LWIR Band Radiometric Performance
(Atmosphere Group)

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with the usual outstanding support from MCST

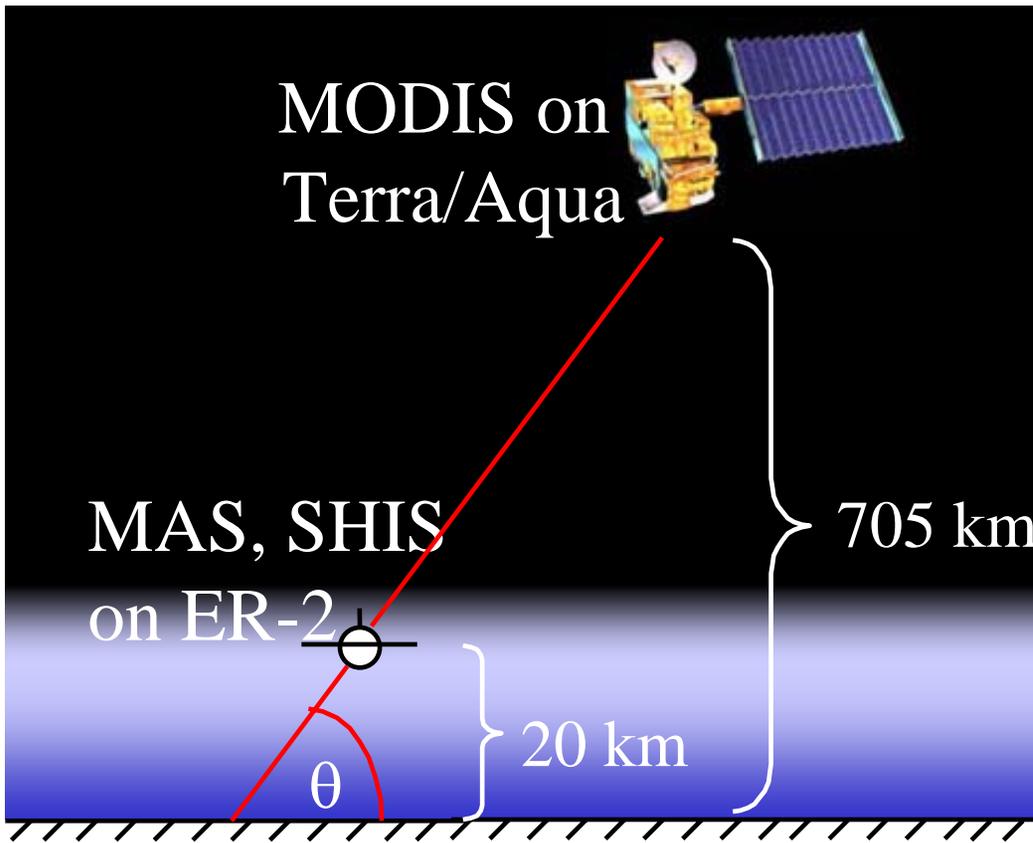Presented at MCST Calibration Subgroup Mtg
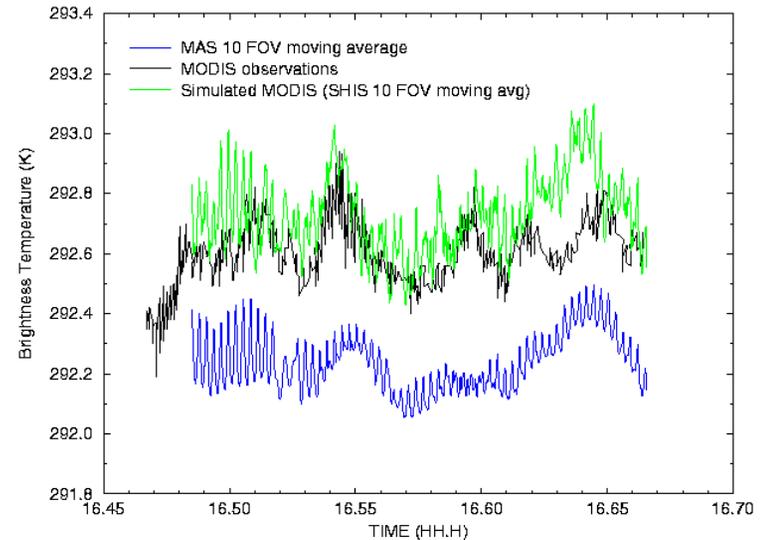Nov. 1, 2006

Outline

- ER-2 aircraft-based assessment of MODIS LWIR band calibration accuracy

- Other assessments of MODIS LWIR calibration accuracy

- Review possible contributions to MODIS radiometric error in LWIR bands

- Summary

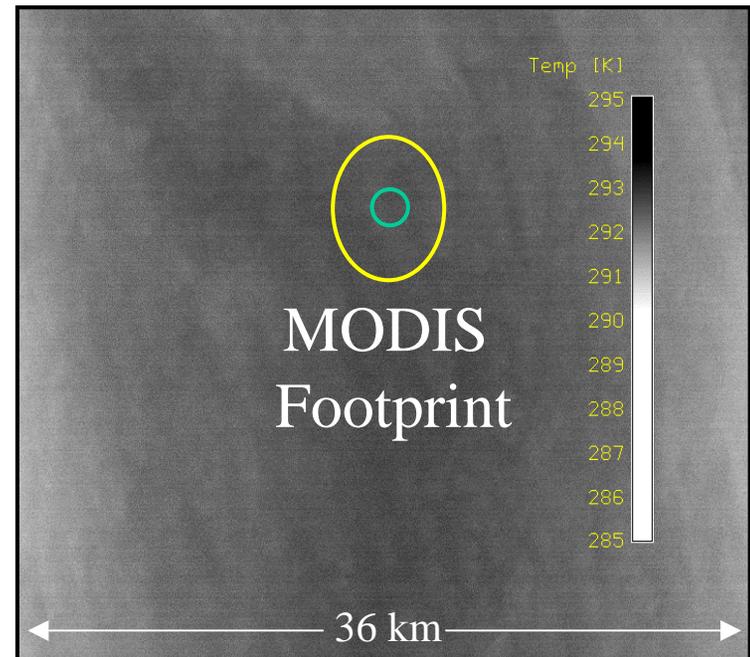# *MODIS Emissive Band Cal/Val from the NASA ER-2 Platform*

1. Collect MODIS and ER-2 co-incident data

MODIS on Terra/Aqua

MAS, SHIS on ER-2

705 km

20 km

θ

2. Transfer SHIS calibration to MAS

Brightness Temperature (K)

- MAS 10 FOV moving average
- MODIS observations
- Simulated MODIS (SHIS 10 FOV moving avg)

TIME (HH.H)

3. Co-locate MODIS FOV on MAS

Temp [K]

