Satellite validation with EM27/SUN measurements in Fairbanks, Alaska

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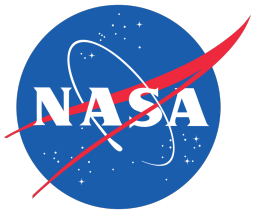
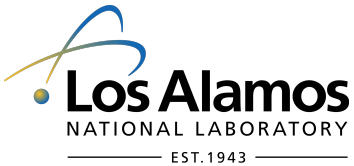


Fairbanks COCCON collaborators:

- Karlsruhe Institute of Technology (KIT): **Frank Hase, Thomas Blumenstock, Qiansi Tu, Matthias Frey, Darko Dubravica**
- Los Alamos National Laboratories (LANL): **Manvendra Dubey, Harrison Parker**



OCO-2 collaborators:

- NASA Jet Propulsion Laboratory (JPL): **Gregory Osterman and many others**
- Colorado State University (CSU): **Christopher O'Dell**

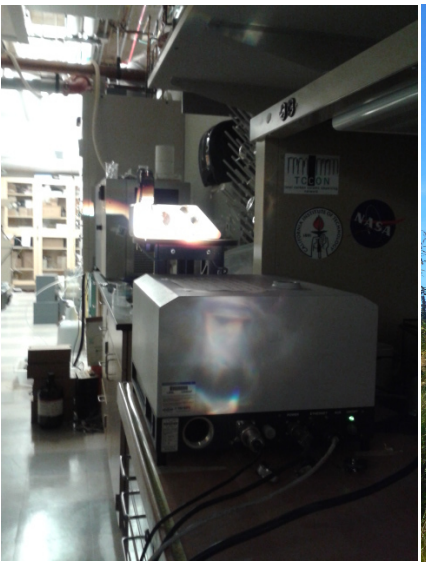
GGG and Caltech collaborators:

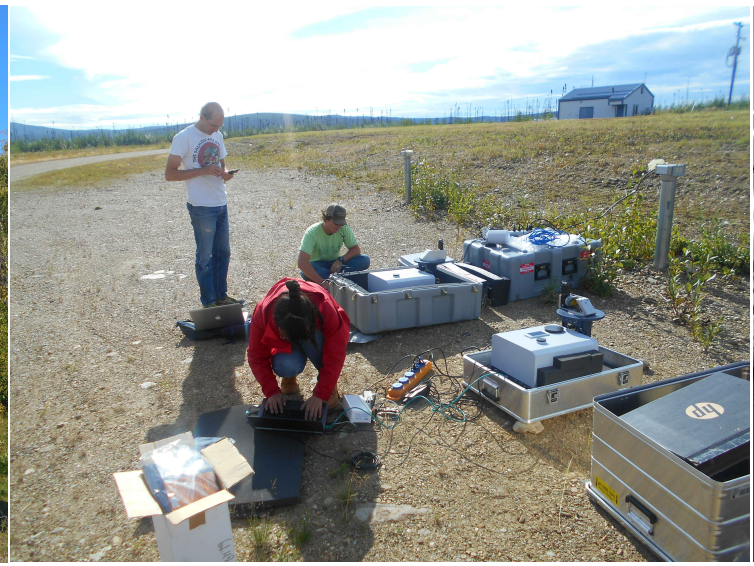
- University of Toronto: **Debra Wunch, Jacob Hedelius, and others**
- Los Alamos National Laboratory (LANL): **Sajjan Heerah**
- University of California Riverside: **Isis Frausto-Vicencio**

