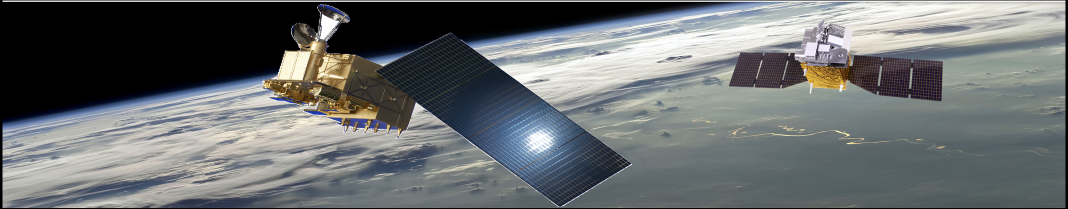

In-Flight Performance of the TanSat Atmospheric Carbon Dioxide Grating Spectrometer

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Introduction

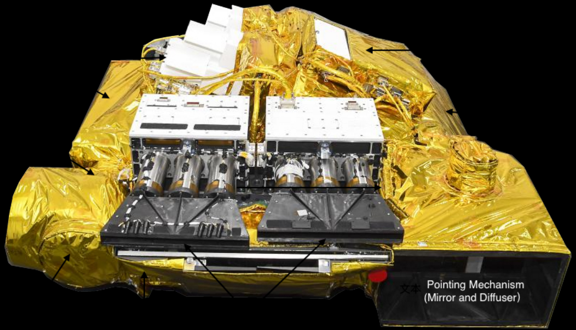


Figure: Physical photograph of the in-flight ACGS

1. TanSat is the first Chinese satellite mission dedicated to measuring the column-averaged CO_2 dry-air mole fraction (X_{CO_2}); for this purpose, TanSat is equipped with the Atmospheric Carbon Dioxide Grating Spectrometer (ACGS), a major spaceborne grating hyperspectral spectrometer suite.
2. TanSat was successfully launched into orbit from JiuQuan Base in Gansu Province, China, on 22 December 2016.
3. The ACGS has been providing global measurements of CO_2 and O_2 spectral bands in reflected sunlight since early February 201

Introduction...

1. The ACGS measurements are calibrated and geolocated to produce level 1 (L1) products that are analyzed to retrieve spatially resolved estimates of X_{CO_2}.
2. It is important that the radiometric and spectroscopic accuracies of the ACGS be meticulously validated.
3. These demanding applications represent the motivation for the characterization of the ACGS radiometric and spectroscopic accuracies provided in this presentation.
4. In addition to understanding the physical basis of the uncertainties in ACGS measurements, it should be possible to achieve even higher accuracies in space-based atmospheric $\mathrm{CO_2}$ measurements in the near future.
5. Since TanSat was launched in 2016, a team of subject matter experts from the government, academic, and industrial sectors has been engaged in in-flight TanSat on-orbit checks that include ACGS calibration and validation activities. Consequently, an on-orbit check was completed in September 2017.

Performance specifications of the TanSat ACGS

Band / Item	O_2A	WCO_2	SCO_2
Spectral Range (nm)	758 - 778	1594 - 1624	2042 - 2082
Spectral Resolution (nm)	0.033 - 0.047	0.120 - 0.142	0.160 - 0.182
Spectral Resolving ($\lambda/\Delta\lambda$)	∼19000	∼12800	∼12250
Spectral Sampling Per FWHM	> 2		
Dynamic Range ($ph/sec/m^2/sr/um$)	SNR=1@$1.2 \times 10^{17} \sim 1.4 \times 10^{21}$	SNR=1@$5.7 \times 10^{16} \sim 4.9 \times 10^{20}$	SNR=1@$6.0 \times 10^{16} \sim 1.6 \times ^{20}$
SNR @ ($ph/sec/m^2/sr/um$)	360@5.8×10^{19}	250@2.1×10^{19}	180@1.1×10^{19}
Abs/Rel Calibration Error(%)	<5 / <3		
Calibration Nonlinearity Error (%)	<2		
Dark Current Error (DNs) (after correction)	<5		
Radiance Response Uniformity (%)(interior of band)	>99.9		
Radiance Response Uniformity (%)(between bands)	>99.0		
Frame Rate (Hz)	∼3.3		

