STAR JPSS 2015 Annual Science Team Meeting
Session 6c
CrIS Calibration Algorithm Analysis

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Day 3, August 27 2014

Background

- In late 2014 it became clear we were comparing results based on different low level interpretations of the calibration algorithm in the ATBD
- A list of 11 equations were clearly identified
- We have reduced to five and testing rigorously
- What are we measuring?
  - An extended FOV off-axis interferogram on sensor sampling grid
- What is the product we are delivering?
  - An equivalent on-axis, single ray spectrum corrected for extended FOV apodization and sensor sampling, with responsivity and FIR filter removed by a two point calibration and with non-linearity corrected
  - The details of the process define different algorithms

Five surviving algorithms

	Algorithm	Parameters	Comment
NOAA A1	$N = (SA_u^{-1} \cdot F_{s\to u} \cdot f_{ATBD}) \cdot \left\{ \frac{S_E - \langle S_{SP} \rangle}{\langle S_{ICT} \rangle - \langle S_{SP} \rangle} \cdot ICT(T, u_{sensor*(1+delta)}) \right\}$	ISA– Sincq, Small N F – Mooney, Small N f – ATBD band_limiting filter ISA = SA^{-1}	Basline delivered in Jan 1015 ratio before ISA F and ISA reversed calibrated in off-axis grid
CCAST	$N = F_{s\to u} \cdot ICT(T, u_{sensor}) \cdot f_{raised\cos} \cdot SA_s^{-1} \cdot f_{raised\cos} \left\{ \frac{S_E - \langle S_{SP} \rangle}{\langle S_{ICT} \rangle - \langle S_{SP} \rangle} \right\}$	ISA– Sincq, Large N F – double FFT f – raised cos filter	calibration ratio first F & ISA next calibrate on sensor grid
NOAA A2	$N = ICT(T, u_u) \cdot \left\{ \frac{F_{s\to u} \cdot f_{ATBD} \cdot SA_s^{-1} \cdot f_{ATBD} \cdot \Delta S_1}{F_{s\to u} \cdot f_{ATBD} \cdot SA_s^{-1} \cdot f_{ATBD} \cdot \Delta S_2} \right\}$	ISA – Sincq, Small N F – Mooney, Small N f – ATBD band_limiting filter	ISA correction and interpolation before calibration ratio small N F and ISA calibrate on user grid
NOAA A3	$N = ICT(T, u_u) \cdot \left\{ \frac{F_{s\to u} \cdot f_{ATBD} \cdot SA_s^{-1} \cdot f_{ATBD} \cdot \Delta S_1}{F_{s\to u} \cdot f_{ATBD} \cdot SA_s^{-1} \cdot f_{ATBD} \cdot \Delta S_2} \right\}$	ISA – Sincq, Large N F – Mooney, Large N f – ATBD band_limiting filter	NOAA 2 + large N F and ISA
NOAA A4	$N = ICT(T, u_u) \cdot \frac{F_{s\to u} \cdot f_{ATBD} \cdot SA_s^{-1} \cdot f_{ATBD} \cdot \left\{ \frac{\Delta S_1}{\lvert \Delta S_2 \rvert} \Delta S_2 \right\}}{F_{s\to u} \cdot f_{ATBD} \cdot SA_s^{-1} \cdot f_{ATBD} \cdot \lvert \Delta S_2 \rvert}$	Same as NOAA 3 plus rephasing	Remove phase due to ZPD shift before calibration calibrate on user grid

$$\Delta S_1 = FIR^{-1} \cdot \left(S_E - \langle S_{SP} \rangle \right)$$
$$\Delta S_2 = FIR^{-1} \cdot \left(S_{ICT} - \langle S_{SP} \rangle \right)$$

SA^{-1} and F are (N x N) maricies, f is a band limiting filter

Formal overview of calibration for all algorithms

- **Formal expression for the FFT of the measured extended FOV interferogram with non-circular FIR before truncation(CrIS processing on spacecraft)**
  - **Double integral over angular extent of the Field stop and wavenumber**
  - **Both the FIR filter and responsivity are inside an integral**
  - **If H were constant in the pass band it could be easily removed (come back to this later)**

$$S_{NCF}[k] = \int_{a1}^{a2} P(a)\cos(a) \int_{u1}^{u2} S_{highres}(u')\rho(u')H(u'\cos(a))L\ Sinq(Lu'\cos(a)-k),N)du'da$$

- **For circular FIR filtering H is already outside the integral(not CrIS)**

$$S_{CF}[k] = H[k]\int_{a1}^{a2} P(a)\cos(a) \int_{u1}^{u2} S_{highres}(u')\rho(u')L\ Sinq(Lu'\cos(a)-k),N)du'$$

- **H and responsivity removed by a two-point calibration that implicitly assumes both can be brought out from the interval.**

$$S_{cal}[k] \propto \frac{S_{scene}[k]-S_{space}[k]}{S_{ICT}[k]-S_{space}[k]}$$

- **“Truth” (UW) is defined using single ray on-axis interferograms in user grid(no FOV integration over angle) with a two point calibration**

$$S_{Truth}[k] = \int_{u1}^{u2} S_{highres}(u')\rho(u')L\ Sinq(Lu'-k),N)du'$$

Unpeeling the Onion

- March 12 2014, UW proposed correction for non-circular FIR
- April 9 2014, STAR Alternate method to correct non-circular FIR
- May 28 2014, UW, working definition of Truth
- Dec 17 2014, CCAST compared to NOAA using clear earth scenes
- Sept 10 2014, LL & Logistikos, correcting ATBD resampling
- Sept 10 2014, LL, Sinc decimation properties
- Sept 24 2014, UW, results for non-circular FIR ringing correction
- Oct 10, 2014, STAR, Optimized ringing correction using resampling
- Jan 14 2015, LL, Exact F computation using analytic approach
- Jan 28 2015, Chen & Han, SA correction of gas cell data picks large N periodic Sinc as basis for SA^{-1}
- Feb 25 2015, Logistikos, Phase correction before calibration NOAA A4, with half the computation time
- March 11 2015, LL, Full simulation side by side comparisons
- March 25 2015 ,STAR, comparison studies rang NOAA 4 highest
- April 15 2015, STAR, Fill LBL simulation (ECMWF) compared to clear ocean
- April 29 2015, UW, Obs minus calc find NOAA 3 & 4 best match
- June 15 2015, LL, Full simulation shows little difference long or short N

Compare NOAA A4 with CCAST using full up simulation

- Simulation
  - Interferograms for scene, ICT, cold space for LBL spectra
  - Full accurate integration of extended FOV
  - Accurate calculation of SA and F transformation matrices
- Full algorithm based calibration
- Effects considered
  - Computational methods for F and ISA
  - Circular and Non-circular filtering
  - Long and Short Sinq(Lu-k,N)
  - Aliasing
  - band pass filter settings

Simulated interferograms

- **LBL spectrum & interpolated UW responsivity**
- **Compute scene, ICT, space for all FOV for each option**
- **Three types of interferograms: on-axis user, on-axis sensor, extended FOV sensor**
- **Full double integration over u and field stop for extended FOV**

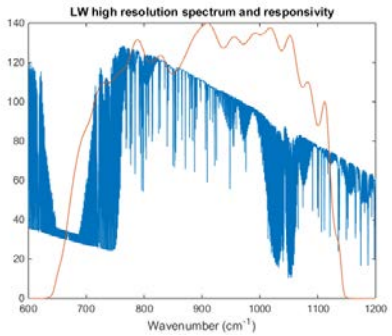
Idealized "Truth"

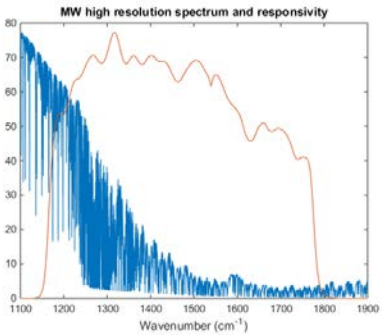
$$I_u[n] = \sum_{m=1}^{M} W_m S_{LBL}(u_m)\rho(u_m) e^{i2\,pin\Delta x_0 u_m} \Delta u_{LBL}$$

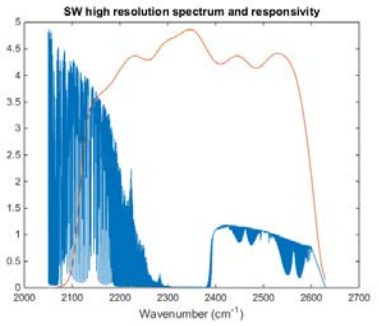
$$I_s[n] = \sum_{m=1}^{M} W_m S_{LBL}(u_m)\rho(u_m) e^{i2\,pin\Delta x u_m} \Delta u_{LBL}$$

CrIS Measured

$$I_x[n] = \sum_{1}^{128} w_q P(a_q)\cos(a_q) \sum_{m=1}^{M} W_m S_{LBL}(u_m)\rho(u_m) e^{i2\,pin\Delta x u_m \cos(a_q)} \Delta u_{LBL}$$







Improved transformation matrices(2015)

- **SA^{-1} matrix corrects extended FOV spectral distortion**

$$SA[k,k'] = \int_{a\min}^{a\max} P(a) \int_{z1}^{z2} Sinq(z-k,N)\, Sinq^*(z/\cos(a)-k',N)\, dz\, da$$

- **F matrix maps from sensor grid (L/N) to user grid (L'/N)**

$$F[k,k'] = \int_{z1}^{z3} Sinq(z-k,N)\, Sinq^*(zL'/L-k',N)\, dz$$

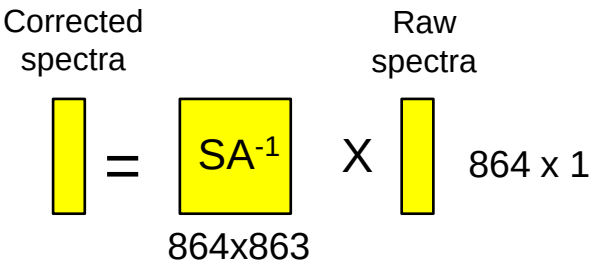
- **High accuracy methods of computation developed**

type	z1	z2	z3	N	error
SA **short** sinq	uLcos(a)	Z1+Nb	na.	Nb	Exact analytic 1.e-14
SA **long** sinq	uLcos(a)-Nb	Z1+2Nb	na.	NbNd	GL quadrature 1.e-12
F long sinq	0	NbNd	uL+Nb	Nb	Exact analytic 1.e-14

Band	Decimated interferogram length Nb	Decimation factor Nd	Long interferogram length Nb*Nd
LW	864	24	20736
MW	1050	20	21000
SW	797	26	20722

