Greenhouse Gas Observations from the proposed Arctic Observing Mission (AOM)

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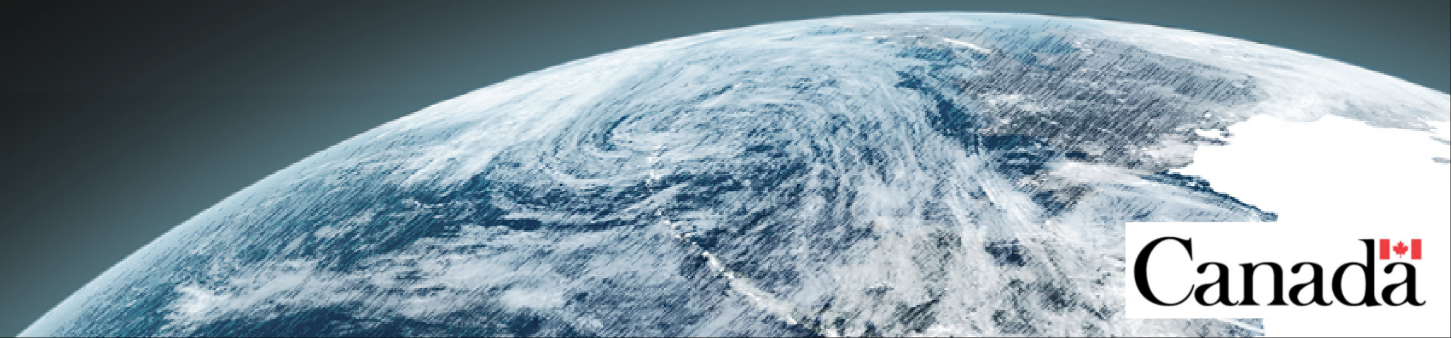
3) ABB Canada

International Workshop on Greenhouse Gas Measurements from Space
Takamatsu, Japan
2025 June 9



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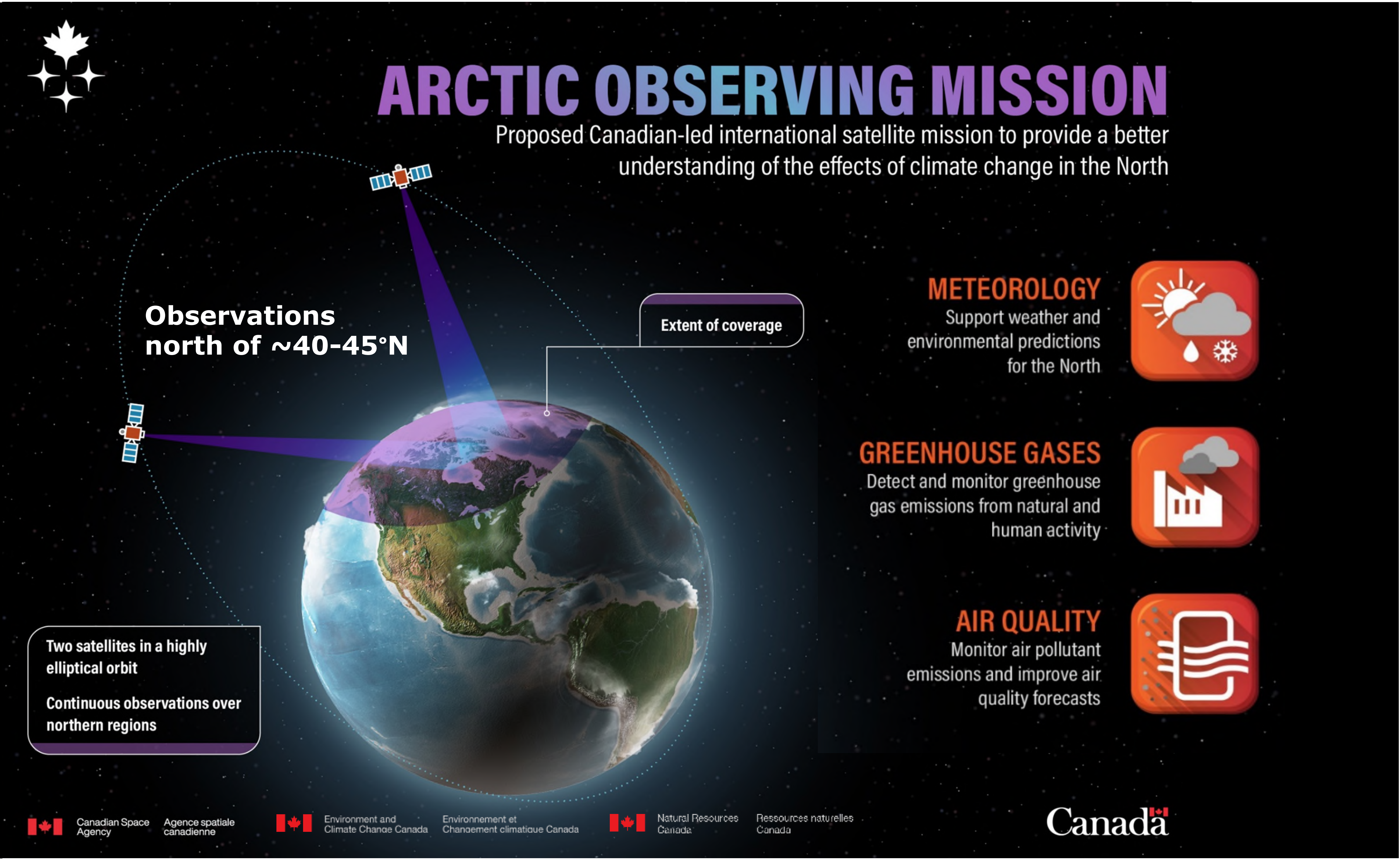
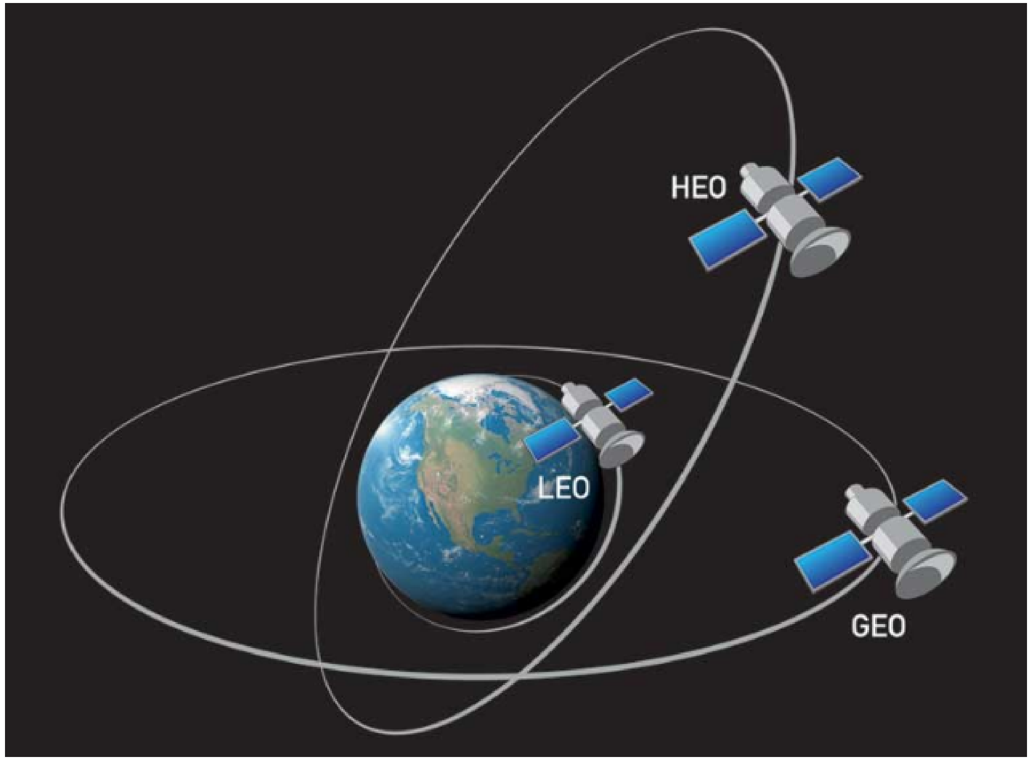

