Environment Canada Environnement Canada

Canada

Une nouvelle ère pour le Canada en télédétection: l'observation ininterrompue de la région arctique

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Le 20 mars 2009

CSA ASC

La mission PCW

- PCW= Polar Communications and Weather

  "Communications et Météorologie polaires"

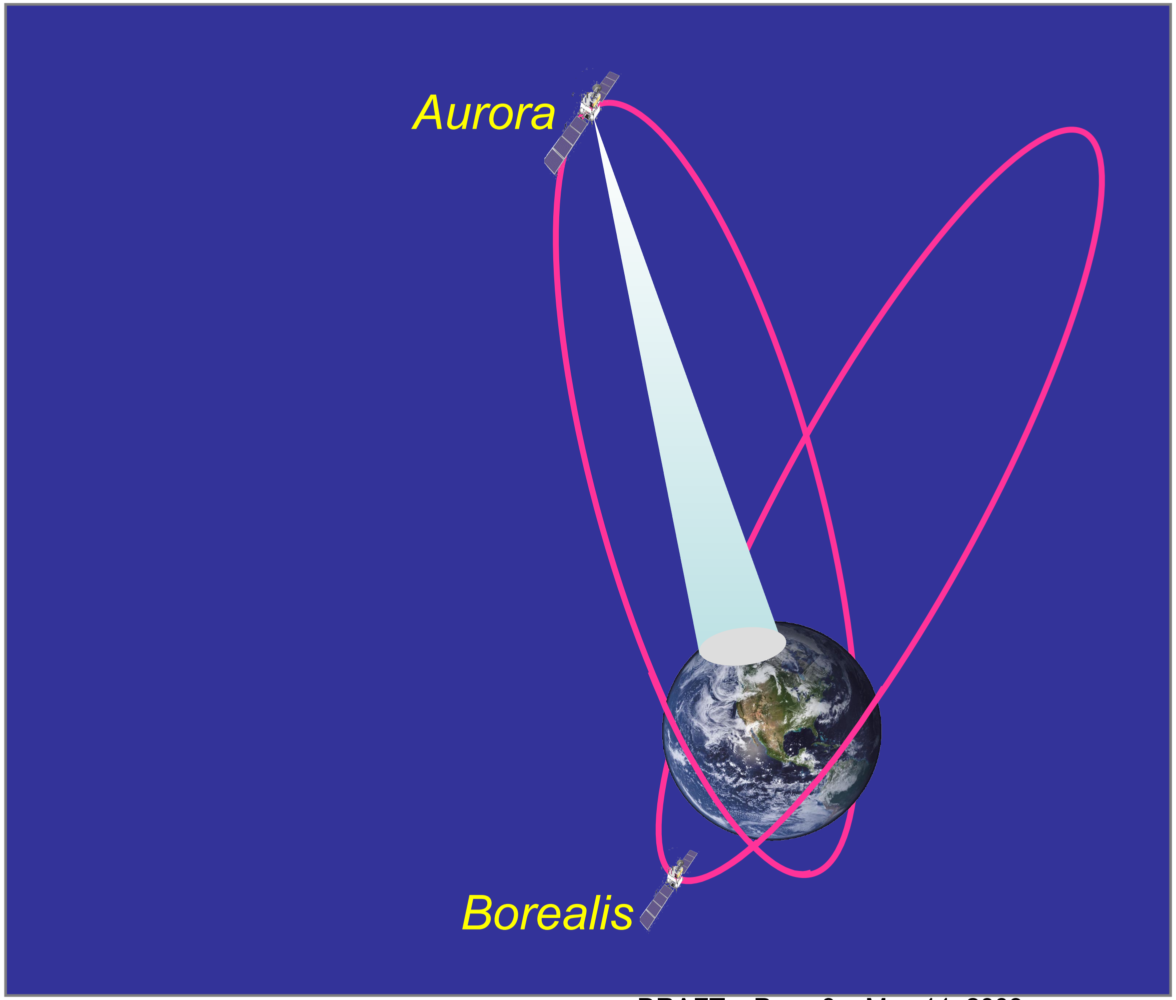
- Concept: observation en continu des régions polaires en utilisant deux satellites en orbite fortement elliptique

- Une nouvelle ère pour le Canada:

  - engagement à fournir des données satellitaires en temps réel pour la prévision (national et international)

  - percée technologique: observation de la Terre d'une orbite elliptique

PCW: Constellation in Molniya Orbit



2 satellites to provide continuous GEO-like imagery 55-90 N
0.5-1 km VIS
2 km IR

12-h period
63.4 deg. inclination

Apogee: ~39,500 km
Perigee: ~600 km

Background on Molniya concept

- Russia:

  - Used extensively for communications in the past
  - Mission including Earth observation planned for ~2015: Arctica

- United States

  - Concept for Earth observation first proposed by Kidder and Vonder Haar (1990)
  - NASA/Goddard proposed a mission in 2004-2005 under Earth Science Pathfinder Program. Main focus was on high latitude winds. Main payload was a 6-channel imager. Stopped at Phase A level.

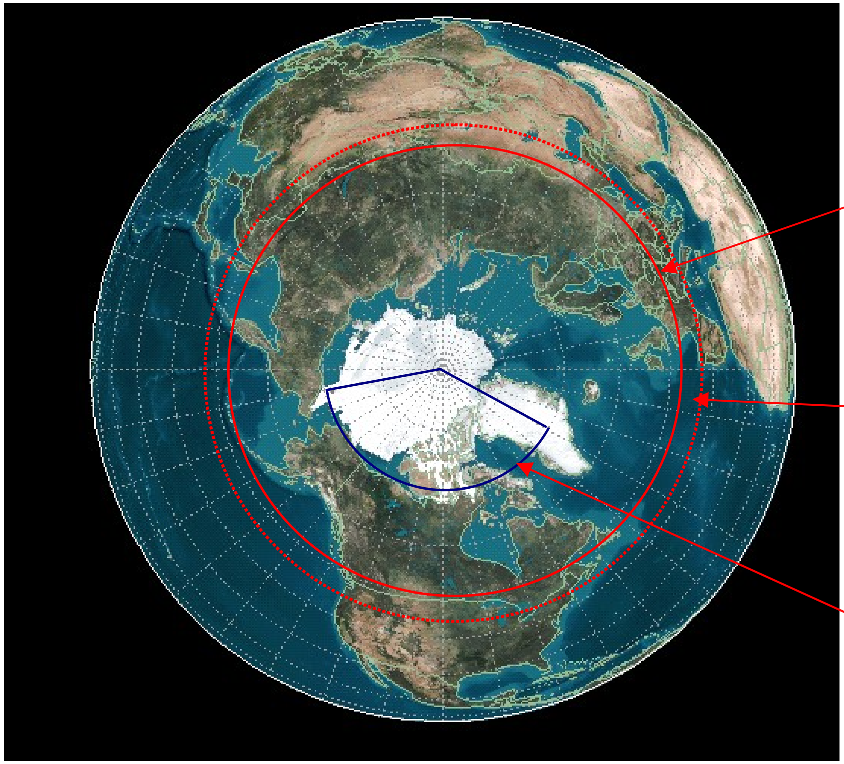
- Canada

  - Visit of Lars Peter Riishojgaard in 2006 presenting NASA concept initiated a strong interest at Canadian Space Agency and Environment Canada.

