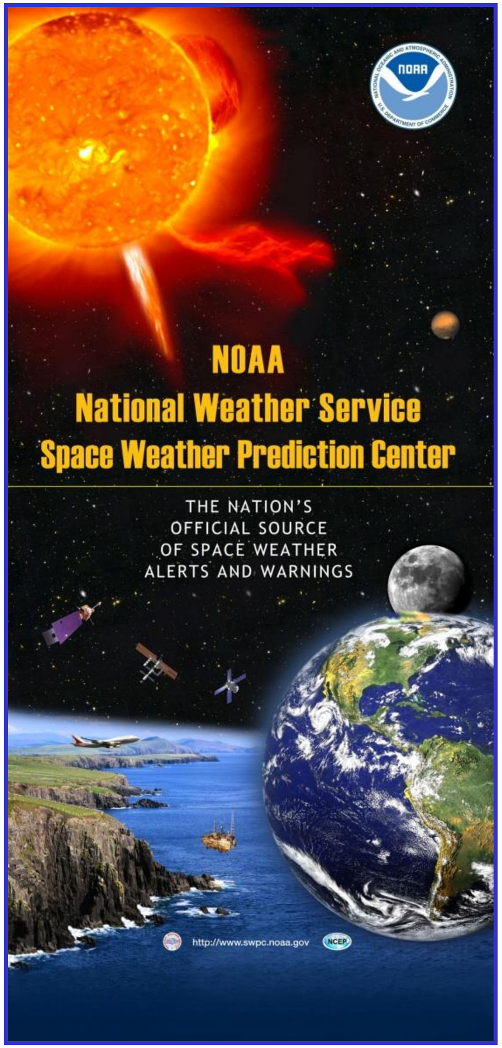
# Geomagnetic Services:
## Research Needed to Fill Operational Gaps




Outline:

- Historical Lessons and Session Goal
- The Geomagnetic Environment
- Current Services and Products
- Potential New Products
- Customer Requirements
- Research Needed to fill Operational Gaps

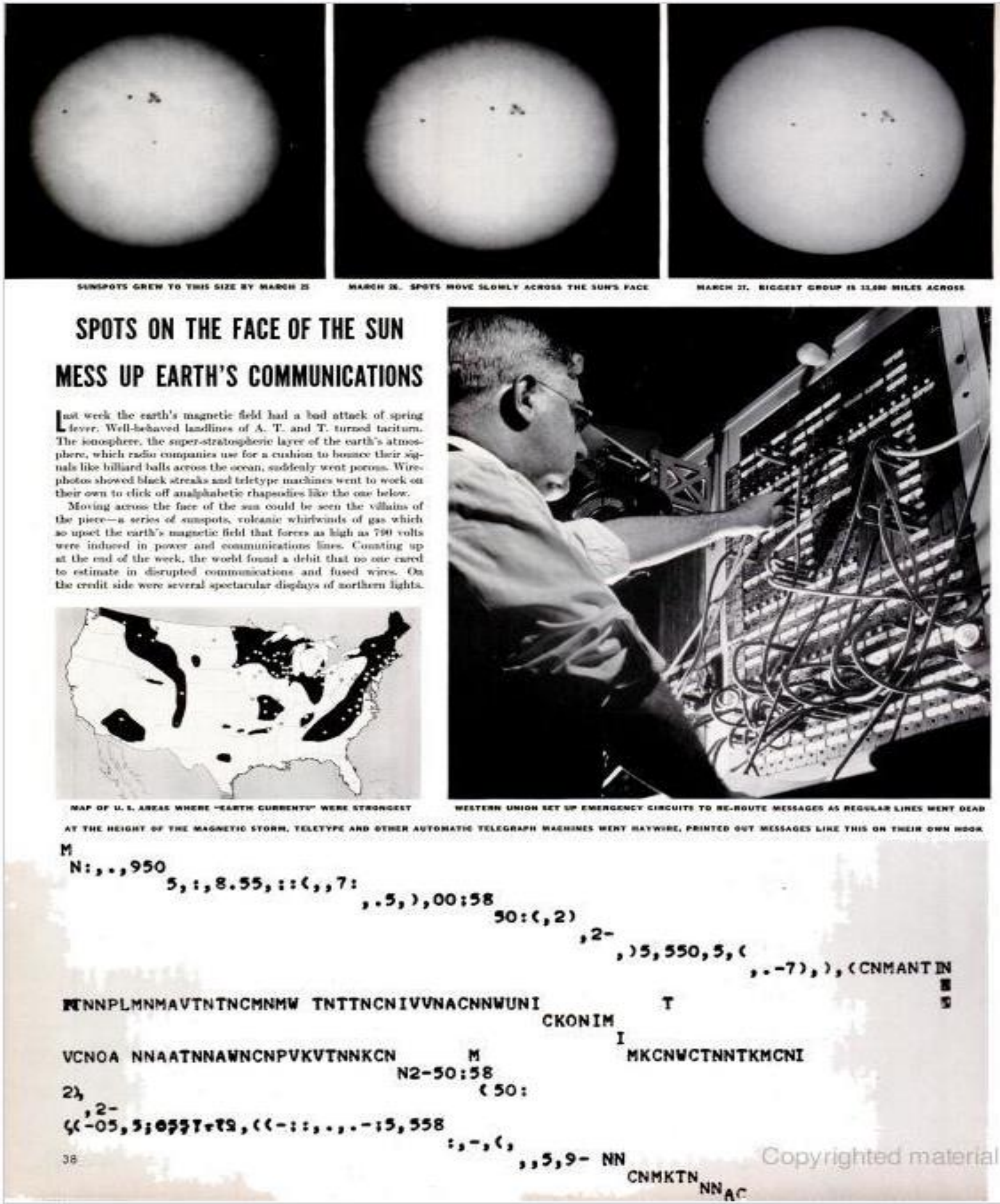
Acknowledgments: Balch ,Doggett, Evans, Kunches, Marshall, Murtagh, Onsager, Rutledge, Steenburgh

