Environment and Climate Change Canada
Environnement et Changement climatique Canada
Canada

Remote Sensing of Arctic and Boreal Atmospheric Composition from a Highly Elliptical Orbit

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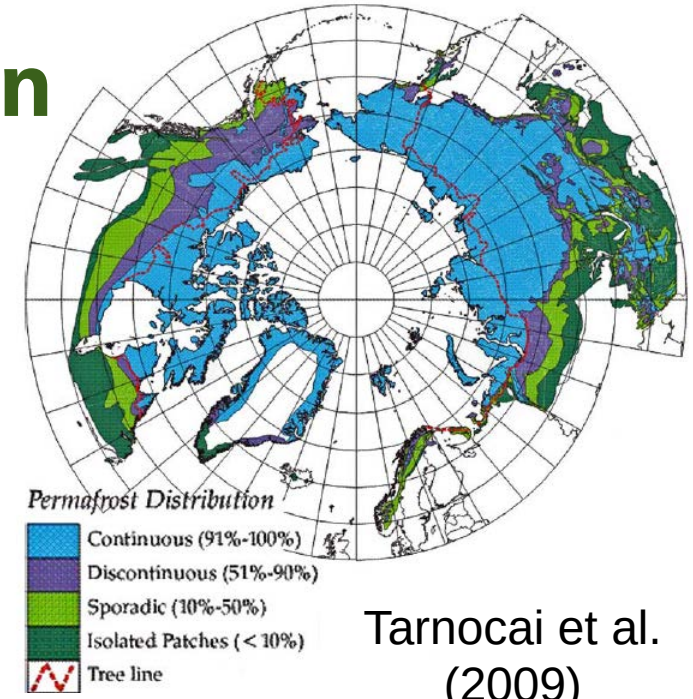
Boreal and Arctic Carbon



Tarnocai et al. (2009)

Boreal Forests

- Longer growing season and increase in disturbances may enhance or reduce their net CO_2 flux

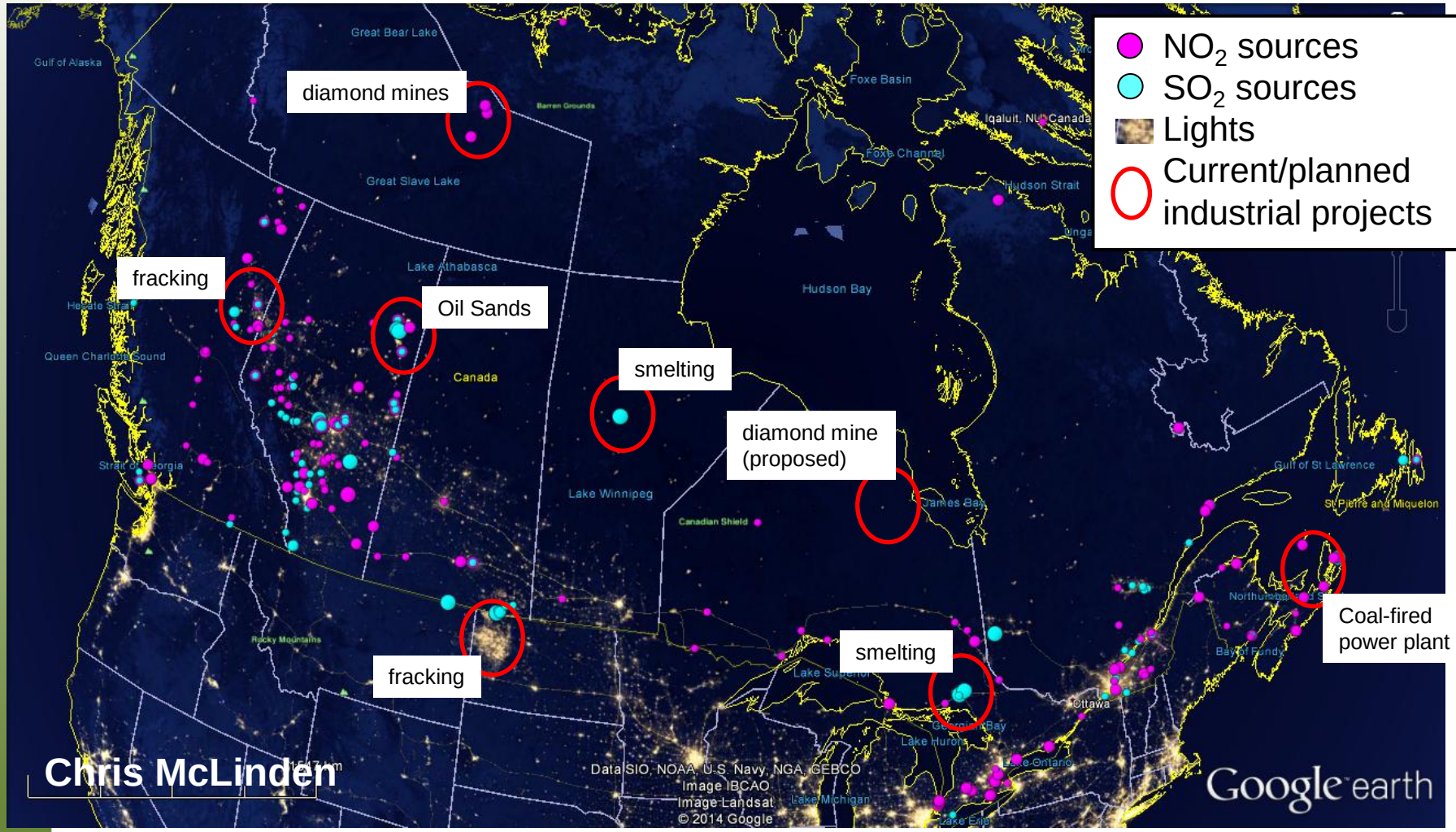
Boreal Forest Extent (2009)
UNEP/GRID-Arendal Maps and Graphics Library

