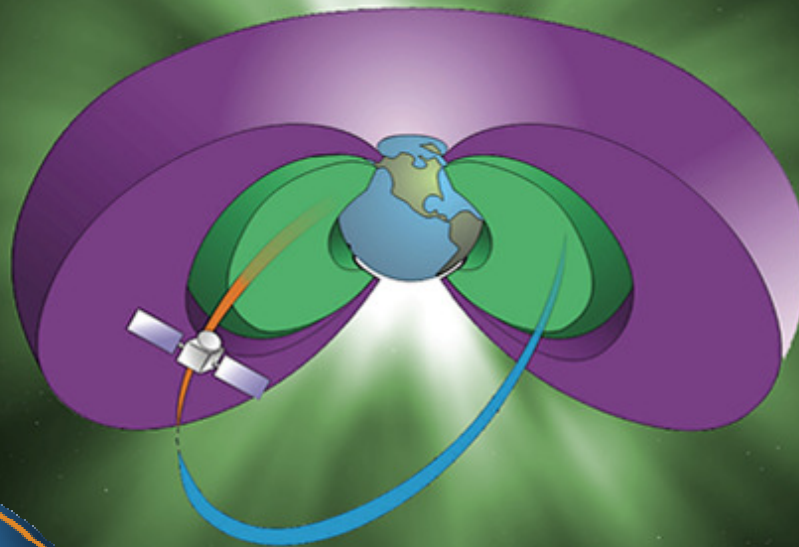




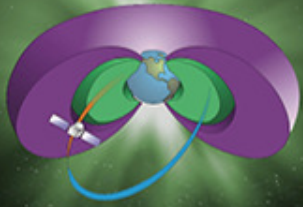
Canadian Space Weather Science and Research: From Discovery to Operations



Institute for Space Science, Exploration and Technology
University of Alberta

Prof. Ian R. Mann,
Department of Physics,
University of Alberta
ian.mann@ualberta.ca

Canadian Space Weather Vulnerability



- Canada's northern location makes it one of the countries most vulnerable to space weather.
- The same geographical advantage makes Canada a prime location for ground-based space weather monitoring.
- Scientific understanding critical for moving from discovery to operations.



Space Weather Effects

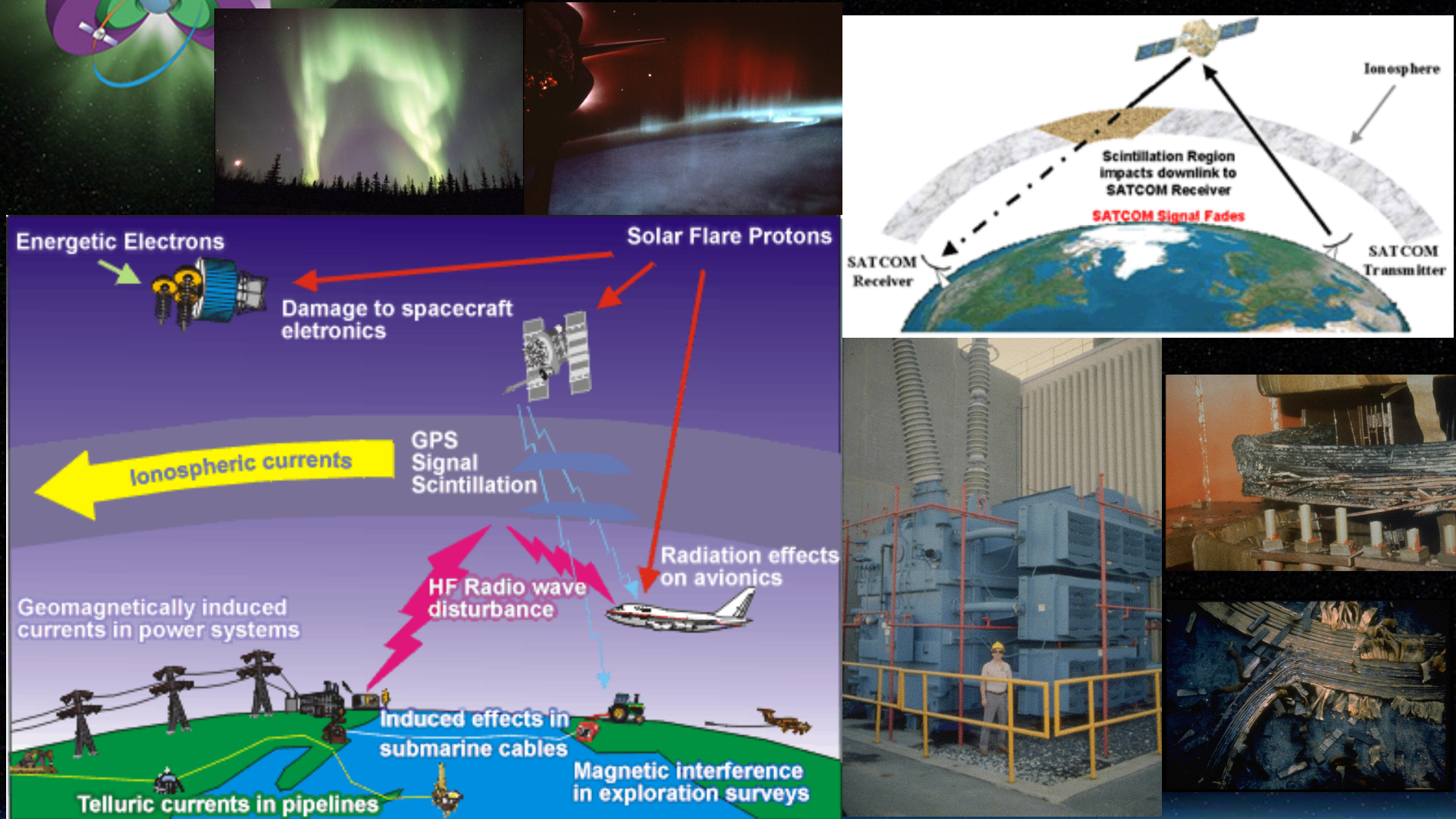


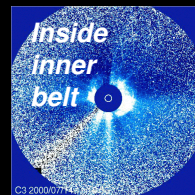
Image courtesy of spaceweather.gc.ca

Ian R. Mann.

UN COPOUS STSC, Vienna, Austria, Feb. 12th 2014.

Space Environment Hazards

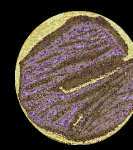
False stars in star tracker CCDs



before



after



Surface degradation from radiation

Solar array power decrease due to radiation damage

Single event effects in microelectronics: bit flips, fatal latch-ups

1101 \Rightarrow 0101

Electronics degrade due to total radiation dose

Solar array arc discharge



Spacecraft components become radioactive



Electromagnetic pulse from vehicle discharge

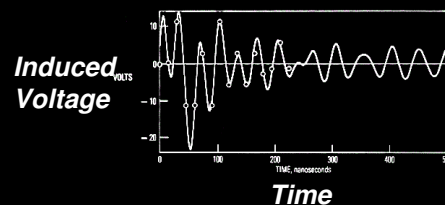
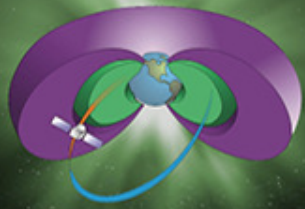


Figure courtesy of Joe Mazur,
The Aerospace Corporation



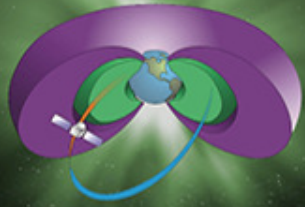
Auroral Tourism



The screenshot shows the Aurora Watch website interface. Numbered callouts highlight specific features:

- 1**: Main Menu (Home, Explanation, DIY Magnetometer, Latest News, Advanced Search, Contact Us, Links)
- 2**: Log In (Username, Password, Remember me, Login, Lost Password?, Register)
- 3**: Aurora Forecast (This website provides a realtime monitor of geomagnetic activity in the Edmonton area and offers a free email alert service to let you know if there may be aurora visible tonight. The current probability of witnessing an aurora tonight is: 12%)
- 4**: Graphs showing current geomagnetic activity for the Edmonton region (and all similar magnetic latitudes). Today's current magnetic activity is shown below.
- 5**: To subscribe to the Aurora Watch email alert service, simply register with your details as shown on the top right. The geomagnetic activity for last night and yesterday is shown below.

www.aurorawatch.ca



Missions of Scientific Discovery and Operational Services

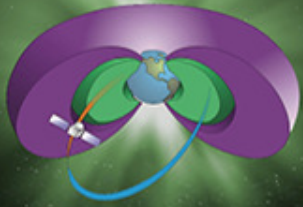
Extensive Ground-based Program

- Solar F10.7 radio flux
- CSA Geospace Observatory (GO) Canada
- Natural Resources Canada (NRCan) Space Weather

Space-based Program

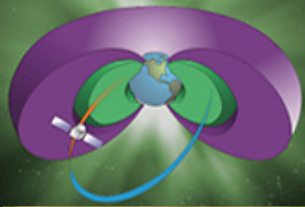
- CSA CASSIOPE/e-POP Small Satellite
- ESA SWARM Mission
- NASA/CSA THEMIS Mission
- Numerous international space agency partnerships
- Proposed Polar Communications and Weather (PCW) mission

Operational Space Weather Services



Observational Programs and Scientific Discovery

Important to trace heliophysical disturbances and space weather from “sun to mud”.

