The Shining Sun: Understanding the Solar Irradiance Variability

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Physikalisch-Meteorologisches Observatorium Davos and World Radiation Center

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Overview

- Observations: total and spectral variations
- Understanding the shining Sun:
  A three component model
- Comparison with observations (short term)
- Long term changes of the magnetic flux
- What for? E.g. a research project
  Variability of the Sun and Global Climate
- Outlook

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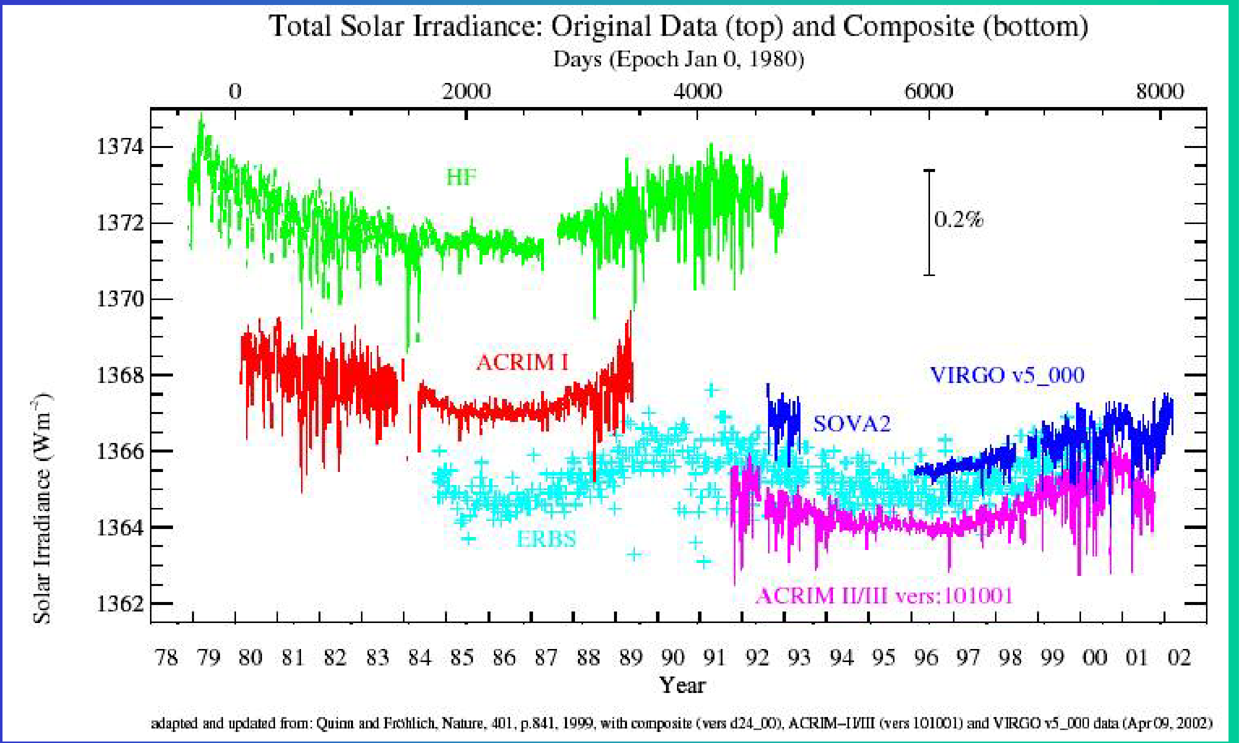
Observations of the Solar Constant



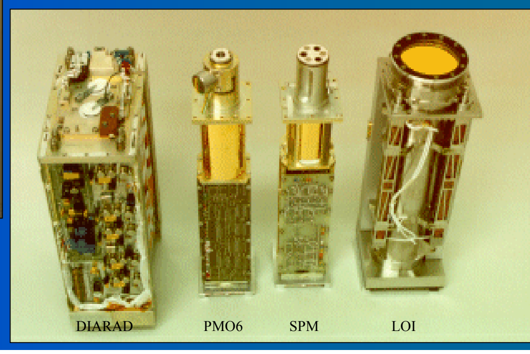
VIRGO
PMOD/WRC experiment on SoHO

- Time series in the integrated (total) solar irradiance and in 3 specral channels in the blue, green, and red light (1 minute sampling).

- Image of the Sun in the green light in low resolution (12 Pixel, 1-Minuten Sampling).

Start SoHO
Dezember 2., 1995

The instruments



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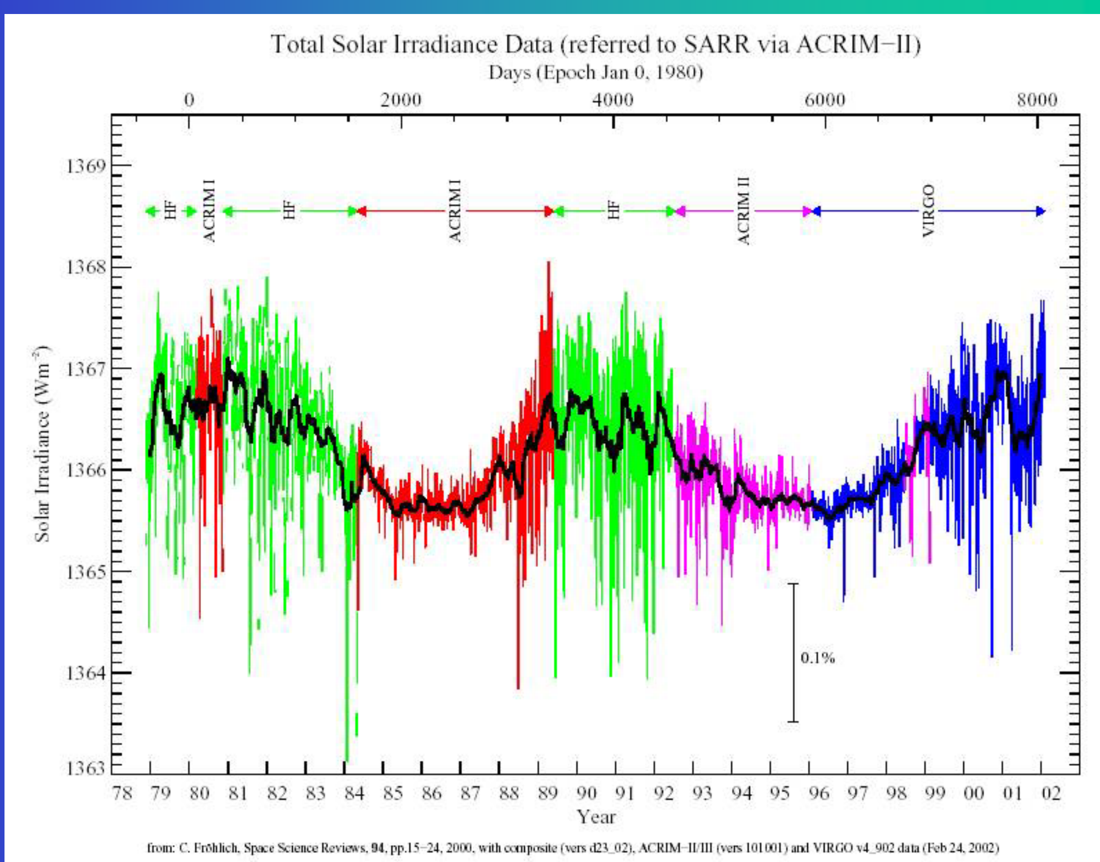
Total Solar Variation



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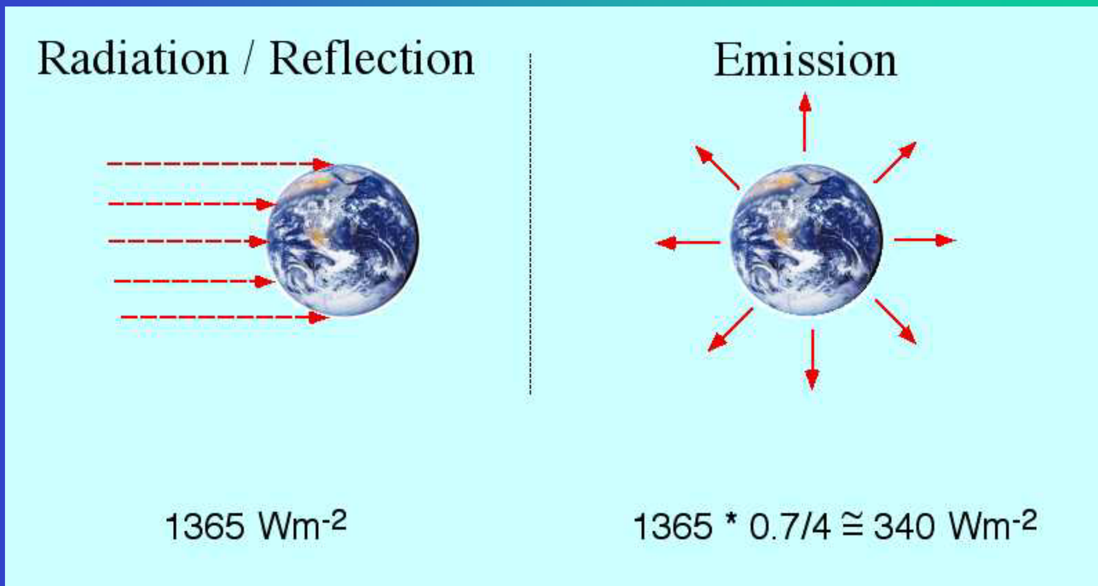
Terrestrial radiation budget



