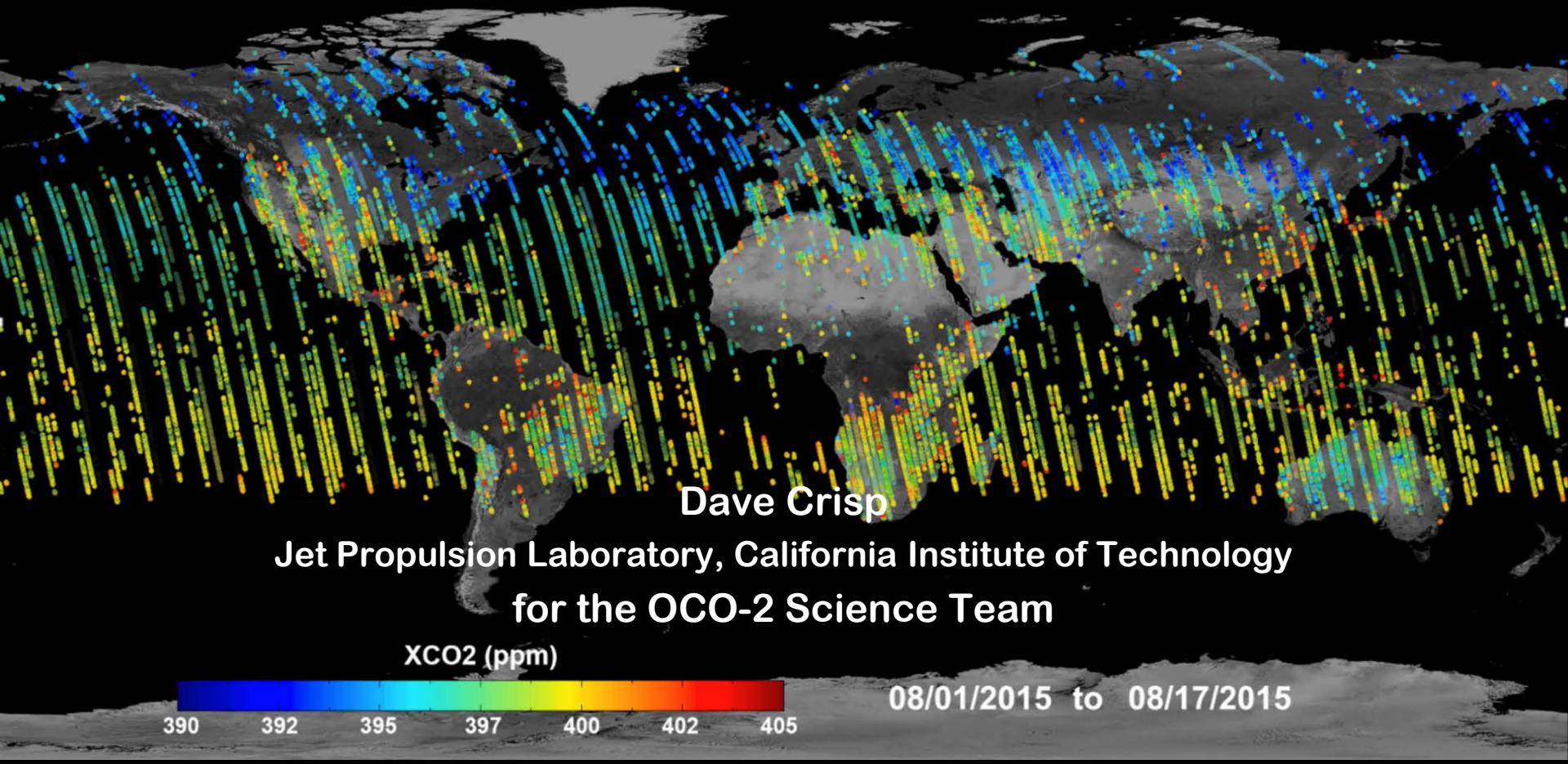
Known Issues with the OCO-2 v7 Product



Dave Crisp
Jet Propulsion Laboratory, California Institute of Technology
for the OCO-2 Science Team

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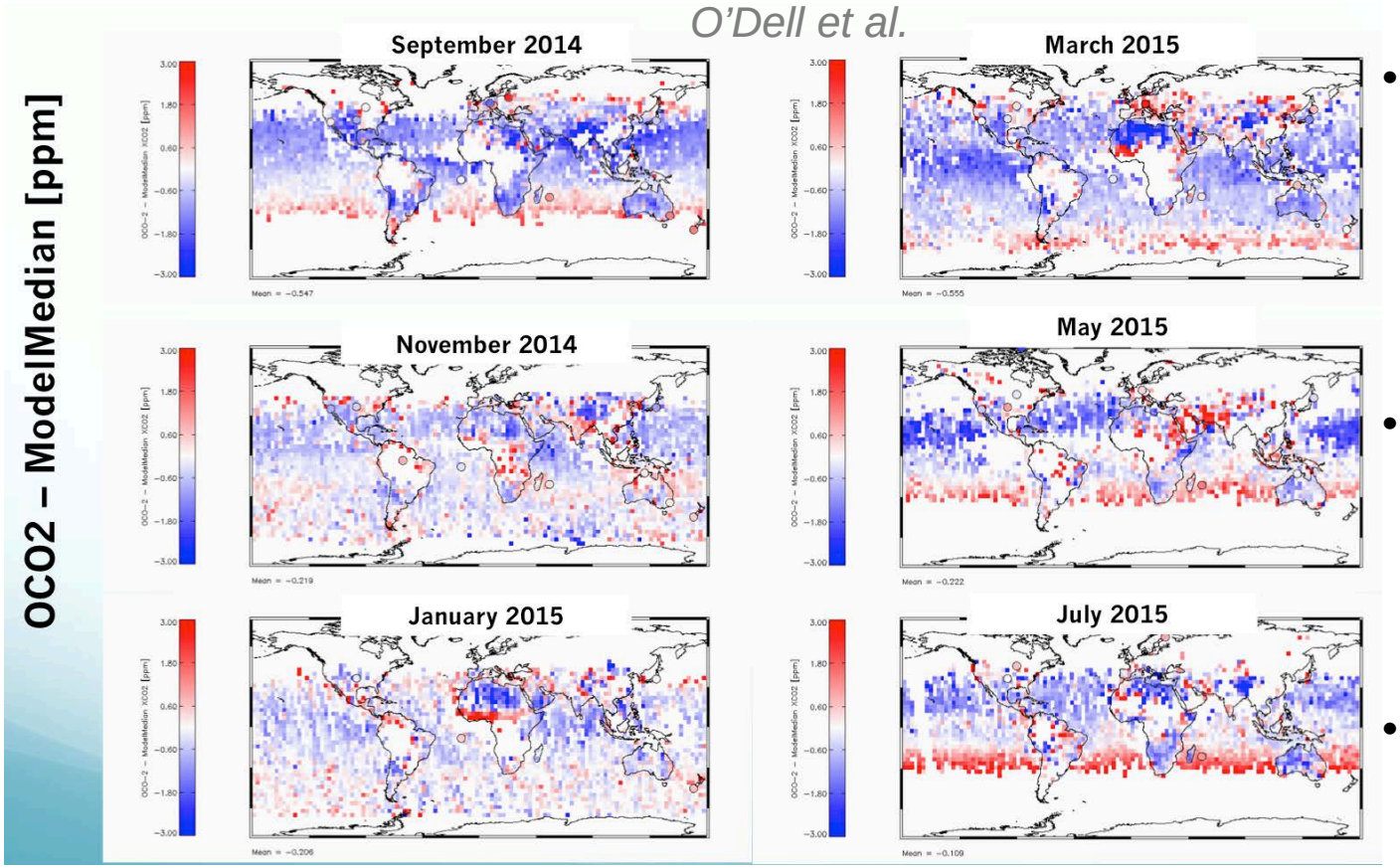
Government sponsorship acknowledged.

Overview

- Over the past several months, several small issues with the OCO-2 Version 7 (V7/V7r) product have been identified
- None of these issues are critical, but, together, they preclude efforts to reduce X_{CO2} errors to < 1 ppm (0.25%) on regional scales
- Issues identifies as part of the Version 8 testing include:
  - Calibration errors
    - A possible 5% high bias in the absolute radiometric calibration, relative to results from Railroad Valley and GOSAT
    - A misattribution of the "slow degradation" in the ABO2 channel as a throughput error rather than a calibration system error
  - Errors in the inputs to the L2 algorithm
    - Errors in the O2 and CO2 gas absorption coefficients
    - Errors in the top-of-atmosphere solar fluxes
    - Misspecification of surface topography in the ECMWF files
  - Intrinsic limitations of the L2 retrieval algorithm
    - Over simplified treatment of the surface reflectance (BRDF)

Example Issue: High Latitude Glint Anomaly

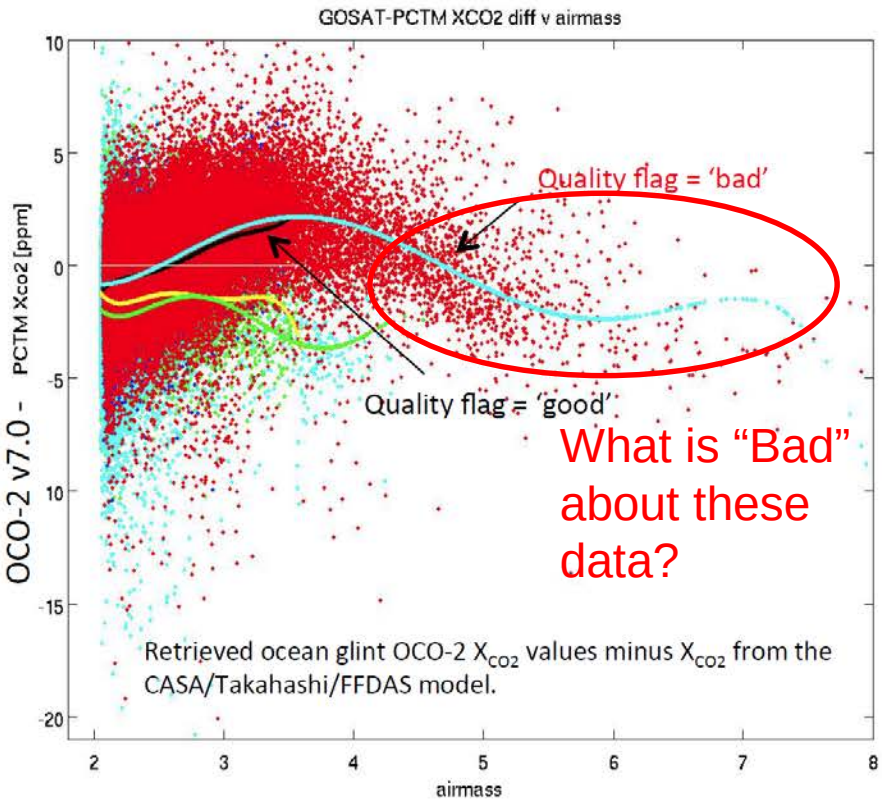
O'Dell et al.

