V6 AIRS Spectral Calibration

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Spectral Calibration Primer

- AIRS measures radiance at 2378 frequencies with 2378 physical detectors, each 50 um wide
- A combination of optics places a distinct frequency range on each detector
- The frequency of each detector is extremely stable, varying less than 1% of frequency spacing over the mission to date
  - For all weather uses and most climate uses the frequencies should be treated as constant
  - For some climate purposes such as long-term trends it is useful to know the frequencies more precisely

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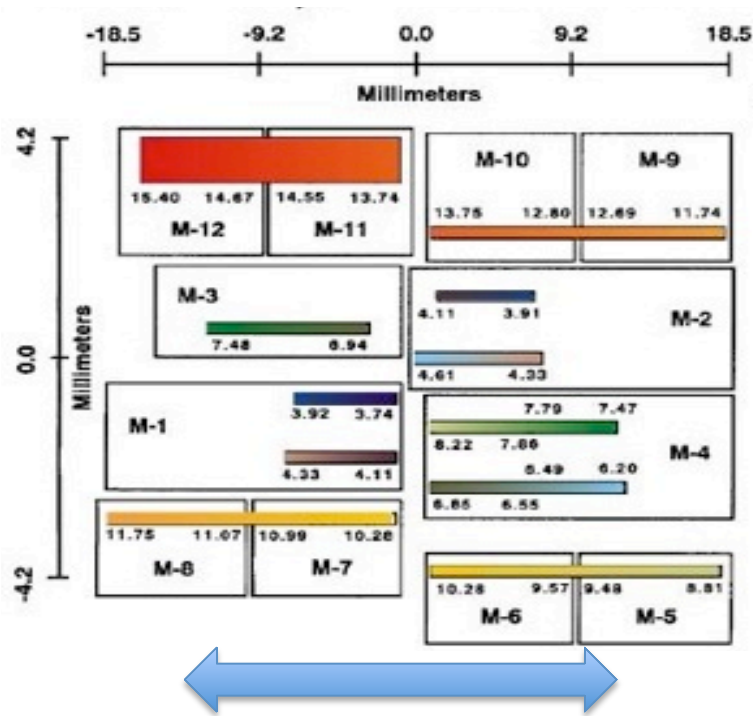
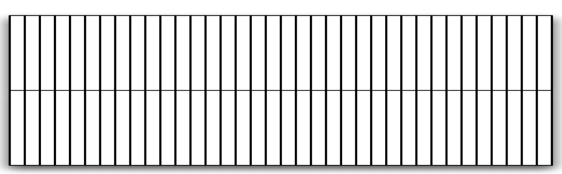
AIRS Focal Plane



Direction of effective focal plane motion

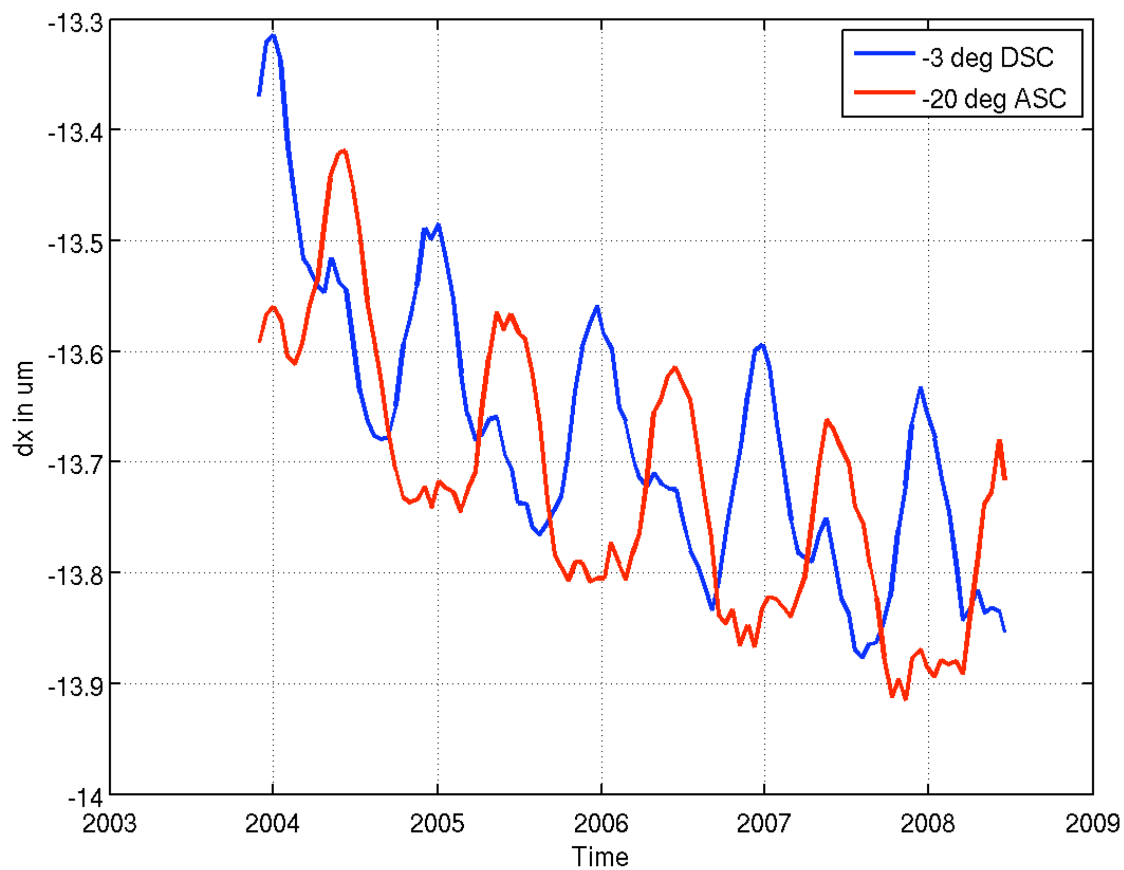


Note on units:

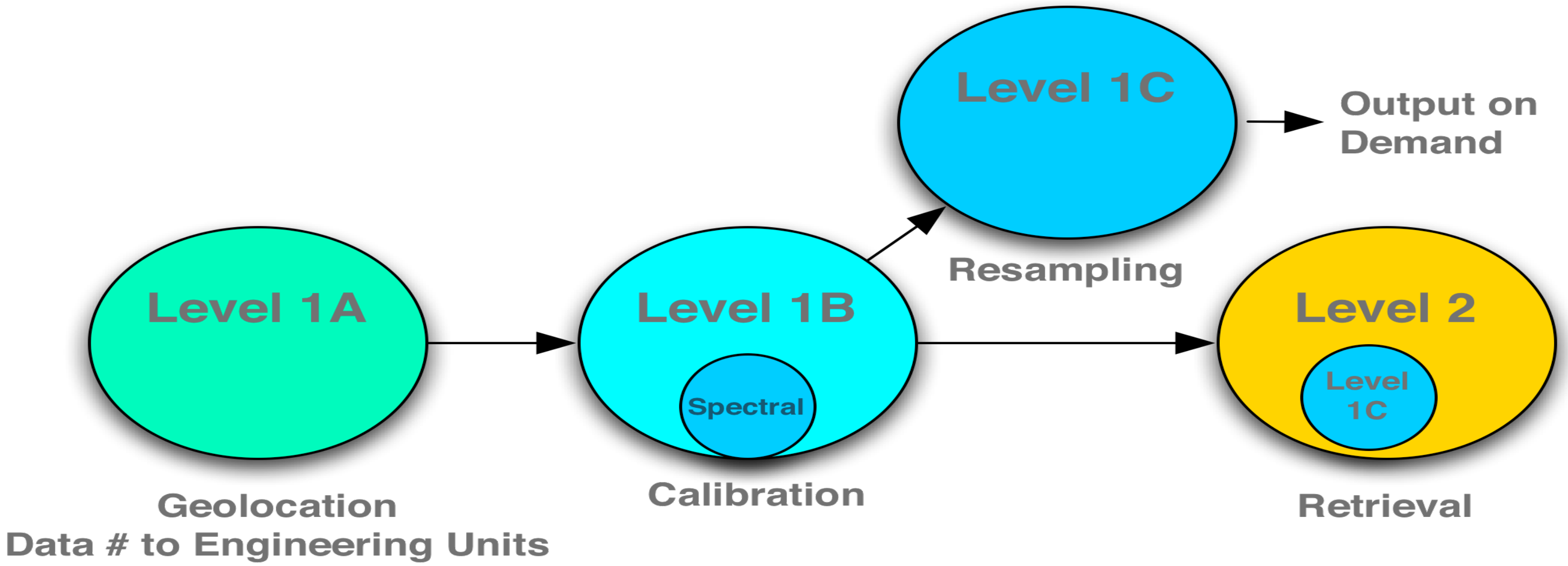
- 1 um in focal plane dimensions is:
  - 2% of channel spacing
  - ~20 cm^{-1} @1000 cm^{-1}
  - ~8.4 ppmf
  - 120 mK change in R Branch brightness temperature
  - 0.02 um wavelength at 10 um wavelength
- 0.1 um in focal plane dimensions is:
  - 0.2% of channel spacing
  - ~2 cm^{-1} @1000 cm^{-1}
  - ~0.84 ppmf
  - 12 mK change in R Branch brightness temperature
  - 0.002 um wavelength at 10 um wavelength

