# Geomagnetic Disturbances (GMDs) – History and Prediction

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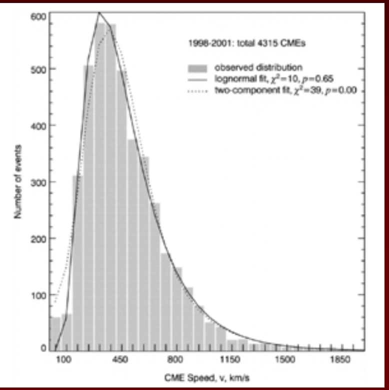
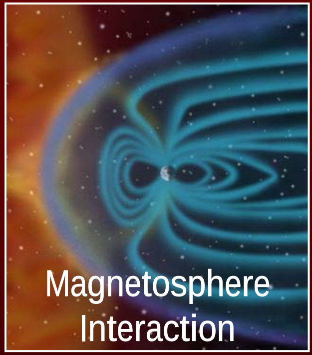
# Components of a GMD (Heliophysics / Space Weather)


## Solar Activity / Solar Wind

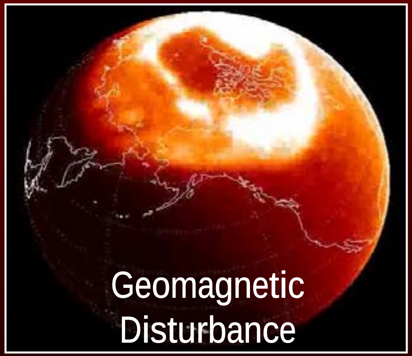
- Sun spots (~11 year cycle)
- Solar flares (radiation burst)
- Coronal mass ejections [CMEs] (eruption of magnetized plasma)




Yurchyshyn, et al., Astrophysical Journal (2005)




http://www.nasa.gov

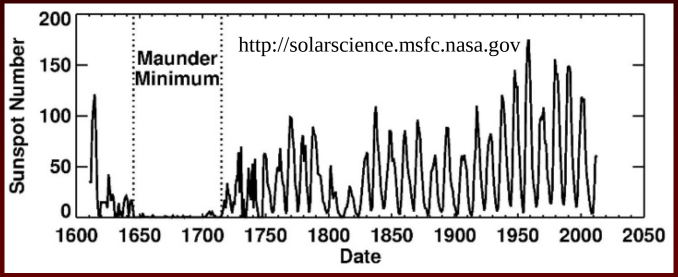



## Geomagnetic Disturbance

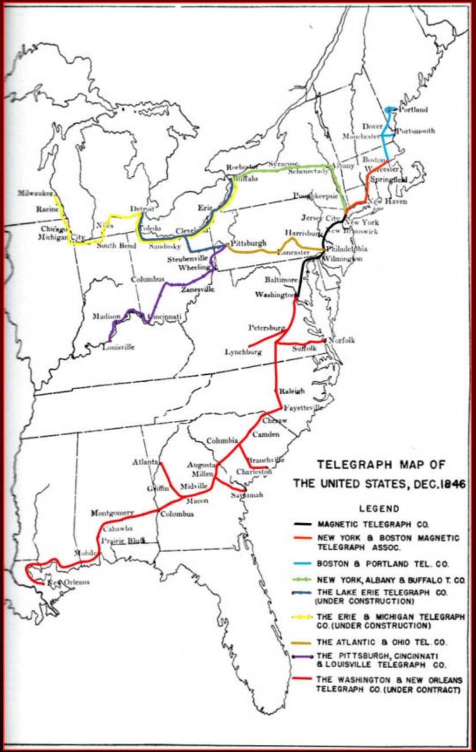
- Magnetosphere disturbed by solar flare or CME
- Electric currents produced in the magnetosphere / ionosphere (aurora)
- Time-changing geomagnetic and geoelectric fields (radiation seen in 8 minutes, <1 to 9 days for CME)

# GMD Early History

- Sunspot cycle ~ 11 years
  Cycles vary from 9 to 14 years
  Cycle amplitude variation
  Note the “Maunder Minimum”




- Intense GMDs can be pinpointed in time by correlating high sunspot activity with intense auroral displays (as far back as 210 BC).
- First measured GMD effect – [Berlin (1806-07)]
  Alexander von Humbolt (geographer/explorer) noted erratic magnetic compass readings during auroral events
- First commercial telegraph - 1838
  Transcontinental connection - 1861




Thompson, Robert Luther. Wiring a Continent: The History of the Telegraph Industry in the United States, 1832-1866

