Study on SNPP CrIS Noise Equivalent Differential Radiance Using Allan Deviation

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STAR ICVS Instrument Performance Review

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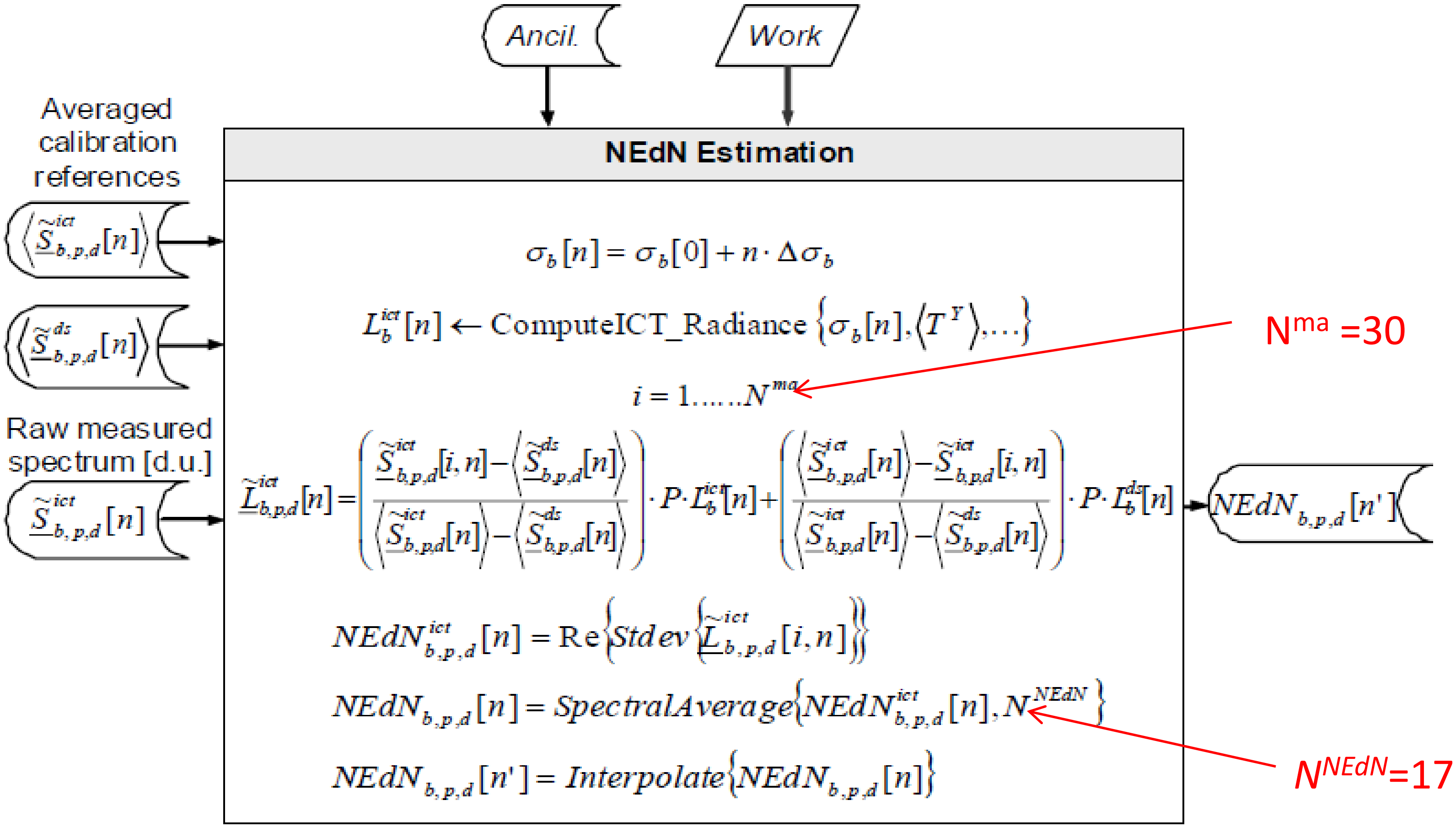
NEdN in CrIS SDR Product



- The NEdN estimate is based on ICT measurements collected within the moving window averaging interval (30 ICTs)
- A "smoothing" function is employed in the spectral domain to further average the NEdN estimate over 17 adjacent spectral bins

Allan Deviation

- The standard deviation (STD) 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.

- To better describe the precision of CrIS radiance at the observed frequency, we can use the Allan deviation:

Overlapped Allan Variance: Stride = τ_0 = sample period

$$\sigma_y^2(\tau) = \frac{1}{2m^2(M-2m+1)} \sum_{j=1}^{M-2m+1} \sum_{i=j}^{j+m-1} \left(y_{i+m} - y_i\right)^2$$

where M is the total number of data (scans) and m is the number of overlapping samples (Riley, 2007 "Handbook of Frequency Stability Analysis")

Data and Method

Derived directly from CrIS RDR data

- ICT and DS interferograms from CrIS RDR data
  a) Apply FFT from interferogram space to spectral space for ICT and DS
  b) Calculate gain: $(C_{ict} - C_{sp})/(R_{ict} - R_{sp})$ for **each scan**, and apply simple calibration
  c) Use standard deviation method to calculate the NEdN
  d) Use Allan deviation method to calculate the NEdN

