Preliminary Results
Characterization of Hydrothermal Systems Using Simulated HyspIRI Data

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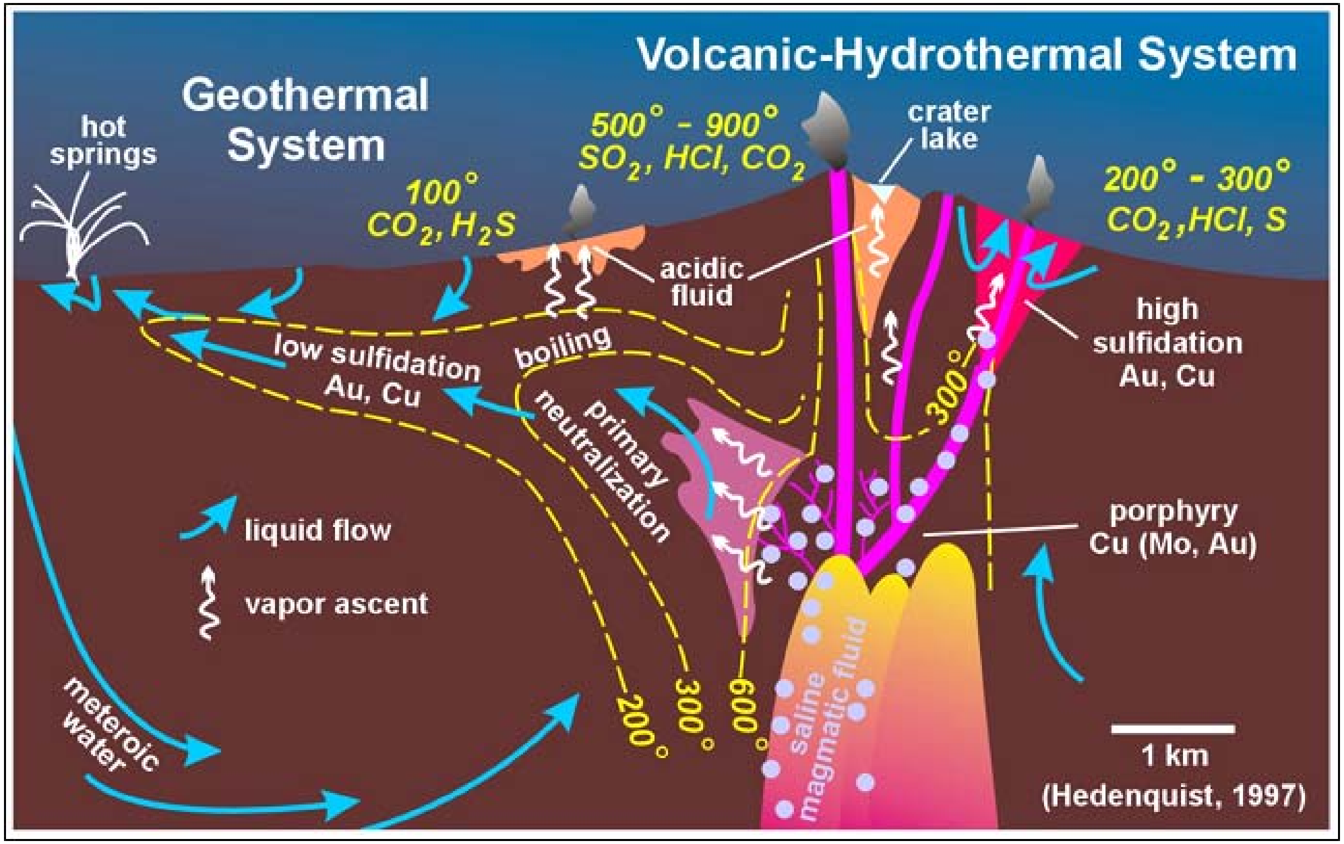
(HyspIRI Preparatory Research Activities)

F. A. Kruse, M. Coolbaugh, J. Taranik, W. Calvin, E. Littlefield, J. Michaels
Dept of Geological Sciences and Engineering
Arthur Brant Laboratory for Exploration Geophysics
University of Nevada, Reno

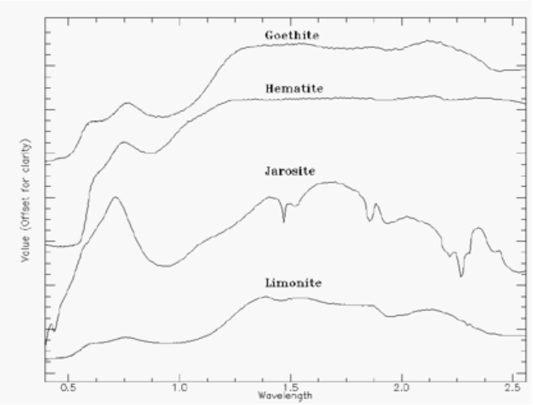
B. Martini
Ormat, Reno, NV

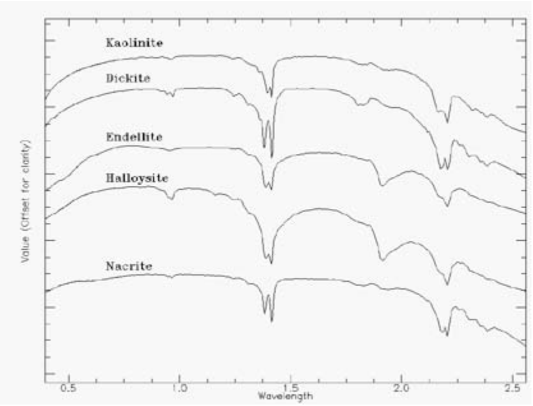
Why Remote Sensing of Hydrothermal/Geothermal Systems?

- **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 can be mapped using HSI and MSI VNIR/SWIR and LWIR approaches**

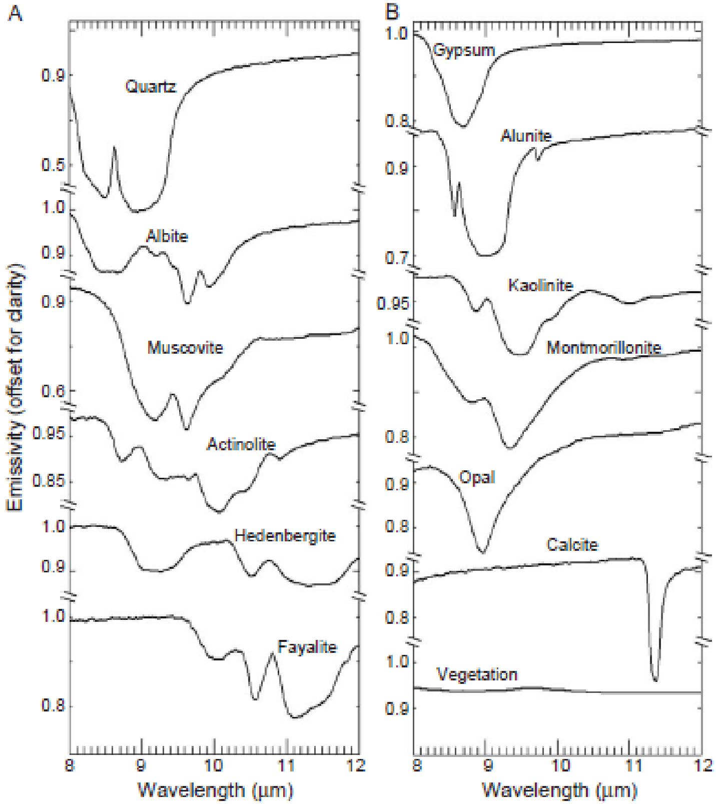


- **VNIR/SWIR spectrometry has clearly demonstrated its capability to identify minerals based on molecular physics**
- **LWIR spectrometry has unique capabilities based on fundamental molecular vibrations**





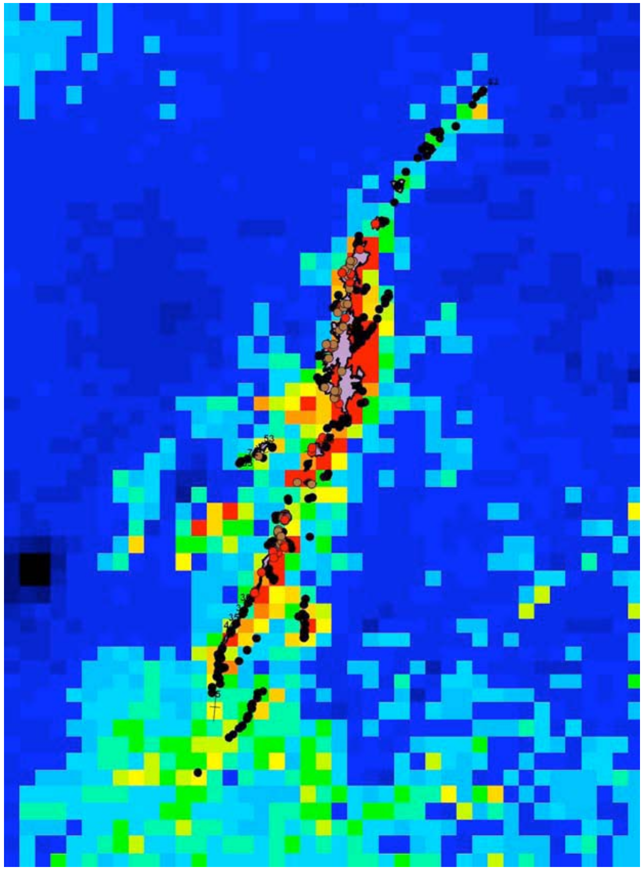
USGS Spectral Library



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 Precursor Project Objectives

Generate HyspIRI-like remote sensing datasets from existing NASA HSI and MSI remote sensing data, and utilize these 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**

Hydrothermal Systems - Some Science Questions

- **How are surface mineral assemblages of hydrothermal systems tied to underlying geologic constraints (lithology, alteration, water chemistry, temperature regimes)? (VQ6, TQ5a, CQ5)**
- **What can surface mineralogy tell us about the morphology and evolution of hydrothermal systems and the link between active geothermal systems and ore deposits? (VQ6, TQ5a)**
- **What surface changes are taking place at active geothermal systems as the result of human activities such as recreation, geothermal energy exploration and drilling, and energy production? (TQ5b, CQ5)**
- **What is the magnitude of surface temperatures at active hot springs and geothermal areas? How do temperatures vary naturally? What can surface temperatures tell us about the morphology and evolution of these systems and temperature at-depth? How does surface temperature respond to geothermal production? (TQ5c)**

Hydrothermal Systems - Some HyspIRI Questions

- What is the effect of the proposed HyspIRI spatial and spectral resolution, and SNR or NEΔT on detection, identification, and characterization of key rocks, minerals, vegetation, and other materials associated with active and fossil geothermal systems utilizing spectral signatures?
- What is the spatial scale of temperature features that can be detected at the proposed HyspIRI 60m spatial resolution?
- What is the temperature contrast required for detection and characterization of geothermal systems at various scales?
- How does spatial mixing affect mineral identification and measurement of temperatures at geothermal systems. What is the magnitude and nature of these mixing effects?

HyspIRI Research Approach

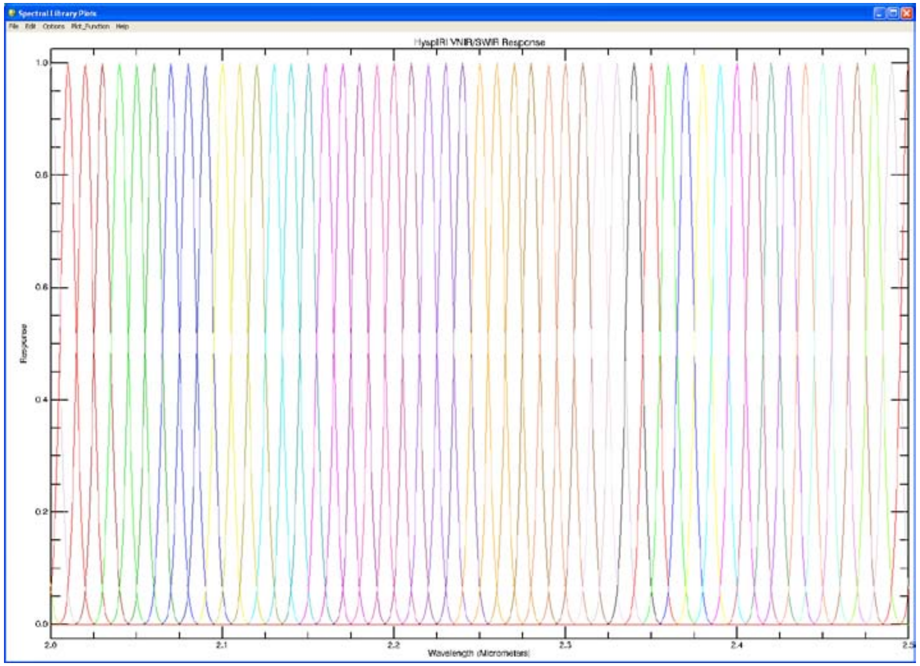
- Build on previous experience with epithermal mineral deposits, geothermal systems, and remote sensing data to try to improve understanding of active and fossil geothermal systems
  - Determination of mineral assemblages (not just the predominant mineral)
  - Detect and map detailed within-species variability (eg: muscovites, chalcedony vs opal, etc.)
  - Map additional rocks and minerals with LWIR
  - Use temperature mapping to quantify surface indicators of active geothermal systems
  - Development of comprehensive system models

Approach (continued)

- Create Simulated HyspIRI Data for 5 Sites (Detailed analysis of at least 3 sites)
  - Steamboat Springs, NV
  - Long Valley, CA
  - Fish Lake Valley, CA (Not shown)
  - Yellowstone, WY (Pending)
  - Cuprite, NV
- Focus on refining mineral mapping and temperature measurement capabilities using merged VSWIR and TIR data Simulation/Analysis Approach

