



Key Largo, Florida | 8–12 April 2013



**Causes and Consequences of the
Extended Solar Minimum
Between Solar Cycles 23 and 24
(4CESM)**

AGU Chapman Conference on Causes and Consequences of the Extended Solar Minimum Between Solar Cycles 23 and 24 (4CESM)

Key Largo, Florida, USA
8-12 April 2013

Conveners

Eduardo A. Araujo-Pradere, CIRES-University of Colorado, USA
Alexis P. Rouillard, Institut de Recherche en Astrophysique et Planétologie, France

Program Committee

Paul Charbonneau, Université de Montréal, Canada
Joseph Borovsky, Los Alamos National Laboratory, USA
Stanley Solomon, National Center for Atmospheric Research, USA
Jeffrey Thayer, University of Colorado at Boulder, USA
David Rusch, NASA, USA
Peter Riley, Predictive Science, Inc., USA
Michael Lockwood, University of Reading, U.K.
Simon Wing, The Johns Hopkins University, USA
Rodney Viereck, Space Weather Prediction Center-NOAA, USA

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AGU Chapman Conference on Causes and Consequences of the Extended Solar Minimum Between Solar Cycles 23 and 24 (4CESM)

Meeting At A Glance

Sunday, 7 April

6:00 p.m.-8:00 p.m. Welcome Reception

Monday, 8 April

8:30 a.m.-9:00 a.m. Welcome and Opening Remarks

9:00 a.m.-10:30 a.m. Space Climate: A Historical Perspective in Light of the Recent Solar Minimum (I)

10:30 a.m.-11:00 a.m. Morning Break

11:00 a.m.-12:35 p.m. Space Climate: A Historical Perspective in Light of the Recent Solar Minimum (II)

12:35 p.m.-1:45 p.m. Lunch (on own)

1:45 p.m.-4:15 p.m. Space Climate: A Historical Perspective in Light of the Recent Solar Minimum (III)

4:15 p.m.-4:45 p.m. Afternoon Break

4:45 p.m.-5:50 p.m. The Causes of Solar Spectral Variations and the Consequences on the Atmosphere-Ionosphere System (I)

Tuesday, 9 April

8:30 a.m.-10:15 a.m. The Causes of Solar Spectral Variations and the Consequences on the Atmosphere-Ionosphere System (II)

10:15 a.m.-10:45 a.m. Morning Break

10:45 a.m.-12:45 p.m. The Causes of Solar Spectral Variations and the Consequences on the Atmosphere-Ionosphere System (III)

12:45 p.m.-1:45 p.m. Lunch (on own)

1:45 p.m.-4:15 p.m. The Causes of Solar Spectral Variations and the Consequences on the Atmosphere-Ionosphere System (IV)

4:15 p.m.-4:30 p.m. Afternoon Break

4:30 p.m.-5:35 p.m. The Causes of Weak Solar Magnetism and the Consequences on the Solar Atmosphere and Heliosphere (I)

Wednesday, 10 April

8:30 a.m.-10:20 a.m. The Causes of Weak Solar Magnetism and the Consequences on the Solar Atmosphere and Heliosphere (II)

10:20 a.m.-10:40 a.m. Morning Break

10:40 a.m.-12:45 p.m. The Causes of Weak Solar Magnetism and the Consequences on the Solar Atmosphere and Heliosphere (III)

12:45 p.m.-1:45 p.m. Lunch (on own)

1:45 p.m.-4:00 p.m. The Causes of Weak Solar Magnetism and the Consequences on the Solar Atmosphere and Heliosphere (IV)

4:00 p.m.-4:15 p.m. Afternoon Break

4:15 p.m.-6:05 p.m. The Causes of Weak Solar Magnetism and the Consequences on the Solar Atmosphere and Heliosphere (V)

7:00 p.m.-9:00 p.m. Conference Banquet

Thursday, 11 April

8:30 a.m.-10:25 a.m. The Weak Solar Wind and the Consequences on the Coupling among the Solar Wind/Magnetosphere/Ionosphere Systems (I)

10:25 a.m.-10:45 a.m. Morning Break

10:45 a.m.-12:45 p.m. The Weak Solar Wind and the Consequences on the Coupling among the Solar Wind/Magnetosphere/Ionosphere Systems (II)

12:45 p.m.-1:45 p.m. Lunch (on own)

1:45 p.m.-3:50 p.m. The Weak Solar Wind and the Consequences on the Coupling among the Solar Wind/Magnetosphere/Ionosphere Systems (III)

3:50 p.m.-4:10 p.m. Afternoon Break

4:10 p.m.-6:20 p.m. The Weak Solar Wind and the Consequences on the Coupling among the Solar Wind/Magnetosphere/Ionosphere Systems (IV)

Friday, 12 April

8:30 a.m.-9:30 a.m. Discussion on The Weak Solar Wind and the Consequences on the Coupling among the Solar Wind/Magnetosphere/Ionosphere System

9:30 a.m.-11:00 a.m. General Discussion/Conclusions on the Recent Solar Minimum/Future Meetings/Proceedings

SCIENTIFIC PROGRAM

SUNDAY, 7 APRIL

6:00 p.m. – 8:00 p.m. **Welcome Reception**

MONDAY, 8 APRIL

Space Climate: A Historical Perspective in Light of the Recent Solar Minimum (I)

Presiding: Stanley C. Solomon, Pete Riley
Largo Ballroom

8:30 a.m. – 9:00 a.m. Welcome and Opening Remarks

9:00 a.m. – 9:25 a.m. **Moira M. Jardine** | Solar activity extrema in the broader context of stellar activity (Invited)

9:25 a.m. – 9:50 a.m. **Frédéric Clette** | Long-term variations in the sunspot number and sunspot properties (Invited)

9:50 a.m. – 10:10 a.m. **Lucia Villanueva** | Analog Model improvement for Sunspot Solar Cycle Minima 1700-2012

10:10 a.m. – 10:30 a.m. **Irina N. Kitiashvili** | Synergy of physics-based dynamo models and observations for prediction of solar activity

10:30 a.m. – 11:00 a.m. Morning Break

Space Climate: A Historical Perspective in Light of the Recent Solar Minimum (II)

Presiding: Stanley C. Solomon, Pete Riley
Largo Ballroom

11:00 a.m. – 11:25 a.m. **Mathew J. Owens** | Solar cycle 24 in a long-term context (Invited)

11:25 a.m. – 11:45 a.m. **Pete Riley** | The Structure of the Solar Corona and Inner Heliosphere during the Recent Solar Minimum and Inferences on Conditions that may have existed during the Maunder Minimum (Invited)

11:45 a.m. – 12:10 p.m. **Jack R. Jokipii** | Understanding Anomalous and Galactic Cosmic Rays at the Last Solar Minimum (Invited)

12:10 p.m. – 12:35 p.m. **Ilya Usoskin** | Long-term reconstructions of solar activity from cosmogenic isotopes and cosmic ray records (Invited)

12:35 p.m. – 1:45 p.m. Lunch

Space Climate: A Historical Perspective in Light of the Recent Solar Minimum (III)

Presiding: Stanley C. Solomon, Pete Riley
Largo Ballroom

- 1:45 p.m. – 2:05 p.m. **Kenneth G. McCracken** | Comparison of the cycle 23/24 solar minimum with solar activity throughout the past 9400 years, and the implications thereof
- 2:05 p.m. – 2:30 p.m. **Judith Lean** | Solar Irradiance Drivers of Space Climate in the Extended 2008-2009 Solar Minimum: Anomalous or Not? (Invited)
- 2:30 p.m. – 2:55 p.m. **Claus Froehlich** | Evidence of a Long-Term Trend in Total Solar Irradiance (Invited)
- 2:55 p.m. – 3:15 p.m. **Yongliang Zhang** | Observations of Ionosphere/Thermosphere Coupling and Response from Solar Max 23 to Solar Max 24
- 3:15 p.m. – 3:35 p.m. **Liyang Qian** | Global Change in the Upper Atmosphere and Ionosphere
- 3:35 p.m. – 4:15 p.m. Discussion on Historical Context of Recent Solar Minimum
- 4:15 p.m. – 4:45 p.m. Afternoon Break

The Causes of Solar Spectral Variations and the Consequences on the Atmosphere-Ionosphere System (I)

Presiding: Eduardo Araujo-Pradere, Dave Rusch
Largo Ballroom

- 4:45 p.m. – 5:05 p.m. **Rodney Viereck** | Solar EUV Irradiance Variability During Solar Minimum
- 5:05 p.m. – 5:25 p.m. **Farhad Shakeri** | The cycle-related solar VUV variability
- 5:25 p.m. – 5:50 p.m. **Martin G. Mlynczak** | SABER: OBSERVING THE PULSE OF THE SUN IN THE ATMOSPHERE OF THE EARTH (Invited)

TUESDAY, 9 APRIL

The Causes of Solar Spectral Variations and the Consequences on the Atmosphere-Ionosphere System (II)

Presiding: Eduardo Araujo-Pradere, Dave Rusch
Largo Ballroom

- 8:30 a.m. – 8:50 a.m. **Leonid V. Didkovsky** | A Change of Solar He II EUV Global Network Structure of the Transition Region as Indicator of Geo-Effectiveness of Solar Minima
- 8:50 a.m. – 9:15 a.m. **John Emmert** | Attribution of Inter-minima Differences in the Thermosphere and Ionosphere (Invited)

- 9:15 a.m. – 9:35 a.m. **Stanley C. Solomon** | Ionospheric Response to 2008-2009 Solar Cycle Minimum
- 9:35 a.m. – 9:55 a.m. **Andrew O. Akala** | Comparison of equatorial TEC at African and American longitudes during the minimum (2009, 2010) and ascending (2011) phases of solar cycle 24
- 9:55 a.m. – 10:15 a.m. **Irina Zakharenkova** | Estimation of the Ionosphere and Plasmasphere Contribution to the GPS TEC under Solar Minimum Conditions
- 10:15 a.m. – 10:45 a.m. Morning Break

The Causes of Solar Spectral Variations and the Consequences on the Atmosphere-Ionosphere System (III)

Presiding: Eduardo Araujo-Pradere, Dave Rusch
Largo Ballroom

- 10:45 a.m. – 11:05 a.m. **CV Anil Kumar** | (WITHDRAWN) A comparative study of chaotic behaviour of Total Electron Content at low, mid and high latitude stations
- 11:05 a.m. – 11:25 a.m. **Zhipeng Ren** | Simulated equinoctial asymmetry of the ionospheric vertical plasma drifts
- 11:25 a.m. – 11:45 a.m. **Alan Burns** | Day and Night Climatology of the F2 peak Ionosphere
- 11:45 a.m. – 12:05 p.m. **Claudia M. Nicoli Candido** | The ionosphere during the last two solar minimum periods over Brazilian region
- 12:05 p.m. – 12:25 p.m. **David E. Siskind** | Effect of non-migrating tides on thermospheric density and composition at solar minimum
- 12:25 p.m. – 12:45 p.m. **Eric K. Sutton** | (WITHDRAWN) The Role of Helium in the Thermosphere During Recent Solar Minima
- 12:45 p.m. – 1:45 p.m. Lunch

The Causes of Solar Spectral Variations and the Consequences on the Atmosphere-Ionosphere System (IV)

Presiding: Eduardo Araujo-Pradere, Dave Rusch
Largo Ballroom

- 1:45 p.m. – 2:05 p.m. **Jeff P. Thayer** | The Impact of Helium on Thermosphere Mass Density Response to Geomagnetic Activity During the Recent Solar Minimum
- 2:05 p.m. – 2:25 p.m. **Xianjing Liu** | Altitude variation of the thermosphere mass density response to geomagnetic storms during solar minimum

- 2:25 p.m. – 2:45 p.m. **Sharon L. Vadas |** (WITHDRAWN) Effects of gravity wave dissipation on the thermosphere and ionosphere from deep convection during the recent solar minimum
- 2:45 p.m. – 3:05 p.m. **Marcin Pilinski |** Measurement and Modeling of Thermospheric Density During Solar Minimum
- 3:05 p.m. – 3:25 p.m. **James M. Russell |** The Unique Opportunity to Study Polar Mesospheric Clouds Provided by the Extended Solar Minimum
- 3:25 p.m. – 4:15 p.m. Discussion on The Causes of Solar Spectral Variations and the Consequences on the Atmosphere-Ionosphere System
- 4:15 p.m. – 4:30 p.m. Afternoon Break
- The Causes of Weak Solar Magnetism and the Consequences on the Solar Atmosphere and Heliosphere (I)**
 Presiding: Simon Wing, Joseph Borovsky
 Largo Ballroom
- 4:30 p.m. – 4:55 p.m. **Laurent Gizon |** Imaging flows inside the Sun during the recent solar minimum (Invited)
- 4:55 p.m. – 5:15 p.m. **Alexander Kosovichev |** Helioseismic Constraints and Paradigm Shift in Solar Dynamo
- 5:15 p.m. – 5:35 p.m. **Sarbani Basu |** Comparing the internal structure of the Sun during the cycle 23 and cycle 24 minima

WEDNESDAY, 10 APRIL

- The Causes of Weak Solar Magnetism and the Consequences on the Solar Atmosphere and Heliosphere (II)**
 Presiding: Simon Wing, Joseph Borovsky
 Largo Ballroom
- 8:30 a.m. – 8:55 a.m. **Petrus C. Martens |** Can Dynamo Theory Explain Protracted Solar Minima? (Invited)
- 8:55 a.m. – 9:20 a.m. **Jie Jiang |** Polar field around cycle minima versus subsequent and preceding solar cycles (Invited)
- 9:20 a.m. – 9:40 a.m. **Irina N. Kitiashvili |** Dynamical coupling between the convection zone and the atmosphere in the quiet Sun
- 9:40 a.m. – 10:00 a.m. **Kim Thibault |** Restoring the baseline solar activity level: a simulation

10:00 a.m. – 10:20 a.m. **Robert J. Leamon** | On the Modulation of the Solar Activity Cycles, and Hemispheric Asymmetry of Solar Magnetism During the Cycle 23/24 Minimum

10:20 a.m. – 10:40 a.m. Morning Break

The Causes of Weak Solar Magnetism and the Consequences on the Solar Atmosphere and Heliosphere (III)

Presiding: Simon Wing, Joseph Borovsky
Largo Ballroom

10:40 a.m. – 11:05 a.m. **David H. Hathaway** | Effects of the Observed Meridional Flow Variations since 1996 on the Sun's Polar Fields (Invited)

11:05 a.m. – 11:25 a.m. **Edgar R. McCarvill** | (WITHDRAWN) NASA/NCAR data show system's polarity reversal change

11:25 a.m. – 11:45 a.m. **Richard C. Altrock** | (WITHDRAWN) The Radical Effect of the Extended Minimum on Long-Term Fe XIV Emission

11:45 a.m. – 12:05 p.m. **William Arden** | "Breathing" PFSS Source Surface for Cycle 23/24

12:05 p.m. – 12:25 p.m. **Richard Frazin** | Solar Cycle Variation of Inverted Temperature Loops in the Solar Minimum Corona

12:25 p.m. – 12:45 p.m. **Edgar R. McCarvill** | (WITHDRAWN) Solar EM basic Induction Principle & Force-fields between Coronal Axis and Heliopause

12:45 p.m. – 1:45 p.m. Lunch

The Causes of Weak Solar Magnetism and the Consequences on the Solar Atmosphere and Heliosphere (IV)

Presiding: Simon Wing, Joseph Borovsky
Largo Ballroom

1:45 p.m. – 2:10 p.m. **Charles W. Smith** | Interplanetary Magnetic Flux and the Protracted Solar Minimum: Balancing CME Eruption with Reconnection (Invited)

2:10 p.m. – 2:35 p.m. **Robert W. Ebert** | Comparing the Global Solar Wind Properties During the Minima Between Solar Cycles 22-23 and 23-24 (Invited)

2:35 p.m. – 2:55 p.m. **Antoinette B. Galvin** | Solar Wind Ion Characteristics During the Recent Extended Solar Minimum

2:55 p.m. – 3:20 p.m. **Nathan A. Schwadron** | Large-scale Magnetic Flux as a Regulator for Solar Wind and Coronal Conditions in the Deep Solar Minimum (Invited)

3:20 p.m. – 3:40 p.m. **Chin-Chun Wu** | Causes of extremely low solar wind density and magnetic fields during 2007-2009 solar minimum

- 3:40 p.m. – 4:00 p.m. **Charles W. Smith** | Interplanetary Turbulence During the Protracted Solar Minimum (Invited)
- 4:00 p.m. – 4:15 p.m. Afternoon Break
- The Causes of Weak Solar Magnetism and the Consequences on the Solar Atmosphere and Heliosphere (V)**
 Presiding: Simon Wing, Joseph Borovsky
 Largo Ballroom
- 4:15 p.m. – 4:40 p.m. **Nat Gopalswamy** | Large Solar Energetic Particle Events of Solar Cycles 23 and 24 (Invited)
- 4:40 p.m. – 5:00 p.m. **Pramod K. Purohit** | Solar Transients affecting Space Weather and their interconnection
- 5:00 p.m. – 5:20 p.m. **John D. Richardson** | Solar minimum in the outer heliosphere
- 5:20 p.m. – 5:45 p.m. **Edmond C. Roelof** | Properties of the Heliosheath during the Recent Protracted Solar Minimum: The Ground State (Invited)
- 5:45 p.m. – 6:05 p.m. **Vladimir A. Florinski** | THE GLOBAL HELIOSPHERE DURING THE PAST SOLAR MINIMUM: CONSEQUENCES FOR GALACTIC COSMIC RAYS
- 7:00 p.m. – 9:00 p.m. **Conference Banquet**

