4.3 SUOMI NPP/JPSS CROSS-TRACK INFRARED SOUNDER (CRIS): RADIOMETRIC AND SPECTRAL PERFORMANCE

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1. INTRODUCTION

The path from research to operations for high spectral resolution infrared sounding has made a major step forward with the flight of CrIS on Suomi NPP. This path dates back to the mid-1980s when retrievals from High-resolution Interferometer Sounder (HIS) aircraft data first demonstrated the significantly increased vertical resolution for temperature and water vapor soundings (factor of 2.5-3 higher) made possible by higher spectral resolution. The HIS spurred a 1990/91 Phase-A instrument design by a team led by the University of Wisconsin-Madison (sponsored by EUMETSAT) that fostered more detailed designs by Exelis (then ITT)/ABB(then Bomem) and inclusion on NPP starting in the mid-1990s.

Now we have the start of an operational series (Joint Polar Satellite Series, JPSS) with sounding from the 930 morning orbit being covered by the Infrared Atmospheric Sounding Interferometer (IASI) on MetOP and from the 1330 orbit by CrIS, which will operationalize the EOS Aqua research capability from the Atmospheric IR Sounder (AIRS). The detailed characterization of the calibration and overall performance needed for successful forecast model assimilation and other applications is proceeding well and has achieved what NOAA refers to as provisional status.

This paper includes an overview of what has been learned from CrIS calibration and validation activities. In brief, all of the radiometric and spectral performance specifications for CrIS have been met and the fundamental calibration accuracy and noise performance specifications have been significantly exceeded. It is clear that the advantages of high spectral resolution IR for weather forecasting and climate demonstrated on-orbit by AIRS and IASI predecessor observations will be largely matched or exceeded by CrIS.

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2. CRIS RADIOMETRIC ACCURACY AND STABILITY

The CrIS radiometric accuracy has proven to be excellent and substantially exceeds the Suomi NPP program requirements that were established primarily for weather applications. This instrument is very well suited to continue, and in several ways to improve on, the high accuracy offered for establishing a valuable climate record from high resolution IR spectra began by the AIRS instrument on the NASA EOS Aqua platform. Much of the substantial calibration accuracy improvement of these spectrometers over lower resolution radiometers stems from the huge improvement in knowledge of the spectral response functions.

For easy reference, the spectral coverage and resolution of CrIS is illustrated by comparison to AIRS and IASI in Figure 1 and its excellent noise performance is shown in Figure 2.

The preflight expectation for CrIS radiometric performance is summarized in figure 3, which shows estimates of 3-sigma brightness temperature uncertainty as a function of scene temperature. Note that after on-orbit refinements are completed "not-to-exceed" uncertainties are expected to be less than 0.2 K.

On-orbit comparisons have also been made to both AIRS and IASI as illustrated for the longwave band in Figure 5. The temporal stability of the comparison between CrIS and AIRS is illustrated in Figure 6.

Drawing on the sensor characterization results to date, a preliminary estimate of the CrIS Sensor Data Record (SDR) in-flight Radiometric Uncertainty (RU) is shown in Figure 7. Opposed to the pre-flight RU estimates showing Thermal Vacuum blackbody views in Figure 3, the in-flight RU can vary depending on the magnitude and shape of the observed spectrum; this example is for an 8-minute granule from 24 February 2012 with a reasonable sample of clear sky spectra. It applies to all nine CrIS FOVs, because of the FOV-to-FOV inter-comparison techniques applied for reducing non-linearity uncertainties on-orbit.

