Agence spatiale canadienne | Canadian Space Agency | Environnement Canada | Environment Canada | Natural Resources Canada | Ressources naturelles Canada

Polar Communications and Weather Mission

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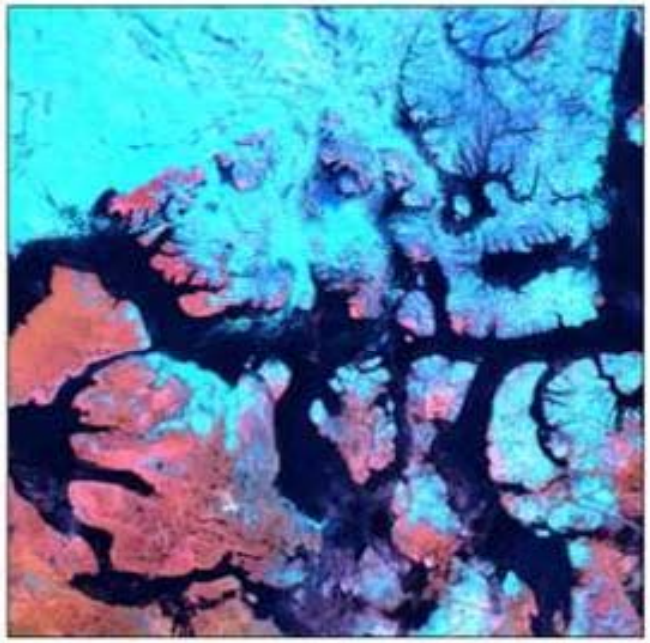
Canada

Outline

- Mission Objectives
- Project status
- Trade-offs and System elements
  - Imager characteristics
  - Orbital trade-offs
- Products and data processing

Renewed Interest in the Arctic

- Increasing economic activities, marine and air traffic
- Acceleration of climate change
- Air pollution transport



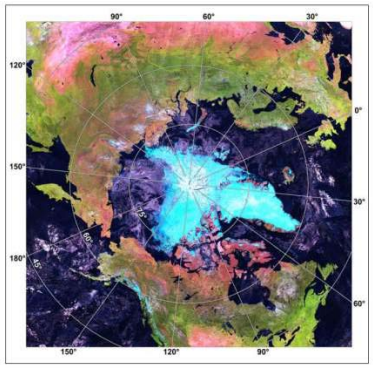
Opening of NW passage
September 2007
From MODIS 250-m imagery

Courtesy: Canada Center
For Remote sensing

Canada

Mission Objectives

Seamless GEO-like imagery over circumpolar area



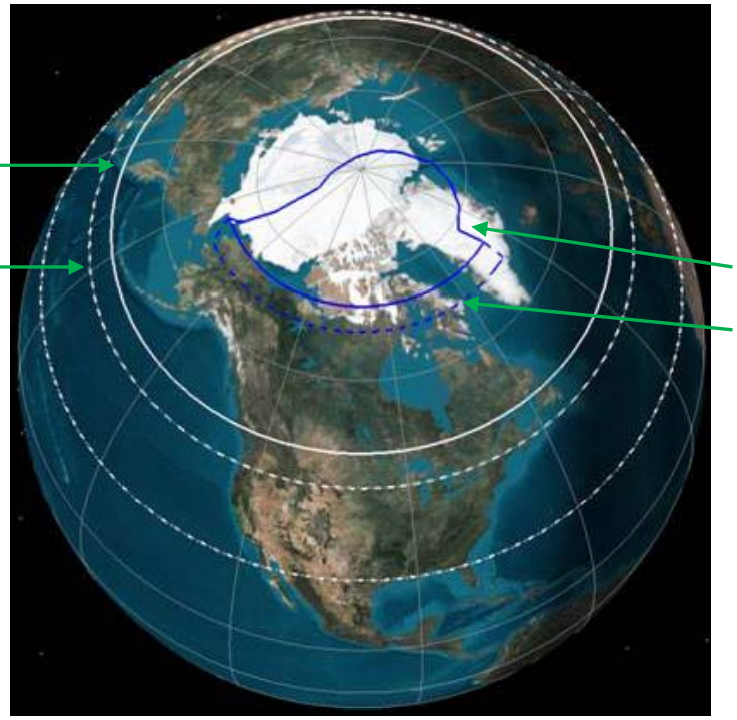
Req'd 50N

Goal 45N

Numerical Weather Prediction

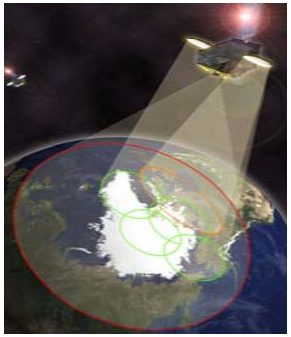
Environmental monitoring & emergency response

Climate change monitoring



Space weather monitoring

Continuous, reliable communications above 70N



AoI

Required

Goal

Security, sustainable Development

Support to Northern Communities

Safety of the Air and Marine Navigation

Arctic Science

Project Status (1)

- Phase 0 completed: September 2008
- Phase A contract awarded: July 2009
- Phase A Major Milestones:
  - Technology Readiness Assessment Review: October 2009
  - Mission Requirements Review: February 2010
  - Preliminary System Requirements Review: June, 2010
  - Phase A industrial contract final review: April 2011
- Target launch: 2018

Project status (2)

- Strong support and buy-in from Stakeholders in Canada and internationally.
- Mature set of User Requirements (URD v.6.0).
- Mission Requirements consistent with
  - 2 satellite constellation in one orbital plane
  - 12h, 16h, or 24h periods for Highly Elliptical Orbit
- Extensive knowledge base with respect to the orbits and the associated radiation environment.
- Meteorological Payload Requirements consistent with existing/planned GEO instruments or custom PCW instrument
- Critical Technologies development contracts award: Fall 2011

Business Models and Project Implementation

- Value for Money analysis of different procurement models:
  - Major Crown Project (traditional government procurement)
  - Public Private Partnership (PPP)
    - Different models to be explored
    - Emphasis on:
      - Effective transfer of performance, schedule and cost, risks to the Contractor
      - Access to capital market
      - Fostering innovation
    - Government of Canada owns the assets and ensures provision of data, and services
    - Meteo services are centralized at the PCW Data Processing Centre under Environment Canada responsibility
- RFI process for PPP
- Socio-economic benefits study (starting fall 2011) will contribute to the business case

Phase A System Level Trade-offs

- Image Navigation and Registration (INR) Analysis,
- Analysis to Increase Imaging period
- Constellation and Orbit Definition Trade-Off
- Communication Payload Beam Pointing Analysis
- Various Trade-Off s of Data Downlink and TTC Downlink options
- Communications Network Topology Analysis

Payloads

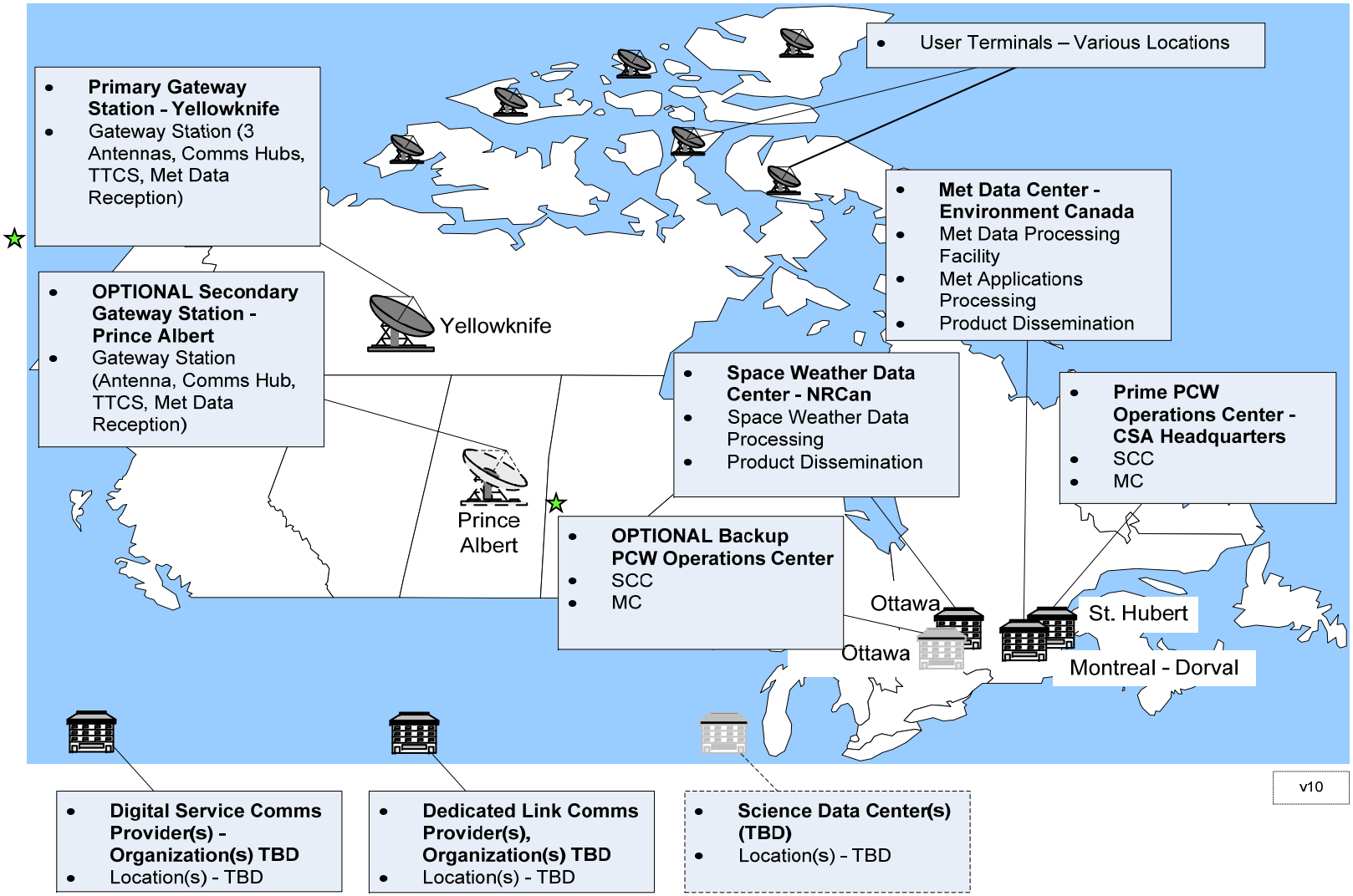
Core mission:

