Solar-Terrestrial Effects
Sun-Weather-and-Climate Relationship

Zerefşan Kaymaz

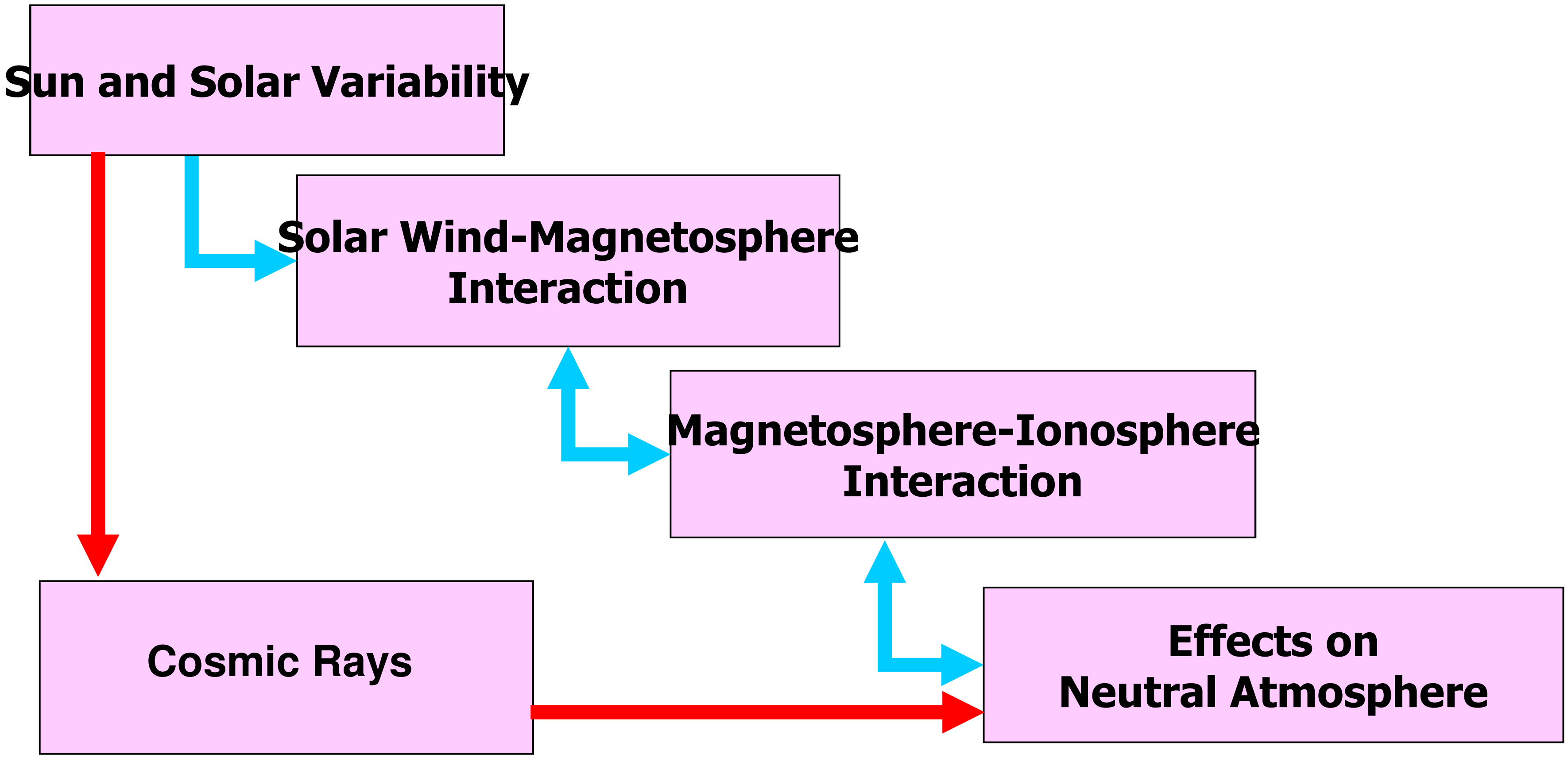
What are the Causes of Climate Variations?

- Internal oscillations in atmosphere-ocean system
- Variations in energy received from the sun
- Variations in energy radiated from away from the Earth

How do we define Solar Variability?

- Total Solar Irradiance
- UV-radiation changes
- Changes in the Solar Wind (Heliosphere)
- Changes in Cosmic ray amount (Heliosphere)

Coupling



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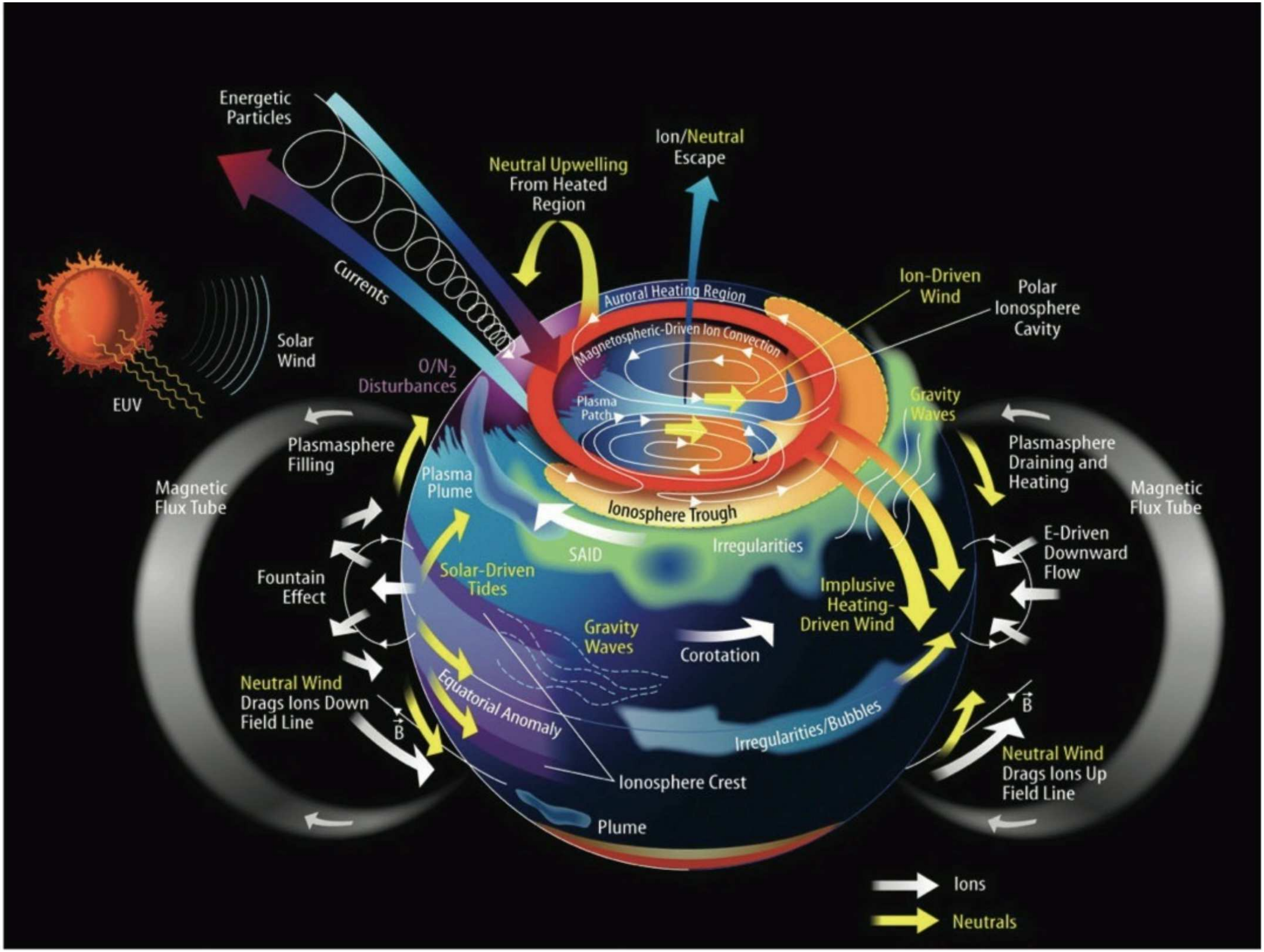
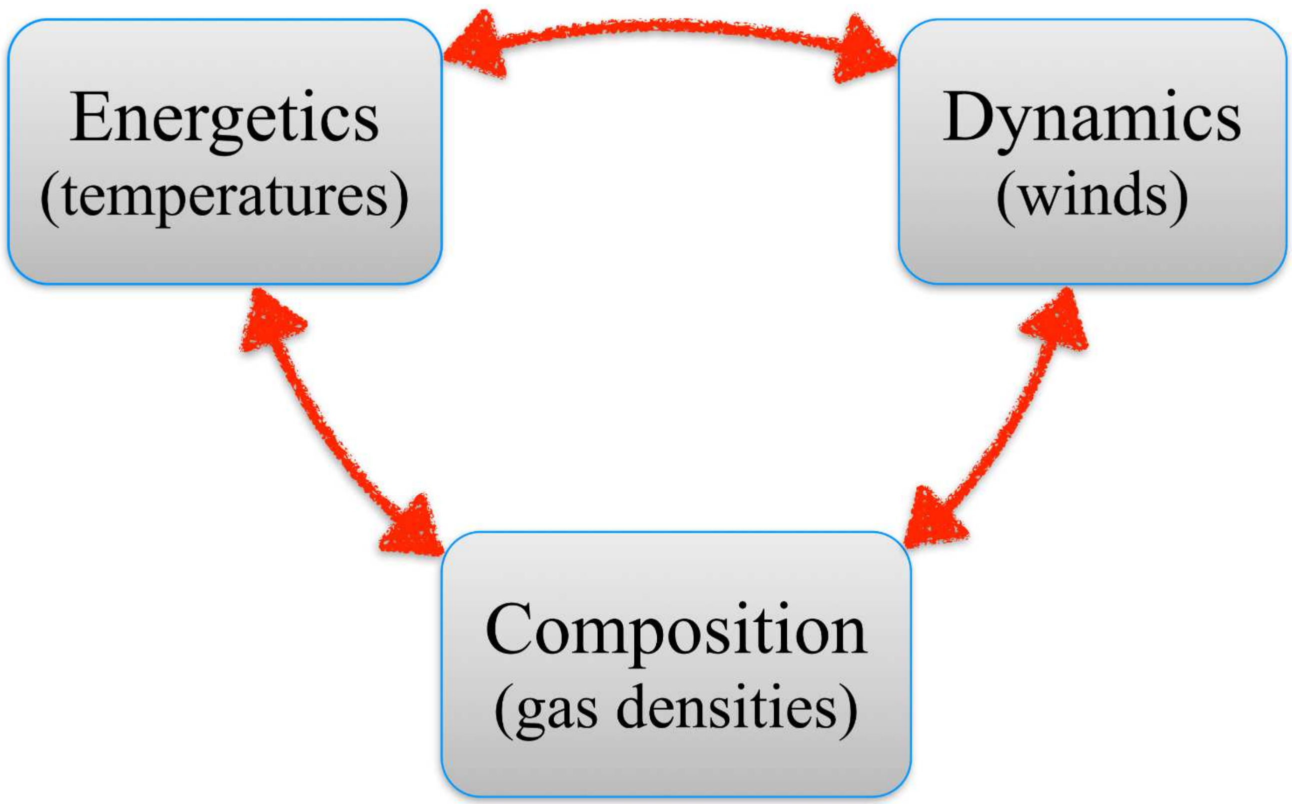


Energetic Particles
Currents
Solar Wind
EUV
Neutral Upwelling From Heated Region
Ion/Neutral Escape
Auroral Heating Region
Magnetospheric-Driven Ion Convection
Ion-Driven Wind
Polar Ionosphere Cavity
O/N_2 Disturbances
Plasma Patch
Gravity Waves
Plasmasphere Filling
Plasmasphere Draining and Heating
Magnetic Flux Tube
Plasma Plume
Ionosphere Trough
Magnetic Flux Tube
SAID
Irregularities
E-Driven Downward Flow
Fountain Effect
Solar-Driven Tides
Implusive Heating-Driven Wind
Gravity Waves
Corotation
Neutral Wind Drags Ions Down Field Line
B
Equatorial Anomaly
Irregularities/Bubbles
B
Neutral Wind Drags Ions Up Field Line
Ionosphere Crest
Plume
Ions
Neutrals

Everything is coupled!



EFFECTS

Atmospheric

- Modifications on ozone
  - Increased UV amounts on the surface
    - Cancer,
    - Immune system problems,
    - Catarakts etc.
- Upper Atmospheric Heating
  - Auroral Heating
  - Joule Heating
  - Magnetospheric Heating
  - Solar energetic particle Heating
  - Cosmic Ray Heating
- Modifications on upper atmospheric wind systems
- Ionospheric TEC Modifications
- Modifications on Climate

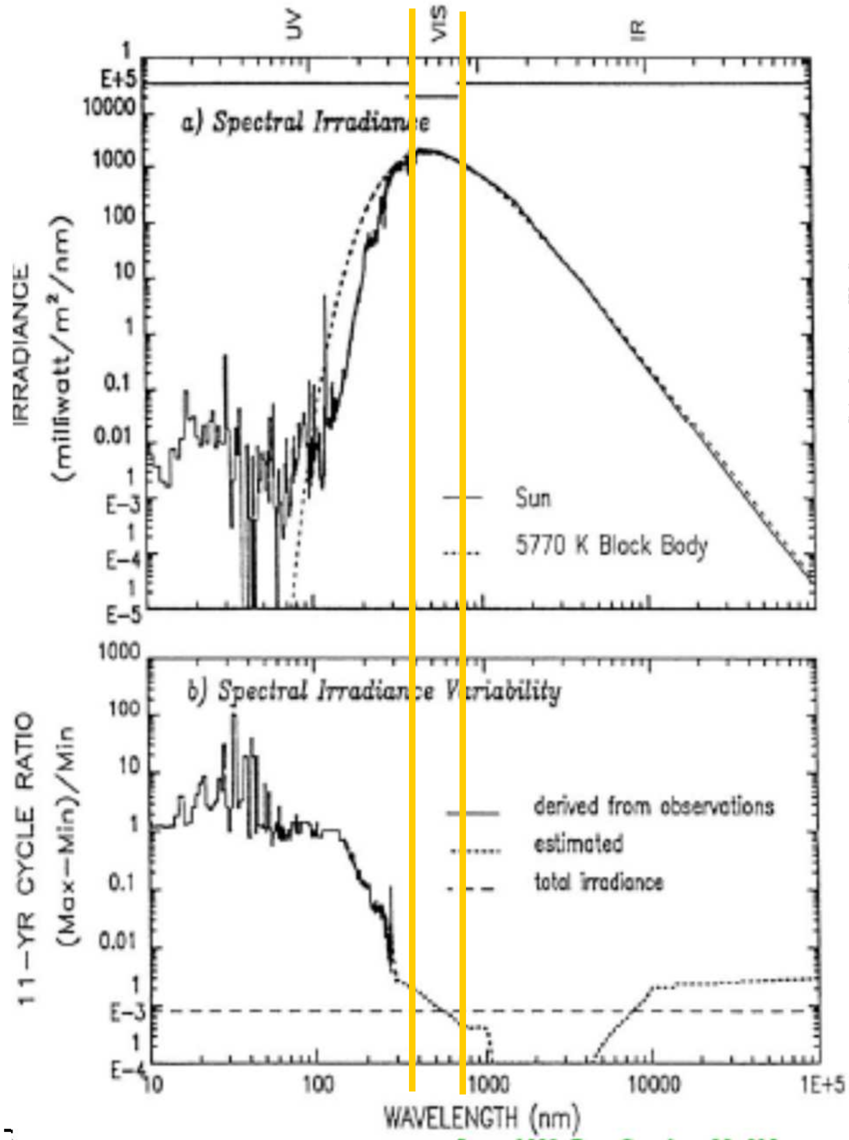
Technological systems

- Satellite technology
  - Spacecraft charging
  - Astronauts
- Communication
  - Navigation
- Electrical Systems
  - Power lines
  - Pipelines
- Earth's global circuit
  - Ionospheric currents
- Radars
  - Radar Range
- Ionospheric Radio Propagation
  - Absorption, Reflection
- GPS Systems

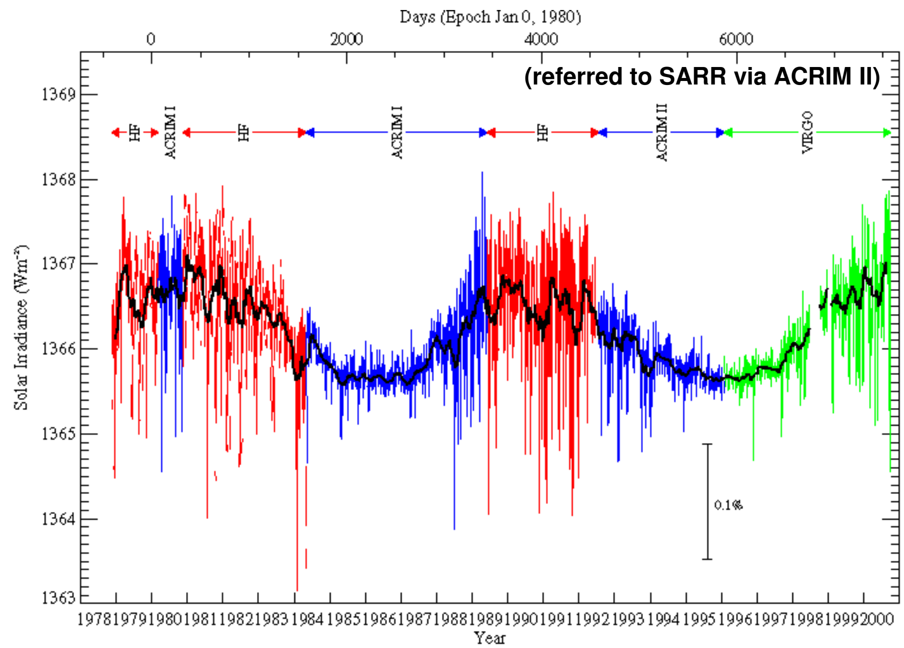
Remember: Heat Sources in Upper Atmosphere

- Heat Production
  - Absorbtion of solar ultraviolet and X-ray radiation
    - →photodissociation, ionization and censequent reactions that liberate heat
  - Energetic charged particles entering the upper atmosphere from the magnetosphere
  - Joule Heating by ionospheric currents
  - Dissipation of tidal motions and gravity waves by turbulence and molecular activity

UV Variability of Solar Spectrum



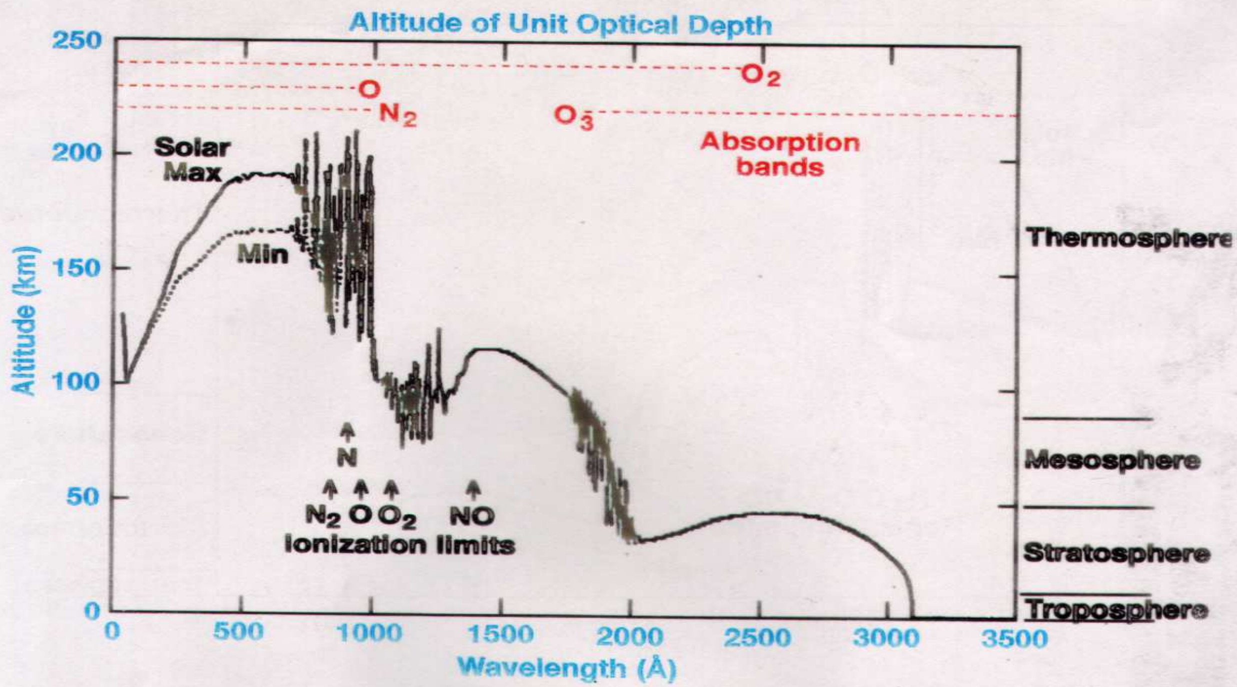
Lean, 1992, Rev. Geophys. 29, 505



Total Solar Irradiance Data

- Spectral radiation is much more pronounced in the short wavelength region

Solar Radiation and Upper Atmosphere



Altitude at which vertically incident UV radiation is attenuated by e^{-1}. Dashed lines at top identify spectral regions where extinction by the indicated species is significant. Arrows give the ionization thresholds of important atmospheric species. Atmospheric regions are given on the right. Altitudes for solar max and min were obtained using the MSIS-86 model (see Section 3.2.1.1) above 90 km; below 90 km, the US standard atmosphere was used. Absorption cross sections were taken from Conway (1988) for N_2, O_2, O in EUV, from Watanabe (1958), Blake *et al.* (1986), Yoshina *et al.* (1983), and Nicolet and Kennes (1988b) for O_2 in the FUV and MUV, and from Molina and Molina (1986) for O_3. Earlier versions of these curves appeared in Lean (1987) and Chamberlain (1978). From R. R. Meier *Ultraviolet Spectroscopy and Remote Sensing of the Upper Atmosphere, Space Science Reviews*, vol. 58, No.1-2, 1991.

