Impacts of Severe Space Weather on Critical Infrastructure

- JASON: a group of academic scientists, mathematicians , and engineers who advise the federal government on technical issues
- For the 2011 Summer Study, DHS tasked JASON to
  - Assess the threat to the electric grid from severe space weather
  - Examine mitigation possibilities
  - Consider how warnings can be improved
- The study included
  - Briefings
  - Visiting the Space Weather Prediction Center
  - Extended communications with agency people in the U.S., Canada, and Finland

The Threat

- It is real and very serious
- Grid behavior is not understood well enough to make accurate predictions of damage from solar storms
- Full-up modeling of the grid is needed
- We heard of large-scale simulations at Oak Ridge, but we could not learn details. Nor could NERC.
- We were told that NERC is developing a national grid monitoring capability
  - Owing to legal & business constraints, data will be kept only for a week
  - The data problem must be fixed to permit post-event forensics and model testing

Mitigation

- At greater risk than most of the U.S., Finland and Quebec have avoided catastrophic damage by
  - Careful transformer design
  - Installing series capacitors in transmission lines & blocking capacitors on transformers
- Protecting valuable equipment from permanent damage is more important than preventing short blackouts, e.g.
  - Setting relays to trip before GIC harmonics damage gear
  - Mandating component design standards
  - Blocking GIC with capacitors in transformer neutrals, coupled with short-circuit protection
  - Using small series-blocking capacitors in lines where neutral-current blocking is not feasible

Observations needed for Warnings

- **Four research satellites supply the most important data**
  - **SOHO, launched in 1995 for a 2-year mission**
  - **ACE, launched in 1997 for a 6-year mission**
    Confirms CME impact in 1 hour or less
  - **STEREO A & B, launched in 2006 for a 14-year mission**
    Supplies 3-D CME structure to initialize numerical projections
- **Urgent need for sustained operational satellites**
  - **Keep DSCOVR on track as interim ACE replacement in 2014**
  - **Consider constellation of small craft in quasi-satellite orbits as permanent ACE replacement**
  - **Develop long-term plan for maintaining 3-D observations to replace STEREO**

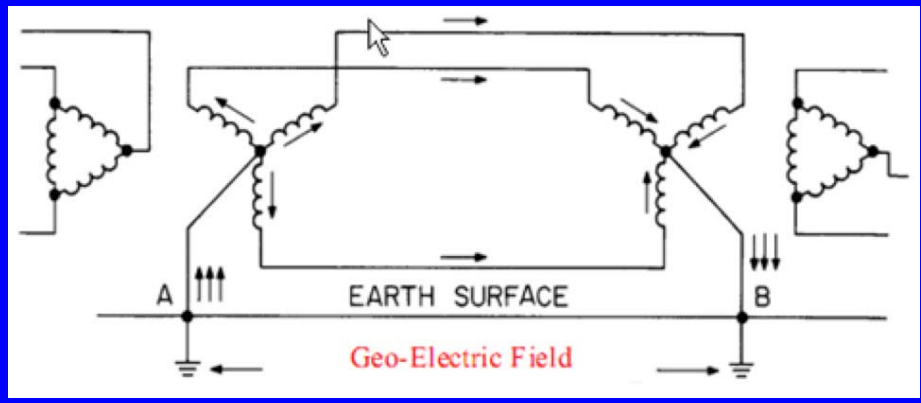
The Space Weather Enterprise

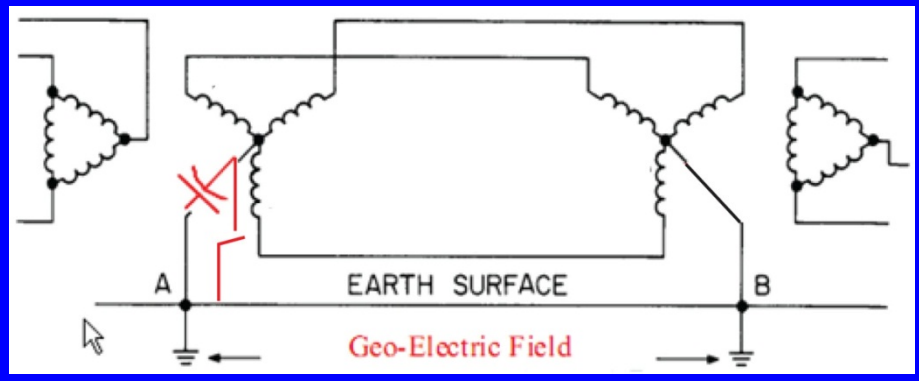
- Using the broader post-9/11 definition of national security, risks from severe space weather qualify as concerns
- Many tasks within federal agencies are working very well, but there are serious gaps between agencies
  - AF & NOAA space weather would be stronger if more tightly coupled
  - Investigate using AF sensors on NOAA satellites
  - A transition path & funding are needed to move NASA research models to NOAA operational forecasts
  - DOE work, e.g. wide-area grid monitoring, should be available to NERC