- Ka – band and X-band communications payload
- Imaging Spectroradiometer
- Space weather suite of instruments

Enhanced mission:

- Phase A studies: FTS under way, funding allocated for other Solar Terrestrial studies
- Potential international enhancements
  - Global Navigation Satellite System payload,
  - Air Traffic Management payload

Ground Segment



Canada

PCW Imager Characteristics (1)

Band #	Wavelength Range (µm)	Mission Priority	Sample Spacing				Radiometric Dynamic Range			Required 1-sigma Noise for Bright Scene ($W/m^2/sr/\mu m$)	Main Applications
			ASD (microradians @ 37500 km) Goal	Max	Approx GSD at apogee±1.5 hours (km) Goal	Max	Dim Scene ($W/m^2/sr/\mu m$)	Bright Scene ($W/m^2/sr/\mu m$)	Max Scene ($W/m^2/sr/\mu m$)		
1	0.45 - 0.49	1	13.3	40	0.5	1.5	5.50	552.1	734.3	< ±1.8	Surface, clouds, aerosols
2	0.59 - 0.69	1	13.3	40	0.5	1.5	4.50	449.1	597.3	< ±1.5	Wind, clouds, ice mapping
3	0.704 - 0.714	2	13.3	40	0.5	1.5	3.80	381.3	507.1	< ±1.3	Water quality, chlorophyll
4	0.85 - 0.89	1	13.3	40	0.5	1.5	2.65	266.4	354.3	< ±0.89	Wind, aerosols, vegetation
5	1.04 - 1.06	2	26.7	80	1.0	3.0	1.85	184.5	245.4	< ±0.62	Snow grain and clouds
6	1.37 - 1.39	2	26.7	80	1.0	3.0	0.10	10.0	13.3	< ±0.033	Cirrus detection
7	1.58 - 1.64	1	13.3	40	0.5	1.5	0.70	67.5	89.8	< ±0.23	Snow-cloud distinction, ice cover
8	2.22 - 2.28	1	26.7	80	1.0	3.0	0.20	19.9	26.5	< ±0.066	Aerosol, smoke, cloud phase

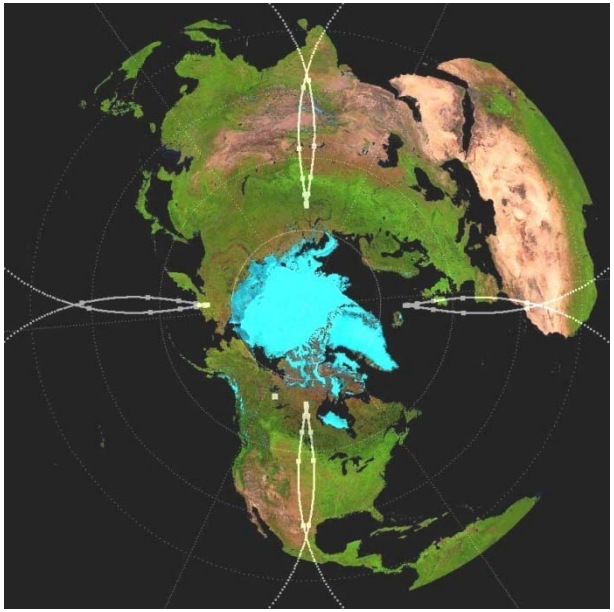
PCW Imager Characteristics (2)

Band #	Wavelength Range (µm)	Mission Priority	Sample Spacing				Radiometric Dynamic Range		1-Sigma Noise Equivalent Delta Temperature (NEDT)		Main Applications
			ASD (microradians @ 37500 km) Goal	Max	Approx GSD at apogee±1.5 hours (km) Goal	Max	Cold Scene Temp (K)	Max Scene Temp (K)	Required NEDT for 240K Scene (K)	Required NEDT for 300K Scene (K)	
9	3.80-4.00	1	40	80	1.5	3.0	240	410	< ±1.66	< ±0.125	Fog, fires, ice/cloud separation, wind, cloud. phase
10	5.77-6.60	1	40	80	1.5	3.0	240	335	< ±0.35	< ±0.15	Wind, high level humidity
11	6.75-7.15	2	40	80	1.5	3.0	240	300	< ±0.35	< ±0.15	Wind, mid level humidity
12	7.24-7.44	1	40	80	1.5	3.0	240	300	< ±0.35	< ±0.15	Wind, low level humidity
13	8.30-8.70	1	40	80	1.5	3.0	240	335	< ±0.35	< ±0.15	Total water, cloud phase
14	9.42-9.80	2	40	80	1.5	3.0	240	335	< ±0.35	< ±0.15	Total ozone
15	10.1-10.6	2	40	80	1.5	3.0	240	335	< ±0.35	< ±0.15	Cloud, surface, cirrus
16	10.8-11.6	1	40	80	1.5	3.0	240	335	< ±0.35	< ±0.15	Cloud, SST, ash
17	11.8-12.8	1	40	80	1.5	3.0	240	335	< ±0.35	< ±0.15	Ash, SST
18	13.0-13.6	1	40	80	1.5	3.0	240	300	< ±0.50	< ±0.35	Cloud height
19	13.5-13.8	2	40	160	1.5	6.0	240	300	< ±0.50	< ±0.35	Cloud height, low level temperature
20	13.8-14.1	2	40	160	1.5	6.0	240	300	< ±0.50	< ±0.35	Cloud height, mid level temperature
21	14.1-14.4	2	40	160	1.5	6.0	240	300	< ±0.50	< ±0.35	Cloud height, high level temperature

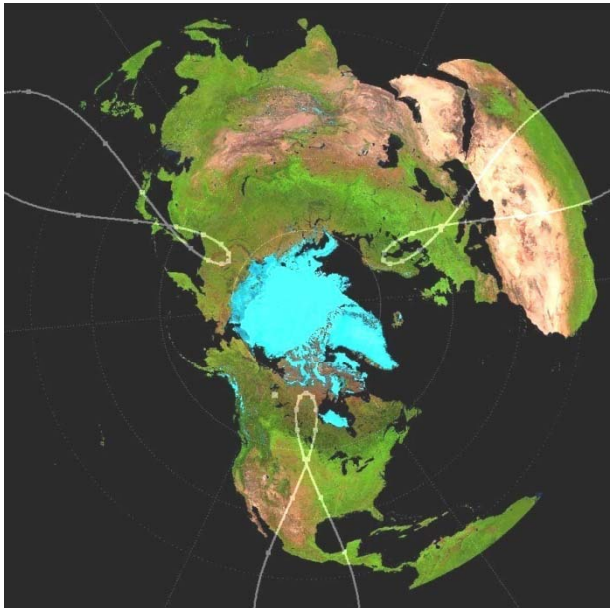
Orbit comparison (2-sat constellation)

Molniya and TAP orbits offer:
- similar high latitude zone coverage
- central view of the North America

