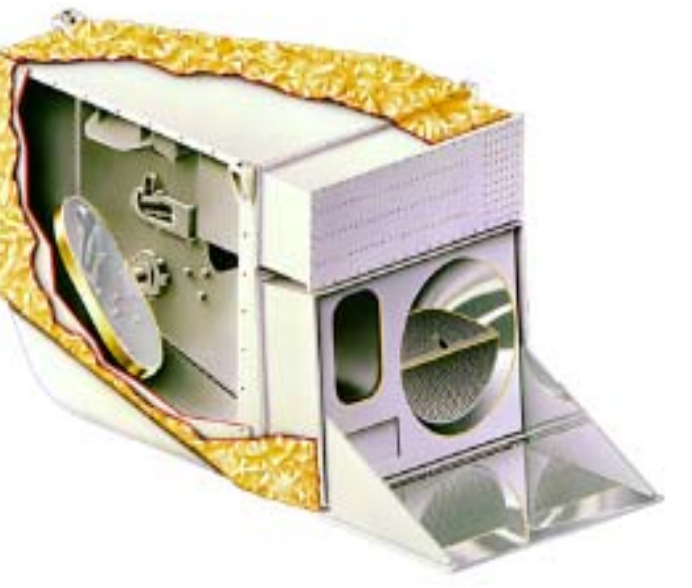




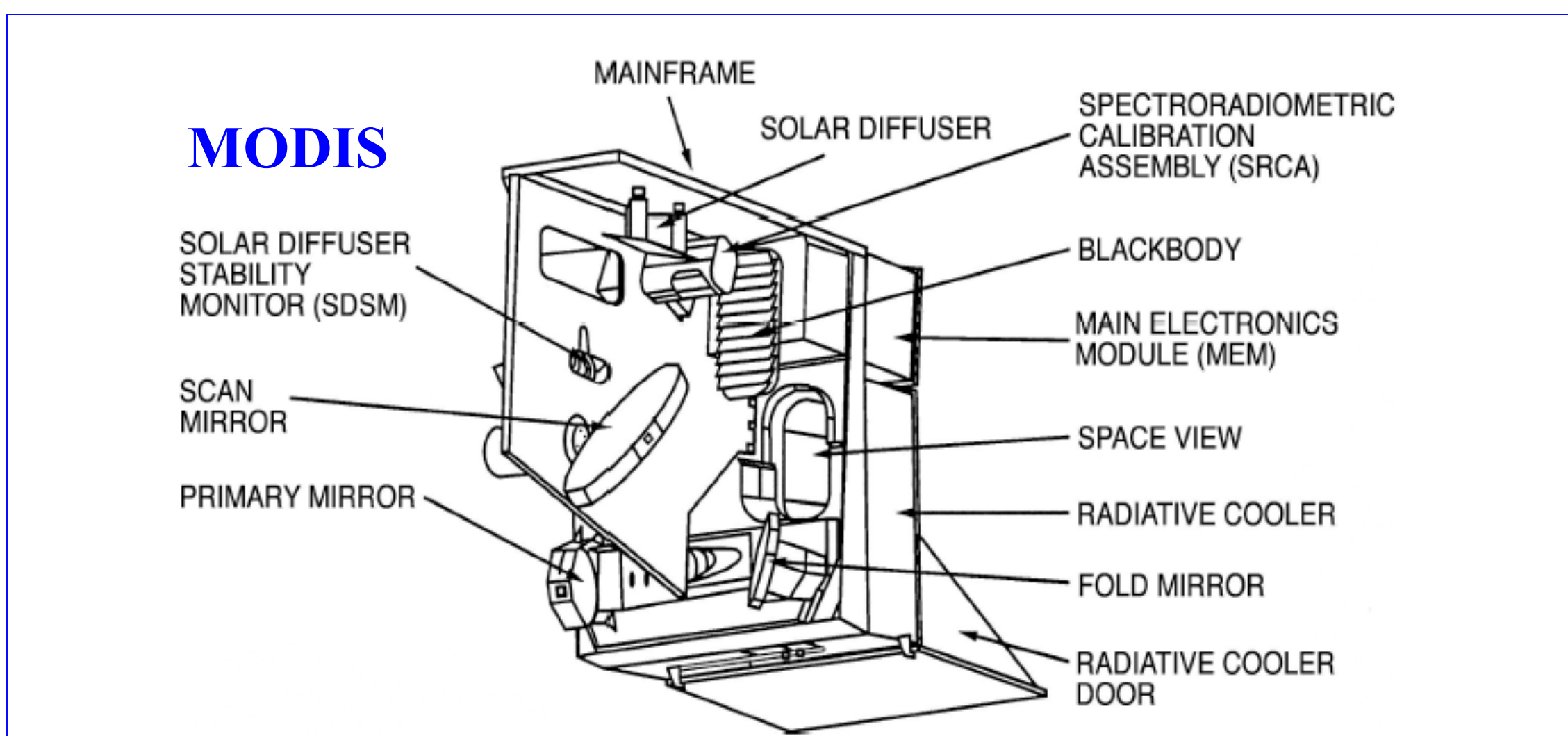
MODIS Thermal Emissive Bands On-orbit Calibration and Performance

