

SORCE Science Team Meeting Summary

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Approximately 80 scientists gathered for the 2010 Solar Radiation and Climate Experiment (SORCE) Science Team Meeting, *Solar and Anthropogenic Influences on Earth: The Current Solar Minimum and Predictions for Future Decades*, May 19-21, in Keystone, CO. The discussions covered a wide range of current solar and earth science research.

A summary of the meeting, including PDF versions of many of the excellent presentations, is available at: lasp.colorado.edu/sorce/news/2010ScienceMeeting/index.html.

Introduction and Meeting Overview

Relative to the past three solar minimum epochs of the space era (1976, 1986, and 1996) the current solar minimum (2008–2009) between Solar Cycles 23 and 24 was unusually prolonged with record numbers of sunspot-free days, record low solar polar magnetic fields, and record high levels of cosmic ray flux. Evidence is accumulating that there have been broad ranging terrestrial responses to the extended inactivity of the Sun. Reduced solar ultraviolet (UV) irradiance and corresponding lower ozone levels may be obscuring the recovery from anthropogenic ozone depletion by Chlorofluorocarbons (CFCs). In the upper atmosphere and ionosphere, temperatures are anomalously cool and densities are reduced relative to previous solar minima; but these changes may also be related to accumulated greenhouse gas cooling in the upper atmosphere.

Key questions addressing the current state of and future expectations for the integrated Sun-Earth system are:

- Are spectral and total solar irradiance levels lower now than during past minima, and how much will they increase during Solar Cycle 24?
- Can we identify anomalous behavior in the solar dynamo and surface flux transport to help understand the recent minimum?
- How are heliospheric changes altering incident cosmic ray fluxes and the Earth's near-space environment?
- Can we reliably discern the terrestrial signatures of the recent minimum—at the surface, in the stratosphere, and in space weather?

Session 1: Total Solar Irradiance (TSI): Comparison of Solar Cycle Minima and Recent Validation Results

Keynote speaker **David Hathaway** [NASA Marshall Space Flight Center] kicked off the meeting with *Meridional Flow Variations: Implications for flux transport models*. Hathaway discussed the uniqueness of the recent solar minimum with impressive videos to show that the meridional flows from weakening polar fields in cycle 23 are the cause of a weak beginning to cycle 24.

The meeting's first session reviewed recent progress on understanding the differences between on-orbit total solar irradiance (TSI) instruments and to what level of accuracy changes between the recent and prior solar minimum can be discerned.

Richard Willson [NASA/Jet Propulsion Laboratory (JPL)], started the TSI instrument talks with an overview of the importance of continuity in past and recent TSI observations, while contrasting the three currently operating TSI instruments. Willson's talk elicited several questions on an annual cycle in the ACRIM III data that is not apparent in other concurrent TSI instruments, and his team is studying possible solar and instrumental effects of this cycle. **Claus Fröhlich** [Physikalisch-Meteorologisches Observatorium (PMOD)—Davos, Switzerland] discussed the differences between the last three solar minima and described a four-component model he uses to fit observed TSI variations. **Wolfgang Finsterle** [PMOD] discussed the PREMOS package onboard the PICARD satellite (launched June 14, 2010) and how their calibration campaigns at both National Physical Laboratory (NPL) and the recently operational TSI Radiometer Facility. This facility compares a TSI instrument against a NIST-calibrated cryogenic radiometer, providing the first ever end-to-end irradiance comparisons under vacuum and at full solar power levels to such a reference.

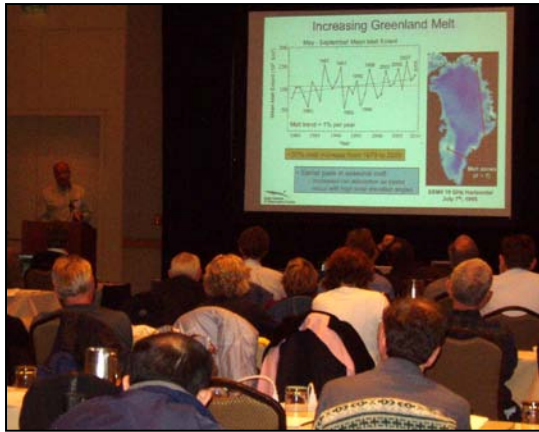
Steven Dewitte [Royal Meteorological Institute of Belgium] gave a status report on SOVIM, and described the measurement differences between the SoHO DIARAD and VIRGO. **Greg Kopp** [LASP, University of Colorado (CU)] summarized the results of recent inter-comparisons of the Glory, SORCE, PICARD, and VIRGO/PMO TSI instruments to the new Glory-funded TSI Radiometer Facility at LASP. These intercomparisons may help to explain and diagnose causes of differences between instruments showed that uncorrected scatter off the front or interior of TSI instruments could well account for erroneously high TSI measurements.

