Space Dynamics Laboratory
Utah State University Research Foundation

NPP and J1 CrIS Instruments Noise Performance

STAR JPSS Science Team Meeting SDL, Exelis, NOAA STAR results

Deron Scott presenting

May 12-16, 2014

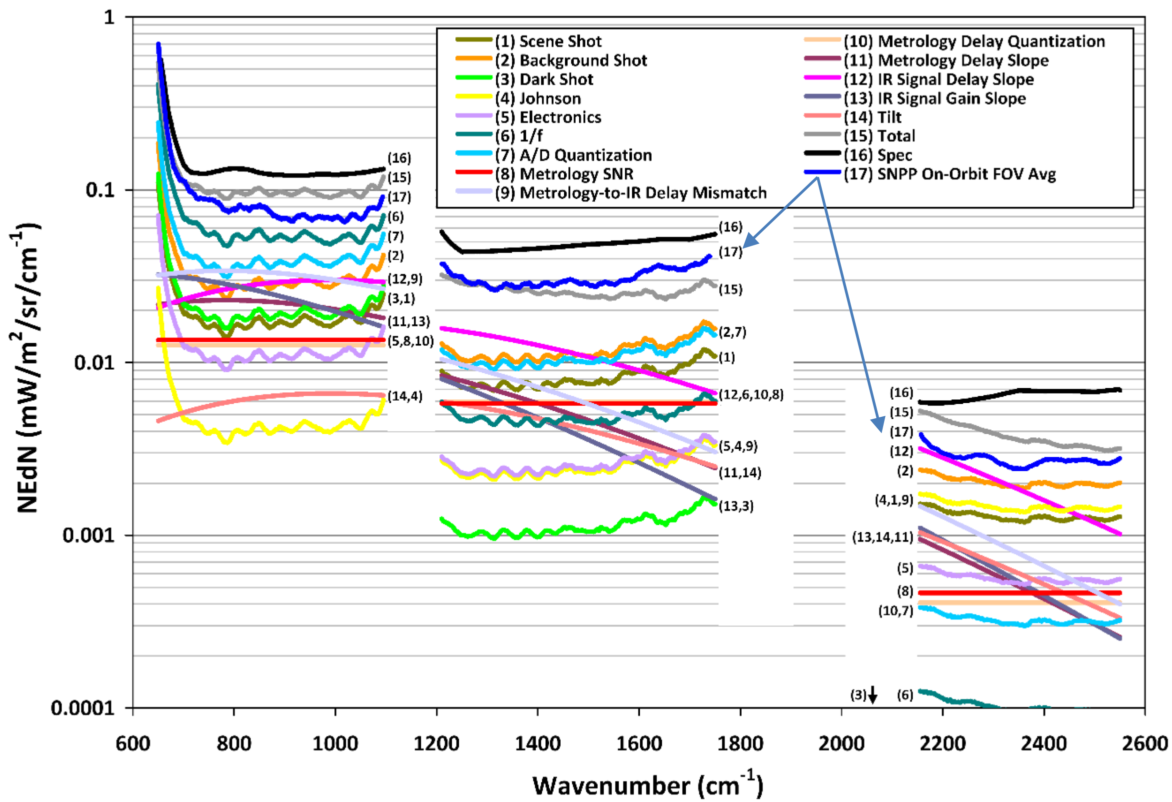
Outline

1. Noise sources and NPP on-orbit real spectra NEdN
2. NPP CrIS on-orbit noise performance as compared to TVAC ground test and heritage AIRS and IASI instruments
3. NPP on-orbit NEdN trend. NEdN stability over different orbital positions (North Pole, Tropics, and South Pole)
4. Small seasonal, spatial, and orbital NEdN variations.
5. Imaginary spectra NEdN as a diagnostic tool to monitor instrument health
6. J1 CrIS instrument NEdN performance (bench and RRTVAC tests)
7. Conclusion.

- Total NEdN is calculated using standard technique (standard deviation)
- PCA technique is used to estimate random NEdN component
- Correlated noise contribution is estimated as:

$$NEdN_{cor} = \sqrt{NEdN_{total}^2 - NEdN_{random}^2}$$

CrIS Instrument Noise Sources

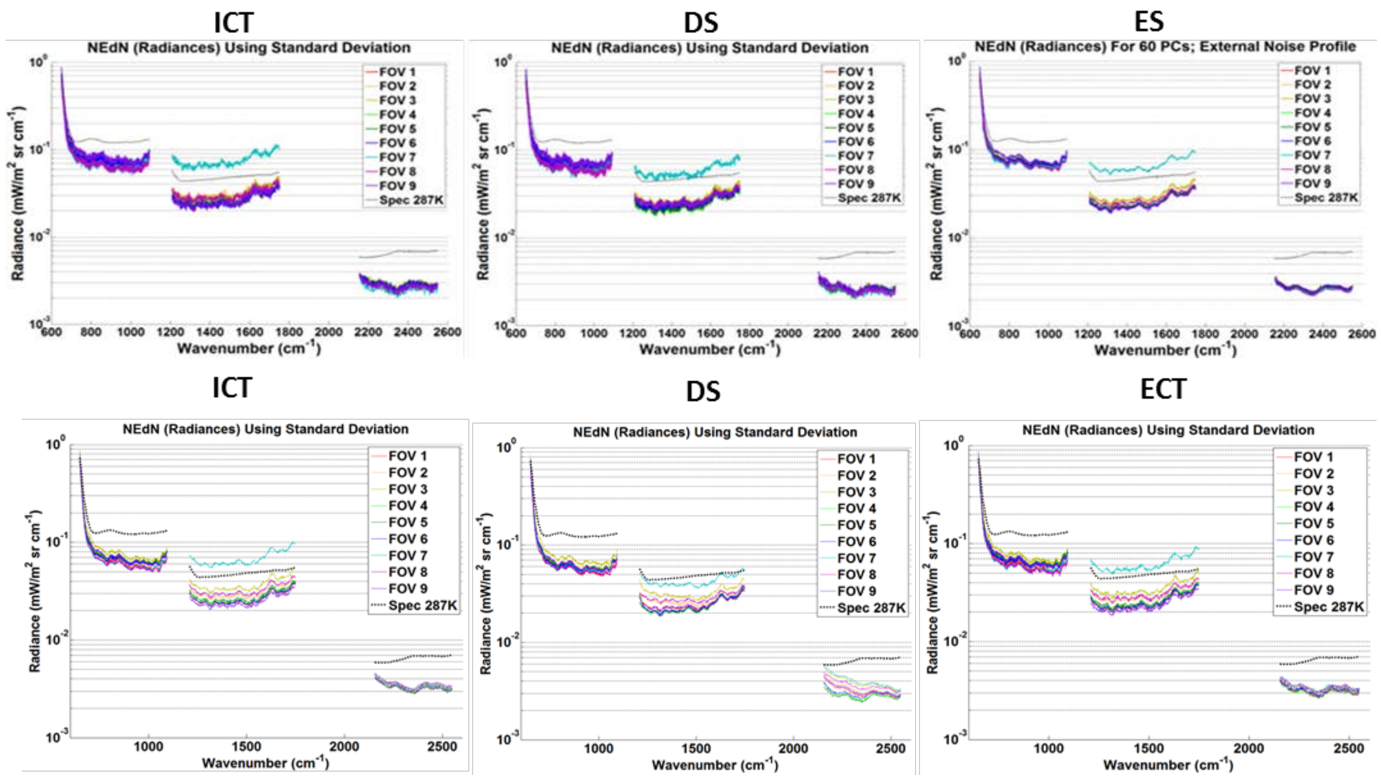


- **Exelis** CrIS NEdN model and simulations: 1-7 detector and electronics noise (random); 8-14 interferogram distortion noise (may lead to spectrally correlated noise component)
- Major contributors: LWIR- 1/f noise; MWIR and SWIR - background shot and IR signal delay slope noise
- Background shot noise dominates in MWIR and SWIR spectral bands in both NPP and J1 sensors.
- Note, under external vibration interferometer induced noise dominates – characteristic slope (12)

NPP: On-orbit NEdN vs TVAC4

On-orbit
January 10, 2013

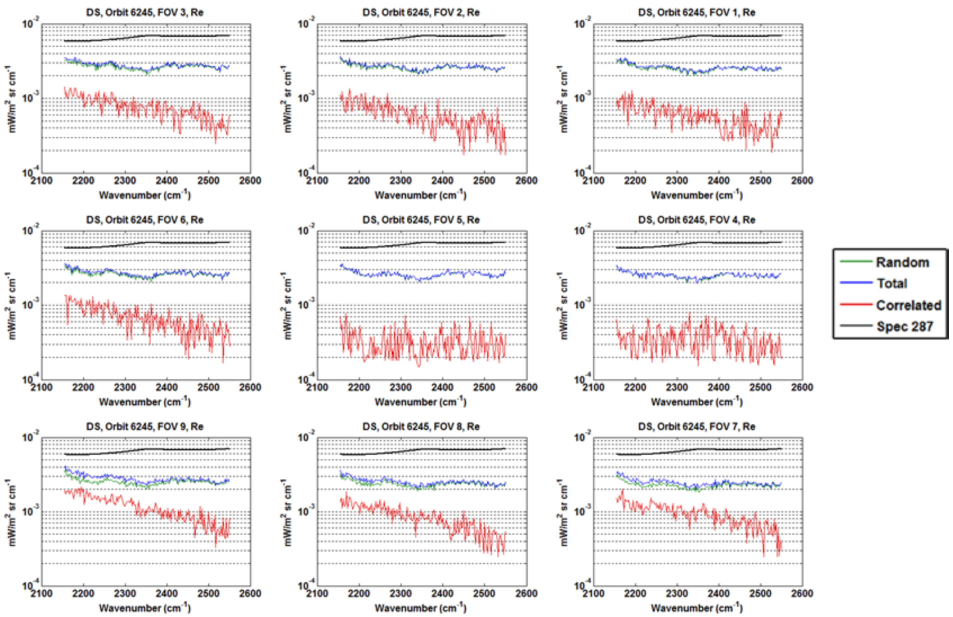
TVAC 4, MN
T_{ECT}=287K



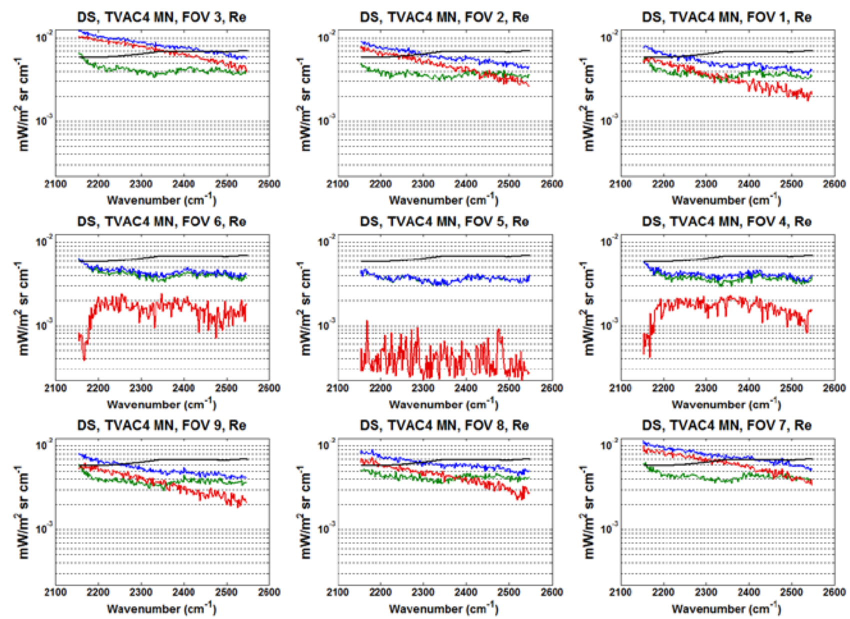
- NEdN in all spectral channels and FOVs (except MWIR FOV7) is well within spec
- On orbit NEdN is practically the same as during TVAC4 ground test
- MWIR FOV7 is slightly out of spec from TVAC4 test probably due to migrating impurities in the IR detector interface (may change after warm-up/cool-down cycle).

NPP: Correlated noise contribution. SWIR DS-worse case

SWIR DS:
Orbit #6245 January 10, 2013

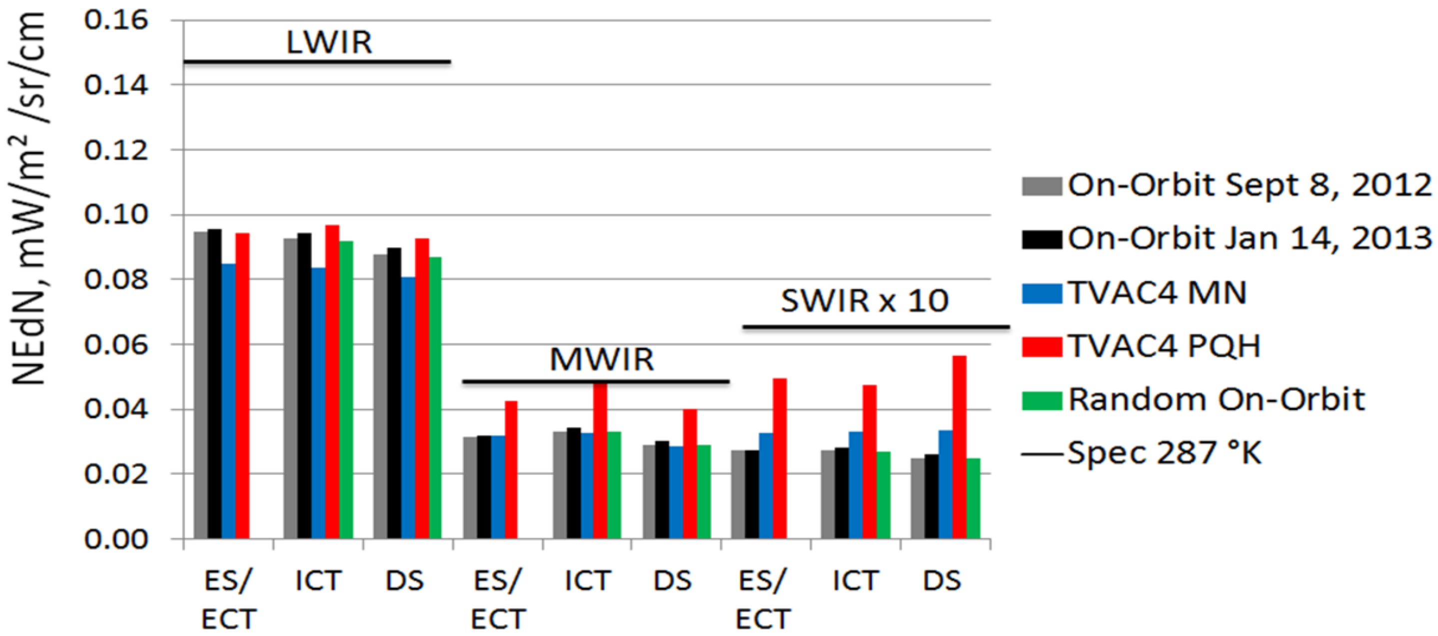


SWIR DS: TVAC4 MN



- On-orbit NEdN exhibit significantly lower correlated noise contribution. During TVAC4 test additional vibration from the test equipment was present
- Vibration test and NEdN simulations conclusions:
  - SWIR NEdN is most sensitive to the external vibration
  - DS is most sensitive to the external vibration as compared to the ICT and ECT
  - Corner FOVs (1,3,7,9) are most susceptible to the vibration

NPP: Average real spectra total NEdN On-orbit vs TVAC4



- Change in the on-orbit NEdN as compared to TVAC4 MN is mostly due to a random noise component (intrinsic detector noise):
  - LWIR: on-orbit random NEdN higher by ~10-12% then TVAC4 MN level
  - MWIR: on-orbit NEdN is at the same level as TVAC4 MN NEdN
  - SWIR: on-orbit random NEdN is smaller by ~15-20% then TVAC MN NEdN
- NEdN is averaged over each spectral band and all FOVs
- 220 spectra were used for each on-orbit and TVAC4 data analysis

NPP: NEdN and NEdT (at 270^0K) comparison with AIRS and IASI

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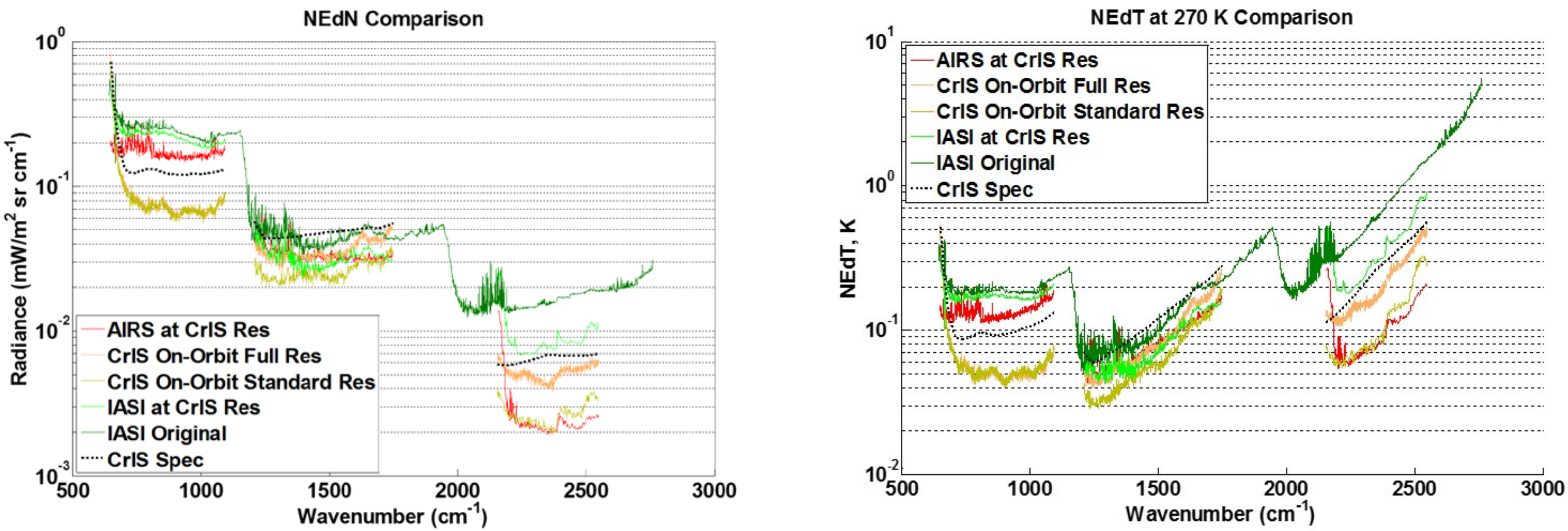

- NEdN is estimated from Earth scene radiances using SDL PCA approach (60 PCs retained)
- CrIS exhibits smaller noise level in LWIR (~x3) and SWIR (~x3) spectral bands than noise estimated from IASI observations reduced to CrIS spectral resolution
- As expected, CrIS full spectral resolution noise in MWIR and SWIR bands is higher by ~x1.4 and ~x2, respectively, as compared to the CrIS standard spectral resolution

NPP: NEdN on-orbit trend over Equator region

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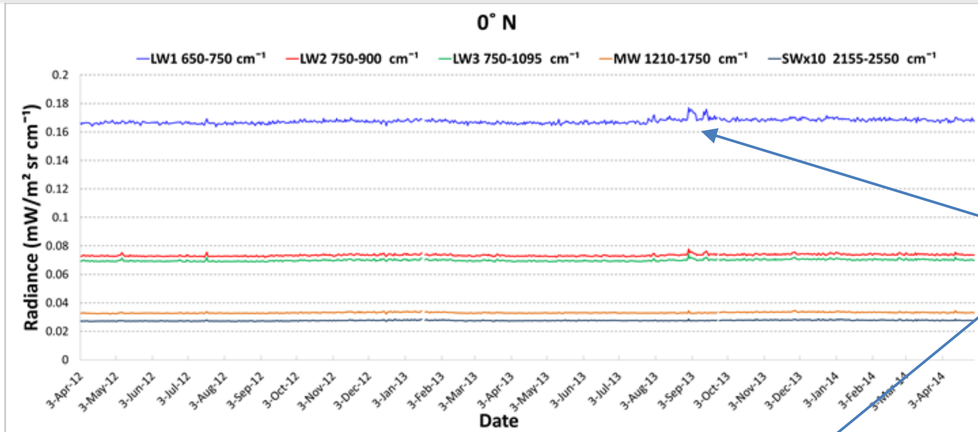
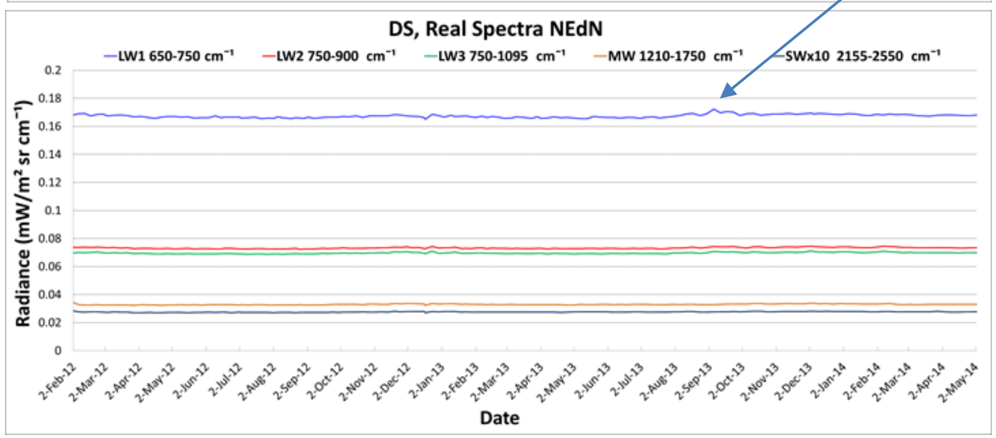
ICT
IDPS NEdN SDR
once a day
04/03/2012-
05/05/2014



LWIR FOV1 anomaly observed in July-September 2013.
No new anomalies were observed since.

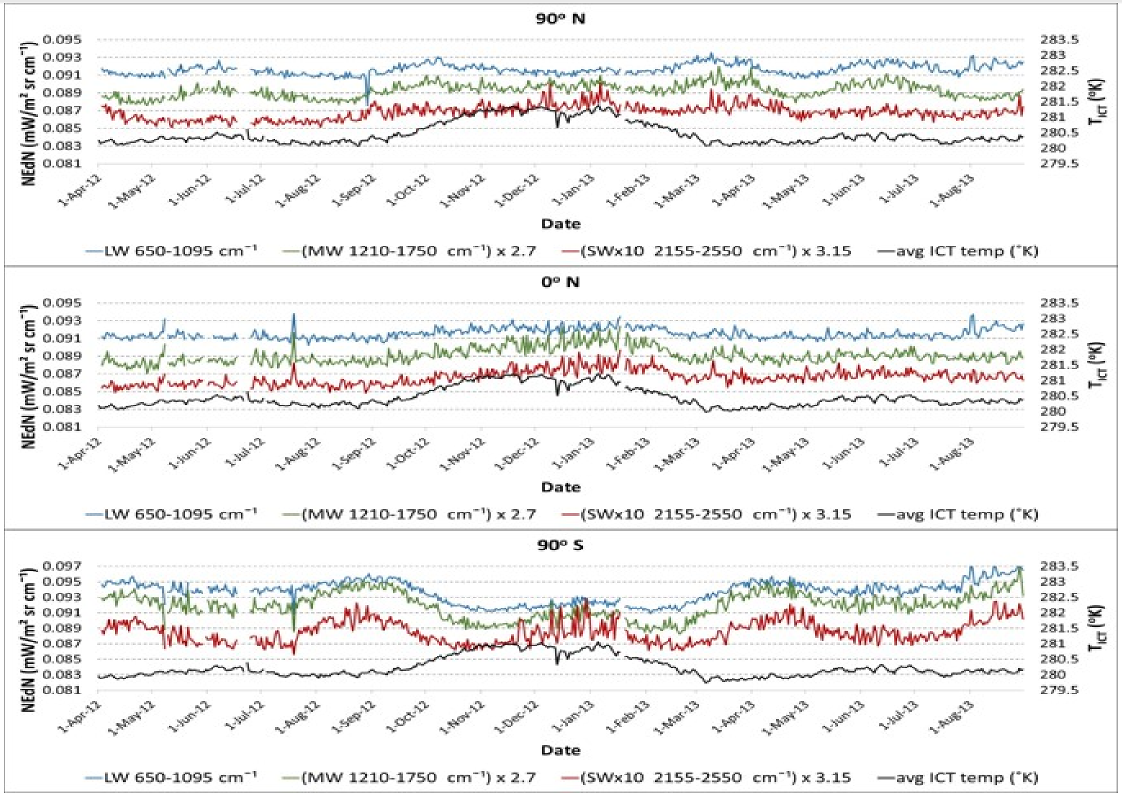
DS
SDL monitoring
once a week
01/21/2012-
05/05/2014



- NEdN remains stable during orbital operations
- LWIR FOV1 NEdN variations of ~(25-50)% were observed in July-September 2013
- NEdN was averaged over all FOVs and over spectral regions:

LWIR:	650-750 (beam-splitter transmittance); 750-900 (possible icing); and 750-195 cm^{-1}
MWIR:	Entire band 1210-175 cm^{-1}
SWIR:	Entire band 2155-2550 cm^{-1}

NPP: Seasonal NEdN variations over NP, Equator, and SP regions



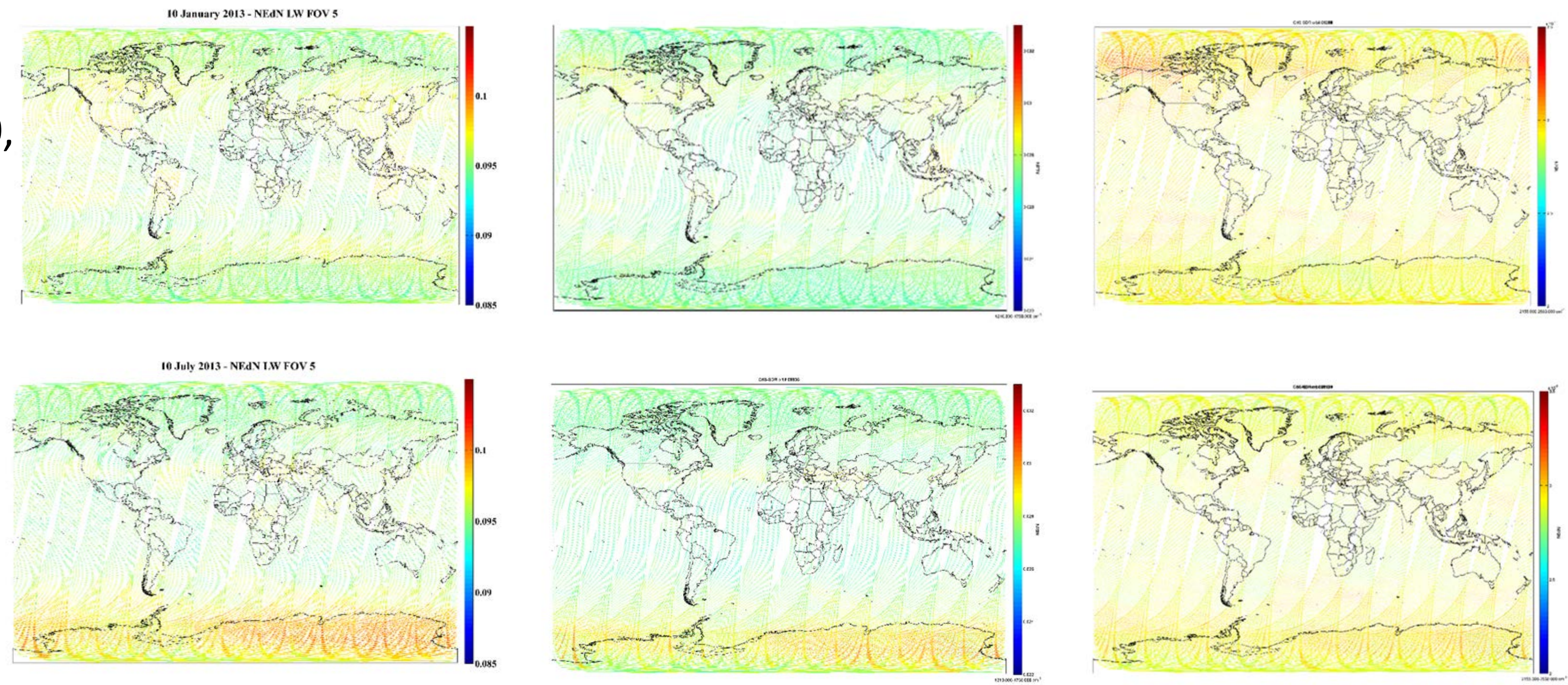
- IDPS SDR NEdN and ICT temperature acquired once a day over NP (90^0N), Equator (0^0N), and SP (90^0S) regions
- At low latitude (~ 65^0 North to -65^0 South) the NEdN seasonal variations do not exceed 2-3% and follow the seasonal variations of the ICT temperature
- larger variations ~ 4-6% are observed over the South Pole. NEdN over both North and South Pole regions exhibit additional seasonal variations during spring and fall.

NPP: Orbital NEdN variations. FOV5

LWIR | MWIR | SWIR

January 10, 2013

July 10 , 2013



- Descending (night time) orbits are shown
- Color scale is chosen +/- 10% of NEdN nominal values
- Small orbital NEdN variations <10% are typical for each FOV
- No NEdN anomalies are observed over the South Atlantic Anomaly region
- Relatively large area of PV HgCdTe detectors and radiation shielding provide reliable protection of the detector array from high energy particles

NPP: Total Imaginary NEdN
On-orbit vs TVAC4 MN

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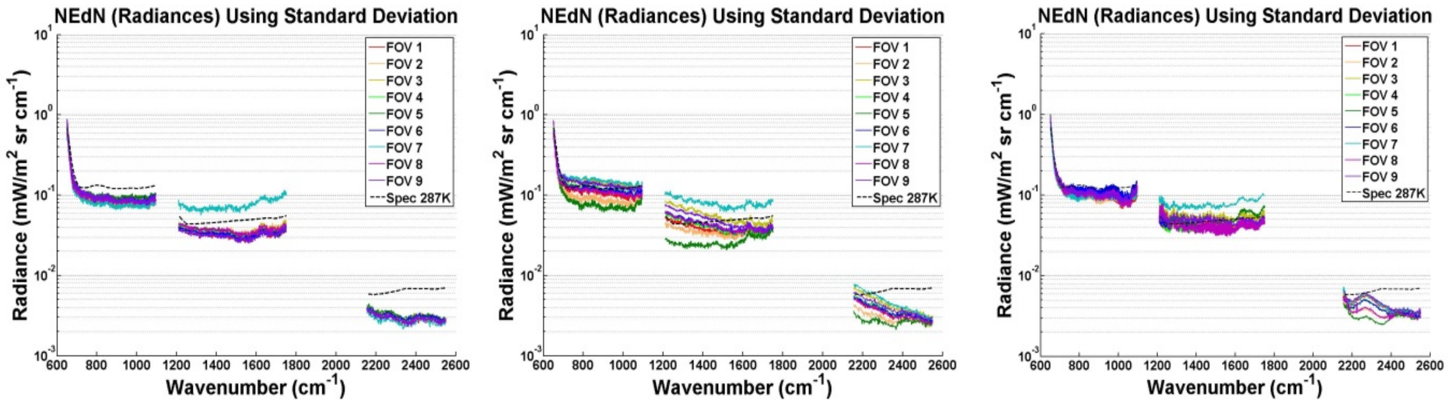
Orbit 6245

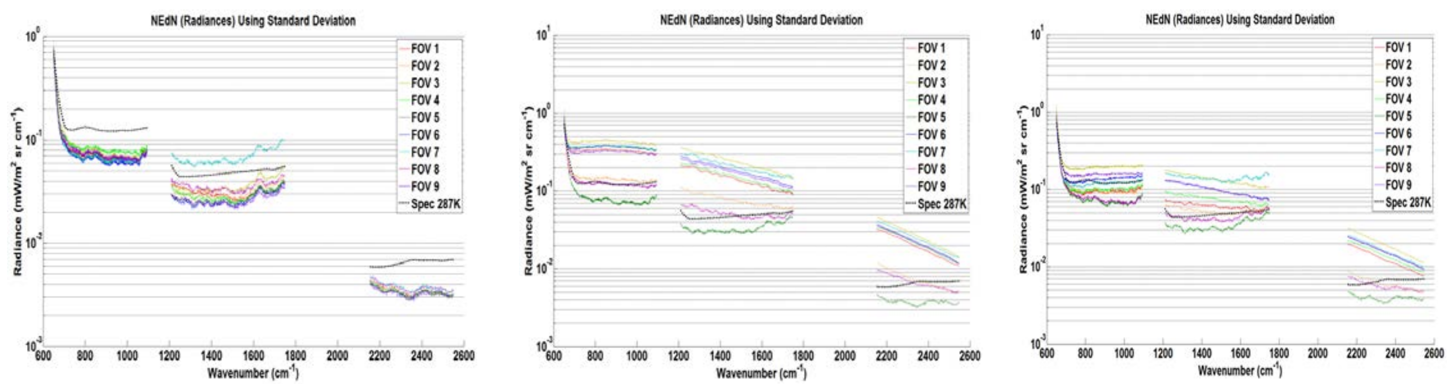
January 10, 2013

ICT | DS | ES



TVAC4 MN

ICT | DS | ECT



- Imaginary NEdN exhibits elevated level due to the spectrally correlated noise component
- Random noise is dominated by the intrinsic detector noise like in real NEdN
- On-orbit imaginary NEdN is lower than during TVAC4 especially for DS derived NEdN
- Negligible contribution of the correlated noise is observed in real NEdN shown previously

