Environment and Climate Change Canada
Environnement et Changement climatique Canada
Canada

Air Quality & Greenhouse Gas Observations from *AIM-North*

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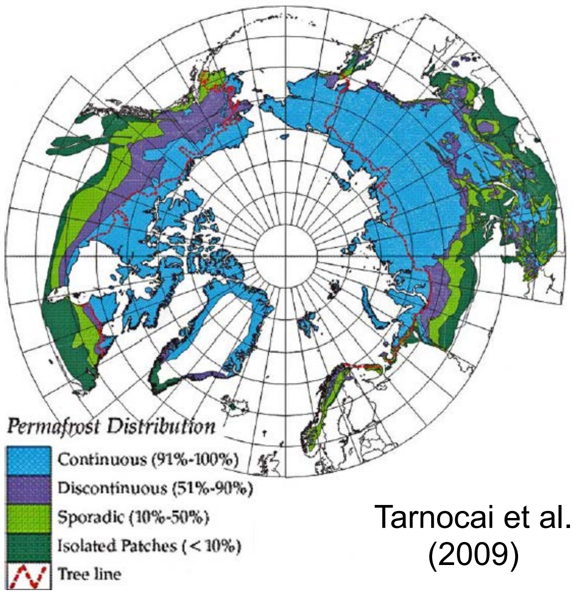
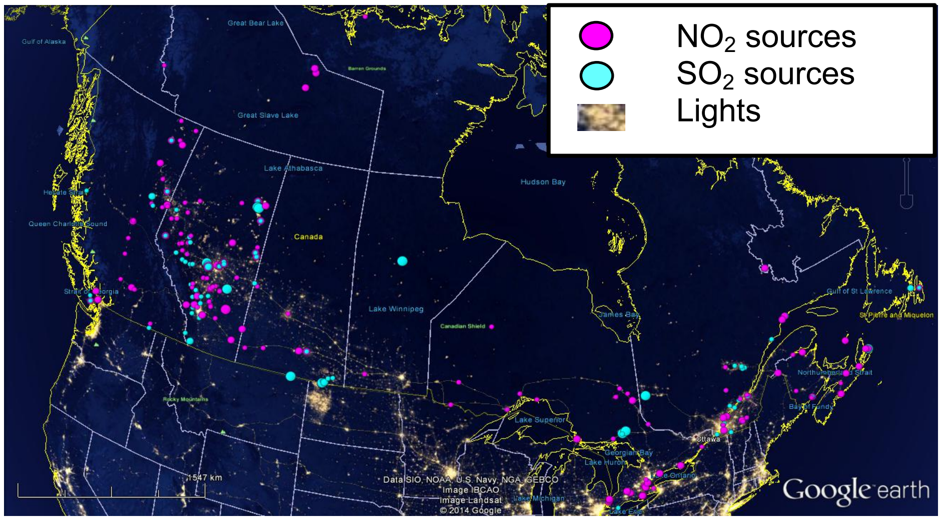
CEOS AC-VC Meeting, June 11, Tokyo, Japan

Carbon Cycle and Air Quality in the North



Tarnocai et al. (2009)



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

- Increasing anthropogenic activity (transport, resource extraction) in the north in a warming climate will result in increasing emissions of GHGs, AQ gases, and aerosols.
- Wildfires are major source of air pollution in spring and summer. Increases in the number and severity of these fires will have implications for air quality and the Canadian carbon cycle.

AIM-North AQ-GHG Synergies

Two mission objectives:

- Better quantify emissions and separate CO_2 emissions from anthropogenic versus biospheric sources (respiration and wildfires) with the help of CO, NO_2, SIF or other supporting observations.
- Improve estimation of northern anthropogenic CO_2 and CH_4 emissions at the scale of a municipality or large industrial source.

CO and CO_2

- Rayner et al. (2014) and other work studied CO/CO_2 ratios for constraining urban anthropogenic emissions and found substantial benefits.