BACKUPS

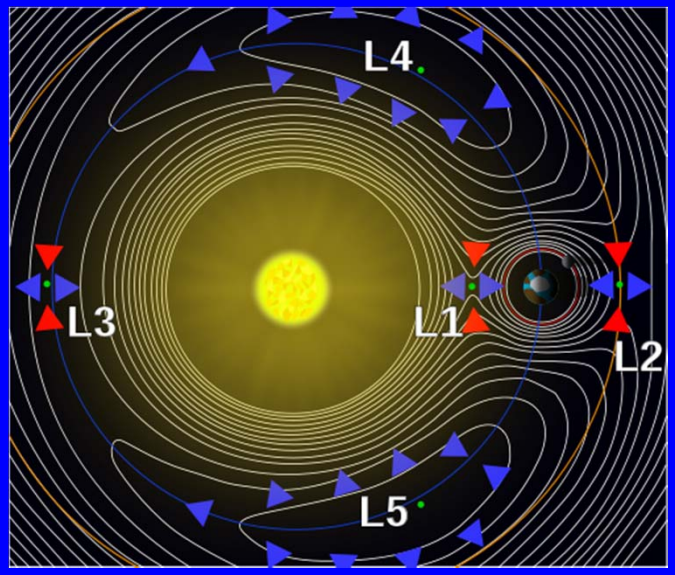
Hydro Quebec: 2001-2002 Test

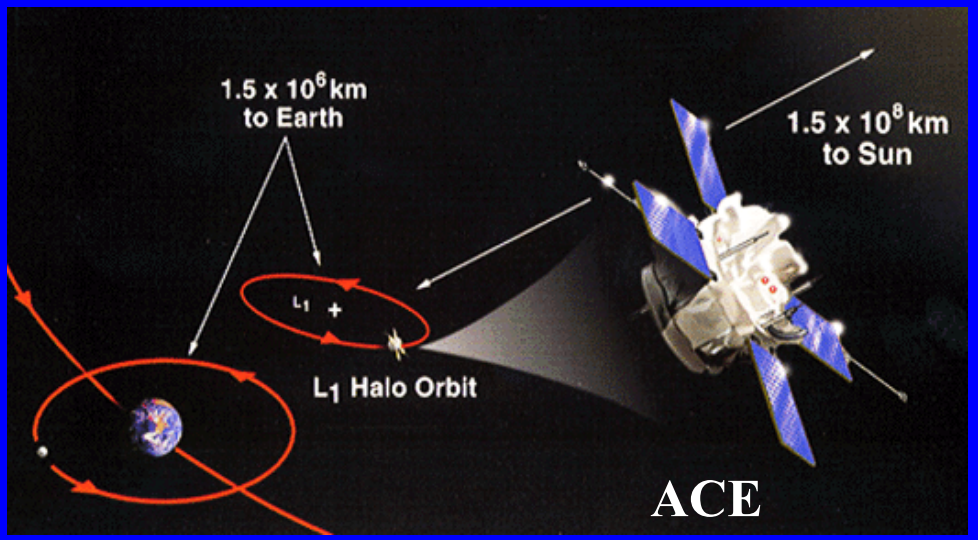
- Installed smaller capacitors between ground and neutral on 3-phase transformer, blocking GIC
- $100k per box
- Fault protection required