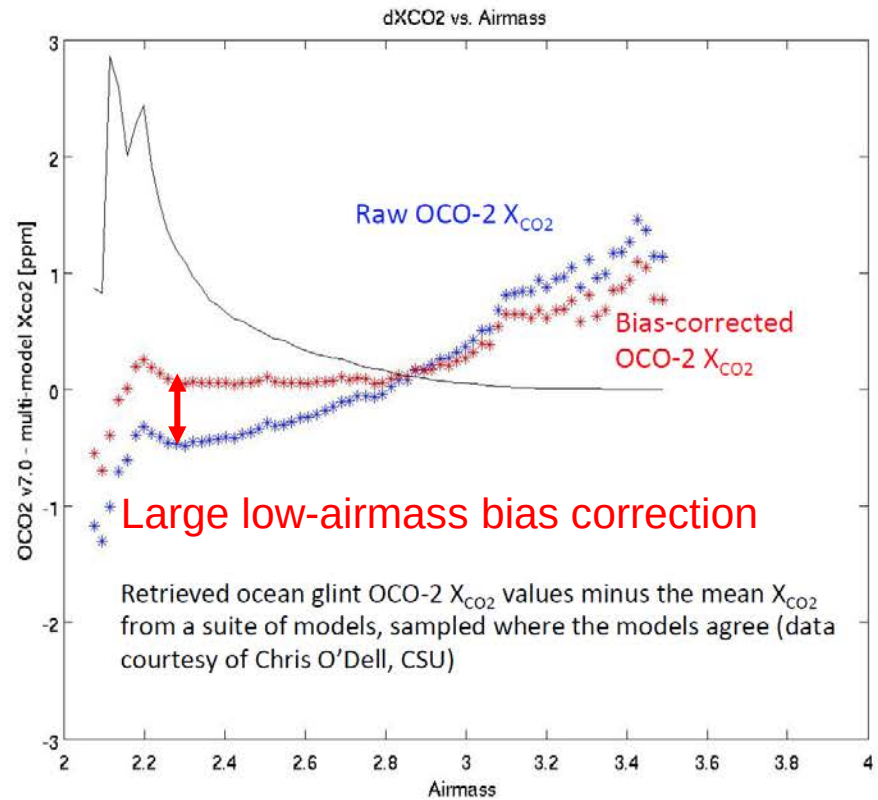


- Glint Ocean data are not consistent with land data at high southern latitudes during southern winter (June – August)
- There few measurements at these latitudes for comparison, but the assumption is that this is a bias.
- The OCO-2 science team has not yet identified the root cause of this apparent bias.

Apparent biases in the OCO-2 L2 XCO2 product, such as the southern hemisphere glint bias have been a major focus to the Version 8 development effort.

Example Issue:
Large, Low Air Mass Bias Correction



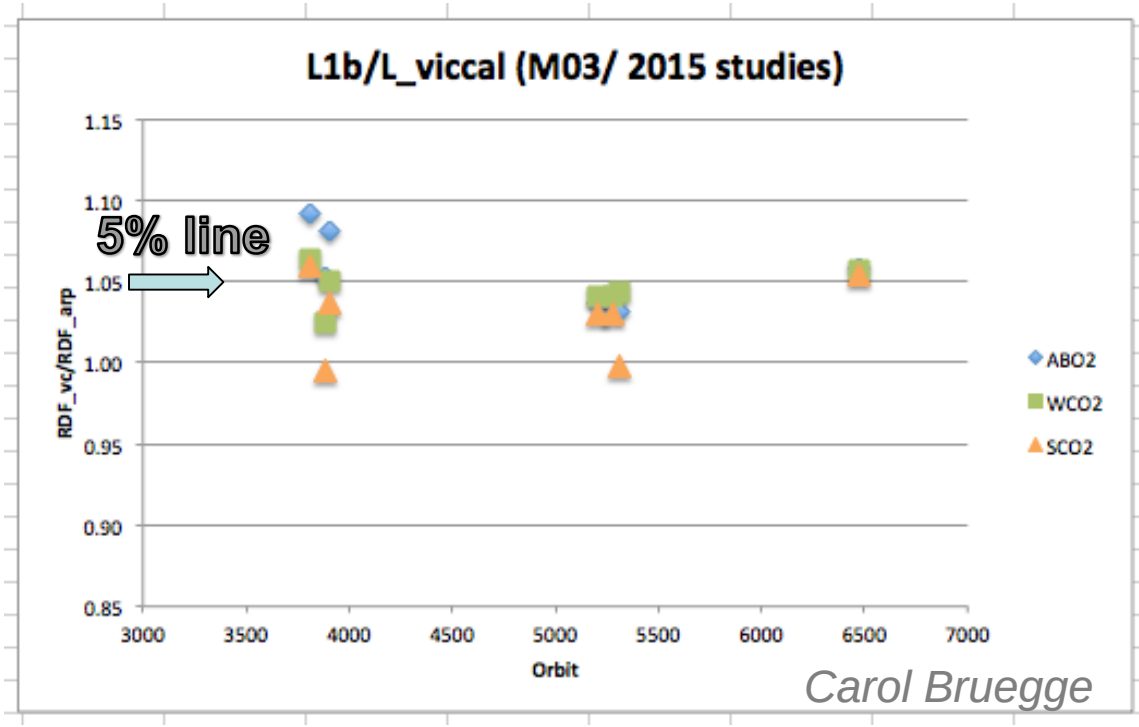


- **While the nominal V7/7r bias correction introduces little change at the largest airmasses, it applies a 0.5 ppm correction at low airmass, a region that covers most of the tropics.**
- **This bias correction has a large impact on flux inversion models.**
- **Marking all data as "bad" beyond airmass 3.5 also restricts coverage.**

Calibration Issues

Absolute Radiometric Calibration: Level 1B vs Vicarious Calibration

- Measurements over Railroad Valley (RRV) suggest that the reported OCO-2 Level 1B radiances may be 5% high compared to Vicarious Calibration (VC) estimates.
  - The radiometric scale is established by trending the response degradation in lamp, solar, and lunar calibration datasets, relative to preflight tests.

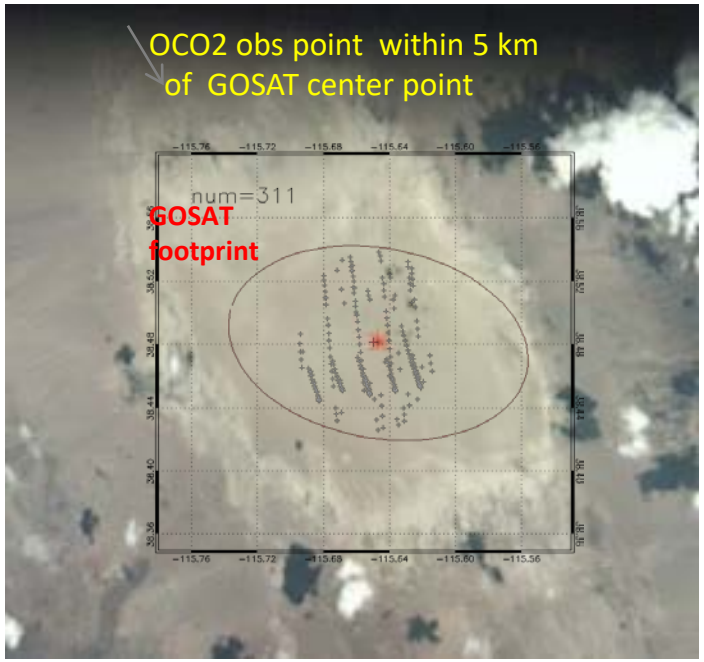


- This change may have occurred after the pre-flight testing, while the instrument was in storage.
- Lunar Calibration data are being analyzed to see if it supports this 5% high bias
  - Preliminary results support a 5-10% high bias, but this is within the error bars

