Assessment of S-NPP CrIS Spectral Calibration Accuracy and Stability

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Abstract

The Cross-track Infrared Sounder (CrIS) on Suomi National Polar-orbiting Partnership Satellite (S-NPP) is a Fourier transform spectrometer and provides a total of 1305 channels for sounding the atmosphere. Quantifying the CrIS spectral accuracy, which is directly related to radiometric accuracy, is crucial for improving its data assimilation in the numerical weather prediction.

Two basic spectral calibration methods are used to assess the CrIS Sensor Data Records (SDR) spectral accuracy and stability: 1). Relative spectral calibration, which uses two uniform observations to determine frequency offsets relative to each other; 2). Absolute spectral calibration, which requires an accurate forward model to simulate the top of atmosphere radiance under clear conditions and correlates the simulation with the observed radiance to find the maximum correlation. In this study, we use Community Radiative Transfer Model (CRTM) and European Centre for Medium-Range Weather Forecasts (ECMWF) forecast fields to simulate the CrIS radiance over tropical clear scenes over ocean.

CrIS spectral stability is so high that we could detect the Earth-rotation Doppler shift (ERDS) from CrIS observations using the relative spectral calibration method for CrIS band 1.

Spectral calibration results show that CrIS has small and consistent FOV to FOV spectral shift in all three bands. The spectral shift is very stable during the satellite mission and better than the instrument requirement. Long-term CrIS SDR spectral stability is very high.

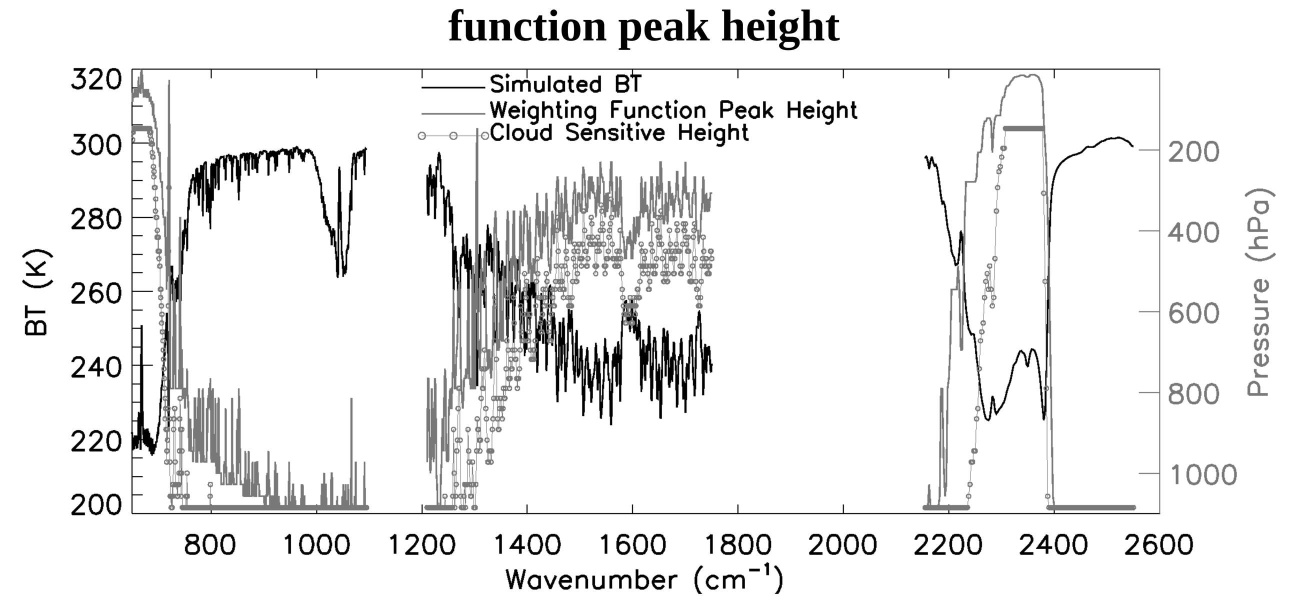
IR Cloud Detection Algorithm

- The channels are first ordered according to their cloud sensitivity (with the highest channels first and the channels closest to the surface last) (McNally and Watts, 2003)
- The overcast variable contains overcast radiances assuming the presence of a black cloud at each of atmospheric layers. The height for a particular channel is assigned by finding the layer where the difference between the overcast and clear radiances is less than 1%.

$$\frac{\left|R_{clear} - R_{cloudy}\right|}{R_{clear}} < 0.01$$

- The resulting ranked brightness temperature departures are smoothed with a moving-average filter in order to reduce the effect of instrument noise.

