Environment and Climate Change Canada | Environnement et Changement climatique Canada

Canada

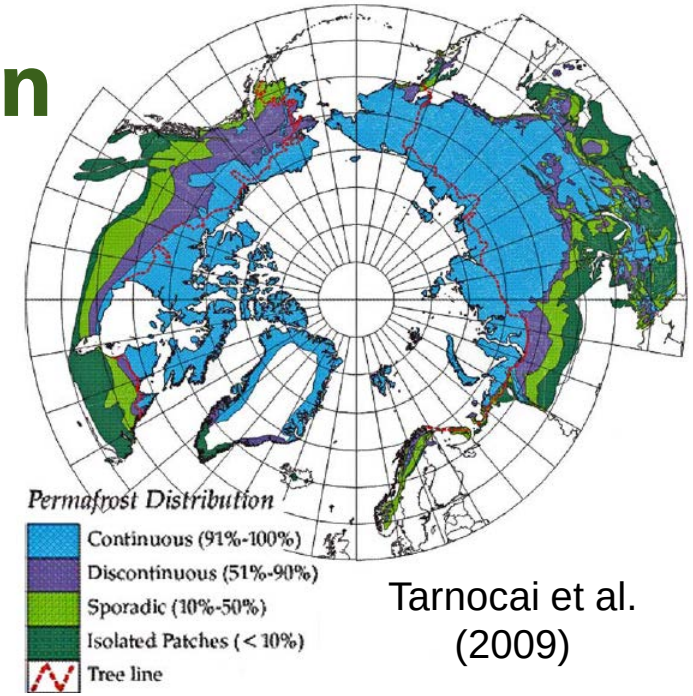
Plans and Progress Toward Greenhouse Gas Observations in the Arctic and Boreal Regions from a HEO mission

Ray Nassar[1*], Chris E. Sioris[1], Chris McLinden[1], Tom McElroy[2], Kaley A. Walker[3], Dylan B.A. Jones[3]

[1] Environment and Climate Change Canada, [2] York University, [3] University of Toronto
***ray.nassar@canada.ca**

IWGGMS-12, Kyoto, 2016-06-09

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 and Arctic Vegetation

- 1672 PgC, twice atm C mass with potential for release of some fraction as CO_2, CH_4
- Arctic "greening" will reabsorb some of this

Northern High Lat Anthropogenic Activity

- Increasing shipping, resource extraction

Northern high latitude satellite observations of CO_2 and CH_4 would be valuable

New Delhi Declaration: Space Agency heads reaffirm commitment to monitor greenhouse gas emissions

Draft April 3, 2016 New Delhi, India – Finalized May 16, 2016

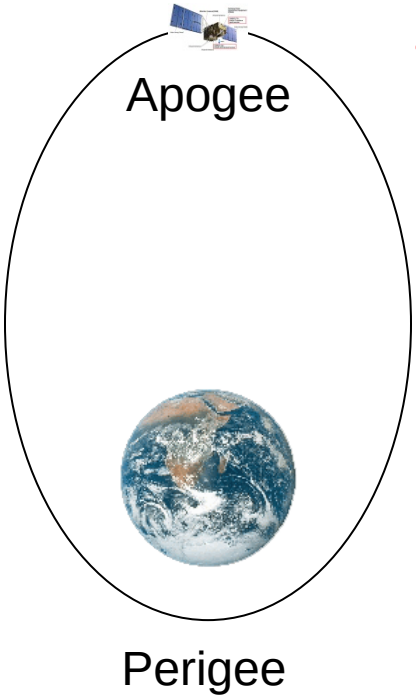
- This new initiative follows on from the Mexico Declaration in 2015, which laid the groundwork for the space agenda of the COP21, stating that “satellite observations are the key element of a global measuring system aimed at verifying the reality of commitments taken in line with the United Nations Framework Convention on Climate Change (UNFCCC)”.

