Mineral Mapping Using Simulated HyspIRI Data

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(HyspIRI Preparatory Research Activities)

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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:

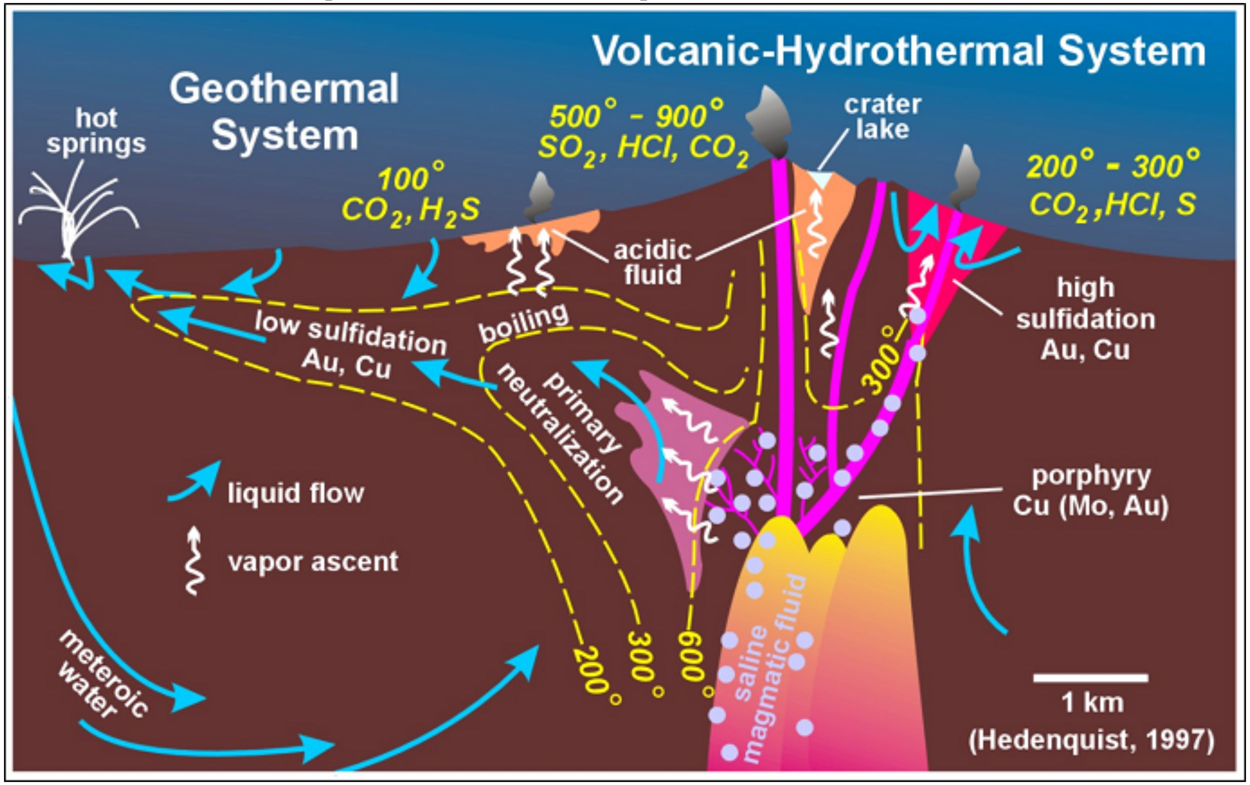
1. Identify, characterize, and map mineral assemblages associated with surface exposures of active and fossil hydrothermal systems
2. Measure surface temperatures and temperature variability associated with active geothermal systems
3. Detect, characterize, and monitor surface changes associated with geothermal resources

Geothermal (hydrothermal) Systems

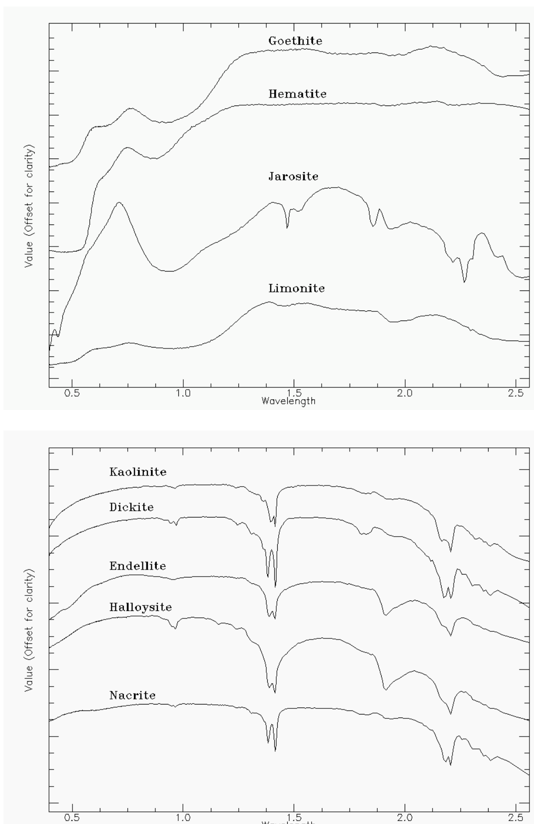
Fossil Hydrothermal System

Why Remote Sensing of Hydrothermal/Geothermal Systems?

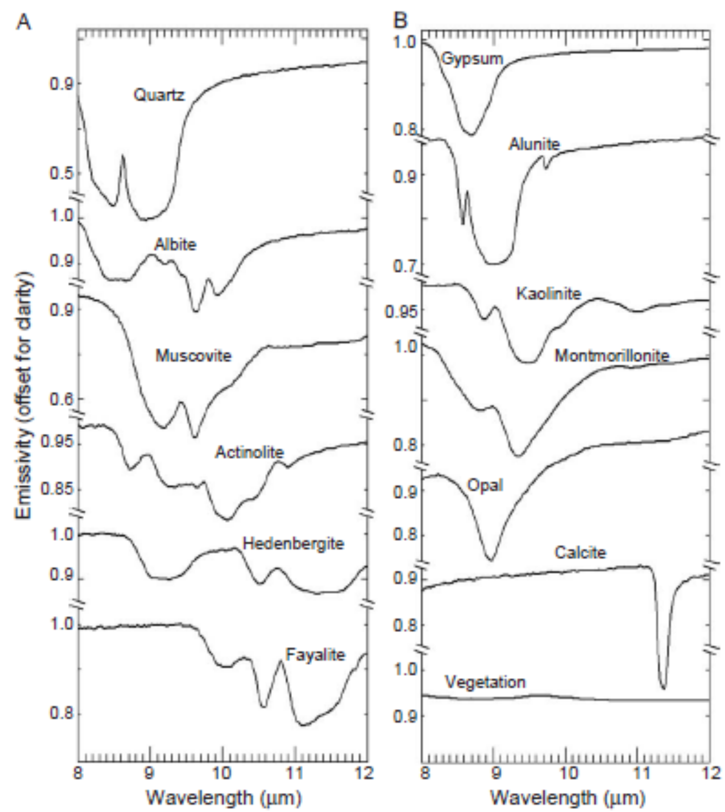
- **High beneficial impact: Ore deposits provide raw materials for industrialized society, while geothermal systems provide abundant energy without many of the problems of fossil fuels**
- **These two are highly related. Surface mineral assemblages and distributions often provide key information about 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**



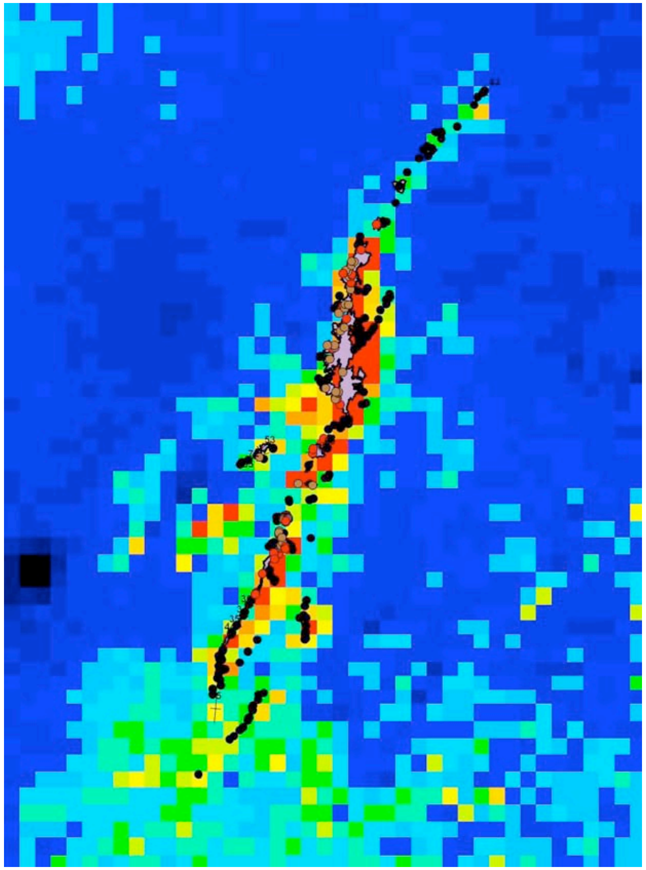
USGS Spectral Library



Vaughan et al., 2005

Surface Temperature Mapping at Geothermal Systems

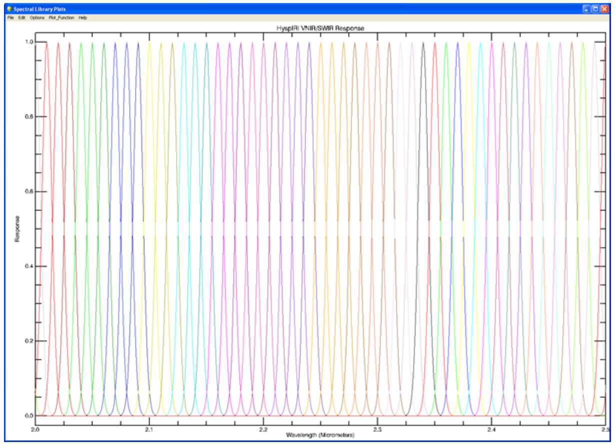
- LWIR Multispectral data provide the additional capability to estimate surface temperature
- Improved understanding of known systems by detecting/ mapping
  - Distribution of heat anomalies and links to subsurface
  - Structural control
  - Outflow areas
- Provide new exploration tools
  - Temperature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



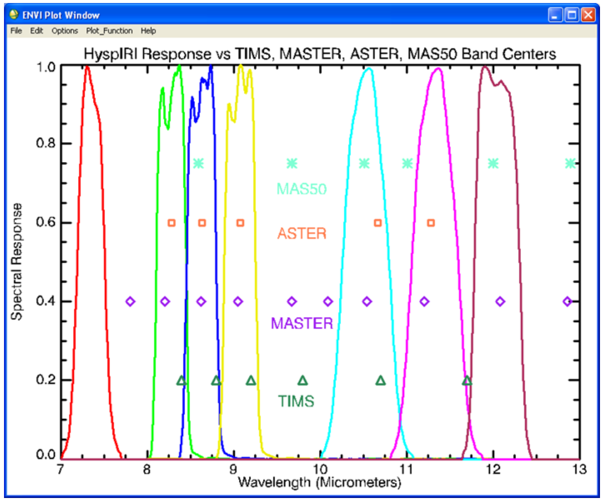
Coolbaugh, 2007 – Temperature Anomalies at Brady Hot Springs Using ASTER. **Small black and brown points indicate field located steam vents or surface hot spots.**

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)

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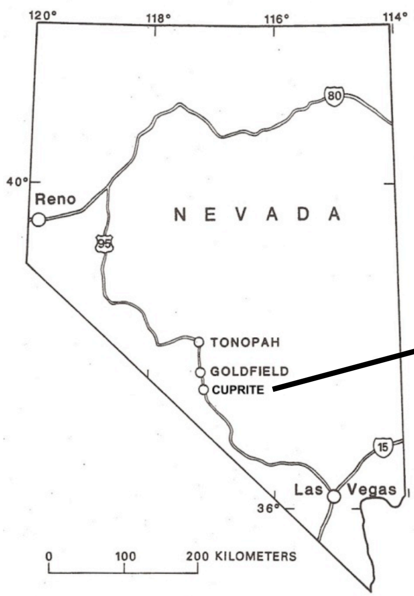
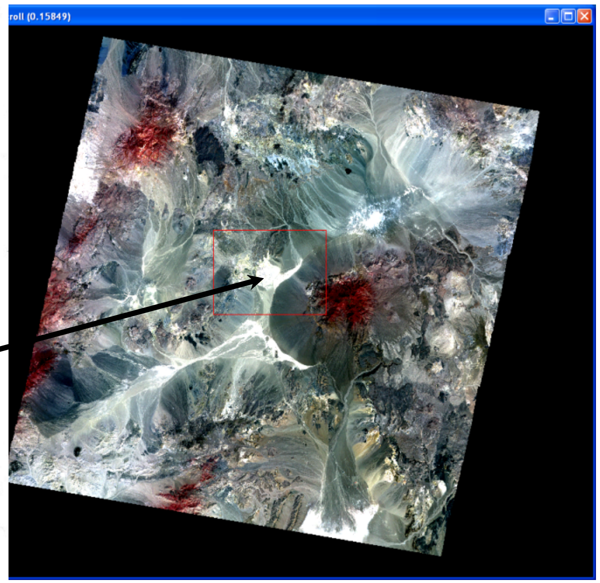
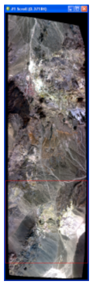
Cuprite, NV, HyspIRI Simulation

