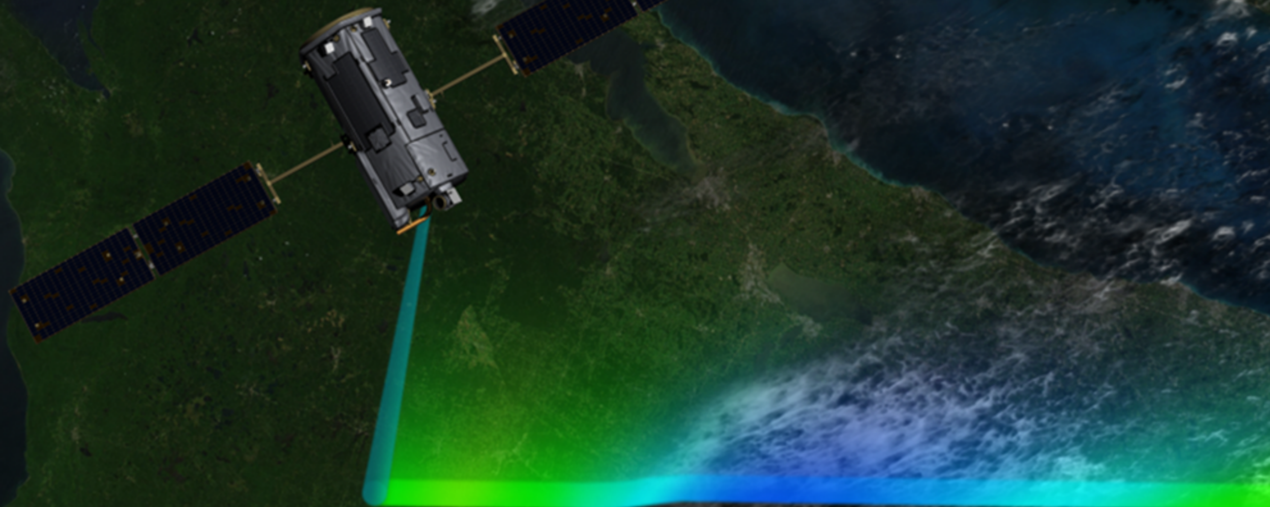
OCO-2 / OCO-3
Status and Near-Term Plans



David Crisp, for the OCO-2/OCO-3 Team

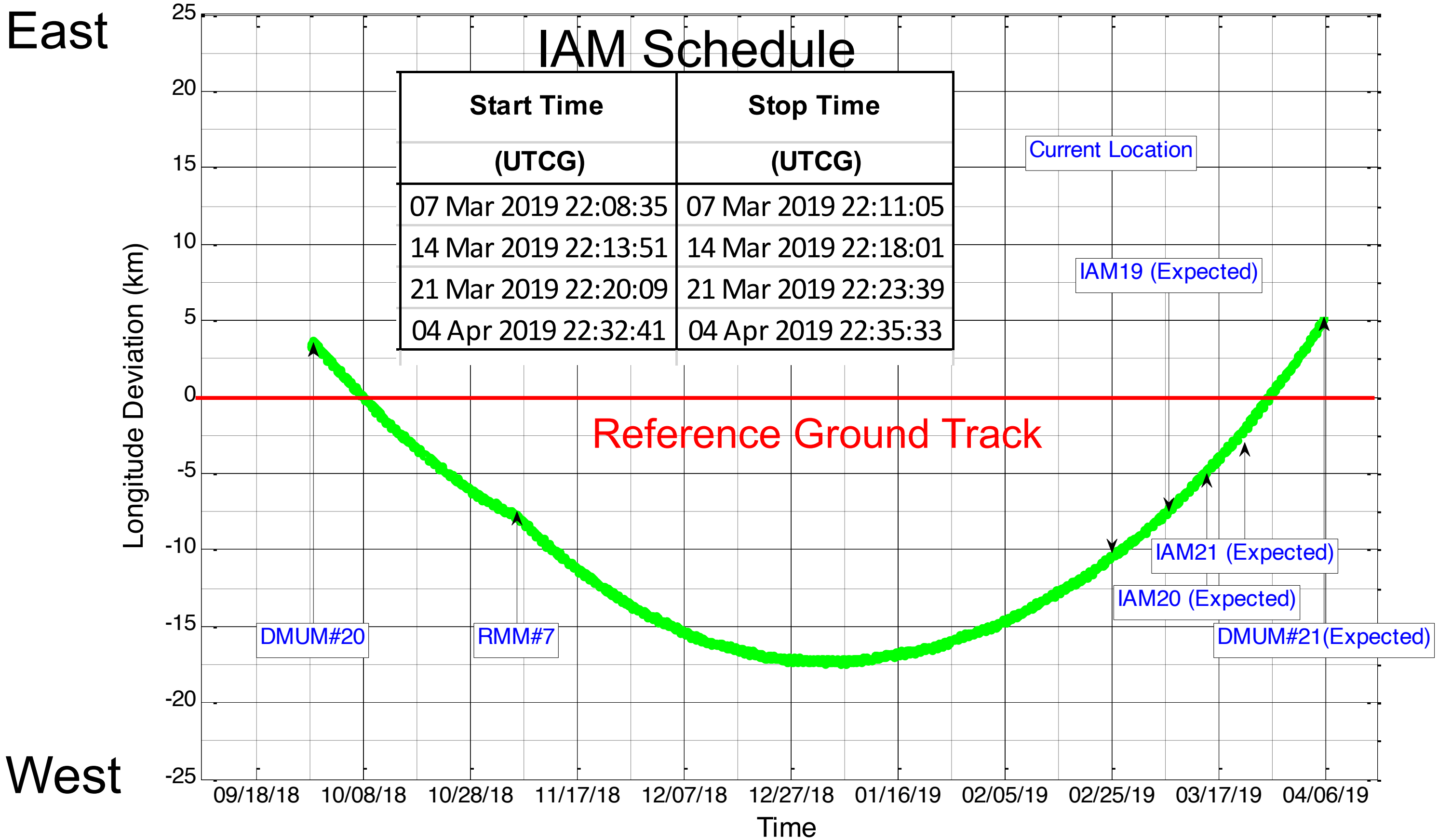
Jet Propulsion Laboratory, California Institute of Technology

March 5, 2019

OCO-2 Status Summary

- Observatory Status: Nominal
  - Next Drag Makeup Maneuver (DMM) tentatively scheduled for 7 March 2019 to coincide with a the annual Inclination Angle Maneuver (IAM)
  - Watch Issue – degradation of z-axis gyro in the inertial measurement unit
    - May affect Lunar Cal an other activities
- Instrument Status: Nominal
  - A Decon is scheduled for 4 - 11 March 2019
    - This date was chosen to reduce the need for a Decon during the northern hemisphere summer and to minimize conflicts with OCO-3 in orbit check-out
- Science Status: Nominal
  - "Build 10" testing plan beginning to come together
    - ABSCO 5.1, Solar, and preliminary EOFs generated
  - ACOS/GOSAT version 9 – production pending completion of operating system upgrade on OCO-2 cluster
- OCO-3 Launch and Early Operations Status and Plans

2019 Orbit Inclination Adjust Maneuver Schedule



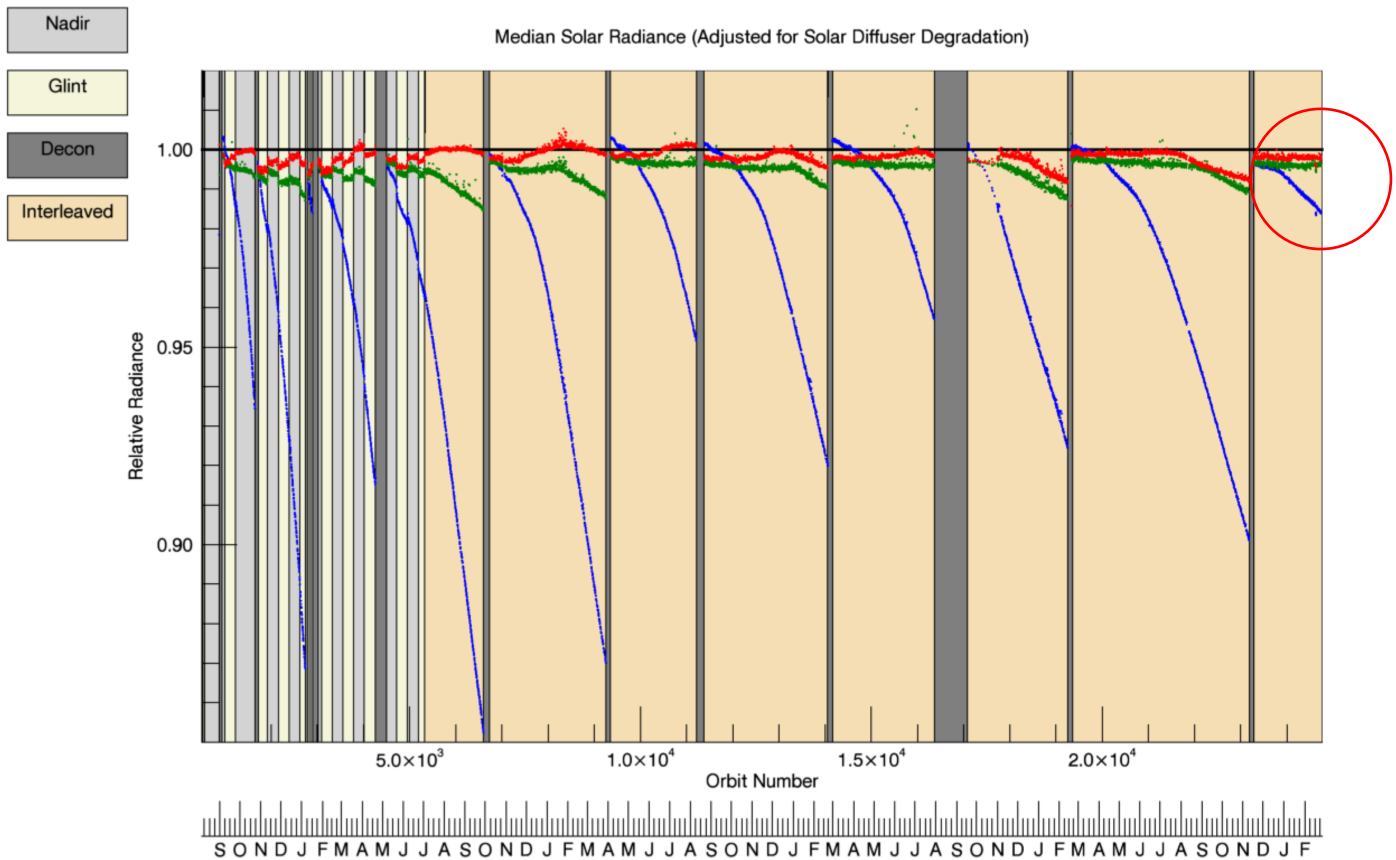
Start Time (UTCG)	Stop Time (UTCG)
07 Mar 2019 22:08:35	07 Mar 2019 22:11:05
14 Mar 2019 22:13:51	14 Mar 2019 22:18:01
21 Mar 2019 22:20:09	21 Mar 2019 22:23:39
04 Apr 2019 22:32:41	04 Apr 2019 22:35:33

