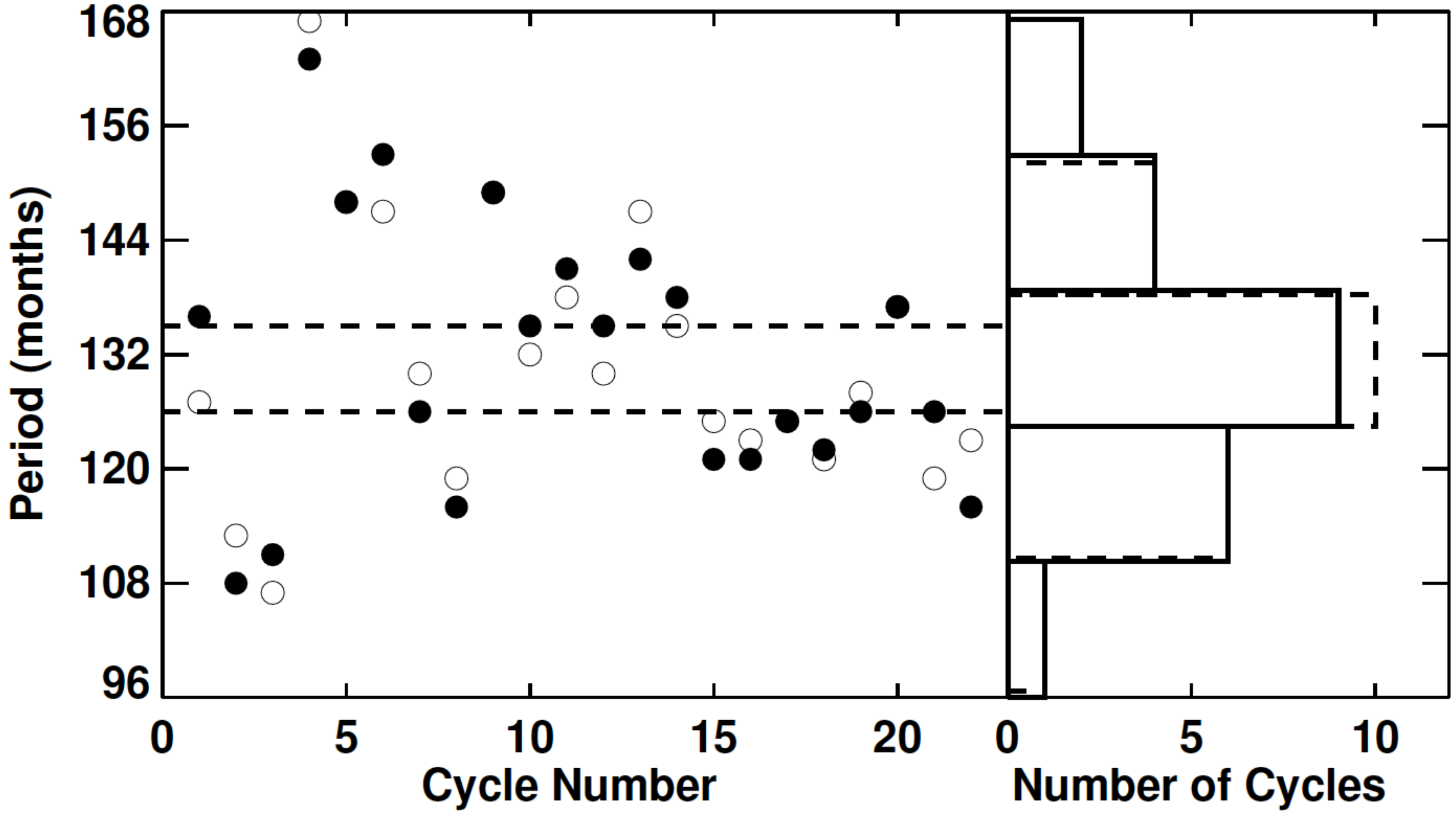
Διάρκεια πρόσφατων κύκλων

21: 10.5 έτη (Μαρ1976-Σεπ1986)

22: 9.9 έτη (Σεπ1986-Αυγ1996)

23: 12.3 έτη (Αυγ1996-Δεκ2008)

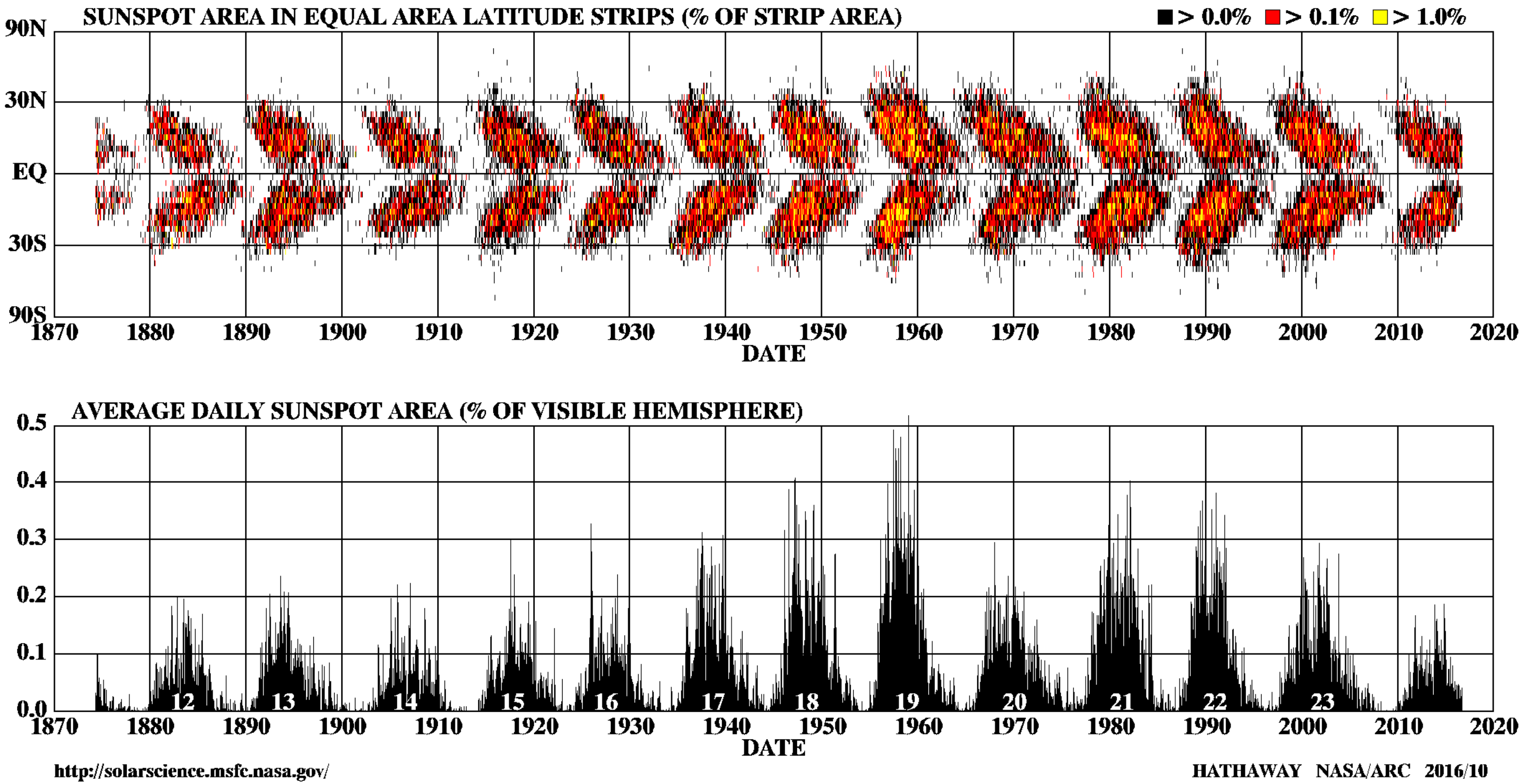
24: 10.1 έτη; (Δεκ2008-Φεβ2019;) – ενδέχεται να έχει ήδη αρχίσει ο 25



168
156
144
132
120
108
96
Period (months)
0
5
10
15
20
Cycle Number
0
5
10
Number of Cycles

Equatorward Drift – Spörer's Law

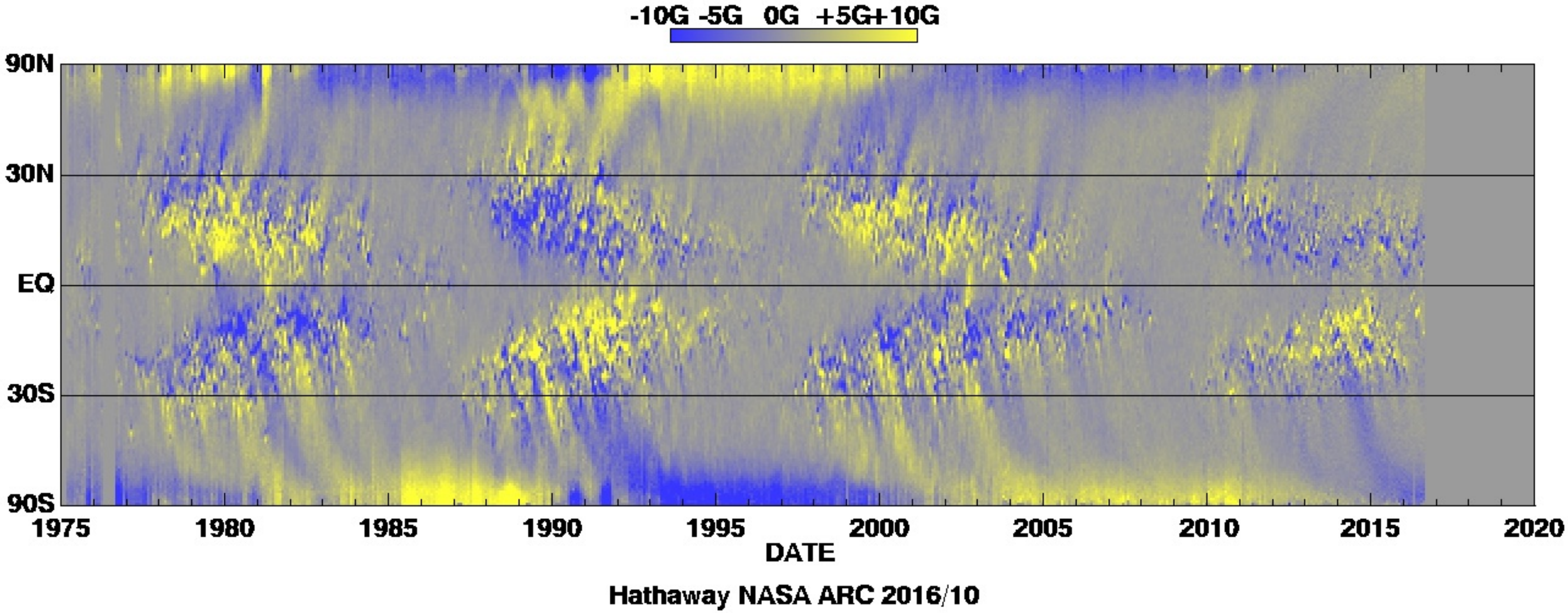
DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS



Sunspots appear in two bands on either side of the equator. These bands drift toward the equator as the cycle progresses and cycles overlap by 2-3 years at minimum.

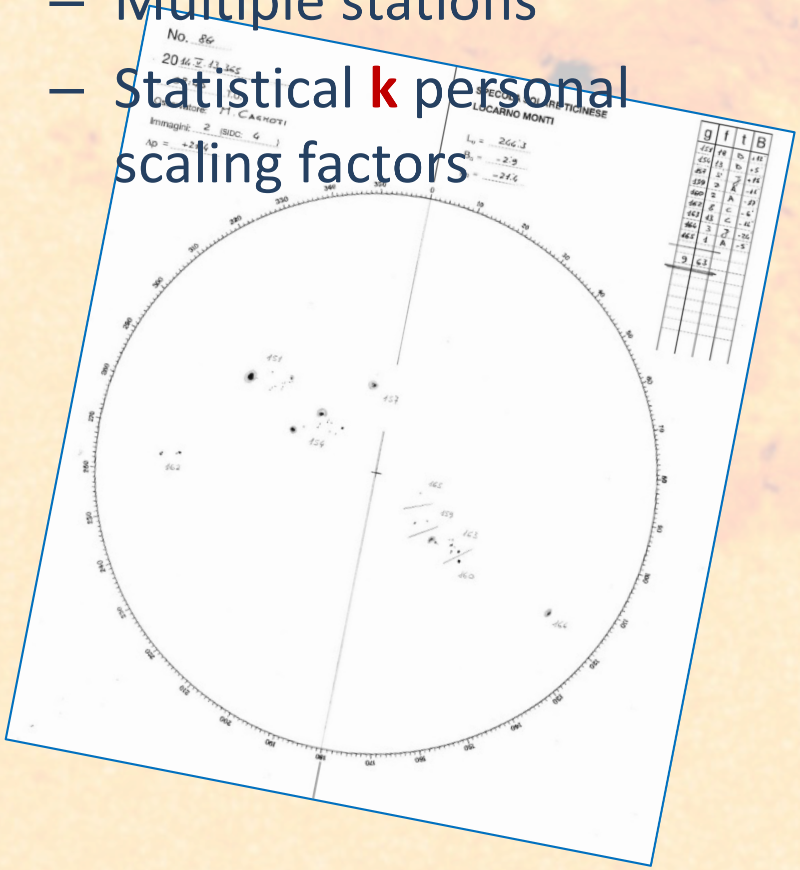
Dryden Flight Research Center Computer Room, 1949

"By 1880, **all of the computers** working at the Harvard Observatory were women"


-10G -5G 0G +5G+10G
90N
30N
EQ
30S
90S
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
DATE
Hathaway NASA ARC 2016/10

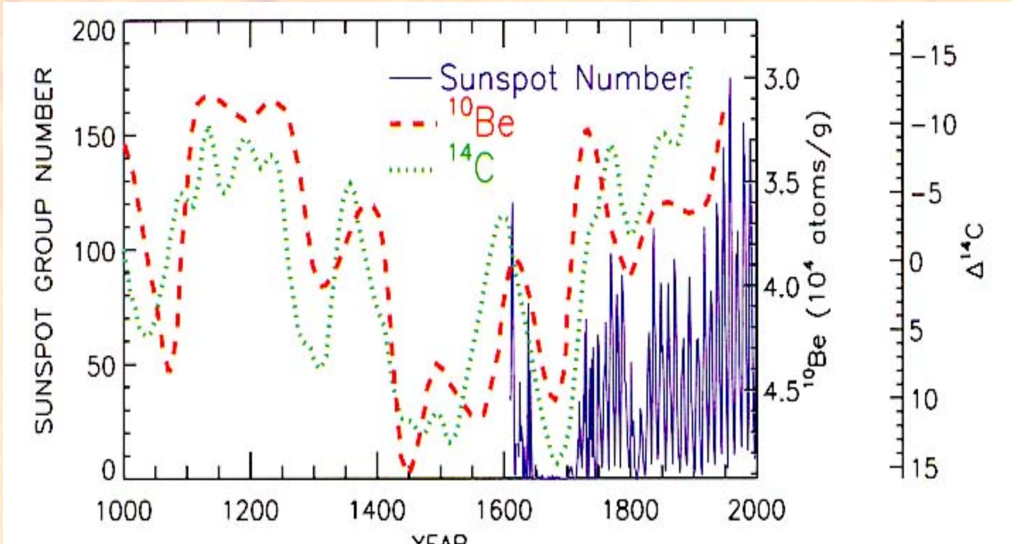
International Sunspot Number: definition

- Wolf Number *(Wolf 1851)*:
  W= k (10 Ng + Ns)
- ≠ **Sunspot number**:
  - Multiple stations
  - Statistical **k** personal scaling factors



Wide range of applications:

- Constraint for **solar dynamo models**
- Quantitative reference for s**olar irradiance** and solar wind reconstructions, **cosmogenic isotopes,** as **timebase** for Sun-driven processes
- Tracer of the long-term solar influences on Earth (**climate change, atmospheric drag, cumulative GIC effects**).



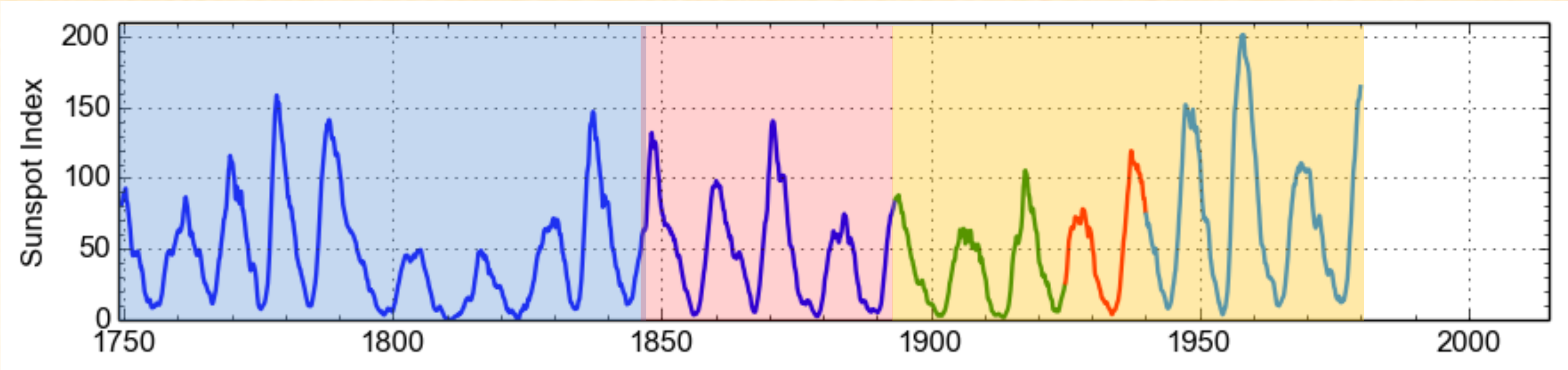
Fröhlich & Lean 2004

The International Sunspot Number is the **key indicator of solar activity.**

This is not because everyone agrees that it is the best indicator

but rather because of the length of the available record.

International Sunspot Number: a composite series



Historical reconstruction (1749-1849):

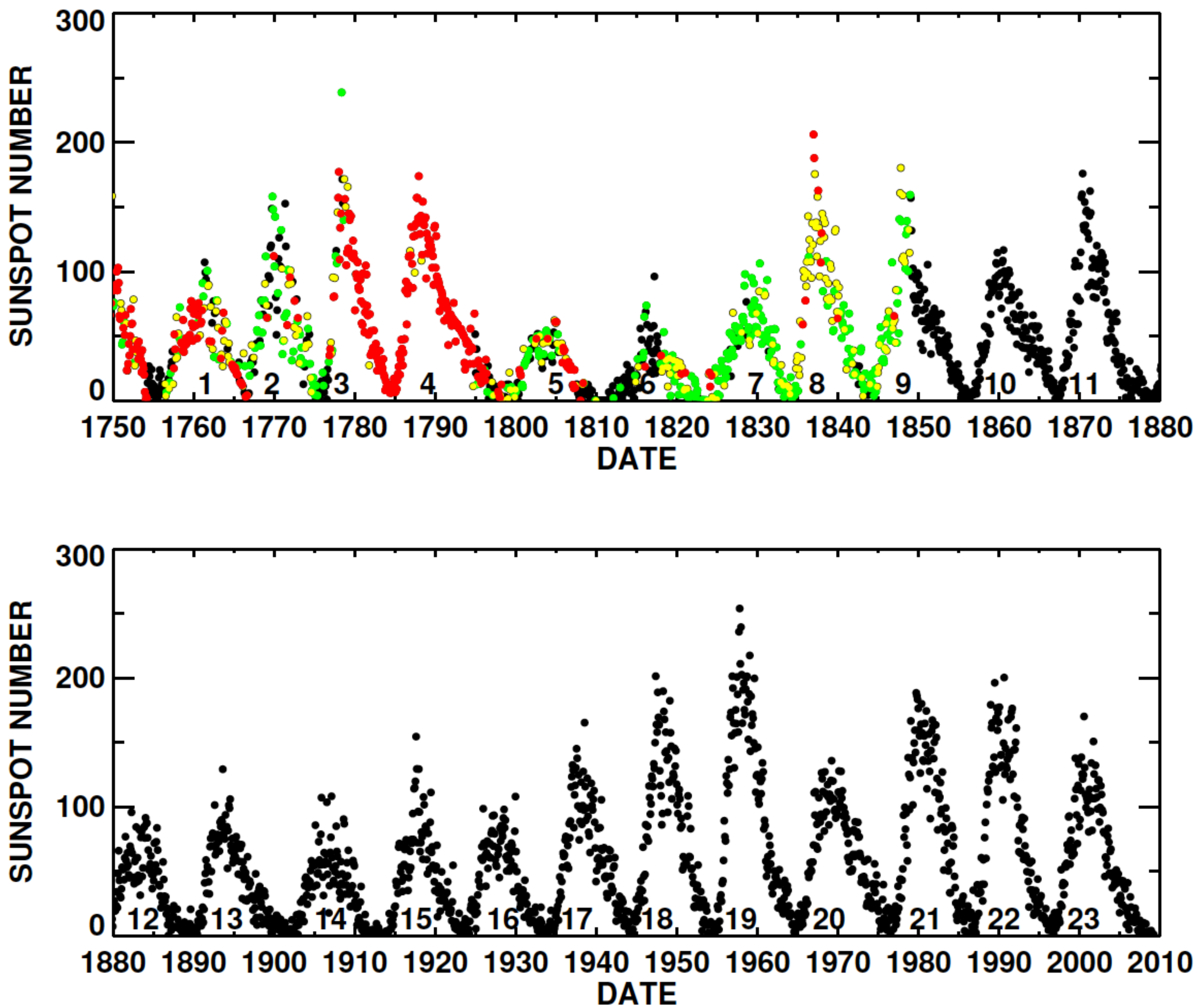
- Scale adjusted to Wolf's observations

Primary Wolf observations (1849-1893):

- Standard 83mm refractor
- Small 37 and 43 mm travel telescopes

Zürich period (1893-1980):

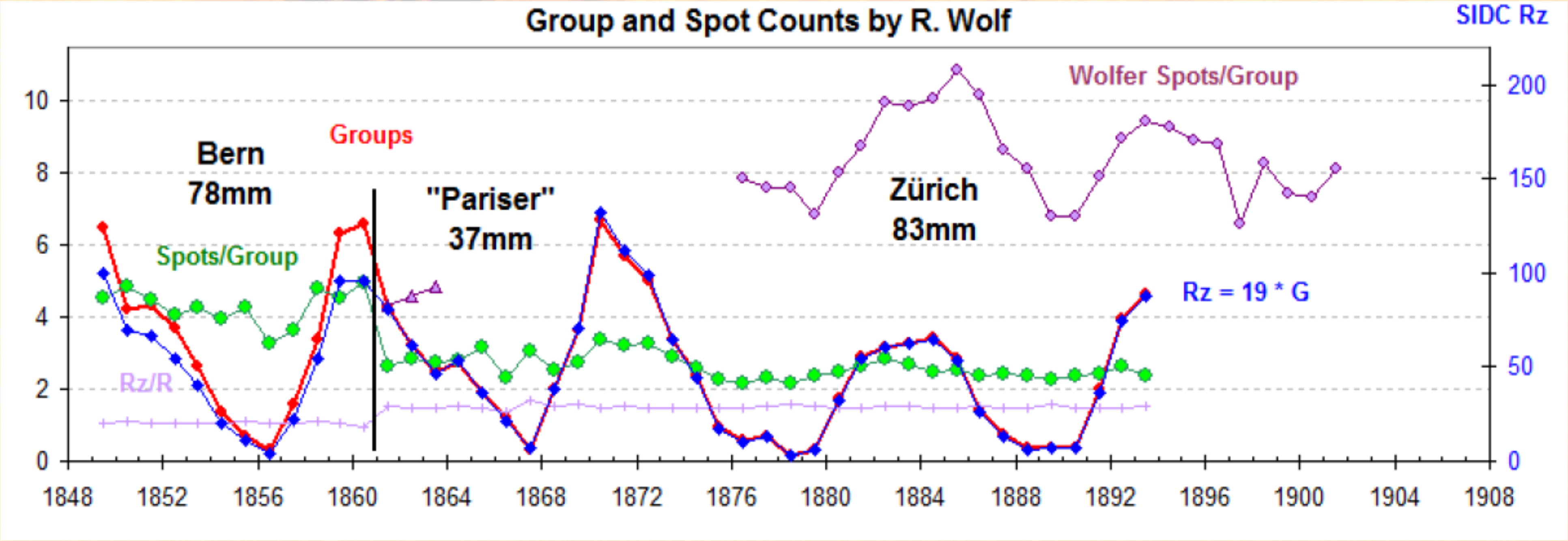
- New counting method: ⇨ **0.6 factor**
- 1955: Zürich + Specola (Locarno) stations



