Pre-Launch Spectral Calibration of the CrIS Sensor on NPOESS/NPP

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Context of Cross-track Infrared Sensor (CrIS)

- CrIS is a new infrared sounder for the NASA NPP platform and the NPOESS operational system, 1:30 am/pm orbit.
- NASA hopes to "bridge" climate measurements between AIRS on EOS/Aqua and CrIS/NPOESS with CrIS on NPP.
- IASI on EUMETSAT's METOP platform (since April 2007) is CrIS's counterpart in the 9:30 am/pm orbit.
- Instrument specifications driven by operational weather forecasting requirements (as they were for AIRS and IASI).
- However, AIRS performance is "climate-quality", IASI appears to be the same (we need more time).
- This work: Assessment of CrIS spectral performance during thermal vacuum testing (Spring 2008), with an eye towards climate quality.

CrIS Instrument

- Interferometer with 0.8 cm OPD
- Three focal planes, each with a 3x3 array of detectors
  - Longwave (LW) focal plane
    - 650-1095 cm^{-1}
    - OPD = 0.8 cm, $\Delta\nu$ = 0.625 cm^{-1}
  - Midwave (MW) focal plane
    - 1210-1750 cm^{-1}
    - Data collect to 0.4 cm, $\Delta\nu$ = 1.25 cm^{-1}
  - Shortwave (SW) focal plane
    - 2155-2550 cm^{-1}
    - Data collect to 0.2 cm, $\Delta\nu$ = 2.50 cm^{-1}
- Metrology laser wavelength determined using on-board Neon lamp measurements, sample rate of ~90 minutes, hopefully asynchronously relative to orbital period.

NPP Thermal Vacuum (TVAC) spectral allocation requirements are 10 ppm for spectral registration and ~0.6% for Instrument Line Shape (ILS) width. NPOESS spectral calibration requirement is 5 ppm.

Frequency Errors in B(T) Units for CO_2 Forcing

- Forcings/Responses
  - Forcing (CO_2 growth rate of 2 ppm/year) is $\sim$0.06K/year at 2388 cm^{-1}.
  - Temperature signal $\sim$0.01K/year
  - AIRS stability $<$0.01K/year (radiometric and frequency) allows CO_2 trends/variability to $<$0.5 ppm.
- Frequency requirements
  - CrIS: ν stability of $\sim$1 ppm = 0.015K at 2388 cm^{-1}
  - Suggests need $\Delta\nu$ errors on CrIS to 1 ppm (0.5 ppm CO_2)
  - CrIS ILS width should remain stable.

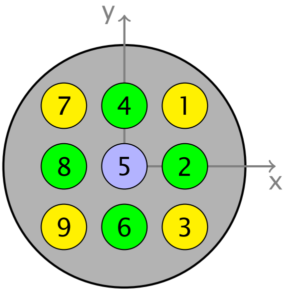
Pre-Flight Spectral Calibration Details

- Detailed ILS Shape
  - Performed on bench (not TVAC) with CO_2 laser, so LW only
  - Highly successful, good test of Sensor Data Record (SDR) software.
- Spectral Calibration and MW/LW ILS Shape (width)
  - Record gas cell spectra for LW (CO_2), MW (CH_4), and SW (HBr): truth for ILS ν and width
  - Collect data at mission nominal temperature (Mn), and PQH/PQL temperatures (relevant to other orbits) that are $\sim \pm$ 28K offset from Mn expected temperature.
  - Data collect includes Neon measurement for each gas
- Bottom line: TVAC spectral calibration was highly successful!

Approach

- Four data collects (plus 2-point radiometric cal measurements if needed)
  1. Hot blackbody (BB): cell full, cell empty; (FT1, ET1)
  2. Cold BB: cell full, cell empty; (FT2, ET2)
  3. Gas cell transmittance $\tau = \frac{FT2-FT1}{ET2-ET1}$
- FT1, etc. are complex count spectra
- Complex part of τ very small
- Each interferogram is converted into an uncalibrated spectrum, averaged, and transformed to on-axis transmittance spectra.
- Our apodization correction matrices are interpolated to the present estimate of the metrology laser λ_{met}.
- The best estimate of λ_{met} minimizes χ^2 between the Obs and Cal τ. (This is a big loop...)
- We allow the observed transmittances to be scaled and offset in this loop. Generally the scale factor is $\sim$ 0.98-0.99 and the offset factor is $\sim$0.01-0.02.

Focal Plane Geometry: CrIS



C Yellow is a “Corner” FOV

S Green is a “Side” FOV

M Blue is the “Middle” FOV

Off-axis FOV spectra are shifted by >500 ppm, etc. UMBC mini-SDR algorithm adjusts these spectra back to effective on-axis measurements. At 1500 cm^{-1}, $\Delta\nu$ of 500 ppm = 6K in B(T).