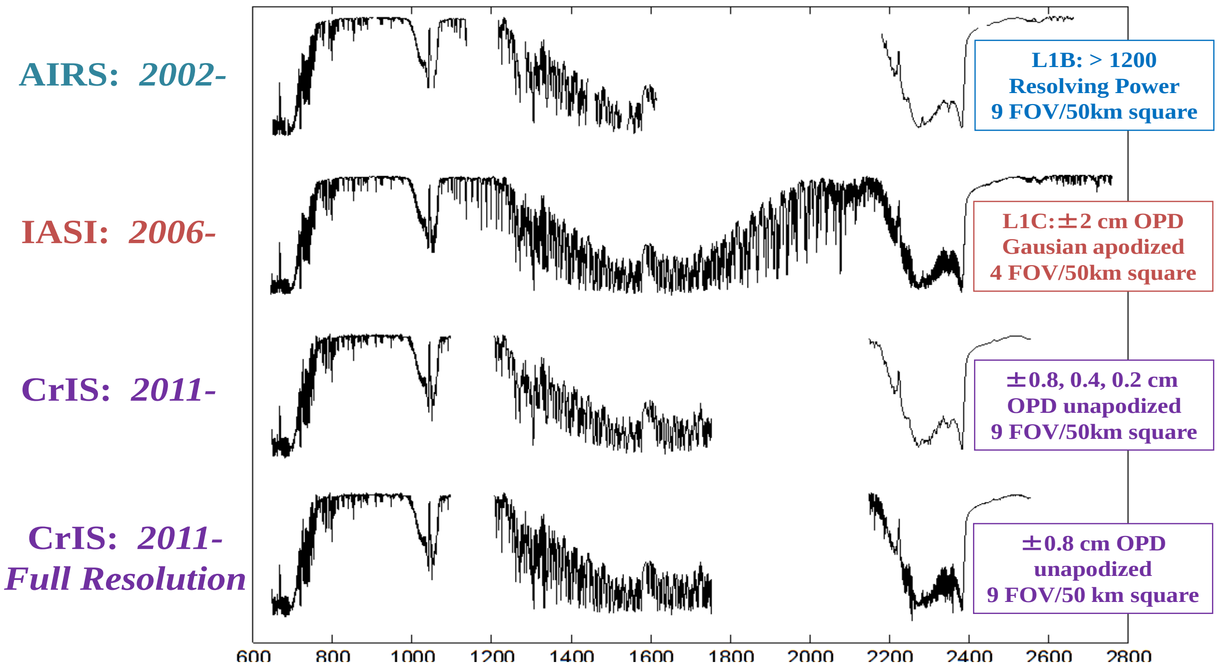


Figure 1. Comparison of brightness temperature spectra from CrIS to AIRS and IASI. These spectra calculated using LBLRTM accurately represent the actual spectral coverage and resolution of each instrument. The AIRS resolution has approximately a constant resolving power ($\nu/\Delta\nu$), while the resolution for both IASI and the full-resolution CrIS are approximately independent of wavenumber. Therefore, after mid-2013 when the full resolution capability of CrIS will be routinely downlinked, the resolution of the newer instruments will be substantially higher than the legacy EOS AIRS for the shorter wavelength regions of the spectra.

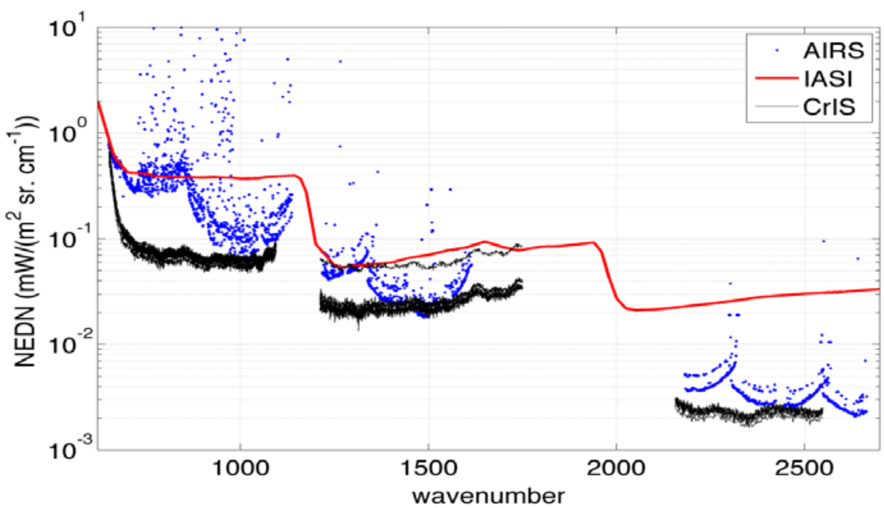


Figure 2. Comparison of CrIS radiance noise (NEDN) to that for AIRS and IASI. Note that in the important 15 micron band region, CrIS noise is about 4 times smaller than both AIRS and IASI. Also noteworthy is the excellent performance even in the shortwave band (2150 to 2600 cm^{-1}). This comparison is made for warm scenes, but even for cold scenes the shortwave noise performance is comparable to that of AIRS.