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

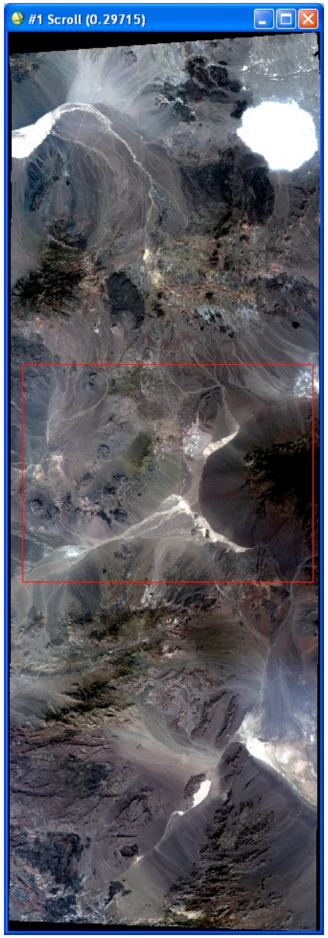


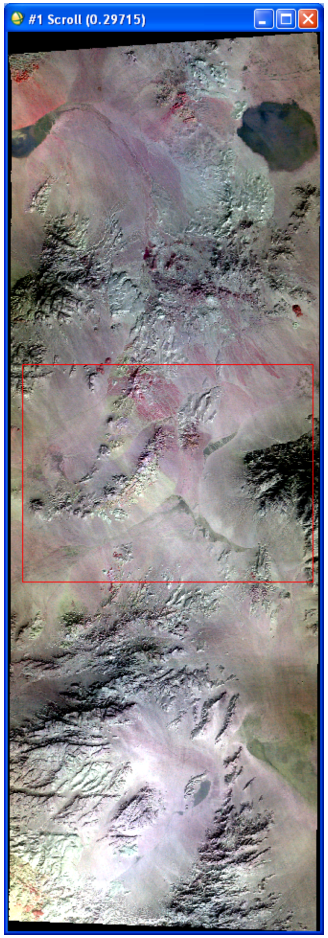


~60km



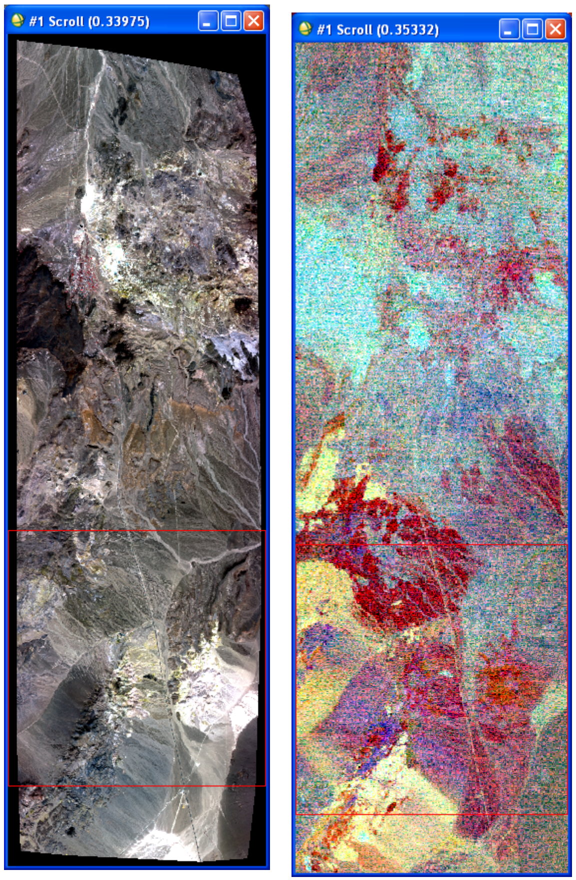
AVIRIS VNIR (15m)
09-20-2006 Ortho



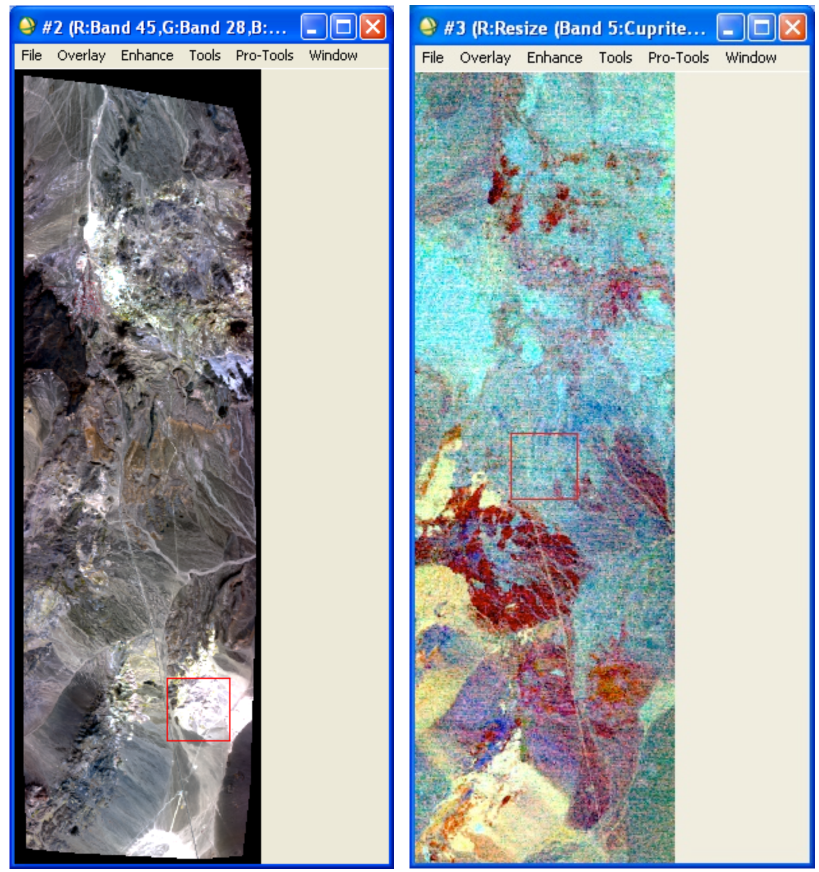


MASTER VNIR and LWIR (34m),
09-20-2006 GLT-Corrected

Cuprite, NV Simulation: We end up with several small simulated datasets !

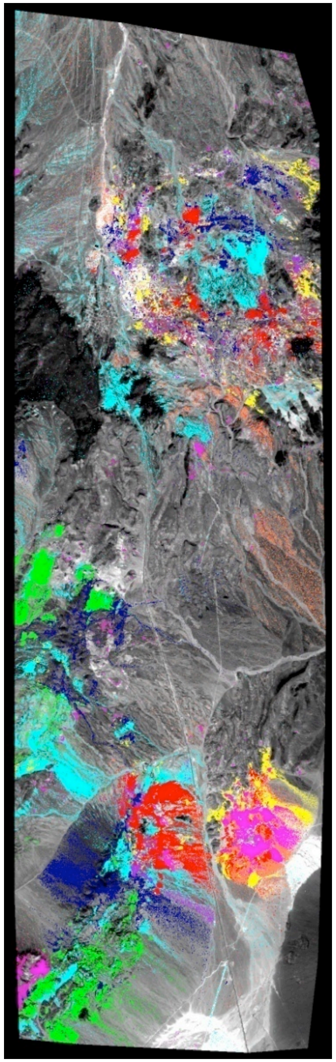


772 x 2493 Left: AVIRIS VNIR (15m) 09-20-2006 Ortho Warped to ASTER Ortho at 15m spatial resolution; Right Master Emissivity @HyspIRI bands



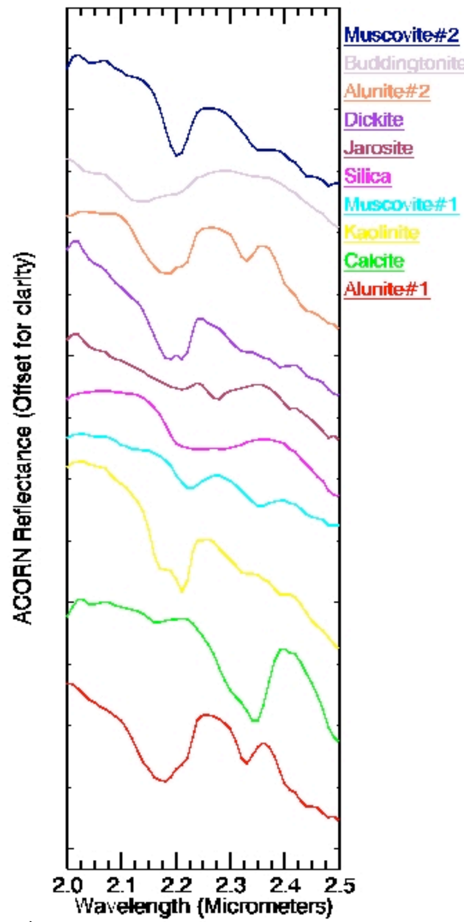
193 x 623 Left: HyspIRI simulated dataset from AVIRIS VNIR (15m) 09-20-2006 Ortho Warped to ASTER Ortho at 60m spatial resolution. Right: MASTER Emissivity @HyspIRI bands and 60m

Cuprite, NV, 2006 AVIRIS
15m-derived SWIR MTMF Mineral Map (Kruse, 2011)

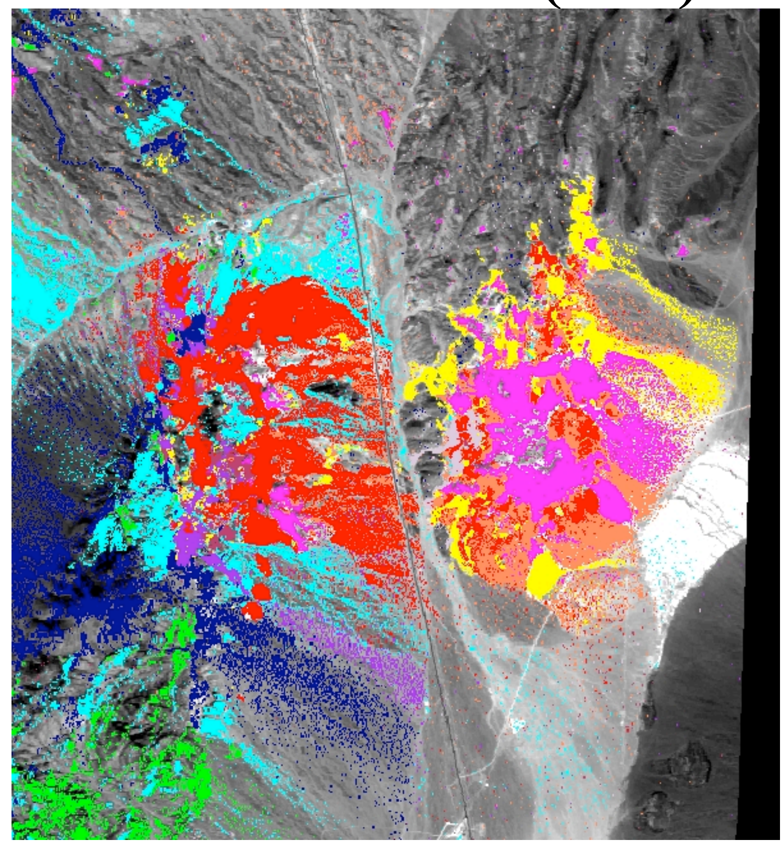


AVIRIS MTMF (60m)

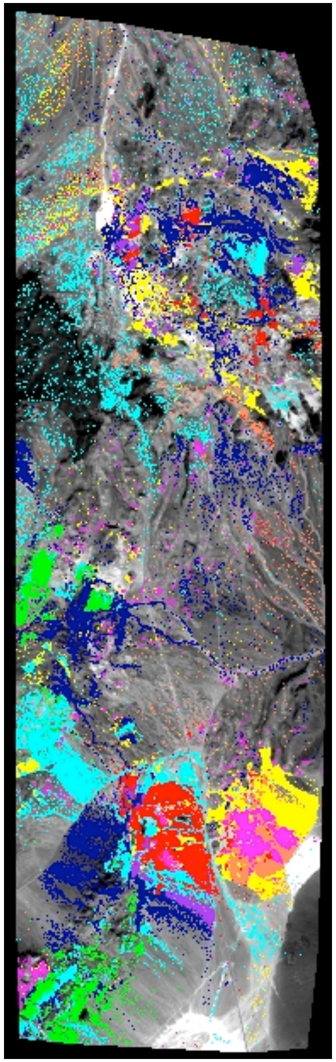
Endmembers



AVIRIS MTMF (60m)

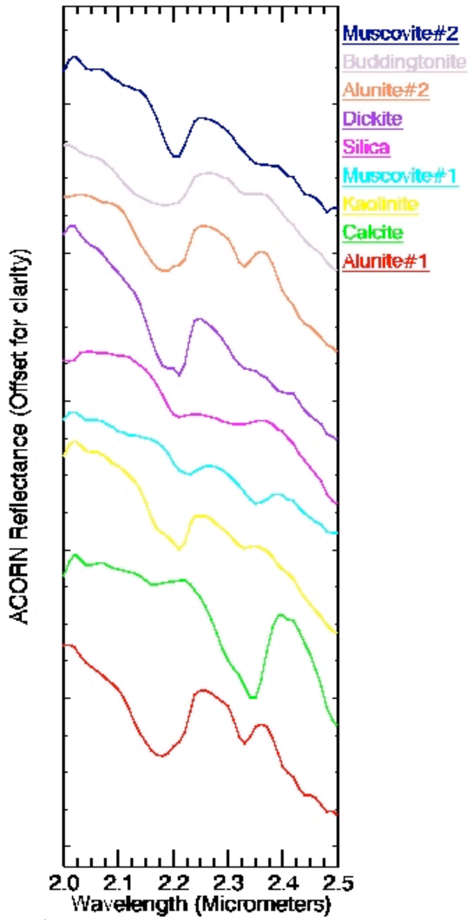


Cuprite, NV, HyspIRI-Simulated
60m-derived SWIR MTMF Mineral Map (Kruse, Unpublished)



HyspIRI MTMF (60m)

Endmembers



HyspIRI MTMF (60m)