NPP: Correlated noise contribution
DS Imaginary NEdN

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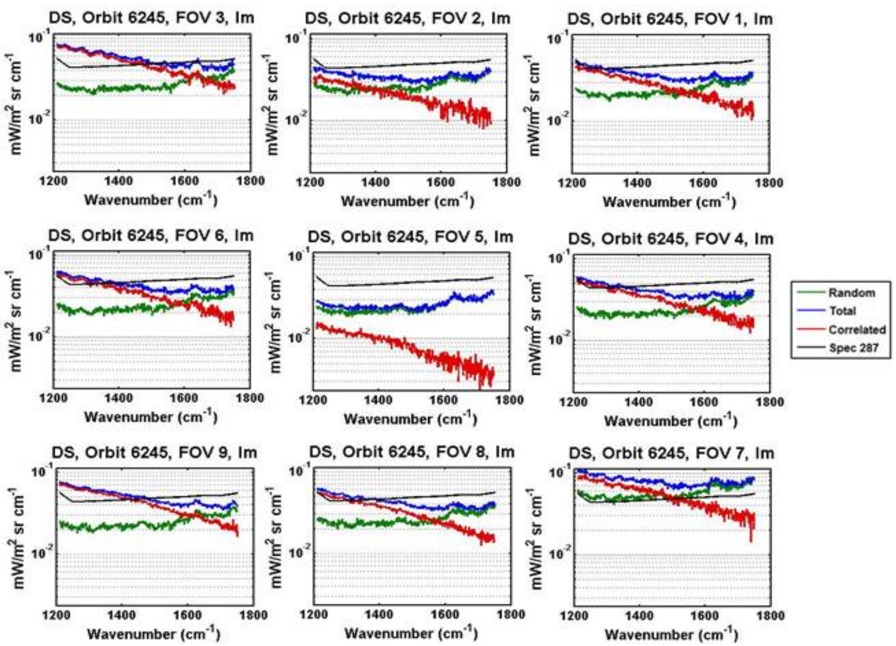
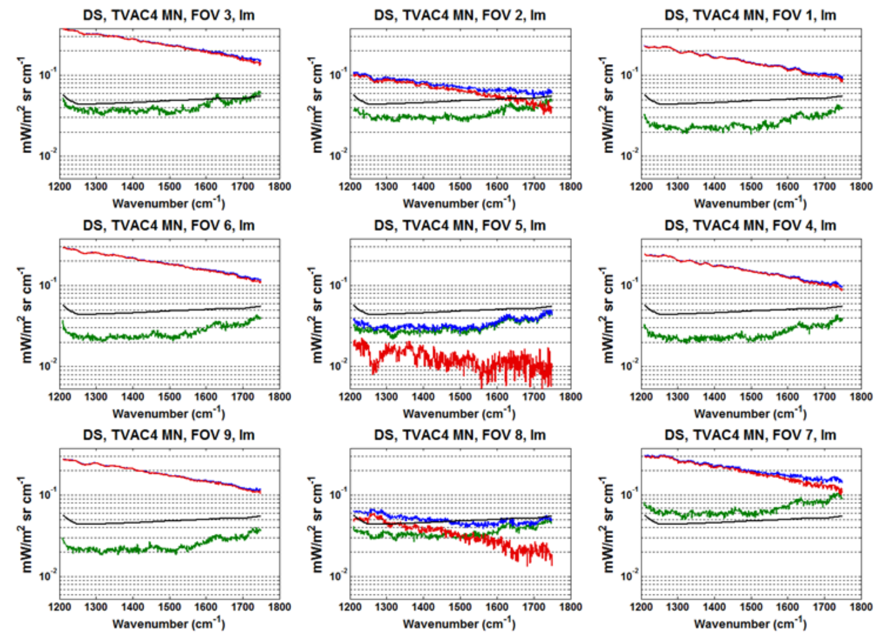
DS: **Orbit 6245**, January 10, 2013



DS: **TVAC4 MN**



- Imaginary NEdN is extremely sensitive to any instrument artifacts and external vibration as compared to real NEdN.
- Corner FOVs are more susceptible to the tilt-induced OPD sample jitter
- DS derived imaginary NEdN has largest vibration sensitivity while ICT target exhibits the smallest vibration susceptibility.
- On-orbit correlated imaginary NEdN significantly lower than during TVAC4

NPP: Average imaginary total NEdN. On-orbit vs. TVAC4

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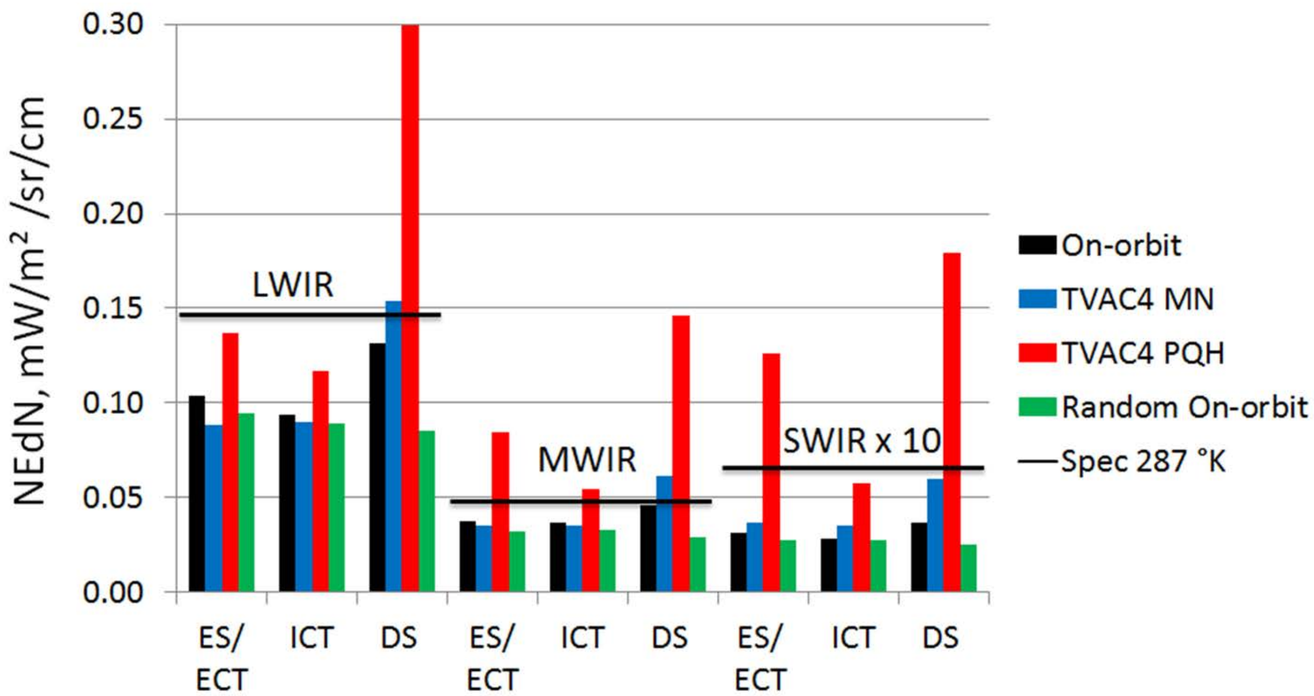

- On-orbit data : orbit # 6245 at January10, 2013 (max increase in the imaginary NEdN)
- During TVAC4 PQH test additional vibration from the test equipment was present
- On-orbit imaginary NEdN is comparable or smaller than TVAC4 MN value
- Only random NEdN component can be estimated on-orbit from ES view using PCA
- NEdN is averaged over each spectral band and all FOVs

NPP: DS derived average imaginary NEdN

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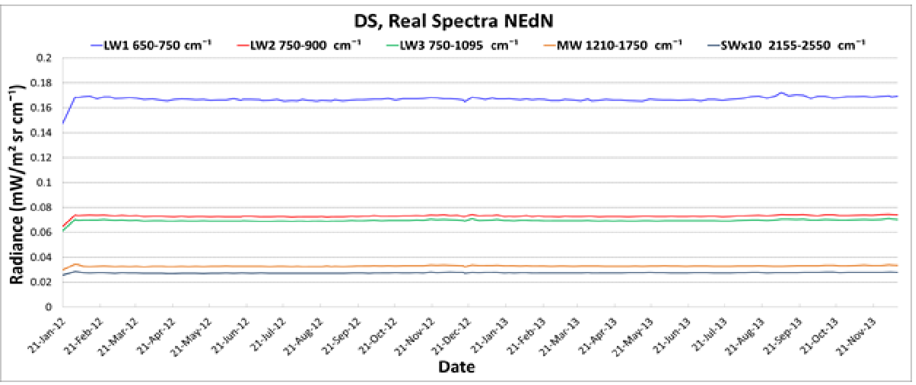
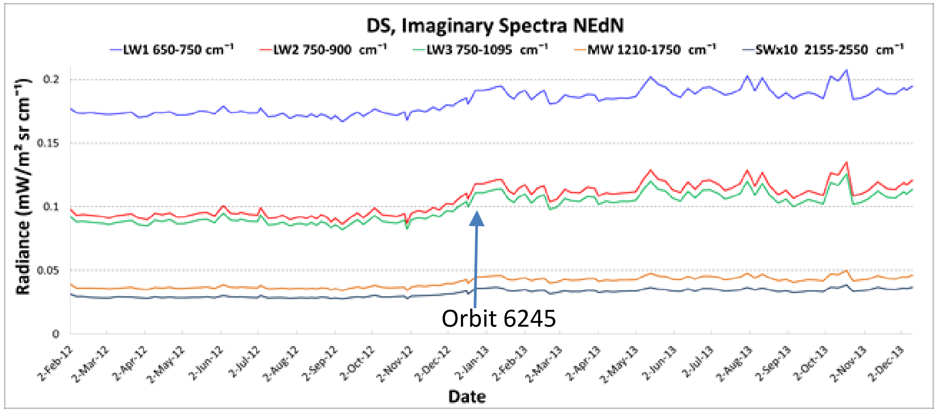
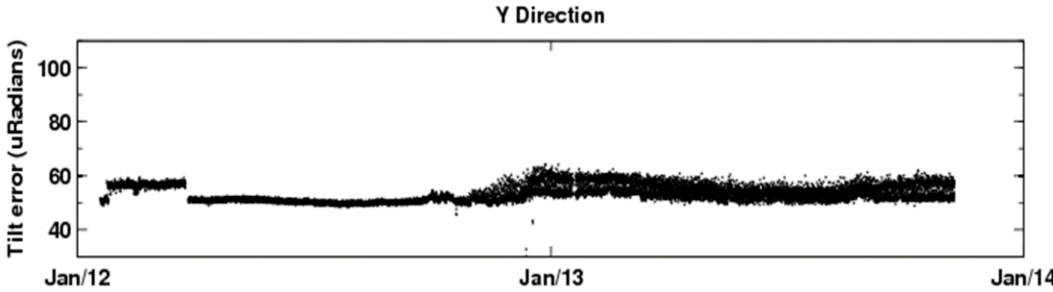
Real spectra NEdN



Imaginary spectra NEdN



STAR NPP CrIS Housekeeping DA tilt error in Y-direction, hourly averaged



- NEdN has increased in the imaginary part of the DS spectra in all spectral bands (~30-40%)
- Increase in the imaginary DS NEdN correlates with DA tilt error in Y-direction
- Practically no change in real spectra NEdN is observed
- Possible source of small additional S/C vibration: ATMS scanning assembly

NPP: Orbital fluctuations in the DS imaginary NEdN

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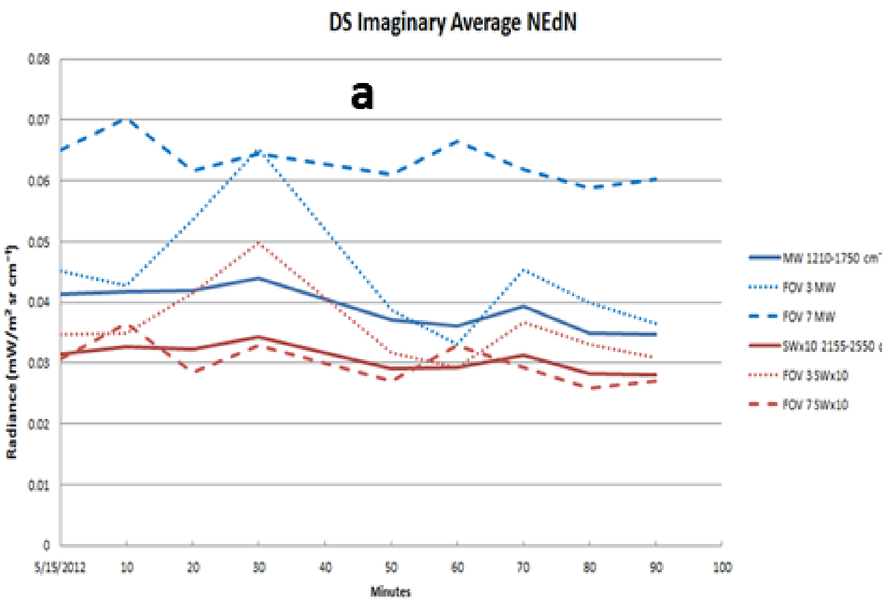
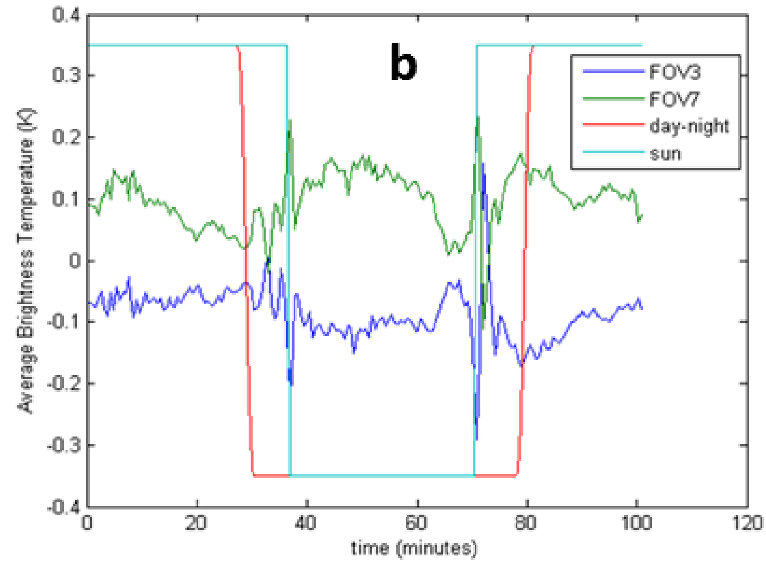
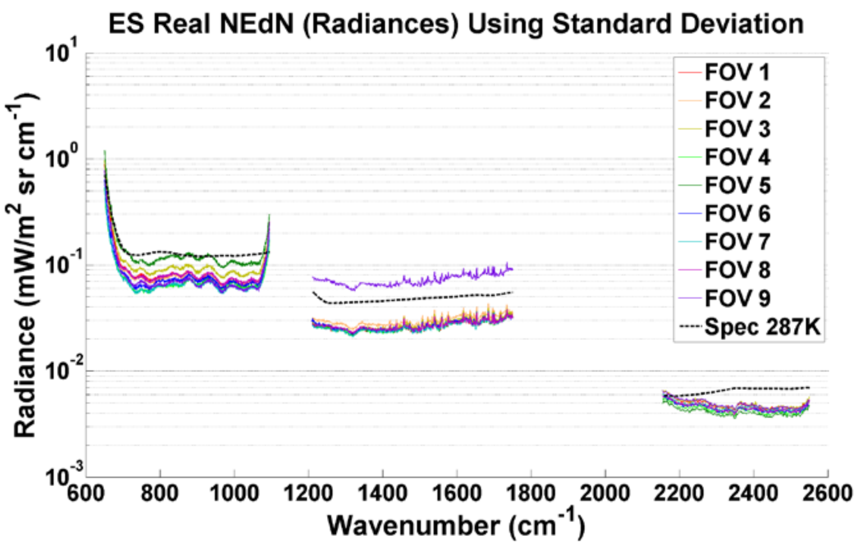




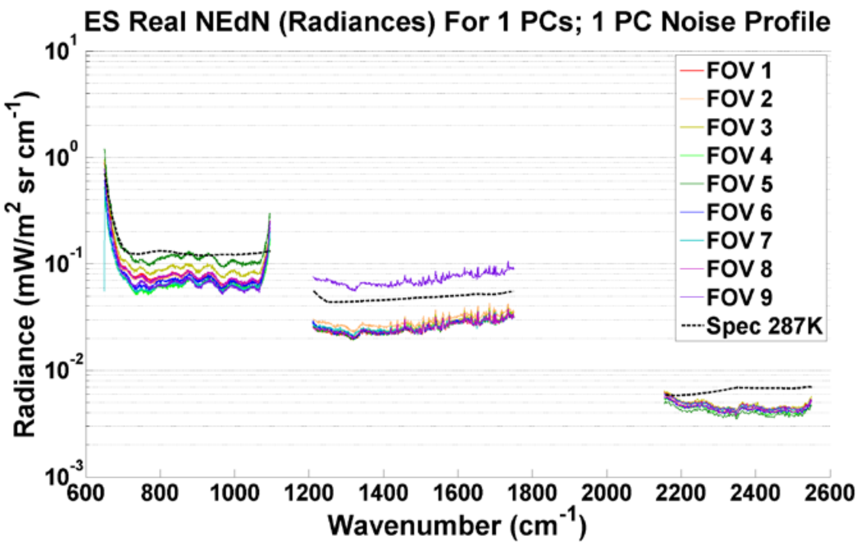
- DS imaginary NEdN exhibit slightly larger fluctuations ~10-30% over time as compared to the real NEdN and ICT derived NEdN (a)
- Variation are due to correlated noise component
- Larger noise occurs near North and South poles when the Sun light hit the Suomi NPP spacecraft during day/night transition (flight time of ~25 and ~80 minutes respectively)
- These variations in the imaginary NEdN correlate with FOV-to-FOV responsivity and small variations in BT of FOV3 and FOV7 (b)

J1 Bench test:
ECT Real NEdN, Standard resolution

Total NEdN



Random NEdN component



- No contribution of correlated noise is observed
- Additional LWIR short wavelength tail is observed. It is probably due to combination of transmission and digital filter.
- MWIR FOV 9 is out of family as FOV7 for NPP CrIS

J1 Bench test:
ECT Real NEdN, Full spectral resolution

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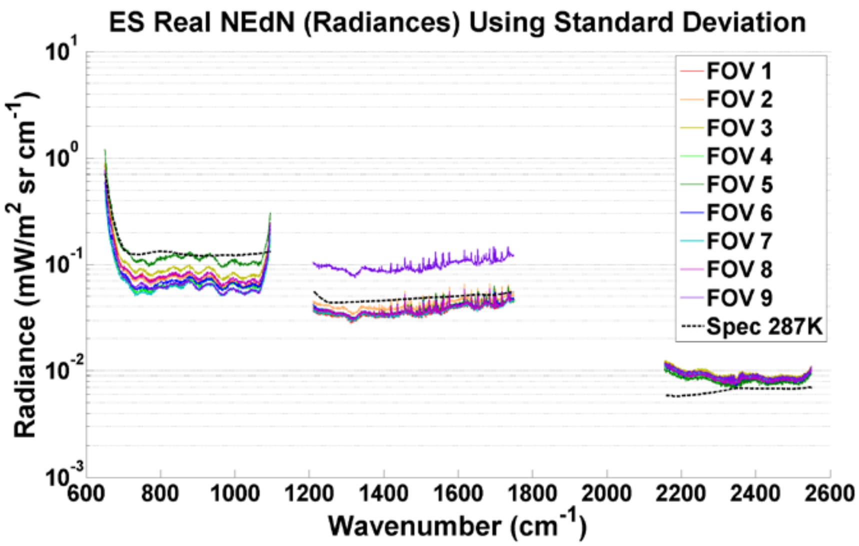
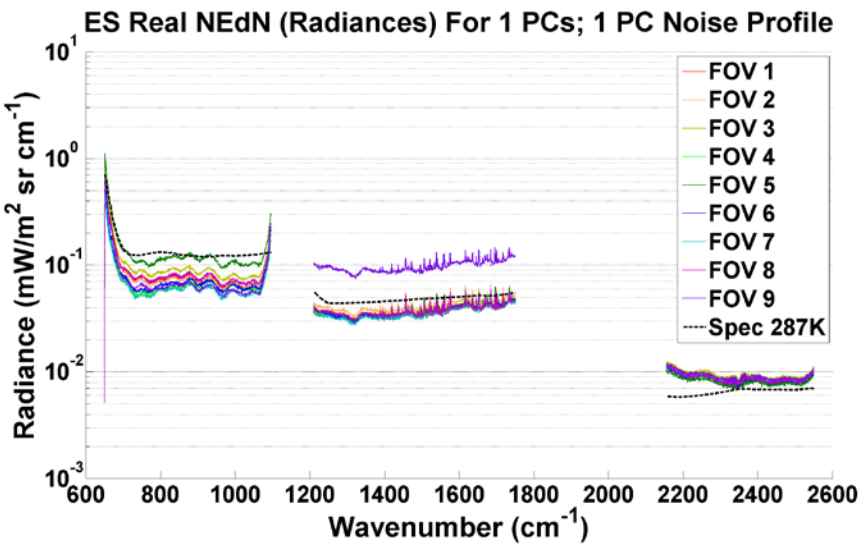
Total NEdN



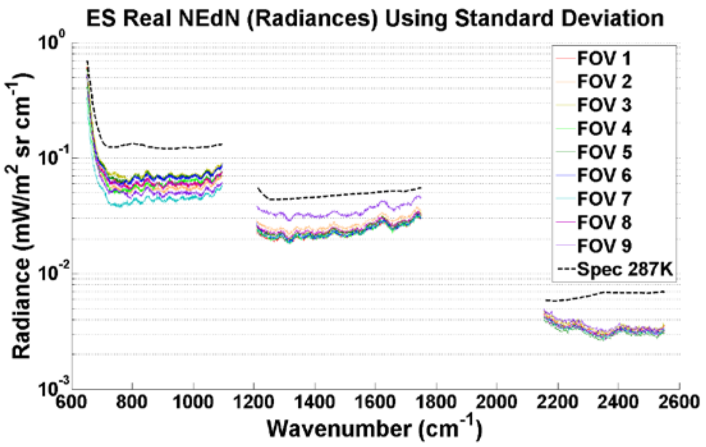
Random NEdN component



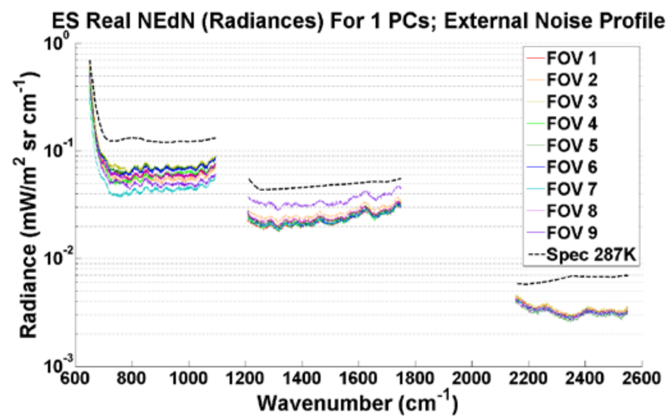
- CrIS full spectral resolution noise in MWIR and SWIR bands is higher by ~x1.4 and ~x2, respectively, as compared to the CrIS standard spectral resolution
- Other features are the same as for standard spectral resolution

RRTVAC: ECT Real NEdN
Standard resolution

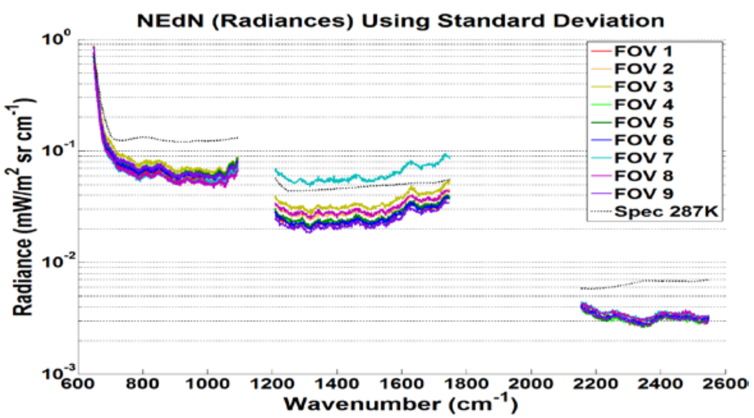
J1 RRTVAC: Total NEdN



J1 RRTVAC: Random NEdN component



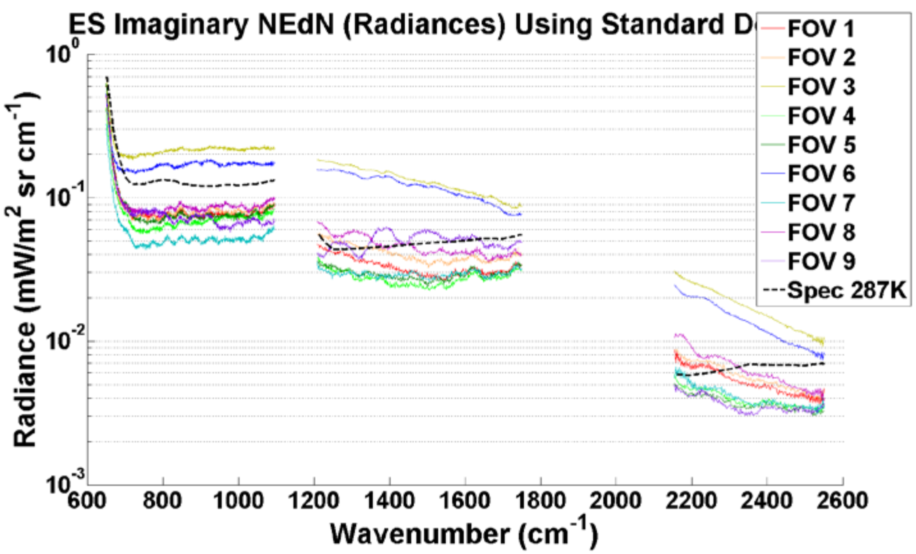
NPP TVAC4 MN: Total NEdN



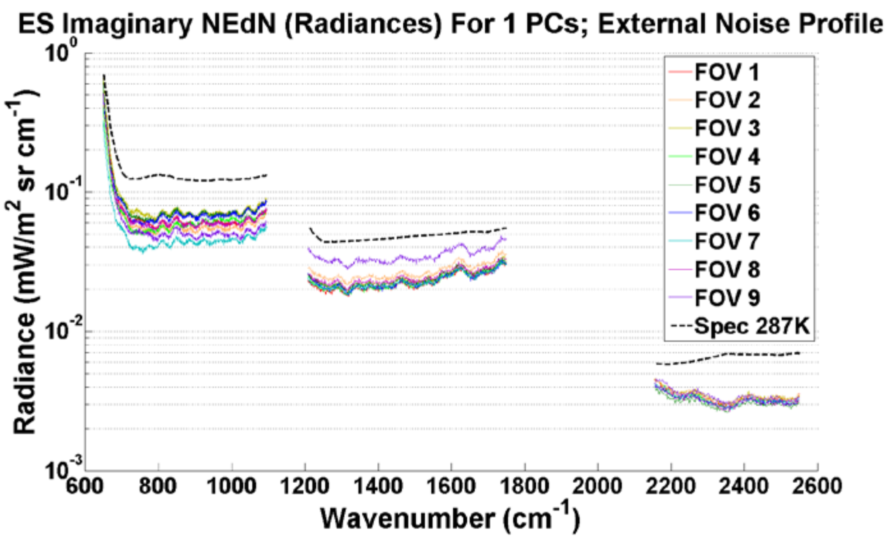
- No contribution of correlated noise is observed
- LWIR short wavelength tail seen in bench not observed
- MWIR FOV 9 is still out of family but is within specification
- J1 has comparable or smaller NEdN than NPP

RRTVAC: ECT Imaginary NEdN
Standard resolution

Total NEdN



Random NEdN component



- Contribution of correlated noise is observed
- Likely an ECT target alignment issue (FOVs 3 &6 higher for all bands)
- Significant FOV 2 FOV calibrated radiances difference also indicative of target alignment issue
- No impact on the real NEdN is observed

Conclusion

1. NEdN level meets mission requirements for both NPP and J1 instruments with a margin of typically 100% (except MWIR FOV 7 NPP instrument).
2. The intrinsic detector noise randomly distributed in spectral domain dominates total instrument NEdN. Negligible contribution of correlated noise is observed.
3. CrIS has comparable or smaller noise levels than AIRS and IASI heritage instruments (~2-3 times smaller in LWIR spectral band)
4. NEdN has remained extremely stable during on-orbit operations. Only small seasonal, orbital and spatial NEdN variations (<10%) are observe on-orbit.
5. Small anomaly (≤50%) in LWIR FOR1 NEdN was observed on July 07 and September 10 and 12,2013. Remains stable on slightly elevated level (<10%)
6. As expected, for both instruments full spectral resolution noise in MWIR and SWIR bands is higher by ~x1.4 and ~x2, respectively, as compared to the CrIS standard spectral resolution.
7. Imaginary NEdN is extremely sensitive to any instrument artifacts and external vibration as compared to the real NEdN and may serve as an important tool to monitor on-orbit performance of CrIS

J1 RRTVAC test (Exelis): Excellent NEdN Performance

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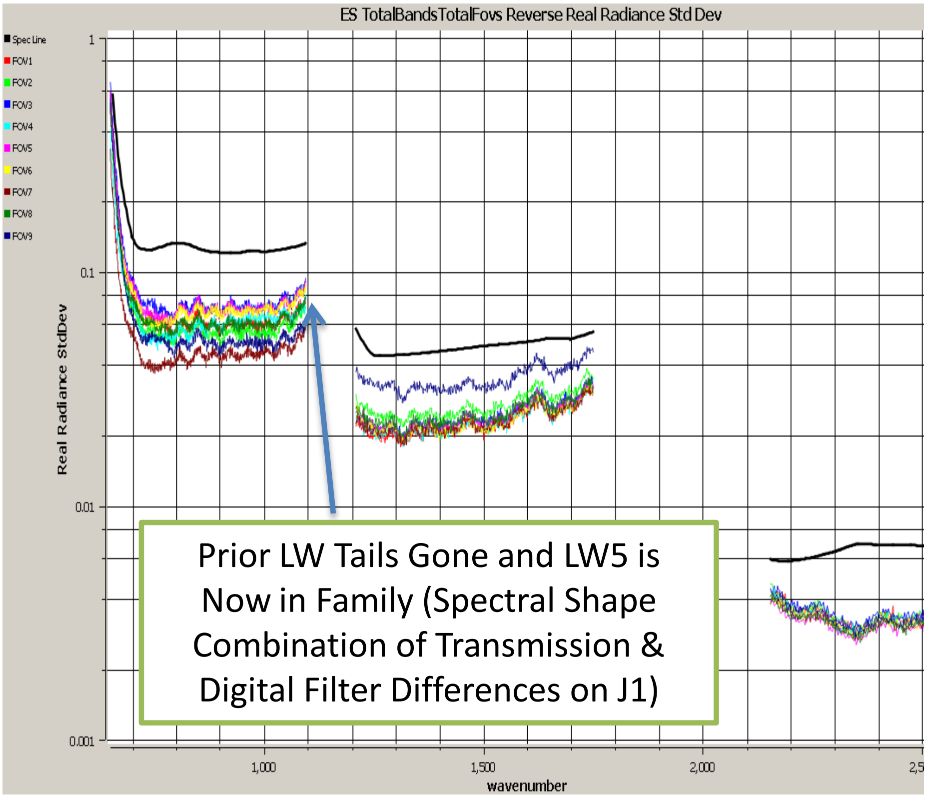
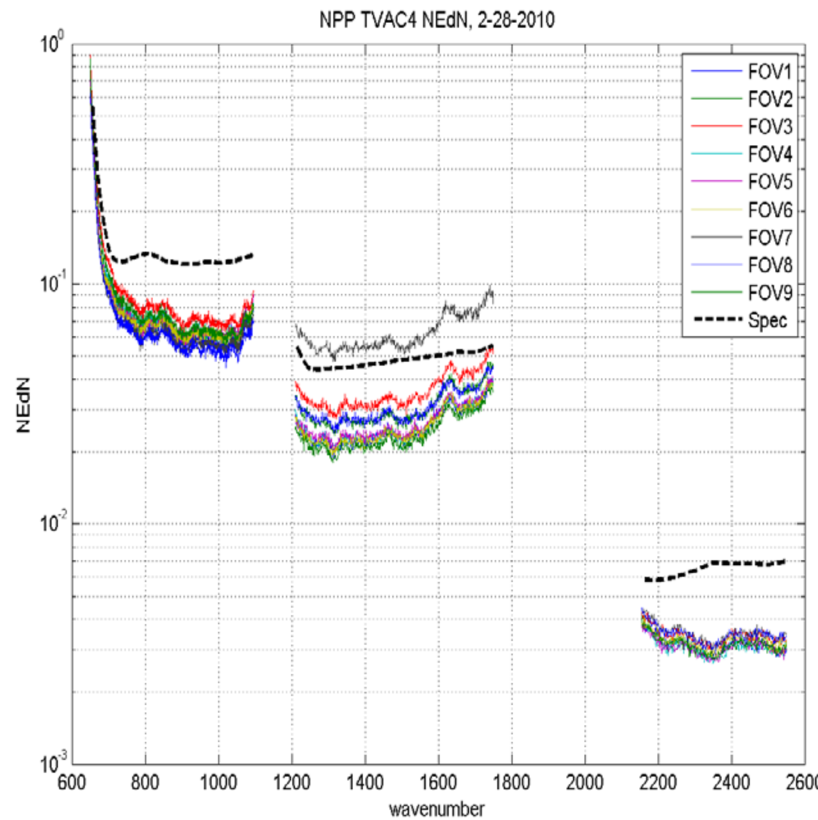
J1 RRTVAC2



NPP



- J1 NEdN Spec Applies Only to MN
- RRTVAC Results Predict Full Compliance (MW9 may still change with cool-downs)

RRTVAC NEdN Performance is Similar or Better than NPP

J1 RRTVAC test (Exelis): Real NEdN vs Imaginary NEdN

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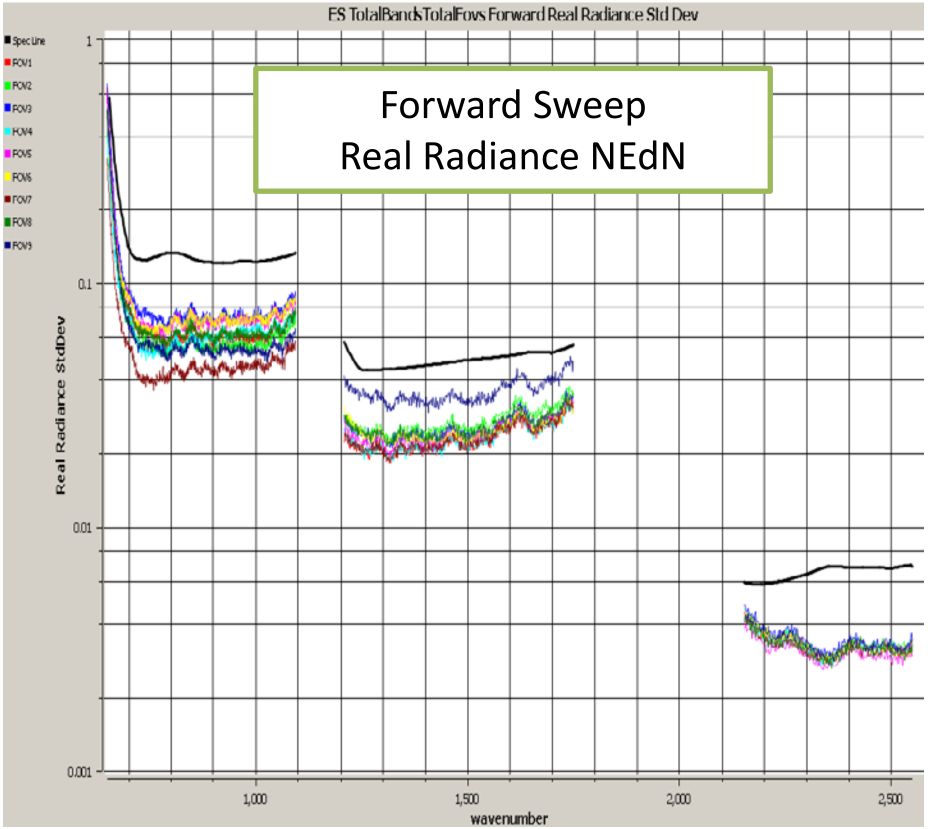