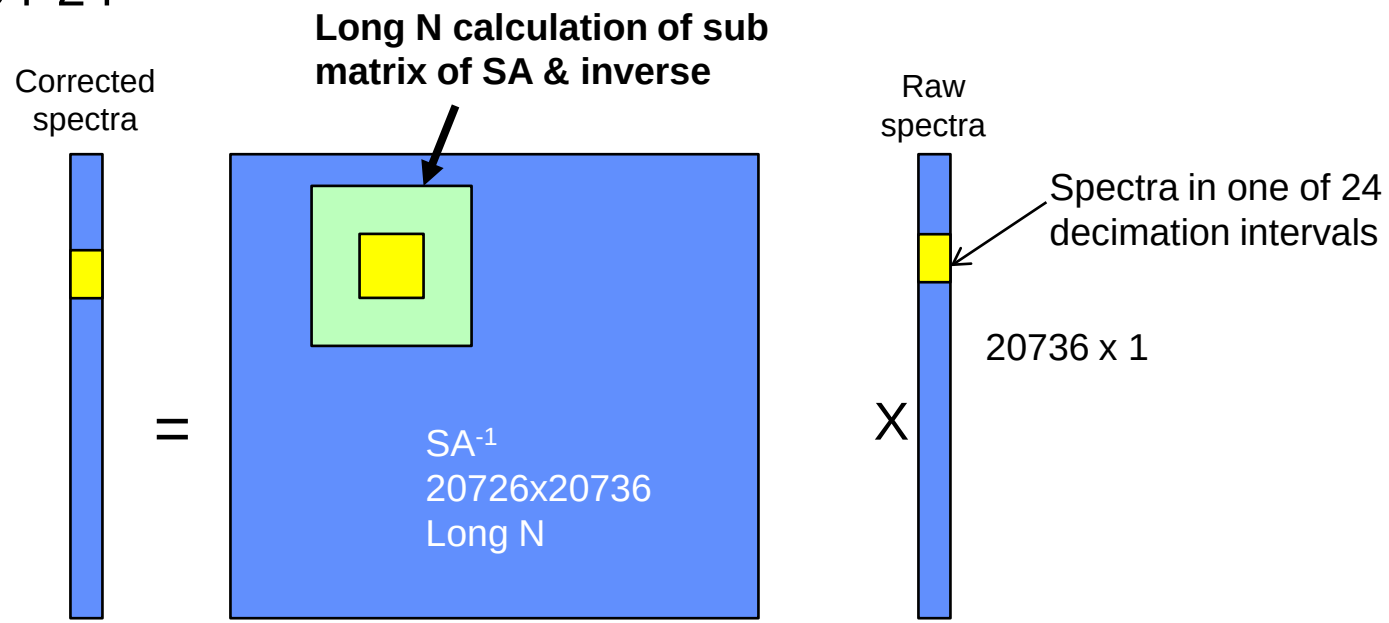
SA^{-1} correction is a matrix operation LW example

Short N=864
Decimated by 24



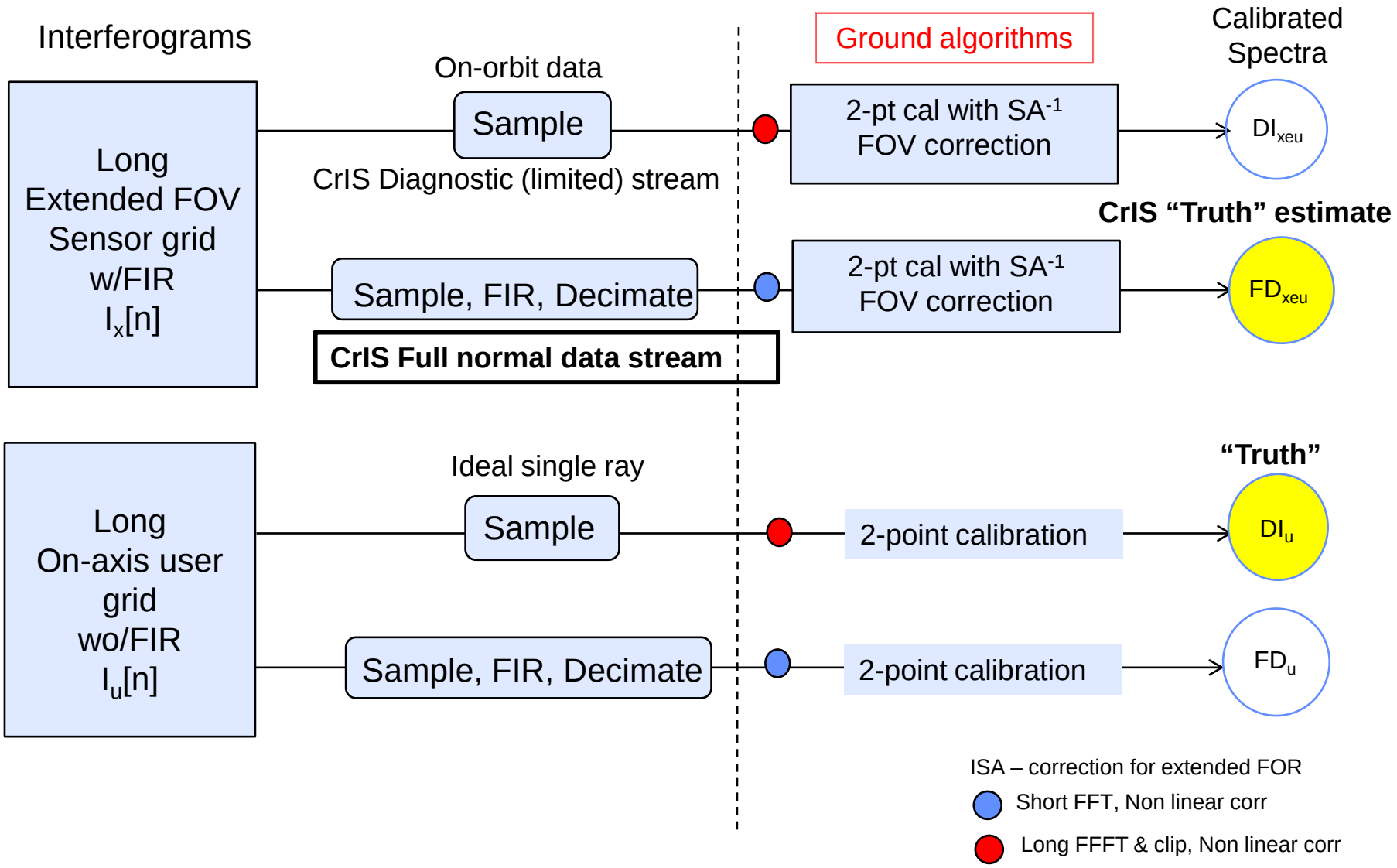
RINGING EFFECTS AT THE EDGES

Long N= 864*24

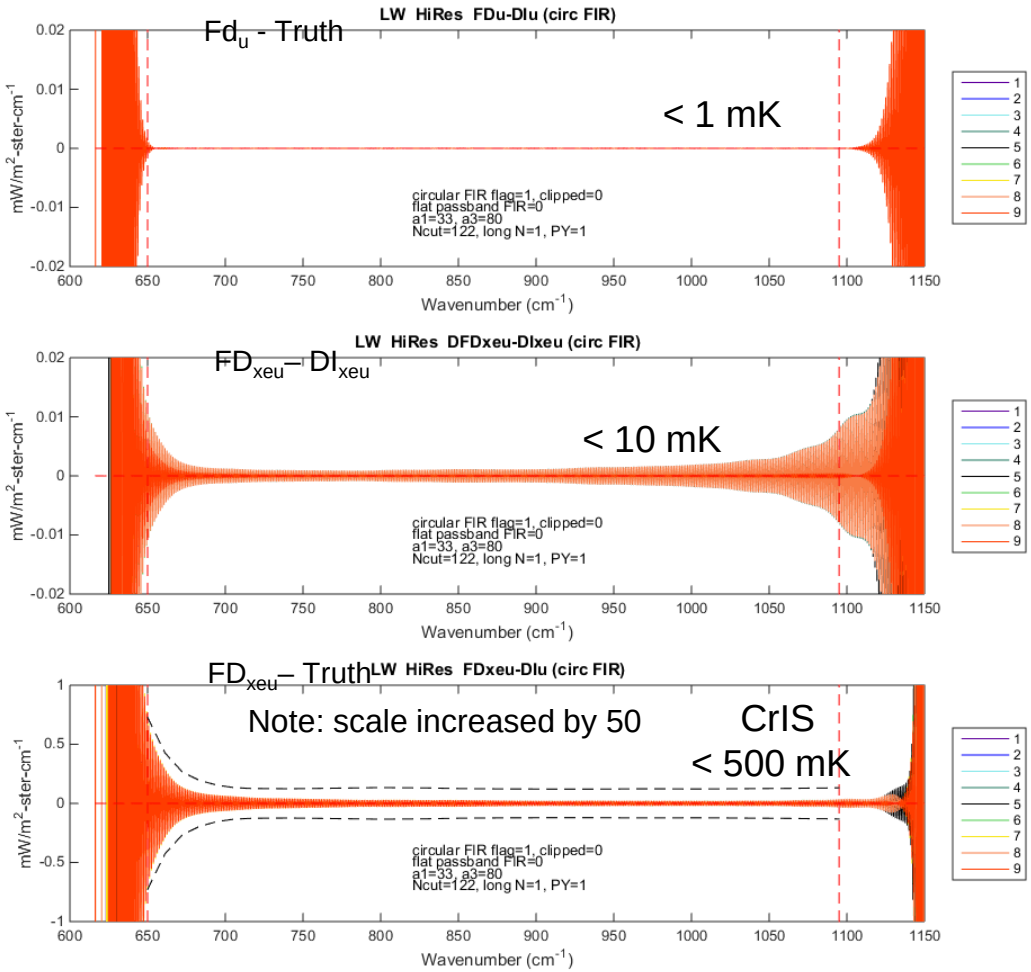


Use bigger matrix to reduce edge effects.
20736^2=429,981,696 double integration matrix elements is prohibitive (72 C_CPS for 36 hours)

Simulated process to convert extended FOV sensor grid to calibrated on-axis user grid spectra

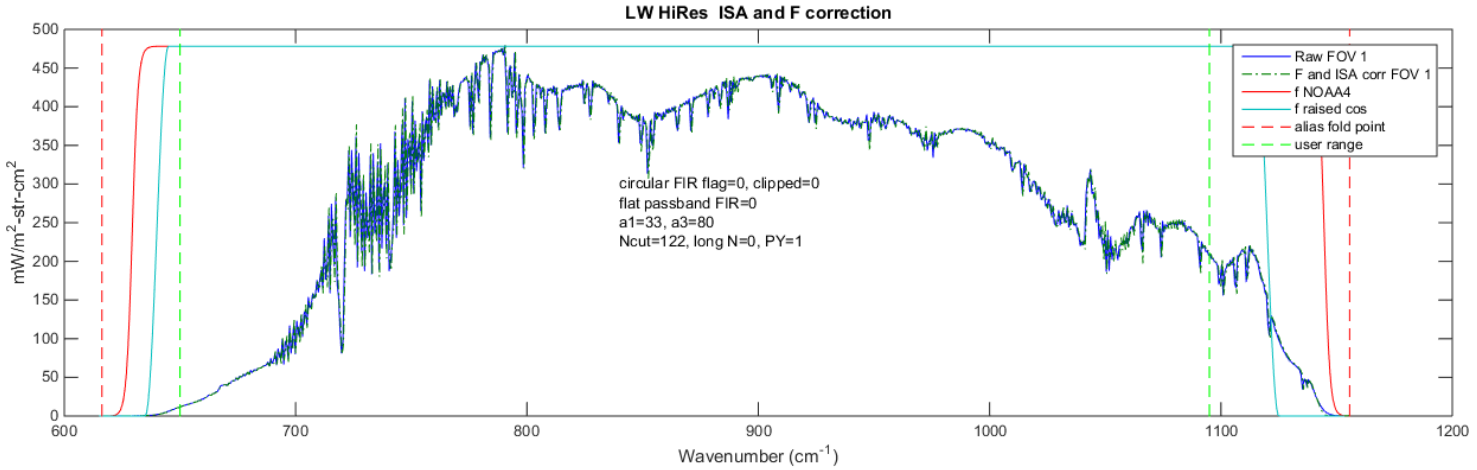


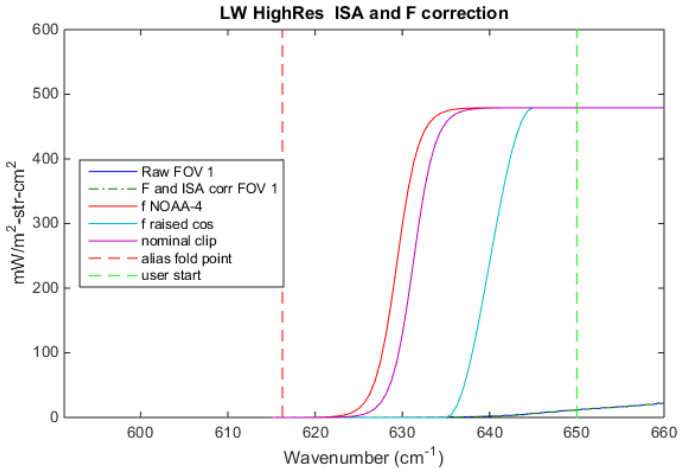
Even with a circular FIR we have an error
FD- Truth NOAA A4