Observations in Fairbanks, Alaska

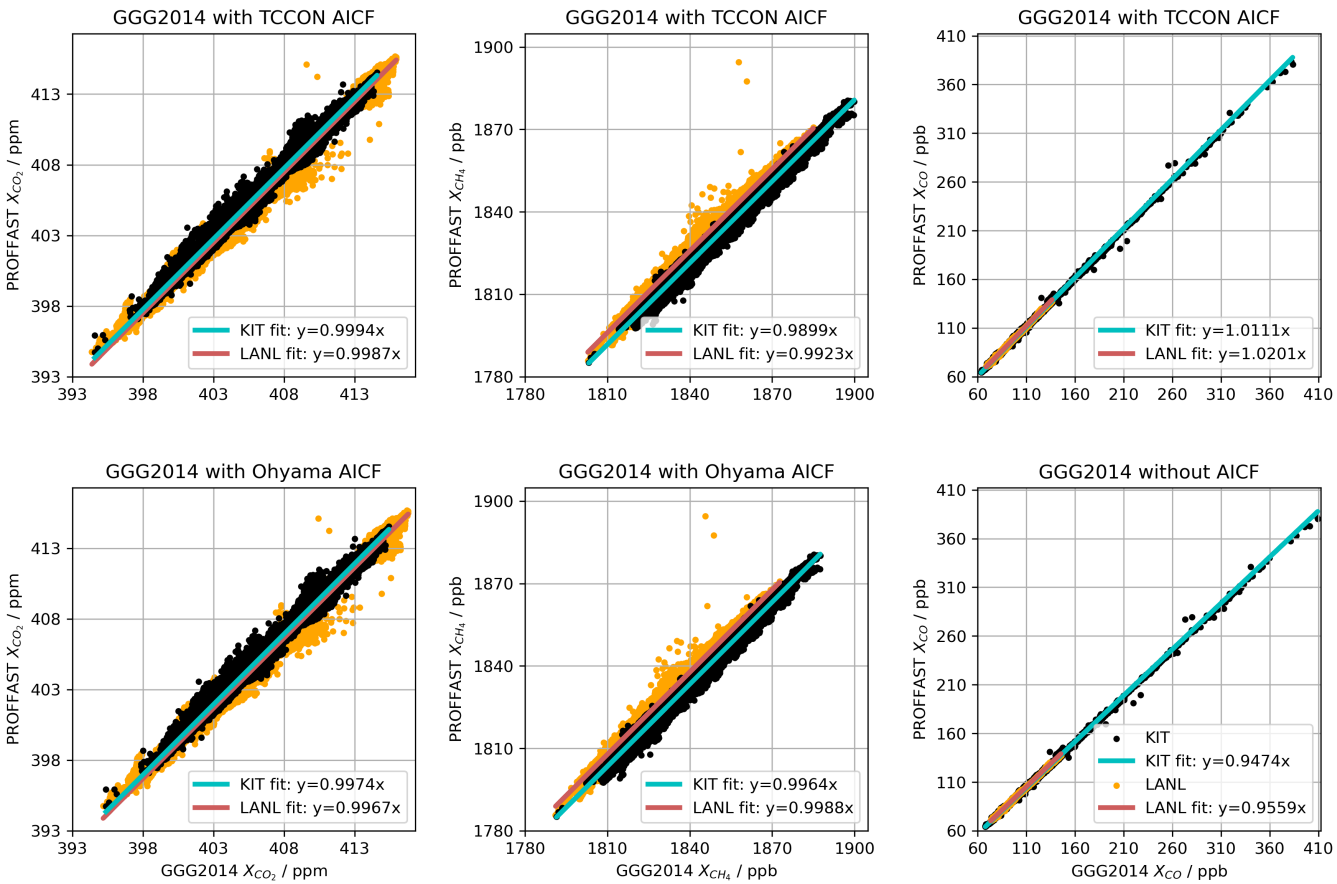
- Field campaign in Fairbanks area August-October 2016 (KIT and LANL EM27/SUNs)
- Observations at UAF March-November 2017 (LANL EM27/SUNs)
- Early 2018 upgrade to dual detector (KIT and LANL EM27/SUNs)
- Observations at UAF ∼April-November 2018-2019 and 2021-present (KIT EM27/SUN)
- Observations at UAF April-August 2020 (LANL EM27/SUN)
- Colocated observations and instrument swap to KIT EM27/SUN in August 2020

- Surface pressure was measured on site with multiple calibration analyses between different pressure measurements, as well as sensitivity tests with the retrievals.
- The altitude on the roof of the Geophysical Institute at UAF was measured with a GPS satellite retriever stationed on the roof.






GGG2014 vs. PROFFAST



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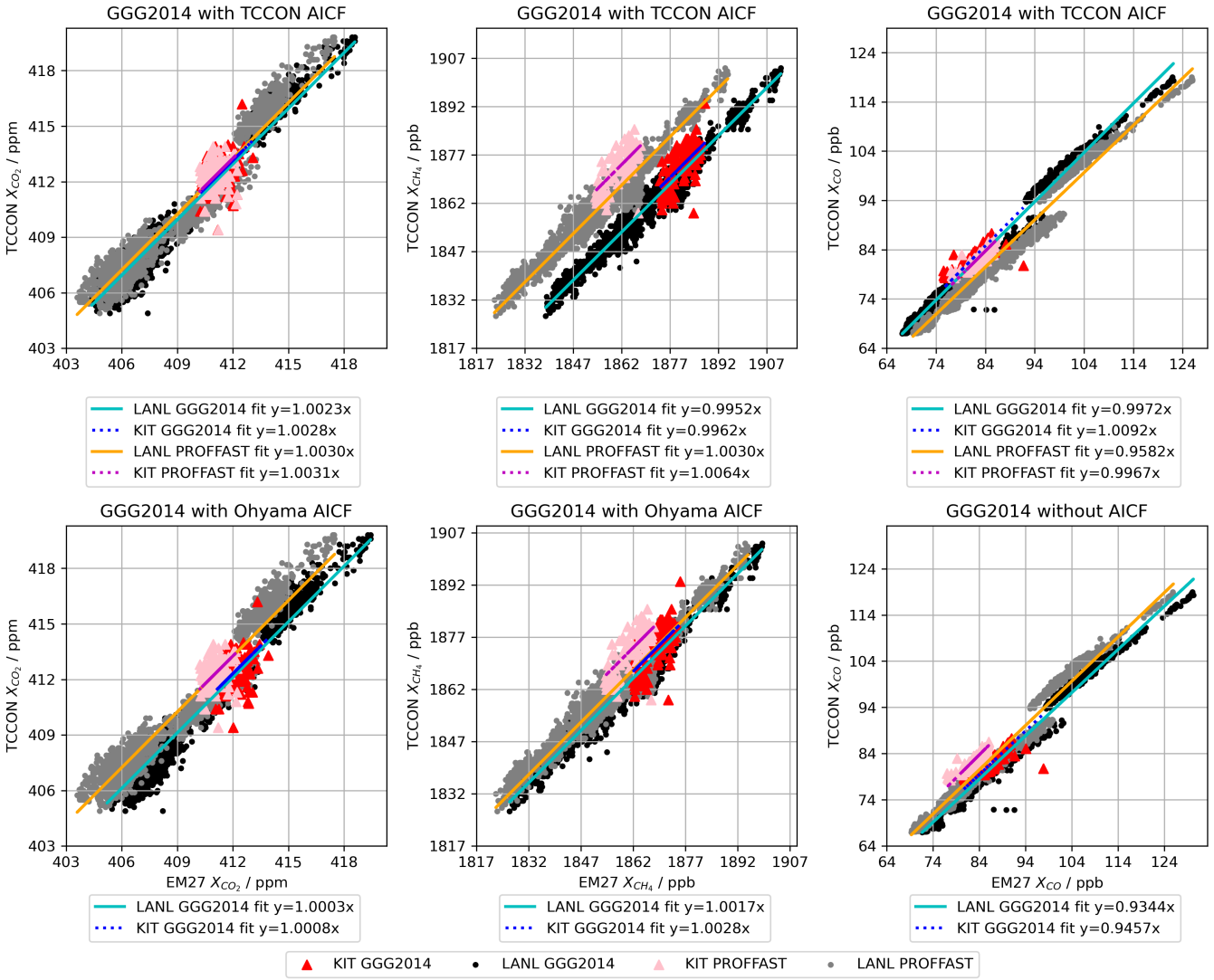
[a] H. Ohyama et al. "Validation of XCO_2 and XCH_4 retrieved from a portable Fourier transform spectrometer with those from in situ profiles from aircraft-borne instruments". In: *Atmos. Meas. Tech.* (2020). DOI: 10.5194/amt-13-5149-2020.

