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CrIS On-orbit Spectral and Radiometric Performance

CALCON Conference 2012

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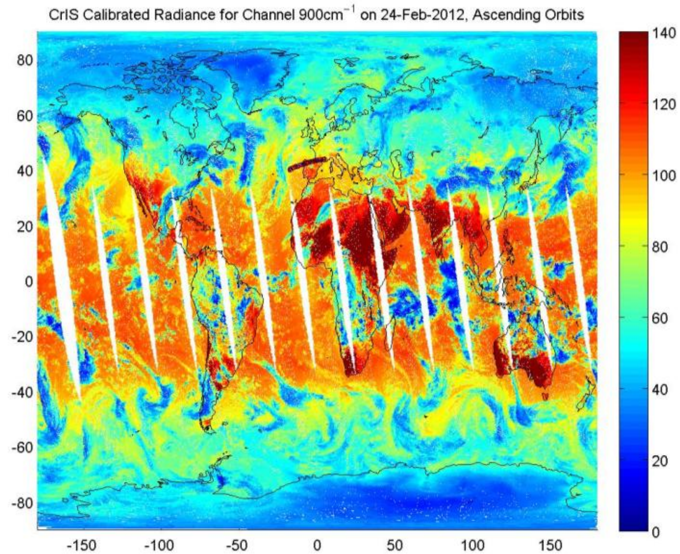
Introduction

- The Cross-track Infrared Sounder (CrIS) operates on the Suomi National Polar-orbiting Partnership (NPP) satellite which launched October 28, 2011
- CrIS ‘First Light’ observations were obtained in January
- Cal-val beta maturity milestone was declared by May
- This presentation provides a summary of the post-launch performance for key instrument parameters



C. Wang, NGAS

Courtesy, Ron Andrews, NGAS

Cross Track Infrared Sounder Sensor Overview

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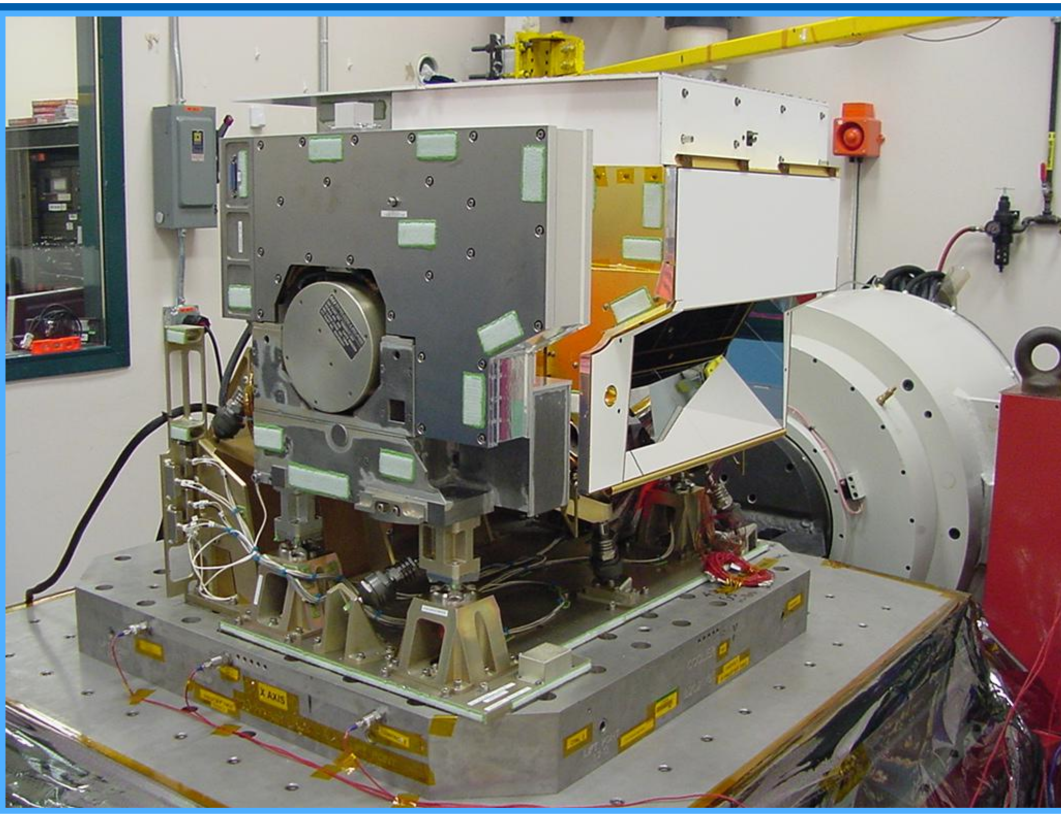


<u>Key Technical Aspects of CrIS:</u>

Fourier Transform Michelson Spectrometer
14 km nadir FOV spatial resolution
Fields of Regard with 3 x 3 FOVs
Photovoltaic Detectors in 3 bands
4-Stage Passive Detector Cooler
2200 km swath width
On-board internal calibration target (ICT)
Supplier: ITT
- Key subcontractors:
  - ABB Bomem: Interferometer, ICT, SDR Algorithm
  - DRS: Detectors
  - AER: EDR Algorithm