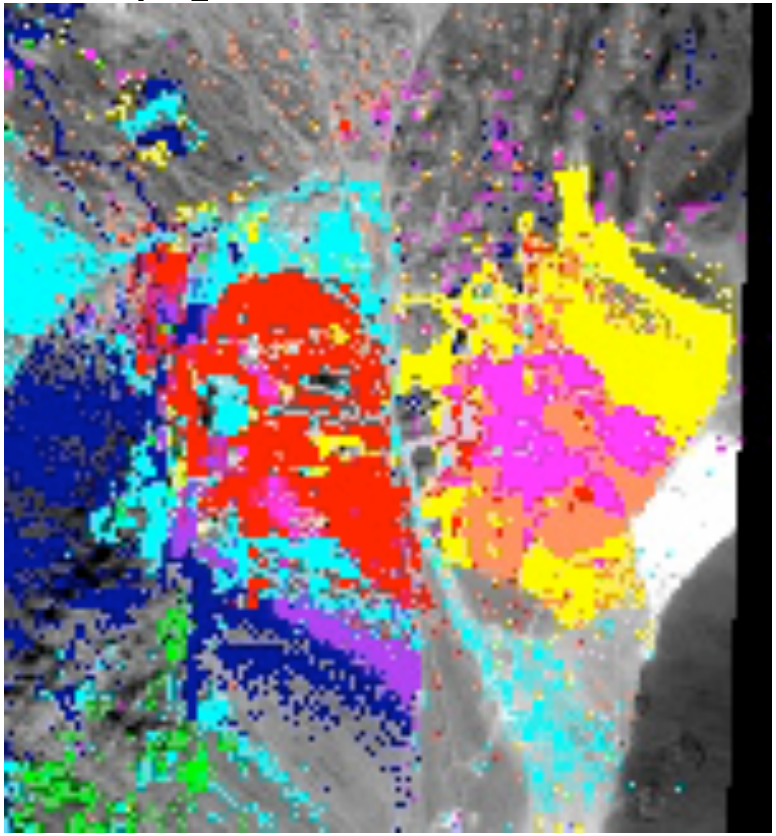
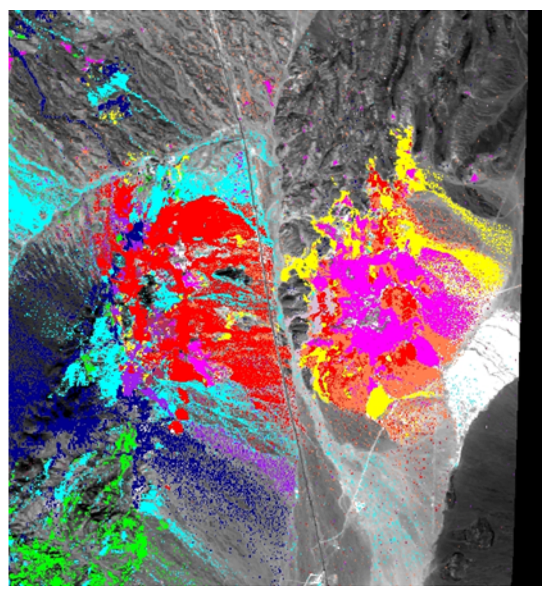
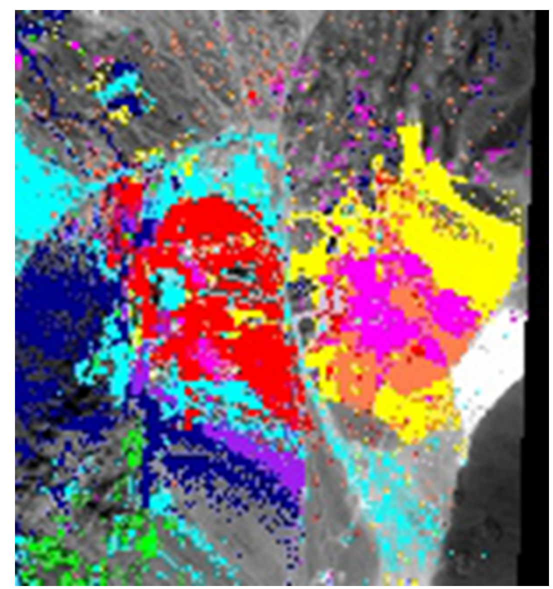


Table 1. Confusion matrix for Cuprite, Nevada, 15 m *versus* 60 m HyspIRI simulation. Overall Accuracy = (1533947/1905364) 80.5068%. Kappa Coefficient = 0.4627.

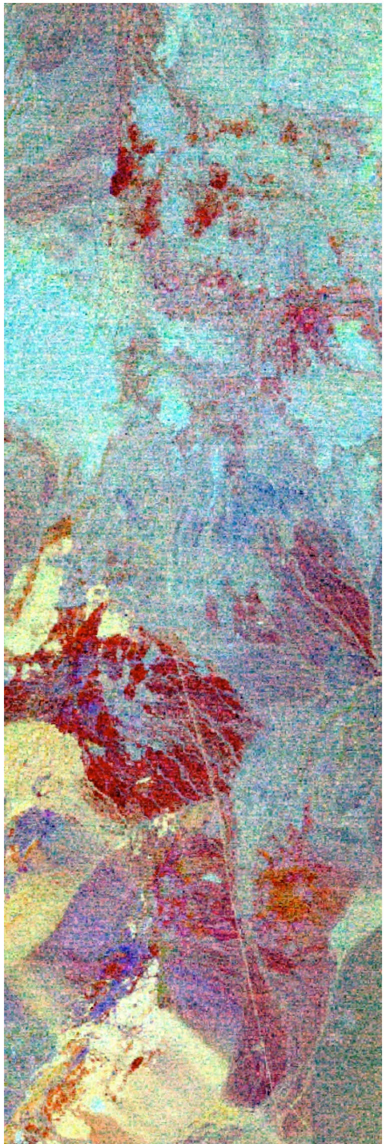
	Ground Truth										
Class	Unclass	Alun#1	Calcite	Kaolinite	Musc#1	Silica	Dickite	Alun#2	Budding.	Musc#2	Total
Unclass	**84.01**	16.52	24.99	5.83	32.64	11.25	22.85	42.74	51.74	19.22	74.82
Alun#1	0.52	**63.83**	0.02	0.91	1.07	0.44	2.71	8.21	2.54	0.21	1.98
Calcite	0.63	0.02	**66.58**	0.01	0.55	0.09	0.09	0.02	0.56	0.35	1.80
Kaolinite	2.42	3.36	0.22	**84.84**	2.85	11.50	5.03	10.53	4.01	0.93	3.58
Musc#1	4.20	2.42	5.63	0.73	**57.25**	1.78	3.56	1.75	9.35	0.44	6.19
Silica	0.89	0.22	0.14	0.13	0.34	**67.63**	0.14	2.41	1.52	0.28	1.53
Dickite	0.45	1.67	0.00	4.21	0.51	0.01	**53.93**	0.16	0.14	0.72	0.86
Alun#2	1.35	9.03	0.05	1.16	0.64	6.50	0.32	**32.47**	0.84	0.19	2.08
Budding.	0.09	0.51	0.06	0.29	0.16	0.01	0.06	0.21	**24.11**	0.04	0.16
Musc#2	5.43	2.42	2.31	1.90	3.99	0.79	11.31	1.49	5.20	**77.62**	7.01
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	**100.00**

Class	**Commission**	**Omission**	**Prod. Acc.**	**User Acc.**
	Percent	**Percent**	**Percent**	**Percent**
Unclass	5.28	15.97	84.03	94.72
Alun#1	34.91	36.17	63.83	65.09
Calcite	31.27	33.42	66.58	68.73
Kaol	73.24	15.16	84.84	26.76
Musc#1	61.56	42.75	57.25	38.44
Silica	54.59	32.37	67.63	45.41
Dickite	58.42	46.07	53.93	41.58
Alun#2	69.22	67.53	32.47	30.78
Budding.	65.21	75.89	24.11	34.79
Musc#2	71.08	22.38	77.62	28.92

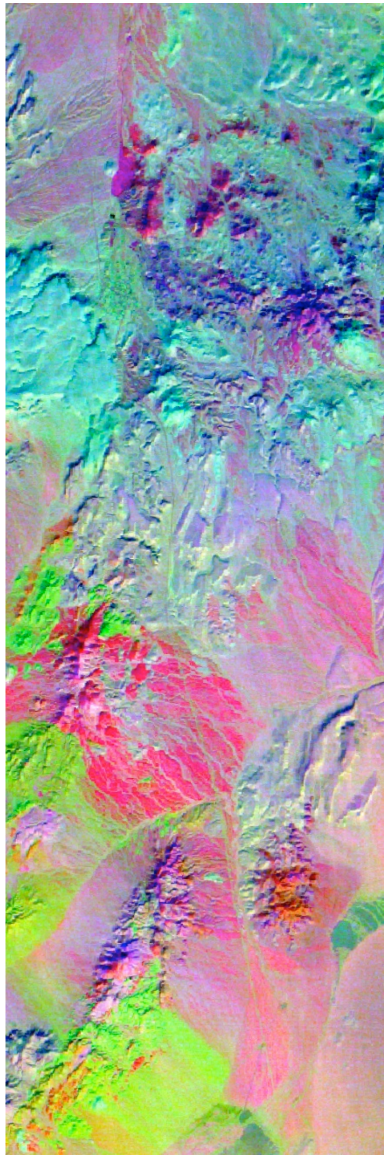




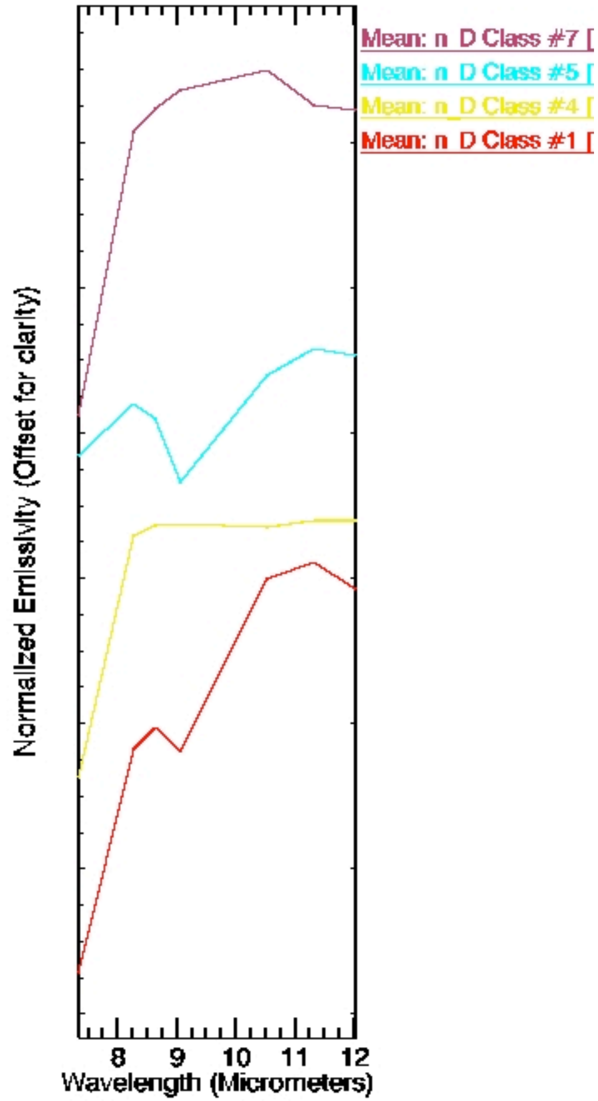
Cuprite, NV 2006 MASTER LWIR (34m)



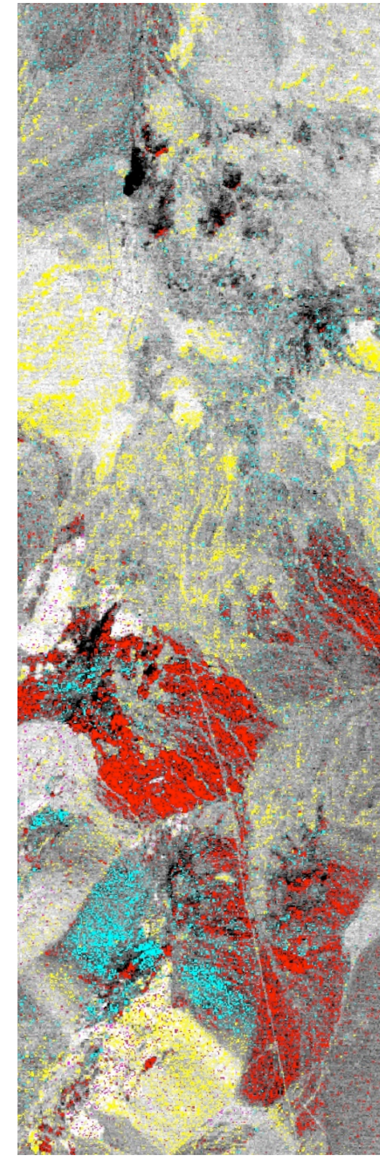
Emissivity



MNF 1, 2, 3



Endmembers



Classification

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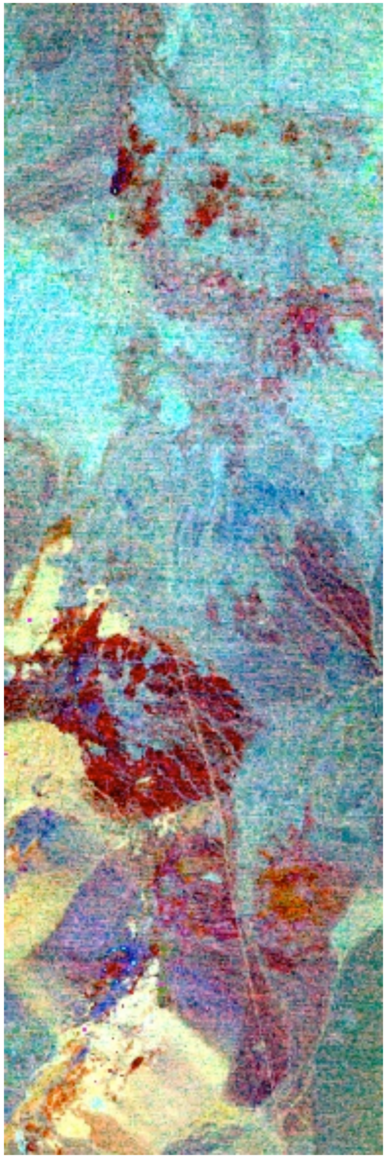
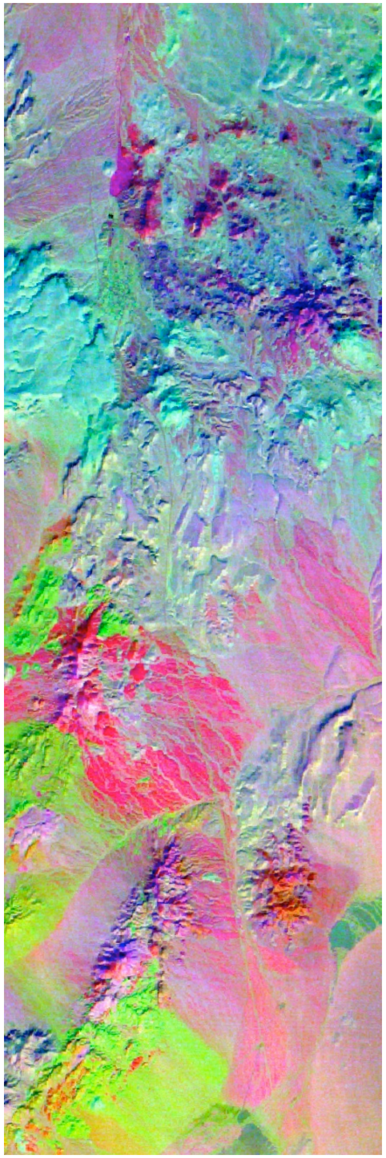
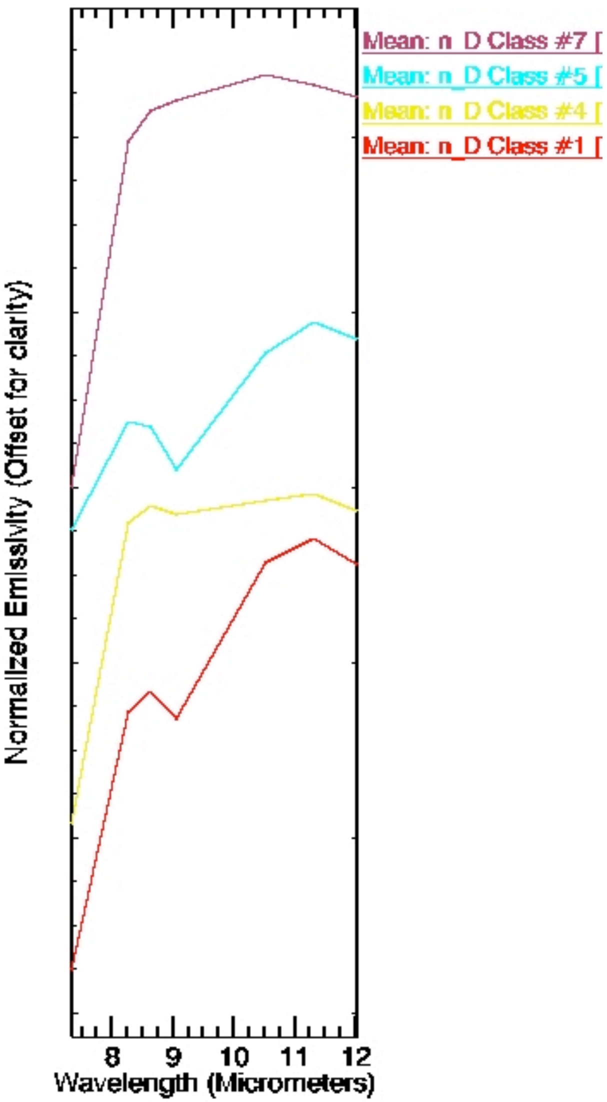
Cuprite, NV 2006 HyspIRI-Simulated LWIR (60m)



