SI Traceable Algorithm for Characterizing Hyper-spectral Infrared Sounder CrIS Noise

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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 the sensor data record (SDR) that can be used for retrievals of the atmospheric temperature and water vapor profiles and can be also directly assimilated in numerical weather prediction models. The Noise Equivalent Differential Radiance (NEdN) is part of CrIS SDR products and represents the amount of random noise in the interferometer data. It is a crucial parameter affecting the accuracy in retrieval and satellite radiance assimilation. In this study, International System of Units (SI) traceable method Allan deviation is used to estimate the CrIS NEdN due to the internal calibration target (ICT) radiance slowly varying with time. Compared to the current standard deviation method, it is shown that the NEdN calculated from Allan deviation is converged to a stable value when a number of samples or average window size is set to 510. Thus, Allan deviation can result in CrIS NEdN SI traceable noise. Also, an optimal averaging of window size is 30 if the NEdN is calculated from the standard deviation [1, 2].

NEdN Estimation Methods

A. Standard Deviation Method:

For RDR data

The gain function at nth channel and ith sample (scan line) is given by

$$\widetilde{G}_{b,p,d}[i,n] = \frac{\widetilde{S}^{ict}_{b,p,d}[i,n] - \widetilde{S}^{dz}_{b,p,d}[i,n]}{L^{ict}_b[n] - L^{dz}_b[n]},$$

where $\widetilde{S}^{ict}_{b,p,d}[i,n]$ and $\widetilde{S}^{dz}_{b,p,d}[i,n]$ are the raw complex spectra of ICT and DS, respectively. $L^{ict}_b[n]$ and $L^{dz}_b[n]$ are the ICT and DS radiances, respectively. The subscripts b, p and d are band, FOV and sweep direction, respectively.

$$NEdN^{ict}_{b,p,d}[n] = \mathrm{Re}\left\{\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(\frac{\widetilde{S}^{ict}_{b,p,d}[i,n] - \sum_{i=1}^{N}\widetilde{S}^{ict}_{b,p,d}[i,n]/N}{\sum_{j=1}^{N}\widetilde{G}_{b,p,d}[j,n]/N}\right)^2}\right\}.$$

For SDR data

The complex calibrated ICT radiance for ith sample in the moving window N^{ma} is given by

$$\underline{\widetilde{L}}^{ict}_{b,p,d}[i,n] = \left(\frac{\widetilde{S}^{ict}_{b,p,d}[i,n] - \langle\widetilde{S}^{dz}_{b,p,d}[n]\rangle}{\langle\widetilde{S}^{ict}_{b,p,d}[n]\rangle - \langle\widetilde{S}^{dz}_{b,p,d}[n]\rangle}\right)\cdot L^{ict}_b[n],$$

where $\underline{\widetilde{S}}^{ict}_{b,p,d}[i,n]$ is raw complex spectrum of ICT for the ith element in moving window at the nth channel. $\langle\widetilde{S}^{dz}_{b,p,d}[n]\rangle$ and $\langle\widetilde{S}^{ict}_{b,p,d}[n]\rangle$ are the raw complex spectra of deep space and ICT, respectively, averaged over N^{ma} measurements.

$$NEdN^{ict}_{b,p,d}[n] = \mathrm{Re}\left\{Stdev\left\{\underline{\widetilde{L}}^{ict}_{b,p,d}[i,n]\right\}\right\}$$

$$NEdN^{SDR}_{b,p,d}[n] = SpectralAverage\left\{NEdN^{ict}_{b,p,d}[n], N^{NEdN}\right\}$$

B. Allan Deviation Method [3, 4]:

- The standard deviation quantifies the spread of the statistical distribution of the measuring values around the mean.
- If the mean is nonstationary, STD is not an appropriate parameter for describing the spread since the mean and deviation never converge to any particular values.
- Since the temperatures of ICT and the optical components slowly vary in orbit, the ICT radiance also slowly varies with time.

$$NEdN^{ict,Allan}_{b,p,d}[n]$$
$$= \mathrm{Re}\left\{\sqrt{\frac{1}{2m^2(N-2m+1)}\sum_{j=1}^{N-2m+1}\left(\sum_{i=j}^{j+m-1}\underline{\widetilde{L}}^{ict}_{b,p,d}[i+m,n] - \underline{\widetilde{L}}^{ict}_{b,p,d}[i,n]\right)^2}\right\},$$

where N is the total number of samples (scans) and m is the number of overlapping samples.