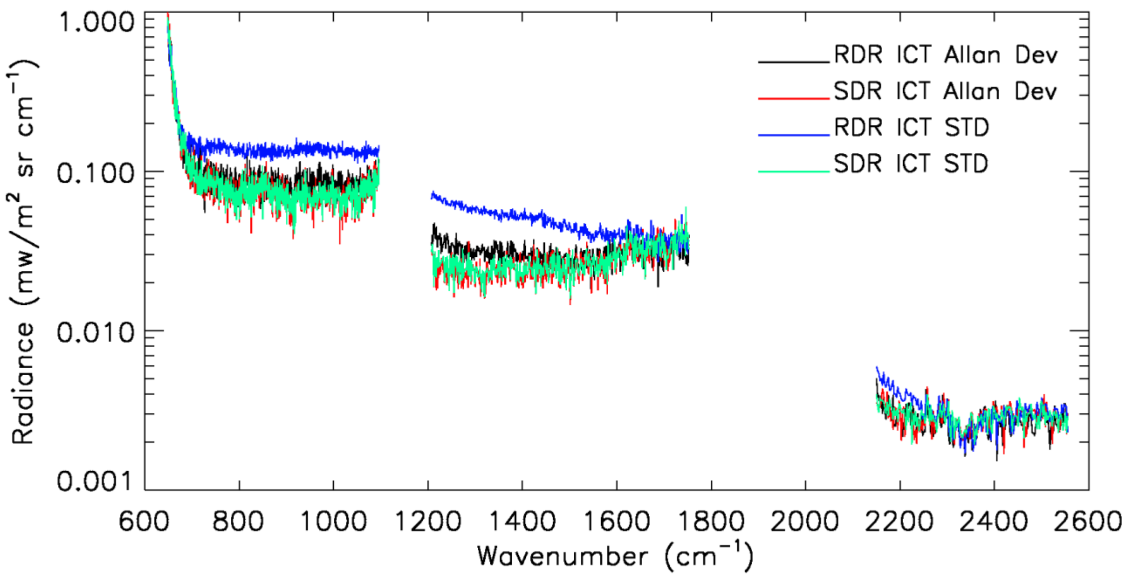
Derived from CrIS ADL output calibrated ICT spectra data

- Calibrated ICT output from CrIS ADL run
  a) Use gain from ICT and DS measurements collected within the **moving window averaging interval** (30 ICTs and 30 DSs)
  b) Use standard deviation method to calculate the NEdN
  c) Use Allan deviation method to calculate the NEdN