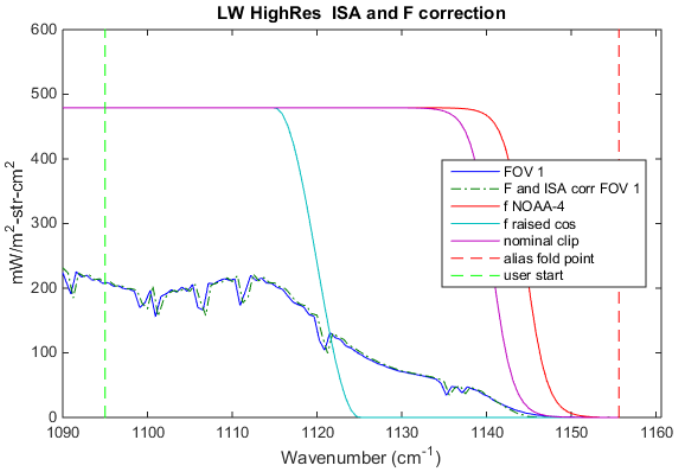


- **FD on-axis: convolution theorem give nearly zero error**
- **extended FOV FD compared to extended FOV DI**
- **Bottom: extended FOV FD compared to truth(on-axis D) (THIS IS CrIS)**
  - **This is the expected ringing due to the full calibration and comparison with truth**

LW raw scene spectra and band limiting filters

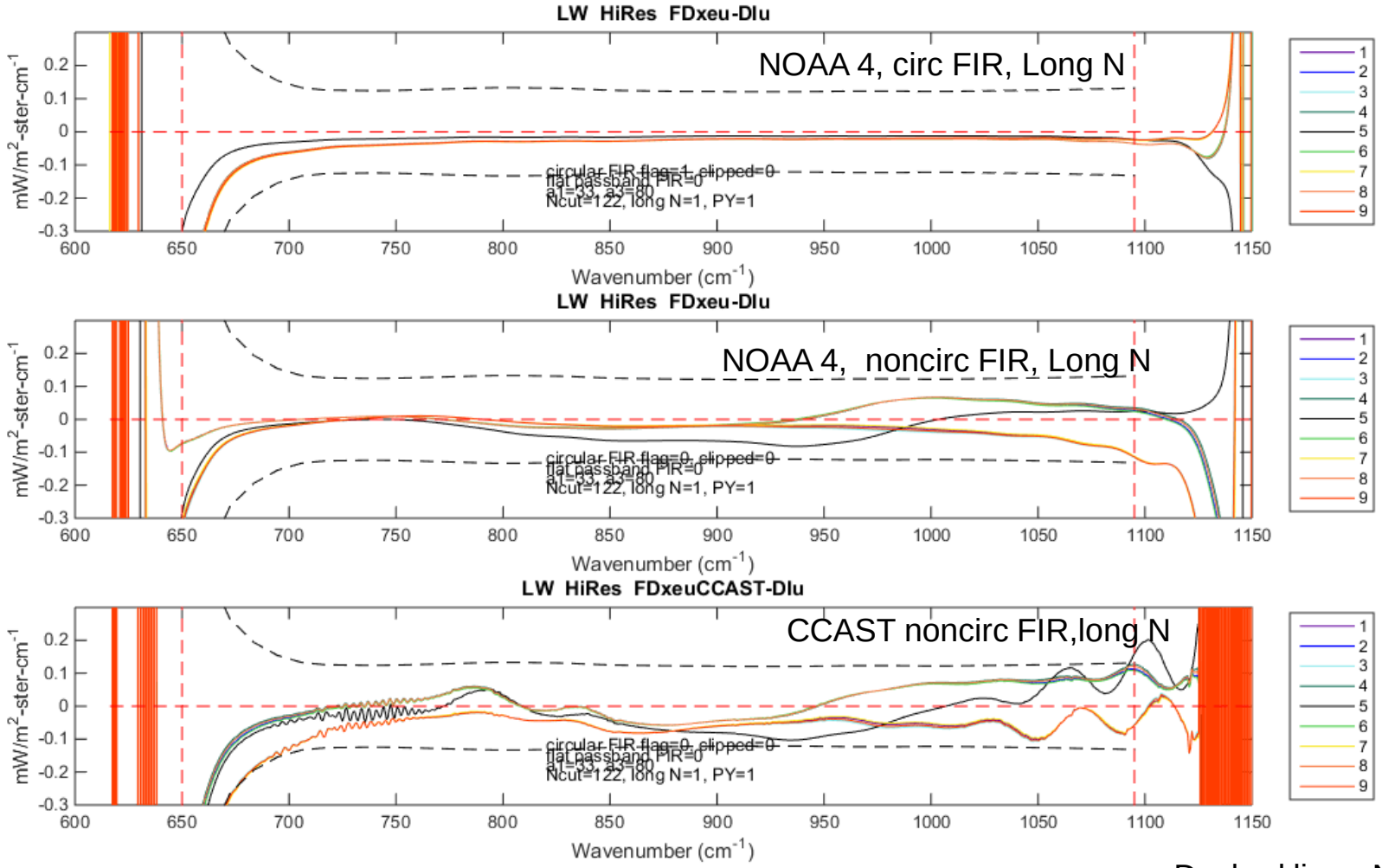






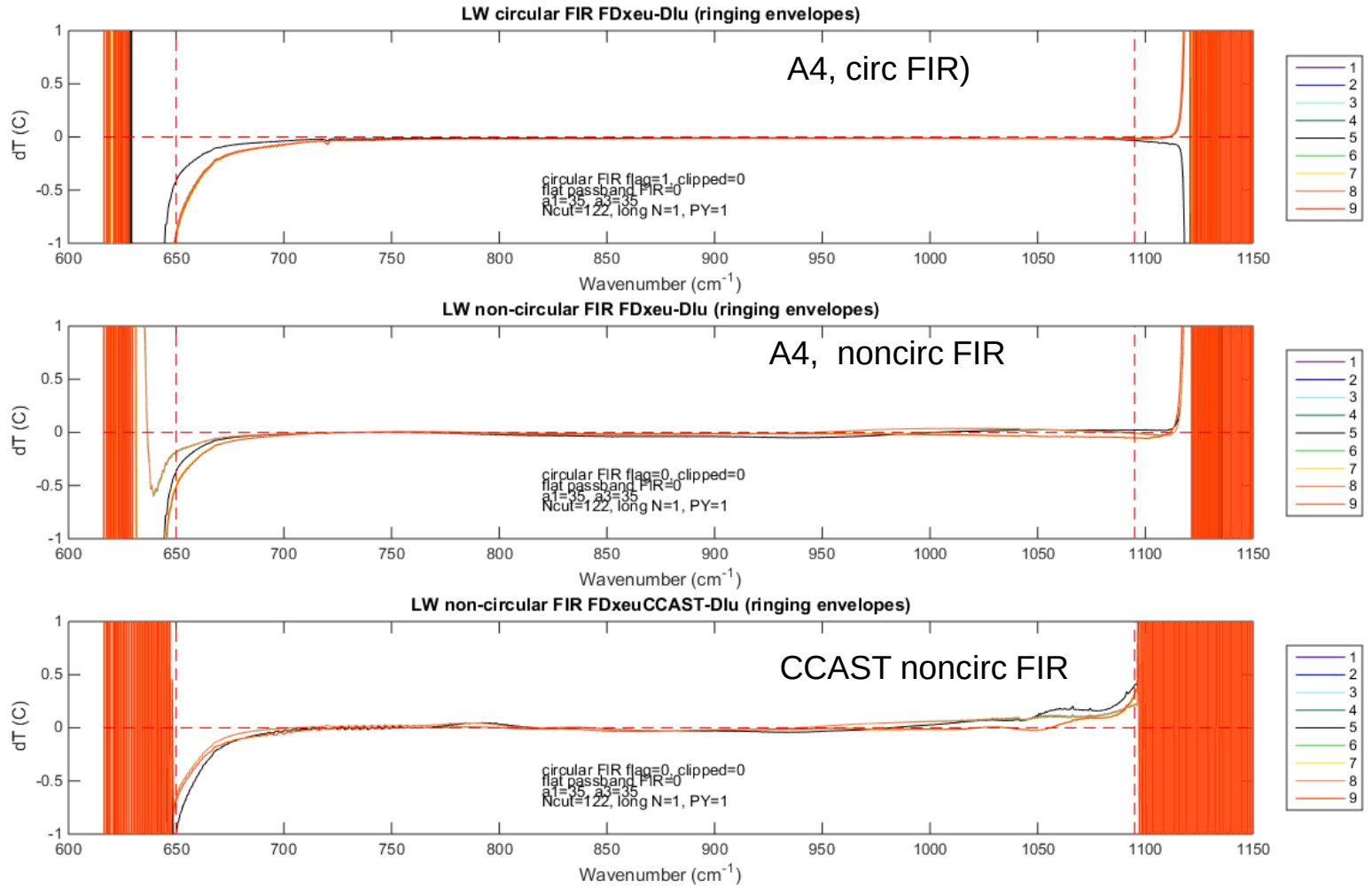
LW A4 and CCAST FD – Truth
Nyquist ringing envelopes

Filtered and decimated off axis spectra (full cal) – long interferogram spectra (full cal)