Graphics: Dr. J. Beer EAWAG, Switzerland

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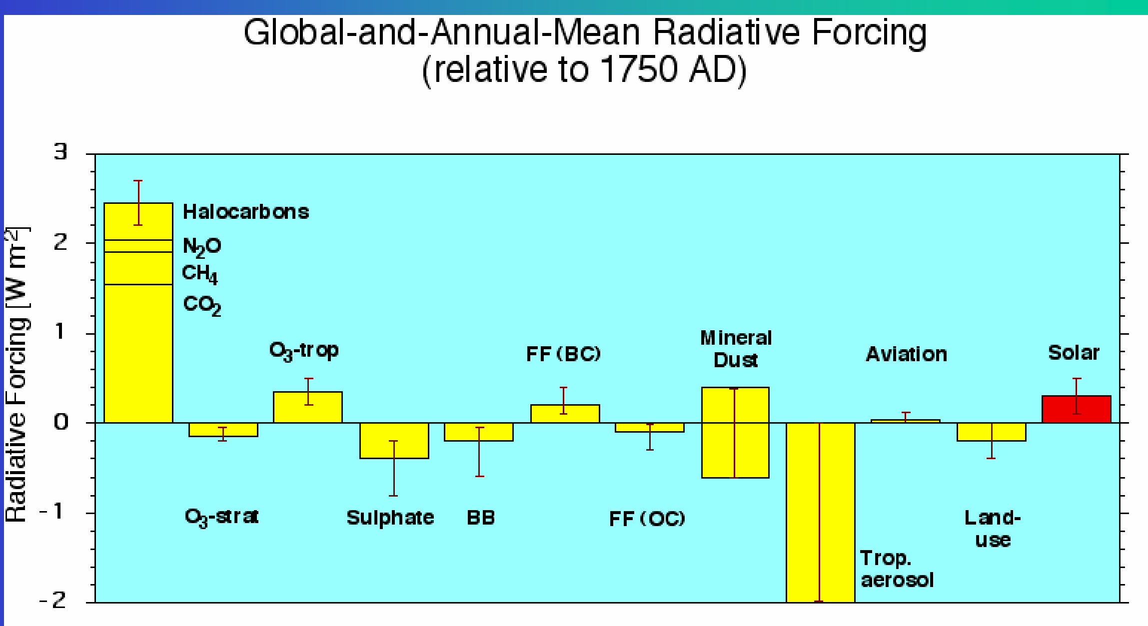
Forcing Factors (solar contribution = 0.1% of 340 W/m^2)



Graphics: Dr. J. Beer EAWAG, Switzerland

IPCC 2001

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Solar UV spectrum

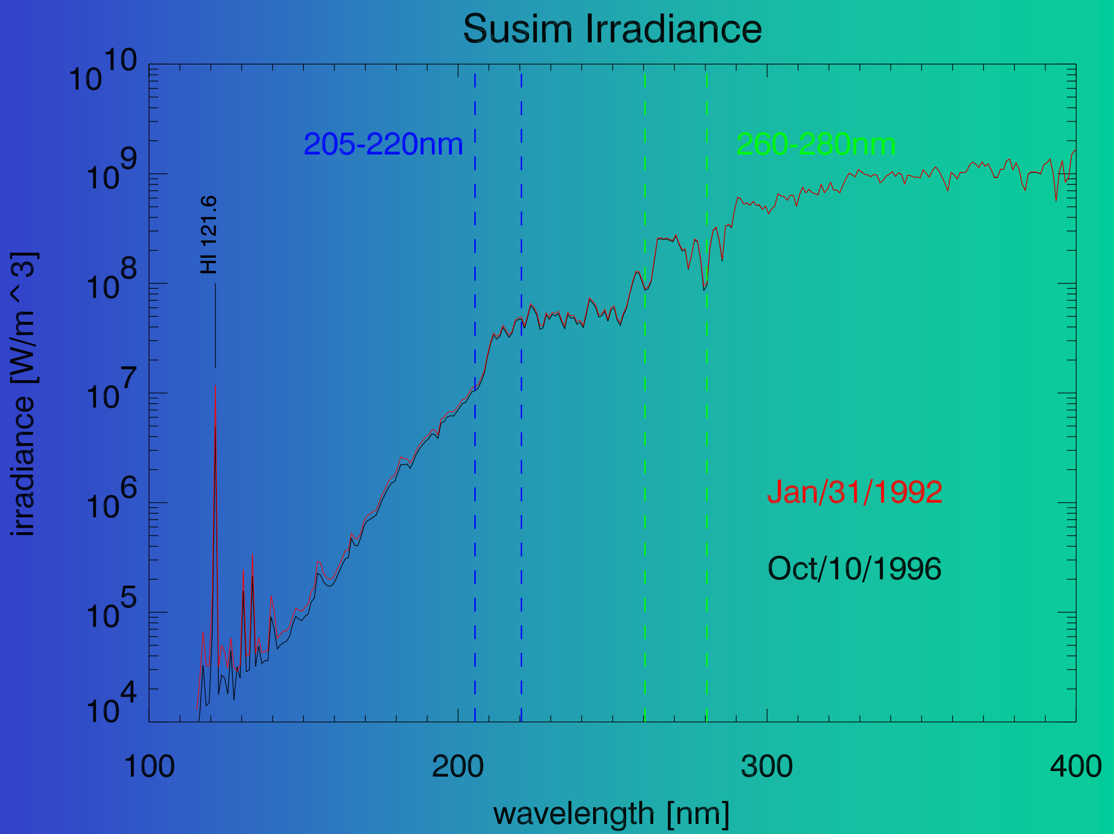

Illustration: M. Haberreiter (personal communication)

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Temporal variation of the Lyman α

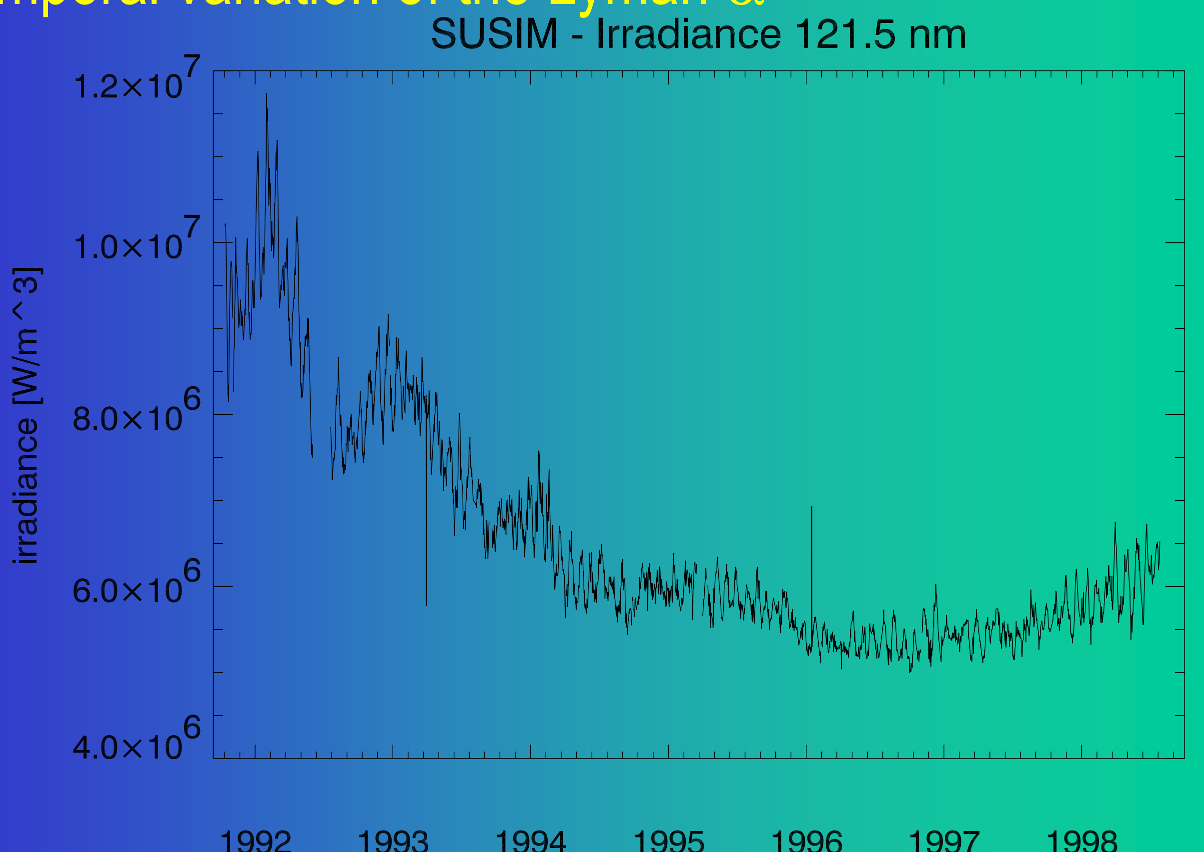

Illustration: M. Haberreiter (personal communication)