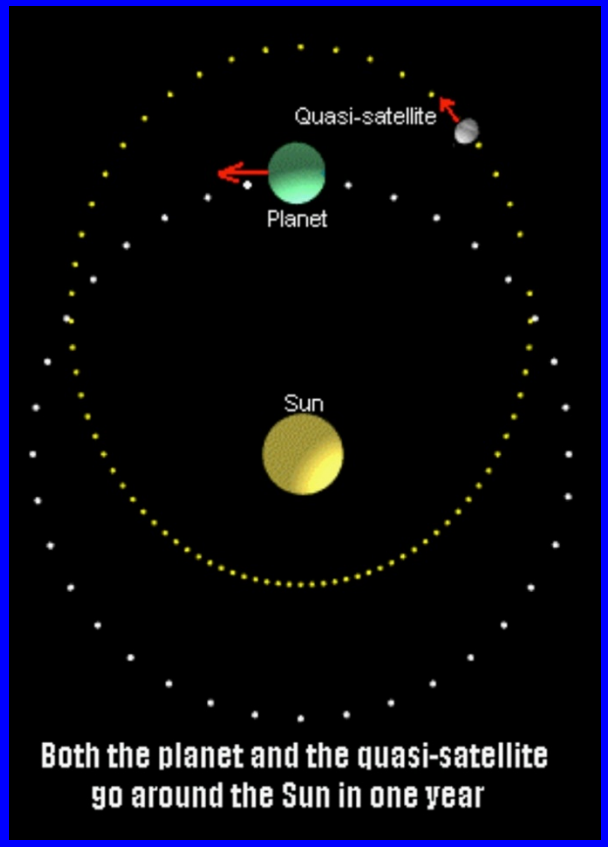
Solar Observations from Lagrange Points

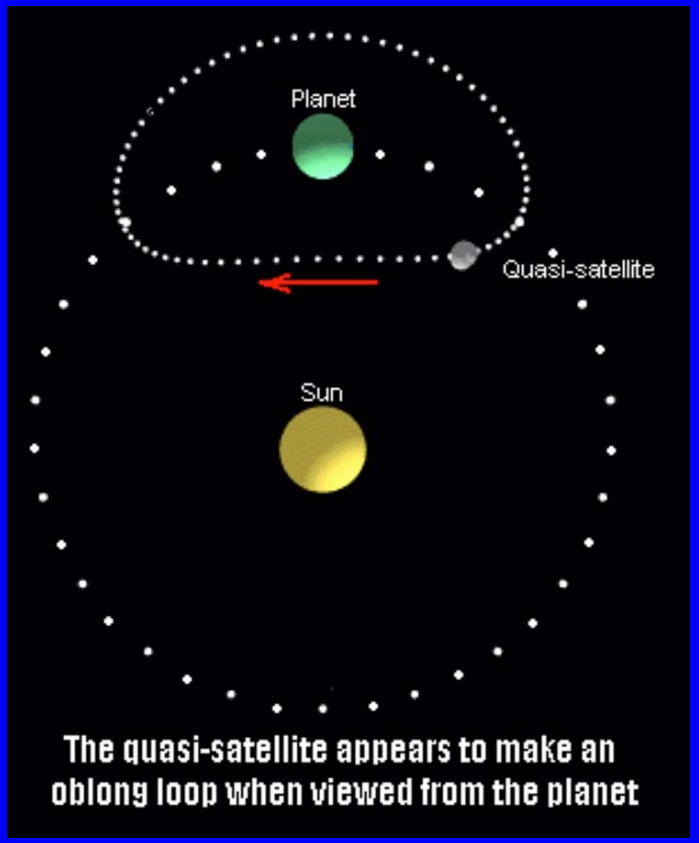




- Sun-earth gravity produces 5 potential saddle-points moving with earth
- L1: ≈ 0.01 AU from earth, CME arrive 30–60 min. before hitting earth
  - SOHO: initial detection from coronagraph
  - ACE: 30-60 minute warning based on B (3 components), particle - speed, temperature, density
- STEREO: (2006 launch, angles opening at 22.5° /year)
  - imagers: EUV, white-light of corona (2) & heliosphere (for CME)

CME Warnings from Quasi-satellites





SWx_Diamond

- 4 satellites
- 0.1 AU apart
- Warnings 10x earlier
- Low launch & insertion energies
- Science missions too

StCyr & Davila (2002)

Wiegert et al.

- Consider a small constellation of cheap satellites in quasi-satellite orbits for long-term near-earth CME warning system
- Can increase 30-60 min warning times to several hours