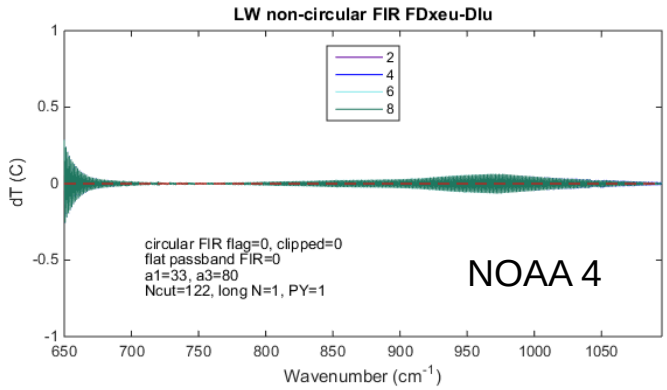


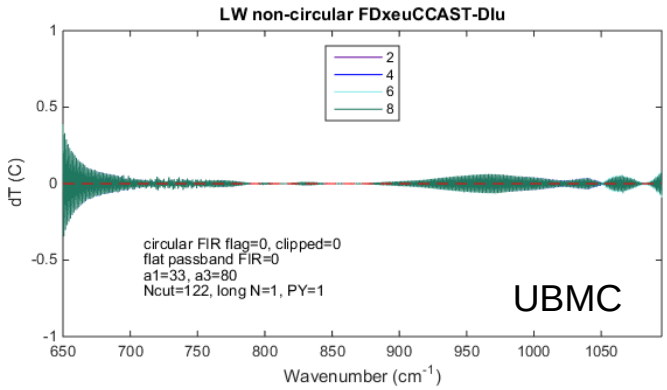
Dashed line - NEDN

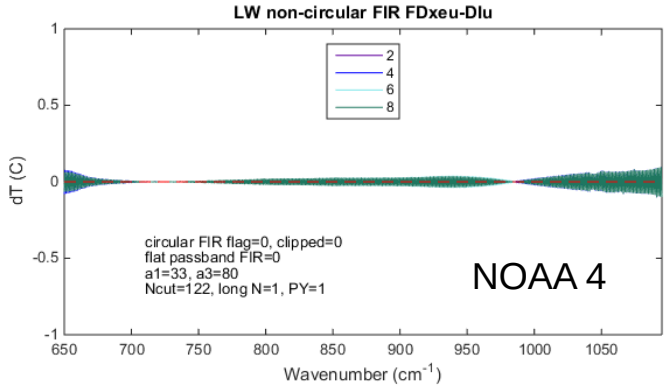
LW color temperature difference for A4 and CCAST relative to TRUTH

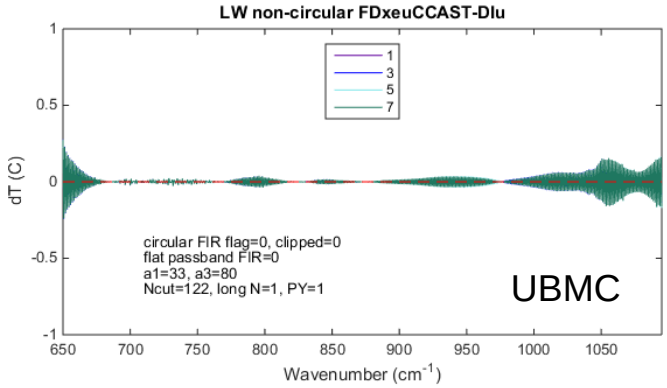


LW A4 and UMBC Differences: FOV – FOV5 LL simulation



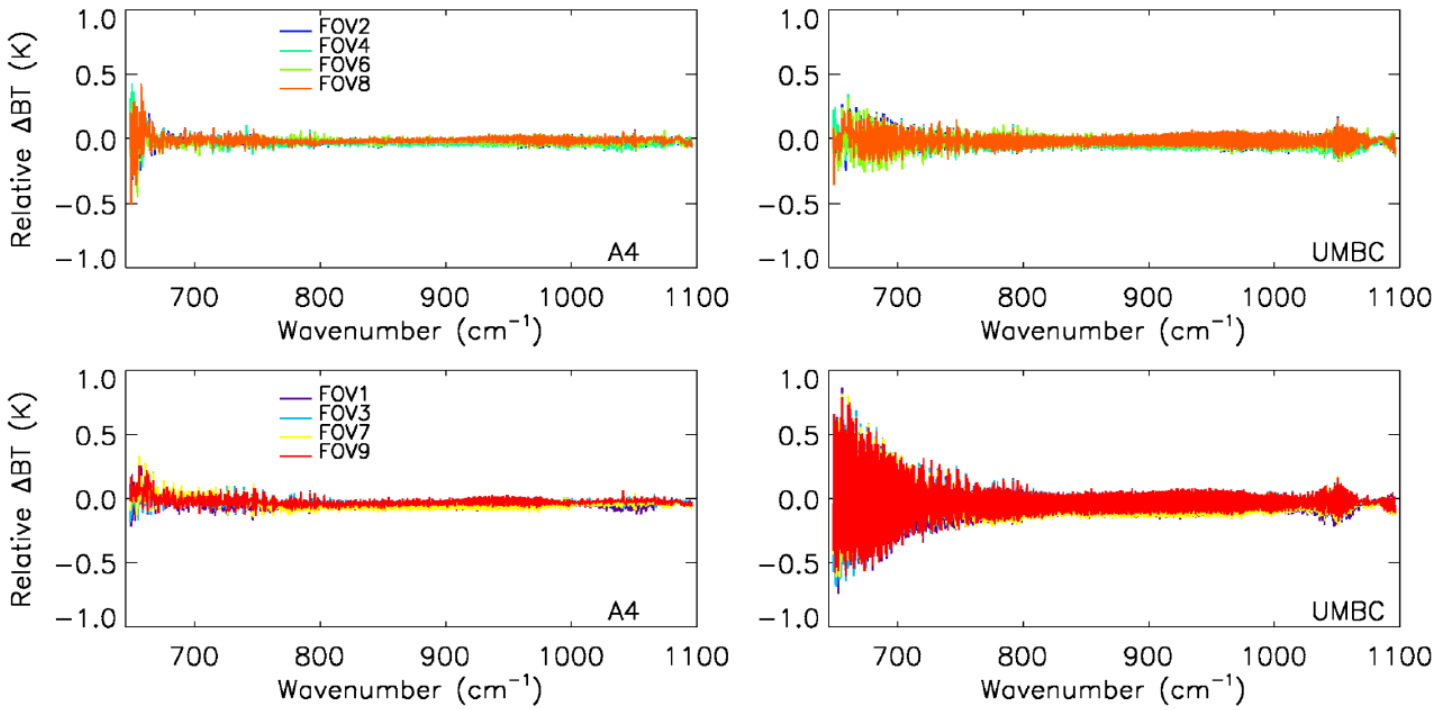






LW A4 and UMBC Differences: FOV –2 – FOV5 STAR Jun10 2015 simulation

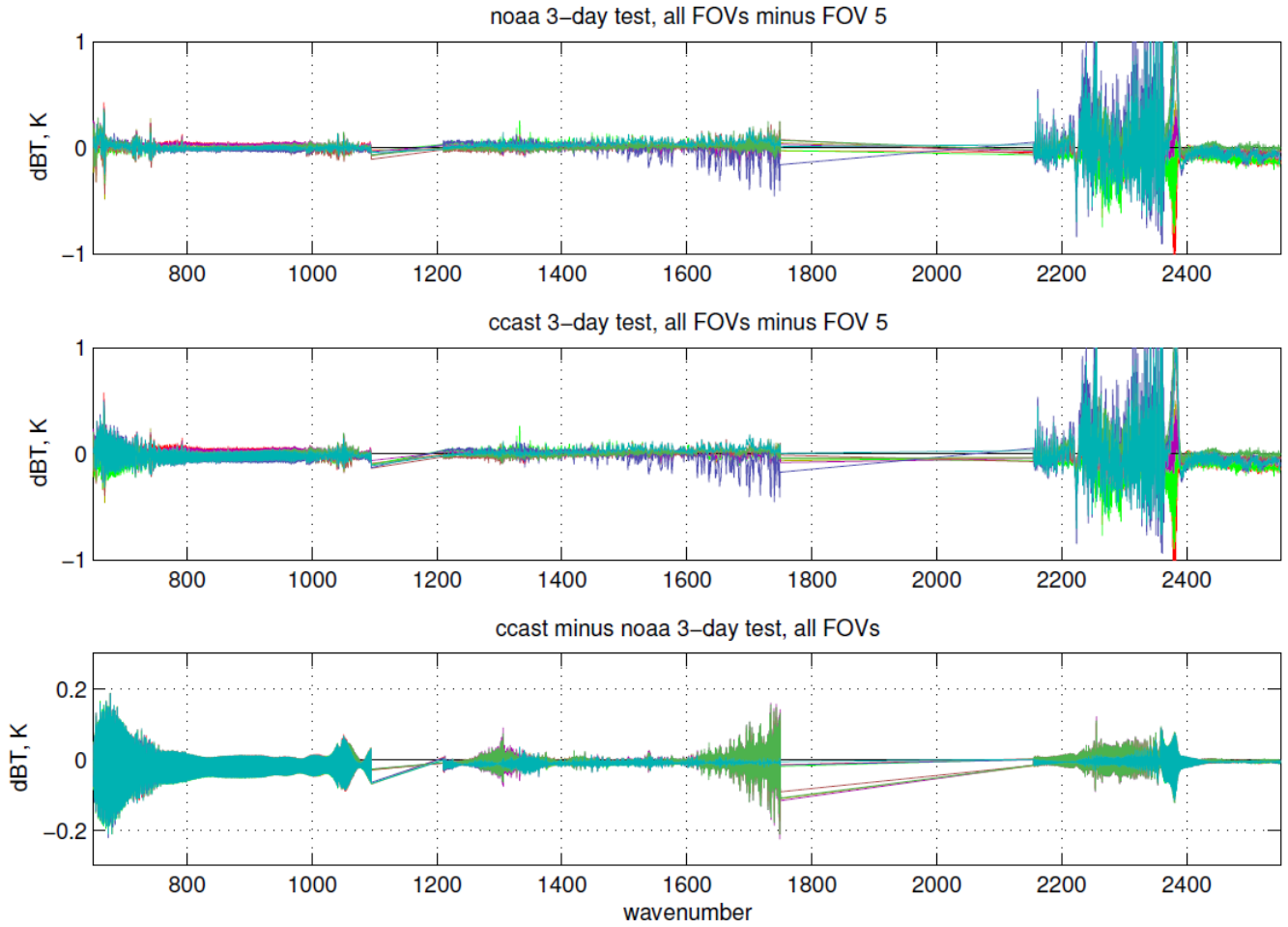
A4 and UMBC Differences: FOV-2-FOV Consistence: $(BT_{obs} - BT_{lbl})_{fov\_i} - (BT_{obs} - BT_{lbl})_{fov\_5}$



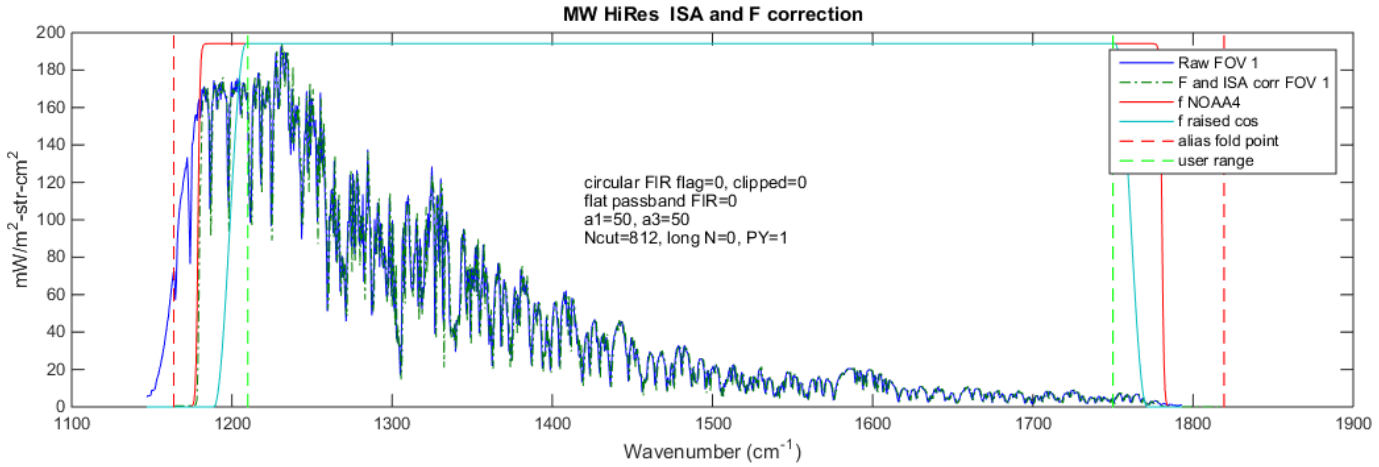
Larger ringing from A-UMBC among corner FOVs