# Space Weather Prediction / History

## (NOAA Space Weather Scales)

| Space Weather Scale | Description | Minor | Moderate | Strong | Severe | Extreme |
|---|---|---|---|---|---|---|
| Geomagnetic Storms | A measure of the disturbances in the geomagnetic field | G1 | G2 | G3 | G4 | G5 |
| Solar Radiation Storms | A measure of radiation levels based on the number of energetic particles | S1 | S2 | S3 | S4 | S5 |
| Radio Blackouts | A measure of disturbances in the ionosphere caused by solar X-ray emissions | R1 | R2 | R3 | R4 | R5 |

- Space Weather Alerts Page (Alerts, watches, warnings)
- Electric Power Community Dashboard (Planetary K index, solar wind prediction, auroral forecast, coronagraph, space weather overview)
- 3-Day Forecast (Space weather scales)

# Geomagnetic Activity Indices

- Ring Current Intensity – Equatorial B (Dst)
- Auroral Electrojet Intensity (AE, AU, AL, A0)
- Planetary Magnetic Field Variation (Kp, Ap, G)

| Scale | Description | Possible Effects |
|---|---|---|
| G1 | Minor | Weak power grid fluctuations |
| G2 | Moderate | Voltage alarms at high latitudes, transformer damage from long duration storms |
| G3 | Strong | Voltage corrections required, false alarms triggered on some protection devices |
| G4 | Severe | Widespread voltage control problems, key assets tripped out from the grid |
| G5 | Extreme | Widespread voltage control and protective system problems, complete collapse or blackouts of grid systems, transformer damage |

| Kp | Ap | G |
|---|---|---|
| 0 | 0 | – |
| 0+ | 2 | – |
| 1− | 3 | – |
| 1 | 4 | – |
| 1+ | 5 | – |
| 2− | 6 | – |
| 2 | 7 | – |
| 2+ | 9 | – |
| 3− | 12 | – |
| 3 | 15 | – |
| 3+ | 18 | – |
| 4− | 22 | – |
| 4 | 27 | – |
| 4+ | 32 | – |
| 5− | 39 | 1 |
| 5 | 48 | 1 |
| 5+ | 56 | 1 |
| 6− | 67 | 2 |
| 6 | 80 | 2 |
| 6+ | 94 | 2 |
| 7− | 111 | 3 |
| 7 | 132 | 3 |
| 7+ | 154 | 3 |
| 8− | 179 | 4 |
| 8 | 207 | 4 |
| 8+ | 236 | 4 |
| 9− | 300 | 5 |
| 9 | 400 | 5 |

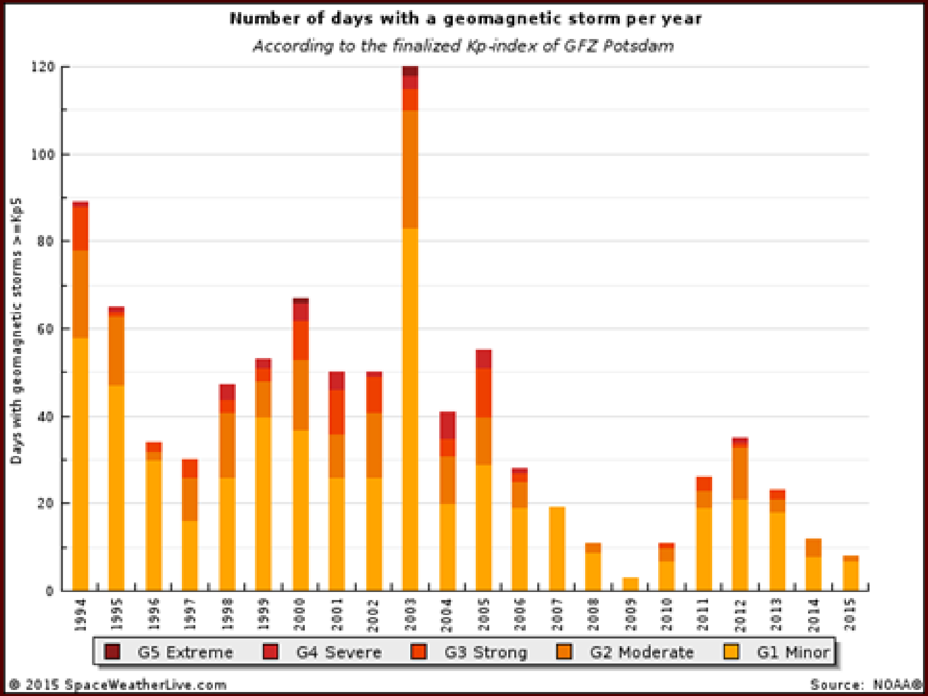
# GMD Prediction Via Satellite

- Satellites monitoring the solar wind (high energy particles) in order to provide early warning of an approaching CME
  - Solar and Heliospheric Observatory (SOHO)
  - Advanced Composition Explorer (ACE)
  - Solar Terrestrial Observatory (STEREO)
  - Geostationary Operational Environmental Satellite (GOES)
  - Polar Operational Environmental Satellite (POES)
  - Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC)




