Insights into CrIS processing using full up simulation

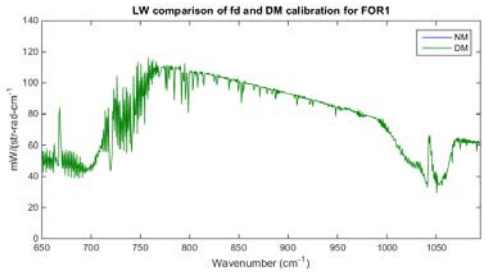
Daniel. L. Mooney
MIT Lincoln Laboratory

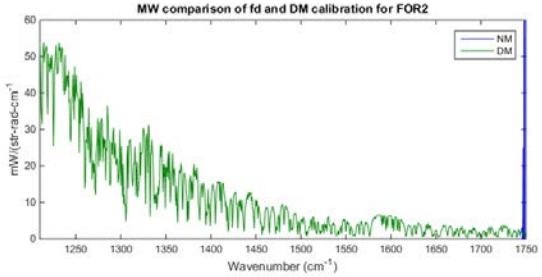
STAR JPSS 2017 Annual Science Team Meeting
NOAA Center for Weather and Climate Prediction, College Park, MD
August 15, 2017

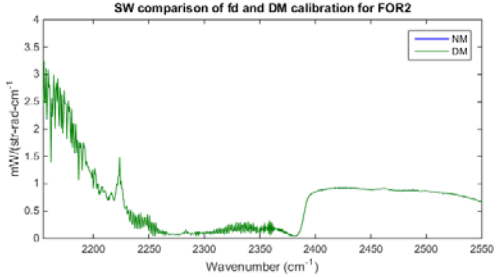
Simulation is useful for

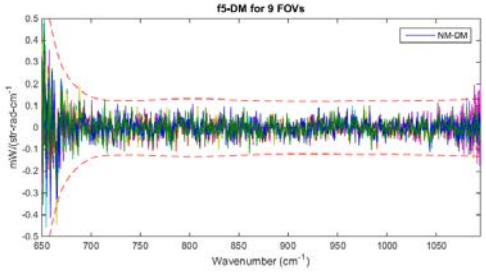
- **Algorithm development and validation**
  - Normal length interferograms
  - Extended length interferograms
  - F and ISA computation and approximation
- **Fault testing**
  - Simulated spikes an known locations using multiple known spectra
  - Dropped fringe counts
- **Algorithm optimization**
  - ISA (small N, large N)
  - ISA (delta function approx.)
  - Band trimming (empirical)
  - Non-linearity

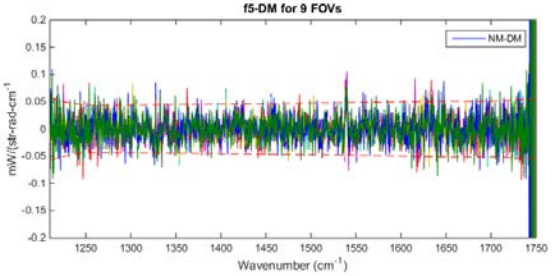
Simulated spectra and errors relative the TRUTH

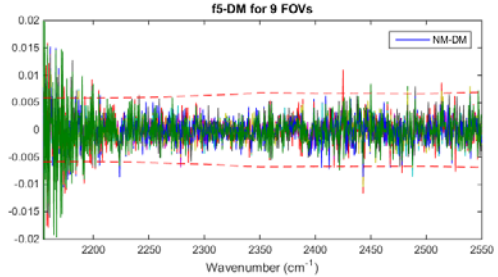












- NOAA88b profiles used with LBLRTLM to create high resolution spectra and interferograms
- Single ray on-axis and extended FOV off –axis interferograms
- Spacecraft processing
- Many different ground algorithms tested
- We can now insert simulated interferograms into operation h5 files to test with operational code
- All error plots are error relative to TRUTH (boresight ray interferogram)

Simulation results for 5 topics

- ISA and F matrix analysis
- Large N and small N psinc computation for optimized algorithm
- Radiance errors relative to NEDN and color temperature errors
- Delta function approximation in optimized algorithm
- Different A4 algorithm options

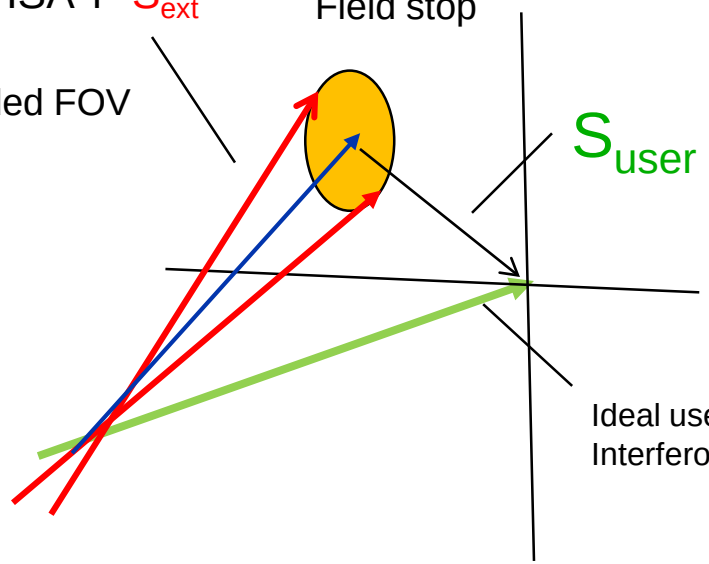
Algorithm optimization for ISA & F

- **Measure an extended FOV off-axis spectrum**
- **ISA is a correction matrix to make an extended FOV look like a single ray interferogram.**
- **F transforms to the user spectral spacing**
- **Process removes most of the FOV variation**
- **S_{user} is the deliverable**

