It's Coming!
In Anticipation of Solar Max

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Large Spot Coming On Now September 21, 2009

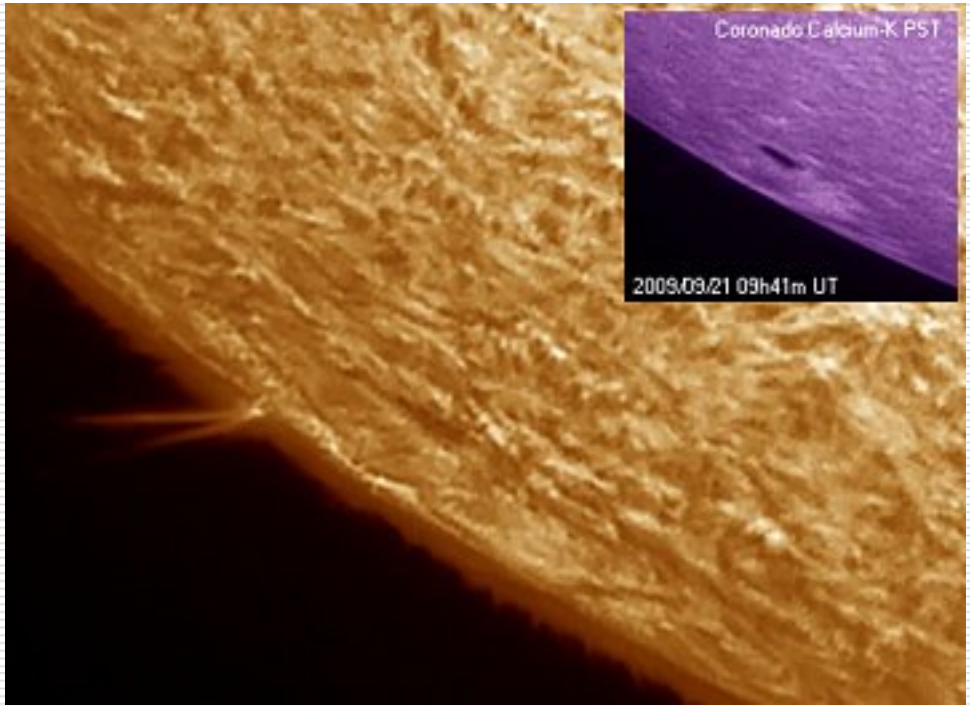
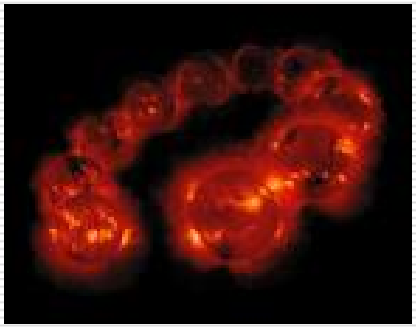
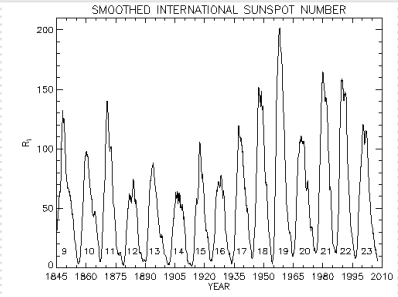


Photo 1053 UTC, Courtesy Peter Lawrence, Selsey, West Sussex, UK

Outline

- **The problem** – space weather
- **The question** – Cycle 24: How strong?
- **The issues** –
  - Science
  - Users
- **The outlook**

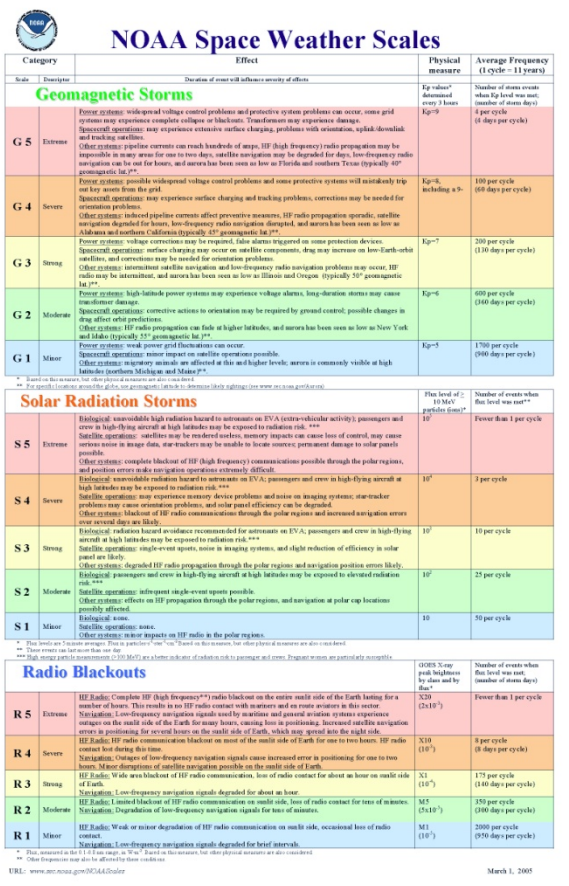




How Does Space Weather Affect Navigation Systems?