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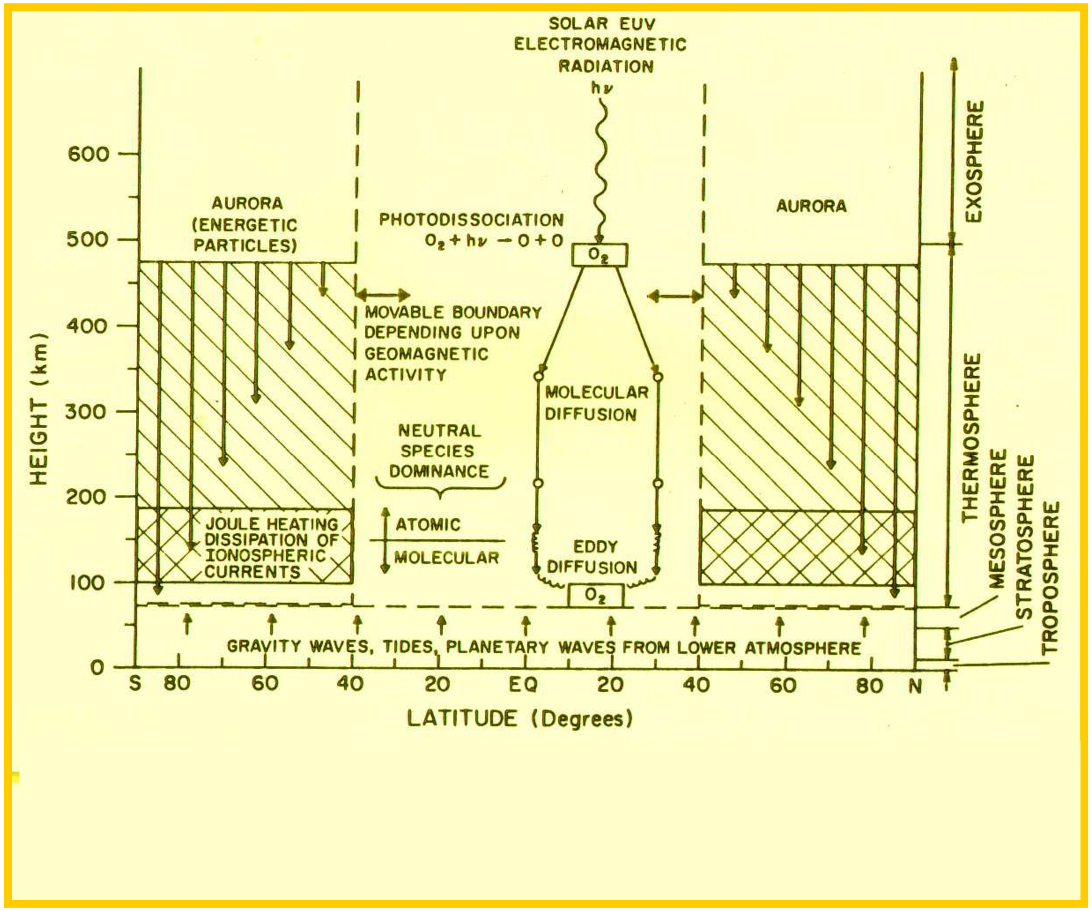
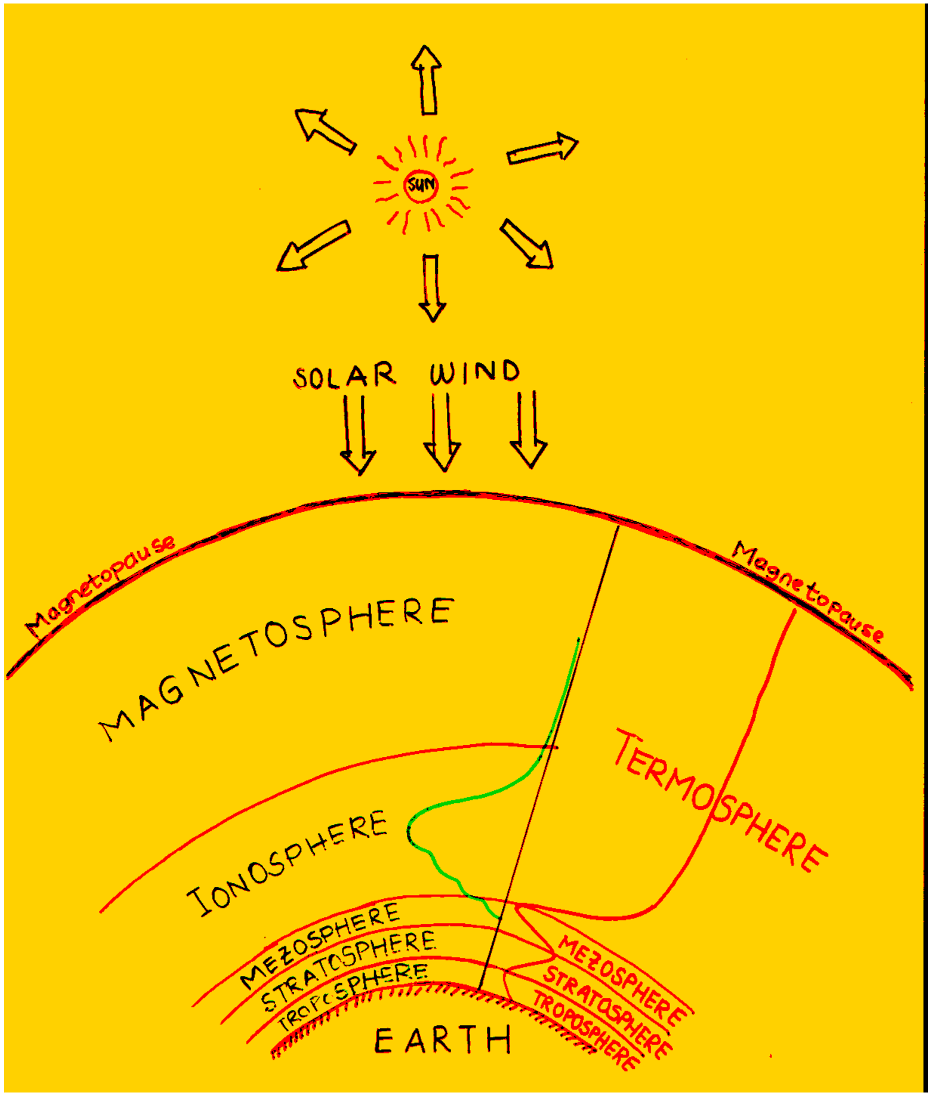
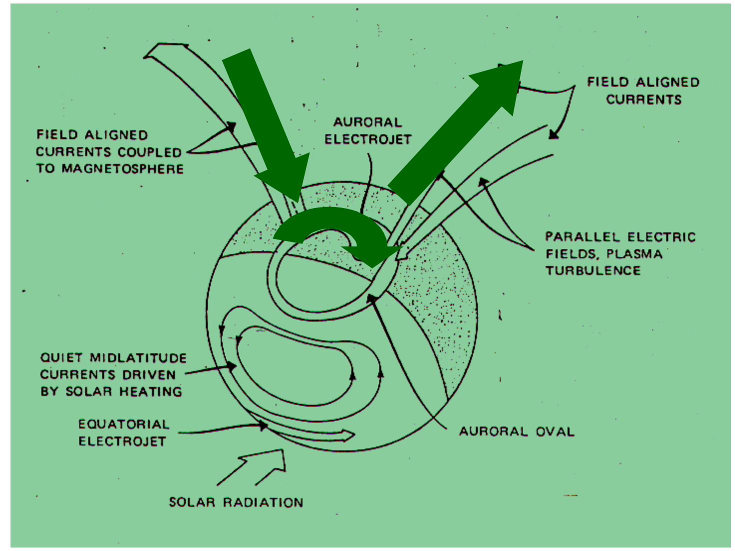
Heat Sources in Upper Atmosphere



- Electrojets and particles from magnetosphere are additional sources for heat
- Auroral Electrojets can dissipate as much as 0.5 W/m2 in the ionospheric E-region heights during a severe storm disturbance
- The energy flux of EUV which drives the normal tide is much smaller than this, about 0.5 mW/m2 above 120 km.





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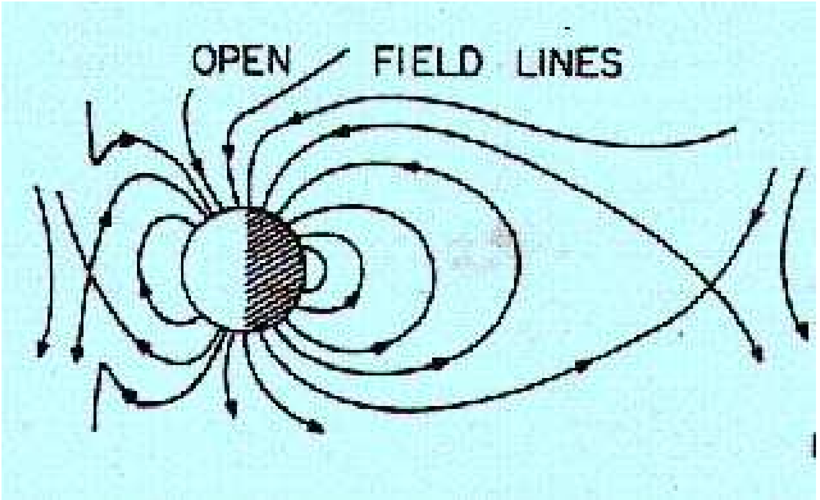
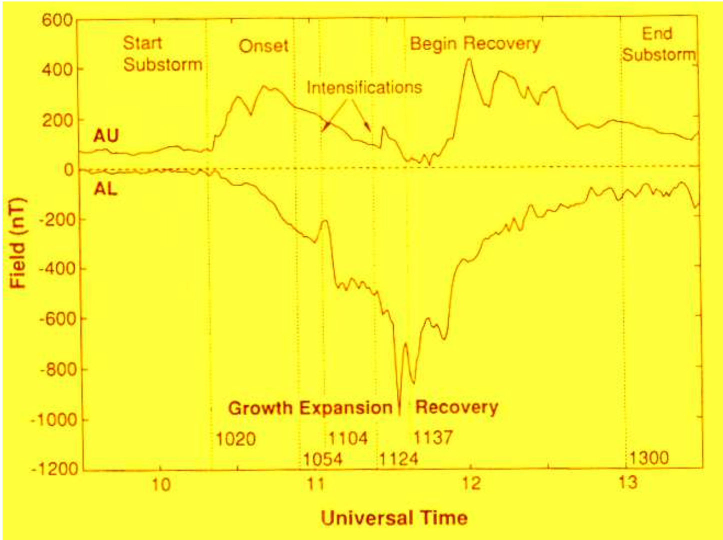
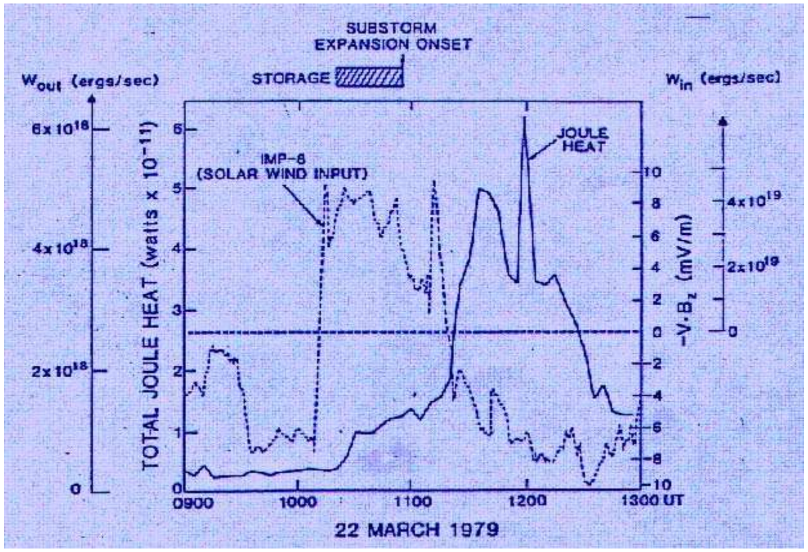
Magnetospheric energy input







0.5 W/m2 versus 0.5 mW/m2 above 100 km

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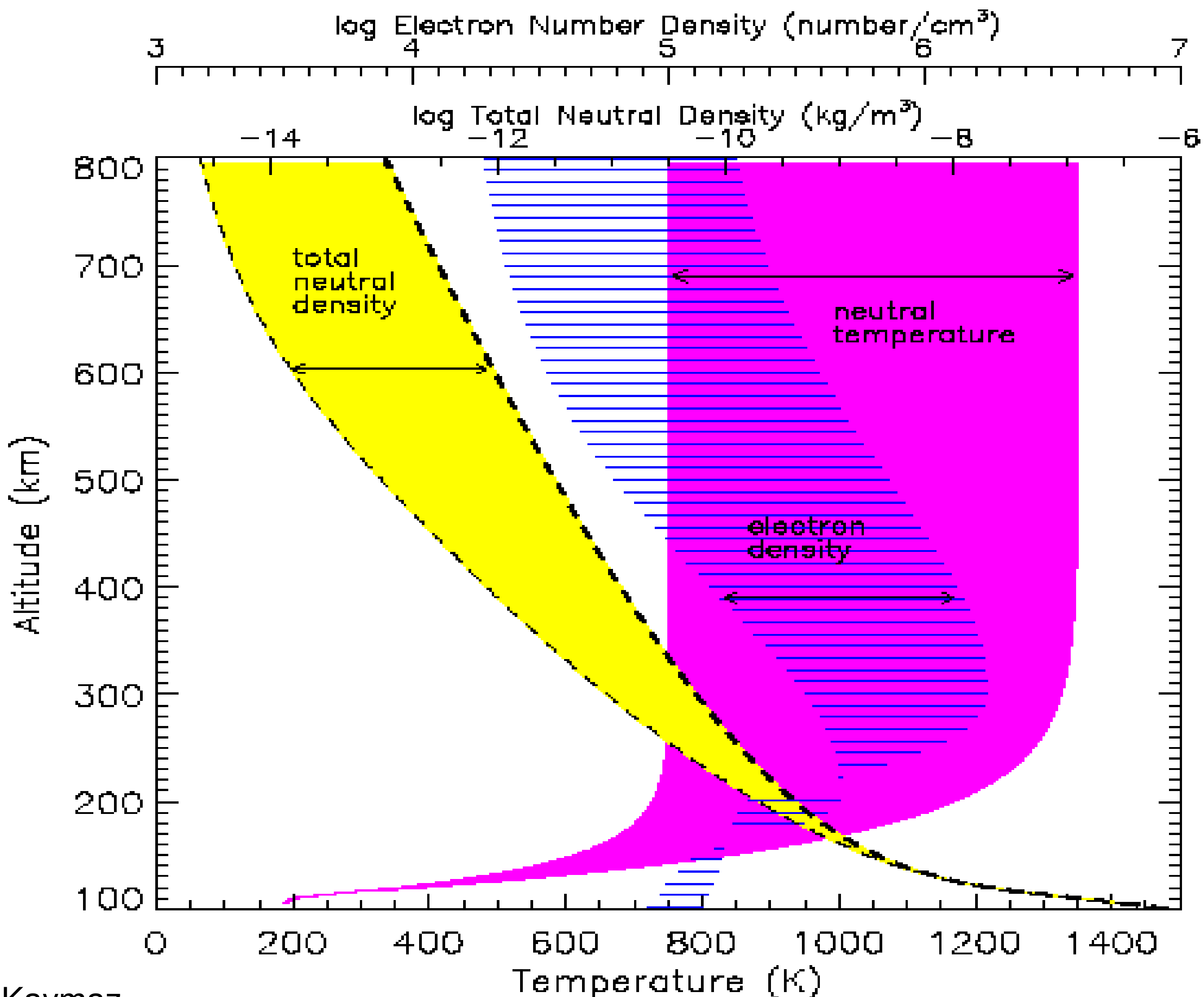
Temperature and Density Distributions and Ranges
Diurnal and Solar Cycle