THURSDAY, 11 APRIL

- The Weak Solar Wind and the Consequences on the Coupling among the Solar Wind/Magnetosphere/Ionosphere Systems (I)**
 Presiding: Rodney Viereck, Jeff P. Thayer
 Largo Ballroom
- 8:30 a.m. – 9:15 a.m. Discussion on The Causes of Weak Solar Magnetism and the Consequences on the Solar Atmosphere and Heliosphere
- 9:15 a.m. – 9:40 a.m. **Jon A. Linker** | Global Coronal Structure and its influence on the Solar Wind in the Ecliptic Plane (Invited)
- 9:40 a.m. – 10:05 a.m. **Philippe L. Lamy** | COMPARING THE SOLAR MINIMA OF CYCLES 23 AND 24: THE VIEW FROM LASCO WHITE-LIGHT CORONAL IMAGES (Invited)
- 10:05 a.m. – 10:25 a.m. **Chin-Chun Wu** | Variability of the heliospheric current/plasma sheet thickness as the cause of solar wind anomaly during the 2007-2008 solar minimum

10:25 a.m. – 10:45 a.m. Morning Break

The Weak Solar Wind and the Consequences on the Coupling among the Solar Wind/Magnetosphere/Ionosphere Systems (II)

Presiding: Rodney Viereck, Jeff P. Thayer
Largo Ballroom

10:45 a.m. – 11:10 a.m. **Geoffrey D. Reeves** | Relativistic Electron Events and Radiation Belt Dynamics During a Deep Solar Minimum (Invited)

11:10 a.m. – 11:35 a.m. **Larry Kepko** | (WITHDRAWN) Does the magnetosphere-ionosphere reach a minimum energy state during protracted minima? (Invited)

11:35 a.m. – 12:00 p.m. **Stephen A. Fuselier** | Location and properties of dayside reconnection during deep minima (Invited)

12:00 p.m. – 12:20 p.m. **Simon Wing** | Solar cycle variations of the field-aligned currents and electron precipitation

12:20 p.m. – 12:45 p.m. **Lynn M. Kistler** | Impact of Deep Solar Minimum on O⁺ Abundance Throughout the Magnetosphere (Invited)

12:45 p.m. – 1:45 p.m. Lunch

The Weak Solar Wind and the Consequences on the Coupling among the Solar Wind/Magnetosphere/Ionosphere Systems (III)

Presiding: Rodney Viereck, Jeff P. Thayer
Largo Ballroom

1:45 p.m. – 2:10 p.m. **Robert L. McPherron** | Why Were Electrojets Weaker during the Last Solar Minimum in 2008? (Invited)

2:10 p.m. – 2:30 p.m. **Don McEwen** | (WITHDRAWN) DAYSIDE AURORAL INTENSITIES DURING SOLAR MINIMUM

2:30 p.m. – 2:50 p.m. **Noora Partamies** | Auroral ionosphere during the deep solar minimum

2:50 p.m. – 3:10 p.m. **William D. Cramer** | Modeling Ring Current Response during CIR-Driven Storms

3:10 p.m. – 3:30 p.m. **Niescja Turner** | Polar Cap Saturation and Geoefficiency in CIR-Driven Storms

3:30 p.m. – 3:50 p.m. **Joseph Borovsky** | The Reaction of the Earth to Helmet-Streamer CIRs and Pseudostreamer CIRs during the Declining Phase and Solar Minimum

3:50 p.m. – 4:10 p.m. Afternoon Break

The Weak Solar Wind and the Consequences on the Coupling among the Solar Wind/Magnetosphere/Ionosphere Systems (IV)

Presiding: Rodney Viereck, Jeff P. Thayer

Largo Ballroom

- 4:10 p.m. – 4:30 p.m. **Iurii Cherniak** | The global structure of ionospheric disturbances at extended solar minimum period
- 4:30 p.m. – 4:50 p.m. **Eduardo Araujo-Pradere** | Some Characteristics of the Global Ionospheric Behavior During During Solar Cycles 22-23 and 23-24 Minima
- 4:50 p.m. – 5:10 p.m. **Stan Solomon** | Anomalously low geomagnetic energy inputs during 2008 solar minimum
- 5:10 p.m. – 5:35 p.m. **Patrick T. Newell** | Substorm Recurrence Times and the Anomalous Minimum (Invited)
- 5:35 p.m. – 6:00 p.m. **Tuija I. Pulkkinen** | Is There a Minimum Number of Substorms During Protracted Solar Minima? (Invited)
- 6:00 p.m. – 6:20 p.m. **Bruce W. Binion** | Extended Solar Minimum Effects on Earthquake Triggers and Resultant Quake Severity

FRIDAY, 12 APRIL

- 8:30 a.m. – 9:30 a.m. **Discussion on The Weak Solar Wind and the Consequences on the Coupling among the Solar Wind/Magnetosphere/Ionosphere System**
- 9:30 a.m. – 11:00 a.m. **General Discussion/Conclusions on the Recent Solar Minimum/Future Meetings/Proceedings**

ABSTRACTS

listed by name of presenter

Akala, Andrew O.

Comparison of equatorial TEC at African and American longitudes during the minimum (2009, 2010) and ascending (2011) phases of solar cycle 24

Akala, Andrew O.^{1,2}; Akala, Andrew^{2,1}

1. Physics, University of Lagos, Lagos, Nigeria
2. Physics, University of Lagos, Lagos, Nigeria

Abstract This study compares equatorial total electron content (TEC) at African and American longitudes during the minimum (2009, 2010) and ascending (2011) phases of solar cycle 24. GPS-TEC data, which were observed at the same local time at two equatorial stations on both longitudes: Lagos (6.52oN, 3.4oE, 3.04oS magnetic latitude), Nigeria; and Pucallpa (8.38oS, 74.57oW, 4.25oN magnetic latitude), Peru were used for the investigation. These data were grouped into daily, seasonal and solar activity sets. Receiver and satellites biases were obtained from the Data Centre of the Bern University, Switzerland, and they were carefully removed from the TEC data. Furthermore, in order to eliminate multipath effects from the data, elevation angle cut-off of 30o was adopted. All the measurements within the hourly bin of a given data set were averaged together to provide a single data point for each local time hour. These GPS-TEC derived averages for non-storm days were thereafter compared with the corresponding values derived by the NeQuick coefficient of IRI-2007. In addition, harmonic analysis technique was used to extract the annual and semiannual components of the amplitudes of the TEC series at both stations. The day-to-day variation in vertical TEC (VTEC) recorded the maximum during 1400–1600 LT hours and minimum during 0400–0600 LT hours at both longitudes. Seasonally, during solar minimum, maximum VTEC values were observed during March Equinox and minimum during Solstices. However, during the ascending phase of the solar activity, the maximum values were recorded during the December Solstice and minimum during the June Solstice. VTEC also increased with solar activity at both longitudes. On longitude by longitude comparison, the African sector generally recorded higher VTEC values over the American sector. Semi-annual variations dominated the TEC series over the African equatorial sector, while the annual variations dominated those over the American equatorial sector. The NeQuick option of IRI-2007 showed better performance at the American longitude than the African longitude, with IRI-2007 underestimating TEC during the early morning hours at both longitudes.

Altrock, Richard C.

(WITHDRAWN) The Radical Effect of the Extended Minimum on Long-Term Fe XIV Emission

Altrock, Richard C.¹

1. Air Force Research Lab, Sunspot, NM, USA

Fe XIV 530.3 nm emission features typically appear at high latitudes near solar maximum and gradually migrate towards the equator, merging with the sunspot “butterfly diagram” (cf. Altrock, 1997, Solar Phys. 170, 411). In 1999, persistent Fe XIV coronal emission appeared near 70° in the north and began migrating towards the equator at a rate 40% slower than the previous two solar cycles. Discerning this process in the south is difficult. However, In 2009 and 2010 an acceleration occurred in both hemispheres, which did not occur in the previous two cycles. Another typical high-latitude process is the “Rush to the Poles” of polar crown prominences and their associated coronal emission, including Fe XIV. The Rush is a harbinger of solar maximum (cf. Altrock, 2003, Solar Phys. 216, 343). Cycle 24 displays an intermittent Rush that is only well-defined in the northern hemisphere. In 2009 an initial slope of 4.6 °/yr was found in the north, compared to an average of 9.4 ± 1.7 °/yr in the previous three cycles. However, in 2010 the slope increased to 7.5°/yr. These radical departures from typical solar-cycle features began during the extended minimum and appear to have had a radical effect on the development of Cycle 24. In Cycles 21 - 23 solar maximum occurred when the the maximum number of Fe XIV emission regions per day (averaged over 365 days and both hemispheres) first reached latitudes of $20^\circ \pm 1.7^\circ$, at similar times in the north and south. Currently the greatest number of emission regions is at 21° in the north and 24° in the south. This indicates that solar maximum is occurring now in the north but not yet in the south. Solar maximum in Cycles 21 - 23 occurred when the center line of the Rush to the Poles reached $76^\circ \pm 2^\circ$, again at similar times in the north and south. In the northern hemisphere this already occurred at 2011.6 ± 0.3 . In the southern hemisphere the Rush is very poorly defined. A linear fit to several maxima will reach 76° in the south at 2014.2, delaying solar maximum in the south until then. Confirming this are the observations that sunspot areas and numbers in the northern hemisphere reached a maximum in late 2011. The southern values are still increasing.

Araujo-Pradere, Eduardo

Some Characteristics of the Global Ionospheric Behavior During During Solar Cycles 22-23 and 23-24 Minima

Araujo-Pradere, Eduardo¹; Fuller-Rowell, Dominic¹; Fuller-Rowell, Tim¹

1. University of Colorado, Boulder, CO, USA

Solar cycle minimum 23/24 has been considered unusually deep and complex. In this presentation we study the ionospheric behavior during this minimum, and show some comparisons against the previous minimum. We have found that although close to the geophysical variability, the ionosphere response during the latest minimum is observable, and significant and consistent enough to consider that it does escape outside the range of normal geophysical variability of the system. Two main ionospheric parameters have been studied, vertical TEC (vTEC, total electron content) and NmF2 (peak concentration of the F region). While vTEC showed a consistent modest decrease of the mean value, NmF2 behavior was less clear, with instances where the mean value for minimum 23/24 was even higher than for minimum 22/23. A similar complex behavior is also shown by the height of the peak concentration (NmF2). This mixed behavior of the ionospheric parameters could indicate the depletion of the total ionospheric plasma content through less EUV ionization (Solomon et al., 2010), while the ionization at the F-region peak, NmF2, more complex, may be explained by the movement of the plasma caused by electric fields or neutral-wind interactions, which could suggest that less plasma was created during the 23-24 minimum, but that the peak density was more sensitive to global neutral dynamics, as well as plasma dynamics.

Arden, William

“Breathing” PFSS Source Surface for Cycle 23/24

Arden, William¹; Norton, Aimee²

1. University of Southern Queensland, Toowoomba, QLD, Australia
2. Stanford University, Stanford, CA, USA

Solar open magnetic flux is a major contributor to the interplanetary magnetic field (IMF), which in turn has a significant impact on the behavior of the Earth's magnetosphere. A widely-used method of computing solar open flux is the potential field source surface, or PFSS, model. PFSS modeling begins with a photospheric magnetic map and extrapolates the surface field to a “source surface,” a sphere surrounding the Sun beyond which all magnetic field lines are assumed to be open (i.e., closing at a distance beyond the Earth). The radius of this source surface, typically taken to be 2.5 solar radii (Rs), can also be taken as a free parameter. Work by others (for example, Lee et al. (2011), Sol. Phys. 269: 367) suggests that lowering the source surface height to values of ~1.5-1.8 Rs during periods of solar minimum yields better agreement between the PFSS model and measured IMF open flux at 1 AU. Our current work examines the evolution of open flux over the whole of

cycle 23 and the first part of cycle 24 using photospheric field maps from the SOHO MDI and SDO HMI instruments. We examine the variation of the PFSS source surface height that provides a best fit to the IMF open flux at 1 AU (using the OMNI 2 data set) for the time periods of 1996 - 2012 (all of cycle 23 and a portion of 24).

Basu, Sarbani

Comparing the internal structure of the Sun during the cycle 23 and cycle 24 minima

Basu, Sarbani¹; Broomhall, Anne-Marie²; Chaplin, William J.³; Elsworth, Yvonne³; Davies, Guy R.³; Larson, Timothy P.⁴; Schou, Jesper⁴

1. Astronomy, Yale University, New Haven, CT, USA
2. University of Warwick, Warwick, United Kingdom
3. University of Birmingham, Birmingham, United Kingdom
4. Stanford University, Stanford, CA, USA

Helioseismic analyses have shown that the dynamics of the solar interior during the cycle 24 minimum were quite different from that of the cycle 23 minimum. Differences were most noticeable in the speed and pattern of the solar zonal flows (otherwise known as torsional oscillations) as well as in the meridional flows. Analysis of low-degree solar oscillation frequencies have also shown that the descending phase of cycle 23 was quite different from that of cycle 22. We perform a detailed analysis of the differences in solar oscillation frequencies during the cycle 23 and cycle 24 minima to determine whether or not the differences indicate any measurable change in solar structure between the two epochs. We also attempt to do the same for the cycle 22 minimum, and the cycle 23 and 24 minima, although the data for the cycle 22 minimum are much more noisy. We use helioseismic data obtained by the Birmingham Solar-Oscillations Network (BiSON) and the Michelson Doppler Imager (MDI) on board SOHO.

Binion, Bruce W.

Extended Solar Minimum Effects on Earthquake Triggers and Resultant Quake Severity

Binion, Bruce W.^{2,1}

1. Research, PPG, Pittsburgh, PA, USA
2. Energy, Alliant Energy, Cedar Rapids, IA, USA

Earthquakes occurring at a depth of 0 - 35 km are often triggered by solar events. During the extended solar minimum there was an opportunity to determine three things: First of all, which quakes and quake regions were the exceptions to external triggers due to fault or tectonic interface complexity, an underlying anomaly in the upper mantle, or no external trigger event leaving a simple movement due to a maximum storage of energy; Second, there was a concern that without a somewhat routine round of trigger events the mechanical energy being stored along faults would not be dissipated and therefore stored until a trigger event or break-over of the fault. Data has shown an increase in triggered quake severity when solar events

resumed; Third, use the quiet time of the Maunder Minimum along with the return of solar events to identify each aspect of forces contributing to triggered earthquakes, to calibrate the threshold values needed to make a difference in each of the known forces, determine which ones effect a change alone and when combined together, that is, solar wind density, wind speed, field direction, and flare x-ray strength. Also, determine other forces that have remained hidden in the data. Study of data from the extended solar minimum has shown a need for a multi-discipline effort to catalog and model the effects of a solar cycle on Earth's surface. There are opportunities for students and seasoned professionals to create real-time imaging that will expand awareness of the ancient affliction of earthquakes.

Borovsky, Joseph

The Reaction of the Earth to Helmet-Streamer CIRs and Pseudostreamer CIRs during the Declining Phase and Solar Minimum

Borovsky, Joseph^{1,2}; Denton, Michael H.^{3,1}

1. Space Science Institute, Boulder, CO, USA
2. University of Michigan, Ann Arbor, MI, USA
3. Lancaster University, Lancaster, United Kingdom

A corotating interaction region (CIR) is formed when fast solar wind of coronal-hole origin overtakes slower plasma of streamer-belt origin: the leading edge of the coronal-hole plasma and the trailing edge of the streamer-belt plasma become compressed in the interaction. During the declining phase of the solar cycle and during solar minimum, CIRs dominate the large-scale structure of the solar wind resulting in 27-day repeating patterns of geomagnetic activity. Several-day-long activations of the magnetosphere can occur during the passage of fast coronal-hole-origin plasma, particularly if the magnetic sector of the coronal-hole plasma is Russell-McPherron effective. The streamer-belt plasma ahead of the CIR can originate either from a helmet streamer or a pseudostreamer on the Sun. The helmet streamer is characterized by a magnetic sector reversal, whereas the pseudostreamer contains no sector reversal. If the fast wind is Russell-McPherron effective, the slow wind preceding a sector reversal will be Russell-McPherron ineffective: this is the case for a helmet-streamer CIR which leads to the common "calm before the storm" that preconditions the magnetosphere for the storm. If the slow wind preceding the CIR is of pseudostreamer origin, no sector reversal will be present, no calm before the storm will occur, and no magnetospheric preconditioning will occur. Other differences between the Earth's reaction to helmet-streamer CIRs and pseudostreamer CIRs are explored: systematic differences in the Alfvén Mach number of the solar wind, efficiencies of the reconnection-coupled solar-wind generator, the strength of the superdense plasma sheet, and dropouts of the outer electron radiation belt.