MODIS Characterization Support Team

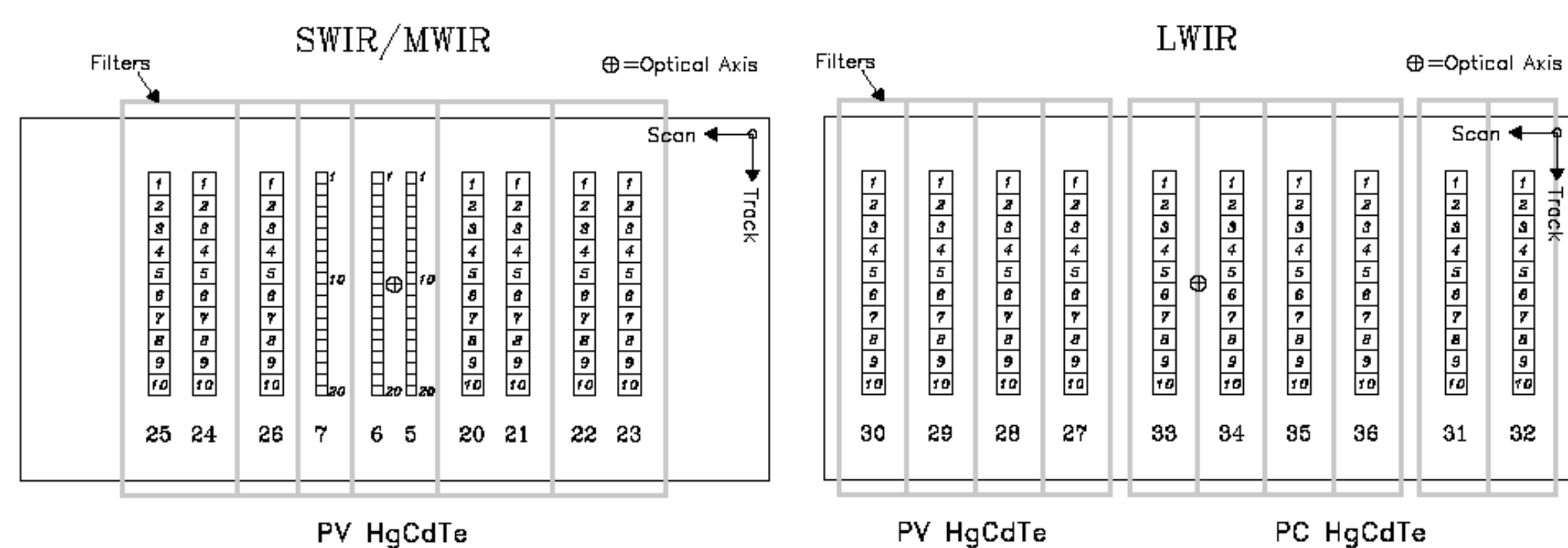


Introduction

- The **MOD**erate Resolution **Im**aging **S**pectroradiometer (**MODIS**) is a key instrument for NASA's Earth Observing System (EOS). It is onboard both **Terra** and **Aqua** spacecrafts. The Terra spacecraft was launched on December 18, 1999 and the Aqua spacecraft on May 4, 2002.
- MODIS has 36 spectral bands with wavelength ranging from 0.42 to 14.5 microns, located on four focal plane assemblies (FPAs), with spatial resolution (at nadir) of 250 m (bands 1-2), 500 m (bands 3-7) and 1000 m (bands 8-36). There are 16 thermal emissive bands (TEB): B20-25 and B27-36, located on the SMIR and LWIR focal planes controlled at 83K on-orbit.
- MODIS 2-sided paddle wheel scan mirror provides a -55 to +55 degree scan of the Earth View (EV) covering a 10 km (at nadir) along track by 2330 km along scan swath.