- If the measured data are stationary, the Allan deviation converges to the twice of the variance so that standard deviation and Allan deviation are the same.
- It generalizes the concept of the second order statistical moment to the case of non-stationary stochastic processes.

NEdN (NEdT) Results

A. Comparison of NEdN from Different Methods and Data Sources
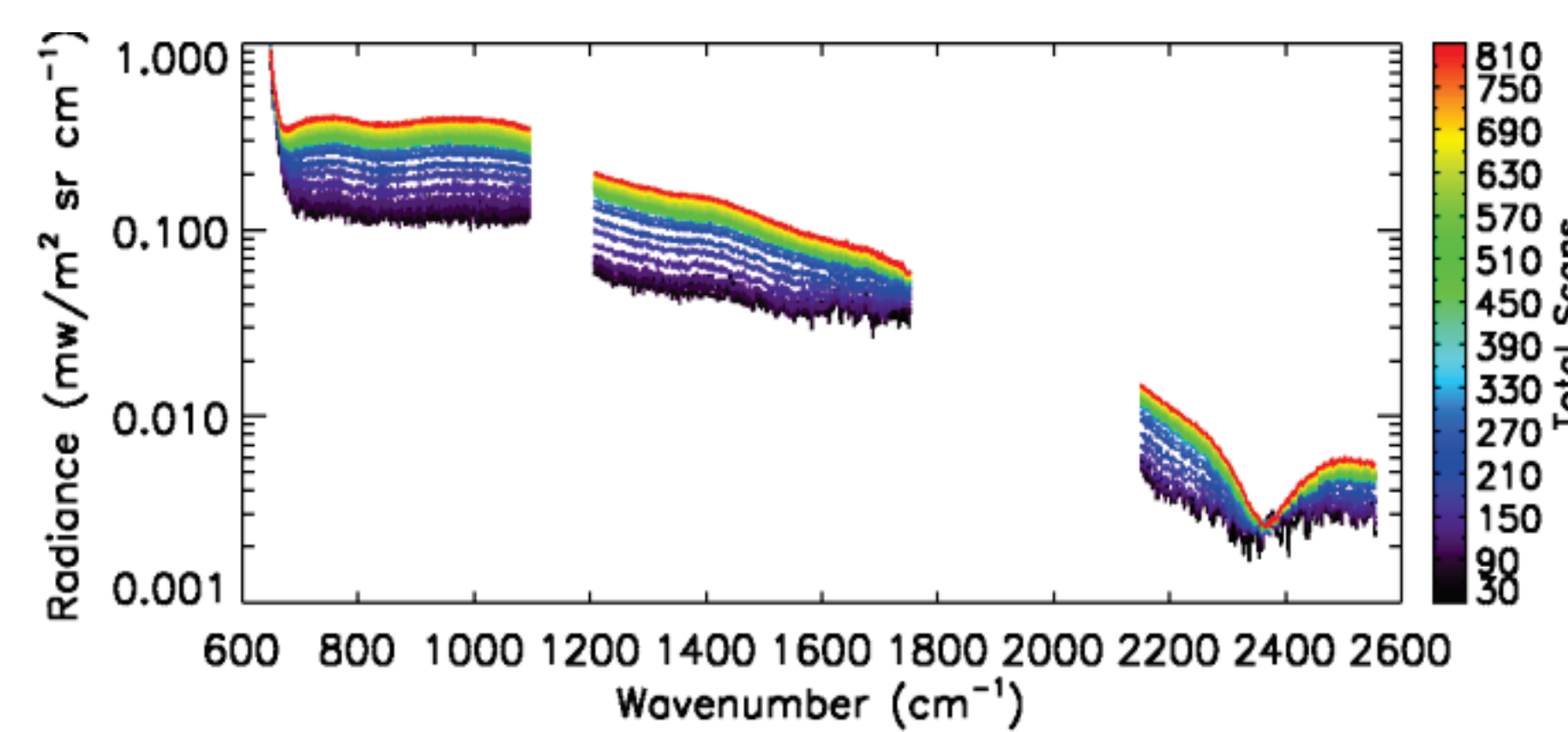

Fig. 1. $NEdN^{std,RDR}$ as a function of scan lines using standard deviation method for CrIS RDR data. The different colors indicate the different total scan lines used to derive the NEdN.
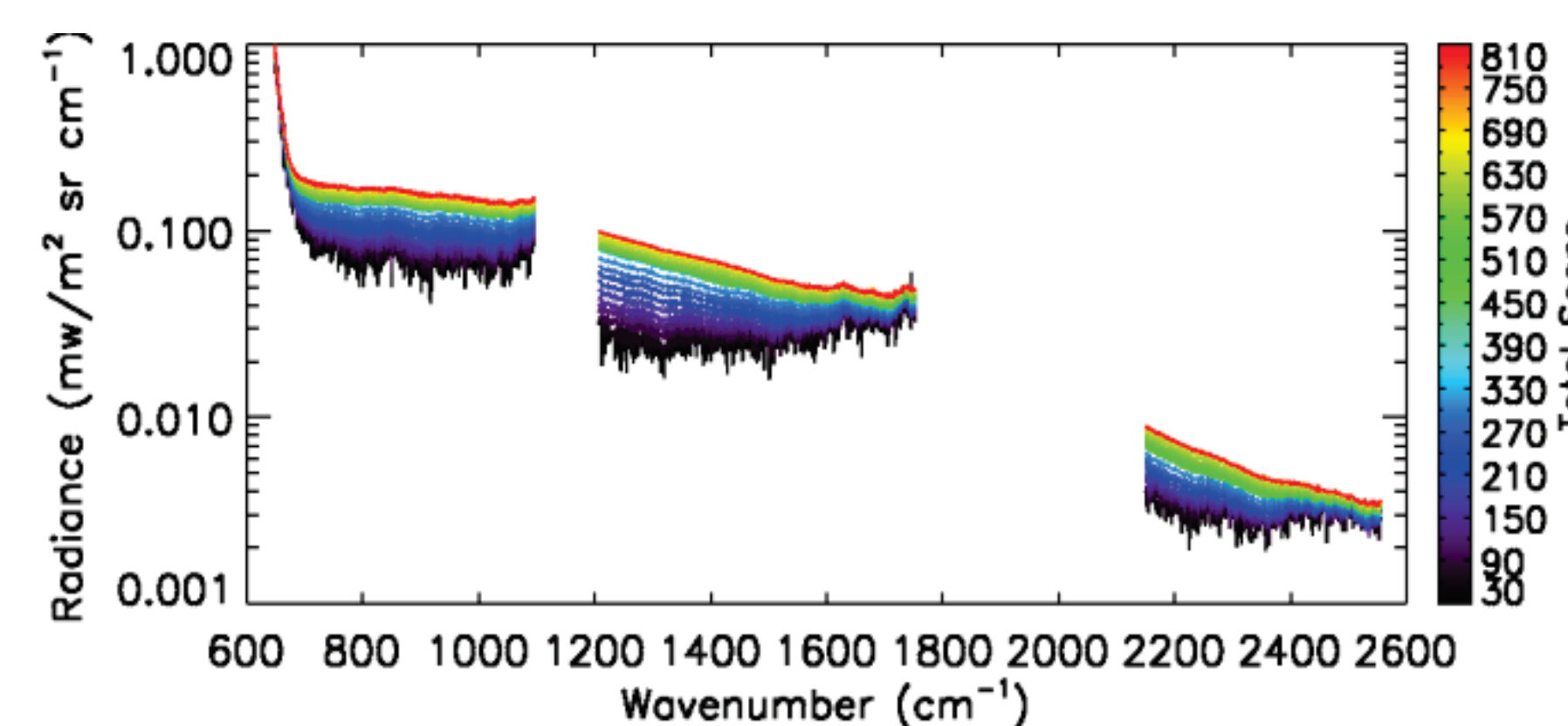

