High Spatial Resolution Thermal Satellite Technologies

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Arizona State University
High Spatial Resolution Thermal Band

- Problem
  - No follow-on exists for Landsat 7 or ASTER high spatial resolution thermal systems
  - Can new technologies be implemented to allow for a low-cost, useful alternative?

- Approach
  - Investigate both traditional cooled cross-track scanners and new architectures (cooled and uncooled) that could enable a low-cost thermal capability
General Approach

Perform Thermal Surveys
- Science
- Application

Set Requirements

Simulate Datasets

Requirements Met?

YES

Perform Design Trades

Define Constraints

NO

Industry or Government

Develop Sensor Model

Requirements Met?

YES

Estimate Cost

Cost Benefit Analysis

GOOD

1st Order System Design

SENSOR Specifications

POOR

Set Requirements

NO
What Has Been Done?

- Landsat 7 Science Team and others were asked for thermal system requirements:
  - Spectral
  - Temperature range
  - NEDT
  - Ground sample distance
  - Point spread function
  - Revisit time

- First order look at present systems and possible uncooled and cooled detector options
  - Standard pushbroom options
  - Backscanned systems
# Thermal Study

## Research or Area of Interest

<table>
<thead>
<tr>
<th></th>
<th>NEDT (K)</th>
<th>Tmin (K)</th>
<th>Tmax (K)</th>
<th>Radiometric Accuracy (%)</th>
<th>GSD (m)</th>
<th>PSF FWHM (m)</th>
<th>Revisit Time (days)</th>
<th>Spectral Band(s)</th>
<th>Other Requirements</th>
<th>Source</th>
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</thead>
<tbody>
<tr>
<td>Cloud Detection for LTAP</td>
<td>0.5</td>
<td>198</td>
<td>310</td>
<td>5%</td>
<td>60 (ideal) 120 (acceptable)</td>
<td>78 m</td>
<td>per image</td>
<td>1-ok, 2 or more better</td>
<td>daylight pairs are very useful</td>
<td>GSFC</td>
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<td>Monitoring Surface Energy and Water Fluxes 1</td>
<td>-0.2</td>
<td>273</td>
<td>310</td>
<td>1K</td>
<td>~100</td>
<td>~100</td>
<td>~15</td>
<td>6-14 um, 6 bands equally spaced</td>
<td>JPL</td>
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<tr>
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<td>0.1</td>
<td>263</td>
<td>343</td>
<td>0.5</td>
<td>20</td>
<td>40</td>
<td>7 (geostationary is better)</td>
<td>10-11microns</td>
<td>10-11AM local time overpass</td>
<td>UW-Madison</td>
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<td>Monitoring Surface Energy and Water Fluxes</td>
<td>0.2</td>
<td>250</td>
<td>360</td>
<td>1K (4%)</td>
<td>30m</td>
<td>30m</td>
<td>weekly</td>
<td>10-11microns</td>
<td>10-11AM local time overpass</td>
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<td>Material Transport in Aquatic Systems</td>
<td>-0.3</td>
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<td>305</td>
<td>1K Absolute</td>
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<td>0.25</td>
<td>260</td>
<td>320</td>
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<td>ETM+</td>
<td>Hourly</td>
<td>Vis/TIR Split Window for ATM</td>
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<td>Agriculture Studies</td>
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<td>Soil Moisture</td>
<td>0.1</td>
<td>273</td>
<td>313</td>
<td>0.5</td>
<td>20</td>
<td>40</td>
<td>7</td>
<td>same as above</td>
<td>JPL</td>
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<tr>
<td>Soil Moisture 1</td>
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<td>350</td>
<td>3K (4%)</td>
<td>30m</td>
<td>30m</td>
<td>weekly</td>
<td>10-11microns</td>
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<td>JPL</td>
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<tr>
<td>Canopy Heat Exchange</td>
<td>0.1</td>
<td>263</td>
<td>343</td>
<td>0.5</td>
<td>20</td>
<td>40</td>
<td>7</td>
<td>same as above</td>
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<tr>
<td>Canopy Heat Exchange 1</td>
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<td>250</td>
<td>350</td>
<td>3K (4%)</td>
<td>30m</td>
<td>30m</td>
<td>weekly</td>
<td>10-11microns</td>
<td>same as above</td>
<td>UW-Madison</td>
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<tr>
<td>Crop Health</td>
<td>0.1</td>
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<td>313</td>
<td>0.5</td>
<td>20</td>
<td>40</td>
<td>7</td>
<td>same as above</td>
<td>JPL</td>
<td></td>
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<tr>
<td>Crop Health 1</td>
<td>0.2</td>
<td>250</td>
<td>350</td>
<td>3K (4%)</td>
<td>30m</td>
<td>30m</td>
<td>weekly</td>
<td>10-11microns</td>
<td>same as above</td>
<td>JPL</td>
</tr>
<tr>
<td>Irrigated Crops</td>
<td>0.1</td>
<td>273</td>
<td>313</td>
<td>0.5</td>
<td>20</td>
<td>40</td>
<td>7</td>
<td>same as above</td>
<td>JPL</td>
<td></td>
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<tr>
<td>Irrigated Crops 1</td>
<td>0.5</td>
<td>273</td>
<td>313</td>
<td>Relative is important</td>
<td>120</td>
<td>120</td>
<td>ETM+</td>
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<td>CU-Boulder</td>
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<td>Irrigated Crops 2</td>
<td>0.2</td>
<td>250</td>
<td>350</td>
<td>3K (4%)</td>
<td>30m</td>
<td>30m</td>
<td>weekly</td>
<td>10-11microns</td>
<td></td>
<td>UW-Madison</td>
</tr>
</tbody>
</table>