http://www.nasa.gov

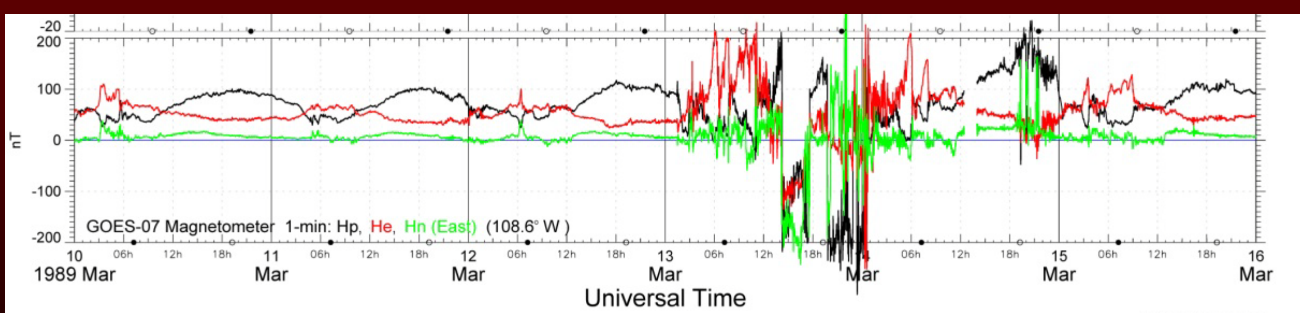
# GMD Strength and Frequency




- GMD frequency exhibits a reasonable correlation to the solar cycle
- The strongest GMD commonly occur off of solar cycle peak.

# Significant GMDs of Note in History

- 28 Aug to 2 Sept 1859 (Carrington Event) – the largest GMD on record, estimated (−800 nT < Dst < −1750 nT), 17.6 hour transit time, combination of two consecutive geomagnetic storms, first ever observation of a solar flare, aurorae observed as far south as Cuba and Hawaii, effects seen worldwide, telegraph systems in US and Europe disabled, spark discharges, fires
- 13 March 1989 (Quebec Blackout Storm) – 3.5 day transit time, Ap = 246 on 3/13, Dst = −600 nT, aurorae observed as far south as Texas and Florida, 7 Hydro Quebec static VAR compensators tripped improperly due to GIC-induced harmonics, complete grid collapse, power outage in Sweden due to GIC



