# Cross-Track Infrared Sounder Pre-launch Calibration Activities and On-Orbit Validation Plans

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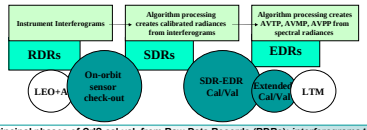
**Introduction:** The Cross-Track Infrared Sounder (CrIS) together with the Advanced Technology Microwave Sounder (ATMS) will provide retrievals of atmospheric moisture and temperature profiles for the National Polar-orbiting Operational Environmental Satellite System (NPOESS). NASA is providing the ATMS that has been tested, characterized and delivered to the spacecraft. The ATMS Provides A/B Advanced Microwave Sounder Unit and Microwave Humidity Sounder capability with 22 microwave sounding channels. On orbit the ATMS provides an atmospheric sounding that is also used to initiate the profile retrieval by the CrIS.

Thermal vacuum (TVAC) tests of the CrIS FM1 sensor are scheduled to complete in March of this year with delivery to the spacecraft shortly thereafter. This paper provides a synopsis of plans for on-orbit verification of sensor characteristics for the CrIS instrument and validation of the atmospheric sounding products.




Principal phases of CrIS cal-val, from Raw Data Records (RDRs): *interferograms* to Sensor Data Records (SDRs): *spectral radiances* to Environmental Data Records (EDRs): *atmospheric profiles*. The green cells are addressed in this paper.

**Key Elements of CrIS Cal-Val:**

**Pre-launch instrument characterization and On-orbit sensor verification**

**SDR Earth scene validation**
- Geolocation/Spatial
- Spectral
- Radiometric

**EDR product validation**
- Atmospheric Vertical Temperature Profile
- Atmospheric Vertical Moisture Profile

**CrIS Sensor Overview:** The CrIS is a Michelson interferometer covering the spectral range of 3.9 to 15.4 µm (650 to 2550 $cm^{-1}$). CrIS provides cross-track measurements of top-of-atmosphere (TOA) radiances to permit the calculation of vertical profiles of temperature and moisture in the Earth's atmosphere. There are three bands in the CrIS spectral range each having different spectral resolutions: long-, mid-, and short-wave (denoted as LWIR, MWIR, and SWIR, respectively).

Key Technical Aspects of CrIS:
- Fourier Transform Spectrometer
- 14 km nadir FOV spatial resolution
- Fields of Regard with 3 x 3 FOVs
- Photovoltaic Detectors in 3 bands (see table below)
- 4-Stage Passive Detector Cooler
- 2200 km swath width
- On-board internal calibration target (ICT)

**Supplier: ITT Industries**
**Key subcontractors:**
**ABB Bomem**: Interferometer, ICT, SDR Algorithm
**DRS**: Detectors
**AER**: EDR Algorithm

**Performance Requirements**

| Band | Wavelength Range (µm) | | Sampling (cm-1) | No. Chan. |
|---|---|---|---|---|
| SWIR | 2155-2550 | 4.64-3.92 | 2.5 | 399 |
| MWIR | 1210-1750 | 8.26-5.71 | 1.25 | 433 |
| LWIR | 650-1095 | 15.38-9.14 | 0.625 | 713 |

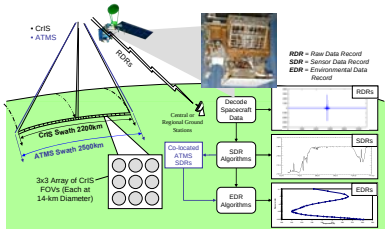
| FOV Shape Requirements: | FOV Diameter (km) | Band-to-band FOV Shape Match (km) |
|---|---|---|
| 70% of Peak Response Width | > 12.7 | +/- 0.4 |
| 90% of Peak Response Width | 14.0 ± 0.2 | +/- 0.2 |
| 10% of Peak Response Width | < 16.0 | +/- 0.3 |
| 1% of Peak Response Width | < 18.0 | N/A |

| Band | Absolute Radiometric Uncertainty |
|---|---|
| LWIR | 0.45% |
| MWIR | 0.58% |
| SWIR | 0.77% |

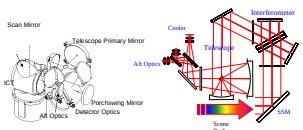
| | |
|---|---|
| ILS Shape | Spectral Uncertainty <1.5% of FWHM of ideal on-axis ILS |
| Spectral Uncertainty | <10 ppm FM1 <5 ppm FM2 |

**Optical Schematics Showing Key Components for Onboard Radiometric Calibration**

The Scene Selection Mirror (SSM) views the internal calibration target (ICT) and deep space during the scan sequence thus providing calibration measurements for each Earth swath scan. The ICT is a wedge-shaped cavity design embedded with two temperature sensors that are traceable to the National Institute of Standards. In addition, a sophisticated radiometric model has been developed to accurately capture contributions of surrounding elements seen by the instrument when viewing the ICT. Spectral calibration is achieved through a wavelength measurement system based on the use of an onboard metrology laser.

