Do Solar Variations Affect Our Climate?

ESA Space Weather Workshop: Looking towards a European Space Weather Programme

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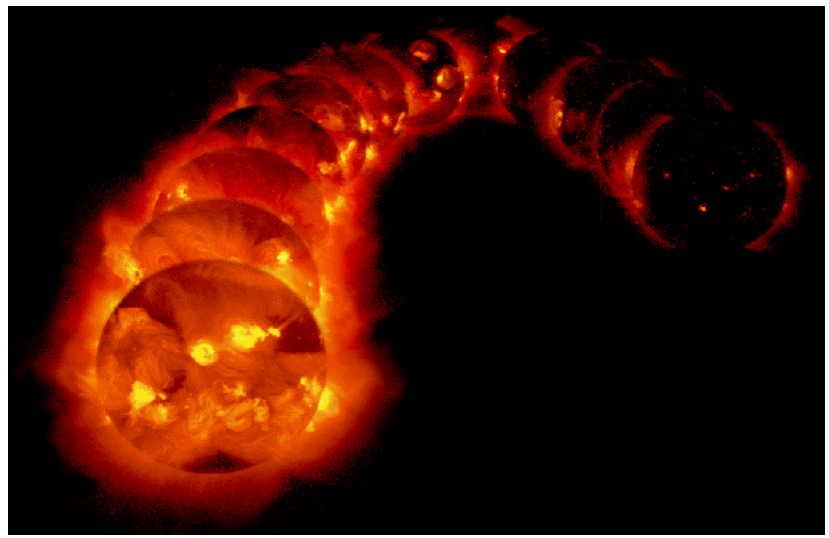
Eigil Friis-Christensen



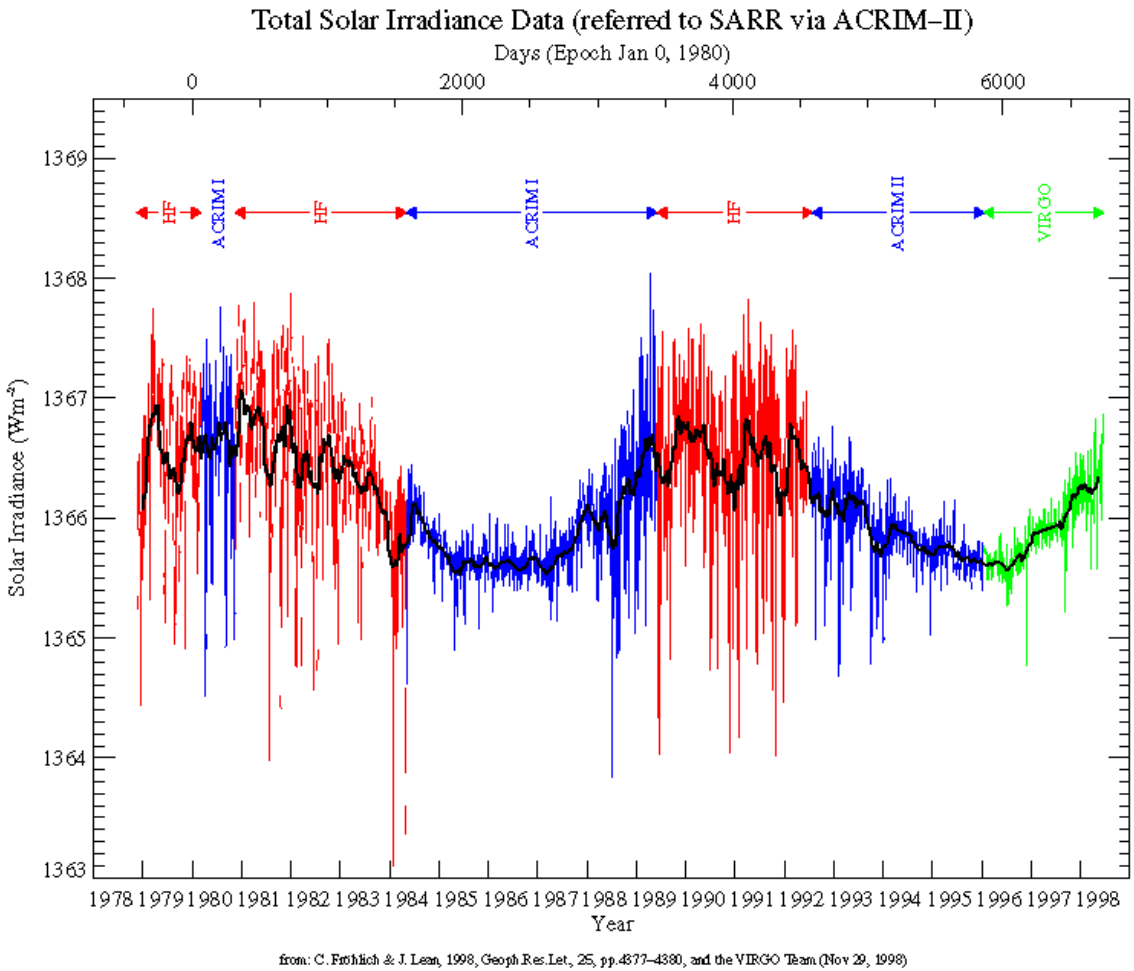
What Are the Causes of Climate Variations?