NO_2 and CO_2

- NO_2 might actually be more useful, with applications such as characterizing CO_2 plume shape and identifying wind direction as demonstrated in recent studies like Reuter et al. (2019) for anthropogenic emissions and wildfires.
- The impact of temporal offsets of a few minutes between NO_2 and CO_2 if they are measured by different instruments, with different scanning strategies, will be studied later in Phase 0 or Phase A.

P.J. Rayner, S.R. Utembe, S. Crowell (2014), Constraining regional greenhouse gas emissions using geostationary concentration measurements: a theoretical study, Atmos. Meas. Tech., 7, 3285–3293, 2014, www.atmos-meas-tech.net/7/3285/2014/

Reuter, M., et al.: Towards monitoring localized CO_2 emissions from space: co-located regional CO_2 and NO_2 enhancements observed by the OCO-2 and S5P satellites, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2019-15, in review, 2019.

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)
  - 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 Air Quality Species Requirements

UV-Vis Dispersive instrument spanning ~290-780 nm
~0.75 nm spectral resolution and ~0.25 nm spectral sampling

Species	Single Obs Precision (1σ)	Accuracy
O_3 (TC)	3% (G), 5% (T)	2% (G), 3% (T)
O_3 (SC)	3% (G), 5% (T)	20% (G), 30% (T)
NO_2 (TC)	3% (G), 5% (T)	10% (G), 15% (T)
NO_2 (SC)	1.0×10^{15} cm^{-2} (G), 1.5×10^{15} cm^{-2} (T)	15% (G), 20% (T)
AOD (C)	0.03 + 15% (G), 0.05 + 20% (T)	0.03 (G), 0.05 (T)
SO_2 (C) (secondary)	*1.0×10^{16} cm^{-2} (G), 1.5×10^{16} cm^{-2} (T)*	*2×10^{15} cm^{-2} (G), 3×10^{15} cm^{-2} (T)*

*(TC) = Tropospheric Column, (SC) = Stratospheric Column, (C) = Total Colum
(G) = Goal, (T) = Threshold

Other secondary species without requirements: HCHO, BrO, OClO, CHOCHO.

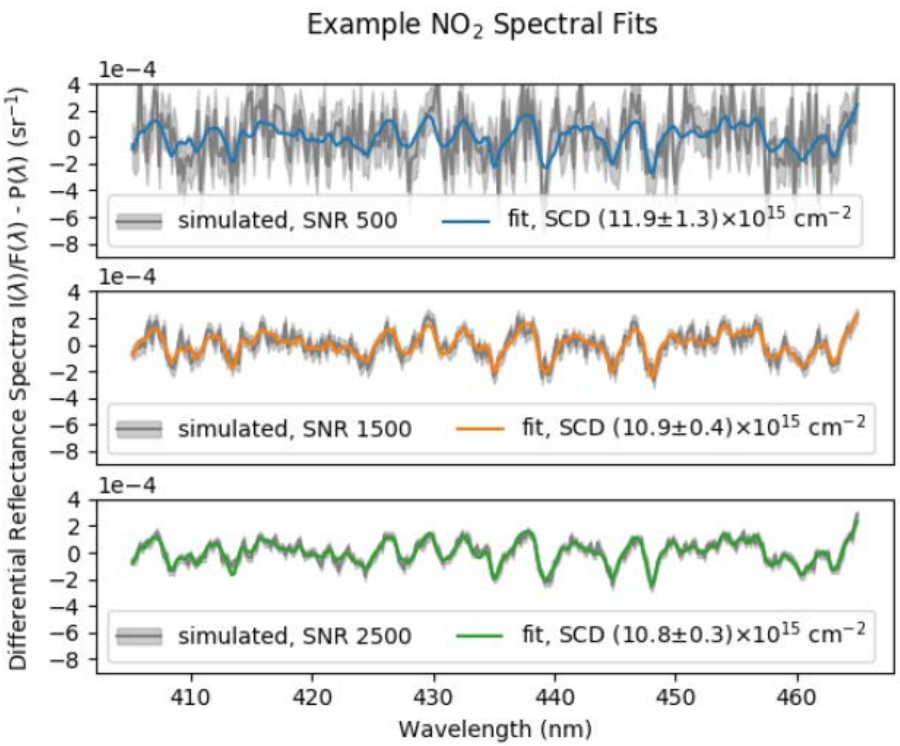
Complementary NIR-SWIR instrument for CO_2, CH_4, CO, SIF & aerosols (see Monday's AIM-North talk)