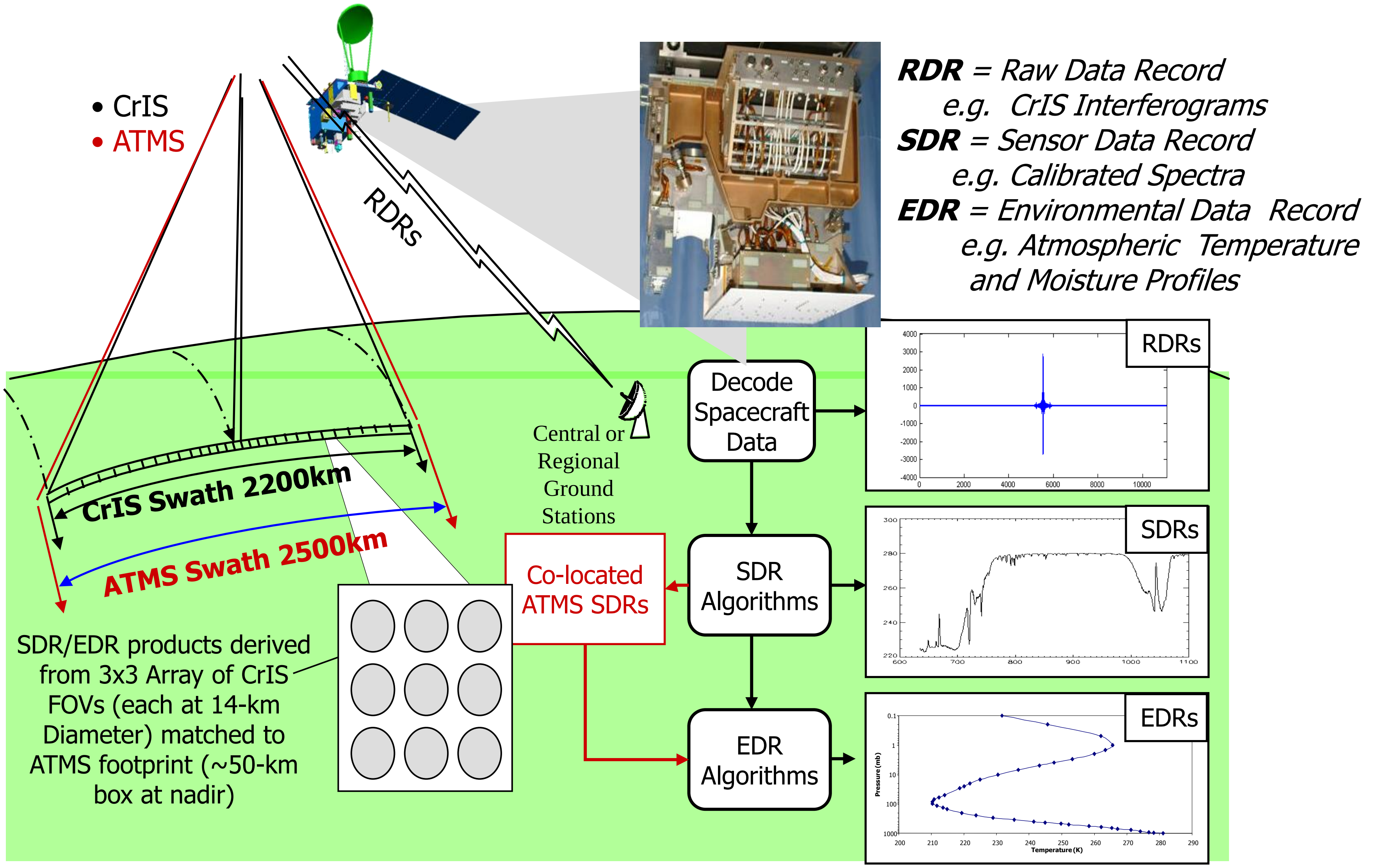
Band	Wavelength Range (cm-1)	(μm)	Sampling (cm-1)	No. Chan.
SWIR	2155-2550	4.64-3.92	2.5	159
MWIR	1210-1750	8.26-5.71	1.25	433
LWIR	650-1095	15.38-9.14	0.625	713

CrIS instrument is a Michelson interferometer infrared sounder covering the spectral range of approximately 3.9 to 15.4 microns.

Performance Requirements

Band	Absolute Radiometric Uncertainty
LWIR	0.45%
MWIR	0.58%
SWIR	0.77%
ILS Shape	Spectral Uncertainty <1.5% of FWHM of ideal on-axis ILS
Spectral Uncertainty	<10 ppm FM1

CrIS and Advanced Technology Microwave Sounder (ATMS) Provide CrIMSS EDR Products



CrIS Pre-launch Performance Requirements

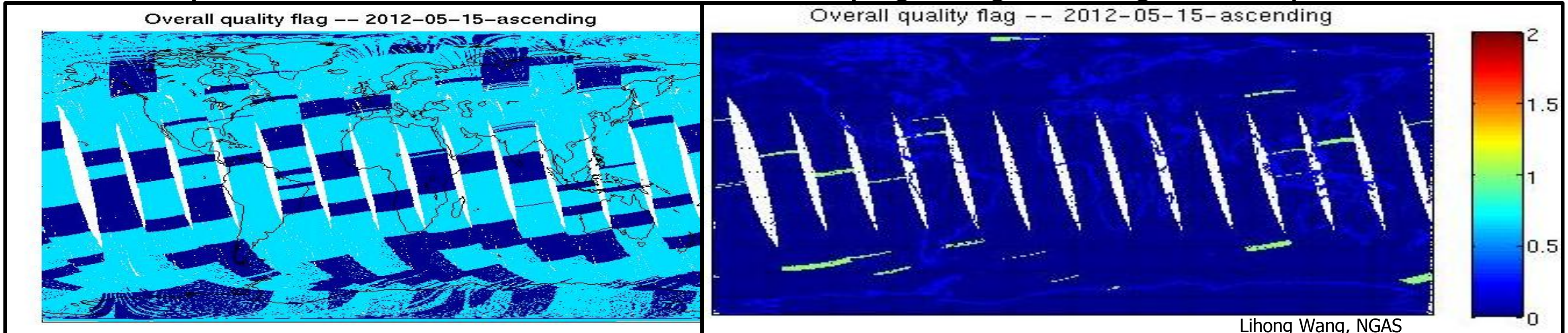
Performance Area	Spec/Figure of Merit
FOV Co-registration	Centroid of the FOV of all channels within a band fall in a circle with a diameter equal to 1.5% of geometric FOV
FOV Shape **Tolerance envelope for nominal altitude at nadir**	70% of Peak Response Width >0.874 FOV diam ± 0.021 Band to Band FOV Shape >0.97FOV diam ± 0.041Band to Band FOV Shape Match 50% of Peak Response Width 10% of Peak Response Width >1.10 FOV diam ± 0.021Band to Band FOV Shape Match 3% of Peak Response Width >1.238 FOV diam
Mapping Uncertainty	3 km, 3 sigma
NEdN @ Nominal BB 287K	<0.12 $mW/m^2/sr/cm^{-1}$ LWIR (excluding <700 cm^{-1} region) <0.05 $mW/m^2/sr/cm^{-1}$ MWIR <0.006 $mW/m^2/sr/cm^{-1}$ SWIR
Radiometric Uncertainty @287 K Blackbody Target	LWIR 0.45% MWIR 0.58% SWIR 0.77%
Short Term Repeatability@287 K Blackbody Target	LWIR 0.16% MWIR 0.17% SWIR 0.20%
Long-term Repeatabiltiy@287 K Blackbody Target	LWIR 0.40% MWIR 0.50% SWIR 0.64%
Spectral Uncertainty	< 10 ppm
ILS Shape Uncertainty	1.5% of the FWHM of the ideal on-axis ILS over the operational life of the sensor
Non-linearity (SDR residual)	<0.11 (LWIR) <0.16 %(MWIR) < 0.21% (SWIR)
Spectral Resolution (on-axis unapodized)	LWIR 0.625 cm^{-1} MWIR 1.25 cm^{-1} LWIR 2.5 cm^{-1}
Measurement Range	Earth scene 180-335 K Black Body 180-310 K

CrIS On-Orbit Performance Highlights

- SDR algorithm performance
  - Quality flag updates and improvements
- Radiometric performance
  - NEdN, non-linearity, sweep direction bias, radiometric accuracy
- Spectral performance
  - FOV to FOV spectral offset and stability
- Geolocation accuracy
  - Determined through comparisons with NPP Visible Infrared Imaging Radiometer Suite (VIIRS)

SDR Algorithm Performance

- CrIS SDR operational code provides Level 1B radiances that are radiometrically and spectrally calibrated, with quality indicators
- Several thresholds for quality flags in current version of operational code (Mx6.2) require tuning and falsely indicate degraded and invalid data
- Most of the flag issues are remedied in the next version Mx6.3 (October 2012 release); this involved about 200 LOC CrIS SDR source code changes and two updated instrument calibration LUTS (e.g. Engineering Packet)