Burns, Alan

Day and Night Climatology of the F2 peak Ionosphere

Burns, Alan¹; Solomon, Stanley¹; Wang, Wenbin¹; Qian, Liying¹

1. NCAR, Boulder, CO, USA

The daytime climatology of the F2-region peak electron densities is dominated by a series of anomalies: the winter anomaly; the annual anomaly; the equatorial anomaly; and the equinoctial peaks. Apart from the lack of a winter anomaly, these anomalies continued to dominate the F2-region ionospheric electron densities in the last solar minimum as well. Coupled with these density changes, the height of the F2 peak also has some very clear climatological patterns. The greatest F2 peak heights are found on the summer side of magnetic equator and near to it. At middle latitudes the F2 peak is higher in summer than in winter as it is at high latitudes. Less work has been undertaken on the F2 peak climatology at night. A collapse of the F2 peak ionosphere is known to occur at midnight, decreasing electron densities. But the question of what else happens at night is an open one. In this work we use COSMIC and ionosonde observations both to describe the summer behavior of the daytime F2 peak ionosphere in the last solar minimum, and extend it to describe what happens to the F2 peak climatology between midnight and dawn. Among our findings are that the midnight collapse does not occur at middle latitudes in summer and that the greatest electron densities between midnight and dawn occur in the middle latitudes, rather than in the equatorial anomaly region. We also use ionosonde data to determine whether this night time data in the 2007-2009 solar minimum is consistent with the night time data in the 1996 solar minimum.

Cherniak, Iurii

The global structure of ionospheric disturbances at extended solar minimum period

Cherniak, Iurii¹; Zakharenkova, Irina¹; Shagimuratov, Irk¹; Krankowski, Andrzej²

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2. GRL, University of Warmia and Mazury in Olsztyn, Olsztyn, Poland

The knowledge about ionosphere is necessary for design and operation of space vehicles, remote sensing, navigation and communication. One of the most challenging tasks in upper atmosphere physics is the proper representation of the ionospheric response to space weather changes. The last extended solar minimum conditions and the beginning of the new 24th solar cycle give us an opportunity to investigate the ionosphere disturbances at background of extremely low electron density values. For study of global structure of ionospheric disturbances was used the different data provided by ground-based and satellite ionosphere measurements. It was processed the data from European,

American, Japanese, and Australian ionosonde networks as benchmark data source. The ionosphere modification on a global scale have been checked with use of Global Ionospheric Maps, provided by international GNSS Service, and data from FORMOSAT-3/COSMIC RO mission. Additionally for estimation of the electron density dynamic at high latitudes was analyzed TEC fluctuations map, created by IGS/EPN, PBO and POLENET data. As case study events have been selected geomagnetic disturbances occurred on October 2008, July 2009, May 2010 and September 2011, when observed more essential ionospheric responses. The global maps of TEC were used in order to estimate large scale storm effects, ionosonde data gives possibilities to study the local peculiarities of the ionosphere disturbances (two parameters have been processed – the NmF2 and hmF2). Additionally for analysis of the height ionospheric structure we combined ionosonde-derived data with the Ne profiles from FORMOSAT-3/COSMIC RO measurements and global distribution of electron density at selected altitudinal intervals. It was resulted that selected moderate geomagnetic storms ($K_p \sim 6$) lead to the different ionospheric response (positive and negative) over European, American, Japan and Australian areas. The global pattern and local temporal and quantitative characteristics of the ionosphere disturbances during selected storms were revealed. For example geomagnetic storm October 11, 2008 lead to short time positive ionospheric disturbance over Europe in TEC values with factor 2, foF2 - with factor 1,5-1,8 and uplifting of F2 layer maximum up to 100 km. Additionally it was carried out the comparison of ionosonde derived foF2 values with IRI-2007 model, that have the storm-time option. It was obtained the qualitative agreement between the ionosonde-derived foF2 values and model calculations for cases of negative ionospheric storms. The best agreement between model and observations results corresponds to the Northern Hemisphere mid-latitude stations. We acknowledge the Australian IPS Radio and Space service and the National Institute of Information and Communications Technology (NICT) in Japan for providing ionosonde data. The authors would like to thank B.W. Reinisch and the Center of Atmospheric Research, University of Massachusetts Lowell for the ionogram data of DIDBase. We are also grateful to International GNSS Service (IGS) for GPS TEC products.

Clette, Frédéric

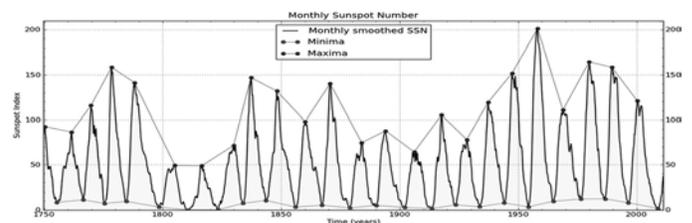
Long-term variations in the sunspot number and sunspot properties (Invited)

Clette, Frédéric¹; Lefèvre, Laure¹

1. SIDC -SILSO, Observatoire Royal de Belgique, Brussels, Belgium

The international sunspot number, based on visual sunspot counts, is widely used as the main reference index characterizing the long-term evolution of solar activity over time-scales of decades to centuries. Given the recent unexpected changes in cycles 23 and 24, it has become even more important to better understand the historical

evolution in the production of this prime index and to assess the long-term stability of its absolute scale. Therefore, we first review the properties of this series, the past and present calculation methods as well as the relation between the sunspot number and other solar indices and standard fluxes available over the last decades. Using such comparisons, a few possible disruptions and biases have recently been identified in this historical sunspot series over the 19th and 20th century, with magnitudes of 10 to 20%. We report recent progresses in the identification of possible causes and we outline the proposed corrections to the standard sunspot number based on those diagnostics. By providing a 400-year perspective, the sunspot index also helps us to better put the recent anomalies of the cycle 23-24 transition in a secular perspective. We will consider here how recent global trends in detailed sunspot properties, like the decline of the average spot core magnetic field (Penn-Livingston effect) or a scale-dependent small-spot deficit, could explain the reported divergence between the sunspot number and several other solar activity indices, like the F10.7cm radio flux. We interpret the current change in the sunspot number as a genuine evolution in the sunspot production. With cycle 24, the Sun is apparently returning to an average activity regime that prevailed during most of the last 300 years, before the tight succession of 5 strong cycles marking the last 60 years. Given this unique “grand-maximum” episode and the observed scale-dependent changes in sunspots, the current solar proxies may need to be re-calibrated to match past weaker solar cycles, using more than a simple linear rescaling. We conclude on the future evolution and extension of the sunspot number record, where the extraction of detailed sunspot information from archives of past sunspot drawings and imagery can play a key role to fulfil the new needs of state-of-the-art solar cycle and dynamo studies, beyond the global spot count leading to the base sunspot number.



Cramer, William D.

Modeling Ring Current Response during CIR-Driven Storms

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2. NASA Goddard Space Flight Center, Greenbelt, MD, USA
3. CRESST and Geospace Physics Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD, USA
4. Department of Astronomy, University of Maryland, College Park, MD, USA

Ring current models have generally performed less well at reproducing the storm-time magnetic disturbance at the Earth's equator (Dst) for storms driven by Corotating Interaction Regions (CIRs) than for those driven by Coronal Mass Ejections (CMEs). The reason for this difference is investigated by modeling ring current response for storms of various strengths and drivers in order to ascertain how those parameters affect the accuracy of the simulation. The Comprehensive Ring Current Model (CRCM) is employed with a steady magnetospheric magnetic field configuration so the focus is on the effects of convection and plasma sheet density. Selected storms cover the complete range of possible storm strengths (based on Dst*) and have associated solar wind parameter values that conform to a typical profile. Model results confirm the importance of convection and boundary conditions on ring current energization. They show excellent agreement with the actual values for CME-driven storms, but much poorer agreement for CIR-driven storms. The dependence of peak modeled Dst* on actual Dst* was found to be statistically different for storms of the two different categories and substorm activity was shown to likely be a factor in the accuracy of Dst reproduction for CIR-driven storms.

Didkovsky, Leonid V.

A Change of Solar He II EUV Global Network Structure of the Transition Region as Indicator of Geo-Effectiveness of Solar Minima

Didkovsky, Leonid V.¹; Gurman, Joseph B.²

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2. GSFC, Goddard, MD, USA

Solar activity during 2007-2009 was very low causing anomalously low thermosphere density. A comparison of solar EUV irradiance in the He II spectral band (26 to 34 nm) from the SOHO/CELIAS/SEM for the two latest solar minima showed a decrease of the absolute irradiance of about 15 % during the solar minimum 23/24 compared to the 22/23 minimum when a yearly running mean filter was used. We found that shorter-term minima including those with the same absolute EUV flux in the SEM spectral band show larger concentration of spatial power in the global network structure for the local minima of 1996 compared to

the minima of 2008-2010. This larger concentration of the spatial power in the Transition region's global network structure is interpreted as a larger number of the larger area features on the solar disk. Such changes of the global network structure during solar minima may characterize, in part, the geo-effectiveness of the solar He II EUV irradiance in addition to the estimations based on its absolute levels.

Ebert, Robert W.

Comparing the Global Solar Wind Properties During the Minima Between Solar Cycles 22-23 and 23-24 (Invited)

Ebert, Robert W.¹; Dayeh, Maher A.¹; Desai, Mihir I.^{1,2}; McComas, David J.^{1,2}; Pogorelov, Nikolai V.³

1. Southwest Research Institute, San Antonio, TX, USA
2. University of Texas at San Antonio, San Antonio, TX, USA
3. University of Alabama at Huntsville, Huntsville, AL, USA

Comparison of fast polar coronal hole solar wind and interplanetary magnetic field (IMF) observations between ~1 – 5 AU from Ulysses during the solar minimum between solar cycles 22-23 and 23-24 revealed significant, long-term variations in the solar wind output from the Sun. The most notable was the slight decrease in fast solar wind speed, more significant reductions in its density, temperature, mass flux, and dynamic pressure, and a similar drop in the IMF strength during the solar cycle 23-24 minimum. The slower, in-ecliptic solar wind observations from Ulysses and 1 AU spacecraft such as ACE and Wind showed similar trends, the slow wind extending to higher latitudes during the 23-24 minimum. In this talk, we describe these reductions in solar wind output, discuss how they provide insight into solar wind energization near the Sun, and examine their effect on the global structure of the heliosphere.

Emmert, John

Attribution of Inter-minima Differences in the Thermosphere and Ionosphere (Invited)

Emmert, John¹; Lean, Judith¹; Meier, Robert²; McDonald, Sarah¹; Drob, Douglas¹; Picone, Michael²

1. Space Science Division, U.S. Naval Research Lab, Washington, DC, USA
2. Dept. of Physics and Astronomy, George Mason University, Fairfax, VA, USA

We investigate differences in thermospheric and ionospheric (T-I) behavior between the two most recent minima of the 11-year solar cycle, using mass densities derived from orbital drag, and ionospheric total electron content (TEC) derived from Global Positioning System (GPS) signals. At 400 km altitude during the year centered on the cycle 23/24 solar minimum (epoch 2008.8), global thermospheric mass density was 36% lower than during the cycle 22/23 minimum (epoch 1996.4). Based on empirical modeling of past behavior of the density data, we estimate that 13% is attributable to lower average solar extreme ultraviolet (EUV) irradiance levels, at least 12% to lower

average geomagnetic activity levels, and the remaining 11% to other effects, including enhanced CO₂ cooling. In contrast, the only global TEC data spanning both solar minima indicate little or no inter-minima change, a result that is difficult to reconcile with a drop in EUV levels. Of the three known drivers of inter-minima global T-I changes (EUV, geomagnetic activity, and CO₂), EUV changes have the greatest uncertainty. In addition, the height dependence of the 2008 mass density anomalies indicates that they arise from both unusually low exospheric temperatures and unusually low concentrations of atomic oxygen. The latter result is supported by ultraviolet remote sensing of the thermosphere, and suggests that changes in lower thermospheric dynamics may be playing a role. We compare the results of our empirical attribution with simulations using the Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM) and the SAMI3 ionosphere model. For the SAMI3 runs, we specify a neutral atmosphere consistent with the orbit-derived mass density.

Florinski, Vladimir A.

THE GLOBAL HELIOSPHERE DURING THE PAST SOLAR MINIMUM: CONSEQUENCES FOR GALACTIC COSMIC RAYS

Florinski, Vladimir A.¹; Guo, Xiaocheng¹; Senanayake, Udara¹

1. CSPAR, University of Alabama, Huntsville, AL, USA

We present a theoretician/modeler view of the past protracted solar minimum throughout the outer heliosphere, from several AU up to the heliopause. During this period the termination shock approached within 80 AU and the heliopause structure within 120-130 AU of the Sun. The shrunk heliosphere with a weaker solar wind and magnetic field was a less efficient barrier to galactic cosmic rays (GCRs) that reached record intensities during that period. We present the results of our global GCR modeling framework simulating their transport from the interstellar boundary to the inner heliosphere. The role of the heliosheath in the GCR modulation process is discussed. We discuss our results in the context of recent Voyager measurements near the interstellar boundary and explore the possibility of cosmic-ray modulation beyond the heliopause. We also discuss the production of anomalous cosmic rays on the flank and tail regions of the termination shock and compare their acceleration and transport during solar cycle periods of opposite polarity.

Frazin, Richard

Solar Cycle Variation of Inverted Temperature Loops in the Solar Minimum Corona

Frazin, Richard¹

1. University of Michigan, Ann Arbor, MI, USA

The combination of Differential Emission Measure Tomography (DEMT) with magnetic models allows determination of the electron density and electron temperature along individual magnetic field lines. The

approach, named the Michigan Loop Diagnostic Technique (MLDT), has been recently first applied to study the last absolute minimum during Carrington rotation (CR) 2077, between solar cycles (SC)-23 and 24. In that work, two types of quiet Sun (QS) coronal loops were identified: 'up' loops in which the temperature increases with height, and 'down' loops in which the temperature decreases with height. While the first ones are expected, the latter ones were a surprise and, furthermore, found to be ubiquitous in the low-latitude corona. In the present work we extend the analysis to several CRs around the last solar minimum. We found that the down population, which is always located in the low-latitude region, maximized when the sunspot number was minimum. The number of down loops systematically increased during the declining phase of SC-23 and diminished during the rising phase of SC-24. We show that some down loop properties can be reproduced within a two-temperature global MHD model that has an enhanced wave reflection coefficient and discuss the implications for coronal heating.

Froehlich, Claus

Evidence of a Long-Term Trend in Total Solar Irradiance (Invited)

Froehlich, Claus¹

1. PMOD/WRC, Davos Dorf, Switzerland

The recent minimum of solar activity showed a substantially lower total solar irradiance (TSI) value than observed during the previous minima. This can be interpreted as evidence of a long-term trend. All the other indices of activity as Sunspot number, F10.7, CaK, MgII, etc show a much smaller change. Thus, TSI reacts to the prevailing surface magnetic fields more pronounced which is due to the fact that the specific contrast of small magnetic fields increases with decreasing field strength. There is no such effect influencing sunspots nor the chromospheric indices. This effect influencing TSI and not the spectral irradiance in the UV (SSI) has important consequences on reconstructions of TSI and SSI back to e.g. the Maunder Minimum.

Fuselier, Stephen A.

Location and properties of dayside reconnection during deep minima (Invited)

Fuselier, Stephen A.¹; Petrinec, S. M.²; Trattner, K. J.²

1. Division 15, Southwest Research Institute, San Antonio, TX, USA
2. Lockheed Martin Advanced Technology Center, Palo Alto, CA, USA

Magnetic reconnection at the Earth's magnetopause is driven by the solar wind. The transfer of mass and energy into the magnetosphere by reconnection depends on the amount of mass in the solar wind, the reconnection rate, and the location of reconnection at the magnetopause. During the recent solar minimum, the dynamic pressure rarely increased above 2 nPa (during high speed streams) and was primarily below 1 nPa. These weak solar wind conditions

resulted in reduced mass transfer because there was less mass in the solar wind to transfer across the magnetopause. Plasma beta is important for determining the reconnection rate at the magnetopause. During the recent solar minimum, the magnetic energy density decreased to low values. However, the plasma energy density was also very low because the density was low. Therefore, plasma beta (and by inference the reconnection rate) was relatively unaffected by the changes in the solar wind during the recent minimum. Finally, the location of reconnection at the magnetopause is determined by the IMF clock angle. There is no evidence of a systematic shift in clock angles in the solar wind that would result in a change in the location of reconnection at the magnetopause. From the standpoint of dayside magnetic reconnection, the primary effect of the recent solar minimum was a decrease in total mass available to transfer across the magnetopause. Other factors that drive magnetic reconnection and plasma transfer remained relatively unchanged.

Galvin, Antoinette B.

Solar Wind Ion Characteristics During the Recent Extended Solar Minimum

Galvin, Antoinette B.¹; Simunac, Kristin D.¹; Jian, Lan^{2, 3}; Farrugia, Charles¹; Lavraud, Benoit⁴

1. Space Science Ctr, Univ of New Hampshire, Durham, NH, USA
2. NASA/GSFC, Greenbelt, MD, USA
3. University of Maryland, College Park, MD, USA
4. IRAP, Toulouse, France

We report solar wind ion trends, including bulk parameters of protons and helium, and iron abundances and charge states as a function of the solar cycle, particularly the recent solar minimum, using OMNI and STEREO data. Sources of the solar wind are known to be linked to the phase of the solar cycle and include coronal holes, coronal mass ejections, and multiple cycle-dependent sources for “slow” solar wind. The differing solar sources are reflected in the proton parameters, the helium to proton elemental abundance ratio, and the Fe abundance and charge states. This past solar minimum was characterized by a significant drop in the proton number flux, sustained periods of slow solar wind, decreased He/H abundances (lower than the previous three minima), and a decrease in the Fe average charge state. The sustained solar minimum included cases of “slow” and “slower” solar wind interactions, small transients, and weak ICMEs.

