The Orbiting Carbon Observatory (OCO) Mission

Watching The Earth Breathe…Mapping CO_2 From Space.

Update on the Validation of OCO-2 XCO_2 Data

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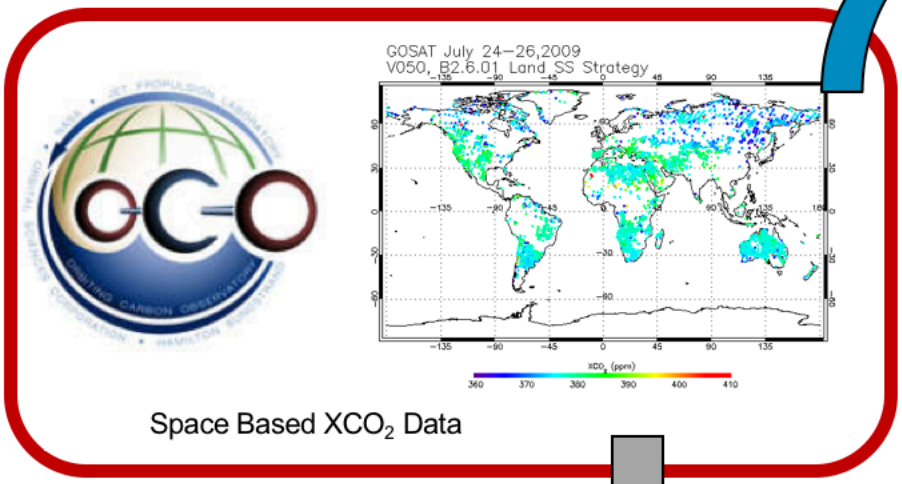
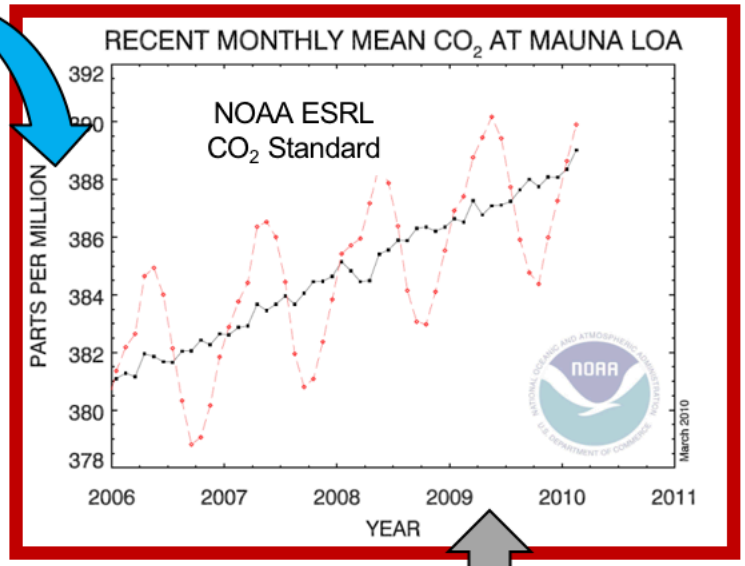
2 University of Toronto
3 California Institute of Technology
4 Colorado St University

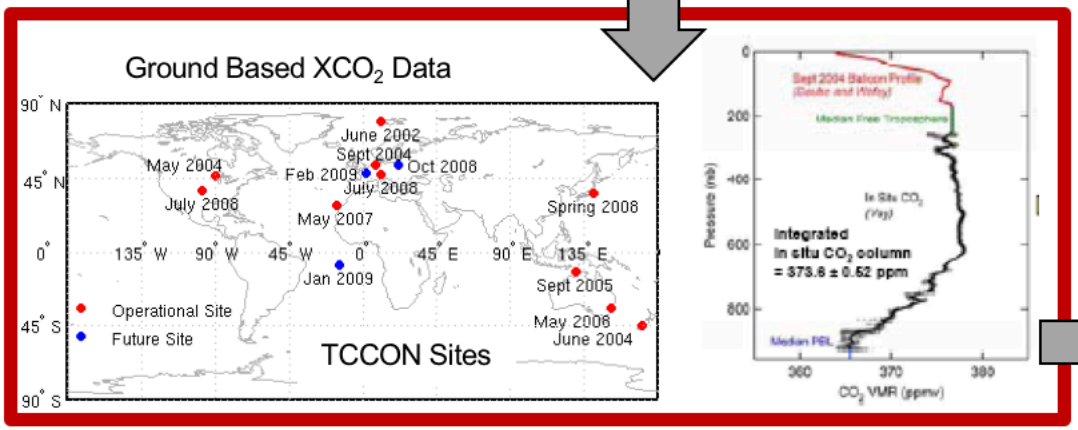
May 8, 2018
International Workshop on Greenhouse Gas Measurements from Space - 14

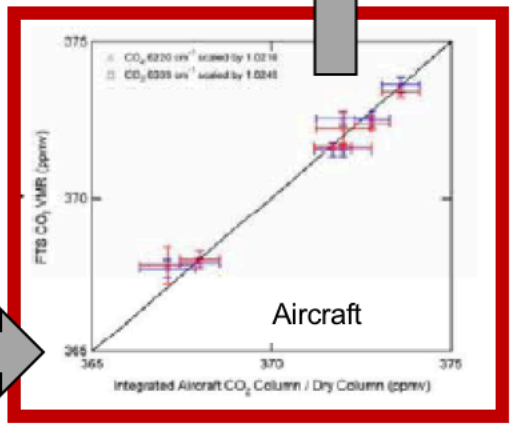
Jet Propulsion Laboratory
California Institute of Technology