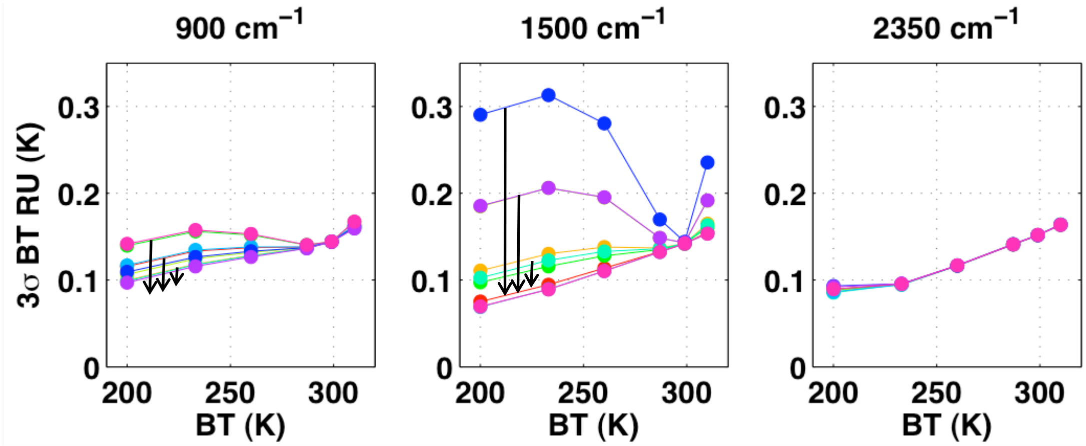


Figure 3. Preflight radiometric uncertainty estimates for blackbody sources in terms of 3-sigma brightness temperature as a function of scene brightness temperature for the center wavelength of each band (left to right: LW, MW, SW). The colored dots identify the field-of-view (FOV) of each element of the CrIS 3x3 detector array defining simultaneous field of regard (FOR) measurements covering 50x50 km at nadir. The wide range of uncertainty in the Midwave and smaller range in the Longwave are caused by FOV non-linearity differences. The black arrows indicate that these differences have been greatly reduced by on-orbit calibration/validation activities as demonstrated in Figure 7 to follow.