- **GSD**: Ground Sample Distance
- **PSF FWHM**: Point Spread Function Full Width Half Maximum (system blur)
- **Tmin, Tmax**: Temperature Range of Phenomena
- **NEDT**: Temperature Sensitivity

Stennis Space Center

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**Cloud Detection for LTAP**

- NEDT: 0.5 K, Tmin: 198 K, Tmax: 310 K, Radiometric Accuracy: 5%
- GSD: 78 m, PSF FWHM: per image
- Revisit Time: ~100 days, Spectral Bands: 6-14 um, 6 bands equally spaced
- Other Requirements: 1-ok, 2 or more better
- Source: GSFC

**Monitoring Surface Energy and Water Fluxes 1**

- NEDT: -0.2 K, Tmin: 273 K, Tmax: 310 K, Radiometric Accuracy: 1 K
- GSD: ~100 m, PSF FWHM: 40 m
- Revisit Time: ~15 days, Spectral Bands: 6-14 um, 6 bands equally spaced
- Other Requirements: 1-ok, 2-to improve ATM cal would be better
- Source: JPL

**Monitoring Surface Energy and Water Fluxes**

- NEDT: 0.1 K, Tmin: 263 K, Tmax: 343 K, Radiometric Accuracy: 0.5
- GSD: 20 m, PSF FWHM: 40 m
- Revisit Time: Hourly, Spectral Bands: Vis/TIR Split Window for ATM
- Other Requirements: 10-11microns
- Source: UW-Madison

**Material Transport in Aquatic Systems**

- NEDT: -0.3 K, Tmin: 273 K, Tmax: 305 K, Radiometric Accuracy: 1 K Absolute
- GSD: ~100 m, PSF FWHM: 30m
- Revisit Time: ~15 days, Spectral Bands: 10-11microns
- Other Requirements: 10-11AM local time overpass
- Source: RIT

**Material Transport in Aquatic Systems 1**

- NEDT: 0.25 K, Tmin: 260 K, Tmax: 320 K, Radiometric Accuracy: 0.2 Absolute
- GSD: 60 m, PSF FWHM: ETM+
- Revisit Time: Hourly, Spectral Bands: Vis/TIR Split Window for ATM
- Other Requirements: 10-11microns
- Source: Brown University

**Agriculture Studies**

- **Soil Moisture**: NEDT: 0.1 K, Tmin: 273 K, Tmax: 313 K, Radiometric Accuracy: 0.5
- GSD: 20 m, PSF FWHM: 40 m
- Revisit Time: 7 days, Spectral Bands: same as above
- Other Requirements: same as above
- Source: JPL

- **Soil Moisture 1**: NEDT: 0.2 K, Tmin: 250 K, Tmax: 350 K, Radiometric Accuracy: 3K (4%)
- GSD: 30 m, PSF FWHM: 30 m
- Revisit Time: Weekly, Spectral Bands: 10-11microns
- Other Requirements: same as above
- Source: UW-Madison

