Progress toward greenhouse gas observations from the Arctic Observing Mission (AOM)

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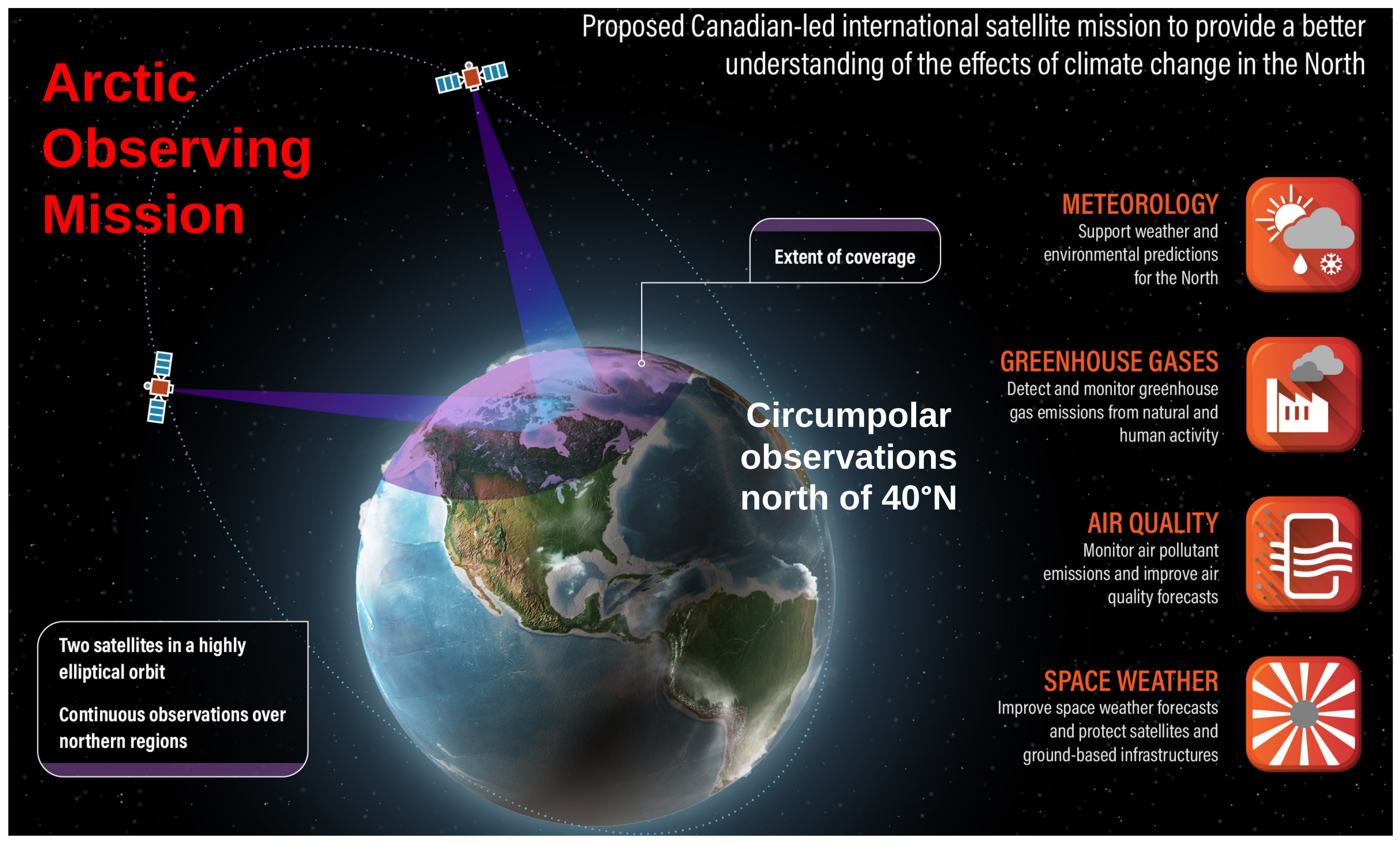
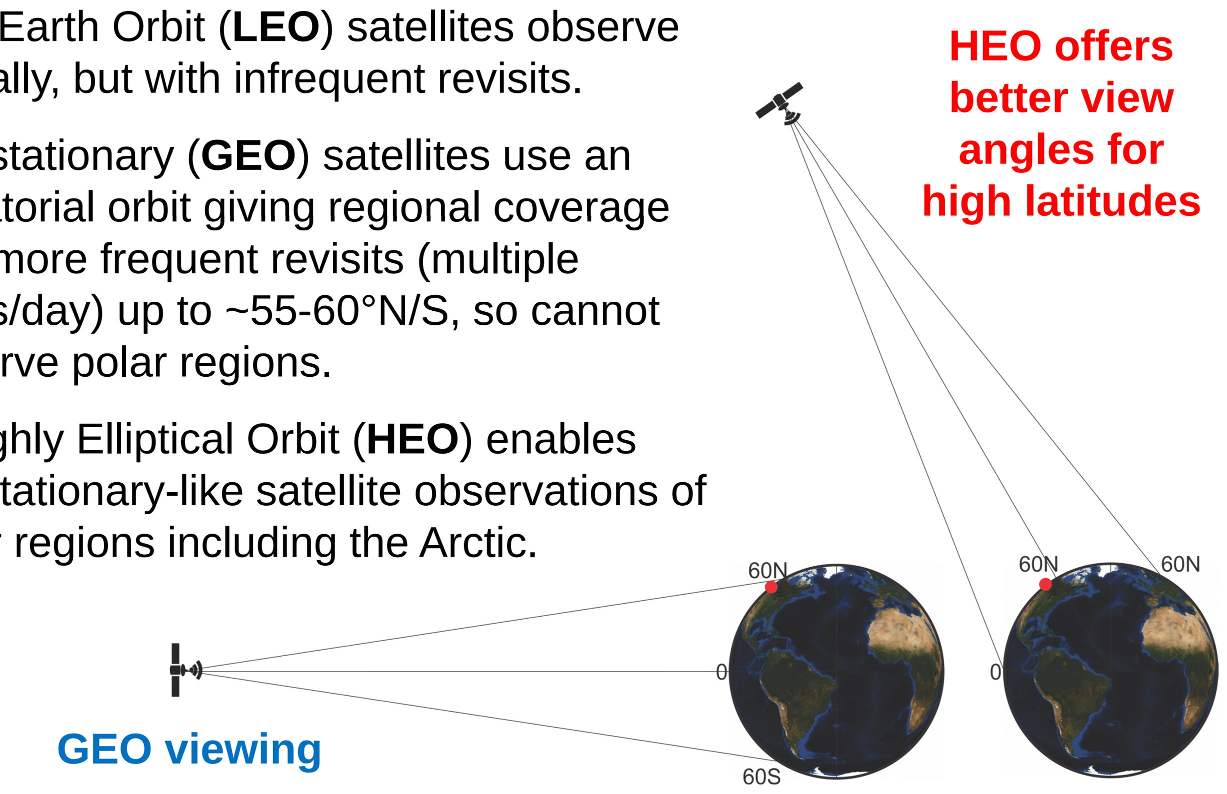
What is the Arctic Observing Mission (AOM)?

