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The Impact Of the AIRS Spatial Response On Channel-To-Channel and Multi-Instrument Data Analyses

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Purpose

- **This presentation has two purposes**
- **Extend prior studies of the impact of the AIRS spatial response**
  - ***From effects on AIRS products alone***
  - ***To comparisons between AIRS and other instruments—in this case, Aqua MODIS***
- **Describe in one place the techniques which have been used to**
  - ***Measure the AIRS spatial response functions pre-launch***
  - ***Verify the measurements in-flight***

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Outline

- **Pre-launch AIRS spatial response measurements**
- **Post-launch verifications using coastal crossings**
  - ***Centroids and geolocation***
  - ***Verification of axes orientations of pre-launch measurements***
- **Science impact of spatial responses on AIRS products**
- **Effects of AIRS spatial response on AIRS/MODIS comparisons**
- **Summary and conclusions**

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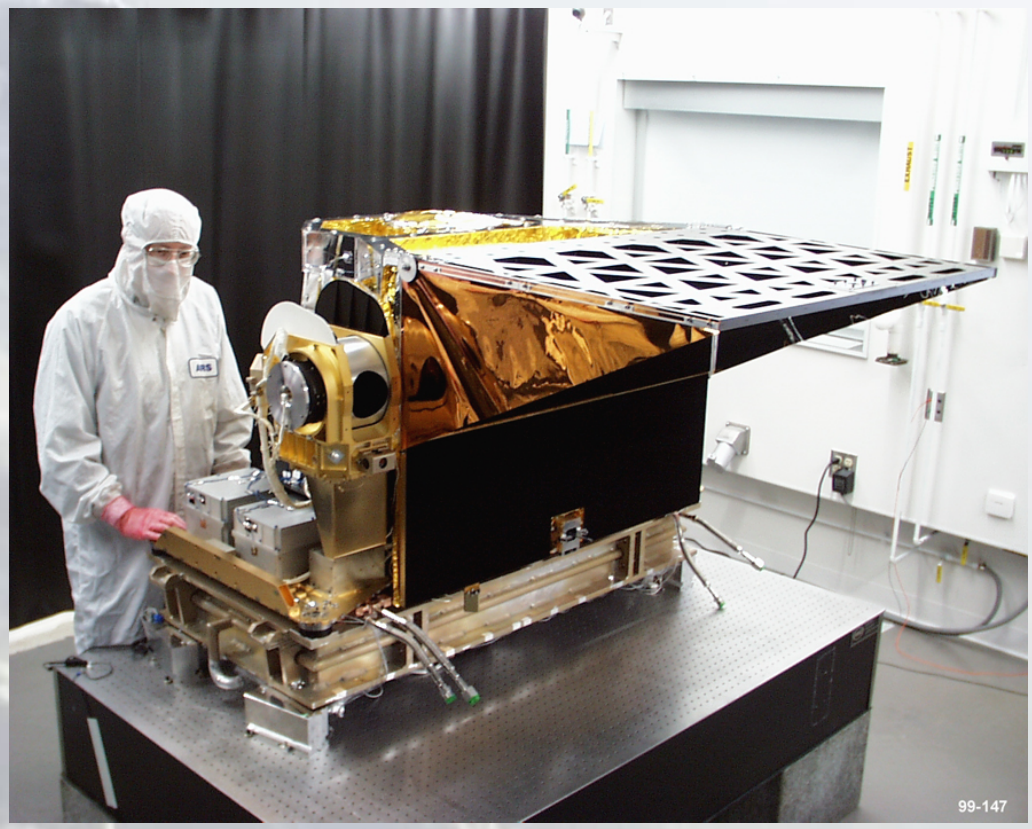
AIRS WAS DEVELOPED BY BAE SYSTEMS

AIRS Requirements

- IFOV : 1.1° x 0.6° (13.5 km x 7.4 km)
- Scan Range: ±49.5°
- IR Spectral Range: 3.74-4.61 µm, 6.2-8.22 µm, 8.8-15.4 µm
- IR Spectral Resolution: ≈ 1200 ($\lambda/\Delta\lambda$)
- No. IR Channels: 2378 IR
- VIS Channels: 4 (0.41-0.44 µm,0.58-0.68 µm, 0.71-0.92 µm,0.49-0.94 µm)
- VIS IFOV: 0.14° (1.7 km)
- Mass: 177Kg, Power: 256 Watts, Life: 5 years (7 years goal)



Background

- AIRS is a grating spectrometer—each of the 2378 IR channels has its own spatial response function
- Most channels have symmetric response functions and well-aligned boresights, meeting the instrument specifications of 99% spatial overlap from channel to channel
- Some channels, especially those near the ends of detector arrays, have significantly asymmetric responses and higher boresight offsets (response function centroids)

Pre-Launch Measurements

- A spatial collimator system was used to direct a point-source beam at programmable angles into the AIRS sensor assembly (no scan mirror present)
- Measurements were made on a 39x39 grid of points centered on the nominal boresight
- Spacing between points in both directions was 0.04 degrees for total coverage of a square 1.52 degrees on a side

