SH31C MCC: 2000 Wednesday 1020h

Variability of Total Solar Irradiance: Measurements and Models *(joint with A, SA, GC)*

Presiding: **R C Willson,** Columbia University**; H Hudson,** University of California, Berkeley

SH31C-01 1025h INVITED

Models of Solar Irradiance on Time Scales of Minutes to Centuries

Sami K. Solanki (+49-5556-979 325; solanki@linmpi.mpg.de)

Max Planck Institute for Aeronomy, Max-Planck-Str. 2, Katlenburg-Lindau 37191, Germany

Solar irradiance varies on all time scales accessible to observations from minutes to the solar cycle. For the Earth's climate even longer time scales are of relevance, from centuries to millennia. A series of models have been or are being constructed to account for the irradiance variations at these different time scales, which are dominated by different physical processes. The results of the modelling are described and, where possible, are compared with the data and are discussed.

SH31C-02 1040h INVITED

The Construction of a Long Term Total Solar Irradiance Record and its Uncertainties.

Steven Dewitte[1] (++32-2-3730624; Steven.Dewitte@oma.be)

Dominique Crommelynck[1] (++32-2-3730600; Dominique.Crommelynck@oma.be)

Alexandre Joukoff[1] (++32-2-3730623; Alexandre.Joukoff@oma.be)

[1] Royal Meteorological Institute of Belgium, Ringlaan 3, Brussels B-1180, Belgium

The DIARAD radiometer is making measurements of the Total Solar Irradiance (TSI) as part of the VIRGO experiment on SOHO since 1996. We present its measurements and its in-flight ageing correction. The SOLCON radiometer has made point measurements of the TSI on the space shuttle in 1992, 1993, 1994, 1998, 2003. We use SOLCON as a reference instrument to make a composite of the TSI measurements of the radiometers ACRIM 2, SOVA 1, SOVA 2, DIARAD/VIRGO, PMO06/VIRGO. For further extension of the composite TSI in the past, a connection with the ACRIM1 measurements is needed. We investigate the possibility to use either the NIMBUS 7 or the ERBS radiometer to make this connection.

SH31C-03 1055h INVITED

Are there links between long-term changes in open solar flux, the distribution of emerged flux, cosmogenic isotopes and the total solar irradiance?

Michael Lockwood[1] (+44 1235 446496; m.lockwood@rl.ac.uk)

Simon S Foster[2] (+44 2380 592099; S.S.FOSTER@soton.ac.uk)

[1] Rutherford Appleton Lab., Space Science Department Chilton Oxfordshire, Didcot OX11 0QX, United Kingdom

[2] University of Southampton, Department of Physics and Astronomy, Hampshire, Southampton SO17 1BJ, United Kingdom

Recent reconstructions of variations in the total solar irradiance (TSI) over the last 300 years are similar in form to the variations of cosmogenic isotope abundances and the inferred variation of the open solar flux over the same interval. These reconstructions show a century-scale drift in TSI which is comparable in magnitude to the amplitude of recent solar cycle changes, namely of order 1 W m-2. In addition, strong links between paleoclimate records and cosmogenic isotopes have been found. These results also suggest a link between open solar flux and total solar irradiance. Modelling of the evolution of emerged flux by Wang et al. (2002) reproduces the inferred large changes (by a factor of order 2) in the open solar flux on century timescales, explaining the changes in cosmic ray fluxes and hence cosmogenic isotope abundance: however, this modelling also suggests that this is not associated with significant change in the photospheric magnetic flux, which modulates TSI on 11-year timescales. Thus the changes in the open flux and cosmogenic isotopes do not appear to be linked to the 100-year drift in TSI. The long-term variation in open flux has been shown to be associated with changes in the heliographic latitude of active regions and we show that the contribution of active region faculae to the TSI has changed by 0.2 W m-2 in the past 100 years because of the directional characteristics of the excess radiation from faculae. This suggests that small flux tubes of the "extended solar cycle", and any long-term change in their latitudes, could also have made a significant contribution to the long-term drift in TSI .