- **Internal oscillations in atmosphere-ocean system**
- **Variation in energy received from the Sun:**
  - Solar irradiance variations - various spectral bands.
  - Cloudiness.
  - Volcanic dust and aerosols.
  - Other aerosols, natural and human induced.
- **Variation in energy radiated away from Earth:**
  - Atmospheric properties, in particular greenhouse gasses like
    - CO_2,Methane, CFCs, Ozone.
    - Cloudiness and water vapor (important part of feed-back mechanisms).
  - Surface properties like
    - Ice cover, land and ocean.
    - Vegetation.
    - Land erosion.

How do we define solar variability in this context?

- **Total solar irradiance**
  - Relatively small during a solar cycle (0.1%)
  - Long-term variations (0.25%?)
- **UV-radiation changes**
  - Small power compared to the visible part of the spectrum.
  - Relatively large variation during a solar cycle (> 1% at stratospheric heights, even more at higher altitudes)
- **Changes in the solar wind (heliosphere)**
  - Extremely small power.
  - Very large relative variations during a solar cycles - and on longer terms.
  - Earth's surface modulation of cosmic ray flux ~ 20%
  - Middle atmosphere formation of odd Nitrogen

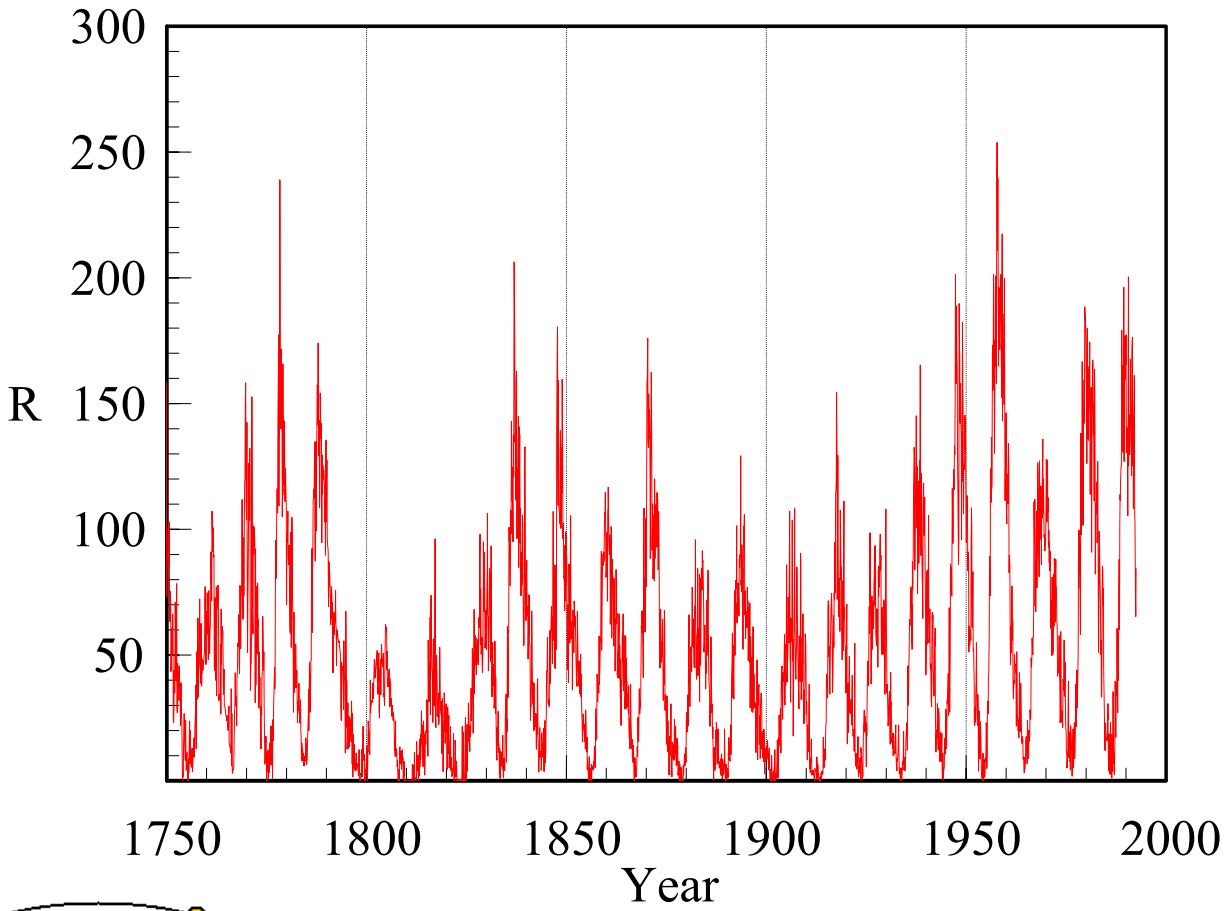
Solar Irradiance Measurements - The Sun as a Star



Irradiance measurements are made by several instruments on SOHO:

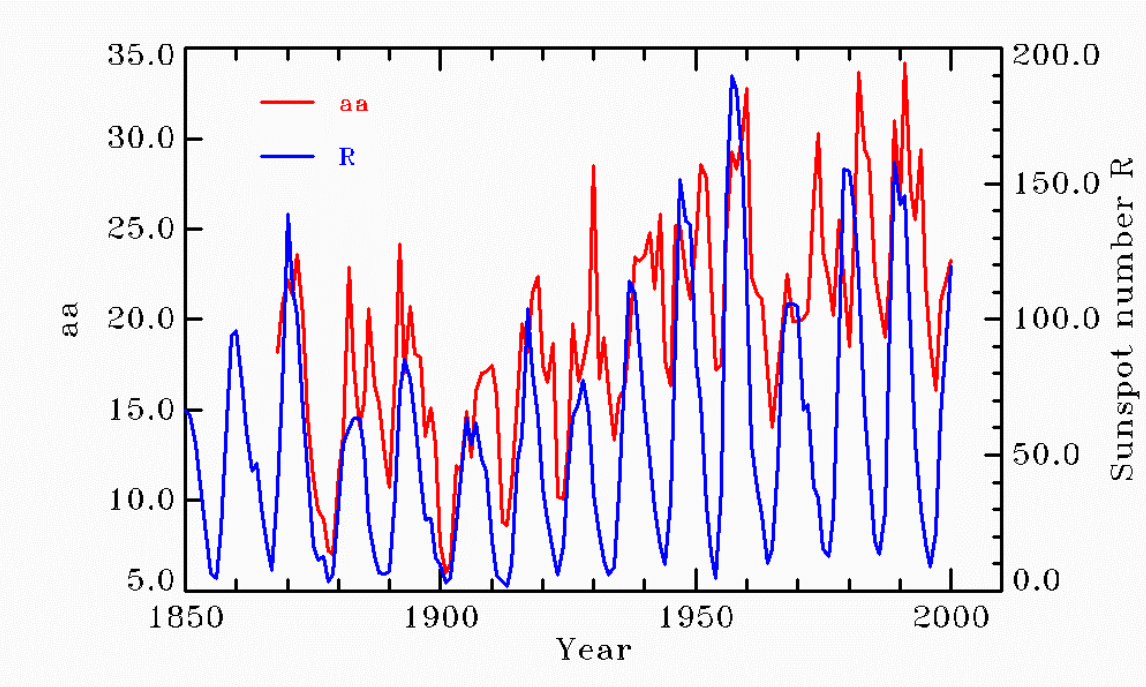
- **VIRGO - Total solar irradiance**
- **SEM (Celias): EUV disk integrated flux from 1-770Å and in He II 304 Å**
- **CDS: EUV 307-380 Å and 515-632 Å Spectral irradiance and 69 full disk images taken each month**