- Arctic weather and climate are changing. Better scientific observations and operational monitoring of the Arctic environment is needed.
- AOM is a proposed mission of 2 satellites in a highly elliptical orbit (HEO) for dense and frequent observations of greenhouse gases (GHGs), air quality (AQ), meteorology and space weather over the north (> 40°N).
- AOM is in a pre-formulation study (Phase 0), jointly led by the Canadian Space Agency (CSA) and Environment and Climate Change Canada (ECCC) in partnership with Natural Resources Canada (NRCan).
- Discussions occurring with some international agencies (NOAA, NASA, EUMETSAT, FMI, …) about potential partnership in AOM.



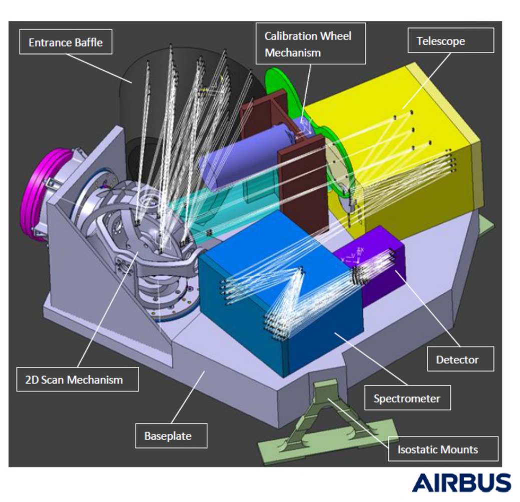
LEO, GEO and HEO

- Committee on Earth Observation Satellites (**CEOS**) constellation architecture for CO_2 and CH_4 recommends use of complementary orbits: LEO, GEO & HEO.
- Low Earth Orbit (**LEO**) satellites observe globally, but with infrequent revisits.
- Geostationary (**GEO**) satellites use an equatorial orbit giving regional coverage and more frequent revisits (multiple times/day) up to ~55-60°N/S, so cannot observe polar regions.
- A Highly Elliptical Orbit (**HEO**) enables geostationary-like satellite observations of polar regions including the Arctic.



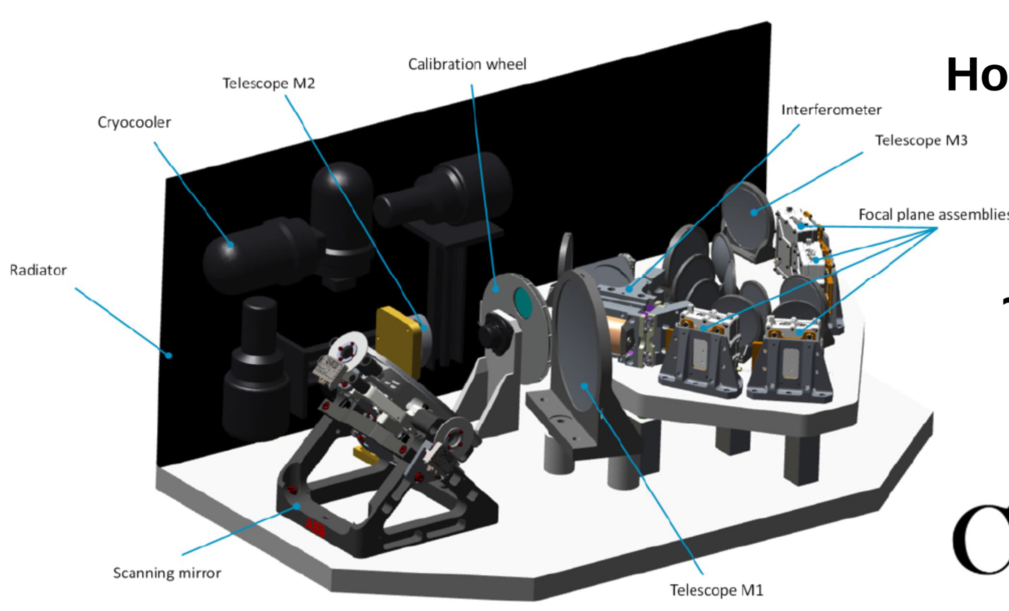
Proposed AOM Instruments

UV-Vis Air Quality Spectrometer



Focus is NO_2 for synergy with CO_2 (~100 kg)

NIR-SWIR GHG Imaging Fourier Transform Spectrometer (IFTS)