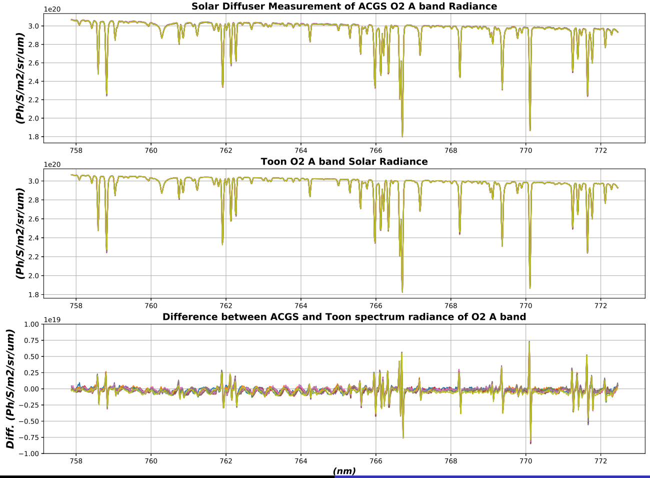
In-flight performance of the TanSat ACGS

1. The in-flight performance and absolute accuracy of any remote sensing satellite instrument are based on the optimal design of the optics, electricity and thermotics systems, ground laboratory calibration, and in-flight refinement of the calibration parameters.
2. The performance of the ACGS was carefully characterized and calibrated twice prior to launch, and the results met the mission requirements [?].
3. The ACGS has performed as expected on orbit. During the first month following its launch in 2016, the spacecraft team completed a functional check of the platform and instruments.

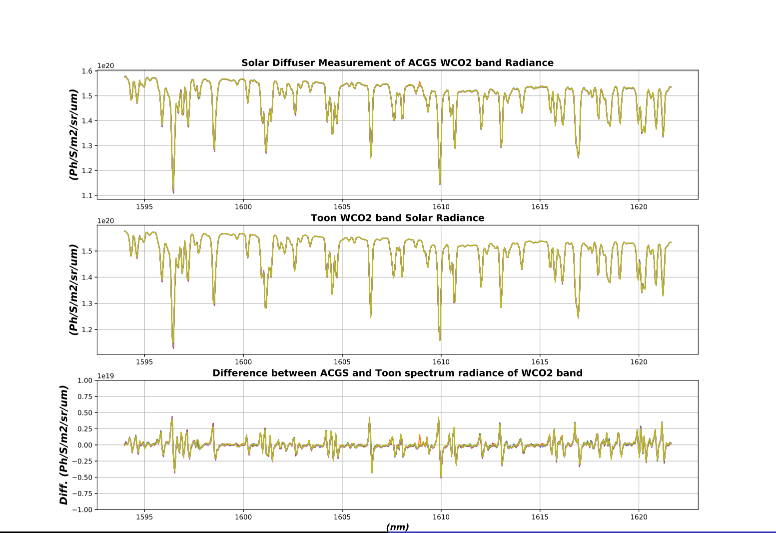
Spectroscopic performance

1. During the flight of TanSat, we used the available Fraunhofer lines of the solar spectrum acquired during solar calibration observations of the ACGS after correcting for the Doppler effect and performed a comparison with the more precise solar spectra database used by OCO-2 as references to validate the spectral accuracy of the centroid wavelength.
2. These figures illustrate remarkable consistencies among the footprints and agreements with the reference spectrum. The spectral calibration accuracy of the O_2 A-band is 0.19 pm, that of the WCO_2 band is 0.27 pm, and that of the SCO_2 band is 4.75 pm, all of which meet the 0.05 FWHM requirement. The spectroscopic performance of the ACGS therefore surpasses mission requirements with a margin.

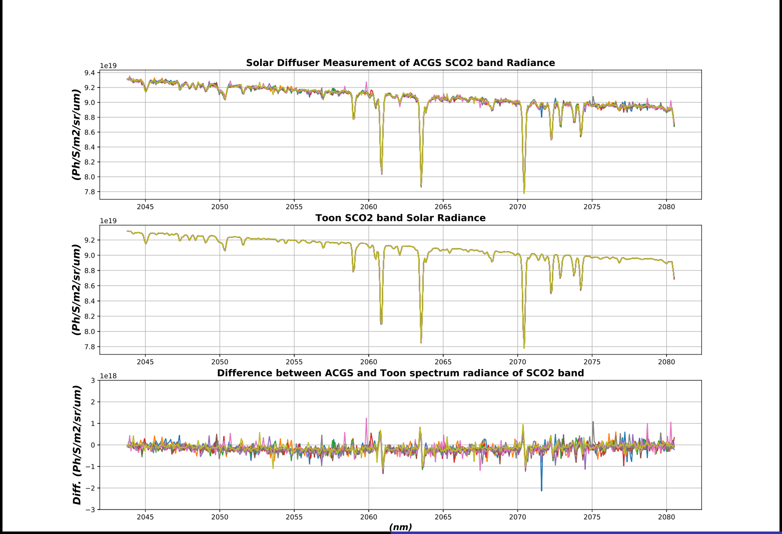
Spectroscopic performance of the ACGS O2 A-band



