The Importance of Space Science for Living Today

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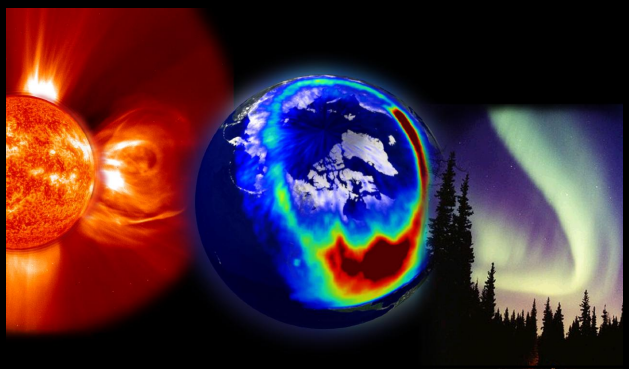

Outline

- Early ideas about solar terrestrial interactions
- The Northern Light Phenomenon
- Space Weather impacts on satellite and ground systems

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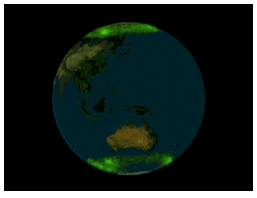
Early ideas about Aurora Borealis

- Galileo Galilei (1564-1642) – who observed sunspots, suggested that aurora was caused by air rising out of the Earth's shaddow to where it can be sunlit
- ~1715 : Edmund Halley – The aurora is ordered by the Earth's magnetic field
- 1731 : De Mairan (French Philosopher) revived the old theory that aurora was reflection of polar ice crystals and snow

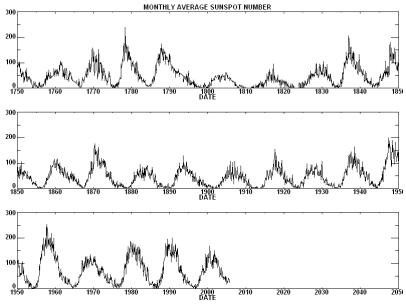
The emergence of solar terrestrial physics

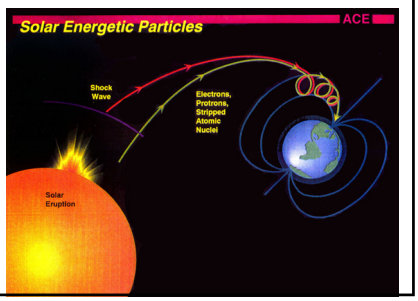
- 1722: George Graham noticed that the compass was always in motion
- 1740 : Anders Celcius confirmed Graham's observation
- 1741: O. Hiorter observed a relationship between auroral activity and geomagnetic activity
- 1770: J. C. Wilcke noted that rays extended upward along the direction of the magnetic field
- 1770: James Cook reported the southern counterpart of the aurora borealis – aurora australis
- 1790: Henry Cavendish triangulated the height of auroral to be between 52 and 71 miles.



Early Ideas on Sun-Earth Connection

- 1851: Edward Sabine was able to show that the intensity of geomagnetic activity varied in concert with solar activity (~10 year)
- 1859 : Richard Carrington identified the connection between a solar flare and geomagnetic activity
- 1878 : H. Becquerel suggested that protons shot off from the Sun were guided by the Earth's magnetic field to the auroral zone.





Kristian Birkeland (1867-1917)

- The "First Auroral Physicist"
- Professor – 31 years old
- Experiment + Theory = Innovation (60 patents)
- Fixation of Nitrogen – gave birth to Norsk Hydro/Yara - a world leading fertilizer company
- After three expiditions in 1902-1903 he conluded that aurora are associated with currents floating along magnetic field lines – The Birkeland currents.