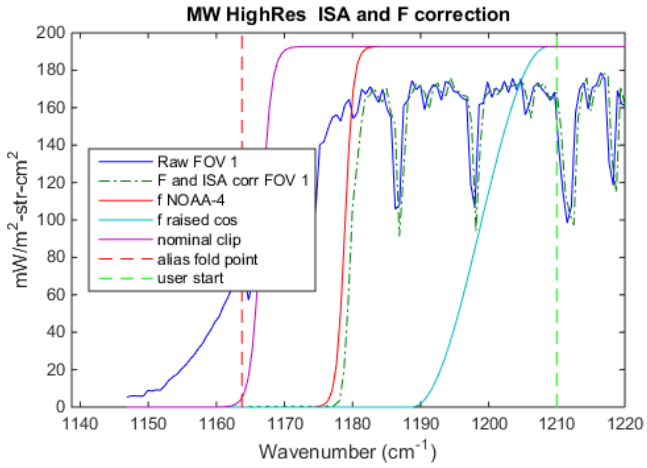
FD – Truth FOVs- FOV5
UMBC ops minus calc Aug 5 2015

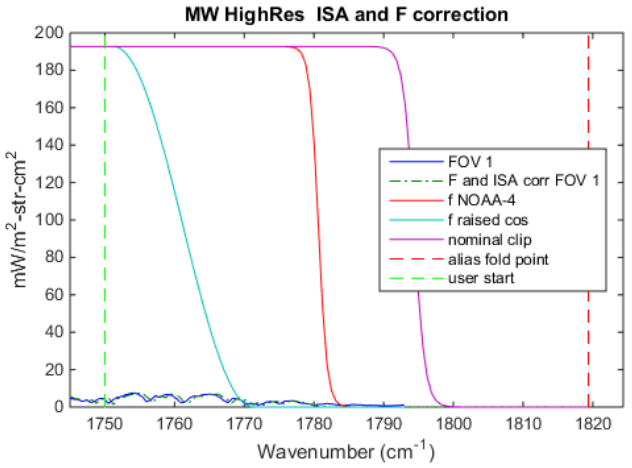
relative test overview



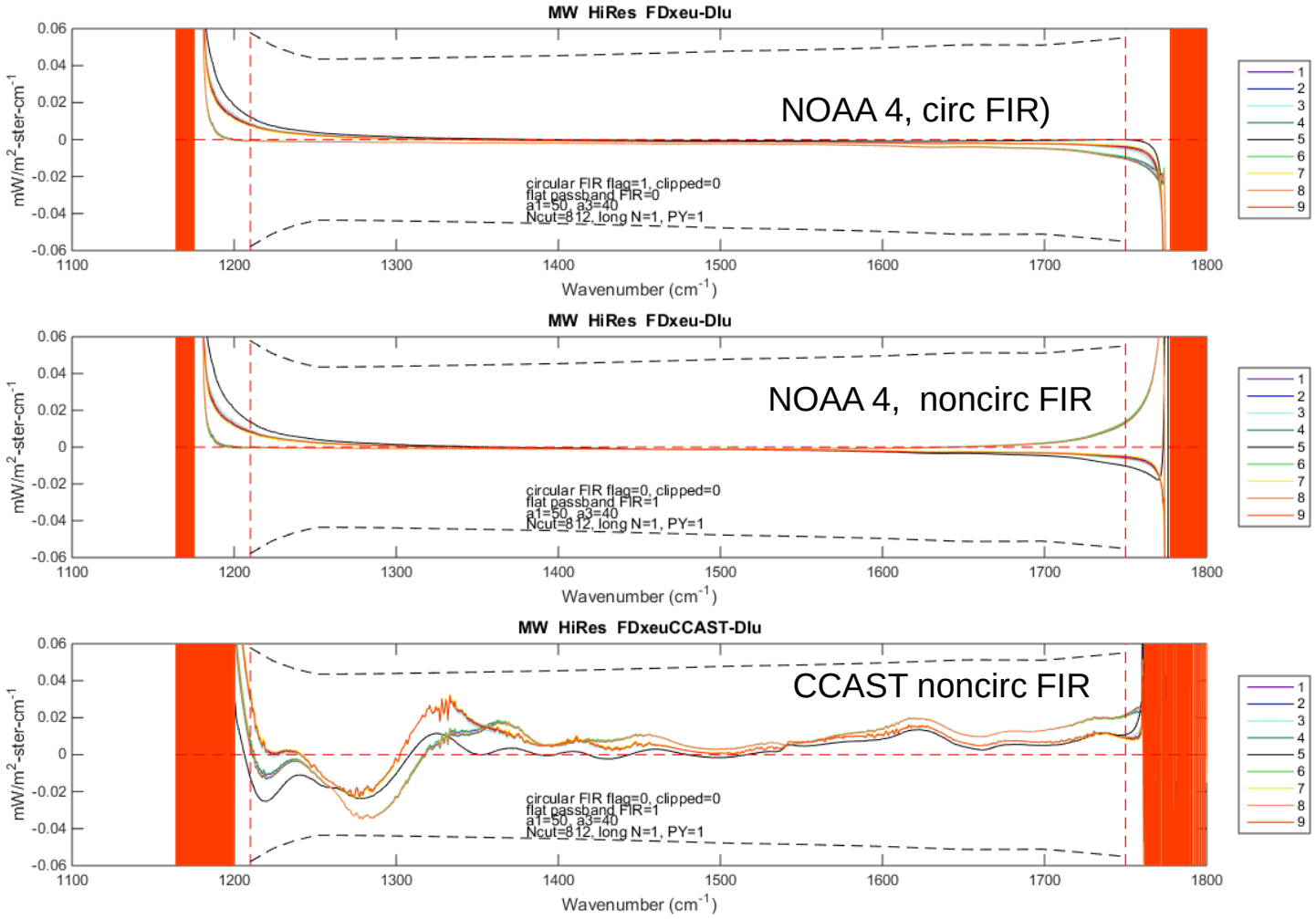
MW raw Scene spectra and band limiting filters





