Environment and Climate Change Canada
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Canada

AIM-North

The Atmospheric Imaging Mission for Northern regions

Ray Nassar, Chris McLinden, Chris Sioris, Joseph Mendonca, Louis Garand, Saroja Polavarapu, Yves Rochon, Felicia Kolonjari, Alexander Trichtchenko, Céline Boisvenue, Markey Johnson, Cristen Adams, Guillaume Drolet, Kaley Walker, Tom McElroy, Debra Wunch, Kim Strong, Norm O'Neill, Dylan Jones, Randall Martin, Zahra Vaziri, Gurpreet Singh, Cameron MacDonald, Frederic Grandmont, Louis Moreau, Johanna Tamminen, Charles Miller, William Simpson

International Workshop on Greenhouse Gas Measurements from Space, Toronto, 2018 May 10

What is *AIM-North* ?

- AIM-North is a proposed mission under consideration by the Canadian Space Agency (CSA) that is led by ECCC with involvement of other government departments, Canadian industry, and Canadian university and international scientists

- It would provide observations of unprecedented frequency, density and quality for monitoring greenhouse gases (GHGs), air quality (AQ) and vegetation in northern land regions (~40-80°N) using a pair of satellites in a highly elliptical orbit (HEO) configuration

- Potential enhancements to AIM-North could provide complementary observations for weather, climate and AQ research and operations

Background and History

- Polar Communications and Weather (**PCW**) mission was a HEO concept for Arctic communications and meteorology
- CSA considered additional instruments under the Polar Highly Elliptical Orbit Science (**PHEOS**) program
- The Weather, Climate and Air quality (**WCA**) instrument suite was an atmospheric research option that completed Phase 0 & A in 2012, PI: Jack McConnell of York University, who passed away July 2013
- PHEOS-WCA Instruments: Imaging Fourier Transform Spectrometer (IFTS) for TIR to SWIR (~0.25 cm^{-1}) and UV-Vis grating Spectrometer (UVS), combined mass ~50-85 kg
- CSA has IFTS technology development (FAST, STDP), aiming for sub-orbital testing on a stratospheric balloon in the coming years

YORK U UNIVERSITÉ UNIVERSITY ABB COM DEV INTERNATIONAL CSA ASC

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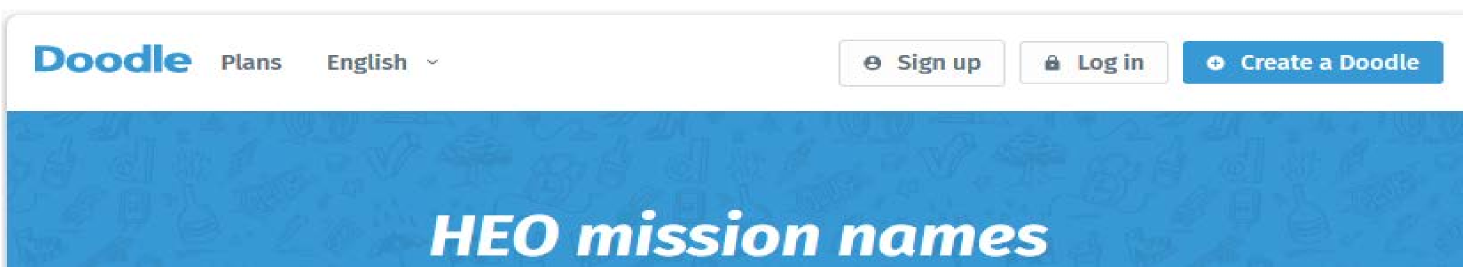
AIM-North

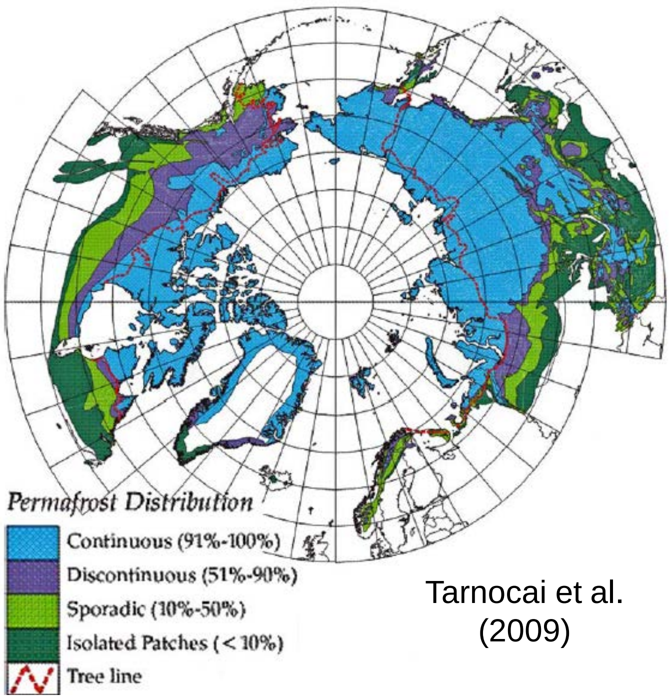
The Atmospheric Imaging Mission for Northern Regions