295
294
293
292
291
290
289
288
287
286
285

MODIS Footprint

36 km
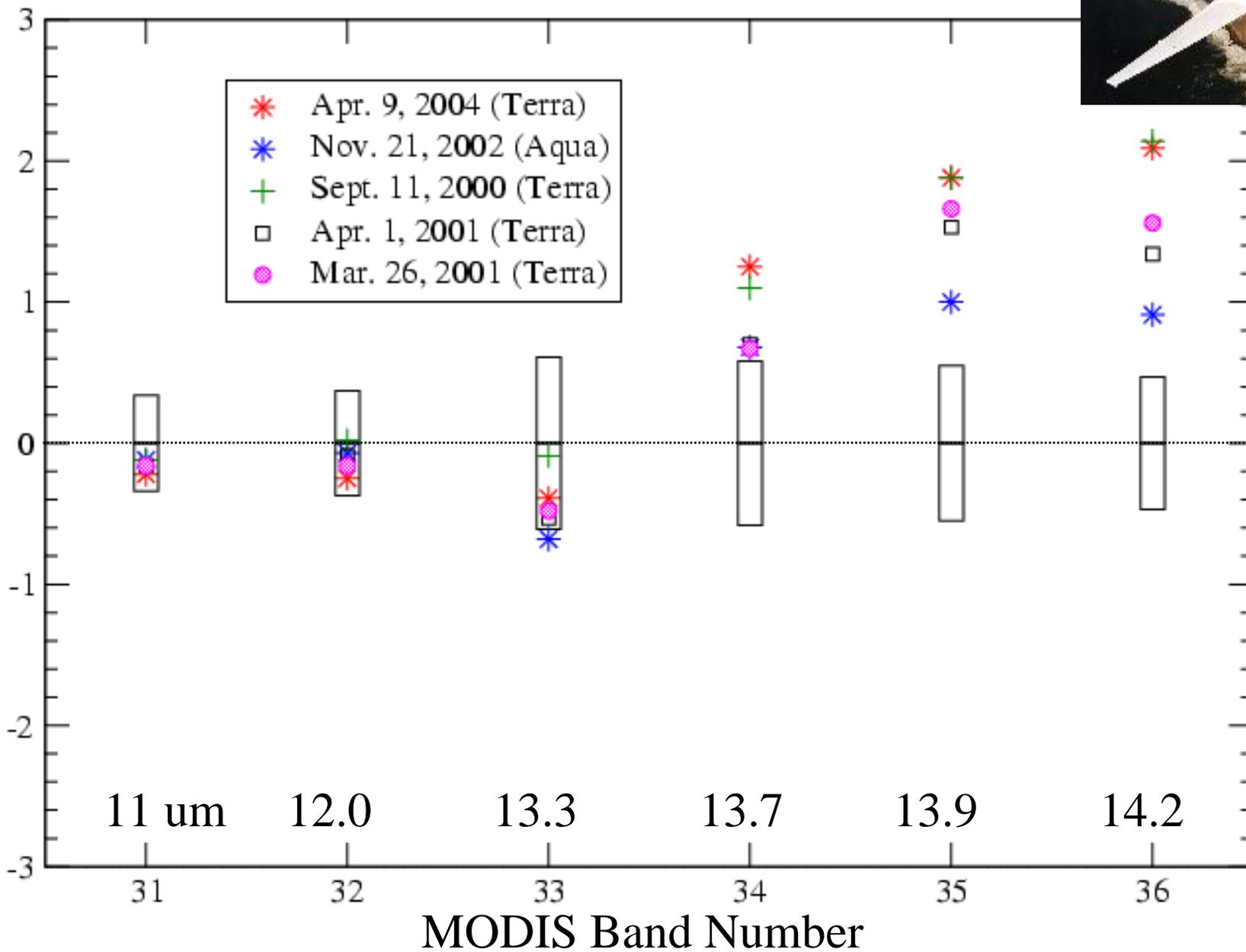
MODIS TIR Band Accuracy Assessment

Collect 5

3 Conclusions about MODIS LWIR Calibration Accuracy

1. MODIS LWIR window bands 31,32 are consistently performing within specification over the lifetime of the missions.

2. MODIS LWIR CO2 bands, esp. bands 35, 36 are consistently performing out-of-specification.

3. The residuals for Terra MODIS CO2 bands are larger (further from specification) than those of Aqua MODIS.
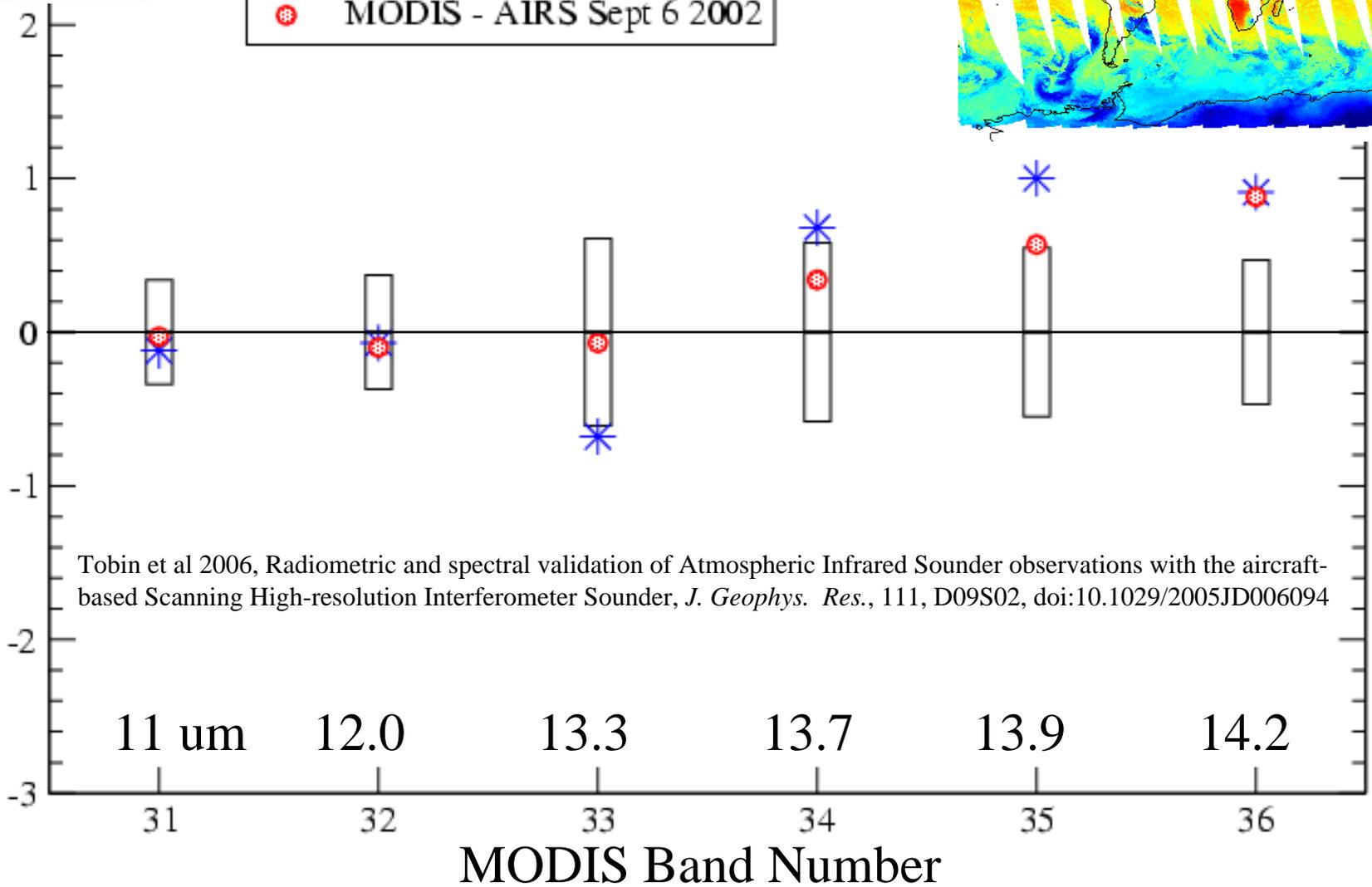
WHY????

