SORCE has 4th Annual Science Team Meeting

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Approximately 60 people attended the 2006 SORCE Science Team Meeting, which was held from September 20-22 at Rosario Resort, on beautiful Orcas Island, Washington State. This year's meeting focused on The Earth's Radiative Energy Budget Related to SORCE. A summary of the meeting, including .pdf versions of the many excellent presentations, is available at http://lasp.colorado.edu/sorce/2006ScienceMeeting/index.htm.

Since its launch in 2003, the SOlar Radiation and Climate Experiment (SORCE) has measured solar irradiance at the top of the Earth’s atmosphere with unprecedented accuracy, precision, and spectral coverage across the ultraviolet, visible, and near-infrared regions of the spectrum. These observations of the top-of-the-atmosphere energy input to the Earth initiate the myriad heat flows illustrated in Figure 1. The SORCE Science team meetings are convened to both highlight SORCE’s unique, state-of-the-art emerging solar irradiance database and to engage the broad scientific community in wide ranging scientific issues involving solar irradiance variability, climate and the Earth’s atmosphere on multiple time scales. Prior meetings (http://lasp.colorado.edu/sorce/meetings.html) have addressed:

- Physical Processes Linking Solar Radiation and Solar Variability with Global Climate Change (Sonoma, CA, 2003)
- Decadal Variability in the Sun and Climate (Meredith, NH, 2004)
- Paleo Connections Between the Sun, Climate, and Culture (Durango, CO, 2005)

The goal of the 2006 meeting was the integration of the SORCE measurements of solar irradiance with observations and models of the Earth's radiation budget and the response of climate to perturbations in energy balance. Some of the key questions addressed were:

- What is the present state of knowledge of the Earth’s radiation budget from space, from within the atmosphere, and at the surface?
- What are the key radiative forcing agents, of natural and anthropogenic origin, and how have their relative influences changed in the past?
- What are the important feedback mechanisms for regulating Earth’s climate?
- What is the sensitivity of climate to induced radiative forcing and over what time scales does climate respond?
As in prior meetings, **Session 1, SORCE Contributions to Earth’s Radiative Energy Budget**, comprised presentations by the SORCE instrument scientists. The SORCE Mission Principal Investigator, **Tom Woods** [LASP, University of Colorado] commenced Session 1 with **Overview of the SORCE Mission and its Future**, followed by **Greg Kopp** [LASP, University of Colorado] who discussed **TSI: The Incoming Side of the Equation**. The record of total solar irradiance (TSI) measured from space is now three-decades long and has a range of approximately 0.3%. According to SORCE’s Total Irradiance Monitor (TIM) the absolute value of TSI is 1361 Wm\(^{-2}\), which is ~5 Wm\(^{-2}\) lower than previously thought. A workshop held in 2005 at NIST on the accuracy of current TSI measurements discussed the potential sources for discrepancies among the various solar radiometers, and developed a plan for the first end-to-end calibration for TSI sensors to be completed under the NASA Glory mission. As Principal Investigator for Glory/TIM, Kopp emphasized that the current inaccuracies necessitate overlapping TSI observations to continue to the long-term record. This is in jeopardy because of the removal of the Total Solar Irradiance Monitor (TSIS) from NPOESS.

SORCE’s Spectral Irradiance Monitor (SIM) is making the first ever measurements of the Sun’s spectral irradiance variations in the near-UV, visible and infrared spectrum. In **The Role of VIS-IR/SIM in Climate Science**, **Jerry Harder** [LASP, University of Colorado] described simulations of variability in direct solar heating of the lower atmosphere in response to varying levels of solar irradiance measured by SIM at wavelengths longer than 200 nm.
Irradiance Comparison Experiment (SOLSTICE II) extends the SIM observations to 120 nm. **Bill McClintock** [LASP, University of Colorado], spoke about *Solar Ultraviolet Irradiance and Its Variability*, presenting composite time series utilizing observations from the SOLSTICE I and SUSIM instruments on the Upper Atmosphere Research Satellite. He then discussed the morphology of solar ultraviolet irradiance variability ranging from hours to the solar cycle. SOLSTICE II resolution of 0.1 nm at 280 nm clearly resolves the emission cores of broad Fraunhofer lines. In *The Role of Spectral Resolution in Measuring the Solar Magnesium II Index*, **Martin Snow** [LASP, University of Colorado] showed how this higher spectral resolution enables a more precise measurement of the Magnesium II index (used widely as a solar activity proxy in irradiance models), and that changes can be inferred on shorter timescales.

