Space Weather and Impacts on GNSS Applications

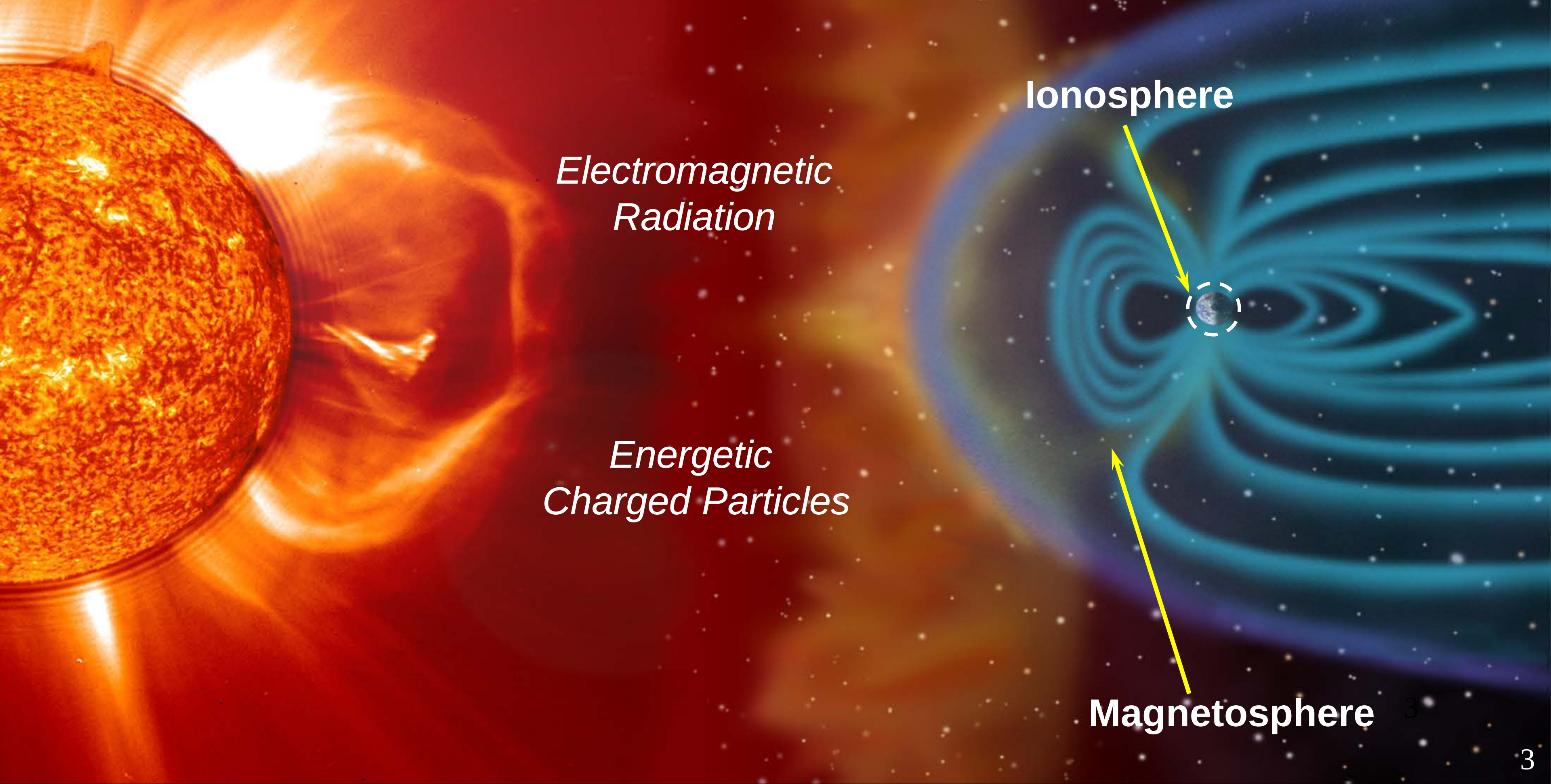
Bob Rutledge
NOAA Space Weather Prediction Center
Boulder, Colorado
October 8th, 2015

Outline

- The Sun/Solar Cycle
- Significant Event History
- Sequence of Events
- Space Weather Phenomena/Impacts
    - Solar Flares
    - Radiation Storms
    - Geomagnetic Storms
- GNSS Impacts and Products

What is Space Weather?

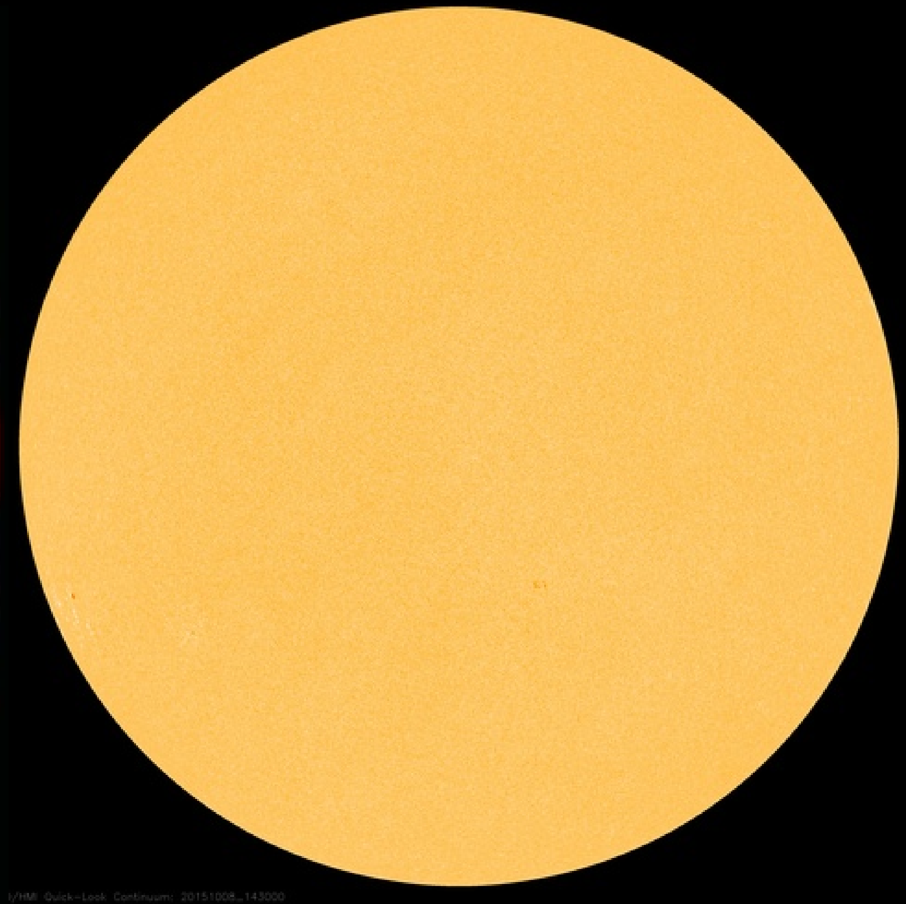
Space weather refers to the variable conditions on the Sun and in the space environment that can influence the performance and reliability of space and groundbased technological systems, as well as endanger human health.



Sunspots and the Solar Cycle

The Sun at Solar Maximum

The Sun Today

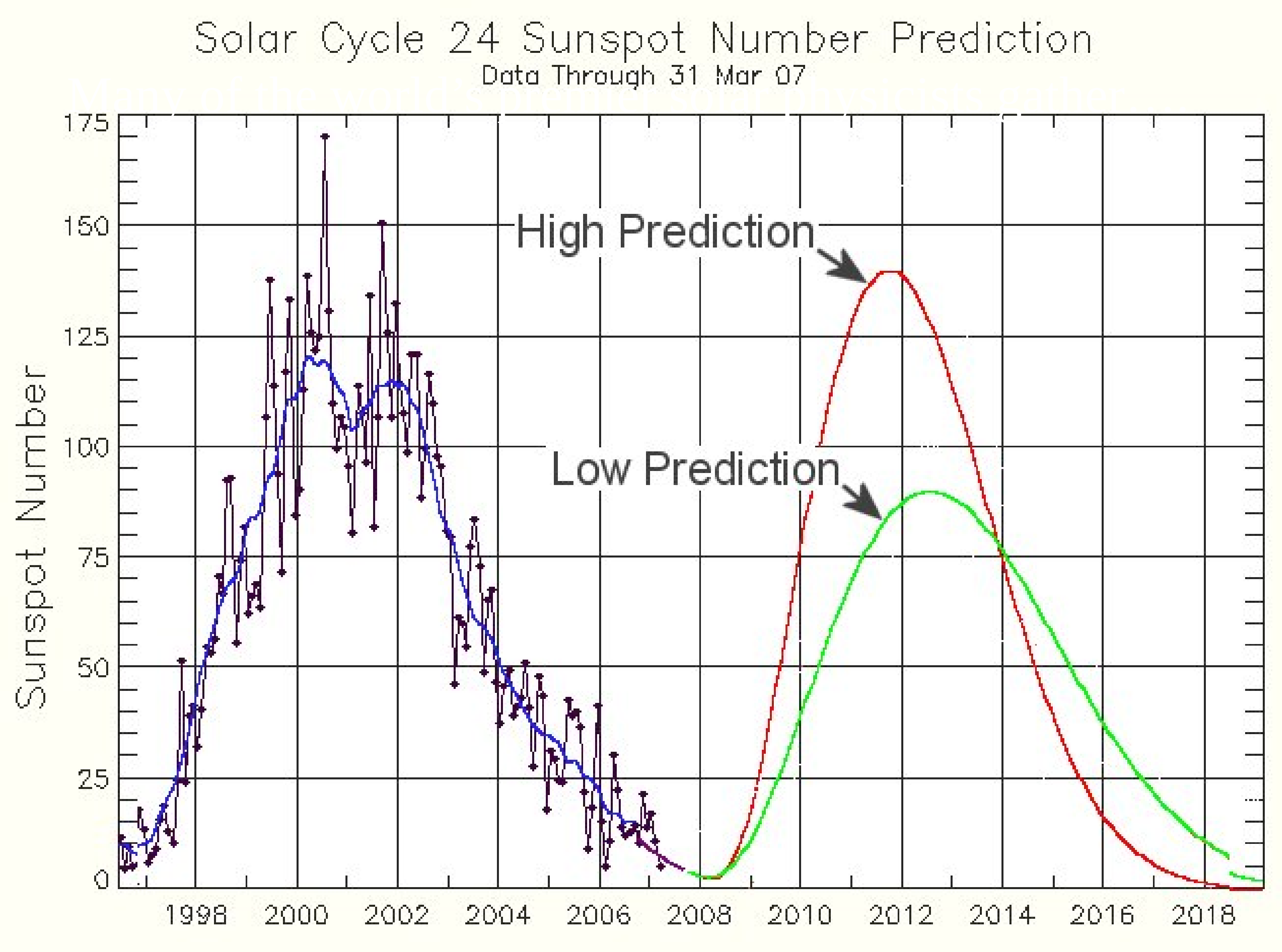


~27 day full rotation

Solar Cycle 24 Predictions

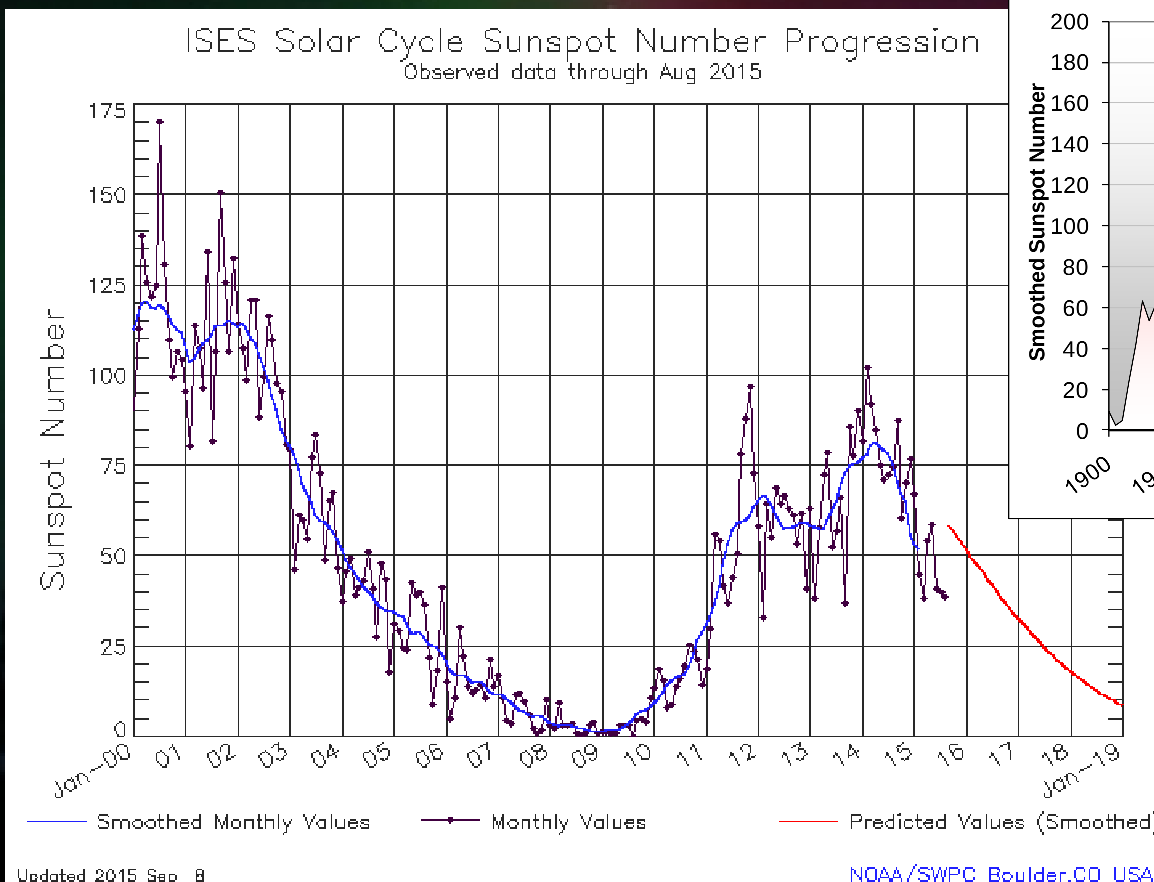
Many of the world’s premier solar physicists gather….

