Geomagnetic Disturbances Electric Power Grid

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Van Allen Probes and AMPERE teams

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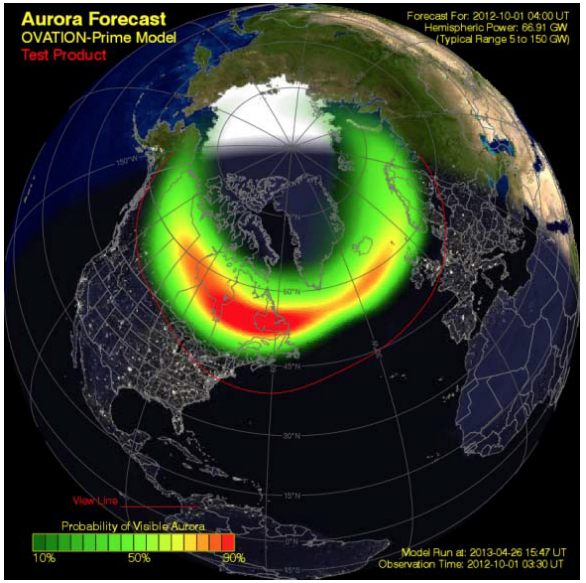
APL
The Johns Hopkins University
APPLIED PHYSICS LABORATORY

Severe Space Weather Issues

- **There are many space weather effects on our advanced technological society**
  - **Radio blackouts and detector/electronic interference/damage from solar flares and radiation**
  - **GPS outages and errors from ionospheric structure and density enhancements**
  - **Airline and other issues of radio communication**
  - **LEO satellite dislocation and drag, debris**
  - **Geomagnetically Induced Currents on conductors**

GIC will be the concentration today

Reports on Impacts of Severe Space Weather on the Electric Power Grid – NRC (2009), Oak Ridge (2010), JASON (2011), Lloyd's (2013)



Power Grid Risk Reports

- **NRC report – Severe Space Weather Events – 2009 NAS**
  - Storms weaker than Carrington-level occurred July 2012 – not Earth bound
  - US infrastructure tightly integrated with electric power
  - Economic impact of prolonged outages
- **Oak Ridge report – Geomagnetic Storms and their impact on the US Power Grid– 2010 Meta-R-319**
  - March 13, 1989 event in Quebec
  - Cycle 19 (1960) through 22 (1995) – high voltage grid increased tenfold
  - Comprehensive simulation modeling of GIC on realistic grid configuration
- **JASON report -11-320 – November 2011 (DHS sponsored)**
  - Model effects of GIC on grid to assess system's vulnerability
  - Install sensors to monitor GIC at key locations of high vulnerability
  - Strengthen current National Space Weather Program
- **Lloyd's 2013: Solar Storm Risk to the North American Electric Grid**
  - Storms weaker than Carrington-level could result in a small number of damaged transformers (around 10-20), but the potential damage to densely populated regions along the Atlantic coast is significant.
  - Insurance policies for business outages – long term power outages would be a major threat and lead to excessive claims

National Research Council Study Report: Severe Space Weather Events – 2009 National Academy of Sciences

