Spectral Analysis of the Primary Flight Focal Plane Arrays for the Thermal Infrared Sensor

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Overview

Thermal Infrared Sensor (TIRS)

• New longwave infrared (10 – 12 micron) sensor for the Landsat Data Continuity Mission
• 185 km ground swath; 100 meter pixel size on ground
• Pushbroom sensor configuration

Issue of Calibration:

• Single detector – only one calibration
• Multiple detectors – unique calibration for each detector – leads to pixel-to-pixel artifacts

Objectives:

• Predict extent of residual striping when viewing a uniform blackbody target through various atmospheres.
• Determine how different spectral shapes affect the derived surface temperature in a realistic synthetic scene.
TIRS Focal Plane Layout

SCA-A (Q020)

SCA-B (Q024)

QWIP array

SCA-C (Q023)

512 rows

1850 cols

640 cols

15-degree FOV, 185 km swath width
Spectral Filter Mask

SCA-A
(Q020)

SCA-B
(Q024)

SCA-C
(Q023)

QWIP outline

Filter holder/mask
TIRS Bands

SCA-A
(Q020)

Dark Band
10.8 um Band
12.0 um Band

SCA-B
(Q024)

SCA-C
(Q023)

12.0 um Band
10.8 um Band
Dark Band
TIRS Requirements

• Spectral Uniformity*:  
  - Bandcenter: <= 50 nm of mean  
  - Bandwidth: <= 5% of mean  
  - Average in-band response: >= 0.8  
  - Response between 0.5 response points : >= 0.4  
  - Response between 0.8 response points: >= 0.7  
  - Band edge slope (0.01-to-0.50): <= 0.4 microns  
  - Band edge slope (0.05-to-0.50): <= 0.3 microns

• CE stability: < 0.4%
• Dark current instability: < 5.1*10^5 electrons/sec
• Noise: < 1000 electrons
• Dark current: < 8.4*10^7 electrons/sec
• Absolute in-band CE: >= 0.3%

* LDCM Thermal Infrared Sensor Requirements Document. 427-15-02 TIRS RD 20090514 Rev A
Requirements Map: 10.8 micron Band

SCA-A (Q020)

SCA-B (Q024)

SCA-C (Q023)

Requirements Map:
White (1) = Pass all requirements
Black (0) = Fail at least one requirement
Requirements Map: 12.0 micron Band

Requirements Map:
White (1) = Pass all requirements
Black (0) = Fail at least one requirement
Science Rows

SCA-A (Q020)

Primary Science Rows

SCA-B (Q024)

SCA-C (Q023)
Every pixel has a slightly different spectral response

To what extent do these different spectral shapes contribute to striping?
Study 1: Uniform Scenes
Calibration

For each detector: calibration curve of signal to BB temperature

Each pixel signal now represented as a brightness temperature
Uniform Scene

\[ S_i = \frac{\int [B(T, \lambda) \cdot \tau_{atm}(\lambda) + L_{atm}(\lambda)] \cdot R_i(\lambda) \cdot d\lambda}{\int R_i(\lambda) \cdot d\lambda} \]

- Same calibration on uniform scene through atmosphere
- Will not return same brightness temperature due to atmospheric terms

What is the residual striping effect due to the atmosphere when viewing a uniform blackbody?
Study 1 Procedure

1. Calibrate
   - 8 Blackbody Temperatures
   - 4 MODTRAN Atmospheres
   - 1850 Pixel Responses (x2)

   $$ S_i = \frac{\int [B(T, \lambda) \cdot \tau_{atm}(\lambda) + L_{atm}(\lambda)] \cdot R_i(\lambda) \cdot d\lambda}{\int R_i(\lambda) \cdot d\lambda} $$

2. Calibrate

3. Residual Striping?
Study 1 Results – 10.8 Band

MODTRAN Standard Atmospheres:

- **Tropical**
- **Mid-Latitude Summer**
- **Mid-Latitude Winter**
- **Sub-Arctic Summer**
Study 1 Results – 12.0 Band

MODTRAN Standard Atmospheres:
- Tropical
- Mid-Latitude Summer
- Mid-Latitude Winter
- Sub-Arctic Summer
Study 1 Observations

- Striping even after radiometric calibration of the detectors
  - Calibration based on a smooth blackbody radiance
  - Atmospheric spectral variations = different integrated signal for a particular detector.