OCO2- GOSAT Spectra Comparison

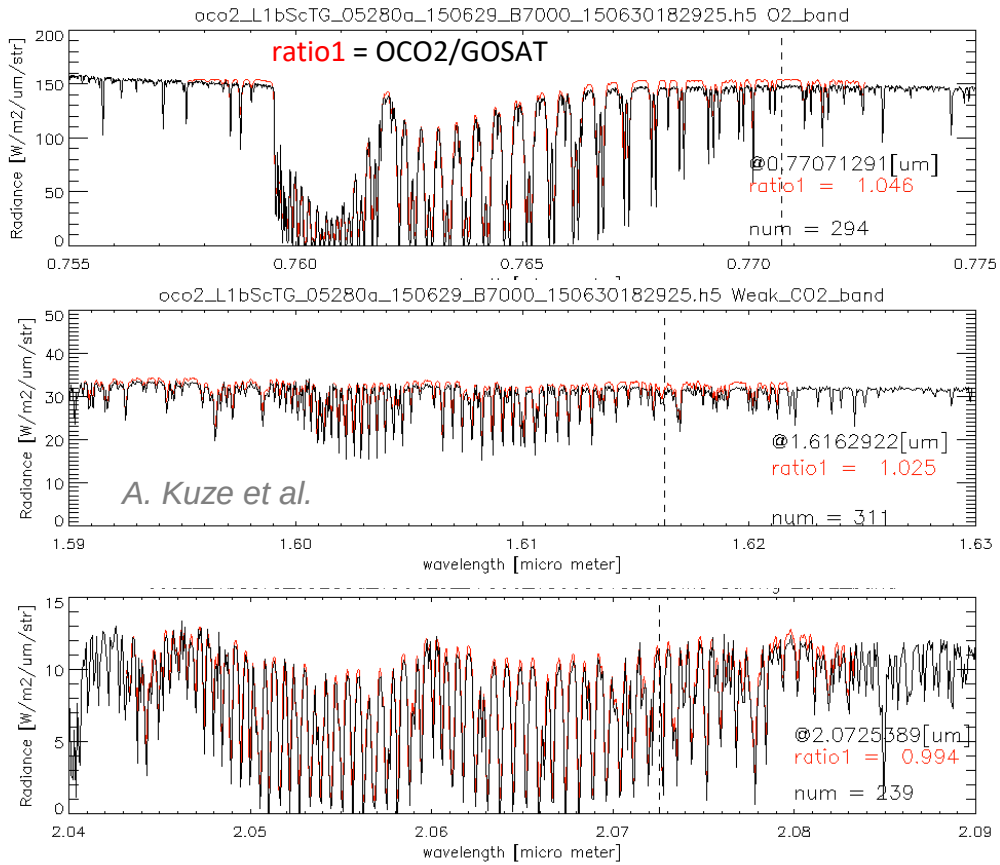
Comparisons between OCO-2 and GOSAT also indicate a ~5% high radiometric bias.

Jun29,2015
OCO2: path139 (looking from West)
GOSAT: path37 (looking from West)



OCO-2 spectra collected within the GOSAT footprint over Railroad Valley, NV on 29 June 2015 are compared.

oco2_L1bScTG_05280a_150629_B7000_150630182925.h5
GOSATTFTS2015062921160370242_1BSPOD161161.01
GOSAT Rad
OCO2 average Rad within 5km of GOSAT cnt point X 2

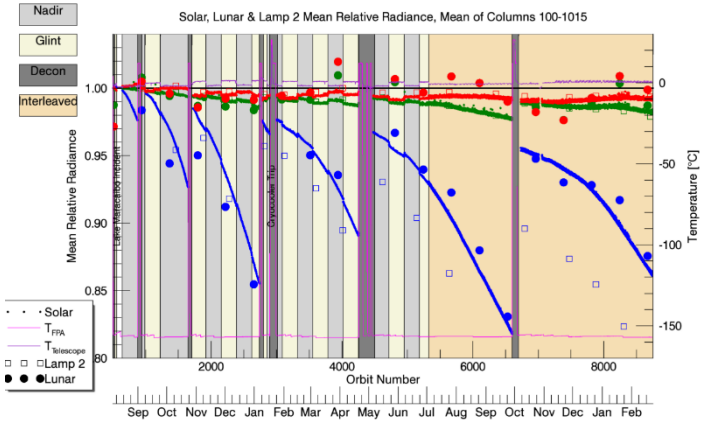


The continuum level of the OCO-2 L1B spectra is typically ~5% above that seen by GOSAT

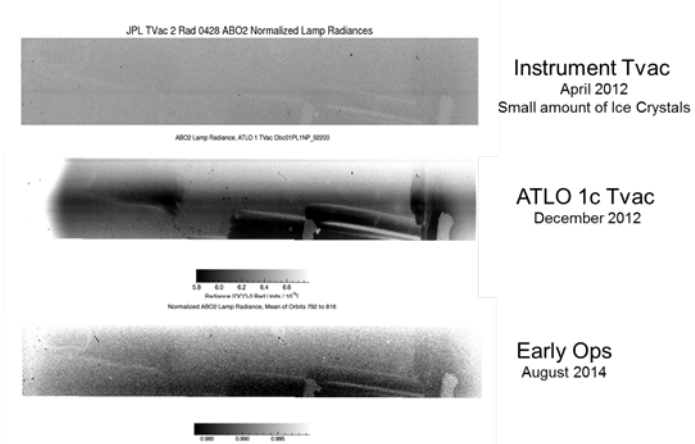
A-Band Sensitivity Variations

The sensitivity degradation has two separate components

- A "fast degradation" reversed by decontamination cycles
  - The ABO2 Tiger team attributed this component to temporary degradation of the anti-reflection coating on the A-band focal plane array detector (FPA) due to ice accumulation on the FPA
- A "slow degradation" that is monotonic
  - There is increasing evidence from Lunar and Vicarious Calibration measurements that this component of the degradation might be due to degradation of the lamp and solar diffusers rather than a throughput loss in the instrument

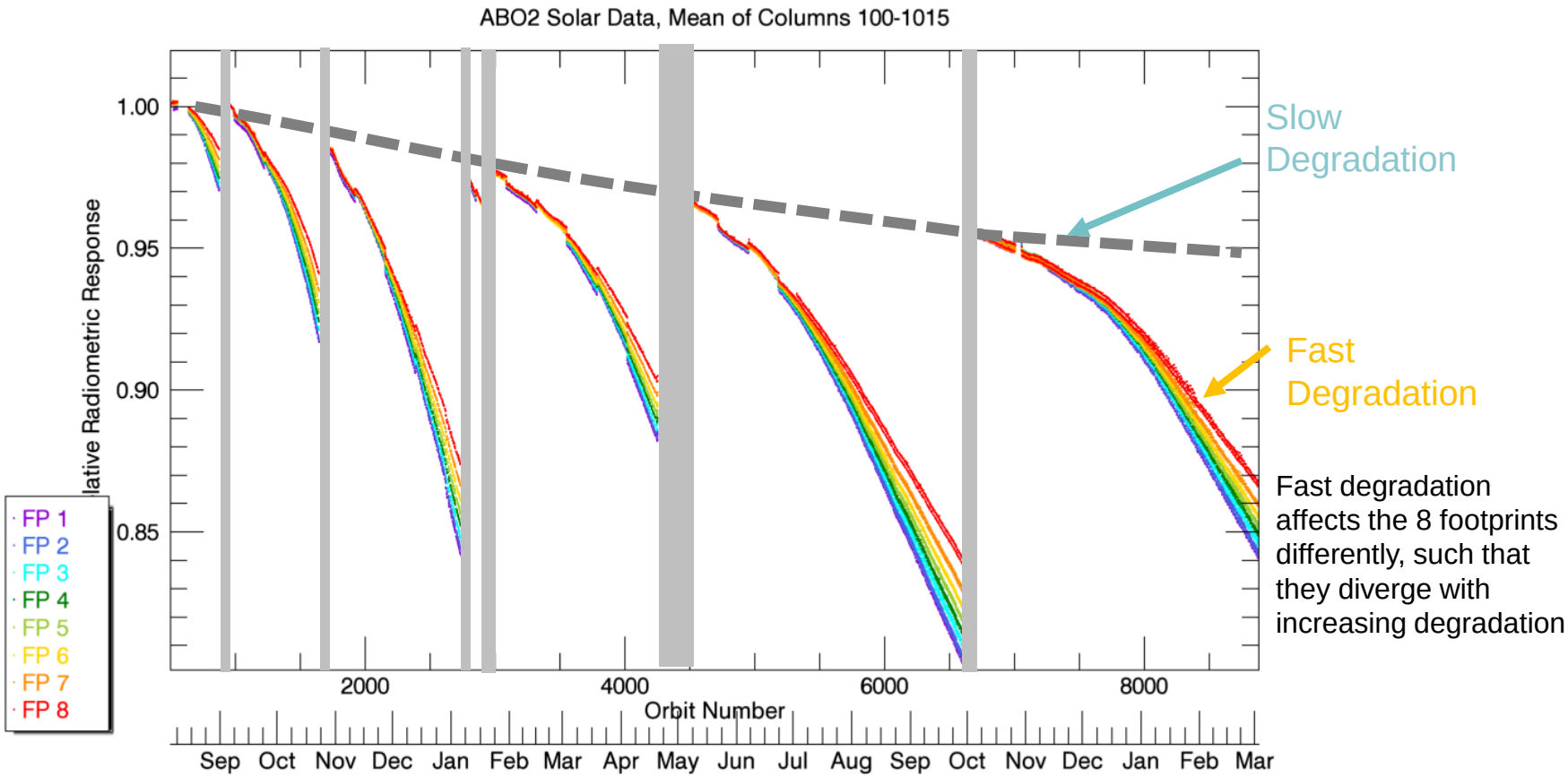


Relative throughput of the ABO2 (blue), WCO2 (green) and SCO2 (red) channels



Images of ice on the ABO2 FPA

ABO2 Sensitivity Degradation Components



Fast degradation affects the 8 footprints differently, such that they diverge with increasing degradation

The "fast" and "slow" components of the ABO2 sensitivity degradation.

