Environment and Climate Change Canada | Environnement et Changement climatique Canada

Canada

AIM-North

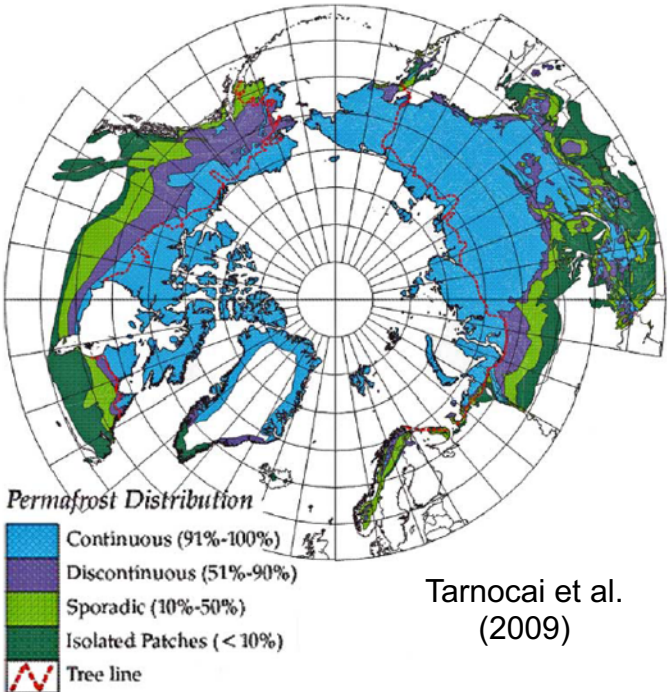
The Atmospheric Imaging Mission for Northern Regions

Ray Nassar[1], **Joseph Mendonca**[1], Chris McLinden[1], Chris Sioris[1], Ryan Cooney[3], Helena van Mierlo[3], Natasha Jackson[3], Ralph Girard[3], Dylan B.A. Jones[2] , Feng Deng[2], Saroja Polavarapu[1], C. Thomas McElroy[4], Cristen Adams[5], J.F. Blavier[6], Céline Boisvenue[7], Adam Bourassa[8], Doug Degenstein[8], Guillaume Drolet[9], Louis Garand[1], Markey Johnson[10], Felicia Kolonjari[1], Bruce Kuwahara[11], Randall V. Martin[12], Cameron MacDonald[11], Charles E. Miller[6], Norm O'Neill[13], Aku Riihelä[14], Sebastien Roche[2], Yves Rochon[1], Stanley P. Sander[11], William R. Simpson[15], Gurpreet Singh[4], Kim Strong[2], Johanna Tamminen[14], Alexander Trishchenko[7], Zahra Vaziri[4], Kaley A. Walker[2], and Debra Wunch[2]

