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Quasi-geostationary observations of CO_2 from a highly elliptical orbit (HEO): a potential method for monitoring northern CO_2 fluxes

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Carbon Cycle at Northern Latitudes

Boreal Forests

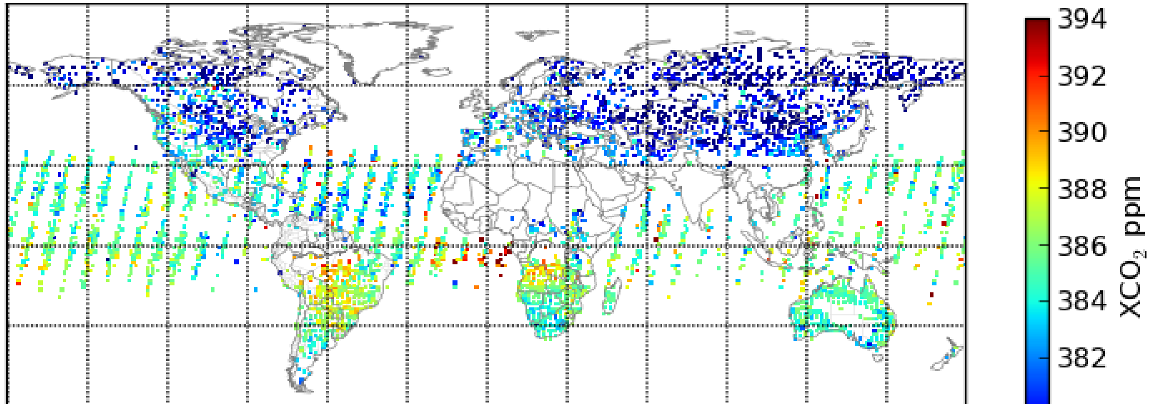
UNEP/GRID-Arendal Maps and Graphics Library
http://maps.grida.no/go/graphic/boreal-forest-extent

- Declining Arctic sea-ice
- Increasing anthropogenic activity, shipping and resource extraction (oil sands ~57°N)
- Permafrost soil 1672 PgC, emissions of 4 to 104±34 PgC by 2100 (Schaefer et al., 2011)

Satellite Orbits and Coverage

- **Low Earth Orbit (LEO)**
- Near-polar plane
- If sun-synchronous, Earth's rotation gives global sampling but only at a fixed overpass time

- **Geostationary Orbit (GEO)**
- Near-equatorial plane ~35,800 km altitude
- Synchronized with Earth rotation to give continuous sampling over selected area (<60°N/S)
- TEMPO / GEO-CAPE, Sentinel-4, GEMS for Tropospheric Chemistry



GOSAT (NIES v2.00 2009-08 averaged at 0.9° x 0.9°)

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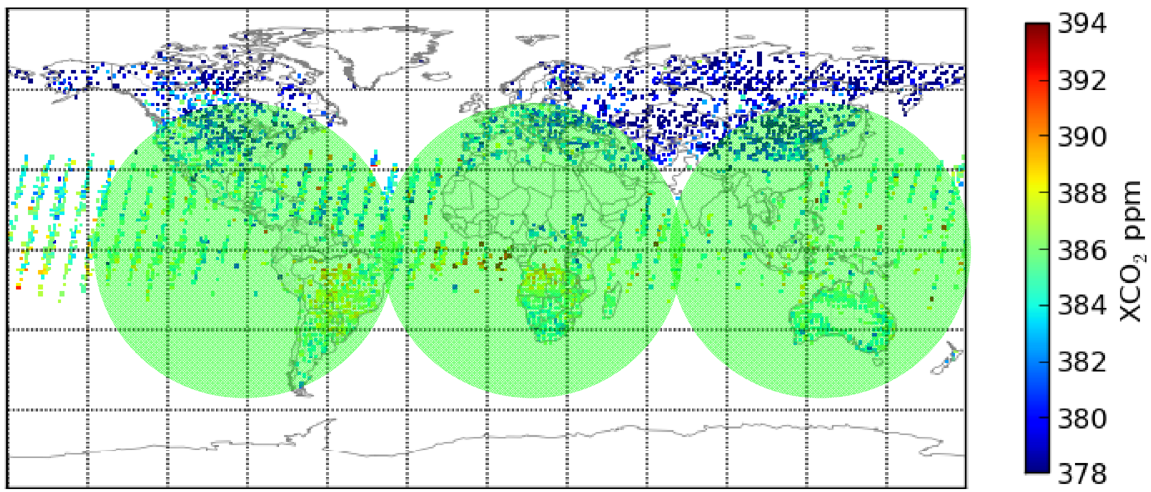
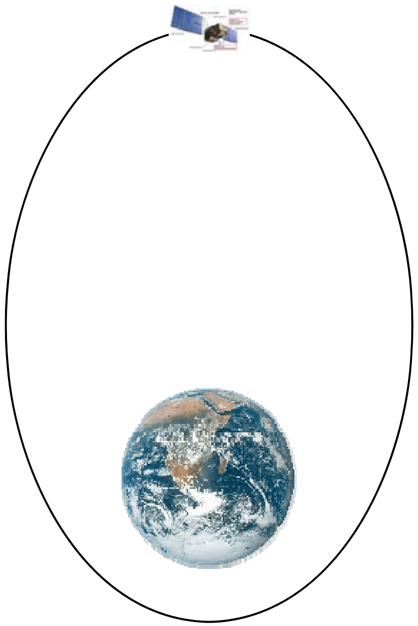