Dual Objectives: Communications & Weather

- Reliable communications in the high latitudes (North of 70º) to ensure:
  - Security
  - Sustainable Development
  - Support to Northern Communities
  - Air and Marine Navigation
- Provide high temporal/spatial resolution meteorological data above 50º N in support of:
  - Numerical Weather Prediction (short to medium range)
  - Environmental monitoring, emergency response
  - Climate monitoring

Area of Interest



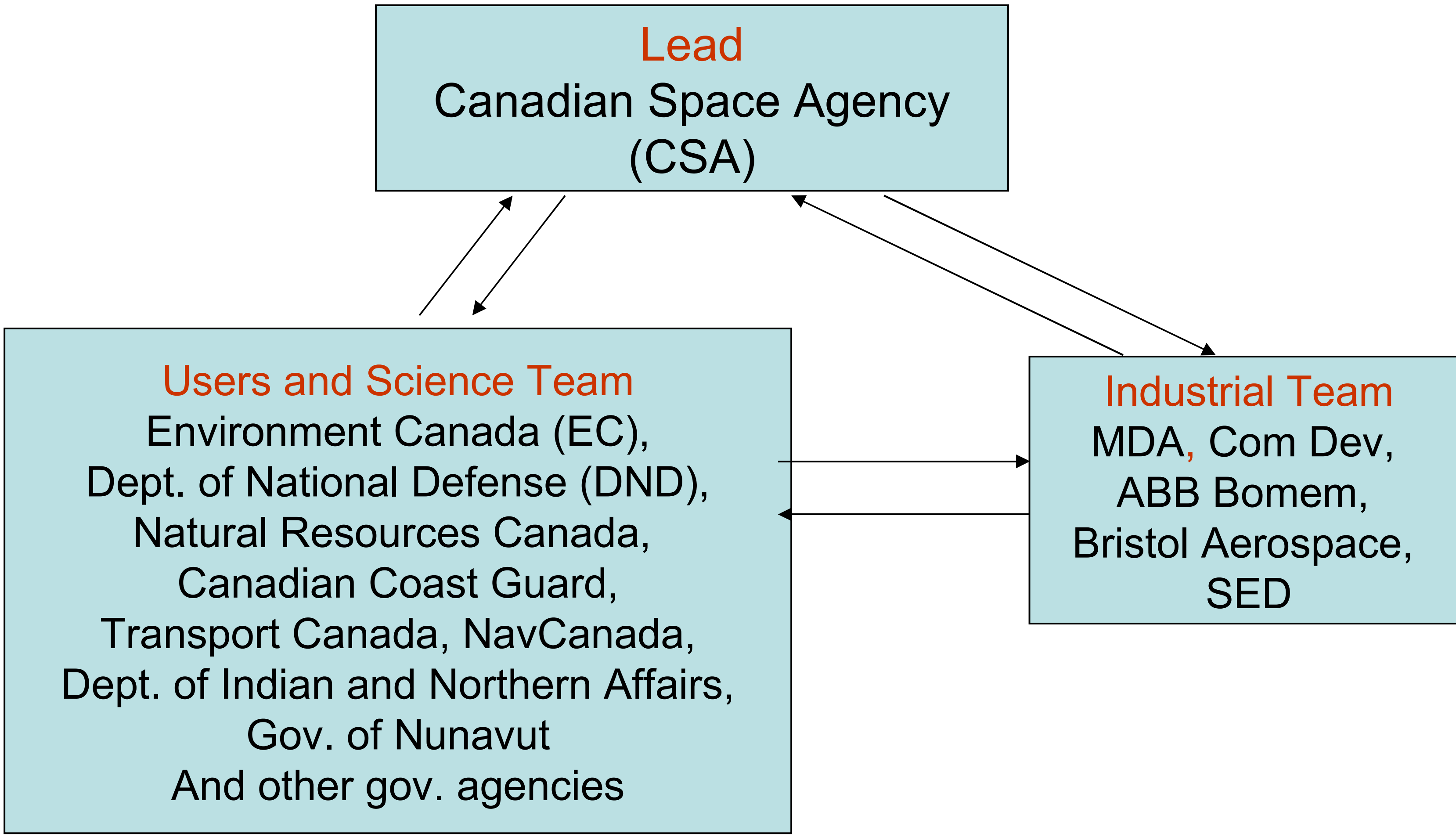
Meteorological Coverage Requirement (50ºN)

Meteorological Coverage Goal (45ºN)

Communications Coverage Requirement

Meteo requirement pertains to the entire circumpolar domain

Mission Development Structure in Phase 0



Mission phases (ESA, CSA)

- Phase 0: Mission proposition based on identified needs from users. Industry evaluates technical feasibility.
- Phase A: Study of mission concepts. More detailed evaluation of feasibility (industry) and added value (science team)
- Phase B: System definition activities
- Phases C, D: Detailed definition, ground testing, production
- Phase E: Launch, commissioning, utilisation

Go-no go decision typically made after Phase A

Mission objectives

- To provide 24/7 communications services everywhere in the Arctic
- To provide continuous meteorological services and information for the entire circumpolar region, with the imagery data "*refreshed*" as frequently as practical. GOAL 15 min
- To improve weather prediction accuracy by providing high quality data currently not available or available with insufficient spatial / temporal resolution
- To improve the monitoring and prediction of air quality variables
- To improve the modeling of physical processes in the Arctic environment
- To develop measures of climate change through high quality monitoring of key atmospheric and surface variables
- To improve observation and forecasting of space weather
- To have a *proto-operational* system in place by 2016 Lifetime of 5 years (goal 7 years)

Applications and Products 1/2

- a) Winds from sequences of images: high priority product
- b) Surface type analysis: ice, snow, ocean, vegetation and surface characteristics such as emissivity, albedo, vegetation index
- c) Surface temperature, detection of boundary-layer temperature inversions, diurnal cycle
- d) Mid-tropospheric humidity/temperature sensitive channels for hourly direct assimilation complementing GEO radiance assimilation
- e) Volcanic ash detection
- f) Nowcasting: severe weather, visibility, icing in support of air and marine traffic

Applications and Products 2/2

- g) Smoke, dust, aerosols, fog in support of air quality models and environmental prediction
- h) Total column ozone
- i) Cloud parameters: height, fraction, temperature, emissivity, phase, effective particle size
- j) Broadband outgoing radiation: total, Vis, IR, window

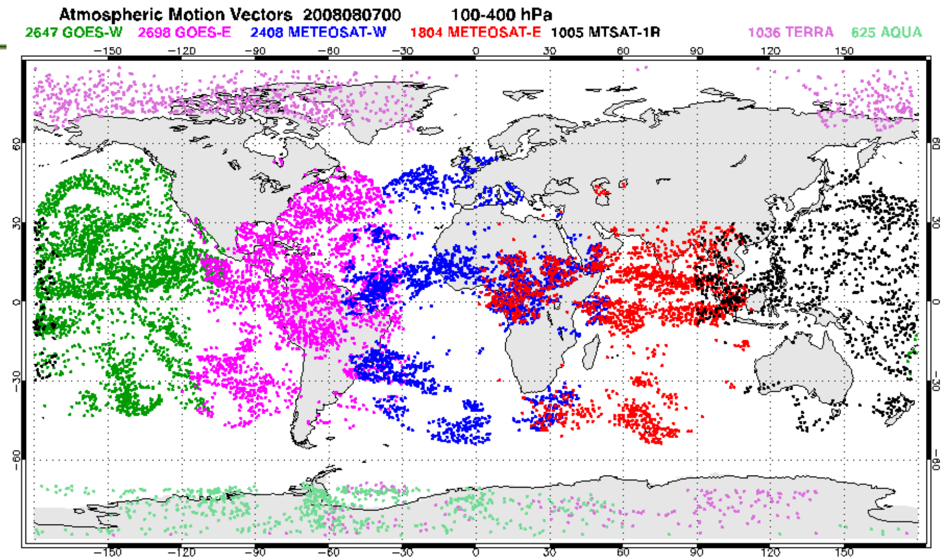
→ The variety of applications imposes a minimum number of spectral channels of the order of 10, preferably ~20.

