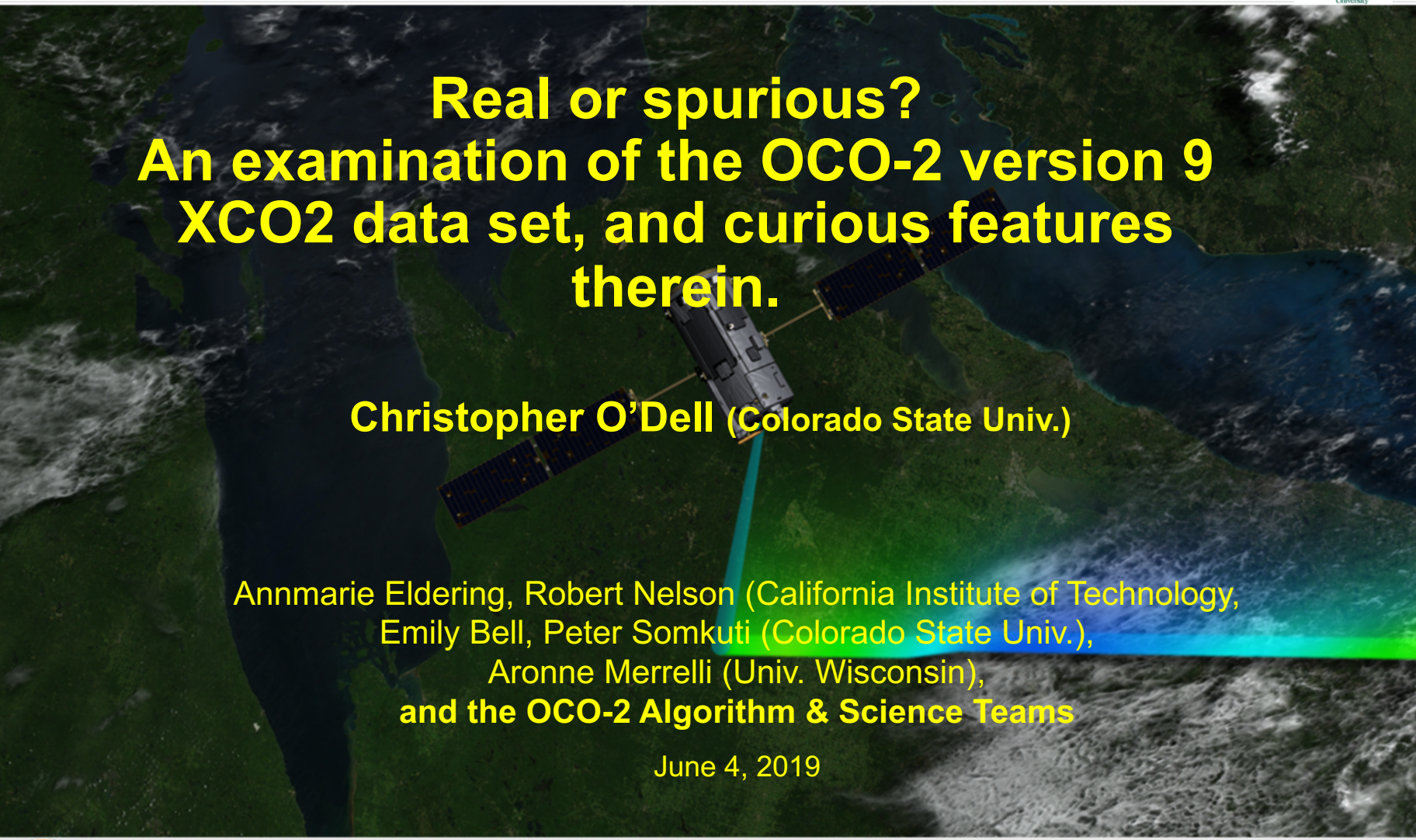


Real or spurious? An examination of the OCO-2 version 9 XCO2 data set, and curious features therein.

Christopher O'Dell (Colorado State Univ.)

Annmarie Eldering, Robert Nelson (California Institute of Technology,
Emily Bell, Peter Somkuti (Colorado State Univ.),
Aronne Merrelli (Univ. Wisconsin),
and the OCO-2 Algorithm & Science Teams

June 4, 2019

Almost Exactly 10 years ago!

First OCO/GOSAT Interface meeting,
Tsukuba, Japan, May 2009

Background

- XCO2 from space has been consistently refined over the last 10+ years
- Errors and biases of several ppm have been reduced to consistently < ~1 ppm.
- Important science is (and can be) done with these error levels.
- But much science will be sensitive to errors at this level; so we must do better if possible!

MILESTONES

GOSAT 2009-present

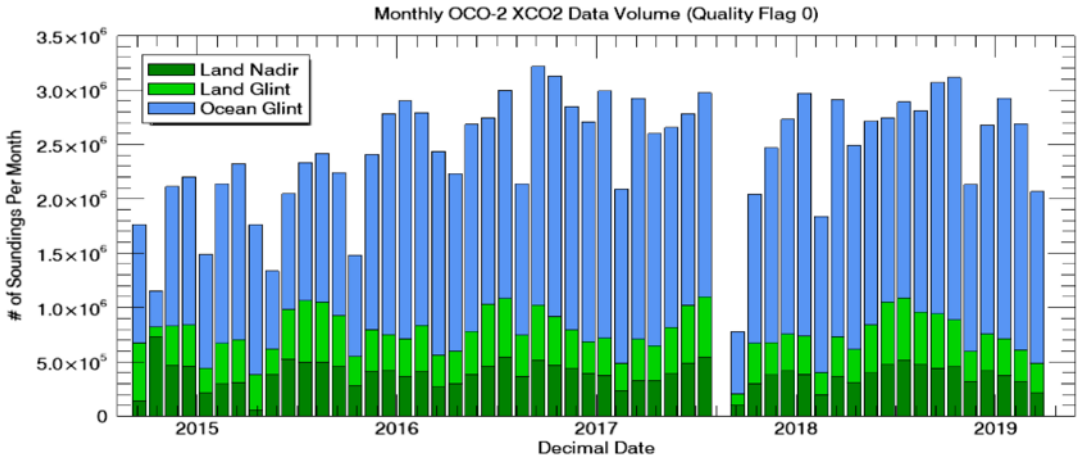
ACOS versions 2.8, 2.9, 2.10, 3.3, 3.5, 7.3