Air Quality Retrieval Studies

- U of Saskatchewan developing L1-->L2 retrievals for total column O_3 and NO_2. Together with an AIM-North UV-vis grating instrument simulator and realistic observing conditions, quantifying SNR and other requirements to determine impacts of changes in instrument design
- Expansion to additional UV-vis species is possible in the near future

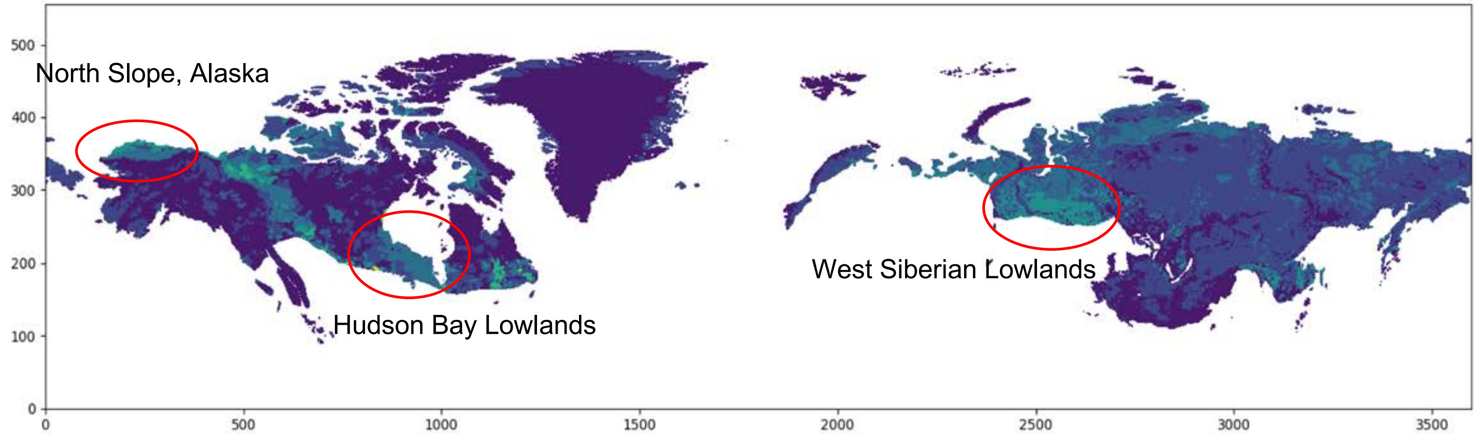
University of Saskatchewan

N. Lloyd,
D. Degenstein,
A. Bourassa



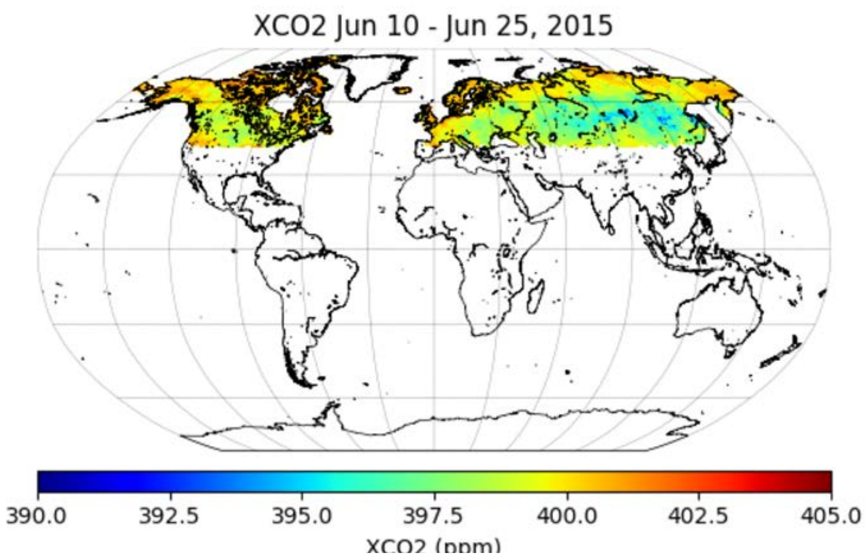
CO_2 OSSEs for AIM-North

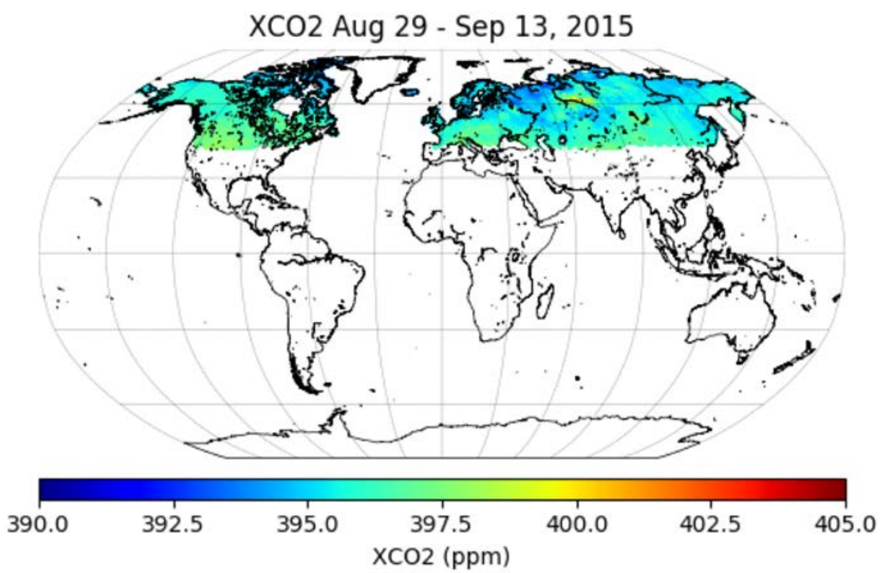
- Past Observing System Simulation Experiment assessed earlier HEO concept for constraining Arctic-Boreal CO_2 fluxes (*Nassar et al.* 2014)
- New OSSES include improved method for simulating observations: orbit, precision, bias, cloud filtering and albedo, etc. (R. Nassar, C. MacDonald)