- 1 minute averages are used.
- PROFFAST (v1.0) has ADCF applied to X_{CO_2}, but no other scaling factors.
- GGG2014 has quality flag and built in scaling factors to tie to WMO scale (intended for TCCON).
- Additional QC applied to EM27/SUN retrievals:
  - first 30 minutes after initial start up discarded
  - PROFFAST:
    - SZA < 82
  - GGG2014:
    - SZA < 82
    - SIA > 90
    - retrieval error in $X_{CO_2} < 5$ ppm
    - retrieval error in $X_{CH_4} < 10$ ppb
- Outliers removed based on difference from 5-point moving average with thresholds of 1 ppm for X_{CO_2}, 5 ppb for X_{CH_4}, and 10 ppb for X_{CO}.

EM27/SUN vs. TCCON (at Caltech)



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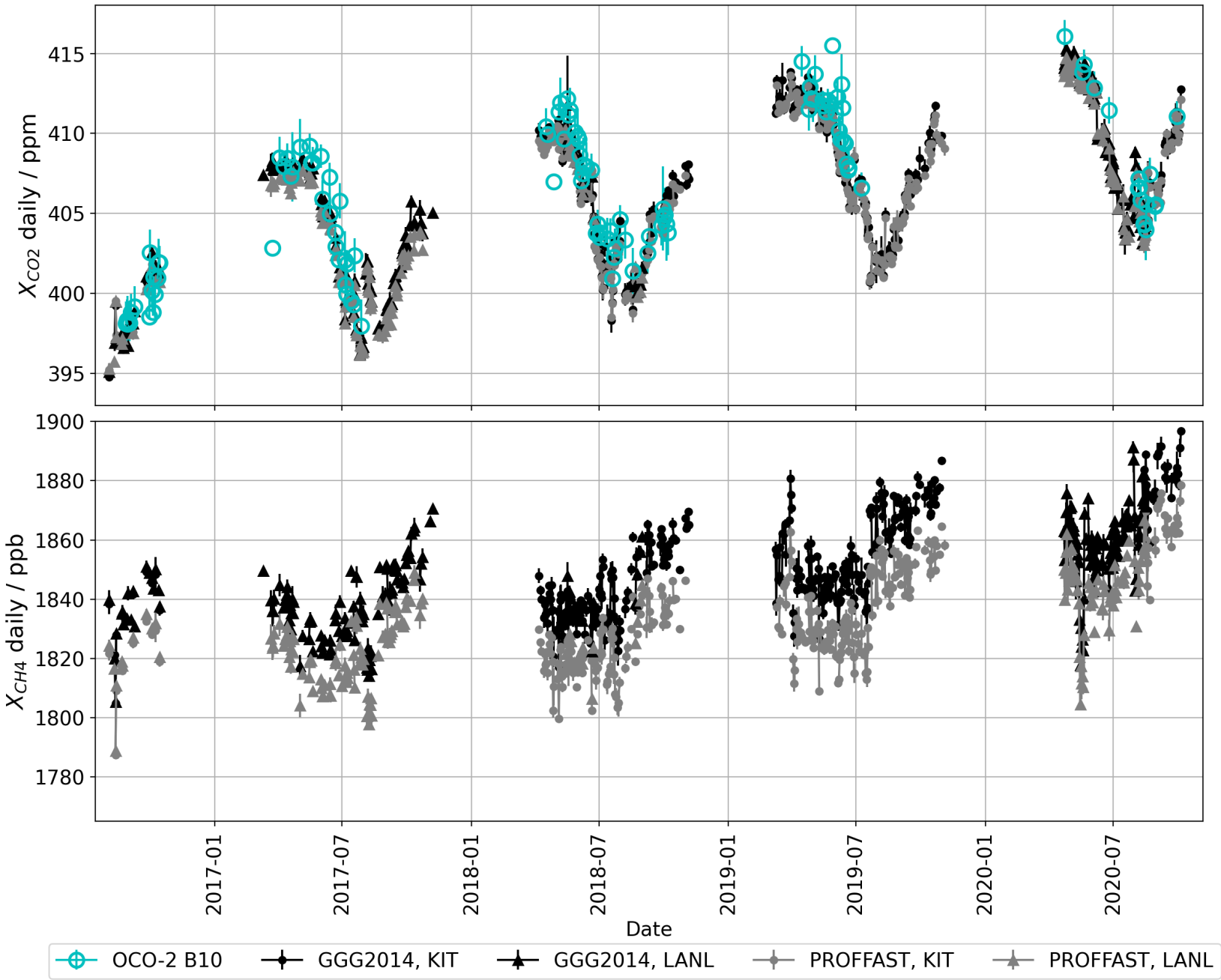
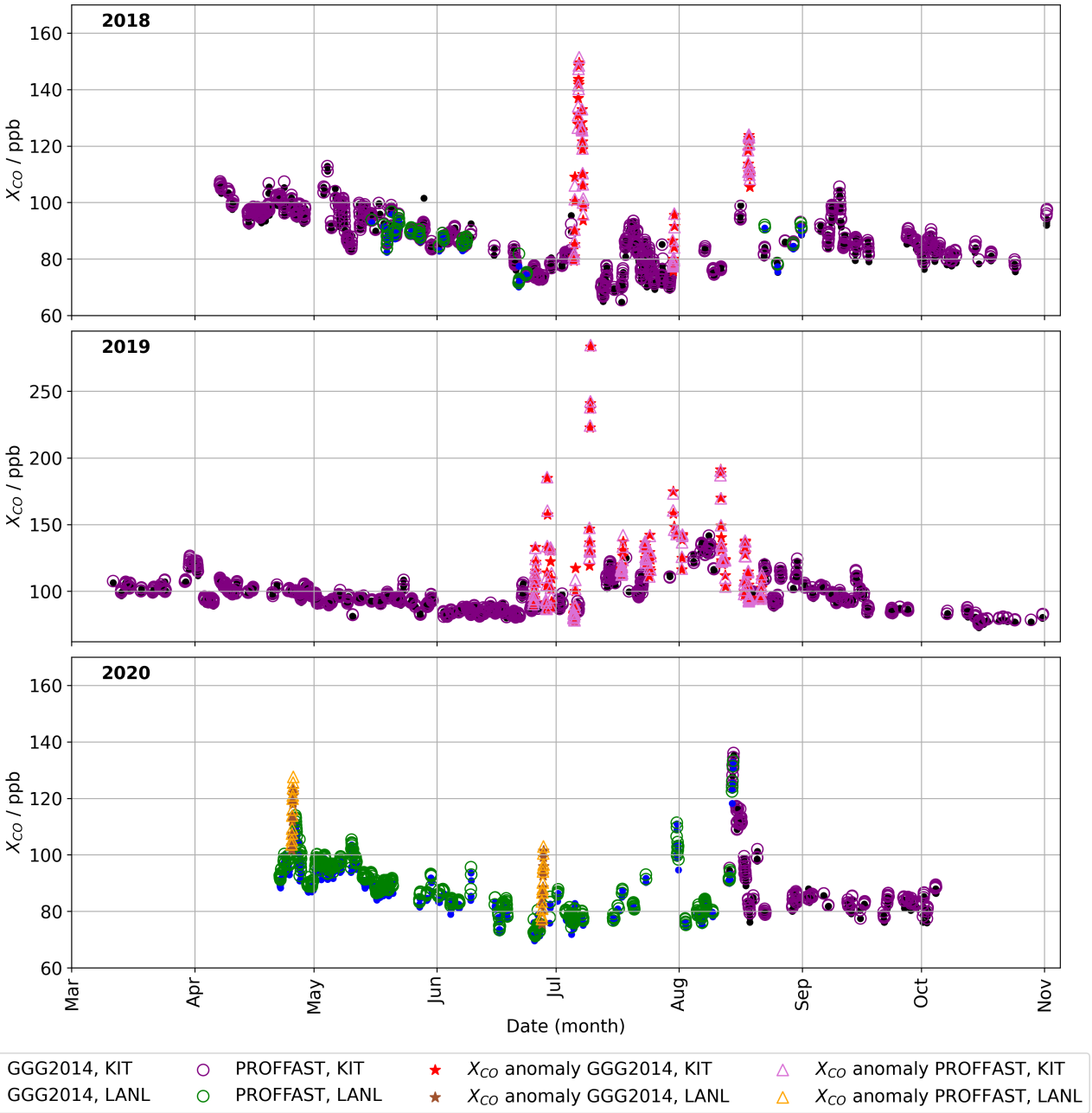
- 1 minute averages are used.
- LANL EM27/SUN operated at Caltech in December 2017, September 2018, September 2019, and January to February 2020 **(including data collected by Sajjan Heerah and Isis Frausto-Vicencio before and after deployment in the California Central Valley)**.
- The KIT EM27/SUN from Fairbanks was at Caltech in December 2019.
- Ohyama AICFs (Airmass Independent Correction Factors) improve agreement between EM27/SUN and TCCON GGG2014 retrievals.

