Environment and Climate Change Canada / Environnement et Changement climatique Canada

Canada

The Potential for Arctic and Boreal CO_2 and CH_4 Observations from a Highly Elliptical Orbit (HEO) Mission

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CEOS AC-VC, CNES, Paris, France - 2017 June 28

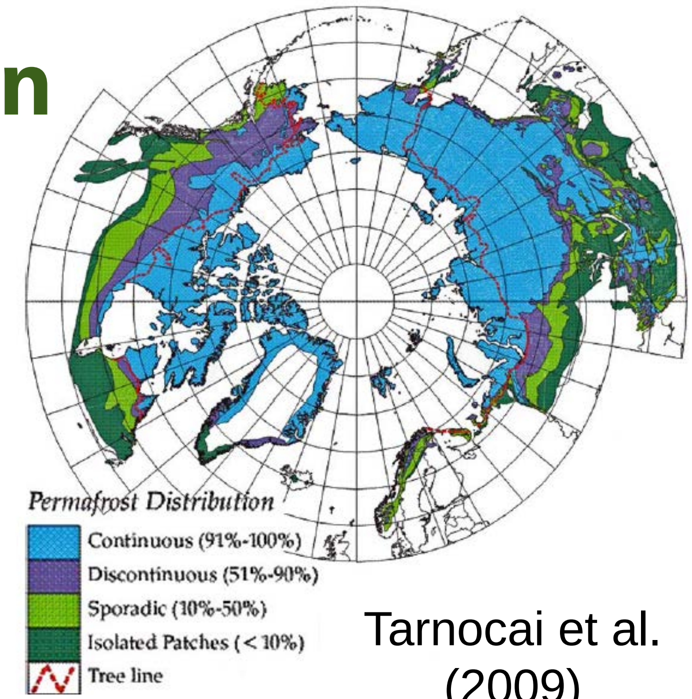
Boreal and Arctic Carbon

Boreal Forests

- Longer growing season and increased disturbances may enhance or reduce net CO_2 flux

UNEP

Boreal Forest Extent (2009)
UNEP/GRID-Arendal Maps and Graphics Library



Tarnocai et al. (2009)

Permafrost

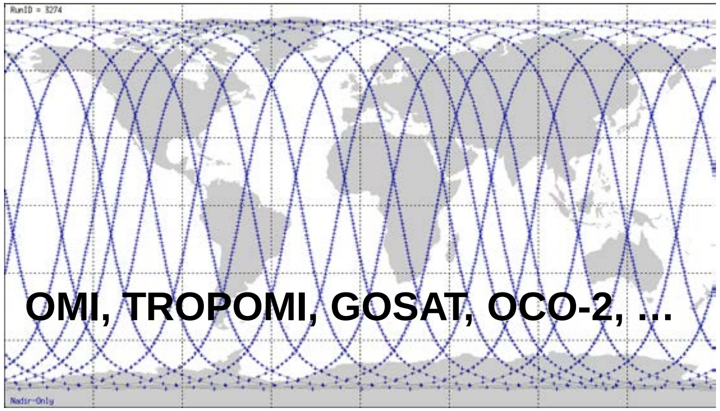
- 1672 PgC, twice atm mass with potential for release of some fraction as CO_2, CH_4
- Wide range of estimates for emissions from thaw 9-114 PgC by 2100 (Schneider von Deimling et al. 2012)
- Uncertainty is coupled with offset of CO_2 emissions by 'greening' of the Arctic

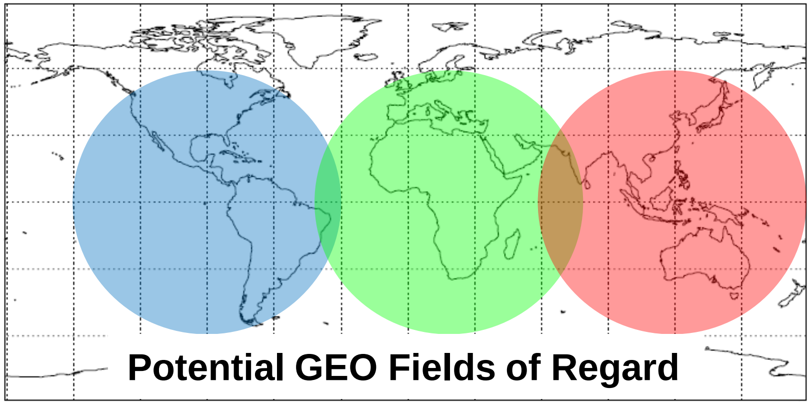
Satellite observations of CO_2 and CH_4 would be valuable

Common Satellite Orbits and Coverage

- **Low Earth Orbit (LEO)**
- Below ~1000 km altitude
- Near-polar plane
- Can give global sampling, but typically observe a given point at constant local time of day

