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Four Years of CARVE-FTS Observations of CO_2, CH_4, CO, and SIF in the Alaskan Arctic: Status Quo and Comparison with Satellite Measurements

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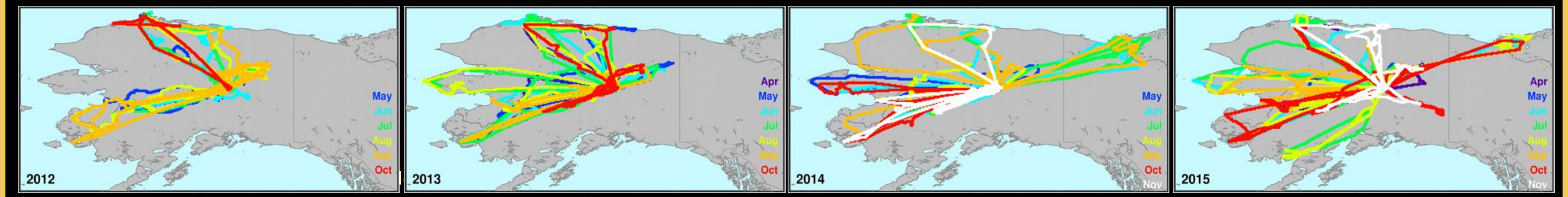
Overview

The Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) is an aircraft-based Earth Venture 1 mission to study the carbon balance of the Alaskan Arctic ecosystem, with a particular focus on carbon release from thawing permafrost. Operating from its base in Fairbanks, AK, the CARVE aircraft covered a range of principle flight paths in the Alaskan interior, the Yukon River valley, and northern Alaska coast around Barrow and Dead Horse. Flight paths were chosen to maximize ecosystem variability and and cover burn-recovery/regrowth sequences. CARVE observations cover the Arctic Spring/Summer/Fall seasons, with multiple flights per season and principle flight paths. Period of science operations: 05/2012 – 11/2015.

The CARVE suite of instruments includes flask measurements and *in situ* gas analyzers for CO_2, CH_4 and CO observations, a FLIR infrared camera for surface conditions, and a nadir-viewing, three-band polarizing Fourier Transform Spectrometer (FTS) for column measurements of CO_2, CH_4, CO, and interfering species (*e.g.*, H_2O, N_2O). The FTS covers the spectral regions of 4,200-4,900 cm^{-1} (CO_2, CH_4, CO), 5,800-6,400 cm^{-1} (CO_2, CH_4, H_2O), and 12,900-13,200 cm^{-1} (O_2, chlorophyll fluorescence), with a spectral resolution of 0.2 cm^{-1}.Science observations in Alaska have been performed between 2012-05-23 and 2015-11-12. Currently, data products from all CARVE instruments for 2012–2015 are publicly available [1].



CARVE FTS Retrieval Approach

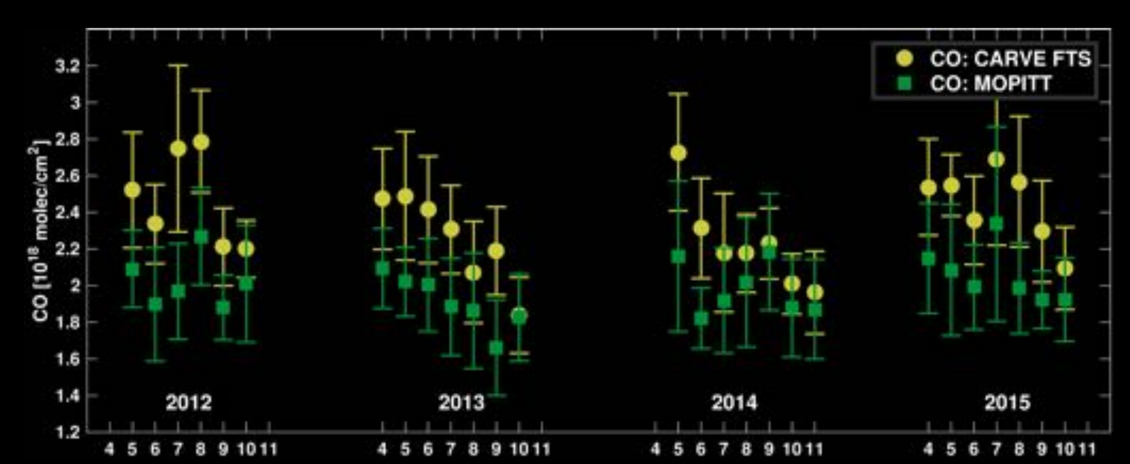
CARVE FTS observations provide total (vertical) and dry-air columns of CO_2, CH_4, CO, and H_2O, as well as solar-induced chlorophyll fluorescence (SIF). The current "quick look" trace gas retrieval approach uses the TCCON GGG software package [2], modified for aircraft nadir-viewing geometry to account for the additional atmospheric light path between the aircraft and the Earth's surface. SIF is retrieved from the spectral regions around the O_2 *A* band, using the approach by Frankenberg *et al*. [3]. While the atmospheric SIF signal is stronger at longer wavenumbers, the CARVE FTS has limited spectral coverage and lower signal-to-noise in that region. SIF is therefore retrieved at shorter wavenumbers, *i.e.*, in the 774—776 nm range. The table below summarizes the retrieval windows for SIF and the various trace gas targets.