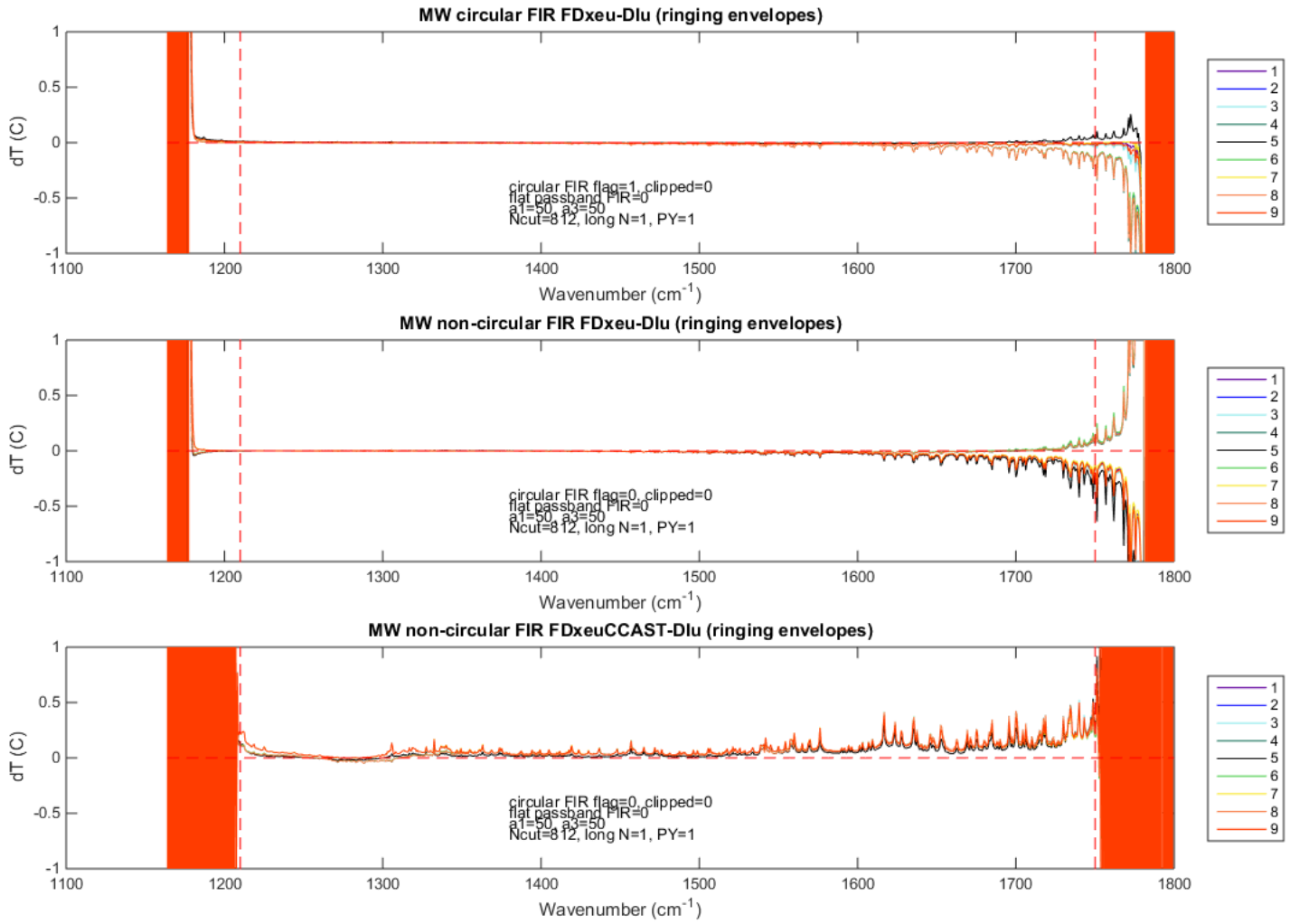


MW FD – Truth NOAA4 and CCAST Nyquist ringing envelopes

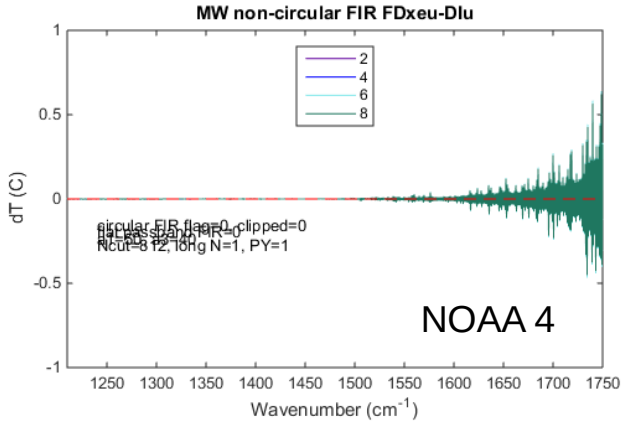


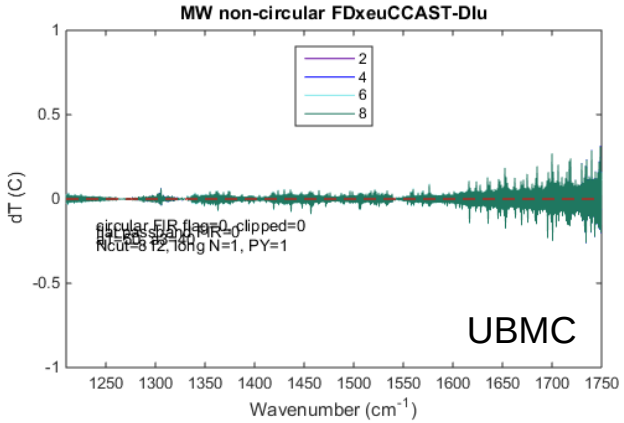
Dashed line - NEDN

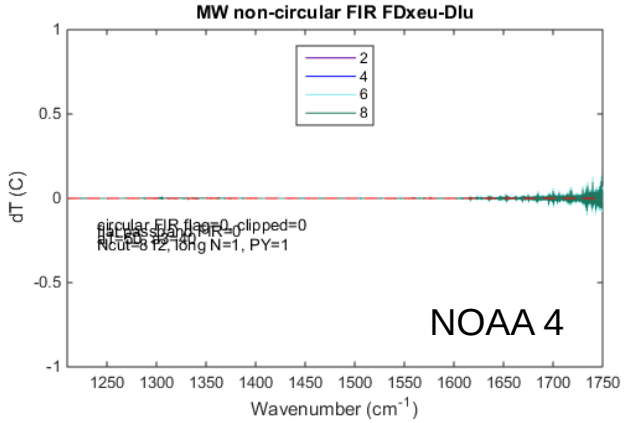
MW Color temperature difference for NOAA4 and CCAST relative to TRUTH

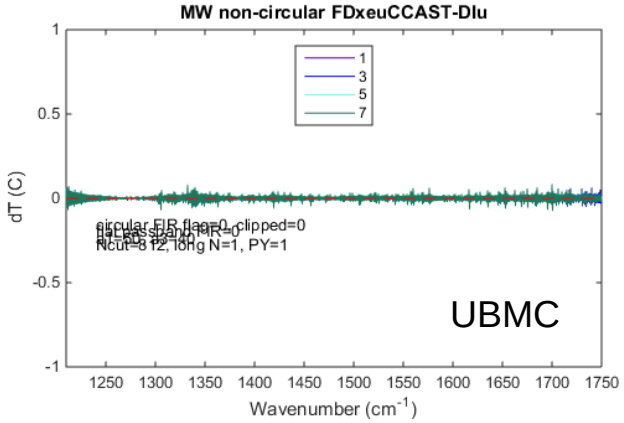


MW A4 and UMBC Differences: FOV –2 – FOV5 LL simulation









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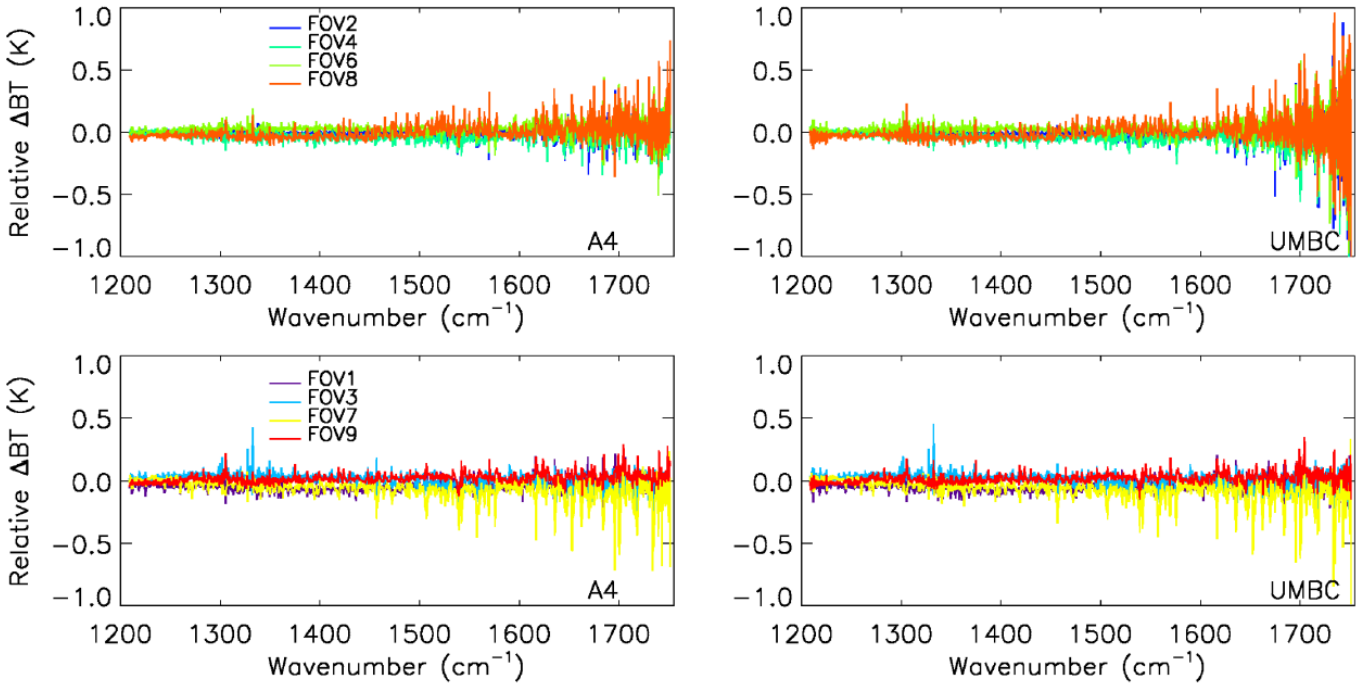

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FD – Truth FOVs- FOV5
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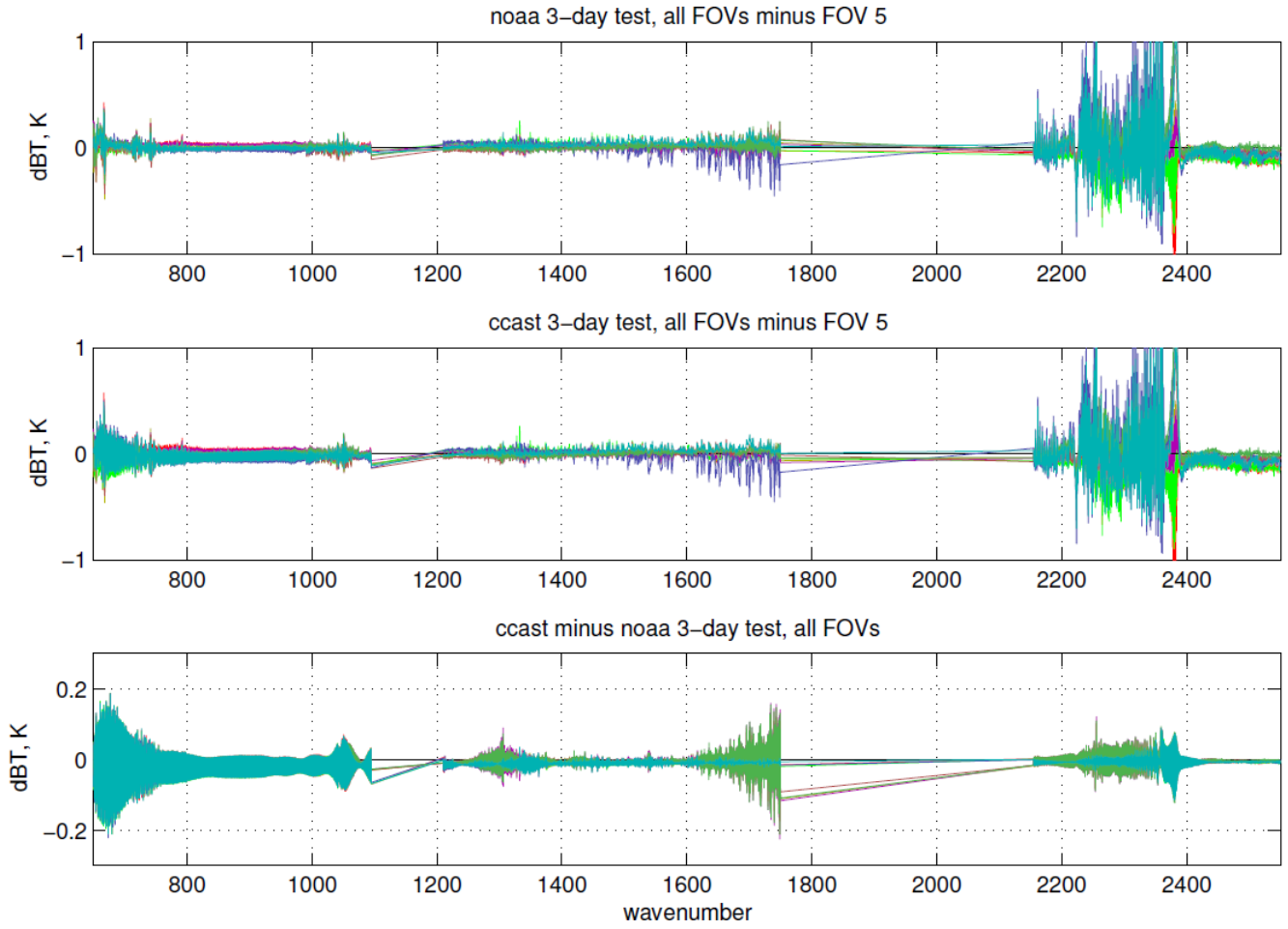
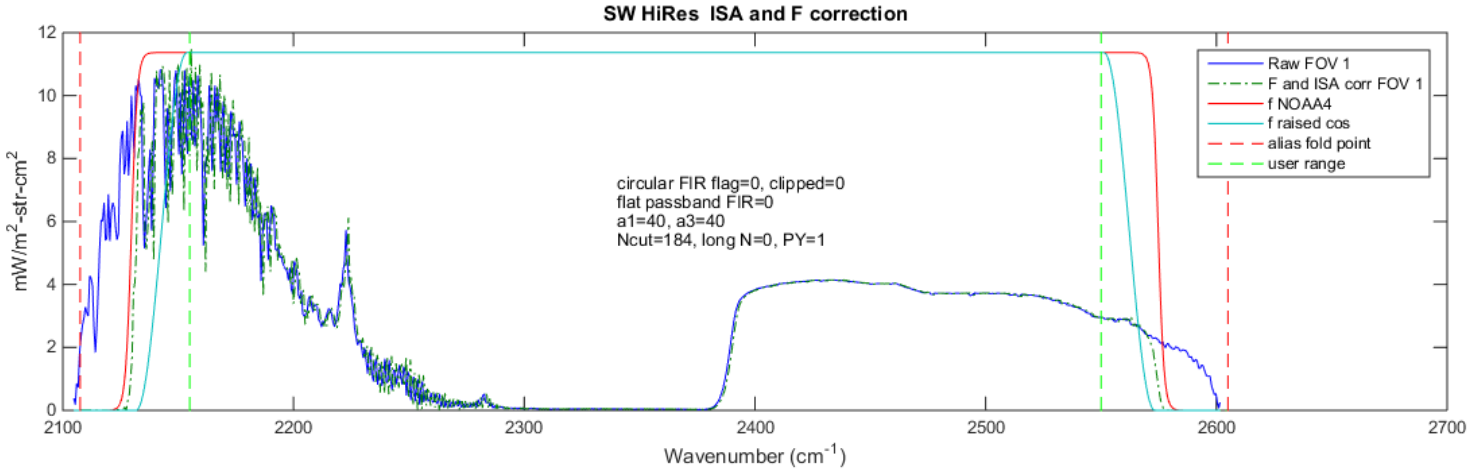
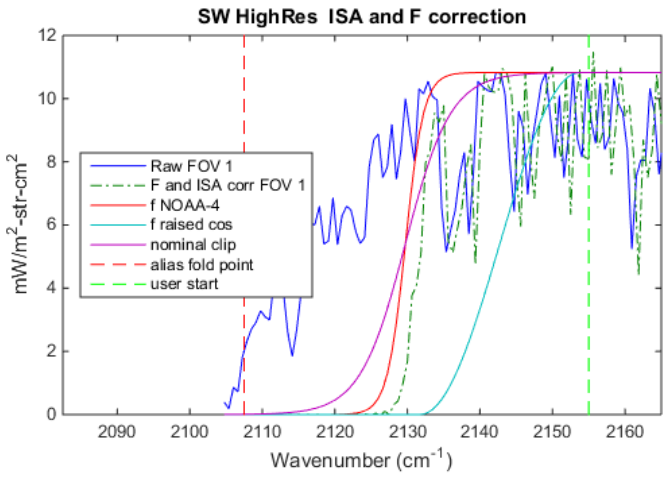
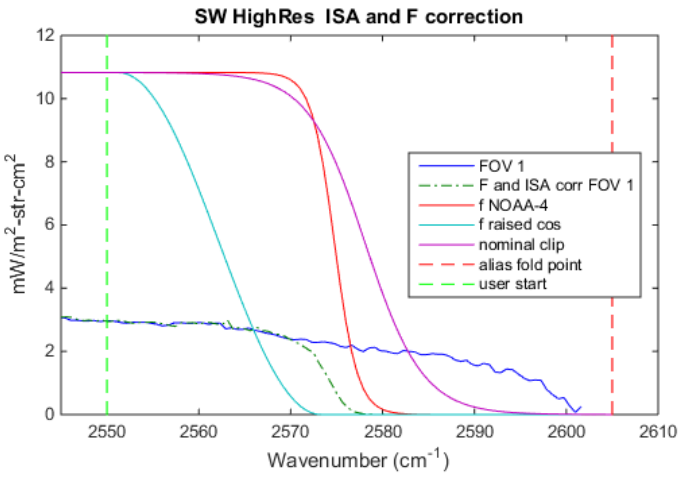