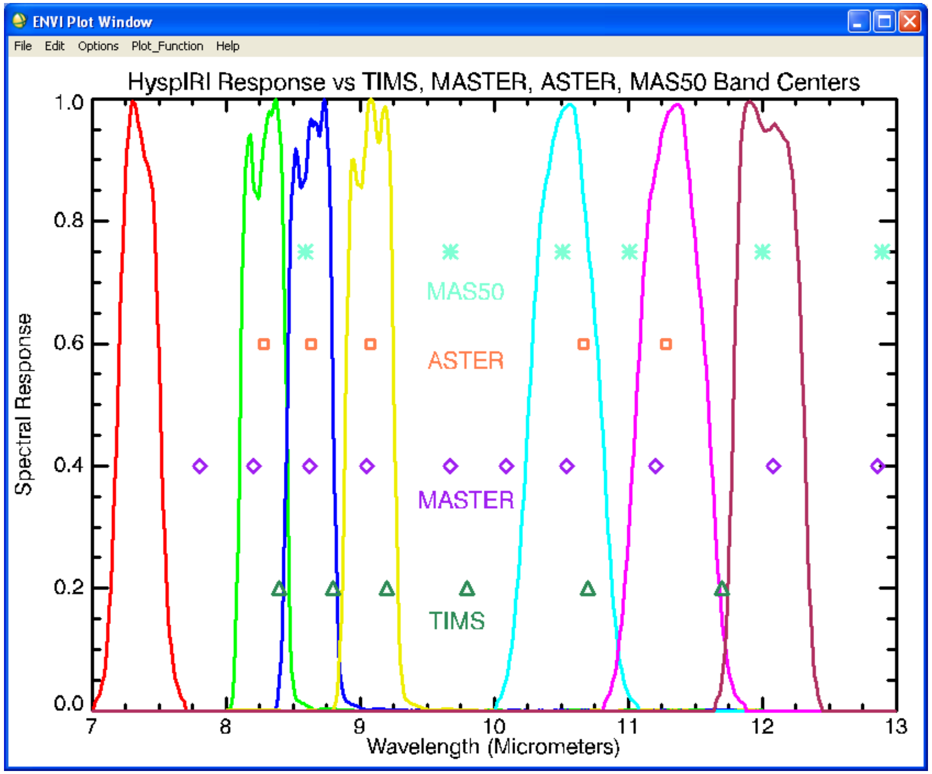
Simulation/Analysis Approach

- Use existing HSI data (AVIRIS, Hyperion, HyMap, SpecTIR) to simulate the VNIR/SWIR component of HyspIRI (~210+ spectral bands 0.38 – 2.52 micrometers with approximately 10nm spectral resolution and 60 m spatial resolution)
  - Atmospheric Correction
  - Spectral Resampling
  - Warp to ASTER Ortho
  - Spatial Resampling
  - SNR Modeling
  - Spectral mapping using Refl. Spectra



Simulation/Analysis Approach

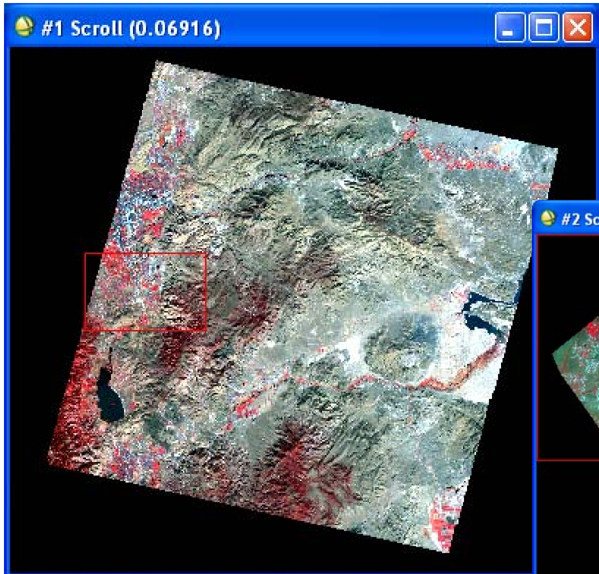
- **Use existing TIR data (TIMS, MASTER, MAS, ASTER, SEBASS) to simulate the TIR component of HyspIRI (1 MWIR band ~4 micrometers and 7 LWIR spectral bands from ~7.3-12.0 micrometers.**
  - Atmospheric Correction
  - Temperature-Emissivity Separation
  - Warp to ASTER Ortho
  - Spatial and Spectral Resampling
  - Spectral Mapping using Emissivity Spectra
  - Additional T corrections (albedo, topo)
  - Temperature mapping and characterization



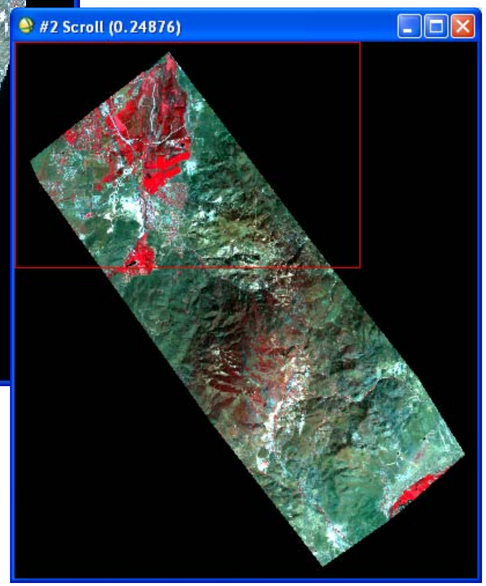
Initial Selected Data Matrix

- Cuprite, NV
  - 2007 ASTER
  - 2006 AVIRIS (16m)
  - 2006 MASTER (34m)
- Steamboat Springs, NV
  - 2006 ASTER (day-night)
  - 1995 AVIRIS (16m)
  - 1999 MASTER (8.8m)
- Fish Lake Valley, CA
  - 2004 ASTER
  - 2003 AVIRIS (3m)
  - 2006 MASTER (11m)
- Long Valley, CA
  - 2002 ASTER
  - 2000 AVIRIS (16m)
  - 2001 MASTER (33m)
  - 2006 MASTER (34m, Day-Night)
- Yellowstone, WY
  - 2004 ASTER
  - 1996 AVIRIS (16m), 1996 MAS (33m)
  - 1996 AVIRIS (16m), 2006 MASTER (3.5m)

Steamboat Springs, NV Simulation

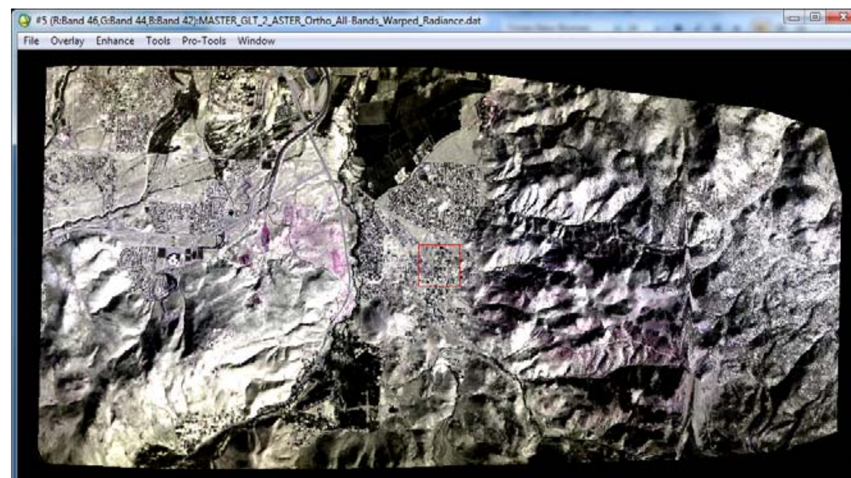


ASTER VNIR (15m) 10-23-2006 Ortho



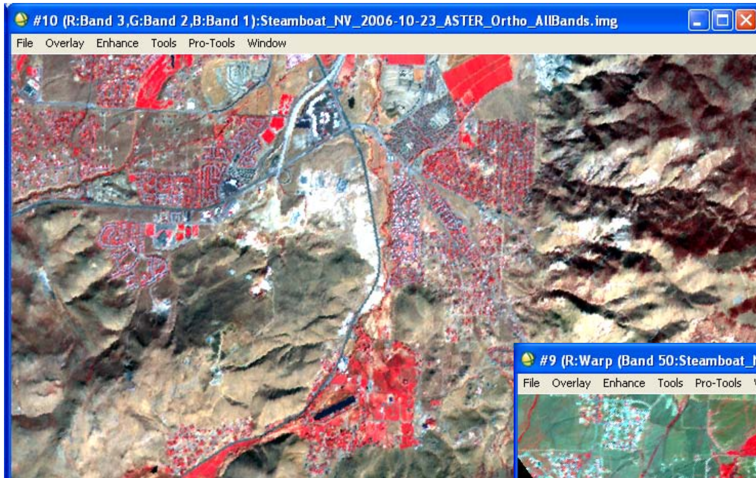
AVIRIS VNIR (15m) 07-22-1995, Warped to ASTER Ortho

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

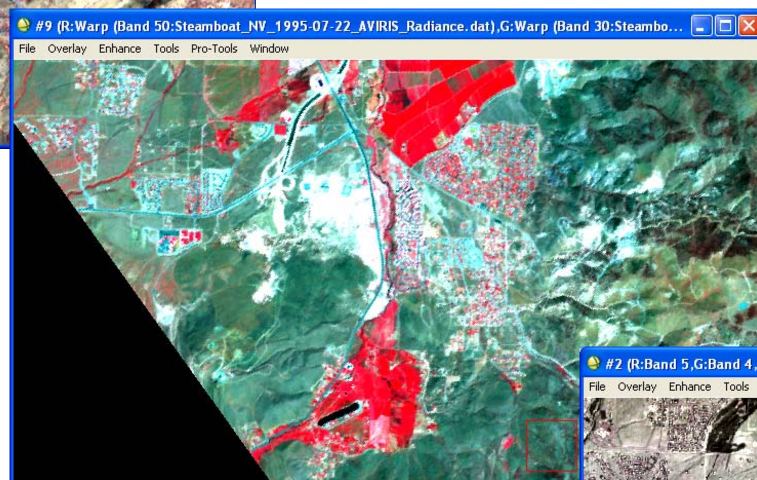


MASTER LWIR (15m), GLT-Cor 09-19-1999, Warped to ASTER Ortho

Steamboat Springs, NV Simulation

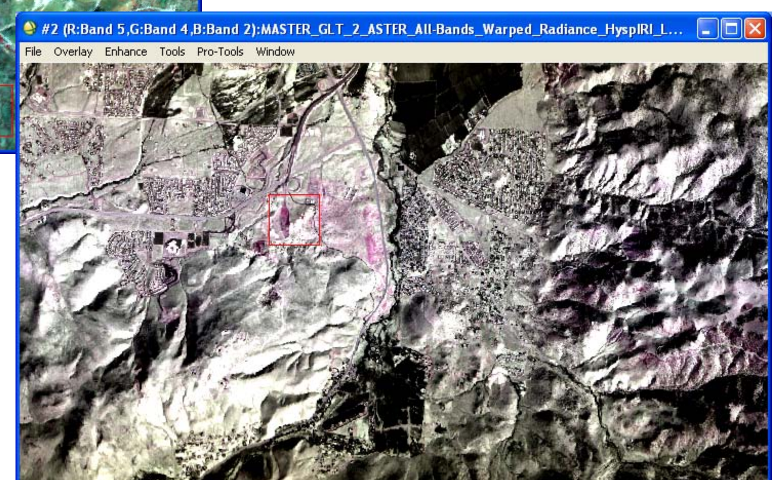


ASTER VNIR (15m)