Mission justification in brief for meteorology

- Essentially spatial coverage: unique capability to view entire circumpolar region nearly simultaneously
- Unsurpassed temporal coverage for polar regions allowing capturing rapidly evolving phenomena
- Synergy of applications with geostationary satellites

Atmospheric Motion Vectors (AMVs) assimilation

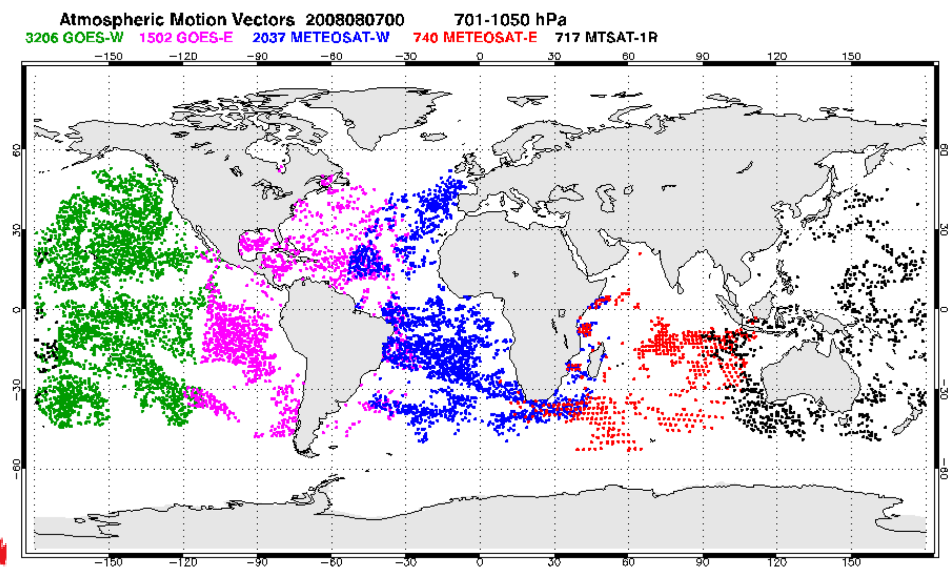
Example of 07 Aug 2008 00 UTC AMV availability



100-400 hPa

Recognized availability gap 55-65 N/S

Terra/Aqua AMVs from 90 min image sequences



700 hPa to surface

No AMVs above 55 N/S

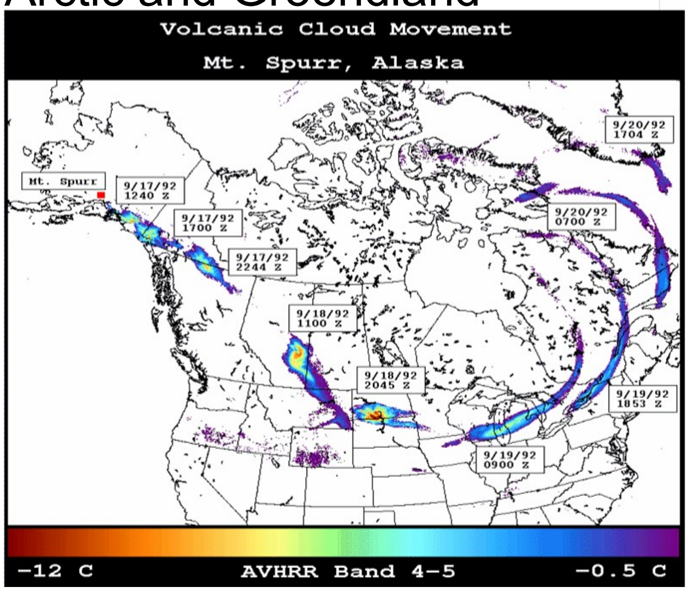
PCW features to serve this application:

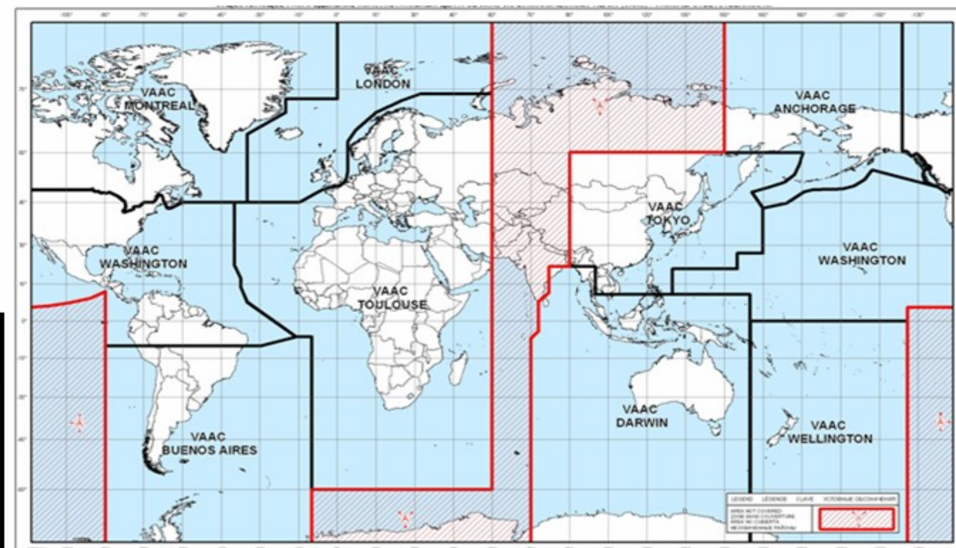
- High temporal sequences
- Simultaneous retrievals
- Stereo views

Volcanic ash application

The 9 VACC areas of responsibility

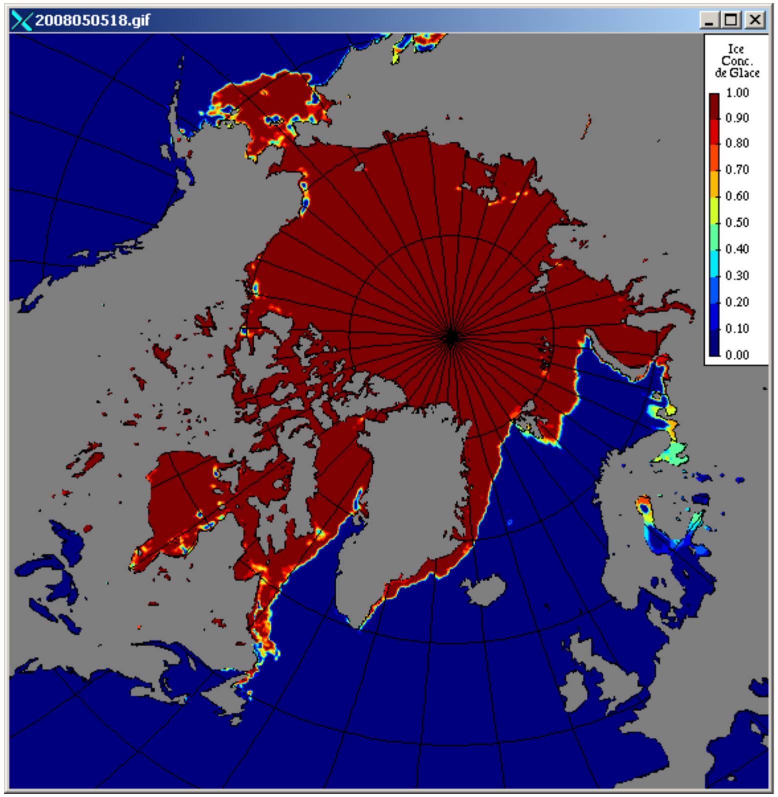
Canada has one of 9 Volcanic
Ash Advisory Centers
(VACC located in Dorval, Qc)
With area of responsibility
Covering a large part of the
Arctic and Groendland