SMIR and LWIR Cold Focal Plane Assemblies Layout (Temperature controlled at 83K)



TEB Key Specifications

Band	λ_{ctr} (μm)	L_{typ} Radiance ($\text{W}/\text{m}^2\text{-}\mu\text{m}\text{-sr}$)	Scene Temperature at L_{typ} (K)	Required NEdT (K)	On-orbit NEdT at L_{typ} (K)	Radiometric Requirement at L_{typ} (%) ¹	Radiometric Requirement at L_{typ} (K)
20	3.79	0.45	300	0.05	0.03	0.75%	0.18
21	3.99	2.38	335	0.20	0.16	1%	0.31
22	3.97	0.67	300	0.07	0.03	1%	0.25
23	4.06	0.79	300	0.07	0.02	1%	0.25
24	4.47	0.17	250	0.25	0.16	1%	0.19
25	4.55	0.59	275	0.25	0.06	1%	0.24
27	6.77	1.16	240	0.25	0.10	1%	0.27
28	7.34	2.18	250	0.25	0.05	1%	0.32
29	8.52	9.58	300	0.05	0.02	1%	0.53
30	9.73	3.69	250	0.25	0.10	1%	0.42
31	11.01	9.55	300	0.05	0.03	0.5%	0.34
32	12.03	8.94	300	0.05	0.03	0.5%	0.37
33	13.36	4.52	260	0.25	0.13	1%	0.62
34	13.68	3.76	250	0.25	0.20	1%	0.59
35	13.91	3.11	240	0.25	0.23	1%	0.55
36	14.19	2.08	220	0.35	0.43	1%	0.47

¹ defined at L_{typ} and between $\pm 45^\circ$ off nadir

*Contact: Xiaoxiong.Xiong-1@nasa.gov

TEB On-orbit Calibration Algorithm

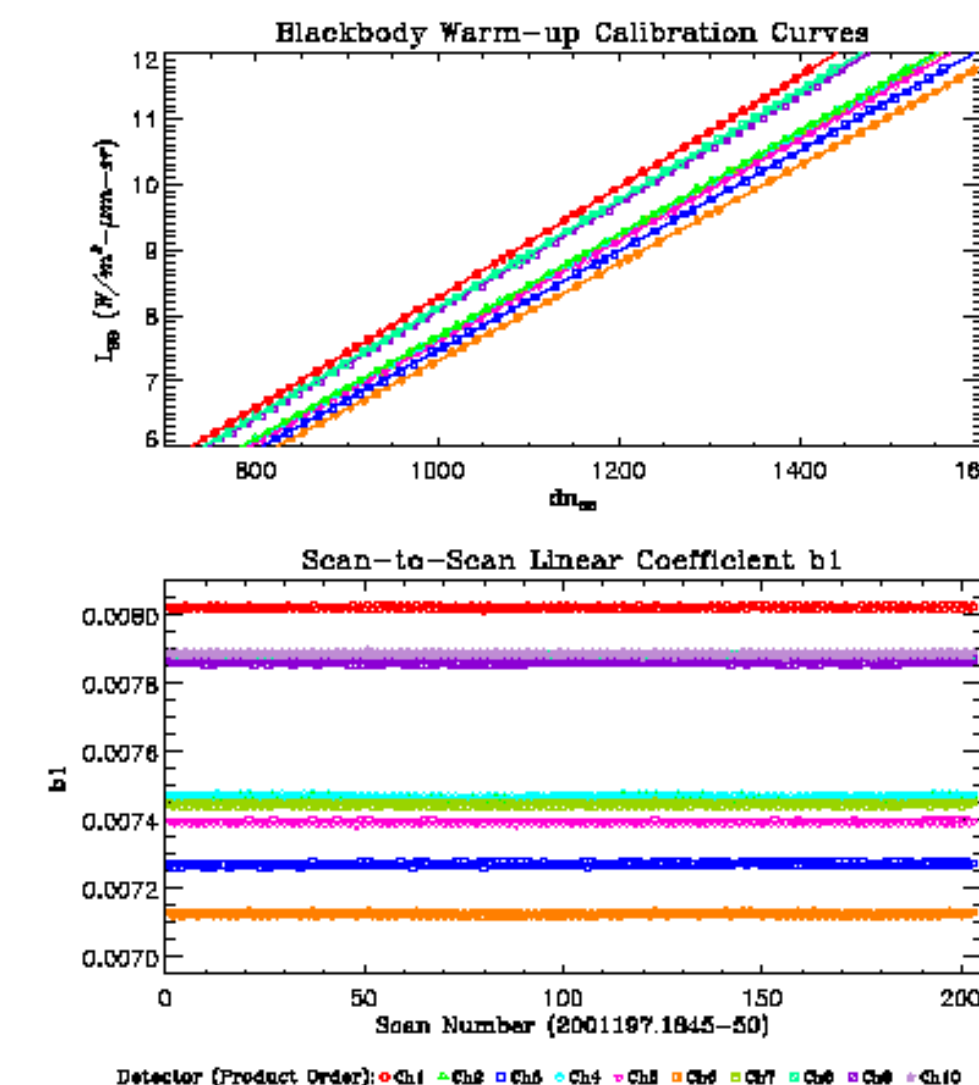
On Board Calibrator (OBC) Blackbody (BB) for On-orbit Scan-to-scan Calibration