- **Canopy Heat Exchange**: NEDT: 0.1 K, Tmin: 263 K, Tmax: 343 K, Radiometric Accuracy: 0.5
- GSD: 20 m, PSF FWHM: 40 m
- Revisit Time: 7 days, Spectral Bands: same as above
- Other Requirements: same as above
- Source: JPL

- **Canopy Heat Exchange 1**: NEDT: 0.2 K, Tmin: 250 K, Tmax: 350 K, Radiometric Accuracy: 3K (4%)
- GSD: 30 m, PSF FWHM: 30 m
- Revisit Time: Weekly, Spectral Bands: 10-11microns
- Other Requirements: same as above
- Source: UW-Madison

- **Crop Health**: NEDT: 0.1 K, Tmin: 263 K, Tmax: 313 K, Radiometric Accuracy: 0.5
- GSD: 20 m, PSF FWHM: 40 m
- Revisit Time: 7 days, Spectral Bands: same as above
- Other Requirements: same as above
- Source: JPL

- **Crop Health 1**: NEDT: 0.2 K, Tmin: 250 K, Tmax: 350 K, Radiometric Accuracy: 3K (4%)
- GSD: 30 m, PSF FWHM: 30 m
- Revisit Time: Weekly, Spectral Bands: 10-11microns
- Other Requirements: same as above
- Source: UW-Madison

- **Irrigated Crops**: NEDT: 0.1 K, Tmin: 273 K, Tmax: 313 K, Radiometric Accuracy: 0.5
- GSD: 20 m, PSF FWHM: 40 m
- Revisit Time: 7 days, Spectral Bands: same as above
- Other Requirements: same as above
- Source: JPL

- **Irrigated Crops 1**: NEDT: 0.5 K, Tmin: 273 K, Tmax: 313 K, Radiometric Accuracy: Relative is important
- GSD: 120 m, PSF FWHM: 120 m
- Revisit Time: ETM+
- Spectral Bands: same as above
- Other Requirements: CU-Boulder

- **Irrigated Crops 2**: NEDT: 0.2 K, Tmin: 250 K, Tmax: 350 K, Radiometric Accuracy: 3K (4%)
- GSD: 30 m, PSF FWHM: 30 m
- Revisit Time: Weekly, Spectral Bands: 10-11microns
- Other Requirements: same as above
- Source: UW-Madison
## Thermal Study (cont.)