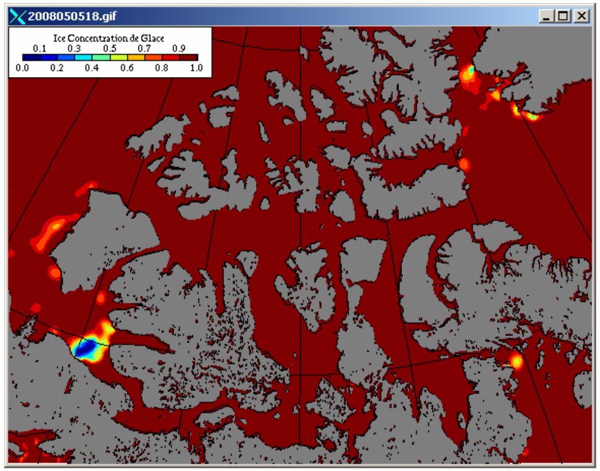
Detection of vocanic ash from AVHRR lacks temporal resolution

Ice analysis application



POLAR grid 15 km ice analysis
AMSR (NT2), CIS ice charts and image analysis (RadarSat, EnviSat)
3D-Var FGAT scheme (twice daily)

Ice fraction

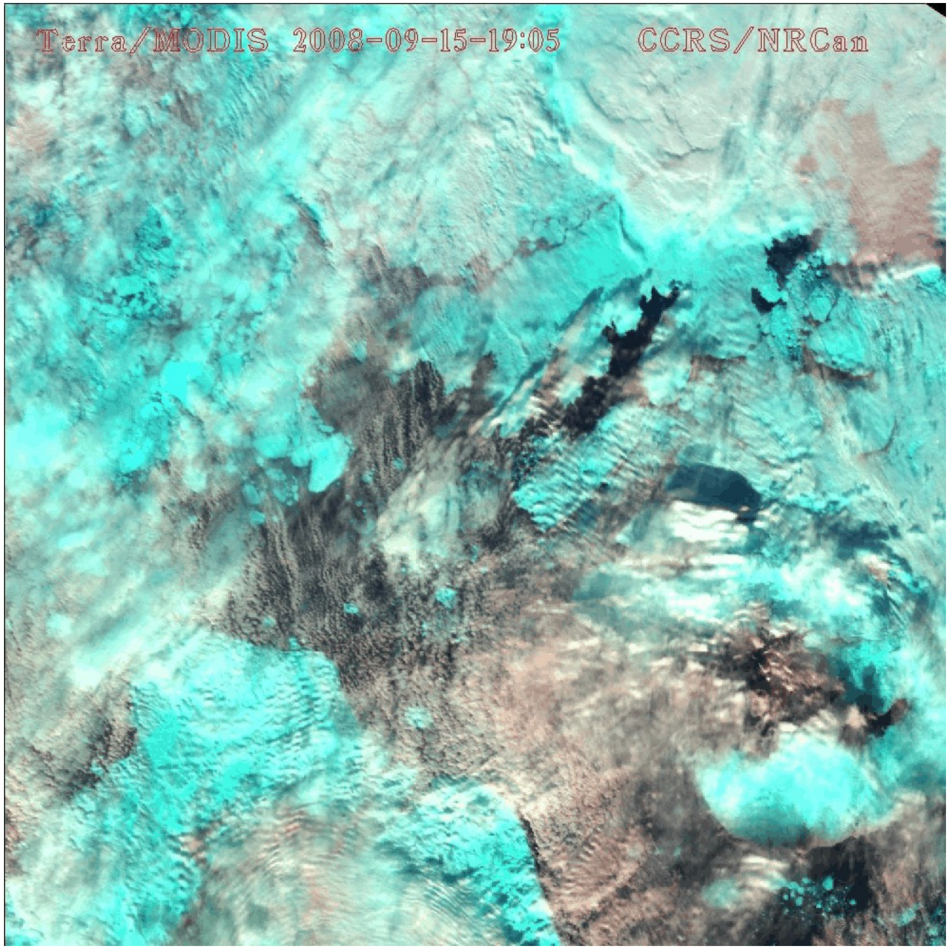


Prototype 5 km over Canadian Archipelago

PCW VIS ch ~500 m could contribute to operational sea ice fraction analysis + some NIR channels

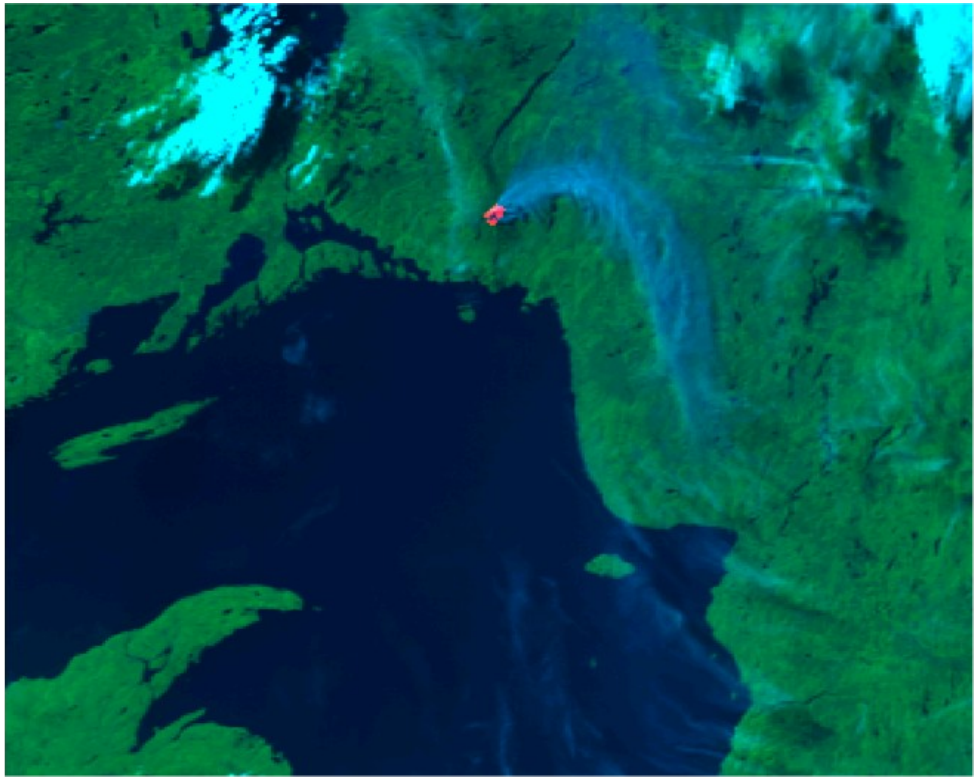
Ice analysis application with Modis

- Uses Modis 250-m VIS imagery (Terra and Aqua)
- Covers June-Sept 2008
- Near Banks, Melville
Islands, Canadian Arctic



Produced by NRCAN (Ottawa)

Forest fire monitoring



Fire extent, intensity monitored
Using 1-km AVHRR data

Responsibility of NRCAN

Model can predict the evolution of the smoke plume from source input combustion rate

Channel selection approach

- Select channels with similar characteristics to those foreseen for next generation of GEO (GOES-R, MTG) as suggested by WMO. Obvious advantages for continuity of applications, synergy

- Reduce risk associated with technology readiness

Proposed imager channels (21) based on ABI, MODIS heritage

Wavelength (microns)	Heritage	Goal spatial resolution (km)	Minimum spatial resolution (km)	Priority 1 = highest	Main applications
0.45-0.49	ABI-01	1	2	2	Surface
0.5-0.6	MODIS-04	0.5	1	2	Vegetation
0.59-0.69	ABI-02	0.5	1	1	Wind, clouds
0.85-0.89	ABI-03	1	2	1	Wind, aerosols, vegetation
1.37-1.39	ABI-04	1	4	2	Cirrus
1.58-1.64	ABI-05	1	2	1	Snow-cloud distinction
2.22-2.28	ABI-06	2	4	2	Cloud phase
3.80-4.00	ABI-07	2	4	1	fog/ fire detection, Ice/cloud separation, wind
5.77-6.60	ABI-08	2	4	2	Wind, humidity
6.75-7.15	ABI-09	2	4	1	Wind, humidity
7.24-7.44	ABI-10	2	4	1	Wind, humidity
8.30-8.70	ABI-11	2	4	2	Total water
9.42-9.80	ABI-12	2	4	2	Total ozone
10.1-10.6	ABI-13	2	4	2	Cloud, surface
10.8-11.6	ABI-14	2	4	1	Cloud, SST, ash
11.8-12.8	ABI-15	2	4	1	Ash, SST
13.0-13.6	ABI-16	2	4	2	Cloud height
13.5-13.8	MODIS-34	2	8	2	Cloud height
13.8-14.1	MODIS-35	2	8	2	Cloud height
14.1-14.4	MODIS-36	2	8	2	Cloud height