ARCTIC OBSERVING MISSION
Proposed Canadian-led international satellite mission to provide a better understanding of the effects of climate change in the North
Observations north of ~40-45°N
Extent of coverage
Two satellites in a highly elliptical orbit
Continuous observations over northern regions
METEOROLOGY
Support weather and environmental predictions for the North
GREENHOUSE GASES
Detect and monitor greenhouse gas emissions from natural and human activity
AIR QUALITY
Monitor air pollutant emissions and improve air quality forecasts
Canadian Space Agency
Agence spatiale canadienne
Environment and Climate Change Canada
Environnement et Changement climatique Canada
Natural Resources Canada
Ressources naturelles Canada
Canada

A CONSTELLATION ARCHITECTURE FOR MONITORING CARBON DIOXIDE AND METHANE FROM SPACE

[Crisp et al. (2018) CEOS White Paper]

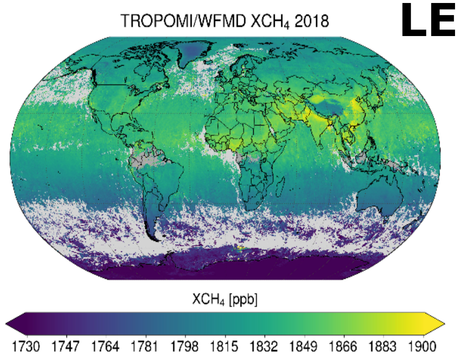
6.1 A CO_2/CH_4 constellation architecture with LEO, GEO and HEO elements

A constellation of CO_2/CH_4 satellites that fully exploits the assets of the LEO, GEO, and HEO vantage points will be needed to meet the demanding GCOS requirements for precision, accuracy, spatial and temporal resolution and coverage summarized in Table 6.1.