Hourly CO_2, CH_4, CO and Solar Induced Fluorescence (SIF) over cloud-free Arctic & Boreal land during daylight

~175 kg

ABB

Canada

Spectral Bands (0.30 cm^{-1} sampling)

Wavelength range (nm)	Wavenumber range (cm^{-1})
758 - 772	12,953 - 13,192
1598 - 1618	6180 - 6258
2042 - 2079	4810 - 4897
2301 - 2380	4195 - 4345

Meteorological Imager

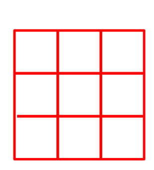
Advanced Baseline Imager (ABI), ~350 kg, 16 channels

Space Weather: in situ particle detectors, magnetometer and UV Auroral Imager

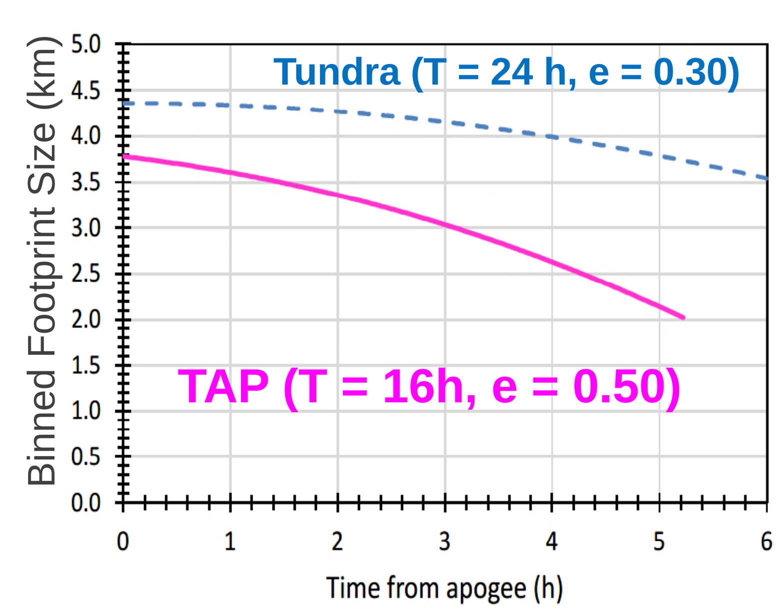
~95 kg

AOM Greenhouse Gas Observation Characteristics

- AOM IFTS will simultaneously image 2 spatial dimensions (128x128 footprints) with a "step-&-stare" approach.
- Each footprint will be based on 3x3 binning of pixels on the focal plane array, with precision requirements for the binned footprints.
- Unbinned pixel footprints are also planned to be available for applications that benefit from high spatial resolution at lower precision.
- Footprint size will vary with altitude during baseline Three Apogee (TAP) elliptical orbit, observing for 2/3 of the 16-hour period for each satellite.
- Expected retrieval precision from past studies (forest albedo, SZA=45°, low aerosol): XCO_2 0.42%, XCH_4 0.62%, XCO 8.6% but new FPA has improved SNRs.



3x3



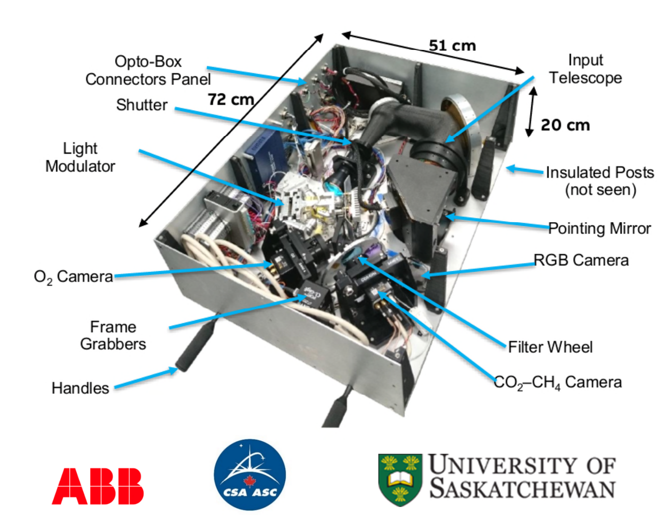
	Binned Footprint	Unbinned footprint
At 40,000 km	3.6 km	1.2 km
TAP average	~ 3.0 km	~ 1.0 km