**Figure 2.** Attendees at the SORCE 4th Annual Science Team Meeting.

**Norman Loeb** [NASA Langley Research Center] commenced **Session 2, Radiative Energy Budget**, with a comprehensive overview of the importance of the Earth’s radiation budget for climate, comparisons between the Clouds and the Earth’s Radiant Energy System (CERES) and other radiation budget datasets, and the error sources in determining the global annual net top-of-the-atmosphere (TOA) radiation. In *Determination of the Earth’s Radiation Budget from CERES*, Loeb pointed out that the SORCE TIM TSI value of 1361 W m$^{-2}$ can account for 1 W m$^{-2}$ out of the current 4 W m$^{-2}$ error in CERES net flux estimate. He also pointed out the inconsistency of CERES with trends derived from Earthshine observations. Two following talks addressed radiation budgets in the atmosphere and at the Earth’s surface. In *An Overview of the Radiation Budget in the Lower Atmosphere*, by **Peter Pilewskie** [LASP, University of Colorado] compared airborne observations from a number of recent experiments with remote sensing of clouds and aerosols, followed by **Ellsworth Dutton** [NOAA, Boulder, Colorado] who described the *Surface Radiation Budget Observations: Progress and Challenge*. The longer and temporally-complete but spatially-sparse ground-based data are used extensively for validation of satellite products, and both datasets are now being examined for climate related variability. In his talk, *The Radiation Budget of an Atmospheric Column in the Tropical Western Pacific*, **Tom Ackerman** [Pacific Northwest National Laboratory, Washington] compared modeled column surface and top-of-atmosphere emitted longwave and reflected shortwave fluxes with their measured counterparts. There was good agreement for surface fluxes and for outgoing longwave radiation but the agreement with TOA reflected radiation was considerably poorer.

Exciting new Earth radiation budget datasets are emerging from the Multiangle Imaging SpectroRadiometer (MISR) and instruments on the Geostationary Earth Radiation Budget (GERB) spacecraft, launched respectively in 1999 and 2002. **Roger Davies** [The University of Auckland, New Zealand] spoke about *Constraints on the Inter-Annual Variation of Global and Regional TOA Radiation Budgets Inferred from MISR Measurements*, showing that the biggest
interannual global anomalies observed by MISR that affect the top of atmosphere radiative budget appear to be those in the effective cloud height, decreasing through 2005 by about 10 m/yr, but apparently reversing the trend in the 2006 data by increasing in height. In the next presentation, *Time-Space Complete Measurement of the Earth Radiation Budget*, **Steven Dewitte** [Royal Meteorological Institute of Belgium] contrasted the high time resolution view from geostationary orbit with high spatial coverage from low Earth-orbit satellites. GERB data, which were released for scientific use in March 2006, are providing beautiful images that allow tracking unique observations of diurnal cycle radiation and interactions of radiation, clouds, aerosols and the atmosphere. **Tony Slingo** [University of Reading, United Kingdom] captivated the meeting with a time sequence of the evolution of a dust storm in Africa (Figure 3), in his talk on *Observations of the Earth’s Radiation Budget from Geostationary Orbit and from the Surface*.

**Figure 3.** Geostationary Earth Radiation Budget (GERB) observations of dust over Africa, from Tony Slingo et al. The upper image is dust product for 1200GMT on 8 March 2006, derived from three infrared channels of the SEVIRI imager on Meteosat-8, with centre wavelengths at 12.0, 10.8 and 8.7 µm. The lower image is outgoing longwave radiation (Wm⁻²) derived from the GERB broadband radiometer. The location of Niamey is marked by a cross on both images. It is important to note that the dust product is derived from the high resolution imager on the satellite, whereas the OLR comes from GERB. (Submitted to *Geophysical Research Letters*).