- "A Concept Study for an Air Quality and GHG observation mission focused on Northern Regions" completed March 2018
  - ECCC: Ray Nassar, Chris McLinden, Chris Sioris, Joseph Mendonca
  - CSA: Ryan Cooney, Marko Adamovic, Ralph Girard
  - Industry: ABB (prime), MDA, Airbus
  - Additional participation by a 'Science Team' (see title slide)
- Options analysis reconfirmed HEO
- *The Future of Canadian Atmospheric Science from Space* (Nov 2017)
- Finally selected a new name… AIM-North!

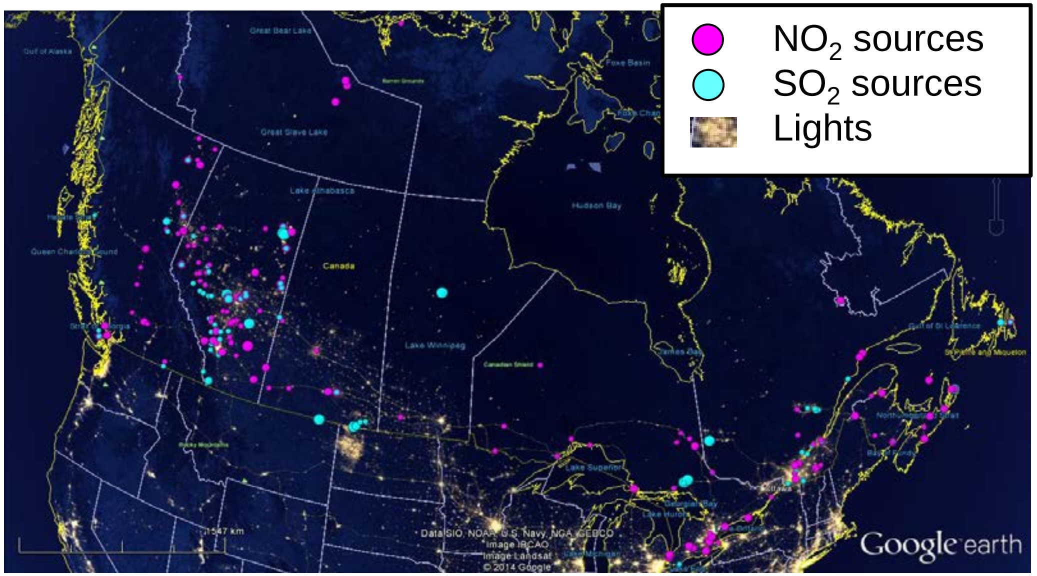


	AIM North: Atmospheric Imaging Mission for Northern regions	NEO: Northern Elliptical Orbiter	EON: Elliptical Orbiter for the North	NAO: Northern Atmospheric Observatory	ABO: Arctic and Boreal Observatory	PHEOS-WCA: Polar Highly Elliptical Orbit Science Weather, Climate and Air quality (old name from Phase 0/A for PCW enhancement)	GESQA: Gaz a Effet de Serre et Qualité de l'Air (internal name used by ABB)	PCAQ: Polar Climate and Air Quality / Polaire pour la Climat et la Qualité de l'Air (PCQA)
9 participants +	✓ 9	✓ 4	✓ 0	✓ 1	✓ 0	✓ 0	✓ 0	✓ 0

Greenhouse Gases and Air Quality in the North



Tarnocai et al. (2009)

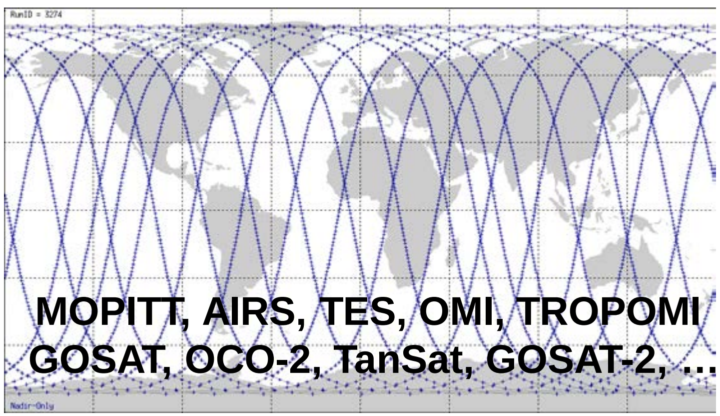


Night light imagery from VIIRS
http://earthobservatory.nasa.gov/Features/IntotheBlack/