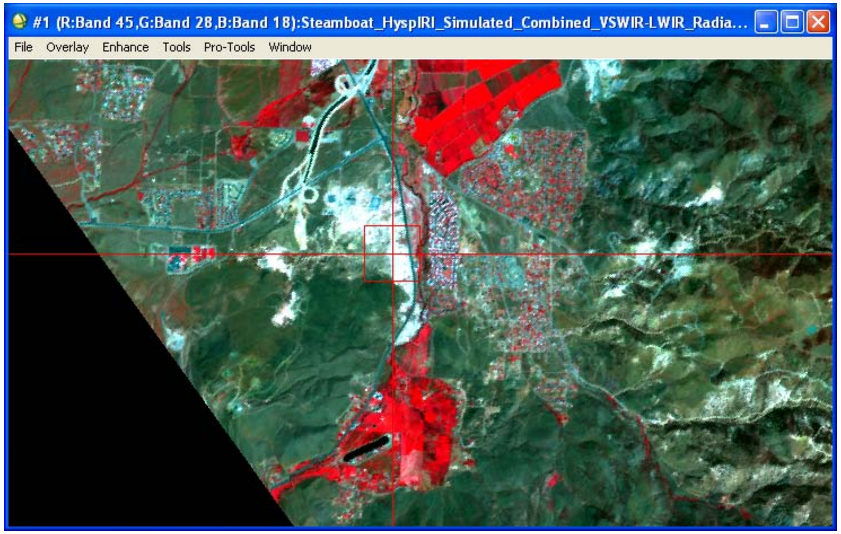


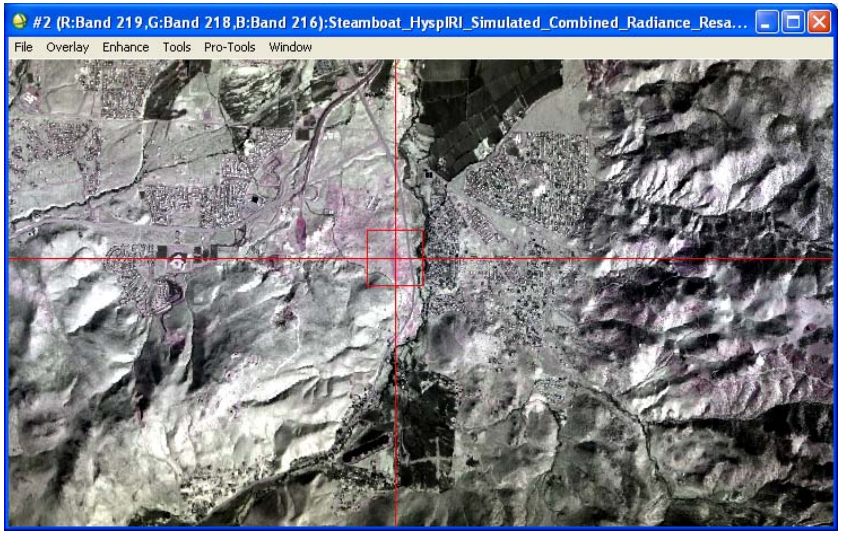
AVIRIS VNIR

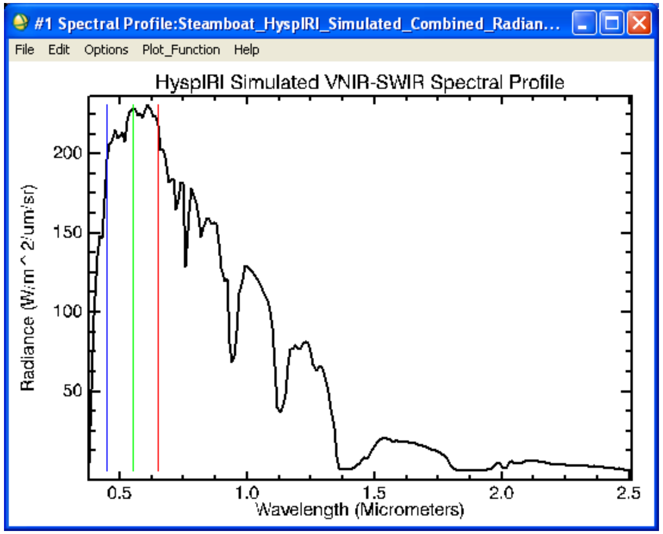
MASTER LWIR



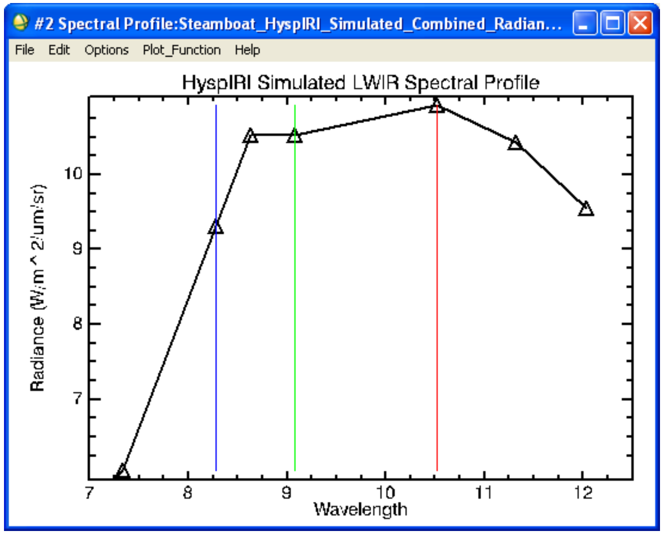
Steamboat Springs, NV Simulation





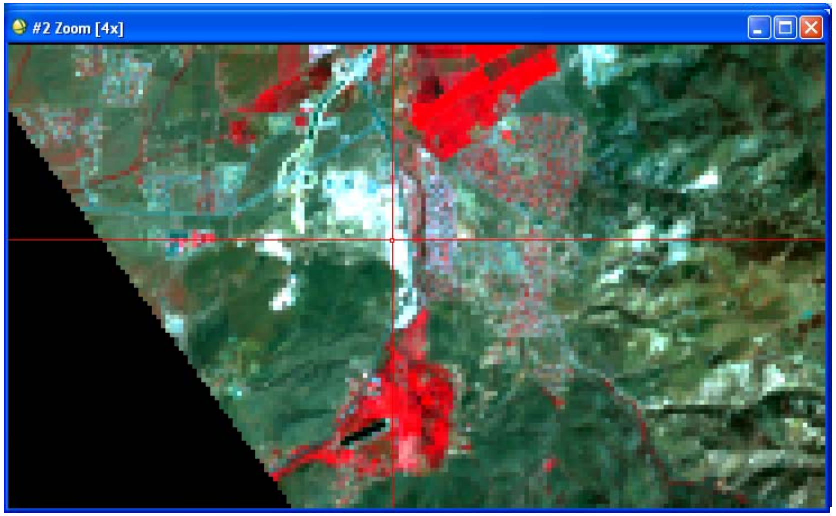


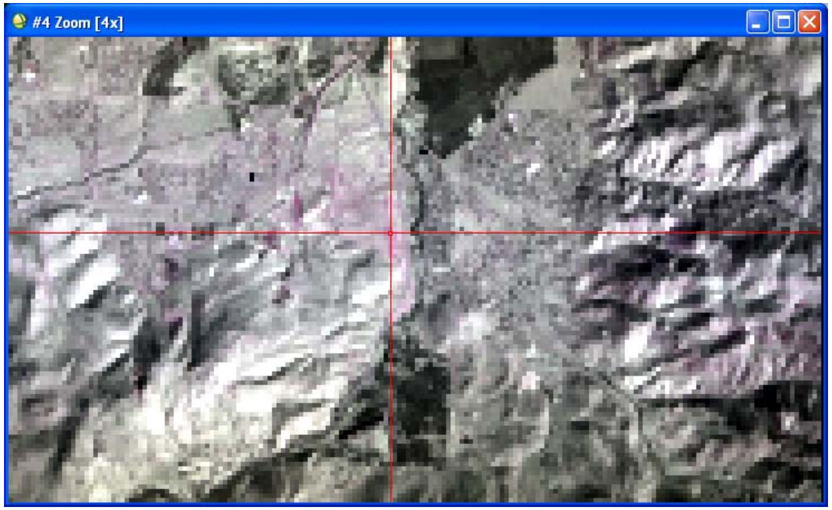
HyspIRI-Simulated VSWIR Radiance (15m)

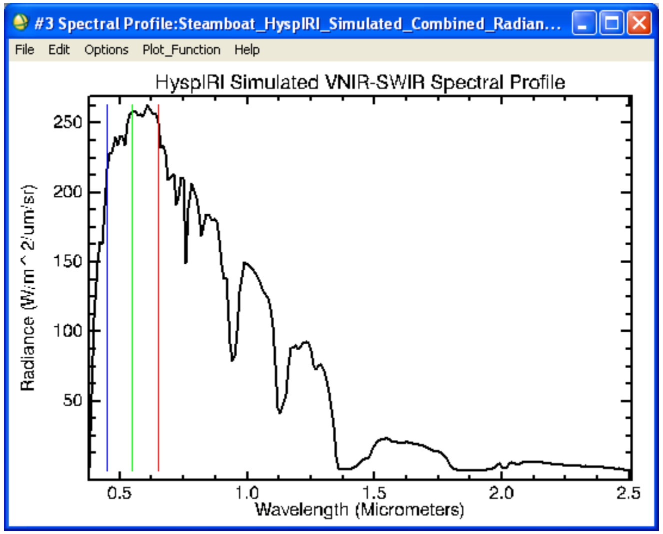


HyspIRI-Simulated LWIR Radiance (15m)

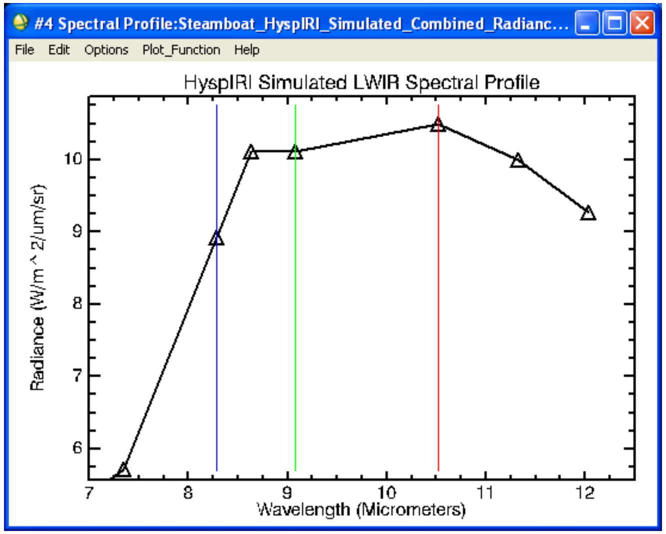
Steamboat Springs, NV Simulation





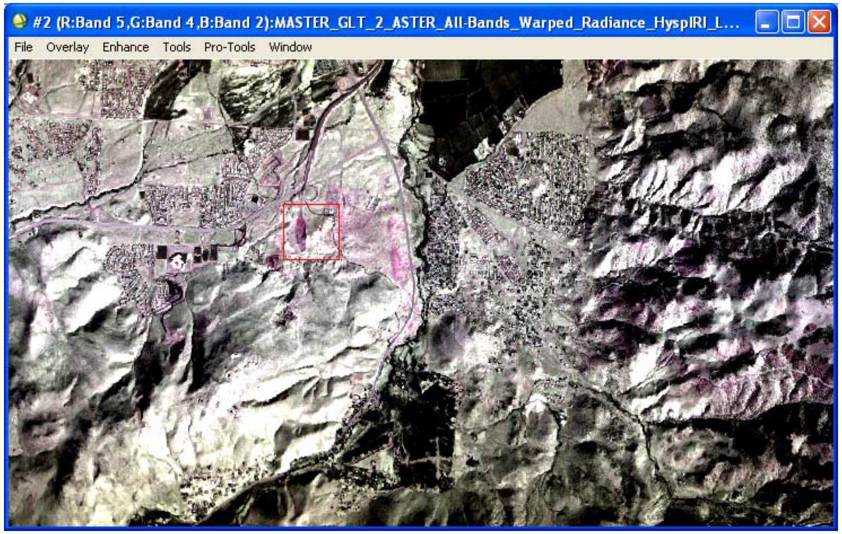


HyspIRI-Simulated VSWIR Radiance (60m)

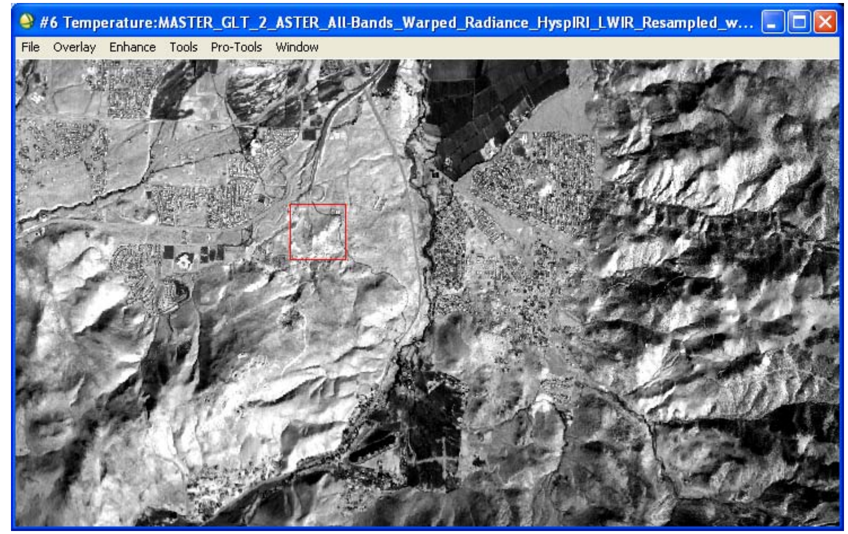


HyspIRI-Simulated LWIR Radiance (60m)

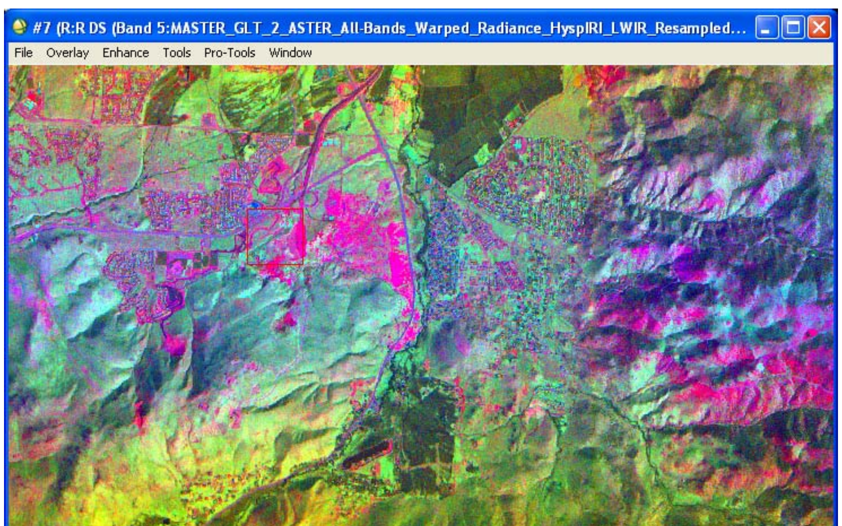
Steamboat Springs, NV Simulation (15m)



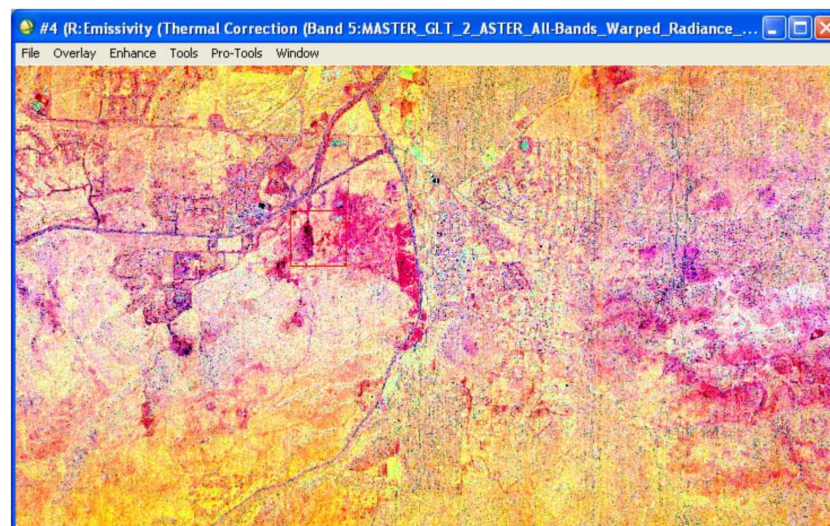
LWIR (10.0, 9.0, 8.2 μm RGB)