Band	O_2	CO_2	CH_4	CO	H_2O	SIF
1	13,060–13,100					12,885–12,920
2		6,180–6,260	6,007–6,145		5,770–5,920	
3		4,805–4,855	4,215–4,305	4,252–4,327	4,695–4,765	

CARVE FTS fitting windows [cm^{-1}].

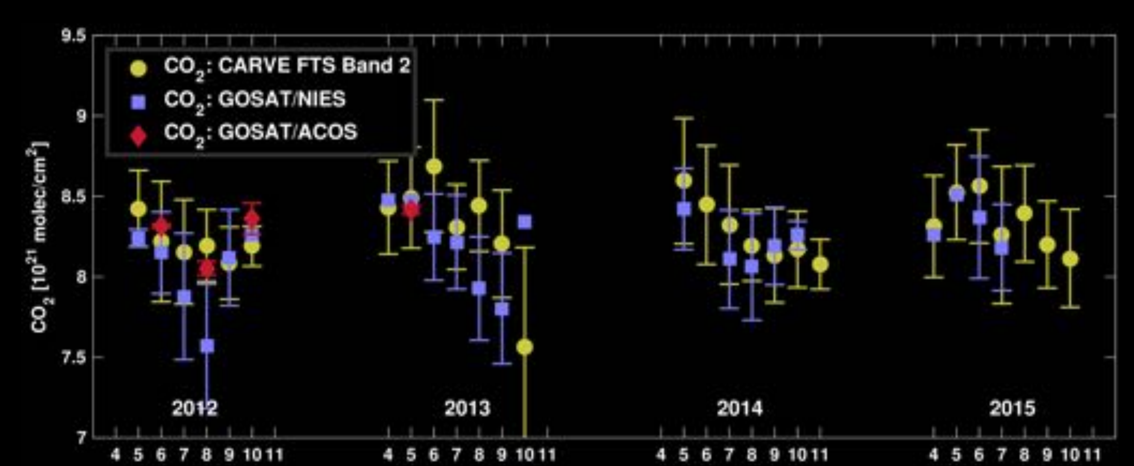
Comparison with MOPITT CO, GOSAT CO_2 and CH_4, and OCO-2 CO_2

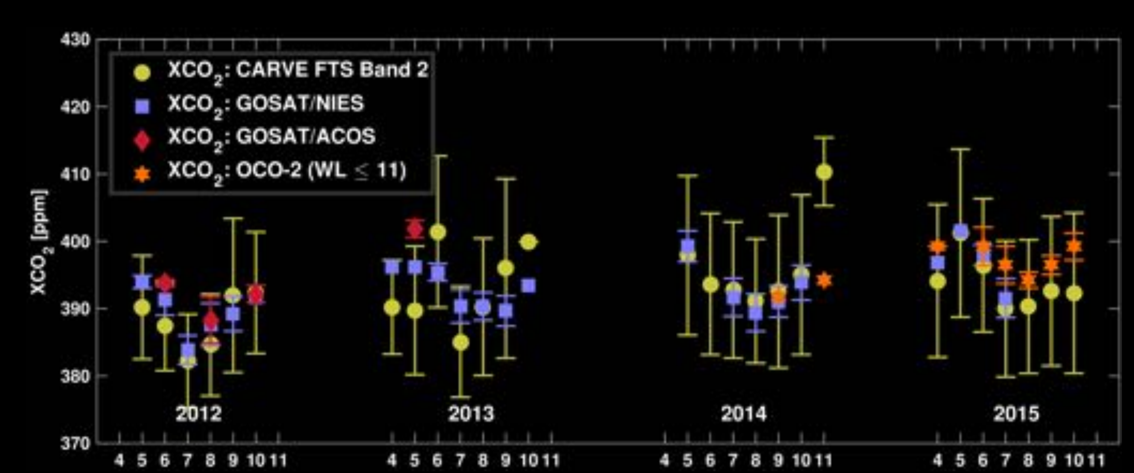
For preliminary comparison with independent satellite observations, CARVE FTS total column measurements of (X)CO_2, (X)CH_4, and CO during 2012—2015 have been averaged by month, over all flight days and flight paths for that month. MOPITT v6 CO observations [4], GOSAT/NIES v2.21/2.31/2.40 (X)CO_2 and (X)CH_4 [5], GOSAT/ACOS v3.4 (X)CO_2 [6,7] , and OCO-2 v7 XCO_2 [8] have been averaged for the same days as the CARVE flights, where available. For improved statistics, the spatial averaging domain for the satellite observations was extended to the whole of Alaska rather than limited to collocated measurements with the CARVE flight tracks.