Current SDR Code Version Mx6.2

Upcoming Version Mx6.3

Distribution of overall quality flag for CrIS Golden Day May 15, 2012

Overall quality definition:
2 – invalid
1 – degraded
0 -- valid

Radiometric Performance Summary

- Instrument working well within sensor requirements
  - Small outages in non-linearity and NEdN for MWIR FOV 7 as expected, based on pre-launch TVAC4 performance
  - Small non-linearity outage for LWIR FOV 9, as expected
- Identified presence of small radiometric bias in interferometer sweep direction, mostly detectable at LWIR opaque wavelengths
  - CrIS onboard digital filter was adjusted on April 18 which reduced these effects. Some residual effects still detected.
- Comparisons of CrIS clear sky radiance with Optimum Spectral Sampling (OSS) forward model calculations based on European Center for Medium-Range Weather Forecasts (ECMWF) show small differences in the window channels

CrIS NEdN Performance Is Excellent For All Bands and All Nine FOVs

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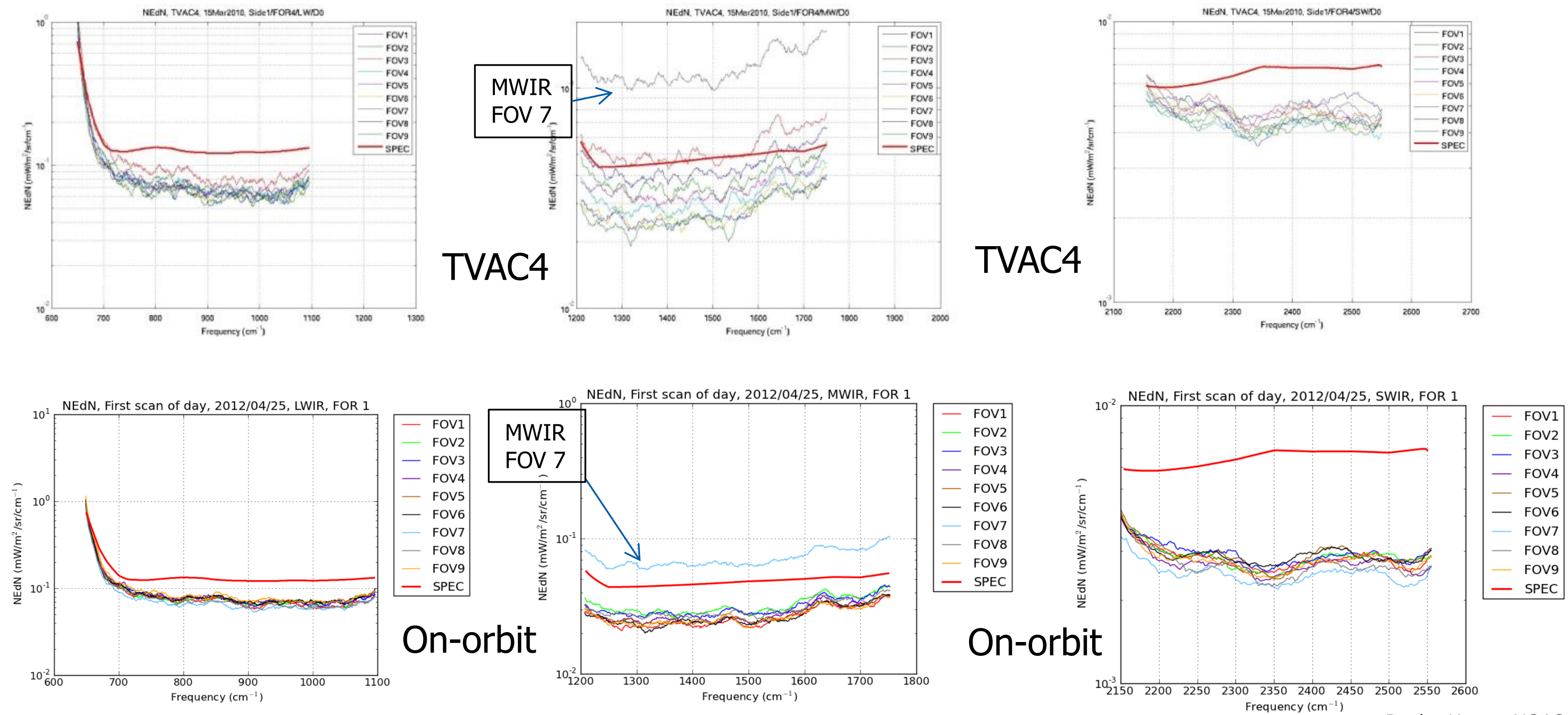

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On-orbit NEdN performance similar to pre-launch, with MWIR FOV7 NEdN slightly out of family

Instrument Nonlinearity Verified On-Orbit

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$$S_{linear} = (1+2\ a_2 V_{DC})\ S_{measured}$$

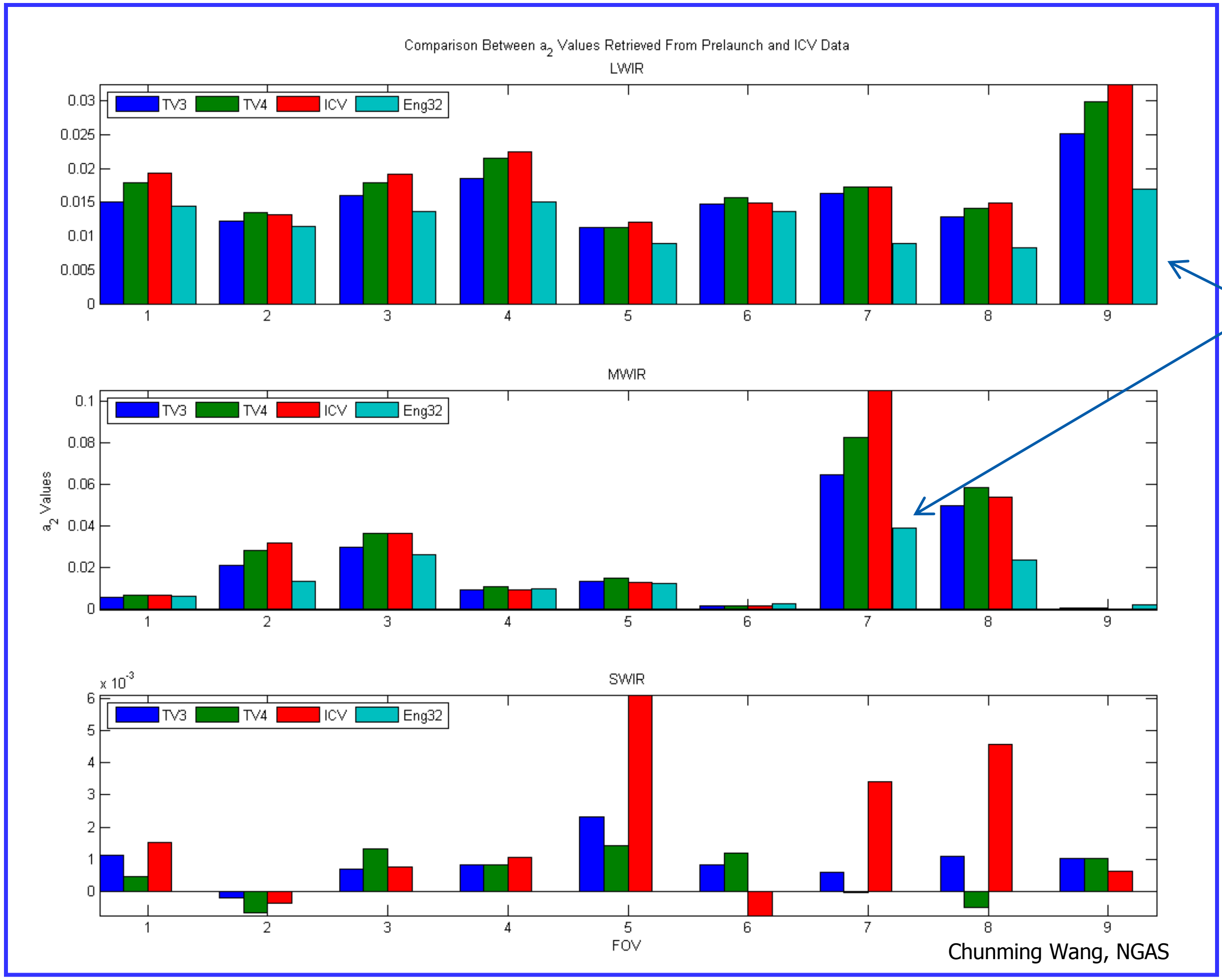
where $S_{measured}$ is the non-linear complex spectrum, a_2 is the quadratic nonlinearity coefficient and V_{DC} is the DC level

