Infrared Hyperspectral Spectrometer Spectral Calibration

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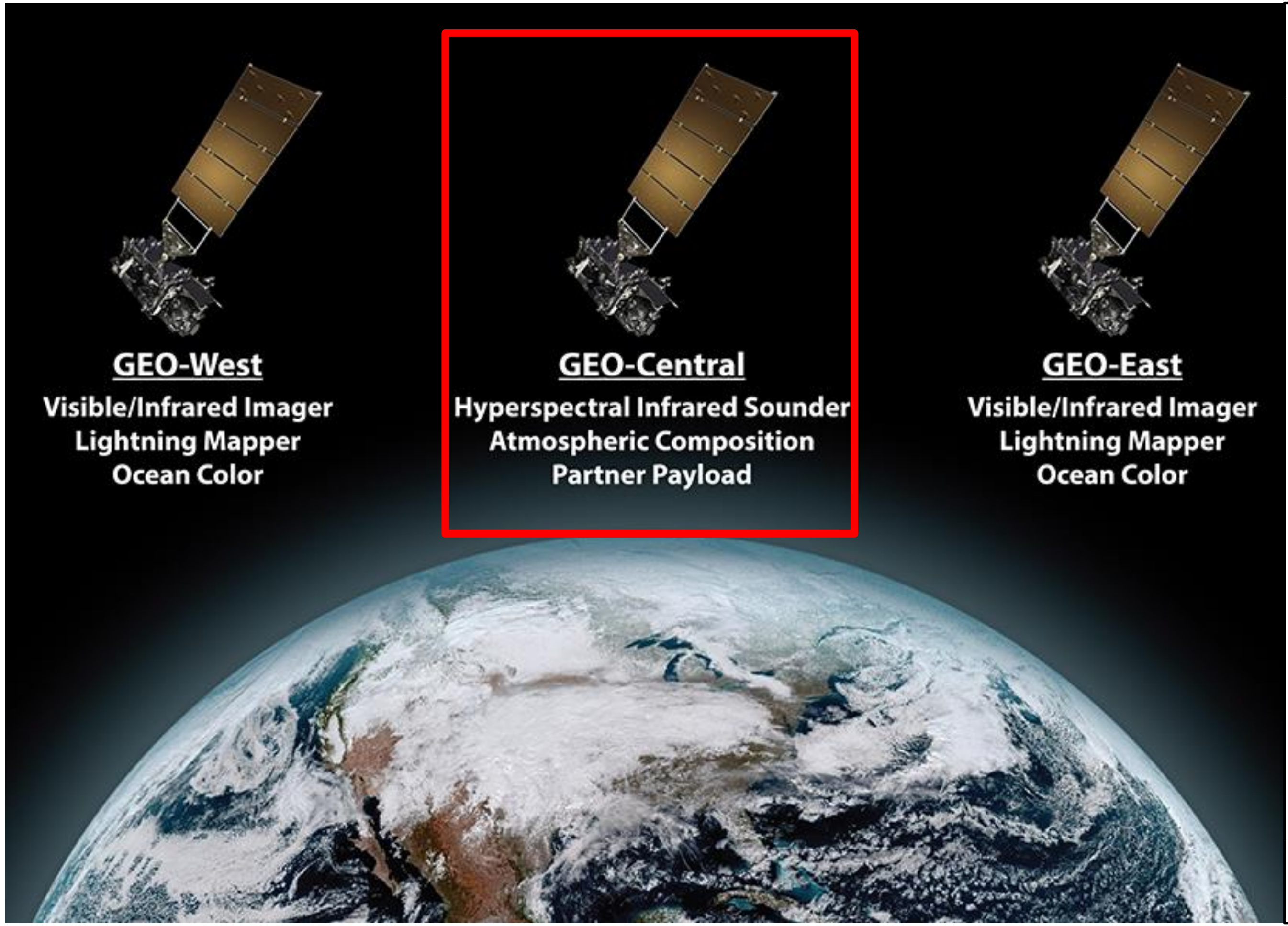
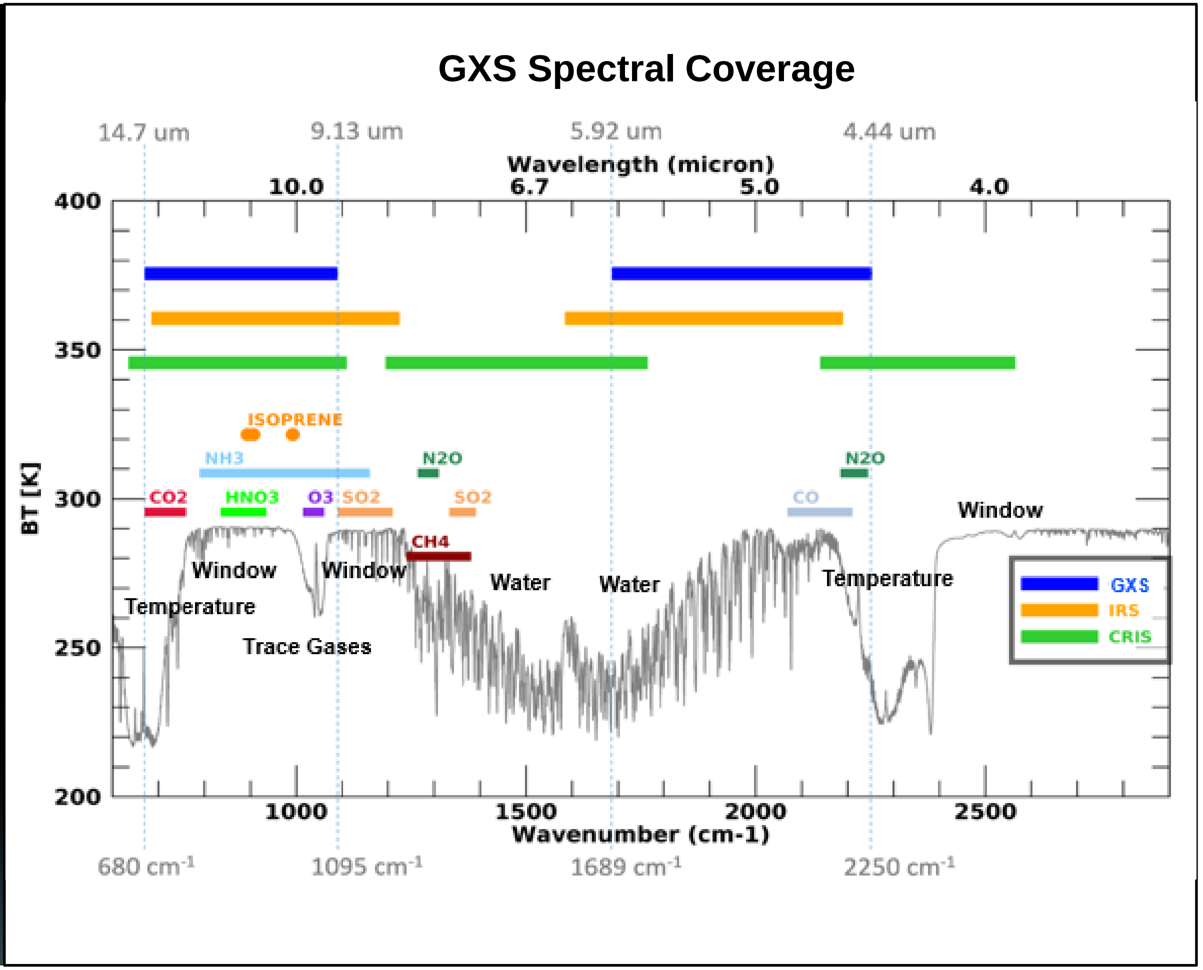
Outline