Emissivity



MNF 1, 2, 3



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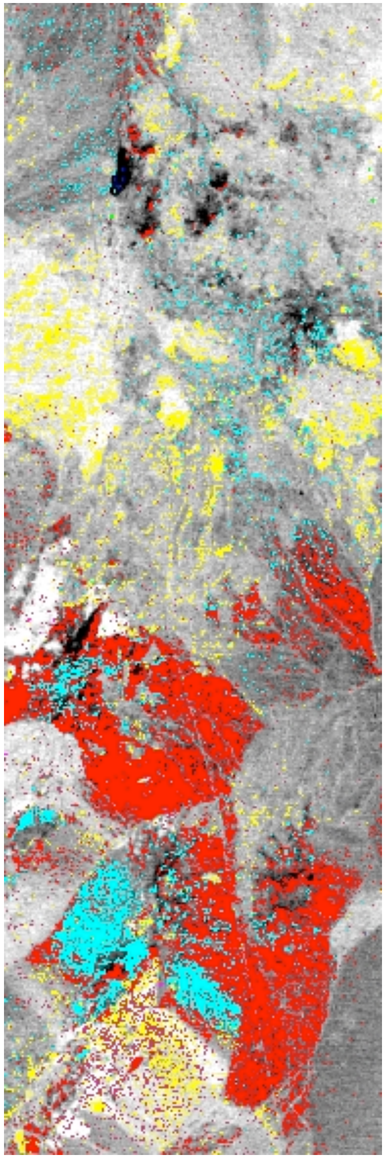

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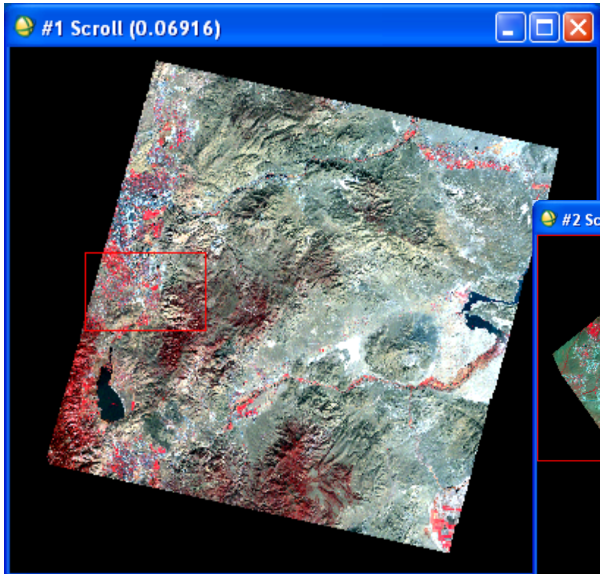
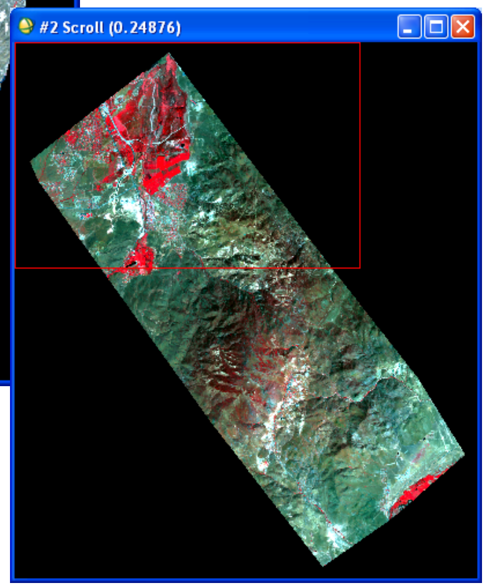
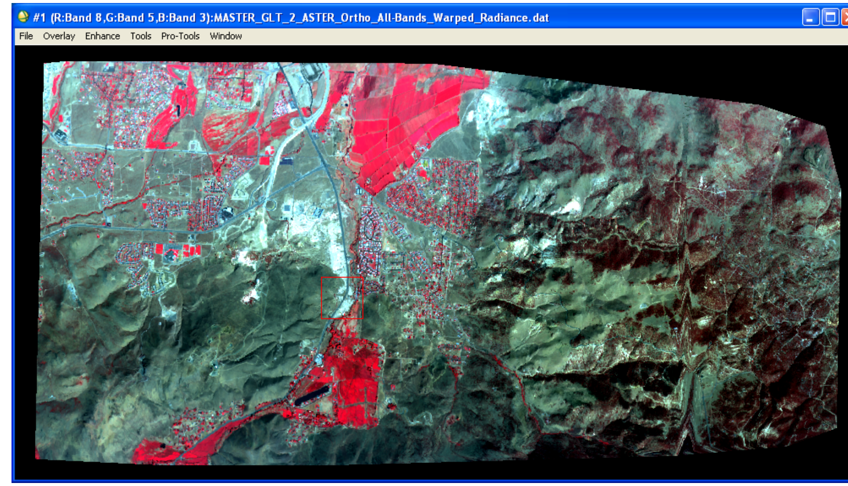
Steamboat Springs, NV Simulation



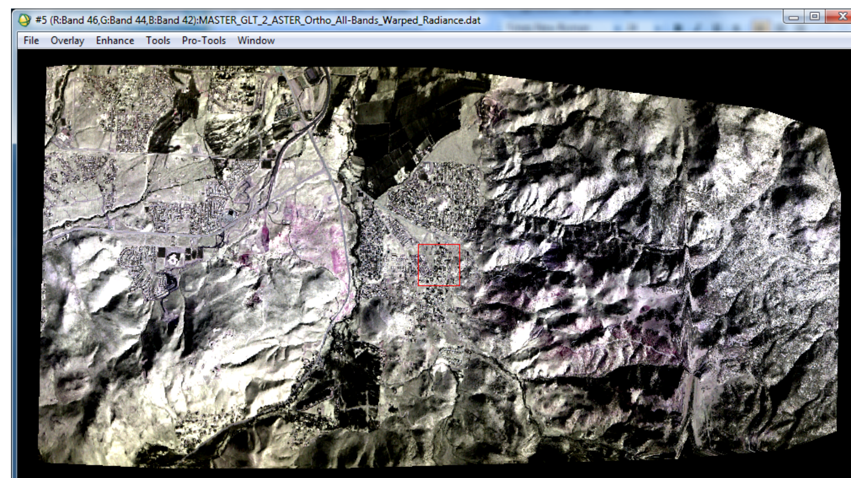
ASTER VNIR (15m) 10-23-2006 Ortho



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

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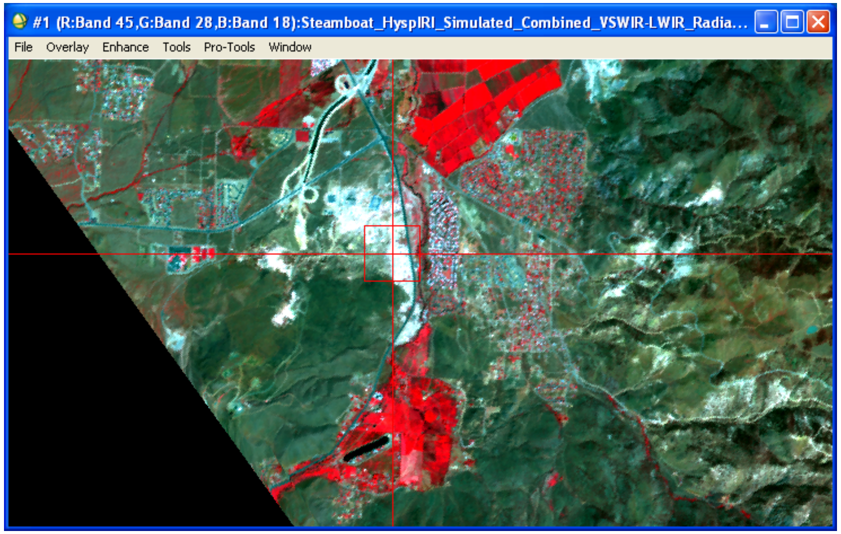
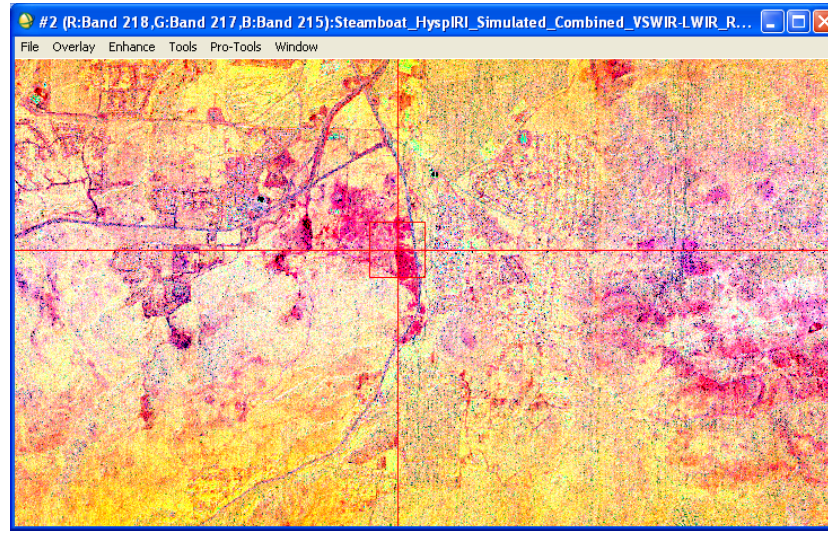
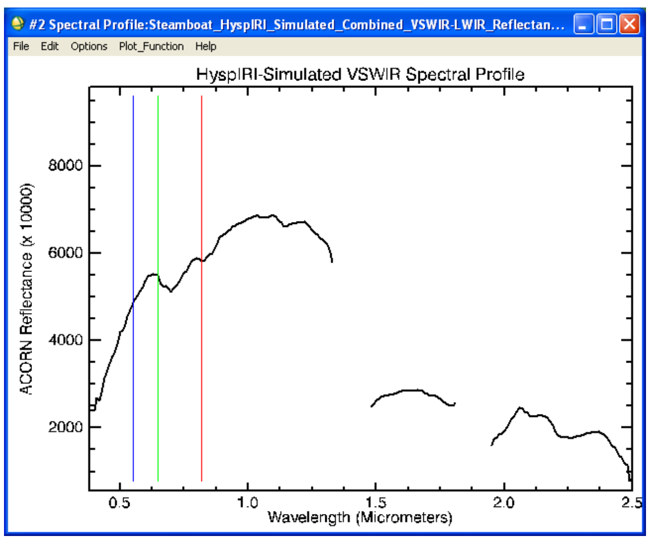
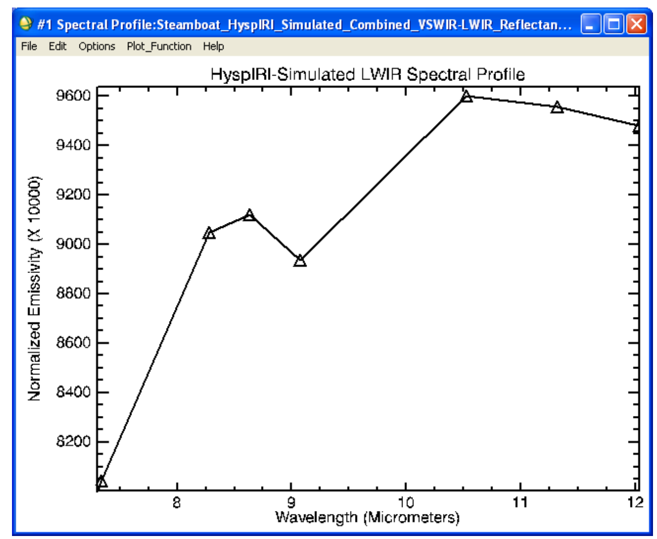
Steamboat Springs, NV Simulation