Sunspot Number R



- Sunspot number R, monthly values
- Period between 9 and 13 y
- Longer periods exist, 60-100 y

Solar and Geomagnetic Activity



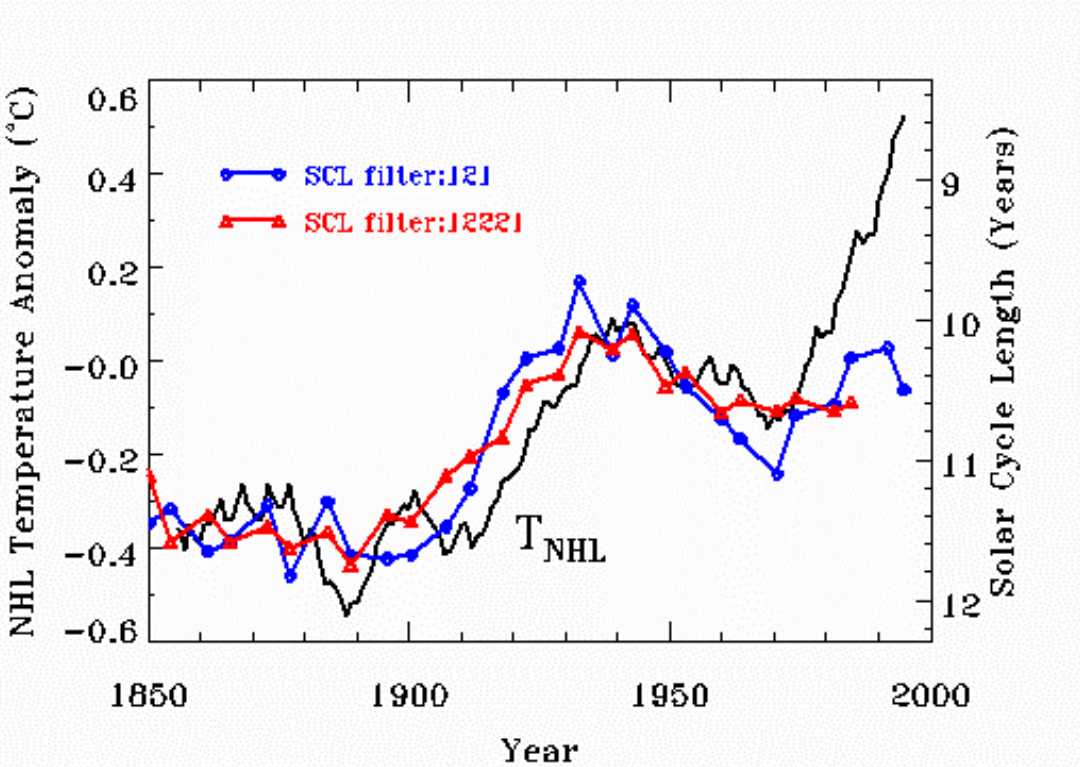
Yearly average

Geomagnetic activity index (aa)

Sunspot number (R)

- Solar activity ~ 11-y period. The rhythm, not the form, is reproduced in geomagnetic activity. Long-term variation is different
- Conclusion: R and aa are different manifestations of solar energy output

Global Temperature and Cycle Length: An Update



- During the latest about 20 years, temperature has increased more than expected - based on the length of the solar cycle
  - The effect of enhanced greenhouse effect is finally seen
  - The climatic effect of solar activity is not fully described by the length of the solar cycle
  - Surface temperature are not representative (Satellite MSU measurements)