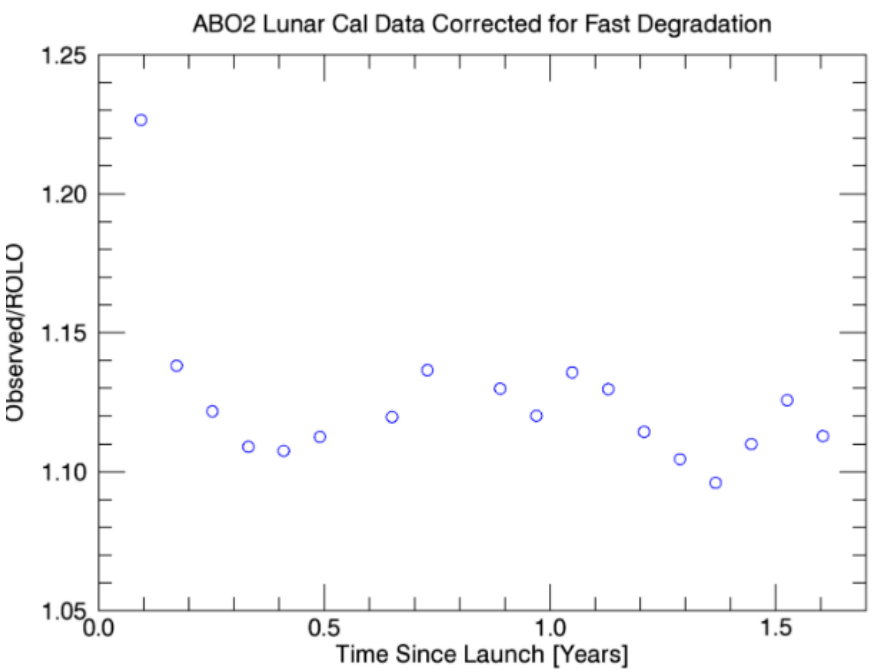
- **The fast component is corrected by decontamination cycles**
- **The slow component is not affected by decontamination cycles**

Impact of ABO2 Sensitivity Degradation on OCO-2 L2 Products

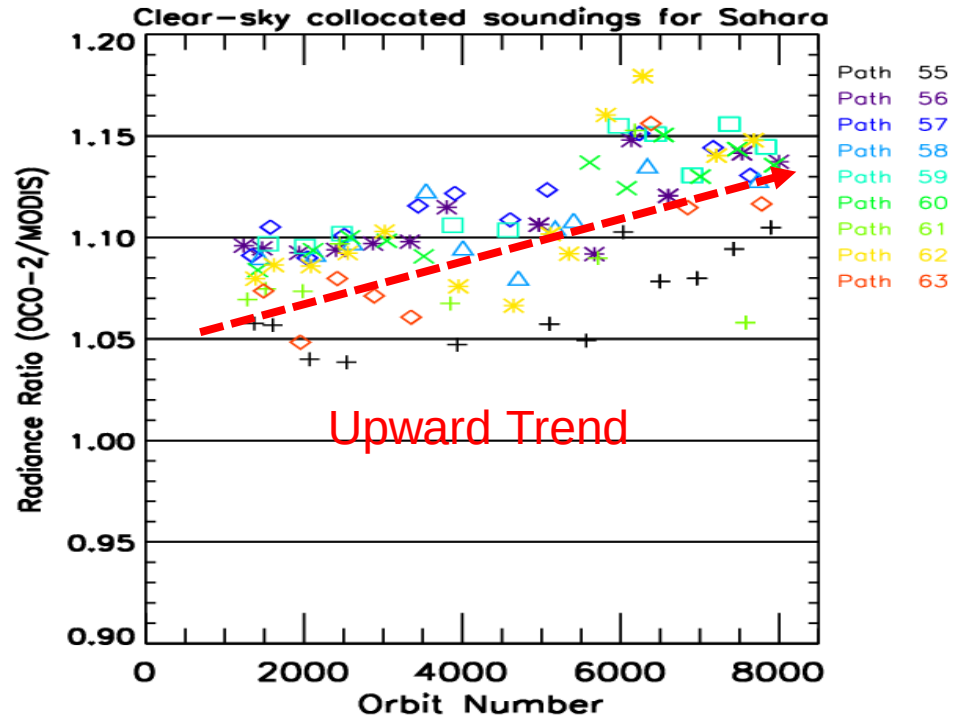
- To date, most assessments of the impact of the ABO2 sensitivity degradation have not discriminated between the "fast" and "slow" components of the degradation
  - Most have sought correlations with the amplitude of the fast degradation
  - These tests indicate that the fits to the observed spectra degrade with increasing contamination (e.g. larger spectral residuals, higher χ^2) but limited changes in X_{CO2}
- Recently attention has been focused on the slow degradation
  - Lunar calibration and vicarious calibration experiments indicate that this signal degradation may be due to degradation of the solar calibrator rather than the instrument optics
  - If this is the case, our approach for correcting for the slow degradation in the L1B product is introducing a progressively larger error in the radiometric calibration
  - The sign of this error reinforces the 5% high bias seen at RRV

Evidence that the Slow Degradation is not a property of the "Science" optical path

All available data indicate that the slow degradation is a property of the solar calibrator, and does not affect



Lunar calibration results show no evidence of slow degradation, once corrected for fast degradation (but support a 10% high bias).



Comparisons with data acquired by MODIS over the Sahara indicate that the OCO-2 L1B calibration is introducing a progressively larger radiometric error

Impact of Absolute Radiometric Errors on OCO-2 Results

- A preliminary series of tests were performed to assess the impact of ABO2 radiometric errors on OCO-2 products
  - OCO-2 spectra were recalibrated to simulate ABO2 calibration errors introduced by the misattribution of the slow degradation, and retrievals were performed and compared B7r products
  - For land/nadir spectra, a 5% ABO2 radiometric error
    - Is largely compensated by changes in surface albedo.
    - Introduces surface pressure errors of ~0.6 hPa
    - Introduces XCO2 errors of about 0.05% (0.2 ppm)
  - For ocean/glint measurements, a 5% ABO2 radiometric error
    - Modified Cox-Munk surface reflectance by changing wind speed
    - Introduces 1.11 hPa (0.1%) errors in surface pressure
    - Introduced XCO2 errors less than 0.05 % (0.2 ppm)
- If these errors scale linearly with absolute radiometric error, they add to those seen in the RRV tests, and are now roughly 1.5 times this large as those described here (and increasing)

Issues with the Input Data Sets

Known Issues

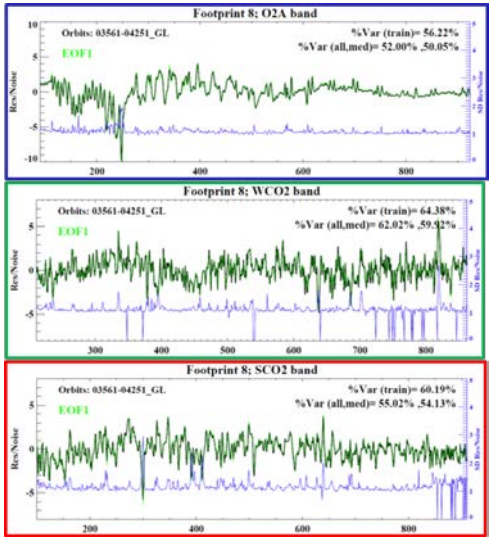
- Uncertainties in O_2 and CO_2 absorption coefficients limit convergence (increase χ^2) and are a known source of bias
  - Improved laboratory measurements and analysis techniques have reduced both spectral residuals and airmass dependent biases

- Errors in top-of-atmosphere solar fluxes
  - Improvements in the solar line list, combined with empirical corrections of the solar continuum further reduce χ^2 and reduce the amplitude of the EOF's

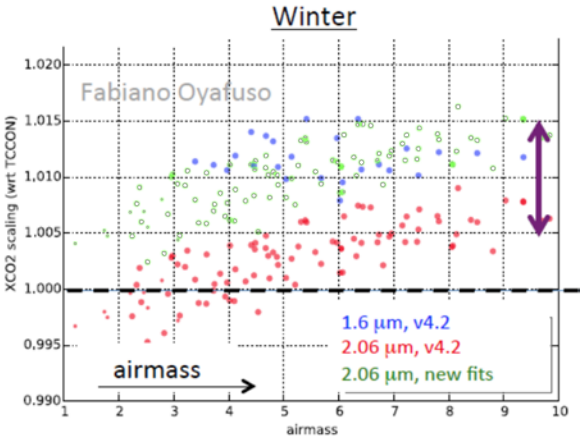
- Prior pressure estimates from ECMWF
  - The L2 algorithm uses information from an ECMWF forecast to specify surface pressure and other meteorological variables
  - On May 11, 2015, ECMWF changed the surface topography database, and this change was missed by the OCO-2 team, introducing differences as large as 100 m in many places
  - The impact of this change on OCO-2 products is under investigation

Known Issues with Absorption Coefficients

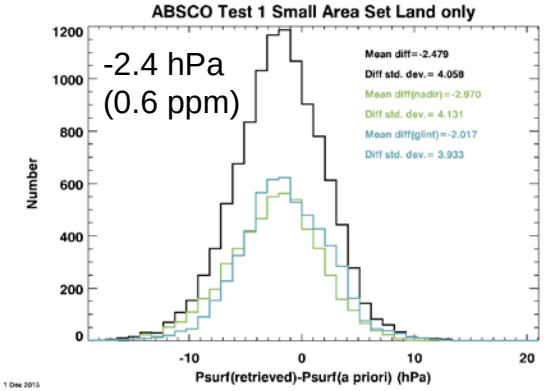
- The Version 4.2 absorption coefficients used for B7/7r products have known deficiencies
  - Neglect to scale O_2 cross section scaling introduces a -2.5 hPa bias (and corresponding 0.6 ppm X_{CO2} bias)
  - spectral residuals as large as 0.5% due to errors in line mixing and temperature dependence (largely corrected by EOF's)
  - Airmass dependent biases in surface pressure and X_{CO2}, seen in both TCCON and XCO2 retrievals



Typical ABSCO V4.2 residuals prior to EOF correction



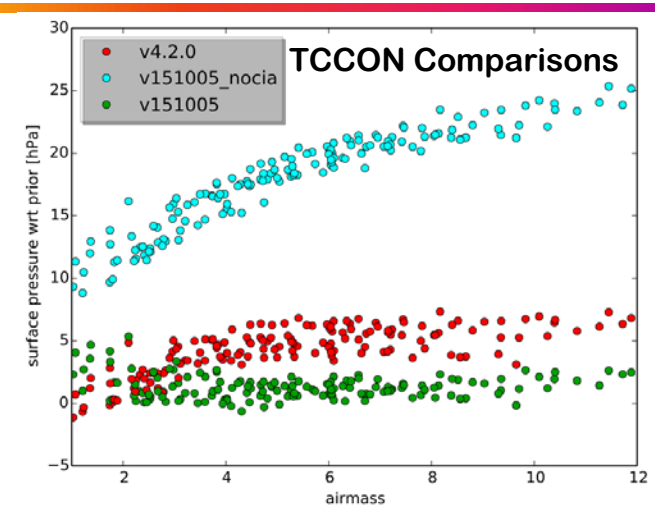
Airmass dependent biases seen in single band TCCON fits (up to 0.5 ppm bias per airmass.