Single Sounding Precision Requirements	
XCO_2	1 ppm (0.25%) (Goal) 3 ppm (0.75%) (Threshold)
XCH_4	9 ppb (0.5%) (Goal) 27 ppb (1.5%) (Threshold)
XCO	5% (Goal) 15% (Threshold)
Solar Induced Fluorescence (SIF)	0.50 W m^{-2} μm^{-1} sr^{-1} (Goal) 1.50 W m^{-2} μm^{-1} sr^{-1} (Threshold)

Band	Required SNR (Threshold / Goal)	Current Best Estimate
1) O_2 *A*	18 / 54	21
2) CO_2	40 / 119	91
3) CO_2	40 / 116	99
4) CO & CH_4	50 / 149	87

IFTS Demonstration Flight

- Sub-orbital demo of IFTS for CO_2 & CH_4 flew over boreal forests from a stratospheric balloon (Aug 2022).
- Nadir viewing from 37 km during 13-hour flight (day+night) gave 4 hours with adequate sunlight.
- 56x56 array of 8.5x8.5 m^2 pixels, integration t =100 s
- Validation with 2 coincident EM27/Suns (F. Vogel).

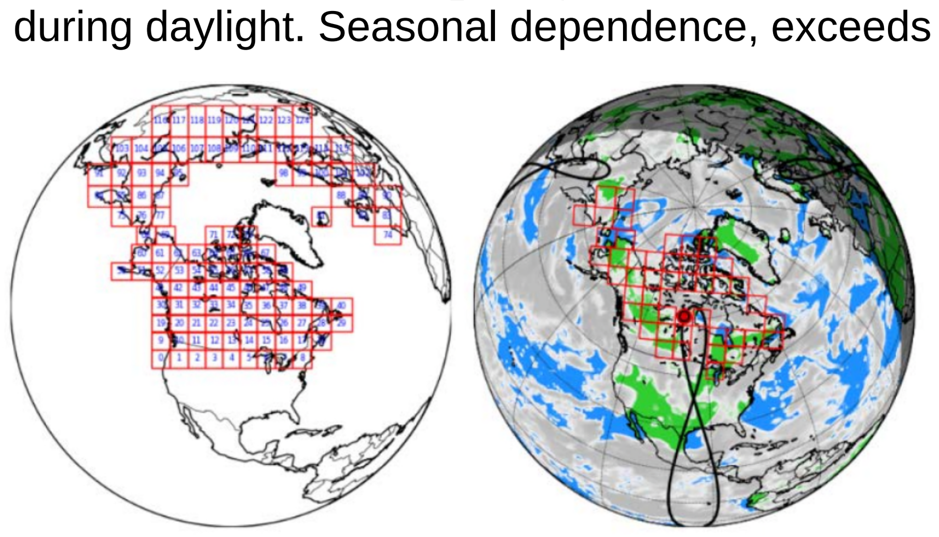


Applications and new paper on AOM's GHG *Intelligent Pointing* approach

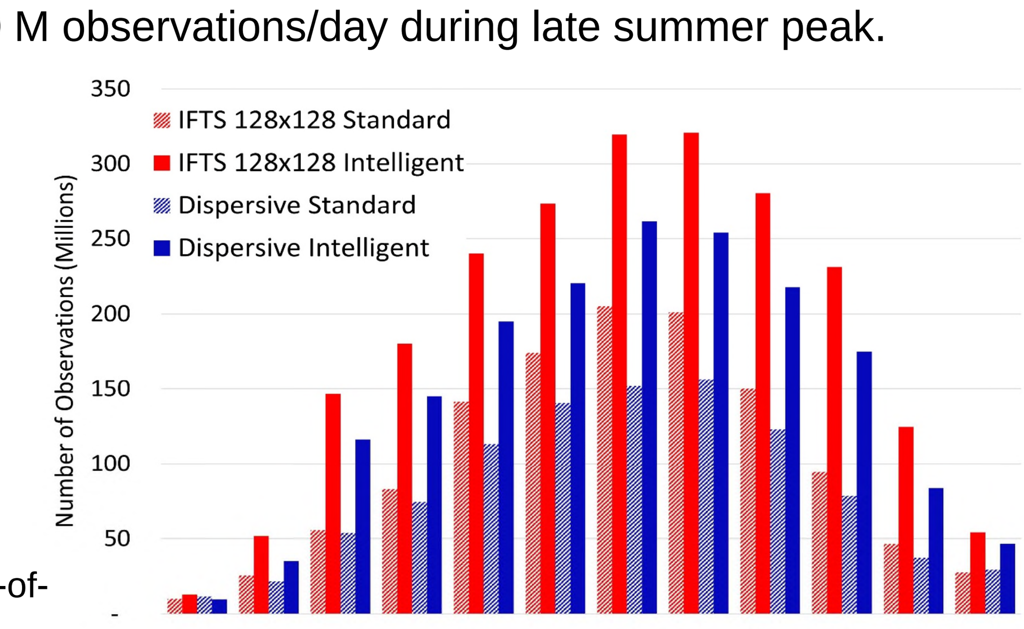
Applications: XCO_2 and XCH_4 measurements for quantifying natural and anthropogenic CO_2 and CH_4 fluxes from forests, wetlands, permafrost, landfills, urban areas, large facilities, oil sands and other resource extraction. **XCO** for wildfire and anthropogenic emissions quantification. **SIF** for info on start, end and intensity of growing season, vegetation productivity and stress.

