

NOAA's Space Weather Prediction Center

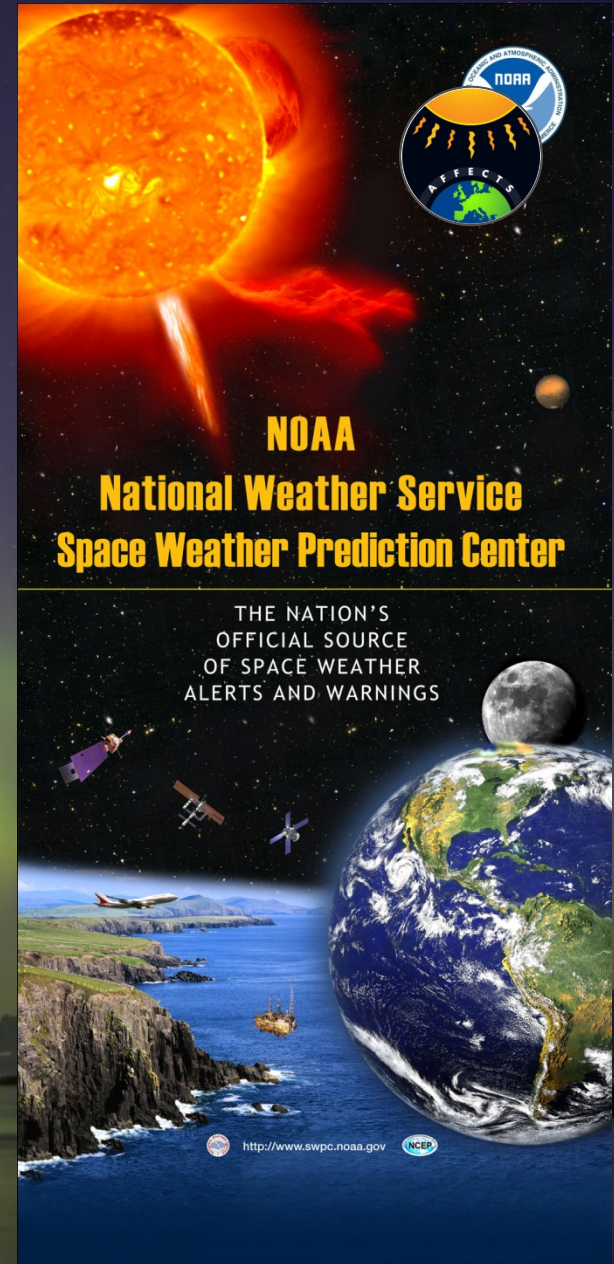
Expanding into the Polar Regions

Rodney Viereck

*SWPC Director of Research and the Space Weather Prediction Testbed
Space Weather Prediction Center*

Our Mission: To provide space weather products and services that meet the evolving needs of the Nation.

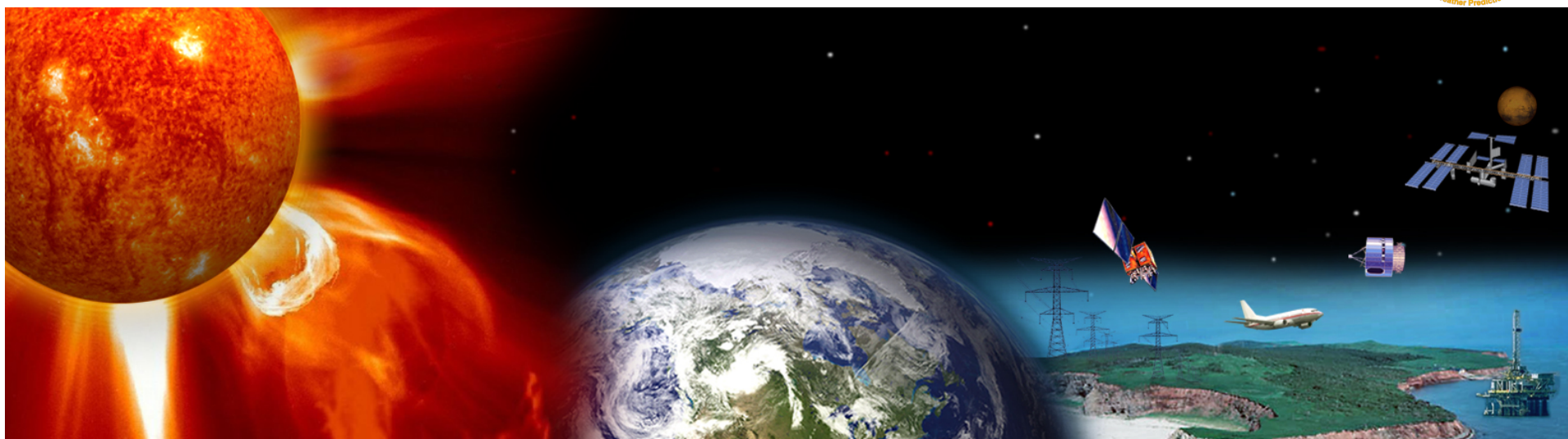
Our Vision: A Nation prepared to mitigate the effects of space weather through the understanding and use of alerts, forecasts, and data products.



Putting Science to Work to Protect the Nation's Technologies from Space Weather



Outline



- **The Space Weather Prediction Center**
- **Space Weather Customers**
- **Products and Services for GPS and HF communication**
- **Plans for improvements for high latitude customers**

NOAA Space Weather Prediction Center

Boulder, Colorado since 1946



Space Weather Prediction Testbed:

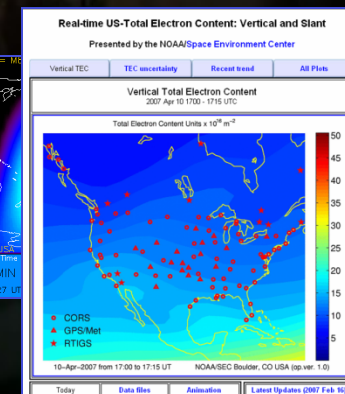
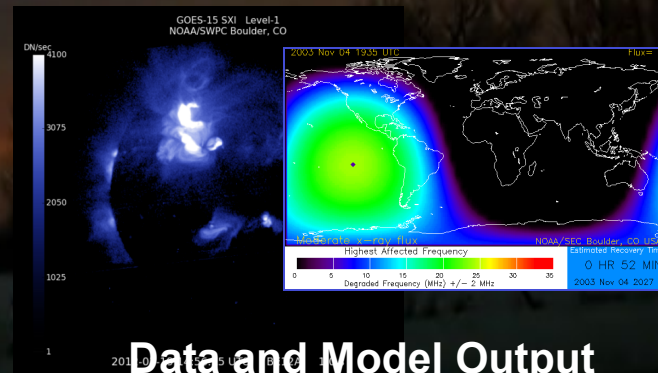
Research and Development

- Applied research
- New Products
- New data
- New models
- Transition from Research to Operations (R2)

Forecast Office:

24/7 Products and Service

- Specifications: Current conditions
- Forecasts: Conditions tomorrow and the days after
- Watches: When conditions are favorable for storm
- Warnings: Storm is imminent
- Alerts: When it is storming now



Data and Model Output



Space Weather Services:

Critical to the World's Economy and Security



- **Electric Utilities**

- Potential for significant disruption of service due to geomagnetic storm with major consequences
- Emergency managers address potential impacts related to space weather events through simulated exercise

- **Aviation**

- Polar route use – ~12,000 flights in 2012
- Next Generation Air Transportation System – GPS based

- **Communication**

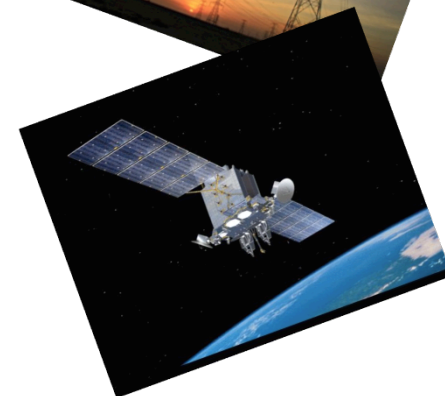
- HF radio communication heavily relied upon by airlines, DOD, Emergency Managers, Search and Rescue, etc...

