

Update on S-NPP CrIS Full Spectral Resolution SDR Processing at NOAA/STAR

Xiaozhen Xiong^{1,2}, Yong Han², Yong Chen^{2,3},
Likun Wang^{2,3}, Denis Tremblay^{2,4}, Xin Jin^{1,2}, Lihang Zhou²

¹Earth Resources Technology, Inc, Laurel, MD 20707, USA

²NOAA Center for Satellite Applications and Research, College Park, MD 20740, USA

³Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD 20740, USA

³Science Data Processing Inc., Laurel, MD 20723, USA

1. INTRODUCTION

The Cross-track Infrared Sounder (CrIS) on Suomi National Polar-orbiting Partnership Satellite (S-NPP) and Joint Polar Satellite System (JPSS)-1 is a Fourier transform spectrometer for atmospheric sounding. The interferograms measured from space together with the calibration data package are transmitted to the ground in a form of Raw Data Records (RDRs). The ground processing software/algorithm converts the interferograms measured into calibrated and geolocated radiance spectra in a form of Sensor Data Records (SDR). The SDR processing system has two packages that share the same processing codes: one is for operational use and running on the Interface Data Processing Segment (IDPS), and the other is the Algorithm Development Library (ADL), which is the offline version of the operational codes in support of the development and testing of the science algorithms. ADL uses file based inputs and outputs, while IDPS uses a Data Management Subsystem (DMS) to manage the inputs and outputs.

After the launch of S-NPP on Oct. 28, 2011, CrIS started to produce measurements in February 2012, which is called in the Normal Spectral Resolution (NSR) mode. The NSR SDR was generated by IDPS and became operational since then (Han et al., 2013a). On December 4, 2014, CrIS on S-NPP was switched to the full spectral resolution (FSR) mode. FSR data started to process at NOAA The Center for Satellite Applications and Research (STAR) since December 4, 2014 using an algorithm that was developed based on the NSR IDPS CrIS SDR software of the version Mx8.5/Block2.0. After the transition of the CrIS instrument from the NSR to FSR mode, the IDPS system continued to process the RDRs into NSR SDRs by truncating the MW and SW band data into the NSR interferograms, and the data is kept in the same way to deliver to the public on NOAA's Comprehensive Large Array-data Stewardship System (CLASS).

The FSR SDR algorithm and some assessment of data quality was given by Han et al.(2015). This paper presented an update about the status of CrIS FSR data processing, including the algorithm improvement, data latency and monitoring. For convenience, the baseline NSR software is referred as NSR-IDPS, while the FSR ADL processing system as FSR-ADL.

2. CRIS Full SPECTRAL CHARACTERISTICS

The CrIS instrument measures interferograms from space. The interferograms are sampled by the instrument Analog-to-Digital (A/D) converters, triggered by the electrical pulses provided by the laser metrology. The Optical Path Difference (OPD) sampling interval is the half of the laser wavelength of about 1550 nm. The length of the recorded interferogram determines the spectral resolution defined as $1/\text{Maximum Path Difference (MPD)}$, where MPD is the maximum OPD of the interferogram. In FSR mode, the interferograms of the three spectral bands are recorded with the same MPD, while on the NSR mode, the interferograms in the Mid-wave (MW) and shortwave (SW) bands were recorded with MPDs at a half of and a quarter of the long-wave (LW) band MPD, respectively. Figure 1 shows the difference of the interferogram MPDs between the NSR and FSR operation modes.