- a_2 nonlinearity correction coefficients retrieved from CrIS diagnostic interferograms collected on February 8-9, 2012
- Quadratic a_2 coefficients retrieved from out-of-band harmonic analysis consistent with TVAC3 and TVAC4 values derived empirically using in-band known external blackbody target
  - LWIR FOV9 and MWIR FOV7 changed slightly
  - SWIR FOVs remain mostly linear
- Minor corrections for LWIR FOV9 and MWIR FOV7 coefficients were made on orbit

Detector Nonlinearity Response Before Launch Compares Well with Nonlinearity Determined On-Orbit

Bars show values of a_2 nonlinearity coefficients determined during TVAC3, TVAC4, the at launch values (Eng32) and the values determined by this study (ICV) for each of the nine detectors and each wavelength band. Study confirms stability of detector response before and after launch.

Eng32 is the launch ready table used to populate calibration parameters



LWIR FOV9 a_2 and MWIR FOV7 a_2 coefficients have been subsequently adjusted to match red bar ICV values

Small Bias Present that Corresponds to Interferometer Sweep Direction

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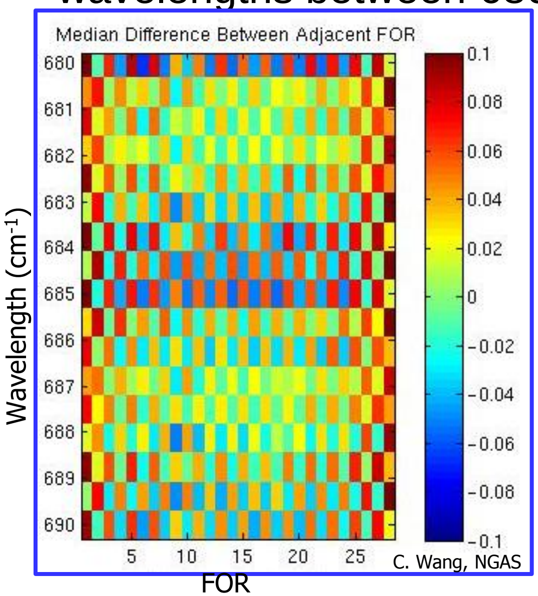
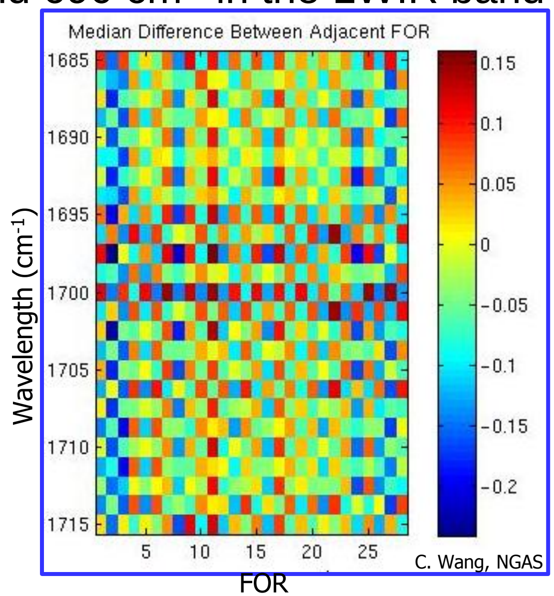
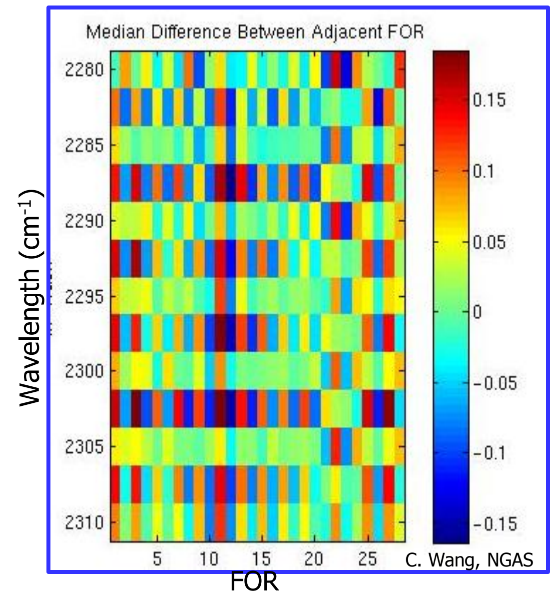
- From one FOR to the next, the sweep direction of the interferogram reverses direction
- Each graph shows the median value of difference in scene brightness temperature between adjacent FORs for each spectral channel corresponding to FOV1, for data averaged over 11 hours on May 15, 2012
- Although the onboard digital filter coefficients were updated April 18 to help reduce sweep direction bias, some residuals remain (striping pattern), that are most apparent at opaque wavelengths between 680 and 690 cm^{-1} in the LWIR band