Spectroscopic performance of the ACGS WCO2 band



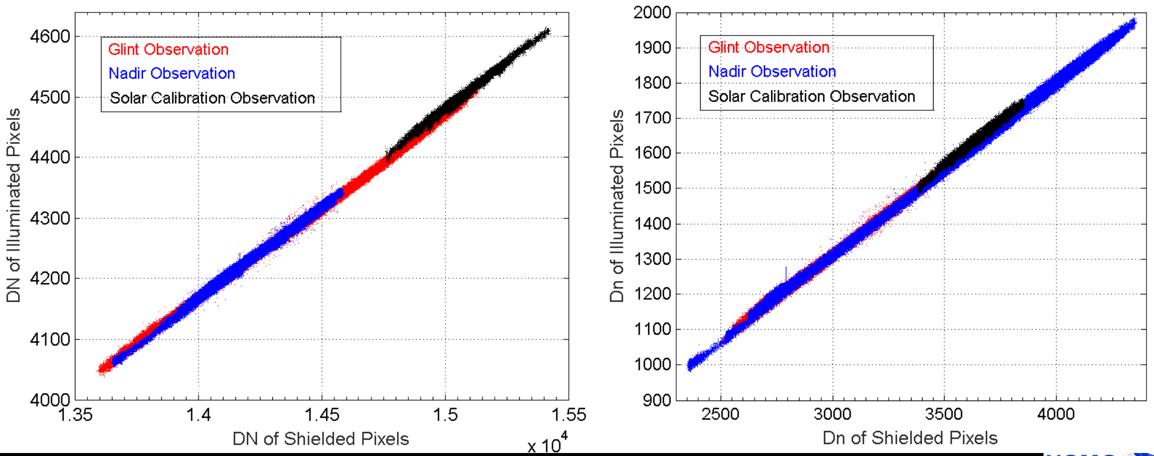
Spectroscopic performance of the ACGS SCO2 band



Dark current

1. Dark current constitutes the response of an instrument detector when it is not actively being irradiated, It is the baseline of instrument radiometric response.
2. For the HgCdTe detectors of the WCO_2 and SCO_2 bands of the ACGS, the response component is sensitive to tiny changes in the ambient temperature, although the temperature is controlled to within 0.3 K in-flight, and thus, it must be corrected routinely on orbit.
3. Preliminary dark current responses as a function of the ambient temperature were established for the two CO_2 bands during the thermal-vacuum (TVAC) testing of the ACGS [Yang2018].
4. The response models of each channel in the two CO_2 bands were rebuilt using in-flight data measured in real time during the first phase of orbital checkout through a few days of continuous full-orbit, in-flight dark current response testing.
5. These models have been used in the preprocessing algorithm of the ACGS L products, and the performance has been validated in our X_{CO_2} retrieval processing. After the corrections used in these models, the dark current error was

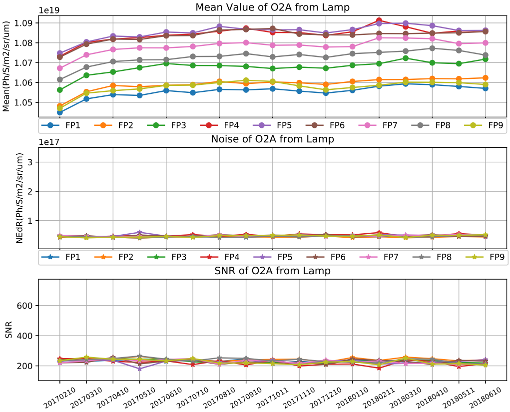
Dark current model of WCO2(left) and SCO2(right) band