[a] H. Ohyama et al. "Validation of XCO_2 and XCH_4 retrieved from a portable Fourier transform spectrometer with those from in situ profiles from aircraft-borne instruments". In: *Atmos. Meas. Tech.* (2020). DOI: 10.5194/amt-13-5149-2020.

X_{CO_2} and X_{CH_4} retrievals



X_{CO} measurements in Fairbanks



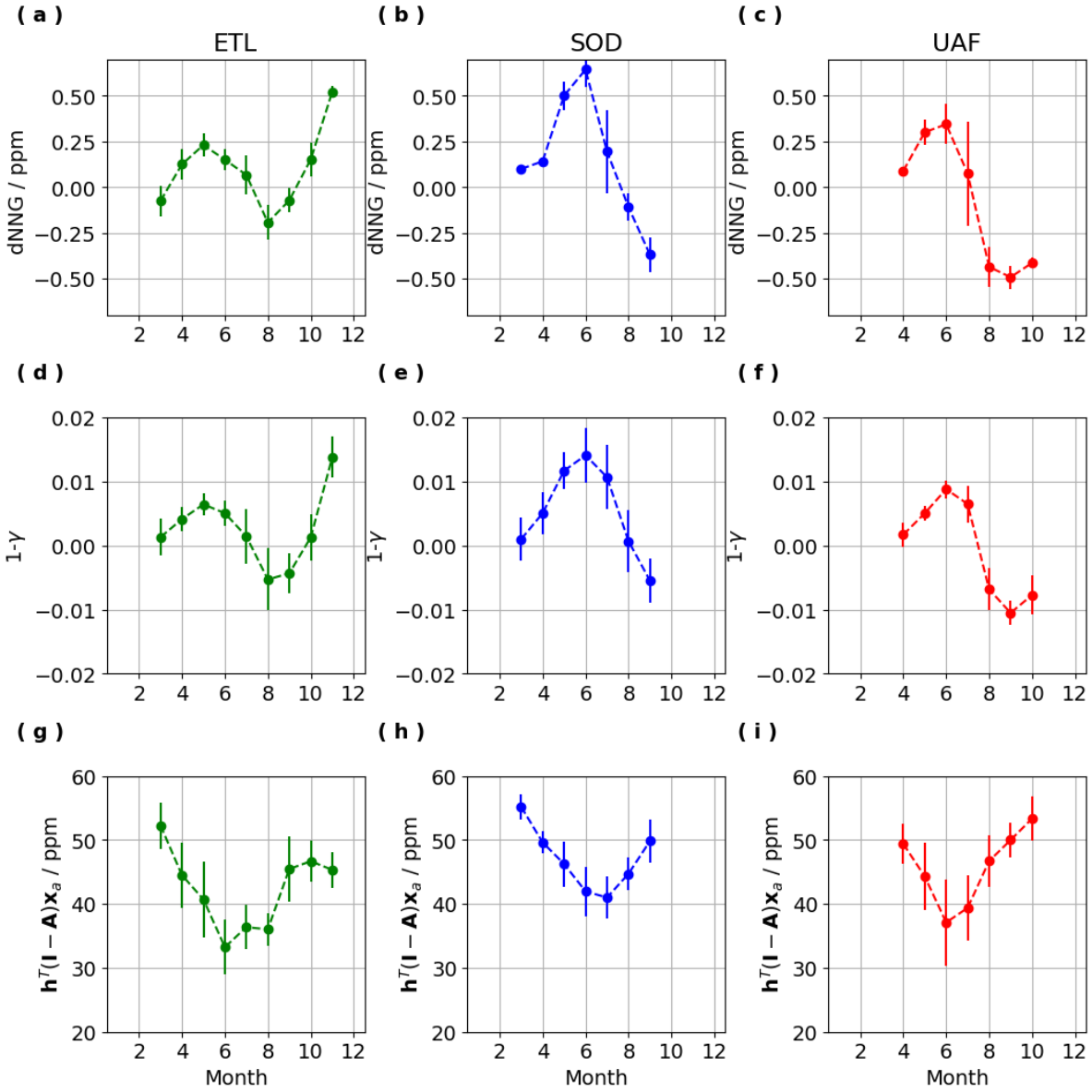
- Hourly averages.
- PROFFAST and GGG2014 retrievals are in close agreement throughout observation period.
- High X_{CO} anomalies are identified as days with daily standard deviation in $X_{CO} > 5$ ppb.
- Note scale change for 2019, when there were many forest fires near Fairbanks.

Averaging kernel correction for OCO-2 comparisons

$$\hat{X_{CO2,grd}} = X_{CO2,grd} + \left(1 - \frac{X_{CO2,grd}}{X_{AP,grd}}\right) \sum_i h_i (1 - a_i')(x_{i\ AP,OCO})$$

- h $\equiv$ pressure_weight; a' $\equiv$ xco2_averaging_kernel; $X_{AP,OCO} \equiv$ co2_profile_apriori (parameters in the OCO-2 lite files)
- $X_{CO2,grd}$ and $X_{AP,grd}$ (from co2_ovc in GGG retrievals) are averaged over 4 hours around local noon, then AK correction is applied to each coincident OCO-2 measurement.
- Correction proposed by Chris O'Dell and derived from Wunch et al. 2011 (ACP, doi: 10.5194/acp-11-12317-2011).
- **Coincidence:** OCO-2 within 5° x 10° region centered on the ground-site. EM27/SUN retrievals within $\pm$ 2 hours of local solar noon.