Fig. 2. $NEdN^{std,SDR}$ as a function of scan lines using standard deviation method for CrIS SDR data. The different colors indicate the different total scan lines used to derive the NEdN.
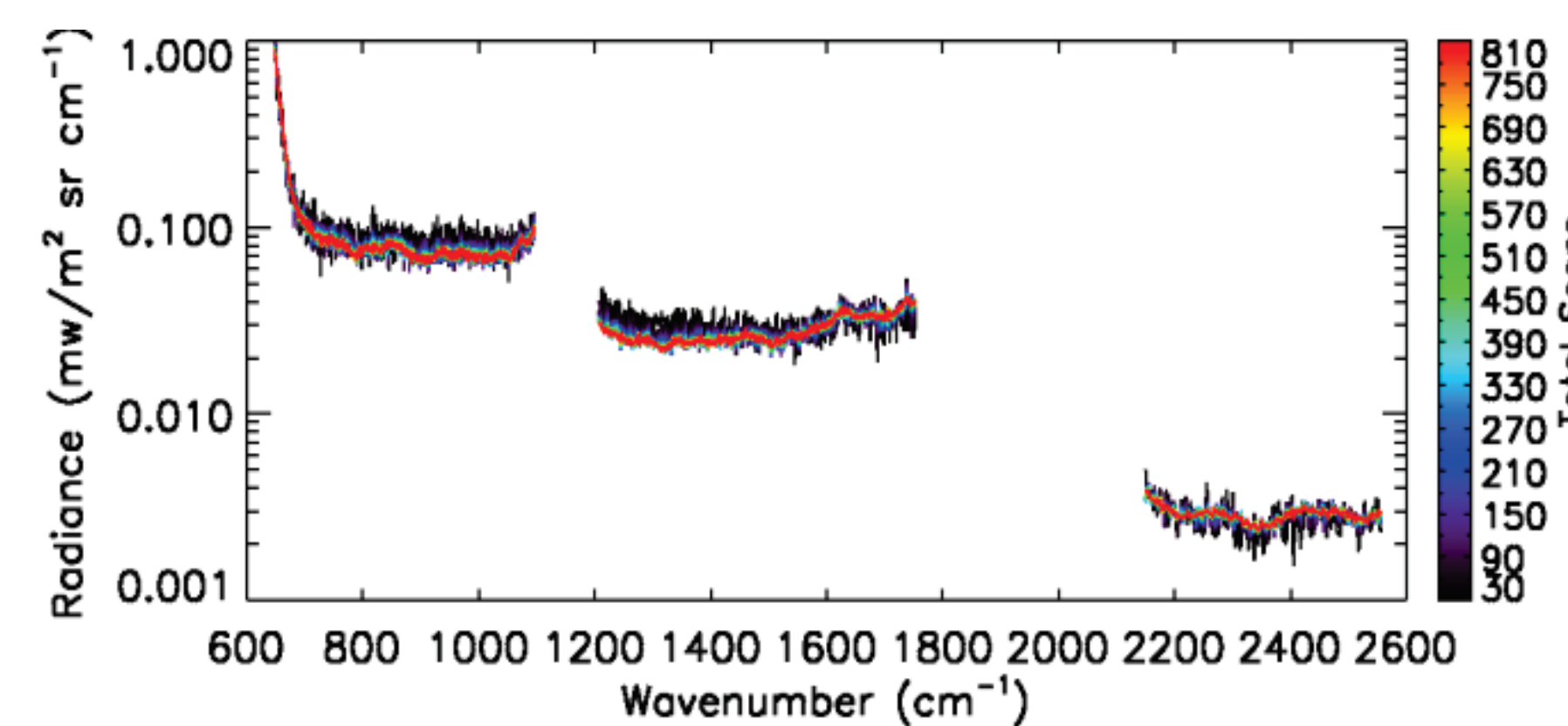

Fig. 3. $NEdN^{Allan,RDR}$ as a function of scan lines using Allan deviation method for CrIS RDR data. The different colors indicate the different total scan lines used to derive the NEdN.