Spectral Shift Since Solar Flare

- This is a UMBC figure
    - JPL results are similar
- Long-term trend is 0.075 um per year
- Seasonal cycle is ~0.2 um of channel spacing peak-to-peak
- Ascending & descending are out of phase, suggesting that the underlying mechanism is heating of spacecraft by earthshine



Spectral Cal Overview



- A process inside Level-1B determines spectral shift
- Level-1C provides clean, shift-compensated radiances on demand
- Level-2:
  - Level-2 **physical retrieval** uses knowledge of shift together with unaltered L1B radiances with a new shift-enabled RTA transmittance model
  - Level-2 **regression** steps use **locally** cleaned, shift-compensated radiances
    - The Level-1C algorithm is embedded in the Level-2 program

Spectral Calibration in Level-1B

- In the currently operational software, Version 5, a spectral calibration routine determines dynamic frequencies using upwelling radiation to 0.4 um RMS
  - These are collected off-line for statistics
    - Seasonal and long-term patterns can be resolved unambiguously
  - These frequencies cannot be used directly for climate
    - A 0.4 um RMS error translates to ~50 mK RMS error in the R branch
    - This is about the same magnitude as the error caused by ignoring the effect
- For V6 we are improving the dynamic measurement
  - Currently 0.1 um RMS
    - Equivalent to 12 mK RMS radiance random error
  - Almost good enough for climate
  - Work continues

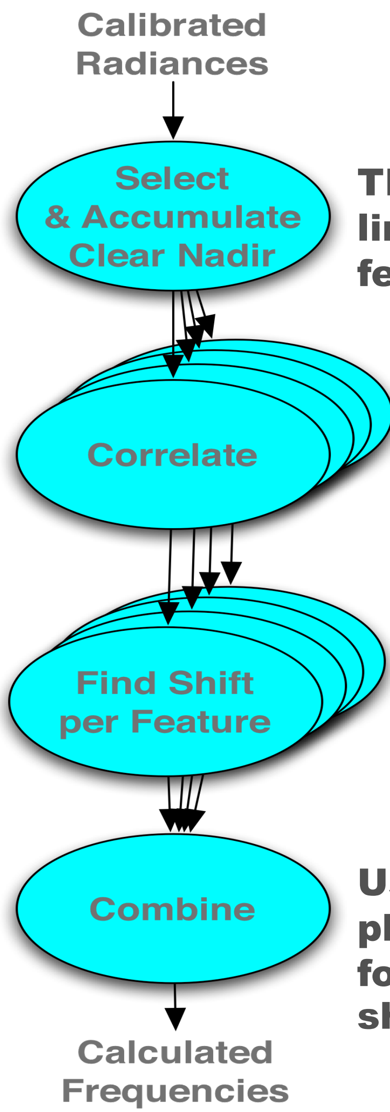
Spectral Calibration in Level-1B

- UMBC is also making per-granule shift determinations for launch-present data (6+ years) using comparisons between spectra calculated from the Level-2 retrieved atmospheric state and cloud-cleared radiances

- Most likely the per-granule shifts for L1C & L2 will come from a model fitted to JPL or UMBC results on historical data, accounting for:
  - Orbital cycle
  - 24-hour cycle
  - Annual cycle
  - Long-term drift (solar cycle?)

V5 Spectral Calibration Approach

- The approach relies on modeled spectra for 34 preselected spectral “features”.
- There are features on all 19 detector modules
- The spectra are modeled for shifts of 0, +/- 10 um, +/-20 um
- Detector spacing is 50 um



The 4 FOVs nearest nadir on each scan line are selected as long as the per-feature contrast is high enough

Calculate correlation of the accumulated radiances in each feature to each of the modeled spectra

Find a shift for each feature by fitting a parabola to the correlations and finding the shift at the peak

Use shift of 7 key features plus physical location of each feature on the focal plane in a multidimensional fit for shift and focal length

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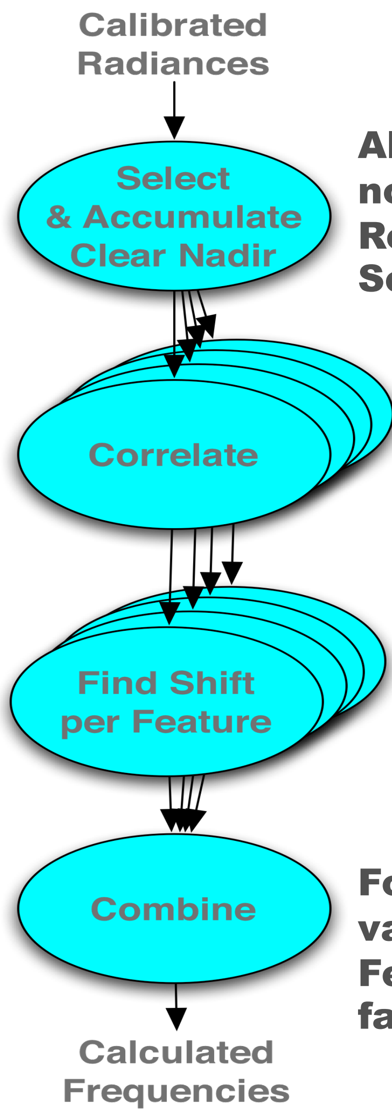
V6 Spectral Calibration Approach

- For V6 we are revisiting every aspect of the calibration algorithm
- We have 49 model climatologies instead of one.
- Spectra are modeled at shifts of 1 um instead of 10 um
- We model varying scan angle, topography, and CO_2, plus pre vs. post flare (Thanks to UMBC)
- New feature set
- Algorithmic details are still in flux



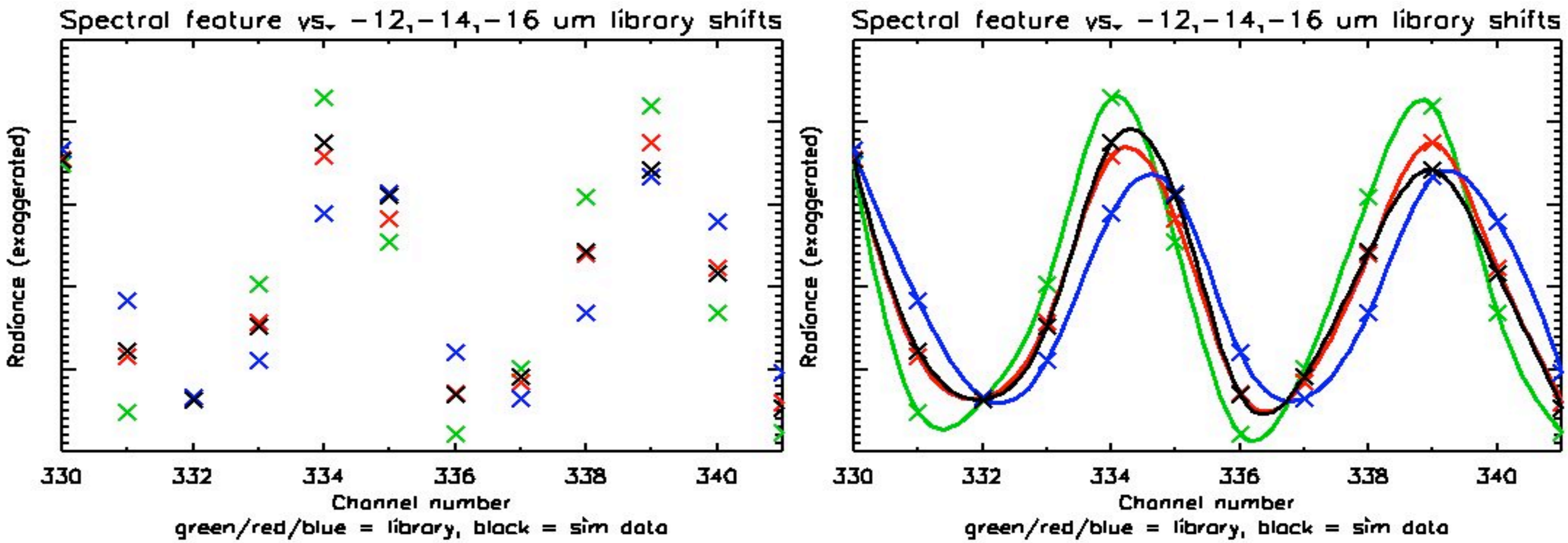
All 90 FOVs on each scan line are used, not just near-nadir. Result may be from median or top 10%. Selection may be via correlation.

Calculate correlation for all 49 climatologies and select climatology per feature.

Ensure fitting a max not a min of correlation.