CrIS channel cloud sensitivity height and weighting function peak height



CrIS Spectral Calibration Method

The correlation coefficient between the two spectra can be written:

$$r_{S_1S_2} = \frac{\sum_{i=1}^{n}(S_{1,i}-\overline{S}_1)(S_{2,i}-\overline{S}_2)}{(n-1)D_{S_1}D_{S_2}} = \frac{\sum_{i=1}^{n}(S_{1,i}-\overline{S}_1)(S_{2,i}-\overline{S}_2)}{\sqrt{\sum_{i=1}^{n}(S_{1,i}-\overline{S}_1)^2(S_{2,i}-\overline{S}_2)^2}},$$

Standard deviation based on the difference of the two spectra:

$$D_{S_1S_2} = \sqrt{\sum_{i=1}^{n}[(S_{1,i}-\overline{S}_1)-(S_{2,i}-\overline{S}_2)]^2 \Big/ (n-1)}.$$

The cross-correlation method is applied to a pair fine grid spectra to get the maximum correlation and minimum standard deviation by shifting one of the spectra in a given shift factor.

Detection of ERDS from CrIS SDRs

Spectral Shift Caused by Earth-rotation Doppler Effect

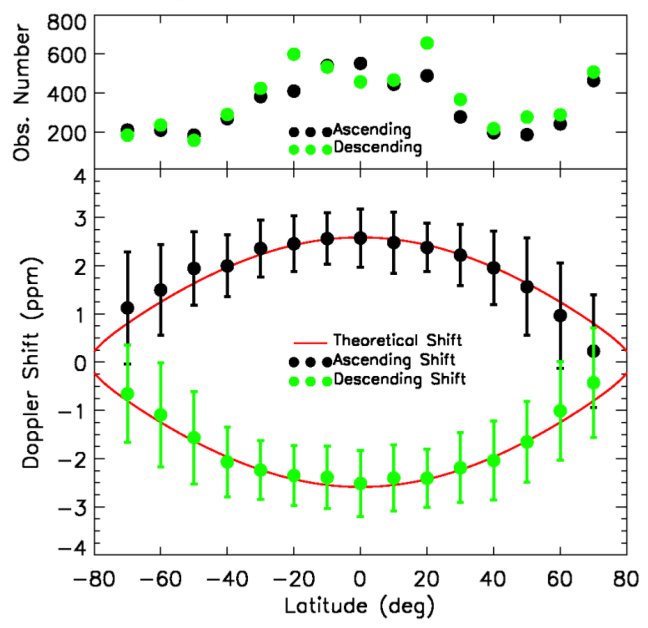
$$\Delta\nu = \pm\frac{\nu}{c}\Omega R\sin(\theta_{zenith})\cos(\lambda)\left|\sin(\phi_{azimuth})\right|,$$

