Solar Spectral Irradiance Objectives for Improved Understanding of Atmospheric Variability

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Accurate and precise knowledge of solar spectral irradiance and its variability are critical throughout terrestrial and planetary atmospheres. This is particularly true for UV and X-ray fluxes that impact the upper atmosphere and ionosphere, but includes visible and infrared irradiance that dominate total solar irradiance, which is important for climate. **A robust ongoing observational and modeling program is needed to understand key spectral regions and how they affect the geospace environment.**

Solar extreme-ultraviolet (EUV) and X-ray irradiance creates the ionosphere, and is the dominant energy source for thermospheric heating and temperature gradients that drive its general circulation. Although geomagnetic disturbances are the dominant cause of the dramatic short-term changes that are generally considered to be “space weather” in the ionosphere-thermosphere, solar rotational and solar cycle variations set the underlying conditions and are larger in amplitude on a global basis. Solar flares also contribute to the short-term variations through ionization and heating. Farther below, far-ultraviolet and middle-ultraviolet variations impact the mesosphere and stratosphere energy balance through absorption by molecular oxygen and by ozone, and drive the complex minor-species chemical processes. Troposphere and surface climate respond more to the visible and infrared fluxes that dominate total solar irradiance (TSI), but it is necessary to characterize the spectral contributions that make up this parameter as well. Therefore, sufficiently resolved spectral observations across the entire electromagnetic spectrum range are necessary to understand the integrated planetary response to the Sun, and they need to be accurate, precise, stable over longer-than-decadal time scales, and coordinated with theoretical and modeling studies of the solar physical processes controlling photon emissions and their variation.

Considerable progress has occurred on the observational side, particularly in solar ultraviolet observations, dating back to instrumentation on UARS, ongoing measurements by the SEE and EVE instruments on TIMED and SDO, respectively, and comprehensive observations from the now-completed SORCE satellite. The Total and Spectral Solar Irradiance Sensor (TSIS) and Extreme Ultraviolet/X-ray Irradiance Sensors (EXIS) provide ongoing monitoring in key wavelength ranges. EXIS is carried on NOAA GOES spacecraft, and will provide invaluable data going forward, albeit in only a few wavelengths, including for operational programs. However, solution to outstanding issues in solar photon interactions with the Earth and planets requires NASA leadership in high-resolution, large wavelength range, high-time-cadence observations and supporting modeling. These issues, and related objectives for future studies, include:

• The spectra of flares, controlling processes for different flare characteristics, and their penetration into Earth’s atmosphere.

• The spatial distribution of active regions, and how it impacts spectral characteristics (e.g., solar center-to-limb variation).

• The level and variability of spectrally-resolved solar irradiance in the soft X-ray region of the spectrum, especially ~0.1 to ~10 nm, where observations are frequently broad-band, and the intensity changes rapidly over time and with wavelength.

• The response of the Earth's E-region ionosphere to these soft X-rays, and whether the solar fluxes are sufficient to create the observed degree of ionization.

• Contributions to ionization in threshold regions, particularly ~90 to ~100 nm, where the combination of solar spectral structure and banded atmospheric absorption cross sections create challenges for ionospheric modeling. This will require particularly high spectral resolution solar observations, and/or supporting theory to characterize the solar spectra, and could be part of the solution to the aforementioned E-region issue.

• The middle-ultraviolet variability problem has not been satisfactorily resolved, with some analyses of observations (e.g., from SORCE) indicating greater-than-expected solar cycle variability, which would impact mesosphere and stratosphere modeling, and comparisons with atmospheric observations.

• The need to move past TSI in climate models and other atmospheric models, toward spectrally-resolved solar inputs.

• The question of the stability of the solar cycle, particularly whether solar minima revert to similar levels or not, across the spectrum and with regard TSI, whether the recent weak solar cycles are indicative of progression toward a "grand minimum" similar to the Maunder minimum circa 1700, and whether grand minima have solar spectra similar to typical solar minima, or can reach lower level of irradiance.

On the terrestrial and planetary side, models and analyses need to be able to effectively employ these potential data. Key areas include:

• Solar cycle amplitude in the thermosphere-ionosphere is supposedly well-known, but it is quite variable, and may be evolving in response to anthropogenic forcing of the atmospheric system.

• The aforementioned E-region problem, and whether it is really an atmosphere/modeling issue or does pertain to solar spectral uncertainties, particularly in the soft X-rays, but not to exclude consideration of the H Lyman-beta line at 102.6 nm.

• Neutral density variations and their effect on drag-induced changes in orbits. This could be potentially important due to recent increases and planned increases in large constellations of small satellites for communications, imaging, and other possible applications.

• Ionosphere-thermosphere models need to be able to incorporate high-resolution SSI, or adopt accurate parameterizations.

On the solar modeling side, first-principles models of solar magneto-hydrodynamic processes need to be able to specify irradiance as well as morphology, and evolve toward self-consistent descriptions of the solar cycle. This is an ambitious undertaking, but the key point here is that including spectral irradiance capability in model development activities is important for goals that relate to solar-terrestrial interactions.

The following is our 30-year vision for the solar irradiance measurements needed to address those issues / objectives:

Years 1-5: Continued program of full-disk SSI and TSI observations, and development of high-spectral-resolution solar irradiance instrumentation. Support for development of solar spectral models, and whole-atmosphere general circulation models that employ latest and most realistic solar information. Planning for long-term stability of the observational capability.

Years 6-10: Development of imaging capability for solar spectral irradiance, including flare spectra, and progress in the critical ~0.1 to ~10 nm soft X-ray region. Ongoing support for the full-disk observational program.

Years 11-20: Deployment of next-generation solar irradiance instrumentation to cover the entire spectrum, including high-spectral resolution capability where required, and imaging capability where needed (e.g., in the EUV and X-rays for active regions and flares).

Years 21-30: Ongoing analysis efforts to inter-calibrate instruments, especially with regard to time-dependent behavior, to reconcile SSI and TSI measurements, and to support the combined utilization of imaging and full-disk observations. Continued development of observational capability. Long-term support of the TSI record.