The Atmospheric Imaging Mission for Northern Regions: AIM-North

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Overview

AIM-North (www.aim-north.ca) is a proposed satellite mission that would provide observations of unprecedented frequency, density and quality for monitoring greenhouse gases (GHGs), air quality (AQ) and vegetation in the Arctic and boreal regions using two satellites in a highly elliptical orbit (HEO) configuration. Atmospheric species and vegetation would be spectroscopically imaged over land from ~40-80°N, multiple times per day. Enhancing the mission with additional spectral bands could provide complementary data for weather, climate and AQ research and operations. Canada has studied HEO mission concepts for communications and Earth observation for about a decade and AIM-North has evolved from these earlier proposals (*Garand et al.*, 2014). AIM-North is currently under consideration by the Canadian Space Agency, but since its pan-Arctic data would be of value to other northern countries, an international partnership is one way to facilitate sharing of AIM-North's costs and benefits.

Scientific Motivation and Technical Approach

Boreal forests are an important global carbon sink, but it is unclear how climate change will alter their net carbon balance in the future. Permafrost is vulnerable to warming, but it is uncertain how much carbon could be released as CO_2 or CH_4 and this uncertainty is coupled with the offset of some CO_2 by uptake from increased Arctic vegetation density. Dense and frequent satellite observations of northern CO_2 and CH_4 from AIM-North would help to reduce these uncertainties (*Nassar et al.*, 2014). Solar Induced Fluorescence (SIF) is as an indicator of photosynthetic intensity, the start, end and intensity of the growing season, provides information on vegetation stress and relates to gross primary production (GPP). Diurnal imaging of SIF would enhance our ability to assess boreal and Arctic vegetation, including their net carbon balance at various space/time scales. Anthropogenic activity and vegetation fires at high latitudes impact air quality. Geostationary (GEO) air quality satellites are planned over the U.S., Europe and East Asia, but coverage over Canada will be limited. AIM-North could provide comparable coverage to these GEO satellites over the high latitudes. Modern weather forecasting also relies on GEO satellites up to latitudes of ~55-60°. Enhancing AIM-North to provide geostationary-like weather observations could significantly improve forecasts at northern high latitudes, with benefits extending to densely populated regions of Canada or Europe.

AIM-North's most unique feature is the use of a highly elliptical orbit (HEO). With two satellites in HEOs inclined at ~63.44°, each satellite would dwell over the Arctic for many hours, enabling quasi-continuous coverage of northern regions. The exact HEO for AIM-North is still to be determined, with multiple options and variations available (*Trichtchenko et al.* 2014; *Garand et al.* 2014, *Trishchenko et al.* 2016). AIM-North would use a dispersive ultraviolet-visible spectrometer (UVS) to measure reflected sunlight to retrieve trace gas species and aerosols for AQ research and operational forecasting (see Table 1). The UVS would span 290-780 nm with a spectral sampling of ~0.4 nm and use push-broom scanning to image northern regions with 3x3 km^2 pixels every ~60-90 minutes of daylight (Fig. 1). AIM-North would use an imaging Fourier Transform Spectrometer (IFTS) to record spectra of reflected shortwave infrared (SWIR) and near infrared (NIR) solar radiation in 4 spectral bands (~0.25 cm^{-1} sampling). The IFTS would image column CO_2, CH_4, CO and O_2 on detector arrays for the four bands in Table 1, to give 3x3 km^2 ground pixels every ~60-90 minutes of daylight. A few isolated lines for SIF retrieval would be included in the IFTS 760-nm band, while the UVS would observe SIF over a broad spectral range. Although both the UVS and IFTS interferometer have heritage in successful Low Earth Orbit (LEO) satellites, imaging from HEO would be a novel application of these technologies.

Table 1. Spectral bands, spectral sampling and target species.