- **GPS**

- Single biggest source of error is ionosphere
- Strong growth in applications – surveying, drilling, precision agriculture, navigation, aviation

- **Space Systems**

- World satellite industry revenues in 2008: >\$144 billion
- Space weather support is critical for manned space flight and NASA robotic missions





Product Distribution

- **Web products**
 - Data, model outputs, forecasts, etc...
- **Product Subscription**
 - Specific products
 - Alert thresholds
 - Automatic notification
- **Direct Contact**
 - Phone call

The screenshot displays the NOAA Space Weather Prediction Center (SWPC) website. The top navigation bar includes links for Site Map, News, and Organization. The main content area is titled 'Current Space Weather Conditions' and features a search bar, a list of links for various products and services, and a table of NOAA Scales Activity. The table shows the current status of various scales, including Geomagnetic Storms, Solar Radiation Storms, and Radio Blackouts. Below the table, there is a section for 'Product Subscription Service' with a sign-in form and a notice about the privacy policy.

NOAA Scale	Range 1 (minor) to 5 (extreme)	Past 24 hours	Current
Geomagnetic Storms		none	none
Solar Radiation Storms		none	none
Radio Blackouts		none	none

Product Subscription Service
NOAA Space Weather Prediction Center

Welcome to the Space Weather Prediction Center's Product Subscription Service. Registered users can sign in below. Forgot your password? Click [here](#).

General Information

Receive alerts, warnings, watches, forecasts, and summaries via email within moments of issue. To sign up: register, select products of interest from various categories, then review your choices.

Note: data, plots, and images are available for you to download [here](#).

Questions? Contact us [here](#).

Sign In

email address
password

[Login](#) [New user? Register here.](#)

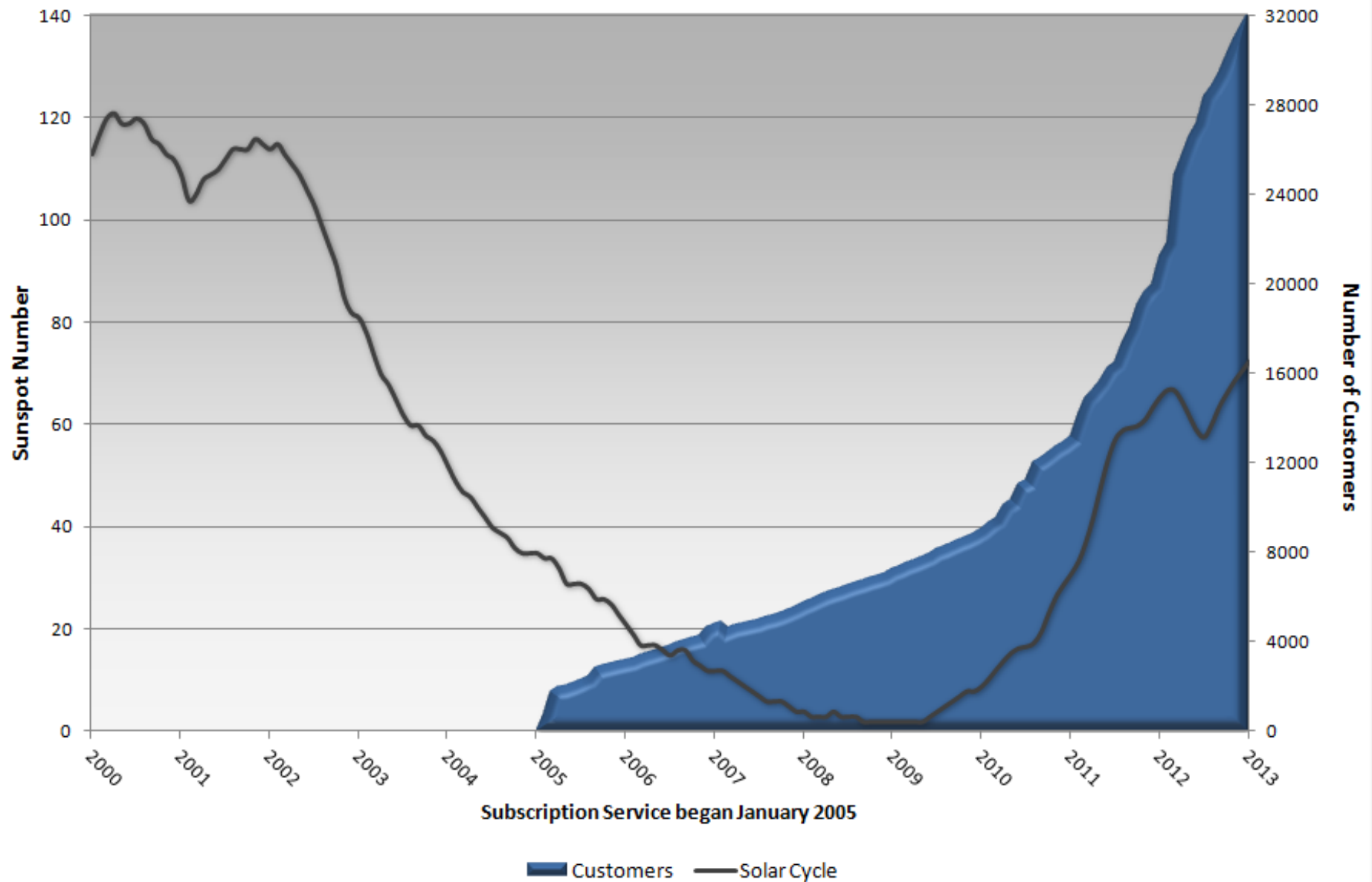
Notice

Privacy Statement: Addresses are used to send alerts, respond to questions, and send information that SWPC considers of interest to our customers. The information provided on the registration form may be used by SWPC for statistical analysis of users. U.S. Government regulations restrict the distribution of user information. No user information is made available to customers, organizations, vendors, or other government agencies. See the NOAA privacy policy [here](#).

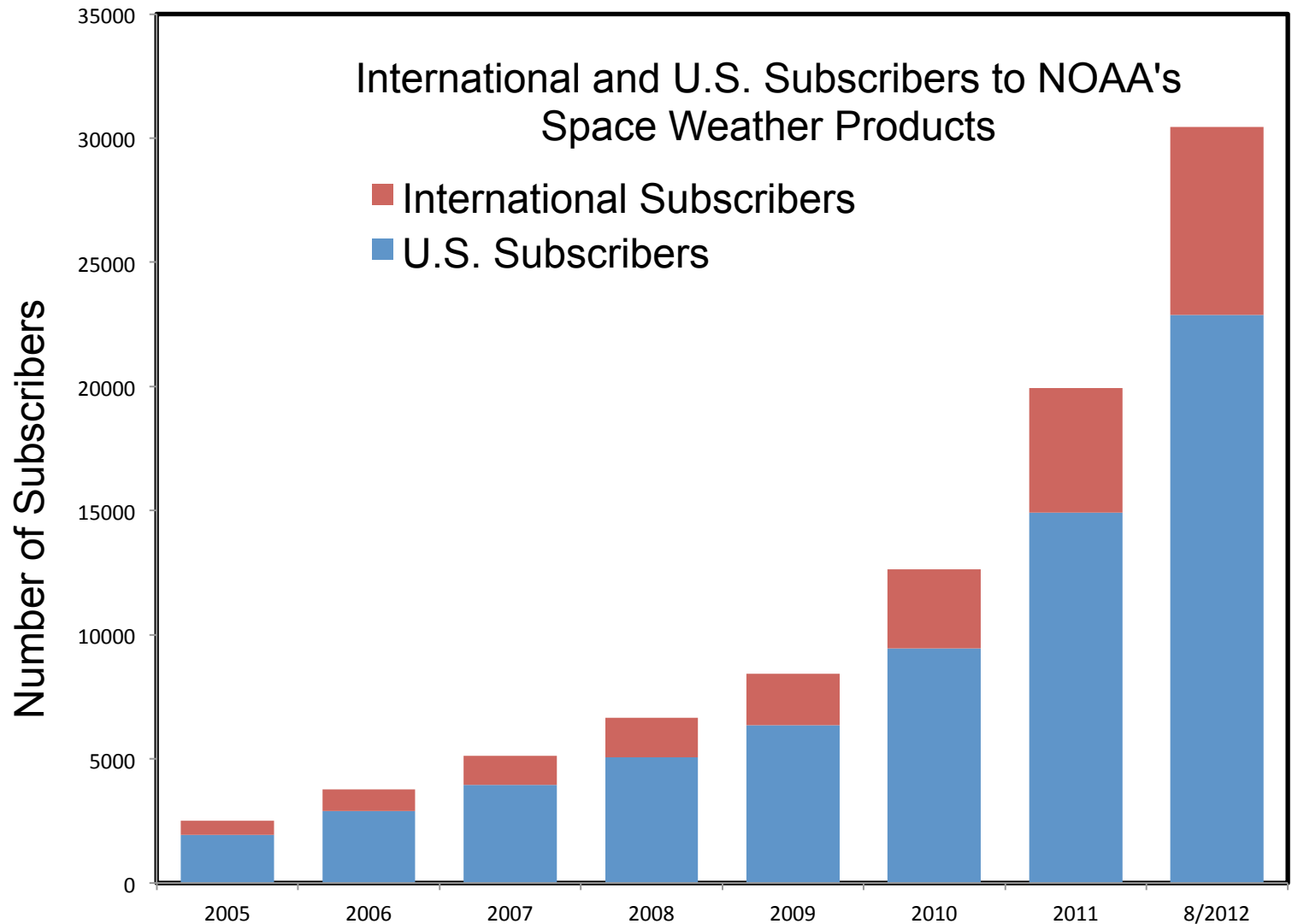
Disclaimer: SWPC makes a concerted effort to distribute products, but this delivery method is not guaranteed. For more information, go [here](#).