LWIR



MWIR

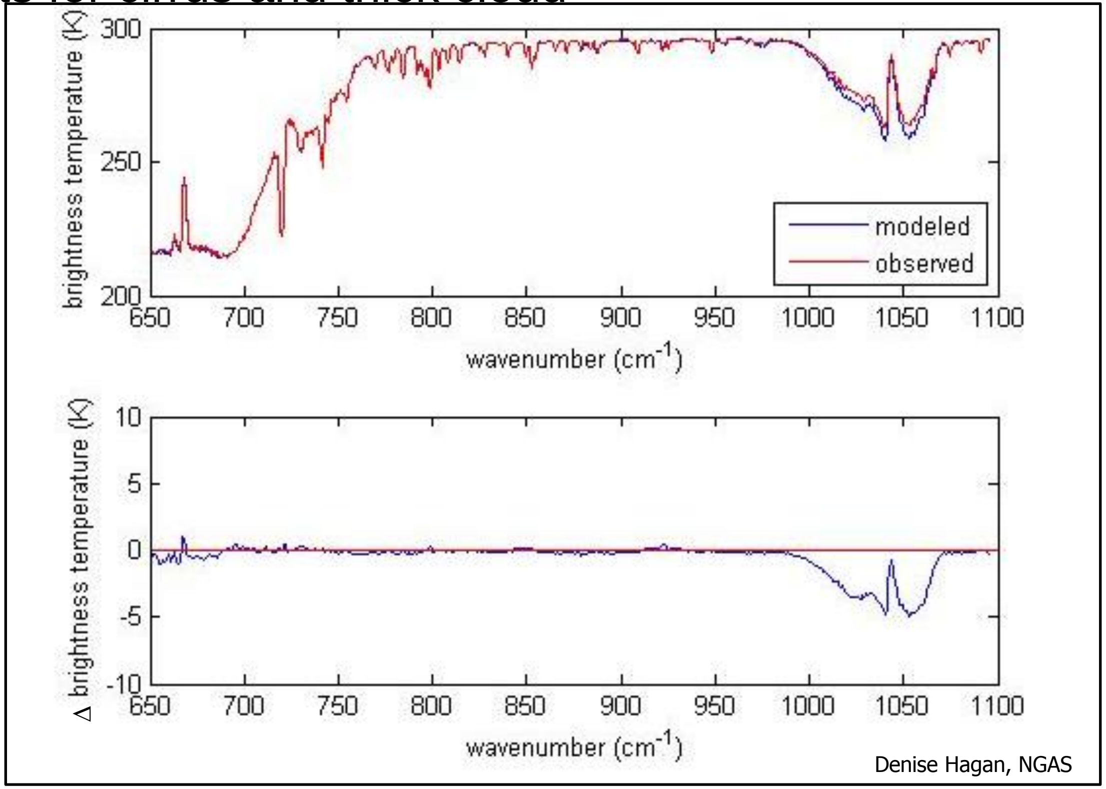


SWIR

Small Differences between CrIS Clear Sky TOA Radiance and Forward Model Calculations

- OSS forward model calculations (derived from ECMWF profiles) are compared with CrIS top-of-atmosphere (TOA) radiances, in clear sky conditions for Golden Day May 15, 2012 – focus on LWIR

- Clear sky determined from scene homogeneity criteria and empirical threshold tests for cirrus and thick cloud

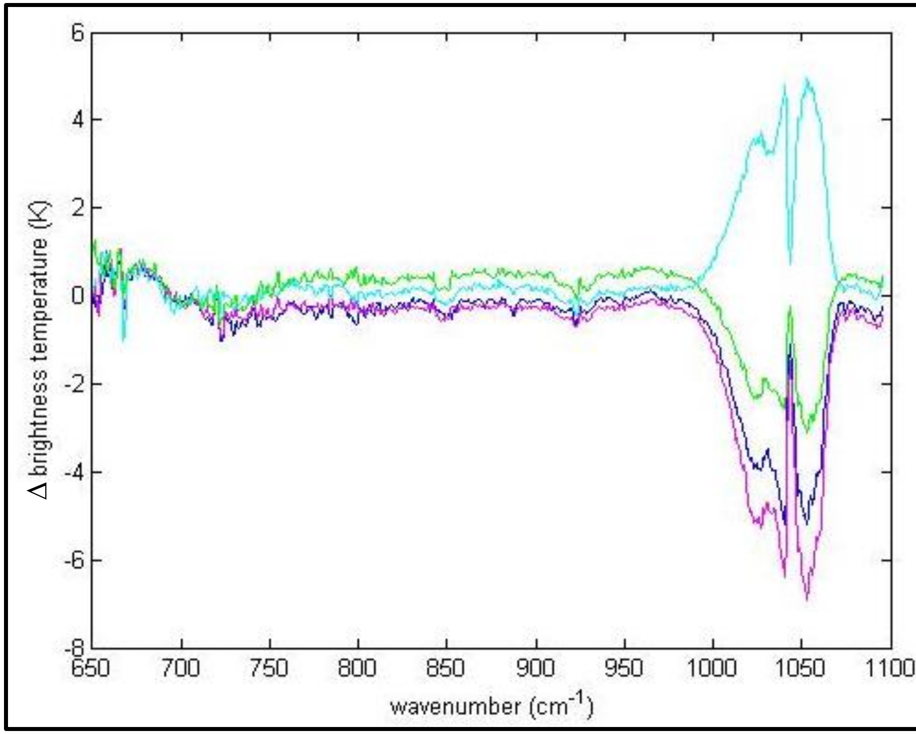


Upper Panel: overlay of modeled and observed spectrum using Blackman-Harris apodization
Lower Panel: difference between modeled and observed

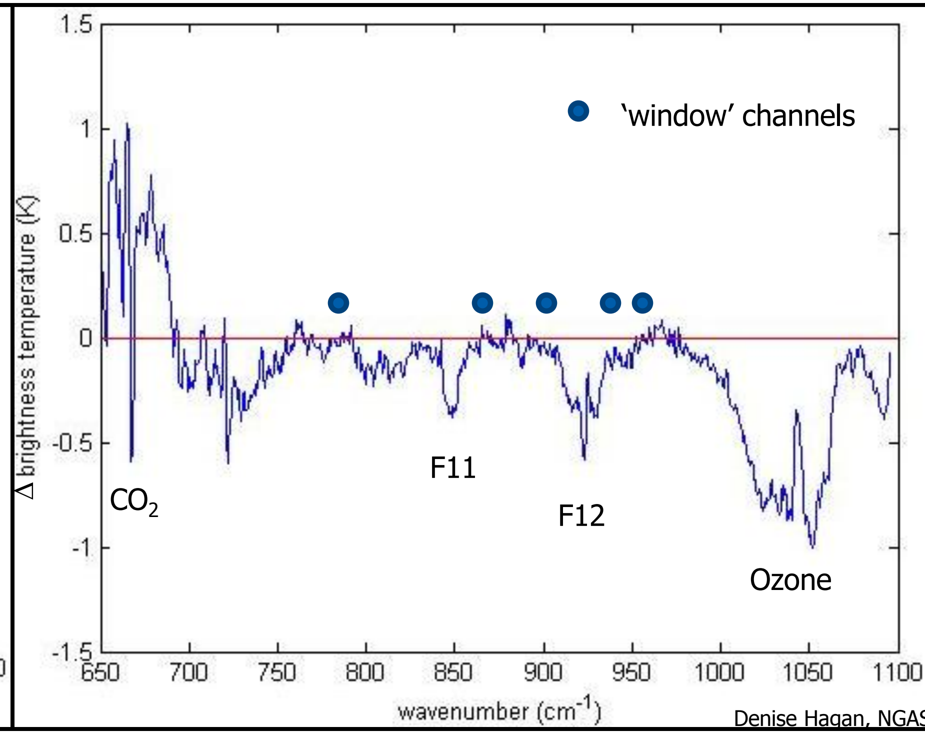
CrIS Window Channel Radiances in Close Agreement with Forward Model Calculations

Residuals of observed minus modeled ensemble average clearly show trace gas absorption features such as F11 and F12, and resolve characteristic markers of these gases with precision of 0.02 K (CrIMSS OSS model includes absorbing species for H_2O, CO_2, N_2O, O_3, CO, CH_4, with only the variations in the vertical profiles of H_20 and O_3 accounted for).