	Band (nm)	Band (cm^{-1})	Spectral Sampling	Target Species
UV-vis grating	280-780	12820-35714	~0.4 nm	O_3, NO_2, BrO, HCHO, SO_2, SIF aerosols and more
NIR & SWIR IFTS	758-762	13118-13192	0.25 cm^{-1}	O_2 A band: p_{surf}, aerosol, SIF
	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}	CH_4 and CO columns
IFTS enhancement	Mid-wave IR (MWIR)		0.25-1.25 cm^{-1}	T, H_2O, O_3, CO, CO_2, CH_4, HNO_3, CH_3OH, HCOOH, PAN, HCN, NH_3, SO_2…
	Longwave IR (LWIR)		0.25-0.50 cm^{-1}	

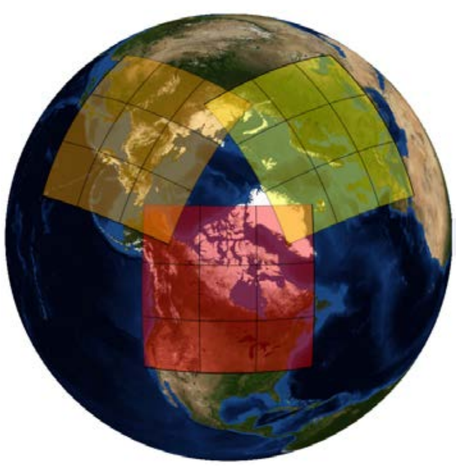

Figure 1. Potential AIM-North imaging approach. Each colored region would be scanned every ~60-90 minutes during daylight.

Adding LWIR/MWIR bands to the IFTS would enable northern measurements of temperature, water vapour and atmospheric motion vectors (for weather forecasts) along with numerous AQ species, and upper tropospheric CO_2 and CH_4 during days, nights and all seasons, but this would increase mass and cost. Other potential enhancements include a cloud imager to improve pointing strategies or a small dedicated aerosol instrument for improved AQ health forecasts.

AIM-North accuracy and precision targets are aligned with international GEO missions. Existing northern validation sites along with some new sites will be required to assess data quality and ensure that accuracy targets are met. Spatially and/or temporally averaging AIM-North data can improve precision beyond target values for some applications. Alternatively, sequentially combining multiple images can yield movie-like views of evolving atmospheric composition.

International and Societal Relevance

The Committee on Earth Observation Satellites (CEOS) Atmospheric Composition Virtual Constellation (AC-VC) group is coordinating a virtual constellation of three GEO satellites complemented by LEO satellites for air quality and a constellation for GHGs is now also beginning to form. AIM-North could observe the same species (many of which are considered Essential Climate Variables or ECVs) in a quasi-geostationary manner over the Arctic and adjacent high latitude land regions. This would extend the constellation for science, to support policy and to contribute to the intercalibration of GEO missions.

Quantification of anthropogenic CO_2 emissions from space (*Nassar et al.*, 2017) is of high interest internationally, but more extensive imaging with a shorter revisit than currently available is needed for all regions of the world. Over 60 space and related member agencies of CEOS agreed to the *New Delhi Declaration* in 2016, which identified the need for better GHG observations to support emission reduction goals under the UN's *Paris Agreement*. Countries are moving forward with LEO and GEO missions to support this goal, but cite a HEO mission to address high latitude regions, as part of the long-term vision (*Pinty et al.*, 2017).

Science Ministers of the 8 Arctic countries and 14 others plus the European Union issued a *Joint Statement on Arctic Science* in 2016 and one of the four themes was *Strengthening and Integrating Arctic Observations and Data Sharing*. Foreign Ministers of the 8 Arctic states signed *The Arctic Science Agreement* in 2017 pledging to develop and expand international scientific co-operation. Finland is chairing the Arctic Council (2017-2019) under the theme *Exploring Common Solutions*, with priorities including *Environmental Protection* and *Meteorological Cooperation*. Since AIM-North's unique northern coverage, spanning all longitudes, would generate valuable data over all Arctic countries, an international partnership, consistent with the high-level aspirations identified above, is one potential way forward to enable sharing of AIM-North's costs and benefits.

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