EO-1 Observations of Volcanoes

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Hilo, Hawaii
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Overview of EO-1 Talk

• Objectives
• ETM+ vs. ALI Comparisons for Etna
• Hyperion Observations of Volcanoes
• Automated Spectral Assessment and Target Acquisition
• Conclusions
EO-1 Objectives

• Investigate the sensitivity of EO-1 instruments to high temperature volcanic thermal anomalies.
  – Active eruptions apparent at 0.9 - 2.5 µm.
  – Active basalt flows have higher reflectance.
• Create more robust algorithms for uniquely determining sub-pixel thermal anomalies.
• Determine required spectral channels.
<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength (µm)</th>
<th>Pixel Size (m)</th>
<th>Landsat 7 Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pan</td>
<td>0.480 - 0.690</td>
<td>10 x 10</td>
<td>0.520 - 0.900 (15m x 15m)</td>
</tr>
<tr>
<td>1’</td>
<td>0.433 - 0.453</td>
<td>30 x 30</td>
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</tr>
<tr>
<td>1</td>
<td>0.450 – 0.515</td>
<td>30 x 30</td>
<td>0.450 - 0.515</td>
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<tr>
<td>2</td>
<td>0.525 – 0.605</td>
<td>30 x 30</td>
<td>0.525 - 0.605</td>
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<tr>
<td>3</td>
<td>0.630 – 0.690</td>
<td>30 x 30</td>
<td>0.630 - 0.690</td>
</tr>
<tr>
<td>4</td>
<td>0.775 – 0.805</td>
<td>30 x 30</td>
<td>0.750 - 0.900</td>
</tr>
<tr>
<td>4’</td>
<td>0.845 – 0.890</td>
<td>30 x 30</td>
<td></td>
</tr>
<tr>
<td>5’</td>
<td>1.200 – 1.300</td>
<td>30 x 30</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.55 – 1.75</td>
<td>30 x 30</td>
<td>1.55 - 1.75</td>
</tr>
<tr>
<td>6</td>
<td>10.40 – 12.50</td>
<td>60 x 60</td>
<td>Not Available on ALI</td>
</tr>
<tr>
<td>7</td>
<td>2.08 – 2.35</td>
<td>30 x 30</td>
<td>2.09 - 2.35</td>
</tr>
</tbody>
</table>
Landsat 7 ETM+ image acquired on 28 October 1999

Event began ~ 17:00, 27 October 1999
Final length ~ 4.9 km
Final volume ~ 5 x 10^6 m^3
The properties of the active channel

$P_{\text{core}} = \frac{R_{4\text{thermal}} - L(\lambda_4, T_{\text{crust}})}{L(\lambda_4, T_{\text{core}}) - L(\lambda_4, T_{\text{crust}})}$

$T_{\text{core}} = 1000 \, ^\circ\text{C}, \quad T_{\text{crust}} < 500 \, ^\circ\text{C}$

$0.04 < P_{\text{core}} < 0.11$

$\bar{\chi} = 0.7$
Properties of the channel the lava channel
Assessing performance of ALI and ETM+ over hot volcanic targets (1)

- Possible to determine sub-pixel surface thermal structure by using 2 separate channels

- Lava flows can be simplified as a 2 component thermal surface:
  a). Hot incandescent core exposed through cracks in crust represented by a fractional area, \( P_h \) & temperature \( T_h \)
  b). Cooler crust occupying pixel fraction \( 1 - P_h \), or \( P_c \) at temperature \( T_c \)

- By setting \( T_h \) to 1000°C (or equivalent magmatic temperature) and completing “dual-band” simultaneous equations, can use 2 bands of unsaturated data to deduce the unknowns \( P_h, T_c \) & \( P_c \)

- Relationship between \( P_h \) & \( P_c \) important in determining lava flow characteristics
Assessing performance of ALI and ETM+ over hot volcanic targets (2)

- ETM+ has been used often for such dual band analysis
- However, band 7 saturates easily over even moderately hot volcanic surfaces (depending on temperature and area of pixel occupied). Over active lava flows band 5 often saturates too
- This prevents dual band solutions
- ALI has an extra band (5p) between ETM+ channels 4 & 5 that is ideally placed for detecting active lava flows without saturating quickly
- ALI also has 2 bands (4 & 4p) within the ETM+ band 4 bandpass
- The ALI ‘dynamic gain’ function should also go some way to prevent saturation over hot volcanic surfaces
- In theory dual band solutions should be easier to obtain using ALI
Assessing performance of ALI and ETM+ over hot volcanic targets (3)

- Currently conducting comparison between ALI & ETM+ in terms of response to lava flows on Mt Etna, Sicily, imaged on 13th July 2001 (fissure fed flows from base of SE crater) and 29th July (flows from the then ongoing flank eruption).

- Wide range of volcanic surfaces available from small fissure fed flows, to large channelized a’a flows and active vents.