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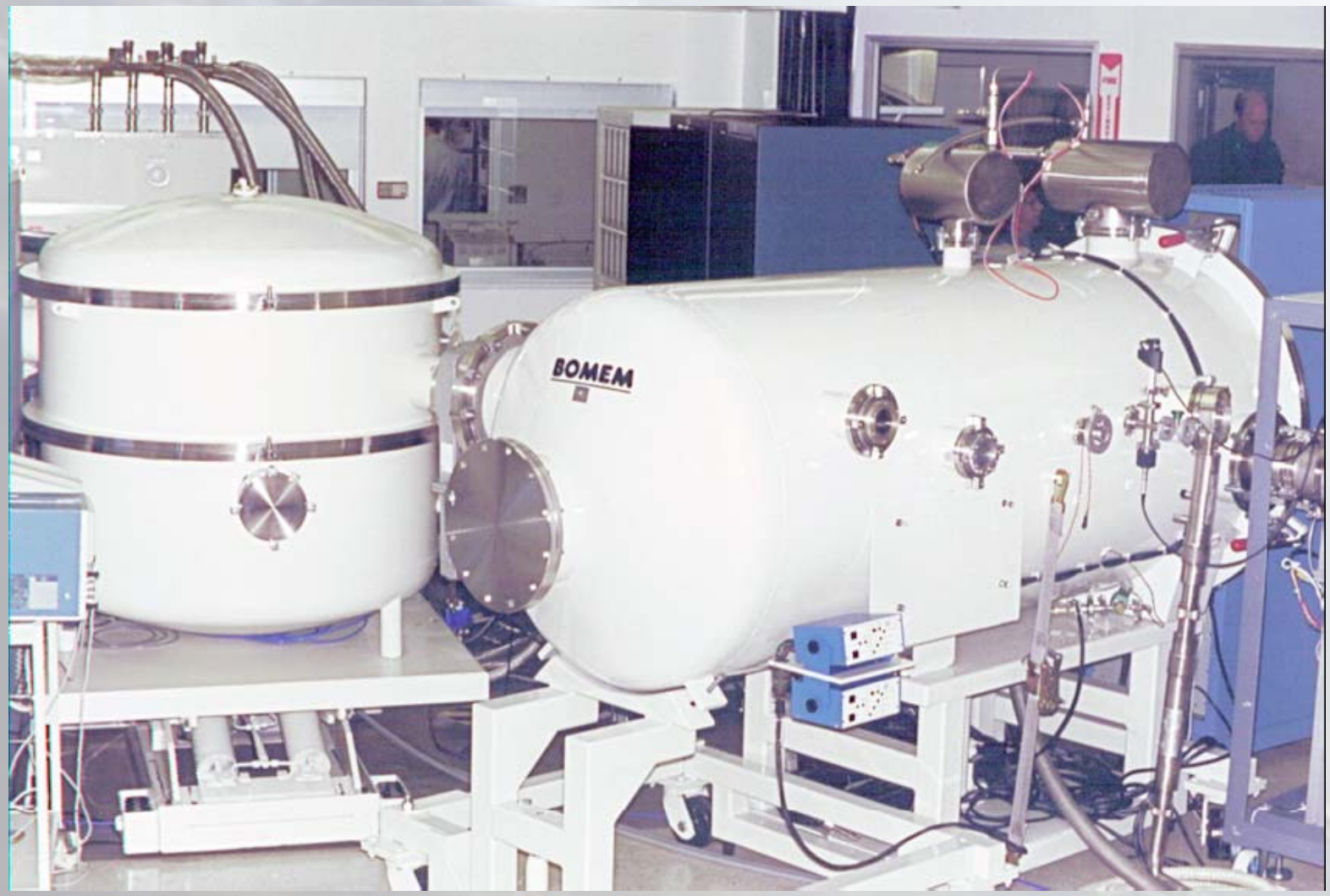
Spatial Collimator and Mini-Thermal-Vac Chamber With IR Sensor Assembly Inside



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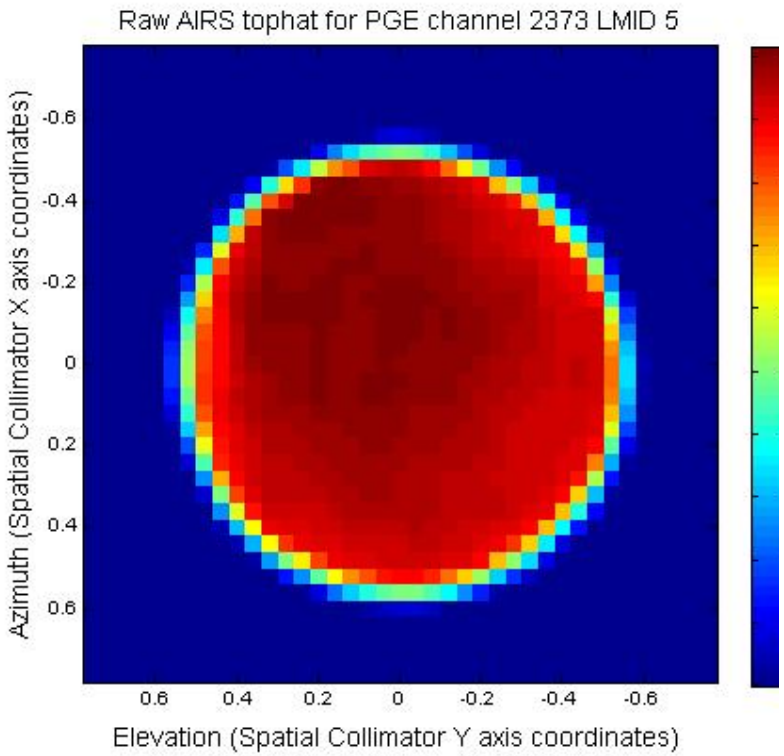
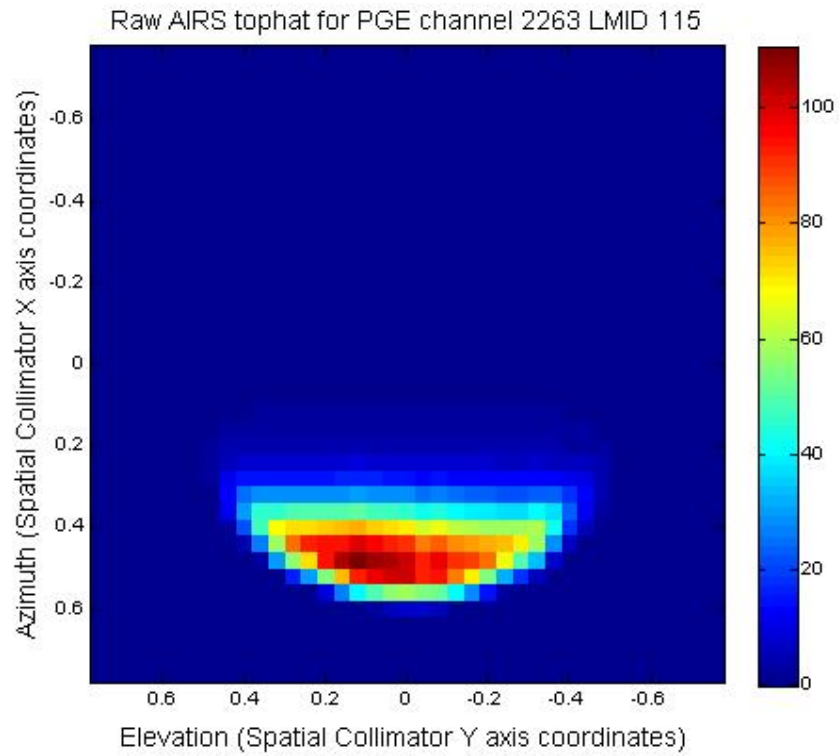
Sample Raw Spatial Response Functions