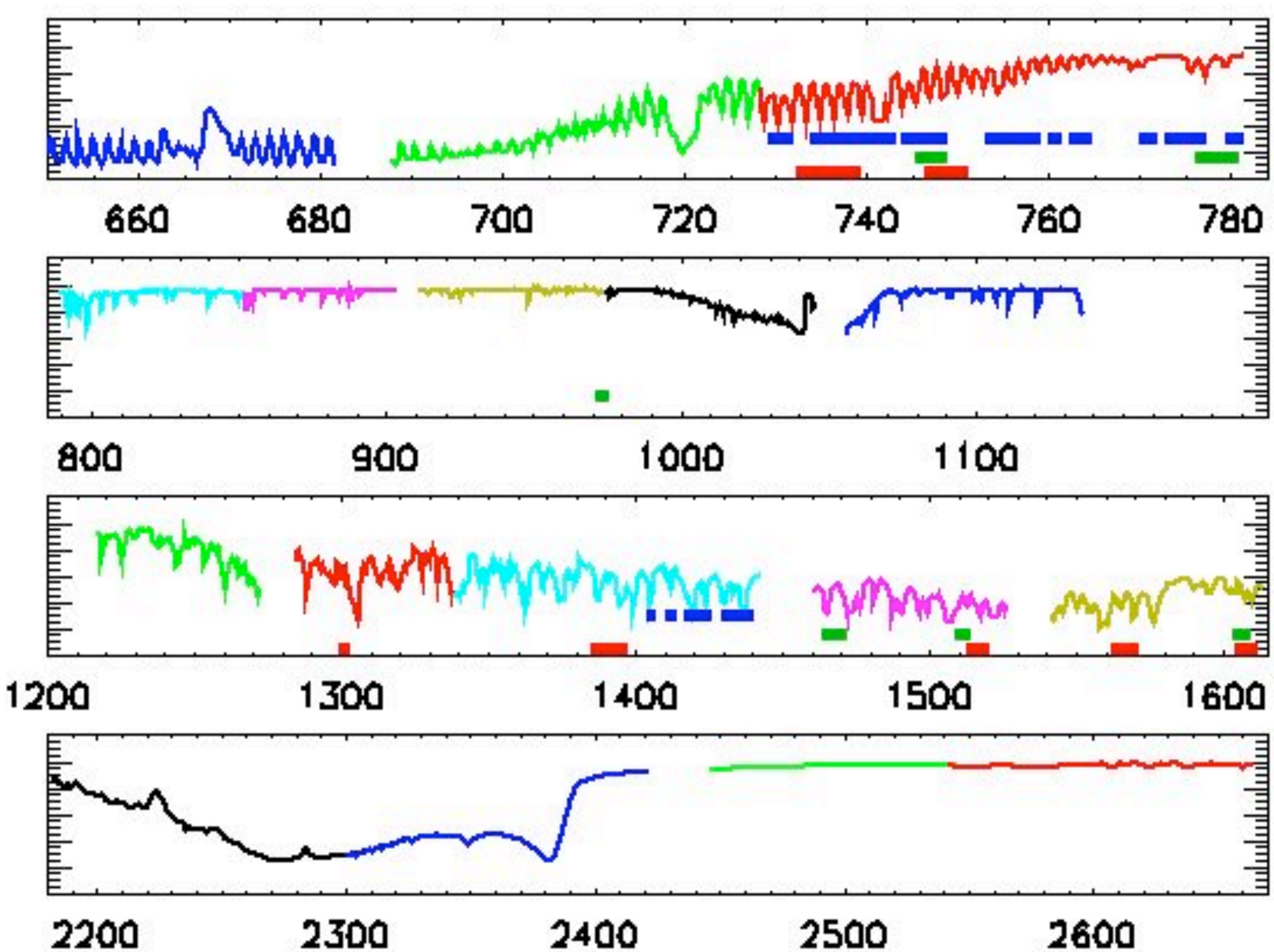
Focal length is no longer permitted to vary so fit is now a more stable 1-d fit. Features weighted based on multiple factors.

A Feature



- Here is data for a feature at 747 cm^{-1}
- The black points are the data to be matched.
- The other colors are a matched reference profile at 3 shifts.
- In the figure on the right spline curves are added to make it easier to visualize

Feature Locations



- Locations of features are marked with colored bars
- Blue=UMBC
- Red=v5
- Green=V6 snapshot

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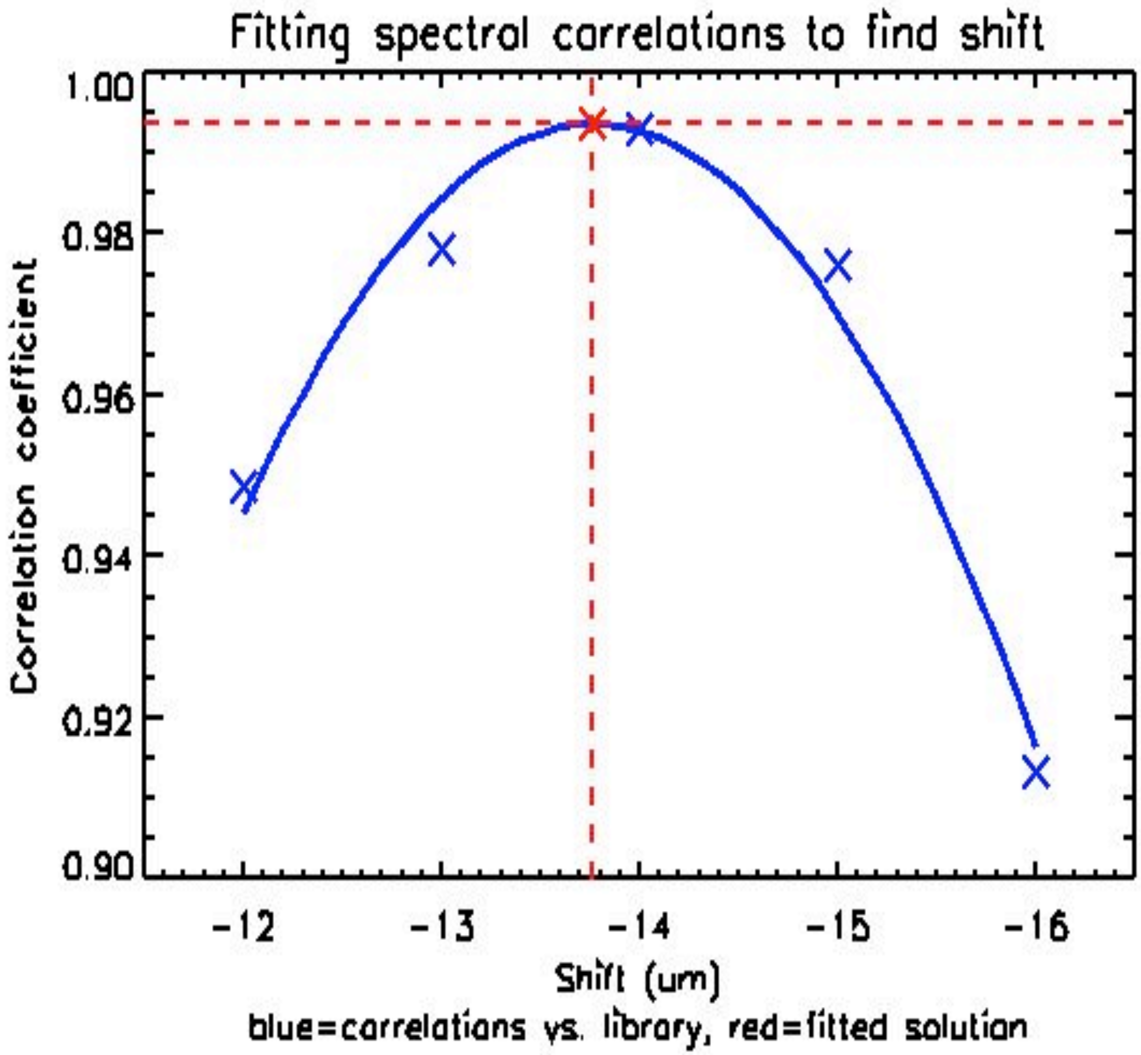
Finding Shift from Correlations



- Correlations are calculated for shifts of -12, -13, -14, -15, and -16 um.
- A parabola is fitted through the correlations.
- The peak for this feature is calculated to be at -13.8 um with a correlation of 0.994