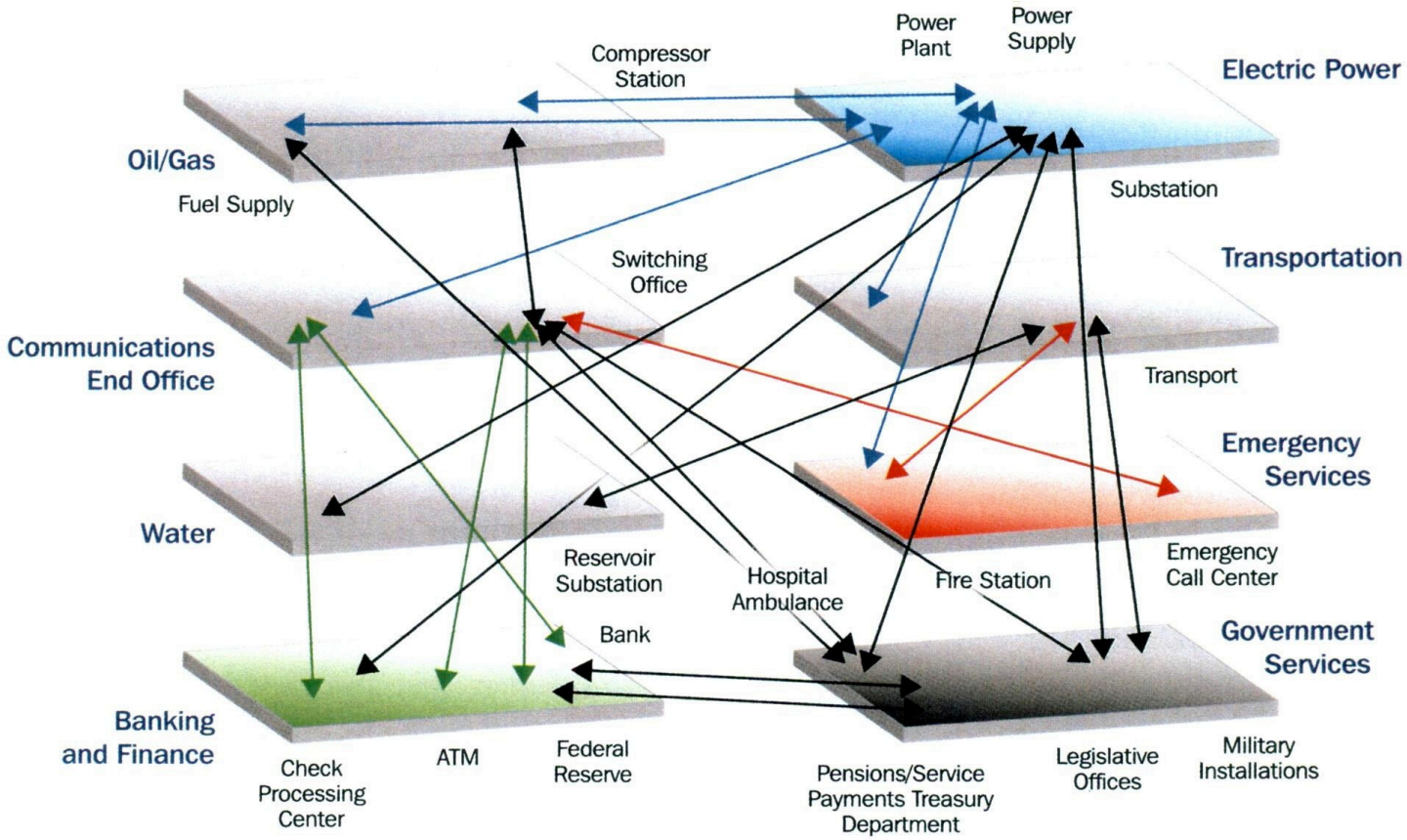
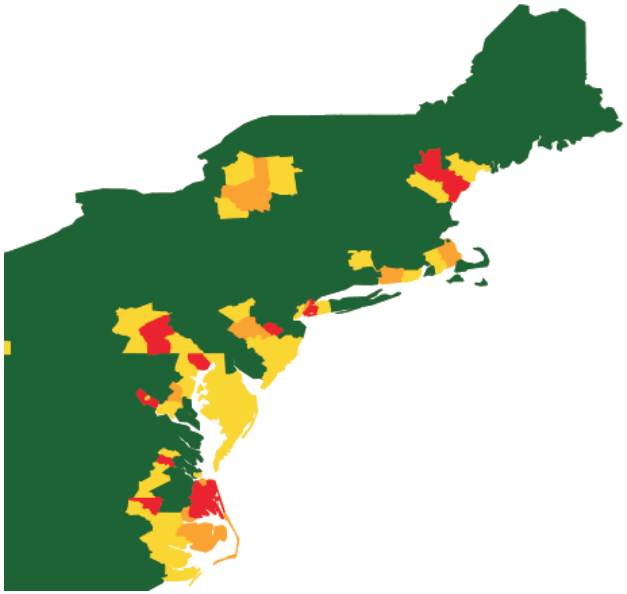
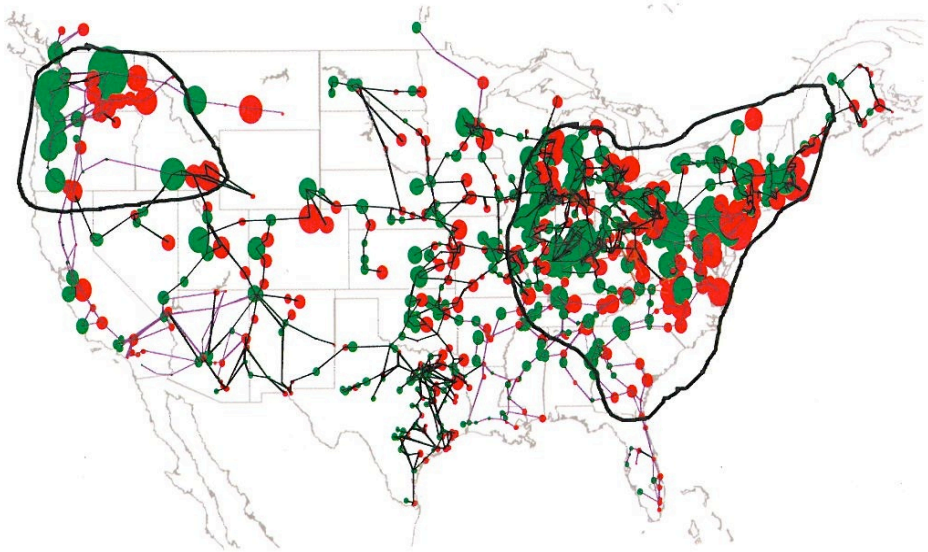