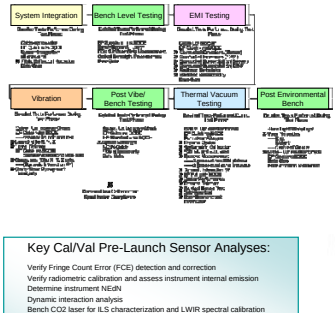



*RDR = Raw Data Record*
*SDR = Sensor Data Record*
*EDR = Environmental Data Record*



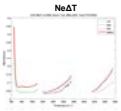

**Prelaunch Instrument Characterization**: CrIS bench and TVAC measurements are essential for characterizing instrument response, assessing sensor performance to specification, validating the SDR production code and development of software methods and tools for on-orbit SDR verification and tuning. Laboratory measurements carried out by ITT are being used to establish the radiometric, spectral and spatial properties of CrIS. Testing has progressed through post-vibe bench testing. The TVAC measurements to be obtained in early 2008 will provide calibration parameters needed for SDR and EDR data processing.

Test Chain That Provides Sensor Characterization; TVAC in Progress



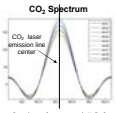

Examples of SDR Radiometric and Spectral Characteristics Important to EDR Retrievals (Preliminary FM1 Bench Test Results)

**NeΔT**



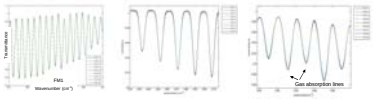
The noise equivalent temperature difference for the LWIR, MWIR and SWIR detectors for FOVS obtained during CrIS bench tests (November 2007).

**$CO_2$ Spectrum**




Overlay of corrected ILS for all 9 CrIS FOVs from tests performed at CO2 laser frequency during CrIS bench tests (November 2007)

**Measured Gas Cell Spectra**



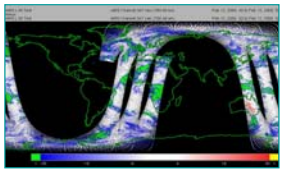

Overlay of 9 FOVs for measured $CO_2$ (LWIR), CH4 (MWIR), HBr (SWIR)

**Key Cal/Val Pre-Launch Sensor Analyses:**
- Verify Fringe Count Error (FCE) detection and correction
- Verify radiometric calibration and assess instrument internal emission
- Determine instrument NEdN
- Dynamic interaction analysis
- Bench CO2 laser for ILS characterization and LWIR spectral calibration
- Slit FOV and Spot FOV (co-registration of FOVs)
- Scan scenario test analysis and long-term radiometric stability
- Linearity (ICT with ECT at various temperature)
- Spectral calibration with gas cell
- Onboard digital filtering verification
- SSM precision and variability (pointing accuracy)
- ICT NIST traceability

The bench ILS tuning process has shown:

(1) FM1 meets FWHM spec allocation
(2) ILS correction results in less than 0.2% peak to peak residual error
(3) Absolute spectral calibration shows excellent match to CO2 laser reference

**CrIS SDR Earth Scene Validation**: The approach for validation of the CrIS spectral radiances follows proven methods for heritage instruments. Techniques and tools have been adapted for CrIS based on EOS AIRS and MetOp IASI Earth scene proxy data.



**AQUA AIRS NCEP GFS model match module [AIRS SDR] minus [AIRS SDR simulated from model defined atmosphere]**

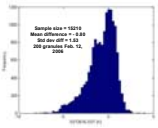
In addition to this cal/val analysis tool, NGST has advanced synthetic modeling capability (Integrated Weather Testbed) that has been applied toward CrIMSS EDR algorithm verification

**CrIS Earth Scene Validation Approach:**

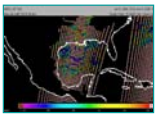
**Radiometric Validation**
- Clear FOV comparisons of spectra with modeled radiances
- Laser and neon lamp stability using atmospheric absorption lines as a reference
- Radiance comparisons with other satellite instruments (AIRS, IASI, VIIRS)
- Radiance comparisons with aircraft underflight FTIR measurements
- Subsetting and trending of window radiances and skin temperature with SST.RTG global data
- Comparisons of cloud-cleared radiances with modeled clear sky radiances
- Subsetting and trending to establish scan angle effects, local and regional bias
- Calibration of ATMS retrievals (essential for quality CC radiance) - Bias correction from co-located raobs or NWP

**Spectral Validation**
- Clear FOV comparisons of spectra with modeled radiances - needed for updating OSS tables to match correct ILS
- Spectral comparisons (cross-calibration) with other satellite instruments (AIRS, IASI, VIIRS)
- Comparisons with aircraft underflight FTIR spectra