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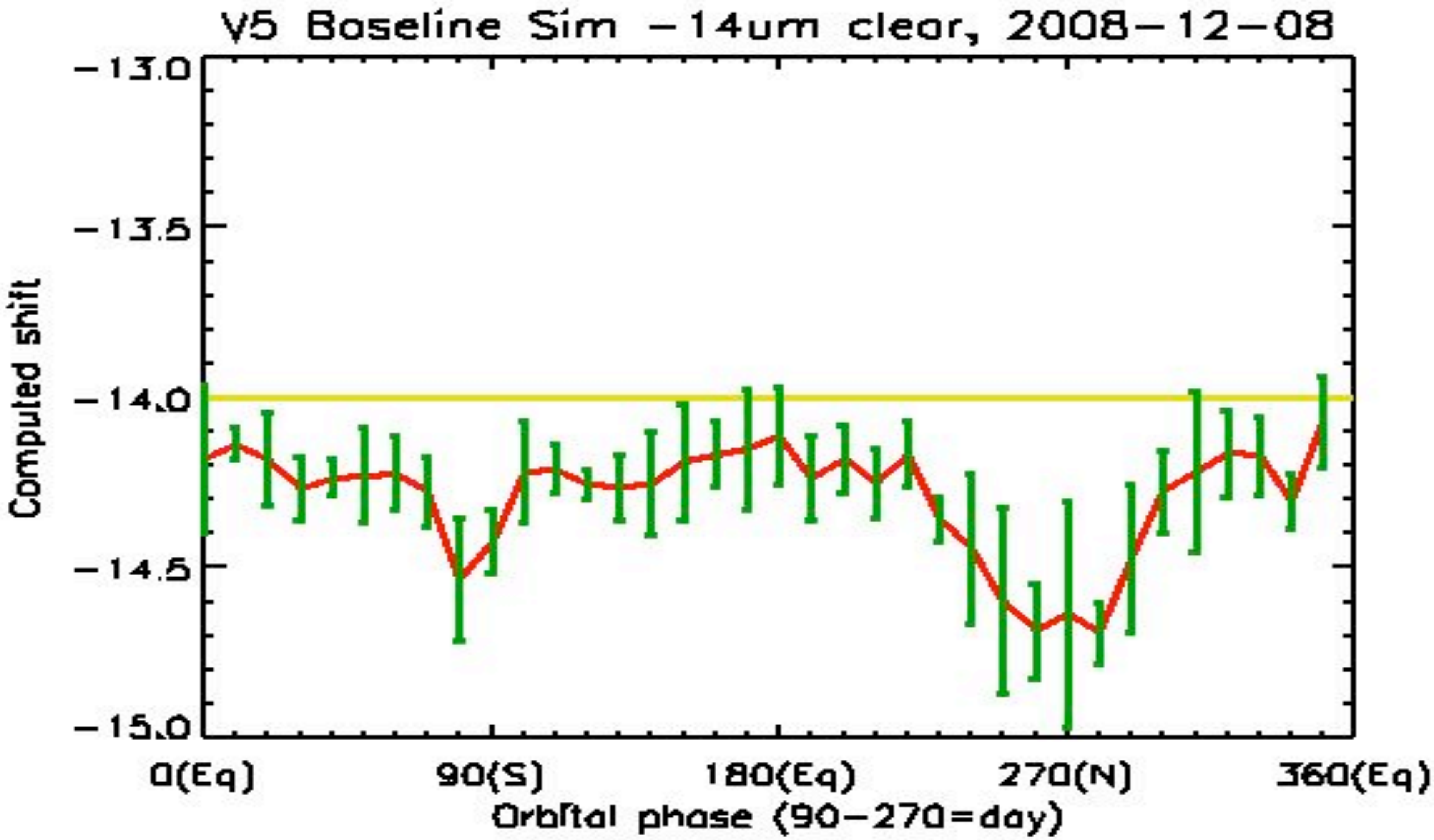
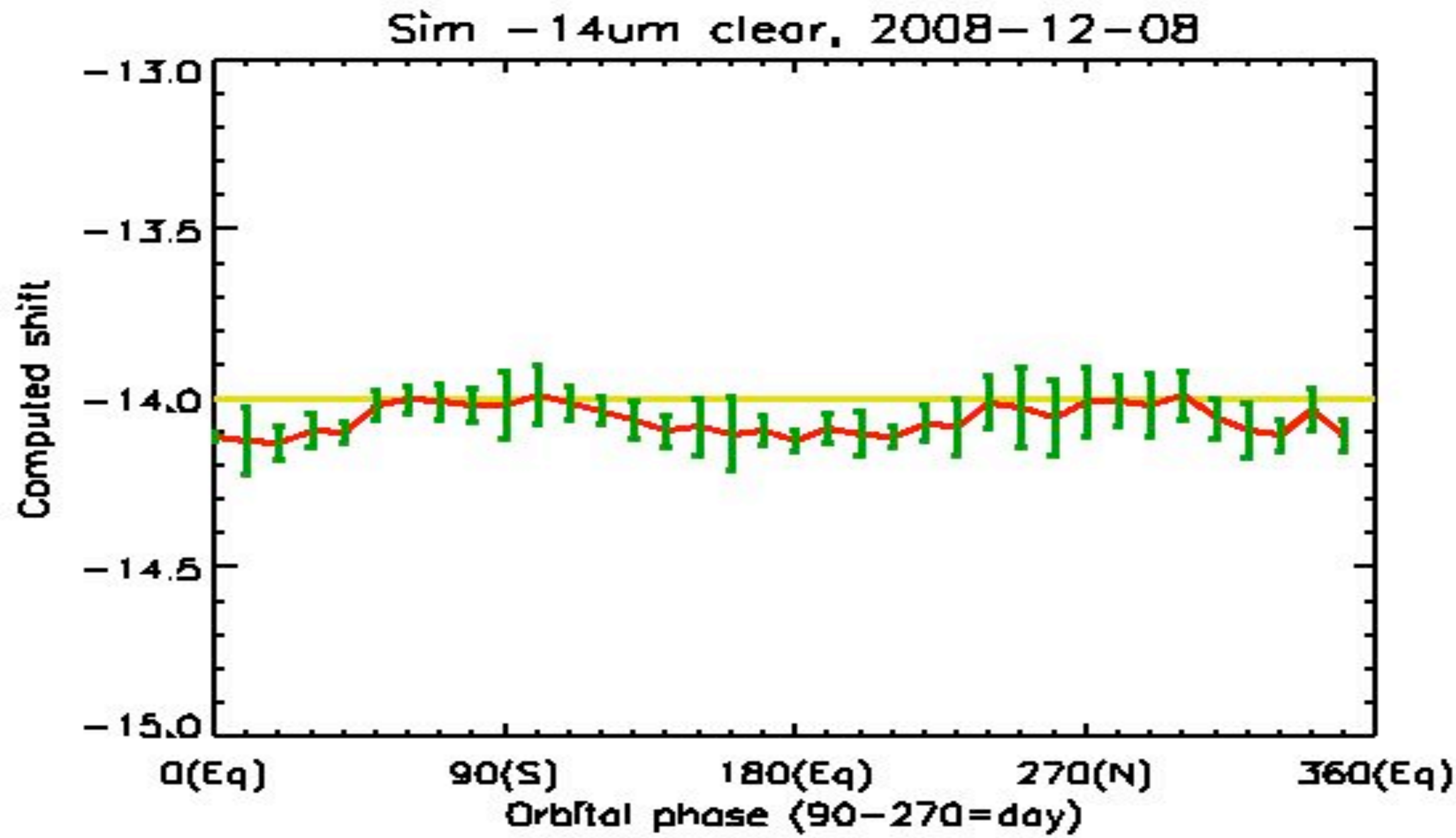
V5 Dynamic Shift for Simulated -14 um Clear