OCO-2 Validation Plan: 2010

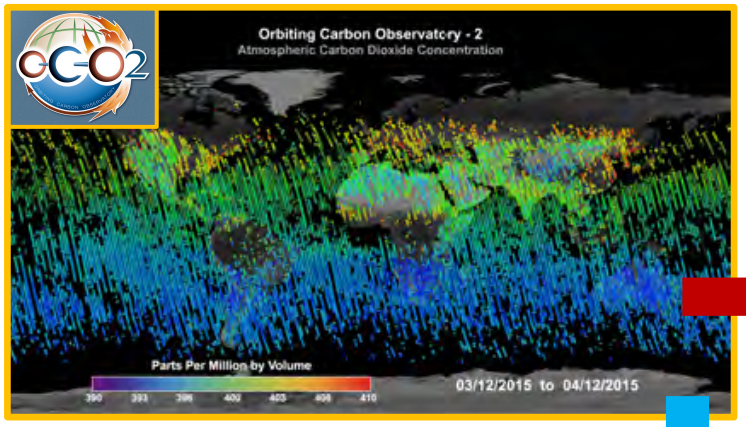


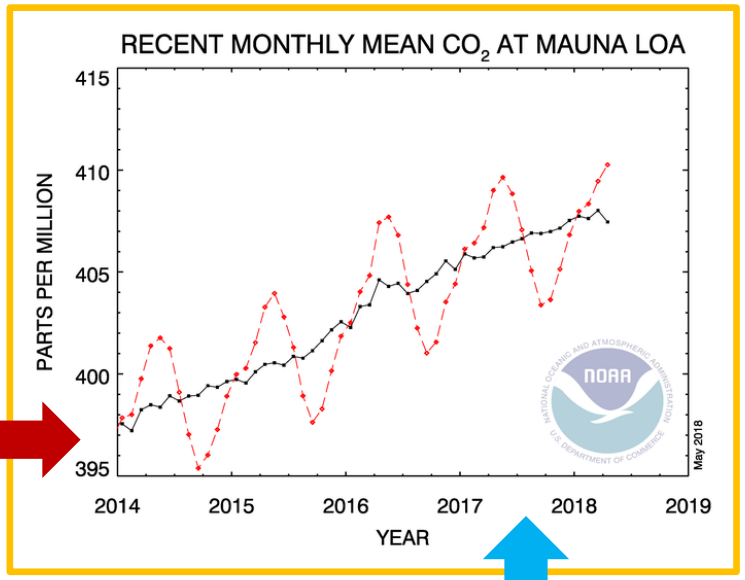


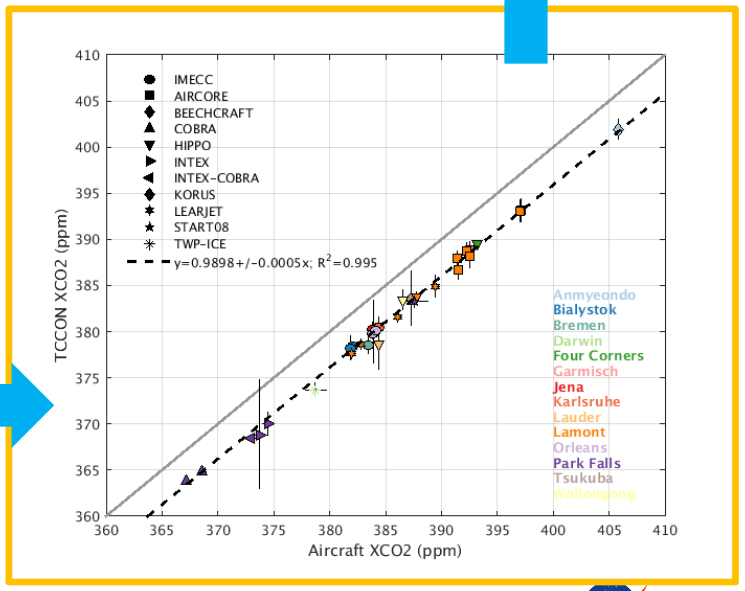




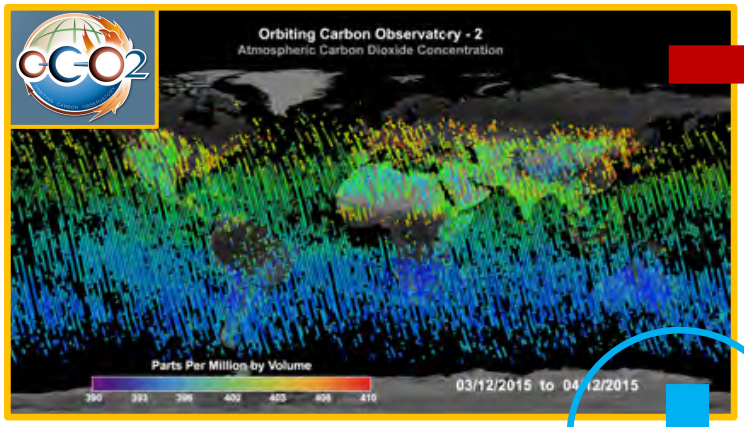
OCO-2 Validation Plan: Now

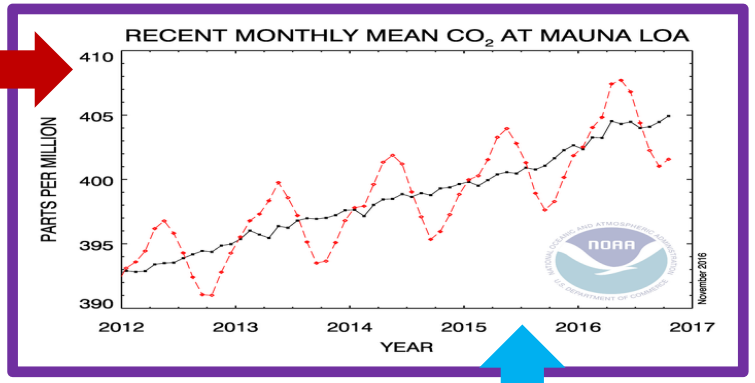


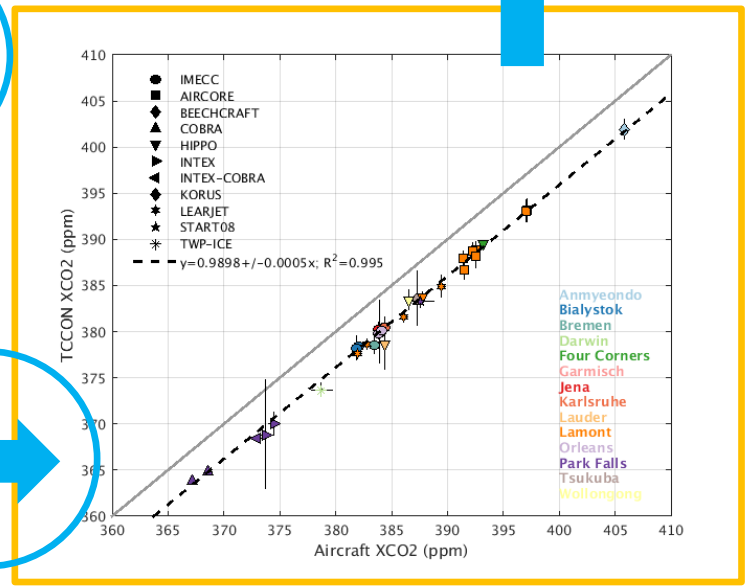




OCO-2 Validation Plan: Now

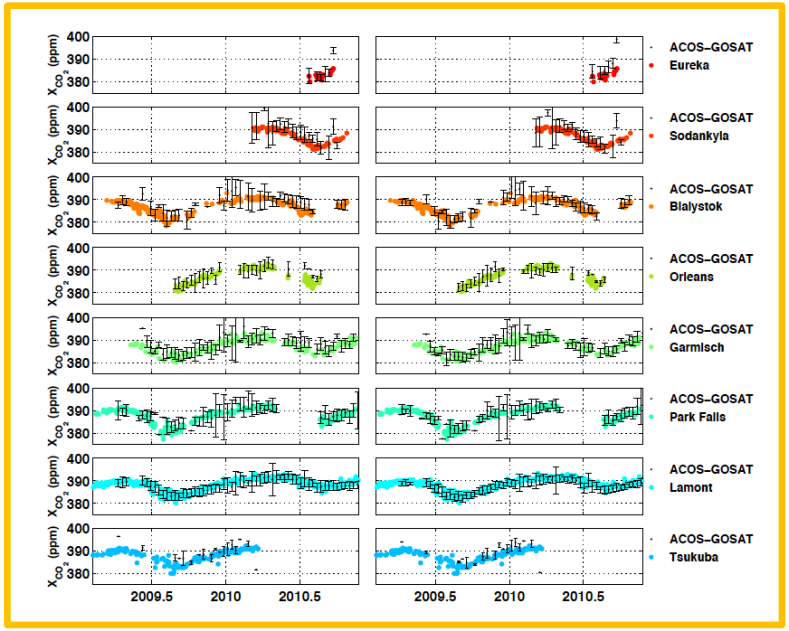






ACOS/GOSAT: Initial Test

- GOSAT data provided a chance to test and refine the details of the plan
- Wunch et al., (2011) showed how the comparisons between TCCON and satellite data should be performed
- Filtering, bias correction, averaging kernels, effect of a priori information, coincidence criteria



Atmos. Chem. Phys., 11, 12317–12337, 2011
www.atmos-chem-phys.net/11/12317/2011/
doi:10.5194/acp-11-12317-2011

Atmospheric Chemistry and Physics

A method for evaluating bias in global measurements of CO_2 total columns from space

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Received: 28 June 2011 – Published in Atmos. Chem. Phys. Discuss.: 22 July 2011
Revised: 21 November 2011 – Accepted: 24 November 2011 – Published: 9 December 2011

Abstract. We describe a method of evaluating systematic errors in measurements of total column dry-air mole fractions of CO_2 (X_{CO_2}) from space, and we illustrate the method by applying it to the v2.8 Atmospheric CO_2 Observations from Space retrievals of the Greenhouse Gases Observing Satellite (ACOS-GOSAT) measurements over land. The approach exploits the lack of large gradients in X_{CO_2} south of 25° S to identify large-scale offsets and other biases in the ACOS-GOSAT data with several retrieval parameters and errors in instrument calibration. We demonstrate the effectiveness of the method by comparing the ACOS-GOSAT data in the Northern Hemisphere with ground truth provided by the Total Carbon Column Observing Network (TCCON). We use the observed correlation between free-tropospheric potential temperature and X_{CO_2} in the Northern Hemisphere to define a dynamically informed coincidence criterion between the ground-based TCCON measurements and the ACOS-GOSAT measurements. We illustrate that this approach provides larger sample sizes, hence giving a more robust comparison than one that simply uses time, latitude and longitude criteria. Our results show that the agreement with the TCCON data improves after accounting for the systematic errors, but that extrapolation to conditions found outside the region south of 25° S may be problematic (e.g., high airmasses, large surface pressure biases, M-gain, measurements made over ocean). A preliminary evaluation of the improved v2.9 ACOS-GOSAT data is also discussed.

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Published by Copernicus Publications on behalf of the European Geosciences Union.

OCO-2 Validation: Today

Wunch et al. (2017) Analysis:

- Comparisons between OCO-2 and TCCON for all OCO-2 observation modes
- Investigated mode differences and dependency on geography
- Looked at variability within target mode observations
- Differences by mode and season
- Time series at individual TCCON sites

Conclusions:

- Aggregated OCO-2 XCO2 estimates generally compare well with TCCON on global scales
  - Absolute mean biases < 0.4 ppm
  - RMS differences < 1.5 ppm
- Biases remain after bias correction
- Variability due to surface brightness and topography
- Ocean glint biases at high latitude
- Latitude bias, largest north of 45°N

Manuscript prepared for Atmos. Meas. Tech.
with version 2014/09/16 7.15 Copernicus papers of the LaTeX class copernicus.cls.
Date: 10 February 2017

Comparisons of the Orbiting Carbon Observatory-2 (OCO-2) X_{CO_2} measurements with TCCON

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[5]University of Bremen, Bremen, Germany
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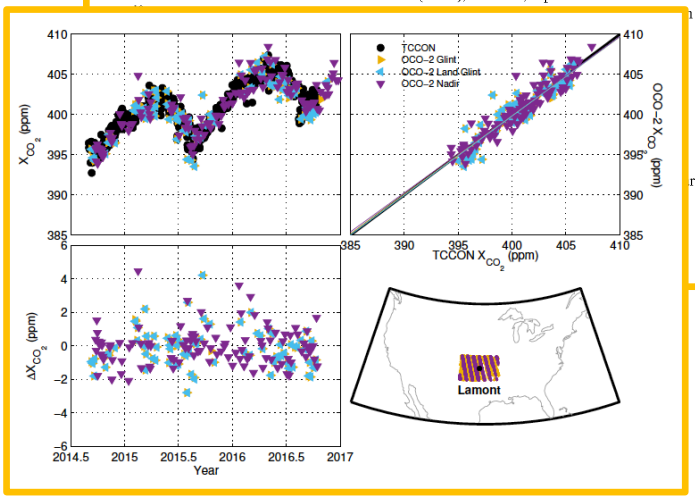
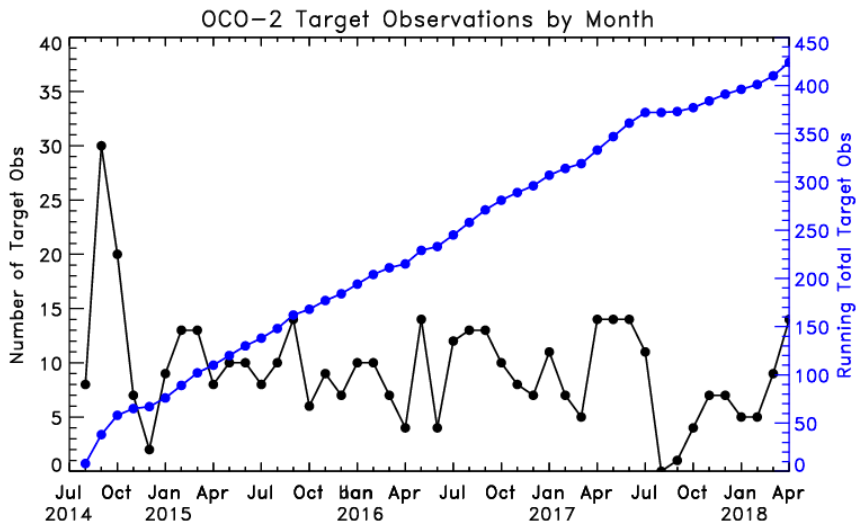
[8]National Institute of Water and Atmospheric Research, Lauder, New Zealand
[9]National Institute for Environmental Studies (NIES), Tsukuba, Japan