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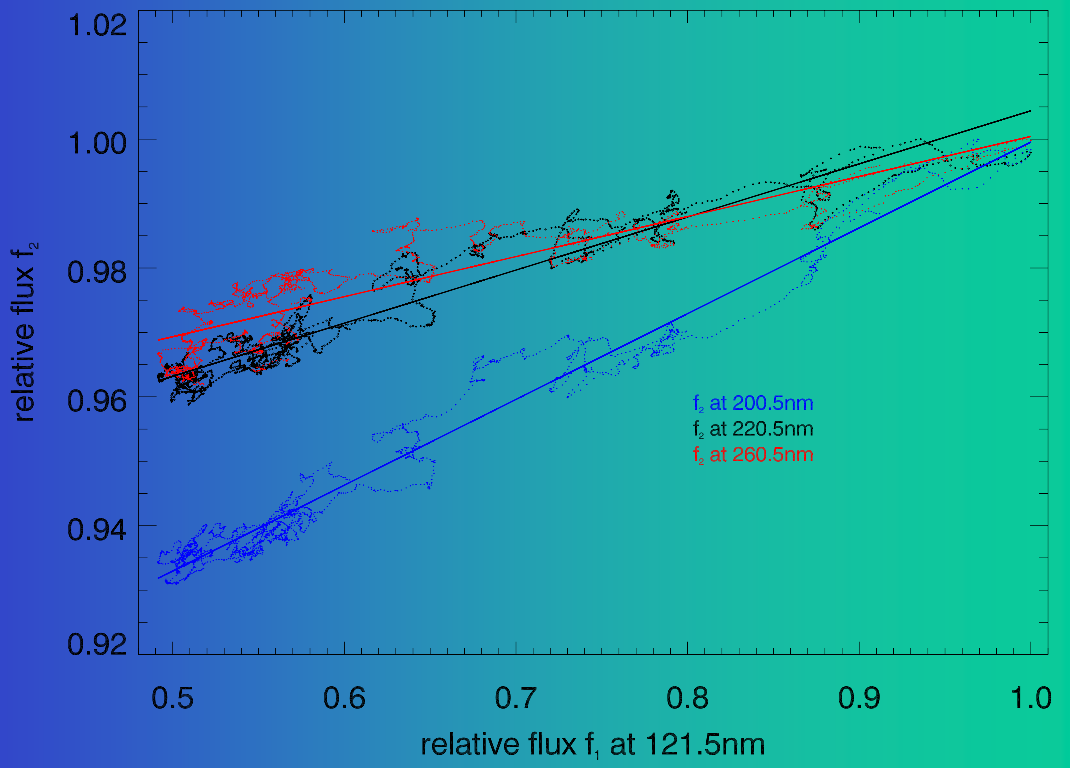
Correlation of UV irradiances



Haberreiter et al. (2002)

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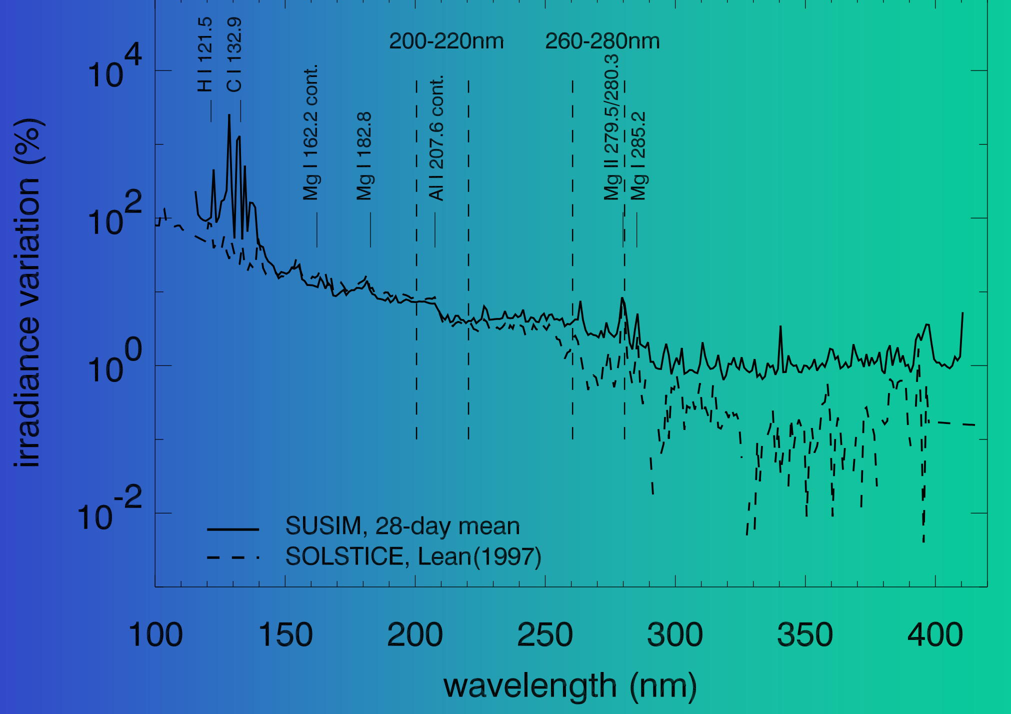
Spectral Variability



Haberreiter et al. (2002)

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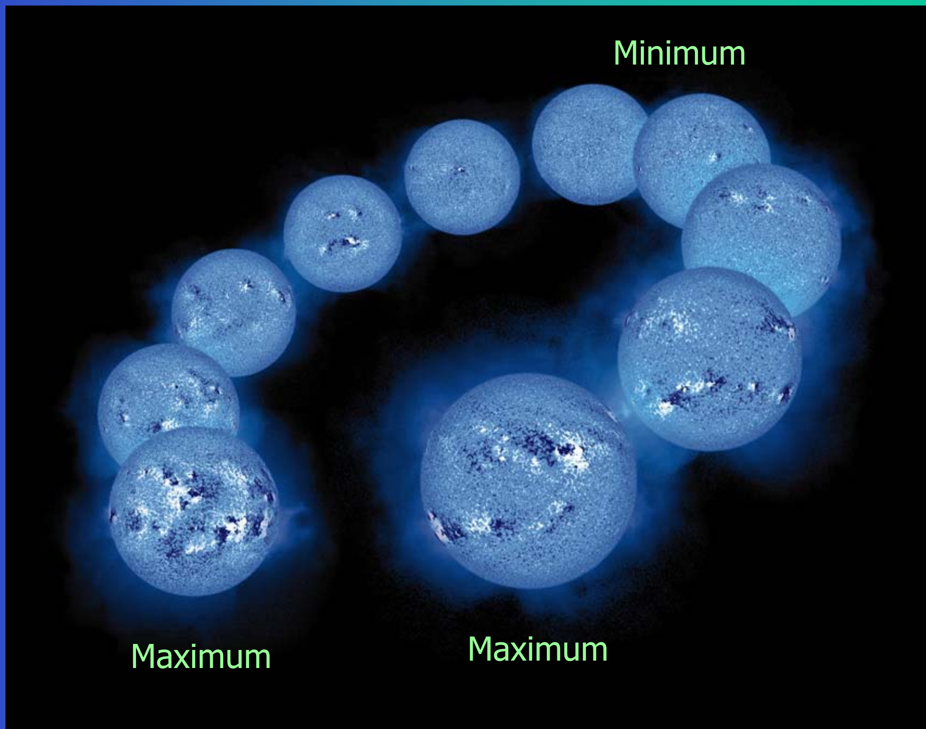
Origin of the irradiance variability: the magnetic cycle