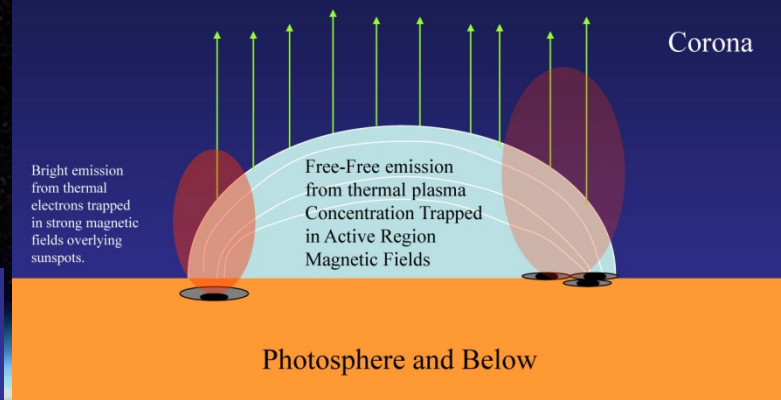


Solar Radio Monitoring: F10.7



- Canadian continuous monitoring of solar 10.7cm radio flux since 1947 at Dominion Radio Astrophysical Observatory (DRAO), Penticton.
- Longest continuous record of solar properties, other than sunspots.

Where Does F10.7 Come From?

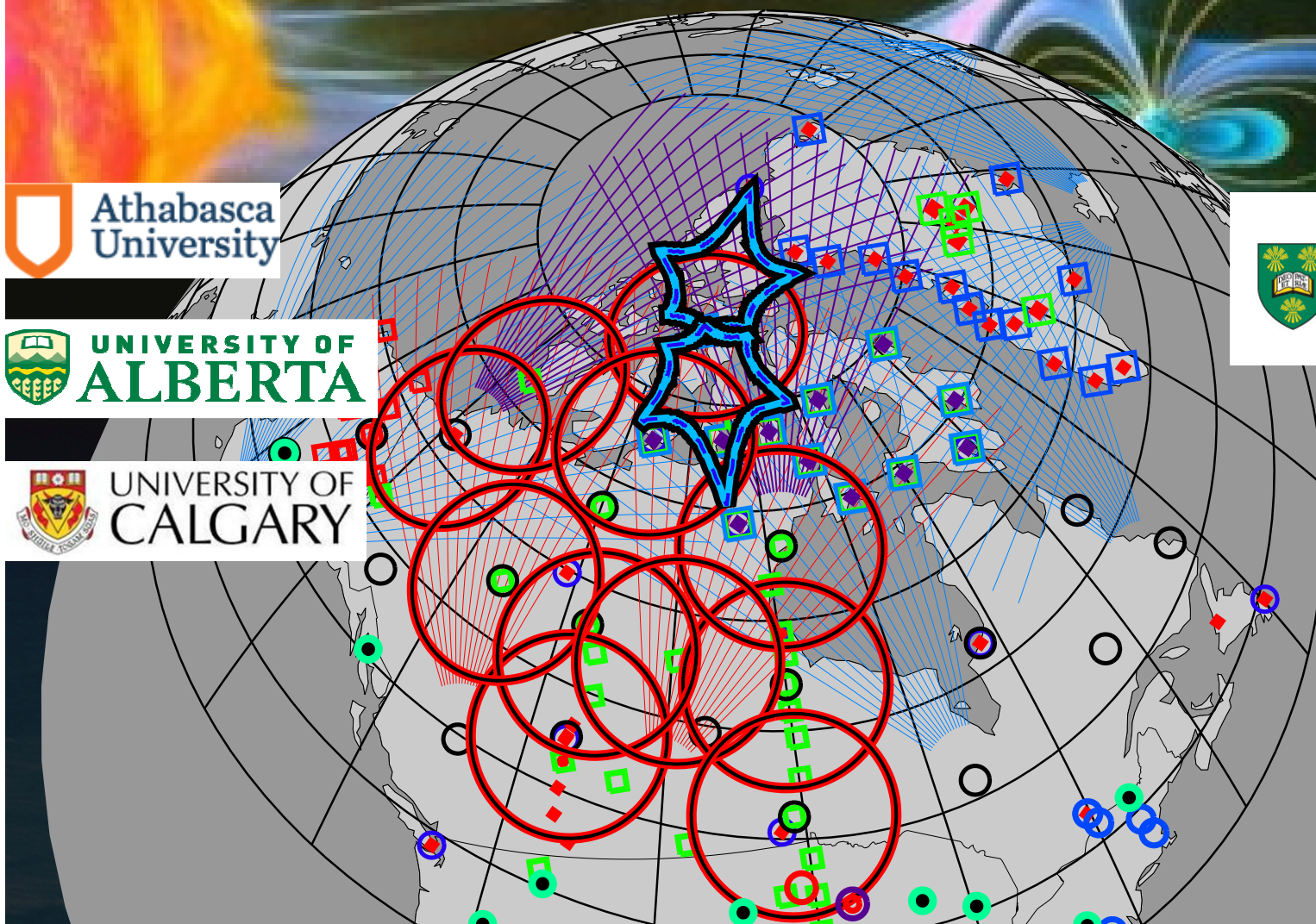


Natural Resources
Canada

Ressources naturelles
Canada

NRC · CNRC

Geospace Observatory (GO) Canada





Space Measurements from the Ground

GPS Satellite
(20 000 km alt)