MODIS TIR Band Accuracy Assessment

Collect 5
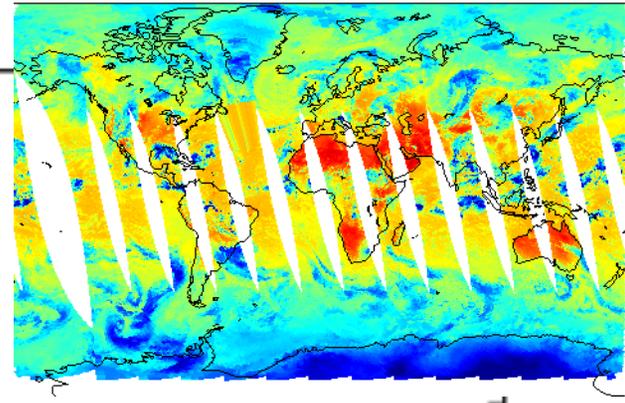
Legend:
- ✳ Nov. 21, 2002 (Aqua)
- ⊛ MODIS – AIRS Sept 6 2002

Tobin et al 2006, Radiometric and spectral validation of Atmospheric Infrared Sounder observations with the aircraft-based Scanning High-resolution Interferometer Sounder, *J. Geophys. Res.*, 111, D09S02, doi:10.1029/2005JD006094

Y-axis: MODIS Observed – Predicted (K)

X-axis: MODIS Band Number

Band labels: 11 um (31), 12.0 (32), 13.3 (33), 13.7 (34), 13.9 (35), 14.2 (36)

Summary of MODIS Comparisons (Uncertainties)

Band	31	32	33	34	35	36
ER-2 avg (T)	-0.17 (0.13)	-0.12 (0.13)	-0.37 (0.15)	0.93 (0.18)	1.74 (0.30)	1.77 (0.37)
Lake Titicaca (T)	0.12 (0.28)	-0.19 (0.28)	0.55 (0.77)	-----	-----	-----
Lake Tahoe (T)	-0.02 (0.3)	-0.10 (0.3)	-----	-----	-----	-----
ER-2 avg (A)	-0.12 (0.13)	-0.07 (0.13)	-0.68 (-.15)	0.68 (0.18)	1.00 (0.30)	0.91 (0.37)
AIRS (A)	-0.03 (0.02)	-0.10 (0.03)	-0.07 (0.11)	0.34 (0.02)	0.57 (0.05)	0.88 (0.06)
Terra – Aqua	0.13	0.19	-----	-----	-----	-----

(T) – Terra; (A) - Aqua

Some Possible Contributors to MODIS Calibration Bias

1. On-orbit Calibration Coefficients
2. Spectral Characterization
3. Optical Cross-talk (Terra only)
4. Out-of-band Filter Leaks
5. Scan mirror reflectivity (RVS)

Other systematic influences include:
- Scan mirror temperature
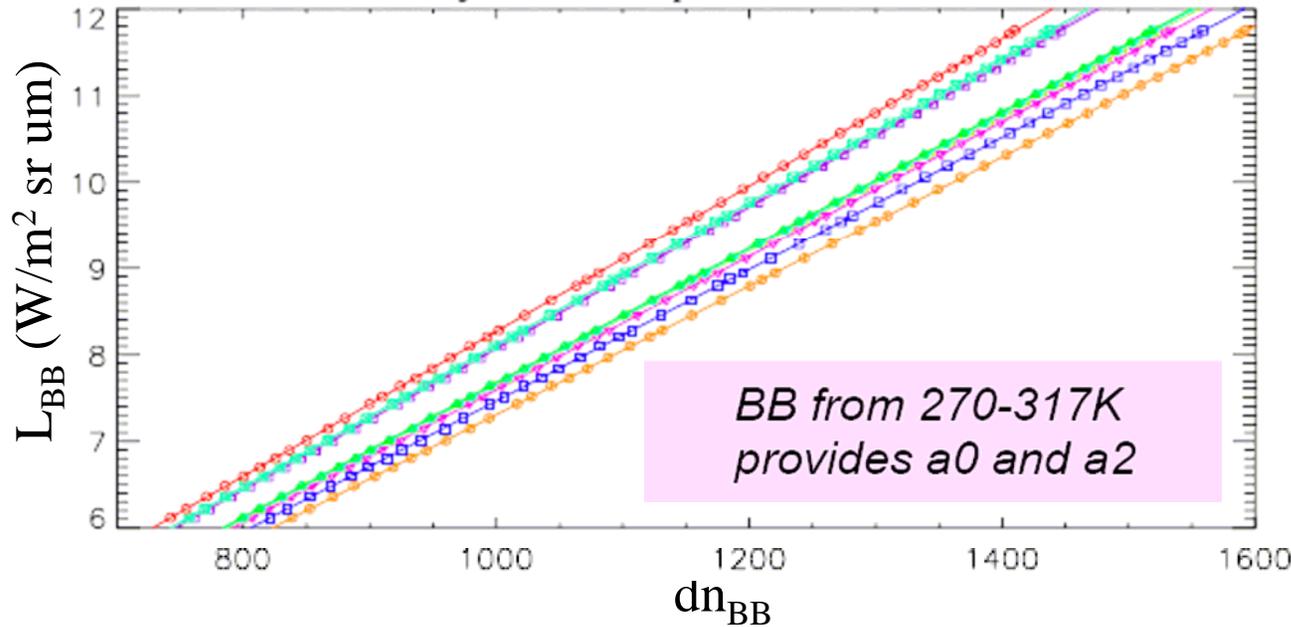- BB emissivity and temperature
- Scan cavity emissivity and temperature

These are expected to be small influences (<0.1 K).

1. On-orbit Cal Coefficients

Blackbody Warm-up Calibration Curves

BB from 270-317K provides a0 and a2

Radiance (TOA), L_{EV}

$$L_{EV} = \frac{1}{RVS_{EV}}\left(a_0 + b_1 \cdot dn_{EV} + a_2 \cdot dn_{EV}^2 - \left(RVS_{SV} - RVS_{EV}\right) \cdot L_{SM}\right)$$

RVS: Response Versus Scan-angle

ε: Emissivity

L: Spectral band averaged radiance
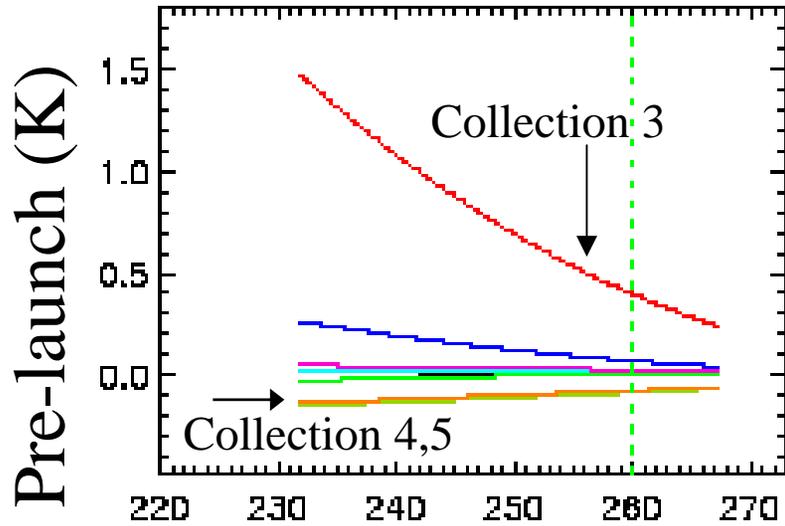
dn: Digital count with background corrected

Calibration coefficient, b1, from BB

$$b_1 = \left(RVS_{BB} \cdot \varepsilon_{BB} \cdot L_{BB} + \left(RVS_{SV} - RVS_{BB}\right) \cdot L_{SM} + RVS_{BB} \cdot \left(1 - \varepsilon_{BB}\right) \cdot \varepsilon_{cav} \cdot L_{cav} - a_0 - a_2 \cdot dn_{BB}^2\right) / dn_{BB}$$
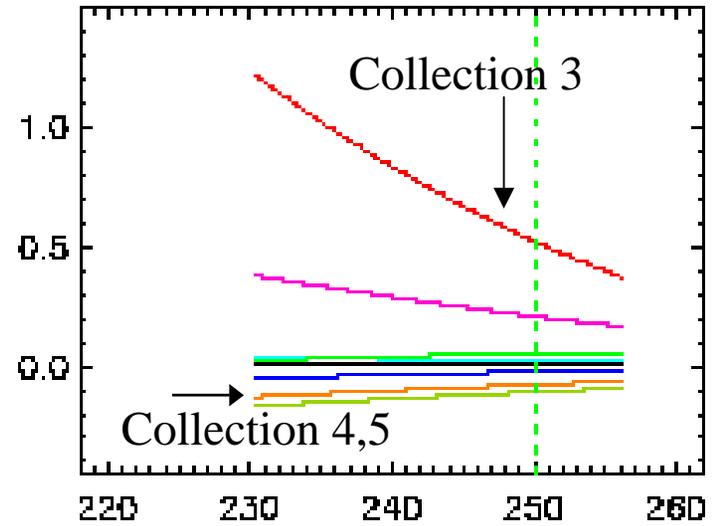
Slide courtesy of MCST

