GNSS Use in the High Arctic: Issues and Solutions from a Canadian Perspective

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ESA Workshop on Usage of GNSS in the High North, Tromsø, Norway, 24-26 June 2009

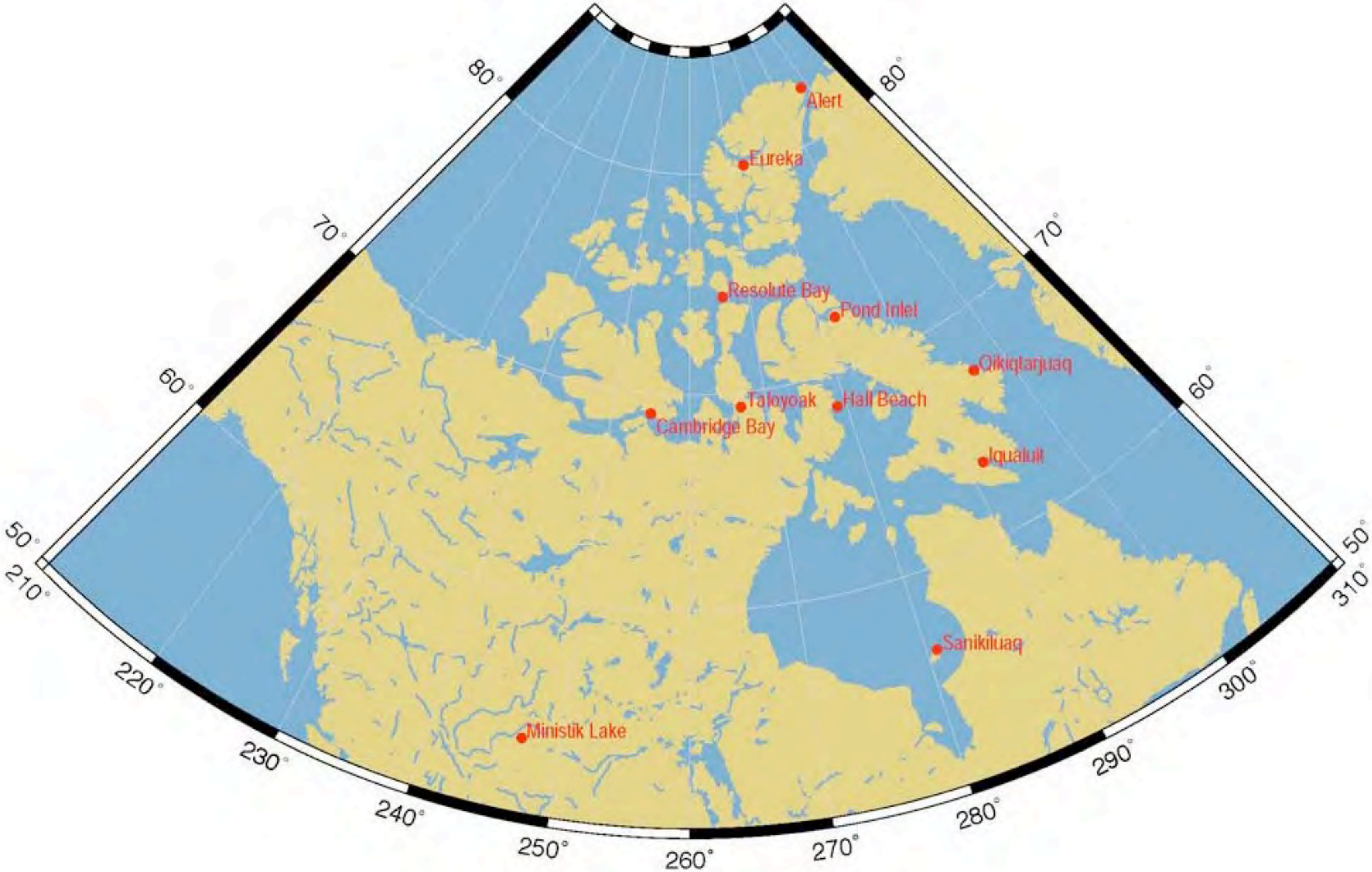
Relevant Experience

- Deployment and operation of the Canadian High Arctic Ionospheric Network.
- Modelling and analysis of GNSS data from around the globe, including the high Arctic (also extensive monitoring of GPS (including modernized GPS), GLONASS, GIOVE, and SBAS signals at UNB).
- Some work with polar-orbiting satellites hosting GPS receivers (CASSIOPE, etc.).

What is CHAIN?

- CHAIN is a network of ionospheric monitoring tools across the Canadian north, mostly in the high Arctic
- Designed to help fill the gap in deployed instruments in polar regions
- Consists of 10 dual-frequency GPS scintillation receivers and 7 digital ionosondes
- Low-rate data transferred in real time using satellite modems
- High-rate data recorded on removable compact hard drives shipped south monthly

CHAIN Sites



Alert
Eureka
Resolute Bay
Pond Inlet
Qikiqtarjuaq
Taloyoak
Hall Beach
Cambridge Bay
Iqaluit
Sanikiluaq
Ministik Lake
80°
70°
60°
50°
80°
70°
60°
50°
210°
220°
230°
240°
250°
260°
270°
280°
290°
300°
310°

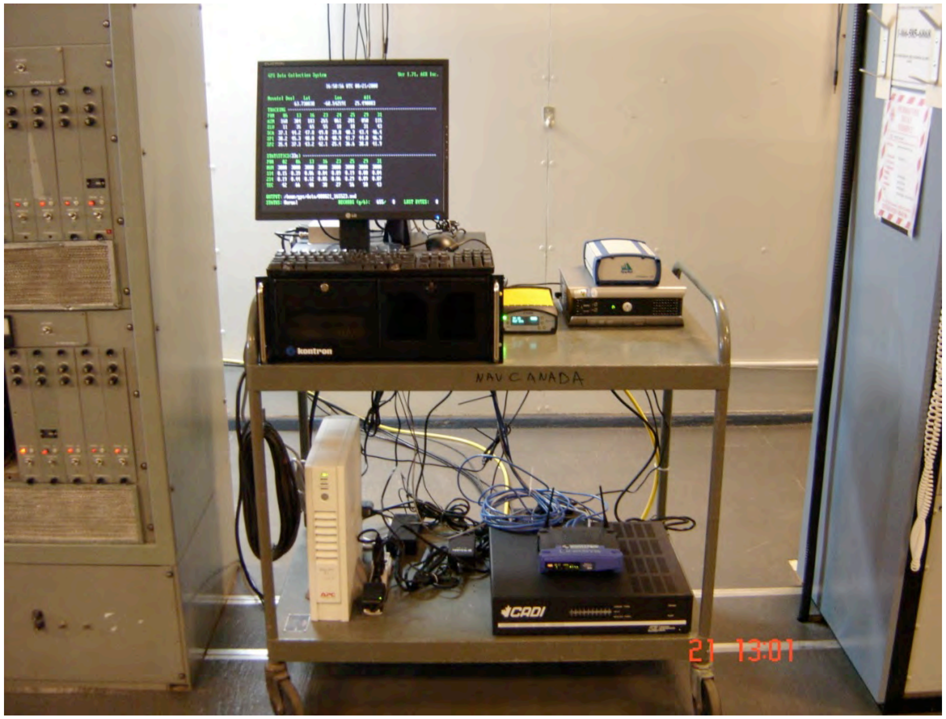
Scientific Objectives of CHAIN

- Improve understanding of the polar cap ionosphere in relation to the Solar Wind - Magnetosphere - Ionosphere coupling and, in particular:
  - Drivers and variabilities of polar cap convection
  - Generation and dynamics of ionization structures in the polar cap
    - Macroscale: tongues of ionization (> 100 km)
    - Mesoscale: polar patches (few hundred km)
    - Microscale: scintillation producing structures (few km)
  - Role of ionosphere in magnetosphere-ionosphere coupling
- Improve handling/modelling of effects on GNSS

Equipment

- GPS Silicon Valley GSV4004B dual-frequency GPS scintillation receivers with NovAtel GPS-702 antennas (mostly)
- Canadian Advanced Digital Ionosondes
- PCs, routers, etc.
- Ka-band satellite Internet using SurfBeam modems, 67-cm dish, and Telesat GEO

Iqaluit



Qikiqtarjuaq

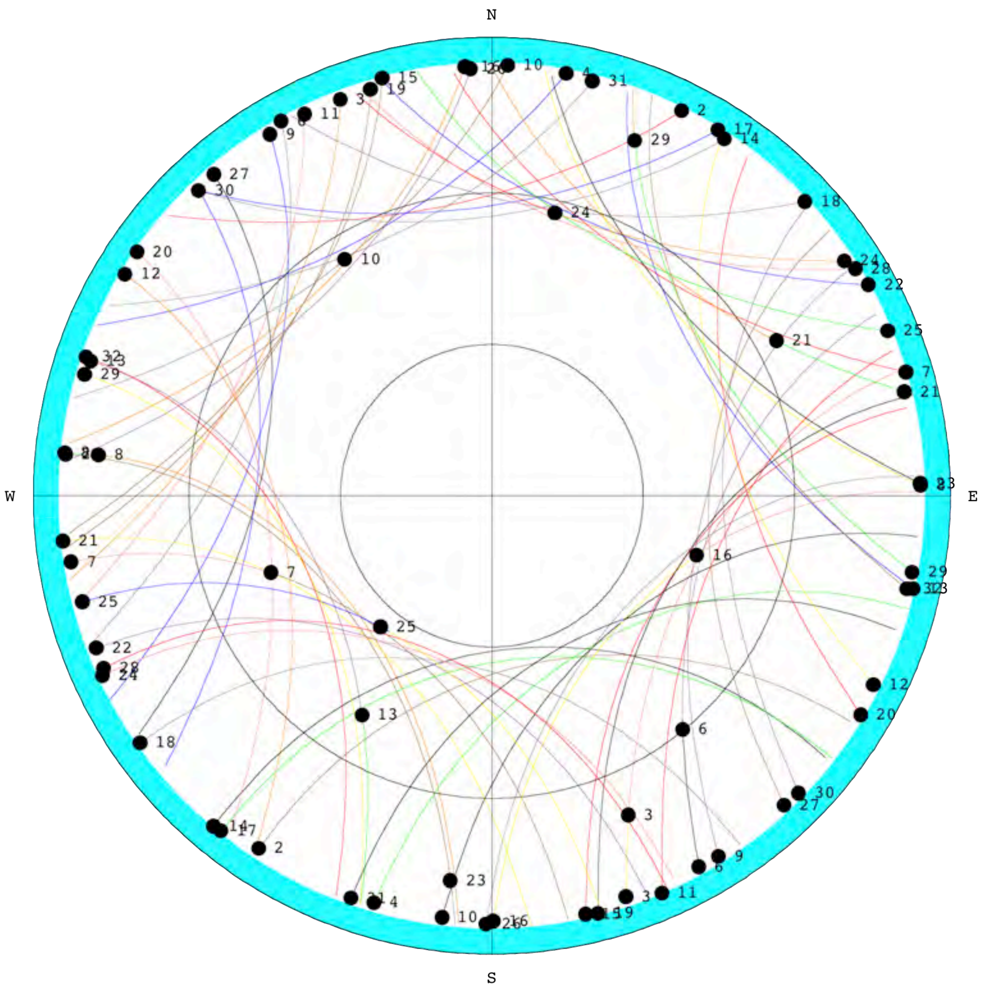
High Arctic GNSS Issues

- GNSS Satellite Visibility
- SBAS Satellite Visibility
- Atmospheric Effects
- Monumentation for Scientific Applications
- Logistics
- Utilities
- Security
- Maintenance