- Geomagnetic Storms
- Solar Radiation Storms
- Radio Blackouts

http://www.swpc.noaa.gov/NOAAscales/

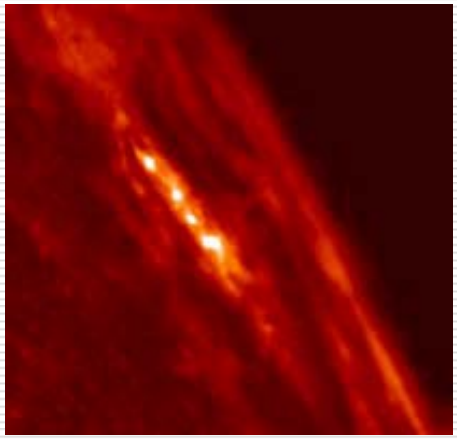


NOAA Space Weather Scales

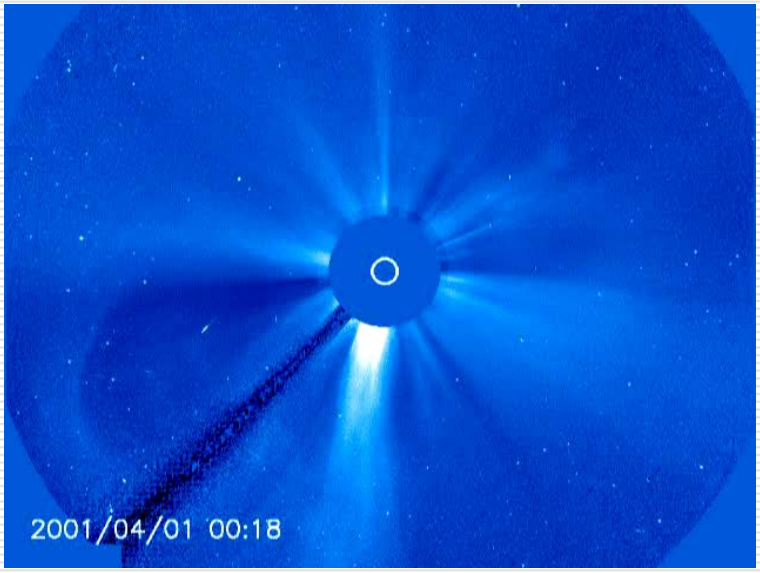
Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**.	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	Power systems: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**.	Kp=8, including a 9-	100 per cycle (60 days per cycle)
G 3	Strong	Power systems: voltage corrections may be required, false alarms triggered on some protection devices. Spacecraft operations: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. Other systems: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.)**.	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	Power systems: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. Other systems: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**.	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**.	Kp=5	1700 per cycle (900 days per cycle)
* Based on flux measure, but other physical measures are also considered. ** For specific locations around the globe, see geomagnetic latitude to determine likely sightings (see www.swpc.noaa.gov/Aurora)				
Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
S 5	Extreme	Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. *** Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. Other systems: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	Biological: unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. Other systems: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. Other systems: degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	Biological: passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.*** Satellite operations: infrequent single-event upsets possible. Other systems: effects on HF propagation through the polar regions, and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S 1	Minor	Biological: none. Satellite operations: none. Other systems: minor impacts on HF radio in the polar regions.	10	50 per cycle
* Plus levels are 5-minute averages. Flux in particles • cm⁻² • sec⁻¹ sr⁻¹ Based on this measure, but other physical measures are also considered. ** These events can last more than one day. *** High energy particle measurements (>100 MeV) are a better indicator of radiation risk to passenger and crews. Pregnant women are particularly susceptible.				
Radio Blackouts			GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
R 5	Extreme	HF Radio: Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. Navigation: Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 ($2x10^{-3}$)	Fewer than 1 per cycle
R 4	Severe	HF Radio: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	HF Radio: Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. Navigation: Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	HF Radio: Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes. Navigation: Degradation of low-frequency navigation signals for tens of minutes.	M5 ($5x10^{-5}$)	350 per cycle (300 days per cycle)
R 1	Minor	HF Radio: Weak or minor degradation of HF radio communication on sunlit side, occasional loss of radio contact. Navigation: Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)
* Flux, measured in the 1.0-8.0 Å band, in W•m⁻². Based on this measure, but other physical measures are also considered. ** Other frequencies may also be affected by these conditions.				
URL: www.swpc.noaa.gov/NOAAscales				March 1, 2005

Eruptive Sun to Affected Earth

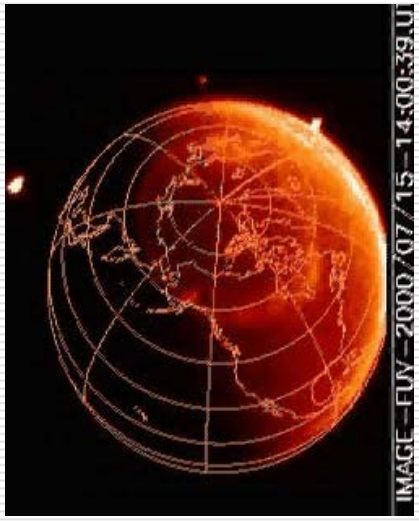
Flare



Coronal Mass Ejection (CME)