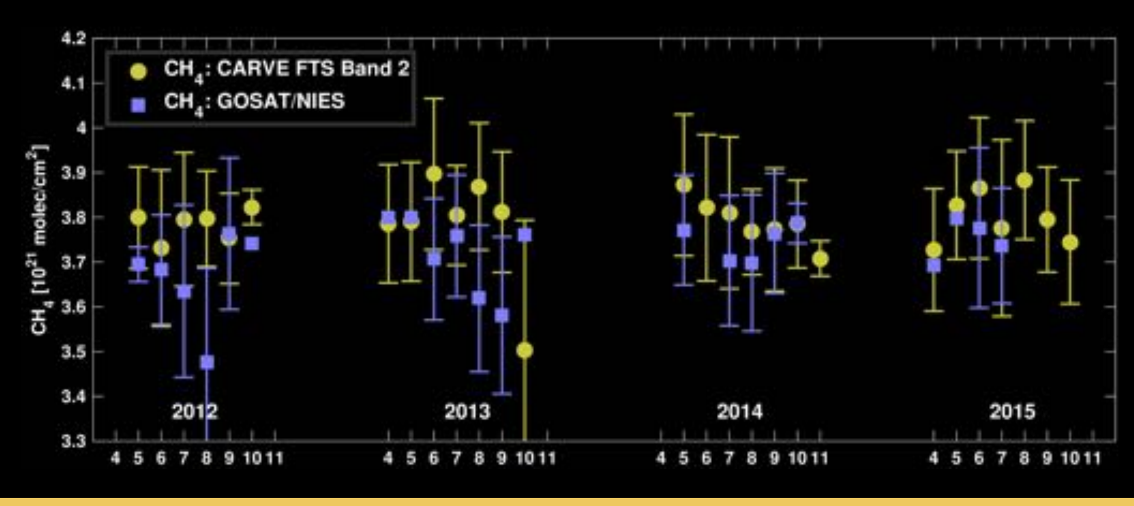


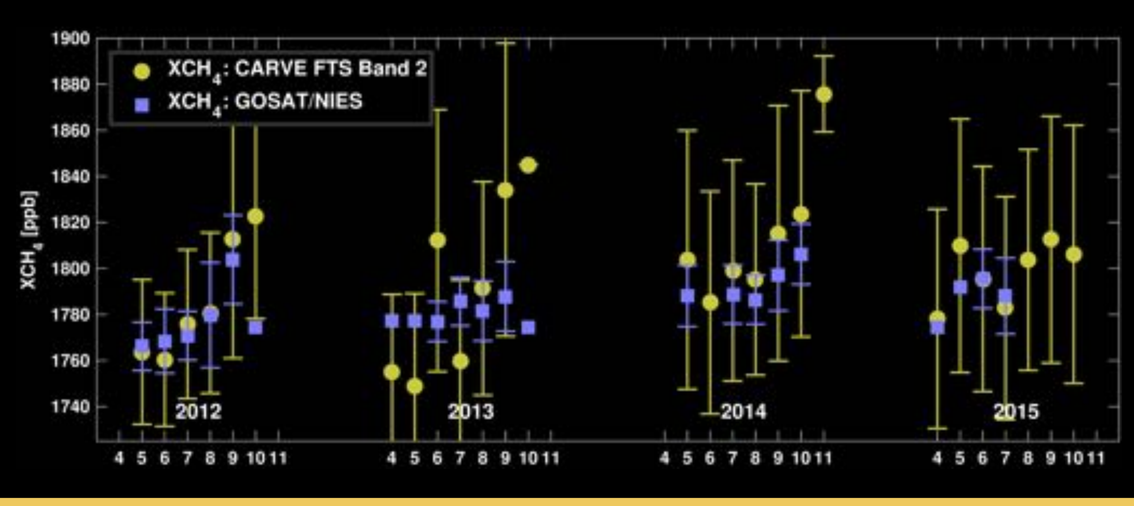
The images show the comparison of the CARVE FTS results with satellite data. Error bars indicate the standard deviation of the averaged total column values rather than actual retrieval uncertainties, since the spread of the column value distribution is dominated by the variation of the retrieved values over the temporal and spatial averaging domain.