Main Imagery requirements (1/2)

Parameter	Nominal requirement	Min requirement	Comment
Total spectral channels:	20	8	Minimum 8 similar to ABI 2-3,5 7,9-10, 14-15
MWIR/LWIR Dynamic Range	100 K to 335 K	150 to 330 K	Varies with channel. 300 K for ABI-9-10 and beyond 13 micron.
Spatio -Temporal coverage for each disc	100 % above 60 N 95 % 55-60 N 85 % 50-55 N	95 % 85 % 70 %	Under normal operations
VNIR/SWIR Ground Sample Distance (GSD)	0.5 km	2 km	At nadir @ 60 N
MWIR GSD	0.5 to 1.0 km	4 km	At nadir @ 60 N
LWIR GSD	2 km	4 km	At nadir @ 60 N. 8-km ok above 13.5 micron)
Field of Regard (FoR)	Earth disc	Incidence angle < 70 d	Full disc advantageous for registration
Time to acquire scene image	5 min	15 min	Complete FoR

Main Imagery requirements (2/2)

Parameter	Nominal req.	Min req.	Comment
Maximum view angle difference between spectral channels	0.1 degree	1 degree	Ideally a target is viewed with same geometry independent of channel
Co-registration of spectral channels	0.1 GSD	0.35 GSD	over the full field of view and over all operating conditions
Signal to Noise Ratio (SNR) VNIR & SWIR	500	300	Calculated for conditions of bright signal
Noise Equivalent Delta Temperature (NEDT) @300 K	0.1 K	0.20 K	MWIR & LWIR 0.35K >13 micron
NEDT @ 240 K	0.20 K	0.40 K	1.0 K @3.9 micron 0.5 K >13 micron
Radiometric accuracy	3 %	5 %	VNIR/SWIR
	0.4 K	1.0 K	MWIR/LWIR
Level-1c repeat cycle	15 min	30 min	To users within 5 min of scene production

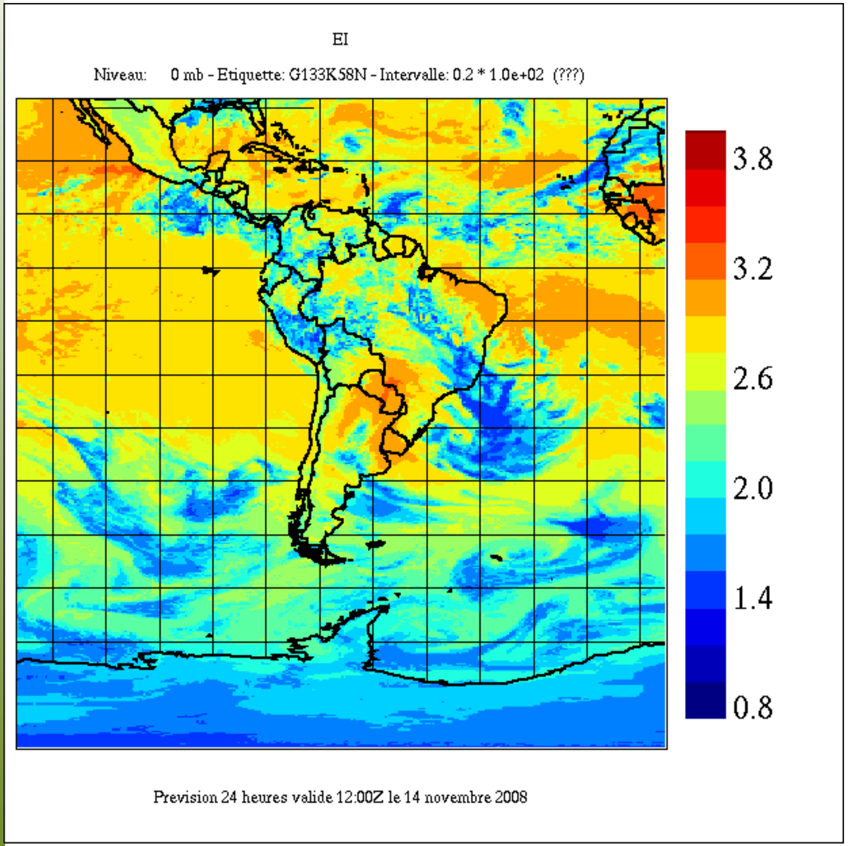
Secondary meteorological payload: broadband radiometer

	Heritage	Optimum/ target resolution (km)	Minimum acceptable spatial resolution (km)	Priority (1 highest)	Main applications
0.3-5.0 mm	ERBE, ScaRaB, CERES, GERB	10 / 20	50	1	Visible budget
0.3-100 mm	ERBE, ScaRaB, CERES, GERB	10 / 20	50	1	Total budget
8-12 mm	ScaRaB, CERES	10 / 50	100	2	Window budget

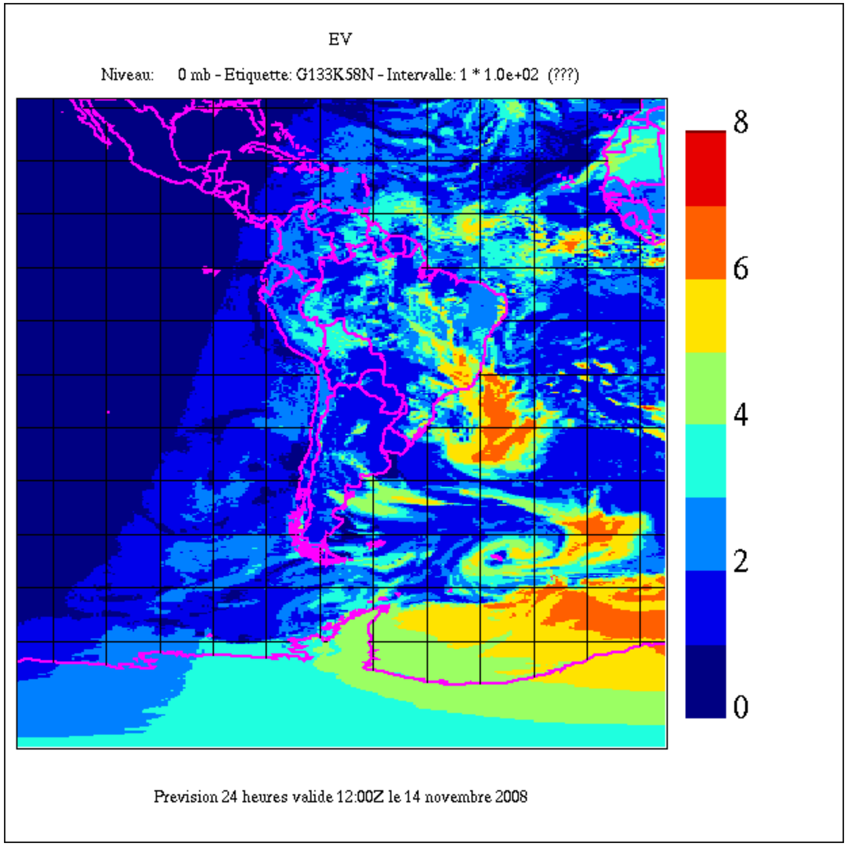
HEO orbit would provide rich variety of sat-sun angles for bi-directional reflectance modeling. GERB-like closest to desired characteristics.