Gizon, Laurent

Imaging flows inside the Sun during the recent solar minimum (Invited)

Gizon, Laurent^{1, 2}; Cameron, Robert¹

1. Max-Planck-Institut fuer Sonnensystemforschung, Katlenburg-Lindau, Germany
2. Institut fuer Astrophysik, Georg-August-Universitaet Goettingen, Goettingen, Germany

We discuss helioseismology results: rotation and meridional flow, their solar-cycle dependence, local flows associated with regions of magnetic activity, and convective flows. Particular attention is paid to the extended inf lows (30-50 m/s) around active regions and their effect on the longitudinally averaged meridional flow. To investigate how the time-varying component of the meridional flow affects the evolution of the magnetic field, we produced a calibrated model of the local inf lows using observations from cycle 23. We then incorporated this calibrated model into surface flux transport calculations, using the RGO sunspot area data as input. The now nonlinear surface transport model reproduces the strong correlation seen between the minima of the Sun's open flux and the strength of the subsequent solar cycle.

Gopalswamy, Nat

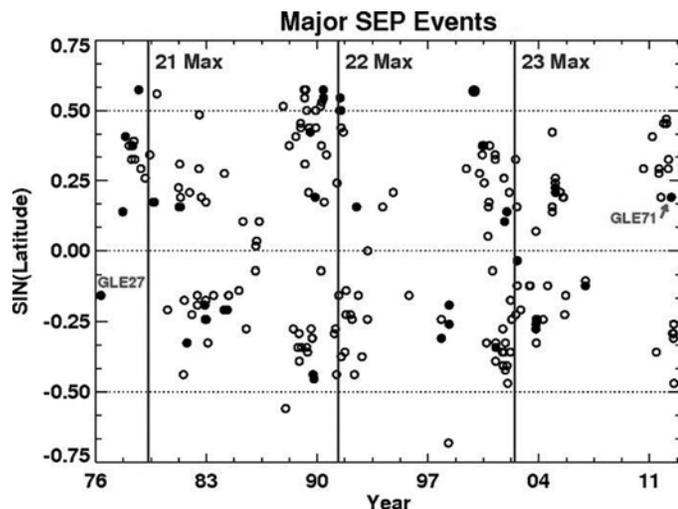
Large Solar Energetic Particle Events of Solar Cycles 23 and 24 (Invited)

Gopalswamy, Nat¹

1. Heliophysics Division, NASA Goddard SFC, Greenbelt, MD, USA

The solar energetic particle (SEP) events of cycle 24 differ from those of cycle 23 in a number of ways. First, there was a long delay of ~4 years from the last SEP event of solar cycle 23 to the first event of cycle 24. This difference is even longer (5.5 years) when the SEP events with ground level enhancement are considered. Furthermore, there was only one GLE event during cycle 24 as of this writing (January 2013). Second, the number of SEP events and the proton intensity are also substantially smaller: during the first 5 years of cycle 23, there were 36 large SEP events (events with an intensity ≥ 10 pfu in the >10 MeV channel) compared to just 23 during cycle 2; only 6 events had intensity ≥ 100 pfu until the end of 2012, compared to 14 during the first 5 years of cycle 23 (until 2001 May 31), four occurring in the rise phase. Finally, the occurrence rate of energetic eruptions such as halo CMEs, interplanetary type II radio bursts, and interplanetary shocks are smaller in cycle 24. One interesting difference that has the opposite tendency is the CME energy: almost all CMEs during cycle 24 are halos (97% compared to just 67% during the first five years of cycle 23) and the CMEs were faster (1604 km/s vs. 1432 km/s). Even though the CMEs associated with large SEP events are very energetic, they seem to be less efficient in accelerating particles. This may indicate a significant difference in the properties of the ambient medium between the two cycles.

<http://cdaw.gsfc.nasa.gov>



Solar energetic particle latitudes since 1976 (open circles). Events with ground level enhancement (GLE) are denoted by filled circles. The vertical lines mark the approximate times of solar maxima of cycle 21, 22, and 23. GLE #27 and #71 are marked.

Hathaway, David H.

Effects of the Observed Meridional Flow Variations since 1996 on the Sun's Polar Fields (Invited)

Hathaway, David H.¹; Upton, Lisa²

1. NASA Marshall SFC, Huntsville, AL, USA
2. Dept. of Physics and Astronomy, Vanderbilt University, Nashville, TN, USA

The cause of the low and extended minimum in solar activity between Sunspot Cycles 23 and 24 was the small size of Sunspot Cycle 24 itself – small cycles start late and leave behind low minima. Cycle 24 is small because the polar fields produced during Cycle 23 were substantially weaker than those produced during the previous cycles and those (weak) polar fields are the seeds for the activity of the following cycle. The polar fields are produced by the latitudinal transport of magnetic flux that emerged in low-latitude active regions. The polar fields thus depend upon the details of both the flux emergence and the flux transport. We have measured the flux transport flows (differential rotation, meridional flow, and supergranules) since 1996 and find systematic and substantial variation in the meridional flow alone. Here we present experiments using a Surface Flux Transport Model in which magnetic field data from SOHO/MDI and SDO/HMI are assimilated into the model only at latitudes between 45-degrees north and south of the equator (this assures that the details of the active region flux emergence are well represented). This flux is then transported in both longitude and latitude by the observed flows. In one experiment the meridional flow is given by the time averaged (and north-south symmetric) meridional flow profile. In the second experiment the time-varying and north-south asymmetric meridional flow is used. Differences between the observed polar fields and those produced in these two experiments allow us to ascertain the effects of these meridional flow variations on the Sun's polar fields.

Jardine, Moira M.

Solar activity extrema in the broader context of stellar activity (Invited)

Jardine, Moira M.¹; Fares, Rim¹; Vidotto, Aline¹; Donati, Jean-Francois²

1. School of Physics and Astronomy, University of St Andrews, St Andrews, United Kingdom
2. Laboratoire d'Astrophysique, Observatoire Midi-Pyrenees, Toulouse, France

Compared to many other solar-mass stars, the Sun is a fairly inactive specimen - a fact generally attributed to its present slow rotation rate. In its youth, however, the Sun was probably much more active. Studies of younger solar-mass stars suggest that the young Sun rotated more rapidly, and probably exhibited much higher levels of magnetic activity coupled with a more powerful wind. The nature of this activity and its impact on orbiting planets may have been quite different to what we observe today. Stars of different masses also show quite non-solar patterns in their spot distributions, activity, magnetic field geometry and surface differential rotation. With the advent of long-term monitoring with spectropolarimetry, coupled with the results from Kepler, the nature of the magnetic cycles on these stars is currently being addressed. In this talk I will review our current understanding of stellar activity and place the Sun in the context of other "solar-like" stars.

Jiang, Jie

Polar field around cycle minima versus subsequent and preceding solar cycles (Invited)

Jiang, Jie¹

1. National Astronomical Observatories, Chinese Academy of Sciences, Beijing, China

The relations of the solar polar field around cycle minima with the subsequent and the preceding solar cycles and the reasons responsible for the relations based on the dynamo models are main topics of the talk, which consists of two parts. The first part is about the positive correlation between the polar field and the subsequent cycle strength, which will be demonstrated using different observations. The pumping-dominated flux transport mechanism under the framework of the flux transport dynamo model takes the surface poloidal field to the tachocline in less than 5 years, which is mainly responsible for the positive correlation. Solar cycles 12-20 is well simulated recently by us using the observed RGO sunspot group data. The surface radial magnetic field evolution from our dynamo model is fully consistent with the output from the surface flux transport model. The second part is about the non-correlation between the polar field and the preceding cycle strength, which will be presented using the observations as well. The meridional flow and the tilt angles of sunspot groups during the preceding cycle largely affect the polar field strength around the solar cycle minima. No direct observations support the cycle-dependence of the overall meridional flow. However, an anti-correlation between the

sunspot group tilts and the cycle strength is well demonstrated by the observation, which serves as a nonlinear mechanism to modulate the polar field generation and to cause the non-correlation. The cycle dependence of the tilt angle may be understood by the superposition of the local inflows towards the activity belt onto the cycle-independent large-scale meridional circulation. Based on these coherent physical pictures, we successfully reconstructed the solar magnetic field, including the solar open flux and so on since 1700 onwards.

Jokipii, Jack R.

Understanding Anomalous and Galactic Cosmic Rays at the Last Solar Minimum (Invited)

Jokipii, Jack R.¹; Kota, Jozsef¹

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The unusual sunspot minimum between cycles 23 and 24 resulted in a galactic cosmic-ray (GCR) intensity which was the highest yet observed. The anomalous cosmic rays (ACR) at the same time did not reach the level of 1987 (two solar minima previously). One plausible interpretation of the difference is that, at the minimum, the magnitude of the interplanetary magnetic field was unusually low. As a result, the diffusion coefficients for both GCR and ACR were larger than usual. This allowed both GCR and ACR to more-readily reach the inner heliosphere. But the larger diffusion coefficient also resulted in fewer ACRs being accelerated in the outer heliosphere. The result is a high GCR intensity and a low ACR intensity in the inner heliosphere. Of course, since the diffusion coefficient depends also on the magnetic fluctuations, changes in turbulence could also contribute to the larger diffusion coefficient. Preliminary modeling of the ACR and GCR supports this picture. These interrelated effects provide an excellent opportunity to improve our understanding of the transport and acceleration of cosmic rays in the heliosphere. We have detailed observations as a function of time and position, in a range of physical parameter space not previously accessible. A number of important questions such as how and where charged particles are accelerated and the effects of the large-scale structure of the heliosphere are still being hotly debated and the new data should contribute to the discussion.

Kepko, Larry

(WITHDRAWN) Does the magnetosphere-ionosphere reach a minimum energy state during protracted minima? (Invited)

Kepko, Larry¹

1. Code 674, NASA GSFC, Greenbelt, MD, USA

It is well established that individual components of magnetosphere-ionosphere coupled system show strong dependence on solar activity. The recent extended solar minimum highlighted these dependencies by driving components into a minimum energy state. For example, the thermospheric density and temperature reached minima not

seen in 47 years, and by the middle of 2009, the outer electron belt had decayed significantly and almost disappeared. One can relate ionospheric conditions to solar radiation output and geomagnetic energy deposition, and magnetospheric activity to solar wind conditions, and develop an intuitive understanding of how the extended solar minimum leads to such extreme minimum conditions. How one assesses whether the coupled magnetosphere-ionosphere system reaches a minimum energy state is not as clear. In this talk, we first examine the pathways and components of M-I coupling, principally ionospheric conditions and geomagnetic activity, and briefly review how they were altered in response to the extreme solar minimum. We then explore the impact of these component level states on M-I coupling to determine how (and whether) the coupled system relaxed to a minimum energy state.

Kistler, Lynn M.

Impact of Deep Solar Minimum on O+ Abundance Throughout the Magnetosphere (Invited)

Kistler, Lynn M.¹; Mouikis, Christopher¹; Liao, Jing¹

1. SSC, Univ New Hampshire, Durham, NH, USA

The CLUSTER spacecraft have now been operating for 12 years, from 2001 through the present time, covering almost a full solar cycle. The CODIF instrument has provided a wealth of data over this time, allowing the solar cycle dependence of the ion composition over the energy range 40 eV/e to 40 keV/e throughout the magnetosphere to be determined for the first time. The solar cycle impacts the magnetosphere in a number of ways. As solar activity declines, the decreased solar EUV flux decreases the ionospheric scale height, which leads to less outflow. The smaller number of CMEs leads to fewer and smaller geomagnetic storms, which also decreases the outflow, both in the cusp and in the nightside auroral regions. In addition, the solar cycle impacts not only the ionospheric outflow, but also the transport, through changes in convection. Thus, different regions of the magnetosphere may be impacted in different ways. In this paper we review recent results on how the deep solar minimum impacted the inner magnetosphere, the ~20 Re plasma sheet, and the lobes. While both decreased EUV and reduced magnetospheric activity decrease the O+ density and O+/H+ ratio in the inner magnetosphere and plasma sheet, the relative roles are different. In the inner magnetosphere, the impact of EUV on the O+/H+ ratio dominates, while the contributions are more equal in the plasma sheet. This shows the importance of transport and also the mixed source for H+ in determining which effect is dominant. The importance of transport is supported by observations in the lobe, that show that much less cusp-origin O+ reaches the 20 Re plasma sheet during solar minimum than during solar maximum compared to the amount that is observed over the polar cap and in the cusp.

Kitiashvili, Irina N.

Synergy of physics-based dynamo models and observations for prediction of solar activity

Kitiashvili, Irina N.¹

1. HEPL, Stanford University, Stanford, CA, USA

Chaotic behavior of solar activity with prominent quasi-periodic 22-year magnetic cycles is a wonderful example, when pure mathematical approaches can show beautiful results and give an impression of simplicity of the solar-cycle prediction problem, but fail to predict the future cycles. For a successful prediction, it is important not only to have the observational data, but also a physics-based theoretical models that describes the basic features of the global dynamics and quasi-periodic variability of the Sun, and to develop a synergy of the data and model. We demonstrate this approach using a simplified turbulent dynamo model that captures some of the main properties of the solar cycle, such as the cycle asymmetry and the Waldmeier effect. However, this dynamo model describes the observed solar activity only approximately, and the predicted activity deviates from the data. Analysis of these deviations through the Ensemble Kalman Filter allows us to account for model uncertainties and sequentially correct the model state, matching the model predictions to the data for a series of the past cycles. This improves estimates of the system state and optimizes parameters of the system in such a way, that each additional solar cycle gives better (or the same quality) prediction for the next cycle. We demonstrate how this data assimilation approach works for prediction of the current cycle at various stages of its evolution, and discuss the current uncertainties and limitations.

Kitiashvili, Irina N.

Dynamical coupling between the convection zone and the atmosphere in the quiet Sun

Kitiashvili, Irina N.¹

1. HEPL, Stanford University, Stanford, CA, USA

Observations show that even during the deepest sunspot minimum the solar surface is covered by weak background magnetic field. We use radiative 3D MHD simulations to model the physical conditions of a quiet-Sun region with the mean magnetic field strength of 10G, and investigate the mechanisms of dynamical coupling between the turbulent convection zone and the atmosphere. The simulations reveal ubiquitous small-scale high-speed jets that can transport mass and energy into the solar corona and feed the solar wind. Analyzing the simulation results we find that small-scale eruptions are produced by ubiquitous magnetized vortex tubes generated by the Sun's turbulent convection in subsurface layers. The swirling vortex tubes (resembling tornadoes) penetrate into the solar atmosphere, capture and stretch background magnetic field, and push surrounding material up, generating quasiperiodic shocks. Our simulations reveal a complicated high-speed flow patterns, and thermodynamic and magnetic structure in the erupting vortex tubes. We found that the eruptions are initiated in the

subsurface layers and are driven by the high-pressure gradients in the subphotosphere and photosphere, and by the Lorentz force in the higher atmosphere layers.

Kosovichev, Alexander

Helioseismic Constraints and Paradigm Shift in Solar Dynamo

Kosovichev, Alexander¹; Pipin, Valery^{2,3}; Zhao, Junwei¹

1. Stanford University, Stanford, CA, USA
2. Institute of Geophysics and Planetary Physics, UCLA, Los Angeles, CA, USA
3. Institute of Solar-Terrestrial Physics, Irkutsk, Russian Federation

Helioseismology provides important constraints for the solar dynamo problem. However, the basic properties and even the depth of the dynamo process, which operates also in other stars, are unknown. Most of the dynamo models suggest that the toroidal magnetic field that emerges on the surface and forms sunspots is generated near the bottom of the convection zone, in the tachocline. However, there is a number of theoretical and observational problems with justifying the deep-seated dynamo models. This leads to the idea that the subsurface angular velocity shear may play an important role in the solar dynamo. Using a model of the internal rotation derived from helioseismology, we develop a mean-field MHD model of dynamo distributed in the bulk of the convection zone but shaped in a near-surface layer. We show that if the boundary conditions at the top of the dynamo region allow the large-scale toroidal magnetic fields to penetrate into the surface, then the dynamo wave propagates along the iso-surface of angular velocity in the subsurface shear layer, forming the butterfly diagram in agreement with the Yoshimura rule and solar-cycle observations. We compare this model with inferences of variations of the interior structure, differential rotation, zonal and meridional flows from SOHO/MDI and SDO/HMI helioseismology data, observed during the transition from Cycle 23 to Cycle 24.

