Pre-Flight CrIS SDR Algorithm Performance Assessment

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Introduction:

The Cross-track Infrared Sounder (CrIS) is one of the primary sensors now under development for the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program, which is the follow-on to the current DMSP and POES meteorological satellite system. CrIS is an interferometric sounding sensor measuring upwelling earth radiances, and these data are used to reconstruct vertical profiles of atmospheric temperature, moisture, and pressure. The CrIS mission is to collect upwelling infrared spectra at very high spectral resolution and with excellent radiometric precision. The Utah State University/Space Dynamics Laboratory (SDL) team is conducting an independent study as part of the Internal Government Study (IGS) team to ensure that CrIS Sensor Data Record (SDR) science and operational algorithms provide accurately calibrated radiances as an independent sounding product and as an input to the three Cross-track Infrared Microwave Sounder Suite (CrIMSS) Environmental Data Records (EDRs). The team has developed a systematic approach to test many aspects of the CrIS SDR algorithms.

- Algorithm-specific tests are designed to check the algorithm performance on the Government Resource for Algorithm Verification, Independent Test, and Evaluation (GRAVITE) environment.
- Synthetic data are used to isolate and access the impact of different controllable sources of errors on the accuracy of the SDR.
- Proxy data are used to provide an increased confidence in the algorithm performance on semi-real-world data.
- Independent CrIS instrument model developed at SDL is used to generate the CrIS-like interferograms (RDR product)
- EDU3 and FM1 test data are used to verify the ability of the SDR algorithms to correct artifacts and imperfections induced by the instrument under different test conditions.
- The Principal Component Analysis (PCA) tools developed at SDL are used to identify PC signature and instrument artifacts/features in spectral domain.

CrIS SDR Science Algorithm Development History

MATLAB Version:

Algorithm developed by ABB Bomem Inc. under subcontract to ITT

The algorithm was tested and verified by Bomem prior to final delivery in October 2003

C++ Version:

ITT reimplemented portions of the algorithm in C++ as an integral part of the System Level testing

NGST/Raytheon team funded ITT to complete the C++ implementation to add additional functionality and to update documentation including ATBD/OAD/Test Plan

C++ version of CrIs SDR Science algorithm 2.1 delivered to NGST/IDPS as a basis for science-grade to operational grade code migration on 08/17/2004. Algorithm was tested at ITT during Wicket-1 test only, no science performance test has been done at ITT. NGST verified the C++ version using ITT test data (the same Wicket -1 test data) and proxy AIRS test data.

The C++ implementation became the baseline CRIS SDR science algorithm

Test data used to test SDR algorithm at NGST and IDPS

Synthetic data:

- Simulated data set provided by ABB Bomem Inc. with science-Matlab version of SDR code. One representative scene from TIGR data set was used to generate various interferograms with sensor effect being added. Bomem RDR generator was used.
- This data set is now used by IDPS team for end-to-end functional and performance testing of operational algorithm

2. Proxy data:

- 6 orbits AIRS data (golden days on 09/06/2002, 01/27/03, and 01/25.03) spectrally mapped to CrIS spectral grid by Joel Susskind are used
- NGST used modified Bomem RDR generator to simulate CrIS interferograms with instrument effects added
- This data set was also supplied to the IDPS team with science C++ SDR algorithm

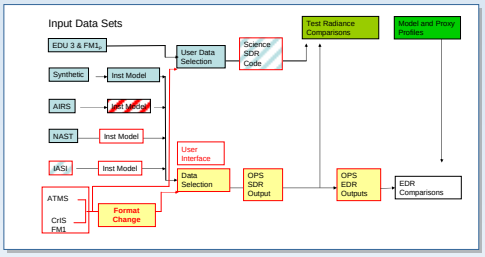
Motivation

- SDR algorithm was tested on limited data sets
- Limited number of sensor effect has been added using Bomem RDR generator for both synthetic and AIRS proxy data sets
- Estimation of SDR algorithms performance is needed on the extended test data with a variety of sensor effects/errors added (errors in spectral calibration, radiometric calibration, and sensor effect correction):

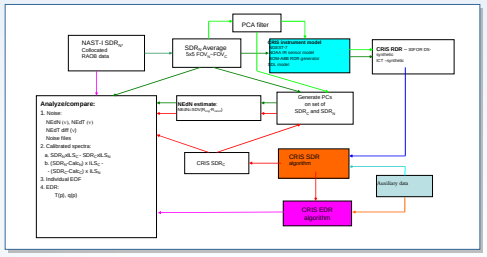
Suggested approach:

- Prepare NAST-I and IASI observations and correlated synthetic spectra data sets as candidate for CrIS proxy data generation
- Use NGEST -7 ITT instrument simulator or independent instrument model developed at SDL to simulate CrIS interferograms with CrIS sensor specific artifacts/errors added
- Develop techniques and expertise to diagnose and analyze CrIS sensor artifacts/errors. PCA analysis of input and CrIS produced radiance spectra is a powerful tool for CrIS SDR noise and artifacts analysis.
- Gain experience in studying individual PCs and individual spectra to characterize instrument-specific artifacts
- Investigate the possibility to apply PCA analysis approach to CrIS EDU and FM test data

GRAVITE-CrIMSS Models and Test Data Sets



CRIS SDR-algorithm test on NAST-I, IASI proxy data



NAST-I data sets:

Several NAST-I data sets are prepared:

1. Synthetic NAST-I radiances (set #1):
   - Collected set of 723 radio-sonde and drop-sonde profiles from February through March 2003 (day and night) around Hawaii
   - Generate noise-free NAST-I radiances using NAST fast OSS RT forward model
   - Add random noise that is Gaussian distributed with SDV derived from real NEdN file