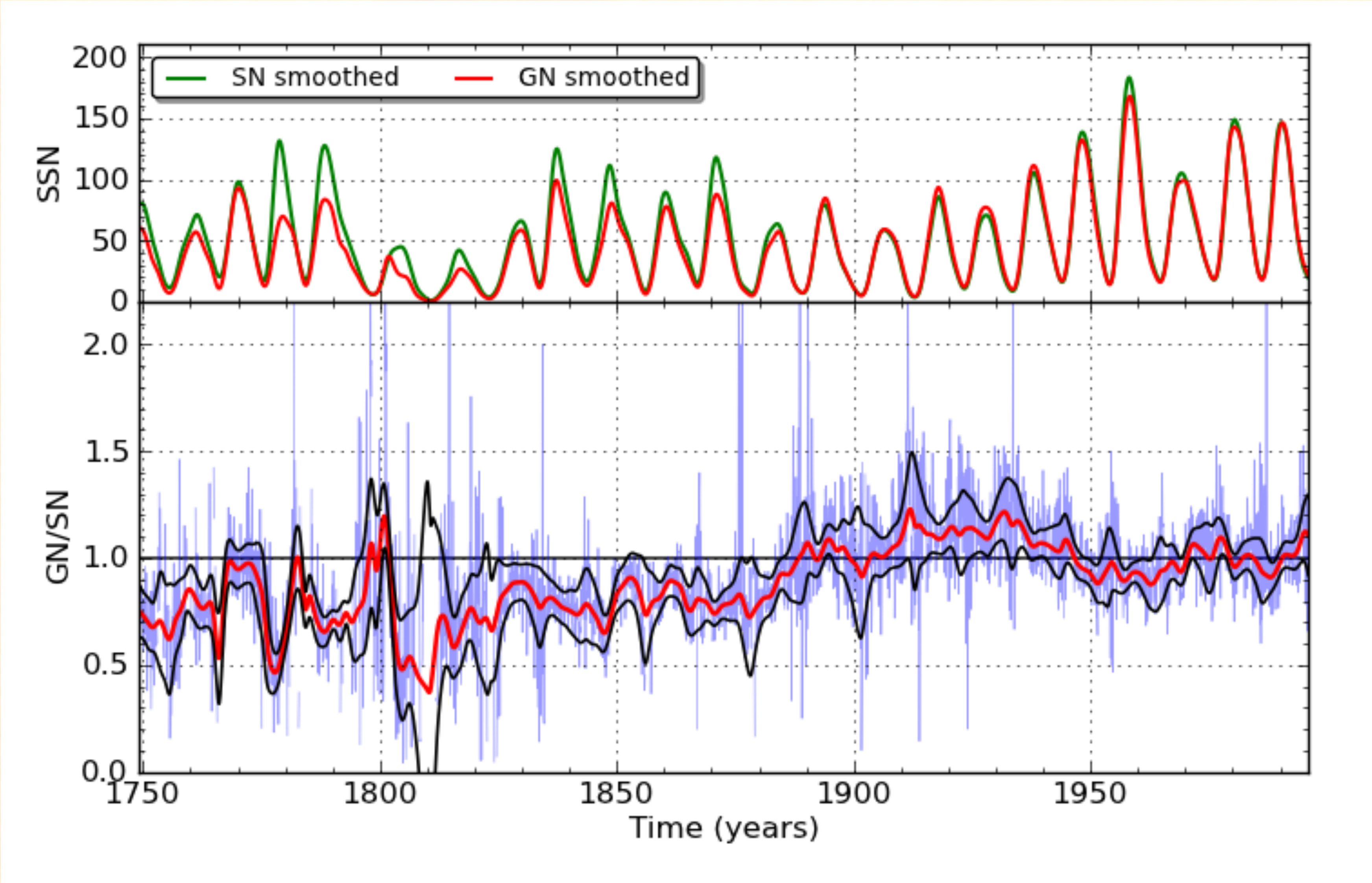
SUNSPOT NUMBER
DATE
300
200
100
0
1750
1760
1770
1780
1790
1800
1810
1820
1830
1840
1850
1860
1870
1880
1
2
3
4
5
6
7
8
9
10
11
SUNSPOT NUMBER
DATE
300
200
100
0
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
12
13
14
15
16
17
18
19
20
21
22
23

Wolf's different telescopes

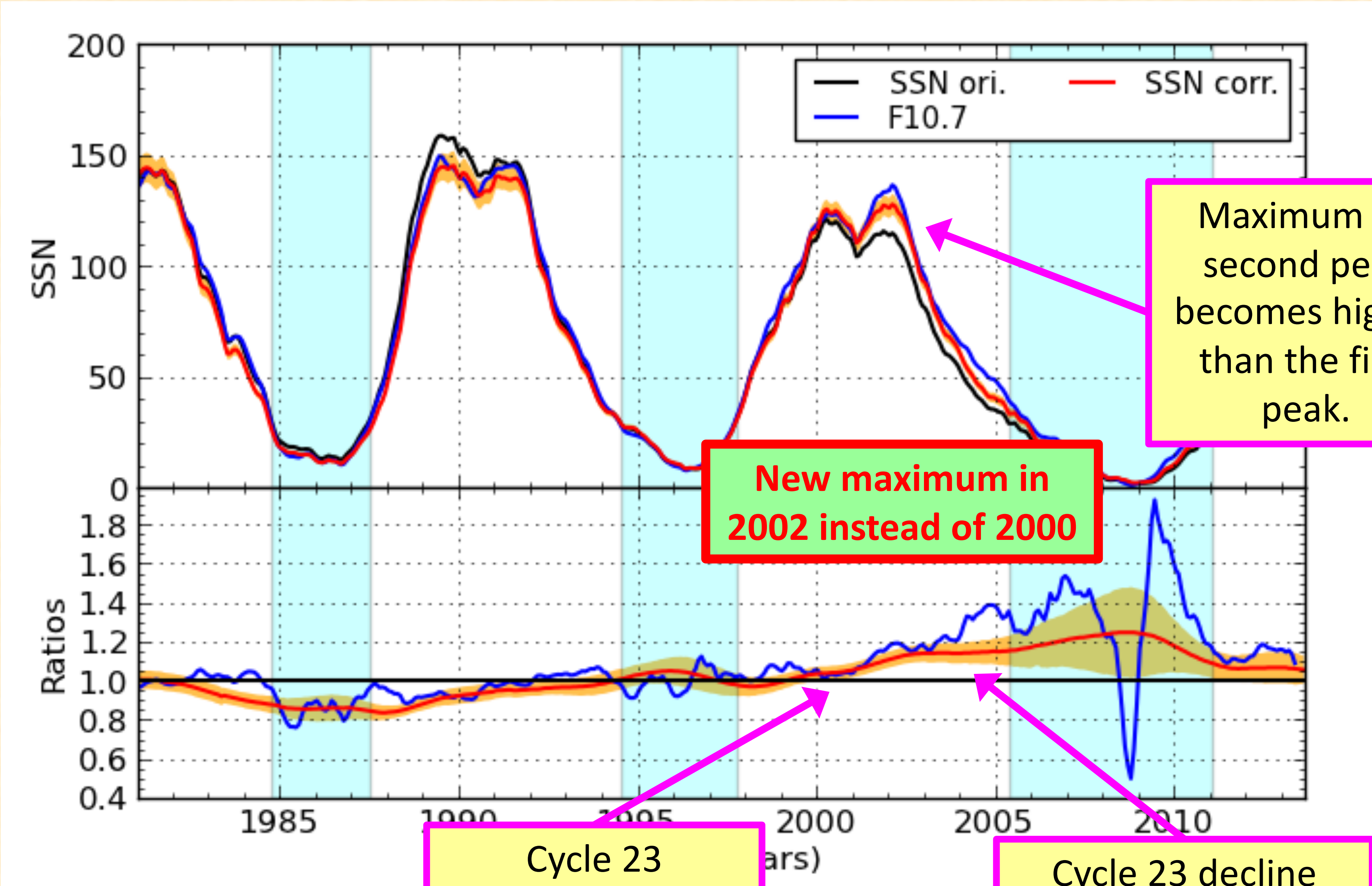
- K coefficient for 37mm "Pariser" travel telescope = 1.5 *(confirmed by current observations by Thomas Friedli, Wolf Gesellschaft, Zürich)*



SN and GN: major discrepancies



Recent cycles

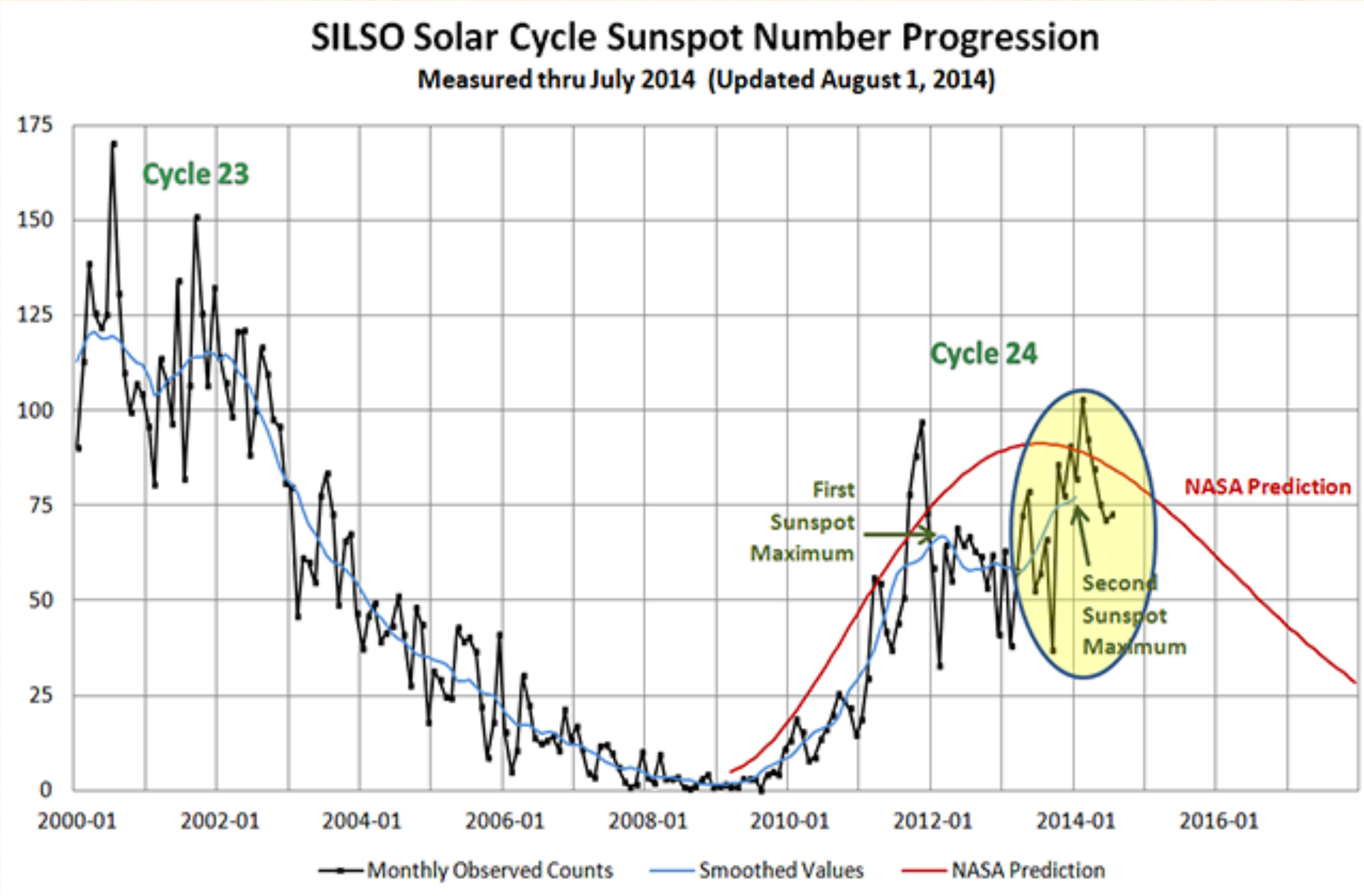


Maximum 23 second peak becomes higher than the first peak.

New maximum in 2002 instead of 2000

Cycle 23 Slightly increased (+ 5 to 10%)

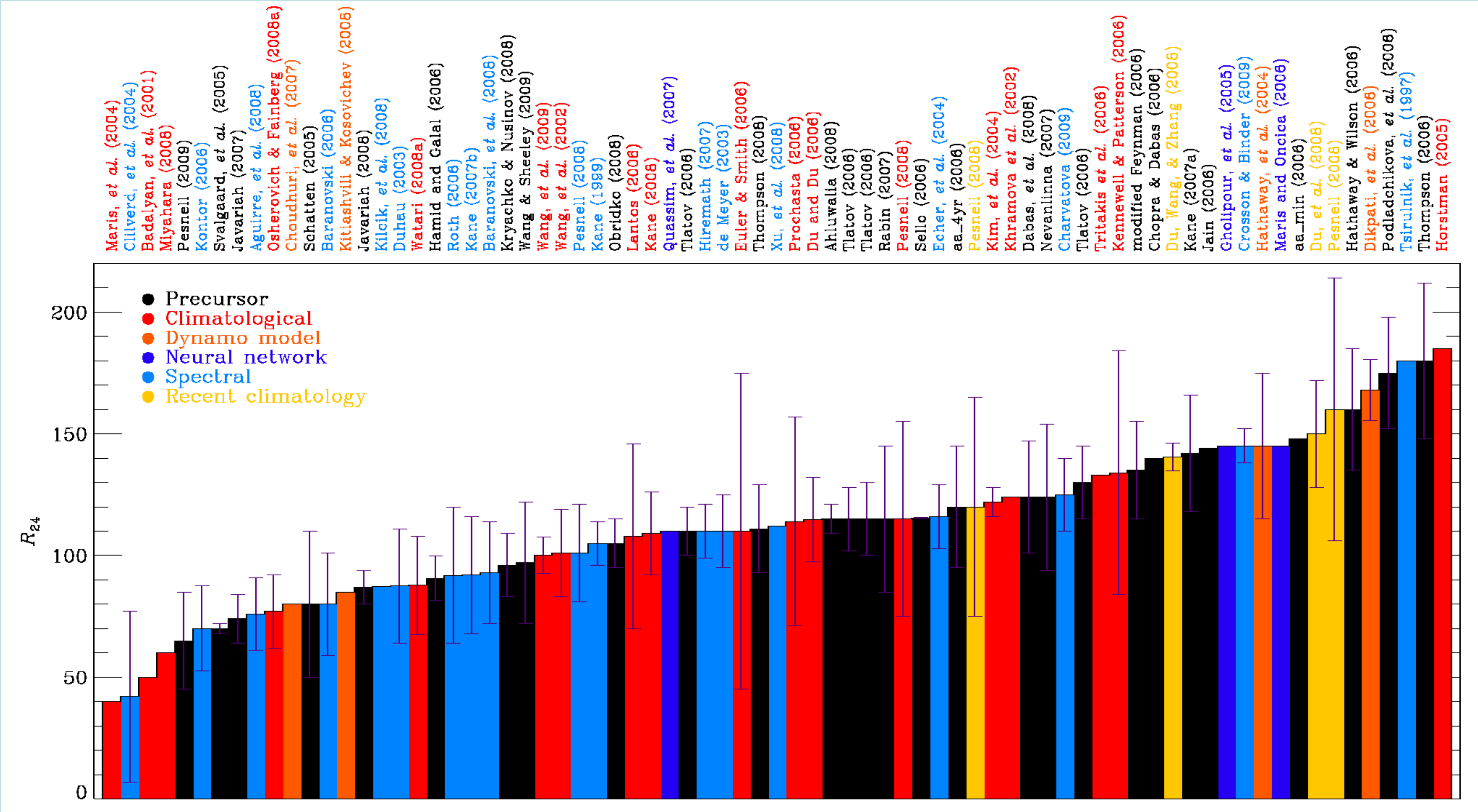
Cycle 23 decline raised by about 20%



SILSO Solar Cycle Sunspot Number Progression
Measured thru July 2014 (Updated August 1, 2014)
175
150
125
100
75
50
25
0
2000-01
2002-01
2004-01
2006-01
2008-01
2010-01
2012-01
2014-01
2016-01
Cycle 23
Cycle 24
First Sunspot Maximum
Second Sunspot Maximum
NASA Prediction
Monthly Observed Counts
Smoothed Values
NASA Prediction

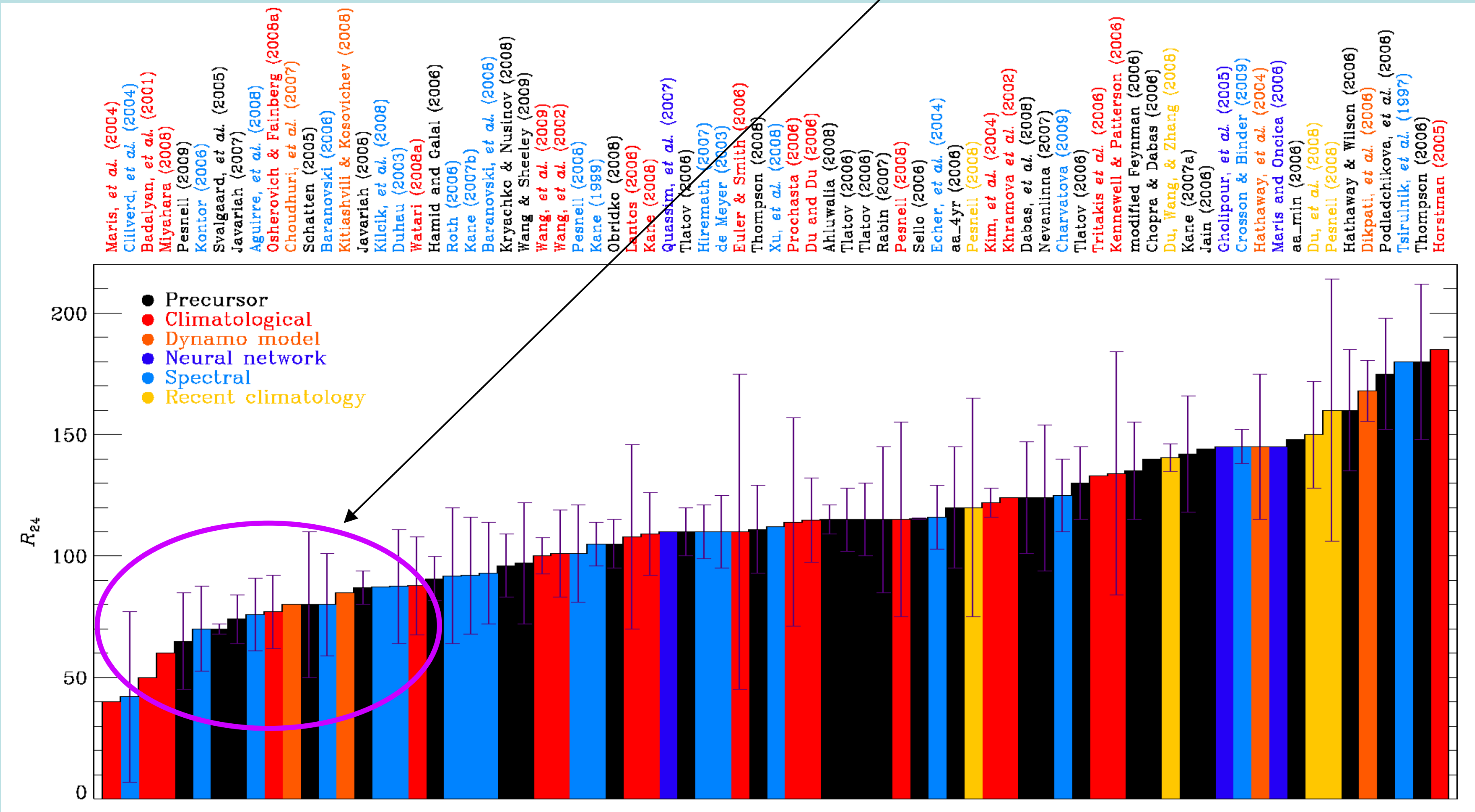
State of the Art: Predicting Cycle 24

Predictions sent to the Prediction Panel

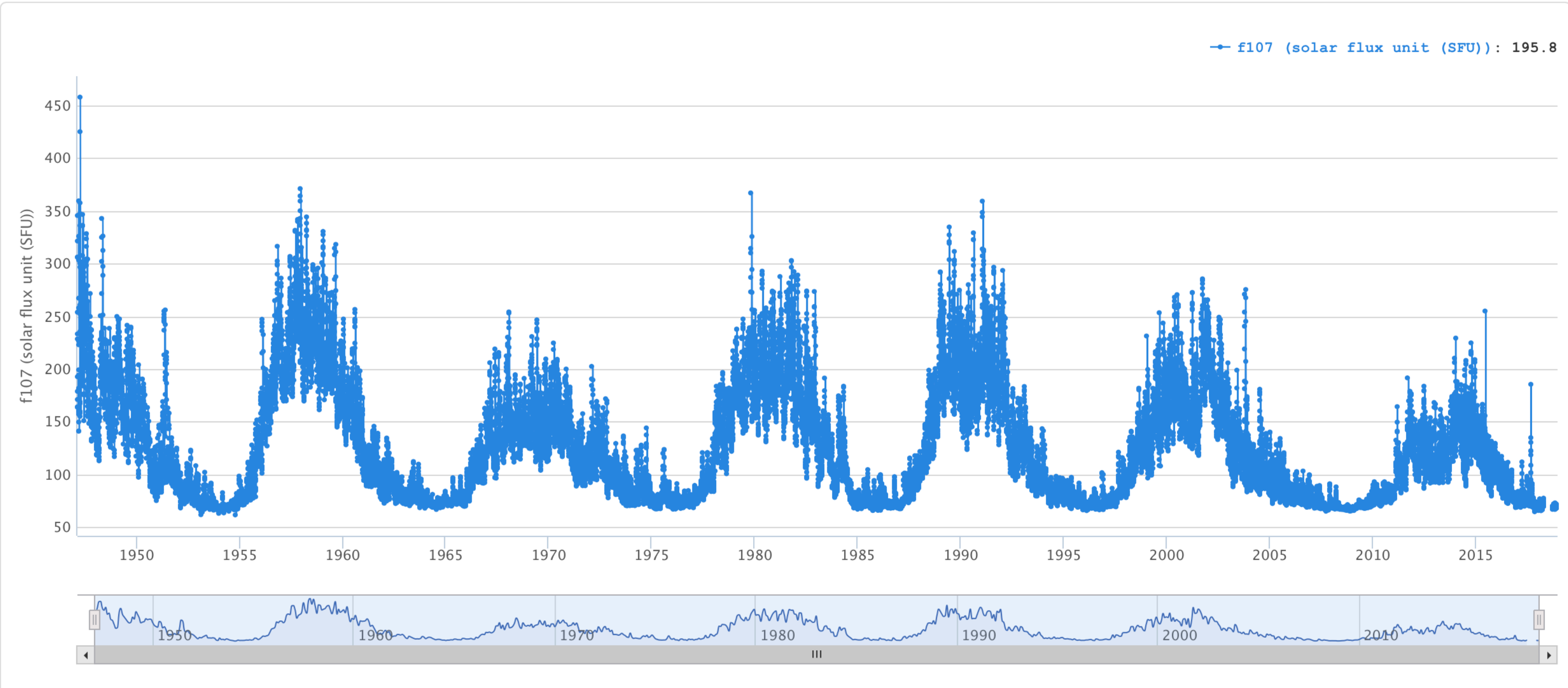


State of the Art: Predicting Cycle 24

What the Sun seems to be doing

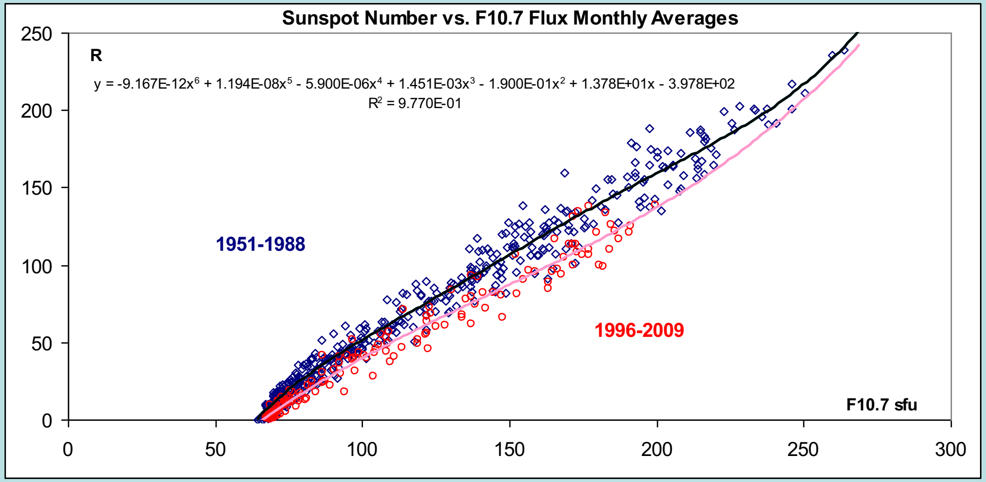


The 10.7cm Solar Flux is the disk integrated emission from the Sun at the radio wavelength of 10.7 cm (2800 MHz)
It is a simpler measure than subjectively counting sunspots and can be performed during cloudy weather