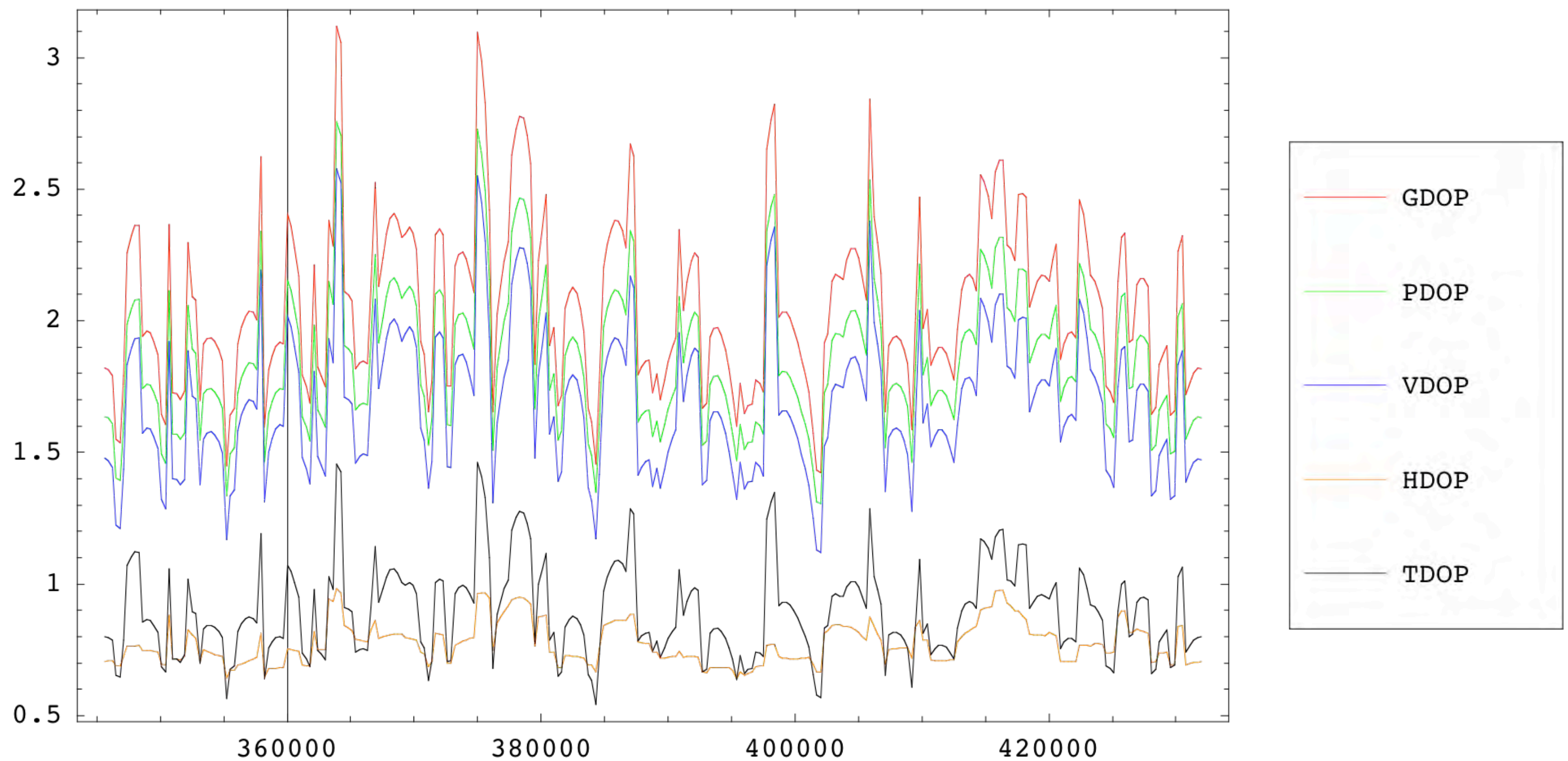
GNSS Satellite Visibility

- Relatively low orbit inclinations means no high elevation angle passes in the far north.
  - GPS: 55°
  - GLONASS: 64.8°
  - Galileo: 56°
- Will have an effect on vertical and 3D positioning, though horizontal positioning accuracy can be quite good.

GPS Sky Plot, Eureka (80.0°N), 21 May 2009



GPS DOPs, Eureka (80.0°N), 21 May 2009



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SBAS Satellite Visibility

- Geostationary SBAS satellites are low on the horizon, if they can be seen at all.
- e.g., at 70°N, a GEO has an elevation angle of 11.5° if due south; at 80°N, 1.3° if due south; elevation angles will be even lower for GEOs not on the observer's meridian.
- From Tromsø (69°40′58″ N 18°56′34″ E):
  - Artemis (21.5°E): 11.8°
  - IOR-W (25°E): 11.7°
  - AOR-E (15.5°W): 8.0°
- Weaker signals; poorer range measurements; blockage by obstructions

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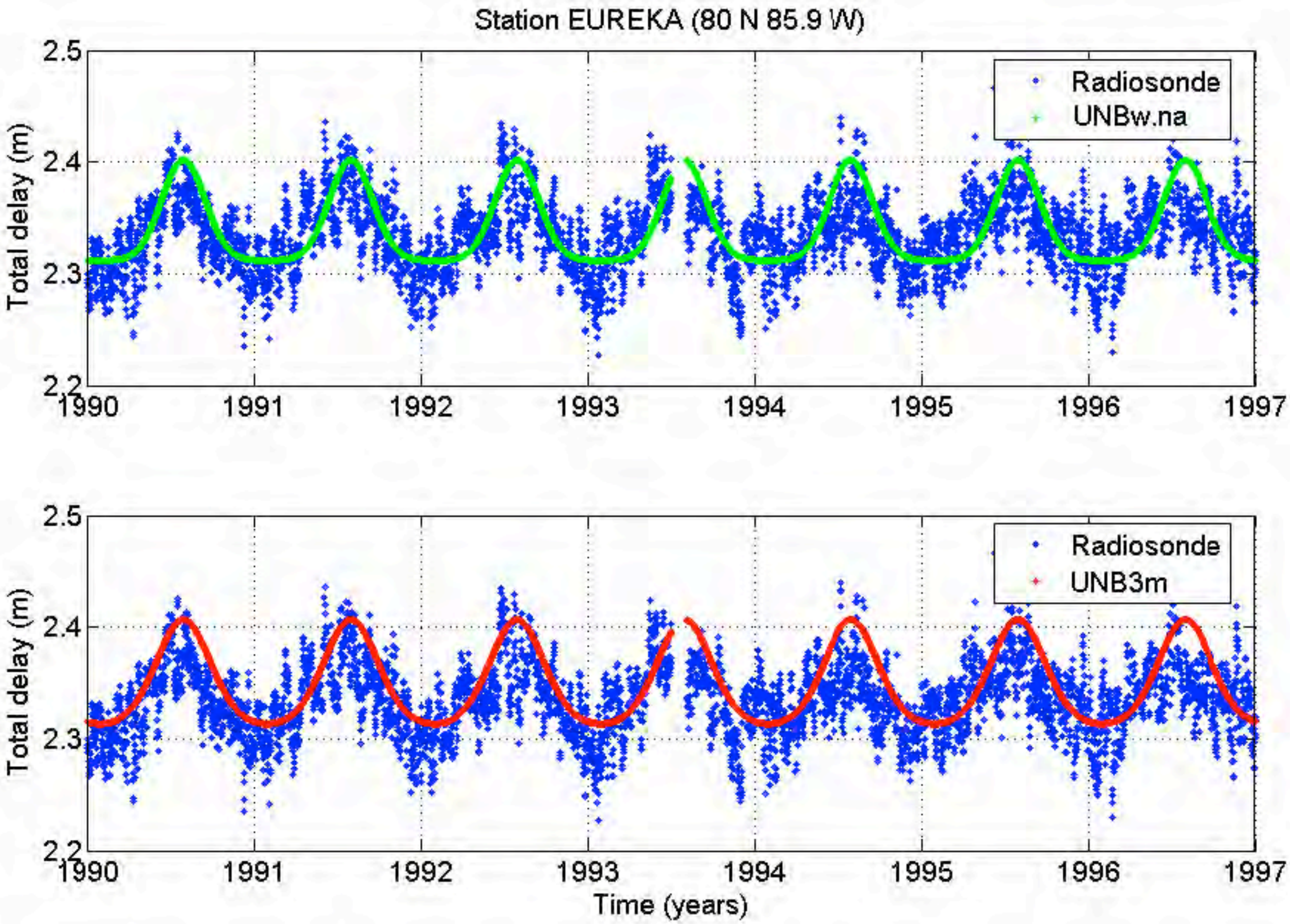
Atmospheric Effects -1

- Neutral atmosphere (troposphere):
  - Unique weather characteristics (generally drier).
  - On average, larger delays due to lower elevation angles of satellites than at mid-latitudes.
  - Global predictive models might not perform as well at high latitudes.
  - Include high-latitude calibration data in developing models (as done for UNBw.na).

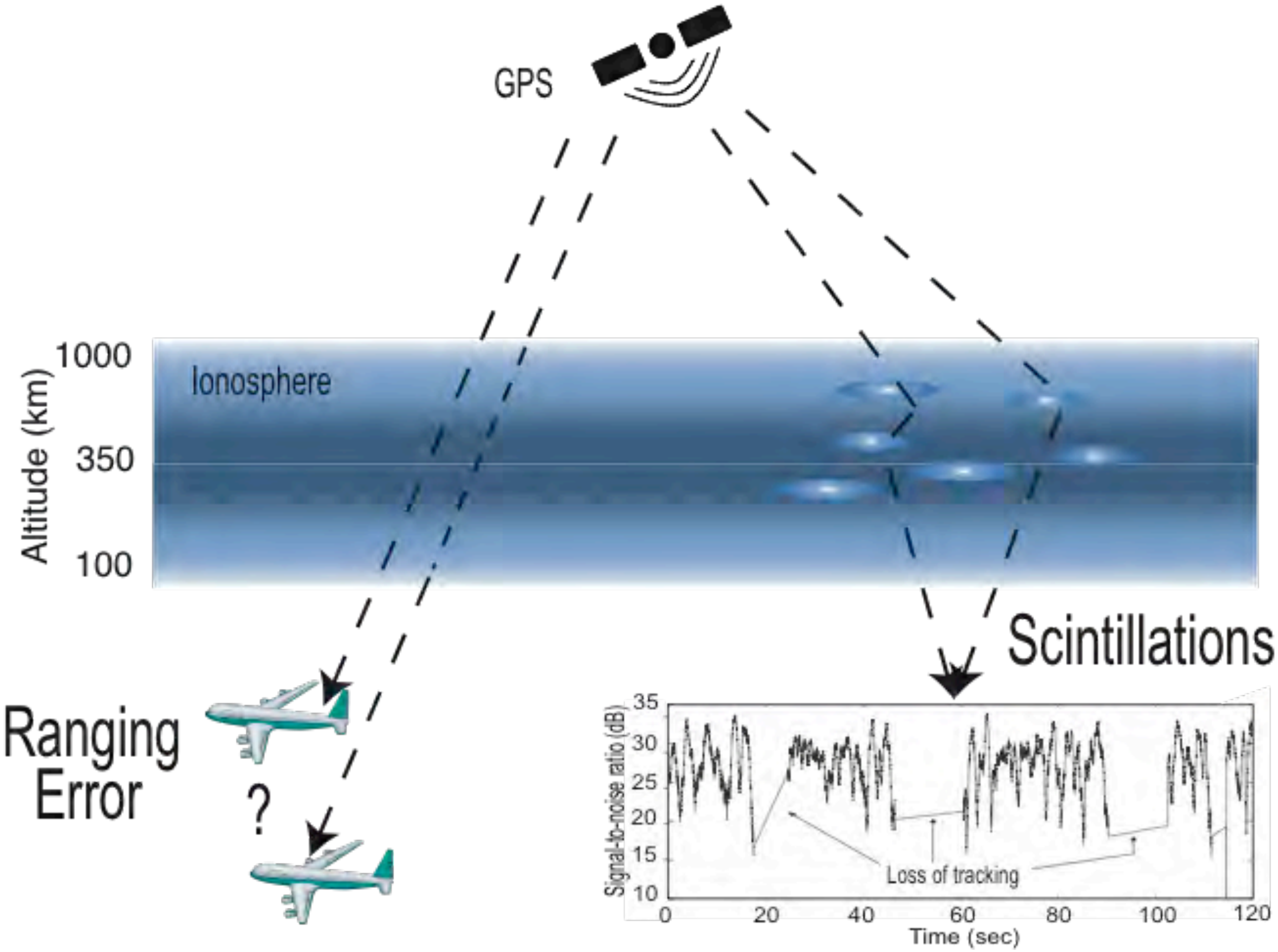
Neutral Atmosphere Delay Prediction



Atmospheric Effects -2

- Ionosphere
  - Behaviour different at auroral and polar latitudes than at mid-latitudes.
  - Single-frequency model might not perform as well at such latitudes due to inability to monitor and capture that behavior and disseminate it to users.
  - Scintillation
    - Effects on single-frequency performance
    - Tracking issues (possible loss of lock)

Ionospheric Effects on GNSS



Courtesy: Cornell University

13/06/09
RBL

High Arctic GNSS Issues

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Monumentation for Scientific Applications

- Able to withstand extreme weather; tamper-proof.
- Pole-mounts on buildings might be acceptable for atmospheric research; high-stability monuments needed for geodynamics studies, etc.
- Ideal bedrock might not be available.
- Difficulties with ice and permafrost:
  - For permafrost in Alaska, UNAVCO is using a thermopile (sealed 4.5-inch diameter steel pipe 21 feet in length filled with CO_2 at a pressure that allows it to exist in both liquid and vapour states at all times), which resists movement due to the freeze-thaw cycle.