Aurora



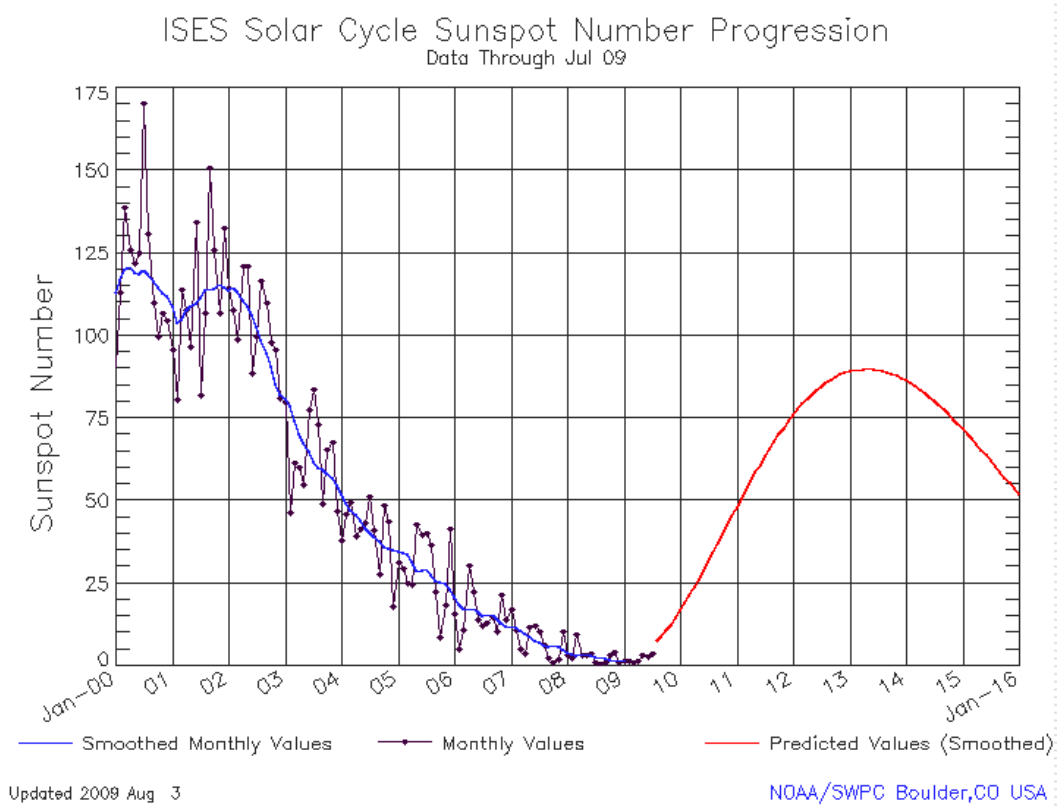
Scorecard

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

Do Spotless Days Forebear A Weak Cycle 24?