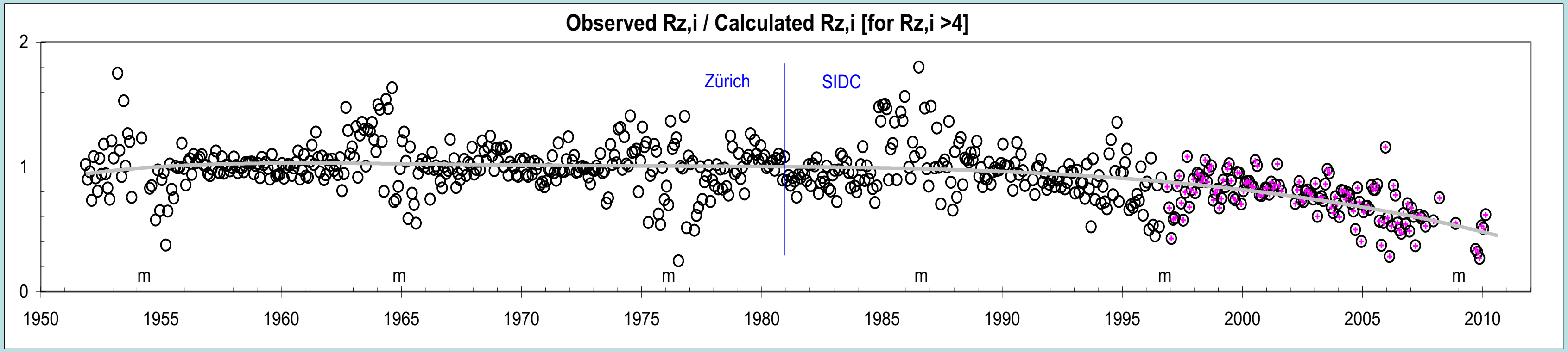
http://lasp.colorado.edu/lisird/data/noaa_radio_flux/

F10.7 Flux Relationship with Sunspot Numbers is Changing



Ratio of observed SSN and SSN computed from F10.7 using formula for 1951-1988

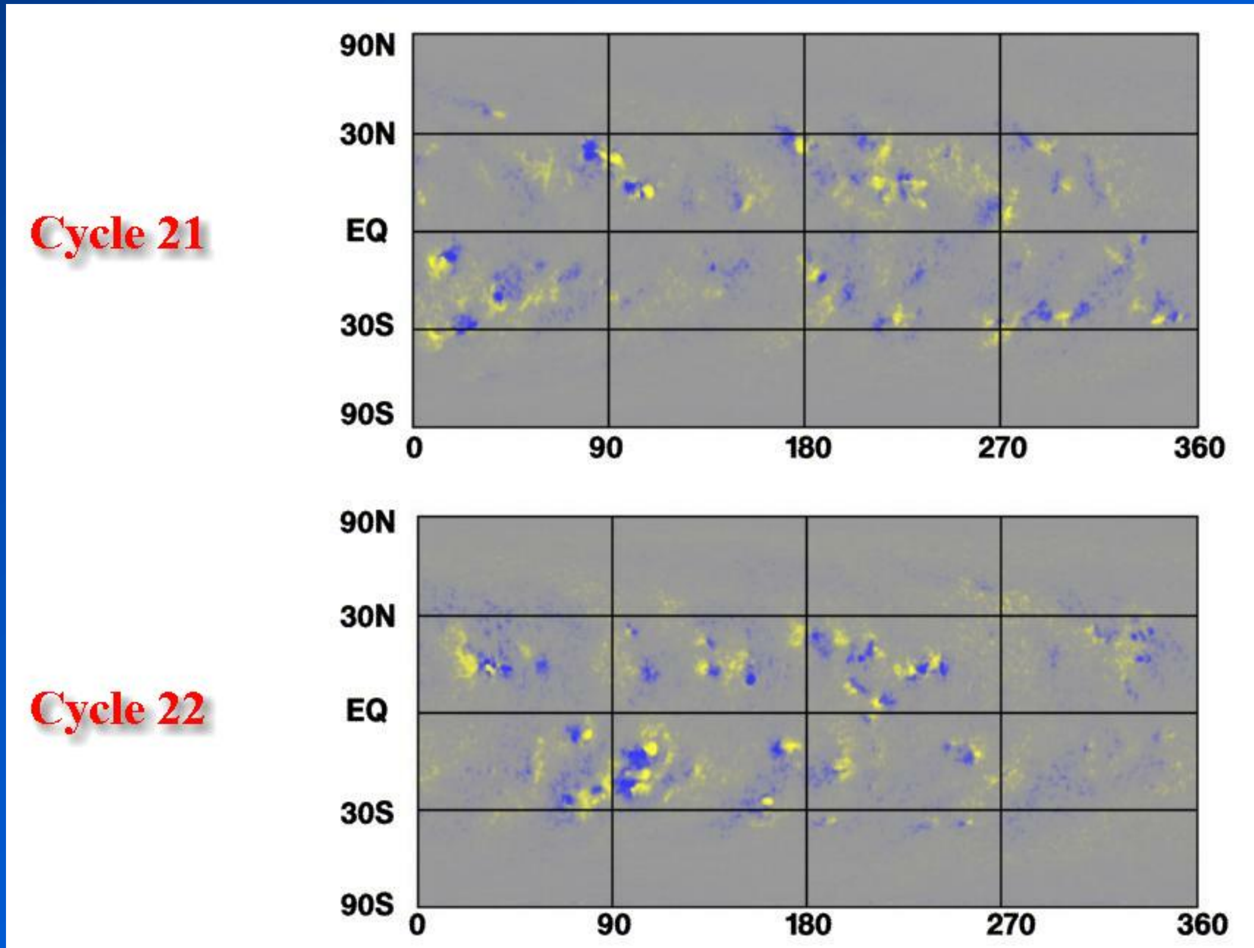
Recent SSN already too low ?



Svalgaard & Hudson, 2009

Hale's Magnetic Polarity Law

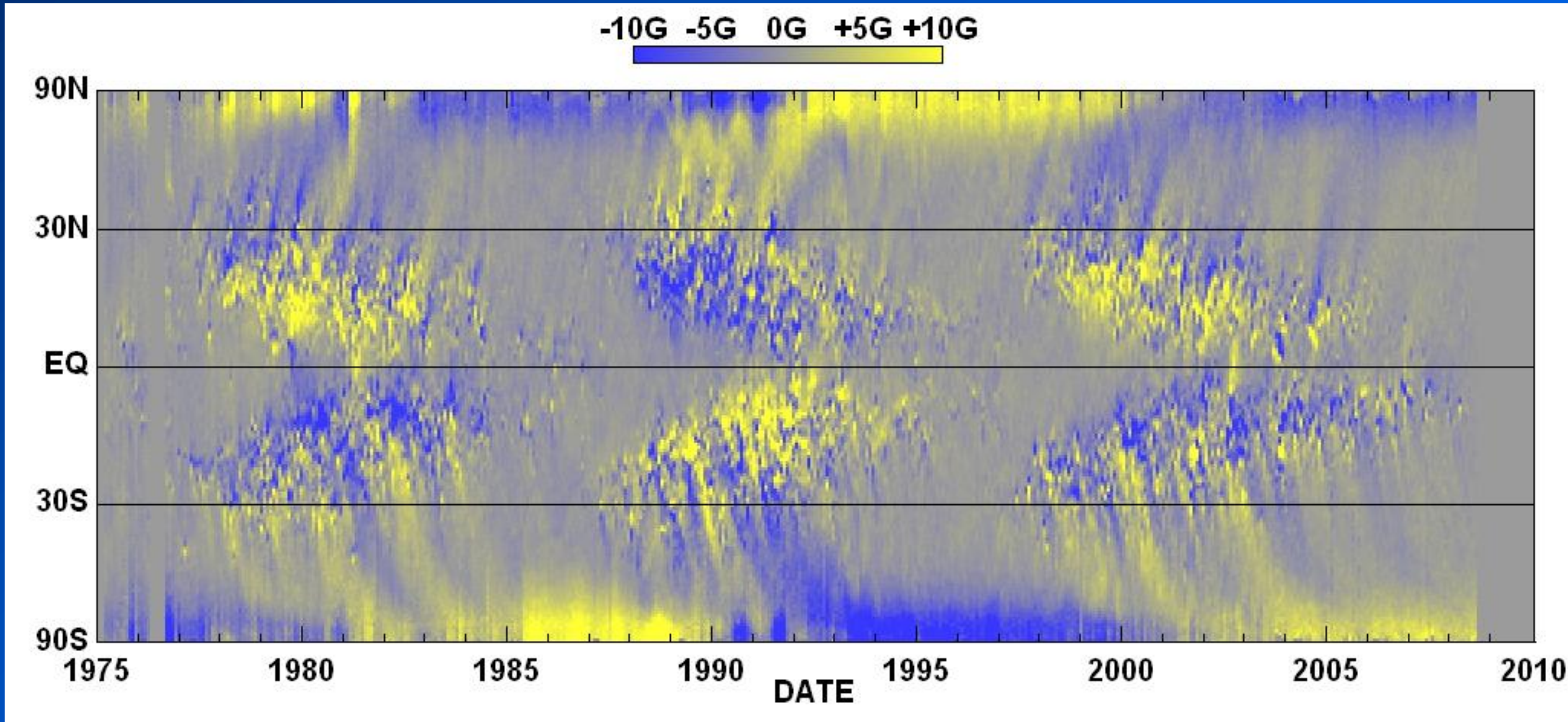
[Hale, 1924]



The magnetic polarity of the sunspots in active regions switches from one hemisphere to the other and from one cycle to the next.

Polar Field Reversals

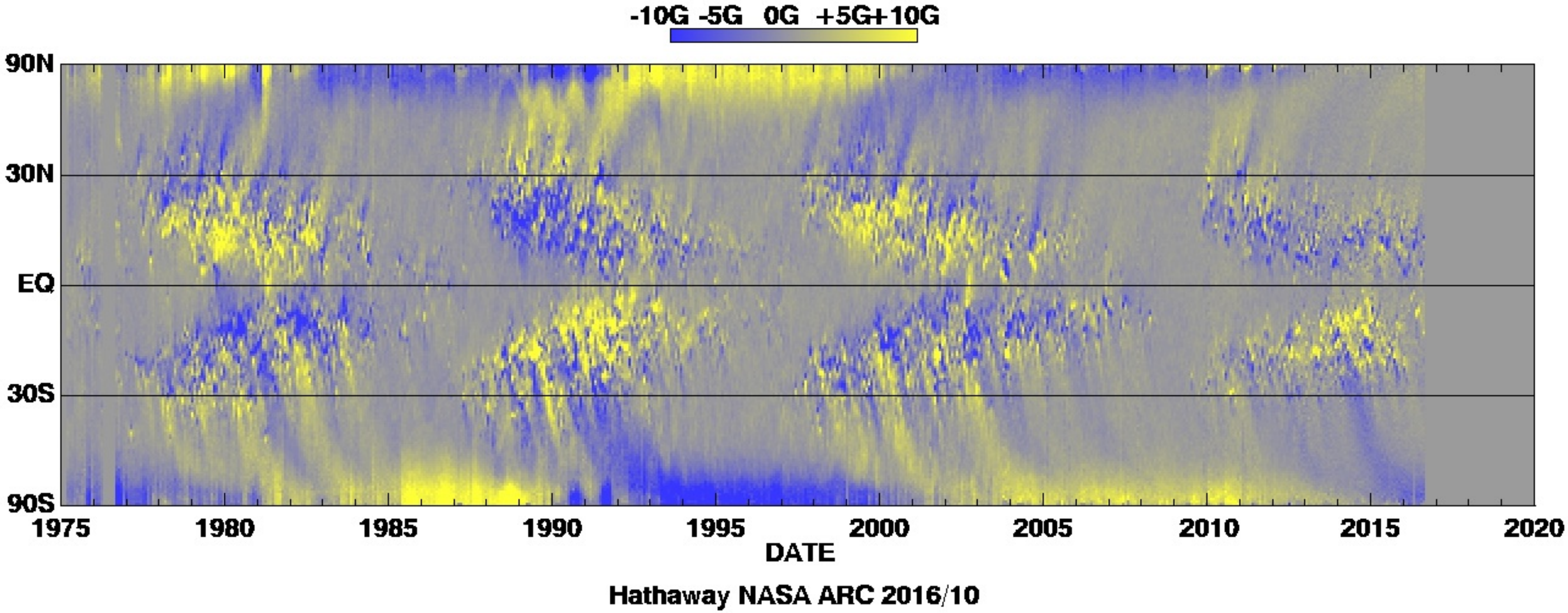
[Babcock, 1959]



The magnetic polarities of the Sun's poles reverse from one cycle to the next at about the time of sunspot cycle maximum.

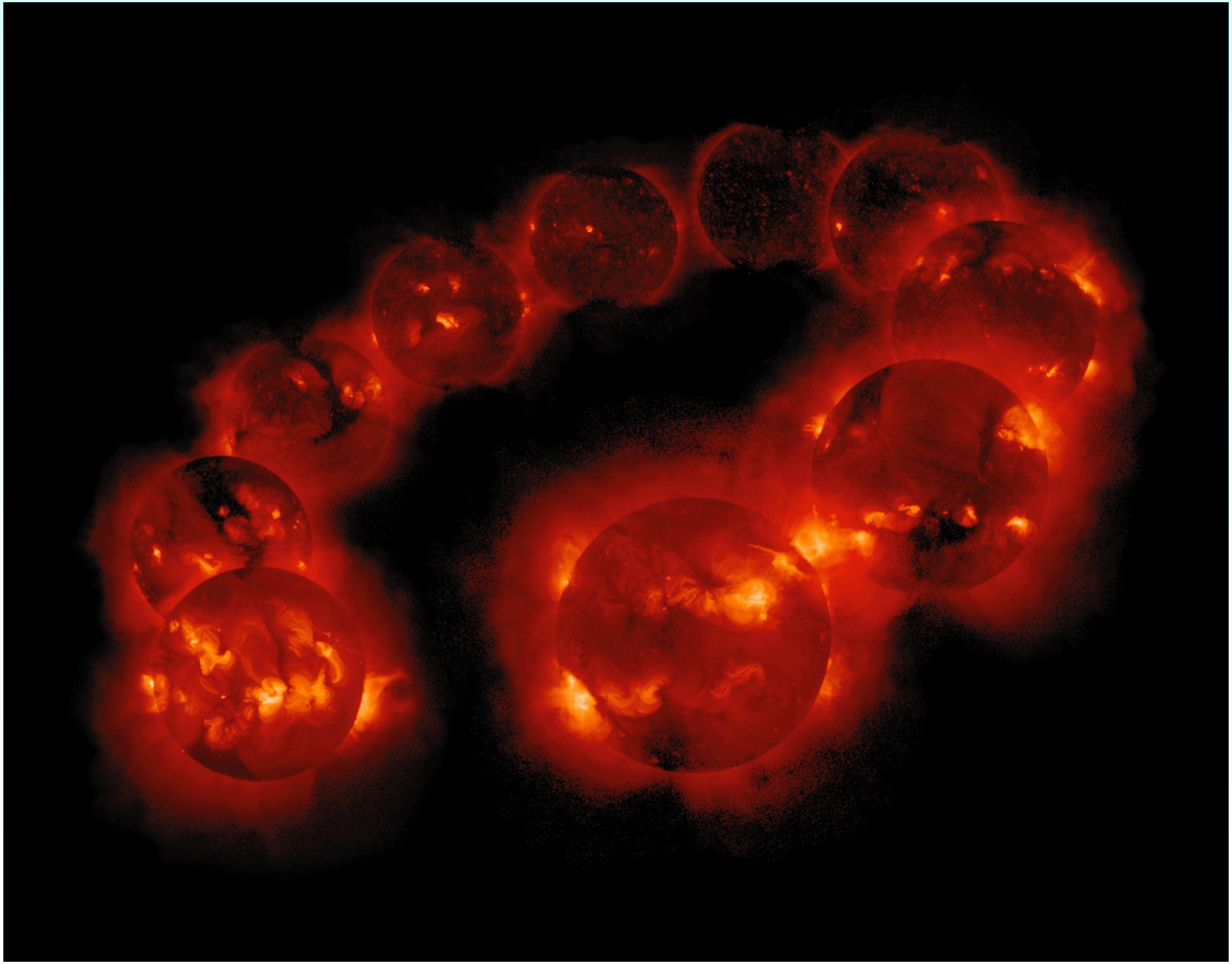
Polar Field Reversals

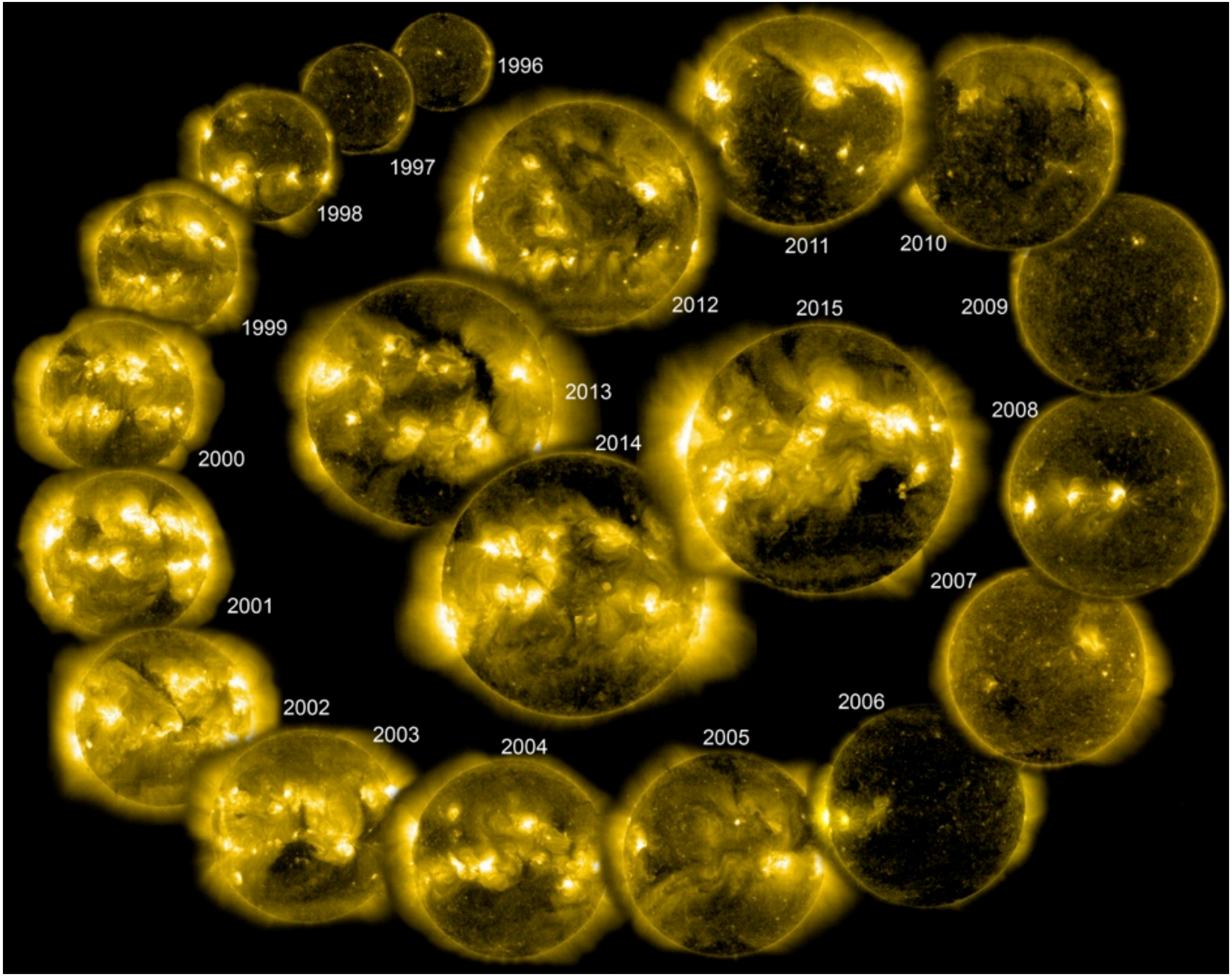
[Babcock, 1959]



The magnetic polarities of the Sun's poles reverse from one cycle to the next at about the time of sunspot cycle maximum.

Yohkoh (Solar A), 1991-2001




1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

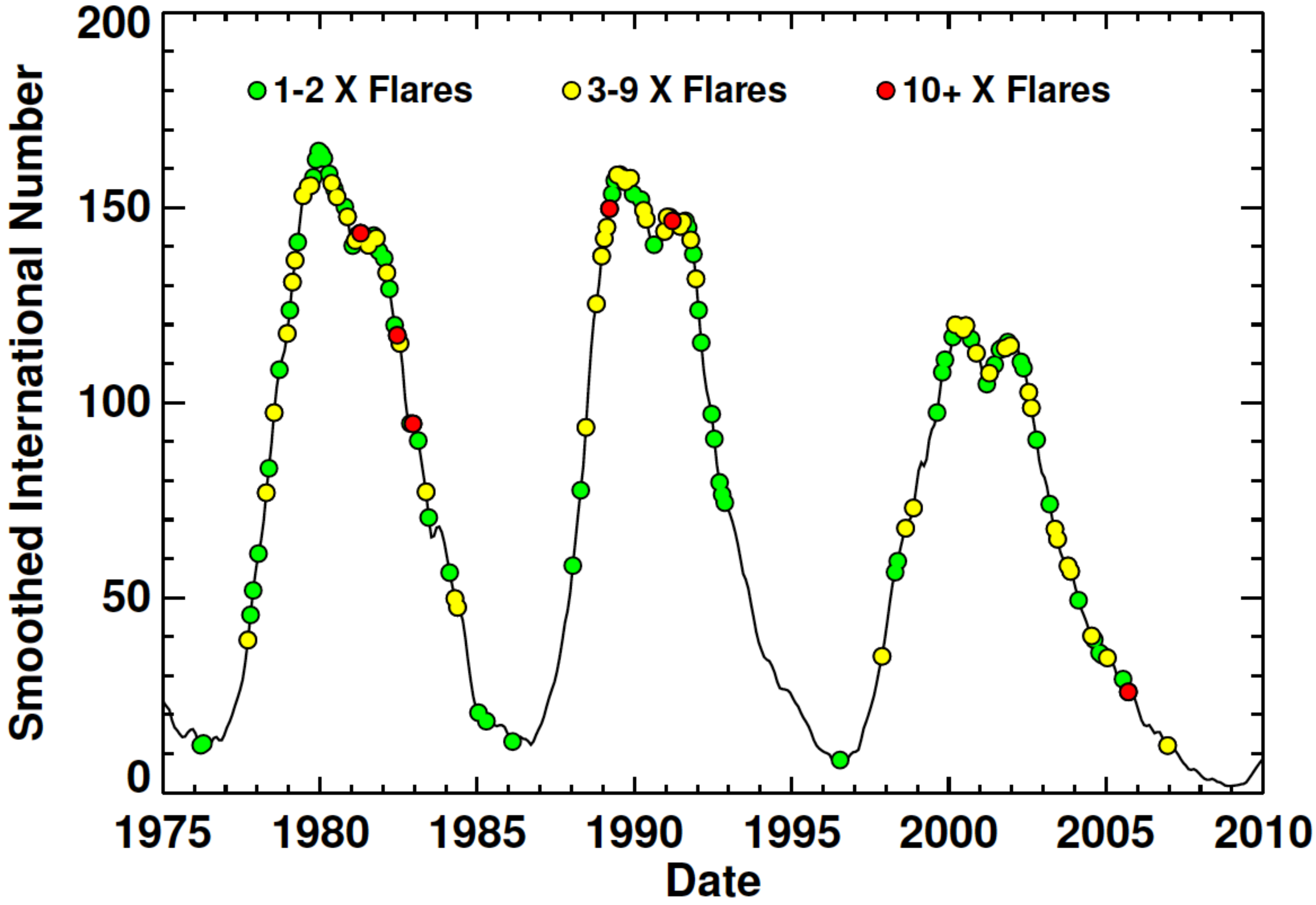


Figure 16: Monthly X-class flares and International Sunspot Number. X-class flares can occur at any phase of the sunspot cycle – including cycle minimum.

