

Long-Term Variations in UV and EUV Solar Spectral Irradiance

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Relevance of the Study of Solar EUV/UV Irradiance

Knowledge of the Solar UV irradiance helps us better understand:

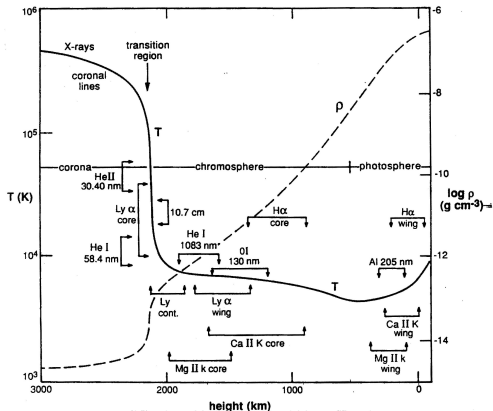
- ▶ Solar mechanisms
- ▶ Earth's atmosphere
- ▶ Earth's climate

Solar EUV/UV and Solar Atmospheric Structure

Solar EUV/UV originates in:

- ▶ corona,
- ▶ transition region,
- ▶ chromosphere, and
- ▶ upper photosphere

where much of the solar irradiance variation occurs.



From: Fox (2004).

Above the temperature minimum, surface structures limit the usefulness of this 1-D model.

Relevance to Earth's Atmosphere

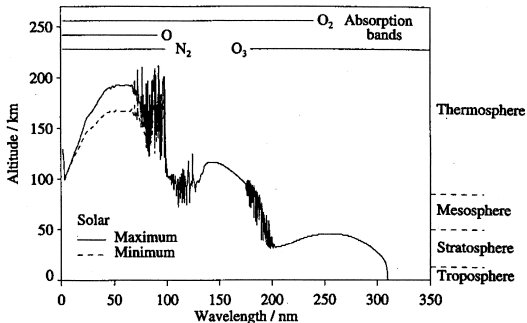
Absorption of Solar EUV/UV

Solar UV absorption drives atmospheric:

- ▶ constituent densities,
- ▶ thermal structure, and
- ▶ dynamics.

Solar UV is absorbed by:

- ▶ ozone (200–320 nm)
- ▶ molecular oxygen (140–242 nm)

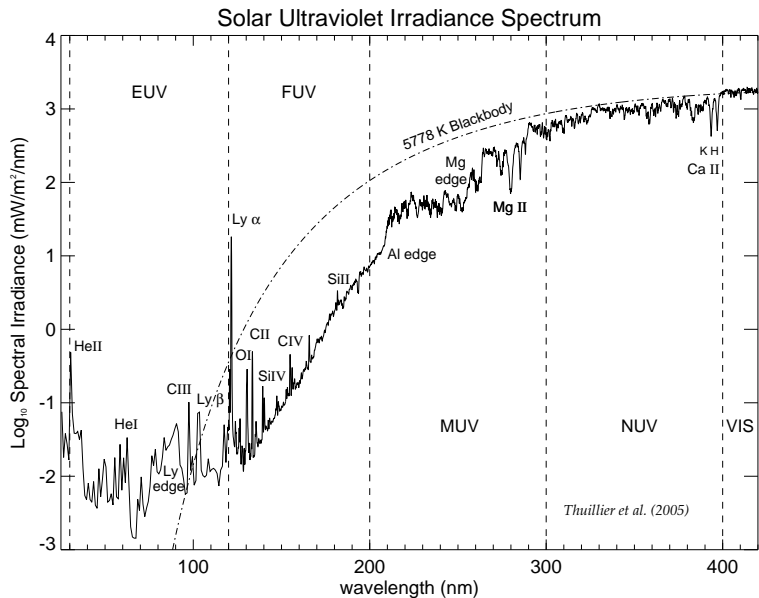


Haight, 2004

Solar UV and Earth's Climate

- ▶ Climate and weather data shows connections to solar activity, e.g. QBO, NAO, and SST.
- ▶ Models show possible solar UV connections to dynamical changes descending from the stratosphere to the troposphere.
- ▶ Cosmogenic isotopes show correlations to climate over the past two millennia, independent of Milankovich (orbital and terrestrial attitude) changes.
- ▶ Solar causal connections to climate are poorly understood. Solar UV variation is a leading candidate.

