Detection of Earth-rotation Doppler Shift from S-NPP Cross-track Infrared Sounder

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Abstract

The Cross-track Infrared Sounder (CrIS) on Suomi National Polar-orbiting Partnership Satellite (S-NPP), is Fourier transform spectrometer, and provides soundings of the atmosphere with 1305 channels. CrIS is a nadir viewing crosstrack interferometer infrared (IR) sounder, the in-track sensor scan angle is adjustable during a cross track scan sequence. The in-track spacecraft motion is compensated by a scan mirror that moves backward. However, the Earth's rotation can result in Doppler shift in the received radiation spectrum at the cross-track scan direction.

In this study, a cross-correlation method is applied to detect the Earth-rotation Doppler shift (ERDS) for CrIS observations. The observations from CrIS exhibit a relative Doppler shift up to 2.5 part per-million (ppm) due to the Earth's rotation near the Equator and at the satellite scan edge for field of regard (FOR) 1 and 30. The magnitude of the Doppler shift varies with the latitude and the scan position of the observation. The Doppler shift detected from CrIS observations is very close to theoretical Doppler shift, which indicates that the spectral stability from CrIS instrument is very high.

Doppler Shift due to Earth's Rotation

The Earth-rotation Doppler shift (ERDS) $\Delta\nu$ is given by [Swadley et al., 2008; Han et al., 2010; Chen et al., 2013]:

$$\Delta\nu = \pm\frac{\nu}{c}\Omega R\sin(\theta_{zenith})\cos(\lambda)\left|\sin(\phi_{azimuth})\right|, \quad (1)$$

where

ν: the frequency of the channel,

c: the speed of light,

Ω: the angular velocity of the Earth's rotation,

R: Earth's radius,

λ: the latitude (positive in Northern Hemisphere, negative in Southern Hemisphere and zero at Equator) of the satellite observation point at the Earth's surface,

θ_{zenith} : the sensor's zenith angle at the surface along the satellite cross-trace direction, positive on the left side when looking along the satellite motion direction (therefore, CrIS FORs 1-15 have positive scan angle, and 16-30 negative scan angle),

$\phi_{azimuth}$: the sensor's azimuthal angle.

The plus and minus signs in Equation (1) correspond to the ascending and descending orbits, respectively.

Cross-Correlation Method

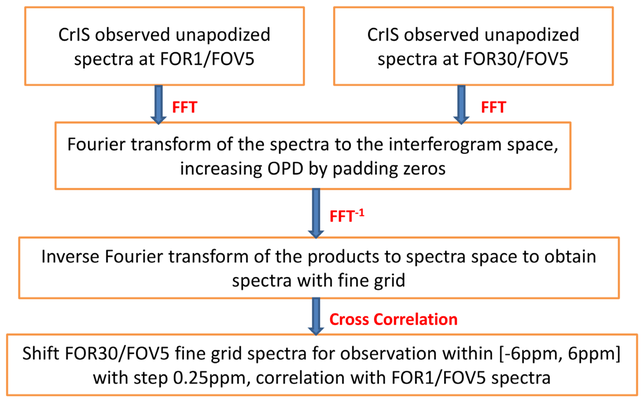

Fig. 1. Scheme to detect the Doppler shift from CrIS observations using cross-correlation method.

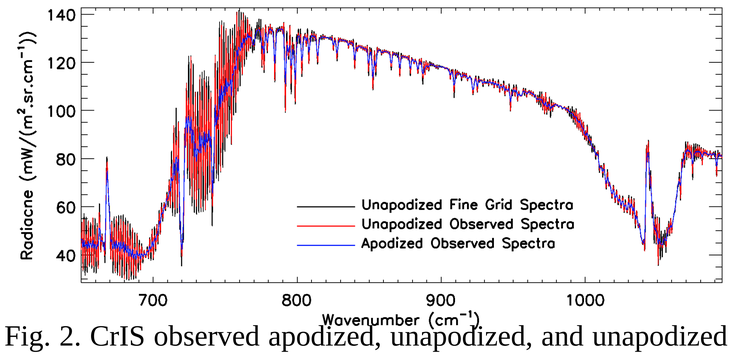

Fig. 2. CrIS observed apodized, unapodized, and unapodized fine grid spectra for long wavelength Infrared channels (band 1).