**Howard J. Singer, NOAA Space Weather Prediction Center**
Space Weather Workshop, Boulder CO, April 17, 2013

*Safeguarding Our Nation's Advanced Technologies*

# Space Weather: Societal and Economic Impact

- March 25, 1940
- Large Geomagnetic Storm
- Western Union set up emergency circuits to re-route messages as regular lines went dead.
- Telegraph lines went haywire.
- Geospace models in operations will help to protect similar, but modern, vital services



SUNSPOTS GREW TO THIS SIZE BY MARCH 25

MARCH 26. SPOTS MOVE SLOWLY ACROSS THE SUN'S FACE

MARCH 27. BIGGEST GROUP IS [illegible] MILES ACROSS

## SPOTS ON THE FACE OF THE SUN MESS UP EARTH'S COMMUNICATIONS

Last week the earth's magnetic field had a bad attack of spring fever. Well-behaved landlines of A. T. and T. turned taciturn. The ionosphere, the super-stratospheric layer of the earth's atmosphere, which radio companies use for a cushion to bounce their signals like billiard balls across the ocean, suddenly went porous. Wirephotos showed black streaks and teletype machines went to work on their own to click off analphabetic rhapsodies like the one below.

Moving across the face of the sun could be seen the villains of the piece—a series of sunspots, volcanic whirlwinds of gas which so upset the earth's magnetic field that forces as high as 790 volts were induced in power and communications lines. Counting up at the end of the week, the world found a debit that no one cared to estimate in disrupted communications and fused wires. On the credit side were several spectacular displays of northern lights.

MAP OF U. S. AREAS WHERE "EARTH CURRENTS" WERE STRONGEST

WESTERN UNION SET UP EMERGENCY CIRCUITS TO RE-ROUTE MESSAGES AS REGULAR LINES WENT DEAD

AT THE HEIGHT OF THE MAGNETIC STORM, TELETYPE AND OTHER AUTOMATIC TELEGRAPH MACHINES WENT HAYWIRE, PRINTED OUT MESSAGES LIKE THIS ON THEIR OWN HOOK