Frequency errors will be written out using the above layout for FOVs.

Methodology: Freq. Calibration

- Keep number of fitted parameters as small as possible
- Start from scratch with gas cell data (similarly start from scratch with in-orbit data)
- First determine effective λ_{met} for each FOV , assuming perfectly aligned rectlinear focal plane geometry.
- Using known value of $d\nu_{obs}/dr$, where r is the radial position of the FOV from the interferometer optical axis, least-squares fit for the focal plane dx, dy, and for λ_{met}.
- Fit rigid focal plane position and metrology laser λ with:

$$d\nu_i^{error} = \left(dr_i \times \frac{d(ppm)}{dr} \right) + d\nu_{met}$$

where

$$dr = \sqrt{(x_i + dx)^2 + (y_i + dy)^2)} - \sqrt{(x_i^2 + y_i^2)}$$

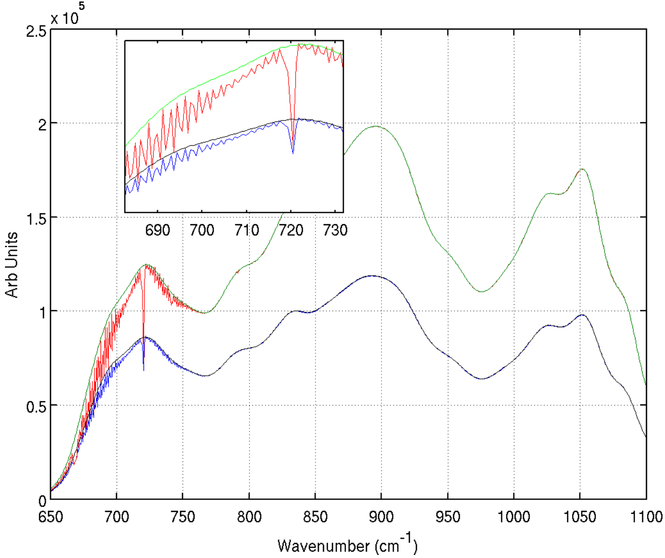
and i is the FOV index. Use 9 FOVs to retrieve dx, dy, and $d\nu_{met}$.

Test Nomenclature

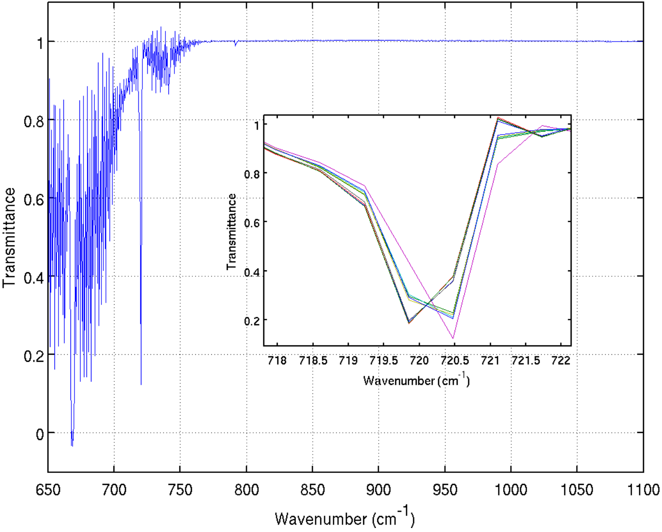
- Test defined by band (LW/MW/SW) and temperature (MN, PQL, PQH)
- Often use gas name (CO_2/CH_4/HBr) instead of band (LW/MW/SW) item Results listed by test sequence as follows:
  1. CO_2, LW at MN
  2. CO_2, LW at PQL
  3. CO_2, LW at PQH
  4. CH_4, MW at MN
  5. CH_4, MW at PQL
  6. CH_4, MW at PQH
  7. HBr, SW at MN
  8. HBr, SW at PQL
  9. HBr, SW at PQH
- If define Neon effective λ with CO_2, LW at MN, then you have 8 independent measurements of Neon calibration system. But, might need offsets for each band, giving 6 independent measurements.