Highly Elliptical Orbit (HEO)

- 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)

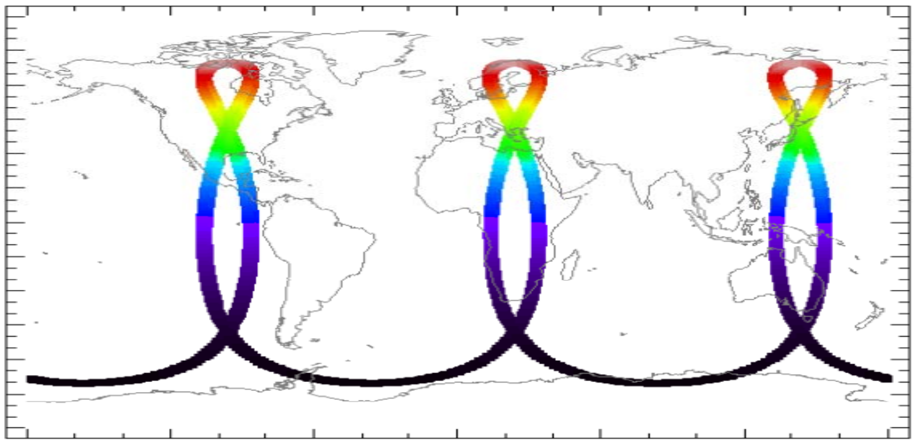
Apogee



Perigee

- 12-24 hour orbit with apogees slightly higher than GEO

Three Apogee Orbit (16-hr)



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

Polar Communications and Weather (PCW)

- Canadian Space Agency led mission with 2 satellites in Highly Elliptical Orbit (HEO) under consideration for launch ~ 2020
- Weather - Environment Canada
  - Operational meteorological imaging instruments for northern latitudes
- Communications - Department of National Defence
  - Increase northern communications capability
- CSA is also considering additional science instruments
- Weather, Climate and Air quality (**WCA**) mission concept is an atmospheric research option that completed Phase A last year, under the Polar Highly Elliptical Orbit Science (**PHEOS**) program

