Environment Canada Environnement Canada

Canada

The Polar Communications and Weather mission, a concrete solution for seamless observation of the Arctic

Joint Center for Satellite Data Assimilation

Camp Springs, MD

Louis Garand (EC) and PCW U&ST

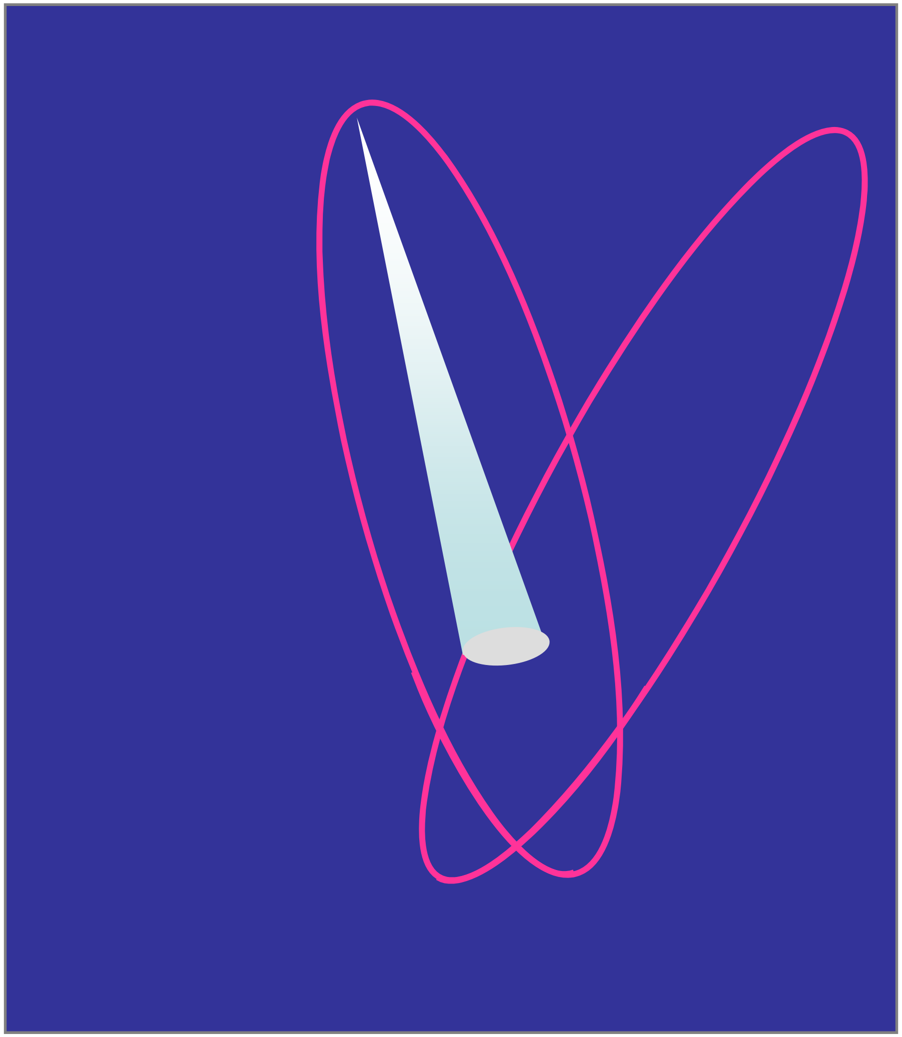
January 13, 2010

CSA ASC

outline

- Brief history of HEO “Molniya” concept
- Goals, Requirements
- Imager characteristics
- Orbital characteristics
- Radiative transfer, simulated datasets, algorithm development
- International context and partnership

Molniya Orbit: basic parameters



2 satellites to provide continuous GEO-like imagery 50-90 N

0.5-1 km VIS
2 km IR

12-h period
63.4 deg. inclination

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

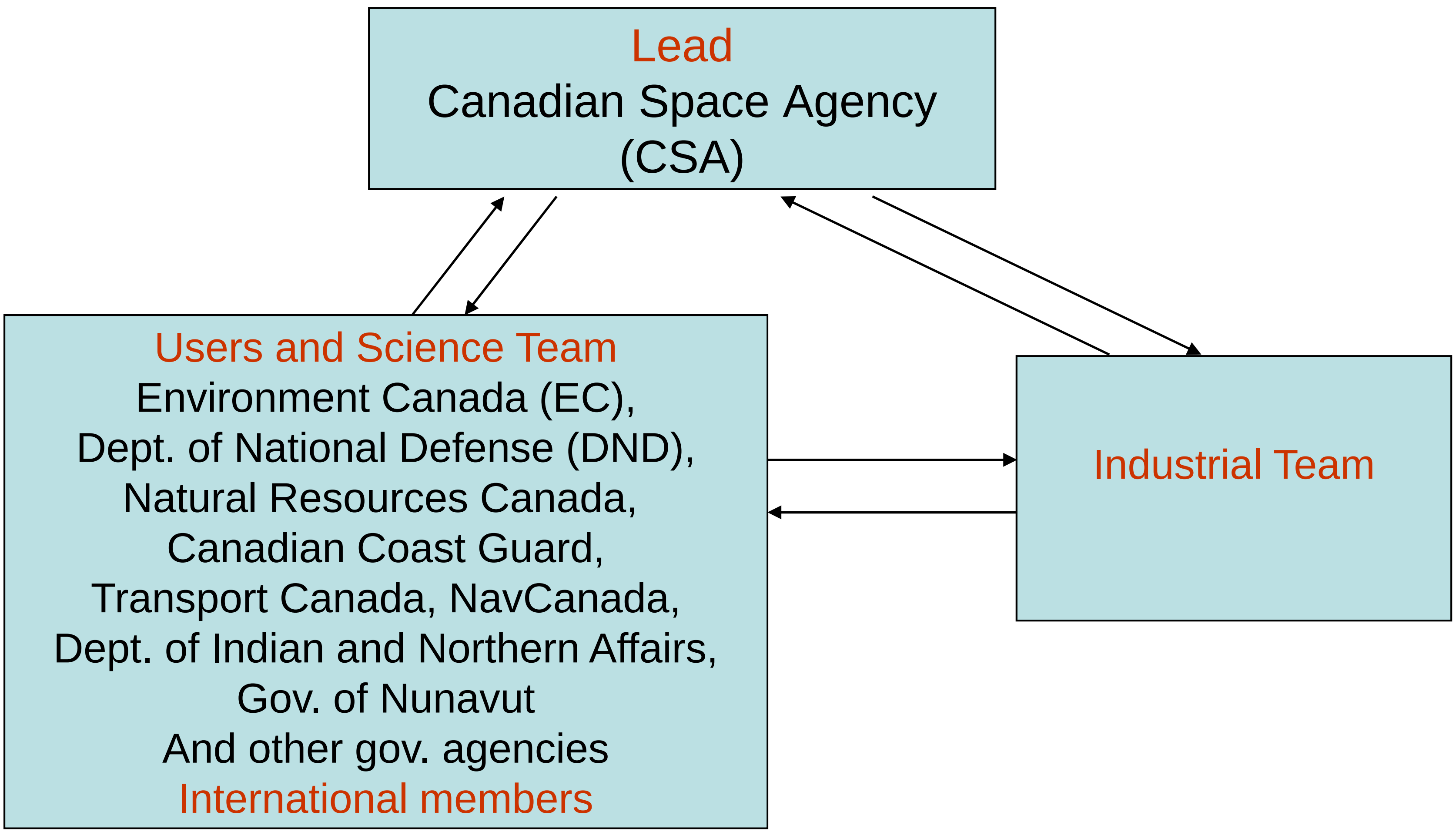
Background on Molniya concept

- **Russia:**
  - Used extensively for communications and classified missions
  - Mission including Earth observation planned: "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**
  - CSA initiated a satcom/HEO mission concept study in 2005
  - Saw the opportunity to take relay from NASA in 2006

PCW, recent history and follow-up

- Phase 0: March-Nov 2008
- 1st Workshop on Arctic Imaging, Copenhagen, Aug 2008
- Phase A: started July 2009
- 2nd Workshop on Arctic Imaging, CSA, Sept. 2009
- Final User Requirements Document, Dec 2009
- Phase A: ends June 2010
- Critical technology assessment to follow Phase A
- Procurement for phases B-C-D Spring 2011
- Launch 2016