OCO-2 is currently ~10 km west of its reference ground track.
The next drag make-up maneuver is scheduled for 7 March, and will be executed as part of the annual Inclination Adjust Maneuver (IAM)

Inertial Measurement Unit Issue

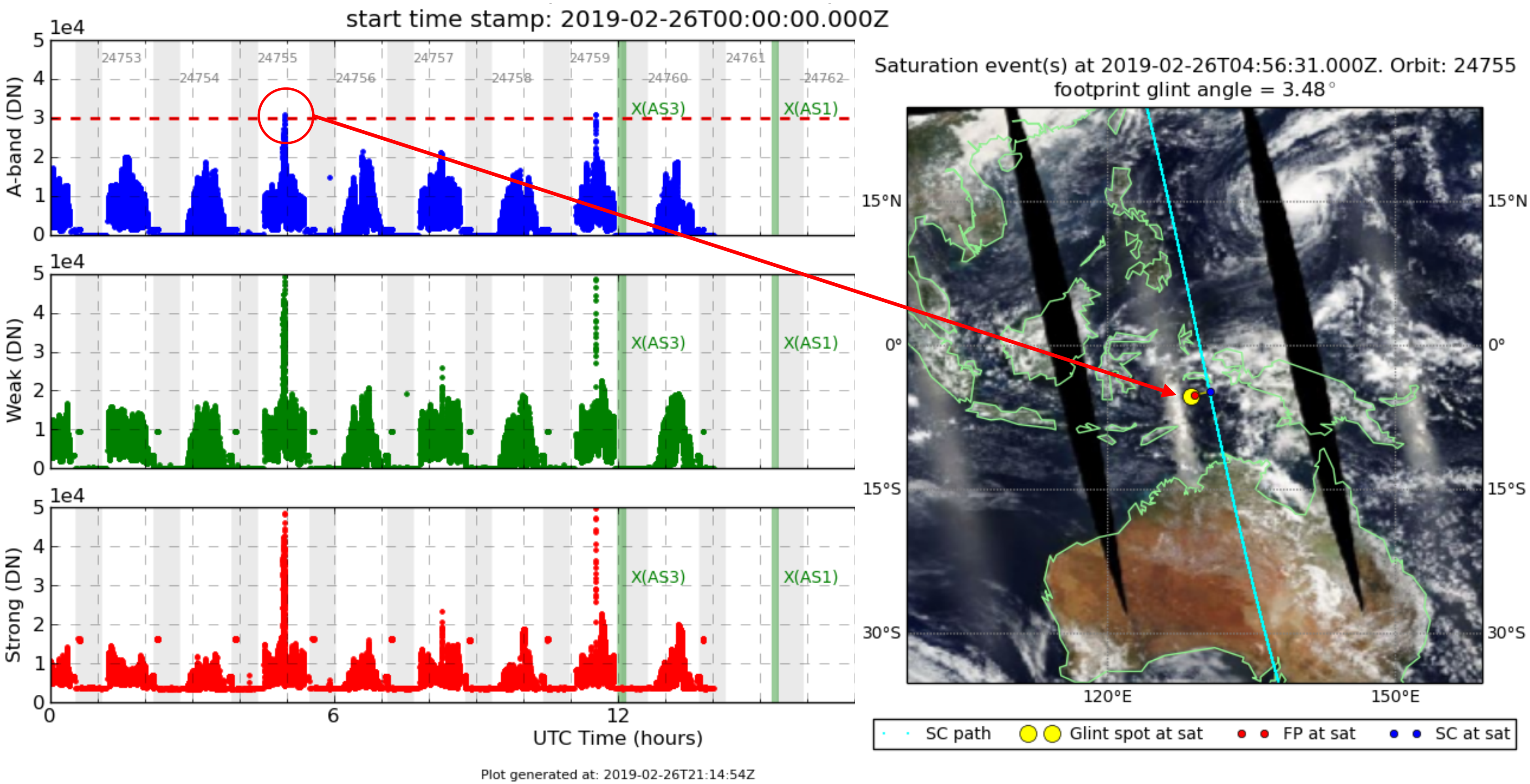
- The OCO-2 attitude control system uses data from a star tracker, an inertial measurement unit (IMU), sun sensors, and a magnetometer to determine the spacecraft attitude.
  - The star tracker is the primary attitude reference, but additional information from the IMU is used to track rotation rates about the x, y, and z axes when the star tracker's field of view (FOV) is occulted by the Earth or contaminated by scattered light from the Sun or Moon
  - The IMU was critical for spacecraft separation from the launch vehicle and for orbit raising maneuvers, where the spacecraft moves too fast for the star tracker to operate
- The IMU includes 3 ring laser gyros for monitoring rotation about the spacecraft's x, y, and z axes. The z-axis is gyro is degrading rapidly.
  - The loss of the z-axis gyro (or the IMU) will not affect nominal operations, but could limit activities such as full-Moon lunar calibration, where the star tracker's FOV is blocked by disk of the Earth. Other impacts are under investigation
  - The flight software must be modified to remove dependencies on the IMU. That effort is currently in the planning stages. More as we have it.

Throughput Trending



The throughput is still > 98% in all 3 channels, but a Decon was scheduled for March 4-11 to reduce need for Decon during the Northern Hemisphere growing season and to reduce conflicts with the OCO-3 commissioning phase.

Saturation by Unusually Intense Glint



We are entering a season where bright ocean glint events are seen at low latitudes. On 26 February, we had 2 saturation events in one day.

Nominal B10 Testing Plan

- ABSCO update - Ongoing
- Solar model update - Done
- Test daily aerosol prior - Ongoing
- Assess impact of removing Psurf from retrieved state vector - Ongoing
- CO_2 prior update (in coordination with TCCON) - Ongoing
- Revise SIF calculation in L2
- Examine processes that affect CO2_grad_del behavior
- Assess value of a CO_2 column (or profile eigenvector) retrieval
- Assess impact of including a non-linear albedo slope
- Investigate including radiance offsets in ABP and in all bands for L2
- Assess convergence criteria and impact of restricting unphysical states
- Include temp profile (or temperature profile eigenvectors) in retrieval
- Assess impact of effort to detect/correct biases due to 3D effects of clouds
- Additional L1b calibration updates

