Calibration Plan for GOSAT Sensors

Kei Shiomi and Shuji Kawakami
Japan Aerospace Exploration Agency

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- FTS calibration
  - Calibration items
  - In-orbit operation
  - Onboard calibration
  - L1 processing
  - Vicarious calibration
- CAI calibration (briefly)
- Summary
TANSO-FTS
Calibration overview of TANSO-FTS

- **Pre-flight Test (PFT)**
  - Radiometric characterization
  - Spectral characterization
  - Alignment

- **Onboard Calibration (OBC)**
  - Dark target
    - Deep space (FTS-SWIR/TIR)
  - Bright target
    - Solar irradiance (FTS-SWIR)
    - Blackbody (FTS-TIR)
  - Spectral calibration for ILS
    - 1.55μm laser (FTS-B2)
  - Lunar observation

- **Vicarious Calibration (VC)**
  - Radiometry
    - Cross calibration – using DB and other satellite data
    - Cal/Val experiment – using in-situ experimental data
    - FTS-CAI relative radiance of 1.6μm band
  - Geometry
    - Pointing accuracy
      - Coastlines
    - Pointing stability
    - Band-to-band registration
    - FTS-CAI registration
      - IFOV monitoring camera
  - Spectral Quality
    - Spectral accuracy
      - Absorption lines
    - SNR
      - Desert
Operation of FTS

Solar Irradiance Cal.
Lunar Cal
FTS SWIR
Solar Flux
FTS TIR

Nominal observation (dayside land, nightside)
Sunglint observation (dayside ocean)
Specific observation (calibration, validation, pipeline)
Pre-flight test characterization
Cross calibration with OCO and GOSAT

- X-calibration with OCO/GOSAT standard radiometers

- 1st step @ JPL (Apr, 2008) Difference < 3%
- 2nd step @ JAXA (Aug, 2008)
Pre-flight test characterization

- **Instrument function**
  - Integrated sphere (Ar lamp)
  - Tunable diode laser

- **Sensitivity (also SNR)**
  - Fixed-point blackbody and integrating sphere
  - Blackbody cavity

- **IFOV**
  - Collimator

### Instrument function

<table>
<thead>
<tr>
<th>Band</th>
<th>Spec</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1P</td>
<td>&lt;0.6 cm⁻¹</td>
<td>0.367</td>
</tr>
<tr>
<td>1S</td>
<td></td>
<td>0.356</td>
</tr>
<tr>
<td>2P</td>
<td>&lt;0.27 cm⁻¹</td>
<td>0.258</td>
</tr>
<tr>
<td>2S</td>
<td></td>
<td>0.257</td>
</tr>
<tr>
<td>3P</td>
<td></td>
<td>0.262</td>
</tr>
<tr>
<td>3S</td>
<td></td>
<td>0.263</td>
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</table>

### SNR

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavenumber [cm⁻¹]</th>
<th>Radiance [W/cm²/sr/cm⁻¹]</th>
<th>Specification</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1P</td>
<td>520 - 1115</td>
<td>6.3e⁻²</td>
<td>345</td>
<td>310</td>
</tr>
<tr>
<td>1S</td>
<td></td>
<td></td>
<td>246</td>
<td></td>
</tr>
<tr>
<td>2P</td>
<td>620 - 3100</td>
<td>5.2e⁻²</td>
<td>322</td>
<td></td>
</tr>
<tr>
<td>2S</td>
<td></td>
<td></td>
<td>257</td>
<td></td>
</tr>
<tr>
<td>3P</td>
<td>5000 - 280K</td>
<td>3.8e⁻²</td>
<td>412</td>
<td></td>
</tr>
<tr>
<td>3S</td>
<td></td>
<td></td>
<td>287</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>700 - 310</td>
<td>280K</td>
<td>283</td>
<td></td>
</tr>
</tbody>
</table>
Pre-flight test characterization
Data sheets

Although the following data are not used for L1 processing, they are separately provided for users.

<table>
<thead>
<tr>
<th>FTS</th>
<th>Data</th>
<th>Pre-launch</th>
<th>L+3M</th>
<th>L+6M</th>
<th>L+12M</th>
</tr>
</thead>
<tbody>
<tr>
<td>IFOV (Response distribution within a pixel if exists)</td>
<td>PFT result</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrument Line Shape Function</td>
<td>PFT result</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity calibration coefficients</td>
<td>PFT result</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Solar Irradiance Cal.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lunar Cal.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vicarious cal.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A model for polarization</td>
<td>PFT result</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Although the following data are not used for L1 processing, they are separately provided for users.*
Deep space and blackbody data will be obtained 4 times nominally, 16 times at maximum in an orbit.