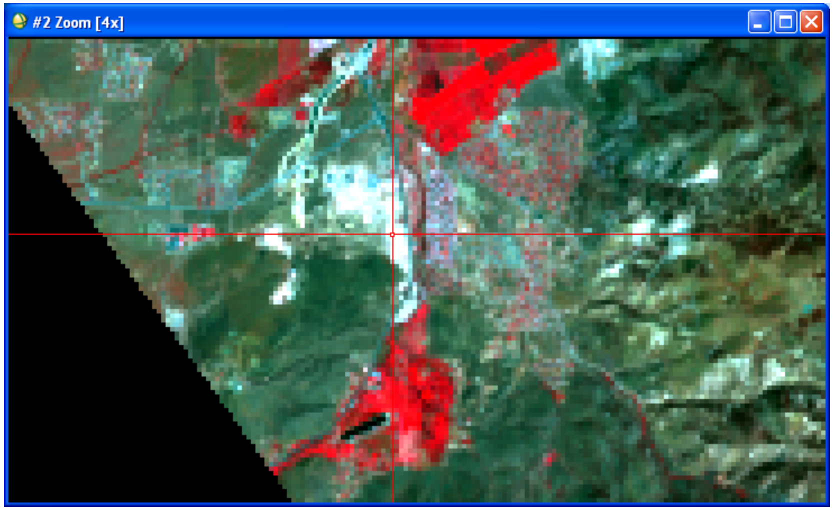


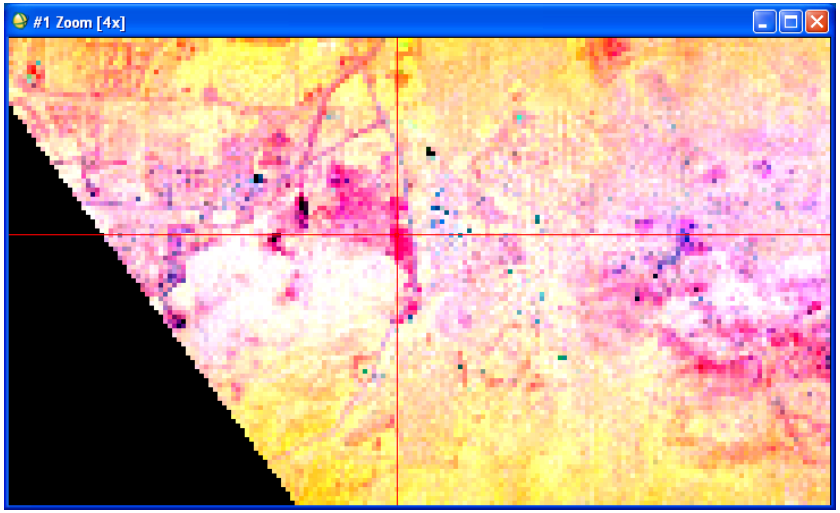
HyspIRI-Simulated VSWIR Reflectance (15m)

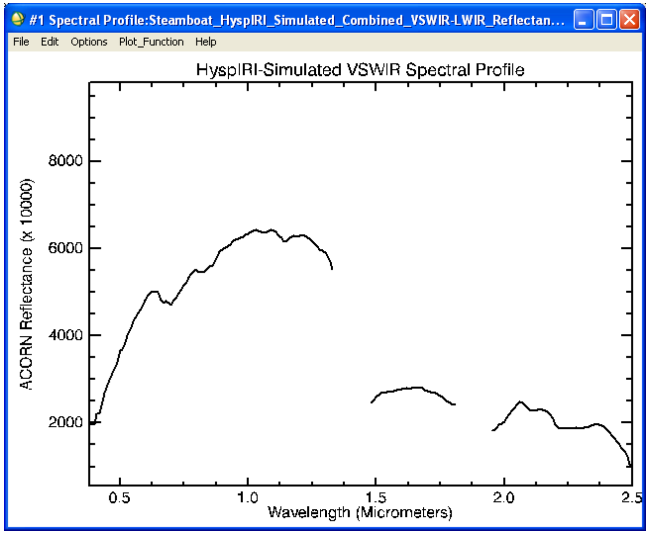


HyspIRI-Simulated LWIR Emissivity (15m)

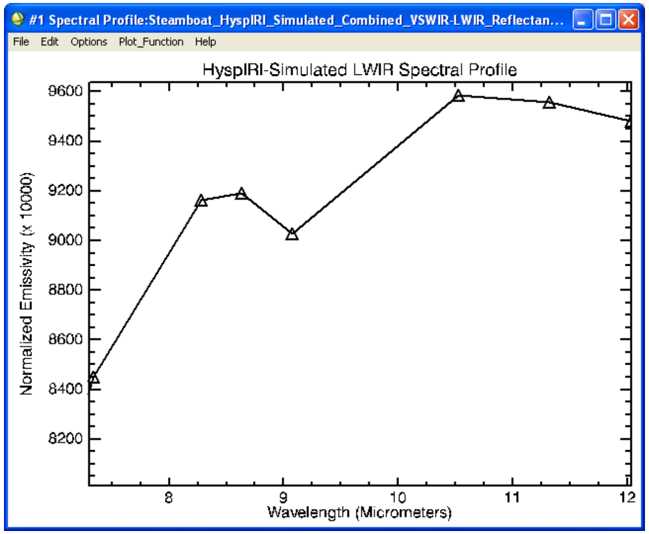
Steamboat Springs, NV Simulation





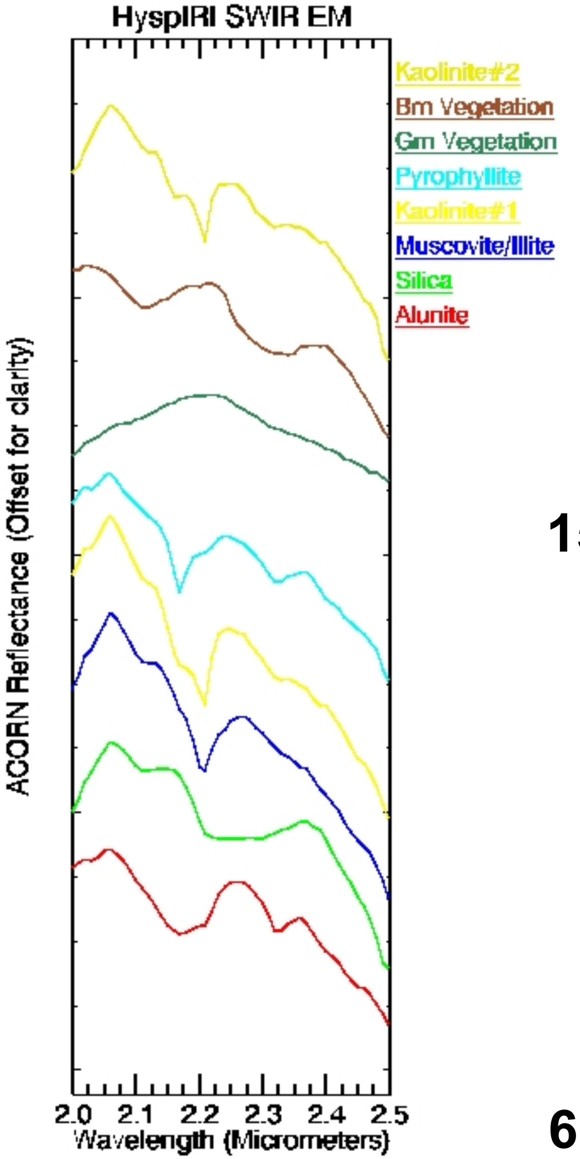


HyspIRI-Simulated VSWIR Radiance (60m)

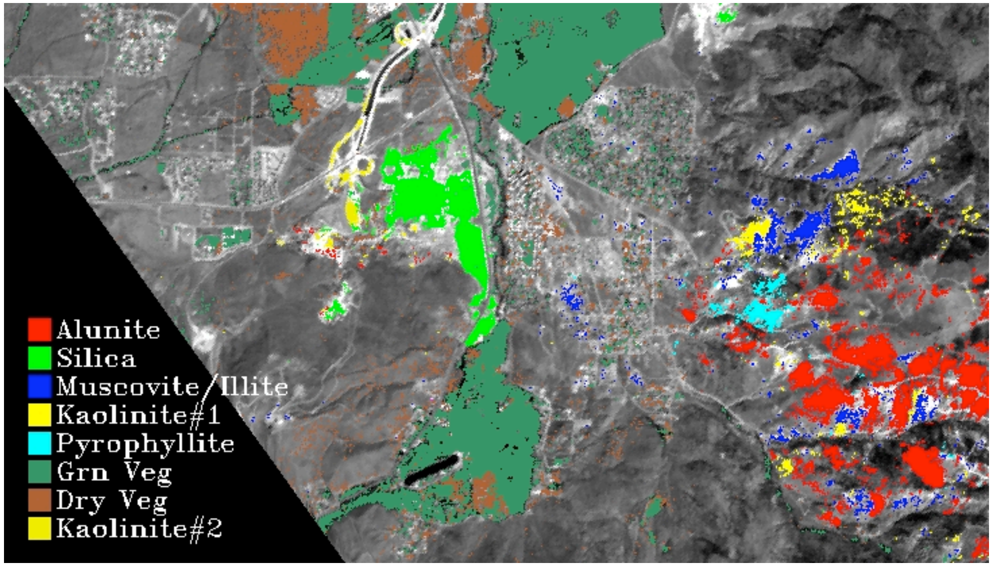


HyspIRI-Simulated LWIR Radiance (60m)

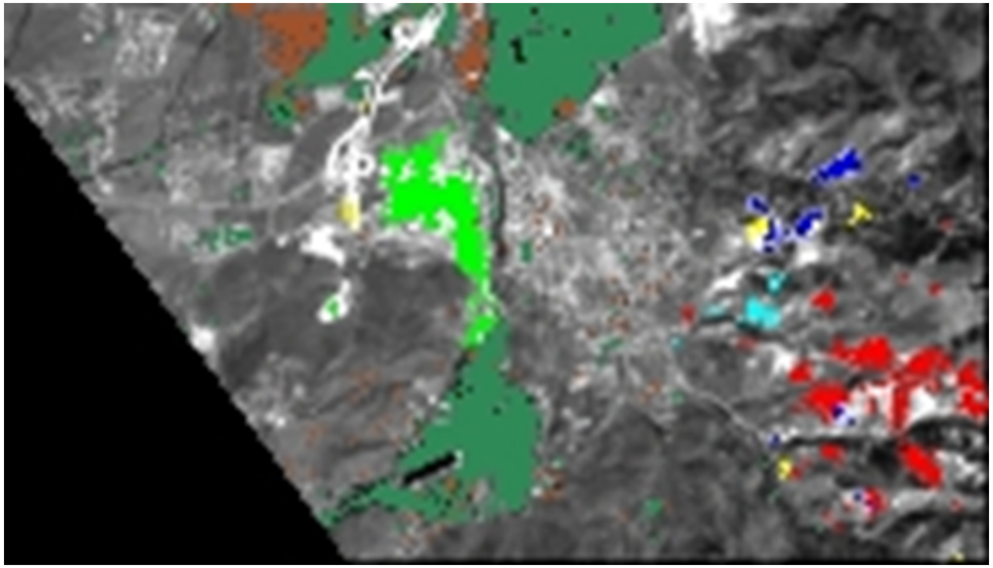
Steamboat Springs, NV Spectral Maps



15m



60m

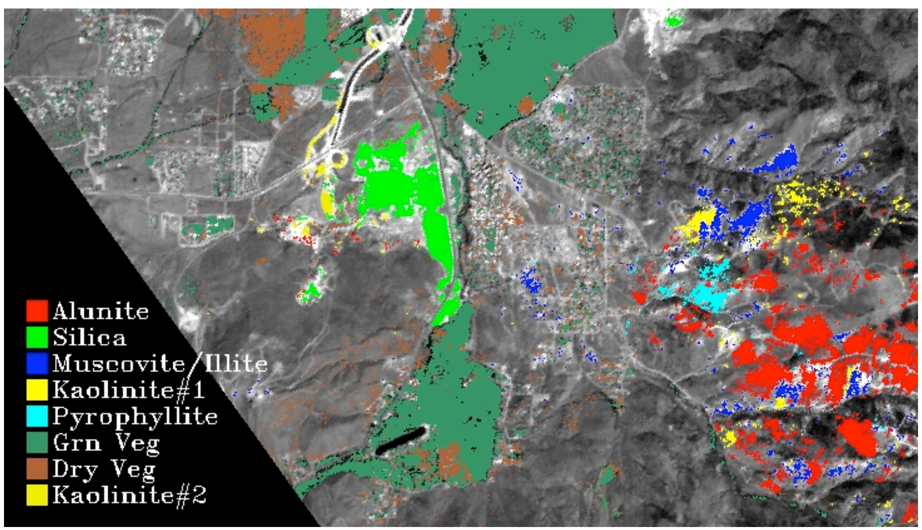


Steamboat Springs, NV Accuracy Assessment

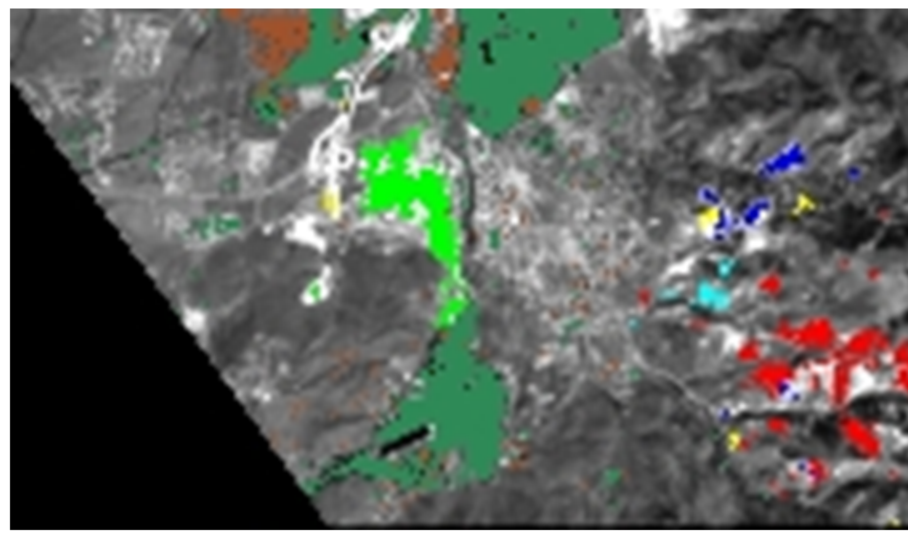
Table 2. Confusion matrix for Steamboat Springs, Nevada, 15 m *versus* 60 m HyspIRI simulation. Overall Accuracy = (278492/302217) 92.1497% Kappa Coefficient = 0.6859.