- As a result, an effective measurement system will be essential to help monitor intended nationally determined contributions. As underlined by the Committee on Earth Observation Satellites (CEOS), “an ambitious long-term goal is operational LEO and GEO constellations measuring greenhouse gases in the atmosphere”.

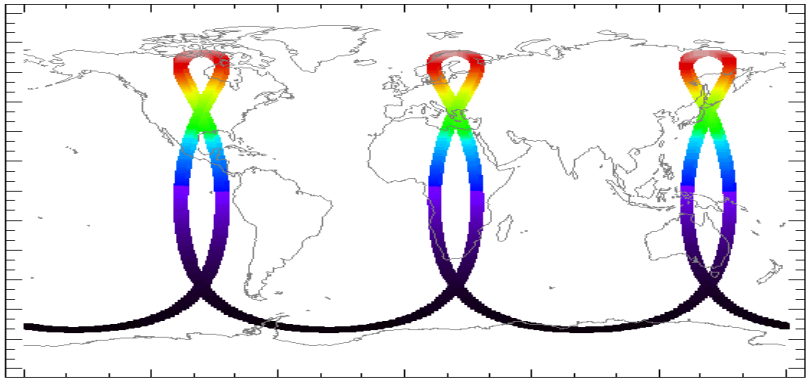
https://presse.cnes.fr/en/new-delhi-declaration-space-agency-heads-reaffirm-commitment-monitor-greenhouse-gases-emissions
https://presse.cnes.fr/en/new-delhi-declaration-comes-effect-worlds-space-agencies-working-tackle-climate-change

Highly Elliptical Orbit (HEO)

- Enormous benefits to GEO + LEO constellation of CO_2 and CH_4, but neither is well-suited for continuous high latitude observations
- Conservation of angular momentum requires faster motion when close to Earth (perigee), slower motion when far from Earth (apogee)
- HEO can give quasi-geostationary observations of the high latitudes



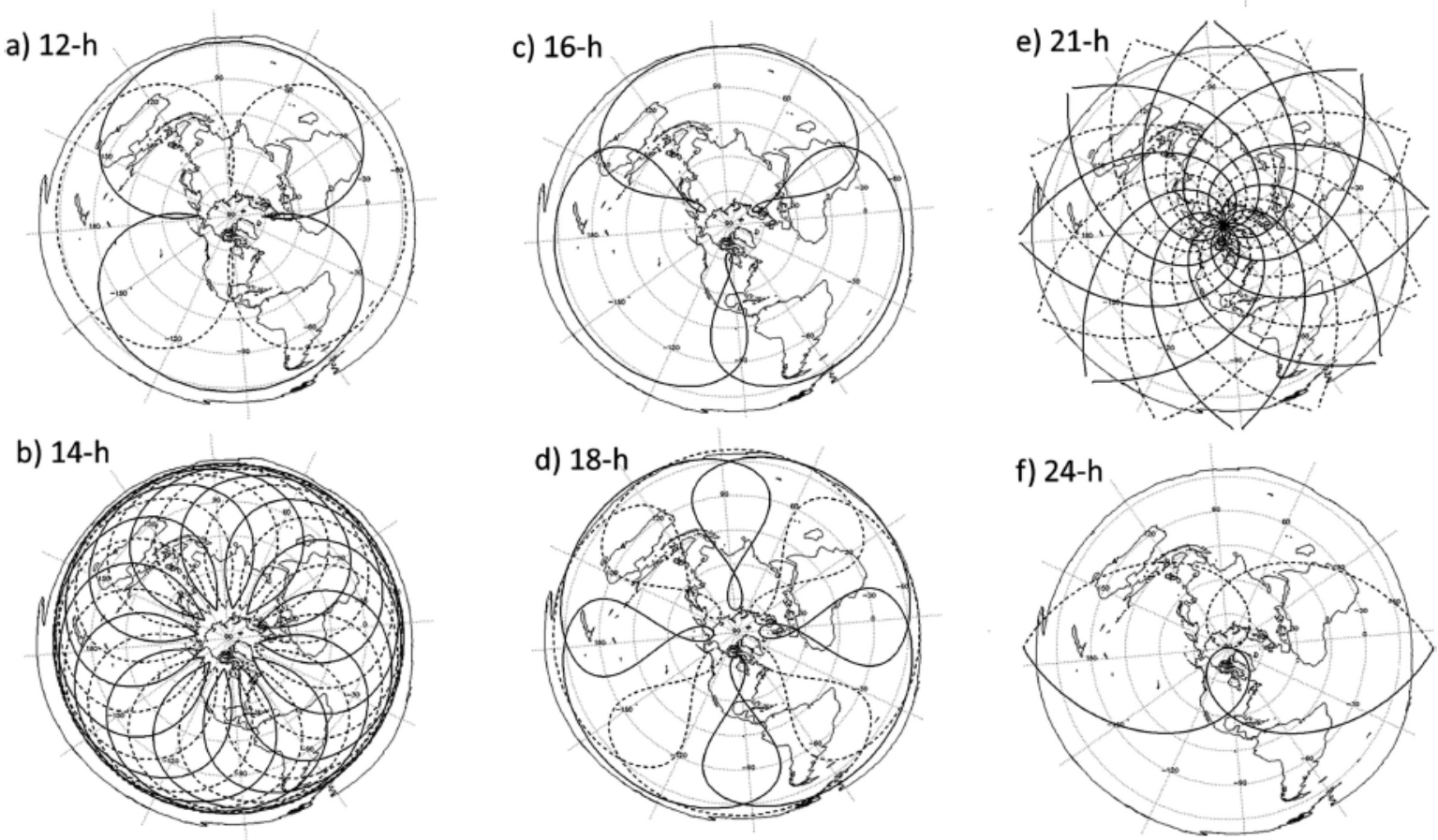
- Example of a HEO is the Three Apogee (TAP) orbit: Period = 16 hr and Apogee altitude = 43,500 km