A breaktrough with the Terrella experiment in 1901

Terrella – a magnetized sphere placed in a vaccum camber

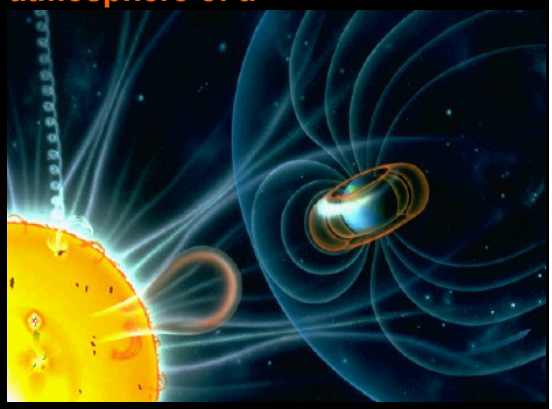
The auroal oval on the 200 kr note

Birkeland currents

Norways fortunate location for observing aurora – day and night

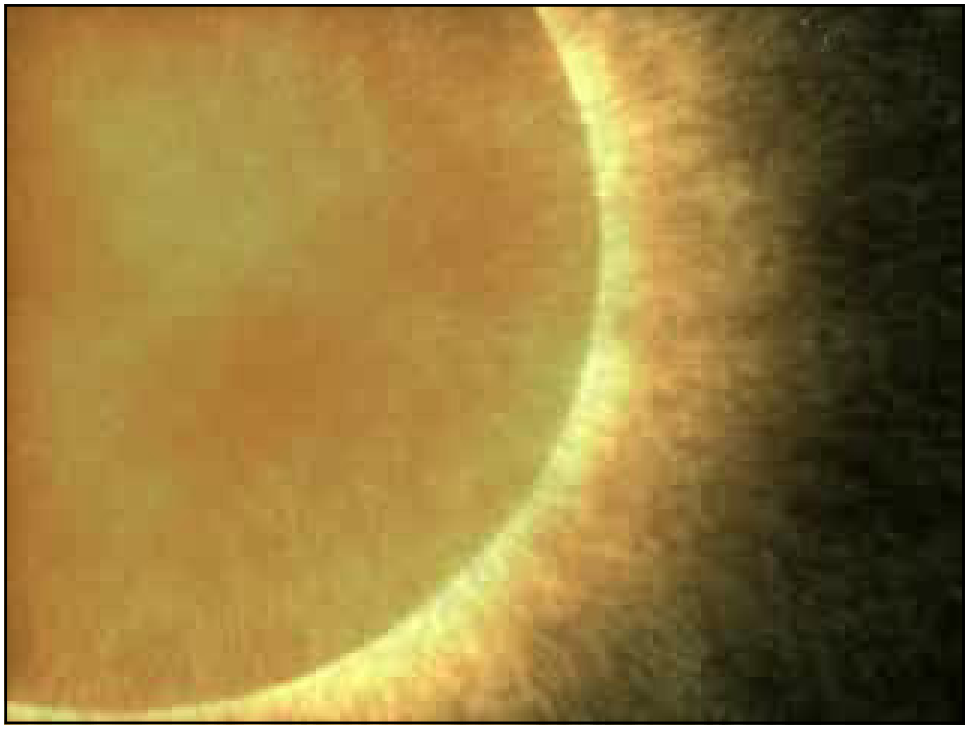
SPACE WEATHER

We live in the extended atmosphere of a variable star – The Sun

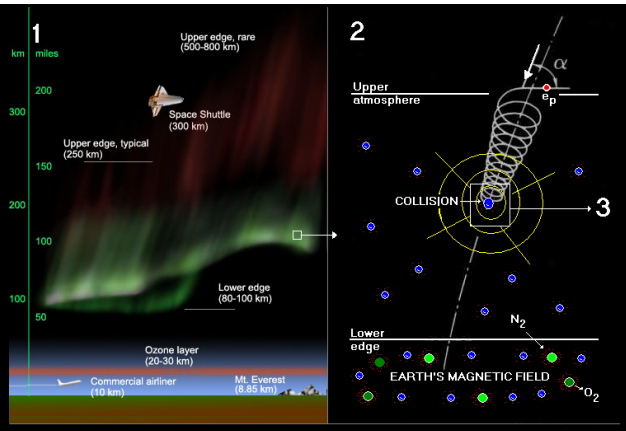


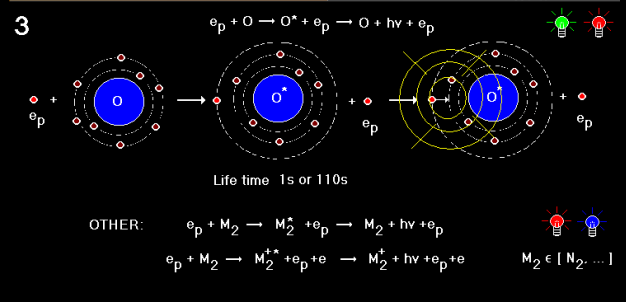
Varying

- Radiation
- Solar Wind
- Energetic Particles

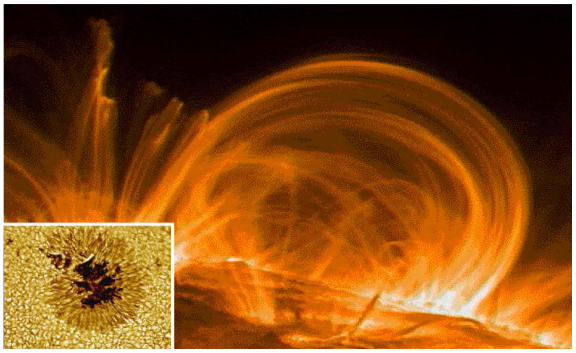


