2009 VICARIOUS CALIBRATION RESULTS FOR THE GREENHOUSE GASES OBSERVING SATELLITE (GOSAT)

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1. INTRODUCTION

The Greenhouse gases Observing SATellite (GOSAT) launched on the 23rd of January 2009 from the Tanegashima Space Center, Japan. It carried two instruments: the infrared Thermal And Near infrared Sensor for carbon Observations - Fourier Transform Spectrometers (TANSO-FTS) and the Cloud and Aerosol Imager (CAI) [1]. The vicarious campaigns were able to address the near infrared bands of the TANSO-FTS instrument (Table 1) and all four bands of CAI (Table 2). In the case of the thermal IR band, much better targets are available for study.

During 2009, two very different campaigns were conducted to validate the radiometric calibration of the GOSAT near-infrared portion of TANSO-FTS. The first involved a large team making measurements of the surface of a dry lakebed in Railroad Valley, NV. The second campaign relied on an aircraft carrying the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) flying over Railroad Valley simultaneously with the GOSAT overpass. The second campaign also provided a chance to validate the calibration of an imager that is also carried by GOSAT. The process of comparing the data sets with very different spatial and spectral resolution and sampling is discussed here.

Validation of the radiometric calibration of instruments in space is a challenge. Many imagers have solved this problem with vicarious calibration technique. In the case of a space-based instrument with very narrow spectral ranges that are centered on atmospheric absorption bands, unique challenges arise.

2. GROUND TARGET

Railroad Valley, NV was selected for our ground campaigns after studying various sites around the world. It offered several attractive features. It is easily reached from a highway running along the western edge of the

TABLE 1: TANSO-FTS Specifications (Band 4 was not part of calibration experiment)

	Band 1	Band 2	Band 3	Band 4
Spectral range (cm^{-1})	12900-13200	5800-6400	4800-5200	700-1800
Spectral range (μ m)	0.775-0.758	1.724-1.562	2.083-1.923	14.286-5.556
Detector	Si	InGaAs	InGaAs	PC-MCT
Spectral resolution (Interval) :	0.2 cm^{-1} (unapodized)			
Instantaneous Field of View:	15.8 mrad (10.5 km at 666 km)			

TABLE 2: CAI Specifications

Parameter	Band 1	Band 2	Band 3	Band 4
Center Wavelength (nm)	380	674	870	1,600
Band Width (nm)	20	20	20	90
Spatial Resolution (IFOV) (km)	0.5	0.5	0.5	1.5
# of Cross track Pixels	2,000	2,000	2,000	500

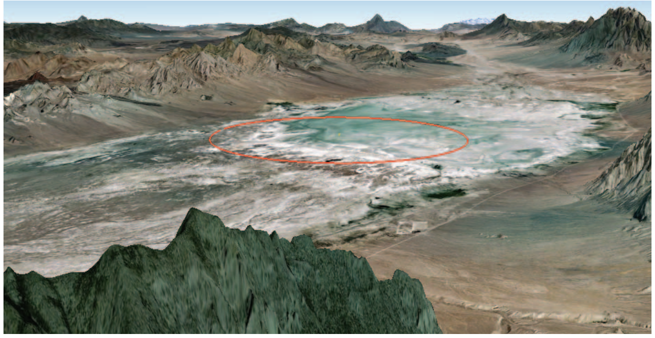

FIGURE 1: Google Earth image of Railroad Valley with TANSO-FTS footprint shown from experiment on 9 October 2009. Footprint is centered at 38.458^o N, 115.705^o W at an elevation of 1,436 meters above sea level.

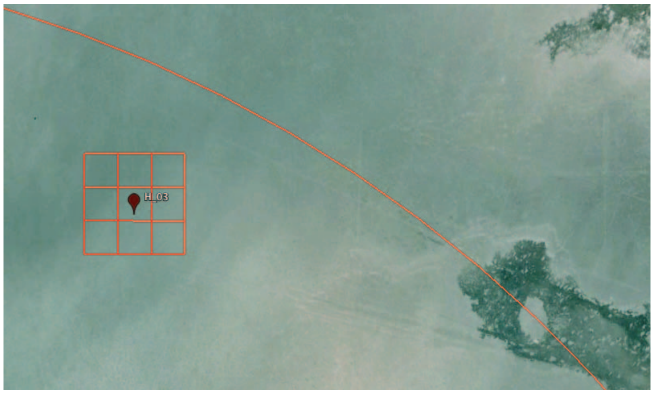

FIGURE 2: Google Earth image of Railroad Valley with the 500 by 500 meter grid shown with a small piece of the edge of the TANSO-FTS footprint.

valley. It is large enough to accommodate the TANSO-FTS which is ~ 12 km (east-west) by ~11.5 km (north-south) when viewing Railroad Valley (figure 1) from an orbit passing just to the east. It is relatively bright in all three TANSO-FTS bands we were attempting to study. It is a very uniform site that minimizes, but as discussed below does not eliminate, the errors associated with extrapolation from the field site to the large TANSO-FITS footprint. Finally, this site has been used successfully by many other space instruments such as MISR, MODIS, Landsat-7 Enhanced Thematic Mapper Plus and ASTER [2,3,4].