High Priority

As Time Allows

ABSCO Tests: TCCON Spectral Residuals over Lamont

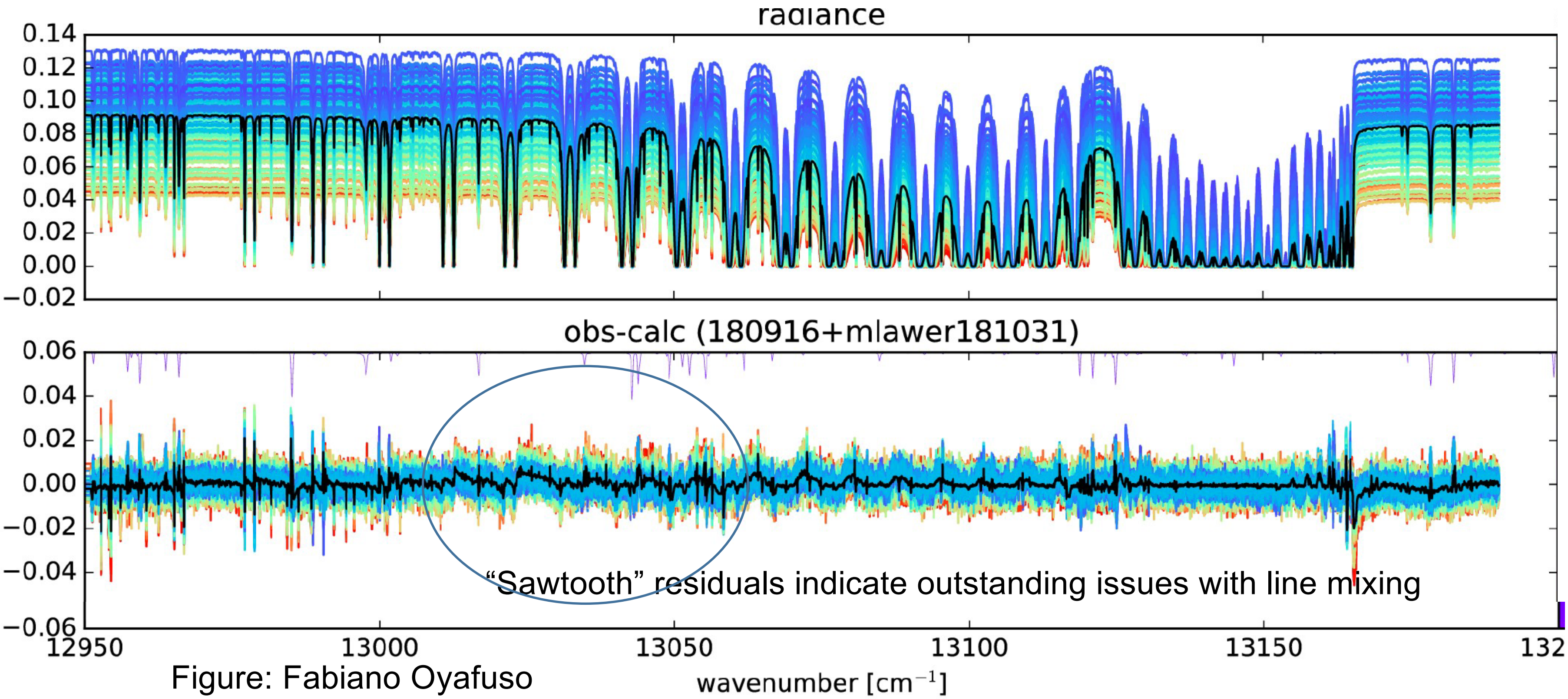
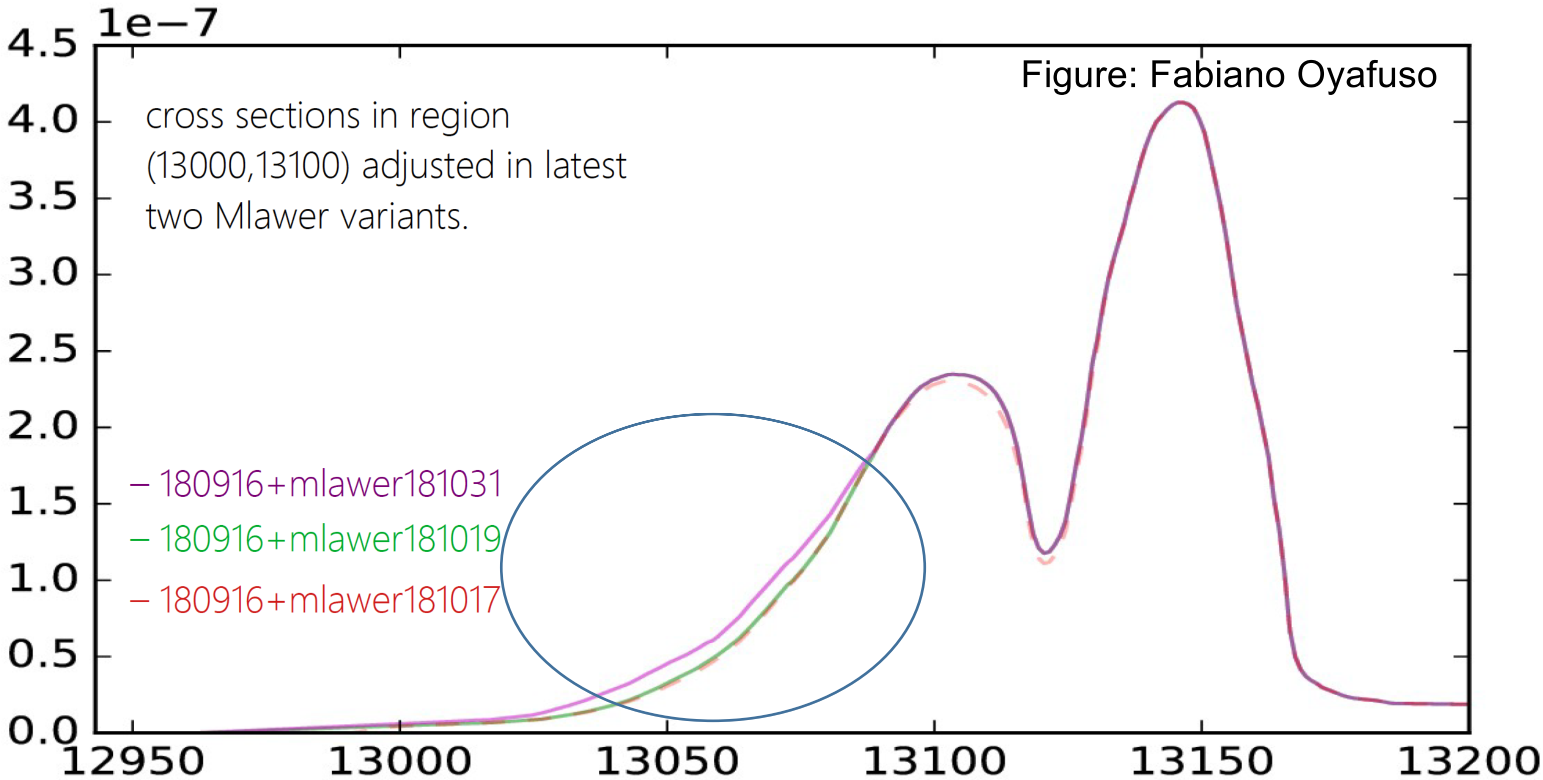


Figure: Fabiano Oyafuso

ABSCO 5.1 includes improvements in the O_2 and H_2O cross sections. It reduces spectral residuals relative to ABSCO 5.0 (used in B8), but does not yet substantially reduce the pole-to-equator pressure biases.

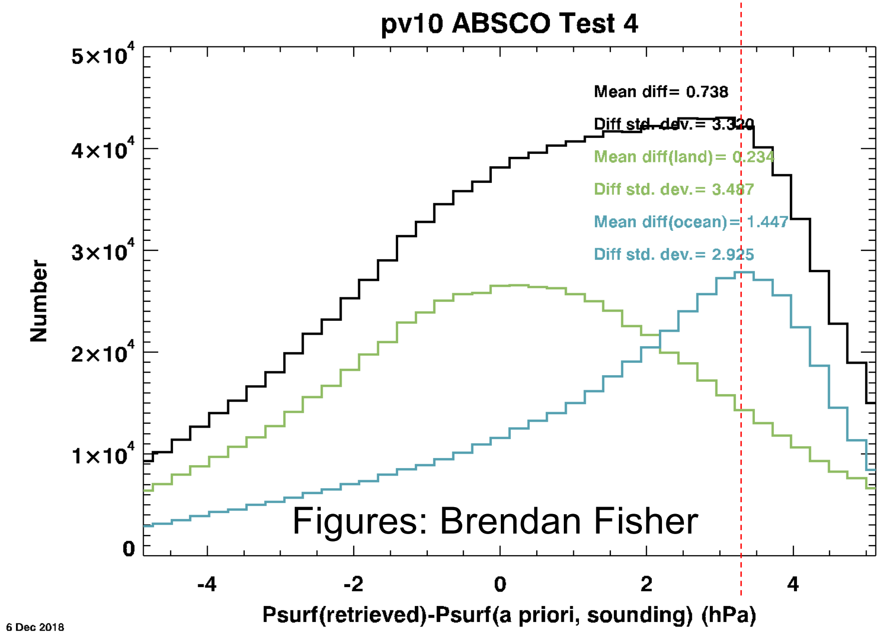
Empirical Collision-Induced Absorption

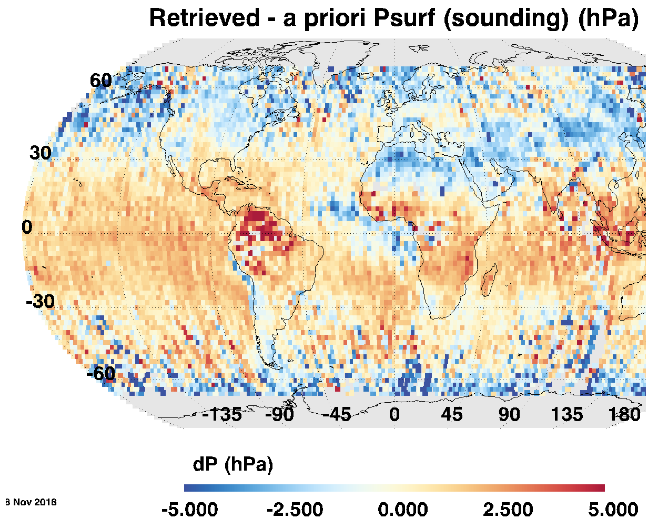


sco meeting (181105)

The empirical collision-induced absorption (CIA) has been refined to reduce residuals and surface pressure biases. Small changes in the CIA can introduce surface pressure biases.

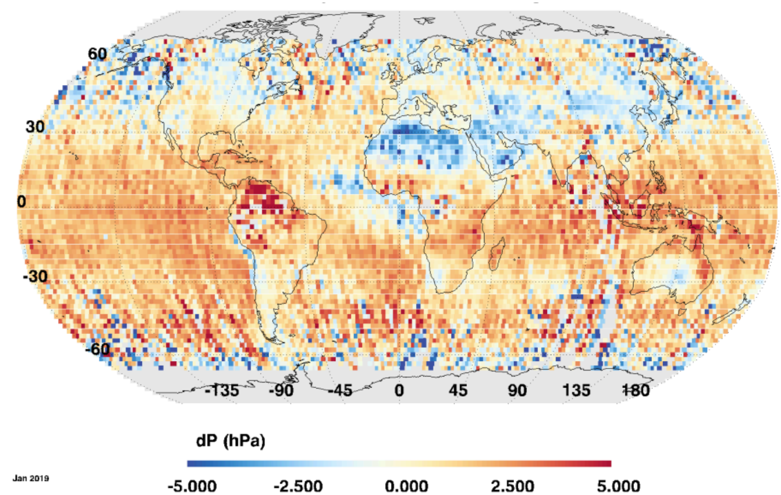
Current Surface Pressure Biases





ABSCO 5.1 results:

- H_2O continuum update reduces water vapor dependence
- O_2 update reduces temperature and air mass dependence, but increases the overall high bias over ocean.



Summary of ABSCO Tests

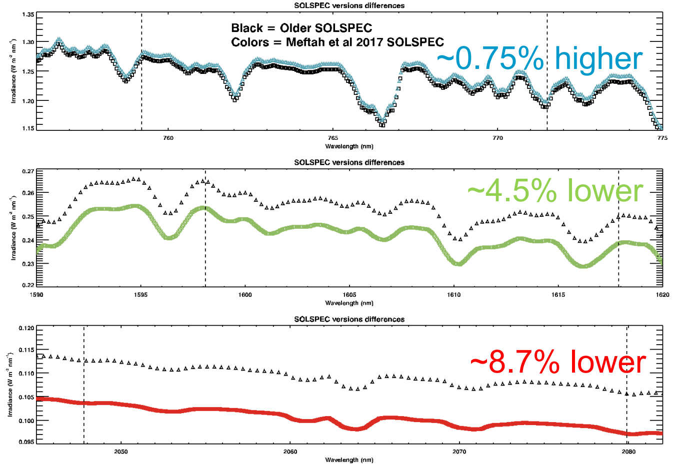
- Recommended H2O and O_2 updates in ABSCO 5.1
  - Recommend "Test 4" ABSCO
    - MT_CKD v3.2 continuum with HITRAN 2012 line parameters
    - v180916 line contribution + 181031 Mlawer empirical CIA
  - Significant reduction in A-band chi-squared compared to B9 No EOF
  - Flattening of latitudinal gradients
    - Corresponds to reduction in temperature dependence in retrieved P_{SUR}
  - Small increase in positive bias in retrieved P_{SUR} relative to prior
- Possible path forward: Implement temperature-dependent CIA
  - Fit for low T cases, fit for high T cases, linearly interpolate/extrapolate?
  - Allows for temperatures outside the Lamont range….