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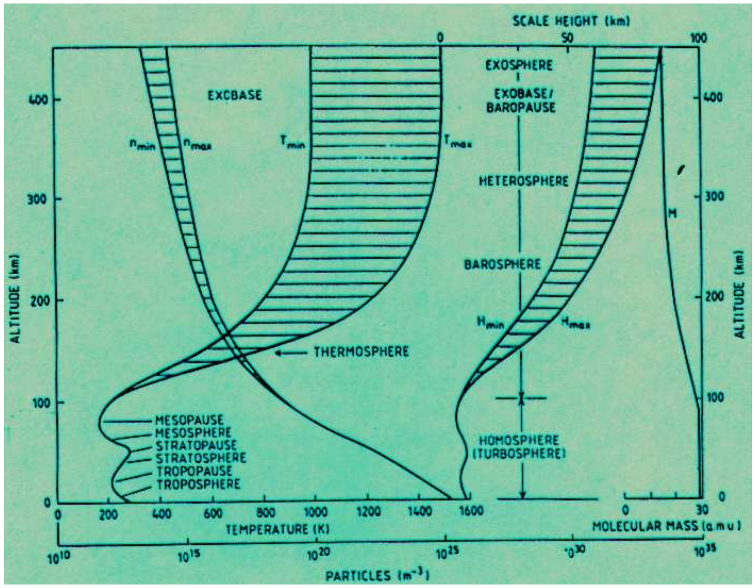
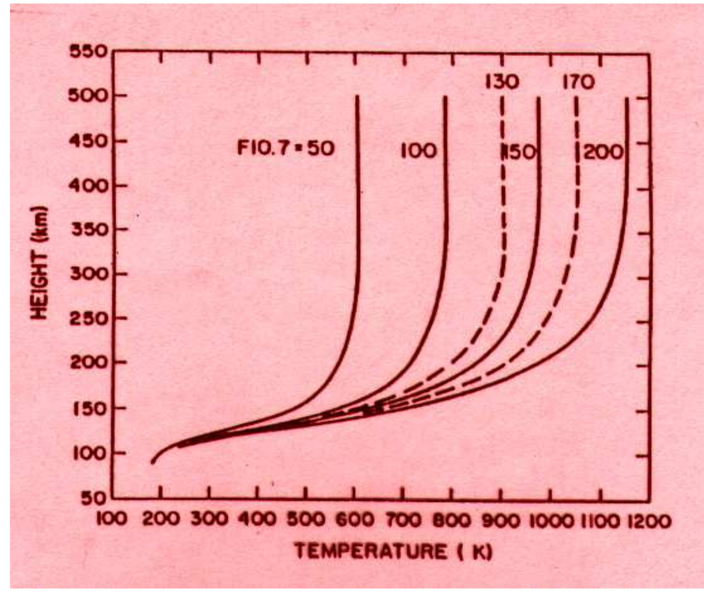
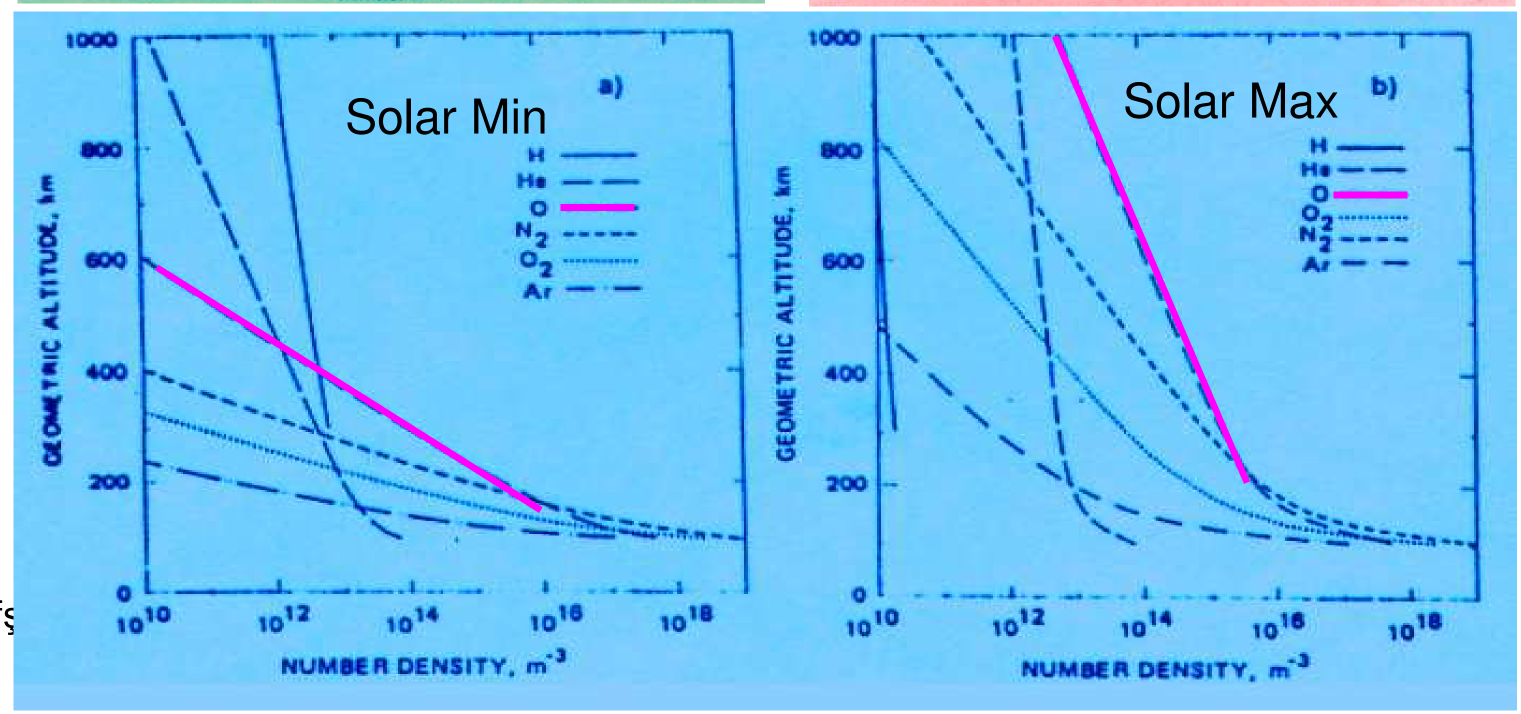
Thermospheric Temperature and Composition and Solar Activity







Zerefş

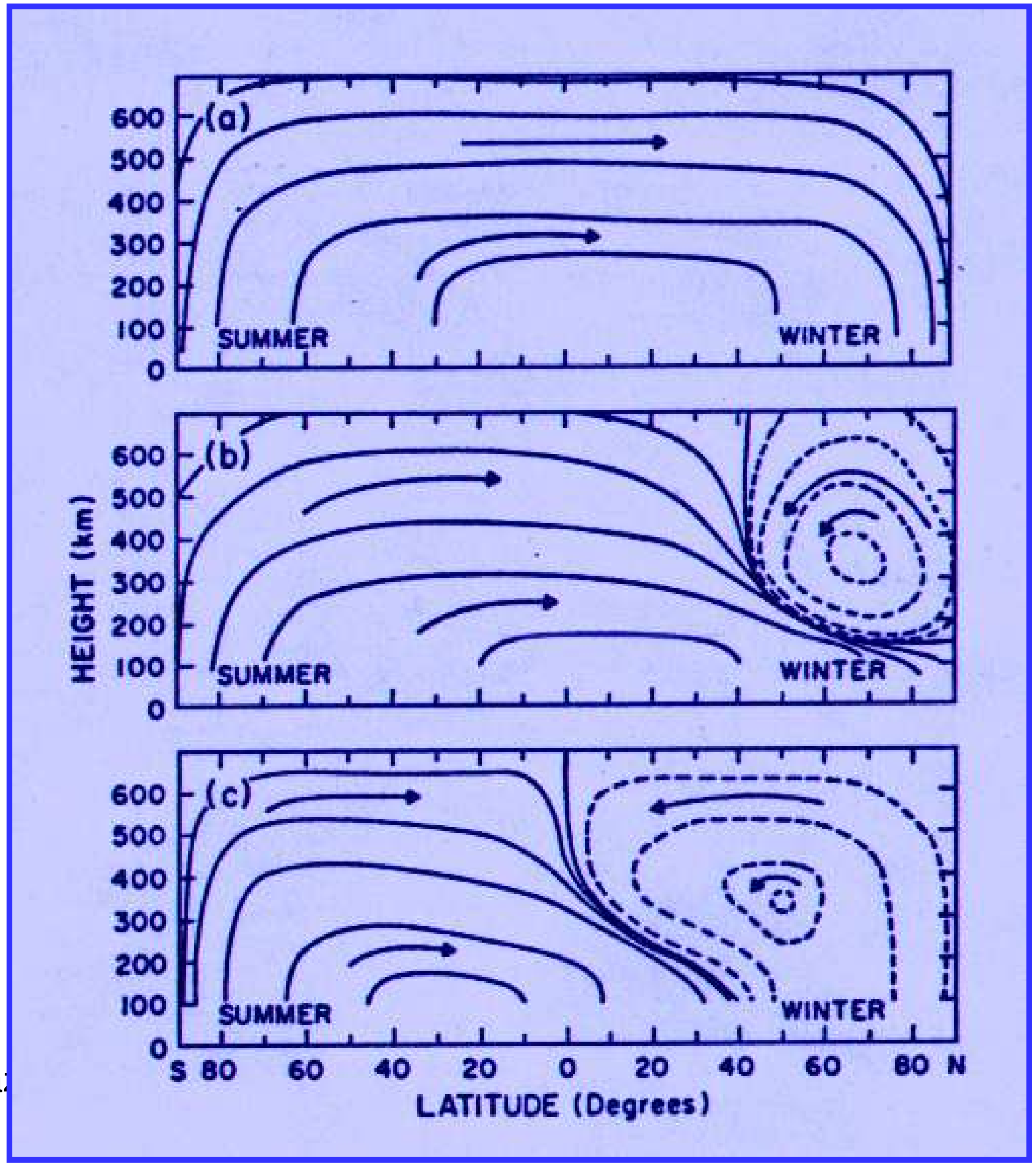
Upper Atmospheric Circulation

Meridional Circulation, Solstice Time

Min Magnetic Acitivity

Ave Magnetic Acitivity

Max Magnetic Acitivity



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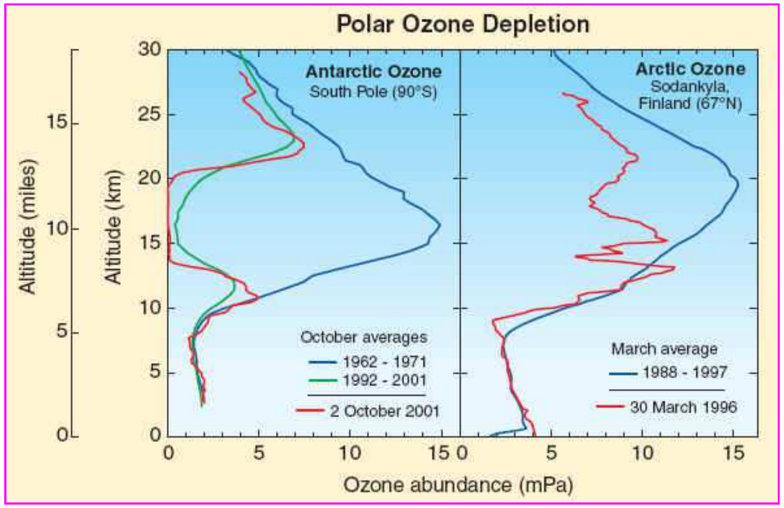
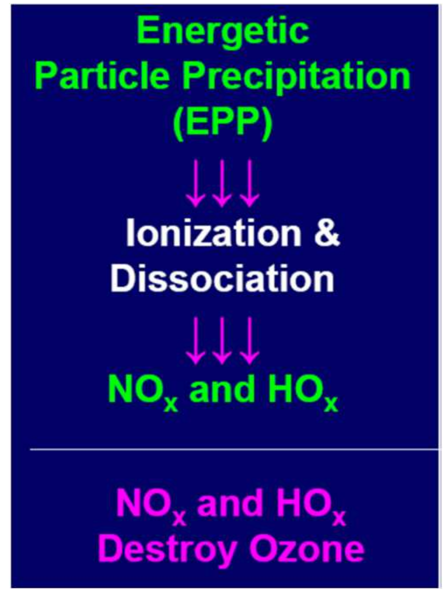
Robble et al., 1977

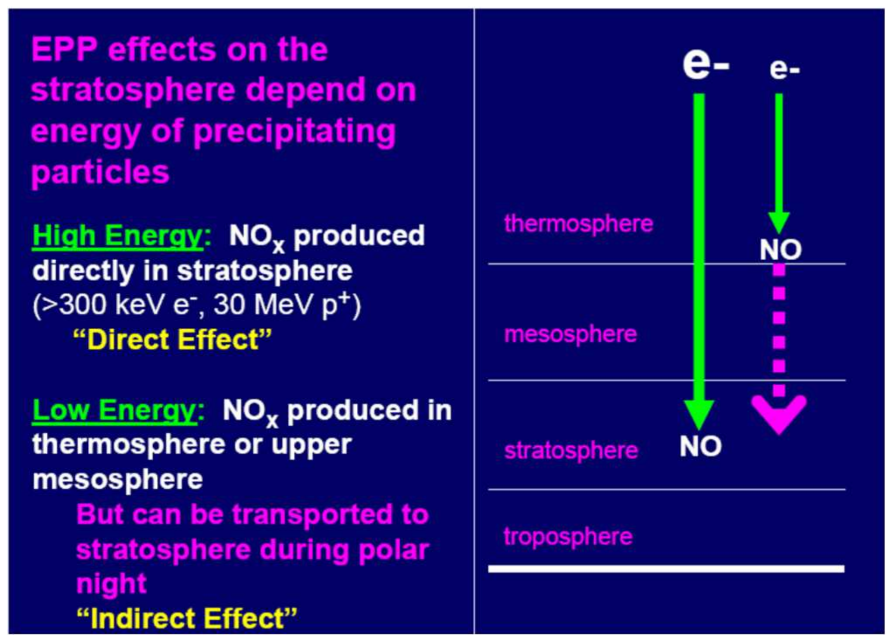
Stratospheric Ozone



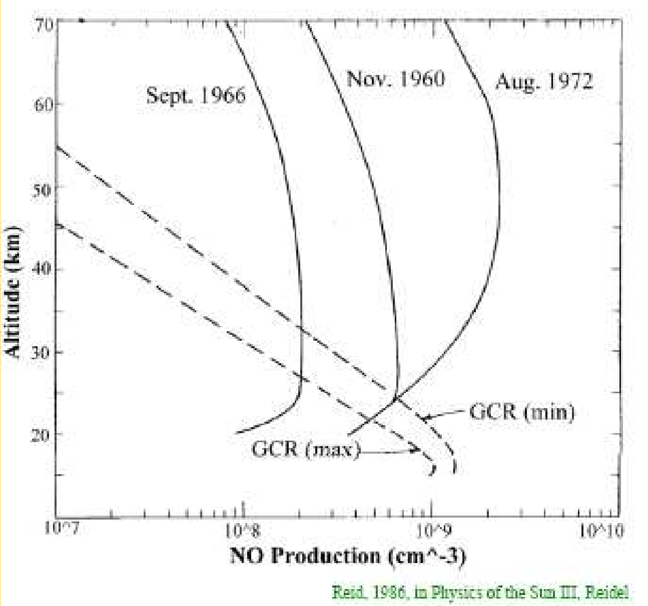


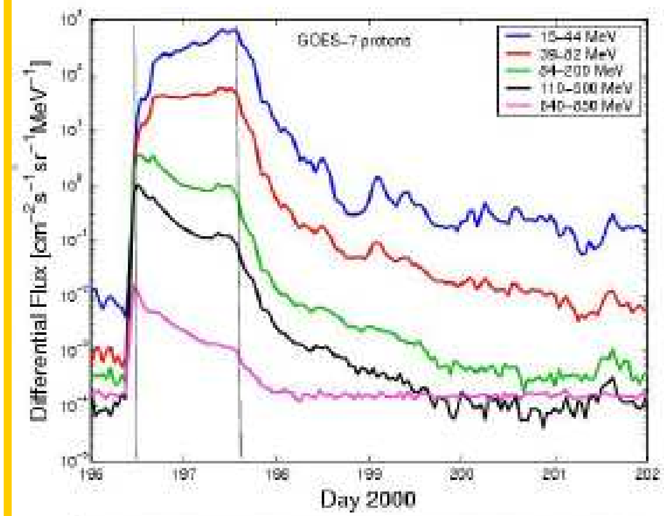
- Ozone Distroying Chemical Reactions
- NO + O3 → NO3 + O2
- NO2 + O3 → NO + O2
- NO2 + hn (photon <400 nm) → NO + O
- N2O5 + hm → NO3 + NO2
- NO3 + hv → NO + O2

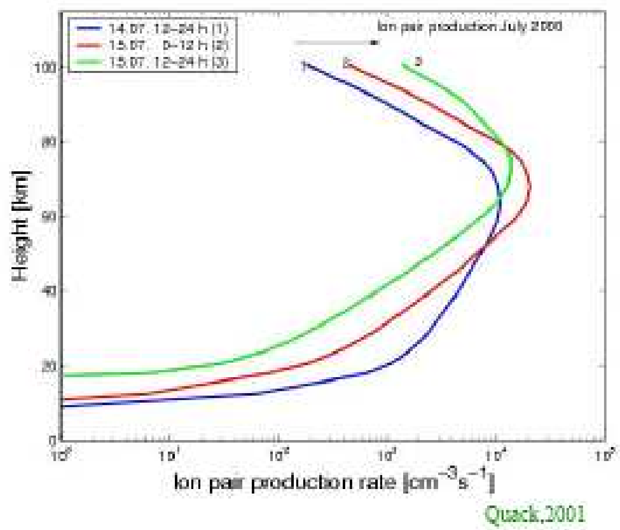
NO – O3



Ozone and SEPs







BASTILLE DAY EVENT
JULY 14, 2000

One individual solar energetic particle event can produce more NOx than the galactic cosmic radiation during an entire solar cycle although the height distribution is different

Ionization down to 10 km

Early in the event ionization at lower altitudes

In the time course of the event ionization shifts to higher altitudes

Ion pair production rates up to about 10^4#/cm^{3}s

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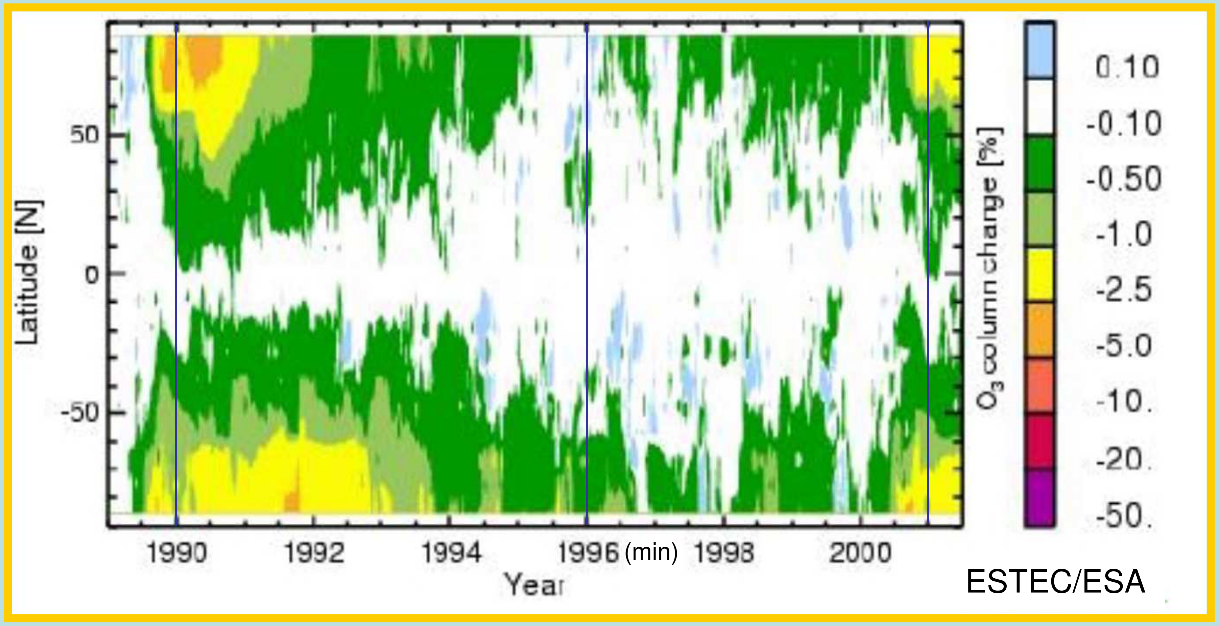
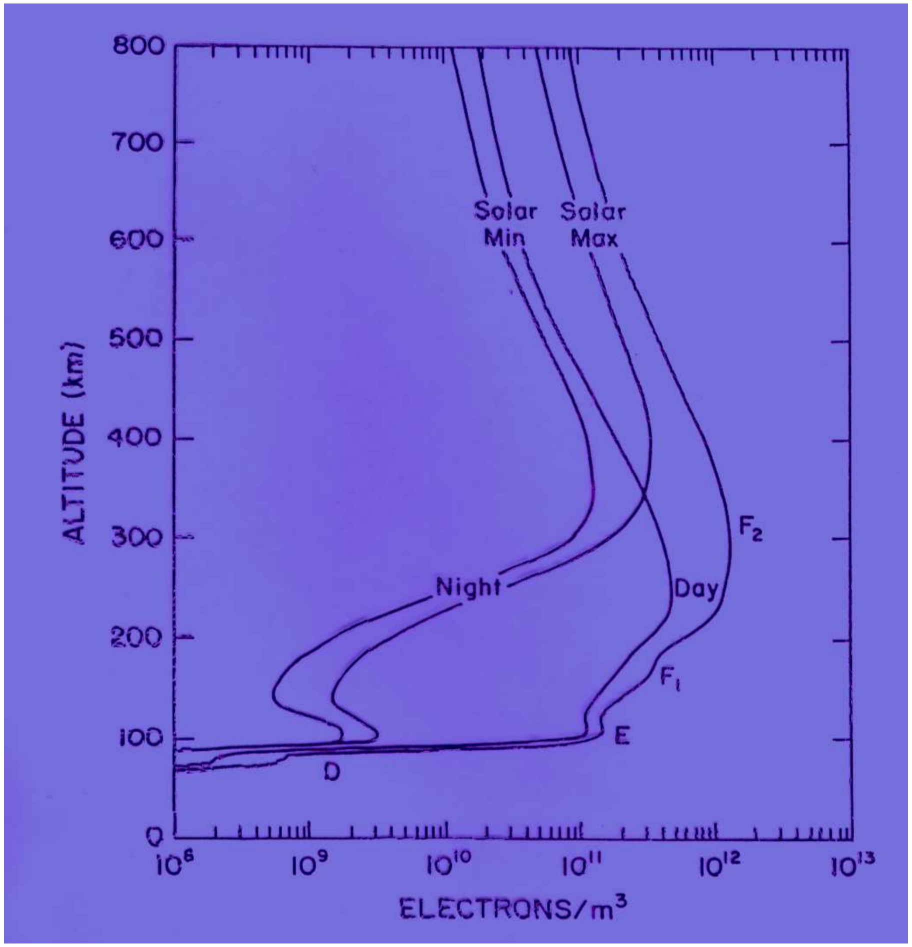
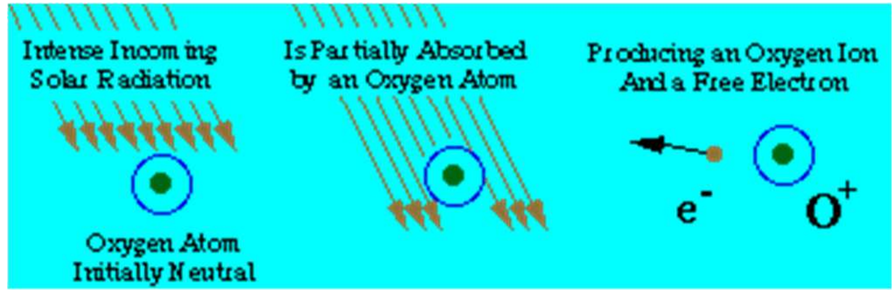
Ozone and Solar Cycle