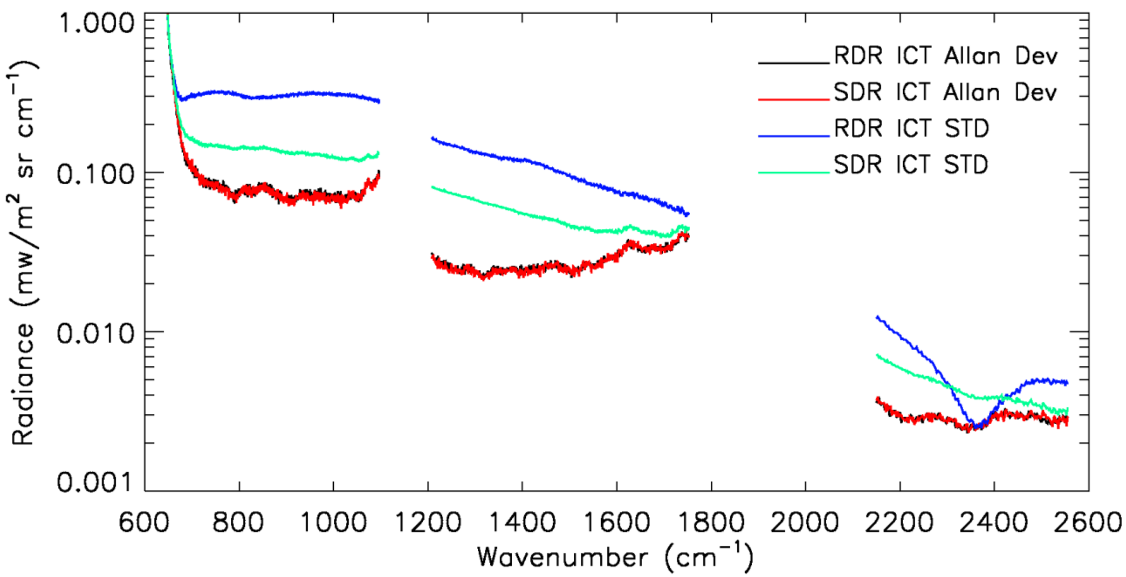
NEdN from CrIS SDR product

NEdN Variations

30 Scans

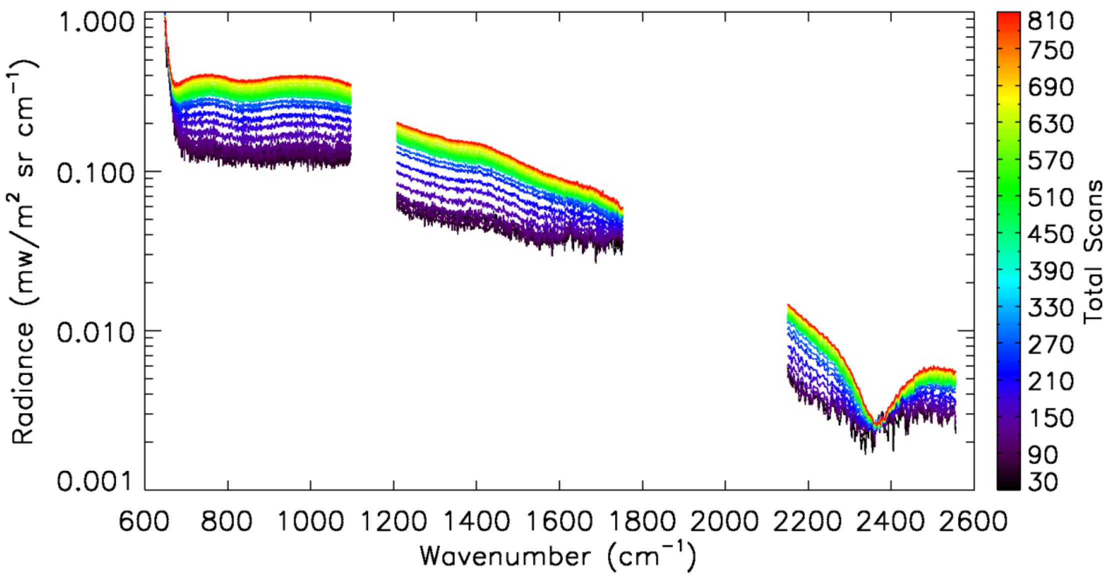


510 Scans

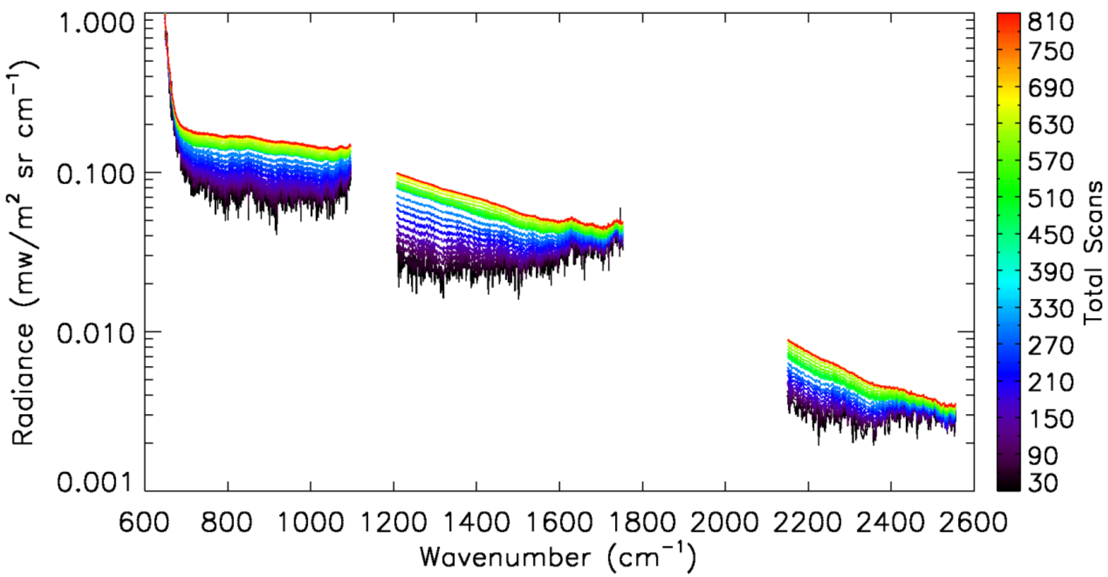


NEdN Using STD

From RDRs