Permafrost

- 1672 PgC, twice atm mass with potential for release of some fraction as CO_2, CH_4
- ~85 PgC by 2100 (0.8-1.1 PgC/yr) by extrapolation of Alaskan measurements (Schurr et al. 2009)
- Models: 104±37 PgC (Schaefer et al. 2011) and 9-114 PgC (Schneider von Deimling et al. 2012) by 2100

Satellite observations of CO_2 and CH_4 would be valuable

Anthropogenic Emissions North of ~45°N



Satellite night light imagery from VIIRS http://earthobservatory.nasa.gov/Features/IntotheBlack/

A Few Current and Future GHG and AQ missions

- **GOSAT** launched in 2009 is a Japanese mission dedicated to measuring CO_2 and CH_4
- **OCO-2** is a NASA CO_2 mission successfully launched on July 2, 2014
- **TanSat** (China) CO_2 mission to launch in Aug 2016
- **GOSAT-2** scheduled to launch around 2018
- **OCO-3** on the Space Station in 2018
- **MicroCarb** CNES CO_2 mission to launch around 2020

- **TropOMI** will launch in Oct 2016
- Successor to **OMI** (Aura)
- Air quality mission along with CH_4
- Wide swath increases coverage

SRON, KNMI, NSO

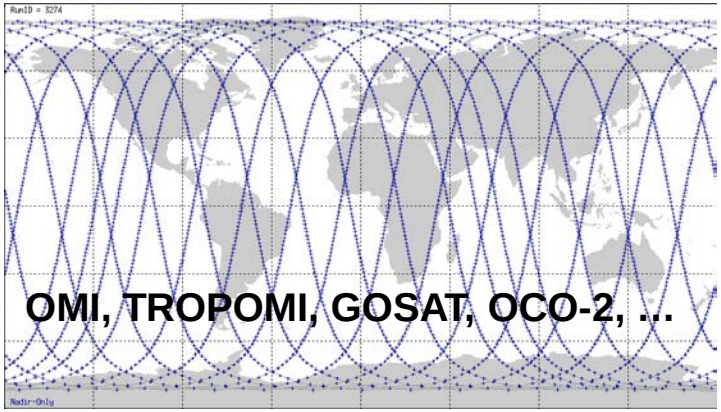
- **TEMPO** will launch around 2019 or later
- Air quality over US, southern Canada (<60°N) and parts of Central America