Terra MODIS LWIR PC Band Calibration

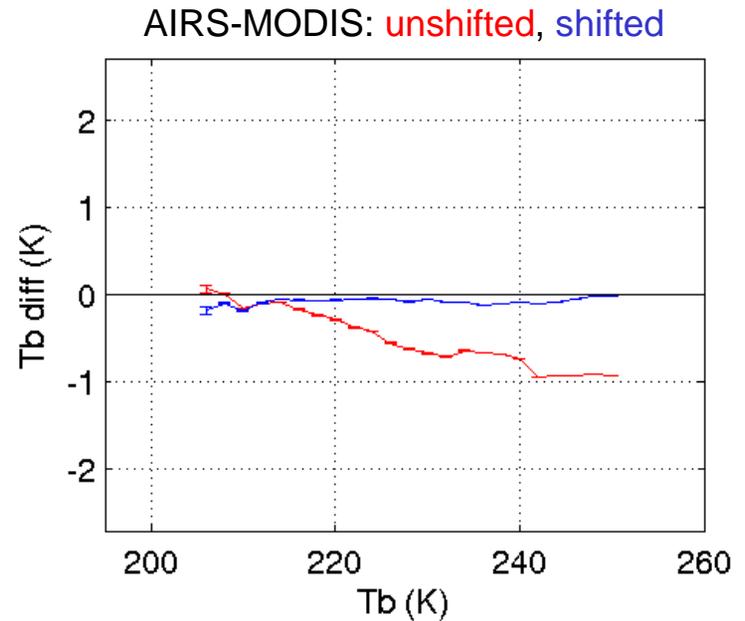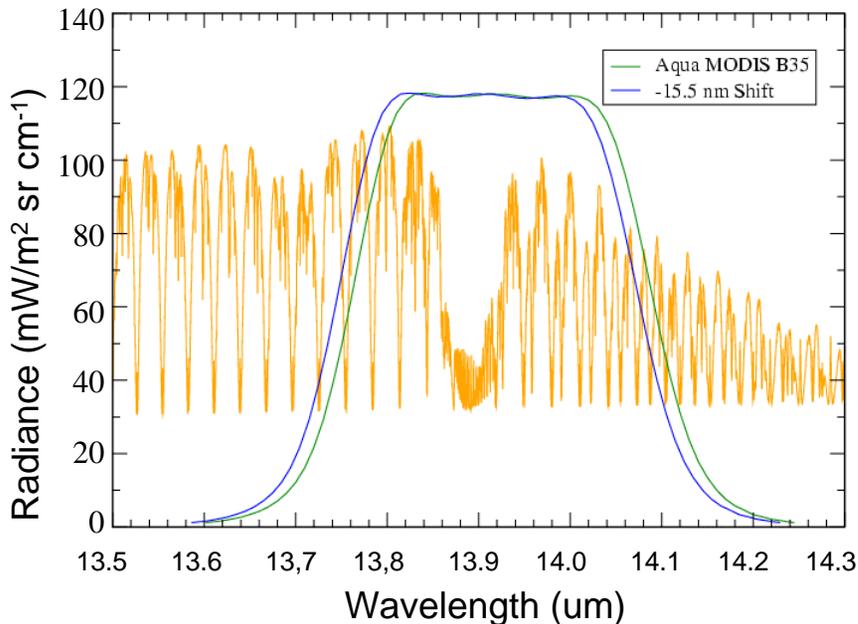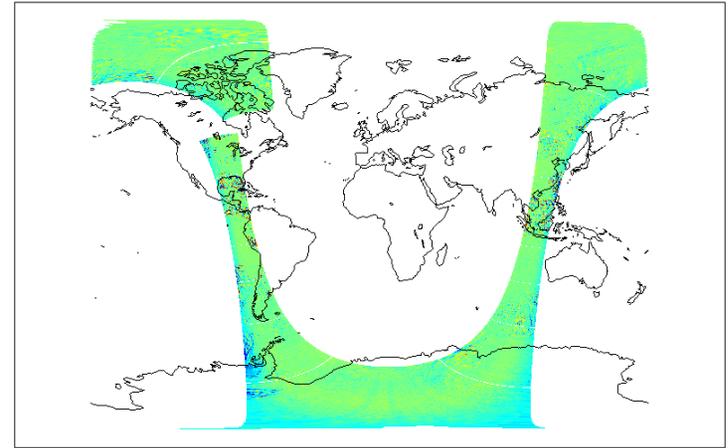## Collection 3 and Collection 4,5 compared to Pre-launch

Slide courtesy of MCST
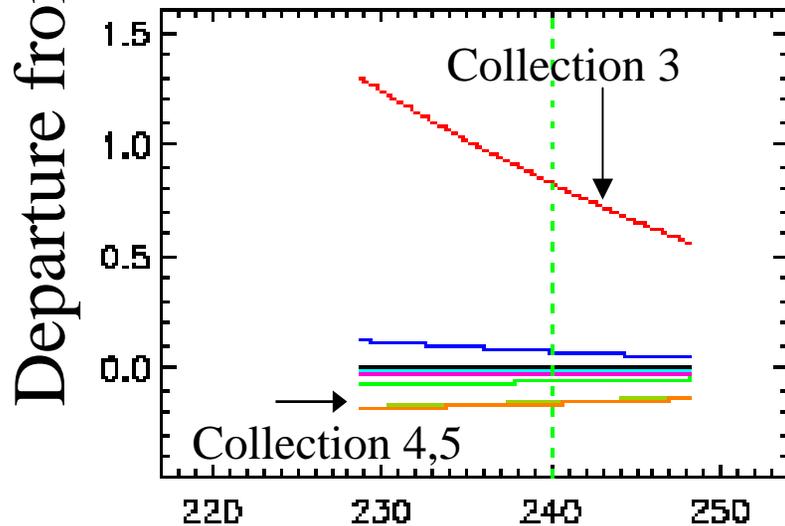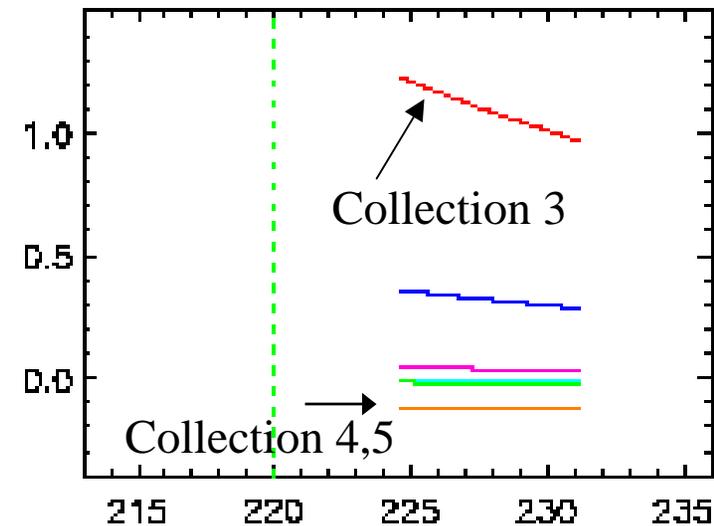
2. Spectral Characterization

MODIS Band 35 (13.9 μm)