In atmospheric 'window' channels, differences between the observed and modeled spectra within 0.1 K.



Overlay of observed minus modeled spectra for clear sky conditions

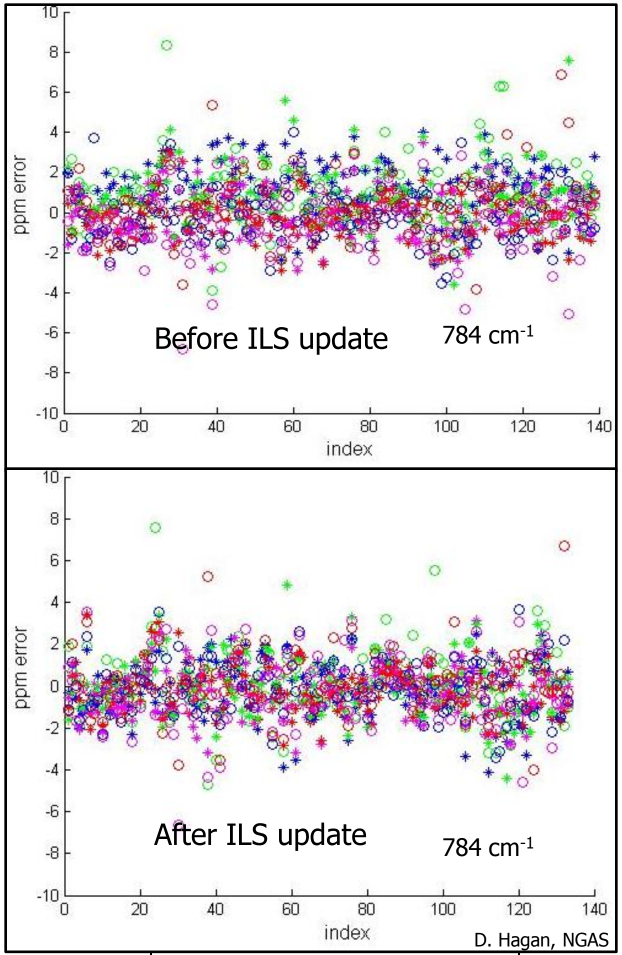


Observed minus modeled for ensemble average

Spectral Performance Determined from Atmospheric Spectral Line Fits

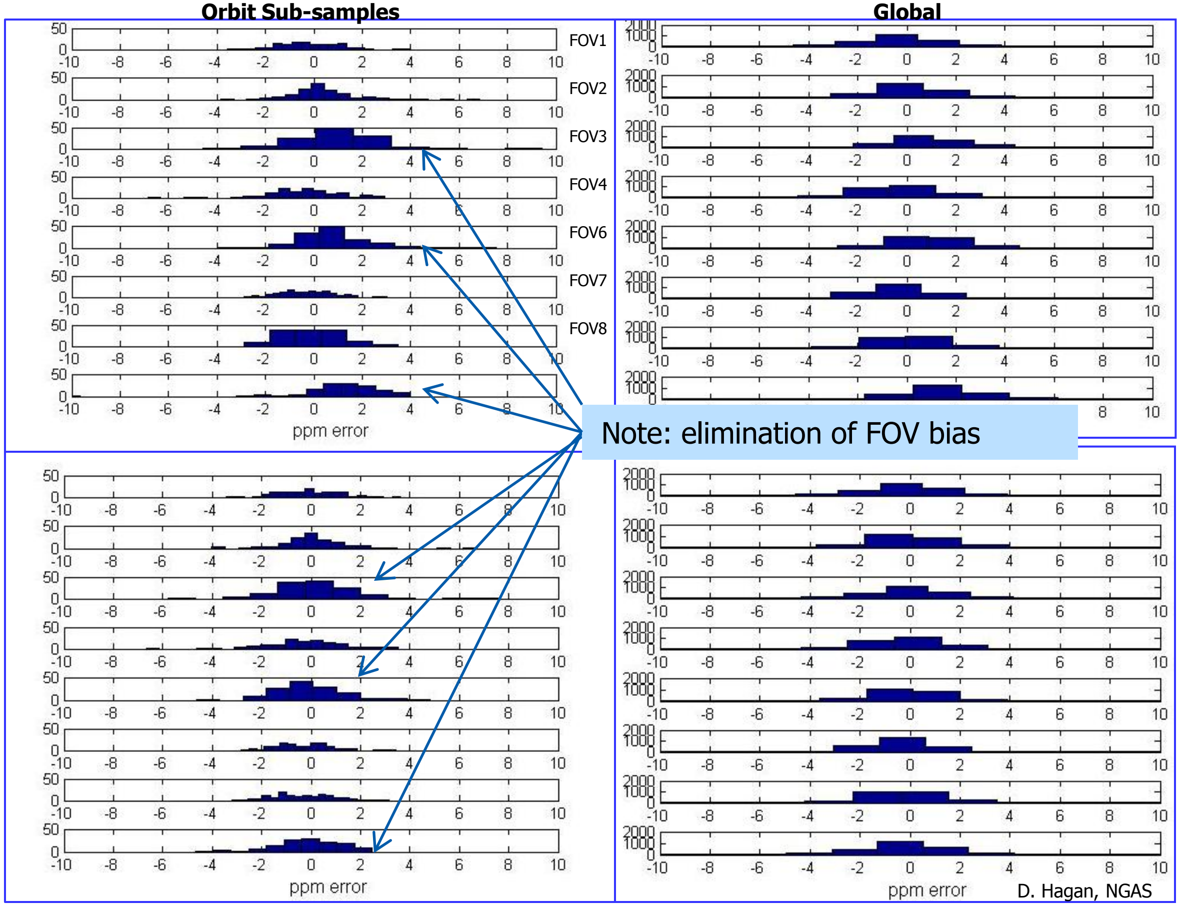
- Use atmospheric spectral lines to assess relative spectral shift between CrIS FOVs
- Calculate ppm offset between side and corner FOVs relative to center FOV
  - Identify clear scenes; perform sinc interpolation for specific line features for each FOV in LWIR; estimate line centers; estimate relative spectral calibration by differencing from center FOV5
  - Initial focus on 784 cm^{-1} and 814 cm^{-1} water vapor lines
- Initial studies detected bias shifts for FOVs 3, 6, 9 relative to center FOV5
- Instrument line shape (ILS) parameters were adjusted in CrIS EngPkt 33 calibration table
- Subsequent studies show elimination of bias offset and 2 ppm peak-to-peak variability
- Statistics of spectral shift appear relatively stable from day to day, with small variation related to orbit position (thought to be tied to S:N in reference water lines and hence artifact of methodology)

