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Canada

AIM-North

The Atmospheric Imaging Mission for Northern regions

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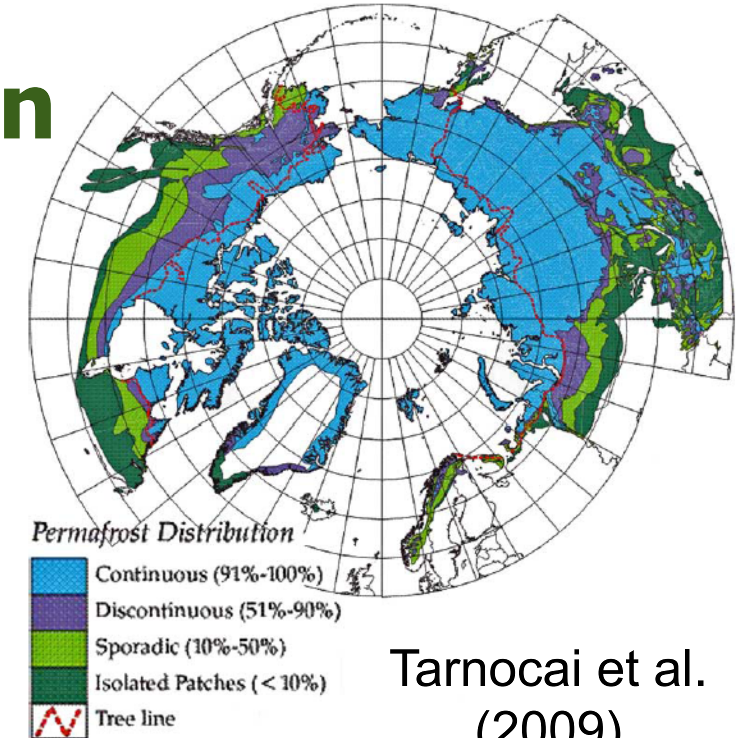
Frederic Grandmont, Louis Moreau, Johanna Tamminen, Charles Miller, William Simpson

CEOS AC-VC, 2018 May 4

What is *AIM-North* ?

- AIM-North is a proposed mission under consideration by the Canadian Space Agency (CSA)
- It could provide observations of unprecedented frequency, density and quality for monitoring greenhouse gases (GHGs), air quality (AQ) and vegetation in northern land regions (~40-80°N) using a constellation of 2 satellites in a highly elliptical orbit (HEO) configuration
- Potential enhancements to AIM-North could provide complementary observations for weather, climate and AQ research and operations
- AIM-North is led by ECCC with involvement other government departments, Canadian industry, and a team of Canadian and international scientists

Boreal and Arctic Carbon



Tarnocai et al. (2009)

Boreal Forests

- Longer growing season and increased disturbances may enhance or reduce net CO_2 flux

UNEP

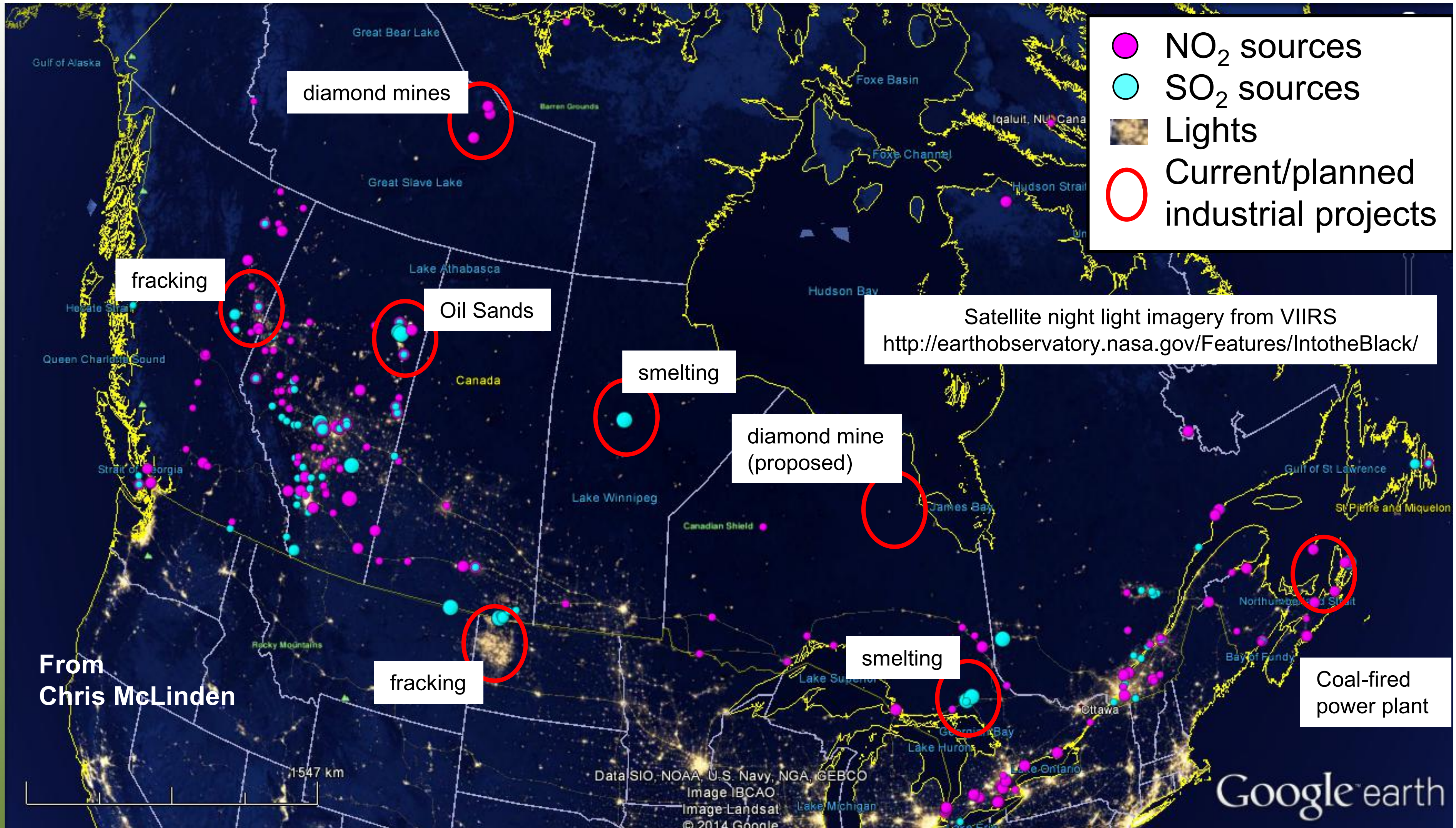
Boreal Forest Extent (2009)
UNEP/GRID-Arendal Maps and Graphics Library