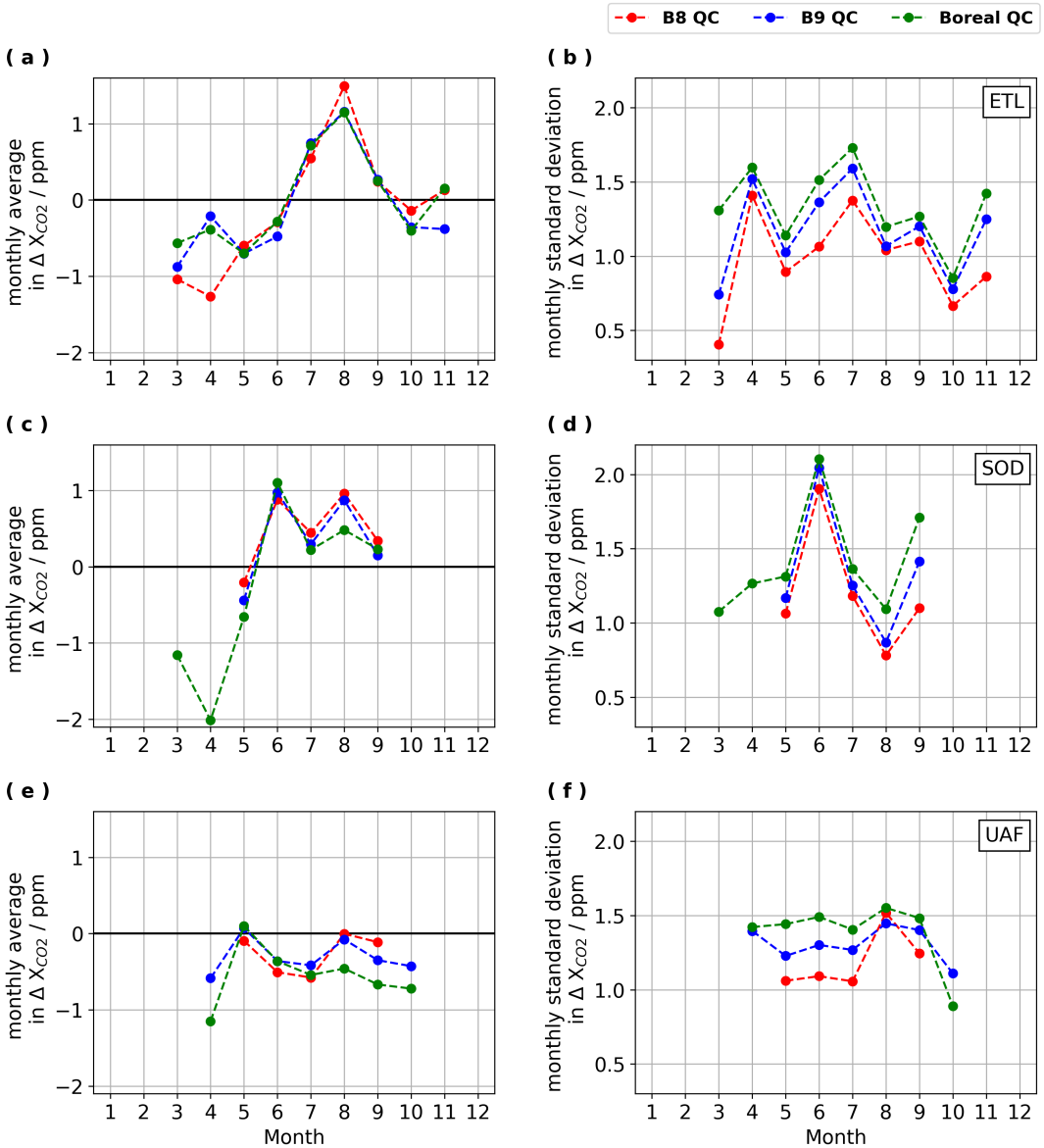
Monthly means of averaging kernel corrections, 2014-2018 OCO-2 B9[1]



- $dNNG = \left(1 - \frac{X_{CO2,grd}}{X_{AP,grd}}\right) \sum_i h_i(1 - a'_i)(x_{i\ AP,OCO})$
- $1 - \gamma = \left(1 - \frac{X_{CO2,grd}}{X_{AP,grd}}\right)$
- $\mathbf{h}^T(\mathbf{I} - \mathbf{A})\mathbf{x_a} = \sum_i h_i(1 - a'_i)(x_{i\ AP,OCO})$
- ETL ≡ East Trout Lake (TCCON);
  SOD ≡ Sodankylä (TCCON);
  UAF ≡ Fairbanks (EM27/SUN, COCCON)

[1] N. Jacobs et al. "Quality controls, bias, and seasonality of CO2 columns in the boreal forest with Orbiting Carbon Observatory-2, Total Carbon Column Observing Network, and EM27/SUN measurements". In: *Atmos. Meas. Tech.* (2020). DOI: 10.5194/amt-13-5033-2020.