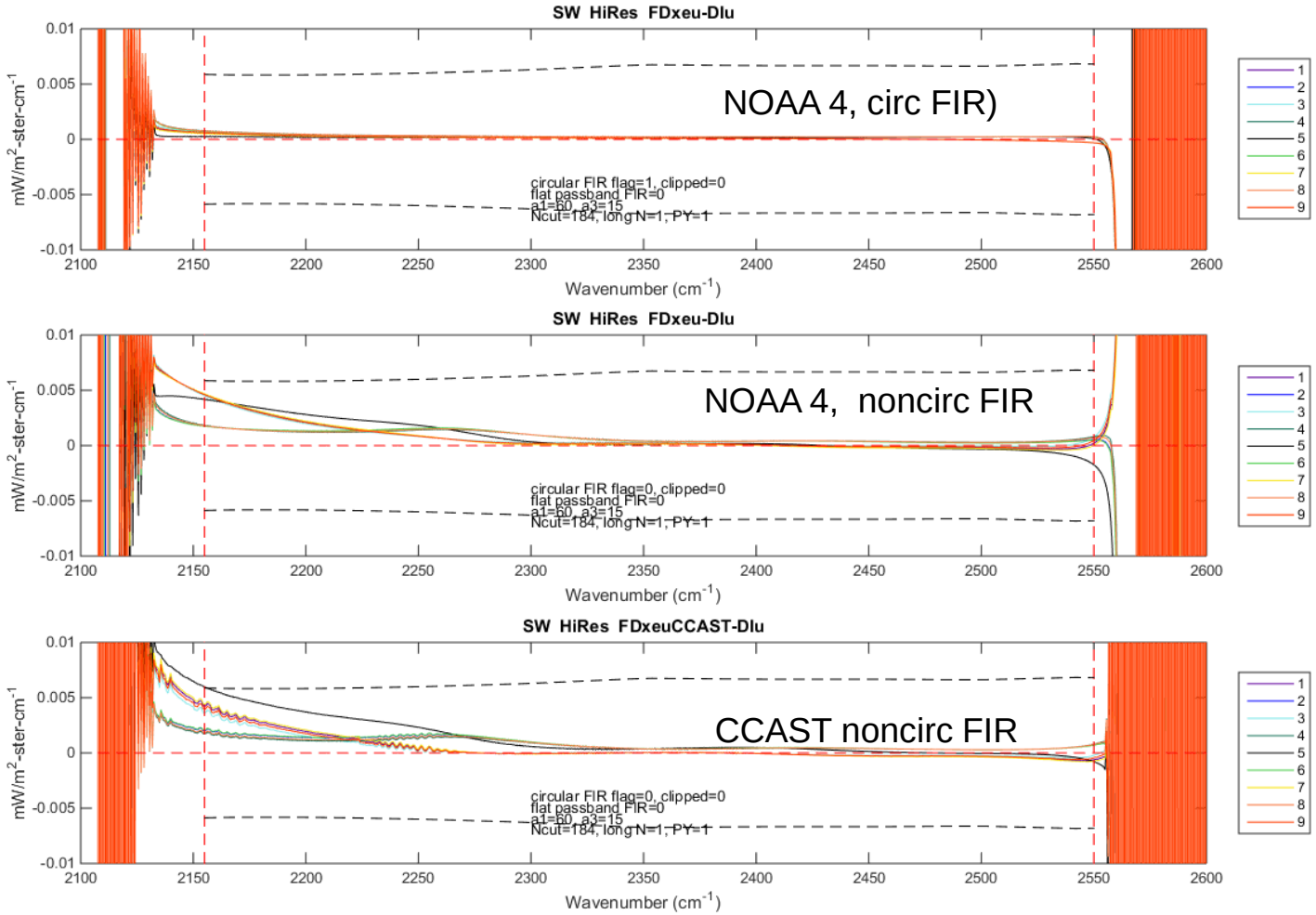
SW band raw spectrum and band limiting filters