Permafrost

- 1672 PgC, twice atm mass with potential for release of some fraction as CO_2, CH_4
- Wide range of estimates for emissions from thaw 9-114 PgC by 2100 (Schneider von Deimling et al. 2012)
- Uncertainty is coupled with offset of CO_2 emissions by ‘greening’ of the Arctic

Satellite observations of CO_2 and CH_4 would help to reduce these uncertainties

Anthropogenic Activity North of ~40°N



Improved observations of air quality (AQ) species in the North can improve AQ forecasting, which can impact the health of Canadians

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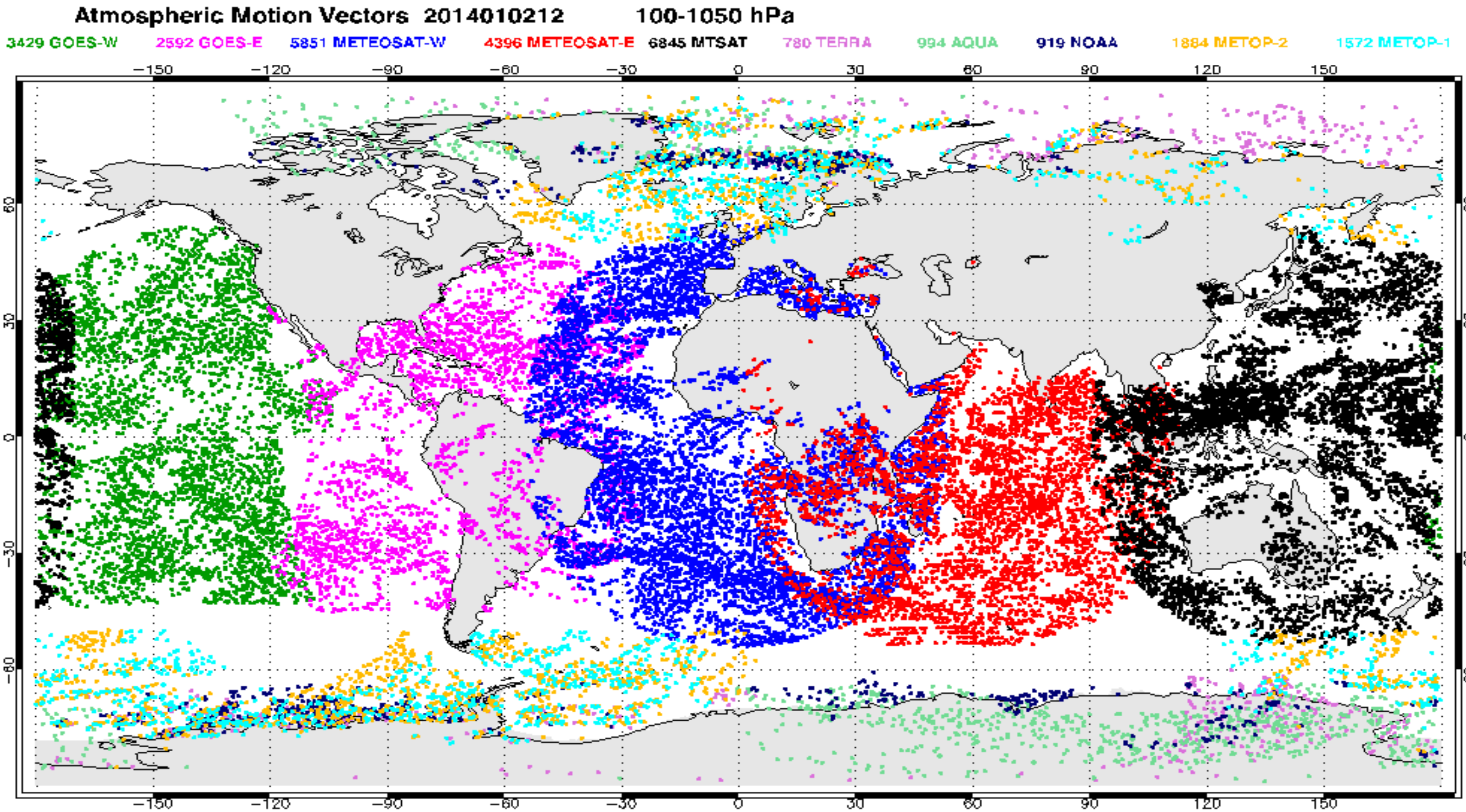
Weather Forecasting in the North

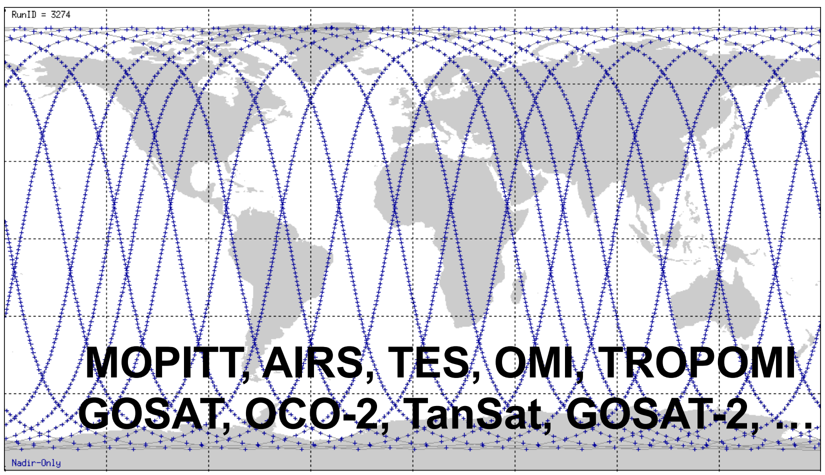


Atmospheric Motion Vectors (AMVs) available for assimilation at the Canadian Meteorological Center (CMC) on January 2, 2014, for the period 9-15 UTC, after thinning and quality control. The 10 data sources (5 GEO and 5 LEO) are identified by a color code.