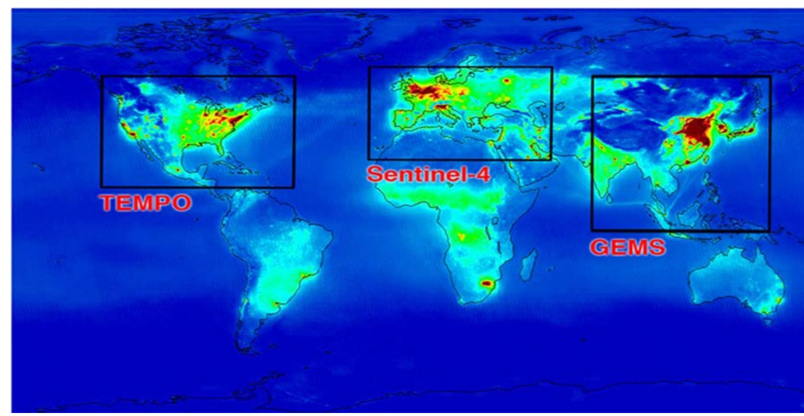
- Warming is causing changes to northern vegetation and permafrost, with a wide range of uncertainty in estimates of northern net CO_2 and CH_4 fluxes
- Increasing anthropogenic activity (transport, resource extraction) in the north is increasing emissions of GHGs and AQ gases and aerosols
- Better observations would improve future climate projections, support GHG and pollutant emission reporting, AQ forecasting which impacts human health

Common Satellite Orbits and Coverage

- **Low Earth Orbit (LEO)**
- Below ~1000 km altitude
- Near-polar plane
- Can give global sampling, but each satellite has a revisit time of days to weeks



- **Geostationary Orbit (GEO)**
- ~35,800 km altitude
- Near-equatorial plane
- Synchronized with Earth rotation allows observations multiple times per day 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

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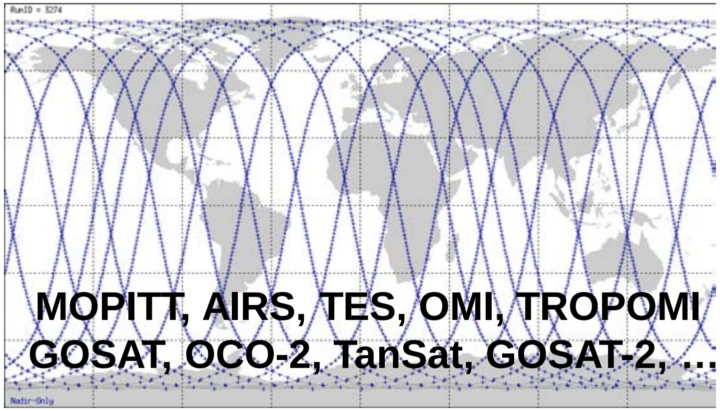