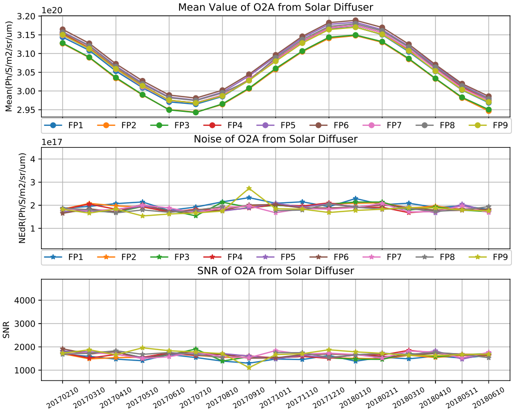


SNR and gain coefficient

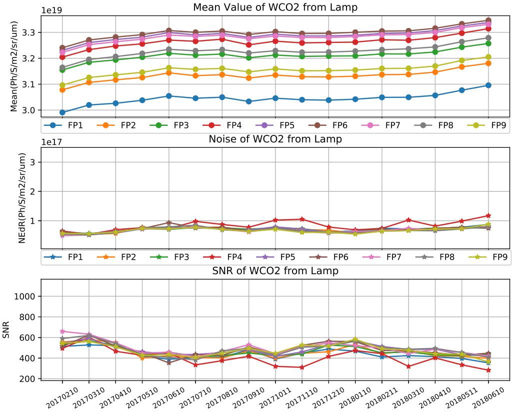
1. The SNR is a measurement that compares the level of desired signal to the level of background noise, that is, the SNR measures the ratio between an arbitrary signal level and noise.
2. Measuring the SNR requires the selection of a reference signal source. In the prelaunch calibration of the ACGS, we used a National Institute of Standards and Technology (NIST)-traceable integrating sphere as the reference signal source to characterize the SNR successfully[Yang2018].
3. In flight, we used measurements of the calibration lamp devices and solar diffuser to evaluate the SNR of the ACGS. In our work, the SNR is defined as the ratio of the mean to the standard deviation of a measured signal.

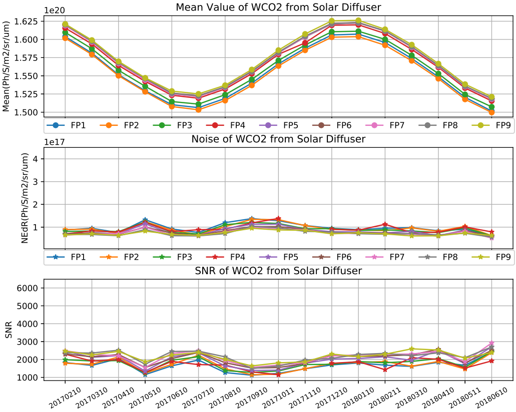
In-flight performance stability of O2 A-band(left: from calibration lamp, right: from solar diffuser)



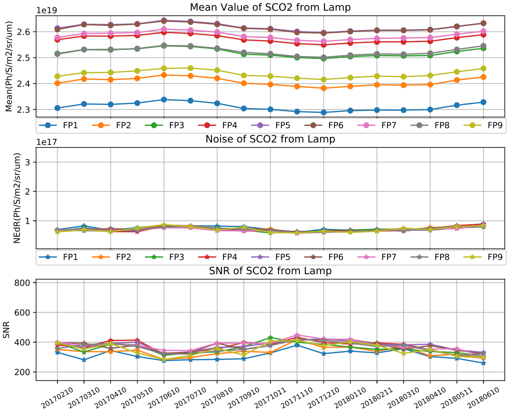


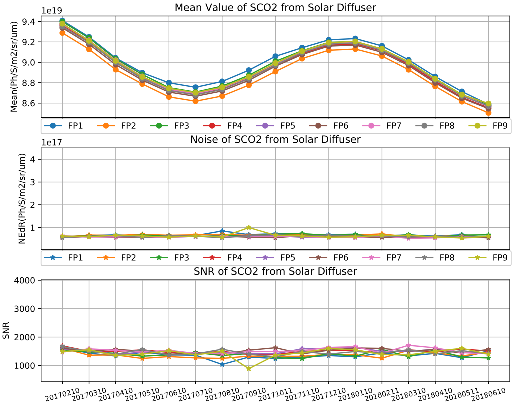
In-flight performance stability of WCO2 band(left: from calibration lamp;,right: from solar diffuser)



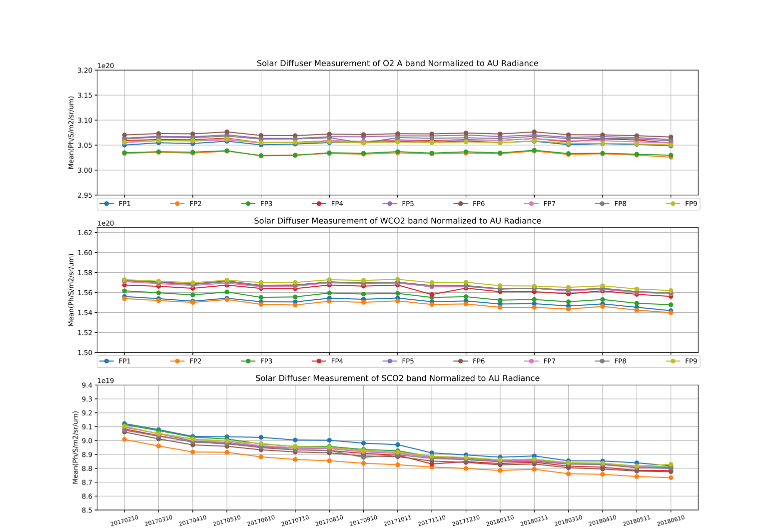


In-flight performance stability of SCO2 band(left: from calibration lamp, right: from solar diffuser)

