Past, Present, and Future Role of Earth Science Research

SORCE's 5th Anniversary Science Meeting
February 5-7, 2008, Santa Fe, NM

Abstracts – Oral Presentations

Tuesday, Feb. 5

Session 1: Variability of the Solar Irradiance Over the Solar Cycle

What We've Learned from SORCE — Solar Cycle Maximum to Minimum

Tom Woods [tom.woods@lasp.colorado.edu], Juan Fontenla, Jerry Harder, Greg Kopp, Bill McClintock, Peter Pilewskie, Erik Richard, and Marty Snow, LASP, University of Colorado.

The total solar irradiance (TSI) and solar spectral irradiance (SSI) from 0.1 nm to 34 nm and from 115 nm to 2400 nm have been measured by NASA's Solar Radiation and Climate Experiment (SORCE), which launched in January 2003. The Sun is the dominant external forcing for climate change, thus the solar irradiance and its variability are critical input for studies of the energetics of Earth's atmosphere, surface, and oceans. This talk will provide an overview of the solar irradiance and its variability as a function of time and wavelength during the SORCE mission starting with the high solar activity typical of solar maximum in 2003 to the low solar minimum-like activity in 2007. The dominant temporal variations are due to flares (minutes-hours), active region evolution and solar rotation (days-weeks), and solar cycle magnetic evolution (months-years). The variations in wavelength are dependent on where in the solar atmosphere the emissions arise. The photospheric emissions, which dominate in the near infrared, visible, and near ultraviolet ranges, vary by about 0.1% over the 11-year solar cycle and are characterized by dark sunspots and bright faculae. The emissions from the solar chromosphere and transition region are easily identified in the extreme ultraviolet and far ultraviolet ranges, and their solar cycle variations of 20% to 300% are associated with the evolution of bright plage and active network features on the Sun. Finally, coronal emissions, which dominate in the X-ray and the lower part of the extreme ultraviolet range, vary by factors of 5 to 1000 over the solar cycle.

SORCE Web / Data Site: http://lasp.colorado.edu/sorce/.

Comparison of Solar Irradiance Variability Models with SORCE Observations

Judith Lean [jlean@ssd5.nrl.navy.mil], Naval Research Laboratory, Washington, DC; and Jerald Harder and Greg Kopp, LASP, University of Colorado, Boulder.

Onboard SORCE, the Total Irradiance Monitor (TIM) and the Spectral Irradiance Monitor (SIM) measure simultaneous changes in both the total and spectral solar irradiance, at ultraviolet, visible and near IR wavelengths, for the first time. Models that combine the calculated bolometric sunspot and facular modulation have been used for many years to reproduce total solar irradiance variations, and account for over 80% of the changes observed by TIM from 2002 to 2006. Models of spectral irradiance changes, which rely on information about the wavelength dependence of the sunspot and facular contrasts, have also been developed, motivated by the need for simulations of climate and atmospheric responses to properly account for a multitude of wavelength-dependent processes that facilitate the Earth's utilization of the Sun's energy. Current spectral irradiance variability models rely on information about the wavelength dependence of sunspot contrasts made

by ground-based observations and facular contrasts estimated by solar atmosphere models. SIM's unique new direct measurements permit the first quantitative assessment of the spectral structure of irradiance variability attributable to sunspot and facular sources, constrained by their integral effects as measured independently by TIM. The observed and modeled total and spectral irradiance variations are quantitatively compared with TIM and SIM observations over the duration of the SORCE mission, which now extends from the maximum to minimum of solar cycle 23. Relating the sunspot and facular contributions to ground-based or other proxy solar observations that extend over many decades permits historical reconstruction of total and spectral irradiance variations over multi-decadal epochs. An example is shown of atmospheric changes associated with the solar cycle, simulated with the GISS model which inputs the modeled spectral irradiance variations in 190 wavelengths bands from 115 to 100000 nm. Solar total and spectral irradiances reconstructed monthly since 1950 are available on the LISIRD and SOLARIS web sites, for use in climate and atmospheric simulations.

<u>The History and Future of TSI and SSI Measurements</u>

Greg Kopp [greg.kopp@lasp.colorado.edu], LASP, University of Colorado, Boulder.

I summarize the total and spectral solar irradiance measurements acquired from space, discussing their accuracies and long-term stabilities critical for studies of Earth climate and solar variability. I also present future needs and improvements for these measurements, describing the temporal and solar variability regimes in which either measurement absolute accuracy or stability combined with continuity have the greatest importance. I then discuss how long-term solar variability detection thresholds drive future mission frequency and longevity.

<u>SOLSPEC Investigation: Measurement of the Absolute Spectral Irradiance from 165 to 3080 nm On-Board SOLAR placed on the International Space Station</u>

Gérard Thuillier [gerard.thuillier@aerov.jussieu.fr] and the SOLSPEC Team, Service d'Aéronomie du CNRS, Verrières-le-Buisson, France.