Source radiance with RSR integration

$$\bar{L}_S = \frac{\sum \text{Planck}(\lambda, T) \cdot \text{RSR}(\lambda)}{\sum \text{RSR}(\lambda)}$$

Band 31 dn vs. L during OBC BB Warm-up



TEB EV Radiance Retrieval (TOA)

$$\bar{L}_{EV}(\theta) = \frac{1}{RV_{S_{EV}}(\theta)} \cdot \{a_0(T_{inst}) + b_1 \cdot dn_{EV}(\theta) + a_2(T_{inst}) \cdot dn_{EV}^2(\theta)\} - (RV_{S_{EV}} - RV_{S_{EV}}(\theta)) \cdot \bar{L}_{SM}$$

Linear calibration coefficient b_1

$$b_1 = \frac{\epsilon_{BB} \cdot \bar{L}_{BB} + (RV_{S_{EV}} - 1) \cdot \bar{L}_{SM} + (1 - \epsilon_{BB}) \cdot \epsilon_{cav} \cdot \bar{L}_{cav} - a_0 - a_2 \cdot dn_{BB}^2}{dn_{BB}}$$

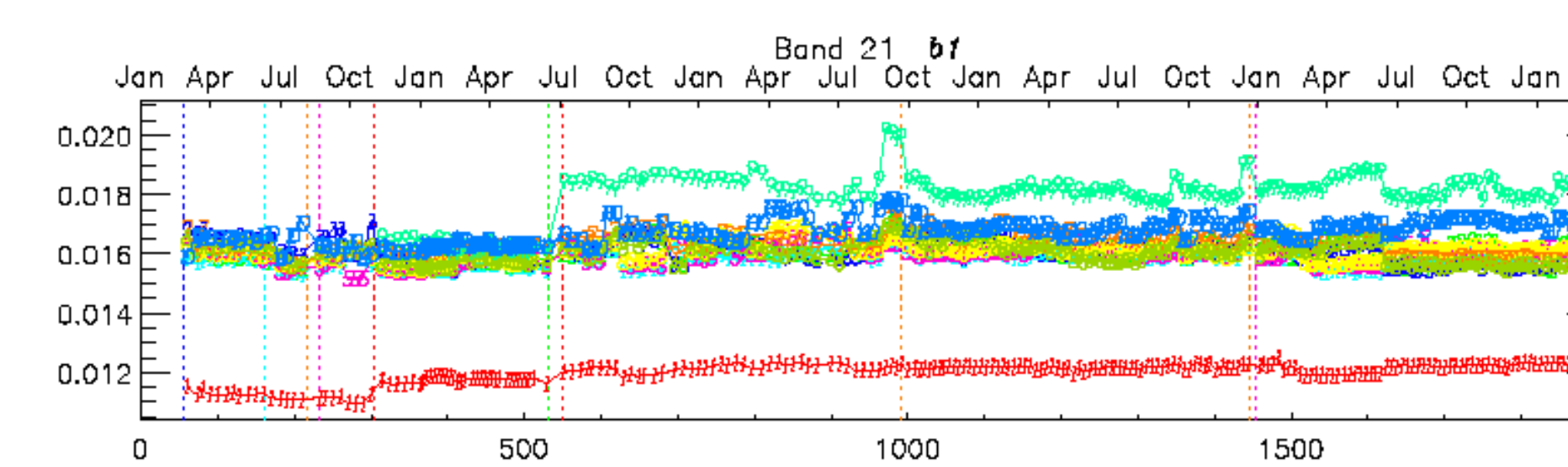
- $a_0(T_{inst})$ and $a_2(T_{inst})$: offset and the non-linear terms extracted from the pre-launch calibration and updated on-orbit from the OBC BB
- b_1 : the linear coefficient measured on-orbit from the OBC BB
- $RV_{S_{EV}}$: response versus scan angle at a given AOI
- $dn_{EV, BB}$: background subtracted instrument signal (digital number)
- L_S : source radiance
- ϵ_S : source emissivity