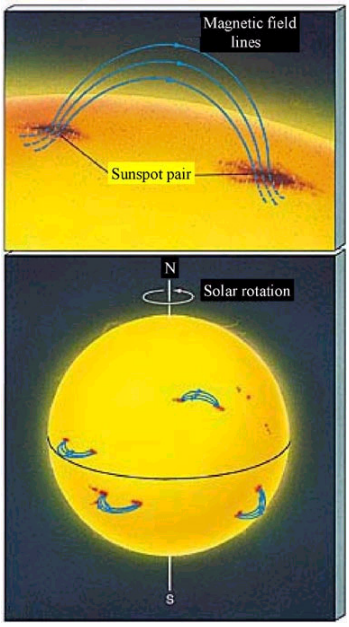
Earth's Atmosphere

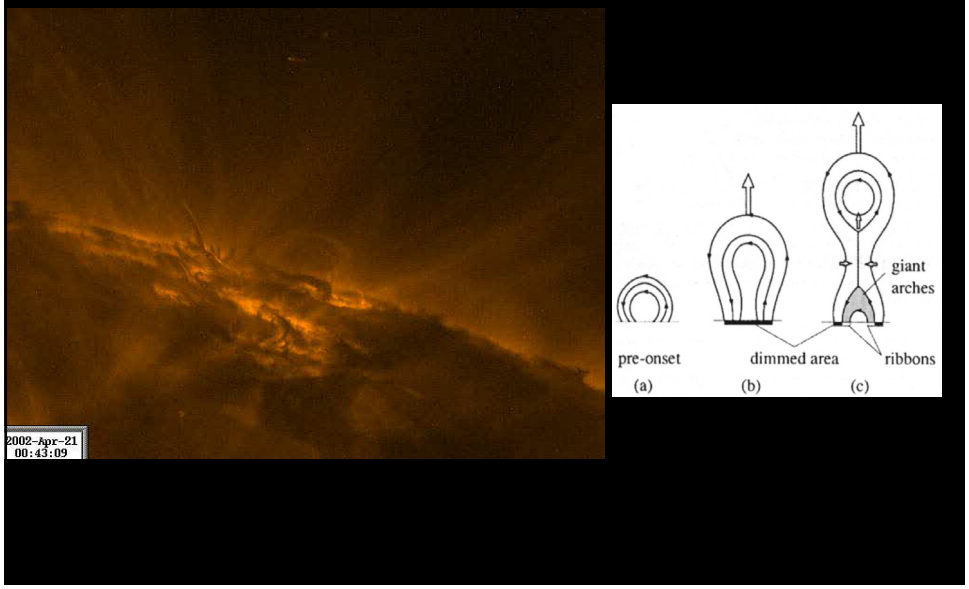


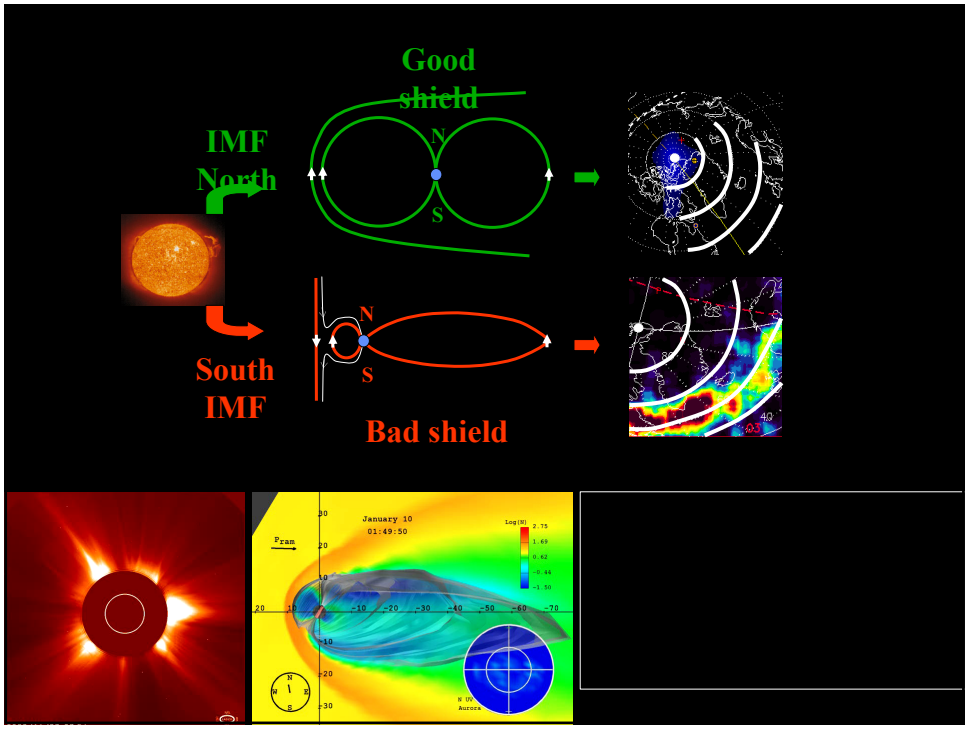


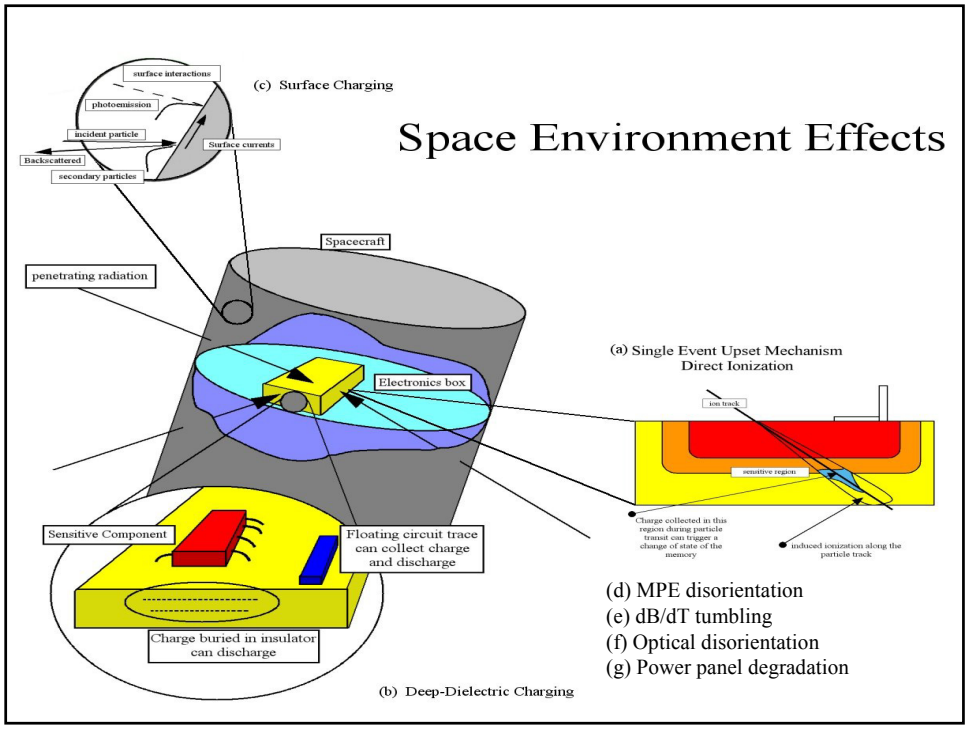
- The Sun does also have a magnetic field
- Sun spots occur in pairs connected by magnetic field lines