SOLAR is a set of three solar instruments measuring the total and spectral irradiance from 16 to 3080 nm for solar, atmospheric and climatology physics. It is an external payload for the COLOMBUS laboratory expected to be launched in December 2007.

The absolute spectral irradiance and its variation are a key input for the understanding of the main properties of the planetary atmospheres such as the composition, thermal structure and dynamics. Climate physics also requires the precise knowledge of the solar spectrum variation in the field of research of the sun-climate connection.

Given the significant improvements in atmosphere modeling, increased accuracy data are needed. Furthermore, solar atmosphere modeling also requires such accurate measurements.

The SOLSPEC objectives is the measurement of the absolute spectral irradiance and its variability from 165 to 3080 nm with the best today achievable accuracy. SOLSPEC has been developed by Service d'Aéronomie (France), Institut d'Aéronomie Spatiale de Belgique, and Landessternwarte (Germany). The instrument is composed of three double spectrometers using concave gratings, including reference sources to check its stability during the three-year mission. SOLSPEC benefits of the heritage of a similar instrument, which flew five times in space (SL1, ATLAS 1-2-3 and EURECA).

It has been recently calibrated by using the black-body of the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig. The absolute calibration performance will be reported as well as the expected accuracy ranging from 1 to 2 percents of the solar measurements in orbit. Today, the launch date is 6 December with first solar observations in early January 2008. If that schedule is achieved, the first solar spectra obtained in orbit will be shown. [Editor's Note: As of 1/29/08, the launch is scheduled for Feb. 7, 2008.]

Measured Total Solar Irradiance Cycle Variability: Status at the End of Cycle 23

Steven Dewitte [Steven.Dewitte@oma.be] and Sabri Mekaoui, Royal Meteorological Institute of Belgium, Brussels.

The Total Solar Irradiance (TSI) is measured from space since 29 years, covering 2.6 11 year solar cycles. Over the last 2 solar cycles, 3 TSI composites are available showing a common 11 year cyclic TSI variation, but disagreeing on possible long term variations of the solar minimum TSI over the solar cycles. We review the new results of the 3 TSI composites over the currently ending cycle 23.

The only instruments that measured the TSI variation over the full cycle 23 – since 12 years – are the VIRGO radiometers DIARAD and PMO on the SOHO satellite. We present the ageing correction of DIARAD and PMO by the DIARAD team, and discuss the differences with the versions available from the PMO team. In addition to the normal exposure dependent ageing corrections applied by both the DIARAD and PMO teams, the PMO team applies additional 'exposure independent corrections' or 'sensitivity changes' which create an artificial downward trend of about 0.4 W/m2 for both DIARAD and PMO.

We compare all available TSI measurements over cycle 23 from DIARAD, PMO, ACRIM2, ACRIM3, ERBS and TIM. They all show the same relative variations except ACRIM3 which shows a faster decline at the end of the cycle. We find that there is no variation of the solar minimum TSI over cycle 23 with an uncertainty of +/- 0.14 W/m2.

TSI Variation: What Can We Learn from the Last Three Solar Cycles?

Claus Fröhlich [cfrohlich@pmodwrc.ch], Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center, Switzerland.

Total solar irradiance measurements from different satellites are available since late 1978 and may be extended back to the minimum between cycles 19 and 20. This time series shows a downward trend of the values of the three minima since 1986. Although the present one may still have not yet reached its minimum value it is already lower than the previous one and the trend observed by VIRGO is confirmed by comparison with ACRIM-II/III and TIM. This trend is not explained by the long-term part of the MgII index; in contrary this index is presently still higher than during the last minimum. On the other hand the values of the IMF at Earth, which is proportional to the open magnetic flux, shows a similar behavior and the cycle-to-cycle variation is very similar to the variation of the 11-year averaged TSI. This may indicate that MgII index does not see the weak magnetic fields which finally seem to produce an important part of the cycle variation and more importantly also the longer term changes.

Long-Term Ground-Based TSI Measurements

Gary A. Chapman, [gary.chapman@csun.edu], San Fernando Observatory, California State University, Northridge.

We will review efforts to model variations in TSI using ground-based photometry, and what can be learned from these models. We will discuss different modeling techniques and show how accurately the models can reconstruct irradiance measurements made by spacecraft. We will argue that the construction of such models is an important adjunct to the measurement of TSI from space-based instruments because it can help identify possible scale changes in a single instrument, help bridge data gaps between two different instruments and, most importantly, will lead to an understanding of the sources of solar variability.

Solar Irradiance: Modes of Variation

Alexander Ruzmaikin [Alexander.Ruzmaikin@jpl.nasa.gov] and Joan Feynman, Jet Propulsion Laboratory, California Institute of Technology.