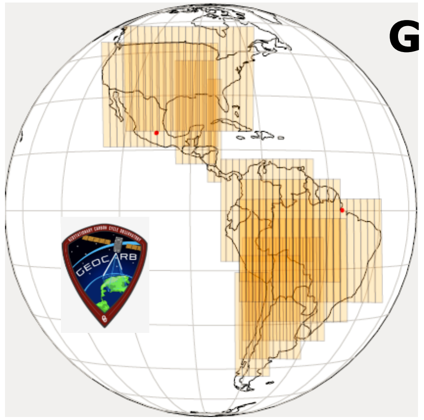


- **Low Earth Orbit (LEO):** Near polar-orbit, global sampling, but low temporal revisit rates
- **Geostationary Orbit (GEO):** Equatorial orbit, rapid revisit rates, but limited to ~60°S-60°N
- **Highly Elliptical Orbit (HEO):** Can be oriented to give quasi-geostationary observations over polar regions

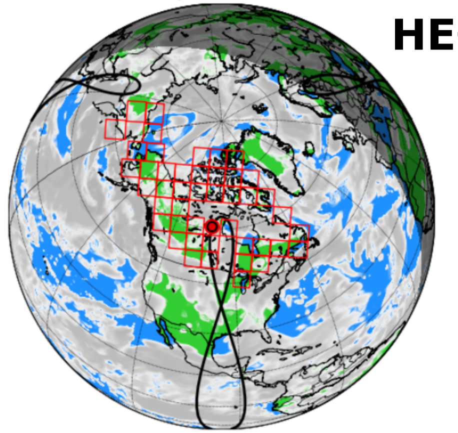
LEO



GEO



HEO



CEOS-CGMS Roadmap, Issue #2 (2024) is the latest coordination effort to implement this vision.

Intelligent Pointing increases the fraction of cloud-free CO_2 and CH_4 observations from space

2023

frontiers | Frontiers in Remote Sensing

https://doi.org/10.3389/frsen.2023.1233803

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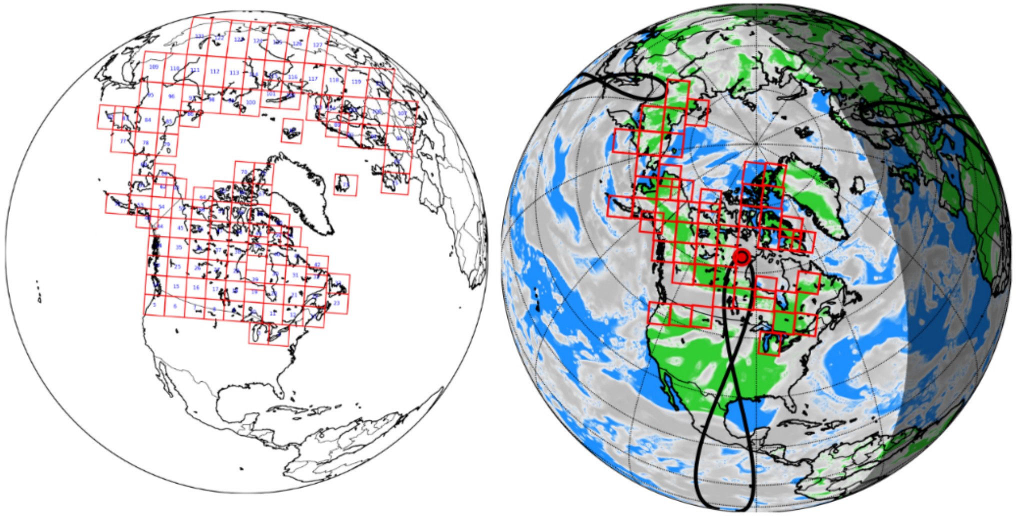
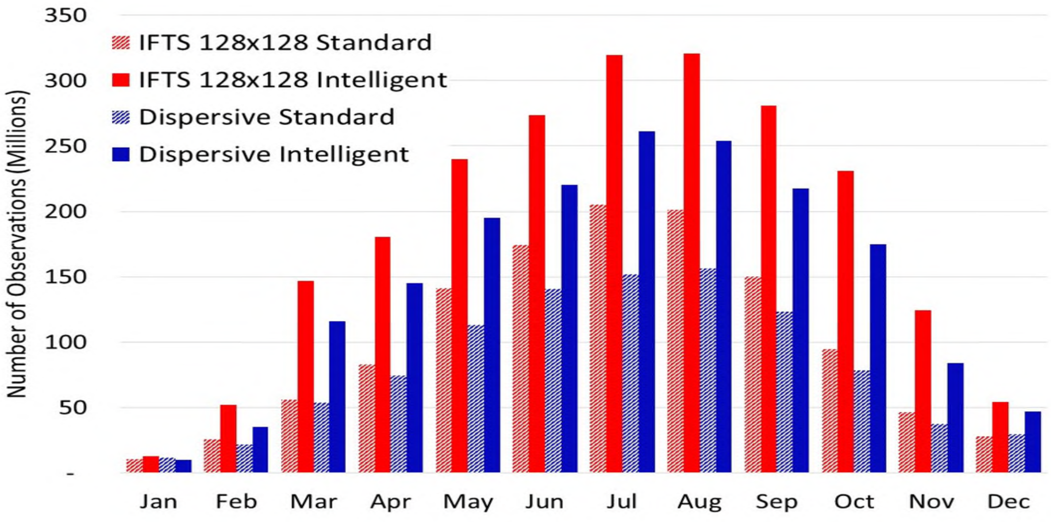
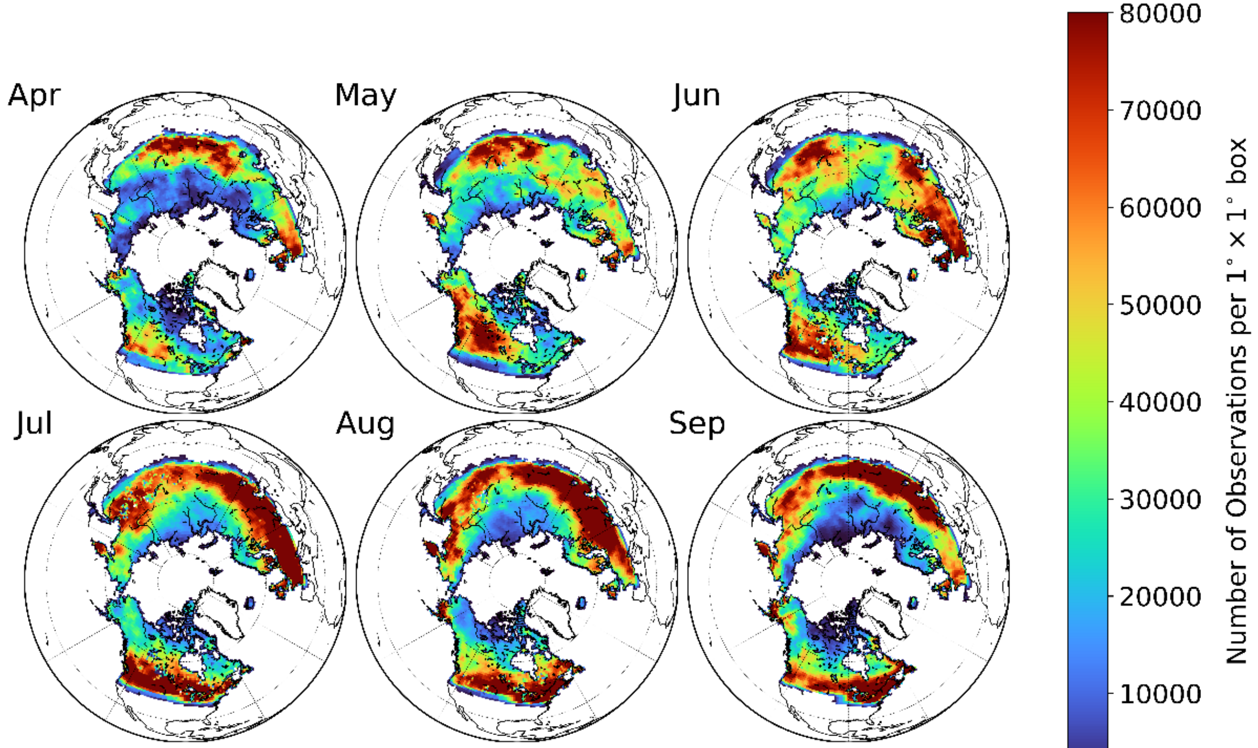