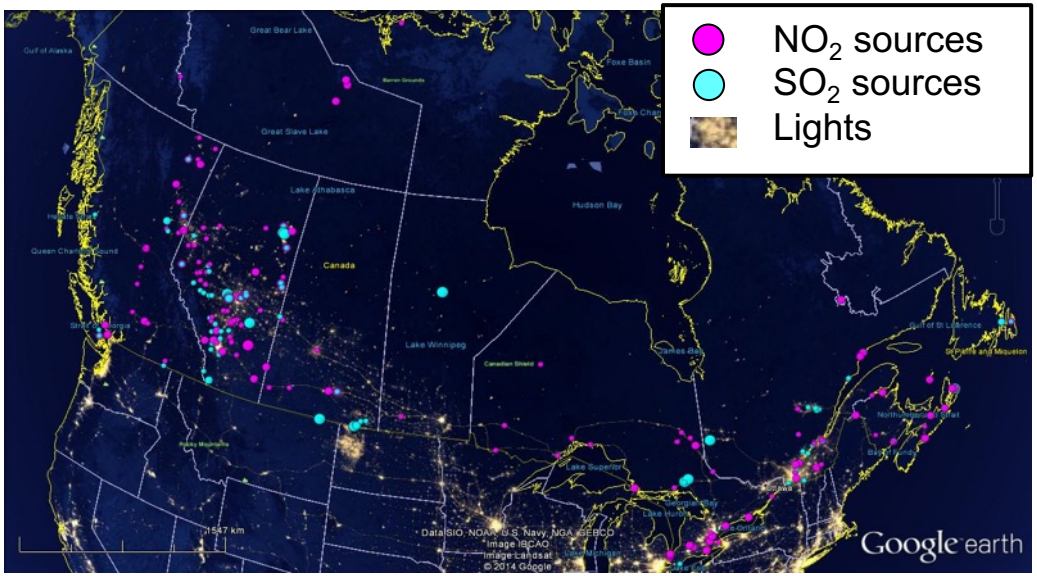
[1]Environment and Climate Change Canada, [2]University of Toronto, [3]Canadian Space Agency, [4]York University, [5]Alberta Environment and Parks, [6]Jet Propulsion Laboratory / California Institute of Technology, [7]Natural Resources Canada,[8]University of Saskatchewan, [9]Québec Ministère des Forêts, de la Faune et des Parcs, [10]Health Canada, [11]University of Waterloo, [12]Dalhousie University, [13]Université de Sherbrooke, [14]Finnish Meteorological Institute, [15]University of Alaska at Fairbanks

IWGGMS15, June 5, Sapporo, Japan

Carbon Cycle and Air Quality in the North



Tarnocai et al. (2009)