SH31C-04 1110h INVITED

Total Solar Irradiance Variability from 1978 to present

Claus Fröhlich (41-81-417-51-36; cfrohlich@pmodwrc.ch)

Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center, Dorfstrasse 33, Davos Dorf 7260, Switzerland

Since February 1996 VIRGO radiometers observe total solar irradiance from SOHO at L1, allowing continuous and uninterrupted observations of the Sun. Besides the 3-month gap during the SOHO vacation in summer 1998 and a few other minor gaps the record covers more than 99% of the almost 8 years of operation. This allows a very detailed assessment of the long-term behaviour of the two VIRGO radiometers, PMO6V and DIARAD. The results of this analysis are presented and their implications for other space radiometers discussed. With these data and those from HF/NIMBUS7, ACRIM-I/SMM and ACRIM-II/UARS a composite of total solar irradiance (TSI) is presented (updated and improved from Fröhlich and Lean, 1998), which covers now almost three solar cycles starting in November 1978, just before the maximum of solar cycle 21. Radiometrically the composite is based on ACRIM-I and ACRIM-II, with the latter shifted to the scale of ACRIM-I. During the gap between ACRIM-I and II the results from the HF radiometer are used. These data need to be corrected for a change which was first detected by comparison with ERBS. The inclusion or omittance of this change is the main reason for the discrepancy between this composite and the one presented by Willson and Mordvinov (2003). The discussion concentrates on this change and its determination by comparison of HF with ERBS and a proxy model for interpolation between its 14-day observations. Comparison of the composite with ERBS over the period from 1984-2003 supports very strongly the validity and need of the HF correction and confirms that TSI had no significant trend over the last 25 years of observation from space. References: C. Fröhlich and J. Lean, 1998, The Sun's Total Irradiance: Cycles and Trends in the Past Two Decades and Associated Climate Change Uncertainties, Geophys. Res. Let., **25**, 4377–4380 R. C. Willson and A. V. Mordvinov, 2003, Secular Total Solar Irradiance trend during solar cycles 21-23, Geophys. Res. Let., **30**, 1199–1202

SH31C-05 1125h INVITED

Spectroscopic increase of the flux from the solar temperature minimum region between the minimum-activity epochs 1984-87 and 1995-98.

William C Livingtson[1] (520 318 8374; wlivingtson@nso.edu)

Eugene H Avrett[2] (eavrett@spd.aas.org)

[1] National Solar Observatory, POB 26732, Tucson, AZ 85726

[2] Harvard-Smithsonian CfA, 60 Garden St, Cambridge, MA 02138

The photosphere is the visible surface of the Sun, the source of the continuous radiation that constitutes over 99% of the energy measured by spacecraft radiometers such as ACRIM. The temperature decreases with height in the photosphere out to a minimum region and then begins to increase in the chromosphere. The cores of the strong Fraunhofer absorption lines are formed just above the temperature minimum region. They do not have emission cores because of scattering effects. The weaker Fraunhofer lines are formed at and below the temperature minimum region. Since 1980 we have used the 1-meter Fourier Transform Spectrometer (FTS) on Kitt Peak to monitor the solar irradiance spectrum, and in particular, the line-center fluxes of the strong Sodium D and Magnesium b lines and 22 other weaker lines, mostly due to iron. A unique feature of this FTS instrument and its feed optics is that, over this 23 year interval, nothing, to our knowledge, has been changed or modified in any way. The central fluxes of all of the above lines decreased between the 1980 activity maximum and the 1986 minimum, as expected, and then increased as active regions again appeared on the disk. In 1990, however, as solar activity began to diminish, the Fraunhofer line fluxes continued to increase. They did not return to their 1986 minimum values during the 1996 minimum. Instead, the central fluxes of the strong lines increased by 10-15%. We have not found any instrumental effects that might account for this result. Preliminary quiet-Sun model calculations indicate that a temperature rise of a few hundred K in the temperature minimum region could account for such increases. However, the Ca K-index (residual flux in a 1-Å passband at the Ca II line center) was the same in 1996 as in 1986, and this places severe constraints on possible increases of quiet-Sun temperatures. Both the Fraunhofer and Ca II line observations represent line-to-continuum ratios, with the various lines and continua formed at different depths. We are investigating whether any combination of temperature variations at different depths might account for these observations. We note that the Willson and Mordvinov composite Total Solar Irradiance (TSI) signal indicated increased output from the Sun in 1995-98 compared to 1984-87. We hope to find an explanation for the Fraunhofer line increases between these two epochs, and, if so, to calculate the corresponding TSI change that would be expected.