OCO-2 Target Mode

Target Location	Date/Time	MODIS Image
Railroad Valley	2018-04-27 20:54:13	
Caltech	2018-04-23 21:15:43	
Wollongong	2018-04-22 03:45:05	
Railroad Valley	2018-04-20 20:48:11	
Rikubetsu	2018-04-19 03:35:19	
Los Angeles	2018-04-18 20:57:20	
Saga	2018-04-18 04:28:14	
Fairbanks	2018-04-17 22:01:43	
Sodankyla	2018-04-14 09:59:37	
Fairbanks	2018-04-08 22:07:49	
Niwot Ridge	2018-04-08 20:21:48	
East Trout Lake	2018-04-07 19:42:40	
Lauder	2018-04-05 03:00:03	
Wollongong	2018-04-04 03:57:04	

- Target Observations during April 2018
- OCO-2 has executed 424 target observations since August 8, 2014
- There were 14 target observations made in April 2018 (Table to left)
- First observations of new target sites Los Angeles, CA and Niwot Ridge, CO

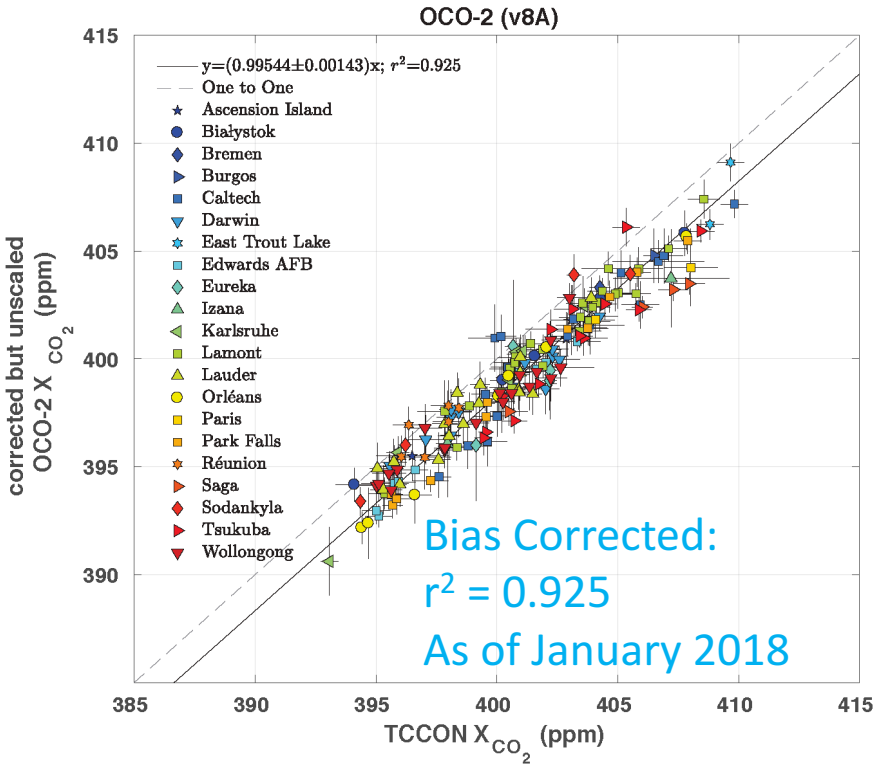


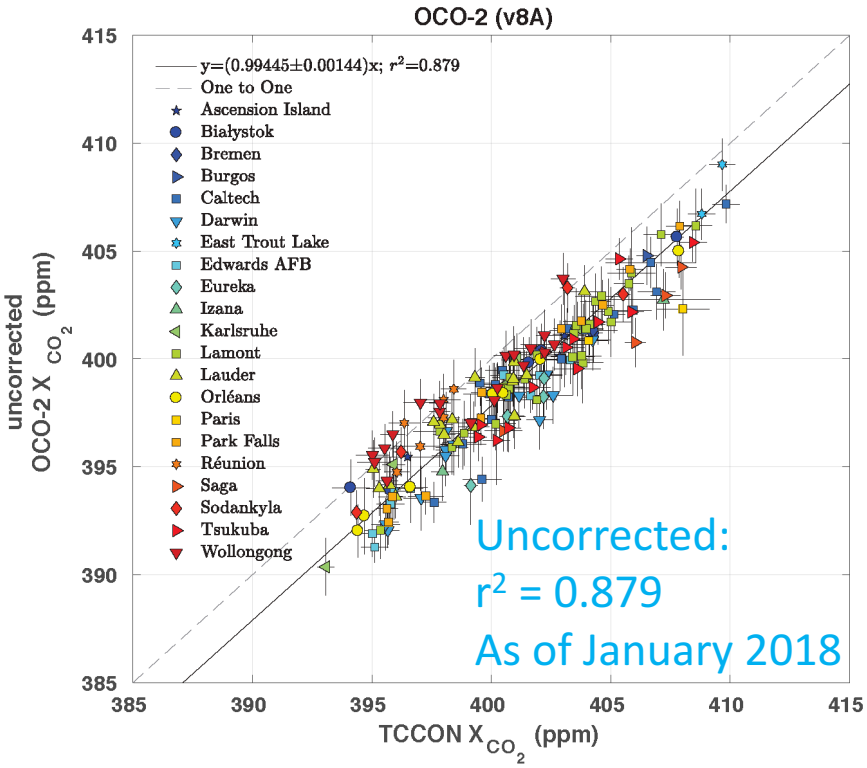
OCO-2 Target Mode

Site	# Obs	April 2018	Last Observation	Site	# Obs	April 2018	Last Observation
Anmyeondo	4	0	2017-02-15 04:46:43	Los Angeles	1	1	2018-04-18 20:57:20
Ascension Island	12	0	2018-01-15 14:40:05	Manaus	4	N/A	2015-07-29 17:40:51
Bialystok	10	0	2017-03-30 11:08:35	Mexico City	3	N/A	2016-01-24 19:56:38
Boulder	0	0	-	Niwot Ridge	1	1	2018-04-08 20:21:48
Bremen	2	0	2016-03-17 12:10:17	Orleans	18	0	2017-04-20 13:04:09
Burgos	3	0	2018-03-23 05:25:54	Paris	5	0	2017-11-14 13:04:24
Caltech	28	1	2018-04-23 21:15:43	Park Falls	22	0	2018-03-10 19:15:24
Darwin	19	0	2017-07-28 05:03:39	Poker Flat/Fairbanks	18	2	2018-04-17 22:01:43
Dryden (Armstrong)	17	0	2017-05-17 20:56:38	Railroad Valley	46	2	2018-04-27 20:54:13
East Trout Lake	4	1	2018-04-07 19:42:40	Reunion Island	28	0	2018-03-07 10:11:31
Eureka	4	N/A	2015-06-28 17:06:58	Rikubetsu	4	1	2018-04-19 03:35:19
Hyytiala	6	N/A	2017-07-01 10:39:52	Rosemount	1	N/A	2016-07-01 19:19:56
Izana	10	0	2018-03-24 14:26:18	Saga	8	1	2018-04-18 04:28:14
Karlsruhe	10	0	2017-07-06 12:33:21	Sao Paulo	1	N/A	2016-02-03 17:03:55
Lamont	43	0	2018-03-13 19:43:45	Shanghai	3	N/A	2016-02-07 05:22:09
Lauder	26	1	2018-04-05 03:00:03	Sodankyla	12	1	2018-04-14 09:59:37
Libya	5	N/A	2017-02-20 11:38:42	Tsukuba	21	0	2018-03-14 03:58:00
Litchfield	0	N/A	-	Wollongong	25	2	2018-04-22 03:45:05

- 19 possible target locations available at launch
- 27 possible target locations available currently (since July 2015)
- Two new target locations starting March 22, 2018:
  - Los Angeles (Surface Observation)
  - Niwot Ridge (SIF)
  - Location of Reunion Island and Boulder targets updated
- Armstrong TCCON currently at JPL (OCO-3 testing)
- Poker Flat target moved to Fairbanks (March 2017)