Solar UV/EUV Irradiance Spectrum



Solar EUV/UV Irradiance Spectrum

- ▶ extends from 30 nm in the EUV to the visible (400 nm)
- ▶ spans roughly 5 orders of magnitude
- ▶ contains about 8.7% of the total solar flux
- ▶ shows exponential increase in FUV to AI-edge (208 nm)
- ▶ for increasing λ , the spectrum is characterized by:
 - ▶ strong emission lines (120–181 nm)
 - ▶ absorption lines (220–400 nm)
 - ▶ line-blanketed continuum
- ▶ continuum at ~ 160 nm from solar temperature minimum

Measurements of the Solar UV/EUV Irradiance

Instrumental Responsivity Calibration

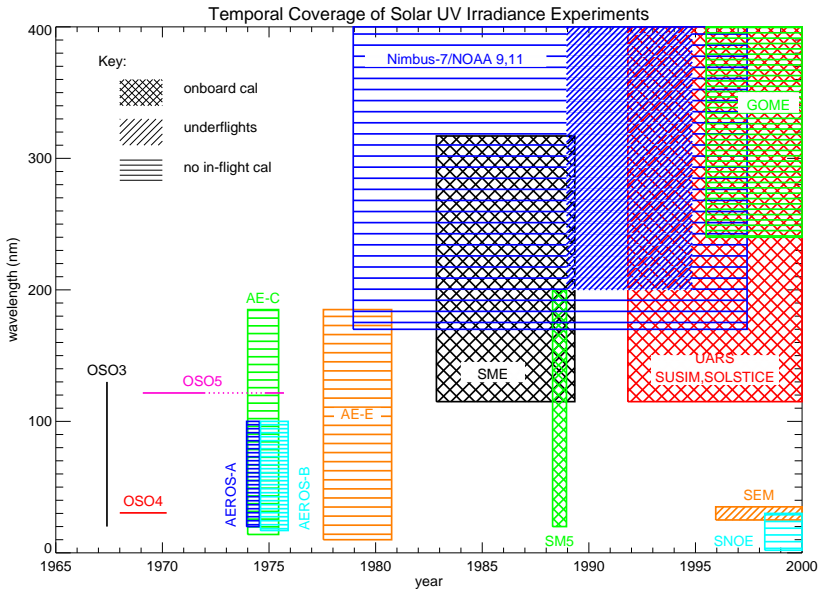
Typical source of largest uncertainty is changing instrumental responsivity.

End-to-end calibration methods utilize measurements which are:

- ▶ stellar (e.g. SOLSTICE, SORCE),
- ▶ of lamps (e.g. SUSIM, SOLSPEC/ISS),
- ▶ “vicarious” (e.g. NOAA-11/SBUV2, SEM), or
- ▶ redundant (e.g. SORCE, TIMED, SUSIM)