- **Geostationary Orbit (GEO)**
- ~35,800 km altitude
- Near-equatorial plane
- Synchronized with Earth rotation with potential for ‘continuous’ sampling over selected area (<60°N/S)





Air Quality moving toward LEO + GEO (like meteorology), GHGs next
Neither LEO or GEO can give continuous observations over the Arctic

NOTES AND CORRESPONDENCE

On the Use of Satellites in Molniya Orbits for Meteorological Observation of Middle and High Latitudes

STANLEY Q. KIDDER AND THOMAS H. VONDER HAAR

Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, Colorado

18 August 1989 and 27 October 1989

ABSTRACT

Time and space sampling is an increasingly critical aspect of Earth observation satellites. The highly eccentric orbit used by Soviet Molniya satellites functions much like a high-latitude geostationary orbit. Meteorological instruments placed on a satellite in a Molniya orbit would improve the temporal frequency of observation of high-latitude phenomena such as polar lows. Consideration of this new sampling strategy is suggested for future

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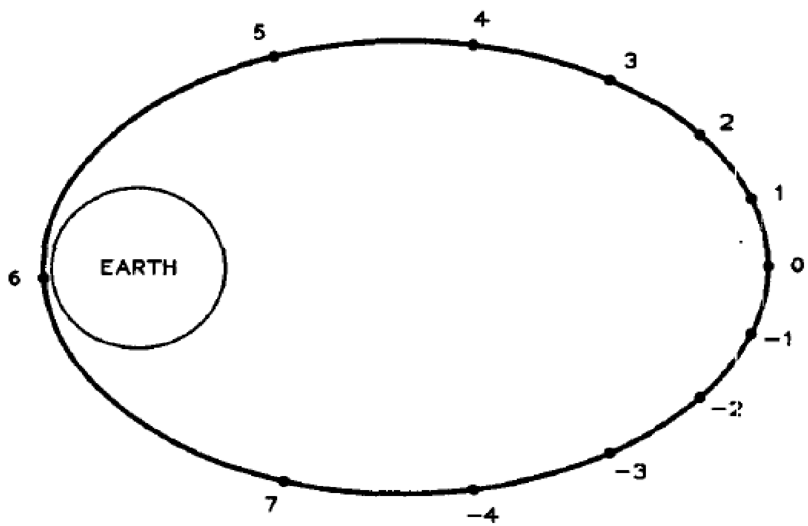


FIG. 4. A Molniya orbit (600 km perigee height) viewed perpendicular to the plane of the orbit. A dot is placed every hour. The labels are hours from apogee.