Figure 7. Schematic illustrating the interconnection of critical infrastructures and their dependencies and interdependencies. As the nation's infrastructures and services increase in complexity and interdependence over time, a major outage of any one infrastructure will have an increasingly widespread impact. (Image courtesy of Department of Homeland Security.)

High Risk Electric Grid Regions



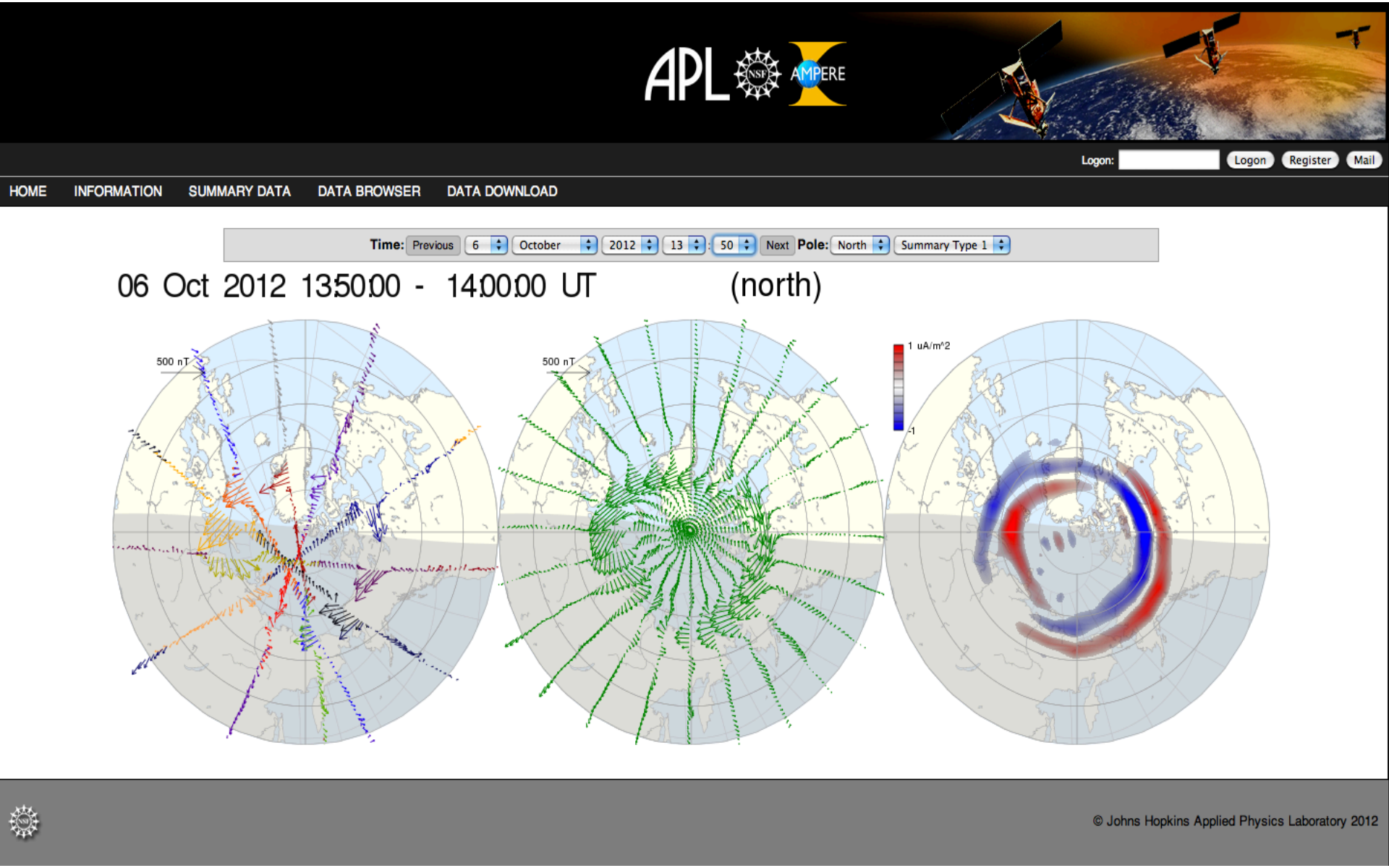
Lloyd's Insurance report - Figure 9: Fraction of EHV transformers damaged by county during an extreme geomagnetic storm scenario. Red and orange are likely to be without power. Yellow is uncertain. Green would be very likely to have power.