SH31C-06 1140h INVITED

Composite total solar irradiance time series show a secular 0.04 %/decade trend

Richard C Willson[1] (619-522-2945; rwillson@acrim.com)

Alexander V Mordvinov[2] (7-3952-42-78-91; avm@iszf.irk.ru)

[1] Columbia University, 1001 B Ave., Ste 200, Coronado, CA 92118, United States

[2] Siberian Branch of Russian Academy of Sciences, P.O. Box 4026, Irkutsk, Sib 664033, Russian Federation

The satellite total solar irradiance (TSI) observational database extends over the past 25 years with useful precision for solar physics and climatology investigations. Willson & Mordvinov (2003) reconciled the published results from various experiments to a common scale using overlapping comparisons to produce a composite TSI time series with sufficient precision to resolve a TSI trend of + 0.04 %/decade between successive solar activity minima. Key to this process is determining the relationship of the results of the non-overlapping ACRIM1 and ACRIM2 experiments. Two overlapping sets of results are available for this purpose: Nimbus7/ERB and the ERBS/ERBE. The ACRIM composite approach, using unaltered results published by the science teams of each experiment demonstrates a + 0.04 %/decade trend between the solar minima of 1986 and 1996 using the more precise Nimbus7/ERB data to relate ACRIM1 & 2 results. The use of ERBS/ERBE results instead produces a negligibly small trend. This is shown to be the effect of uncorrected ERBS/ERBE degradation during the 2 year ACRIM gap whose magnitude and direction account for the trend difference precisely. A further illustration of this difference is the PMOD composite TSI model of Frohlich & Lean (1998) which uses ERBS/ERBE results to relate ACRIM1 and ACRIM2. It differs from the ACRIM composite in two significant respects: a negligible trend between solar minima and lower TSI at solar maxima. Our findings indicate PMOD's lower trend and lower TSI during solar cycles 22 and 23 maxima result from their use of the ERBS/ERBE data and are therefore artifacts of its uncorrected degradation. Lower PMOD TSI during the maximum of cycle 21 is the result of the modifications of published Nimbus7/ERB and ACRIM1 data made to produce better agreement with a TSI solar proxy regression model. These modifications are not based on reevaluation of basic experiment data or algorithms and are therefore less likely to be correct than the analyses by the ACRIM and Nimbus7/ERB science teams. Lastly, it has not been demonstrated that regression models employed by the PMOD composite are competitive with satellite TSI observations in precision or traceability and are therefore of dubious value in justifying modifications of published TSI observations. References: Frohlich & Lean, GRL., v. 25, 4377 (1998), Willson & Mordvinov, GRL, v. 30, 1199 (2000)

URL: http://www.acrim.com

SH31C-07 1155h INVITED

What is the Accuracy of the Total Irradiance Monitor?

Greg A. Kopp[1] (303-735-0934; Greg.Kopp@LASP.Colorado.edu)

George Lawrence[1] (George.Lawrence@LASP.Colorado.edu)

Gary Rottman[1] (Gary.Rottman@LASP.Colorado.edu)

[1]Laboratory for Atmospheric and Space Physics, University of Colorado 1234 Innovation Dr., Boulder, CO 80303, United States

The Total Irradiance Monitor (TIM) on NASA's SOlar Radiation and Climate Experiment (SORCE) is the most recently launched instrument to monitor the total solar irradiance (TSI). We present results from the first of the TIM's five years of operations and discuss the current knowledge of the instrument's accuracy. To date, we find the four instrument channels in good agreement and extremely robust against solar exposure. Such instrument characterizations and measurement accuracies influence the observational scenarios appropriate for determining long-term solar variability, and currently favor overlapping measurements of very stable TSI-monitoring instruments.

URL: http://lasp.colorado.edu/sorce/

SH32A MCC: Level 2 Wednesday 1330h

Total Solar Irradiance Monitoring: Results and Strategies Posters *(joint with A, SA, GC)*

Presiding: **R C Willson,** Columbia University**; J M Pap,** University of Maryland Baltimore County

SH32A-1098 1330h POSTER

NIST evaluation and calibration of several key parameters for the SORCE Total Irradiance Monitor (TIM): aperture area, diffraction effects, and cavity reflectance

Eric L. Shirley[1] (3019752349; eric.shirley@nist.gov)

Leonard M. Hanssen[1] (3019752344; leonard.hanssen@nist.gov)

B. Carol Johnson[1] (3019752322; cjohnson@nist.gov)

Joel B. Fowler[1] (3019752341; joel.fowler@nist.gov)

Maritoni Litorja[1] (3019758095; maritoni.litorja@nist.gov)

[1]Optical Technology Div., NIST, 100 Bureau Dr., MS 8441, Gaithersburg, MD 20899-8441, United States