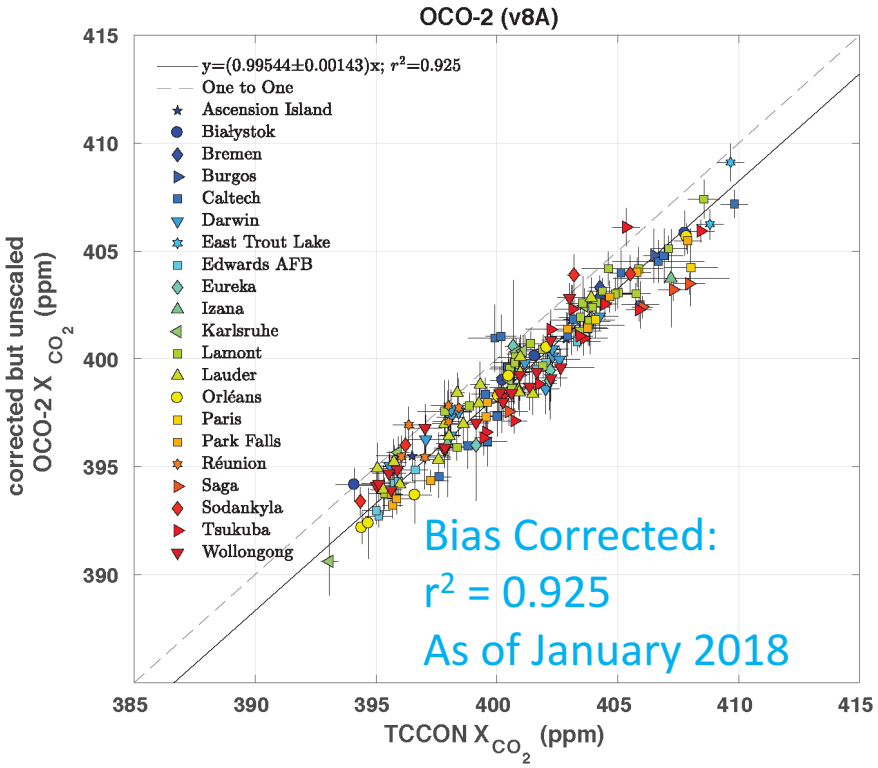
OCO-2 Comparisons to TCCON: Target Mode

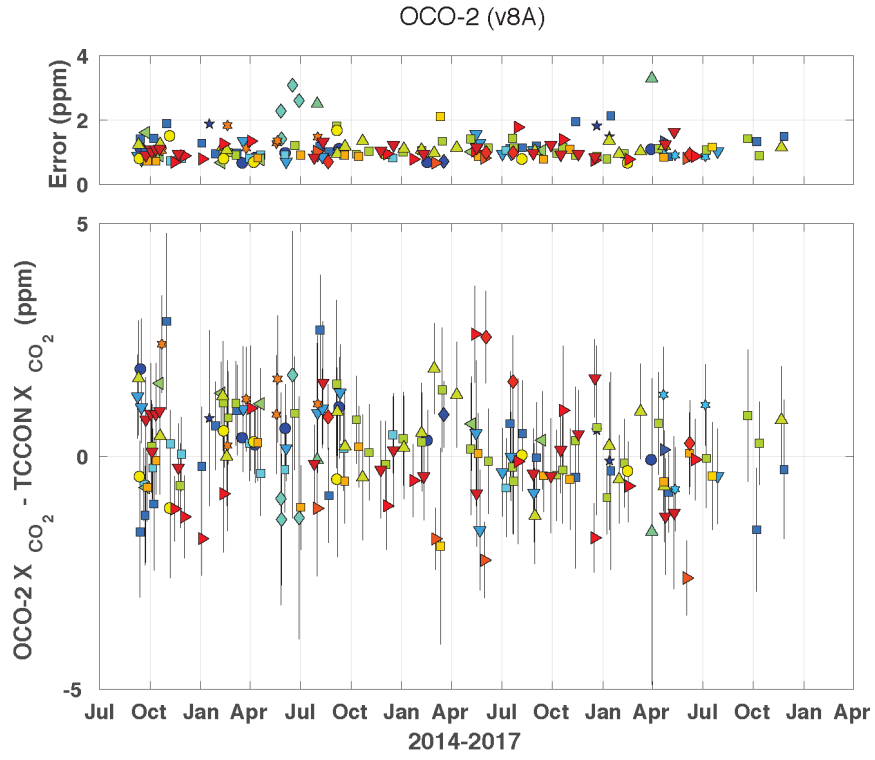




Figures from Matthäus Kiel

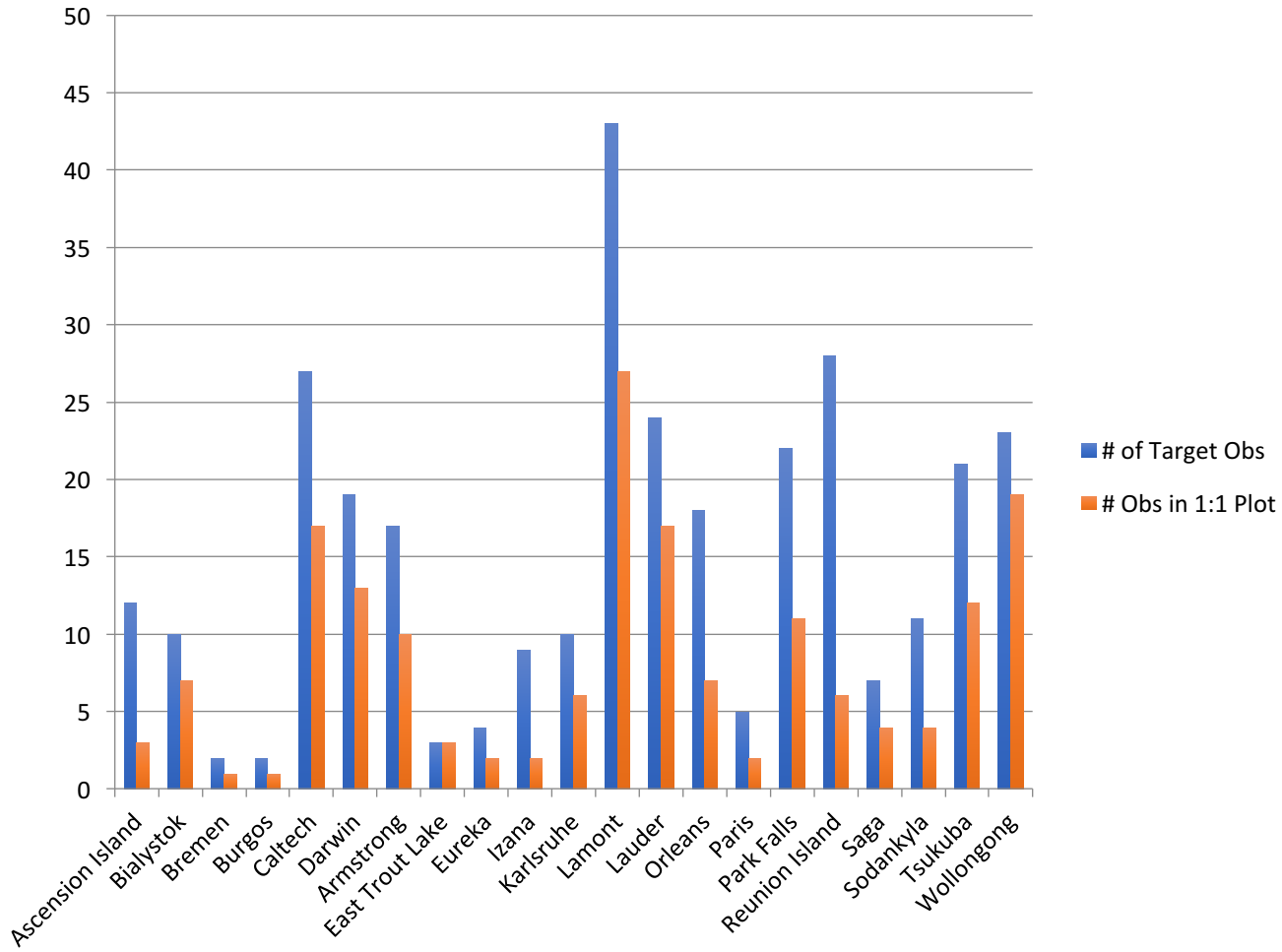
OCO-2 Comparisons to TCCON: Target Mode, Time Series





Figures from Matthäus Kiel

Selecting Targets



- Considerations that go into whether to select a target:
  - Weather
  - TCCON site status
  - Time since most recent clear sky target selection
  - Not too many targets in a region over a short period of time
- Some sites are easier to get than others:
  - European sites sometimes overridden due to ground contacts

Selecting Targets: TCCON

Total Carbon Column Observing Network (TCCON)

Dear TCCON Partner,

Your TCCON site is included in the list of potential OCO-2 targets for the following period, from 2018-04-27 12:40:48 UTC to 2018-05-06 22:32:09 UTC. The dates and times under consideration for your site are:

parkFallsWI 2018-04-27 14:15:22 CDT (2018-04-27 19:15:22 UTC)
parkFallsWI 2018-04-29 14:03:01 CDT (2018-04-29 19:03:01 UTC)
parkFallsWI 2018-05-01 13:50:51 CDT (2018-05-01 18:50:51 UTC)
parkFallsWI 2018-05-06 14:09:05 CDT (2018-05-06 19:09:05 UTC)

Please take a moment now to update your site's operational status, as this information is a critical part of the decision-making process for determining which site to target:

https://tccon-wiki.caltech.edu/Sites/Park_Falls/Operational_Status

Selections will be made by 5 PM Pacific Time before a scheduled target and you will be notified at that time if your site has been selected.

The OCO-2 Validation Team thanks you, in advance, for your participation! Questions or concerns can be directed to Greg Osterman (Gregory.B.Osterman@jpl.nasa.gov) or Coleen Roehl (coleen@gps.caltech.edu).