SWPC-Home

Customer Growth SWPC Product Subscription Service



International and U.S. Subscribers to NOAA's Space Weather Products



Customers (Sample)

Airlines	Surveying and Mapping	Electric Power	Satellites
Aer Lingus	AE & E Trucking, Etc., LLC	Allegheny Power	Lucent Technologies
Air Canada	AEI-CASE Engineering	Ameren Corporation	AeroMap U.S.
Air China	Airmag Surveys	Bechtel Nevada	Aerospace Corporation
Air Europa	Associated Engineers, Inc	Bonneville Power Administration	Alcatel Space
Air Line Pilots Association	Athens Group (oil & gas)	Central Maine Power	American Space Culture Foundat
Air New Zealand	Baker Hughes (drilling)	Cleco Power LLC	AMSAT-France
AirMed Inc.	Banks	<ul style="list-style-type: none"> • Every Major Airline • Every Major US Power Company • Every Major Satellite Company • US Defense Dept. • NASA • US Dept. of Energy • US Department of Homeland Security • US Federal Aviation Administration • 32,000 Specific Customers • 15 – 20 Million Web Hits a day 	
Airservices Australia	Barr Er		
Alaska airlines	Bennet		
Allied Pilots Association	Black H		
ALPA Japan	Carver		
American Airlines	Christo		
American Eagle airlines	Clarida		
American Trans Air	Consul		
Boeing / Flight Test	DGR O		
British Airways	Diamor		
Bushmail	Earth E		
Cathay Pacific Airway	Eastern		
Continental Airlines	Excel C		
Emirates	Geoco		
FedEx	GeoLo		
German ALPA	Global		
Icelandic ALPA	GRW A		
Irish Aviation Authority	Halcyo		
Jet Aviation Business Jets	J. D. B		
korean air	Johnson Engineering	PJM Interconnections LLC	New Skies Satellites
Lufthansa	Jones, Wood & Gentry, inc	PSEG Nuclear LLC	NG Space Technology
Lufthansa Cargo	marine R/D Survey	Puget Sound Energy	North Star Data
Northwest Airlines	NC Geodetic Survey	Soreq NRC	Northrop Grumman
Oslo Lufthavn AS	Nexen Inc. (oil)	Swedish Geological Survey	Oceaneering Space Systems
Qantas Airways	NOVA Engineering & Consulting, Int'l.	Texas-New Mexico Power	OmniStar, Inc.
Raytheon Aircraft Co.	NYS Professional Engineer	Transpower NZ Ltd	ORBCOMM
SCTA	Old Dominion Freight Lines	US NRC	Orbital Sciences Corp
SkyWest Airlines	Olson Trucking	We Energies	PT Asia Cellular Satellite
Sun Country airlines	Oxy (oil & gas)	Western Area Power Admin.	Raytheon
Sundt air (Norway)	Pape-Dawson Engineering		Rockwell Collins, Inc.
Swales Aerospace	PGS Onshore		SES Americom
United Airlines	Planning Consultants, Inc.		SES ASTRA
APLA, Argentina	Portland Natural Gas Transmission		Sirius Satellite Radio
ATA Airlines	Raymac Surveys		Skyway, Inc.
NetJets	Schlumberger Drilling & Measurements		Space Engineering Development
North American Airlines	Seelye		Space Imaging

Space Weather Scales

Simplifies space weather

- Three Categories

- The G-Scale

Geomagnetic Storms

CMEs



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)
Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
		Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); high radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 100 chest x-rays) is possible	10 ⁵	Fewer than 1 per cycle

* Based on this measure, but other physical measures are also considered.

** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (see www.sec.noaa.gov/Aurora)

Geomagnetic Storms

			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	<u>Power systems:</u> widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. <u>Spacecraft operations:</u> may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. <u>Other systems:</u> 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)

R-Scale

Radio Blackouts

Solar Flares

		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.		
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 0.1-0.8 nm range, in W m⁻². Based on this measure, but other physical measures are also considered.

** Other frequencies may also be affected by these conditions.



Typical Sequence of Events

The Solar Flare (R-Scale)

- Little or no warning (a big challenge for researchers)
- Solar x-ray flux increases by 5 orders of magnitude in 15



GOES-12 SXI

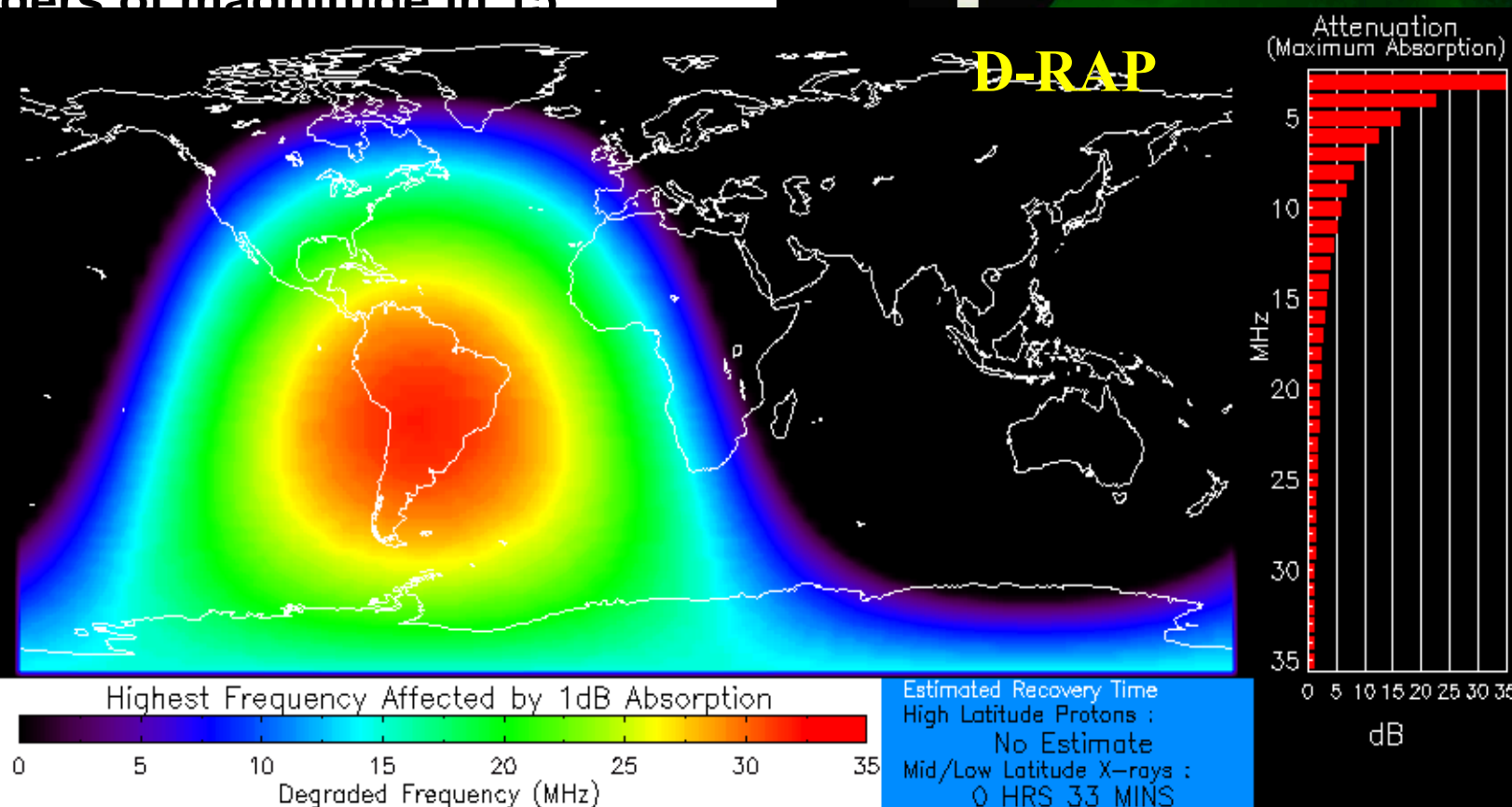
<http://sxi.ngdc.noaa.gov>

<http://www.sec.noaa.gov/sxi>

GOES-12 SXI-0 AR Level-1C
Scale NOAA/SEC
(10⁻¹ DN/s)
Boulder, CO
849.