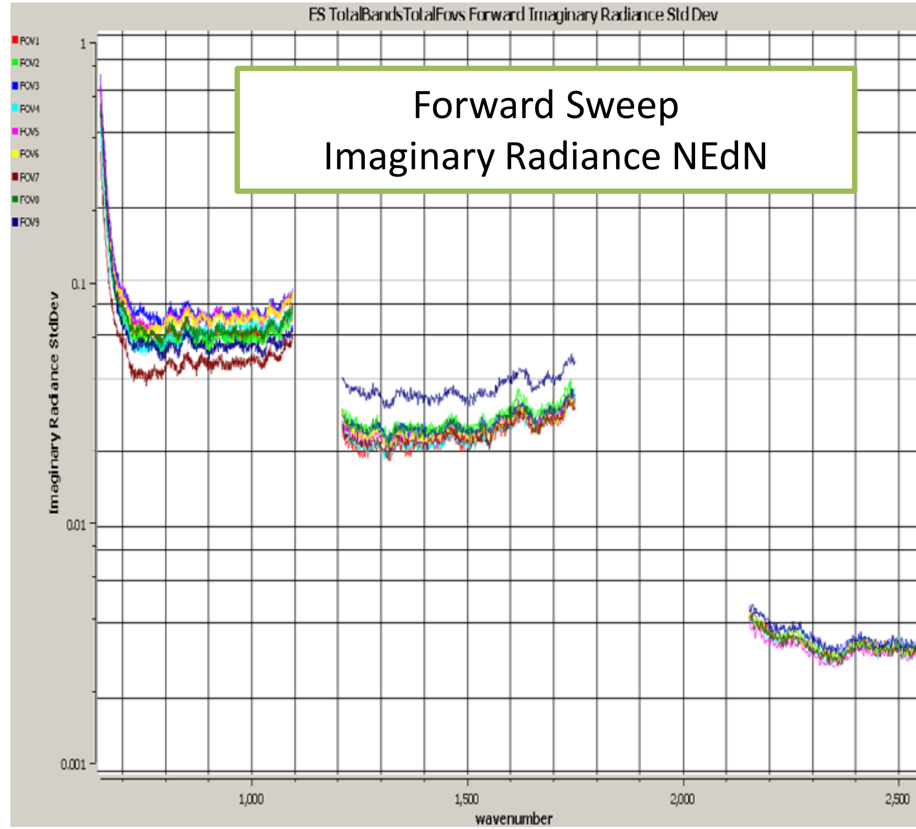

- Small increase in the imaginary noise is observed (the same was observed for NPP sensor). No impact on the real NEdN is observed.
- Most probably it is due to correlated noise component (analysis is underway)
- This is typical for normal FTS instrument performance

Preparation of CrIS Full Resolution Processing

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STAR JPSS Annual Science Team Meeting, May 12-16, 2014

Contents

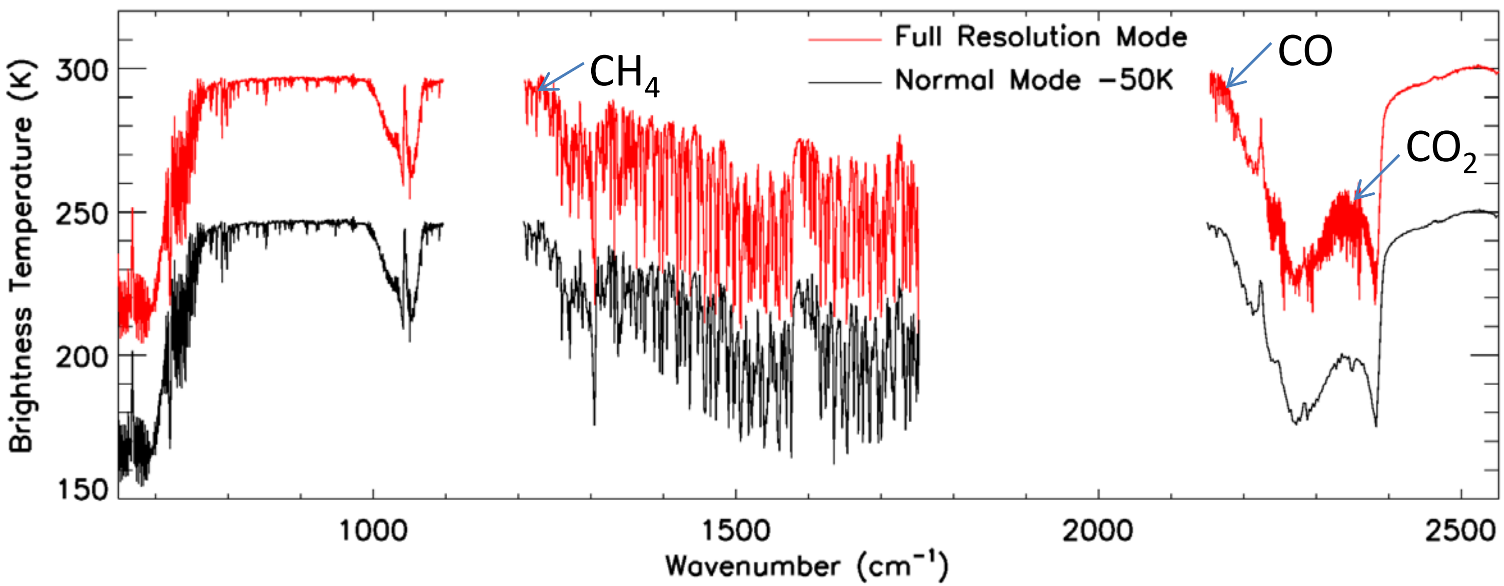
- Prototype ADL to generate CrIS full resolution mode Sensor Data Records (SDR)
- Comparison of different calibration approaches in ADL full resolution mode
- Radiometric accuracy assessment
  - Difference between observation and forward model simulation
  - Double difference (DD) between CrIS and IASI
  - Simultaneous Nadir Overpass (SNO) between CrIS and IASI
- Spectral accuracy assessment
  - Absolute spectral validation
  - Relative spectral validation
- Summary

CrIS Normal Resolution and Full Resolution SDR

- CrIS can be operated in the full spectral resolution (FSR) mode with 0.625 cm^{-1} for all three bands, total 2211 channels, in addition to normal mode with 1305 channels
- NOAA will operate CrIS in FSR mode on December 2014 to improve the profile of H_2O, and the retrieval of atmospheric greenhouse gases CO, CO_2, and CH_4

Red: Full resolution

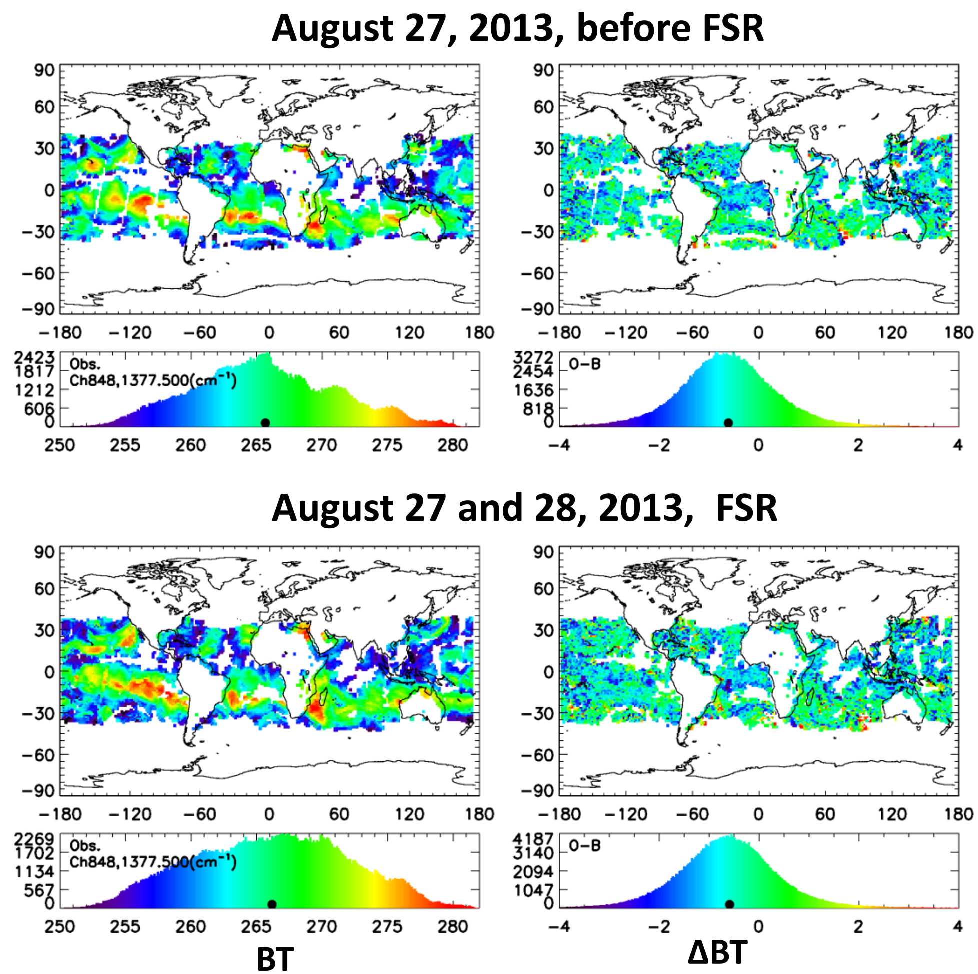
Frequency Band	Spectral Range (cm^{-1})	Number of Channel (unapodized)	Spectral Resolution (cm^{-1})	Effective MPD (cm)
LWIR	**650 to 1095**	**713* (717)**	**0.625**	**0.8**
MWIR	**1210 to 1750**	**433* (437)**	**1.25**	**0.4**
		865* (869)	**0.625**	**0.8**
SWIR	**2155 to 2550**	**159* (163)**	**2.5**	**0.2**
		633* (637)	**0.625**	**0.8**



CrIS Normal Resolution SDR Generated from the FSR RDR

- Up to date, the FSR mode has been commanded three times in-orbit (02/23/2012, 03/12/2013, and 08/27/2013)
- CrIS normal mode SDR can be operationally generated from IDPS with the FSR RDR truncation modulus

CrIS normal mode SDR
Ch 848, 1377.5 cm^{-1},
water vapor channel



- Results show that the SDR from FSR has similar features compared to SDR generated from low resolution RDR
- Both radiometric and spectral uncertainty are consistent with SDR generated from low resolution RDR

Prototype ADL to Generate CrIS Full Resolution SDR

- A prototype ADL in full resolution model is developed based on ADL42&Mx8.3
- CrIS full resolution SDR are successfully generated offline using the three times in-orbit FSR RDR test data
- Different calibration approaches are implemented in the code in order to study the ringing effect observed in CrIS normal mode SDR and to support to select the best calibration algorithm for J1
- Code is modularized and flexible to run different calibration approaches, but need to be recompiled before running
- A lot of work still need to be done to make the code ready for delivery, such as calibration algorithm, Correction Matrix Operator (CMO), code interface, etc.
- Other models such as CCAST from UMBC/UW can also generate the CrIS full resolution SDR

Calibration Approaches

Item	Member	Calibration	CMO Principals	Calibration Order	
1	IDPS	$N=(SA_u^{-1}\cdot F_{s\to u}\cdot f_{ATBD})\cdot\left\{\frac{S_E-S_{SP}}{S_{ICT}-S_{SP}}\cdot ICT(T,u_{sensor*(1+delta)})\right\}$			
2	ADL/CSPP	$N=(SA_u^{-1}\cdot F_{s\to u}\cdot f_{ATBD})\cdot\left\{\frac{S_E-S_{SP}}{S_{ICT}-S_{SP}}\cdot ICT(T,u_{sensor*(1+delta)})\right\}$	$SA_u^{-1}\cdot F_{s\to u}$		4th Best & Baseline
3	Exelis (old)	$N=\left(SA_u^{-1}\cdot F_{s\to u}\cdot f_{ATBD}\right)\cdot\left\{\frac{S_E-S_{SP}}{S_{ICT}-S_{SP}}f_{BH}\cdot\left[SA_u^{-1}\cdot F_{s\to u}\right]^{-1}\cdot ICT(T,u_{sensor})\right\}$			
4	UMBC/UW** option A	$N=F_{s\to u}\cdot f\cdot SA_s^{-1}\cdot\left\{f\cdot\frac{FIR^{-1}\cdot(S_E-S_{SP})}{FIR^{-1}\cdot(S_{ICT}-S_{SP})}\cdot ICT(T,u_{sensor\_off\_axis})\right\}$		Calibration first, then CMO	
5	CCAST Cal mode 1	$N=F_{s\to u}\cdot f\cdot SA_s^{-1}\cdot\left\{\frac{FIR^{-1}\cdot(S_E-S_{SP})}{FIR^{-1}\cdot(S_{ICT}-S_{SP})}\cdot ICT(T,u_{sensor\_off\_axis})\right\}$			2nd Best
6	UMBC/UW** option B	$N=F_{s\to u}\cdot\left\{ICT(T,u_{sensor})\cdot f\cdot SA_s^{-1}\cdot\left\{f\cdot\frac{FIR^{-1}\cdot(S_E-S_{SP})}{FIR^{-1}\cdot(S_{ICT}-S_{SP})}\right\}\right\}$			
7	CCAST Cal mode 2	$N=F_{s\to u}\cdot f\cdot\left\{ICT(T,u_{sensor})\cdot SA_s^{-1}\cdot\left\{\mathrm{Re}\left[\frac{FIR^{-1}\cdot(S_E-S_{SP})}{FIR^{-1}\cdot(S_{ICT}-S_{SP})}\right]\right\}\right\}$	$F_{s\to u}\cdot SA_s^{-1}$		
8	LL(old)*	$N=\left\{\frac{M\cdot\left(FIR^{-1}\cdot(S_E-S_{SP})\right)}{M\cdot\left(FIR^{-1}\cdot(S_{ICT}-S_{SP})\right)}\right\}\cdot ICT(T,u_{user})$			
9	Proposed(1)	$N=F_{s\to u}\cdot f_{ATBD}\cdot\left\{\frac{SA_s^{-1}\cdot\left(FIR^{-1}\cdot(S_E-S_{SP})\right)}{SA_s^{-1}\cdot\left(FIR^{-1}\cdot(S_{ICT}-S_{SP})\right)}\cdot ICT(T,u_{sensor})\right\}$			Best
10	Proposed(2)	$N=ICT(T,u_{user})\cdot\left\{\frac{F_{s\to u}\cdot SA_s^{-1}\cdot f_{ATBD}\cdot\left(FIR^{-1}\cdot(S_E-S_{SP})\right)}{F_{s\to u}\cdot SA_s^{-1}\cdot f_{ATBD}\cdot\left(FIR^{-1}\cdot(S_{ICT}-S_{SP})\right)}\right\}$		CMO first, then Calibration	
11	Exelis(new)	$N=\left\{\frac{\left(SA_u^{-1}\cdot F_{s\to u}\cdot(S_E-S_{SP})\right)}{\left(SA_u^{-1}\cdot F_{s\to u}\cdot(S_{ICT}-S_{SP})\right)}\right\}\cdot ICT(T,u_{user})$	$SA_u^{-1}\cdot F_{s\to u}$		3rd Best

Most Desired Properties

From Dan and Joe 01/15/2014
(Preliminary Rankings of Calibration differences by Organization RevH - v2.xlsx)

Proposed 2 as Reference Calibration Approach

- Proposed 2 as reference calibration approach

$$N = ICT(T, u_{user}) \cdot \left\{ \frac{F_{s\to u} \cdot SA_s^{-1} \cdot f_{ATBD} \cdot \left(FIR^{-1} \cdot (S_E - S_{SP}) \right)}{F_{s\to u} \cdot SA_s^{-1} \cdot f_{ATBD} \cdot \left(FIR^{-1} \cdot (S_{ICT} - S_{SP}) \right)} \right\}$$

- *SA* matrix with delta approximation and sincq instead of sinc (Yong Han "correctionMatrix_withSincq_STAR.pptx" on 01/15/2014)

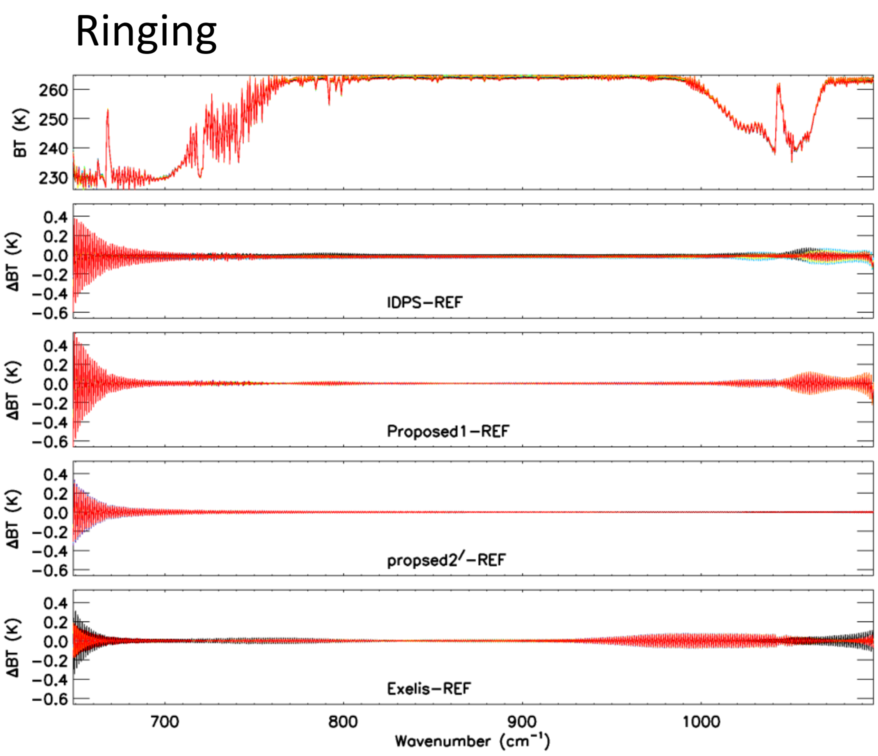
$$SA[k', k] \approx \int d\sigma' Sincq(2MPD(\sigma_{k'} - \sigma'))ILS(\sigma', \sigma_k)$$

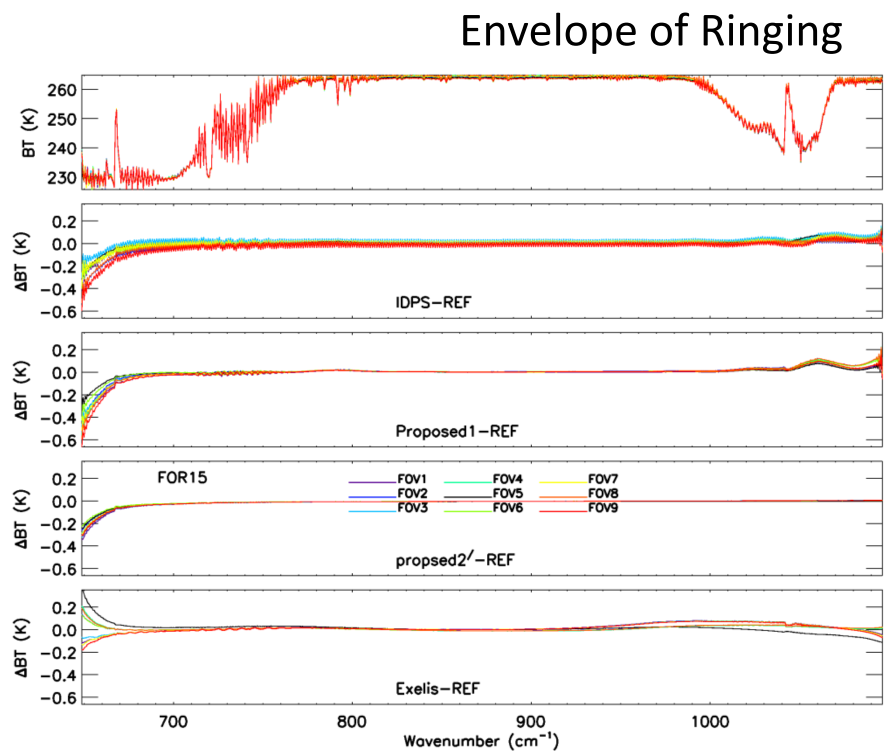
- Proposed 2/ : Interpolation to user grid using extended resampling method with larger N' instead of N
 (Yong Han: "star_resampling_study.pdf" on 03/12/2014 and "Ring_reduction_withResampling_9Apr_2014.pdf" on 04/09/2014)

$$S_{k'} = \sum_{k=0}^{N-1} S_k \frac{1}{N'} \frac{Sin(\pi \frac{\sigma_{s,k'} - \sigma_{u,k}}{\Delta\sigma_u})}{Sin(\pi \frac{\sigma_{s,k'} - \sigma_{u,k}}{N'\Delta\sigma_s})}$$

N' = DecimationFactor x N
N: Original spectrum binsize

Differences among Calibration Approaches for FOR15 and Band1

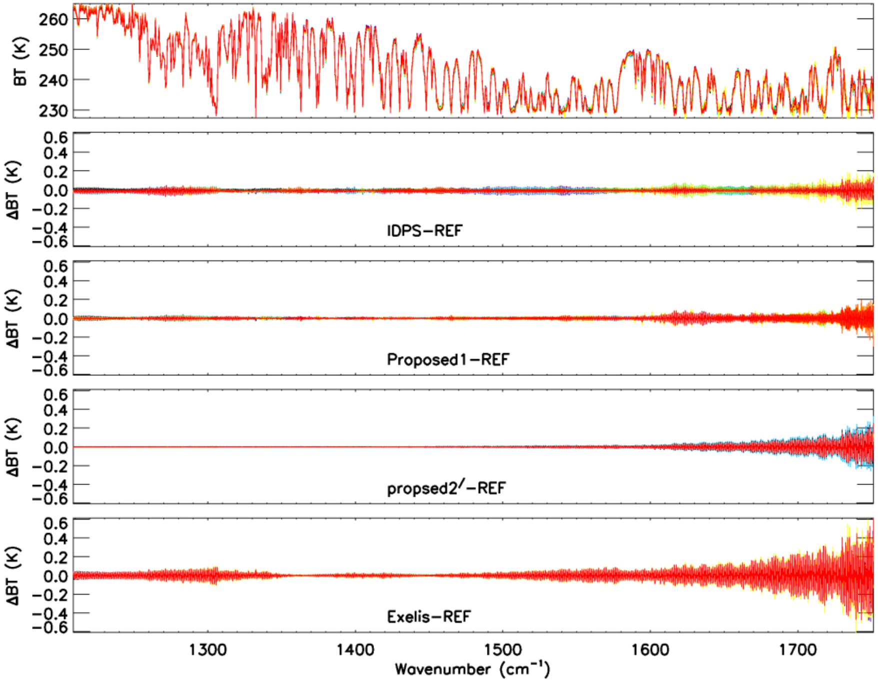




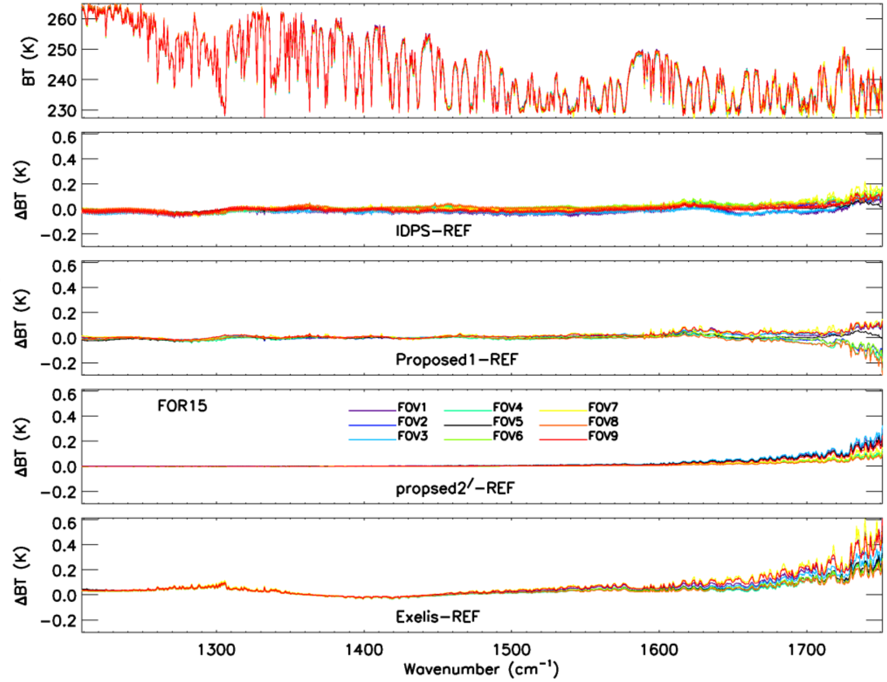
- The full resolution spectra were produced with a modified ADL code based on ADL42&Mx8.3 from full spectral resolution RDRs, collected when the CrIS was operated in the full spectral resolution mode on 08/27/2013
- Except for the proposed2/ algorithm, all others use the same resampling method from ATBD
- Significant ringing among different approaches at the both band edges

Differences among Calibration Approaches for FOR15 and Band2

Ringing



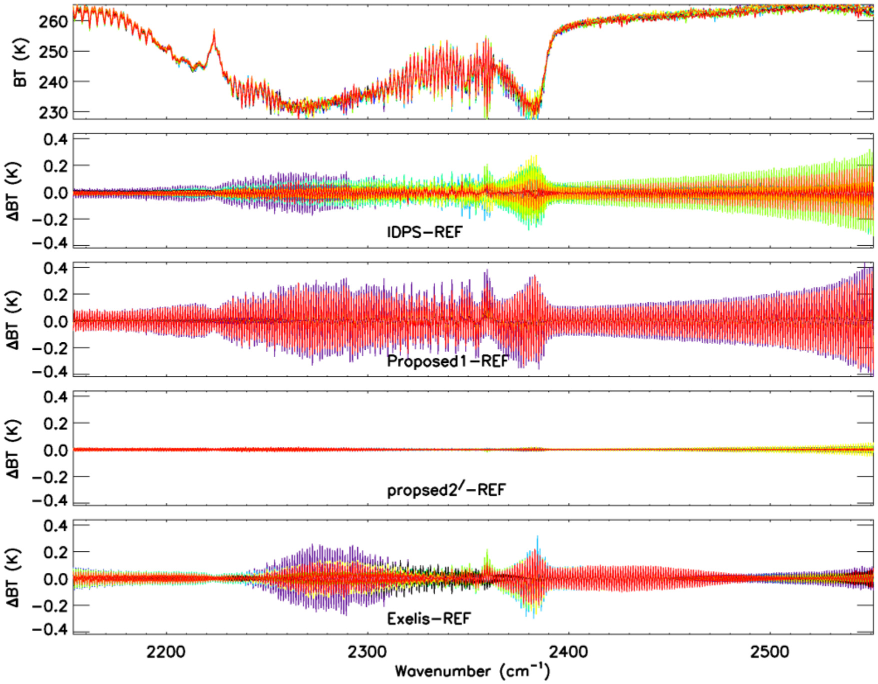
Envelope of Ringing



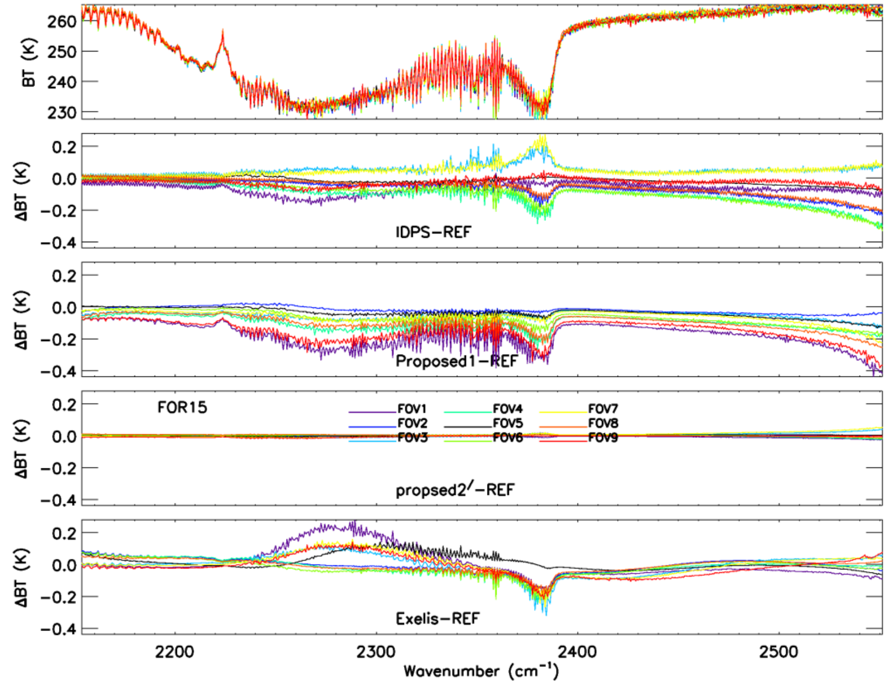
- Significant ringing among different approaches at the end of band edge

Differences among Calibration Approaches for FOR15 and Band3

Ringing



Envelope of Ringing



- Significant ringing at the band edge for IDPS and Proposed1
- Large ringing for the cold channels
- Which approach to use for the J1 algorithm? Need to define the truth reference, and consider the code interface changes and computing efficiency

CrIS Radiometric Assessment

- Validation of August 27-28, 2013 full spectral resolution data
- ADL42Mx8.3 used to generate full spectral resolution SDRs with updated non-linearity coefficients, ILS parameters, and sincq function for Correction Matrix Operator (CMO) for IDPS calibration approach.
- Assessment approach 1: Biases between CrIS observations and simulations using ECMWF analysis/forecast fields and forward model CRTM (Community Radiative Transfer Model)

$$BIAS = \overline{(Obs - CRTM)}$$

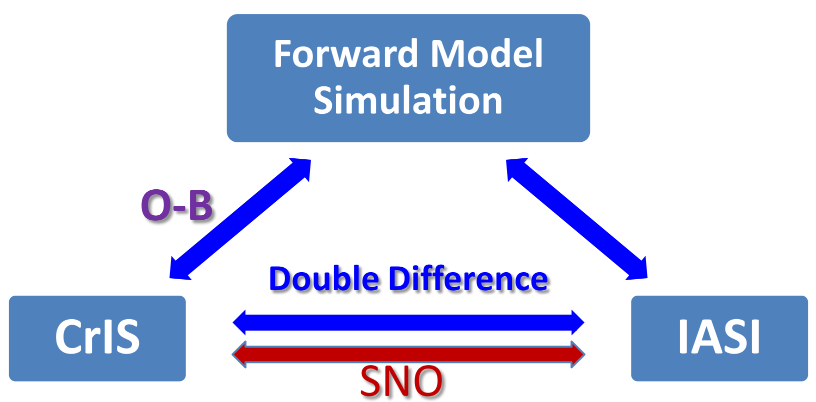
- Assessment approach 2: Double difference between CrIS and IASI on MetOp-a/b (converted to CrIS) using CRTM simulation as a transfer tool

$$DD = \overline{(Obs - CRTM)}_{CrIS} - \overline{(Obs - CRTM)}_{IASI2CrIS}$$

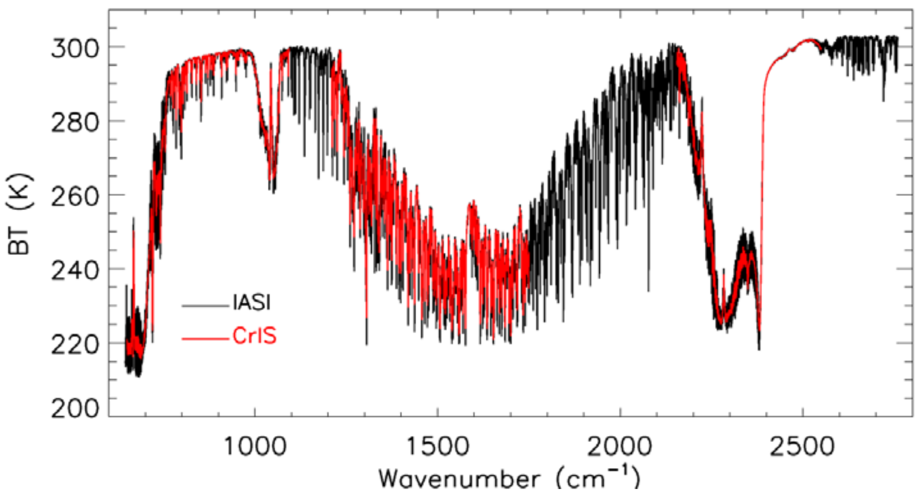
- Assessment approach 3: SNO difference between CrIS and IASI converted to CrIS

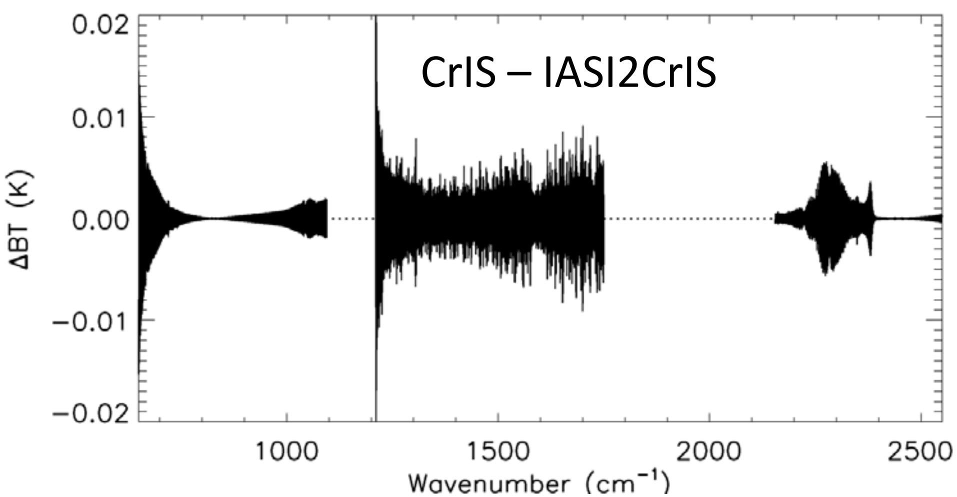
$$BT_{diff} = BT_{CrIS} - BT_{IASI2CrIS}$$

Three Approaches



Resample IASI to CrIS





IASI Observed Spectra

↓ FFT^{-1}

Inverse Fourier transform of the spectra to the interferogram space

↓ Apodization Function

1) De-Apodization with IASI SRF
2) Truncation to CrIS OPD
3) Apodization with CrIS SRF

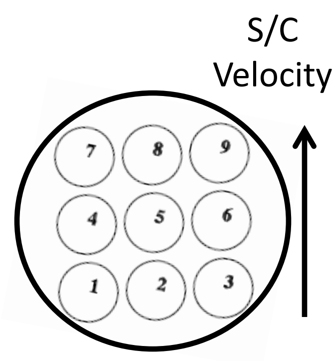
↓ FFT

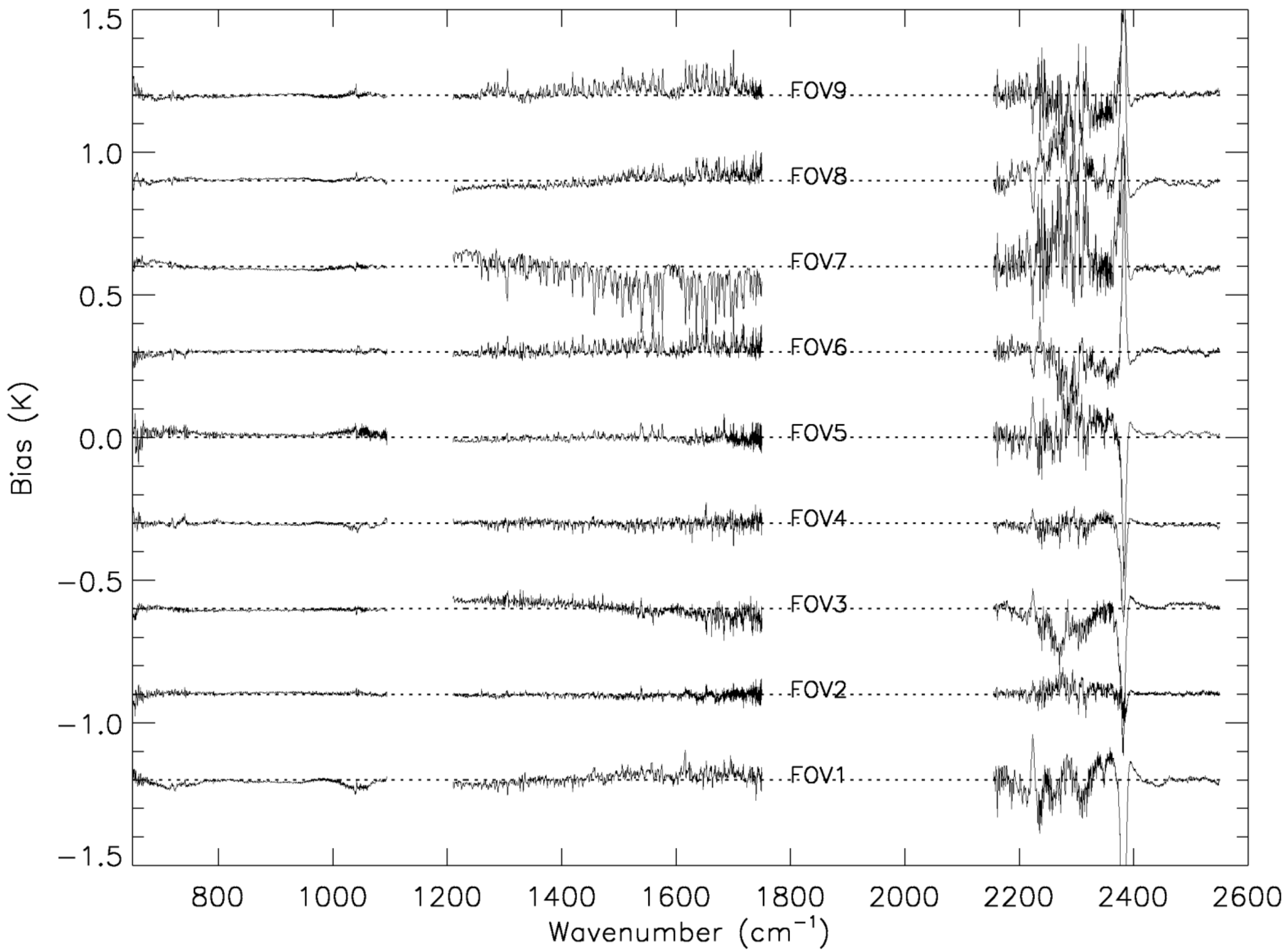
Fourier transform of the products to spectra space, resampling the spectra on CrIS wavenumber basis.