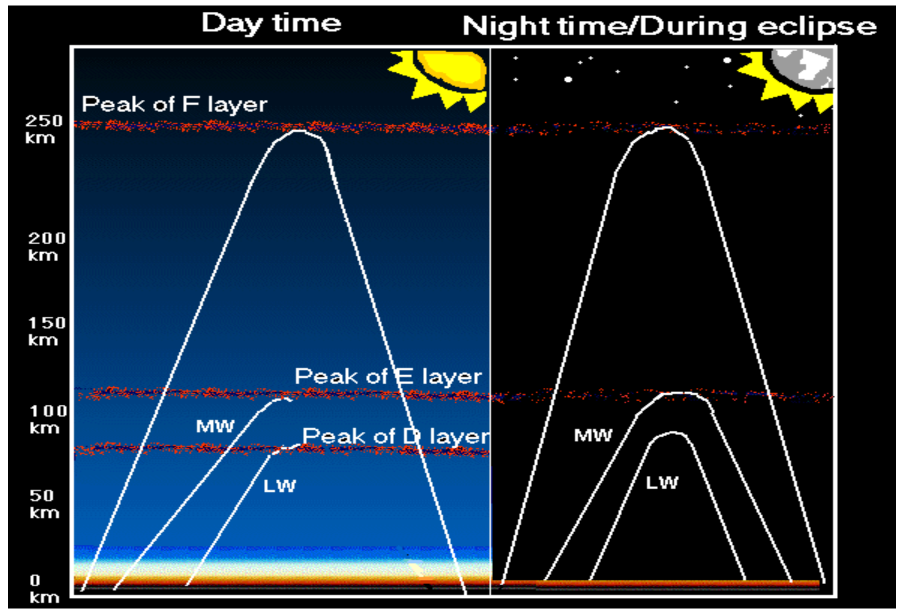


- Ozone depletion more pronounced during maximum than minimum
- Ozone depletion extends down to mid-latitudes (during solar maximum, even to low latitudes) although particles are incident only over the polar cap

IONOSPHERE







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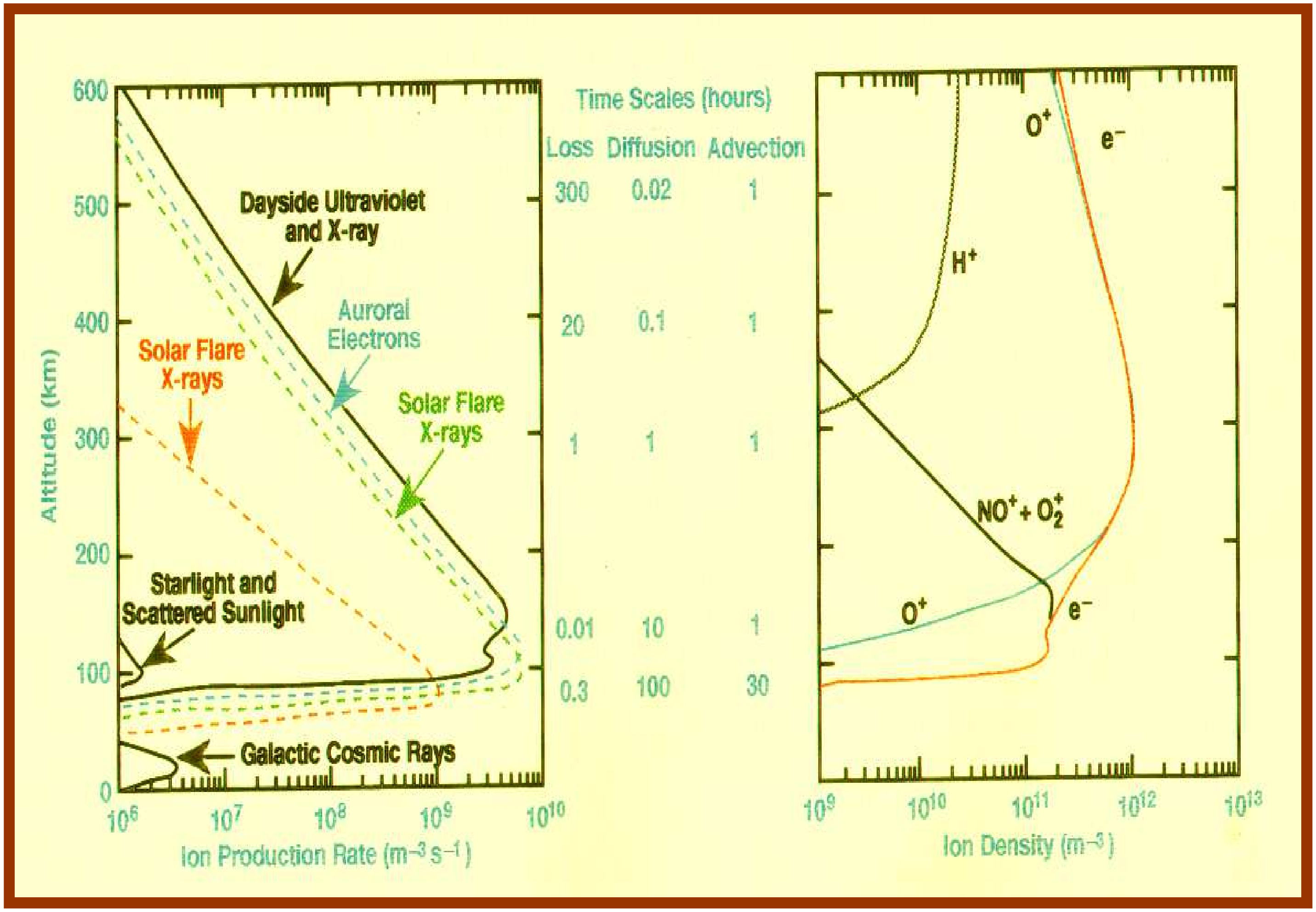
Ionospheric Regions and Solar Activity

Solar Min-Solar Max

Ionization due to
- Solar Flares
- Auroral Particles



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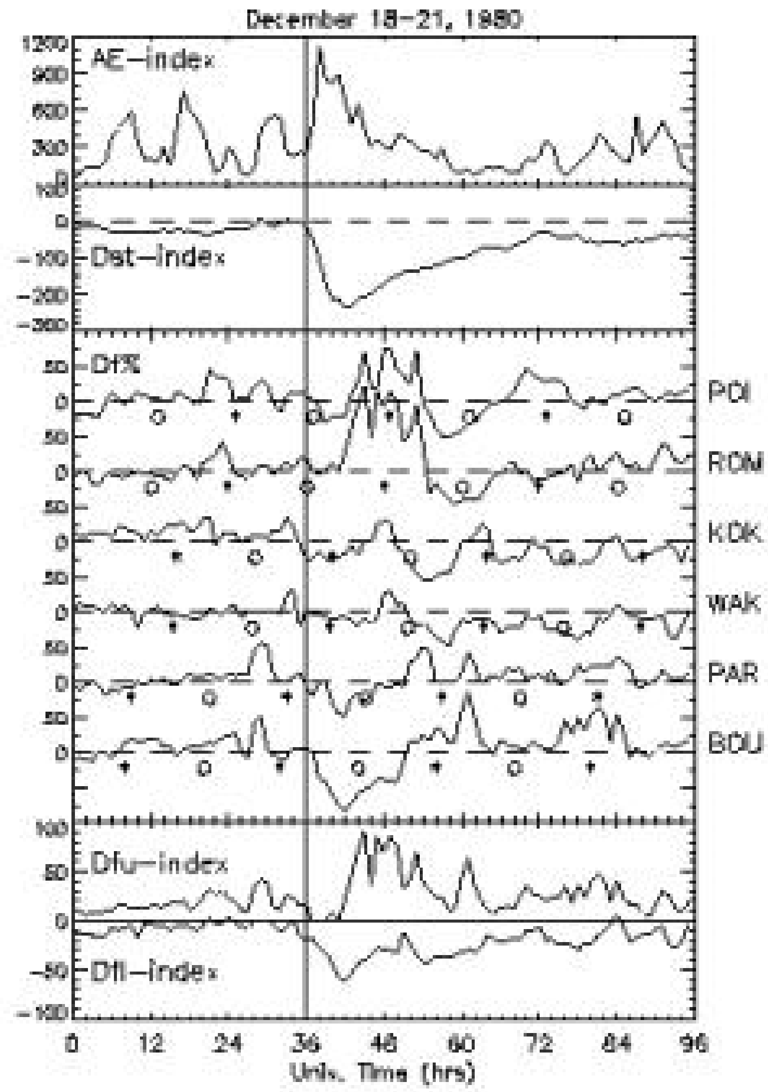
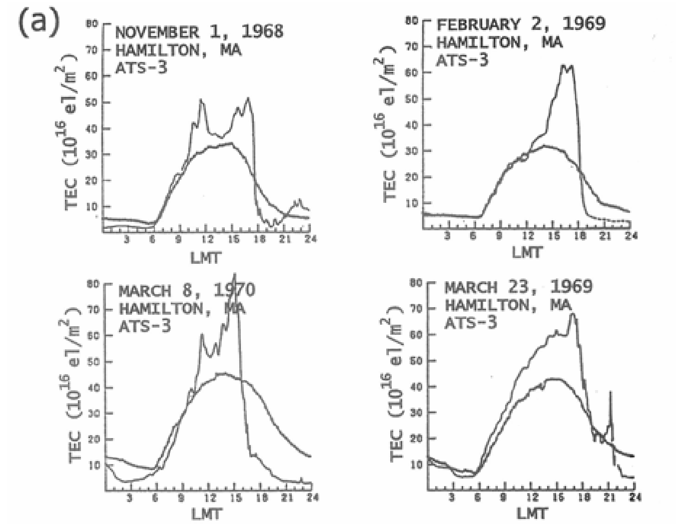
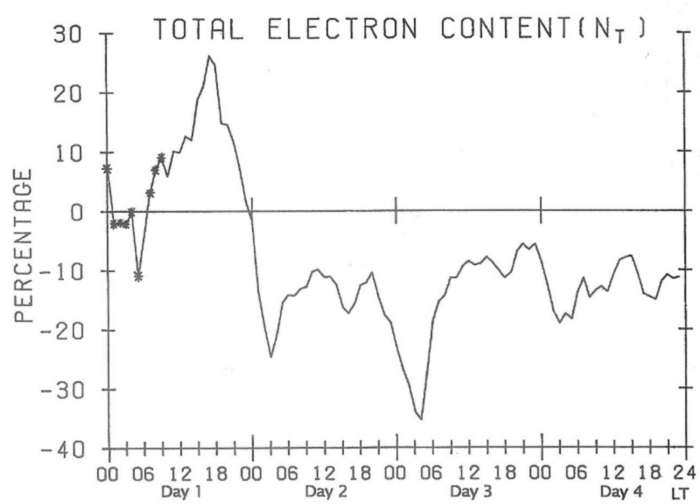
Ionospheric Storms



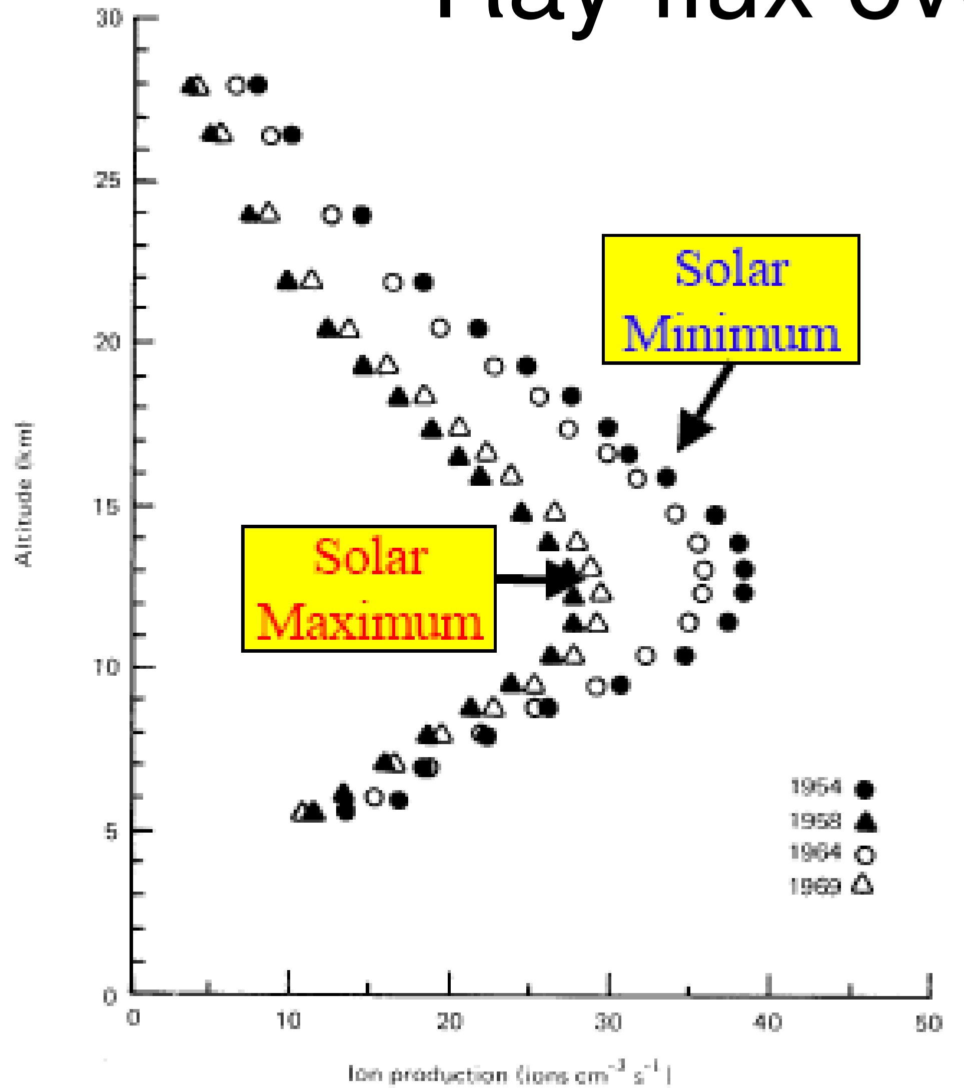




- TEC observations during magnetospheric substorms
- Mendillo, 2007, Reviews of Geophysics

Z

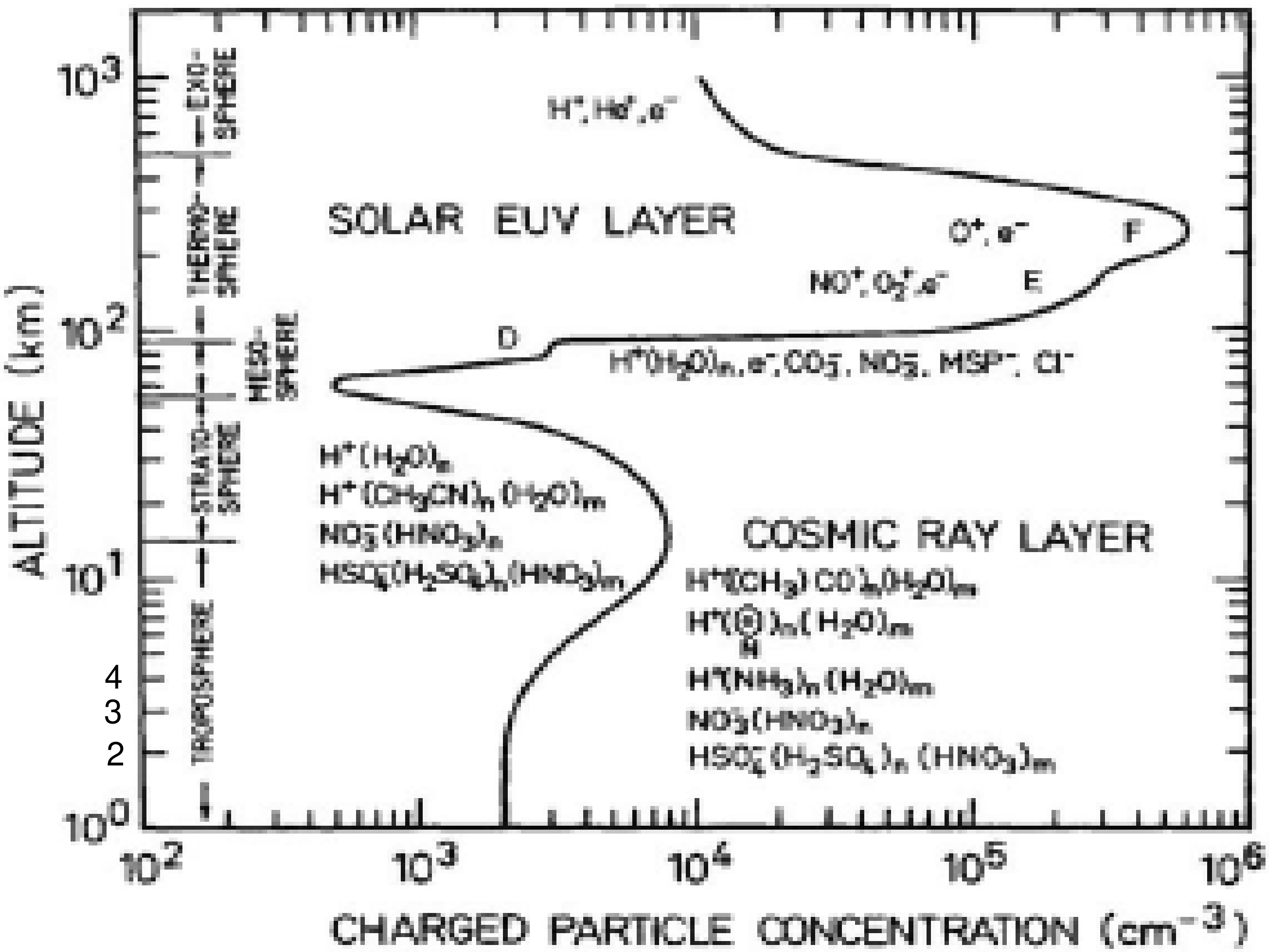
Ion Pair production due to Cosmic Ray flux over Thule



"The meteorological variable subject to the largest solar-cycle modulations in the dense layers of the atmosphere is the ionization produced by cosmic rays"

E.P. Ney, 1959, Nature

Charged Particle Density profile



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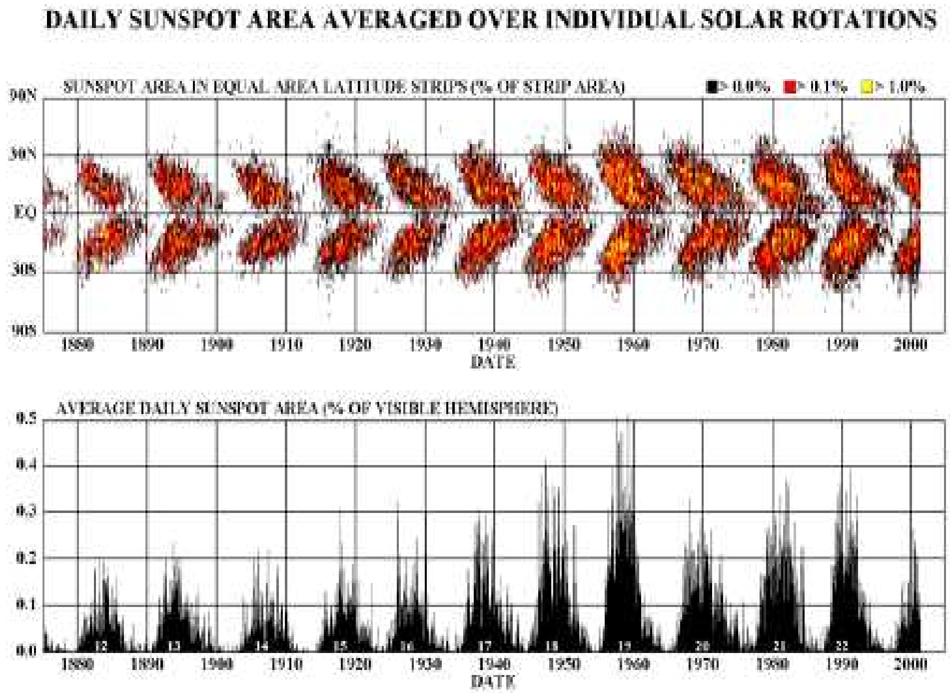
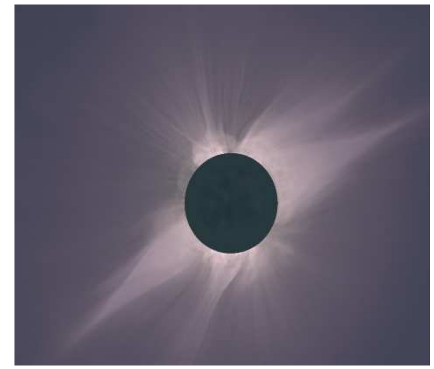
Viggiano and Arnold, 1995

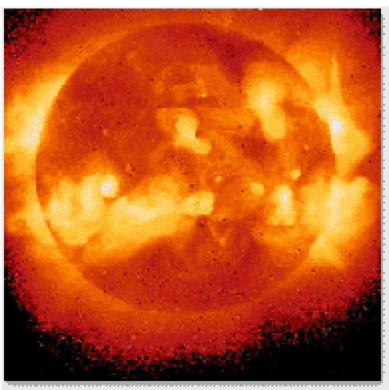
Solar Connection

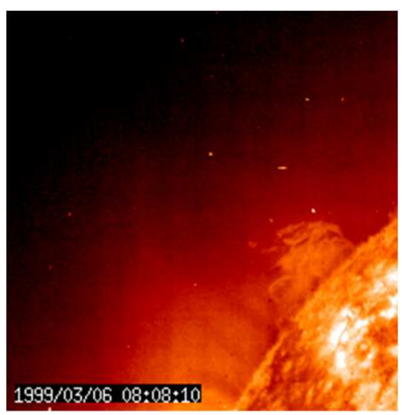
- Why/What is the issue with Cosmic Rays?