TIM measures total solar irradiance E, through the ratio of total power Φ, recorded by an active-cavity radiometer, to entrance aperture area A. The as-measured power and area have uncertainties and corrections because of many complicating effects. Here we consider uncertainties in aperture-area measurements, diffraction, and cavity reflectance, all of which were analyzed at NIST. TIM has an entrance aperture that limits its radiation reaching the radiometer. Geometrically, all radiation passing through should land on the cavity opening. Thus, an entrance aperture area is a critical parameter. Areas were measured by two methods: a non-contact (optical) technique that located points on an aperture perimeter, fitted the points to a circle, and calculated the area, and a relative technique that equated the ratio, of the area to the area of a standard aperture, to the ratio of measured flux transmitted through the two apertures. We will discuss aspects of uncertainty in these measurements. Knowing the area of the entrance aperture is insufficient to know the instrument throughput, however, partly because of diffraction effects. Diffraction at the entrance aperture causes some light that geometrically would enter the cavity to miss it. Also, three non-limiting baffles between the entrance aperture and cavity can cause radiation diffracted at the entrance aperture to be re-scattered onto the cavity opening. We considered all of these diffraction effects in detail, and will discuss the diffraction correction on measured power and its uncertainty. Radiation reaching the cavity can be absorbed or reflected by the radiometer cavity cone. NIST performed directional hemispherical spectral reflectance measurements on several auxiliary TIM radiometer cones from 1 μm to 18 μm. The NIST system combines a custom infrared integrating sphere, unique absolute reflectance measurement method, and Fourier-transform spectrophotometer. These data augment the primary reflectance measurements done at seven discrete wavelengths in the visible, near- and mid-infrared, verifying discrete wavelength measurements in the infrared and spectral continuity across the infrared.

SH32A-1099 1330h POSTER

Magnetic Field and Long-Term Solar Irradiance Variations Over Solar Cycles 21 to 23

Judit M. Pap[1] (301-286-7511; papj@marta.gsfc.nasa.gsfc)

Michael Turmon[2] (818-393-5370; turmon@aig.jpl.nasa.gov)

Kacie E. Shelton[2] (818 393-5341; kacie@aig.jpl.nasa.gov)

Linton E. Floyd[3] (202-767-2258; linton.floyd@nrl.navy.mil)

Roger Helizon[2] (818-354-2488; roger@simdac.jpl.nasa.gov)

[1]University of Maryland Baltimore County, NASA/Goddard Space Flight Center, Code 680.0, Greenbelt, MD 20771, United States

[2]Jet Propuslion Laboratory, 4800 Oak Grove Dr., Pasadena, CA 91109, United States

[3]Interferometric Inc., Naval Research Laboratory, Code 7660, Washington, DC 20375, United States

Total solar and UV irradiance has been measured from various space platforms over the last two and half solar cycles. Results based on these multi-decade measurements have demonstrated that both total and UV irradiances change on time scales of days to decades, confirming that our Sun is indeed a variable star. High spatial and temporal resolution photometric and magnetic field observations conducted by the SOHO/MDI experiment and also from the ground have demonstrated that the surface of the Sun and its outer atmosphere are highly variable on almost all spatial scales. To understand the physical causes of irradiance variations, it is necessary to study the spatial and temporal characteristics and evolution of the solar magnetic fields and to establish to what extent solar magnetic features may contribute to irradiance variations. In this paper we analyze the total solar and UV irradiance composites compiled from various space measurements starting in late 1978. To establish the effect of surface magnetic activity on irradiance variations as a function of the solar cycle, we show the association of the absolute value of the full disk magnetic field strength data measured and compiled at the National Solar Observatory at Kitt Peak for the time interval of 1978 to date. Using various pattern recognition techniques, we compare the observed irradiance variations with solar features (sunspots and faculae), derived from the MDI and Kitt Peak magnetograms from 1996 and 1992, respectively.

SH32A-1100 1330h POSTER

Long-Term Total Irradiance Composites and Models

Roger Helizon[1] (818-354-2488; roger@simdac.jpl.nasa.gov)

Judit M. Pap[2] (301-286-7511; papj@marta.gsfc.nasa.gov)

[1]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, United States

[2]University of Maryland Baltimore County, NASA Goddard Space Flight Center, Code 680.0, Greenbelt, MD 20771, United States