Devendra Lal [Scripps Institute of Oceanography, University of California] estimated solar activity over the past 35,000 years based on magnetic flux and solar plasma emitted by the Sun. **Alexander Shapiro** [PMOD] concluded the session by sharing the PMOD/WRC Code Solar Irradiance (COSI) physical model which allows researchers to reconstruct annually averaged total and solar spectral irradiance measurements back to the Maunder Minimum. His results indicate a 6 W/m^2 decrease in TSI at the Maunder Minimum, indicating forcings in TSI as large as 1 W/m^2 .

Session 2: Climate Changes: What's the Future Going To Be?

Keynote speaker **Georg Feulner** [Potsdam Institute for Climate Impact Research—Germany] described Sun-climate interactions, and presented results of simulations with a fully coupled

climate model forced with solar irradiance corresponding to past Grand Minima (of which he models four over the last 1000 years). He extrapolated future scenarios for global warming, showing that a new prolonged Maunder Minimum would only slightly decrease future global warming, with a -0.3°C effect due to lower solar irradiances being swamped by anthropogenic induced increases of 4°C .



Through researching ice sheet response to climate, **Waleed Abdalati** [CIRES, CU] explained how *in situ* observations and robust process models are helping us understand the nature of the changing ice cover, the processes that govern it, and what the implications may be for life on Earth. He gave an interesting perspective that even the fast present day ice melts pale compared to some historical melts in terms of their effects on sea level rise.

Figure 1. Waleed Abdalati [CIRES, CU] presented *Ice Sheet Responses to past and Current Climate Forcings*.

Session 3: Solar Spectral Irradiance (SSI): Solar Cycle Variation and Model Comparisons

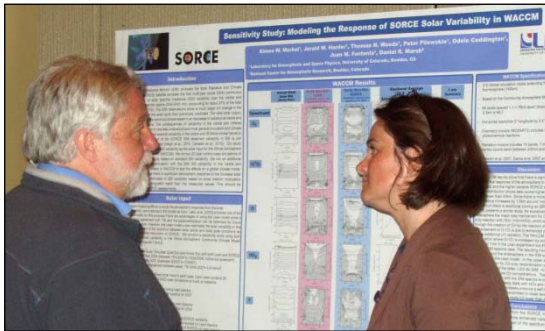
Session chair **Tom Woods** [LASP, CU] began with a short tribute to **Richard (Dick) Donnelly**, who passed away in August of 2009. Donnelly was a physicist at the National Oceanic and Atmospheric Administration / Space Environment Center (NOAA/SEC) for thirty years where he made significant contributions to the solar-terrestrial community.



Jerry Harder [LASP, CU—*SORCE LASP Project Scientist*] lead the session with a talk entitled *Measured and Modeled Trends in Solar Spectral Irradiance Variability in the Visible and Infrared*. The Spectral Irradiance Monitor (SIM) measurements show rotational modulation of spectral irradiance due to the evolution of solar activity. SIM observations indicate trends in solar spectral irradiance (SSI) over solar cycle time periods that are both in and out of phase with the (TSI). **William Ball** [Imperial College—London, U.K.] discussed how the SIM measurements have been used in the SATIRE model, comparing data from April 2004–November 2009. The results show good agreement with short-term detrended spectral regions, but his model cannot explain the long-term trends in the UV and NIR. **Matt DeLand** [Science Systems and Applications Inc.] has been comparing data sets from different satellite instruments and results are showing both absolute offsets and time-dependent differences that vary between spectral ranges. DeLand has generated a new UV composite from these multiple data sets, and sees no difference between the minimum values for Solar Cycles 21 and 22 within the uncertainty of the data. **Cassandra Bolduc** [University of Montreal] has used the quiet sun, sunspots, and faculae to construct both total and spectral irradiance time series. The differences are used to estimate the network contribution to the spectral irradiance variations down to 60 nm at different cycle phases.