- Temporary EOFs have been derived for this version of ABSCO 5.1

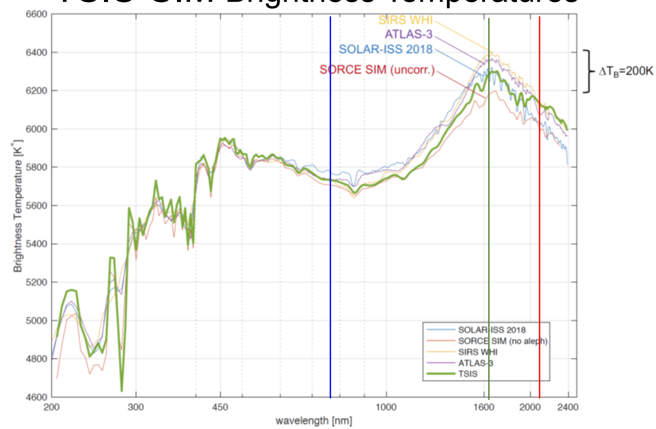
Updates to the Top of Atmosphere Solar Flux

- Accurate estimates of the top-of-atmosphere solar flux are critical to X_{CO2} retrievals
- For OCO-2, we construct the solar spectrum by combining a high resolution solar "transmission spectrum" (provided by Geoff Toon) and a continuum derived from the ATLAS 3 SOLSPEC experiment
- Two recent studies have identified biases in the ATLAS 3 SOLSPEC fluxes
    - Reanalysis of the ISS SOLar SOLSPEC observations (Meftah et al. 2018)
    - New data from the ISS TSIS SSI instrument (Richard et al. 2018)
- Both studies show the largest differences in the CO_2 channels

Solar ISS values are:



TSIS-SIM Brightness Temperatures

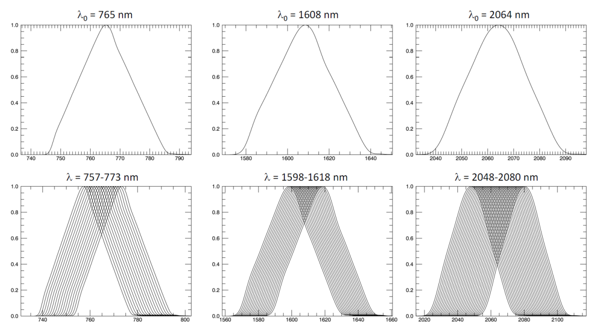


Largest Differences seen in the SWIR

Adjusting the OCO-2 Solar Continuum

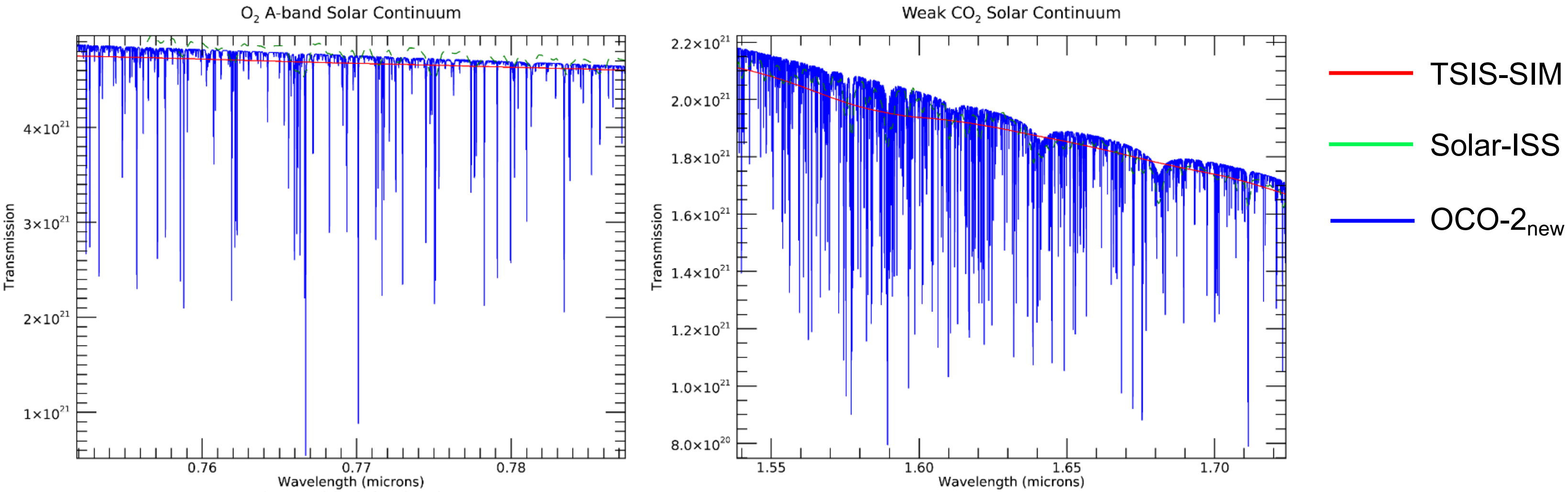
Approach:

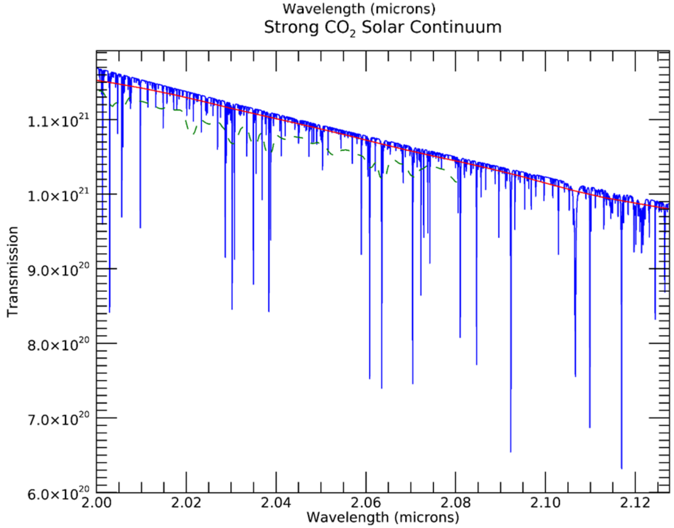
- Current OCO-2 solar spectral continuum in each channel (v6/v7/v8) was compared to the Solar-ISS solar spectra recently received from Meftah et al. and the TSIS-SIM solar spectra from Richard et al.
  - The TSIS-SIM values were adopted as the standard here
- The OCO-2 continuum values were:
  - Scaled by a multiplicative offset and slope (offset + slope*(λ-λ_{min})),
  - Multiplied by the high resolution transmission spectrum
  - Convolved with the TSIS-SIM Spectral Response Function (SRF)
- Plotting convention in plots that follow:
  - Original OCO-2 L2 continuum plotted in grey,
  - Scaled continuum plotted in black
  - TSIS-SIM plotted in red
  - Solar-ISS plotted in green
  - High-res OCO-2 solar spectra (blue)



TSIS-SIM SRF

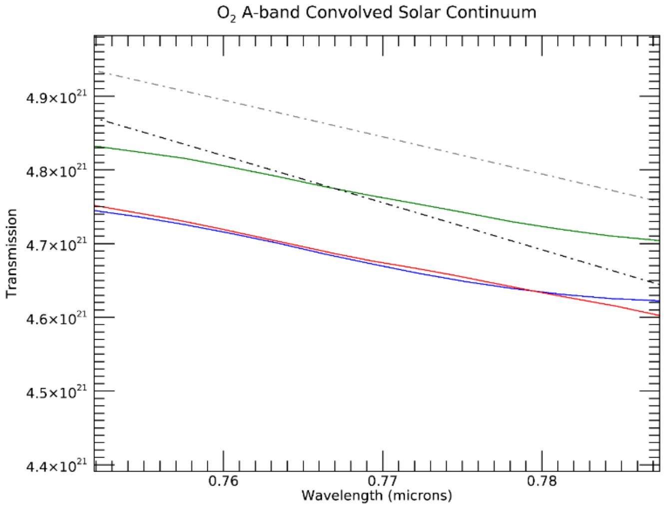
Solar Spectral Databases

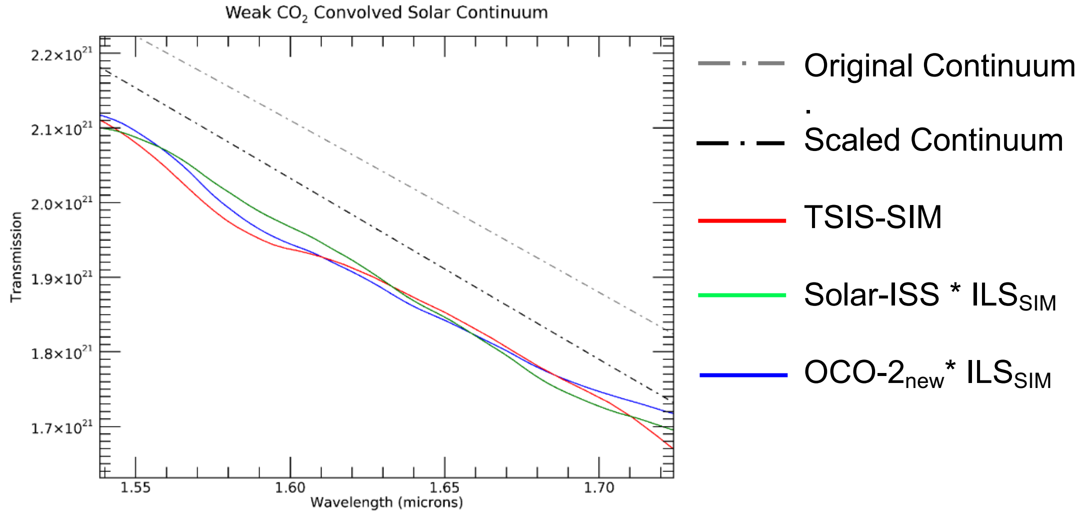


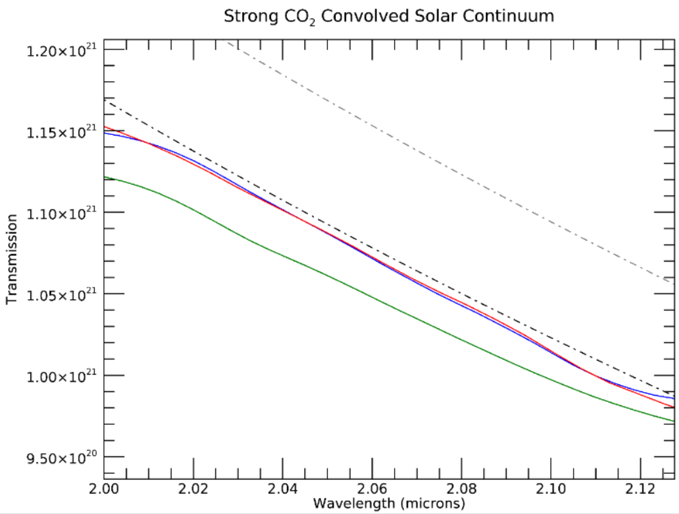


The OCO-2 continuum was scaled and then multiplied by the high-resolution solar line spectrum to produce a high resolution solar spectrum (blue). This spectrum is compared to the TSIS-SIM (red) and Solar-ISS spectrum (green) in each channel. The ABO2 and WCO2 channels have far more strong solar lines than the SCO2 channel.