TOA radiation fluxes from forecast models: available at every time step

IR **X 100 W/m2**



Solar **X 100 W/m2**



BBR to be used for model validation and to improve bi-directional reflectance models
With PCW: available for the first time continuously over Arctic

Space weather instruments

- Objective: Real-time monitoring of the local (to the satellite) space environment to provide diagnostics of satellite anomalies or communication degradation (passage in Van Allan radiation belts twice per orbit)
- Support PCW space weather forecasts to be provided by Canadian Space Weather Forecast Centre

Priority to high energy particle sensors (similar to EPS, HEPAD on GOES)

- Trapped electrons with energies greater than 500 KeV
- Trapped protons with energies greater than 1 MeV
- Solar protons and ions, ~1-500 MeV
- Magnetic field disturbances

Mission Overview

- Architecture: constellation of two satellites in HEO (Molniya-type, 12 hours)
- Orbit: two planes with apogees over Atlantic and Pacific
- Payloads: Communications (Ka-band) and Meteorological payload suits on each satellite
- Bus: Canadian SmallSat Bus (to be inaugurated on CASSIOPE-2009)
- Ground segment: based on existing Canadian infrastructure with potential addition of the Northern Ground Station
- Operations: government operated
- Launch: 2016
- Lifespan: 5 years-requirement, 7 years - goal
- Partnership: Open for international and Public-Private Partnership

Phase 0 Overview

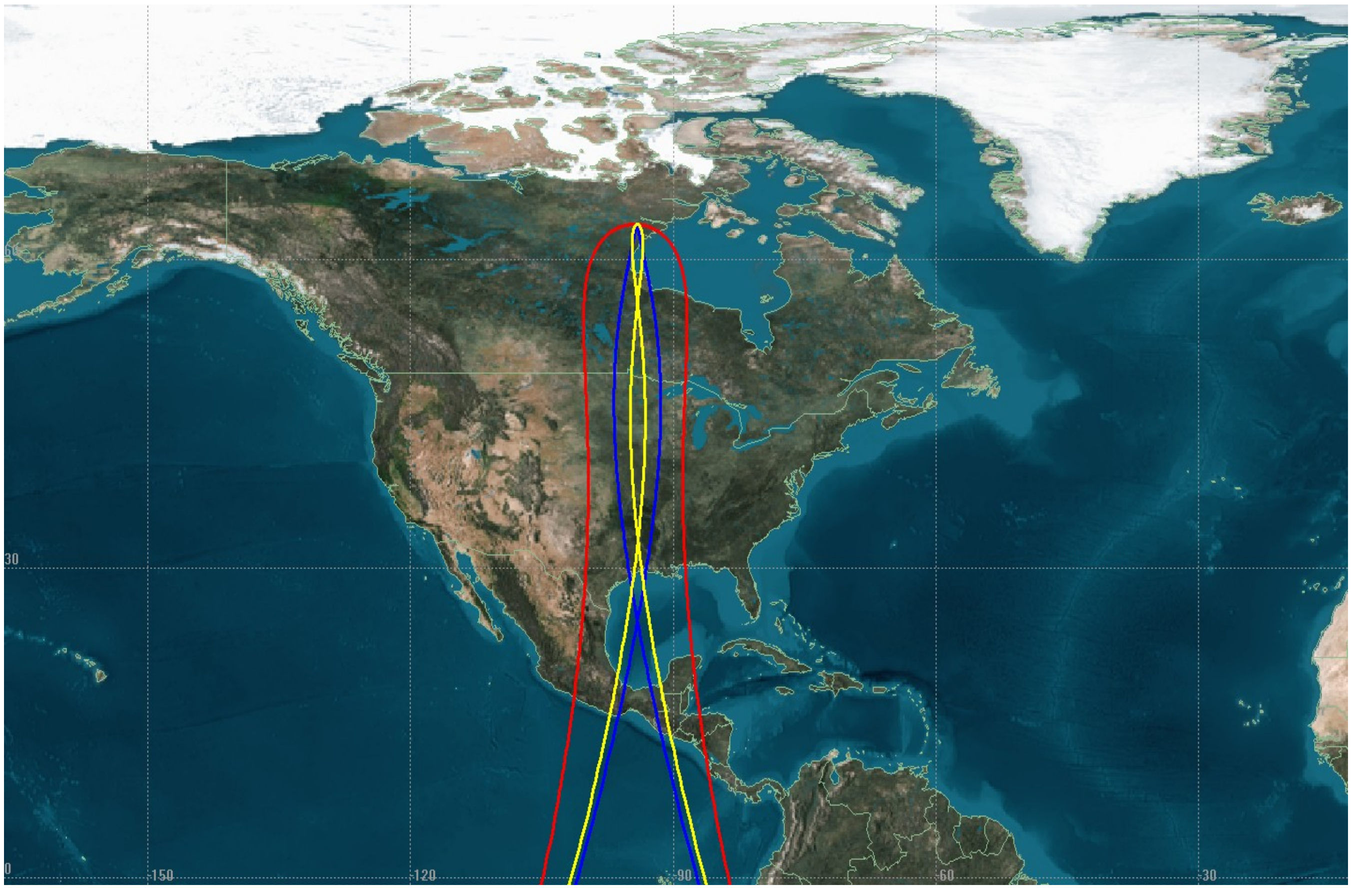
- Completed October 2008 (started November 2007)
- Funding: CSA (60%), DRDC (20%), EC (20%)
- Main Outcomes:
  - Users Requirements Document
  - Preliminary Mission and System Requirements Document
  - Compliant System Concept: dual goal is achievable
  - Mission Development Plan, including lifecycle cost
  - Phase A justification and planning
  - High priority ranking by CSA and governmental partners

Orbital Trade-Offs

- Molniya 12-h has been evaluated as the best compromise vs. other options: Tundra 24-h, Cobra 8-h or MEO (requiring at least 4 satellites)
- Molniya 12-h with 2 satellites: 4 % of area above 50 N not covered on average
  - Gap area circles around earth for 2 satellites in one plane
  - Gap area always at the same region, maximum 1-5 h from apogee for two orbital planes
- 2-planes best for symmetrical views (stereo) +
  - possible advantages of having only 2 apogee points versus 4

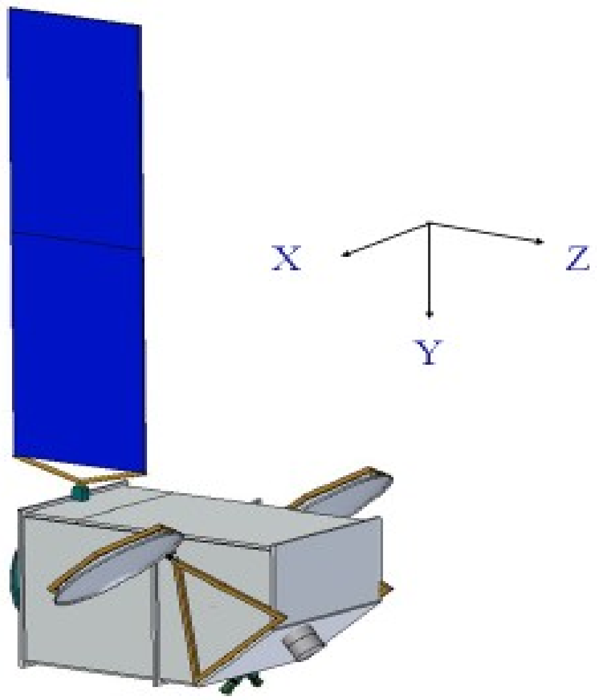
  apogee points over Pacific and Atlantic would limit gaps in that area (e.g. no gaps in Canada and Russia)