Theoretical Algorithms based on a sensor model

$S_{sensor} = f*ISA*f* S_{ext}$

- Collapse extended FOV
- Spectral shifts
- ILS change



$S_{user} = F*S_{sensor}$

Ideal user grid single ray Interferogram and spectrum

LW simulation summary all floating point Plotted is error from TRUTH

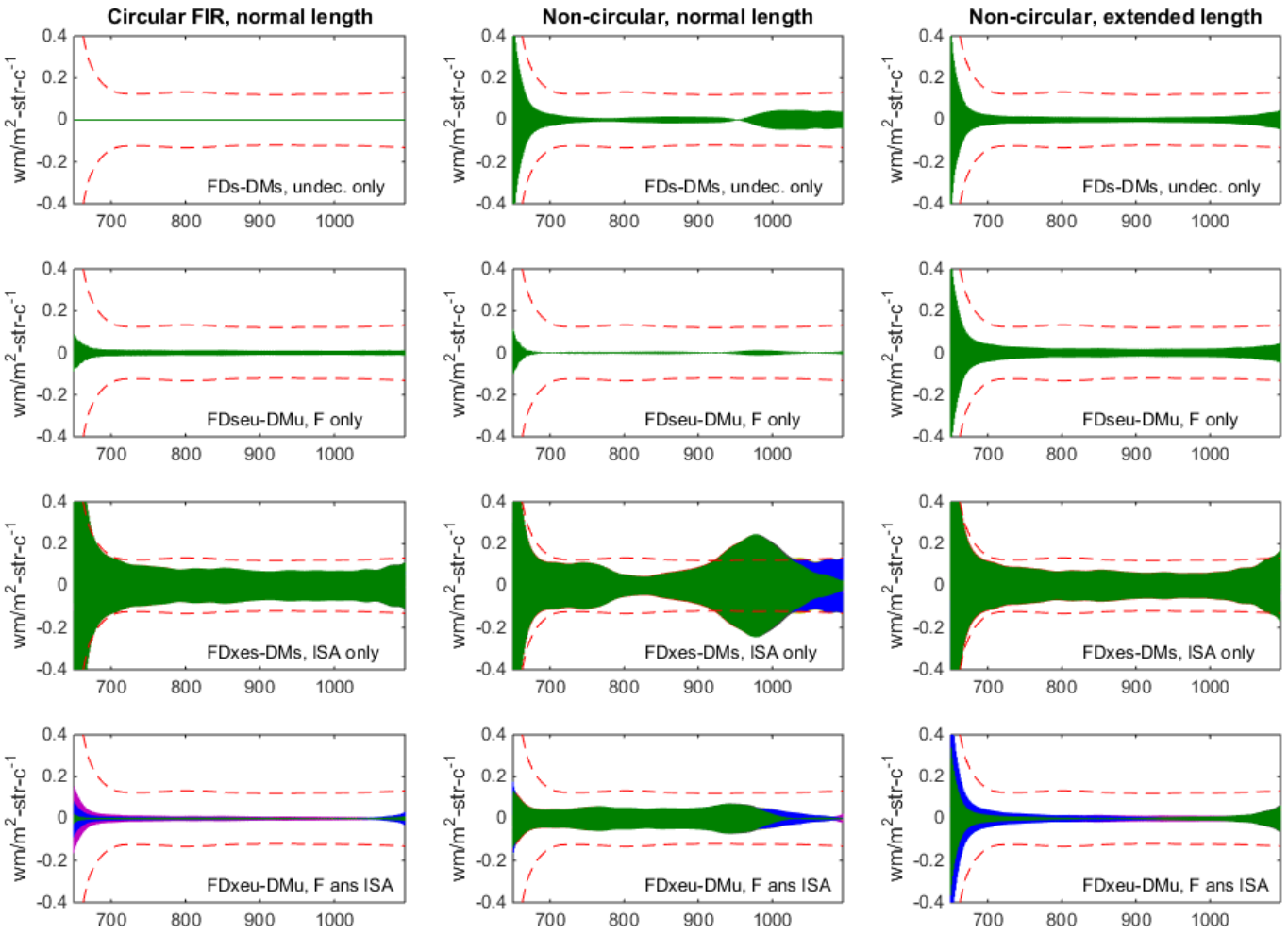
Case

1. on-axis undec. only

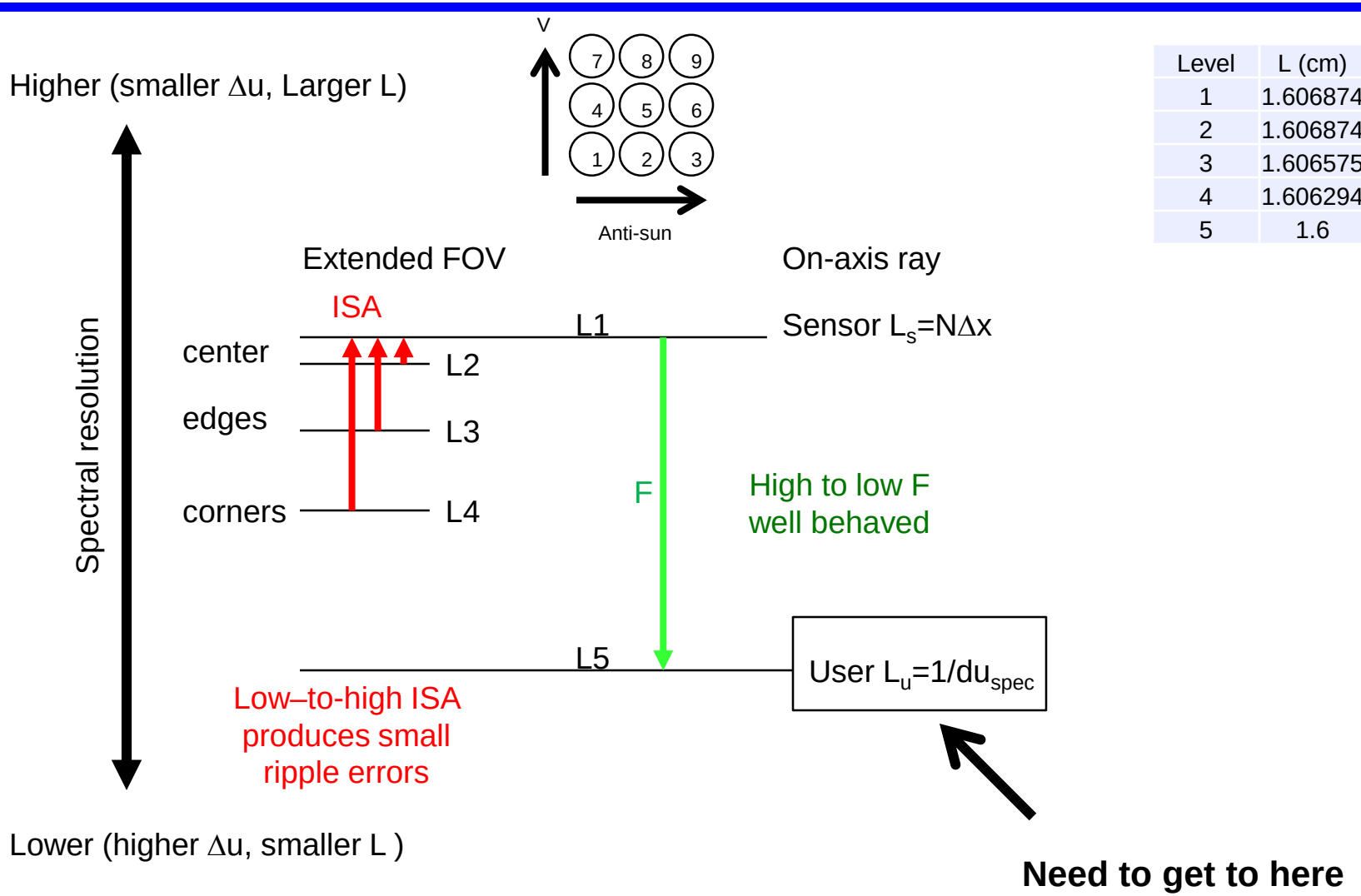
2. F only

3. ISA only

4. F & ISA



Different sampling intervals produce different spectral resolution

