Solar Reference Spectra and Their Use

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Introduction

- Solar irradiance is primary energy source for terrestrial system.
- Important to know absolute value and relative variations, for both integrated measurement and spectral dependence.
- Sun represents a valuable calibration source for satellite instruments:
  - Easy access
  - High intensity
  - Relatively stable compared to on-board sources
  - Many spectral features for wavelength calibration
- Some “features” also represent challenges for operational use:
  - Exposure-dependent degradation (particularly in UV)
  - Large dynamic range needed to co-exist with Earth view data
  - Natural variability in UV region
  - Complex spectral structure
- This presentation will briefly discuss some issues associated with using reference solar spectra.

Reference Spectra - Comments

- No single instrument measures all spectral regions of interest (X-ray, UV, visible, IR) simultaneously. Thus, any “reference” spectrum is likely to be a composite of measurements from multiple instruments, using different bandpasses, probably taken at different times.
- Some reference spectra are constructed using measurements from one data set, but adjusted radiometrically through comparisons with another data set.
- Differences in spectral resolution are particularly important in the UV, where many Fraunhofer lines occur. The definition of “high” resolution can depend on the requirements of the user.
- Frequent sampling in the data set may not equal high spectral resolution. Check the background story before using the data.

Reference Spectra - 1

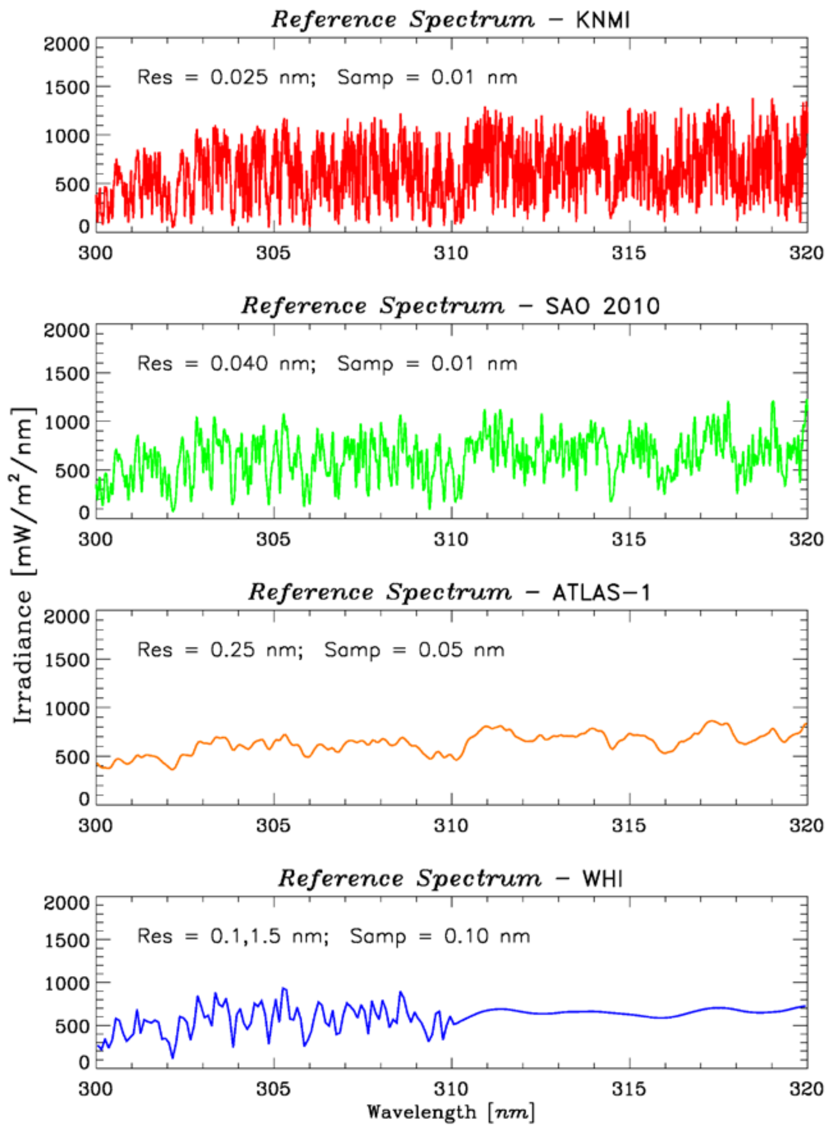
- **KNMI** [*Dobber et al.*, 2008].
  - Covers 250-550 nm.
  - *Hall and Anderson* [1991] for 200-310 nm, *Kurucz et al.* [1984] for 310-550 nm.
  - Original data have very high resolution ($\Delta\lambda$ = 0.025, 0.005 nm).
  - Convolve with 0.025 nm bandpass, sample at 0.01 nm.
  - Adjust radiometric calibration to match lower resolution reference spectrum (average of UARS SUSIM data).
- **SAO** [*Chance and Kurucz*, 2010].
  - Covers 200-1001 nm.
  - *Hall and Anderson* [1991] for 200-310 nm, *Kurucz et al.* [1984] for 310-1001 nm.
  - Convolve with 0.04 nm bandpass, sample at 0.01 nm.
  - Adjust radiometric calibration to match lower resolution reference spectrum (*Thuillier et al.*).