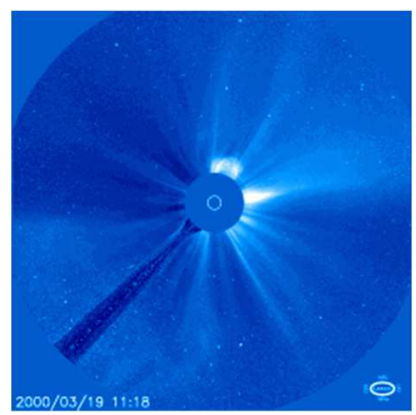
Sunspots – an “indicator” of Solar energy output











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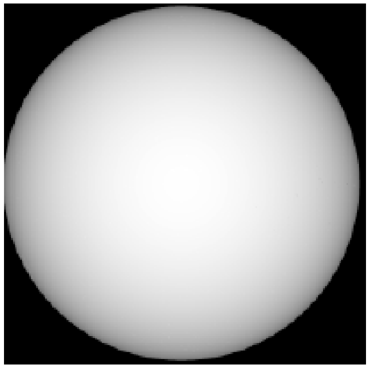
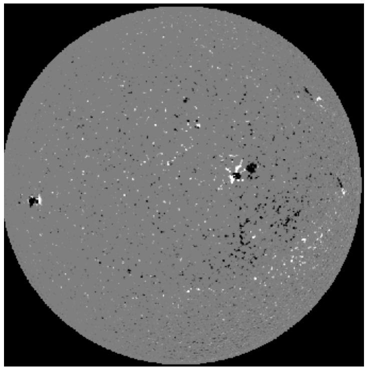
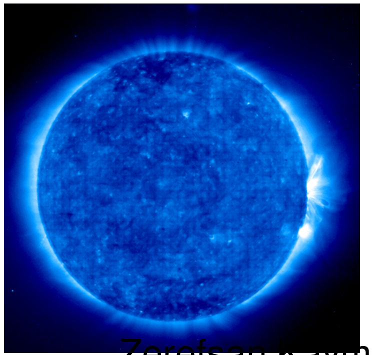
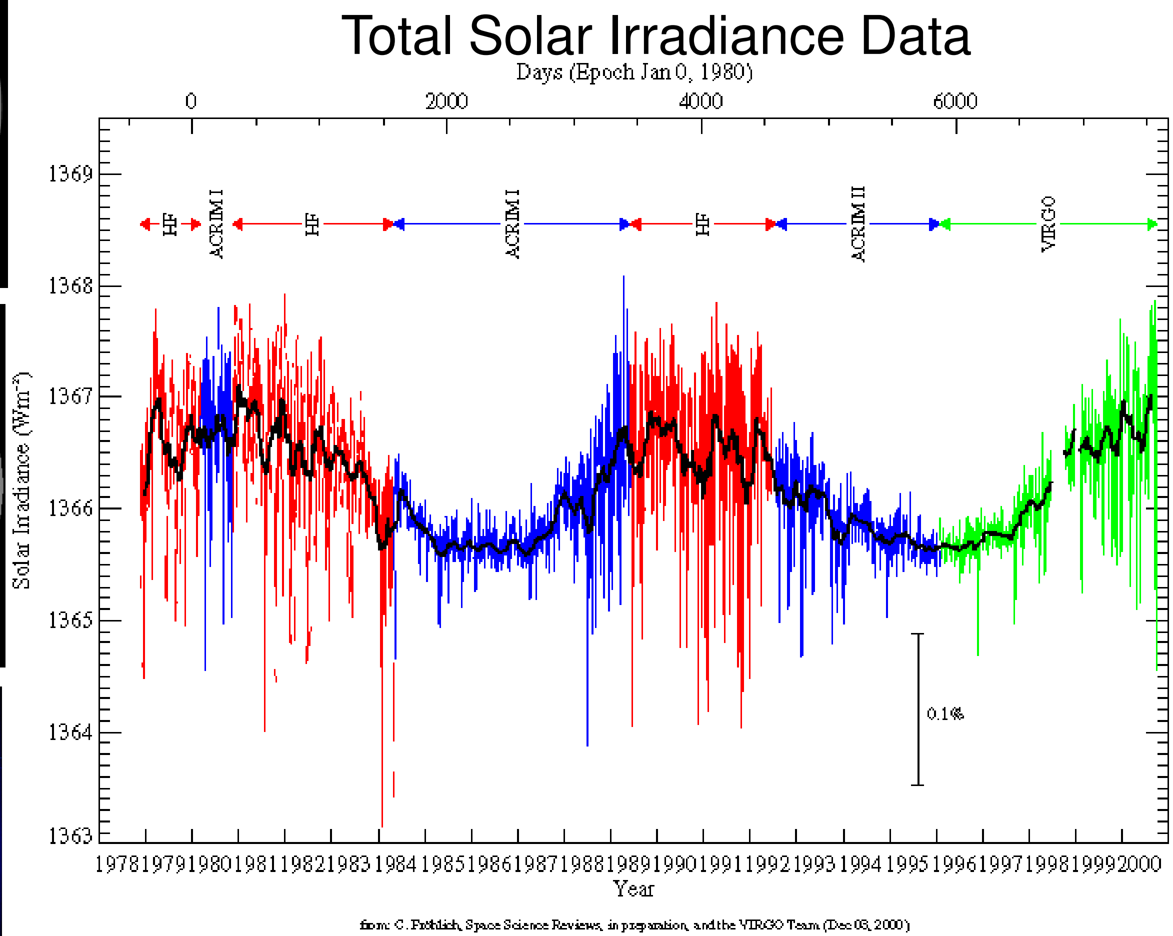
Variable Sun

1996

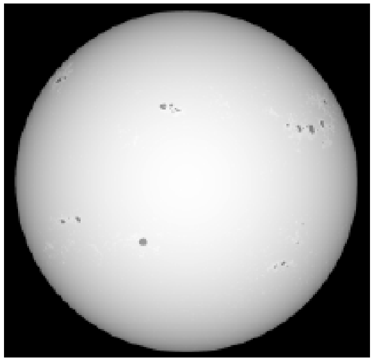


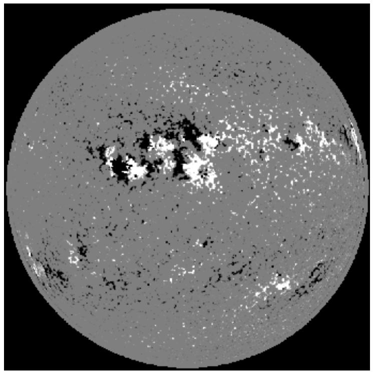


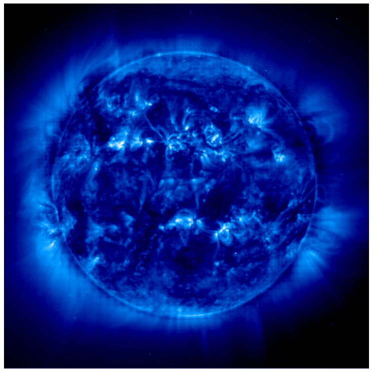




2000







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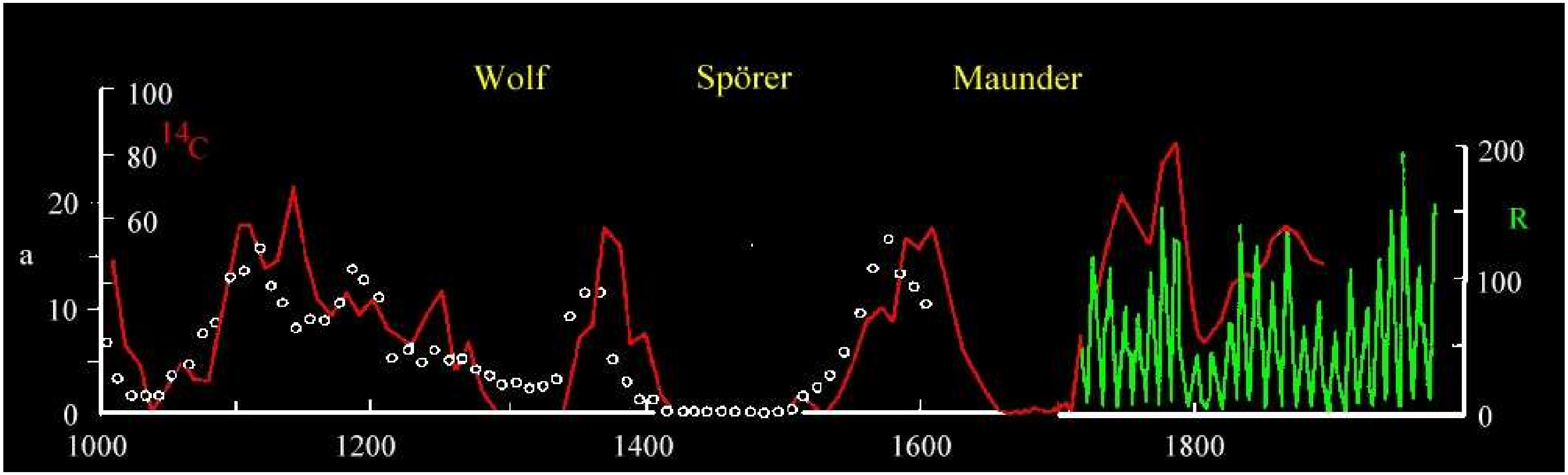
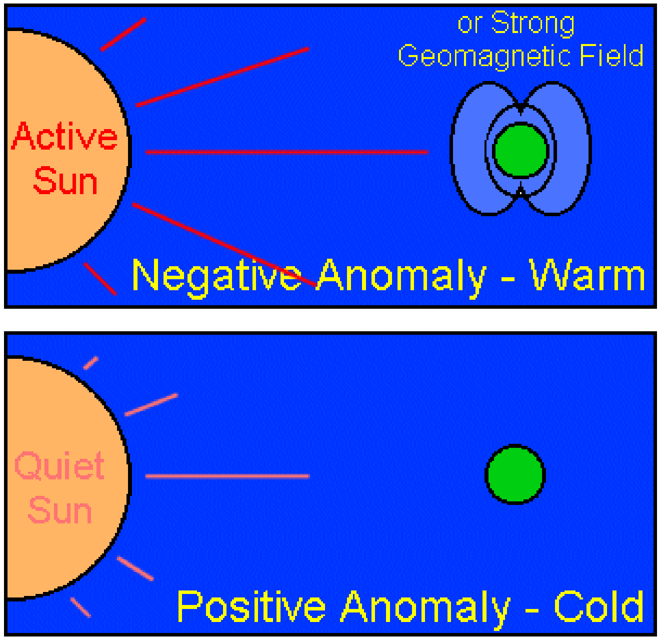
Solar Magnetism, Sunspots and Climate





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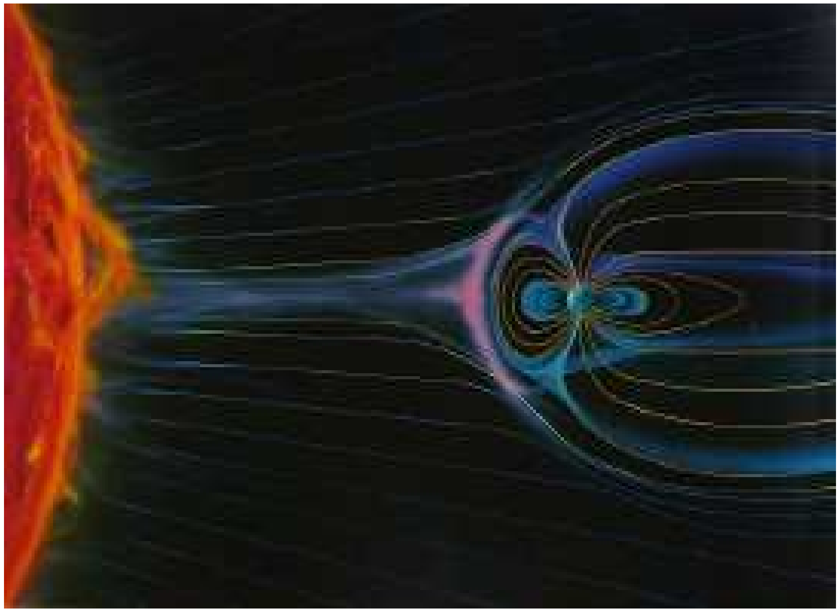
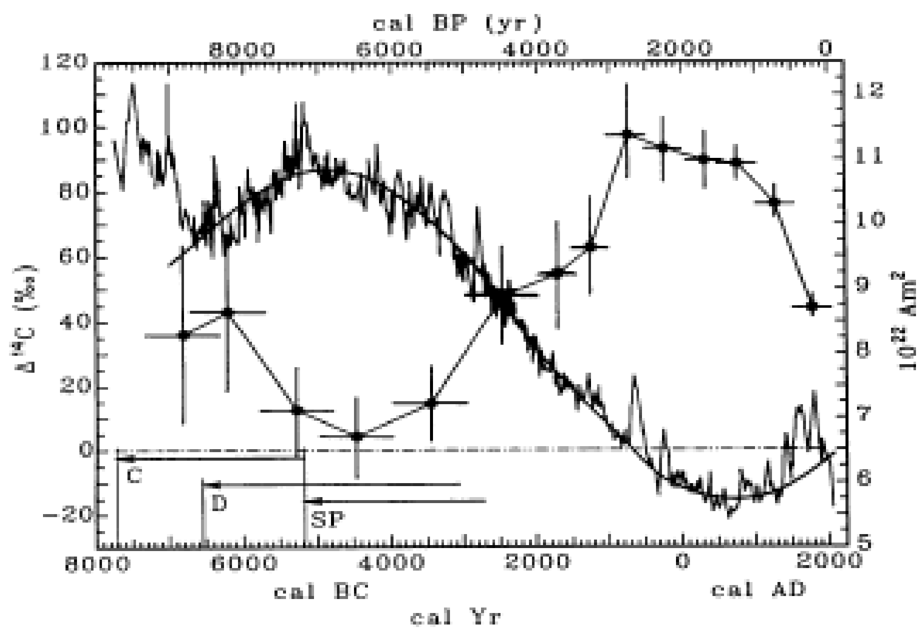
Earth’s magnetic field and the Heliosphere



- **Earth’s magnetic field and production rate of Carbon 14 caused by cosmic rays**



- Solar wind variations affect the production rate of C14

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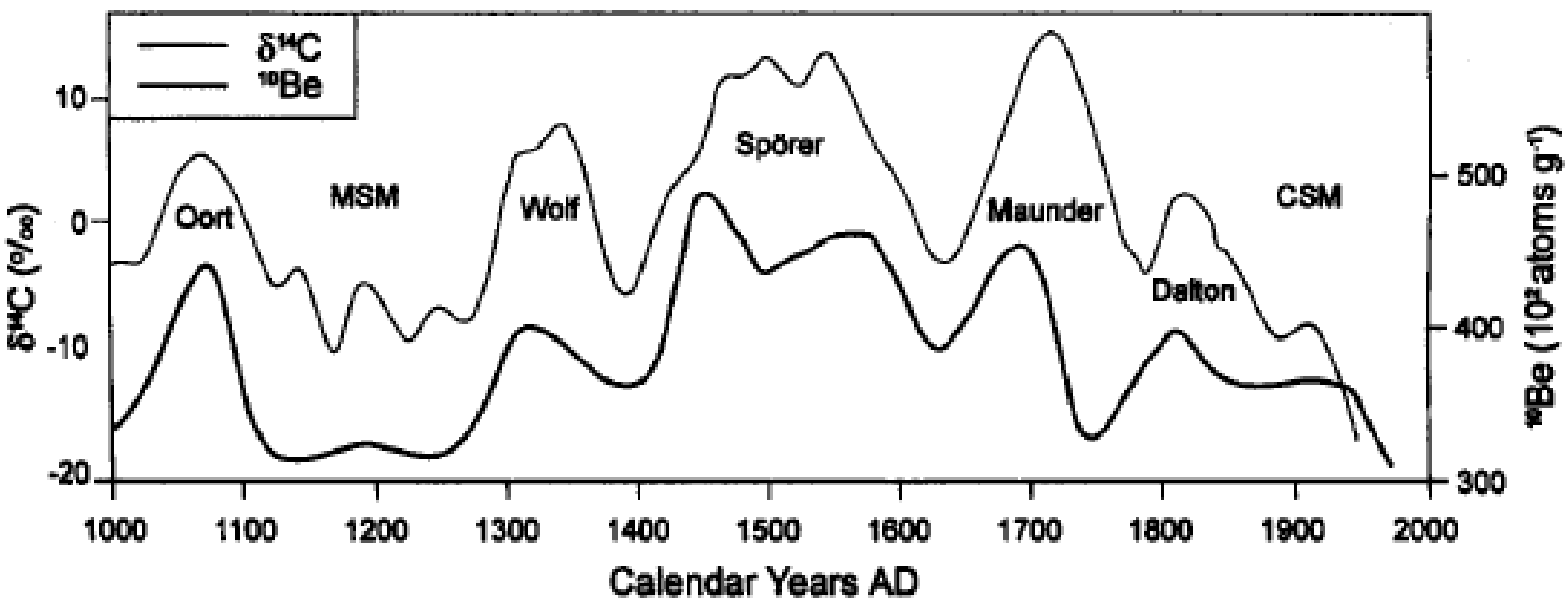
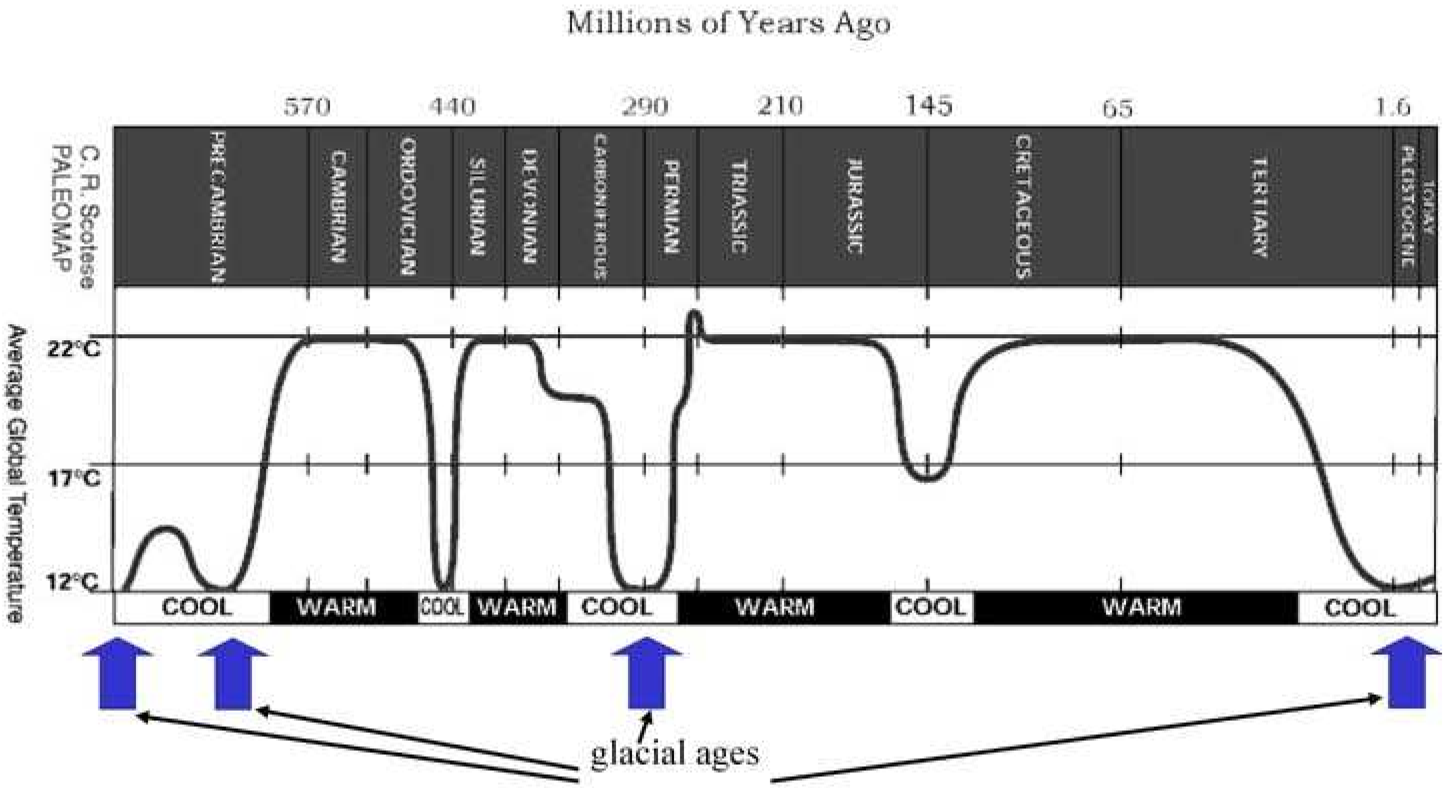
Production rate C14 and Be 10