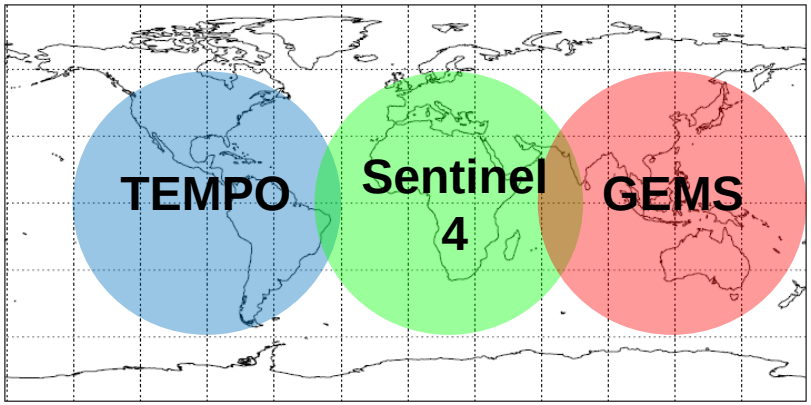
Tropospheric Emissions: Monitoring of Pollution

Common Satellite Orbits and Coverage

- **Low Earth Orbit (LEO)**
- Below ~1000 km altitude
- Near-polar plane
- Can give global sampling, but typically observe a given point at constant local time of day

- **Geostationary Orbit (GEO)**
- ~35,800 km altitude
- Near-equatorial plane
- Synchronized with Earth rotation with potential for ‘continuous’ sampling over selected area (<60°N/S)

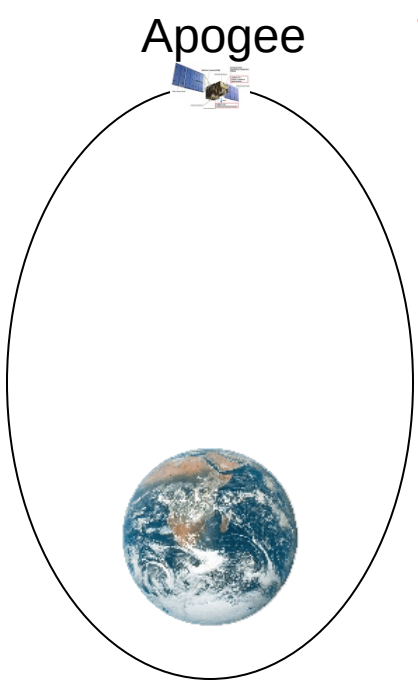




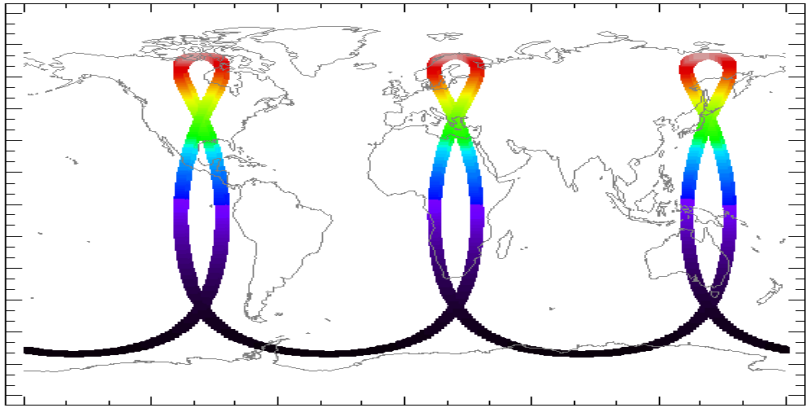
Air Quality moving toward LEO + GEO (like meteorology), GHGs next?
Neither LEO or GEO can give continuous observations over the Arctic

Highly Elliptical Orbit (HEO)

- WMO Vision for the Global Observing System (GOS) in 2025
- Conservation of angular momentum requires faster motion when close to Earth (perigee), slower motion when far from Earth (apogee)