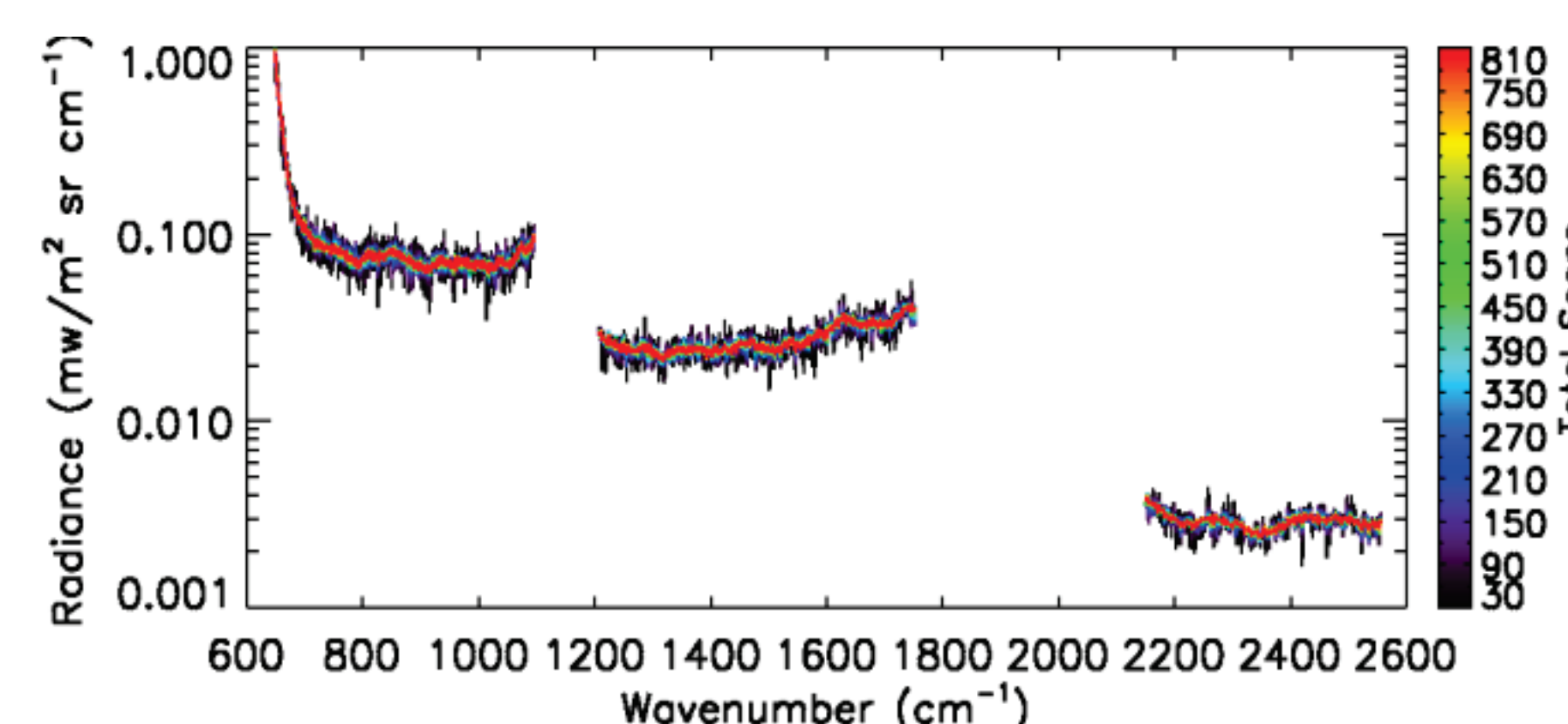
Fig. 4. $NEdN^{Allan,SDR}$ as a function of scan lines using Allan deviation method for CrIS