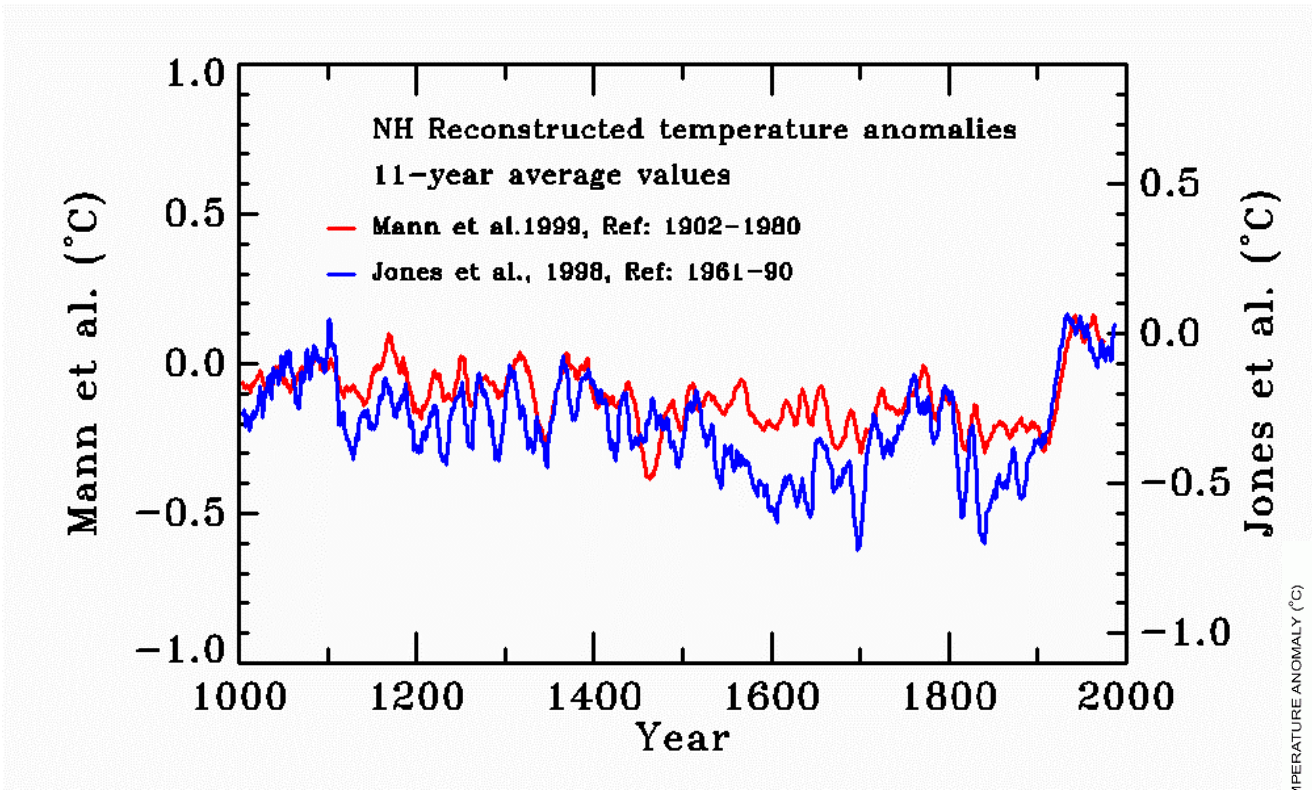
IPCC 1990: *Increase by 0.3 to 0.6°C over last century* ***broadly consistent*** *with climate model predictions.*

FCL 1991: *Major part of temperature changes during last century well correlated with solar activity.*

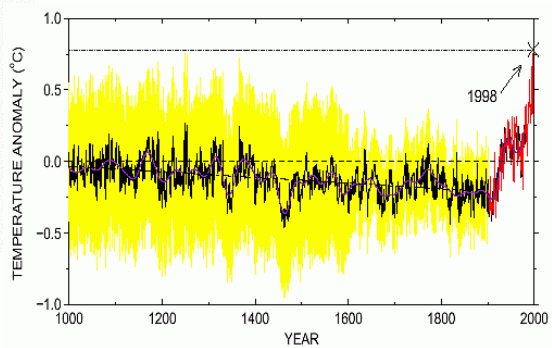
IPCC 2001: *Temperature increase during the last 50 years mainly caused by human activity.*