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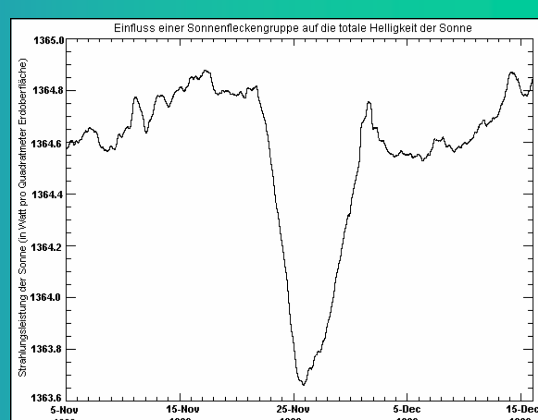
Sun spots reduce the solar irradiance



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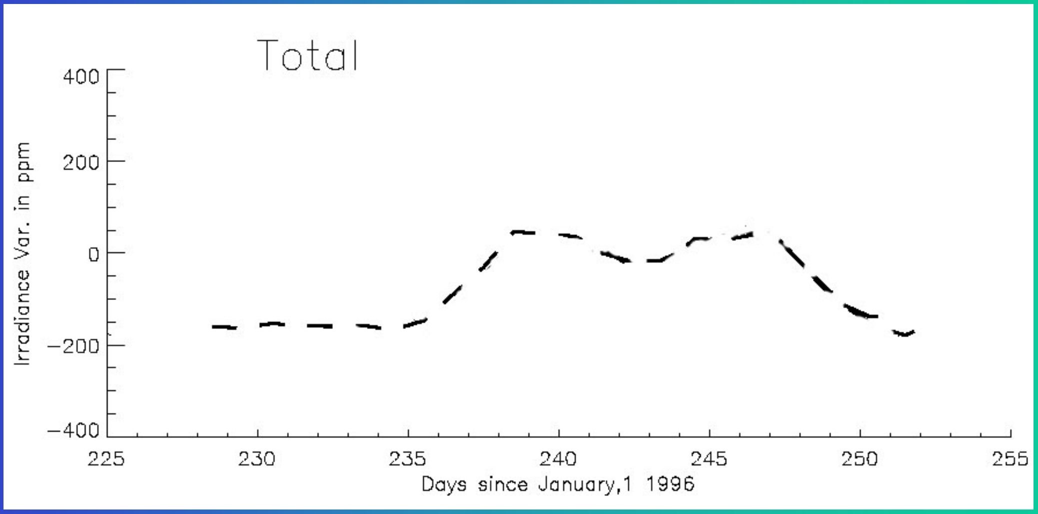
Faculae increase the solar irradiance



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Understanding the solar irradiance variability

3-component model:
quiet sun — faculae — sun spots

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simple approach:

- quite Sun (time independent): Kurucz' solar model
- only one T(h) representing an average sunspot (T_{eff}=5150 K)
- only one T(h) representing an average facular region

- no proxies - filling factors are based on observed magnetic flux (MDI observations)
- radiation transfer (in LTE) based on Kurucz Atlas9 model and CCP7 ODF's

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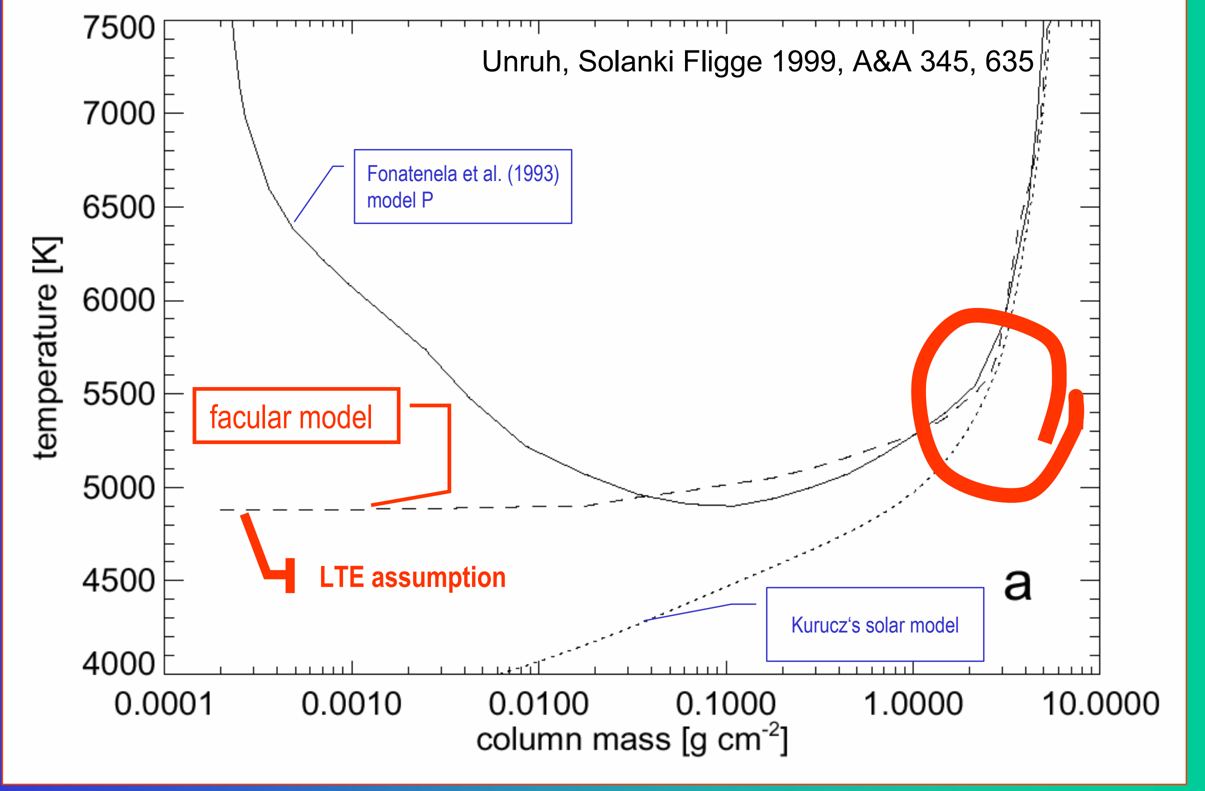
facular temperature structure



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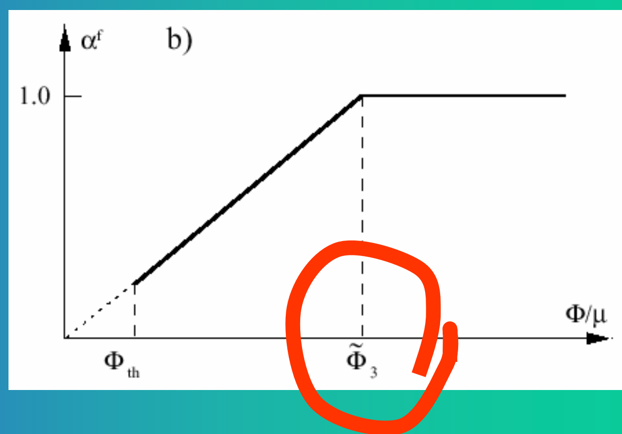
3-component model – filing factors α observed

$$
\begin{aligned}
I^{tot}_{i,j}(\lambda;t) = (1-\alpha^{s}_{i,j}(\Phi;t) & -\alpha^{f}_{i,j}(\Phi;t)) \cdot I^{q}(\mu(i,j),\lambda) \\
& +\alpha^{s}_{i,j}(\Phi;t) \cdot I^{s}(\mu(i,j),\lambda) \\
& +\alpha^{f}_{i,j}(\Phi;t) \cdot I^{f}(\mu(i,j),\lambda).
\end{aligned}
$$

$$\alpha^{s}_{i,j}(\Phi;t) = 1$$



s = sun spot

f = faculae

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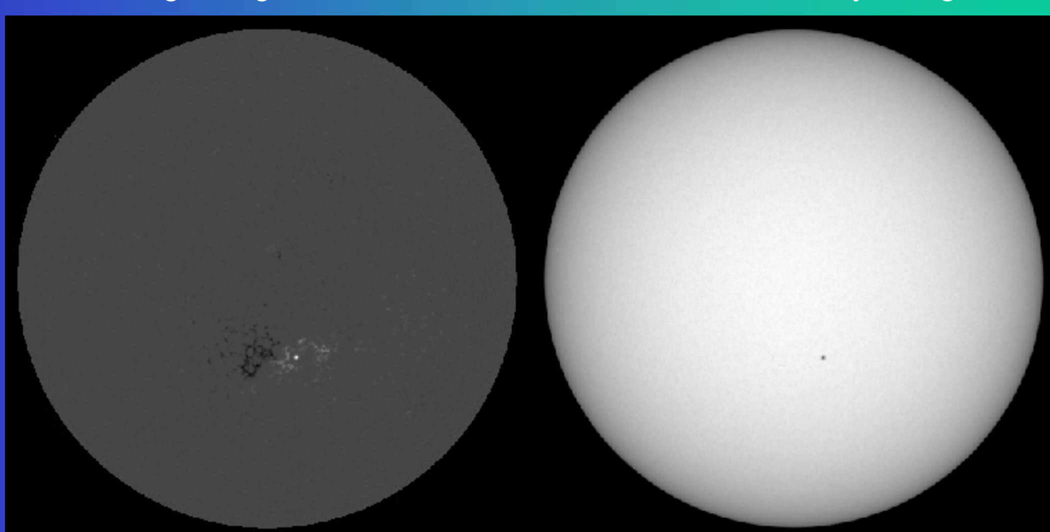
facular and sunspot effective areas (1)

