Mineral Mapping Using Simulated HyspIRI Data

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Acknowledgments

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  • The Arthur Brant Laboratory for Exploration Geophysics at the University of Nevada, Reno
  • The Remote Sensing Center at the Naval Postgraduate School
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Presentation Summary

• Objectives
• Introduction to Geothermal/Hydrothermal Systems
• Mineral Spectroscopy
• Temperature Mapping Example
• Simulation Approach and Methods
• Selected Results
• Summary and Conclusions
HyspIRI Precursor Project Objectives

Generate HyspIRI-like remote sensing datasets from existing NASA HSI and MSI remote sensing data

1. Airborne Visible Infrared Imaging Spectrometer (AVIRIS) for HyspIRI VSWIR simulations
   - Original Data: 0.38 – 2.52 µm, 224 spectral bands, 10nm spectral resolution, various spatial resolutions
   - Simulated Data: 0.4 – 2.5 µm, 213 spectral bands, ~10nm spectral resolution, 60m spatial resolution

2. MODIS/ASTER Airborne Simulator (MASTER) for HyspIRI TIR simulations
   - Original Data, 50 bands 0.4 – 12.9 µm, various spatial resolutions (~3 to 35m)
   - Simulated Data: 7 bands 7.3 – 12.03 µm per response curves, 60m spatial resolution
HyspIRI Precursor Project Objectives

Evaluate HyspIRI-simulated data’s capabilities to:

1. Identify, characterize, and map mineral assemblages associated with surface exposures of active and fossil hydrothermal systems

2. Measure surface temperatures and temperature variability associated with active geothermal systems

3. Detect, characterize, and monitor surface changes associated with geothermal resources
Geothermal (hydrothermal) Systems

Fossil Hydrothermal System
Why Remote Sensing of Hydrothermal/Geothermal Systems?

• High beneficial impact: Ore deposits provide raw materials for industrialized society, while geothermal systems provide abundant energy without many of the problems of fossil fuels

• These two are highly related. Surface mineral assemblages and distributions often provide key information about their origin and nature. Many minerals associated with these systems can be mapped using remote sensing

• For geothermal systems, surface temperature also provides clues to underlying processes
– VNIR/SWIR spectrometry has clearly demonstrated its capability to identify minerals based on molecular physics
– LWIR spectrometry has unique capabilities based on fundamental molecular vibrations
Surface Temperature Mapping at Geothermal Systems

- LWIR Multispectral data provide the additional capability to estimate surface temperature
- Improved understanding of known systems by detecting/mapping
  - Distribution of heat anomalies and links to subsurface
  - Structural control
  - Outflow areas
- Provide new exploration tools
  - Temperature anomalies and magnitudes
  - “Blind” Systems
- Develop Methods for Monitoring
  - System characteristics and Natural variability
  - Exploitation Changes

Coolbaugh, 2007 – Temperature Anomalies at Brady Hot Springs Using ASTER. Small black and brown points indicate field located steam vents or surface hot spots.
HyspIRI Simulation: Methods

- Generate orthorectified ASTER base image at 15m spatial resolution
- AVIRIS Reflectance
  - Resample AVIRIS to HyspIRI bands using band centers and FWHM
  - Perform Reflectance Conversion using ACORN
  - Geocorrect AVIRIS full dataset @15m to ASTER base
  - Spatially resample to 60m (aggregate pixels)
- MASTER Emissivity and Temperature
  - Resample MASTER Emissivity to HyspIRI using band responses
  - Atmospherically correct using ISAC
  - Perform emissivity-temperature separation
  - Scale emissivity x 10000. to roughly match VSWIR reflectance range and convert to Integer
  - Geocorrect MASTER full dataset @15m to ASTER base
  - Spatially resample to 60m (aggregate pixels)
Study Areas

- Generate Simulated HyspIRI Data and Analysis Results for:
  - Cuprite, NV (fossil hydrothermal system)
  - Steamboat Springs, NV (geothermal)
  - Long Valley, CA (geothermal)
  - Fish Lake Valley, NV (geothermal)
  - Yellowstone, WY (geothermal)
Cuprite, NV, HyspIRI Simulation

ASTER VNIR (15m)
04-28-2007 Ortho

AVIRIS VNIR (15m)
09-20-2006 Ortho

MASTER VNIR and LWIR (34m),
09-20-2006 GLT-Corrected
Cuprite, NV Simulation: We end up with several small simulated datasets!