Small Spectral Errors Identified On-Orbit and Corrected



FOV Number to Color:
1 2 3 blue red green (circles)
4 6 magenta (circle) green (cross)
7 8 9 red magenta blue (crosses)

Before ILS updates (at launch parameters EngPkt 32)



After ILS updates (on-orbit revised parameters EngPkt 33)

No Significant Spectral Error Detected Between Measurements and OSS Forward Model

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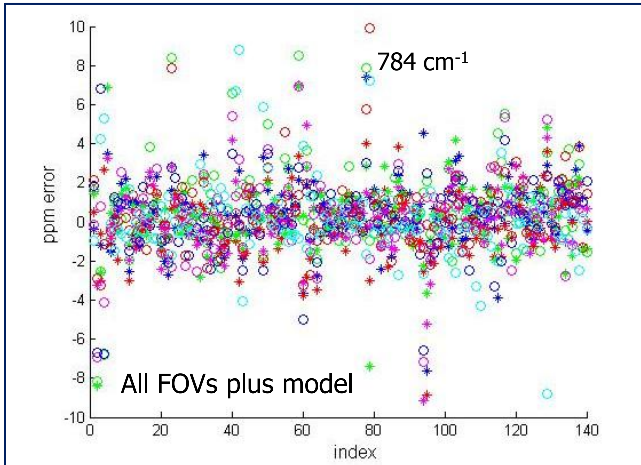
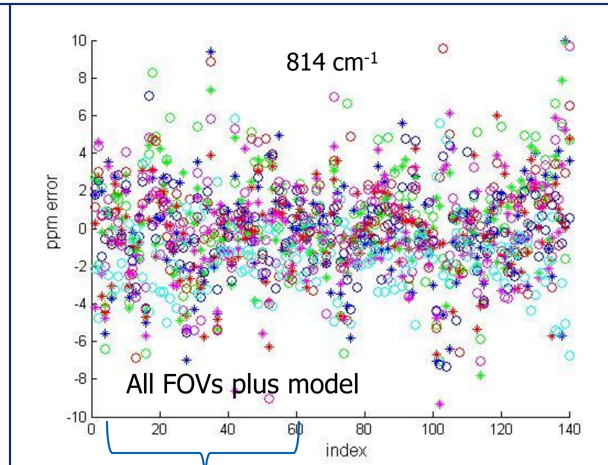
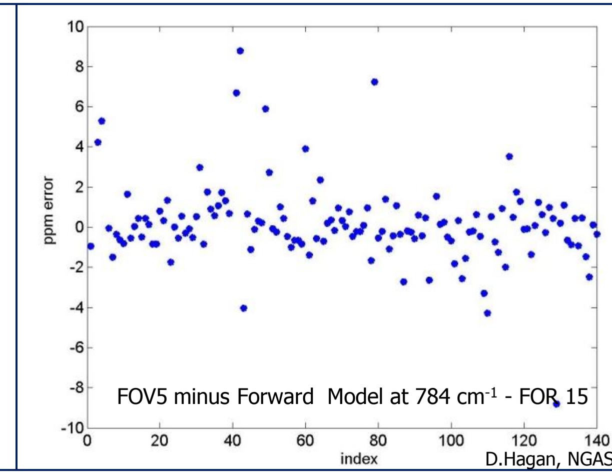




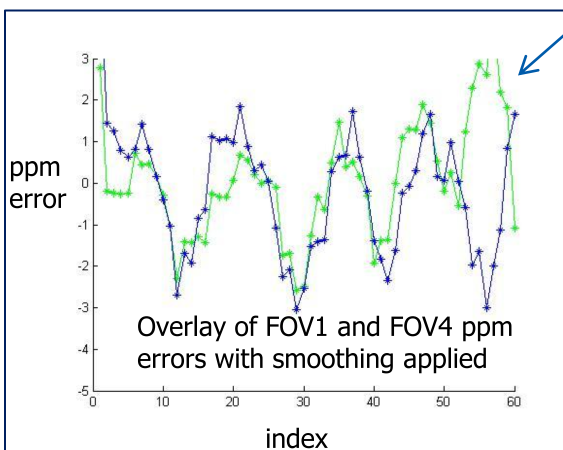


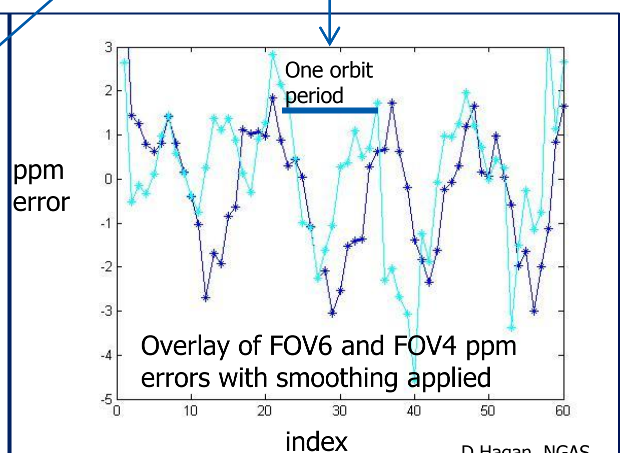
FOV Number to Color:
1 2 3 blue red green (circles)
4 5 6 magenta (circle) cyano (circle) green (cross)
7 8 9 red magenta blue (crosses)

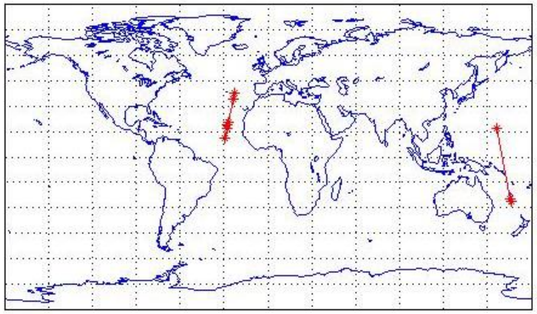
cyan: FOV5 minus OSS forward model

Observe more dispersion and slight bias at 814 cm^{-1}, related to orbital S/N sensitivity for this water line

CrIS center FOV5 and OSS forward model radiances do not show significant spectral shift







Data samples contributing to periodicity in ppm error for orbit 2 (ascending and descending nodes)