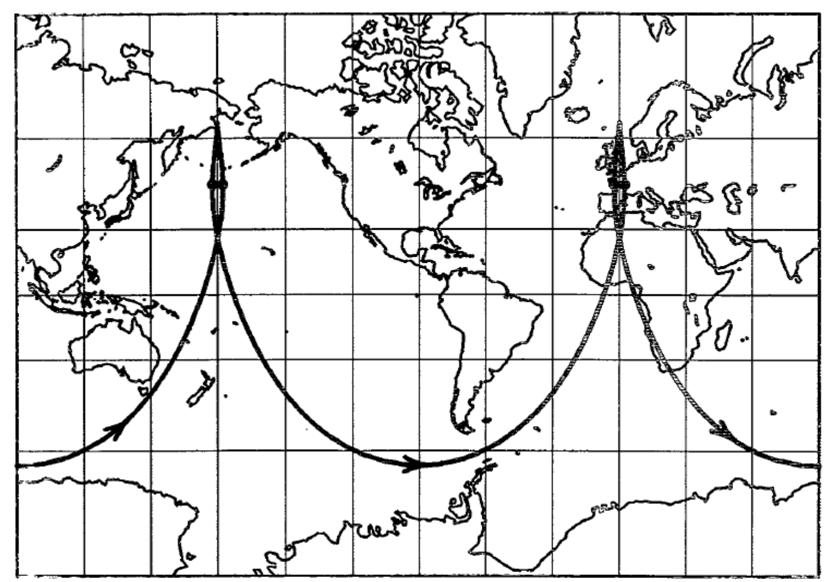
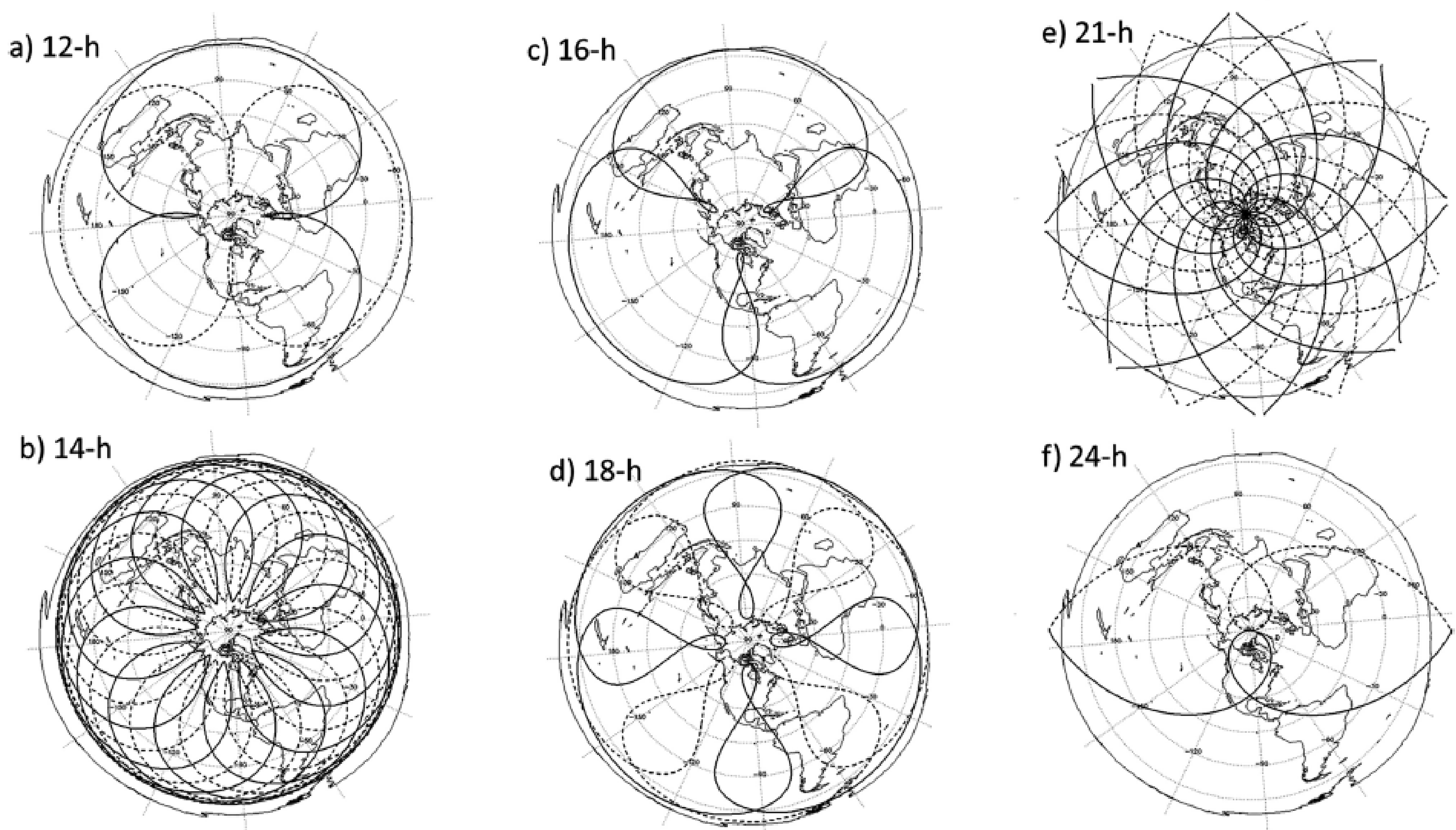


FIG. 5. Ground track of a satellite in a Molniya orbit with apogee at latitude 63.4°N and longitudes 0° and 180°. A dot is placed 4 h before and 4 h after apogee. The satellite spends two-thirds of its time north of the dots, which occur at 46.8°N and ±2.3° longitude from apogee.

Many Highly Elliptical Orbit (HEO) Possibilities

Can vary orbital period, apogee altitude (~40,000-48,500 km), perigee altitude, inclination, etc.



Trishchenko and Garand (2011), *J. Atm. Ocean Tech., 28, 977-992.*
Trishchenko, Garand, Trichtchenko (2011)*, J. Atm. Ocean Tech., 28, 1407-1422.*
Trichtchenko, Nikitina, Trishchenko, Garand (2014), *Adv. Space. Res. 54, 2398-2414.*
Garand, Trishchenko, Trichtchenko, Nassar (2014), *Physics in Canada*, 70, 4, 247-254.
Trishchenko, Garand, Trichtchenko, Nikitina (2016), *BAMS*, 19-24.

Background / History on Canadian Plans

- Polar Communications and Weather (PCW) was a proposed Canadian mission consisting of 2 satellites in a Highly Elliptical Orbit (HEO) configuration
- Main objectives of PCW were to expand Arctic communications (National Defence) capabilities and provide meteorological observations (Environment and Climate Change Canada)
- Canadian Space Agency (CSA) also considered additional science instruments under the Polar Highly Elliptical Orbit Science (**PHEOS**) program
- The Weather, Climate and Air quality (**WCA**) mission concept is an atmospheric research option that completed Phase 0 and A in 2012 (PHEOS-WCA PI was Prof. Jack McConnell of York U)