Past Temperatures



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Maunder Minimum

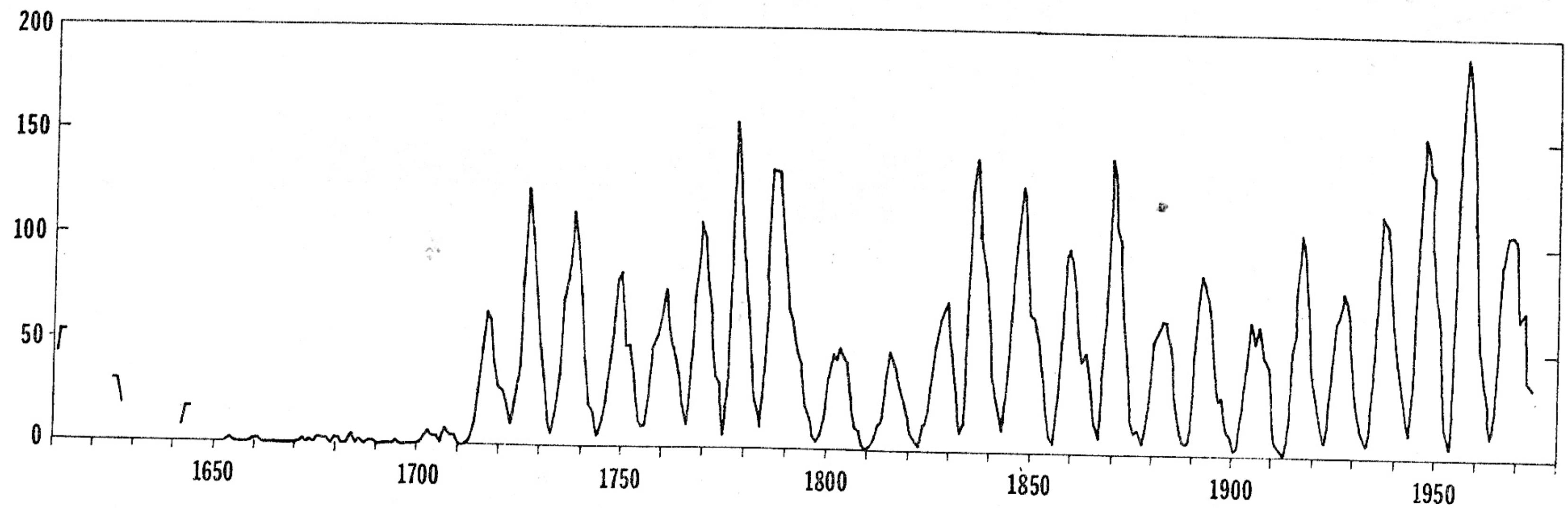
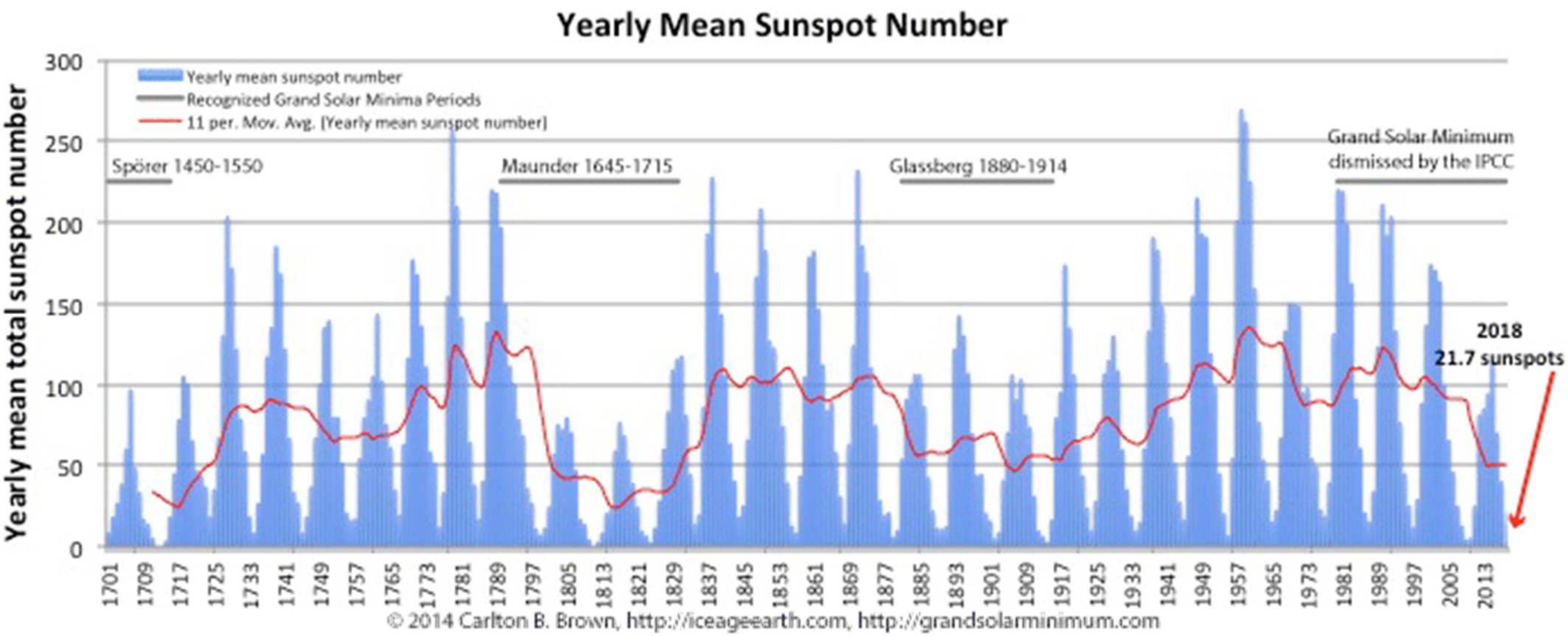


Figure 3. Annual mean sunspot number, AD 1610-1975, from Waldmeier (1) and Eddy (14), based on controlled observation from 1853 and reconstructed from less complete observations in earlier periods. Period from 1645-1715 is the Maunder Minimum.



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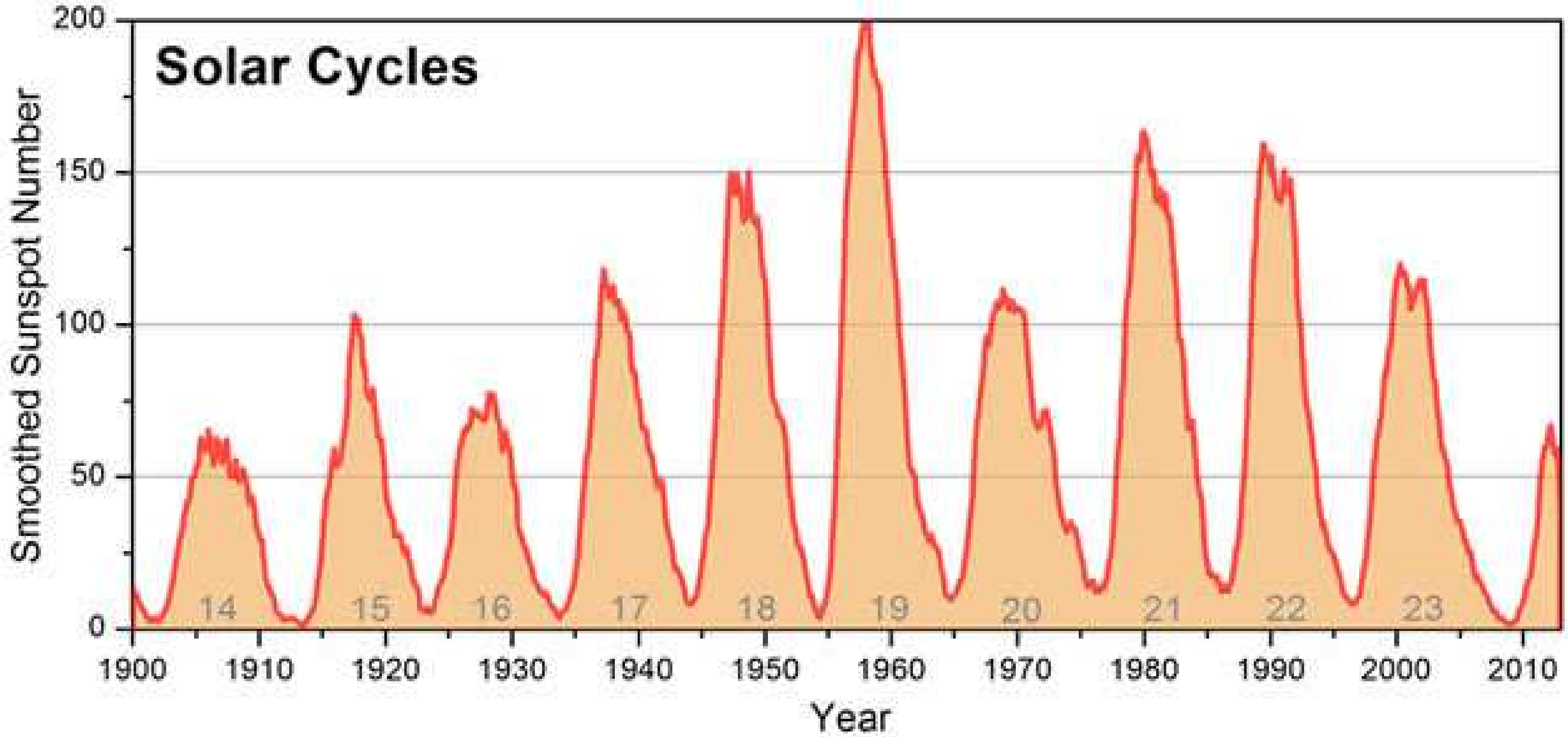
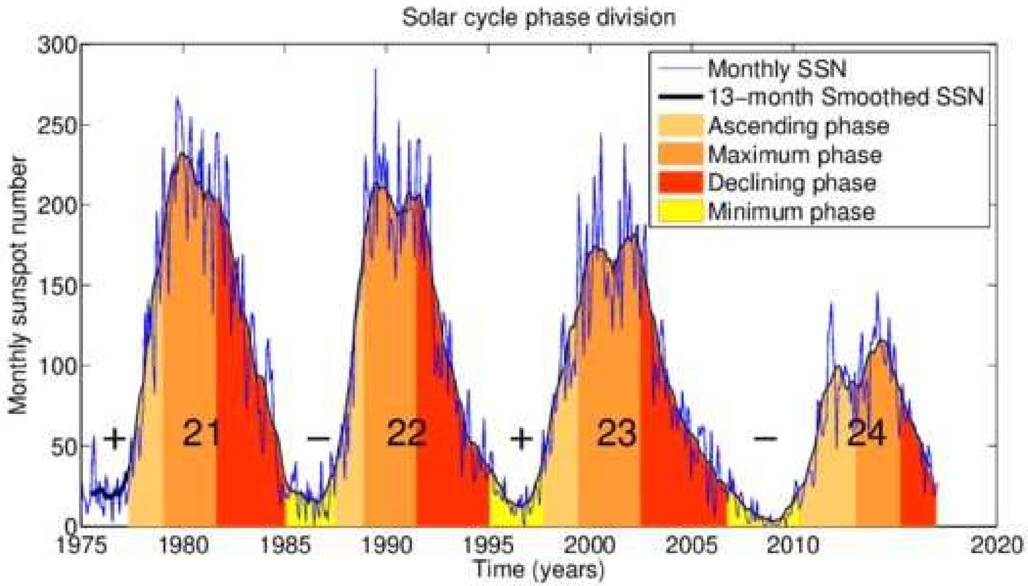
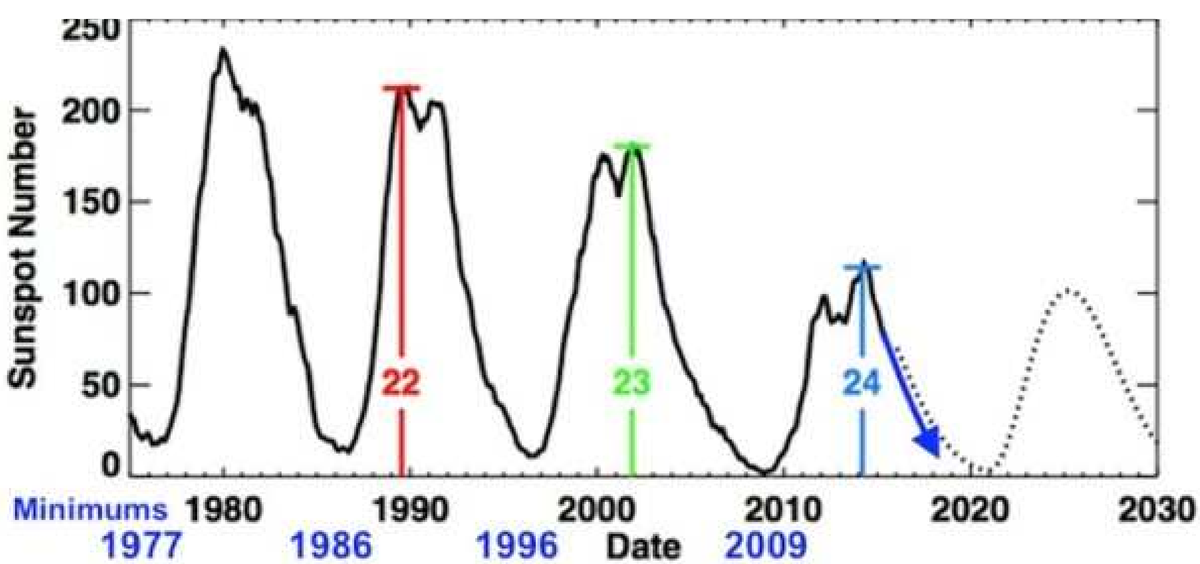


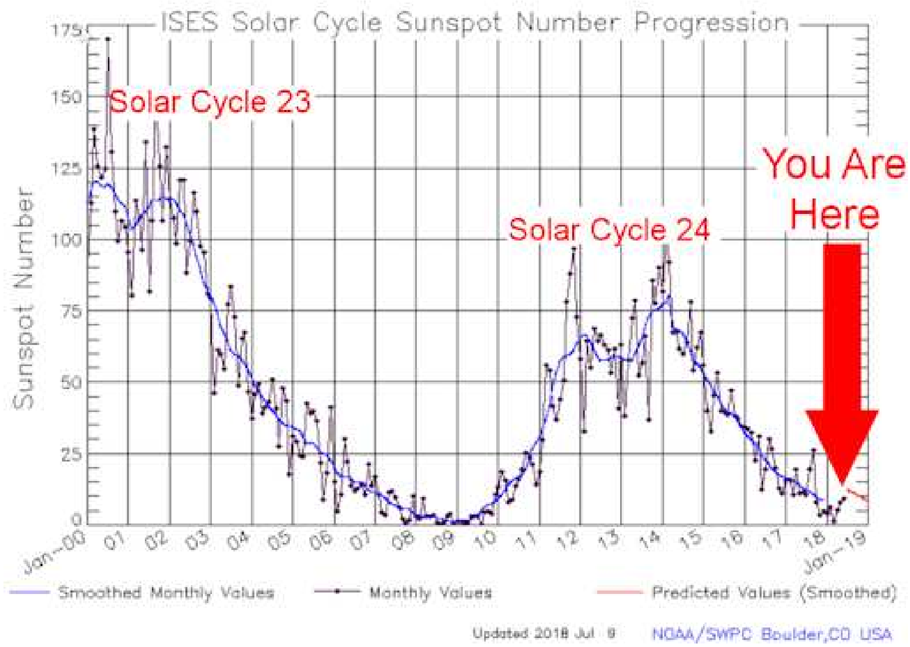
Solar Cycles
Smoothed Sunspot Number
Year
0
50
100
150
200
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
14
15
16
17
18
19
20
21
22
23

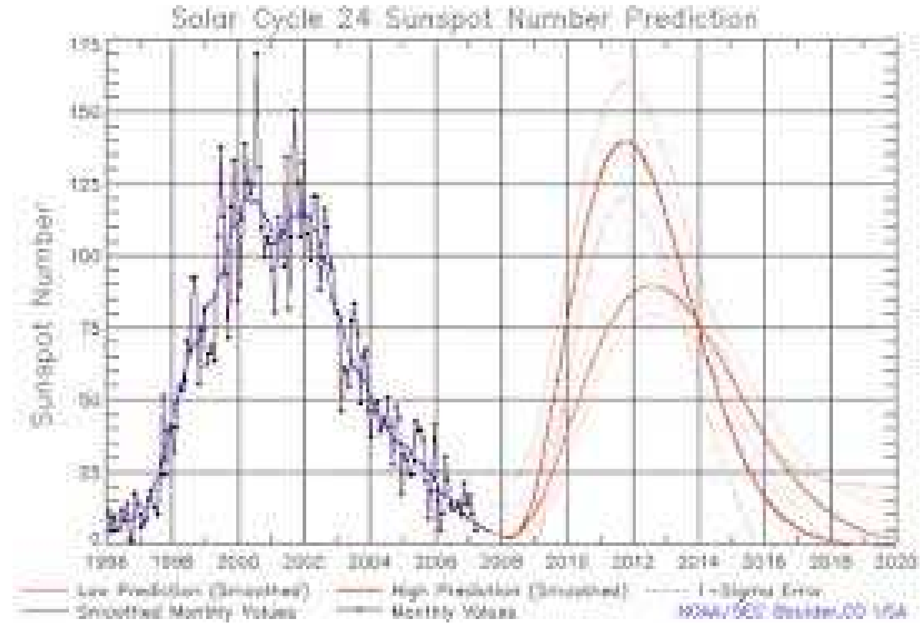


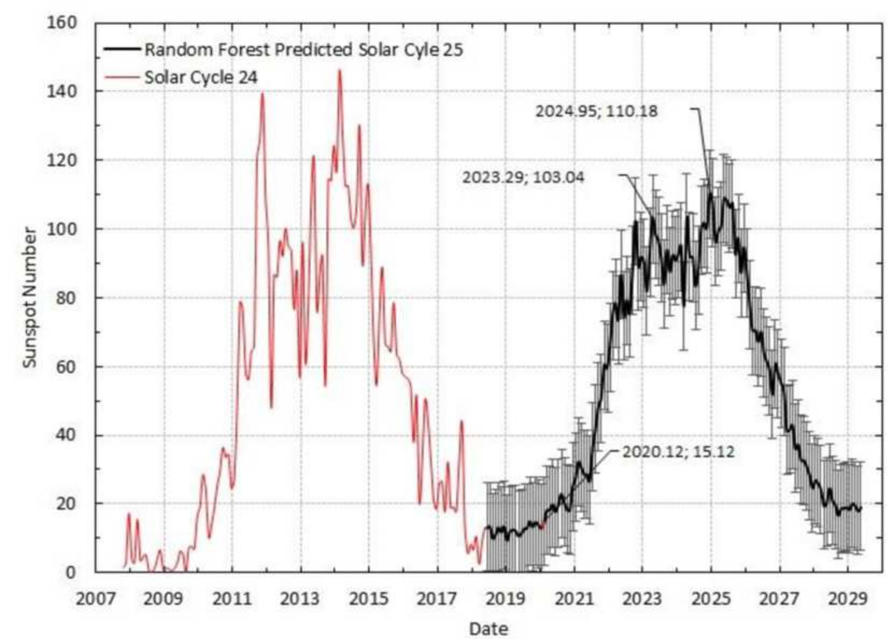
Solar cycle phase division
Monthly SSN
13-month Smoothed SSN
Ascending phase
Maximum phase
Declining phase
Minimum phase
Monthly sunspot number
Time (years)
+ 21 − 22 + 23 − 24