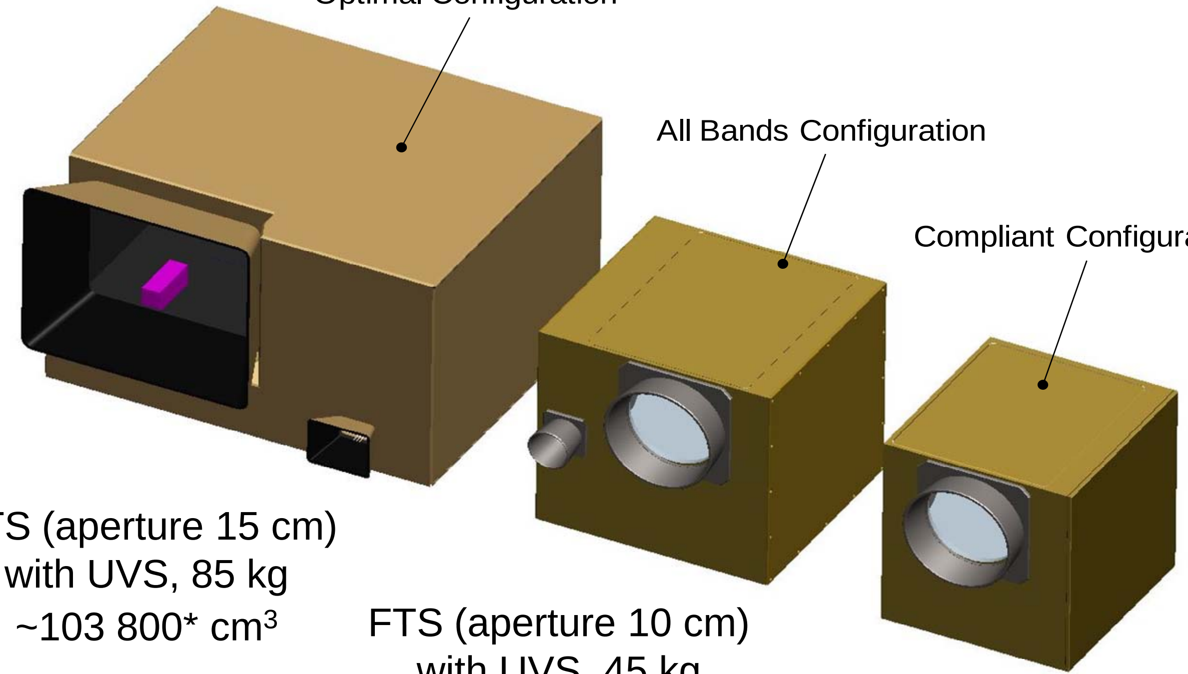
PHEOS-WCA Instrument Configurations

- 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

*volumes shown with 20% contingency

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Observing System Simulation Experiment (OSSE)

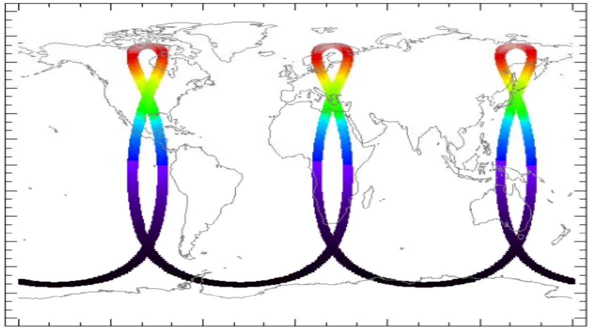
- Objective: Compare the potential information contributed for constraining CO_2 surface fluxes at northern latitudes from HEO vs. LEO

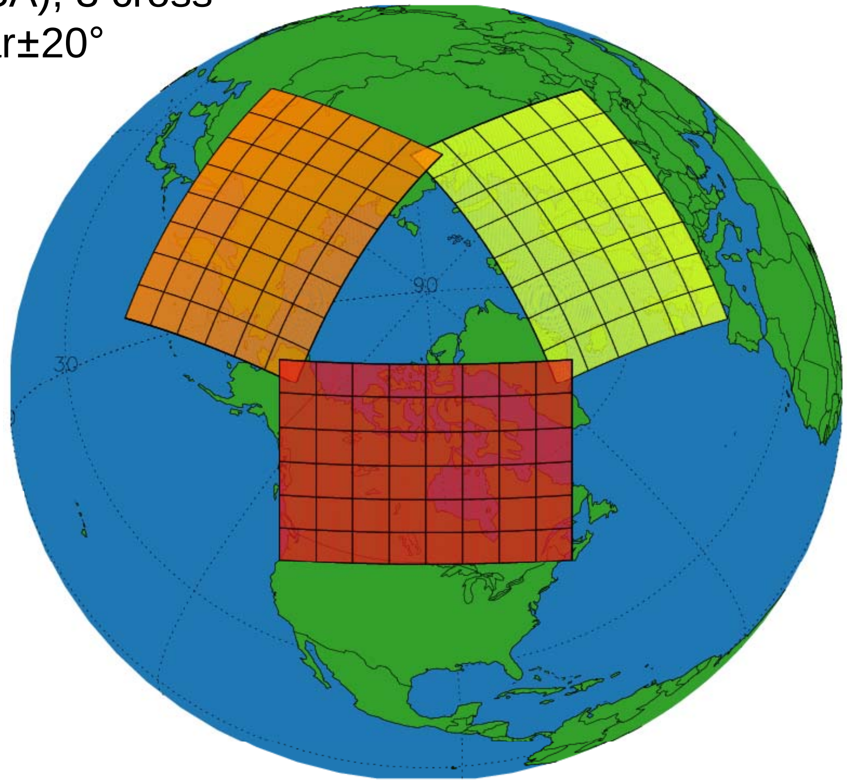
- Approach:
  - Run a model (GEOS-Chem) simulation to obtain a CO_2 distribution to use as the 'Truth'
  - Create 'synthetic observations' for a LEO mission (GOSAT) and a HEO mission (PHEOS-WCA) by sampling the model at hypothetical observation locations/times then adding noise
  - Assimilate each set of synthetic observations to get optimized estimates of CO_2 fluxes and assess posterior flux precision and bias relative to the 'Truth'