- **Normal AIRS spatial response function at the time of the testing**

- **Extremely asymmetrical example**
- **Due to shadowing of a detector near the end of an array**

In-Flight Spatial Response

- The raw response functions are not immediately applicable to flight data
- After testing, a field stop was added which limited the spatial response to 0.6 degrees in the in-scan direction
- The presence of the scan mirror introduces an additional reflection into the system
- As the scan mirror rotates, so does the spatial response
- The AIRS scanner is NOT a stepper, but is in continuous motion—thus the actual response is smeared in the in-scan direction
- The smearing improves the channel-to-channel uniformity of the spatial response, but does not eliminate all variability

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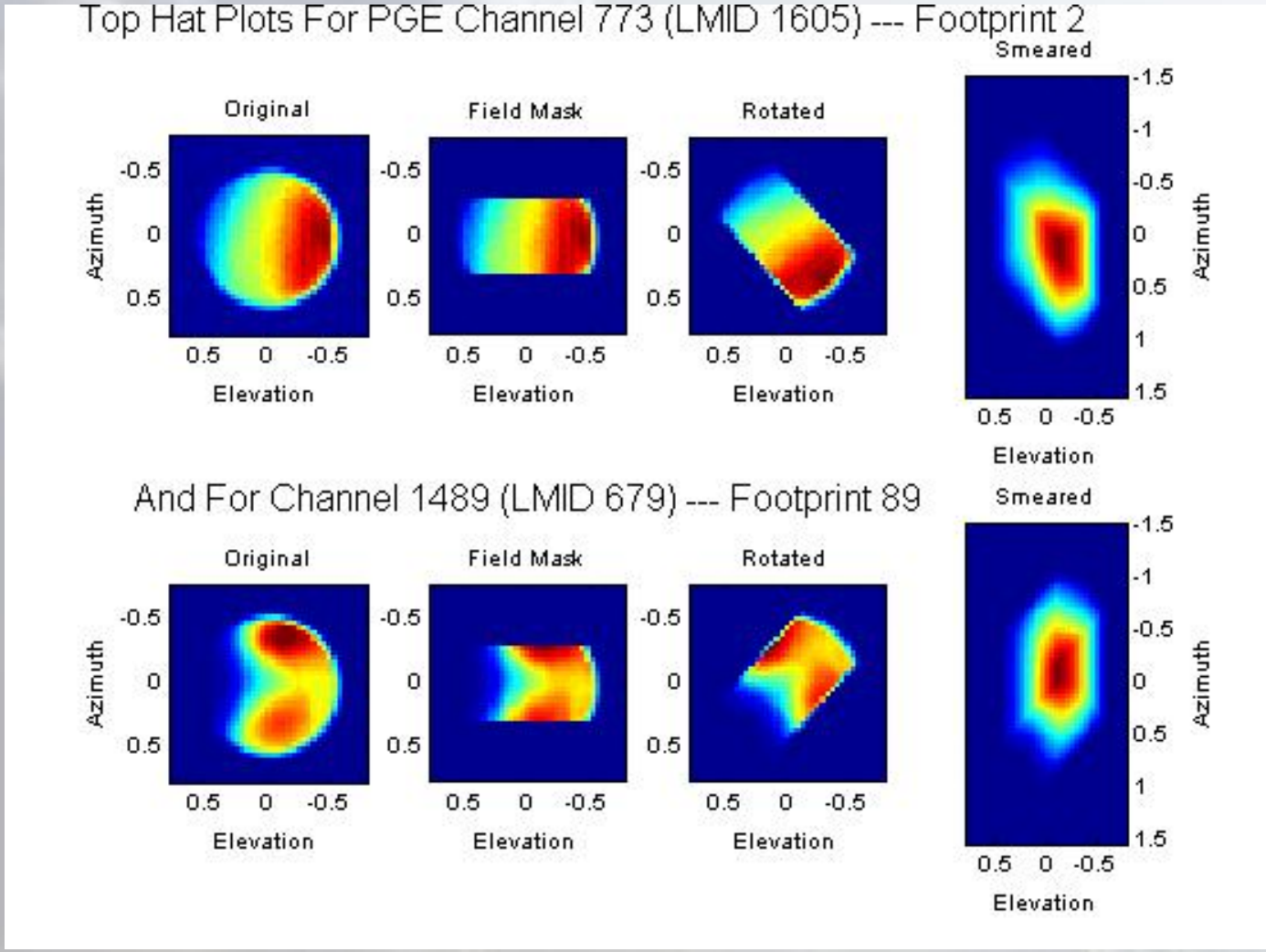
Processing Of Pre-Launch Spatial Response Functions



Summary Of Post-Launch Verifications

- **Coastal Crossings**
  - ***Centroid verification (effect on geolocation)***
  - ***Orientations of the x-y axes of the measured 2-D response functions***
    - The measurements were made before a change to the optics was made
    - The measurements were made without the scan mirror in place
    - The measurements were of course made before the instrument was integrated with the spacecraft
- **Analysis of AIRS and MODIS overlapping scenes**
  - ***Used to verify the full 2-D response function measurements***

Geolocation Check Using Coastal Crossings

- Early analysis of coastal crossings showed that there was an error amounting to about 2 km (in a 15 km footprint) on the ground
- The software used in the geolocation process is included in the EOS toolkit used by all EOS instruments and had been thoroughly checked out—so the error had to be in the data or very early in the calculation, before the toolkit was used
- Although not considered likely, this could have been due to a systematic problem with the spatial response measurements
- In fact, it turned out to be due to a small error in the software in the very first step—conversion from scan mirror raw data numbers to scan angles
- All AIRS products now available at the Goddard DAAC were prepared using correct geolocation parameters
- This episode points out the importance of verifying ground measurements in flight wherever possible, even for apparently simple quantities

Measured Spatial Response Orientation Verification

- **Because some detectors have significantly non-uniform or asymmetrical responses, it is important to know the orientation of the measured spatial response functions**
  - ***In the 39x39 arrays, measured in spatial collimator coordinates, which way represents increasing scan angle?***
  - ***Which direction is the same as the spacecraft motion?***
- **A careful trace through the various coordinate systems involved (spatial collimator, AIRS instrument including scan mirror, and spacecraft) was performed analytically**
- **The results were verified using difference images from pairs of channels with asymmetric responses**
  - ***One pair differed significantly in the in-scan direction***
  - ***The other differed in the along-track direction***
- **Once again, coastal crossings provided the input data**