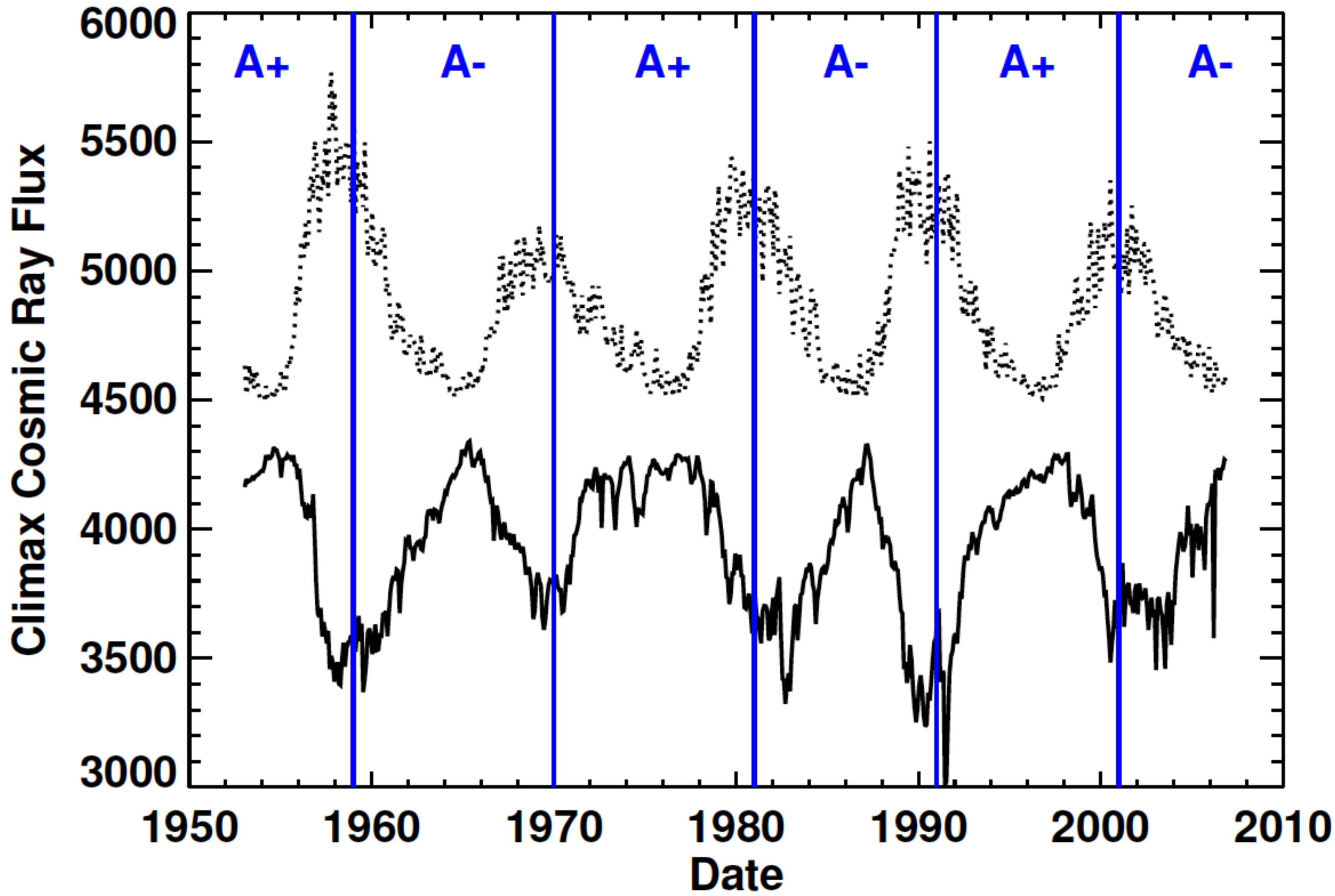
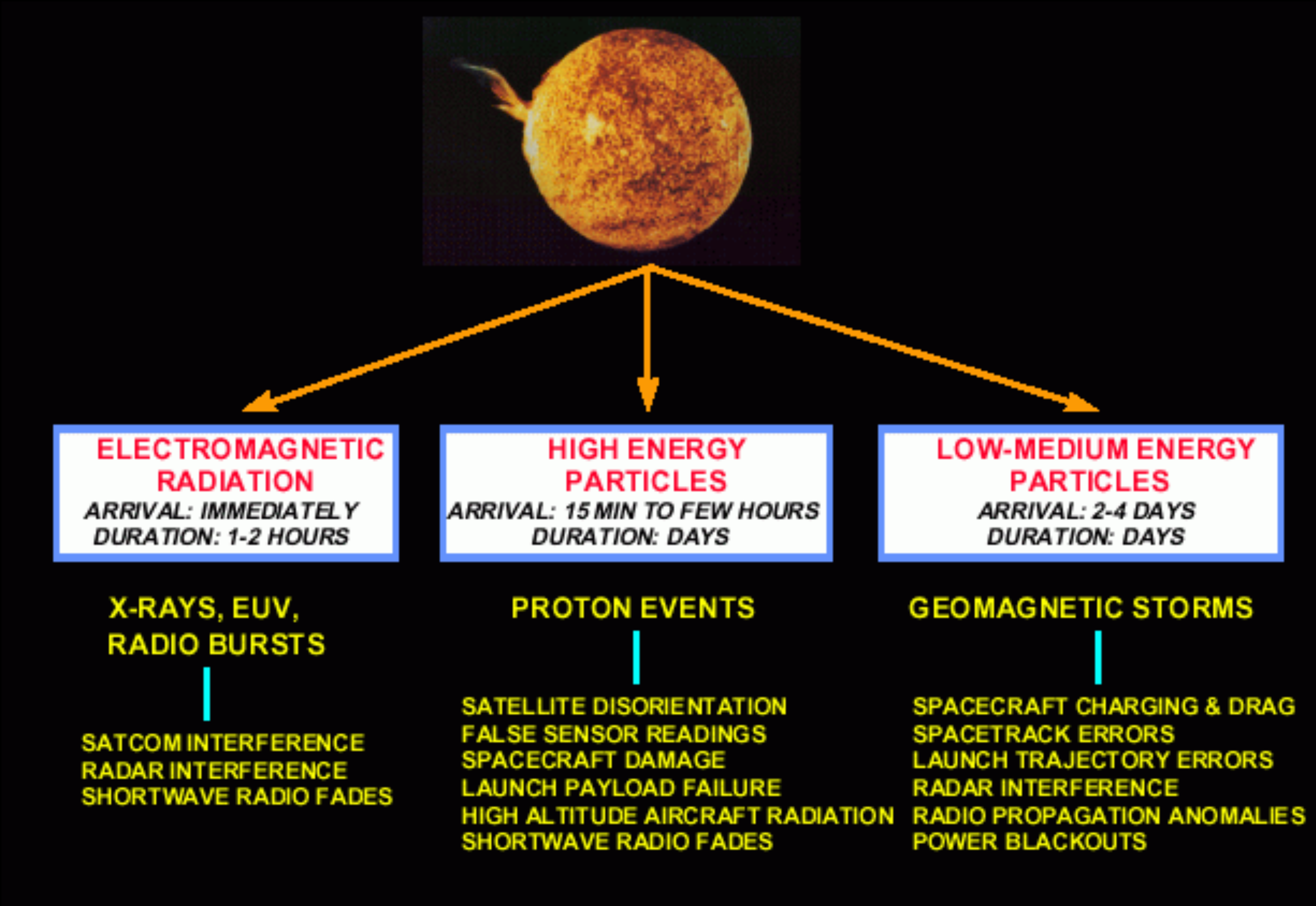


Figure 20: Cosmic Ray flux from the Climax Neutron Monitor and rescaled Sunspot Number. The monthly averaged neutron counts from the Climax Neutron Monitor are shown by the solid line. The monthly averaged sunspot numbers (multiplied by five and offset by 4500) are shown by the dotted line. Cosmic ray variations are anti-correlated with solar activity but with differences depending upon the Sun's global magnetic field polarity (A+ indicates periods with positive polarity north pole while A– indicates periods with negative polarity).

Effects of the Dynamic Sun

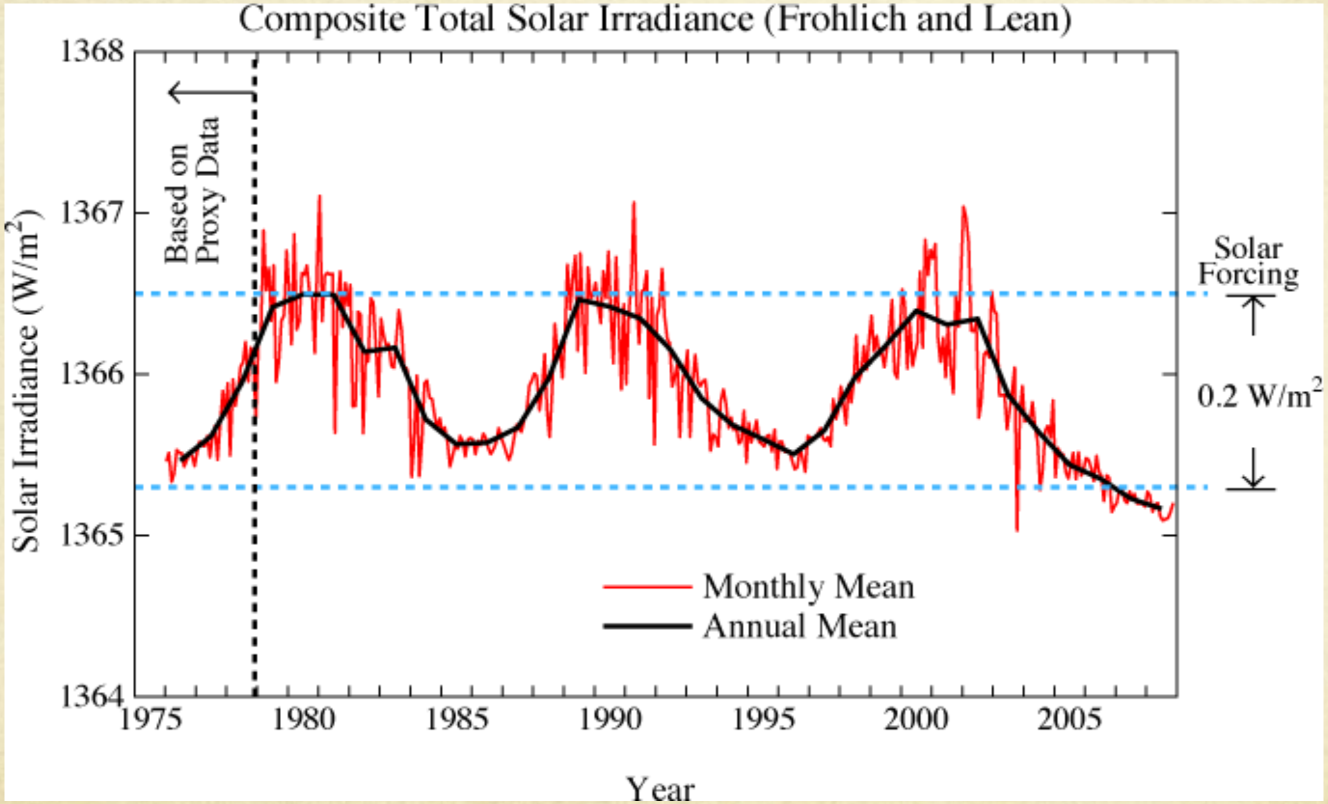


Source: Flares | CMEs/Flares | CMEs/Coronal Holes

Ηλιακή μεταβλητότητα και κλίμα
Solar variability and Earth climate

Ηλιακή μεταβλητότητα

Μετρήσεις στο διάστημα, που άρχισαν στις 16 Νοεμβρίου 1978 από τον δορυφόρο Nimbus 7, έδειξαν ότι **η ηλιακή σταθερά δεν είναι σταθερά**

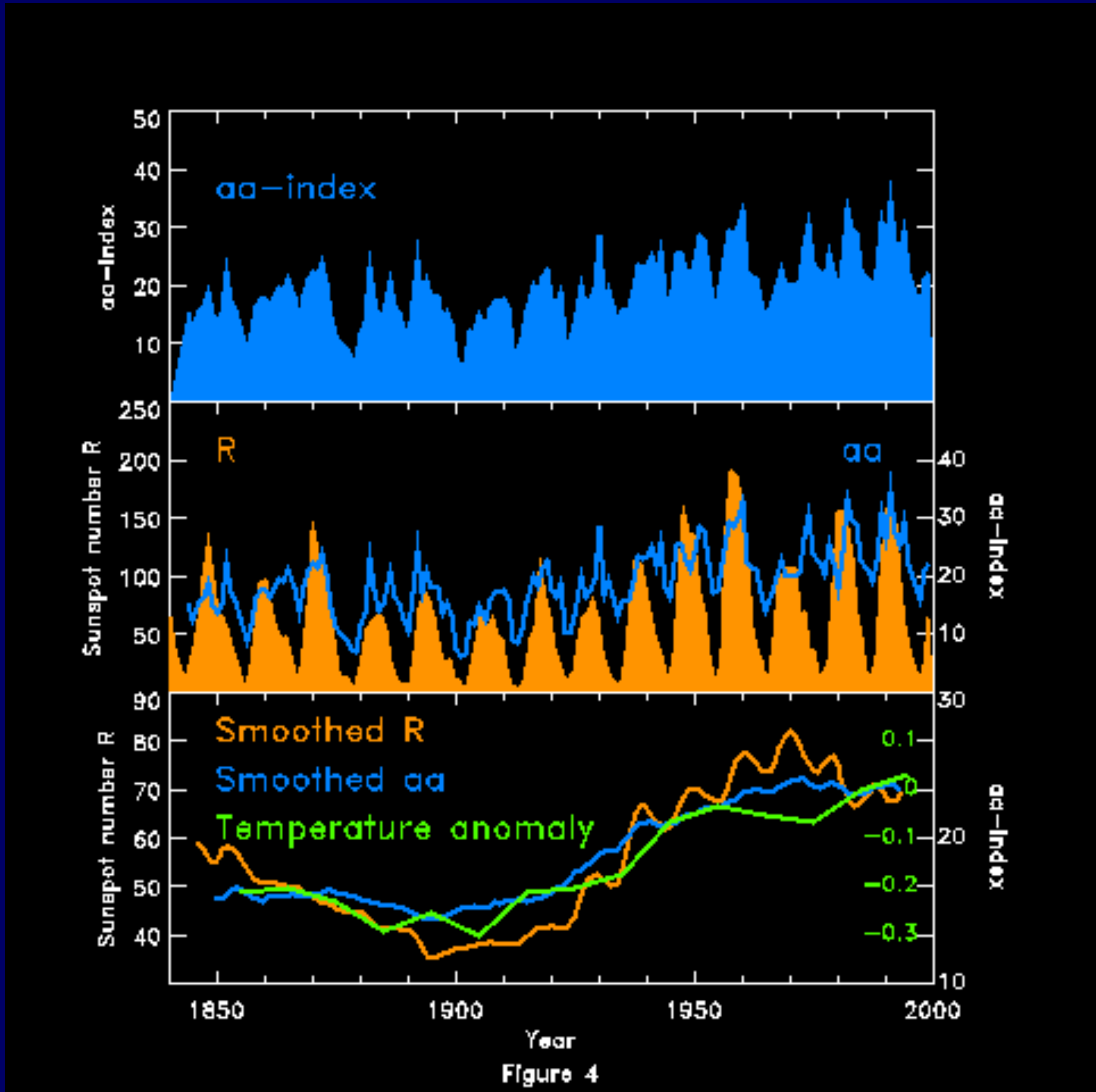


0.1 – 0.2% variation in flux. Earth's surface temperature vary by 0.1 – 0.2^{o} C. During little ice age global cooling 0.2^{o} C

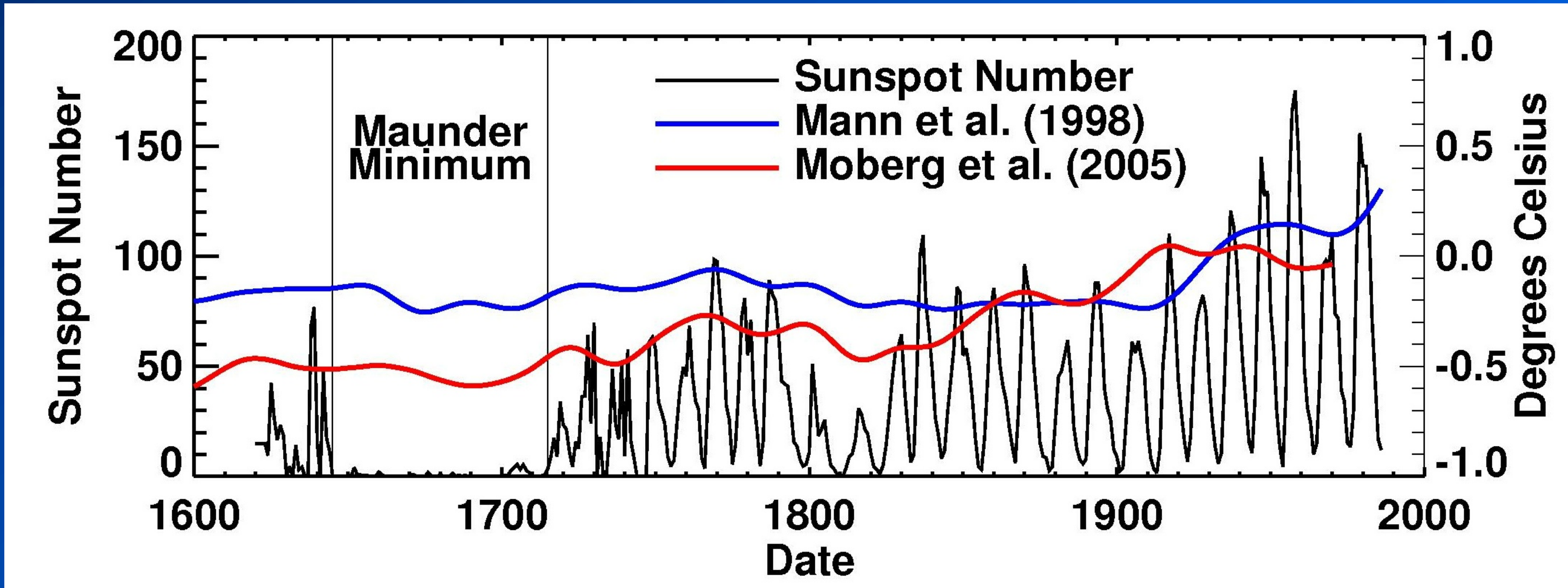
ΗΛΙΑΚΗ ΜΕΤΑΒΛΗΤΟΤΗΤΑ

Αν και η ροή σε UV, EUV και X αποτελεί ελάχιστο μέρος της συνολικής ηλιακής ακτινοβολίας, η επίδραση στην ανώτερη ατμόσφαιρα της Γης είναι πολύ σημαντική.

Long-term solar activity variations correlate with global temperature changes



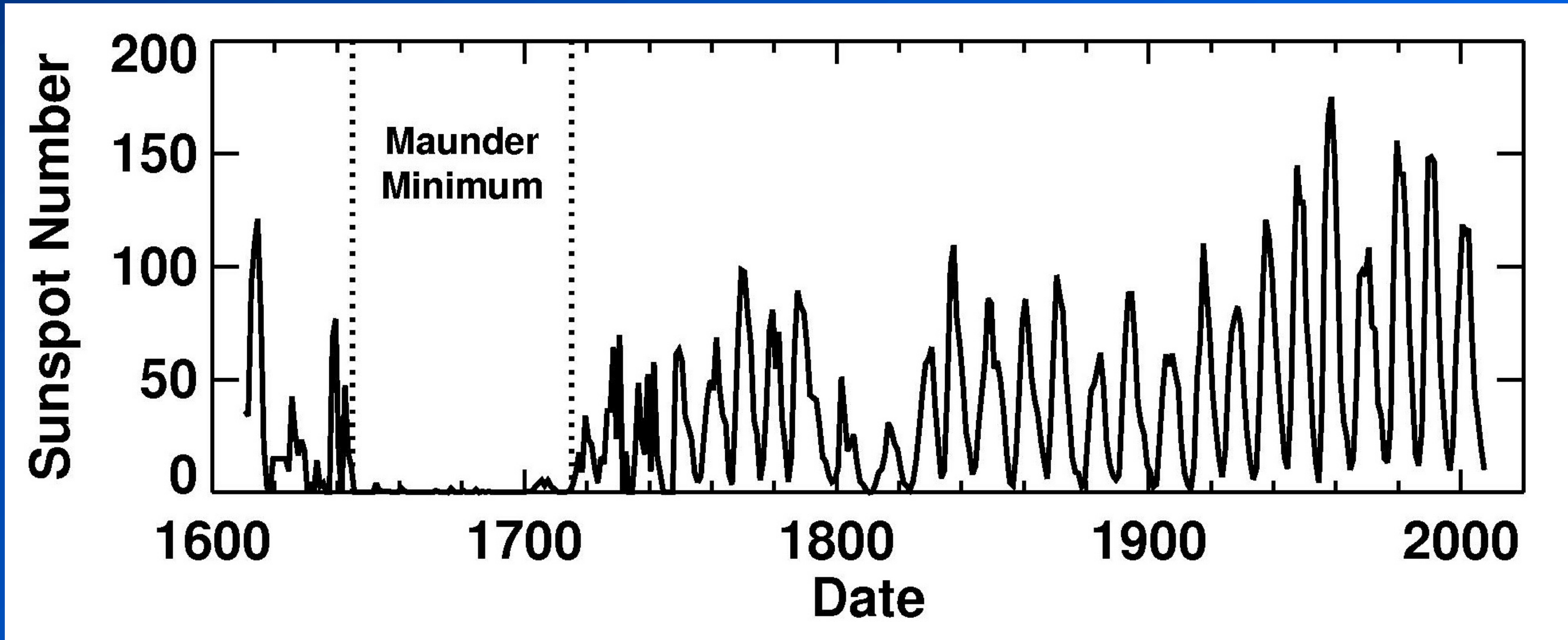
The Climate Connection



Solar cycle related variations are evident in the terrestrial temperature record. Estimates of the variations in temperature at the Earth's Surface (Mann et al. 1998, Moberg et al. 2005) show **significant correlations with variations in the amplitude of the sunspot cycle**. The total solar irradiance has varied by about 0.1% over each sunspot cycle since 1978. The UV irradiance varies by about 3-4%. The precise connections between solar variability and climate are uncertain.

The Maunder Minimum

[Maunder, 1894]



The existence of the Maunder Minimum is now well established by the efforts of Hoyt and Schatten. They have tabulated daily observations with nearly complete coverage over the period of the Maunder Minimum (1645 to 1715). Observations of sun-like stars also indicate similar periods of inactivity.