905
LIN

- m
- Fl
- X-
- io
- la
- De
- Di
- Ai
- gr



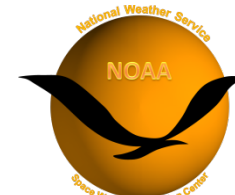
NO NEW X-RAY FLUX FOR 4 MINUTES

28 February Minor X-ray flux

Normal Proton Background



Typical Sequence of Events The Radiation Storm (S-Scale)



- Proton flux increases by four orders of magnitude 30 minutes to a day after the flare

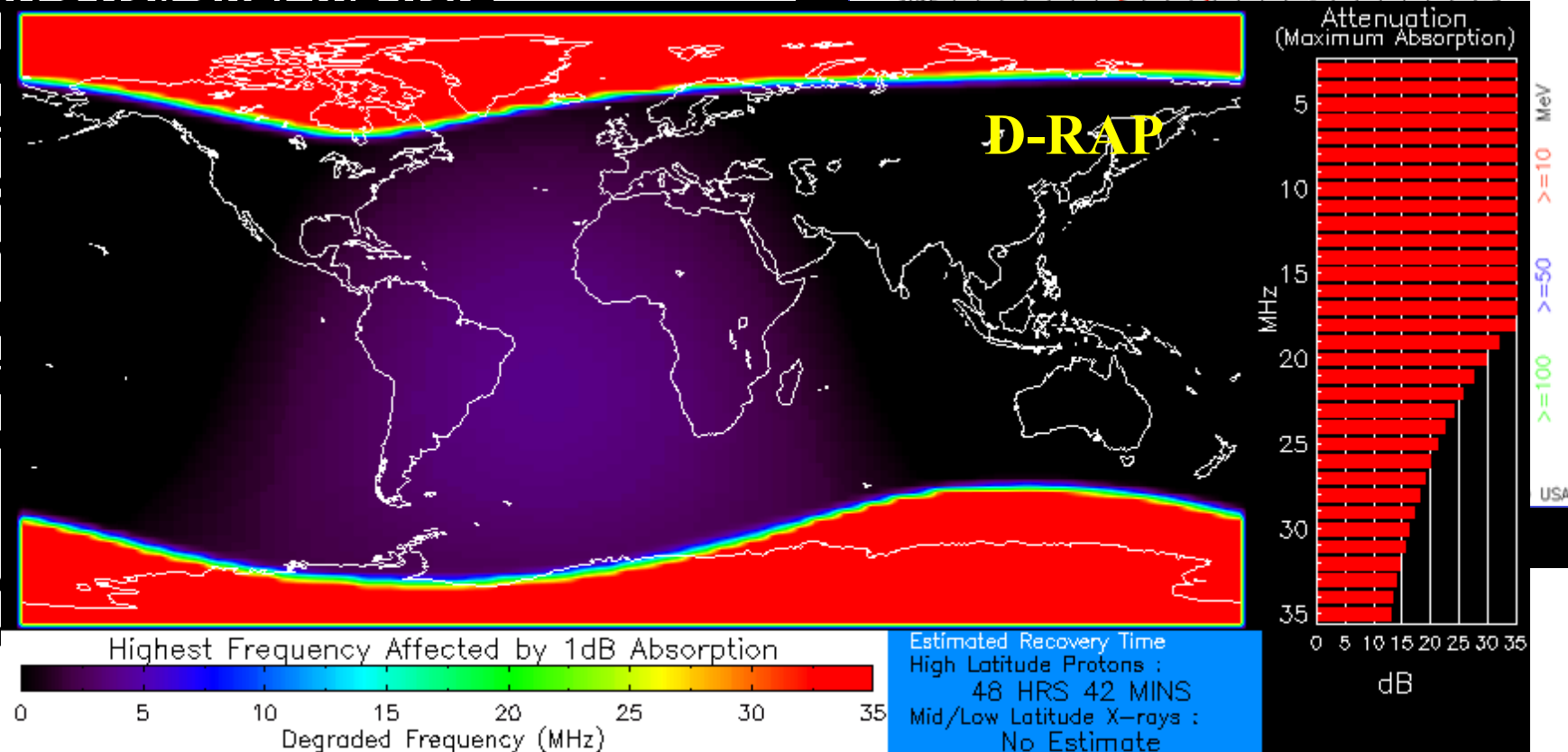


GOES EPS
Energetic Solar Protons

GOES11 Proton Flux (5 minute data)

Begin: 2003 Oct 28 0000 UTC

D-RAP

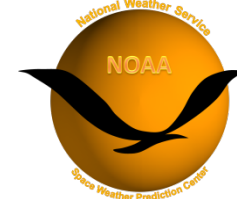


Normal X-ray Background
Product Valid At : 2012-01-24 13:41 UTC

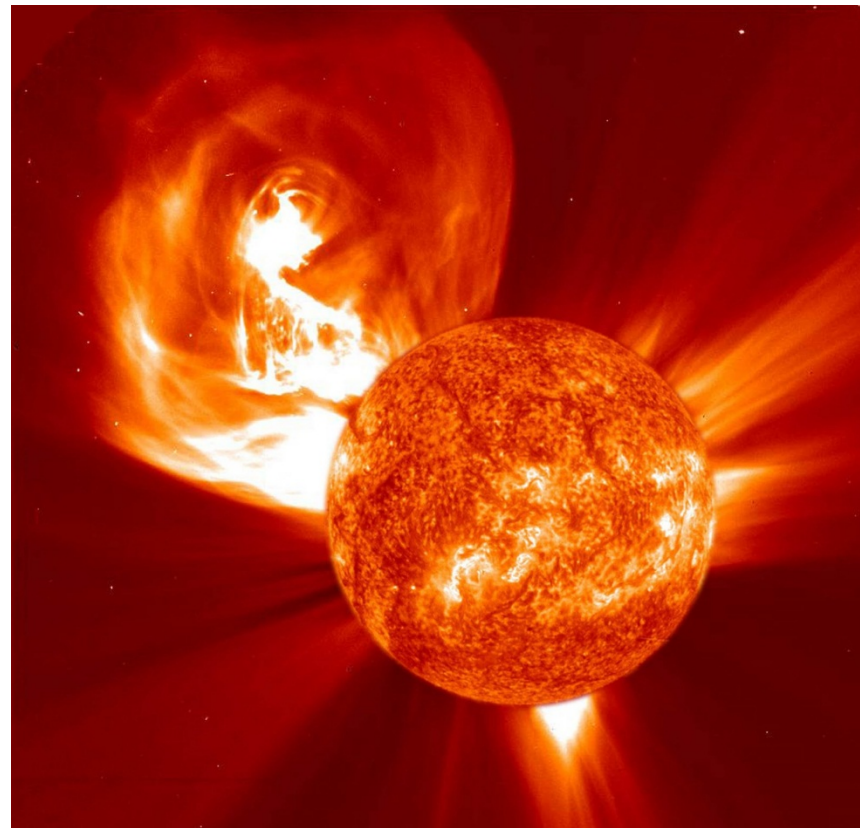
Strong Proton Flux
NOAA/SWPC Boulder, CO USA

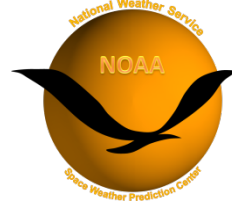


Typical Sequence of Events Geomagnetic Storm (G-Scale)