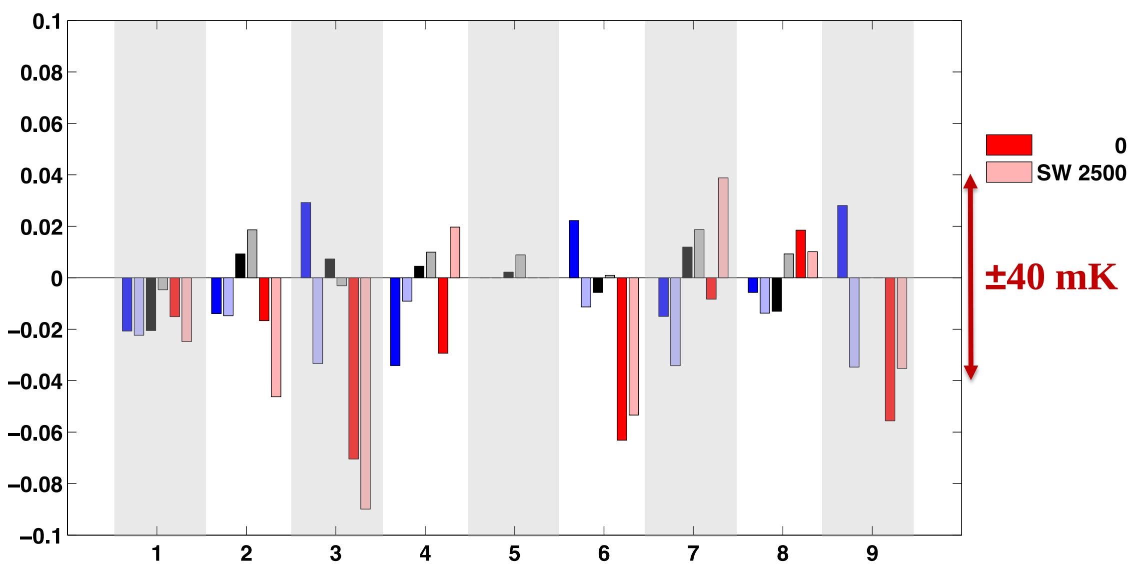


Figure 4. On-orbit brightness temperature comparisons among CrIS nine individual FOVs composing each 50x50 km FOR for six sample wavenumbers. Note that most differences are less than ±30 mK. The major exceptions are SW pixels 3, 6, and 9, an anomaly that is still being studied. In general, these relative comparisons that inherently include some errors from the on-orbit comparison process are excellent and consistent with the expectations of Figure 3. Further refinements are still planned before final “validated” status is declared.