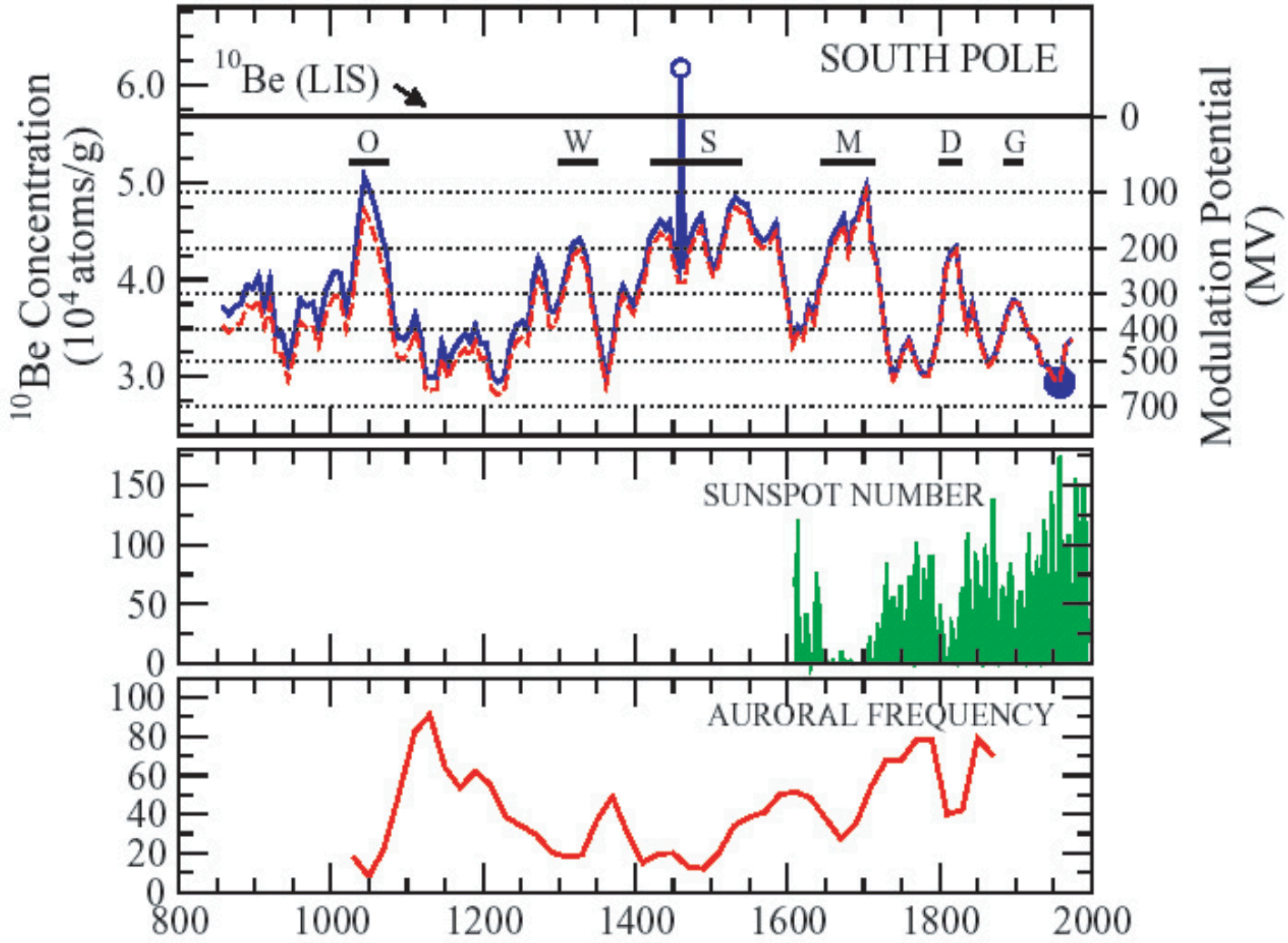
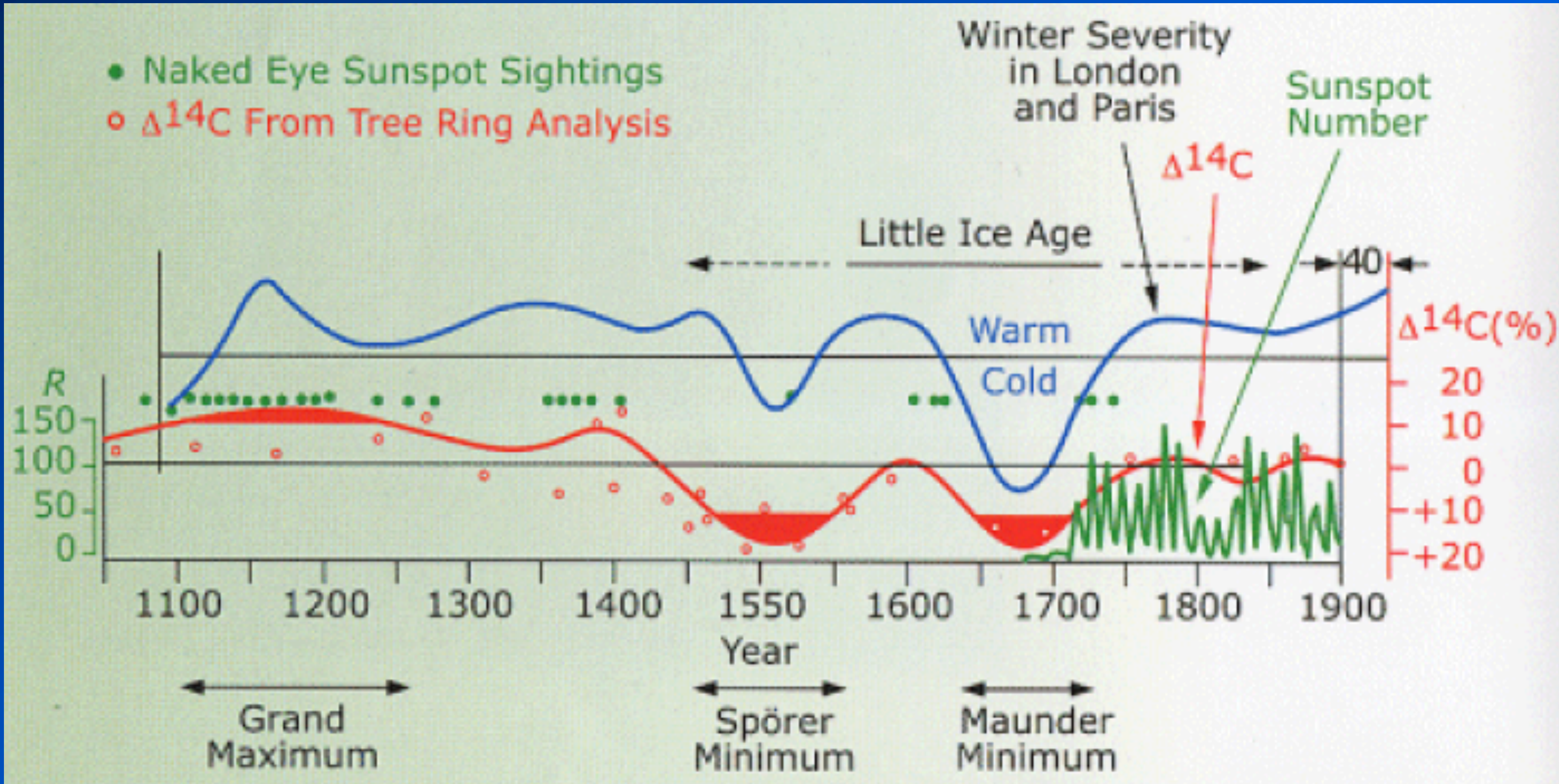


FIGURE 1.1.2 ^{10}Be concentrations measured in ice core samples from the South Pole provide a record of the variability in the GCR flux at 1 AU for the period 850 CE to 1958 CE. Intensities are highest during secular minima in solar activity, as denoted in the top panel by the letters and bold horizontal bars and indicated in the second and third panels by the sunspot number and auroral frequency, respectively. (O = Oort minimum; W = Wolf minimum; S = Spoerer minimum; M = Maunder minimum; D = Dalton minimum; and G = Gleissberg minimum.) SOURCE: McCracken et al., 2004. Copyright 2004, American Geophysical Union. Reproduced by permission of American Geophysical Union.



• Naked Eye Sunspot Sightings
∘ Δ14C From Tree Ring Analysis
Winter Severity in London and Paris
Sunspot Number
Δ14C
Little Ice Age
40
Warm
Cold
Δ14C(%)
R
150
100
50
0
20
10
0
+10
+20
1100
1200
1300
1400
1550
1600
1700
1800
1900
Year
Grand Maximum
Spörer Minimum
Maunder Minimum

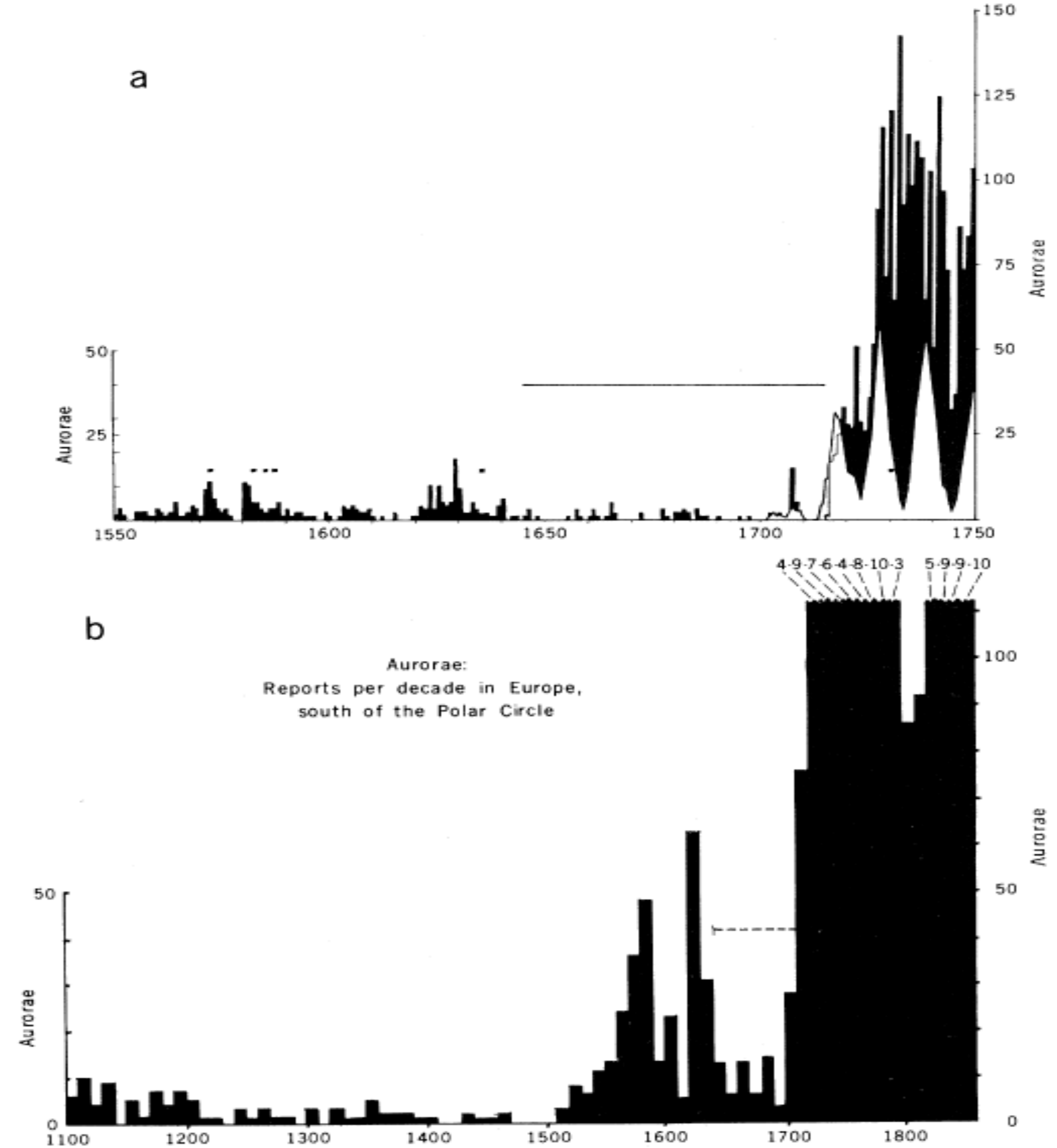
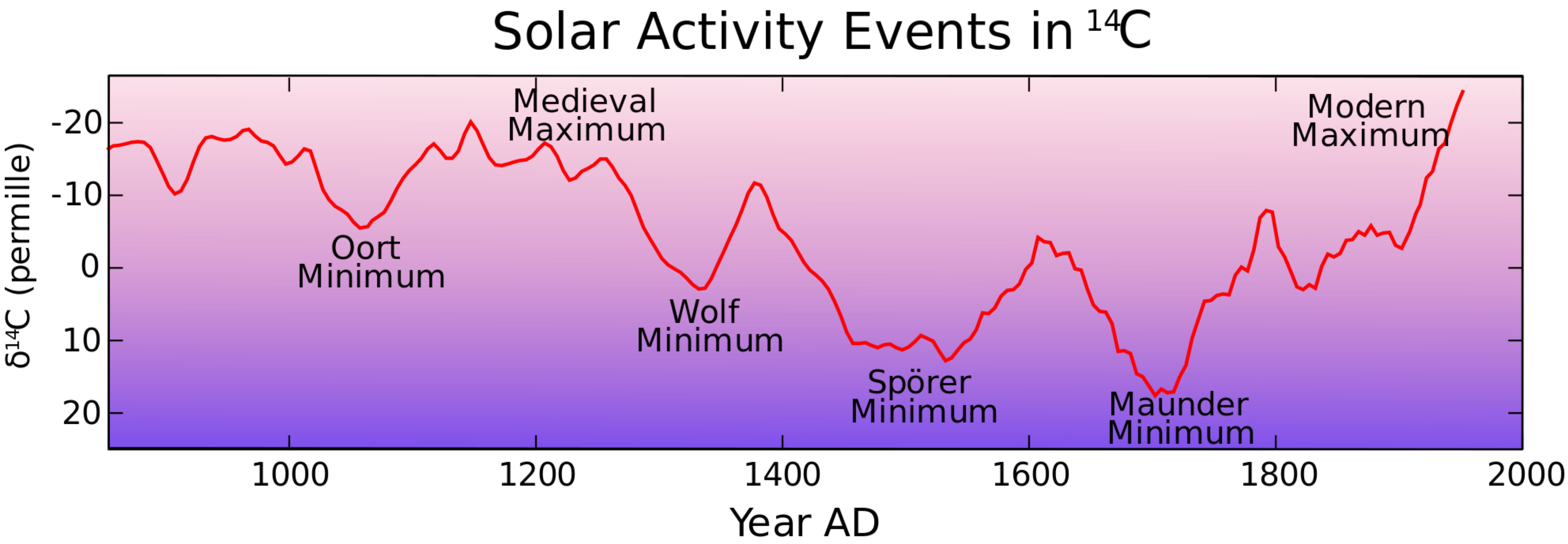
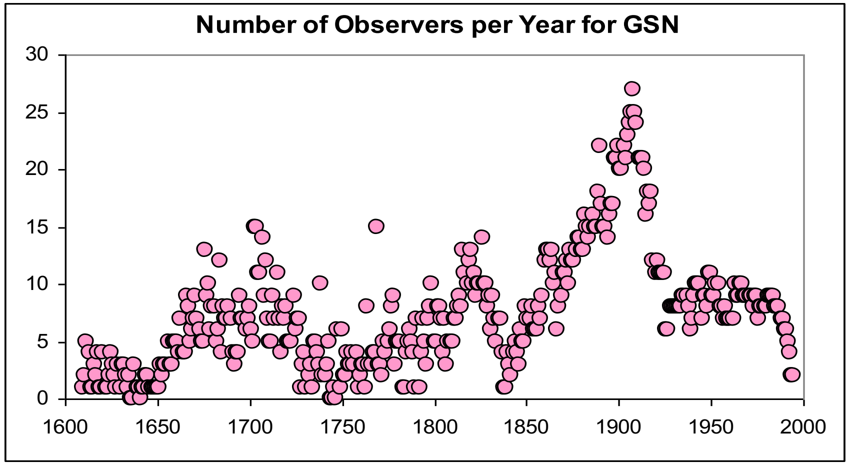


Fig. 4. Reported aurorae [from Fritz (37)]. (a) All reports, from 1550 to 1750 by year, with the annual mean sunspot number superposed as white curves at the right and Far East aurorae (*43, 44, 46*) shown as solid squares. (b) Reports per decade in latitudes 0° to 66°N; counts after 1715 must be multiplied by the numbers shown at the top right of the plot. The period of the Maunder Minimum is shown in each diagram as a horizontal line.



Solar Activity Events in ^{14}C
Medieval Maximum
Modern Maximum
Oort Minimum
Wolf Minimum
Spörer Minimum
Maunder Minimum
-20
-10
0
10
20
δ14C (permille)
1000
1200
1400
1600
1800
2000
Year AD

More Realistic Assessment



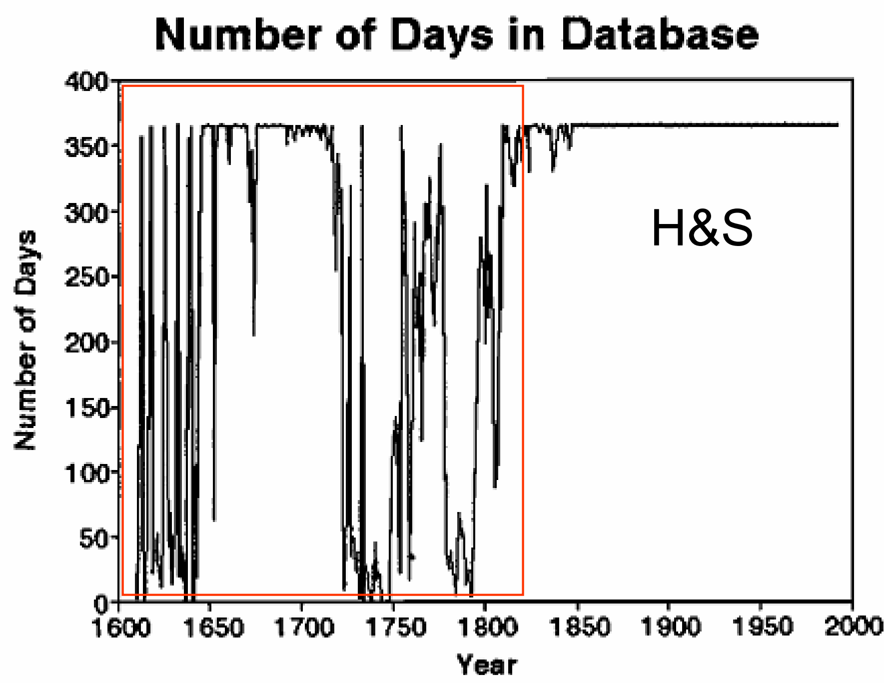
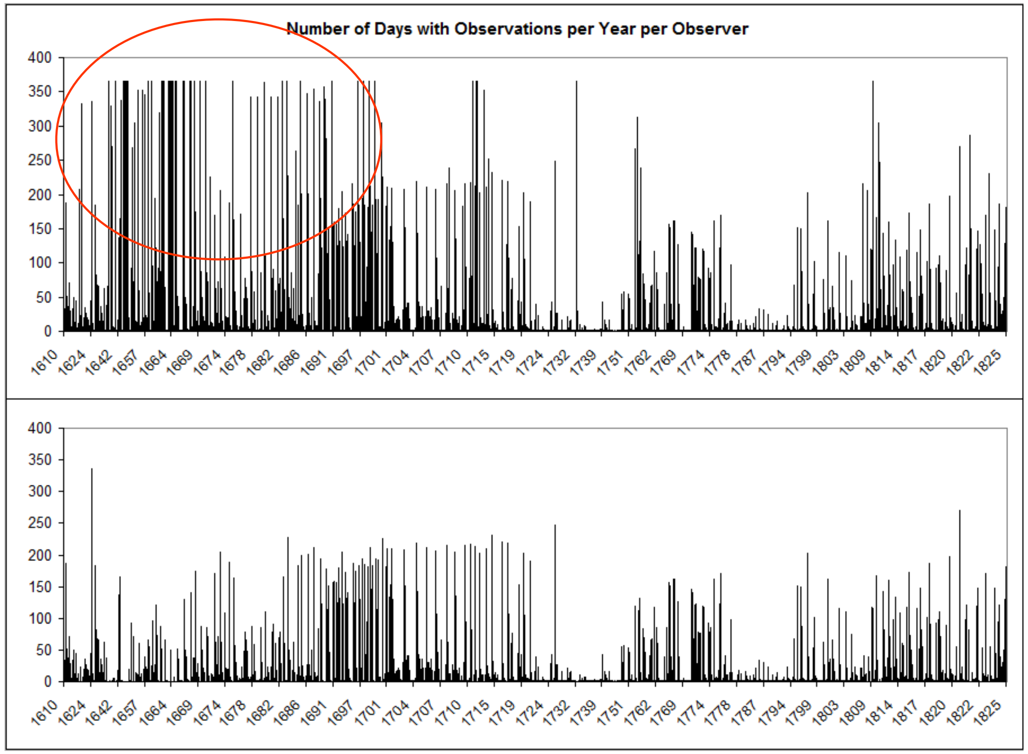


Figure 3. The number of days each year for we which have observations or interpolated values. If more than 5% of the days are observed in a year, a good yearly mean can usually be found. Most years meet this criteria. Note that the Sun was well observed during the Maunder Minimum.

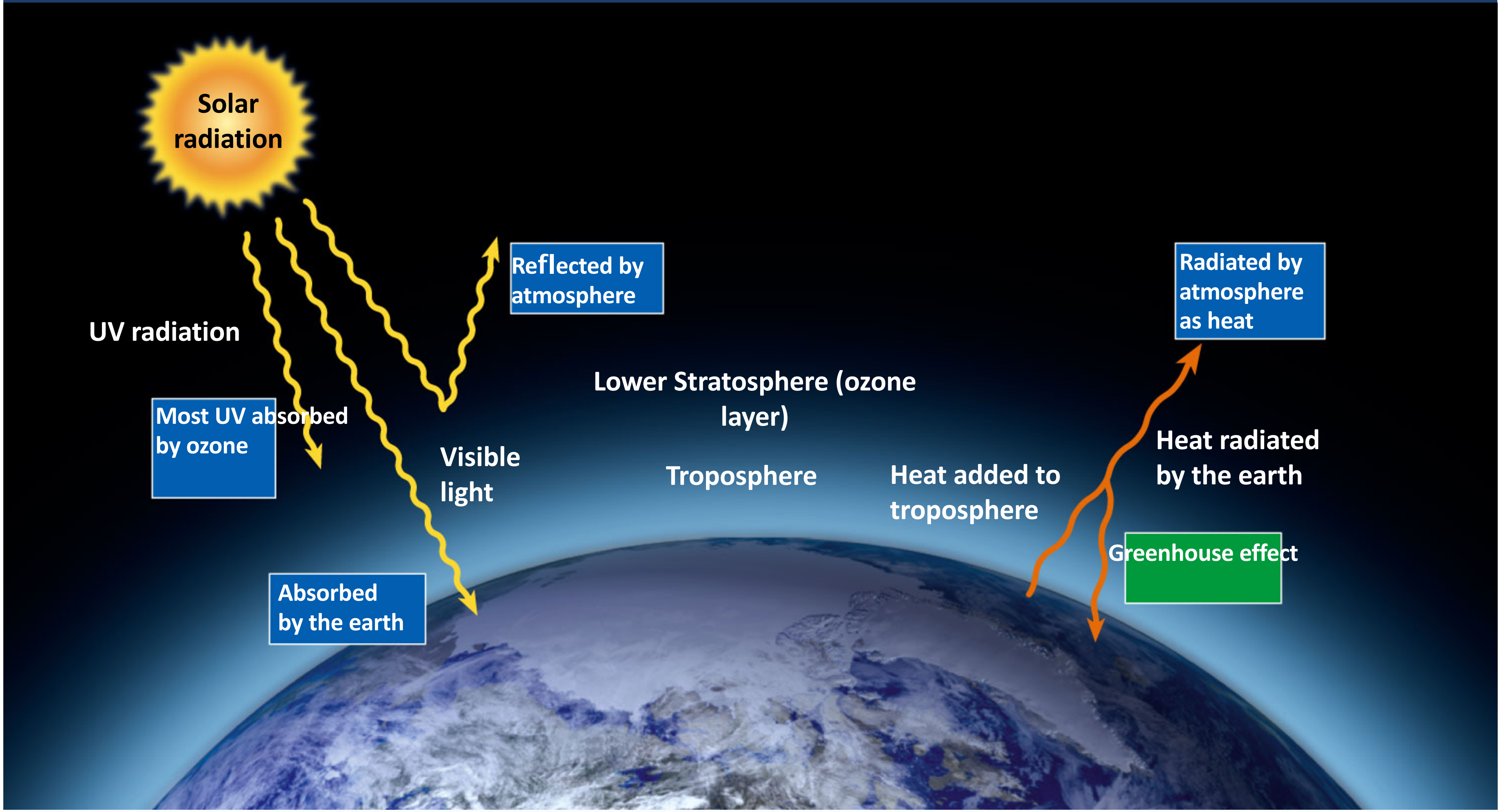
5% of 365 is ~20 days



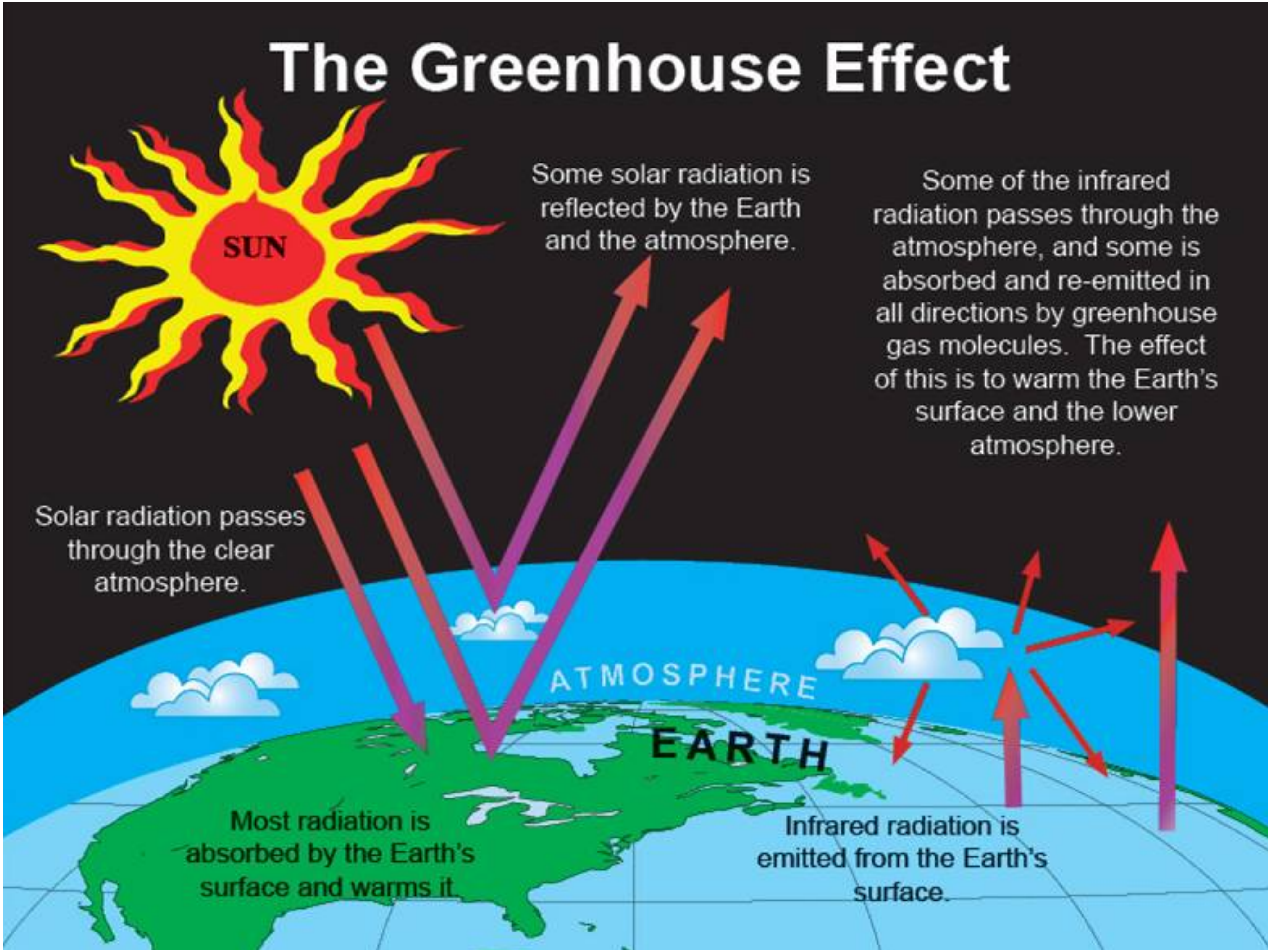
1610 1700 1825

Even after eliminating the spurious years with 'no missing data' there are enough left to establish that the Maunder Minimum had very few visible sunspots and was not due to general lack of observations