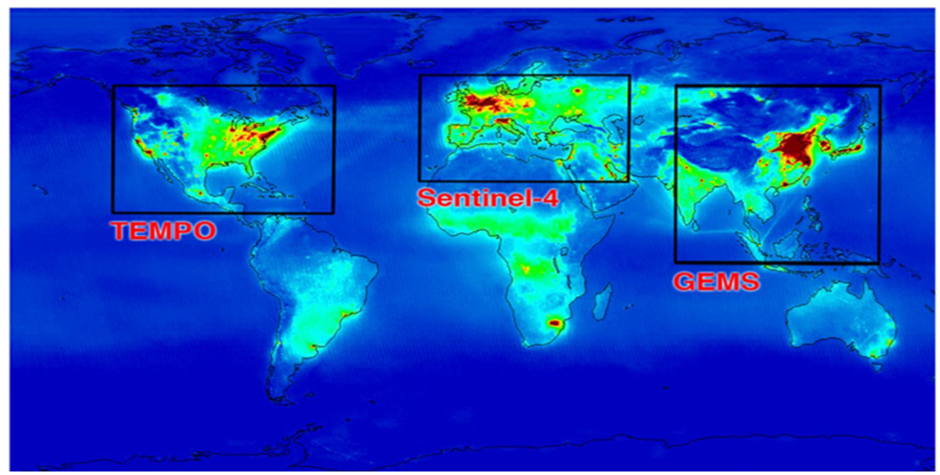
Louis Garand et al. (2014), Physics in Canada

Common Satellite Orbits and Coverage

- **Low Earth Orbit (LEO)**
- Below ~1000 km altitude
- Near-polar plane
- Can give global sampling, but each satellite has a revisit time of days to weeks



- **Geostationary Orbit (GEO)**
- ~35,800 km altitude
- Near-equatorial plane
- Synchronized with Earth rotation allows observations multiple times per day over selected area (<60°N/S)



Air Quality moving toward LEO + GEO (like meteorology), GHGs next
Neither LEO or GEO can give continuous observations over the Arctic

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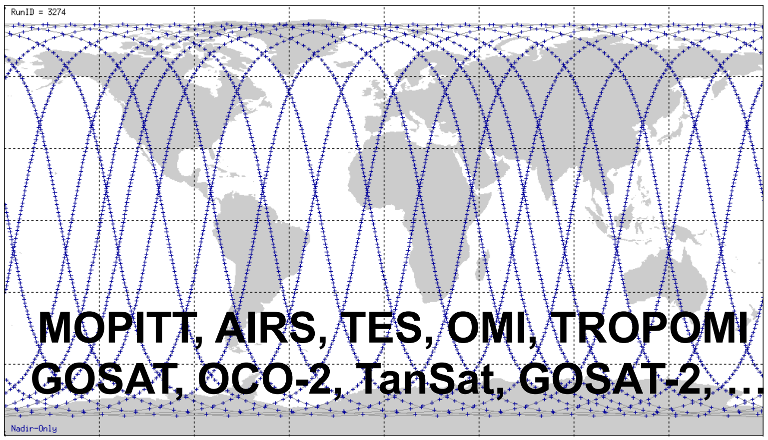

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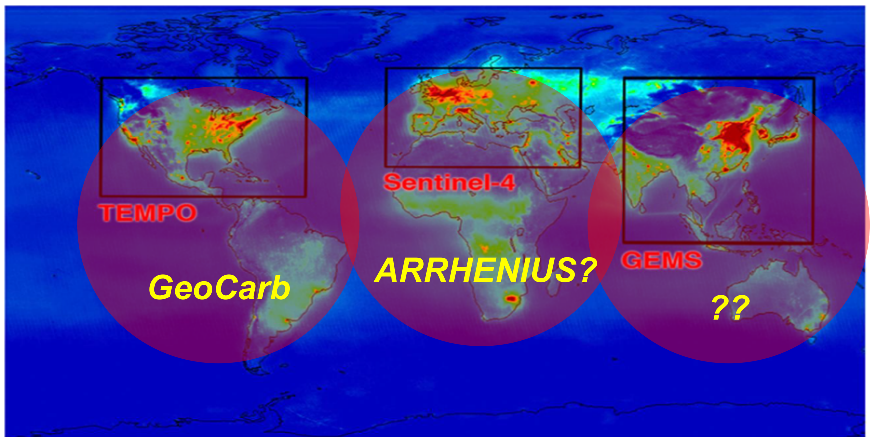