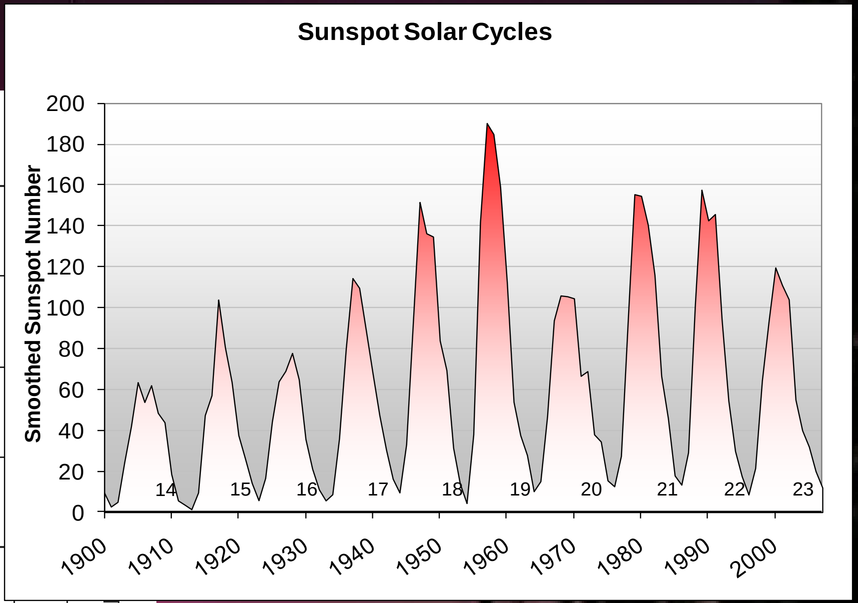
Solar Cycle 24 Predictions



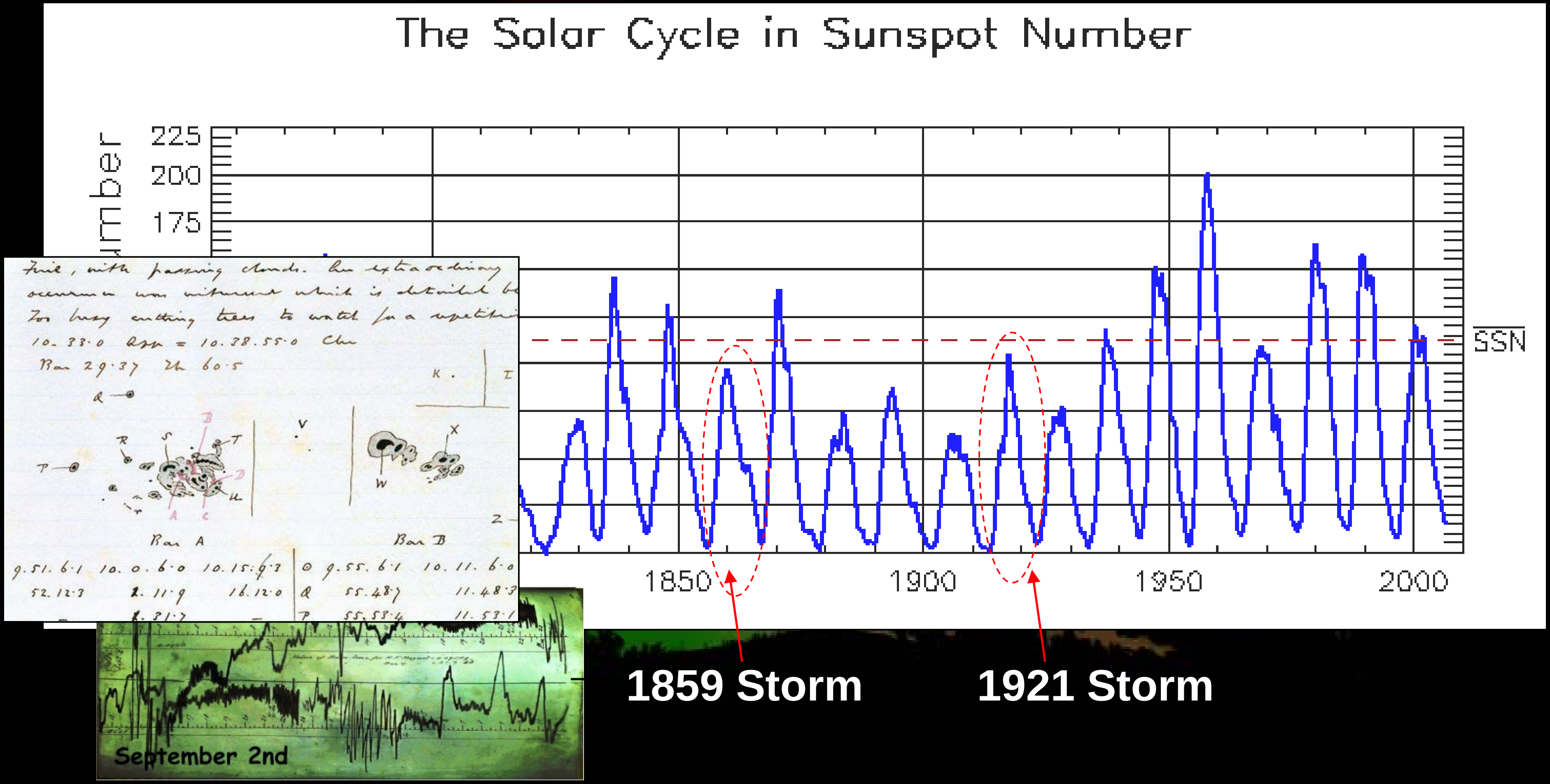
Solar Cycle Update

- Cycle 23 began in May 1996
- Peak in April 2000 with SSN = 120
- Solar Minimum in December 2008
- Solar Cycle 24 Underway





- Large geomagnetic storms can occur with smaller cycles
- Some of the largest geomagnetic storms on record occurred during smaller than average cycles (no causality implied)



Pergamon

Adv. Space Res. Vol. 22, No. 1, pp. 17–27, 1998

Printed in Great Britain
0273-1177/98 $19.00 + 0.00

PII: S0273–1177(97)01096–X

THE EFFECTS OF GEOMAGNETIC DISTURBANCES ON ELECTRICAL SYSTEMS AT THE EARTH'S SURFACE

D. H. Boteler*, R. J. Pirjola*,** and H. Nevanlinna**

* *Geomagnetic Laboratory, Geological Survey of Canada, 1 Observatory Cres., Ottawa, Ontario, K1A 0Y3, Canada*
** *Finnish Meteorological Institute, P.O. Box 503, FIN-00101 Helsinki, Finland*

ABSTRACT

Geomagnetic disturbances have affected electrical systems on the ground for over 150 years. The first effects were noted on the early telegraph in the 1840s and in this century magnetic storms have caused power system blackouts and phone system outages. Affected systems include all those that use electrical conductors: whether for transmission of power or signals or where the conducting properties are incidental to their use such as with pipelines and railway tracks. In power systems geomagnetically induced currents cause partial saturation of power transformers producing transformer heating and distortion of the ac waveform leading to misoperation of relays and other equipment. On pipelines, induced currents may contribute to corrosion but also present a problem with the electrical surveys of the pipe performed to monitor the corrosion prevention systems. Severity of these effects depends on disturbance size, proximity to the auroral zone, and the conductivity structure of the Earth. Also significant are system parameters such as the use of higher resistance coatings on pipelines and the linking of power systems into larger networks. In this paper we have attempted to catalogue all the published reports of geomagnetic effects on electrical systems and show their occurrence in the context of the solar cycle and geomagnetic activity variations for the years 1844 to 1996.

INTRODUCTION

On 13 March 1989, one of the biggest magnetic storms this century sent electric currents surging through power systems in N. America and northern Europe. The result was saturation of transformers, overload of equipment, lines tripped out of service, burn-out of transformers, and the collapse of the Hydro-Québec power system, leaving the 6 million residents of Québec without power for over 9 hours (Allen et al, 1989). These effects and the near-collapse of other systems have prompted a renewed research effort to understand how the geomagnetically induced currents (GIC) affect electrical systems at the Earth's surface.

Research into geomagnetic effects on electrical systems dates back to the last century and the early days of the telegraph. Varley (1873) reports on the aurora he observed in 1847 in the south of England and commented that, at the same time, all telegraph lines in operation in Great Britain were stopped by earth currents. He thought it might be said that this was the first time attention was fully drawn to the subject, and it was taken up not only by the officers of the telegraph company, but also by the Astronomer Royal. During a major storm in 1859 telegraph operators in Boston and Portland were able to disconnect their batteries and "for more than one hour they held communication with the aid of celestial batteries alone" (Prescott, 1866).

Telluric currents produced by a major magnetic storm in 1921 started fires at several telegraph stations in Sweden (Karsberg et al, 1959) and fire was again a danger to telegraph equipment during a major storm on March 24, 1940 (Harang, 1941). The major storm of August 4, 1972, produced an outage of the L-4 phone cable system in the mid-western US (Anderson et al, 1974). Submarine cables have also been affected by magnetic disturbances, and transatlantic communication from Clarenville, Newfoundland, to Oban, Scotland, during the magnetic storm of February 10, 1958, proceeded as alternately loud squawks and faint whispers

APPENDIX: MAGNETIC DISTURBANCES THAT HAVE AFFECTED ELECTRICAL SYSTEMS AT THE EARTH'S SURFACE

1847, Mar. 19 Sept.24-25 Oct. 23-25	Spontaneous deflections observed in the needles of the electric telegraph in England. It was noticed that the largest deflections occurred whenever aurora were visible. (Barlow, 1849; also see Varley, 1873).
1848, Oct 27-28	Occasion of heavy disturbances on the telegraph (Burbank, 1905). Matteucci remarked the coincidence of aurora with interruptions in telegraphic communications, produced by telluric currents (Angot, 1897, p 138).
Nov. 17	Appearance of the aurora coincided with effects on the electric telegraph between Florence and Pisa (Prescott, 1866, p 317).
1851, Sept.	Prescott (1866) reports, " a remarkable aurora, which took complete possession of all the telegraph lines in New England, and prevented any business from being transacted during its continuance".
1852, Feb. 19	Brilliant auroral display observed. Associated with it were currents that burnt through the chemical paper used with the Bain's chemical telegraph in the northeastern US (Prescott, 1866, p 318).
1859, Aug. 28 - Sept. 2	Mr O. S. Wood, Superintendent of the Canadian telegraph lines, says: "... so completely were the lines under the influence of the aurora borealis, that it was found utterly impossible to communicate between the telegraph stations, and the line was closed for the night". Problems also reported by telegraph operators in New York, Washington, Philadelphia, Vermont and Massachussetts (Prescott, 1860, 1866; also see Clement, 1860) and Gothenburg, Sweden (Rubenson, 1882). At all telegraphic stations in France service was impeded during the whole of September 2 (Blavier, 1859; see also Angot, 1897).
1869, May 30	Out of the sixteen lines which terminated in the telegraphic office at Basle, six were almost useless during the two hours that the phenomena lasted (Angot, 1897, p 141).
1870, April 5 & Oct 24	Coincidences between aurora borealis and telluric currents in telegraphic service noted by Angot (1897), p 142.
1872, Feb 4	The telluric currents attained an extraordinary development during the aurora which was one of the most extensive known. The disturbances in telegraphic communication were not less extensive. In Germany all the lines were affected, and communication was for a long time impossible between Cologne and London. Telluric currents were also observed in England, France, Austria, Switzerland, Italy and Turkey. Transmission of messages was also prevented on submarine cables, especially on the line from Lisbon to Gibraltar, on the line from Suez to Aden, and from Aden to Bombay, and on the transatlantic cable from Brest to Duxbury (Angot, 1897; see also Arrhenius, 1903).
1872 - 1873	Earth current effects on Atlantic cables (Graves, 1873), wrongly attributed to earthquakes.
1882, Nov 17	Telluric currents observed in England were, according to Preece [Superintendent of the Telegraph] five times as strong as the current usually employed in telegraphy. Communication was interrupted as long as the disturbance lasted (Angot, 1897, p 143).
1891	Electromotive force of 768 volts was recorded on the Western Union lines between New York and Buffalo, the circuits varying from 450 to 480 miles in length. On several occasions the strength of the earth current reached nearly 300 mA, compared to normal working currents that did not exceed 35 mA (Finn, 1903).
1892, July 16	Serious interruption of wire service in US (Sanders, 1961). Burbank (1905) gives details of voltages observed on various lines, including 210 volts, about 9 V/km, on line from New York to Elizabeth, N.J.
1894, Mar 30-31	Telegraph operators had been supplied with telephones and heard a variety of sounds produced by earth currents in the lines (Preece, 1894).

http://www.sciencedirect.com/science/article/pii/S027311779701096X

NOAA Space Weather Scales

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

Category		Effect	Physical measure	Average Freq. (1 cycle = 11 yrs)
Scale	Descriptor	Duration of event will influence severity of effects		
Radio Blackouts				
R 5	Extreme	**HF Radio:** Complete HF (high frequency**) radio blackout on t sunlit side of the Earth lasting for a number of hours. This result radio contact with mariners and en route aviators in this sector. **Navigation:** Low-frequency navigation signals used by maritim aviation systems experience outages on the sunlit side of the Ear hours, causing loss in positioning. Increased satellite navigation positioning for several hours on the sunlit side of Earth, which n into the night side.		
R 4	Severe	**HF Radio:** : HF radio communication blackout on most of the s Earth for one to two hours. HF radio contact lost during this tim **Navigation:** Outages of low-frequency navigation signals cause error in positioning for one to two hours. Minor disruptions of s navigation possible on the sunlit side of Earth.		
R 3	Strong	**HF Radio:** Wide area blackout of HF radio communication, los contact for about an hour on sunlit side of Earth. **Navigation:** Low-frequency navigation signals degraded for abo		
R 2	Moderate	**HF Radio:** Limited blackout of HF radio communication on sur of radio contact for tens of minutes. **Navigation:** Degradation of low-frequency navigation signals fo minutes.		
R 1	Minor	**HF Radio:** Weak or minor degradation of HF radio communicat side, occasional loss of radio contact. **Navigation:** Low-frequency navigation signals degraded for bri		

* Flux, measured in the 0.1-0.8 nm range, in W·m^{-2}. Based on this measure, but considered.
** Other frequencies may also be affected by these conditions.

Radio Blackouts

Category		Effect	Physical measure	Average Freq. (1 cycle = 11 yr)
Scale	Descriptor	Duration of event will influence severity of effects	Flux level	Number of
Solar Radiation Storms				
S 5	Extreme	**Biological:** unavoidable high radiation hazard to astronauts on E' vehicular activity); high radiation exposure to passengers and cre commercial jets at high latitudes (approximately 100 chest x-rays **Satellite operations:** satellites may be rendered useless, memory cause loss of control, may cause serious noise in image data, star be unable to locate sources; permanent damage to solar panels po **Other systems:** complete blackout of HF (high frequency) comm possible through the polar regions, and position errors make navi operations extremely difficult.		
S 4	Severe	**Biological:** unavoidable radiation hazard to astronauts on EVA; radiation exposure to passengers and crew in commercial jets at h (approximately 10 chest x-rays) is possible. **Satellite operations:** may experience memory device problems a imaging systems; star-tracker problems may cause orientation pr solar panel efficiency can be degraded. **Other systems:** blackout of HF radio communications through th regions and increased navigation errors over several days are like		
S 3	Strong	**Biological:** radiation hazard avoidance recommended for astrona passengers and crew in commercial jets at high latitudes may rec radiation exposure (approximately 1 chest x-ray). **Satellite operations:** single-event upsets, noise in imaging syster reduction of efficiency in solar panel are likely. **Other systems:** degraded HF radio propagation through the pola navigation position errors likely.		
S 2	Moderate	**Biological:** none. **Satellite operations:** infrequent single-event upsets possible. **Other systems:** small effects on HF propagation through the pol navigation at polar cap locations possibly affected.		
S 1	Minor	**Biological:** none. **Satellite operations:** none. **Other systems:** minor impacts on HF radio in the polar regions.		