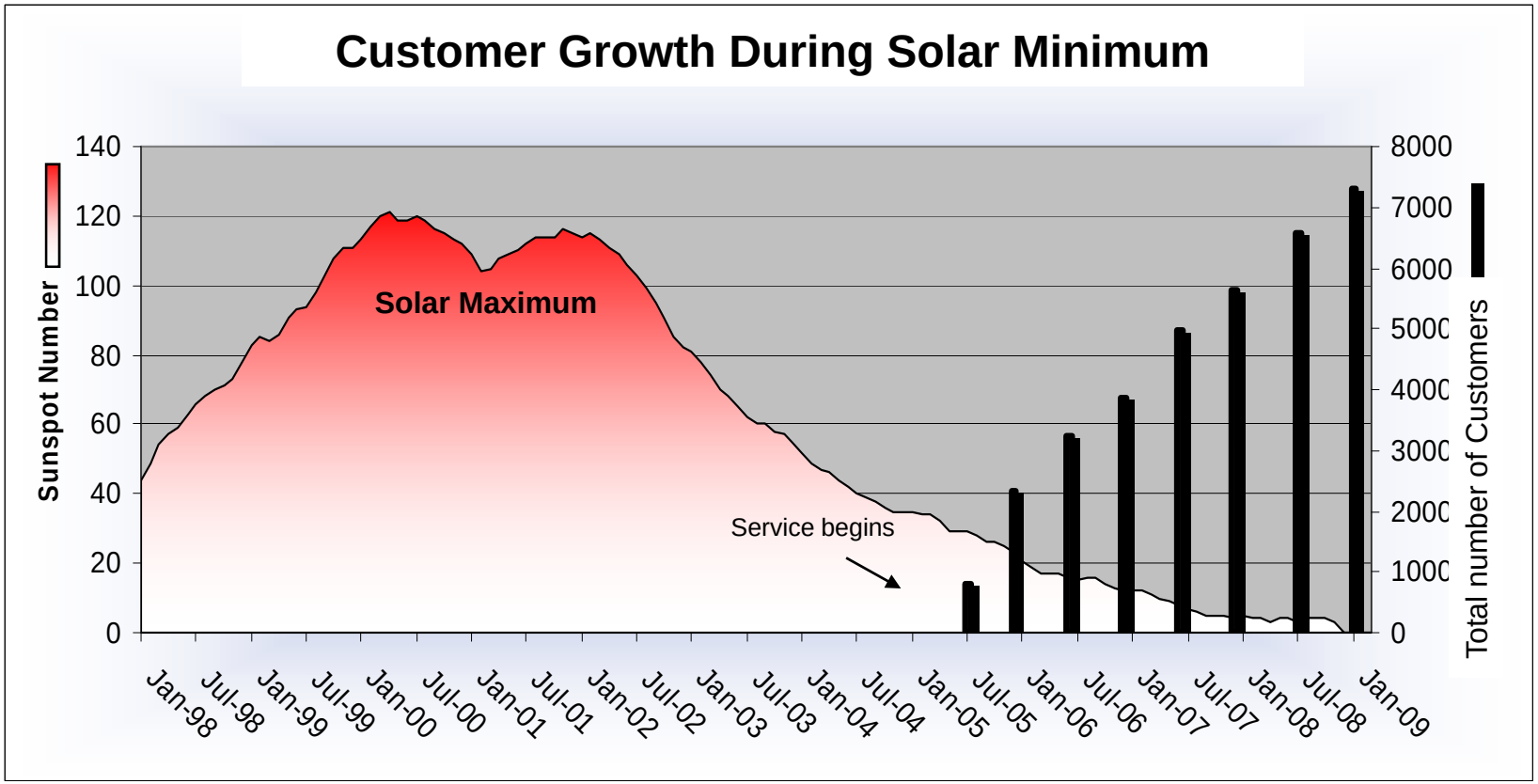
May 2009 Prediction

- 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



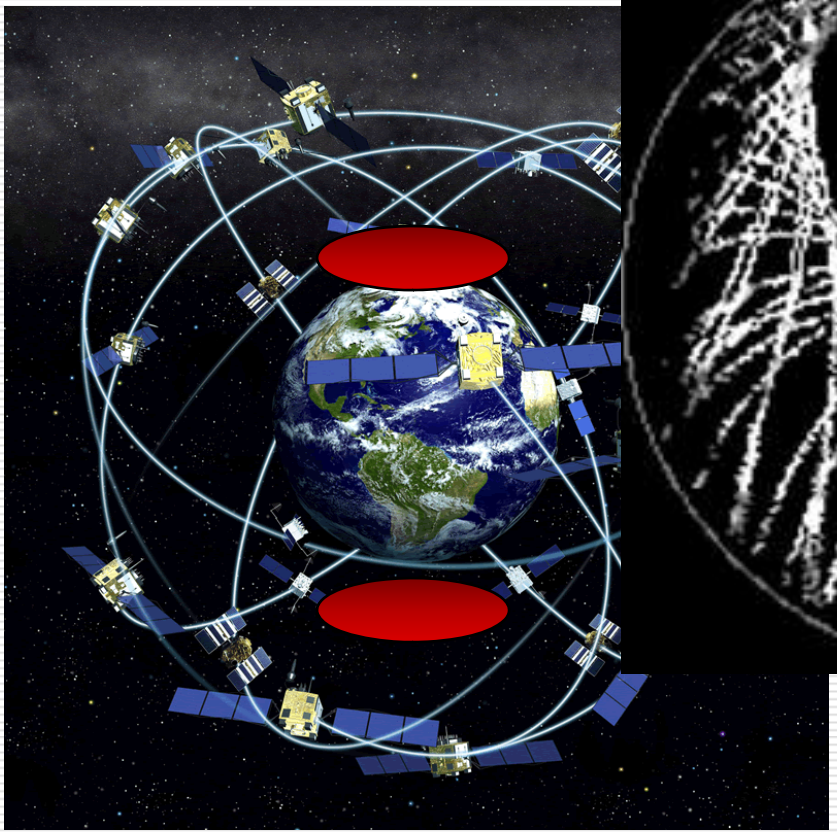
USSTRATCOM	Inmarsat	FEMA	Boeing	FAA
White House Communications Agency	L-3 Communications	Florida Division of Emergency Mgnt.	British Petroleum America	Bonneville Power Administration
Washington St. Dept of Transportation	Caterpillar, Inc.	Alaskan Airlines	United Launch Alliance	Salem and Hope Creek Nuclear Stations

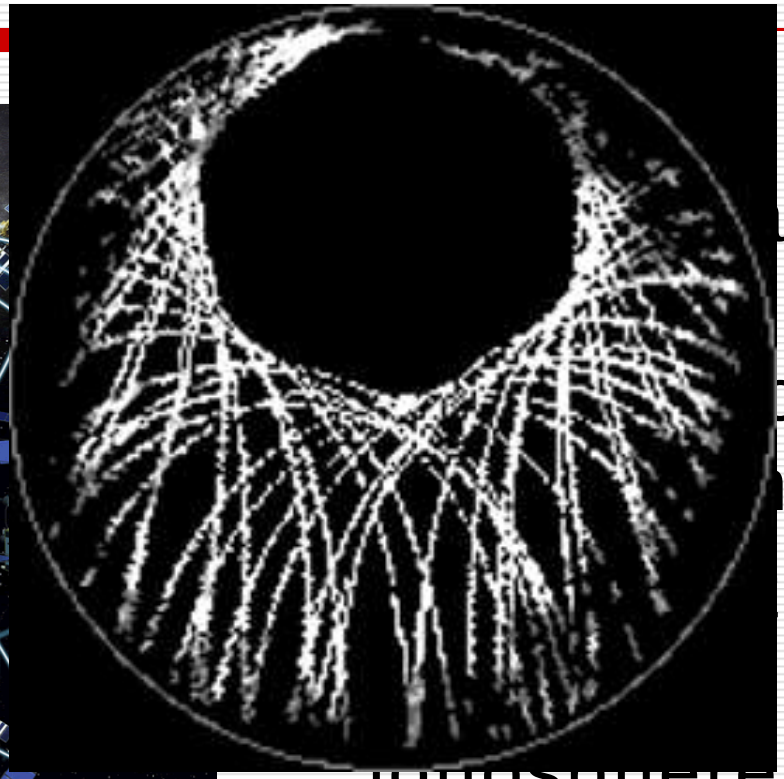
Example of Registrants in 2008

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





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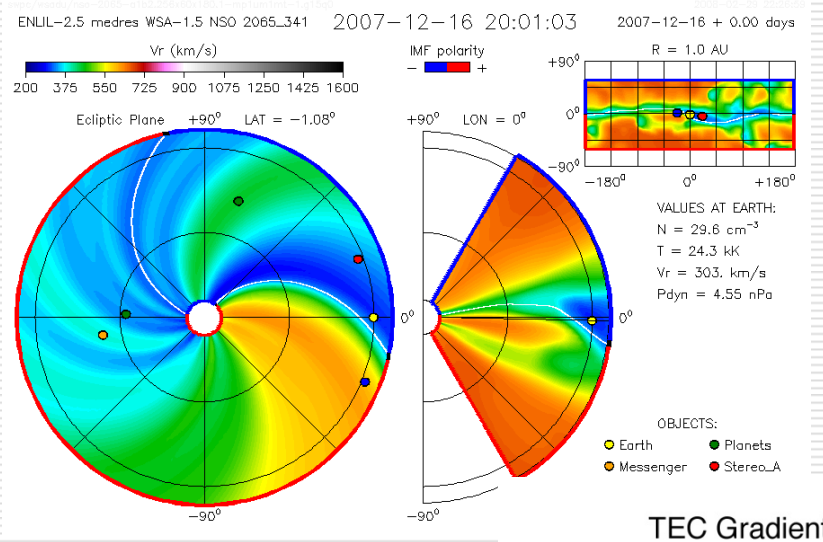
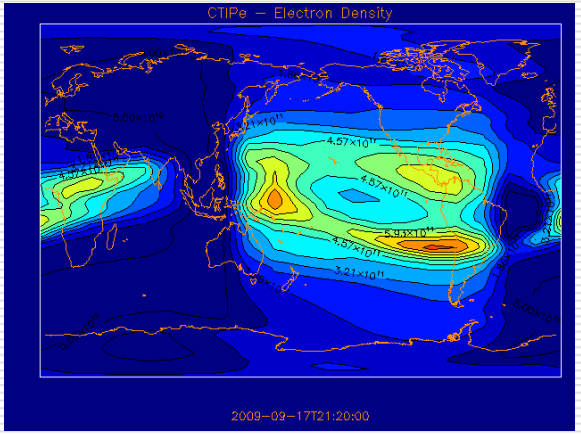
ionosphere