- Nature run: Environment Canada Carbon Assimilation System (EC-CAS) simulation for 2015 at 0.45° x 0.45° (S. Polavarapu, M. Neish), driven with CarbonTracker fluxes plus extra permafrost emissions of 0.9 Pg C (R. Nassar, C. MacDonald)



These are permafrost regions that are experiencing rapid thawing (Turetsky et al., 2019).

CO_2 OSSEs for AIM-North





AIM-North Pseudo-data & OSSE

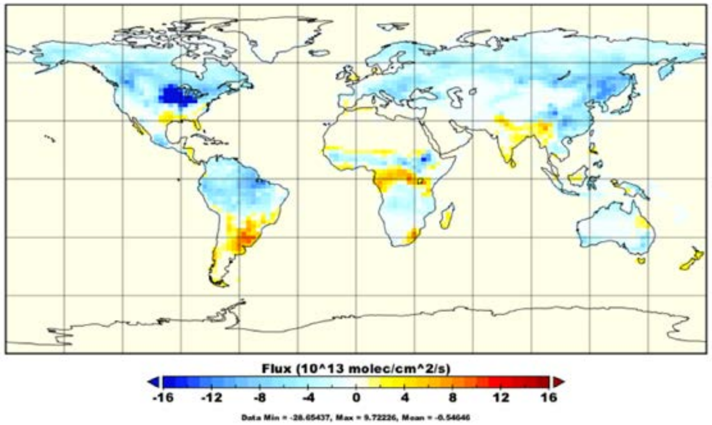
- 2 satellites in HEO.
- Molniya – 12 hour orbit with 4 apogees.
- IFTS FOV 128 x 128 pixels with 3 minute stare.
- Intelligent pointing
- Pseudo-data assimilated using the GEOS-Chem 4D-Var assimilation scheme to estimate 14-day fluxes.
- Conducted a global assimilation at 2° x 2.5° and a regional assimilation at 0.25° x 0.3125° over Canada.