Spectrally-Convolved Results







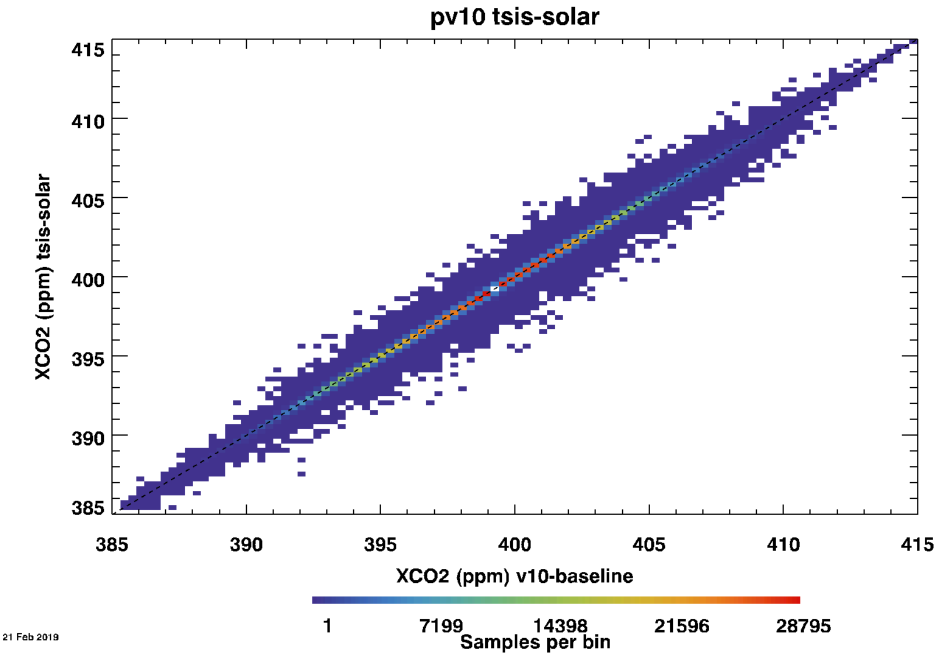
The OCO-2 high resolution solar spectrum with the scaled continuum was convolved with the TSIS-SIM spectral response function (SRF, blue) and compared to the TSIS-SIM (red) and the Solar-ISS spectrum (also convolved with the TSIS-SIM SRF (green)) to validate the scaled values.

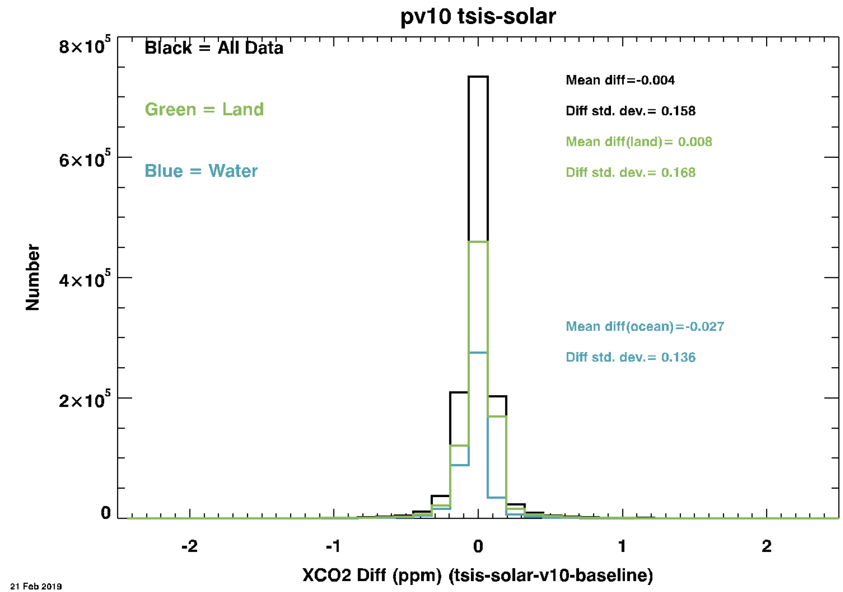
Summary of Results

OCO-2 Continuum Scaling Factors:

- ABO2 Scaling:
  - $(0.987 - 0.3\ \Delta\lambda) \times F_{c(old)}$, $\Delta\lambda = (\lambda - \lambda_{min})$, $\lambda_{min} = 0.751880\ \mu m$
- WCO2 Scaling:
  - $(0.97 - 0.11\ \Delta\lambda) \times F_{c(old)}$, $\Delta\lambda = (\lambda - \lambda_{min})$, λ_{min} = 0. 1.53846 μm
- SCO2 Scaling:
  - $0.935 \times F_{c(old)}$, No slope correction needed
- With these scaling factors, the OCO-2 solar spectrum produces better fits the TSIS-SIM spectrum than the Solar-ISS spectrum does.
  - The Solar-ISS result are ~1.6% higher, comparable, and 2.5% lower than the TSIS-SIM and scaled, convolved OCO-2 results in the ABO2, WCO2, and SCO2 channels, respectively
- An updated OCO-2 L2 solar spectrum file with the scaling factors listed above was used test the impact of these solar flux changes on the results of the L2 algorithm

Impact on Retrieved XCO_2

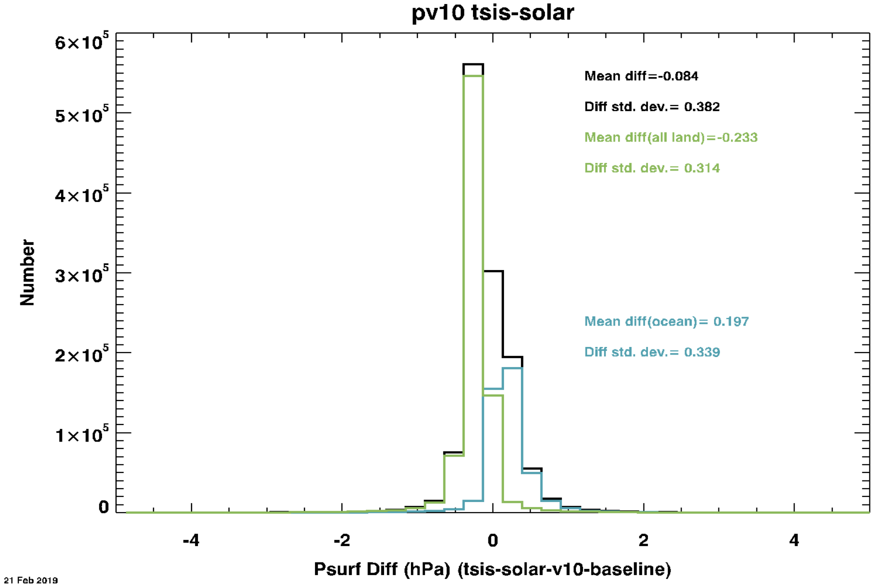


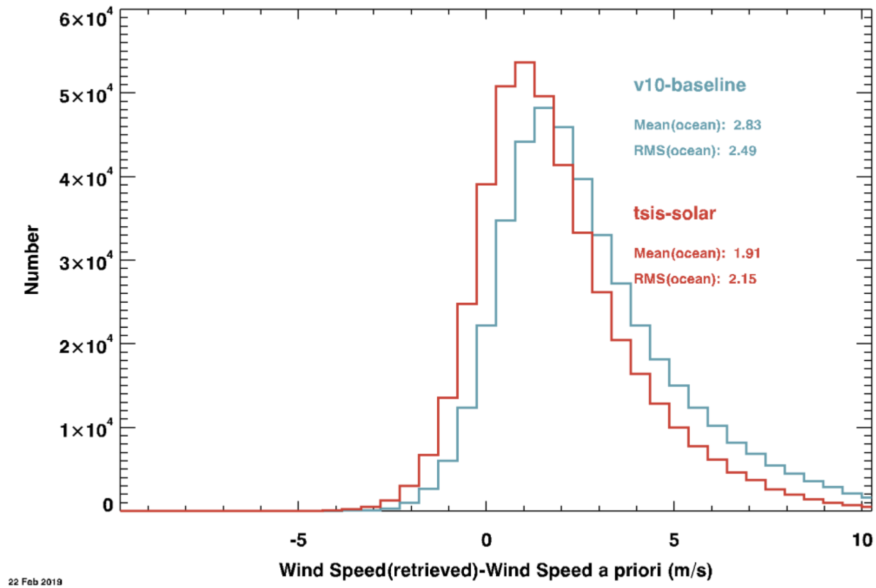


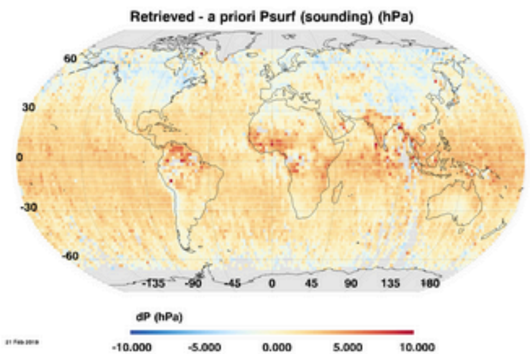
No significant change in XCO_2 between versions of the retrievals with old and new solar fluxes