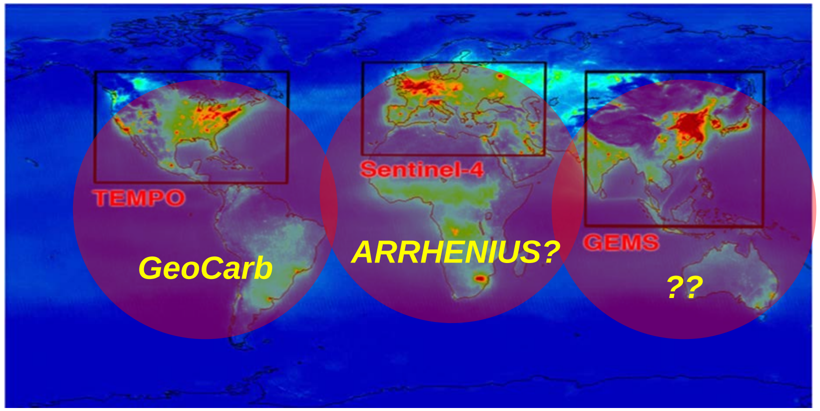

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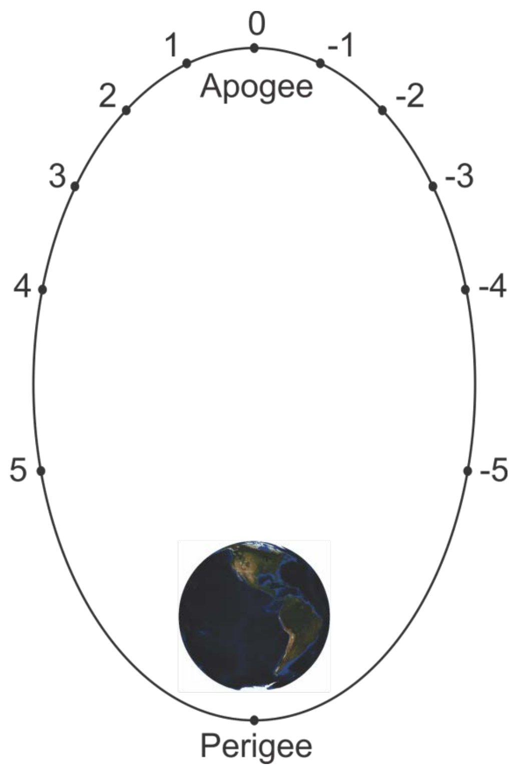
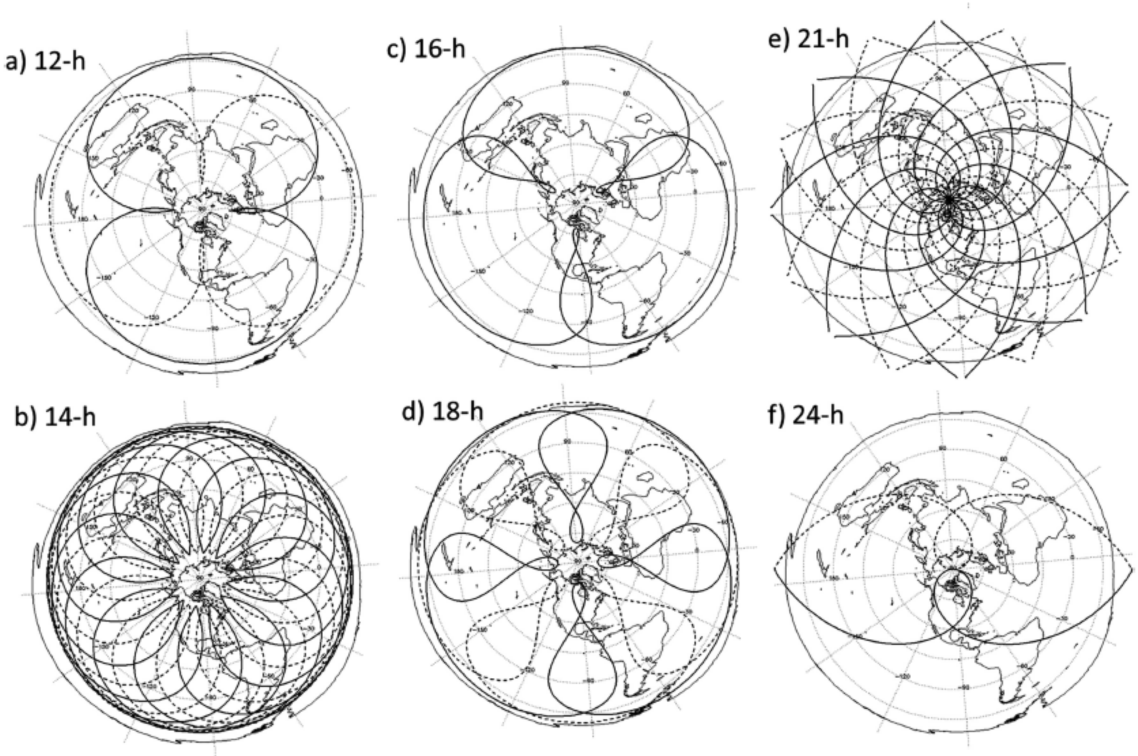
Highly Elliptical Orbit (HEO) Possibilities

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.

AIM-North Observing Approach

UV-Vis: 1-D push-broom scanning with 3x3 km^2 pixels and ~70-90 min. repeat
IFTS: Stare and image Field of View (FoV) with 3x3 km^2 with 2D Focal Plane Array covering the Field of Regard (FoR) with ~70-90 min. repeat

2 HEO satellites with accuracy and precision linked to GEO AQ and GHG missions.

Extending daylight coverage to land ~40-80°N.

Orbit possibilities and variations on IFTS scanning and pointing are still being explored.

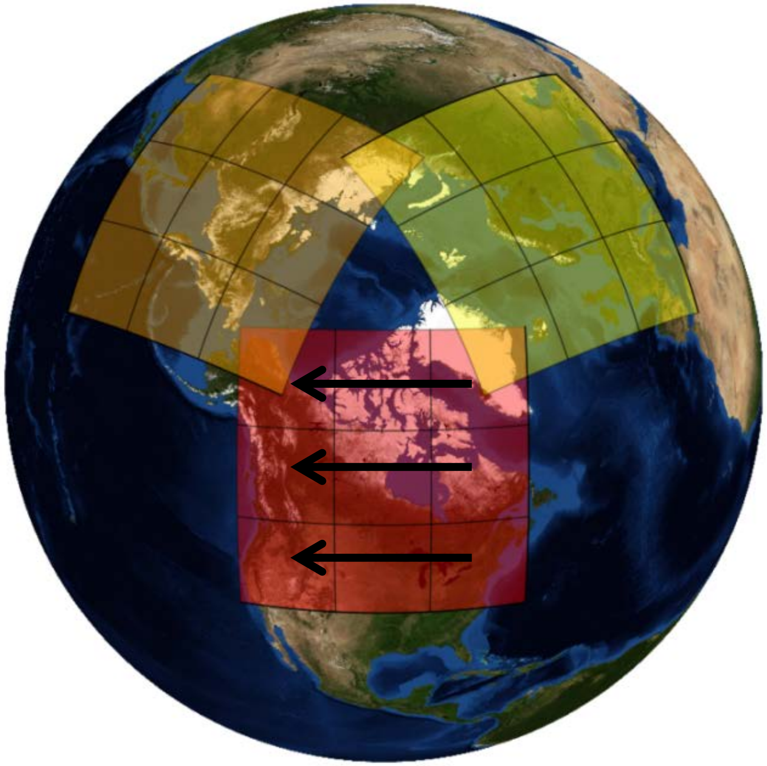


Figure by Cameron MacDonald (U. Waterloo)

Frequent imaging yields movie-like views of daytime atmospheric composition!