Past Temperature

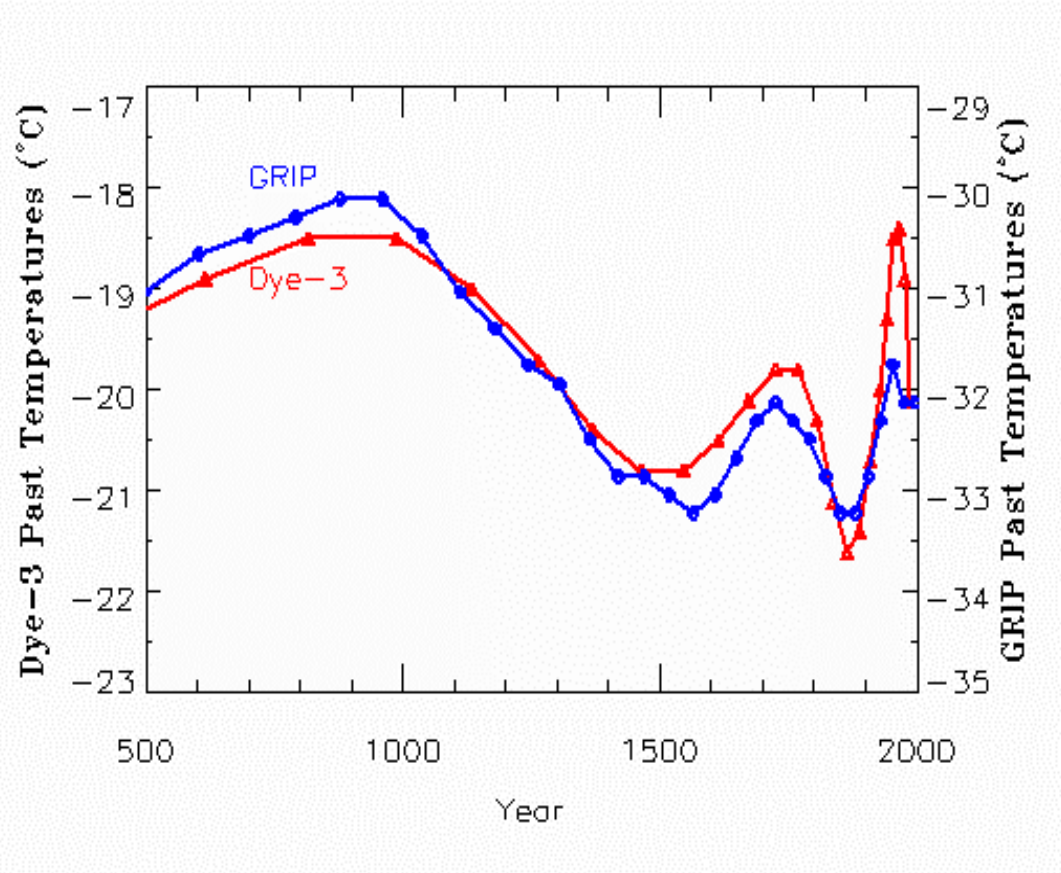
11-Year Mean Values of Reconstructed Temperatures



- Jones et al.
  - No assumptions
    - Traditional averaging
- Mann et al.
  - Assumptions:
    - Relationships between temperature variations at different sites are unchanged in time



Past Temperatures - Greenland Ice Sheet



Reconstruction of past temperatures based on bore hole data from two sites:

Dye-3 and Grip on the Greenland Ice Sheet.