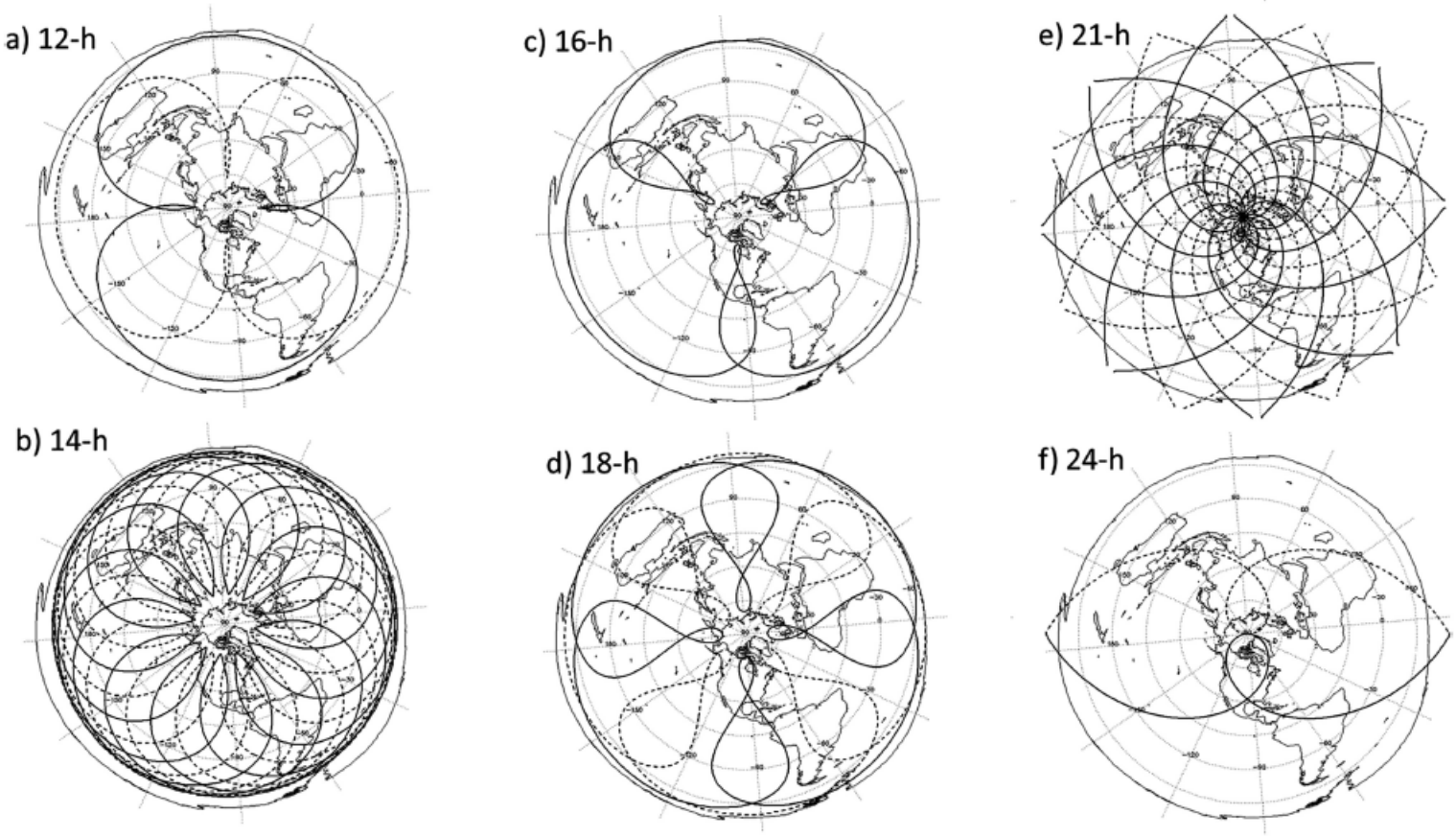
- Example of a HEO is the Three Apogee (TAP) orbit: Period = 16 hr and Apogee altitude = 43,500 km



Trishchenko, Garand, Trichtchenko (2011), Three-Apogee 16-h Highly Elliptical Orbit as Optimal Choice for Continuous Meteorological Imaging of Polar Regions, J. Atmos. Ocean. Tech., 28, 1407.