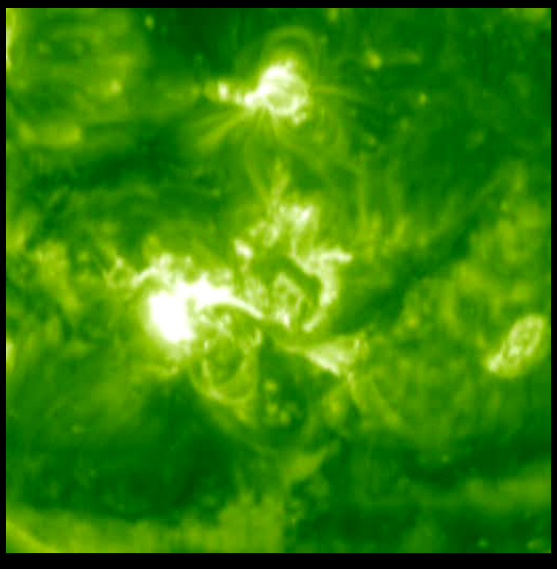





Good shield
IMF North
N
S
South IMF
N
S
Bad shield
January 10
01:49:50
Pram


Space Environment Effects
surface interactions
photoemission
incident particle
Backscattered
secondary particles
Surface currents
(c) Surface Charging
Spacecraft
penetrating radiation
Electronics box
Sensitive Component
Floating circuit trace can collect charge and discharge
Charge buried in insulator can discharge
(b) Deep-Dielectric Charging
(a) Single Event Upset Mechanism
Direct Ionization
ion track
sensitive region
Charge collected in this region during particle transit can trigger a change of state of the memory
Induced ionization along the particle track
(d) MPE disorientation
(e) dB/dT tumbling
(f) Optical disorientation
(g) Power panel degradation

Close-up from SOHO EIT Sensor
Bastille Day 2000 Event (minutes later)



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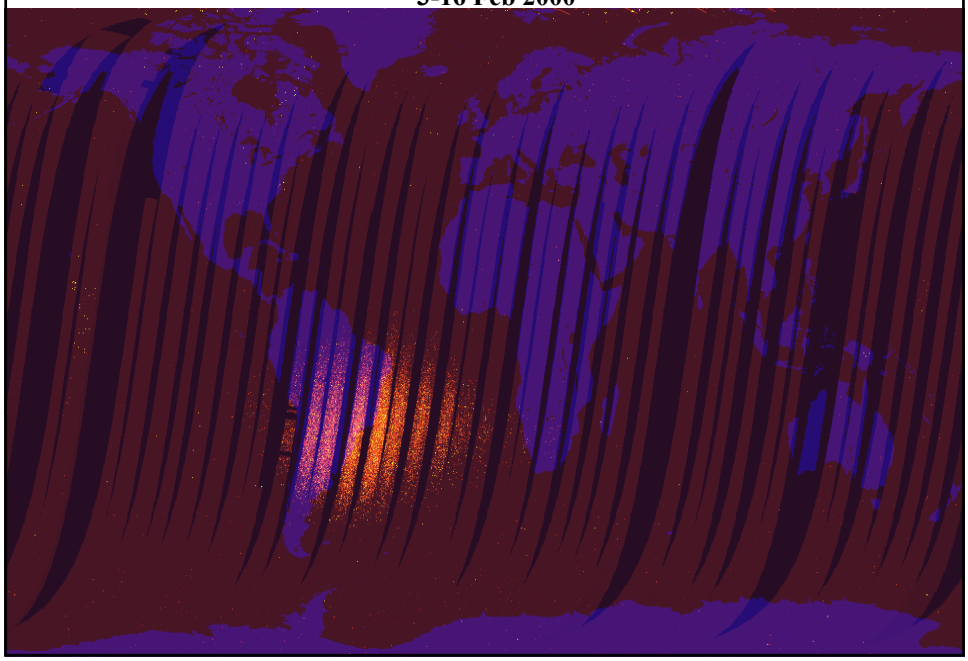
Satellite Anomalies: 14-16 July 2000 Proton Event & Geomagnetic Storm, Ap*=192