MDI magnetogramm continuum intensity image



August 30, 1996

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facular and sunspot effective areas (1)

maps for faculae for sunspots

August 30, 1996: active region dominated by faculae

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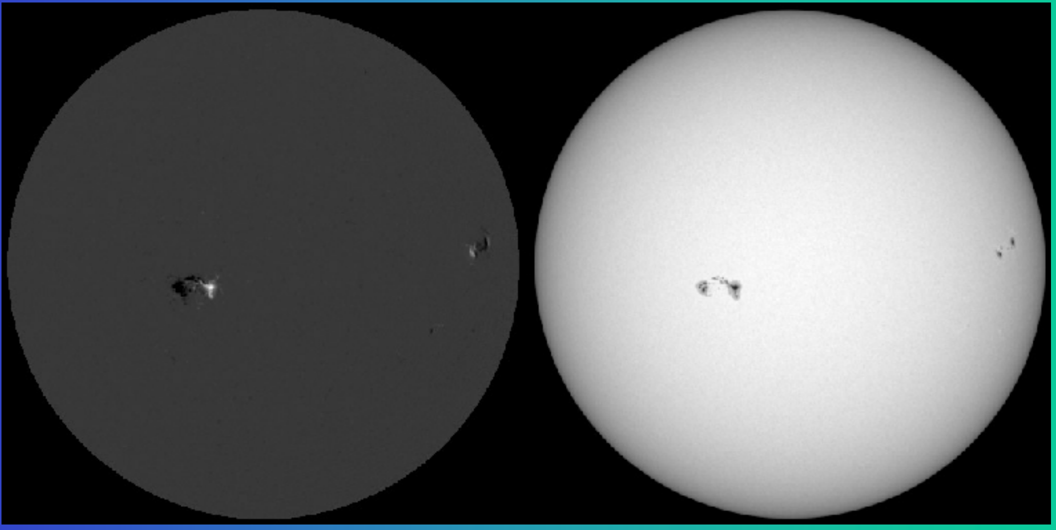
facular and sunspot effective areas (2)

MDI magnetogramm continuum intensity image



November 25, 1996

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facular and sunspot effective areas (2)

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maps for faculae for sunspots

November 25, 1996: faculae ***and*** sunspot extracted

Comparison with observations (1)

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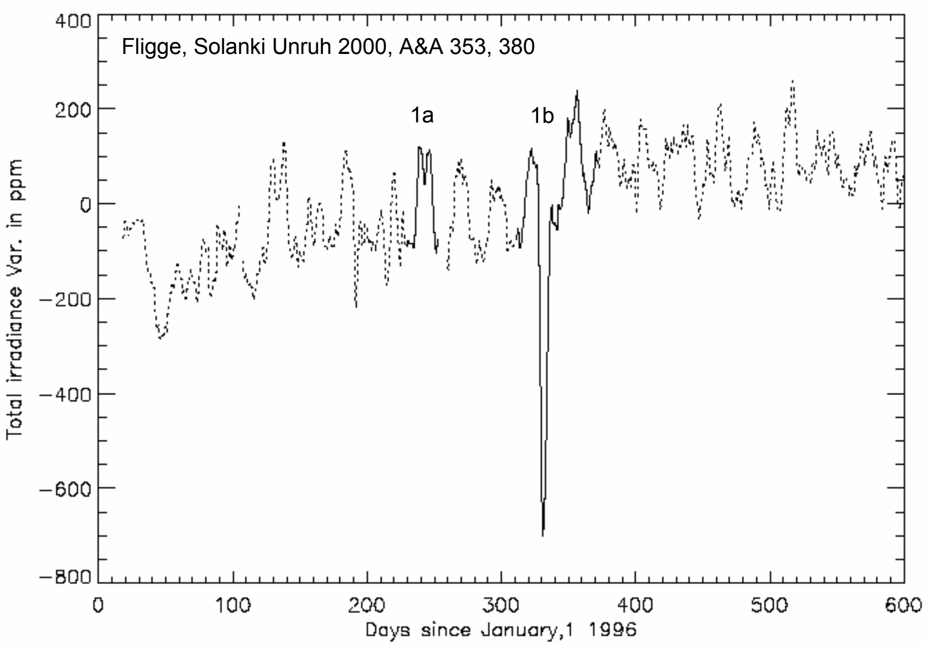
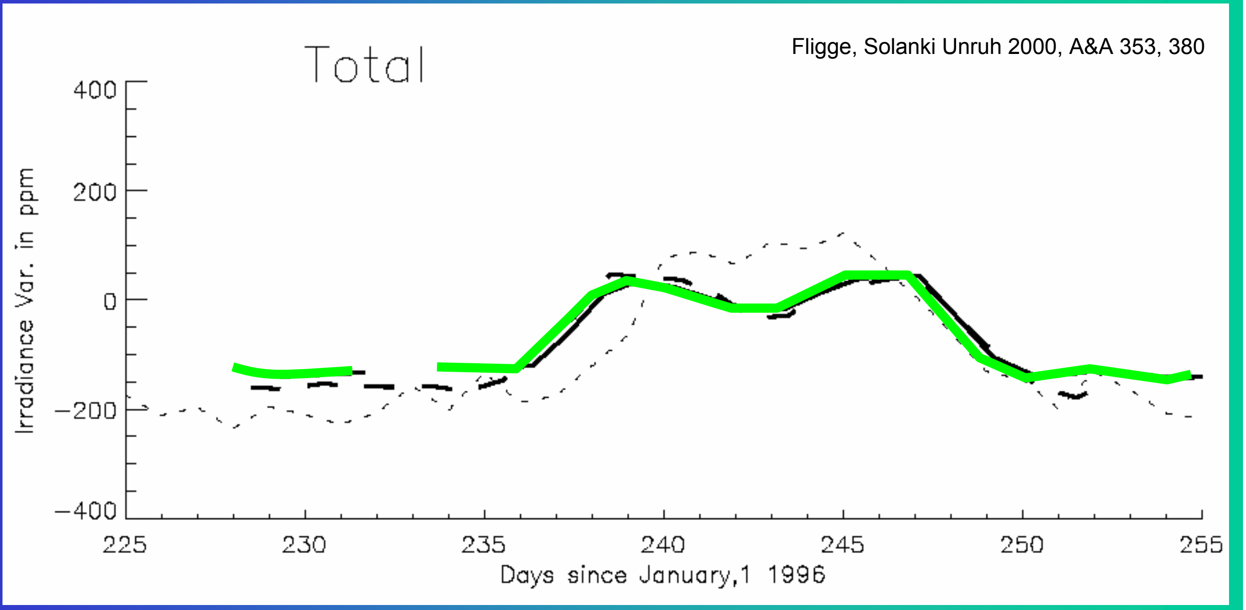


Fig. 5. Variability of total solar irradiance as measured by VIRGO during its first two years of operation. We reconstruct solar irradiance variations over the periods marked by the solid, thick lines.