Temperature

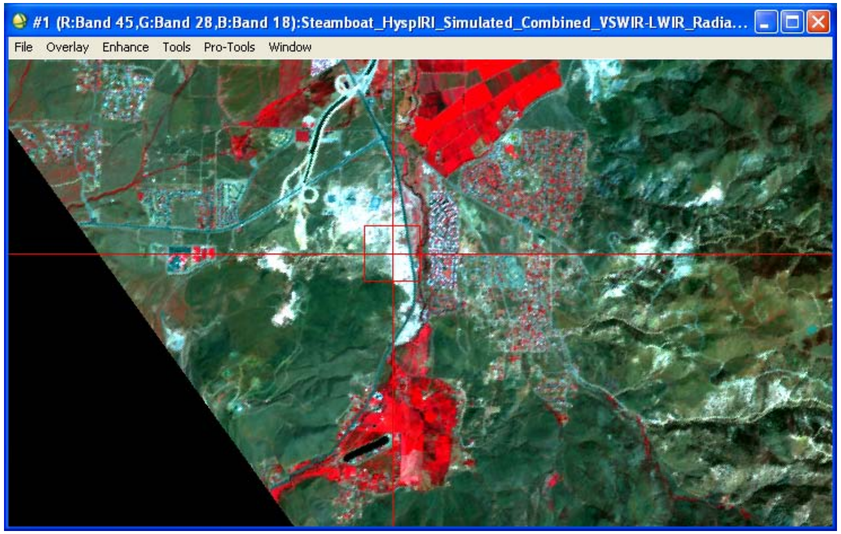


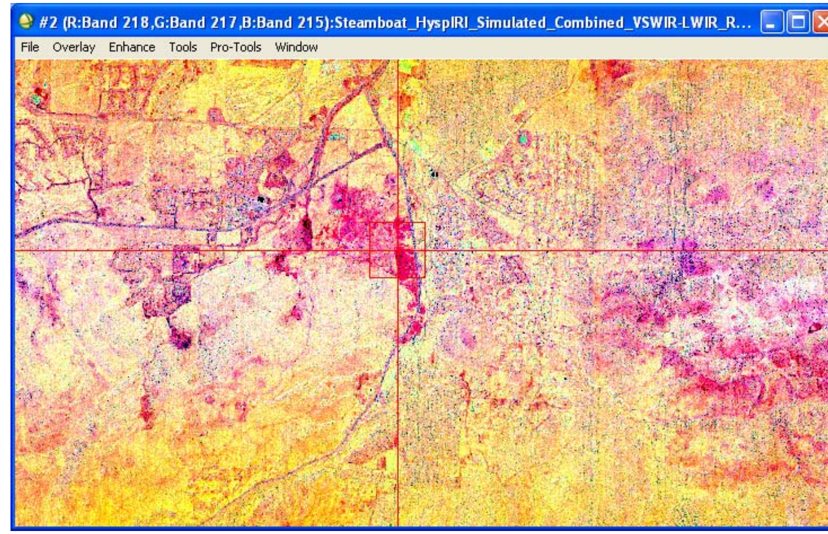
Decorellation Stretch

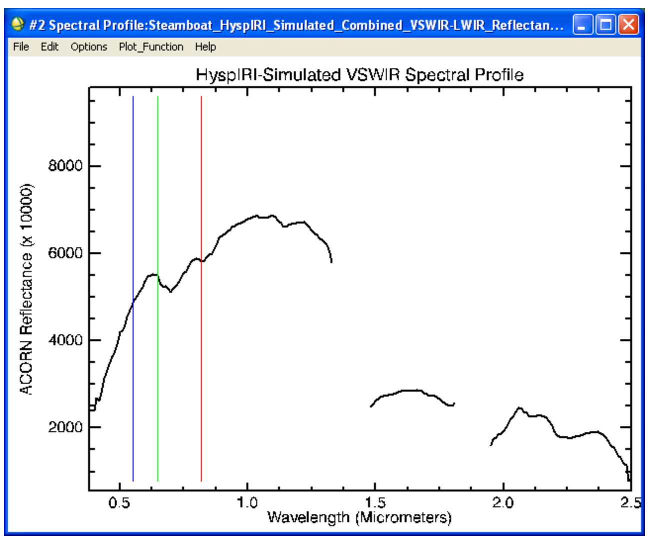


Normalized Emissivity

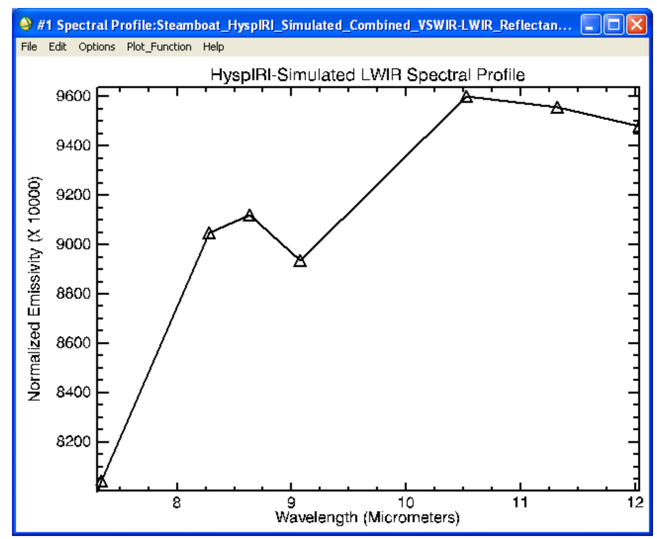
Steamboat Springs, NV Simulation







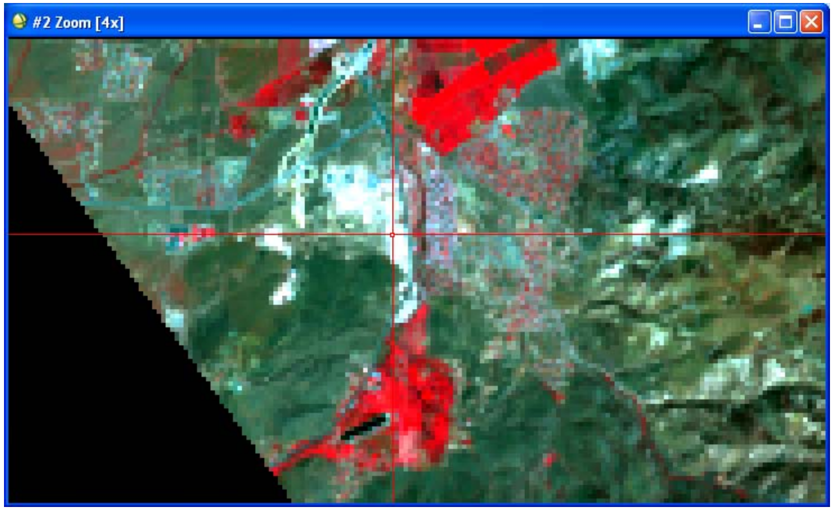
HyspIRI-Simulated VSWIR Reflectance (15m)

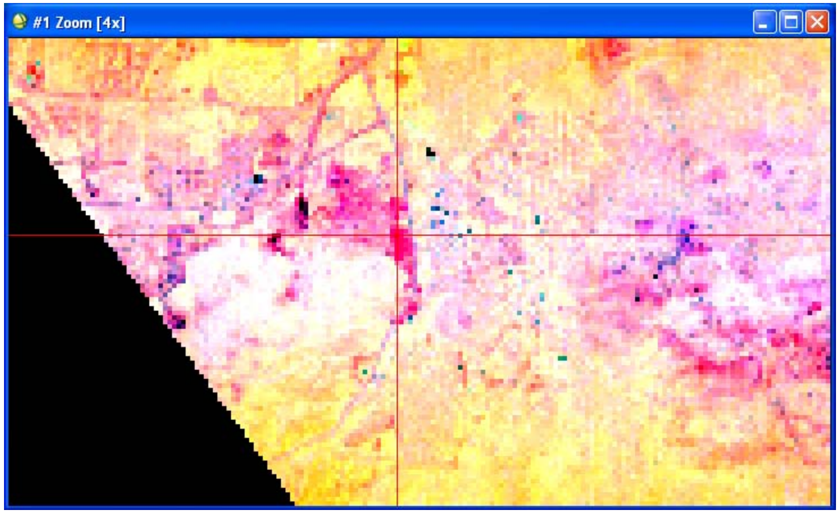


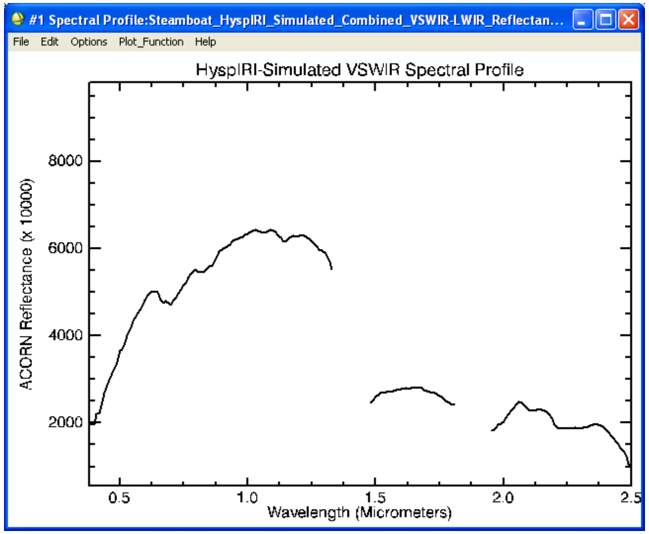
HyspIRI-Simulated LWIR Emissivity (15m)

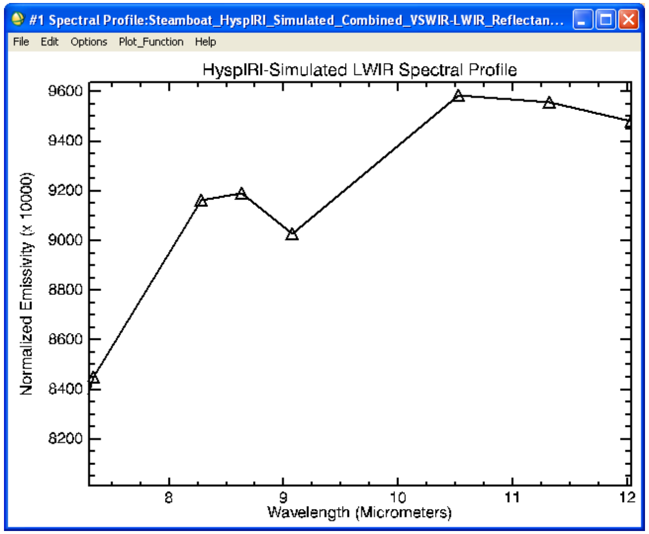
F. A. Kruse ♦ 303-499-9471 ♦ fkruse@unr.edu ♦ http://www/unr.edu/mines/able

Steamboat Springs, NV Simulation





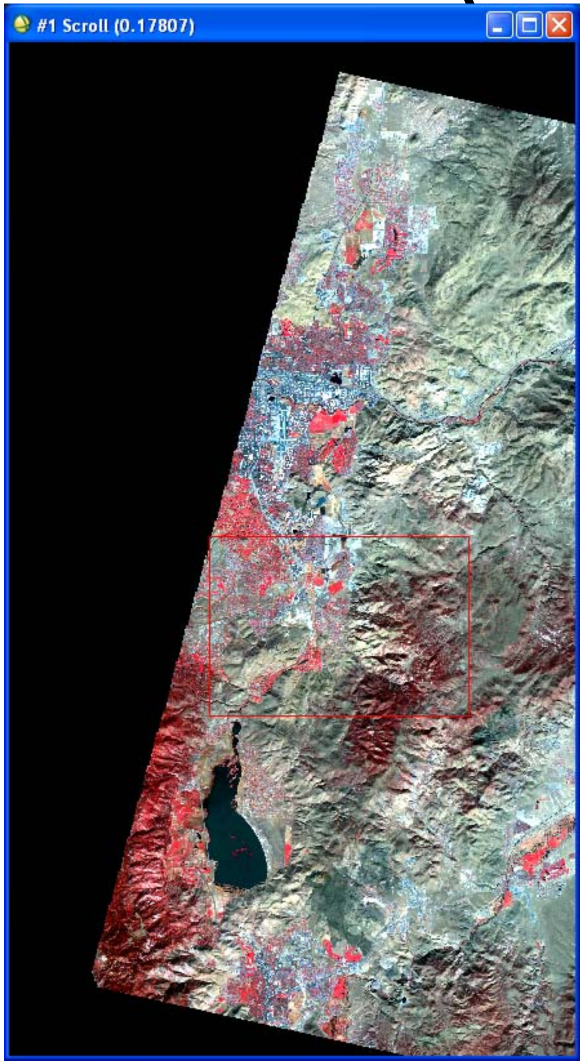




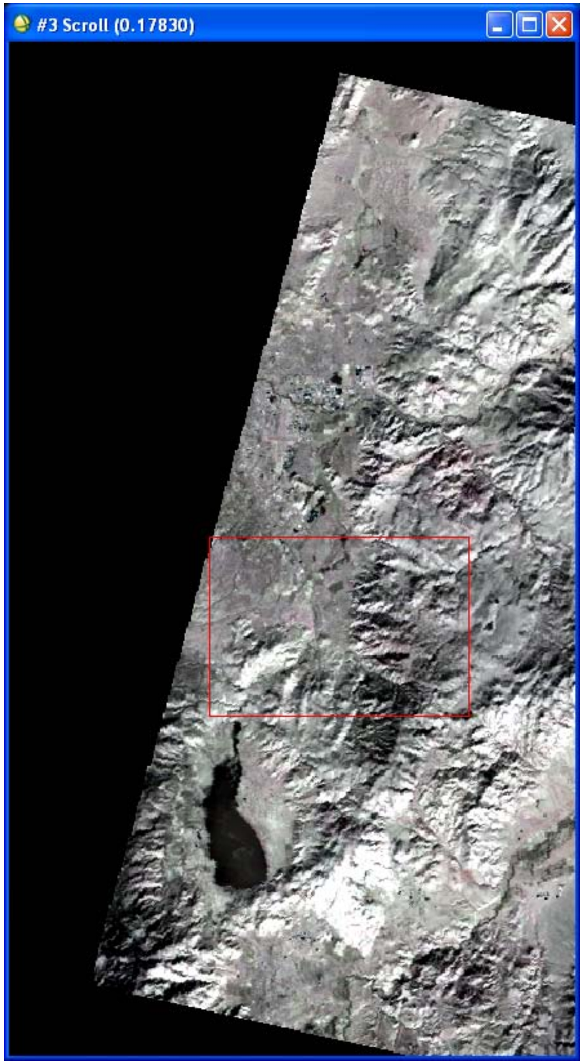
HyspIRI-Simulated VSWIR Radiance (60m)

HyspIRI-Simulated LWIR Radiance (60m)

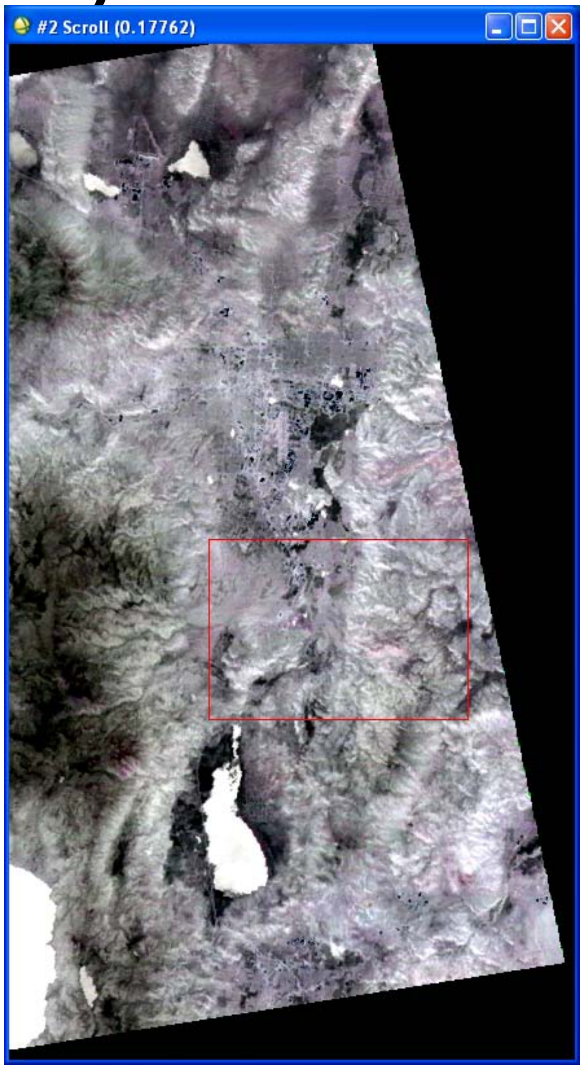
Steamboat Springs, NV ASTER Day-Night (10-23-2006 and 10-24-2006)