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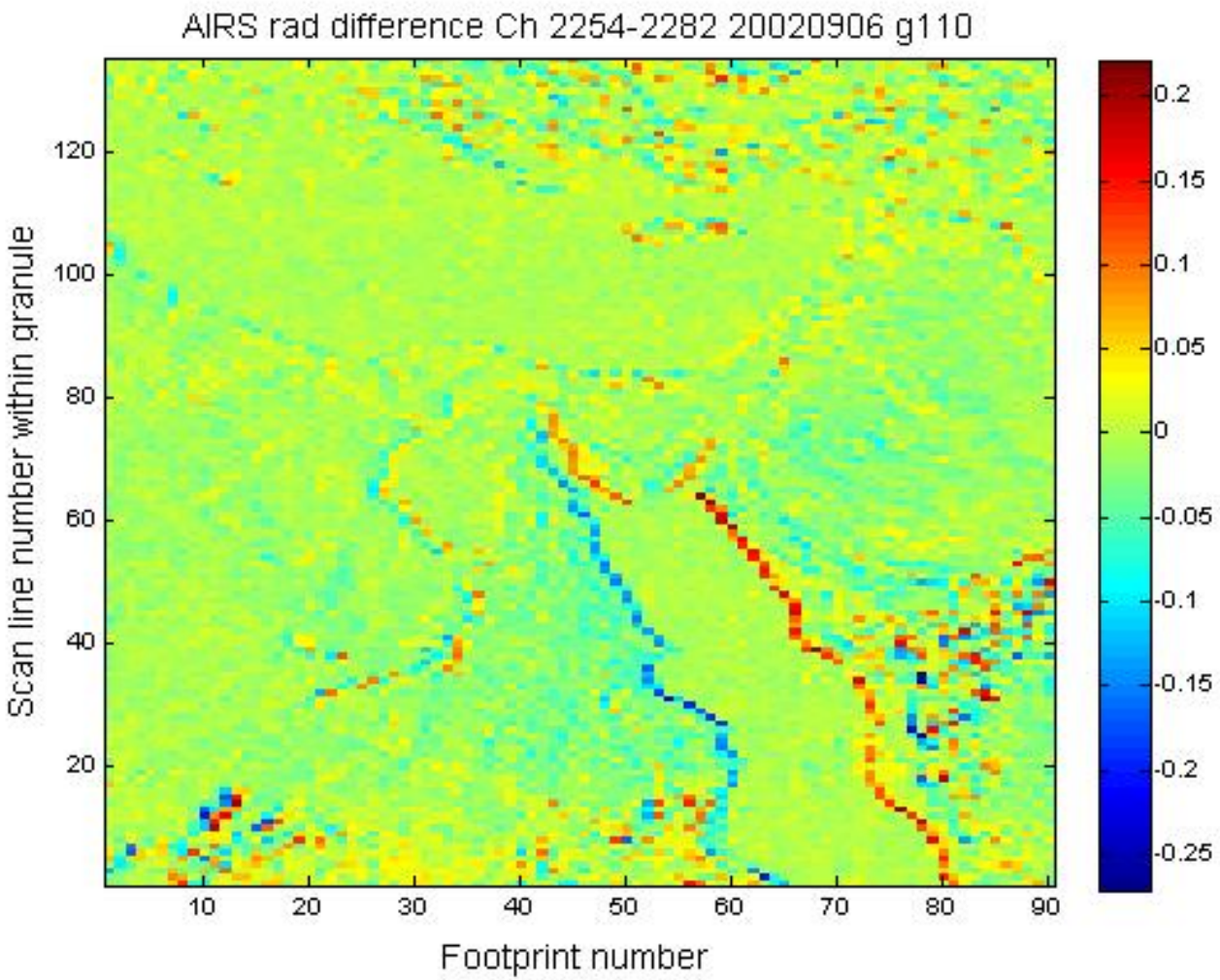
Verification Of Spatial Response Orientation



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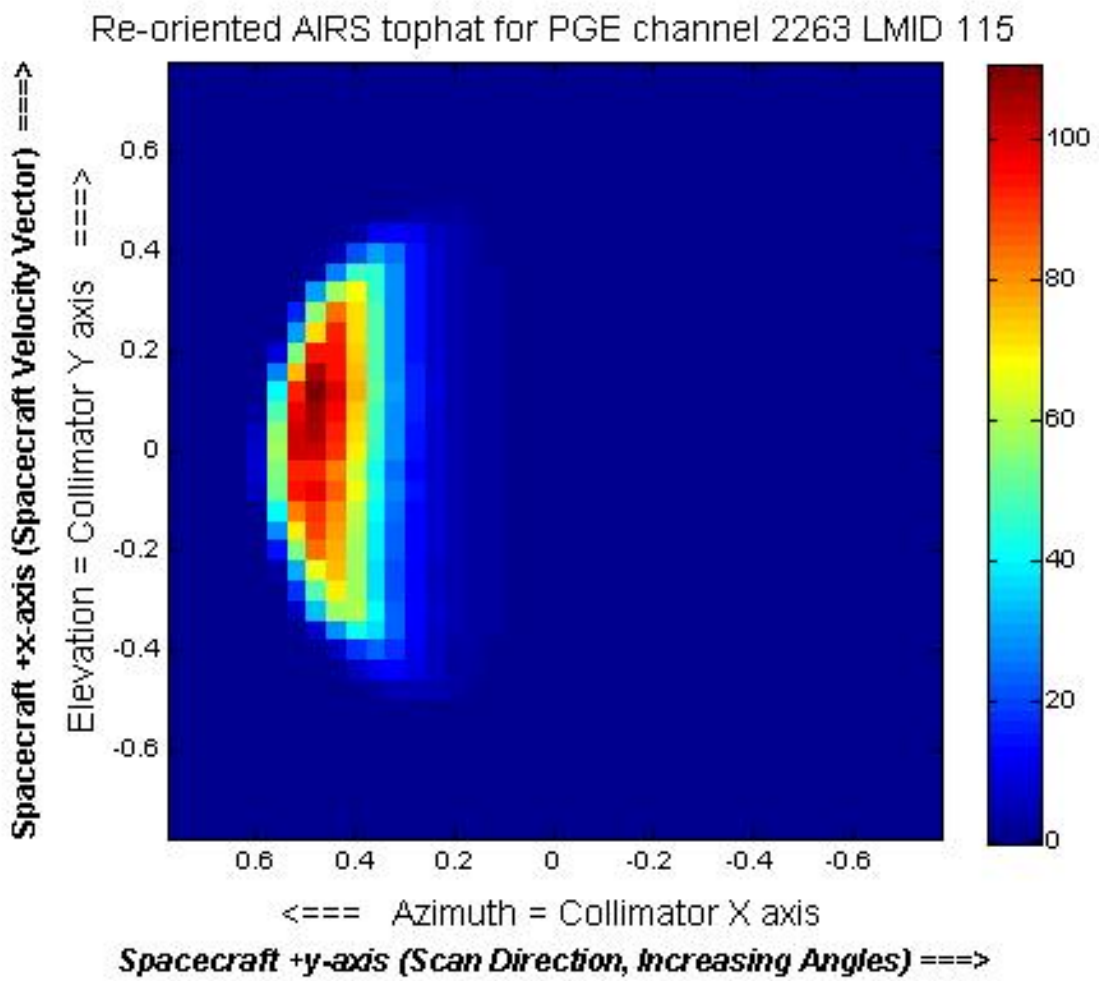
Orientation Results



