National Aeronautics and Space Administration

Explorer Greenhouse gases.

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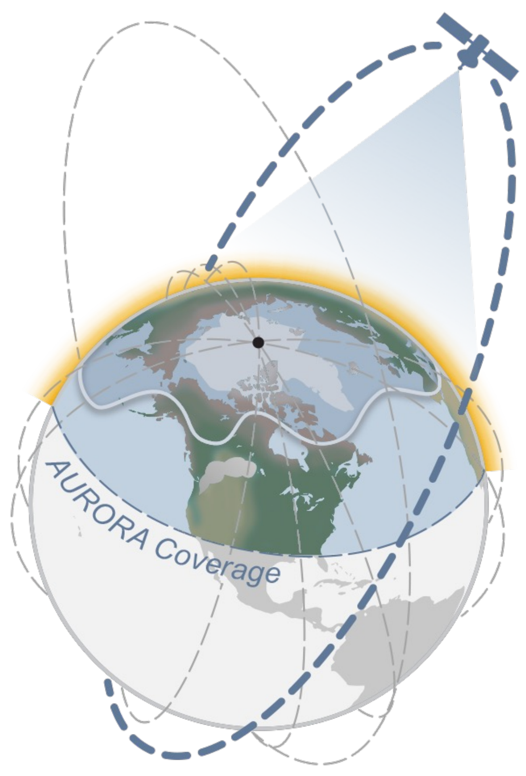

Figure 1. AURORA measures arctic CO_2 + CH_4 to inform global C balance

Objectives: Our GHG ESE concept maturation objectives aim to resolve long-standing questions about C emissions resulting from emerging tipping points in critical ecosystems, for example (a) permafrost thaw in Arctic, (b) methane production in tropical wetlands, (c) CO2 outgassing from northern Africa, and (d) peatland drainage in southeast Asia. We address these critical questions using retrieval and flux OSSEs, leveraging multi-spectral (NIR + TIR) retrievals of multiple species (CO2, CH4, CO, SIF, wind), and sub-daily to daily spatially resolved mapping. Our objectives are to: (1) Quantify grid scale flux uncertainty reduction due to (a) multispectral retrievals (NIR+TIR), (b) subdaily sampling, and (c) joint GHG/wind retrieval; (2) Determine the detectability of abrupt GHG emissions enabled by NIR+TIR retrieved partial columns; (3) Optimize PanFTS instrument design to achieve pan-Arctic (**Fig 1**) and global (**Fig 5**) GHG science.

Background: The 2017 Earth Decadal Survey (DS) established the NASA ESE mission line, which calls for PI-led concepts in 7 investigation categories over the next decade. This proposal focuses on concept and technology maturation for a TO concept focusing on GHGs. Our concept considers panFTS in different orbits (HEO, GEO, MEO) to optimize C cycle science return at regional- to global- scale.

Approach and Results: Our technical approach consists of 4 steps:

(1) **Retrieval OSSE.** Incorporate Pan-FTS configuration into RTM and retrieval simulation, combining TIR and NIR bands from a single instrument to retrieve column and partial column CO_2, CH_4, and CO at global scale. Determine GHG concentrations with sufficient surface sensitivity and precision during day and night to resolve surface flux variability across land surface gradients. The combined daytime NIR+TIR bands achieve 2-2.5 DOFs and 0.25-0.4% precision at 12 x 12 km with 7.5 minute/FOV stare time (**Fig 2**)

(2) **The Flux Inversion OSSE. Le**verage JPL CMS-Flux inversion system to assimilate Pan-FTS column and partial column data to quantify flux retrieval and uncertainty reduction relative to PoR. We are working to retrieve and assimilate CO_2 partial columns within CMS-Flux to localize CO_2 emission processes. Work using CO2M pseudo-data shows 50-100% uncertainty reduction at sub-continental scale (**Fig 3**). Ongoing experiments using subdaily pseudo-data at high latitudes (AURORA) will quantify further uncertainty reduction at regional and grid scale (5x4) in weekly intervals, to achieve enhanced grid scale uncertainty reduction over CO2M.

(3) **Flux Perturbation OSSE**. Leverage forward atmospheric transport simulations to determine detectability of slow and abrupt emissions. Preliminary work using flux anomalies in GEOS-Chem shows improved detection of anomalies with more frequent column sampling, (**Fig 4**).

(4) **PanFTS trade studies**. Focus on optimization of the interferometer design, evaluating aspects of the digital FPA.