Blackbody and Cavity Emissivity

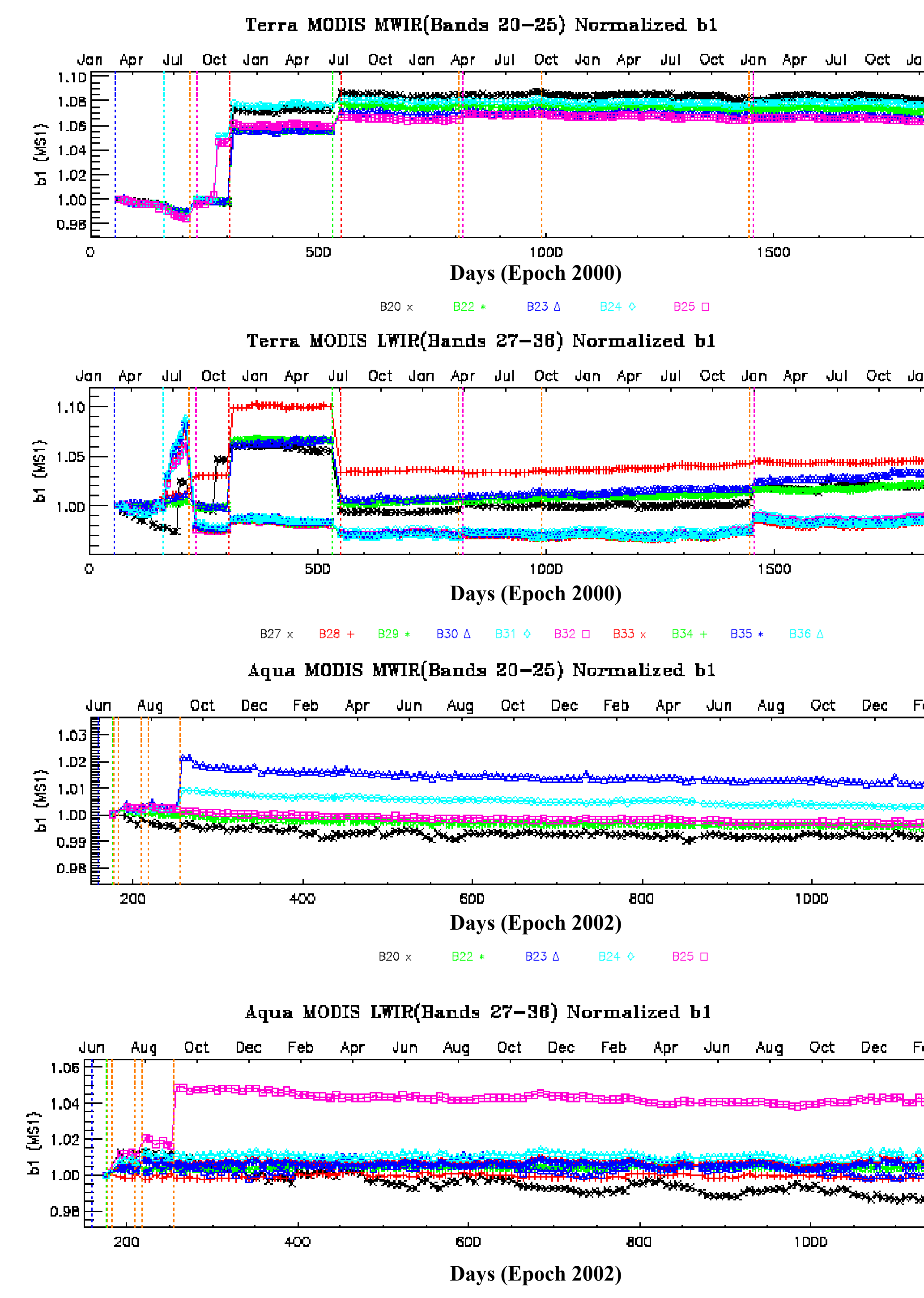
- Blackbody emissivity (ϵ) was characterized pre-launch. The Earth view radiance uncertainty caused by the error of the Blackbody emissivity is less than 0.2% at L_{typ} for all TEB.
- Cavity emissivity was set to 0.85 carrying uncertainty of 0.05 for all TEB prior to launch. It results less than 0.05% uncertainty in radiance retrieval at L_{typ} for all TEB.