Sounding rocket

Aurora

Airglow

Meteors

Noctilucent clouds

Nacreous clouds

F

E

D

Mags

ULF Waves,
GICs

GPS

scintillation

SuperDARN
plasma velocity

Imagers

Auroral
Dynamics

VLF

receivers

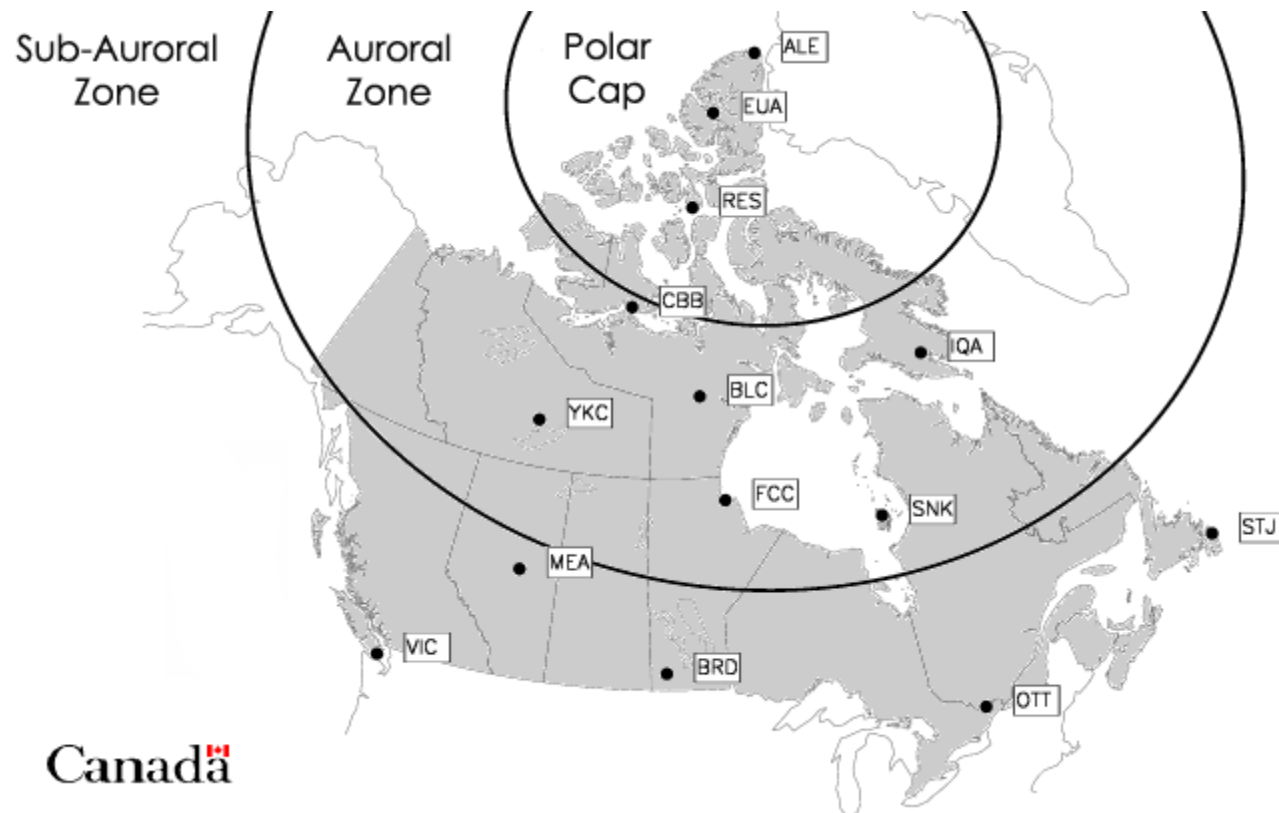
CADI

ionosphere layers
altitudes

Riometer

Absorption

Natural Resources Canada (NRCan) Space Weather Hazards Program



- NRCan Canadian Magnetic Observatory Network (CMON)
- NRCan riometer network



CSA CASSIOPE/e-POP Small Satellite

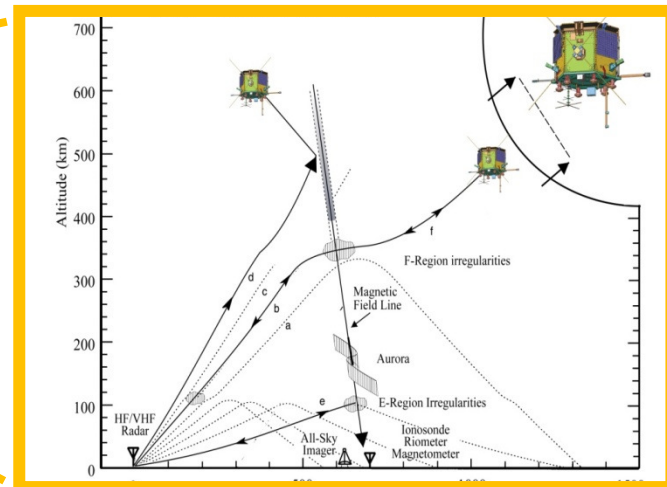
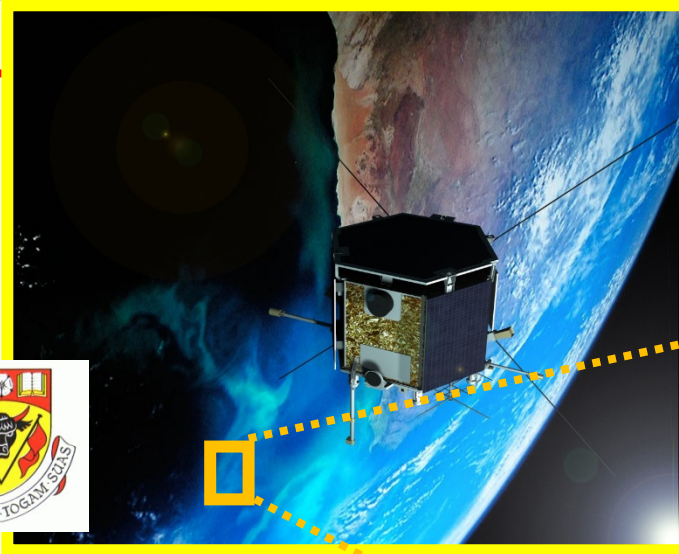
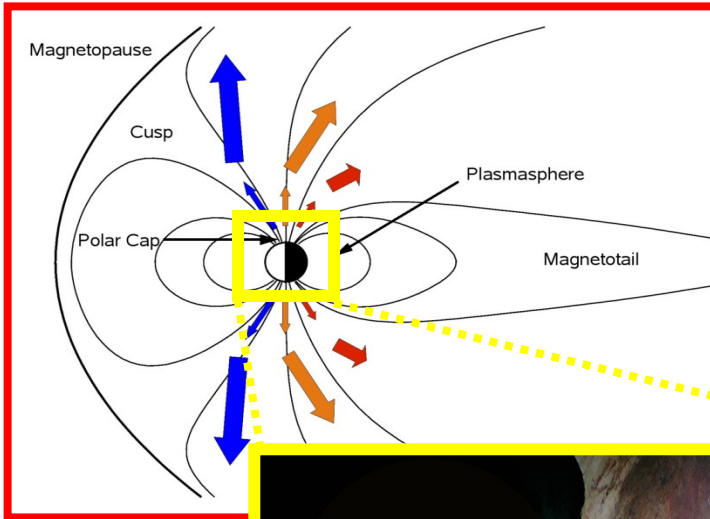
<http://epop.phys.ucalgary.ca>

Enhanced-Polar Outflow Probe (e-POP)

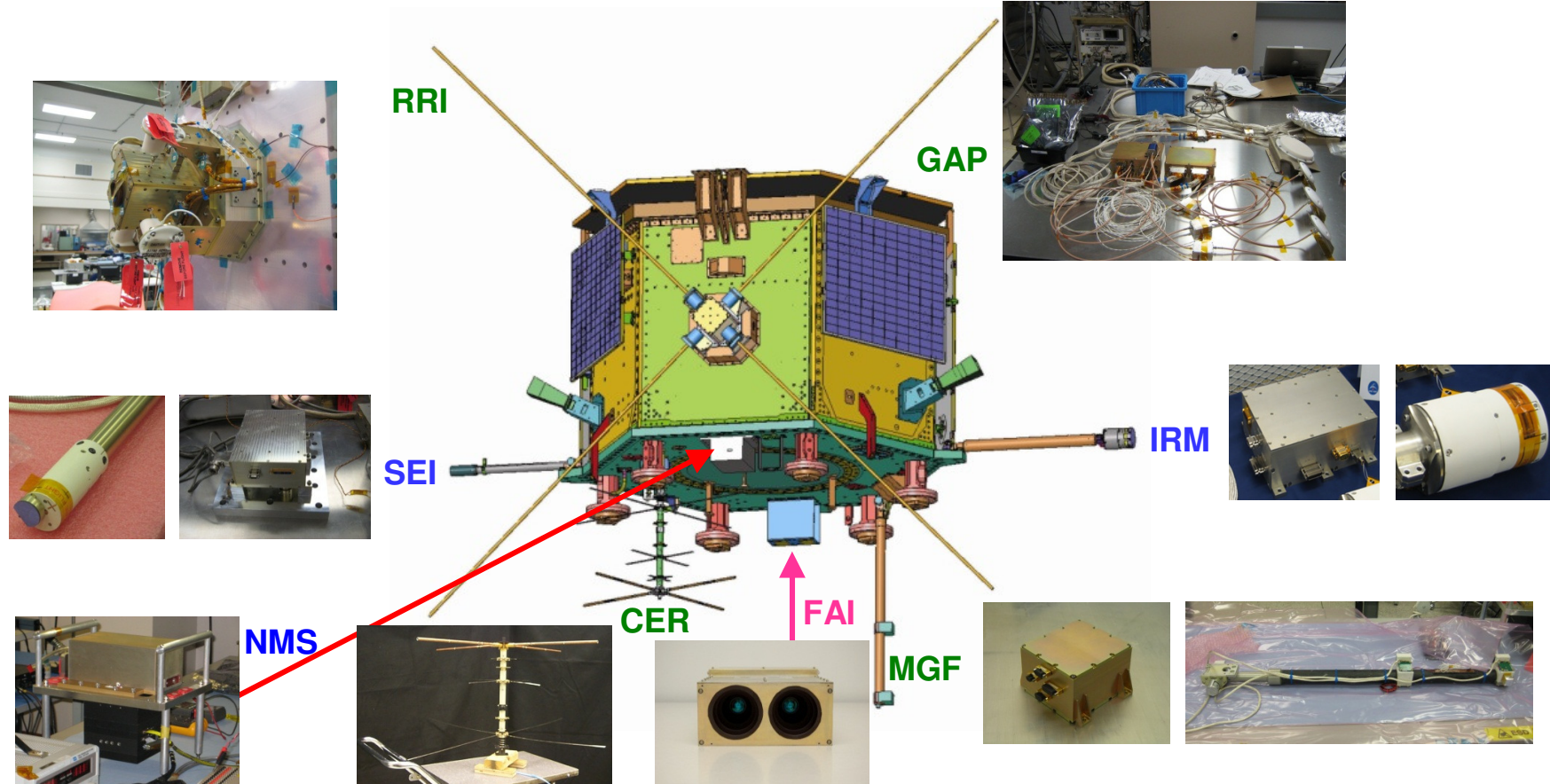
Science: Plasma outflow, neutral upwelling, aurora, radio propagation, related space weather effects in ionosphere

E-POP Space Weather Applications:

- Transient plasma density gradients (affect HF/GPS radio propagation)
- Neutral upwelling and drag (which affect orbits of LEO satellites)



e-POP Instrument Payload

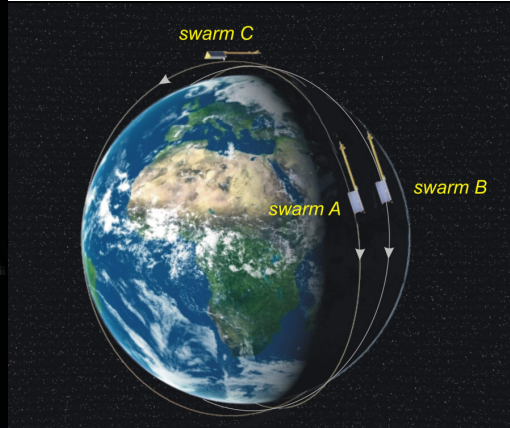


Launched 2013/09/29, 09:00 PDT
Polar orbiter: 325 × 1500 km, $I = 80^\circ$

	IRM	Imaging ion mass spectrometer	Yau/Calgary		MGF	Magnetic field instrument	Wallis/Calgary
	SEI	Suprathermal electron imager	Knudsen/Calgary		RRI	Radio receiver instrument	James/CRC
	NMS	Neutral mass velocity spectr.	Hayakawa/JAXA		GAP	GPS attitude and profiling	Langley/UNB
	FAI	Fast auroral imager	Cogger/Calgary		CER	Coherent EM radio tomogr.	Bernhardt/NRL



