**Second Year Progress Report 1, *Developing a Climate Data Record for Total and Spectral Solar Irradiance***
**NOAA Award Number NA09NES4400016**
**National Environmental Satellite Data and Information Service Program Office (NESDISPO)**
**Reporting Period: 08/01/2010 - 01/31/2011**
**Principal Investigator: Peter Pilewskie, Laboratory for Atmospheric and Space Physics, University of Colorado**

During this reporting period funding commenced for our collaborators from the Naval Research Laboratory (NRL) and from the National Institute of Standards and Technology (NIST). It was reported in the previous report that we will simply slide our schedule by one year to account for these delays.

Although it occurred just beyond the end of this reporting period (but, obviously, in time for this report), a major achievement was the completion of our first CDR Community Workshop, 23-24 February, 2011. At this meeting we discussed some of the broad goals, objectives, and tasks for the Solar Irradiance CDR Project, but we maintained a single focus for the workshop: defining the requirement for total solar and solar spectral irradiance. The motivation for this of topic were twofold: 1) there has been considerable activity over the past decade in defining and refining solar irradiance requirements, for a variety of reasons, but in part due to the transit from "research to operation", from NASA missions (SORCE and Glory) to the future joint NOAA/NASA JPSS mission TSIS. Along the way, the sources of justification and interpretation of original NPOESS IORD EDRs to the current existing requirements became blurred. The opportunity presented itself to address these issues among the multidisciplinary members of the Solar Irradiance CDR Development Team, other scientists at LASP (where the workshop was help), and members of the Boulder Sun-Climate community.

Participants included Judith Lean (NRL), Joe Rice and Allan Smith (NIST), Bob Cahalan (NASA GSFC), Bill Denig and Rodney Viereck (NOAA), Rolando Garcia, Dan Marsh, and Anne Smith (NCAR), and Peter Pilewskie, Erik Richard, Jerry Harder, Odele Coddington, Chris Pankratz, Doug Lindholm, Aimee Merkel, Juan Fontenla, and Marty Snow (LASP).

<u>Presentations and Summary Discussions</u>

Peter Pilewskie provided the opening presentation, outlining the general objectives of the workshop and the broader goals of the Solar Irradiance CDR Development team. He stated that the primary focus was to derive, refine, and justify what measurement requirements (with greatest attention given to accuracy, stability, and precision) are needed to create a solar irradiance climate data record. The role of the CDR Team, composed of experts in calibration, characterization, algorithm development and science data processing, and irradiance composites and variability modeling is to insure data stewardship of total and spectral irradiance CDR (numerous tasks associated with this) and to serve as TSIS science advisory board. Ultimately, the team will provides data sets, source codes, and documentation for the user community which includes scientists, students, policy-makers, societal applications.

Jeff Privette, the Acting Manager for the CDR Project, presented "The Evolving Research to Operations Process for NOAA's Satellite Climate Data Records." He emphasized that the goal of the project is long-term information preservation through the generation CDRs, a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change. He revisited the Maturity Matrix which is becoming accepted internationally as a standard for defining CDR maturity and trending toward operational missions.  He discussed the two-phase model for bringing a CDR into NOAA operations.

Rodney Viereck presented a detailed history of the NPOESS-JPSS Solar Irradiance Requirements. Part of the reason behind recent changes reflects NASA-NOAA differences between research and operations focused.  In the IORD 1 solar irradiance was added to the NPOESS program and SSI had only 2 bands. In the IORD 2 SSI reflected the full spectral capabilities of current sensors.  Requirements were based more on capabilities. The current interpretation is to make the requirements defensible, and not what is based primarily on capabilities. The new JPSS requirements for TSIS reflect this; the current TSIS design meets all JPSS threshold requirements.

Peter Pilewskie filled in for Greg Kopp to present science justifications for TSI Requirements. Based on our understanding of Maunder Minimum TSI changes we desire to resolve a change on the order of 0.1% change over 100 years.  This pushes the limit of stability (0.001%/year) of most current sensors. However, as Greg Kopp has demonstrated in papers and presentations, improved accuracy decreases time-to-detection and thus enhances the quality of the TSI CDR. With TIM on Glory and TSIS Tim detecting a Maunder-like trend could be as short as ten years, in the absence of natural variability.

Judith Lean discussed the Science Justification for SSI Requirements.  She showed that ENSO, volcanic aerosols, solar forcing, and anthropogenic effects can be combined in a model to account for most of the surface temperature trend (correlation coefficient = 0.92). She presented SSI composites from UARS SOLSTICE and SUSIM and TIMED SEE, SORCE SOSICE and SIM in the spectral bands from 150-170 nm,  230-250 nm, and 300-350 nm, showing varying levels of agreement among the data.  There was additional discussion about current SIM observations and how they differ from spectral models. She presented the general steps in the Lean NRL spectral model, showing high fidelity with observations on rotational timescales by divergence beyond that. This is an active area of work within the SORCE and TSIS teams to validate and quantify uncertainties in SIM.