Kumar, CV Anil

(WITHDRAWN) A comparative study of chaotic behaviour of Total Electron Content at low, mid and high latitude stations

Eapen, Suja²; Kumar, CV Anil¹

1. Mathematics, Indian Institute of Space Science and Technology, Trivandrum, India
2. Mathematics, Mar Thoma College, Thiruvalla, India

We analyse and compare the dimensions and the measures of complexity of Total Electron Content (TEC) measured at a low, mid and high latitude stations (Lat: 280, 400 and 600) during the months from January to April of a low solar activity year, 2008 using nonlinear techniques. The Mutual Information, Fraction of False Nearest Neighbours, Correlation Dimension and Maximum Lyapunov Exponents (MLE) are estimated from the diurnal variation reduced data sets. The computed correlation dimensions of the data at

low, mid and high latitude stations are respectively 12.5216 ± 0.08729 , 9.3212 ± 0.09641 , 12.303 ± 0.06441 . The hourly MLEs calculated for the respective data sets are 0.101, 0.092, 0.143. It is evident that correlation dimension of the mid latitude station is lower than that of the other stations. It is also noted that the correlation dimension varies as non-integer values between 9 and 13 in all cases, indicating low dimensional behaviour of the underlying dynamics. The MLE estimates indicating the measure of complex dynamics is less at the mid latitude station compared to the one at low and high latitude stations. The results on the surrogate data test on all the dynamical invariants considered also suggest the rejection of the null hypothesis that the TEC belongs to the family stationary linear Gaussian stochastic model. The analysis establishes that the underlying dynamics is a low dimensional deterministic system showing chaotic nature. The same analysis is carried out for the quiet and storm period extracted from the data and obtained interesting behaviour. The storm period taken into study is March 8-15 and the quiet period is March 16-23. In all the three stations, it is observed that the correlation dimension is low (non integer values between 2 and 5) and Lyapunov exponent is high (The respective hourly MLEs for low, mid and high latitude stations are 0.091, 0.126 and 0.116 respectively) during storm period while the correlation dimension is high (non integer values between 10 and 12) and Lyapunov exponent is low (The respective hourly MLEs for low, mid and high latitude stations are 0.064, 0.065 and 1.00) during the quiet period. The results show that global dynamics is less complex and controlled by more number of parameters at mid latitude stations compared to that of low and high latitude stations. Interestingly the local dynamics during quiet period is less complex and influenced by more number of parameters compared to that of storm period at low, mid and high latitude stations considered.

<http://www.iist.ac.in/scientists/c-v-anil-kumar/profile.html>

Lamy, Philippe L.

COMPARING THE SOLAR MINIMA OF CYCLES 23 AND 24: THE VIEW FROM LASCO WHITE-LIGHT CORONAL IMAGES (Invited)

Lamy, Philippe L.¹; Barlyaeva, Tatiana¹; Llebaria, Antoine¹

1. Lab Astrophysique Marseille, Marseilles Cedex 13, France

The LASCO-C2 coronagraph aboard SOHO has now completed 17 years of quasi-continuous white-light imaging of the corona from 2 to 6 solar radii, thus allowing an unprecedented view of its evolution over a solar cycle and a half. In this presentation, we concentrate on the comparison between the minima of cycles 23 and 24 as seen in the corona. The extensive correction of the raw images, their absolute calibration, the separation of the K-corona, the derivation of two-dimensional maps of the electron density and the generation of accurate synoptic maps performed by the LASCO team at Laboratoire d'Astrophysique de Marseille (formerly Laboratoire d'Astronomie Spatiale) are at the basis of the quantitative and structural analysis. Temporal

variations of the radiometry of the corona and of its electron content, either global or integrated in limited regions (e.g., equatorial versus polar) are compared with various proxies of solar activity in order to identify the driving mechanisms that control the activity of the corona. Our synoptic maps of unsurpassed spatial and temporal resolutions are then used to infer the magnetic topology of the corona that extends in the inner heliosphere and its evolution with the solar cycle is clearly revealed by its large scale structures. We highlight the similarities and differences between the structures that were present during the past two minima. Finally, we rely on our ARTEMIS-II catalog of coronal mass ejections (CMEs) to compare their rates and properties (spatial distribution, velocity, mass) during these minima and the following rising phases.

<http://lam.oamp.fr/>

Leamon, Robert J.

On the Modulation of the Solar Activity Cycles, and Hemispheric Asymmetry of Solar Magnetism During the Cycle 23/24 Minimum

Leamon, Robert J.^{1,2}; McIntosh, Scott W.³

1. Science Mission Directorate, NASA Headquarters, Washington, DC, USA
2. Department of Physics, Montana State University, Bozeman, MT, USA
3. HAO, NCAR, Boulder, CO, USA

We address the origin of the 11-year (quasi-)periodicity of the sunspot cycle by tying it to the significant temporal overlap of activity bands belonging to the 22-year magnetic activity cycle. Using a systematic analysis of ubiquitous coronal brightpoints, and the prevalent magnetic scale on which they form, we are able to observationally demonstrate the entirety of the 22-year magnetic activity cycle. The phases of the sunspot cycle occur as landmarks in the interaction and evolution of the overlapping activity bands in each hemisphere. The unusual conditions of the recent Cycle 23/24 minimum can be directly attributed to the asymmetry (southern lag) between the two hemispheres of the sun. The work presented establishes significant observational constraints for models of the origins of solar magnetic activity and will, as a result, improve our understanding of the structure of the heliosphere and the modulation of our star's radiative and particulate output. We demonstrate how the Sun can descend into, and recover from, Grand Minima. Even if that is not where we're headed, we show why Cycle 25 is likely to be even weaker than Cycle 24.

Lean, Judith

Solar Irradiance Drivers of Space Climate in the Extended 2008-2009 Solar Minimum: Anomalous or Not? (Invited)

Lean, Judith¹

1. Space Science Division, Naval Research Laboratory, Washington, DC, USA

The Sun's photon output at EUV and UV wavelengths is the dominant energy source for the thermosphere, and creates its embedded ionosphere. Changes in EUV and UV irradiance during the solar activity cycle control the climatology of these regions, which exhibit pronounced 11-year and 27-day cycles. However, observations of the solar irradiance drivers have been made only intermittently during the past few decades, and suffer from myriad instrument sensitivity changes that compromise the determination of true irradiance variability, especially on times scales of years to decades. Separating solar and instrumental effects in the extant solar irradiance database is especially critical for comparing the 2008-2009 solar minimum with the prior 1996 minimum, since differences between the two cycle minima are considerably smaller than changes from cycle minimum to maximum, and comparable in magnitude to instrumental instabilities. Observations of EUV irradiance variations in solar cycle 23 have been made since 1996 by SOHO/SEM, since 2002 by TIMED/SEE and since 2010 by SDO/EVE. Only the SOHO/SEM observations cover both the 2008-2009 and 1996 cycle minima; they suggest that solar EUV irradiance was 15% lower in 2008 than in 1996. In contrast, models of EUV irradiance variations developed by connecting the TIMED/SEE observations with appropriate proxy indices suggest little or no change in the level of solar EUV irradiance during recent cycle minima. This may be because the models lack additional solar sources of EUV irradiance variability not represented by the proxies, or it may be because the observations have undetected instrumental drifts. Real differences in solar EUV and UV irradiance between the 2008-2009 and 1996 solar cycle minima would produce corresponding changes in the thermosphere and ionosphere. But reliable identification of the expected solar-driven changes is difficult because of concurrent influences from geomagnetic activity, internal oscillations, and the lower atmosphere. Scenarios are examined that interpret the long-term ionospheric record of global total electron content in terms of multiple drivers, with the goal of better quantifying the solar versus other drivers of space climate during the extended solar minimum between cycles 23 and 24.

Linker, Jon A.

Global Coronal Structure and its influence on the Solar Wind in the Ecliptic Plane (Invited)

Linker, Jon A.¹; Mikic, Zoran¹; Riley, Pete¹; Lionello, Roberto¹; Titov, Viacheslav¹; Downs, Cooper¹

1. Predictive Science Inc., San Diego, CA, USA

The minimum preceding solar cycle 24 was characterized by unusual properties when compared with the previous cycle and other space age minima. These features include many more spotless days, weaker polar magnetic field strengths, weaker interplanetary magnetic fields, and persistent isolated equatorial coronal holes. We discuss 3D models of the solar corona and solar wind and what they tell us about how coronal structure gives rise to the solar wind measured near the ecliptic plane. We compare and contrast the most recent solar minimum with the minimum occurring prior to cycle 23. Research supported by NASA, NSF, and AFOSR.

Liu, Xianjing

Altitude variation of the thermosphere mass density response to geomagnetic storms during solar minimum

Liu, Xianjing¹; Thayer, Jeffrey P.¹; Burns, Alan²; Wang, Wenbing²

1. University of Colorado at Boulder, Boulder, CO, USA
2. National Center for Atmospheric Research, Boulder, CO, USA

The recent solar minimum resulted in a contracted thermosphere where smaller scale heights led to a steeper change in composition with height. As a consequence, the thermosphere gas mass density response to geomagnetic activity is more acutely dependent on altitude as composition varies more significantly during geomagnetic storms in the solar minimum period. This study investigates how the dynamics of composition transitions in the thermosphere due to the extremely low solar flux and regular geomagnetic activity alters the response of the mass density with height. The interplay of temperature enhancements and mean molecular weight changes during geomagnetic activity lead to a diversity of change in mass density with height. It is found that the oxygen-to-helium transition altitude is quite dynamic and, through molecular weight changes, can significantly influence the mass density response to geomagnetic activity. Observations of mass density behavior inferred from coplanar CHAMP and GRACE accelerometer measurements near 350 km and 500 km provided an opportunity to study, at two different altitudes, the response of the thermosphere mass density to the geomagnetic storm during the December 01-10, 2008 near the solar minimum period. Helium and oxygen concentrations are estimated from the CHAMP (350 km) and GRACE (500 km) density measurements and indicate a dominant amount of helium in the winter hemisphere at GRACE altitudes. In fact, the oxygen-to-helium transition

altitude lies below GRACE in the winter hemisphere during this period. We will describe the impact this transition region has on mass density response to geomagnetic activity with altitude as a consequence of the extreme solar minimum.

Martens, Petrus C.

Can Dynamo Theory Explain Protracted Solar Minima? (Invited)

Martens, Petrus C.^{1, 2}; Nandi, Dibyendu³; Munoz-Jaramillo, Andres²

1. Department of Physics, Montana State University, Bozeman, MT, USA
2. Smithsonian Astrophysical Observatory, Cambridge, MA, USA
3. Dept. of Physical Sciences, Indian Institute of Science Education and Research, Mohanpur, India

The minimum in activity between solar cycle 23 and 24 has been the deepest in the space age, with an unusually large number of days without sunspots and weak solar dipolar field. This has had consequences for the heliosphere and planetary atmospheres - given the weak solar wind, low solar irradiance and radio flux and historically high values of cosmic ray flux that has characterized this minimum. The origin of this peculiar minimum has been the subject of much research. Here we present a physical explanation of this deep minimum, and other minima like it, based on simulations of the solar dynamo mechanism and based on observations of the torsional oscillations as markers of the variation in solar internal flows. Our simulations have led to a somewhat surprising result, which, however, provides a self-consistent solution to both of the unusual features of this minimum; namely, the long period of missing sunspots and the very weak solar polar field strength. While our simulations certainly answer the question in the title in the positive, the objection has been raised that the meridional flows leading up to protracted minima that we assume in our model are inconsistent with observations of surface magnetic flux transport. I will demonstrate here that our results are in fact compatible with these observations, based upon the observed fact that the surface plasma flows derived from Doppler measurements are different from the flow velocities of magnetic flux elements at the surface. Reference: "The Unusual Minimum of Sunspot Cycle 23 a Consequence of Meridional Plasma Flow Variations", Dibyendu Nandy, Andres Munoz-Jaramillo, and Petrus C. H. Martens 2011, *Nature*, 471, 80-82.

<http://solar.physics.montana.edu/martens/>

McCarvill, Edgar R.

(WITHDRAWN) NASA/NCAR data show system's polarity reversal change

McCarvill, Edgar R.¹

1. Solar Physics, LeRam Power Systems (unregiste, Sicamous, BC, Canada

(WITHDRAWN)

McCarvill, Edgar R.

(WITHDRAWN) Solar EM basic Induction Principle & Force-fields between Coronal Axis and Heliopause

McCarvill, Edgar R.¹

1. LeRam Power Systems (unregiste, Sicamous, BC, Canada
WITHDRAWN

McCracken, Kenneth G.

Comparison of the cycle 23/24 solar minimum with solar activity throughout the past 9400 years, and the implications thereof

McCracken, Kenneth G.¹; Beer, Juerg²

1. University of Maryland, Woodlands, NSW, Australia
2. Eawag, Dubendorf, Switzerland

We use a 9400 yr paleocosmic ray (PCR) record based on ¹⁰Be data from icecores from Greenland and Antarctica, and the ¹⁴C tree-ring record, to determine the significance and implications of the cycle 23/24 sunspot minimum. The PCR record is normalized to the modern neutron monitor record, allowing direct comparisons of the historic cosmic ray intensities and solar activity with the present era. During the past 9400 yr there were ~26 "Grand Minima" similar to the Maunder and Spörer Minimum, and a large number (circa 30) of intervals of reduced solar activity similar to those corresponding to the weaker sunspot cycles circa 1900, and the cycle 23/24 minimum. The Grand Minima are not evenly distributed, there being several intervals of >1200 yr during the past 9400 yr when there were no Grand Minima, while those intervals were populated with many events such as the cycle 23/24 minimum, and the solar cycles circa 1900AD. Using cosmogenic, neutron monitor, and satellite data, we conclude that the solar activity and heliospheric fields during the 23/24 minimum were similar to those associated with the 11-year maxima in the early part of the Maunder Minimum, but significantly greater than those during the most profound 11-year minima at the end of the Maunder Minimum. Using cosmic ray modulation theory, we conclude that the heliospheric magnetic field strength during the cycle 23/24 minimum was a factor of ~3 greater than that during the most profound 11-year minima in the Maunder and Spörer Minima. Finally we discuss similarities in the cosmic ray and heliospheric magnetic records between the intervals 1972-76 and 2006-2009 that may provide additional insight into the manner in which the solar dynamo has operated throughout the past 9400yr.

McEwen, Don

(WITHDRAWN) DAYSID E AURORAL INTENSITIES DURING SOLAR MINIMUM

Sivjee, Abas¹; McEwen, Don^{2, 1}

1. Embry Riddle Aeronautical University, Daytona Beach, FL, USA
2. Physics, University of Saskatchewan, Saskatoon, SK, Canada

A multi-channel meridian scanning photometer operated at the Amundsen-Scott Research Station at the South Pole through the winters 2006 to 2010, which included the recent extended Solar Minimum. The dayside auroral intensities as monitored by the OI 630 nm channel were examined in relation to the ACE measurements of Solar Wind parameters. In particular, fluctuations in auroral intensities are compared with variations in IMF component strengths. The IMF Dayside aurora was detected continuously, at levels as low as 50R, even with the weakest solar wind dynamic pressures. Reconnection processes between the solar wind and magnetosphere in these conditions will be discussed.

McPherron, Robert L.

Why Were Electrojets Weaker during the Last Solar Minimum in 2008? (Invited)

McPherron, Robert L.¹; Baker, Daniel N.²; Pulkkinen, Tuija³

1. Earth & Space Sciences, Univ Calif Los Angeles, Los Angeles, CA, USA
2. Lab. for Atmos. and Space Phys, University of Colorado, Boulder, CO, USA
3. School of Elec. Eng., Aalto University, Espoo, Finland

The eastward and westward auroral electrojets are driven by a combination of effects of solar wind driving and unloading of energy stored in the Earth's magnetic tail. The AU and AL indices are proxies for the strength of these electrojets and contain information about the generation processes. We define the solar wind coupling strength as the ratio of an index to a coupling function after a time longer than the transient response time of the electrojets which is typically 3-4 hours. The magnetosphere is almost never stationary for this long but this ratio is given by the area under the linear prediction filter relating the input to output. Since the magnetosphere is not linear we obtain approximate coupling strengths using local linear filters. We have done this for the entire history of hourly observations of the solar wind (1966-2012). We evaluate the ability of four different coupling functions to predict the indices. These include "opt" a new function that is the optimum predictor for AL; "ucf" the Universal Coupling Function; VBs the rectified solar wind electric field; and "eps" the epsilon function. The functions respectively predict 67.3, 65.9, 61.2, and 43.6 % of the AL index. All functions reveal the same average behavior as a function of time, although eps is extremely variable compared to other functions. Coupling strength increases during the declining phase of the solar cycle reaching its largest value at solar minimum. It then

decreases more rapidly during the rising phase of the next cycle. The coupling strength at solar minimum has decreased during the last two minima. Additionally it reached its lowest values ever observed in 2010 the year after the last minimum. We show that the parameter controlling the coupling strength is the ratio of the strength of fluctuations in the index to fluctuations in the coupling function.

Mlynczak, Martin G.

SABER: OBSERVING THE PULSE OF THE SUN IN THE ATMOSPHERE OF THE EARTH (Invited)

Mlynczak, Martin G.¹

1. 21 Langley Blvd, NASA Langley Research Ctr, Hampton, VA, USA

The SABER instrument on the NASA TIMED satellite continues to operate flawlessly after more than 11 years on orbit. The SABER data record includes temperature, ozone (including two techniques in the daytime), hydroxyl (two separate band systems), atomic oxygen (day and night), atomic hydrogen (day and night), nitric oxide emission, radiative cooling rates, heating rates due to absorption of solar radiation, and heating rates due to exothermic chemical reactions. The SABER dataset is the most comprehensive record of the thermal structure, chemical composition, and energy budget of the mesosphere and lower thermosphere. Evidence of the 11-year solar cycle is evident in all SABER measurements. In particular, the maximum observed changes in all SABER parameters occur during the deep minimum of solar cycle 23. Temperature, ozone, OH emission, atomic oxygen, and radiative cooling rates all decrease from 2002 through the deep minimum in 2008-2009 and then increase again. In contrast, atomic hydrogen increases and peaks during the deep minimum, and decreases afterwards. Solar influence on shorter timescales on the order of days is also evident, especially in the thermosphere. The different timescales for solar influence are indicative of various mechanisms, including solar UV variability and solar wind variability, which influence the atmosphere. Finally, recent SABER data from 2011 and 2012 clearly illustrate the influence of solar cycle 24. The SABER measurements of thermospheric radiative cooling peaked in late 2011, suggesting that the maximum of solar cycle 24 has already occurred.