Swarm Electric Field Instruments

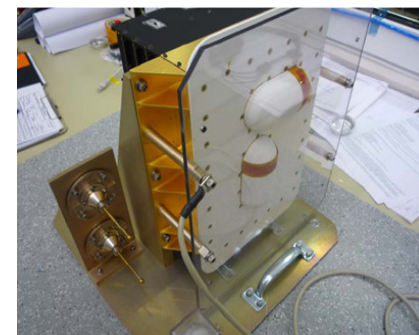
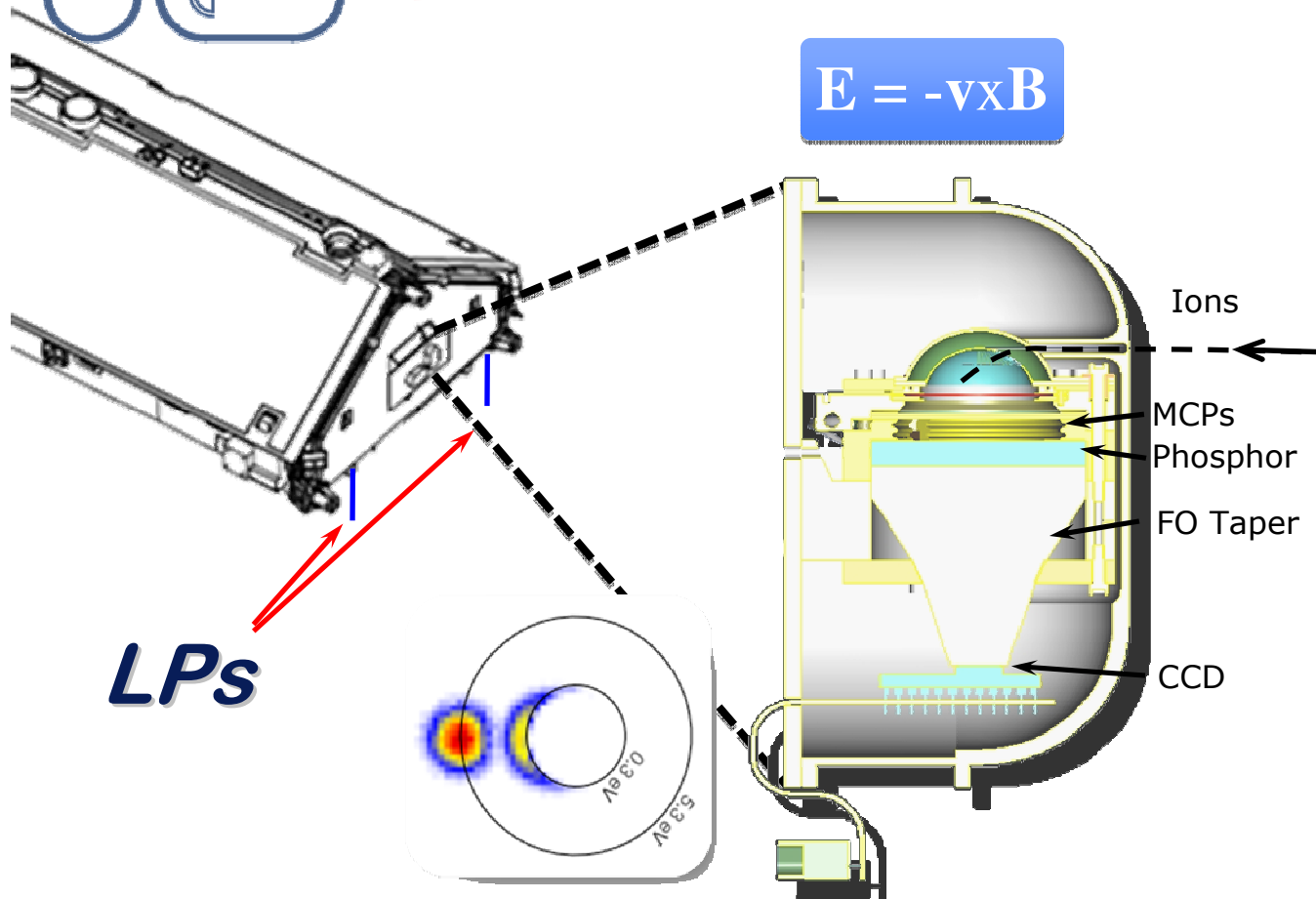


Launched 22nd Nov, 2013; $\sim 88^\circ$ inclination, 2 satellites altitude ~ 450 km (10s km apart), 1 at ~ 530 km (several hrs local time away)



TII sensor on Swarm

$$E = -v \times B$$



Imaging electrostatic analyzer, electro-optical detection

Langmuir probe

x 2 per satellite

3D velocity
from orthogonal
analyzers

Coarse ion
moments
@16Hz

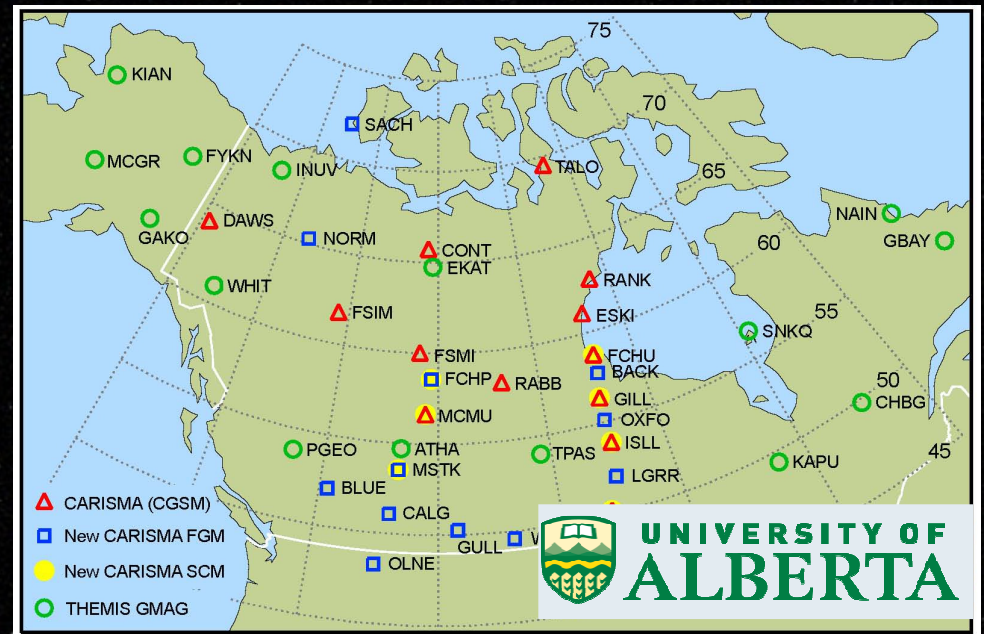
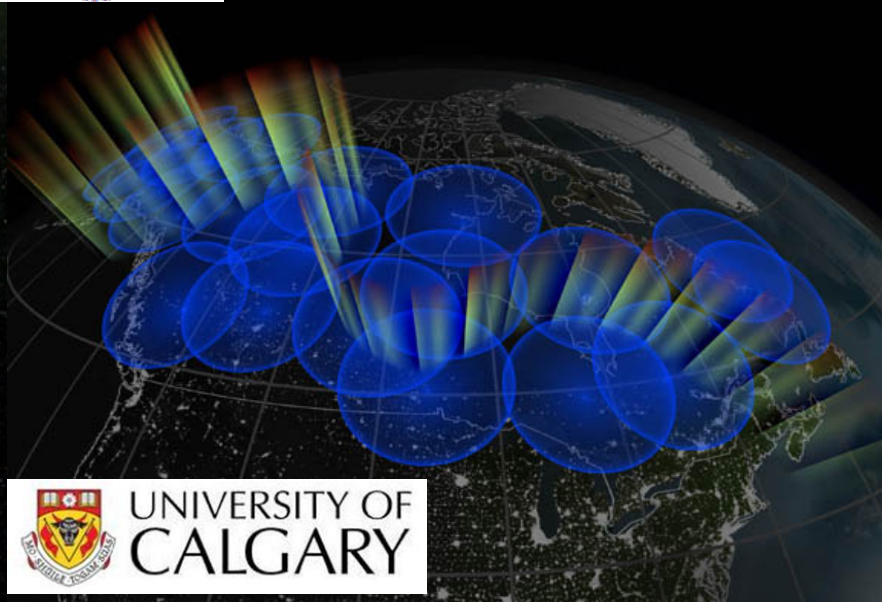
Calibrated
products @ 2Hz