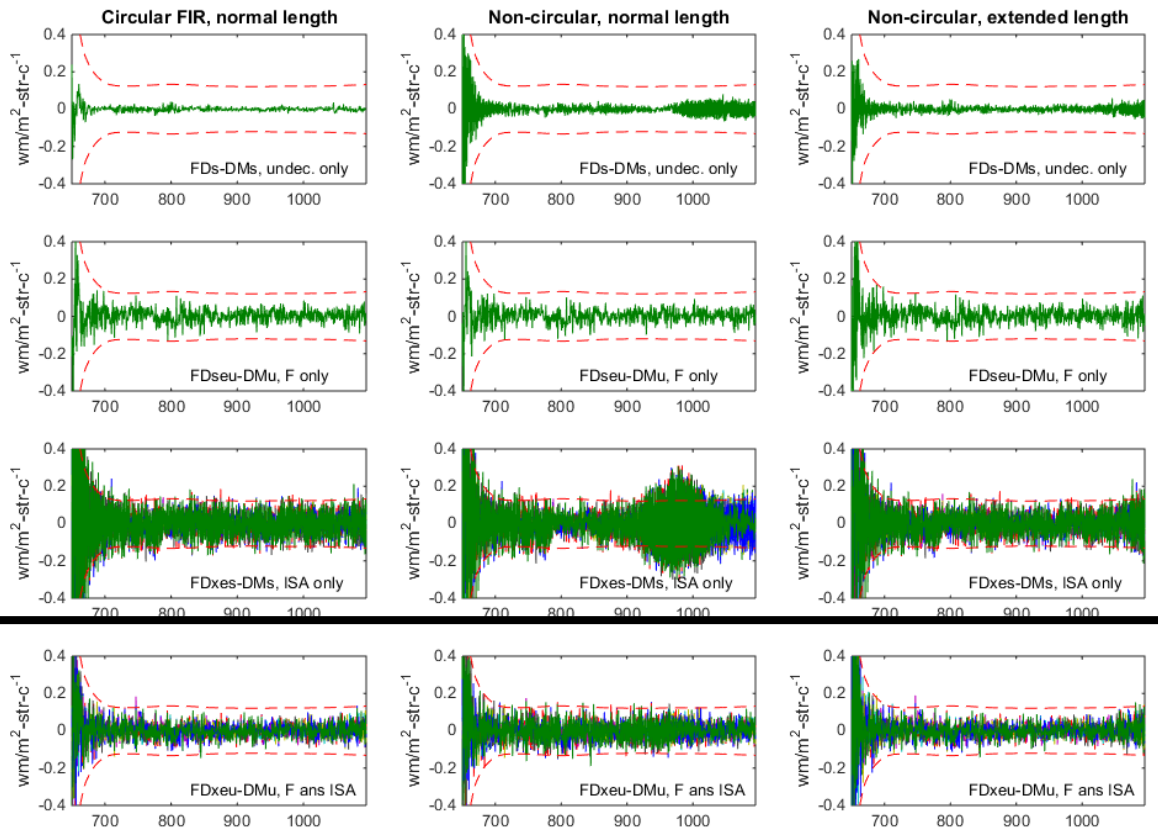


Level	L (cm)
1	1.606874
2	1.606874
3	1.606575
4	1.606294
5	1.6

LW simulation summary DM 14 bit FIR floating point with truncation at 13 bits

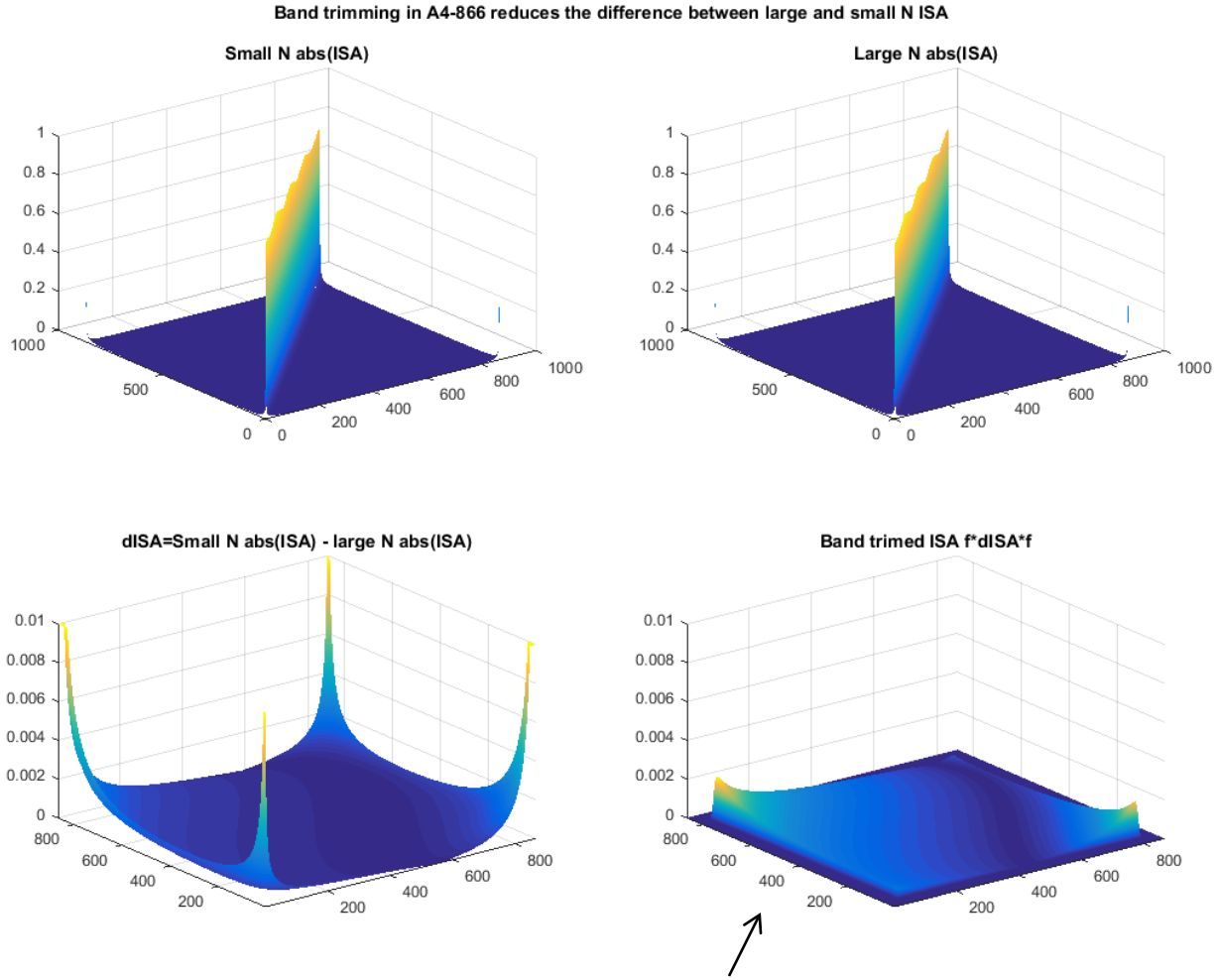
Case

1. undec. only
2. F only
3. ISA only
4. F & ISA



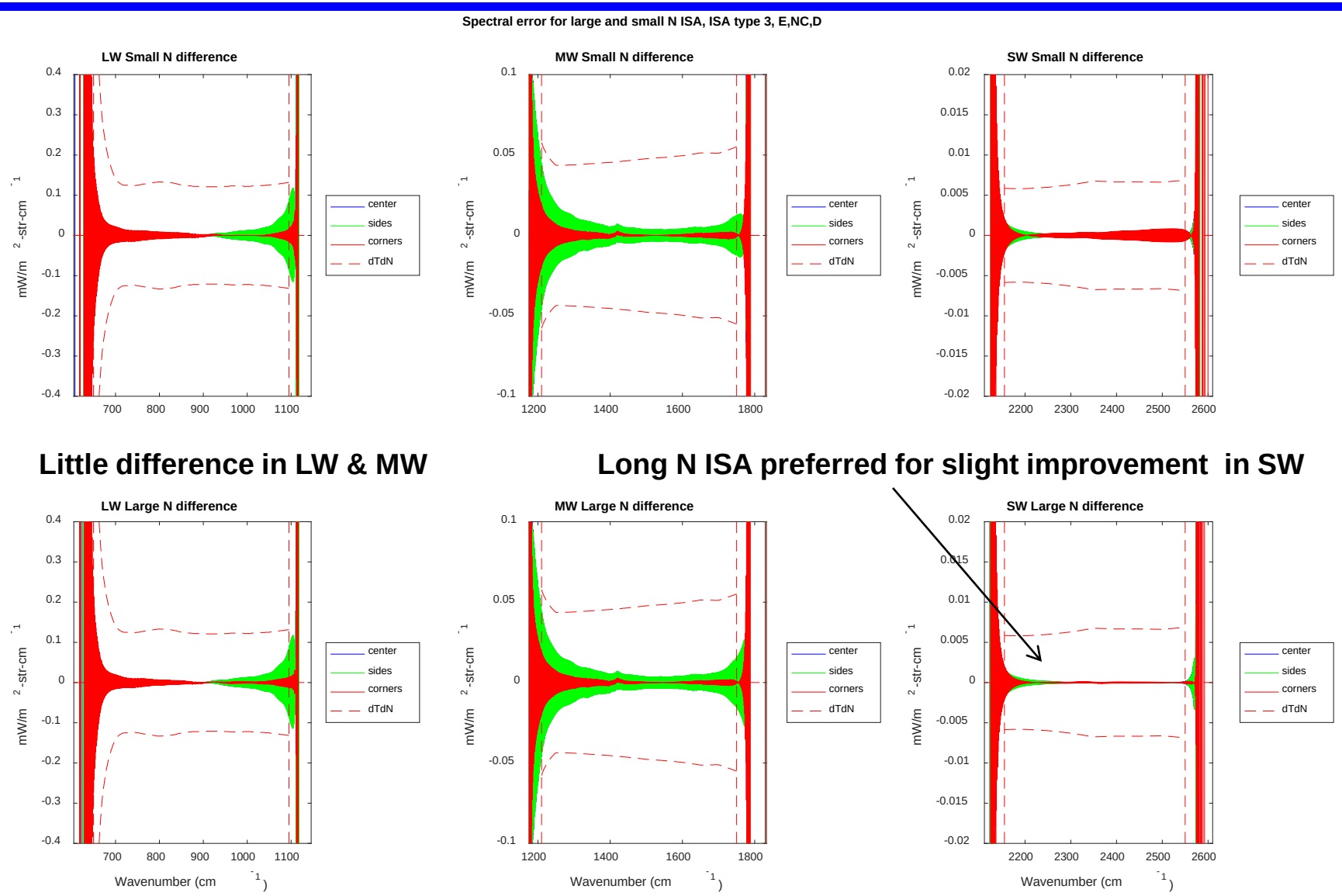
Some insight gained into F & ISA. But any useful analysis must consider the entire calibration process due to compensating effects in process