Lunar calibration will be operated at full moon once a year.

1.55 μm ILS laser for B2 will be operated once a month.
FTS Level 1
Radiometric calibration

SWIR band
\[ I_{\text{scene}}, I_{\text{Solar \_irrad \_cal}} \]

TIR band
\[ I_{\text{scene}}, I_{\text{deep \_space \_cal}}, I_{\text{blackbody \_cal}} \]

※sensitivity correction (gain, non-linear, phase correction)

\[ S(\sigma) = \int_{-\text{MPD}}^{\text{MPD}} I(x) e^{-2\pi i x \sigma} \, dx \]

※sensitivity correction (reflectance, polarization, BRDF correction)

L1A Interferogram

Uncorrected spectrum

Corrected spectrum

L1B Spectral Radiance

SWIR band
\[ S_{\text{scene}}, S_{\text{Solar \_irradi \_cal}} \]

TIR band
\[ S_{\text{scene}}, S_{\text{deep \_space \_cal}}, S_{\text{blackbody \_cal}} \]

2-point calibration

SWIR band
\[ S_{\text{scene}}, S_{\text{Solar \_irradi \_cal}} \]

TIR band radiance
\[ L_{\text{scene}}(\sigma) = \frac{S_{\text{scene}} - S_{\text{deep \_space \_cal}}}{S_{\text{blackbody \_cal}} - S_{\text{deep \_space \_cal}}} - \varepsilon_{\text{blackbody}} \frac{B(T_{\text{blackbody}})}{S_{\text{blackbody \_cal}} - S_{\text{deep \_space \_cal}}} \]
Vicarious calibration

- Comparison with other spectrometers
  - OCO-TANSO
    - OCO spectrum is an exact reference for TANSO.

- Comparison with other imagers
  - Aqua/MODIS-TANSO
    - Comparison between Aqua/MODIS and TANSO in 1.6μm band is possible with total radiance level.

- Comparison by using physical parameters
  - Reflectance DB at stable or well-known site (SWIR band)
    - Without appropriate active sensors for TANSO reference, the simulated radiance for reference is produced if we have reflectance DB from the analysis of past data.
  - Sea surface temperature DB (TIR band)
    - Estimated SST by split window is compared with Reynolds OI-SST or AMSR-E microwave radiometry SST.
Preparation of Post-launch Cal/Val

- The radiometric and geometric accuracies will be estimated at nadir view at first.
  - Scene selection for
    - Radiance comparison with other similar sensor and DB simulation
    - Geolocation
    - Cal/Val locations
**Geometric study of FTS**

**Estimation of GCPs / scenes**

<table>
<thead>
<tr>
<th>Month</th>
<th>Num of CAM scene (nadir)</th>
<th>Num of CAM scene inc. 3 GCPs</th>
<th>③ (② \times \text{ISCCP clear sky rate} ) Estimated CAM scenes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar</td>
<td>5192</td>
<td>125</td>
<td>40</td>
</tr>
<tr>
<td>Jun</td>
<td>5104</td>
<td>196</td>
<td>64</td>
</tr>
<tr>
<td>Sep</td>
<td>5148</td>
<td>198</td>
<td>69</td>
</tr>
<tr>
<td>Dec</td>
<td>5182</td>
<td>86</td>
<td>28</td>
</tr>
</tbody>
</table>

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**GOSAT**

**JAXA**
Comparison with OCO and GOSAT

- Nadir match-up of OCO and GOSAT
  - OCO: continuous swath observation at 13:26LT
  - GOSAT: separate pointing observation at 13:00LT

Match-up points in a day (Distance < 10km, Time < 30 min)
TANSO-CAI
Operation of CAI

<table>
<thead>
<tr>
<th>CAI onboard calibration</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset</td>
<td></td>
<td></td>
<td>Nightside observation</td>
<td></td>
</tr>
<tr>
<td>Radiance</td>
<td></td>
<td></td>
<td>Lunar observation (1 / year)</td>
<td></td>
</tr>
</tbody>
</table>
Geomeric study of CAI

- It is difficult to identify the land/ocean features from UV channel.
- The GLI 380nm image data is available and preliminary checked.
- The identified points is white sand shore and snowfield shore.
- GCPs of 380nm channel is estimated less than the other visible and SWIR channels.
TANSO calibration is conducted by PFT, OBC, and VC.

Sensor performance is characterized in PFT and sensor parameters are provided for development of L1 processing system.

Calibration factors are optimized using OBC data in operation of L1 processing.