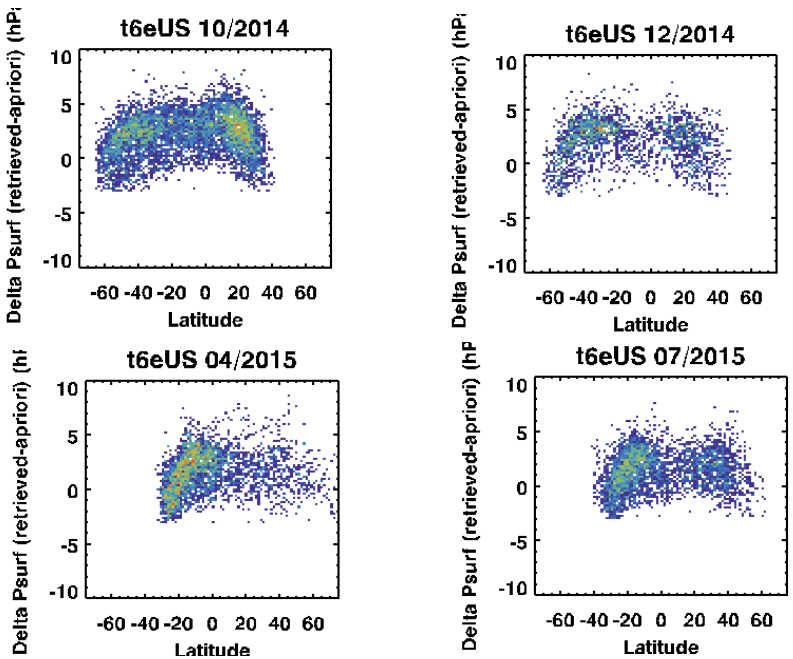


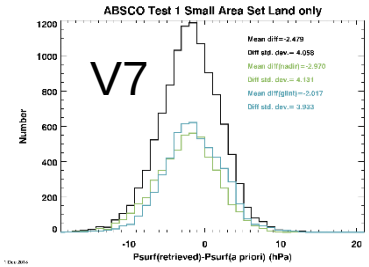
ABO2 surface pressure biases.

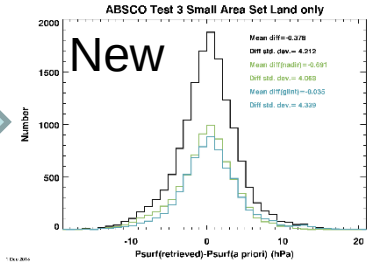
Revised ABO2 Absorption Coefficients

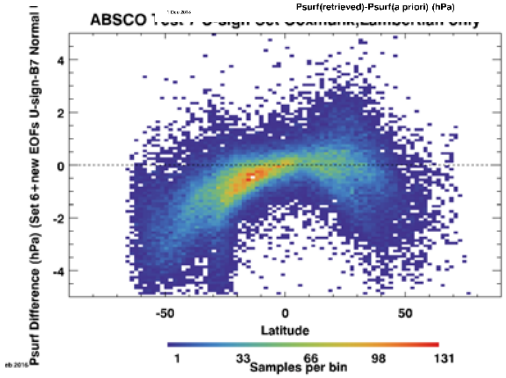
- Preliminary results for the revised ABSCO table reported at the Nov 2015 Science Team meeting showed:
  - Reduced bias
  - Smaller residuals
- Tests with larger datasets show latitude and airmass-dependent biases

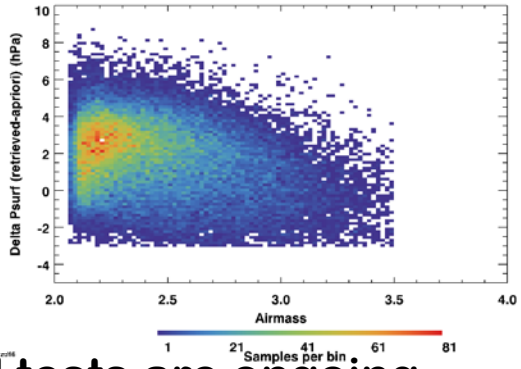








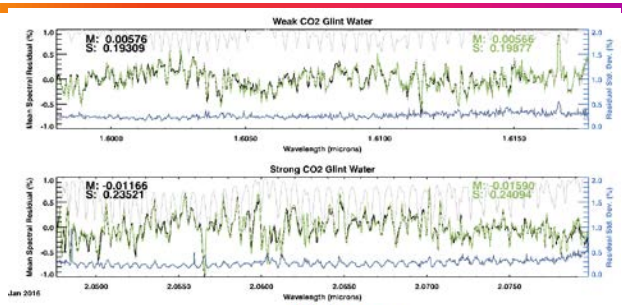


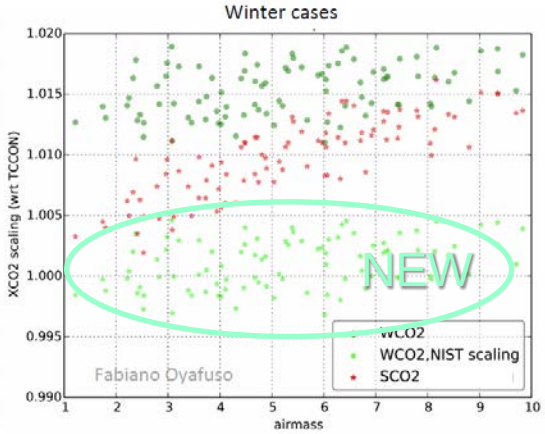


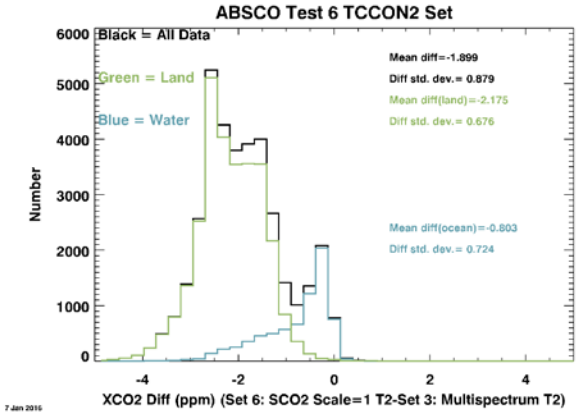
Additional tests are ongoing

Revised CO2 Absorption Coefficients

- Revised (v5) WCO2 and SCO2 absorption coefficients have smaller residuals and reduced bias
- Current scaling approach:
  - Use NIST-scaled WCO2 values
  - Scale SCO2 values by 1.006
- Different effects on Land/Ocean
  - -2 ppm difference over land (no SO2 scaling)
- **Outstanding issues & further work**
  - **Line mixing/line shape in SCO2 band**
    - Goal is to remove empirically-added absorption in SCO2
    - Caltech plans for SCO2 CRDS measurements
  - **"Reference" line intensities**
    - Caltech plans SCO2 CRDS measurements

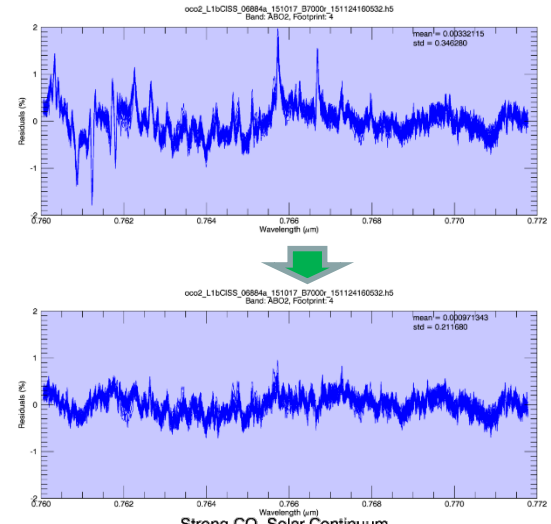


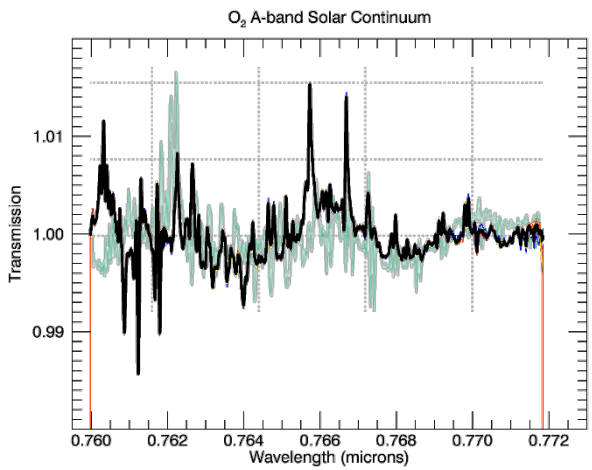


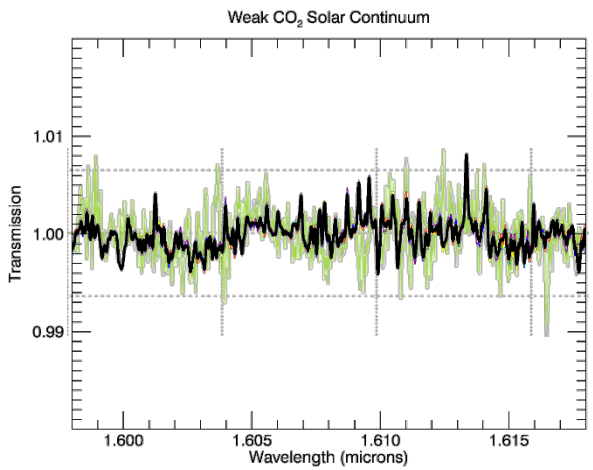


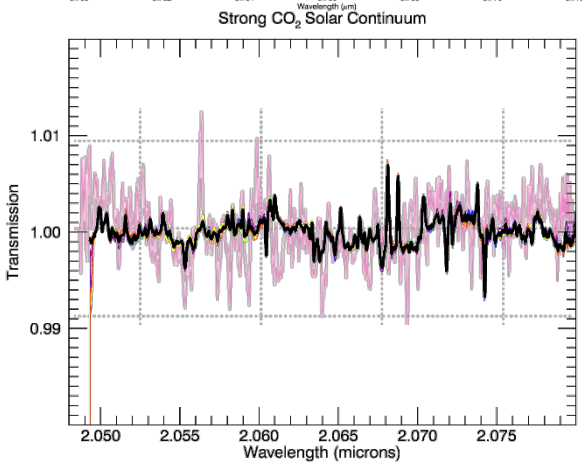
Revised Solar Line List and Continuum

- Recent improvements in the solar line list explain many of the most persistent spectral residuals
- Empirical fits to the Solar Doppler data further reduce spectral residuals further
- Impact on X_{CO2} retrievals under investigation
  - Should reduce solar contributions to EOF's