Generating Synthetic Observations

Recreated GOSAT orbit using SPENVIS (ESA), 3 cross track obs: orbit track, ±263 km, glint subsolar±20°

Three-APogee (TAP) orbit





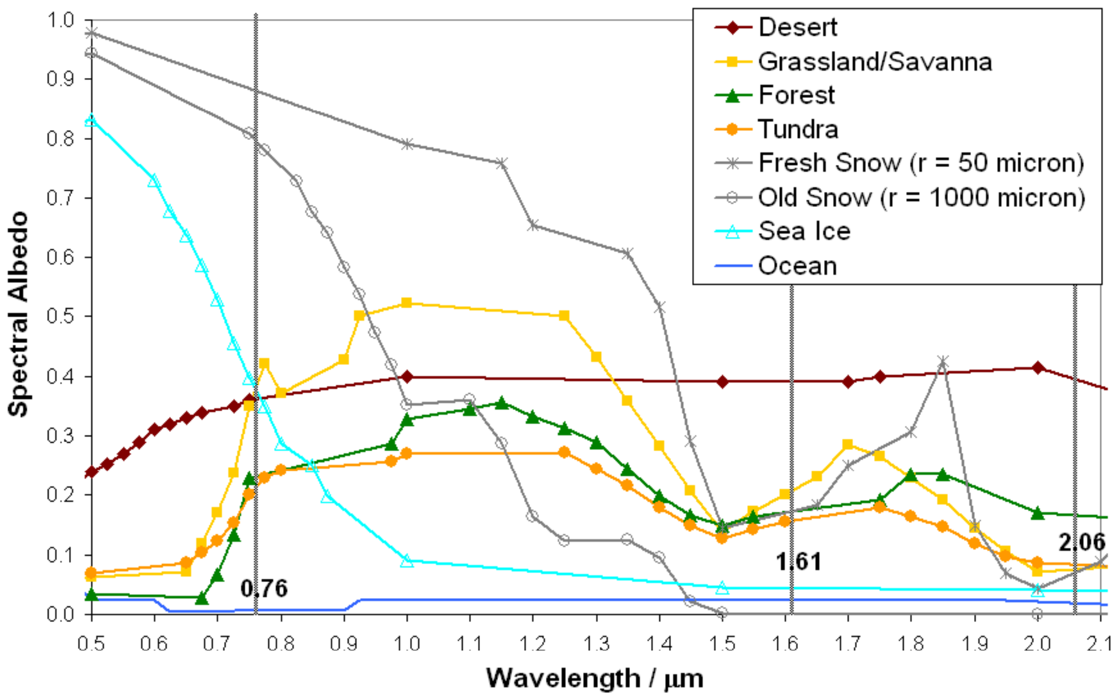
2 satellites, 8h apart in co-planar 16h orbit
Apogee ~43,500 km, Perigee ~8100 km
3 Apogees/day (8:00 and 16:00 local time)
observing ±4 h from apogee giving up to
16 h of data per 48 h per region