Other Highly Elliptical Orbits

- Numerous HEO possibilities by varying the orbital period and apogee altitude (40,000 - 48,500 km, so higher than GEO: 35,800 km)



Garand, Trishchenko, Trichtchenko, Nassar (2014), Physics in Canada, 70, 4, 247-254

Polar Communications and Weather (PCW)

- Canadian mission with 2 satellites in Highly Elliptical Orbit (HEO) configuration, under consideration for post-2020 launch
- Main objectives are to expand Arctic communications (National Defence) capabilities and provide meteorological observations (Environment and Climate Change Canada)
- Canadian Space Agency (CSA) also considered additional science instruments under the Polar Highly Elliptical Orbit Science (**PHEOS**) program
- The Weather, Climate and Air quality (**WCA**) mission concept is an atmospheric research option that completed Phase A in 2012 (PHEOS-WCA PI was Prof. Jack McConnell of York U)

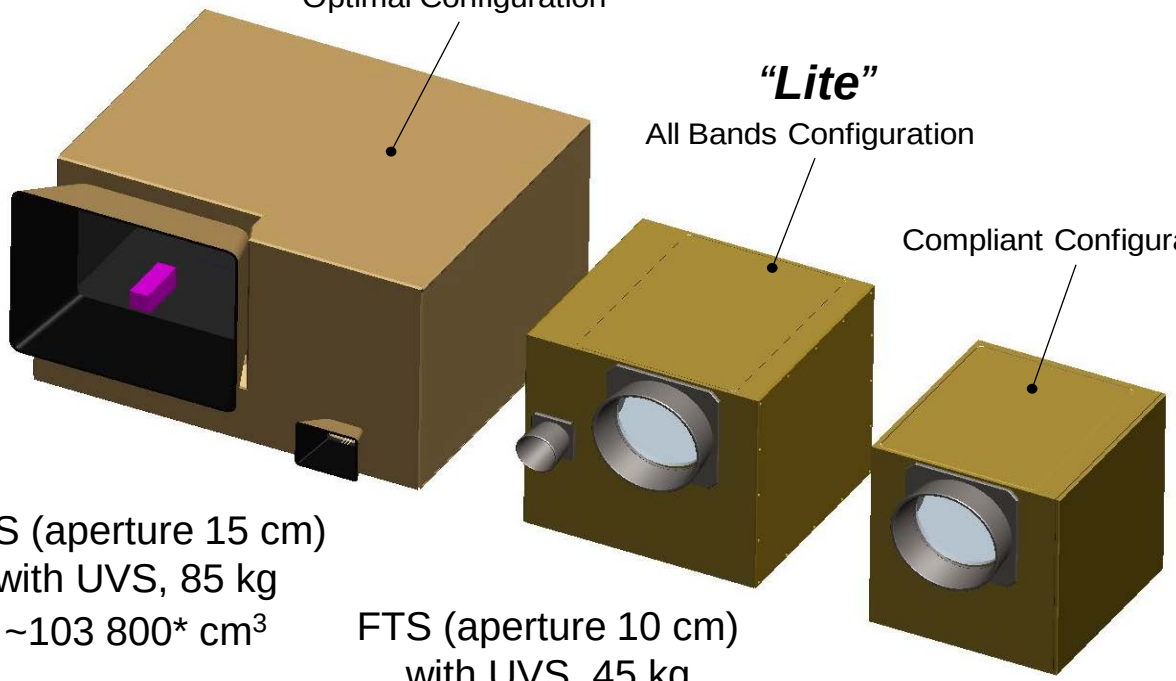
PCW-PHEOS-WCA Instrument Configurations

- Fourier Transform Spectrometer (FTS)
- UV-Visible Spectrometer (UVS)

CSA Allocations

Size:
30 x 30 x 30 cm^3
(27 000 cm^3)

Mass: 50 kg
Power: 100 W



FTS (aperture 15 cm)
with UVS, 85 kg
~103 800* cm^3

FTS (aperture 10 cm)
with UVS, 45 kg
~35 128* cm^3

O_2 A band and SWIR CO_2

FTS (aperture 10 cm)
No O_2 A band or SWIR CO_2
No UVS, 37 kg
~25 184* cm^3

*configuration volumes given with 20% contingency

PCW-PHEOS-WCA Spectral Bands / Species

Optimal and All-Band (Lite) Compliant

		Band (μm)	Band (cm^{-1})	Resolution	Target species
FTS	1	6.7 – 14.2	700 - 1500	0.25 cm^{-1}	T, H_2O, O_3, CO, CO_2, CH_4, HNO_3, CH_3OH, HCOOH, PAN, HCN, NH_3, SO_2…
	2	3.7 – 5.6	1800 - 2700	0.25 cm^{-1}	
	3a	1.66 - 1.67	5990 - 6010	0.25 cm^{-1}	**CH_4 columns**
	3b	1.60 - 1.67	5990 - 6257	0.25 cm^{-1}	**CO_2 and CH_4 columns**
	4	0.760-0.766	13060-13168	0.50 cm^{-1}	**O_2 A band (p_{surf}, aerosol)**
UVS		0.280-0.650		~ 1 nm	O_3, NO_2, aerosol, BrO, HCHO, SO_2, …