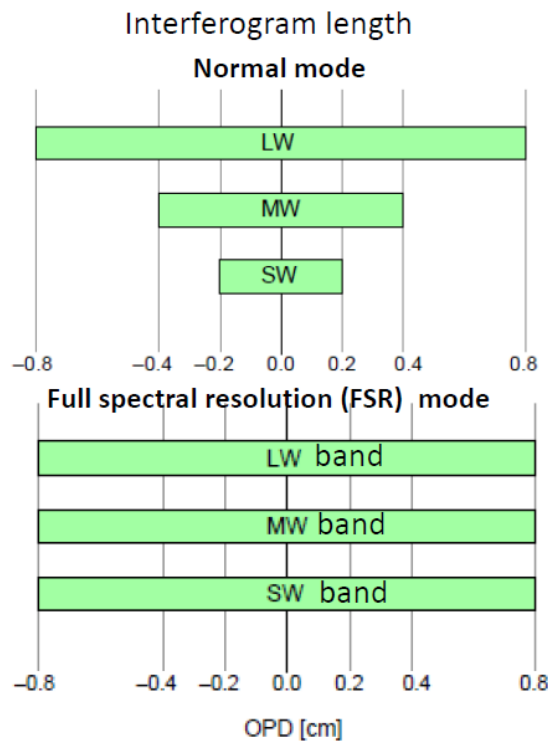


Figure 1. The CrIS double-side NSR and FSR mode interferogram OPDs.

To show the difference of interferogram measurements in NSR and FSR modes, Figure 2 shows two examples of the interferograms. From Figure 2 we can see that, compared to the NSR mode, in FSR mode the sampling points for Longwave Infrared (LWIR) was kept the same as 866; while for Middle Wave Infrared (MWIR), the number of sampling points increases from 530 to 1052; and for Short Wave Infrared (SWIR), it increases from 202 and 799. To further improve the calibration accuracy, a few more points were added in LWIR and SWIR since 19 November 2015, and now there are 874 points in LWIR, 1052 in MWIR and 808 in SWIR. A summary of the spectral characteristics of the NSR and FSR mode spectra is listed in Table 1, and we can see that CrIS on S-NPP provided measurements in 1305 channels in its normal mode, and after its switch to FSR mode, the spectral resolutions in all three bands are the same as 0.625 cm^{-1} , providing measurements in 2211 channels..

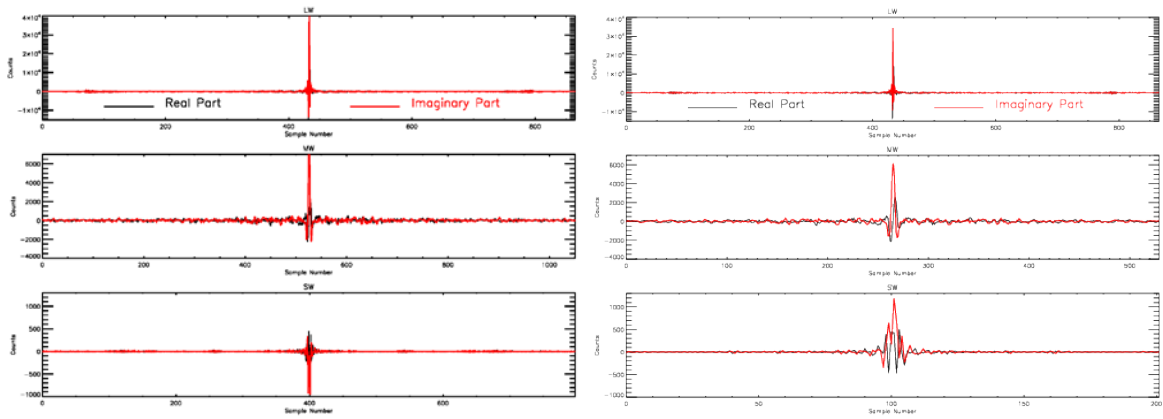


Figure 2. Examples of S-NPP CrIS interferograms for FSR (left panel) and NSR (right). The numbers of sampling point for LWIR are the same as 866, but for MWIR they are 530 and 1052 and for SWIR they are 202 and 799 for NSR and FSR, respectively.

Table 1. CrIS NSR mode and FSR mode SDR spectral characteristics.