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, which is 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 0 and A in 2012 (PHEOS-WCA PI was Prof. Jack McConnell of York U)

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, …

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

ABB

COM DEV INTERNATIONAL

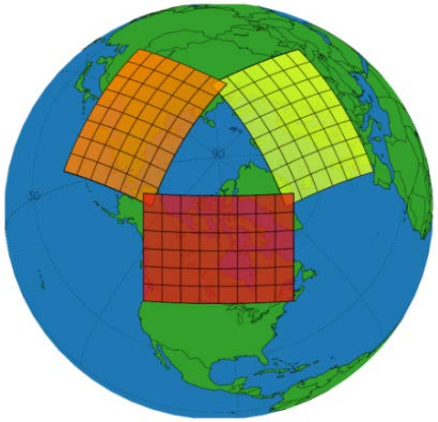
Designed and built ACE-FTS, CrIS and GOSAT/GOSAT-2 interferometers

Designed and built MOPITT, OSIRIS, …

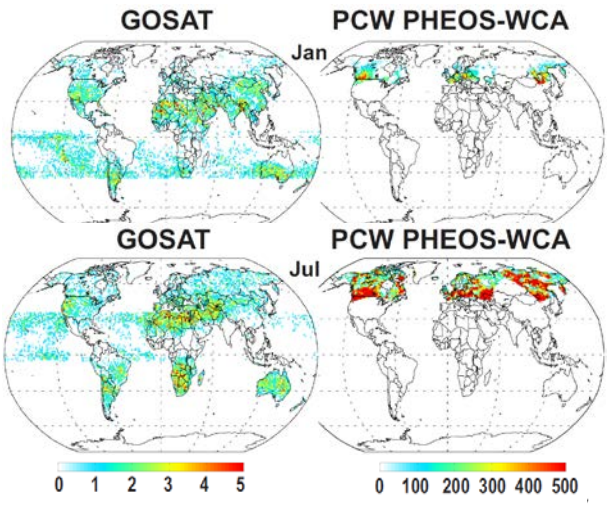
Study on CO_2 observations from HEO

- 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

PHEOS-WCA-FTS Fields of Regard



Simulated obs numbers per 1°x1° grid box



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

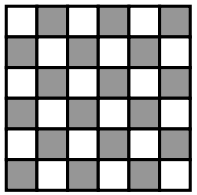
Progress Toward HEO CO_2 and CH_4

- Will test a HEO pointing mechanism from a high altitude balloon (~35 km) from Ft. Sumner New Mexico, late Aug / early Sept 2016. PI: Tom McElroy, CSA Flights for Advancement of Science and Technology (FAST) Program.