SDR data. The different colors indicate the different total scan lines used to derive the NEdN.
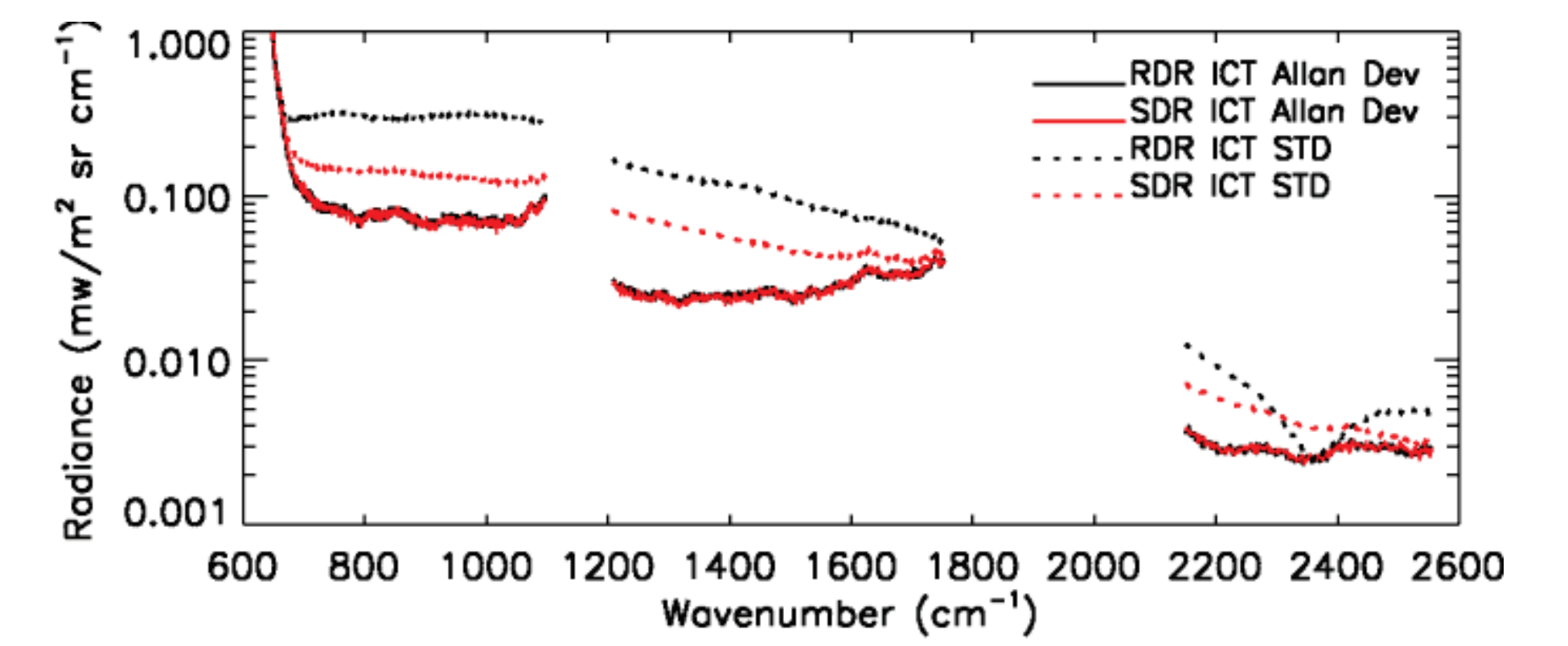