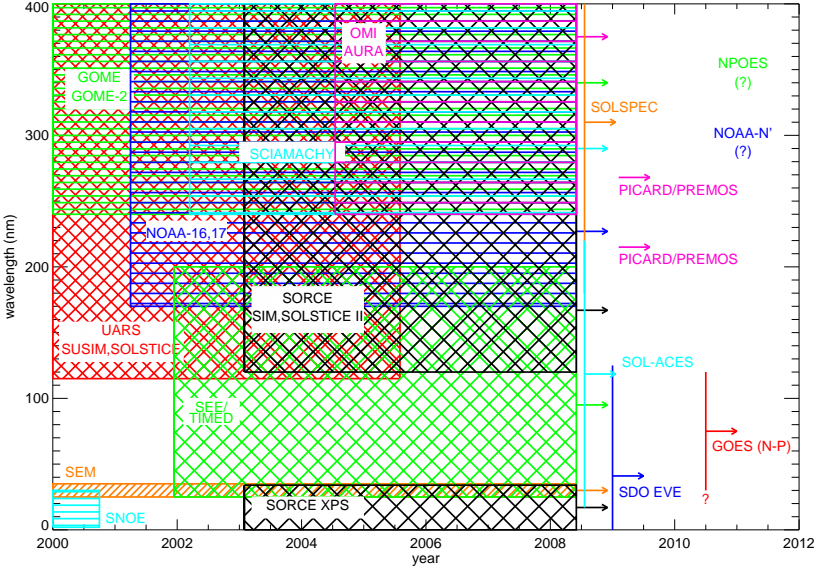
Measurements of the Solar UV Irradiance

Coverage of Past Experiments



Measurements of the Solar UV Irradiance

Coverage of Present and Future Experiments



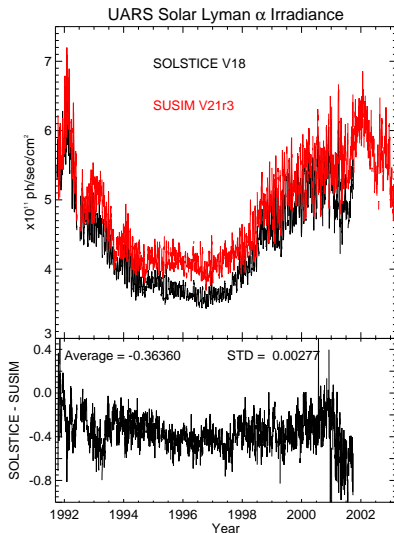
Solar UV Irradiance Experiments: Data Comparisons

Data Comparisons: Ly- α

Upper panel shows the Ly- α irradiances from **SUSIM** and SOLSTICE.

Lower panel displays their differences.

The two experiments show better relative than absolute agreement (mostly).



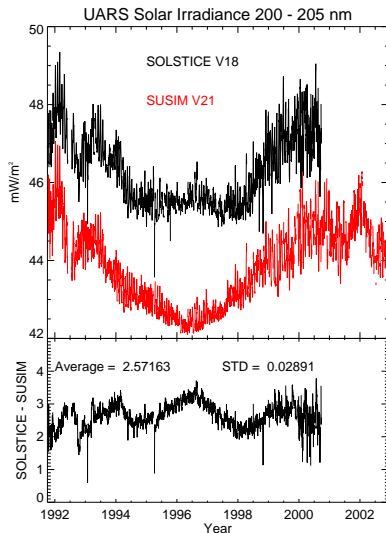
Solar UV Irradiance Experiments: Data Comparisons

Data Comparisons: 200–205 nm Integrated Irradiance

Upper panel are the 200–205 nm integrated irradiances from **SUSIM** and SOLSTICE.

Lower panel displays their differences.

The two experiments show better relative than absolute agreement (mostly).



Solar UV Irradiance Variations

Sources and spatial distribution of UV radiance

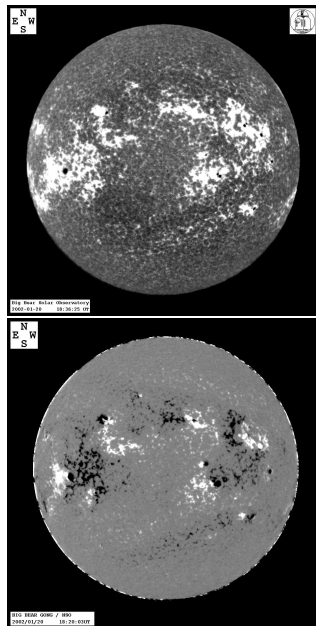
Variations in received solar UV irradiance are caused by the emergence and decay of active regions as they transit the solar disk.

Active regions contain enhanced:

- ▶ UV brightness (faculae and plages)
- ▶ localized enhanced magnetic fields

Upper right: BBSO Ca II k line brightness

Lower right: GONG Magnetogram (*Sources: BBSO*)