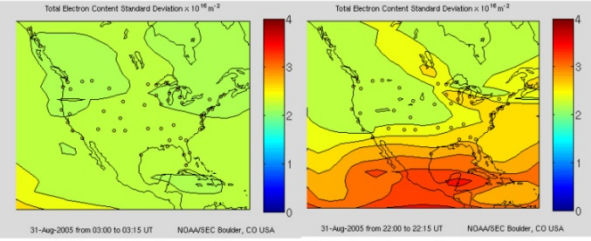
GNSS Products from SWPC





TEC Gradient Product

Use information on TEC gradients to estimate time interval needed to record dual-frequency GPS data to achieve cm level positioning accuracy



quiet ionospheric conditions small gradients, shorter intervals

disturbed ionospheric conditions - steeper gradients, longer intervals

1. Model CME from Sun
2. Model TEC globally
3. Focus on regional issues

Scintillations & GNSS Loss-of-Lock

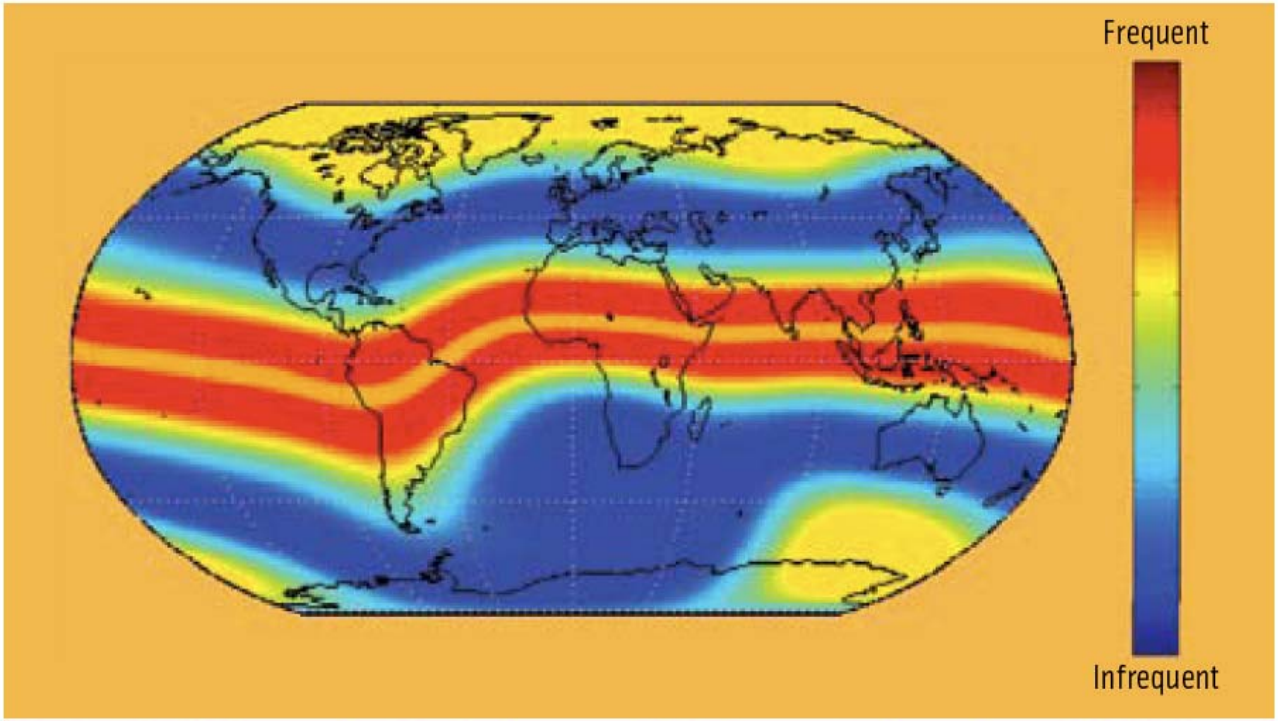
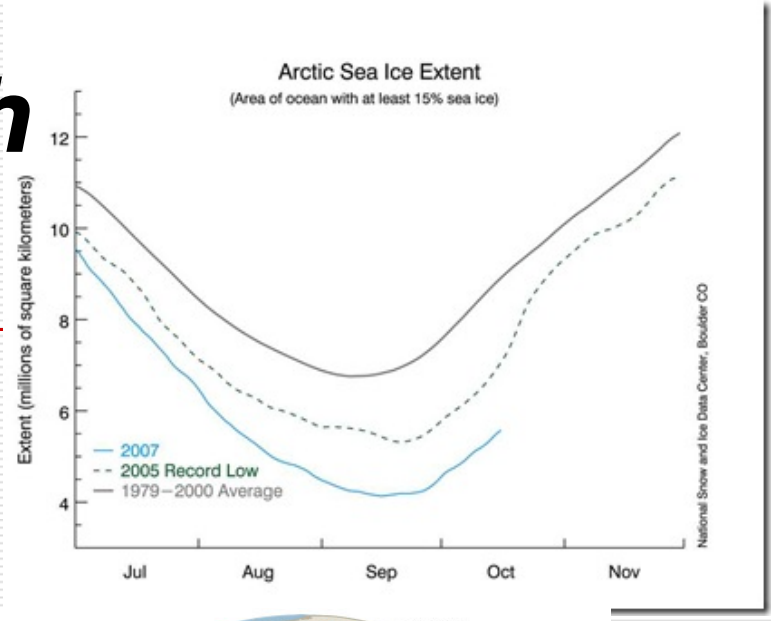


FIGURE 1 Scintillation map showing the frequency of disturbances at solar maximum. Scintillation is most intense and most frequent in two bands surrounding the magnetic equator, up to 100 days per year. At poleward latitudes, it is less frequent and it is least frequent at mid-latitude, a few to ten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

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

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:

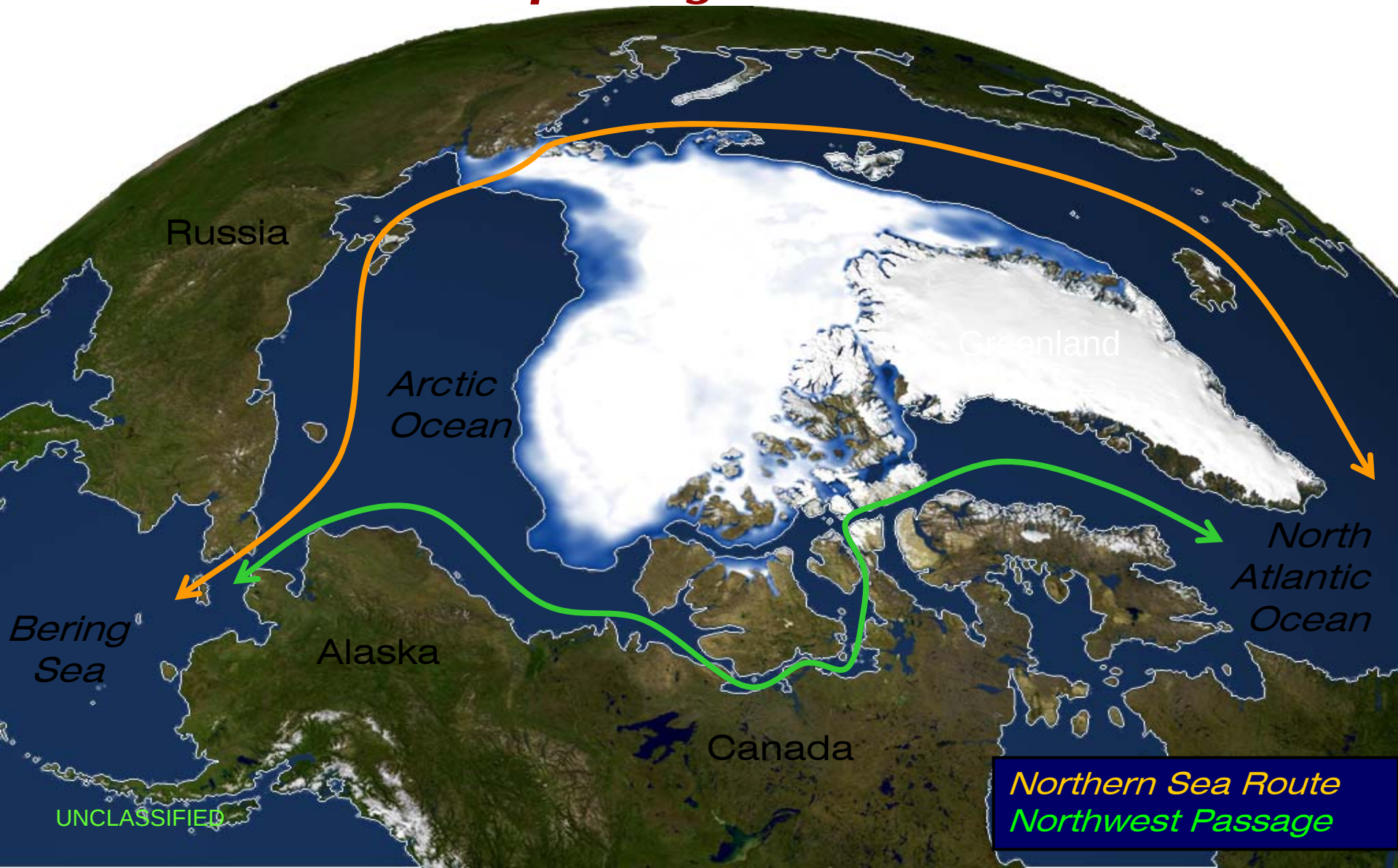
YOKOHAMA, JAPAN
12,894 miles via Suez Canal,
8,452 miles via Northeast Passage

SHANGHAI, CHINA
12,107 miles via Suez Canal,
9,297 miles via Northeast Passage

VANCOUVER, CANADA
10,262 miles via Panama Canal,
8,038 miles via Northeast Passage