3. SUMMER FIELD CAMPAIGN

The GOSAT team and the NASA-funded Atmospheric Carbon Observations from Space (ACOS) team conducted a joint vicarious calibration campaign. The team collected surface measurements for six areas of Railroad Valley during GOSAT over flights on six days between June 23rd and July 5th, 2009. Since two independent teams were collecting data on each day, some of these sites were measured multiple times. Seven sets of measurements were found to be of sufficient quality to process for calibration purposes.

The primary data from the ground measurements was a set of spectra collected with ASD Inc. FieldSpec units. For about two hours centered on the GOSAT over flight, teams would map out the reflectance of two 500 by 500 meter squares. The positions of the squares were selected to have the highest uniformity as measured by CAI and MODIS. To correct for the atmospheric absorption, spectralon panels were regularly observed during the measurement period.

Review of the data showed inconsistency in the results that are thought to be due to operator-to-operator differences. It is thought that a significant part of these irregularities may come from undesirable variation in the angle of the FieldSpec lens with the surface, which creates uncorrectable BRDF errors in the retrieved reflectance. Also of concern are instrument stability issues, as well as interpolation in time of the spectralon panel measurements.

In addition to the spectrometer measurements, radiosondes were released to provide temperature and humidity profiles for use in the simulation of top-of-atmosphere radiance.

4. PRELIMINARY ANALYSIS OF SUMMER FIELD CAMPAIGN

For the 500 by 500 meter areas, typical surface reflectances versus wavelength were derived using the FieldSpec measurements. Attempts were made to filter out data where the spectra varied unexpectedly during the experiment due to instability in the instrument pointing or drift in the FieldSpec itself.

The reflectances from the small area were then extended to the much larger TANSO-FTS footprint. The process introduces two uncertainties. The first is due to the spectral extrapolation required due to the fact that MODIS and CAI both have bandpasses centered in atmospheric windows while TANSO-FTS has its bandpasses centered on strong absorption lines. The second is due to the vast differences in spatial sampling; the areas

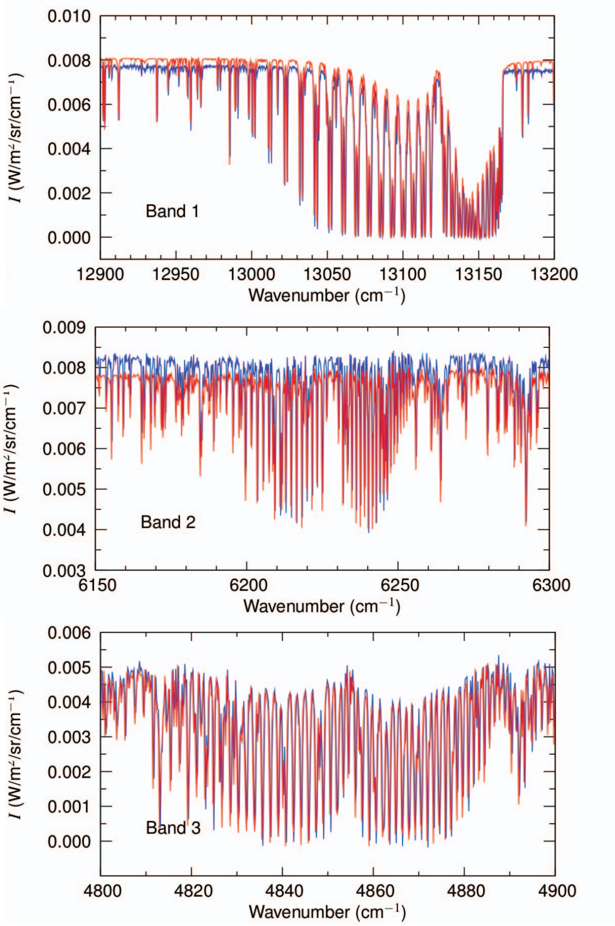

FIGURE 3: Example of modeled (red) vs measured (blue) radiances for Railroad Valley. These were collected on 2 July 2009 using a ground site centered at 38.501^o N, 115.681^o W. MODIS data from 4 July 2009 used to extend small area sampled on ground to TANSO-FTS footprint.