- **ASCA** (Advanced Satellite for Cosmology and Astrophysics) – lost attitude fix resulting in solar array misalignment and power loss, satellite probably lost (in P.C. Klanowski list).
- **GOES-8 & -10** – SEM Electron sensor problems, power panels
- **ACE** (Advanced Composition Explorer) – Temporary SW and other sensor problems
- **WIND** – Permanent (25%) loss of primary transmitter power & Temporary loss of Sun and star sensors
- **SOHO** (also **YOHKOH** & **TRACE**) – High energy protons obscure solar imagery
- **GEO** and **LEO** Satellites – S/C orientation problems during MPE
- **GEO** Satellites lost ~0.1 amp output from solar arrays

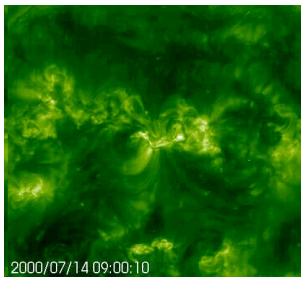
SAT-ND Timeline
in-orbit failures in 2000

22 Nov 2000	Galaxy VII	Secondary SCP fails; **total loss**
4 Nov 2000	Insat 2B	Loss of attitude control twice for unknown reasons
31 Oct 2000	Echostar IV	Number of lost transponders has reached 26 out of 44
26 Oct 2000	Terra	Telemetry Monitor 16 turned off Science Formatting Equipment, reason unknown
28 Sep 2000	Galaxy VIII-i	Loss of xenon ion propulsion systems. Life span reduced by 10 years
12 Sep 2000	Garuda 1	Antenna-related anomaly discovered during testing by manufacturer Lockheed Martin
27 Aug 2000	Solidaridad 1	Failure of backup SCP. Declared **total loss**
15 July 2000	ASCA (Astro-D)	Satellite started spinning during high solar activity. Safe mode. Declared **total loss** later
28 April 2000	Türksat 1C	Temporary loss of service for 55 minutes (safe mode, caused by electrostatic discharge in orbit)
31 Mar 2000	Echostar IV	Number of lost transponders (22) has reached 50% of total (44)
21 Mar 2000	Hotbird 2	Temporary loss of service for 9 hours
3 Mar 2000	Satmex 5	84-minute outage; safehold mode triggered by faulty ground control software

TERRA – MISR Data Before Shutter Opening
3-16 Feb 2000

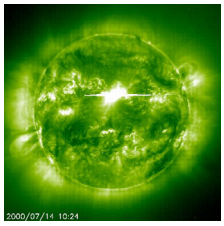


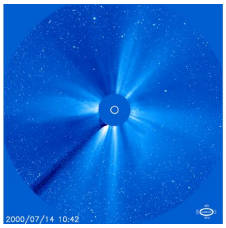
Solar Storms Takes Toll on Ozone

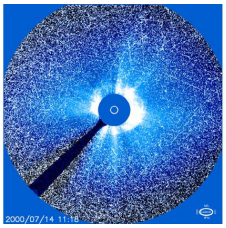


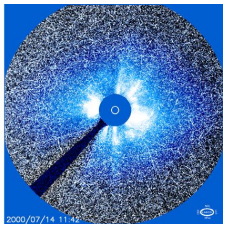
- **Large proton events deplete the upper level ozone for weeks to month (Jackman et al. GRL 28, 2883, 2001).**
- **These short term effects can destroy up to 70% of the ozone in the middle mesosphere.**