CrIS Geolocation Accuracy Determined from VIIRS

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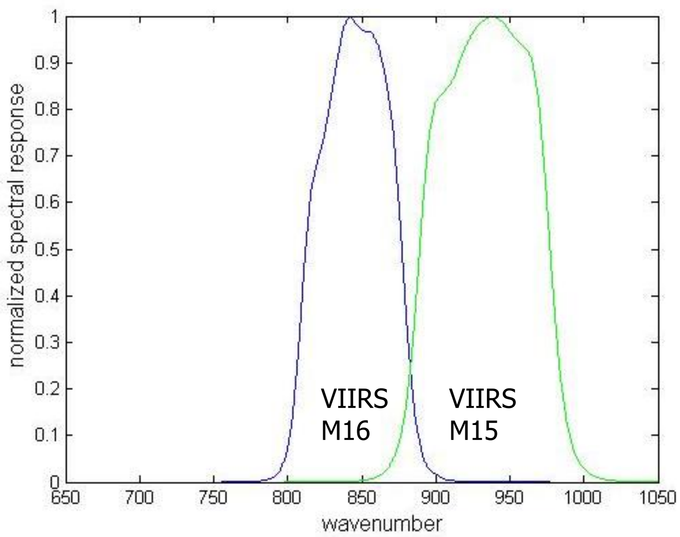
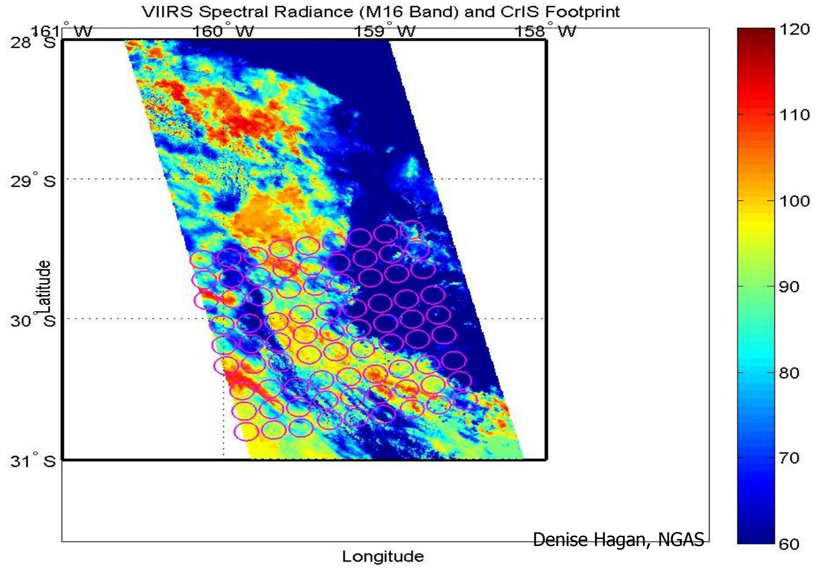
- VIIRS geolocation accuracy verified to within very small values (-21 m bias, 80 m rmse, R. Wolfe)
- Performed cross correlation between co-located CrIS and VIIRS (CrIS radiance convolved to match VIIRS spectral bandpass; VIIRS M-band pixels convolved to match CrIS footprint) to find minimum in radiance difference in least squares sense
- Shift VIIRS pixel across track and along track in region near center of CrIS geolocation
- Technique identified error in CrIS geolocation
- NOAA STAR found error in SDR operational code and correction was implemented





Comparison of normalized residuals of CrIS/VIIRS convolved radiances (May 15, 2012 Golden Day)

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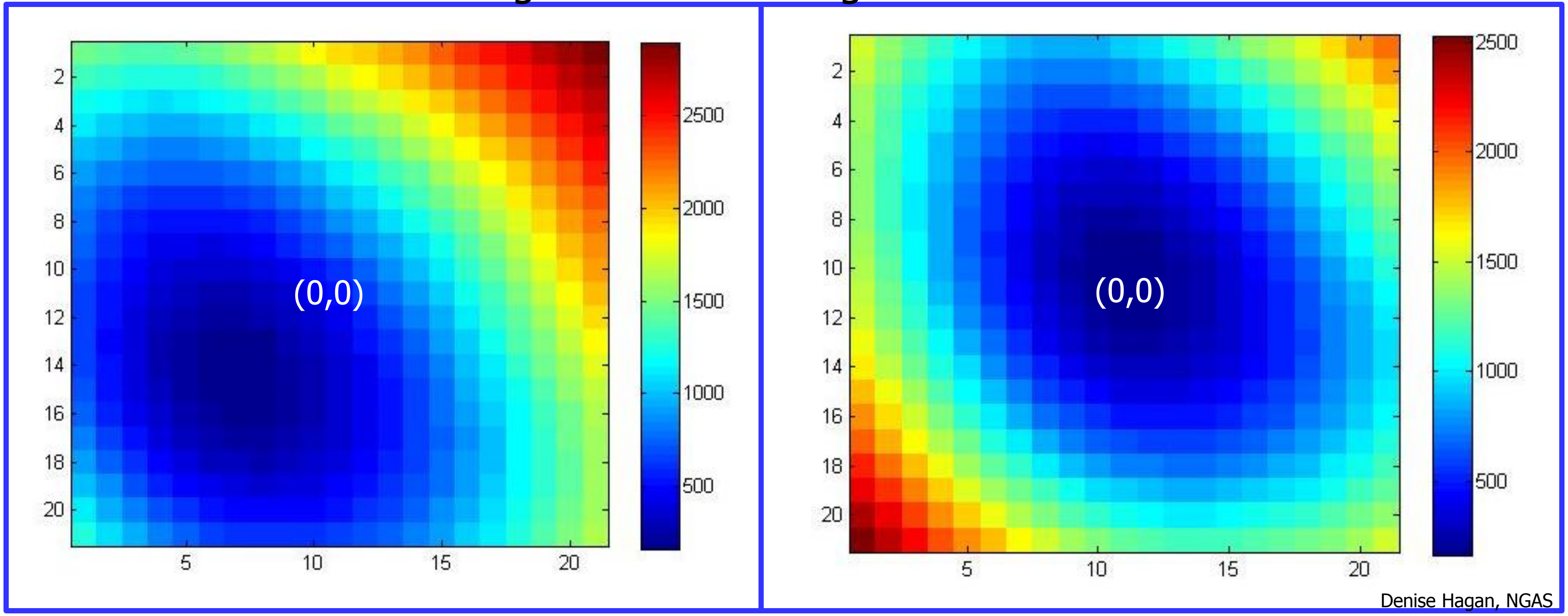
2D correlation arrays showing regions of minimum in radiance residuals centered on VIIRS region around CrIS geolocation center



Current operational data before correction: Required VIIRS pixel shift (to achieve minimum in correlation) is -4 cross track and 3 along track (e.g. equivalent to geolocation errors of about 3 and 2 km, respectively).

Data after SDR code correction: Pixel shift is zero cross track and -1 along track (e.g. nominally an error equivalent to about 750 m at nadir).

Version Mx6.3 of CrIS SDR operational code will no longer exhibit systematic geolocation offset (available October, 2012)

Summary

- CrIS is meeting and exceeding pre-launch performance requirements
  - NEdN (noise, precision) are very low; the MWIR FOV 7 detector performs as expected based on pre-launch calibration
  - Non-linearity response behaves as expected based on pre-launch calibration; minor tuning required on-orbit
  - Radiometric calibration is excellent and meeting requirements
  - Spectral accuracy well within the 10 ppm requirement (closer to 2 ppm!)
  - Geolocation accurate within VIIRS pixel size at nadir

- CrIS on-orbit performance results demonstrate importance of
  - comprehensive instrument ground-based calibration and testing
  - end-to-end algorithm testing, to enable rapid transition to operations

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