Frequency Band	Spectral Range (cm^{-1})	Mode	Number of Channel (unapodized channel)	Spectral Resolution (cm^{-1})	Effective MPD (cm)
LWIR	650 to 1095	both	713* (717)	0.625	0.8
MWIR	1210 to 1750	NSR	433* (437)	1.25	0.4
		FSR	865* (869)	0.625	0.8
SWIR	2155 to 2550	NSR	159* (163)	2.5	0.2
		FSR	633* (637)	0.625	0.8

One major benefit for CrIS to produce FSR data is to improve the retrieval of atmospheric trace gases, such as CH_4 , CO and CO_2 which are listed in the level-1 requirements in JPSS-1. Figure 3 shows two examples of the spectra in NSR and FSR modes, generated by NSR-IDPS and FSR-ADL, respectively. This measurement was located at (24.4°N, 43.5°E) in November 30, 2015. Compared to NSR, the spectral resolution for FSR is the same in LWIR, but it is doubled in MWIR and four times in SWIR. Due to the increase of spectral resolution, the absorption line structure of CO absorption in SWIR is evident for FSR, which is smoothed out in NSR data.

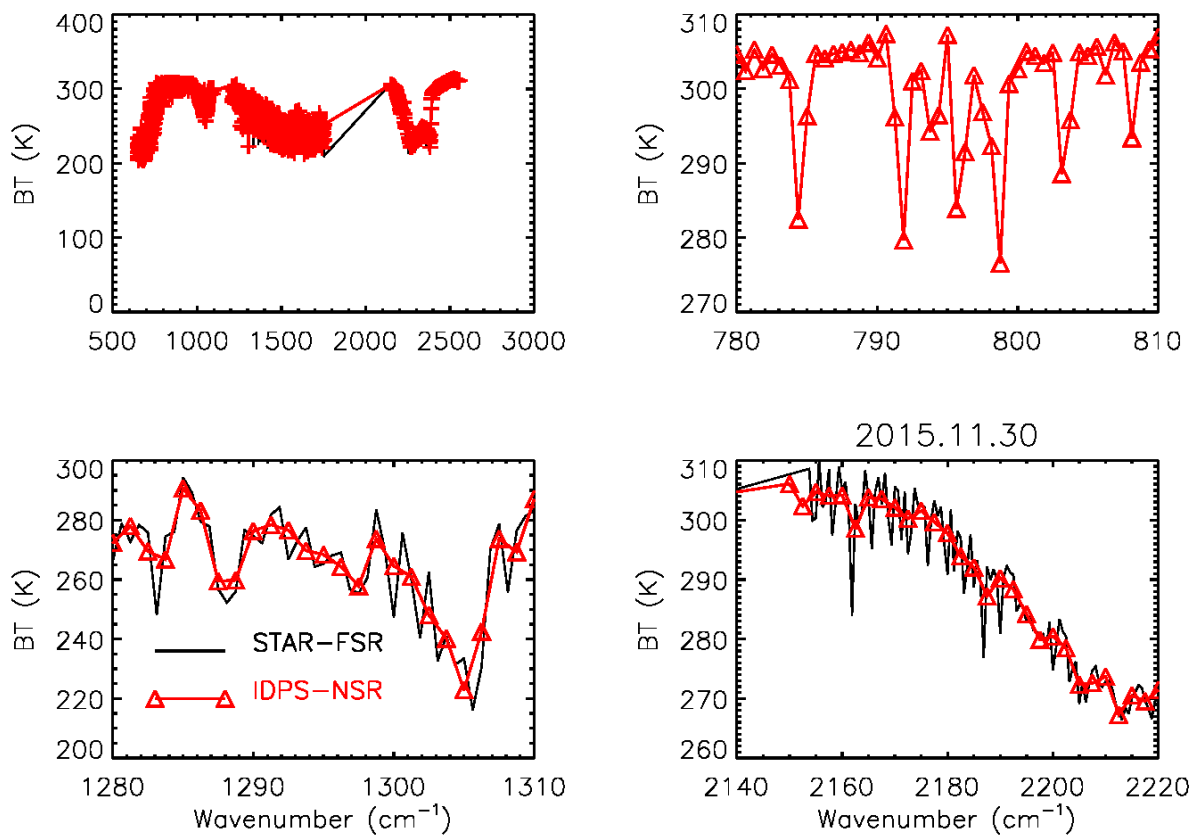


Figure 3. One example of calibrated FSRR (black) and NSR (red) spectra (top left panel) from the same interferogram measurement on November 11, 2015. Other panels are zoom-in of small portions of the LWIR (upper right), MWIR(lower left) and SWIR (lower right) spectra.

3. Calibration Algorithm and FSR Data Status

The SDR processing algorithm flow for NSR-IDPS and FSR_ADL processing systems is shown in Figure 4. The algorithm module flow remains unchanged from the baseline code to the FSR code. The main components of the calibration algorithms include the Fast Fourier Transform (FFT) of the interferograms to raw spectra, detector nonlinearity (NL) correction, radiometric calibration, spectral calibration, and geolocation calculation, as well as the radiance noise estimation. More detail of the retrieval algorithm can be referred to Han et al. (2015).