- Resampling error from IASI to CrIS resolution is very small (less than 0.02 K) since IASI spectra cover CrIS spectra for all three bands

CrIS Nadir FOV-2-FOV Variability (FOR 15 and 16) for Clear Sky over Oceans

$$BIAS_{FOV_i} = \overline{(Obs - CRTM)_{FOV_i}} - \overline{(Obs - CRTM)_{all}}$$

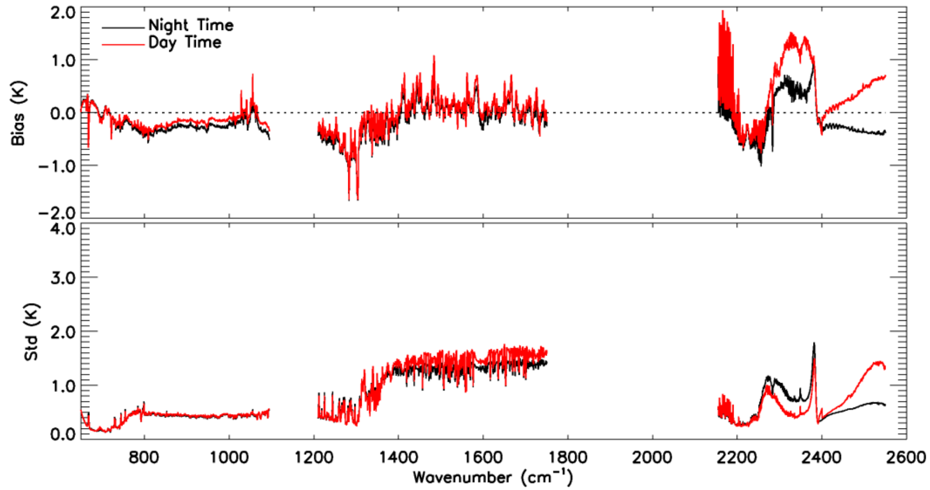




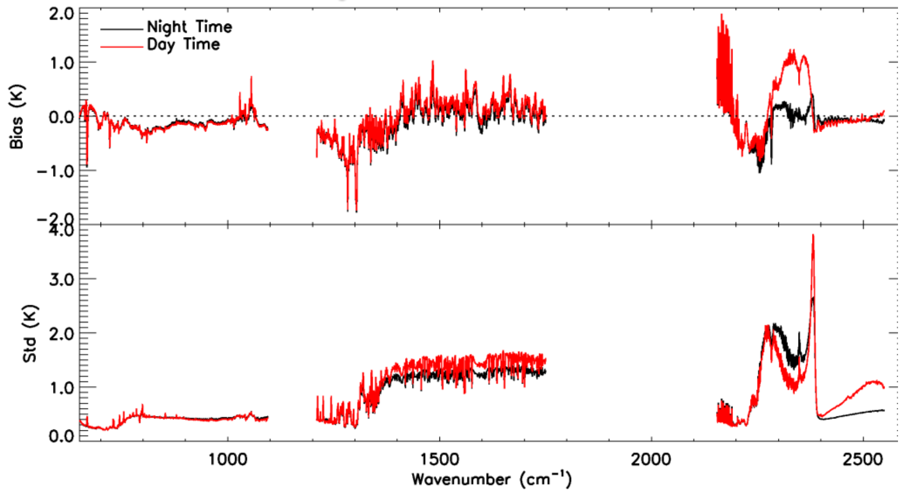
- **FOV-2-FOV variability is small, within ±0.3 K for all the channels**

CrIS and IASI2CrIS NWP Biases: Clear Ocean Scenes

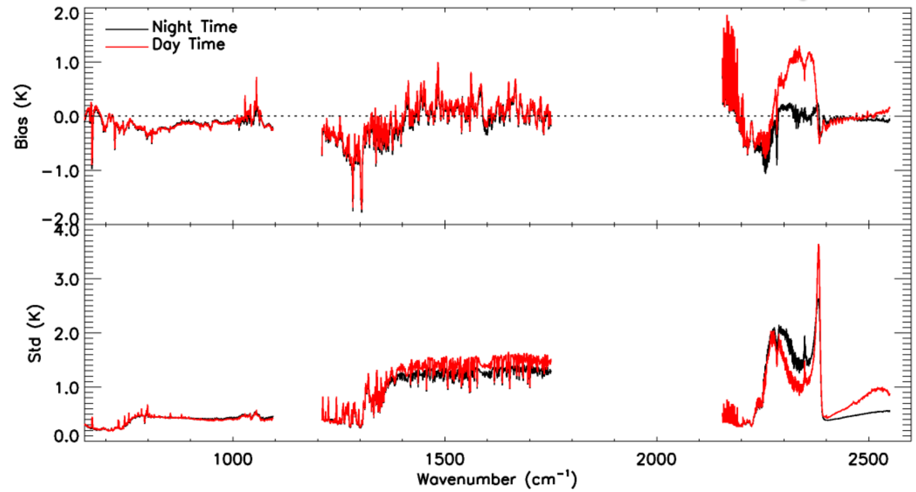
CrIS



IASI2CrIS MetOp-a



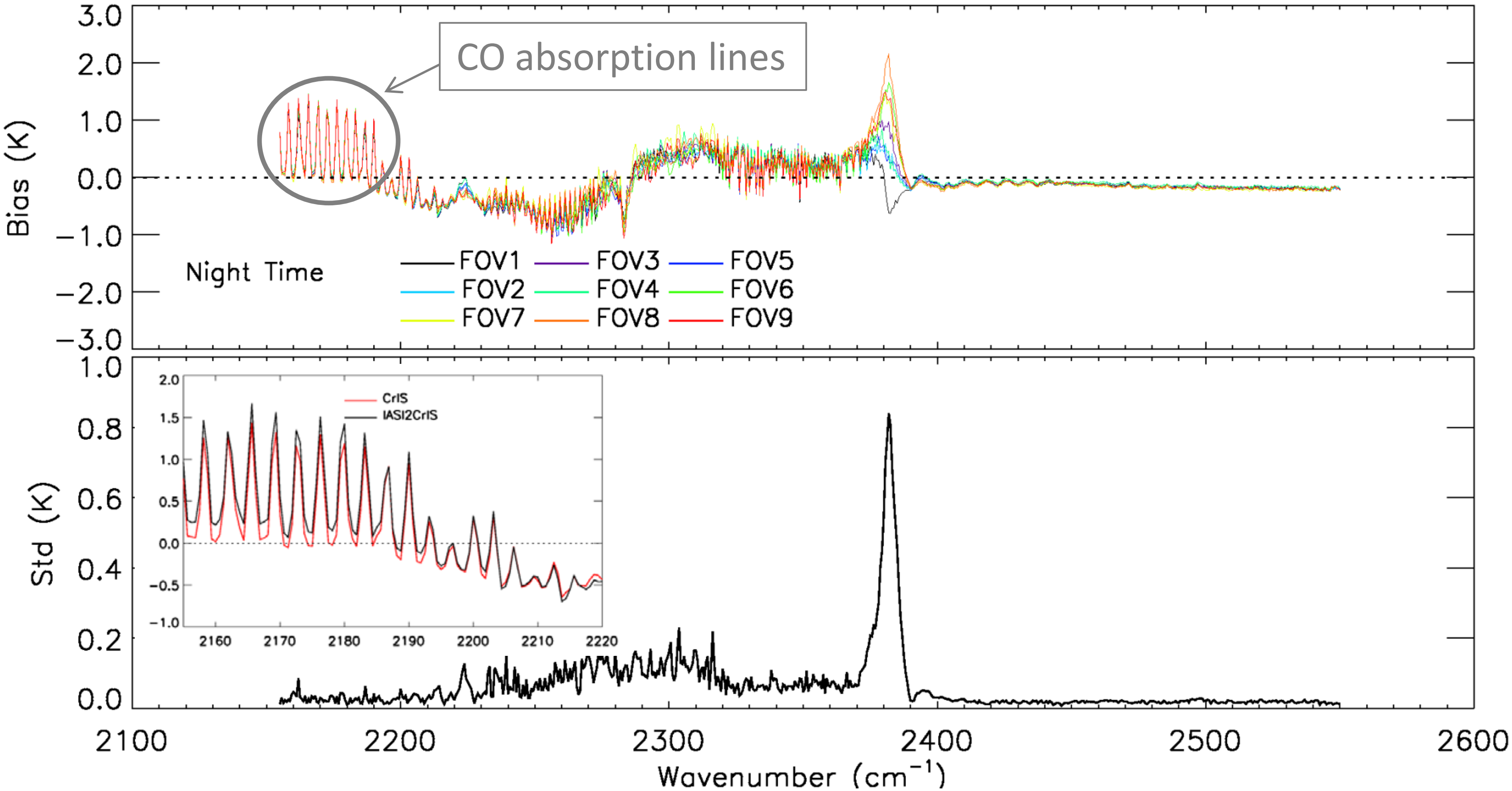
IASI2CrIS MetOp-b



- Good agreement between CrIS observation and simulation using ECMWF
- Very good agreement between CrIS and IASI
- Smaller standard deviation for CrIS than IASI in band 3

CrIS Nadir Bias for Shortwave

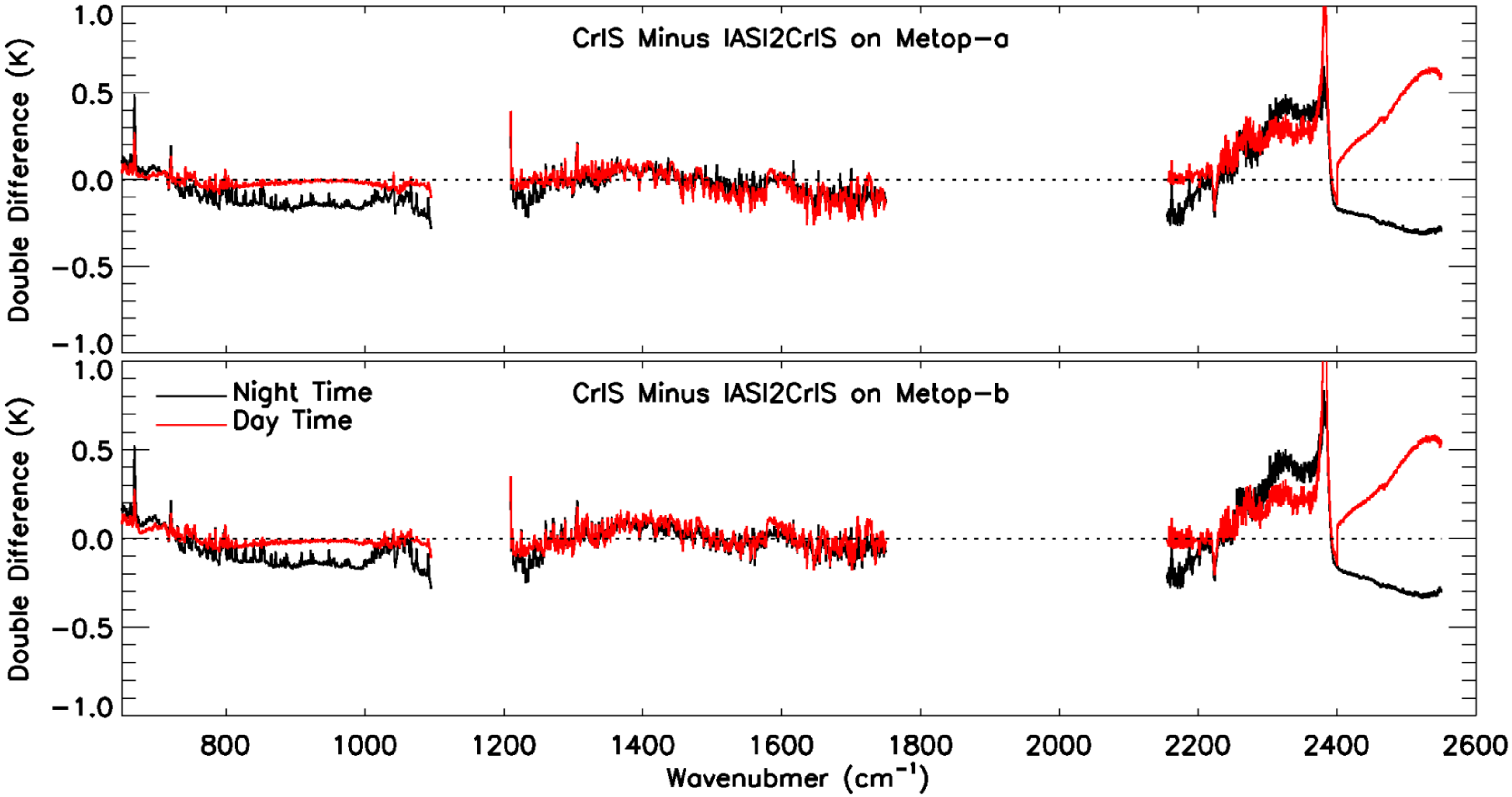
$$BIAS_{FOV_i} = \overline{(Obs - CRTM)_{FOV_i}}$$



- Good agreement between IASI and CrIS, better than bias with CRTM
- CO high bias errors due to CO default profile in CRTM
- CrIS and IASI window channels differ by 0.1 K due to diurnal variation in the SST

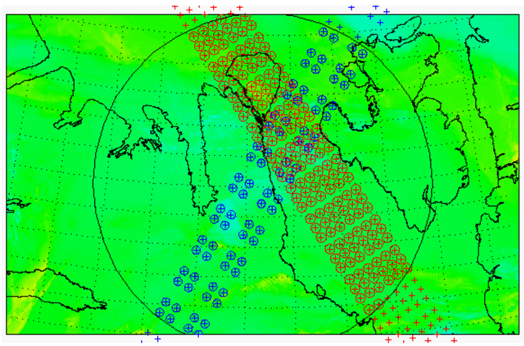
Double Difference between CrIS and IASI2CrIS

$$DD = \overline{(Obs - CRTM)_{CrIS}} - \overline{(Obs - CRTM)_{IASI2CrIS}}$$



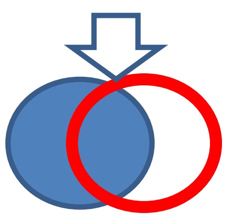
- Double difference between CrIS and IASI using CRTM simulations as transfer target are within ±0.3 K for most of channels
- For 4.3 µm CO_2 strong absorption region, CrIS is warmer than IASI about 0.3-0.5 K
- CrIS and IASI window channels differ by 0.1 K due to diurnal variation in the SST

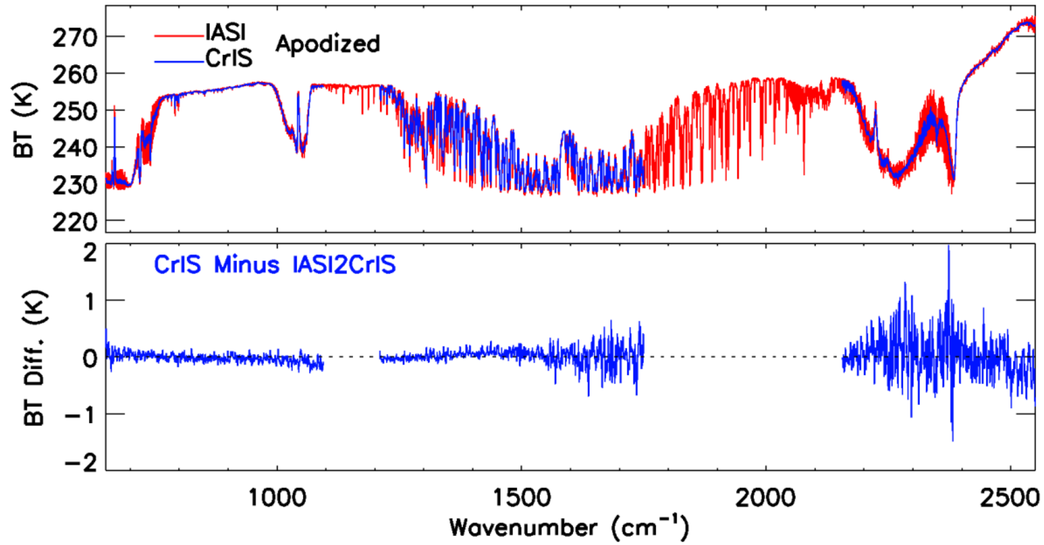
SNOs between CrIS and IASI

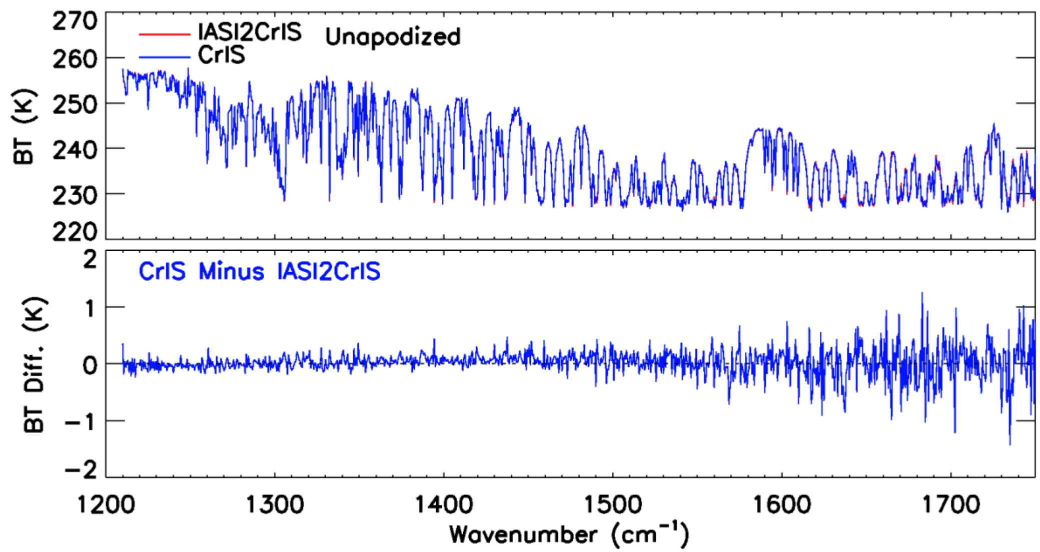


SNO Criteria

- Time difference: <= 120 seconds
- Pixel distance: <=(12+14)/4.0 km = 6.5 km
- Zenith angle difference: ABS(cos(a1)/cos(a2)-1) <= 0.01

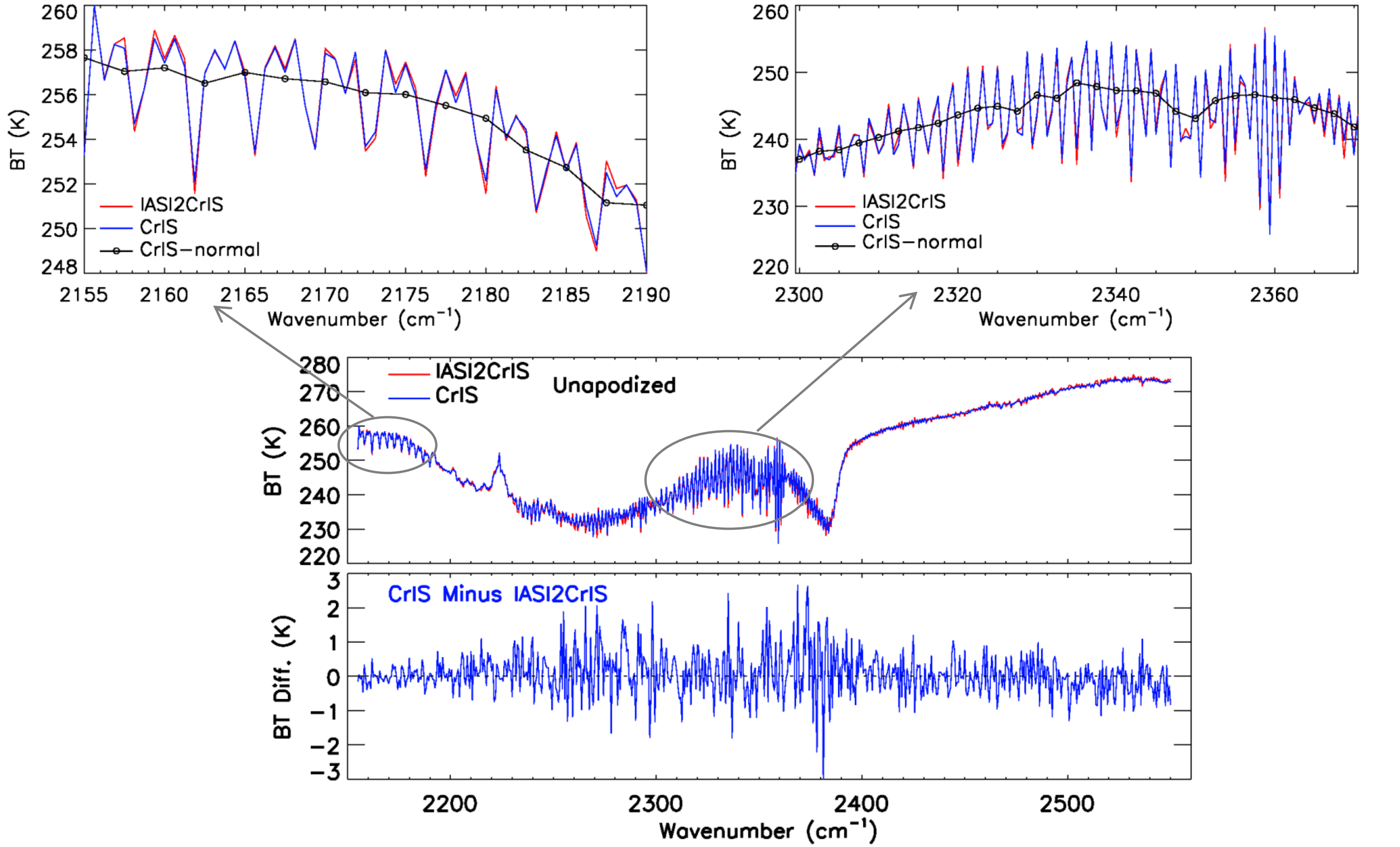






- SNO agreement is very good for band 1. Also good for band 2, but larger BT difference toward the end of band edge
- Large BT differences in cold channels for band 3

SNOs between CrIS and IASI: Details



- Although there is large BT difference in band 3, line structures in CO and CO_2 region show very agreement between CrIS and IASI
- Line structure in CO (2155-2190 cm^{-1}) region provides very good information to retrieve CO amount, and line structure in CO_2 absorption band (2300-2370 cm^{-1}) provides very good spectral calibration information

CrIS Spectral Assessment: Cross-Correlation Method

- Two basic spectral validation methods are used to assess the CrIS SDR spectral accuracy
- Relative spectral validation, which uses two uniform observations to determine frequency offsets relative to each other
- Absolute spectral validation, which requires an accurate forward model to simulate the top of atmosphere radiance under clear conditions and correlates the simulation with the observed radiance to find the maximum correlation

Correlation coefficient between the two spectra:

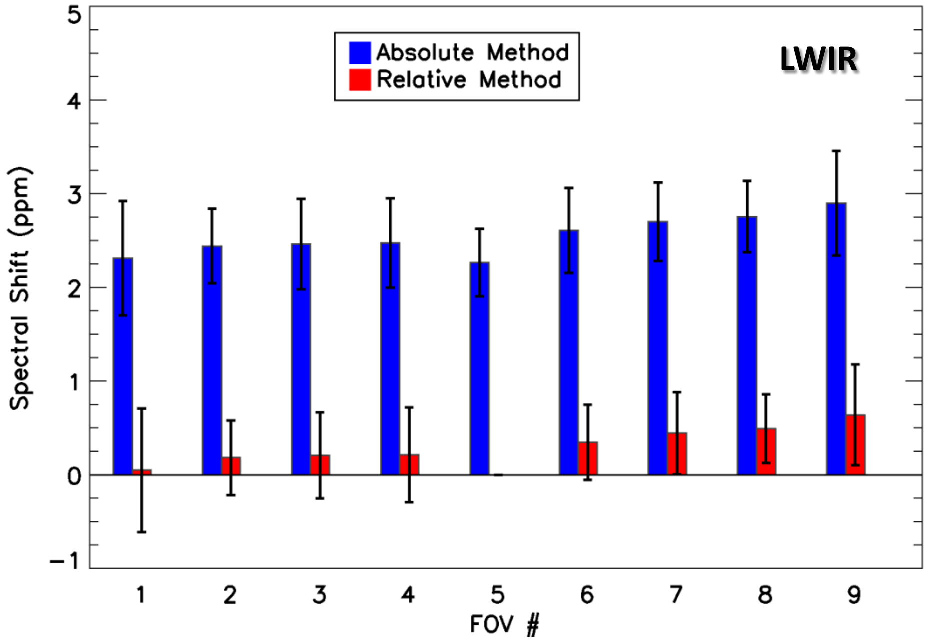
$$r_{S_1S_2} = \frac{\sum_{i=1}^{n}(S_{1,i}-\overline{S_1})(S_{2,i}-\overline{S_2})}{(n-1)D_{s_1}D_{S_2}} = \frac{\sum_{i=1}^{n}(S_{1,i}-\overline{S_1})(S_{2,i}-\overline{S_2})}{\sqrt{\sum_{i=1}^{n}(S_{1,i}-\overline{S_1})^2(S_{2,i}-\overline{S_2})^2}},$$

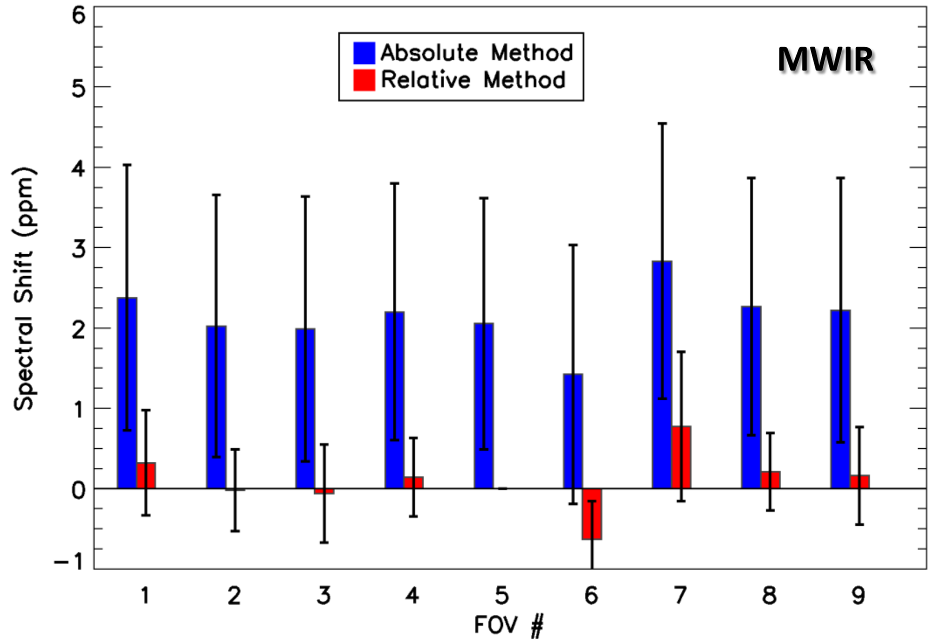
Standard deviation based on the difference of the two spectra:

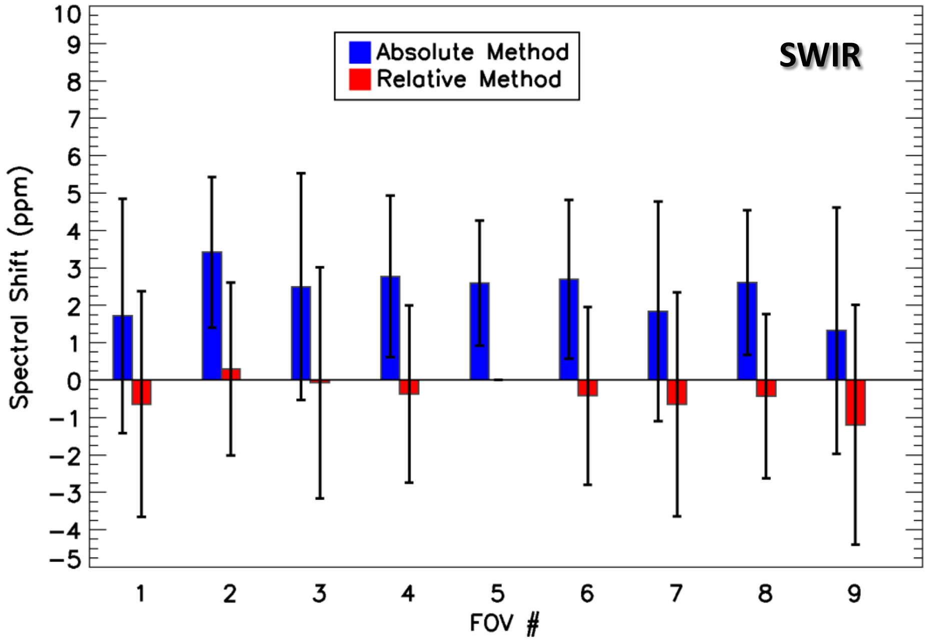
$$D_{S_1S_2} = \sqrt{\sum_{i=1}^{n}[(S_{1,i}-\overline{S_1})-(S_{2,i}-\overline{S_2})]^2 \Big/ (n-1)}.$$

The cross-correlation method is applied to a pair fine grid spectra to get the maximum correlation and minimum standard deviation by shifting one of the spectra in a given shift factor

CrIS Spectral Uncertainty







- Absolute cross-correlation method: between observations and CRTM simulations under clear sky over oceans to detect the spectral shift
- Relative method: observations from FOV 5 to other FOVs
- Frequency used: 710-760 cm^{-1} , 1340-1390 cm^{-1} , and 2310-2370 cm^{-1}
- **Spectral shift relative to FOV5 are within 1 ppm**
- **Absolute spectral shift relative to CRTM within 3 ppm**

Summary

- The CrIS full resolution SDRs generated from the modified ADL were assessed
- Different calibration approaches are implemented in ADL to study the ringing
- CrIS full resolution SDR radiometric uncertainty:
  - FOV-2-FOV radiometric differences are small, within ±0.3 K for all the channels
  - Double difference with IASI are within ±0.3K for most of channels
  - SNO results versus IASI show that agreement is very good for band 1 and band 2, but large BT differences in cold channels for band 3
- CrIS full resolution SDR spectral uncertainty:
  - Spectral shift relative to FOV5 are within 1 ppm
  - Absolute spectral shift relative to CRTM simulation are within 3 ppm

Inter-comparison of Hyperspectral Sounders Towards Establishing Hyperspectral Benchmark Radiance Measurements

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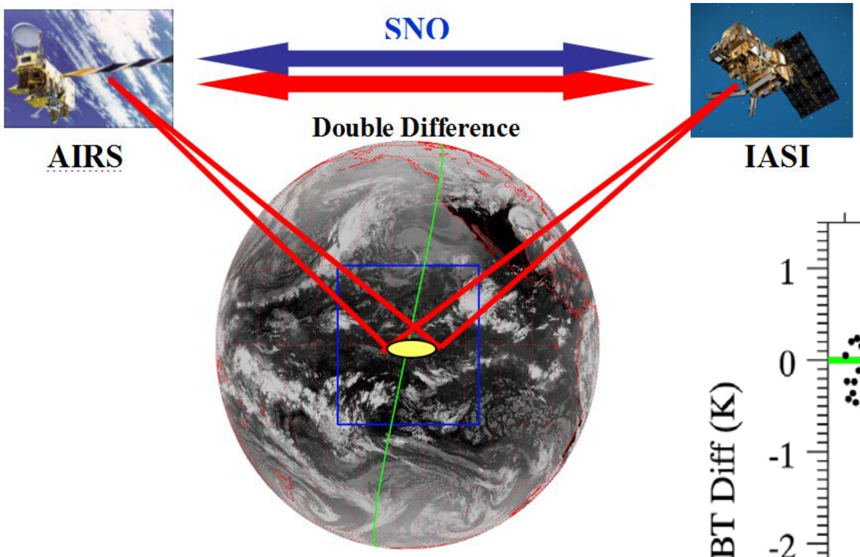
2014 STAR JPSS Science Meeting, NCWCP; May 14 2014