Overlap with GEO observations gives intercalibration opportunities beyond LEO.

AIM-North Spectral Bands / Species

Baseline

Enhancement

	Band (nm)	Band (cm^{-1})	Spectral Sampling	Target species
UV-vis grating	280-780	12820 - 35714	~ 0.4 nm	O_3, NO_2, aerosol, BrO, HCHO, SO_2, SIF & more
NIR-SWIR IFTS	758-762	13122 - 13186	0.25 cm^{-1}	O_2 *A* band: p_{surf}, aerosol Solar Induced Fluorescence
	1570-1587	6300 – 6370	0.25 cm^{-1}	CO_2 columns
	2042-2079	4810 – 4897	0.25 cm^{-1}	CO_2 columns
	2301-2380	4195 – 4345	0.25 cm^{-1}	CO and CH_4 columns
Mid/LWIR IFTS	Longwave IR		~0.50 cm^{-1}	T, H_2O, O_3, CO, CO_2, CH_4, HNO_3, CH_3OH, HCOOH, PAN, HCN, NH_3, SO_2…
	mid-IR		~1.25 cm^{-1}	

- IFTS with 16.5 cm aperture would be ~141 kg (~199 kg with enhancement)
- UVS would be ~51 kg

*30% contingency included above

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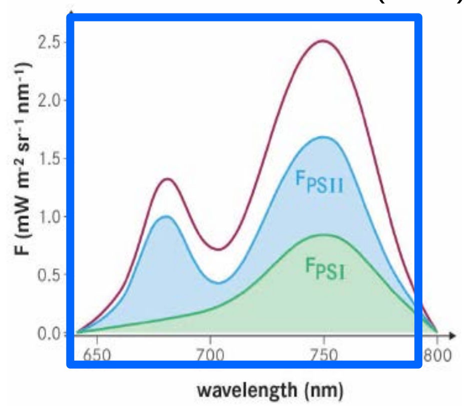
AIM-North Precision and SNR

- IFTS: high spectral resolution and narrow bands deliver good precision with modest SNRs, but NIR band is limiting
- SNR requirements determined with MODTRAN 5.2, Gaussian noise, fit differences between simulated spectra using a linear regression (see poster C6.6 by Chris Sioris)
- Precision goals: XCO_2 0.25% ≈ 1 ppm, XCH_4 0.50% ≈ 9 ppb, XCO = 5% with a threshold of 3 times the goal
- Assume CO_2 and O_2 contribute equally to XCO_2 uncertainty, giving each a requirement of $0.25\%/\sqrt{2}$ while for XCH_4 and XCO, O_2 impact is smaller

Band (μm)	SNR Goal	SNR Threshold	SNR Expected
O_2 (0.76)	88	30	75
CO_2 (1.61)	119	40	130
CO_2 (2.06)	116	39	120
CH_4 & CO (2.3)	130	43	120

SIF Retrieval Opportunities

Figure from FLEX Report for ESA EE-8 mission selection (2015)



SIF is an indicator of photosynthesis, plant stress and the start, end and intensity of growing season

Broad spectral coverage of SIF from UVS (blue)

IFTS O_2 window (red) has strong oxygen lines and isolated Fraunhofer lines:
758.4-762.1 nm (13121.6-13185.7 cm^{-1})