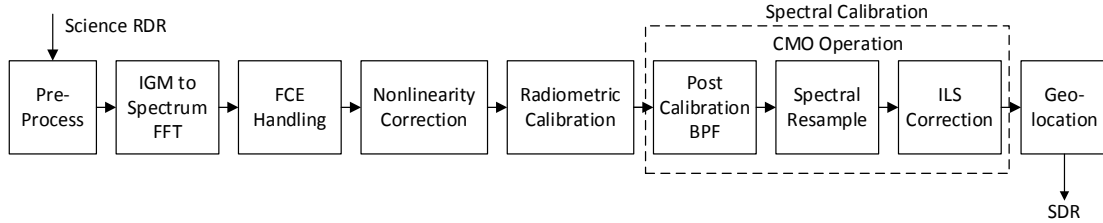


Figure 4. S-NPP CrIS SDR processing flow.

The calibration equation for FSR-ADL system in version 1 is similar to NSR-IDPS:

$$S_{ES,cal} = SA^{-1} \cdot F \cdot f \cdot \left\{ \frac{S_{ES} - \langle S_{DS} \rangle}{\langle S_{ICT} \rangle - \langle S_{DS} \rangle} B_{ICT} \right\} \cdot \quad (1)$$

Where the variables S_{ICT} , S_{DS} and S_{ES} are raw spectra of the Internal Calibration Target (ICT), Deep Space (DS) and Earth Scene (ES), the quantities inside of the angled brackets $\langle \dots \rangle$ are averaged within the so-called sliding window (30 consecutive spectra), and B_{ICT} , f , F and SA^{-1} are the ICT radiance, post-filter, resampling matrix and self-apodization correction matrix, respectively (JPSS Configuration Management Office, 2011). The ICT radiance is computed with the Planck function with the self-apodization and contributions from ICT surrounding environment taking into account. The post-filter suppresses the noisy signals in the so-called guide bands that results in the radiometric calibration ratio in Eq. (1) (see Table 2 for in-band and guide-band definition in Han et al. (2015)). The resampling matrix performs two functions: a) changing the spectral resolution to the required resolution and b) interpolating the spectrum from the sensor grid to the required frequency grid. The self-apodization correction matrix corrects the spectral distortion due to radiance beam divergence effect. The three components, f , F and SA^{-1} , are combined into a single matrix, referred as Correction Matrix Operator (CMO). The CMO is a component of spectral calibration in Eq. (1), and it is used together with the components in the brackets $\{ \dots \}$ and the NL correction to perform the radiometric calibration.