Reference Spectra - 2

- **ATLAS-1, ATLAS-3** [*Thuillier et al.*, 2004].
  - Covers 0.5-2400 nm.
  - Rocket data (1994) for 0.5-120 nm; UARS SUSIM and SOLSTICE for 120-200 nm; UARS SUSIM and SOLSTICE, ATLAS SUSIM, SSBUV, SOLSPEC for 200-400 nm; SOLSPEC for 400-870 nm; SOSP for 870-2400 nm.
  - UV: Smooth to 0.25 nm resolution, sample at 0.05 nm; Visible: resolution = 0.5 nm, sampling = 0.2-0.6 nm.
  - Average individual data sets together where available.
  - Each reference spectrum represents single date.
- **WHI** (Whole Heliospheric Interval) 2008 [*Woods et al.*, 2009].
  - Covers 0.1-2400 nm.
  - Rocket EVE + TIMED SEE for 0.1-120 nm; SORCE SOLSTICE for 120-310 nm; SORCE SIM for 310-2400 nm.
  - Resolution = 0.1 nm in UV, ~1.5-30 nm from near-UV to near-IR. Sampling = 0.1 nm throughout.
  - Each reference spectrum represents narrow range of dates (~1 week).
  - Reference spectra scaled to TIM TSI values.

Resolution and Sampling

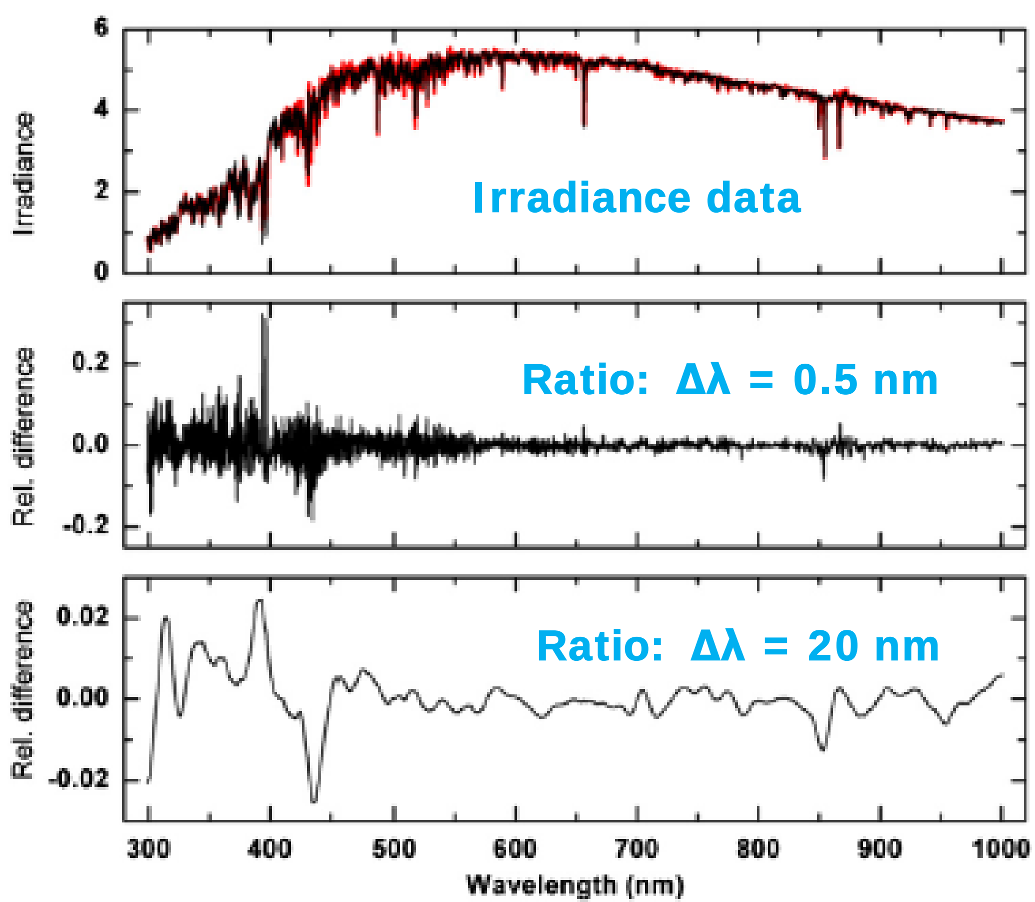
- Same spectral region (300-320 nm) and absolute scale used for all panels in this figure.
- Effect of bandpass change between KNMI and SAO is apparent, even with same input data set.
- Satellite measurements (bottom two panels) have lower resolution.
- WHI spectrum shows change in original instrument resolution when SIM data begin at 310 nm.



Absolute Difference - 1

- Comparisons at higher resolution are very sensitive to convolution method, intensity at peaks of spectral features, accuracy of wavelength scales.
- Smoothing to lower resolution necessary to evaluate radiometric differences.