- Typically ~70% of Earth is covered by clouds
- *Intelligent Pointing* pioneered by GOSAT-2, but simulations suggest it is more effective from HEO and GEO than LEO
- With real-time cloud information to guide IFTS pointing, AOM could obtain ***hourly*** revisit during daylight for cloud-free land north of 40°N for most of the year

Canada's Strategy for Satellite Earth Observation

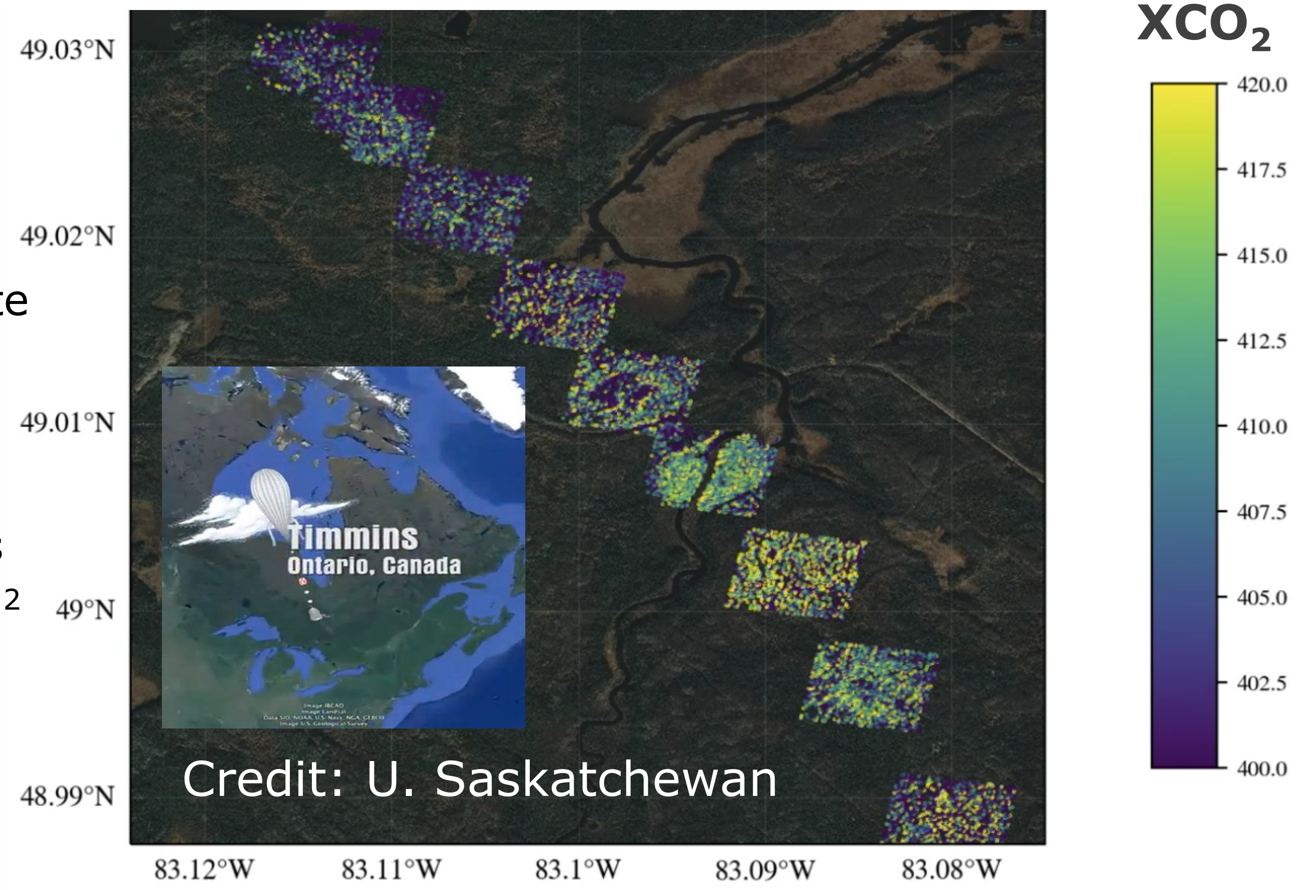
High-altitude balloon prior to launch.
Credit: ECCC-CSA