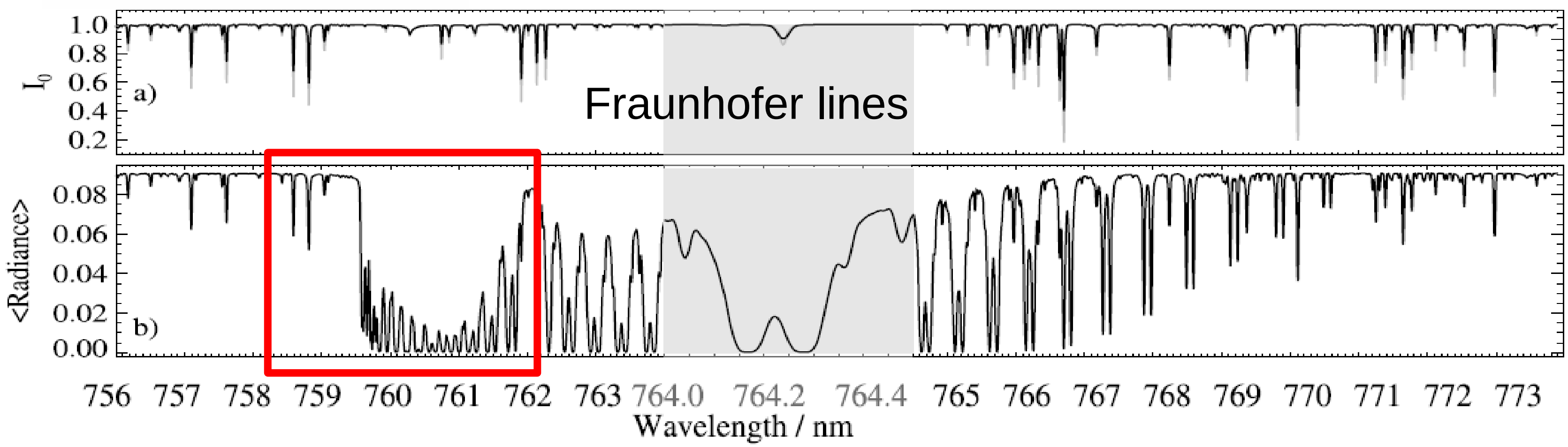
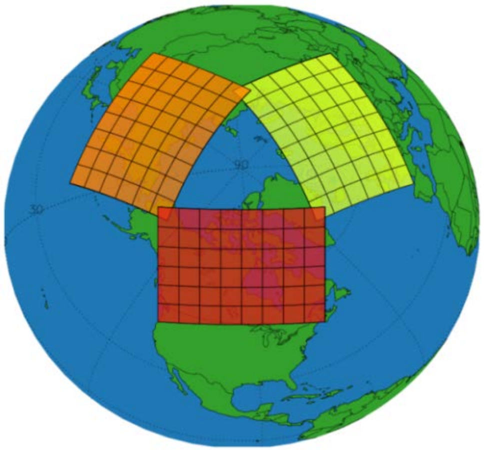


Figure from: Frankenberg, Butz and Toon (2011), Disentangling chlorophyll fluorescence from atmospheric scattering effects in O_2 A-band spectra of reflected sun-light, GRL, 38, L03801.

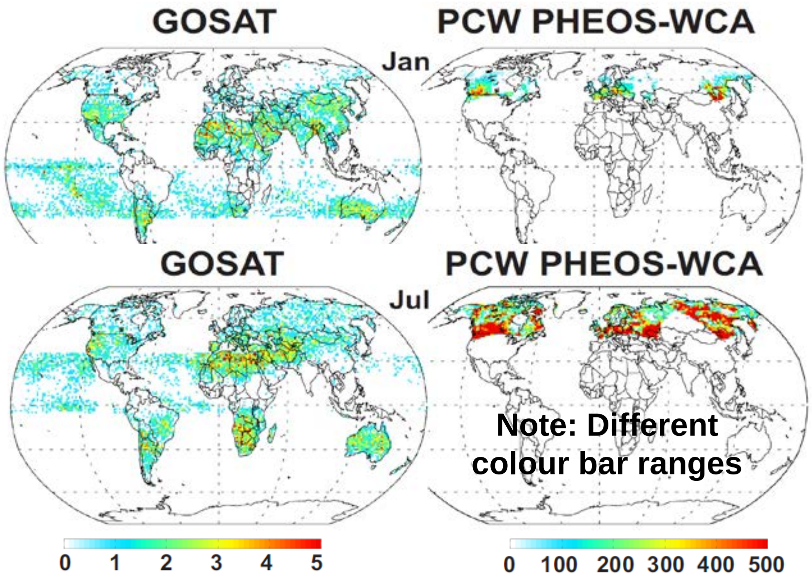
Past OSSE on CO_2 Observations from HEO

- Simulations compared the potential information from PHEOS-FTS vs. GOSAT for constraining Arctic and Boreal CO_2 surface fluxes using synthetic CO_2 observations.

PHEOS-FTS Fields of Regard



Number of observations per 1°x1° per month



GOSAT mean simulated obs per month: 14973
NIES v2, 1st year of mission: 14393

- PHEOS-FTS could give flux uncertainty *reductions* relative to GOSAT of ~30% annually and ~45% in summer
- Plan to generate new HEO synthetic observations with smaller pixels, better precision, changes to orbit assumptions for participation in coordinated AQ-GHG OSSEs

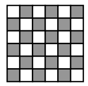
Nassar, Sioris, Jones, McConnell (2014), Satellite observations of CO_2 from a highly elliptical orbit for studies of the Arctic and boreal carbon cycle, *J. Geophys. Res.* 119, 2654–2673, doi:10.1002/2013JD020337.