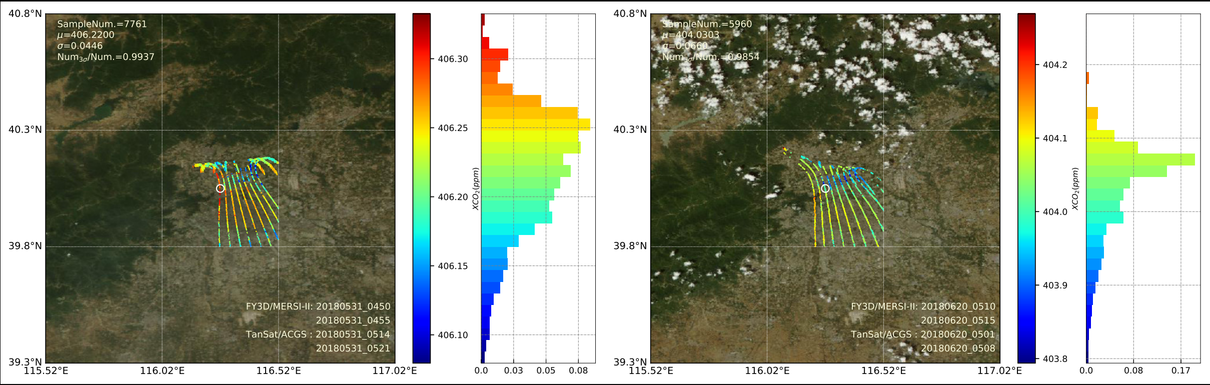




Normalized to AU Radiance of ACGS Solar Diffuser Measurement



Validation of ACGS XCO_2 Using Target Observation Model of TanSat



Validation to ACGS XCO2(3σ) at Beijing Ground Station in 2018

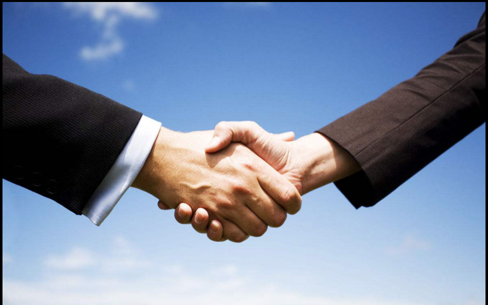
Date	FTS125HR (ppm)	ACGS(ppm)	Precision(ppm)	Bias(ppm)	Samples(n)	Confidence
Mar. 08	407.71	408.00	1.15	-0.29	9074	95.54%
Apr. 16	409.87	408.62	2.22	+1.25	11250	98.74%
May 04	408.74	409.49	0.91	-0.75	10843	96.27%
May 31	407.09	405.78	2.88	-1.31	11602	99.81%
June 20	403.30	404.89	1.76	-1.59	10912	97.13%
Aug. 20	402.32	400.00	0.11	+2.32	11597	98.05%
Nov. 21	408.01	408.05	1.13	-0.04	10242	99.52%
Dec. 04	408.15	409.52	0.53	-1.38	10174	96.64%
Average	/	/			/	

Validation to ACGS XCO_2 using FTS 125HR Measurement

Summary

1. In this study, we evaluated the in-flight spectroscopic and radiometric performance of the ACGS using measured data from solar diffuser and halogen tungsten lamp devices.
2. In-flight calibration and validation work of the ACGS has achieved success, and the radiometric and spectral performance specifications have met the mission requirements.
3. The Ver 2.0 L1 products were released to the world on 1 February 2018 (http://satellite.nsmc.org.cn/portalsite/default.aspx).
4. The estimated absolute spectral calibration uncertainty is less than one-tenth of the spectral resolution, and the estimated radiometric uncertainty is less than 5% in the O_2 A-band, WCO_2 and SCO_2 band.
5. In February 2018, the NSMC TanSat team completed the research and software development phase of a full physical inversion algorithm for X_{CO_2}. The software has since been put into operation, the initial accuracy verification has been completed, and large-scale batch processing and validation efforts are underway.

THANK YOU FOR YOUR ATTENTION!



THANK YOU FOR YOUR ATTENTION!