AIM-North
The Atmospheric Imaging Mission for Northern Regions

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**CEOS AC-VC Meeting, June 10, Tokyo, Japan**
• CO₂ and CH₄ 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

• Better observations would improve future climate projections, support GHG and pollutant emission reporting

• 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.

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
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.
## 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\textsubscript{4} and CO Retrievals: U. Toronto (D. Wunch, K. Strong)
- NO\textsubscript{2} and O\textsubscript{3} Retrievals: U. Saskatchewan (D. Degenstein, A. Bourassa)
- CO\textsubscript{2} Observing System Simulation Experiment: U. Toronto (D. Jones, F. Deng)

## ECCC science: CO\textsubscript{2} / SIF retrievals, orbits, intelligent pointing, point source estimation

## User Requirements Document (URD) soon to be developed by full science team

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<tr>
<th>CSA Phase Names</th>
<th>Description</th>
<th>Phase A</th>
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<tr>
<td>Phase 0 (Pre-Phase A)</td>
<td>Mission Definition</td>
<td>System Definition</td>
<td>Preliminary Design</td>
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<td>Manufacturing, Assembly, Integration, Testing, Launch, Commissioning</td>
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**AIM-North** CO₂, CH₄, CO, SIF Requirements

<table>
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<tr>
<th>Species</th>
<th>Precision (1σ)</th>
<th>Accuracy</th>
</tr>
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<tr>
<td>CO₂</td>
<td>0.25%, ~1 ppm (G), 0.75%, ~3 ppm (T)</td>
<td>0.05%, ~0.2 ppm (G), 0.15%, ~0.6 ppm (T)</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.50%, ~9 ppb (G), 1.50%, ~27 ppb (T)</td>
<td>0.1%, ~2 ppb (G), 0.3%, ~6 ppb (T)</td>
</tr>
<tr>
<td>CO</td>
<td>5% (G), 15% (T)</td>
<td>5% (G), 15% (T)</td>
</tr>
<tr>
<td>SIF</td>
<td>0.30 Wm⁻² sr⁻¹ mm⁻¹ (G), 0.90 Wm⁻² sr⁻¹ mm⁻¹ (T)</td>
<td>n/a</td>
</tr>
</tbody>
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*(G) = Goal, (T) = Threshold

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<tr>
<th>Band</th>
<th>FTS Band (nm)</th>
<th>FTS Resolution (nm)*</th>
<th>Dispersive Band (nm)</th>
<th>Dispersive Resolution (nm)</th>
<th>SNR Required (based on FTS)</th>
</tr>
</thead>
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<tr>
<td>O₂</td>
<td>758.0 - 762.3</td>
<td>~0.0174</td>
<td>757.9 - 772.0</td>
<td>0.0474</td>
<td>88 (G), 30 (T)</td>
</tr>
<tr>
<td>CO₂</td>
<td>1598 - 1618</td>
<td>~0.078</td>
<td>1591.5 - 1621.2</td>
<td>0.101</td>
<td>119 (G), 40 (T)</td>
</tr>
<tr>
<td>CO₂</td>
<td>2042 - 2079</td>
<td>~0.127</td>
<td>2045.0 - 2085.0</td>
<td>0.136</td>
<td>116 (G), 40 (T)</td>
</tr>
<tr>
<td>CO &amp; CH₄</td>
<td>2301 - 2380</td>
<td>~0.167</td>
<td>2300.6 - 2345.6</td>
<td>0.153</td>
<td>130 (G), 43 (T)</td>
</tr>
</tbody>
</table>

*Constant FTS spectral sampling of 0.25 cm⁻¹

UV-Vis dispersive instrument for O₃, NO₂, aerosol, BrO, HCHO, SO₂, SIF & more
AIM-North Greenhouse Gas Retrieval Studies

- Preliminary SNR requirements from earlier studies will be updated
- Adapting OCO-2 full physics algorithm to assess AIM-North instrument level requirements to meet CO₂, CH₄, 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 km² pixels & 20 cm aperture (≤ 150 kg) with ~60-180 second integration time meets SNR requirements (G/T), while smaller 3x3 km² 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 km² 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
\(e = 0.50, \ i = 63.435^\circ,\) apogee local noon on July 25

IFTS FOV = 128x128 pixels, ~4x4 km² (sub-satellite but changes with VZA altitude), 45 stares in 90 minutes

Animation by Bruce Kuwahara
Summary and Potential Path Forward

- AIM-North would provide quasi-geostationary observations of CO₂, CH₄, 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

- 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
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 CH₄ 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