Homeland Security

Freedom of Navigation in the Arctic



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The Way Forward- Awareness

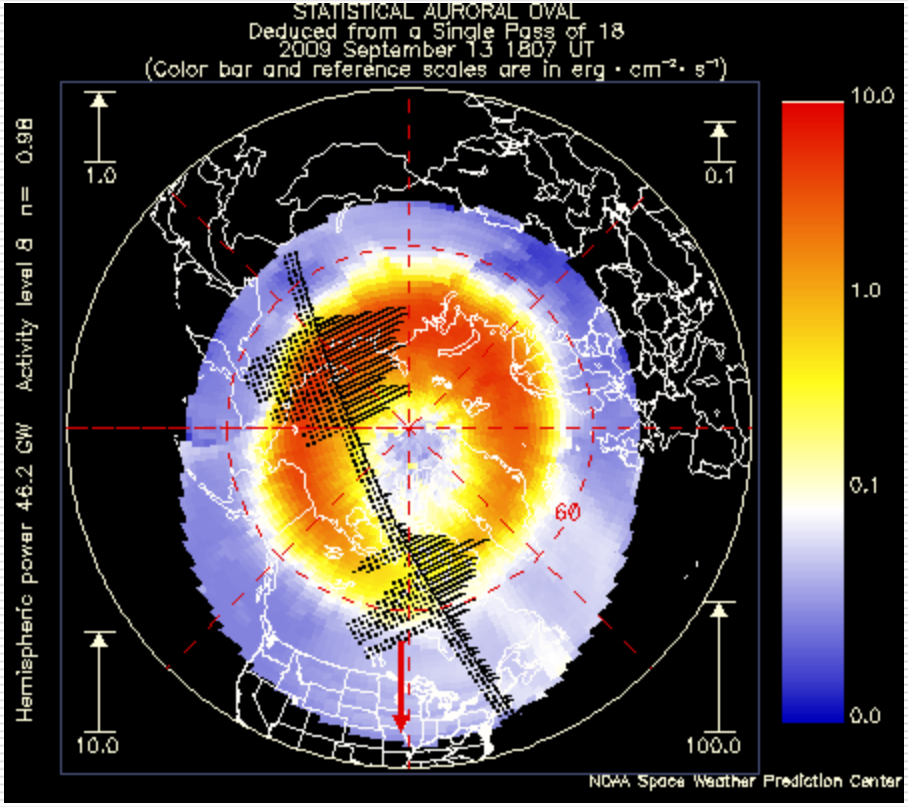
Arctic Domain Awareness

- 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



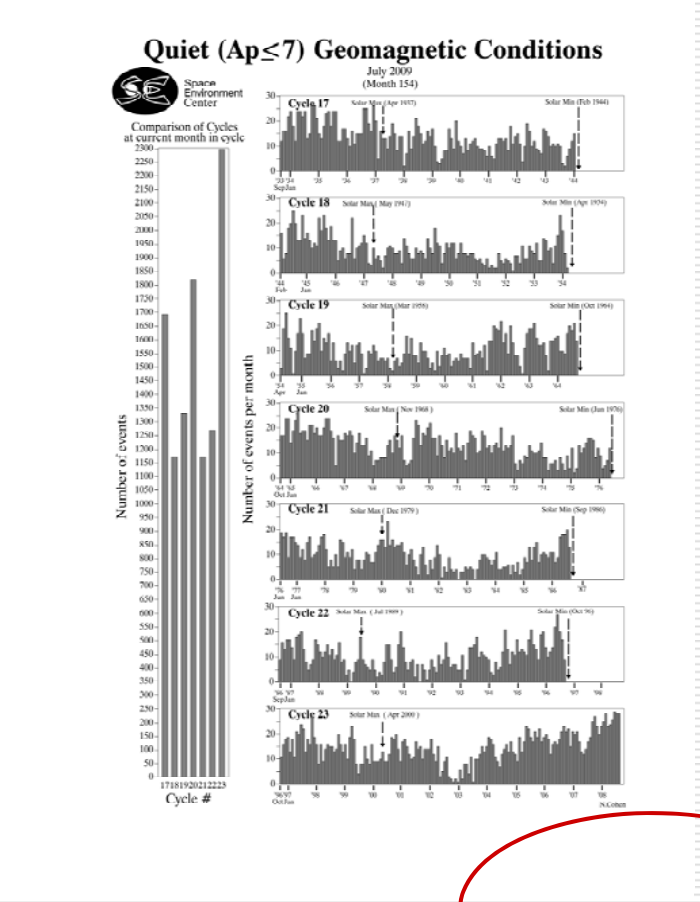
http://www.swpc.noaa.gov/pmap/index.html

Conclusion

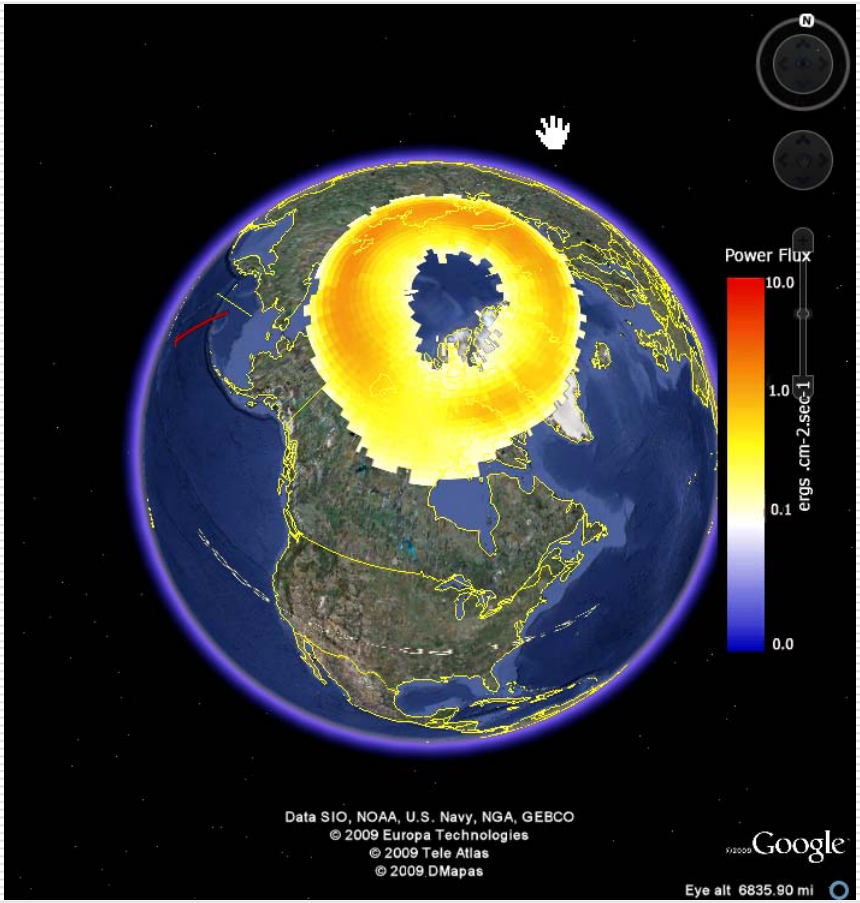
- The problem – foul space weather looms
- The question – Cycle 24: How strong? **Average cycle; sunspot number =90, maximum May, 2013**
- The issues
  - Science – challenged
  - Users – surprised (?)
- The outlook
  - Sun is starting to rumble, activity picking up