OCO-2 2014-present

ACOS versions 7, 8, 9

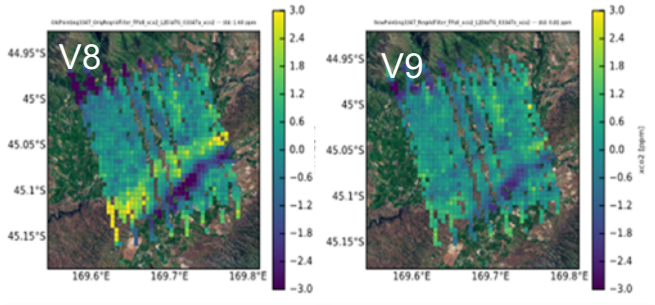
But First: OCO-2 Observatory Status

- As of March 31, 2019, we have ~133M good-quality XCO2 soundings. 2/3rd are ocean glint, 1/3rd are land.
- One long data outage (51 days) in Aug-Sep 2017
- We continue to decontaminate the instrument regularly, which results in the loss of about one week of data every 6 months.
- The Inertial Measurement Unit (IMU) has a degrading gyro. We will switch to using the startracker for all our pointing knowledge beginning in later June 2019.
- Instrument is in good health and should be able to operate for many years to come.

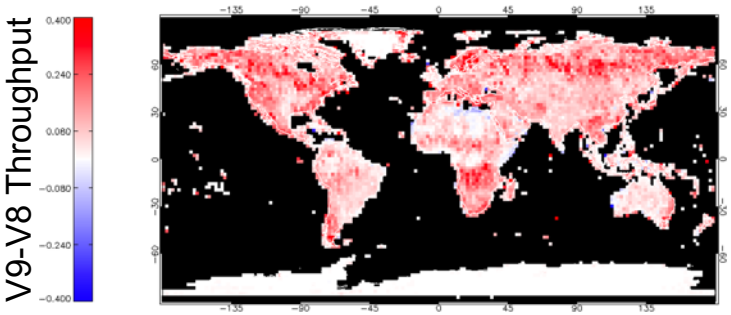


The OCO-2 V9 Product

- The OCO-2 Team released the Version 9 (V9) product on 10/15/2018.
- These updates
  - Reduce bias in the presence of rough topography
  - Provide better sampling over topical and boreal forests with slightly more scatter
- Described in O'Dell et al. (AMT, 2018) and Kiel et al. (AMT, 2019) and available through the NASA GES-DISC.
- The B10 product (expected 2020) is under development and will include several minor improvements:
  - Rob Nelson Poster 8 Today: *Aerosol parameterization.*
  - Le Kuai Poster 19 Today: *B10 overview*