V6 Candidate Dynamic Shift for Simulated -14 um Clear



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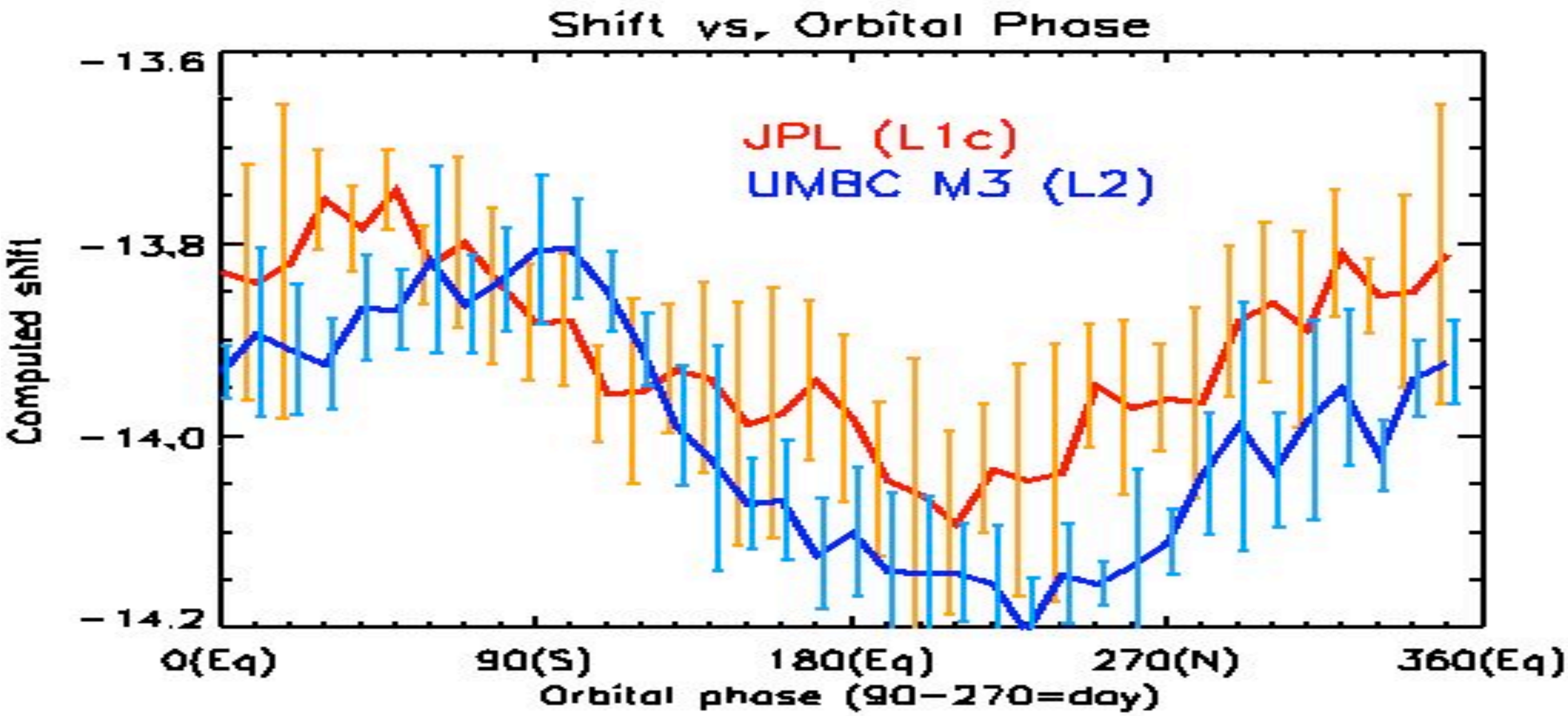
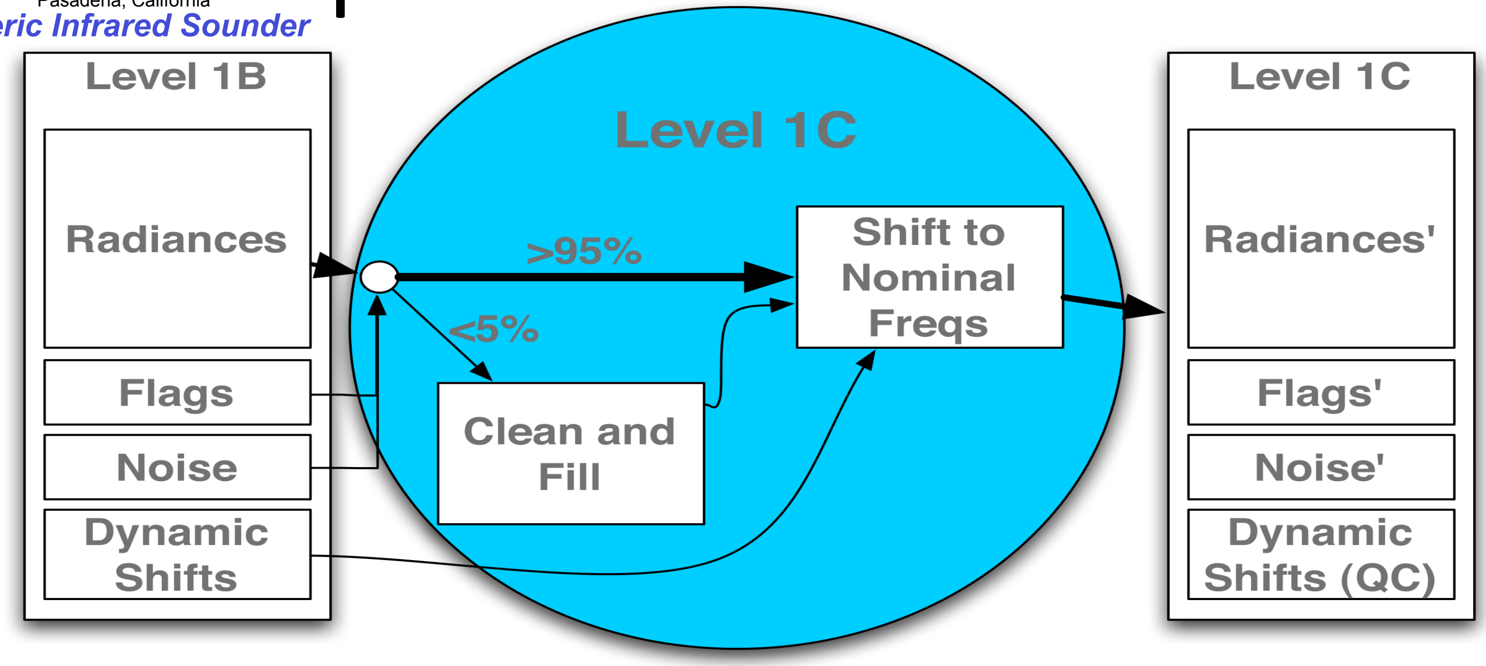
JPL & UMBC v6 Spectral Shift



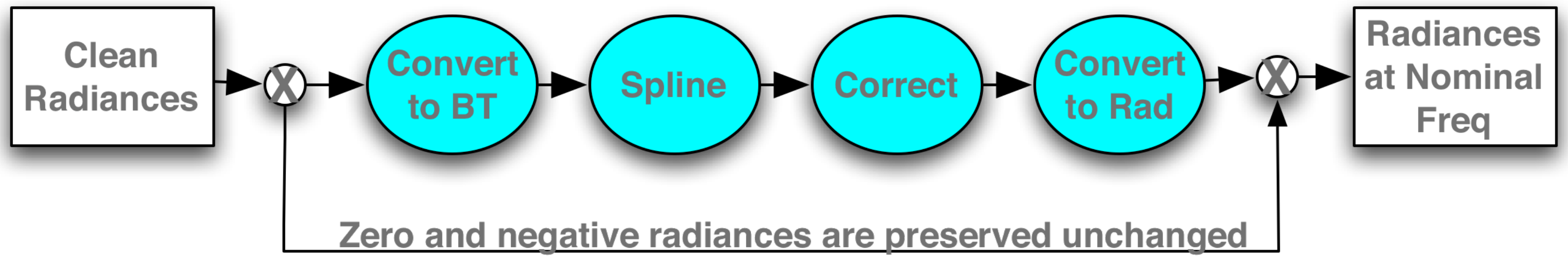
- UMBC results for shift as a function of orbital phase are compared to latest JPL results
- Correlation is 0.78

Spectral Calibration in Level-1C



- In Level-1C the shifts are known and the radiances are adjusted to what would have been seen if there were no spectral shift.
  - Channels in need of replacement are determined
  - Gaps are filled
    - First filled roughly with neighboring channels
    - Filled more precisely with PCA
    - Please see, "Level 1C spectra from the Atmospheric Infrared Sounder (AIRS)", Denis A. Elliott, Hartmut H. Aumann, Yibo Jiang, and Steven E. Broberg. Proceedings of SPIE Optics and Photonics 2008; Remote Sensing, vol. 7081, 7081-19 (2008).
  - Radiances are shifted (BT domain, spline per module)
  - Shifted radiances are output (on demand), optionally with filled values.

Spectral Shifting



- A cubic spline is applied in brightness temperature (BT) units and is performed per module
- The correction is proportional to the spline adjustment
  - It provides correction where the curvature of the spectrum changes too rapidly for the spline.
  - It is trained using the UMBC simulated day at 2 shifts.

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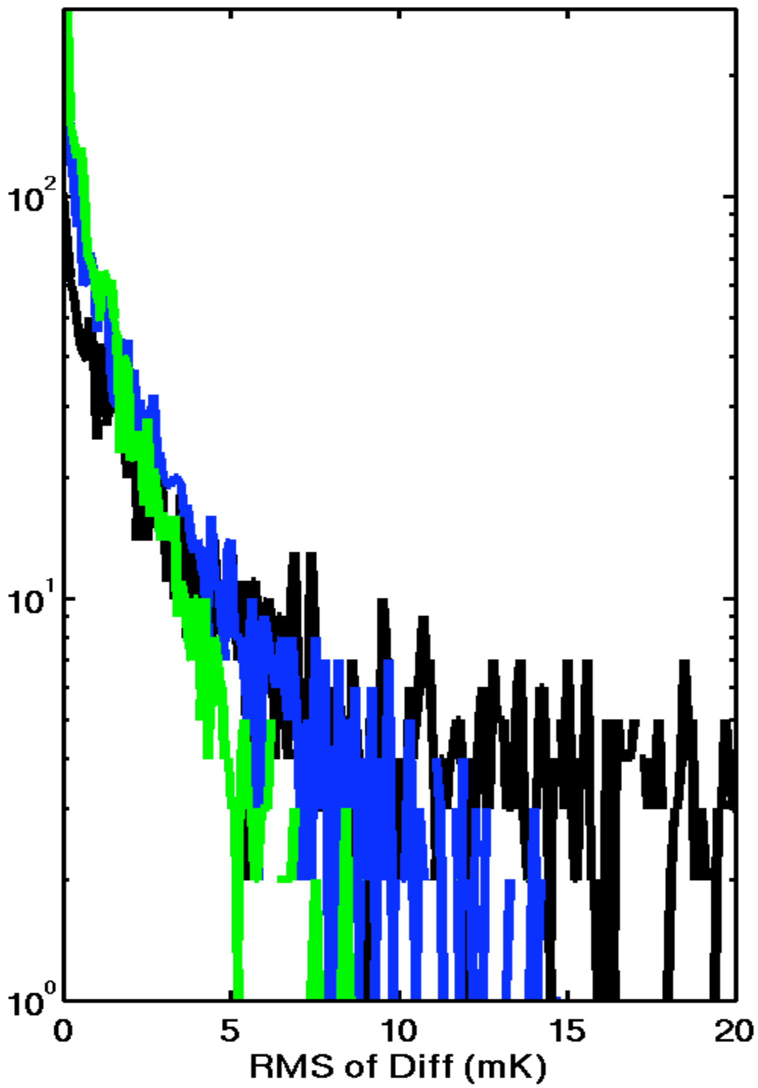
Level-1C Success