AIRS Spatial Response Science Impact

- It has been shown (by Chris Barnet of NOAA and the AIRS Science Team) that there is no discernible impact on temperature and humidity profile retrieval accuracy, at the retrieval resolution of 45 km, for typical AIRS misalignments
- The only effect on retrievals is the addition of a small amount of noise, on the order of 0.1K
- In high contrast scenes at 15 km resolution, there can be significant effects due to differing boresight directions for different AIRS channels
- These effects are much more significant for the minority of AIRS channels whose overlaps are less than 99%

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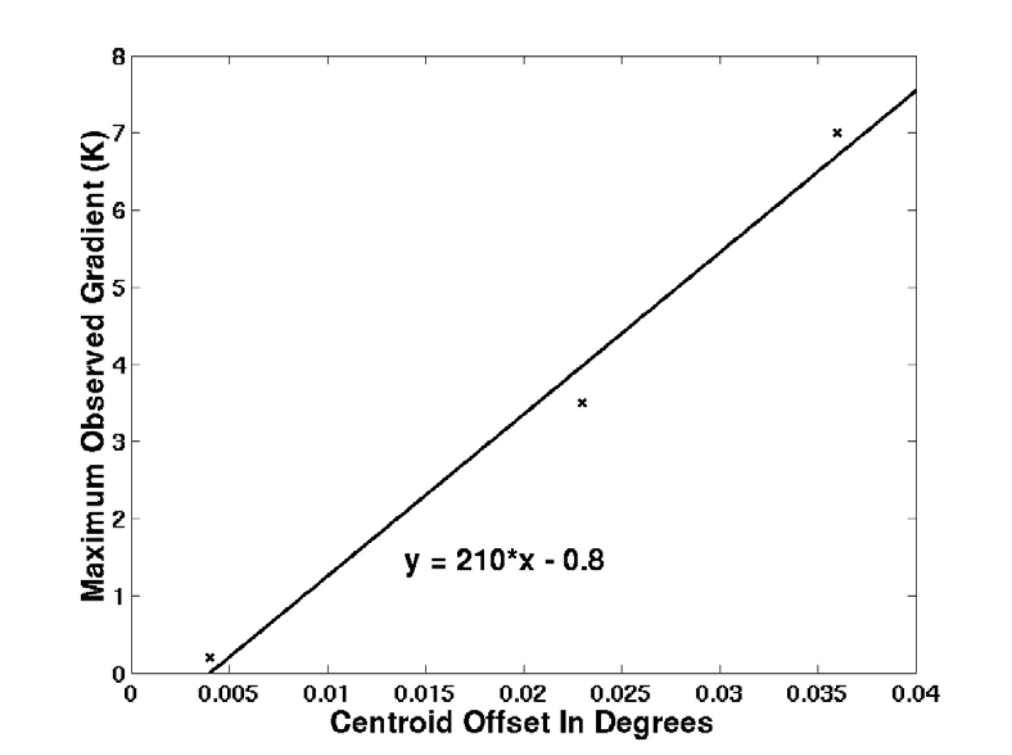
Maximum Gradients Versus Boresight Offset

- In a March 2005 paper presented at SPIE Orlando we analyzed three pairs of channels in a single high contrast scene
  - *Very well aligned*
  - *Moderately misaligned*
  - *Unusually misaligned*
- The maximum apparent gradients seen in difference images were proportional to the boresight offsets as measured pre-launch
- This result underscored the importance of understanding the instrument spatial response when drawing conclusions



Verification Of 2-D Response Functions

- **The basic assumption of this analysis is that an AIRS scene can be considered to be a convolution of an Aqua MODIS scene with the AIRS spatial response function**
- **Aqua MODIS**
  - ***Flies on the same platform as AIRS***
  - ***Is also a cross-track scanner, so it has very similar ground coverage***
  - **It has about 14 times better spatial resolution than AIRS**

