Satellite observations of CO₂ from a highly elliptical orbit (HEO) for studies of the carbon cycle at northern latitudes

Ray Nassar¹, John C. McConnell², Dylan B.A. Jones³, Chris E. Sioris², Kaley A. Walker³ and Henry Buijs⁴
¹Environment Canada (ray.nassar@ec.gc.ca), ²York University, ³University of Toronto, ⁴ABB Group

Northern CO₂

- Northern CO₂ uptake/emission from Boreal forests, anthropogenic activity and especially permafrost should be monitored in the future

Why a Highly Elliptical Orbit (HEO)?

- Low Earth Orbit (LEO): often sun-synchronous for atmospheric satellites, which gives overlap at fixed local time
- Geostationary Orbit (GEO): common for meteorological and communication satellites, continuous coverage ~60°N-60°S
- Highly Elliptical Orbit (HEO): can quasi-geostationary coverage of polar region by dwelling near apogee (farthest point from Earth) with 2 or more satellites

Polar Communications and Weather (PCW) is an Arctic-focused Canadian HEO mission to launch around 2019

PCW Orbit Track (48 h)

Three Apogee (TAP) orbit
  - HEO with 16 h period
  - 2 satellites spaced 8 h apart with same ground track
  - 3 apogees/day
  - Apogee altitude ~43,500 km
  - Perigee altitude ~8100 km

PCW-PHEOS-WCA Concept

- Canadian Space Agency is considering additional instruments for PCW under the Polar Highly Elliptical Orbit Science (PHEOS) program including the Weather, Climate and Air quality (WCA) concept
  - Instruments: Fourier Transform Spectrometer (FTS) and a UV-Vis grating spectrometer (UVS)
  - XCO₂ capability is desirable, but puts WCA over the size and mass allocations (30x30x30 cm³, 50 kg)

Proposed FTS Spectral Bands (cm⁻¹)
- 700-1500, 1800-2700, 5990-6257 (NIR CO₂ and CH₄)
- 13060-13168 (O₂ A-band)

Optimal: FTS aperture 15 cm, UVS included
- All spectral bands, 85 kg, ~103 800 cm³

All Band: FTS aperture 10 cm, UVS included
- All spectral bands, 45 kg, ~35 128 cm³

No O₂ A-band or NIR CO₂
- 37 kg, ~25 184 cm³

Observing System Simulation Experiment (OSSE) Details

Model:
- GEOS-Chem using CarbonTracker-2010 bio and ocean fluxes, plus CDIAC fossil fuels, GFEDv3

Synthetic observation locations:
- LEO - Recreated GOSAT orbit using SPENVIS, obs over land and glint (sub-solar angle ±20°)
- HEO - 3 Apogees: 65°N at 95°W, 35°E, and 155°E at 8:00 or 16:00 local time.
  - Field of Regard (FOR): 4480 x 3300 km² = 8 (56x56) arrays x 6 (56x56) arrays, 10x10 km² pixels.
  - Observing time: 4 h from apogee giving up to 16 h of data per 48 h per region.
  - 100 second scan x 48 arrays = 80 min to scan region (12 obs per pixel per 48 h).
  - Checkerboard pattern of data-thinning to meet downlink requirement, and observe only every other repeat cycle to accommodate other observing priorities. No glint capability.

Objective:
- Compare the ability to constrain northern high latitude CO₂ surface fluxes from HEO vs. LEO observations

Method:
- Run model to get a CO₂ distribution to use as the ‘Truth’
- Create ‘synthetic observations’ for GOSAT-like orbit (LEO) and TAP orbit (HEO) by sampling the model at hypothetical observation locations/times and adding noise
- Assimilate each set of synthetic observations to optimize estimates of CO₂ fluxes and assess posterior flux uncertainties

Results:
- HEO gives dense coverage of land north of ~50°N in summer
- Lower posterior CO₂ flux uncertainties and biases from HEO than from LEO for northern mid/high latitude land regions, especially from the ‘Optimal’ instrument configuration

Conclusion:
- PCW-PHEOS-FTS with NIR CO₂ measurement capability would be an extremely valuable asset for monitoring northern CO₂ sources and sinks, synergistic with LEO & GEO missions