It’s Coming!
In Anticipation of Solar Max

Joe Kunches
Space Weather Prediction Center
National Centers for Environmental Prediction
National Oceanic and Atmospheric Administration
Boulder, Colorado
USA
Large Spot Coming On Now
September 21, 2009

Photo 1053 UTC, Courtesy Peter Lawrence, Selsey, West Sussex, UK
Outline

- The problem – space weather
- The question – Cycle 24: How strong?
- The issues – Science, Users
- The outlook
How Does Space Weather Affect Navigation Systems?

- Geomagnetic Storms
- Solar Radiation Storms
- Radio Blackouts

http://www.swpc.noaa.gov/NOAA scales/
Eruptive Sun to Affected Earth

Flare

Coronal Mass Ejection (CME)

Aurora
<table>
<thead>
<tr>
<th>Active Region Number</th>
<th>Cycle Number</th>
<th>Location</th>
<th>Date Numbered</th>
</tr>
</thead>
<tbody>
<tr>
<td>11025</td>
<td>24 (new cycle)</td>
<td>N17E32</td>
<td>31 Aug 2009</td>
</tr>
<tr>
<td>11024</td>
<td>24 (new cycle)</td>
<td>S25E02</td>
<td>4 Jul 2009</td>
</tr>
<tr>
<td>11023</td>
<td>24 (new cycle)</td>
<td>S22E15</td>
<td>23 Jun 2009</td>
</tr>
<tr>
<td>11022</td>
<td>24 (new cycle)</td>
<td>S27E01</td>
<td>22 Jun 2009</td>
</tr>
<tr>
<td>11021</td>
<td>24 (new cycle)</td>
<td>S16W85</td>
<td>18 Jun 2009</td>
</tr>
<tr>
<td>11020</td>
<td>24 (new cycle)</td>
<td>N22E07</td>
<td>9 Jun 2009</td>
</tr>
<tr>
<td>11019</td>
<td>24 (new cycle)</td>
<td>N27E37</td>
<td>1 Jun 2009</td>
</tr>
<tr>
<td>11018</td>
<td>24 (new cycle)</td>
<td>S33E25</td>
<td>24 May 2009</td>
</tr>
<tr>
<td>11017</td>
<td>24 (new cycle)</td>
<td>N18E13</td>
<td>14 May 2009</td>
</tr>
<tr>
<td>11016</td>
<td>23 (old cycle)</td>
<td>S08W71</td>
<td>30 Apr 2009</td>
</tr>
<tr>
<td>11015</td>
<td>24 (new cycle)</td>
<td>N22W79</td>
<td>22 Apr 2009</td>
</tr>
<tr>
<td>11014</td>
<td>23 (old cycle)</td>
<td>S04W10</td>
<td>7 Mar 2009</td>
</tr>
<tr>
<td>11013</td>
<td>24 (new cycle)</td>
<td>N26E12</td>
<td>25 Feb 2009</td>
</tr>
<tr>
<td>11012</td>
<td>23 (old cycle)</td>
<td>S06E53</td>
<td>12 Feb 2009</td>
</tr>
<tr>
<td>11011</td>
<td>23 (old cycle)</td>
<td>S12W34</td>
<td>20 Jan 2009</td>
</tr>
<tr>
<td>11010</td>
<td>24 (new cycle)</td>
<td>N18E33</td>
<td>10 Jan 2009</td>
</tr>
<tr>
<td>11009</td>
<td>24 (new cycle)</td>
<td>S26W73</td>
<td>11 Dec 2008</td>
</tr>
<tr>
<td>11008</td>
<td>24 (new cycle)</td>
<td>N33W09</td>
<td>11 Nov 2008</td>
</tr>
<tr>
<td>11007</td>
<td>24 (new cycle)</td>
<td>N35E02</td>
<td>31 Oct 2008</td>
</tr>
<tr>
<td>11006</td>
<td>24 (new cycle)</td>
<td>S27W63</td>
<td>17 Oct 2008</td>
</tr>
<tr>
<td>11005</td>
<td>24 (new cycle)</td>
<td>N26E42</td>
<td>12 Oct 2008</td>
</tr>
<tr>
<td>11004</td>
<td>23 (old cycle)</td>
<td>S08W17</td>
<td>11 Oct 2008</td>
</tr>
<tr>
<td>11003</td>
<td>23 (old cycle)</td>
<td>S23E28</td>
<td>5 Oct 2008</td>
</tr>
<tr>
<td>11002</td>
<td>24 (new cycle)</td>
<td>N25W27</td>
<td>23 Sep 2008</td>
</tr>
<tr>
<td>11001</td>
<td>23 (old cycle)</td>
<td>N06E14</td>
<td>12 Sep 2008</td>
</tr>
<tr>
<td>11000</td>
<td>23 (old cycle)</td>
<td>S13E24</td>
<td>19 Jul 2008</td>
</tr>
<tr>
<td>10999</td>
<td>23 (old cycle)</td>
<td>S02E60</td>
<td>17 Jun 2008</td>
</tr>
</tbody>
</table>
Do Spotless Days Forebear A Weak Cycle 24?
May 2009 Prediction