- Responsive gain and offset (Radiometric calibration)
- Laser wavelength (Spectral calibration)

The vicarious procedures are prepared for radiometric, geometric, spectrometric calibration.

Accuracy of L1 spectra will be evaluated by comparison with other satellite observed radiance or physical parameters.
backup
## Pre-flight Test Items

<table>
<thead>
<tr>
<th>Item</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal to Noise Ratio</td>
<td>Halogen lamp Integrating Sphere (SWIR)</td>
</tr>
<tr>
<td></td>
<td>Large Aperture Cavity Blackbody in TVT (TIR)</td>
</tr>
<tr>
<td>Instrument Line Shape Function</td>
<td>Ar lamp Integrating Sphere and Tunable diode laser</td>
</tr>
<tr>
<td>(shape and wavelength)</td>
<td></td>
</tr>
<tr>
<td>Radiometric Response</td>
<td>Fix Point Blackbody and Integrating Sphere</td>
</tr>
<tr>
<td>(Non liner correction if exists)</td>
<td>Large Aperture Cavity Blackbody (TIR)</td>
</tr>
<tr>
<td>IFOV (Response distribution within a pixel if exists)</td>
<td>Collimator with Alignment test</td>
</tr>
<tr>
<td>Diffuser BRDF</td>
<td>Spherical Distributed Detectors</td>
</tr>
<tr>
<td>Onboard Laser temperature dependency</td>
<td>Wavelength meter</td>
</tr>
<tr>
<td>Response Stability</td>
<td>Halogen lamp Integrating Sphere and light source monitoring radiometers</td>
</tr>
<tr>
<td>Stray Light</td>
<td>Halogen lamp Integrating Sphere and CO2 cell</td>
</tr>
<tr>
<td>Micro-vibration</td>
<td>Ar lamp Integrating Sphere and Shaker</td>
</tr>
</tbody>
</table>
FTS L1 processing flow of SWIR

Interferogram (FTS L1A) → Quality check (spike detection) → Low-freq correction → Corrected Interferogram → FFT → Phase correction → Corrected Spectrum → Spectral calibration → Final Spectral Radiance (L1B) → Conversion (output to radiance)

In PFT: Standard light source is calibrated by fixed-point blackbody.
In orbit: Onboard calibration and Vicarious calibration
Cross Track

FTS IFOV=10.5 km
CAI IFOV=0.5, 1.5 km

TANSO-CAI Swath
900 km

88 – 260 km

Satellite Direction
(Along Track)

Cross Track

<table>
<thead>
<tr>
<th>Cross-track pattern</th>
<th>Distance bet. points (at 30deg in latitude)</th>
<th>Exposure (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>790 km</td>
<td>4x3</td>
</tr>
<tr>
<td>3</td>
<td>260 km</td>
<td>4x3</td>
</tr>
<tr>
<td>5</td>
<td>160 km</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>110 km</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>88 km</td>
<td>1</td>
</tr>
</tbody>
</table>
**TIR interferogram**

Scene flux

- **Bandpass filters of B1-3**
- **(-) IGM**
- **(+ IGM**
- **B4 detector**

**Beam splitter**

- **Dichroic filters of B1-3**
- **Modulator**

**Modulated light**

- **Unmodulated light**

**Target** | **Relations bet. input and inner radiations** | **IGM**
---|---|---
Deep space | Input(3K) < Inner(265K) | +
Blackbody | Input(290K) > Inner(265K) | -
Observation | Input(270-320K) >=< Inner(265K) | + -

**Interferogram** (scan 1)

**Spectrum** (scan 1)

**Phase** (scan 1)
TIR calibration

- Input radiance is injected by a vacuum blackbody source of 300 K.
- The calibration is operated by 2-point complex calibration using onboard blackbody and cooled shroud for deep space.

\[ L_{\text{Obs}}(\sigma) = \frac{S_{\text{Obs}} - S_{\text{D Scal}}}{S_{\text{BB cal}} - S_{\text{D Scal}}} \varepsilon_{BB} B(T_{BB}) \]

- The phase is approximately zero after calibration.
- The calibrated equivalent brightness temperature is estimated around 300K of input radiance.
The ILS of B2P was estimated by using the onboard 1.55μm laser after reflection of the solar diffuser.

Measured ILS (FWHM=0.255cm⁻¹) satisfies the specification requirement.
The sampling laser wavelength was estimated to an accuracy of 1E-4 %.
As a result, the spectral axis was evaluated to an accuracy of 0.004 cm⁻¹.
Simple procedure for spectral calibration will be implemented after selection of effective absorption lines.