ν : channel frequency; Ω: Earth angular velocity

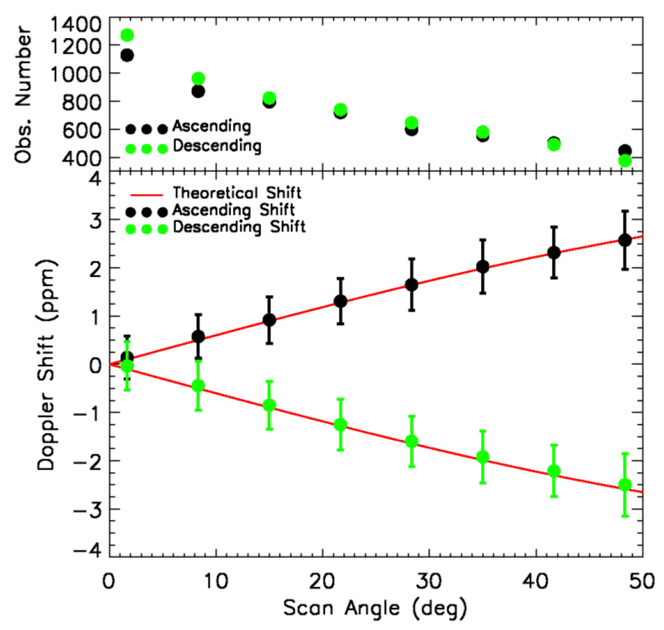
R: Earth's radius; λ: Latitude

$\Phi_{azimuth}$: Satellite azimuth angle; θ_{zenith}: Satellite zenith angle.

FOR1 frequency shift relative to FOR30



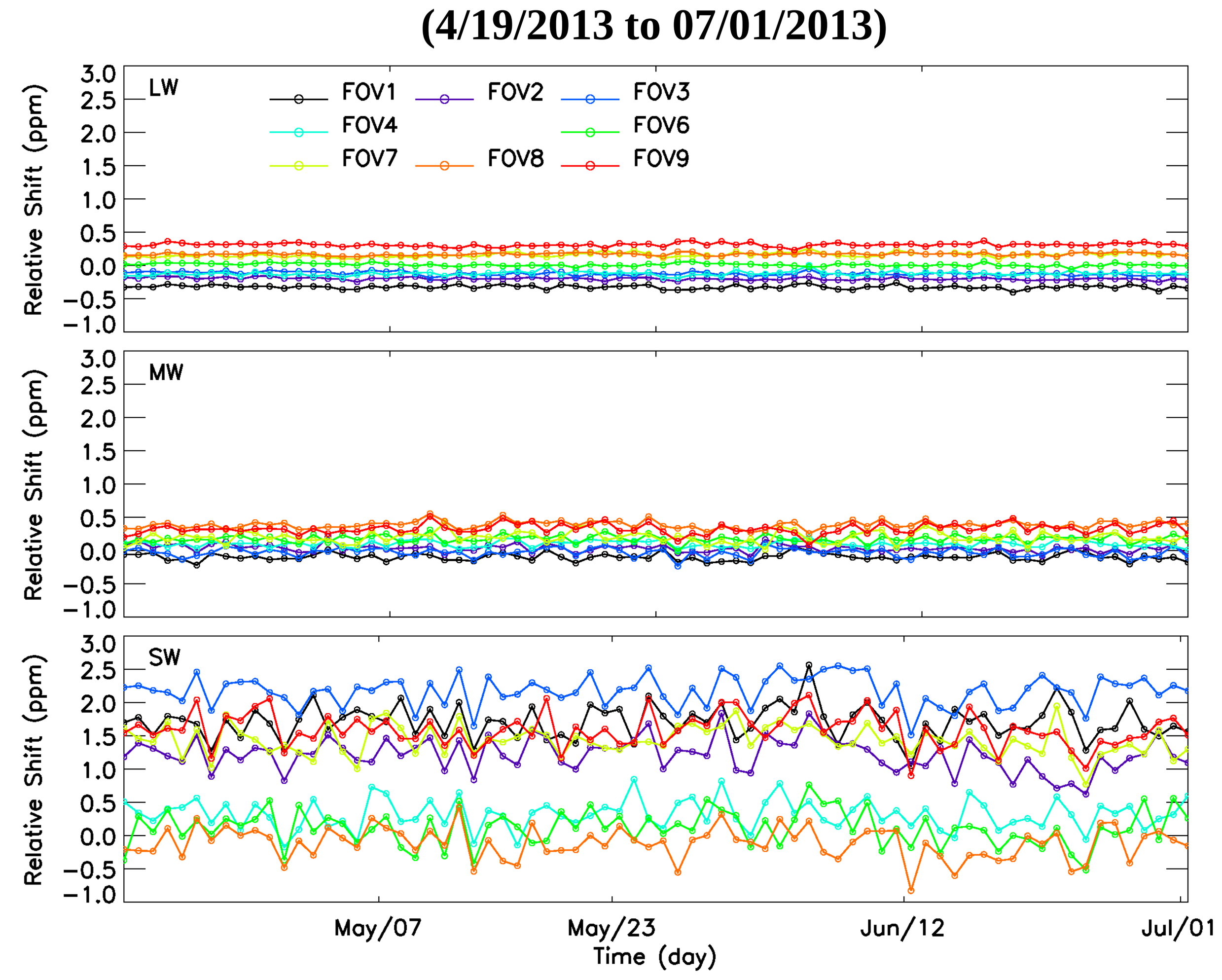
Doppler shift at near Equator



(Chen, et al. 2013)