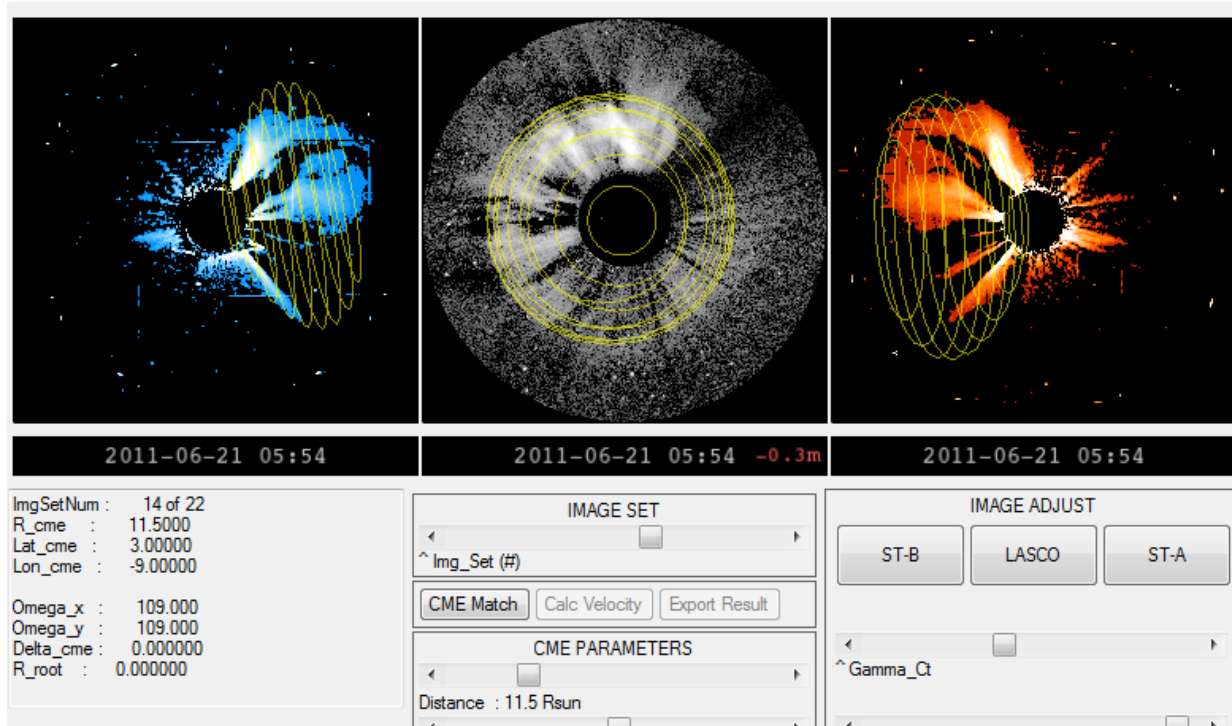
- The sun erupts with with a massive Coronal Mass Ejection (CME)
- A billion tons of material are thrown into space and headed for Earth.
- Traveling at 2000 km/sec it will take 20 hours to reach arrive
- But will it hit Earth?





CME Analysis Tool

- Using coronagraph data from SOHO and Stereo, the forecasters have three views of the CME
 - They must identify the size, speed, and direction
- The CAT tool allows forecaster to coordinate the three views and identify the parameters



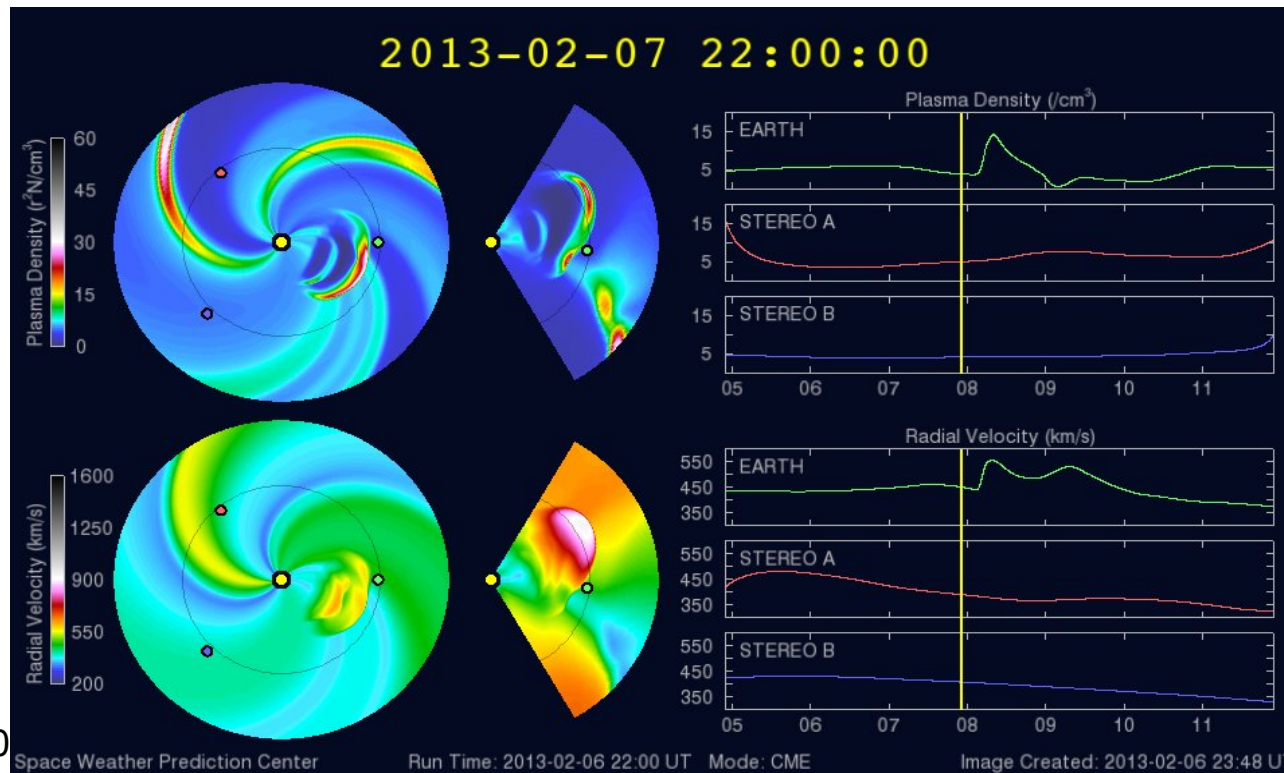


The WSA Enlil Mode

<http://www.swpc.noaa.gov/wsa-enlil/>



- Once the CME parameters have been determined, they are used to initiate the WSA-Enlil model of the solar wind.
- The model will predict if and when the CME will hit Earth





Typical Sequence of Events Geomagnetic Storm (G-Scale)



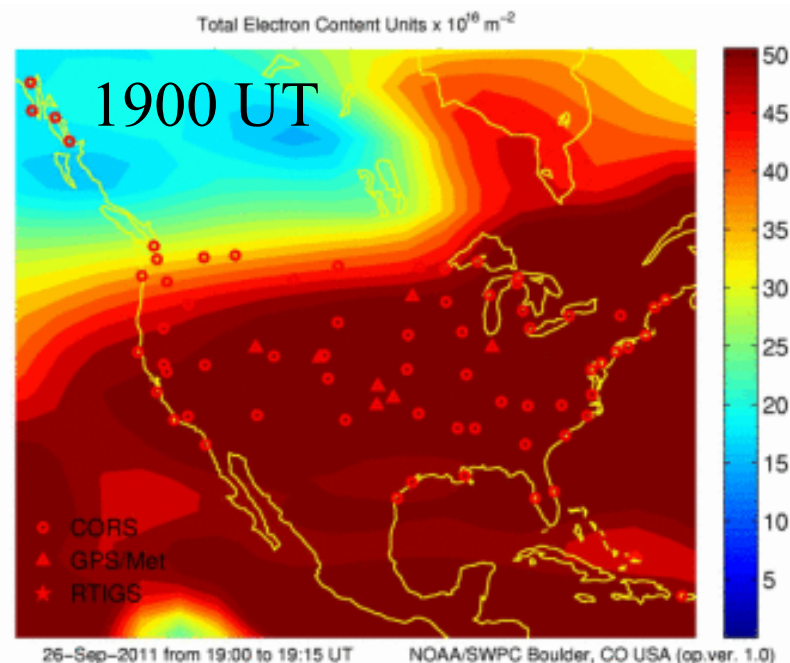
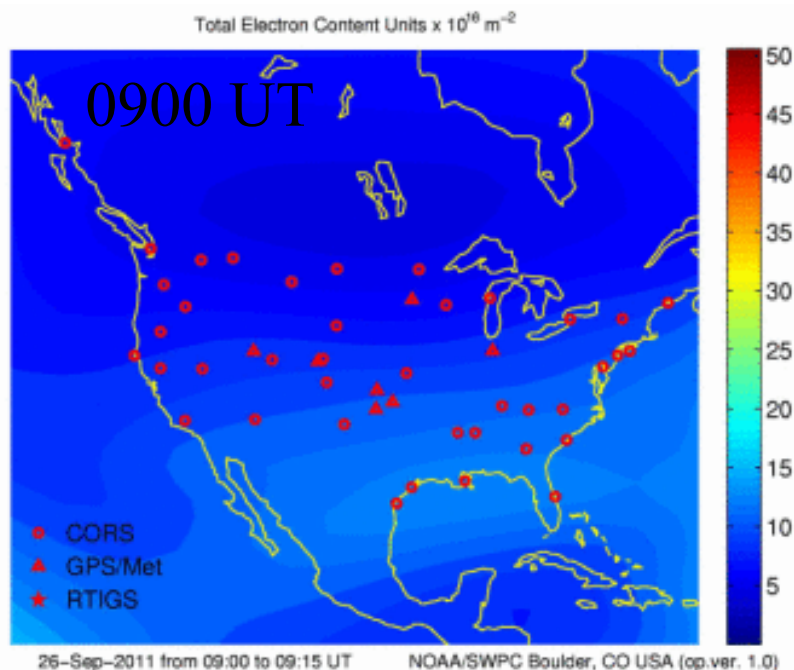
- The CME arrives at Earth
- The magnetosphere is energized
- Electrons and protons are accelerated into the upper atmosphere and ionosphere of the polar regions
- Currents in the ionosphere induce currents in the electric power lines (power outage)
- The ionosphere is energized disrupting HF communication and GNSS navigation
- There is Aurora