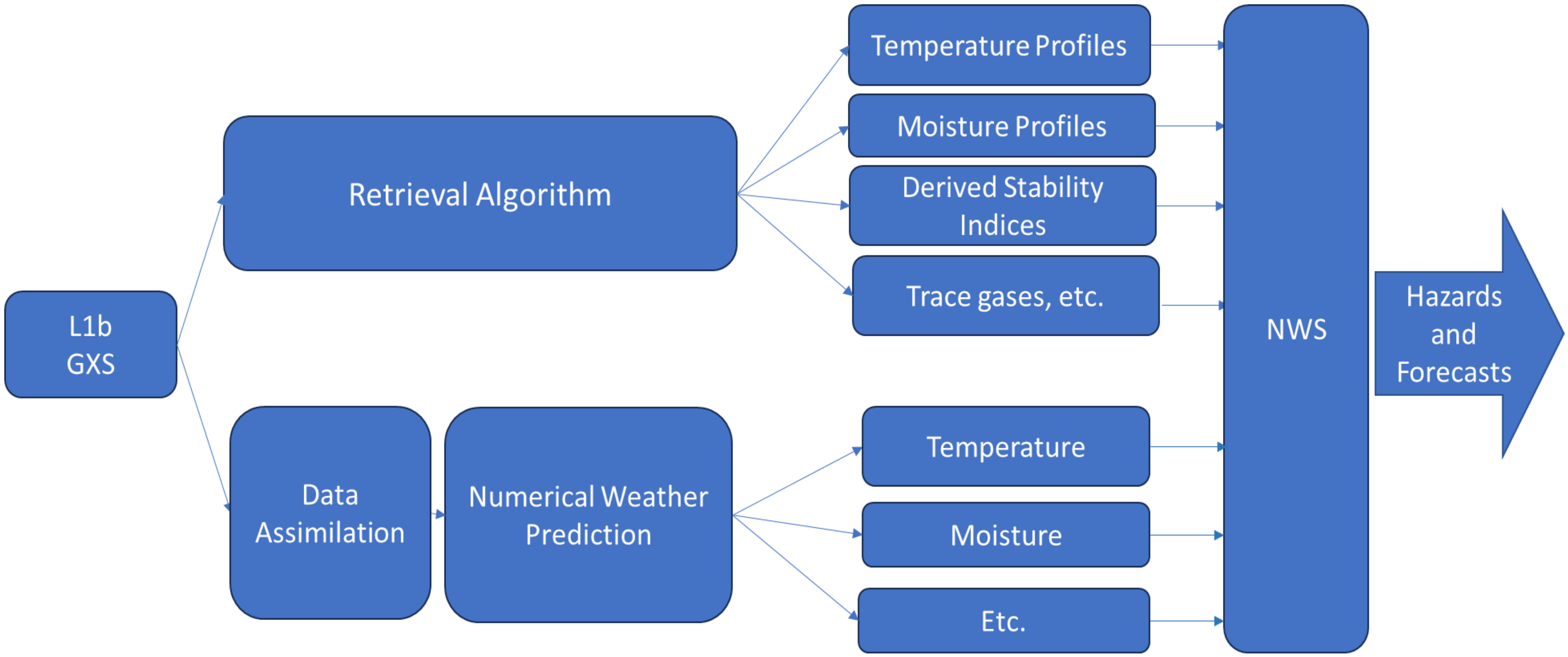
- Background: GeoXO constellation and GeoXO Sounder (GXS)
- GXS Level 1b data uses
- Spectral correction for NWP
- Methodology
- Analysis
- Results
- Future Work

GeoXO Constellation and GeoXO Sounder (GXS)