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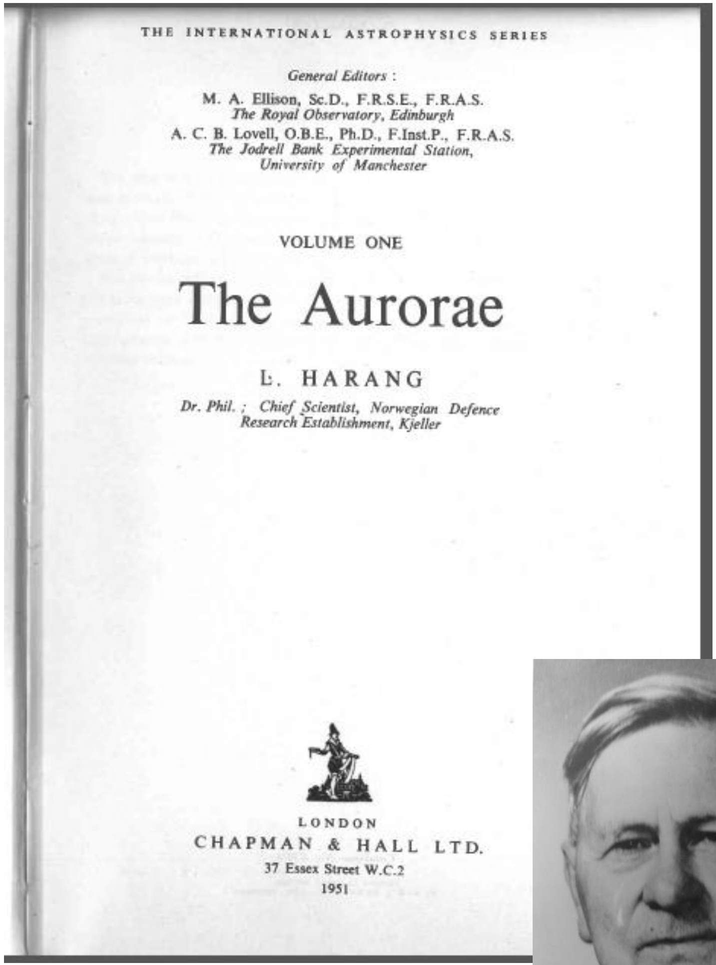
Life Magazine, vol 8, no 15, page 38, April 8, 1940.

# Space Weather: Societal and Economic Impact

"On the lines to Syltefjord and Makkaur all fuses (4 amp.) burnt through. Sparks and permanent arcs were formed in the coupling racks and watch had to be kept during the night to prevent fire from breaking out”

Log of the Vardø Station
Norwegian Telegraph Service
24 March, 1940


THE INTERNATIONAL ASTROPHYSICS SERIES

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VOLUME ONE

The Aurorae

L. HARANG

*Dr. Phil. ; Chief Scientist, Norwegian Defence Research Establishment, Kjeller*

LONDON
CHAPMAN & HALL LTD.
37 Essex Street W.C.2
1951

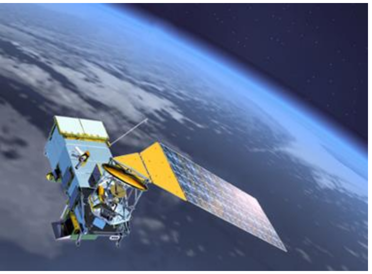
The Aurorea, Leiv Harang, 1951.