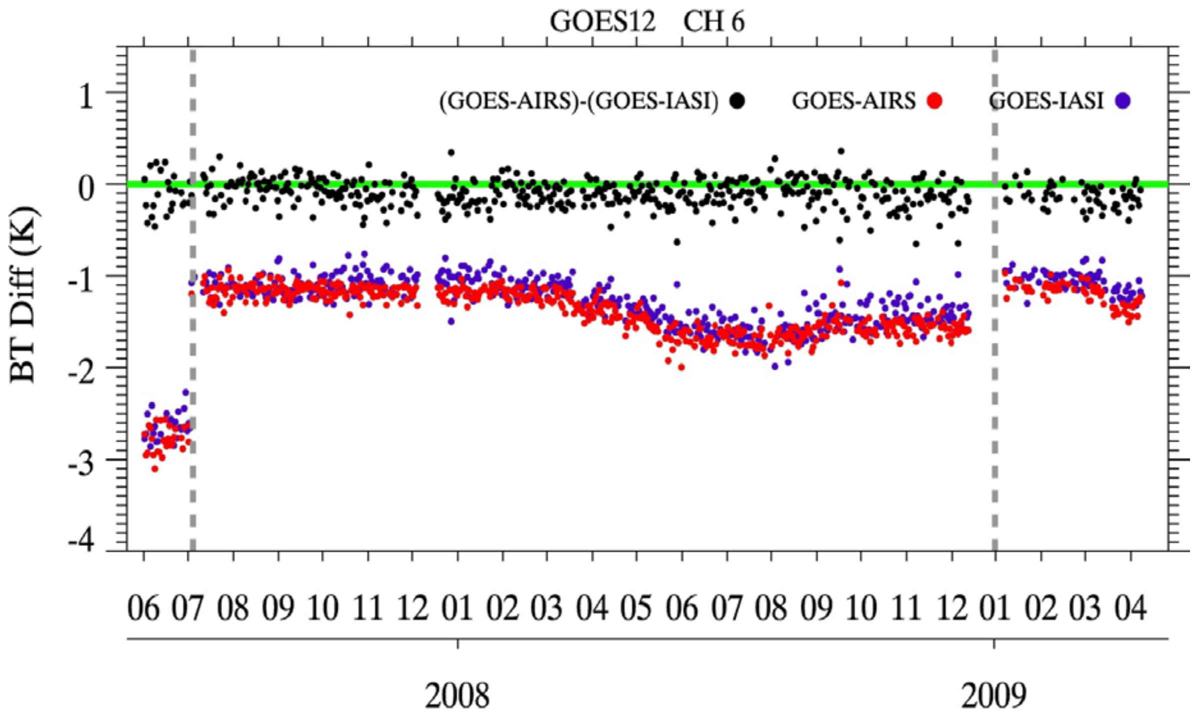
Outline

- Motivation
- Methodology
- Results
- Conclusion

Radiances Consistency of CrIS, IASI, and AIRS



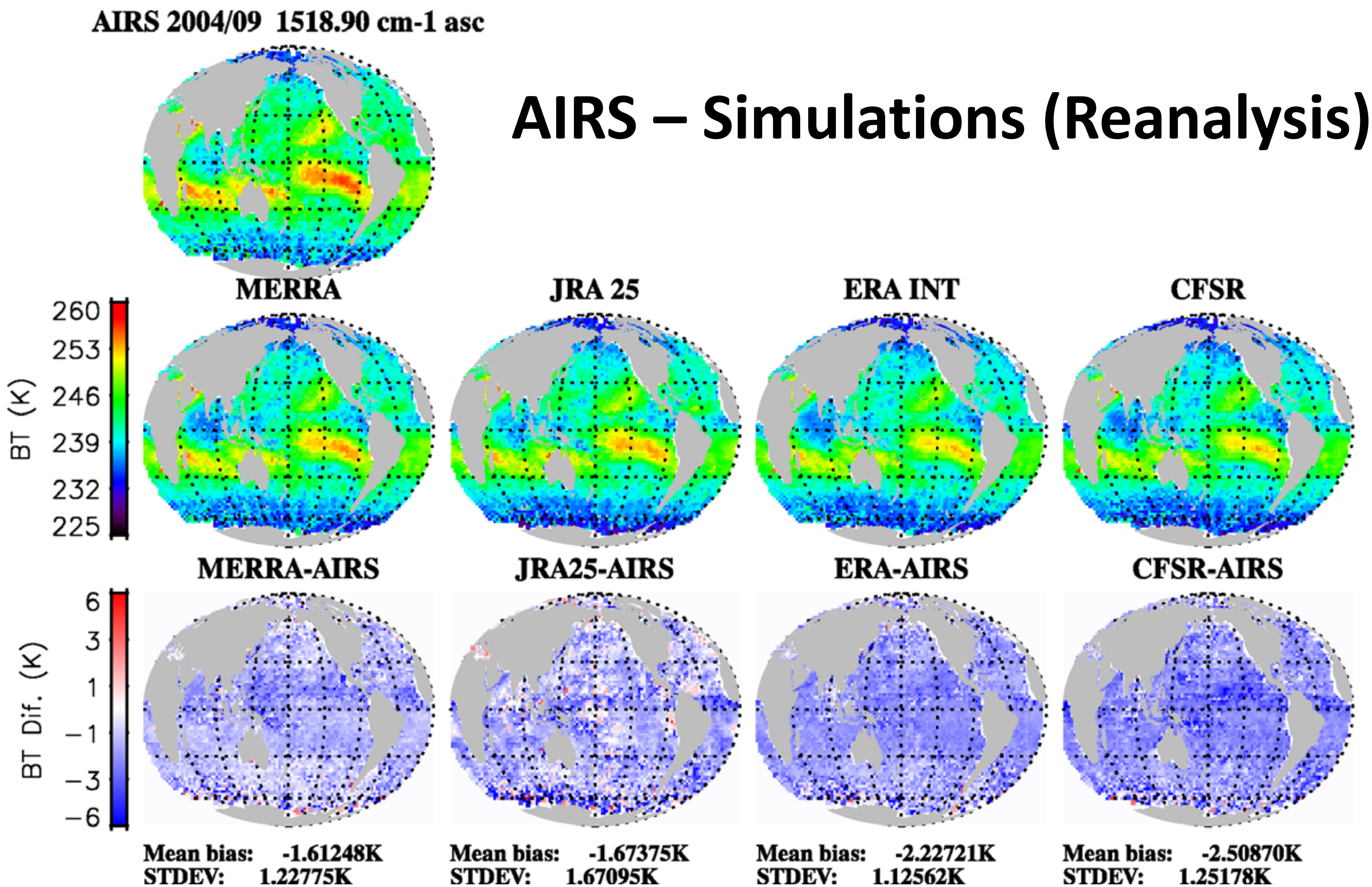
GSICS Framework:
Independent Calibration Assessment



Each Agency routinely uses AIRS/IASI to assess calibration accuracy of its own geostationary instruments

Spectral and radiometric consistency among CrIS, AIRS and IASI is significant for GSICS community.

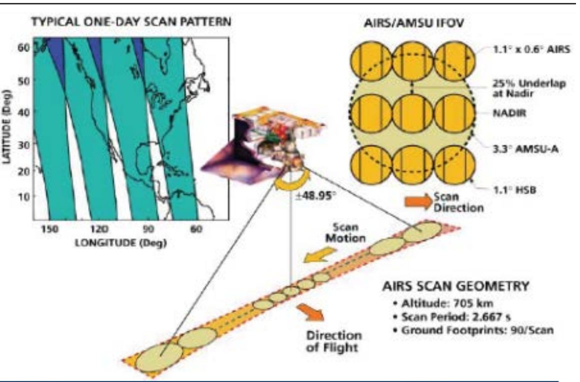
Model Verification

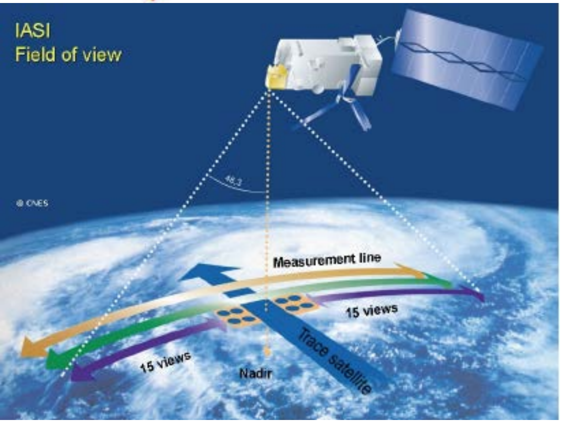


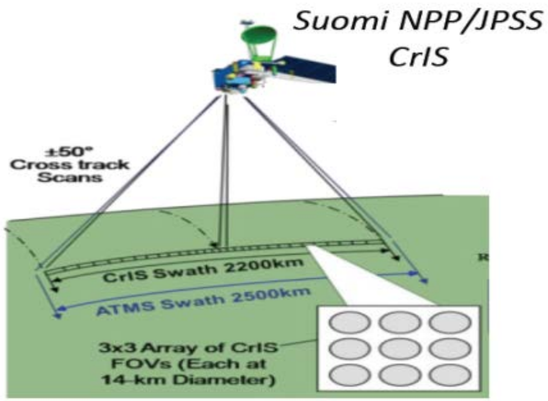
AIRS – Simulations (Reanalysis)

Hyperspectral radiance measurements can serve as a benchmark for model assessment, but the consistency is the key.

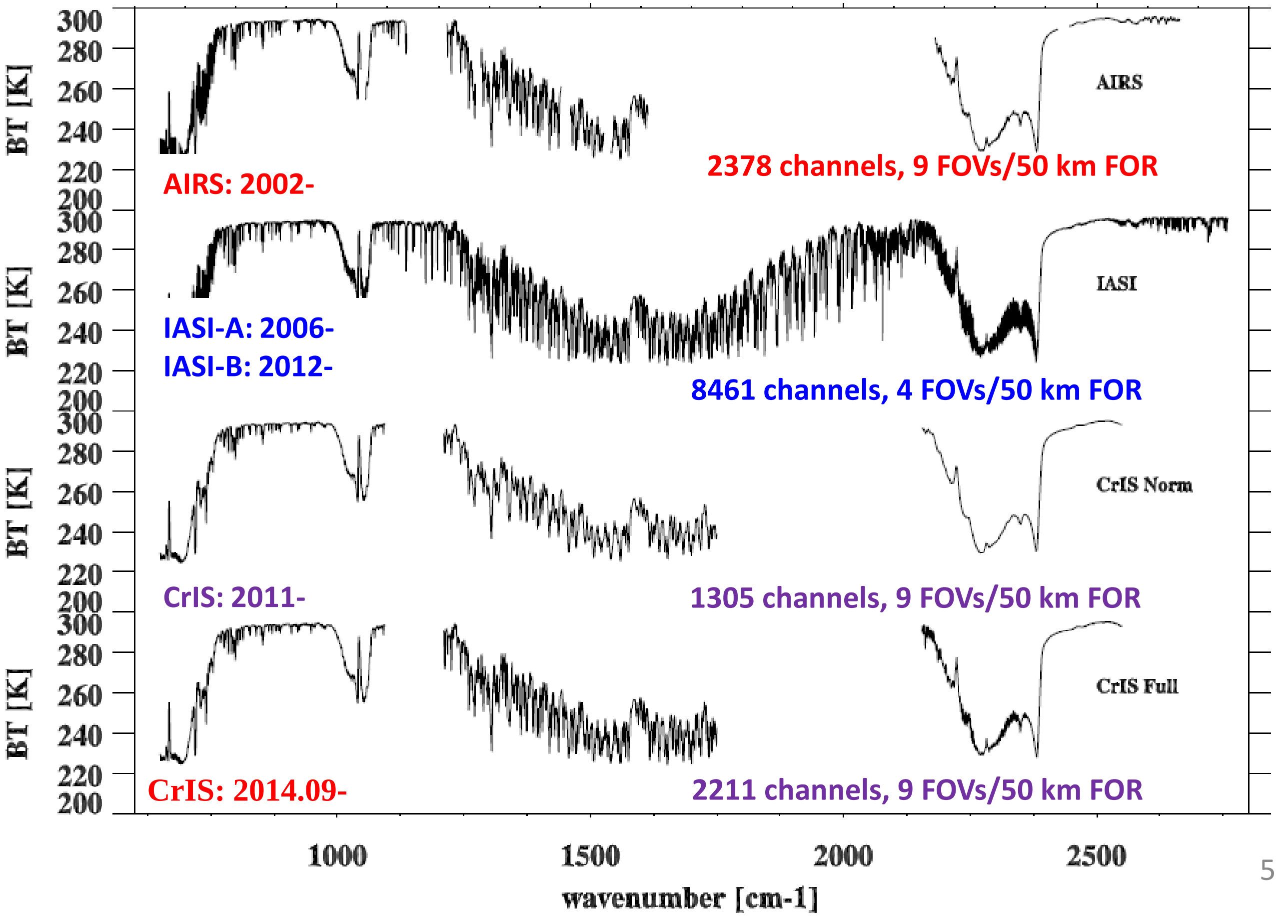
Instrument and Spectral Characteristics



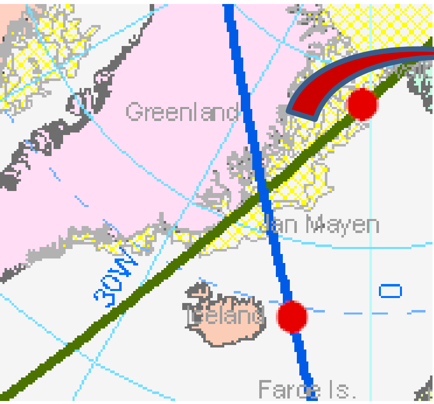




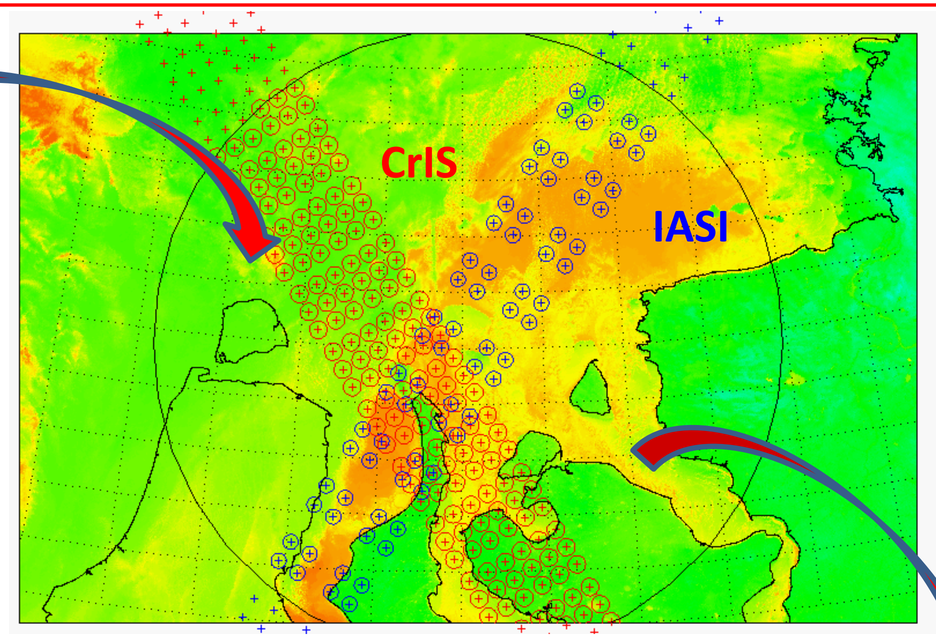
Spectral Coverage and Resolution of AIRS, IASI, and CrIS



Simultaneous Nadir Overpass (SNO)



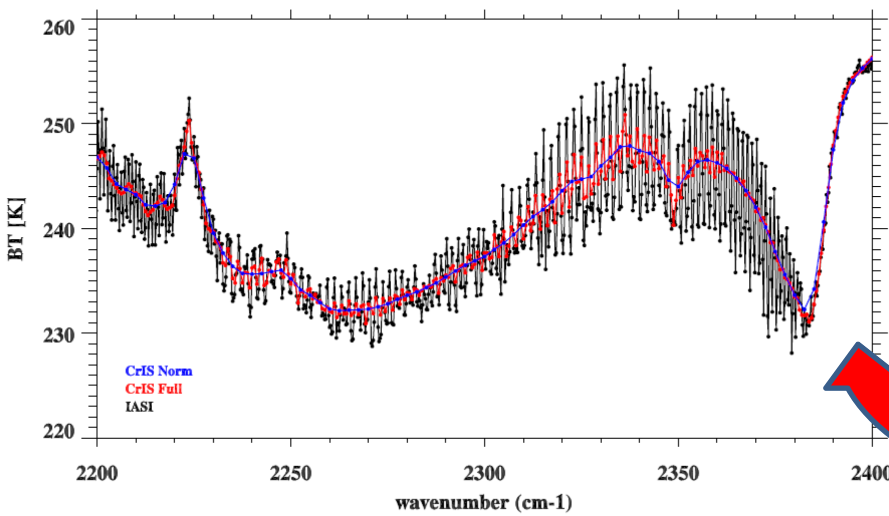
From Changyong Cao

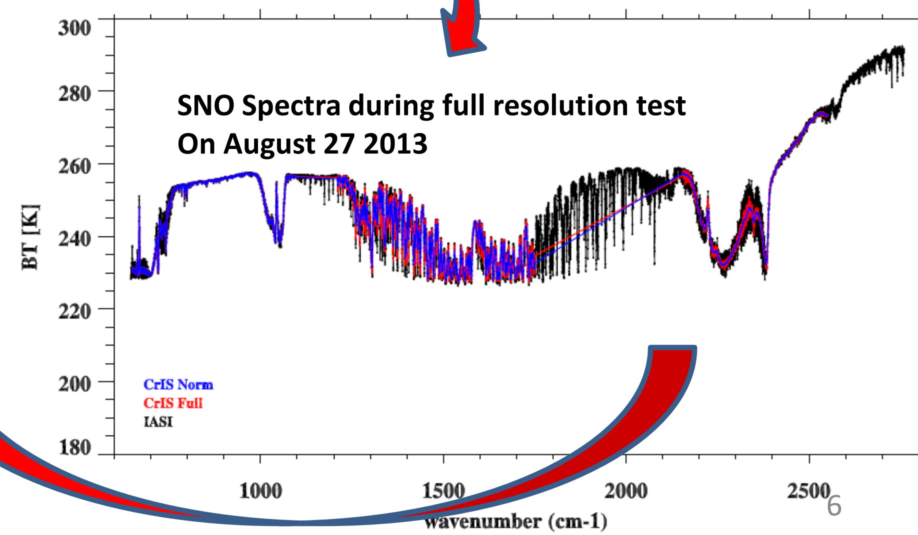


Time Difference: <= 120 Sec

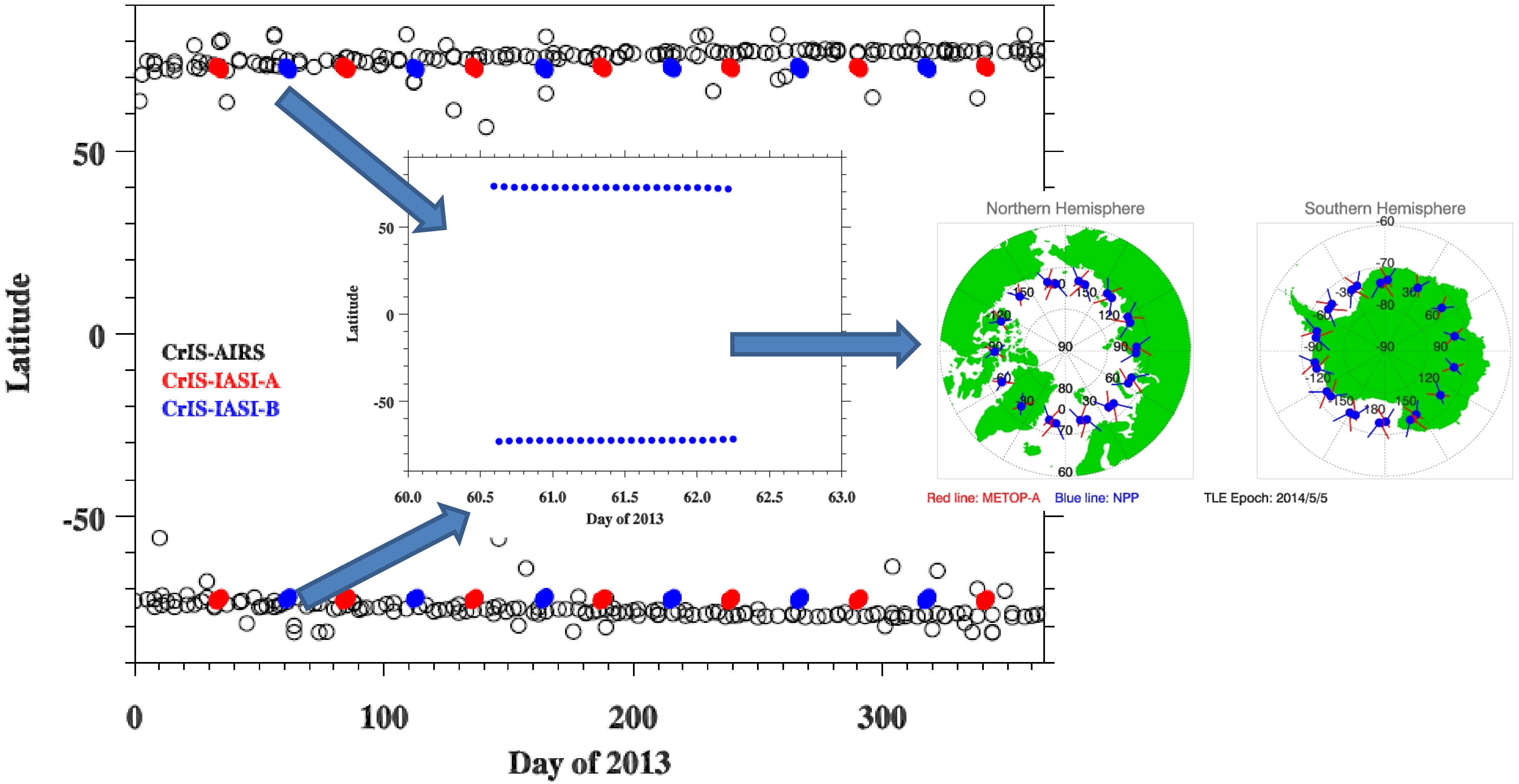
FOV distance difference: <=(12+14)/4.0 km = 6.5 km

Angle Difference: ABS(cos(a1)/cos(a2)-1) <= 0.01



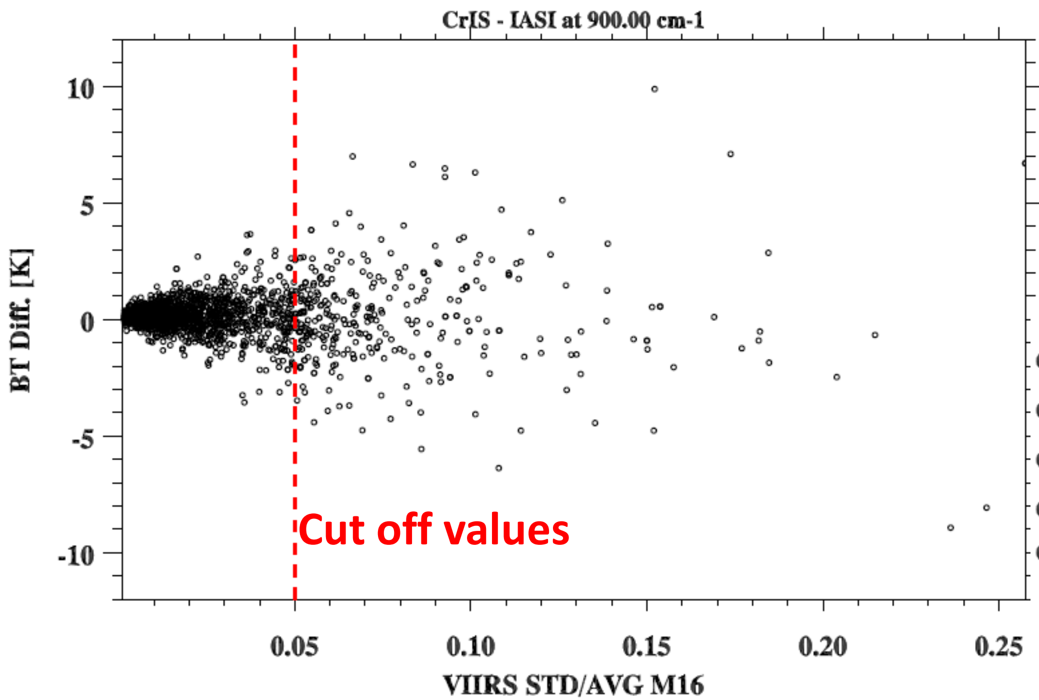


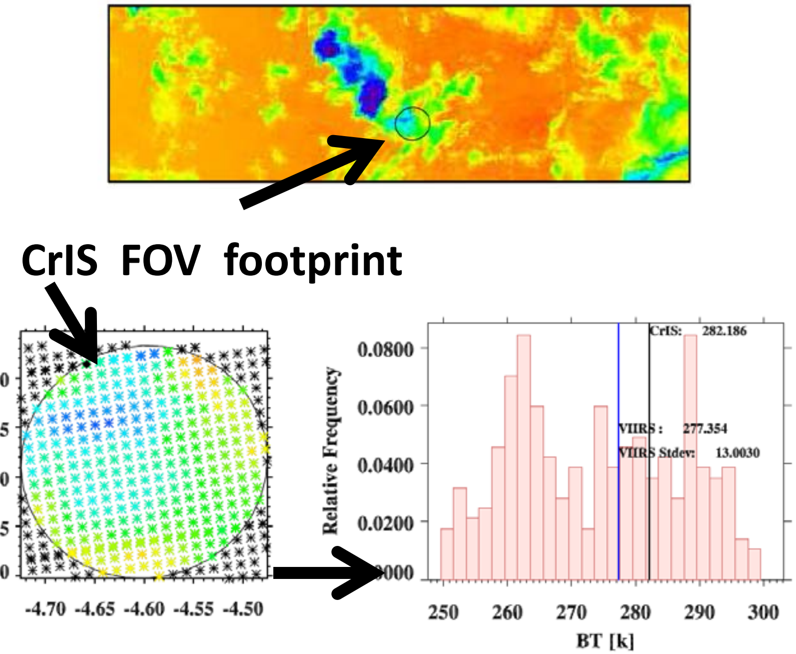
SNOs Latitude Distribution Time Series



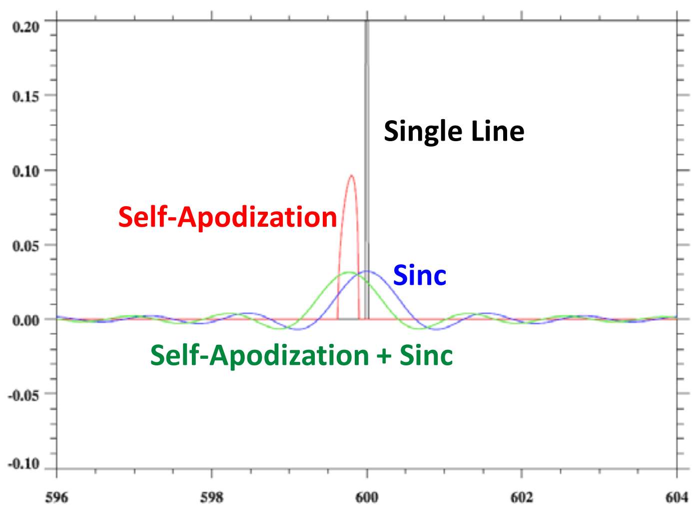
The SNOs between SNPP and Aqua occurred every 2-3 days.
the SNOs between MetOp and SNPP occurred every 50 days.
Fortunately, once an SNO event occurs, their orbits will continuously cross each other every orbit.

Scene Uniformity Effects





Histogram of VIIRS radiances

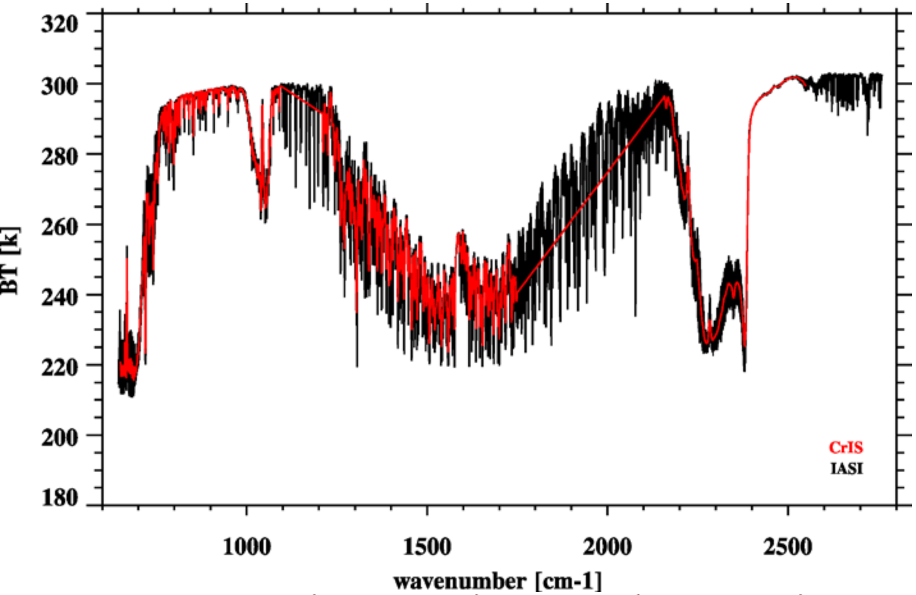


Radiance nonuniformity within the instrument's FOV affects ILS associated with each true wavenumber

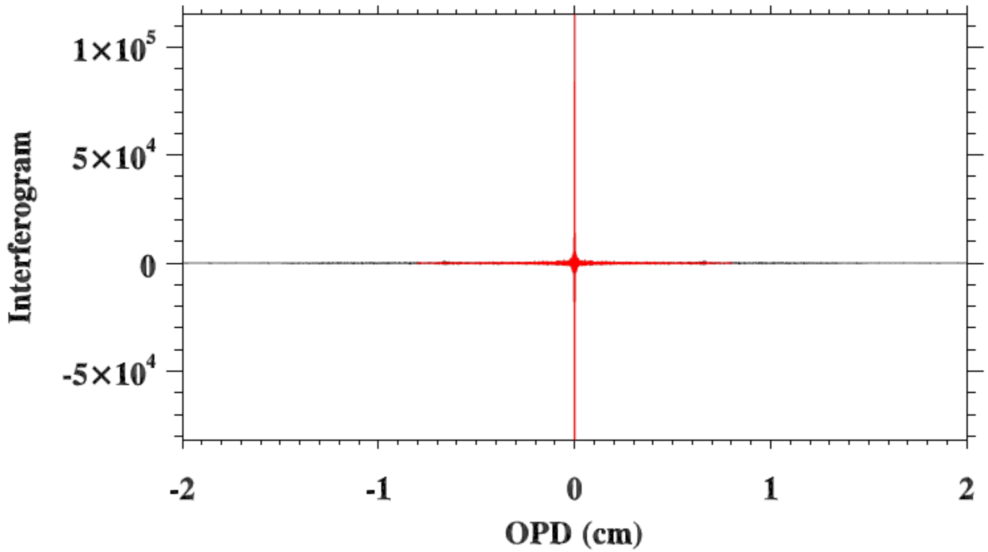
Inhomogeneous scenes can introduce spatial collocation uncertainties.

The standard deviation to mean ratio of the VIIRS radiances in band 16 is used to select uniform scenes.

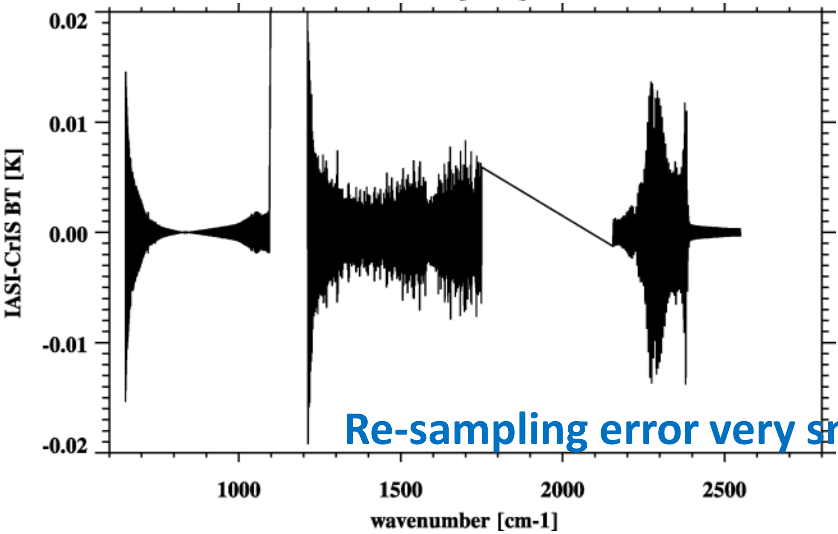
Resample IASI to CrIS



Fourier Transform



1) De-Apodization of IASI spectra
2) Truncation of IASI spectra
3) Apodization using CrIS Hamming Apodization function

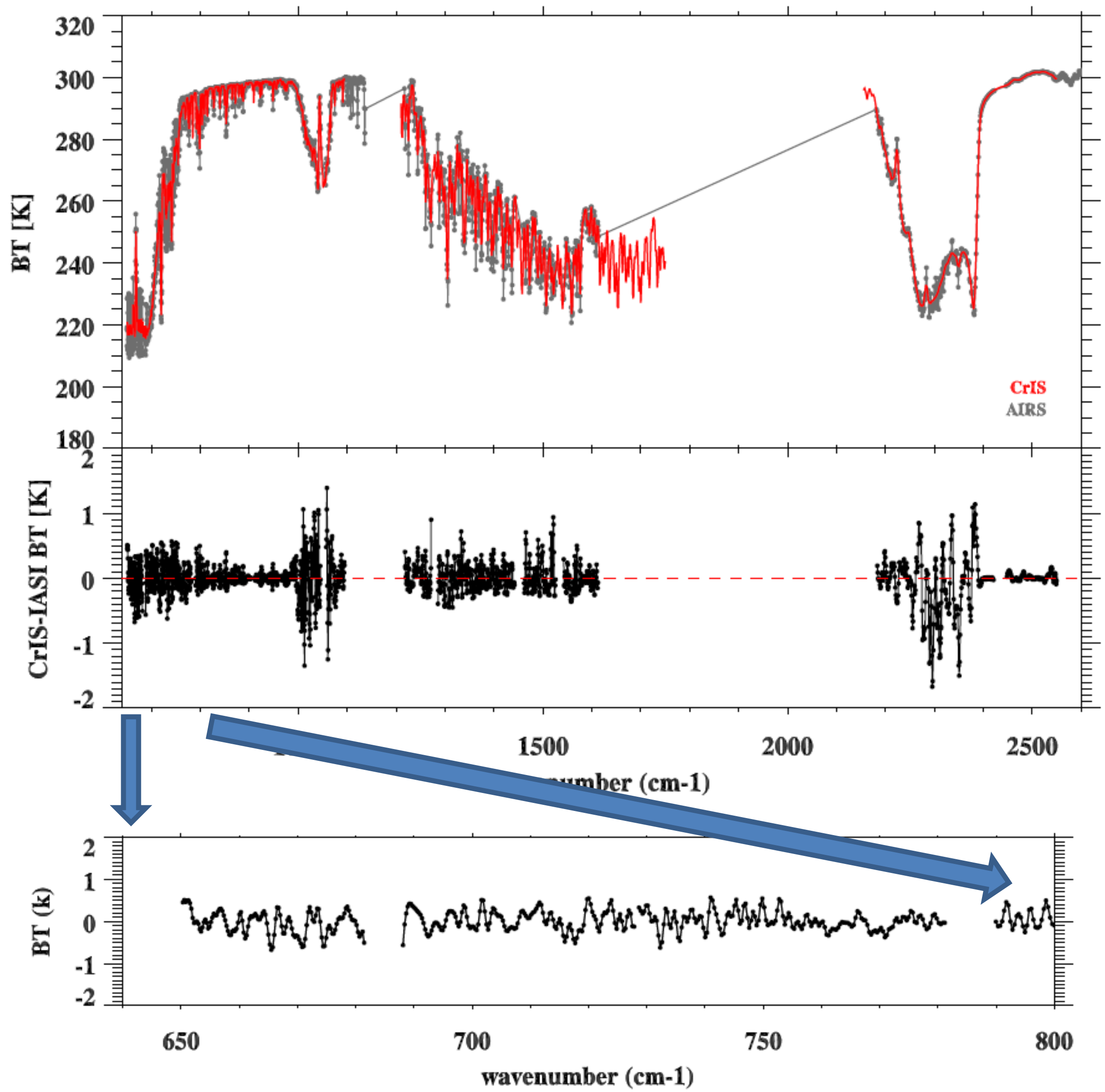


Re-sampling error very small

Inverse Fourier Transform

CrIS versus AIRS:
The best we can do without reducing the spectral resolution

- AIRS Spectrum is convolved with CrIS SRFs (three bands) at each AIRS spectral grid
- Resembling CrIS into high-resolution data (e.g. 2^15) and they are convolved with AIRS SRFs
- After that, they are at the same spectral grid
- The results should be carefully interpreted with cautious.