Radiation Storms

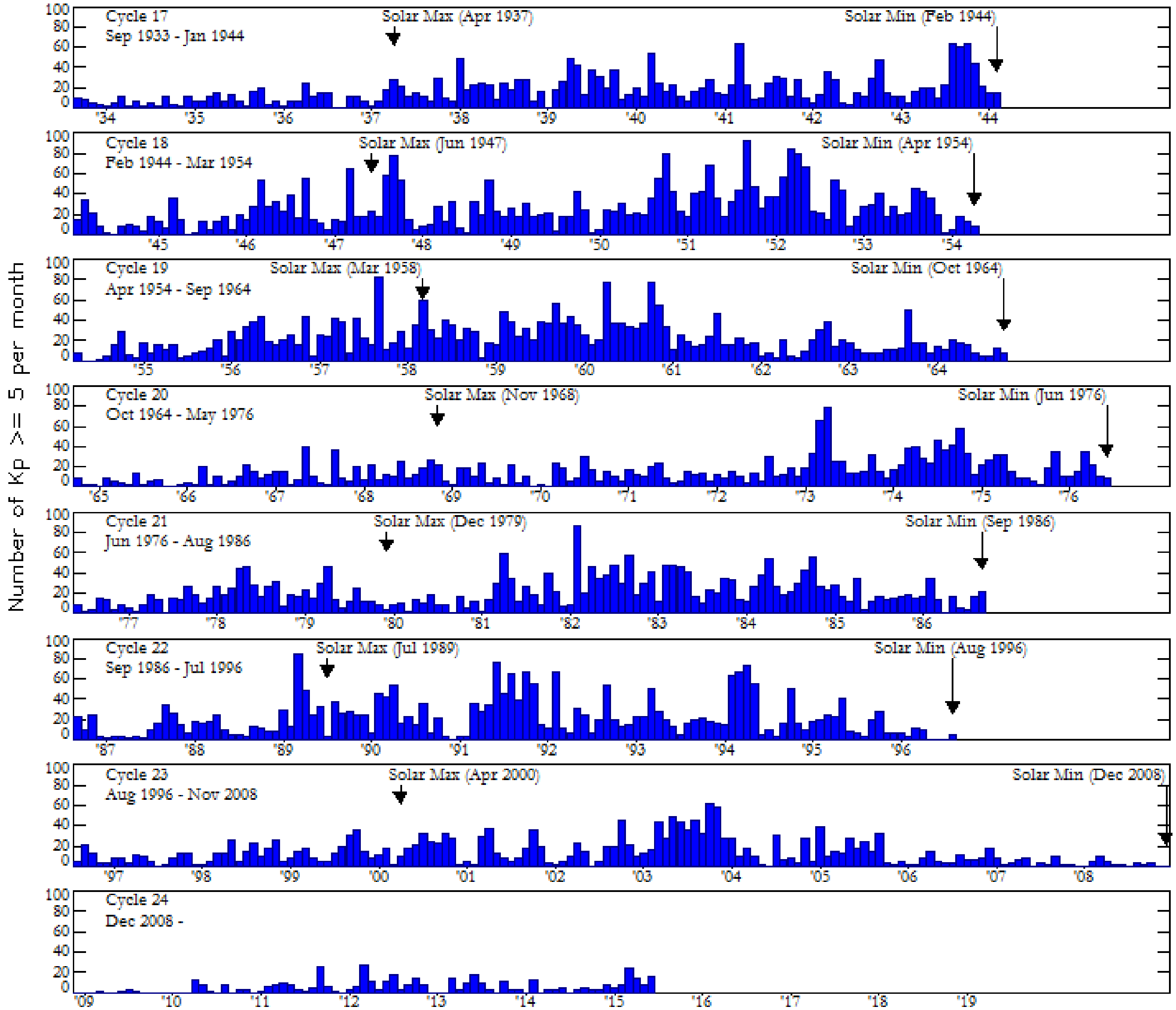
Category		Effect	Physical measure	Average Freq. (1 cycle = 11 yrs)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met
G 5	Extreme	**Power systems:** : widespread voltage control 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)

Geomagnetic Storms

Periods with Kp >= 5

June 2015

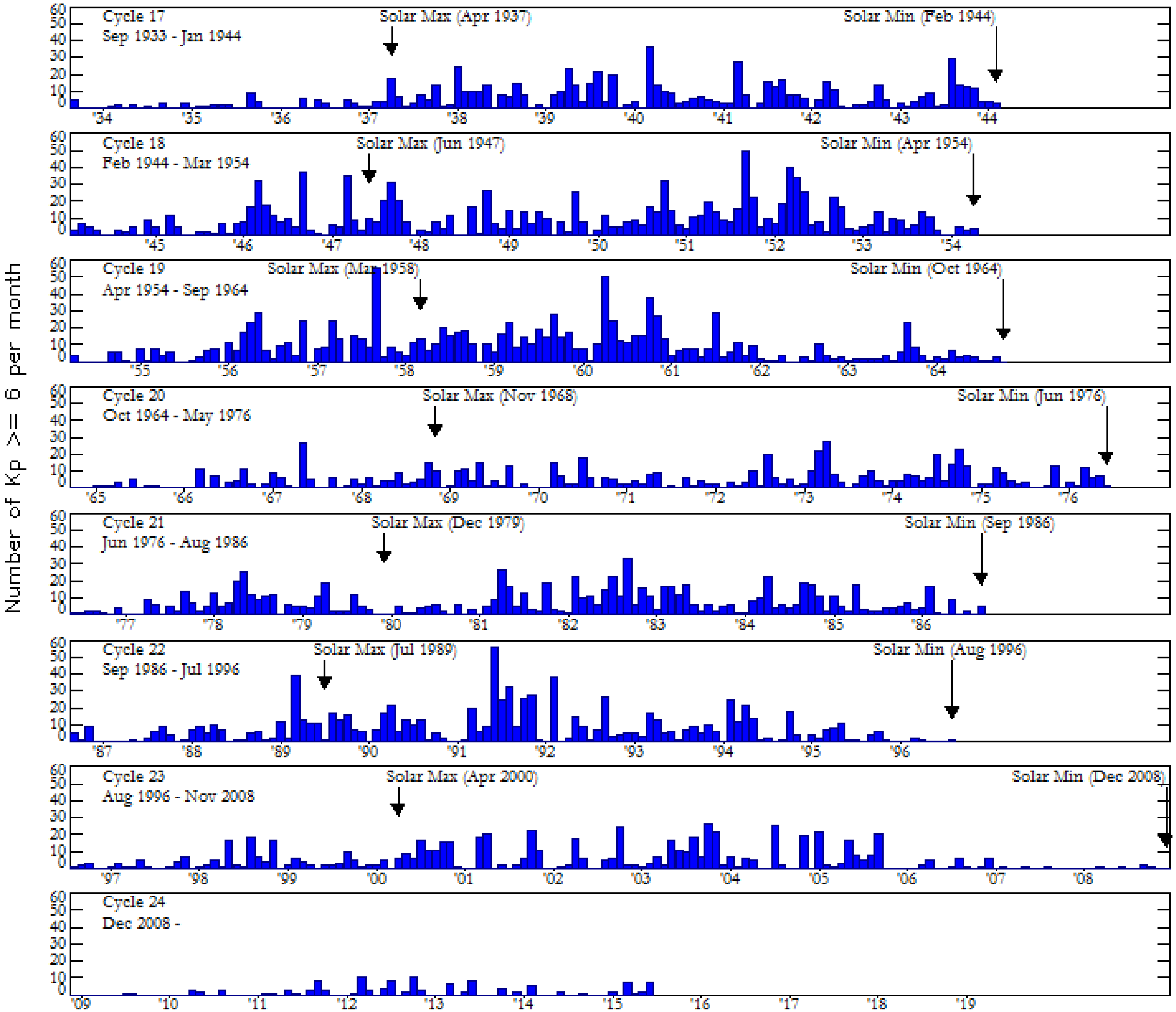
(Month 79)



Periods with Kp >= 6

June 2015

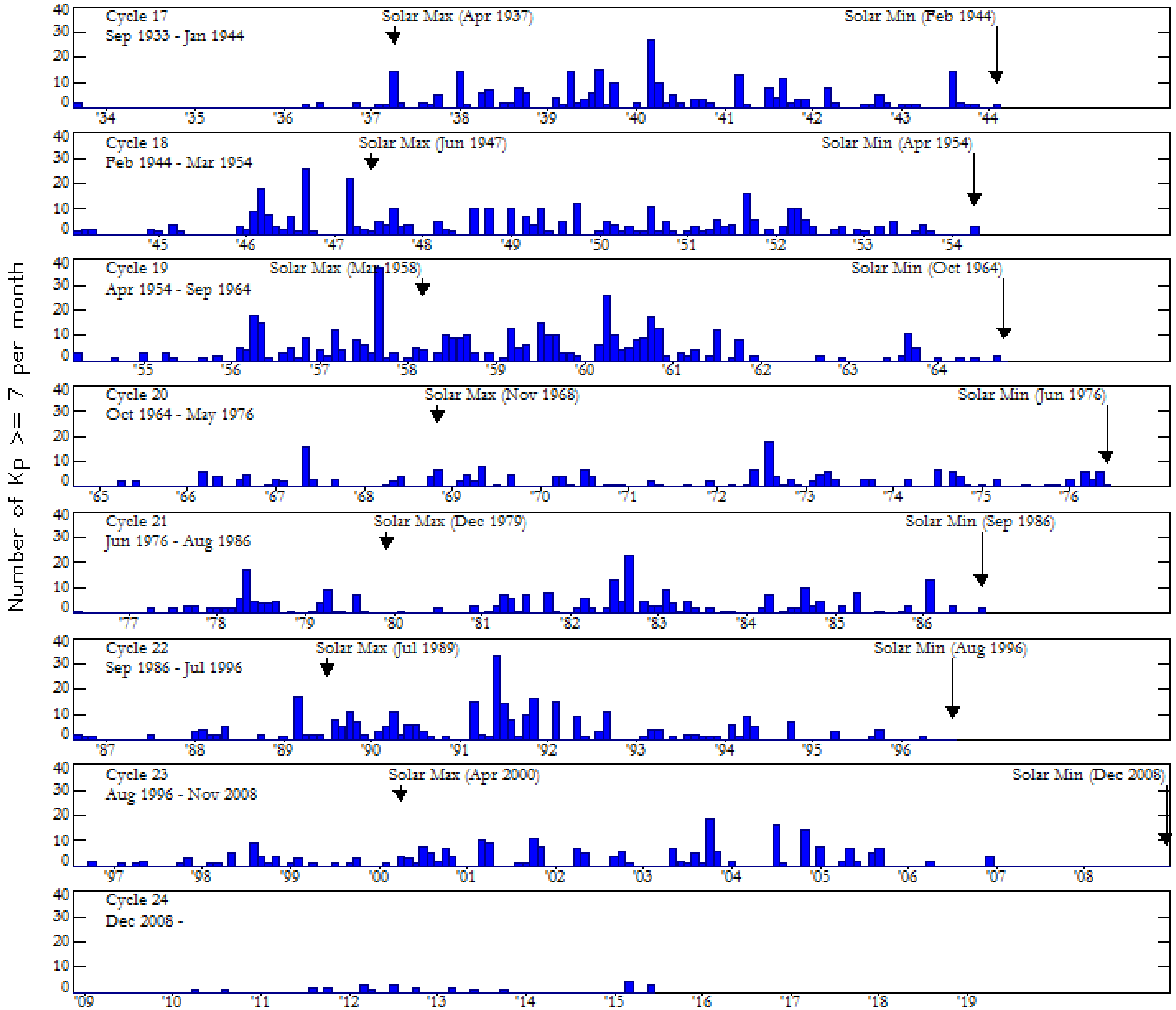
(Month 79)



Periods with Kp >= 7

June 2015

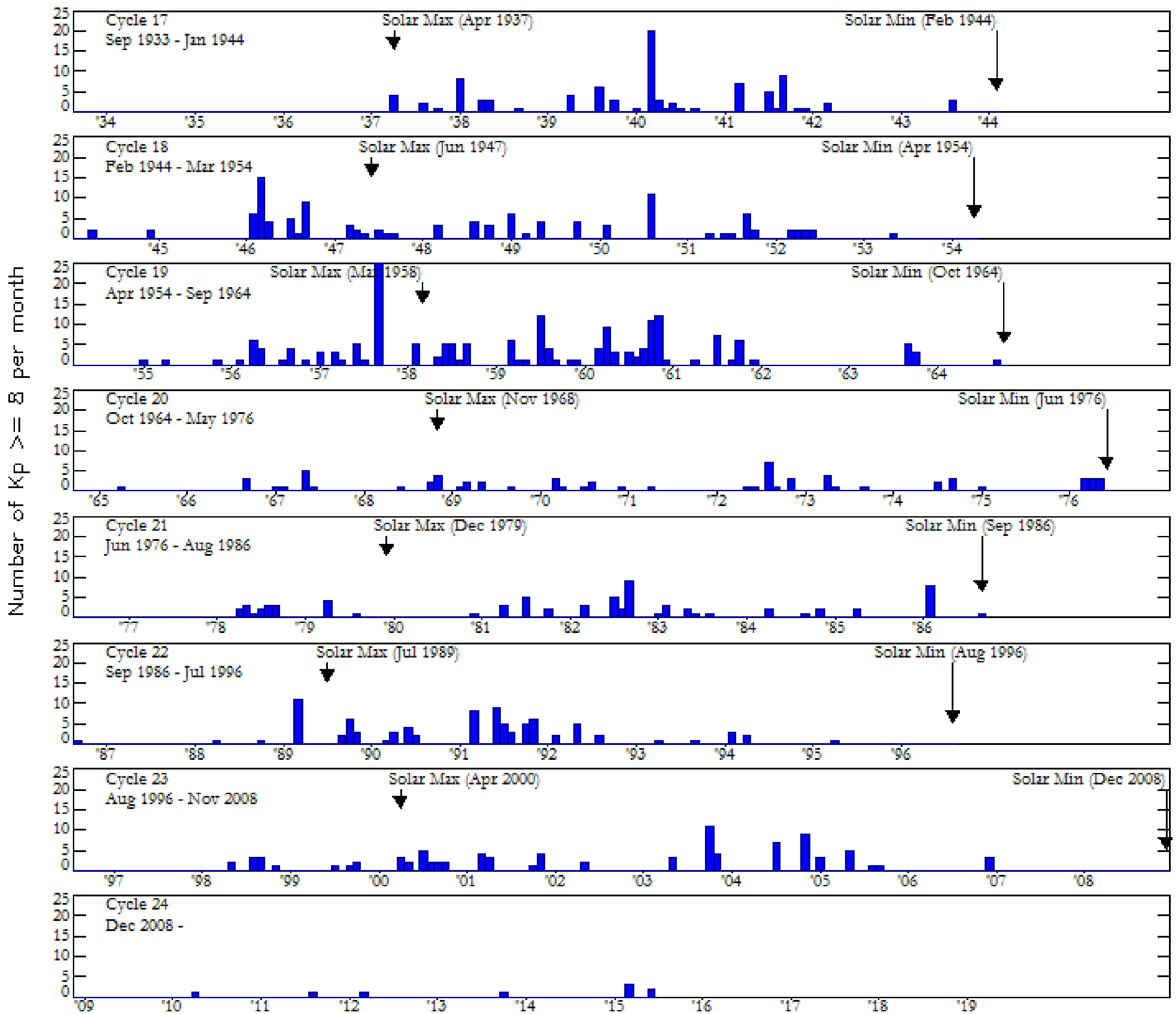
(Month 79)