Brought to my attention by D. Evans

# Geomagnetic Services: Research Needed to Fill Operational Gaps

# Session Goal

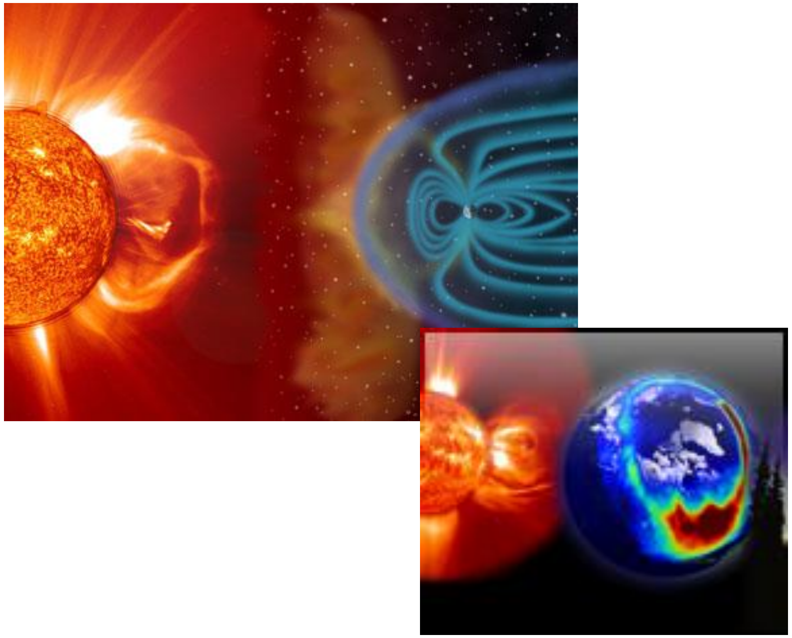


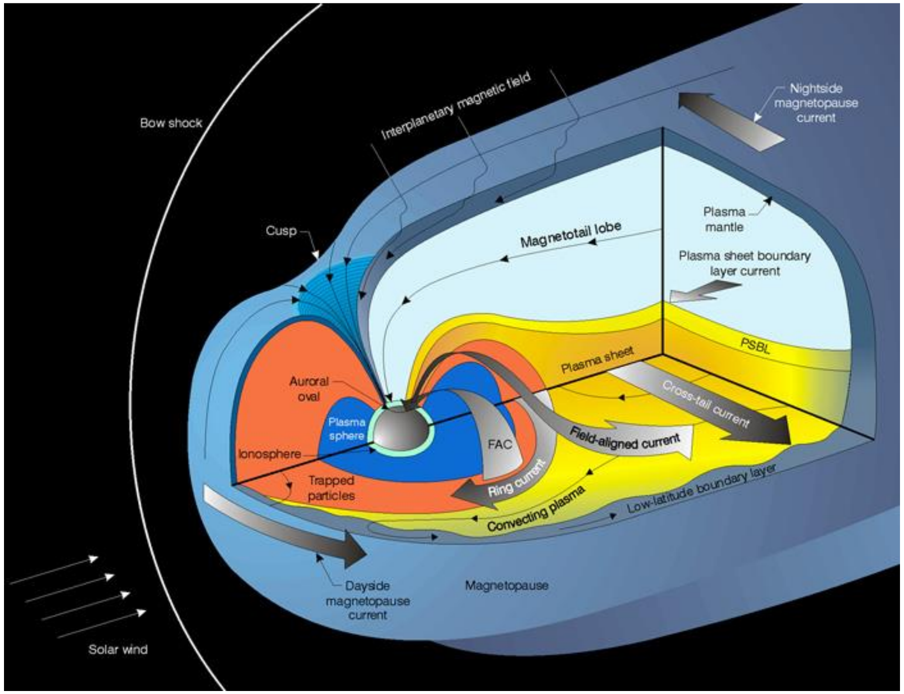



- SWPC provides a diverse suite of geomagnetic services and products
- Services need to continually improve to meet increased customer demand
- **Therefore, today’s goal is for operations to identify where research is needed to provide new understanding, tools, techniques, and models that can fill the gap between services provided today and those needed now and in the near future?**
- Following this introduction, hear from a user:
  Don Watkins, Bonneville Power Administration
- Then, a panel discussion with audience participation:
  - Jenn Gannon, USGS
  - Antti Pulkkinen, NASA
  - Don Watkins, Bonneville Power
  - Michael Wiltberger, NCAR HAO

# What is our Geomagnetic Environment?

- Geomagnetic services are needed to support humans and technological systems that operate in the **region between Earth's surface and the interface between Earth's magnetic field and the solar wind**.
- **Solar influences, such as solar radiation, solar energetic particles, the solar wind, high-speed streams, and coronal mass ejections all affect the geomagnetic environment**, including its ionized matter, radiation belts, and current systems; and cause effects such as storms, substorms and ionospheric disturbances.

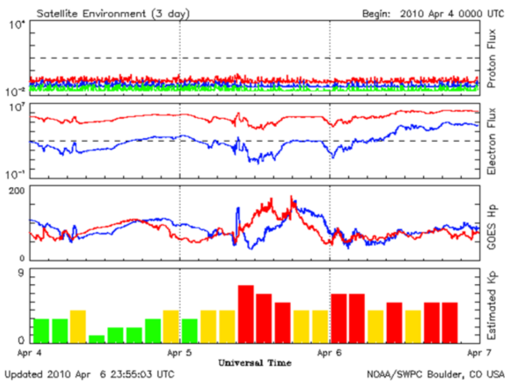




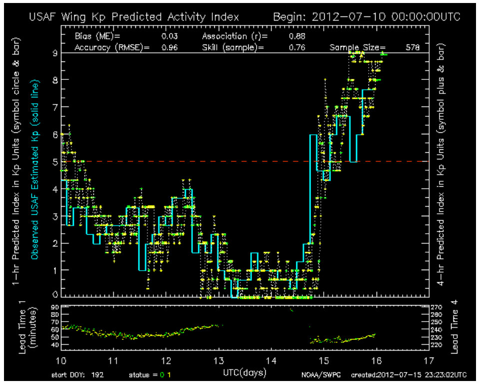
# Today's Geomagnetic Products and Services