Raw Magnitude Spectra

Hot BB: empty/filled, Cold BB: empty/filled

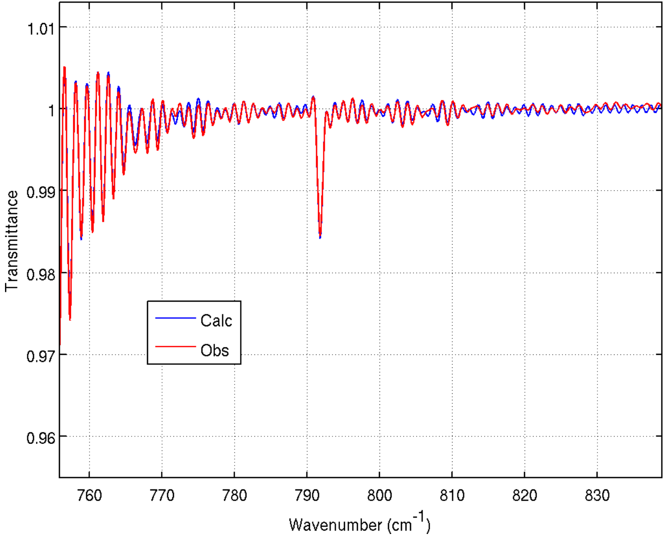


Uncorrected Raw CO_2 Spectrum

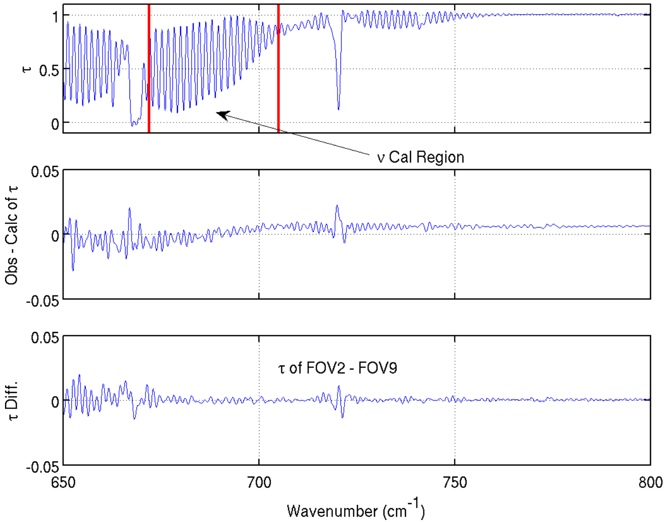


LW CO_2 FOV8 Obs versus Calc

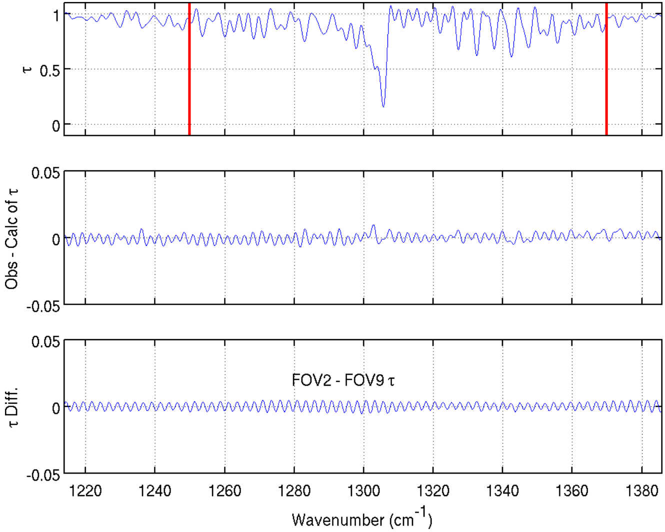
Signal-to-Noise is Outstanding, as is Stability



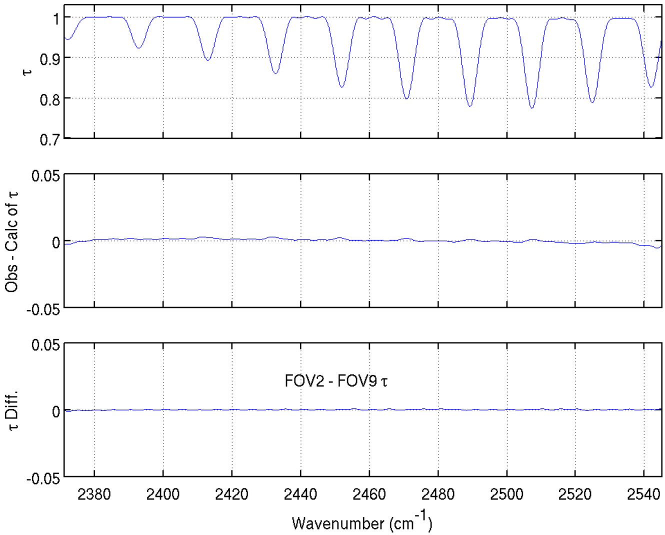
LW-CO_2 Summary



MW-CH_4 Summary



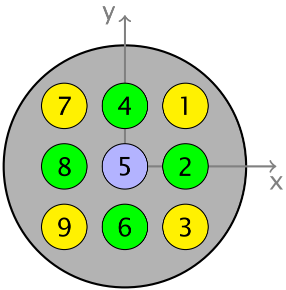
SW-HBr Summary



Focal Plane Appears to Shift *Slightly* with Temperature

Change in effective $d\nu_{met}$ errors for LW (CO_2) from PQL to PQH (in ppm) are:

3.2	2.7	3.2
-1.7	-1.9	-1.3
-5.1	-5.9	-5.2



This behavior allows separation of metrology laser wavelength from focal plane alignment.