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Logistics

- Transportation:
  - How?
  - Costs
- Not unique to GNSS operations.

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Utilities

- Electricity
  - Commercial availability?
  - Reliability?
  - Storage batteries / UPS
  - Solar (little use in winter)
  - Wind power
- Communications
  - Commercial availability (phone line, etc.)?
  - Satellite communications (visibility issues?)
  - UHF/Microwave link

High Arctic GNSS Issues

- GNSS Satellite Visibility
- SBAS Satellite Visibility
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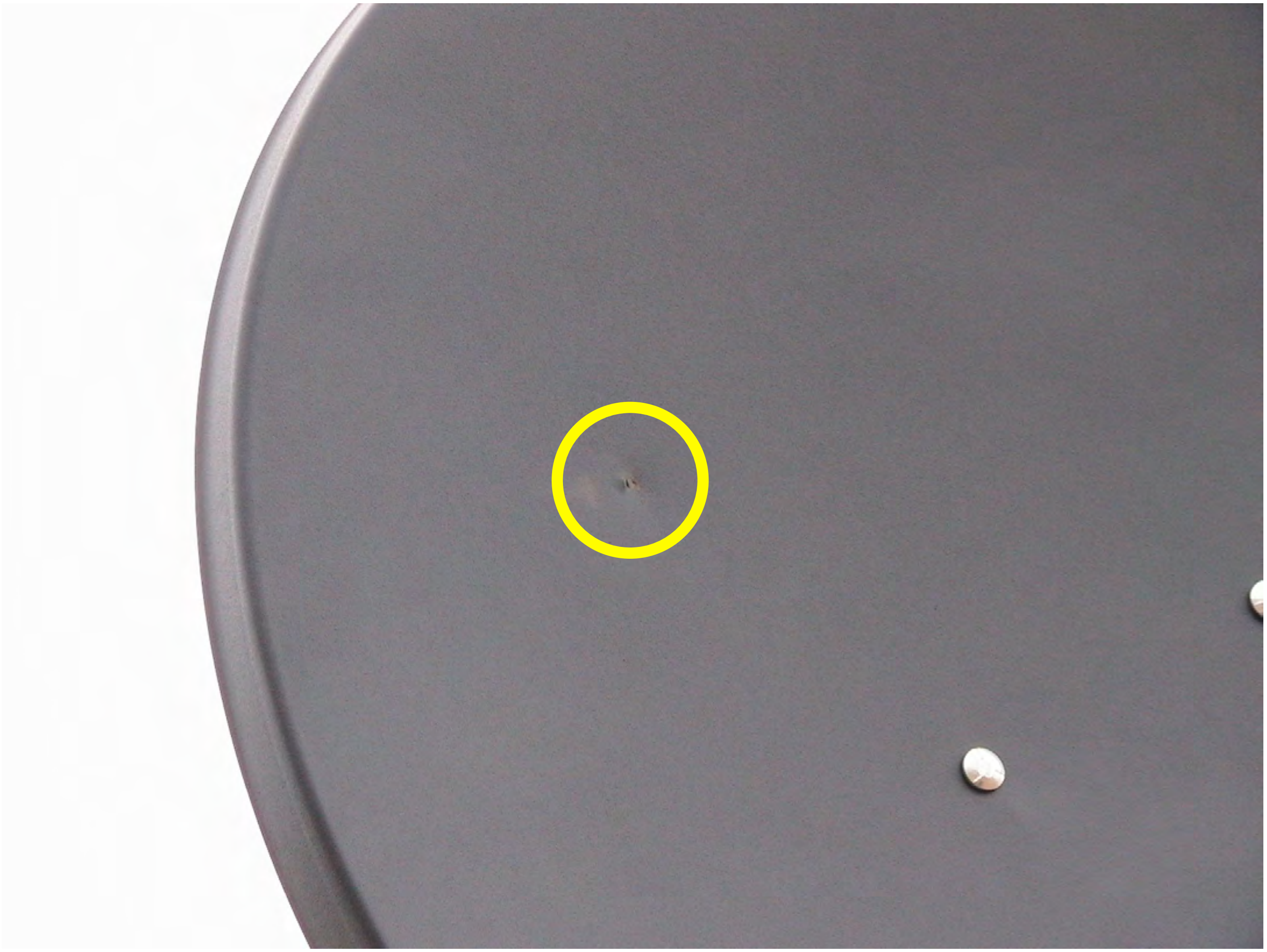
- Logistics
- Utilities
- **Security**
- Maintenance

Security

- Isolated, unattended stations.
- Precautions to avoid damage by people and wildlife.
- Minimize accessibility.
- Use of motion detectors, sirens / loudspeakers, video cameras for strategic installations.

Damage to Communications Antenna



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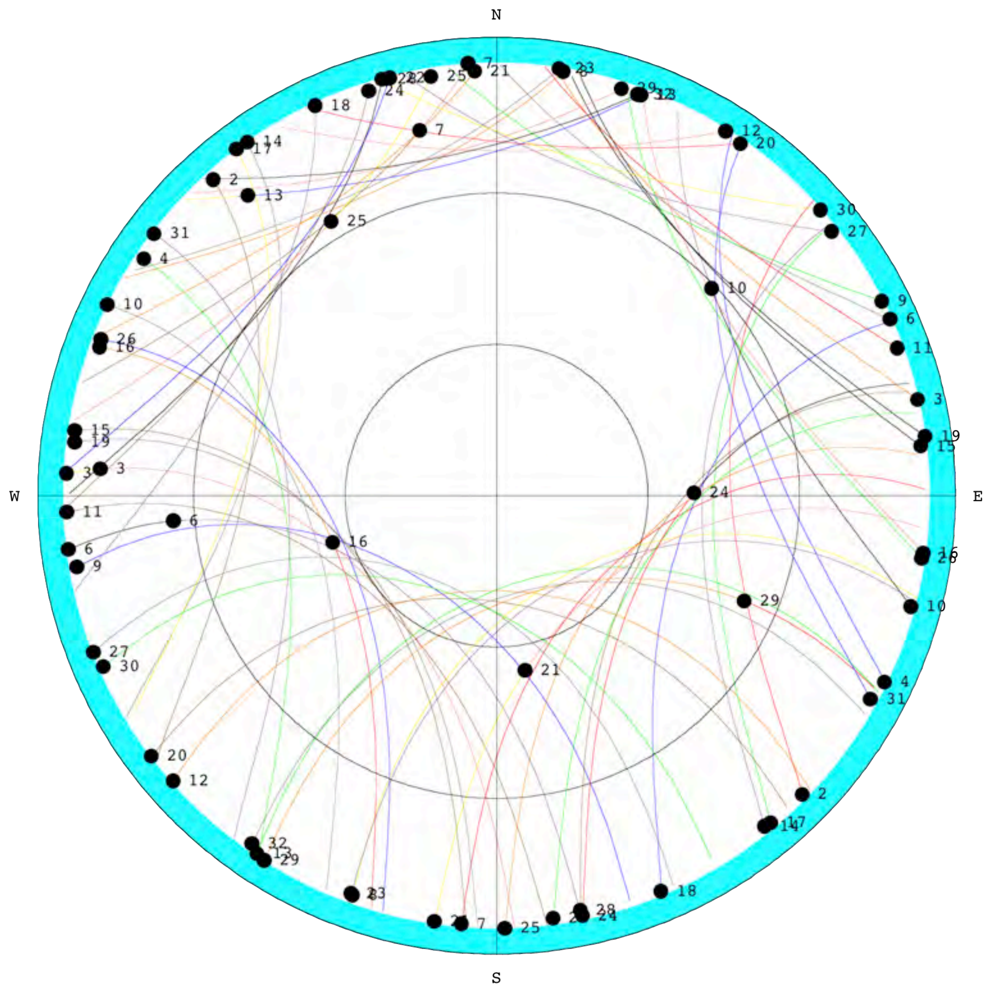
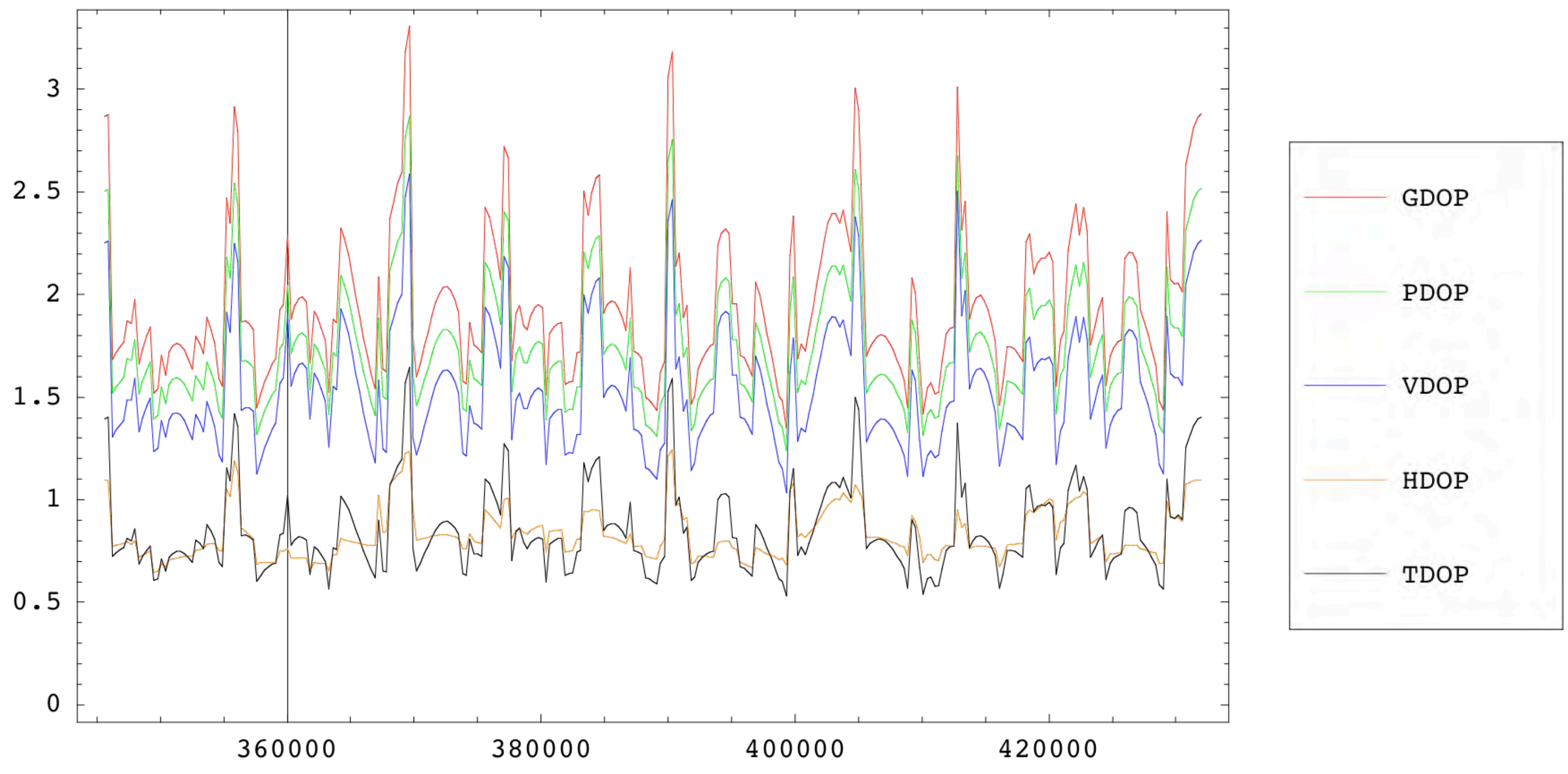
Maintenance

- Need for high reliability / redundancies for continuous operation.
- Logistics for speedily carrying out repairs.
- Use of indigenous nearby personnel.
- Snow scoop-out from choke-ring antennas.