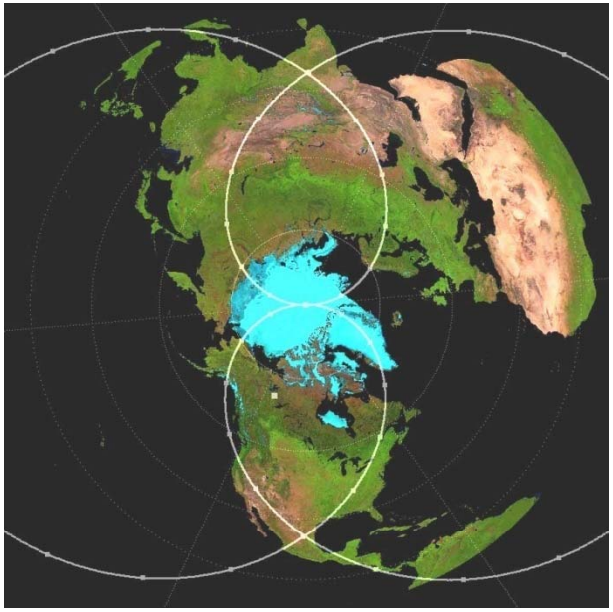
Molniya (12-h)
Apogee: 39,800 km



TAP (16-h)
Apogee: 43,500 km

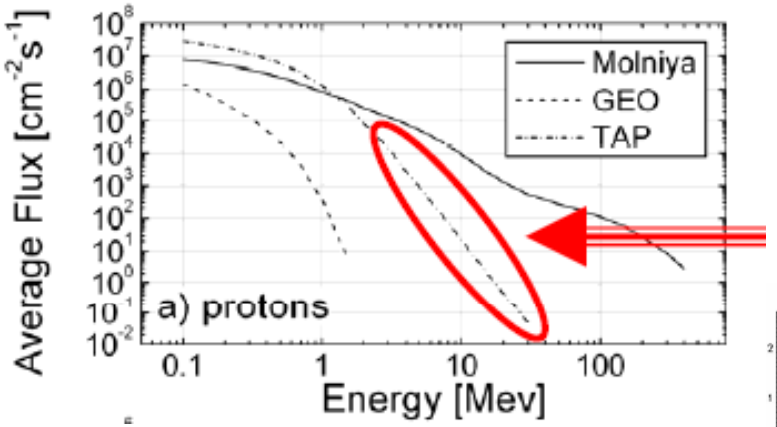


Tundra (24-h)
Apogee: 48,300 km

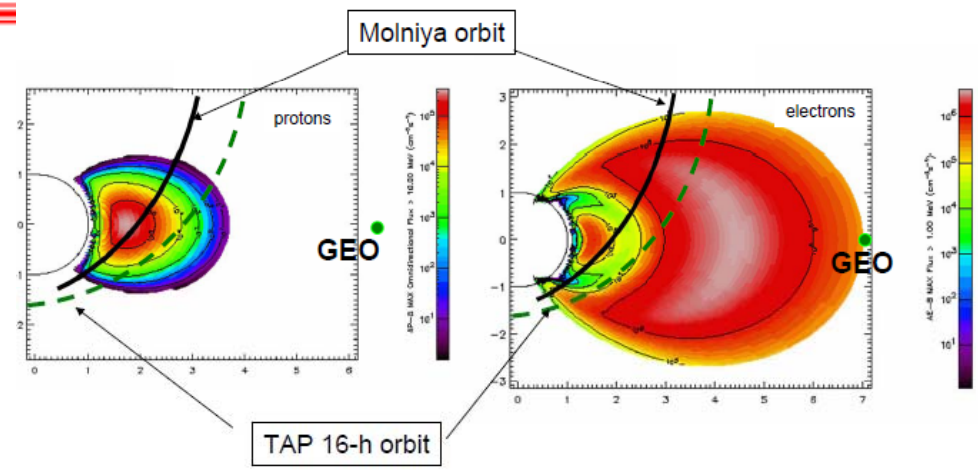


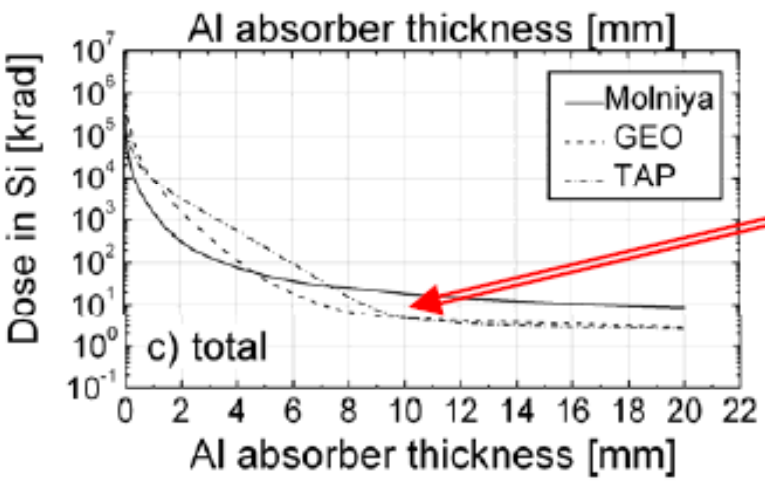
24-h (modified Tundra) orbit:
- no central view of the North America
- data reception requires 2 receiving stations

Comparison of Radiation Environment



- Trapped proton flux for Tundra and GEO are similar
- Factor of 10^3 - 10^4 less flux of high energy trapped protons in TAP than Molniya



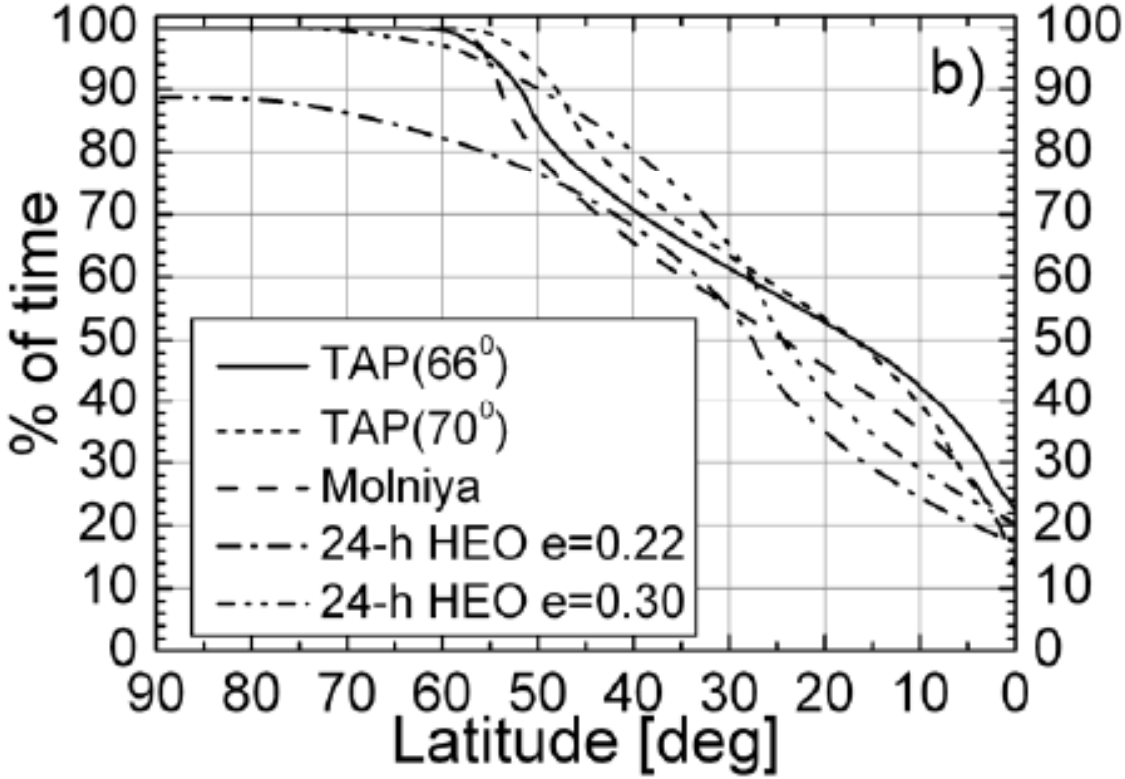


With 7mm of Al shield, the trapped proton dose is negligible in TAP
With 9mm of Al total dose in TAP orbit becomes similar to GEO

Canada

Trishchenko et al, JTECH, 2011 (in press)

Zonal mean spatial coverage



Requirement on coverage:

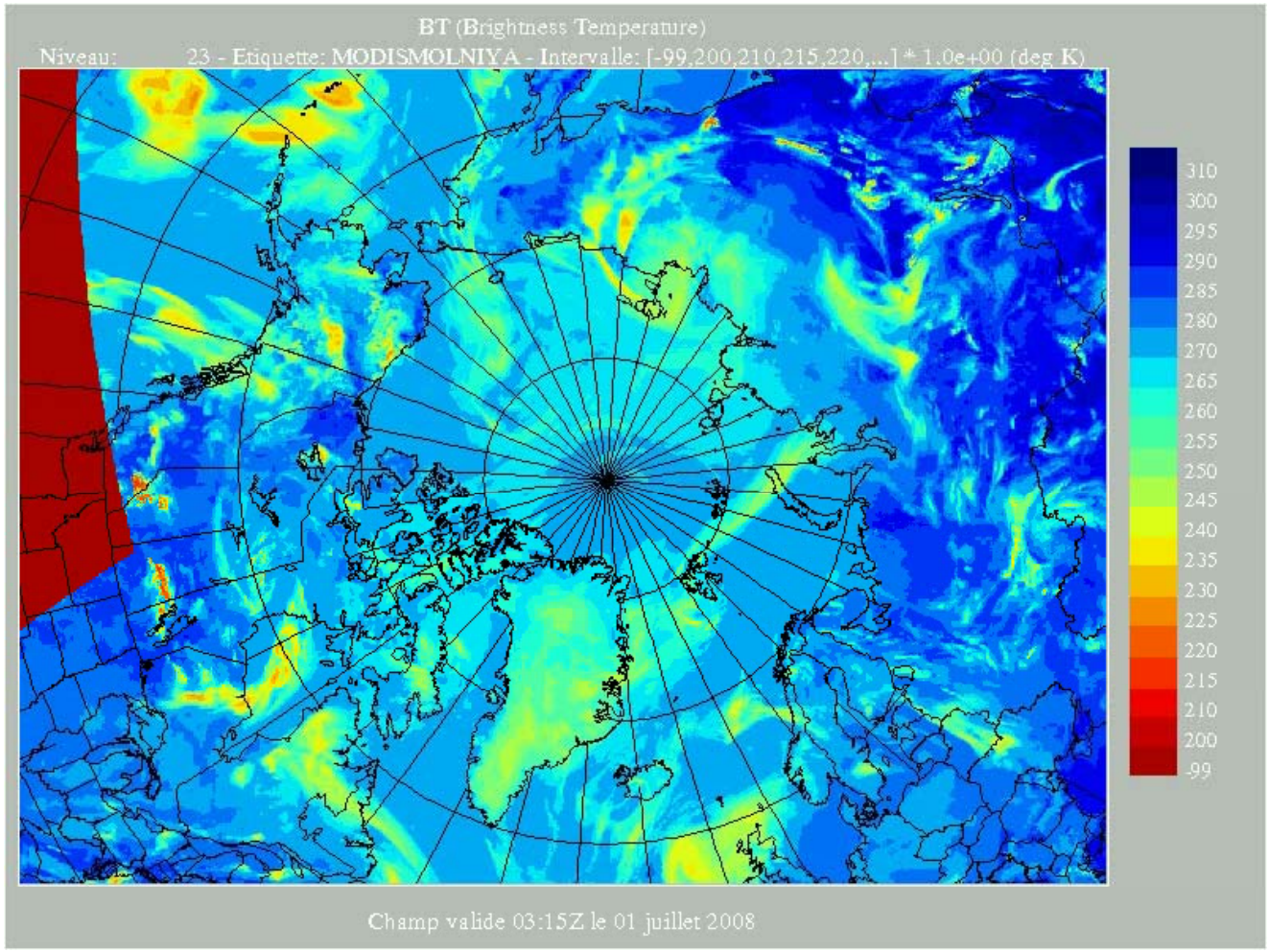
- 100 % above 65 N
- 95 % for 60-65 N
- 90 % for 55-60 N
- 80 % for 50-55 N

- Two satellites, maximize imaging per satellite
- VZA < 70 deg applies
- Reception at Yellowknife

Canada

Trishchenko et al, JTECH, 2011 (in press)

24-h Molniya simulation from 10 km model output, 11 μm, 2 sats, 15 min imagery



Red denotes
VZA > 70 deg

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Preliminary List of Priority 1 Products (NRT)

CATEGORY	PRODUCT	Repeat Cycle	Latency	COMMENT
Imagery	Level 1C imagery	15 min*	15 min*	Calibrated, mapped to standard grid 1.5 km VIS, 3 km IR
	Level 2 imagery	15 min*	30 min**	Composite of 2 satellites
Priority 1 - Near Real Time Level 2 products derived from Level 1C	AMV: Atmospheric Motion Vectors	1 hour	1 hour	Latency is w.r.t. centre time of triplets/duos used for tracking
	Cloud mask	15 min*	30 min**	Basis for many L2 products
	Cloud height, amount, emissivity, temperature	15 min*	30 min**	Important for AMV
	Volcanic ash height (optical depth)	15 min*	30 min**	When active. Done at Dorval volcanic ash advisory center. Could develop a SO_2 product as well.
	Fog and surface visibility	15 min*	30 min**	
	Forest fires. Hot spots	15 min*	30 min**	Product generated at Canadian Forest Service (CFS) or by NRCan for CFS
	Clear radiances	15 min*	30 min**	For direct assimilation in NWP analyses

* Goal as shown Maximum 20 min

** Goal as shown Maximum 35 min

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Preliminary List of Priority 2 Products

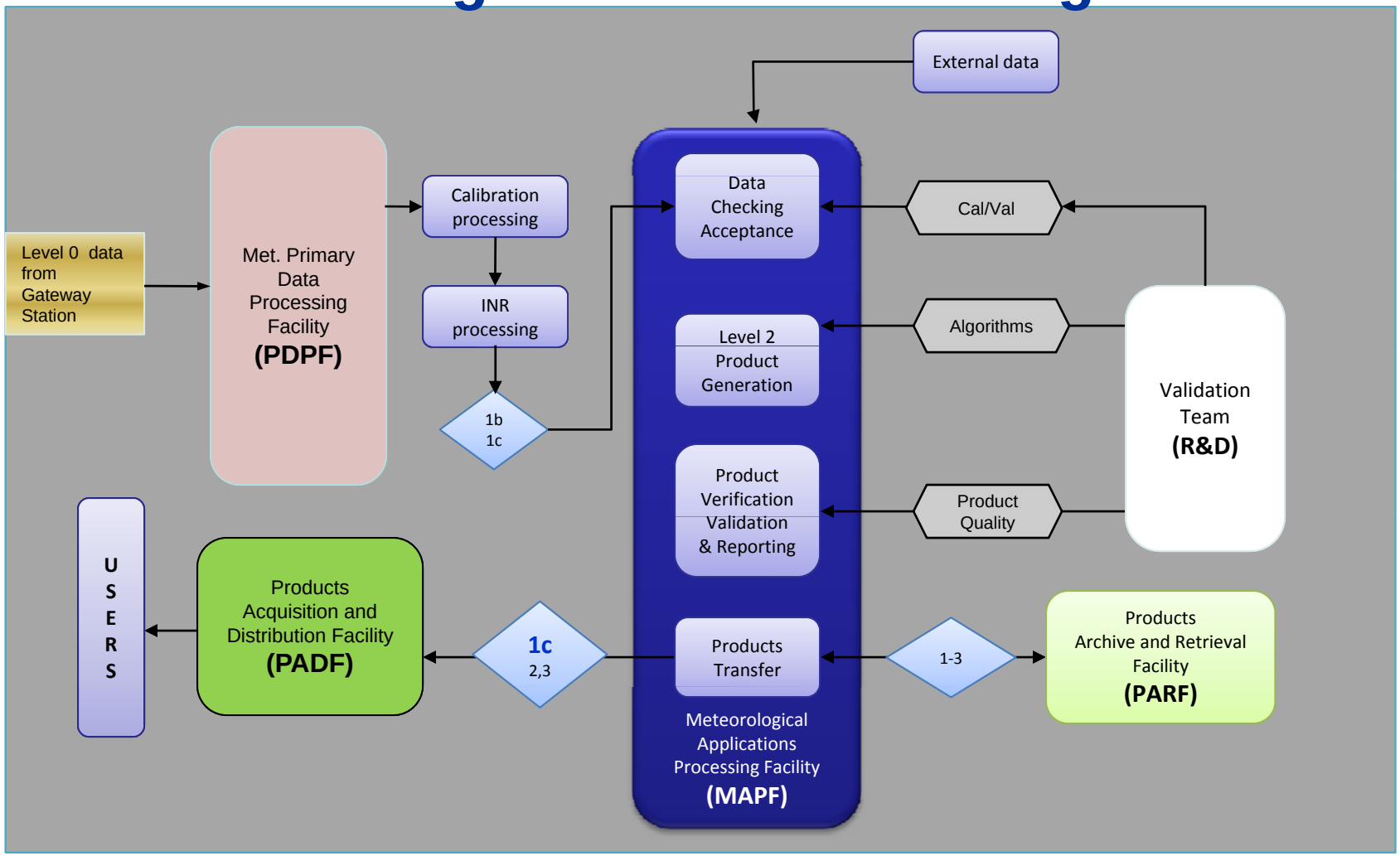
CATEGORY	PRODUCT	Repeat Cycle	Latency	COMMENT
Priority 2 – Level 2/3	Snow/ice mapping (cover and depth)	6 hours	6 hours	Resolution 3 km.
	SST: sea surface temperature	1 hour	2 hours	Resolution 3 km
	LST: land surface temperature	1 hour	2 hours	Resolution 3 km
	Surface albedo	6 hours	6 hours	Resolution 10 km
	Aerosol optical depth	1 hour	1 hour	Resolution 10 km
	Atmospheric stability index	1 hour	1 hour	Resolution 10 km
	Aircraft icing threat	15 min*	15 min*	Resolution 10 km
	Total ozone	1 hour	1 hour	Resolution 10 km

* Goal as shown Maximum 20 min

Preliminary List of ECV Products

CATEGORY	PRODUCT	Repeat Cycle	Latency	COMMENT
Priority 2 - Level 3 climate essential variables (ECV)	NDVI: Normalized Difference Vegetation Index	1 day	1 day	Resolution 1.5 km
	FPAR	1 day	1 day	Fraction of Absorbed Photosynthetically Active Radiation. Resolution 1.5 km
	LAI: Leaf Area Index	1 day	1 day	Resolution 1.5 km
	Radiative fluxes	1 hour	1 day	Resolution 10 km (SW, LW at surface and TOA)
	Land surface emissivity	1 day	1 day	Resolution 3 km
Archive Products	Levels 0, 1C and 2 are archived forever at CMC, and Level 1B for 5 years. In addition rotating archive of Level 0 at ground receiving station.			
Note :Level 2 products are retrievals made from Level 1C. Level 3 products defined at a coarser resolution. Surface parameters are only available in clear air (mask =0) or when the sun angle allows. In areas devoid of observations, the pixels are either left blank or replaced by a previously obtained value.				