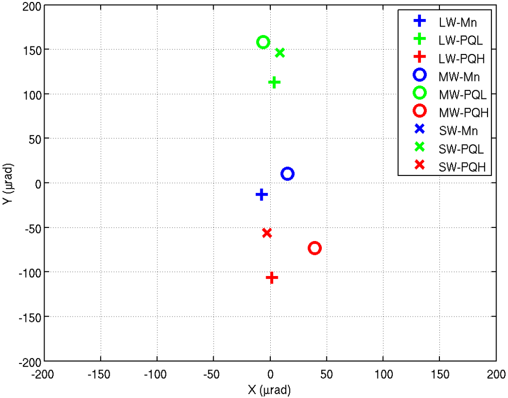
Observed Focal Plane Positions

Assuming rigid movement of each 3x3 focal plane

Mission Band	Nominal focal plane position dx (urad)	dy (urad)
LW	124	-496
MW	146	-472
SW	134	-438

Note: SW derived from average of PQL and PQH, SW Mn HBr data has liens

But, figure below shows dy changes with temperature



Observed (gas cell) versus Computed ν_{met}

(All Units are PPM).

Test	Constant FP (max-min)	Fitted FP (max-min)	Fit Improvement	$d\nu_{met}$	$d\nu_{met}$ minus bias
LW Mn	2.2	2.1	0.1	-3.0	-0.1
LW PQL	7.2	3.5	3.7	-2.4	0.6
LW PQH	5.7	2.7	3.0	-3.7	-0.8
MW Mn	3.0	2.8	0.2	-3.0	-0.1
MW PQL	7.4	2.2	5.1	-2.0	0.9
MW PQH	5.2	2.6	2.6	-3.0	-0.1
SW Mn	17.5	18.9	-1.4	-2.8	0.1
SW PQL	5.8	2.2	3.6	-2.4	0.6
SW PQh	3.2	2.2	1.0	-4.2	-1.2

Mean improvement for fitted FP (excluding HBr SW Mn) is 2.4 ppm.

Mean $d\nu_{met}$ = -2.9 $\pm$ 0.7 ppm

If use LW (CO_2) Mn -3.0 ppm $d\nu_{met}$ to calibrate Neon:

- Neon_cal becomes +18.0 ppm higher than NIST value
- Expect +14.7 ppm higher due to FOV divergence (taken from ITT)
- Agreement to within 3.3 ppm is remarkable

Additional Improvements?

- The CrIS spectral calibration has a 1-sigma std. of 0.7 ppm with 2 adjustable parameters (dx, dy) for each operating temperature.
- Are additional adjustments warranted?
- Note that weather centers won't bookkeep FOV ID.
- Answer: Since LW and SW ν calibration errors are reasonably correlated ($\sim$ 0.8) over FOV #'s between tests, small additional changes in FOV geometry could be warranted.

CrIS ILS Width Measurements

Generate obs-calc transmittances with a set of empirical apodizations, using a sinc function. This keeps OPD the same, but allows full-spectrum determination of observed line widths. Compare widths from (1) noiseless *computed* single-spike spectra convolved with no sinc apodization, and with (2) sinc apodization that minimizes obs-calcs to determine measured versus observed width.

- LW (CO_2): Obs widths $\sim$0.2% broader, apodization $<$ 1.5%
- MW (CH_4): Obs widths $<$0.06% broader, apodization $<$ 0.4%
- SW (HBr): Obs widths $\sim$0.8% narrower (direct measurements, with KB apodization)

ASL

Conclusions

- CrIS frequency calibration using the Neon lamp worked extremely well in TVAC.
- $\sim$ 1ppm accuracy at a single operating temperature with only 2-3 adjustable parameters (x, y, Neon Cal).
- Some evidence that further adjustments to the focal plane could be warranted.
- Measured CrIS ILS widths also appear to be extremely accurate, well within specifications.
- Congratulations to ITT!
- Thanks to the IPO (Karen St.Germain) and NASA (Jim Gleason, NPP Project) for funding this work; and to Dan Mooney and Bill Blackwell for the CrIS SDR Matlab reader .