

Jet Propulsion Laboratory
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Outstanding Issues in Satellite-based CO_2 (and CH_4) retrievals

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With contributions from the OCO-2/3 teams

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The XCO_2 Goal

We have a goal (my own interpretation):

To deduce accurate, science- and policy-relevant surface fluxes of CO2 at nation-state (or better) & monthly scales using top-down inversion systems driven by in-situ and satellite CO2 data.

To achieve this goal, we require:

- Extremely well-calibrated reflected sunlight spectra

OCO-2 Has Largely Achieved this!
Gold standard for future sensors!

- **Highly accurate retrieved XCO2 from those spectra**

< 0.5 ppm (0.12%)
(CO2M MRD)
< 0.2 ppm (0.05%)
(Common Opinion)

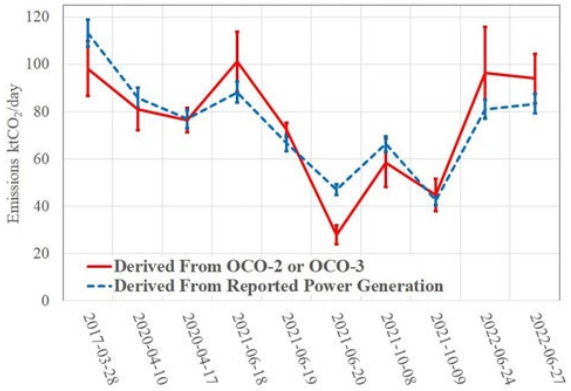
- Robust top-down carbon source/sink inversion systems (with accurate transport and well-specified priors)

The Current XCO_2 Situation

- Useful science with policy relevant information is starting.

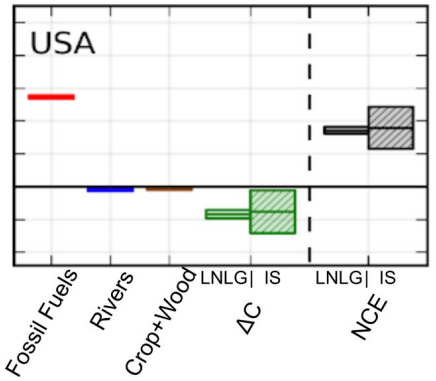
Nassar et al., 2022
OCO 2/3 Measurements of Belchatow power plant

LOCAL SCALES



Byrne et al., 2022
OCO-2 contributions to Global Stock-Take

REGIONAL/GLOBAL SCALES



- Systematic errors in XCO2 are larger than 0.5 ppm.
  - Theory: Inst+Met+Spec+Aerosols, 1σ

    0.6 ppm Ocean, 0.8 ppm land (Connor et al, 2016; McGarragh et al, 2023)
  - Actual (OCO-2 v11.1, 1σ):

    0.5 ppm Ocean, 0.7 ppm land

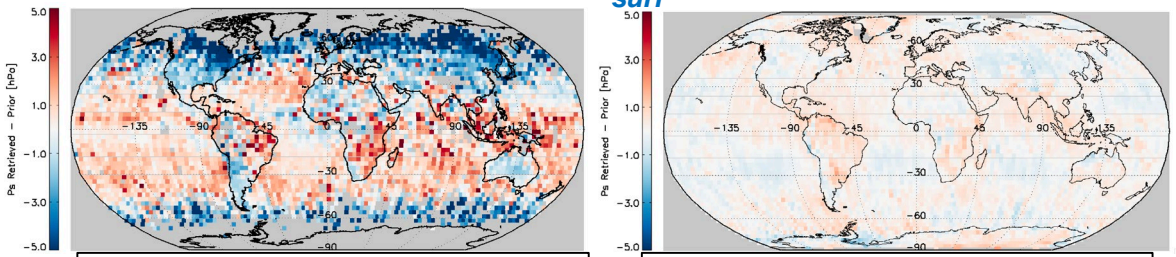
- What is dominating these systematic errors?

Surface Pressure Information

- Column gas columns are **1st -order sensitive** to surface pressure.
- Retrieved surface pressure is not sufficiently accurate
- Prior surface pressure accuracy depends on:
  - Accuracy of Meteorological Reanalysis (ERA-5, GEOS5, JRA, etc)
  - Accuracy of target surface altitude (DEM)
  - Geolocation Accuracy

$$X_{CO2} = \frac{Column\ CO_2}{Column\ Dry\ Air} \propto \frac{Column\ CO_2}{P_{surf}}$$