## Data, Tools and Models Inform Forecasts and Products

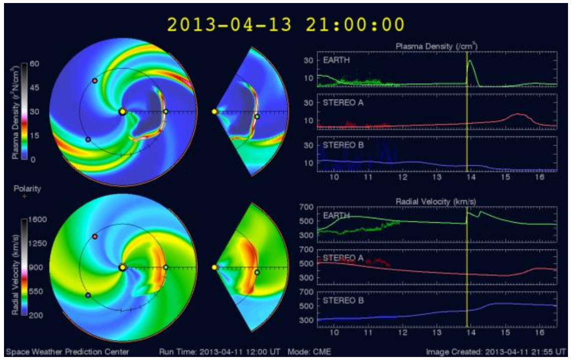
### Satellite Environment




### Wing Kp




### WSA Enlil




## SWPC Forecast Products and Focus

| Products | Cadence of Updates | Focus |
|---|---|---|
| Watches, Warnings, and Alerts | As Conditions Change | Operations, Life and Property |
| WWV Text Forecast | 3 hours | Drives Tailored Products |
| 3 Day Forecast | 12 hours | General, Public, Media |
| Forecast Discussion | 12 hours | Technical, Scientific |
| SGARF | 24 hours | Joint NOAA/DoD |

Credit: D. Marshall, Forecaster

# Space Weather Scales

- **3 Categories**
  - **Geomagnetic Storms**

    (CMEs)
  - **Solar Radiation Storms**

    (Particle Events)
  - **Radio Blackouts**

    (Solar Flares)

http://swpc.noaa.gov

## NOAA Space Weather Scales

| Category: Scale | Category: Descriptor | 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.<br>Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites.<br>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<br>(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.<br>Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems.<br>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<br>(60 days per cycle) |
| G 3 | Strong | Power systems: voltage corrections may be required, false alarms triggered on some protection devices.<br>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.<br>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<br>(130 days per cycle) |
| G 2 | Moderate | Power systems: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage.<br>Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions.<br>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<br>(360 days per cycle) |
| G 1 | Minor | Power systems: weak power grid fluctuations can occur.<br>Spacecraft operations: minor impact on satellite operations possible.<br>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<br>(900 days 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)

| Scale | Descriptor | Effect | Physical measure | Average Frequency |
|---|---|---|---|---|
| **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. ***<br>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.<br>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.***<br>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.<br>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.***<br>Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely.<br>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.***<br>Satellite operations: infrequent single-event upsets possible.<br>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.<br>Satellite operations: none.<br>Other systems: minor impacts on HF radio in the polar regions. | 10 | 50 per cycle |

* Flux levels are 5 minute averages. Flux in particles·$s^{-1}$·$ster^{-1}$·$cm^{-2}$ 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.

| Scale | Descriptor | Effect | Physical measure | Average Frequency |
|---|---|---|---|---|
| **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.<br>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<br>($2x10^{-3}$) | 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.<br>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<br>($10^{-3}$) | 8 per cycle<br>(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.<br>Navigation: Low-frequency navigation signals degraded for about an hour. | X1<br>($10^{-4}$) | 175 per cycle<br>(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.<br>Navigation: Degradation of low-frequency navigation signals for tens of minutes. | M5<br>($5x10^{-5}$) | 350 per cycle<br>(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.<br>Navigation: Low-frequency navigation signals degraded for brief intervals. | M1<br>($10^{-5}$) | 2000 per cycle<br>(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.