675 Full images/day

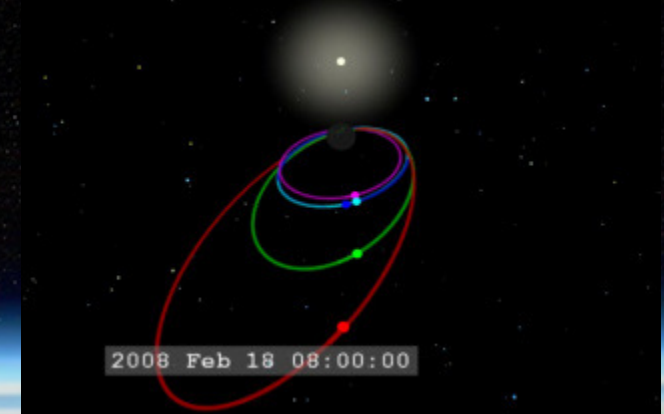
Electric Field Instrument (Canada) and Langmuir Probes (LPs; Sweden)



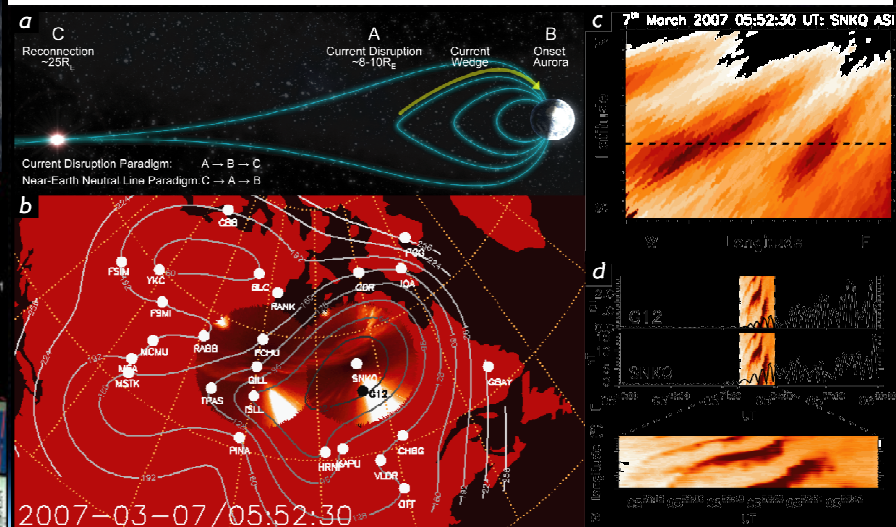
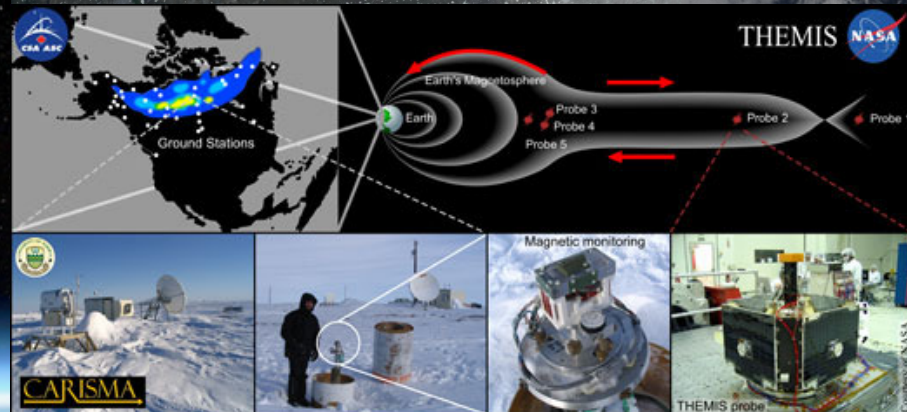
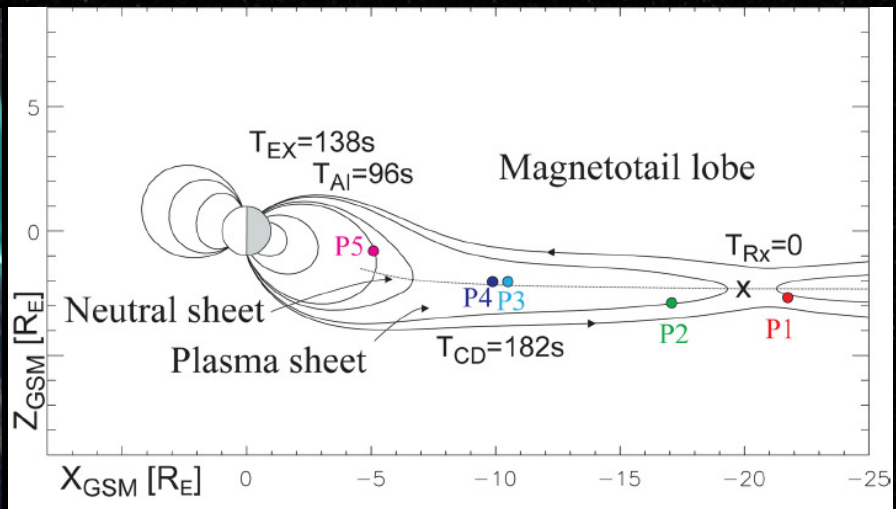
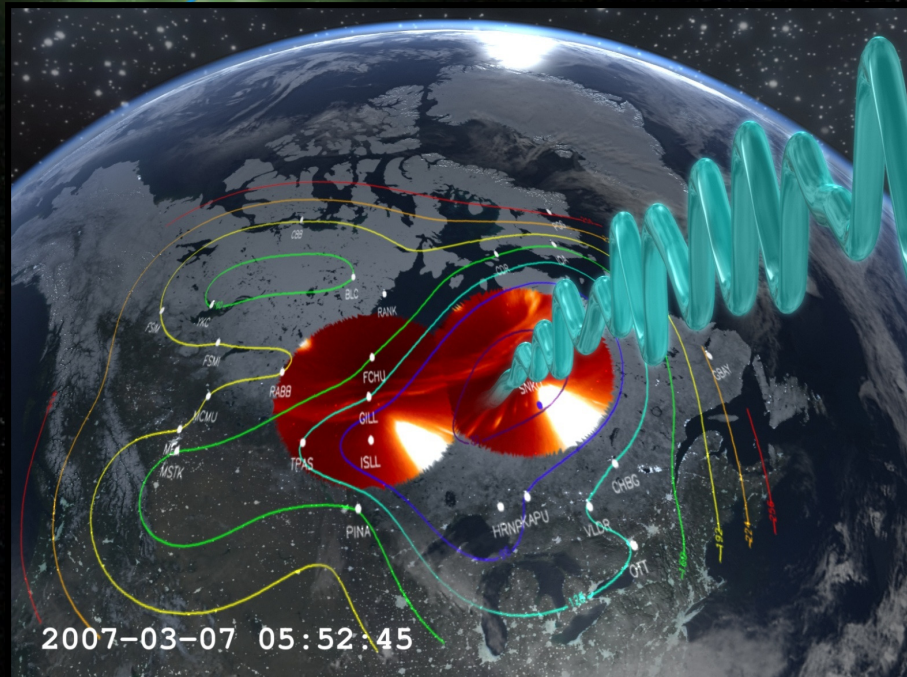
NASA-CSA THEMIS mission

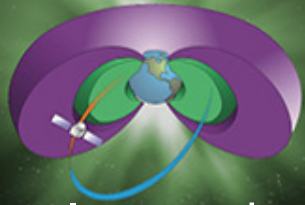


Canada plays a significant instrument role in THEMIS Ground-based Observatory Network in support of in-situ mission.



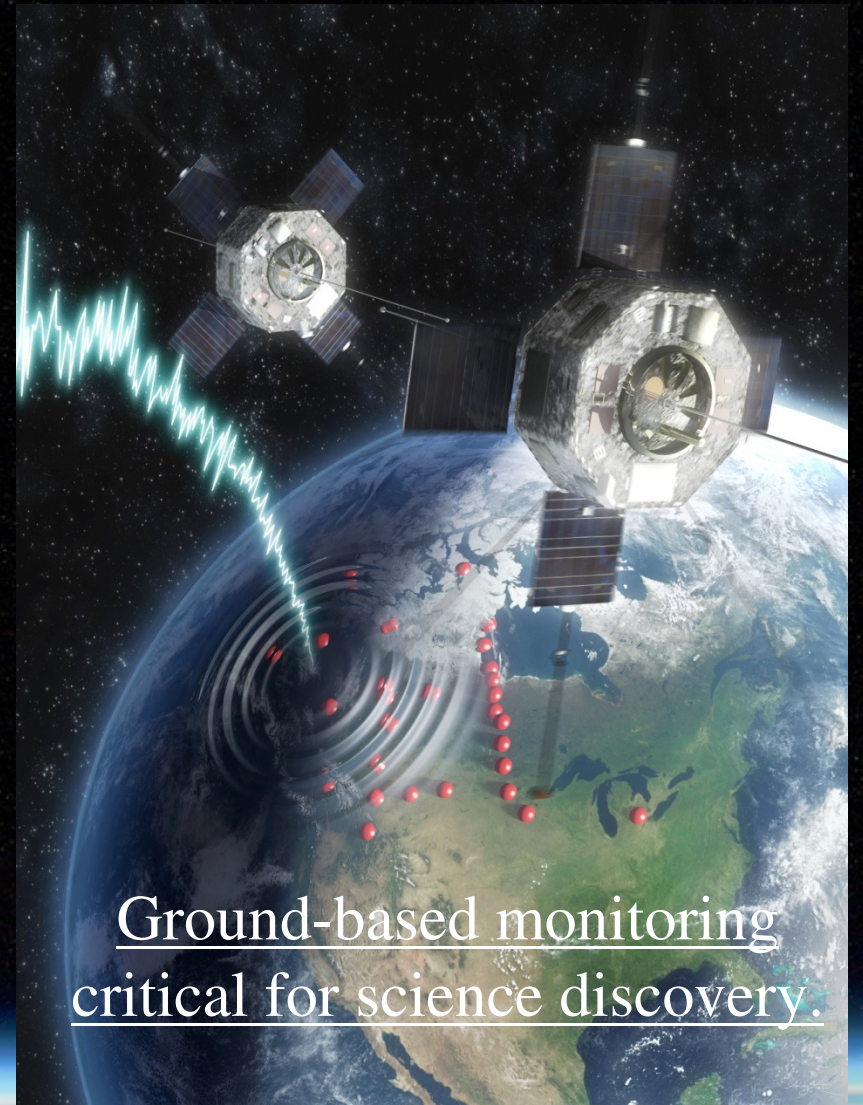
Significant Discoveries about Ignition of Substorm Onset