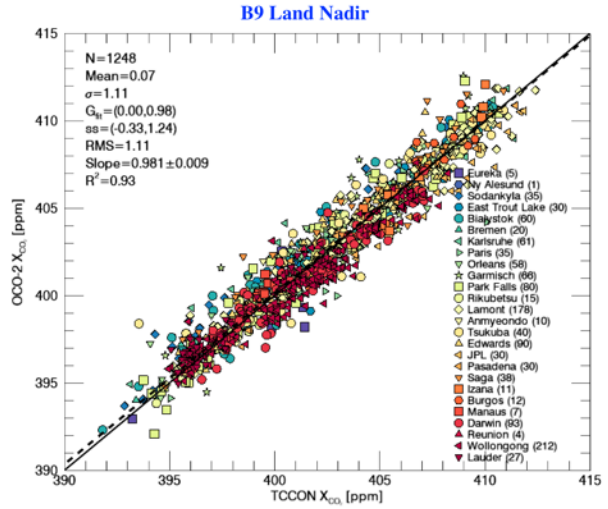


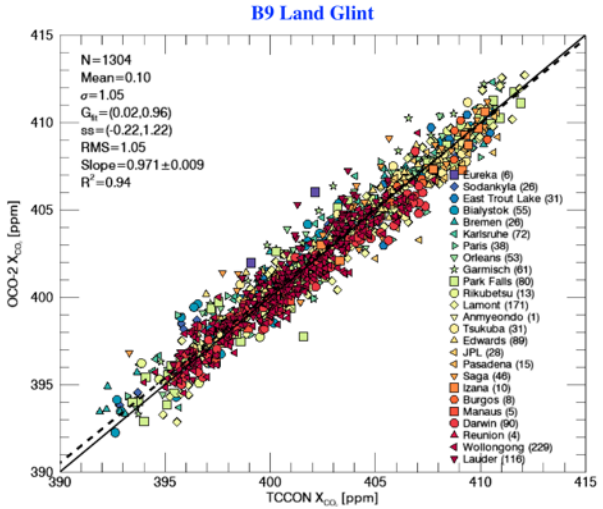
Pointing Correction Reduces XCO_2 Bias

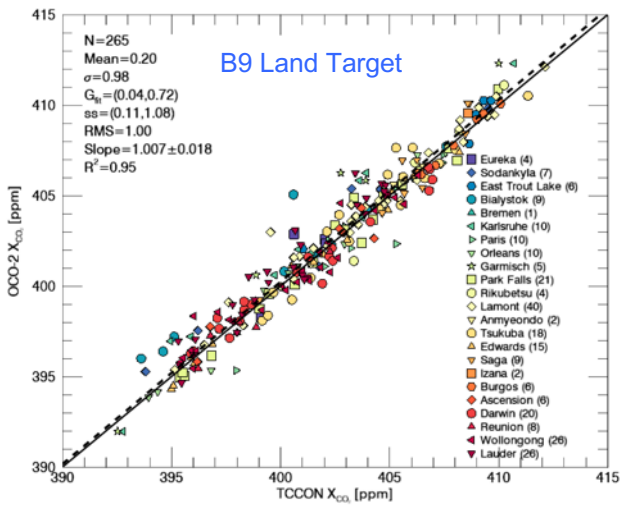


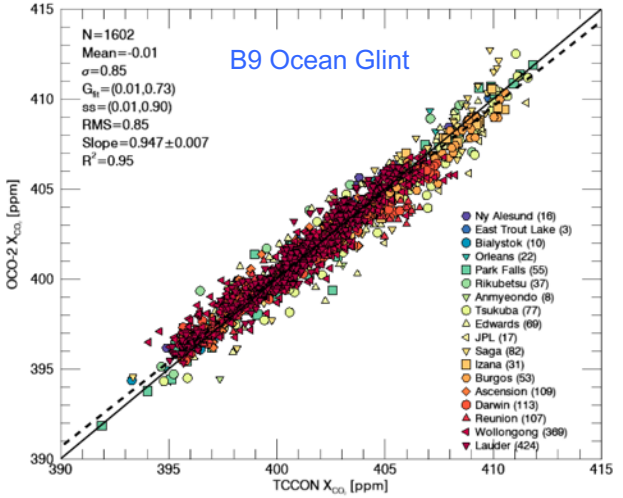
Improved Coverage over Tropical and Boreal Forests

B9 vs. TCCON







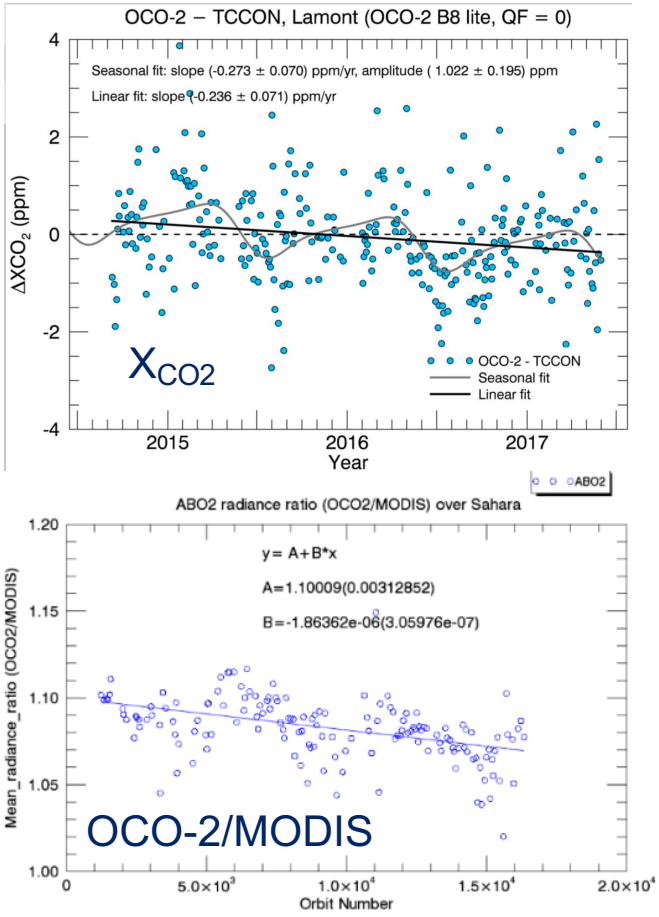


Notes

- Each symbol is an **overpass-mean,** and represents the average of 100s of soundings.
- Only good quality, bias-corrected XCO2 are used.
- AK corrections are included.
- Land Nadir & Glint are very comparable and can be treated as a single dataset.
- Ocean glint has low random errors than land data (and there is more of it).

Long Term XCO2 Drift?

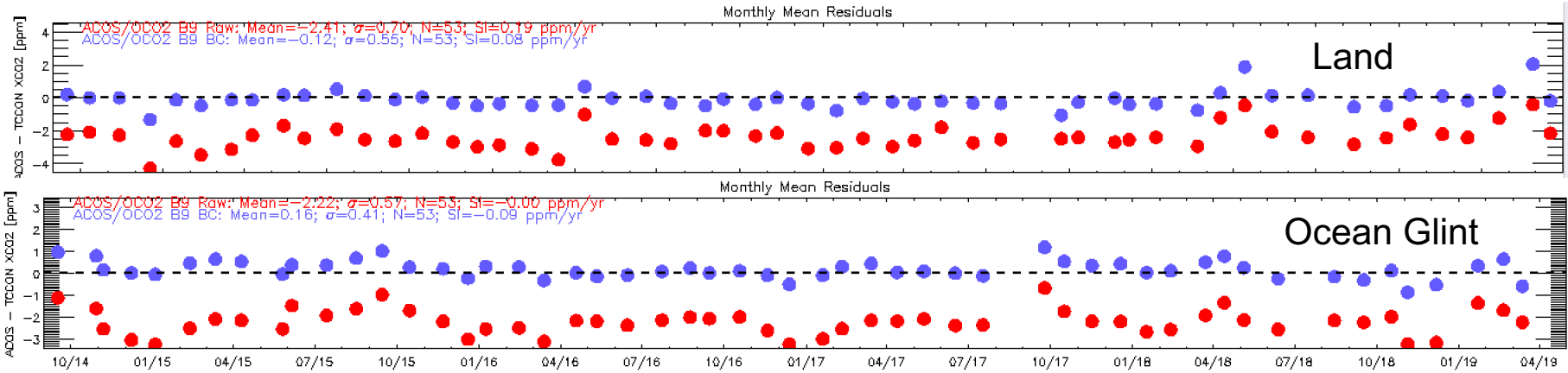
- Initial comparisons of the OCO-2 V8 product with TCCON and Models indicate a long-term drift (-0.2 to -0.4 ppm/yr)
- Including the AK correction cut the trend in half, to -0.1 to -0.2 ppm/yr.
- Trends could be caused easily by radiometric drifts, which are exhibited by comparisons with MODIS.



TCCON plot courtesy H. Lindqvist

Long Term XCO2 Drift?