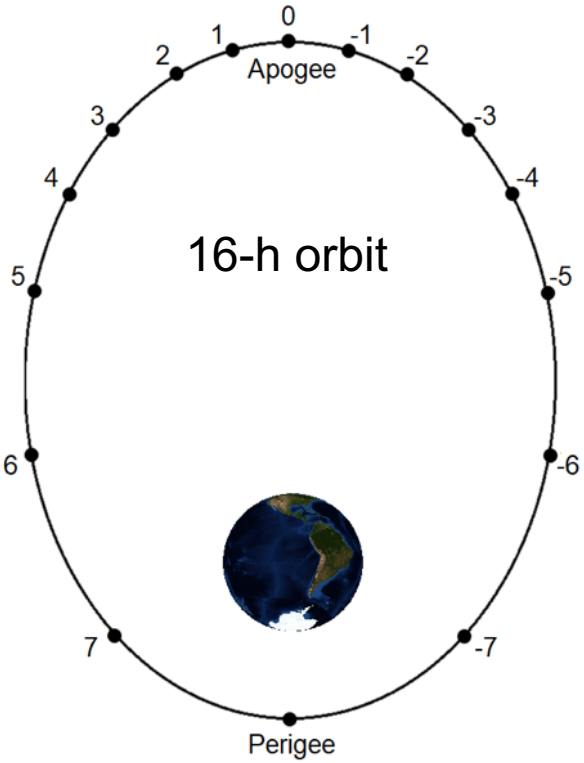


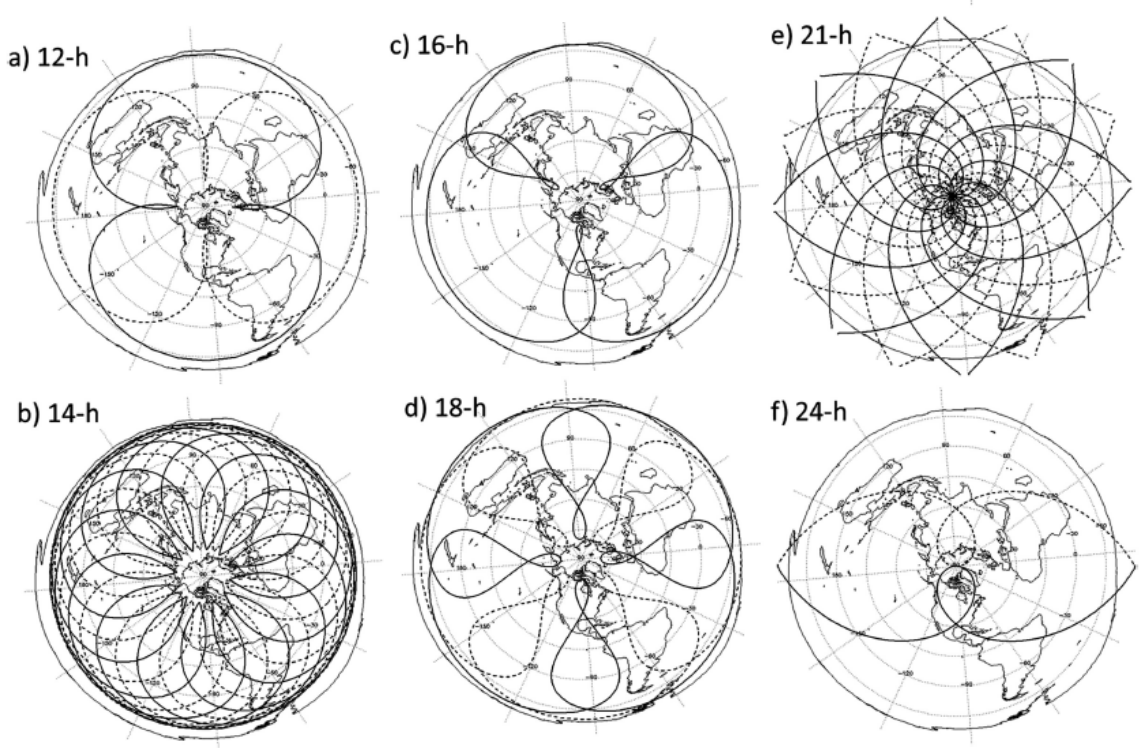
Night light imagery from VIIRS
http://earthobservatory.nasa.gov/Features/IntotheBlack/

- CO_2 and CH_4 fluxes from permafrost, Boreal forests and other northern landscapes for the coming years are highly uncertain
- 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 and AQ forecasting which impacts human health
- New international LEO and GEO missions are coming, but these will not give sub-daily revisit over high latitudes for monitoring or process studies

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 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 only ~50-85 kg
- CSA has funded IFTS technology development, aiming for sub-orbital testing on a stratospheric balloon in the coming years
- Planned IFTS on MTG-IRS and NASA JPL IFTS studies/technology development: GEO-FTS and IFTS on Mt. Wilson, California
- Mission concept feasibility study involving ECCC, CSA and industry contractors led to AIM-North stand-alone mission

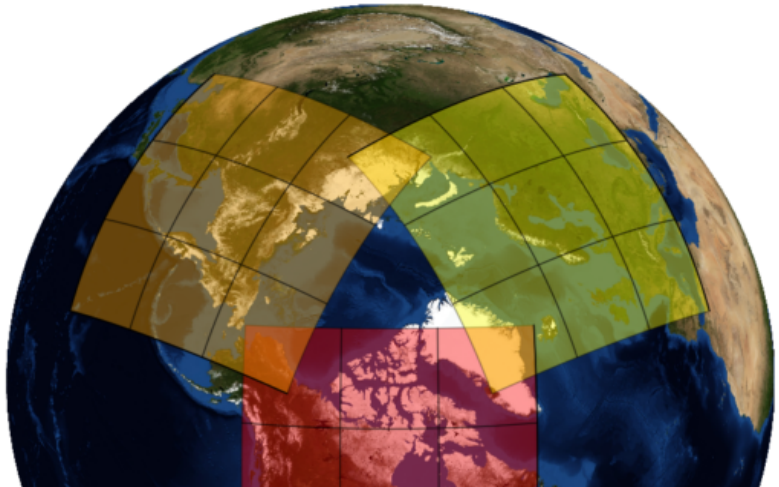
www.aim-north.ca

AIM-North

THE ATMOSPHERIC IMAGING MISSION FOR NORTHERN REGIONS

AIM-North is an innovative satellite mission concept that is under consideration by the Canadian Space Agency (CSA). The mission is currently undergoing Phase 0 studies.