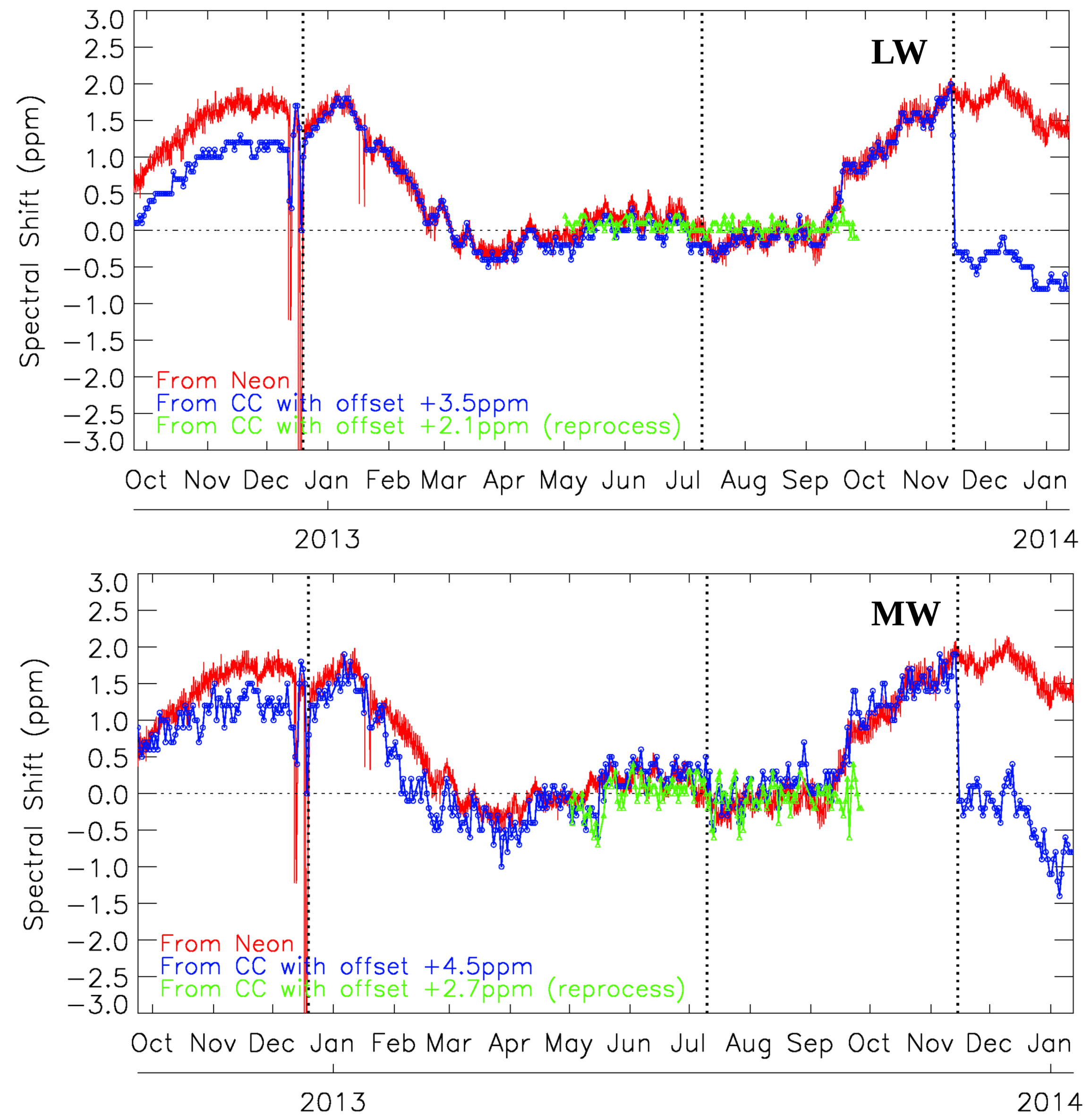
FOV to FOV5 Relative Spectral Shift

Time series of spectral shifts with respective to FOV5 (4/19/2013 to 07/01/2013)