Le (Elva) Kuai and Brendan Fisher

Pressure and Wind Speed Changes





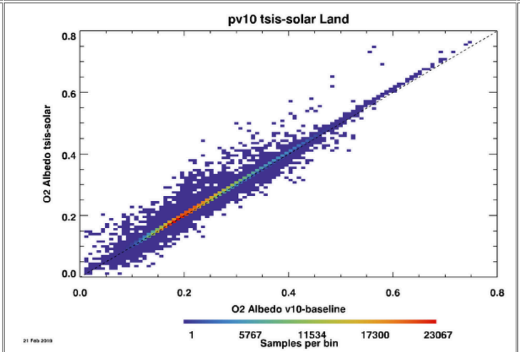
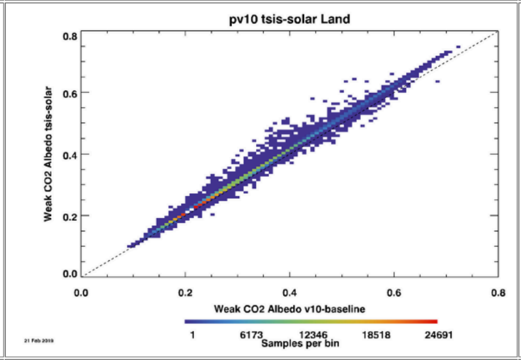
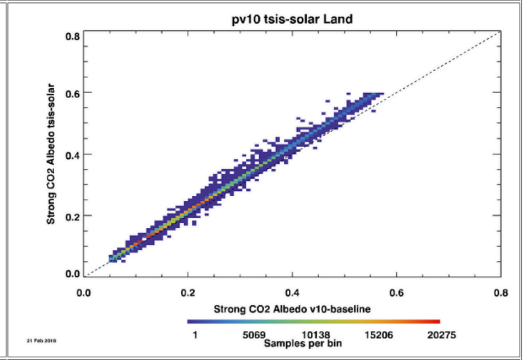
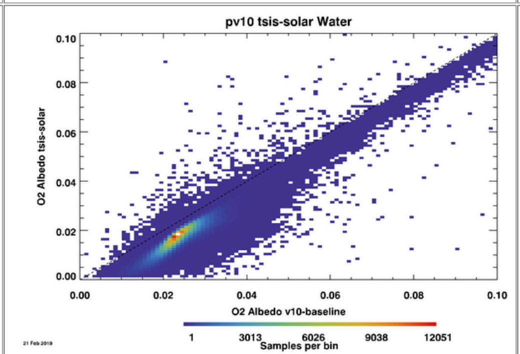
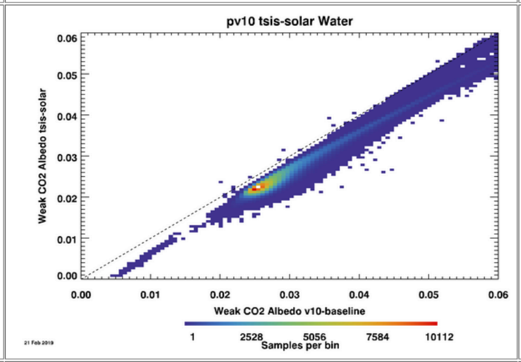
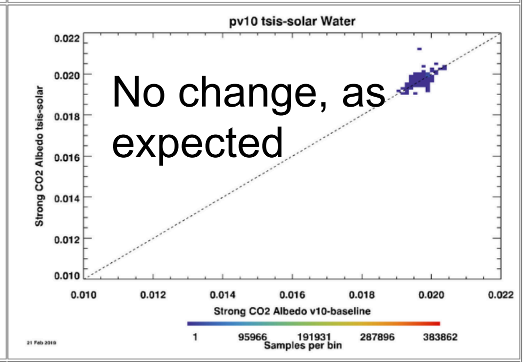


Psurf changes are small:
-0.2 hPa over Land, +.2 hPa over water

Cox-Munk wind speed estimates over the ocean are lower for the revised solar fluxes. The reduced solar flux in the SCO2 channel is compensated by a reduced wind speed and increased glint brightness at OCO-2's glint off-pointing angles.

Le (Elva) Kuai and Brendan Fisher

Changes in the Retrieved Albedos

	O2	Weak CO2	Strong CO2
Albedo correlation Land:			
Albedo correlation Water:			

- Water: Reduced Lambertian term in the O_2 and weak CO_2
  - No change in SCO2 because glint albedo set in this channel
- Land: Albedo slightly higher in TSIS-SIM-solar test.
- Albedo slopes slightly reduced

Le (Elva) Kuai and Brendan Fisher

Conclusions

- XCO_2: no significant change.
- Psurf: no significant change.
  - Retrieved P gets slightly closer to a priori
- Albedo:
  - Reduced Lambertian term in ABO2 and WCO2 channels over water (as expected)
  - Slightly higher albedo in the SCO2 channel over land, compensating for the reduced flux
- Wind speed:
  - Cox-Munk wind speed is derived from the SCO2 channel. A reduced wind speed in this channel is needed to increase the glint brightness to compensate for the reduced solar flux in this channel
- AOD total:
  - No significant change
- Recommendation: Use New solar data in L2 retrieval algorithm - Yes.

Aerosol Prior Tests

- Motivation: more realistic aerosol priors should help us retrieve a better X_{CO_2}

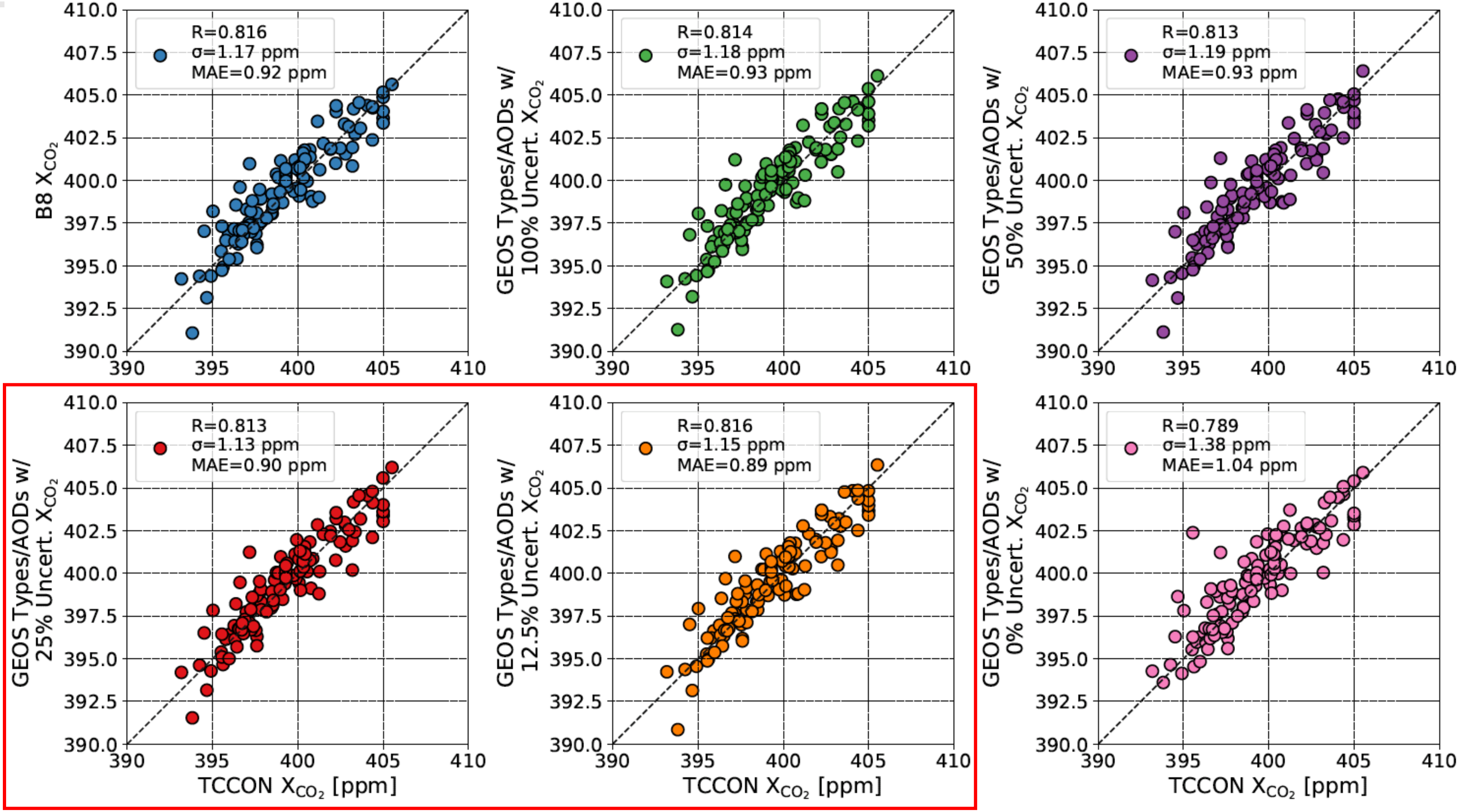
- Methodology: Use 3-hr. GEOS-5 aerosol types & AODs as priors for the two tropospheric types with a prior ln(AOD) uncertainty of:

% Uncert. of B8	1σ on ln(AOD)	1σ AOD range on prior of 0.1
100%	2.0 (same as B8)	0.01 – 0.74
50%	1.0	0.04 – 0.27
25%	0.5 (Nelson 2018)	0.06 – 0.17
12.5%	0.25	0.08 – 0.13
0%	0.001	0.1 – 0.1

- Validation: TCCON & model median suite

Rob Nelson and Chris O'Dell

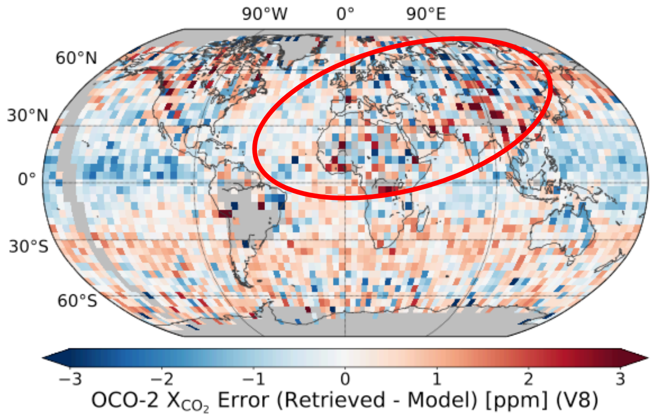
TCCON Validation – Reducing Prior Uncertainty Improves Fits

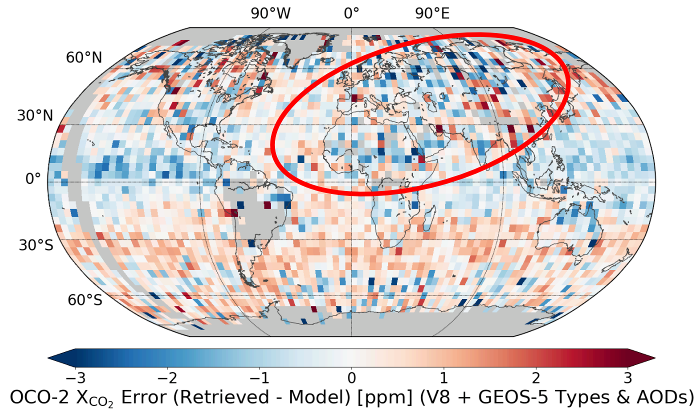


- 25% and 12.5% look best

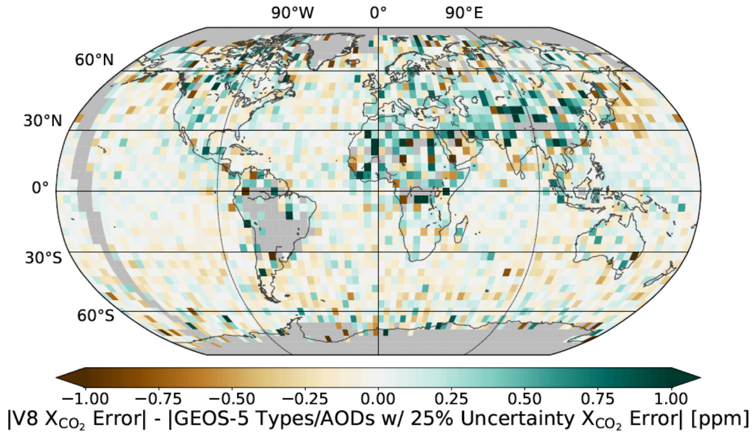
Rob Nelson and Chris O'Dell

Model Validation





- High biased X_{CO_2} over Northern Africa and Central Asia is reduced by using GEOS-5 Types/AODs with lower prior uncertainties.