Comparison with observations (1a)



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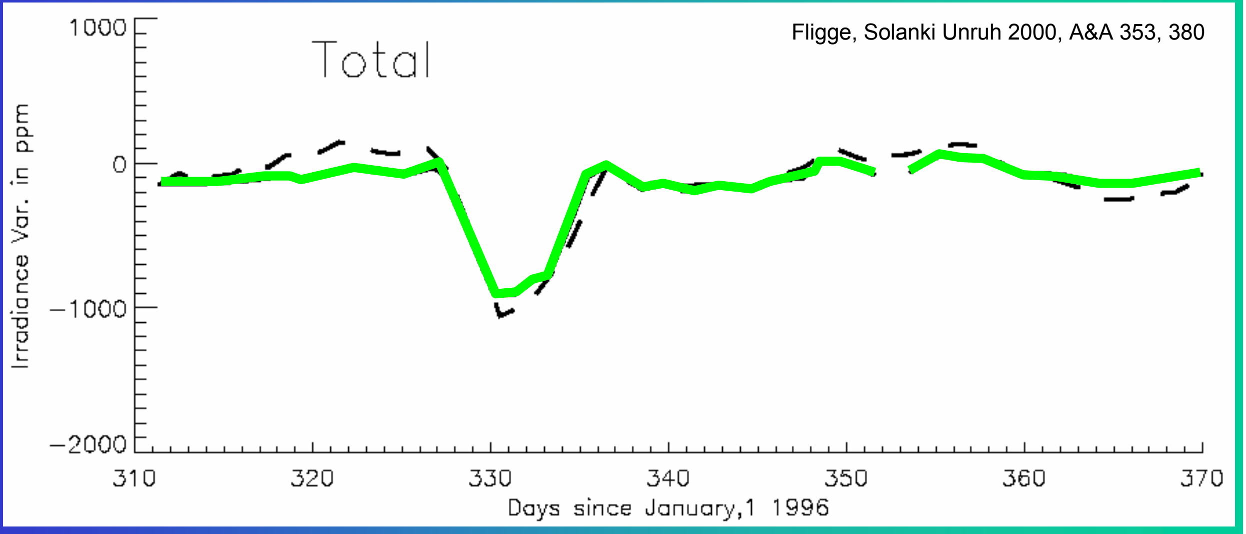
Comparison with observations (1b)



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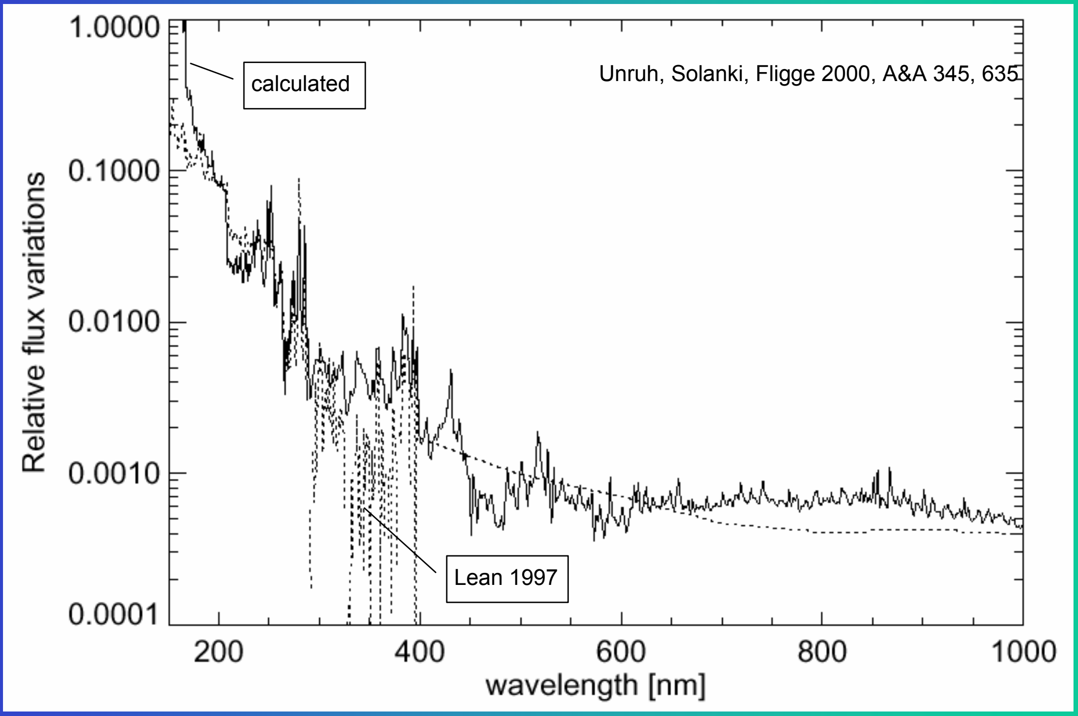
Comparison with observations (2): spectral variation between maximum and minimum



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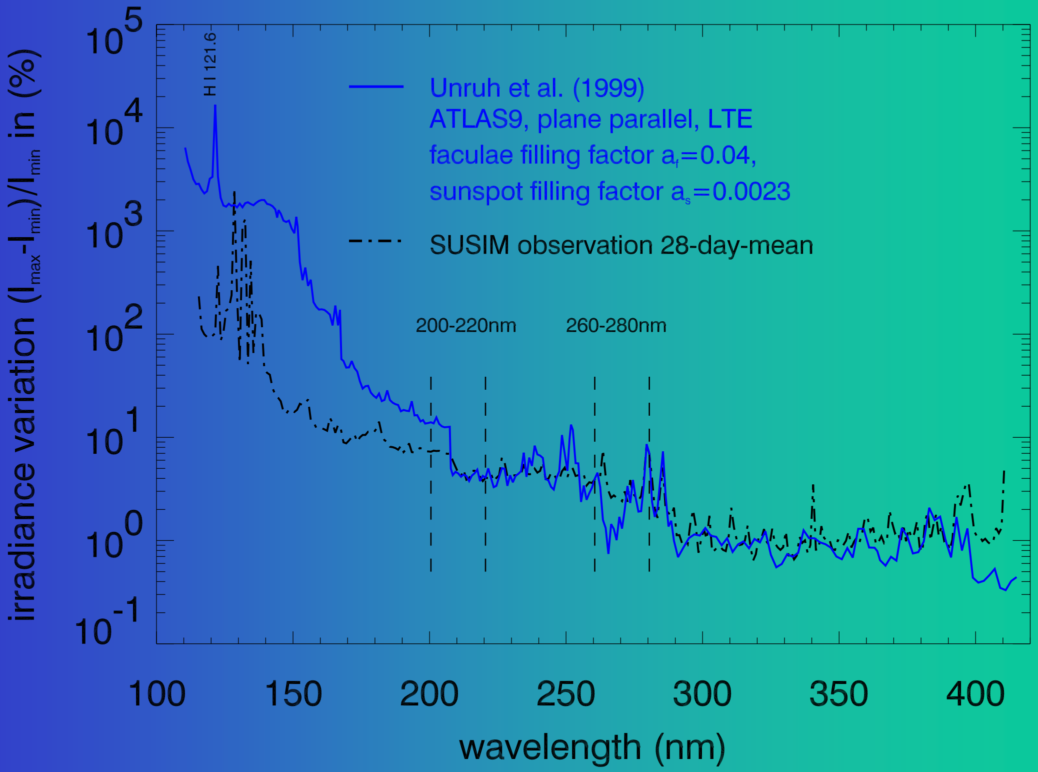
Comparison with observations (3): spectral variation between maximum and minimum



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Long term changes of the magnetic flux

- The magnetic flux produced by the solar dynamo appears at the solar surface in the form of *active* and *ephemeral* regions

  $\Rightarrow$ dϕ/dt ~ f(sunspot area)

- the magnetic field is distributed on the solar surface and disappears slowly by diffusion and reconnection process

  $\Rightarrow$ dϕ/dt ~ ϕ

- it is expected that the magnetic field appears faster than it disappears

  $\Rightarrow$ the cycle length influences the observed magnetic field !

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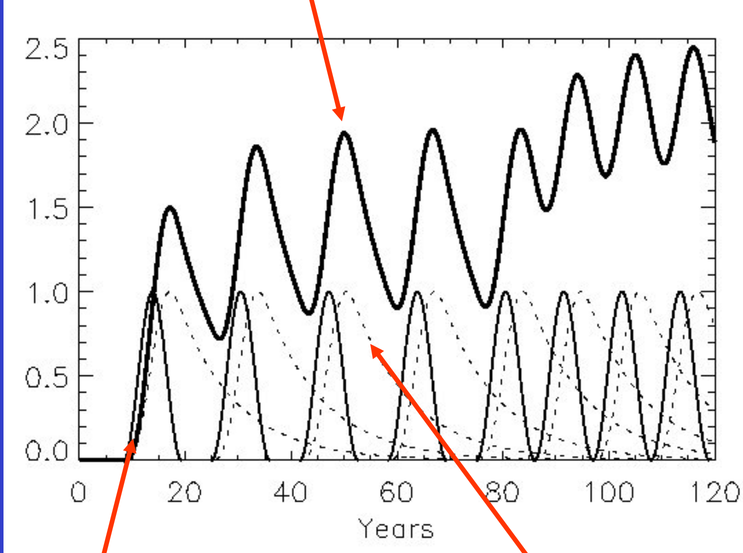
Cycle length and open background flux

Solanki, Schüssler, & Fligge 2000

Background flux



Cyclic flux injection

Slow decay

- cyclic flux injection
- slow decay (~years)
- shorter cycles
  $\rightarrow$ more flux/time
  $\rightarrow$ stronger background field
- effect amplified by solar anticorrelation between cycle length and strength

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fractions of solar irradiance variations due to solar surface magnetism (lower limit estimates)

- Solar rotation time scale: ≥ 90%
- Activity cycle time scale: ≥ 90%
- Secular (centuries) time scale: ?