Since December 4, 2014, the NOAA STAR provides routine processing of the FSR data and makes the SDR data available to the public via the STAR FTP site (<ftp://ftp2.star.nesdis.noaa.gov/smcd/xxiong/>). The SDR file names are tagged with labels

“star”, “f” and “01”, meaning the data are processed at the NOAA/STAR site with the full spectral resolution SDR software and algorithm version 01. Since the format and data fields of the SDR files have not been changed, the CrIS SDR User’s Guide (Han et al., 2013b) written for the NSR SDRs still applies to the FSR SDR product, except the descriptions on the dimension and resolutions of the MW and SW bands. The similar codes were shared with CIMSS to process FSR data separately.

The current data latency is between 12-18 hours (Figure 5a). Here we used the RDR data from NOAA STAR Collaborative Environment Data Repository (CEDR). In the spring of 2015, we have ever speed-up the processing and delivery by downloading RDR data from the Government Resources for Algorithm Verification, Independent Test and Evaluation (GRAVITE), processing and uploading to NOAA STAR ftp site, and the best latency we can reach is between 3-6 hours (Figure 5b). This latency is limited by the receiving of RDR data on GRAVITE, which is about 2 hours, the transfer data from GRAVITE to NOAA, the speed of Linux we used to process the SDR data, and uploading data to STAR ftp site. Considering there are many repaired granules that require the system to repeat check these granules, reprocessing, and clean-up the old one on the ftp site, we turned to use the RDR data from NOAA STAR CEDR, which has a latency of 6 hours (Fig.5a) and the repaired granules are mostly removed. So far, there is no user requirement of real-time FSR data.

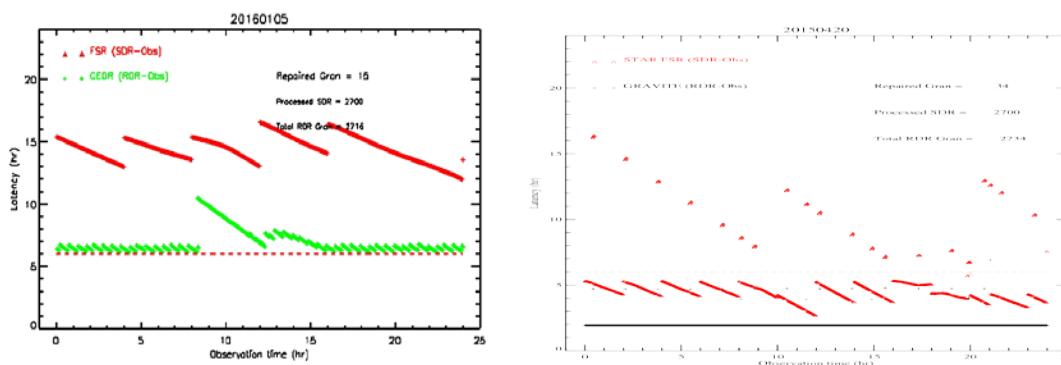


Figure 5 Latency of current CrIS FSR data processing and delivery (left panel). Right panel is almost the smallest latency that can be reached using RDR data from GRAVITE data directly.

In addition to our maintenance and check to the status of the generated FSR data at NOAA STAR, a few users also download and backup the FSR data every day. The FSR data status and quality are also monitored by the integrated Calibration/Validation System (ICVS), and the results can be found in NOAA STAR ICVS website:

(http://www.star.nesdis.noaa.gov/icvs/status_NPP_CrIS_FSR.php). From December 4, 2014 to present, over 99.9% CrIS FSR data have been generated (Figure 6) and achieved. The three days

with a few hours' losing granules are on 10 July 2015, 19 November 2015, and 17 January 2016, and the reasons are due to the CrIS instruments operation in space, not the SDR software processing problems. In addition to the data delivered via STAR ftp site, which is refreshed every 7 days, data can be also delivered via GRAVITE site, which is refreshed in 34 days. Currently, we donot main the routine data delivery on GRAVITE, instead, we upload the data on GRAVITE upon the request by users only.