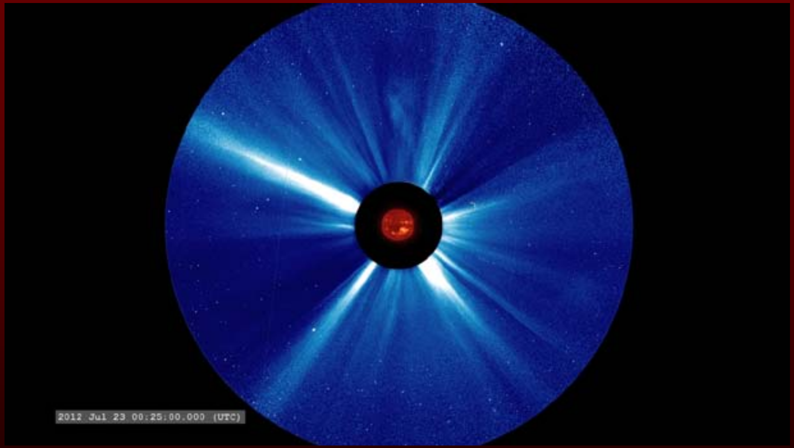

GOES 7 NOAAWeather Satellite Magnetometer Data

# Significant GMDs of Note in History (cont.)

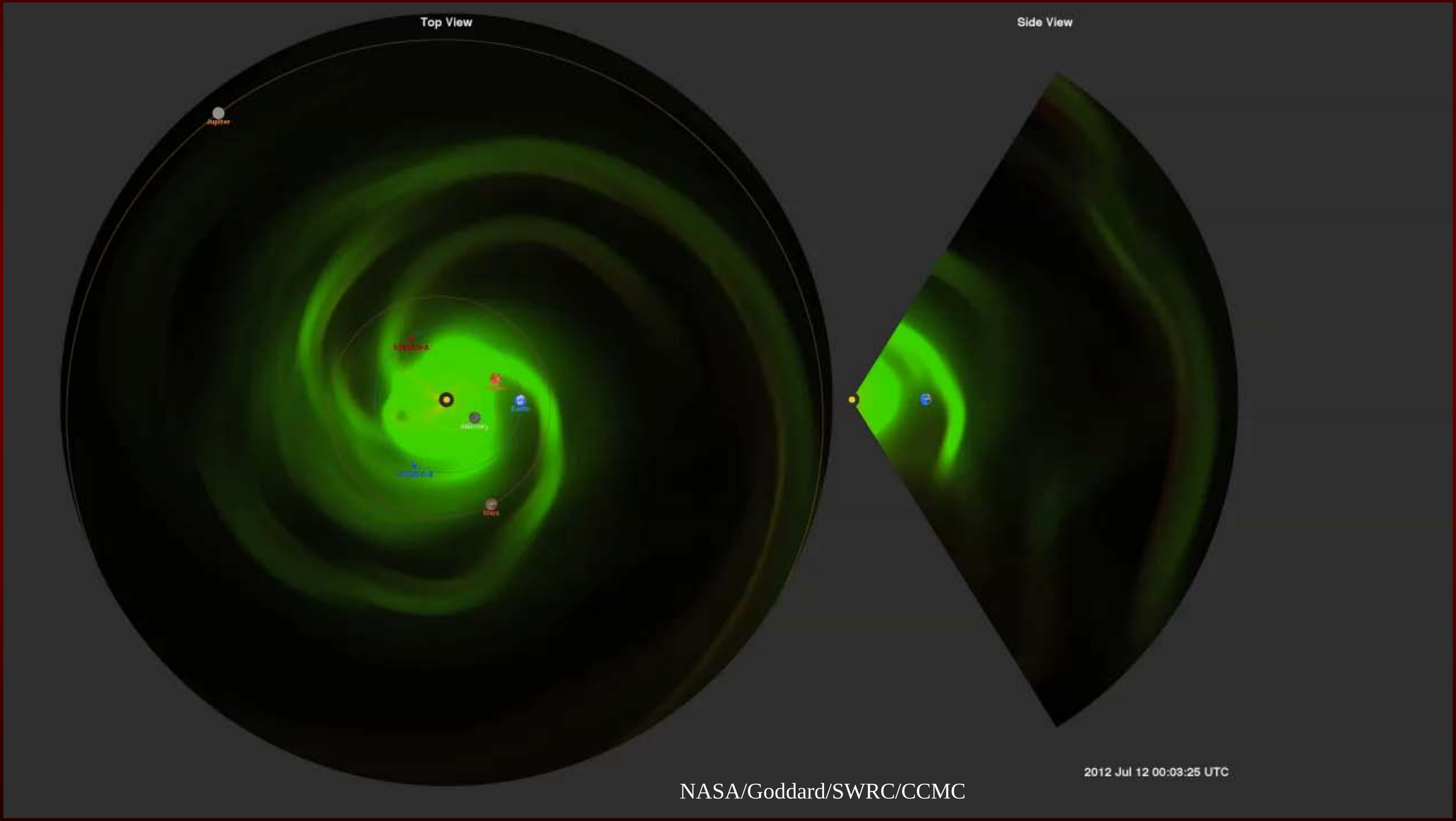
- 29 October 2003 (Halloween Storm) – 19 hour transit time, Ap = 204 on 10/29, Dst = −383 nT, CME/solar flare combination (Nov. 4, one of the most powerful flares ever detected), aurorae over most of North America, Japan's Midori-2 satellite lost due to CME, multiple satellite anomalies due to solar flare
- 23 July 2012 (Carrington-Class Near Miss) – propagation speed comparable to Carrington Event (> 2000 km/s), estimated Dst = −1200 nT, two CMEs separated by 10 to 15 minutes, CMEs would have been directed toward earth had they occurred one week earlier