Accurate long-term total and spectrally resolved solar irradiance measurements are required for full understanding of the response of Earth's atmosphere and climate to irradiance changes. Space-based irradiance observations over the last two and a half solar cycles span a time interval too short to reveal secular changes and/or to establish conclusively whether there are significant changes in the amplitude or the character of irradiance variations on longer time scales. Since the time period of interest far exceeds the lifespan of any single experiment, continuous measurement programs must be formulated to compile composite irradiance time series from data of several experiments. Because the absolute accuracy of the current measurements is limited ($\pm$0.2%) in case of total irradiance, overlapping and redundant measurements are needed to ensure that the resulting composite data sets represent the "true" solar behavior. However, the largest obstacle in creating the current long-term total irradiance composite is the two-year gap between the SMM/ACRIM I and UARS/ACRIM II measurements. Adjustment of the ACRIM I and ACRIM II data now must be made through the Nimbus-7/ERB and/or the ERBE measurements. While using the published Nimbus-7/ERB data set, Willson (1997) concluded that the minimum of cycle 22 was higher than the minimum of cycle 21, while Fröhlich and Lean (1998) claim that no trend can be seen in total irradiance within the current measurement accuracy. In this paper we compare various total irradiance time series and composites. Specifically, we will compare the Nimbus-7, ERBS, ACRIM II and EURECA total irradiance data for the 1991-1993 time frame and the ACRIM II, and VIRGO data for the time frame of 1996-2000 to clarify whether the minimma of cycles 21 and 22 are the same or they are indeed diffferent. Fröhlich, C. and Lean, J.: 1998, In *Proceedings of the IAU Symposium 185*, (ed. F.L. Deubner), Kluwer Academic Publishers, p. 89. Willson, R.C.: 1997, *Science* **277**, 1963.

SH32A-1101 1330h POSTER

First Results Of The Solar Bolometric Imager

Pietro N. Bernasconi[1] (443-778-8970; pietro.bernasconi@jhuapl.edu)

Peter Foukal[2] (pfoukal@world.std.edu)

Harry H.A.C. Eaton[1] (443-778-4506; harry.eaton@jhuapl.edu)

Dave M. Rust[1] (443-778-5414; david.rust@jhuapl.edu)

[1]JHU/Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723-6099, United States

[2]Heliospherics, Inc., Nahant, Nahant, MA 01908, United States

On September 1 2003, the Solar Bolometric Imager (SBI) successfully observed the Sun for several hours while suspended from a balloon in the stratosphere above New Mexico. The SBI represents a totally new approach in finding the sources of the solar irradiance variation. The mission provided the first bolometric (integrated light) maps of the solar photosphere, that will allow to evaluate the photometric contribution of magnetic structures more accurately than has been achievable with spectrally selective imaging over restricted wavebands. The more accurate removal of the magnetic features contribution will enable us to determine if solar irradiance variation mechanisms exist other than the effects of photospheric magnetism. The SBI detector was an array of 320 x 240 thermal IR elements whose spectral absorptance has been extended and flattened by a deposited layer of gold-black. The telescope was a 30-cm Dall-Kirkham with uncoated primary and secondary pyrex mirrors. The combination of telescope and bolometric array provided an image of the Sun with a flat spectral response between 0.28 and 2.6 microns, over a field of view of 917 x 687 arcsec with a pixel size of 2.8 arcsec. The observing platform was the gondola previously used for the Flare Genesis Experiment (FGE), retrofitted to house and control the SBI telescope and detector. During the 9 hours of flight the SBI gathered several thousand bolometric images that are now being processed to produce the first maps of the total solar irradiance. The SBI flight is also providing important engineering data to validate the space worthiness of the novel gold-blackened thermal array detectors, and to verify the thermal performance of the SBI's uncoated optics in a vacuum environment. In this paper we will briefly describe the characteristics of the SBI, its in flight performance, and we will present the first results of the analysis of the bolometric images. This work was funded by NASA under grant# NAG5-10998.

SH32A-1102 1330h POSTER

Solar irradiance variation during rapid sunspot growth

H. Jabran Zahid[1] (jabran@ssl.berkeley.edu)

Claus Frohlich[2] (cfrohlich@obsun.pmodwrc.ch)

Hugh Hudson[1] (510-643-0333; hhudson@ssl.berkeley.edu)

[1]SSL/UCB, Space Sciences Lab, UC, Berkeley, CA 94720-7450, United States

[2]PMO Davos, Dorfstrasse 33, Davos Dorf CH 7265, Switzerland

Large sunspot areas correspond to dips in the total solar irradiance (TSI), a phenomenon associated with the local suppression of convective energy transport in the spot region. Observations show a strong correlation between spot area and TSI. During the growth phase of a sunspot, though, other physics might conceivably affect this correlation. In this study we analyze the growth phase of NOAA active region 8179, in which large sunspots suddenly appeared near disk center at a time when few competing sunspots or plage regions were present on the visible hemisphere. The spot area of AR 8179 increased by a factor of two in less than 12 hours on March 13, 1998. The study makes use of the continuum images from SOHO/MDI and total-irradiance data from SOHO/VIRGO. We find that the area/TSI correlation does not significantly differ from the expected pattern of correlation, a result consistent with high thermal conductivity even at small depths below the photosphere. We have also searched for localized irradiance variations (transient bright rings) associated with the period of rapid growth. We discuss the significance of this lack of irradiance signatures of spot formation.