Tom Woods [LASP, CU—*SORCE PI*] discussed how the current solar cycle minimum was clearly different than the last few minima in that open magnetic flux was about 30-40% lower, solar wind pressure was about 40% lower, EUV was 15% lower, and there were more low-latitude coronal holes. **Jeff Hall** [Lowell Observatory] described spectral variations of the Sun using Lowell's Solar Spectral Spectrograph measurements of the Sun and stars. He noted that young stars vary inversely with activity in the B and Y spectral bands, surprisingly similar to what SIM observes in solar cycle variations. **Gérard Thuillier** [LATMOS-CNRS—France] showed a composite spectrum from three missions, giving the ATLAS spectral solar irradiance composite with an accuracy of about 3%, and discussed possible causes of the differences between ATLAS 3 and SOLSPEC-ISS in the infrared, although their agreement in the UV and visible is very good.

Poster Session – Wednesday afternoon, May 19



Graduate student **Jean-François Cossette** [University of Montreal] explains his poster, *Thermodynamic Signature of Magnetic Cycles in Global Simulations of Solar Convection*, to **Gerard Thuillier** [LATMOS-CNRS]. This year's meeting drew more students than ever before.

Aimee Merkel [LASP, CU] discusses her research on modeling the SORCE solar variability into the Whole Atmospheric Community Climate Model (WACCM) with **Robert Cahalan** [NASA GSFC] during an afternoon Poster Session. Over 20 posters were featured in the session.



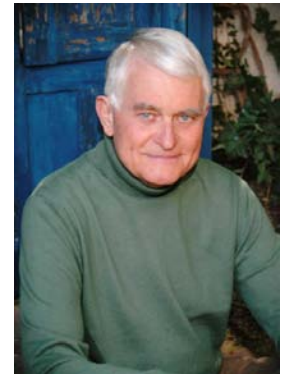
Session 4: Atmosphere and Ozone Changes: Has the Ozone Recovery Started Yet?

Session 4 was dedicated to the present understanding of the influences of solar spectral irradiance variations on atmospheric and ozone processes. **Rich Stolarski** [NASA GSFC] kicked off Thursday morning describing the impact of solar variability on stratospheric ozone and temperature. When comparing the simulations of the effects with analysis of the long-term ozone data records, results reveal that the global average response to the UV solar variability ($S_{\max} - S_{\min}$) shows that the ozone response to lower stratospheric heating is much smaller (and opposite) to the photolysis response (which dominates). **Joanna Haigh** [Imperial College] shared her research using SORCE SIM measurements in a two-dimensional stratospheric climate model to explore the impact of solar spectral variability on solar radiative forcing of climate and ozone photochemistry. This is one of the first detailed investigations using the full solar spectrum out to the near-IR in detailed coupled climate and chemistry modeling. The results show that incorporation of the SORCE spectral variability produces a reduction of lower mesospheric ozone and an increase in the mid- to upper-stratosphere at higher solar activity. If correct, this type of spectral variability may have had significant impact on previous solar cycles, or on

longer timescales, requiring an entire revision of the attribution of causes to observed variations in temperature throughout the atmosphere. **Ka-Kit Tung** [University of Washington] discussed the annual rate of warming from solar minimum to solar maximum in relation to that due to greenhouse gases and the need to establish the significance of a near Earth’s surface response to solar-cycle variability. Finally, the session chair, **Robert Cahalan** [NASA GSFC] presented *Modeling the Temperature Responses to Spectral Solar Variability on Decadal and Centennial Time Scales*. Central to the analysis was the incorporation of the SORCE SIM results during the declining phase of Solar Cycle 23.