GXS Level 1b Data Flow



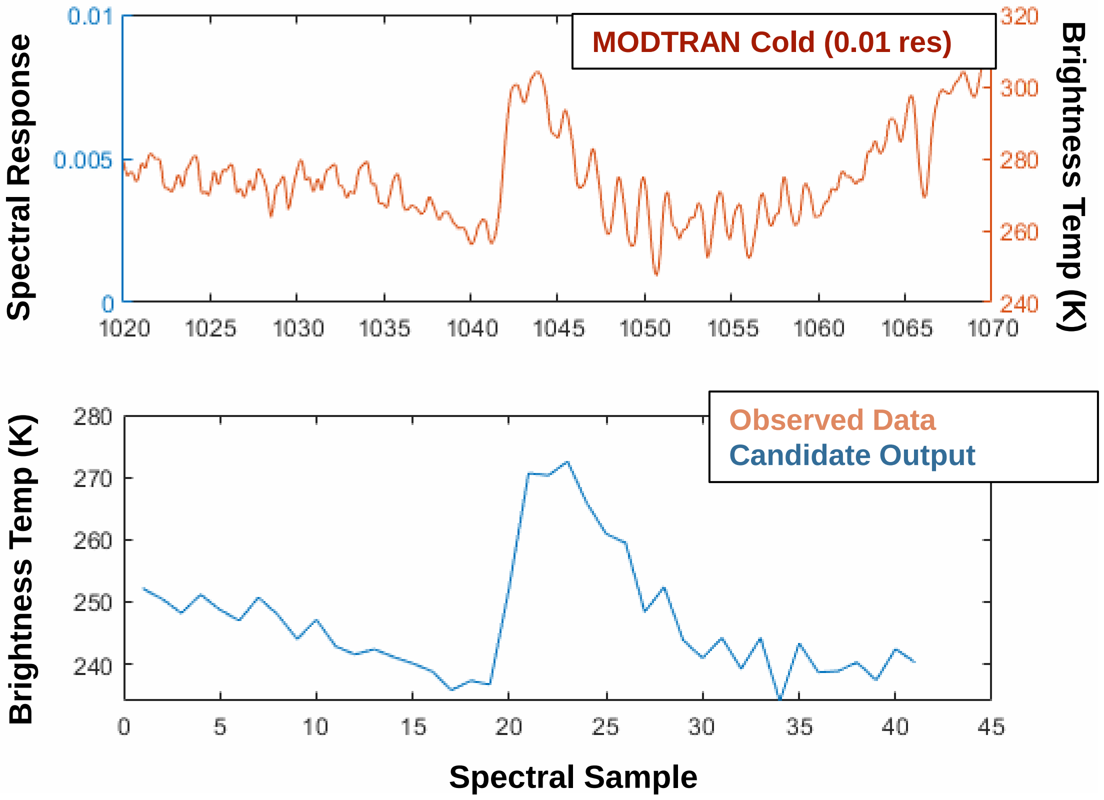
Spectral Correction for NWP

- For existing NWP data assimilation to fully utilize GXS data, the GXS spectral information must be precisely captured and spectrally corrected, as needed due to instrument artifacts, onto a temporally-stable fixed spectral grid.
- GXS requirements therefore necessitate spectral stability at Level 1b for all spatial locations.
- Existing polar orbital sounder data from NASA’s Atmospheric Infrared Sounder (AIRS) and NOAA’s Cross-track Interferometric Sounder (CrIS) employ these types of corrections
  - AIRS L1c is corrected
  - CriS L1b is corrected to “user grid”

Spectral Correction Methodology

- **Implemented a cross-correlation based spectral correction algorithm for hyperspectral IR sounders**
  - **Assumes that the SRF* width and spacing are known**
  - **Finds the band centers that, when applied to a MODTRAN spectrum, best match the observed data**
  - **Best match is defined as the center location that maximizes cross-correlation**
  - **Spectra from clear ocean pixels yield the most consistent results**

Demonstration of Cross-Correlation Procedure



Cross-correlation $$\rho = \frac{\boldsymbol{x\hat{x}}}{\overline{\boldsymbol{x}}\,\overline{\boldsymbol{\hat{x}}}}$$