PCW Meteorological Data Processing Centre



Total staff: ~75

Conclusion

- PCW represents a truly novel and elegant solution to close the gap in global communication services and meteorological observation coverage in the Arctic:
  - 12-21 channel imager with spatial sampling from 0.5 km to 3 km would provide continuous observations over the Arctic with refresh rate <20 minutes;
  - The set of operational products and Essential Climate Variables (ECVs) are highly compatible with WMO, NOAA & EUMETSAT objectives
  - Observations from HEO orbit provide very rich geometry (including dual views) that should lead to improved atmospheric and surface products
  - PCW data would be included as part of Global Space-Based Inter-Calibration System (GSICS) to ensure the quality of data products

- Phase A clearly demonstrated feasibility. Interesting opportunities for international collaboration have been identified and are being actively pursued
- PPP is key to project implementation
- EC is looking forward to work with Alaska on the preparation for both GOES-R and PCW processing and applications

Partnership opportunity

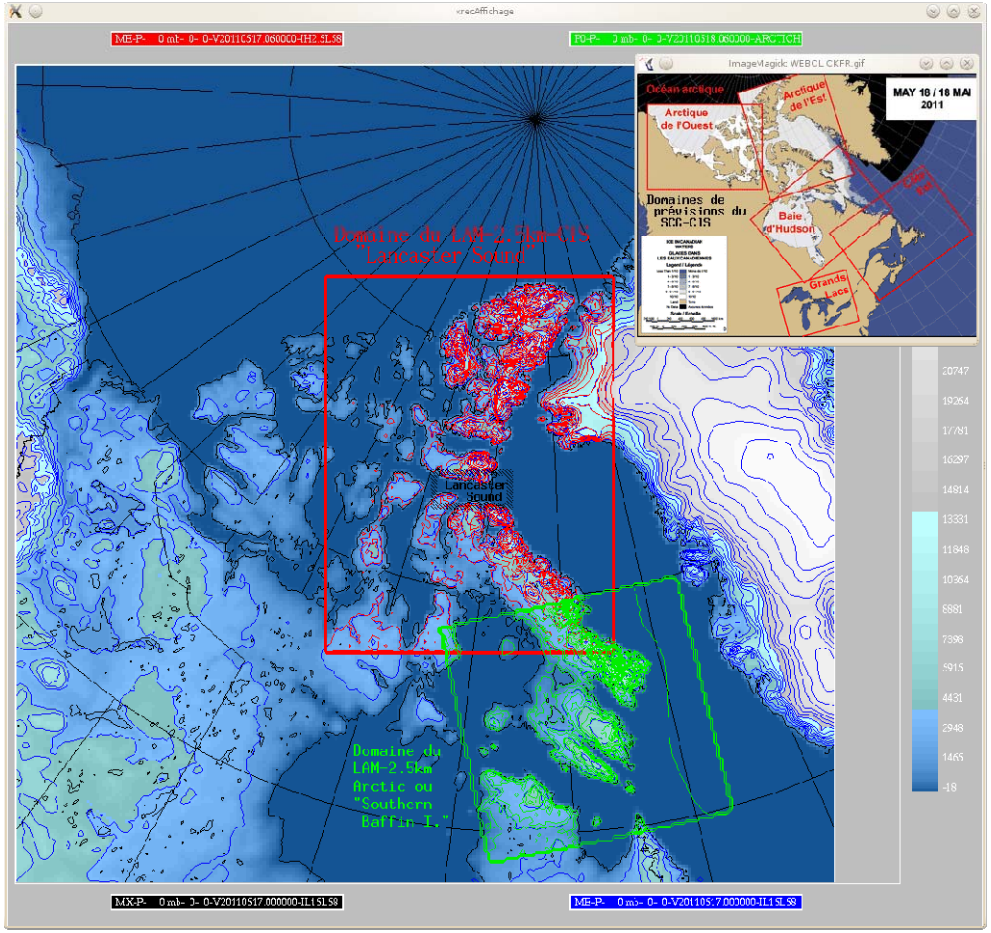
Some of current EC capabilities relevant for cooperation with Alaska

- Fast radiative transfer model to simulate PCW and/or GOES imagery
- Model output on chosen Arctic sectors at 2.5 km
- AMV capability (U.W software)
- Volcanic Ash Advisory Center in Dorval (uses AVHRR)
- Comprehensive data assimilation capability
- Air quality models
- GOES-E/W disks received and various products produced
- Expertise on fog/visibility modeling and remote sensing
- Expertise on ice mapping (using AMSR and AVHRR)
- OSSE capability
- Expertise from NRCan on ECV, surface variables in Arctic

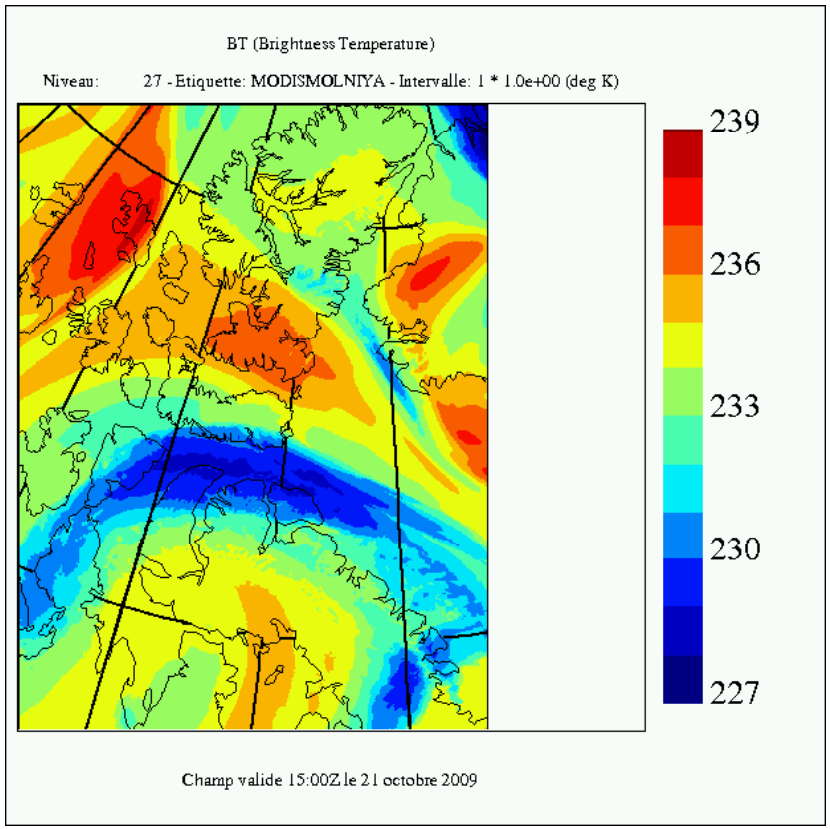
Specific arrangements with Alaska: possibilities

- Back-up receiving station
- Specific link for privileged early reception of PCW data
- Cross-validation of products on same area
- Continuity of applications at limit of GOES-R domain
- Calibration via GSICS

2.5 km resolution domains used at EC



6.7 micron simulated BT



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Back-up slides

Orbital trade- off for Arctic usage

(2 satellite constellation)

12hr HEO

- Provides excellent area coverage with apogee height similar to GEO
- Passes through Van Allen belts and is sensitive to trapped protons
- Critical inclination 63.4 deg makes apogee location stable