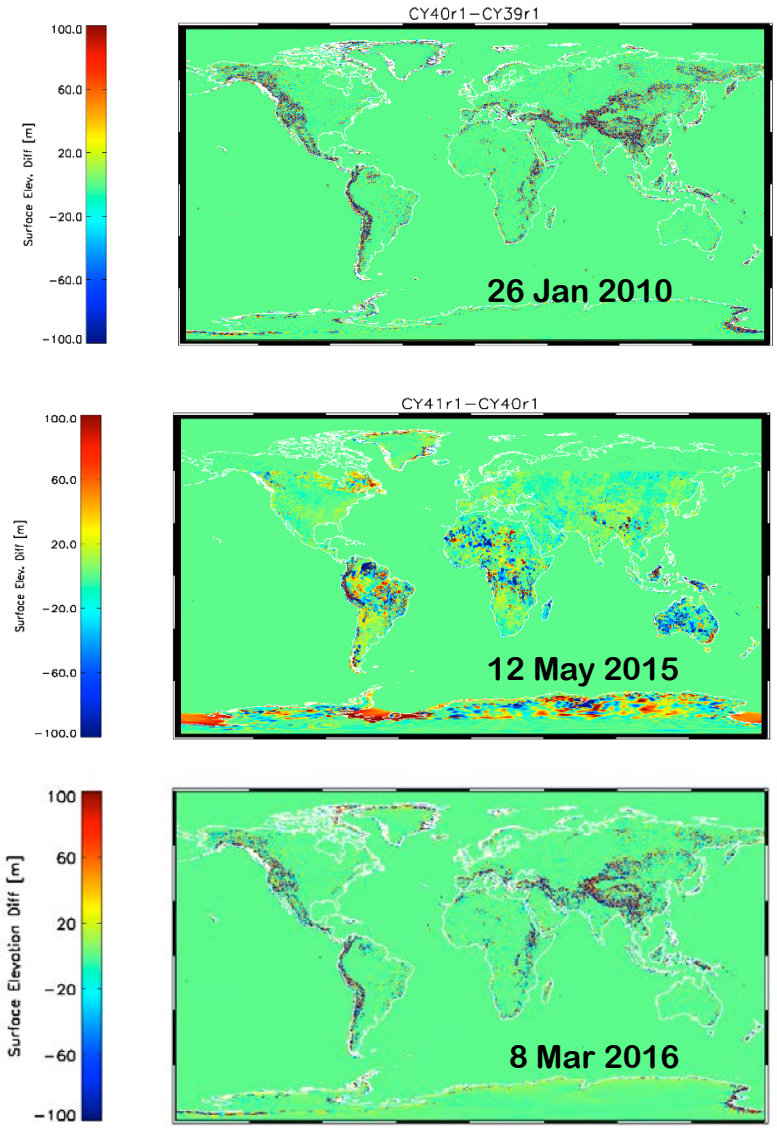




Empirical corrections to solar continuum based on 11 Solar Doppler Calibration tests (black lines) account for much of the structure seen in v7 EOF#1 (colored lines). Footprint-to-footprint variations, due to calibration errors, should now be the major contribution.

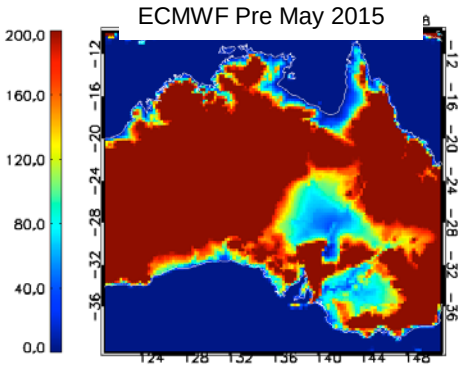
ECMWF Topography
[Chris O'Dell]

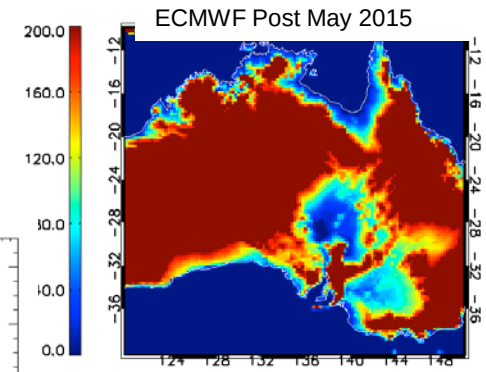
- ECMWF elevation field at 0.25x0.25 deg has changed three times since GOSAT launched:
  - 26 Jan 2010: ECMWF resolution increased.
  - 12 May 2015 (12 UTC): underlying topography was updated.
  - 8 Mar 2016 (12 UTC): the horizontal resolution changed.
- Our Prior surface pressure calculation makes a correction from the ECMWF elevation to OCO-2 elevation
- If we assume incorrect ECMWF elevation (by specifying the wrong elevation file), this directly maps into an error in our PRIOR surface pressure.

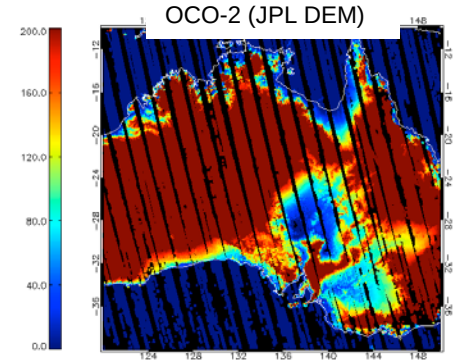


Implications for OCO-2
[Chris O'Dell]

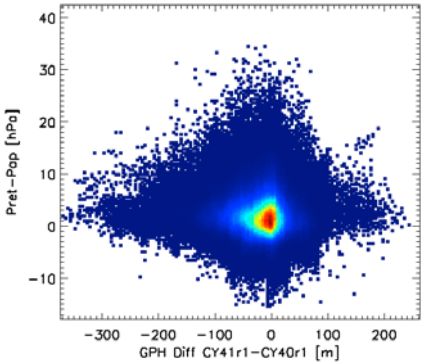
- In Nov 2014, we discovered that ECMWF elevation field had changed in 2010.
  - Fixed in version B5 to use updated GPH file.
- Since 12 May 2015, errors in the prior have been introduced because we did NOT update the GPH file to reflect CY41r1.



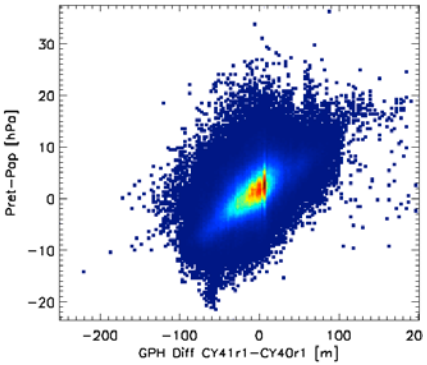




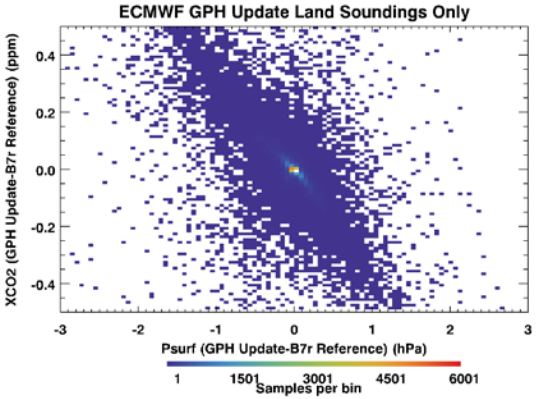
Evidence for Change



Australia Land, WL<15
Before May 12, 2015



Australia Land, WL<15
After May 12, 2015



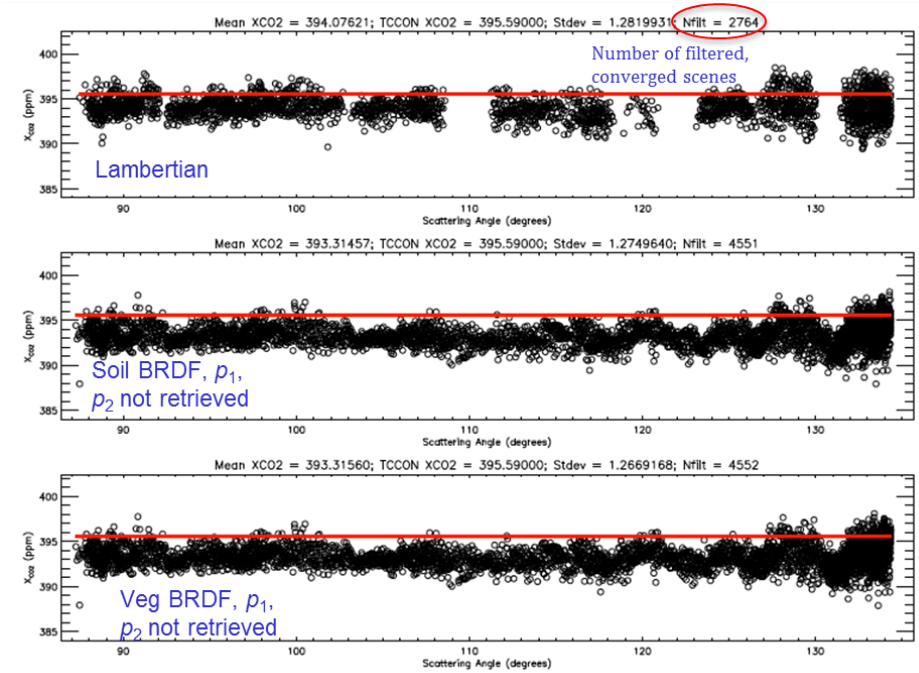
XCO2 change

Effects of May 12 2015 Topography Change
[Chris O'Dell]