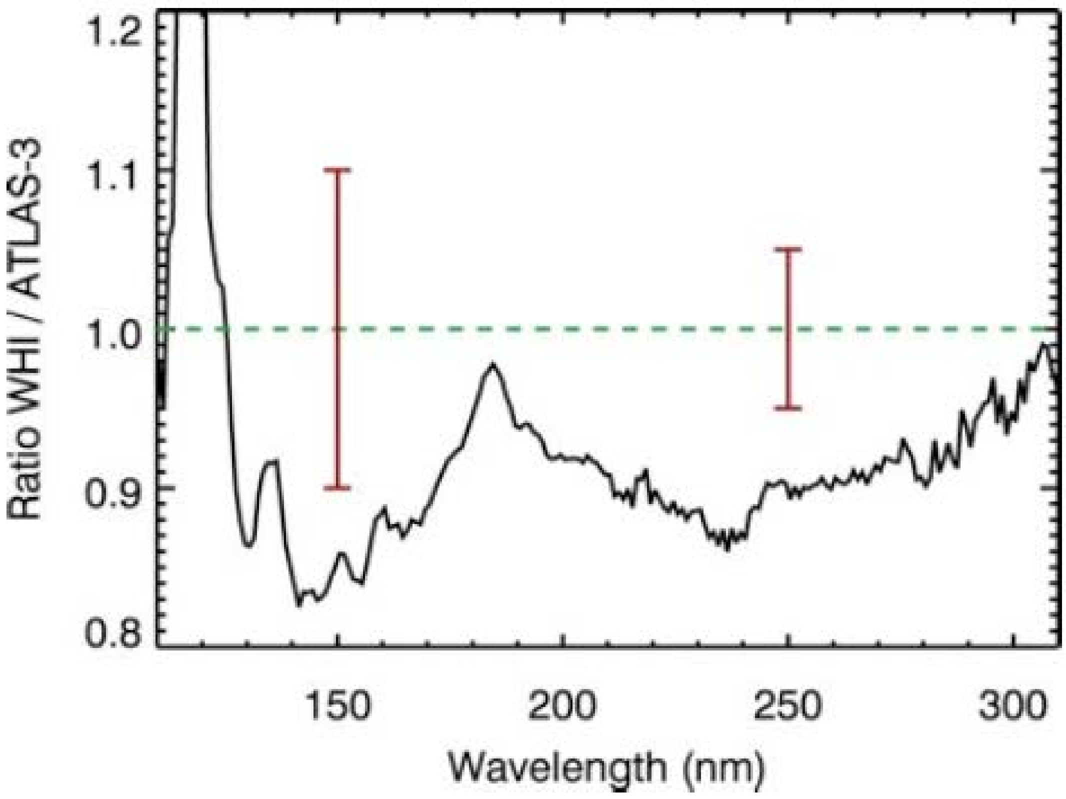
K. Chance, R.L. Kurucz / Journal of Quantitative Spectroscopy & Radiative Transfer 111 (2010) 1289–1295



Absolute Difference - 2

- Smoothing irradiance data to lower resolution necessary to evaluate radiometric differences.
- Some comparisons still show differences that exceed quoted uncertainties.

SORCE SOLSTICE vs. UARS SUSIM, SOLSTICE



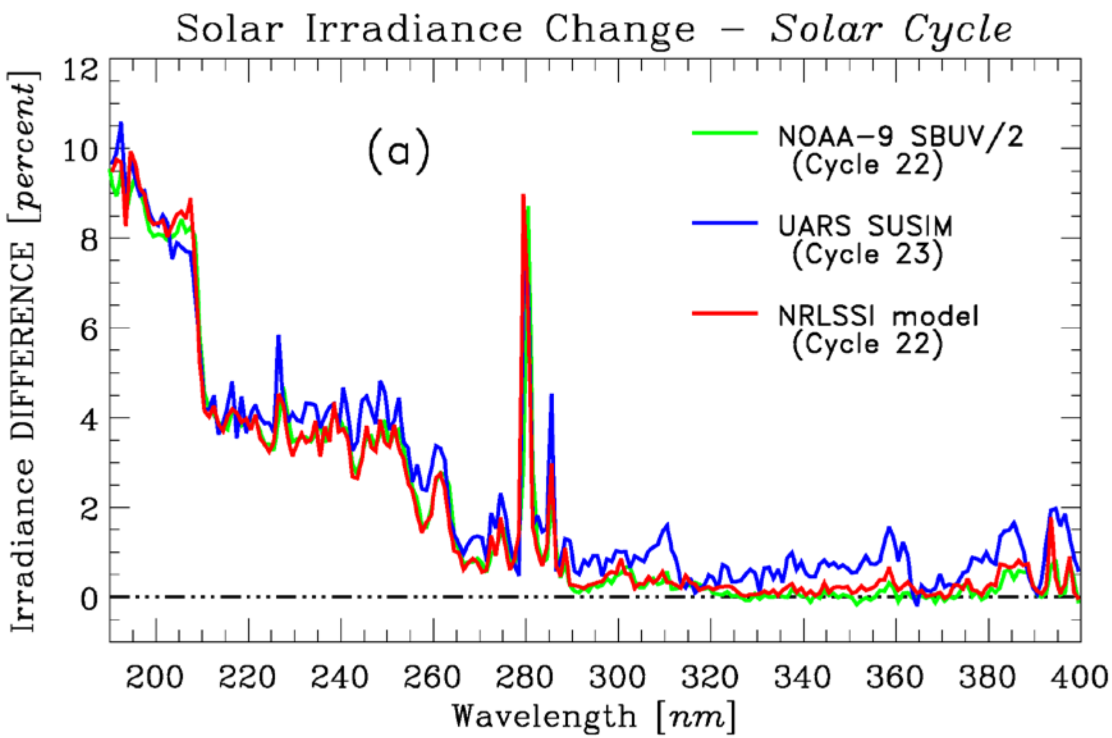
Woods et al. [2009]

Solar Activity

- Solar irradiance shortward of 300 nm varies on short-term (~27-day) and long-term (~11-year) time scales.
- Longward of 300 nm, only Fraunhofer lines show variations exceeding ~0.5% (magnitude of variability is resolution-dependent).
- Spectral dependence of solar variations appears to be very consistent for both short and long time scales.
- Therefore, we can use solar UV activity proxy (*e.g.* Mg II index) and wavelength-dependent “scaling factors” to estimate irradiance change with time.