- Also have ALI imagery for Mt Etna from 20th June (Levantino flows), 23rd July (flank eruption flows) and 7th August 2001 (flank eruption flows).

- Hoping to get ETM+ imagery for these dates so can extend the study to incorporate small fissure fed flows and cooling history of flows from the flank eruption after it ceased in ~mid August 2001.
Etna Eruption of July, 2001

29th July 2001 09.25AM
Flows from Mt Etna flank eruption
A: Fissure of 20/07/01 2600-2700m
B: Summit craters
C: Flows from 17/07/01 2950m fissure
D: Flows from 17/07/01 2700m fissure
E: Monte del Lago vents 18/07/01 2500m
F: Flows heading towards Monte Nero degli Zappini
G: Flows passing cable car stations
H: Eruptive fissure of 18/07/01 nr Monte Calcarazzi 2100m
I: Flows passing Monte Silvestri & Monte Nero
J: Flow front, nr Monte Concilio

Rif. Sapienza

Magnified section of flows nr Monte Lago vents

Location of all images

13th July 2001 09.22AM
Flows from Levantino fissure at base of SE crater
K: Flows from fissure at base of SE cone (Levantino)
No solutions available (Band 7 saturated)
Pixel area = \( P_h(T_h) + P_c(T_c) = 1 \)

\( P_h \) = fractional area occupied by surface at \( T_h \) (assumed 1000°C)

\( T_c \) = temperature (°C) of remaining surface area

<table>
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<tr>
<th>ALI</th>
<th>ALI 5 &amp; 5p</th>
<th>ALI 5 &amp; 5p</th>
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<tr>
<td>ALI 5 &amp; 5p</td>
<td>Ph = 0.00186 Tc = 402</td>
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<tr>
<td>ALI 5p &amp; 4p</td>
<td>Ph = 0.00859 Tc = 595</td>
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<td>ALI 5p &amp; 4p</td>
<td>Ph = 0.01685 Tc = 595</td>
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<tr>
<td>ALI 5p &amp; 4p</td>
<td>Ph = 0.0104 Tc = 544</td>
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<tr>
<td>ALI 5p &amp; 4p</td>
<td>Ph = 0.0031 Tc = 647</td>
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<table>
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<th>ETM+</th>
<th>ETM 7Lg &amp; 5Lg</th>
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<tr>
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<td>ETM 7Lg &amp; 5Lg</td>
<td>Ph = 0.00106 Tc = 185</td>
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<tr>
<td>ETM 7Lg &amp; 5Lg</td>
<td>Ph = 0.00055 Tc = 247</td>
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<tr>
<th>ALI</th>
<th>ALI 7 &amp; 5</th>
<th>ALI 7 &amp; 5p</th>
<th>ALI 5 &amp; 5p</th>
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<td>ALI 7 &amp; 5</td>
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<td>Ph = 0.00072 Tc = 239</td>
<td>-</td>
<td>-</td>
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<tr>
<td>ALI 7 &amp; 5</td>
<td>Ph = 0.00073 Tc = 245</td>
<td>-</td>
<td>-</td>
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<tr>
<td>ALI 7 &amp; 5p</td>
<td>Ph = 0.0007 Tc = 236</td>
<td>-</td>
<td>-</td>
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<tr>
<td>ALI 7 &amp; 5p</td>
<td>Ph = 0.00072 Tc = 239</td>
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<tr>
<td>ALI 7 &amp; 5p</td>
<td>Ph = 0.00073 Tc = 245</td>
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<tbody>
<tr>
<td>ETM 7Lg &amp; 5Lg</td>
<td>Ph = 0.00098 Tc = 201</td>
</tr>
</tbody>
</table>

Image shown is from ALI
ETM+ ALI Comparisons

ETM+ 29/07/01 Flows near Montagnola

(i) ETM+ Bands 7 & 5

(ii) ETM+ Bands 5 & 4

ALI 29/07/01 Flows near Montagnola

(i) ALI Bands 5 & 5p

(ii) ALI Bands 5p & 4p

Dot size represents $F_i$, at
300°C scaled to pixel

$F_i$ represented as fraction of 1,
equivalent to total pixel area

Pixel size $= 4000$ m

Symbols:

- High reflectance
- Low reflectance
- No reflection
Assessing performance of ALI and ETM+ over hot volcanic targets (4)

- Previous slides show simple comparison between ALI & ETM to transects along a section of flow near Monte Calcarazzi on 29th July 2001
- Equivalent ETM+ image shows channels 5 & 7 often saturated
- No saturation evident in ALI Level1R data
- Very few dual band solutions available using ETM+ data
- Many solutions evident using ALI bands 4p, 5p, 5 & 7
- Solutions using ALI bands 4p, 5p & 5 appear accurate and compare well with contemporary ground based thermal data and also published data
- Three bands of unsaturated useable data available with ALI permitting use of “triple band” models (& therefore more accurate lava flow observations). This not at all feasible with ETM+
Assessing performance of ALI and ETM+ over hot volcanic targets (5)