(Changes to the CO spectroscopy in the latest TCCON GGG version increased average CARVE CO by roughly 10%.)



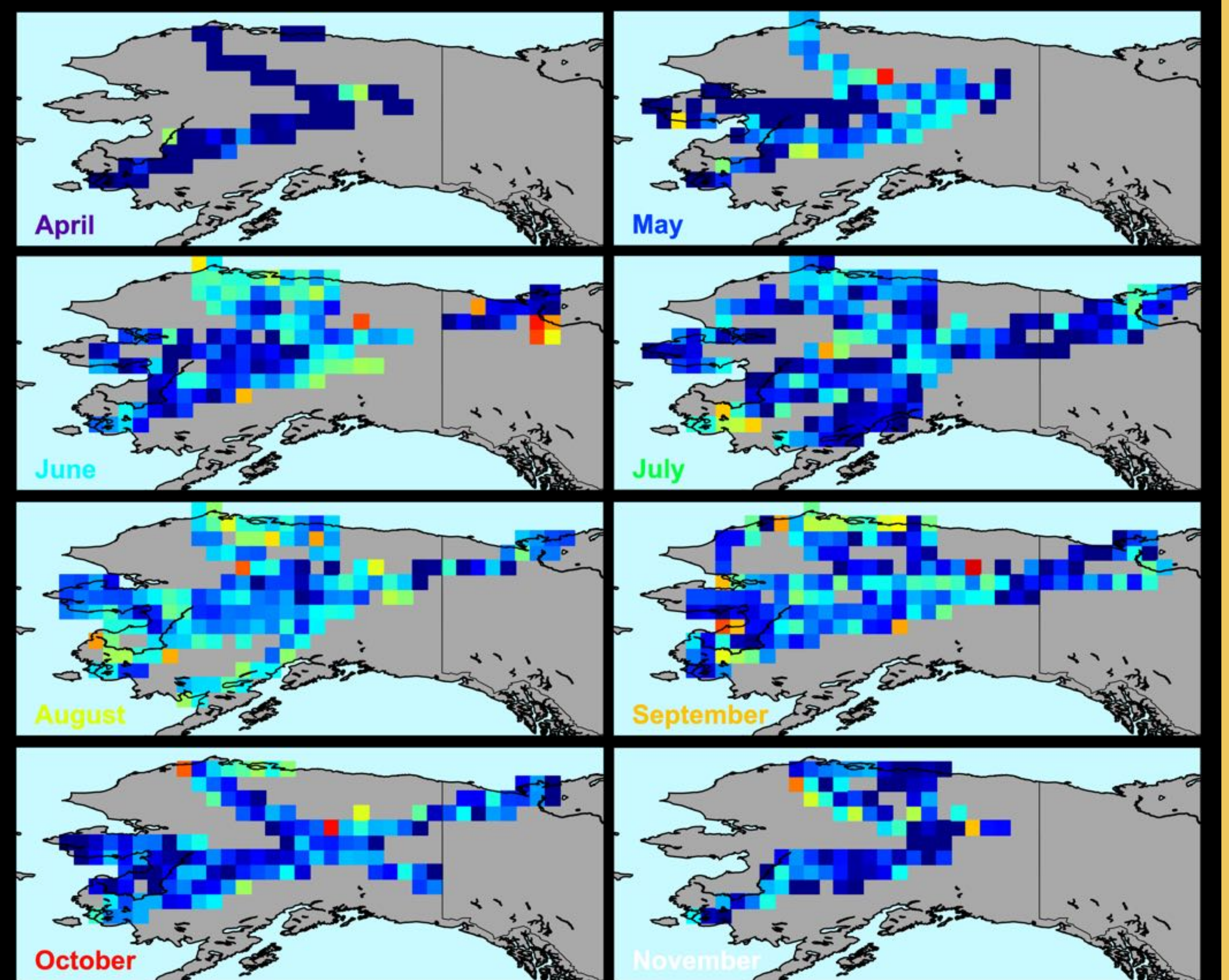


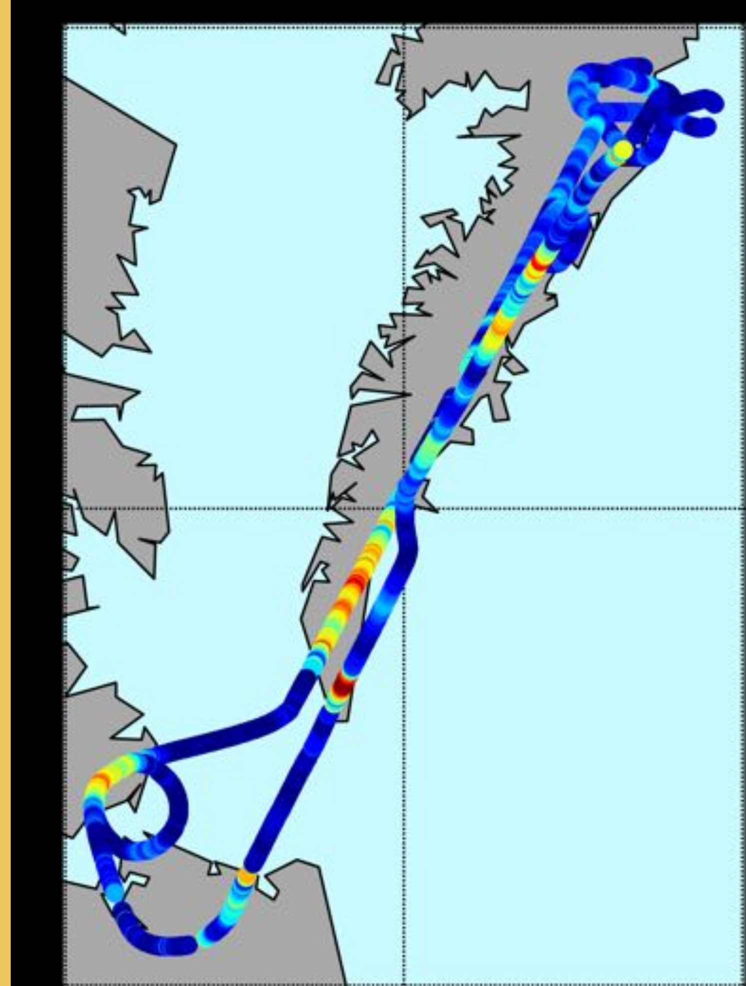




Solar-Induced Fluorescence from CARVE

SIF retrievals from CARVE have been initiated recently and are still preliminary. The FTS is as yet not radiometrically calibrated, thus SIF values cannot be compared directly to independent observations from OCO-2 or GOSAT. In the images, warmer colors represent higher SIF values, thus higher plant activity and higher carbon uptake. Next steps will focus on algorithm refinement and tuning, as well as the radiometric calibration of the FTS using blackbody measurements.





Above: 1°x1° averages of CARVE SIF observations by month over the 2012—2015 observation period. Warmer colors represent higher SIF values, corresponding to increased plant activity. SIF data have been normalized to the continuum signal. The color scale covers he SIF value range of 0—5%.

Left: Absolute SIF values (not averaged or normalized) from the test flight on 2012-05-13 over Wallops Island, VA, for an FTS co-adding factor of 25. SIF plotrange is 0—$5x10^{-5}$.

[1] CARVE Public Release Data Portal, at http://ilma.jpl.nasa.gov.