Solar Cycle Variations

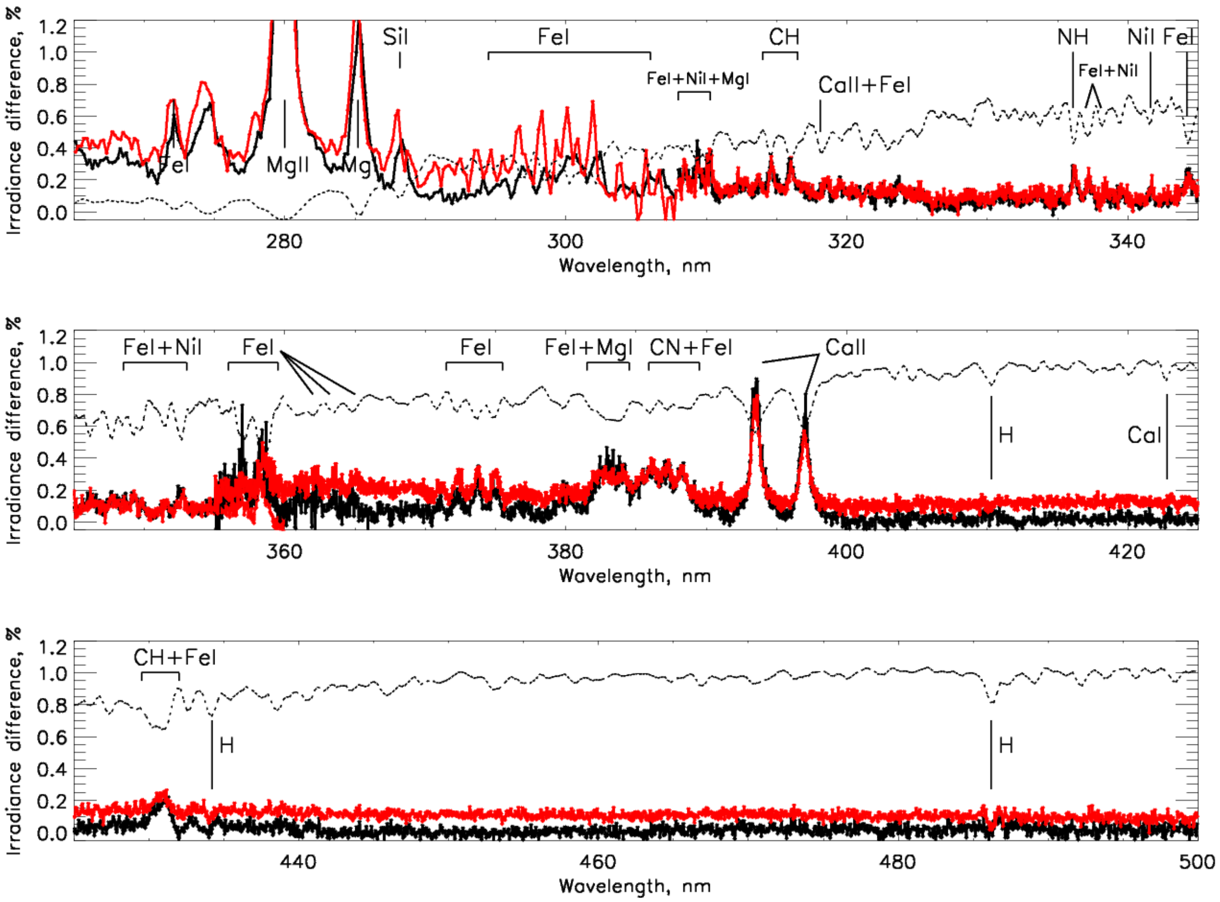
- Spectral dependence shows distinct features due to atomic species in Sun.
- Variations generally less than 1% beyond ~300 nm.
- Good agreement between data sets from two solar cycles, semi-empirical model.