AIRS-MODIS,no shift
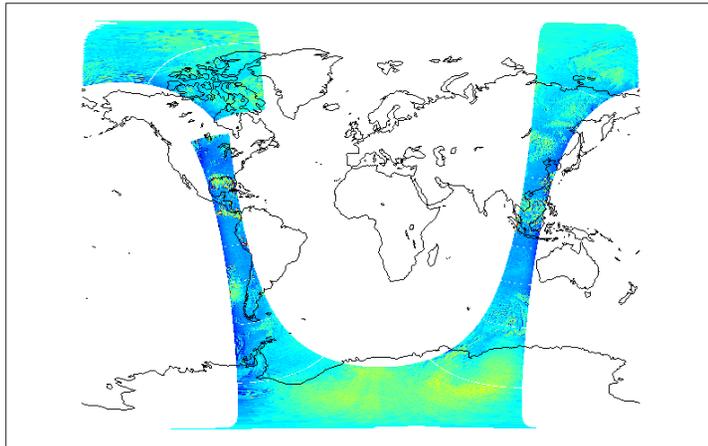
AIRS-MODIS,MODIS SRF shifted by +0.8 cm^{-1} (15.5 nm)

AIRS-MODIS: unshifted, shifted

Pre-Launch RSR Uncertainty Analysis

| Band Number	Wavelength (nm)	Measurement Error[1]	SpMA Absolute Wavelength Error[2]	Temperature Shift on Wavelength Uncertainty[3]	RSS 1-Sigma Wavelength Uncertainty (%)	RSS 1-Sigma Wavelength Uncertainty (nm)	Tobin et al spectral shift to match MODIS and AIRS (nm)
31	11016.4	.043%	.025%	.023%	.055%	6.1 nm	-----
32	12030.2	.010%	.025%	.015%	.031%	3.7 nm	-----
33	13363.1	.006%	.025%	.015%	.030%	4.0 nm	-----
34	13681.5	.009%	.025%	.015%	.031%	4.2 nm	-15.0 nm
35	13912.7	.005%	.025%	.015%	.030%	4.2 nm	-15.5 nm
36	14196.5	.019%	.025%	.015%	.035%	5.0 nm	-20.2 nm

[1] – based on variation in the five spot filter measurements

[2] – based on comparison with forward model CO_2 absorption feature at 13880 nm.

[3] – assumed to be ½ of correction amount
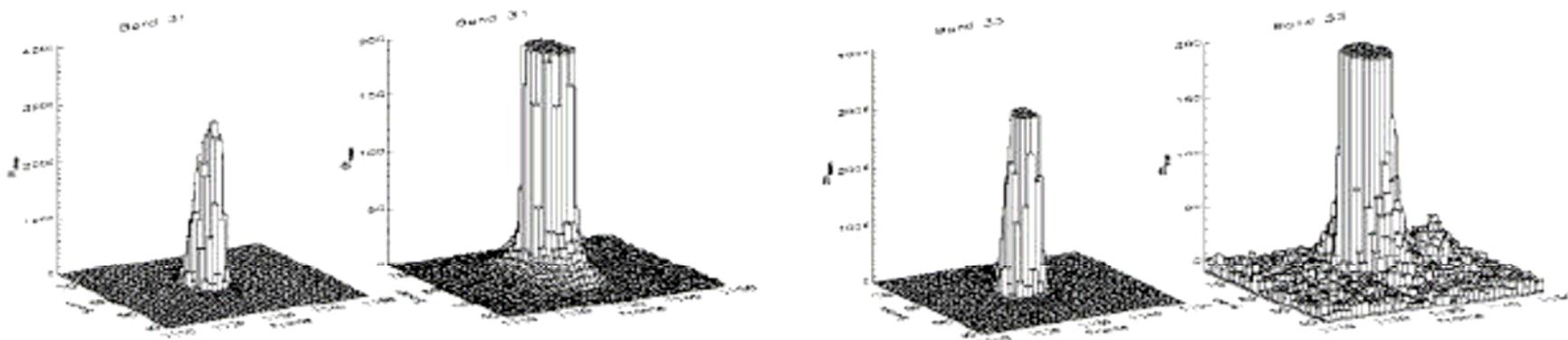
3. PC Band Optical Cross Talk (Terra only)
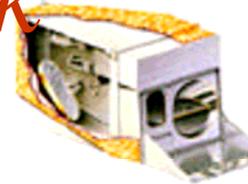
LWIR focal plane

PC Bands (32-36) $11\mu m$ Optical Leak

➢ Leak from Band 31 ($11\mu m$) filter into Bands 32-36 substrate and strikes the PC detectors from within.

➢ Cross-talk signals observed from pre-launch testing and on-orbit Moon observation.
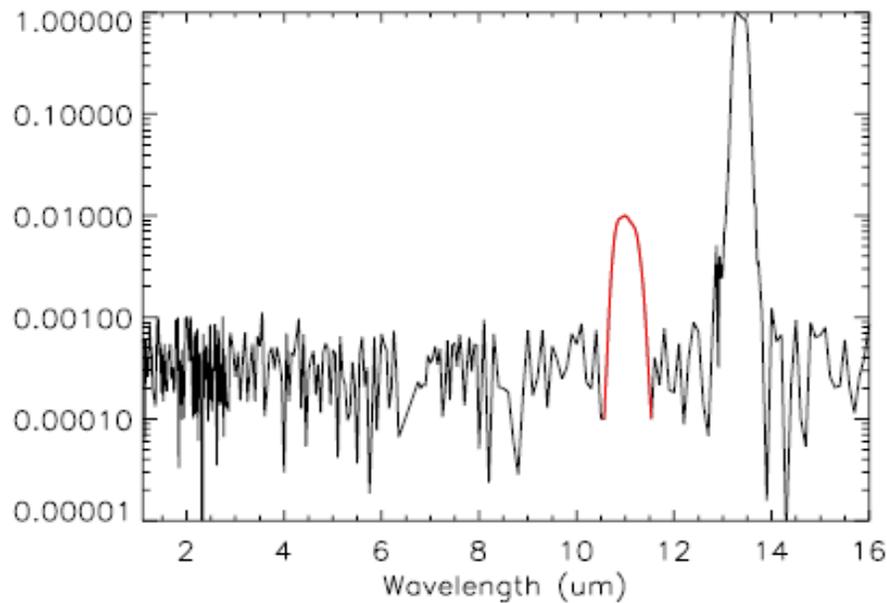
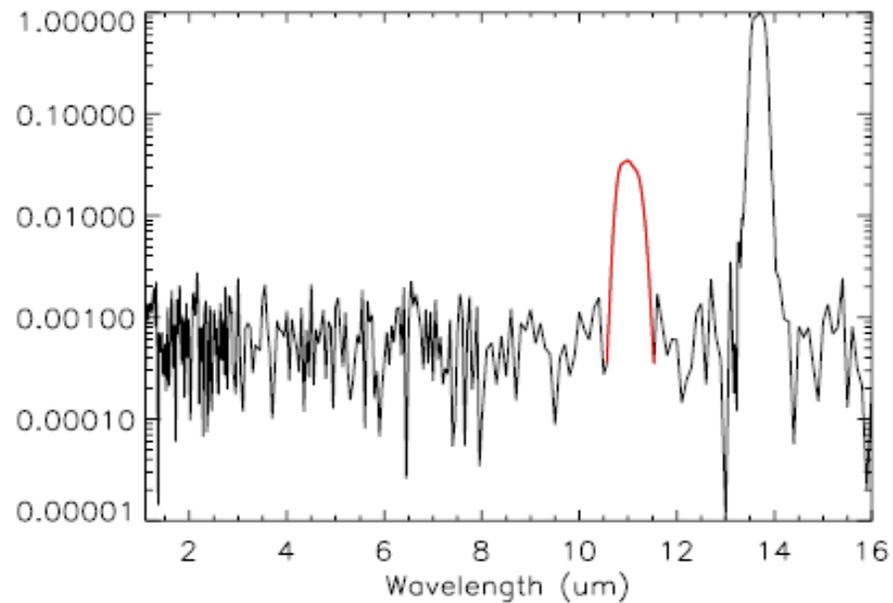Moon Observation of Bands 31 and 33 on day 2000084

For $B = 32 \sim 36$

$$dn_{EV}^{corrected}[B, D, F] = dn_{EV}[B, D, F] - PC\_XT[B,D] \cdot dn_{EV}[Band31, D, F + \Delta F_{offset}[B]]$$