AIM-North would provide observations of unprecedented frequency, density and quality for monitoring greenhouse gases (GHGs), air quality (AQ), clouds and solar induced fluorescence (SIF) from vegetation in northern regions. AIM-North would use a constellation of two satellites in a highly elliptical orbit (HEO) configuration, enabling observations over land from about 40-80°N, multiple times per day. Enhancing the mission with additional spectral bands could provide complementary observations for weather, climate and AQ research and operations. The project is a collaborative effort between Environment and Climate Change Canada (ECCC), CSA, other federal and provincial government departments, Canadian academia, Canadian industry and international scientists.



Phase 0

2019	2021	2022	…	…	2026 ?		
CSA Phase Names	**Phase 0 (Pre-Phase A)**	**Phase A**	**Phase B**	**Phase C**	**Phase D**	**Phase E**	**Phase F**
Description	Mission Definition	System Definition	Preliminary Design	Detailed Design	Manufacturing, Assembly, Integration, Testing, Launch, Commissioning	Operations	Disposal

- Mission Objectives Document (MOD) with objectives and observing requirements
- ~18-month study with focus on instrument technologies and configuration:
  - Option 1) Imaging Fourier Transform Spectrometer (GHGs) + Dispersive (AQ)
  - Option 2) Dispersive (GHG) + Dispersive (AQ) Instrument
  - Option 3) Combined Dispersive (GHG and AQ) Instrument
  - Cloud imager is now baselined to inform pointing decisions
- CSA is funding 3 AIM-North science contracts:
  - CH_4 and CO Retrievals: U. Toronto (D. Wunch, K. Strong)
  - NO_2 and O_3 Retrievals: U. Saskatchewan (D. Degenstein, A. Bourassa)
  - CO_2 Observing System Simulation Experiment: U. Toronto (D. Jones, F. Deng)
- ECCC science: CO_2 / SIF retrievals, orbits, intelligent pointing, point source estimation
- User Requirements Document (URD) soon to be developed by full science team

AIM-North CO_2, CH_4, CO, SIF Requirements

Species	Precision (1σ)	Accuracy
CO_2	0.25%, ~1 ppm (G), 0.75%, ~3 ppm (T)	0.05%, ~0.2 ppm (G), 0.15%, ~0.6 ppm (T)
CH_4	0.50%, ~9 ppb (G), 1.50%, ~27 ppb (T)	0.1%, ~2 ppb (G), 0.3%, ~6 ppb (T)
CO	5% (G), 15% (T)	5% (G), 15% (T)
SIF	0.30 Wm^{-2} sr^{-1} mm^{-1} (G), 0.90 Wm^{-2} sr^{-1} mm^{-1} (T)	n/a