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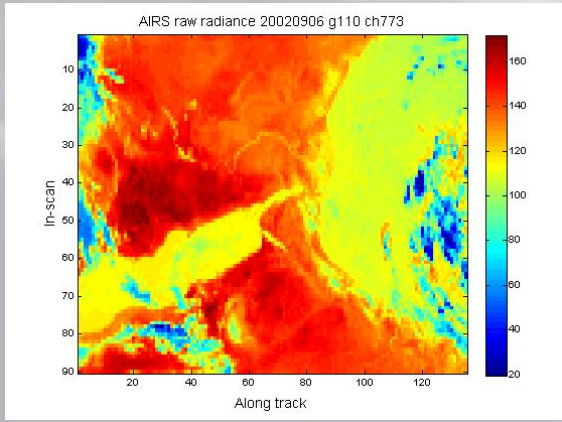
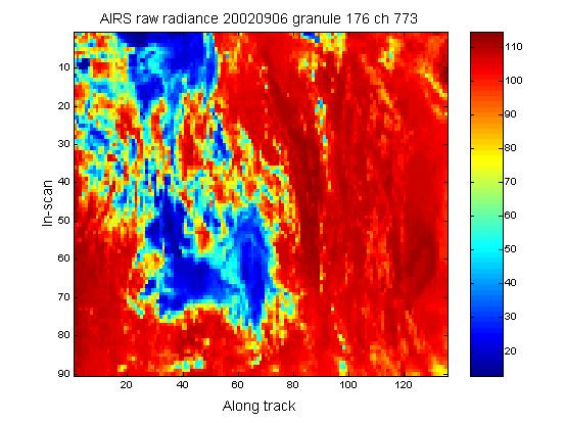
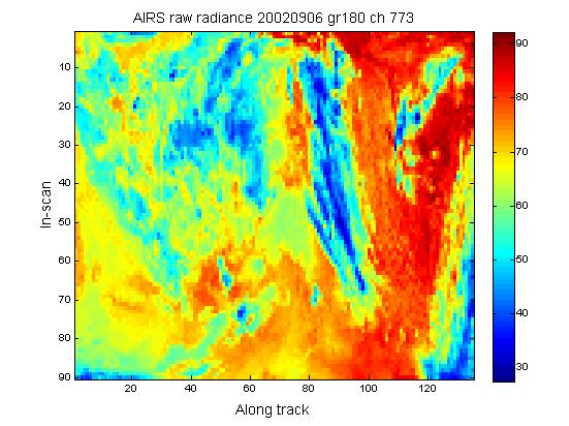
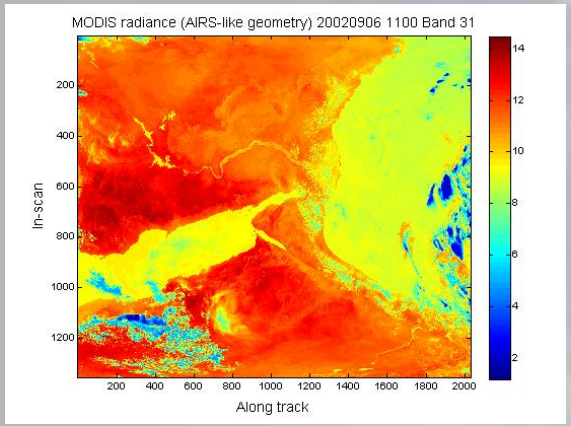
Data Used

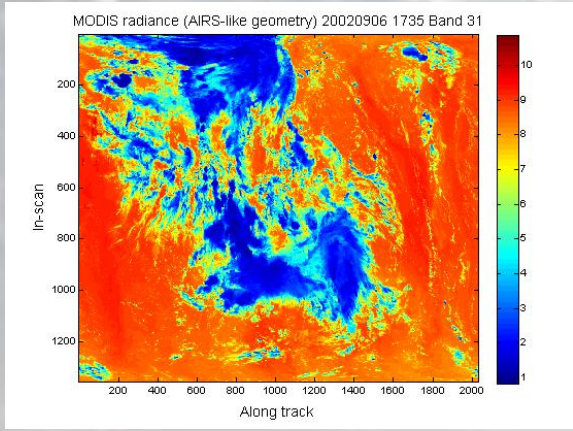
- **12 AIRS granules from September 6, 2002**
- **13 MODIS granules which overlap the AIRS granules**

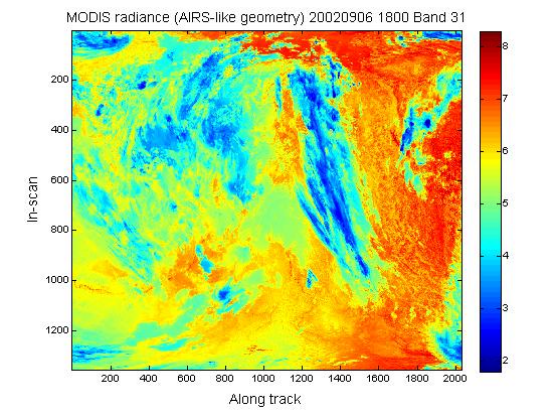












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Direct Brightness Temperature Comparison

- **For each AIRS pixel near nadir, find a corresponding MODIS brightness temperature using three different methods**
  - ***Single MODIS pixel at same location as AIRS pixel***
  - ***Average of a square (21x21) neighborhood of MODIS pixels centered at same location as the AIRS pixel***
  - ***Weighted average of the square neighborhood, where weights are from the AIRS spatial response function resampled to MODIS resolution***
- **For all three methods the MODIS data were resampled so that one MODIS pixel fell exactly on the nominal location of the AIRS pixel**
- **For AIRS brightness temperatures we used the average of three channels near 11 microns (within MODIS Band 31)**
- **For MODIS we used Band 31**

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MODIS Resampling (Conceptual)