Fig. 5. Comparison of NEdN calculated from RDR and SDR data, using methods standard deviation and Allan deviation for a total scan line of 510.

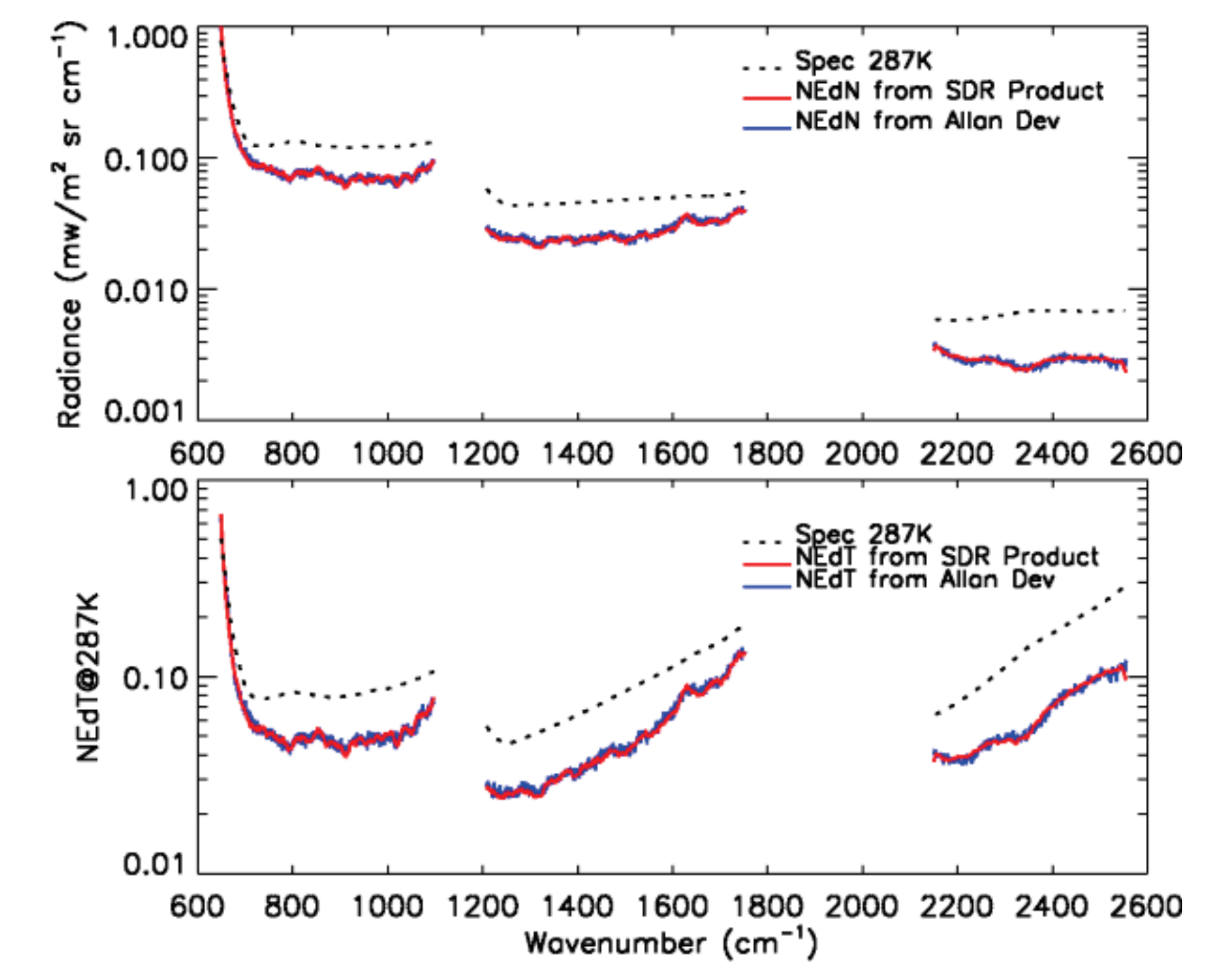### B. Evaluation of CrIS NEdN (NEdT) from SDR Product