DeLand and Cebula **[2012]**

Solar Variations – UV, Visible

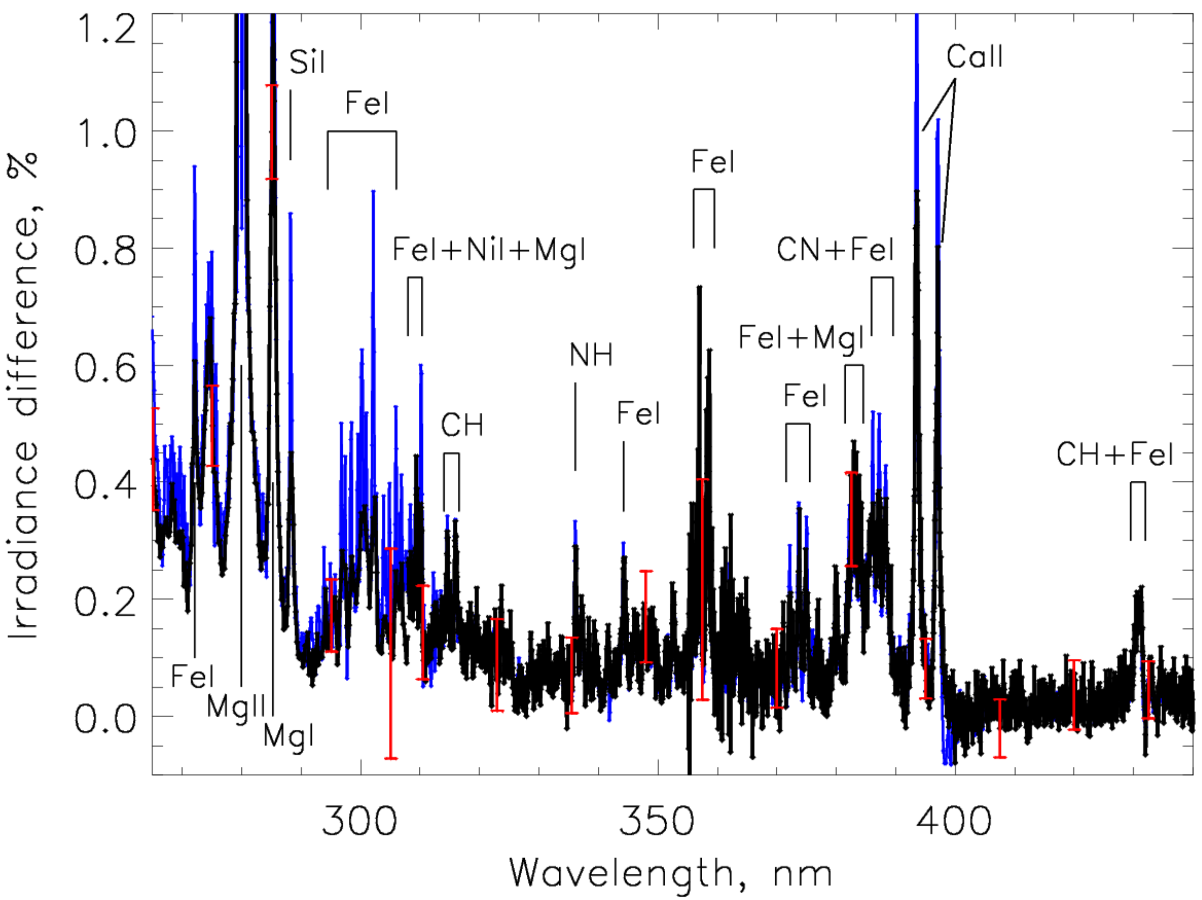
- Better OMI instrument resolution (0.4 nm) shows small features at Fraunhofer lines.
- Generally very good agreement between long-term changes (*red*) and short-term changes (*black*).



Adapted from *Marchenko and DeLand* [submitted to *Ap. J.*, 2014]

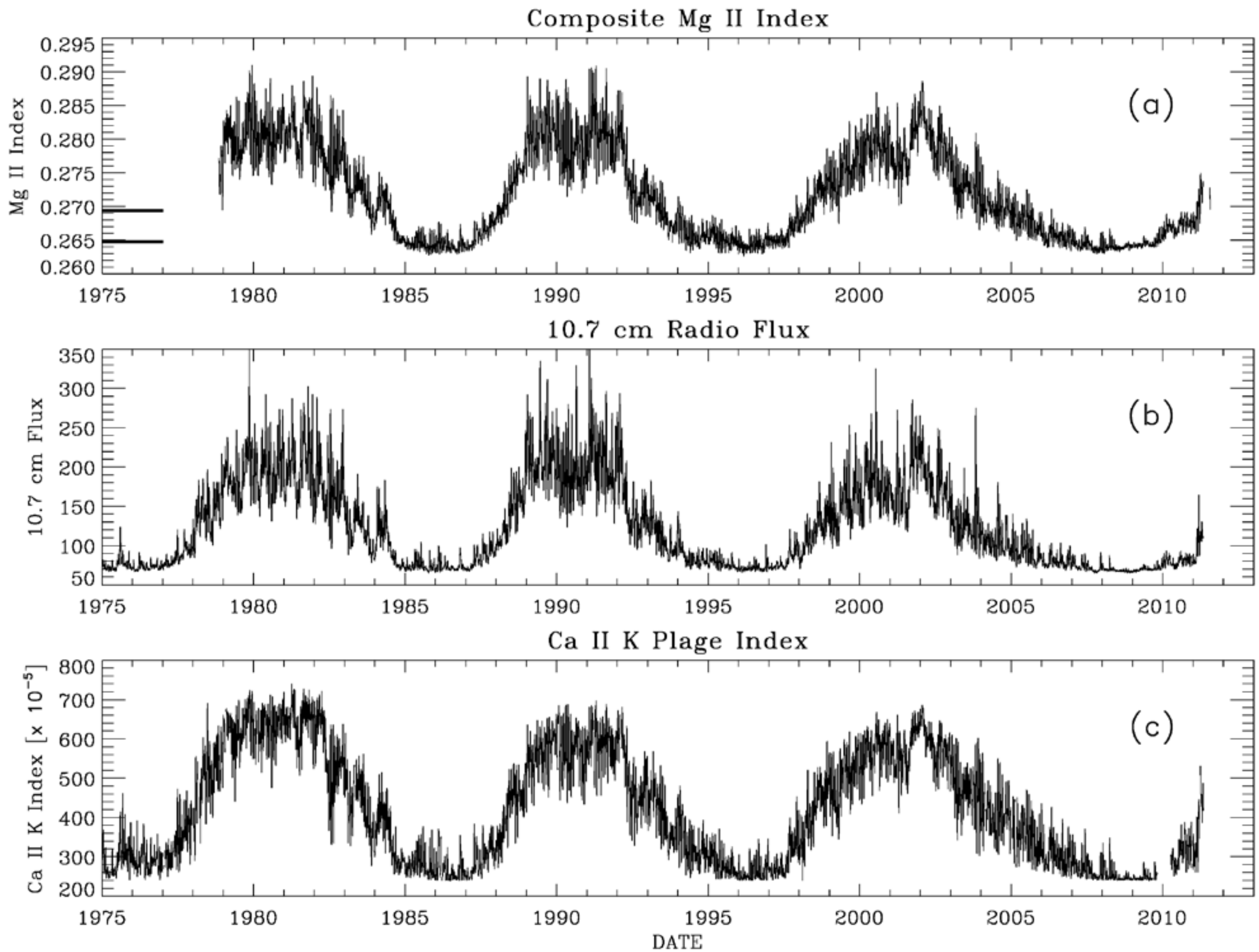
Solar Variations – Resolution

- Short-term variations during Cycle 24 calculated using same dates for both instruments.
- Larger variations observed at major lines for GOME-2 (*blue*, Δλ = 0.2 nm) than for OMI (*black*, Δλ = 0.4 nm).