PFM in-band shown with FM1 out-of-band response
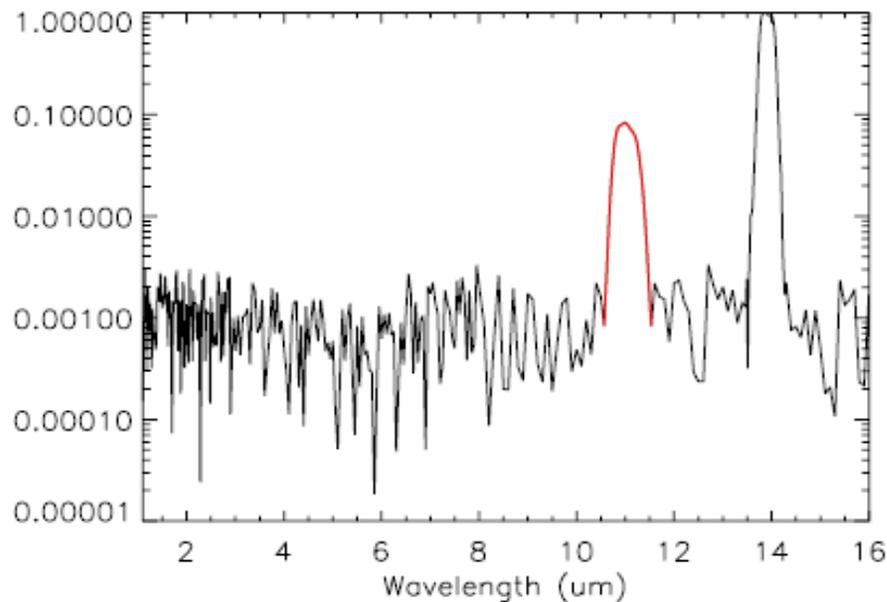and Estimation of PC optical Crosstalk from B31

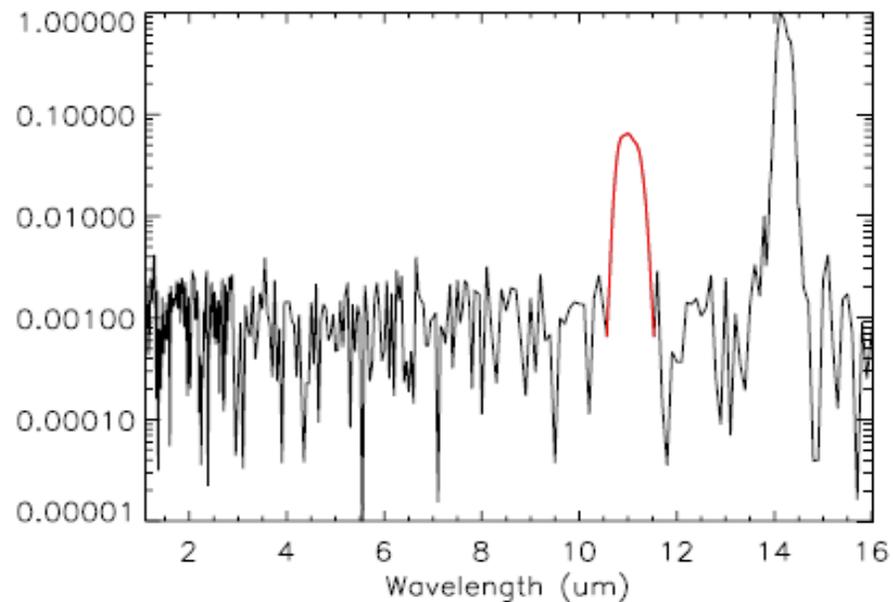Terra MODIS Optical Leak Correction

Day 06194, 1615 UTC

Baja

Temp [K]

330
320
310
300
290
280
270
260
250
240

11um

Temp [K]

240
238
236
234
232
230
228
226
224
222
220

Pre launch correction   14.2um

14.2um

Temp [K]