- Histogram over 2378 channels showing RMS difference in mK
- Black: RMS diff between -14 um and -15 um
  - This is the RMS error when we ignore spectral shifts entirely (v5)
  - Some channels exceed 20 mK
- Blue: RMS difference between true -15 um data and -14 um data spline-shifted to -15 um
  - All are under 15 mK
- Green: RMS difference between true -15 um data and -14 um data spline-shifted and corrected to -15 um
  - All are under 10 mK

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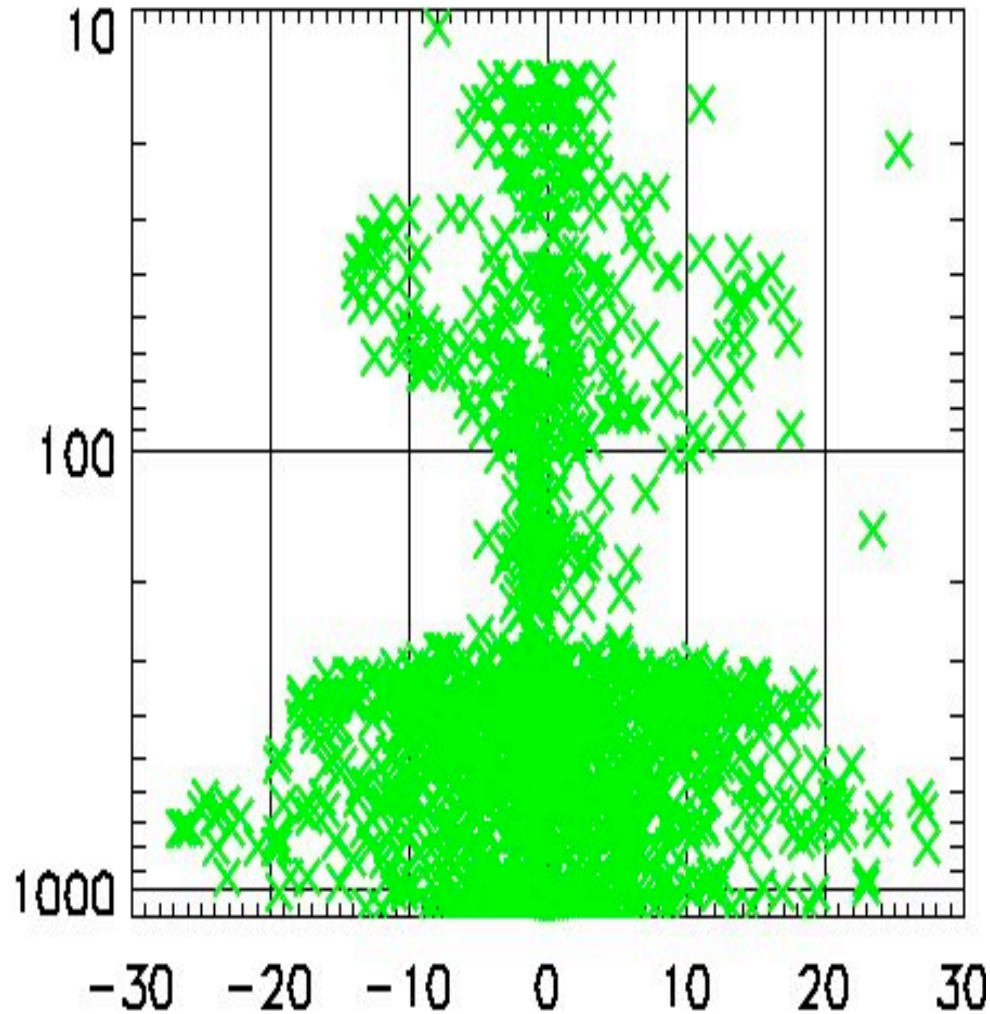
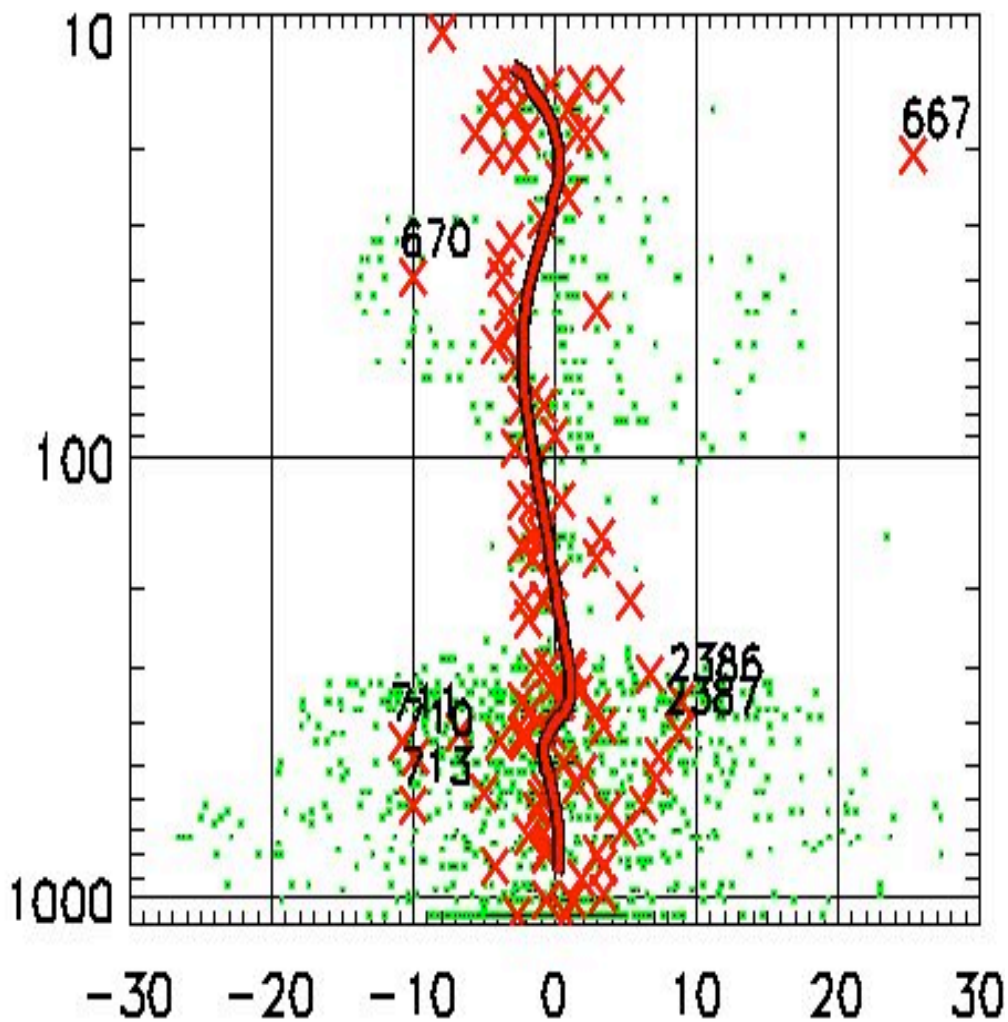
Spectral Shift L2 Impact

- The average change in Brightness Temperature for a 0.075 um/year trend in focal plane position is shown.
- Channels are placed vertically at the centroid of their weighting functions
- All 2378 channels are shown.