Pre and post trimming filters reduce the differences between long and short ISA matrices



Current operational A4_866 algorithm uses pre and post trimming filters with large N ISA

Small N ISA and large N ISA spectral error ripple for Extended I, NonCirc FIR, double and A4-874-3p



Little difference in LW & MW

Long N ISA preferred for slight improvement in SW

Analytic derivative of color temperature and color temperature error

- **Temperature noise amplified by color temperature derivative with respect to scene radiance N**

- **$dT = T(N) - T(N_{TRUTH}) = dT/dN(N) * N_{ripple\ error} + O(0.01\%)$**

- **dT/dN(N) is a well behaved analytic function of N and u**
  - **N is radiance W/cm2-str-cm^{-1}=1.e7*mW/m2-str-cm^{-1}**
  - **T is kelvins**
  - **u is wavenumber (cm-1)**
  - **2006 CODATA values: c1=1.1910427e-12, c2=1.4387752**

- **Derivative scales as $1/zN^2 \sim 1/N$**

BB radiance

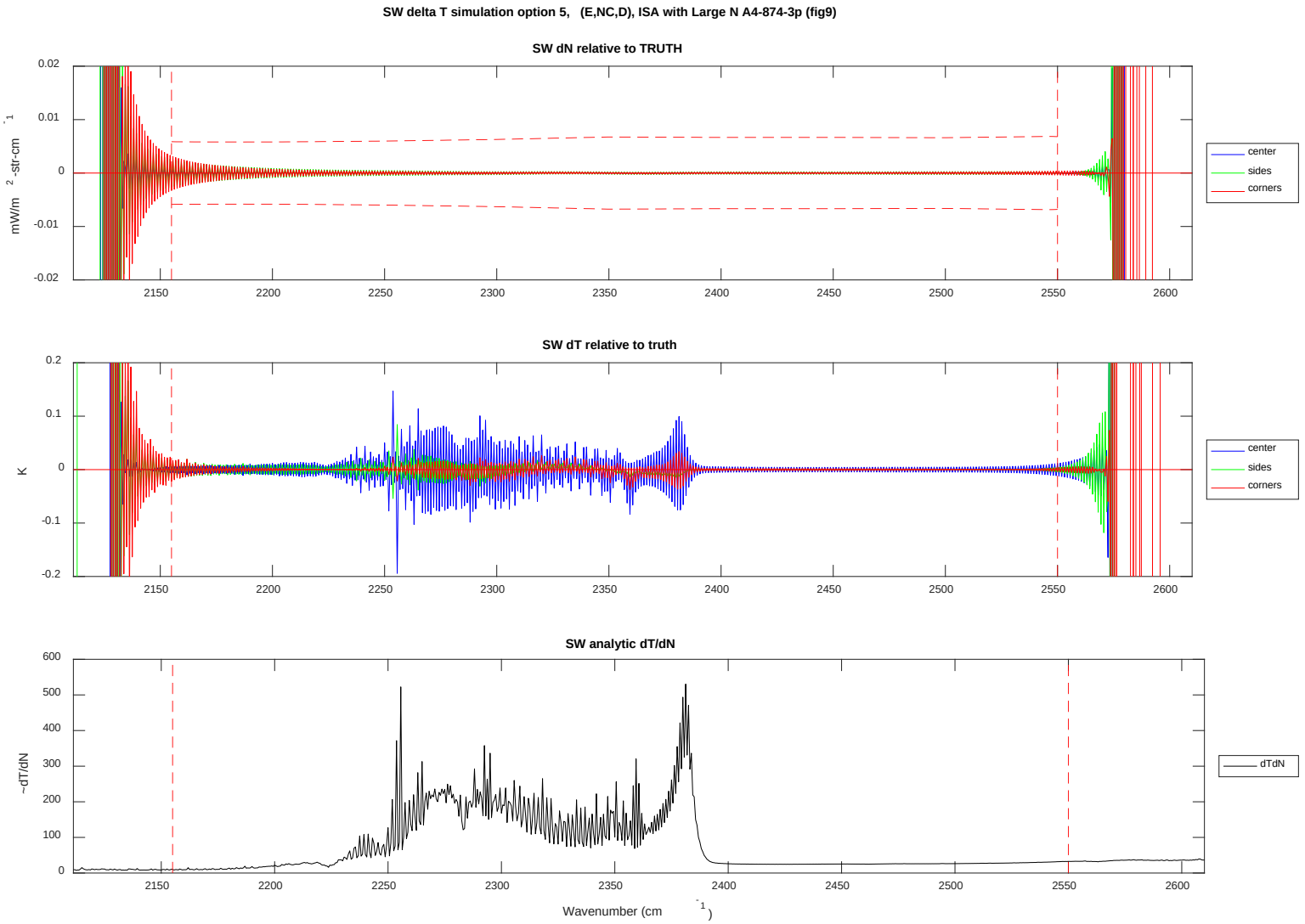
$$N(u,T) = \frac{c_1 u^3}{\exp(c_2 u / T) - 1}$$