Session 5: Space Weather Effects Observed During This Solar Cycle Minimum

Before the session began, **Robert Cahalan** [NASA GSFC] presented a thoughtful tribute to John Allen “Jack” Eddy who passed away in June 2009. Cahalan acknowledge that Jack Eddy was extremely influential in Solar Physics. There was open audience participation and fond reflections from many of Jack’s former colleagues over a long and uniquely interdisciplinary scientific career. He was a careful and unselfish researcher that will truly be missed. It was also noted that there is presently a petition, submitted to the Solar Physics Division of the American Astronomical Society, to name the next significant solar minimum “The Eddy Minimum” to honor his contributions to the long-term solar record.



John Emmert [NRL] opened Session 5 with a talk entitled *Observations of Record-low Thermospheric Density During the Current Minimum*. Emmert described how global-average thermospheric total mass density, derived from the drag effect on the orbits of many space objects, is being used to study the behavior of the thermosphere during the prolonged cycle 23/24 solar minimum. Anomalously low density appears to have started in 2005, when solar extreme ultraviolet irradiance was well above the prolonged low levels of the Solar Cycle 23/24 minimum. **Liying Qian** [High Altitude Observatory (HAO), NCAR] discussed the thermospheric and ionospheric response to the recent prolonged solar activity minimum. During the 2007–2009 solar minimum period the upper atmosphere and ionosphere were cooler, lower in density, and consequently lower in altitude (back to about 1970). Moreover, a study including the Carrington rotational analysis of the low-latitude coronal holes showed that polar coronal holes were ~ 20% smaller in 2008 compared to the 1996 minimum, but large mid and low latitude holes persisted during this extended minimum.

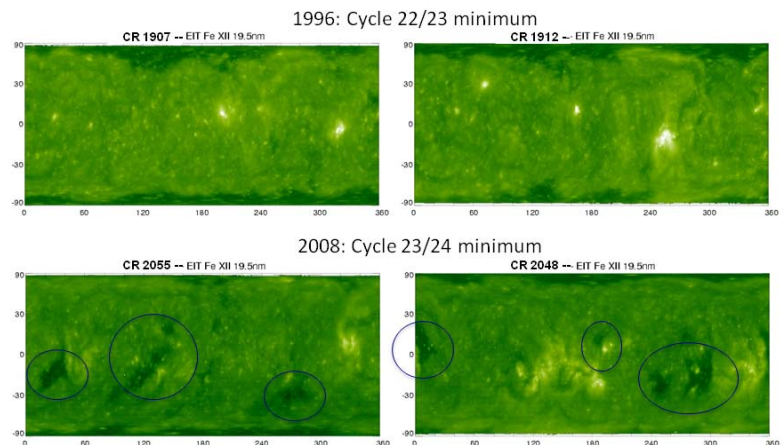


Figure 2. Comparison of mid- and low-latitude coronal holes between the recent 2008 solar cycle minimum with the previous 1996 solar cycle minimum. Credit: Liying Qian, HAO, NCAR.

Eduardo Araujo-Pradere [CIRES, CU and NOAA, Space Weather Prediction Center] discussed comparisons obtained by modeling the thermosphere and ionosphere neutral and plasma parameters with a physical model to a range of observations used to judge the abnormality of the last solar minimum. The comparisons between model and data determine if model drivers, such as EUV input or magnetospheric sources, have to be outside the range expected from past climatology. **Giuliana de Toma** [HAO, NCAR] presented her analysis of the evolution of the polar magnetic fields and coronal holes during the extended solar minimum between cycle 23 and 24, and their implications for the solar wind and effects on the Earth's near-space environment. In the final talk of the session **David Webb** [Boston College] discussed the Whole Heliosphere Interval (WHI), an in-depth study of the Sun-Earth system for a solar rotation in March–April 2008 and the Whole Sun Month (WSM) campaign in August–September 1996. The recent solar minimum was exceptionally quiet, with sunspot occurrence the lowest in 75 years, solar wind density and interplanetary magnetic field (IMF) strength at the lowest values ever observed, and geomagnetic indices and solar EUV fluxes the lowest in three solar cycles.

Session 6: Solar Physics: What Do We Learn About the Sun from this Unique Cycle Minimum?