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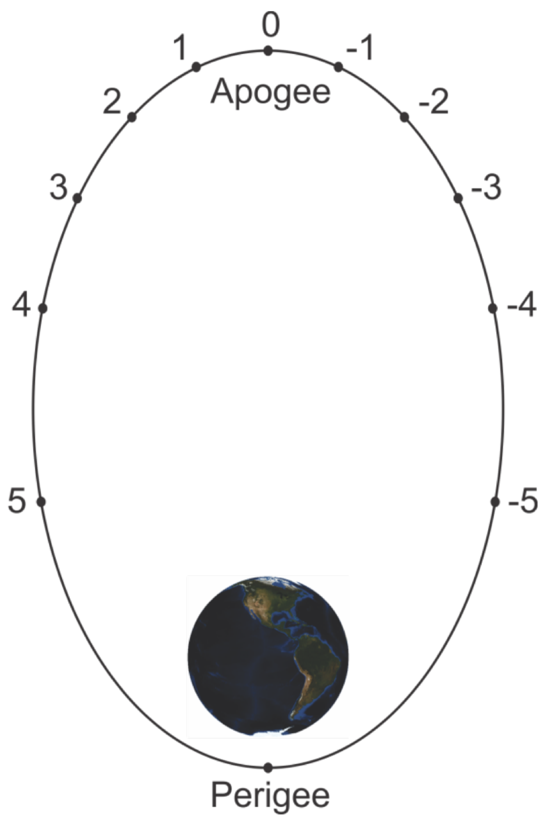
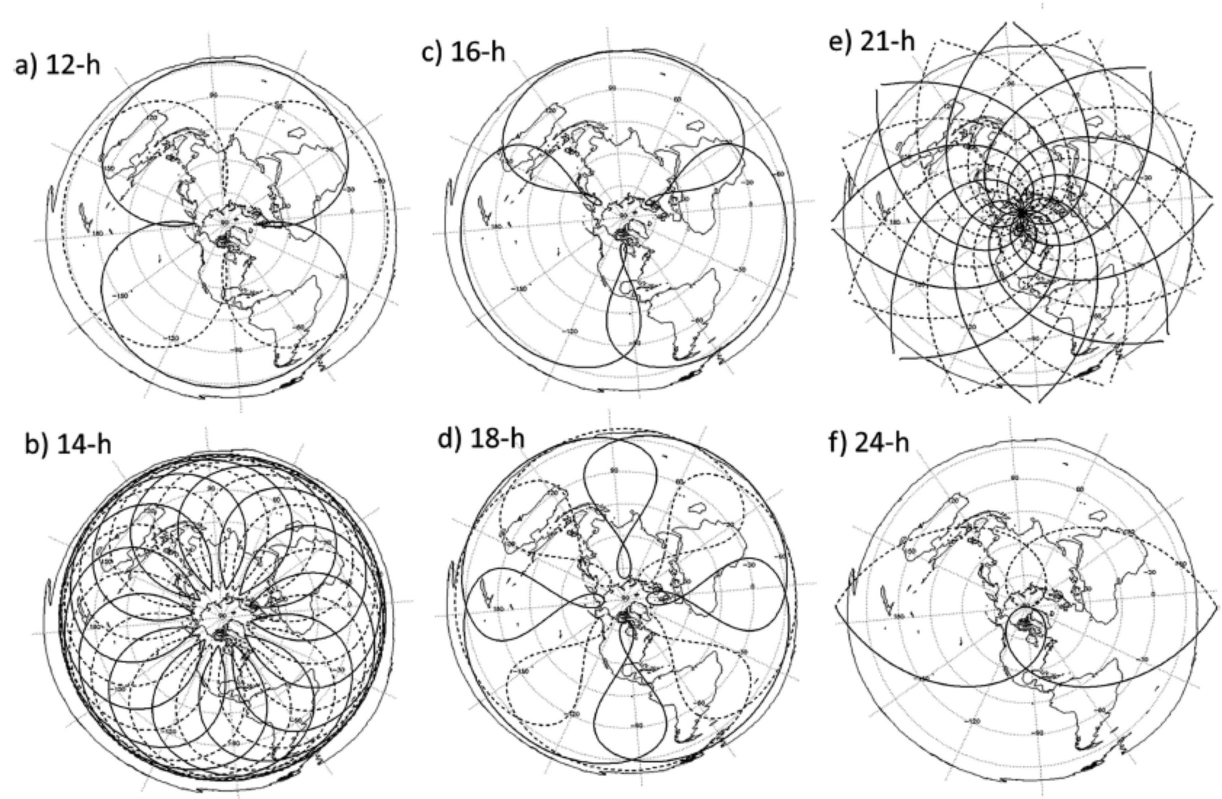
Highly Elliptical Orbit (HEO) Possibilities

Can vary orbital period, apogee altitude (~40,000-48,500 km), perigee altitude, inclination, etc.





Trishchenko and Garand (2011), *J. Atm. Ocean Tech., 28, 977-992.*
Trishchenko, Garand, Trichtchenko (2011)*, J. Atm. Ocean Tech., 28, 1407-1422.*
Trichtchenko, Nikitina, Trishchenko, Garand (2014), *Adv. Space. Res. 54, 2398-2414.*
Garand, Trishchenko, Trichtchenko, Nassar (2014), *Physics in Canada*, 70, 4, 247-254.
Trishchenko, Garand, Trichtchenko, Nikitina (2016), *BAMS*, 19-24.

Background and History

- Polar Communications and Weather (**PCW**) was a HEO concept to expand Arctic communications capabilities (DND) and provide Arctic meteorological observations (led by Louis Garand of ECCC)
- CSA considered additional instruments under the Polar Highly Elliptical Orbit Science (**PHEOS**) program as enhancements to PCW
- 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 ~50-85 kg
- CSA continues to fund IFTS technology development with plans for sub-orbital testing on a stratospheric balloon in 2019/2020

YORK UNIVERSITÉ UNIVERSITY · ABB · COM DEV INTERNATIONAL · CSA ASC

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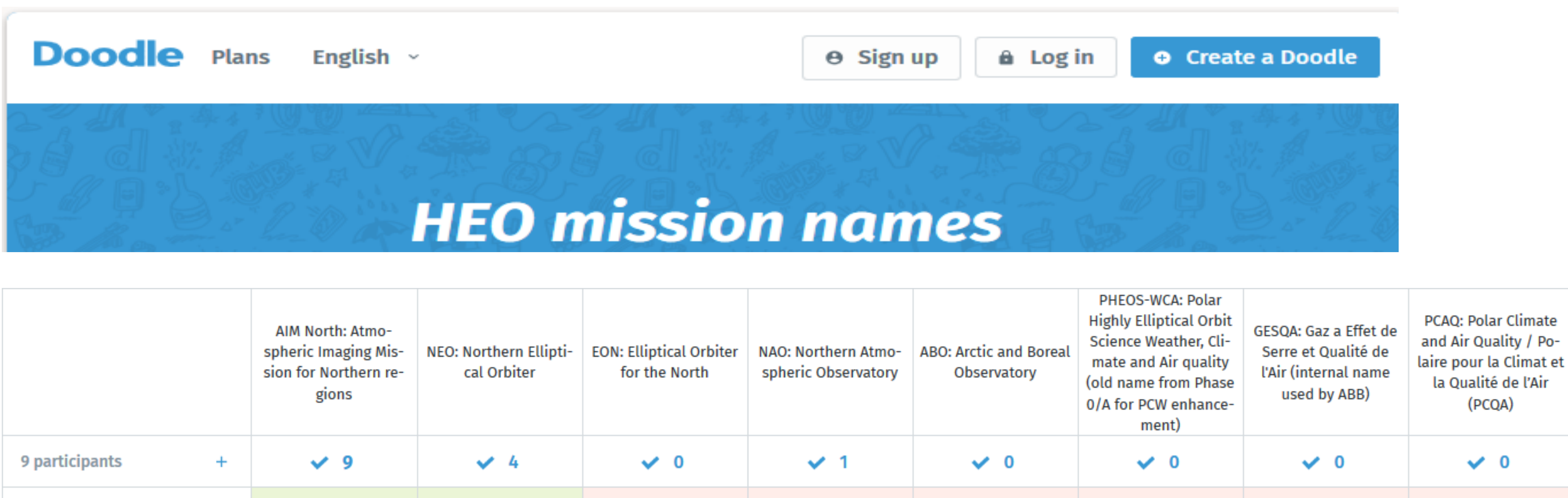
AIM-North