Monthly OCO-2 bias with GGG2014. 2014-2018 OCO-2 B9[2]



- Comparing to the EM27/SUN yields less seasonality in OCO-2 biases than comparing to TCCON measurements at East Trout Lake and Sodankylä.
- Monthly standard deviation in OCO-2 bias also tends to be less variable from month to month at Fairbanks.

[2] N. Jacobs et al. "Quality controls, bias, and seasonality of CO2 columns in the boreal forest with Orbiting Carbon Observatory-2, Total Carbon Column Observing Network, and EM27/SUN measurements". In: *Atmos. Meas. Tech.* (2020). DOI: 10.5194/amt-13-5033-2020.

OCO-2 vs. EM27/SUN NNG for B9 and B10 in Fairbanks

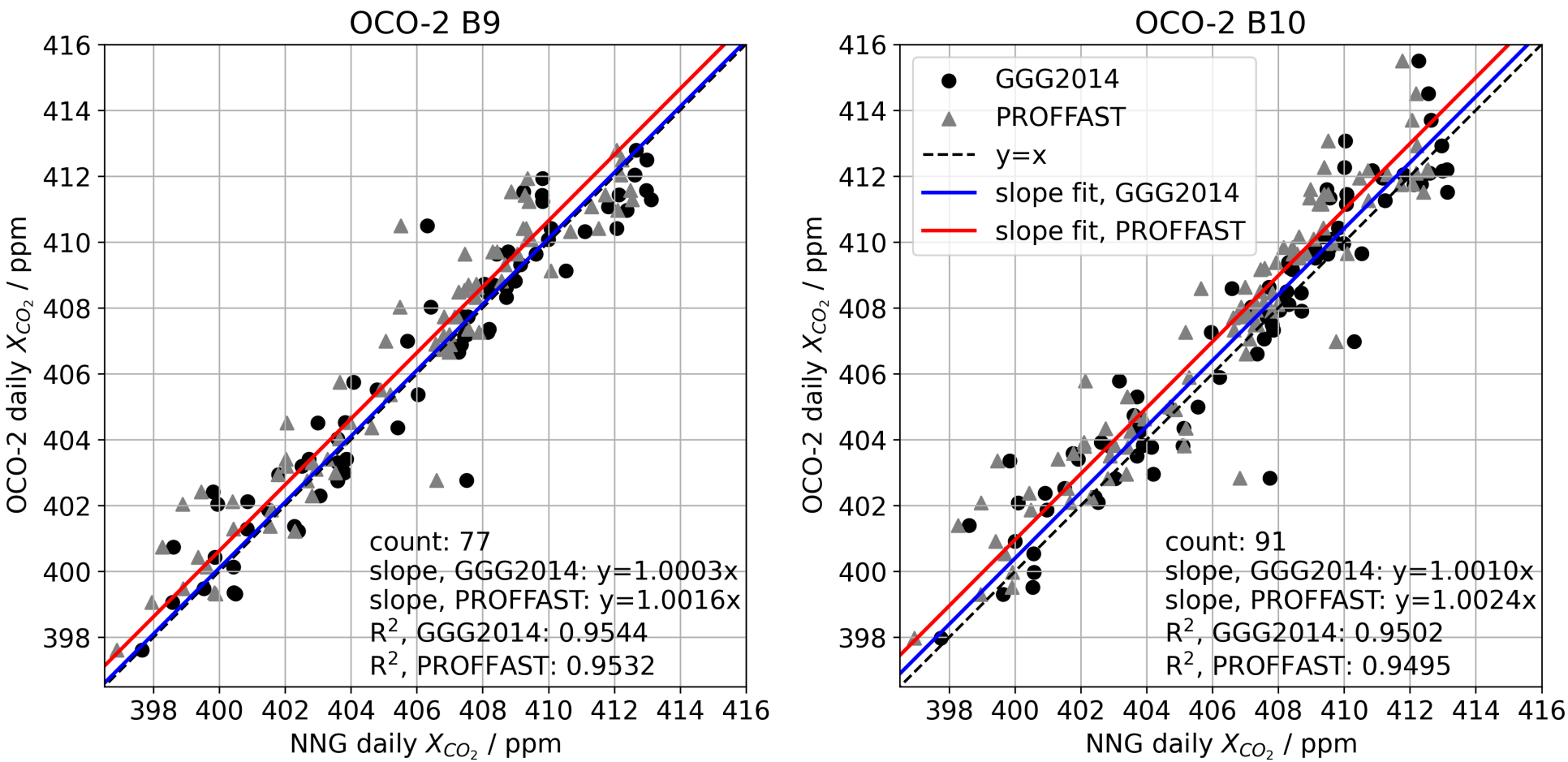
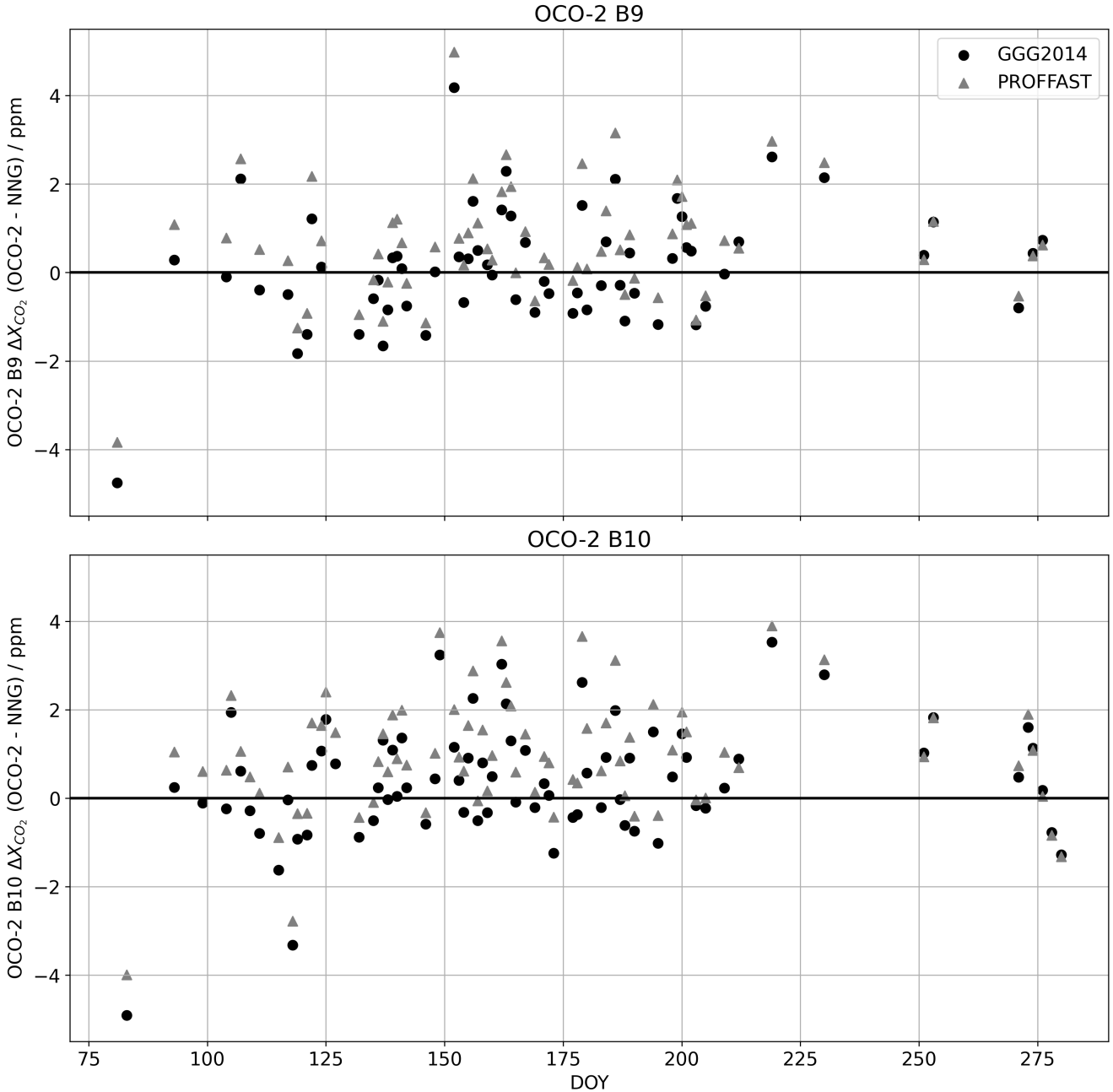