Color temperature and derivative

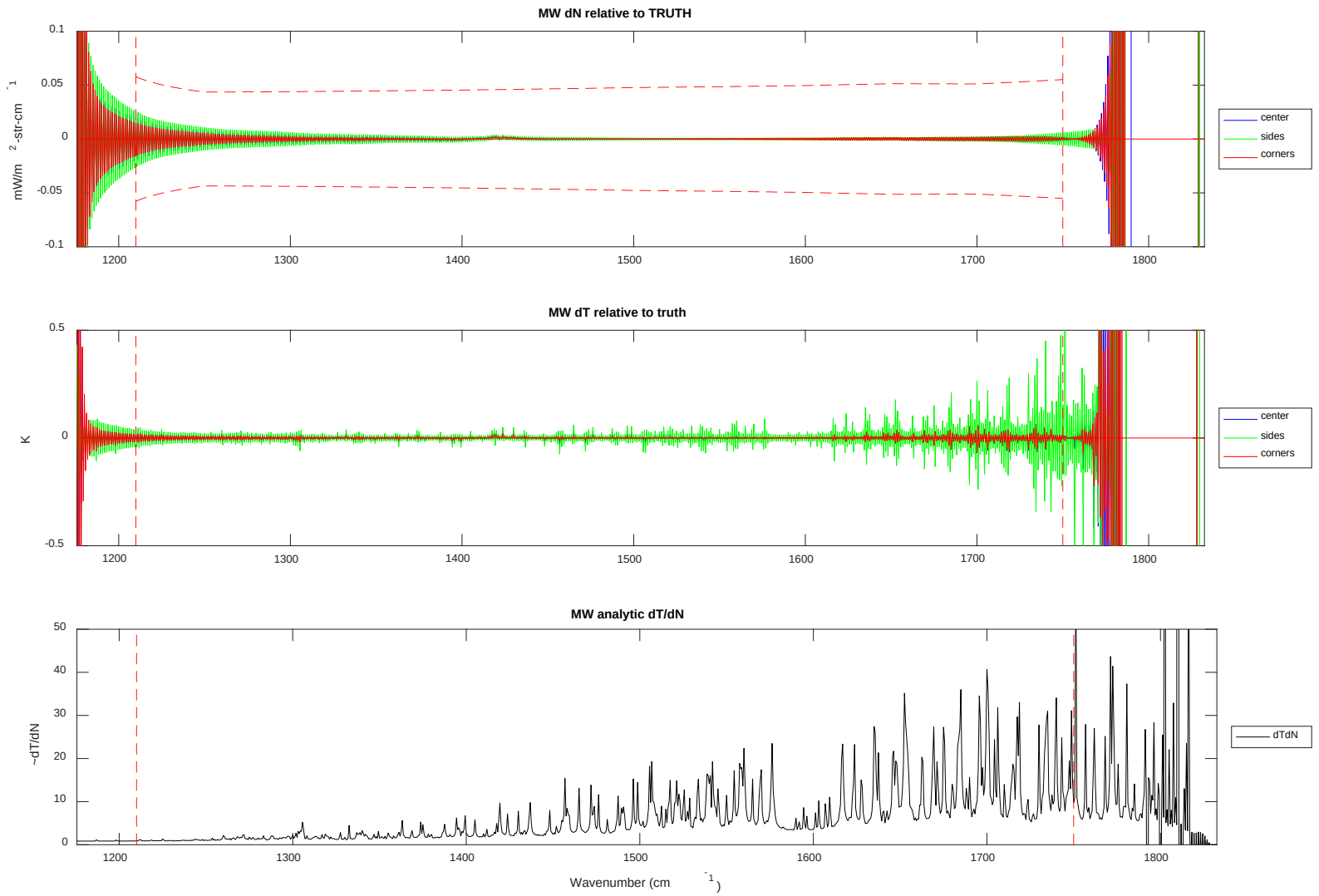
$$T(u,N) = \frac{c_2 u}{\ln(z)}, \qquad z = \frac{c_1 u^3}{N} + 1$$

$$\frac{dT}{dN}(u,N) = \frac{c_2 u}{z \ln(z)^2} \frac{c_1 u^3}{N^2}$$

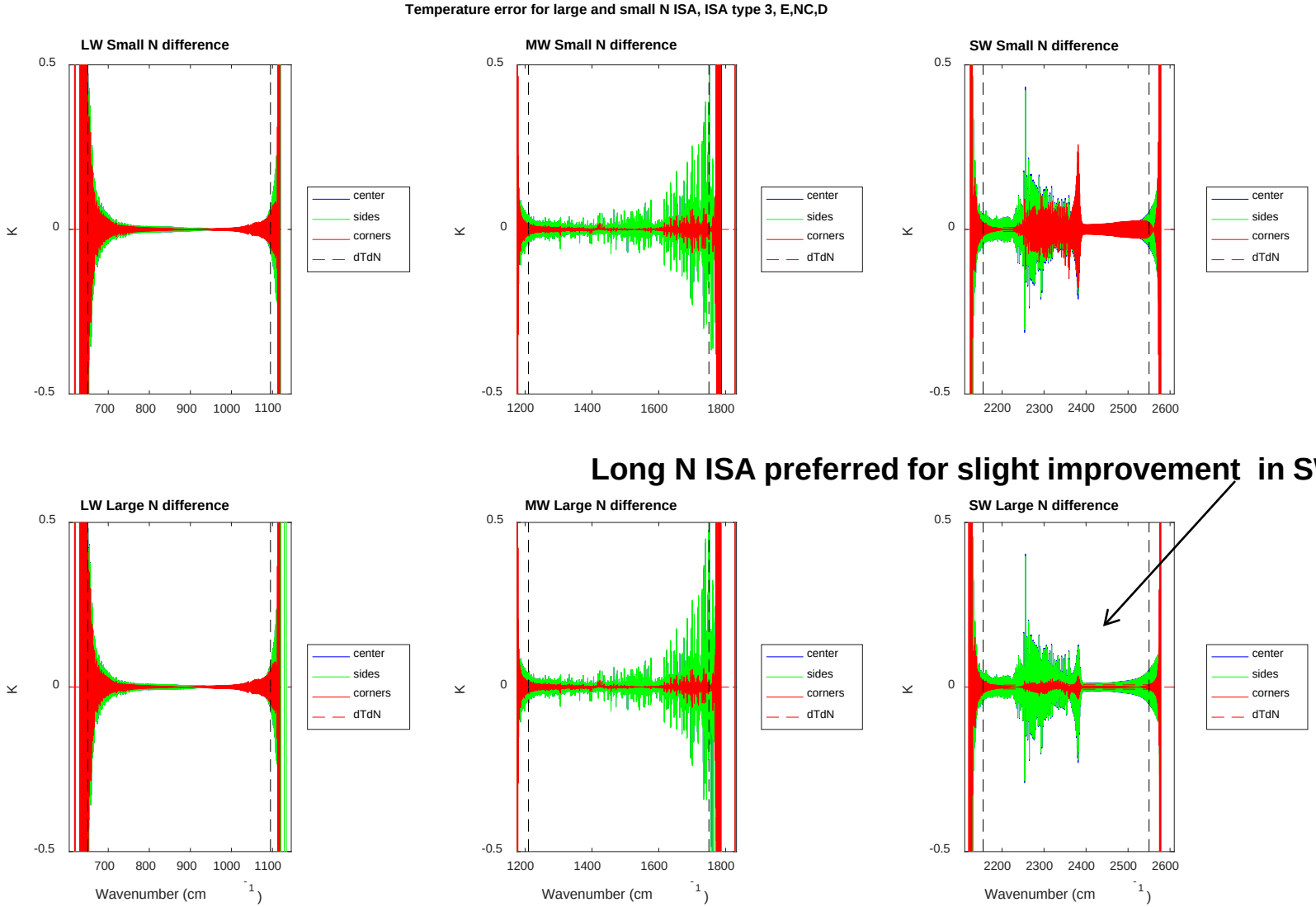
SW spectral ripple error E,NC,D and temperature error and analytic derivative dT/dN with respect to radiance



MW spectral ripple error E,NC,D and temperature error and analytic derivative dT/dN with respect to radiance