	Ground Truth									
Class	Unclass	Alunite	Silica	Mus/Ill	Kaol#1	Pyroph	G. Veg	D. Veg	Kaol#2	Total
Unclass	**98.02**	55.35	20.06	75.08	83.11	58.39	18.77	60.21	77.21	88.43
Alunite	0.20	**44.58**	0.00	0.20	0.07	0.13	0.00	0.01	0.00	1.30
Silica	0.19	0.01	**79.73**	0.00	0.00	0.00	0.00	0.19	0.00	1.31
Mus/Ill	0.08	0.04	0.00	**24.56**	0.83	0.00	0.00	0.00	0.00	0.28
Kaol#1	0.03	0.00	0.00	0.08	**15.15**	0.00	0.00	0.00	1.33	0.10
Pyroph	0.03	0.01	0.00	0.00	0.00	**41.49**	0.00	0.00	0.00	0.13
G. Veg	0.95	0.00	0.14	0.00	0.00	0.00	**80.41**	4.77	0.00	7.03
D. Veg	0.48	0.00	0.02	0.08	0.00	0.00	0.82	**34.82**	0.00	1.38
Kaol#2	0.01	0.00	0.05	0.00	0.83	0.00	0.00	0.00	**21.46**	0.05
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	**100.00**

Class	**Commission Percent**	**Omission Percent**	**Prod. Acc. Percent**	**User Acc. Percent**
Unclass	6.76	1.98	98.02	93.24
Alunite	13.34	55.42	44.58	86.66
Silica	12.63	20.27	79.73	87.37
Mus/Ill	25.96	75.44	24.56	74.04
Kaol#1	28.29	84.85	15.15	71.71
Pyroph	19.00	58.51	41.49	81.00
G. Veg	13.18	19.59	80.41	86.82
D. Veg	33.93	65.18	34.82	66.07
Kaol#2	32.64	78.54	21.46	67.36

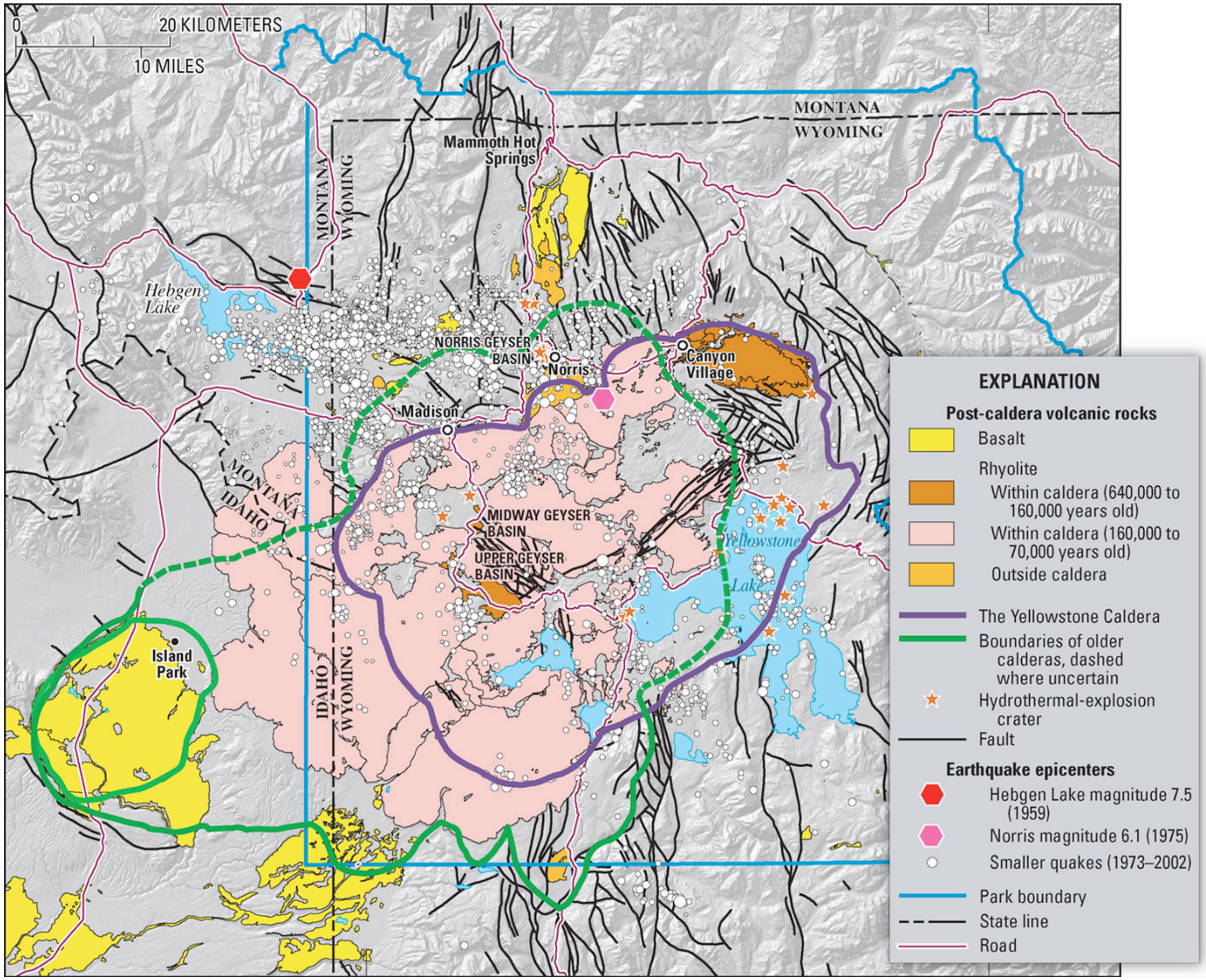


15m

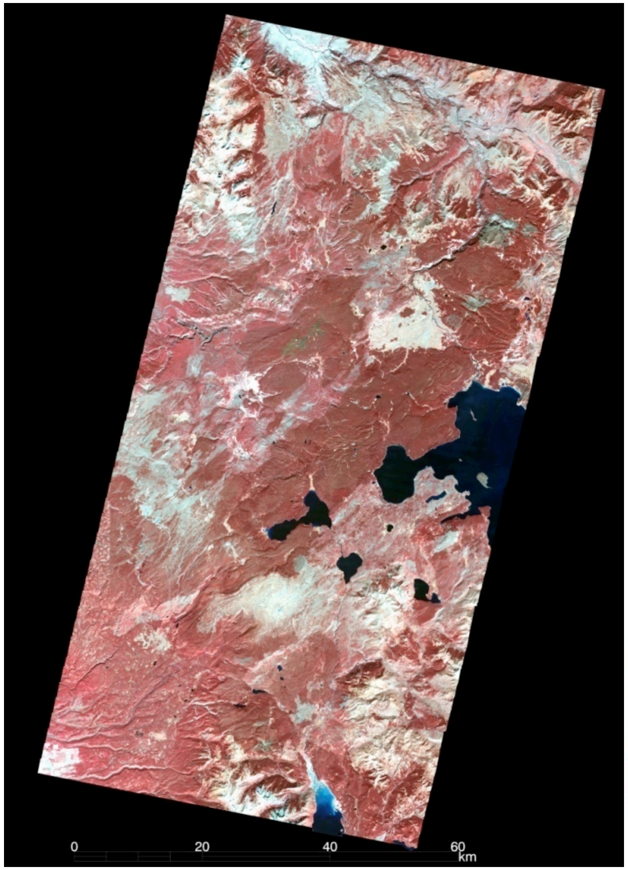


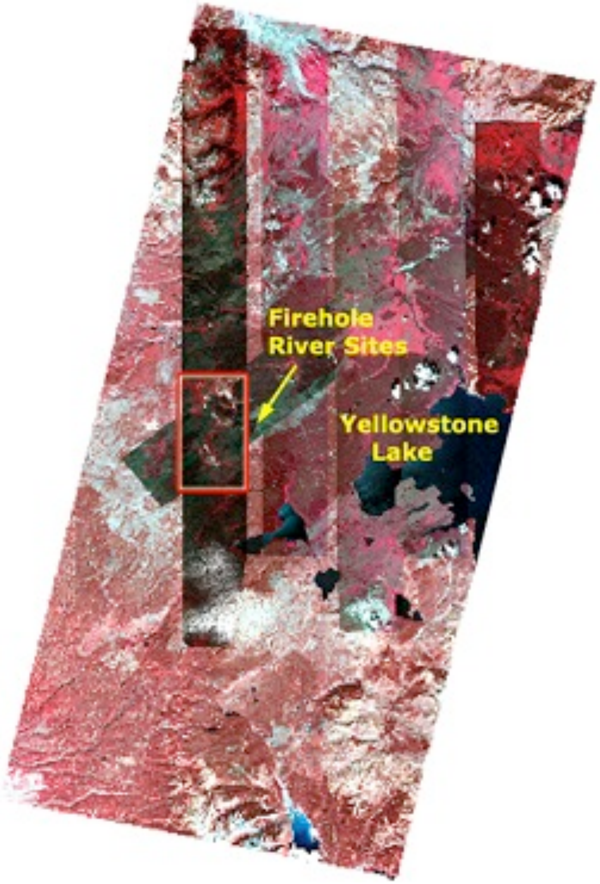
60m

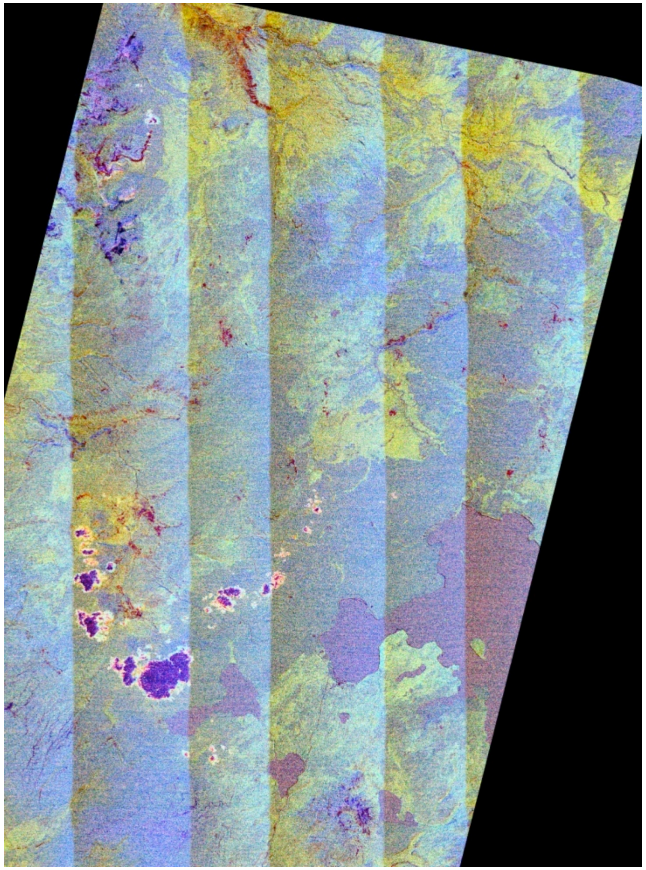
Yellowstone WY Example



Yellowstone, WY HyspIRI Simulation







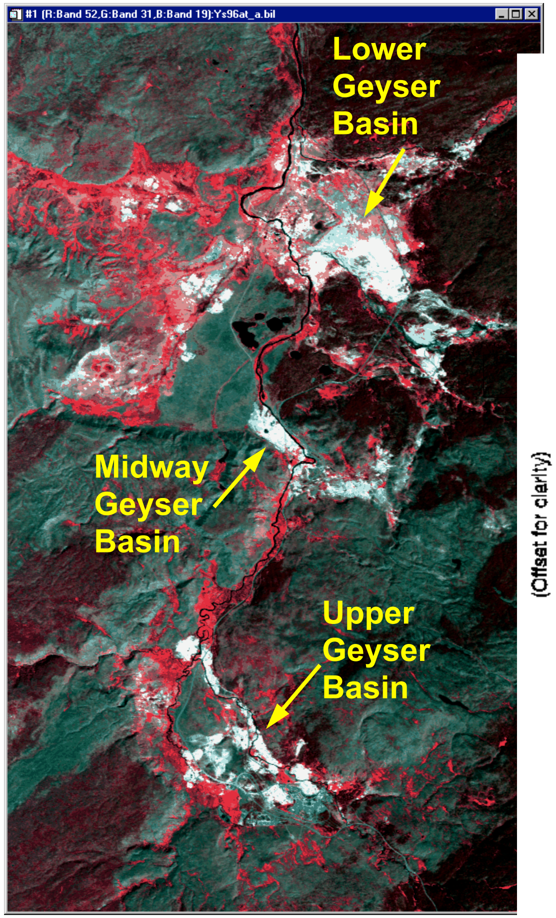
ASTER VNIR (15m)
09-08-2000 Ortho

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

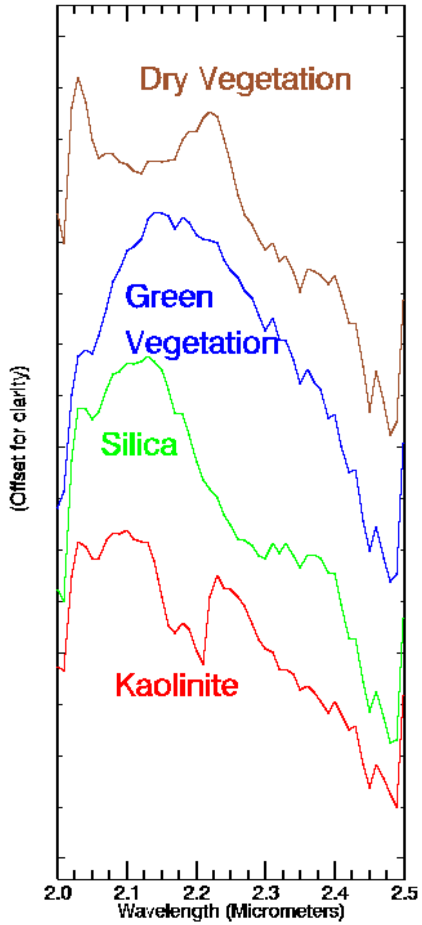
MASTER LWIR Emissivity
09-25-2006

F. A. Kruse ♦ 303-499-9471 ♦ fakruse@nps.edu ♦http://www.nps.edu/Academics/Centers/RemoteSensing

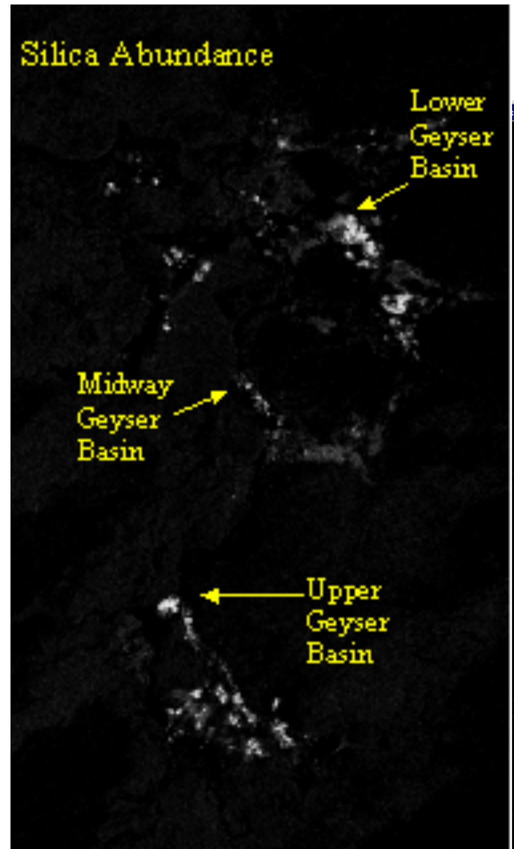
AVIRIS Results (15m) Firehole River Alkaline, with Acid Sulfate on margins