Solar UV Irradiance Variations

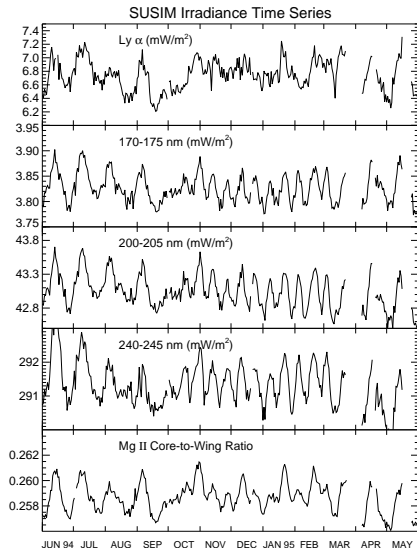
Time series characteristics

UV irradiance time series
periodicities dominated by:

- ▶ solar rotation (~ 27 day)
- ▶ solar cycle (~ 11 yr)

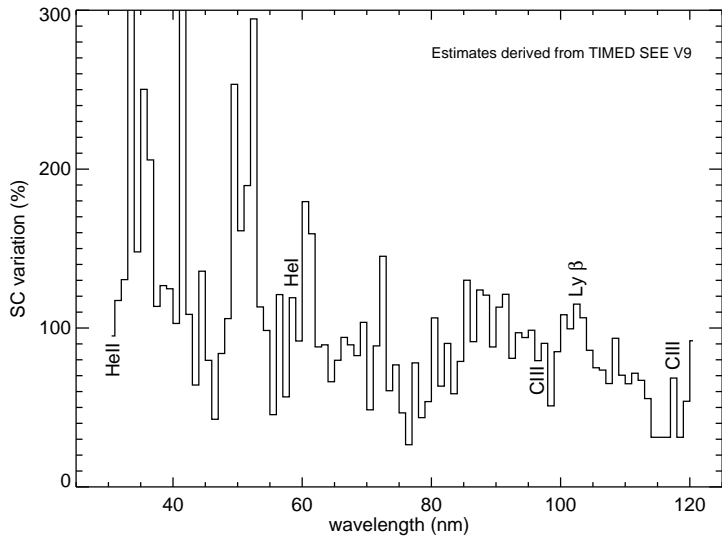
Variation at different wavelengths
are in phase.

Occasionally, the short-term
behavior can be quite different
among various wavelength ranges
(see figure).



EUV Irradiance Variation over the Solar Cycle

wavelength dependence in the EUV (30–120 nm)



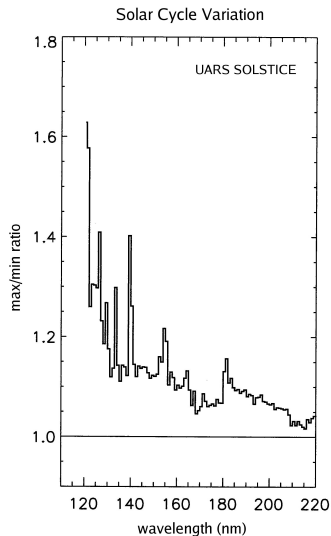
Solar UV Irradiance Variation over the Solar Cycle

wavelength dependence in the FUV (120–200 nm)

Variations shown are derived from UARS SOLSTICE; similar results have been obtained from SUSIM and NOAA-11 SBUV2.

Relative FUV irradiance variations are larger:

- ▶ for shorter wavelengths, and
- ▶ in emission lines (e.g. Ly- α , CII, SiIV, CIV, and SiII).



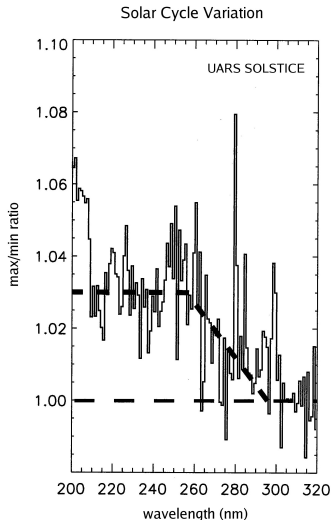
Adapted from: Rottman, Floyd, and Viereck (2004).

Solar UV Irradiance Variation over the Solar Cycle

wavelength dependence in the MUV (200–300 nm)

Relative variations are roughly constant up to about 263 nm with larger variations in absorption line cores (e.g. Mg II).

Above about 290 nm, the variation is below experimental uncertainties.