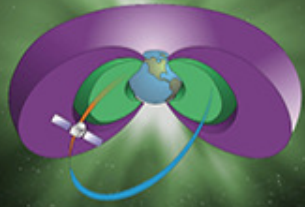


Radiation Belt Mission Support

- International priority: IAGA Policy (2009) Resolves that:
“member nations of IAGA co-operate and collaborate to the maximum extent possible in their pursuit of observational and modelling programs for radiation belt studies.”
- Support to n-situ missions, such as :
 - NASA Van Allen Probes (2012).
 - Russian RESONANCE (2016)
 - Japanese ERG (2016)
- Exploiting ground-satellite conjunctions key for understanding wave-particle acceleration and loss processes.
- ***Represents niche Canadian role.***

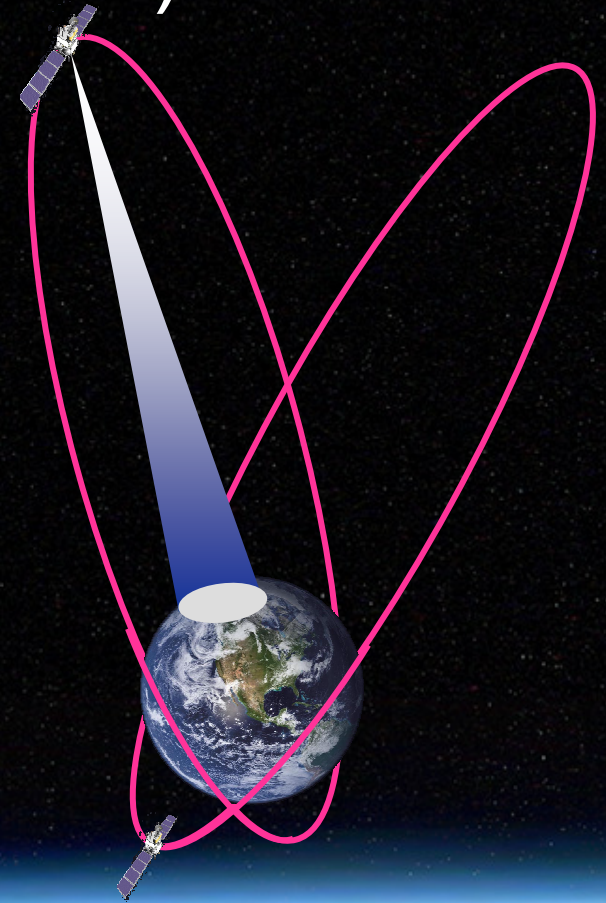


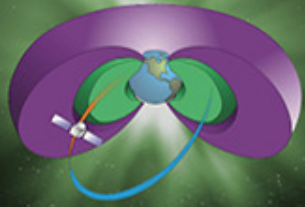
Ground-based monitoring
critical for science discovery.



Proposed Canadian Polar Communications and Weather (PCW) Mission

- Proposed mission focussing upon 24/7 polar communications and weather capacity.
- Reflects Canadian challenges and interests as a country operating in a changing polar north, including maintaining sovereignty and security.
- Includes **space weather** payload as primary payload, reflecting its importance.
- Mission still under study; if approved mission development may begin in 2016.

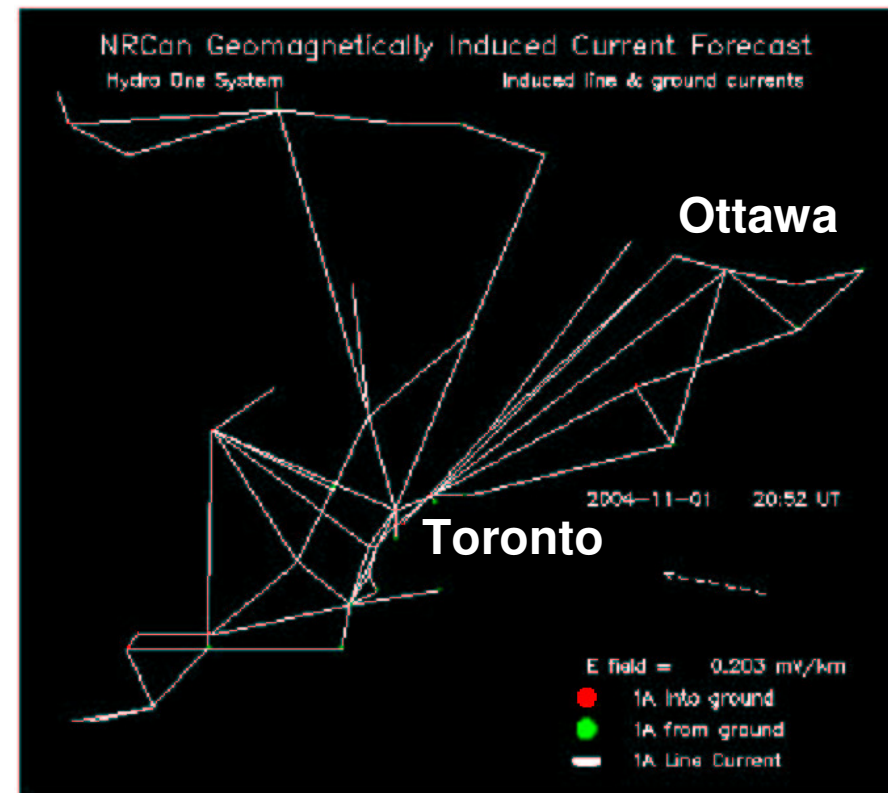
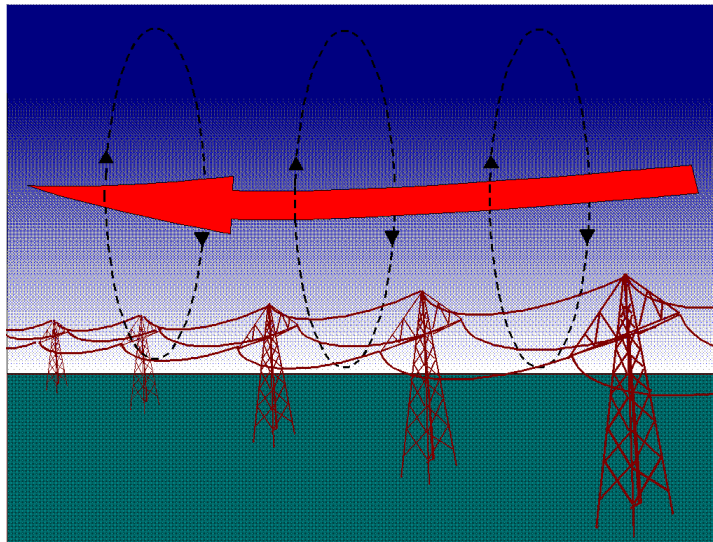
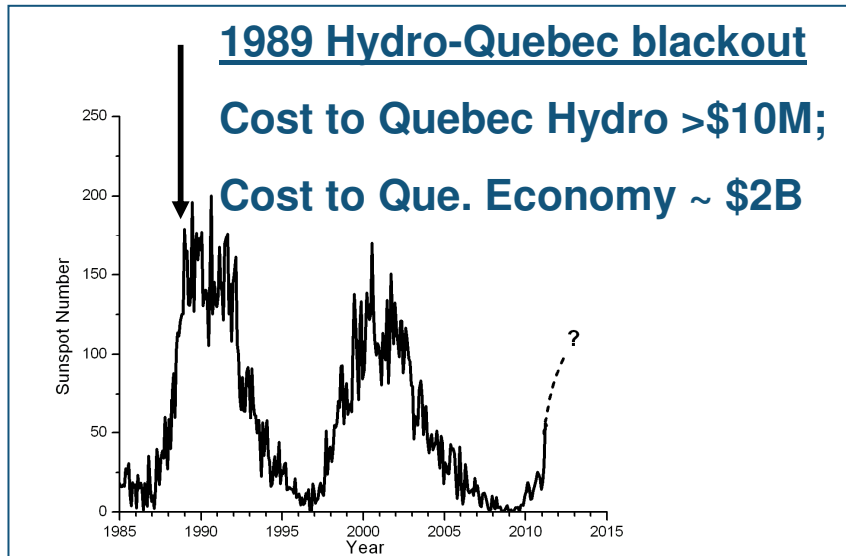