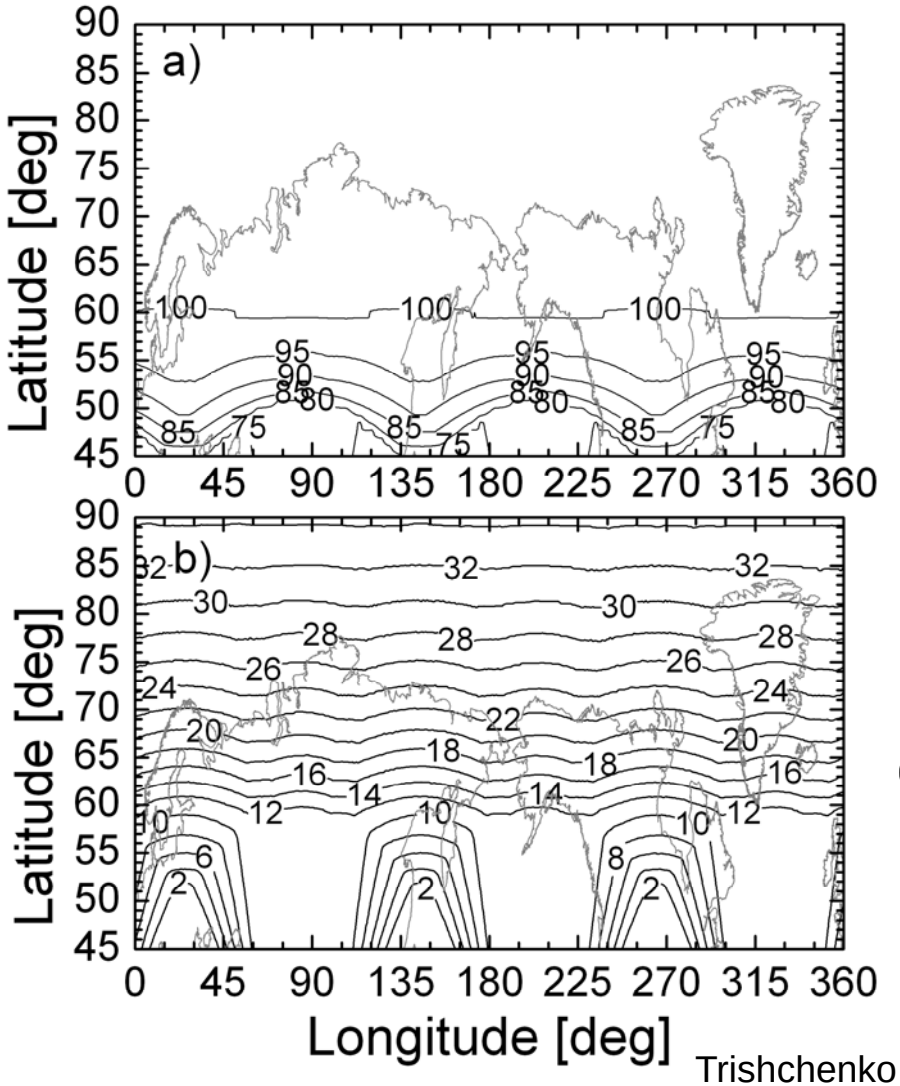
24hr HEO

- Inclination > 80 deg needed to get reasonable imaging coverage
- High apogee and ground speed and are not ideal for imaging
- Avoids Van Allen belts for trapped protons
- Significant Orbital maintenance required
- Communications services are more difficult because a satellite cannot see the opposite hemisphere as it descends from apogee and is then at much lower latitude

16 hr HEO has intermediate features of both

- Critical inclination gives reasonable coverage , but 66 deg inclination is better
- Largely avoids Van Allen belts for trapped protons
- Larger Orbital maintenance required for 66 deg

PCW (2-sat) spatial coverage

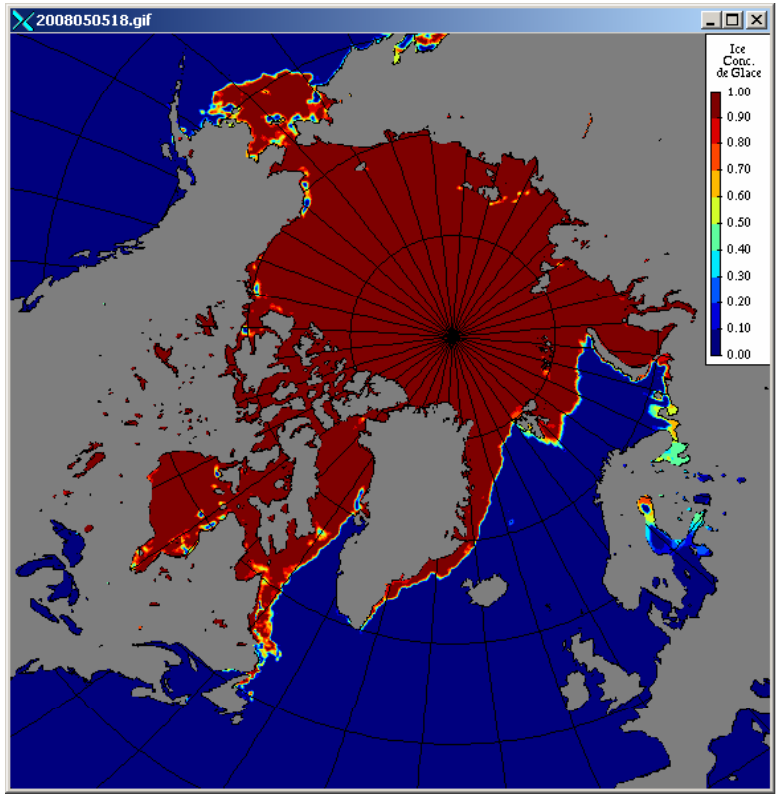


Combined 2-sats
TAP 16-h orbit

Dual views
(simultaneous imaging)

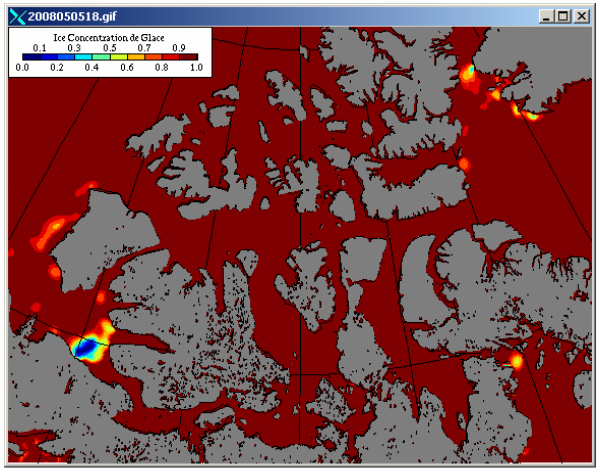
Trishchenko et al, JTECH, 2011 (submitted)

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



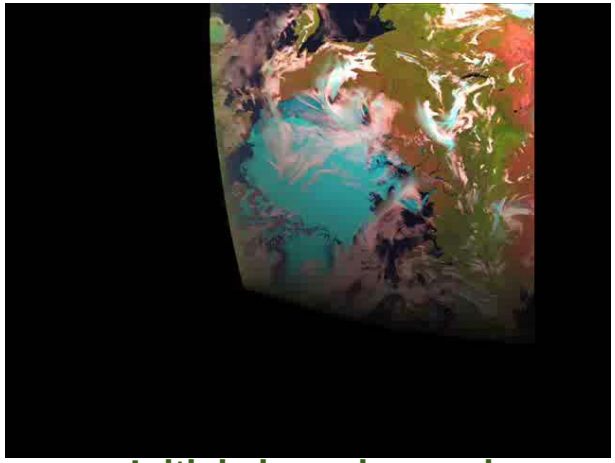
Prototype 5 km over Canadian Archipelago

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

Canada

Improved Clear-Sky Statistics

Start: July 1, 2008 3:00UT

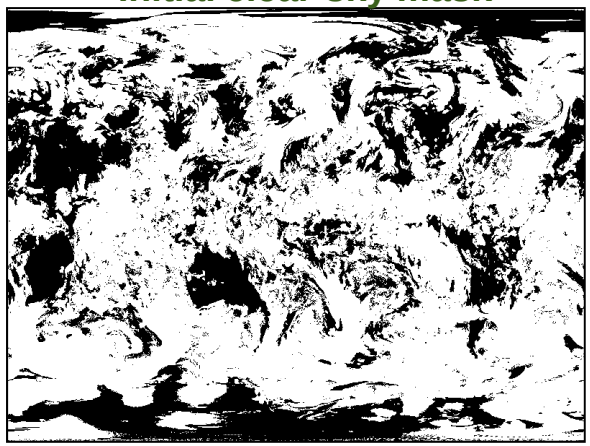


Daily mean cloud fraction : 69% (64%)

Mean cloud fraction after clear-sky compositing (every 15min over 24hrs) : 34% (32%)

(50^0N-90^0N)