O = original MODIS O = Resampled MODIS X = AIRS center

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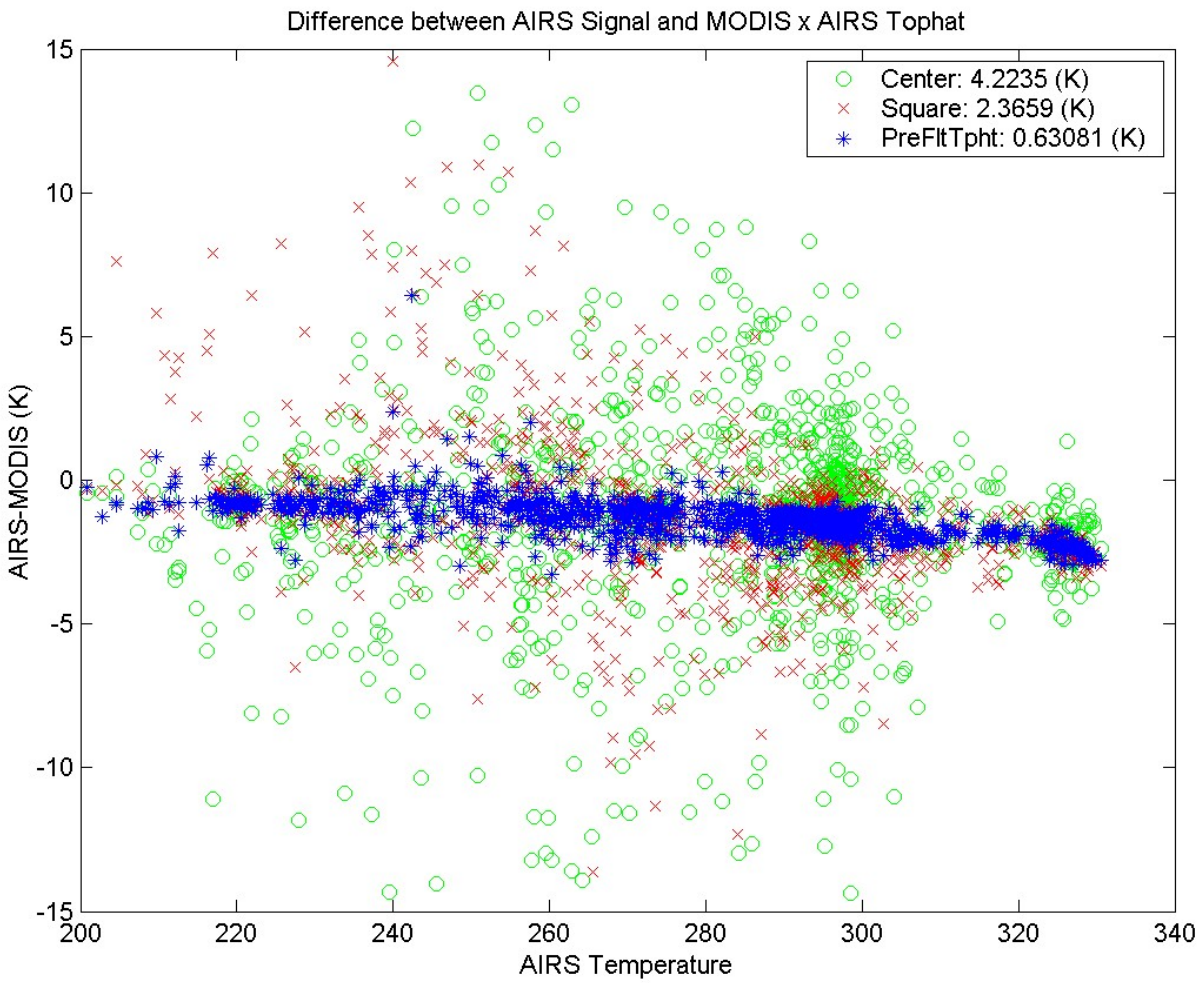
AIRS/MODIS Comparison At 11 Microns (MODIS Band 31)



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Results Of Direct Comparison

- Co-located pixel difference has standard deviation of 4.2 K
- Average of square neighborhood has st. dev. 2.4 K
- Weighted sum using measured spatial response gives 0.6 K
- <u>The key point is that the scatter has been significantly reduced</u>
- Implies that the pre-flight measured spatial responses are reasonable and consistent with what we see in flight
- Implies that MODIS-AIRS comparisons have improved reliability if the AIRS spatial response is taken into account

Radiometry bias

- **The slope and negative bias of the AIRS vs. MODIS brightness temperature plot are due to spectral differences**
  - ***The three AIRS channels we used did not properly synthesize the MODIS spectral response***
  - ***They put too much emphasis on water channels, which produce lower brightness temperatures than window channels***
- **The following paper, by Steve Broberg et. al., discusses AIRS/MODIS radiometric comparisons using carefully selected AIRS channels, but does not fully account for the AIRS spatial response**
- **As our next step we intend to repeat our analysis using the same channels used by Broberg et. al.**
- **We expect to see the bias disappear**

Calculate AIRS SRF From Flight Data

- Another area of current work is an attempt to calculate the AIRS spatial response from flight data alone
- The basic assumption, again, is that an AIRS image is equal to a MODIS image convolved with the AIRS spatial response function
- We are using the same data used in the direct brightness temperature comparison
- So far we have used both Fourier transform and matrix inversion techniques to solve for the AIRS spatial response

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Calculate AIRS SRF Using Matrix Inversion

- **Use the following matrix equation**
- $$[M]_{1309,425}[s]_{425,1} = [A]_{1309,1}$$
  - ***[A] is a set of AIRS nadir pixels in an image which overlaps the MODIS image***
  - ***[M] is a set of neighborhoods of pixels in a MODIS image—the center of the neighborhood is at the location of an AIRS nadir pixel***
  - ***[s] is the desired AIRS spatial response***
- **This equation is solved for the best-fitting [s]**
- **So far this method has not produced good results**
- **There are several geometric and radiometric problems which will need to be resolved before this technique can be used effectively, including but not limited to**
  - ***Differences in the details of how the MODIS and AIRS scanners work***
  - ***MODIS and AIRS spectral sensitivity differences***

Summary And Conclusions

- Each AIRS channel has its own spatial response function, which was measured before launch
- We have verified those measurements in flight
- Coastal crossing analyses have shown that the measured centroids are correct in that geolocation results are as expected
- The orientation of the spatial response functions has been confirmed using coastal crossings
- The pre-launch full 2-D response functions have been shown to improve comparisons between MODIS and AIRS radiometry, significantly reducing scatter in high-contrast scenes
- We have not yet succeeded in independently deriving reasonable spatial response functions directly from flight data