Solar UV Proxy

- Numerous data sets are available, with similar overall behavior.
- Mg II index has best physical connection to UV irradiance.
- Be aware of resolution (*see next slide*).



DeLand and Cebula **[2012]**

Mg II Index - Resolution

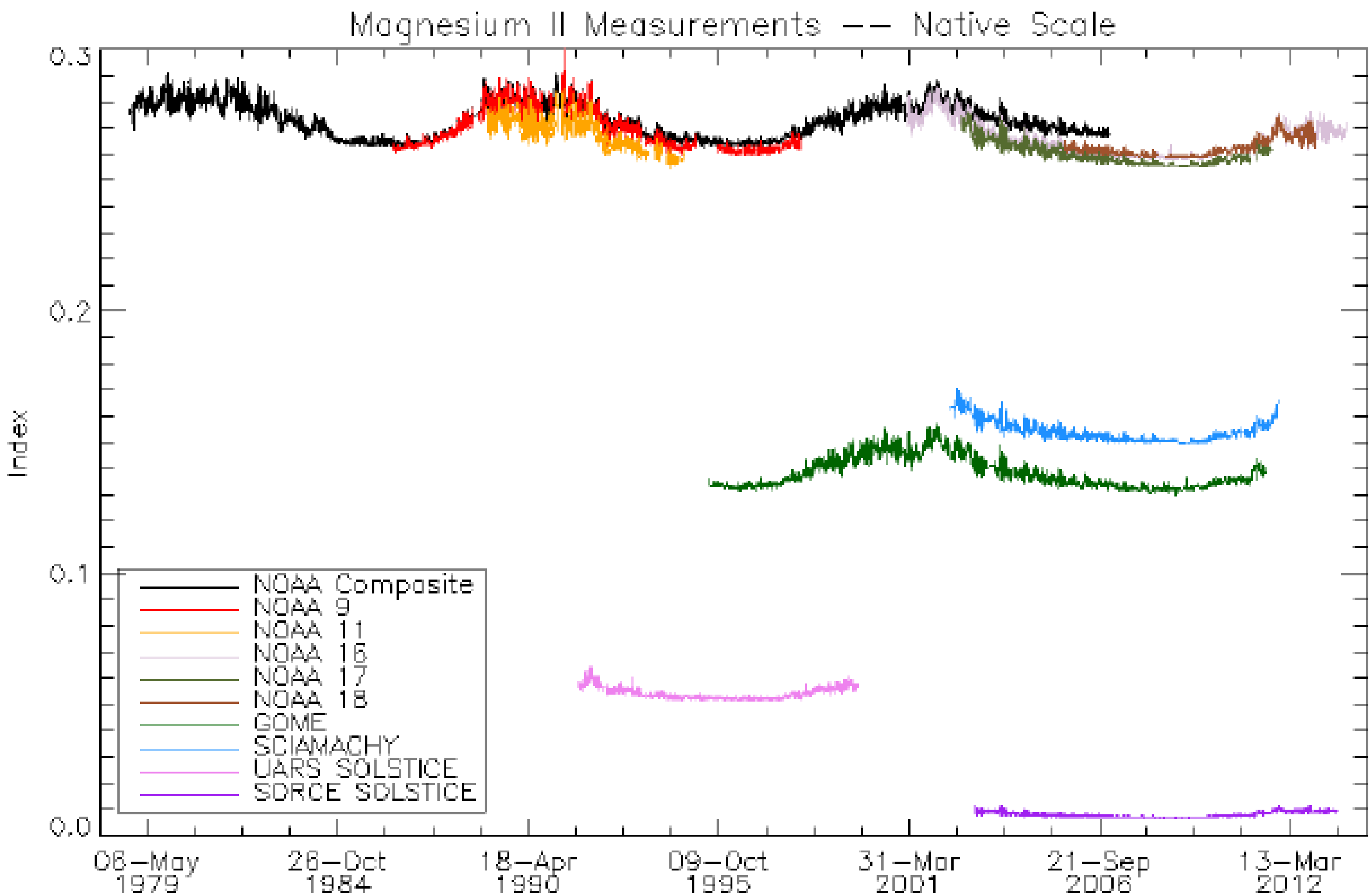
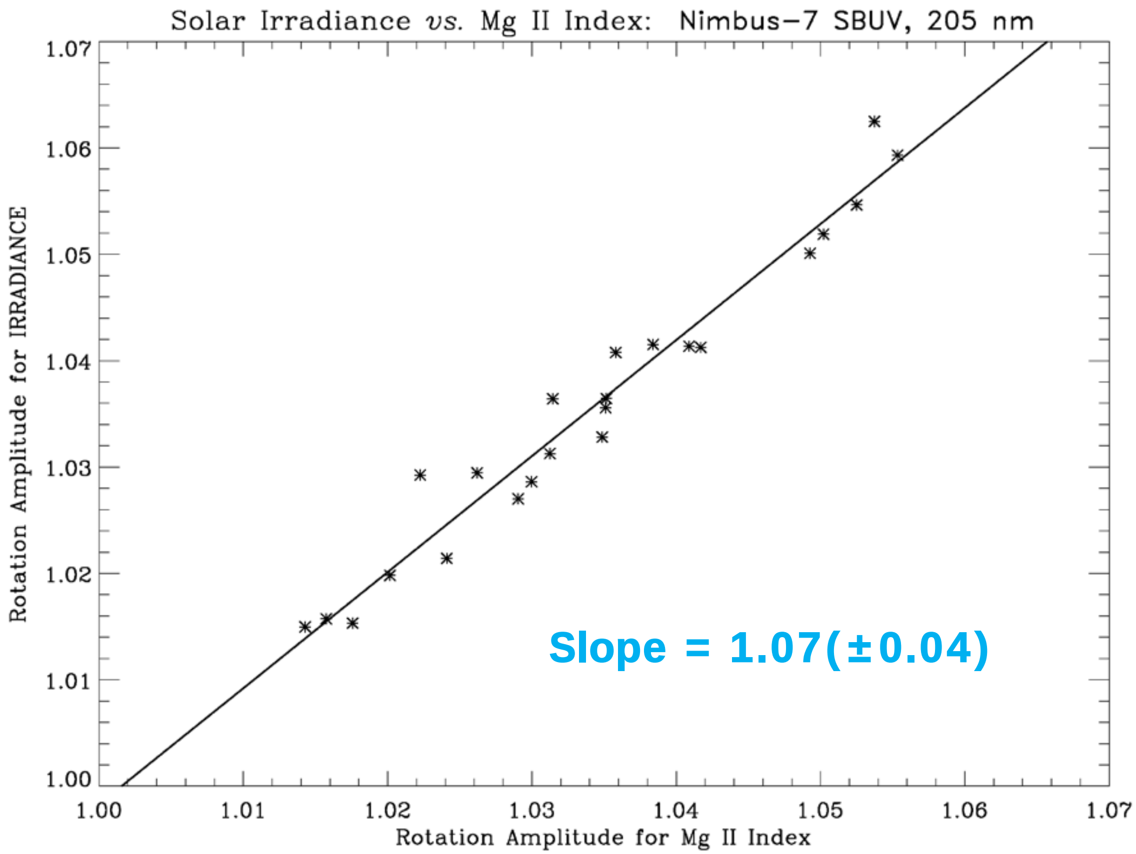