- ABB is carrying out continual development of imaging FTS technology (2016-2017) for GEO and HEO applications with CSA funding through the Space Technology Development Program (STDP), balloon testing of IFTS for CO_2 and CH_4 could follow

Imaging Fourier Transform Spectrometer (IFTS)

- FTS simultaneously measures all wavelengths as the instrument modulates the optical path length, interferogram is later transformed mathematically to a spectrum
- 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
- With an IFTS, both dimensions of a 2D focal plane array can be used for spatial info giving 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



IFTS Field of View

Adapted from ABB

Northern CO_2 and CH_4 Mission

Joint CSA - ECCC led opportunity for renewed mission concept, building off past work: “Air Quality and GHG mission focused on Northern Regions” (2016-2017) with the potential to be separate from PCW. Will re-examine:

- Orbit: All possibilities back on the table LEO, HEO, …
- Bands: GHG and AQ now higher priority than meteorology -> TIR?
- Grating or FTS?
- Full instrument trade studies (bands, spectral/spatial resolution …)
- Assess costs

Review of bids from multiple industry-academic teams has just been completed by CSA and ECCC.

Stricter Precision and Accuracy Requirements

	"Northern Mission"	PHEOS-WCA	CEOS-CGMS resp to GCOS	CarbonSat
XCO_2 precision (ppm)				
Goal (G)	**1.0**	4.0	1.0	1.0
Breakthrough (B)			3.0	
Threshold (T)	**3.0**	8.0	8.0	3.0
XCO_2 bias (ppm)				
(G)	**0.2**	4.0	0.2	0.2
(B)			0.3	
(T)	**0.6**	8.0	0.5	0.5
XCH_4 precision (ppb)				
(G)	**9.0**	72.0	9.0	6.0
(B)			17.0	
(T)	**27.0**	180.0	34.0	12.0
XCH_4 bias (ppb)				
(G)	**2.0**	36.0	1.0	2.5
(B)			5.0	
(T)	**6.0**	72.0	10.0	5.0

References:

- PHEMOS Weather, Climate and Air Quality User Requirements Document, J.C. McConnell and B.H. Solheim, Editors, 2012 March 26 (converted to mole fractions from % assuming 400 ppm CO_2 and 1800 ppb CH_4)
- 2015 Update of Actions in The Response of the Committee on Earth Observation Satellites (CEOS) to the Global Climate Observing System Implementation Plan 2010 (GCOS IP-10)
- CarbonSat – Earth Explorer 8 Report for Mission Selection, European Space Agency (ESA), 2015

Footprint Selection

Footprint size (km^2)	"Northern Mission"	PHEOS-WCA	CarbonSat	GeoCarb	G3E
Goal	**4 x 4**	10 x 10	2 x 2	2.7 x 3.0	2 x 3
Breakthrough	**7 x 7**				
Threshold	**10 x 10**	20 x 20	2 x 3		

Note: Footprint values are not exact since they increase away from the sub-satellite point

- To achieve a smaller footprint while still controlling costs, we will revisit trade-offs (bands, spectral resolution, SNR, integration time, etc.) based on experience with GOSAT, OCO-2, other proposed LEO and GEO mission concepts and our planned analyses with updated science objectives

- Model studies planned at ECCC on observing requirements to estimate high latitude anthropogenic point source, area source or urban emissions (building on past CarbonSat and GeoCARB work)

Summary and Conclusions

- There is still hope for a HEO CO_2 and CH_4 mission
- Much more work to be done!