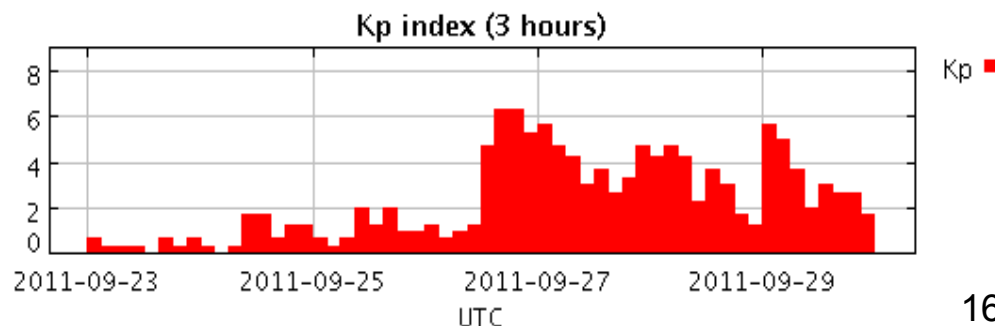


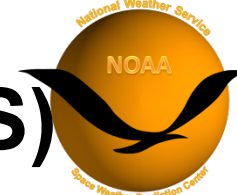
US-TEC: For Single Frequency GPS/GNSS:

US TEC: An Assimilative model for GPS users in the US September 26, 2011 Geomagnetic Storm



FAA's Wide Area Augmentation System (WAAS), a system of GPS signal corrections for aircraft navigation, was impacted. During the geomagnetic storm, the WAAS procedures were unavailable.





Customer Requirements (GPS/GNSS)

- **Navigation:**
 - Shipping through the NW passage saves 6000km off of a 22000km trip from New York to Hong Kong (28%)
 - Avoiding ice and navigating in the arctic requires reliable GPS positioning information
 - Oil and mineral exploration in arctic regions
 - Drilling and surveying require precision GPS/GNSS
- **Communication:**
 - US Airlines use polar routes extensively (12000/year US – Asia)
- **Space Weather at High Latitudes is Stronger than at lower latitudes**

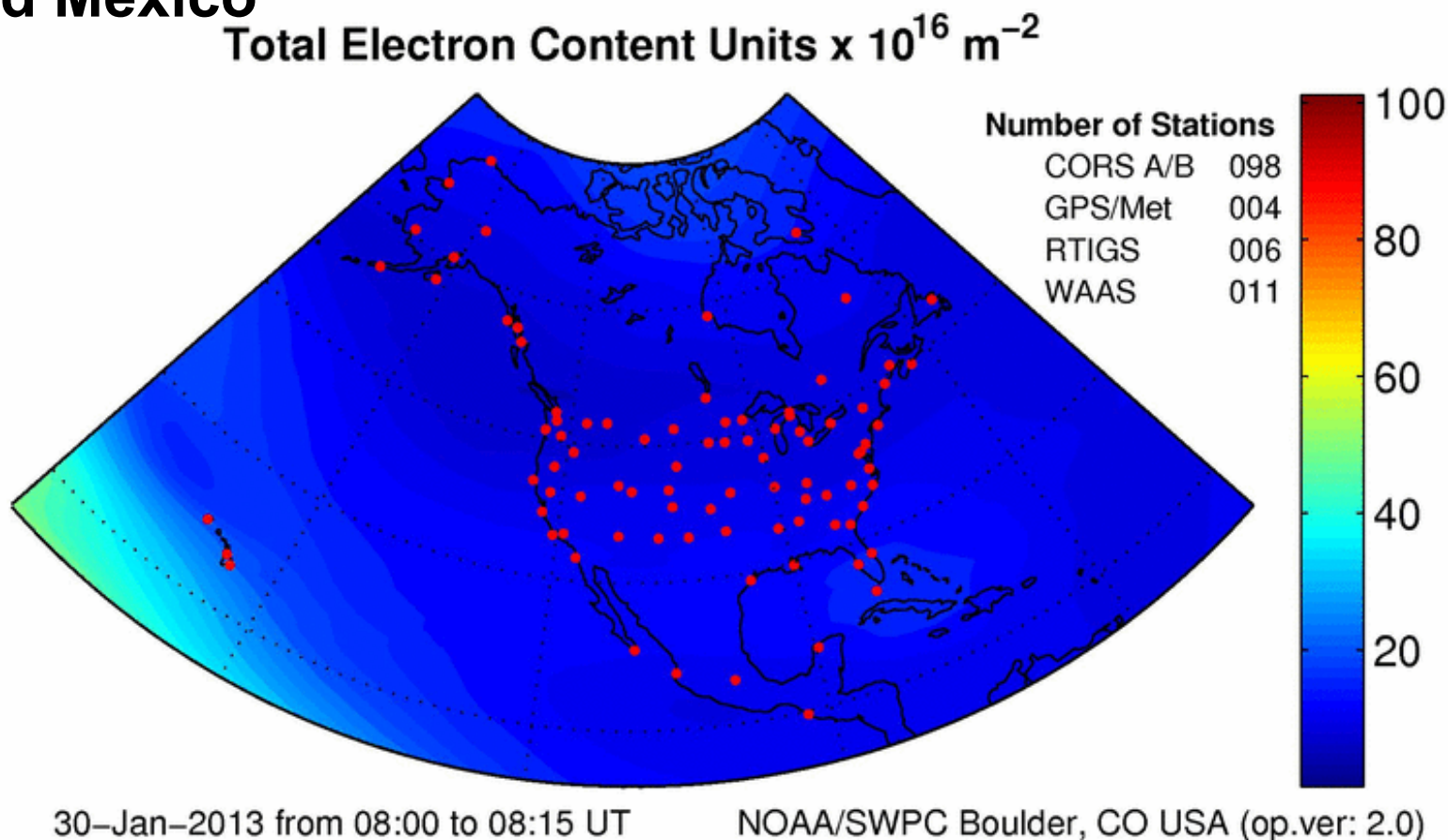


“When Aurora is Strong, GPS is wrong”



Next Steps: Go North

- NA TEC (North America TEC) **Test Product**: An expanded version of US-TEC that includes Alaska and Mexico