CSA ASC

PCW-PHEOS-WCA Spectral Bands / Species

Optimal and All-Band (Lite) Compliant

		Band (μm)	Band (cm^{-1})	Resolution	Target species
FTS	1	6.7 – 14.2	700 - 1500	0.25 cm^{-1}	T, H_2O, O_3, CO, CO_2, CH_4, HNO_3, CH_3OH, HCOOH, PAN, HCN, NH_3, SO_2…
	2	3.7 – 5.6	1800 - 2700	0.25 cm^{-1}	
	3a	1.66 - 1.67	5990 - 6010	0.25 cm^{-1}	**CH_4 columns**
	3b	1.60 - 1.67	5990 - 6257	0.25 cm^{-1}	**CO_2 and CH_4 columns**
	4	0.760-0.766	13060-13168	0.50 cm^{-1}	**O_2 A band (p_{surf}, aerosol)**
UVS		0.280-0.650		~ 1 nm	O_3, NO_2, aerosol, BrO, HCHO, SO_2, …

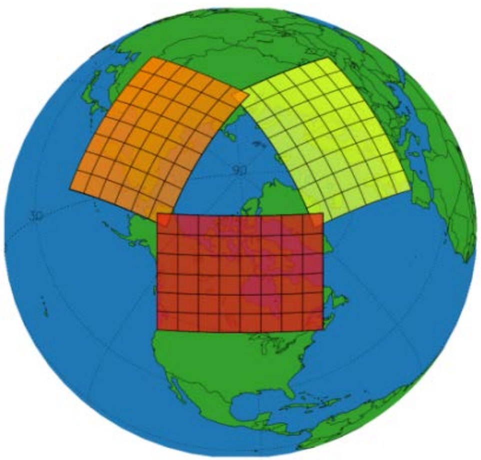
ABB — Designed and built ACE-FTS and CrIS, GOSAT and GOSAT-2 interferometers

COM DEV INTERNATIONAL — Designed and built MOPITT and ACE-MAESTRO

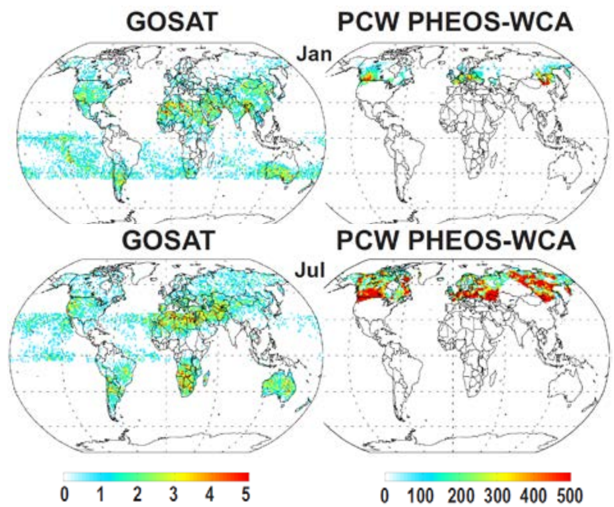
FTS and UVS would *image* high latitude land regions

OSSE Comparing CO_2 observed from HEO with GOSAT

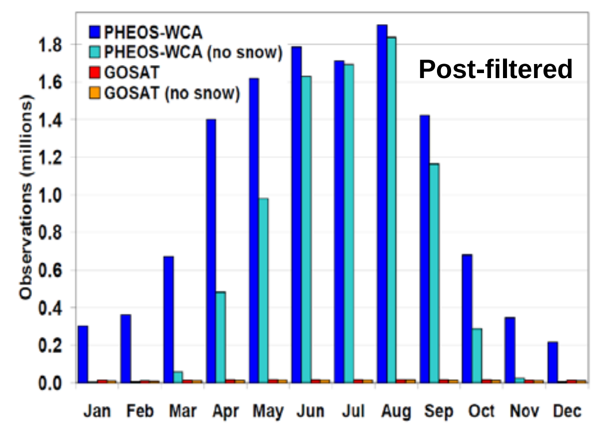
PCW PHEOS-WCA-FTS Fields of Regard



Num obs numbers per 1ºx1º



Seasonal Distribution of Obs



- PCW PHEOS-FTS flux uncertainty *reductions* relative to GOSAT would be ~45% summer, ~30% annual for *Optimal* instrument configuration
- Largest uncertainty and potential for change to Arctic/boreal carbon cycle (boreal forests growing/disturbance and permafrost thaw) is in summer, when PCW PHEOS-FTS offers the greatest potential constraints

Nassar, Sioris, Jones, McConnell (2014), Satellite observations of CO_2 from a highly elliptical orbit for studies of the Arctic and boreal carbon cycle, J. Geophys. Res. 119, 2654–2673, doi:10.1002/2013JD020337