Solar Irradiance varies on multiple time scales. We identify the major modes of variability of the solar irradiance without making a prior assumption of any expected period of variation. We use the Empirical Mode Decomposition (EMD) method to accomplish this task. This method is based on adaptive filtering allowing the presentation of the data time series as a small number of non-linear and non-stationary modes. The method is well suited for describing the non-stationary nature of solar irradiance variability. We apply the EMD to the SORCE total and spectral irradiance data to identify the modes of variation on time scale shorter than the “11-year” cycle. For extracting modes and trends on longer time scales we use reconstructed irradiances.

Comparison of Long-Term Solar UV Irradiance Data Set and Proxy Model Data

Matthew T. DeLand [matthew_deland@ssaihq.com] and Richard P. Cebula, Science Systems and Applications, Inc. (SSAI), Lanham, MD.

The creation of sophisticated atmospheric models that can accurately represent variations in the Earth’s climate on decadal and longer time scales requires a proper characterization of temporal and spectral variations in solar ultraviolet irradiance. Existing solar UV data sets from individual satellite instruments do not cover more than one 11-year solar cycle. Various proxy models have been developed based on single irradiance data sets to provide long-term solar irradiance values, but these models have not typically been evaluated against other irradiance measurements from different time periods. We have recently created a composite solar UV irradiance data set using overlapping data sets from multiple instruments (SME, SBUV/2 on NOAA-9 and NOAA-11, SUSIM and SOLSTICE on UARS), covering the period November 1978 – July 2005 and the wavelength interval 120-400 nm. We will present comparisons between this data set and calculated UV irradiance values based on the model of Lean *et al.* [1997]. We will examine the relationship between these data sets in terms of absolute agreement, spectral dependence, and time dependence on different scales.

Irradiance Variations on Rotational Timescales: A Comparison Between SORCE Measurements and the SATIRE Model

Yvonne C. Unruh [y.unruh@imperial.ac.uk], Imperial College, London, UK; Natalie A. Krivova and Sami K. Solanki, Max-Planck-Institut fuer Sonnensystemforschung, Germany; and Jerald W. Harder, LASP, University of Colorado.

We compare the spectral irradiance variations observed with SORCE/SIM to the variations modeled using SATIRE for wavelengths spanning from 200 to 1600 nm during a number of solar rotations in 2004. The agreement between the measurements and the model is good at most wavelengths, in particular between 400 and 1300 nm, though the model fails below 220 nm as well as for some of the strong NUV lines.

The model allows us to disentangle the facular and spot contributions to the variability; this shows a shift from faculae-dominated variability in the NUV spot-dominated variability above approximately 400 nm.

Predictions of the Solar Cycle, Past and Present

Doug A. Biesecker [doug.biesecker@noaa.gov], NOAA Space Weather Prediction Center, Boulder, CO.

Interest in predictions of the level of solar activity years into the future are widely anticipated and required, both by the general science community and from customers of space weather products. Some customers would like forecasts as much as 17 years in the future. Since 1979, NOAA has periodically convened panels and workshops to address this need. The most recent panel released its initial prediction for solar cycle 24 in April, 2007. In this talk, we will review the modern techniques for predicting the solar cycle, from the precursor method of Ohl in the 1960's to the dynamo models of the 2000's. This will be followed by a summary of the results of each NOAA panel, including what each panel recommended and the bias shown in favor of specific techniques. Finally, we will review those techniques considered most promising in the present day and the prediction released by the solar cycle 24 panel.

Session 2: Atmospheric Models, Processes, and Solar Irradiance

NASA's Earth Observations of the Global Environment: Our Changing Planet and the View from Space

Michael D. King [michael.d.king@nasa.gov], NASA Goddard Space Flight Center, Greenbelt, MD.

Observations of the Earth from space over the past 30 years has enabled an increasingly detailed view of our Earth's atmosphere, land, oceans, and cryosphere, and its many alterations over time. With the advent of improvements in technology, together with increased understanding of the physical principles of remote sensing, it is now possible to routinely observe the global distribution of atmospheric constituents, including both cloud and aerosol optical properties, land surface reflectance, sea ice and glaciers, and numerous properties of the world's oceans.

This talk will review the current status of recent NASA Earth observing missions, and summarize key findings. These missions include EOS missions such as Landsat 7, QuikScat, Terra, Jason-1, Aqua, ICESat, SORCE, and Aura, as well as Earth probe missions such as TRMM and SeaWiFS. Recent findings from CloudSat and CALIPSO from the Earth System Science Pathfinder program will also be summarized, if time permits.

Due to its wide utilization by the Earth science community, both in the US and abroad, special emphasis will be placed on the Moderate Resolution Imaging Spectroradiometer (MODIS), developed by NASA and launched onboard the Terra spacecraft in 1999 and the Aqua spacecraft in 2002. As the quintessential instrument of the Earth Observing System, it is widely used for studies of the oceans, land, and atmosphere, and its lengthening time series of Earth observations is finding utilization in many communities for both climate, weather, and applications use.

Long-Term Multi-Dataset Analysis

David J. Lary [David.J.Lary@nasa.gov], NASA, Goddard Space Flight Center, Greenbelt, MD.

