Continuing the Total and Spectral Solar Irradiance Data Record: Response to the National Academy of Science Decadal 2017-2027 Decadal Survey for Earth Science and Applications from Space

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1. Background

Radiative energy from the Sun establishes the basic climate of the Earth's surface and atmosphere and defines the terrestrial environment that supports all life on the planet. Solar radiation, nearly four orders of magnitude larger than all other external sources of energy, fuels atmospheric dynamics and chemistry along with photosynthetic processes in the biosphere, and drives interactions among the atmosphere, oceans, ice, and land. External solar variability on a wide range of scales ubiquitously affects the Earth system, and combines with internal forcings, including anthropogenic changes in greenhouse gases and aerosols, and natural modes such as ENSO, and volcanic forcing, to define past, present, and future climates. Understanding these effects requires continuous measurements of total and spectrally resolved solar irradiance that meet the stringent requirements of climate-quality accuracy and stability over time.

The current uninterrupted 37-year total solar irradiance (TSI) climate data record is the result of several overlapping instruments flown on different missions. This record clearly exhibits variability over the 11-year solar cycle and on shorter time scales. (Note that the current solar cycle 24 exhibits the lowest level of solar activity since the start of the satellite era.) Measurement continuity, required to link successive instruments to the existing data record to discern long-term trends despite calibration offsets between instruments, makes this important climate data record susceptible to loss in the event of a gap in measurements. While improvements in future instrument accuracy may reduce the risk of a gap, a timely 2017 launch of TSIS-1 to the International Space Station (ISS) followed by TSIS-2 in 2022 will ensure continuity of the solar irradiance record well into the next decade.

A newer record of solar spectral irradiance (SSI) commenced with the launch of the Solar Radiation and Climate Experiment (SORCE) in 2003. The measurement of SSI is fundamental to interpreting how the atmosphere responds solar variability, identifying the physical mechanisms of response, and validating climate model sensitivity to spectrally varying solar forcing. These data also provide a basis for improving proxy-derived solar spectral models, which can be used to simulate past climate states and validate hypotheses on past and future climate change.

2. Key Challenges for Earth System Science

At the core of the objectives that define the requirements for continued measurements of solar irradiance from space are these questions from the *NASA Science Mission Directorate Science Plan* [2014]:

> *How is the global Earth system changing?*
> *What are the sources of change in the Earth system and their magnitudes and trends?*
> *How will the Earth system change in the future?*

Answering these questions relies on a climate observing system capable of unambiguously distinguishing long-term trends from internal variability and attributing the causes to their underlying physical mechanisms [*Wielicki et al.*, 2013]. Solar irradiance is one cornerstone of such an observing system, providing the only source of external energy that is balanced, or not, at the outer boundaries of the atmosphere by reflected solar radiation and Earth's emission.

One of the greatest challenges to the continuity of the solar irradiance record is the same one facing all other space-based observations: how does the nation prioritize its investments in Earth Science space assets? In particular, climate change monitoring that relies on sustained and highly accurate and stable measurements over long periods of time must be balanced with other programmatic goals within NASA and other agencies – this was the theme of the recently published National Research Council (NRC) Report on *Continuity of NASA Earth Observations from Space: A Value Framework* [2015]. The value-based decision approach recommended in that report provides the basis for meeting the challenge of maintaining continuity of the solar irradiance data record and is covered in the following sections.

2.1 Existing and Planned Capabilities and New Investments

The current implementations for solar irradiance monitoring will secure the near-term data record if they proceed as planned. SORCE, launched in 2003 to measure TSI and SSI, is now in its seventh year of extended mission with an ailing battery that limits it to it to a daytime-only operations mode. In the event that SORCE should fail before TSIS-1 launches in 2017, the Joint Polar Satellite System (JPSS) deployed the TSI Calibration Transfer Experiment (TCTE) in 2013 to connect the SORCE and TSIS TSI calibration scales; NOAA has extended TCTE, originally a one-year mission, to December 2017 in order to overlap with TSIS [*Woods et al*., 2014]. The impact of a gap in the TSI record has been studied and quantified in two separate studies [*Kopp and Lean*, 2011; 2013] and the implementation of TCTE was recommended in the NRC *Report on Evaluating NOAA's plan to Mitigate the Loss of Total Solar Irradiance Measurements from Space* [2013]. These studies provided quantifiable metrics that can help assess both the quality and relative value of solar irradiance measurements as recommended in the recent NRC report *Continuity of NASA Earth Observations* [2015].