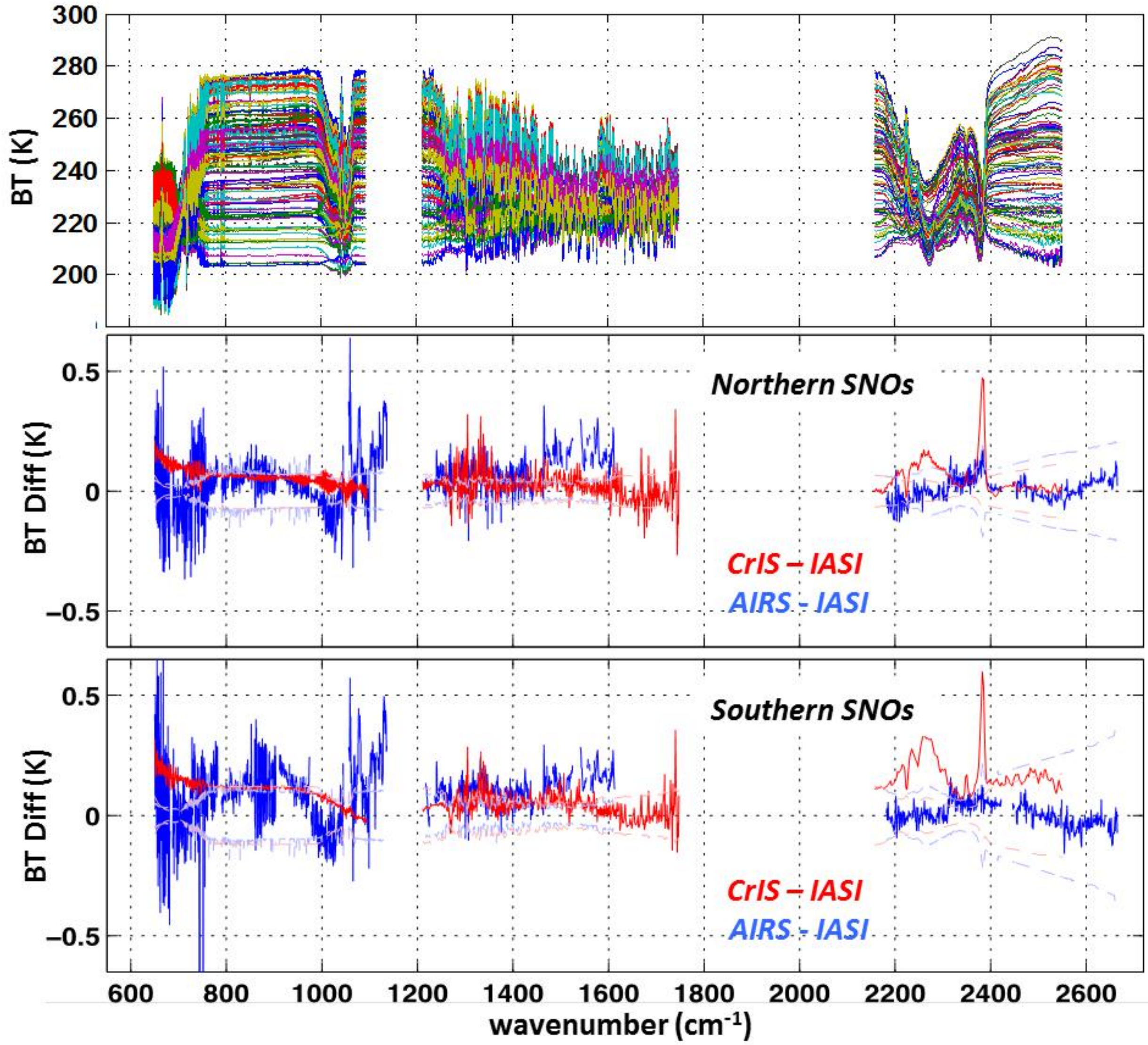


Figure 5. Summary of on-orbit comparison between CrIS brightness temperature spectra and both AIRS and IASI. All data from February-November 2012 that meets inter-comparison criteria (within 20 minutes, and 3° degrees viewing angle, with viewing angle <30° for AIRS and near nadir for IASI) is used. The dashed curves are error estimates indicating that most of these differences are significant. While these results will be the subject of detailed studies for considerable time, it is clear that the agreement is very good, especially between CrIS and IASI.

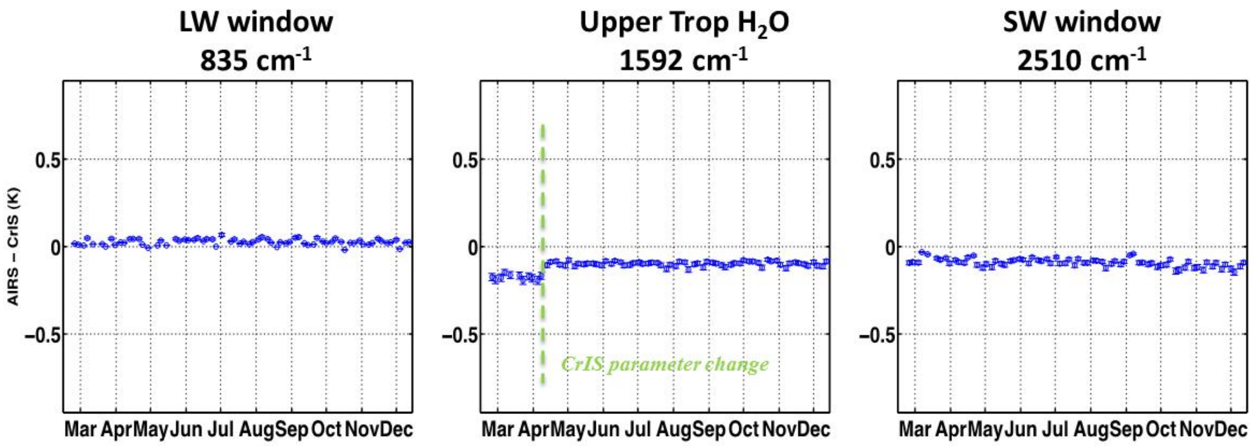


Figure 6. Temporal stability of AIRS minus CrIS daily mean differences for three sample wavenumbers. The small jog in April was caused by an upload of new calibration parameters for CrIS. Note that the differences are usually significantly less than ±0.2 K.