*SRF = Spectral response function

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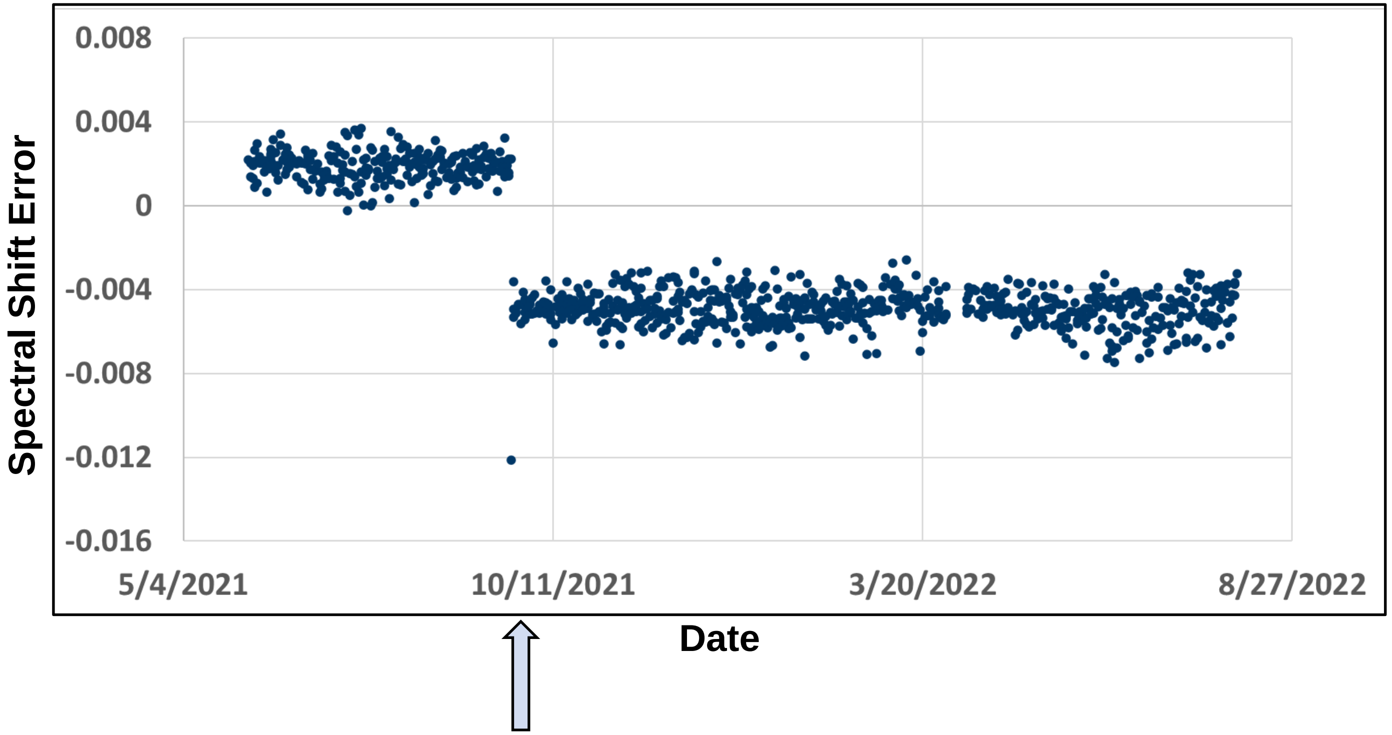
Spectral Correction Methodology

- **Compared methodology to AIRS, which also uses cross correlation**
- **Investigated algorithm's ability to detect changes**
  - **Aqua spacecraft maneuvered on 9/23/21**
  - **AIRS band centers shifted ~ 9 ppm (0.006 cm-1)**