**Session 3, Radiative Forcings**, was dedicated to the memory of Yoram Kaufman and his contributions to understanding aerosol and cloud radiative forcing. **Robert Cahalan** [NASA...
Goddard Space Flight Center], SORCE Project Scientist and the Head of Goddard’s Climate and Radiation Branch, where Kaufman worked since 1979, introduced the session with a tribute to Kaufman and his professional and personal influences on the community. In Session 3, meeting attendees learned about current understanding of a wide range of climate forcings from a series of informative talks covering changes in solar output, regional land use, aerosols, greenhouse gases and albedo.

Climate responses to solar cycle variability likely include direct surface heating, indirect processes involving UV radiation and the stratosphere, and modulation of internal climate system circulation patterns. Judith Lean [Naval Research Laboratory] illustrated each of these in her talk Solar Radiative Forcing, emphasizing that longer-term Sun-Clim ate associations remain ambiguous, in part due to calibration offsets among solar radiometers and in-flight sensitivity drifts, and in part because of incomplete understanding of long-term solar variability mechanisms. Current understanding points to a smaller irradiance increase since the Maunder Minimum than previously thought. As the SORCE observations demonstrate, the solar UV irradiance that creates the ozone layer varies by an order of magnitude more than the total solar irradiance. Mark Weber [University of Bremen, Germany] showed through his presentation, Solar Variability and its Links to Ozone-Climate Interaction, that the direct radiation impact on lower stratospheric ozone (as represented by total ozone) is rather small, so solar irradiance variability must alter ozone via dynamical feedbacks. Using satellite total ozone data starting in 1979 (SBUV, TOMS, GOME) he also showed that the recent increase in ozone in both hemispheres has a rather minor contribution from changing halogen levels, but are in large part related to the increasing strength of the Brewer-Dobson circulation governing ozone transport into high latitudes and the rise of solar cycle 23.

Climate forcings are typically quantified on global scales, and need to be better understood on the regional and local scales, as Roger Pielke Sr. [CIRES, University of Colorado] articulated. He spoke on Regional and Global Climate Forcings – The Need to Move Beyond a Focus of the Radiative Forcing of the Well-Mixed Greenhouse Gases, emphasizing that the IPCC Reports, the CCSP Report on surface and tropospheric temperature trends, and the U.S. National Assessment have overstated the role of the radiative effect of the anthropogenic increase of CO\textsubscript{2} relative to the role of other human climate forcings (e.g., land use changes) on global warming, and more generally, on climate variability and change. Atmosphere-ocean general circulation models (AOGCMs) are part of the current climate assessment by the Intergovernmental Panel on Climate Change (IPCC) and there are substantial discrepancies among the AOGCMs in the ensemble and between the AOGCMs and reference line-by-line codes. Bill Collins [National Center for Atmospheric Research] presented an evaluation of Radiative Forcing by Greenhouse Gases and its Representation in Global Models. In some cases the differences occur because the AOGCMs neglect particular absorbers, while in others it is due to the methods for modeling the radiative processes. These differences have important implications for interpreting variations in forcing and response across the multi-model ensemble of AOGCM simulations assembled for the IPCC fourth assessment report (AR4). Collins presented promising new mathematical methods for improving the accuracy of the radiative parameterizations in global models. Collins summarized by presenting the Kiehl and Trenberth energy budget diagram (see Figure 1) along with updated changes in global heat flow quantities based upon 10 years of Community Climate System Model (CCSM) research.

Various types of aerosols were discussed for their influences on climate. In his presentations, Using Models and Measurements to Understand and Constrain the Direct Effect of Aerosols on Climate, Brian Cairns [Goddard Institute for Space Studies, University of Columbia] explained
that one if the most significant but least certain forcings is that caused by aerosols and the reasons are due to variable aerosol composition leading to either heating or cooling, their relative short lifetimes, and the highly heterogeneous global distribution. Cairns discussed how new remote sensing measurements using airborne and spaceborne polarimetry, planned for the Glory mission, can be used to reduce the uncertainty in the radiative forcing of climate by aerosols, as well as reduce uncertainties in the processes that must be modeled in order to predict the future forcing of climate by aerosols.