GPS Sky Plot, Tromsø (69.7°N), 21 May 2009



GPS DOPs, Tromsø (69.7°N), 21 May 2009



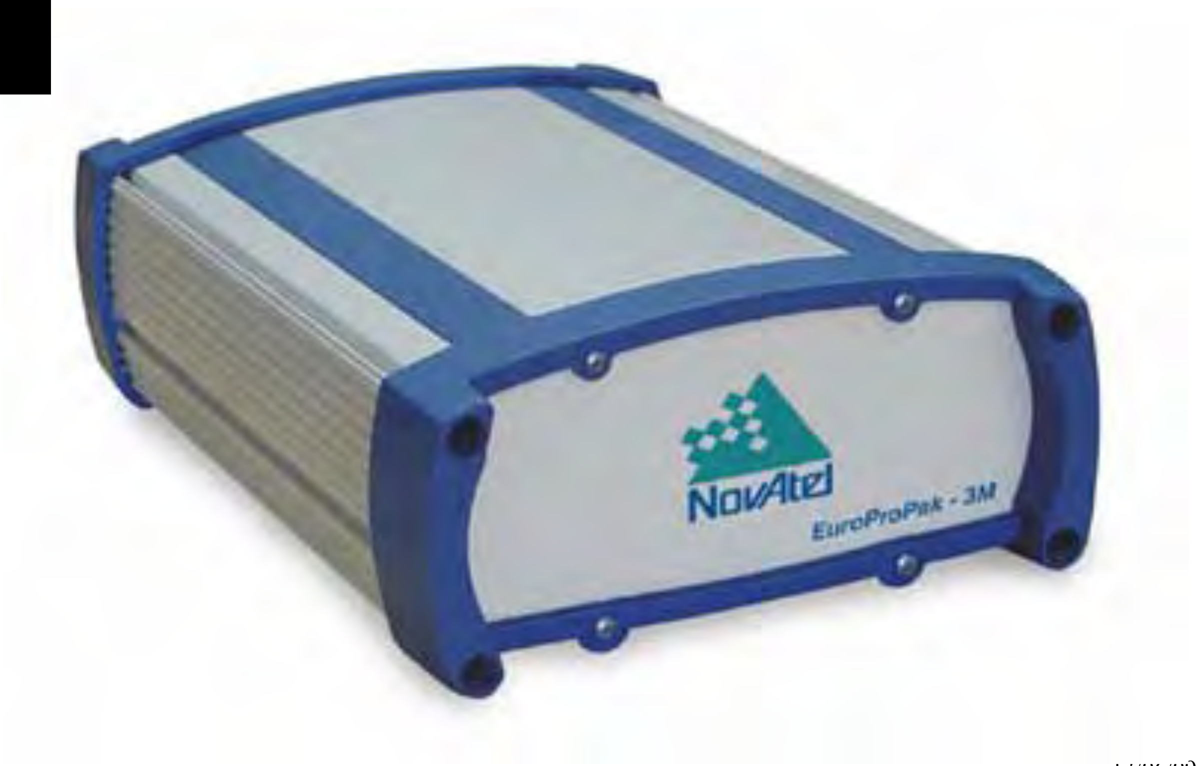
Outline

- Motivation
- What is CHAIN?
- CHAIN instruments
- Status
- Data products
- Synergy with other systems

GSV4004B (10)

- NovAtel EuroPak-3M L1/L2 aviation-product receiver with a low phase-noise oven-controlled crystal oscillator
- Modified firmware
- 10 GPS channels and 3 SBAS channels
- Provides pseudorange and carrier-phase measurements at up to 50 Hz rate as well as sigma-phase and S4 scintillation measurements and total electron content (TEC)
- GPS Silicon Valley (A.J. van Dierendonck)

GSV4004B Receiver and GPS702 Antenna



Canadian Advanced Digital Ionosonde

- Height range up to 512 km (to be increased to 1000 km) with 6 km resolution.
- The digital control system provides high flexibility. Multiple operating modes are available.
- Frequency range from 1 to 20 MHz. Three standard sweeps: low-res (100 freqs.), medium-res (200 freqs.), high-res (400 freqs). Step size: linear or log.
- PC-based.
- Transmitter: 600W solid state.
- Receiver: four or more receivers for spaced antenna measurements.

Canadian Advanced Digital Ionosonde (7)

Cambridge Bay CADI Set-up

Iqaluit: CHAIN and WAAS Site

Acknowledgements

- Canada Foundation for Innovation
- New Brunswick Innovation Foundation
- Canadian Space Agency
- Natural Sciences and Engineering Council of Canada
- University of Western Ontario
- CHAIN Science Team