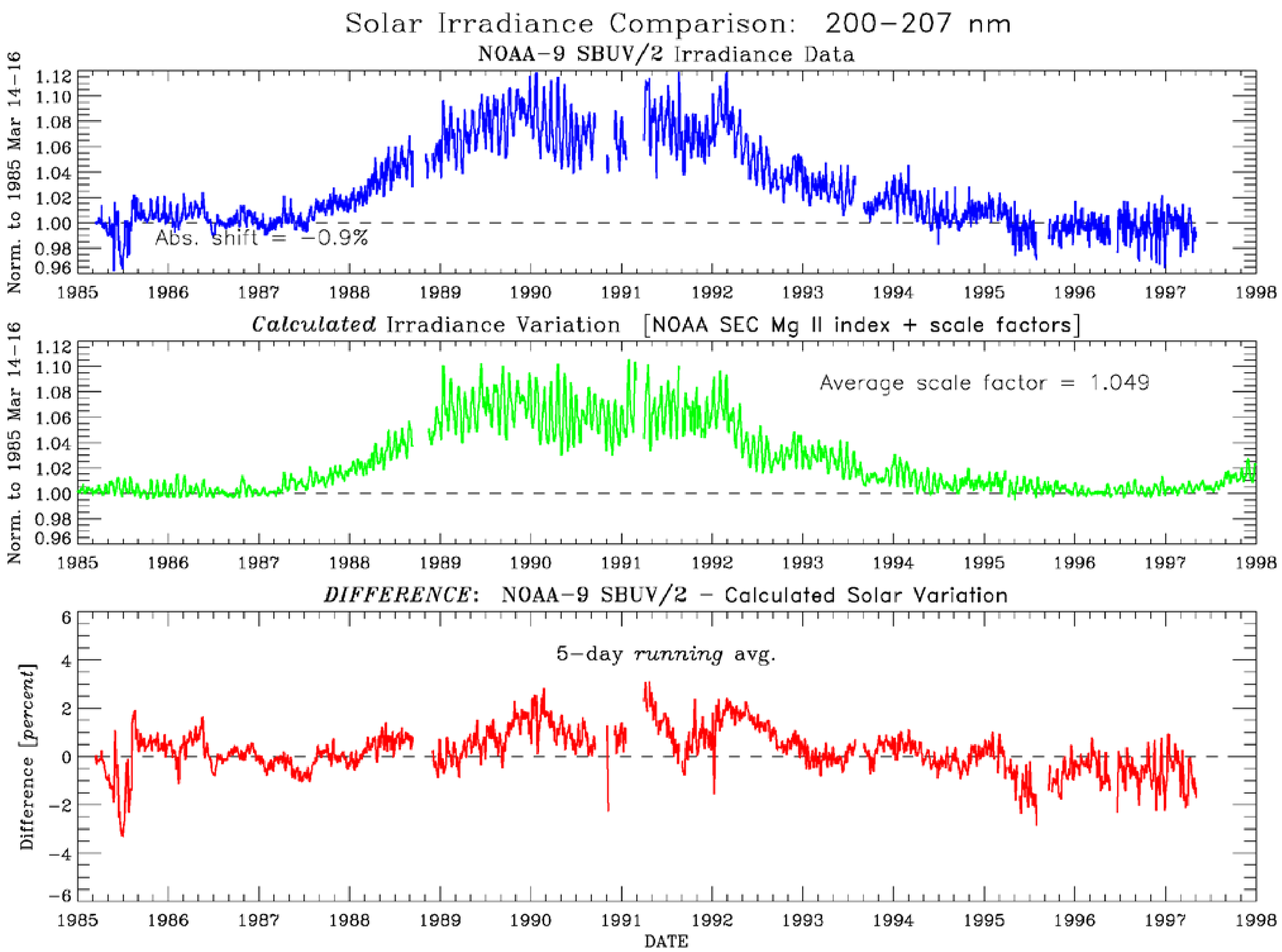
Figure courtesy of Marty Snow, 2014 SORCE Meeting