Each region/apogee: 48 scans for 100 sec each, consisting of 56x56 array of 10x10 km^2 pixels. Checkerboard pattern of data-thinning to meet downlink requirement, and observations *every other* repeat cycle to accommodate other observing priorities

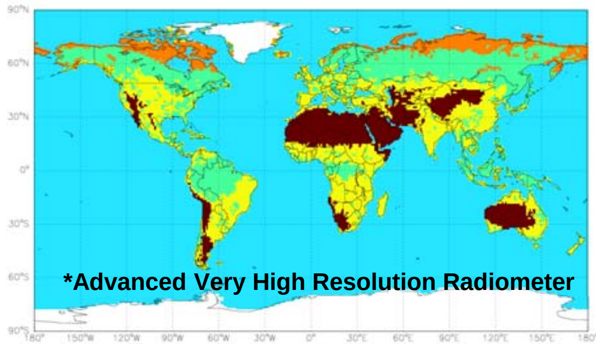
Solar Zenith Angle, Albedo, Cloud

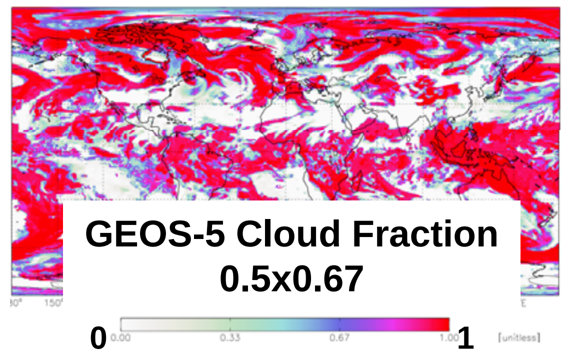
Calculated Solar Zenith Angle (SZA) for each obs and only retained when SZA < 85°

Spectral Albedo Values from MODTRAN



AVHRR* 1°x1° surface types





Signal-to-noise ratio depends on albedo of surface for each band.
Nadir XCO_2 retrievals over ocean, sea-ice and old snow are assumed unlikely.
Used GOSAT v2.0 averaging kernels and covariances for these surface types, scaled according to SNRs (reduced precision by factor of 2 over seasonal snow).