Addressing scientific issues usually involves the analysis of multiple datasets. We present a framework for bringing together multiple datasets from many missions to address some key-questions in atmospheric chemistry. This framework enables dataset validation, bias identification, bias correction, and the production of self-consistent analysis using Kalman filter data assimilation. Several examples will be shown.

Temperature and Ozone Response to the 11-year Solar Cycle in the Tropical Stratosphere as Revealed by Ensemble Simulation of Chemistry-Climate Model

Kiyotaka Shibata [kshibata@mri-jma.go.jp], Meteorological Research Institute (MRI), Tsukuba, Japan; and Kunihiko Kodera, Nagoya University, Japan.

Ensemble simulation of five members was made with the chemistry-climate model of Meteorological Research Institute (MRI-CCM) under the CCMVal REF1 scenario, in which observed forcings of SST, sea-ice, greenhouse gases, halogens, the 11-year solar cycle, and volcanic aerosols are given. The integration period covers 25 years from November 1979 to December 2004. Multiple linear regression analysis is used to isolate specific signals from the anomalies in temperature and ozone data using reference variables of the mean value, the linear trend, the QBOs at 20 and 50 hPa, the volcanic aerosols of El Chichón and Mount Pinatubo, El Niño/Southern Oscillation (ENSO), and the 11-year solar cycle. As an ensemble average of the annual-mean solar signals, MRI-CCM reproduced observed feature of ozone in the tropical stratosphere: the first maximum in the lower stratosphere and the second one in the upper stratosphere. Analysis of temperature and ozone solar signal for each member reveals that the first ozone maximum comes from a chemical effect of intensified UV radiation and cooling due to upwelling and that the second one is a dynamical effect due to transport of ozone-rich air accompanying downwelling.

Wednesday, Feb. 6

The Aura Mission

Mark Schoeberl [Mark.R.Schoeberl@nasa.gov], NASA Goddard Space Flight Center, Greenbelt, MD.

Aura was designed to probe the chemistry of the troposphere as well as the stratosphere. Two instruments, the Microwave Limb Sounder, the Tropospheric Emission Spectrometer (TES) and the Ozone Monitoring Instrument (OMI) have provided some remarkable information on pollution, long range pollution transport and strat-trop exchange. This talk will review some of the more startling observations and some new science that we are seeing in the Aura data.

Estimating When the Antarctic Ozone Hole Will Recover

Paul A. Newman [Paul.A.Newman@nasa.gov], NASA Goddard Space Flight Center, Greenbelt, MD; Eric R. Nash; Anne R. Douglass; J. Eric Nielsen; Steven Pawson; and Richard S. Stolarski.

The Antarctic ozone hole develops each year and culminates by early spring (late September - early October). The severity of the hole has been assessed from satellites using the minimum total ozone value from the October monthly mean (depth of the hole) and by calculating the average area coverage during this September-October period. Profile information shows that ozone is completely destroyed in the 14-21 km layer by early October. Ozone is mainly destroyed by halogen (chlorine and bromine) catalytic cycles, and these losses are modulated by temperature variations.

Because atmospheric halogen levels are responding to international agreements that limit or phase out production, the amount of halogens in the stratosphere should decrease over the next few decades. Using projections of halogen levels combined with age-of-air estimates, we find that the ozone hole is recovering at an extremely slow rate and that large ozone holes will regularly recur over the next 2 decades. We estimate that the ozone hole will begin to show first signs of size decrease in about 2023, and the hole will fully recover to pre-1980 levels in approximately 2070. Estimates of the ozone hole's recovery from models reveal important differences that will be discussed.

A Description of Hydrometeor Layer Occurrence Statistics Derived from the First Year of Merged CloudSat and CALIPSO Data

Jay Mace [jay.mace@utah.edu], University of Utah; Qiuqing Zhang; Mark Vaughn; Roger Marchand; Graeme Stephens; Chip Trepte; and Dave Winker.

The occurrence statistics of hydrometeor layers covering the earth's surface is described using the first year of millimeter radar data collected by CloudSat merged with lidar data collected by CALIPSO (July 2006-June 2007). These satellites are flown in a tight orbital configuration so that they probe nearly the same volumes of the atmosphere within 10-15 seconds of each other. This configuration combined with the capacity for millimeter radar to penetrate optically thick hydrometeor layers and the ability of the lidar to detect optically thin clouds, has allowed us to characterize the vertical and horizontal structure of hydrometeor layers with unprecedented precision. We find that the global hydrometeor coverage demonstrates a fairly smooth annual cycle with a range of 3% peaking in October 2006 and reaching a minimum in March 2007. The geographic distribution of hydrometeor layers defined in terms of layer base and layer thickness is described. The predominance of geometrically thin boundary layer clouds is illustrated as is the spatial distribution of upper tropospheric ice clouds in the tropics. The co-occurrence of multiple layers is shown to be a strong function of latitude and geography with co-occurring middle level (3km< layer base<6 km) and high level (base > 6km) layers being predominant over the continents. Cloud layer overlap is also examined and a bias due to an assumption of maximum fractional overlap in coarse resolution models is quantified and shown to be on the order -5 to -7% globally maximizing over the high latitude continents of the Northern Hemisphere.