Mission Development Structure

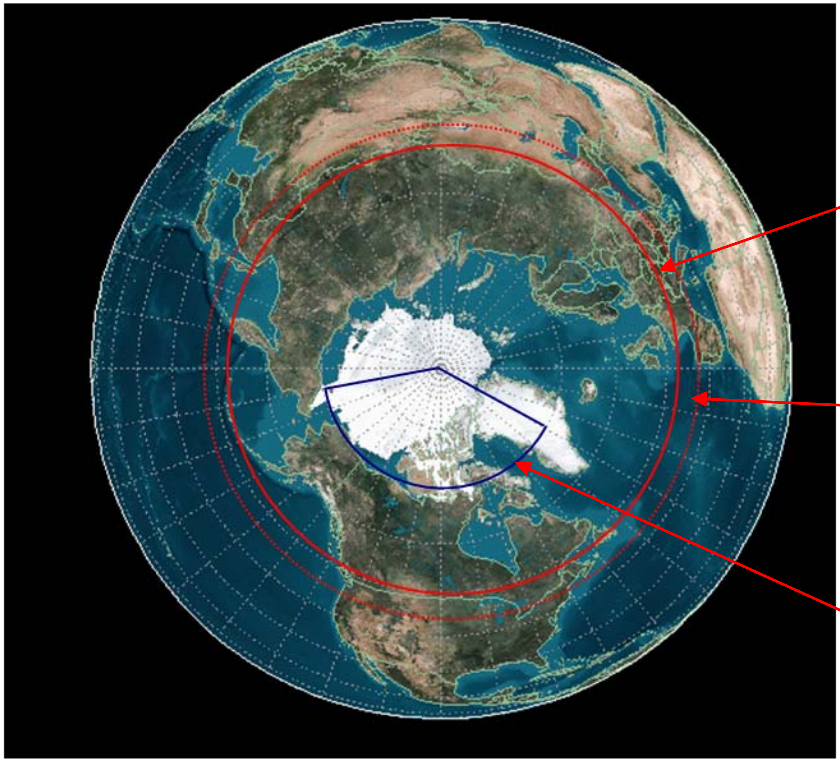


PCW: Dual Objectives

- 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

Environment Canada Environnement Canada
Canadian Space Agency Agence spatiale canadienne
Canada

Area of Interest



Meteorological Coverage Requirement (50ºN)

Meteorological Coverage Goal (45ºN)

Communications Coverage Requirement

Meteo requirement pertains to the entire circumpolar domain

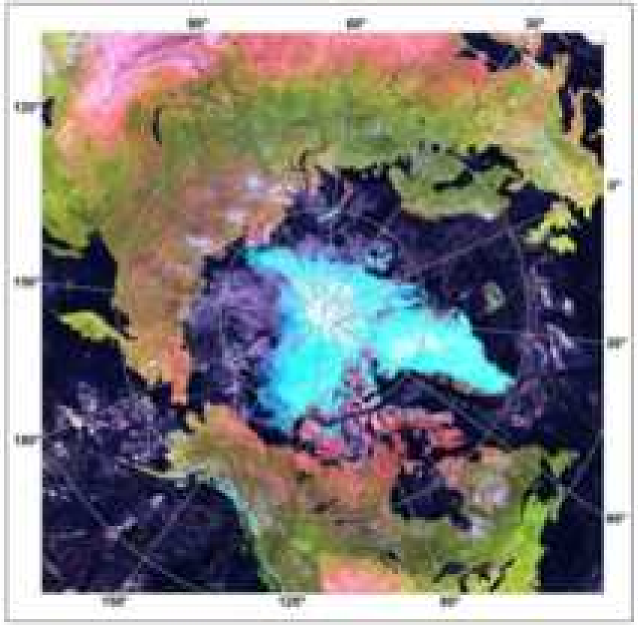
Specific Objectives (meteorology)

- 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 develop measures of climate change through high quality monitoring of key atmospheric and surface variables
- To have the observing system with 2 satellites in place by 2016. Lifetime of 5 years (goal 7 years).

→ PCW to have an operational status linked to NRT meteorology
New mandate for Canada

Increasing interest in Arctic region

- Increasing economical 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

Communications requirements in KA and X bands

Frequency Band	Earth to Space	Space to Earth
Military X Band	7.9 – 8.4 GHz	7.25 - 7.75 GHz
Commercial Ka Band	29.5 – 30.0 GHz	19.7 – 20.2 GHz
Military Ka Band	30.0 – 31.0 GHz	20.2 – 21.2 GHz

Available frequency bands.

Northern reception location facility to be determined

Meteorology: expected products

- 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

Meteorology: expected products

- f) Smoke, dust, aerosols, fog in support of air quality models and environmental prediction
- g) Total column ozone
- h) Cloud parameters: height, fraction, temperature, emissivity, phase, effective particle size

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, and international cooperation.

- Reduce risk associated with technology readiness

PCW Channels

Band No.	Subgroup	Wavelength (microns)	Heritage	GSD (km)	Main applications
1	VNIR	0.45-0.49	ABI-01	1	Surface, clouds, aerosols
2		0.59-0.69	ABI-02	0.5	Wind, clouds, ice mapping
3		0.85-0.89	ABI-03	0.5	Wind, aerosols, vegetation
4	SWIR	1.04-1.06	SGLI SW1	1	Snow grain, clouds
5		1.37-1.39	ABI-04	2	Cirrus detection
6		1.58-1.64	ABI-05	1	Snow-cloud distinction, ice Mapping
7		2.22-2.28	ABI-06	2	Cloud phase, size
8	MWIR	3.80-4.00	ABI-07	2	fog/ fire detection, ice/cloud separation, wind, phase. Fire Radiation Power (FRP)
9		5.77-6.60	ABI-08	2	Wind, humidity
10		6.75-7.15	ABI-09	2	Wind, humidity
11		7.24-7.44	ABI-10	2	Wind, humidity
12	LWIR	8.30-8.70	ABI-11	2	Total water, cloud phase
13		9.42-9.80	ABI-12	2	Total ozone
14		10.1-10.6	ABI-13	2	Cloud, surface, cirrus
15		10.8-11.6	ABI-14	2	Cloud, SST, ash
16		11.8-12.8	ABI-15	2	Ash, SST
17	LIRCO2	13.0-13.6	ABI-16	2	Cloud height
18		13.5-13.8	MODIS-34	2	Cloud height, low level temperature
19		13.8-14.1	MODIS-35	2	Cloud height, mid level temperature
20		14.1-14.4	MODIS-36	2	Cloud height, high level temperature

Not on Future GOES

Canada

Main imagery requirements (1/2)

Parameter	Requirement
Spatio -Temporal coverage for each disc	100 % above 60 N 95 % 55-60 N 85 % 50-55 N
GSD	0.5-2 km
Field of Regard (FoR)	View angles up to at least 70 deg
Time to acquire scene image	< 10 min
Maximum time difference between spectral channels	5 sec
Relative knowledge of Geo-location	0.35 GSD

Main imagery requirements (2/2)

Parameter	Requirement
Signal to Noise Ratio (SNR) VNIR & SWIR	300
Noise Equivalent Delta Temperature (NEDT) @300 K	< 0.15 K
NEDT @ 240 K	0.35 K
Radiometric accuracy	5 % VNIR/SWIR
	0.5 K SWIR/LWIR
Total disk repeat cycle	15 min
Spatial resolution	< 1.3 GSD
Availability of reliable data, spatial and temporal	95%

Imager critical technology: some items

Instrument issues

- Scan mirror assembly
- Onboard calibration sub-system
- IR detectors beyond 12 microns (not available in Canada)
- Stripe pattern filters
- Thermal isolation and control
- Cryo-coolers

Products

- Data processing preparation: prototypical data stream. Proxy data and ATBDs

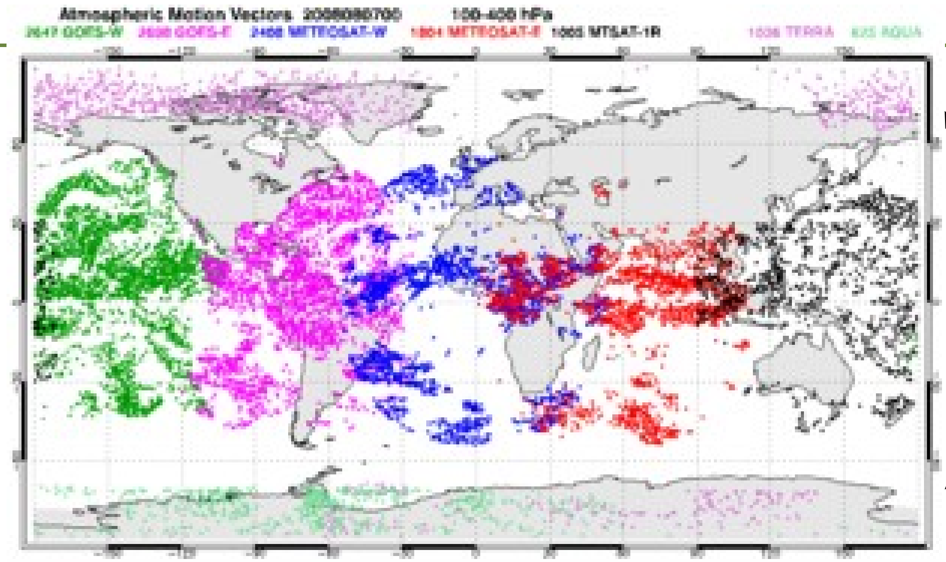
Volcanic ash application

The 9 Volcanic Ash advisory Centers (VACC) areas of responsibility

- Invaluable data to Dorval, London, Moscow and Anchorage VACCs.
- Addition of 0.87 micron channel expected to largely reduce false alarms.
- Major improvement over LEO (AVHRR) also linked to seamless coverage.