<table>
<thead>
<tr>
<th>Research or Area of Interest</th>
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<th>Tmin (K)</th>
<th>Tmax (K)</th>
<th>Radiometric Accuracy (%)</th>
<th>GSD (m)</th>
<th>PSF FWHM (m)</th>
<th>Revisit Time (days)</th>
<th>Spectral Band(s)</th>
<th>Other Requirements</th>
<th>Source</th>
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<tr>
<td>Volcanology</td>
<td>1</td>
<td>275</td>
<td>1500</td>
<td>5</td>
<td>15</td>
<td></td>
<td>8</td>
<td>8.1-8.4, 8.4-8.8, 10.2-11</td>
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<td>JPL</td>
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<tr>
<td>Volcanology 1</td>
<td>3</td>
<td>273K</td>
<td>373K</td>
<td>5%</td>
<td>1m</td>
<td>1.2m</td>
<td>1-1000</td>
<td>0.4-2.5um: 5 bands; 3-5um: 2 bands; 8-12um: 5 bands</td>
<td>Predawn observations are highly desirable for thermal bands</td>
<td>JPL</td>
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<tr>
<td>Geologic mapping of surface deposits (e.g., ashfall, lava flows, pre-existing terrain, fumarolic alteration)</td>
<td>0.5</td>
<td>273K</td>
<td>373K</td>
<td>1%</td>
<td>1m</td>
<td>1.2m</td>
<td>1-1000</td>
<td>3-5: 2 bands; 8-12: 5 bands</td>
<td>Predawn observations are highly desirable for thermal bands</td>
<td>JPL</td>
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<tr>
<td>Low temperature thermal mapping (&lt;1000degC)</td>
<td>5</td>
<td>373K</td>
<td>1073K</td>
<td>5%</td>
<td>3m</td>
<td>3.6m</td>
<td>1-10</td>
<td>3-5: 2 bands</td>
<td>Night observations highly desirable</td>
<td>JPL</td>
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<td>Moderate temperature thermal mapping (1000-8000degC)</td>
<td>10</td>
<td>1073</td>
<td>1573</td>
<td>10%</td>
<td>10m</td>
<td>12m</td>
<td>1-3</td>
<td>1-2.5: 3 bands; 3-5: 2 bands</td>
<td>Night observations highly desirable</td>
<td>JPL</td>
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<td>High temperature thermal mapping (&gt;8000degC)</td>
<td>0.1</td>
<td>190K</td>
<td>273K</td>
<td>&lt;1%</td>
<td>300m</td>
<td>360m</td>
<td>1-3</td>
<td>3: 5: 2 bands; 7-14: 10 bands</td>
<td>Day/night observations</td>
<td>JPL</td>
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<tr>
<td>Ash plume detection/discrimination/tracking</td>
<td>0.1</td>
<td>190K</td>
<td>273K</td>
<td>&lt;1%</td>
<td>100m</td>
<td>120m</td>
<td>1-3</td>
<td>3-5: 2 bands; 7-14: 10 bands</td>
<td>Day/night observations</td>
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<td>Ash plume temperature/plume height</td>
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<td>273K</td>
<td>&lt;1%</td>
<td>100m</td>
<td>120m</td>
<td>1-3</td>
<td>3-5: 2 bands; 7-14: 10 bands</td>
<td>Day/night observations</td>
<td>JPL</td>
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<td>SO₂ plume detection</td>
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<td>190K</td>
<td>273K</td>
<td>&lt;1%</td>
<td>100m</td>
<td>120m</td>
<td>1-3</td>
<td>3-5: 2 bands; 7-14: 10 bands</td>
<td>Day/night observations</td>
<td>JPL</td>
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<tr>
<td>Urban Heat Islands</td>
<td>0.3</td>
<td>275</td>
<td>325</td>
<td>2</td>
<td>5</td>
<td>8</td>
<td>8.1-8.4, 10.2-11</td>
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<td>JPL</td>
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<td>Land Cover / Land Use</td>
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<td>340</td>
<td>±1</td>
<td>60-90</td>
<td>100-150</td>
<td>16 ≤</td>
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<td>Land Cover / Land Use 1</td>
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<td>340</td>
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<td>Seasonal</td>
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<td>2</td>
<td>15</td>
<td>16</td>
<td>5-6 bands</td>
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<td>273</td>
<td>320</td>
<td>1k</td>
<td>~100</td>
<td>~100</td>
<td>~15</td>
<td>1-ok, 2-better</td>
<td></td>
<td>RIT</td>
</tr>
</tbody>
</table>

- **GSD** Ground Sample Distance
- **PSF FWHM** Point Spread Function Full Width Half Maximum (system blur)
- **Tmin, Tmax** Temperature Range of Phenomena
- **NEDT** Temperature Sensitivity
• Many Landsat thermal applications will work with >60 meter GSD data
• Wide range of requirements indicates that more work is necessary to define them better
• This workshop should help provide such definition
Traditional TIR Architectures

- Cross-track scanning systems
- Cooled either actively or passively
- Small number of HgCdTe detectors
- Typically large GSD; Landsat is the smallest of the cross-track scanning systems at 60 m
- Telescope diameter typically driven by SNR considerations and not diffraction
- Most systems are multispectral
## Existing TIR Systems

**Satellite** | **Sensor** | **Architecture** | **Band** | **Spectral Range [µm]** | **Detector Material** | **Telescope Diameter [cm]** | **GSD [m]** | **MTF @ Nyquist** | **Swath [km]** | **Quant. [bit]** | **NEAT [K]**
--- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | ---
Landsat 7 | ETM+ | Cross-track scanner | 6 | 10.4 - 12.5 | HgCdTe | 40 | 60 | 0.3 | 185 | 8 of 9 |  
Terra | ASTER | Cross-track scanner | 10 | 8.125 - 8.475 | HgCdTe | 24 | 90 | 0.35 | 60 | 12 | 0.2  
NOAA | AVHRR | Cross-track scanner | 4 | 10.3 - 11.3 | HgCdTe | 20 | 1100 | 0.3 | 2800 | 10 | 0.12  
 | 5 | 11.5 - 12.5 |  
Terra | MODIS | Cross-track scanner | 27 | 6.535 - 6.895 | HgCdTe | 18 | 1000 | 0.35 | 2330 | 12 | 0.25  
MTI | MTI | Pushbroom | L | 8.00 - 8.40 | HgCdTe | 36 | 20 | 12 | 12 | 0.025  
 | M | 8.40 - 8.85 |  |  |  |  |  |  |  |  |  |  
 | N | 10.20 - 10.70 |  |  |  |  |  |  |  |  |  |  
ERSI-2 | ATSR-2 | Conical scanner | 1 | 11.5 - 12.3 | 11 | 1100 | 500 | 12 | 0.02 |  
 | 2 | 10.6 - 11.3 |  

