Long-term high resolution observation of the extra-terrestrial solar output from 150 nm to 2500 nm

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11 year solar cycle and climate

- 17th century ("Maunder minimum"): 
  - "little ice age"
  - famous Dutch winter paintings

- Other cyclic variations overlaying the 11y solar cycle (Schwabe) have periods of 87 years (Gleissberg) and 210 years (De Vries-Suess)
Solar variability, ozone, and climate

- 11-year solar cycle signature in sea surface temperature (SST) and ozone
- Note: recent increase in SST (+0.8°C) is not explained by the rather quiet sun (+0.1°K) but is related to increases in greenhouse gases (+0.7°K)
Changes in UV solar irradiance over a solar cycle

- UV irradiance observations from space cover solar cycles 21, 22, 23
- Largest variations observed in the UV spectral range

Rottmann, 2000

Mg II emission at 280nm

Weber et al., 2007
Spectral contribution to TSI (solar constant)

- UV contributes to about 9% to the total solar irradiance, but 30-60% to solar cycle variability of TSI (≈0.1%)
- Can we confirm this by satellite observations?
Past and future UV/Vis irradiance monitoring from space

**optical solar irradiance satellite instruments**

- **SBUV (Nimbus, N9, N11)** 180-400 nm
- **SME** 120-320 nm
- **SOLSTICE (UARS)** 115-400 nm
- **SUSIM (UARS)** 115-400 nm
- **GOME (ER82)** 240-790 nm
- **SCIAMACHY (ENVISAT)** 220-2400 nm
- **SOLSTICE (SORCE)** 115-320 nm
- **SIM (SORCE)** 200-3000 nm
- **OMI (AURA)** 250-400 nm
- **GOME2 (METOP)** 240-800 nm
- **SOLSPEC (ISS)** 180-3200 nm
- **SBUV2 180-400 nm**

- **1980**
- **1985**
- **1990**
- **1995**
- **2000**
- **2005**
- **2010**

- UV irradiance monitoring from space since 1978
- only few missions cover visible/NIR wavelengths:
  - GOME
  - SCIAMACHY
  - SIM
  - GOME2
- disadvantage of „atmospheric sounders“ (GOME, SCIAMACHY, SBUV):
  - lack of rigorous inflight calibration
Global Ozone Monitoring Experiment (GOME)

- **launched:** 1995
- **Orbit:** near polar, sun-synchronous (inclination: 98°), altitude 785 km (LEO)
- **Measurements:** solar irradiance, atmospheric O3, NO2, BrO, OCIO,...
**SCIAMACHY aboard Envisat/ESA**

**Scanning Imaging Spectrometer for Atmospheric Chartography** (SCIAMACHY)

- **launched:** 2002
- **Orbit:** near polar, sun-synchronous (inclination: 98°), altitude 785 km (LEO)
- **Measurements:** solar irradiance, atmospheric O3, NO2, BrO, OCIO, CH4, CO2, CO...
Why near-polar orbit?

- **Advantage**: complete global coverage for atmospheric sounding (within few days), example ozone hole
- **Disadvantage**: overpass at fixed local time (e.g. 10am ENVISAT)
Need for geostationary orbit: air pollution monitoring (NO2)

Fig. 1. Variability of tropospheric pollutants at Ascot/London, 23.-24.7.1999. Indicated are also the overpass times of LEO AM platforms like ERS-2, ENVISAT or METOP and the potential sub-hourly temporal coverage of geostationary system.

Richter et al., 2005

Advantage of a geostationary (equatorial) orbit:

- Diurnal variations of air pollutants (day/night, rush hour, etc.)

Missions are proposed: GEOSCIA, GEOTROPE

Burrows et al., 2004
Why do UV atmospheric sounder measure solar irradiance?

- Retrieval of trace gas amounts (here) ozone from sun-normalised radiances (reflectances)

Ozone bands at the UV absorption edge (UV protection!)

DOAS (325-335nm): O3 column retrieval
FURM (290-355nm): ozone profile retrieval
GOME and SCIAMACHY solar spectrum

- Direct full disc solar measurements with diffuser once a day (GOME & SCIAMACHY)
- Fraunhofer absorption lines (metals, H) are signatures of the solar atmosphere (photosphere and chromosphere)

*Skupin et al., 2005

Weber et al., 1998, Weber 1999
**Solar Irradiance Monitor**

*Launched:* 2003

*Orbit:* inclination: 40°, altitude 620 km

*Measurements:* solar irradiance (twice a day)
SIM solar measurements 250-2500 nm

- SIM measures twice a day
- formation height of radiation in the solar atmosphere can be determined from the solar spectrum

Mean solar surface temperature (lower photosphere): T=5800K
What are the sources for irradiance variations?

- Main contributions come from magnetic surface features

- Sun spots (dark)

- Faculae (bright)
Faculae and plages contribute to UV variations (brighter)

Short-term variations show the 27-day solar rotation period (active regions moving in and out from earth’s view)
Irradiance variations in the visible

- Sun spots (darker) contribute to variations in the visible
- Variations in visible are smaller by a factor of 10
Irradiance variations in the near IR

![Graph showing irradiance variations](image)

- Very small variation on the order of 0.1% in the near IR

1400 nm
The entire optical spectral range (up to 2400 nm) is measured daily since 2002 from space.

Tiny variations due to solar activity on the order of 0.1% are detectable!
Solar irradiance observations from space can be carried out from different orbits

- near polar Low Earth Orbit (LEO): SCIAMACHY, GOME, etc.
- LEO with inclination of ~40-50°, h=700 km: SIM, SOLSTICE
- shuttle orbit: SOLSPEC (shuttle/ISS)
- geostationary orbit:: GEOSClA, GEOTROPE (still in proposal phase)
- Lagrangian points: SOHO

Equatorial LEO may be of interest for better spatial sampling of the tropical region for atmospheric soundings (resolution of 1km on the surface, geostationary: ~20 km)

A copy of this talk can be downloaded from www.iup.uni-bremen.de/~weber/cospar_IAF
Appendix
Solar-terrestrial coupling: "Space weather"

SUN
- convection zone
- radiative zone
- core
- surface
- atmosphere
- sunspot
- bright active region

EARTH
- solar wind
- particles and magnetic fields
- photons
- bow shock
- surface atmosphere
- plasmasphere
- magnetosphere
Formation height of solar radiation

- Some 99% (i.e. 300 - 5000 nm) of radiative output emerges from the photosphere.

Fröhlich & Lean, 2004
Origin of solar variability

- variations in received solar UV irradiance are caused by the emergence and decay of active regions as they transit the solar disk.
- Active regions contain enhanced:
  - UV brightness (faculae and plages)
  - localized enhanced magnetic fields

- Solar UV/vis radiation originates
  - upper photosphere
  - chromosphere
  - transition region
- Solar UV below 400 nm contributes about 30% to total solar flux (solar constant)

Fox, 2004

GONG magnetogram