Periods with Kp >= 8

June 2015

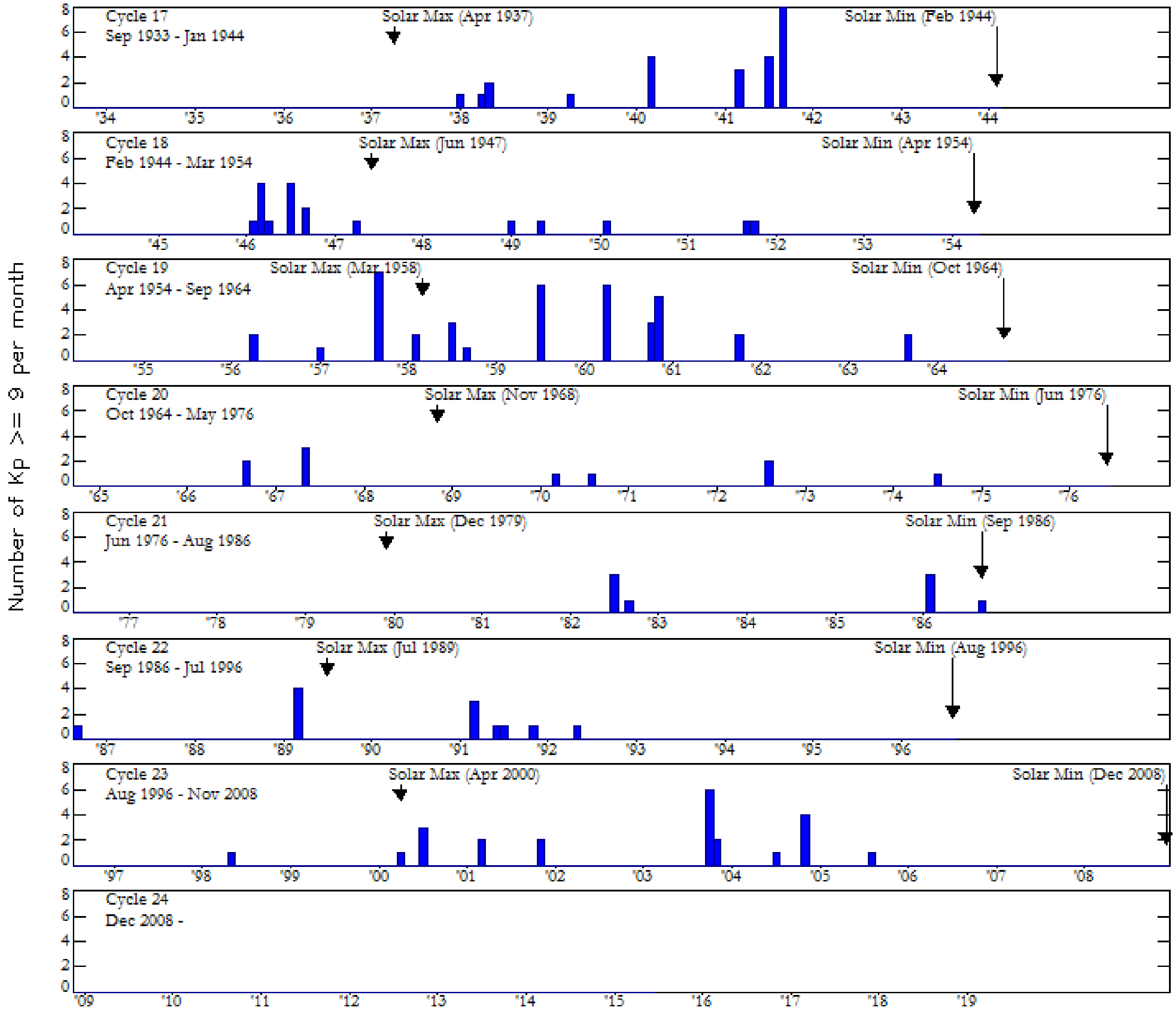
(Month 79)



Periods with Kp >= 9

June 2015

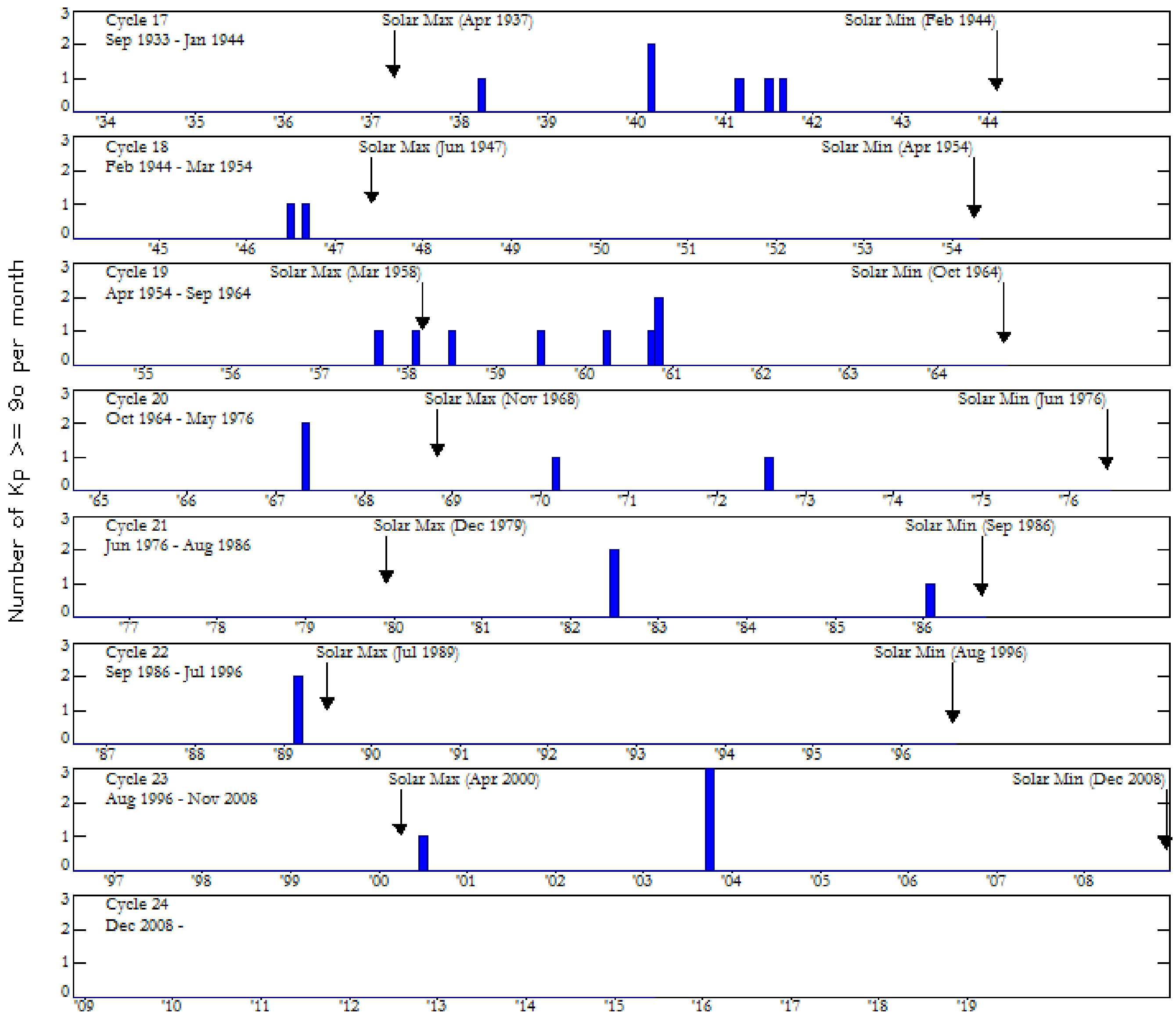
(Month 79)



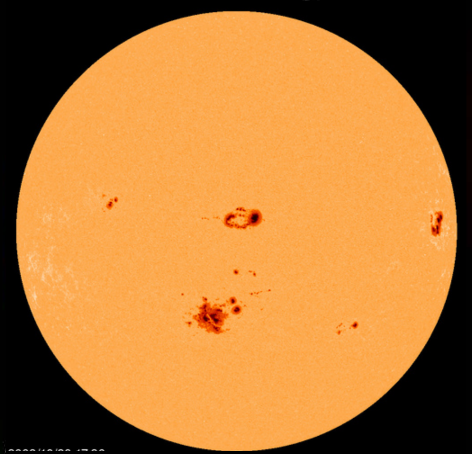
Periods with Kp >= 9o

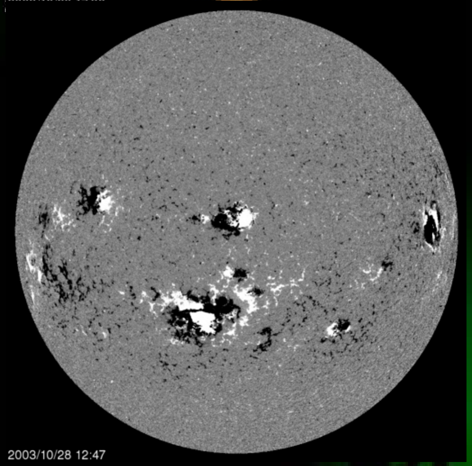
June 2015

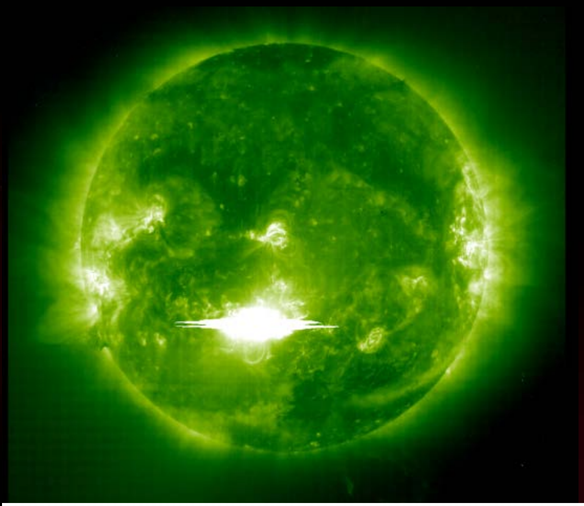
(Month 79)

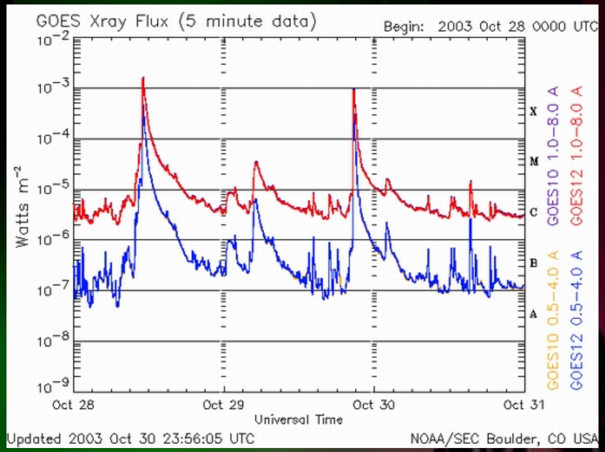


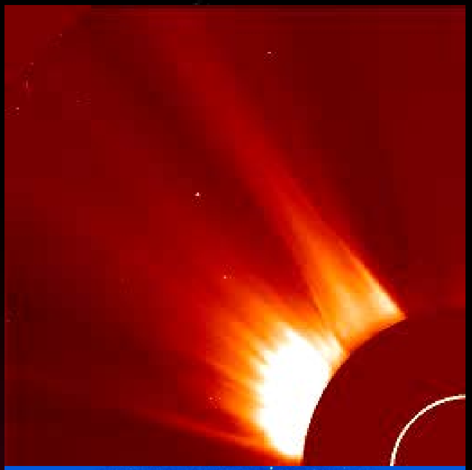
Sequence of Events

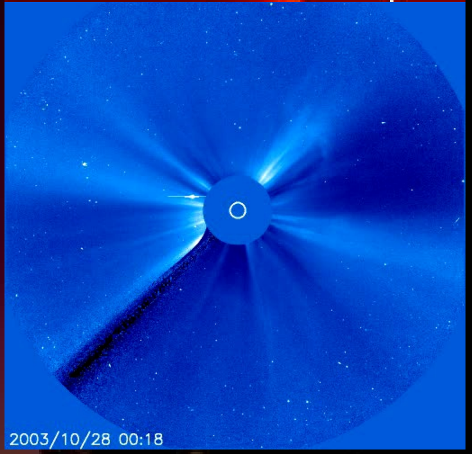






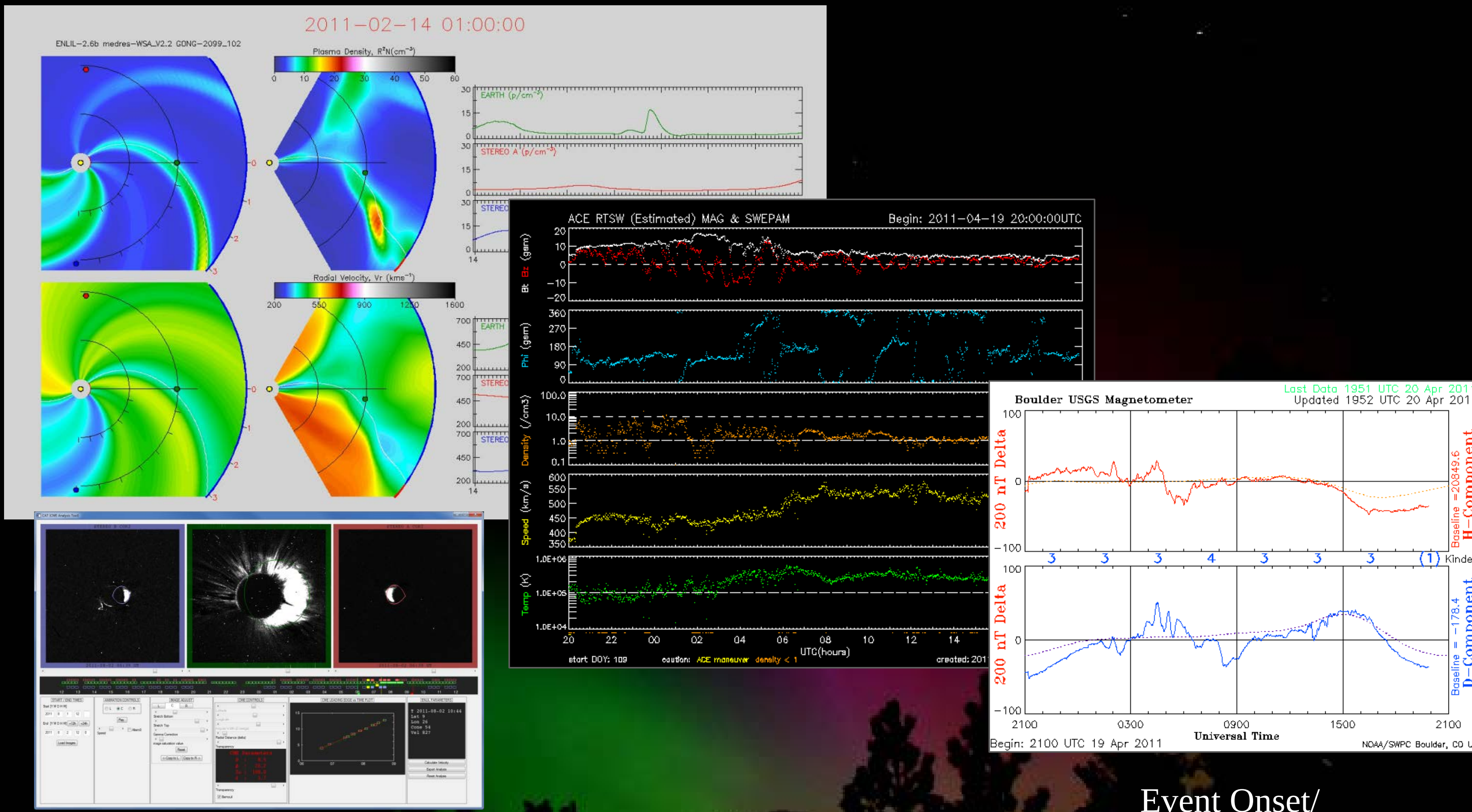






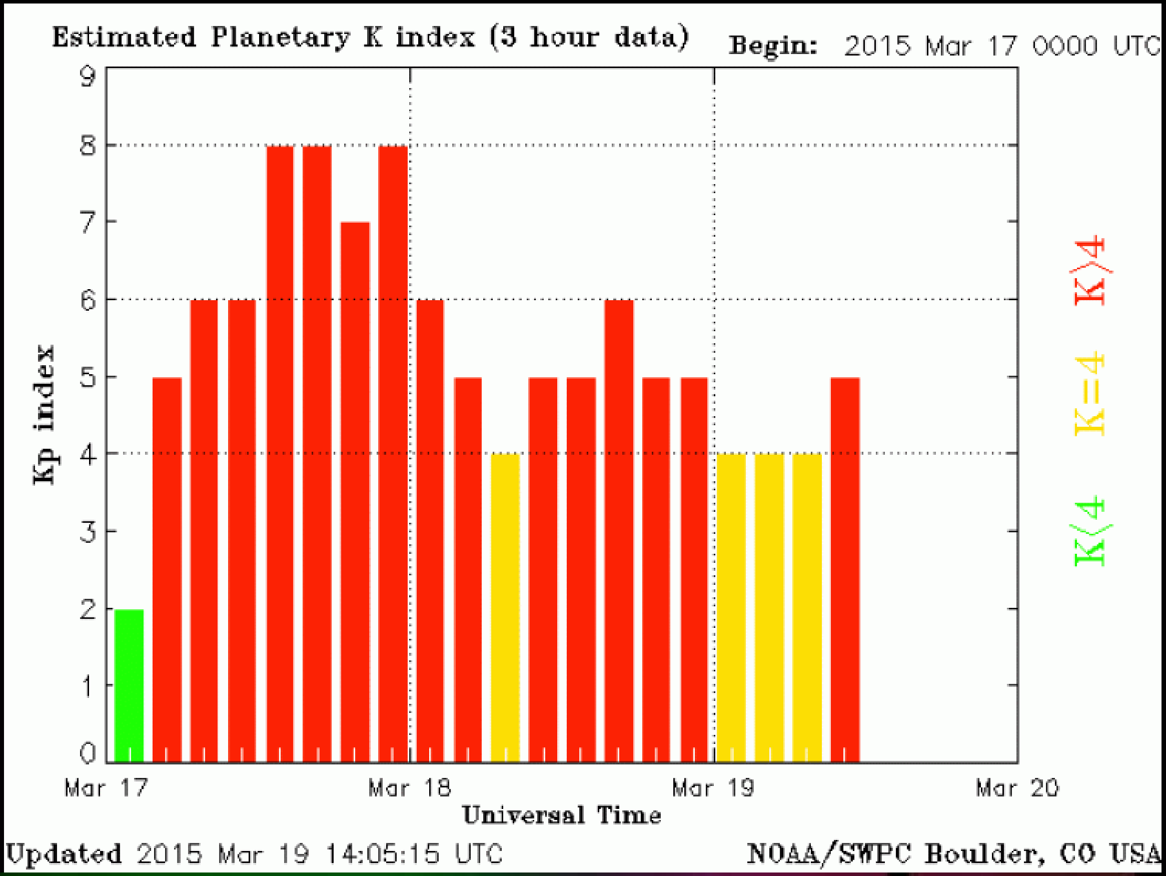
Conditions are Favorable for Activity (Probabilistic Forecasts) → Event Occurs → Coronal Observations