Space Weather Risks and Operations

Electrical Transmission Systems

Risk: Catastrophic power system blackouts



Mitigation:
Real-time alerts via NRCan's forecast services and geomagnetically-induced current (GIC) simulators



Natural Resources
Canada

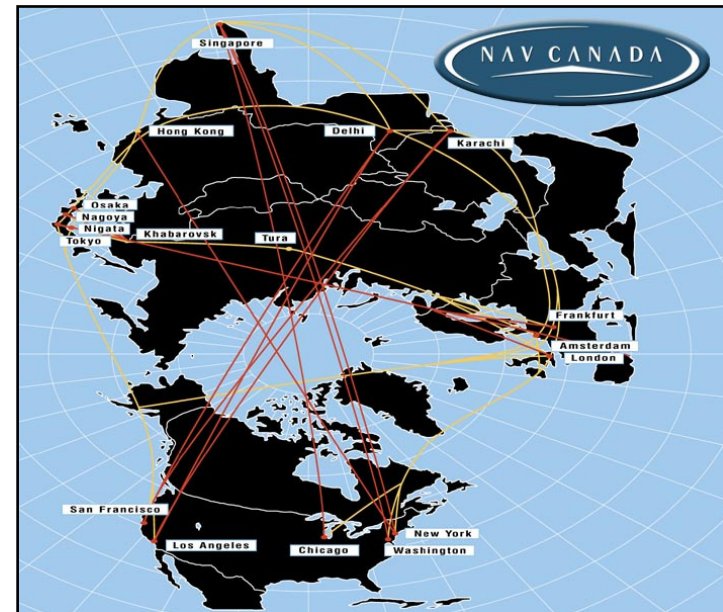
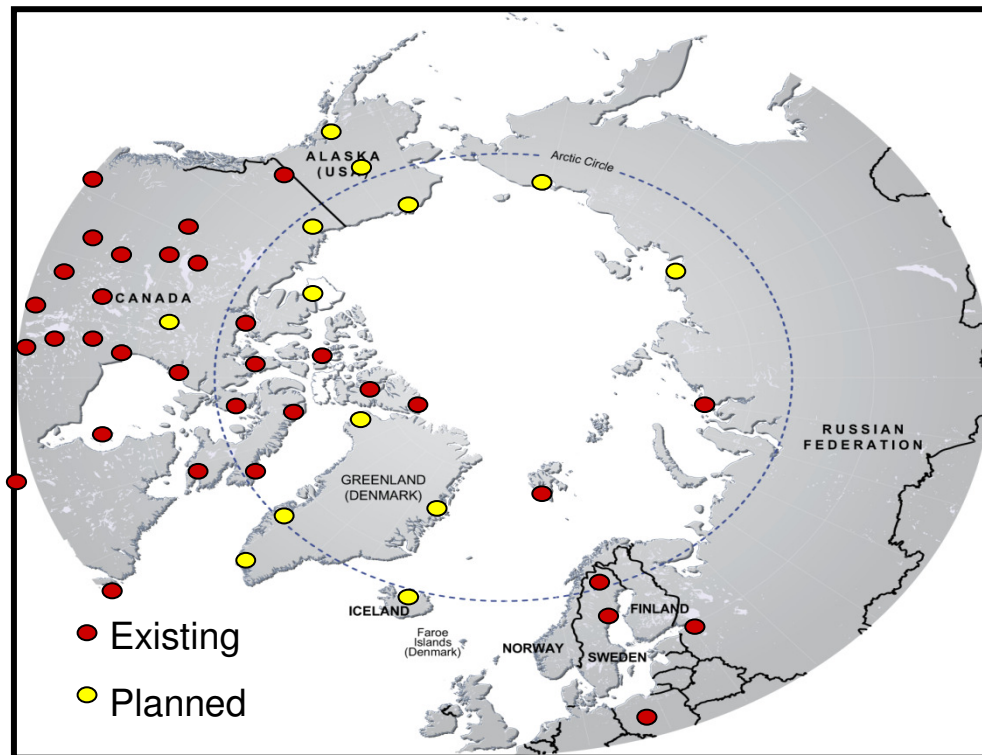
Ressources naturelles
Canada

Canada

Communication Systems

Risk: Air traffic safety

- It costs an airline an average of \$100K for each diverted flight;
- A 2005 space weather event resulted in United Airlines diverting 26 flights.



Mitigation: Integration of SW alerts and forecasts into aviation operations



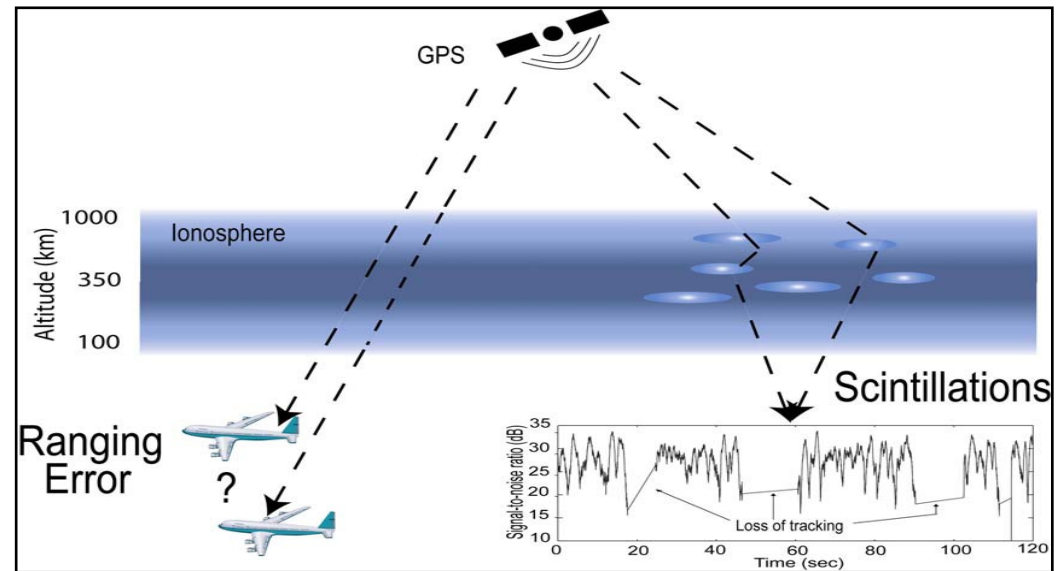
Natural Resources
Canada

Ressources naturelles
Canada

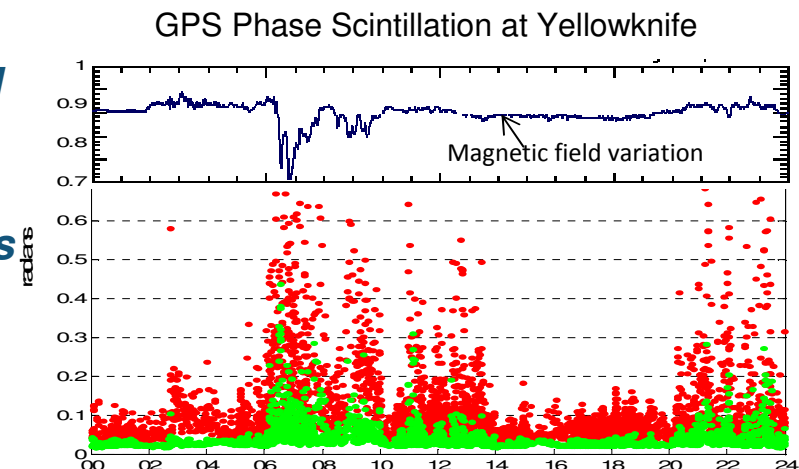
anada

GNSS Systems

Risk: All position and time dependent operations – e.g. travel (land, air & sea), surveying & banking.