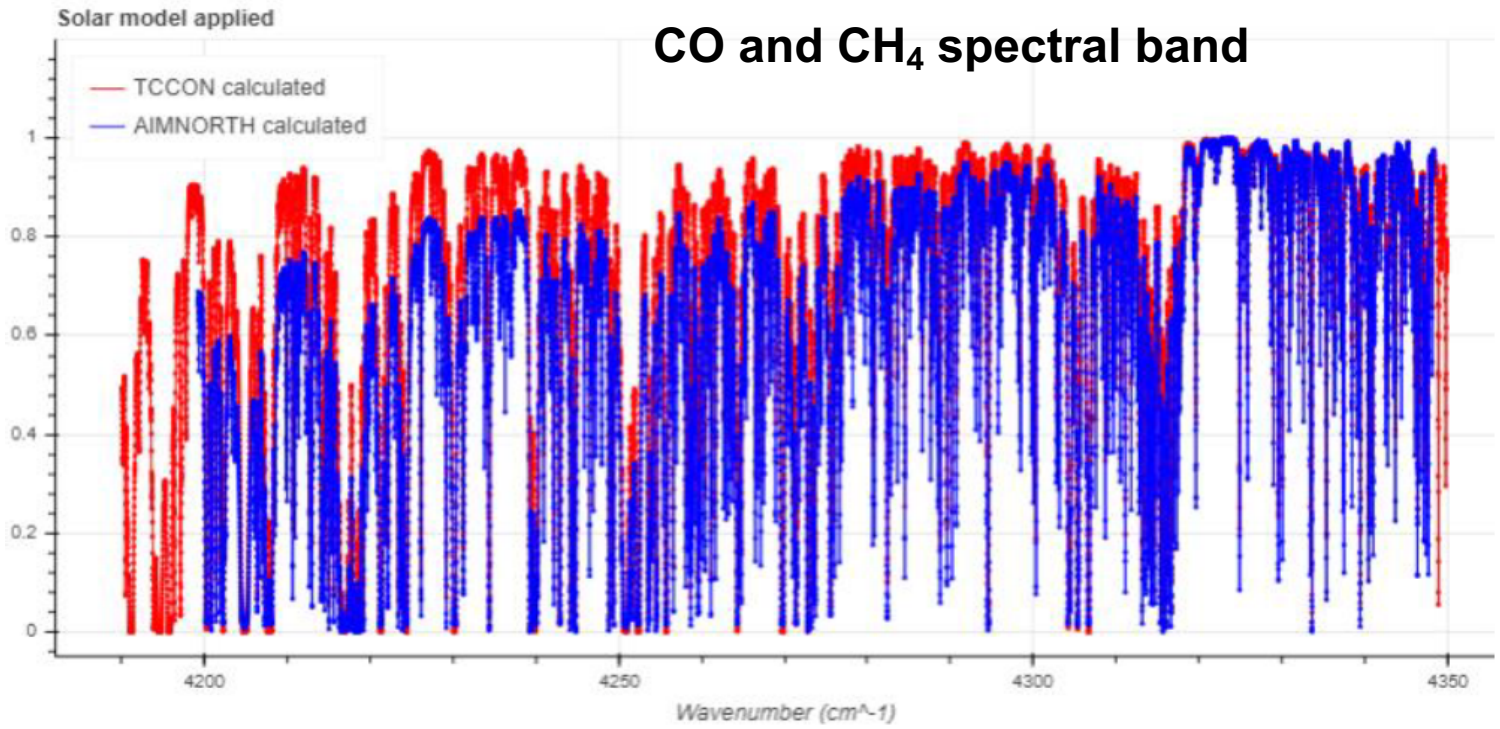
*(G) = Goal, (T) = Threshold

Band	FTS Band (nm)	FTS Resolution (nm)*	Dispersive Band (nm)	Dispersive Resolution (nm)	SNR Required (based on FTS)
O_2	758.0 - 762.3	~0.0174	757.9 - 772.0	0.0474	88 (G), 30 (T)
CO_2	1598 - 1618	~0.078	1591.5 - 1621.2	0.101	119 (G), 40 (T)
CO_2	2042 - 2079	~0.127	2045.0 - 2085.0	0.136	116 (G), 40 (T)
CO & CH_4	2301 - 2380	~0.167	2300.6 - 2345.6	0.153	130 (G), 43 (T)