- Updated comparisons show little drift vs. TCCON
  - Ocean: -0.09 ppm/yr (uncertainty ~ 0.1 ppm/yr)
  - Land : +0.08 ppm/yr (uncertainty ~ 0.1 ppm/yr)

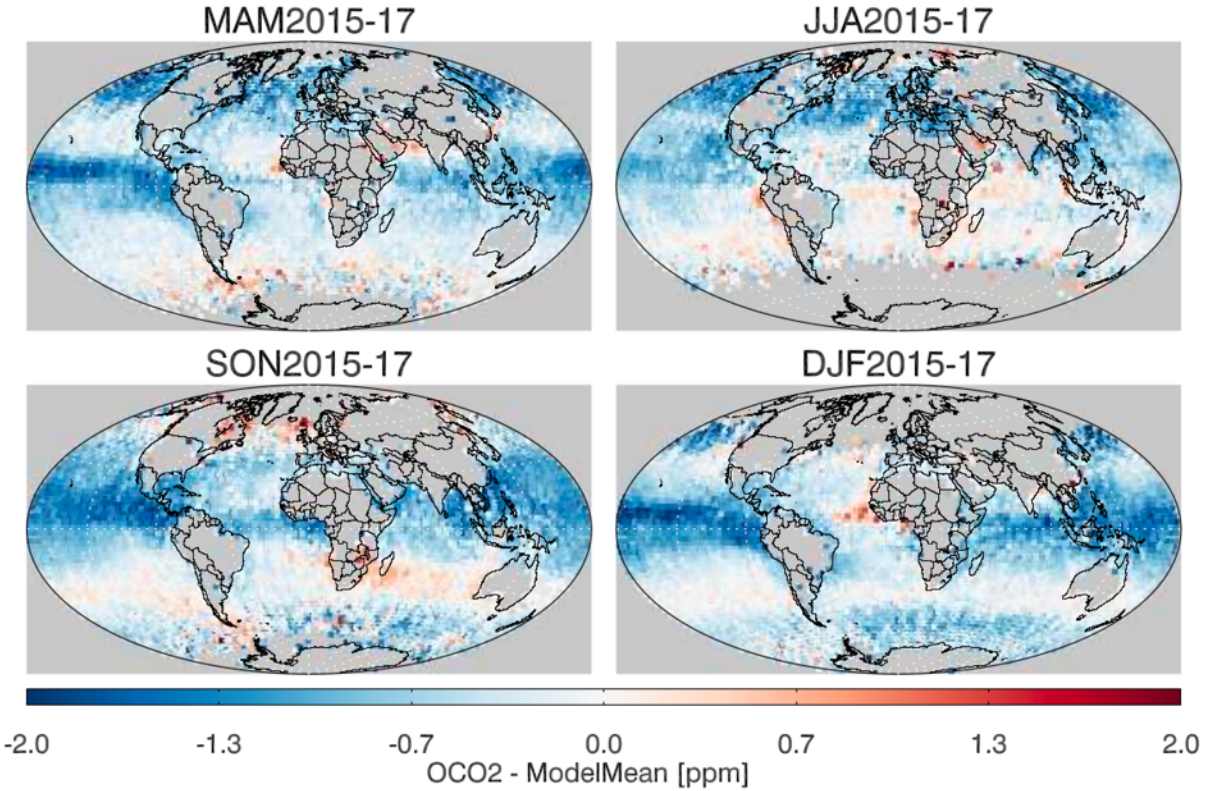


Bias-Corrected

Raw

An ocean bias?

- Comparisons to models suggest a low ocean bias in OCO2 v9 in the tropical and NH midlatitude oceans, of -0.5 to -1.5 ppm.



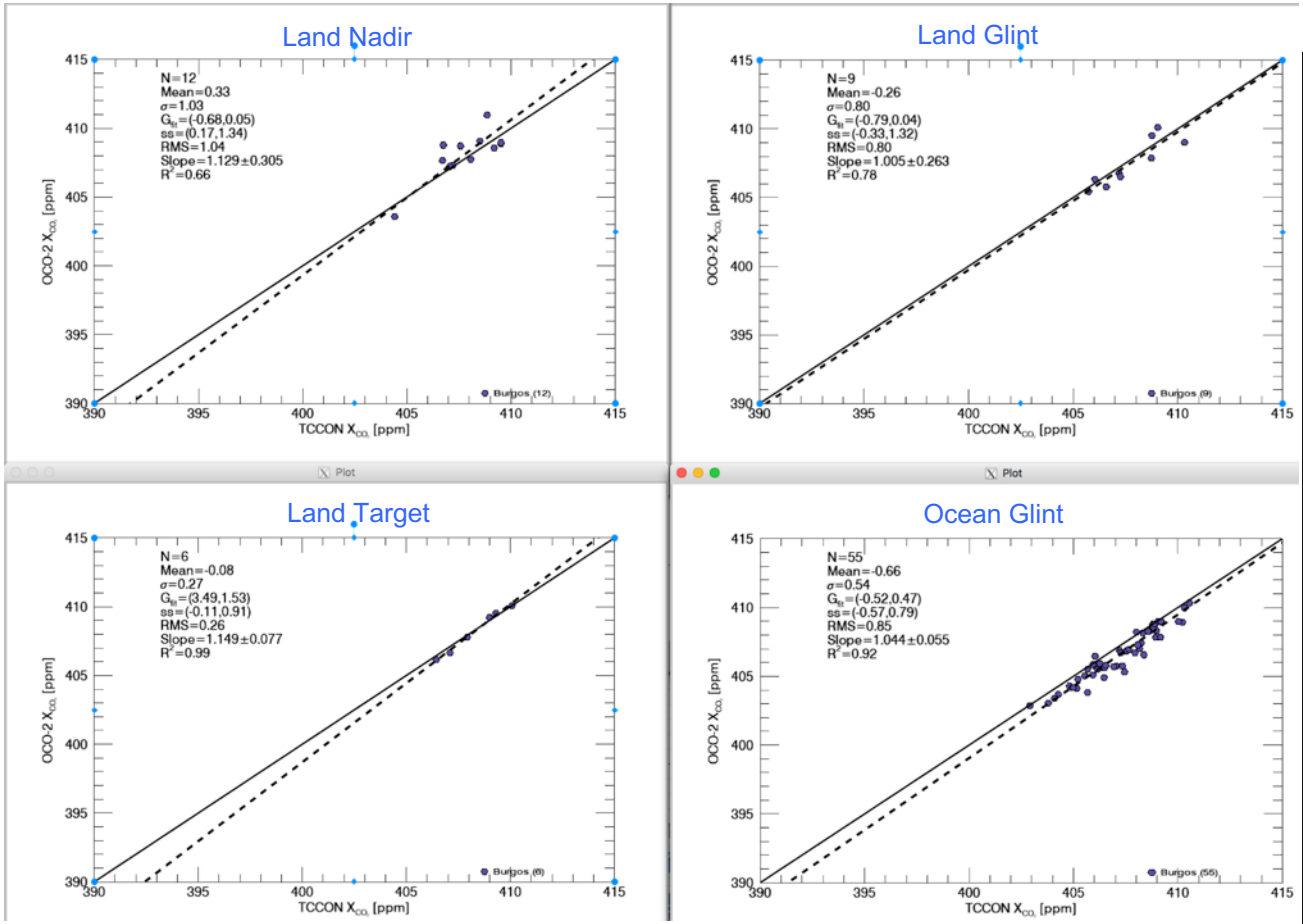
Comparison of OCO2 XCO2 to a mean of 4 Models: CarbonTracker2017, CAMS 2018v1, Jena s04-v4.2, UnivEd v4.0 Models all optimized vs. in-situ data