Solar storm and proton event on 14 July 2000 (SOHO images)

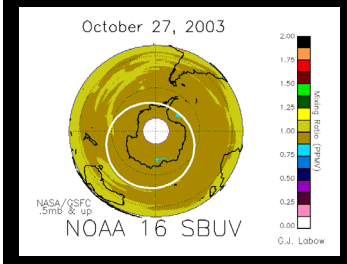


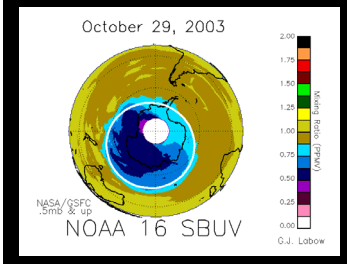




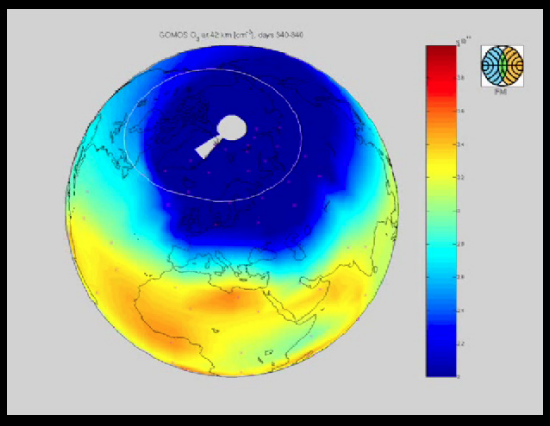


SPE affects Ozone in the Southern Polar Cap (at 0.5 hPa or ~55 km)

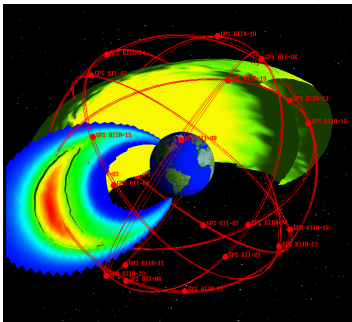




SPE Depleted ozone for 8 months (~42 km)

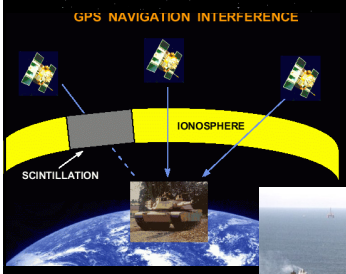


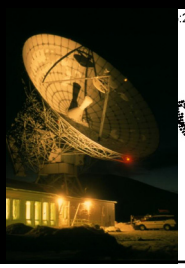
Source: Charles Jackman & Gordon Labow (NASA)

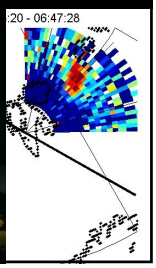


Navigation systems (GPS)

- Turbulence and irregularities in the ionosphere give rise to scintillations in the satellite to ground signal
- The Total Electron Content (TEC) along the path of a GPS signal can introduce a positioning error (up to 100 m)
- More severe in the arctic regions
- The effects on GPS could be one of the most significant space weather effects due to the planned reliance of this system in the future.