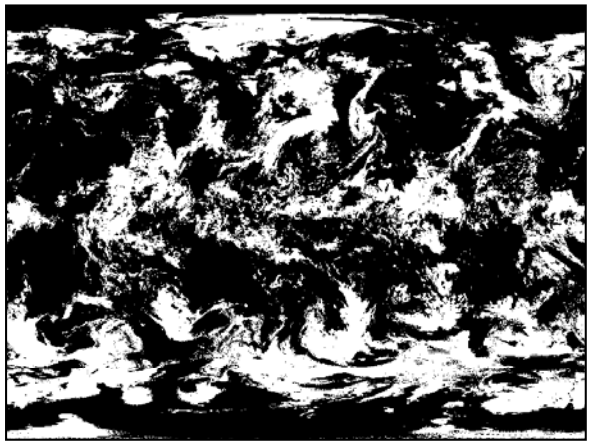
Initial clear-sky mask



clear

cloud

Accumulated clear-sky mask after 24hrs



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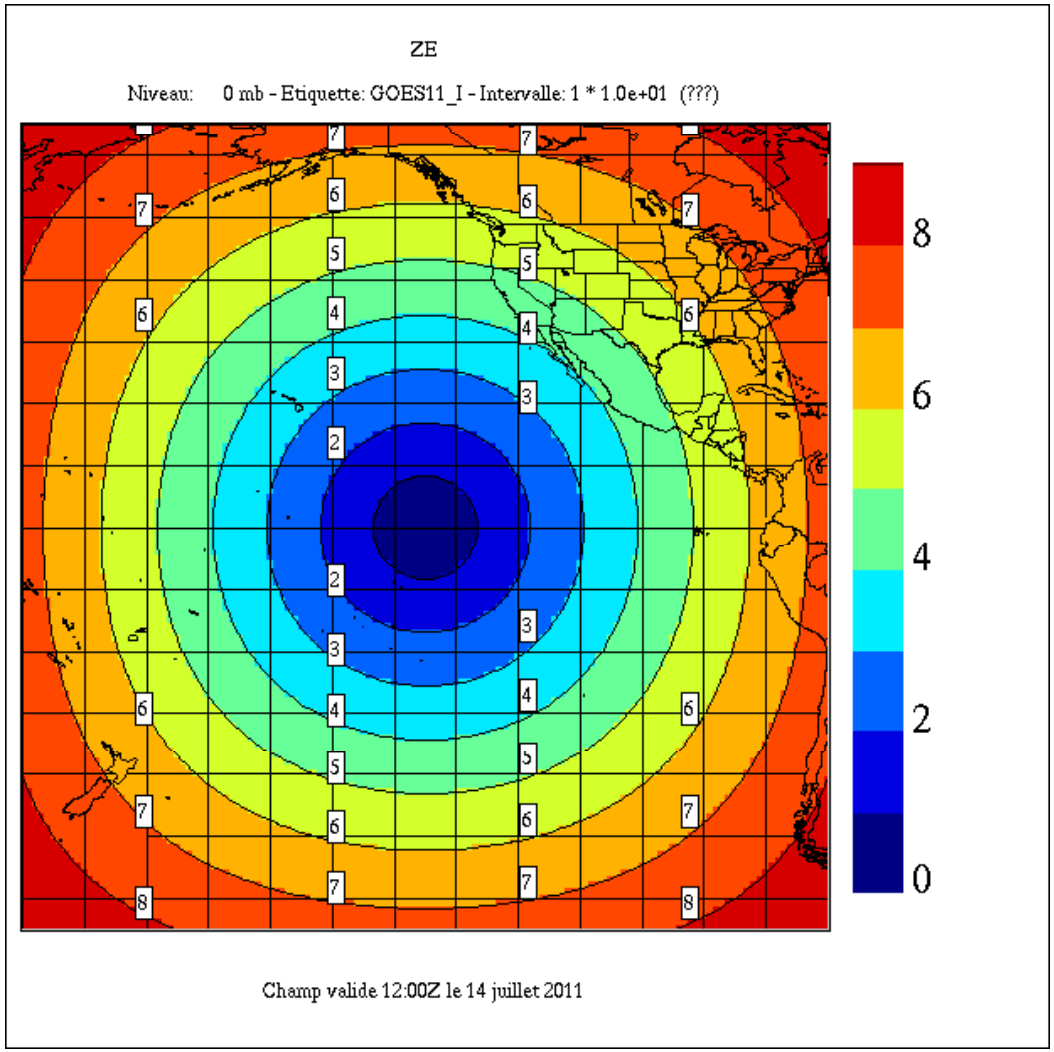
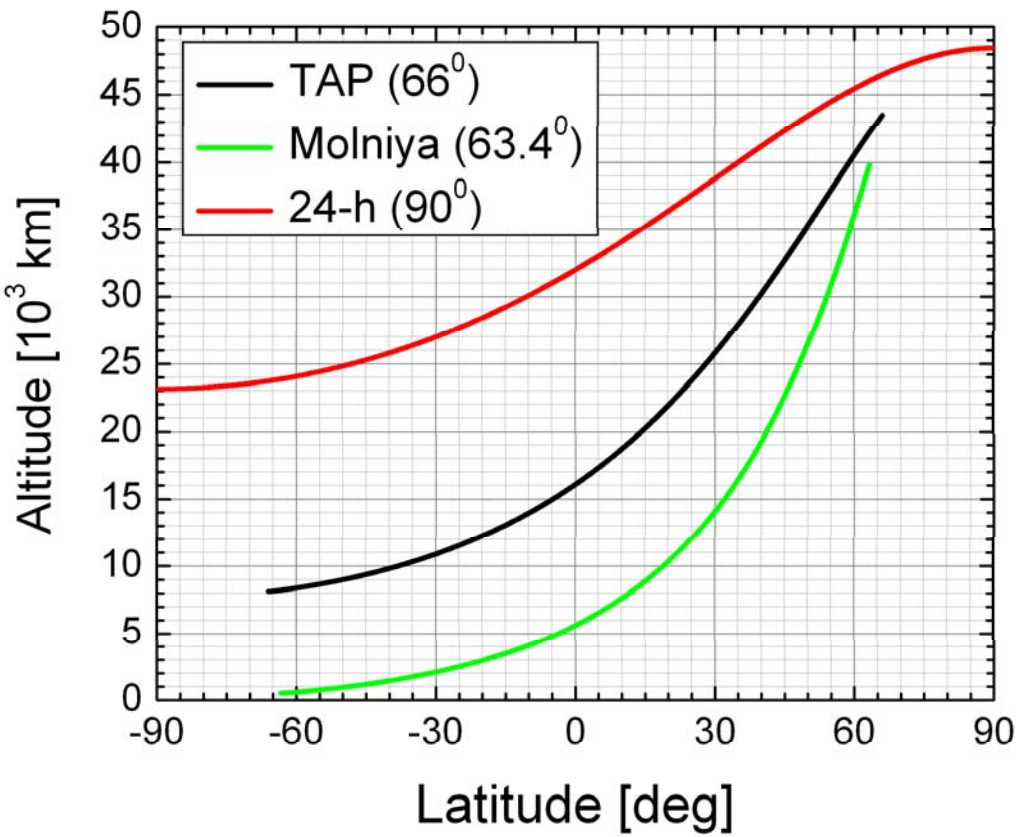
Viewing angle from GOES-W



VZA > 70 deg for most of Alaska

Satellite altitude for various orbits



Height at 40 N (central US)

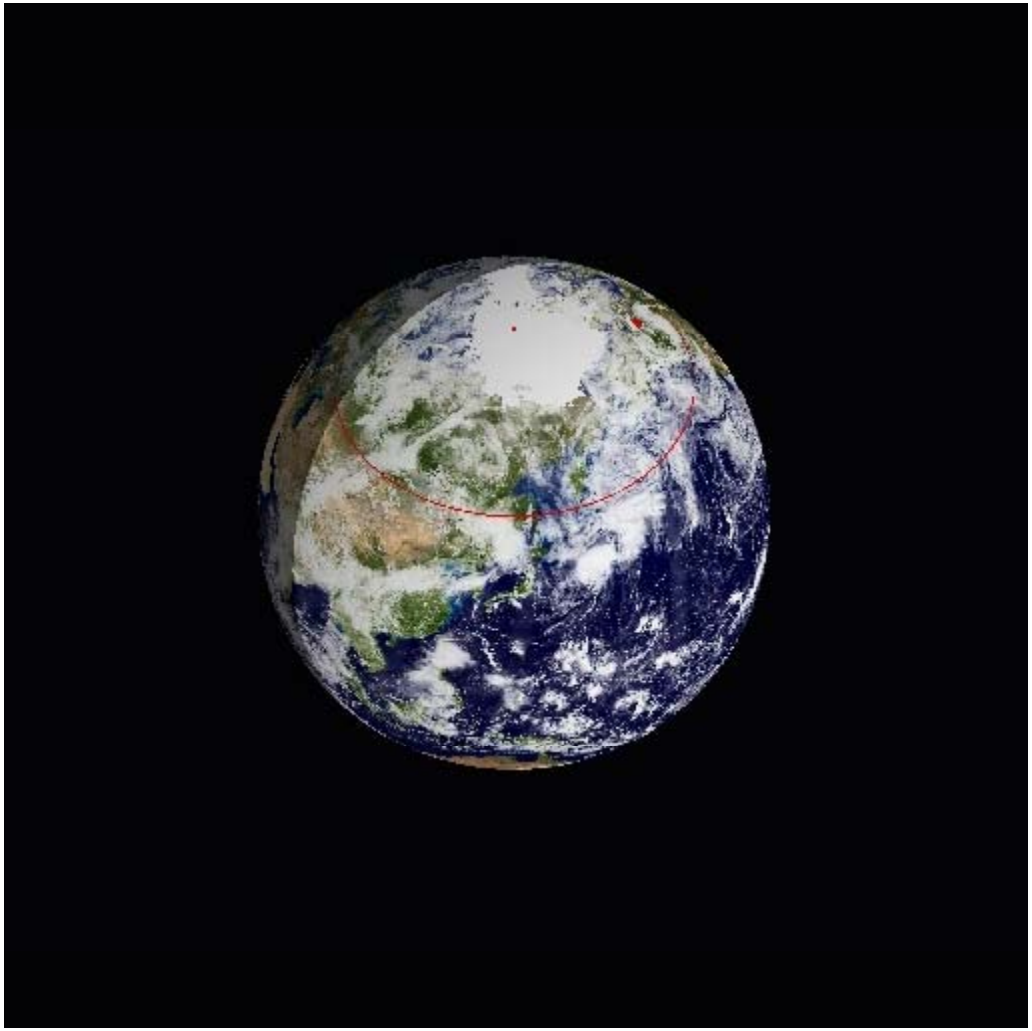
TAP: 30,000 km
Molniya: 19,500 km
24-h: 41,200 km