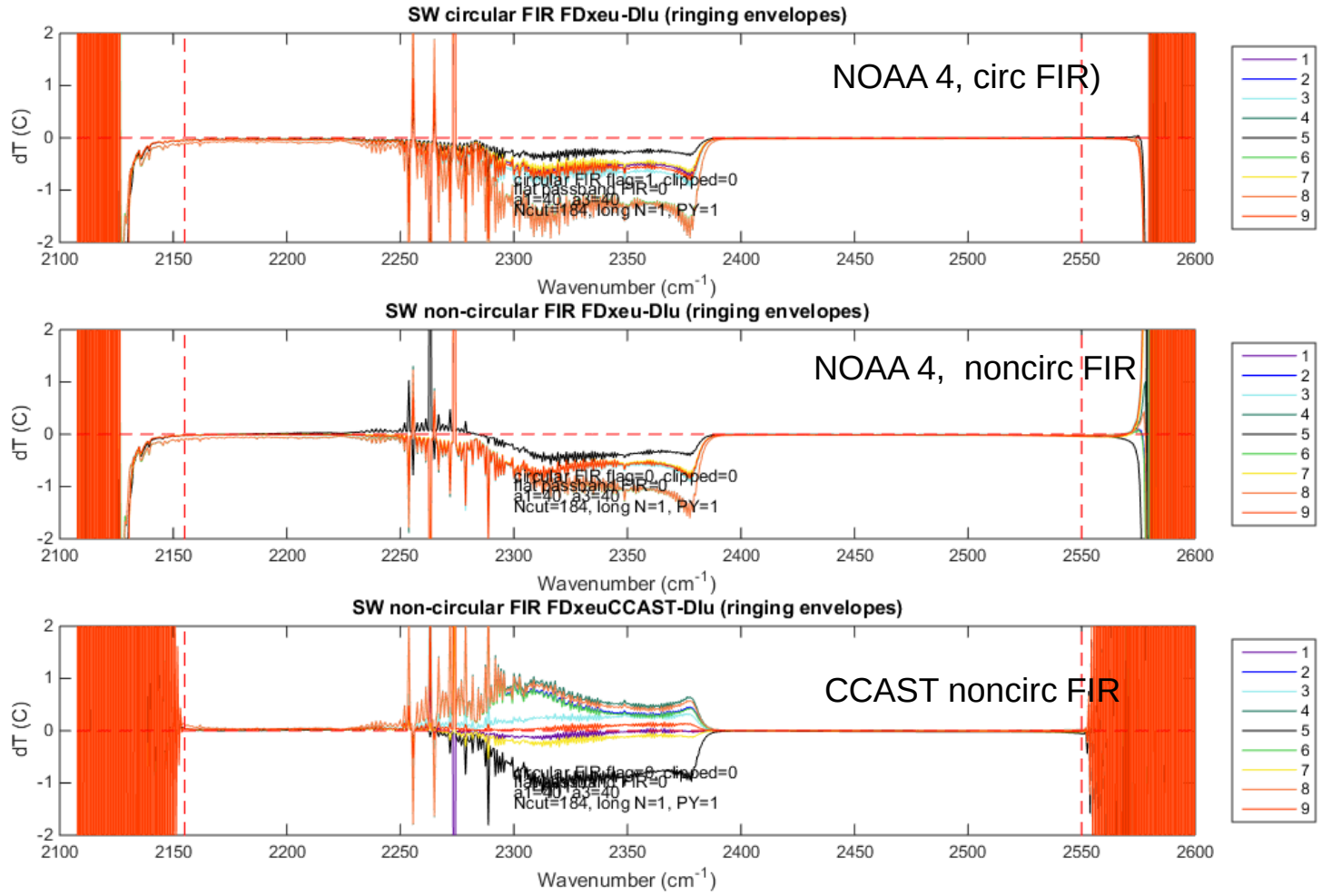


SW non-circ FIR A4 and CCAST Nyquist ringing envelopes

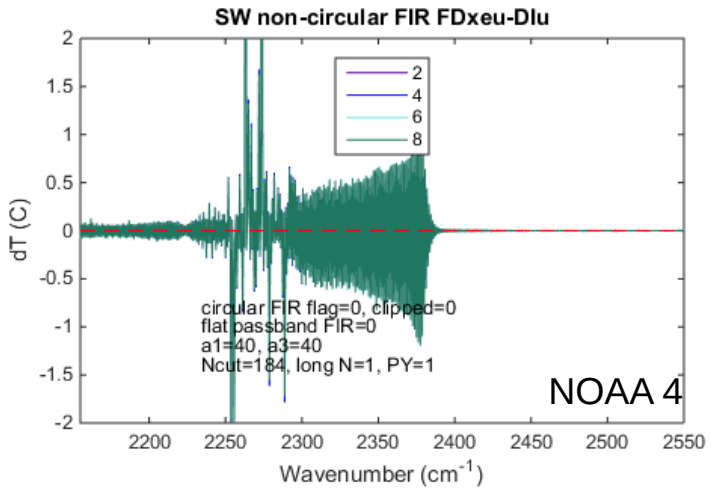


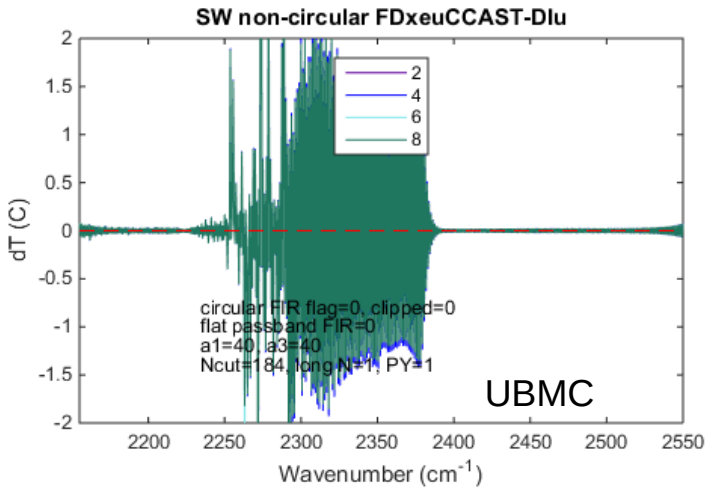
Dashed line - NEDN

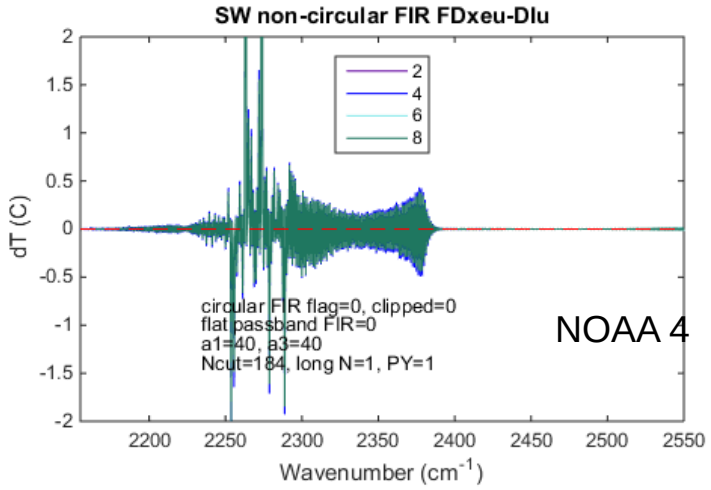
SW Color temperature difference for A4 and CCAST relative to TRUTH

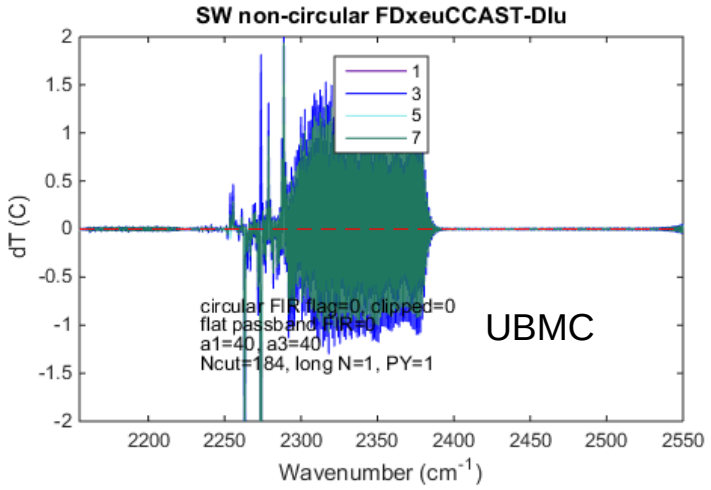


SW A4 and UMBC Differences: FOV –2 – FOV5 LL simulation



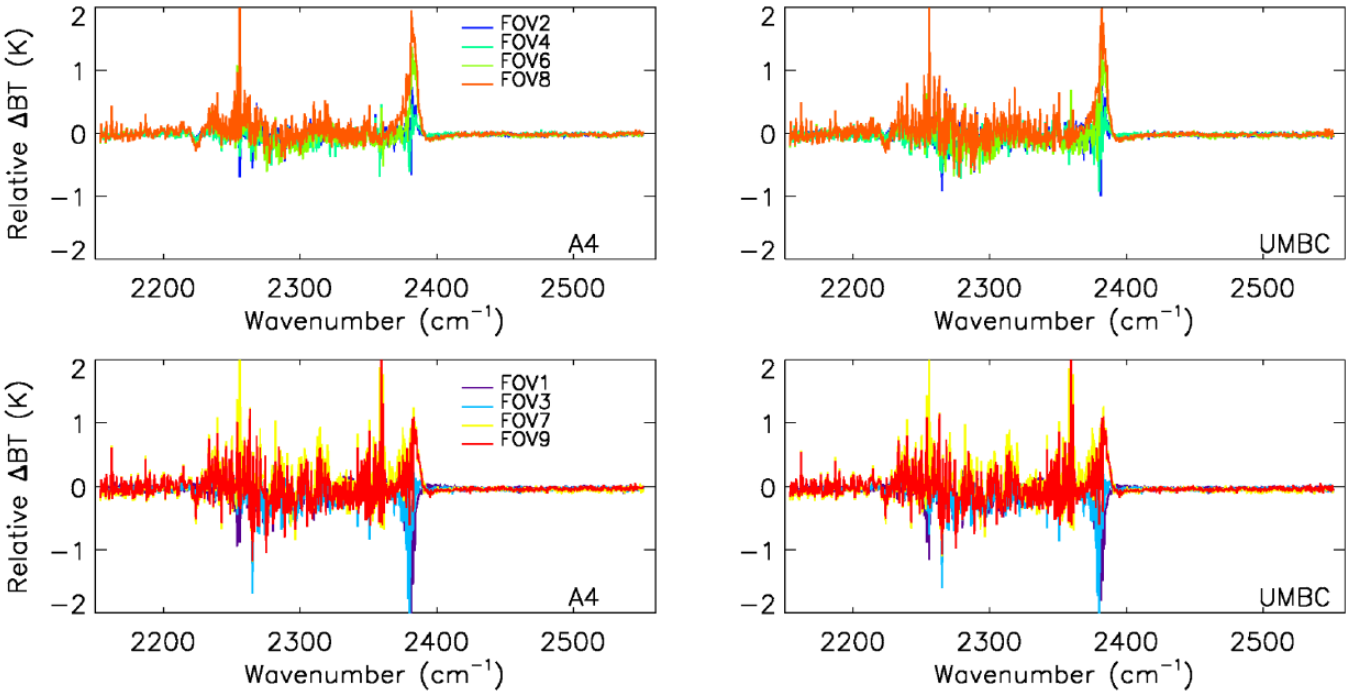






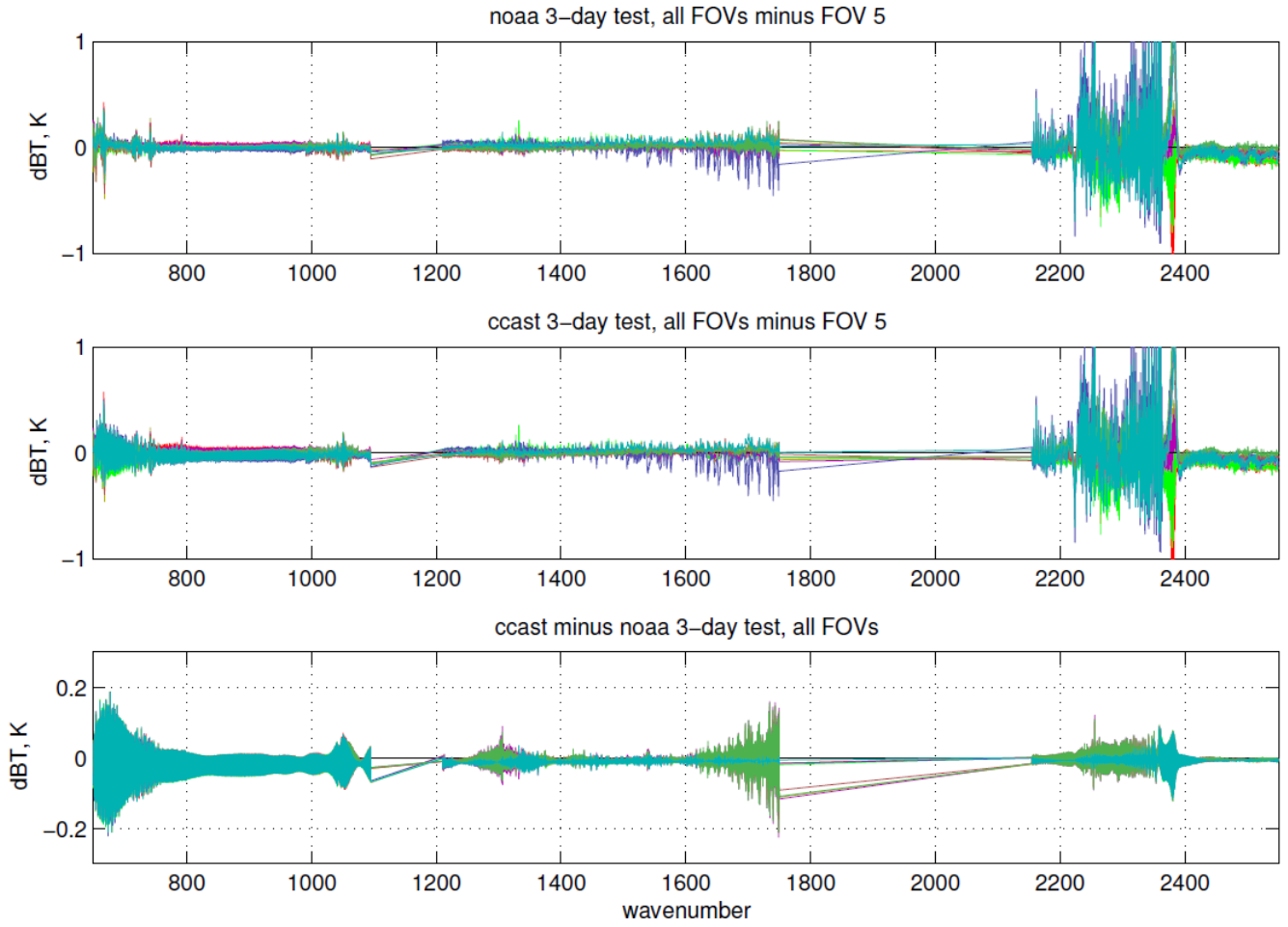
MW A4 and UMBC Differences: FOV –2 – FOV5 STAR Jun10 2015 simulation

A4 and UMBC Differences: FOV-2-FOV Consistence: $(BT_{obs} - BT_{lbl})_{fov\_i} - (BT_{obs} - BT_{lbl})_{fov\_5}$



FD – Truth FOVs- FOV5
UMBC ops minus calc Aug 5 2015

relative test overview



Summary

- **Significant improvement inunderstanding, precision, and speed of the numerical calibration**
- **Focusing on NOAA and CCAST performance optimization**
- **Ongoing work**
  - **Flat passband FIR filters to get closer to circular filter result**
  - **Aliasing of MW and SW spectra**
- **Incorporating optimizations into production code**