ASTER VSWIR (CIR)
0.81, 0.66, 0.56 μm (RGB)



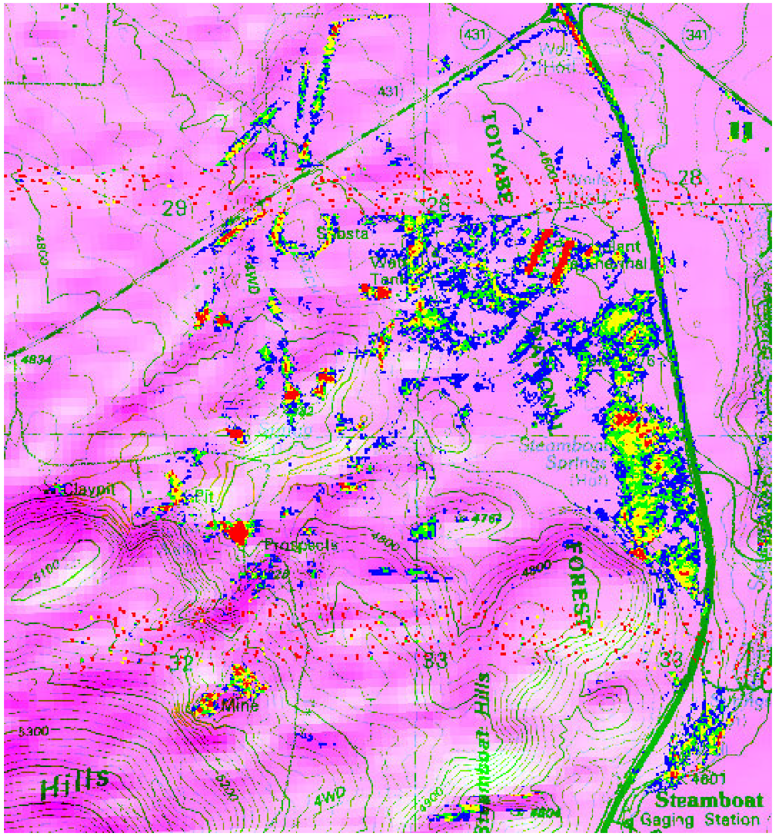
ASTER LWIR (Day)
10.7, 9.1, 8.3 μm (RGB)



ASTER LWIR (Night)
10.7, 9.1, 8.3 μm (RGB)

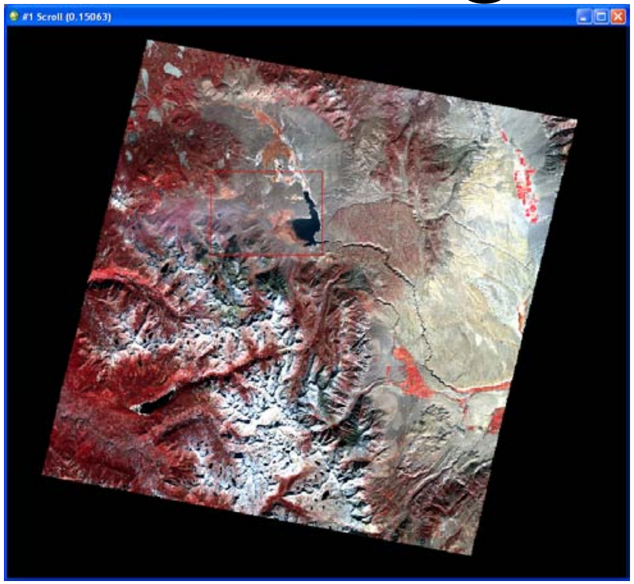
Steamboat Next Steps

- **HyspIRI Simulation**
  - **HyspIRI SNR model vs Sim-Data SNR**
  - **Mineral mapping**
- **ASTER Calibration/Corrections and Temperature**
  - **ASTER Radiance Corrections using "Unit Conversion Coefficients" from HDF**
  - **ACORN Reflectance (Day)**
  - **ISAC Atmospheric Correction (Day-Night)**
  - **Normalized Emissivity (Day-Night)**
  - **Coolbaugh Day-Night Temperature corrections setup and test**

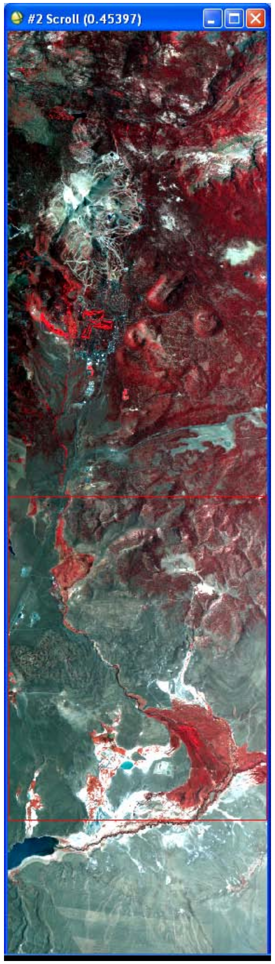


Coolbaugh et al., 2000 – Temperature Anomalies at Steamboat Springs

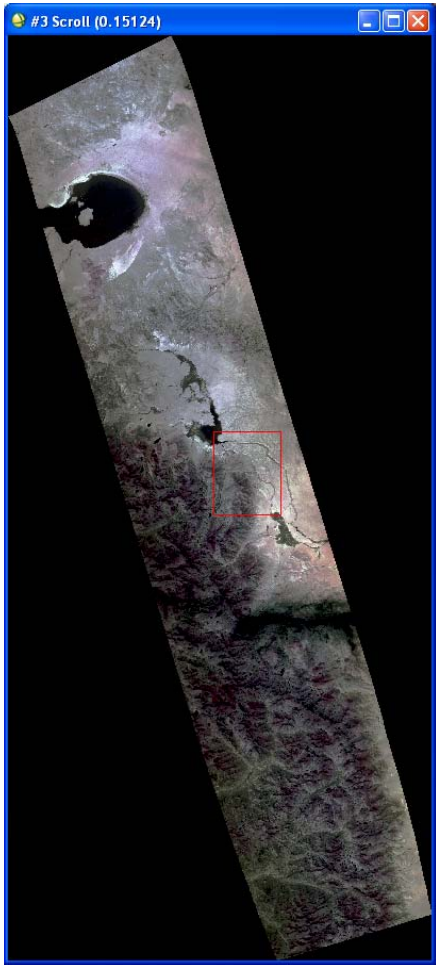
Long Valley, CA Simulation



ASTER VNIR (15m) 10-30-2002 Ortho

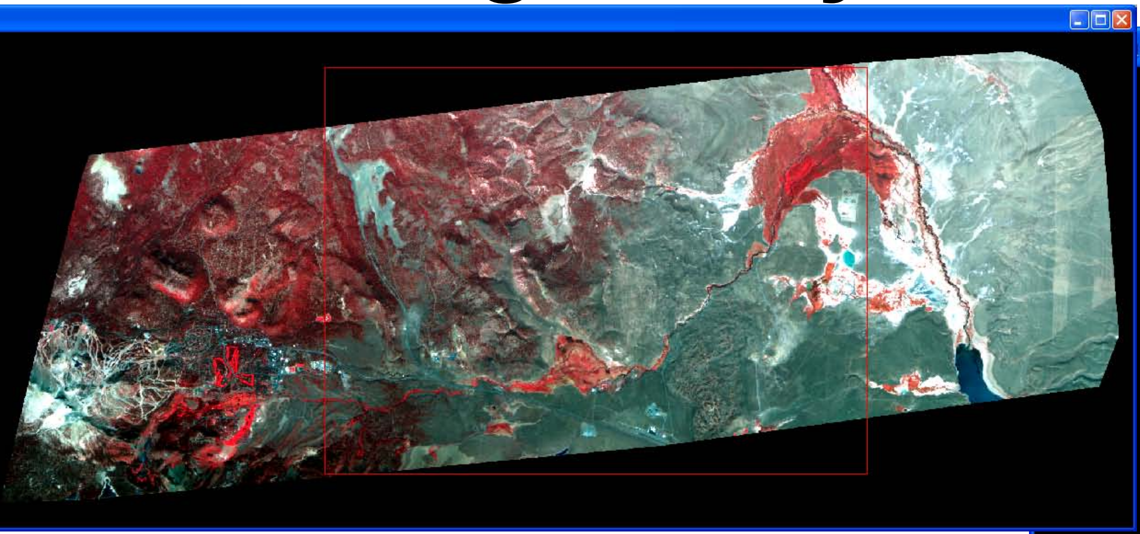


AVIRIS VNIR (15m) 09-15-2000 (no Geo)

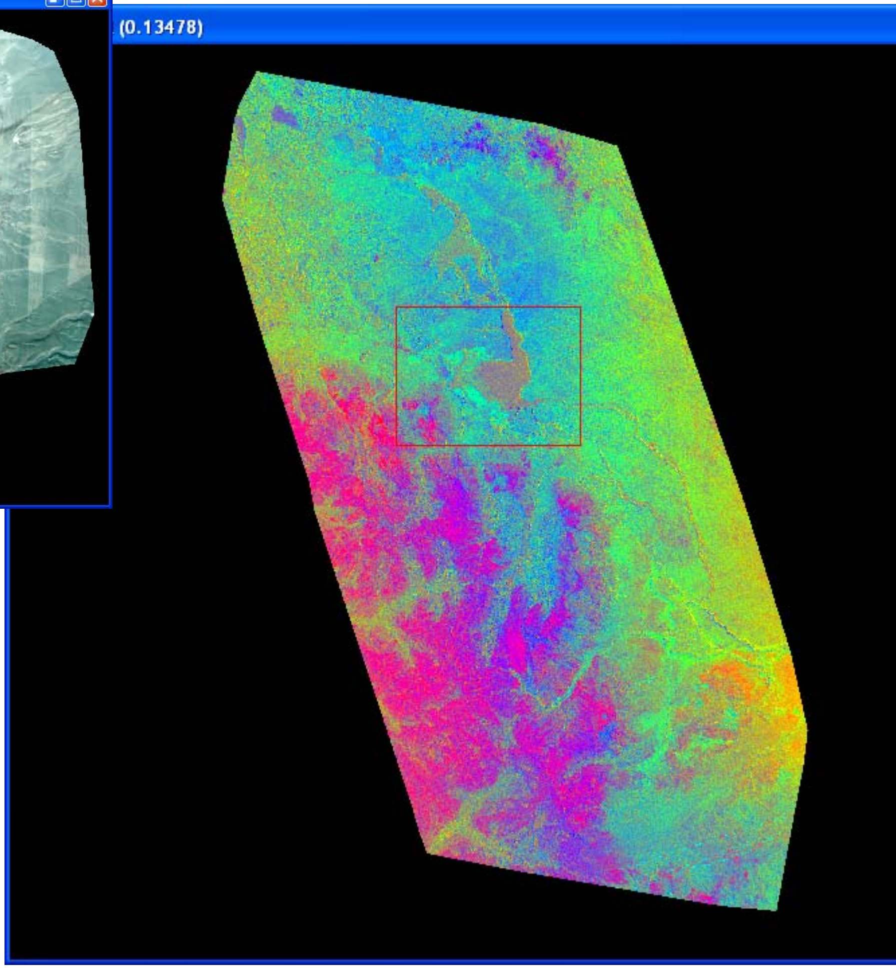


MASTER LWIR (33m), 08-18-2001 GLT-Corrected

Long Valley, CA Simulation



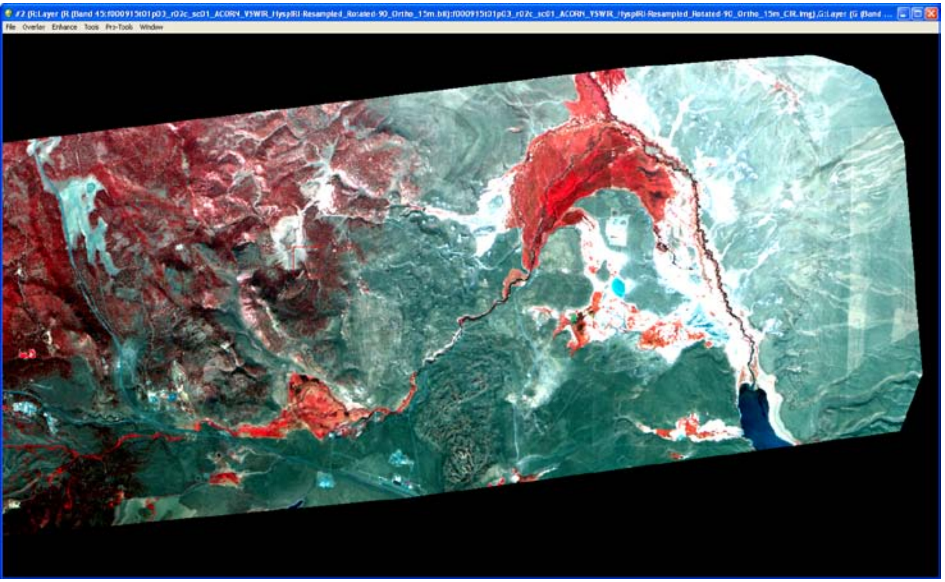
AVIRIS VNIR (15m)
09-15-2000 (warp to ortho ASTER)



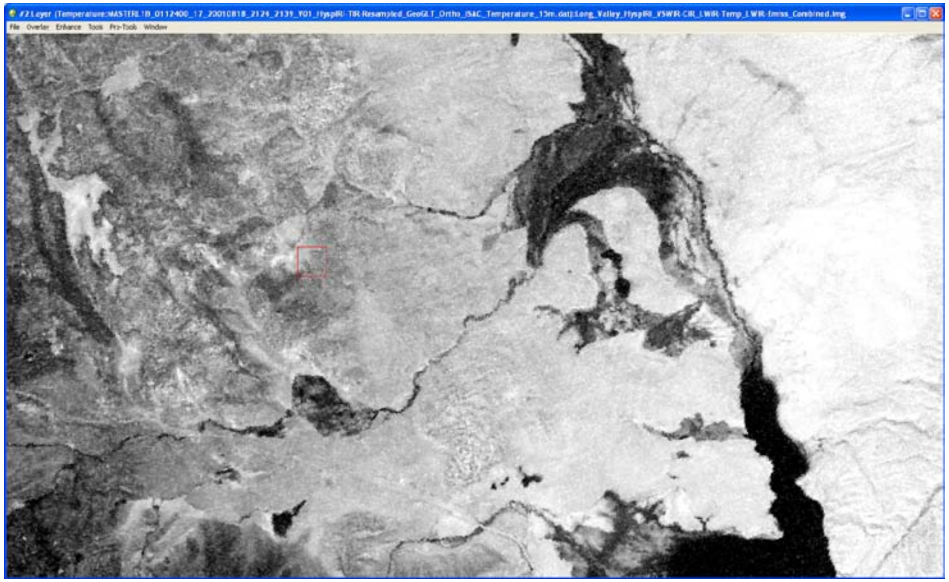
VSWIR Reflectance
+ LWIR Emissivity
= lithology and mineralogy