**Notes:**
- NEAT: Noise Equivalent Temperature
- MTF: Modulation Transfer Function
- GSD: Ground Sample Distance
- Swath: Ground Swath
- Quant.: Quantization Level
- ETM+: Enhanced Thematic Mapper Plus
- ASTER: Advanced Spaceborne Thermal Emission and Reflection Radiometer
- AVHRR: Advanced Very High Resolution Radiometer
- MODIS: Moderate Resolution Imaging Spectroradiometer
- MTI: Moving Target Indicator

**Source:** Stennis Space Center

**Image:** DRAFT
Uncooled Pushbroom Pathfinding Thermal Instruments

- Thermal Emission Imaging System IR Sensor (THEMIS)
  - Flown on Mars Orbiter launched April 2001 to map Martian surface mineralogy
  - Uncooled Raytheon microbolometer array (320x240 50 μm pitch pixels)
    - Pushbroom imager with precision-aligned stripe filter
    - 9 bands between 6.2 and 15.5 μm
    - f/1.6 optics
    - 4.4 degree FOV
    - 12.9 cm aperture
    - 30 Hz readout
    - 100 m GSD
  - ~ $12M for instrument
New Thermal Architectures

- Pushbroom systems and framing cameras can provide significant sensitivity advantages over cross-track scanners
- SNR $\sim$ (no. of detectors) $0.5$
- Benefits of increased integration time associated with pushbroom systems and framing cameras:
  - Higher SNR
  - Smaller GSD
  - Potential use of uncooled detectors
Infrared Detector Types

- **Cooled detectors**
  - Photovoltaic or photoconducting mechanisms; HgCdTe and GaAs quantum well devices
  - High framing rates and low noise

- **Uncooled detectors**
  - Rely on a thermal response: bolometric, pyroelectric, and thermionic devices
  - Have slow framing rates and are relatively insensitive
  - Lighter and smaller system packaging possible
Uncooled Framing Camera/Pushbroom Pathfinding Thermal Instruments

- Infrared Spectral Imaging Radiometer (ISIR)
  - Flown on space shuttle mission STS-85 in August 1997 as part of a cloud science experiment
  - Uncooled Lockheed Martin microbolometer array (327x240 pixels)
    - Framing imager with filter wheel
    - 3 narrow bands at 8.55, 10.8, and 11.8 μm
    - 1 broad band at 7-13 μm
    - 250 m GSD
    - 85 km swath from shuttle altitude
    - f-number 0.73, lens diameter 50 mm
    - NEDT 0.01-0.06 °K at all wavelengths with TDIx40 for a 300 °K scene temperature
    - Ambient and cold inflight calibration capability
Uncooled Framing Camera/Pushbroom Pathfinding Thermal Instruments (cont.)

- Extremely good quality imagery was obtained for each band
- Accuracy goal was met to within a factor of 2 or 3
  - Pre-production prototype detector used
Potential New Configurations

- Cooled detectors
  - Advanced Land Imager (ALI) pushbroom architecture (common telescope for all bands)
    - Multispectral Thermal Imager (MTI)

- Uncooled detectors
  - ALI pushbroom architecture (common telescope for all bands)
  - Custom TIR system separate from ALI
    - Framing camera and filter wheel (ISIR)
    - Pushbroom multispectral system (THEMIS)
Uncooled Thermal Detector Characteristics

- Primarily developed for military systems: f/1 optics, 30-60 Hz framing rates
- Microbolometers
  - Silicon micro-machined devices provide excellent thermal isolation from substrate
  - Highest sensitivity demonstrated: f/1 optics, 30-60 Hz framing rate, NEDT ~ 20 mK
- Pyroelectric
  - Older technology: f/1 optics, 30 Hz framing rate, NEDT ~ 100 mK
  - Requires a chopper
- Emerging technologies: Thermionic, SAW Oscillators, Capacitive
Silicon Microbolometers

- Black absorber with a broadband response (atmospheric window 8-14 microns) thermistor
- Typical FPA
  - 320x240 pixels with 50 μm pitch
  - 640x480 pixels with 25 μm pitch
  - Very high fill factor >90%
  - Thermal time constant ~10 ms