Widening band 4 would enable retrieval of chlorophyll fluorescence like GOSAT / OCO-2
What else could be measured? Snow, fires, other vegetation parameters, …

ABB — Designed and built ACE-FTS, CrIS and GOSAT interferometer

COM DEV INTERNATIONAL — Designed and built MOPITT and ACE-MAESTRO (EMS Technologies)

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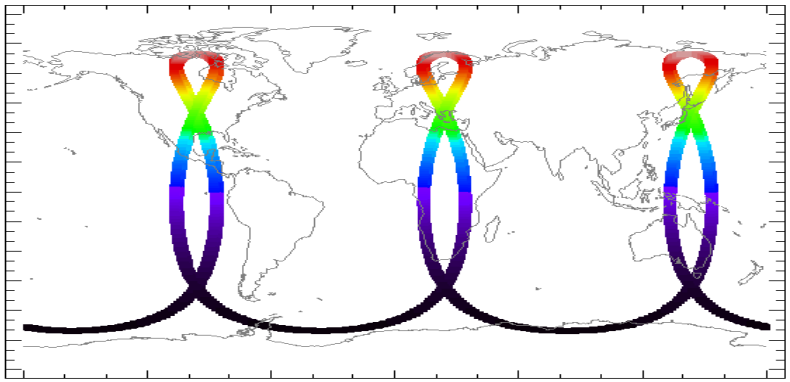
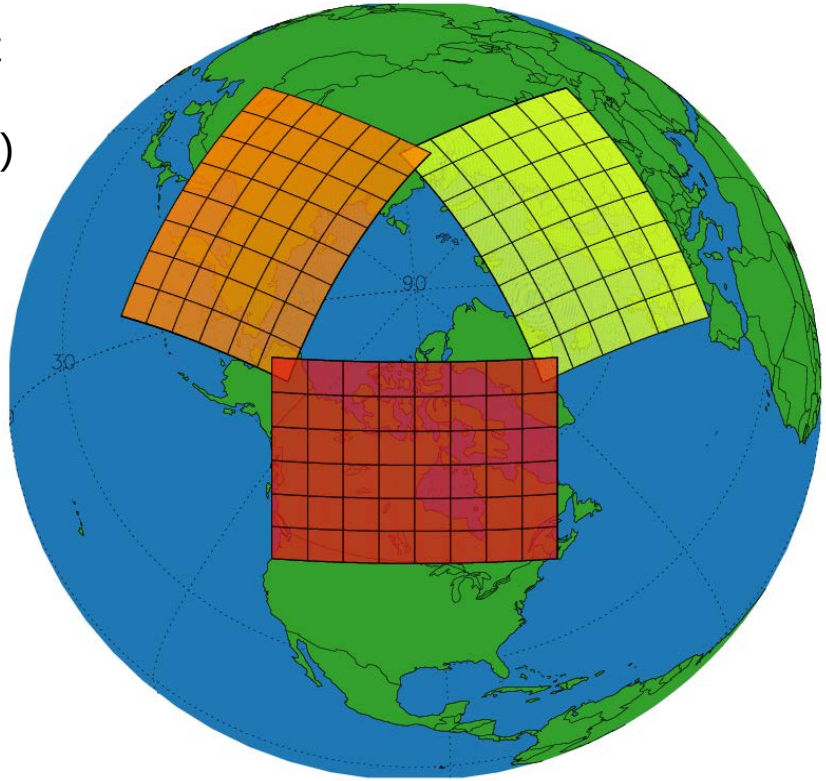
FTS Imaging from Three Apogee Orbit

- 2 satellites, 8h apart in co-planar 16h orbit
- Apogee ~43,500 km, Perigee ~8100 km
- Observe 3 apogees/24 h (from 2 satellites)
- For apogee at local noon, observing ±4 h, so up to 8 h of data per day per region



Trishchenko et al. (2011), J. Atmos. Ocean. Tech.