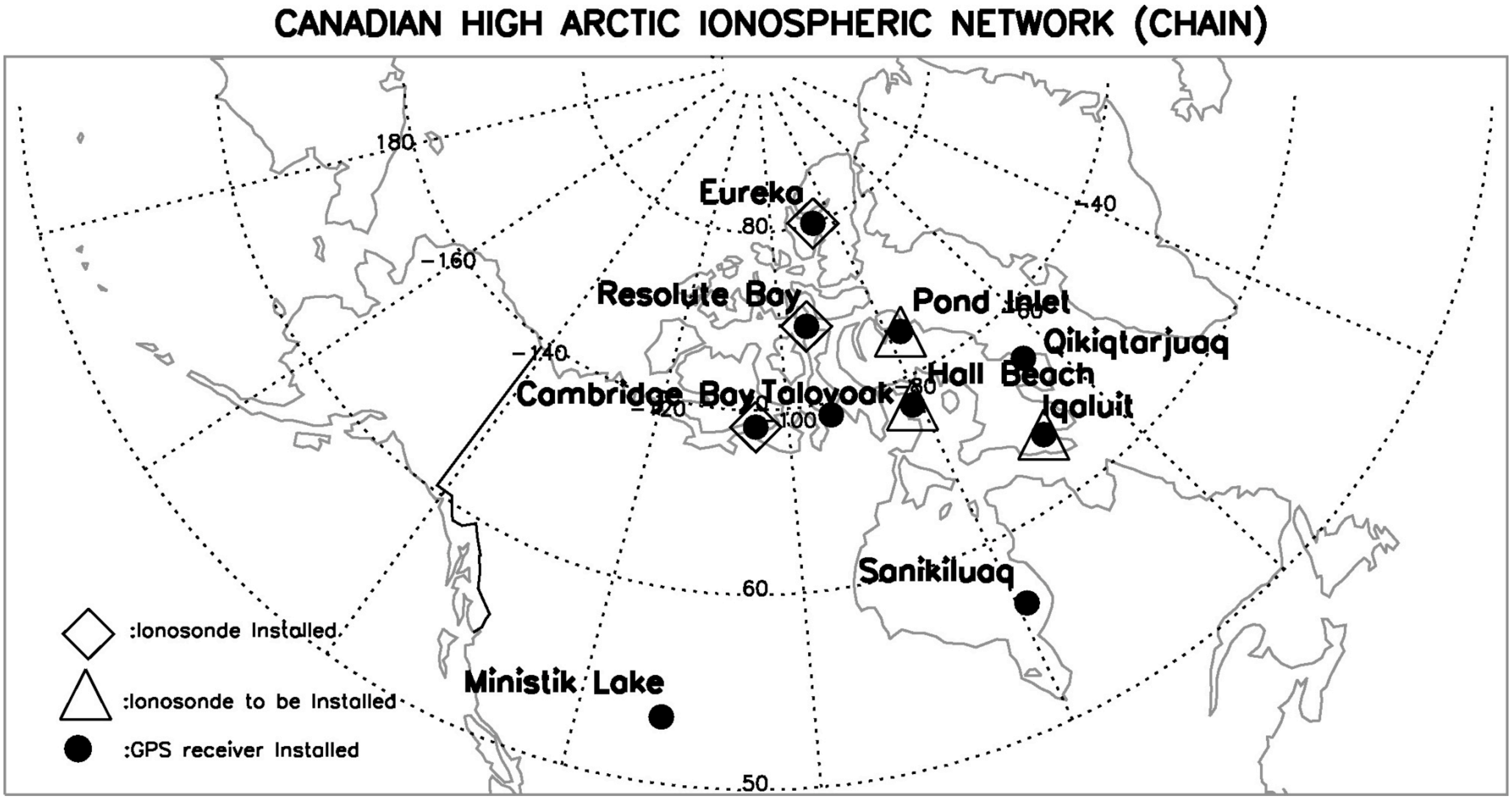
Qikiqtarjuaq-2

Pond Inlet


OVER
1000 VOLTS
LESS THAN
1000 VOLTS
GPS Data Collection System
25 17:29


25 17:41

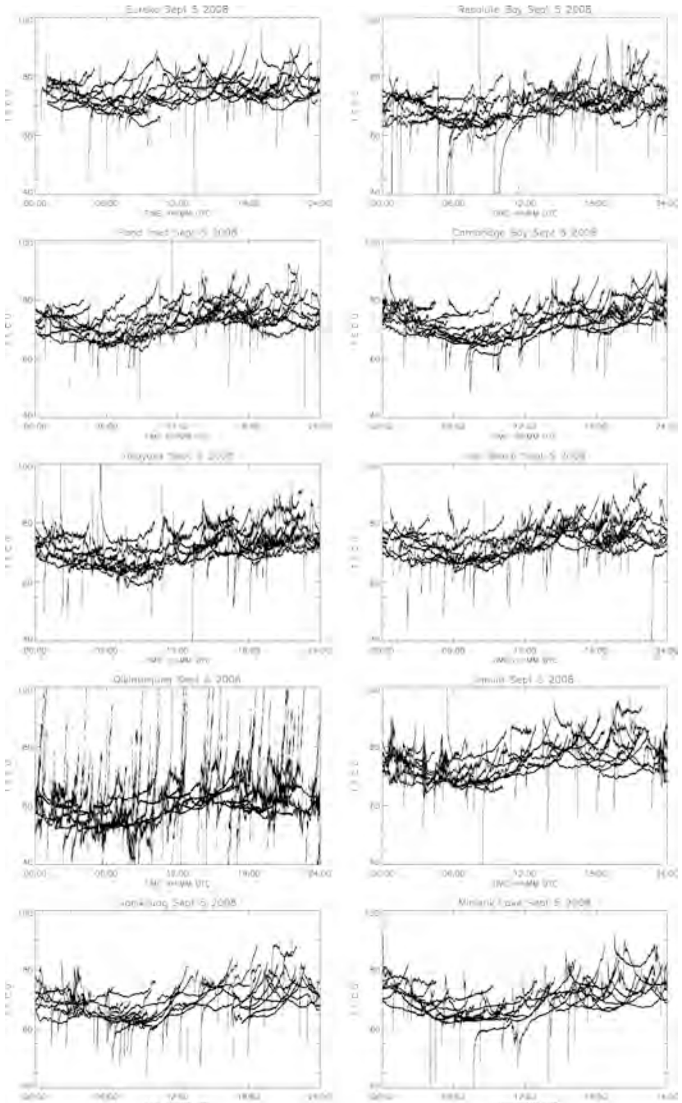
CHAIN Stations



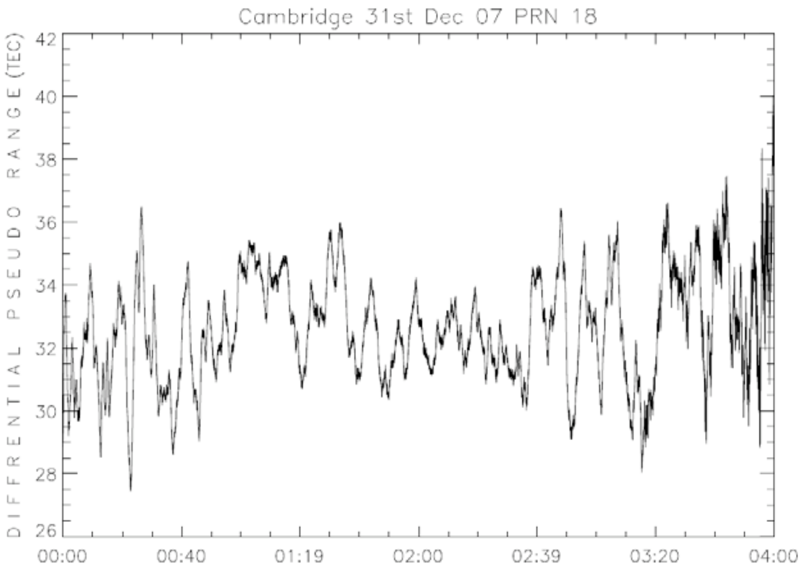
All CHAIN GPS receivers have been installed
Three new CADIs will be installed in July 2009

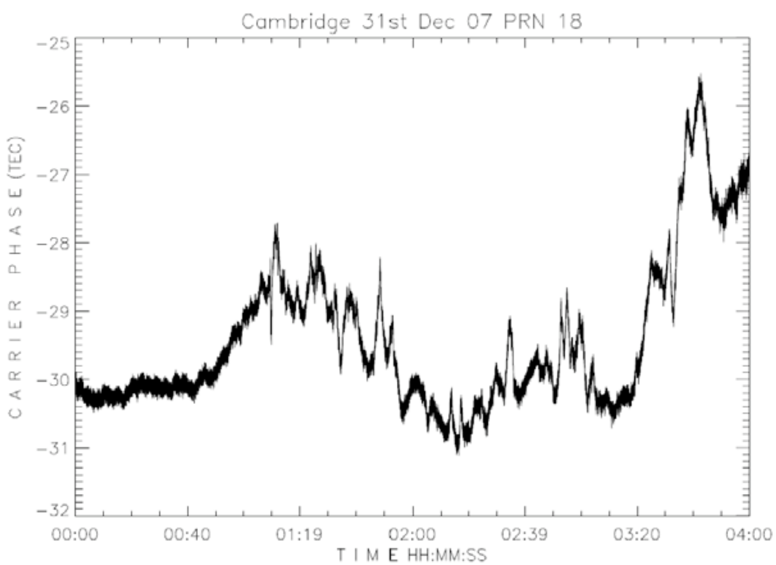
Data - GPS

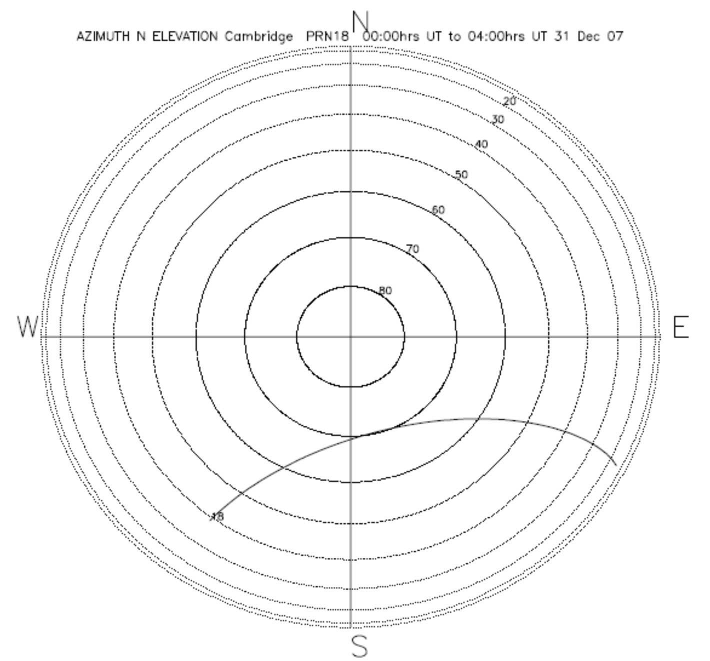
- Sampling rate – 50 Hz – Regular GPS observables (TEC) + scintillation parameters