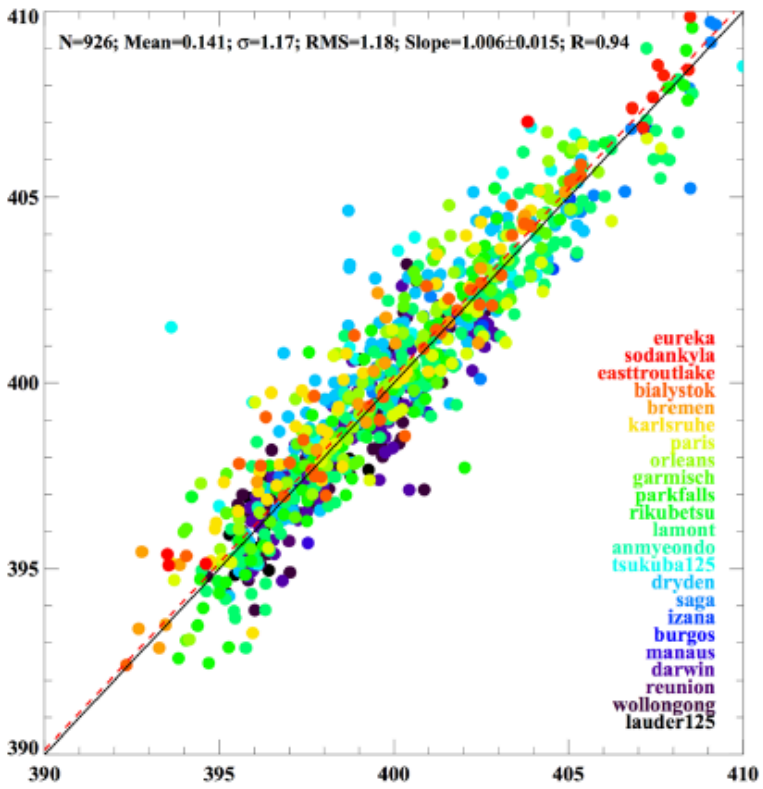
Thank you,
The OCO-2 Validation Team

- The entire OCO-2 validation plan is based on obtaining TCCON data
- We alert TCCON PIs about possible target observations a week ahead of time
- We alert TCCON PIs about selected targets 12-24 hours ahead.
- TCCON PIs keep their status updated on the TCCON wiki allowing that status to be factored into target decisions
- Provide quick turn around for TCCON data coincident with target observations

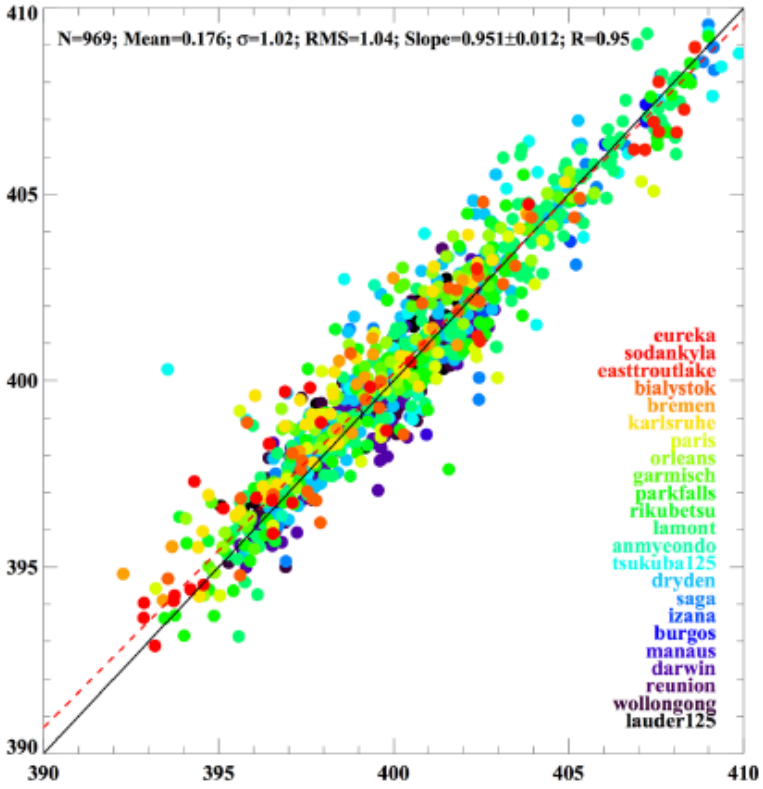
Continued thanks to our TCCON partners for all their work to make OCO-2 a success!