Figure: Daily average of OCO-2 retrievals in the 5°x10° coincidence region centered on UAF versus NNG (near-noon ground): daily average of retrievals within ±2 hours of local solar noon.

ΔX_{CO_2} (OCO-2 - NNG) by day of year (DOY) for B9 and B10 in Fairbanks



- More coincident data in B10, but more high biases.
- OCO-2 tends to be biased high in summer and biased low in spring and fall.
- PROFFAST tends to retrieve slightly lower X_{CO_2} than GGG2014, which yields higher ΔX_{CO_2} (OCO-2 - NNG) when comparing to OCO-2.

Conclusions

- The Fairbanks data record is in its 6th year and data collection is ongoing. GGG2014 retrievals for 2016-2019 are publicly accessible[3] and hopefully PROFFAST retrievals will be available on the COCCON website in the near future.
- The EM27/SUN FTS has great potential for filling gaps in global data for satellite validation efforts, and spectral resolution of the EM27 instrument is more comparable to that of satellites like OCO-2.
- GGG2020 is pretty much finalized and there is a new version of PROFFAST. Both of these algorithm upgrades may yield improved agreement between GGG and PROFFAST retrievals as well as between EM27/SUN and TCCON retrievals.
- Appropriate scaling factors (AICF for GGG retrievals and calibration to the KIT reference EM27/SUN for PROFFAST) are also important for making valid comparisons. Nasrin Pak is working to develop AICF for GGG2020 based on comparisons to AirCORE measurements.
- Seasonality in OCO-2 bias relative to the EM27/SUN in Fairbanks is less pronounced than compared to East Trout Lake or Sodankylä TCCON.
- OCO-2 B10 standard quality controls and bias correction yield more coincident data at Fairbanks, but also some higher biases.

[3] N. Jacobs et al. *Fairbanks, AK EM27/Sun observations of XCO2, XCH4, and XCO with GGG2014*. 2021. DOI: 10.3334/ORNLDAAC/1831. URL: https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1831.

Monthly OCO-2 bias with GGG2014, 2014-2019 B9 and B10 (no AK corrections)