Notes

- Many ocean TCCON stations in areas where there is little or no bias (Ascension, Reunion, Lauder, Wollongong, Darwin)
- No TCCON stations in tropical pacific where the bias is worst.

Data Courtesy of:
Andrew Jacobson, David Baker, Abhishek Chatterjee, Christian Rodenbeck, Frederic Chevallier, Paul Palmer & Liang Feng

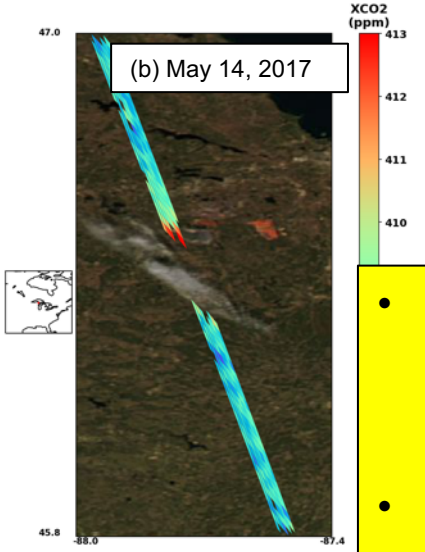
Breaking the Tie: Burgos (Phillipines)

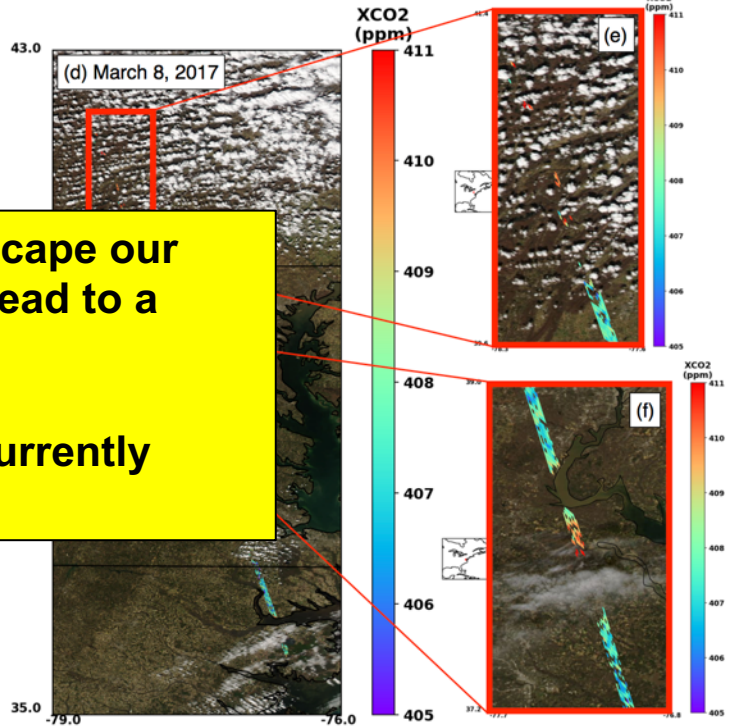


- Land data is unbiased (especially target)
- Ocean data shows a clear low bias of ~ -0.6 ppm, suggesting a retrieval problem
- Additionally, Saga & Izana both show low ocean biases of -0.5 to -1 ppm.
- Initial comparisons to ATOM data agree with models, disagree with OCO2 (S. Kulawik).
- Possible spectroscopy error, work in progress!

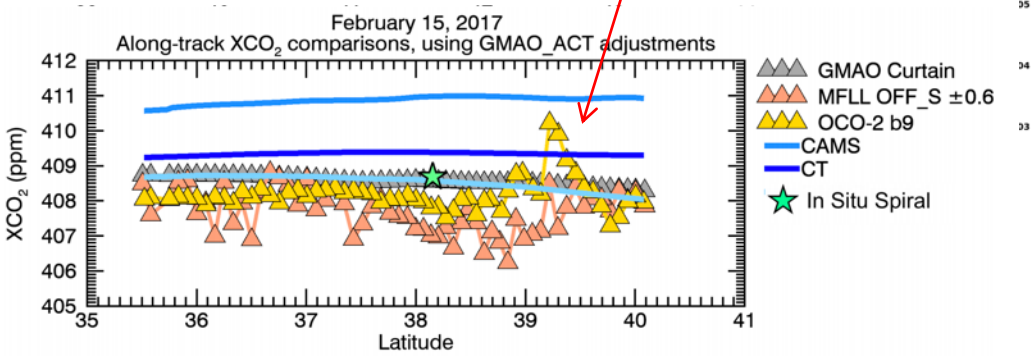
Data Courtesy Burgos TCCON Team

Cloud Shadows





- **Cloud shadows can often escape our quailty filters, and typically lead to a high bias.**
- **This is a filtering problem, currently without a solution.**