NRC Severe Space Weather report, 2009 – Figure 5: Regions susceptible to power grid collapse (Image courtesy of John Kappenman) – reflection of population density

Recommendation/Mitigation

- Industry/researchers to conduct power system simulations with geomagnetic disturbance input, preferably with regional, not global input
- Stabilize and improve warnings from space weather observational and prediction systems; NOAA's Space Weather Prediction Center - actionable warnings to users
- Universal GIC monitoring and operational procedures developed by North American Electric Reliability Corporation
- Engineering solutions, blocking capacitor systems, recovery storage, transformers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-1
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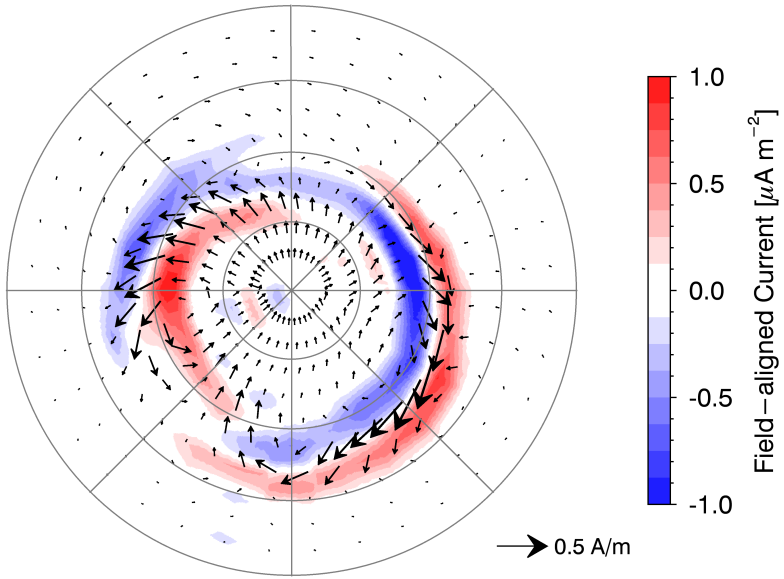
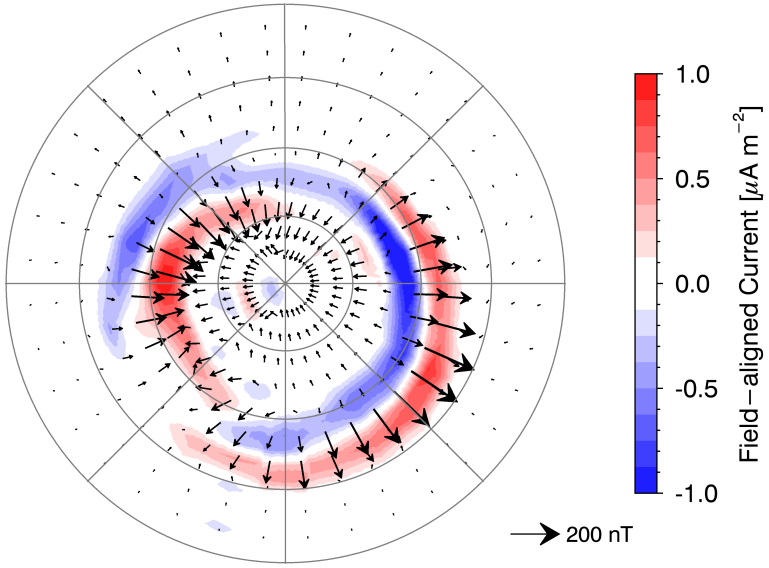
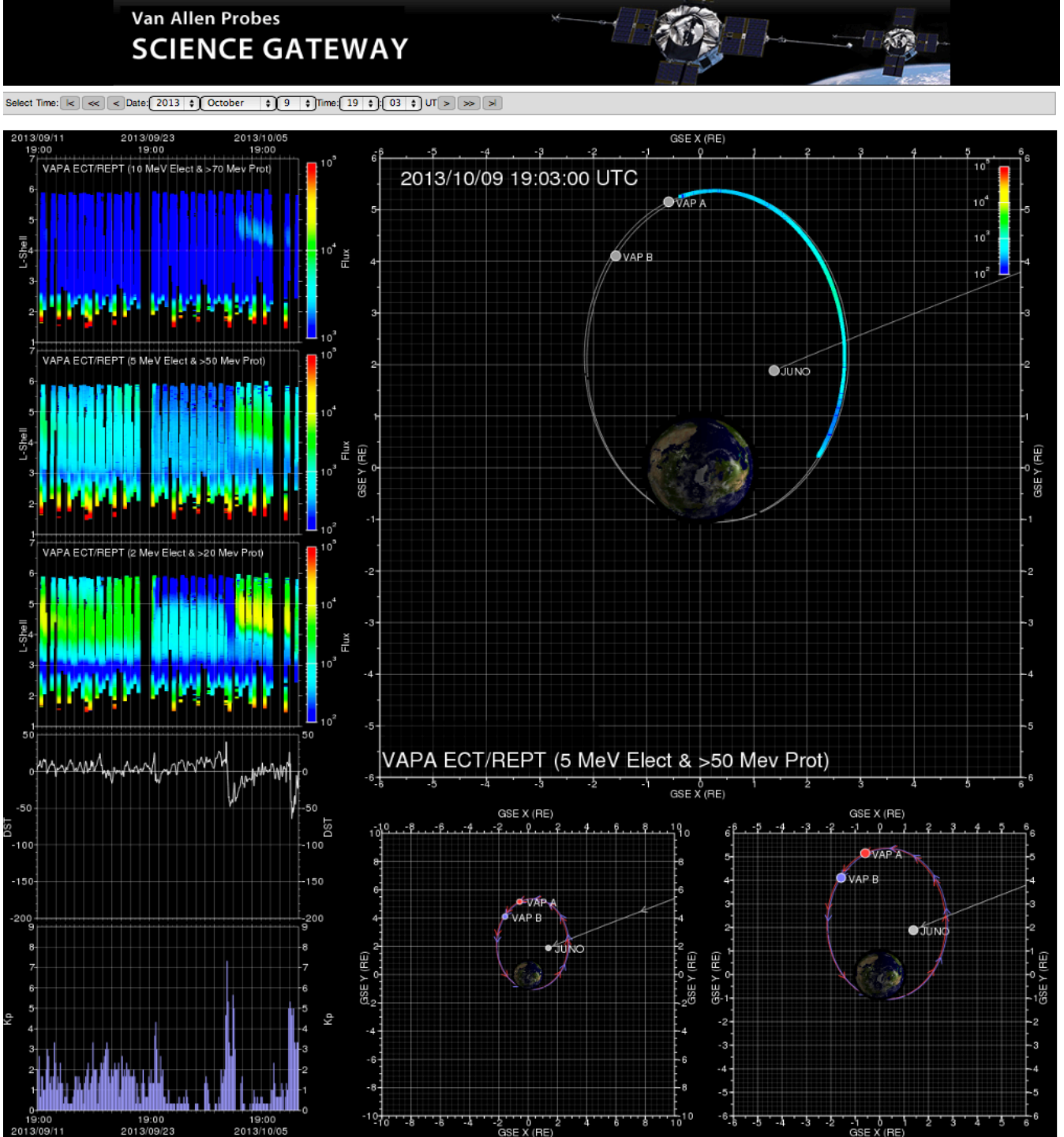
Hall currents – Earth Surface dB