Spatial Resolution Drivers

• Fundamental
  – Orbit altitude (the lower the better)
  – Telescope diameter
  – NEDT

• Engineering
  – Detector size
  – Focal lengths
  – Framing rates
  – Data rates and storage
Thermal GSD Trades

- GSD usually set approximately to FWHM of PSF
- Two sensor characteristics drive PSF:
  - Framing rate
    - Smear is defined as how far a pixel moves in an integration time
    - Typically GSD ~ Orbital Velocity / Frame Rate
  - Telescope diameter
    - Ground spot size for a diffraction limited system is controlled by Airy Diffraction Pattern
    - Ground spot size ~ 2.44 Wavelength*Range/Telescope Diameter
Frame Rate Trades for Landsat Orbit

<table>
<thead>
<tr>
<th>Framing Rate (Hz)</th>
<th>Smear (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.00</td>
<td>250.1</td>
</tr>
<tr>
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60 Hz framing rate limits GSD to 125 meters
Telescope Diameter Trades

Diffraction limited resolution (Rayleigh criteria)

Ground Spot Size = $2.44 \lambda \frac{\text{Range}}{\text{Diameter}}$

$\lambda = 11.5 \, \mu m$

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<th>Telescope Diameter (cm)</th>
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<td>10.4 cm Telescope Diameter</td>
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ALI
157 m Ground Spot Size
12.5 cm Telescope Diameter

ETM+
50 m Ground Spot Size
40 cm Telescope Diameter
Detector Thermal Time Constant 10 ms

7.5 km/sec produces a 75 m 1/e exponential response
Thermal Time Constant & Spatial Resolution

Detector Thermal Time Constant 10 ms

Spatial width m

Ground Speed km/sec
Custom Thermal Infrared Sensor (Point Design)

- F-number 1.8
  - A little fast but probably achievable (THEMIS f-number 1.6)
  - NEDT for Landsat Band 300 K Background
- NEDT of a single detector ~ 0.3 K with a TDI of 1; TDI of 25 could produce a 0.06 k NEDT system!!!!!
Custom Thermal Infrared Sensor (Point Design) (cont.)

- Detector spot size 50.5 μm at l = 11.5 μm
  - ~ 1542 detectors at 50 μm pitch for 185 km swath with 120 m GSD
  - ~ Five 320x240 FPAs
  - Many detectors available for other bands
  - ASTER-like instrument
  - Oversampling: use 25 μm pitch detectors and oversample PSF
Possible FPA Configuration

Double bank of uncooled microbolometer detector arrays

Spacecraft Direction

5,000 50 \(\mu\text{m}\) pitch detectors or 10,000 25 \(\mu\text{m}\) pitch detectors

320x240 or 640x480 detector FPA
Backscanning System

- Trade off coverage for GSD by backscanning the system
  - Used by 1 m class GSD commercial systems such as IKONOS and QuickBird
  - Cutting the ground speed down by a factor of 2 or more produces dramatic results
  - Improved NEDT for a fixed GSD
- 30 m GSD or better system possible with backscanning, creating a high system with MTI-like performance without cooled detectors
• Landsat 7 thermal imagery was synthesized from ATLAS 10-meter imagery

• Microbolometer-simulated imagery was produced with several parameters varied
Microbolometer 30 m detector; 60 m PSF; 125 m smear; 0.3 K NEDT; decimation (3x3). Final product: 30 m GSD.
LDCM Thermal Trade Simulation

Landsat 7 60 m detector; 60 m PSF; NEDT 0.22 K; decimation (6x6).
Final product: 60 m GSD.
LDCM Thermal Trade Simulation

Microbolometer 60 m detector; 120 m PSF; 125 m smear; NEDT 0.30 K; LPF (2x2); decimation (6x6). Final product: 60 m GSD.
Microbolometer 60 m detector; 120 m PSF; 125 m smear; no noise; LPF (2x2); decimation (6x6). Final product: 60 m GSD.
Microbolometer 30 m detector; 60 m PSF; 125 m smear; no noise; decimation (3x3). Final product: 30 m GSD.
Summary

- Conventional microbolometer pushbroom mode offers potential for low-cost LDCM thermal or ASTER capability with at least a 60-120 meter GSD
- Backscanning could produce MTI-like performance without cooled detectors
- Cooled detectors could produce hyperspectral thermal class system or extremely high spatial resolution class instrument
**REPORT DOCUMENTATION PAGE**

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