Understanding aerosols effects on clouds is perhaps the most challenging part of determining how aerosols are affecting the climate. In his fascinating presentation, *The Aerosol Indirect Effect*, Jim Coakley [Oregon State University] used observations of the response of marine stratocumulus to aerosols generated by ships off the west coast of the U.S. to estimate the aerosol indirect radiative effect. He showed that by increasing cloud cover fraction, the increase in particulate pollution causes radiative forcing comparable to that for the changes in droplet numbers and radii. There is additional uncertainty in cloud radiative forcing in regions where Sea-salt aerosols (SSA) are the dominant aerosol species. Antony Clarke [University of Hawaii] spoke on *An Ultrafine Sea-Salt Flux from Breaking Waves: Implications for CCN in the Remote Marine Atmosphere*. He reported measurements showing that SSAs extend to sizes an order of magnitude smaller than previous published values. When newly determined fluxes of ultrafine SSA are applied to oceanic whitecaps it implies strong regional and temporal differences become apparent in the open-ocean surface number flux. The introduction of an ultrafine component of SSA into the GISS II-prime general circulation model increased calculated CCN over most oceanic regions by several to 10% relative to the SSA source functions without an ultrafine component.

2.1-μm

**Figure 4.** Jim Coakley used ship tracks (arrow) to better understand aerosol indirect effects. This image is from Aqua 1-km MODIS, 1915 UTC, 11 June 2002. Comparisons are made under conditions such that the only difference between affected clouds with nearby pristine clouds is the additional particle loading.
Finally in this session, Steven Lloyd [The Johns Hopkins University] revisited the issue of Earth radiation budget discrepancies between CERES and Earthshine. He described *A 27-Year Composite Dataset of Global UV Effective Reflectivity from the TOMS and SBUV(2) Satellite Instruments* that provides insight into the issue of long-term changes in the effective albedo of the Earth (i.e., “global dimming”) and climate feedback mechanisms (i.e., “global warming”).

The fourth and final session of the meeting, **Session 4, Climate Responses and Feedbacks**, began with K.K. Tung [University of Washington] who presented *Climate Sensitivity Inferred from Atmosphere’s Response to the Radiative Forcing of the 11-Year Solar Cycle, including Feedbacks*. He explained that uncertainties in model predictions of equilibrium global mean warming due to a doubling of atmospheric CO$_2$ are due to differing magnitudes of the feedback processes, including water-vapor, ice-albedo, and clouds, which in aggregate magnify the climate response by a factor $g \sim 1$ to 3. Using recent instrumental records to estimate climate sensitivity, he established a “largest lower bound” in response to a doubling of CO$_2$. A solar cycle signal with a globally averaged surface warming of 0.17 +/-0.04 K for each Wm$^{-2}$ increase in total solar irradiance translates into 0.80 +/-0.19 K per Wm$^{-2}$ of direct radiative forcing, about the same as the Vostok ice core result but with smaller uncertainties. These results rule out models predictions of equilibrium warming less than 2.3 K and exclude the possibility of no positive climate feedback. Incoming solar radiation is a dominant process of the upper ocean heat budget, except in relatively narrow regions with strong upwelling currents in the upper ocean. In his talk *Ocean-Atmosphere Interfaces in Climate*, David Halpern [NASA Headquarters] explained that buoy measurements of incident shortwave radiation are essential in combination with satellite measurements of incident shortwave radiation in the development of radiation fields at the surface over the global ocean. Important, complex and possible non-linear climate processes occur as a result of air-sea interactions, for example, enhanced global ocean absorption of anthropogenic longwave radiation due to increasing amounts of atmospheric greenhouse gases, producing a rise in global sea level, and El Niño and La Niña links to redistributions of heat in the upper ocean along the Pacific equator, producing a redistribution of heating in the atmosphere.