Atmospheric Motion Vectors (AMVs) assimilation

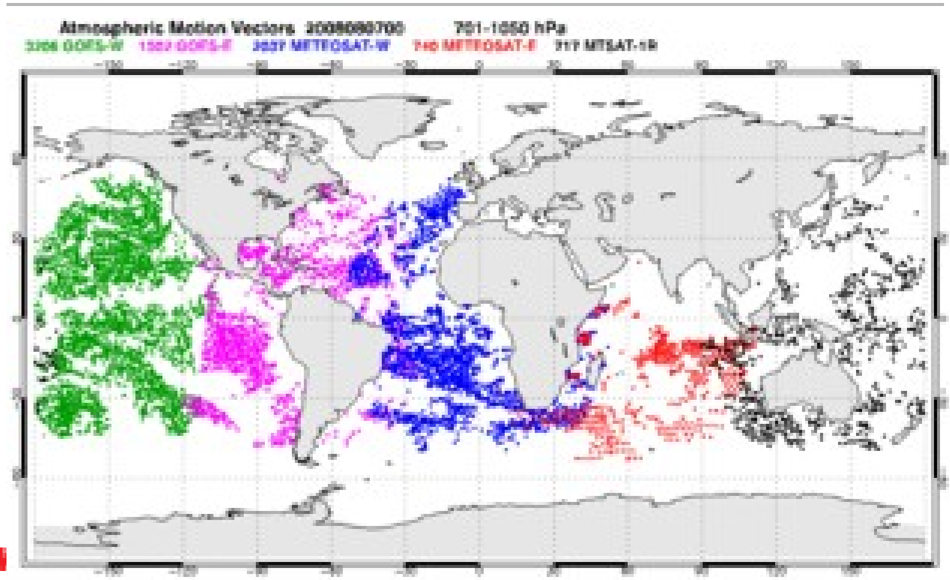
Example of 07 Aug 2008 00 UTC AMV availability



100-400 hPa

Recognized availability gap 55-65 N/S

Terra/Aqua AMVs



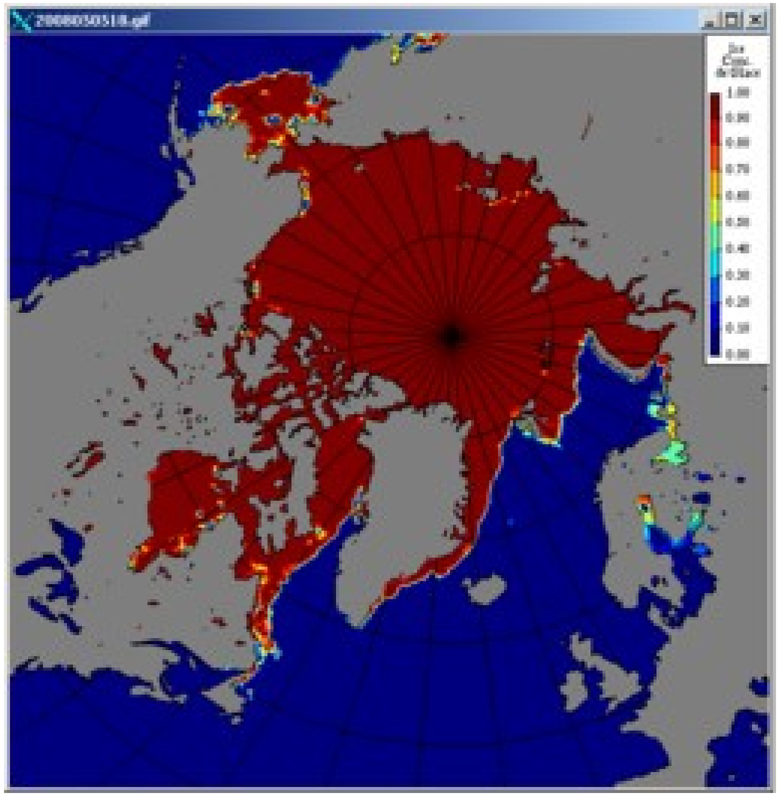
700 hPa to surface

No AMVs above 55 N/S

PCW features to serve this application:

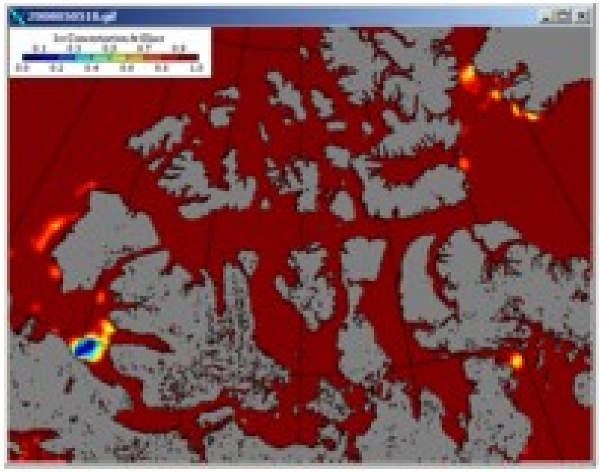
- High temporal sequences
- Simultaneous retrievals
- Stereo views

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

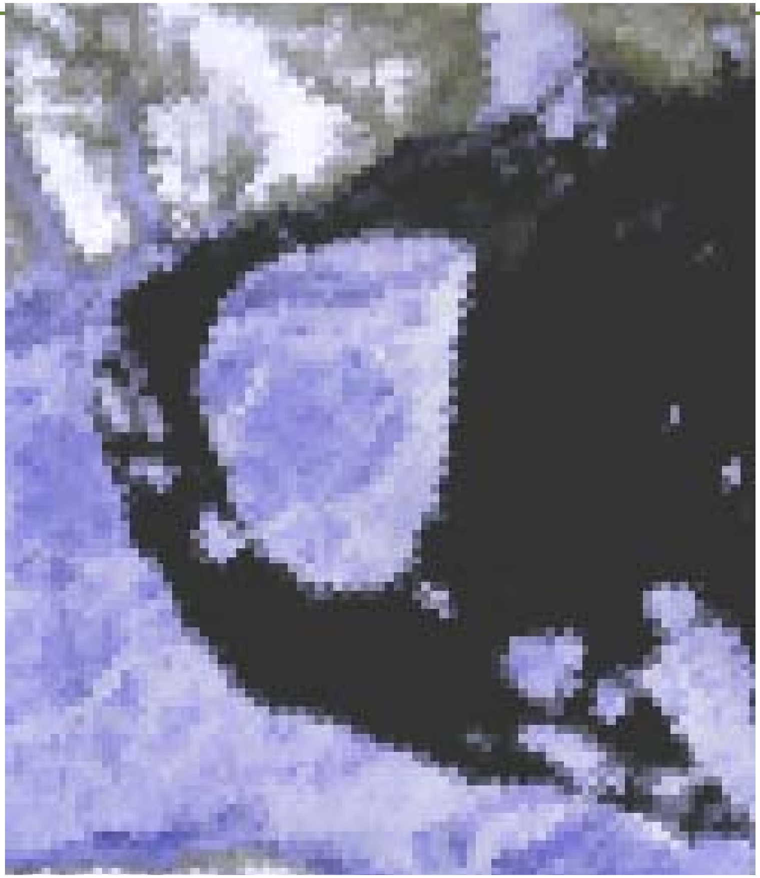


Prototype 5 km over Canadian Archipelago

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

SAR Can't do the Whole Job

July 1 RADARSAT-1 and AVHRR image of Lancaster Sound.