Color Infrared Composite



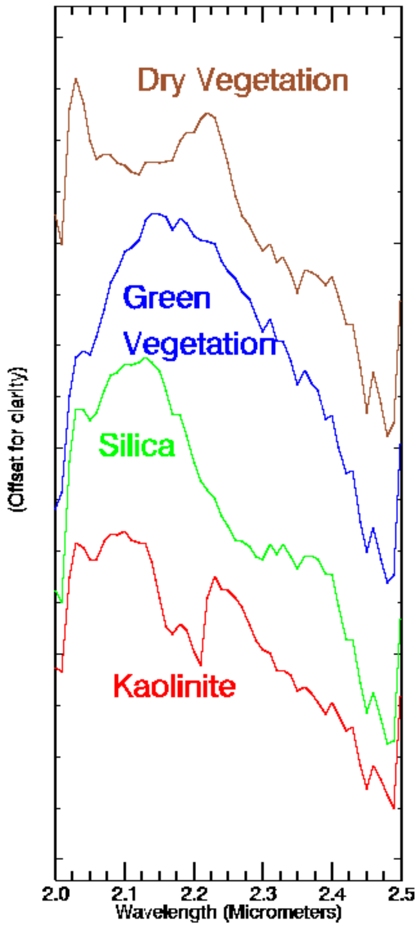
Endmember Spectra



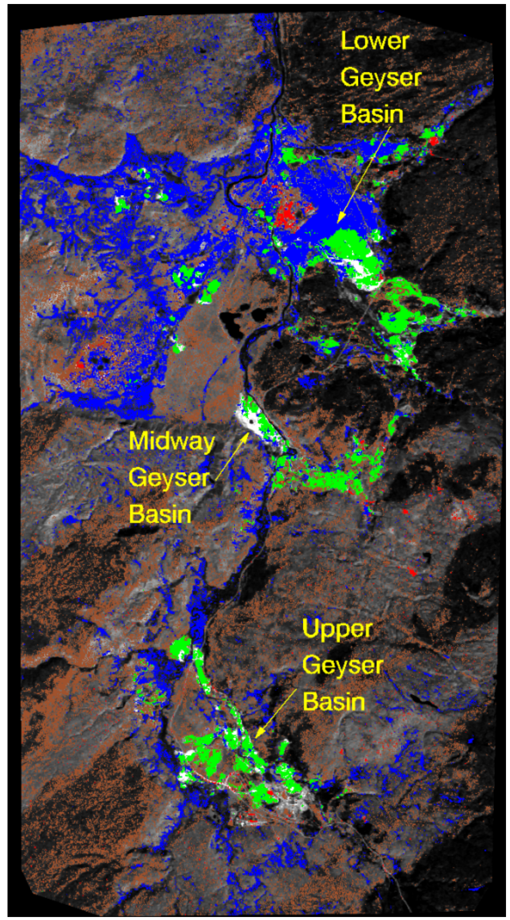
Silica

Kaolinite

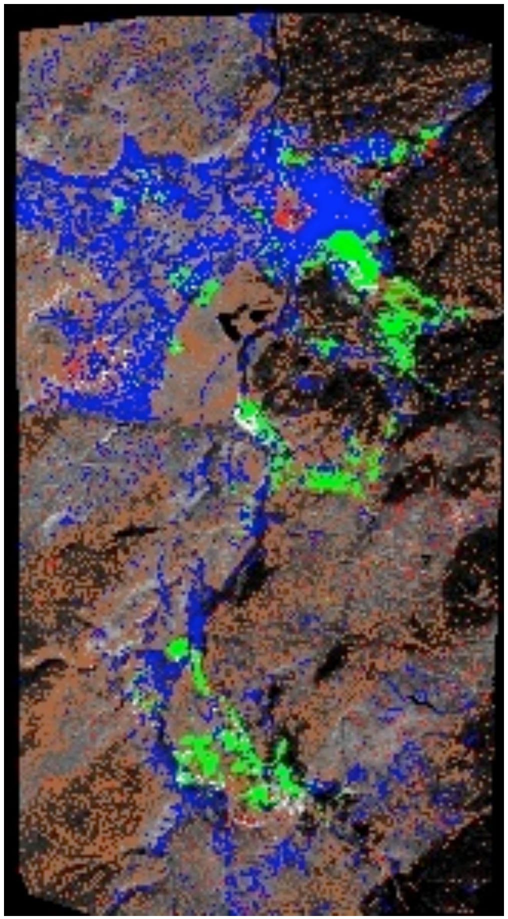
Compare AVIRIS Results (15m) and HyspIRI-Sim (60m) Firehole River Alkaline, with Acid Sulfate on margins



Endmembers



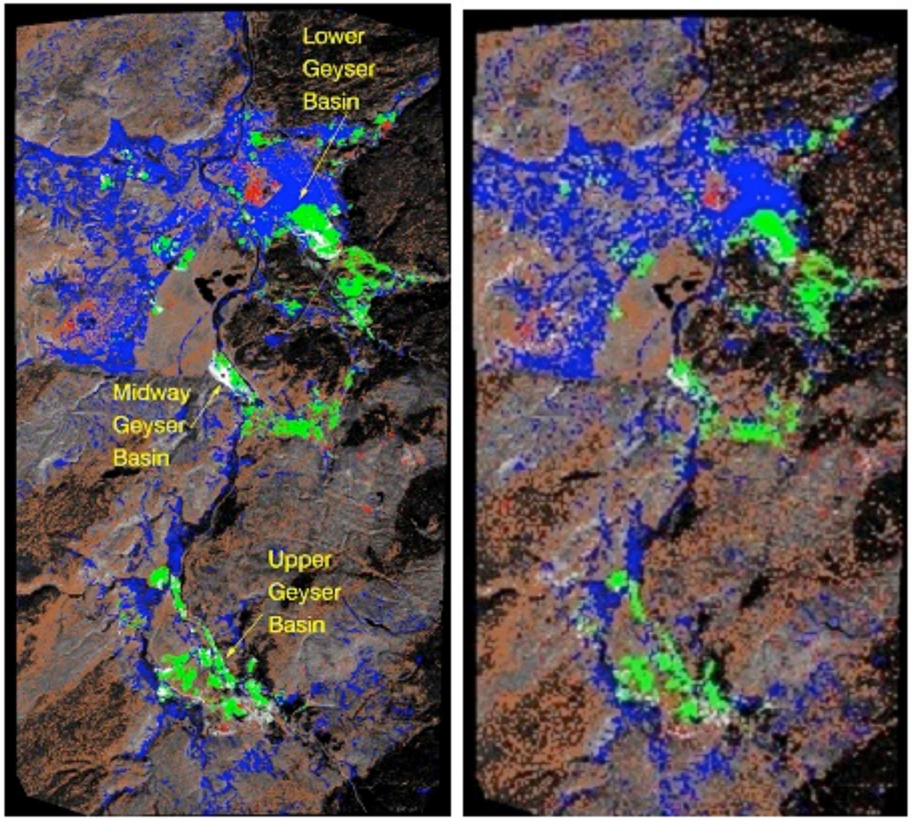
AVIRIS (15m)



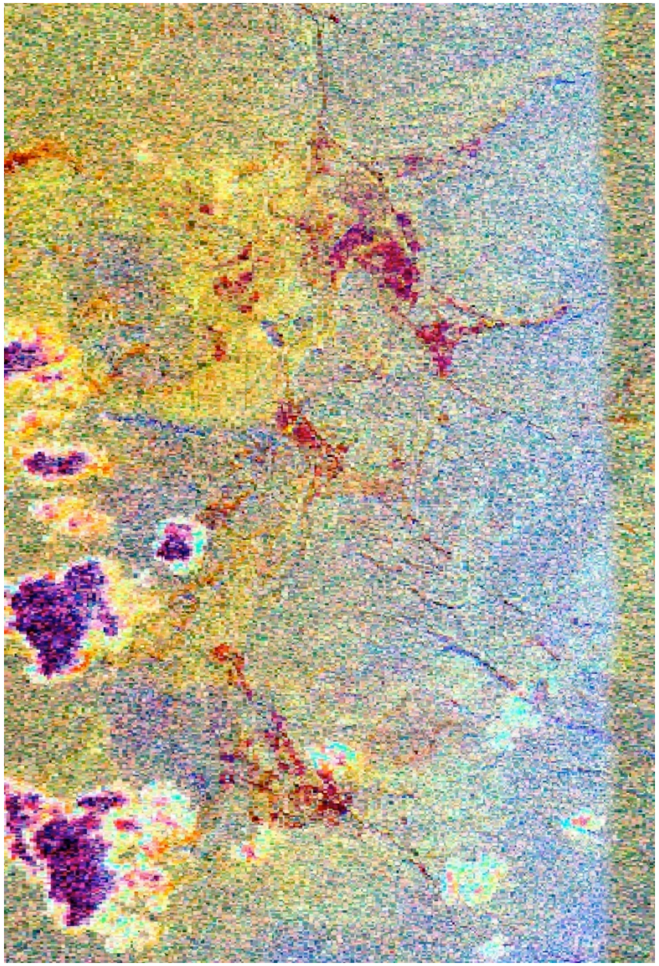
HyspIRI-Sim (60m)

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

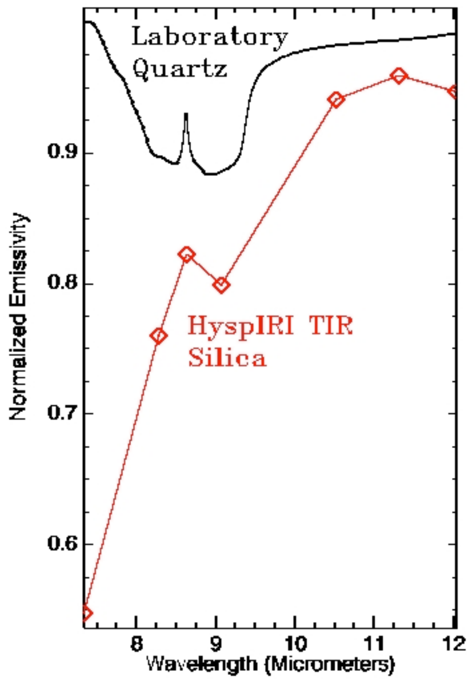
	Ground	**Truth**				
Class	Unclass	Kaolinite	Silica	Grn Veg	Dry Veg	Total
Unclass	**76.89**	49.41	12.86	35.44	51.63	68.03
Kaolinite	1.12	**19.15**	0.36	0.45	1.03	1.11
Silica	0.93	3.18	**69.17**	2.34	1.41	2.84
Grn Veg	5.62	5.61	8.76	**56.01**	3.06	9.82
Dry Veg	15.44	22.65	8.85	5.77	**42.66**	18.20
Total	100.00	100.00	100.00	100.00	100.00	**100.00**
Class	**Commission**	**Omission**	**Prod. Acc.**	**User Acc.**		
	Percent	**Percent**	**Percent**	**Percent**		
Unclass	15.93	23.11	76.89	84.07		
Kaolinite	92.49	80.85	19.15	7.51		
Silcia	39.09	30.83	69.17	60.91		
Grn Veg	49.33	43.99	56.01	50.67		
Dry Veg	67.65	57.34	42.66	32.35		

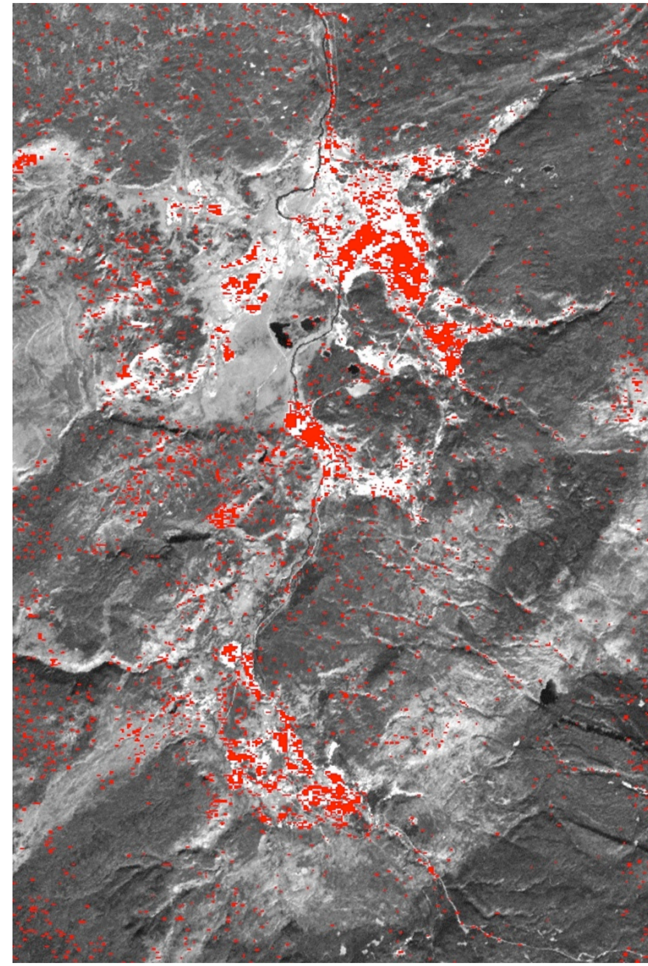


MASTER Mineralogy YS (Firehole River) 2006
35m Native Spatial Resolution



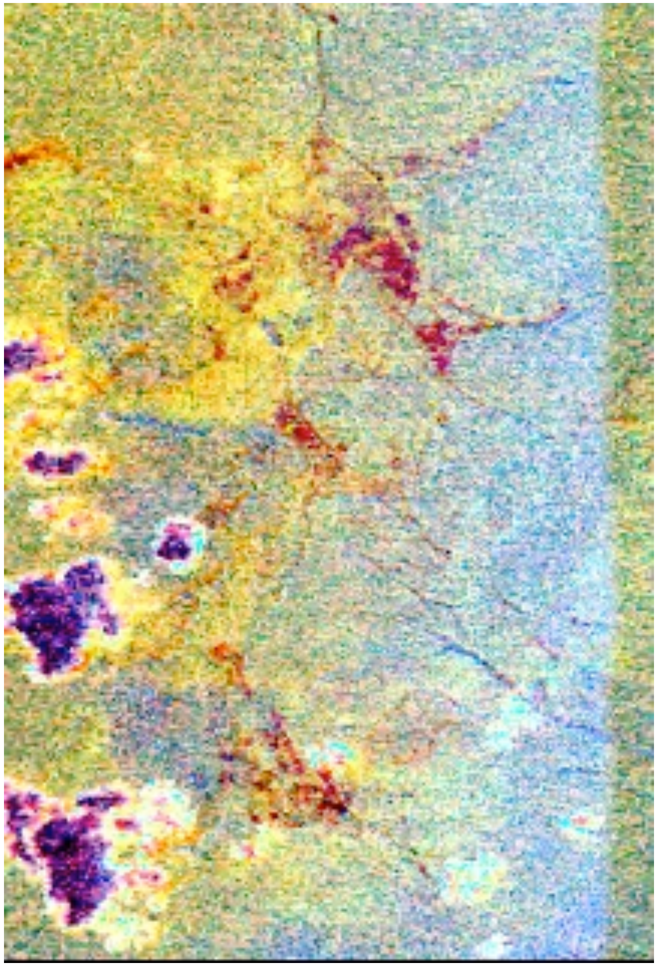
Emissivity (10.5, 9.1, 8.3 μm, RGB)
Note Clouds and Shadows (purple)



