Quality Assessment of the Radiometric and Spectral Calibration of the FY4A Geostationary Interferometric Infrared Sounder (GIIRS) using NOAA-20 CrIS and METOP-B IASI as On-Orbit Reference Sensors

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SUMMARY

With the support of a NOAA Hurricane Supplemental grant to JCSDA and the UW-Madison SSEC, a collaborative assessment has been performed of the first imaging Fourier Transform Spectrometer (FTS) in geostationary orbit on the CMA FY4A satellite. The following key findings are listed below;

(1) Spectral Calibration
(a) CMA spectral calibration of a 32x4 focal plane array (FPA) for the GIIRS LW band fails to remove diurnal and seasonal variations of about 20 ppm.
(b) A UW SSEC theoretical model for a generic imaging FTS has been used to map spectral calibration residuals into realistic physical motion of the sensor optical axis relative to the FPA.
(c) An efficient spectral resampling correction method has been developed as a potential pre-processing step in NWP data assimilation.

(2) Radiometric Calibration
(a) CMA real-time ground calibration was found to introduce unnecessary radiometric biases in spectral ranges with low optical transmission due to outgassing contamination.
(b) FY4A GIIRS thermal instability causes a periodic radiometric error with a period of about 4 minutes which is not correctable using the calibration views at 15-minute intervals.

DATA

The FY4A GIIRS data is obtained in near-real time at the UW-Madison SSEC Data Center via EUMETCAST Terrestrial Data transmission. Ancillary data from FY4A are obtained directly from the CMA ftp site.

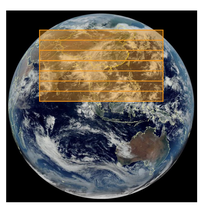
FY4A Geostationary Satellite Station Location ~ 105 E

Background True Color Image is from the FY4A Advanced Geostationary Radiation Imager (AGRI) multi-channel imager.

Shaded area indicates the Geostationary Interferometric Infrared Sounder (GIIRS) Sounding Region.

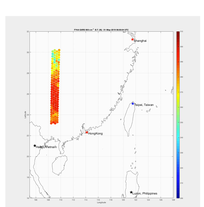
2 Hour Repeat Time.

Each E/W Swath ~ 15 minutes.



FY4A GIIRS Focal Plane is 32x4 with four columns and 32 rows of detectors all observing the same scene simultaneously. FY4A GIIRS has two focal planes to cover the Longwave (LW) 15 micron CO2 band and 8-12 micron longwave window and a mid-wave/short-wave H2O band for temperature and water vapor sounding.

The FPA dwell is approximately 11 seconds with the step and stare motion from west to east. The individual footprint diameter is about 15 km at nadir and the field of regard of the FPA is about 70 km by 500 km.



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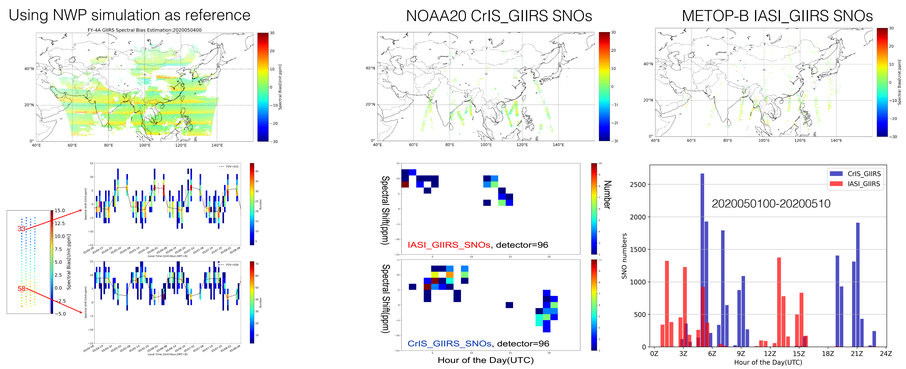
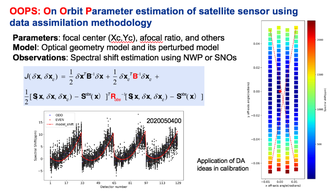
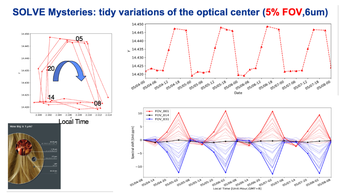
FY4A GIIRS SPECTRAL MONITORING

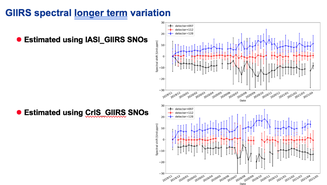


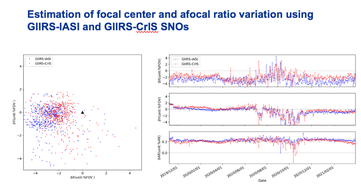
- Spectral monitoring using NWP OmB indicates a diurnal variation in spectral calibration.
- The FY4A spectral calibration variation is confirmed using SNOs with NOAA20 CrIS and METOP-B IASI which sample the China region four times a day.
- An efficient method of spectral monitoring and spectral correction has been developed that is suitable for near real-time pre-processing of the GIIRS observed radiances.





