WHI Working Group 2A: Quantifying the Quiet Sun / Irradiance for Solar Cycle Minimum (Version 2)

Tom Woods, Phil Chamberlin, Jerry Harder, Rachel Hock, Erik Richard, Marty Snow

LASP / University of Colorado

<tom.woods@lasp.colorado.edu>
Whole Heliosphere Interval (WHI) 2008

- Whole Heliosphere Interval is an international coordinated observing and modeling effort to characterize the 3-dimensional interconnected solar-heliospheric-planetary system.
- Period is March 20, 2008 to April 16, 2008
  - Solar Carrington Rotation 2068
Quantifying the Quiet Sun

• WHI period of April 10-16, 2008 chosen for the quiet Sun interval
  – Perhaps not solar cycle minimum, but it did turn out to be quiet solar conditions
  – Additional goal is to compare to Whole Sun Month (WSM, 1996) results (Thur PM discussion)

• Quiet Sun – Scott McIntosh leading
  – Conditions / references / results from many solar imagers
    • SOHO – SUMER, CDS, EIT (part of WSM 1996 study)
    • Hinode - SOT, XRT TRACE STEREO SECCHI, EUVI

• Solar Cycle Minimum Irradiance – Tom Woods leading
  – TIMED SEE, SORCE, Rocket EVE, SOHO SEM, SBUV
Solar Cycle Minimum Yet?

• Standard definition of “solar cycle minimum” is the minimum in SSN smoothed over 1-year
• \( <\text{SSN}> \) minimum level \( \sim 0-5 \)

• Not seen minimum yet!
• however minimum will not be obvious until 6 months after the event …
PSPT Images Used to Identify Solar Features

April 12-14 were very quiet days

<table>
<thead>
<tr>
<th></th>
<th>Features areas (relative to solar disk area)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>2008/04/12</td>
<td>0.07283</td>
</tr>
<tr>
<td>2008/04/14</td>
<td>0.06446</td>
</tr>
</tbody>
</table>
Solar Activity During WHI April 10-16, 2008 QS Interval

- PSPT images are used to generate feature areas

- Moderate solar activity in late March

- Very low solar activity during April 10-16
Solar Irradiance Data Sets

- **TIMED Solar EUV Experiment (SEE)**
  - XPS: 0.1-27 nm, $\Delta \lambda \sim 8$ nm
  - EGS: 27-194 nm, $\Delta \lambda \sim 0.4$ nm
- **Solar Radiation and Climate Experiment (SORCE)**
  - XPS – same as on TIMED SEE
  - SOLSTICE: 115-308 nm, $\Delta \lambda \sim 0.1$ nm
  - SIM: 200-2400 nm, $\lambda/\Delta \lambda \sim 30$
  - TIM: total solar irradiance (TSI)
- **SOHO Solar EUV Monitor (SEM)**
  - 26-34 nm and zeroth order 0-50 nm
- **SDO EUV Variability Experiment (EVE)**
  - Rocket EVE: 6-105 nm, $\Delta \lambda \sim 0.1$ nm
  - Suborbital rocket launched 14 April 08
- **NOAA SBUV**: 200-400 nm
Two Spectra to Prepare for WHI Interval

• “Quiet Sun” (solar cycle minimum) Reference Spectrum
  – WHI Quiet Sun dates of Apr 10-16 (Rocket 14-Apr-2008)

• “Active” Reference Spectra
  – “Sunspot” active spectrum: March 25 – March 29
  – “Faculae” active spectrum: March 30 – April 4

• Compare these new results to model and previous reference spectra
  – Models: SRPM, NRLEUV, VUV2002
  – Reference Spectra: Thuillier (ATLAS 1&3), ASTM-E490
    – ATLAS-3 Reference Spectrum:
      – May 1997 rocket measurement for < 119 nm
      – March 1995 UARS and ATLAS-3 observations for > 119 nm
Spectral Distributions for WHI Irradiance Sets

- **How to combine?**
  - consider accuracy, spectral resolution, degradation, etc.
  - select wavelength boundaries or averages?

- **SORCE XPS (0-40)**
- **SORCE SOLSTICE (115-310)**
- **TIMED SEE EGS (26-195)**
- **TIMED XPS (0-40)**
- **Rocket EVE (6-106)**

- **NOAA SBUV (165-400)**
- **SORCE SIM (200-2400)**

- **Wavelengths:**
  - 0.1 nm
  - 6 nm
  - 27 nm
  - 115 nm
  - 200 nm
  - 300 nm
  - 1600 nm
  - 2400 nm
Solution for Reference Spectra (version 1&2)

• Spectral Intervals / Resolution
  – 0.1-nm intervals on 0.05-nm centers
  – Note that SIM instrument resolution (above 310 nm) is much less than 0.1-nm

• Selected Wavelength Intervals
  – Did have to fill 113-116 nm (no measurements)
WHI Solar Irradiance – Full Range 0-2400 nm
WHI Solar Irradiance: Rocket EVE & SEE

LASP SSI Reference for WHI-2008

Irradiance (W/m²/nm)

Wavelength (nm)
WHI Solar Irradiance: SORCE SOLSTICE
WHI Solar Irradiance: SORCE SIM
WHI Solar Irradiance: Solar Variability

- Average of the active spectrum to minimum spectrum
  - Red represents negative variability (sunspot darkening)
WHI & Atlas-3 Comparison: EUV

- EUV range in Atlas-3 is actually based on May 1997 rocket measurement and old AE-E (EUV81) variability. Expect accuracy for Atlas-3 EUV to be ~50%
WHI & Atlas-3 Comparison: FUV-MUV-NUV

- FUV-MUV-NUV range in Atlas-3 is based on UARS SOLSTICE and UARS SUSIM, and validated with Atlas SUSIM, SOLSPEC, SBUV observations
- These results are from March 1995 (not solar cycle minimum)
- Accuracy / validation at 3-10% [Woods et al., JGR, 1996]
WHI & Atlas-3 Comparison: Visible & NIR

- Atlas-3 Visible and NIR results are from Atlas SOLSPEC
- Expected accuracy of ~2%
WHI Solar Irradiance Files

- **ref_solar_irradiance_whi-2008_ver2.dat**
  - text data file – see header information for more details

- **IDL code : plot_whi_ref.pro**
  - supporting code: read_dat.pro, setplot.pro, rainbow.pro
  - supporting files: atlas3_1-nm.dat, vuv2002_whi-2008.dat

- **plots (subdirectory, graphics are in JPEG format)**
  - Spectra plots:
    - whi_ref_both, whi_ref_0-120nm, whi_ref_100-310nm, whi_ref_300-2400nm
  - Solar variability (ratio Mar / Apr – 1.0)
    - whi_ref_variability (red = negative changes, sunspot blocking)
  - Comparison to ATLAS-3 (ratio WHI Apr / ATLAS-3)
    - whi_ref_ratio_atlas3, whi_ref_ratio_atlas3_0-120nm, whi_ref_ratio_atlas3_120-310nm, whi_ref_ratio_atlas3_300-2400nm