MASTER LWIR (33m), 08-18-2001 GLT-Corrected, ASTER Ortho, decor stretch

Long Valley, CA Simulation



AVIRIS VNIR (15m) 09-15-2000 (Overlap)



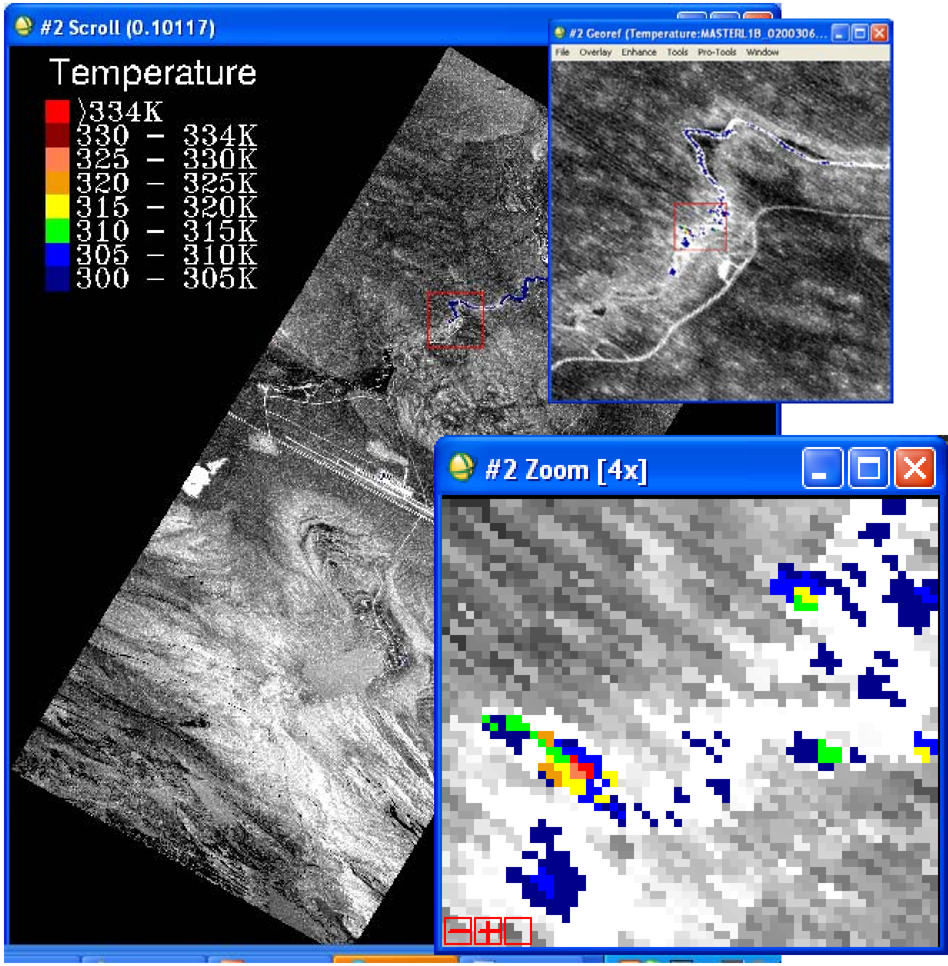
MASTER LWIR (33m), 08-18-2001 Temperature (Overlap)

MASTER LWIR (33m), 08-18-2001 Emissivity 6, 5, 3 (Overlap)

Long Valley MASTER Temperature (night), 16 June 2002

- **3.4m MASTER**
- **Scene Temperature Variability**
- **300 – 305K: 3943 Pixels**
- **305 – 310K: 192 Pixels**
- **310 – 315K: 94 Pixels**
- **315 – 320K: 67 Pixels**
- **320 – 325K: 39 Pixels**
- **325 – 330K: 14 Pixels**
- **330 – 334K: 0 Pixels**
- **>334K: 4 Pixels**

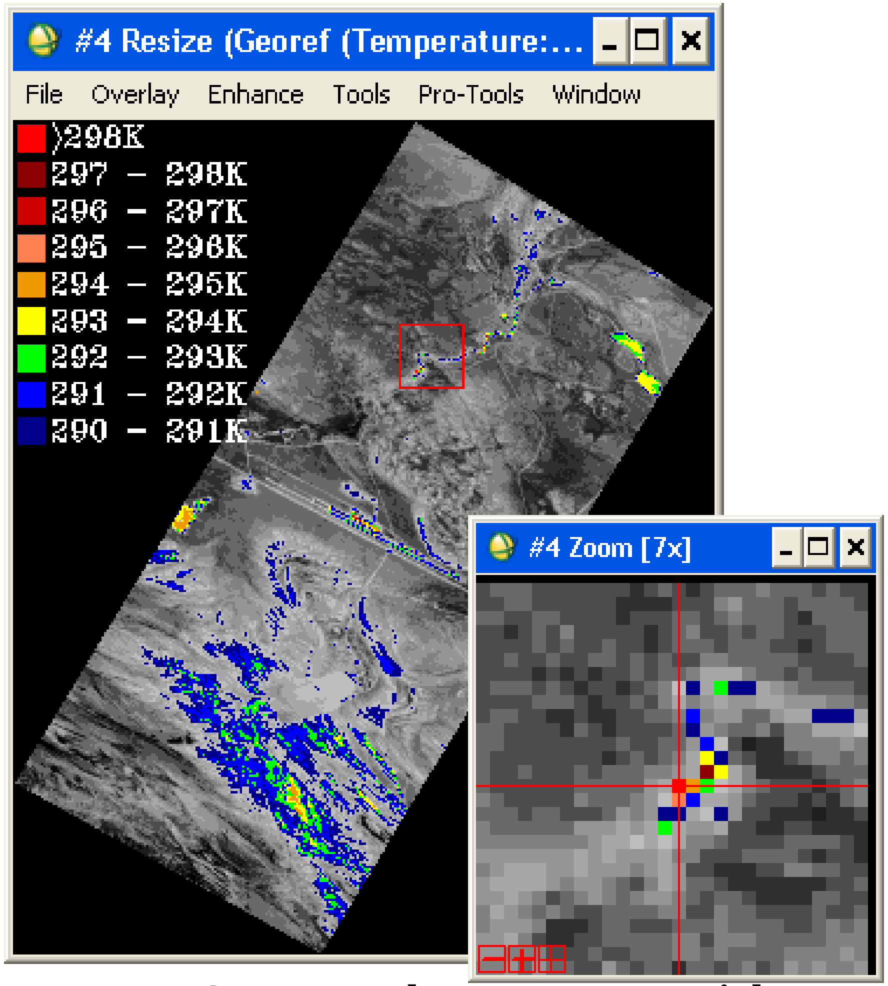
- **Geothermal Outflows**



TES-Extracted Temperature, Night-Time MASTER, (Hot Creek), Long Valley, CA

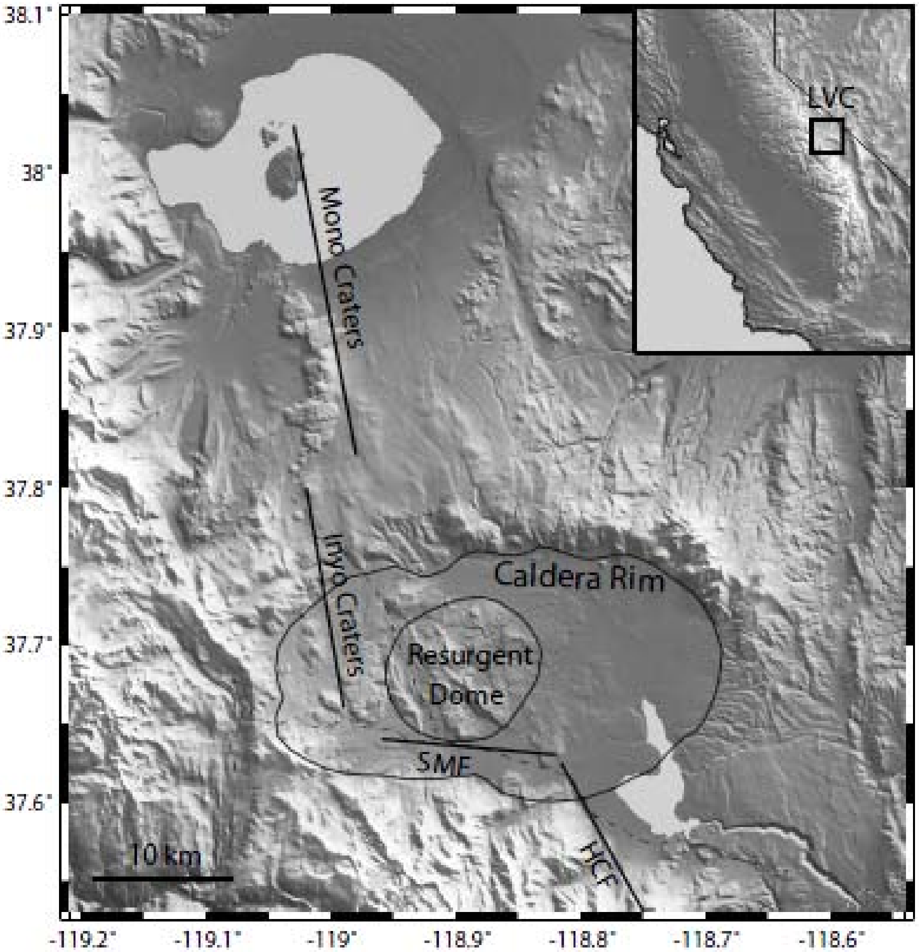
Long Valley 60m HyspIRI TIR Simulation (night), 16 June 2002

- 60m HyspIRI Simulation using MASTER, Temperatures >290K
- Scene Temperature Variability
  - 290 – 291K: 4486 Pixels
  - 291 – 292K: 2438 Pixels
  - 292 – 293K: 950 Pixels
  - 293 – 294K: 323 Pixels
  - 294 – 295K: 87 Pixels
  - 296 – 297K: 12 Pixels
  - 297 – 298K: 8 Pixels
  - >298K: 1 Pixel
- "Hot" Spots
  - Water
  - Residual Solar (Topographic) Effects
  - Albedo effects
  - Geothermal Effects



HyspIRI TES-Extracted Temperature, Night-Time MASTER, (Hot Creek), Long Valley, CA

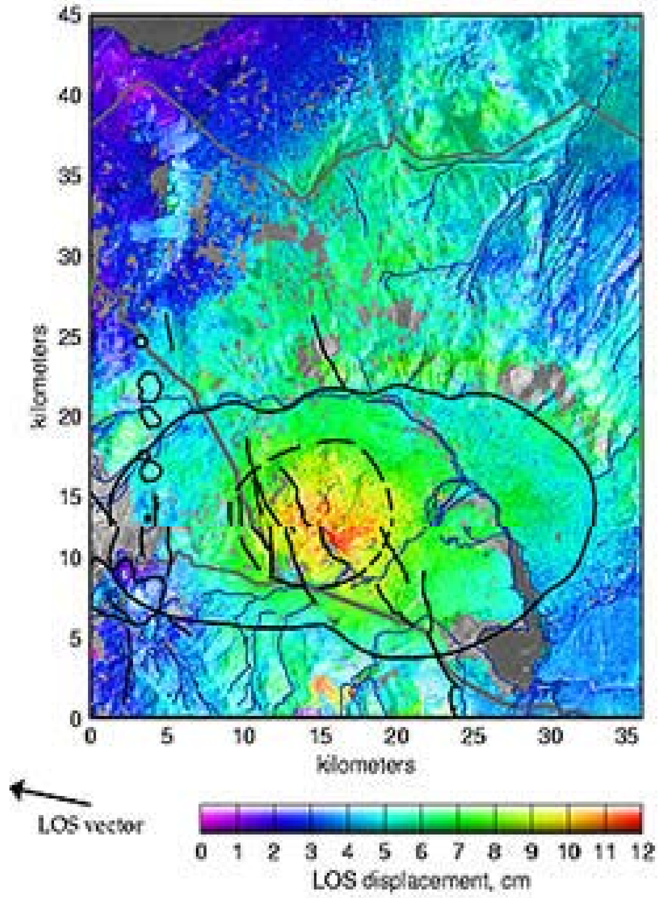
Long Valley, CA Synergy (eg: DESdynI): Structural Elements from InSAR



South Moat Fault (SMF) and Hilton Creek Fault (HCF)

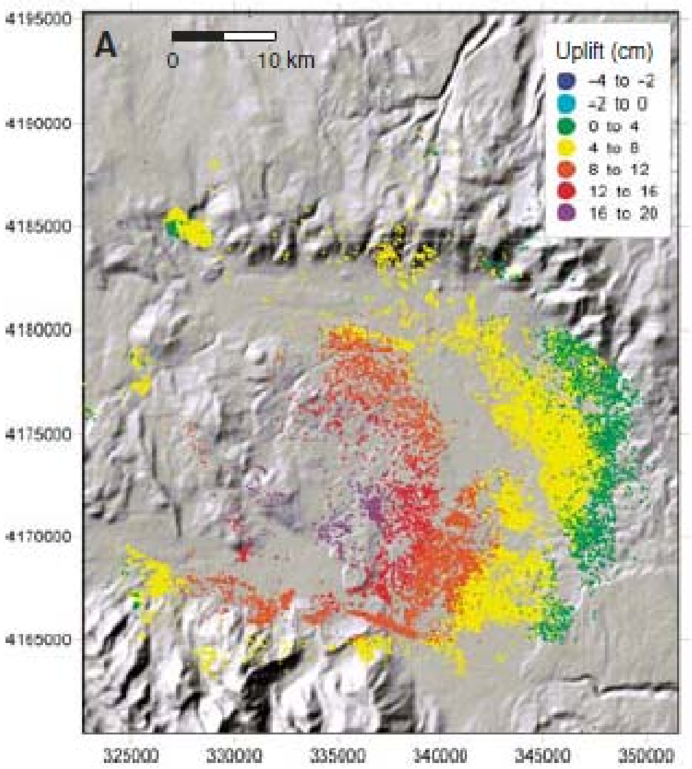
(Newman et. al., 2005)