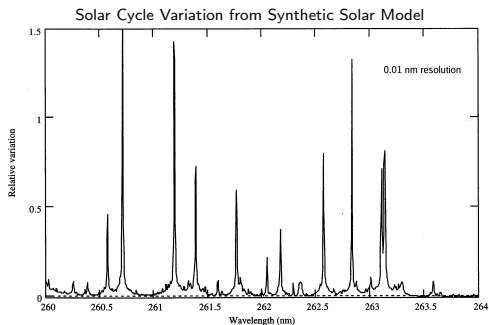
Adapted from: *Rottman, Floyd, and Viereck (2004)*.

Solar UV Irradiance Variation over the Solar Cycle

wavelength dependence in the NUV (300–400 nm)

Relative variations are:

- ▶ much stronger in absorption lines
- ▶ uncertain, but less than 1% overall
- ▶ estimates obtained through signal detection methods



From: *Fox* (2004).

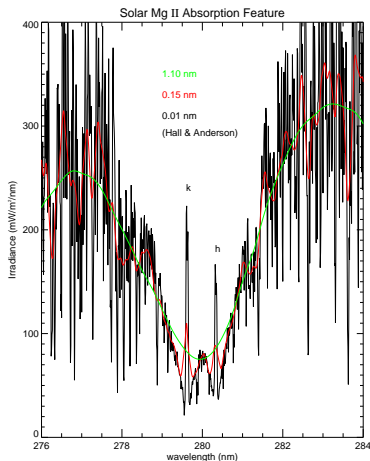
Contribution of UV Irradiance Variation

to total solar irradiance (TSI) variation

- ▶ UV energetic variation dominated by longer wavelengths
- ▶ larger relative variations below 200 nm are insignificant
- ▶ variation for 300–400 nm highly uncertain
- ▶ contribution of UV to TSI variation (0.1%) range from 17% to 60%

Solar Mg II Core-to-Wing Ratio Index

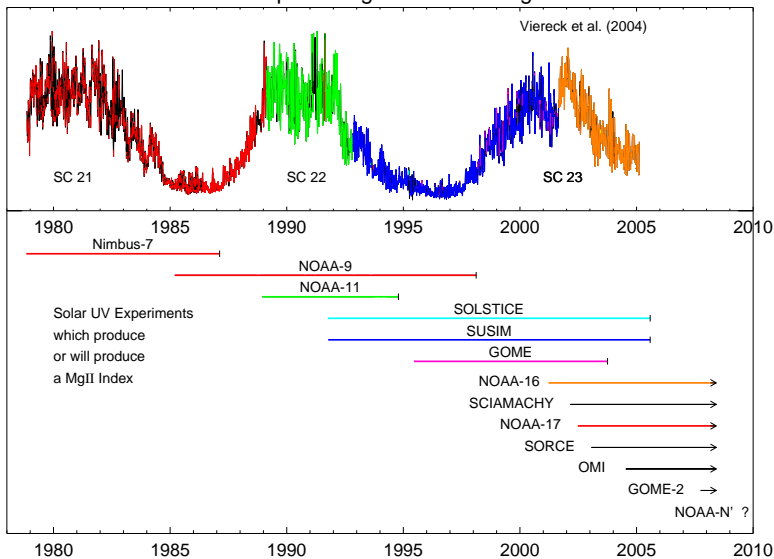
- ▶ irradiance ratio of the core of the MgII absorption feature (280 nm) and its nearby wings
- ▶ sensitive to the large solar variation in the core while effectively removing instrumental effects which vary weakly with λ
- ▶ derived from the measurements of many experiments having unique instrumental properties (e.g. resolution)
- ▶ various Mg II index series are linearly related ($r > 0.98$).