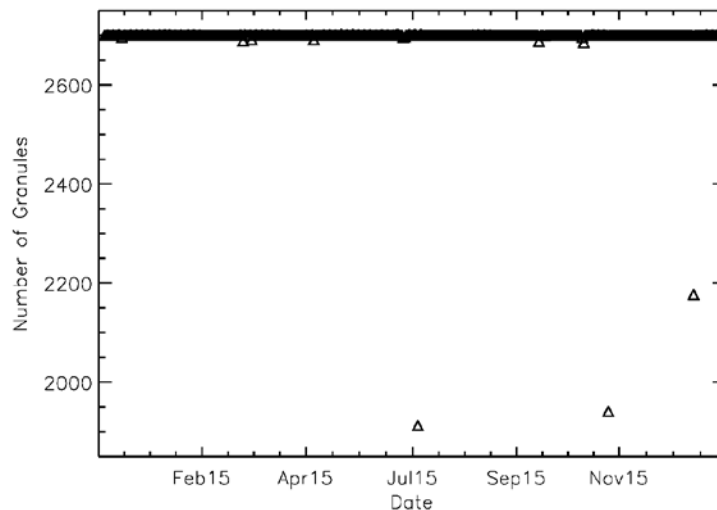


Figure 6 The number of granules of CrIS on S-NPP processed at NOAA STAR since December 4, 2014 to present. In general, 2700 granules are processed per day. Data losing on 10 July 2015, 19 November 2015 and 17 January 2016 are due to the CrIS instruments operation on satellite.

4. SUMMARY AND FUTURE WORK

An ADL-based CrIS FSR SDR processing system has been used to process the FSR RDRs into FSR SDRs at NOAA STAR since 4 December, 2014, and data is delivered via STAR ftp site (<ftp://ftp2.star.nesdis.noaa.gov/smcd/xxiong/>) to the public with a latency of 12-18 hours. A better latency of 3-6 hours can be made but has no user requirement so far. From 4 December, 2014 to present, over 99.9% data have been processed and archived at NOAA STAR, and there are only three days with significant data losing and the losing is duo to the operation of CrIS instrument in space.

The CrIS SDR team continues to improve the calibration algorithms for S-NPP FSR data processing. Since the CrIS instrument on JPSS-1 is the same as on S-NPP, the improved algorithm becomes the baseline algorithm that will be used for CrIS on JPSS-1.

ACKNOWLEDGMENT

This work was supported by JPSS program. The authors thank to the CrIS SDR Science team members for their contributions in SDR algorithm development and validations. The science team includes the groups of University of Wisconsin-Madison, led by D. Tobin, University of Maryland at Baltimore County, led by L. Strow, Space Dynamics Laboratory, led by D. Scott, Massachusetts Institute of Technology, Lincoln Laboratory, led by D. Mooney, Exelis Inc., led by L. Suwinski, Northrop Grumman Aerospace Systems, led by D. Gu, NASA Langley Research Center, Led by D. Johnson, and members from NOAA/DESDIS/STAR.

REFERENCE

JPSS Configuration Management Office, 2011: Joint Polar Satellite System (JPSS) Cross Track Infrared Sounder (CrIS) Sensor Data Records (SDR) algorithm theoretical basis document (ATBD), *JPSS office, document code 474: 474-00032, October 2011*. [Available online at <http://www.star.nesdis.noaa.gov/jpss/ATBD.php#S796056>].

Han, Y., et al., 2013a: Suomi NPP CrIS measurements, sensor data record algorithm, calibration and validation activities, and record data quality. *J. Geophys. Res. Atmos.*, 118, doi:10.1002/2013JD020344.

Han, Y., Y. Chen, X. Jin, D. Tremblay and L. Wang, 2013b: Cross Track Infrared Sounder (CrIS) Sensor Data Record (SDR) User's Guide – Version 1, *NOAA NESDIS Technical Report* 143.

Han, Y., Y. Chen, X. Xiong, X. Jin, (2015), S-NPP CRIS Full Spectral Resolution SDR Processing and Data Quality Assessment, AMS 2015 Proceedings.