Molniya-type Orbits Ground Tracks



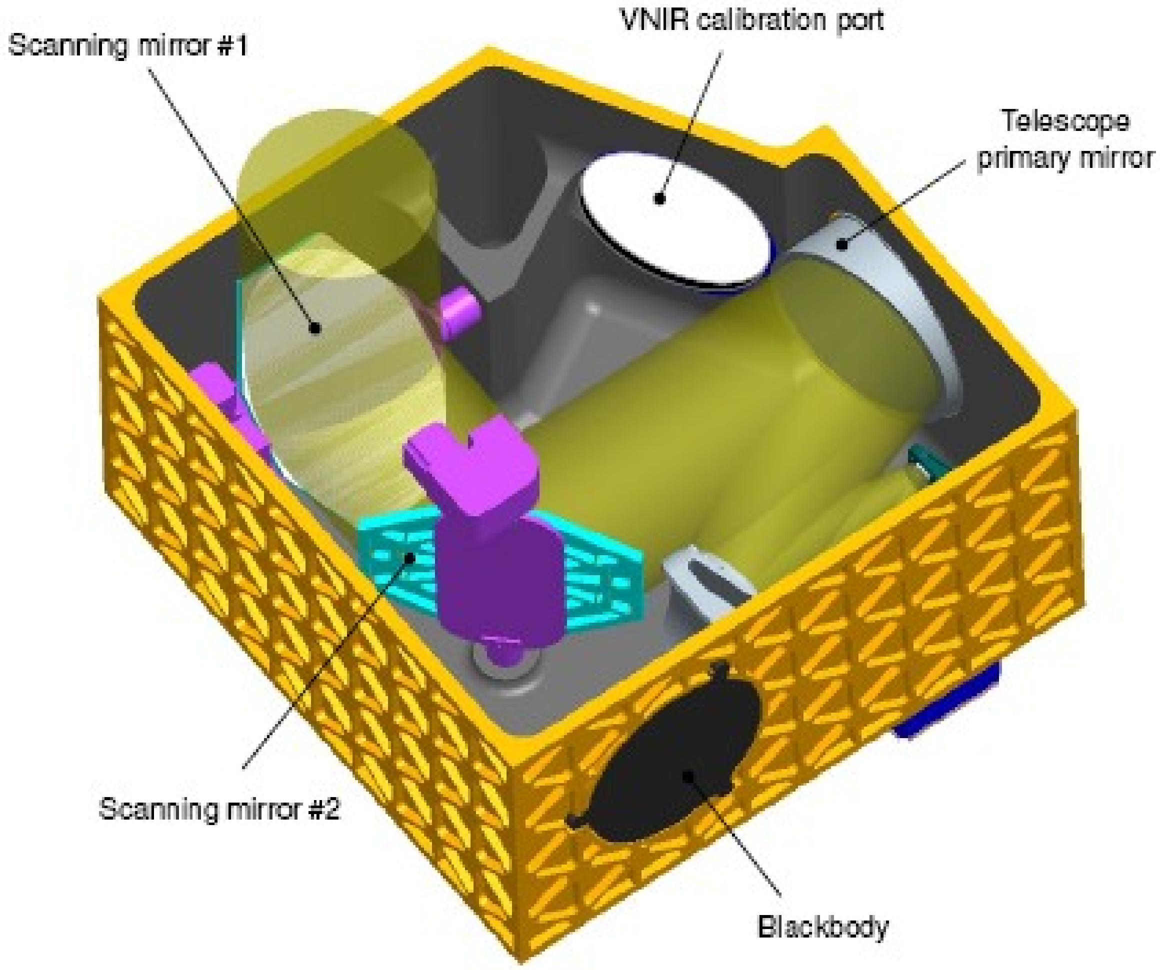
Dependency on orbit excentricity

Phase 0 Results: Preliminary Bus Concept



Mass:	**1319 kg**
Power:	**1233 W**
Pointing Knowledge:	**7.6 arcsec**
Pointing Control:	**55.1 arcsec**

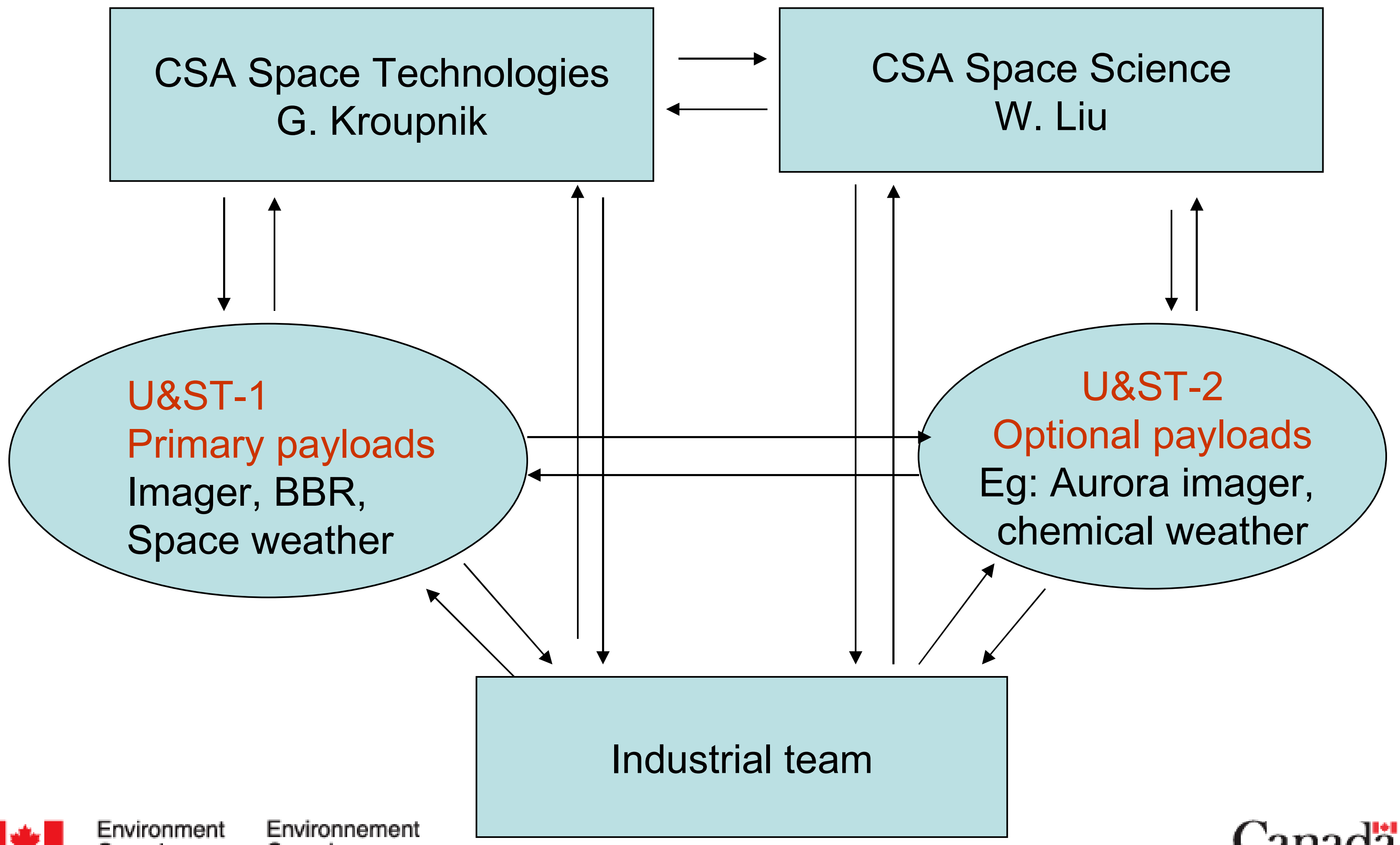
Phase 0 Results: Meteo Payload Concept



PCW Payloads (committed/possible)