URL: *www.sec.noaa.gov/NOAAScales* March 1, 2005

# Geomagnetic Storm Scales

| Category | | Effect | Physical measure | Average Frequency (1 cycle = 11 years) |
|---|---|---|---|---|
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| G 3 | Strong | Power systems: voltage corrections may be required, false alarms triggered on some protection devices.<br>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.<br>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<br>(130 days per cycle) |
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* 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 Storm Warning** issued upon detection of CME at L1 on ACE

- 15-45 MIN forecast

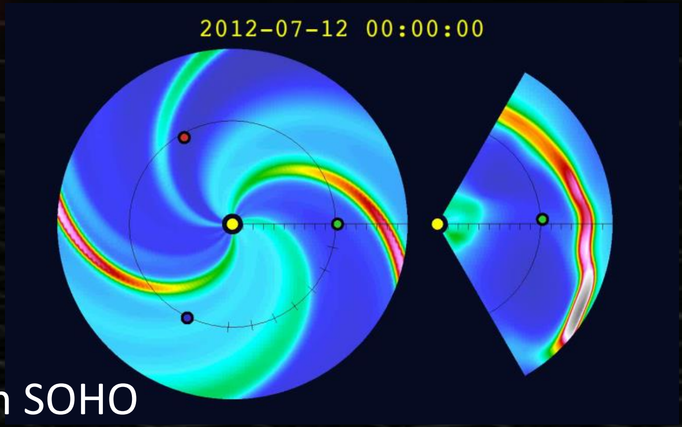
**L1**

**Geomagnetic Storm Alert** issued upon onset of geomagnetic storm using USGS magnetometers

- Current condition

**Geomagnetic Storm Watch** issued upon detection of Earth-directed coronal mass ejection (CME) on SOHO LASCO and STEREO coronagraphs

- 1-3 day forecast



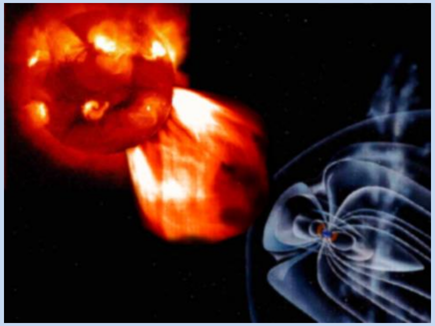

CME measurements from SOHO and STEREO drive the Enlil model which predicts arrival time

# Potential New Geomagnetic Services Product Geospace Model

- Goal: Evaluate Geospace models (MHD and empirical) to determine which model(s) are ready for transition to operations
- Focus: Regional K and dB/dt (important to electric utilities)
- Partnership: Evaluation at NASA/Goddard CCMC working with SWPC, modelers and science community

Select Models and Events → Establish Metrics → Model-Data Comparisons → CCMC Reports to SWPC

Model(s) selection (FY13) by SWPC based on CCMC reports, internal and external advice, and following considerations:



Solar Influences on Geospace Predicted with Geospace Models using Solar Wind Input

- Strategic Importance
- Operational Significance
- Implementation Readiness
- Cost to Operate, Maintain, and Improve