Sequence of Events



Analysis and Prediction → ACE Observation → Event Onset/ Ground-Based Observation

Practical Challenges



Issued: 2015 Mar 17 0030 UTC
Geophysical Activity Forecast: G1 (Minor) or greater geomagnetic storms are Expected on 18 Mar associated with a combination of the recurrent southern Pole connected coronal hole high speed stream (CH HSS) and CME arrival

Event-Driven Product Definitions

- Watches; The conditions are favorable for occurrence
- Warnings; disturbances that are imminent, expected in the near future with high probability
- Alerts; observed conditions meeting or exceeding thresholds

From: SWPC Product Subscription Service Sent: Fri 12/2/2011 5:29 PM
To: Robert.Rutledge@noaa.gov
Cc:
Subject: WARNING: Geomagnetic K-index of 4 expected

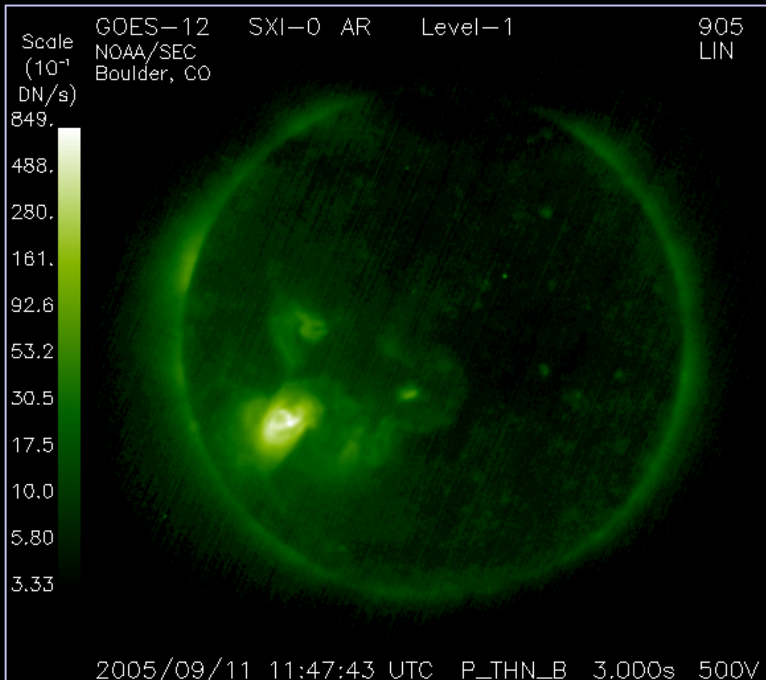
Space Weather Message Code: WARK04
Serial Number: 1846
Issue Time: 2011 Dec 03 0025 UTC

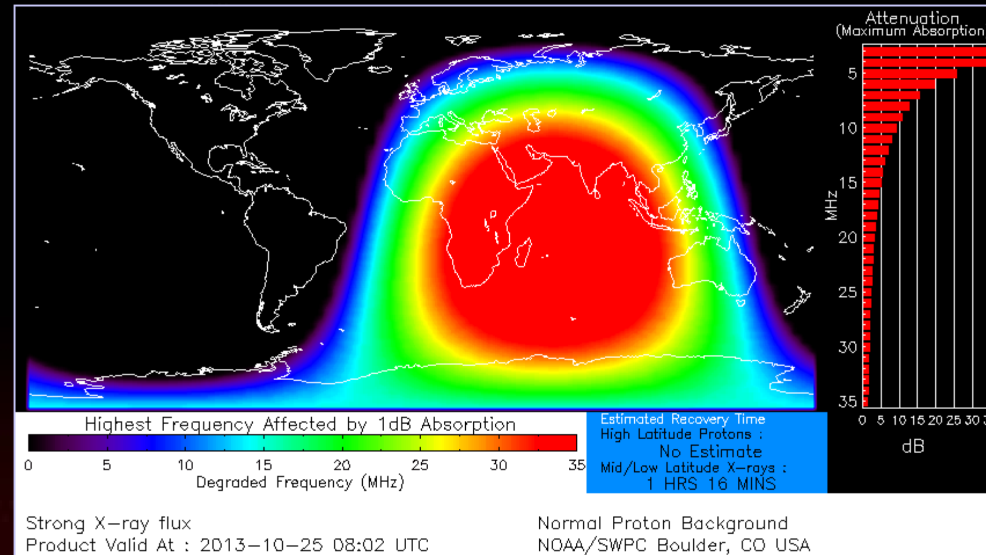
WARNING: Geomagnetic K-index of 4 expected
Valid From: 2011 Dec 03 0130 UTC
Valid To: 2011 Dec 03 0600 UTC
Warning Condition: Onset

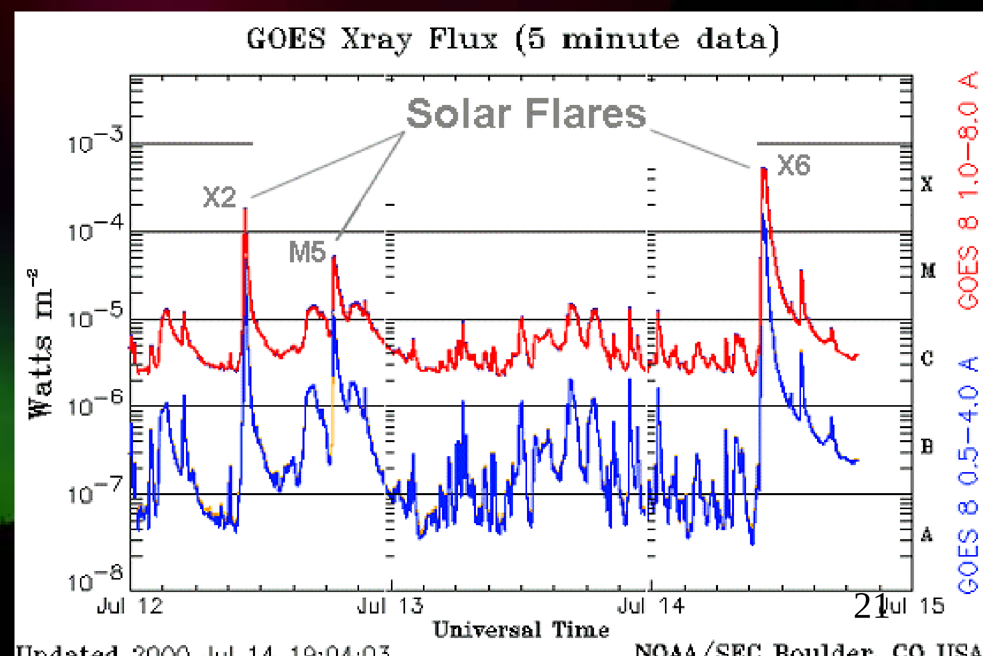
NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/NOAAscales

Thank you for using the Product Subscription Service. If you would like to remove a product subscription or update the personal information in your account, go to the Product Subscription Site. Please do not use the from address for correspondence, as it is not monitored. For comments or help, please contact SWPC Help.

Solar Flares *(Radio Blackouts – R Scale)*

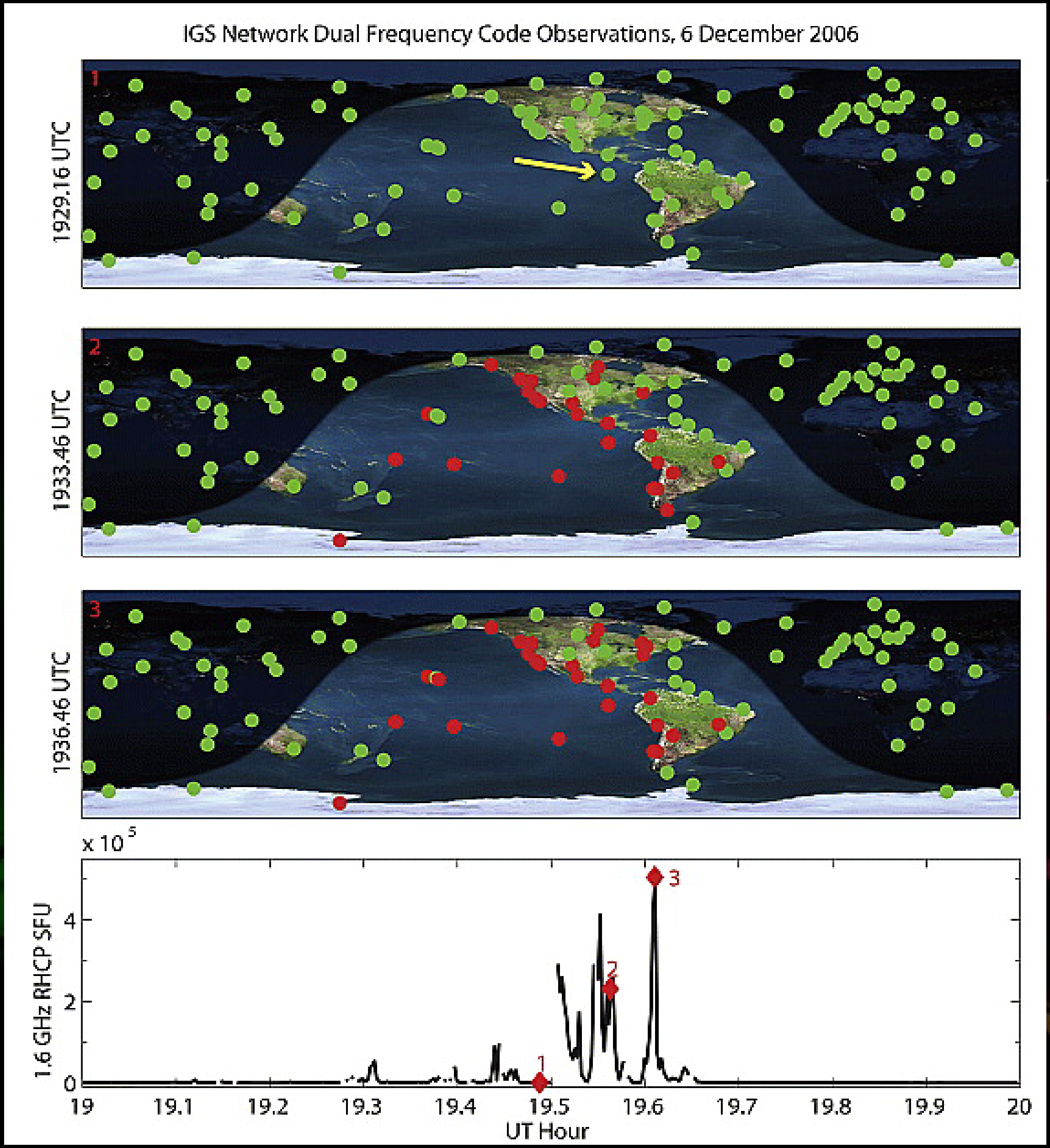






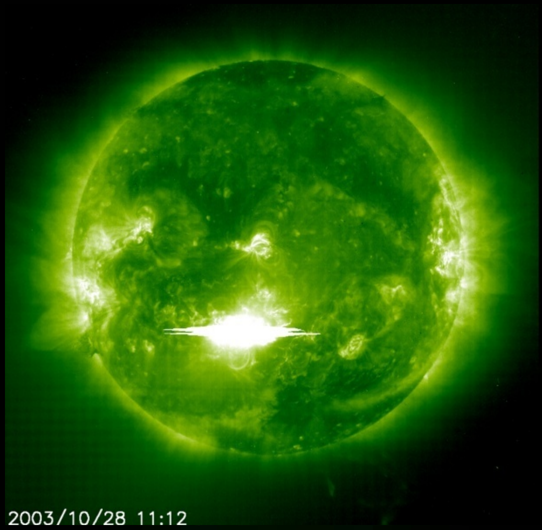
- Arrival: 8 minutes, photons
- Duration: Minutes to 3 hours
- Daylight-side impacts
- Probabilistic 1, 2, 3-day forecasts
- Alerts for exceeding R2 (only)
- Summary messages post-event

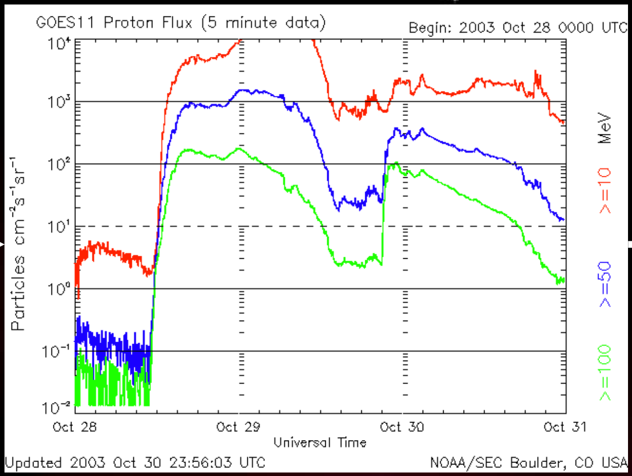
Effect of intense December 2006 solar radio bursts on GPS receivers

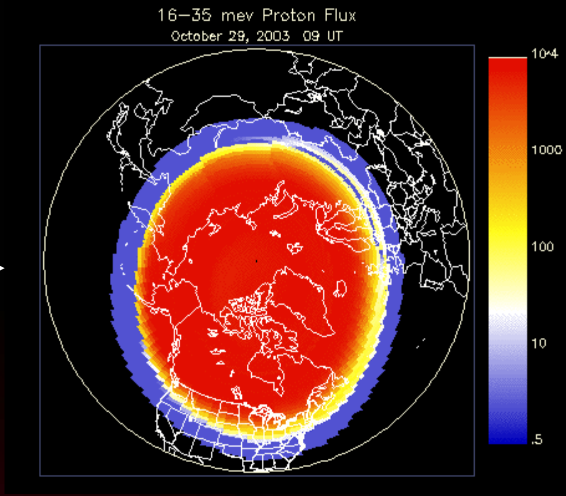


Cerruti, A. P., P. M. Kintner Jr., D. E. Gary, A. J. Mannucci, R. F. Meyer, P. Doherty, and A. J. Coster (2008), Effect of intense December 2006 solar radio bursts on GPS receivers, Space Weather, 6, S10D07, doi:10.1029/2007SW000375.