Updates on CrIS SDR Calibration Parameters and Software

Provisional status since Jan 31, 2013

To be done

Mx6.3/6.4
2012-10-15

- Geo bug fixed
- Imgy rad. DQF implemented
- Stage2cooler drift limit lifted
- EngPktV35

Mx7.1/7.2
2013-07-10

- MW Imgy limit lifted to 0.88
- Time stamp fix for monthly shift
- Full-res truncation module inserted
- **Bit-trim table stored in CMO file**
- FIR coefficients are updated
- **Handling Missing pixel/scan**
- Handling short granule
- Handling invalid Geolocation
- **Re-tasking procedure changed**

Mx8.0
2013-11-14

- **Re-sampling laser wavelength for initial CMO saved in CMO file**
- **Time stamp overflow bug fixed**

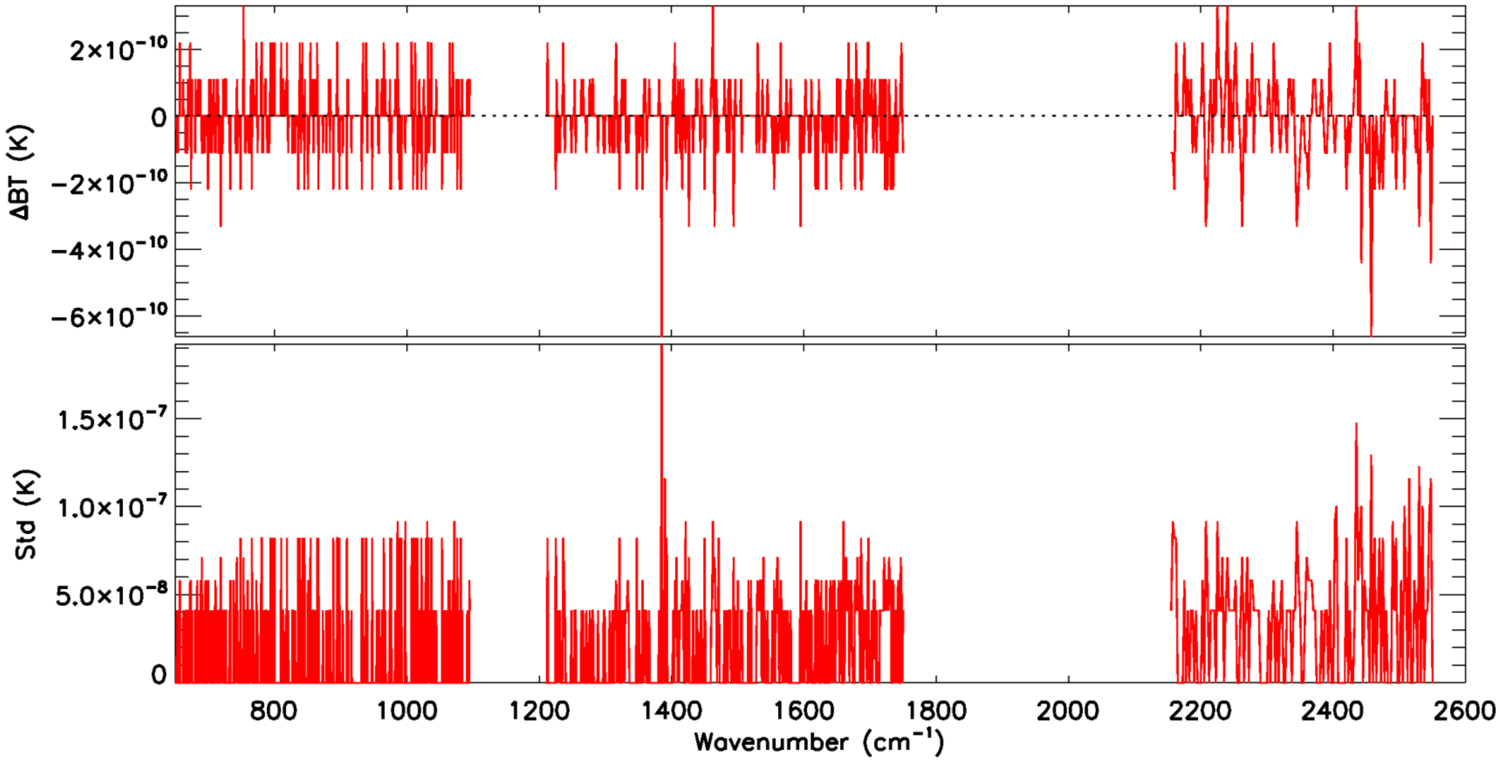
Mx8.1/8.2
On 2014-02-17

- FOV5 ILS equation error
- Non-linearity equation format change
- Lunar intrusion flag bug
- RDR impulse noise count data type
- One-scan shift of reference window

The data used in this study were reprocessed using ADL4.0 (comparable to Mx8.1/8.2) with EP36.

From Xin Jin/STAR

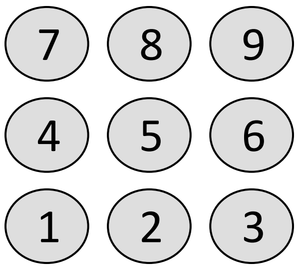
Comparison between ADL and IDPS

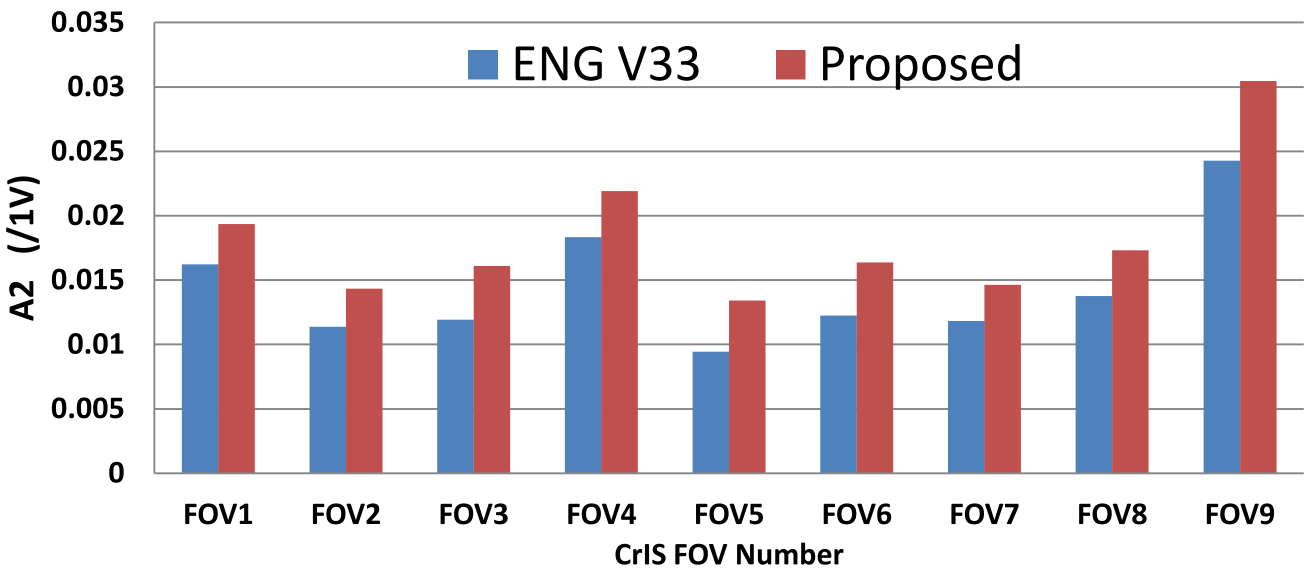


The differences between ADL and IDPS are negligible.

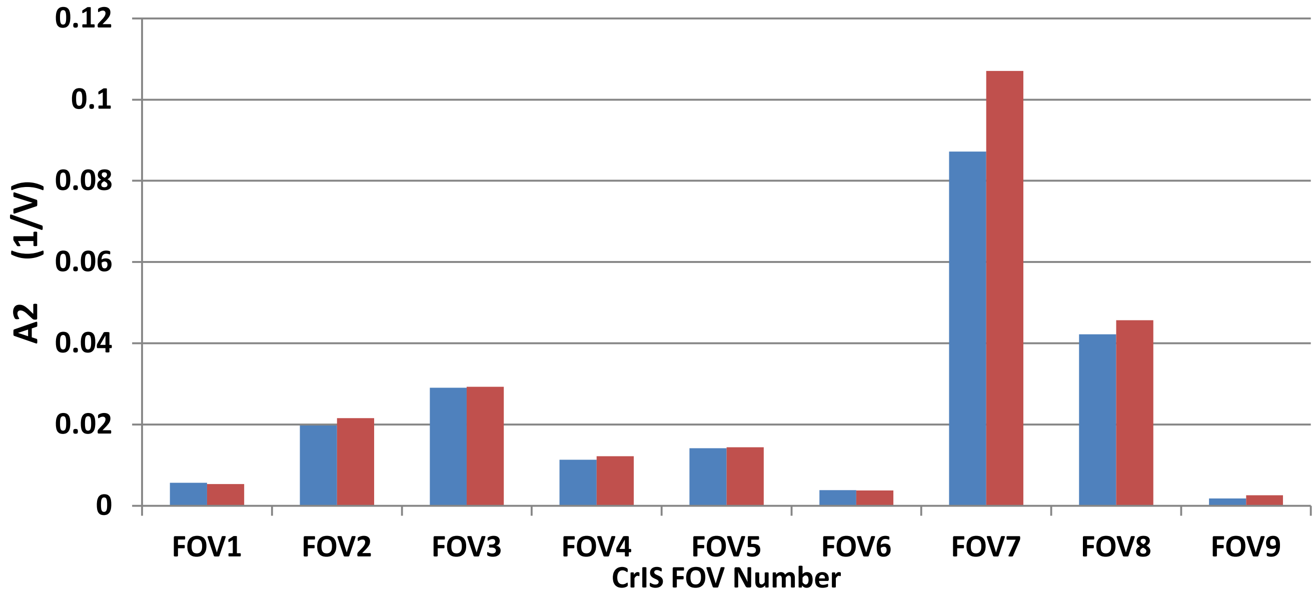
From Xin Jin/STAR

Non-linearity Coefficient Changes



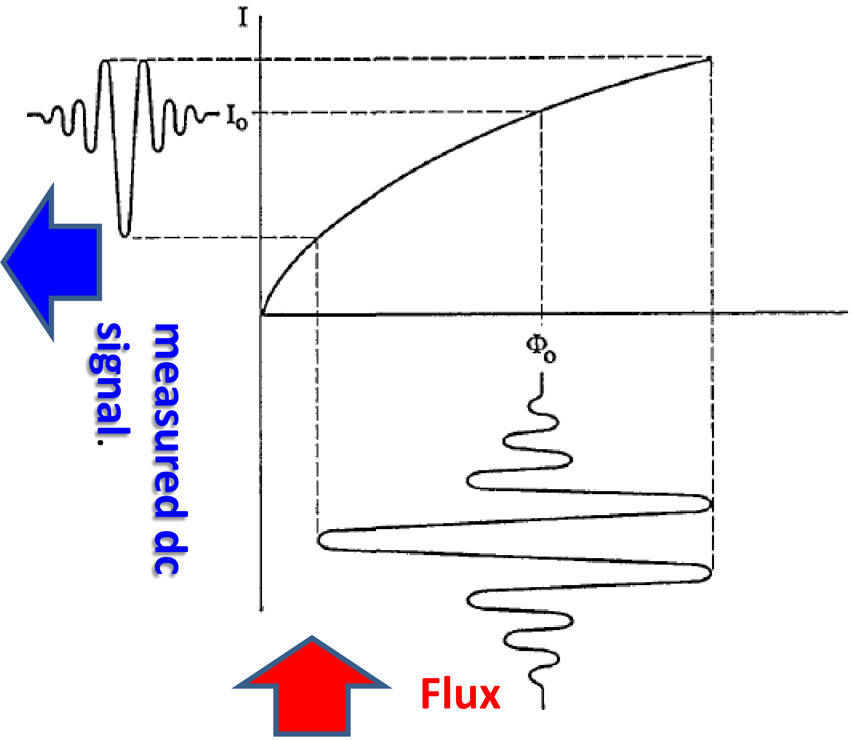


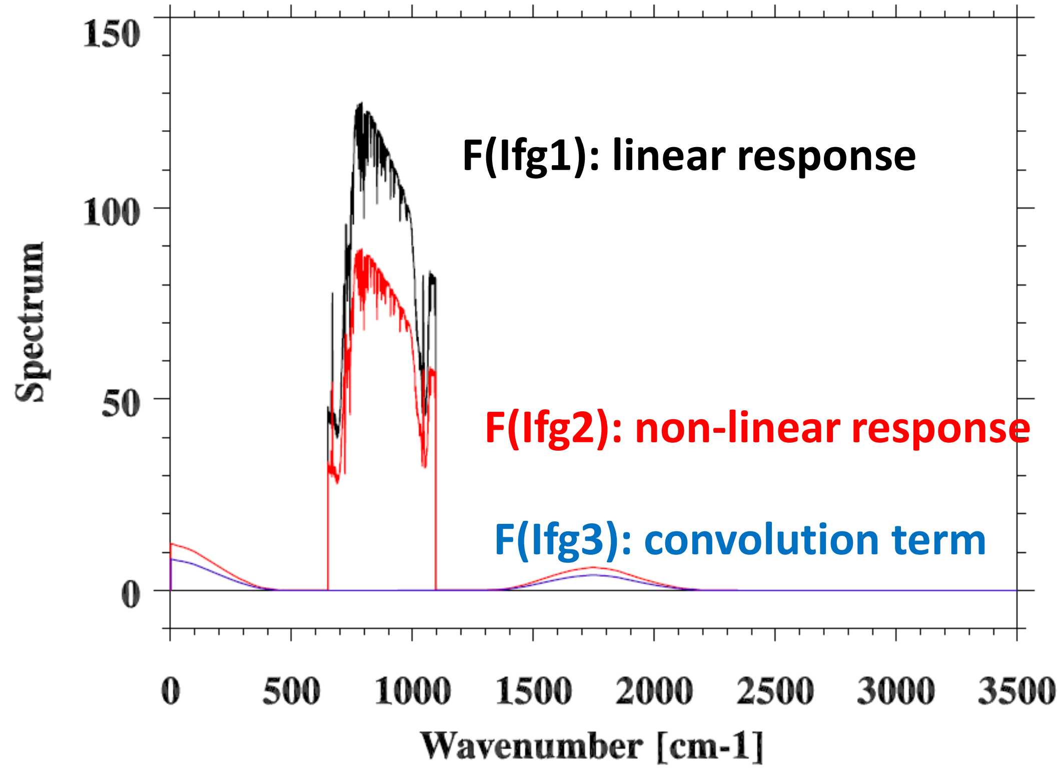
Longwave band



Middlewave band

For a non-linear detector



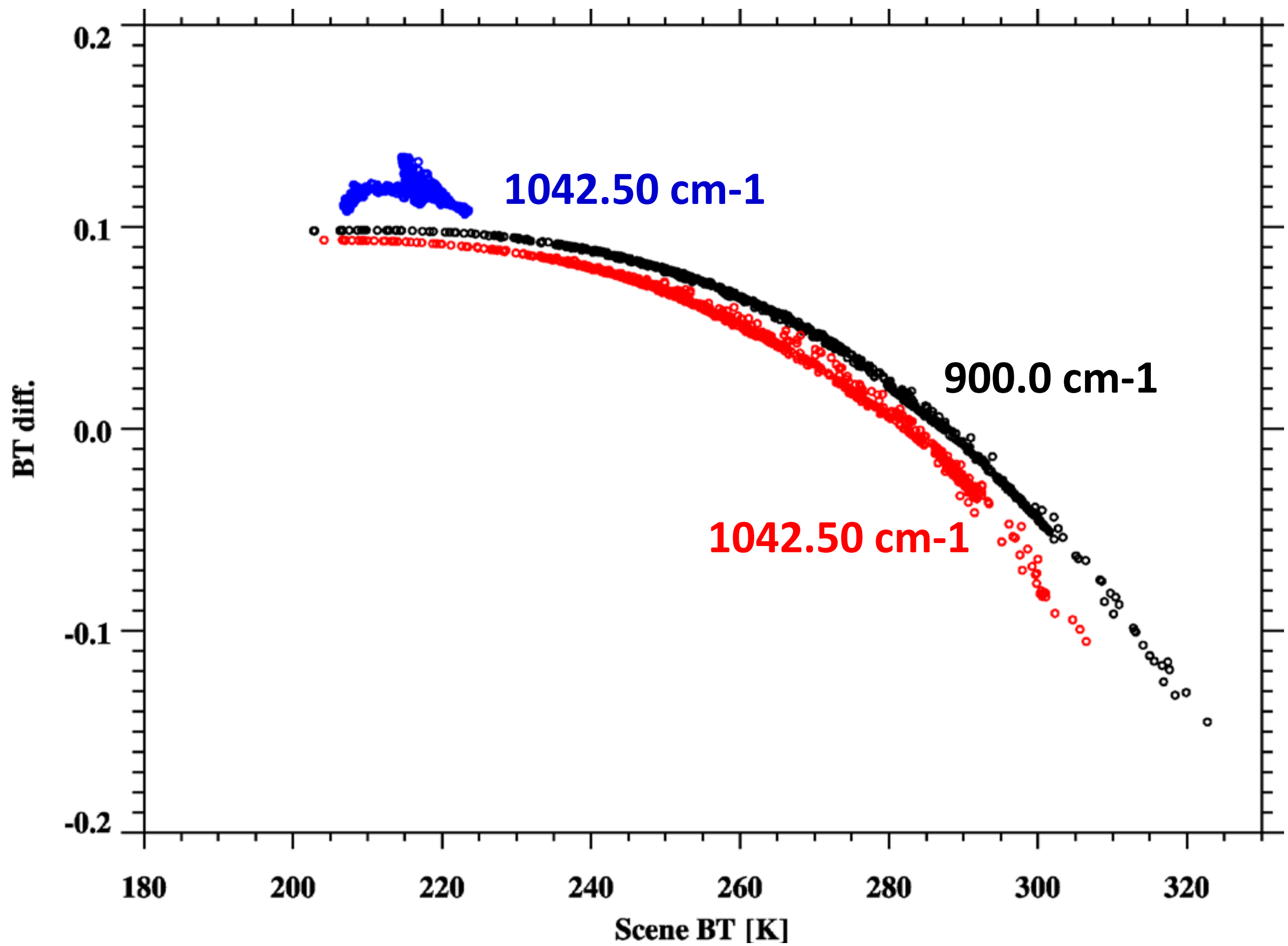


Hypothetical detector-response curve exhibiting nonlinearity. The horizontal axis represents the absolute magnitude of the photon flux and the vertical axis represents the measured dc signal.

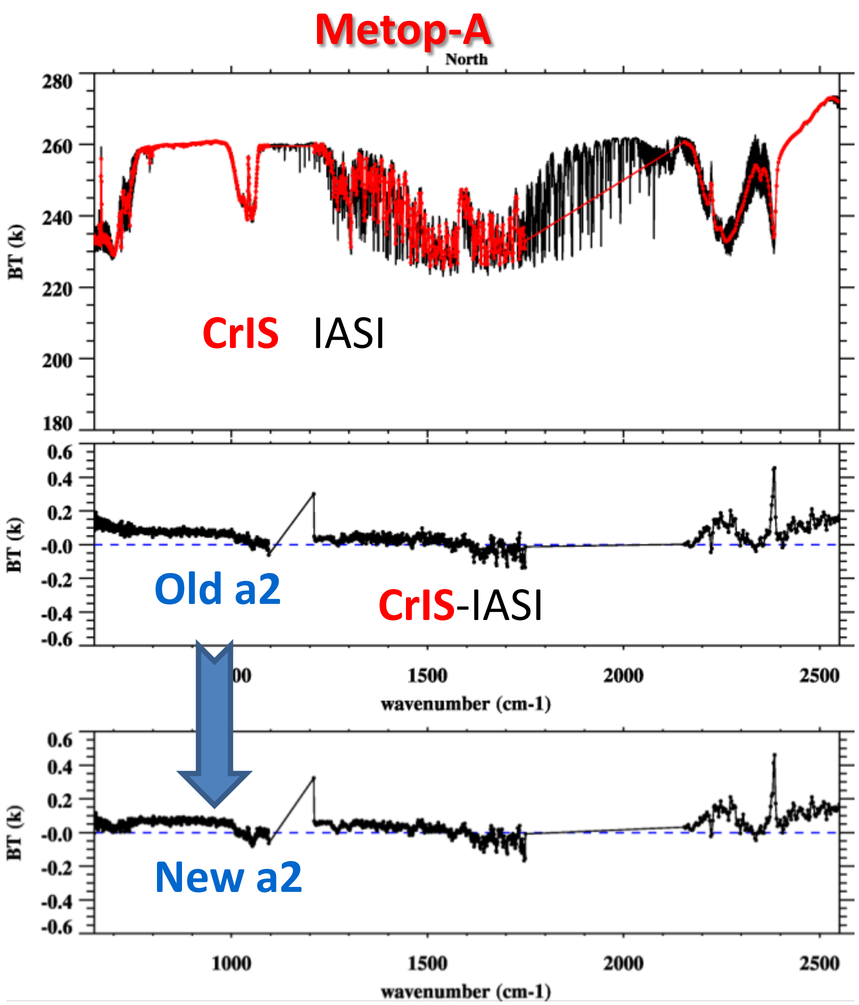
Non-linearity responses in spectral domain.

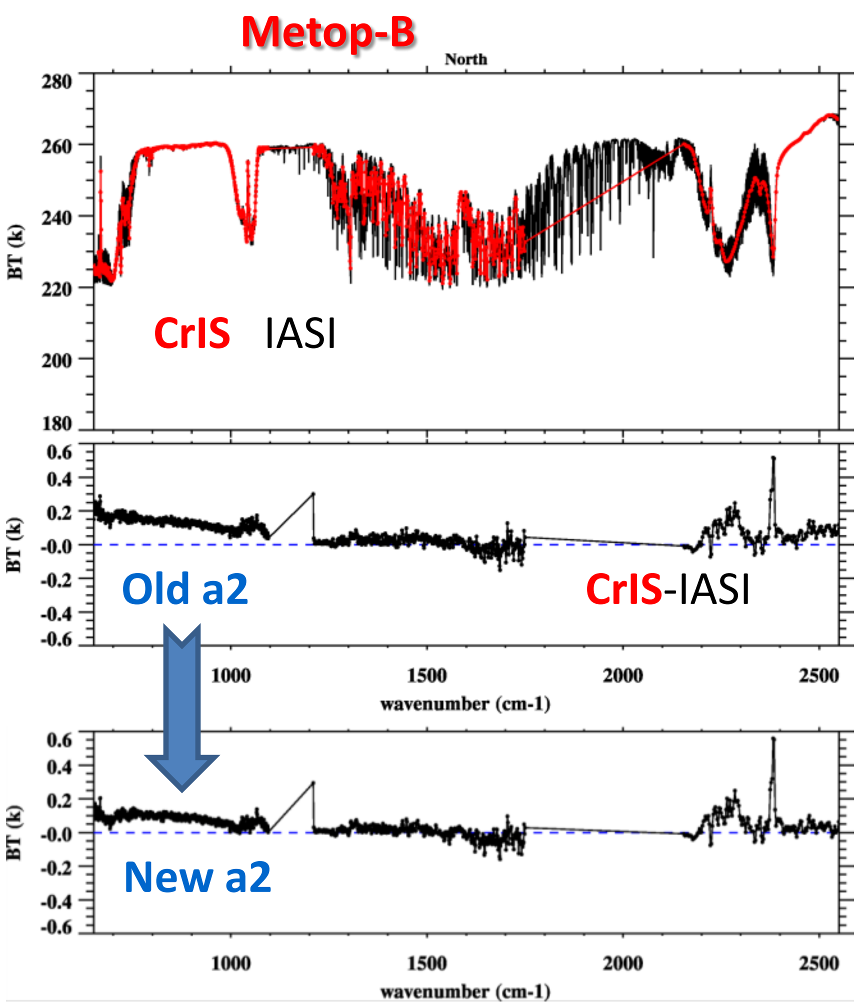
From Abrams et al. 1994

Longwave FOV 5
BT changes: Old a2 – New a2



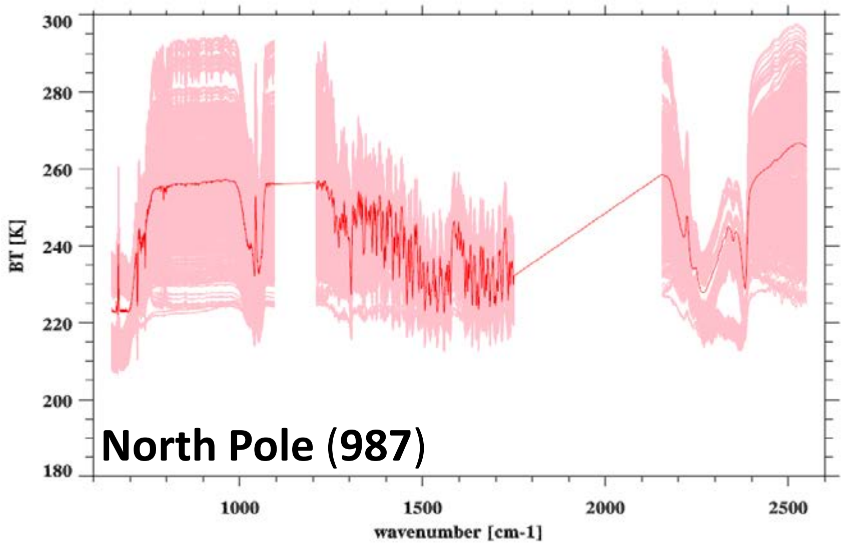
CrIS-IASI with New a2 values

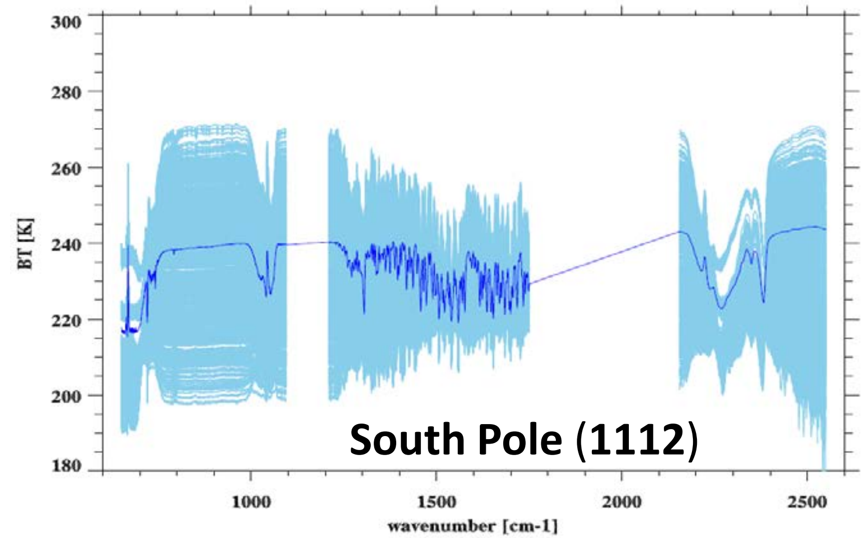


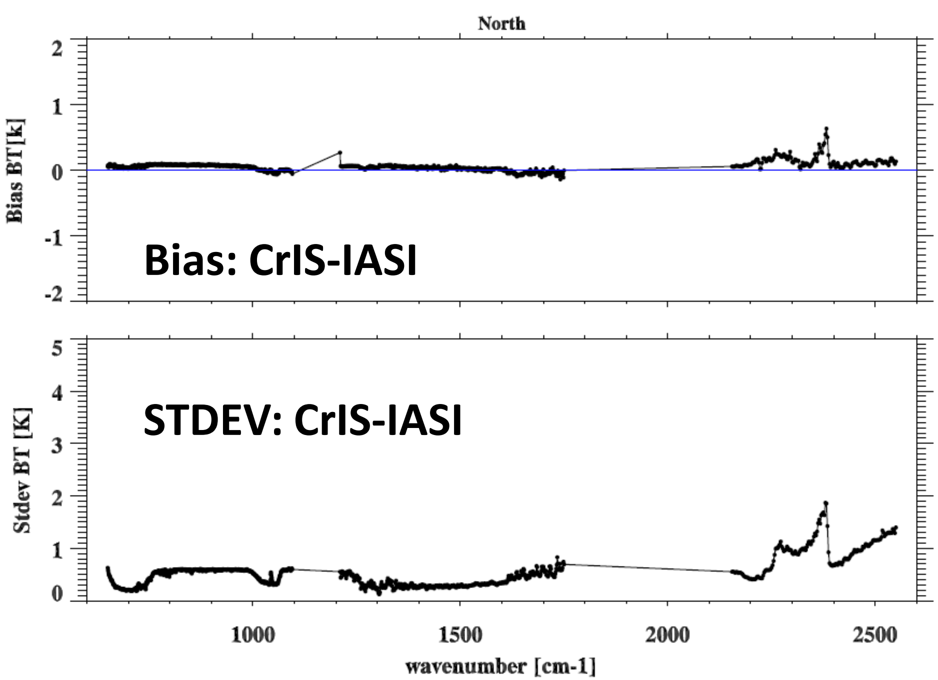


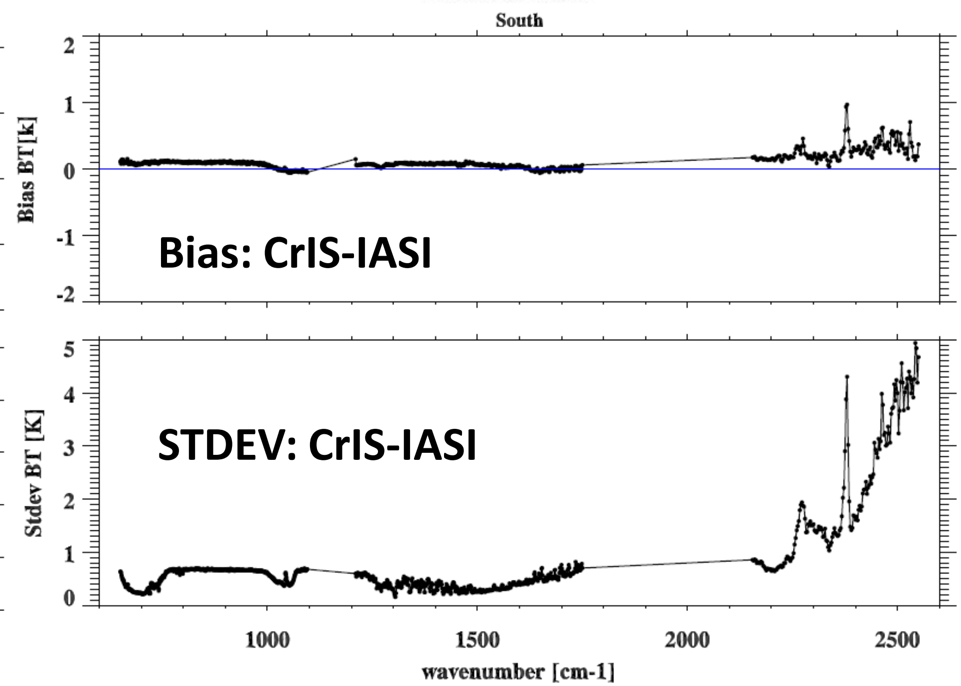
The differences between CrIS-IASI is reduced at LW bands with new a2 values.