Dahl-Jensen et al.
Science 1998

Atmospheric Ionisation Density Profile

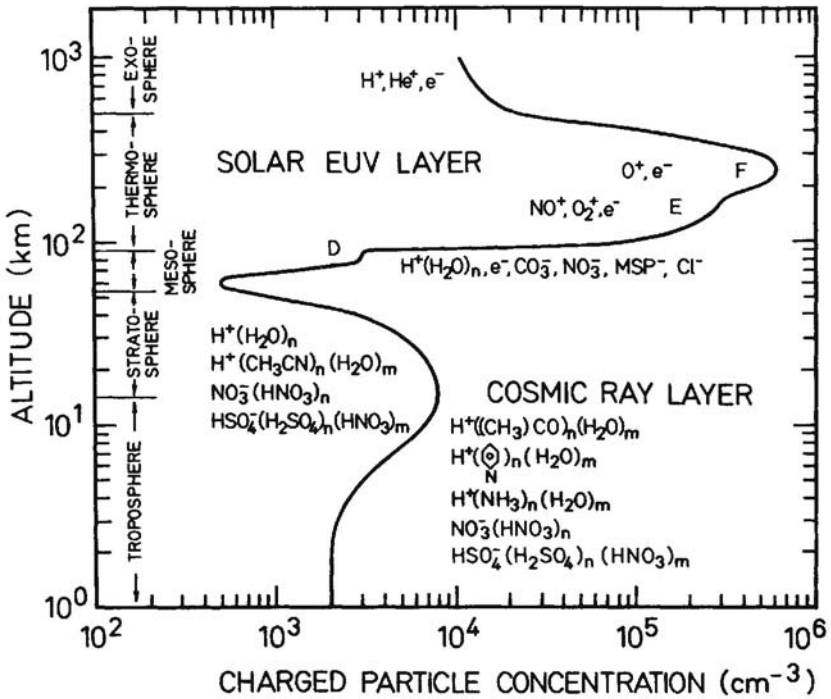
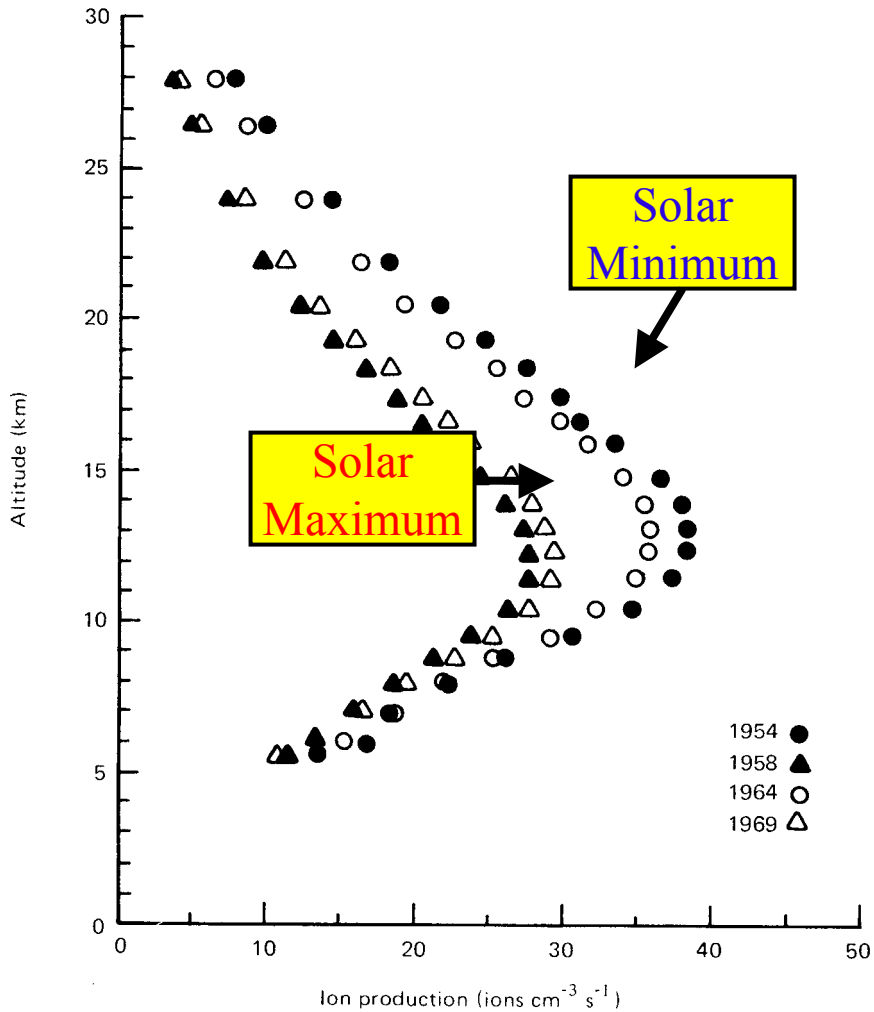


Figure 1.1.1 Typical ionization density profile of the atmosphere as a function of altitude. For each height regime, the major ions species are listed.