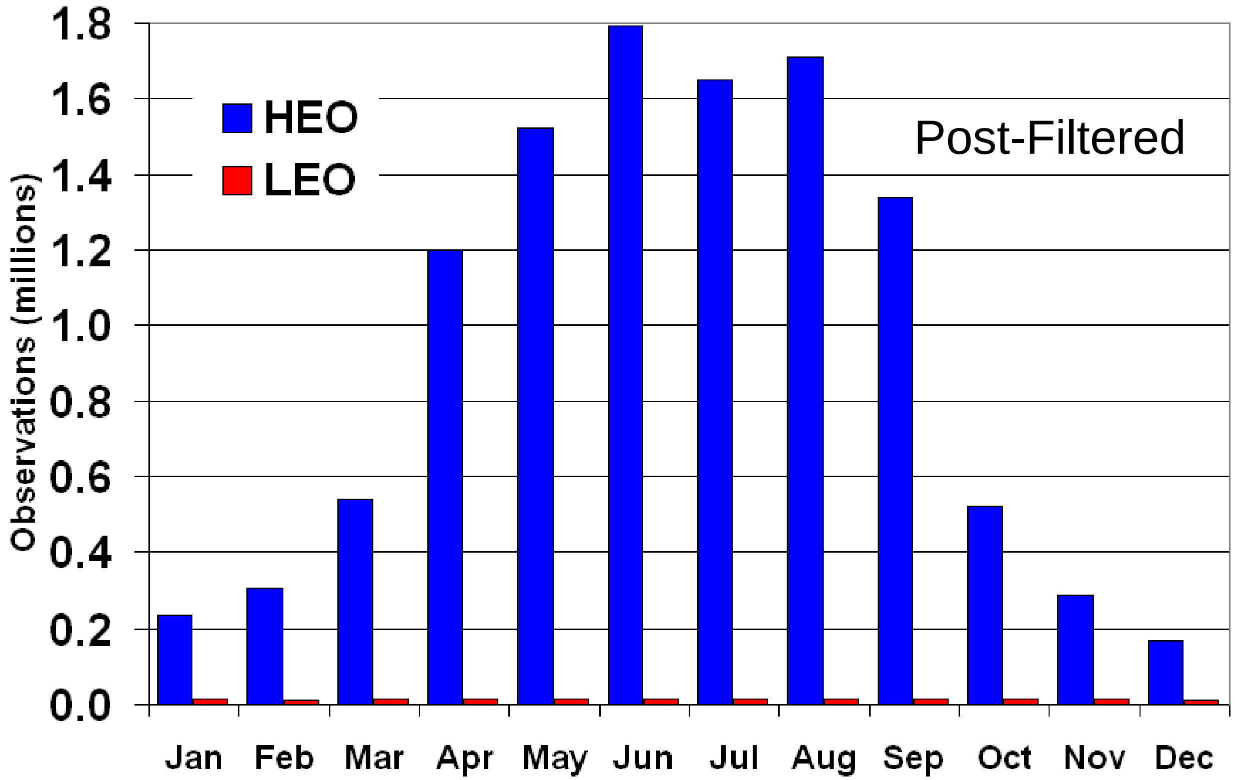
SNR Comparison to Estimate Precision

Instrument	Altitude (km)	Aperture (cm)	Scan Time (s)	1.61 μm res (cm^{-1})	Assumed albedo at 1.61 μm	SZA	SNR at 1.61 μm	Source
TANSO-FTS	665.96	6.8	4	0.20	0.3	30°	> 300	Yokota et al. (2009) SOLA
						60°	**> 228**	Calculated
PHEOS-FTS Optimal (85 kg)	41,200 (max 42,500)	15.0	100	0.25	0.4	60°	> 150	Phase-A closure report (2012)
					0.3		**> 134**	Calculated
PHEOS-FTS All-band (45 kg)	41,200 (max 42,500)	10.0	100	0.25	0.4	60°	> 100	Phase-A closure report (2012)
					0.3		**> 91**	Calculated