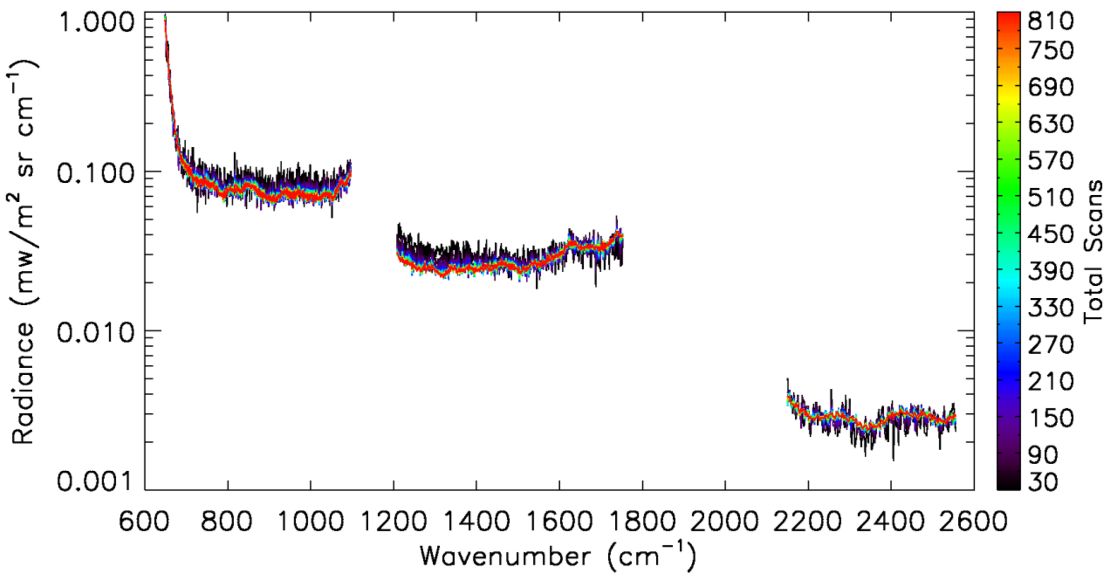


From SDRs

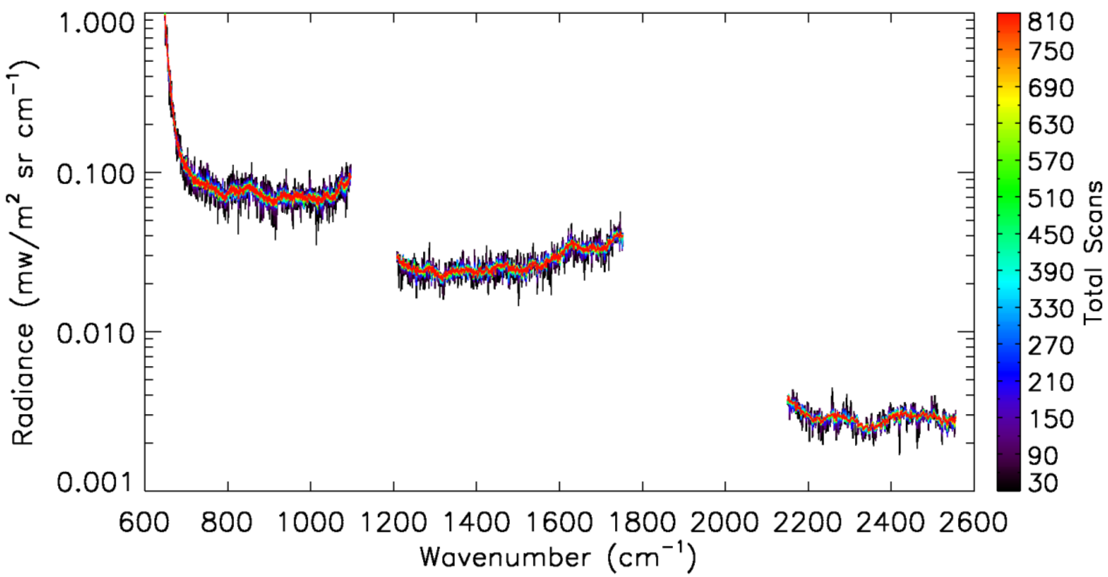


NEdN Using Allan Deviation

From RDRs

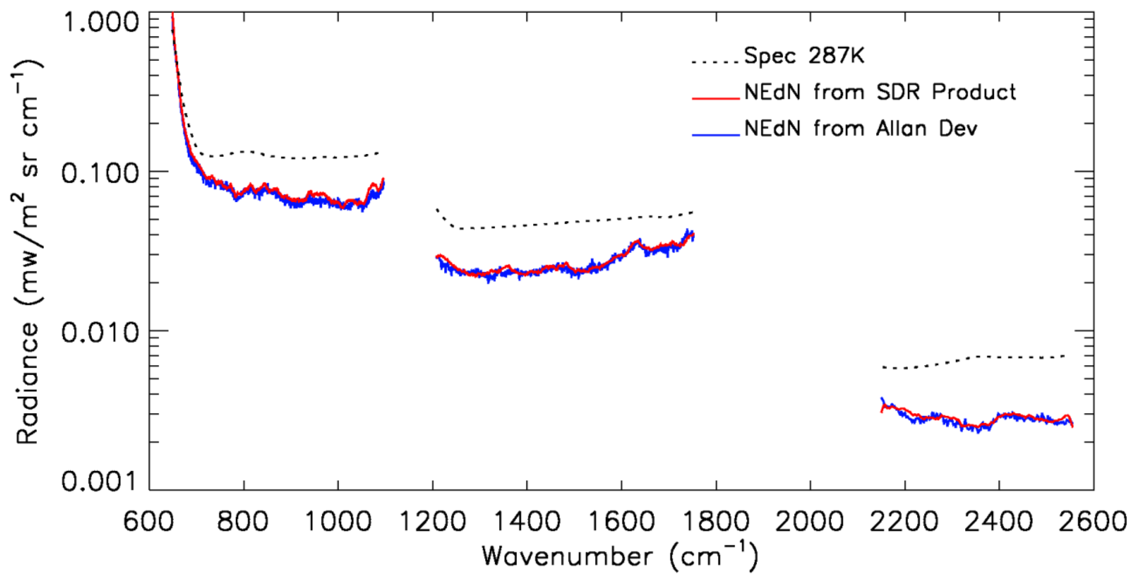


From SDRs

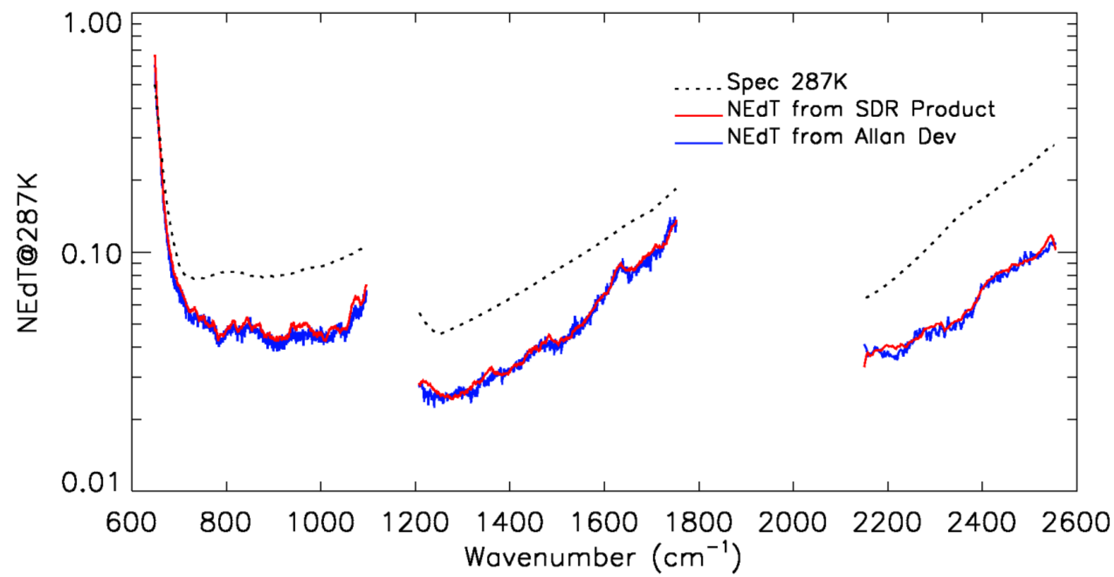