On the Connection between Solar Spectral Irradiance, Planetary Wave Drag and the Zonal-Mean Circulation

Terrence R. Nathan [trnathan@ucdavis.edu] and John Albers, University of California, Davis; and Eugene C. Cordero, San Jose State University, CA.

An ever-increasing body of evidence shows that changes in solar spectral irradiance (SSI) over the 11-year solar cycle (SC) can produce changes in stratospheric ozone. Changes in stratospheric ozone can in turn produce changes in planetary wave drag (PWD) via longitudinal variations in ozone heating, which was recently expounded upon in a paper by Nathan and Cordero (2007, JGR-Atmospheres). Because SSI-induced changes in PWD may have potentially far-reaching consequences for the global circulation, including the zonal-mean flow, the Brewer-Dobson circulation and stratosphere-troposphere communication, it is important to understand the connection between SSI and PWD. In this study we employ analytical and numerical models of

the extratropical atmosphere to examine the connection between SSI and PWD. The models couple radiation, ozone and dynamics and provide in a relatively simple but self-consistent way the means to explicitly identify the pathways that connect changes in SSI to the wave-driven zonal-mean circulation. The sensitivity of the stratospheric circulation, particularly stratospheric sudden warmings, to changes in SSI associated with the SC is addressed.

Session 3: Models of Solar Processes Affecting Climate

Processes that Cause Solar Irradiance Variability

Mark Miesch [miesch@ucar.edu], High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO.

Convection transports energy from the deep solar interior to the photosphere where it is then radiated into space. The structure of solar convection therefore has important implications for solar irradiance variations on both local and global scales. Furthermore, baroclinicity induced by convective momentum and energy transport is now thought to play an important role in the maintenance of the solar differential rotation and meridional circulation, giving rise to a weak but persistent temperature increase of several Kelvin toward the poles. Finally, convection and the mean flows it maintains play an essential role in the solar dynamo, establishing patterns of magnetic activity which dominate solar variability on time scales of days to centuries. I will review recent insights into solar convection and dynamo processes obtained from high-resolution numerical simulations within the context of photospheric measurements and helioseismic inversions. I will also discuss other aspects of solar dynamo theory of relevance to solar irradiance observations including tachocline instabilities, torsional oscillations and longer-term solar variability.

Magnetic Flux Transport Modeling

Karel Schrijver [schryver@lmsal.com], Lockheed Martin, Advanced Technology Center, Palo Alto, CA.

Upon emergence from the solar interior, the Sun's magnetic field is moved about within the photosphere by a combination of flows, including the (super-)granular convection, the differential rotation, and the slow meridional advection towards the poles. On time scales up to a few years, the solar magnetic field disperses much like model runs for a randomly-walking, signed scalar that adds to like-signed concentrations or cancels against concentrations of the opposite sign. On time scales from years to centuries, however, inconsistencies show up that suggest that other processes also play a role. These may imply modulations of the global transport processes across the solar surface or a failure of the 2-dimensional description. I will review the successes and problems of the transport modeling for the surface magnetic field and for the heliospheric field resulting from it.

Solar Irradiance and Activity Reconstructions on Timescales up to Millennia

Sami K. Solanki [solanki-office@mps.mpg.de] and N. A. Krivova, Max-Planck-Institut fuer Sonnensystemforschung, Germany.

Directly measured indicators of solar activity are available since the Maunder Minimum, while irradiance measurements reach back to 1978 only. Going further back in time requires reconstructions of these two quantities. Depending on the time scale such reconstructions require different strategies. We present reconstructions of solar activity for times before the Maunder minimum and reconstructions of solar irradiance on different time scales.

Modeling the Spectral and Total Irradiance from Solar Atmospheric Structures

Juan Fontenla [juan.fontenla@lasp.colorado.edu], Mark Rast, and Jerry Harder, LASP, University of Colorado, Boulder.

Currently, several research groups model the solar irradiance through the identification of typical structures found on the solar surface. These methods construct the solar irradiance spectrum and the TSI by assembling the contributions depending on the characteristics of the structures associated with each pixel. The link between dynamo theory and solar irradiance is currently hampered by the lack of physical understanding of the origin and evolution of the magnetic field structuring and of how this affects the temperature and density distribution in the solar atmospheric structures that contribute to the irradiance spectrum.

Modeling of solar atmospheric structures physical properties allows the linking of spatially resolved observations of the solar spectrum with measurements of the solar spectral and total irradiance. However, an important missing link is the understanding of how the magnetic field physically determines or is determined by these structures. The answer to this question will be found when high spectral, spatial and temporal resolution observations are combined with realistic MHD and plasma simulations that allow for quantitatively interpreting such complex data. Currently, Hinode observations and magneto-convection simulations are making progress in that direction, but there is still much progress to be done.