Sunspot Number
22
23
24
Minimums
1977
1986
1996
2009
Date







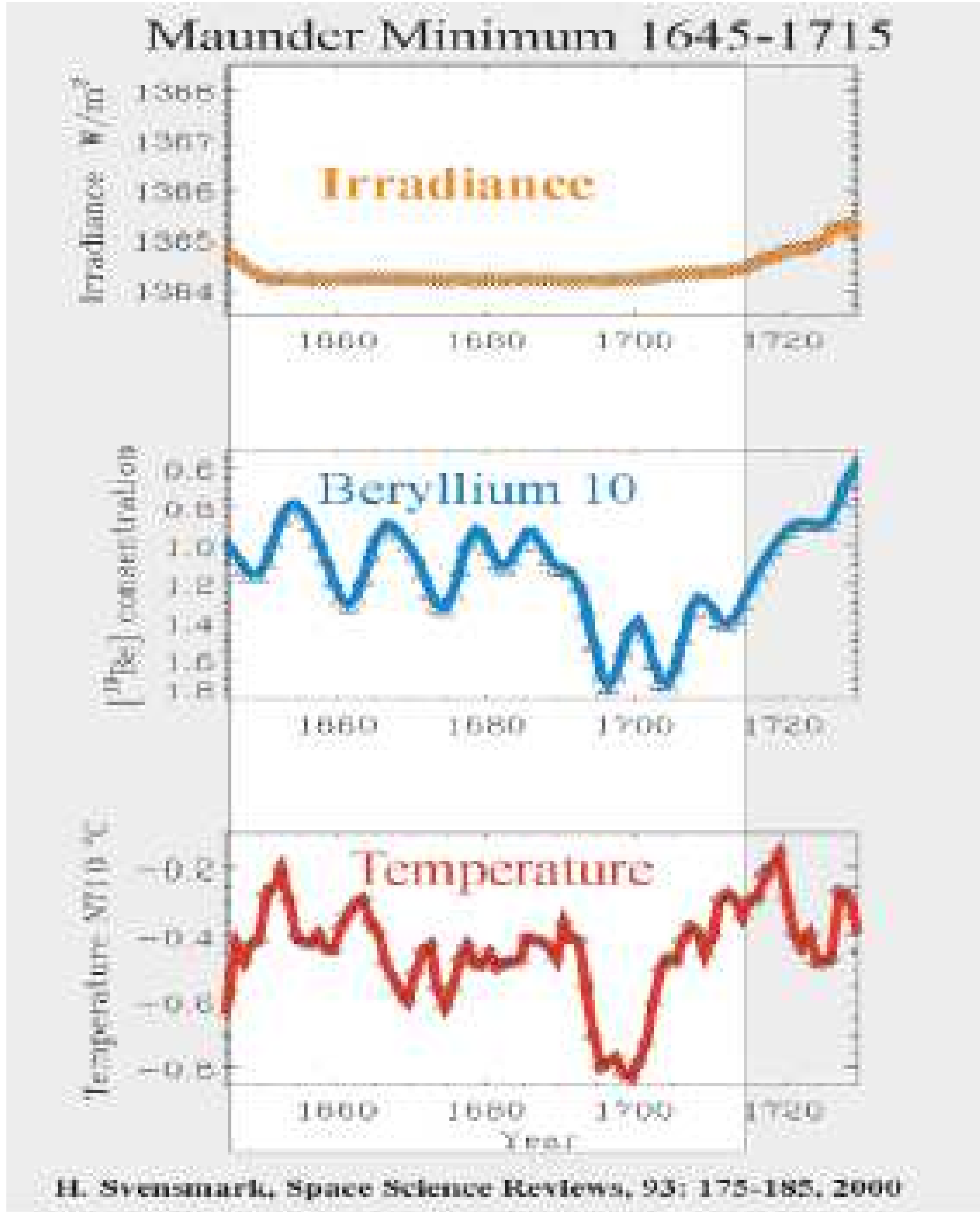
Zerefşan Kaymaz

Maunder Minimum

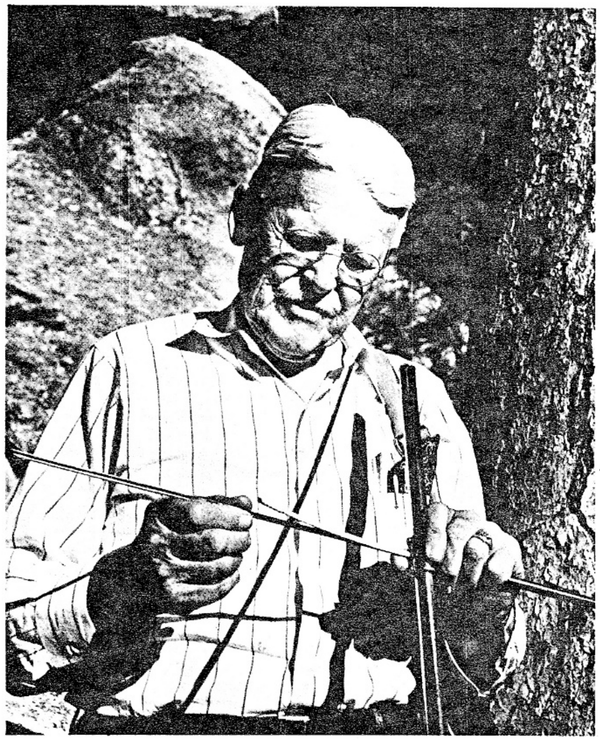
- **Reconstructions of Solar irradiation indicate very small variations at a very low level**

- **Beryllium-10 isotope indicate a significant modulation caused by changes in the cosmic ray flux-likely caused by changes in solar magnetic fields**

- **Reconstructed temperatures follow Be-10**



Solar activity and Tree Rings



Andrew Ellicott Douglass (1867-1962). (photo by Charles W. Herbert, Western Ways, courtesy of the Laboratory of Tree-Ring Research, University of Arizona.)

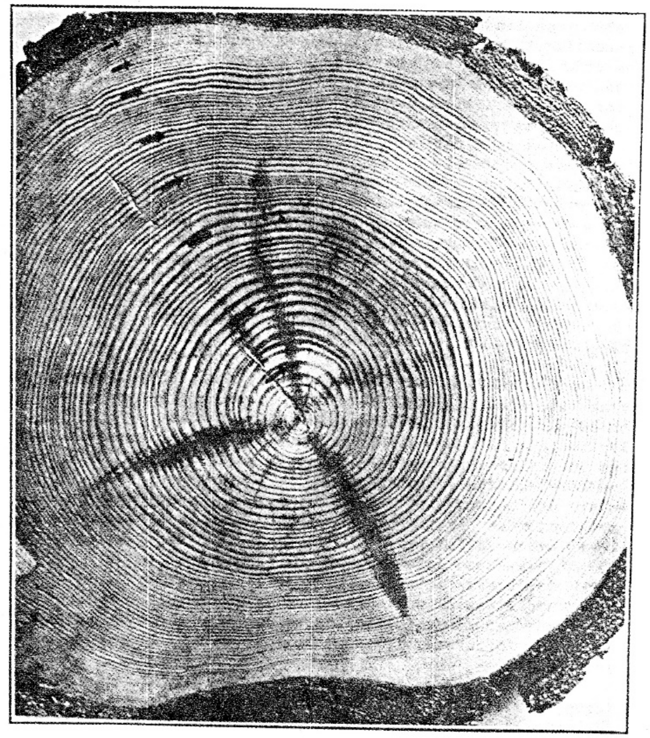


Figure 1. Section of a Scotch pine from a tended forest at Eberswalde, Prussia, planted in about 1820 and cut in 1912. Arrows, placed by Douglass, mark years of maximum sunspot number, showing, in this selected sample, an apparent correlation with maximum annual tree growth. From Douglass (4), Vol. I, pp. 37-39, 74-76.

Zerefşan Kaymaz

Solar activity, icebergs, temperature, winter severity index

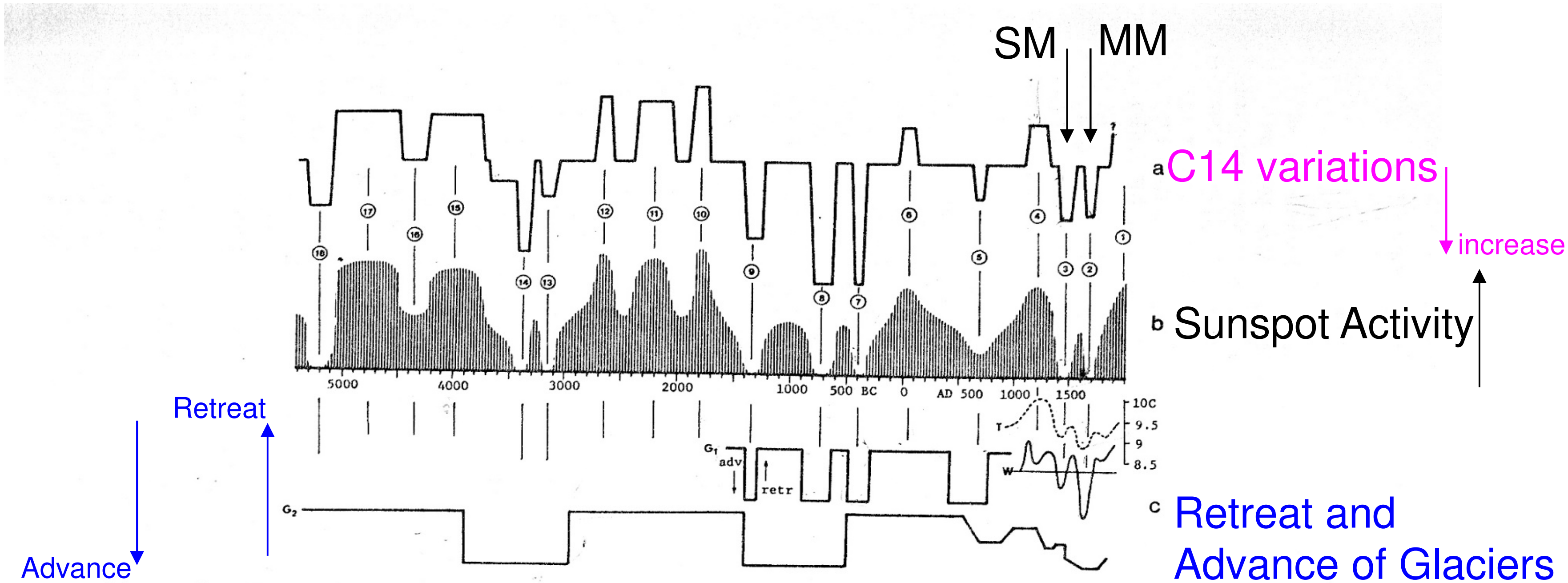


Figure 5. Interpretation of radiocarbon deviations in terms of solar effects, with climate correlation from Eddy (28). Curve (a): persistent radiocarbon deviations from Figure 4, plotted schematically and normalized to feature 2 (Maunder Minimum): downward excursions, as in Figures 2, 4 indicate increased ^{14}C and imply decreased solar activity. Circled numbers identify features described in Table 1. Curve (b): interpretation of (a) as a long-term solar activity envelope (of possible sunspot cycle). Curve (c): four estimates of past climate. Step curve G_1: times of advance and retreat of Alpine glaciers, after Le Roy Ladurie (35); curve G_2: same, for worldwide glacier fluctuations, from Denton and Karlen (36); curve T: estimate of mean annual temperature in England (scale at right) after Lamb (34); curve W: winter-severity index (colder downward) for Paris-London area, from Lamb (33, 34).

Solar activity and C-14

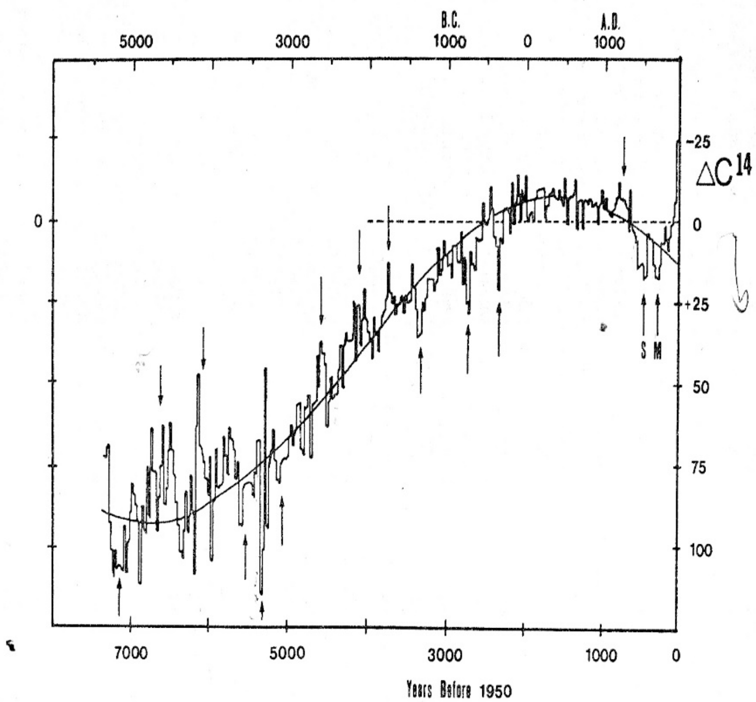


Figure 4. Radiocarbon deviation, as in Figure 2, from tree-ring samples since about 5000 B.C., from Lin, Fan, Damon, and Wallick (26). Solid curve, also from (26), represents strength of earth's magnetic moment, derived from paleomagnetic data by Buch (16). Features selected as possible solar excursions in Table 1 are marked with arrows.

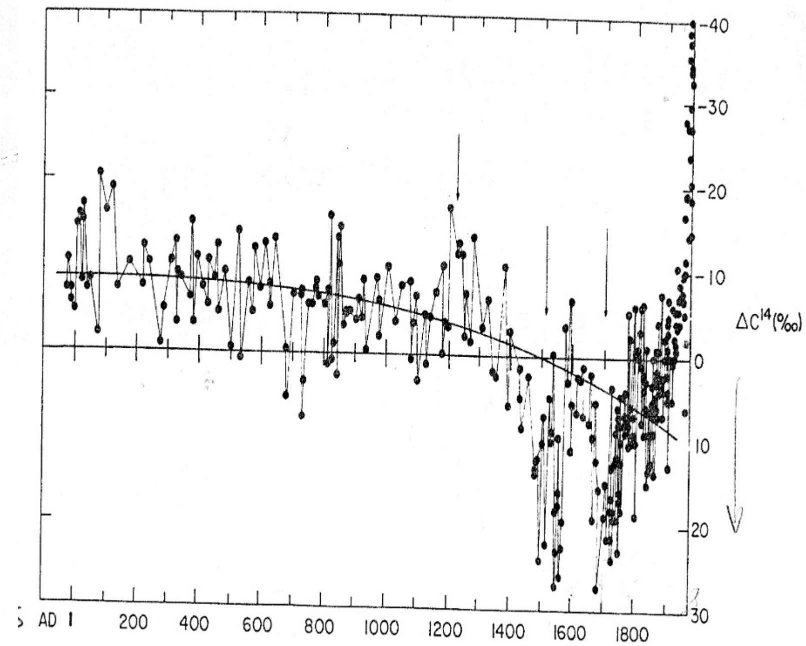
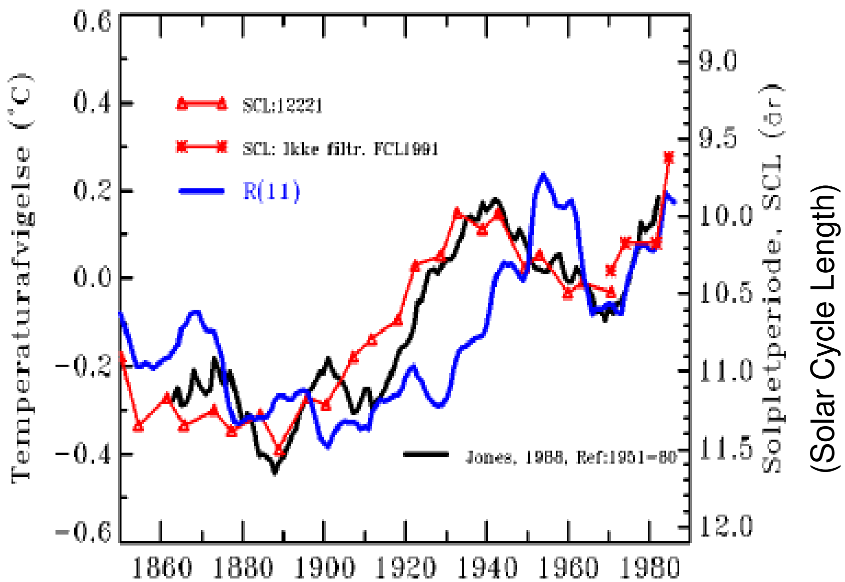


Figure 2. Radiocarbon deviation derived from dated tree-ring samples, AD 1 to present, from Damon (15). Deviations of ^{14}C relative to ^{12}C, in parts per mil, are plotted with positive excursions (increased relative ^{14}C) downward, in the direction of decreased solar activity. Zero level is arbitrary norm for 1890. Arrows mark persistent features identified as possible solar anomalies: right to left, Maunder Minimum, Sporer Minimum, Medieval Maximum.