NEdN/NEdT from Allan Deviation and SDR Product

Normal
Spectral
Resolution
FOV1



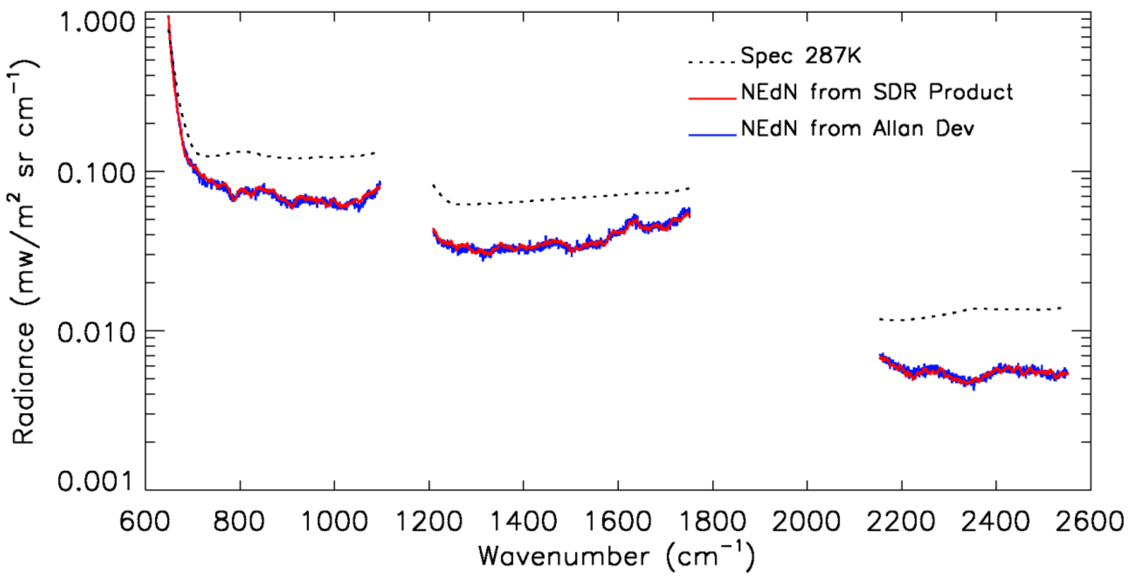
NEdN



NEdT

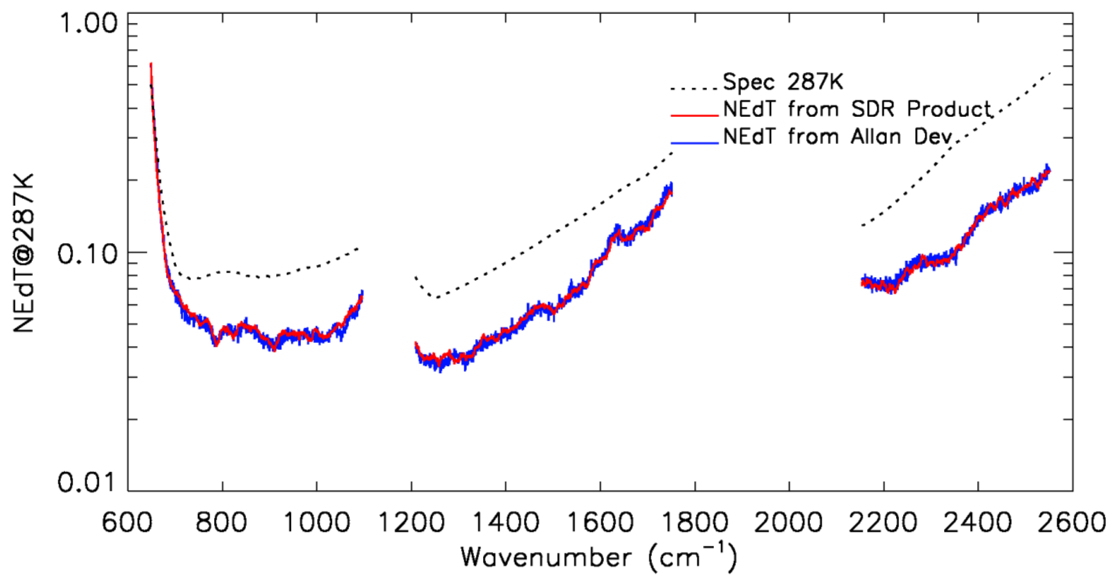
NEdN/NEdT from Allan Deviation and SDR Product