CrIS versus IASI/MetOp-A

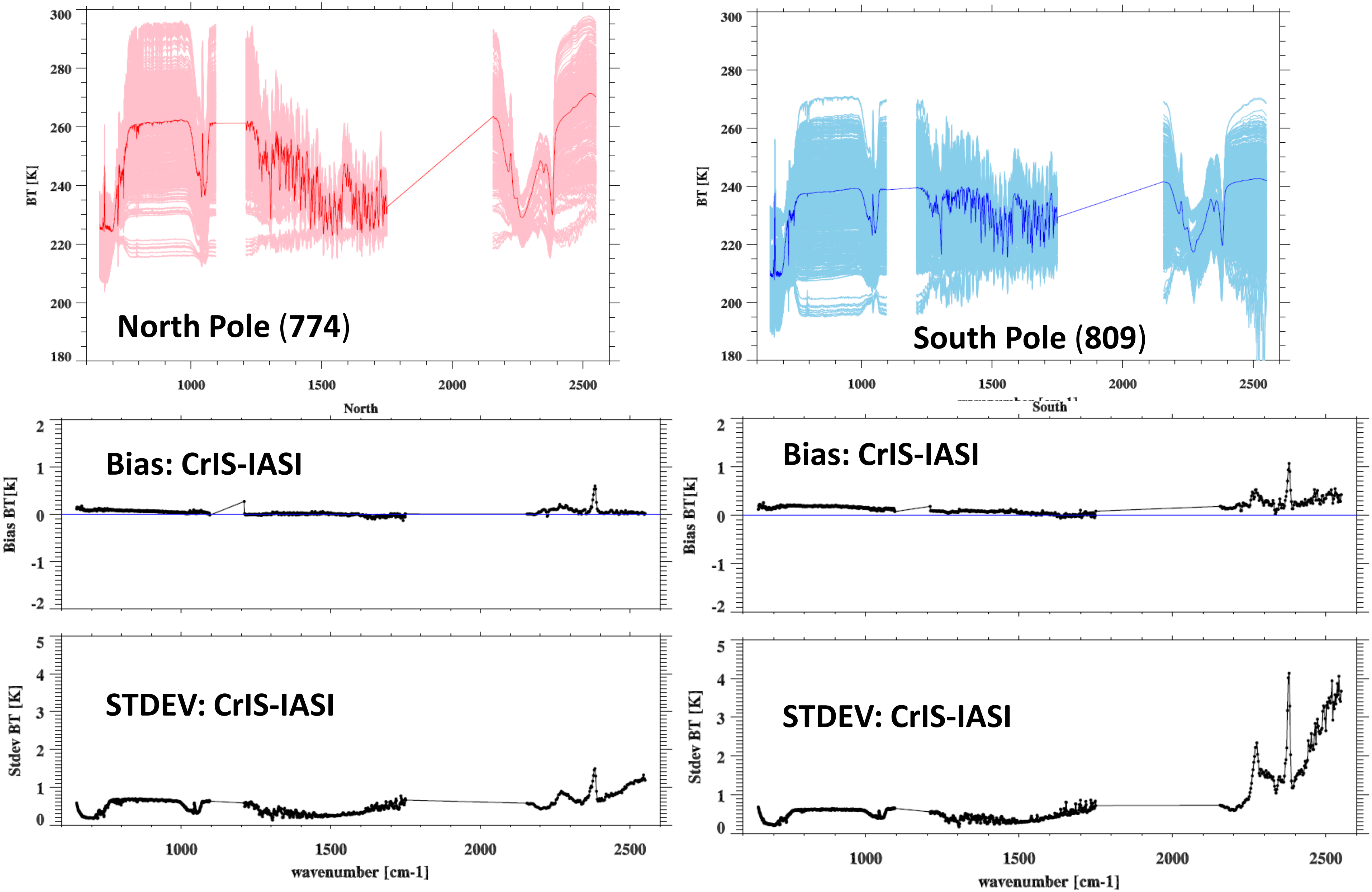




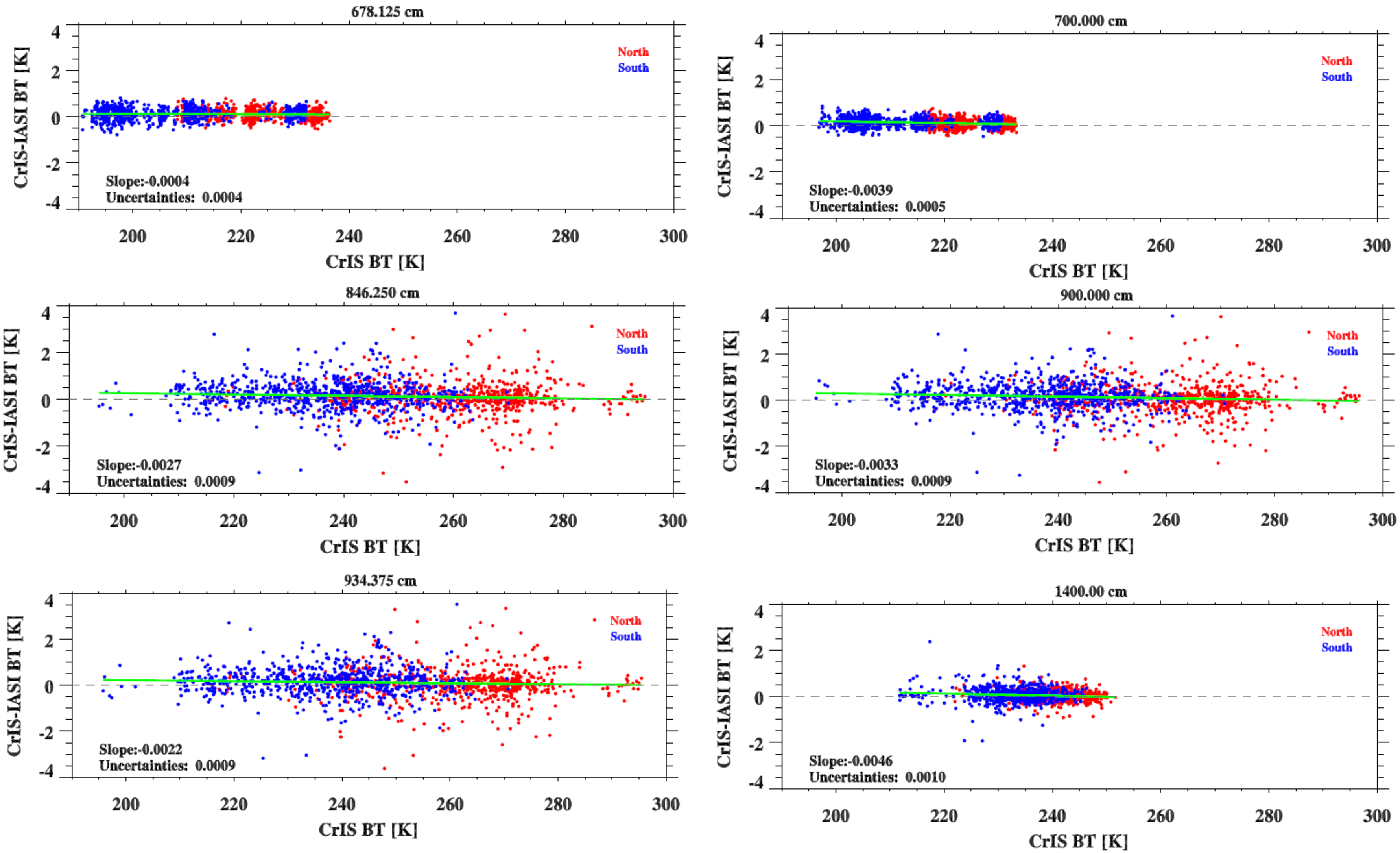




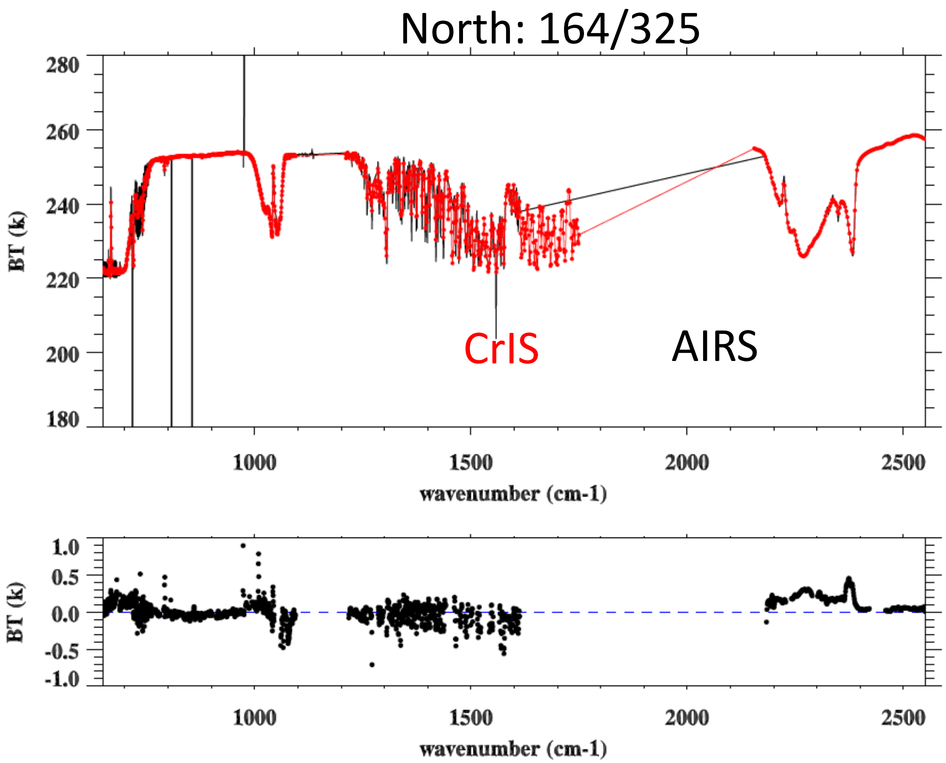
CrIS versus IASI/MetOp-B

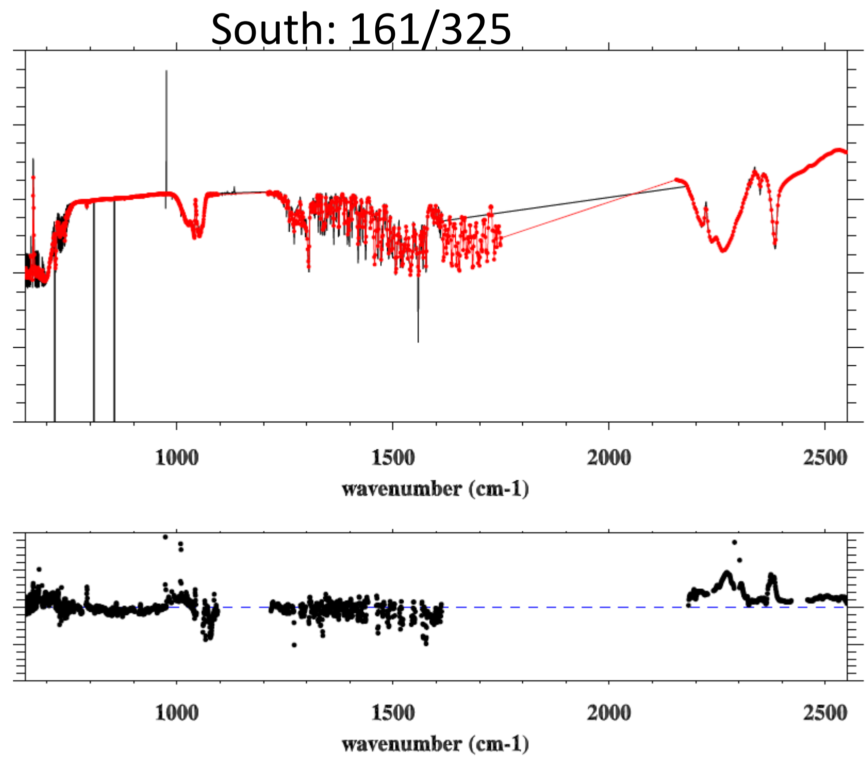


Scene-Dependent Bias



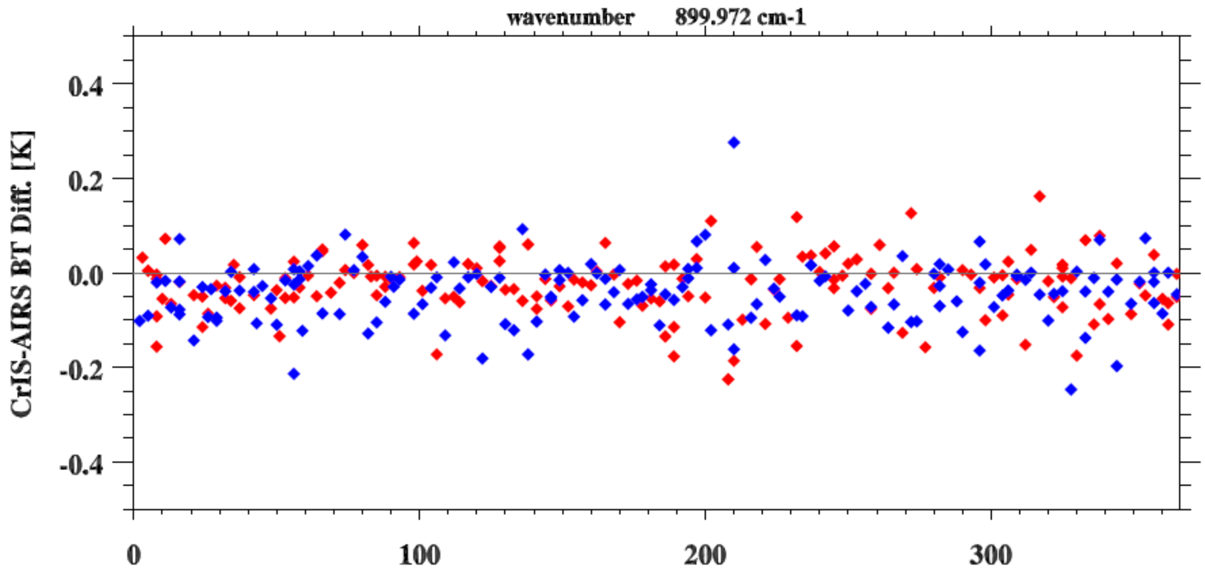
CrIS versus AIRS
Daily averaged SNO observations



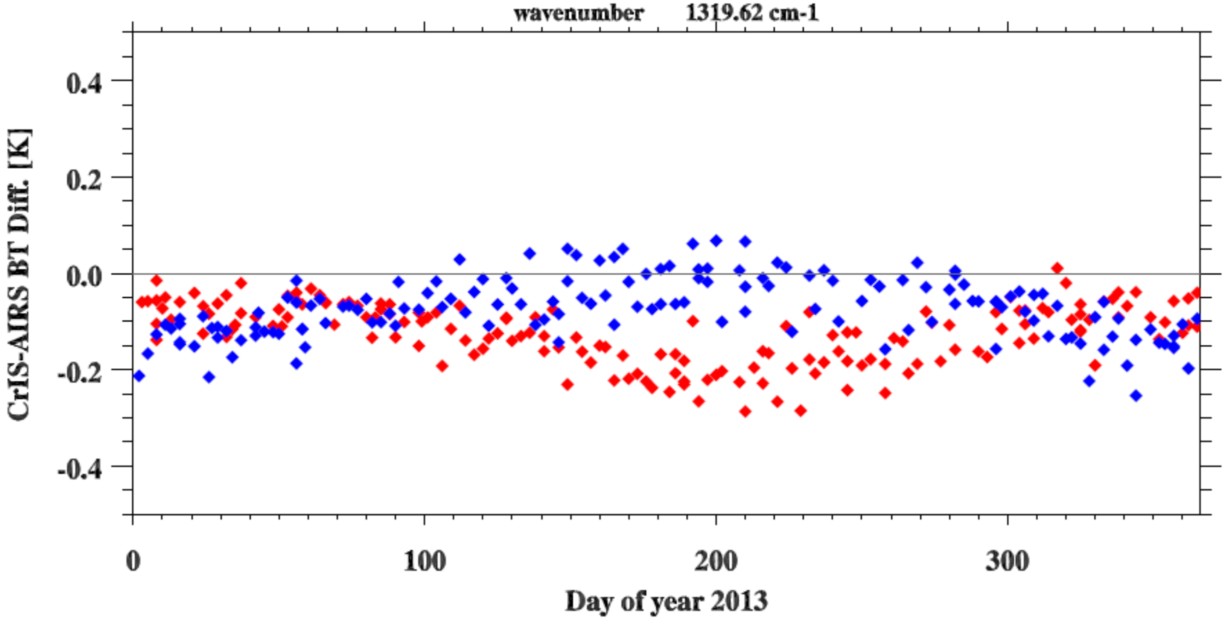


Large spread could be due to the resampling uncertainties and AIRS band channels

Time Series of CrIS-AIRS



Atmospheric Window



Water Vapor Window

Conclusion

- Radiometric and spectral consistency of four IR hyperspectral sounders is fundamental for GSICS and climate application.

- Inter-comparison of CrIS with IASI/Metop-A, IASI-Metop-B, and AIRS have been made for one year's of SNO observations in 2013.

- CrIS vs. IASI
  - CrIS and IASI well agree each other at LWIR and MWIR bands with 0.1-0.2K differences
  - No apparent scene dependent bias
  - At SWIR band, a sharp increases can be clearly seen at spectral transition region. The reason is still under investigation.

- CrIS vs. AIRS
  - Resampling errors still remain when converting AIRS and CrIS onto common spectral grids.
  - CrIS and AIRS well agree each other at LWIR and MWIR bands within 0.4 K differences
  - At SWIR band, a sharp increases can be clearly seen at spectral transition region.
  - A weak seasonal variation can been seen for CrIS-AIRS at water vapor absorption region.

- Lessons learned for JPSS CrIS: Non-linearity play an important role for CrIS radiometric accuracy and should be carefully evaluated during the prelaunch test.

- The comparison will be continued until end of sensor mission, which will provide fundamental information about consistency of hyperspectral sounders to the community.

Proxy Dataset for Testing and Evaluating J1 CrIS SDR Products

Xin Jin, Mark Esplin, Lihong Wang, Denis Tremblay, Ninghai Sun, Yong Han, Yong Chen, Likun Wang, Fuzhong Weng

Introduction

- **Why we need proxy data**
  - Proxy datasets, including simulation, original or modified observation, are critical for evaluating algorithm and testing system robustness
- **What we have**
  - **Data**

i. SNPP and J1 CrIS TVAC data

ii. SNPP CrIS science and telemetry RDR since Day 1 of the mission

iii. Intact collection of ancillary files such as TLE, PolarWander and CMO.

  - **Memo**

i. Processing log of all SNPP CrIS operational RDR and SDR granules since Day 1 of the mission, including anomaly warning messages down to pixel level: *rcris_diary_of_yyyymmdd.txt, scris_diary_of_yyyymmdd.txt*

ii. A diary manually maintained to record any mission-related event/action/anomaly

  - **Software**

I. Matlab scripts to manipulate every bit of the CCSDS binary data.

II. ICVS: A web-based instrument monitoring and product evaluation system

Readiness of CrIS proxy dataset: Menu

1. **Functional**
   1. Golden day
   2. Full resolution
2. **Sensitivity test for science**
   3. Non-linearity correction
   4. ILS correction
   5. Geolocation calibration
   6. Lunar intrusion
3. **Instrument anomaly**
   7. Fringe Count Error
   8. Laser wavelength leaps (CMO update)
   9. Incorrect time stamp
   10. Scene select module (SSM) position counter error
   11. ICT temperature anomaly
   12. ICT scene impulse
   13. Impulse noise mask
4. **Engineering**
   14. Bit trim mask (sun glint)
5. **Abnormal inputs**
   15. (1) Missing scan(s), (2) Missing Earth scene packet(s), (3) Missing deep space packet(s), (4) Missing ICT packet(s), (5) Missing 8-sec telemetry packet(s), (6) Missing engineering packet, (7) Missing spacecraft diary(s)
   16. Automatic/Manual re-tasking

Readiness of CrIS proxy dataset: Functional

1. **Functional**
   1. Golden day
      1. Our RDR dataset can cover any golden day since Jan 30, 2012, determined by the team decision
   2. Full resolution
      1. Data for three full-resolution tests are all archived: (Case 1) Feb 22~23, 2012; (Case 2) Mar 12~13, 2013; (Case 3) Aug 27~28, 2013
      2. Full resolution RDR will be routinely available after December, 2014

February, 2012

Su	Mo	Tu	We	Th	Fr	Sa
29	30	31	1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	1	2	3
4	5	6	7	8	9	10

Case 1:
Intensive cal/val stage
Bit trim mask not optimized
FIR filter not improved

March, 2013

Su	Mo	Tu	We	Th	Fr	Sa
24	25	26	27	28	1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31	1	2	3	4	5	6

Case 2:
Probationary data stage
Bit trim mask not optimized

August, 2013

Su	Mo	Tu	We	Th	Fr	Sa
28	29	30	31	1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31
1	2	3	4	5	6	7

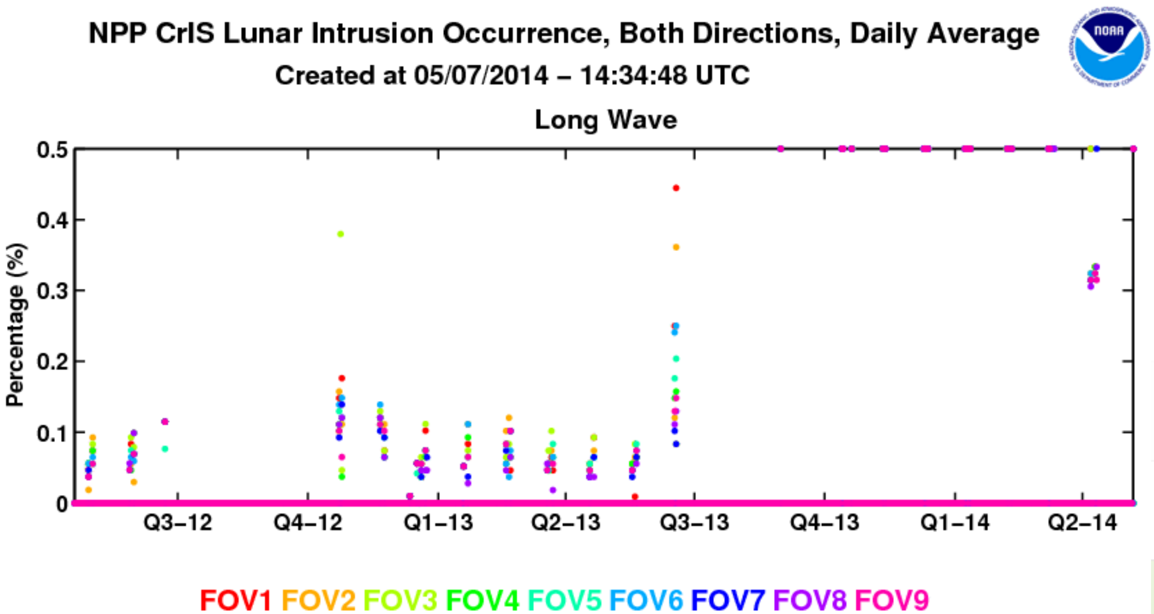
Case 3:
Probationary data stage
Bit trim mask optimized
Impulse noise mask not improved
Mid-wave bin size increased from 1039 to 1052

Readiness of CrIS proxy dataset: Sensitivity

2. Sensitivity test for science

3. Non-linearity correction
4. ILS correction
5. Geolocation calibration
6. Lunar intrusion
   - Enough cases are collected for testing

(Items 3–5: Dataset + EngPkt tools)

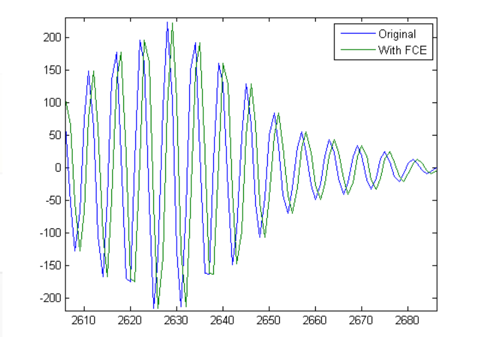


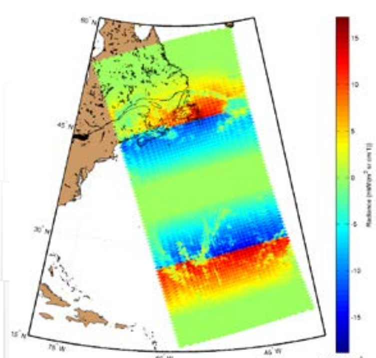
Readiness of CrIS proxy dataset: Instrument

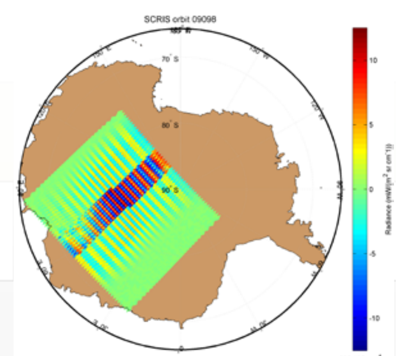
3. Instrument

7. Fringe Count Error

- The real FCE case has never been found since the SNPP mission. Only a false alarm happened on 10:07, Dec 11, 2013. SDL provided several simulated cases:
  - LWIR Diagnotic mode
    orbit 01303 on Feb 28, 2012
  - Mid-latitude scencs
    SCRIS_npp_d20130912_t1626499_e1627197_b09723_c20130912224348119785_noaa_ops.h5 **to**
    SCRIS_npp_d20130912_t1638019_e1638317_b09723_c20130912230335907566_noaa_ops.h5
  - Very cold Antarctic scene
    SCRIS_npp_d20130730_t1616419_e1617117_b09098
    SCRIS_npp_d20130730_t1622019_e1622317_b09098







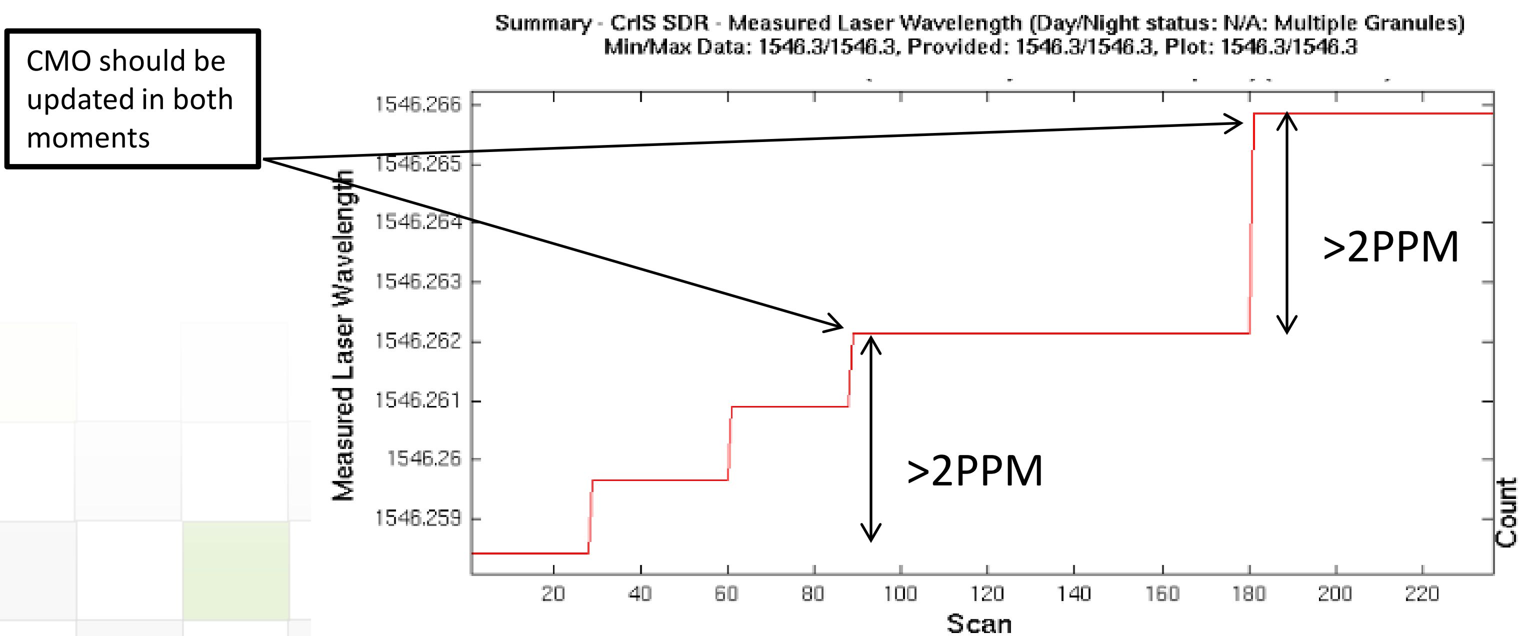
Esplin, SDL

Left: Diagnostic mode interferogram; **Mid**: Imaginary radiance over Mid-lat; **Right**: Imaginary radiance over Antarctic

3. Instrument

8. Laser wavelength leaps (CMO update)

- The Sampling laser wavelength of S-NPP CrIS is very stable since the mission. The measurements of laser wavelength in some RDR granules are manually modified to create a dataset to test the functionality of automatic CMO update.



3. Instrument

9. Incorrect time stamp
   - The real time stamp error in RDR has not been found yet
   - Lihong Wang of NGAS created a case to test the system response to the incorrect time stamp: The number of day since 1598 for all DS LW FOV2 in the following granule is changed from 20381 to 20380 to simulate a RDR time stamp error

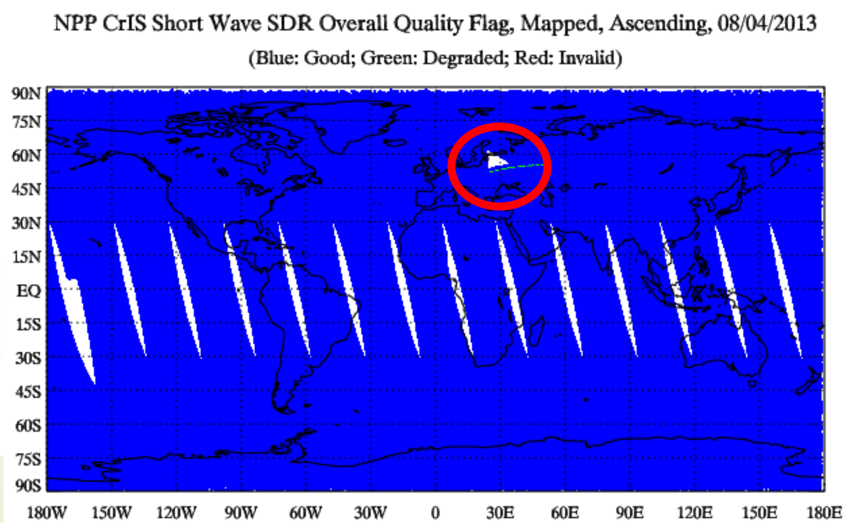
RCRIS-RNSCA_npp_d20131020_t0331004_e0331324_b10254_c20131020044721180606_noaa_pop.h5

3. Instrument

10. Scene select module (SSM) position counter error

- 5 cases have been recorded:

(1) RCRIS-RNSCA_npp_d20120928_t0942093_e0942413
(2) RCRIS-RNSCA_npp_d20121212_t1534078_e1534398
RCRIS-RNSCA_npp_d20121212_t1534398_e1535118
(3) RCRIS-RNSCA_npp_d20121223_t0104276_e0104596
RCRIS-RNSCA_npp_d20121223_t0104596_e0105316
(4) RCRIS-RNSCA_npp_d20130804_t1024338_e1025058
RCRIS-RNSCA_npp_d20130804_t1025058_e1025378
(5) RCRIS-RNSCA_npp_d20140213_t2348499_e2349219



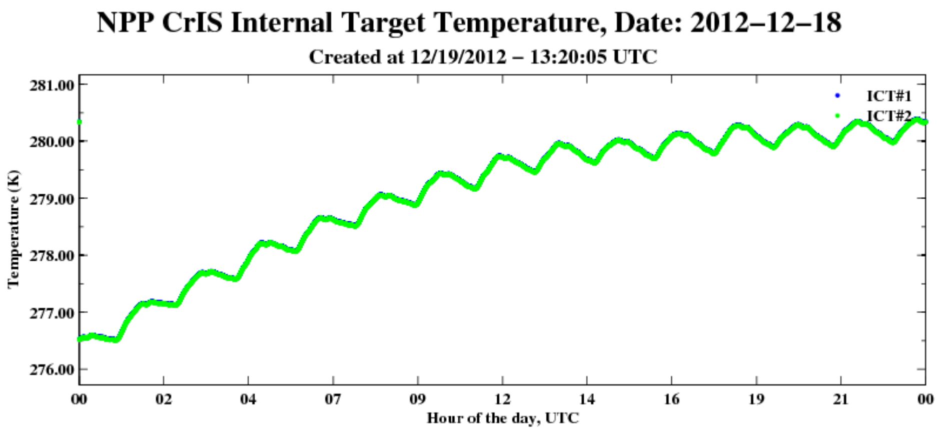
Currently, when such an anomaly happens, the moving window containing the bad values is skipped without processing

3. Instrument

11. ICT temperature anomaly

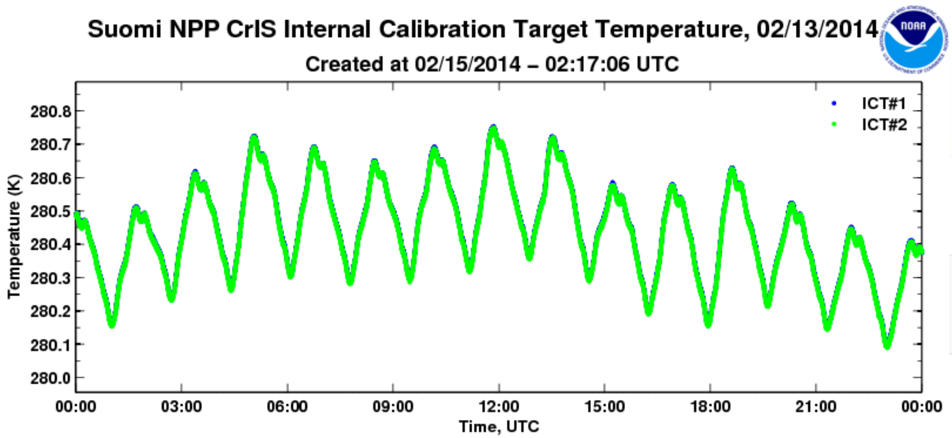
- ICT temperature quickly increased more than 4K on Dec 18, 2012 after CrIS was switched to safe mode, and the nominal daily variation is less than 0.8K

ICT anomaly



This case will be used to test the program response to dramatic ICT drifting. Some quality flags should be triggered.