SATELLITE EO IN ACTION: Testing New Technology for Monitoring Greenhouse Gases from Space

Canadian industry leads the world in Fourier Transform Spectrometer (FTS) technology and is currently advancing it to better observe atmospheric gases from space. FTS enables satellite imaging of critical gases such as carbon dioxide (CO_2) and methane (CH_4) that are leading causes of climate change. The technology also supports the surveillance of other important greenhouse gas emissions from sources such as permafrost thaw and forest fires in a warming climate. Canada is targeting application of this new technology as part of future missions, particularly to monitor the Arctic more closely. In preparation, the GC, along with industry and academia, are working together to test prototypes using high-altitude balloons. These high-altitude balloon experiments allow scientists to test how the instrument operates in the cold, low-pressure environment of the stratosphere, a precursor to the instrument one day operating in space.

IFTS Balloon Demo Flight

- Imaging FTS CO_2 & CH_4 balloon measurements over boreal forest, launched from CSA-CNES facility (Timmins, ON) made August 22, 2022 to demonstrate IFTS technology for AOM
- Nadir viewing from 37 km altitude during 13-hour flight (daylight & night), with 4 h of adequate SZA
- 0.76 micron, filter wheel for 1.6 micron band options
- InGaAs detector observing 56x56 array of 8.5x8.5 m^2 pixels, 100 s integration time
- 2 Bruker EM27/Sun ground-based FTSs (Felix Vogel, ECCC) to validate the IFTS observations
- Demo was very informative on indirect observing factors that affect data quality



BRUKER

Qian et al (2024, SPIE) https://doi.org/10.1117/12.3030957

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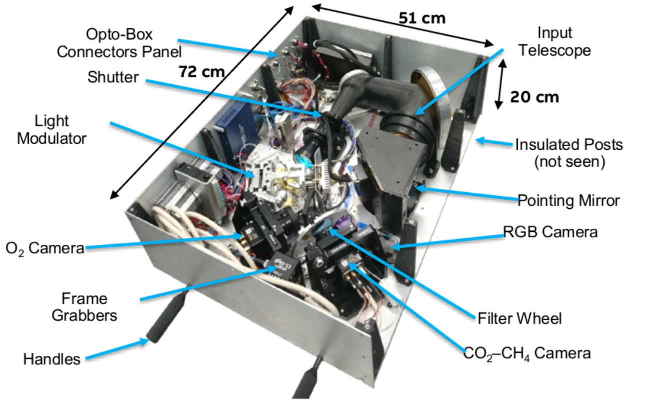
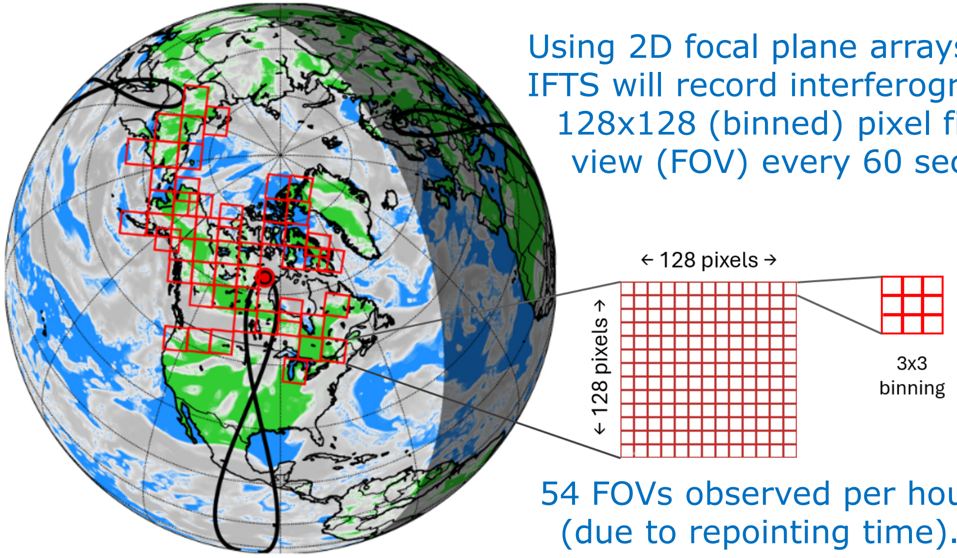
EM 27/SUN Series