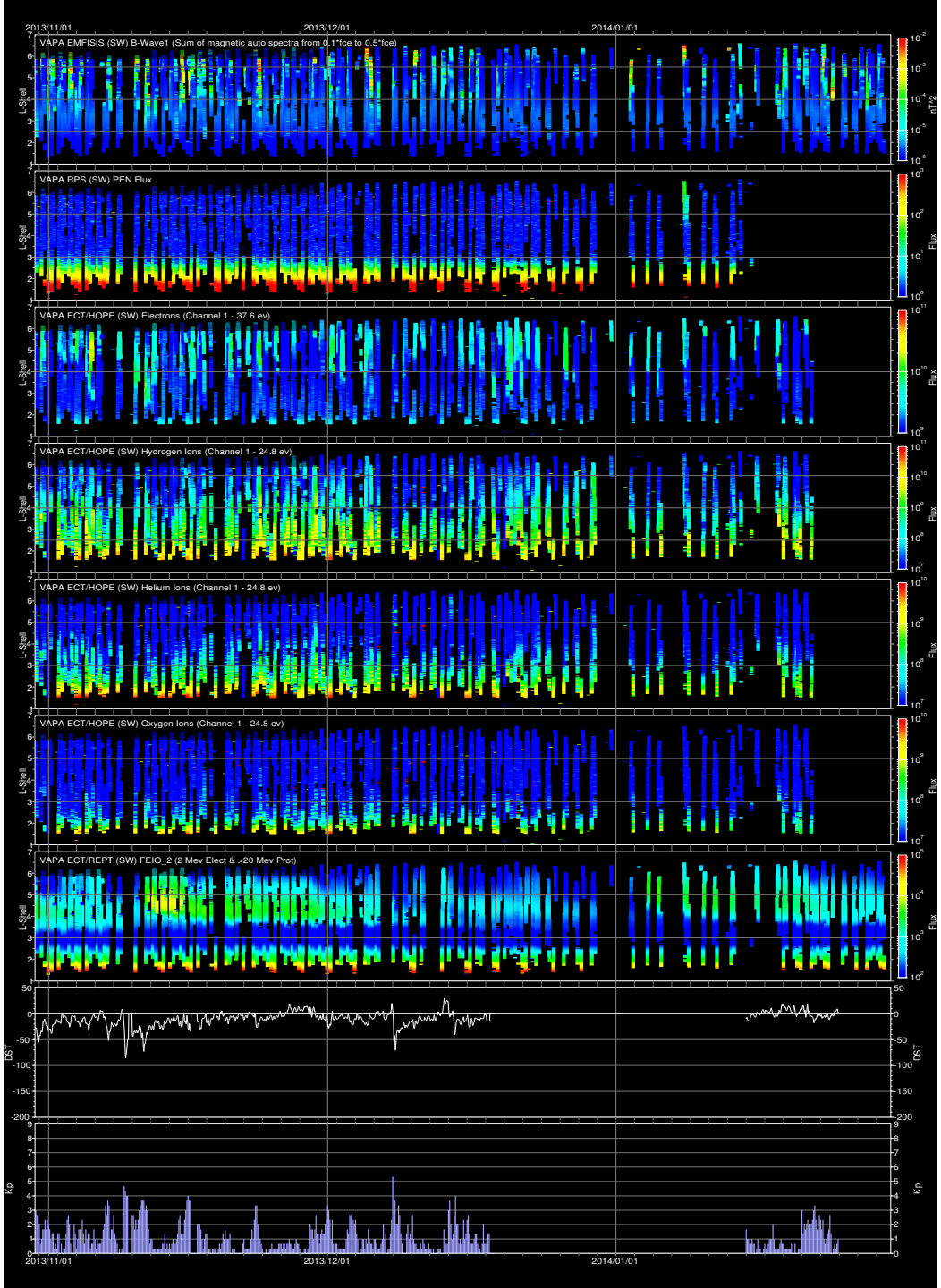
In browser, input:

“RBSP Gateway”
Click: Space Weather Context



Future real-time data space weather options via:

“RBSP Gateway”
Click: Space Weather Context

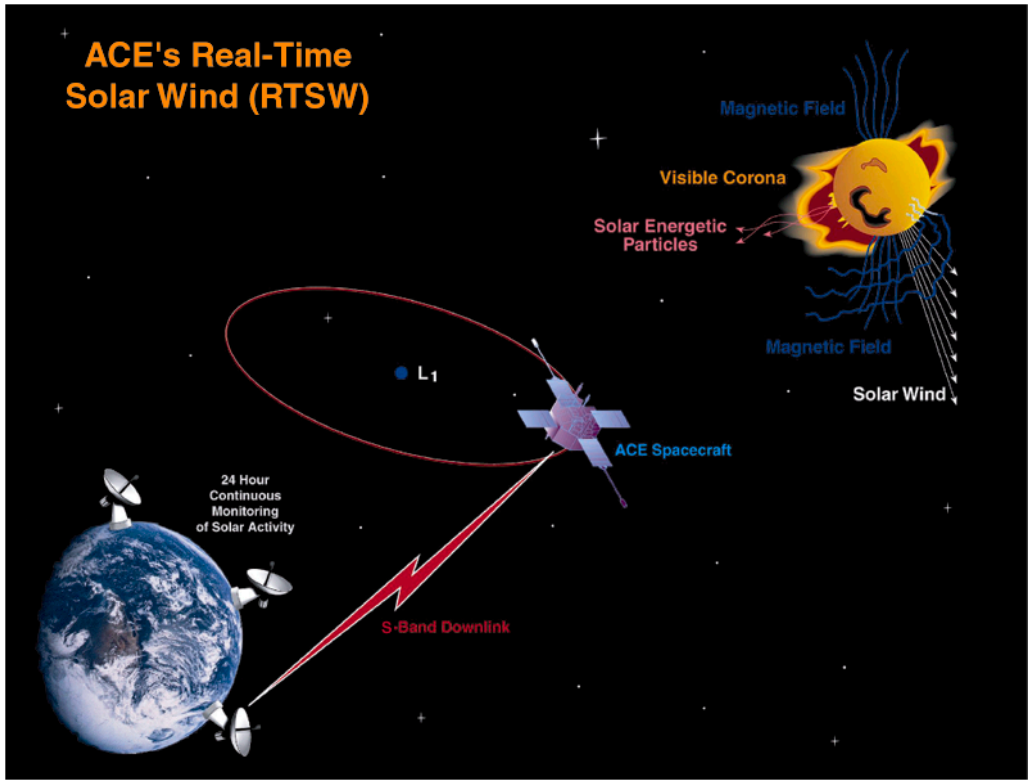


Summary timelines of recent events

- **Juno flyby – 9 October 2013**
  - **CME launched 2 days previous, predicted to arrive after flyby; arrival at Earth was half a day before flyby – small storm event that severely diminished the outer radiation belts**
- **Week of 6 January 2014**
  - **Fast CME launched 7 January, arrival predicted to be in one day with accompanying large geomagnetic storm, possible deflection; arrival at earth was in two days with minor impact, small -Bz**
  - **Van Allen Probes spacecraft maneuvers scheduled for 9 Jan postponed**
  - **Antares launch to ISS from Wallops delayed**
- **Solution: Improved CME observations in order to assess initial characteristics of CMEs at less than 20 Rs – approximate inner boundary of NOAA's WSA-Enlil propagation code**
- **Obvious advantage of dual and off – Sun-Earth line remote observations, e.g. L5 or L4, in determining CME characteristics of velocity, size, direction, shape and density - especially for fast events**

ACE Early Warning for Space Weather

- ACE Real-Time Solar Wind measurements provide early warning capability
- NOAA/AFWA use data to provide operational space weather products to civil operations and warfighters
  - Over the past 15 years, these data have become critical to the user community, in particular the electric power grid and GPS operators; these data have been labeled a “single point failure” in the space weather prediction system

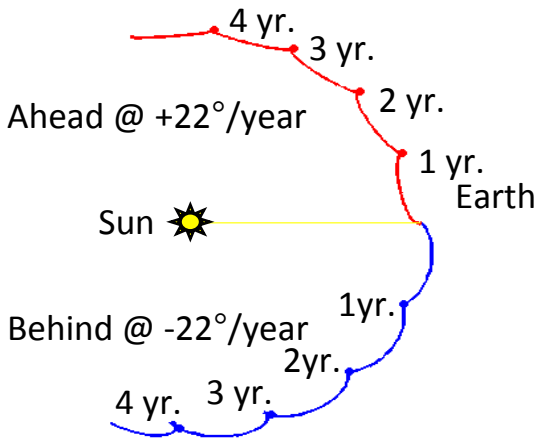


ACE Satellite Reaches End of Life in 2022 and DSCOVR (Launch 2015) Reaches End of Life in 2020. APL has Studied Follow On for Potential Small Satellite Solution.