Some Current Canadian HEO Activities

- CSA Flights for the Advancement of Science and Technology (FAST) program activity "Balloon demonstrator of an imaging FTS" led by C. Tom McElroy (2014-2017)
- CSA Space Technology Development Program (STDP) funding awarded to ABB for continual development of imaging FTS technology for GEO and HEO applications: "Concept for Technology Demonstration of an Imaging Fourier Transform Spectrometer – iFTS" (2016-2017, just completed)
- Joint CSA - ECCC led opportunity (R. Nassar, C. McLinden, C. Sioris) for " A Concept Study for an Air Quality and GHG observation mission focused on Northern Regions" awarded to ABB (prime) with Airbus and MDA (2016-2017, now underway)
- CSA STDP opportunity for an "Elegant Breadboard of an imaging Fourier Transform Spectrometer (iFTS) for Climate Observations" (~18 months starting in late 2017)

“Concept Study for an Air Quality and GHG Mission focused on Northern Regions”

- Starting point: Observing requirements for CO_2, CH_4, and air quality gases (secondary objectives: weather observations, solar induced fluorescence)

- “Options Analysis” for achieving the science requirements
  - existing measurements/missions
  - New satellite(s) in LEO, MEO, GEO or HEO?
  - Instrument design: grating or FTS?

- “Preliminary Design”
  - Bands – which bands, resolution and width to balance SNR/spectral coverage, O_2 band at 0.76 μm vs. 1.27 μm
  - Ground Instantaneous Field of View – reduce data loss to clouds and potential to quantify anthropogenic GHG point sources

- Feasibility and costs (including launch) for different options

Stricter CO_2 and CH_4 Observing Requirements

	"Northern Mission"	PHEOS-WCA	CEOS-CGMS resp to GCOS	CarbonSat
XCO_2 precision (ppm)				
Goal (G)	**1.0**	4.0	1.0	1.0
Breakthrough (B)			3.0	
Threshold (T)	**3.0**	8.0	8.0	3.0
XCO_2 bias (ppm)				
(G)	**0.2**	4.0	0.2	0.2
(B)			0.3	
(T)	**0.6**	8.0	0.5	0.5
XCH_4 precision (ppb)				
(G)	**9.0**	72.0	9.0	6.0
(B)			17.0	
(T)	**27.0**	180.0	34.0	12.0
XCH_4 bias (ppb)				
(G)	**2.0**	36.0	1.0	2.5
(B)			5.0	
(T)	**6.0**	72.0	10.0	5.0

Footprint size (km^2)	"Northern Mission"	PHEOS-WCA	CarbonSat	GeoCarb	G3E
Goal	**4 x 4**	10 x 10	2 x 2	3 x 6*	2 x 3
Breakthrough	**7 x 7**				
Threshold	**10 x 10**	20 x 20	2 x 3		

*oversampled to 3x3 km^2

References:

- PHEMOS Weather, Climate and Air Quality User Requirements Document, J.C. McConnell and B.H. Solheim, Editors, 2012 March 26 (converted from % assuming 400 ppm CO_2 and 1800 ppb CH_4)
- 2015 Update of Actions in The Response of the Committee on Earth Observation Satellites (CEOS) to the Global Climate Observing System Implementation Plan 2010 (GCOS IP-10)
- CarbonSat – Earth Explorer 8 Report for Mission Selection, European Space Agency (ESA), 2015, G3E – Butz et al. (2015), GeoCarb – Moore et al. (2016)

Key Result of Options Analysis: Orbits

- 2 HEO satellites are needed for required quasi-continuous coverage, but equivalent high latitude coverage would require 8 LEO satellites or 4 Mid-Earth Orbit (MEO) satellites

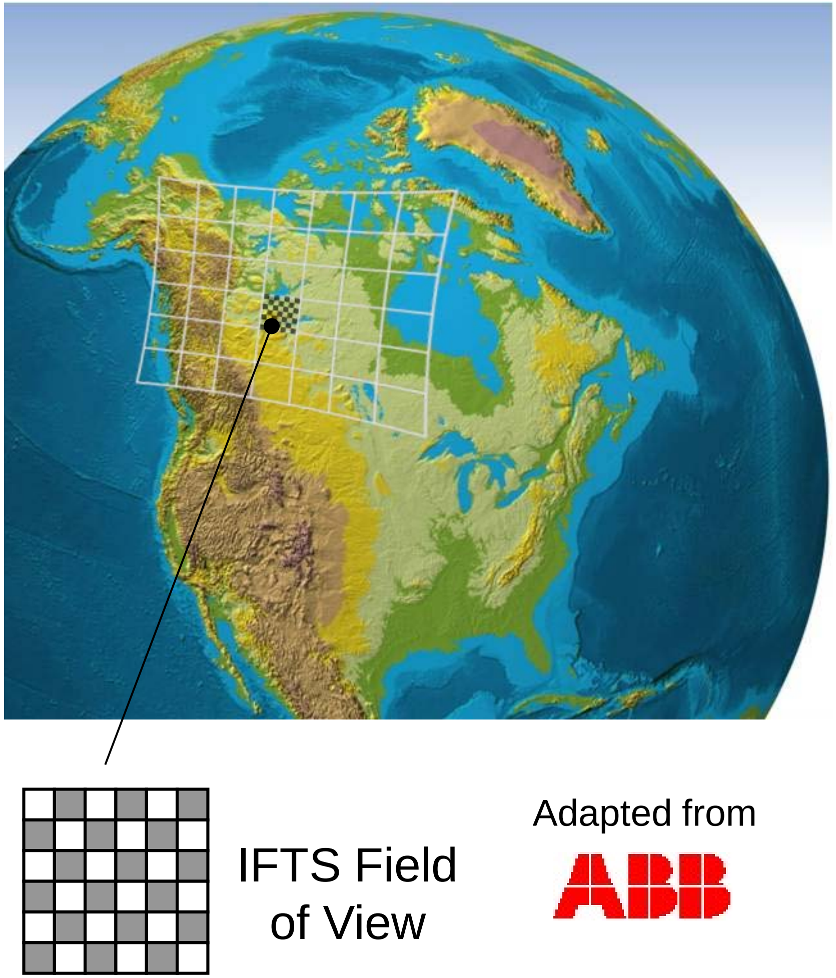
- Included assumptions of scale:
  - 2 satellites cost 1.75 x single
  - 4 satellites cost 2.75 x single
  - 8 satellites cost 4.00 x single