Bruce Kuwahara

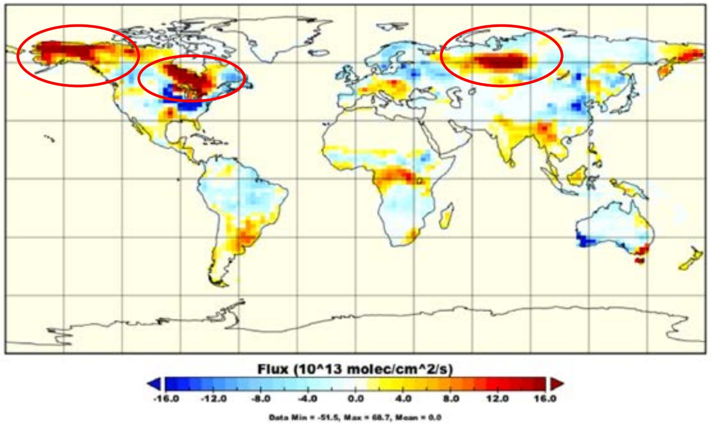
CO_2 OSSEs: Global (2°x2.5°)

- Global OSSE: assess the potential to recover CO_2 flux magnitude and seasonality for the northern terrestrial biosphere overall including permafrost emissions.

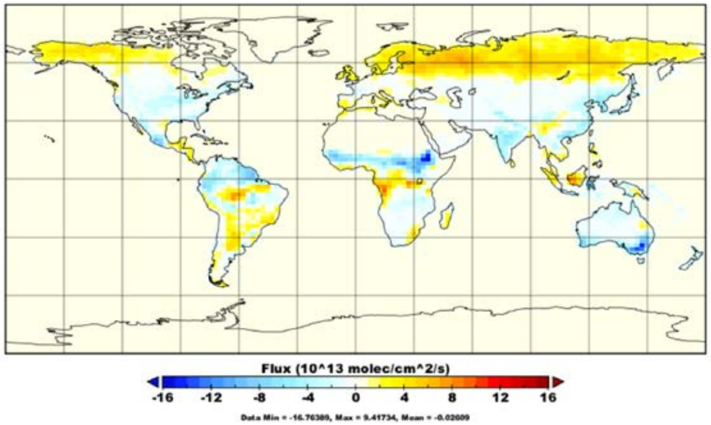
Prior terrestrial biospheric fluxes (14-28 Aug)



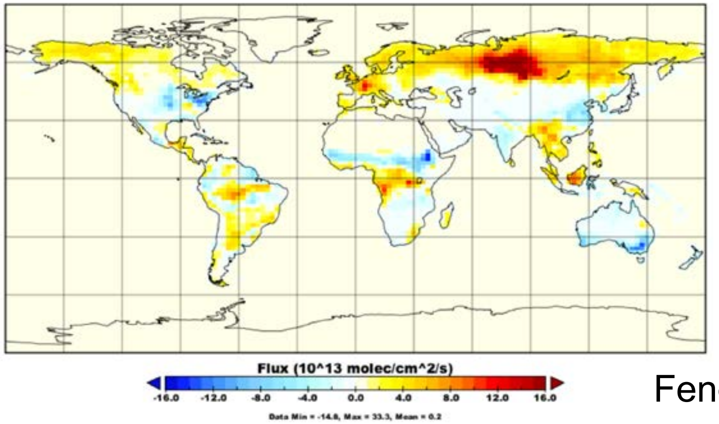
Posterior terrestrial biospheric fluxes (14-28 Aug)



Prior terrestrial biospheric fluxes (13-27 Sept)



Posterior terrestrial biospheric fluxes (13-27 Sept)