Anomaly Detection on AIRS Data



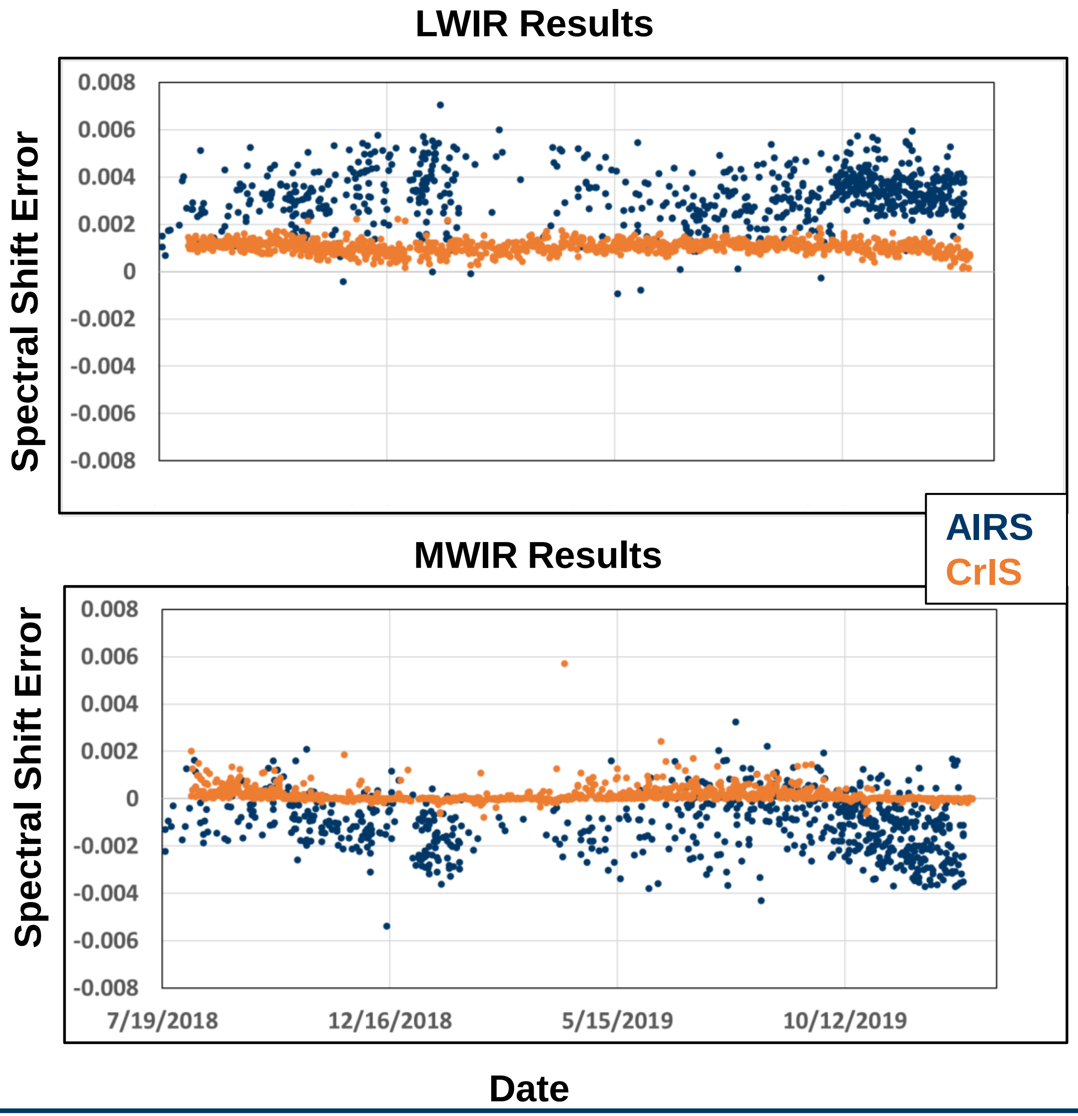
Cross correlation clearly detects changes caused by maneuver