Status: magnetic evolution can be modeled, contribution of other sources is unknown

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uncertainties in the modeling

- SOHO/MDI sensitivity:
  the weakest and most common field component is missed
- only a single facular component in models
  evidence that weak network and stronger plage show very different brightness signatures
- neglected flux tube physics
  faculae are poorly represented by plane-parallel atmospheres

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What for ?

Influence on the terrestrial climate?

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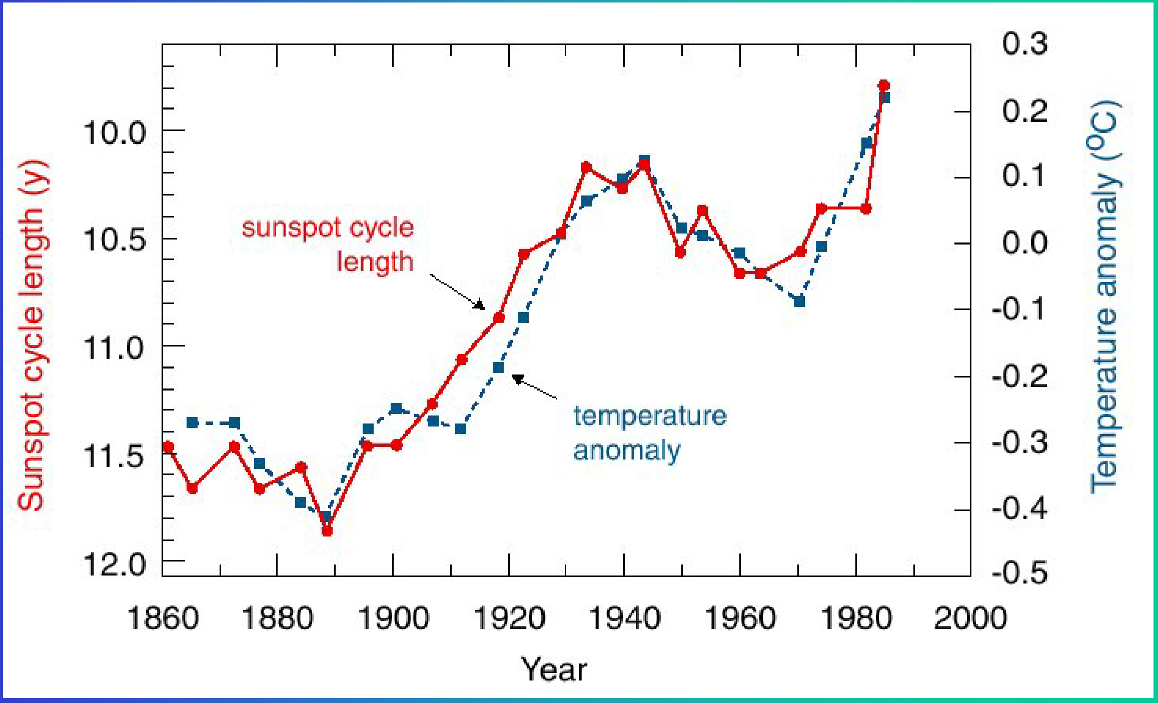
Cycle length and terrestrial temperature



Friis-Christensen & Lassen (1991)

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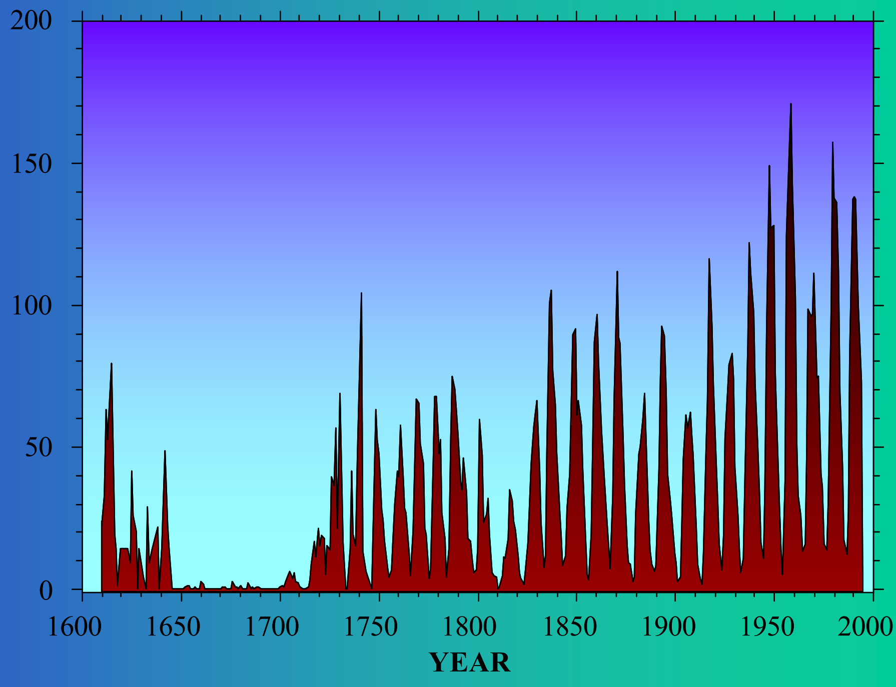
sun spot numbers



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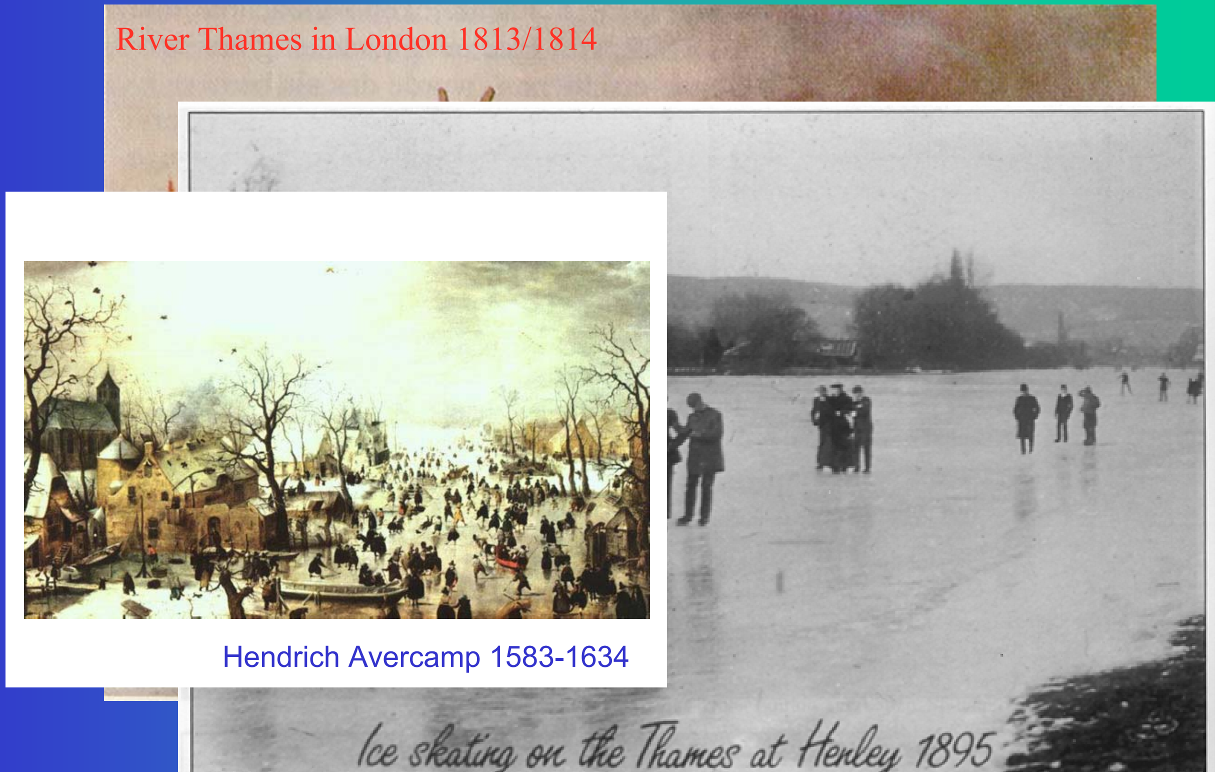
climate anomalies

illustration: Dr. J. Beer EAWAG, Switzerland



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Davos-ETH Zürich “Poly-project”
Variability of the Sun and Global Climate

Aim:

- Search for mechanisms how the solar variations influences the terrestrial climate
- Investigate past climate changes from the point of view of a possible variation of the solar irradiation