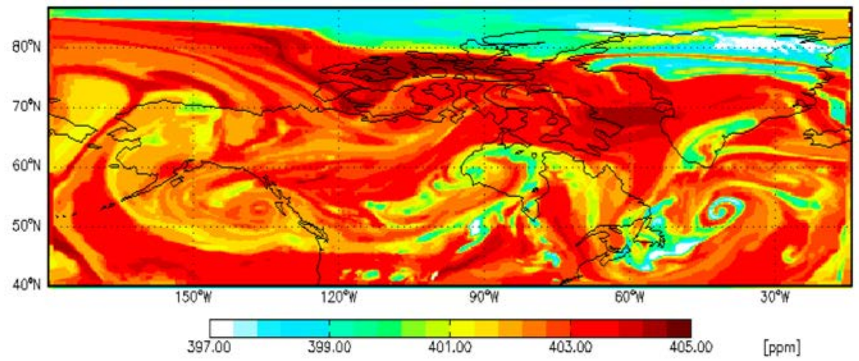


Feng Deng

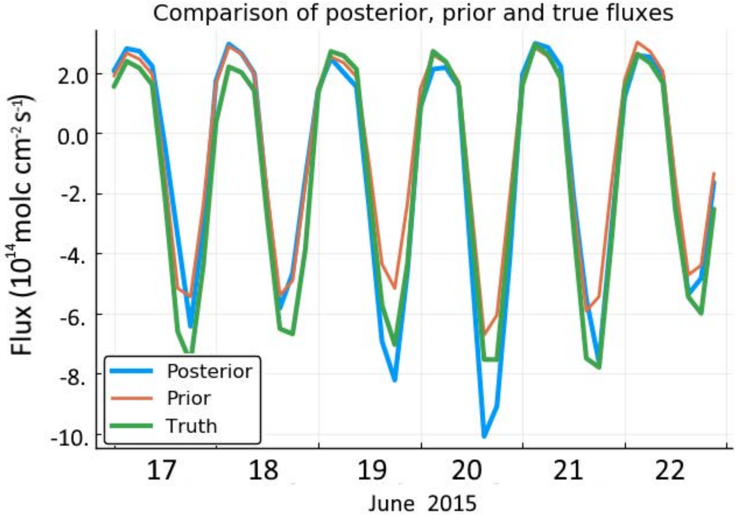
CO_2 OSSEs: Regional (0.25°x0.3125°)

Regional OSSE: assess whether the sub-daily revisit times can provide constraints on diurnal variations in the fluxes.

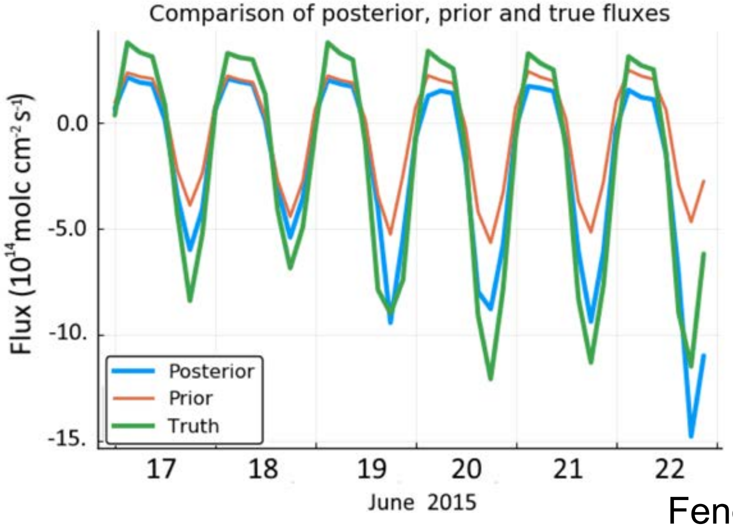
GEOS-CO_2 at 0 GMT on 15 June 2015 at 500 hPa



Fluxes at 56°N, 100°W



Fluxes at 50°N, 115°W



Feng Deng

Summary and Potential Path Forward

- AIM-North would provide quasi-geostationary observations of AQ and GHG species over northern land (~40-80°N).
- AQ-GHG synergies through CO & CO_2 and NO_2 & CO_2 observations by instruments on the same spacecraft.
- 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 km^2 to 4x4 km^2 pixels are small enough for point source or urban studies.

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

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

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Industry Team:

ABB

AIRBUS DEFENCE & SPACE

MDA