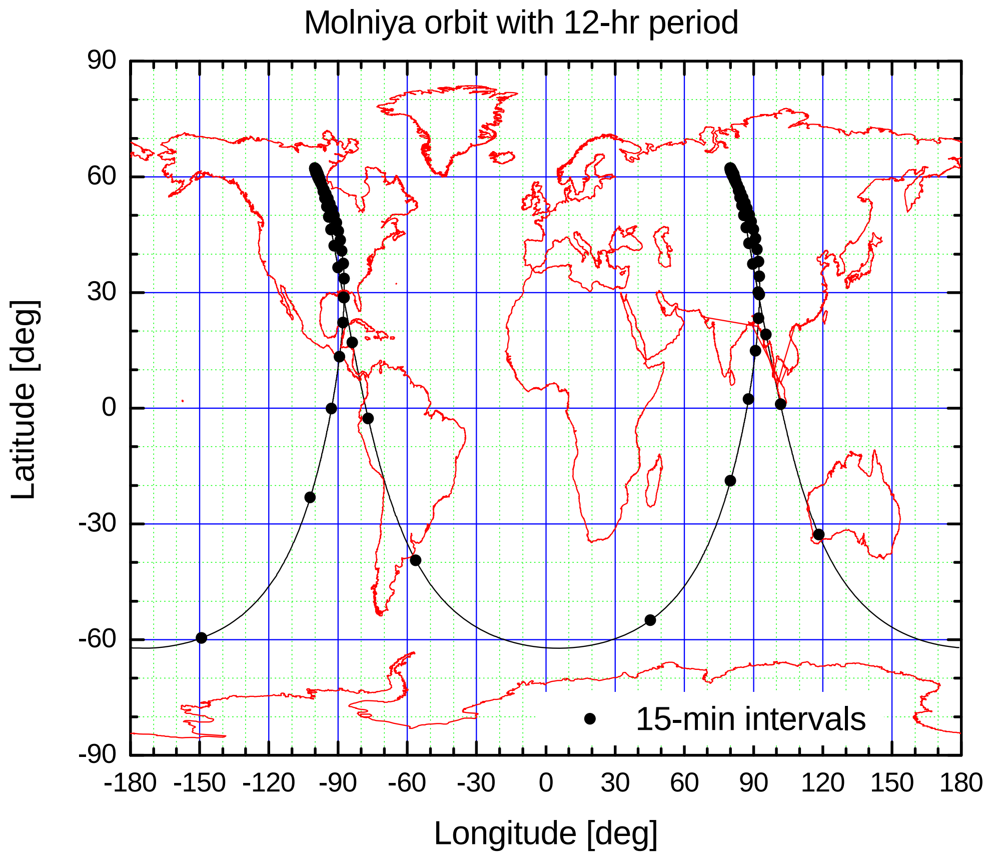


- Clear sky VIS/IR data provides consistent ice-water separation and surface melt information at a regional scale

Some properties of the Molniya orbit

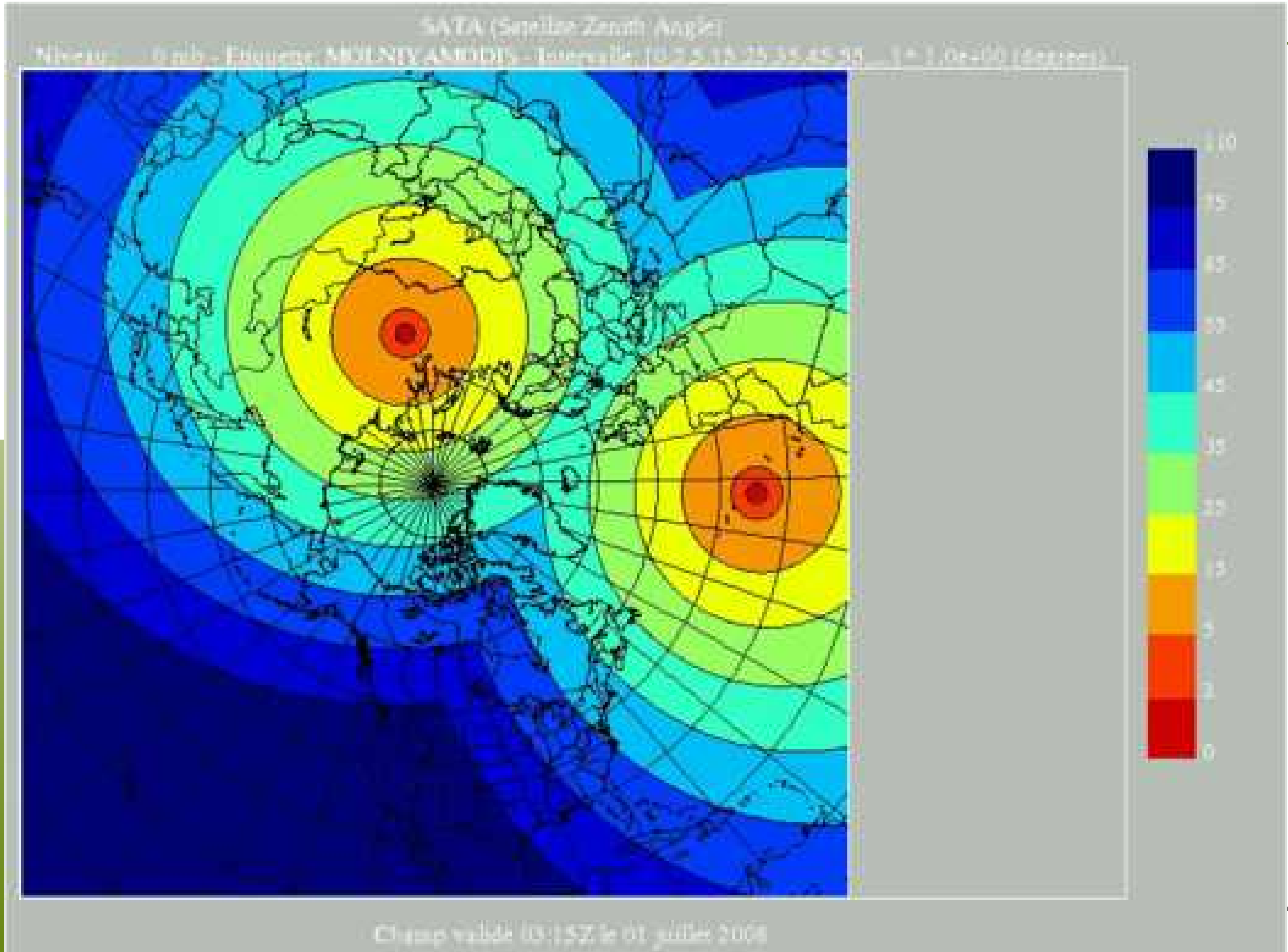
- Apogees/perigees have fixed positions
- Period is slightly less than 12-h resulting in precession of about 3.5 h per year w.r.t sun vector.
- 2 sats in 2 planes: 2 apogee points, largest coverage gaps occur on other side of globe
  - SAT-2 reaches a given apogee point 6-h behind SAT-1
  - once a day, at +/- 3h from apogee, SAT1 and SAT2 are at same nadir position (redundancy)
- 2 sats in 1 plane: 4 apogee points, gaps evenly distributed. Best for stereo views.
  - The 4 apogees, 90 deg long apart, occur at same local time