*Constant FTS spectral sampling of 0.25 cm^{-1}

UV-Vis dispersive instrument for O_3, NO_2, aerosol, BrO, HCHO, SO_2, SIF & more

AIM-North Greenhouse Gas Retrieval Studies

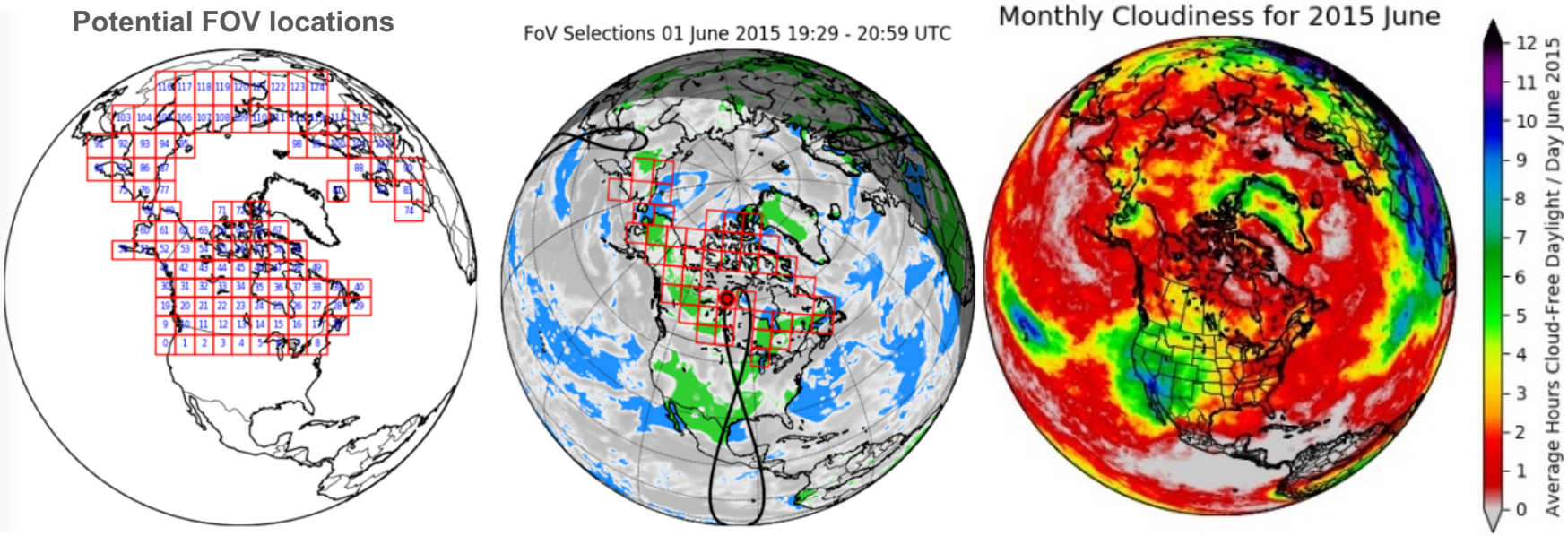


Joseph Mendonca, Sebastien Roche, Debra Wunch, Kim Strong

- Preliminary SNR requirements from earlier studies will be updated
- Adapting OCO-2 full physics algorithm to assess AIM-North instrument level requirements to meet CO_2, CH_4, CO, & SIF precision requirements (G/T) for both a grating and IFTS
- Testing retrieval sensitivity to instrumental and geophysical sources of bias