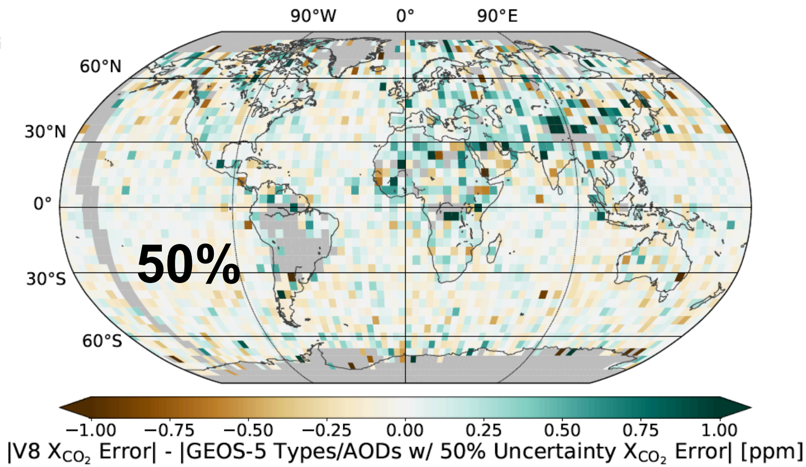
Color is the change in abs(bias) vs. V8

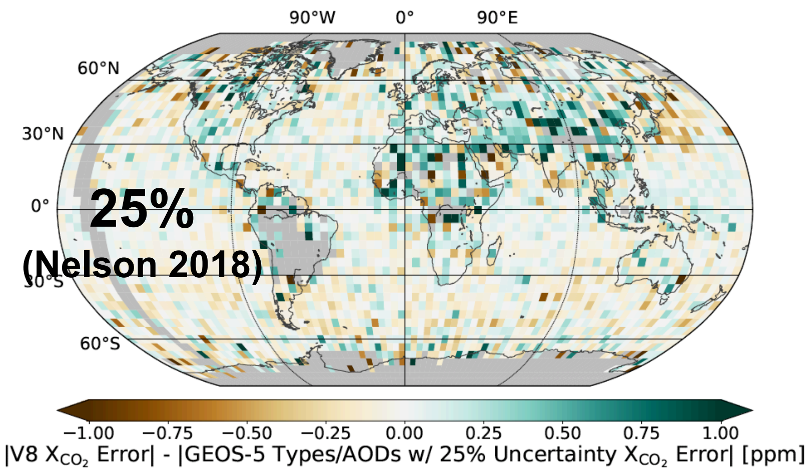
- Green = bias decreased
- Brown = bias increased

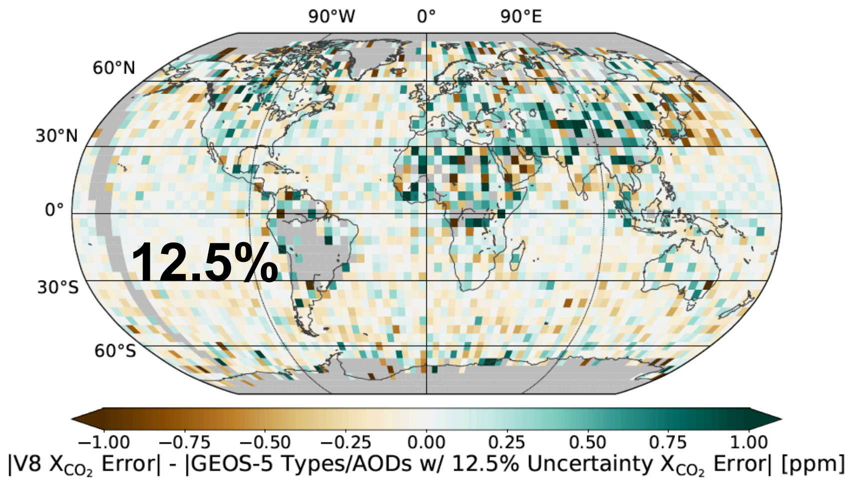
Rob Nelson and Chris O'Dell

Model Validation

- Color is the change in abs(bias) vs. V8
  - Green = bias decreased
  - Brown = bias increased







- Regional improvement is consistent, best with 25% & 12.5% uncert.
  - N. Africa + C. Asia σ_{error} = **2.15** ppm (V8) **1.96** (50%), **1.87** (25%), **1.84** (12.5%)

Conclusions

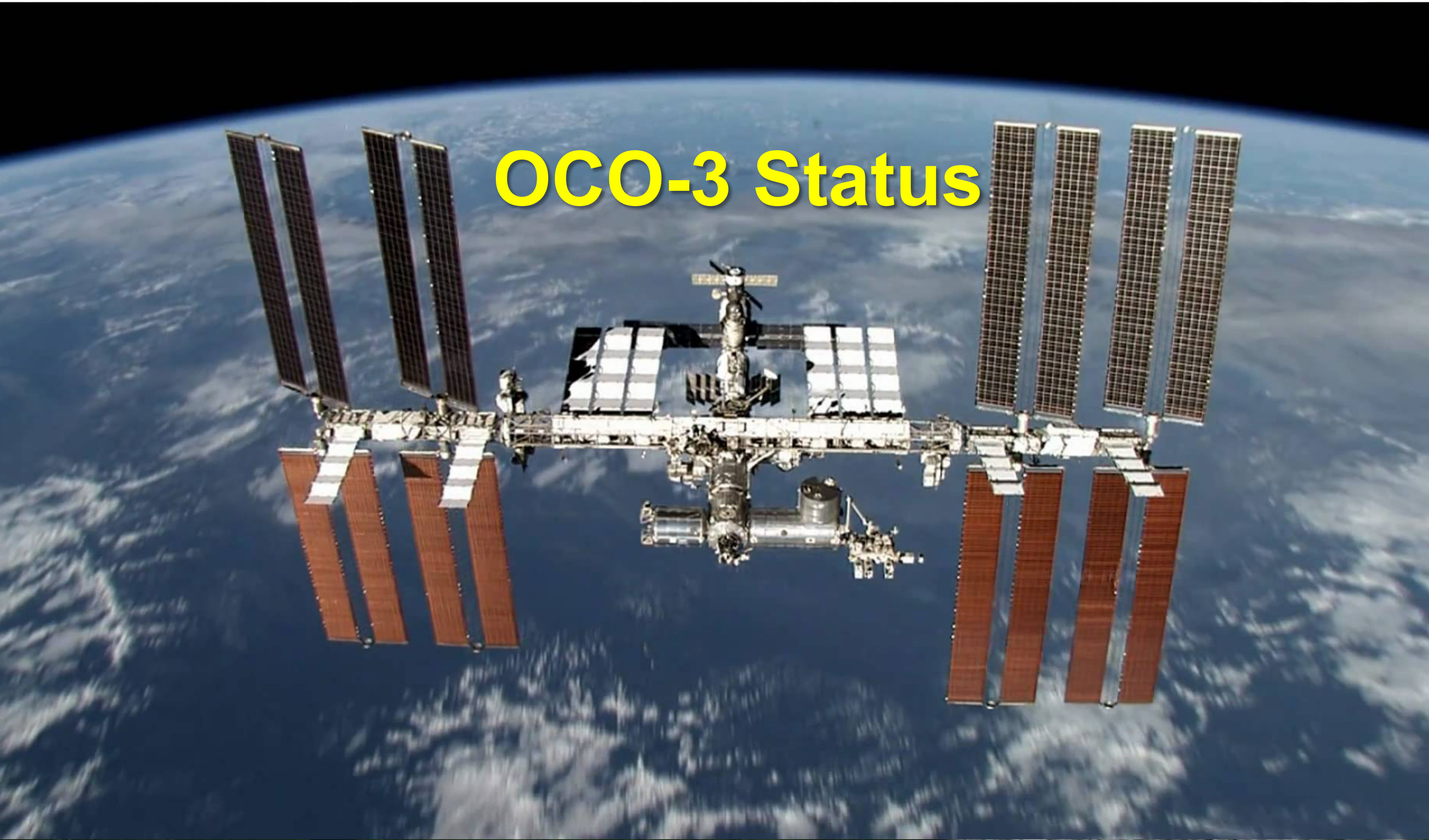
- Using GEOS-5 types + AODs with 25% or 12.5% of the B8 uncertainty looks best against both TCCON and model validation
  - 25% = 1σ prior uncert. of 0.5 on the two tropospheric ln(AOD)s
  - 12.5% = 1σ prior uncert. of 0.25 on the two tropospheric ln(AOD)s

Aerosol Test Recommendations

- Use GEOS-5 types + AODs as prior w/ 25% and 12.5% uncert. of V8 for the two tropospheric aerosol types (not ST!)
  1. Set the prior uncertainty on ln(AOD) to 0.5 instead of 2.0 (25%)
  2. Set the prior uncertainty on ln(AOD) to 0.25 instead of 2.0 (12.5%)
  3. Try the 25% prior uncertainty, but take the prior AOD as the TOTAL from GEOS-5, not just from the two dominant types; i.e. use the two dominant types, but scale them so their sum matches the model total.