Full Spectral Resolution FOV1



NEdN

NEdN increases by a factor of **1.41** and **2.0**, due to the increase of spectral resolution of **2** and **4** for the MW and SW bands, respectively, compared to normal resolution SDR



NEdT

Noise Increased by Self-Apodization Correction

Let ε' be the noise of the spectrum S' before SA correction. The Spectrum after SA correction is

$$S = SA^{-1}(S' + \varepsilon')$$

, assume the mean value of ε' = 0, i.e E(ε') = 0

Thus, the noise vector after the SA correction is

$$\varepsilon = SA^{-1}\varepsilon'$$

The noise of the k-th spectral bin is

$$\varepsilon_k = \sum_j a_{k,j}\varepsilon'_j$$

, where $a_{k,j}$ is the element of the SA^{-1} matrix

Statistically, the noise is estimated as the Expectation or mean of an ensemble of samples:

$$NEdN_k^{\ 2} = E\{\varepsilon_k^{\ 2}\} = E\{\sum_j a_{k,j}^{\ 2}\varepsilon'^{\ 2}_j\} + E\{\sum_{j\neq i} a_{k,j}a_{k,i}\varepsilon'_j\varepsilon'_i\} = E\{\sum_j a_{k,j}^{\ 2}\varepsilon'^{\ 2}_j\}$$

$$= \sum_j a_{k,j}^{\ 2}E\{\varepsilon'^{\ 2}_j\} = \sum_j a_{k,j}^{\ 2}NEdN'^{\ 2}_j$$

= 0 , assuming uncorrelated noise among channels

If the $NEdN_j$ is roughly the same magnitude among channels, the NEdN after SA^{-1} is

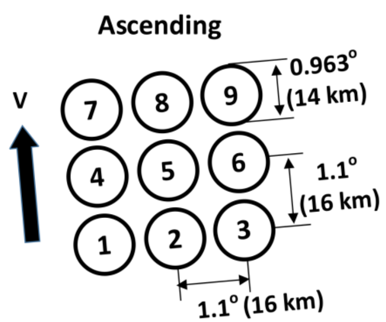
$$NEdN_k = \sqrt{E\{\varepsilon_k^{\ 2}\}} = NEdN'\sqrt{\sum_j a_{k,j}^{\ 2}}$$