Backup

BACKUP

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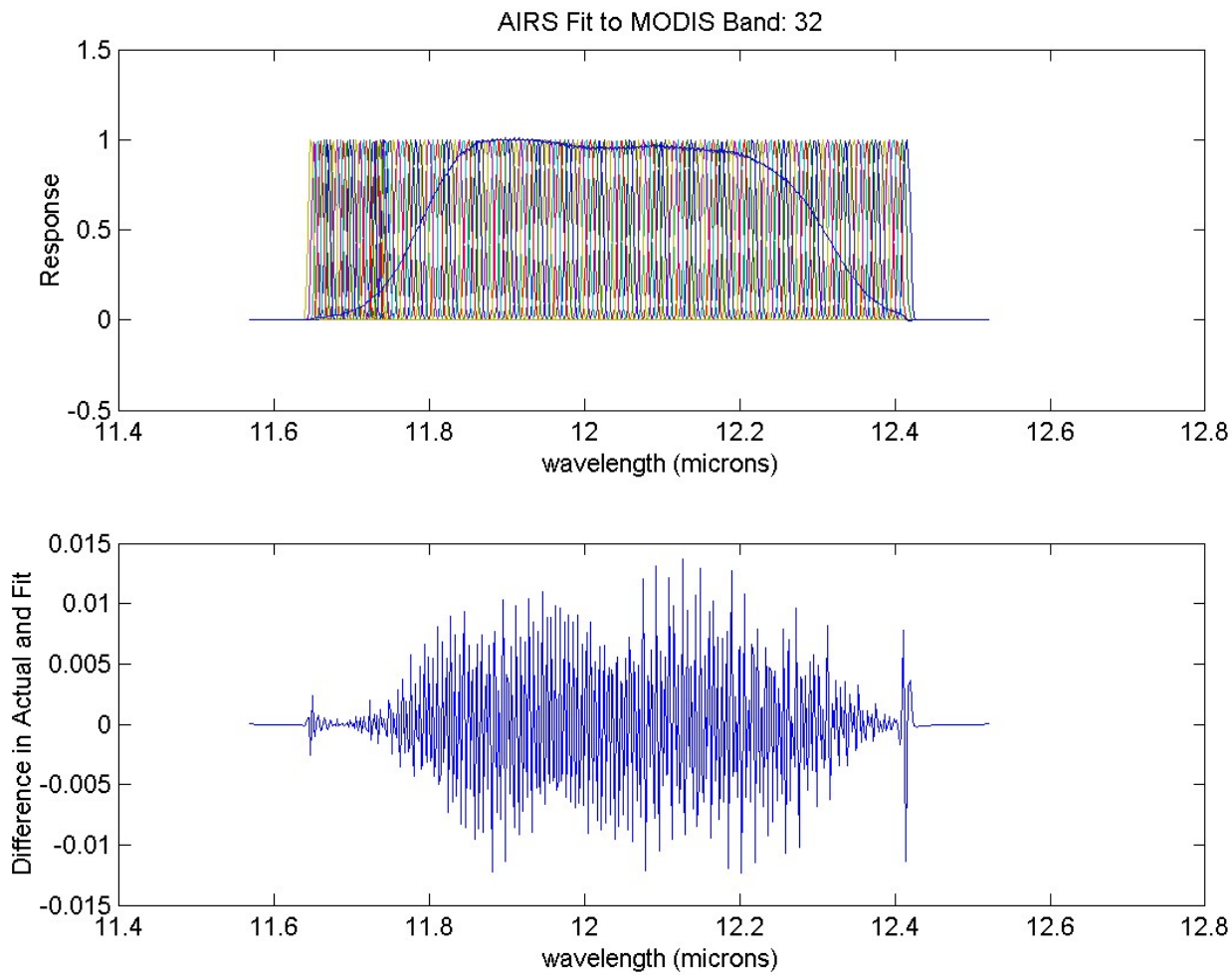
AIRS Synthesis Of MODIS Band 32



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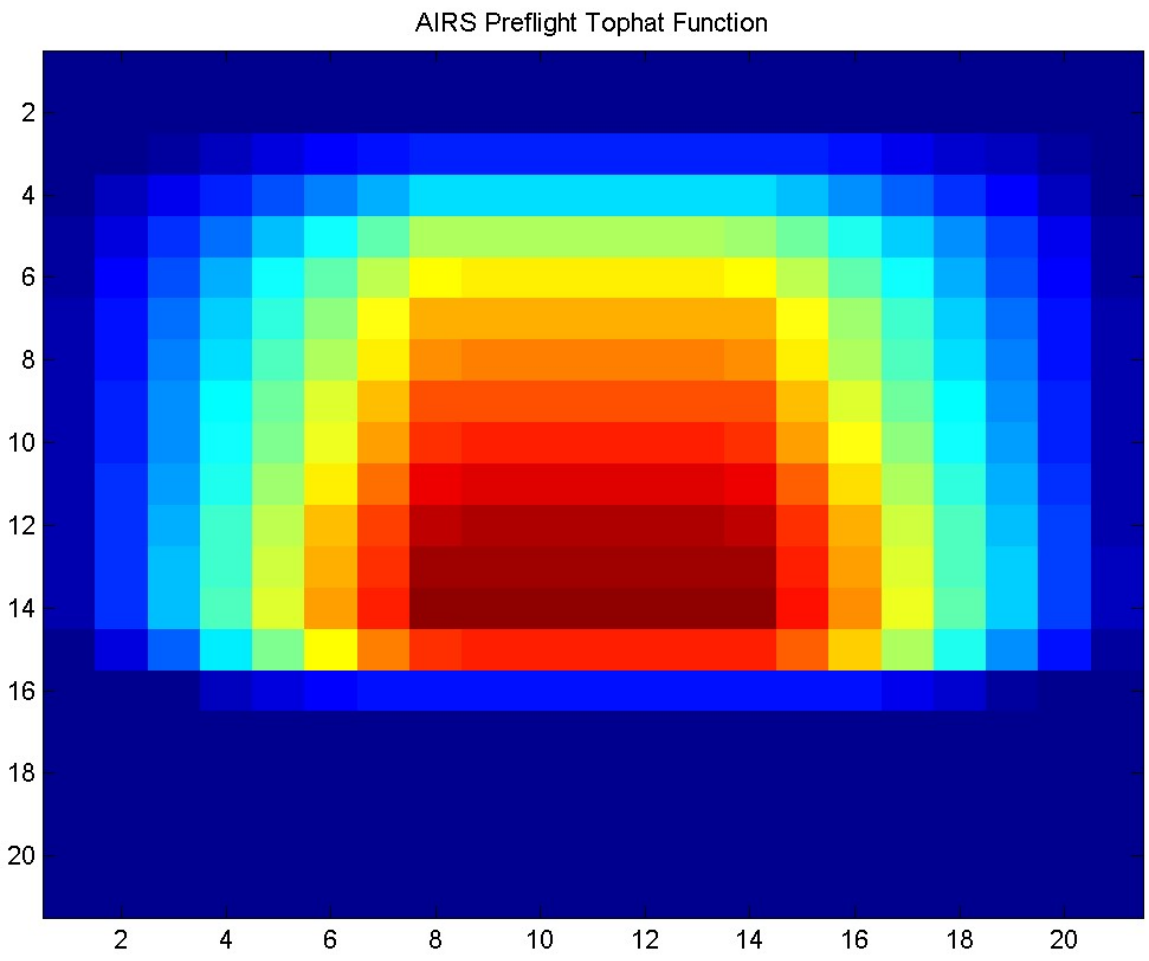
AIRS 11-Micron Channel Spatial Response Used