*DSM = Deep Space Maneuver

GXS Cross-Correlation Algorithm Implementation Refinement

- **Evaluated algorithm performance in MWIR and LWIR absorption features for CrIS and AIRS over 2 years of data**
  - **Employed available clear pixels, which varies daily in the fixed local region**
  - **Removed large outliers caused by single spectral outlier point**
  - **Additional AIRS instrument-level effects remain**

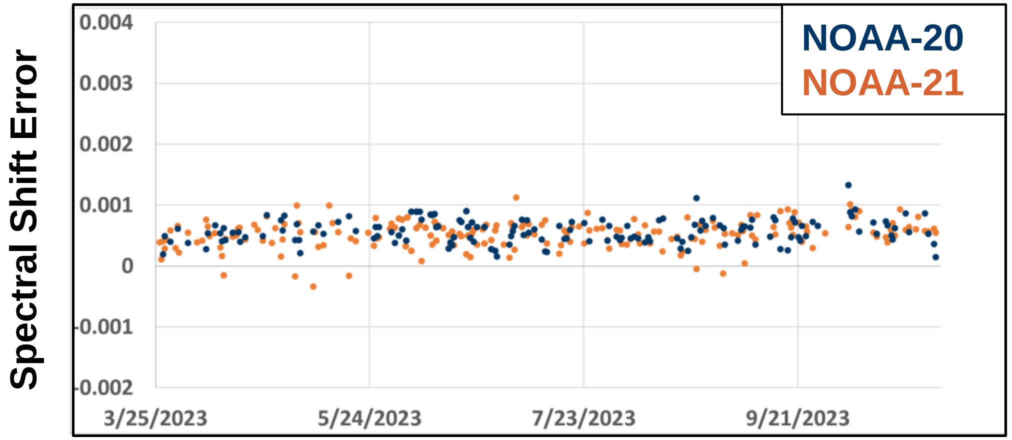
		Mean	Standard Deviation
AIRS	LWIR CO_2	0.0033	0.0013
	MWIR H_2O	-0.0011	0.0012
CrIS	LWIR CO_2	0.0016	0.0004
	MWIR H_2O	0.00004	0.0005



Analysis

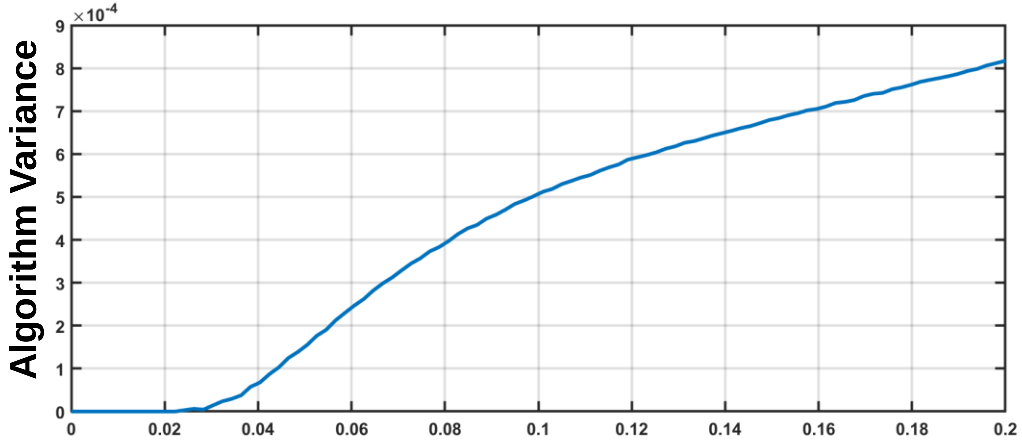
- **Applied algorithm to NOAA-20 CrIS and NOAA-21 CrIS to study day-to-day variability**
  - **Instrument data are consistent**
  - **Observed spread of 0.0005 cm^{-1}**
- **Studied the expected data spread with respect to varied levels of NEdN**
  - **CrIS NEdN level expected spread ~0.0003 cm^{-1}**
  - **AIRS NEdN level expected spread ~0.0008 cm^{-1}**
- **Expected spread at required GXS LWIR NEdN level is ~ 0.0008 cm^{-1}**