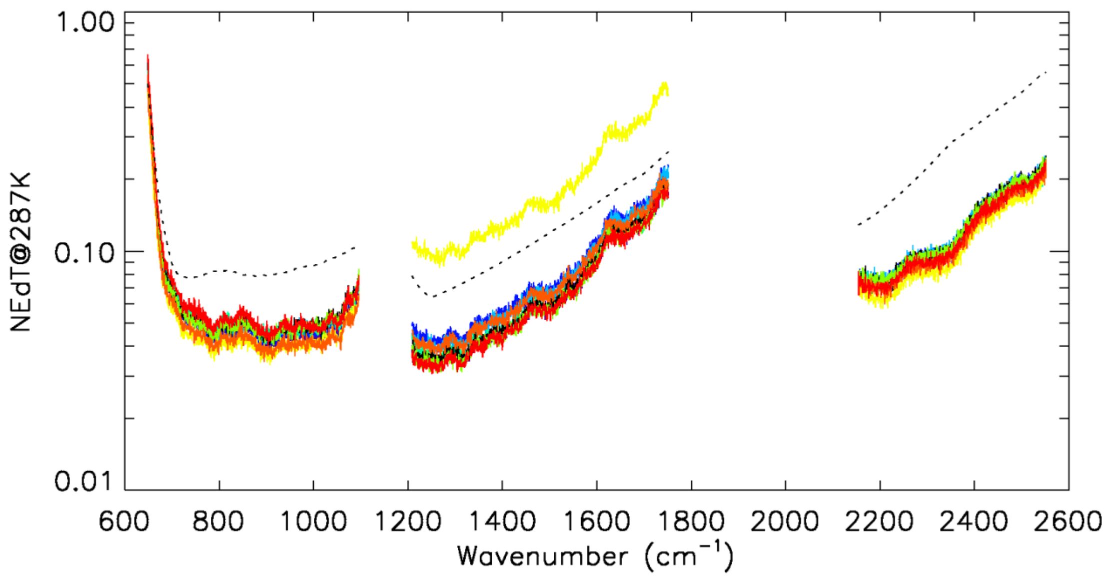
Noise amplification factor

Yong Han, "Study Notes on Noise Increase due to SA Correction", 08/11/2014

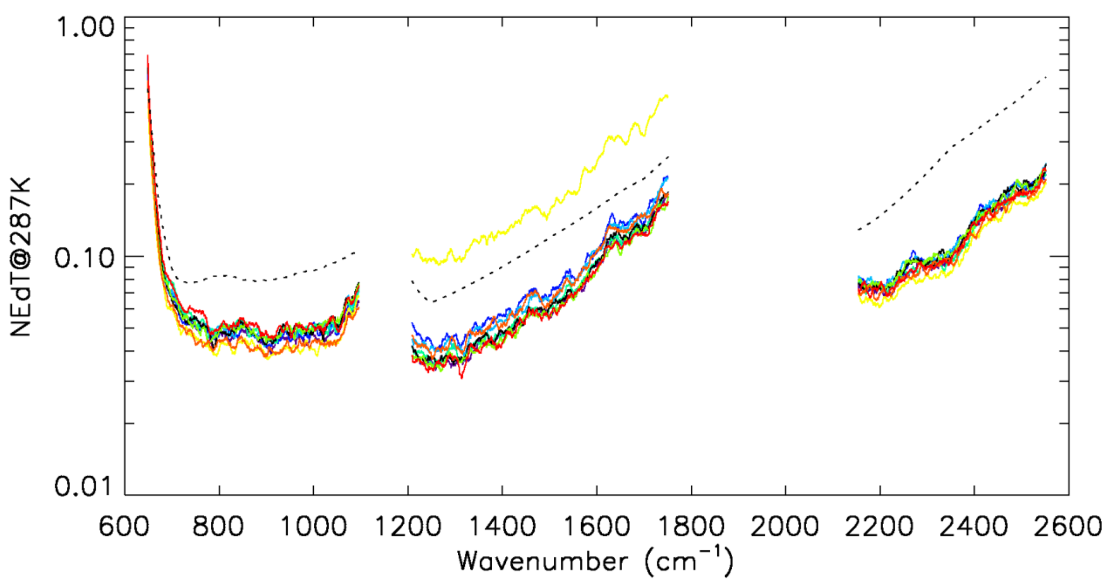
NEdT from Allan Deviation and SDR Product