On Thursday, the meeting broke-up mid afternoon so attendees could ferry to San Juan Island to the SORCE Science Dinner. Widely known for his superlative and successful leadership as SORCE’s first PI, Gary Rottman [LASP, University of Colorado] entertained diners with a ridiculously funny, widely irreverent and clever lecture on the “Price of Gasoline and other Large Numbers”.

**Figure 5.** K.K. Tung from the University of Washington.

**Figure 6.** Gary Rottman entertained the SORCE Science Dinner attendees with his tales of the Earth/Sun/Science funding connection.

Robert Cahalan [NASA Goddard Space Flight Center] opened Friday’s session, a continuation of **Climate Responses and Feedbacks**, with his talk on Three-Dimensional Cloud Properties and
Climate. Cahalan discussed the major international effort toward advancing computational radiative transfer tools documented in the “Intercomparison of 3 Dimensional Radiation Codes” (I3RC) and he addressed a number of important questions, such as: How do the physical and radiative properties of clouds depend on resolution? How do cloud scaling or fractal properties impact Earth's climate, or does it matter? How might cloud scaling properties help improve the measurement and modeling of clouds? What breakthroughs might be expected in cloud research in the next decade?

Earth’s ice and snow regions are crucial and sensitive feedbacks operating within the climate system. In his illuminating presentation, *Recent Changes in Earth’s Cryosphere*, Ken Jezek [The Ohio State University] documented how the polar ice sheets, sea ice, seasonal snow cover, glaciers, permafrost and ice-atmosphere interactions are changing (Figure 7). A variety of space-based observations (e.g., from MODIS, InSAR, IceSat) provide dramatic evidence of recent changes. On longer time scales, there is a world wide retreat of glaciers and a century-long permafrost warming. Impacts of cryosphere variations are likely widespread, and may include global sea level rise and involve biological processes. Repeated continental scale observations of the polar regions are needed to capture and compare in space and time the interactions of ice, ocean, atmosphere and land. Determining the long-term impacts of a changing cryosphere on other components of the Earth system is a future challenge, as is predicting the responses of snow, glaciers, ice sheets, permafrost, and sea ice to changing climate.

![Figure 7. Retreat of the Jakobshavn Ice Stream (Ken Jezek).](image)

As the next two talks in Session 4 described, simulations with atmospheric and climate models are key tools for assessing possible mechanisms of climate change. Steve Rumbold [University...
of Reading, United Kingdom] described simulations of the Effect of the 11-Year Solar Cycle on Stratospheric Temperatures, using a narrow band model to obtain radiative heating rates and a fixed dynamical heating model to assess the resultant temperature change in the stratosphere between solar minimum and maximum. The key results are a solar signal in annual mean temperature (solar maximum minus minimum) of ~1.8 K at the equatorial stratopause, a lower stratosphere sub-tropical signal (~0.5 K in the Northern Hemisphere) and an equatorial middle stratosphere minimum response, which is in agreement with some previous studies. In his talk Solar Forcing and Abrupt Climate Change over the Last 100,000 Years, Jose Rial [University of North Carolina] compared ice core data of the last 100,000 years with climate models of low and intermediate complexity, to show that the source of the abrupt Dansgaard-Oeschger oscillations is a form of convective instability of the thermo-haline circulation (THC). He suggested that the abruptness of these oscillations is controlled by the response of the sea ice, whose rapid advances and retreats, triggered by the switching THC, are accelerated by ice-albedo and greenhouse gas (GHGs) feedbacks. The modeling results indicate that solar forcing organizes the free oscillations to form the characteristic pattern of abrupt climate change over the last ice age.

Figure 8. E. J. Zita began her talk about teaching Earth’s radiative energy budget in a climate change classroom with the Goldilock Hypothesis (image is by Pearson Prentice Hall Inc., 2004): Venus (left) is too hot because it is closer to the Sun, Mars (right) is too cold because it is farther away and Earth (center) is just right! Phytoplankton (top) also contribute to climate regulation.