OCO-2 Nadir/Glint Observations vs TCCON: Land

B7, land Nadir+Glint



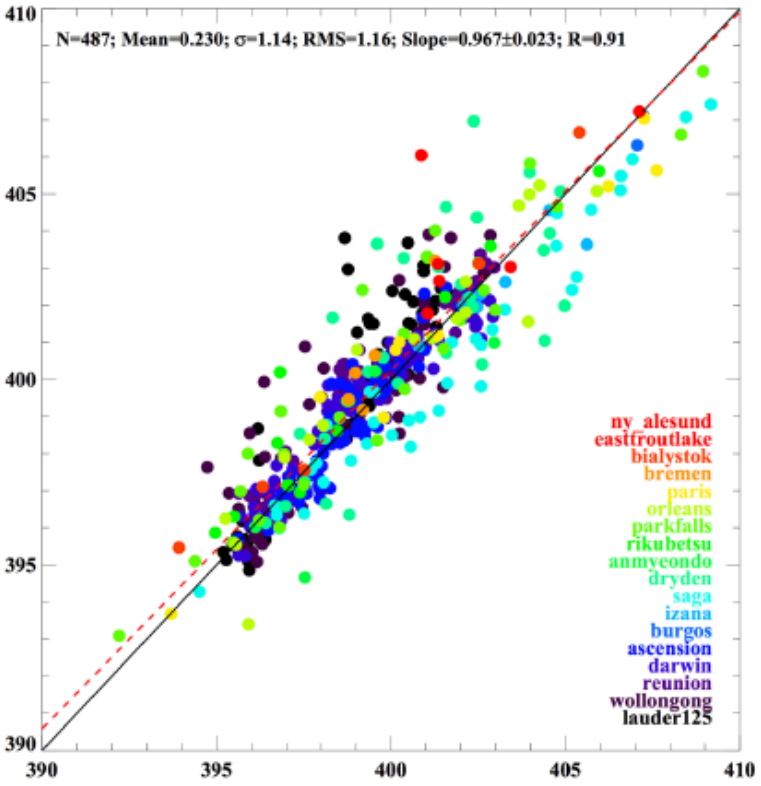
B8, land Nadir+Glint



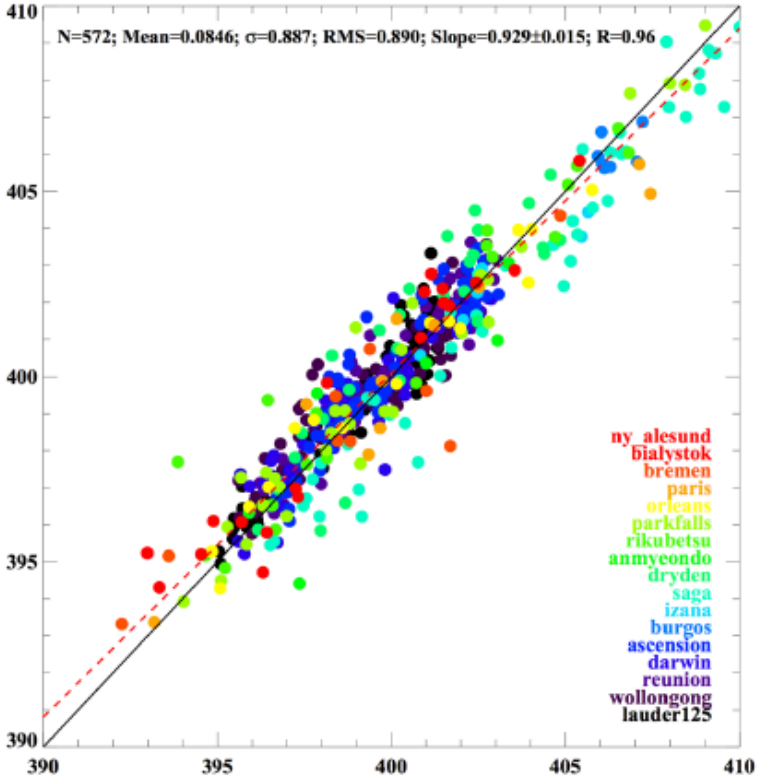
Figures from Chris O'Dell

OCO-2 Nadir/Glint Observations vs TCCON: Land

B7, ocean Glint



B8, ocean Glint



Figures from Chris O'Dell

OCO-2 Comparisons to TCCON: By Site

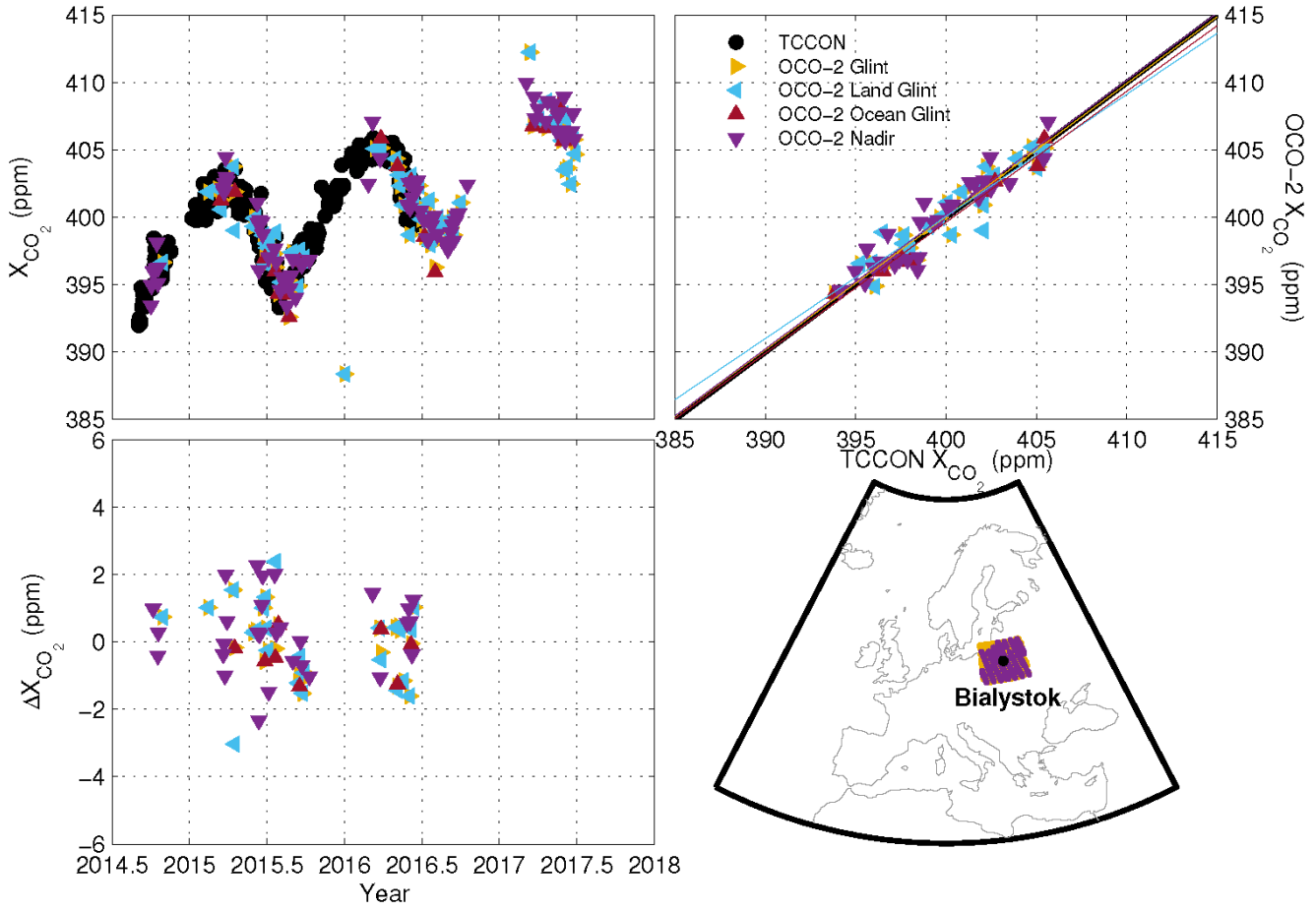
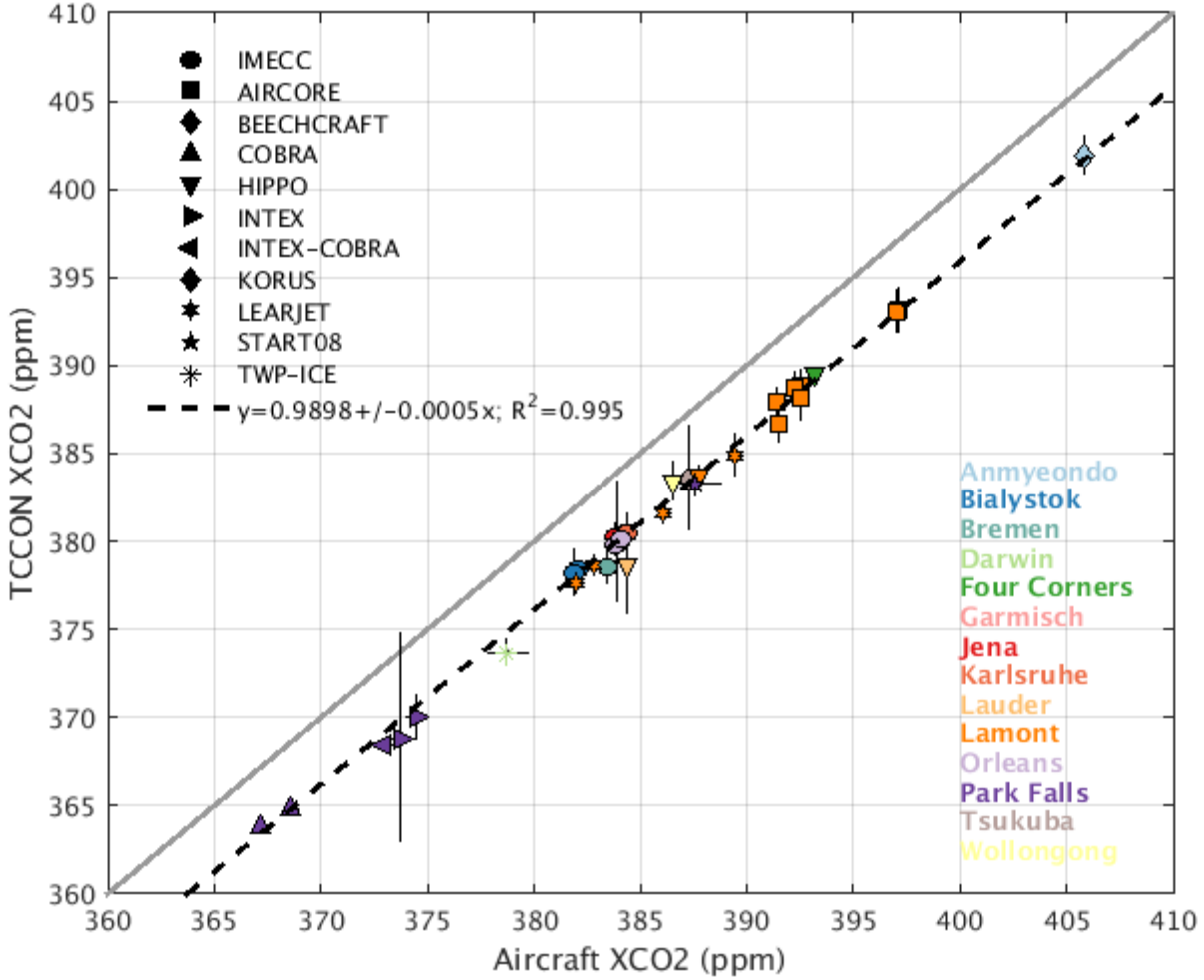


Figure from Debra Wunch

TCCON Comparison to Aircraft, AirCore

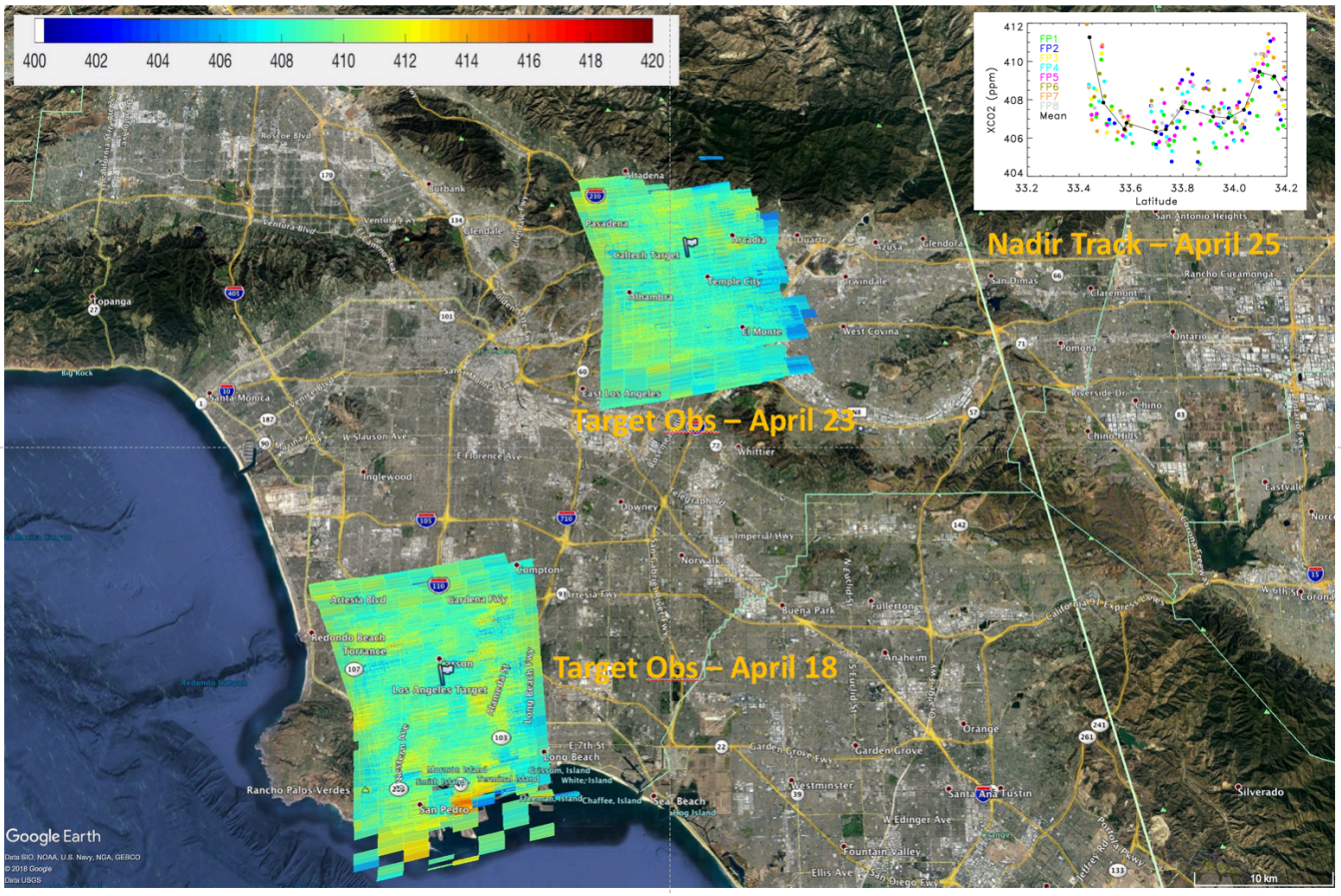


- Additional aircraft data points from KORUS-AQ and ATom
- AirCore flights from Lamont and Lauder
- Additional profiles from AirCore launches this summer at North American sites