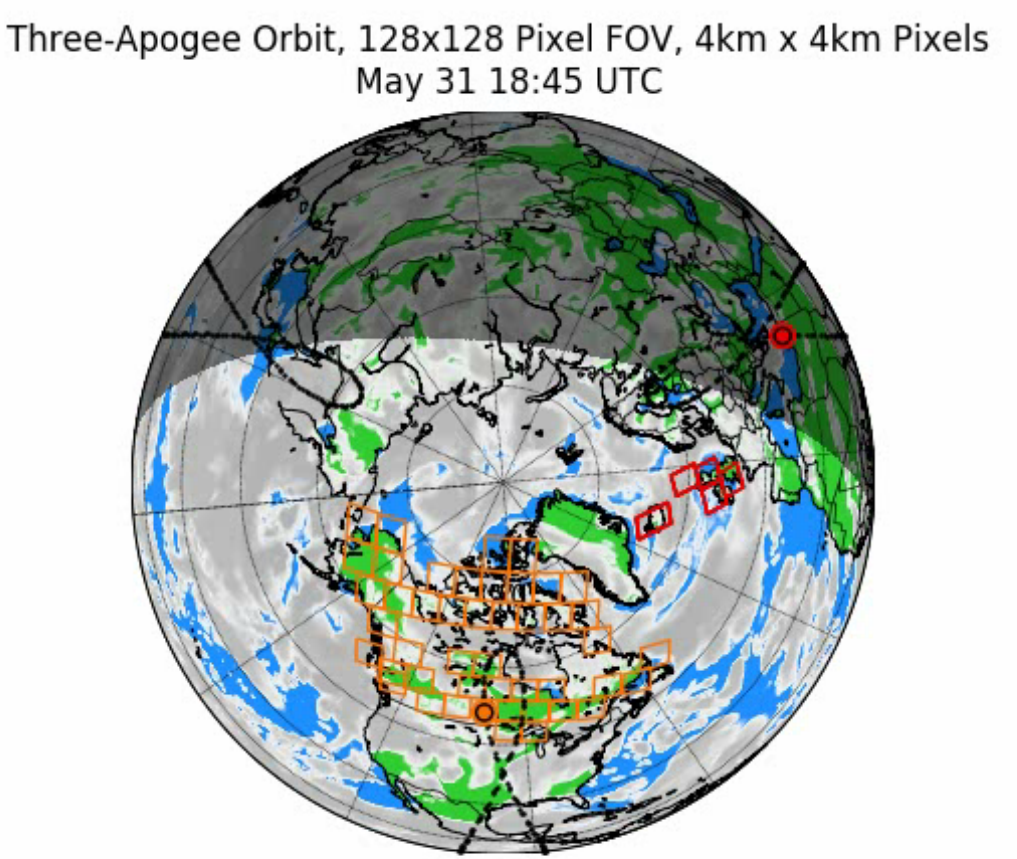
AIM-North Phase 0 IFTS Observing Scenarios

- IFTS would use a step-and-stare approach to scan, but trade space still being explored
- Improved upon mission concept plan with a new baseline detector: faster (up to 14 kHz) but smaller (128x128 pixels), larger pixel pitch, built-in electronics
- 4x4 km^2 pixels & 20 cm aperture (≤ 150 kg) with ~60-180 second integration time meets SNR requirements (G/T), while smaller 3x3 km^2 pixels require ≥25 cm aperture
- Plan for intelligent pointing with assistance of a small onboard cloud imager



Potential FOV locations from 95°W apogee with a 128x128 pixel FOV and 4x4 km^2 pixels (left). NASA MERRA-2 cloud cover for 2015-06-01 17:30 UT and 45 selected FOV positions for a 90 minute period. Satellite and TAP orbit track also shown (center). Over a full month, all northern land (40-80°N) could be observed during cloud free opportunities (right).

AIM-North Intelligent Pointing Example



~70% of Earth covered by cloud at any moment

Real-time cloud data can inform pointing decisions (pioneered by GOSAT-2) to focus on clearest regions

Simulation uses MERRA-2 cloud info every 90 minutes

2 satellites, 16-hr TAP orbit (e = 0.50, i = 63.435°, apogee local noon on July 25)

IFTS FOV = 128x128 pixels, ~4x4 km^2 (sub-satellite but changes with VZA altitude), 45 stares in 90 minutes

Animation by Bruce Kuwahara

Canada

CO_2 OSSEs for AIM-North

- Past Observing System Simulation Experiment assessed earlier HEO concept for constraining Arctic-Boreal CO_2 fluxes (*Nassar et al.* 2014)
- New OSSEs now underway with intelligent pointing and AIM-North observing requirements (smaller pixels and better precision)
- Improved method for simulating observations: orbit, precision, bias, cloud filtering and albedo, etc. (R. Nassar, C. MacDonald)
- 1-year of XCO_2 from high resolution model CO_2 simulation (EC-CAS, 0.45°x0.45°, S. Polavarapu, M. Neish) driven with CarbonTracker fluxes plus extra permafrost emissions (R. Nassar, C. MacDonald)
- Global (2°x2.5°) and nested (0.25°x0.3125°) GEOS-Chem 4Dvar assimilations (F. Deng, D. Jones) are able to recover CO_2 flux magnitude and seasonality for northern terrestrial biosphere overall and even permafrost emissions

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.