Latitudinal Variation in the Solar Intensity During the Decline of Cycle 23

Mark Rast [mark.rast@lasp.colorado.edu], LASP, University of Colorado, Boulder.

We have measured latitudinal variation in the solar photospheric intensity using images from the Precision Solar Photometric Telescope at the Mauna Loa Solar Observatory. Along with the expected brightening of the solar activity belts, we have found a weak enhancement of the mean continuum intensity at polar latitudes (continuum intensity enhancement ~ 0.1 - 0.2% corresponding to a brightness temperature enhancement of ~2.5K). The appears to be thermal in origin and not due to a polar accumulation of weak magnetic elements, with both the continuum and CaIIK intensity distributions shifted towards higher values with little change in shape from their mid-latitude distributions. We discuss this result, efforts to understand systematic instrumental and processing errors in the data, and the potential to measure cycle dependent center-to-limb variation with consequent implications for solar structure.

Estimating the Next Solar Cycle

David Hathaway [david.hathaway@nasa.gov], NASA, Marshall Space Flight Center, Huntsville, AL.

Our understanding of the solar cycle has progressed to the point where sunspot data assimilated into dynamo models can reproduce the strengths of the last eight cycles and are providing estimates for the strength of the next solar cycle. Prior to these recent developments in dynamo theory, solar cycle predictions were made on the basis of statistical correlations between cycle strength and prior measurements of quantities such as geomagnetic activity or the Sun’s polar magnetic field strength. The newer dynamo models do make some connections between cycle strength and these previously used indicators. However, we are currently faced with a dilemma: one dynamo prediction (Dikpati, deToma, & Gilman, 2006) and one statistical precursor (geomagnetic activity - Hathaway & Wilson, 2006) suggest a very strong cycle while another dynamo prediction (Jiang, Chatterjee, & Choudhuri 2007) and another statistical precursor (polar field strength – Svalgaard, Cliver, & Kamide, 2005) suggest a very weak cycle. In this presentation I will explore the foundations of these predictions. This scientific dilemma should lead to new insights when the Sun reveals what it has in store for cycle 24.

How Star-Like is the Sun; How Solar-Like are the Stars?

Thomas R. Ayres [thomas.ayres@colorado.edu], Center for Astrophysics and Space Astronomy (CASA), University of Colorado, Boulder.

The guiding principle of the so-called Solar-Stellar connection (SSC) is that the Sun is a perfectly normal example of a G-type dwarf of the Milky Way's metal-rich Pop I. If this is true, we can use broad surveys of the distant but numerous field and cluster stars to help inform our understanding of general solar phenomena, such as the still enigmatic magnetic cycle; and similarly apply detailed measurements of solar processes to help us wrap theory around the sometimes rather curious behavior encountered among the myriad stars. If, on the other hand, the Sun actually deviates significantly from the normal behavior of stars, we not only lose our proximity leverage to answer broader cosmic questions, but also run the risk of over-applying hard-won stellar wisdom to an inapplicable case. This is particularly a concern in long term irradiance studies, where we might appeal, for example, to the photometric properties of G-type stars currently thought to be in Maunder Minimum-like states to project possible historical solar influences on terrestrial climate. Trying to establish how star-like is the Sun is complicated, and often frustrated, by the very different observational techniques applied in daytime astronomy compared with the sensitivity-disadvantaged "dark side." Here, I will provide a general review of areas where the Sun and stars appear to be congruent in their behavior, and areas where they appear not to be so similar. A key example is the nearby Alpha Centauri system, whose main component ("A") is considered a near twin of the Sun. Alpha Cen A, however, completely disappeared from X-ray sight in 2005, according to a careful study by the highly sensitive XMM-Newton observatory. This was reported at the time as completely unprecedented behavior for the corona of the Sun, or any Sun-like star previously observed by the broad X-ray survey of the earlier ROSAT satellite. Is this what a Maunder Minimum is like in X-rays? Or, was the "darkening of the solar twin" caused by some unrecognized instrumental effect? The surprising answer bears directly on the subject of this talk, and suggests that the stellar feedback part of the SSC is alive and well.

Brightness Variations of Solar Analogs during Activity Cycles and Grand Minima

Jeffrey C. Hall [jch@lowell.edu], G. W. Lockwood, and Brian A. Skiff, Lowell Observatory, Flagstaff, AZ; and Gregory W. Henry, Tennessee State University, Nashville.