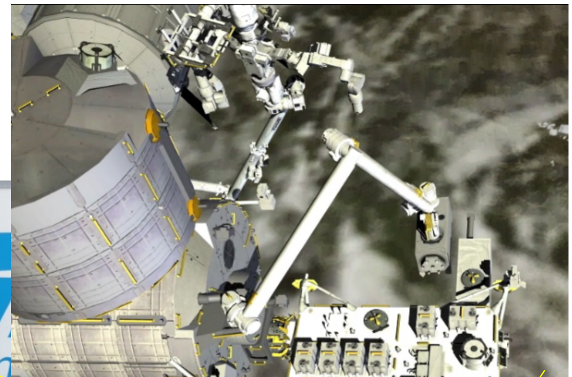
Rob Nelson and Chris O'Dell

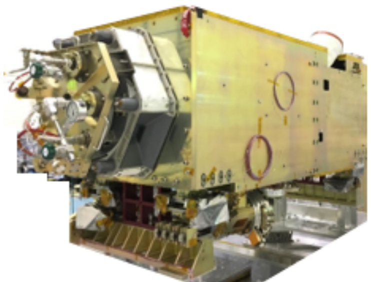
OCO-3 Status



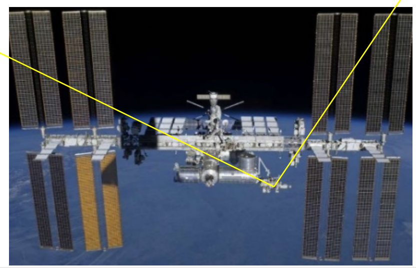
OCO-3 Status Update

- OCO-3 is currently in storage at Cape Canaveral
  - Current launch date: No Earlier than 25 April 2019
    - Successful launch of Crew Dragon on 2 March should keep this on schedule
  - We are still planning to hold a Science Team meeting in conjunction with the launch, but this plan may be revised if the launch slips further
  - JPL Guest Ops has distributed launch surveys – complete and return ASAP

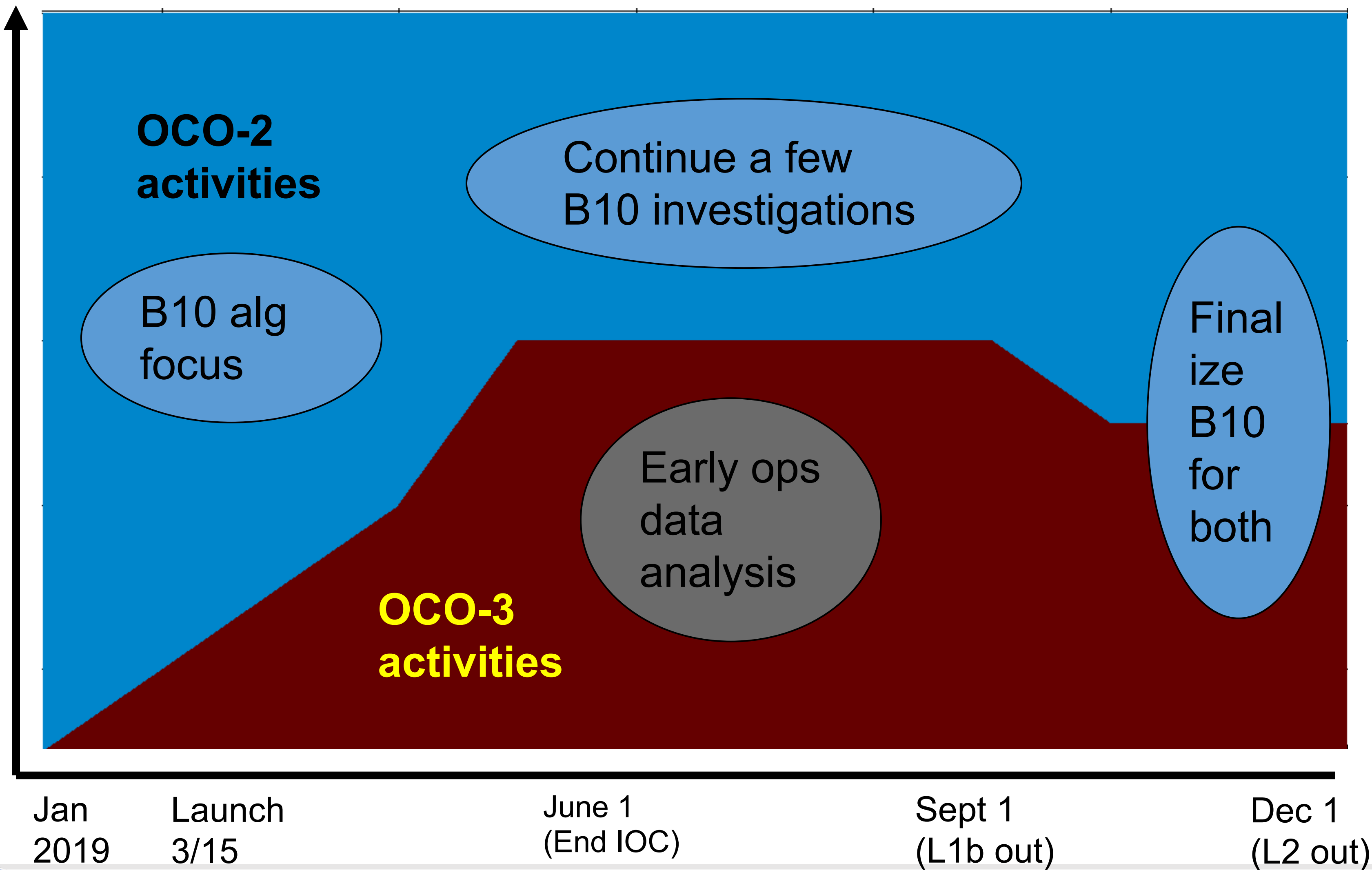




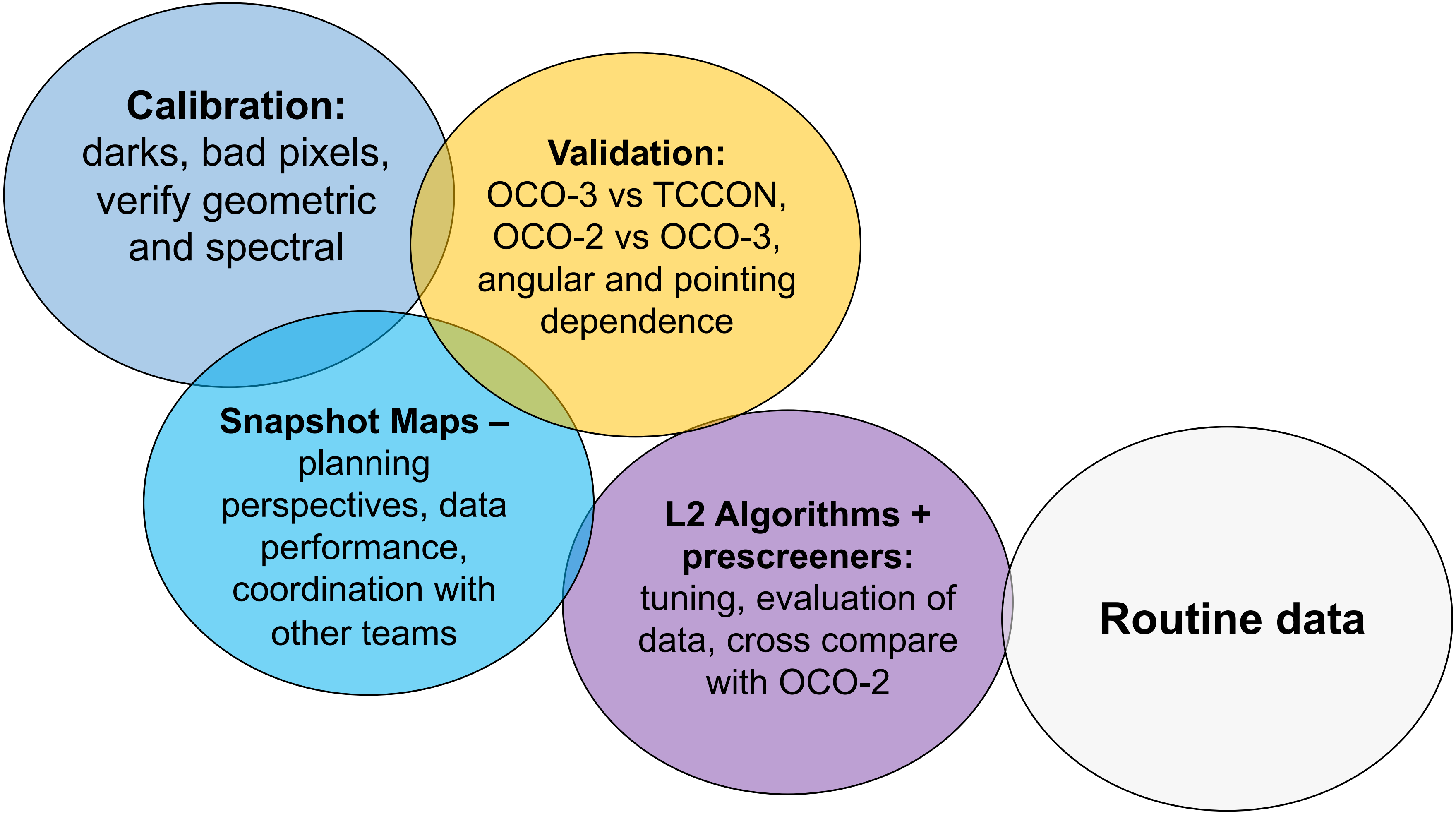
The OCO-3 Team



Integrating OCO-2 and OCO-3 Activities



Snapshot of Early Ops Activities



Key Near Term Activities

Blue text indicates items that have been updated since the last report. Red text indicates that there may be a changes.

Planned Date	Activity Description
11-13 Mar	UQ Breakout meeting, Pasadena, CA
25 Apr	OCO-3 Launch, Cape Canaveral, FL
24-26 Apr	OCO-2/OCO-3 Spring Science Team Meeting, Coco Beach, FL
7-12 Apr	EGU General Assembly, Vienna
13-17 May	ESA Living Planet Symposium, Milan, Italy
21-22 May	NOAA ESRL GMD Annual Conference, Boulder
3-5 Jun	IWGGMS-15, Sapporo, Hokkaido, Japan
10-12 Jun	CEOS AC-VC, Tokyo, Japan
17-20 Jun	CALCON, Logan Utah
30 Jun-5 Jul	2019 RRV Campaign
7-18 Jul	27th IUGG General Assembly 8-18 July, Montreal, Canada
26-29 Aug 2019	Chapman Conference: Carbon-Climate Feedbacks, San Diego