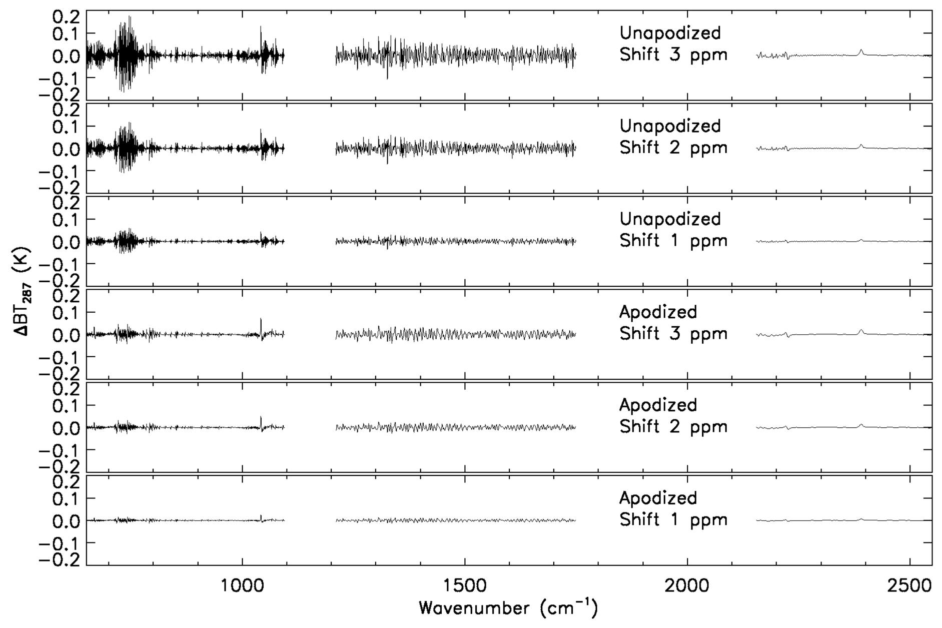


Absolute Spectral Shift

Time series of CrIS spectral shift between observations and simulations



- Time series spectral shift for IDPS SDRs from 09/22/2012 to 01/12/2014, and ADL reprocess SDRs with updated non-linearity coefficients and ILS parameters from 05/01/2013 to 09/26/2013 (with CMO update daily).
- Bands 1 and 2 FOV 5 spectral shift is determined by using cross-correlation (CC) method between CRTM simulations and observations.
- The Neon ZERO shift time is determined by the Correction Matrix Operator (CMO) update on Dec 19, 2012. The vertical lines indicate three CMO update times in IDPS: 12/19/2012, 07/10/2013, 11/14/2013
- Offsets of +3.5 ppm (2.1 ppm) for band1 and +4.5 ppm (2.7 ppm) for band2 from the CC results are used to match the Neon result in IDPS (ADL reprocess).



Effect of spectral shift on CrIS brightness temperature for a typical warm scene with respect to an effective BT of 287 K for three different spectral shifts (1 ppm, 2 ppm, and 3 ppm) at CrIS three bands for both unapodized and apodized spectra.

Conclusion

This study assesses the CrIS spectral calibration accuracy and stability using relative and absolute correlation methods. Earth-rotation Doppler shift can be detected by using CrIS observations which indicates CrIS spectral is very stable. FOV to FOV relative spectral shift is consistent within 1 ppm for bands 1 and 2. Absolute spectral shift has 3.5 ppm (2.1 ppm) offset wrt CRTM for LWIR, and 4.5 ppm (2.7 ppm) offset for MWIR for IDPS (ADL reprocess). The spectral uncertainty at both bands meet requirement (10 ppm). Long-term CrIS SDR spectral stability is very high during the satellite mission.