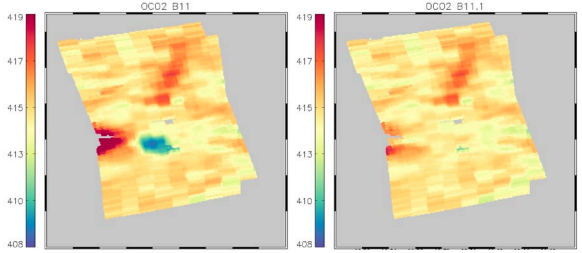
March 2018 P_{surf} Differences



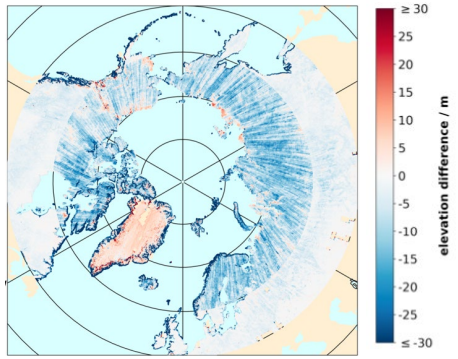
OCO2 – GEOS5-FPIT [hPa]
-0.1 ± 2.2 hPa
0.04 ± 0.9 ppm

ERA5 – GEOS5-FPIT [hPa]
0.1 ± 0.7 hPa
-0.04 ± 0.3 hPa

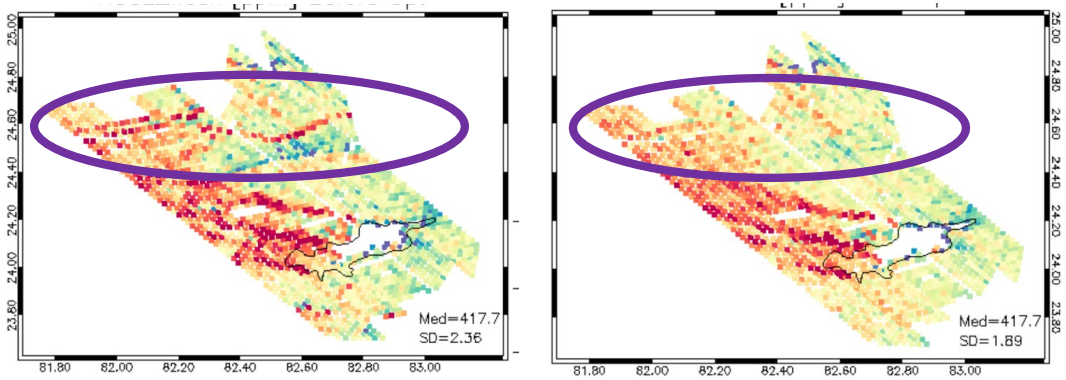
OCO2 XCO2 over Belchatow



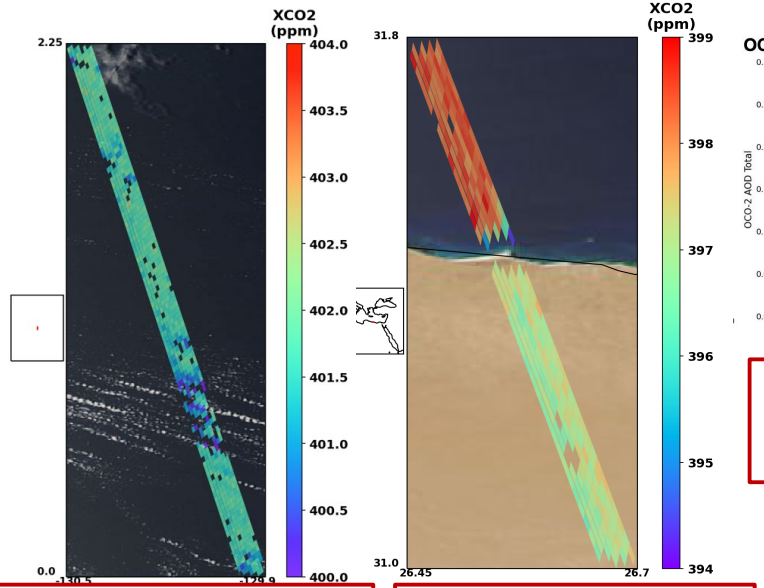
NASADEM – Copernicus [m]



OCO-3 SAM over Sasan Ultra Mega power plant region, India, Feb 2022 [S. Pandey]