- Primary
  - 2-way HDR antenna/transponder sub-system (Ka)
  - Imaging Spectroradiometer (20 channels, 0.5-1 km VIS, 2 km IR)
  - Space weather instruments
- Secondary
  - Scientific instruments:
    - Broadband radiometer
    - Aurora Imager
    - Atmospheric composition instrument (UV-NIR)
    - Fourier Transform spectrometer (IR, similar to IASI)

Phase A PCW structure



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Phase A Overview

- Phase A to start May 2009, end Dec 2010
- Expected Main Outcomes:
  - System Requirements Document
  - Ground Segment Requirement Specification (update)
  - Spacecraft Requirement Specification (update)
  - Bus Requirement Specification
  - Payload Requirement Specification (update)
  - Mission Development Plan, including lifecycle cost
  - Government led studies supporting mission merit
  - Treasury Board submission seeking phases B/C/D approval

Partnership Opportunities

- Extension of membership in the Users & Science Team to the international partner organizations
- Joint Definition Study
  - Via CSA: government and intergovernmental agencies
  - Via Prime Contractor: private/commercial entities
- Phase B and beyond: Partnership mission (International and/or PPP) (TBC)

Creation of EC PCW office

- Concept in principal approved for Phase A
  - 200 K/year budget for EC studies supporting PCW
  - start April 1 2009
  - MoU to be signed with CSA

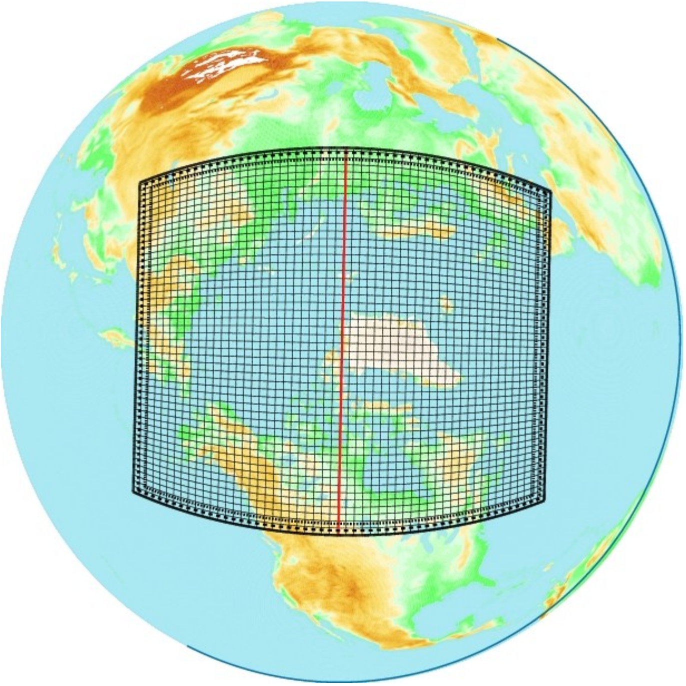
- MoU EC-NRCan considered

Some Phase A U$ST tasks

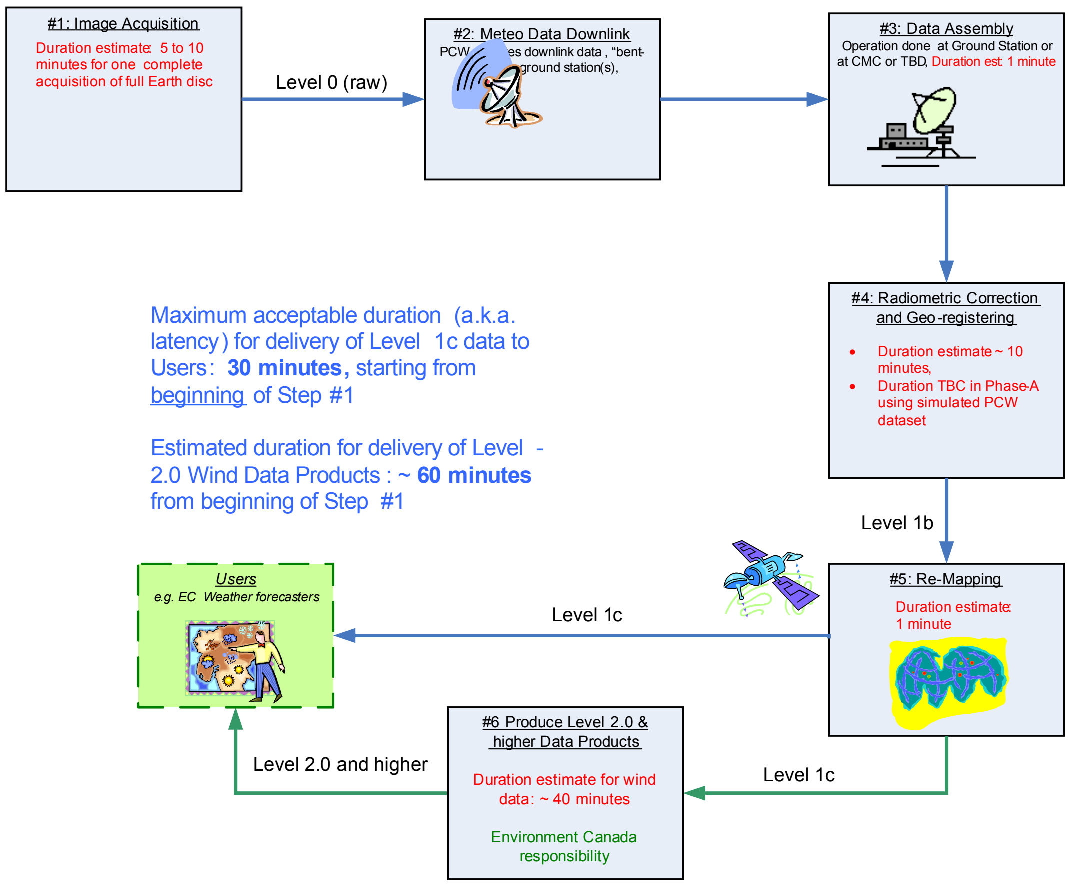
- With industry, end-to-end simulator of PCW imager from Level 0 (raw) to Level 1c (calibrated/navigated):
  - scanning process, channel co-registration
  - image rectification
  - remapping from 1b to 1c
- Adapt U-Wisconsin AMV software to our environment
- Radiative transfer model adapted to PCW: production of simulated radiances
- Ground segment, data delivery detailed scenarios
- Observing System Simulation Experiment (OSSE) for impact of PCW-retrieved winds: informal offer from JCSDA on this
- Extend U$ST to interested international partners

Polar-GEM 15-km grid for IPY

- Currently used in IPY research
- Can be run at higher resolution for PCW radiance simulations



Delivery cycle of level 1 (radiances) and 2 (e.g winds) products



Remapped Level 1c images available within 30 min, winds 60 min

Principaux défis pour EC et partenaires

En supposant que

- ASC s’occupe du contrôle du satellite et de la réception des données brutes
- Le CMC reçoit les données au niveau 1C

Défis:

- Préparation du nouveau mandat en phases A-D
- Maintien/amélioration de la chaîne de production des produits opérationnels; livraison en temps réel aux usagers nationaux et internationaux. Archivage.

Conclusion

- PCW répond à des besoins bien identifiés du Canada:
  - Communications septentrionales
  - Souveraineté et sécurité nationales
  - Météorologie opérationnelle
  - Monitoring environnemental, urgences
  - Monitoring du climat
- Avec PCW, le Canada fera sa part comme fournisseur de données satellitaires pour la prévision numérique du temps.
- PCW représente un défi technologique de taille que l'ingéniosité canadienne peut relever. Les bénéfices potentiels sont très grands.
- Accords bilatéraux en vue avec la plupart des pays de la région circumpolaire arctique.