Spectral Shift as a Function of Latitude

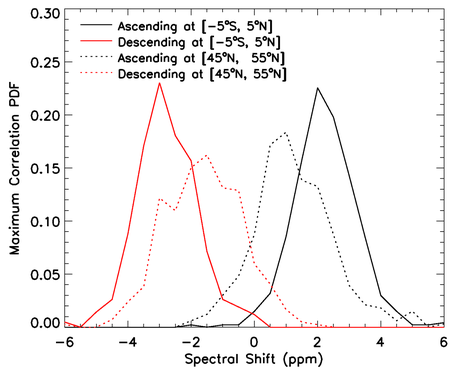

Fig. 3. Maximum correlation Probability Distribution Function (PDF) as a function of spectral shift detected from CrIS observations.

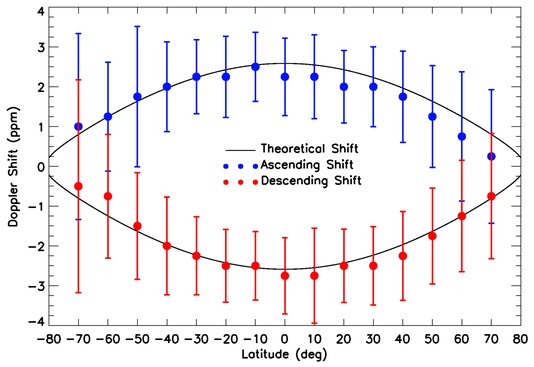

Fig. 4. Doppler shift detected from CrIS observations and simulated from theory using Equation (1).

Spectral Shift as a Function of Scan Angle

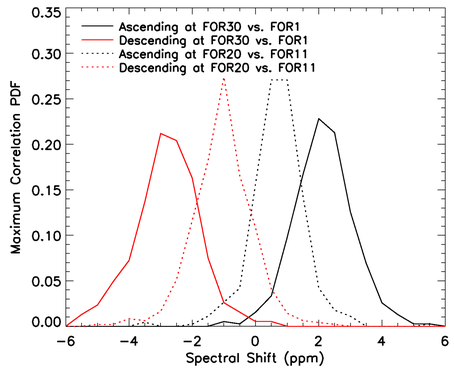

Fig. 5. Maximum correlation Probability Distribution Function (PDF) as a function of spectral shift detected from CrIS observations for FOV 5 at different FOR pairs near Equator (from 5°S to 5°N)

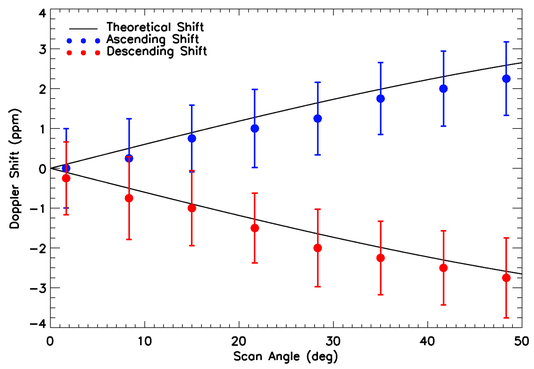

Fig. 6. Doppler shift detected from CrIS observations for FOV 5 at different FOR pairs near Equator (from 5°S to 5°N). The FOR pairs are: [1, 30], [3, 28], [5, 26], [7, 24], [9, 22], [11, 20], [13, 18], and [15, 16].

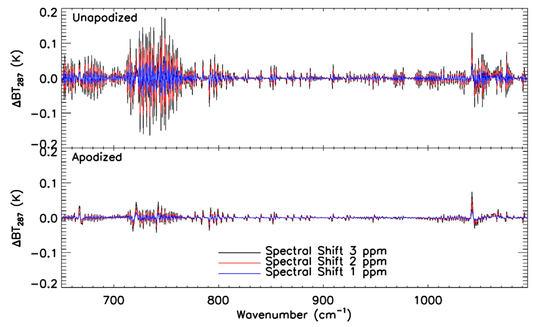

Fig. 7. Effect of Doppler shift on CrIS brightness temperature.

Conclusion

The observations from CrIS exhibit a relative Doppler shift up to 2.5 ppm due to the Earth's rotation near the Equator and at the satellite scan edge for FORs 1 and 30. The magnitude of the Doppler shift varies with the latitude and the scan position of the observation, and has different sign for ascending (positive) and descending (negative). All of these findings are very close to and consist with theoretical Doppler shift, which indicates that CrIS instrument has very high spectral stability. For apodized spectra, the impact of the spectral shift from ERDS on brightness temperature can be negligible. However, for unapodized spectra, the impact on brightness temperature must be taken into account in order to accurately use CrIS data.