For Atmospheric Measurements



AOM Greenhouse Gas Data Plan Outline

By observing mainly clear sky areas using a cloud mask from the Met imager, the IFTS can obtain hourly column-averaged CO_2, CH_4 and CO observations and solar induced fluorescence (SIF) observations over cloud-free land north of 40°N during daylight. CO_2 and CH_4 will be assimilated in a model to obtain surface fluxes.



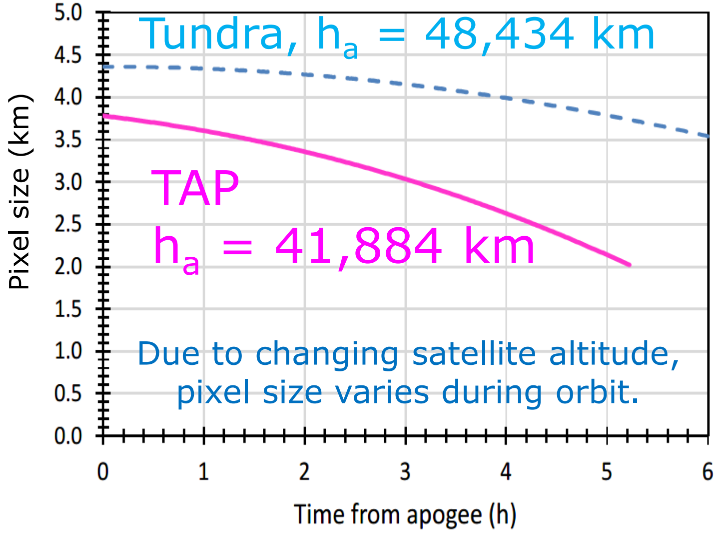
Using 2D focal plane arrays (FPAs), IFTS will record interferograms in a 128x128 (binned) pixel field-of-view (FOV) every 60 seconds.

54 FOVs observed per hour (due to repointing time).

Each binned pixel is made up of 9 'unbinned' pixels, which can potentially be available for applications that favor spatial resolution over precision (if pointing stability goal can be achieved and increased data rate can be accommodated).

	Binned Pixel	Unbinned Pixel
At 40,000 km	3.6 km	1.2 km
TAP orbit average	~ 3.0 km	~ 1.0 km

*Only binned pixels meet threshold precision & accuracy



Level 0

Interferograms, later transformed to spectra

Level 1

Baseline spectral sampling interval 0.30 cm^{-1}

Band	Wavelength (μm)	Wavenumber (cm^{-1})	SNR Goal & Threshold	Expected SNR
1) O_2 A	0.758 – 0.772	12953–13192	54 / 18	20
2) CO_2 – 1	1.598 – 1.618	6180–6258	119 / 40	91
3) CO_2 – 2	2.042 – 2.079	4810–4897	116 / 40	99
4) CH_4, CO	2.301 – 2.380	4195–4345	140 / 50	87

Level 2

Expected precision (1σ) for binned pixel	
XCO_2	~2 ppm (~0.5%)
XCH_4	~18 ppb (~1.0%)
XCO	~ 5 %
SIF	~1.5 $Wm^{-2}\ sr^{-1}\ \mu m^{-1}$

Level 3

Hourly 3D CO_2 and CH_4 fields (1°x1°)

Level 4

Monthly CO_2 and CH_4 surface fluxes (1°x1°)

L3/L4 latency will meet requirements of G3W

IFTS+:

Adding LWIR and MWIR bands could yield additional GHG and related data products

Adding a 5th IFTS band

- Baseline AOM IFTS has 4 NIR-SWIR bands.

- Conducted an industry study on adding a LWIR band ~7.4-14.7 μm (~680-1350 cm^{-1}), similar to LEO sounders (e.g. IASI, CrIS) & GEO of 2030s (GXS, MTG-IRS, GIIRS, Himawari Sounder).

- Gives temperature, water vapor, O_3, NH_3, SO_2, HNO_3, isoprene, mid-tropospheric CO_2, and N_2O and mid-tropospheric CH_4 with widest version of band.