Nassar, Sioris, Jones, McConnell (2014), JGR

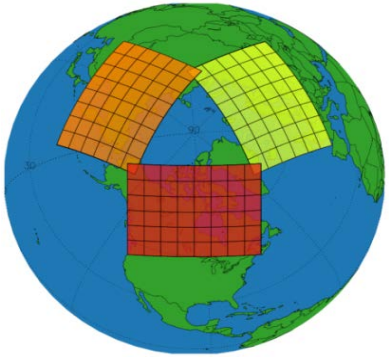
- Quasi-geostationary viewing: 100 second scan of each small box with a 2D 56x56 array of 10x10 km^2 pixels, taking ~80 minutes to observe a region, repeat
- Viewing scenario for UVS would be somewhat different (~8x8 km^2 pixels)

Study on CO_2 observations from HEO Mission

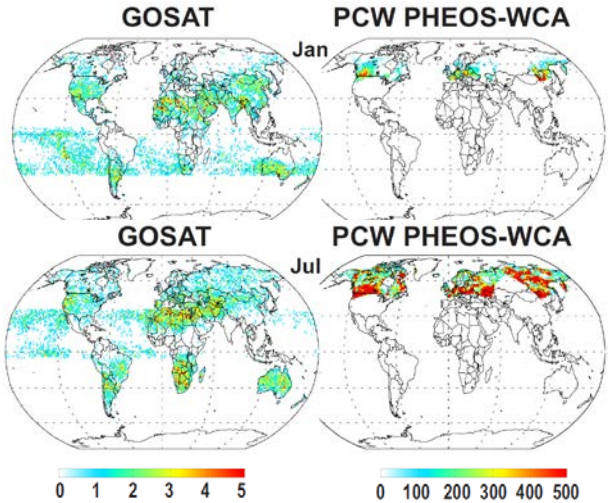
- Generated 1-year of synthetic CO_2 observations from PHEOS-FTS and GOSAT accounting for orbits, instrument observing characteristics, sunlight, clouds, snow / surface properties, etc. in an Observing System Simulation Experiment (OSSE) to compare their ability to constrain Arctic and boreal CO_2 sources and sinks
- Posterior Arctic / boreal land flux uncertainties from PHEOS-WCA were lower than from GOSAT by 30% annually and 45% in summer
- Largest interannual variability and uncertainty in summer (boreal forest growing, disturbance and permafrost thaw) when PHEOS-FTS offers greatest potential constraints

Nassar, Sioris, Jones, McConnell (2014), Satellite observations of CO_2 from a highly elliptical orbit for studies of the Arctic and boreal carbon cycle, Journal of Geophysical Research, 119, 2654-2673, doi:10.1002/2013JD020337

PCW WCA-FTS Fields of Regard



Simulated obs numbers per 1ºx1º grid box



Take Home Message

- Highly Elliptical Orbit (HEO) satellite observations can greatly improve coverage over Northern regions, complementing planned international LEO and GEO missions (and ground-based data) for AQ, GHGs and meteorology

- PCW-PHEOS-WCA team (academia, government and industry) proposed a mission concept that completed Phase A study in March 2012, which could meet these needs but optimal instrument configuration requires CSA to relax mass/volume constraints

- What's next?

Future Plans and Path Forward

- Will test PHEOS-FTS CO_2 and CH_4 imaging and pointing from a high altitude balloon (~35-40 km) to launch from New Mexico, late August / early September 2016 (PI: Tom McElroy)

- CSA providing funding to ABB for continual development of imaging FTS technology (2016-2017)

- Joint CSA - ECCC led opportunity for renewed mission concept studies for an “Air Quality and GHG mission focused on Northern Regions” includes consideration of a standalone HEO mission and instrument trade studies (2016-2017) with bids from multiple industry teams now under review

- Studies planned at ECCC (2016-2019) using currently available high latitude LEO satellite data (OMI, OCO-2, etc.) and modelling/assimilation systems to optimize observing characteristics for a HEO Air Quality and GHG mission