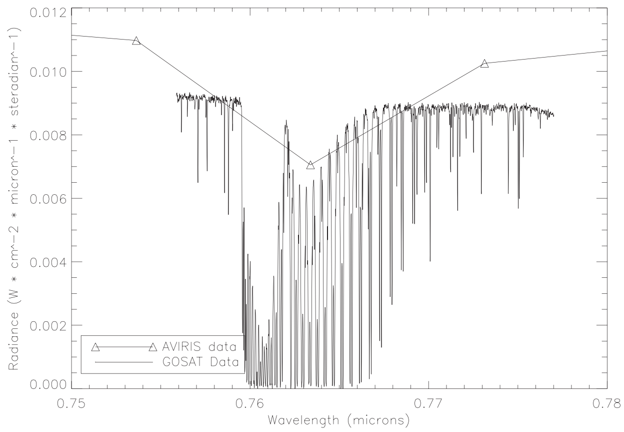

FIGURE 4: TANSO-FTS data overplotted with AVIRIS data averaged over TANSO-FTS footprint. The difference in spectral resolution and sampling is very apparent.

covered by the ground team were ~0.25 km^2 while the TANSO-FTS footprint is ~110 km^2 (figure 2). Using these estimated reflectances, a radiative transport model was used to estimate the top-of-atmosphere spectra at the resolution of TANSO-FTS (figure 3).

A rough estimate of the uncertainty for this calculation is ~7%. The largest terms are thought to be the FieldSpec measurements (~5%) and the extrapolation to the large TANSO-FTS footprint (~4%). Other terms include BRDF correction, aerosol uncertainty and polarization correction (all $\leq$ 1%).

The results using the ACOS system validate the TANSO-FTS calibration for bands 1 and 3 to within the uncertainty, while the simulated radiances for band 2 fall below the measured values. The GOSAT team, employing an independent radiative transport model and using CAI data rather than MODIS to perform the spatial extrapolation, made a similar comparison. These results show all three bands are within the uncertainty of the measurements. Work is continuing in order to understand the cause of the discrepancy between the ACOS and GOSAT team methods.

5. FALL CAMPAIGN

Due to questions about the importance of the radiative transport models and the issues associated with the spectral interpolation and spatial extrapolation, we decided to try a completely different approach. On October 9th, 2009 AVIRIS flew over Railroad Valley, NV at an altitude of 19,700 meters, coincident in time with the GOSAT overpass. Since AVIRIS was above most of the Earth's atmosphere and measured the whole playa at all of the wavelengths under study, it was hoped that this near top-of-atmosphere measurement would be much easier to compare to the space based measurements of the TANSO-FTS.

At the ~20 km altitude of our flight, the AVIRIS instrument collects ~11 km swathes at ~15 meter resolution from 400 to 2,500 nm with a spectral sampling of ~10 nm [5]. AVIRIS flew three paths parallel to the GOSAT ground track, offset by ~ 5 km east-west. These partially overlapped providing two measurements of most of the TANSO-FTS footprint from different angles, thus providing a constraint on the BRDF of the surface. As predicted from a model built from MODIS data, the differences were small for the relevant viewing geometries involved.

This provided ~650,000 independent spectra sampling the TANSO-FTS footprint, each with a SNR ratio of several hundred to over a thousand to one across the spectral range. This is far superior to the sampling available for a ground team walking on the playa.

6. PRELIMINARY ANALYSIS OF FALL CAMPAIGN

Soon after beginning to work with the data, it became clear that the advantages of the aircraft data were offset with some disadvantages. Where as the surface measurements yielded estimate of reflectance that could be used in a radiative transport simulation to predict top of atmosphere radiance, AVIRIS measured the spectra directly. The advantages of having much better spatial and spectral range are offset by sampling the atmospheric lines at a much lower spatial resolution (figure 4).

The preliminary analysis shows that Band 1 has a clear offset that implies that the TANSO-FTS response has dropped ~10% since the summer campaign. This can be seen in the offset of the continuum in Figure 4. Bands 2 and 3 show agreement to within a few percent. Long term tracking of stable ground targets and the on-board calibration system has detected a degradation of the response of Band 1, but of much smaller magnitude. Work will continue to try to explain this discrepancy.

With the better spatial sampling, it was possible to use the AVIRIS data to also attempt a vicarious calibration of CAI. Band 1 in the near-UV showed a significant difference (possibly due to the different viewing geometries between TANSO-FTS and AVIRIS) while the other bands provided reasonably good fits.

7. NEXT STEPS

Work continues to determine the cause of the discrepancies between the ACOS and GOSAT team methods. Current areas of interest are BRDF corrections and differences in the absorption coefficients used in the radiative transport models.

We are also starting to plan the 2010 vicarious calibration campaign. In this case, we will attempt to collect four days of surface measurements - at least one day of which will also have an AVIRIS over flight. To improve the stability of the FieldSpec pointing, we are beginning the design a fixture that will hold the collecting optics at a more repeatable attitude. The field campaign is tentatively scheduled for late June 2010; preliminary results may be ready for presentation during the conference.

8. ACKNOWLEDGEMENTS

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