Composite Solar Mg II Core-to-Wing Ratio Index

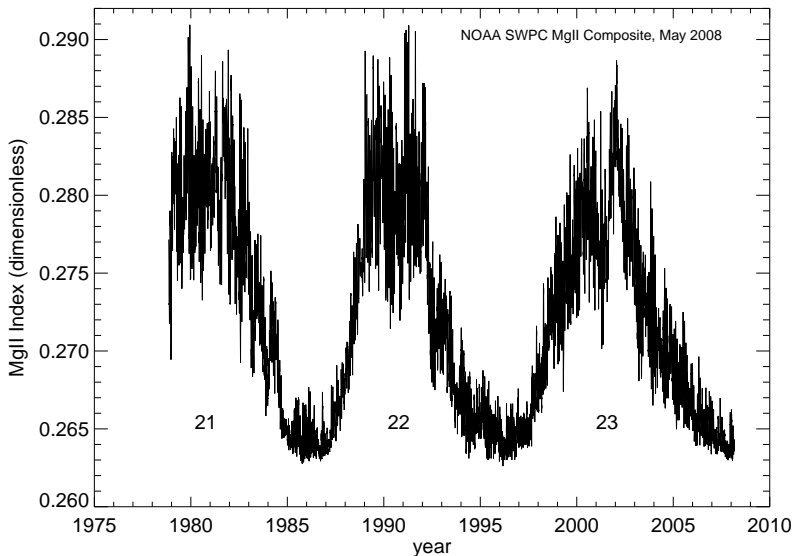
components of 2004 version

NOAA SEC Composite Mg II Core-to-Wing Ratio Index



Composite Solar Mg II Core-to-Wing Ratio Index

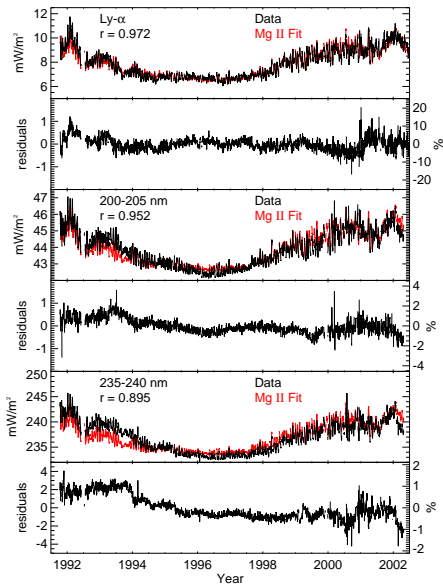
current version (2008)



Comparison of Mg II Index with UV Irradiances

SUSIM Ly- α , 200–205 nm, and 235–240 nm

- ▶ Relative long-term variations of the UV irradiance (120–290 nm) are well described by the Mg II index (within experimental uncertainties).
- ▶ Above 290 nm, *Lean et al.* (1997) report that sunspots also contribute significantly.
- ▶ Uncertainty as a fraction of the solar variation grows for increasing λ .



Solar Ultraviolet Irradiance Research

Theoretical and modeling research

Composite Mg II Index (Viereck, Weber, and others)

Composite solar UV irradiances (Snow, DeLand, and others)

Solar cycle dependence of solar UV irradiance (Floyd, Pagaran, and others)

Empirical past and predictive models of solar UV irradiance (Tobiska and others)

Semi-empirical models of solar UV irradiance (Solanki, Krivova and others; Morrill and others; Ermolli and others; Unruh and others)

Synthetic solar irradiance model (Fontenla, Kurucz and others)

Solar Ultraviolet (UV & EUV) Irradiance

Interesting Questions for Further Research

- ▶ What are the detailed mechanisms of solar UV irradiance variation?
- ▶ What is the connection between magnetic activity and UV irradiance variations?
- ▶ What is the contribution of UV variation to that of the TSI?
- ▶ How much does the solar UV vary over time periods longer than the solar activity cycle?
- ▶ What was the solar UV irradiance during the Maunder Minimum?
- ▶ How well does the Mg II index describe relative irradiance variations from the EUV to the visible?

Suggested and Planned Future Directions

for solar EUV/UV irradiance research

- ▶ Continued UV spectral irradiance measurements especially those by instruments with in-flight end-to-end calibrations
- ▶ Improvements in long-term calibration of UV instruments (e.g. SORCE)
- ▶ Imaging in the UV (e.g. Picard) perhaps from different directions with simultaneous UV irradiance measurements
- ▶ Continued and improved measurements of solar activity indices (e.g., $F_{10.7}$, Mg II, He 1083 EW, and even SSN)

Acknowledgements

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