- Minimum for mid-latitude winter atmospheres and maximum for tropical atmospheres
  - Tropical atmosphere: higher transmission and path radiance effects = magnify striping artifacts

- Striping minimized for temperatures of 270 - 280 K
  - Contrast between the target temperature and effective atmospheric temperature.
  - Transmission losses compensated by path radiance

- Striping is generally greater in 12.0 micron channel
  - Wider bandwidth more susceptible to spectral variations

The residual artifacts expected to be small (max standard deviations 35 mK and 57 mK)
Study 2: Realistic Scenes
Infrared Sensor

![Diagram](image)

**Realistic Scene**

\[
S_i = \frac{\int [\epsilon(\lambda)B(T, \lambda) \cdot \tau_{atm}(\lambda) + L_{atm}(\lambda)] \cdot R_i(\lambda) \cdot d\lambda}{\int R_i(\lambda) \cdot d\lambda}
\]

- Replace uniform scene with realistic scene
  - Various emissivities
- Group pixel responses into classes
  - Representative spectral shapes

How do different band shapes affect the brightness temperature in a realistic scene?
DIRSIG Lake Tahoe Image

DIRSIG Thermal Radiance image [W/m²/sr/um]

- Lake: Water, sea-level
- Terrain: Various land cover types, Relief via DEM
- Panels: Various emissivities, Various temperatures
- Atmosphere: Uniform atmosphere for entire scene, Atm. terms generated via MODTRAN
DIRSIG Lake Tahoe Image

DIRSIG Thermal Radiance image [W/m²/sr/um]
Spectral Response Classes

1850 Pixel Responses (x2)

K-means Classifier

2 spectral shapes per band

Apply each band shape to the entire DIRSIG scene
DIRSIG Product

- 4 band shapes (2 for each band)

- 4 MODTRAN Standard Atmospheres:
  - Tropical, Mid-Latitude Summer, Mid-Latitude Winter, Sub-Arctic Summer

- 2 TIRS bands * 2 band shapes per band * 4 atmospheres = 16 DIRSIG radiance images

Percent Difference between shape 1 and shape 2 for the 10 micron band

Express results as % difference images:

\[
\frac{|L_{\text{shape}1} - L_{\text{shape}2}|}{\text{mean}(L_{\text{shape}1}, L_{\text{shape}2})} \cdot 100\%
\]
Percent difference (shape 1 – shape 2) for 10.8 micron band

Percent difference (shape 1 – shape 2) for 12.0 micron band

Tropical  Mid-Latitude Summer  Mid-Latitude Winter  Sub-Arctic Summer
Study 2 Observations

- Temperature differences generally greater in 12.0 micron channel
  - wider bandwidth more susceptible to spectral variations
  - greater variation in 12 micron band shapes

- Temperature differences greatest for tropical atmosphere
  - higher transmission and path radiance effects = increased spectral variation

- Material type affects temperature differences (very subtle)
  - lower emissivity materials less susceptible to band shape
  - lower emissivity = more reflected atmosphere = less contrast between ground and atm.

- Results consistent with previous study

Band shape differences expected to be 0.1% and a 0.2%
Spectral requirements analysis to choose best candidates for primary science rows

Predict residual pixel-to-pixel artifacts for science row candidates:
  • Residual striping when viewing uniform target through atmosphere
    - Very small striping expected (35 mK and 57 mK for the 10.8 and 12.0 micron bands respectively)
  • Band shape influence on brightness temperatures in a realistic scene
    - Temperature differences between band shapes expected to be small (0.1% and 0.2% for the 10.8 and 12.0 micron bands respectively)

Modeling tools (MODTRAN and DIRSIG) utilized to predict instrument performance before instrument is built
Acknowledgements

- Detector Characterization Lab at NASA Goddard
  Nicholas Boehm, Chao-Hsi Chang, Roger Foltz, Mike Hickey, Duncan Kahle, Emily Kan, Augustyn Waczynski

- Digital Imaging and Remote Sensing Lab at RIT

References


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Backup Slides
Blackbody Temperatures

Blackbody radiance curves at various temperatures with the mean band shapes shown for reference.
Atmosphere Types

MODTRAN Standard Atmospheres:

- Tropical
- Mid-Latitude Summer
- Mid-Latitude Winter
- Sub-Arctic Summer

**Atmospheric Transmission**

**Atmospheric Path Radiance**

![Graphs showing atmospheric transmission and path radiance across different wavelengths for MODTRAN standard atmospheres.](image-url)
Pixel-to-Pixel Uniformity Requirements

• **Full Field of View:** The standard deviation of all pixel radiances across the FOV within a band shall not exceed 0.5% of the average radiance

\[ \sqrt{\frac{\sum_{i=1}^{N} (L_i - \bar{L})^2}{N - 1}} \leq 0.005 \cdot \bar{L} \]

• **Banding:** (1) The root mean square deviation from the average radiance across the full FOV for any 100 contiguous pixel radiances within a band shall not exceed 0.5% of that average radiance

\[ \sqrt{\frac{\sum_{i=n}^{n+99} (L_i - \bar{L})^2}{100}} \leq 0.005 \cdot \bar{L} \]

• **Banding:** (2) The standard deviation of the radiances across any 100 contiguous pixels within a band shall not exceed 0.5% of the average radiance across the full FOV

\[ \sqrt{\frac{\sum_{i=n}^{n+99} (L_i - \bar{L})^2}{99}} \leq 0.005 \cdot \bar{L} \]

• **Streaking:** The maximum value of the streaking parameter within a band shall not exceed 0.005

\[ \left| L_i - \frac{1}{2} (L_{i-1} + L_{i+1}) \right| \leq 0.005 \]

* Pixel data has been radiometrically calibrated using on-board blackbody method discussed earlier
Full Field of View

- All pixels meet FOV requirement for all conditions

\[
\sqrt{\frac{\sum_{i=1}^{N}(L_i - \bar{L}_i)^2}{N-1}} \leq 0.005
\]

<table>
<thead>
<tr>
<th>Blackbody Temperature</th>
<th>TRP</th>
<th>MLS</th>
<th>MLW</th>
<th>SAS</th>
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<tbody>
<tr>
<td></td>
<td>St. Dev.</td>
<td>0.5% mean</td>
<td>St. Dev.</td>
<td>0.5% mean</td>
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<tr>
<td>260</td>
<td>0.0019 ≤ 0.0328</td>
<td>0.0017 ≤ 0.0293</td>
<td>0.0001 ≤ 0.0244</td>
<td>0.0009 ≤ 0.0264</td>
</tr>
<tr>
<td>270</td>
<td>0.0012 ≤ 0.0353</td>
<td>0.0010 ≤ 0.0326</td>
<td>0.0002 ≤ 0.0291</td>
<td>0.0003 ≤ 0.0303</td>
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<tr>
<td>280</td>
<td>0.0004 ≤ 0.0381</td>
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<td>0.0008 ≤ 0.0412</td>
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<td>0.0010 ≤ 0.0400</td>
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<td>0.0055 ≤ 0.0565</td>
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<td>0.0031 ≤ 0.0684</td>
<td>0.0050 ≤ 0.0633</td>
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Band 2: 12.0 um

<table>
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<th>Blackbody Temperature</th>
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<td>St. Dev.</td>
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<td>0.0048 ≤ 0.0332</td>
<td>0.0030 ≤ 0.0296</td>
<td>0.0002 ≤ 0.0242</td>
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<td>0.0031 ≤ 0.0437</td>
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<td>0.0050 ≤ 0.0463</td>
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<td>0.0060 ≤ 0.0530</td>
<td>0.0033 ≤ 0.0614</td>
<td>0.0048 ≤ 0.0559</td>
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</table>
Banding (1)

- All pixels meet banding (1) requirement for all conditions

\[ \sqrt{\frac{\sum_{i=n}^{n+99} (L_i - \bar{L})^2}{100}} \leq 0.005 \cdot \bar{L} \]

### Band 1: 10.8 um

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<th># Pixels Failing Requirement</th>
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### Band 2: 12.0 um

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Banding (2)

- All pixels meet banding (2) requirement for all conditions

\[
\sqrt{\frac{\sum_{i=n}^{n+99}(L_i - \bar{L})^2}{99}} \leq 0.005 \cdot \bar{L}
\]

<table>
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<tr>
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<th>Band 2: 12.0 um</th>
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Streaking

- Greater than 99.8% of pixels meet streaking requirement for all conditions

\[
\left| L_i - \frac{1}{2} \left( L_{i-1} + L_{i+1} \right) \right| \leq 0.005 \]

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