Credit: ACT-America Campaign & Emily Bell

Riyadh "False Plume" Case

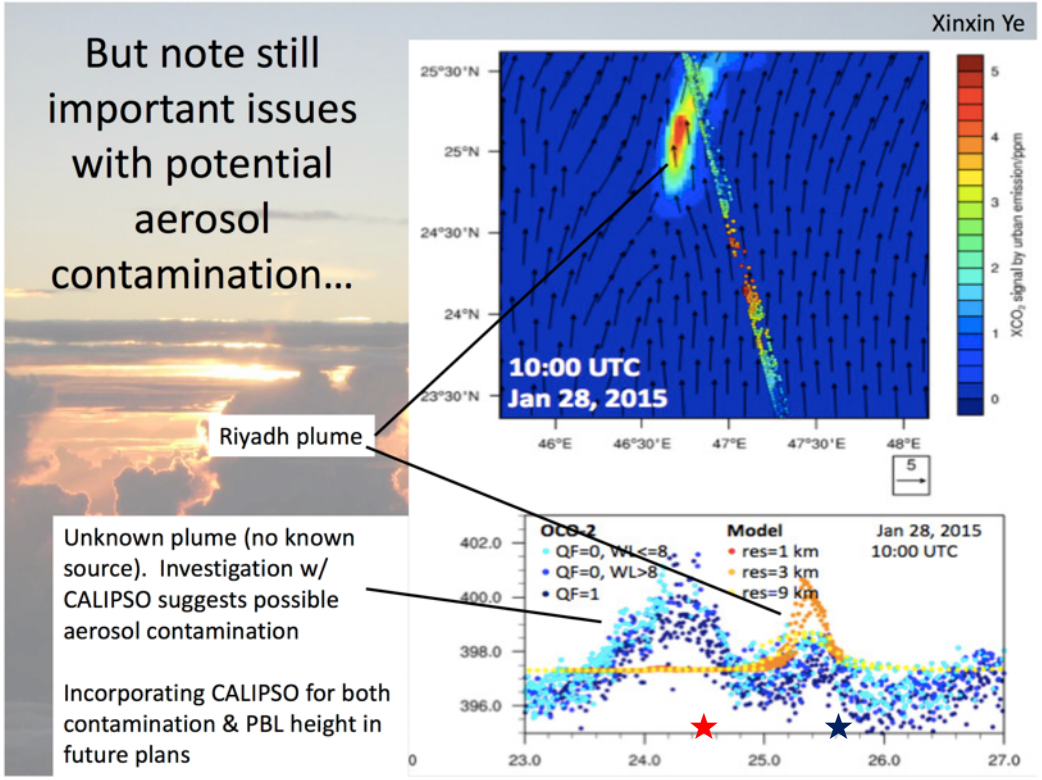
Identified at the OCO2 science team meeting Fall 2017*

XCO_2 "bump" at 25.4° (★) is maybe real, and corresponds to the expected XCO2 plume from Riyadh, given the wind field.

The XCO_2 feature at 24.25° (★) is likely some sort of aerosol related bias.

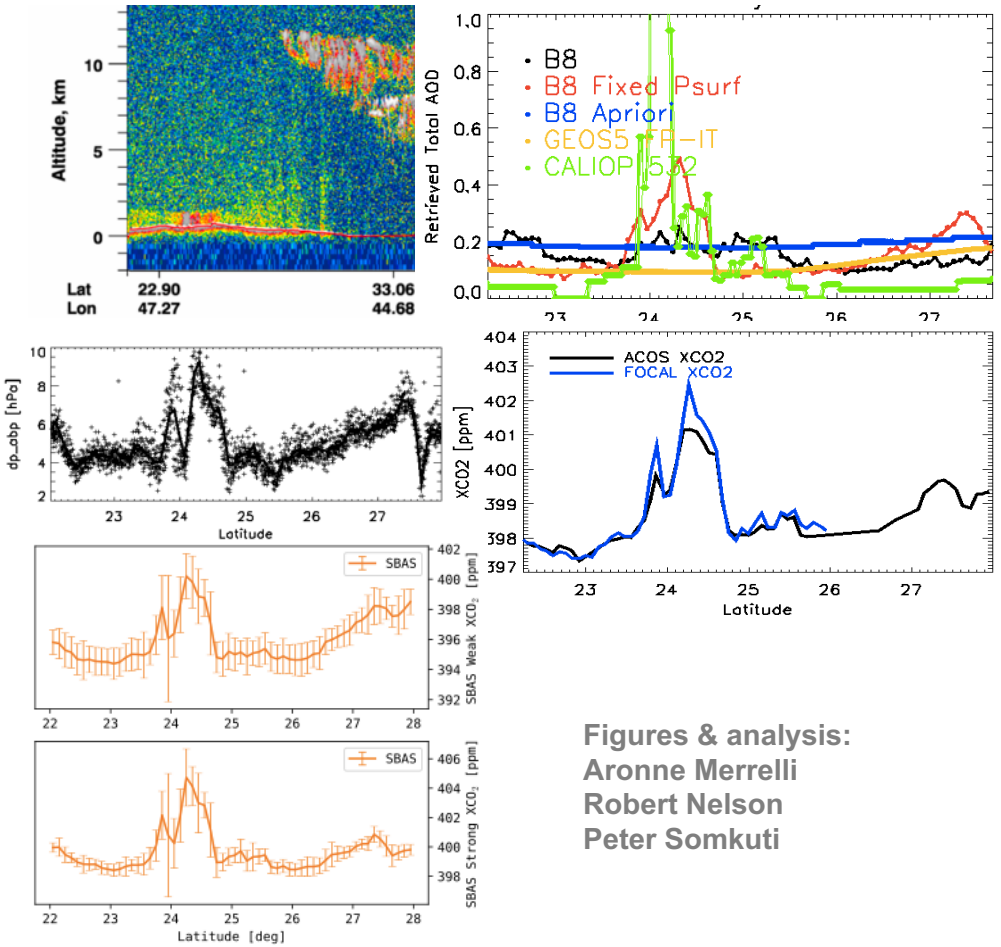
This was V7 data, but V8/V9 does not substantially change the picture.