C. Roehl, et al., Feist et al., Shiomi et al., Kivi et al., Posters on Tuesday

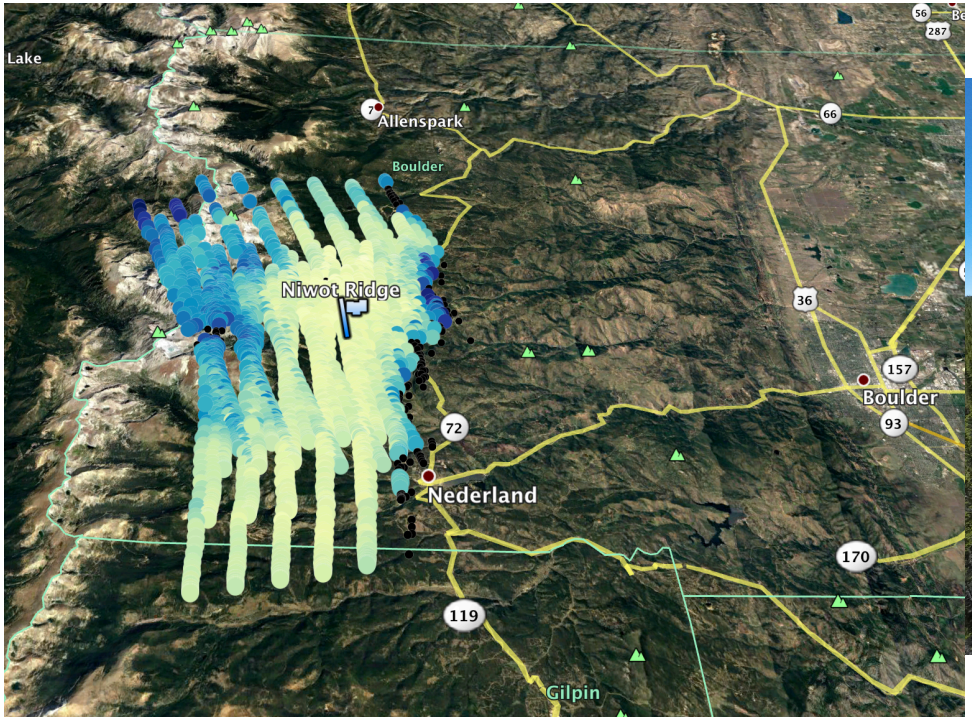
New Target: Los Angeles

- Site in Los Angeles near observation sites for the JPL Megacity Carbon Project and strong emission sites
- Southern California observations in April 2018 shown



New Target: Niwot Ridge

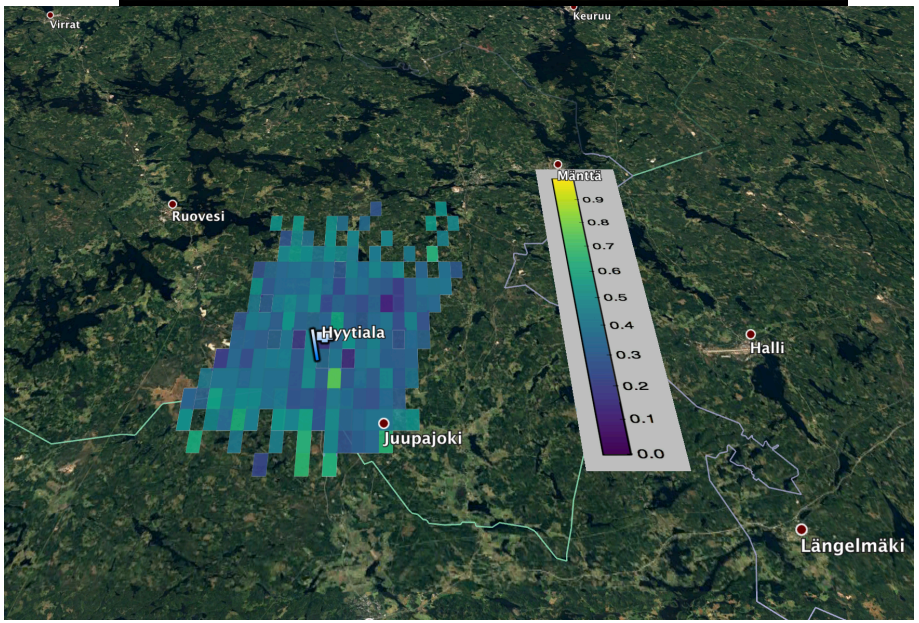
- Site for SIF analysis
- Elevation of 10,000 ft near Boulder, CO (40.0329N, 105.5464W)
- Target location contains evergreen needle forest and barren areas for contrast
- Tower with SIF spectrometer



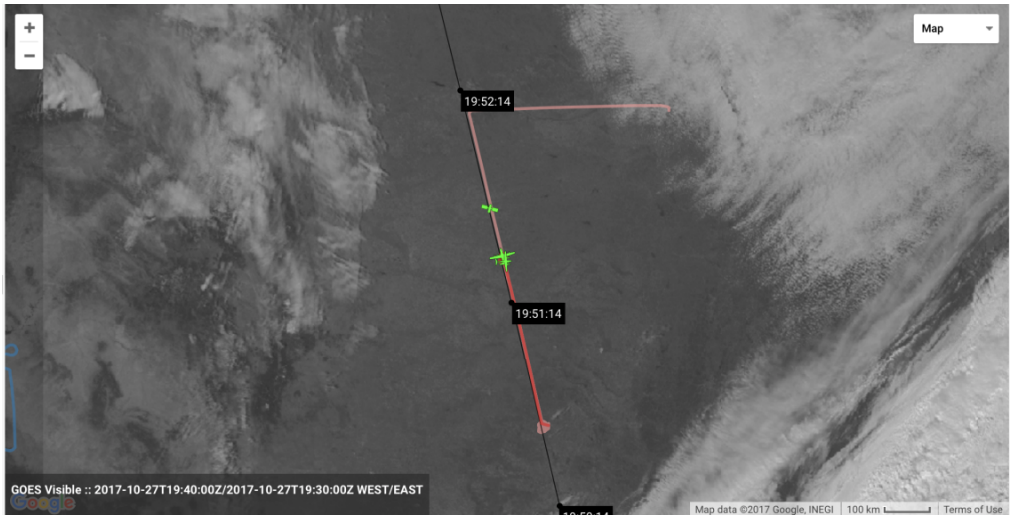
SIF Target - 2017: Hyytiälä

- Hyytiälä, Finland was a target site from March 2017 to March 2018 - SIF focus
- In support of the Fluorescence Across Space and Time (FAST) campaign
- Surface measurements, drone observations and Flux Tower

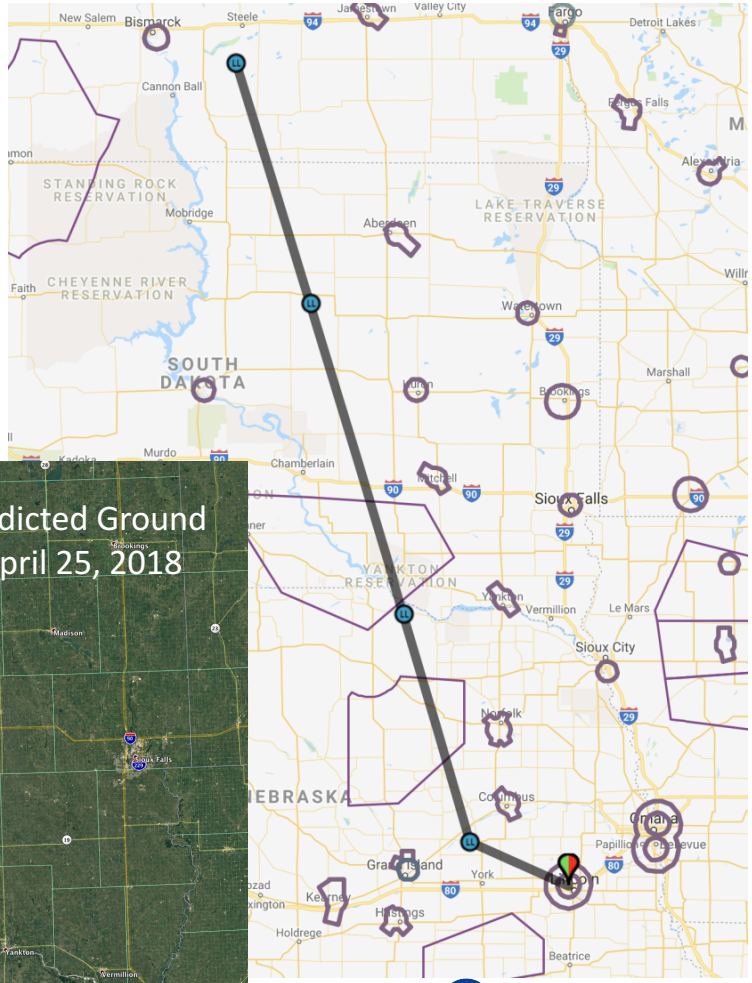
Albert Porcar Castell et al.