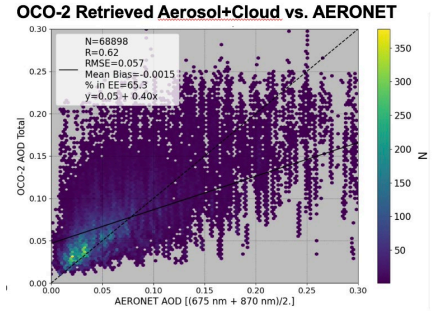


Aerosol-induced errors



Cloud-induced low biases over water

Aerosol-induced land/water biases

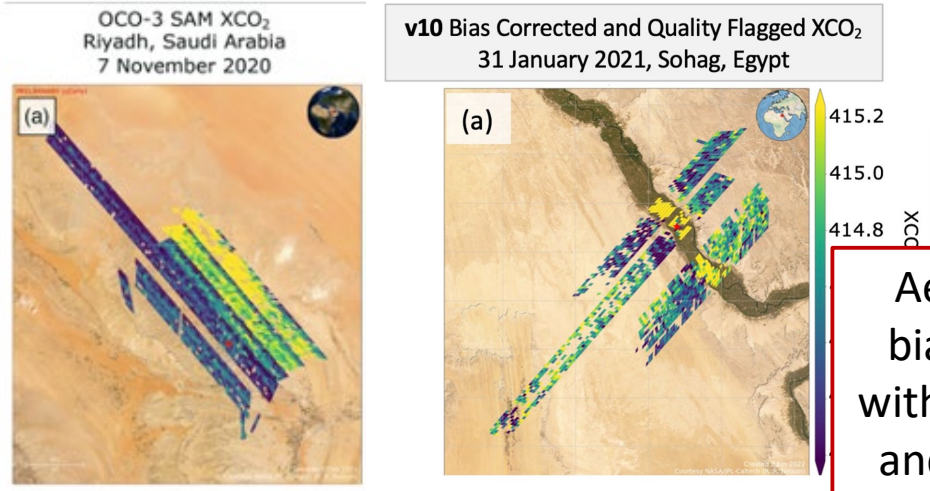


OCO-retrieved AODs are poor

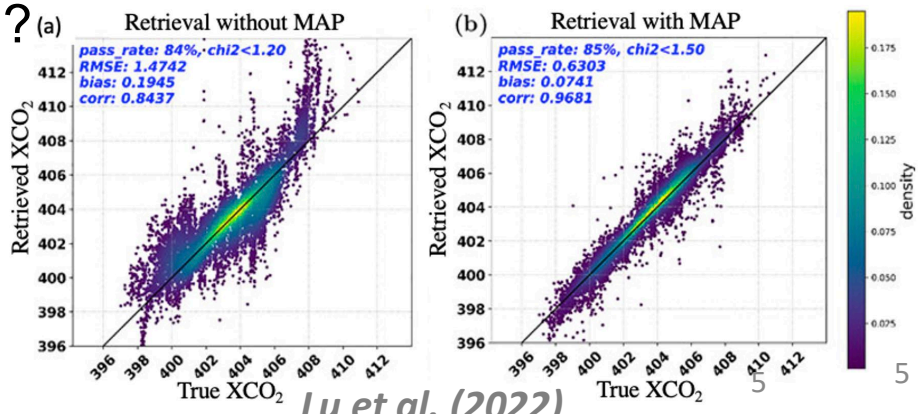
- Cloud-induced errors over land and water; even 3D-effects in otherwise clear pixels. (Massie et al., 2023)
- Simulations show that aerosols main cause of geometry- and albedo-correlated biases in OCO-3 SAMs (Bell et al., 2023). Also affects CH4 (Somkuti et al, 2023)!
- Can we find a 1-size-fits-all aerosol parameterization?

Retrieval	Aerosol Scheme	#Params	Reference
ACOS	5 fixed types, AODs+heights	9	O'Dell et al., 2018
UoL-FP	2 Aerosols + Cirrus: full profiles	60	Cogan et al., 2012
RemoTeC	1 variable type: AOD, Height, Size	3	Butz et al., 2011
NIES	2 Aerosols: profiles; Cirrus: AOD+Height	14	Yoshida et al., 2013; Someya et al., 2023
FOCAL	1 type: AOD, Height, Angstrom Exponent	3	Reuter et al. (2017), Noel et al. (2021)

- Do we need accurate *a priori* aerosols, such as from MAP on CO2M?



Aerosol-induced biases correlated with geometry (left) and albedo (right)



Lu et al. (2022)

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Take-home messages

- We've greatly improved in ability to measure XCO_2 with satellites over the last ~15 years.
- Systematic XCO_2 errors still limit both science and policy uses of our data.
- **Aerosol-induced errors** are the largest contributor to systematic errors in ACOS retrievals, with only limited improvements over the last decade+. **Can we improve without dedicated aerosol sensors?**
- The dry air column (= **surface pressure**) is also critical, but the current method of using the prior can be subject to important uncertainty sources. **Can we improve, and do we need to?**
- These same types of errors affect XCH_4 retrievals as well!
- Local/Urban systematic errors need less stringent requirements.