772 x 2493 Left: AVIRIS VNIR (15m) 09-20-2006 Ortho Warped toASTER Ortho at 15m spatial resolution; Right Master Emissivity @HyspIRI bands

193 x 623 Left: HyspIRI simulated dataset from AVIRIS VNIR (15m) 09-20-2006 Ortho Warped toASTER Ortho at 60m spatial resolution. Right: MASTER Emissivity @HyspIRI bands and 60m
Cuprite, NV, 2006 AVIRIS
15m-derived SWIR MTMF Mineral Map (Kruse, 2011)
Cuprite, NV, HyspIRI-Simulated 60m-derived SWIR MTMF Mineral Map (Kruse, Unpublished)

Endmembers

HyspIRI MTMF (60m)
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<th>Alun#1</th>
<th>Calcite</th>
<th>Kaolinite</th>
<th>Musc#1</th>
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**Table 1.** Confusion matrix for Cuprite, Nevada, 15 m *versus* 60 m HyspIRI simulation.

Overall Accuracy = (1533947/1905364) 80.5068%. Kappa Coefficient = 0.4627.

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Cuprite, NV 2006 MASTER LWIR (34m)

Emissivity

MNF 1, 2, 3

Endmembers

Classification
Cuprite, NV 2006 HyspIRI-Simulated LWIR (60m)

Emissivity

MNF 1, 2, 3

Endmembers

Classification
Steamboat Springs, NV Simulation

ASTER VNIR (15m)
10-23-2006 Ortho

AVIRIS VNIR (15m)
07-22-1995, Warped to ASTER Ortho

MASTER VNIR (9m @15m), 09-19-1999
GLT-Corrected, Warped to Ortho ASTER

MASTER LWIR (9m @15m), GLT-Cor
09-19-1999, Warped to ASTER Ortho
Steamboat Springs, NV Simulation

HyspIRI-Simulated VSWIR Reflectance (15m)  
HyspIRI-Simulated LWIR Emissivity (15m)
Steamboat Springs, NV Simulation

HyspIRI-Simulated VSWIR Radiance (60m)  
HyspIRI-Simulated LWIR Radiance (60m)
Steamboat Springs, NV Spectral Maps

HyspIRI SWIR EM

Kaolinite#2
Am Vegetation
Grn Vegetation
Pyrophyllite
Kaolinite#1
Muscovite/Illite
Silica
Alunite

ACORN Reflectances (Offset for clarity)

Wavelength (Micrometers)

15m

60m

Alunite
Silica
Muscovite/Illite
Kaolinite#1
Pyrophyllite
Grn Veg
Dry Veg
Kaolinite#2
Steamboat Springs, NV Accuracy Assessment

Table 2. Confusion matrix for Steamboat Springs, Nevada, 15 m versus 60 m HypsIRI simulation. Overall Accuracy = (278492/302217) 92.1497% Kappa Coefficient = 0.6859.

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For 15m and 60m resolutions, the confusion matrix shows the accuracy assessment results. The overall accuracy, 92.1497%, indicates a high level of agreement between the actual and predicted land cover classes. The Kappa Coefficient of 0.6859 suggests moderate agreement beyond chance.
Yellowstone WY Example
Yellowstone, WY HyspIRI Simulation

ASTER VNIR (15m)
09-08-2000 Ortho

AVIRIS VNIR (15m)
07-14-1997, 08-06-1996

MASTER LWIR Emissivity
09-25-2006
AVIRIS Results (15m) Firehole River
Alkaline, with Acid Sulfate on margins