- The geometry of a 2-D focal plane array of detectors (32 rows x 4 columns) perpendicular to a FTS optical axis is defined by the angles from the axis to each detector.
- Small perturbations of these angles can be accurately represented as a simple equation.
- The above left figure shows the formula for small angular deviations fit to OmB PPM shifts. The above right figure shows how the diurnal spectral shifts are explained by the motion of the LW FPA in a circular pattern relative to the FTS optical axis (~6 μm or ~5% of a FOV).





- Relative to the start of the CMA GIIRS V3 data in November 2019, the long-term trend in the GIIRS spectral calibration has been monitored using SNOs with CrIS and IASI.
- Using the formula for small angular variations, a Least Squares fit to the change in focal plane center (dX, dY) and afocal ratio (dAR) was derived from the PPM shifts.
- The detectors near the center of the focal plane are relatively unaffected while the detectors near the extremes of the FPA are most sensitive to small relative motions of the FPA.

FY4A GIIRS RADIOMETRIC ASSESSMENT

Line-by-Line (LBLRTM v12) calculations for "clear" scenes using ERA5 were performed by Michelle Loveless to evaluate two time periods separated by two years: 2 March 2017 and 10 May 2019.

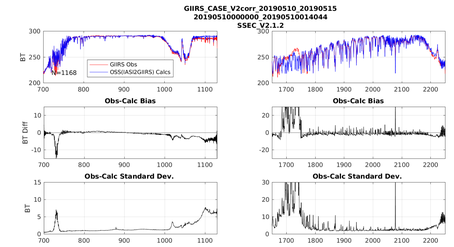
1] March 2nd, 2017. Processed at SSEC from uncalibrated L0 GIIRS data using the Revercomb et al. (1988) calibration equation. No systematic biases are found in noisy spectral regions. However, short-term instability was found in the radiometric calibration.

2] May 10th, 2019. Processed by CMA using the operational calibration algorithm which DOES NOT use Revercomb et al (1988) therefore does not properly remove the anomalous phase in regions of low instrument response. This study strongly recommends that CMA adopt the Revercomb et al. 1988 calibration equation used for operational calibration of IASI and CrIS FTS data to avoid these serious radiometric errors.

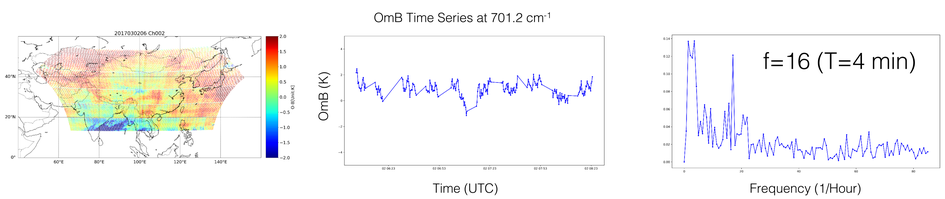
CMA Observation minus LBL Calculation →

Improper calibration equation causes bias. →

Contamination causes increased noise. →



A time series of GIIRS minus RTTOV calculations (OmB) was analyzed to assess short term radiometric stability using NWP radiance calculations as a reference. A Fourier analysis indicates a time dependent error with period of about four minutes. This period is not removed by the 15-minute interval calibration views of internal blackbody and deep space. Unfortunately, the size of the radiometric errors and the periodicity represents a serious degradation of FY4A GIIRS radiometric stability and consequently a degradation in the reproducibility of radiance spectra over the China region.



CONCLUSIONS

1. NOAA FUNDED AN ASSESSMENT OF THE FIRST GEOSTATIONARY HYPERSPECTRAL INFRARED SOUNDER BY SSEC AND THE JCSDA.
2. THE GIIRS ON CMA FY4A SATELLITE (105E) IS INTENDED AS A TECHNOLOGY DEMONSTRATION.
3. SATELLITE INTER-CALIBRATION USING SIMULTANEOUS NADIR OVERPASSES WAS PERFORMED WITH NOAA20 CRIS AND METOP IASI.
4. NWP ASSESSMENT OF OMB USING JEDI/CRTM WAS USED TO CHARACTERIZE DIURNAL CALIBRATION ERRORS.
5. SATELLITE INTER-CALIBRATION AND NWP ANALYSIS LEAD SIMILAR FINDINGS;
   a) SPECTRAL CALIBRATION SHOWS A DIURNAL VARIATION WHICH IS NOT CURRENTLY REMOVED IN CMA GROUND PROCESSING.
   b) RADIOMETRIC CALIBRATION SHOWS BOTH LONG TERM BIASES AND SHORT-TERM VARIATIONS NOT HANDLED IN CMA PROCESSING.
6. ERRORS OF THE MAGNITUDE SEEN IN FY4A GIIRS ARE NOT EXPECTED FOR MTG IRS OR FOR FUTURE U.S. GEO IR SOUNDERS.
7. THE RECENT LAUNCH OF FY4B WITH A NEW GIIRS SENSOR WILL PROVIDE AN OPPORTUNITY FOR FURTHER ASSESSMENT.
8. WE ENCOURAGE CMA TO WORK WITH INTERNATIONAL PARTNERS ON MAKING THE IMPROVEMENTS REQUIRED FOR NWP DA.

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