# Potential New Geomagnetic Services Product: Regional Electric Field

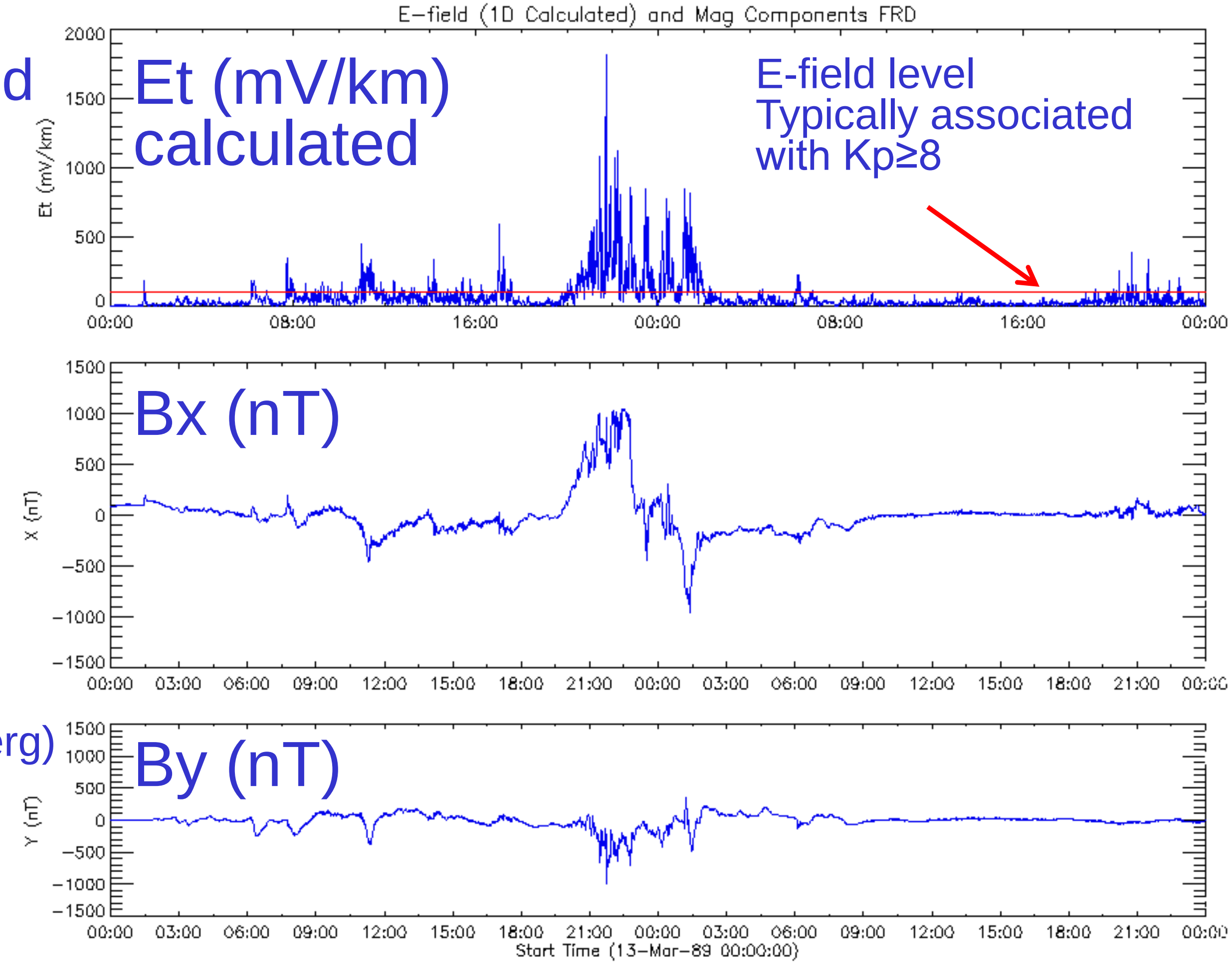
- Electric field calculated from ground-based observed magnetic variations using 1-D ground conductivity model
- Collaborative activity involving:

USGS (Gannon, Bedrosian)

SWPC (Balch)

NRCAN (Trichtchenko, Fernberg)

Station FRD




March 13, 1989

# Example of Evolving Customer Requirements

| Electric Utilities | | | |
|---|---|---|---|
| Geoelectric Field Vector | 6 hr. forecast, updated hourly | Various Power Companies | To know the key ingredient that plays into the GIC at selected points, is a critical parameter for the industry. To do this requires local dB/dt and geologic conductivities. |
| K-7 Geomagnetic Storm Warnings | Minutes to hours Operators want as much lead time as possible, but any lead time is considered useful | North America Electricity Reliability Corp.<br><br>Midwest Independent System Operator<br><br>Electricity Reliability Coordinators | The Midwest Independent System Operator receives the K-index forecast. If the index is K-7 or higher, MISO notifies all NERC reliability coordinators concerning the level and expected duration of the specific event. These forecasts are shared with all power system operating entities throughout North America so that those power systems that are particularly susceptible |

SWPC Customer Requirements for Space Weather Services

See: http://www.swpc.noaa.gov/Services/index.html

# Some Topics for Discussion on: Research Needed to fill Operational Gaps in Geomagnetic Services

- **Solar Wind Drivers (Observations and models):** lead time, accuracy, observation location and instrumentation; model improvements
- **Geospace Response (Observations and models):** What model improvements are needed? E.g. in MHD, empirical and GIC models? What sensitivity studies are needed and what limits model accuracy? What observations are missing? What data are already available in real-time or could be made available? How are data and model results best presented to forecasters? Are there ways to improve coordination among the operations, research, and commercial services to better serve customers? How do models perform for extreme events?
- **Can we follow a CME from sun to Earth?**
- **Can we predict Bz with longer lead time than provided by L1?**
- **Can we identify data and models that already exist that can provide improved services today? What more needs to be done to make them ready for operations?**
- **-- and more….**