- While a single LEO satellite is less expensive than other options, considering hardware, operation and launch, HEO is still probably the most cost-effective for a focus on high latitude observations

- The specific HEO will still need to be determined in future work, including an analysis of de-scoped option of a single HEO satellite

Imaging Fourier Transform Spectrometer (IFTS)

- FTS simultaneously measures all wavelengths as the instrument modulates the optical path length, interferogram is later transformed mathematically to a spectrum
- With a grating spectrometer using a 2D focal plane array, one dimension is used for the spectral domain and the other for the spatial domain
- With an IFTS, both dimensions of a 2D focal plane array can be used for spatial info giving an image directly
- IFTS from GEO or HEO can step-and-stare across the field of regard
- Proven technology used in Canada-France-Hawaii telescope (SITELLE, Mauna Kea) 4 million pixels

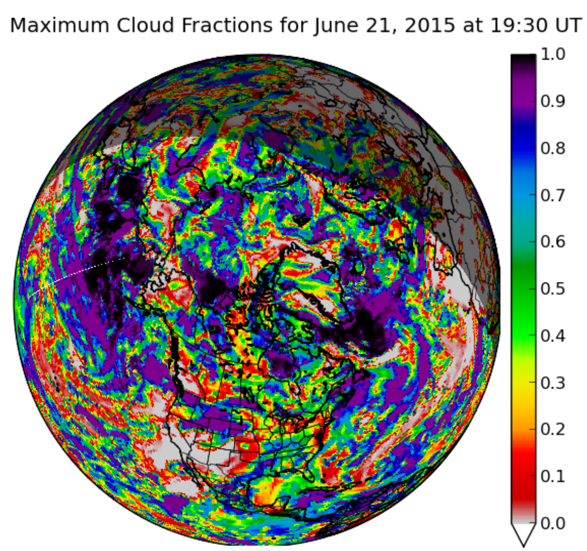


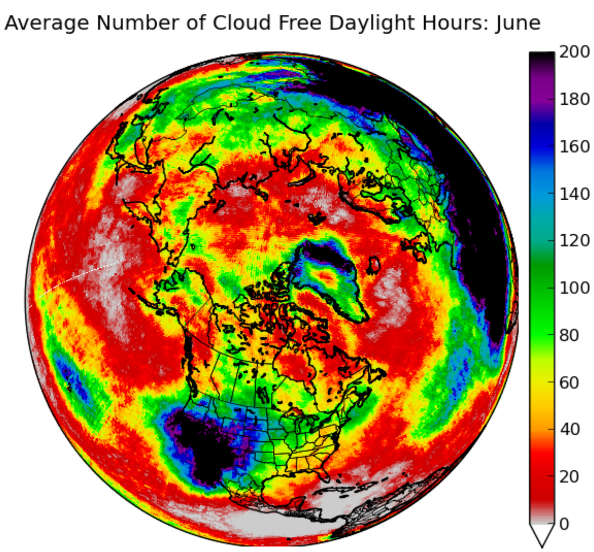
Adapted from ABB

Intelligent Pointing

- About 70% of the Earth is covered by clouds at any given moment and CO_2 & CH_4 retrievals are very sensitive to clouds, so ~90% of all obs are lost
- Japan's GOSAT-2 (LEO) to launch in 2018 will use intelligent pointing, but intelligent pointing would be so much more powerful from HEO or GEO
- Greater pointing flexibility from GEO/HEO, and since every location is cloud-free at some time, and somewhere is always cloud-free potential for 100% cloud-free observations or could focus on events/regions or interest
- Should we get cloud info from UVS, extra imager, or forecasts?