***(Eric Kort, Emily Yang, Thomas Lauvaux, Xinxin Ye, John Kin, Dien Wu, Tom Oda)**



Riyadh "False Plume" case

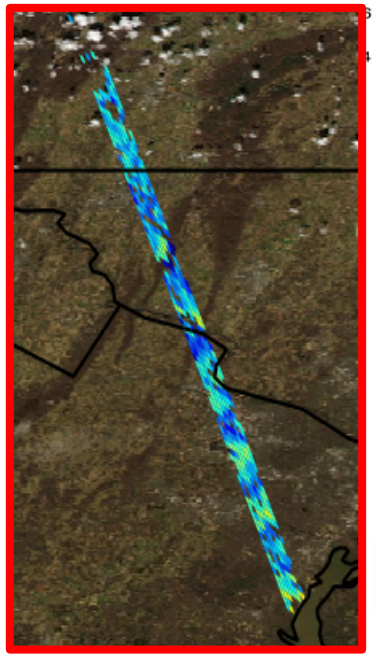
- CALIPSO and MODIS both see a dust layer with AOD ~ 0.5.
- Another retrieval (FOCAL, courtesy M. Reuter) also sees the plume.
- Extensive testing suggests this is a path lengthening effect in all 3 bands, that our retrieval puts into the surface pressure rather than into aerosol.
- A large dust aerosol layer near the surface seems to fit the data.
- A fixed Psurf retrieval seems to partially mitigate this problem and is under investigation.

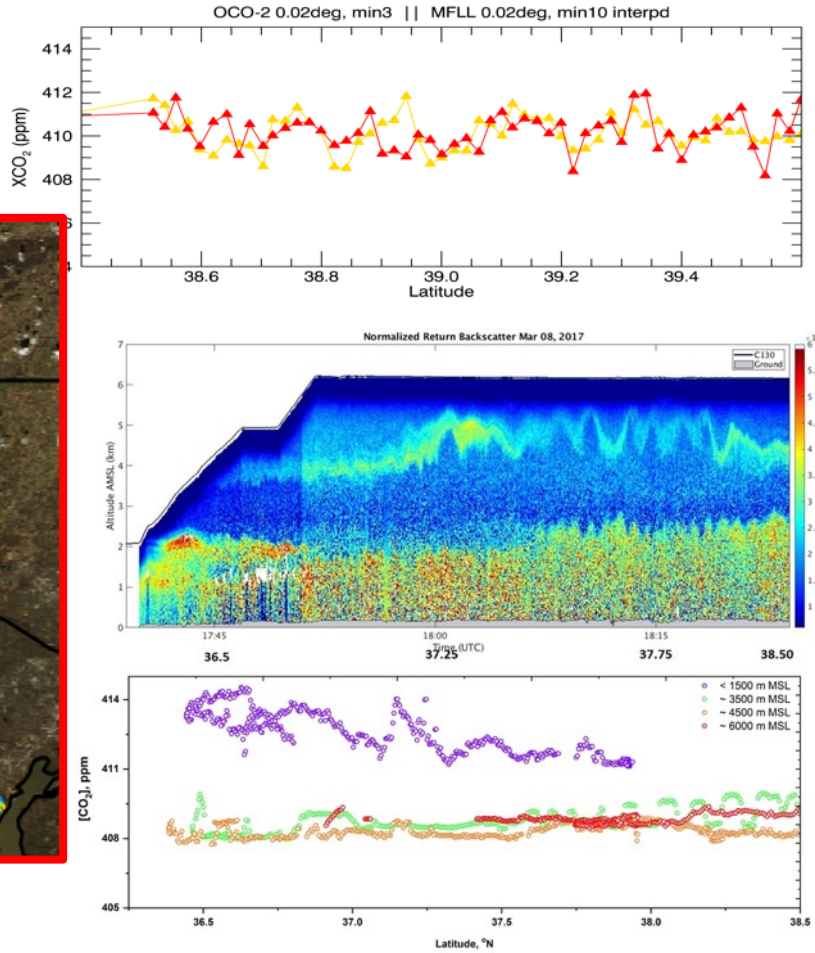


Figures & analysis:
Aronne Merrelli
Robert Nelson
Peter Somkuti

Atmospheric Waves
March 8, 2017, DC Area, ACT-America case

- 1-2 ppm amplitude wave patten seen in March 8, 2017 clear area in eastern United States. Wavelength ~ 20 km.
- Perhaps seen in MFLL, very hard to say.
- Waves seen in the area by the cloud physics Lidar.
- Some waves also seen in in-situ XCO2 at 3.5 km.
- Are these XCO2 variations real?
- Seems unlikely – need a mechanism for the atmopsheric wave to horizontally repartition CO2, unless sources somehow are doing it.
- Under investigation!