Newell, Patrick T.

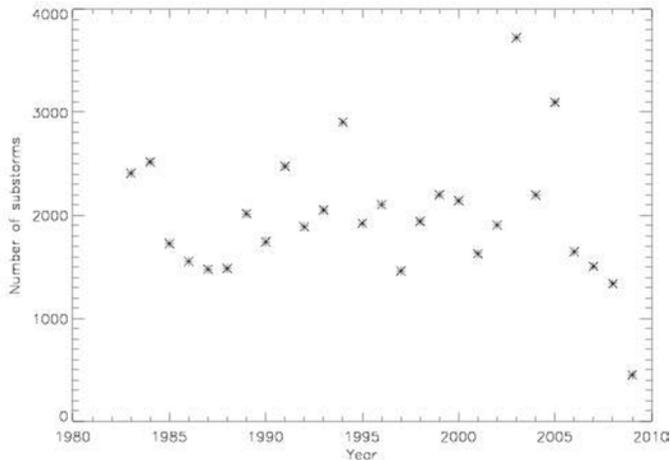
Substorm Recurrence Times and the Anomalous Minimum (Invited)

Newell, Patrick T.¹; Gjerloev, Jesper¹

1. Applied Physics Lab, Johns Hopkins Univ, Laurel, MD, USA

We investigated the yearly number of substorms and their recurrence rate using 53,000 substorms identified from 1980-2009 from SuperMAG. Contrary to popular assumption, the number of substorms in a year (or indeed, the average intensity of aurora) has only a very weak

correlation to solar cycle or common proxies such as F10.7. However in 2009 the substorm occurrence rate plummeted to unprecedented levels, with only about 450 substorms in the year (compared to the long term average of around 2000, with all previous minima well above 1000 substorms. As a result, in 2009, unlike previous years, there were often several consecutive days with a single substorm. The depth of this minimum cannot easily be explained in terms of solar wind parameters, solar UV insolation, or the past behavior around previous solar minima. We explore the implications of this profound minima for solar-solar wind-magnetosphere coupling.



Nicoli Candido, Claudia M.

The ionosphere during the last two solar minimum periods over Brazilian region

Nicoli Candido, Claudia M.¹; Batista, Inez S.¹

1. Aeronomy Division, INPE, Sao Jose Dos Campos, Brazil

The low latitude ionosphere presented unusual characteristics during the last solar minimum period (solar cycle 23/24) over Brazil. Plasma densities presented values lower than the previous solar minimum (solar cycle 22/23), as observed by digisondes. Additionally, an abnormal occurrence rate of spread-F over Cachoeira Paulista (22.4° S, 45° W, dip angle: -37°) was observed during June solstice. Ionograms revealed distinct patterns of spread-F associated with midnight/post-midnight irregularities. Over the equatorial region, it was observed significant decreases in the plasma densities during nighttime hours with no-echoes in the ionograms lasting for several hours. On the other hand, abnormal spread-F patterns were also observed during of ascending phase of the current solar cycle over the equatorial region. We analyzed data from digisondes at two equatorial sites, Sao Luis (44.2° W, 2.33° S, dip angle: -6.9°) and Fortaleza (38.45°W, 3.9° S, dip angle: -16°) and at the low latitude station Cachoeira Paulista. Finally we present and discuss a statistical study of the plasma irregularities as well as the unusual signatures of spread-F/plasma irregularities observed in ionograms.

Owens, Mathew J.

Solar cycle 24 in a long-term context (Invited)

Owens, Mathew J.¹

1. Department of Meteorology, Uinversity of Reading, Reading, United Kingdom

Solar cycle 24 looks set to be the weakest of the space age, both in terms of sunspot number and the heliospheric magnetic field (HMF). The most recent observations of the solar polar field polarities suggest the Sun is presently very close to solar maximum, despite the HMF only just reaching the level of previous solar minima. In order to put these observations in long-term context, I'll summarise the available proxies for the HMF and what they tell us about the Sun in the past. Then, probably imprudently, I'll speculate about what this means for future solar variations.

Partamies, Noora

Auroral ionosphere during the deep solar minimum

Partamies, Noora¹; Whiter, Daniel¹; Mylly, Minna¹; Juusola, Liisa¹; Kauristie, Kirsti¹

1. Arctic Research Unit, Finnish Meteorological Institutu, Helsinki, Finland

The MIRACLE ground-based network of auroral imagers and magnetometers in Fennoscandia and Svalbard has been used to monitor the long-term evolution of auroral occurrence and magnetic disturbances. The unique data set covers the past two solar minima including automatic and continuous optical and magnetic measurements. This study examines the behaviour of auroral ionosphere during the past deep solar minimum. We compare the evolution in the auroral region during the previous two minima of the solar cycles 22 and 23. We examine ground magnetic activity at the average auroral oval latitudes, as well as the southern and northern part of the auroral region with respect to the properties of the solar wind driving. We further analyse the development of optical auroral occurrence, auroral structures and the peak emission altitude during the declining phase of the solar cycle 23.

Pilinski, Marcin

Measurement and Modeling of Thermospheric Density During Solar Minimum

Pilinski, Marcin¹; Crowley, Geoff¹

1. Suite 221, ASTRA LLC., Boulder, CO, USA

The response of thermospheric neutral density during the extended solar minimum between cycles 23 and 24 has been observed in satellite drag data and has been investigated in terms of solar EUV and geomagnetic input sensitivity in first-principles models such as TIE-GCM at 400km [Solomon et al. 2011]. We present the first multi-altitude TIME-GCM results of the thermospheric density response during the extreme solar minimum as well as the sensitivity of TIME-GCM to various models of EUV and geomagnetic inputs. TIME-GCM densities during the recent

solar minimum are compared with densities measured by CHAMP and GRACE as well as densities derived from observations of orbital decay. Following the work of previous researchers we confirm that driving the model with MgII core-to-wing index results in better agreement between density observations and TIME-GCM model results. We also explore how assimilative specification of geomagnetic forcing (AMIE) compares with empirical drivers based on indices during this solar minimum.

Pulkkinen, Tuija I.

Is There a Minimum Number of Substorms During Protracted Solar Minima? (Invited)

Pulkkinen, Tuija I.¹; Partamies, N.²; Tanskanen, E. I.²; Kilpua, E.³; Palmroth, M.²; Kissinger, J.⁴; McPherron, R. L.⁵

1. School of Electrical Engineering, Aalto University, Espoo, Finland
2. Finnish Meteorological Institute, Helsinki, Finland
3. Department of Physics, University of Helsinki, Helsinki, Finland
4. NASA Goddard Space Flight Center, Greenbelt, MD, USA
5. Department of Earth and Space Sciences, University of California, Los Angeles, CA, USA

The solar minimum in 2008-2009 was exceptionally well observed in the magnetosphere by the prime phase of the Themis 5-spacecraft mission. During the two years, over 200 periods of extended steady conditions in the magnetosphere were recorded. These steady magnetospheric convection (SMC) events comprise periods exceeding 90 min in duration during which no major reconfiguration events (such as substorms) occur in the magnetosphere - ionosphere system. Using available listings of SMC and of substorm occurrence extending over a solar cycle we examine how much the occurrence frequencies and event durations change during the deep solar minimum. Furthermore, we examine in more detail the end phases of the SMC periods using observations both in the magnetotail and in the solar wind to understand what caused the SMC periods to come to an end. The differences in the magnetospheric configuration during and at the end of the SMC periods, possible triggers in the solar wind, amount of energy input from the solar wind to the magnetosphere, and the location and intensity of auroral electrojets are used to discuss the occurrence frequency of dynamic events under such long-term quiet conditions.

Purohit, Pramod K.

Solar Transients affecting Space Weather and their interconnection

Purohit, Pramod K.¹; Tripathi, Sharad C.²; Khan, Parvaiz A.²; Muhammad, Aslam A.²; Gwal, Ashok K.²

1. Physics, National Institute of Technical Teachers' Training and Research, Bhopal, India
2. Physics, Barkatullah University, Bhopal, India

We probe the spectral hardening of solar flares emission in view of associated solar proton events (SEPs) at earth and

coronal mass ejection (CME) acceleration as a consequence. In this investigation we undertake 60 SEPs of the Solar Cycle 23 alongwith associated Solar Flares and CMEs. We employ the X-ray emission in Solar flares observed by Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) in order to estimate flare plasma parameters. Further, we employ the observations from Geo-stationary Operational Environmental Satellites (GOES) and Large Angle and Spectrometric Coronagraph (LASCO), for SEPs and CMEs parameter estimation respectively. We report a good association of soft-hard-harder (SHH) spectral behavior with occurrence of Solar Proton Events. In addition, we have found a good correlation ($R=0.71$) in SEPs spectral hardening and CME velocity. We conclude that the Protons as well as CMEs gets accelerated at the Flare site and travel all the way in interplanetary space and then by re-acceleration in interplanetary space CMEs produce Geomagnetic Storms in geospace. This seems to be a statistically significant mechanism of the SEPs and initial CME acceleration in addition to the standard scenario of SEP acceleration at the shock front of CMEs.

Qian, Liying

Global Change in the Upper Atmosphere and Ionosphere

Qian, Liying¹; Solomon, Stanley¹; Akmaev, Rashid²

1. NCAR High Altitude Observatory, Boulder, CO, USA
2. NOAA, Boulder, CO, USA

Anthropogenic increases of greenhouse gases warm the troposphere but have a cooling effect in the middle and upper atmosphere. The steady increase of CO₂ is the dominant cause of upper atmosphere trends; other drivers are long-term changes of radiatively active trace gases such as CH₄, O₃, and H₂O, secular change of solar and geomagnetic activity, and evolution of the Earth's magnetic field. In this presentation, we will review observational and modeling results on global changes in the upper atmosphere, including global cooling in the mesosphere and thermosphere and the resulting long-term changes in the ionosphere. In addition, we will discuss possible trends in wave activity. Changes in atmospheric dynamics, both as a consequence of global change in the lower and middle atmosphere and as a possible driver of trends in the upper atmosphere, is one of the critical open questions regarding trends in the upper atmosphere and ionosphere.

Reeves, Geoffrey D.

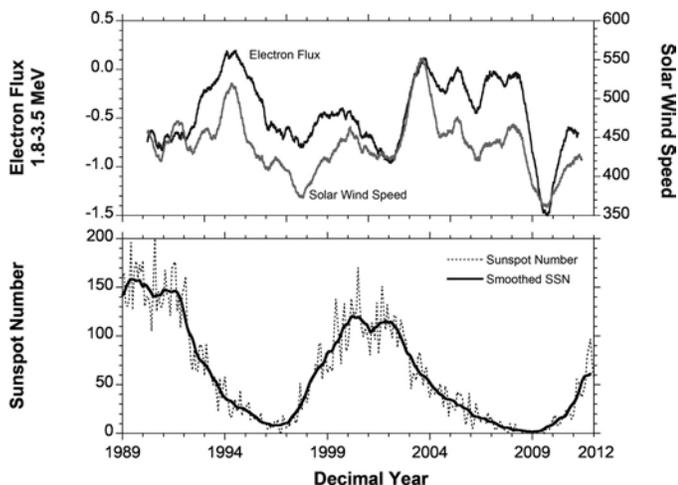
Relativistic Electron Events and Radiation Belt Dynamics During a Deep Solar Minimum (Invited)

Reeves, Geoffrey D.¹; Morley, Steven¹; Niehof, Jon¹; Cunningham, Greg¹; Larsen, Brian¹

1. Space Science & Applications, Los Alamos National Laboratory, Los Alamos, NM, USA

The intensity of relativistic electron fluxes in the Earth's radiation belts are known to vary over the course of the solar cycle. As with geomagnetic activity (K_p , Dst) the peak

relativistic electron fluxes are not observed at sunspot maximum. However, while geomagnetic activity generally has two peaks that precede and follow sunspot maximum, relativistic electron fluxes typically exhibit one peak during the declining phase of sunspot number when high speed streams from solar coronal holes produce co-rotating interaction regions (CIRs) in the solar wind. Conventional wisdom suggests that electron intensity (particularly at geosynchronous orbit) is roughly correlated with solar wind velocity once speeds reach a high-speed threshold of 500-600 km/s. Electron fluxes typically peak several days after the onset of a high-speed stream presumably due to continuous energization by radial diffusion and resonant wave-particle acceleration. Recently Reeves et al., [2011 and 2013] examined the long-term dynamics of relativistic electrons including the recent deep solar minimum when 27-day average solar wind speeds dropped to ~300 km/s and relativistic electron fluxes dropped by more than an order of magnitude. During this exceptionally quiet period the radiation belts might be expected to slowly decay due to a lack of energization events. What is observed, however, is that episodic enhancements of radiation belt fluxes are still observed in association with increases in solar wind speed even when the peak speeds are exceptionally slow. Additionally the distribution of relativistic electron fluxes relative to the 1-year average (or baseline) level is approximately the same during this exceptional minimum as it was during other parts of the previous two solar cycles - including the 1996 solar minimum and the 1994 and 2003 high-speed stream driven years. In this paper we will discuss the occurrence of relativistic electron “events” based on both absolute flux and flux relative to a variable baseline. We will also discuss what radiation belt dynamics under extremely weak driving can tell us about radiation belt acceleration, transport, and loss in general and implications for current theoretical understanding.



365-day running averages of relativistic radiation belt electron fluxes and solar wind speeds over the last two solar cycles. Exceptionally low radiation belt fluxes and solar wind speeds were observed in the past solar minimum.

Ren, Zhipeng

Simulated equinoctial asymmetry of the ionospheric vertical plasma drifts

Ren, Zhipeng^{1,2}; Wan, Weixing²; Liu, Libo²; Xiong, Jiangang²

1. High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO, USA
2. Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China

Using TIDM-IGGCAS-II model and tidal winds below 105 km from TIMED/TIDI observations, we study the influence of the lower thermospheric tidal winds below 105 km on the equinoctial asymmetry of the equatorial vertical $E \times B$ plasma drifts. Although a series of other non-migrating tides also affect the vertical drift asymmetry, the simulated equinoctial asymmetry in vertical drift are mainly driven by the migrating diurnal tide (DW1), migrating semidiurnal tide (SW2), DE3, and DW2 non-migrating tides. The asymmetry in daytime vertical drift varies with local time and longitude, and mainly shows three features. First, the simulated daytime vertical drift during March Equinox is larger than that during September Equinox in most of longitudinal sectors. This asymmetry is mainly driven by the semiannual oscillation (SAO) of the migrating diurnal tide in the tropical MLT region, and the equinoctial asymmetry of the migrating semidiurnal tide also play an important role in the generation of this asymmetry. Second, the daytime vertical drift asymmetry in Eastern Hemisphere is more significant than that in Western Hemisphere. Our simulation suggests that the longitudinal variation of the geomagnetic fields and DW2 tides play important roles in the generation of this hemisphere difference. Thirdly, there is an obvious wavenumber-4 longitudinal structure in the vertical drift asymmetry. Our simulation suggests that this wavenumber-4 structure is mainly driven by the equinoctial asymmetry of the DE3 tide.

Richardson, John D.

Solar minimum in the outer heliosphere

Richardson, John D.¹

1. Kavli Center, MIT, Cambridge, MA, USA

The Voyager spacecraft are at 122 AU (V1) and 100 AU (V2). During the recent solar minimum V1 was in the heliosheath and V2 crossed the termination shock into the heliosheath. Currently V1 seems to be in a boundary layer in front of the heliopause. This paper discusses the numerous effects of the recent solar minimum in the outer heliosphere. These include 1) changes in the termination shock and heliopause locations, 2) changes in the tilt of the heliospheric current sheet which may control where reconnection is important in the heliosheath, 3) changes in the locations of fast and slow solar wind which may cause deviations in the large-scale flow speed in the heliosheath, 4) formation of CIRs which may be observed in the heliosheath as quasi-periodic changes in particle intensity, 5) variation in the modulation of cosmic rays, and 6) changes in the plasma

density. The most recent Voyager data will also be discussed.

Riley, Pete

The Structure of the Solar Corona and Inner Heliosphere during the Recent Solar Minimum and Inferences on Conditions that may have existed during the Maunder Minimum (Invited)

Riley, Pete¹; Linker, Jon A.¹; Lionello, Roberto¹

1. Predictive Science Inc., San Diego, CA, USA

The recent solar minimum in late 2008 was unique in many ways, and raised a number of fundamental scientific questions. For example: Why was the global dynamic pressure of the solar wind lower than in any of the previous 3 solar cycles? What caused the unusually high tilt angle of the Sun's dipole field, and what were the consequences? Why was the interplanetary magnetic field 1/3 weaker than in the previous minimum? Additionally, the recent minimum may foretell an impending slide into a grand solar minimum on the scale of the Maunder minimum, during which time sunspots all but disappeared during a 70-year period between 1645 and 1715. In this presentation, we explore the structure of the corona and heliosphere during the recent minimum and compare and contrast it with conditions that may have existed during the Maunder minimum in an effort to understand the extremes of quiescent solar conditions. To achieve this, we use a combination of: (1) MHD model results; (2) remote solar observations and in situ measurements of the recent minimum; and (3) a range of less reliable "observations" made during the Maunder Minimum period. We conclude that the most likely state of the corona during the Maunder Minimum was not merely that of the 2008 minimum, as has been suggested in several recent studies. Instead, we argue that the Sun's photospheric magnetic field was substantially reduced (by up to an order of magnitude), which led to, and is consistent with the observations associated with this period. We discuss the implications of this work in terms of future long-term space weather forecasting.