Spectral Shift L2 Impact

- Channels used in temperature retrieval are red.
- The worst case for a temperature channel is 25 mK/year @ 667 cm^{-1}
  - 100 mK day/night
  - 70 mK winter/summer
- The smoothed fit is always under 3 mK/year
  - 12 mK day/night
  - 8 mK winter/summer



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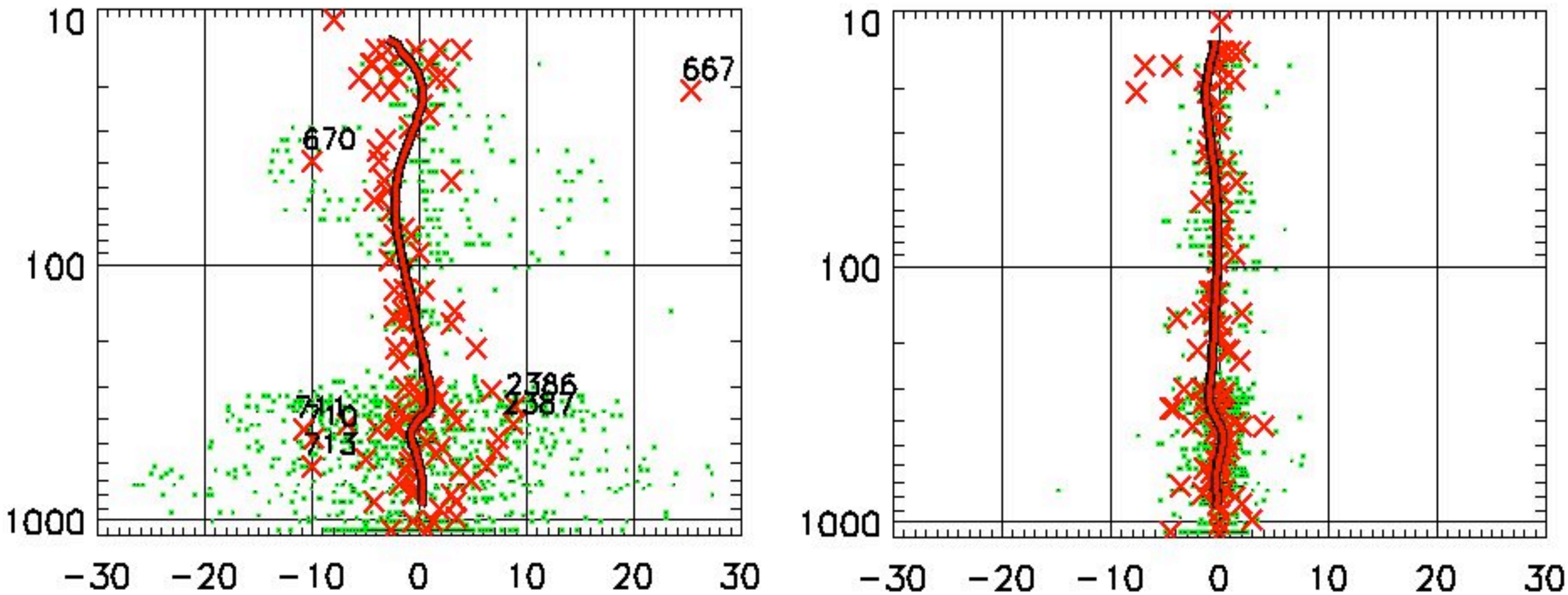
Level-1C Compensation Decreases the Impact of Spectral Shift

Apparent BT Trend from Uncorrected Spectral Trend | Apparent BT Trend from Corrected Spectral Trend



- Spectrally shifting can decrease the impact of shifts on Level-2
- Already 3x-6x improved
- Our v6 goal is a 10x reduction in this impact

Spectral Shift Impact on Level-2

- UMBC provided a test data set of 1 whole day (2008-12-08) simulated at two spectral shifts:
  - -14 um
  - -15 um
  - Delta of 1 um represents ~13 years of long-term drift at current rate
  - 1 um is approximately 3x the peak-to-peak amplitude of the orbital cycle (~0.3 um peak-to-peak)
  - 1 um is approximately 5x the peak-to-peak amplitude of the seasonal cycle (~0.2 um peak-to-peak)
  - Comparing results of (IR-Only) retrievals on these two runs can show the impact of spectral shift on retrieved products
  - The V6 goal is an order-of-magnitude decrease in this impact.

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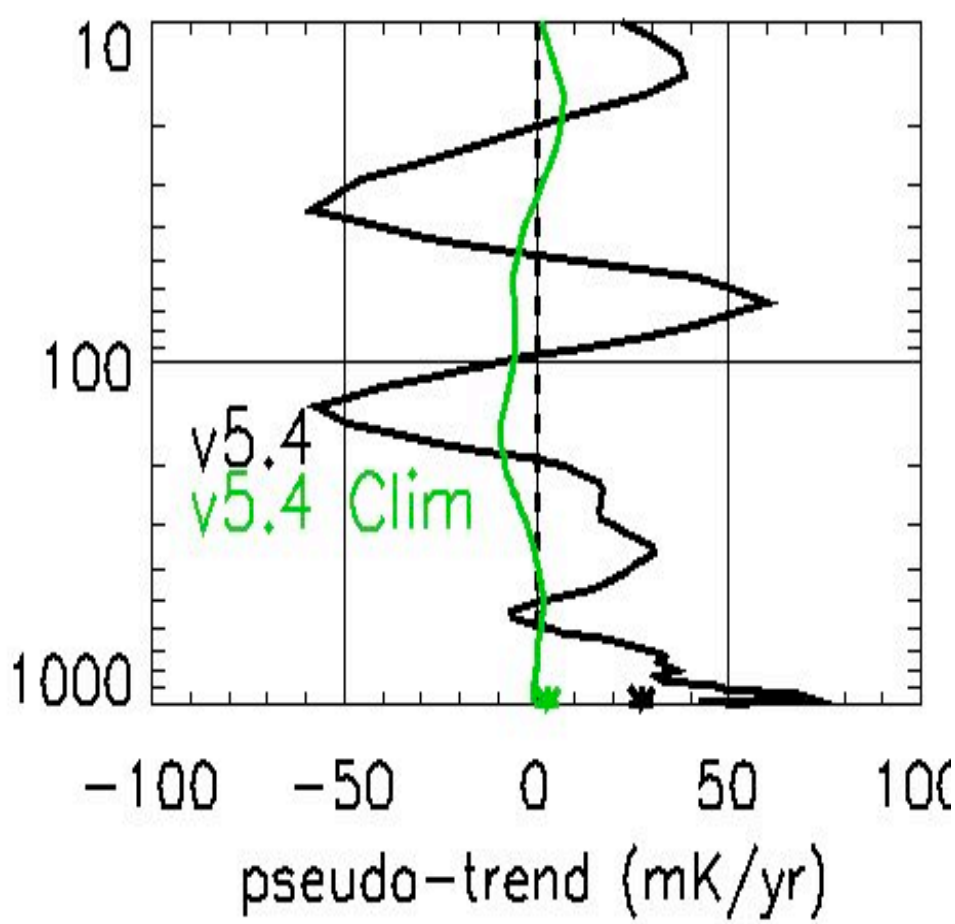
Spectral Shift Impact on Level 2

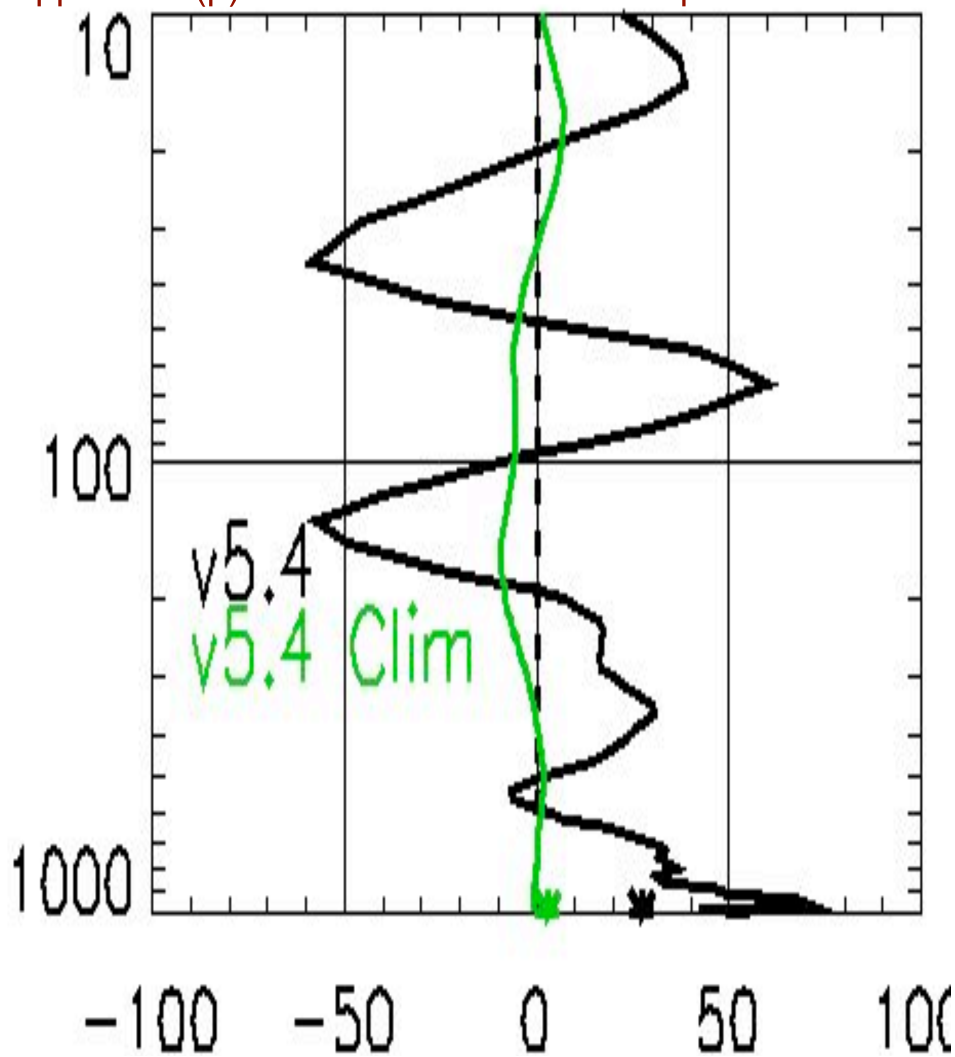
Apparent T(p) Trend from Uncorrected Spectral Trend