The Atmospheric Imaging Mission for Northern Regions

- "A Concept Study for an Air Quality and GHG observation mission focused on Northern Regions" completed March 2018
  - ECCC: Ray Nassar, Chris McLinden, Chris Sioris, Joseph Mendonca
  - CSA: Ryan Cooney, Marko Adamovic, Ralph Girard
  - Industry: ABB (prime), MDA, Airbus
  - Additional participation by a 'Science Team' (see title slide)
- Options analysis reconfirmed HEO
- Finally selected a new name… AIM-North!



	AIM North: Atmospheric Imaging Mission for Northern regions	NEO: Northern Elliptical Orbiter	EON: Elliptical Orbiter for the North	NAO: Northern Atmospheric Observatory	ABO: Arctic and Boreal Observatory	PHEOS-WCA: Polar Highly Elliptical Orbit Science Weather, Climate and Air quality (old name from Phase 0/A for PCW enhancement)	GESQA: Gaz a Effet de Serre et Qualité de l'Air (internal name used by ABB)	PCAQ: Polar Climate and Air Quality / Polaire pour la Climat et la Qualité de l'Air (PCQA)
9 participants +	✓ 9	✓ 4	✓ 0	✓ 1	✓ 0	✓ 0	✓ 0	✓ 0

AIM-North Observing Approach

UV-Vis: 1-D push-broom scanning with 3x3 km^2 pixels and ~70-90 min. repeat
IFTS: Stare and image Field of View (FoV) with 3x3 km^2 with 2D Focal Plane Array covering the Field of Regard (FoR) with ~70-90 min. repeat

2 HEO satellites with accuracy and precision linked to GEO AQ and GHG missions.

Extending daylight coverage to land ~40-80°N.

Orbit possibilities and variations on IFTS scanning and pointing are still being explored.

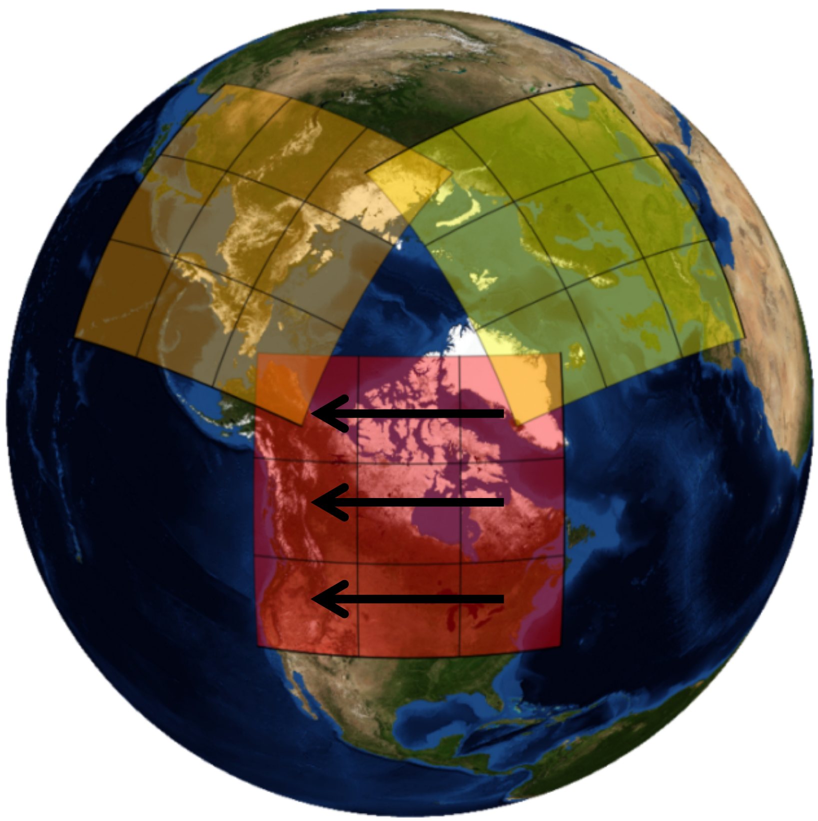


Figure by Cameron MacDonald (U. Waterloo)

Potential for intelligent pointing for cloud avoidance.

Frequent imaging yields movie-like views of daytime atmospheric composition!

Overlap with GEO observations gives intercalibration opportunities beyond LEO.