Bob Cahalan presented a second talk on Science Justification for SSI Requirements. He explained that estimates related to energy balance continue to evolve. The underlying spectral dependence in those estimate often not often understood. SSI variability is only part of the story; relative phase between varying spectral bands is important, as is suggested by current source SIM observations.  The bulk of the energy deposited in the atmosphere at UV wavelengths is dominated by the 300-400 nm band, a historically “under-observed” band . He reviewed some of the climate model simulations using SIM spectral variability.

Jerry Harder gave a “WACCM Perspective” on SSI-Climate connections showing sensitivity studies on the response of solar spectral variability in WACCM. He posed the questions: Can requirements be set?  How do we ‘sanctify’ the absolute calibration of SSI? He recommended a study on source based (synchrotron or blackbody sources) versus detector based (using SIRCUS laser sources) calibrations, and a demonstration of reciprocity between the two methods.  Currently there is no standard method of on-orbit calibration validation; perhaps a combination of the two methods is required. Instrument design has to explicitly allow for sensitivity corrections; you cannot assume anything about how the instrument will degrade. Recommendations: NIST involvement is critical; degradation correction will continue to evolve and should be documented; advanced physics-based modeling must accompany the measurements.

Erik Richard spoke about current SSI instrument Capabilities, Calibration, and a SIMRF update. He listed three steps to establish the response of a flight instrument relative to SI units:

1. Transfer calibration from known “standard” (i.e. flight underpass)
2. Measure instrument response against an irradiance standard
3. Validate instrument characterization via an absolute standard by characterizing each term in the measurement equation.

Changes in SIM for SORCE to TSIS represent “lessons learned.” Prism degradation will be reduced through ultra-clean optics. Improvements in the noise characteristics of ESR and photodiodes and pre-launch accuracy will be achieved. The largest contributors to the SIM error budget are prism transmission, instrument function area, and ESR efficiency.

Joe Rice gave a presentation on TSIS SSI Calibration, listing new spectral radiance/irradiance activities at NIST:
1. SIRCUS-type tunable lasers, now on loan to LASP.
2. Absolute Spectrally-Tunable Detector-Based Source. This could replace some lamp-illuminated integrating sphere applications.
3. Hyperspectral Image Projector (HIP): A dispersed super-continuum white-light laser source is used to simulate spectral image cubes at 2 nm resolution.

Joe also presented slides on Cryogenic electrical substitution radiometry and how this was used to develop the TRF (TSI cal/val) and now SIMRF (SSI cal/val).

Odele Coddington discussed the approach of the TSIS ATBD, how to “merge” CDR requirements within it, and presented a schedule and milestones. It was decided a second ATBD to describe the process by which a composite record is made will be required for the CDR Project but will almost certainly be an independent document from the TSIS ATBD. The TSIS ATBD will discuss the need for composite record and a continuous satellite record, laying the groundwork for a future foundation of irradiance measurements.

Chris Pankratz described the solar irradiance science data processing procedures and plans by first listing the SORCE TIM and SIM data system. LASP is responsible for processing, managing, analyzing, distributing, and reprocessing the science data products. Data is routinely delivered to NASA GES DISC (formerly known as DAAC). This can be reproduced for TSIS with either the NOAA NCDC or NGDC replacing the NASA DISC as the primary archive. Interactive data access provided is on SORCE and LISIRD web sites; LISIRD will also serve TSIS data. SORCE data processing takes place within 1-7 days; preliminary data products are processed within 24 hours. TSI and SSI Level 3 Science ate products released daily in ASCII format. SSI data is delivered to DISC in HDF5. The recommended TSIS data processing approach is similar to SORCE and Glory because LASP is highly experienced with this kind of data processing, management and distribution. Data products will be archived at the NOAA NCDC or NGDC (to be determined) for public dissemination. Finally, Chris reviewed the CDR Maturity Matrix, and covered the CDR team’s rationale for current projections in each of the fields.

Final Discussion including Future workshop topics:

It was determined that the solar spectral irradiance CDR will be the focus of the next climate data record workshop, likely (but not yet certain) to be fall 2011. The workshop will focus on SSI composites, reconstructions, and validations of sensors in the satellite era. Science team members from past, current, and future missions will be invited to the workshop. All of the slides from this workshop will be available soon on a LASP website.

Other Activities This Period

In addition to preparation and execution of the Solar Irradiance CDR Community Workshop, another major activity to occur was the panning for a new SORCE SIM validation activity. The CDR team is working on new methods for SSI validation. The details of the validation plan, initial results, and schedule will be provided in the next semi-annual report. As mentioned at the Community Workshop, this will be the focus for the next workshop.