Gary Rottman [LASP, CU—*Original SORCE Principal Investigator*] chaired Thursday afternoon's session which featured keynote speaker **Oran R. (Dick) White** [LASP, CU]. White began with a historical perspective on research in the field of solar variability over a long and distinguished career, and finished with some recent results on the decreasing contrast of sunspots in the current solar cycle. The discussion of changes in the properties of sunspots continued with **Ken Tapping** [Herzberg Institute of Astrophysics—British Columbia] discussing the relationship of F10.7 cm radio flux to sunspot number. **Eva Robbrecht** [Royal Observatory of Belgium—Brussels] gave a presentation on how the polar field strength is almost 50% weaker in Cycle 23. **Leif Svalgaard** [Stanford University] presented on uncertainties in predicting the strength of the next solar cycle for a variety of indicators.

The next few presentations changed gears from observations to models. **Paul Charbonneau** [University of Montreal] gave a talk on his global MHD model that starts from first principles of physics. The group then received an update of the solar cycle prediction from **Mausumi Dikpati's** [HAO, NCAR] flux transport dynamo model and how it compares to the NRL surface flux transport model. A vigorous discussion followed, and **Tom Woods** [LASP, CU] suggested that there should be a dedicated splinter session to discuss this topic at the next SORCE meeting.

Returning to measurements rather than models, **Joan Feynman** [JPL] presented observations of the cosmic ray flux that showed how the peculiar behavior of the current solar cycle actually started decades previously. **Andrés Muñoz-Jaramillo** [Montana State University] discussed the consequence of changes to the meridional surface flows affecting the solar cycle. **Marty Snow** [LASP, CU] then presented irradiance results that show that the dominant activity in the declining phase of the solar cycle appears to rotate with a period 26.4 days, and that this active longitude persists for the last three solar cycles. The final talk in the session was another discussion of the record high cosmic ray fluxes seen during 2009 and 2010 from **Richard Mewaldt** [CalTech]. Mewaldt also showed a comparison to the Be¹⁰ record which indicated that the cosmic ray fluxes for the previous 50 years was anomalously low compared to the entire data record.

SORCE Science Dinner – Thursday, May 20



After an interesting day of talks, the group went to the beautiful **Keystone Ranch** for a special dinner for all attendees and their guests.

This cozy historical 1930's homestead is where rustic elegance is combined with extraordinary cuisine served in a warm atmosphere. The evening



was the perfect temperature to enjoy the view off *The Ranch's* back patio before a wonderful dinner.

The Ranch photos by Rich Stolarski.

Session 7: Recommendations for the Future: How to Improve the Climate Data Record?

The final session was dedicated to looking forward and how long-term records of solar irradiance measurements are needed to advance critical aspects of the scientific understanding of the Earth climate system. The session began with keynote speaker **John Bates** [NOAA, National Climate Data Center] giving an excellent overview of the path forward and the challenges for maintaining continuity for climate measurements and the challenges for the development of new observation technologies. While NOAA is making major contributions to the nation through existing climate services, there is a rising demand for expanded climate services across a broader, social, economic, ecological, and resource framework. The group discussed future opportunities for long-term solar irradiance monitoring using the NOAA/NASA Joint Polar Satellite System (JPSS), as well as alternate flight options that are under study to ensure sensor overlap. In the following talk **Peter Pilewskie** [CU/LASP] continued on this theme and discussed the importance of the TSIS program toward achieving an accurate long-term total and spectral irradiance Climate Data Record (CDR). Central to this is a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change. Given the present restructured program uncertainties and the fact that the first flight of TSIS is yet to be determined, there is serious concern that delays beyond 2014 will increase the probability of a measurement gap in the Total Solar Irradiance (TSI) record.

Madhulika (Lika) Guhathakurta [NASA Headquarters] presented an overview of the present and future goals of the NASA *Living With a Star* (LWS) Program with regard to effectively addressing those aspects central to the connected Sun–Earth system that directly affect life and society. Guhathakurta also presented an overview of the diversity of educational programs and opportunities for the next generation of researchers including Heliospheric textbooks, Summer School programs, and Visiting Scientist and Postdoctoral fellowship programs. In the final presentation of the session **Dean Pesnell** [NASA, GSFC] gave an excellent overview of the recently launched Solar Dynamics Observatory (SDO) Mission. Pesnell showed stunning data from all of the instruments including the Extreme ultraviolet Variability Experiment (EVE), the Atmospheric Imaging Assembly (AIA), and the Helioseismic and Magnetic Imager (HMI). Ultimately, the SDO science investigations will help determine how the Sun's magnetic field is

generated and structured, how this stored magnetic energy is released into the heliosphere as the solar wind, energetic particles, and variations in the solar irradiance.