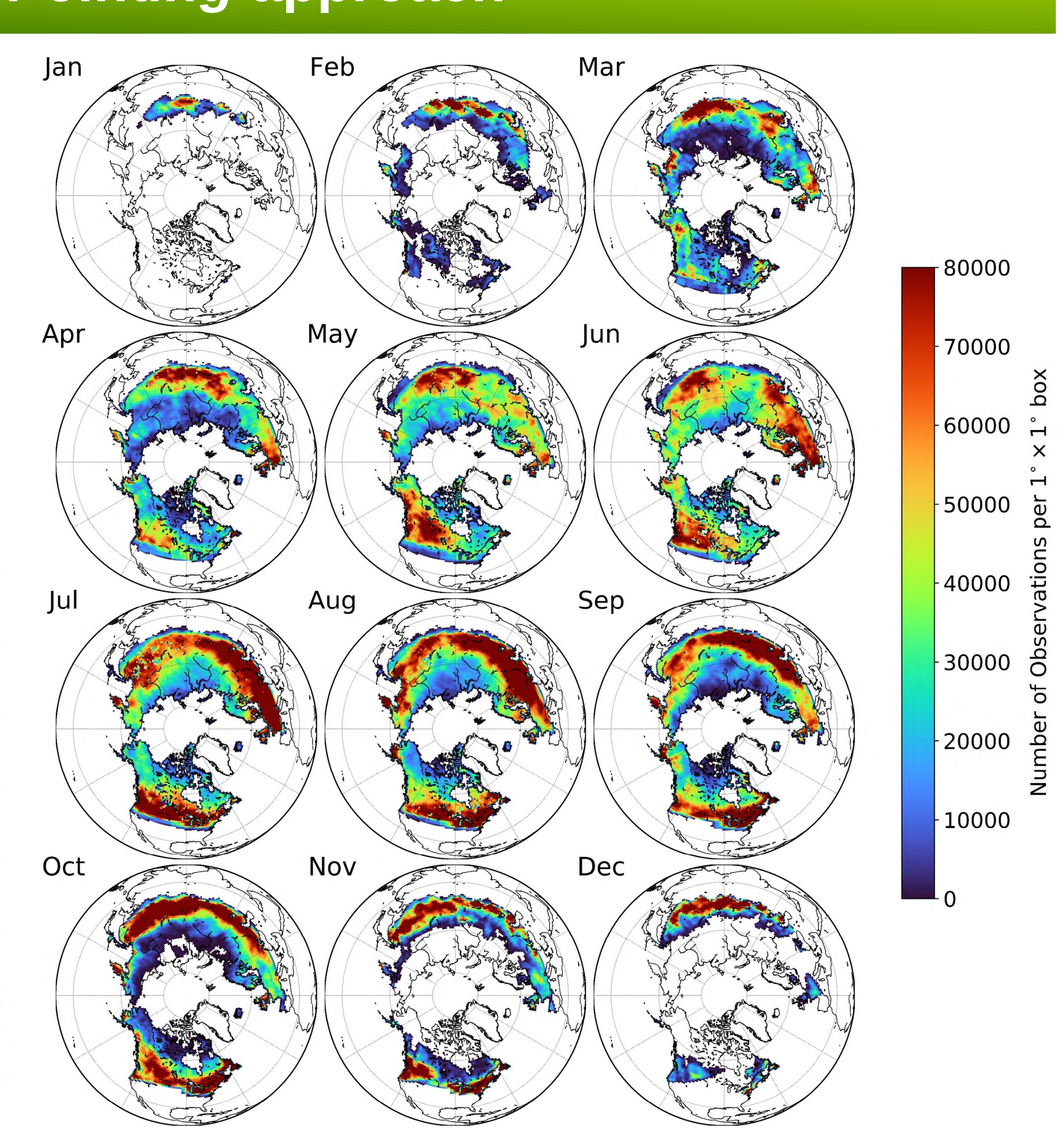
Intelligent Pointing: Cloud mask from meteorological imager enables IFTS to spend time pointing at the least cloudy areas, greatly increasing the yield of cloud-free observations. Square FOV is found to be more efficient at scanning irregular shapes (coasts, gaps in clouds) than dispersive spectrometer slit projection.

Resulting Data: Hourly CO_2, CH_4, CO and Solar Induced Fluorescence (SIF) over cloud-free Arctic & Boreal land during daylight. Seasonal dependence, exceeds 10 M observations/day during late summer peak.



Left: Boxes show possible positions for 128x128 ~4x4 km^2 pixel field-of-view (FOV) from apogee at 95°W, accounting viewing angles. **Right:** Example of AOM IFTS FOV locations in 1 hour based on clouds (NASA MERRA-2 0.5°x0.67° cloud fractions >0.1), sunlight and view angles with satellite position (red circle) and orbit tracks (black line).





R. Nassar, C.G. MacDonald, B. Kuwahara, A. Fogal, J. Issa, A. Girmenia, S. Khan, C.E. Sioris, *Intelligent pointing increases the fraction of cloud-free CO_2 and CH_4 observations from space*, Frontiers in Remote Sensing, https://doi.org/10.3389/frsen.2023.1233803

Status and Plans

- AOM Pre-formulation study (concluding in December 2024) will refine the mission concept and orbit, update the AQ and GHG instrument designs, clarify roles of potential partners and provide cost estimates for implementation of a short list of mission configurations.
- Plan for a Canadian funding request in late 2025 and decision in 2026.
- If successful, development and implementation will follow with aim of a 2034 launch and ~10 years of operations.
- Free and open GHG data for science, operational monitoring and alignment with WMO Global Greenhouse Gas Watch (G3W) enhanced operational phase.

Canada