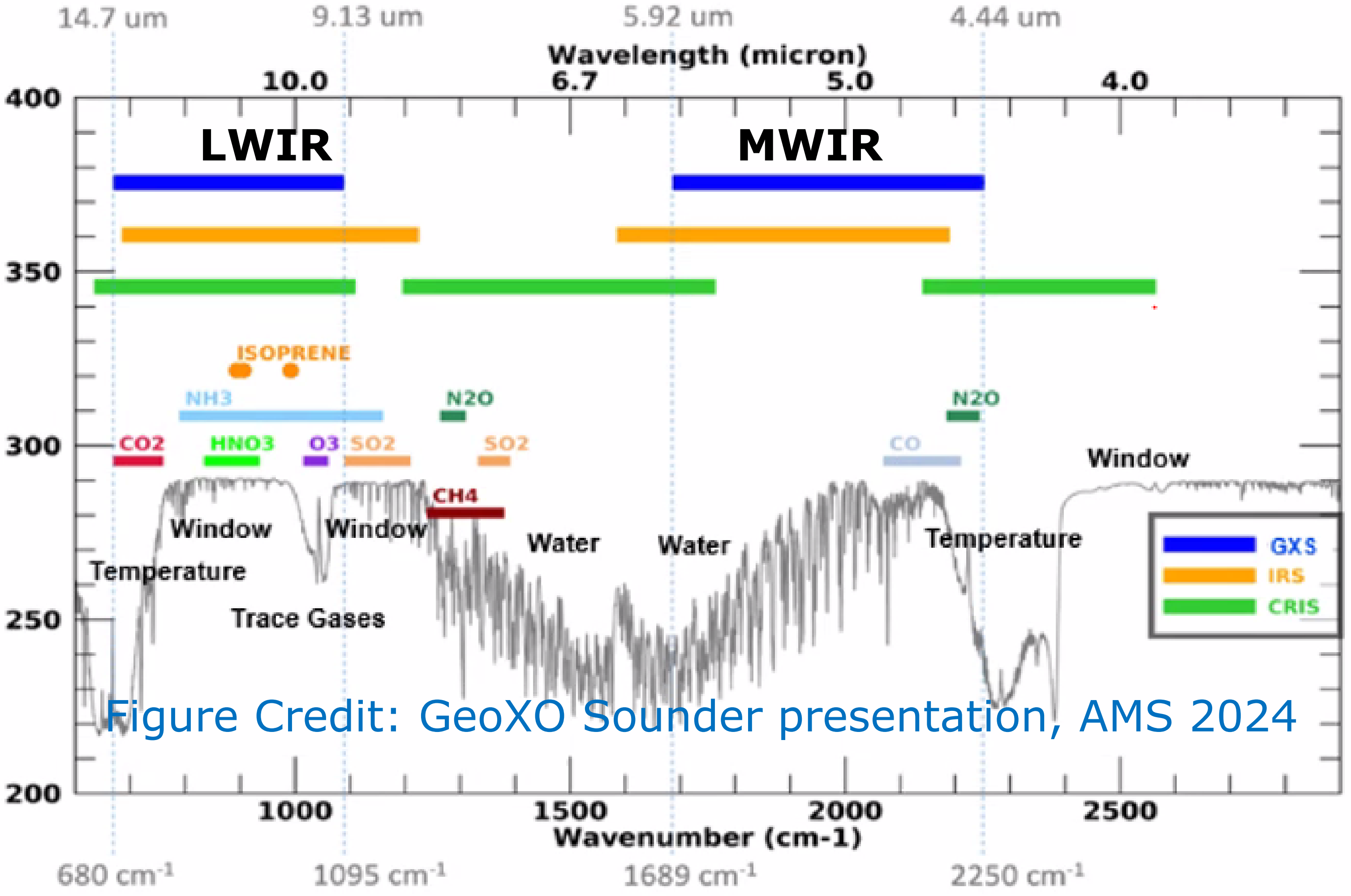
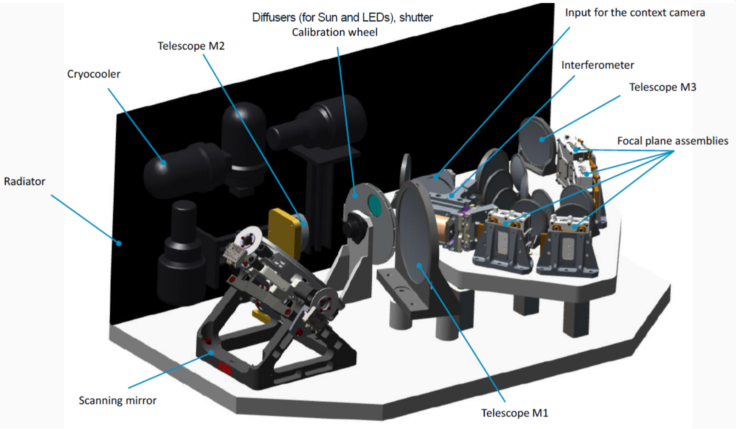