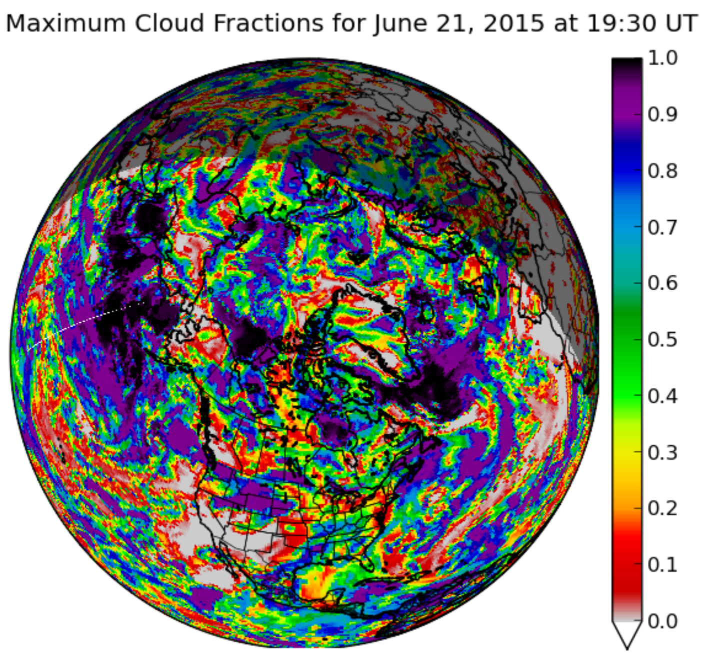
*Precision of observations over snow degraded by a factor of 2

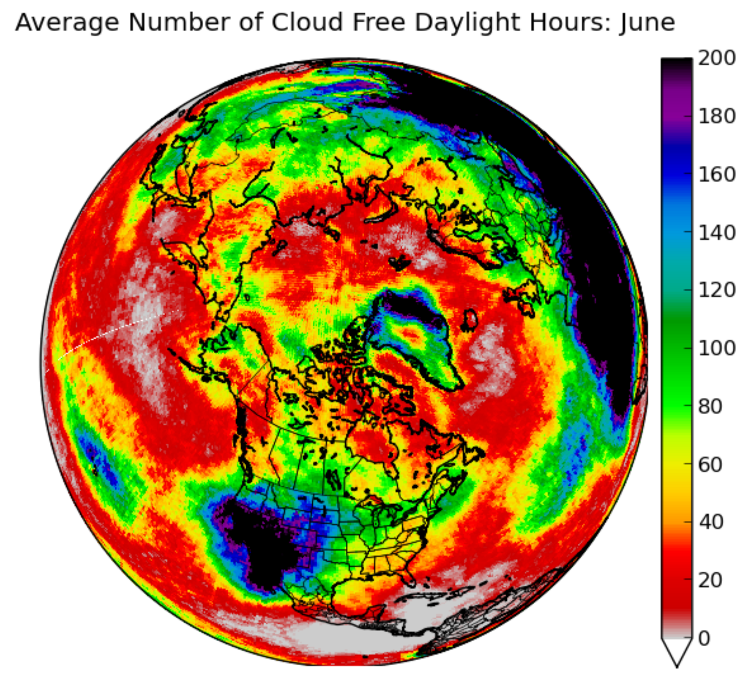
HEO Intelligent Pointing

- Intelligent pointing would be so much more powerful from HEO or GEO than LEO
- Greater pointing flexibility from GEO/HEO since essentially every location is cloud-free at some time, and there is always somewhere cloud-free to view
- Smarter pointing could focus on clear regions or just events/regions or interest
- An extra imager for cloud/aerosol data could help inform pointing

Could point the FOV to scan only in clearest regions







Figures: Dan Sehayek (U. Waterloo)

Moving Forward

- An ECCC Deputy Minister has sent a letter to CSA supporting two missions: AIM-North and a Snow Radar mission to advance to Phase 0 (no other Earth observation missions are at the same level of study by CSA), decision in May 2018
- Phase 0 would last ~18 months (after selection of new industry team) would include technical studies and new associated science activities within ECCC and Canadian universities
- Could launch in ~7 years (~2025) if selected/funded by CSA, but would be an expensive project for CSA to do independently
- Exploring opportunities for international participation and even partnerships at the space agency level to help the mission happen

AIM-North Team

Government of Canada Members
- Ray Nassar (ECCC, Climate Research Division) – PI and greenhouse gas (GHG) observations
- Chris McLinden (ECCC, Air Quality Research Division) – Air quality (AQ) species observations
- Louis Garand (ECCC, Meteorological Research Division) – Potential meteorological enhancements
- Chris Sioris (ECCC, AQRD) – Retrievals and Analysis
- Joseph Mendonca (ECCC, CRD) – Validation and GHG Retrievals
- Saroja Polavarapu (ECCC, CRD) – Modelling and Assimilation for GHGs
- Felicia Kolonjari (ECCC, CRD) – Inter-departmental/International collaboration and policy
- Yves Rochon (ECCC, AQRD) – Modelling and Assimilation for Air Quality
- Alexander Trichtchenko (Natural Resources Canada, Canada Centre for Mapping and Earth Observation) – Orbits
- Céline Boisvenue (Natural Resources Canada, Canadian Forest Service) – SIF observations over forests
- Markey Johnson (Health Canada) – Air quality impacts on health