For TAP 95 W apogee path, data reception at Yellowknife starts at about 33 N (height of ~27,000 km, 5.3 h to apogee)

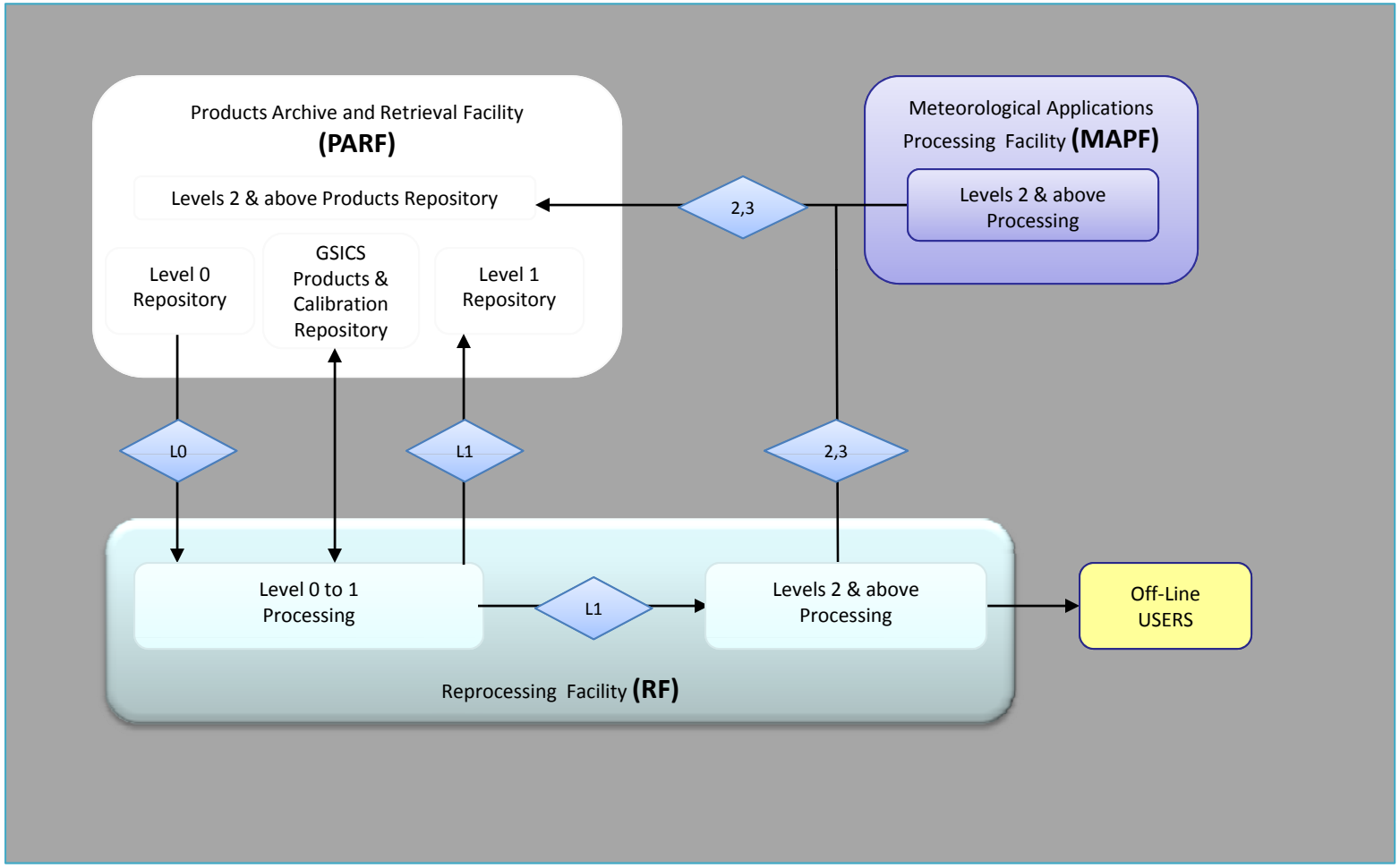
For Molniya, reception starts at About 45 N (H= ~22,500 km) 4.0 h to apogee

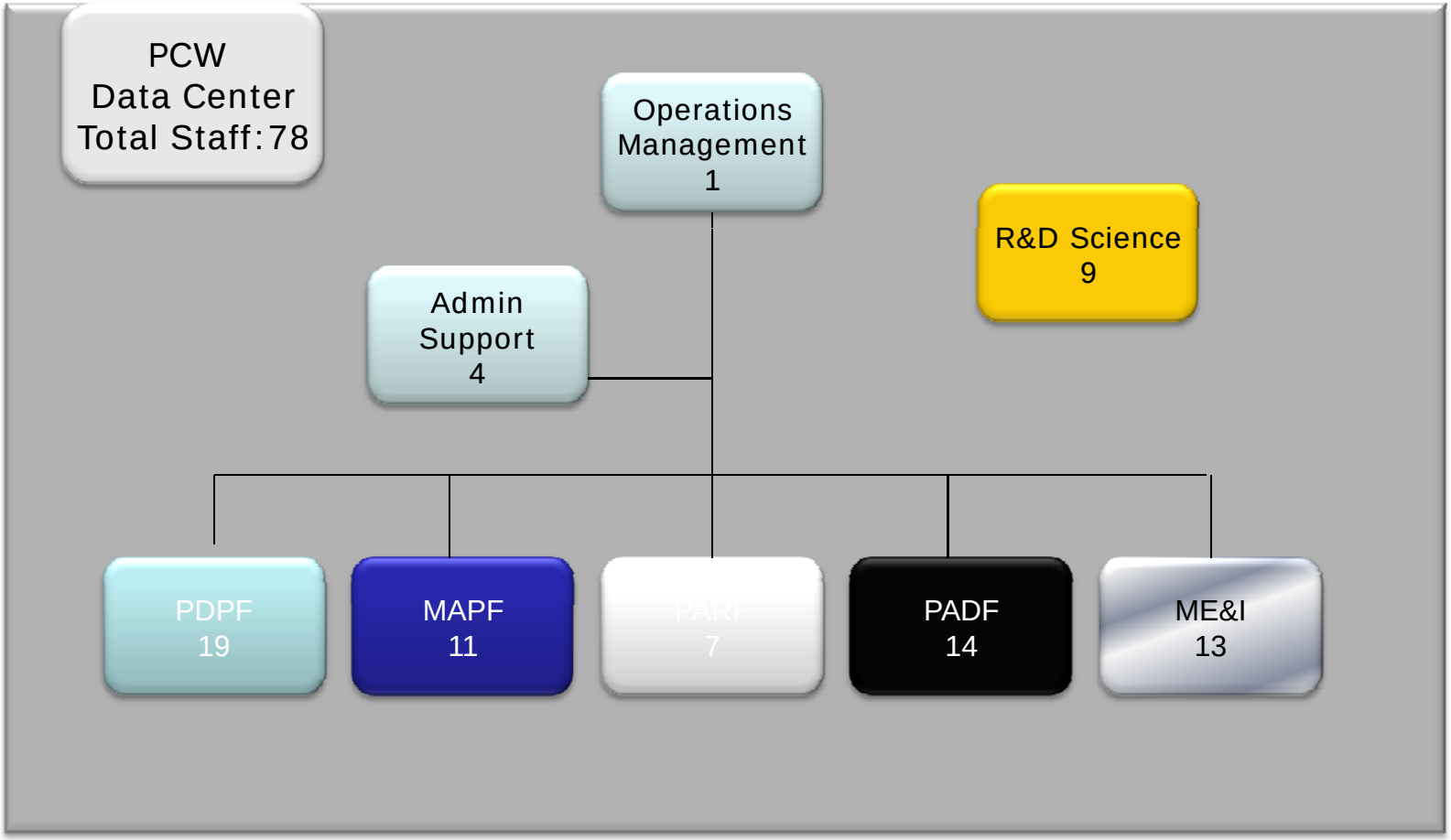
Canada

View of the Earth from Tap orbit (48-h)



PCW Application Ground Segment Functional Architecture: Reprocessing Facility



Canada

PCW Data Processing Center Manpower Resources (Summary)