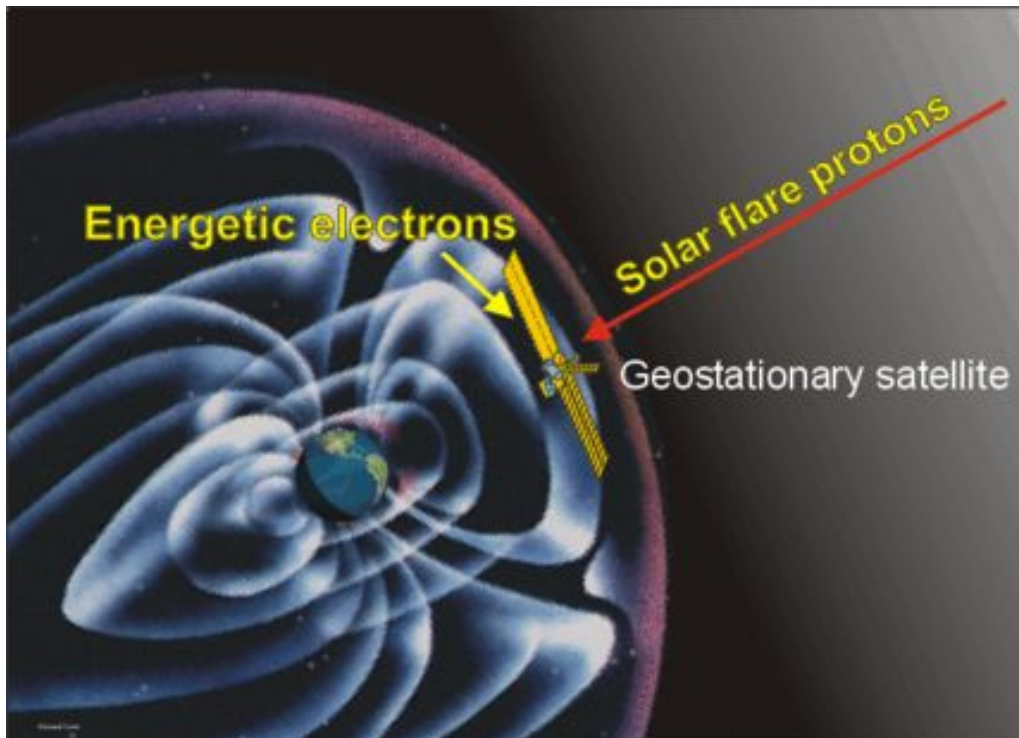


The NRCan space weather team have joined forces with the NRCan Geodetic Survey and Universities to investigate the extent of the problem in different regions of Canada, especially the auroral zone and polar regions where space weather disturbances are more intense.

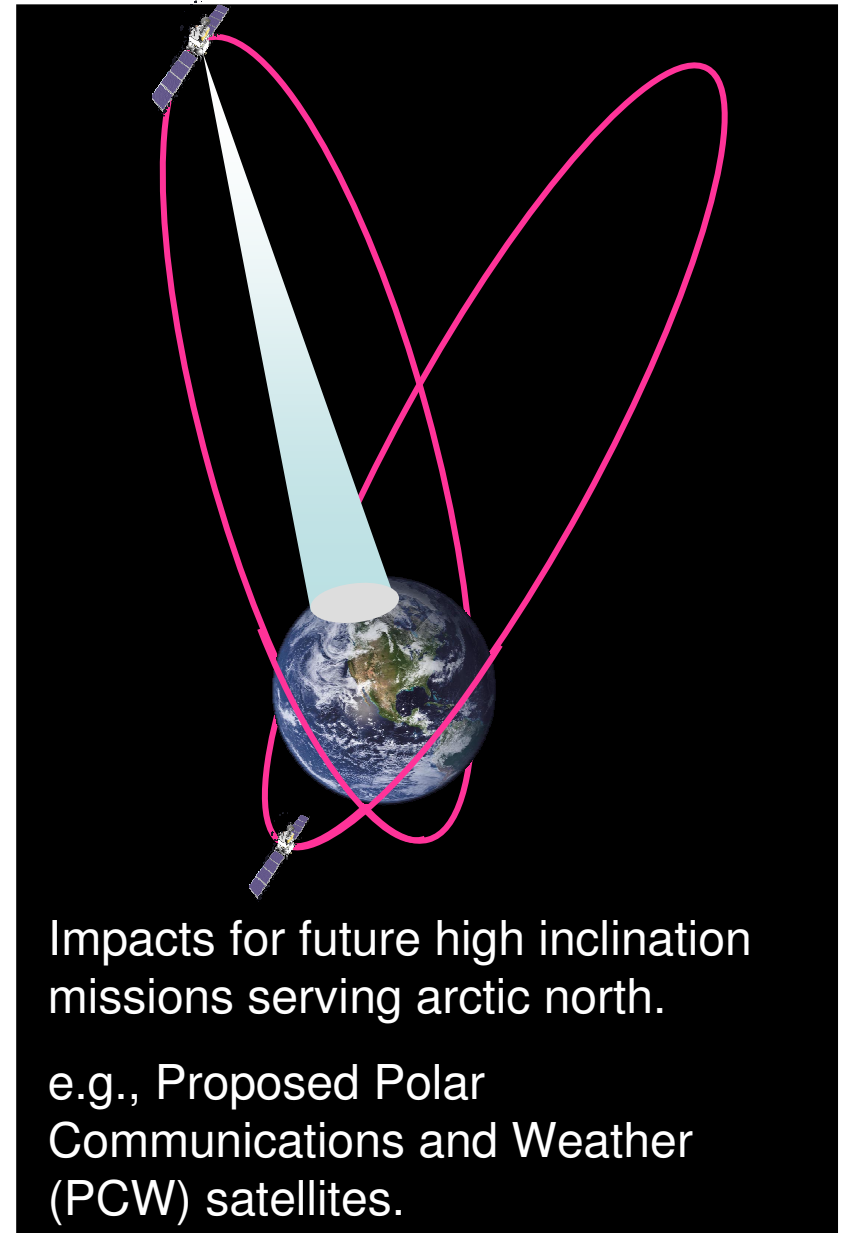


Satellite Systems

Risk: *Satellite safety & operations*

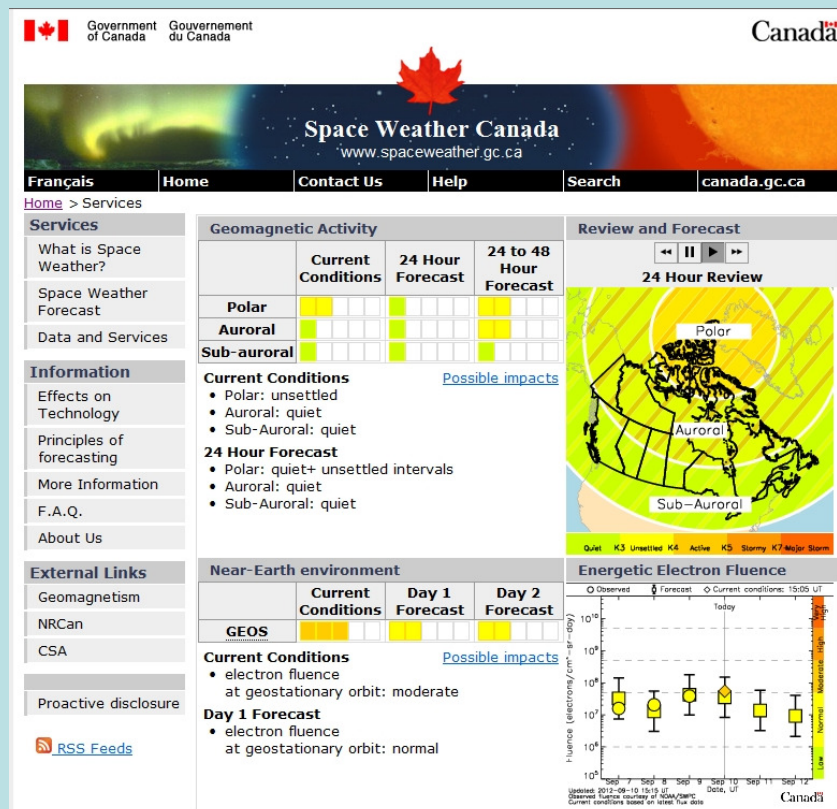


Mitigation: *SWAIS (Space Weather Anomaly Investigation System)*

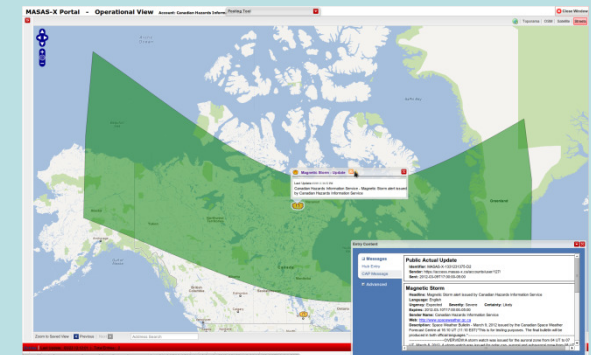


Operational links of NRCan Space Weather Forecasting

Canadian Space Weather Forecast Centre
NRCan Canadian Hazards Information Service



Government Operations Centre



Critical Infrastructure Operators

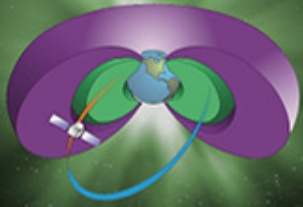


Natural Resources
Canada

Ressources naturelles
Canada

Also supported by modelling programs at U.
Alberta, U. de Montreal, Queens U.

Canada



Summary and Conclusions

- Mitigating space weather impacts and accurate forecasting requires ***further scientific discovery***.
- Substorm and radiation belt science discoveries, and understanding space weather impacts, continues apace. ***Critical Infrastructure Protection*** is a key future focus.
- ***Ground-based networks*** co-ordinated with ***satellite missions*** offer key opportunity and niche Canadian strength.
- COPUOS STSC ***Space Weather agenda item*** provides beginnings of international cooperation framework for maintaining the long-term sustainability of outer space against space weather effects.
- Canada stands ready through a ***new space policy framework***, using both ground-based and in-situ missions, and leveraging collaborations between government, academia and industry, to make a significant contribution to this priority international endeavour.