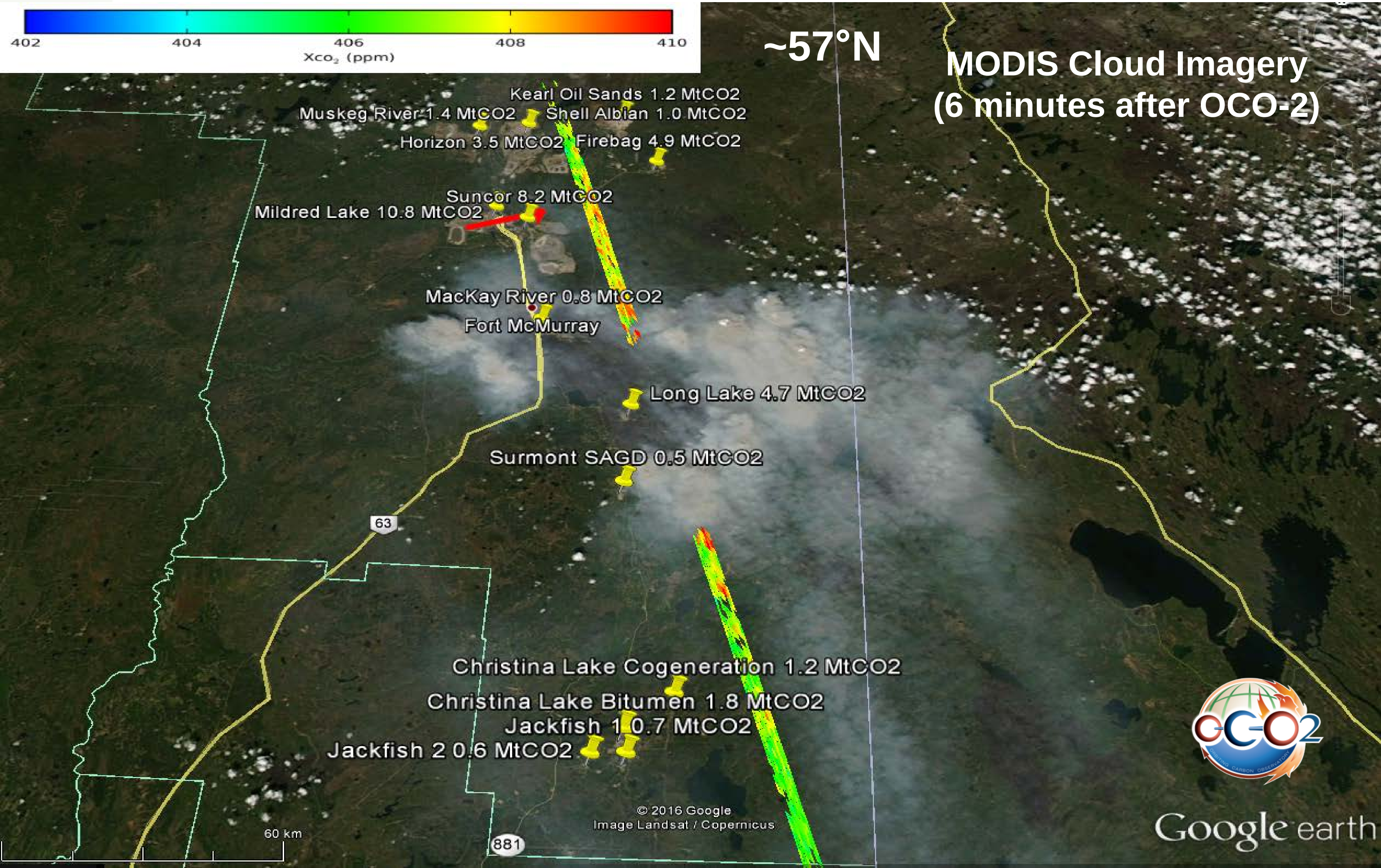
Point the FOV to scan only in clearest regions