Global temperature and Sunspots



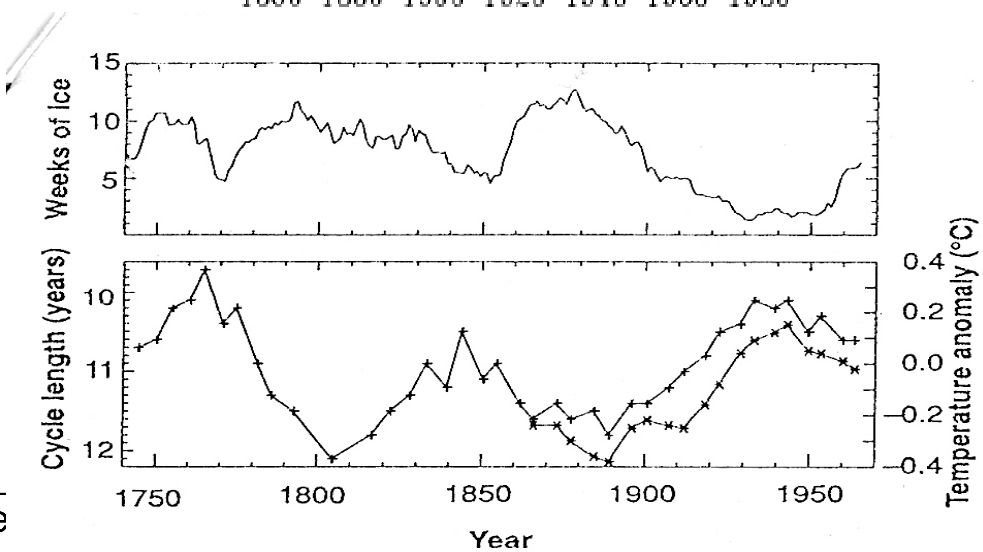
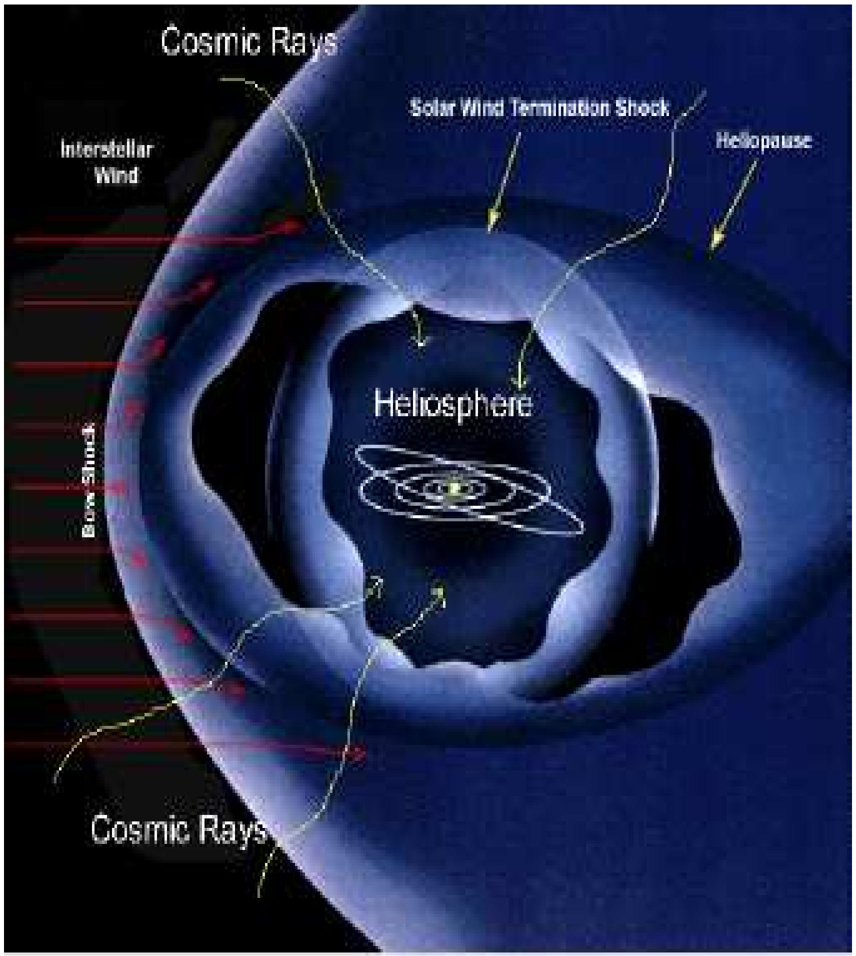


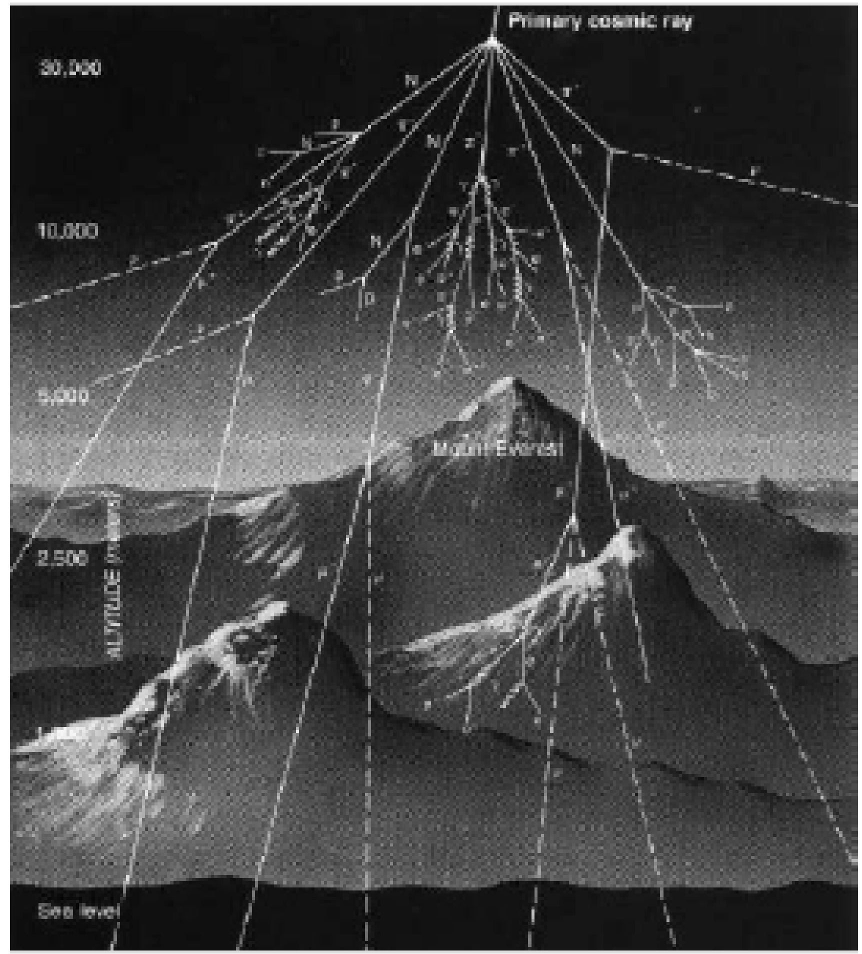
Fig. 3. (**Top**) 22-year running mean of the amount of sea ice around Iceland from 1740 to 1970 during summer months (represented by the number of weeks when ice was observed). (**Bottom**) Smoothed sunspot cycle lengths from 1740 to 1970 (left-hand scale) and Northern Hemisphere mean temperature (right-hand scale).

Zere

Friis Christensen, 1991

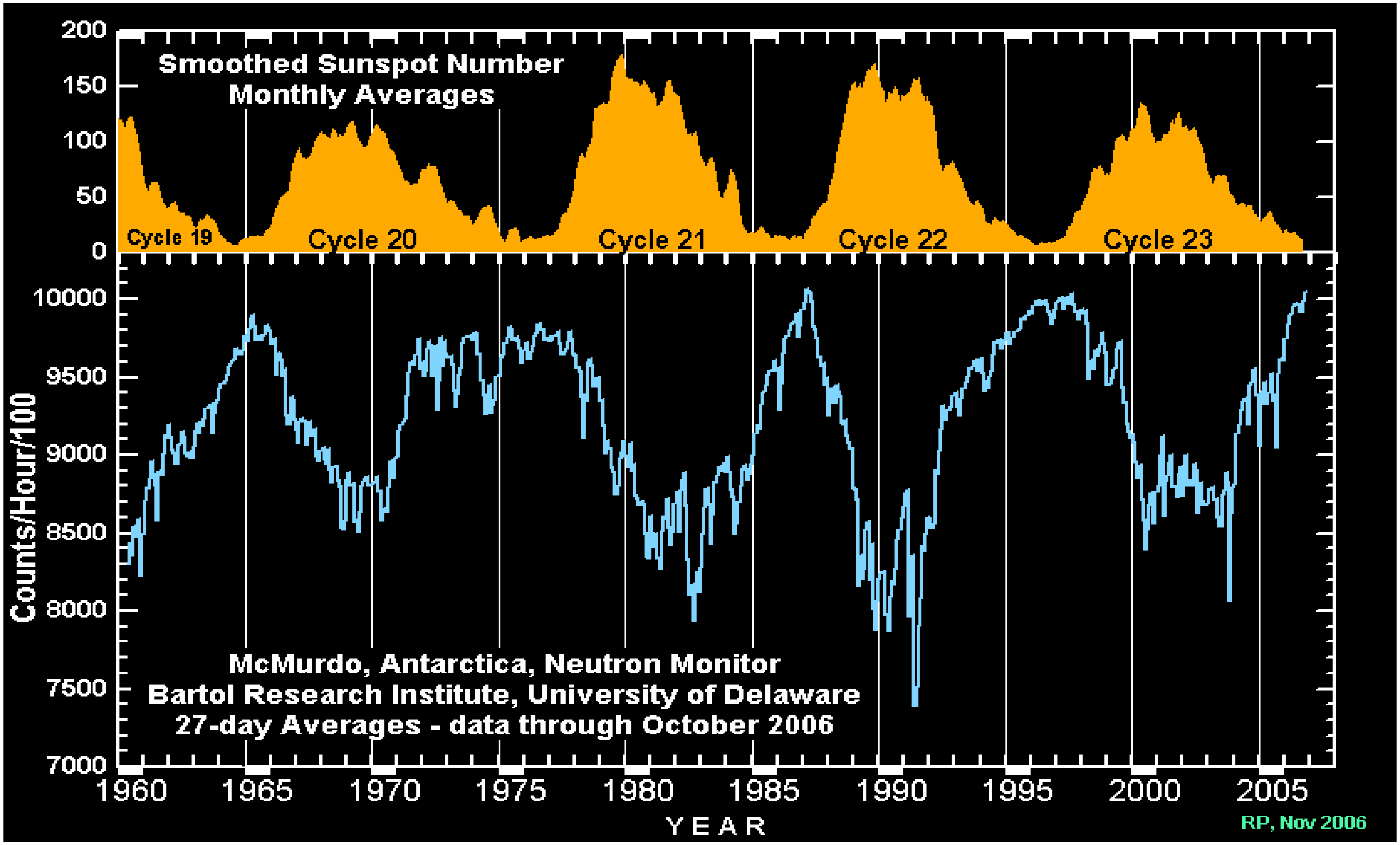
Cosmic Rays and Clouds





Zerefşan Kaymaz

COSMIC RAYS AND THE SOLAR CYCLE



- Solar activity rises and falls with a period of about 11 years.
- The number of sunspots indicates the level of solar activity.
- Emissions of matter and electromagnetic fields from the Sun increase during high solar activity, making it harder for Galactic cosmic rays to reach Earth.
- Cosmic ray intensity is lower when solar activity is high.

Cosmic Rays and Cloudiness

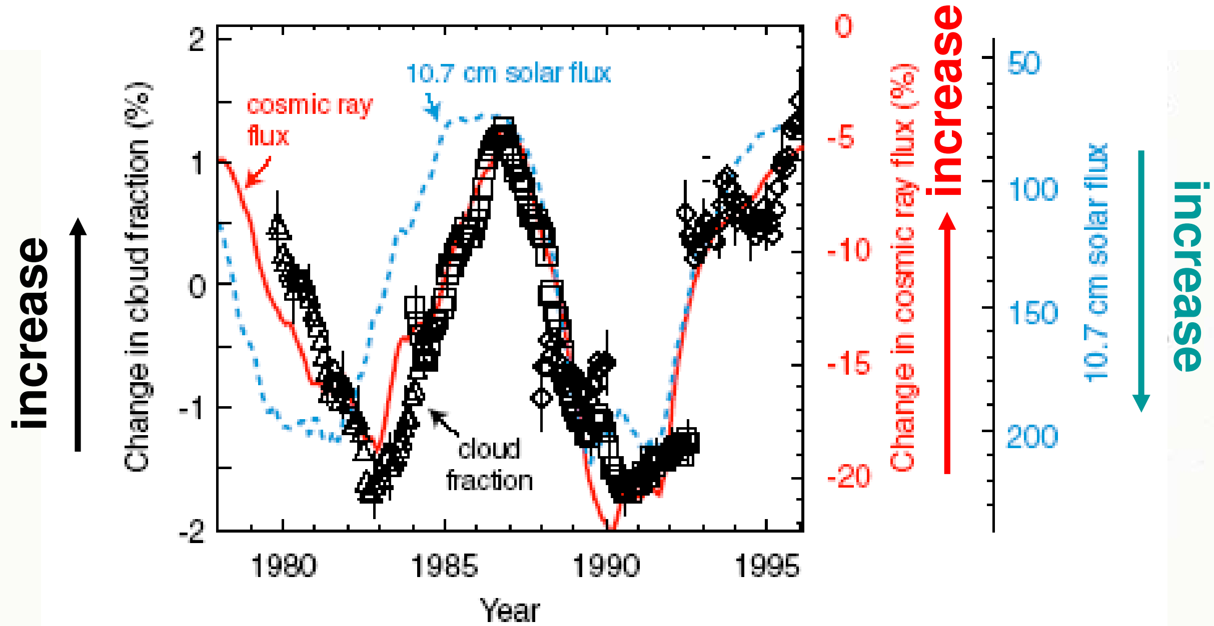
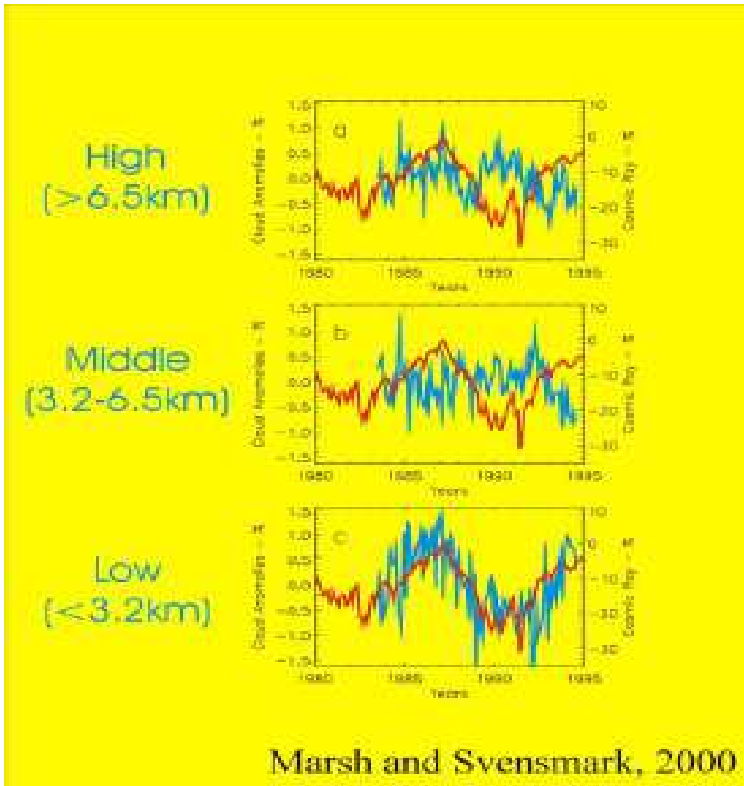
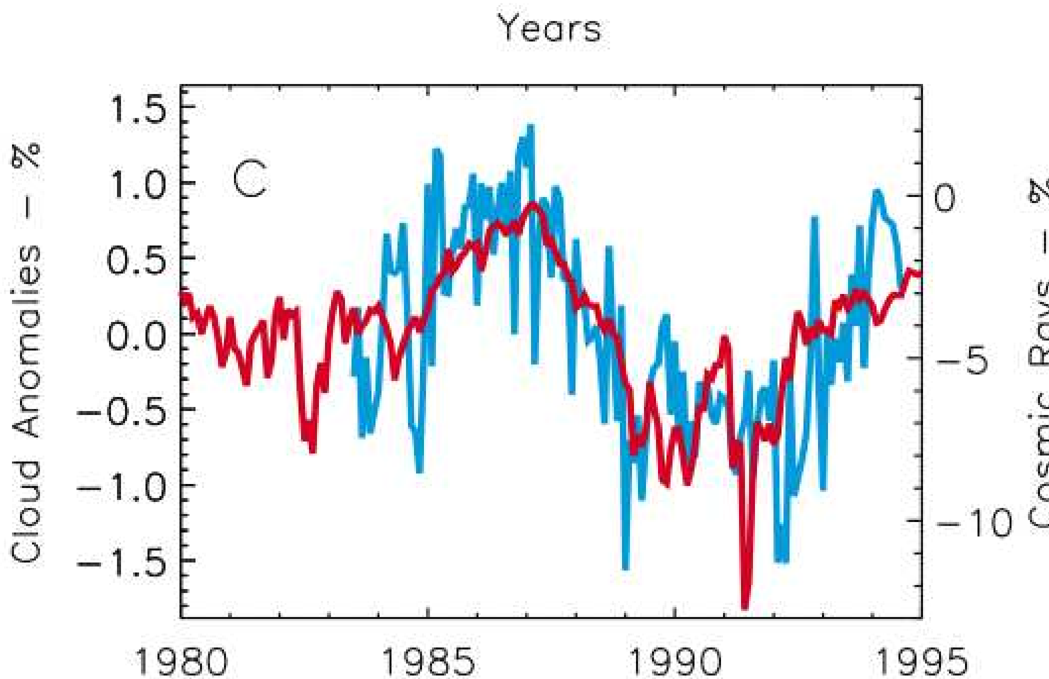


Figure 2. Composite figure showing changes in the Earth's cloud cover from four satellite cloud data sets together with cosmic rays fluxes from Climax (*solid curve*, normalized to May 1965), and 10.7 cm solar flux (*broken curve*, in units of 10^{-22} W m^{-2} Hz^{-1}). Triangles are the Nimbus7 data, squares are the ISCCP_C2 and ISCCP_D2 data, diamonds are the DMSP data. All the displayed data have been smoothed using a 12 months running mean. The Nimbus7 and the DMSP data are total cloud cover for the Southern Hemisphere over oceans, and the ISCCP data have been derived from geostationary satellites over oceans with the tropics excluded.

Cosmic Ray and Cloud Types

Cosmic Ray Intensity at Huancayo)





GCR → 2 % absolute change in low cloud cover over a solar cycle corresponds to a Change in net cloud forcing of ~ 1.2 W/m^2

Ion induced nucleation

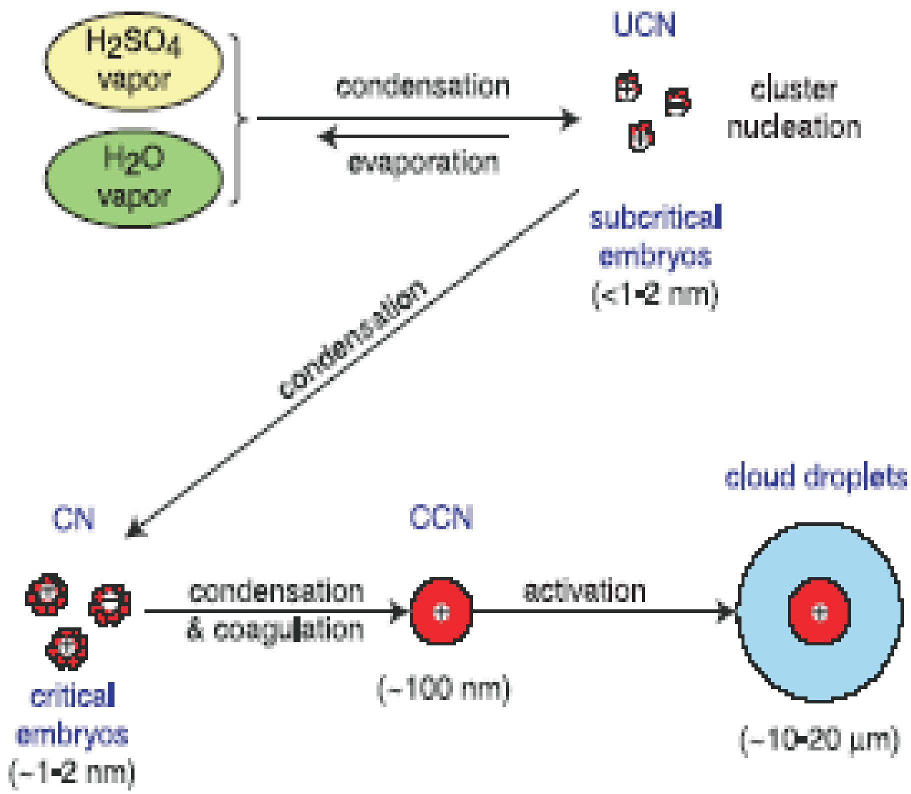


Fig. 3. An "ion-aerosol clear-air" mechanism proposed to link variations in cosmic ray intensity with cloudiness. The diagram shows the ion-catalyzed nucleation of new ultrafine condensation nuclei (UCN) from trace condensable vapors in the atmosphere, which may then grow into new cloud condensation nuclei (CCN).

- **Low clouds are affected**
- **Implies an effect on water vapor clouds –not ice clouds**
- **Aerosols –via production of cloud condenstaion nuclei (CCN) –are important for the cloud formation**
- **How are CCNs formed?**
  - **Insufficient understanding.**
- **Do electric charges play a role?**
  - **Yes according to new research results, computer simulations**
- **What is missing?**
  - **Experimental proof**
    (CLOUD Project at CERN, France)

Carslaw, 2002

Summary of sun-cosmic ray-climate

- Changes in total irradiance
- Changes in UV-radiation
- Changes in energetic particle flux
- All components may work together

Consequences

- Variations in neutral density above 100 km
- Variations in thermospheric circulation
- Variations in ionospheric electron density
- Variations in ozone amount
- Variations in cloud cover/cloudyness