Flow of Energy to and from the Earth

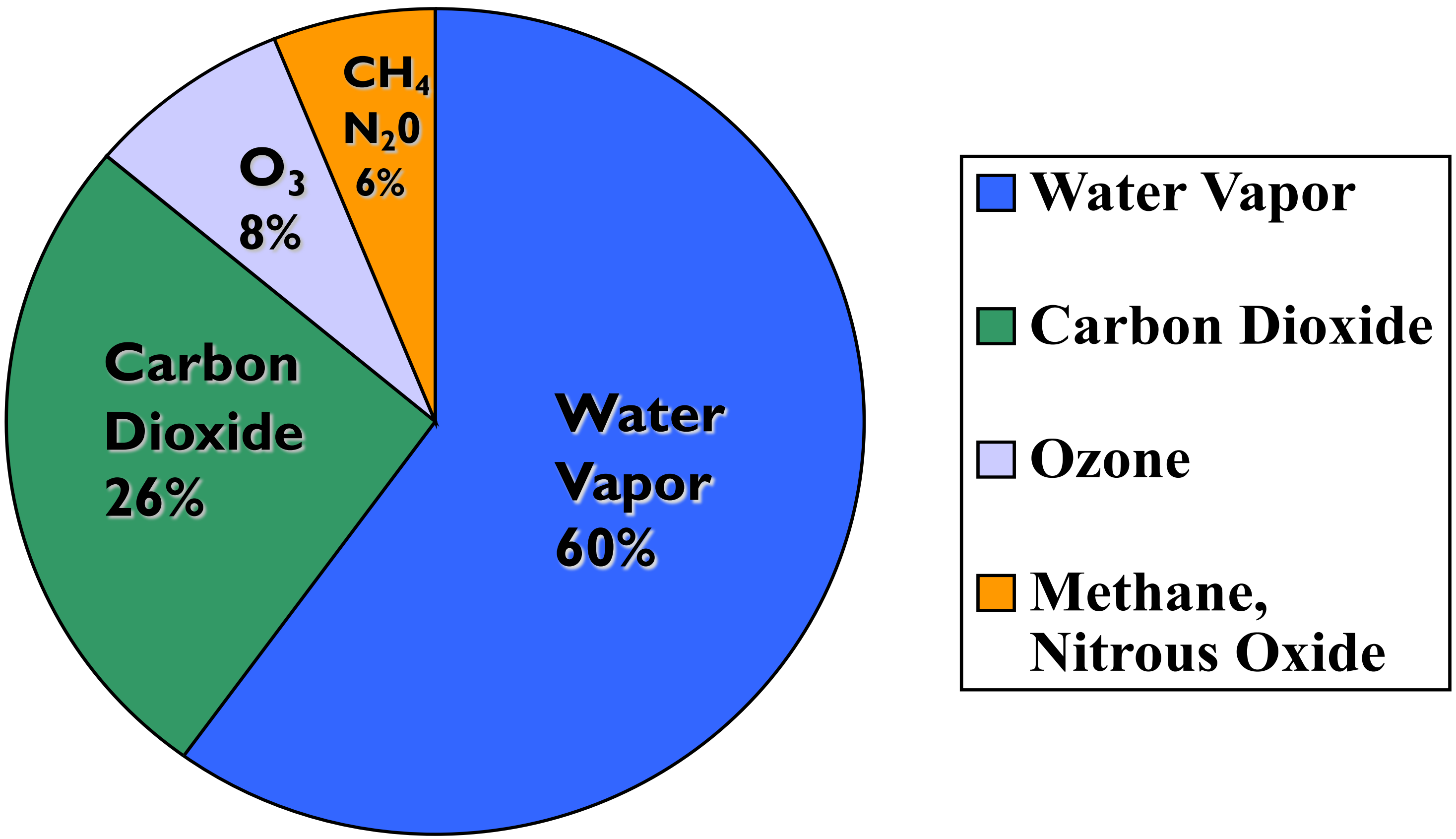


From: Miller (2010) Living in the Environment


The Greenhouse Effect
SUN
Some solar radiation is reflected by the Earth and the atmosphere.
Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower atmosphere.
Solar radiation passes through the clear atmosphere.
ATMOSPHERE
EARTH
Most radiation is absorbed by the Earth's surface and warms it.
Infrared radiation is emitted from the Earth's surface.

Earth would be -19° C without atmosphere. 99% of the atmosphere is N and O which are transparent to radiation

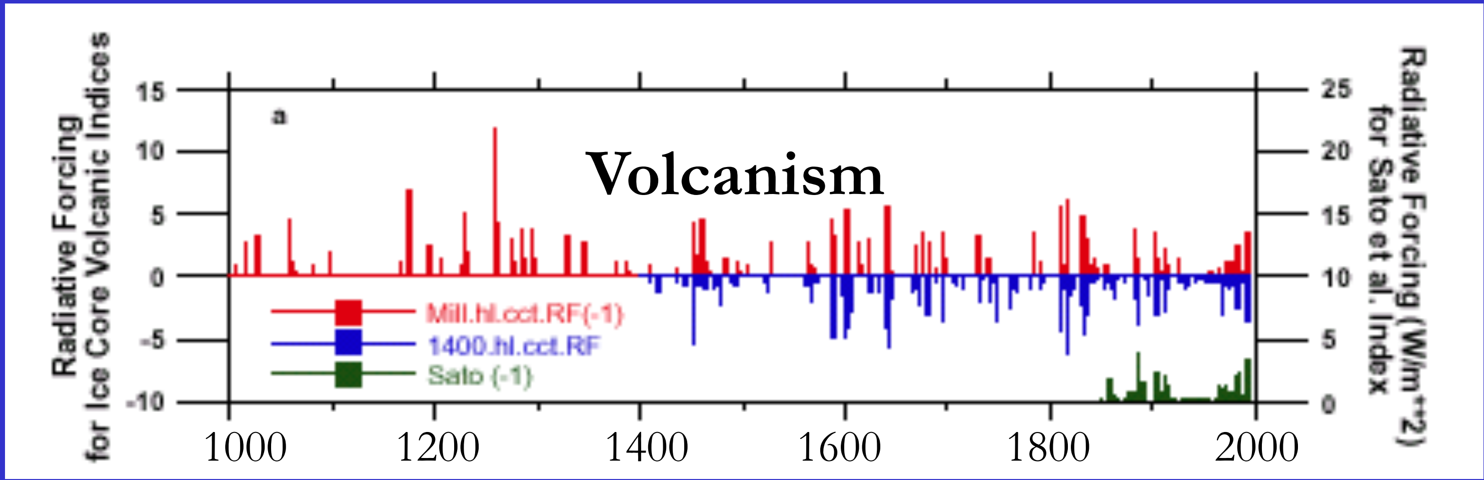
The Natural Greenhouse Effect



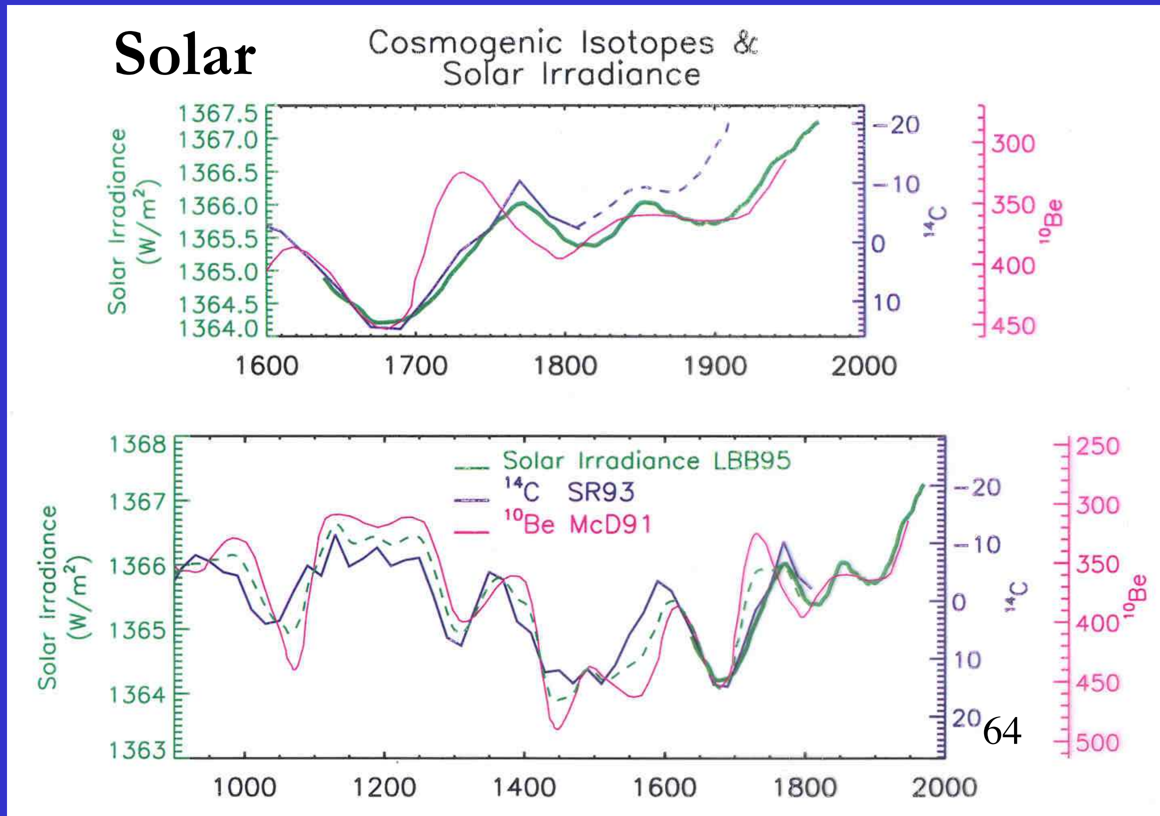
Clouds also have a greenhouse effect

Kiehl and Trenberth 1997

CLIMATE FORCINGS



Natural

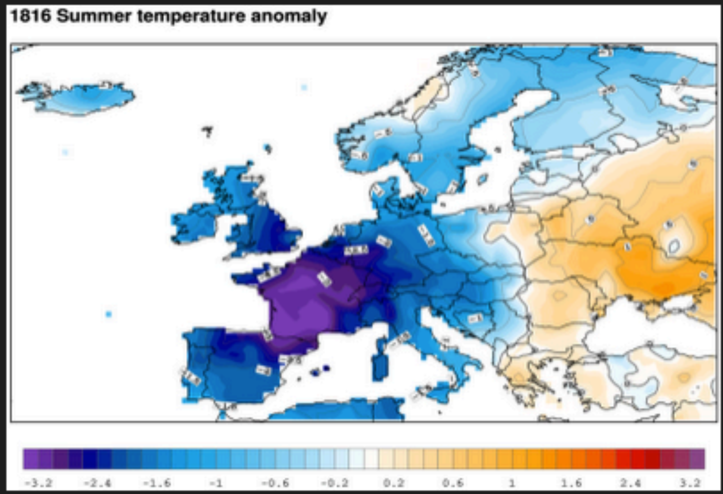


Crowley, T.J., Causes of Climate Change Over the Past 1000 Years, *Science*, *289* 270-277, 2000.

Diamonds and Rust

Monday, April 11, 2011

Volcano eruption in Indonesia caused famine in Europe



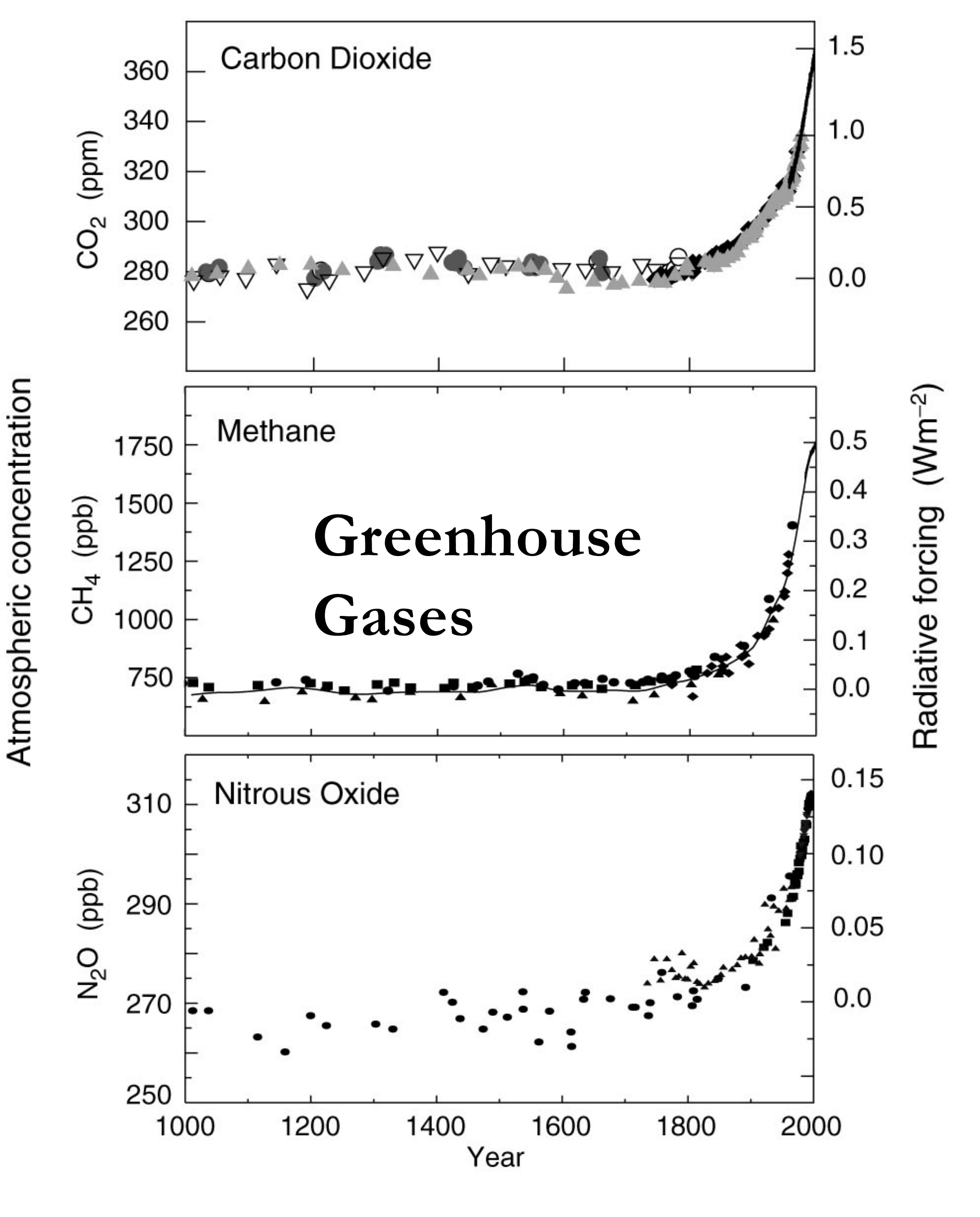
1816 summer temperature anomaly with respect to 1971-2000 climatology

The April 1815 eruption of Mount Tambora was the most powerful volcano eruption in recorded history. Mount Tambora is situated on the island of Sumbawa in Indonesia. At least 6 months and probably about 3 years of increased steaming and small phreatic eruptions preceded the 1815 eruption. A moderately large explosive eruption occurred on 5 April 1815, from which ash fell in east Java and thunderlike sounds were heard up to 1,400 kilometers away. A still larger eruption occurred on **10-11 April 1815**, beginning as "three columns of fire rising to a great height" and ultimately ejecting about 50 cubic kilometers of magma. The eruption had a Volcanic Explosivity Index ranking of 7, a super-colossal event that ejected immense amounts of volcanic dust into the upper atmosphere. It was the world's largest eruption since the Hatepe eruption over 1,630 years earlier in AD 180.
The Tambora eruption column lowered global temperatures, and some experts believe this led to global cooling and worldwide harvest failures, sometimes known as the **Year Without a Summer**.
The Year Without a Summer (also known as the Poverty Year, Year There Was No Summer and Eighteen Hundred and Froze to Death) was 1816, in which severe summer climate abnormalities caused average global temperatures to decrease by about 0.4–0.7 °C, resulting in major food shortages across the Northern Hemisphere and leading to the worst famine of the 19th century.

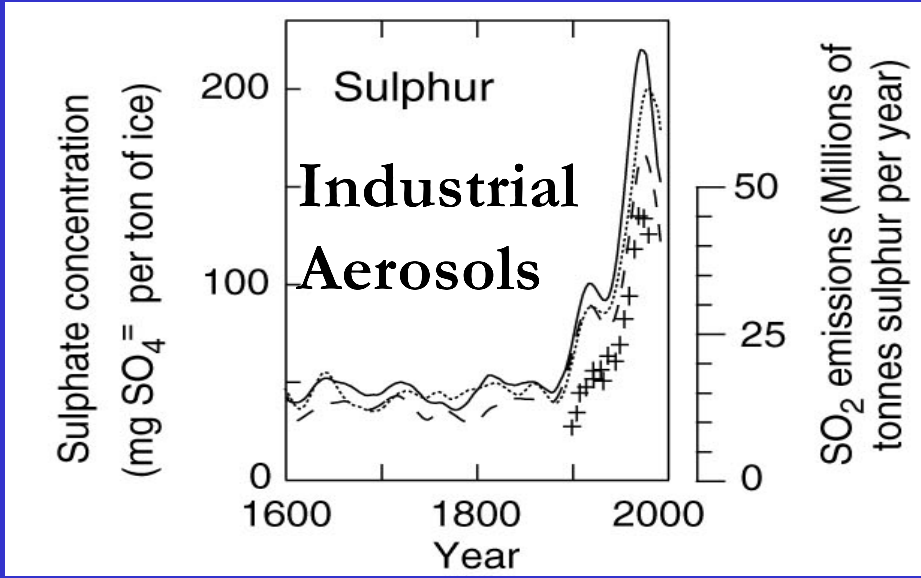
Posted by Yannis at 11:20 PM

G+1 +2 including You

CLIMATE FORCINGS



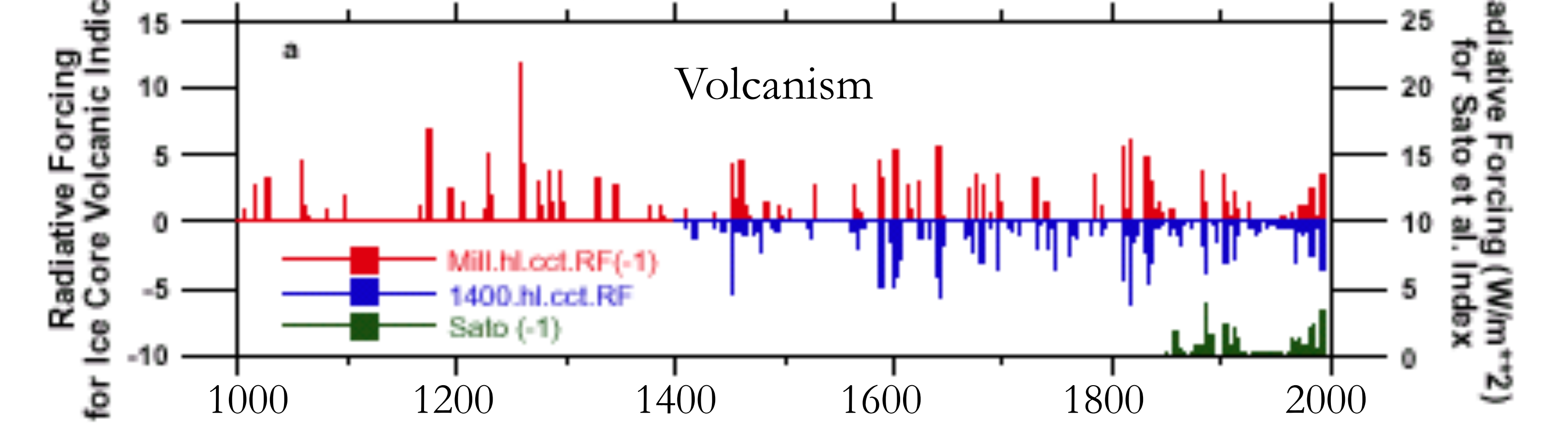
Anthropogenic

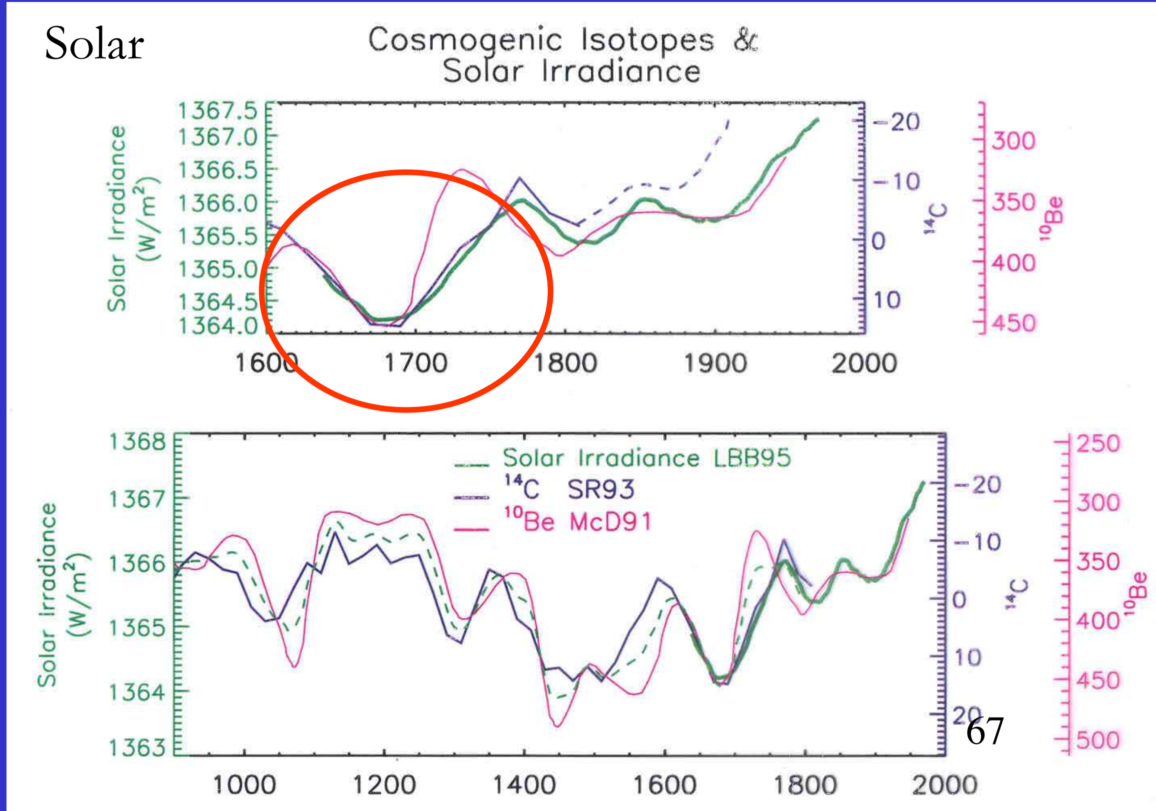


Climate Change 2001: The Scientific Basis, Houghton, J.T., et al. (eds.), Cambridge Univ. Press, Cambridge, 2001

Influence of Natural Radiative Forcing

Crowley, T.J., Causes of Climate Change Over the Past 1000 Years, *Science*, *289* 270-277, 2000.