LW small N ISA and large N ISA delta Temperature ripple error for E,NC,D



Long N ISA preferred for slight improvement in SW

Delta function approximation

- **SA matrix is a double integral over wavenumber and off asis angle**

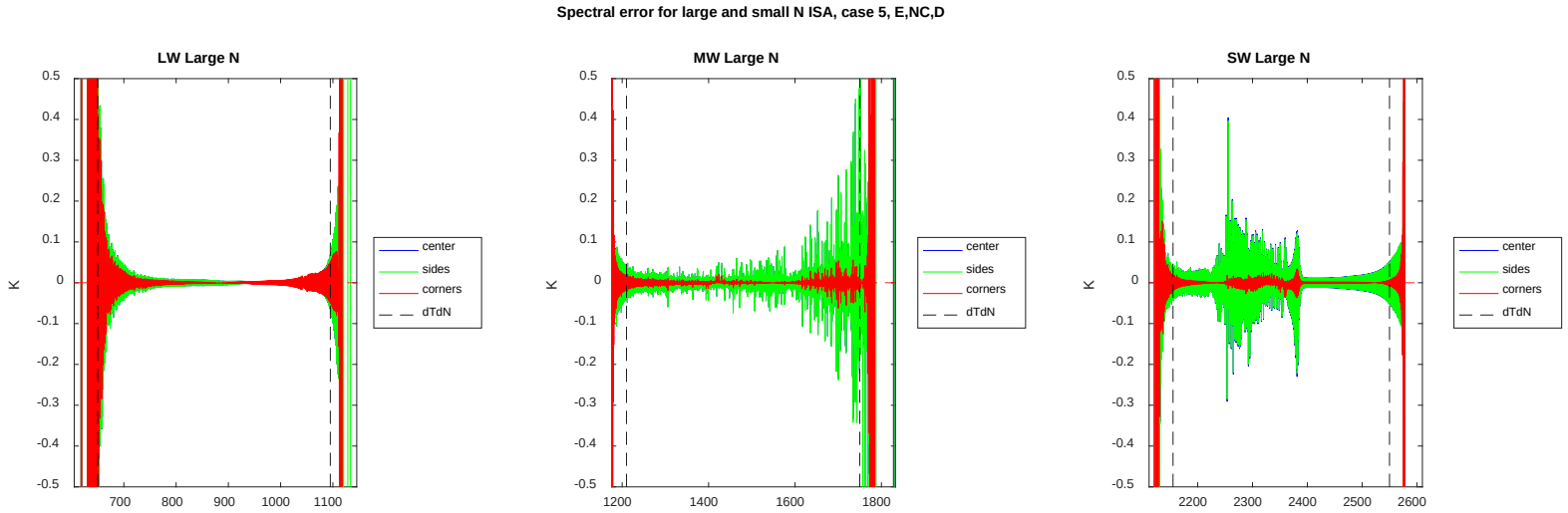
$$SA[k,k] = \int_{a\min}^{a\max} \int_{u_0}^{u_0+N/(L\cos(a))} P(a)\cos(a)Lpsinc(uL\cos(a)-k)\,psinc^*(uL-k')duda$$

- **Considerable computation simplicity assuming second psinc is a delta function**
  - **Used in A4 algorithm**

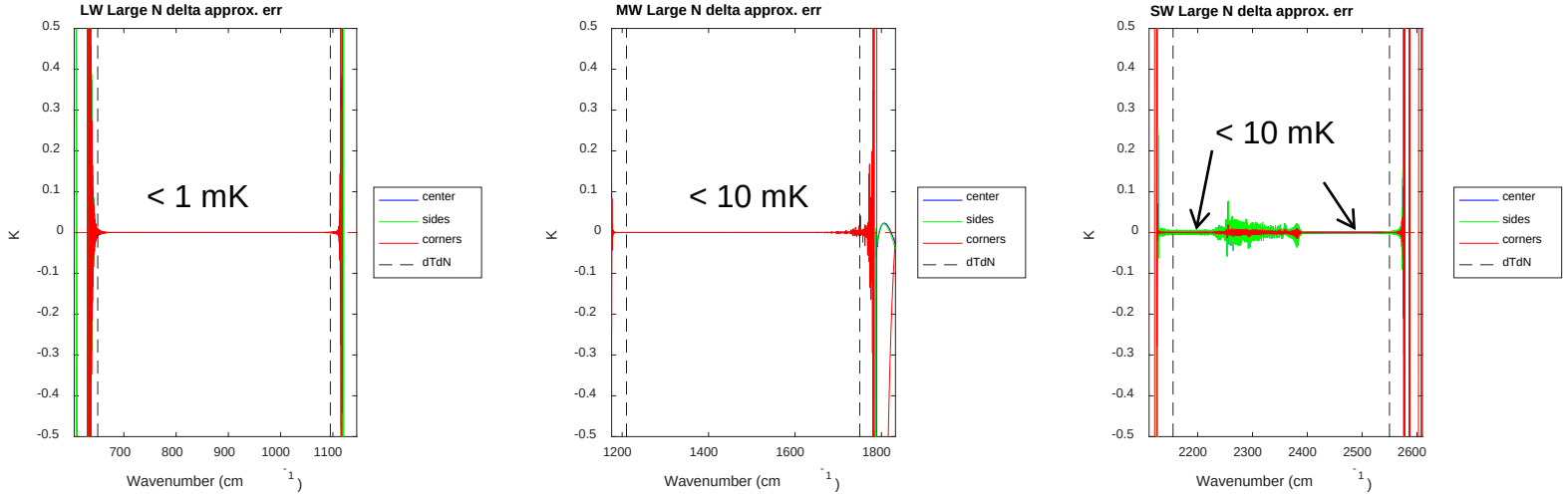
$$SA[k,k] = \int_{a\min}^{a\max} \int_{u_0}^{u_0+N/(L\cos(a))} P(a)\cos(a)Lpsinc(k\cos(a)-k)da$$

- **What is the impact of this approximation on the calibrated radiance**

Temperature delta function approximation errors for an optimized algorithm (E, NC, D) are small



Delta approx. errors are an order of magnitude lower in SW, lower in MW and LW



Current A4 algorithm (2017) variations being studied, consider A4_866, A4_874_3p, A4_874_3p comparison

- **Winner in 12 algorithm bake off**
- **Current variations under study are different ways M can be computed**
- **Very empirical studies**

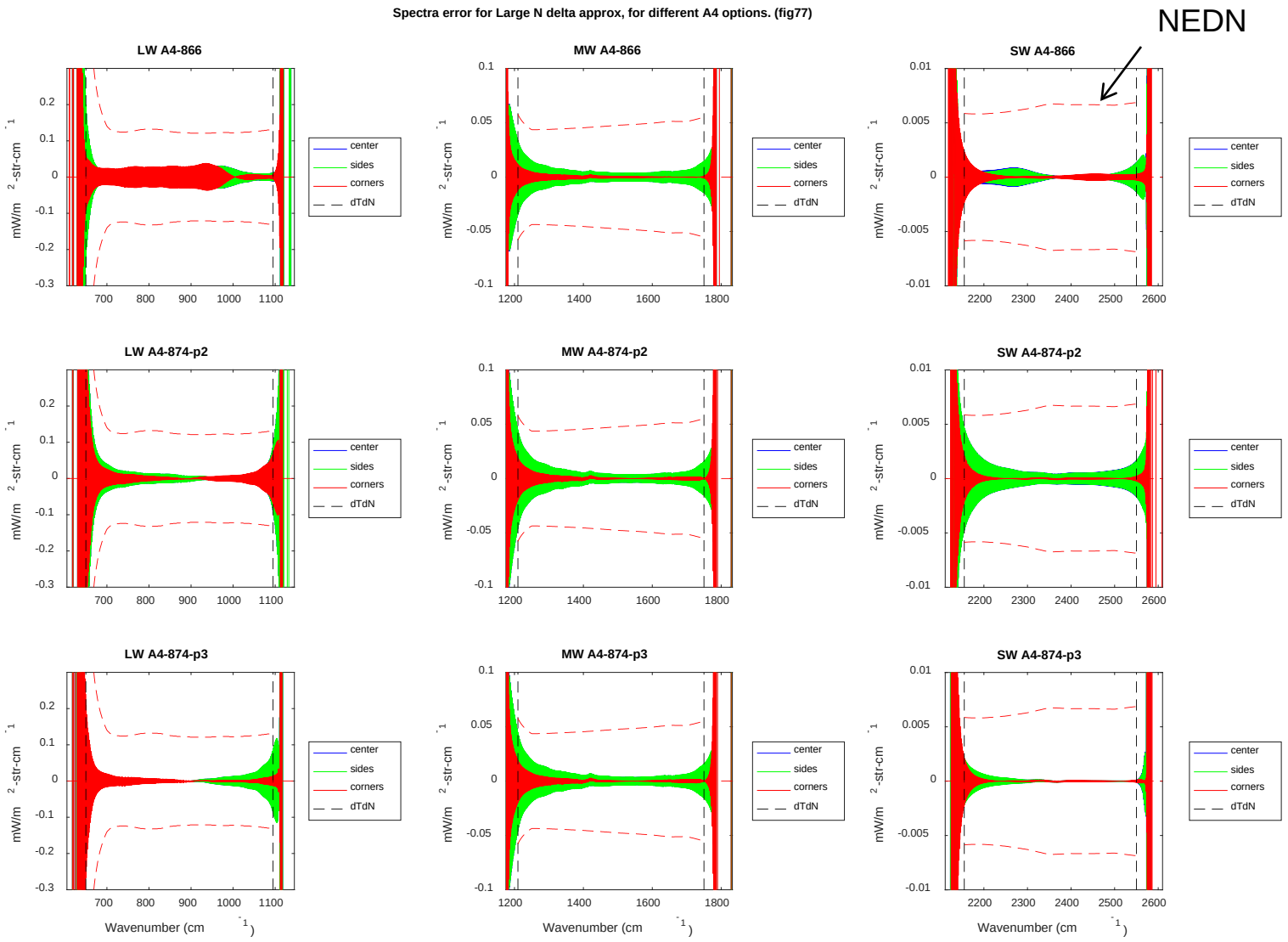
$$S_{Cal} = ICT_u \cdot \frac{M \cdot \left[\frac{\Delta S_1}{\Delta S_2} \left| \Delta S_2 \right| \right]}{M \cdot \left| \Delta S_2 \right|} \qquad \Delta S_1 = (S_{ES} - < S_{SP} >)$$