AIM-North Spectral Bands / Species

Baseline

Enhancement

	Band (nm)	Band (cm^{-1})	Spectral Sampling	Target species
UV-vis grating	280-780	12820 - 35714	~ 0.4 nm	O_3, NO_2, aerosol, BrO, HCHO, SO_2, SIF & more
NIR-SWIR IFTS	758-762	13122 - 13186	0.25 cm^{-1}	O_2 *A* band: p_{surf}, aerosol Solar Induced Fluorescence
	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}	CO and CH_4 columns
Mid/LWIR IFTS	Longwave IR		~0.50 cm^{-1}	T, H_2O, O_3, CO, CO_2, CH_4, HNO_3, CH_3OH, HCOOH, PAN, HCN, NH_3, SO_2…
	mid-IR		~1.25 cm^{-1}	

- IFTS with 16.5 cm aperture would be ~141 kg (~199 kg with enhancement)
- UVS would be ~51 kg

*30% contingency included above

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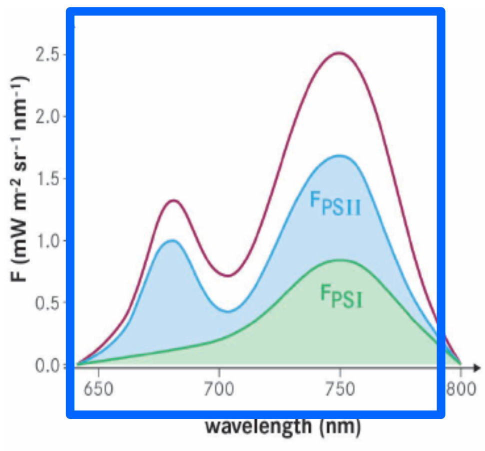
AIM-North Precision and SNR

- UVS: spectral resolution and SNRs aligned with GEO AQ missions
- IFTS: high spectral resolution and narrow bands deliver good precision with modest SNRs, but NIR band is limiting
- Precision goals: XCO_2 0.25% ≈ 1 ppm, XCH_4 0.50% ≈ 9 ppb, XCO = 5%
- Assume CO_2 and O_2 contribute equally to XCO_2, giving each a requirement of $0.25\%/\sqrt{2}$ while for XCH_4 and XCO, O_2 has smaller impact
- Required SNRs determined by propagating precisions, based on noisy simulated radiances

Band (μm)	SNR Goal	SNR Expected
O_2 (0.76)	88	75
CO_2 (1.61)	119	130
CO_2 (2.06)	116	120
CH_4 & CO (2.3)	130	120

SIF Retrieval Possibilities



Broad spectral coverage of **Solar-Induced Fluorescence** (SIF) from UVS (blue box)

IFTS O_2 window (red box) has strong oxygen lines and isolated Fraunhofer lines:
758.4-762.1 nm (13121.6-13185.7 cm^{-1})

Figure from FLEX Report for ESA EE-8 mission selection (2015)

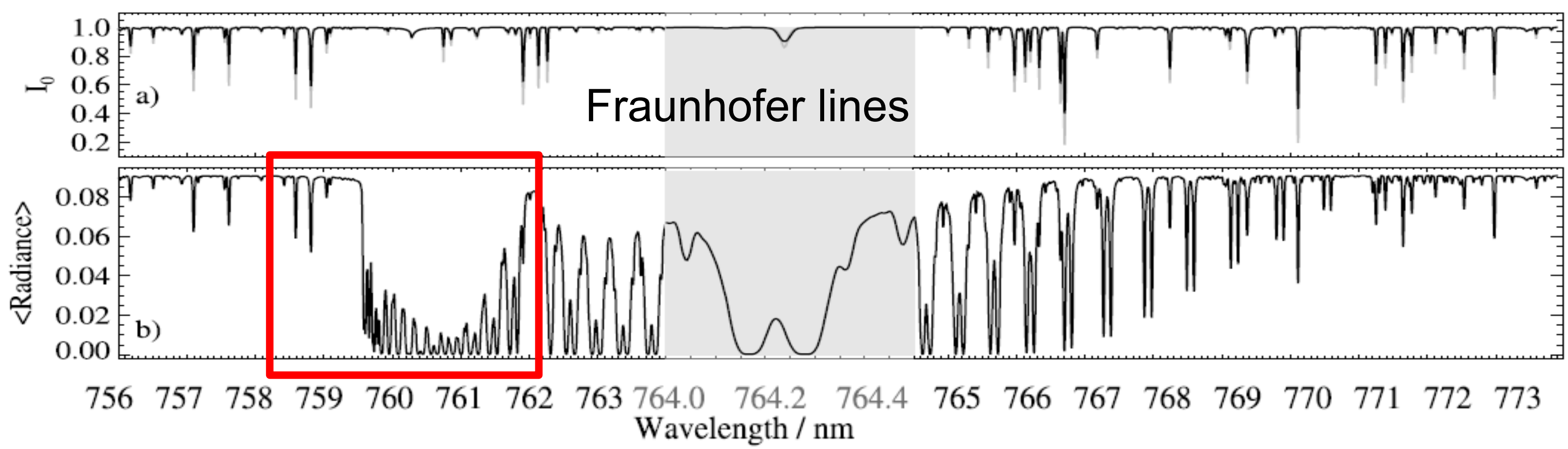
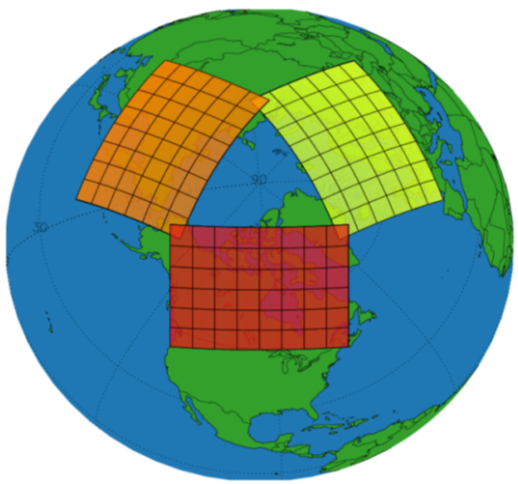


Figure from: Frankenberg, Butz and Toon (2011), Disentangling chlorophyll fluorescence from atmospheric scattering effects in O_2 A-band spectra of reflected sun-light, GRL, 38, L03801.