Molniya ground track

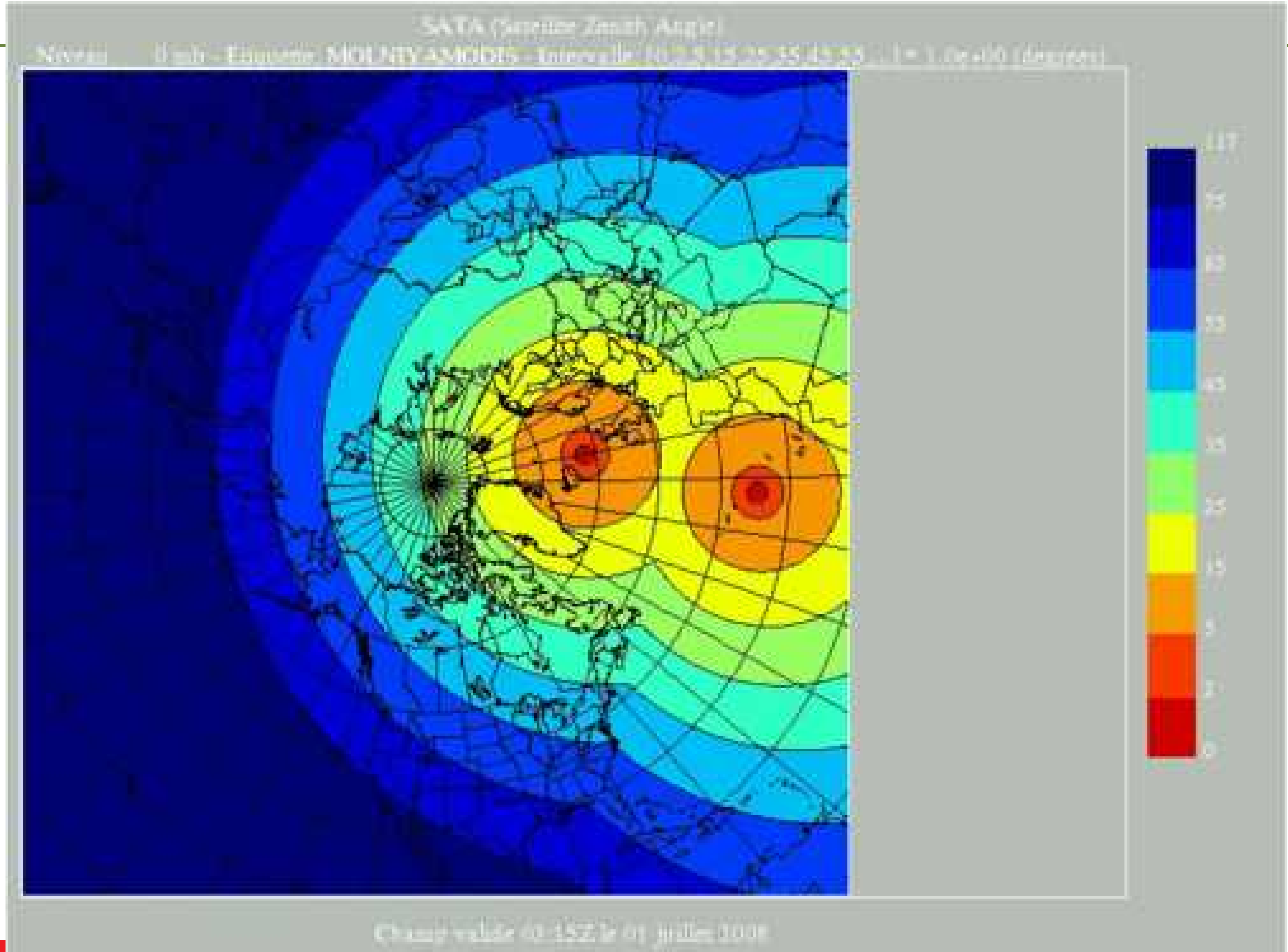


View of region of interest at least 9 hr on 12 hr period

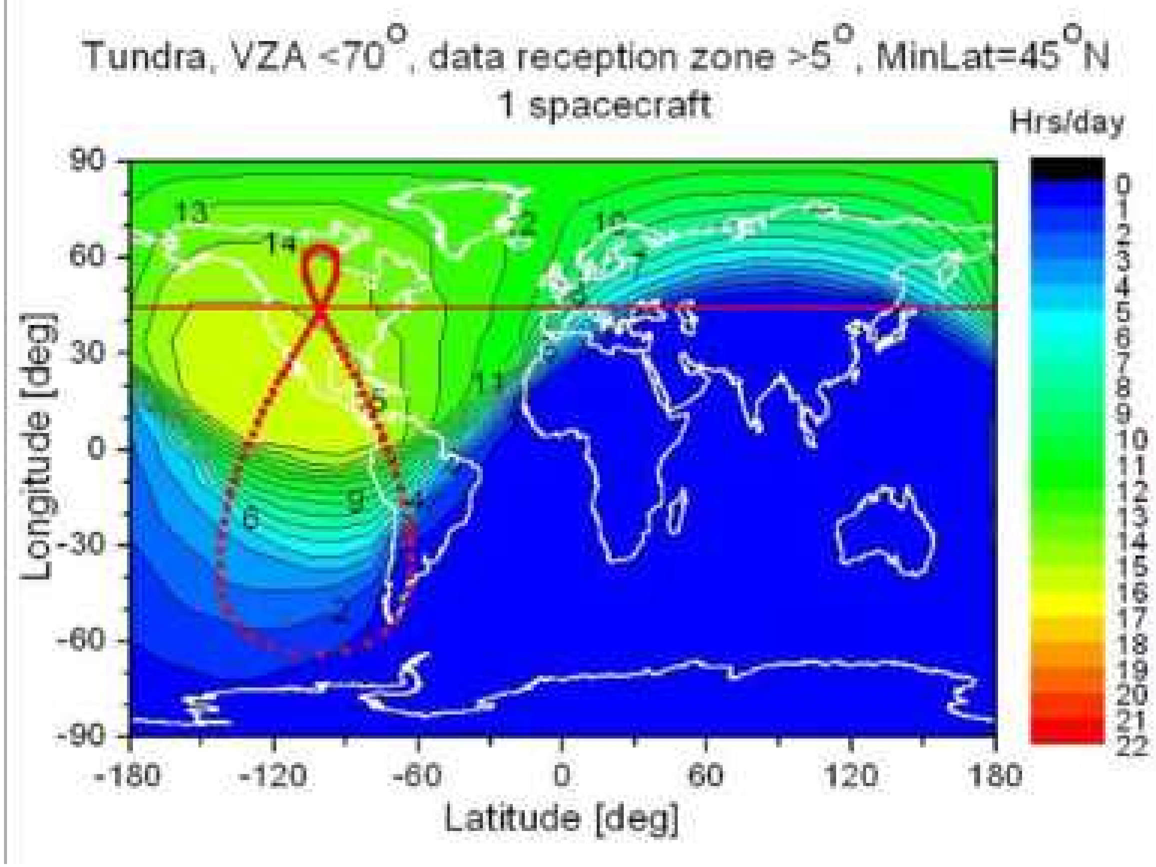
1 plane, apogees 100W,10W,80E,170E, 24-h animation



2 planes, apogees 10W, 170E, 24-h animation



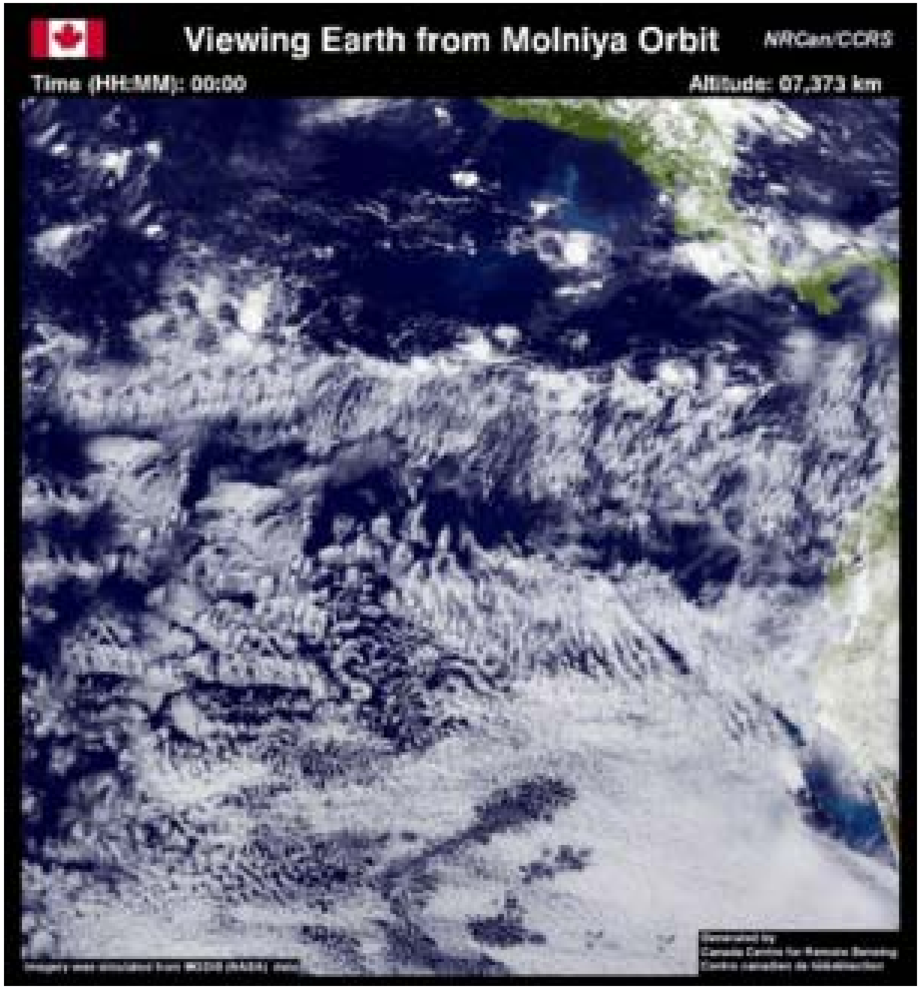
Toundra (24-h) orbit



Apogee: ~47,110 km
Perigee: ~20,000 km

Best for comms, but second best for meteo due to higher apogee and larger coverage gaps than Molniya

On board with PCW



Challenge for scanning and positioning: height and speed continuously changing.