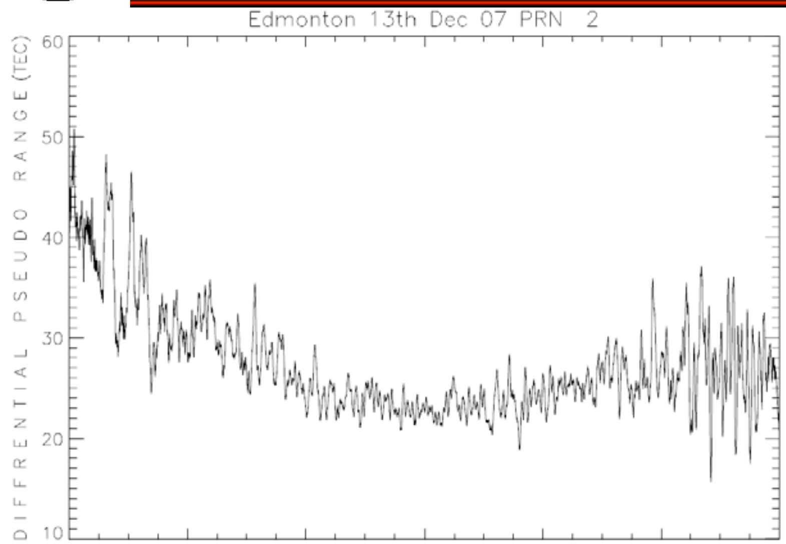
TEC – Cambridge Bay

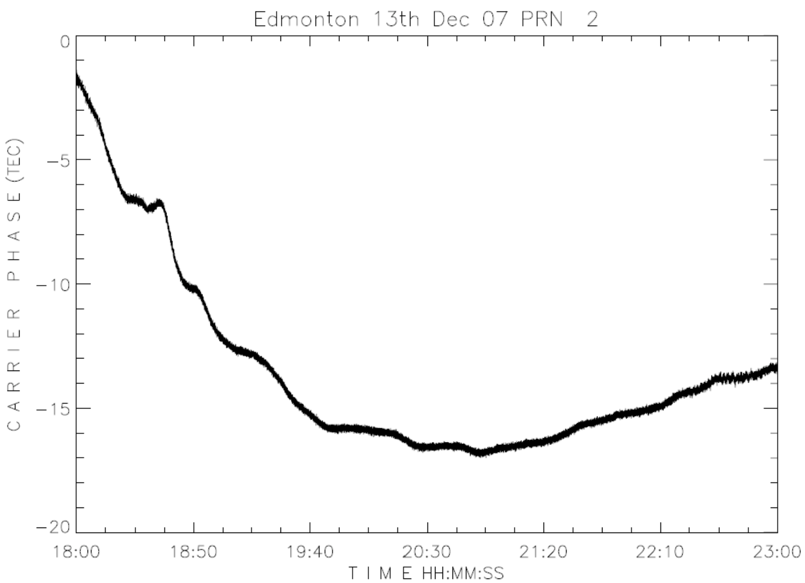


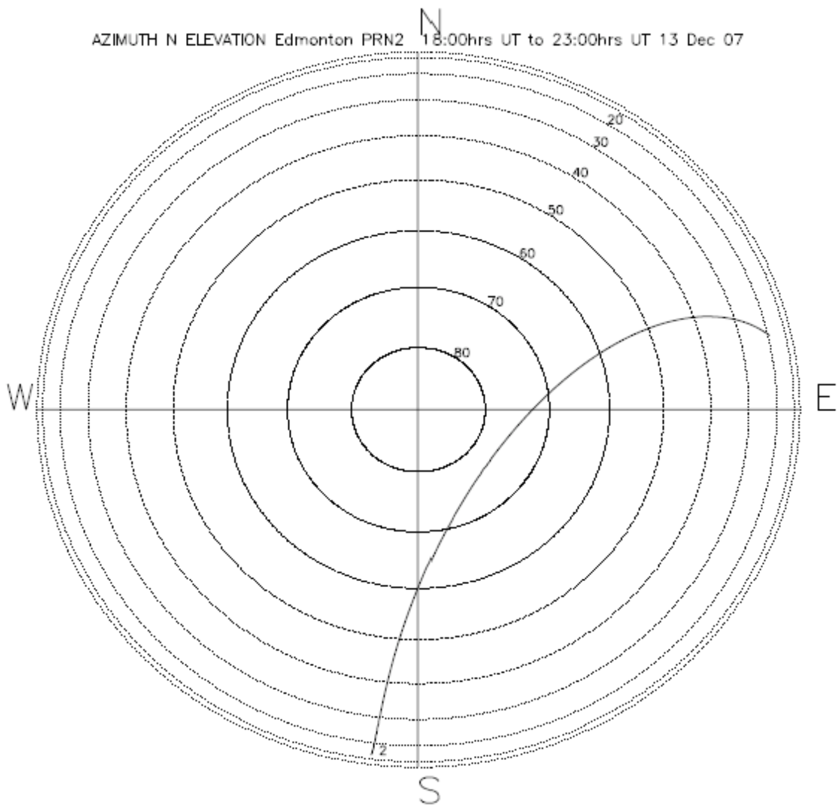




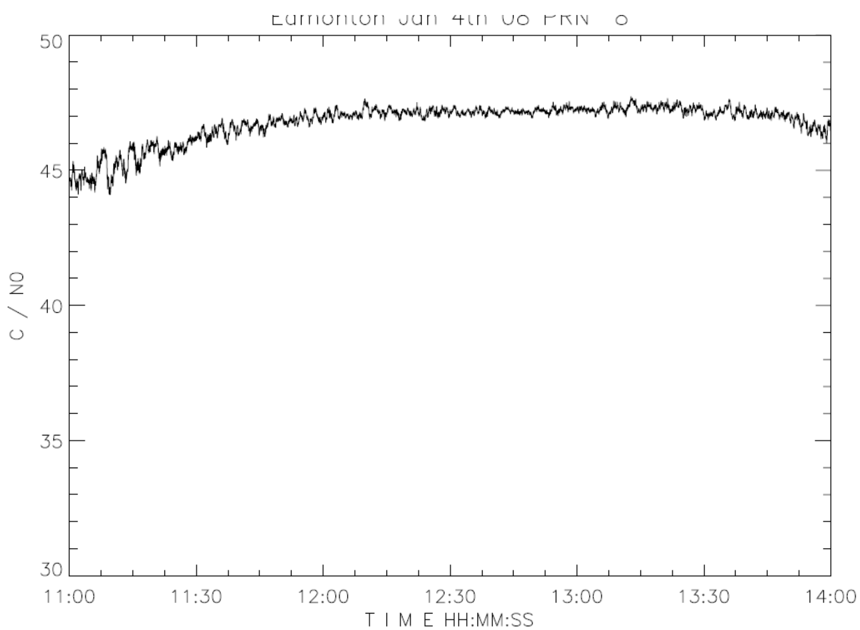
TEC - Edmonton

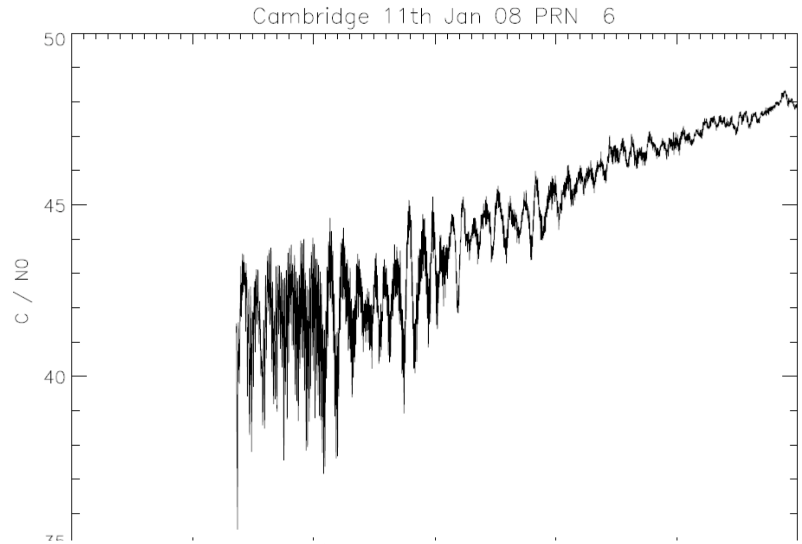


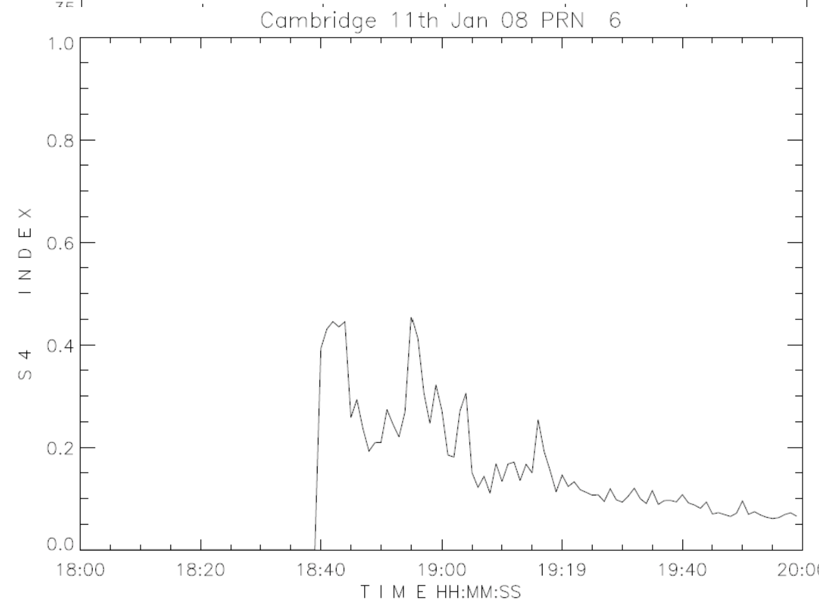




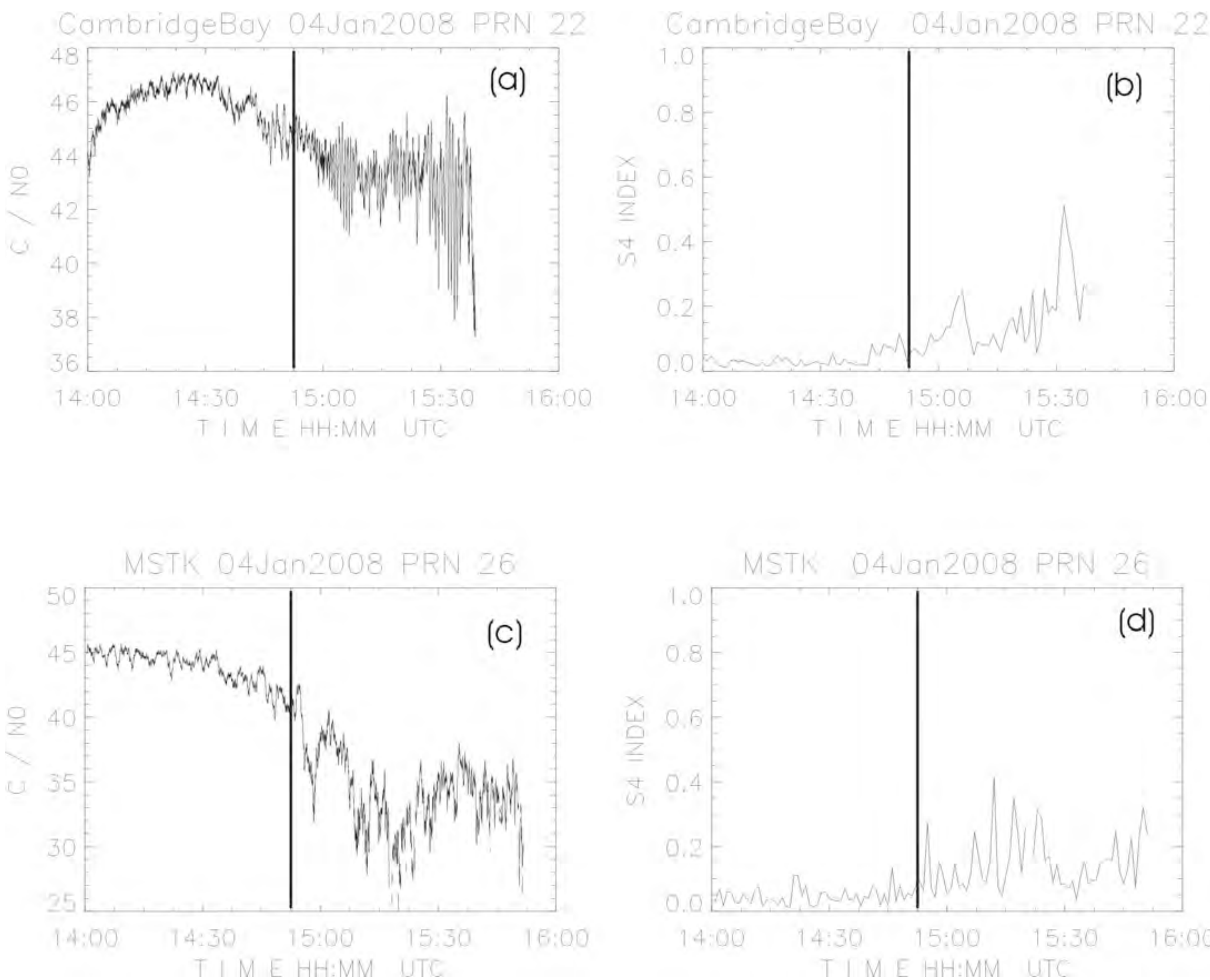
Scintillation





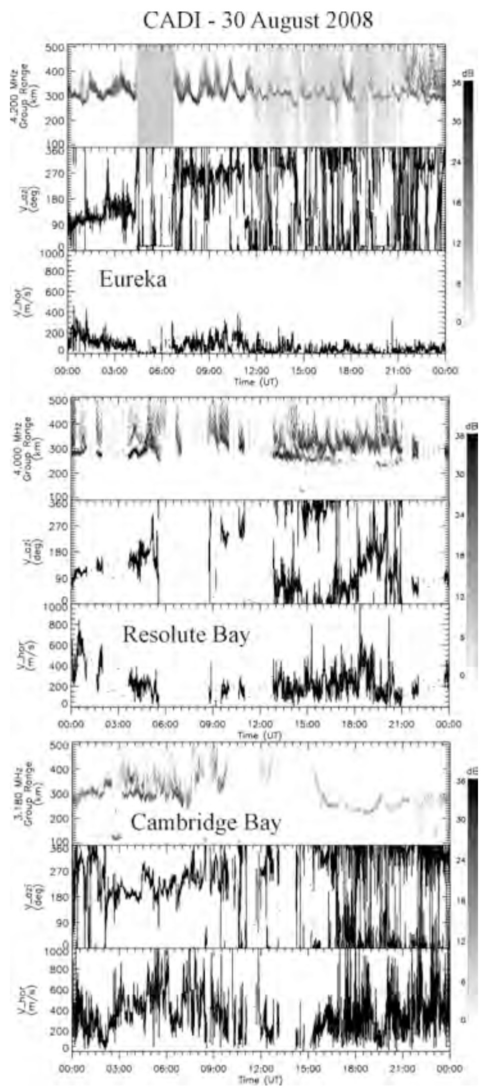


Possible Scintillation Event



Data - CADI

- Fixed frequency drift measurement every 30s
- Swept frequency ionogram every minute

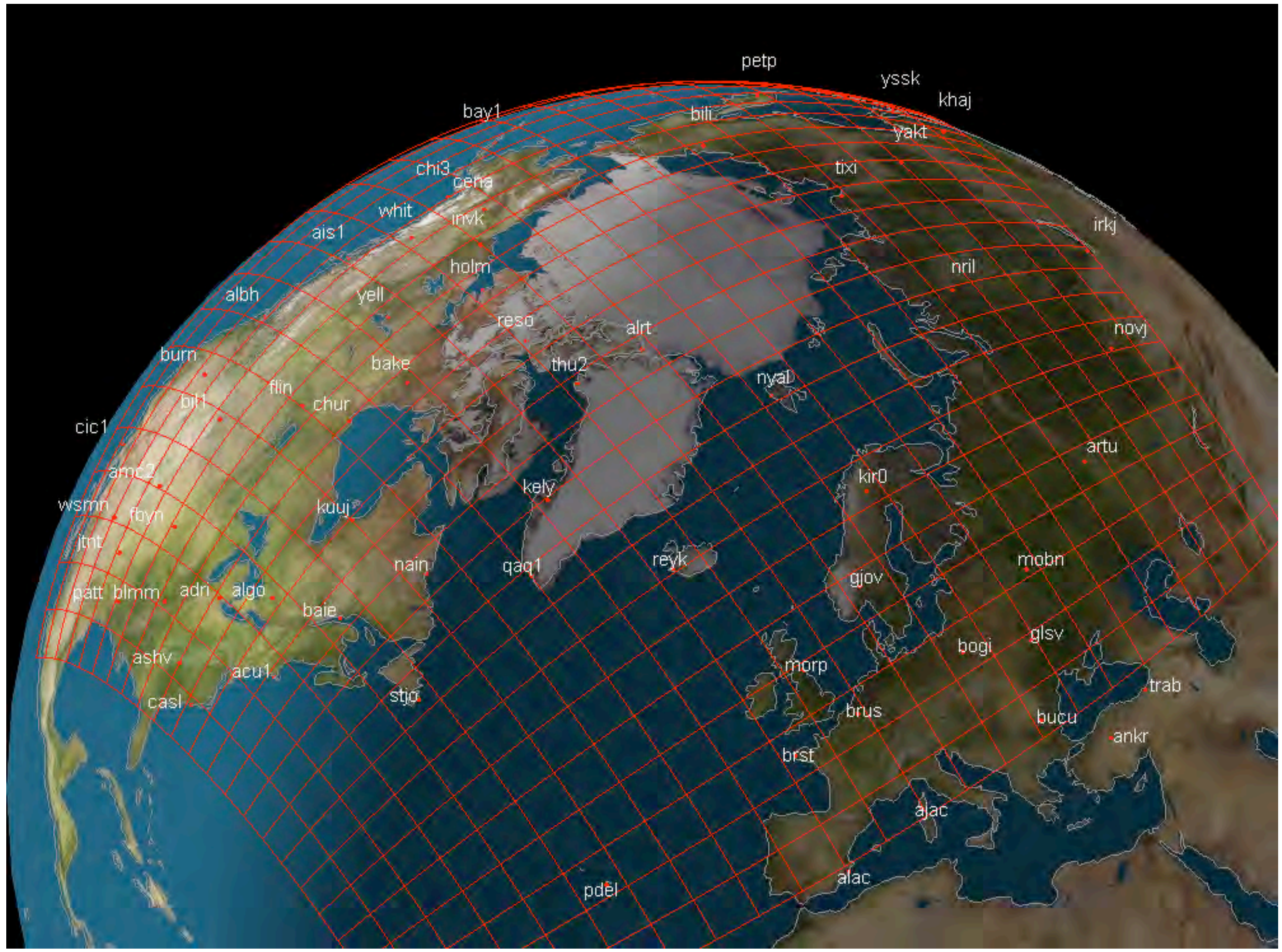


GPS Tomography Using MIDAS

Global distribution of ionospheric plasma density can be deduced from characteristics of GPS signals acquired by ground-based network of GPS receivers.