Inflation and deflation associated with Magma activity under "resurgent dome"

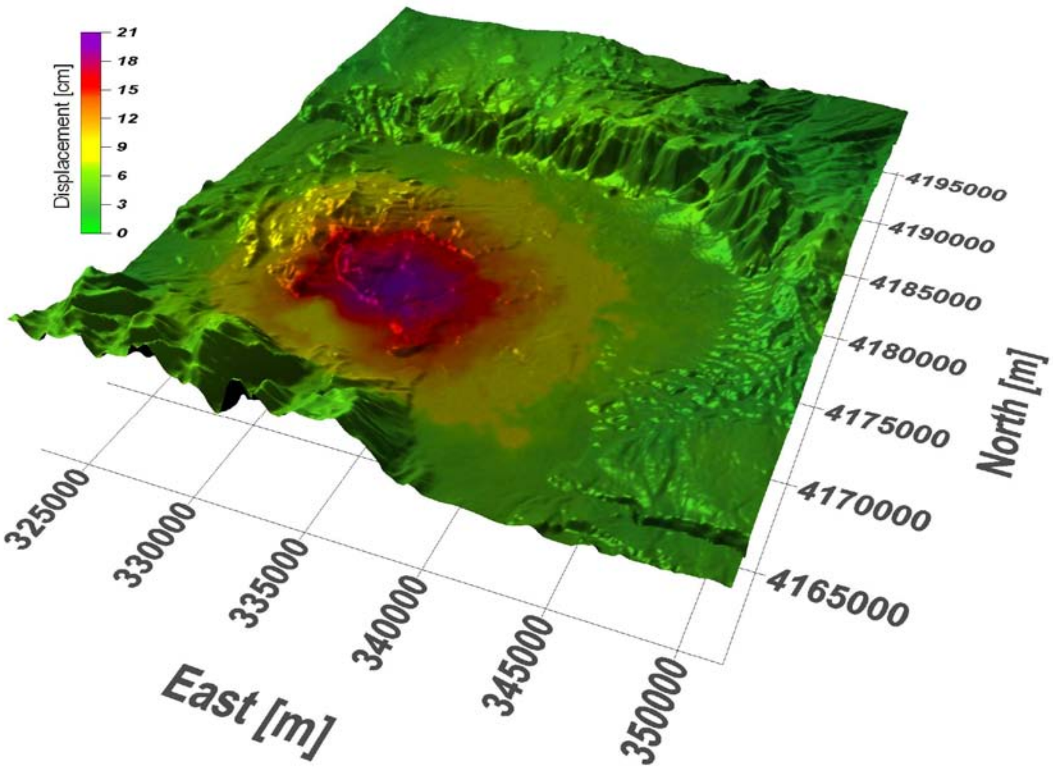


1992 - 1995

Long Valley, CA Synergy (eg: DESdynI):
Structural Elements from InSAR



Inflation and deflation associated with magma activity under “resurgent dome”



1992–1999 ERS Data:
SAR interferometry (InSAR

Tizzani et al., Geology, 2009

http://eopi.esa.int/esa/

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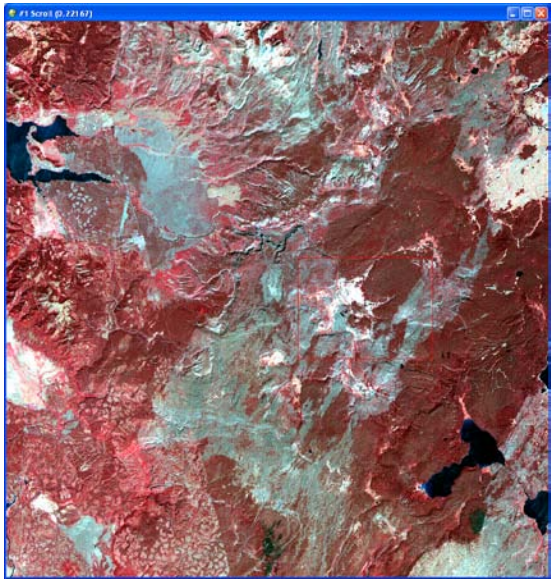
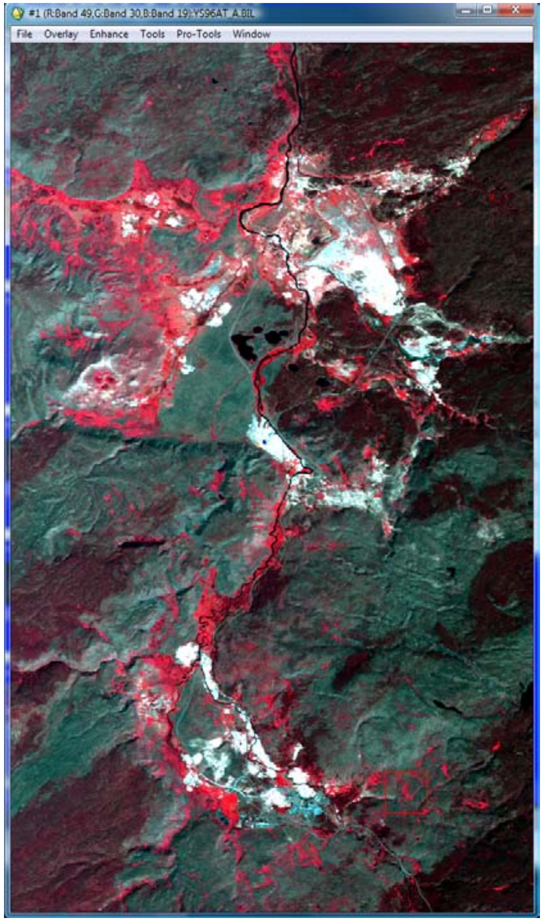
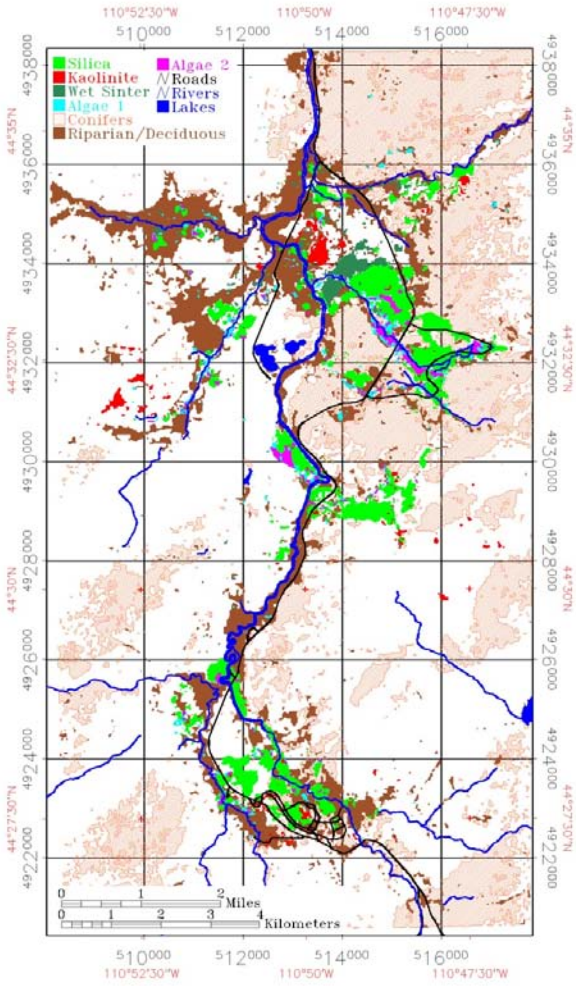
Yellowstone, WY Simulation



ASTER VNIR (15m)
08-06-2004 Ortho



AVIRIS VNIR (15m)
08-06-1996 no geo

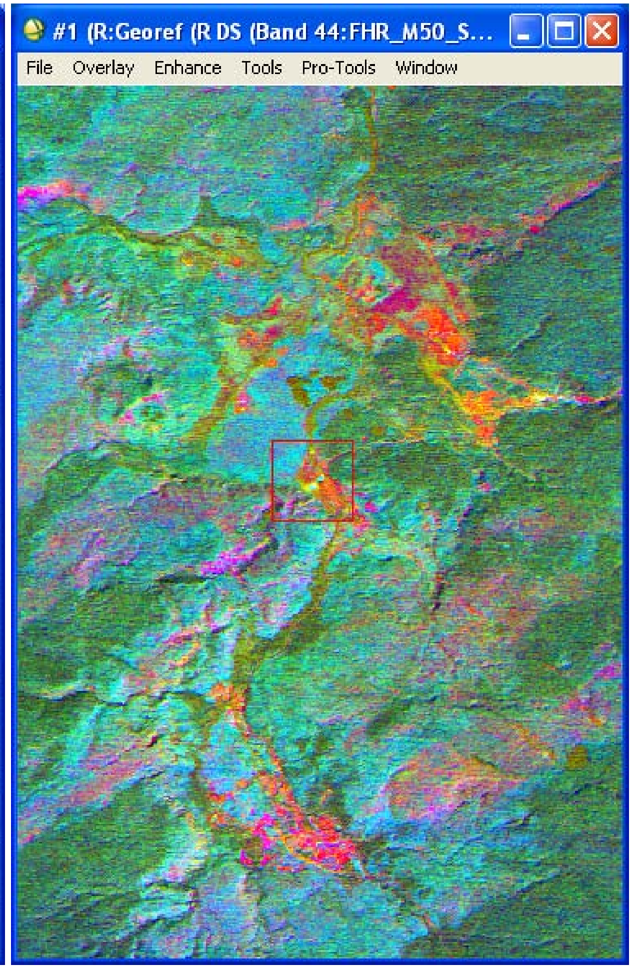


Mineral Mapping Results

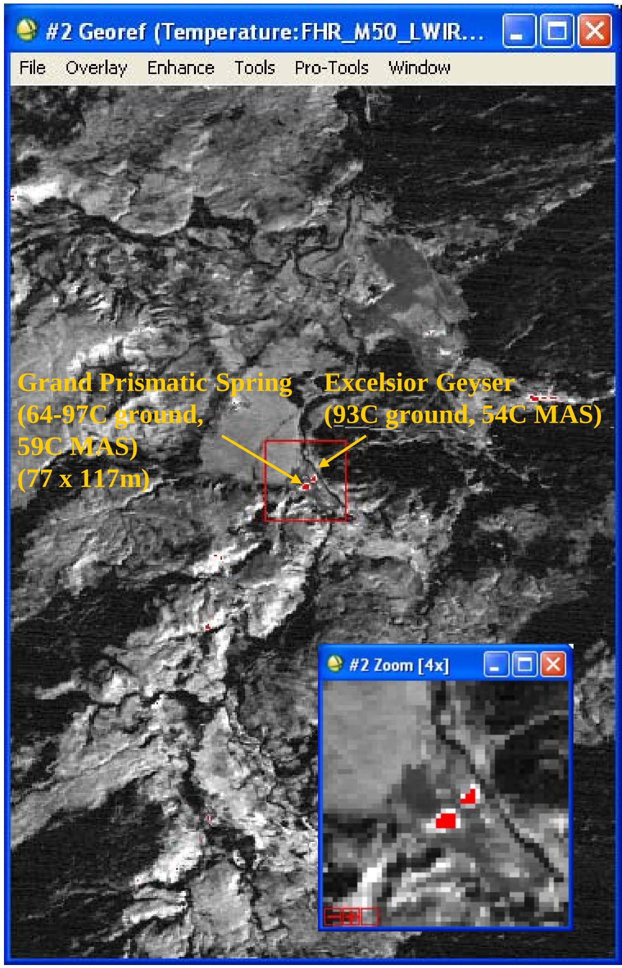
F. A. Kruse ♦ 303-499-9471 ♦ fkruse@unr.edu ♦ http://www/unr.edu/mines/able

MAS data (33m) were acquired of portions of the park in 1996 (Midway Geyser Basin at center)

True Color



Decor 5, 3, 1



Temperature

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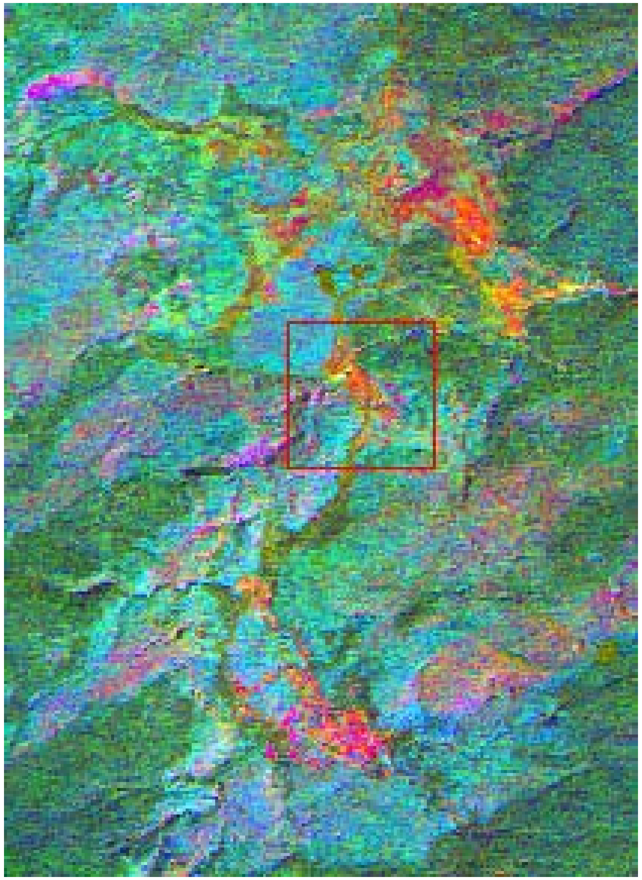
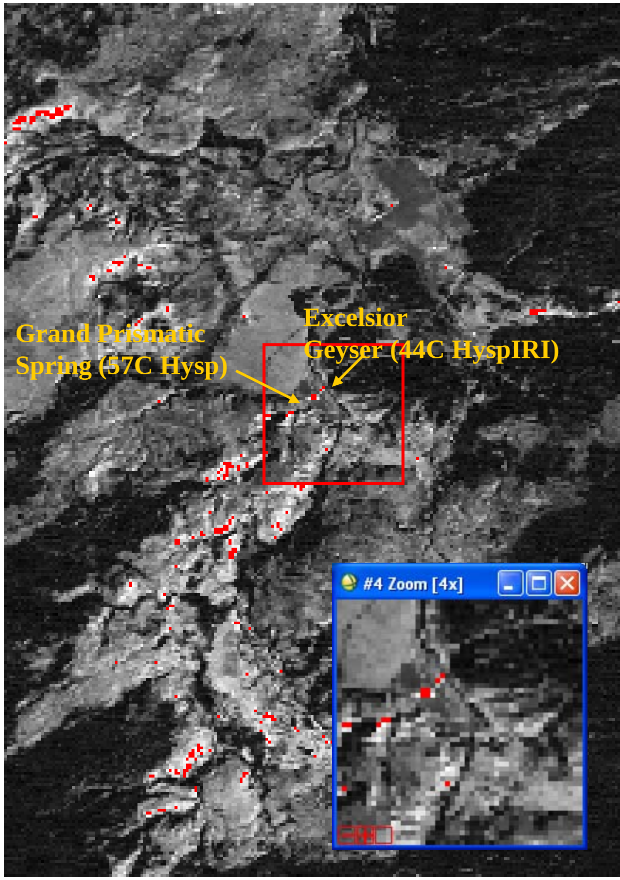
HyspIRI Simulation using MAS data @60m)