Cross-CrIS Comparison



Date

Variance of Results vs NEdN



NEdN

Estimated GXS Spectral Correction using AIRS data

Spectral Correction Terms	Errors	
Standard deviation after cross-correlation bias correction, where bias is detected from cross-correlation using SRFs and variety of spectral shifts relative to pre-launch baseline	0.0013	cm^{-1}
Prelaunch characterization with time/solar loading, temperature (cooling variations), and location on array provides SRFs	0.0026	cm^{-1}
Interpolation error to new spectral grid	0.00095	cm^{-1}
Additional drift over time	0.001125	cm^{-1}
RSS for total spectral correction error from comparison	**0.00326**	cm^{-1}

- **GXSPORD requires 0.0034 cm^{-1} (5 ppm) at 680 cm^{-1} and 0.0084 cm^{-1} at 1689 cm^{-1}**
- **Estimated spectral correction knowledge for a GXS using AIRS data**
  - **Cross-correlation method used AIRS on-orbit data**
  - **Prelaunch characterization is conservative (2x cross-correlation)**
  - **Computed interpolation error using AIRS data**
  - **AIRS long term drift reported to be 0.5 ppm, with separate additional seasonal variations and other events**

Cross-correlation, combined with other conservative errors, gives 0.0033 cm^{-1} and meets 0.0034 cm^{-1} (5 ppm)

Line Center Stability using AIRS data

Stability Terms	Errors	
Standard deviation after cross-correlation bias correction, where bias is detected from cross-correlation using SRFs and variety of spectral shifts relative to pre-launch baseline	0.0013	cm^{-1}
Any change relative to prelaunch characterization vs time/solar loading, temperature, and potentially location on array	0.0026	cm^{-1}
Interpolation error to new spectral grid	0.00095	cm^{-1}
RSS for total spectral correction error from comparison	**0.00306**	cm^{-1}

- **GXSPORD requires 0.0034 cm^{-1} (5 ppm) at 680 cm^{-1}**
- **Estimated spectral stability for a GXS using AIRS data**
  - **Removing drift over time from previous budget**

Cross-correlation, combined with other errors, gives 4.8 ppm error and meets 5 ppm spectral stability

Recommendations for GXS

- Determine bias over entire array on orbit and monitor for spectral health
  - Use cold cloud-free ocean scenes to determine bias
  - Spread in correction is likely (standard deviation observed in real data)
  - Plan 30-60 minute calibrations to monitor drift, on scale of sounding disk observations
- Model spectral, spatial, temporal, and thermal sensitivities over these time scales pre-launch
- Design needed calibration algorithm corrections to include these effects
  - Bypass usage post-launch if not needed
- Characterize any spectral, spatial, temporal, and thermal sensitivities pre-launch, including TVAC, and update values in algorithms
  - Bypass usage post-launch if not needed
- Measure any spectral, spatial, temporal, and thermal sensitivities post-launch, and update values in algorithms
- Validate data on orbit with other spectral references

Summary and Future Work

- **Method to handle spectral calibrations for spectral smile or other spectral shifts was developed and spectral knowledge was estimated**
  - **Required spectral knowledge of ≤ 5 ppm at 680 cm^{-1} can be met**
- **Method uses a single truth spectrum is currently envisioned, with hourly corrections possible in algorithm using actual data**
  - **Required spectral stability of ≤ 5 ppm at 680 cm^{-1} can be met**
- **Consider refining optimal choice for a reference MODTRAN spectrum, where only bias and not spread of data is impacted**
  - **Bias contribution included in budgets above**