"Maunder Minimum"

Solar activity changes

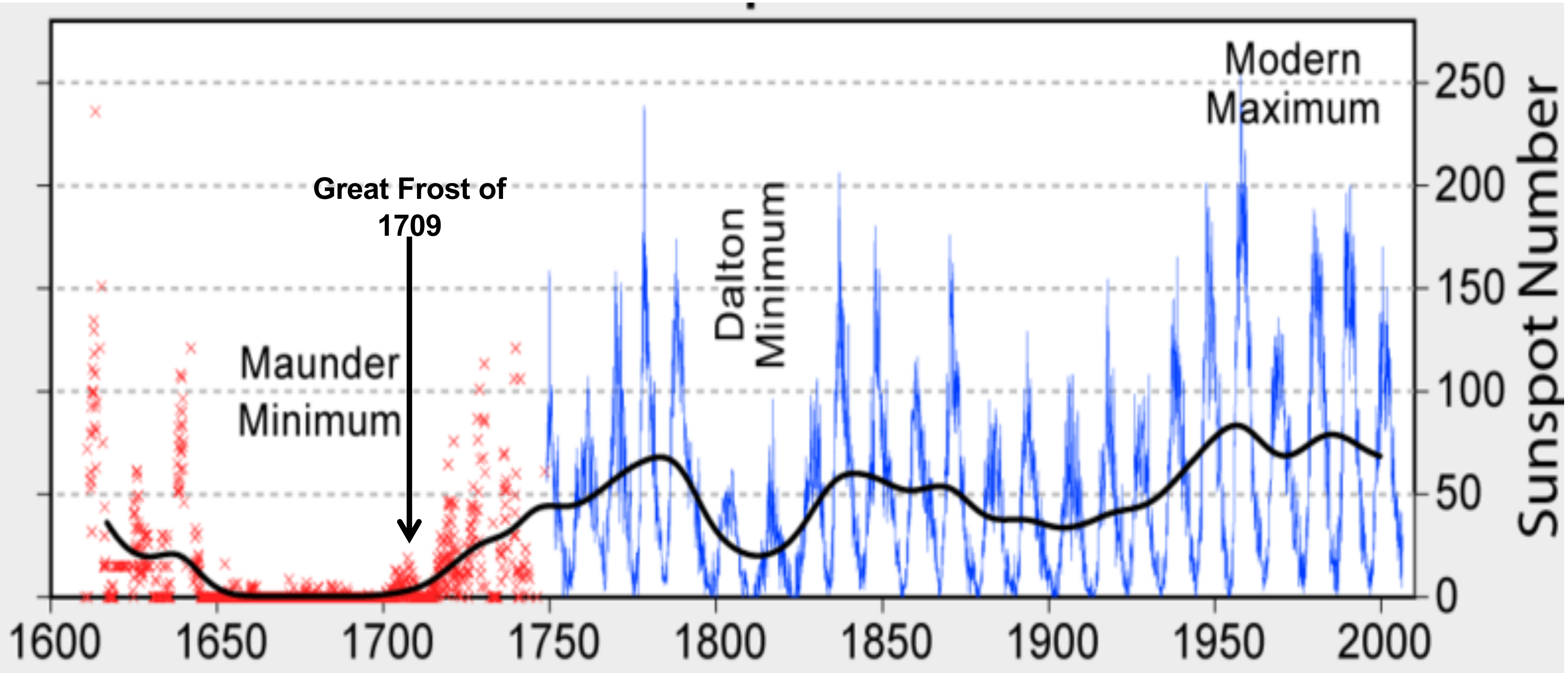
- Changes in solar activity affecting climate have been the subject of considerable investigation over many years and have often been controversial.
- Observational and modelling techniques improved.

Observational techniques

- ^{14}C and ^{10}Be isotopes in tree rings / ice cores
- Surface stations
- Since 1979 satellite (Nimbus 7)

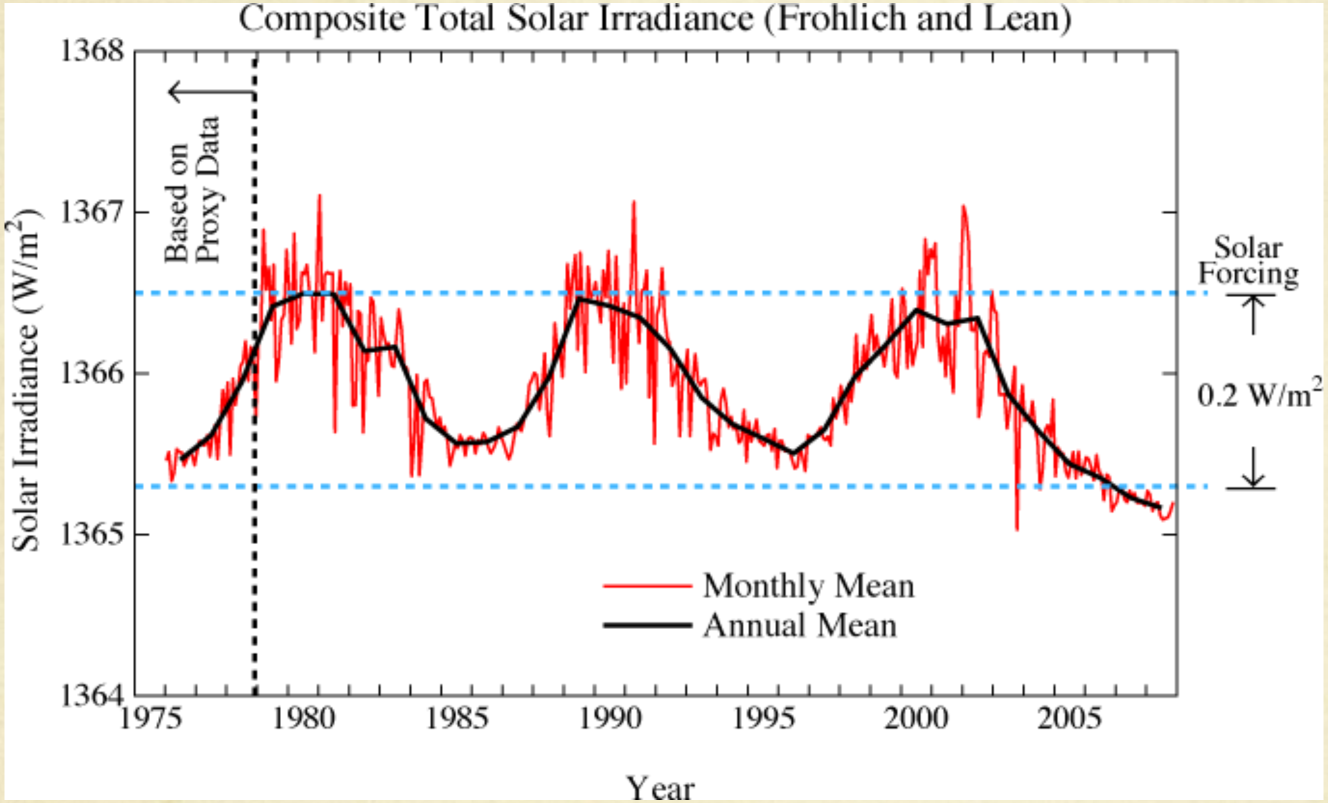
Historical Proxies for TSI

- **Total Solar Irradiance** goes back ~ 40 years (Nimbus 7)
- Sunspots: go back ~ 400 years
- Rates of growth of tree rings ~ 1000 years
- ^{14}C content of organic matter: yet further back



Sunspots and short-term climate change?

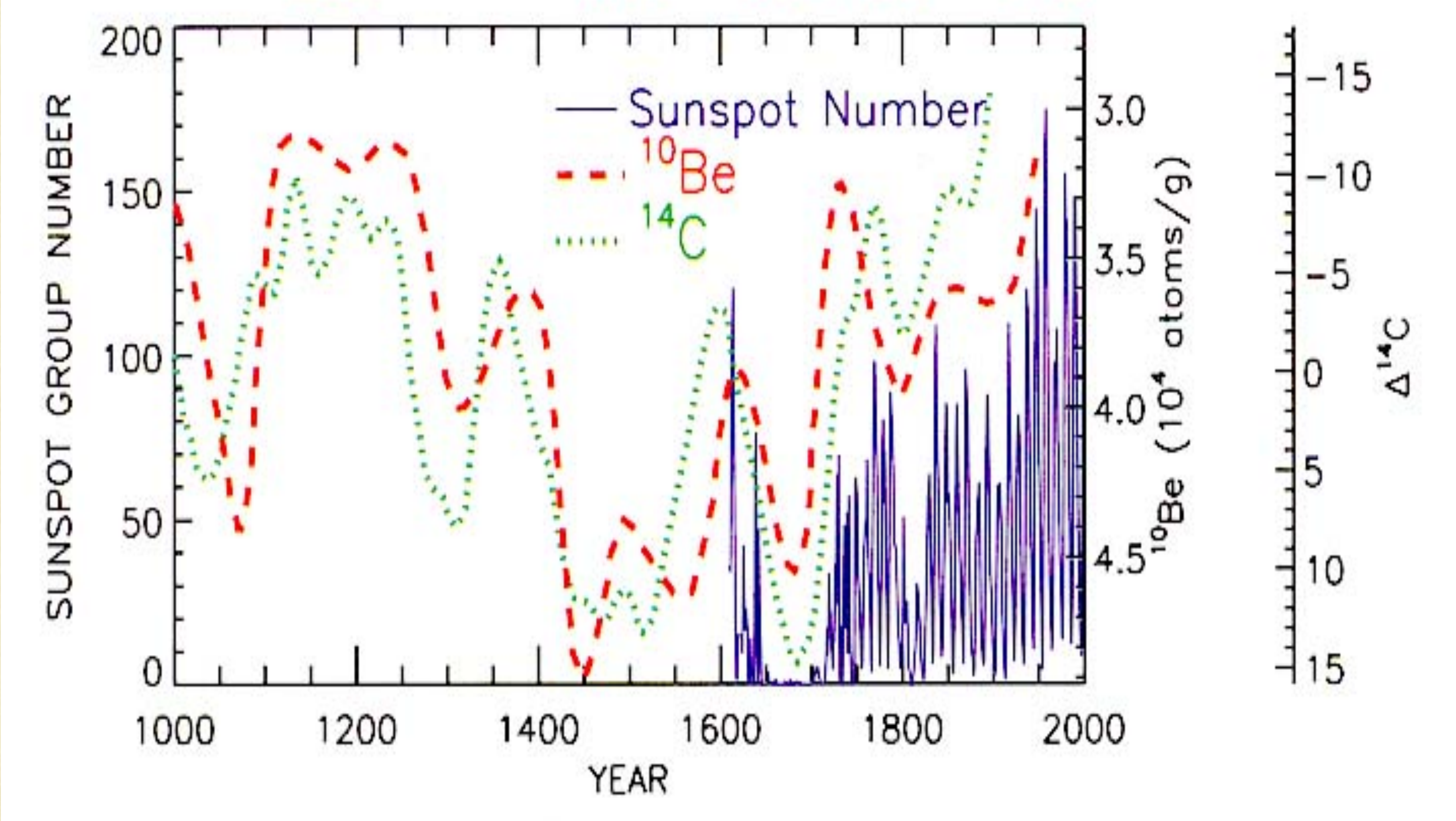
Solar irradiance – energy flux W/m^2 at upper atmosphere



0.1 – 0.2% variation in flux

Earth's surface temperature vary by 0.1 – 0.2^o C

During little ice age global cooling 0.2^o C



Sunspot Number
^{10}Be
^{14}C
SUNSPOT GROUP NUMBER
200
150
100
50
0
1000
1200
1400
1600
1800
2000
YEAR
3.0
3.5
4.0
4.5
^{10}Be (10^4 atoms/g)
−15
−10
−5
0
5
10
15
Δ^{14}C

How do we track solar activity?

10-Be ("beryllium-10") is a cosmogenic isotope that is produced when cosmic rays bombard Earth's atmosphere. When the Sun is active its magnetic field protects the Earth and little ^{10}Be accumulates in ice and sediments.

Να αναφέρω και άνθρακα (Hathaway2010, 3.9 Radioisotopes in tree rings and ice cores)
Hathaway TheSolarCycle LivingReviews2010.pdf

Reconstructions of total solar irradiance

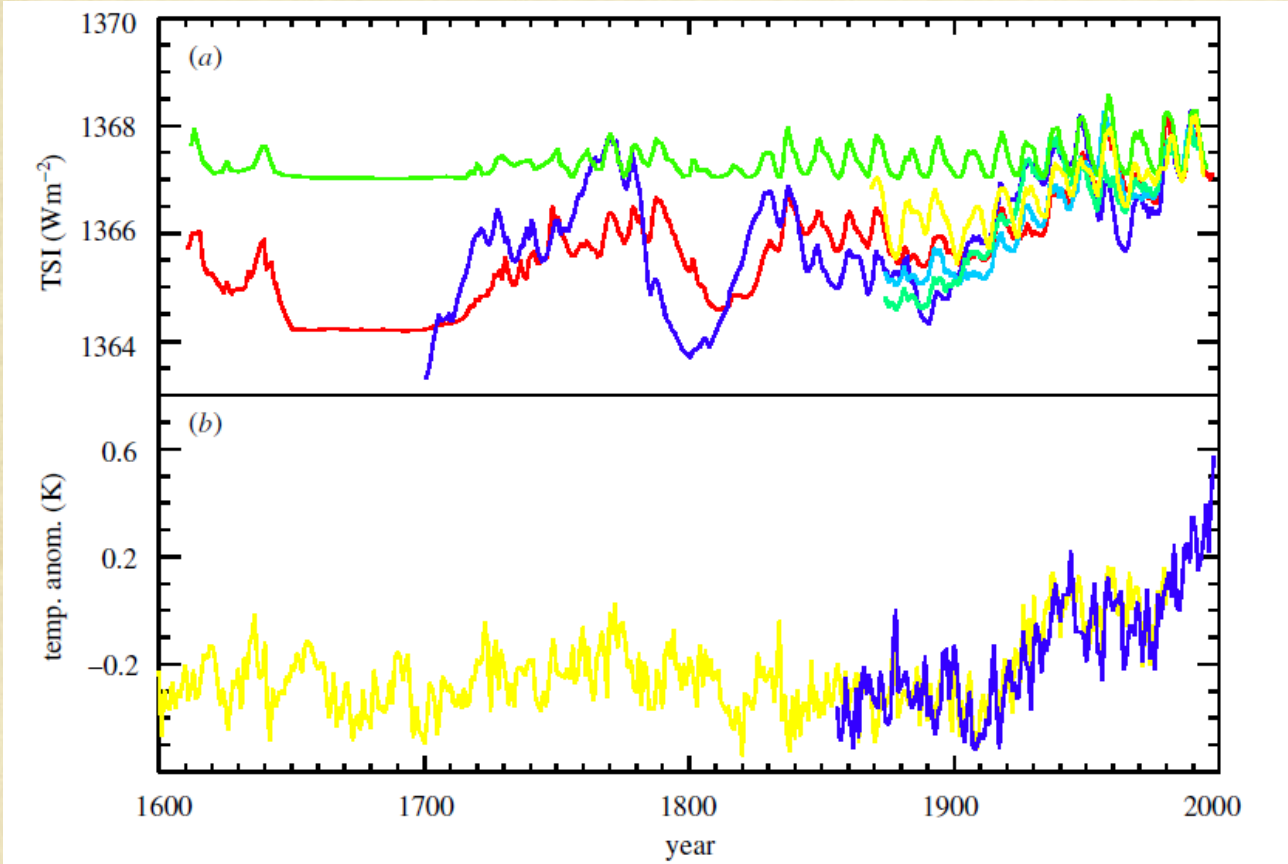
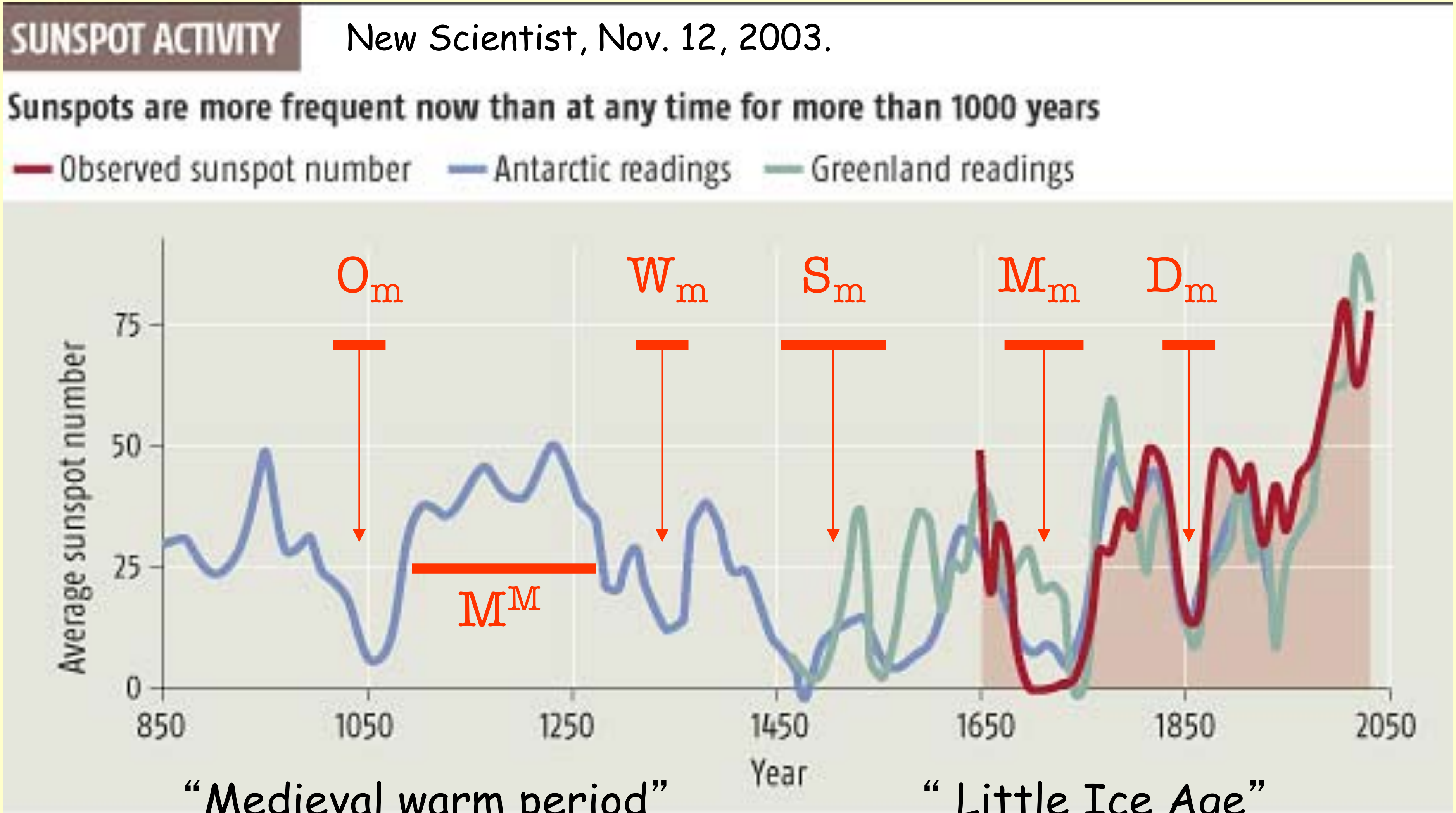


Figure 1. (*a*) Reconstructions of total solar irradiance from group sunspot numbers, scaled to Nimbus-7 measurements 1979–1993, green line; Lean *et al.* (1995), red line; Hoyt & Schatten (1993), violet line; Solanki & Fligge (1998), cyan and blue lines; Lockwood & Stamper (1999), yellow line. (*b*) Reconstructions of surface temperature: global average anomalies relative to 1961–1990 average (Jones *et al.* 1999), violet line; Northern Hemisphere average (Mann *et al.* 1998), shifted to match Jones *et al.*'s record in overlapping period, yellow line. Adapted from figure 2 of Haigh (2000) with permission from the Royal Meteorological Society.

- Five TSI reconstructions show large differences.
- A maximum increase in TSI of ca. 3.9 Wm^{-2} since the Maunder minimum.
- Suggest a solar-induced warming in global average surface temperature of ca. 0.35 K since that time.