The next leg of the solar irradiance measurement record will follow the five-year TSIS-1in the 2022 time frame. In FY2016 TSIS will be transferred from NOAA to NASA and plans for the follow-on mission, TSIS-2, will commence. Considering that the ISS is currently extended to operate only through 2024, now is the time for developing and investing in the framework that ensures solar irradiance data continuity well into the future while meeting the challenges that NASA faces within its Earth-observing portfolio.

New and highly capable small spacecraft bus designs, the roll out of small low-cost launch vehicles, and a 25-year plan to provide continuous and overlapping TSI and SSI data records are all components of a low risk/high reliability implementation plan with lower annual cost than past concepts. Such a model also adheres to the recommendations in *Earth Science and Applications from Space: A Midterm Assessment of National Imperatives for the Next Decade and Beyond* [*NRC*, 2012] for new, highly flexible observing and implementation strategies for observing the Earth system. ***We recommend that this small satellite approach for solar irradiance data continuity be given high priority in the new Decadal Survey.***

2.2 Links to Other Observations

Solar irradiance continuity is fundamental to assessing Earth's radiative energy budget and therefore, is directly linked to the current Clouds and the Earth's Radiant Energy System (CERES) and future Radiation Budget Instrument (RBI) measurements of outgoing Earth radiation from space. Moreover, surface monitoring networks and airborne science missions that monitor the surface and in situ energy budgets, respectively, provide the necessary connections to the incoming solar energy. High accuracy solar irradiance measurements will also provide on-orbit calibration of Earth-viewing climate sensors as well as SI-traceability for inter-calibration of a host of other sensors as described in *Wielicki et al.* [2013] and *Lukashin et al.* [2015].

2.3 Scientific and Societal Benefits

Quantifying the relative contributions to climate change requires accurate knowledge of all of the terms in Earth's energy budget, of which the Sun is the overwhelmingly dominant source. In a 2005 congressional briefing on recent climate change, University of Massachusetts Professor Raymond Bradley stated that trying to understand the Earth's climate without measuring the Sun's output is *"... like trying to balance your checkbook when you don't know what your income is - it's very hard to do*."

Because of its inherent value to climate science, the continued monitoring of solar irradiance will help guide policy decisions in the response, mitigation, and adaptation to climate change. When data are not available or lack the required accuracy and stability, confusion and misinformation abound. Claims about the Sun's role in the past century's observed climate anomalies without the data to back them up obstruct the scientific process and muddy the waters in establishing the role of humans in climate change.

2.4 Science Communities Involved

Fundamental objectives related to solar irradiance monitoring extend to a broad science community that includes studies on Earth energy budget, process-oriented remote sensing applications, climate and atmospheric modeling, and atmospheric composition. Note that because most General Circulation Models (GCMs) and weather models now extend from the surface to 80 km or higher, solar spectral irradiance is now an essential input – the evidence clearly demonstrates that having a proper stratosphere improves terrestrial forecasts. Long-term solar irradiance monitoring is also relevant to heliophysics research and space weather operations [*Denig et al*., 2015].

3. Timeliness of Addressing the Challenges

There are both scientific and programmatic motivations for addressing the challenges of maintaining the solar irradiance data record over the coming decade. The science rests on well-founded requirements of establishing a trusted climate observing network that can monitor trends in fundamental climate variables – is this case, the energy available for the entire Earth system. Programmatically, the continuous and long-term monitoring of solar irradiance must be balanced within the broader goals of NASA Earth Science. ***New concepts for a low-risk, cost efficient observing strategy to maintain the solar irradiance record for decades to come should be a priority in the new Decadal Survey.***

4. The Need for Space-based Observations

The requirements for a climate-quality data record of solar irradiance prohibit the measurements from anywhere but space. Corrections for atmospheric extinction from high altitude observatories and even from aircraft and balloon measurements far exceed baseline requirements for TSIS accuracy and stability. The continuous monitoring achievable only from space also mitigates sampling anomalies and helps separate solar trends from instrument degradation.

References

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