Color Infrared Composite

Endmember Spectra

Silica

Kaolinite

Kaolinite Abundance

Silica

Dry Vegetation

Green Vegetation

Silica

Kaolinite

Midway Geyser Basin

Upper Geyser Basin

Lower Geyser Basin
Compare AVIRIS Results (15m) and HyspIRI-Sim (60m) Firehole River Alkaline, with Acid Sulfate on margins

Endmembers

Dry Vegetation
Green Vegetation
Silica
Kaolinite

AVIRIS (15m)

HyspIRI-Sim (60m)
Table 3. Confusion matrix for Yellowstone, Wyoming, 15 m versus 60 m HyspIRI simulation. Overall Accuracy = (542160/775992) 69.8667%. Kappa Coefficient = 0.3471.

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MASTER Mineralogy YS (Firehole River) 2006
35m Native Spatial Resolution

Emissivity (10.5, 9.1, 8.3 μm, RGB)
Note Clouds and Shadows (purple)

MTMF LWIR Silica Map
MASTER Mineralogy YS (Firehole River) 2006
60m HyspIRI-Sim Spatial Resolution

Emissivity (10.5, 9.1, 8.3 µm, RGB)
Note Clouds and Shadows (purple)

MTMF LWIR Silica Map
MASTER Temperature YS (Firehole River) 2006
35m Native Spatial Resolution

Ground-Observed Temperatures
GP: 64 – 97C
EG: 93C

Grand Prismatic Spring
57C (135F)

Excelsior Geyser
52C (125F)

MASTER LWIR Temperature (Density Sliced)
MASTER LWIR Temperature (Temperatures >50C)
MASTER Temperature YS (Firehole River) 2006
60m HyspIRI-Sim Spatial Resolution

Ground-Observed Temperatures

GP: 64 – 97°C
EG: 93°C

Grand Prismatic Spring
52°C (126°F)

Excelsior Geyser
39°C (103°F)
Summary and Conclusions

• Simulations demonstrate HyspIRI as a remote sensing tool for characterizing, mapping, and monitoring hydrothermal systems
  – SWIR spectral bands (reflectance) at ~10nm spectral resolution perform moderately well for mineral mapping
  – HyspIRI simulated SWIR data successfully detected and mapped a wide variety of characteristic minerals, including jarosite, alunite, kaolinite, dickite, muscovite-illite, montmorillonite, pyrophyllite, calcite, buddingtonite, and hydrothermal silica at several fossil and active hydrothermal systems
  – 60m spatial resolution doesn’t strongly affect SWIR mineral mapping for most hydrothermal systems (though some smaller features lost)
Summary and Conclusions

- Errors of commission and omission provide insight to the causes of misclassification
  - Similar minerals and smaller areas of alteration are not mapped well by the simulated 60m HyspIRI data
  - Confusion matrix analyses of the SWIR datasets show overall classification accuracy ranging from 70 to 92% for the 60m HyspIRI simulated data relative to 15m AVIRIS data
  - Scale dependent spectral mixing due to spectral mixing with adjacent pixels appears to be the cause of most errors
Summary and Conclusions

• HyspIRI simulated TIR bands complement the VSWIR bands
  – LWIR spectral bands (emissivity) provide additional mineral information
  – Temperature extraction provides surface temperature information critical for geothermal applications
  – 60m spatial resolution doesn’t strongly affect LWIR mineral mapping for most hydrothermal systems (though some smaller features lost)
  – 60m spatial resolution negatively impacts temperature determinations for active geothermal systems (thermal mixing for small targets)
Last Words

• What will HyspIRI give us that other sensors can’t provide?
  – Combined, simultaneous VSWIR hyperspectral and TIR multispectral
  – Global coverage at scale that will allow development of a geographic database “inventory” of hydro/geothermal systems
  – Temporal monitoring (of active geothermal systems and other dynamic geologic systems)

• Acceptable tradeoff = principally loss of spatial detail linked to spectral mixing
Additional Documentation

• SWIR results published in:
  
    http://www.mdpi.com/2072-4292/3/8/1584/ (Open Access)

• HyspIIRI simulated datasets available on request