Fig. 6. Comparison of NEdN from CrIS normal spectral resolution SDR product and NEdN from Allan deviation using SDR data for a total scan line of 510 (top panel) and the corresponding NEdT at blackbody temperature 287 K (bottom panel). Note that the specification of NEdN (NEdT) at 287 K (black dash line) is also shown.
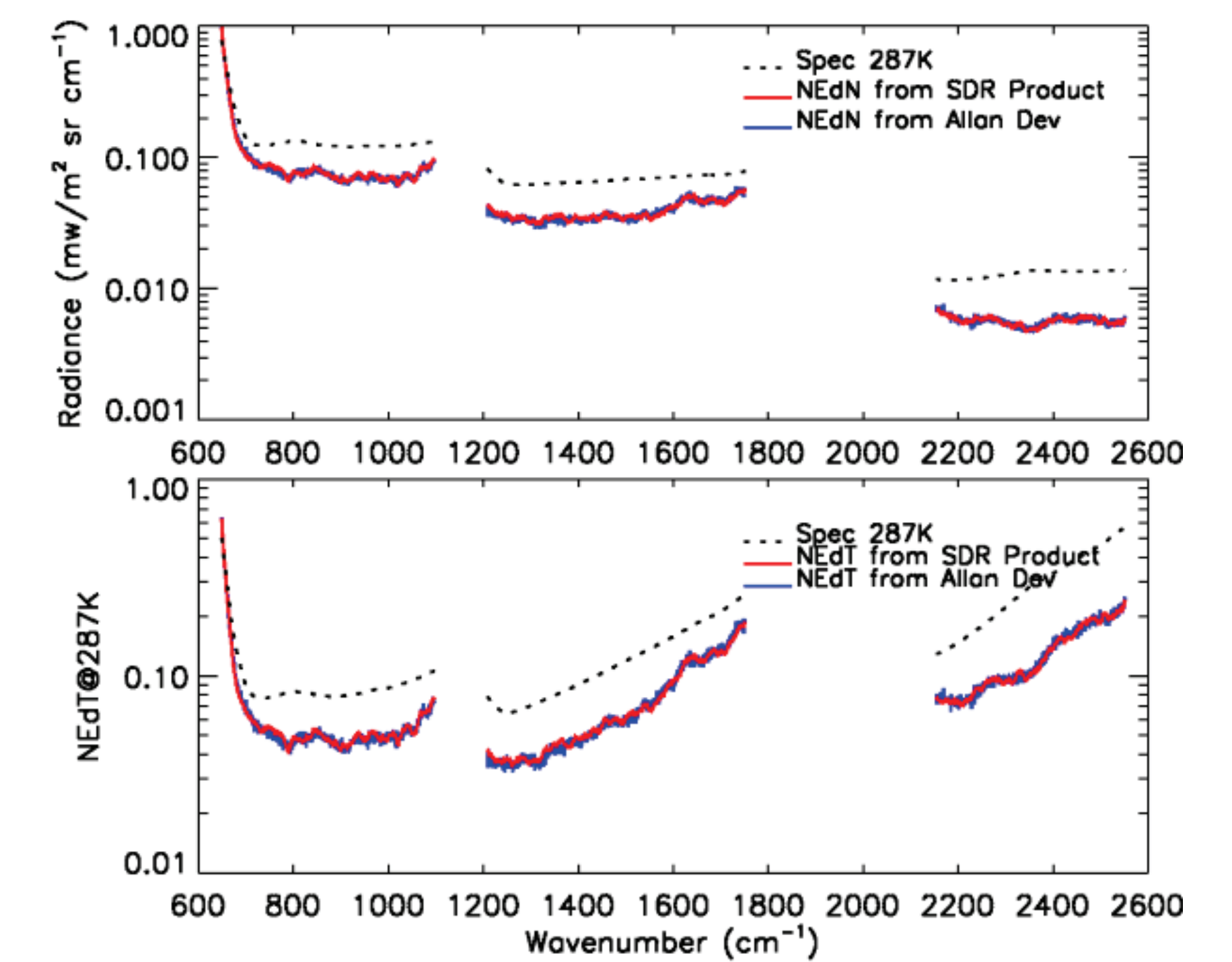

Fig. 7. Same as Fig. 6, but for CrIS full spectral resolution. CrIS full spectral resolution noise is higher by ~ ×1.4 and ~ ×2 due to the increase of spectral resolution of 2 and 4 in MWIR and SWIR bands, respectively, as compared to the CrIS normal spectral resolution.

Conclusion

- In this study, Allan deviation method is used to characterize the instrument NEdN performance.
- Results show that Allan deviation is a better approach than standard deviation in computing the CrIS NEdN.
- The NEdN calculated from Allan deviation can be converged if using enough scan lines (around 510 scan lines) to derive regardless of using calibrated SDR data or uncalibrated RDR data.
- Allan deviation can lead to SI traceable noise characterization for CrIS instrument.
- Comparison of the NEdN calculated from Allan deviation method and the NEdN from SDR product indicates that NEdN from SDR product averaging window size of 30 is optimal.

References

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