SZA change $\sqrt{\cos(60^\circ)/\cos(30^\circ)} = 0.7598$

Albedo change $\sqrt{0.30/0.40} = 0.8660$

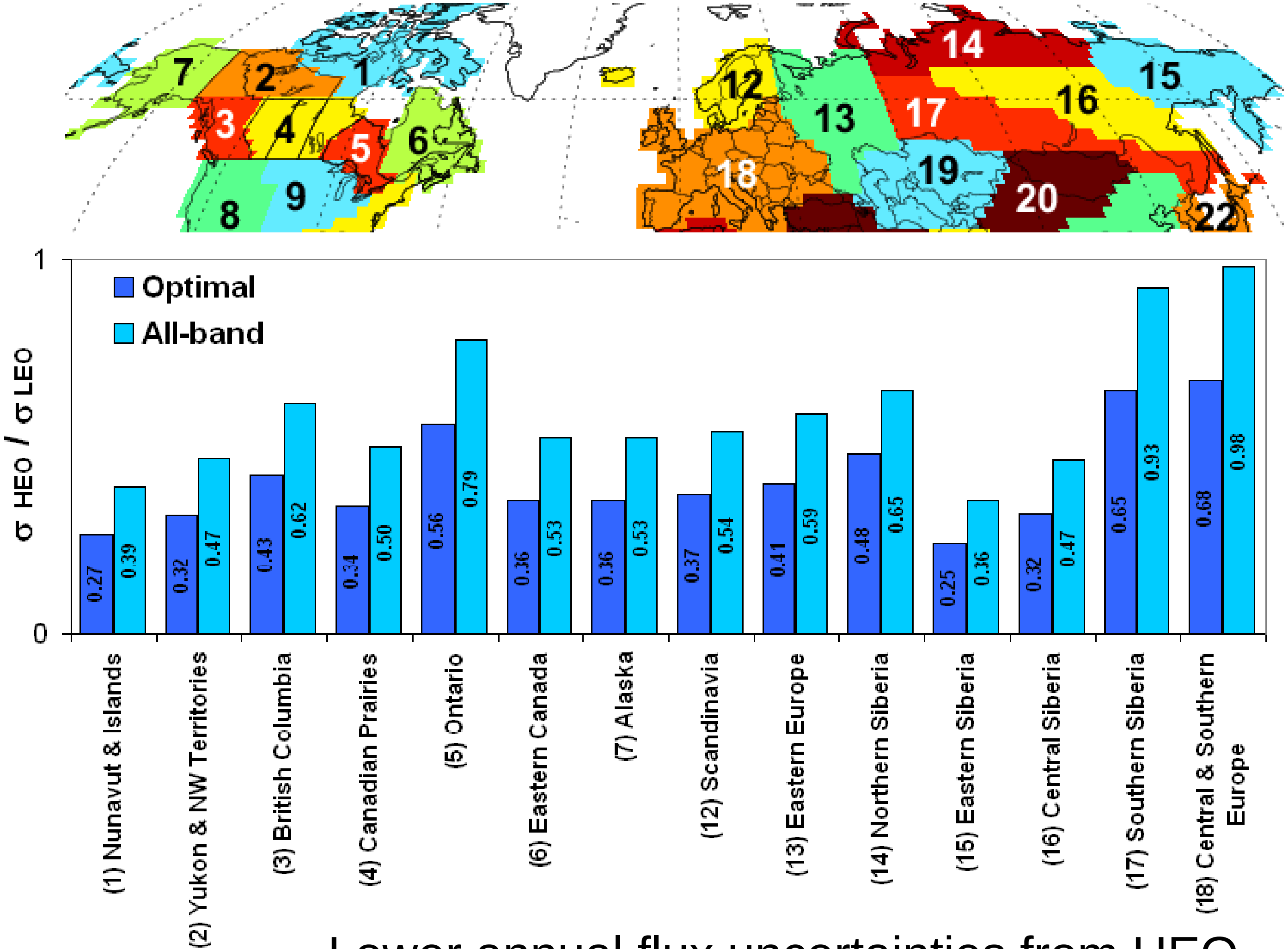
Number of Observations



~14,000 early afternoon obs/month from GOSAT

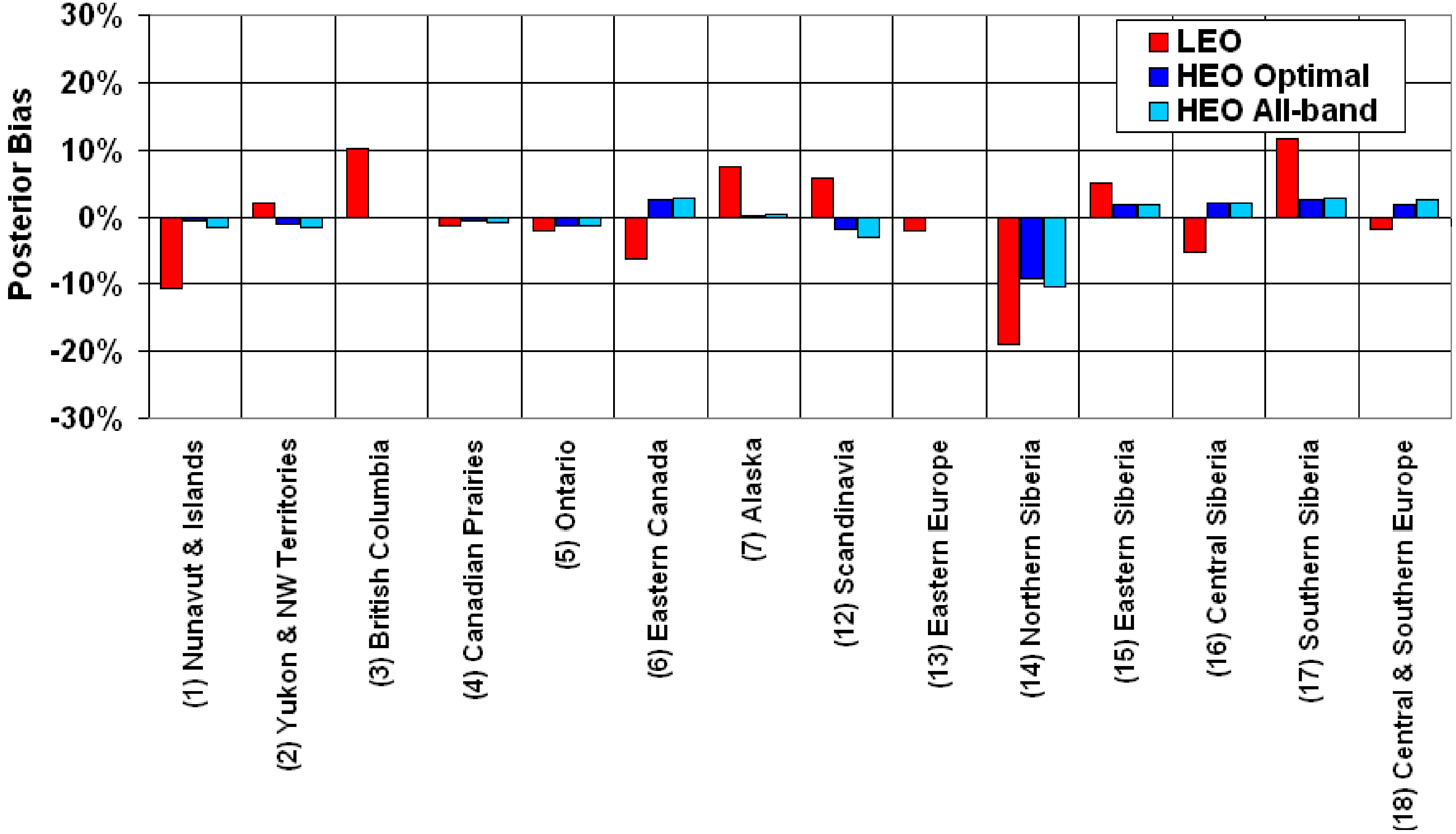
Up to 1.8 million *daytime* obs/month from HEO (with 2D detector array)