$$\Delta S_2 = (< S_{ICT} > - < S_{SP} >)$$

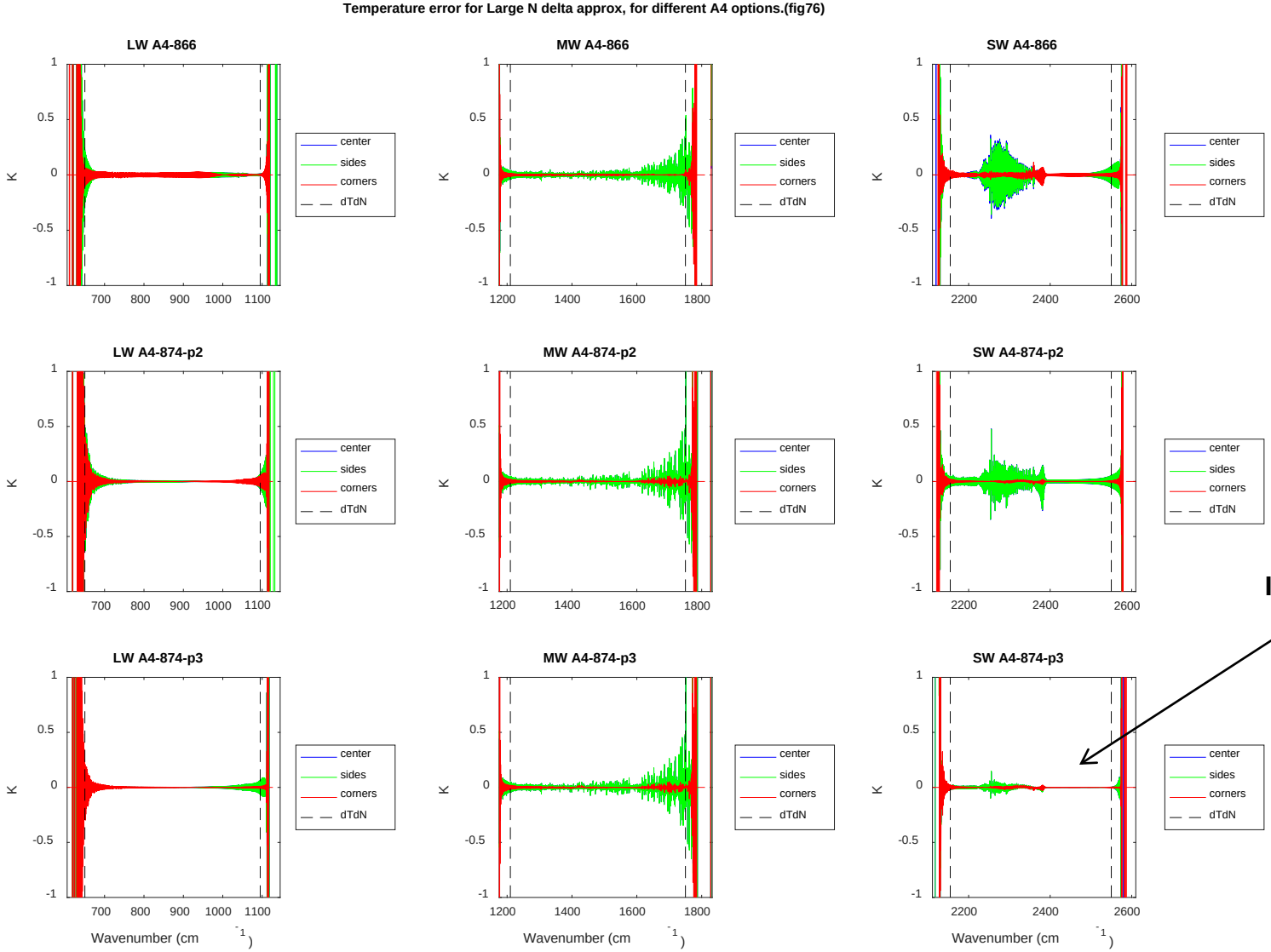
		M-Matrix	Sumulation ID 1	2	3	4	5	7
			N,C, D	N,NCF,T	N,CF,T	E, NC, T	E, NC, D	N,NC,D
Normal length [866 1052 799]	MIT	$F_{s\to u} \cdot f_{ATBD} \cdot SA_s^{-1}$	Y	Y	Y	N	N	Y
	A4-866	$F_{s\to u} \cdot f_{ATBD} \cdot SA_s^{-1} \cdot f_{ATBD}$	Y	Y	Y	N	N	Y
Extended length [874 1052 808]	MITx	$F_{s\to u} \cdot f_{ATBD} \cdot SA_s^{-1} \cdot F_{trunc}$	N	N	N	Y	Y	N
	A4_874_2p	$F_{s\to u} \cdot f_{ATBD} \cdot SA_s^{-1} \cdot f_{ATBD} \cdot F_{trunc}$	N	N	N	Y	Y	N
	A4_874_3p	$F_{s\to u} \cdot f_{ATBD} \cdot SA_s^{-1} \cdot f_{ATBD} \cdot F_{trunc} f_{long}$	N	N	N	Y	Y	N

N – normal length interferograms, E – extended length interferograms
C – circular FIR, NC non-circular FIR
D – double precision, T –truncated integer arithmetic