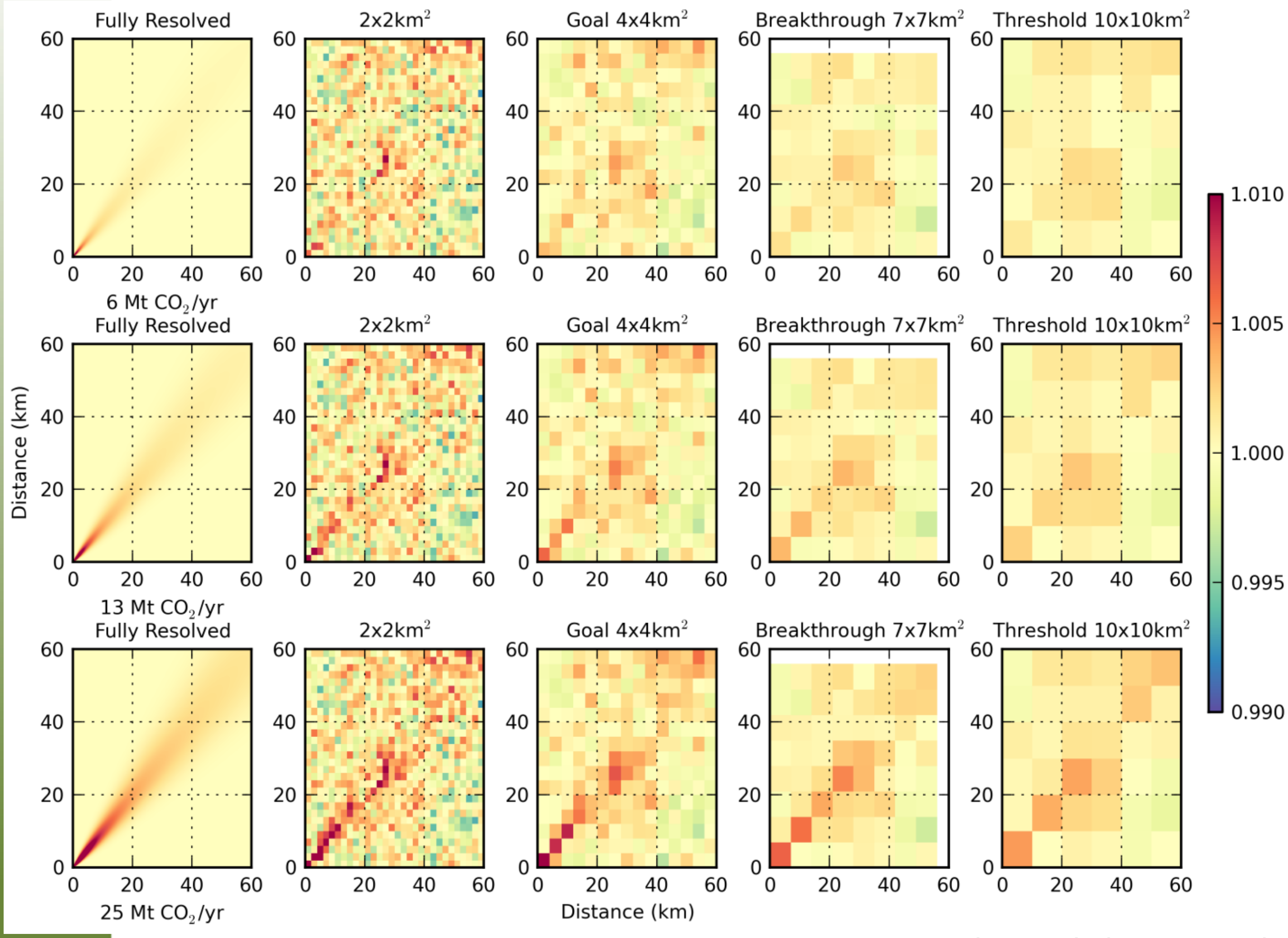


Dan Sehayek (U. Waterloo)

OCO-2 Flyby of Alberta Oil Sands 2016 May 15



Footprint Studies for Point Source Emission



Noise at 2x2 km^2 = 1 ppm but reduces with area for larger pixels.

Considered biases due to terrain, albedo, footprint, Atmospheric stability clouds, interfering sources.

ECCC simulations show that larger footprints improve source estimation with biases in wind direction, but smaller footprint give better results in general and with biases due to terrain, albedo, cloud, and interfering sources.

Tim G. Hill (U. Waterloo)

Department of Defence proceeding without meteorological or atmospheric component

2016

2017

SPACENEWS

NEWS OPINION VIDEO LAUNCH BUSINESS MISSIONS

Canada eyes $2.4 billion Arctic satellite communications constellation

by Mike Gruss — June 30, 2016

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Canada talking to U.S., Norway and Denmark about footing bill for new Arctic military satellite

David Pugliese, Ottawa Citizen | March 14, 2017 5:17 PM ET

More from David Pugliese, Ottawa Citizen

http://spacenews.com/canada-eyes-2-4-billion-arctic-satellite-communications-constellation/
http://news.nationalpost.com/news/canada/canada-talking-to-u-s-norway-and-denmark-about-footing-bill-for-new-arctic-military-satellite

Potential Paths Forward ?

- New Phase A study for standalone northern GHG-AQ mission?
- Polar *Climate* and Weather (PCW) ?
- Independent Canadian mission by CSA ?
- Canada is on the ESA governing council under a cooperation agreement. ESA Sentinel-9 or other opportunity with ESA or EUMETSAT ?
- Partnership with one or more Arctic countries ? Finland chairing Arctic Council 2017-2019, priorities include *Environmental Protection* and *Meteorological Cooperation*