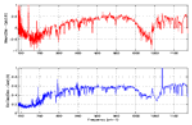
**Geolocation Validation**
- Geolocation performance evaluation and co-registration with ATMS – update ATMS footprint matching coefficients; update local angle adjustment tables
- Coastline crossings using clear FOVs and window channels




Radiometric trending approach: Real time global NCEP SST (RTG.SST) compared to AIRS adjusted window radiance (2616 $cm^{-1}$). A different channel selection will be used for CrIS

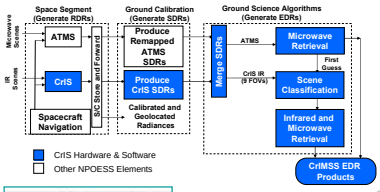


AQUA AIRS clear FOR search module - Utilizes spatial coherence test threshold for clear ocean detection As confidence in VIIRS and CrIS geolocation is gained, VIIRS data can be used to identify clear CrIS FOVs



[AIRS SDR] minus [AIRS SDR simulated from final retrieved atmosphere] for spatial coherency corresponding to clear FORs in Gulf of Mexico scene (red = bias; blue = std)

**CrIMSS EDR Product Validation:** The validation approach for the CrIMSS EDRs follows proven methods for heritage NASA EOS AIRS, NOAA HIRS and AMSU instruments. The forward model in the physical retrieval algorithm based on the Optimal Spectral Sampling technique developed at AER. The forward model computes radiances corresponding to a given atmospheric and geophysical state (temperature, water vapor and ozone profiles, surface properties, cloud properties, etc.), as well as derivatives (Jacobian) of radiances with respect to atmospheric and surface parameters, for use by the inversion module. The forward model must accurately model the CrIS ILS function.




**CrIMSS EDR Validation Approach:**

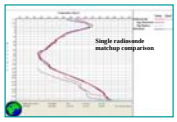
Compare ATMP and AVMP with global raob database

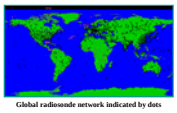
Compare ATMP and AVMP with NWP model data

Compare ATMP and AVMP with other satellite retrieved products

Compare ATMP and AVMP with ARM site data (dedicated radiosonde launches) and other field campaign data (aircraft retrieved profiles, dropsondes, lidar, GPS and other specialized atmospheric measurements)

Compare NCEP SST with skin temperature Intermediate Product



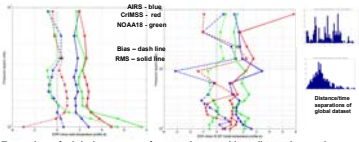



**Global radiosonde network indicated by dots**

**Global Matchup Stats:**

**Radiosonde Match beginning for Satellite: AQUA AIRS**
**BaseDay: 02/12/2006 Julian Day: 43**

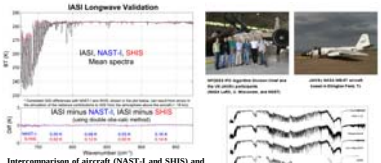
| | |
|---|---|
| Number of reports in the Unified Raob file: | 1861 |
| Number of failed radiosondes: | 276 |
| Number of vertical extent failures: | 149 |
| Number of data gap failures: | 123 |
| Number of superadiabatic failures: | 0 |
| Number of inversion failures: | 87 |
| Number of mixing ratio screening failures: | 254 |
| Number of climatological limit failures: | 4 |
| Number of missing first SigLev failures: | 0 |
| Number of raobs available for matching: | 1585 |




Examples of global averages for match-ups with radiosondes and NCEP GSF model data but without QC; QC work in progress.

Match-ups with the global radiosonde network is the backbone of the CrIMSS EDR validation but standard sondes are not accurate enough for upper atmosphere water vapor validation

Recommend radiosondes be released at well-instrumented ARM sites before and during satellite pass. Other instruments will automatically collect data on surface and atmospheric properties which greatly improve the accuracy of EDR match-ups Advanced sondes can improve validation of upper atmospheric water vapor.




**Intercomparison of aircraft (NAST-I and SHIS) and satellite (IASI) data acquired during Joint Airborne IASI Validation Experiments (JAIVEx.) in May 2007. IASI declared operational following campaign.**

Aircraft campaign underflights provide measurements for both spectral and radiometric validation. Aircraft in situ measurements are valuable for high altitude water vapor validation and sub-visible cirrus detection.

**Summary:**

- **End-to-end plan (from pre-launch instrument characterization to on-orbit validation) in place for CrIMSS Cal/Val**
- **Plan evolved from recommendations by expert team consisting of NASA, NOAA, ITT, AER and Academia who drafted CrIS SDR Task Network**
- **Current focus on CrIS instrument characterization (bench and TVAC data); this activity couples with development of on-orbit sensor verification software tools**
- **SDR/EDR calibration/validation software in development and patterned after methods used for heritage instruments (NASA EOS AIRS/AMSU)**
- **Campaigns and field measurements identified to support mission Cal/Val activities**