Effects on Civil Aviation

- **Aircrafts communication systems at HF/VHF**
- **Terrestrial HF communication systems**

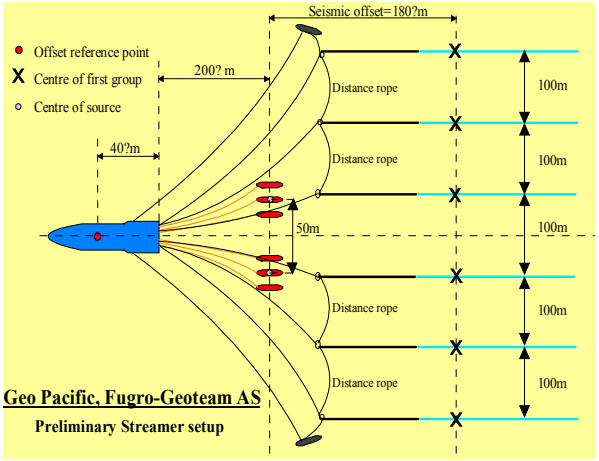
Recent effects on polar routes

Northwest Airlines: diverted a Detroit-Beijing flight to a non-polar route due to both HF communication problems (radio blackout) and a solar radiation storm, forcing an unscheduled stop at Fairbanks for fuel. This caused a 3 hour delay and an estimated $100,000 cost to NWA.

Re-routing and delays are costly to the airlines: fuel cost/ crew delays/ additional crews

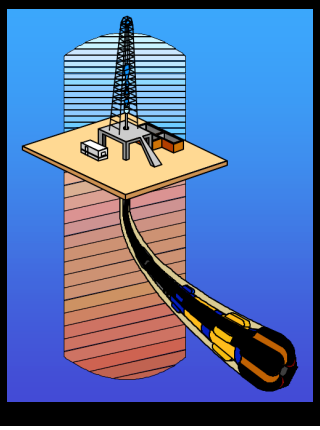
Geological Surveys

- **Search for oil and gas relies on very accurate positioning**



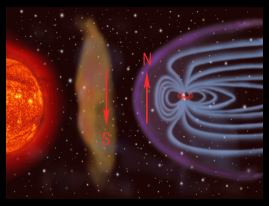
Directional drilling

- Search for oil and gas (geomagnetic surveys)
- Directional drilling
  - Oil industry relies on geomagnetic maps to guide the drill and monitor the well direction.
  - Relies on corrections from ground based magnetometers

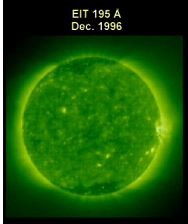


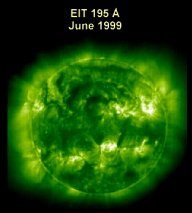
Effects from the Halloween Storms 2003

- **Aircrafts communication systems at HF/VHF suffered severe degradation and periods of complete blackout (above 57 degrees N) during Polar Cap Absorption (PCA)**
- **Terrestrial HF communication systems experienced outages during the radiation storms (PCAs) for arctic paths.**
- **Trans-polar flights were re-routed from Polar 3 to Polar 4 routs to avoid radiation hazards.**
- **HF radio relay paths in Antarctica experienced over 130 hours of blackout during the Halloween storms.**

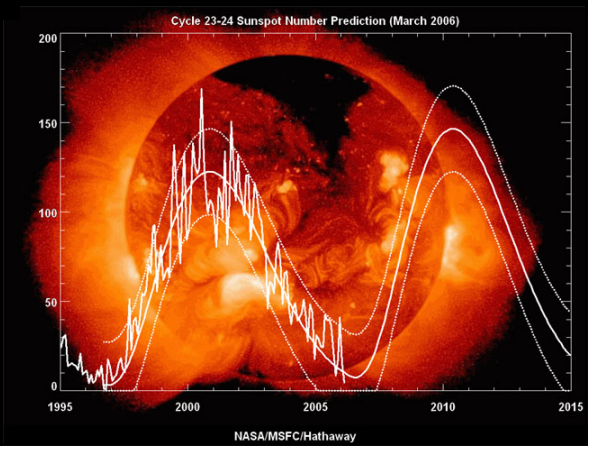


- **More than 20 satellites (many of them Earth Observation satellites) and spacecrafts were affected. Half of NASA satellites affected. 1 Japanese satellite lost**
- **US Coast Guard to temporarily shut down LORAN C navigation system.**





How large is the next solar maximum going to be?



Aurora at other planets seen by Hubble Space Telescope (UV)