Biospheric CO_2 Flux Uncertainties



Lower annual flux uncertainties from HEO

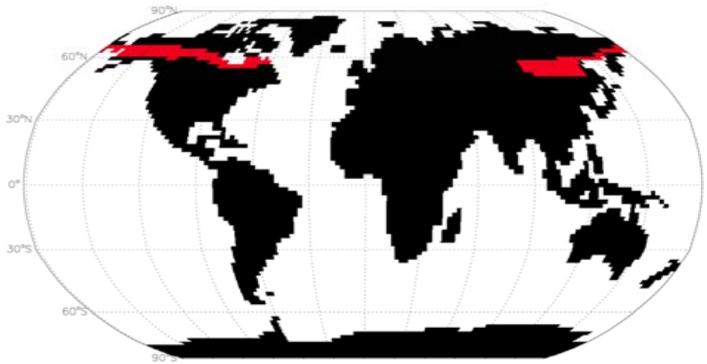
Biospheric CO_2 Flux Biases



Lower annual flux biases from HEO

Could we detect CO_2 emissions from permafrost thaw?

• Simulated slow emission of CO_2 from permafrost thaw: 0.2 PgC Jul-Sep over 6 million km^2 (Schuur et al. suggest 0.8-1.1 PgC/yr by 2100)



• Generated synthetic obs from this simulation and carried out an inversion to quantify these emissions, assuming no prior knowledge

• Although the total (biospheric + permafrost perturbation) fluxes could be constrained within ~2% and assigned to the proper spatial region, distinguishing permafrost emissions from background biospheric fluxes is much like the challenge of separating biospheric fluxes from fossil fuel emissions, making complementary measurements (i.e. CH_4, chlorophyll fluorescence, NDVI, Leaf Area Index (LAI), soil moisture or freeze/thaw, …) extremely valuable

Summary and Conclusions

- CO_2 fluxes at northern high latitudes are important to monitor and HEO allows quasi-geostationary viewing
- OSSEs demonstrate lower CO_2 flux uncertainties and biases from the proposed HEO mission relative to GOSAT for northern mid- and high latitudes (accounting for obs coverage and sensitivity, SNRs, SZA, surface properties, cloud cover, snow cover, etc.)
- Annual CO_2 biospheric flux uncertainties for Canada, Alaska and Northern Eurasia average 39% of those from GOSAT for the *Optimal* configuration and 57% for a smaller configuration (although transport errors, retrieval biases and horizontal correlations have not been accounted for); however, benefits could increase for shorter time periods
- Major emissions of CO_2 from permafrost thaw could likely be detected from HEO, but complementary measurements would be required to disentangle the permafrost emissions from the background biospheric fluxes