NEdT for Full Spectral Resolution for all 9 FOVs **before SA correction**





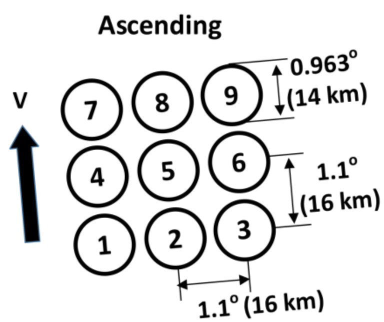
NEdT from Allan Deviation

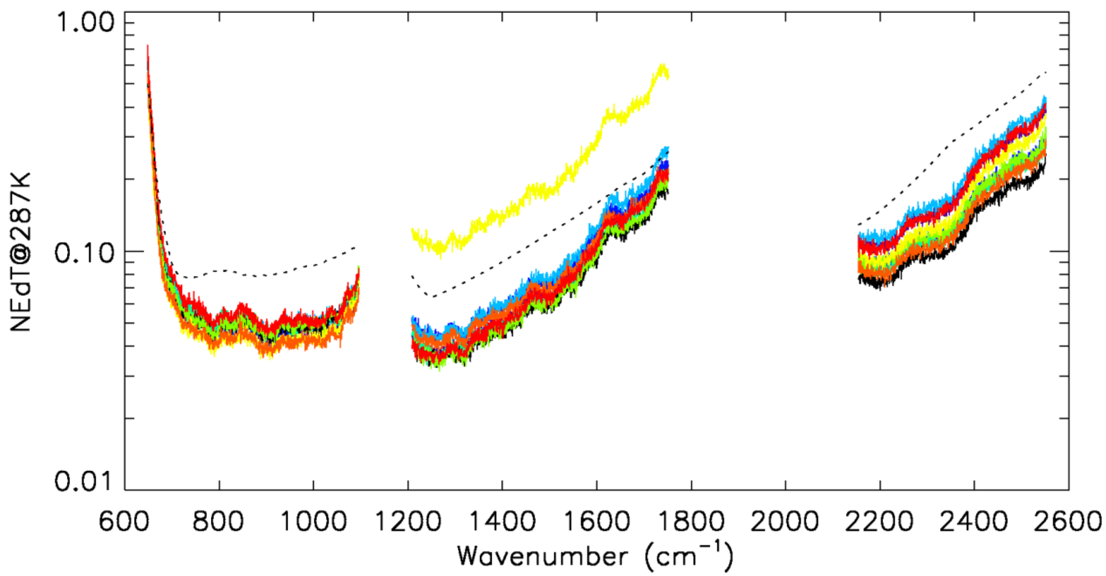


NEdT from SDR Product

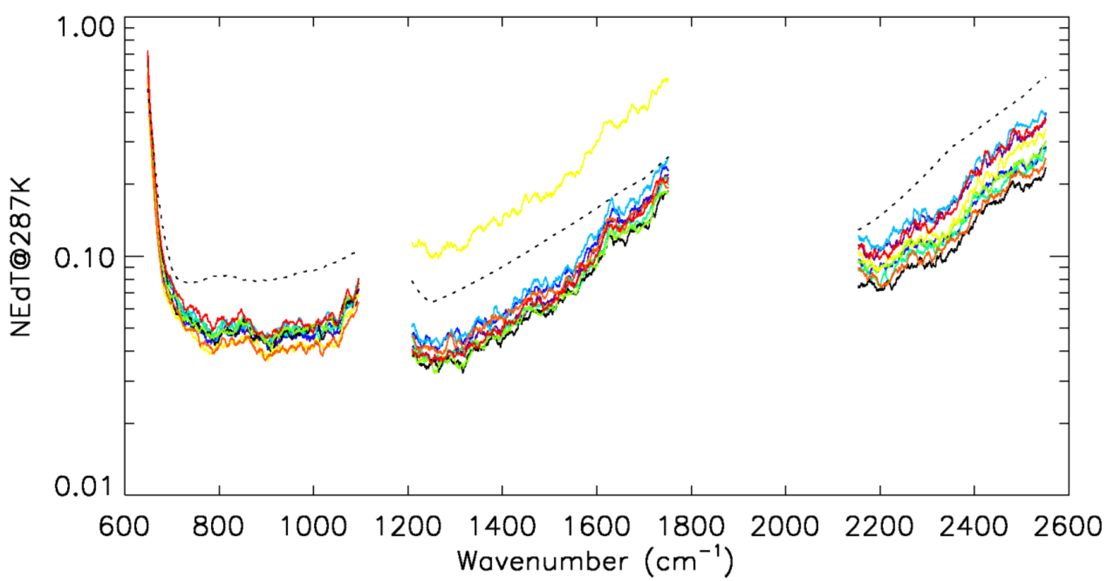
NEdT from Allan Deviation and SDR Product

NEdT for Full Spectral Resolution for all 9 FOVs **after SA correction**





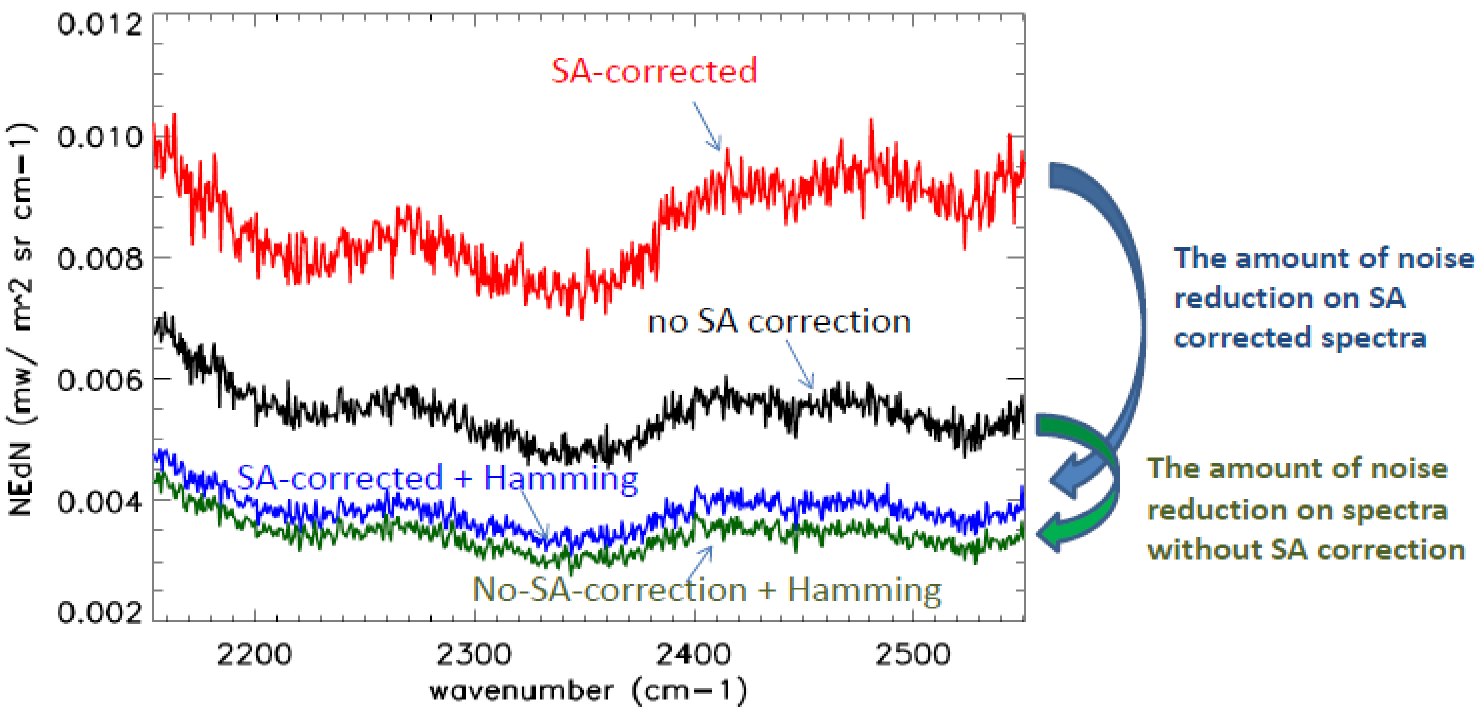
NEdT from Allan Deviation



NEdT from SDR Product

NEdN increases by **5 – 20%** and **15 – 75%** for MW and SW bands, respectively due to SA correction

Noise Reduction by Hamming Apodization (SW)



Due to negative correlation, noise reduction on SA corrected spectra is larger than that on uncorrected spectra

Yong Han, "CrIS SDR Noise after SA Correction and Apodization", 10/22/2014

Conclusions

- Allan deviation is a better method than standard deviation to calculate the NEdN for CrIS
- NEdN calculated from Allan deviation can converge if using enough scan lines to derive regarding of SDR or RDR data
- NEdN from CrIS SDR product is good and basically the same as that from Allan deviation