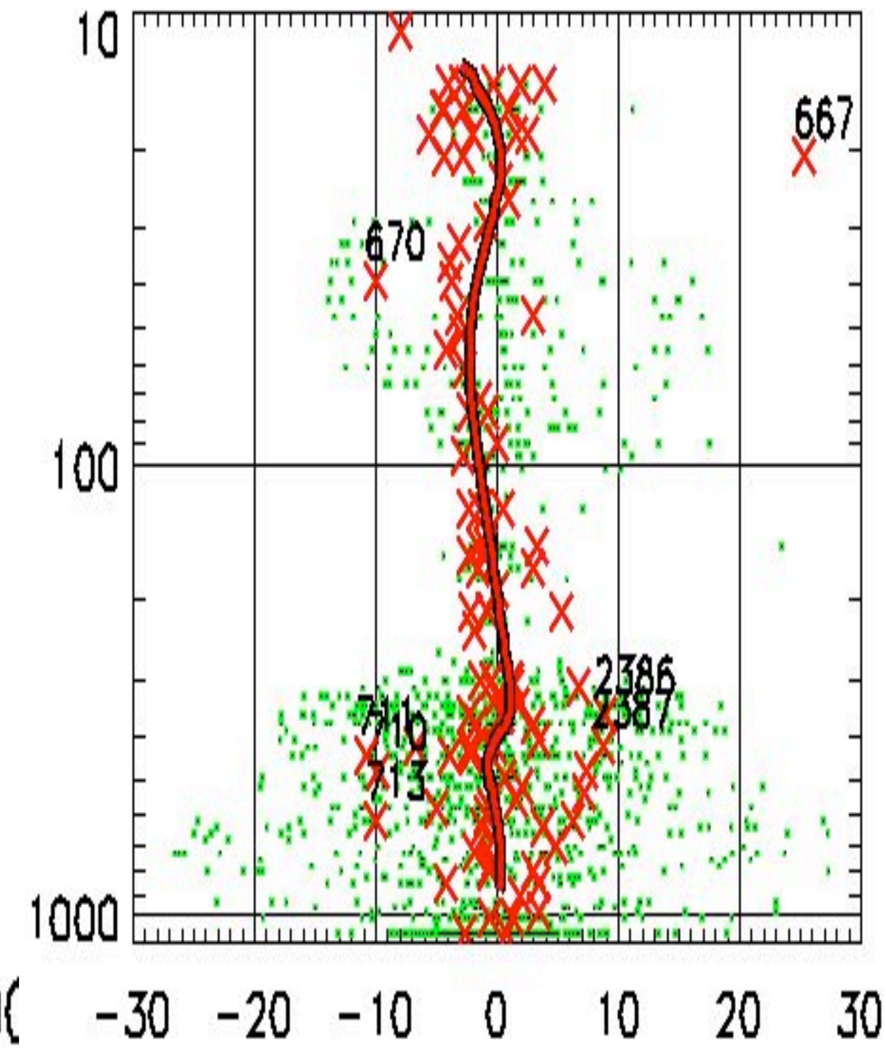
- Impact is up to 60 mK/yr
  - ~240 mK day/night
  - ~180 mK winter/summer
- This is ~1/4 of the trend measured by NOAA
  - This implies that there are other, larger causes of trends
  - But it is still big enough that it must be addressed in v6
- Climatology first guess nearly eliminates this effect.
  - But NOAA reports that using similar first guesses only reduces the overall trend they're seeing by ~50%

Profile Comparison

Apparent T(p) Trend from Uncorrected Spectral Trend



Apparent BT Trend from Uncorrected Spectral Trend



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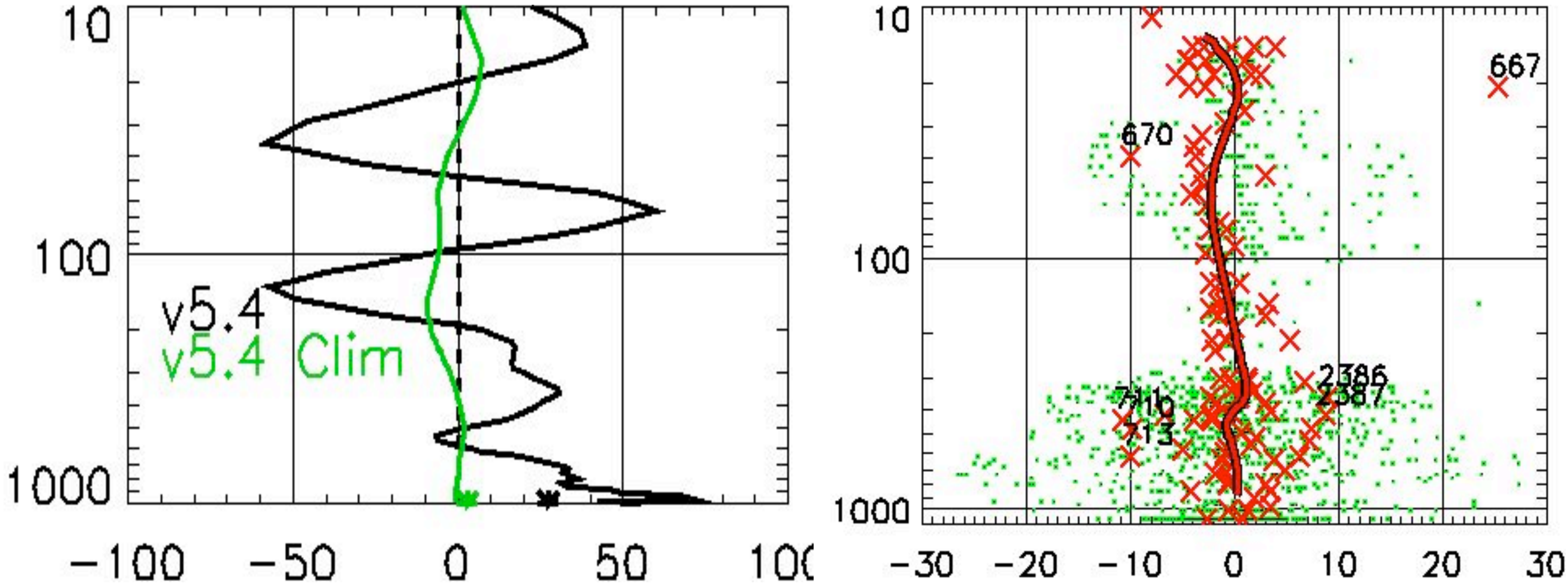
Profile Comparison



- The shifts in individual channels are not sufficient to explain the shift in the Level-2 products
- Cloud clearing may amplify the effect near the surface
- Regressions may misinterpret spectral shifts
  - The shift of -15 um in particular is far outside their training range
- The tropopause region is channel-poor.

Remaining V6 Tasks

Level-1B:

- Continue to refine L1B dynamic shift determination
  - Select additional reference spectra
  - Tune feature selection
  - Refine algorithm
- Models:
  - Fit models to UMBC and JPL shifts for historical data
  - Reconcile UMBC & JPL models
  - Evaluate the need for future dynamic model updates
- Implement & Test

Level-1C:

- Refine algorithm to meet 10x goal
- Implement & Test
- Evaluate performance for on-demand processing

Level-2:

- Implement embedded L1C
- Implement use of dynamic frequencies

Conclusions

- V5 spectral calibration is accurate enough for weather and many but not all climate applications.
- 0.1 um RMS spectral accuracy is attainable
  - 0.1 um ~= 12 mK RMS. (R branch)
  - This will make Level-1C clearly a climate product.
- The sensitivity of Level-2 to frequency shifts can be eliminated using algorithmic modifications and precise knowledge of frequencies.
- UMBC full-day cloudy simulations are an extremely useful tool