Solar Radiation Storms *(S Scale)*

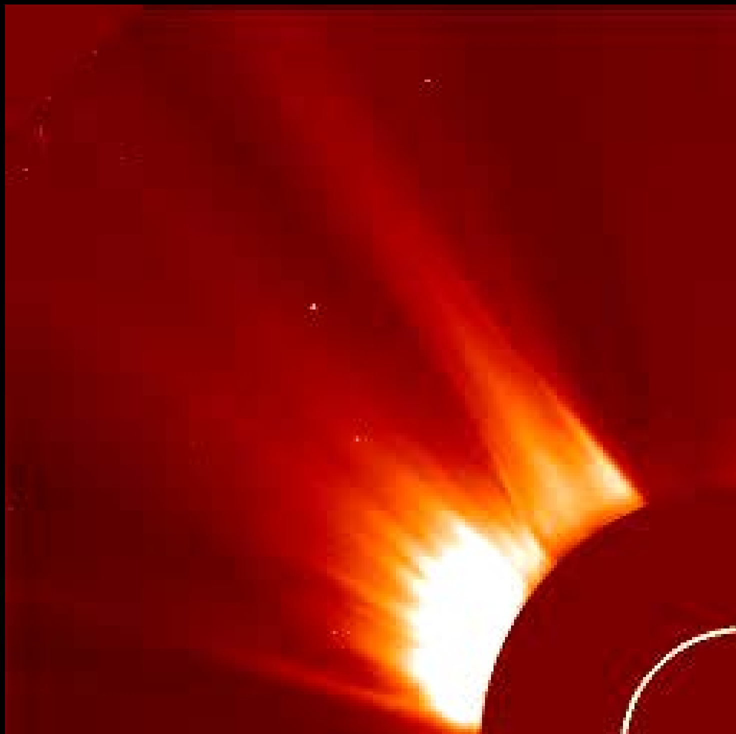






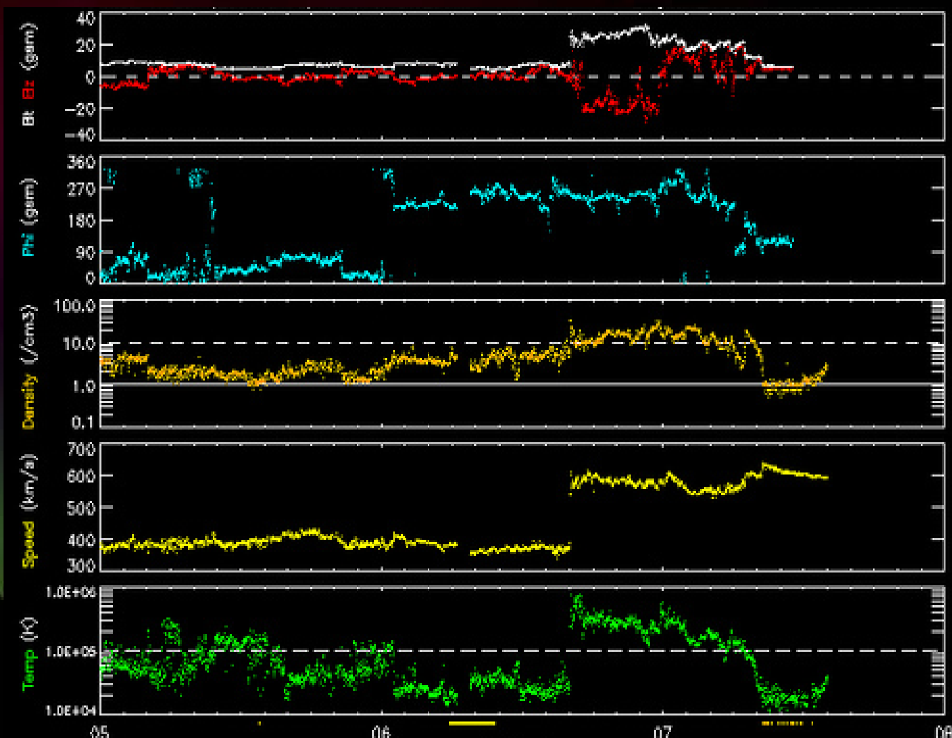
- Arrival: 10’s of minutes to several hours
- Duration: hours to days
- Short-term warnings pre-onset
- Alert for threshold crossing
- Summary post-event

Geomagnetic Storms *(G Scale)*



• Coronal Mass Ejections (CMEs) create geomagnetic storms
•Arrival: ~18 – 96 hours
• Duration: Hours to a day or two
• Creates ionospheric storms, geomagnetically induced currents, aurora

• 1-3 Day watch products based on coronagraph observations and modeling
• Short-term (~15-60 min) warnings based on measurement at ACE spacecraft

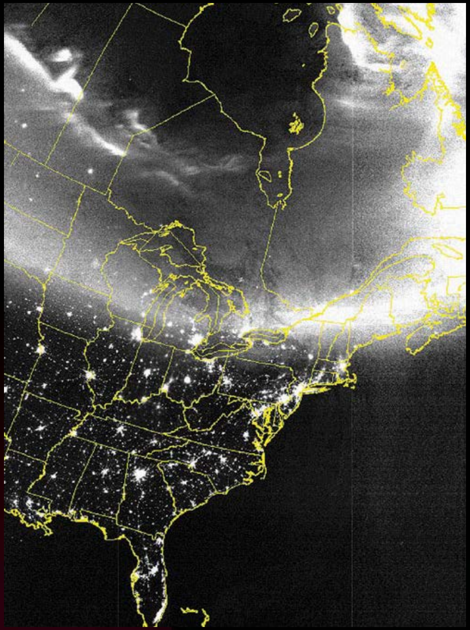


Impacts on Electric Power Grid

- CME impacts Earth’s magnetic field

- Fluctuations generate electric fields on Earth. These geomagnetically induced currents (GIC) can flow into power lines and transformers

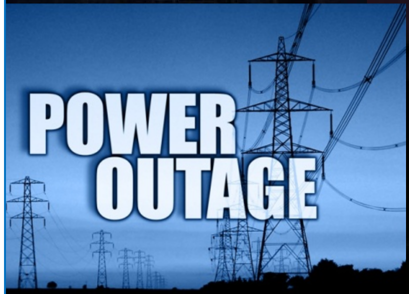
- Leads to transformer saturation and over-heating, voltage drops, transformer damage, or protective device trips

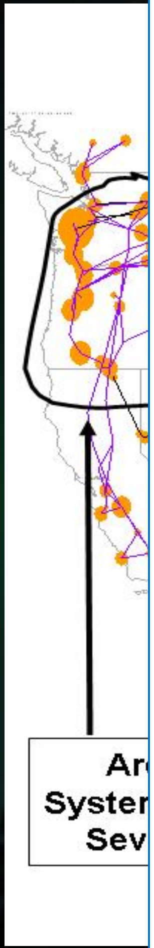


Transformer winding failure

Transformer exit-lead overheating

High Impact/Low Frequency Threat…





Media Release:

Loss of Reactive Power, Voltage Instability Most Likely Outcome from GMD, NERC Report Finds

February 29, 2012

ATLANTA – <u>Loss of reactive power is the most likely outcome from a severe solar storm centered over North America</u>, a report released by the North American Electric Reliability Corporation (NERC) finds. Significant losses of reactive power could lead to voltage instability and, if not identified and managed appropriately, power system voltage collapse could occur…..

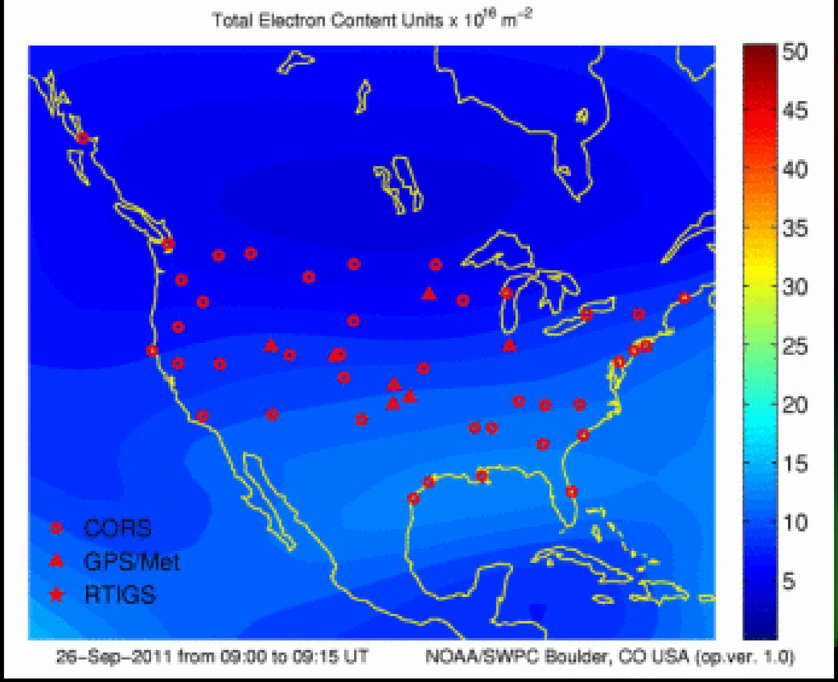
Forecasting Space Weather Conditions for GPS

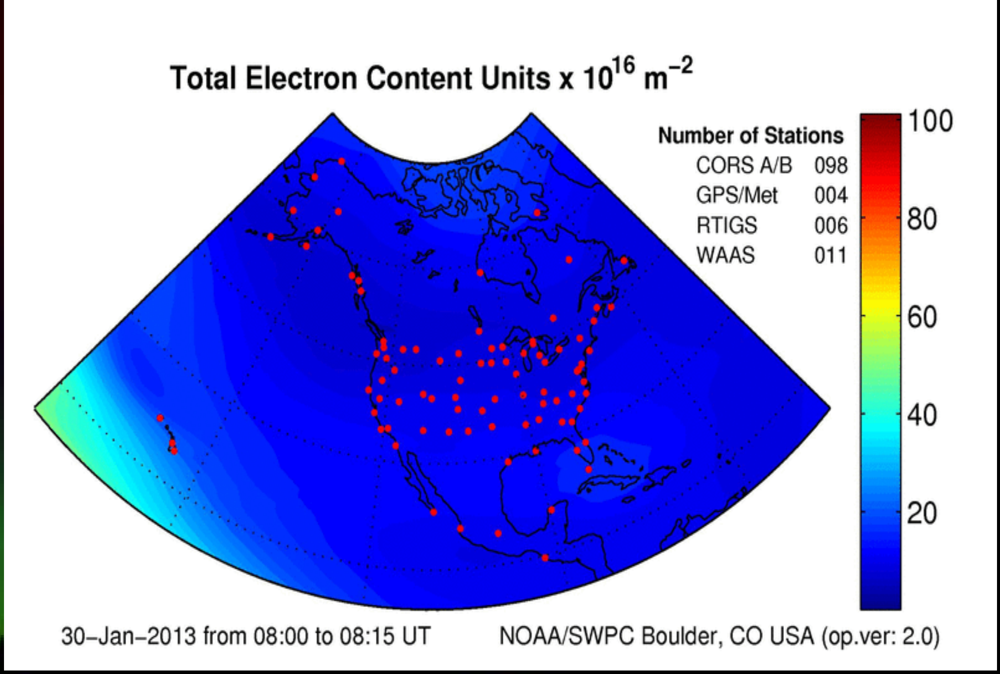
- High to Mid Latitudes
  - Primary driver is geomagnetic activity and the aurora
- Mid to Low Latitudes
  - A major driver is the lower atmosphere
    - Requires forecast modeling of the whole atmosphere from the ground to space

Current Products: Regional Specification

Current:
US-TEC: Provides real-time specification of Total Electron Content over the US

Upgrade:
North America-TEC: Provide real-time specification of Total Electron Content over the North America (Operational ~2016)





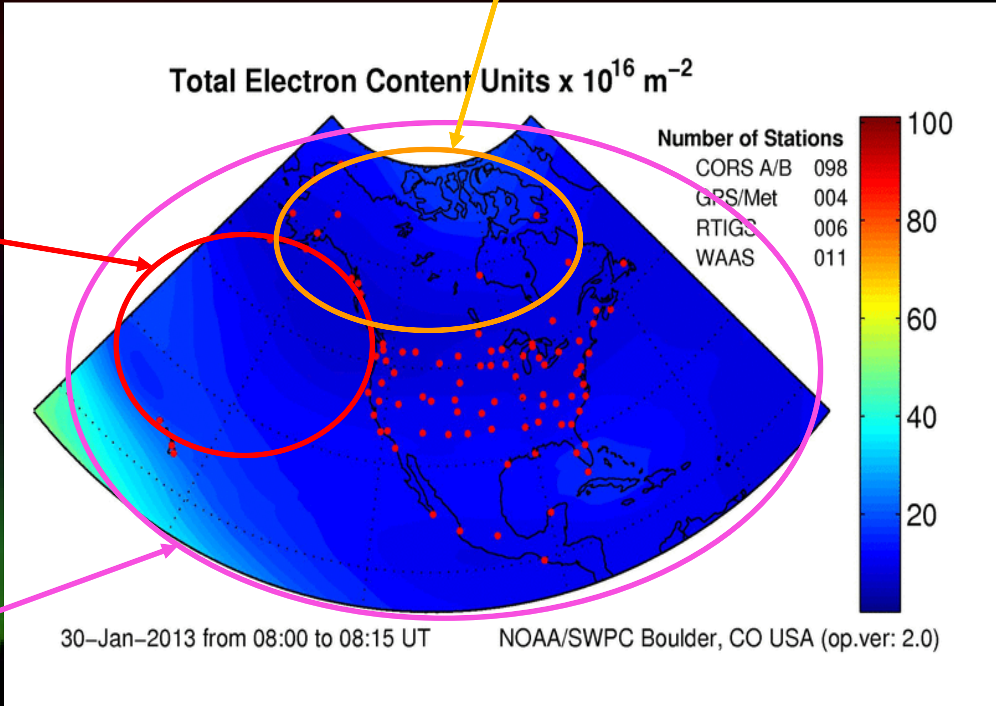
Data Limitations for Current Nowcast Products

- **Current products limited by lack of global data coverage**
  - **Need more data in the arctic**
  - **Need data over oceans**

– Working to get more real-time GPS data from high latitude/arctic regions
  – Use of NTRIP to access more data
  – Plate Boundary Observatory

Air Force SBIR: Partner with USAF and ASTRA to develop a ground GPS receiver and data processing system that will work on ocean buoys

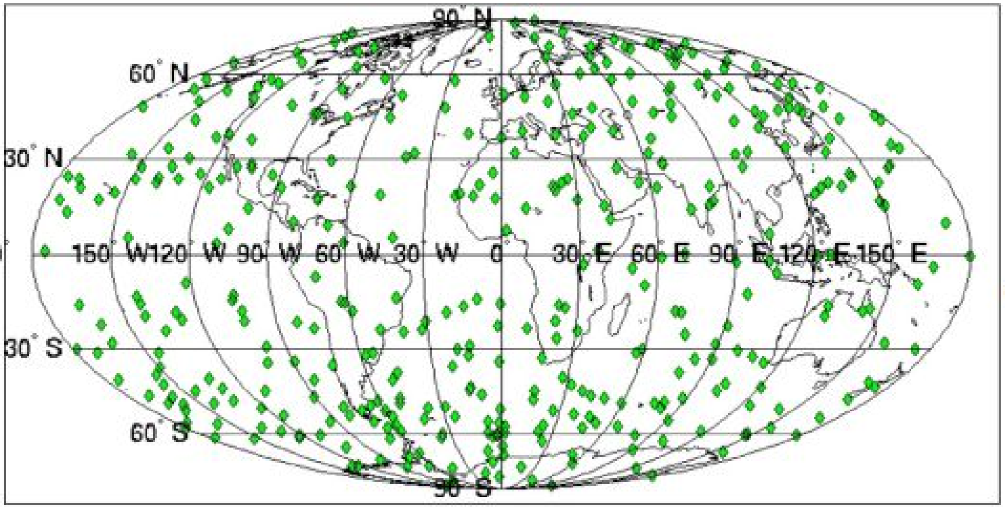
- NOAA Data Buoy Center will assist with design and deploy test models on the TAO Buoys in the mid Pacific