240
238
236
234
232
230
228
226
224
222
220

Collection 4,5
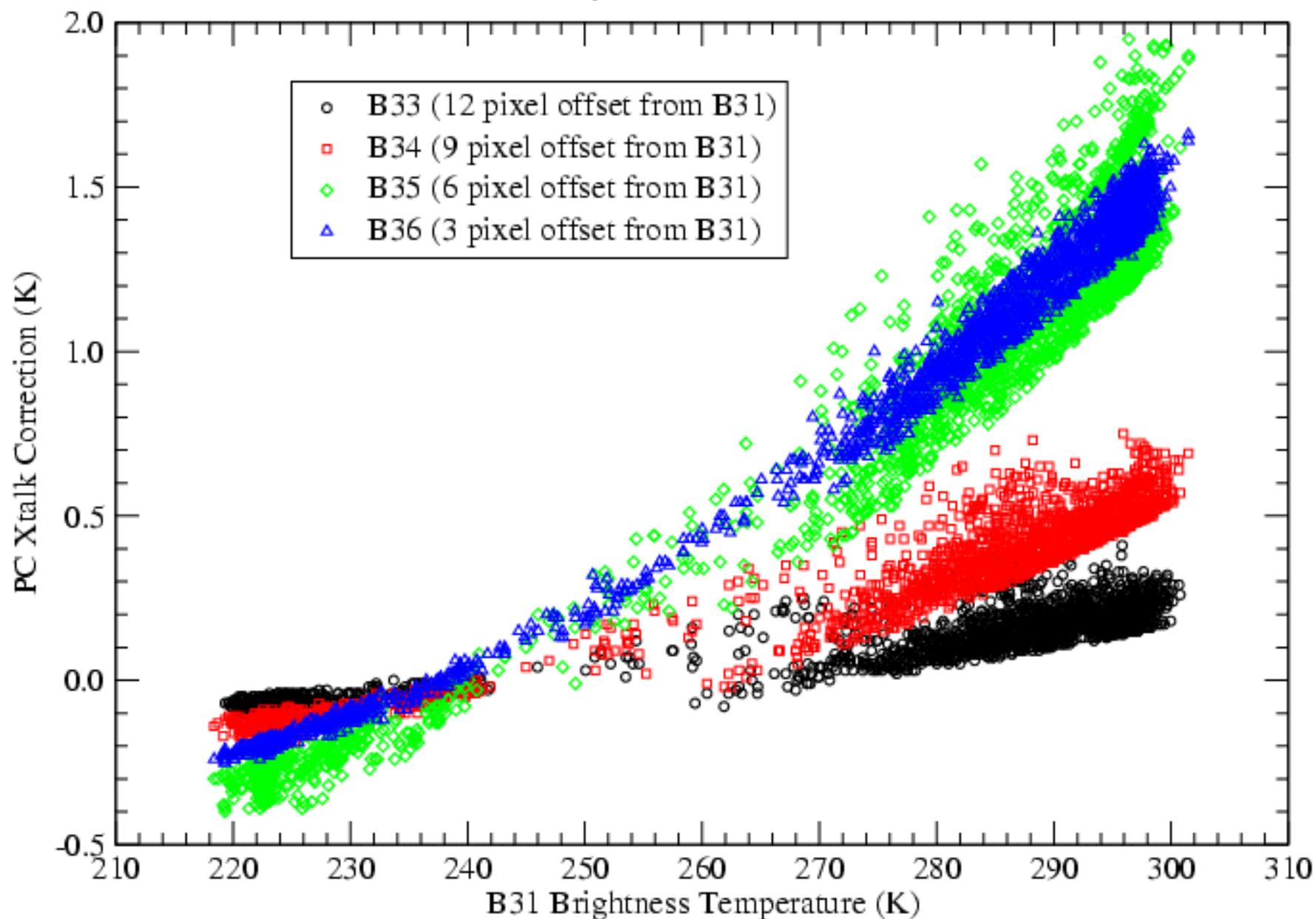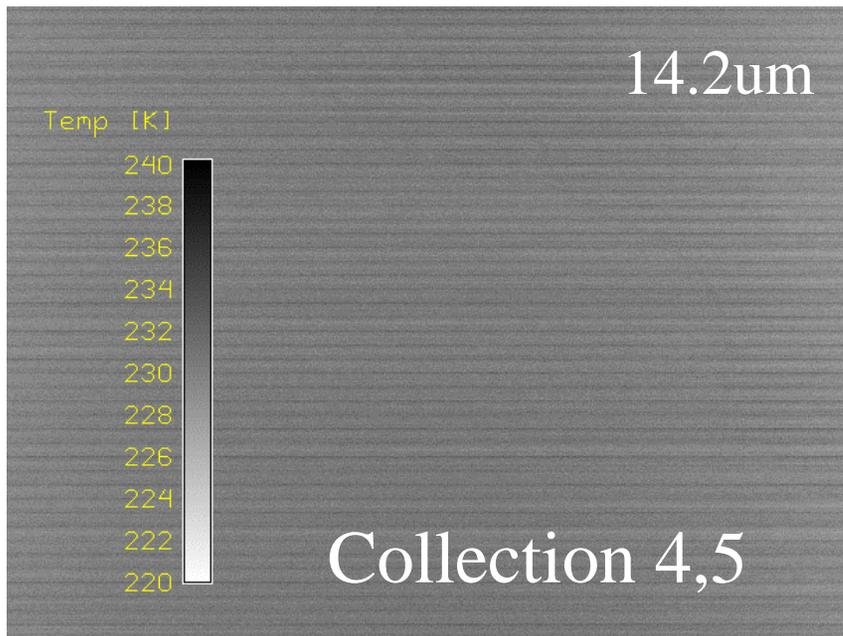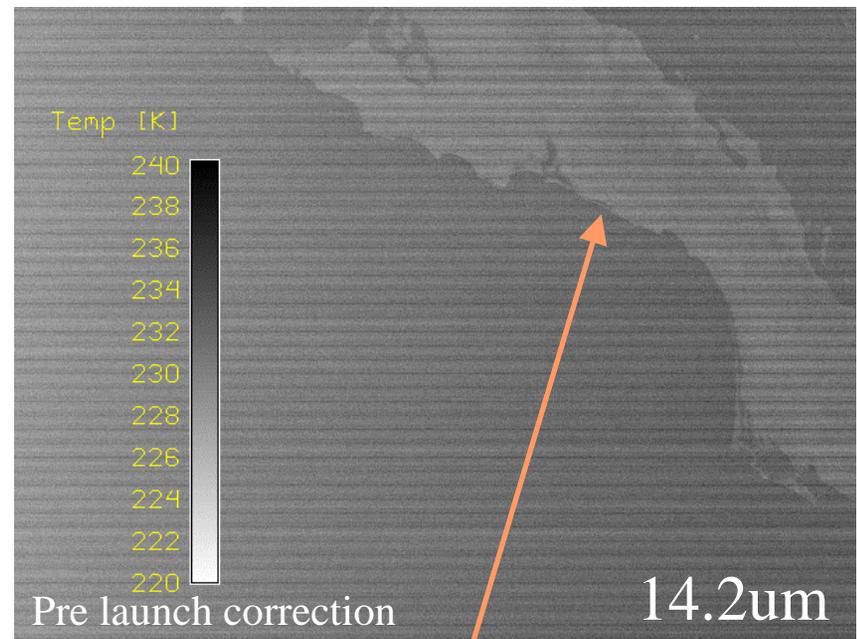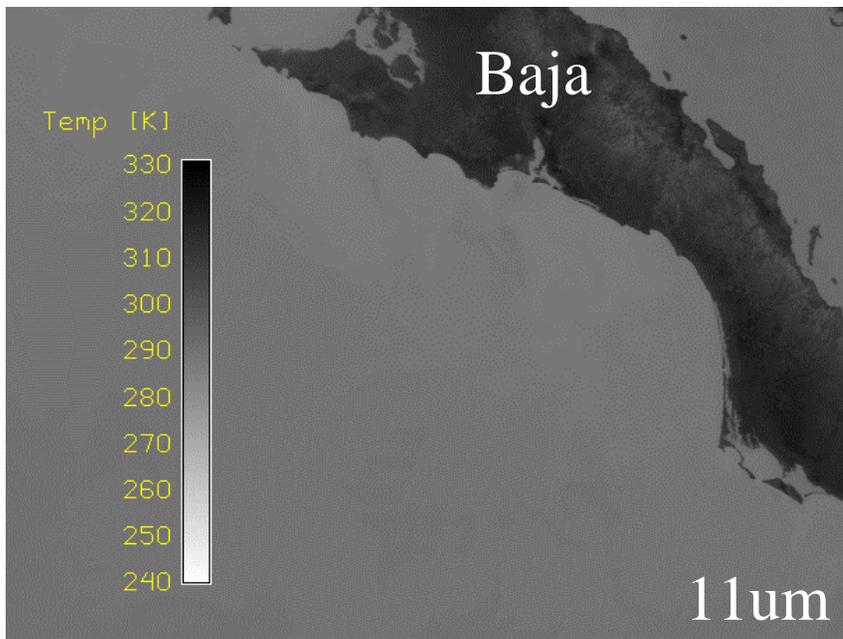
Doubling the PC_XT correction causes Baja California to show up as a cold feature in Terra MODIS Band 36 data. This is a-physical!

4. Out-of-Band Filter Leaks

Aqua MODIS Merged IB + OOB RSR

- PC07I and PC07D measurements merged using two different techniques:
  1. In band peak (Method "1")
  2. SpMA spectrum peak (Method "2")
- Data only for center channel of each band
- Merged by Steve Broberg at SBRS

Problem: *The noise floor of this data is too high to gain useful knowledge about OOB influence on MODIS PC LWIR bands.*

Relative Response (vertical axis)