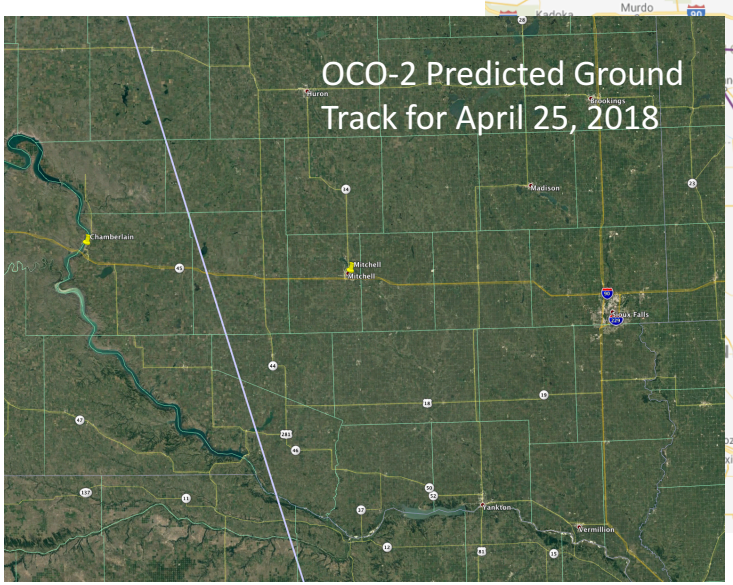
Aircraft: ACT-America



B-200 Flight Plan
April 25, 2018

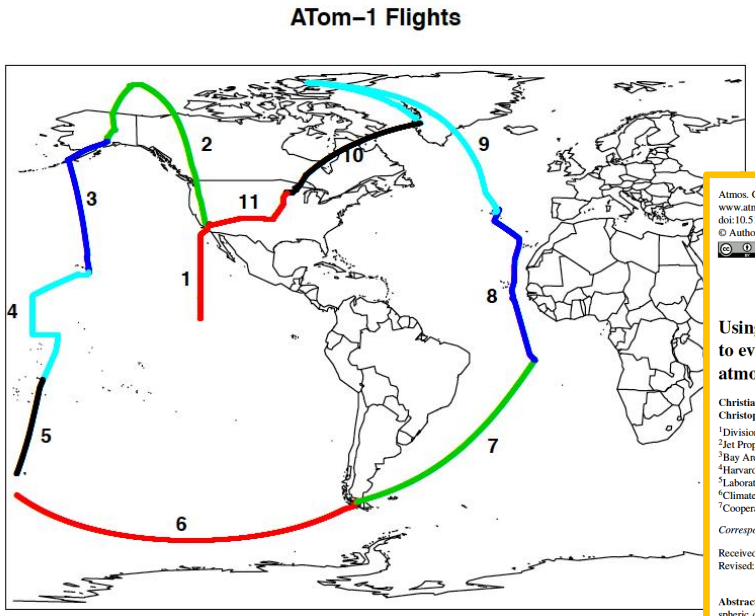


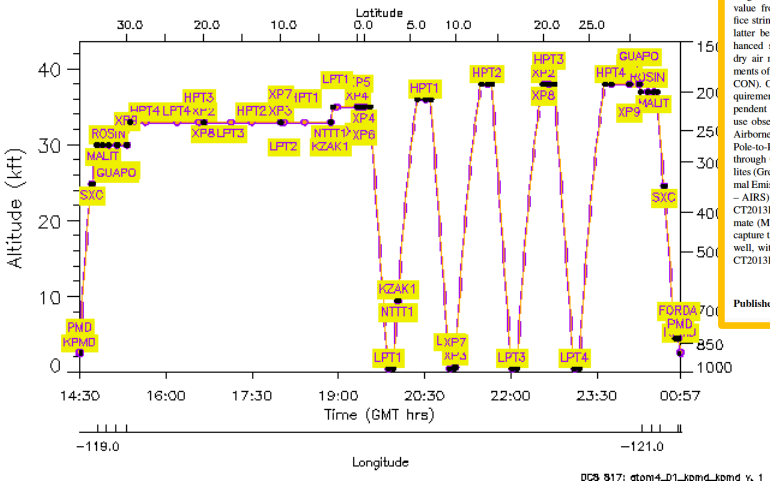
- There have been 12 OCO-2 under flights during ACT-America:
  - Summer 2016 – July 27, August 5, 27
  - Winter 2017 – February 13, 15, March 8
  - Fall 2017 – October 22, 27, November 9
  - Spring 2018 – April 18, 25, 27
- Analysis of ACT-America Lidar measurements of CO2, OCO-2 observations and model results ongoing (Emily Bell, Colorado St. University)

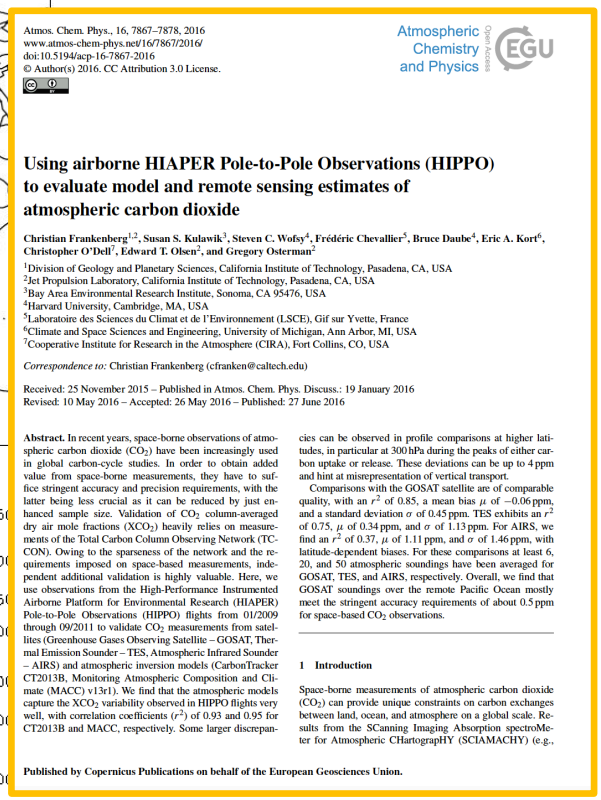


Aircraft: ATom

- ATom flights have provided vertical profiles at several TCCON sites: Ascension Island, Lamont, Park Falls, Edwards/Armstrong, Eureka and Lauder (12 soundings total)
- ATom observations (including profiles) over the ocean will be helpful for OCO-2 validation analysis (work currently just underway)
  - This was prototyped with an analysis using ACOS/GOSAT data with HIPPO data (Frankenberg et al., 2016)







Atmos. Chem. Phys., 16, 7867–7878, 2016
www.atmos-chem-phys.net/16/7867/2016/
doi:10.5194/acp-16-7867-2016
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Atmospheric Chemistry and Physics

Using airborne HIAPER Pole-to-Pole Observations (HIPPO) to evaluate model and remote sensing estimates of atmospheric carbon dioxide

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Received: 25 November 2015 – Published in Atmos. Chem. Phys. Discuss.: 19 January 2016
Revised: 10 May 2016 – Accepted: 26 May 2016 – Published: 27 June 2016

Abstract. In recent years, space-borne observations of atmospheric carbon dioxide (CO_2) have been increasingly used in global carbon-cycle studies. In order to obtain added value from space-borne measurements, they have to suffice stringent accuracy and precision requirements, with the latter being less crucial as it can be reduced by just enhanced sample size. Validation of CO_2 column-averaged dry air mole fractions (XCO_2) heavily relies on measurements of the Total Carbon Column Observing Network (TCCON). Owing to the sparseness of the network and the requirements imposed on space-based measurements, independent additional validation is highly valuable. Here, we use observations from the High-Performance Instrumented Airborne Platform for Environmental Research (HIAPER) Pole-to-Pole Observations (HIPPO) flights from 01/2009 through 09/2011 to validate CO_2 measurements from satellites (Greenhouse Gases Observing Satellite – GOSAT, Thermal Emission Sounder – TES, Atmospheric Infrared Sounder – AIRS) and atmospheric inversion models (CarbonTracker CT2013B, Monitoring Atmospheric Composition and Climate (MACC) v13r1). We find that the atmospheric models capture the XCO_2 variability observed in HIPPO flights very well, with correlation coefficients (r^2) of 0.93 and 0.95 for CT2013B and MACC, respectively. Some larger discrepancies can be observed in profile comparisons at higher latitudes, in particular at 300 hPa during the peaks of either carbon uptake or release. These deviations can be up to 4 ppm and hint at misrepresentation of vertical transport.

Comparisons with the GOSAT satellite are of comparable quality, with an r^2 of 0.85, a mean bias μ of −0.06 ppm, and a standard deviation σ of 0.45 ppm. TES exhibits an r^2 of 0.75, μ of 0.34 ppm, and σ of 1.13 ppm. For AIRS, we find an r^2 of 0.37, μ of 1.11 ppm, and σ of 1.46 ppm, with latitude-dependent biases. For these comparisons at least 6, 20, and 50 atmospheric soundings have been averaged for GOSAT, TES, and AIRS, respectively. Overall, we find that GOSAT soundings over the remote Pacific Ocean mostly meet the stringent accuracy requirements of about 0.5 ppm for space-based CO_2 observations.

1 Introduction

Space-borne measurements of atmospheric carbon dioxide (CO_2) can provide unique constraints on carbon exchanges between land, ocean, and atmosphere on a global scale. Results from the SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) (e.g.,

Published by Copernicus Publications on behalf of the European Geosciences Union.

Summary

- Validation of OCO-2 data by comparisons to TCCON has worked well
- TCCON continues to provide information on the state of OCO-2 data
- Expansion of the TCCON has provide new opportunities to validate under different conditions
- OCO-3 will utilize the validation plan doing comparisons to TCCON data
- Also learning about OCO-2 data from comparison to models, results from the Flux Inversion group
- Analysis ongoing for comparisons to aircraft data and portable FTS (EM27)
- Upcoming campaigns: Railroad Valley, Orleans, Sodankyla, North American TCCON sites
- Continuing work at Fairbanks (Niki Jacobs) with EM-27 and target observations