The Pan-FTS is capable of imaging on 6.6 minute timescales over ~2000 km x 2000 km spatial region across five spectral bands spanning 650 cm-1 to 14500 cm-at <0.1 cm^{-1} spectral resolution and < 4 km spatial resolution. No previous flight instrument has matched its sensitivity, ability to discriminate GHG concentrations in L/U troposphere, or ability to study multiple targeted observables at multiple timescales. This SRTD has demonstrated the potential for panFTS to produce novel GHG science over the pan-Arctic using sub-daily mapping of vertical profiles in HEO, and global GHG science using daily global mapping from MEO (**Fig 5**).

Profiles	CO2 (SWIR + TIR)		CH4 (SWIR + TIR)	
	DOFS (Column)	Mean Precision (Surf-500hPa)%	DOFS (Column)	Mean Precision (Surf-500hPa)%
Spring Forest Day	2.5	0.37	1.8	0.51
Spring Snow Night	1.9	0.49	1.7	0.57
Summer Forest Day (S)	2.2	0.43	1.9	0.52
Summer Forest Day (N)	2.3	0.38	2.1	0.54
Summer Snow Day	2.1	0.41	2.0	0.59
Fall Forest Night	1.8	0.39	1.4	0.61
Fall Forest Day	2.1	0.38	1.8	0.49
Winter Forest Night	1.9	0.62	1.2	0.87
Winter Snow Night	1.9	0.62	1.2	0.87

Figure 2. AURORA Retrieval OSSEs (panFTS in HEO) show that combined SWIR and TIR retrievals provide 2 DOFs (< 0.5% precision in LT) in column in daytime (yellow highlight).

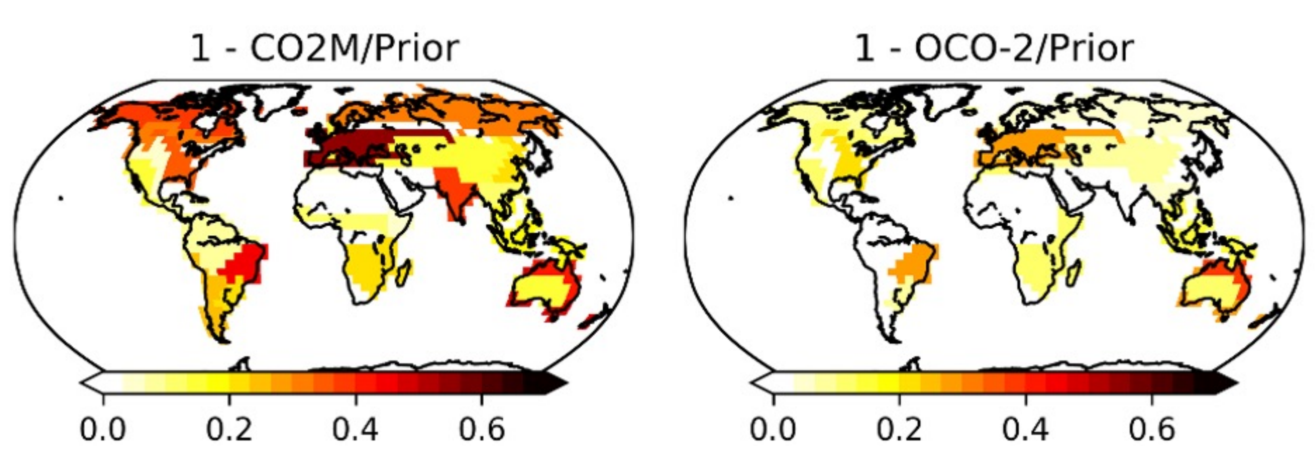

Figure 3*. Regional flux uncertainties decrease with high repeat frequency, but grid scale reductions are elusive. This example shows regional uncertainty reductions of 50-75% in CO2M (left, 3 day sampling), and <20% for OCO-2 (16-day).*