Observations of Sun-Like Stars can be used to infer the probable envelope of solar brightness excursions prior to the advent of direct measurements. Of particular interest are (1) observations of secular activity and brightness changes in stars at successive activity cycle minima and (2) examination of the brightness variations of stars in, and transitioning to and from, grand minima. The time series of solar analogs from Lowell Observatory's Solar-Stellar Spectrograph (SSS) project now span 10-13 years for most true solar analogs of $V < 7.5$, and for most of these targets, we also have a decade or more of contemporaneous photometry from Tennessee State University's Automatic Photometric Telescopes at Fairborn observatory. In this talk, I will (1) provide the requested brief tutorial of the field, (2) present the photometric and spectroscopic time series for targets exhibiting some of the key phenomena noted above, and (3) discuss what our present understanding of the long-term behavior of solar analogs implies for the brightness history of the Sun, especially in regard to its transitions to and from Maunder Minimum-like phases.

Session 4: Climate Models, Processes, and Solar Irradiance

IPCC Report and Possible Solar Contributions to Climate Change

Caspar Ammann [Ammann@ucar.edu], National Center for Atmospheric Research, Climate and Global Dynamics Division – Paleoclimatology, Boulder, CO.

With the release of the extensive 4th Assessment Report of IPCC, a new era of broad acceptance of the unusual nature of the ongoing warming has been achieved. Recent advances in the available record combined with improved understanding of the climate system have now clarified remaining conceptual uncertainties and removed most of the contentious scientific issues that the increase in greenhouse gases is the dominant cause of the ongoing changes. Natural external forcing factors, such as solar variability and explosive volcanism, can explain a substantial amount of hemispheric scale climate variability prior to the 20th century. However, since at least the mid-20th century, these natural factors have been already been overwhelmed by anthropogenic forcing and their contribution to large scale mean climate will further diminish in the near future. There remain a number of highly relevant questions to be addressed by the climate change research community:

* a need to better understand long term feedbacks in the carbon cycle and the response of polar ice sheets to the warming; and how these factors affect future sea level,
* in order to make the science most relevant to local and regional decision makers (as well as the broad public), a more solid prediction of regional climate impacts are necessary.

What role could the sun-climate link play in these issues? While solar forcing over the recent past was non-negligible, it was probably quite small in amplitude. Nevertheless, climate variations in many areas around the world show a quasi systematic relationship with solar variability over a number of time scales. The proposition is made that past solar-induced climate variability driven by coupled atmosphere-(chemistry)-ocean dynamics could serve as benchmark for climate models to test their capability in representing the regional Earth System response to external forcing. Solar forcing lends itself particularly well because its variability at various time scales can be traced back for centuries and millennia while anthropogenic forcing is limited to a single, one sided, and relatively short trend so far. Thus, better understanding solar-induced changes in the past might help us sharpen the detection and assess the current capabilities in predicting the regional, greenhouse gas induced changes in the near future.

Modeling the Wavelength and Time Dependence of Solar Forcing of Earth's Atmosphere and Ocean Mixed Layer

Robert F. Cahalan [Robert.F.Cahalan@nasa.gov], NASA Goddard Space Flight Center, Greenbelt, MD; Guoyong Wen [wen@climate.gsfc.nasa.gov], NASA Goddard Space Flight Center & UMBC; Peter Pilewskie, LASP, University of Colorado; and Drew Shindell, NASA Goddard Institute for Space Studies.

In this study, we have extended a simple 1D radiative convective equilibrium model (Arking, 2005) to include the time dependence in studying the response of the ocean mixed layer and atmospheric temperatures to spectral variations of solar radiation as observed by the Spectral Irradiance Monitor (SIM) on SORCE. The UV, NIR and VIS, force the stratosphere, troposphere, and ocean mixed layers, respectively. Preliminary RCM (Radiative-Convective Model) results show significant differences in temperature profiles when driven by the SIM spectral solar irradiance (SSI) as compared to responses to other scenarios of change of TSI without spectral variations. We discuss plans to test the physical concepts suggested by this simple 1D model by studying similar forcing scenarios applied to GISS 3D model.

Reference:
Arking, A., "Effects of Bias in Solar Radiative Transfer Codes on Global Climate Model Simulations," *Geophys. Res. Lett.*, 32, L20717, doi: 10.1029/2005GL023644, 2005.

Thursday, Feb. 7

Fire vs Fire: Do Volcanoes or Solar Variability Contribute More to Past Climate Change?

Thomas Crowley [thomas.crowley@ed.ac.uk] and Gabriele Hegerl, School of Geosciences, The University of Edinburgh, Scotland.

Geologists in particular are quick to ascribe past centennial scale climate changes to solar variability. But successively refined records of volcanism from ice core studies suggest that pulses of volcanism explain more decadal temperature variance than can be linear linked to cosmogenic isotope variations. Formal statistical detection and attribution studies arrive at the same conclusion.

However, there still seems to be some (literally) wiggle room for perhaps a small contribution from solar. An example will be given from a 2000 year northern hemisphere temperature reconstruction that suggests (at least at the time of writing this abstract) that there may be a moderately significant solar linkage at ~200 year period.

Given time, a somewhat disconcerting apparent correlation between pulses of volcanism with the Dalton, Maunder, and Sporer Minima will be discussed. Given the unlikely physically significant correlations between the two, the possibility will be explored that cosmogenic records may have an uncorrected overprint from volcanically driven climate change.