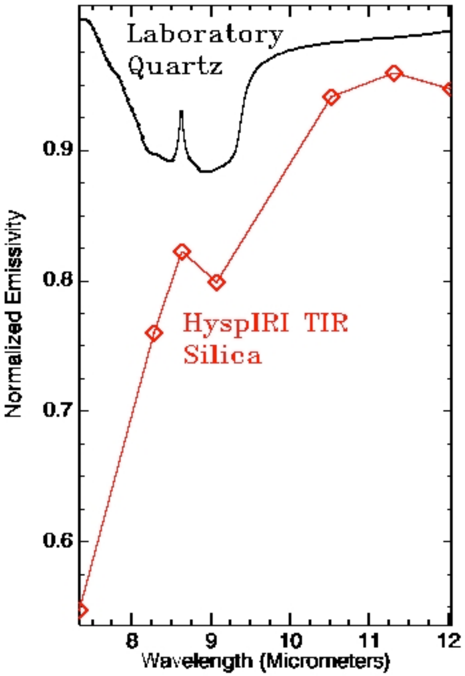


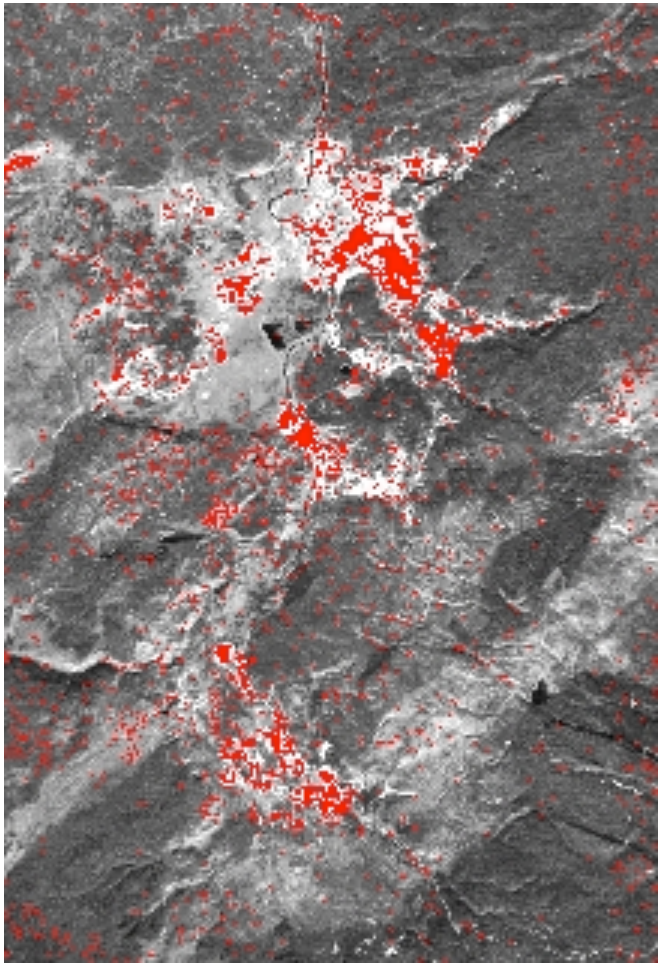
MTMF LWIR Silica Map

MASTER Mineralogy YS (Firehole River) 2006
60m HyspIRI-Sim Spatial Resolution



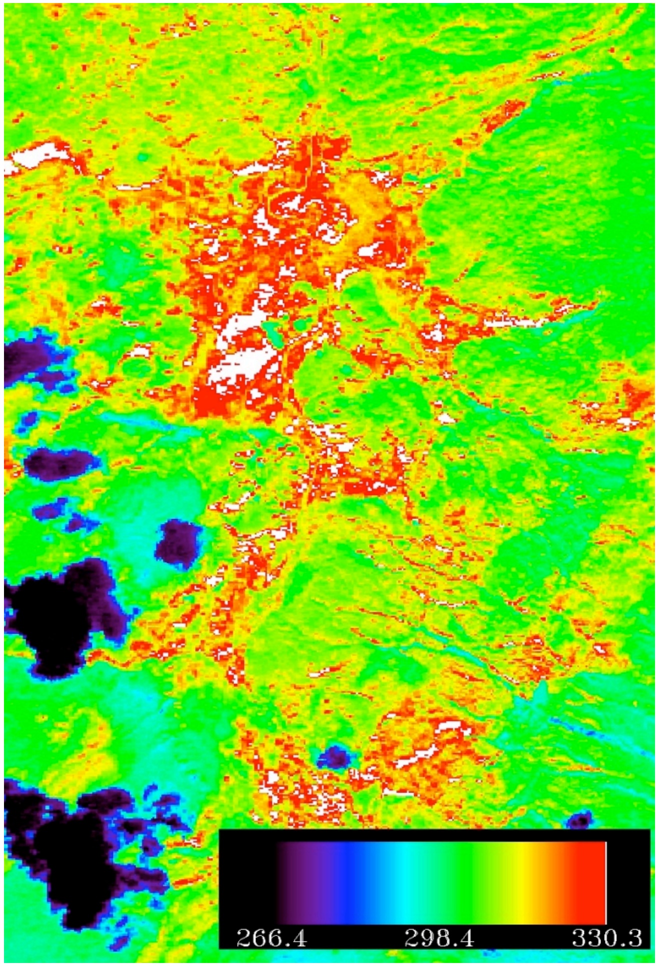
Emissivity (10.5, 9.1, 8.3 μm, RGB)
Note Clouds and Shadows (purple)



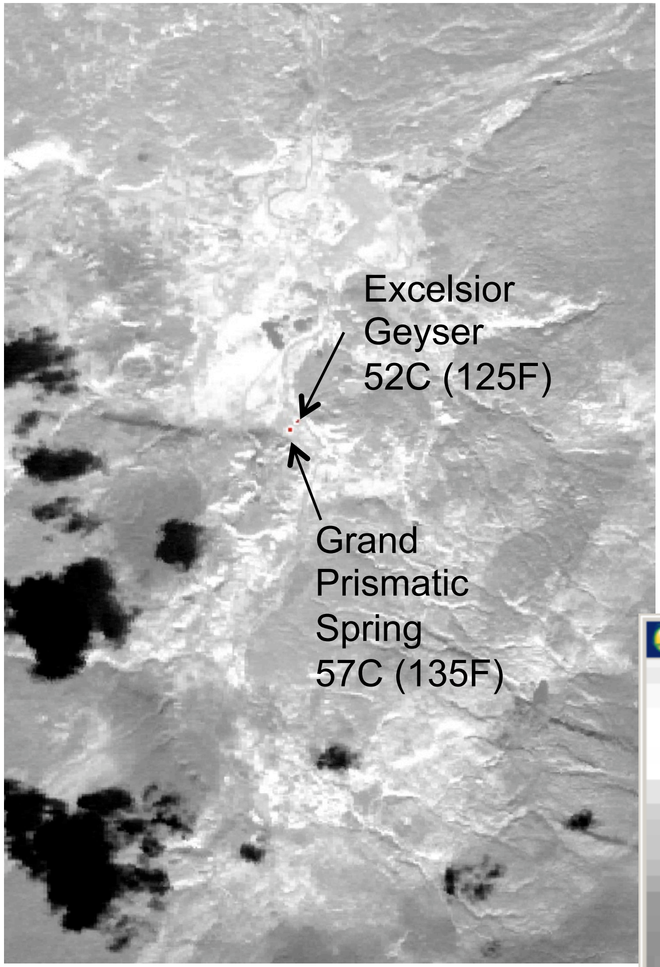


MTMF LWIR Silica Map

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



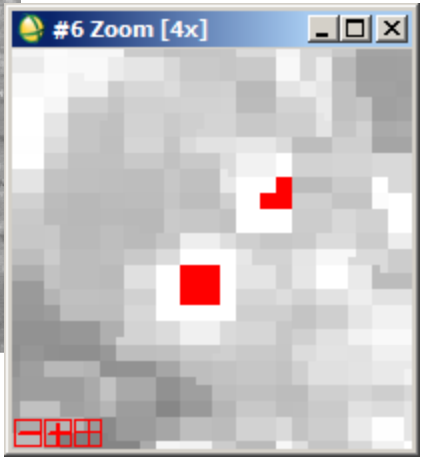
MASTER LWIR Temperature (Density Sliced)



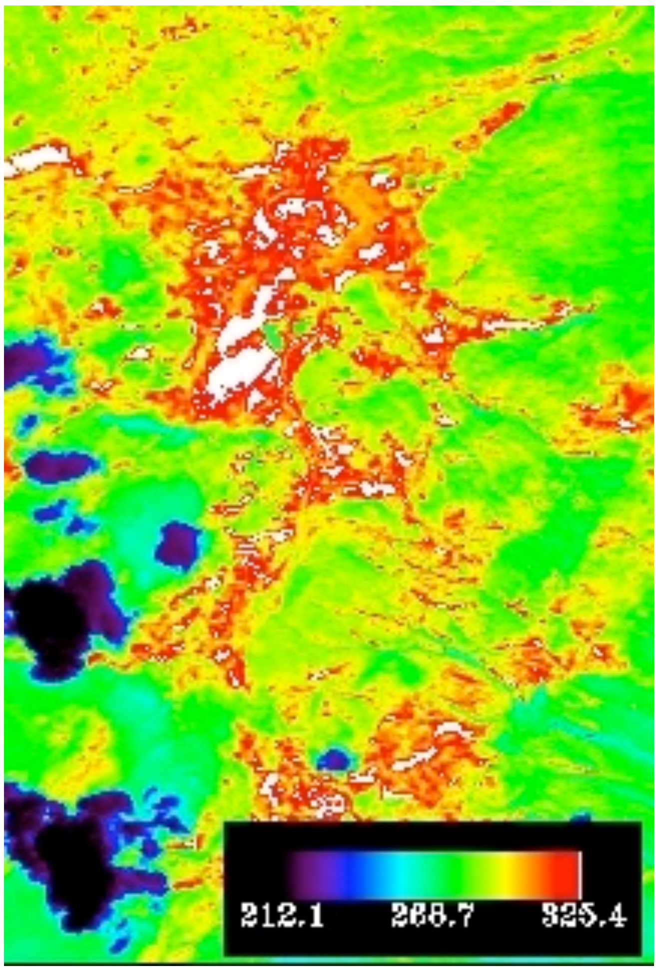
MASTER LWIR Temperature (Temperatures >50C)

Ground-Observed Temperatures

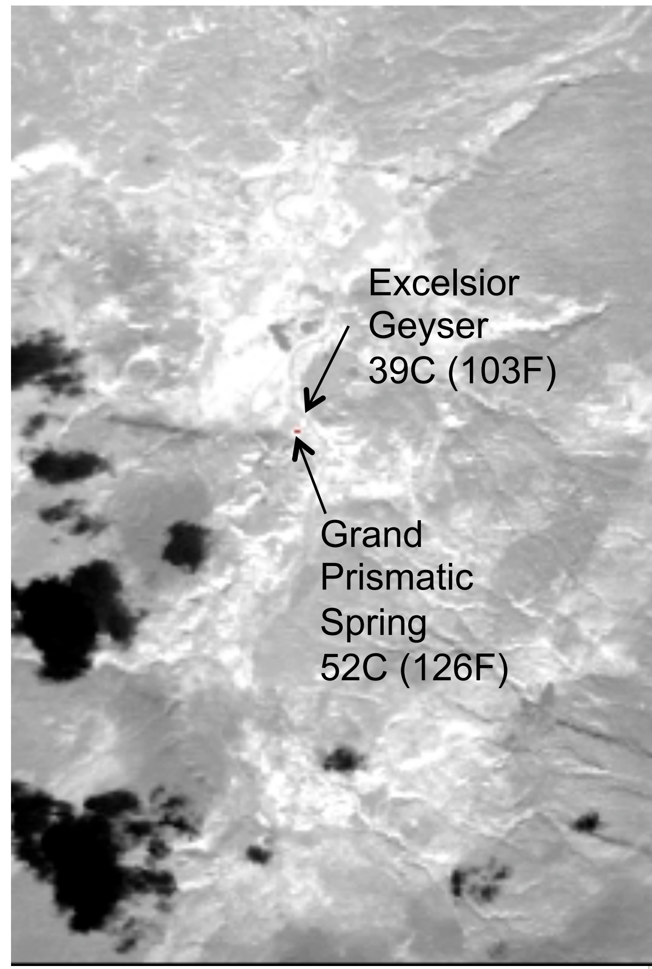
GP: 64 – 97C
EG: 93C



MASTER Temperature YS (Firehole River) 2006
60m HyspIRI-Sim Spatial Resolution



MASTER LWIR Temperature (Density Sliced)



MASTER LWIR Temperature (Temperatures >50C)

Ground-Observed Temperatures

GP: 64 – 97C
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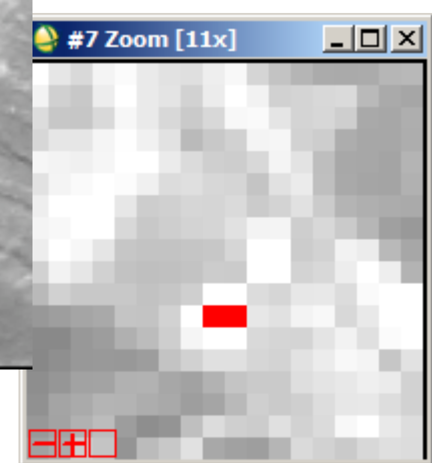

Summary and Conclusions

- 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:**
  - Kruse, F.A., Taranik, J.V., Coolbaugh, M., Michaels, J., Littlefield, E.F., Calvin, W.M., and Martini, B.A., 2011, Effect of Reduced Spatial Resolution on Mineral Mapping Using Imaging Spectrometry – Examples Using HyspIRI-Simulated Data: *Remote Sensing*, v. 3, p. 1584-1602. http://www.mdpi.com/2072-4292/3/8/1584/ (Open Access)
- **HyspIRI simulated datasets available on request**