STEREO Space Weather Mission

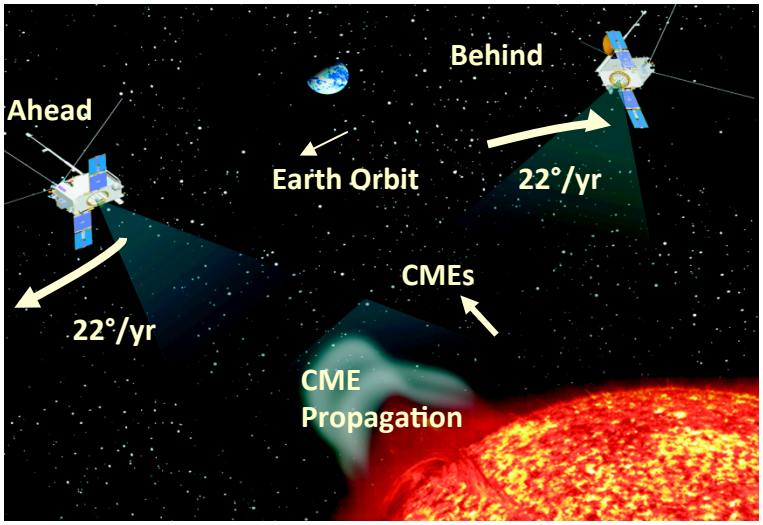
(Solar TErrestrial RElations Observatory)

- Two spacecraft in heliocentric orbit about the Sun; one ahead of the Earth and one Behind the Earth
- Track the buildup & lift-off of magnetic energy on the Sun & the trajectory of Earth-bound CMEs in 3-D
- Launched October 2006
- NASA/GSFC Solar Terrestrial Probes
  - JHU/APL: Mission Integrator and spacecraft provider
  - NRL
  - University of California at Berkeley
  - University of Minnesota and Observatorie de Paris
  - University of New Hampshire



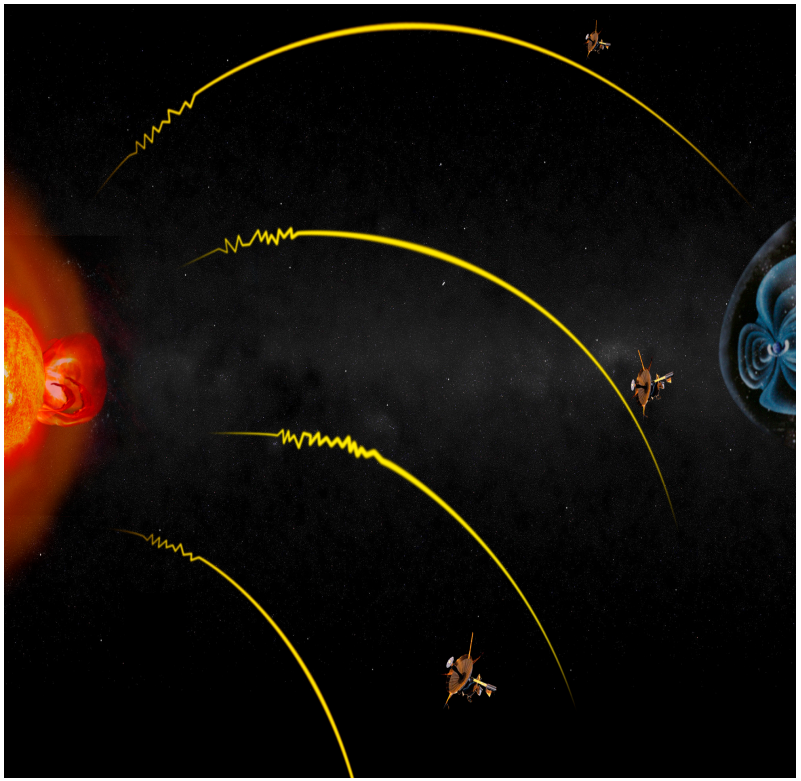
Spacecraft

- Mass: 620kg, Power: 475 watts
- Instruments measure:
  - Ultraviolet Imager and coronagraph
  - Particles & magnetic fields
  - Ion composition
  - Radio burst tracker



Way Forward?

- Provide a permanent, affordable solution to upstream solar wind observations at L1
- Initialize mission concept process to define an L5 capability
- Enable improved forecasting capability with L5, etc.
- Quantify improvement of CME characterization



Summary

- **Stabilize and improve warnings from space weather observational and prediction systems; NOAA's Space Weather Prediction Center - actionable warnings to users**
  - **Electric power operators among other space weather customers rely heavily on forecast accuracy**
- **Continue progress in understanding and observing the Sun – Earth system**
- **Develop critical observation set to satisfy input needs of warning system and of models**

Thanks

JOHNS HOPKINS
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Applied Physics Laboratory