NAST-I observations during THORPEX mission on February-March 2003 ER-2 high altitude aircraft (H~ 20km) on March 03 off the coast of Hawaii:

2. Data set #2 including FOVs of whole flight with all observation angles (7982 FOVs with 16% of cloudy pixels)
3. Data set #3 including only 5 closest to nadir FOVs along the straight portions of the flight (2115 FOVs with 28% of cloudy pixels)
4. Data set #4 including cloud free 5 closest to the nadir pixels (1325 FOVs)

SDL CrIS Instrument Model

Major instrument effects are simulated including:

- Spectral transmittance/reflectance of all major components/subsystems

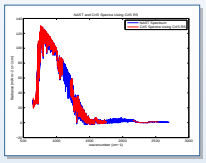
Instrument background flux

- Proper OPD sampling interval and proper number of pre-filtered interferograms samples
- In-phase and out-of-phase interferograms
- Instrument line shape (unique for each FOV)
- Major noise sources (photon noise, detector shot noise, preamp noise)
- Detector dark current
- Detector spectral quantum efficiency
- Electrical signal processing chain including detector preamplifier, analog filter, analog-to-digital converter, complex digital filter and decimation using actual filter coefficients

SDL CrIS Model results have been compared with NGEST (developed by ITT) to verify first order accuracy

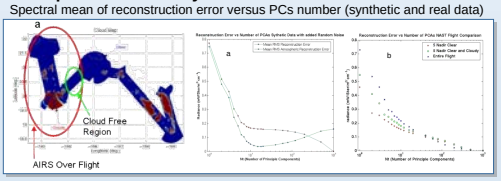
Example results from the SDL CrIS Instrument Model

- A NAST-I spectrum (shown in blue) was used as input to the SDL CrIS Instrument Model
- The model results were formatted as CrIS RDRs
- The modeled RDRs were run through the ABB Bomem Science Code 3.0.0 to produce CrIS SDRs (shown in red)



Examples of PCA analysis of NAST-I data:

Spectral mean of reconstruction error versus PCs number (synthetic and real data)

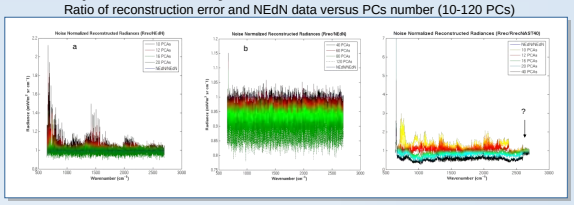


1. **Synthetic data set**. Blue dots- reconstructed error with respect to the true atmospheric spectra (noiseless). Minima corresponds to the optimal PCs number for reconstruction.

2. **Real NAST-I observations**: Set #2- entire flight, #3 – nadir only, and #4 – nadir, clear. There is no truth atmospheric data. Optimal number of PC may be estimated according to Antonelli et al. (minimal slope of this dependences).

Examples of PCA analysis of NAST-I data:

Ratio of reconstruction error and NEdN data versus PCs number (10-120 PCs)

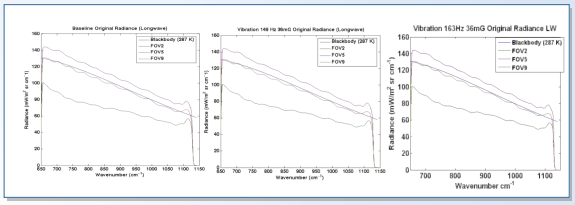


Difference with synthetic data:
Reconstruction errors continue decrease fast with increase in PCs number
Reconstruction errors exhibits slight spectral dependence
At the edge of SW band unexpected jump is observed

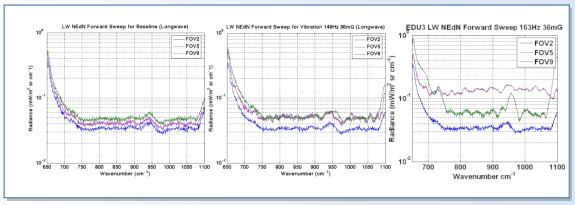
CrIS EDU3 Dynamic Interaction test data:

Validation of PCA tool for estimation of spectrally correlated noise contribution

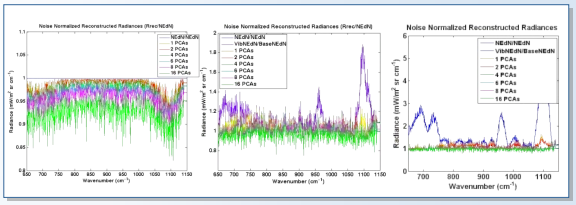
LW spectrum: Baseline, 149Hz, and 163Hz Earth view for FOVs 2, 5, and 9



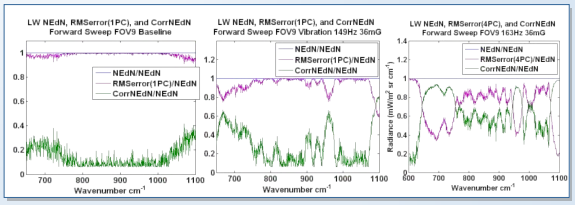
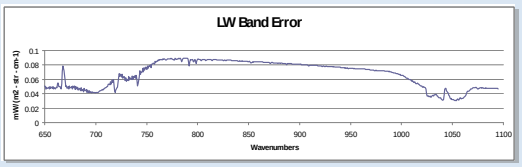
LW NEdN: Baseline, 149Hz, and 163Hz Earth view of FOVs 2, 5, and 9



LW PCA reconstructed noise normalized by baseline NEdN for FOV9: baseline, 149Hz, and 163Hz 36mG



LW random and correlated noise for FOV: baseline, 149Hz, and 163Hz 36mG NEdN,



LW spectral errors due to ICT error of 0.08K