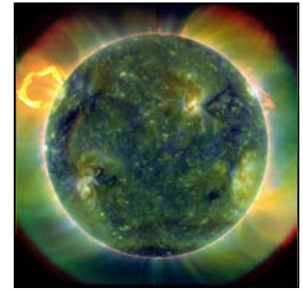


Figure 3. Composite SDO AIA image capturing early solar activity during the onset of Solar Cycle 24. AIA produces eight images every 10 seconds – that’s 70,000 images a day! Credit: Dean Pesnell, NASA GSFC.

Meeting Conclusion / Discussion

To conclude **SORCE Science Meeting Tom Woods** [LASP, CU] summarized the presentations and science discussions that had occurred over the previous 2.5 days. The workshop raised several intriguing questions that we may hope to answer as we embark on a new solar cycle with unprecedented new measurement capabilities.

- *What is the long-term trend in TSI observations?* The recent trends at current solar cycle minimum suggest that the solar Modern Maximum period might be on the decline. Continued observations by **SORCE TIM** and new TSI measurements from **NASA Glory**, **ESA SOLAR**, and **ESA PICARD** are expected to continue the TSI record into Solar Cycle 24.
- *What is the solar cycle variation in the near-infrared (NIR)?* The **SORCE SIM** data yield an inverse relationship with solar cycle that is higher near infrared levels during cycle minimum. New validation is anticipated for the SSI measurements with the **ESA SOLAR** instruments recently installed on the International Space Station.
- *How big will Solar Cycle 24 be?* There are interesting, but conflicting, predictions for both high and low levels for the next maximum in 2012-2013. Time will tell which prediction, if any, is correct.



SORCE Science Team Meeting Group Photo, by Rich Stolarski.

The **SORCE** team extends a warm thanks to all participants for making this meeting another success. Future plans are to meet again in Fall 2011. As new information becomes available, it will be posted to the **SORCE Science Meetings** website: lasp.colorado.edu/sorce/meetings.html.

Pre-Meeting Workshops

Before the official SORCE Science Meeting began, there was a full day of pre-meeting events on May 18. The morning featured two parallel workshops.

Jerry Harder [LASP, CU] led a workshop on ***Solar Spectral Irradiance (SSI) and Climate Modeling***. The workshop's goals were to: 1) promote the use of SSI and its variability in a variety of applications including climate, chemistry, and radiative transfer; 2) emphasize climate processes and mechanisms of climate response to SSI variability, with the ultimate goal of improving understanding of SSI-climate interactions; and 3) foster new interactions between the modeling community and the SORCE science team. Approximately 20 scientists were in attendance.

Greg Kopp [LASP, CU] led a workshop on ***Total Solar Irradiance (TSI) Validation*** that focused on the status of on-orbit TSI instruments and plans for ground validations such as those that have been done or are being planned on at LASP's TSI Radiometer Facility (TRF). The ultimate goal was to share current status and ideas to improve the overall TSI record.

Oran R. (Dick) White Recognition

Oran R. (Dick) White [LASP, CU] was the guest of honor on Tuesday afternoon, May 18, at a special seminar entitled "*Where did the first 50 years go?*" **Gary Rottman** [LASP, CU] organized and emceed the program which began with a talk from **Kim Malville**, who was a graduate student at the same time as White. **Bill Livingston** [NOAO, National Solar Observatory] described the early ground-based work that he and White did at Kitt Peak National Observatory and Sacramento Peak Observatory. Dick also spent many years at NCAR's High Altitude Observatory, and **Tom Bogdan** [NOAA, Space Weather Prediction Center] entertained the



audience with his memory of White's many contributions. **Gary Rottman** concluded the program with a general recollection of White's many significant contributions to solar physics research, before opening the floor to attendees to share their memories and heartfelt appreciation for White and all he has accomplished in his career (thus far).

Oran R. (Dick) White surrounded by his wife, Patricia Johnson, and his son, Will White, following a special seminar in his honor to kick off the 2010 SORCE Science Meeting.