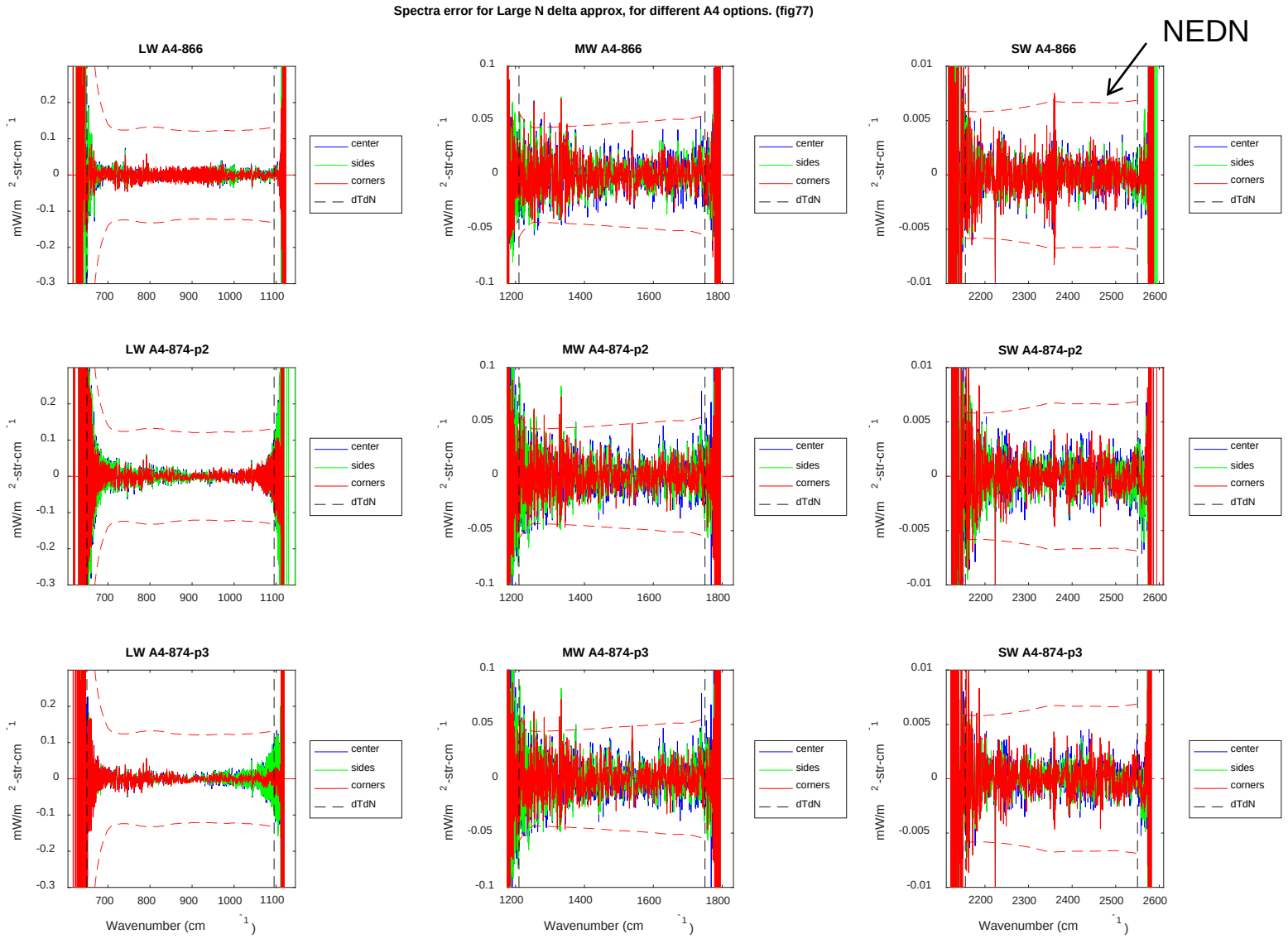
Spectra ripple envelope errors relative to TRUTH (double precision) for different A4 algorithm options



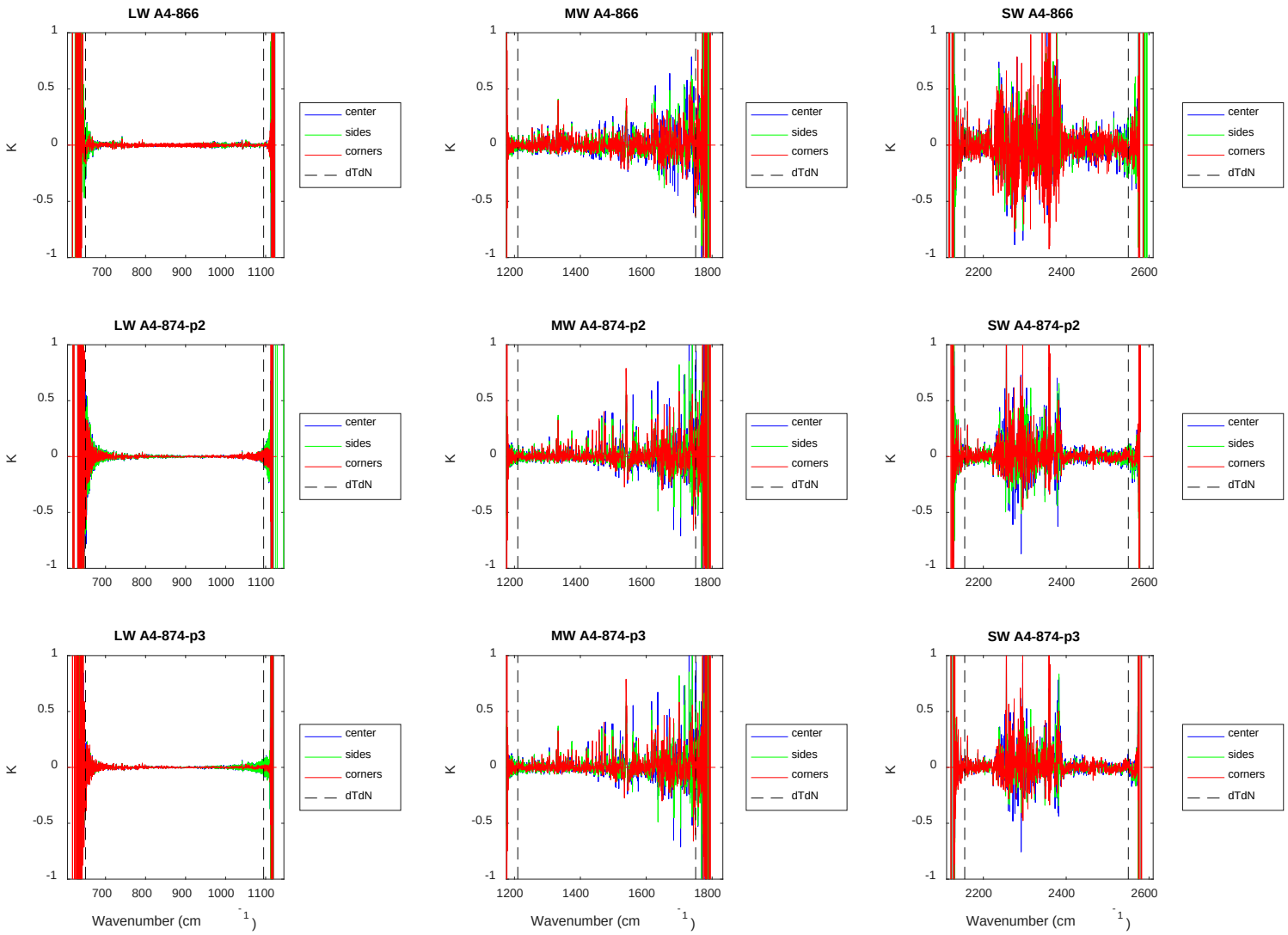
Temperature ripple error envelopes relative to TRUTH (double precision) for different A4 algorithm options



Spectra ripple envelope errors relative to TRUTH (integer truncation) for different A4 algorithm options



Temperature errors relative to TRUTH (truncated integer) for different A4 algorithm options



Summary

- The current operational STAR A4 algorithm has been optimized significantly
  - Simulating a noise free double precision CrIS is useful to compare performance
  - Differences between A4 options are small
  - A4_874_3p algorithm is best so far
  - Truncation noise at FIR output and 14 bit A/D at input mask differences for single interferograms
  - Averaging spectra with different amplitudes required of operational spectra to see same subtle differences.
- Future work with non-linearity testing, fringe shift recovery, and spike recovery