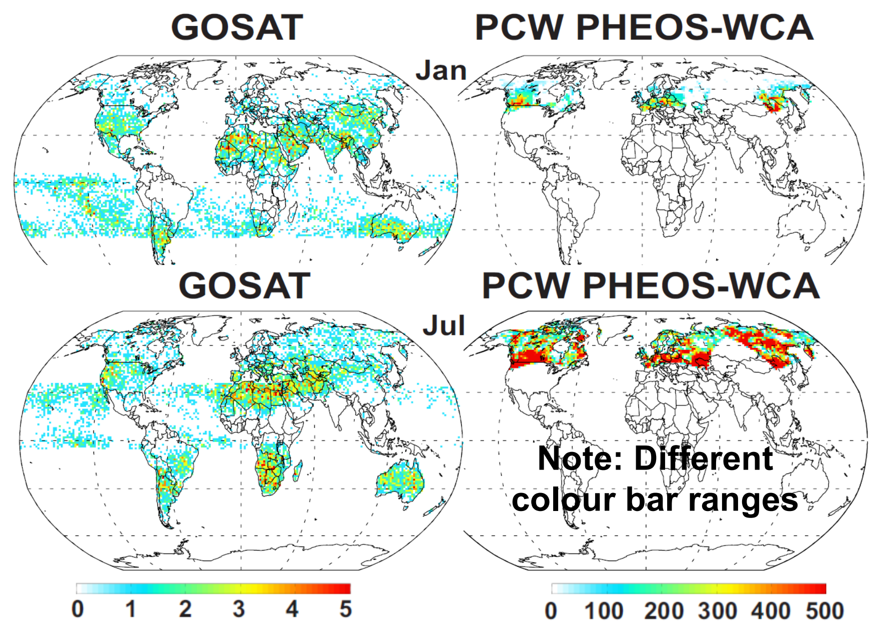
Past OSSE on CO_2 Observations from HEO

- Simulations compared the potential information from PHEOS-FTS vs. GOSAT for constraining Arctic and Boreal CO_2 surface fluxes using synthetic CO_2 observations.

PHEOS-FTS Fields of Regard



Number of observations per 1°x1° per month



- PHEOS-FTS could give flux uncertainty *reductions* relative to GOSAT of ~30% annually and ~45% in summer
- Plan to generate new HEO synthetic observations with smaller pixels, better precision, changes to orbit assumptions for participation in coordinated AQ-GHG OSSEs

GOSAT mean simulated obs per month: 14973
NIES v2, 1st year of mission: 14393

Nassar, Sioris, Jones, McConnell (2014), Satellite observations of CO_2 from a highly elliptical orbit for studies of the Arctic and boreal carbon cycle, *J. Geophys. Res.* 119, 2654–2673, doi:10.1002/2013JD020337.

*Precision of observations over snow degraded by a factor of 2

Moving Forward

- ECCC Deputy Minister sent a letter to CSA supporting AIM-North and a Snow Radar mission to advance to Phase 0 (no other Earth observation missions are at the same level of study by CSA), decision in mid/late May 2018
- Phase 0 decision by CSA coming in mid/late May 2018. Phase 0 would last ~18 months (after selection of new industry team) would include technical studies and new associated science activities within ECCC and Canadian universities
- Could launch in ~7 years (~2025) if fully funded, but this a costly endeavor for CSA to do independently
- We welcome international participation, cooperation/coordination with GEO missions and even partnerships at the space agency level to help make AIM-North a reality

AIM-North Team

Government of Canada Members

- Ray Nassar (ECCC, Climate Research Division) – PI and greenhouse gas (GHG) observations
- Chris McLinden (ECCC, Air Quality Research Division) – Air quality (AQ) species observations
- Louis Garand (ECCC, Meteorological Research Division) – Potential meteorological enhancements
- Chris Sioris (ECCC, AQRD) – Retrievals and Analysis
- Joseph Mendonca (ECCC, CRD) – Validation and GHG Retrievals
- Saroja Polavarapu (ECCC, CRD) – Modelling and Assimilation for GHGs
- Felicia Kolonjari (ECCC, CRD) – Inter-departmental/International collaboration and policy
- Yves Rochon (ECCC, AQRD) – 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

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) – Validation
- Kim Strong (University of Toronto) – Validation
- Norm O'Neill (Université de Sherbrooke) – Aerosols
- Dylan Jones (University of Toronto) – Modelling and Assimilation for GHGs and AQ
- Randall Martin (Dalhousie University) – Modelling and Assimilation for Air Quality

Industry Members

- Frederic Grandmont (ABB Canada) – Instruments and spacecraft
- Louis Moreau (ABB Canada) – Instruments and spacecraft

International Members

- Johanna Tamminen (Finnish Meteorological Institute) – Analysis of GHG and AQ data
- Charles E. Miller (NASA) – Arctic and Boreal Carbon Cycle Science
- William Simpson (University of Alaska at Fairbanks) – Arctic Atmosphere and Carbon Cycle

http://www.aim-north.ca
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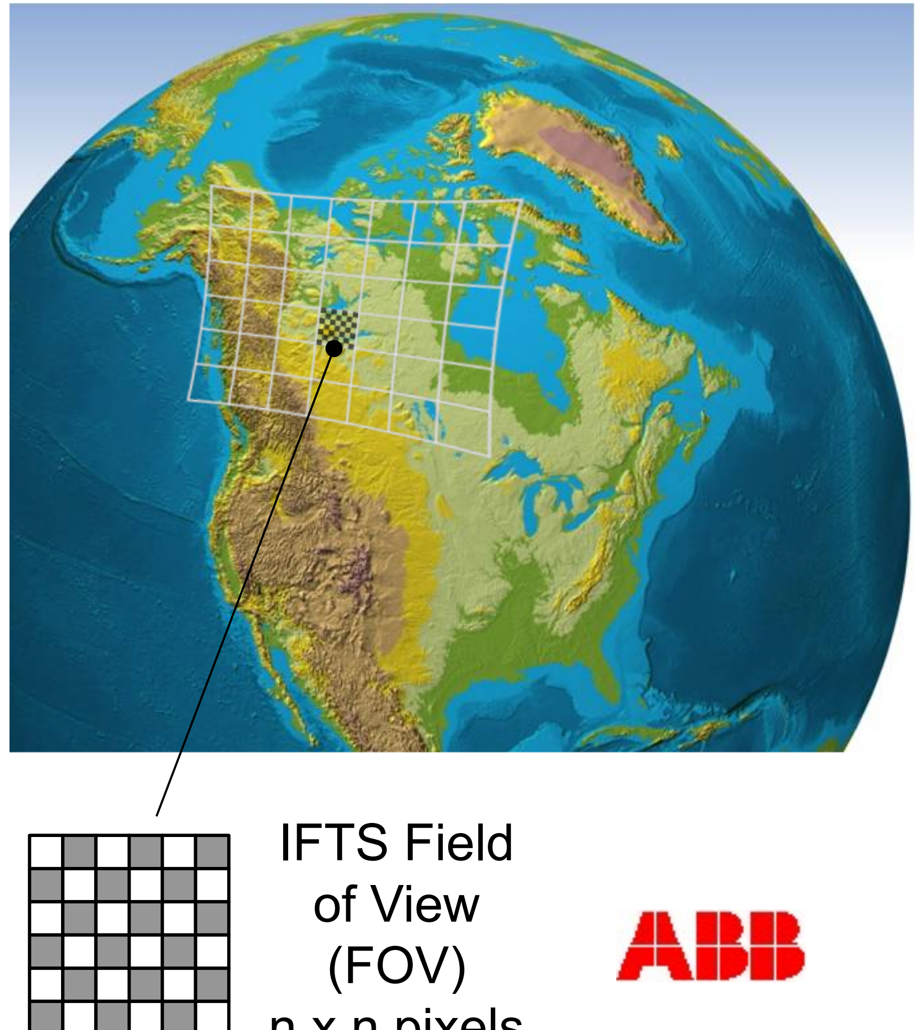
Grating or Imaging Fourier Transform Spectrometer (IFTS)