Network of ground-based dual-frequency GPS receivers can be used for global tomographic reconstructions of the ionosphere.

This work is being performed by Dimitry Pokhotelov, formerly with the University of Bath

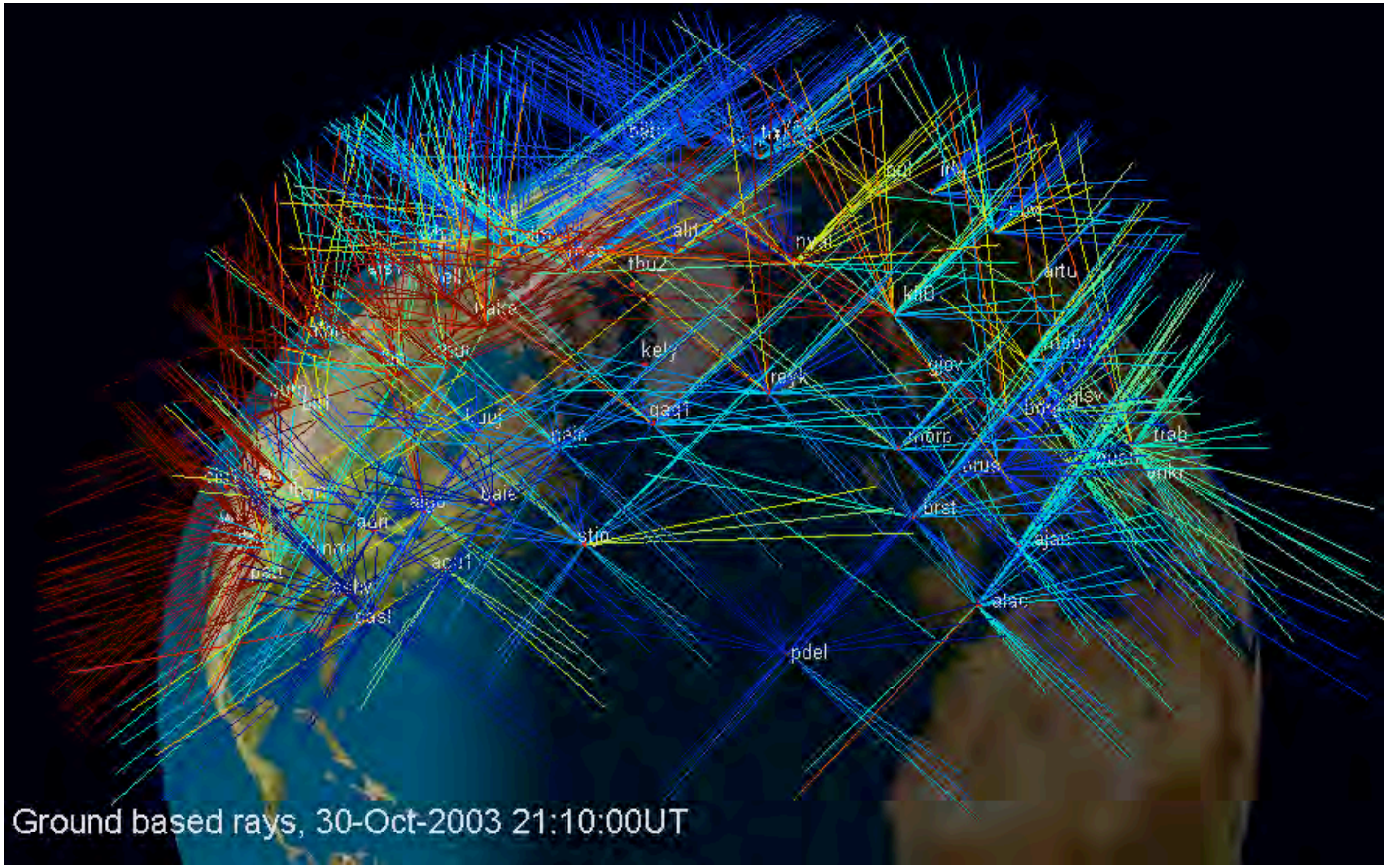


GPS Rays - Slant TEC

Integrated electron concentration along the line of sight from the GPS spacecraft to the receiver

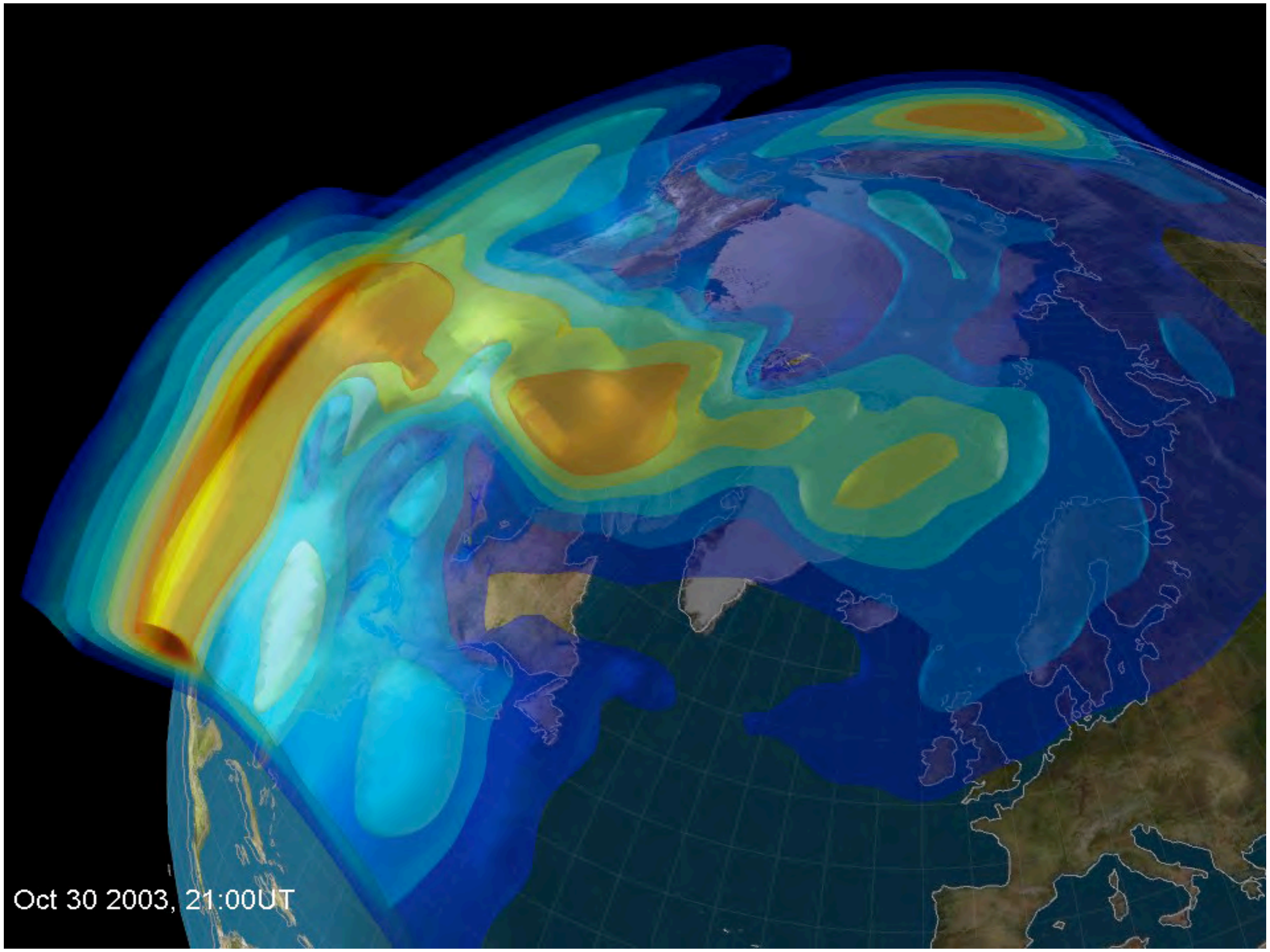
$$\mathrm{TEC} = \int_S^R N(r,\theta,\phi)\, ds$$

Slant TEC can be inferred by measuring either the phase advance or the group delay between L1 and L2 signals



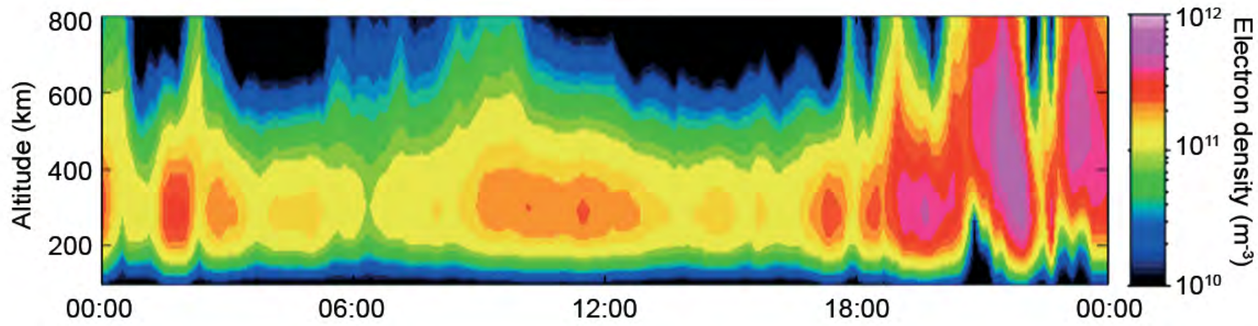
Results of the Reconstruction: Plasma Density

The tomographic inversion of the GPS data using a three-dimensional time-dependent inversion algorithm can reveal the spatial and temporal distribution of ionospheric electron density