STEREO A
Coronograph Image

http://svs.gsfc.nasa.gov

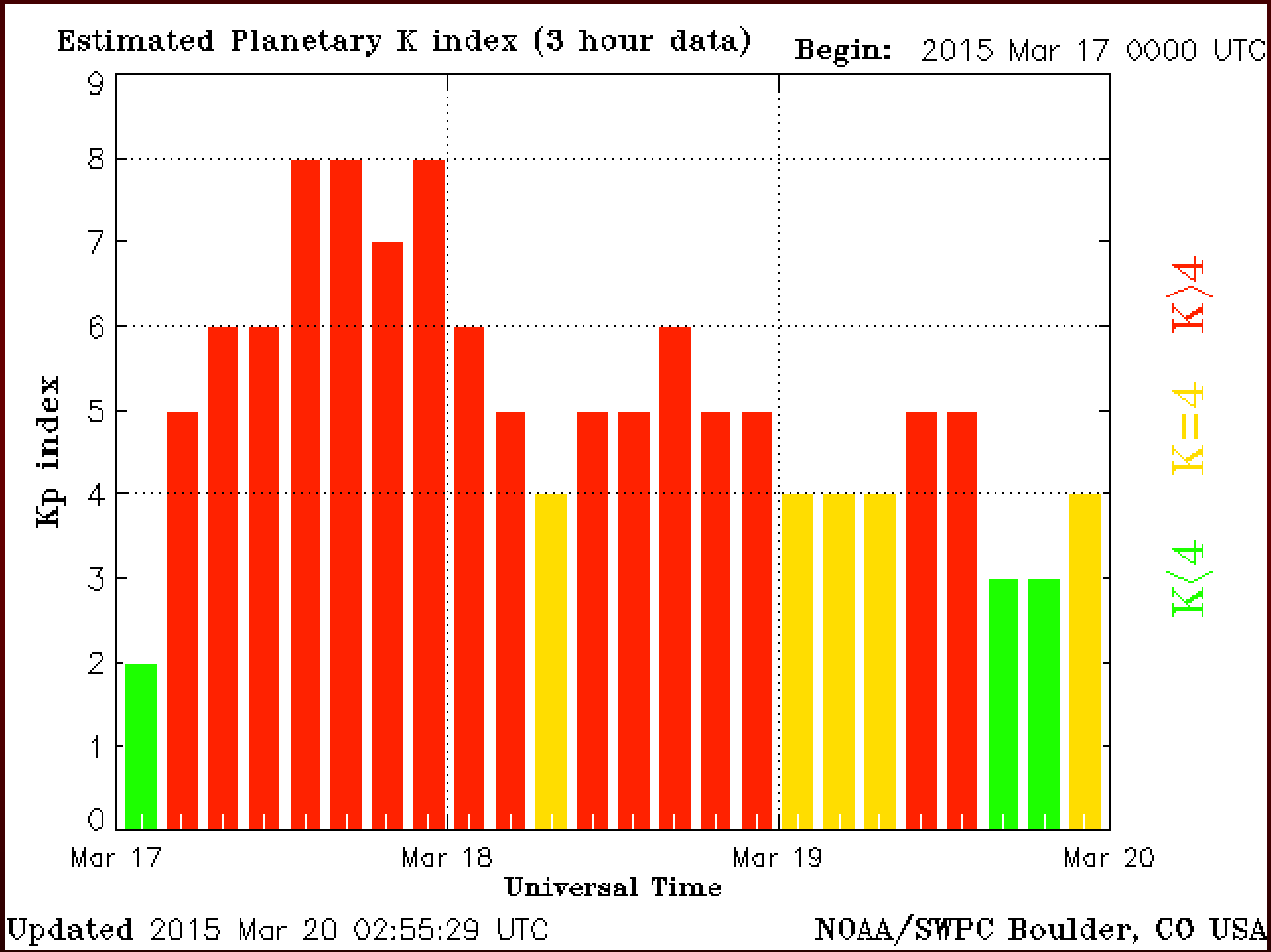


# Carrington Near Miss
## (12 to 27 July 2012)




NASA/Goddard/SWRC/CCMC

# GMD (17-18 March 2015)



# Summary

- Space weather prediction system enhancements are needed:
  - More space-based and ground-based sensor data collection
  - Improved characterization of GMD strengths and frequencies
  - Increased worldwide cooperation in support of space weather infrastructure
- Make significant progress toward CME-to-GIC prediction tool.
  - The geometry and makeup of a CME is complex
  - The interaction of the CME with the magnetosphere and ionosphere is complex
  - The conductivity distribution at depth in the earth is complex
- The current GMD alert system is insufficient
  - Index is global but the resulting GICs are local
  - A 0-5 scale is insufficient to differentiate the effects of GMD events