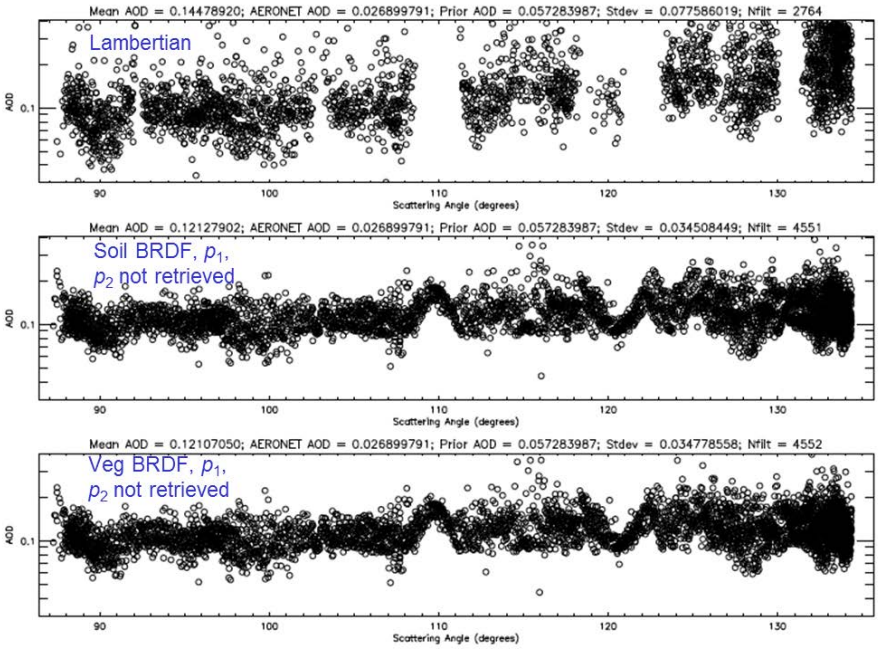
- Problems anticipated:
  - Cloud screening over some land areas impacted, as surface pressure prior can change by up to 20 hPa (though typically much less).
  - Small impacts on XCO2, since we rely less strongly on ECMWF prior surface pressure (+/- 4 hPa)
- Problems seen in early testing
  - Change in ABP screening. (not analyzed here)
  - Change in Psurf_Ap (directly related to GPH error)
  - No real change in retrieved XCO2
  - No real change in retrieved Psurf.
  - Change in Bias-corrected XCo2 due to -0.3 * (Pret-Pap) term in bias correction.
- We can correct for the Bias Correction term with a simple fix?
  - Slope between ΔGPH and Δ(Pret-Pap) is 0.09 hPa/m.
  - Direct fit between ΔGPH and ΔXCO2_Bc is ~0.03 ppm/m.
  - Could advise users to make this correction, or release new lite files with the correction applied).

Limitations in the L2 Algorithm

BRDF Tests, Lamont Target, Orbit 1362 (1)



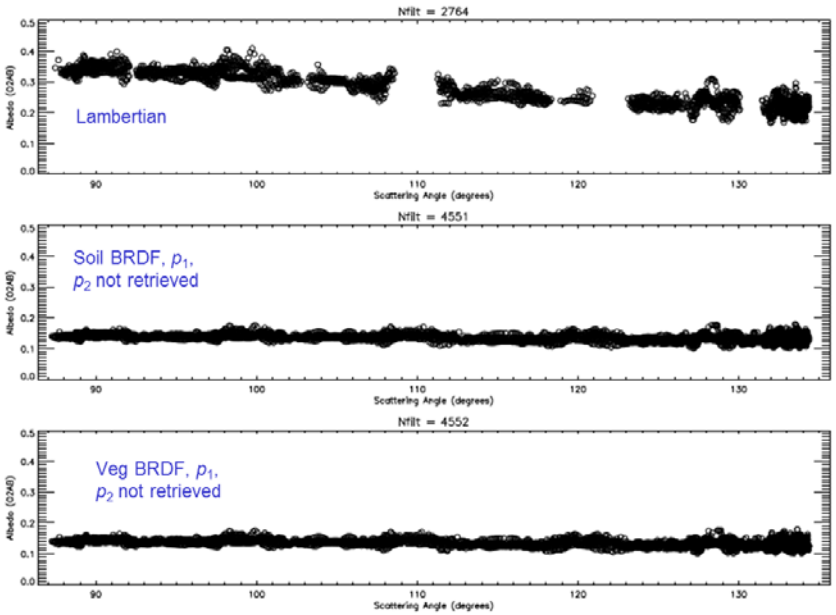
XCO2 retrievals using a Lambertian BRDF (top) are compared to those using a simplified Soil (middle) and Vegetation (bottom) BRDF



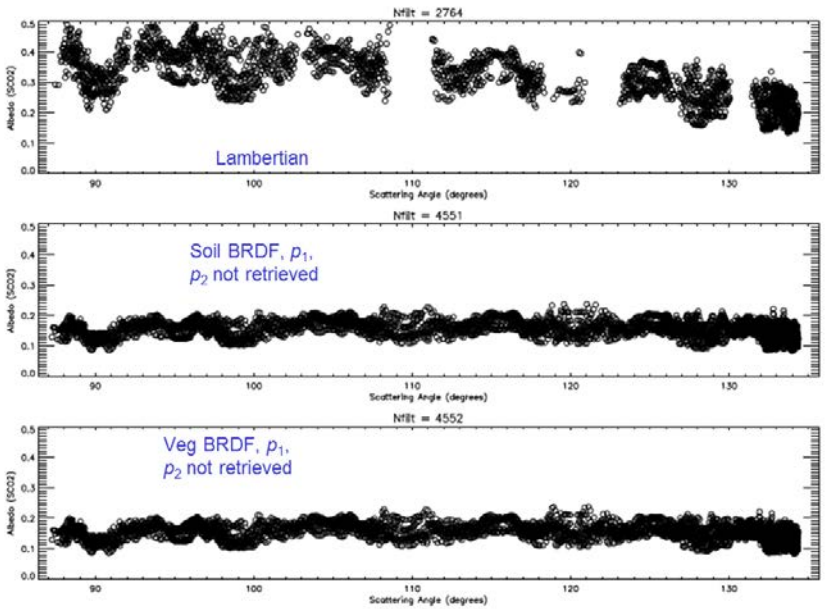
Aerosol optical depth retrievals using a Lambertian BRDF (top) are compared to those using a simplified Soil (middle) and Vegetation (bottom) BRDF.

Both the simplified Soil and Vegetation BRDF functions reduce the scatter and increase the yields for XCO2 and aerosol optical depth retrievals when compared to the current Lambertian surface albedo.

BRDF Tests, Lamont Target, Orbit 1362 (2)



Surface reflectance retreivals in the O2 A-band using a Lambertian BRDF (top) are compared to those using a simplified Soil (middle) and Vegetation (bottom) BRDF



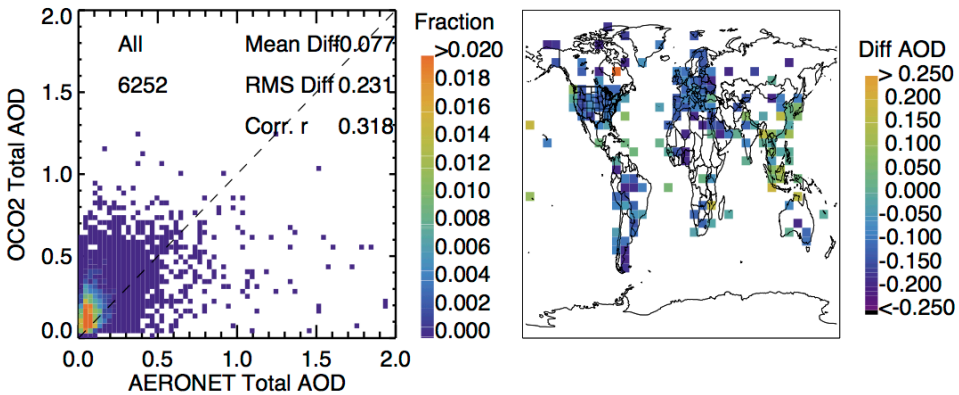
Surface reflectance retreivals in the Strong CO2 band using a Lambertian BRDF (top) are compared to those using a simplified Soil (middle) and Vegetation (bottom) BRDF

Both the simplified Soil and Vegetation BRDF functions reduce the scatter and systematic, observation-angle-dependence of the surface reflectance when compared to the current Lambertian surface albedo.