The meeting ended with the articulation of challenges for understanding Earth Radiation Budget, and the application of Earth Radiation Budget science to the classroom. In his talk, The Observation of the Earth Radiation Budget: A Set of Challenges, Dominique Crommelynck [Royal Meteorological Institute of Belgium] identified problems associated with high spatiotemporal, spectral, and angular variability of the target, the imperfect spectral integration of the measured radiation, and the conversion of filtered radiances to total irradiance. Science teacher and regular SORCE meeting attendee, E. J. Zita [The Evergreen St. College, Olympia,
Washington gave the last talk of the meeting. In *Earth’s Energy Balance: Climate Change Workshops*, she described the “Fire and Water” program in which a solar physicist and a biological oceanographer will co-teach an integrated undergraduate program in fall 2006. Students will analyze questions such as: What would Earth’s equilibrium temperature be without a greenhouse effect? What is the effect of clouds on the atmospheric radiation budget? How does inclusion of ocean and ice albedo change this equilibrium? How do variables such as plankton and temperature contribute to changes in albedo? In addition to providing meeting attendees with an instructive glimpse into classroom teaching, she plans to include data and methods from the SORCE meeting in some more advanced workshops.

**Tom Woods** [LASP, University of Colorado] concluded the highly enjoyable 4th Annual SORCE meeting with a summary of the excellent presentations and engaging science discussions, and thanked Vanessa George for the beautiful vistas, fine social events and whale sightings enjoyed during the past two and a half days.

During the Poster Reception, attendees had an opportunity to peruse the contributed posters while enjoying drinks, appetizers and social interactions.

Figure 9. Greg Kopp, LASP, University of Colorado, discusses his poster presentation with Mark Weber from the University of Bremen in Germany, during the Wednesday afternoon poster session.

Antony Clarke, University of Hawaii
*Biomass Burning and Pollution Aerosol over North America: Organic Components and Their Influence on Spectral Optical Properties and Humidification Response*

Matt DeLand, Science Systems and Applications, Inc., Maryland
*Maintaining the Solar UV Database in the 21st Century*

Frank Eparvier, LASP, University of Colorado
*How TIMED-SEE uses FUV data for validation and calibration*

Juan Fontenla, LASP, University of Colorado
*The Solar Radiation Physical Modeling System*

Claus Fröhlich, Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center, Switzerland
*Comparison of the WRC-85 Solar Spectral Irradiance with RSSV1 and the SPM of VIRGO/SOHO*
Barry Knapp, LASP, University of Colorado  
*SORCE Solar Irradiance Data Products*

Greg Kopp, LASP, University of Colorado  
*Could You See an Earth-Type Planetary Transit of a Solar-Type Star? Another Use of TIM Data*

Robert Kurucz, Harvard-Smithsonian Center for Astrophysics, Massachusetts  
*High Resolution Irradiance Spectrum from 300 to 1000 nm*

Jeff Morrill, Naval Research Laboratory, Washington, DC  
*A Model of Long-Term Variability of Solar UV and EUV Irradiance*

Julia Saba, Lockheed Martin, ATC Solar & Astrophysics Lab, Maryland  
*Rapid Solar Cycle Onset – Potential New Climate Study Tool?*

Martin Snow, LASP, University of Colorado  
*The LASP Interactive Solar Irradiance Database (LISIRD)*

Martin Snow, LASP, University of Colorado  
*UARS and SORCE SOLSTICE Calibration and Comparisons*

Mark Weber, University of Bremen, Germany  
*Solar UV/Vis/NIR Spectral Irradiance from SCIAMACHY and GOME*

Guoyong Wen, NASA GEST and NASA GSFC  
*Deriving Historical TSI Variations from Lunar Borehole Profiles*

When the dates for the 2007 SORCE Science Meeting, to be held in Santa Fe, New Mexico, are definite, the information will be posted to the SORCE Meeting website –  
[http://lasp.colorado.edu/sorce/meetings.html](http://lasp.colorado.edu/sorce/meetings.html).