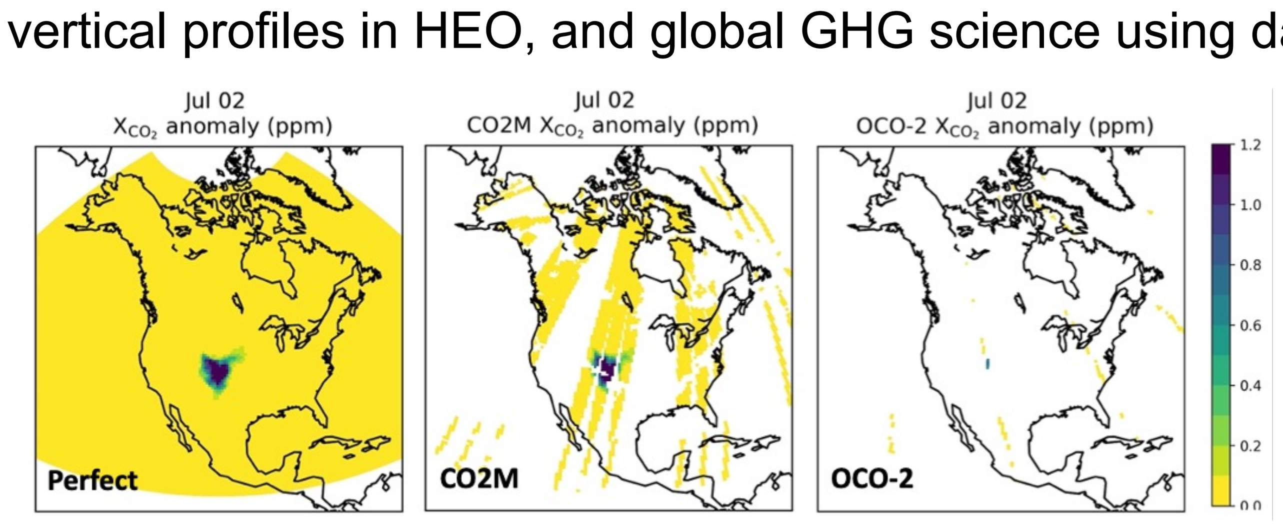

Figure 4*. Signal detection OSSE shows importance of high repeat frequency for observing episodic pulses. This example shows XCO2 signatures in forward model simulations for 10 Tg C pulse emissions from July 1-3, which is better detected by CO2M than OCO-2.*

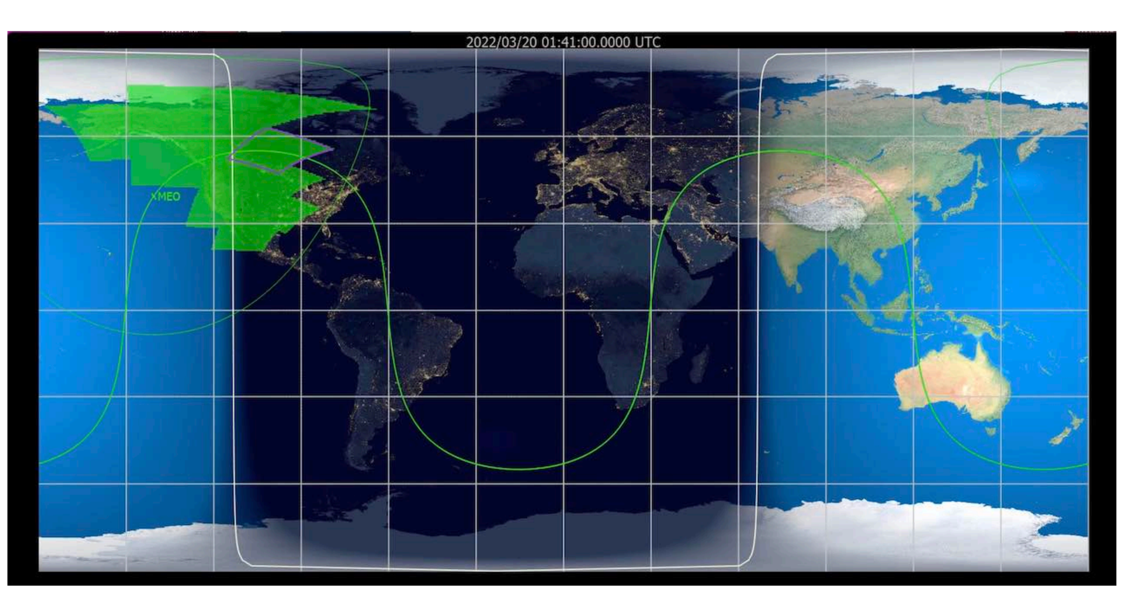

Figure 5. Medium Earth Orbit (MEO) has potential to provide global daily terrestrial coverage.

Significance/Benefits to JPL and NASA:

Retrieval OSSE's demonstrate the potential of the JPL designed multi-spectral panFTS retrieve sub-daily maps of CO2 and CH4 vertical profiles (2+ DOFs; sfc – 500 mb, 500 mb – TOA) in high latitudes from HEO. This offers advanced GHG spectral, spatial, and temporal sampling relative to PoR. Increased sampling of pan-Arctic across multiple dimensions will significantly advance our ability to detect slow and abrupt carbon emissions across land surfaces, reduce carbon-climate feedback NASA goals, and address key DS GHG objectives.

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