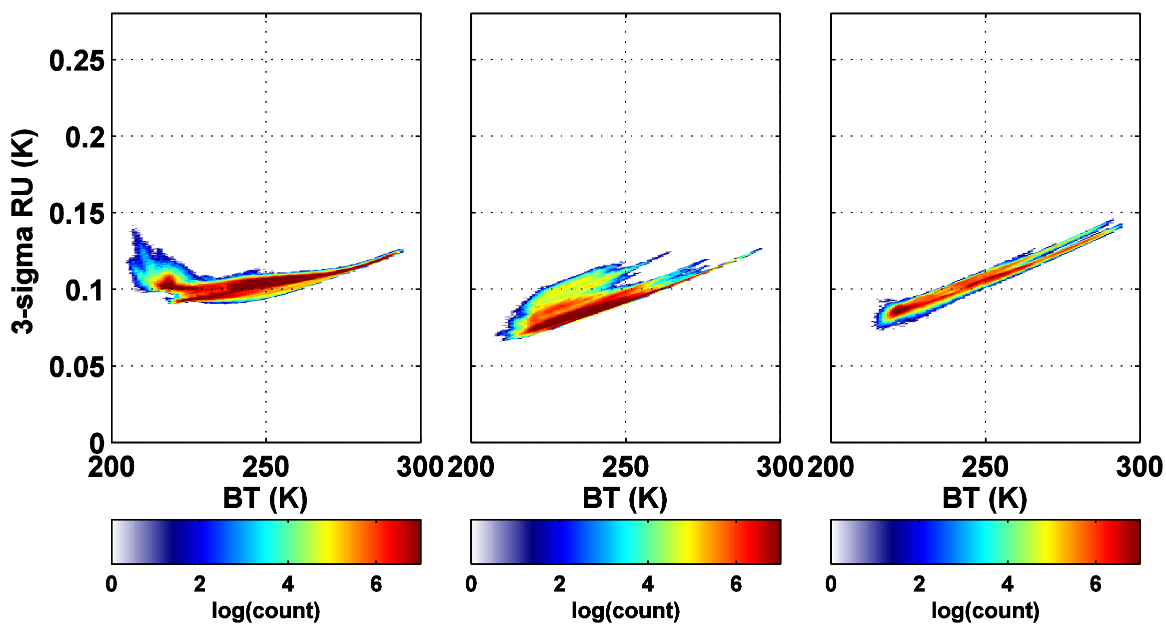


Figure 7. Sample of on-orbit 3-sigma Brightness Temperature uncertainty for 24 February 2012.

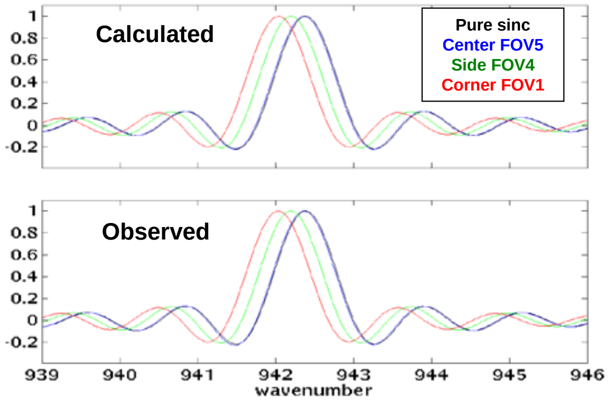
There are a couple of relatively small liens on CrIS radiometric performance that are currently under investigation, namely (1) larger than expected Gibbs ringing that effects some wavelengths, and (2) an unexplained difference with both AIRS and IASI for regions of very low radiance in the shortwave band. These issues are being studied as part of both our NASA and NOAA activities.

In Summary, the sample comparisons with AIRS and IASI shown in this section make it clear that the basic CrIS spectral radiances, which have the same spatial sampling properties as AIRS, are capable of continuing the EOS data record.

3. CRIS SPECTRAL CALIBRATION ACCURACY AND STABILITY

The CrIS spectral calibration accuracy and stability are also excellent and generally better than 1 ppm. As such, it is an improvement over the EOS AIR sensor which displays substantially larger changes during every orbit and from year to year.

Again for easy reference, we show the pre-flight spectral response measurements (or Instrument Line Shapes, ILS) compared to those expected from the way the CrIS sensor was built in Figure 8. Analysis techniques for normalizing the ILS to a sinc function for all FOVs were proven before launch.