Credit: ACT-America Campaign & Emily Bell

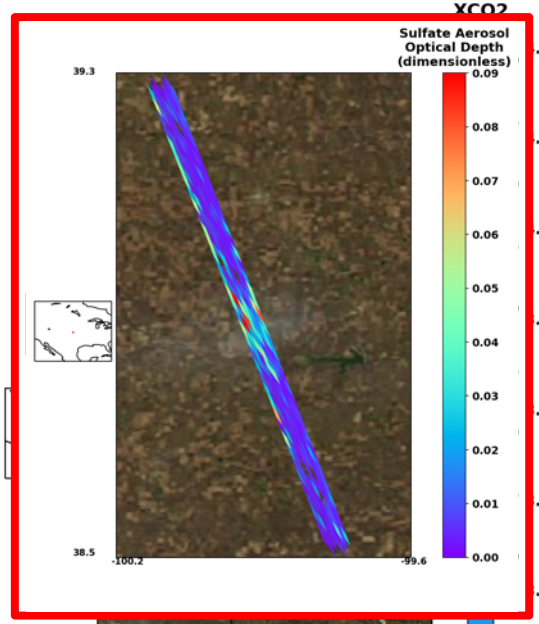
Agricultural Burning in Kansas? Oct 22, 2017, ACT-America Case

- 0.7 ppm XCO2 enhancement seen overtop of MODIS-Aqua smoke plume; colocated with increase in retrieval sulfate aerosol.
- Traced to a single farm in central Kansas.
- Based on crop data for this farm plus LandSat, estimated that 101 acres of Alfalfa was burned.
- Back of the envelope calculations:
  - 200-300 MgC burned
  - ~0.25 ppm plume enhancement
- Combination of real + aerosol effects?

2 hours earlier, MODIS/Terra:

Landsat

Value	Category	Count	Acreage
4	Sorghum	1035	230.2
24	Winter Wheat	495	110.1
36	Alfalfa	454	101
5	Soybeans	363	80.7



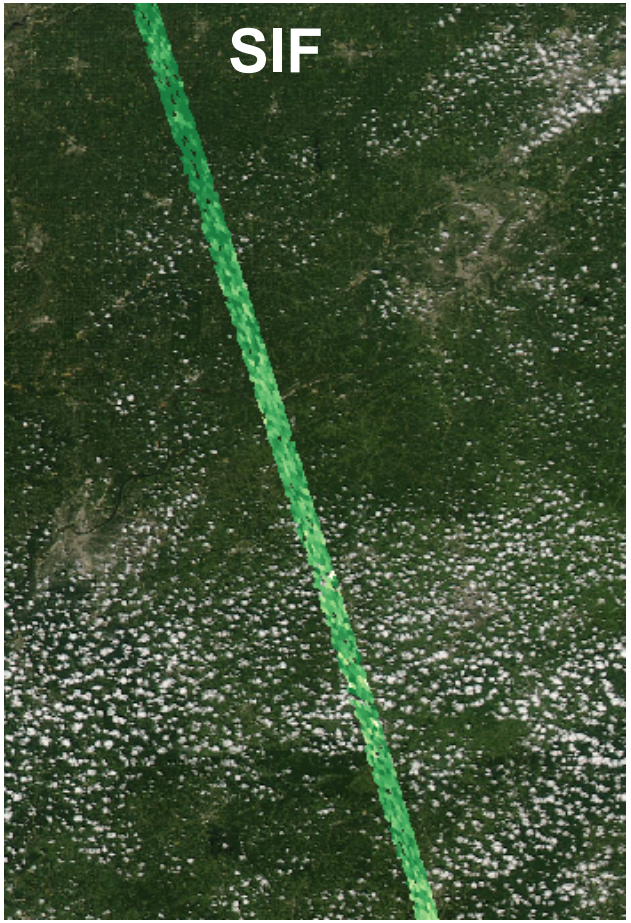
Analysis by:
Emily Bell (CSU),
Robert Nelson (JPL),
Andrew Schuh (CSU),
Jessica McCarty (CSU)

OCO-2 Data Coming to NASA's Worldview in Early 2019

- *Variables*
  - Bias-corrected, Quality-filtered XCO2
  - Bias-corrected, Quality-filtered XCO2 with the NOAA ESRL daily global mean XCO2 subtracted
  - Total Column Water Vapor
  - SIF at 757 nm
  - SIF at 771 nm
  - Blended SIF

Worldview: https://worldview.earthdata.nasa.gov/

NOAA ESRL Daily Global Mean XCO2: ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_trend_gl.txt



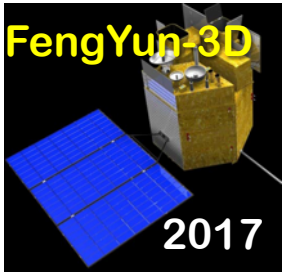
OCO-2 overpass of the Ghent Generating Station in Kentucky on August 13, 2015

Credit: Heather Cronk (CSU)

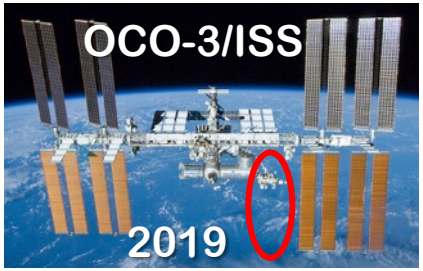
Retrieval Improvements may impact all these present and future satellites

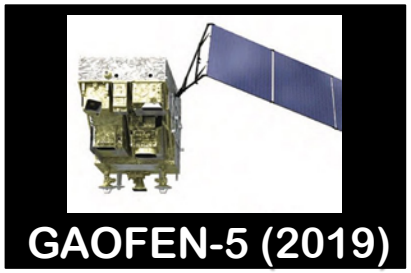
PAST

PRESENT

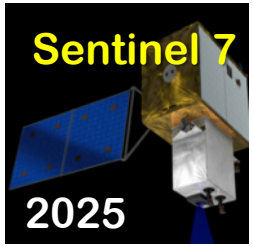


NEAR FUTURE





LATER



Take-aways

- The initial inference of a long-term negative trend in OCO2 XCO2 is not borne out by a longer time-scale analysis. Any trend appears < ~0.1 ppm/yr.
- There apparent low bias in tropical ocean OCO-2 data appears to be satellite bias. There is some indication that it could be related to water vapor spectroscopy.
- Various scale-scale features in the OCO-2 data appear:
  - False XCO2 “plume” associated with low-level dust layer.
  - High-biased XCO2 in some cloud shadow regions.
  - Wave structures in XCO2 associated with atmospheric waves: unclear.
  - High XCO2 associated with agricultural burning in the US in Autumn: at least partially real.
- Some of the small-scale problems can be solved by filtering
- Others must be fixed by the retrieval itself, either through improved aerosol treatment, spectroscopy, or other.