Band 21 (Fire Detection) Calibration

- Fixed coefficients (with mirror side dependency) used in the L1B calibration
- On-orbit OBC Blackbody warm-up cycle limits to 270-315K. Five years of Terra MODIS B21 b_1 at 290K shows stable trending except for one detector.

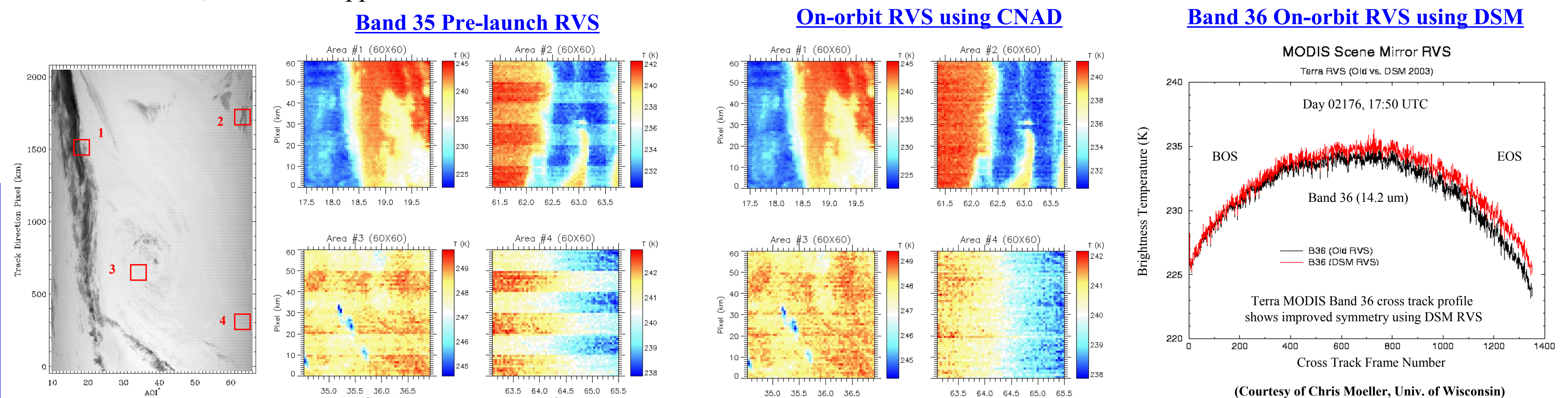


TEB On-orbit Response b_1 (Band averaged) Trending



Response Versus Scan Angle (RVS) of the Scan Mirror

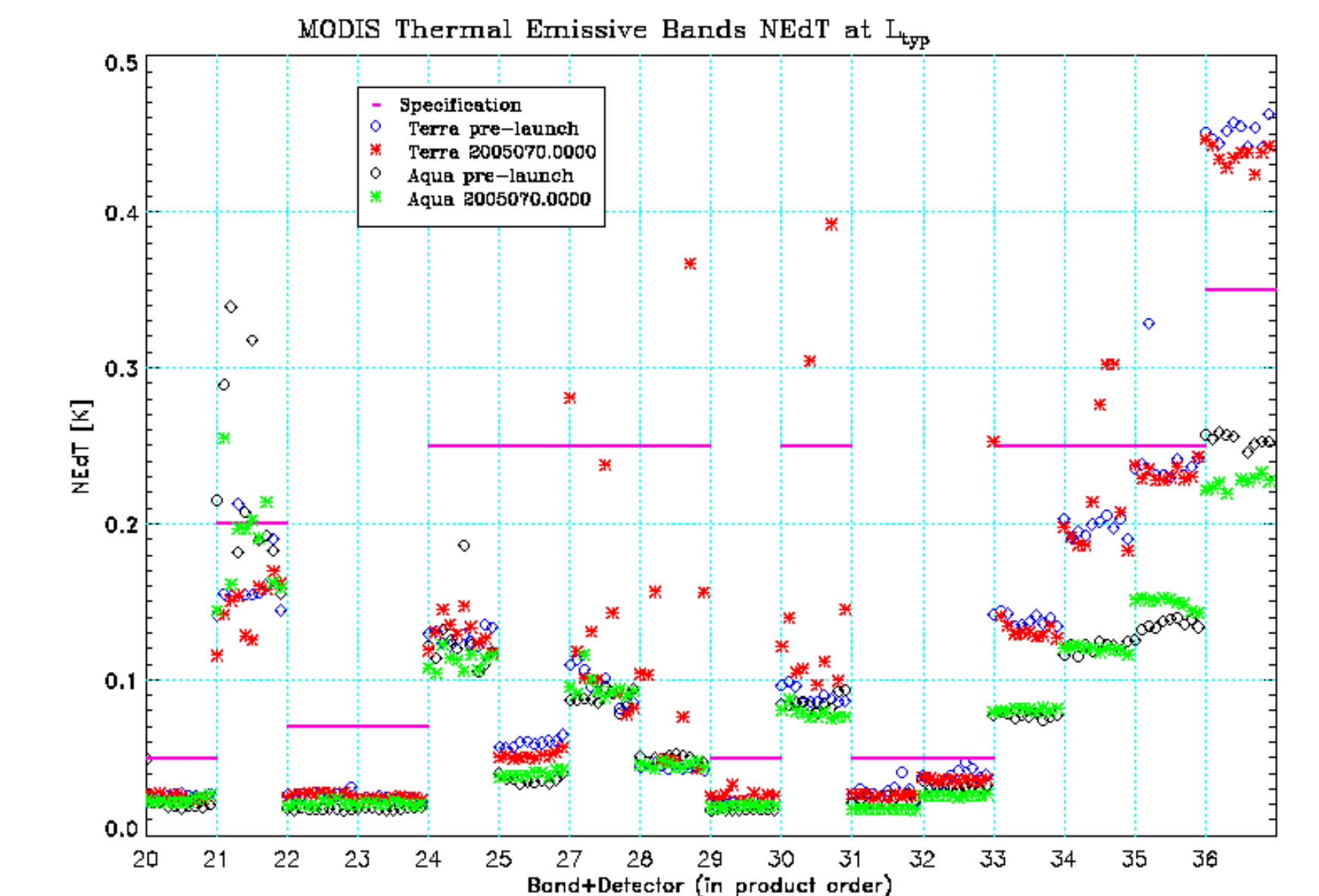
- No valid system level RVS measurements for TEB of Terra MODIS (PFM).
- Witness sample reflectance measurements (by NPL) and fixed optics parameters (C_{FIX}) derived from the Aqua MODIS (FM1) system level measurements RVS are used to derive the PFM (Terra) RVS: $RVS \propto \frac{p_s + p_e}{2} + C_{FIX} \cdot \frac{p_s - p_e}{2}$
- At launch, same RVS applied to both sides of the scan mirror.



Challenging Issues

- (1) Uncertainty and stability of band 21 at high temperatures.
- (2) On orbit RVS change
- (3) Stripping and noisy detectors.
- (4) Mirror Side Correlated Noise (MSCN) patterns change on orbit.

Terra and Aqua NEdT Comparison



LWIR PC Bands 11 μm Optical Leak - from B31 to B32-36 (Terra only)

Band 33 detector 5 response over the Moon