		Center FOV	Side FOV	Corner FOV
centroid (cm^{-1})	Obs	942.367	942.195	942.034
	Calc	942.366	942.195	942.034
FWHM (cm^{-1})	Obs	0.747	0.757	0.767
	Calc	0.751	0.759	0.767
Lfoot	Obs	0.358	0.329	0.313
	Calc	0.347	0.328	0.313
Rfoot	Obs	0.347	0.326	0.311
	Calc	0.345	0.329	0.313

Figure 8. CrIS Instrument Line Shapes measured with a CO_2 laser compared to calculations.

The results of relative FOV-to-FOV comparisons achieved for provisional SDR status are shown in Figure 9. These results also demonstrate a high degree of relative stability.

Finally, the absolute spectral calibration for CrIS is based on its own Neon lamp wavelength reference measurements, which can be verified using spectral calibration from lines in the atmospheric spectrum. There is also a highly stable diode laser used to trigger sampling of the interferogram signal. The stability of diode laser relative to the Neon calibration lamp is illustrated in Figure 10 (prepared by Larrabee Strow, UMBC).

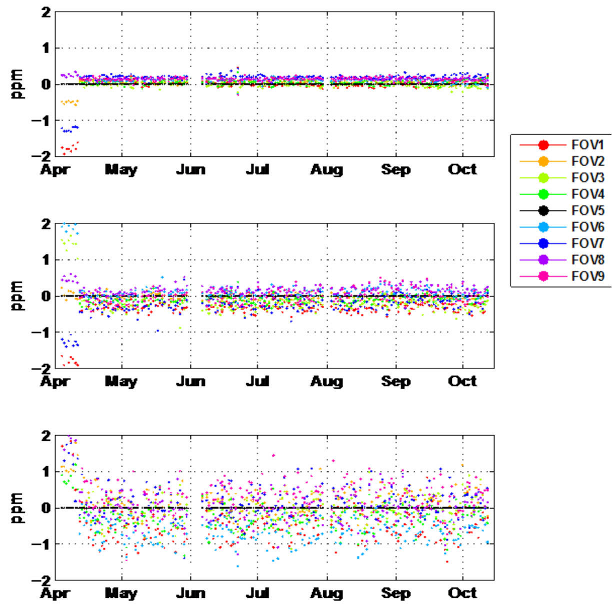


Figure 9. On-orbit comparison of agreement among nine FOV spectral calibration.

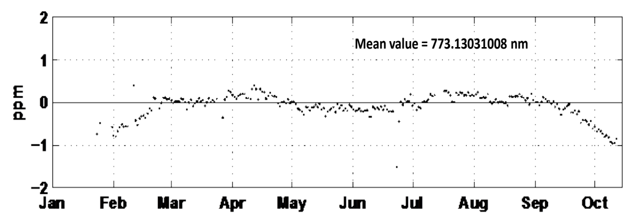


Figure 10. Stability of the FTS sampling laser relative to the on-board Neon calibration source is on the order of 1 ppm.

Verification of the CrIS spectral calibration has been performed using line-by-line calculations based on laboratory (HITRAN) measurements of gaseous absorption lines in the infrared. The assessment of the accuracy of the atmospheric verification is in progress, but preliminary results by UMBC are consistent with the neon calibration.

4. SUMMARY OF COMPARISON TO EOS AIRS

The overall performance of the CrIS advanced sounder is excellent, assuring that it is fully capable of continuing where AIRS leaves off. More specifically,

a. Detailed assessments of radiometric uncertainty suggest that is it at least as accurate as AIRS. Relative comparisons with IASI and AIRS actually suggest that it may turn out to be notably better than AIRS.
b. While the spectral knowledge of CrIS and AIRS are both excellent, the spectral properties of CrIS are even better known and more stable than those of AIRS.
c. The spectral resolution of the full resolution CrIS (routine downlink expected mid-2013) is substantially higher than AIRS.
d. The noise performance of CrIS is superior,
e. Spatial sampling properties and spectral coverage are very nearly the same.

Therefore, the overall information content for weather forecasting and climate applications (climate process studies, creating long-term climate products, and assessing long-term trends) is certainly at least equal to that of the legacy EOS sensor.

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