Provincial Government Members
- Cristen Adams (Alberta Environment and Parks) – Air quality observations
- Guillaume Drolet (Québec Ministère des Forêts, de la Faune et des Parcs) – SIF observations over forests

University Members
- Tom McElroy (York University) – Pointing, Imaging FTS, sub-orbital testing
- Kaley Walker (University of Toronto) – FTS and Arctic Science
- Debra Wunch (University of Toronto) – Validation
- Kim Strong (University of Toronto) – Validation
- Norm O'Neill (Université de Sherbrooke) – Aerosols
- Dylan Jones (University of Toronto) – Modelling and Assimilation for GHGs and AQ
- Randall Martin (Dalhousie University) – Modelling and Assimilation for Air Quality
- Zahra Vaziri (York University, student) – Pointing, Imaging FTS, sub-orbital testing
- Gurpreet Singh (York University, student) – Pointing, Imaging FTS, sub-orbital testing

Industry Members
- Frederic Grandmont (ABB Canada) – Instruments and spacecraft
- Louis Moreau (ABB Canada) – Instruments and spacecraft
- Stephane Lantagne (ABB Canada) – Imaging FTS

International Members
- Johanna Tamminen (Finnish Meteorological Institute) – Analysis of GHG and AQ data
- Charles E. Miller (NASA) – Arctic and Boreal Carbon Cycle Science
- William Simpson (University of Alaska at Fairbanks) – Arctic Atmosphere and Carbon Cycle

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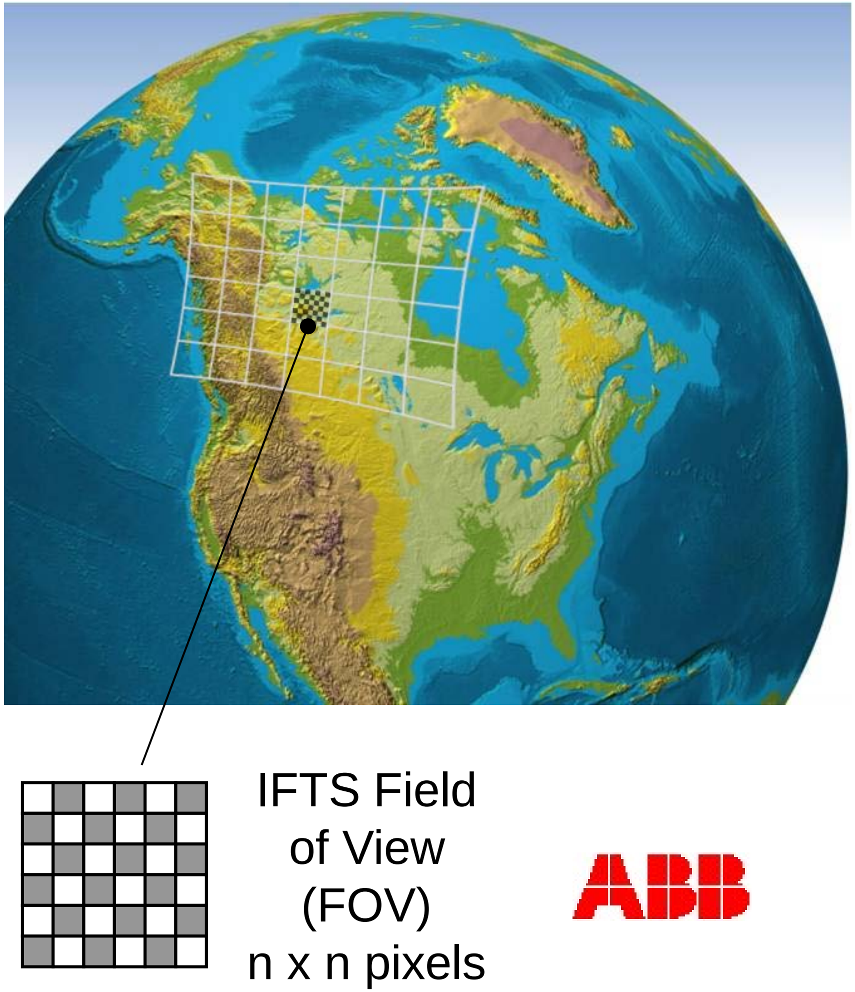
Grating or Imaging Fourier Transform Spectrometer (IFTS)

Extra Slide

- 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
- FTS simultaneously measures all wavelengths as the instrument modulates the optical path length, interferogram is later transformed mathematically to a spectrum, so with an IFTS, both dimensions of a 2D focal plane array can be used spatially to give 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
- High commercialization potential for IFTS for Earth Observation: atmospheric research or GEO weather satellites



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