Summary and Potential Path Forward

- AIM-North would provide quasi-geostationary observations of CO_2, CH_4, CO, SIF and air quality species over the North
- Phase 0 (Jan 2019 – late 2020) will result in preliminary instrument and system designs in preparation for Phase A and *potential decision could follow*
- OSSEs show AIM-North CO_2 observations could provide strong constraints on Arctic and Boreal CO_2 fluxes including the ability to estimate permafrost CO_2 emissions, while 3x3 to 4x4 km^2 pixels are small enough for point source or urban studies
- Intelligent pointing strategy could greatly improve the efficiency of the GHG observing concept by use of a small cloud imager
- Could also use cloud data from a full met imager if AIM-North instruments are hosted on a HEO meteorological satellite and early discussions are underway with NOAA and ESA/EUMETSAT on partnership possibilities

AIM-North Team

Government of Canada Members

- Ray Nassar (Environment and Climate Change Canada) – PI and greenhouse gas (GHG) observations
- Chris McLinden (ECCC) – Air quality (AQ) species observations
- Chris Sioris (ECCC) – Retrievals and Analysis and instrument configuration
- Helena van Mierlo (Canadian Space Agency) – CSA Study Manager
- Ryan Cooney (CSA) – CSA Study Lead
- Ralph Girard (CSA) – CSA Portfolio Manager
- Natasha Jackson (CSA) – Mission Design Engineer
- Marcus Dejmek (CSA) – CSA Science Liaison
- Louis Garand (ECCC) – Potential meteorological enhancements
- Joseph Mendonca (ECCC) – Validation and GHG Retrievals
- Saroja Polavarapu (ECCC) – Modelling and Assimilation for GHGs
- Felicia Kolonjari (ECCC) – Inter-departmental/International collaboration and policy
- Yves Rochon (ECCC) – 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

http://www.aim-north.ca
ray.nassar@canada.ca

Canadian 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) – GHG retrievals and GHG validation
- Kim Strong (University of Toronto) – GHG retrievals and trace gas validation
- Norm O'Neill (Université de Sherbrooke) – Aerosols
- Dylan Jones (University of Toronto) – Modelling and Assimilation for GHGs and AQ
- Feng Deng (University of Toronto) – Modelling and Assimilation for GHGs
- Randall Martin (Dalhousie University) – Modelling and Assimilation for Air Quality
- Doug Degenstein (University of Saskatchewan) – Air quality gas retrievals
- Adam Bourassa (University of Saskatchewan) – Air quality gas retrievals
- Bruce Kuwahara (University of Waterloo, student) – Orbits and Pointing Strategies
- Cameron MacDonald (University of Waterloo, student) – Orbits and Pointing Strategies
- Sebastien Roche (University of Toronto, student) – CO and CH_4 Retrievals
- Nicholas Lloyd (University of Saskatchewan, student) – Air quality gas retrievals
- Zahra Vaziri (York University, student) – Pointing, Imaging FTS, sub-orbital testing
- Gurpreet Singh (York University, student) – Pointing, Imaging FTS, sub-orbital testing

International Members

- Johanna Tamminen (Finnish Meteorological Institute) – Analysis of GHG and AQ data
- Aku Riihelä (Finnish Meteorological Institute) – Cloud imager and data
- Charles E. Miller (NASA/JPL) – Arctic and Boreal Carbon Cycle Science
- Stanley Sander (NASA/JPL) – Imaging FTS
- Jean-Francois Blavier (NASA/JPL) – Imaging FTS
- William Simpson (University of Alaska at Fairbanks) – Arctic Atmosphere and Carbon Cycle

Industry Team:

ABB

AIRBUS DEFENCE & SPACE

MDA