Solar activity and Earth's climatic phases in the last 1150 yrs



"Medieval warm period" " Little Ice Age"

Phases of solar activity in last millennium

Approximate times of sunspot minima (X_m)

AD 1000 - 1050 O_m = Oort minimum
AD 1280 - 1340 W_m = Wolf minimum
AD 1420 - 1540 S_m = Spörer minimum
AD 1650 - 1710 M_m = Maunder minimum
AD 1795 - 1825 D_m = Dalton minimum

Approximate times of sunspot maxima (X^M)

AD 1100 -1230 M^M = medieval maximum
AD 1900 - 2000… (current maximum)

Variations and periodicity

Solar radiation as main element of space weather, varies at very different time scales.

due to solar activity

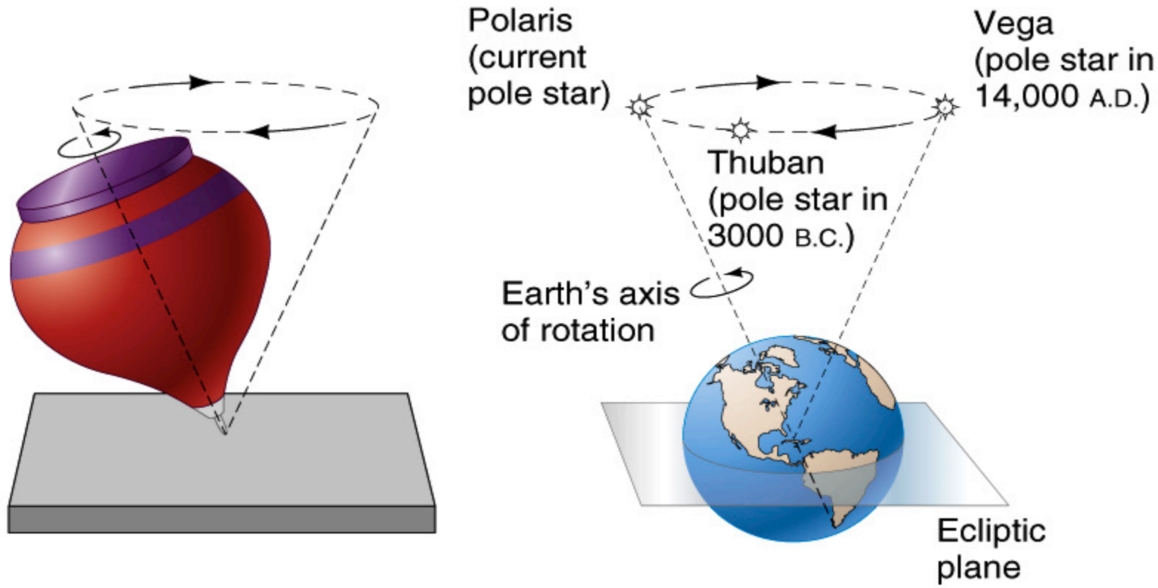
- **~27 days** (Solar rotation)
- **~11.2 years** (Schwabe cycle, cycle of solar activity)
- **~22 years** (Hale cycle)
(magnetic cycle : the original magnetic polarity is restored every second 11-year)
- **80-90 years** (Gleissberg cycle)
(seen by an enveloping curve of peaks of sunspot record)
- **~205 years** (de Vries cycle):
Sporer minimum (AD 1420-1540)
Maunder minimum (AD 1645-1715)

due to solar-terrestrial coupling

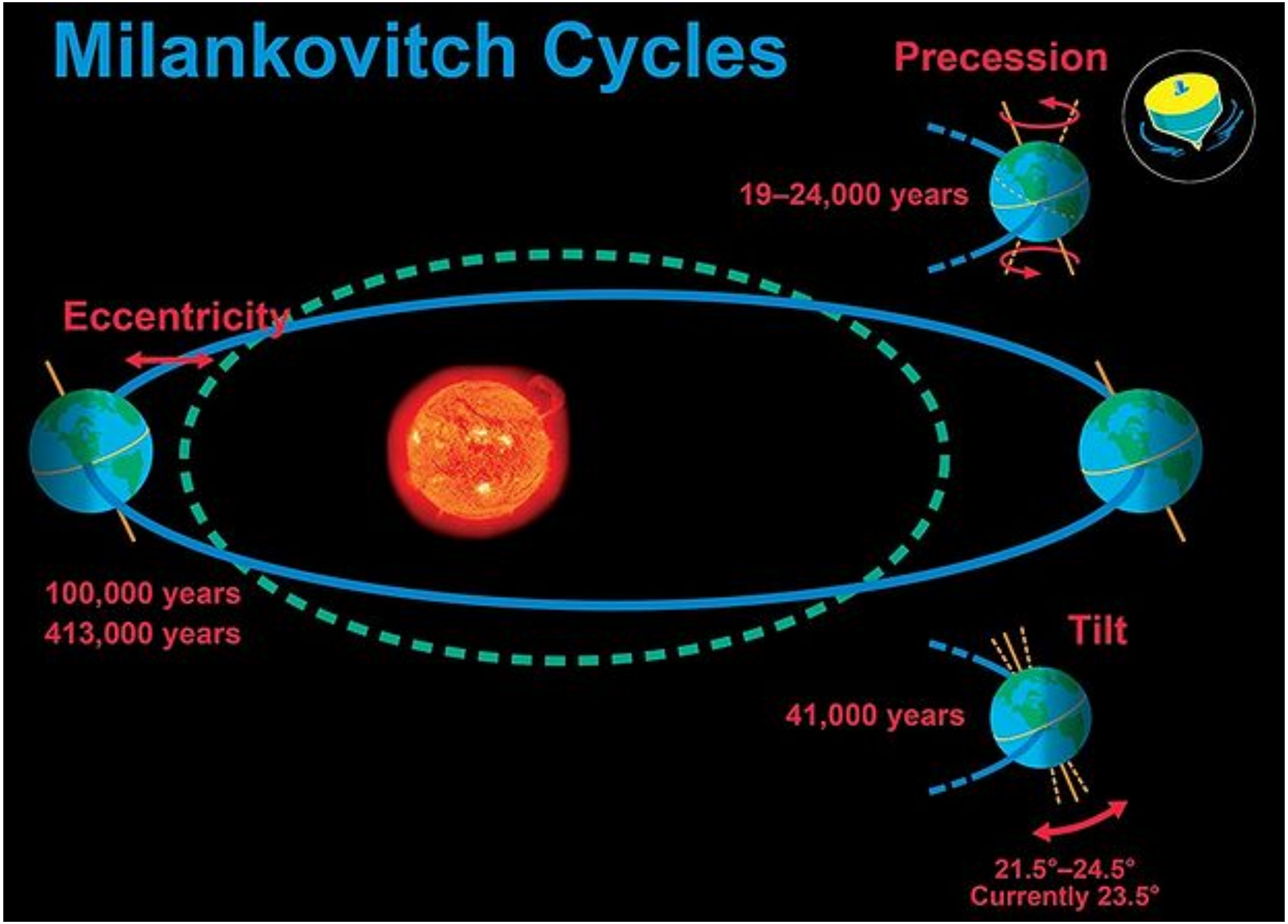
- **Seasonal variations**
(related with seasonal variations of geomagnetic activity --> variations of outer belt electron population);
due to motions of the Earth around Sun (--> annual changes in the Earth's atmosphere introduce seasonal modulation in low-altitude trapped proton population)
- **Daily variations** of Earth's magnetic dipole
(due to axial rotation of the Earth; angle between dipole and rotational axes ~11 deg.)

Longer cycles – important for effects related with Earth's climate and long term trends

Milankovitch Cycles -- Precession

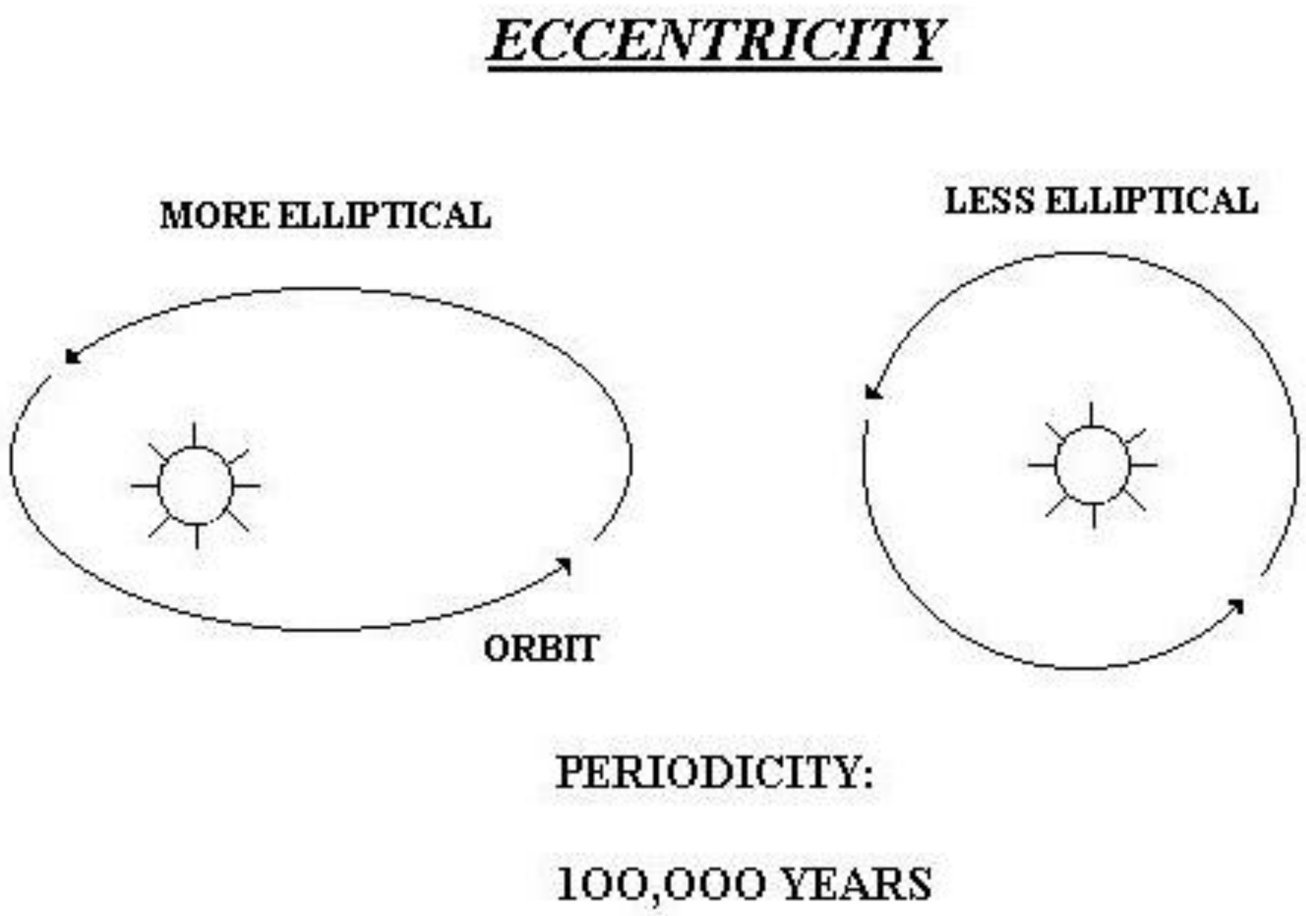


- *Milankovitch cycles* -- regular natural variations in the Earth's orbit around the sun
  - Obliquity -- 41,000yr period
  - Eccentricity -- 95,000yr period (125k, 400k)
  - Precession -- 24,000yr period

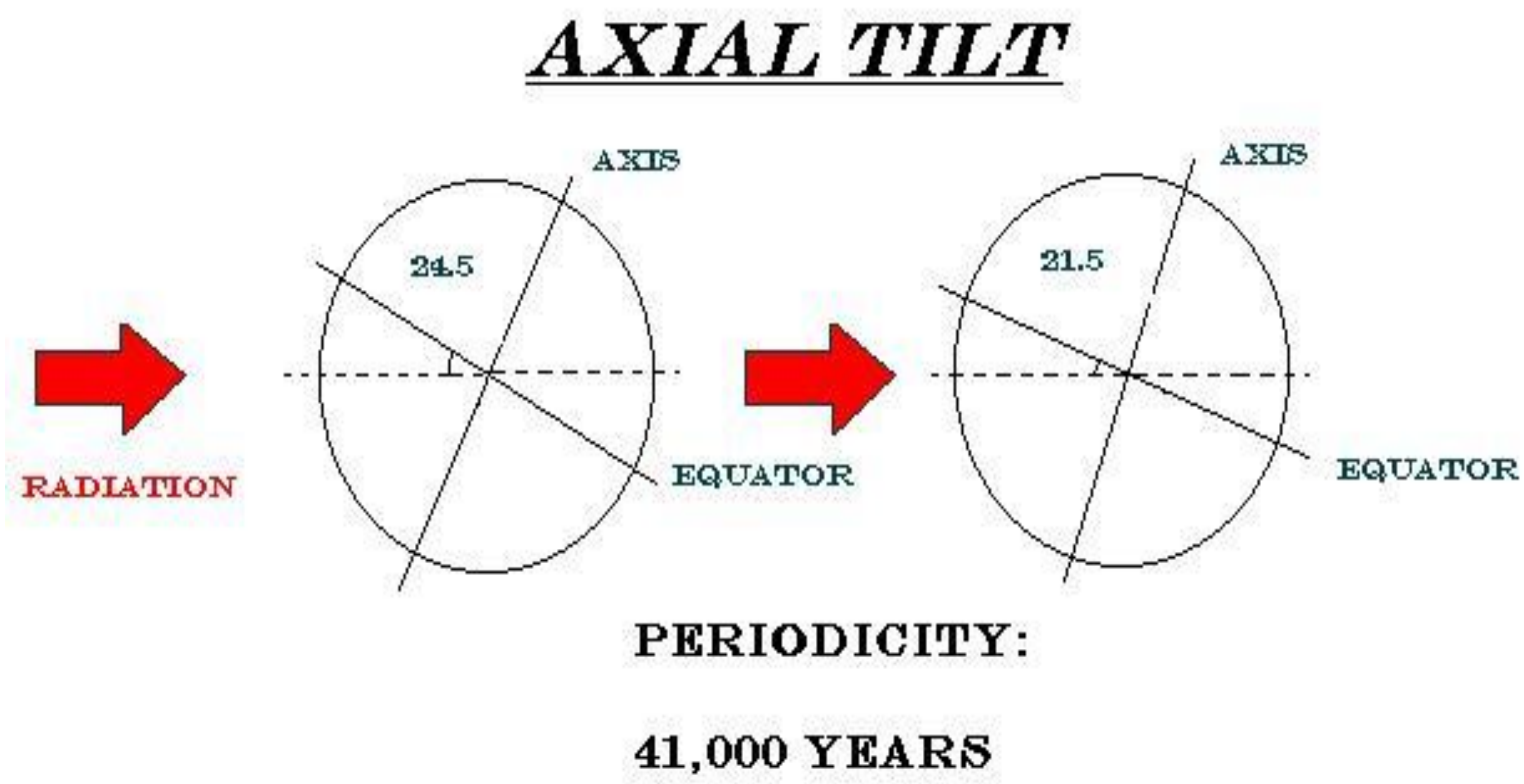


Milankovitch Cycles
Precession
19–24,000 years
Eccentricity
100,000 years
413,000 years
Tilt
41,000 years
21.5°–24.5°
Currently 23.5°

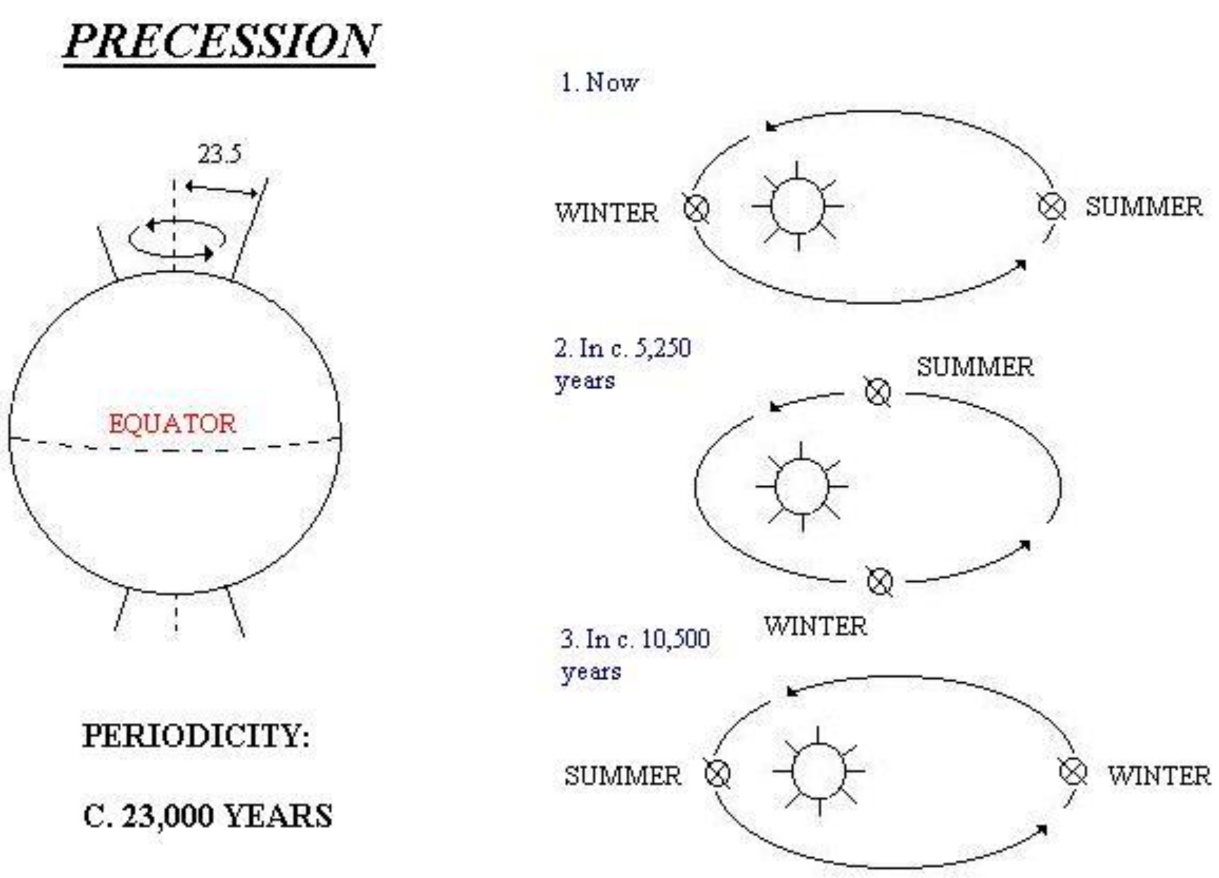
Milankovitch Theory



Milankovitch Theory



Milankovitch Theory



Changes in land configuration and surface characteristics

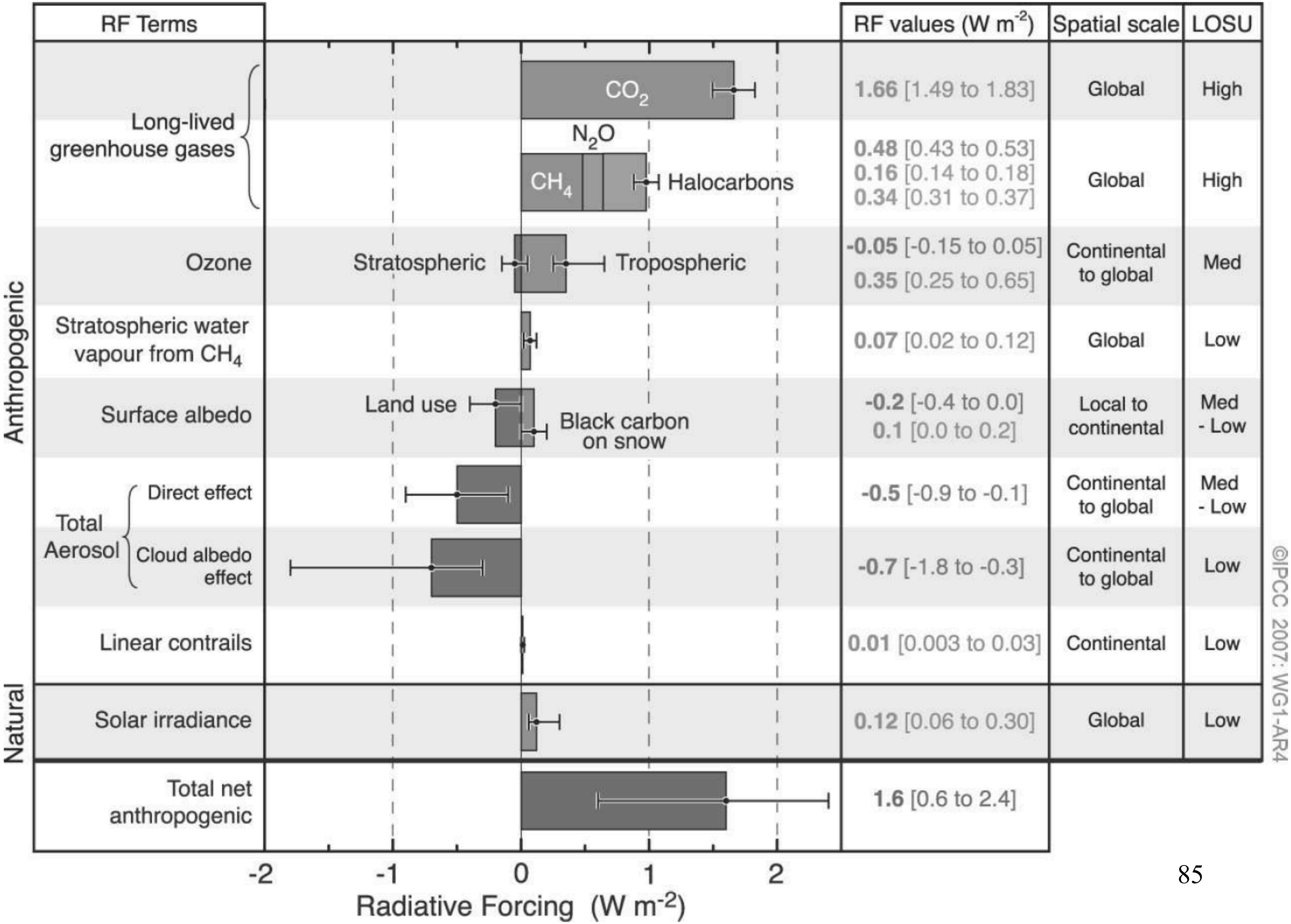
- **Plate tectonics** gradually changes the configurations of the mountains and oceans
- **Mountain building and land erosion** affect climate over geologic time
- **Land use changes** such as deforestation and desertification change albedo, surface temperatures, and water balance

Changes in **atmospheric aerosols** affect the amount of solar energy that can reach the Earth's surface

- Major **volcanic eruptions** inject great amounts of aerosols into the atmosphere over days or weeks, leading to temporary climate cooling
- Residence times of tropospheric aerosols is a few years
- Residence times of stratospheric aerosols is a few decades

Changes in **radiation-absorbing gases**

- Anthropogenic contributions of CO_2
  - Increased exponentially since the mid 19th century due to fossil-fuel burning
  - Increased CO_2 concentrations leads to increased atmospheric absorption of IR radiation
  - Increased anthropogenic greenhouse gases in the atmosphere can lead to increased atmospheric water vapor (the most important greenhouse gas)


RF Terms
RF values (W m-2)
Spatial scale
LOSU
CO2
N2O
CH4
Halocarbons
Long-lived greenhouse gases
1.66 [1.49 to 1.83]
Global
High
0.48 [0.43 to 0.53]
0.16 [0.14 to 0.18]
0.34 [0.31 to 0.37]
Global
High
Ozone
Stratospheric
Tropospheric
-0.05 [-0.15 to 0.05]
0.35 [0.25 to 0.65]
Continental to global
Med
Stratospheric water vapour from CH4
0.07 [0.02 to 0.12]
Global
Low
Surface albedo
Land use
Black carbon on snow
-0.2 [-0.4 to 0.0]
0.1 [0.0 to 0.2]
Local to continental
Med - Low
Total Aerosol
Direct effect
-0.5 [-0.9 to -0.1]
Continental to global
Med - Low
Cloud albedo effect
-0.7 [-1.8 to -0.3]
Continental to global
Low
Linear contrails
0.01 [0.003 to 0.03]
Continental
Low
Solar irradiance
0.12 [0.06 to 0.30]
Global
Low
Anthropogenic
Natural
Total net anthropogenic
1.6 [0.6 to 2.4]
-2
-1
0
1
2
Radiative Forcing (W m-2)
©IPCC 2007: WG1-AR4

Cloud cover and cosmic rays

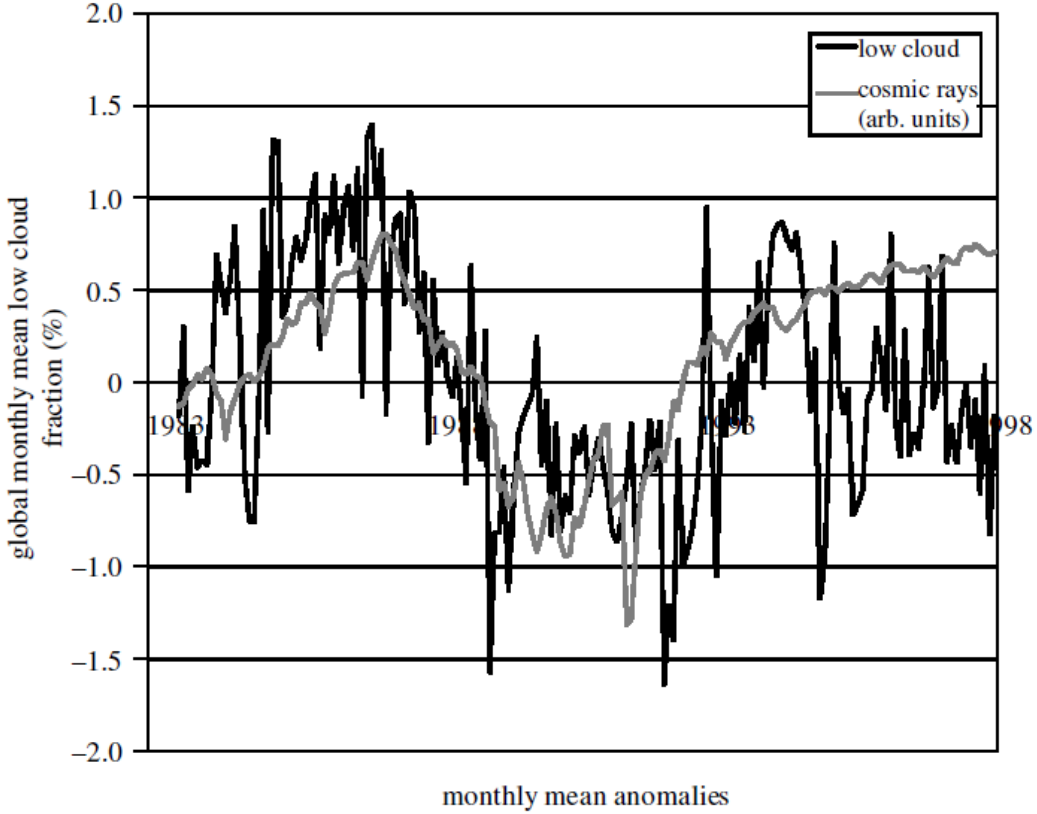


Figure 2. Black curve, global mean low cloud amount from the International Satellite Cloud Climatology Project (ISCCP) D2 dataset; grey curve, cosmic rays measured at Climax, CO, USA. A 12-month running mean has been applied to both datasets.

Marsh & Svensmark (2000) demonstrated a high degree of correlation between low cloud cover, from the ISCCP satellite D2 dataset, and cosmic rays between 1984 and 1994

Conclusions

1. Analyses of global mean temperature records suggest a **detectable signal of solar influence** on decadal, centennial and millennial time-scales.

2. The **warming** that occurred during the latter half of the 20th century cannot be ascribed entirely to solar influences.

3. **Variations in UV** and solar-induced changes in ozone may have an effect on radiative forcing but additionally may affect climate through a dynamical response to solar heating of the lower stratosphere.

4. General circulation **models** are able to produce some of the observed patterns of response to solar activity but generally **underestimate the magnitude**.