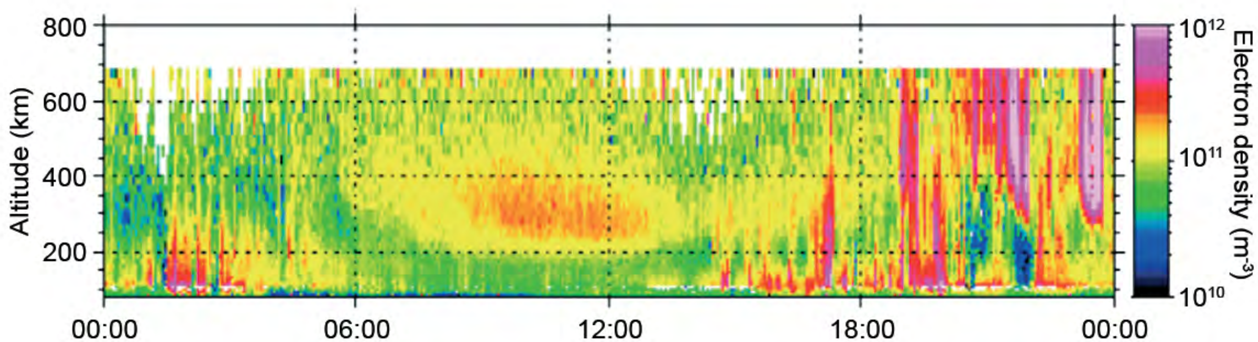


Comparison with ISR measurements

Electron density during 30-Oct-2003 storm as a function of height and UT



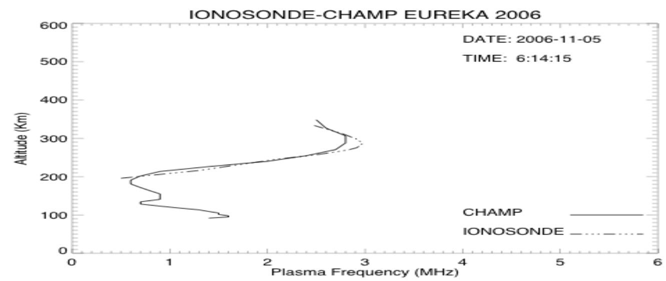
MIDAS



EISCAT Tromsø

e-POP/CASSIOPE Connection

- Validation/Calibration of GAP Occultation profiles



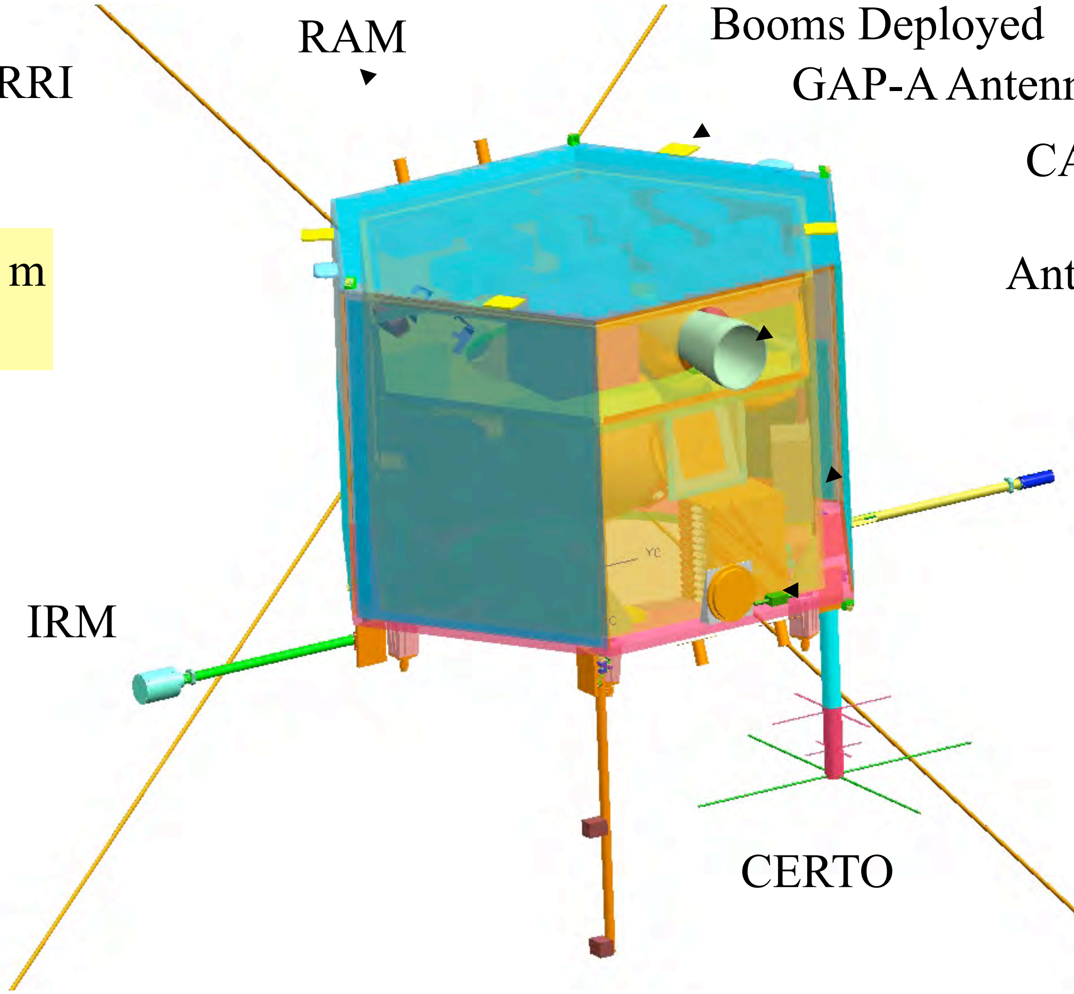
- CADIs for RRI

- Orbit electron density information for SEI/ calibration

Scientific possibilities – Leaving to the wisdom and Imagination of the USERS!

CASSIOPE

1.8 m × 1.2 m
≈ 500 kg

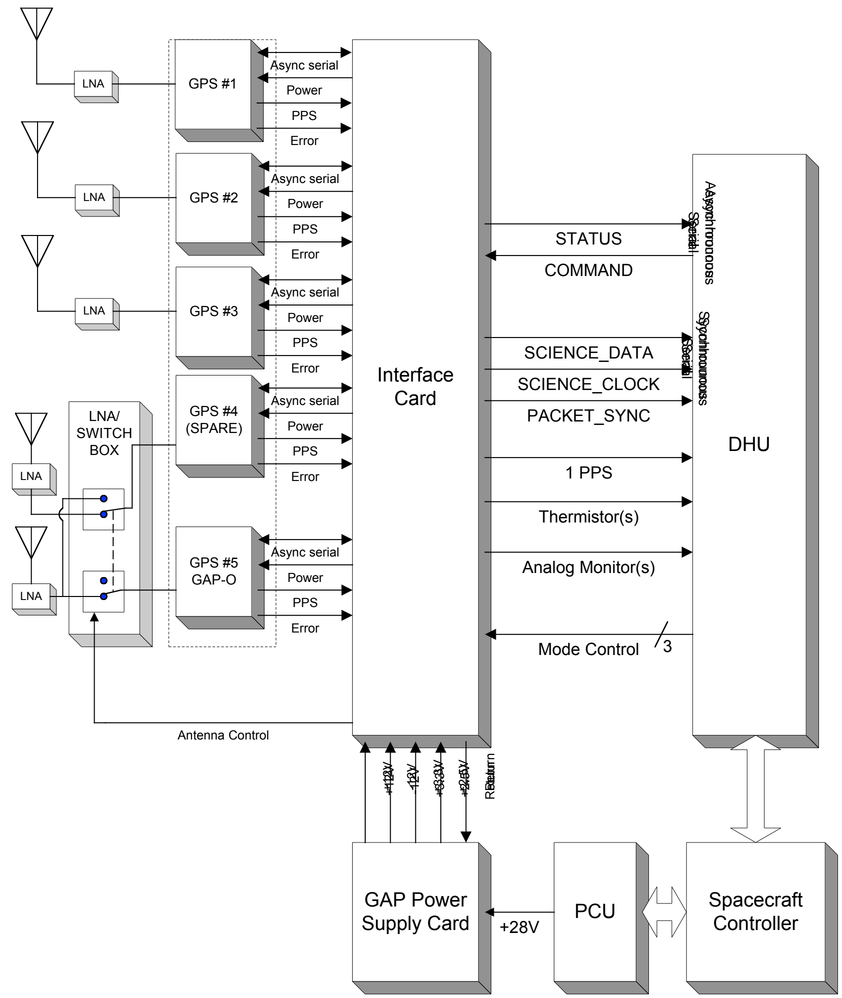


Background image courtesy of Bristol. S/C is for illustrative purposed only.

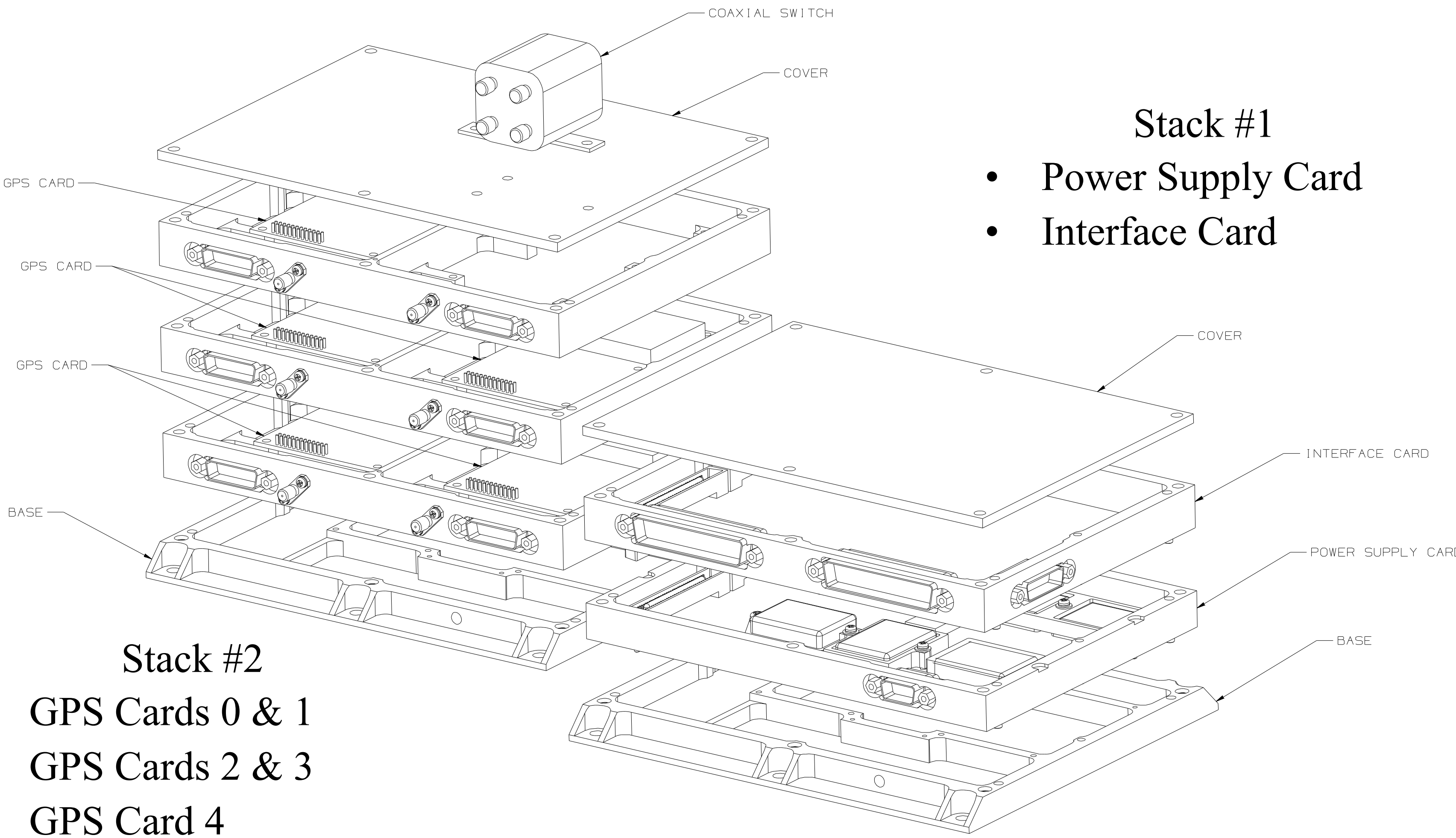
GAP Functional Description

- Instrument consists of:
  - An interface card
  - Power supply card
  - 5 GPS cards (includes one spare)
  - 5 GPS antennas and LNAs
  - Antenna/LNA switch

- GAP-A and GAP-O functions combined into a single instrument



Instrument Overview



Stack #1
- Power Supply Card
- Interface Card

Stack #2
- GPS Cards 0 & 1
- GPS Cards 2 & 3
- GPS Card 4
- Coaxial switch

Data Availability - CHAIN Website