[2] TCCON GGG, algorithm description and software available at https://tccon-wiki.caltech.edu/Software/GGG (registration required).
[3] Frankenberg *et al*., *Remote sensing of near-infrared chlorophyll fluorescence from space in scattering atmospheres: implications for its retrieval and interference with atmospheric CO_2 retrievals*, Atmos. Meas. Tech., 5, 2012.
[4] MOPITT CO v6, product user's guide available at http://www.acd.ucar.edu/mopitt/v6_users_guide_beta.pdf
[5] Morino *et al*., *Preliminary validation of column-averaged volume mixing ratios of carbon dioxide and methane retrieved from GOSAT short-wavelength infrared spectra*, Atmos. Meas. Tech., 4, 2011.
[6] O'Dell *et al*., *The ACOS CO_2 retrieval algorithm – part1: description and validation against synthetic observations*, Atmos. Meas. Tech., 5, 2012.
[7] ACOS/OCO CO_2, data center https://oco.jpl.nasa.gov/ocodatacenter/, v3.4 product guide available at http://disc.sci.gsfc.nasa.gov/datareleases/acos-version-3.4
[8] OCO-2 Science Team/Michael Gunson, Annmarie Eldering (2015),*OCO-2 Level 2 full physics retrievals of bias-corrected XCO2 and other select fields aggregated as daily files, version 7*, GES DISC.

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