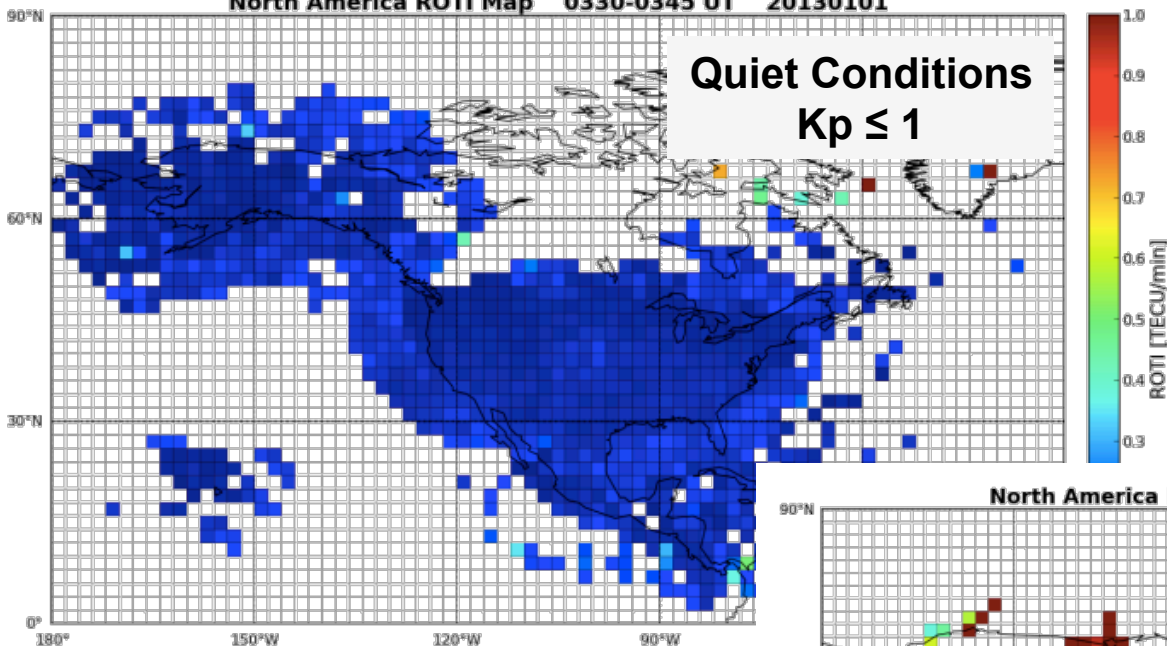


ROTI: For Precision GPS/GNSS

GPS Rate of TEC Index

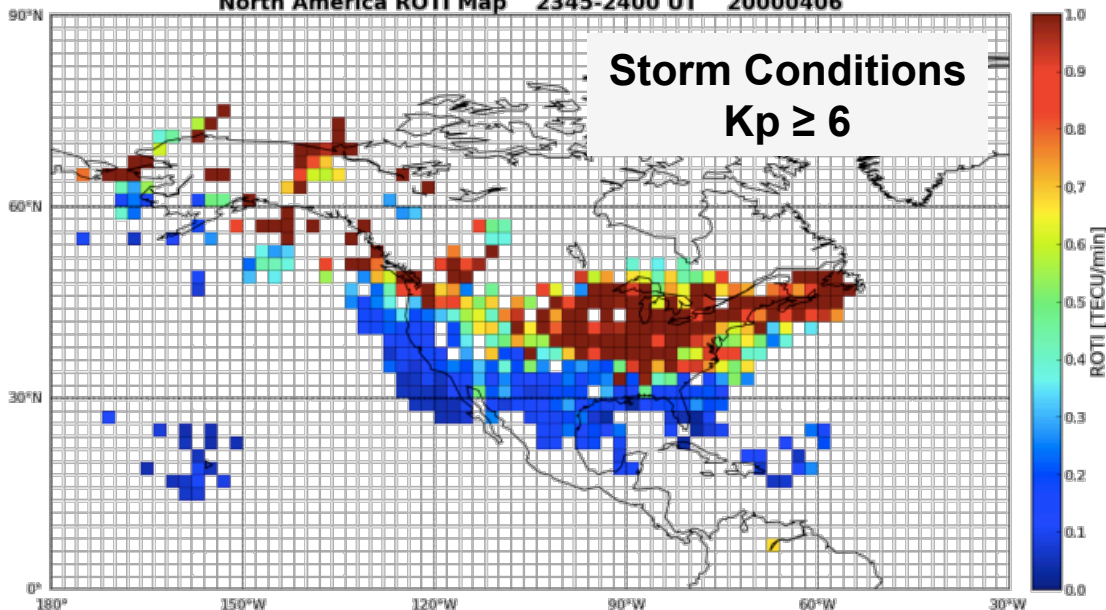


North America ROTI Map 0330-0345 UT 20130101



- An index of GPS/GNSS accuracy
- Based on ground-based observations of single frequency GPS/GNSS observations (1-30 sec sample rate)

North America ROTI Map 2345-2400 UT 20000406



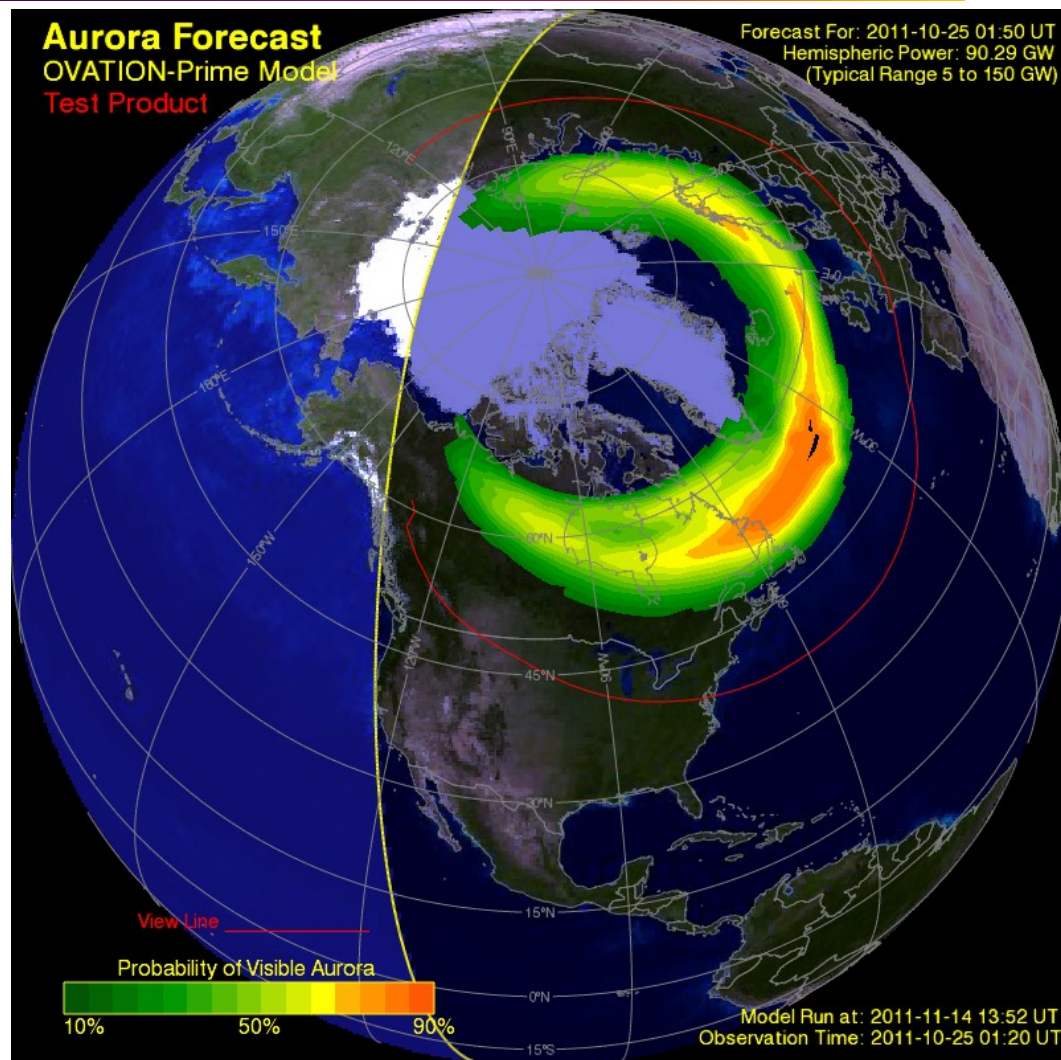
ROTI: Prepared by Propagation Research Associates and NASA Jet Propulsion Lab



Short-term Aurora Forecast



- 30-40 minute forecast based on ACE solar wind and interplanetary magnetic field
- Currently running in real-time at NOAA at Helios.swpc.noaa.gov/ovation
- Updates every 5 minutes
- Model has been upgraded to include bigger storms
- OVATION Developed at Johns Hopkins University, APL
- Fully operational by October 2013
- Situational Awareness
- Tourism





Medium-Term Aurora Forecasts

(Under Development)