- Solar Minimum occurred in December 2008
- Cycle 24 will be average
  - $R_i = 90$
  - May, 2013
SWPC Product Subscription Service

• 1,695 New Subscription Customers in 2008

Customer Growth During Solar Minimum

Example of Registrants in 2008
Space Weather Effects

- Issues include:
  - High latitude ionosphere (aviation, maritime, geophysical)
  - Middle and low latitude radio impacts (Dec., 2006 massive burst)

- Evolving (during solar minimum) technologies:
  - GIOVE A & B; GPS L2C, L5
  - FAA ADS-B
GPS: Consequences of a 55° Inclination

From high latitudes, all satellites are relatively low on the horizon. This means they must look through "thick" ionosphere.
GNSS Products from SWPC

1. Model CME from Sun
2. Model TEC globally
3. Focus on regional issues
Scintillations & GNSS Loss-of-Lock

Reference: Kintner et al, InsideGNSS, July/August, 2009

FIGURE 1 Scintillation map showing the frequency of disturbances at solar maximum. Scintillation is most intense and most frequent in two bands surrounding the magnetic equator, up to 100 days per year. At poleward latitudes, it is less frequent and it is least frequent at mid-latitude, a few to ten days per year.
Navigation at High Latitudes

- Global warming causes polar ice melt
- Less ice means more sea lanes
- GPS looks through "thick" ionosphere (55° inclination)
- Space weather hot spot!

A Shortcut Across The Top of the World

The Northeast Passage, across the Arctic Ocean, provides a shorter alternative for cargo vessels travelling between Europe and Asia than using the Suez Canal. It is shorter than the Panama Canal route for some voyages between the North American west coast and Europe.

LENGTH OF A VOYAGE TO ROTTERDAM FROM:

- YOKOHAMA, JAPAN
  - 12,894 miles via Suez Canal
  - 8,462 miles via Northeast Passage
- SHANGHAI, CHINA
  - 12,167 miles via Suez Canal
  - 8,397 miles via Northeast Passage
- VANCOUVER, CANADA
  - 10,262 miles via Panama Canal
  - 8,038 miles via Northeast Passage

Source: The Russian Ministry of Transport

The New York Times
Freedom of Navigation in the Arctic
The Way Forward - Awareness
Arctic Domain Awareness

- Air Patrols
  - ‘Eyes on’ above the Arctic Circle
  - Provide scientists platforms of opportunity
  - Media opportunity to increase ADA at the global level
Off Shore Oil Exploration
NOAA Polar Operational Environmental Satellites (POES)

- Allows heightened situational awareness
- Sets a path for improved space weather services

http://www.swpc.noaa.gov/pmap/index.html
Conclusion

- The problem – foul space weather looms
- The question – Cycle 24: How strong? 
  Average cycle; sunspot number = 90, maximum May, 2013
- The issues
  - Science – challenged
  - Users – surprised (?)
- The outlook
  - Sun is starting to rumble, activity picking up
The Quiet of Solar Minimum

Quiet (Ap<-7) Geomagnetic Conditions

September 21, 2009

49th Civil GPS Service Interface Committee, Savannah
SWPC Google Earth Overlay
Solar EUV Shows No Start

SOHO Solar EUV Monitor

Photon Flux (cm$^2$/sec)

Year

1 - 50 nm Band
26 - 34 nm Band
Solar Data Show Start of New Cycle

Courtesy Mark Rast, PSPT
Future SWx Prediction Models: USTEC to GEOTEC

Europe (EUREF)

IHY-Africa

GPS occultations