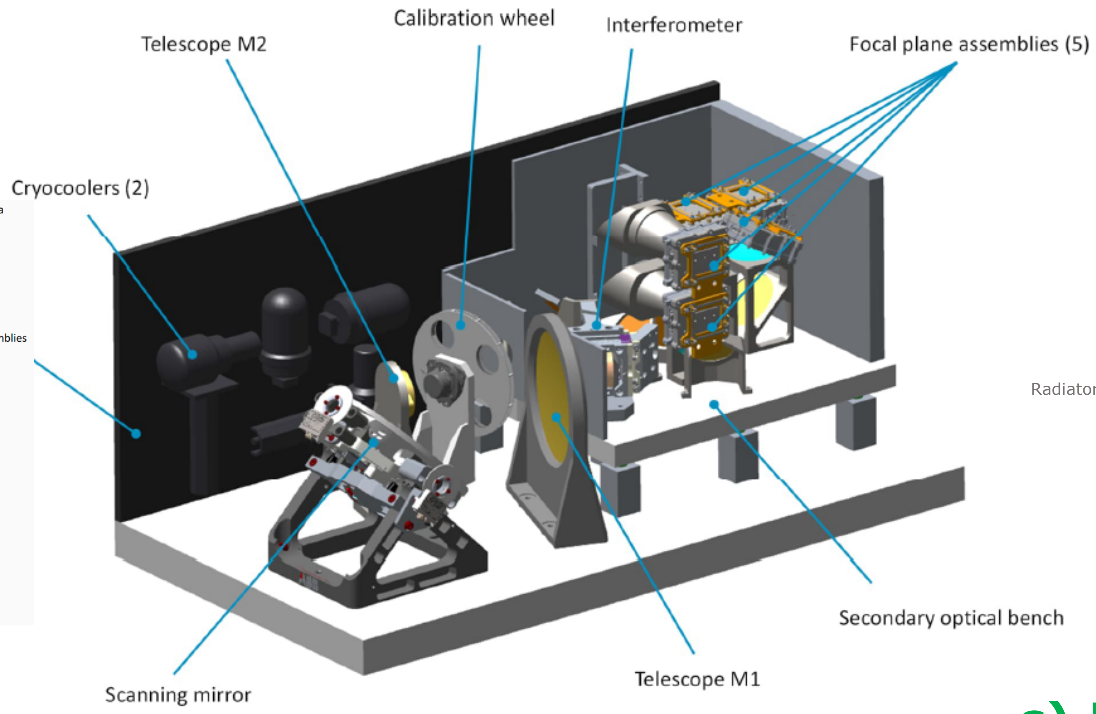
Figure Credit: GeoXO Sounder presentation, AMS 2024

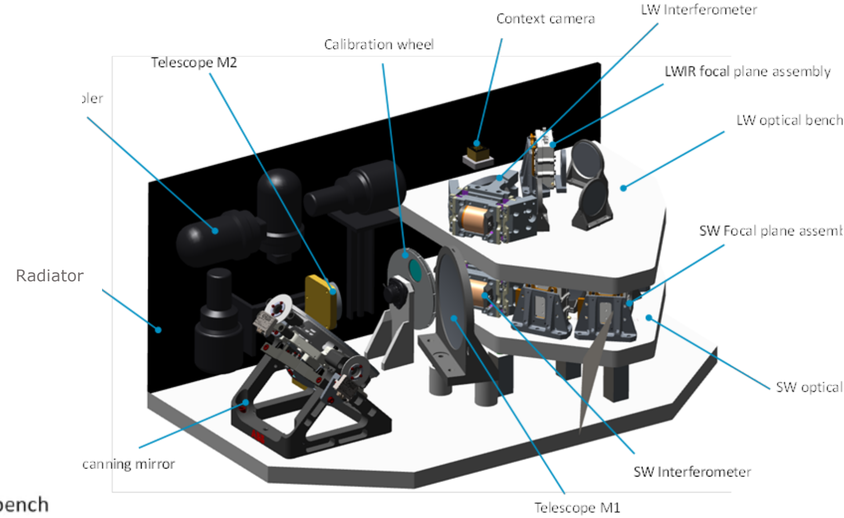
- Unlike XCO_2 and XCH_4, CO_2 and CH_4 profiles with mid-tropospheric sensitivity could be observed over land/water, day/night and summer/winter.

AOM IFTS Configurations

ABB







a) 4-band IFTS: 176 kg

4 FPAs in a single plane. Beamsplitter selected for NIR-SWIR and SNRs meet requirements.

b) 5-band single-interferometer IFTS: 371 kg

5th FPA is out of plane. 3D arrangement requires more rigidity beyond optical bench. One interferometer with an uncoated beamsplitter results in lost efficiency over wide spectral range (NIR-SWIR-LWIR). Maintain SNR by compensating with larger fore optics, but longer focal length means larger overall volume and casing.

c) 5-band dual-interferometer IFTS: 225 kg

Dual interferometer design adds <50 kg, no added volume. Each beamsplitter is optimized for its spectral region so SNR for NIR-SWIR is maintained. Interferometers can operate at different spectral sampling/resolution. Spacious 2nd level has room for possible 6th band (MWIR) for further benefits.

AOM Timeline and Next Steps

2022-2025 (Pre-formulation Studies – Phase 0)

- Completed IFTS sub-orbital demo (stratospheric balloon flight), NOAA-funded meteorological imager GEO to HEO adaptation study, a socio-economic benefits study (EuroConsult), published intelligent pointing paper and balloon IFTS proceedings, user consultation workshops, ….
- **AOM Mission Design Contract was completed March 2025**
- Outstanding technology study to acquire and test a large-format HgCdTe focal plane array for IFTS
- Planning ground segment: data reception, processing and applications plan
- Securing letters of support from partners: NOAA, EUMETSAT and others
- Preparing a funding request with hope for a possible decision in 2026

If successful …

2027-2037 (Phases A-D)

- Detailed design, build, launch and on-orbit commissioning

2037-2047 (Phase E)

- AOM operations (10-year mission)

Canada