Potential additional payloads

Requests For Proposals (RFP) just sent by Canadian Space Agency for possible added payloads on PCW. Areas include:

- Atmospheric remote sensing (ex: FTS for greenhouse gases and sounding, UV-VIS-NIR for chemical species).
- Plasma physics, aurora imaging, particle dynamics, magnetic field.

Phase A U&ST activities

- End-to-end simulator of PCW imager from Level 0 (raw) to Level 1c (calibrated/navigated):
  - scanning process
  - channel co-registration
  - remapping from 1b to 1c
- Data processing preparation, proxy radiances
- OSSE related to AMV (?)
- Ground segment, data acquisition/distribution scenarios
- Other aspects of mission

Radiative transfer, simulated imagery

Software developed to compute PCW all sky radiances from model output using:

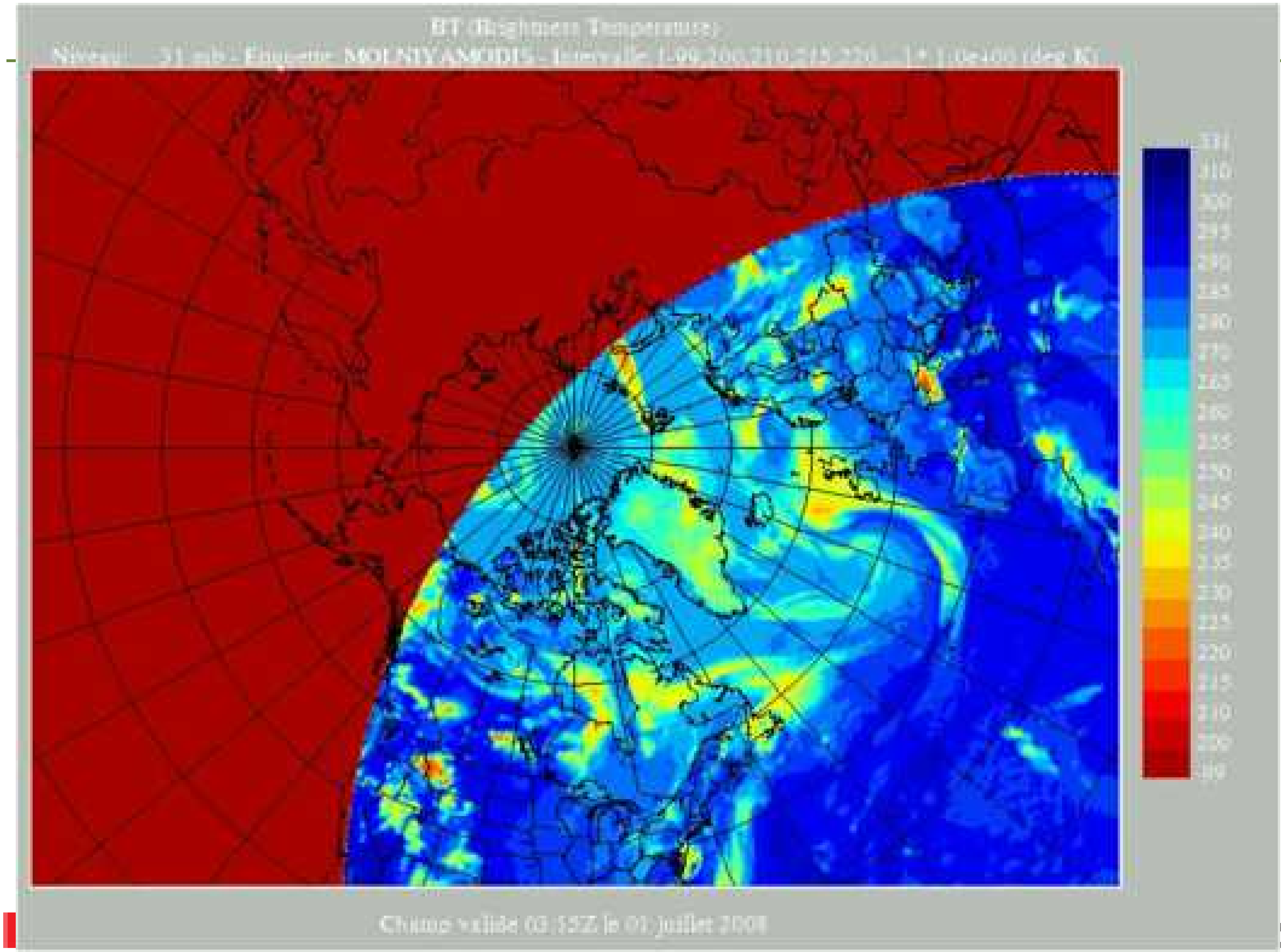
- RTTOV (can simulate current sensors, no VIS, NIR)
- CRTM (can simulate ABI specifically, no VIS, NIR)
- In house code to cover VIS, NIR channels

Model output:

- Global 35 km
- Arctic circumpolar 45-90 N, 10 km
- Limited area, 1300X1700 km, 2.5 km

Orbit defines viewing angles

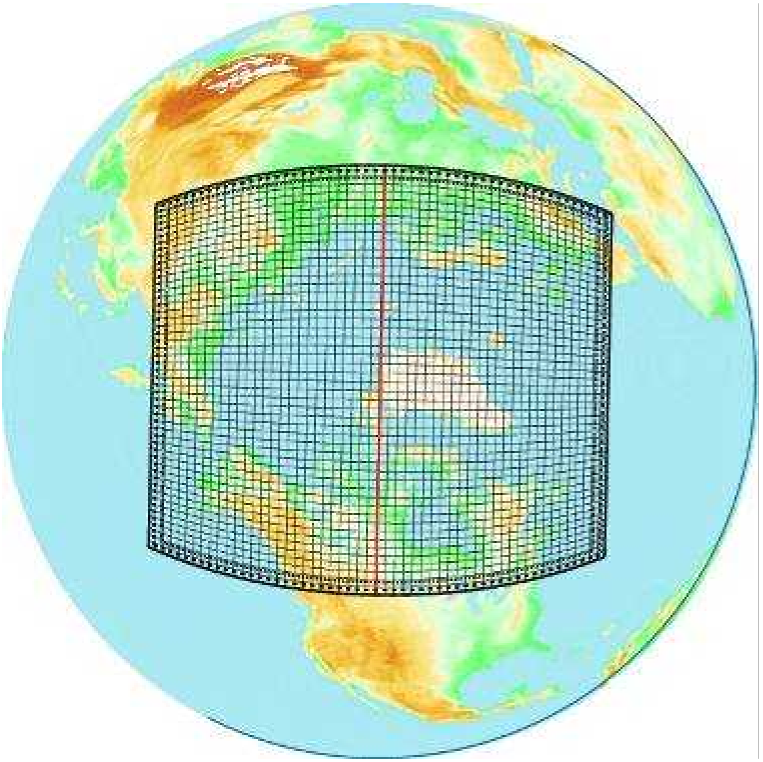
1 sat 24-h Animation MODIS ch 31 (11µm), glogal gem 35 km, RRTOV model