Nominal ICT

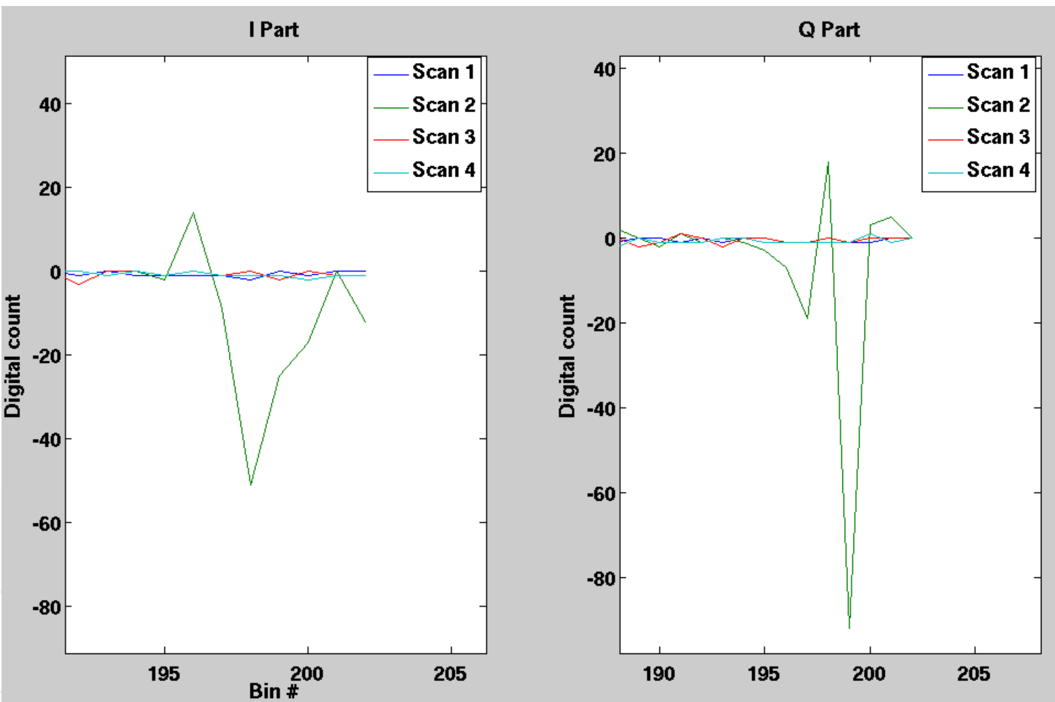


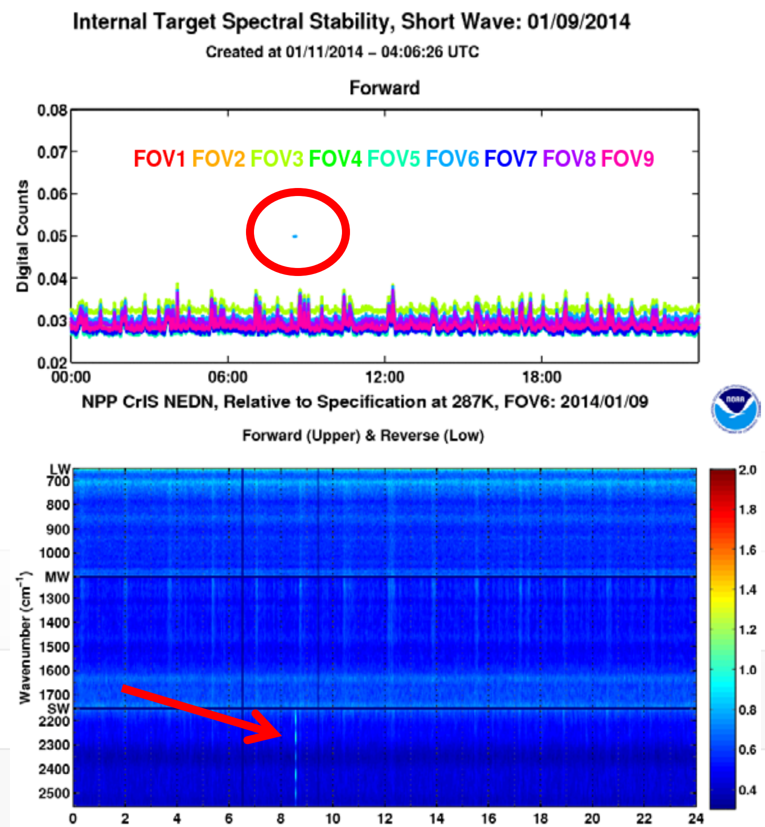
Readiness of CrIS proxy dataset: Instrument

3. Instrument

12. ICT scene impulse

- ICT interferogram occasionally gets corrupted by random impulse, resulting in excessive spectral noise. No quality checks for this anomaly in current algorithm. Abundant cases are prepared for testing new algorithms dealing with this issue.



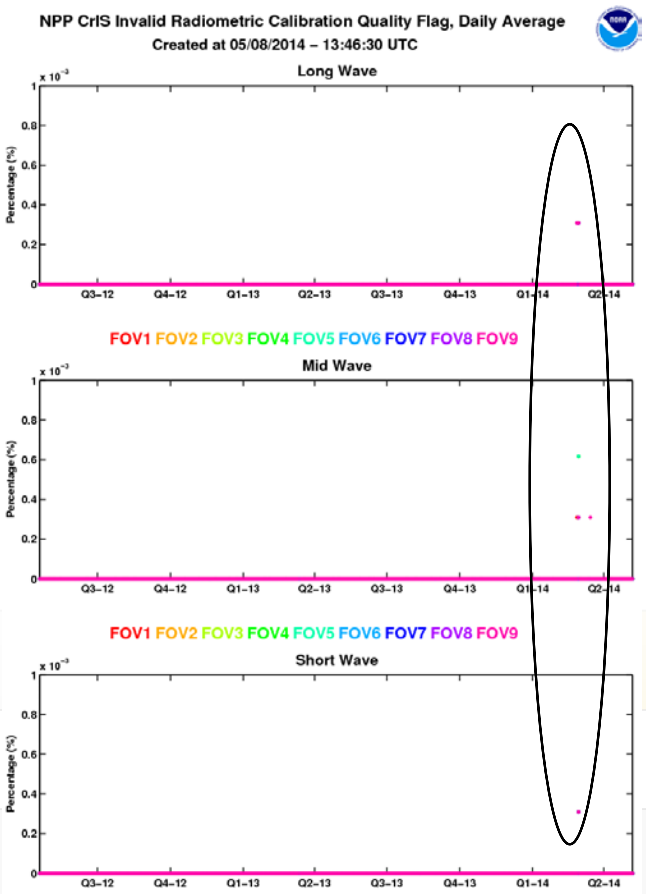


3. Instrument

13. Impulse noise

- Too many impulse noise counts could corrupt an interferogram. Although SNPP CrIS is well sheltered, some cases are still found. The following cases are found to be the reason of the false alarm of 'Invalid Radiometric Calibration' in IDPS operational SDR products:

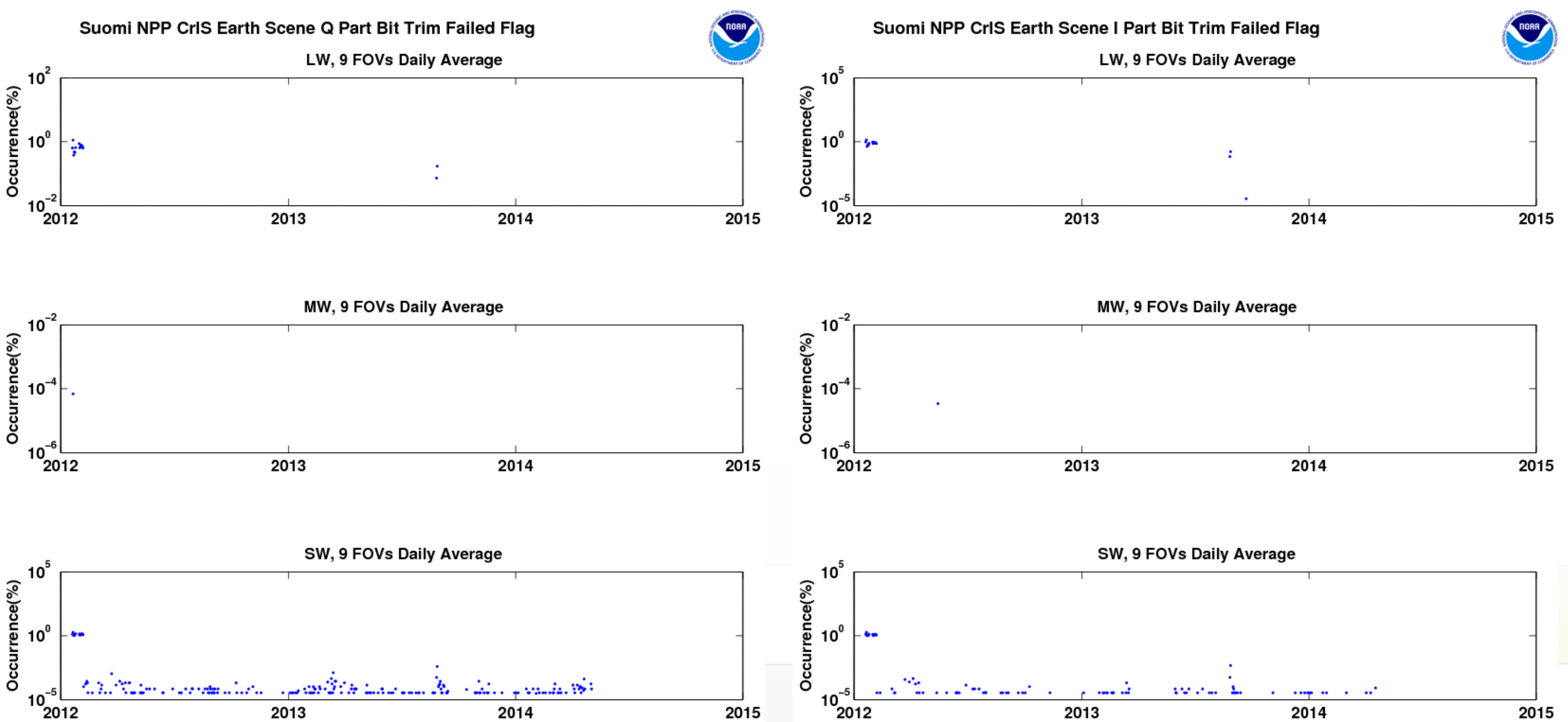
SCRIS_npp_d20140226_t1429539_e1430237_b12091
SCRIS_npp_d20140228_t0459299_e0459597_b12113
SCRIS_npp_d20140315_t1821379_e1822077_b12334



4. Engineering

14. Bit trim mask saturation

- Abundant BTM cases are available. Most of them are over ocean due to SW sun glint. A few of them are over hot desert or high altitudes with strong surface reflectivity.



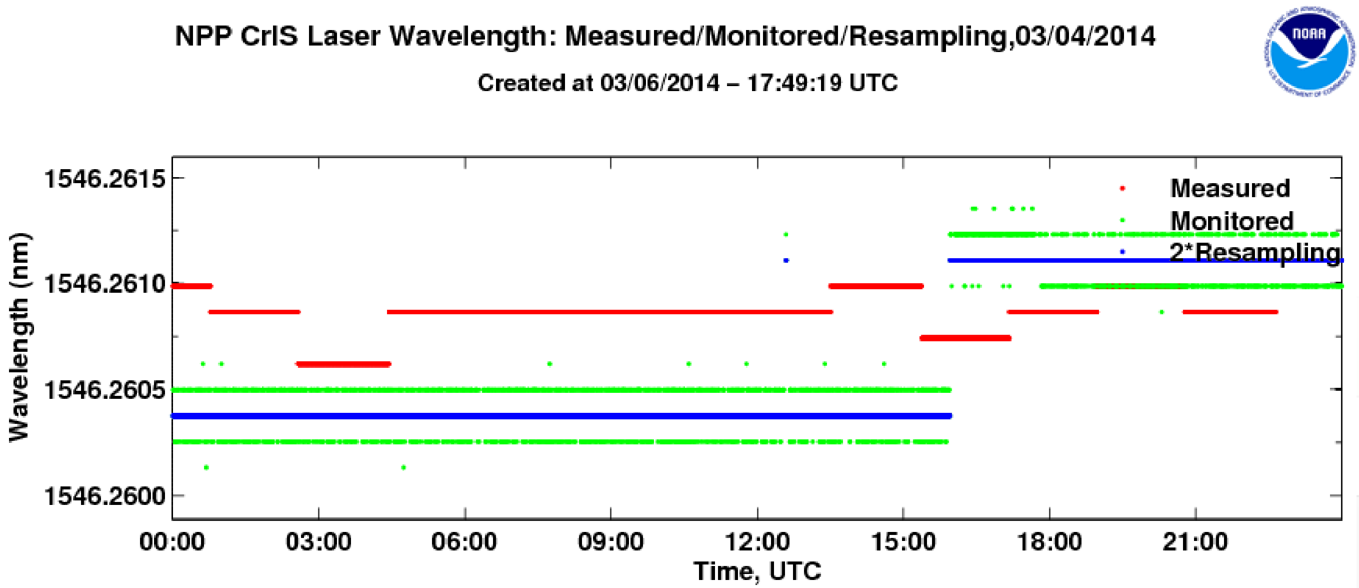
5. Abnormal inputs

15. Abundant cases are ready for the tests of the following anomalies and/or their combinations:
    (1) Missing one or more scan(s)
    (2) Missing Earth scene packet(s)
    (3) Missing deep space packet(s)
    (4) Missing ICT packet(s)
    (5) Missing 8-sec telemetry packet(s)
    (6) Missing engineering packet
    (7) Missing spacecraft diary(s)

5. Abnormal inputs

16. Automatic/Manual re-tasking

- It is found that the interaction between Re-tasking procedure and the main processing line is extremely subtle. Anomalies caused by the bugs hidden in this part include: (i) sudden change of re-sampling laser wavelength; (ii) incorrect measured laser wavelength record; (iii) difficulty of indentifying CMO matrix used in the procedure.
- Several cases are prepared.



Conclusions

- **Proxy data is invaluable for evaluating algorithm and testing system robustness**
- **We have prepared abundant cases during the SNPP CrIS trending/monitoring/debugging and we are still collecting new cases. All of these cases will be part of the J1 proxy dataset**
- **We have convenient tools to manipulate the dataset to create new cases for new requirement for J1**

THE VALUE OF PERFORMANCE.

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NGAS Support to CrIS SDR CalVal

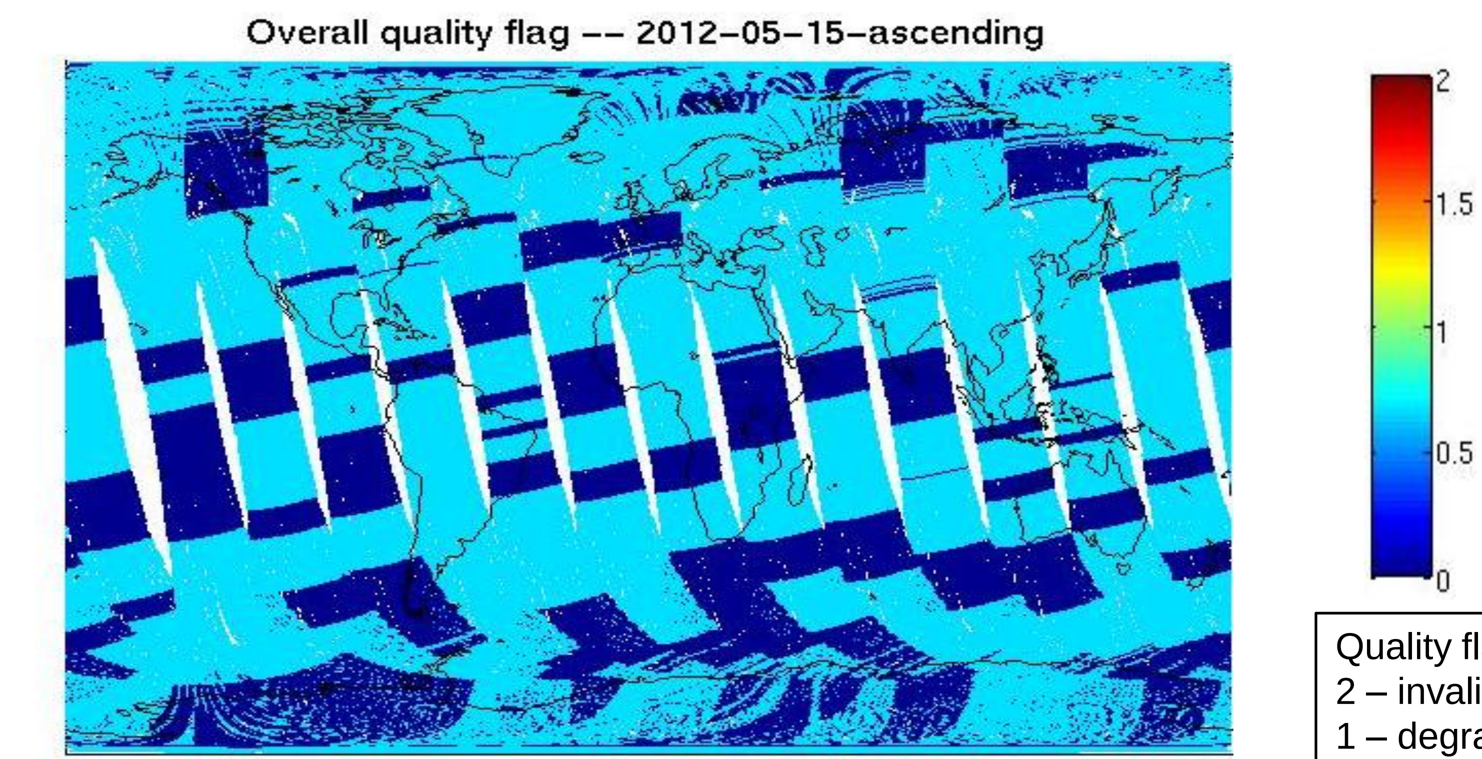
Degui Gu

May 14, 2014

NGAS Activities in Supporting CrIS SDR CalVal

- Supported CrIS SDR algorithm/data product DR investigations
  - 27 DRs formally assigned to NG team to investigate since Launch
- Developed, verified and implemented CrIS SDR algorithm code updates using G-ADA
  - 8 CrIS SDR code update packages delivered to DPES since Launch
  - All major algorithm modules are affected and significantly improved by the CrIS CalVal team (ILS correction, Radiometric calibration, Quality flags, Robust error handling)
- Supported SDR performance assessment and characterization
- J-1 SDR algorithm development
  - Science improvement
  - Software development

CrIS SDR Data Product at Mission Start



Quality flag
2 – invalid
1 – degraded
0 -- valid

Distribution of overall quality flag for CrIS Golden Day May 15, 2012. Note CrIS SDR data were incorrectly labeled as degraded extensively

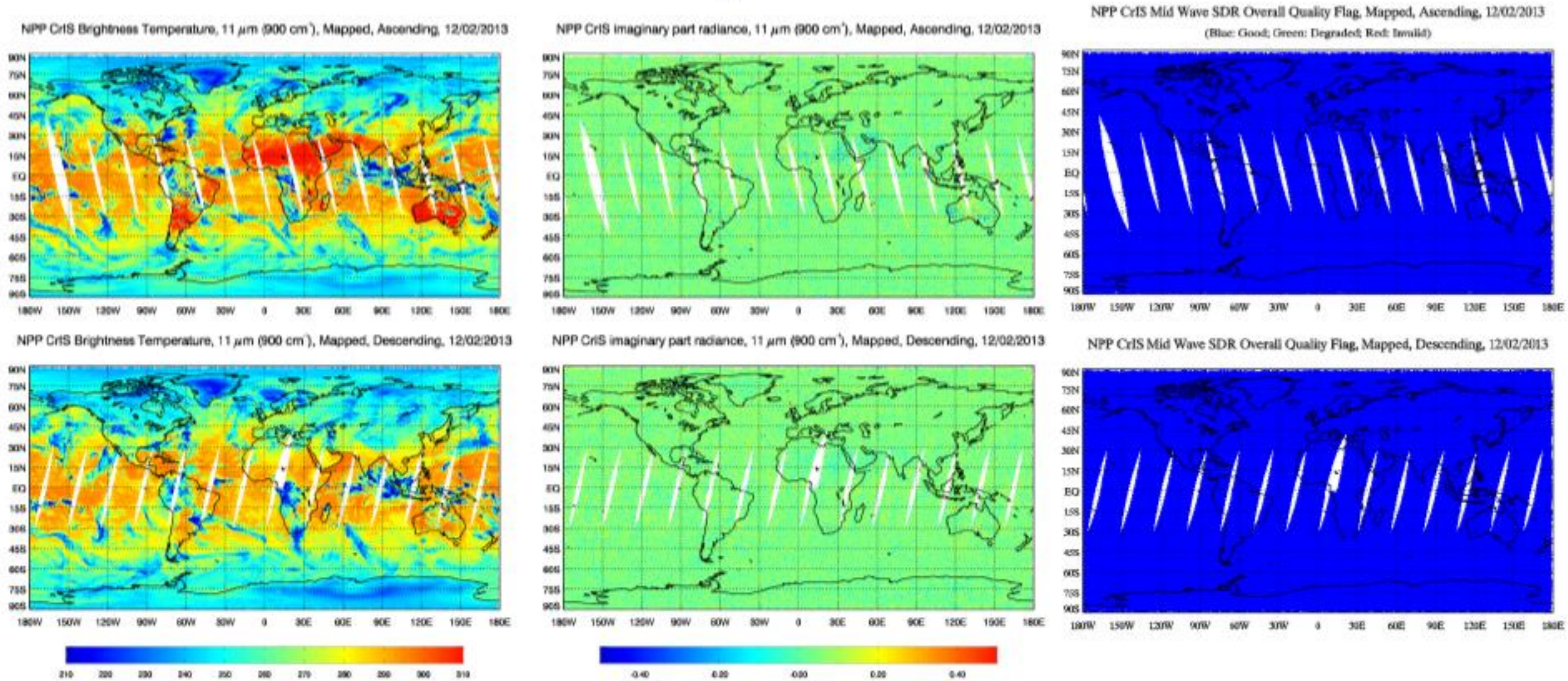
Significantly Improved CrIS SDR Algorithm to Produce Quality SDR Data Products

Example of data quality after Mx8.0

Real radiance

Near zero Imaginary radiance indicates good real radiance

Overall SDR quality flag
Blue - good



-0.4 0.0K 0.4

900 cm^{-1} channel

16

(Courtesy of Yong Han, STAR)

CrIS SDR Algorithm Code Updates to Resolve DR7542

- DR 7542: CrIS SDR NEdN with zero values
  - Zero NEdN values were found in operational CrIS SDR valid data products
- Root cause
  - The code internally uses the binSize of ICT spectrum of the 1st scan in the sliding window to compute NEdN values
  - When this ICT spectrum is determined by the algorithm to be invalid, its binSize is set to zero and therefore NEdN is never computed. Later the algorithm writes out the default value of zeros for NEdN in the CrIS SDR data product
- Code updates
  - Update 1: In the extreme case when all ICT spectra in the sliding window are invalid, NEdN values can not be computed. In this case, the code should output fill values for NEdN instead of zero. Modified code to replace zero NEdNs with fill values (-999.8)
  - Update 2: Fix the identified code bug to compute and output valid NEdN values. Rather than using the binSize of the first ICT spectrum in the sliding window (not guaranteed to be always valid), the code is modified to search through the sliding window for a valid spectrum and use its binSize to compute NEdN values

CrIS SDR Algorithm Code Updates to Resolve DR7466

- DR 7466: Occurrence of extended SDR anomaly due to time stamp error
  - A corrupted time stamp of a reference spectrum should only affect SDR radiances that are calibrated using the specific reference spectrum. But extended anomaly is observed and persists for a longer period of time
- Root cause:
  - Algorithm checks for invalid reference (Deep/ICT) spectra to exclude them from being saved in a buffer. They are flagged using the SDR_Invalid flag. But later the code uses the RDR Missing flag to determine whether to remove invalid reference data from the calibration window buffer, causing misalignment
- Code updates
  - Modify the code to check SDR Invalid flag instead of RDR Missing flag to determine whether an invalid SDR reference spectrum should be removed from the buffer
  - Update other part of the code to be consistent with the above code change

Proposed a new Approach for CrIS Spectral Calibration

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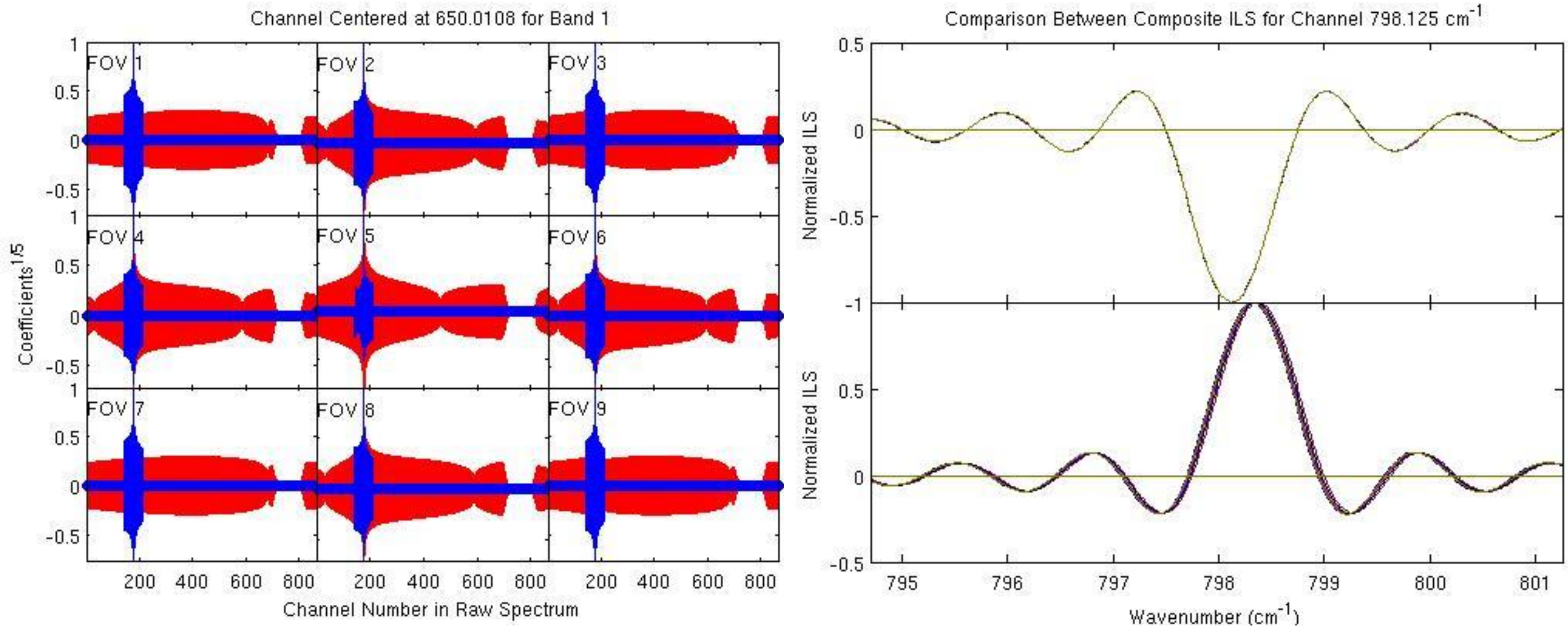
- Least square approximation of the user required ILS by combining native sensor ILS based on detailed modeling of sensor effects
  - Ideal point detector, finite size detector, Finite Impulse Filter, decimation
  - Current SDR algorithm does it in two steps, also by combining native sensor ILS of all bins in each band, but the coefficients are computed based on physical/mathematical models
- The new approach performs frequency resampling and self-apodization correction in one simple step
- The new approach is intended to ensure consistency between CrIS SDR data products and the presumed ILS used by the user community in developing their forward models (e.g., CRTM, OSS RTM in CrIMSS EDR algorithm)

Comparison of ILS Generated by CrIS SDR Algorithm and the new Approach



The new approach provided an objective criterion for evaluating different calibration approaches, assuming that instrument ILS can be accurately modeled

Verification of CrIS SDR Performance Using TVAC Data

NORTHROP GRUMMAN

- Issue: significant errors observed in TVAC data after processing using the CrIS SDR algorithm
  - Wavelength dependent and up to ~0.3% in the SW band
- Root cause: most of the errors are due to the instrument operator being removed from the calibration equation
  - Should be

$$L^S = F_{INT}^{-1}\left[\frac{\tilde{S}^S - \langle \tilde{S}^{DS}\rangle}{\langle \tilde{S}^{ICT}\rangle - \langle \tilde{S}^{DS}\rangle}\right] \cdot F_{INT} L^{ICT}$$

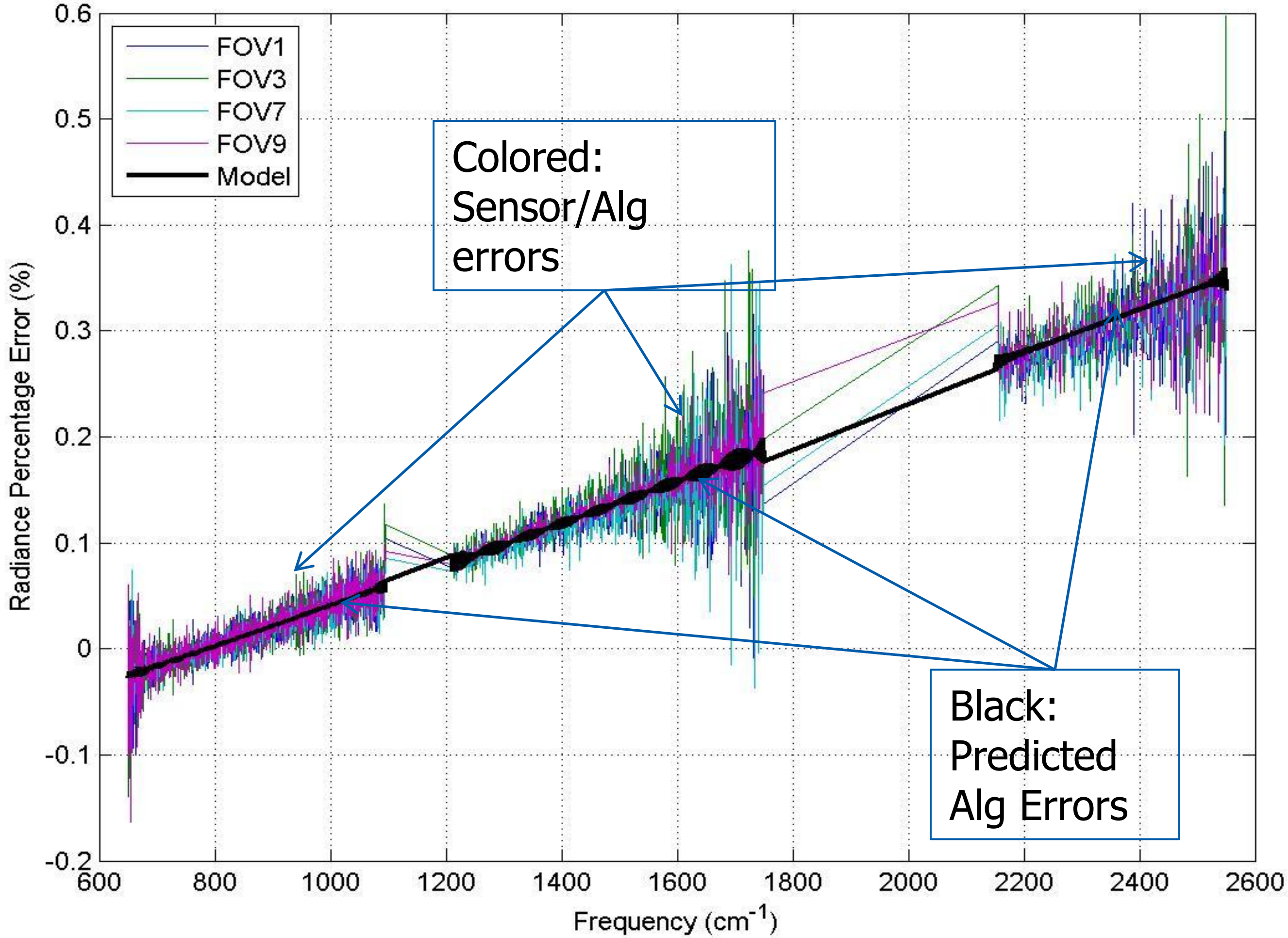
  - Implemented in the code

$$L^S = F_{INT}^{-1}\left[\frac{\tilde{S}^S - \langle \tilde{S}^{DS}\rangle}{\langle \tilde{S}^{ICT}\rangle - \langle \tilde{S}^{DS}\rangle}\right] \cdot L^{ICT}$$

F_{INT} is the instrument operator that represents the ILS effects, including all effects that the instrument might introduce such as self-apodization, IGM modulation, etc. The notation implies that the radiance has been affected by the instrument

F_{INT} Effect on Radiometric Calibration

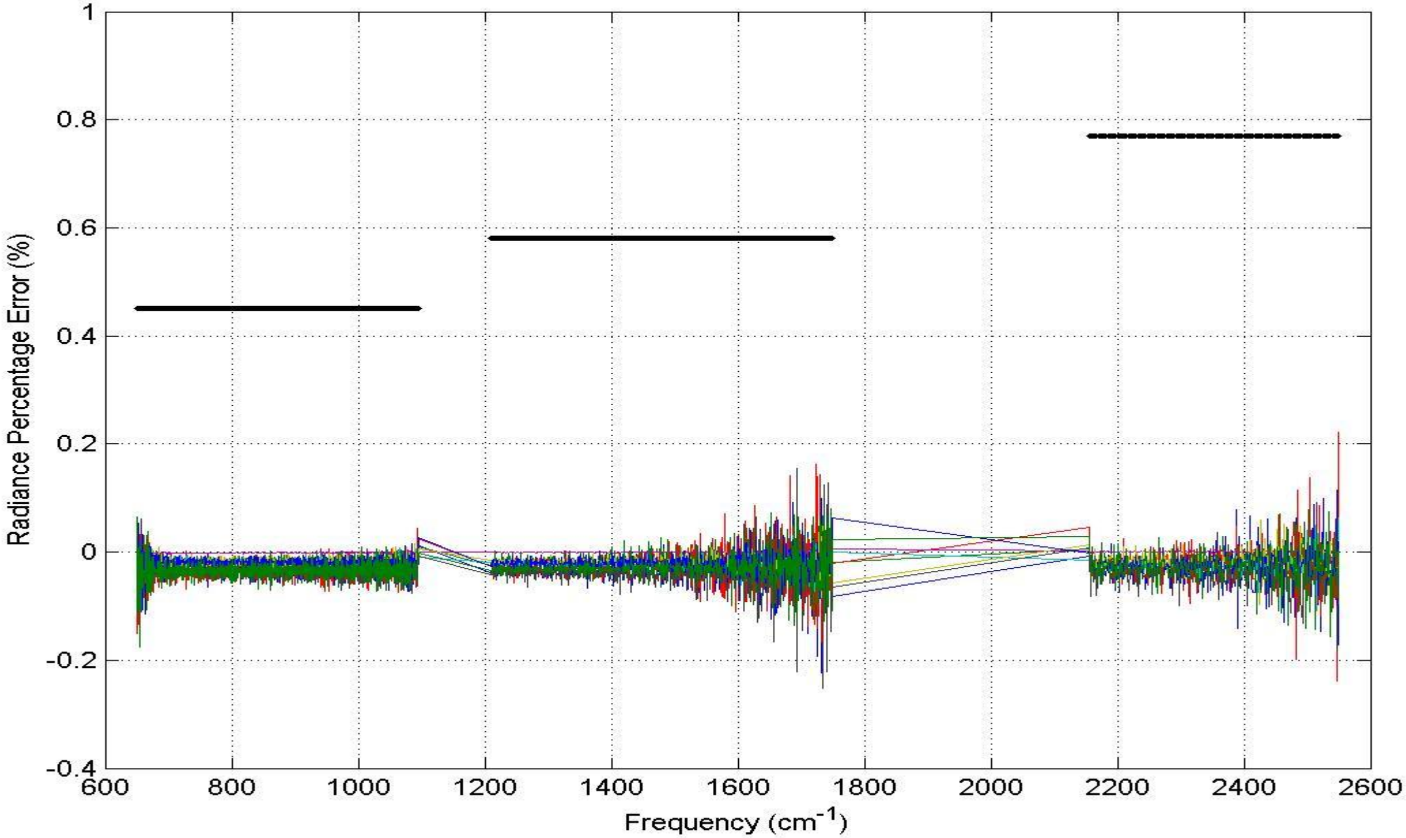
The observed radiance errors in TVAC data are consistent with the predicted algorithm errors due to dropping the F_{INT} term in the calibration equation



Improved Radiometric Calibration After SDR Algorithm Update

- Small residual errors suspected to be caused by SA correction matrix not properly normalized

Difference between new baseline results and "ILS-Off" results ("Truth")



Next Steps

- Continue to Support S-NPP CrIS SDR Cal/Val
- Support J-1 SDR algorithm development
- Support to CrIS sensor TVAC test data analysis
  - Verification of both sensor performance and algorithm performance using TVAC data