Approach:

- Combine astrophysics with GCM calculations

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Davos-ETH Zürich „Poly project”
Variability of the Sun and Global Climate

- Modeling of the solar UV irradiance variation
- Search for mechanisms how the solar variations influence the terrestrial climate
- Investigate past climate changes due to the variability of the solar irradiation

Participating institutes:

PMOD/WRC, Davos, Institute of Astronomy, Institute of Atmospheric and Climate Science, Zurich

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Davos-ETH Zürich „Poly project"
Variability of the Sun and Global Climate

Global climate model calculations with interactive photochemistry (GCM/PC):

- expand existing troposphere-stratosphere-mesosphere version of GCM/PC to allow for a detailed ***spectral*** specification of the incident radiation
- evaluate the effects of variations in spectral solar irradiance input on ozone and other trace gases

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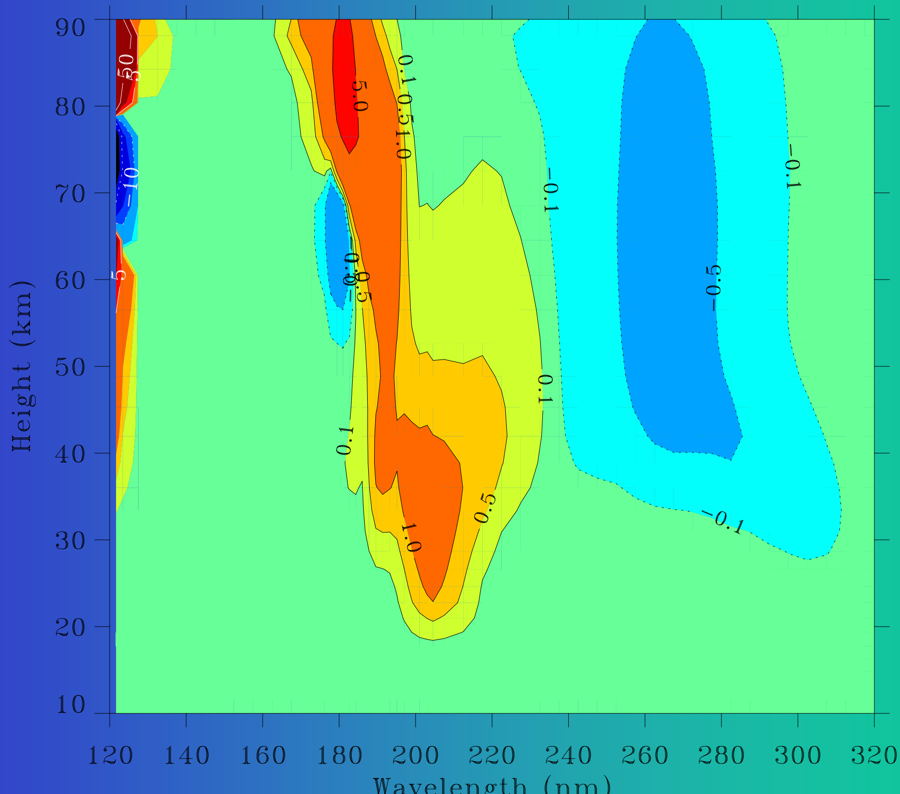
1D pilot study: What UV-wavelength is important?



dO_3 (‰/nm): Ozone mixing ratio changes (%) due to a 10% increase of the spectral solar flux during solar cycle (Rozanov et al. 2002)

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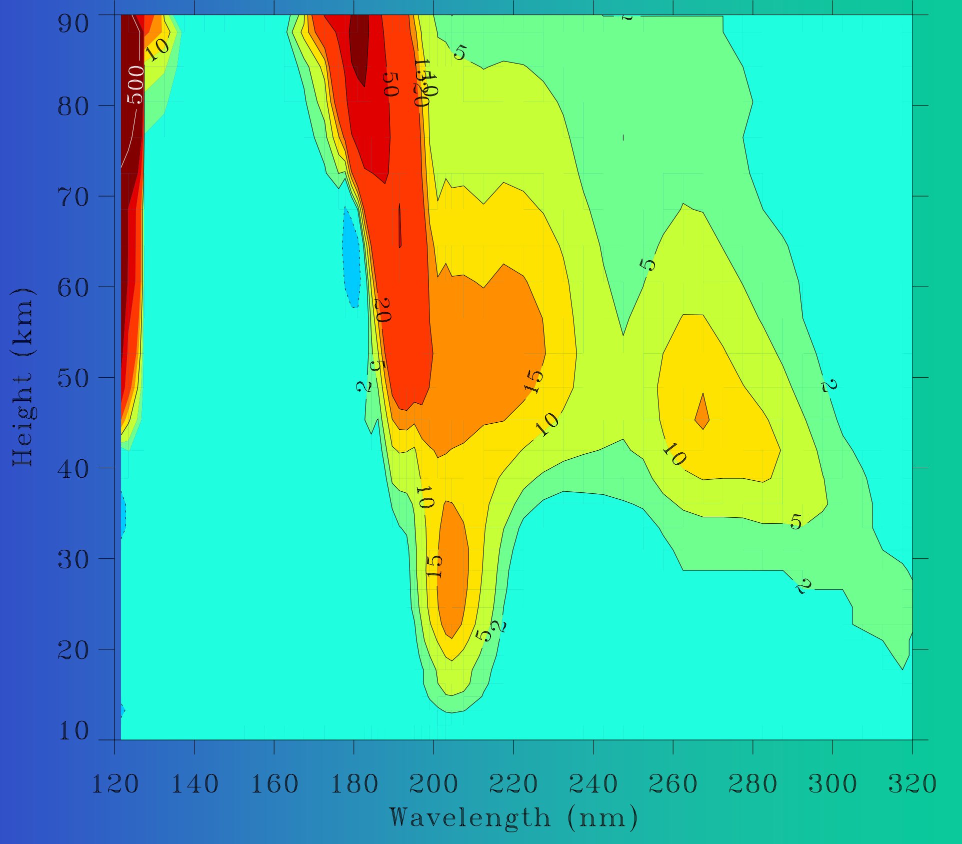
Temperature sensitivty dT (K/nm ·1000)



Rozanov et al. (2002)

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goal for the immediate future

calculate detailed UV-spectra for the

100 – 300 nm

wavelength range

as a function of time for the SoHO era

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outlook

modeling improvements:

- improved description of faculae and network
- non-LTE calculations for the UV
- reconstructions of spectral irradiance for pre-SoHO era

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measurements

theoretical work relies on ...

... continuous and accurate measurements of the total and spectral solar irradiance changes ...

SORCE – SOVIM – PICARD – (SDO) – (SOLAR ORBITER) ...

radiometers in space are important !

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end of slide show

Organization

Project Manager
PMOD/WRC
Dr. Eugene Rozanov

T. Wnezler IfA
solar physics

M. Haberreiter PMOD/WRC
prediction of solar spectrum

working in the same office

T. Egorova PMOD/WRC
photochemical routines
and GCM calculations

Ph.D. student IfCR
GCM improvements
and comparison
with observations

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papers by the Zürich/Lindau/London/Davos group:

1. 2002 A&A...388.1036 Ortiz, A.; Solanki, S. K.; Domingo, V.; Fligge, M.; Sanahuja, B.: *On the intensity contrast of solar photospheric faculae and network elements*
2. 2002 A&A...383..706 Solanki, S. K.; Schüssler, M.; Fligge, M.: *Secular variation of the Sun's magnetic flux*
3. 2000 Natur.408..445 Solanki, S.K.; Schüssler, M.; Fligge, M.: *Evolution of the Sun's large-scale magnetic field since the Maunder minimum*
4. 2000 A&A...353..380 Fligge, M.; Solanki, S.K.; Unruh, Y.C.: *Modeling irradiance variations from the surface distribution of the solar magnetic field*
5. 1999 GeoRL..26.2465 Solanki, S.K.; Fligge, M.: *A reconstruction of total solar irradiance since 1700*
6. 1999 A&A...345..635 Unruh, Y.C.; Solanki, S.K.; Fligge, M.: *The spectral dependence of facular contrast and solar irradiance variations*
7. 1998 A&A...335..709 Fligge, M.; Solanki, S.K.; Unruh, Y.C.; Froehlich, C.; Wehrli, Ch.: *A model of solar total and spectral irradiance variations*
8. 1998 A&A...332.1082 Fligge, M.; Solanki, S.K.: *Long-term behavior of emission from solar faculae: steps towards a robust index*
9. 1998 GeoRL..25..341 Solanki, S.K.; Fligge, M.: *Solar irradiance since 1874 revisited*
10. 1998 A&A...329..747 Solanki, S.K.; Unruh, Y.C.: *A model of the wavelength dependence of solar irradiance variations*

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