Roelof, Edmond C.

Properties of the Heliosheath during the Recent Protracted Solar Minimum: The Ground State (Invited)

Roelof, Edmond C.¹

1. Space, Johns Hopkins University/Applied Physics Laboratory, Laurel, MD, USA

The observational exploration of the heliosheath (HS) - the immense region between the solar wind termination shock (TS) and the transition to the interstellar plasma - has occurred during the decline and protracted minimum of Solar Cycle 23 and is continuing as Solar Cycle 24 approaches its (relatively low) maximum. We know from prior remote-sensing of HS dynamics by 2-4 kHz radio emissions detected by the Voyagers (VGR1/2) beginning in 1983, that the present HS is much less active than it was in Solar Cycles 21-23. We have had in-situ plasma, magnetic field, and energetic ion measurements in the HS since the TS

shock crossings of VGR1 (16 Dec 2004) and VGR2 (30 Aug 2007). However, our all-sky energetic neutral atom (ENA) images of 1-6 keV proton populations throughout the HS did not begin until 2009, with all-sky coverage from Cassini/INCA of 5-55 keV ENA images increasing significantly in 2010. IBEX-Hi and Cassini/INCA images have established that the dynamics of the HS is dominated by the variations in the pressure of 1-10 keV interstellar pickup protons. It takes about one year for the (equatorial) solar wind to advect the pickup protons about 90 AU or so from the Sun to the TS, and thereafter, the TS-heated pressure variations must propagate outward through the HS, which we now know from VGR1 is at least 27 AU thick. In addition, each 1 keV ENA H takes another year to travel from the HS back to form the IBEX images at 1 AU. Consequently, our suite of VGR/IBEX/Cassini observations of the HS began with just as we were entering the protracted solar minimum, i.e., we have been observing the "ground state" that the heliosheath assumes during unusually low levels of solar activity.

Russell, James M.

The Unique Opportunity to Study Polar Mesospheric Clouds Provided by the Extended Solar Minimum

Russell, James M.¹; Bailey, Scott M.²

1. Hampton University, Hampton, VA, USA
2. Virginia Tech, Blacksburg, VA, USA

Polar Mesospheric Clouds (PMCs) are a high latitude, summertime phenomenon that have captured the interest of many observers due to their remarkable appearance in the night sky. These clouds form just below the mesopause, the coldest region on Earth. Increasing numbers of PMCs and their brightness since their first reported observation in 1885 have led to the suggestion that these clouds are an indication of change in the upper atmosphere. The Aeronomy of Ice in the Mesosphere (AIM) is a NASA Small Explorer mission dedicated to understanding why PMCs form and why they vary. Launched in April of 2007, the first four years of AIM observations occurred during a period of exceptionally stable and low solar activity. This is relevant as PMC properties are known to be anti-correlated with solar activity (with a possible lag of about one year) due to either or both of solar irradiance induced temperature changes and water photodissociation. Observing PMCs during an extended period of uniquely stable solar activity has facilitated a significant paradigm shift in our understanding of PMCs. With a key driver of PMCs, i.e. the solar output, held constant, significant variability in the clouds is still found. This variability has been traced to dynamical influences from both lower altitudes and opposite hemispheres, revealing that PMCs are in fact a diagnostic of global atmospheric dynamics. In addition, there is indication that launch vehicle exhaust at low latitudes can influence PMCs. In this talk we will discuss how PMC science has benefited from the recent extended solar

minimum and describe the improved understanding of the mesopause region that is being achieved.

Schwadron, Nathan A.

Large-scale Magnetic Flux as a Regulator for Solar Wind and Coronal Conditions in the Deep Solar Minimum (Invited)

Schwadron, Nathan A.^{1, 4}; Smith, C.¹; Kasper, J.²; Korreck, K.²; Stevens, M.²; Maruca, B.²; Kiefer, K.²; Lepri, S.³; McComas, D. J.⁴; Spence, H.¹

1. University of New Hampshire, Durham, NH, USA
2. SAO, Cambridge, MA, USA
3. U. Michigan, Ann Arbor, MI, USA
4. SwRI, San Antonio, TX, USA

Recent in situ observations of the solar wind show that charge states (e.g., the O7+/O6+ and C6+/C5+ abundance ratios) and α -particle composition evolved through the extended, deep solar minimum between solar cycle 23 and 24 (i.e., from 2006 to 2009). Prior investigations have found that both particle flux and magnetic field strength gradually decreased over this period of time. We find that (for a given solar wind speed) the coronal electron temperature (as derived from O7+/O6+ and C6+/C5+ measurements from ACE) likewise decreased during this minimum. We use the Schwadron and McComas (2003) solar wind scaling law to show that cooler coronal electron temperatures are naturally associated with lower particle fluxes because downward heat conduction must be reduced to keep the average energy loss per particle fixed. The results of the scaling law should apply to all solar wind models and suggest that the evolution of the solar wind is linked to the solar dynamo, which caused the large-scale coronal magnetic field strength to decrease in the deep, extended minimum. Thus, the open and large-scale solar magnetic field behaves as a regulator for the solar wind, coronal temperatures and coronal densities. We have utilized the scaling law to project coronal electron temperatures backward in time throughout the space age and find that these temperatures have been decreasing in successive temperature maxima since 1987 but were increasing in successive temperature maxima from 1969 to 1987. Our results demonstrate how the solar dynamo via large-scale solar magnetic fields may control the properties of solar wind and the corona, which in particular explains why the solar wind achieved such an anomalous state in the recent deep solar minimum.

Shakeri, Farhad

The cycle-related solar VUV variability

Shakeri, Farhad^{1, 2}; Teriaca, Luca¹; Solanki, Sami K.¹

1. Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany
2. Georg-August-Universität Göttingen, Göttingen, Germany

The last solar minimum has been unusual compared to previous minima. The high number of spotless days, the substantially reduced heliospheric magnetic field strength

and the low open magnetic flux of the recent solar minimum, all make it unusual. At the same time, the total solar irradiance has dropped below the values known from previous minima (since space-based radiometric measurements are available). Recent studies of the Sun's total magnetic flux find that the distribution function of the flux has also changed significantly. On the other hand, the Sun's 10.7cm flux has remained nearly unchanged. This is a puzzling results that poses an important question: Why should the coronal emission remain unchanged when the magnetic field decreases? The CDS spectrometer aboard SOHO has a broad temperature coverage and has been taking regular scans along the solar central meridian for the last 15 years. We analyzed this enormous data set to look to the radiance distribution of quiet areas around Sun center to verify if and how the radiance distribution undergoes measurable variations along the cycle. To focus more specifically on the last two minima, we chose a 1-year interval at each solar minimum and studied variations in various radiance distribution parameters. The study was confined to two emission lines at chromosphere and transition region: He I and O V, respectively. We deduced from the analyses that there is no meaningful difference in the He I line radiance distribution between the last two minima. However, in the case of the O V emission line a significant difference is found, with a higher ratio between the brightest and darkest areas of the quiet Sun being observed during the minimum of Cycle 22. Explanations for this result, including possible instrumental effects, are discussed..

Siskind, David E.

Effect of non-migrating tides on thermospheric density and composition at solar minimum

Siskind, David E.¹; Drob, Douglas P.¹

1. Space Science Division, Naval Research Laboratory, Washington, DC, USA

We present results from the NCAR thermosphere-ionosphere-electrodynamics general circulation model (TIEGCM) using a bottom boundary condition from the Advanced Level Physics High Altitude (ALPHA) version of the Navy's operational global weather forecast system (NOGAPS). NOGAPS-ALPHA consists of a forecast module and a data assimilation (DA) system. We use the 6 hourly cycled DA system to initialize a series of forecasts which are output every hour. The hourly output allows the resolution of higher order tidal modes such as the semidiurnal and terdiurnal tides. In addition, a full spectrum of non-migrating tides, dominated by the DE3 component, are seen. These are validated by comparison with previously published model results and with observations. Several year-long simulations of the TIEGCM are reported using combinations of NOGAPS-ALPHA winds and temperatures along with different values of eddy diffusion (K_{zz}) at the bottom boundary. Our results indicate that inclusion of non-migrating tides along with high values of K_{zz} act in concert to lower the calculated ionospheric electron

densities. Our baseline value of K_{zz} yields ionospheric electron densities which are up to a factor of 2 lower than observations. This appears to be due to a change in the abundance of molecular to atomic constituents. When K_{zz} is significantly lowered, the calculated electron densities come closer to observations. We suggest that the resolved eddy fluxes from the non-migrating tides can at least partially obviate the need for an assumed high value of K_{zz} for the bottom boundary of the TIEGCM.

Smith, Charles W.

Interplanetary Magnetic Flux and the Protracted Solar Minimum: Balancing CME Eruption with Reconnection (Invited)

Smith, Charles W.¹

1. EOS / SSC, Univ. New Hampshire, Durham, NH, USA

There is a growing recognition that the interplanetary magnetic flux results from a balance between the introduction of new field lines via CME eruption and the removal of field lines via reconnection below the Alfvén critical point. Typically, we think of CMEs introducing closed field lines, but once the ejecta reaches sufficient distance from the Sun, the distinction between open and closed field lines as a measurable property is no longer viable. Closed field lines stretched to sufficient distances are, for all practical purposes, open field lines. At the same time magnetic reconnection occurring between two open field lines of opposite polarity below the Alfvén critical point results in the ejection of two previously open field lines and the reduction of magnetic flux in the interplanetary medium. One can model the changing interplanetary flux by simply noting the time variability of CME eruptions. The recent protracted solar minimum allowed reconnection to drive the interplanetary field to unprecedented low values and provided a direct measure of the reconnection rate when undriven by CME eruption. We will apply these ideas to solar wind observations and illuminate some of the implications for future minima.

Smith, Charles W.

Interplanetary Turbulence During the Protracted Solar Minimum (Invited)

Smith, Charles W.¹

1. EOS / SSC, Univ. New Hampshire, Durham, NH, USA

For decades the interplanetary physics community has debated the roles of waves and turbulence. The debate centers on three complimentary views: Noninteracting waves, waves forming weak turbulence, and turbulence where waves are at most a component of the overall dynamics. Regardless of the view and with remarkable generality, the theory of third moment structure functions yields universal expressions describing the nonlinear cascade of energy and other quantities. These expressions are directly applicable to solar wind measurements. They provide unambiguous and conclusive values for energy transport and, by implication, solar wind heating rates. We compare computed energy

cascade rates to measured heating rates and find very favorable agreement. When these same expressions are applied to solar minimum measurements we find no significant difference in the description of interplanetary turbulence. The cascade rate may be reduced, but the overall nonlinearity scales in the same manner as observations of solar maximum conditions.

Solomon, Stan

Anomalously low geomagnetic energy inputs during 2008 solar minimum

Deng, Yue¹; Huang, Yanshi¹; Solomon, Stan²; Qian, Liying²; Knipp, Delores³; Weimer, Daniel⁴; Wang, Jing-Song⁵

1. University of Texas at Arlington, Arlington, TX, USA
2. High Altitude Observatory, Boulder, CO, USA
3. University of Colorado, Boulder, CO, USA
4. Virginia Tech, Hampton, VA, USA
5. China Meteorological Administration, Beijing, China

The record-low thermospheric density during the last solar minimum has been reported and it has been mainly explained as the consequence of the anomalously low solar extreme ultraviolet (EUV) irradiance. In this study, we examined the variation of the energy budget to the Earth's upper atmosphere during last solar cycle from both solar EUV irradiance and geomagnetic energy, including Joule heating and particle precipitation. The global integrated solar EUV power was calculated from the EUV flux model for aeronomic calculations (EUVAC) driven by the MgII index. The annual average solar power in 2008 was 33 GW lower than that in 1996. The decrease of the global integrated geomagnetic energy from 1996 to 2008 was close to 29 GW including 13 GW for Joule heating from Weimer2005 and 16 GW for particle precipitation from NOAA Polar-Orbiting Environmental Satellites (POES) measurements. Although the estimate of the solar EUV power and geomagnetic energy vary from model to model, the reduction of the geomagnetic energy was comparable to the solar EUV power. The Thermosphere Ionosphere Electrodynamic General Circulation Model (TIEGCM) simulations indicate that the solar irradiance and geomagnetic energy variations account for 3/4 and 1/4 of the total neutral density decrease in 2008, respectively.

Solomon, Stanley C.

Ionospheric Response to 2008-2009 Solar Cycle Minimum

Solomon, Stanley C.¹; Qian, Liying¹

1. High Altitude Observatory, Natl Ctr Atmospheric Research, Boulder, CO, USA

Observations of the neutral thermosphere during the extended 2008-2009 solar minimum period found anomalously low density, implying that thermospheric temperature was also lower than usual for solar minimum. A variety of solar measurements and proxies indicated commensurately lower levels of solar extreme-ultraviolet (EUV) irradiance, although there remains considerable

uncertainty concerning the magnitude of the reduction. Recent model simulations [Solomon et al., 2010; 2011] demonstrated that a ~10% decrease in solar EUV from the previous solar minimum, combined with a modest decrease in geomagnetic activity, and a small contribution from long-term global cooling due to increases in anthropogenic carbon dioxide, could explain the neutral density changes. The next question is how this pertains to the ionosphere. Numerous published observational studies have shown that ionospheric densities during 2008-2009 were lower than during previous solar minima, but there was considerable deviation from one location to another, and from one data analysis to another, with one global indicator showing little or no change. In this paper, we review model results from the NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM) that obtain agreement with neutral density changes. The ionospheric changes predicted by these simulations are presented, and compared with the evidence from ionospheric measurements.

Sutton, Eric K.

(WITHDRAWN) The Role of Helium in the Thermosphere During Recent Solar Minima

Sutton, Eric K.¹; Qian, Liying²; Solomon, Stanley C.²

1. AFRL-RVBXI, Kirtland AFB, NM, USA
2. NCAR High Altitude Observatory, Boulder, CO, USA

The previous solar minimum exhibited sustained low levels of solar extreme ultraviolet radiation and geomagnetic activity. This affords the opportunity to study upper-atmospheric conditions that are outside the domain of the available historical data and empirical models of the thermosphere. With the decline of solar and geomagnetic activity, neutral helium becomes dominant at progressively lower altitudes and pressure levels. We present a new physics-based model of thermospheric composition – an extension of TIE-GCM – that includes the transport and dynamics of neutral helium as a major constituent. Previous models have included helium as a minor constituent, simulating the effect of the major constituents on helium while ignoring the reverse; however, these assumptions generally limit the model to non-solar minimum conditions and/or lower altitudes. The main effect of helium in the thermosphere is a seasonal modulation of the mean molecular weight. The decrease in the mean molecular weight and accompanying increase in scale height in the winter hemisphere, where helium is more densely concentrated, cause an increase in the geopotential height of the pressure surfaces. This effect further couples into the momentum equations where a difference of >20 m/s directed away from the winter helium bulge is observed. Using this model, we compare the two previous solar cycles (ca. 1996 and 2008) to resolve the differences in helium content, the amplitude of seasonal variations, and response to geomagnetic disturbances.

Thayer, Jeff P.

The Impact of Helium on Thermosphere Mass Density Response to Geomagnetic Activity During the Recent Solar Minimum

Thayer, Jeff P.¹; Liu, Xianjing¹; Pilinski, Marcin²; Burns, Alan³

1. Aerospace Eng Sciences, University of Colorado, Boulder, CO, USA
2. Atmospheric and Space Technology Research Associates, Boulder, CO, USA
3. National Center for Atmospheric Research, Boulder, CO, USA

High-resolution mass density observations inferred from accelerometer measurements on the CHAMP and GRACE satellites are employed to investigate the thermosphere mass density response with latitude and altitude to geomagnetic activity during the recent solar minimum. The cold thermosphere during the recent solar minimum, extending from 2007 to 2010, led to atmospheric contraction where small constituent scale heights result in a more rapid transition from heavy to light neutral species with altitude. Coplanar orbital periods in February 2007 and December 2008 revealed the altitude and latitude response in thermosphere mass density for their respective winter hemispheres was influenced by the relative amount of helium and oxygen present. The CHAMP-to-GRACE (C/G) mass density ratio depends on two terms; the first proportional to the ratio of the mean molecular weight to temperature and the second proportional to the vertical gradient of the logarithmic mean molecular weight. For the relative levels of helium and oxygen in February 2007, the winter hemisphere C/G mass density response to geomagnetic activity, although similar to the summer hemisphere, was caused predominantly by changes in the vertical gradient of the logarithmic mean molecular weight. In December 2008, the significant presence of helium caused the mean molecular weight changes to exceed temperature changes in the winter hemisphere leading to an increase in the C/G ratio with increasing geomagnetic activity, in opposition to the decrease observed in the summer hemisphere that was caused primarily by temperature changes. The observed behavior is indicative of composition effects influencing the mass density response and the dynamic action of the oxygen to helium transition region in both latitude and altitude will lead to complex behaviors in the mass density at GRACE altitudes throughout the extended solar minimum from 2007 to 2010.

Thibault, Kim

Restoring the baseline solar activity level: a simulation

Thibault, Kim¹; Charbonneau, Paul¹

1. Université de Montréal, Montréal, QC, Canada

We have developed a network evolution model which explicitly treats small-scale interactions between elementary

magnetic flux elements. The model is the Monte Carlo type in 2D, approximates flux tubes by points, and makes them undergo random displacements on a rectangular surface representing the photosphere. The simulation's step length corresponds to a granule diameter and the time step to a granule turnover time. The model includes the following surface processes: emergence of flux tubes, displacement on granular convection, coalescence/cancellation, and submergence. These processes, especially coalescence, contribute to build up the network. Sunspot injection and disintegration is included for active Sun simulations. We use our model to test how long it takes the active Sun to recover its baseline activity level during a Maunder-type minimum. In particular, we analyse magnetic concentration size distribution over time once we turn off sunspot injection.