Viggiano and Arnold, 1995

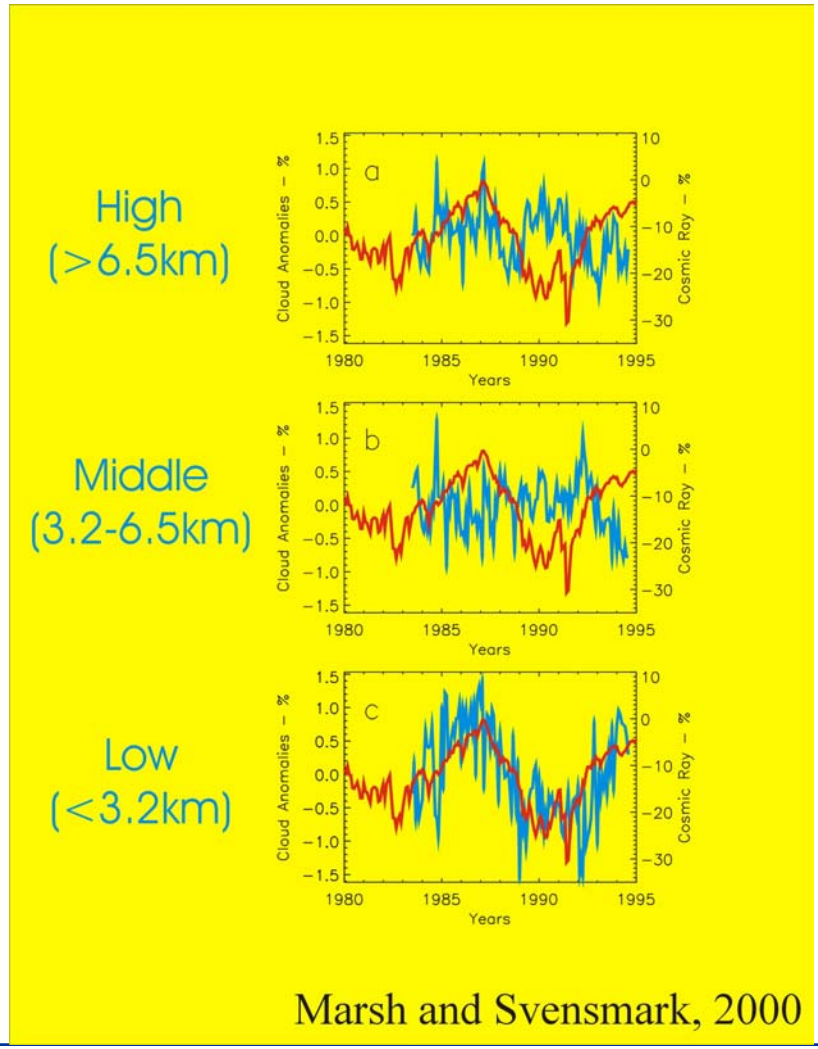
Ion pair production over Thule



"The meteorological variable subject to the largest solar-cycle modulation in the dense layers of the atmosphere is the atmospheric ionisation produced by cosmic rays."

E.P. Ney, Nature, 1959.

Cloud Types and Cosmic Rays



Physical mechanisms - formation of clouds

- **Low clouds are affected**
  - Implies an effect on water vapour clouds - not ice clouds
  - Aerosols - via production of cloud condensation 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

Conclusion

- **Changes in total irradiance**
  - Some effect is probable
- **Changes in UV-radiation**
  - Decadal variations in observed parameters can be modeled
  - Systematic effects observed at high altitudes - less at the surface
- **Changes in energetic particle flux**
  - Cosmic ray flux
    - Effect on cloud nucleation seems a promising mechanism - potentially large effect
  - Energetic electron precipitation
    - effect on ozone may be similarly effective as UV effect
- **All components may work together**
  - and do not exclude an effect of the increased amount of greenhouse gases