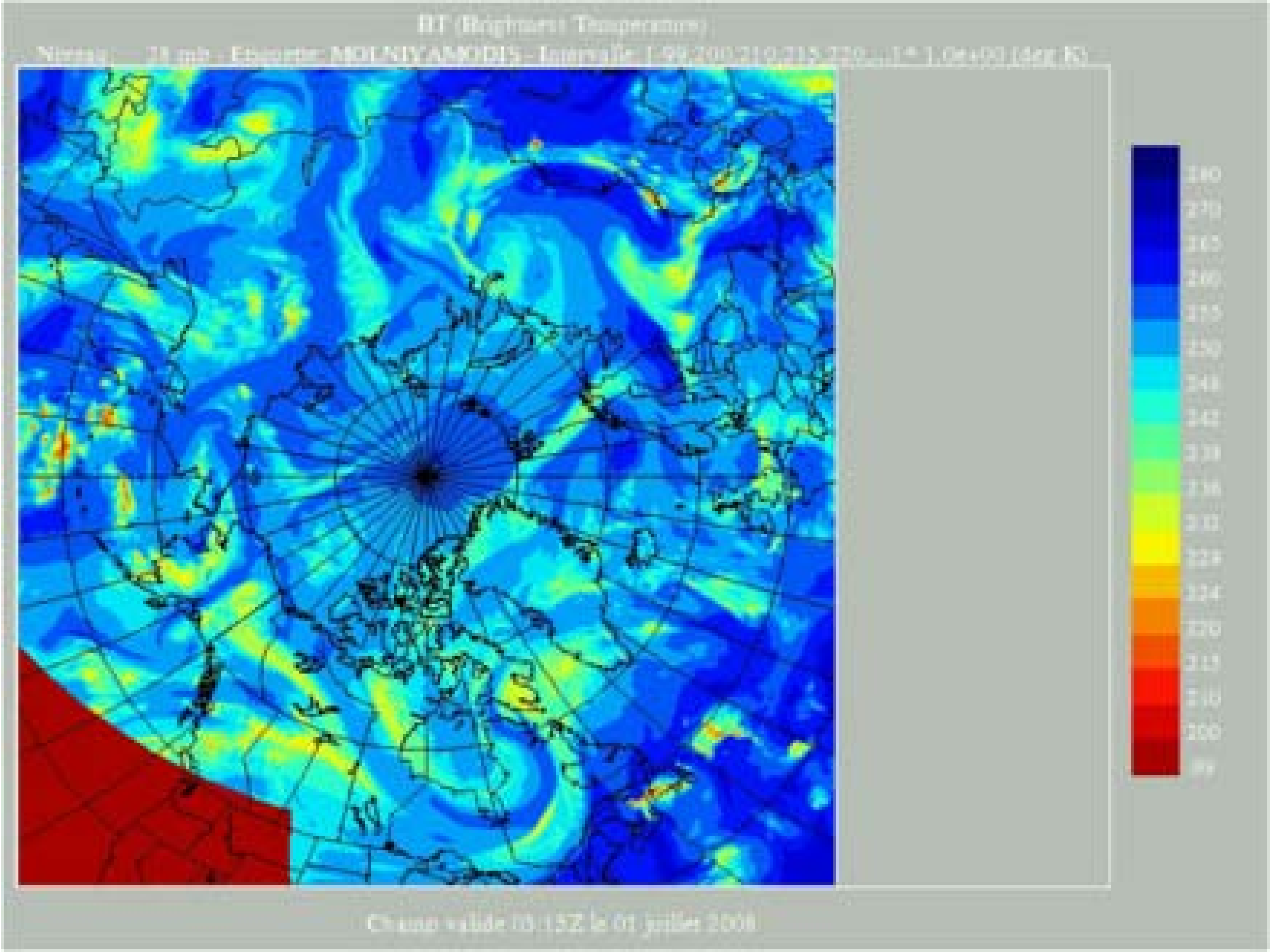
Polar-GEM grid for IPY

- Currently used in IPY research

  at 15 km resolution
- Was ran at 10 km resolution



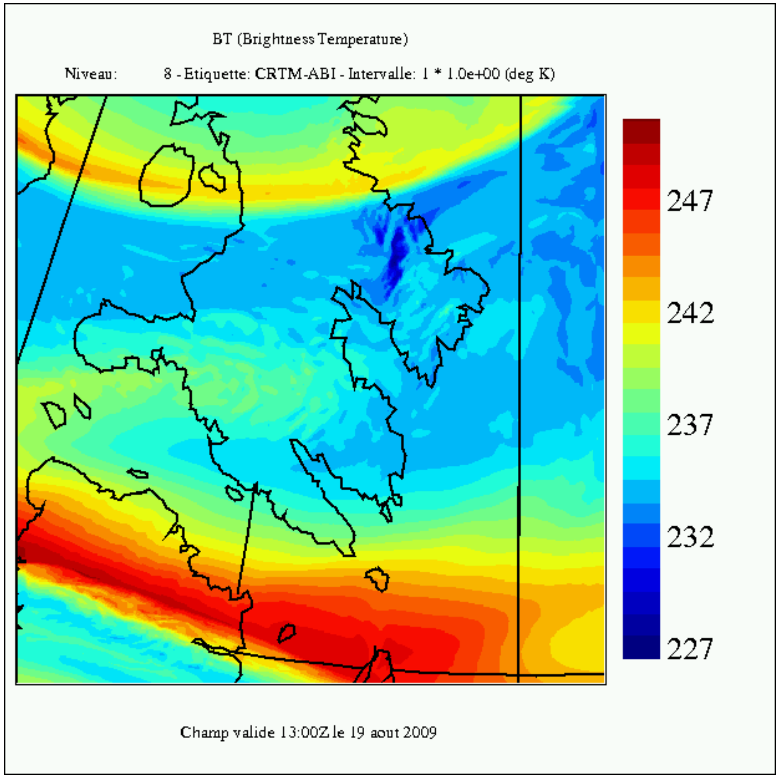
2 sats, 1 plane 24-h simulation, 15 min intervals, Modis ch 28 (7.3 μm), 10 km, RTTOV model