Additional Slides

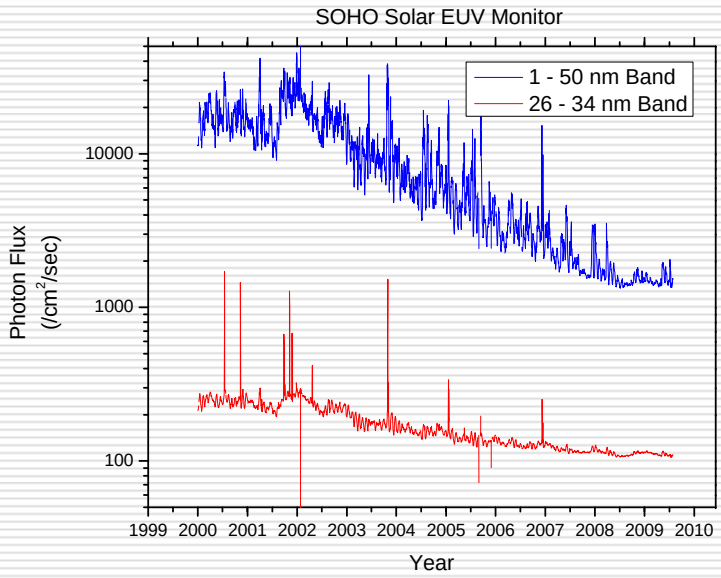
The Quiet of Solar Minimum



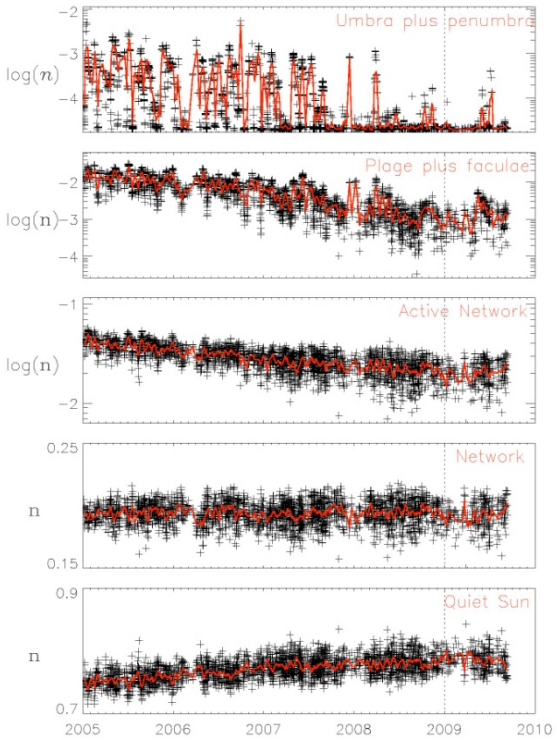
SWPC Google Earth Overlay



Solar EUV Shows No Start

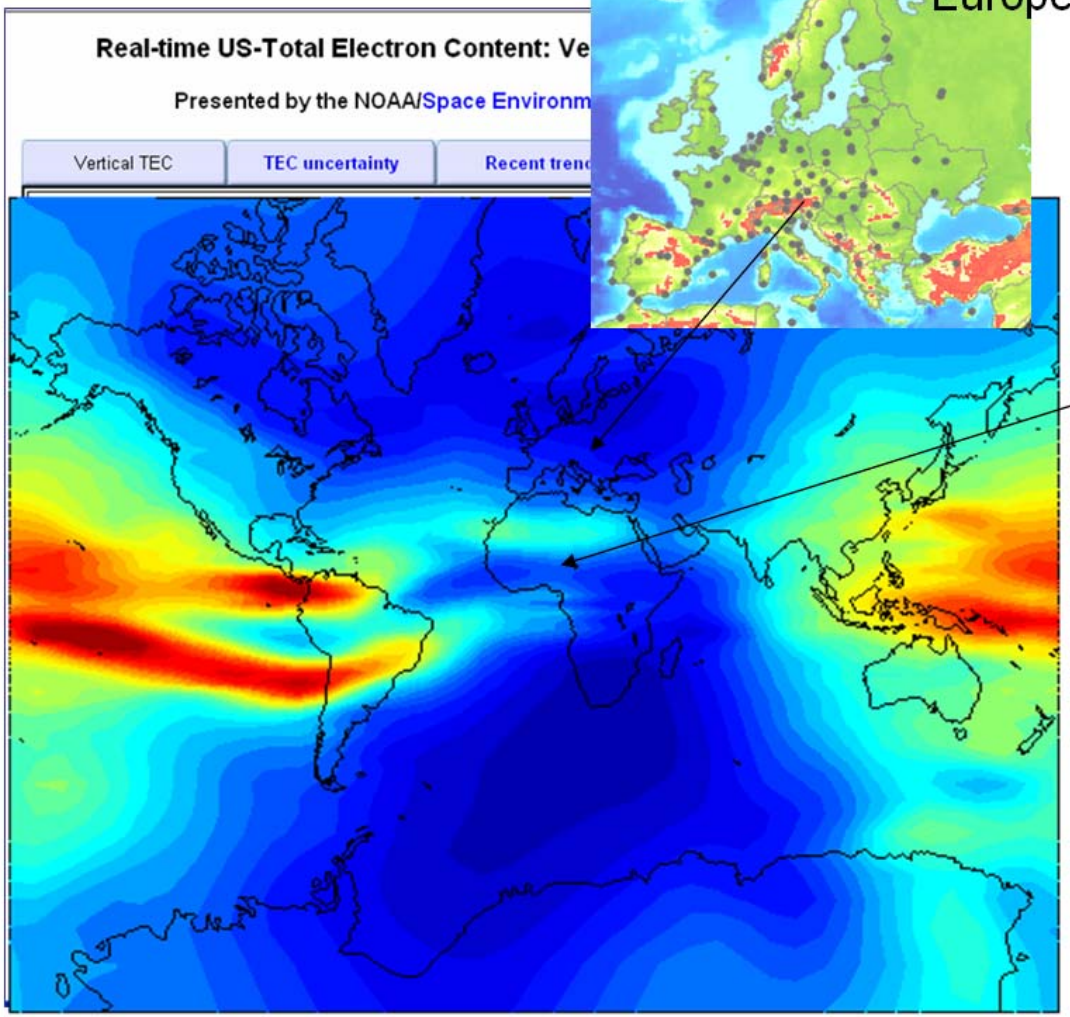


Solar Data Show Start of New Cycle

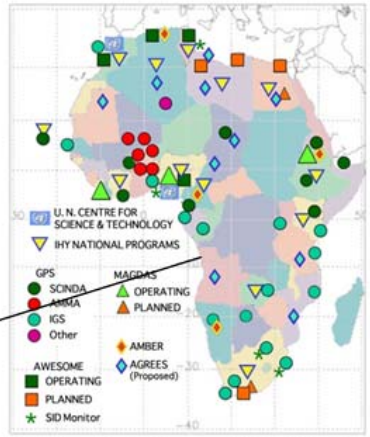


Courtesy Mark Rast, PSPT

Future SWx Prediction Models: USTEC to GEOTEC



Europe (EUREF)



IHY-Africa

GPS occultations