Scaling Factors

- Calculate max/min ratio for irradiance over solar rotation to minimize sensitivity change effects.
- Calculate ratio for same dates with Mg II index.
- Slope of linear regression fit gives "scaling factor". Good dynamic range is preferred.
- Value of scaling factor at any wavelength depends on instrument resolution for both irradiance and proxy.



Proxy Results



Conclusions

- Many high resolution reference solar spectra have been constructed for different purposes.
- Understanding how a reference spectrum was created helps to make it more useful.
- At wavelengths shorter than 300 nm, natural solar variations should also be considered for best results.
- Mg II proxy index can be used with (instrument-dependent) scaling factors to determine adjustments as a function of wavelength and time.

References

- Dobber, M., et al. [2008], *Solar Phys.* **249**, 281-291.
- Hall, L. A., and Anderson, G. P. [1991], *J. Geophys. Res.* **96**, 12,927-12,931.
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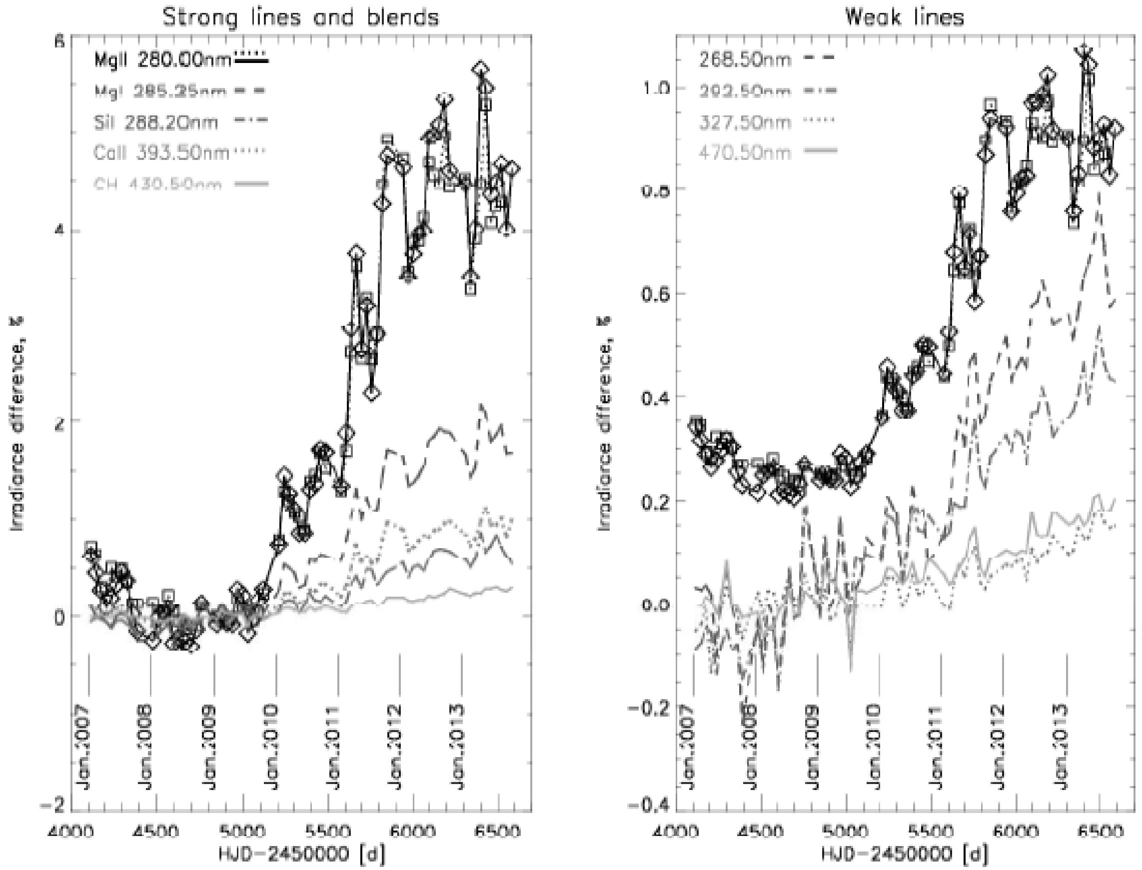
- Thuillier, G., et al. [2004], *Solar Variability and its Effects on Climate*, American Geophysical Union, p. 171-194.
- Woods, T., et al. [2009], *Geophys. Res. Lett.* **36**, L01101, doi:10.1029/2008GL036373.
- DeLand, M. T., and Cebula, R. P. [2012], *J. Atmos. Solar-Terr. Phys.* **77**, 225-234.

Backup Figures

OMI Irradiance Time Series

- Solar cycle variations derived from OMI irradiance measurements.
- Analysis benefited from location of data set in solar cycle, well-behaved instrument, hyperspectral data.
- Still required monthly averages to get useful results at longer wavelengths.



Marchenko and DeLand **[2014]**