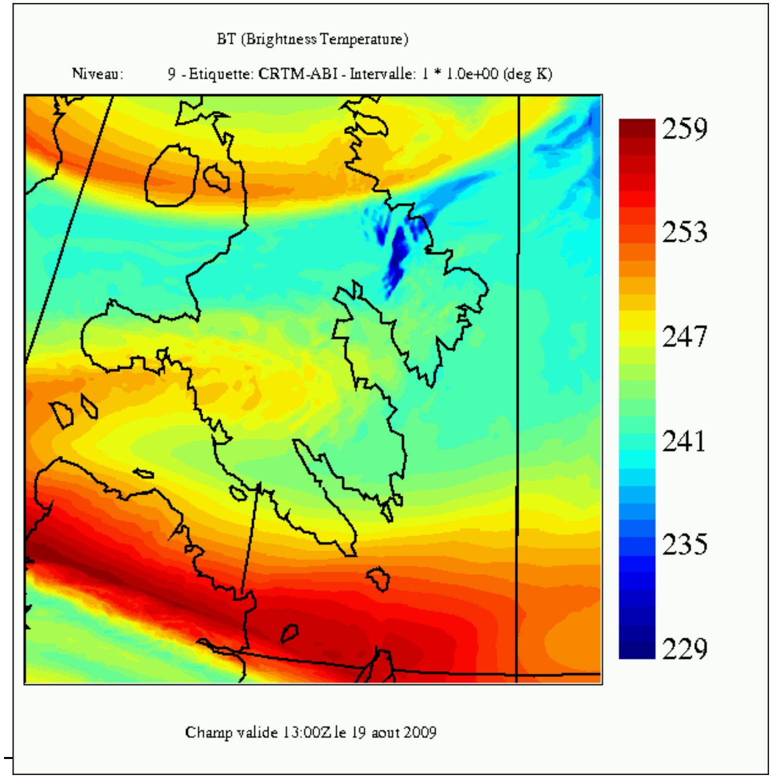
No data for view Angles > 75 deg

Proxy ABI radiances from LAM-2.5 km output using CRTM, ~1100 x 1100 km domain

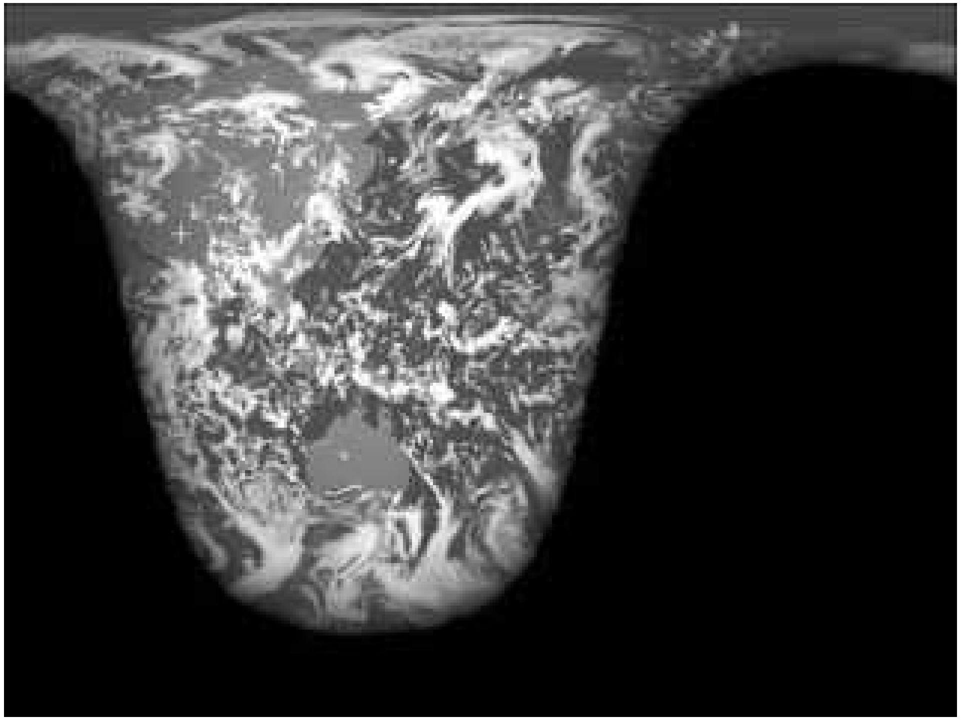
ABI ch8 6.3 μm



ABI ch9 6.9 μm



Modeling of shortwave channels



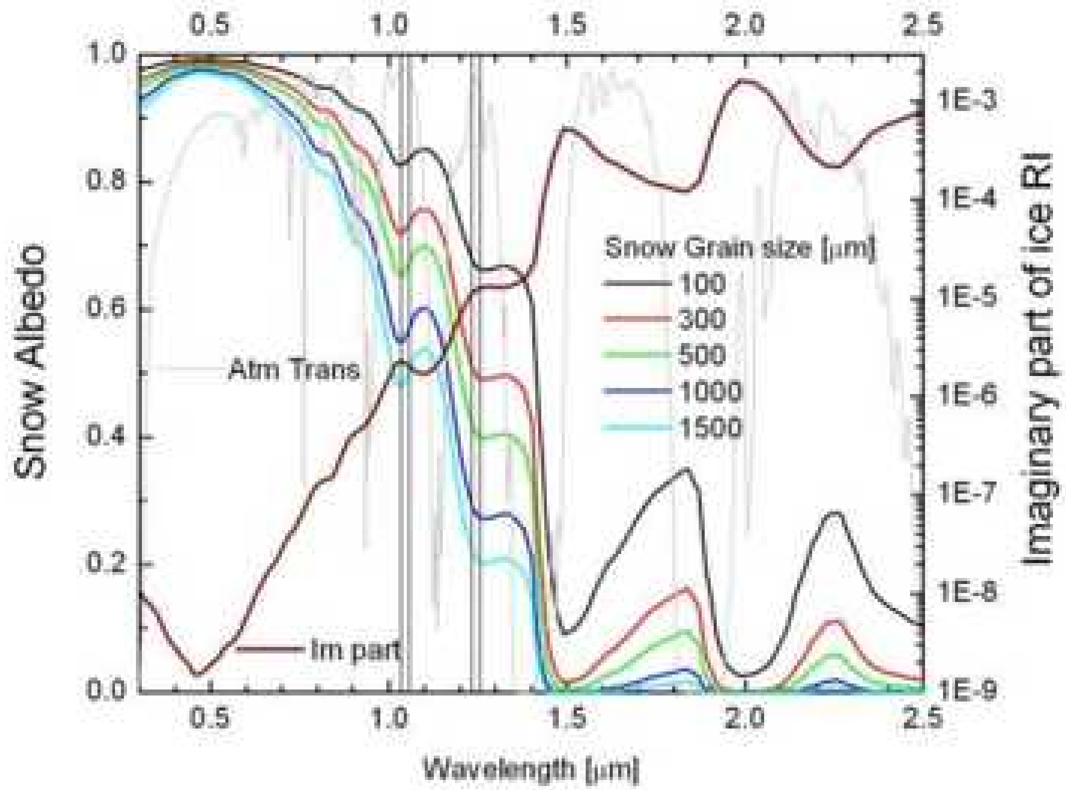
SBDART code (U. Santa Barbara

With DISORT solver and LOWTRAN

Adapted to PCW

Response functions

Snow grain sensitivity: best at 1.04 and 1.24μm
(Suggested from U. Bremem)



Snow grain impacts on Albedo notably in range 0.8-1.4 μm

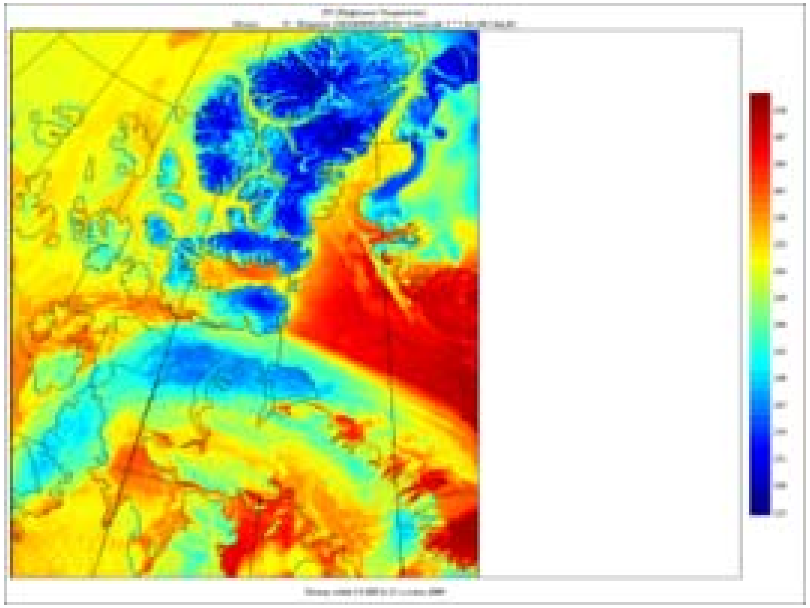
The 2 channels are in atm. Windows

Higher radiances at 1.04 than 1.24 μm

Link to snow-water equivalent, latent heat

AMV related activities (1/2)

- Collaboration with U. Wisconsin to generate winds from high resolution proxy radiances
- Plan to import AMV software



6.7 and 11 micron proxy at 2 km
sent to CIMSS
Winds were extracted
Comparison with model “truth”
And US background winds under way
As well height assignment checked
Against model-derived cloud top

Preliminary results to be presented at
AMV workshop, Tokyo, Feb 2010

AMV related activities (2/2)

- Planning OSSE using alternate method based on ensembles, used to evaluate impact of Aeolus winds (lidar, 2011) after Tan et al (ECMWF Tech Memo 510, 2007).
  - uses real data for all types except that under evaluation
  - impact based on reduction of spread in ensembles
  - tuning required using real observations
  - AMV extracted from model output in “likely places” and error assignation not trivial

PCW in International context

- Endorsement of HEO concept by WMO

  - Participation to IGEOLAB-2 (Sept 2007, and upcoming IGEOLAB-3 (Jan 27, 2009)

- International Users and Science Team formed

  26 members from:

US: NOAA, NASA

Finland: FMI

Sweden: SMHI

Germany: U. Bremem

ECMWF

ESA

EUMETSAT

- Eventual participation to CGMS, GSICS

PCW INTL U&ST

Todd Arbetter (NOAA) Niels Bormann, ECMWF Changyong Cao (NOAA) Pablo Clemente-Colon (NOAA) Juhani Damski (FMI) Adam Dybbroe (SMHI) Andrew Heidinger (NOAA) Sean Helfrich (NOAA) Georg Heygster (U. Bremem) Alain Hilgers (ESA) Alexander Ignatov (NOAA) Mike Kalb (NOAA) Karll-Goran Karlsson (FMHI) Jeff Key (NOAA)	Alexander Kokhanovsky (U. Bremem) Marianne Koenig (EUMETSAT) Shobha Kondragunta (NOAA) Jarkko Koskinen (FMI) Juha-Pekka Luntama (ESA) Patrick Minnis (NASA Langley) Terry Onsager (NOAA) Jouni Pulliainen (FMI) Steve Platnick (NASA Goddard) Lars Peter Riishojgaard (JCSDA) Yrjo Sucksdorff (FMI) Anke Thoss (SMHI)

Specific US-Canada collaboration

Meteorology

- MOU already in place between EC and NOAA-NESDIS which could include PCW
- Coordination with GOES-R on data processing, calibration, algorithm development, product distribution

Space segment possibilities

- Adaptation of ABI key components for PCW
- Evaluation of launch possibilities

Conclusion

- PCW will provide for the first time seamless observation of the Arctic.
- High-level meteorology requirements for PCW were inspired by strong synergy with GOES-R as well as identified needs specific to the Arctic.
- Phase-A activities focuses on demonstrating added value and feasibility of the mission.
- International interest is a very important asset.
- Key milestone is procurement for Phases B-C-D in spring 2011.

- Thanks