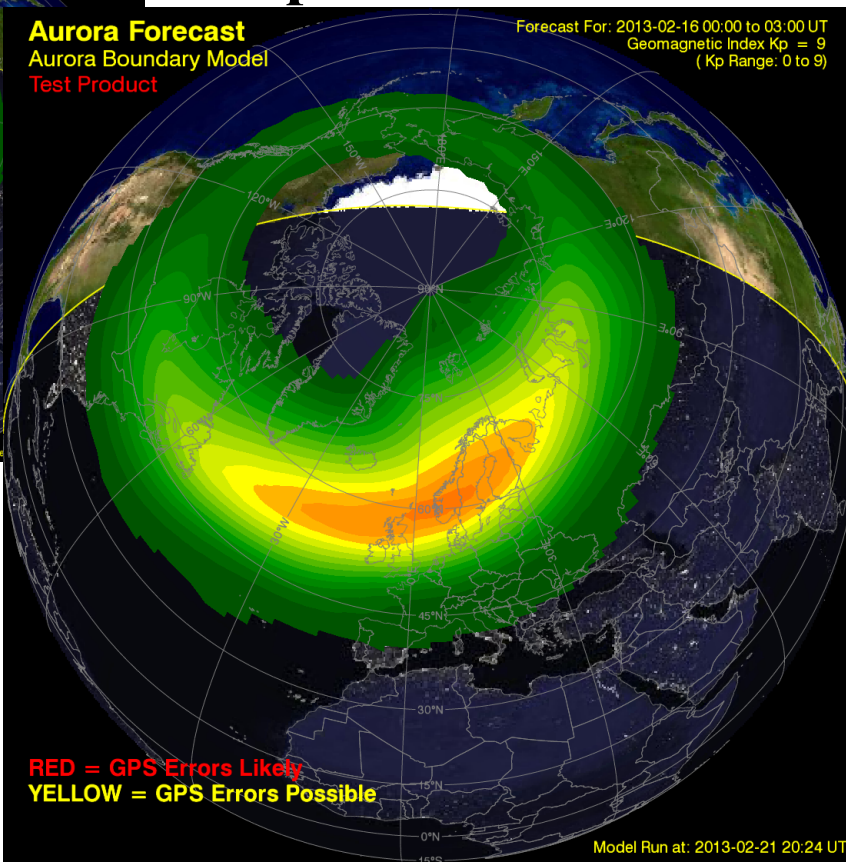
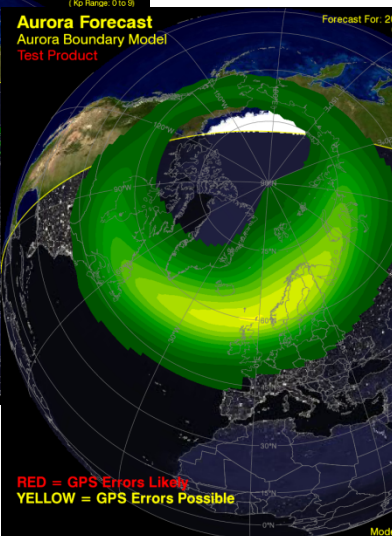
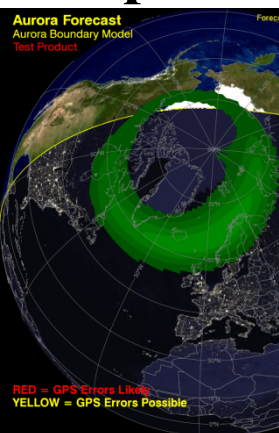


- Three day auroral forecast on a three-hour cadence
- Driven by forecasts of Kp (new product)

Kp = 3

Kp = 7

Kp = 9



SWPC Kp Forecast for
16 February 2013

Date	Time	Kp
02/16/2013	12:00	2
02/16/2013	15:00	2
02/16/2013	18:00	3
02/16/2013	21:00	3
02/17/2013	00:00	3
02/17/2013	03:00	4
02/17/2013	06:00	4
02/17/2013	09:00	5
02/17/2013	12:00	6
02/17/2013	15:00	5
02/17/2013	18:00	5
02/17/2013	21:00	4
02/18/2013	00:00	4
02/18/2013	03:00	5
02/18/2013	06:00	3
02/18/2013	09:00	3
02/18/2013	12:00	2
02/18/2013	15:00	2
02/18/2013	18:00	1
02/18/2013	21:00	1
02/19/2013	00:00	1
02/19/2013	03:00	1
02/19/2013	06:00	1
02/19/2013	09:00	1

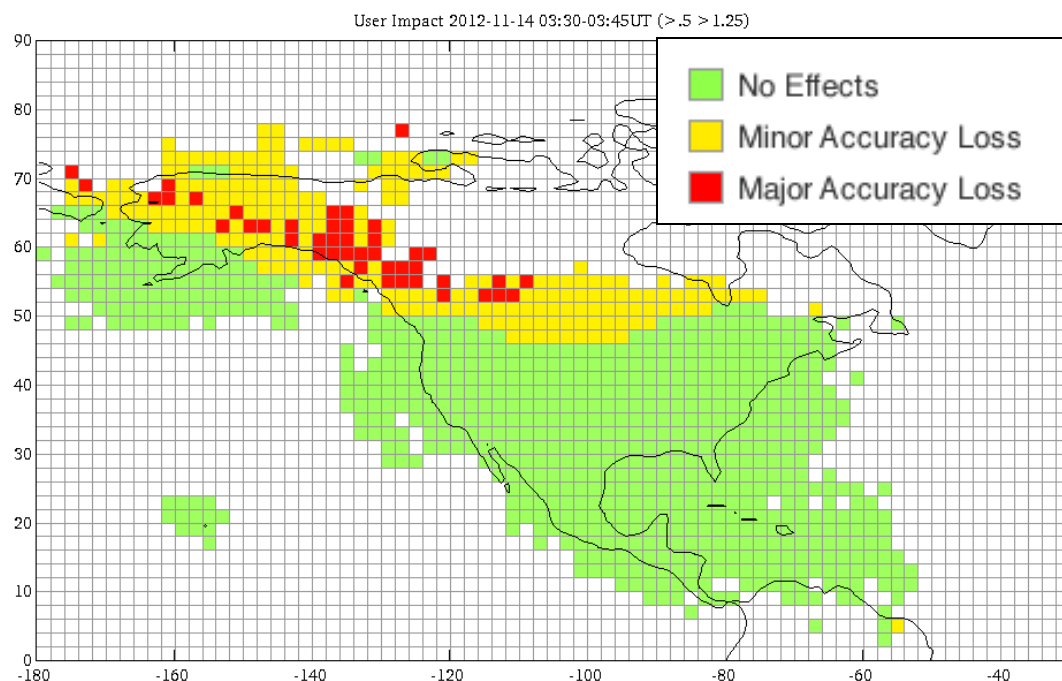
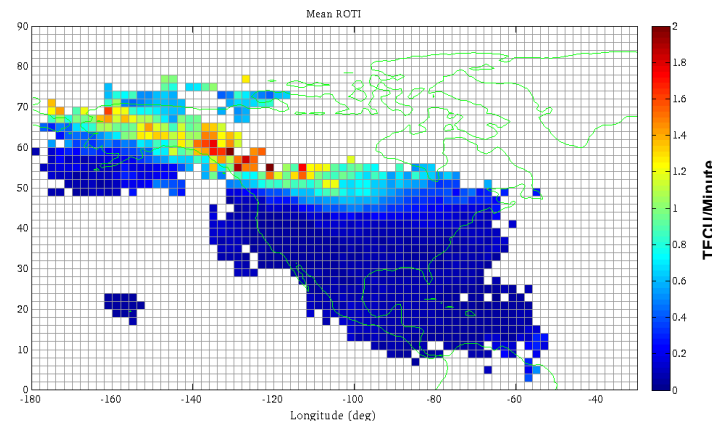
Developed at Johns
Hopkins University, APL



Make it Simple

- Customers want products that are easier to interpret
- Proposed new product for precision GPS users

Prepared by Propagation Research Associates
and NASA Jet Propulsion Lab





AFFECTS Project

- **Improve CME and solar wind analysis**
- **New geomagnetic forecasts**
- **Global ionosphere product**
- **Ionosphere forecast product**
- **Ionosphere Index (I-Scale)**
- **SWPC Contribution**
 - **Direct access to satellite data (ACE, GOES...)**
 - **CAT for analyzing CMEs**
 - **WSA-Enlil, for propagating CMEs**
 - **Coupled Thermosphere Ionosphere Plasmasphere with electrodynamics (CTIPe)**
 - **Physics-based model for testing and improving the SWACI ionosphere model.**



Questions?



**3 Day
Forecast of
Aurora**