- Solutions involving ALI band 7 result in $T_c$ values being too low with corresponding $P_c$’s too high
- Comparison between ALI band 7 pixels over hottest portions of lava flows in Level0 and Level1R data show that band 7 pixels saturated (DN=4095) in Level0
- This suggests that dual band solutions involving band 7 will be erroneous as radiance value given in Level1R data is at best a minimum radiance value and not the true value at that particular wavelength
- Very little (no) information freely available on ‘dynamic gain’ operation to predict at exactly what surface temperatures/areal fractions ALI band 7 will saturate
- ALI Level1R method of flagging saturated pixels needed?
Hyperion Observes Etna - July 13

Hyperion bands 213, 152, and 32 were used to create this RGB image. Lava flow activity from the base of the South East cone before larger eruptive episode on July 17, 2001. Hyperion data are limited to a 7.5 km swath width because the sensor is 512 element array which effectively collects 30 m spatial resolution pixels.
Hyperion Observes Etna - July 22

Part of a Hyperion image on left showing more extensive eruption.

Saturation of detectors over hot channels cause a radiance echo in Hyperion data.

We are working to reconstruct the original analog signal from the saturated pixels and the radiant echo.
Hyperion Spectra - July 22, 2001

Lave Profile Spectra: July 22th 2001

- bkgd X:73 Y:3593
- mid start X:53 Y:3631
- edge start X:51 Y:3631
- tip X:144 Y:3656
- crater X:45 Y:3614

Wavelength vs Radiance graph.

400 600 800 1000 1200 1400 1600 1800 2000 2200 2400
0 10 20 30 40 50 60 70 80 90 100
<table>
<thead>
<tr>
<th>Spectrum</th>
<th>Crust Temp</th>
<th>Hot Temp</th>
<th>Area Hot</th>
</tr>
</thead>
<tbody>
<tr>
<td>J 13 - CTB</td>
<td>346 C</td>
<td>994 C</td>
<td>0.0025</td>
</tr>
<tr>
<td>J 13 - MM</td>
<td>874 C</td>
<td>876 C</td>
<td>0.45</td>
</tr>
<tr>
<td>J 13 - CTS</td>
<td>976 C</td>
<td>978 C</td>
<td>0.47</td>
</tr>
<tr>
<td>J 13 - TipX</td>
<td>210 C</td>
<td>900 C</td>
<td>0.00034</td>
</tr>
<tr>
<td>J 22 - MS</td>
<td>726 C</td>
<td>1075 C</td>
<td>0.090</td>
</tr>
<tr>
<td>J 22 - CX</td>
<td>487 C</td>
<td>1075 C</td>
<td>0.022</td>
</tr>
<tr>
<td>J 22 - RS*</td>
<td>1054 C</td>
<td>1058 C</td>
<td>0.690</td>
</tr>
</tbody>
</table>
Ertà Ale Lava Lake, Ethiopia

Recent observers note that the lake is usually covered by a solid crust. Overturning events occur randomly.

Data from 2.1 - 2.5 µm could not be used because of saturation.

Best fit: $T_c = 952^\circ C, T_h = 955^\circ C, A_h = 0.135$
EO-1 Hyperion temperatures of 952-955°C show period of high activity. Radiance here is integrated across the entire lake surface. Data collected for 3 days in February 2002.
Lascar Lava Dome, Chile

Lascar last erupted in July, 2000. This spectrum was acquired from Lascar volcano lava dome.

Best Fit: $T_c = 505^\circ C$, $T_h = 1100^\circ C$, $A_h = 0.0081$

Corresponds to 7.3 m$^2$ of molten lava within pixel.
Automated Assessment and Targeting of Hazards

MODIS Thermal Alert Map 01/20/02

ASTER image 01/28/02
Papers in Prep


• Donegan, S., and L.P. Flynn, Comparison of the response of the Landsat 7 ETM+ and the Earth Observing-1 ALI over active volcanic lava flows, to be submitted to IEEE, November, 2002.
Current Work

1) Get Hyperion data sets for Kilauea to allow temporal comparison.
2) Order ETM+ images of 2001 Etna eruption to expand ALI comparisons.
3) Incorporate field data where possible
   - Sonia Calvari (Catania, ITALY - FLIR images
   - Erta Ale radiometer data
4) Work out correction for radiance echo for Hyperion.
Conclusions

1) ALI’s spectral bands allow for complete numerical solution of the lava flow field.

2) Splitting ETM+ band 4 (ALI 4 and 4’) is great for high temperature assessment.

3) Saturation will not be resolved because of many orders of magnitude increase in radiance. More near-IR spectral bands (band 5’) Non-linear radiometric range?

5) Current generation of near real-time sensors can be used to target EO-1.