Turner, Niescja

Polar Cap Saturation and Geoefficiency in CIR-Driven Storms

Turner, Niescja¹; Cramer, W. D.¹; Borovsky, Joe²

1. Physics and Space Sciences, Florida Tech, Melbourne, FL, USA
2. Space Science Institute, Boulder, CO, USA

Energy coupling in magnetic storms is a fundamental issue in magnetospheric physics. Magnetic storms due to Corotating Interaction Regions (CIRs) elicit different responses in the magnetosphere than those prompted by other types of solar wind driving conditions such as CMEs. In particular, CIR-driven storms are more geoefficient, coupling more energy into the magnetosphere-ionosphere system per input energy from the solar wind than storms driven by CMEs. Here, we analyze the physics behind these well-established differences. In particular, we discuss the role of polar cap saturation in mediating the energy coupling capability of the solar wind to the magnetosphere in storm events. We show why the CIR and CME storms differ in this way, and we generalize our findings to all storms regardless of the type of storm driver. In addition, we will delve specifically into the differences in ring current responses during CIR and CME-driven events and discuss their relevance to the overall energy budget.

Usoskin, Ilya

Long-term reconstructions of solar activity from cosmogenic isotopes and cosmic ray records (Invited)

Usoskin, Ilya¹

1. Sodankylä Geophysical Observatory, University of Oulu, Oulu, Finland

While the data of directly observed sunspots is available for the past centuries, longer time series are required for many purposes, from purely astrophysical (constraints on solar/stellar dynamo) to geophysical (assessments on possible solar influence on climate). In order to reconstruct solar activity in the past, one has to use indirect proxy methods, the most useful being based on cosmogenic

isotope records. Cosmogenic isotopes are produced by energetic cosmic rays in the Earth's atmosphere and, after complicated transport and redistribution in the terrestrial system, are stored in natural stratified archives like, e.g., trees or polar ice. Such archives can be independently dated with high precision. The most common cosmogenic isotopes are radiocarbon ¹⁴C measured in tree rings and ¹⁰Be in ice cores from Antarctica and Greenland. Applying this method to data on cosmogenic ¹⁴C and ¹⁰Be measured in independently dated natural archives, one can evaluate long-term variability of solar activity on centennial-to-millennial time scales. Here I present a brief review of the modern methods of long-term solar activity reconstruction.

Vadas, Sharon L.

(WITHDRAWN) Effects of gravity wave dissipation on the thermosphere and ionosphere from deep convection during the recent solar minimum

Vadas, Sharon L.¹; Liu, Hanli²

1. CoRA, NorthWest Research Associates, Boulder, CO, USA
2. HAO, NCAR, Boulder, CO, USA

In this talk, we show new global simulation results which model the gravity wave effects in the thermosphere and ionosphere from deep convection over the entire Earth for a 13 day period during the recent extreme solar minimum. We find that large-scale changes in the background neutral wind, temperature, plasma frequency, and TEC accompany the dissipation of these convectively-generated gravity waves.

Viereck, Rodney

Solar EUV Irradiance Variability During Solar Minimum

Viereck, Rodney¹; Machol, Janet²; Snow, Marty³; Solomon, Stan⁴

1. NOAA/SWPC, Boulder, CO, USA
2. NOAA NGDC, Boulder, CO, USA
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The terrestrial response to a long and low solar minimum manifests itself primarily in the ionosphere/thermosphere region of Earth's upper atmosphere. Observations of atmospheric neutral density during this most recent solar minimum have shown significant deviations from previous minima. One of the primary energy inputs for this atmospheric region is solar Extreme UltraViolet (EUV) irradiance. The ratio of solar min-to-max irradiance variation ranges from 30% to 300% or more across these wavelengths and this large variability is reflected in similar changes in neutral density. By comparison, the irradiance variations from minimum to minimum are nearly constant. Unfortunately, there are very few measurements from which the variations from minimum to minimum can be derived. This is due to a lack of measurements that span 11 year solar cycles and/or calibration accuracies that are larger than the minimum-to-

minimum variations themselves. Thus proxies for solar irradiance are usually used to represent these long-term trends. The proxies typically used are sun spot number, F10.7 cm radio flux, and the Mg II core-to-wing ratio. But as is often the case with proxy data sets, they capture the gross features of the actual irradiance but not the more subtle details such as the minimum-to-minimum variations. In this presentation we will attempt to quantify the solar irradiance variability from minimum to minimum. We will present the various data sets and proxies that are often used to study secular trends in the solar EUV irradiance and try to show how each correlates with the actual EUV irradiance. We will compare the min-to-min solar EUV irradiance variations with other solar drivers of the upper atmosphere such as the CME driven geomagnetic storms.

Villanueva, Lucia

Analog Model improvement for Sunspot Solar Cycle Minima 1700-2012

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The smooth sunspot number R12 is the monthly solar index mainly used along more than 3 solar cycles in programs of Ionospheric prediction for HF radio communication frequencies. Several authors present different models for the maximum Rmax of solar cycles when a new Solar Cycle is becoming evident, the peak value of a solar cycle is crucial for estimation of a usable band wide for long term HF radio planning, however poor attention is paid to minima in such predictions. Recently Villanueva et al. (2012) presented an analog model using a long term modulation algorithm for Rmax of Solar Cycle Maxima. The model is based on the concept of signal transmission. The 11 year solar cycle takes place as a carrier modulated by Rmax and Rmin. In this paper, we specify and improve the model considered for solar minima Rmin and show that the minimum number of sunspots in the solar cycle 23-24 minima is closely related to the Maunder minima with a period around 100 years better than 110 years considered in the previous model to fit better the maxima long term variability of R12. Here it is also shown the statistical difference of data and model predictions in the minima from 1700 to 2012 and predictions for next solar minimum on the light of our new results. References: L. Villanueva (2012) 9th esww, Brussels. Session 2, Poster 44

Wing, Simon

Solar cycle variations of the field-aligned currents and electron precipitation

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Field-aligned current (FAC) density ($J//$), intensity, latitudinal width (Λ), ionospheric (Σp), and precipitating electron energy flux (ϵ) are examined during the solar cycle

23 with a particular focus on afternoon region-1 (R1) where the current flows upward. Apparently, the responses of R1 $J//$, FAC intensity, and Λ to solar cycle depend to a large extent on whether or not the FACs are located on open or closed field lines. At 12 – 17 MLT, where the field lines are frequently or partly open, the velocity shear at the boundary layer can play a significant role in generating FAC. $J//$ also has a strong dependence on Σp . The F10.7 index, which is often used as a proxy for the ionizing solar EUV and which exhibits a strong solar cycle variation, can affect Σp . However, the change in Σp due to solar EUV is largely compensated by ϵ , which roughly anti-correlates with solar cycle. As a result, the total Σp , which takes into account the contributions from both electron precipitation and solar EUV, only shows a weak solar cycle variation. Consequently, the solar cycle variations in $J//$ and FAC intensity reflect mostly V_{sw} variation. In this region, Λ does not appear to have a strong dependence on solar cycle in this region. In contrast, at 18 – 23 MLT, the field-lines are mostly closed and pressure gradient can play a significant role in generating $J//$, which apparently has a weak solar cycle dependency. However, Λ exhibits some solar cycle variation and as a result, FAC intensity also exhibits a solar cycle variation. In the open afternoon R1, an increase in n_{sw} increases $J//$, decreases maximum peak E_e (proxy for $\otimes\phi//$), but has little effect on maximum ϵ . In the same R1 region, an increase in V_{sw} increases $J//$, maximum peak E_e , and maximum ϵ . The dependencies of $J//$, maximum peak E_e , and maximum ϵ are consistent with the Knight relation and the voltage generator at the magnetopause boundary in the afternoon open R1.

Wu, Chin-Chun

Causes of extremely low solar wind density and magnetic fields during 2007-2009 solar minimum

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The extremely low solar wind density and magnetic field observed at the near-Earth orbit during the 2007-2009 solar minimum years has been attributed to an inflation of the heliosphere/plasma sheet (HCS/HPS). The inflation of HCS/HPS hypothesizes that HCS/HPS is thicker if Sun's polar magnetic field is weaker and is thinner if Sun's polar magnetic field is stronger [Wu et al., 2013]. In this study, we use photospheric magnetograms from NSO, MWO or WMO stations to study possible causes of the extreme. Specifically, we compute averages of the solar magnetic field for two different periods: 1995-1997 and 2007-2009. We also integrate the magnetic field over the equatorial (< 7.5 degrees), the polar (47.5-87.5 degrees), and the mid-latitude (12.5-42.5 degrees) regions. It is found that the averaged r-component of the magnetic field (Br) is smaller in the 2007-2009 period than in the 1995-1997 period by ~33% in

the polar region, ~36% in the mid-latitude region, and ~11% in the equatorial region. When moving outward with the solar wind, the relatively large magnetic field at the equator may inflate the HCS/HPS at a farther distance causing the extremely low solar wind density and magnetic field at the equator during 2007-2009. Work of CCW was supported by NRL 6.1 programs (e.g., ISES).

Wu, Chin-Chun

Variability of the heliospheric current/plasma sheet thickness as the cause of solar wind anomaly during the 2007-2008 solar minimum

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A recent study of global magnetohydrodynamics numerical simulation has proposed that inflation of heliospheric current/plasma sheet (HCS/HPS) may contribute to the extremely low solar wind density and magnetic field observed near the Earth orbit during the 2007-2009 solar minimum years [Wu et al., TAO, in press, 2013]. The HCS/HPS inflation hypothesis suggests that HCS/HPS is thicker (thinner) if Sun's polar magnetic field is weaker (stronger), and the extremely low solar wind density and magnetic field is a result of an anomalously inflated HCS/HPS. Observations of the global solar magnetic field at the photosphere level from Wilcox Solar Observatory indicate a smaller high-to-low latitude ratio of magnetic field pressure, suggesting a thicker HCS/HPS [Wu et al., to be presented at this workshop]. Here we provide more observational evidence from ULYSSES. Over its entire mission between 1991 and 2009, the ULYSSES spacecraft orbited the Sun three cycles. It flew across the solar equator around ~1.4 AU three times during February-March 1995, April-July 2001, and June-September 2007. Solar activity was at near minimum in 1995 and 2007 but at maximum in 2001. We analyze ULYSSES in situ solar wind plasma and magnetic field data at daily resolution. ULYSSES detected a heliosphere current/plasma sheet (HCS/HPS) while it was traversing the solar equator in 1995 and 2007. It is found that the HPS is ~50% thicker in heliospheric latitude in 2007 than that in 1995 (68.5° versus 44.9°). Altogether, we conclude that the relative strength of the high-latitude to low-latitude solar magnetic field/pressure plays an important role in controlling solar wind and field parameters near the Earth environment. (Work of CCW was supported by NRL 6.1 program.)

Zakharenkova, Irina

Estimation of the Ionosphere and Plasmasphere Contribution to the GPS TEC under Solar Minimum Conditions

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Comparative analysis of GPS TEC data and FORMOSAT-3/COSMIC radio occultation measurements was carried out during period of the extremely prolonged solar minimum of cycle 23/24. COSMIC data for different seasons corresponded to equinox and solstices of the years 2007-2009 were analyzed. All selected electron density profiles were integrated up to the height of 700 km (altitude of COSMIC satellites), the monthly median estimates of ionospheric electron content (IEC) were retrieved with use of spherical harmonics expansion. Monthly medians of TEC values were calculated from diurnal variations of GPS TEC estimates during considered month. Joint analysis of GPS TEC and COSMIC data allows us to extract and estimate electron content corresponded to the ionosphere (its bottom and topside parts) and the plasmasphere ($h > 700$ km) for different seasons of 2007-2009. In order to analyze seasonal behaviour of plasmaspheric contribution to GPS TEC at the different regions we selected several specific points with coordinates, corresponded to the approximate positions of different, mid-latitude and low-latitude, ionospheric sounding stations. Such points were selected at Northern America, European and Asian regions, Southern America, Southern Africa and Australia. For each specific points GPS TEC, COSMIC IEC and ECpl estimates were analyzed. Percentage contribution of ECpl to GPS TEC indicates the clear dependence from the time and varies from a minimum of about 25-50% during day-time to the value of 50-75% at night-time. Contribution of both bottom-side and topside IEC has minimal values during winter season in compare with summer season (for both day- and night-time). On average bottom-side IEC contributes were about 5-10% of GPS TEC during night and about 20-27% during day-time. Topside IEC contributes about 15-20% of GPS TEC during night and about 35-40% during day-time. The obtained results were compared with TEC, IEC and ECpl estimates retrieved by Standard Plasmasphere-Ionosphere Model that has the plasmasphere extension up to 20,000 km (GPS orbit).

Zhang, Yongliang

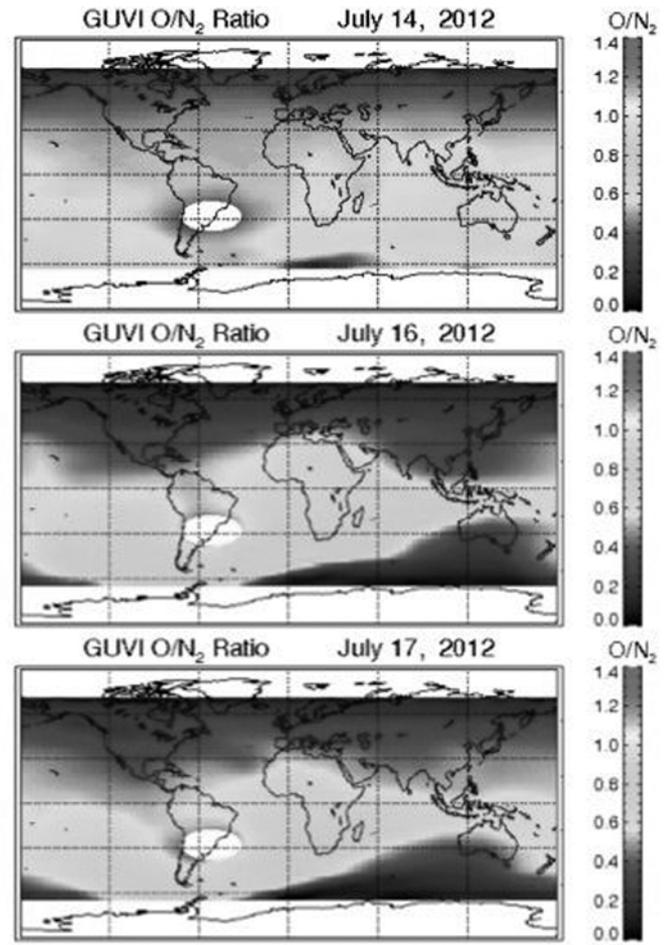
Observations of Ionosphere/Thermosphere Coupling and Response from Solar Max 23 to Solar Max 24

Paxton, Larry J.¹; Miller, Ethan¹; Zhang, Yongliang¹; Kil, Hyosub¹; Schaefer, Robert¹; Demajistre, Robert¹; Smith, Daniel¹; Talaat, Elsayed¹

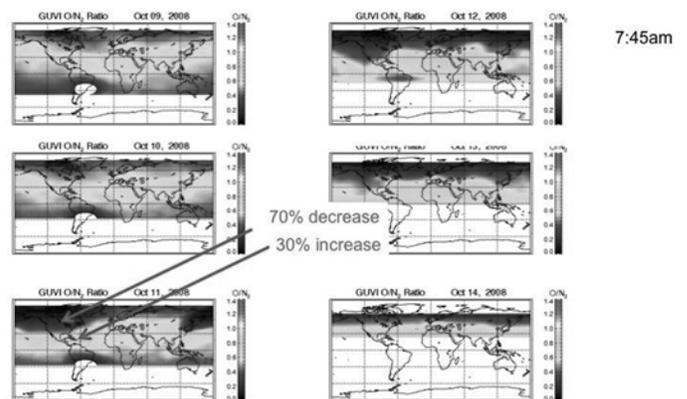
1. Applied Physics Lab, The Johns Hopkins University, Laurel, MD, USA

The prolonged solar minimum period between the peak of Solar Cycle 23 and Solar Cycle 24 provides us with a unique opportunity to explore whether we really understand the physics of the coupled whole atmosphere system or whether there are frontier issues that remain to be explored. During solar minimum one would expect that we should be able to measure the baseline state of the thermosphere and clearly examine the forcing of the ionosphere from below. In addition, we should be able to explore whether the dynamical response of the I/T system to geomagnetic disturbances is faithfully reproduced by our models – and that ability to reproduce the behavior is consistent from event to event. In this paper we present results from the TIMED/GUVI instrument to address these questions. In particular, we discuss: the utility of O/N_2 as a tracer of the dynamics; the utility of UV signatures as tracer of the longitudinal variability of the nightside ionosphere; and a somewhat integrated view of the response of the coupled system.

<http://guvi.jhuapl.edu>



Typical map of changes in thermospheric circulation as we approach solar maximum.



Typical solar minimum response. The depth of depletion in O/N_2 is as large as during a significant geomagnetic disturbance. The latitudinal extent of the depletion is sensitive to the strength of the circulation in the upper atmosphere.