Provisional summary judgement: solar may be at best marginally significant on the multidecadal to centennial time scale.

Exploring the Tropospheric Response to Solar Forcing

David Rind [drind@giss.nasa.gov], NASA Goddard Institute for Space Studies, NY; Judith Lean, NRL, Washington DC; and Patrick Lonergan and Jean Lerner, Columbia University, NY.

The investigation of the influence of solar cycles on the stratosphere/troposphere system has become increasingly sophisticated in the last decade, due to a combination of empirical analyses and modeling studies. However, there is still considerable uncertainty about the actual tropospheric response to changes in solar radiative output, and the potential mechanisms involved. At least three competing theories have been proposed: surface absorption of solar radiation changes altering tropospheric dynamics directly; surface absorption changes amplifying the natural modes of ocean-atmosphere coupling; and tropospheric responses driven from the stratosphere due to changes in stability or planetary wave propagation. While not necessarily mutually exclusive, these have some opposing interpretations and cause-effect relationships which we examine with an extensive set of climate model simulations.

Spectrally-differentiated solar radiation from 1950-2005 is input to GISS Global Climate/Middle Atmosphere Model 3 in four different atmospheric configurations and in conjunction with differing oceanic conditions (some 1500 years of simulations). Simulations in which the ocean is not allowed

to respond emphasize the solar “stratospheric forcing” of the troposphere, while simulations with the full ocean response illustrate the solar “surface-driving” capability. Analyses of the model simulations address the following: Do the standard runs reproduce the observed stratospheric and tropospheric temperature changes? Do the ∆SSTs in the calculated ocean runs match those in the historical data? Do the circulation and precipitation changes match those claimed for solar forcing? Are the results dependent on the ozone change profile; or the model resolution; or the other climate forcings that have been occurring?

Modeling Solar Cycle Impacts on Tropical Hydrology and Proxy Records

Gavin A. Schmidt [gschmidt@giss.nasa.gov] and D. T. Shindell, NASA Goddard Institute for Space Studies, NY; and C. Field, Columbia University, New York City.

Proxy records of past climate provide potential archives for assessing the impact of solar forcing on climate. However, those records are not necessarily easy to interpret. We report on recent advances in modeling the impact of solar forcing including full atmospheric chemistry, particularly on the tropical hydrological cycle, and whether (and how) those changes might be recorded in proxy archives. We will focus on records of 10Be in polar ice cores, and oxygen-isotope records in a variety of settings.

Climate Forcing Since 1960: What Does the Moon Have to Say?

Richard A. Keen [richard.keen@colorado.edu], University of Colorado, Dept. of Atmospheric and Oceanic Sciences, Boulder.

About once per year, on average, the moon is eclipsed as it passes into the Earth's shadow; at these times the moon can be used as a remote sensor of the global average optical depth of stratospheric aerosols of volcanic origin. The moon is visible during a total lunar eclipse due to sunlight refracted into the shadow (umbra) by the Earth's atmosphere (primarily by the stratosphere). Stratospheric aerosols can affect the observed brightness of the eclipsed moon, and the optical thickness of the aerosol layer can be determined from the difference between observed and predicted brightness of a lunar eclipse.

Eclipse data from 1960 to 2007 and from 1880 to 1888 suggest that the Pinatubo eruption in 1991 perturbed the stratospheric aerosol layer at least as much as that of Krakatau in 1883. The aerosol veil from Pinatubo disappeared between 1993 and 1996. Since 1997, stratospheric aerosols have been at or near background levels; this is the longest period with a clear stratosphere since before 1960.

CLARREO Overview

David Young [David.F.Young@nasa.gov], NASA Langley Research Center, Hampton, VA; and Don Anderson, NASA Headquarters, Washington, DC.

The Climate Absolute Radiance and Refractivity Observatory (CLARREO) Mission has been recommended in the NRC Decadal Survey as a key component of the future climate observing system. NASA and NOAA share responsibility for CLARREO. The NOAA component involves the continuity of measurements of incident solar irradiance and Earth energy budget by flying the TSIS and CERES sensors that were removed from NPOESS. The NASA portion involves the measurement of spectrally resolved thermal IR and reflected solar radiation at high absolute accuracy. Coupled with measurements from on-board GPS radio occultation receivers, these measurements will provide a long-term benchmarking data record for the detection, projection, and attribution of changes in the climate system. In addition, the SI traceable radiances will provide a source of absolute calibration for a wide range of visible and IR Earth observing sensors, greatly increasing their value for climate monitoring.

We will review the scientific objectives of CLARREO, possible mission configurations, and the potential impacts on climate science that the CLARREO data will provide. A summary of initial NASA preparations for implementation of this mission will also be presented.

NASA ES New Mission Concepts for the Future

Steve Volz, NASA Headquarters, Washington, DC.