Suggested revisions were submitted to the CDR Project for the Global Climate Observing System (GCOS) Publication 107, GCOS Satellite-specific Requirements, section 3.1.6, *ECV Earth Radiation Budget*. In addition to revisions to the requirements, it was recommended that solar irradiance should be separated from Earth Radiation Budget (ERB) in this ECV.

**Second Year Progress Report 2, *Developing a Climate Data Record for Total and Spectral Solar Irradiance***
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**Principal Investigator: Peter Pilewskie, Laboratory for Atmospheric and Space Physics, University of Colorado**

1. During this reporting period Solar Irradiance CDR team member Judith Lean (NRL) reported on significant progress toward the list of tasks associated with construction of solar irradiance composite and modeling:

<u>Records updates and analyzed to present:</u>

- Updated individual instrument TSI data records
- Cross calibrate current and successive TSI instruments
- Inter-compare independent irradiance measurements
- Estimate effects of orbit limitations on measurements
- Construct composite TSI record
- Seek consistency among measurements and models to identify areas needing improved understanding
- Release record to scientific community climate studies
- Develop and update sunspot darkening function: Multiple Mg and Ca K indices analyzed and compared

<u>Work is in progress:</u>

- Develop and update facular brightening functions.
- Combine the sunspot darkening and facular brightening functions to model the extant composite records of solar irradiance .
- Compare and validate the models with irradiance records.
- Develop, update and validate historical records of solar activity.
- Apply the new parameterizations to historical indices of sunspot darkening and facular brightening, to reconstruct solar irradiance on climate time scales, prior to the direct observations.
- Release and facilitate the use of historical reconstructions and irradiance variability models to the climate change community.

2. We have updated our transition plan. The following list plans for ATBD, Data, Source Code and Documentation.

<u>TSIS ATBD (Estimated date of delivery: late 2012</u>

- The TSIS ATBD will lay the groundwork for a future foundation of irradiance measurements (i.e., the need for a composite record, continued satellite record, etc.).
- Includes sections on Instrument Design, Instrument Calibration and Characterization, Science Operation Modes, Degradation Corrections, Validation, Data Product Requirements and Description, and Production of Science Data.
- Need requirements for 'Revision History' and 'Processing Outline'

Climate Algorithm Theoretical Basis Document (C-ATBD)

- Result of community workshop: two ATBDs required: one for TSIS and one for the composite solar irradiance data record.

Data Format

- For SORCE, TSI and SSI Level 3 Science products are released daily in ASCII format (SSI data also available in IDL save file).
- SSI data is delivered to DISC (formerly the DAAC) in HDF5, and there is a move toward delivering it in ASCII. TSI is delivered in ASCII.
- LASP maintains a local archive of level 0 (raw telemetry) and level 1-3 of TSI and SSI data.
- Interactive data access is also available on the SORCE and LISIRD web sites.
- Similar data formats are planned for TSIS. LASP can produce in NetCDF if needed.

Quality of Metadata

- SORCE had no associated metadata requirements. TSIS will conform to metadata standards.
- NOAA NetCDF guidelines for Metadata will not be a problem for LASP.
- LASP is moving towards a Time Series Server, which is a service-based data access where the output format is user-specified and the files (including metadata) are generated dynamically.

Size of data set

- For SORCE, a full mission of Level 3 TSI data (6-hourly data) is 1.83 MB and the Level 3 SSI data is 26 MB. Level 2 data is considerably larger.
- TSIS data set size will be very similar.

Source Code

- LASP has revision control and issue tracking systems.
- LASP has configuration management procedures for software and calibration of data.
- Data products are versioned and traceable to corresponding software and calibration releases.
- LASP shares source code with the science community upon request and delivers it to a public archive facility at the end of the mission.
- Will comply with all CDR standards for TSIS.
- Research missions generally do not require source code portability (cross-platform): LASP typically makes implementation decisions that support platform independence. Ex: SORCE processing code has been executed on Solaris, Linux, Windows, and MacOS.

Level of Documentation

- For SORCE, the documentation are provided on the SORCE website, and supplemented by SORCE instrument papers.
- For TSIS, LASP will produce documentation that corresponds to appropriate climate data record standards/guidelines.

Language

- For SORCE, data processing is implemented with a combination of programming languages: JAVA, Fortran, C, IDL, other languages (such as UNIX shell scripts).
- For TSIS, a similar implementation is expected.

README

- For SORCE, information about data products and discovery information is present on the SORCE website.
- For TSIS, LASP will provide the information that is appropriate for climate data record standards/guidelines.

3. We have initiated a new, independent reprocessing of SORCE Solar Irradiance Monitor (SIM) Data. SIM is the first instrument to continually monitor the solar spectral irradiance over 95% of the solar spectrum. The data record is now seven years long. SORCE has provided a new understanding of the spectral variability across the ultraviolet, visible, and near infrared with potential climate implications. This effort is to validate the trends found thus far and to refine uncertainty estimates. Further details and initial results will be presented during the next reporting period.