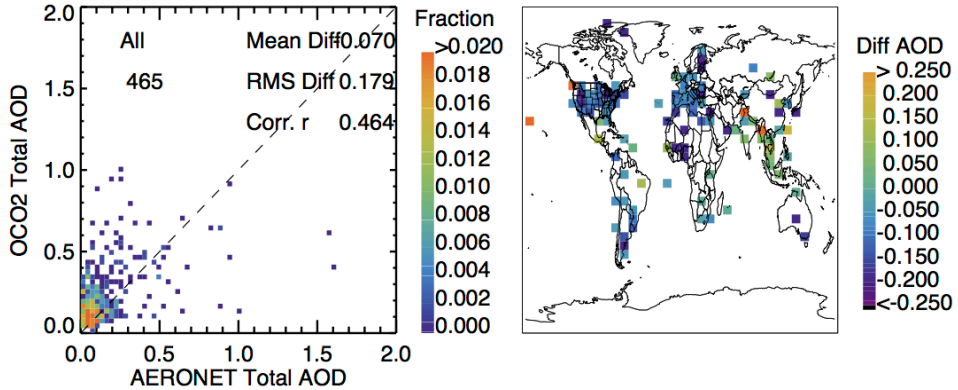
Aerosols

- The OCO-2 algorithm
  - Currently uses a MERRA monthly mean prior
  - Shows little or no skill in predicting aerosols

Coincidence criteria, C1: 100km, 3 hr



Coincidence criteria, C2; 10 km, 0.5 hr



Prefer correlation coefficient for coincident criteria C2

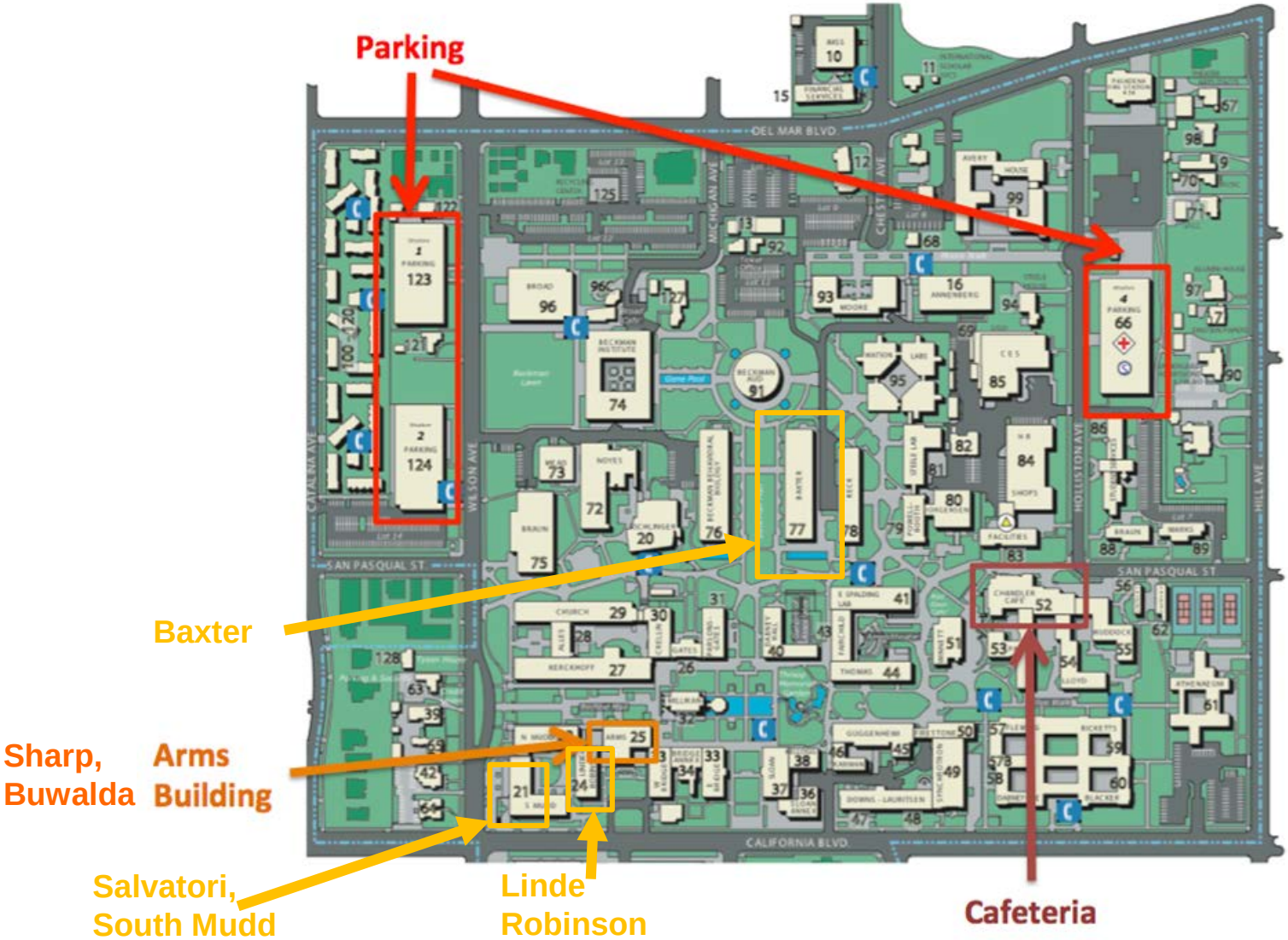
- 10 km; 0.5 hour, adequate sampling ocean/land
- ➢ Consistent performance for ACOS GOSAT v3.5 (r = 0.47 reported by Nelson, 2015)
- Tests of daily MERRA and GEOS5 Priors under way
- Impact of revised ABSCO tables large but unknown

Other Changes Under Investigation

- Improved CO2 prior (from TCCON)
- Improved Cirrus Cloud prior
  - simple test performed, and seems to improve performance
- SIF prior
- Other issues missed or misinterpreted?

OCO-2 Science Team Meeting

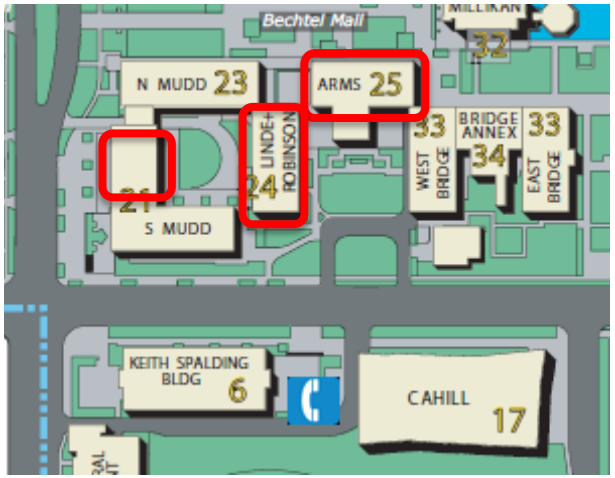
The OCO-2 Science Team Meeting
Caltech, March 21-23



The OCO-2 Science Team: March 21 Breakout Groups

Monday, March 21st - Breakout groups

Validation - webex 995 345 764	Sharp	9am-12	Greg Osterman
Spectroscopy - webex 997 563 767	Buwalda	9am - 3pm	V. Payne
Clouds - webex 990 639 693	136 Linde Robinson	9am-12	Merrelli/Crisp
Uncertainty Quantification - webex 990 605 372	Salvatori	9am-12	A. Braverman
Flux - webex 998 448 966	Sharp	1-5pm	D. Baker
Local sources	integrated with flux		



The OCO-2 Science Team: March 22
Baxter Lecture Hall, Webex 991 821 105

Topic	Discussion Leader	Start Time	duration (min)
Registration and check in		8:15 AM	30
Welcome from HQ	Ken Jucks	8:45 AM	5
Welcome, Overview, Logistics and Introductions	Dave Crisp	8:50 AM	15
Mission Status	P.J. Guske	9:05 AM	10
Introductions (all team members)	ALL	9:15 AM	15
Validation Overview	Paul Wennberg/ Wunch	9:30 AM	20
Data/ Algorithm Performance Overview	Eldering & O'Dell	9:50 AM	20
BREAK		10:10 AM	30
SIF overview	Christian Frankenberg	10:40 AM	25
UQ overview	Amy Braverman	11:05 AM	25
Discussion	ALL	11:30 AM	20
LUNCH		11:50 AM	70
Flux team breakout - kick off (rest of day structured by DB)	David Baker	1:00 PM	120
BREAK	ALL	3:00 PM	30
rest of flux breakout	flux team	3:30 PM	100
Discussion	All	5:10 PM	20
End of Day	ALL	5:30 PM	0

The OCO-2 Science Team: March 23
Baxter Lecture Hall, Webex 991 821 105

Topic	Discussion Leader	Start Time	duration (min)
Registration and check in		8:00 AM	30
Welcome, Overview and Logistics	Dave Crisp	8:30 AM	10
Overview of proposed algorithm changes	Chris O'Dell	8:40 AM	10
L1b Updates	Eldering	8:50 AM	10
ABSCO Update	Vivienne Payne	9:00 AM	20
BRDF Update	Vijay Natraj	9:20 AM	20
Aerosol Update	Dejian Fu	9:40 AM	20
BREAK	ALL	10:00 AM	30
data use recommendations	Eldering/O'Dell	10:30 AM	10
Discussion	ALL	10:40 AM	10
preprocessor updates	Chris/Tommy	10:50 AM	15
local studies report	Eric Kort	11:05 AM	30
OCO-3 update	Eldering	11:35 AM	15
LUNCH	ALL	11:50 AM	75
local stduy - next steps	Eric Kort	1:05 PM	20
Cloud theme group integrated report & plans	Aronne Merrelli	1:25 PM	30
Discussion	ALL	1:55 PM	15
flux group plan	David B	2:10 PM	30
algorithm plan	Chris O'Dell	2:40 PM	20
BREAK	ALL	3:00 PM	30
UQ plan	Amy Braverman	3:30 PM	20
validation plan	Greg Osterman	3:50 PM	20
spectroscopy plan	Vivienne Payne	4:10 PM	20
Discussion	All	4:30 PM	10
Review of day/ Action items	Crisp/Eldering	4:40 PM	20
End of Day	ALL	5:00 PM	

OCO-2 Progress Reports

Please send you OCO-2 Progress Reports to Ken Jucks

BEFORE THE SCIENCE TEAM MEETING NEXT WEEK!

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Other Upcoming Meetings

- 17-22 April 2016: EGU, Vienna
- 17-22 April 2016: International Radiation Symposium, Auckland
- 9-13 May 2016: ESA Living Planet Symposium, Prague
- 17-18 May 2016: NOAA ESRL GMD Annual Meeting, Boulder
- 22-26 May 2016: JpGU, Makuhari Messe, Japan
- 7-9 June, 2016: IWGGMS-12, Kyoto, Japan
- 10 June, 2016 OCO-2/GOSAT TIM, Nara, Japan
- 6-8 July, 2016: O2 A-band Workshop, KNMI, De Bilt, Netherlands
- 31 July-5 Aug, AOGS 2016, Beijing, China
- 12-16 December, AGU, San Francisco, CA, U.S.A.
- Save the Date: 18-21 April 2017, A-Train Science Symposium, Pasadena, CA, U.S.A.