Band 33 (13.3 um) — high noise floor — method 1, method 2
Band 34 (13.6 um) — method 1, method 2
Band 35 (13.9 um) — method 1, method 2
Band 36 (14.2 um) — method 1, method 2
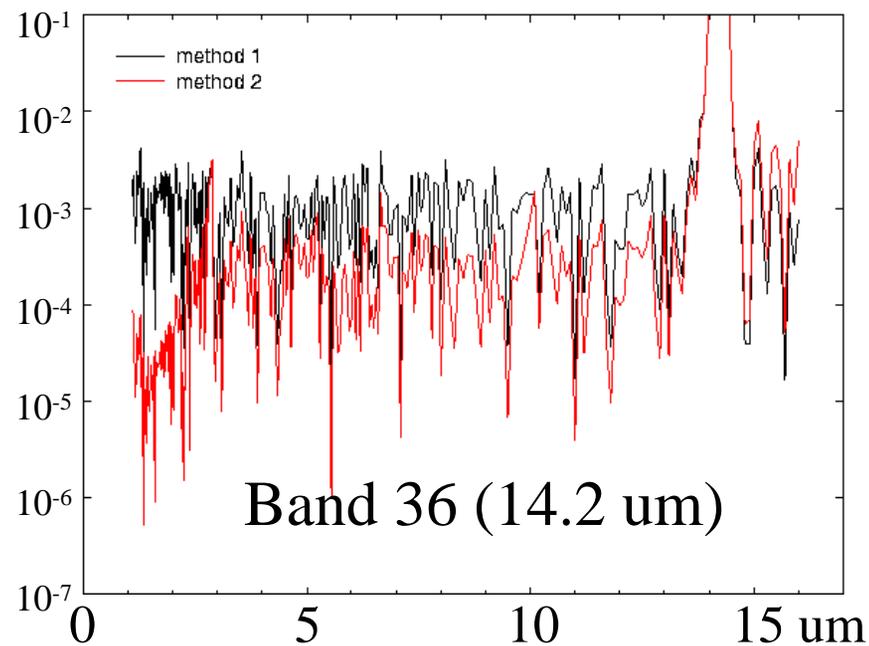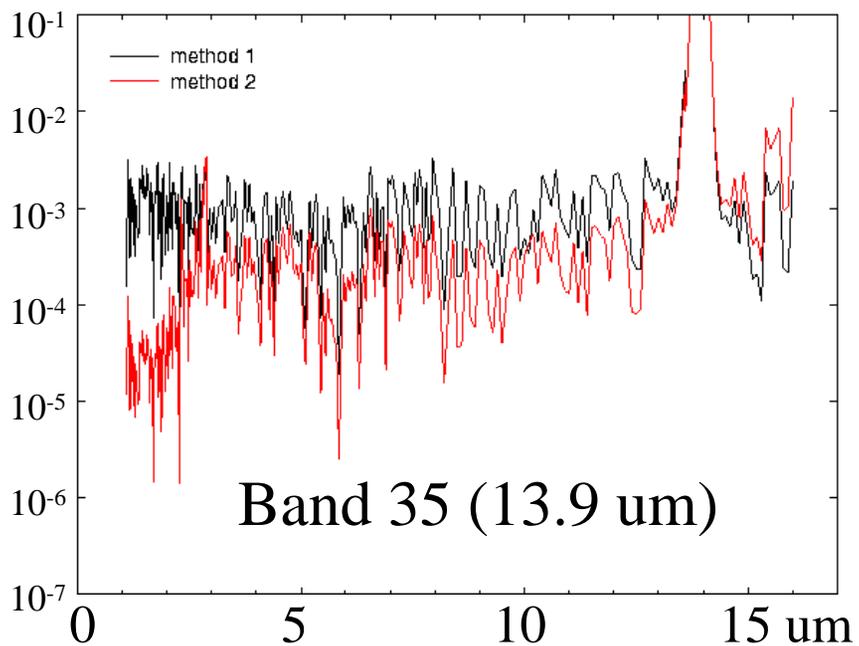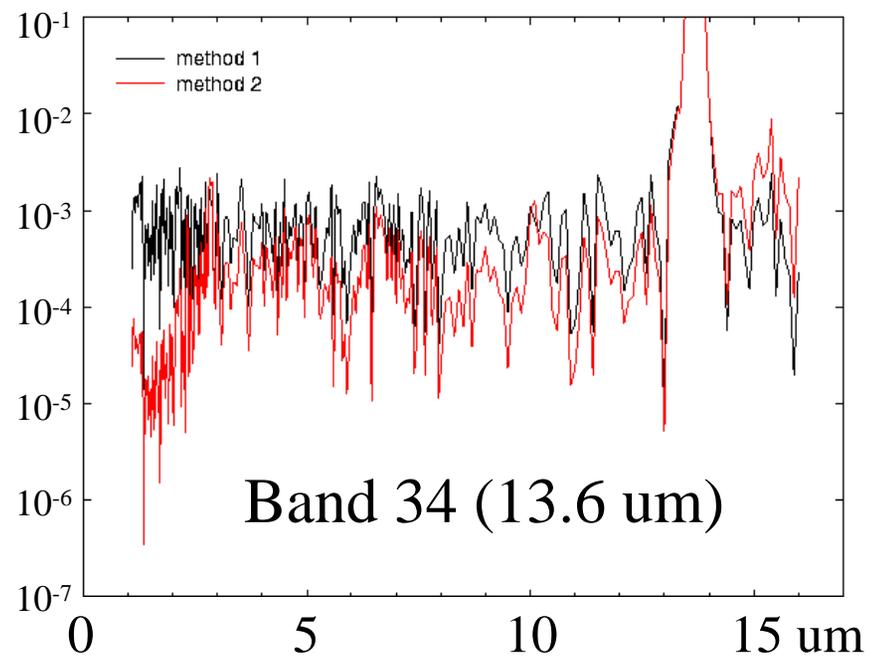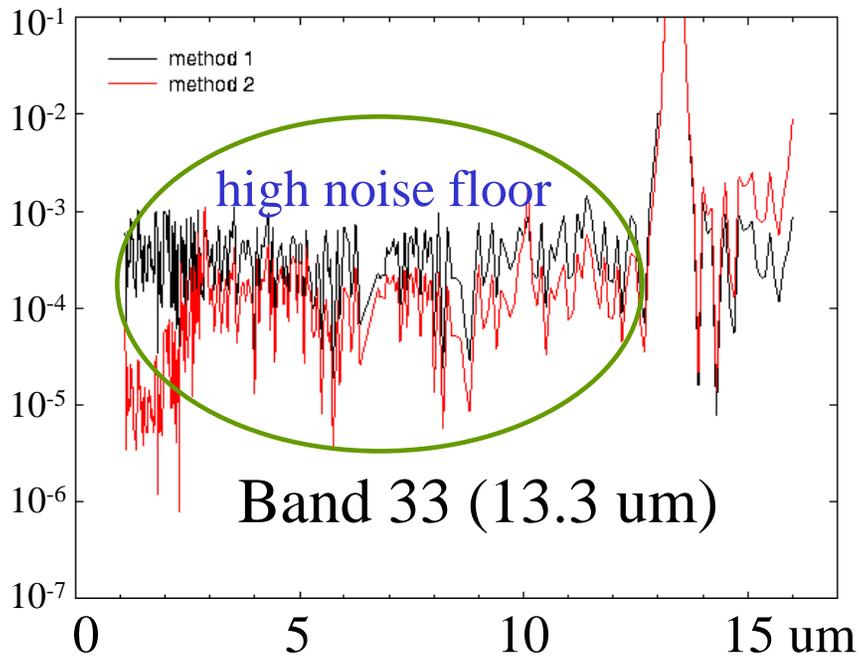
5. Scan Mirror Reflectivity (RVS)

- The calibration equation includes RVS terms:

$$L_{EV} = \frac{1}{RVS_{EV}}\left(a_0 + b_1 \cdot dn_{EV} + a_2 \cdot dn_{EV}^2 - \left(RVS_{SV} - RVS_{EV}\right) \cdot L_{SM}\right)$$

- Uncertainty based on variation of RVS for 10 detectors of each band:
  - Band 34:   .0058   (<0.10 K)
  - Band 35:   .0046   (<0.10 K)
  - Band 36:   .0054   (<0.15 K)

- **Caveat!** On-orbit evaluations, including DSM, have significantly changed and improved upon the Terra MODIS pre-launch RVS characterization.

Survey of Possible Influences

Band	33	34	35	36
Cal Coefficients	0.1	0.1	0.2	0.2
Spectral Response	0.2	0.2	0.2	0.3
Cross talk (Terra)	0.2	0.3	0.4	0.5
Filter Leaks (OOB)	?	?	?	?
Scan Mirror RVS	0.1	0.1	0.1	0.2
Additive Bias (Terra)	+/-0.6	+/-0.7	+/-0.9	+/-1.2
ER-2 Terra Bias	-0.37	0.93	1.74	1.77
Additive Bias (Aqua)	+/-0.4	+/-0.4	+/-0.5	+/-0.7
ER-2 Aqua Bias	-0.68	0.68	1.00	0.91

Summary (1/2)

- Both Terra and Aqua MODIS 11 and 12 um window bands are shown by a number of independent approaches to be performing excellently over the lifetime of the mission

- ER-2 based comparisons indicate that Terra MODIS LWIR atmospheric bands 34-36 are performing out-of-specification with biases > 1 K.

- ER-2 based and AIRS based comparisons indicate that Aqua MODIS LWIR atmospheric bands 34-36 are performing out-of-specification with biases approaching 1 K.

Summary (2/2)

- Possible contributors to MODIS calibration bias:
  - Calibration coefficient error is deemed small (<0.2 K) based on comparisons to pre-launch calibration
  - A spectral shift estimate based on matching Aqua MODIS and AIRS radiances is significantly larger than the pre-launch spectral uncertainty for these bands.
  - Based on image analysis, it doesn't appear that the Terra MODIS 11 um optical cross talk correction can be increased significantly to explain the large Terra bias.
  - Scan mirror uncertainty is small, but history has shown that characterization changes can exceed the uncertainty.
  - OOB influence from spectral filter leaks is essentially untested due to poor quality pre-launch test data.