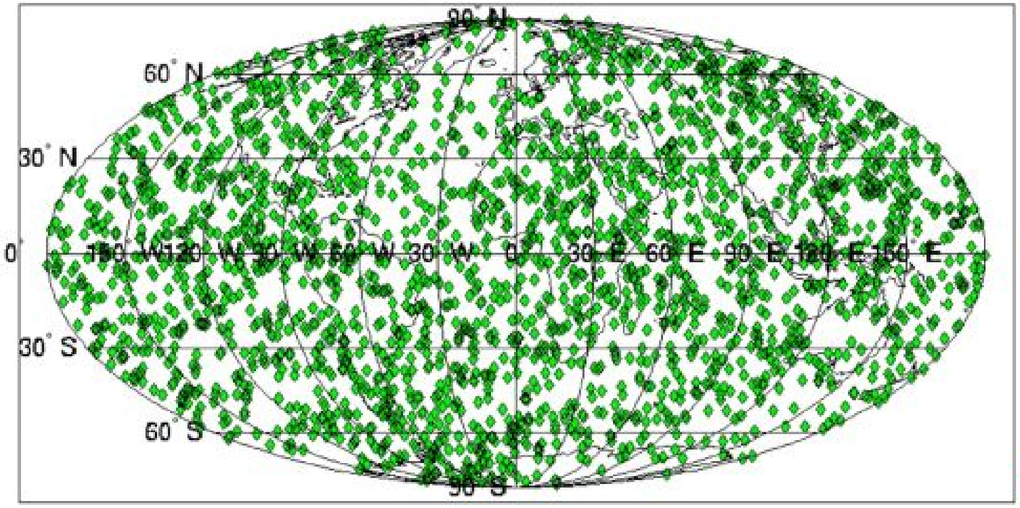
Developing data assimilation techniques to use COSMIC II data

From COSMIC 1 to COSMIC 2

COSMIC Occultations: 3 hours



COSMIC-II Occultations, ALL S/C, GPS/Galileo/Glonass: 3 hours

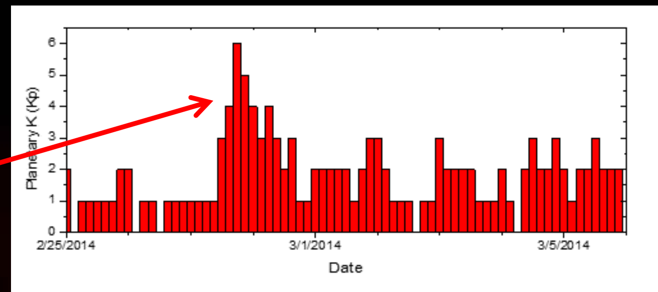


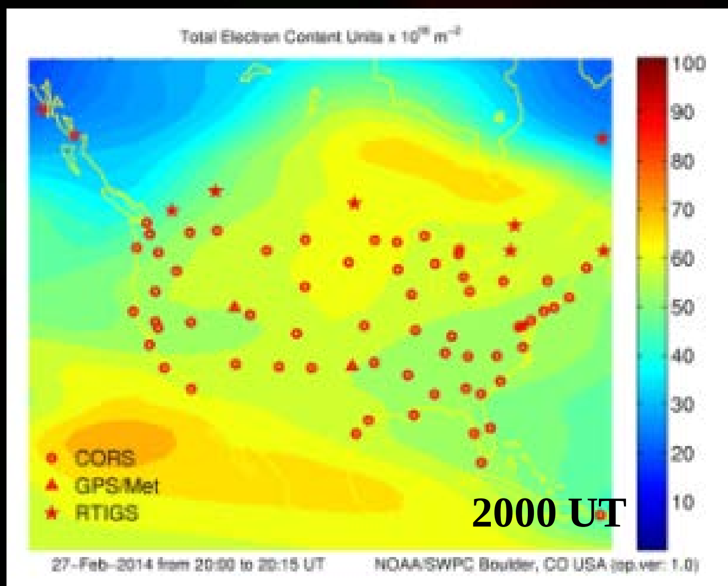
Comparison of sounding distribution over three hour periods between COSMIC and fully implemented COSMIC 2 is shown.

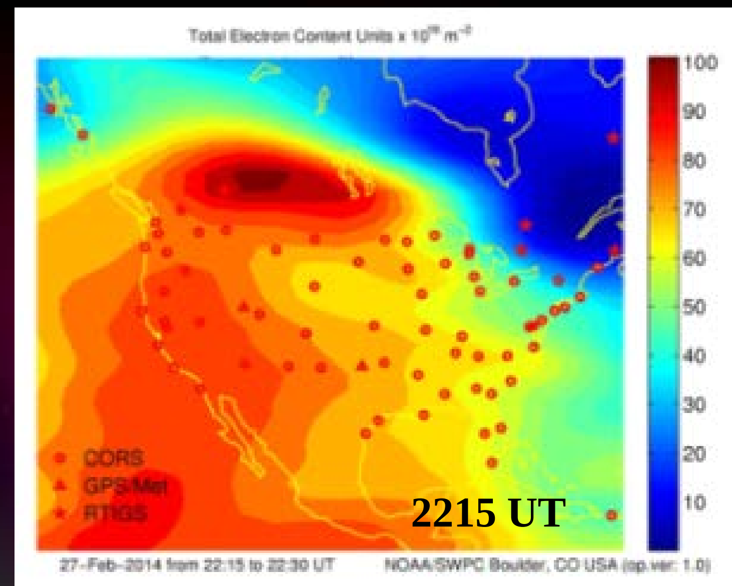
- **With COSMIC II**
  - **8000-12000 profiles per day using GPS and GALILEO as sources**
  - **Average profile within 45 minutes**
  - **Full vertical profile – deeper into lower troposphere**
- **Still Will Feature**
  - **All weather**
  - **Day and night**
  - **No bias or drift**
- **For Space Weather:**
  - **0.001 TEC Unit relative**
  - **Electron Density Profile 10%**
  - **S4 index uncertainty – 0.1**
    - **(Scintillation)**
- **Requires < 15 mins data latency for Space Wx situational awareness.**

Impact of a Moderate Geomagnetic Storm

Moderate Geomagnetic Storm:
Kp of 6 on a scale of 0-9, or
NOAA Category G2







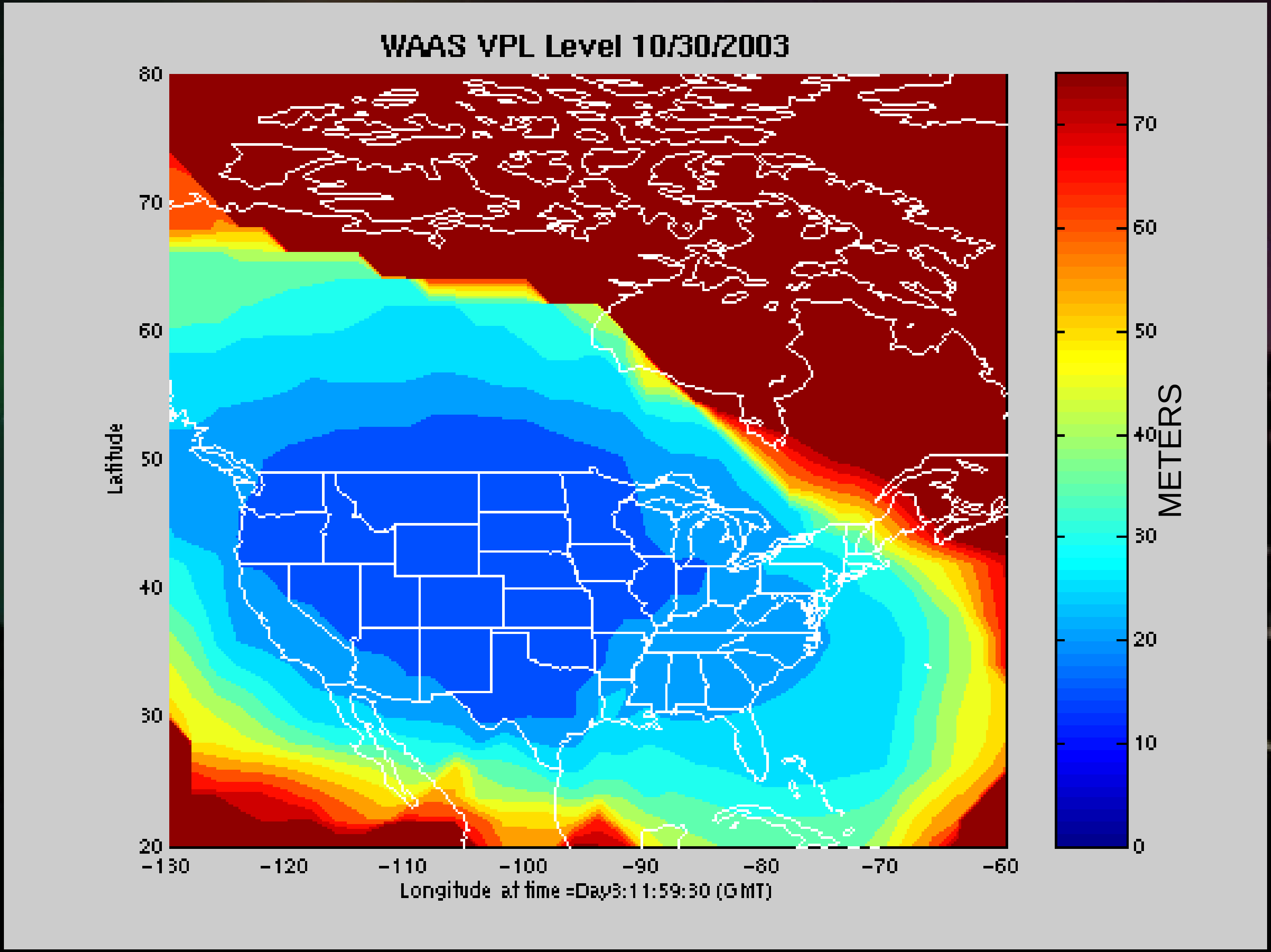
FAA Msg to SWPC:

"An Ionospheric Storm began on 2/27/14. The Satellite Operations Specialists were alerted at the WAAS O&M by a Significant Event 757 at 2120 Zulu. So far, LPV and LPV200 service has not been available in Eastern Alaska and Northeastern CONUS. At times, North Central CONUS and all of Alaska have lost LPV and LPV200 Service."

Note: LPV is Localizer Performance with Vertical Guidance which takes the aircraft down to 250 ft altitude

GPS IMPACT – U.S. Federal Aviation Administration (FAA) Wide Area Augmentation System (WAAS)

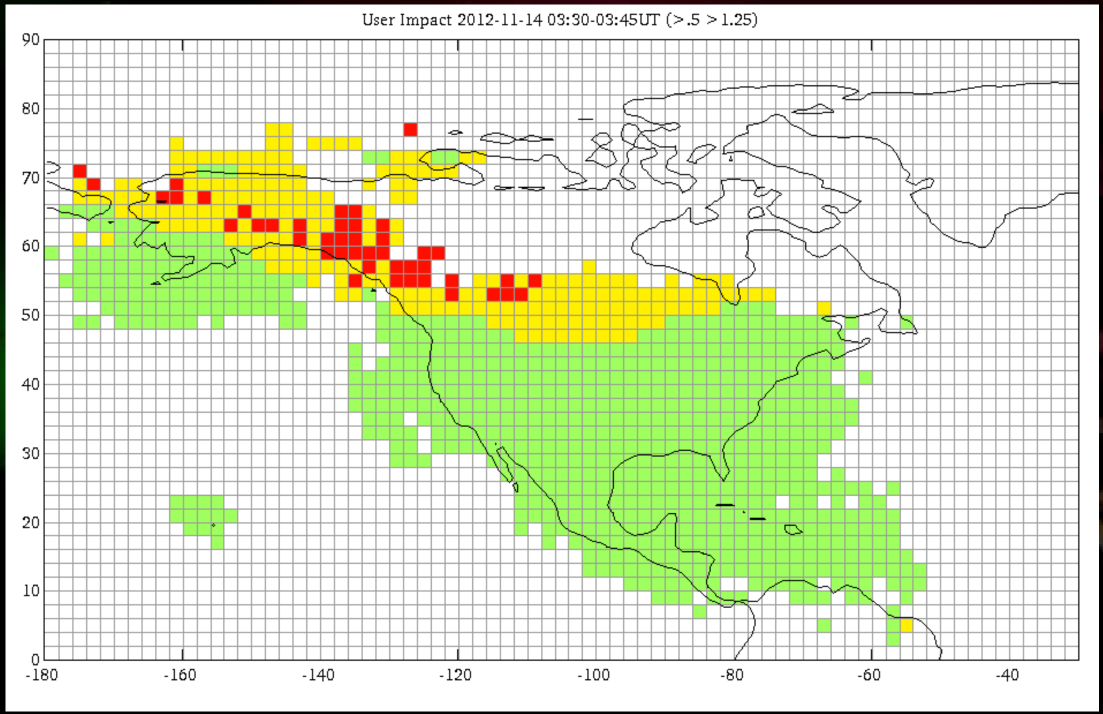
- Intense geomagnetic and ionosphere storms occur on 29 and 30 Oct, 2003
- Acceptable vertical error limits were exceeded for 15 and 11-hour periods



Products for Precision Applications of GPS

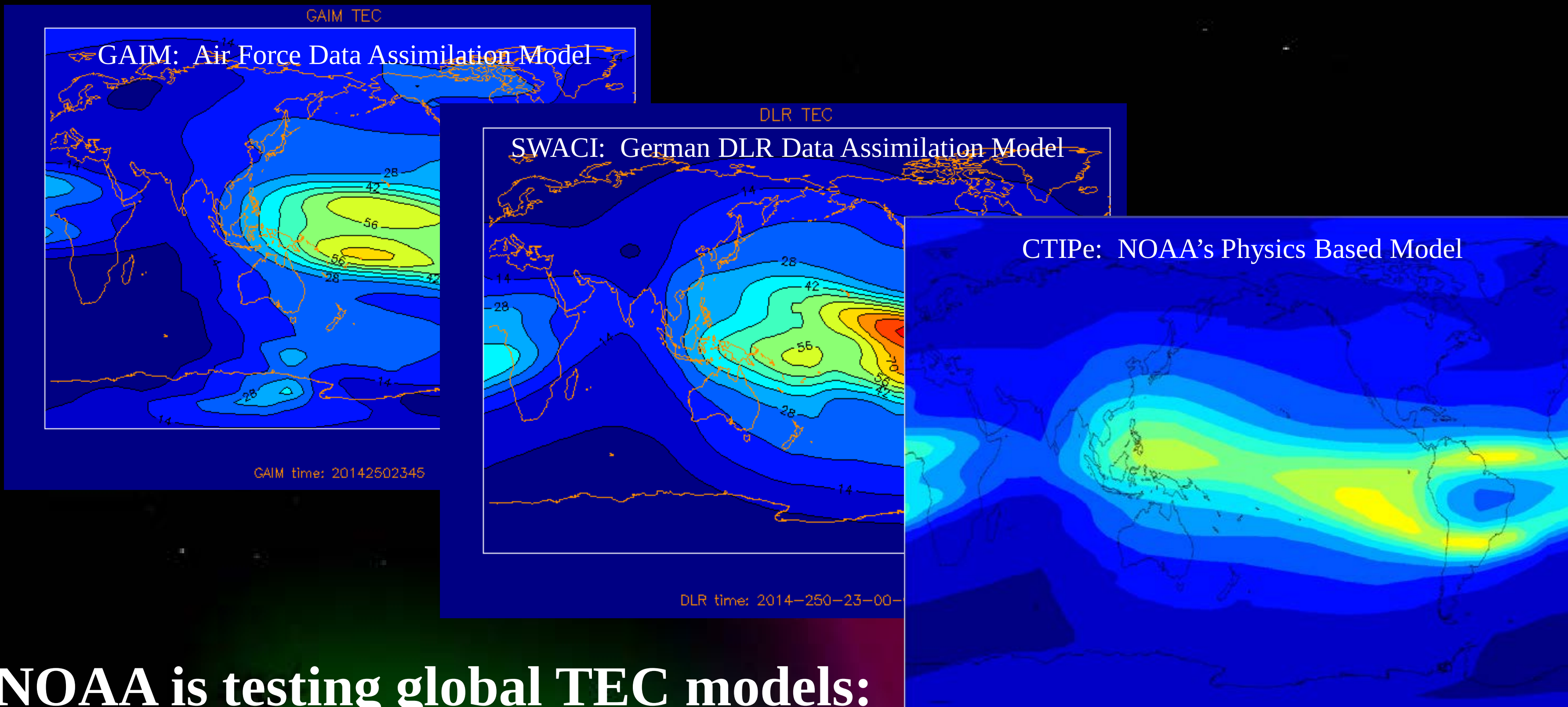
Specification of ionosphere/thermosphere conditions that lead to GPS/GNSS errors and outages