Extra Slide

- With a grating spectrometer using a 2D focal plane array, one dimension is used for the spectral domain and the other for the spatial domain
- FTS simultaneously measures all wavelengths as the instrument modulates the optical path length, interferogram is later transformed mathematically to a spectrum, so with an IFTS, both dimensions of a 2D focal plane array can be used spatially to give an image directly
- IFTS from GEO or HEO can step-and-stare across the field of regard
- Proven technology used in Canada-France-Hawaii telescope (SITELLE, Mauna Kea) 4 million pixels
- High commercialization potential for IFTS for Earth Observation: atmospheric research or GEO weather satellites



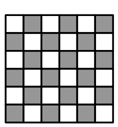
ABB

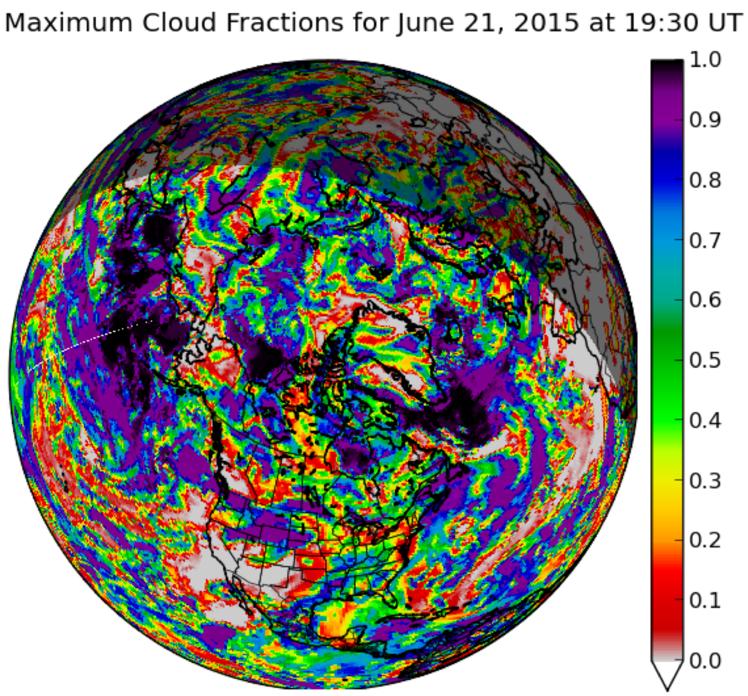
Extra Slide

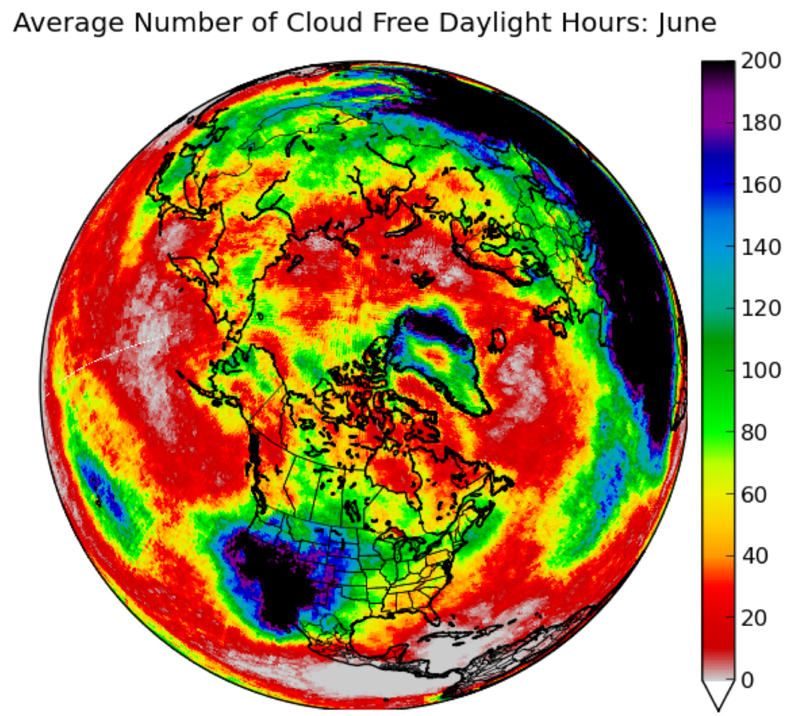
HEO Intelligent Pointing

- Intelligent pointing would be so much more powerful from HEO or GEO than LEO
- Greater pointing flexibility from GEO/HEO since essentially every location is cloud-free at some time, and somewhere is always cloud-free
- Smarter pointing could focus on clear regions or just events/regions or interest
- Get cloud info from UVS, extra imager, or forecasts?

Could point the FOV to scan only in clearest regions







Figures: Dan Sehayek (U. Waterloo)