- **Rate Of TEC Index (ROTI) provides dual-frequency GPS users with estimates of scintillation**
- **NOAA SBIR: Partner with *Propagation Research Associates* to develop maps of scintillation for dual-frequency GPS error based on ground-based GPS receivers**
- **Test Product in 2016**



ROTI: A Real-time Map of GPS Scintillation Likelihood

Developing Global Specification Product



NOAA is testing global TEC models:

- **Air Force GAIM**
- **DLR SWACI**
- **NOAA CTIPe available at http://helios.swpc.noaa.gov/ctipe/**

Modeling at NOAA – A Sun to Earth Continuum

Partnerships with the Space Weather Research Community

Solar/Solar Wind

Magnetosphere/
Ionosphere

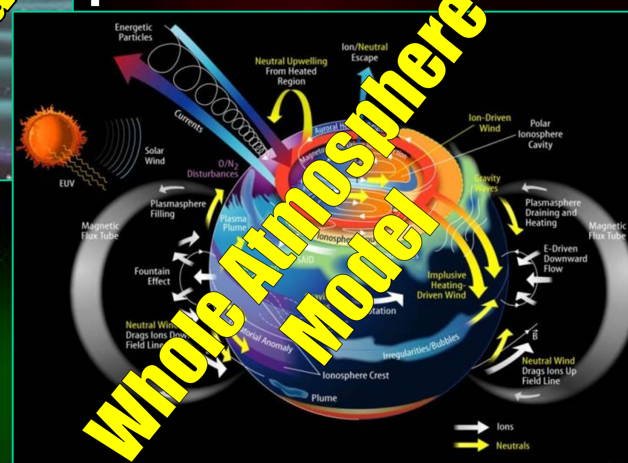
WSA-Enlil

Space Weather Modeling Framework-Geospace

Currently in
Operations

2016

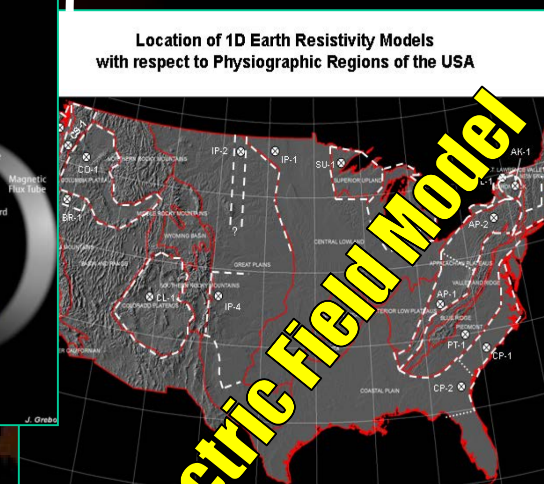
Ionosphere/
Atmosphere



Whole Atmosphere Model

2018

Earth's surface

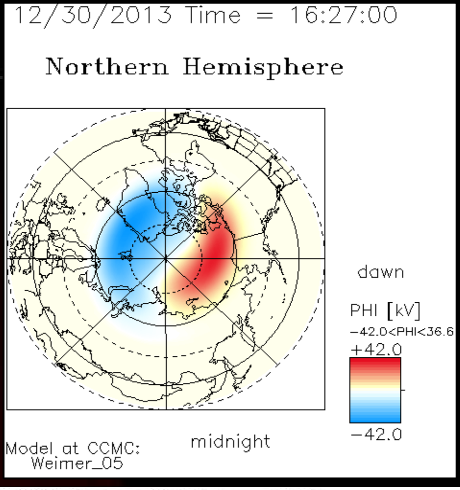


Electric Field Model

2016

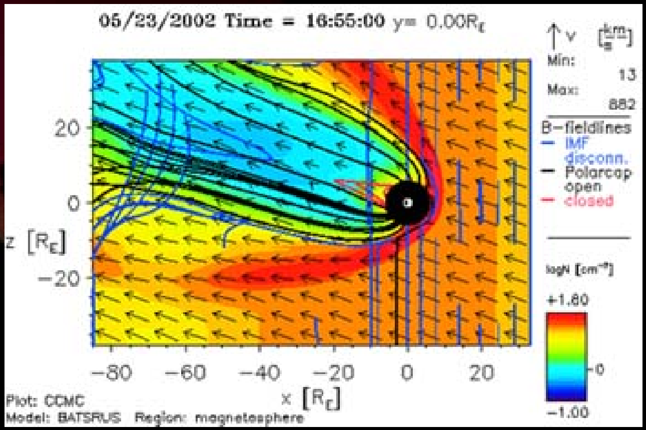
Magnetosphere/Ionosphere

- In partnership with Community Coordinated Modeling Center, Geospace models identified for transition to operations:
  - *U. of Michigan Space Weather Modeling Framework - Full physics-based magnetohydrodynamic (MHD) model*



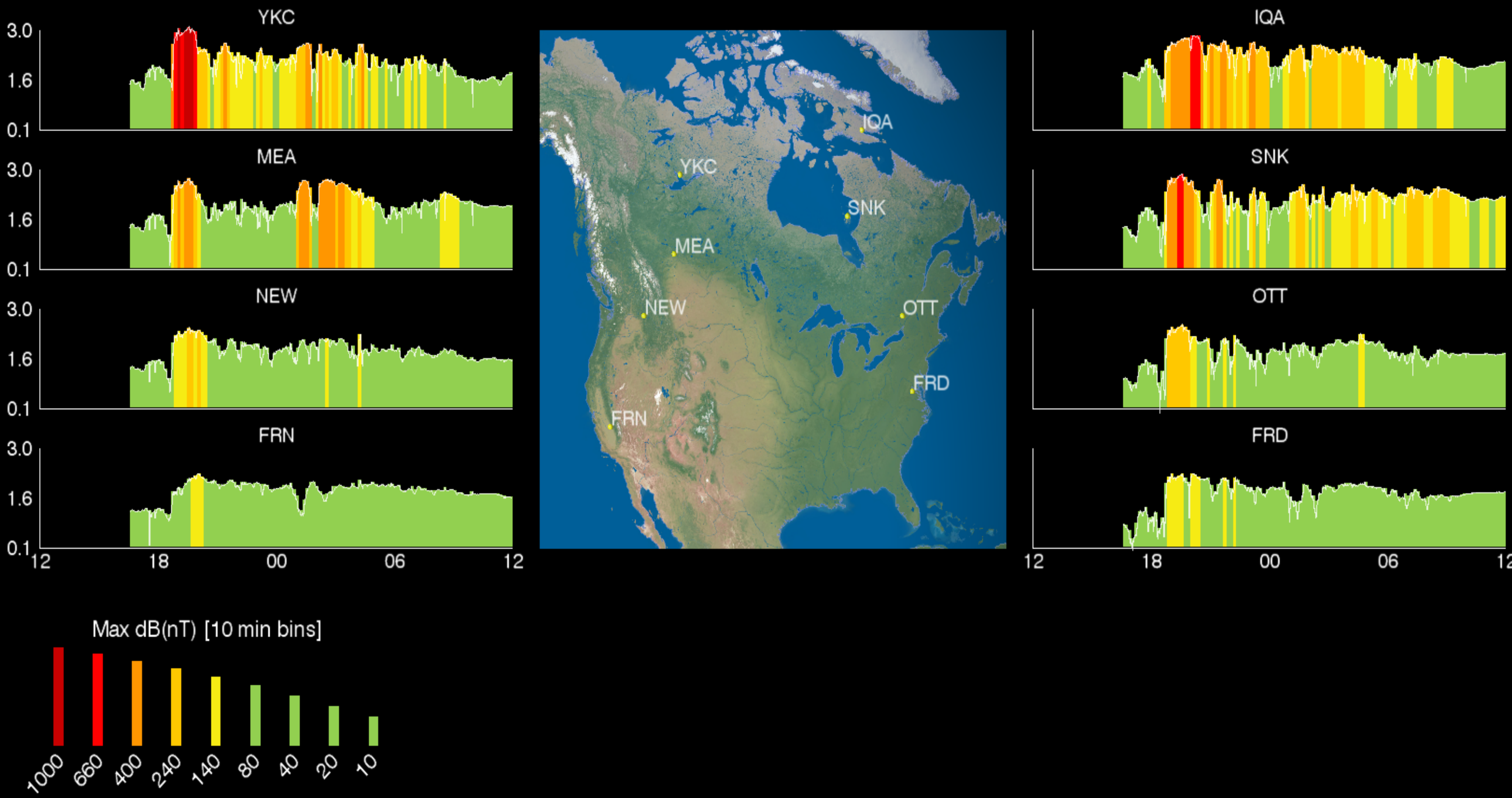
- Provide regional specification and short-term forecasts of geomagnetic conditions

Transition complete in 2016



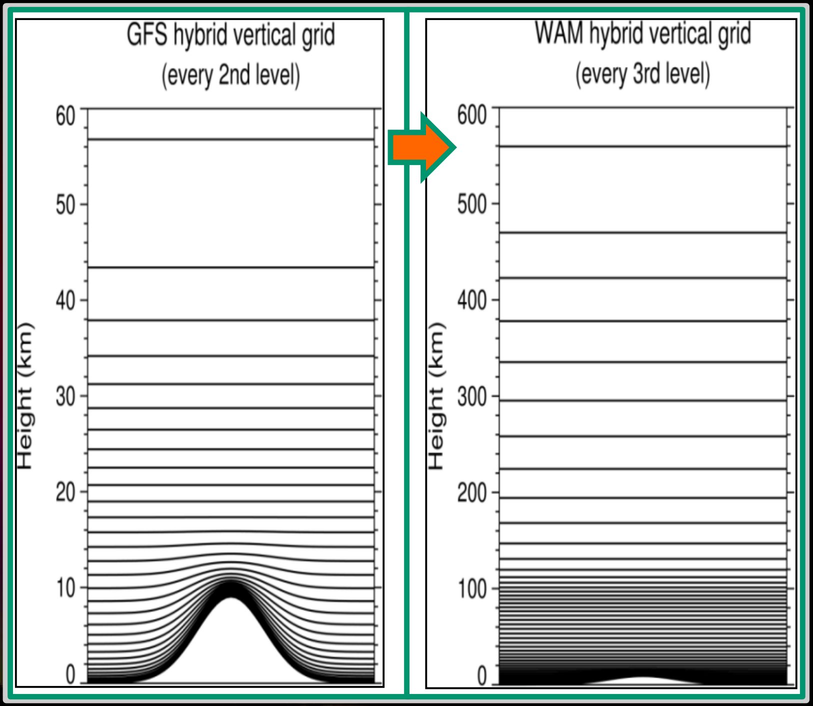
Example Geospace Model Output

SWMF Geospace : Regional dB 22nd-23rd June 2015
North American Sector



Ionosphere/Atmosphere

- ✓ Implementing the Integrated Dynamics in Earth's Atmosphere (IDEA)/Whole Model (WAM) with University of Colorado
- ✓ Multiyear project to raise the top of operational GFS to 600km
- ✓ Couples ionosphere/plasmasphere prediction capabilities, with current weather prediction model
- ✓ Predicts lower atmosphere impact on ionospheric (and vice versa)



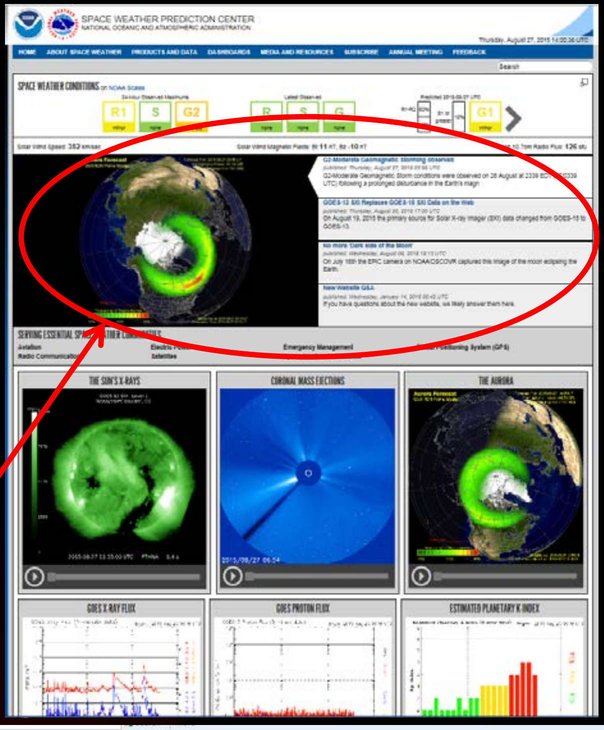
Expected benefits:

- ✓ Improved forecasts/lead times for ionospheric conditions that can disrupt GPS & communications
- ✓ Improved terrestrial forecasts from upper atmosphere coupling

Transition complete by 2017

Information Dissemination

- Phone Contact for Critical Stakeholders: NASA, Commercial Airlines, Power Generation and Distribution, FEMA, etc.
- Product Subscription Service: Email-based, no cost subscription service open to all
- Website: Data, products, and models all available there. Tops News heading that will provide updates for elevated space weather
- Facebook: Active updates and education, <u>secondary to official product dissemination means</u>. Twitter in work.
- Active Media Support during significant events



NOAA Space Weather Prediction Center

Boulder, Colorado

www.spaceweather.gov


Backup Slides

Satellite Observations

DSCOVR

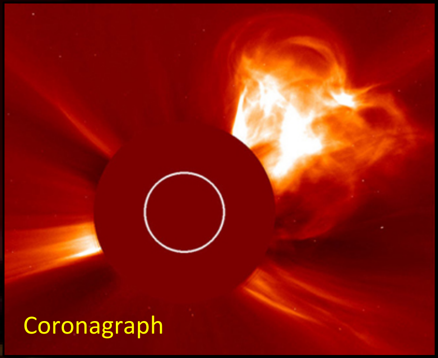
Operationally dedicated – Ensure continuity of solar wind measurements: Launch January, 2015

GOES-R

NOAA's next-generation of Geostationary Operational Environmental Satellites: Continuity of existing measurements, updated imager, inclusion of heavy ion measurements: Launch 2016

Operational Coronagraph

- High priority to replace ESA-NASA SOHO/LASCO Coronagraph
- RFI issued in Feb 2014 for DSCOVR follow-on… Combines coronograph and in situ mag/plasma



L5 observation would improve forecasting