True Color

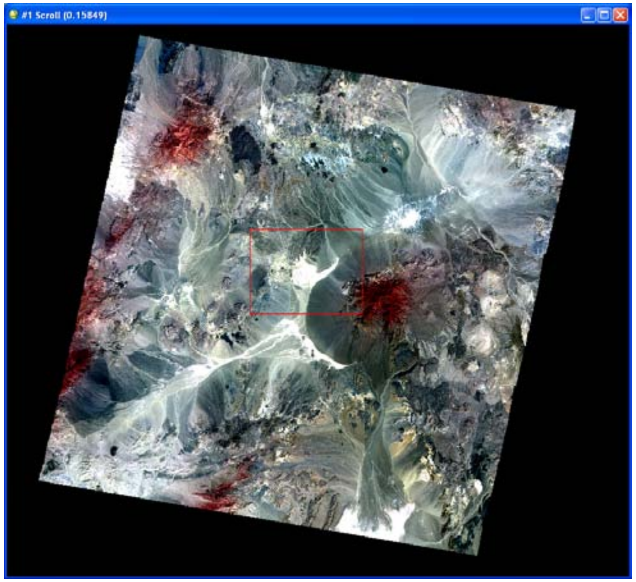


Decor 5, 3, 1

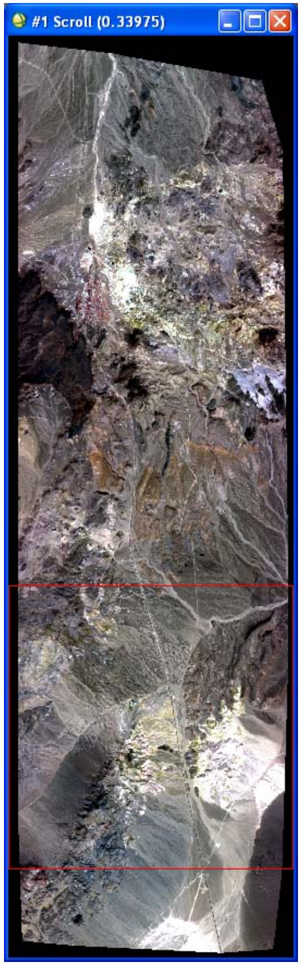


Temperature

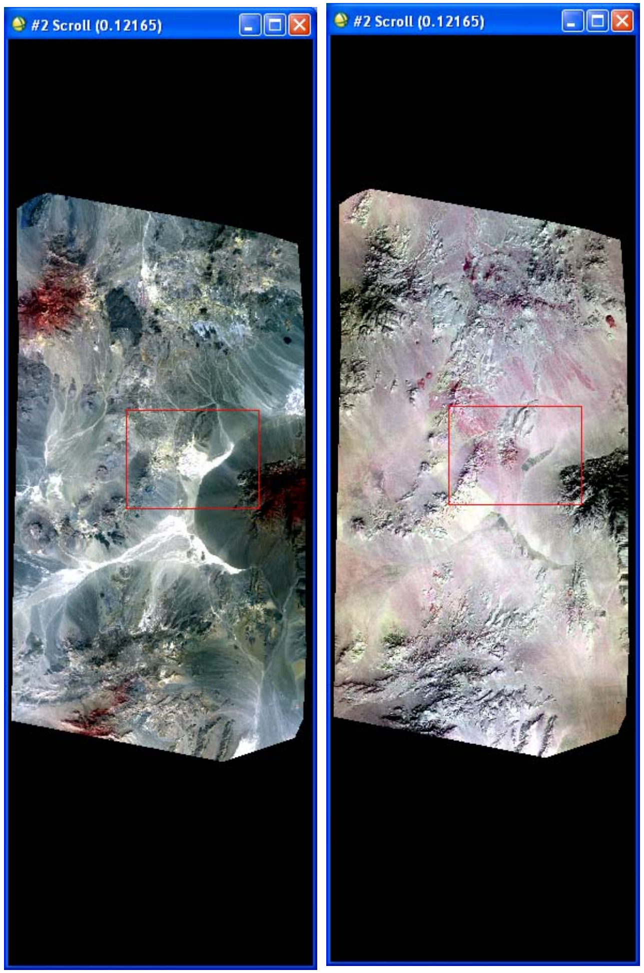
Cuprite, NV Simulation



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

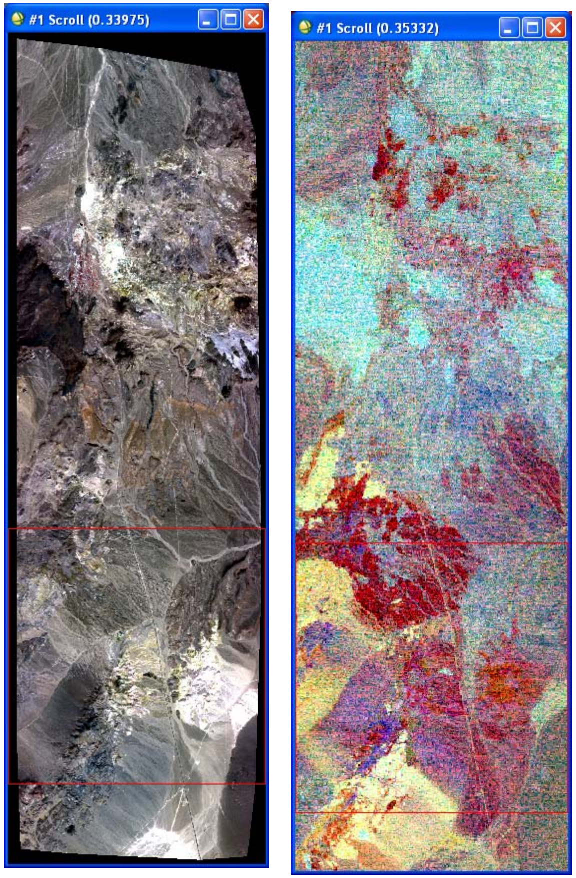


AVIRIS VNIR (15m)
09-20-2006 Ortho
Warped to ASTER Ortho

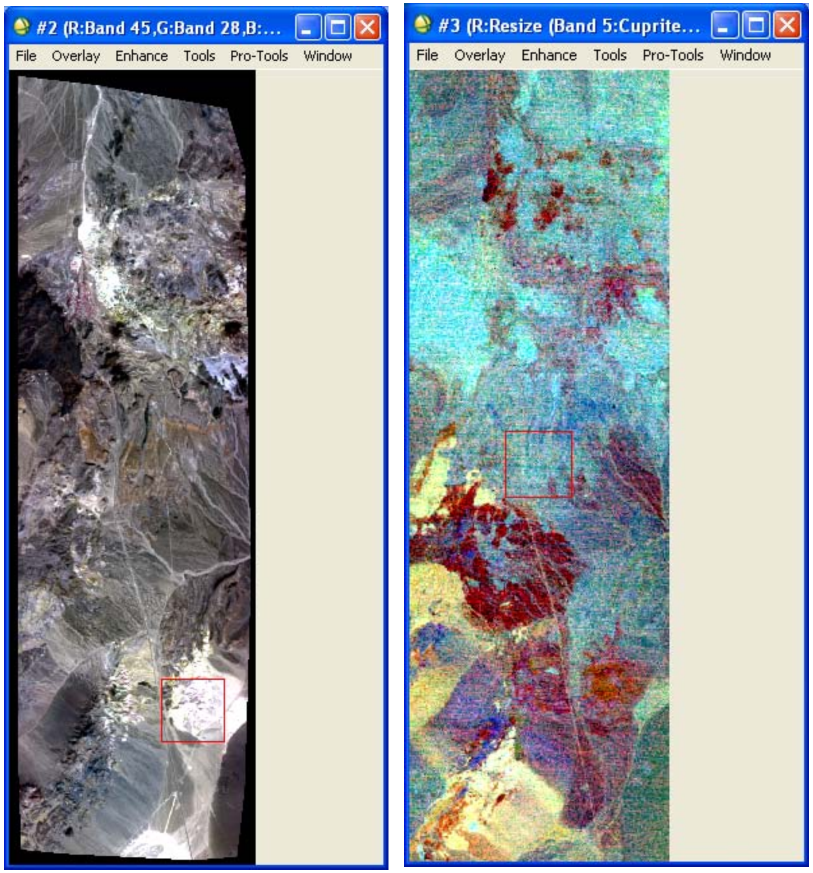


MASTER VNIR and LWIR, 09-20-2006 GLT-Corrected Warped to ASTER Ortho

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 60m spatial resolution; Right Master Emissivity @HyspIRI bands

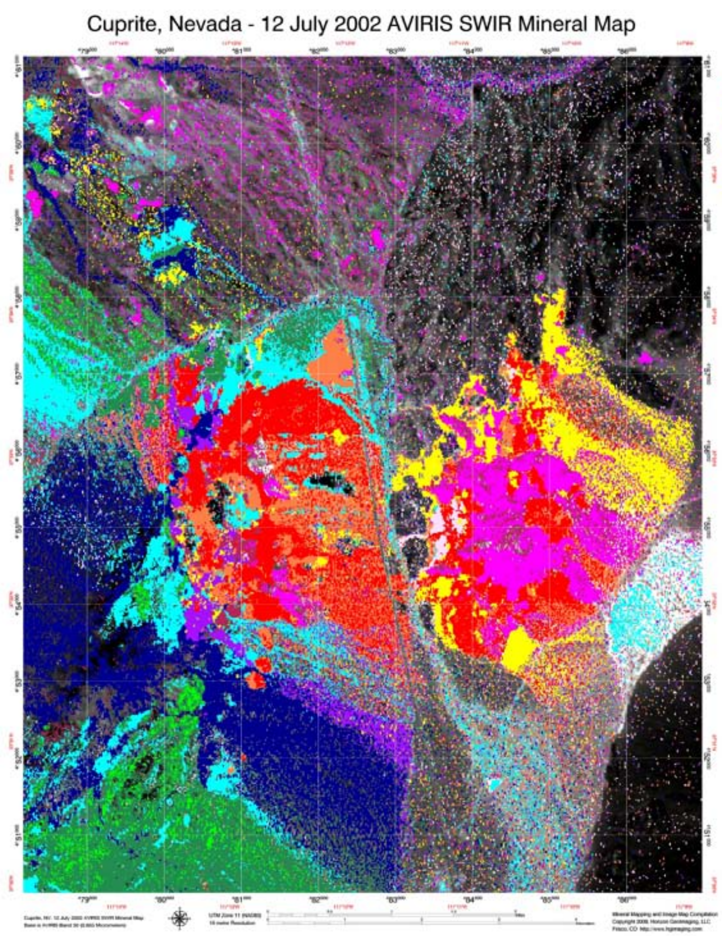


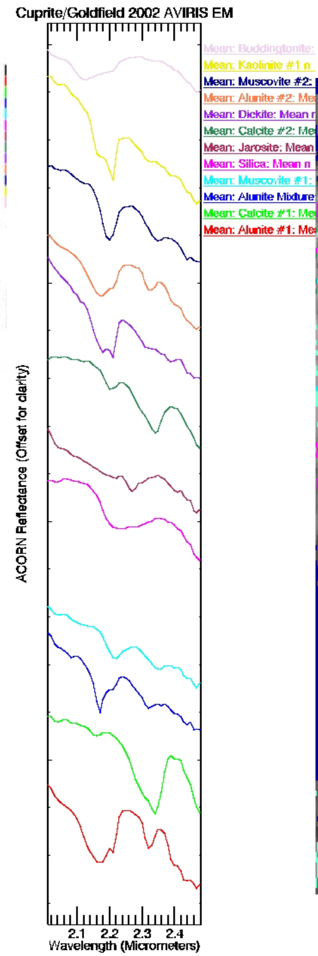
193 x 623 Left: HyspIRI simulated dataset from AVIRIS VNIR (15m) 09-20-2006 Ortho Warped to ASTER Ortho at 60m spatial resolution. Right: MASTER Emissivity @HyspIRI bands and 60m

F. A. Kruse ♦ 303-499-9471 ♦ fkruse@unr.edu ♦ http://www/unr.edu/mines/able

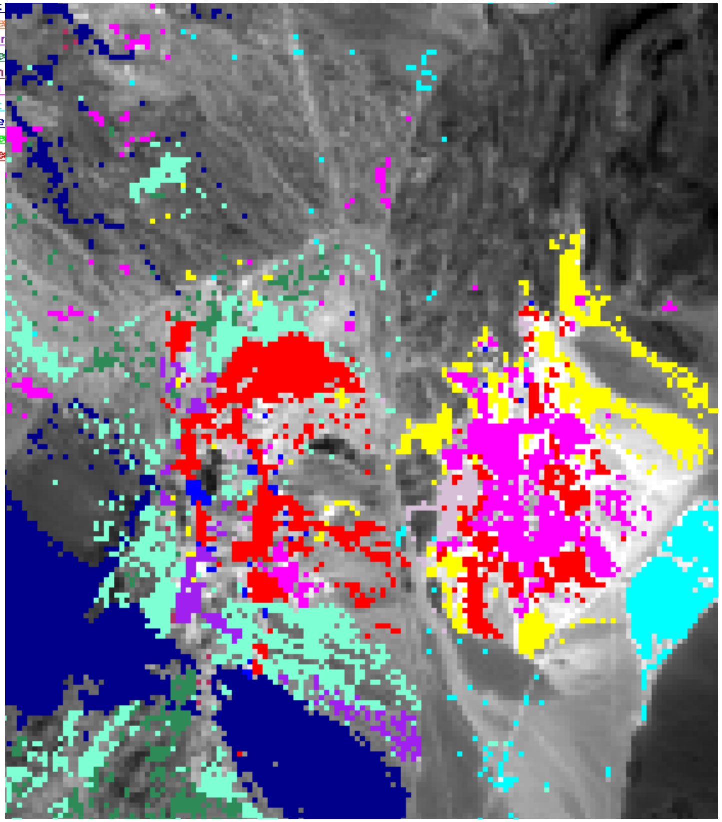
Cuprite, NV 2002 AVIRIS versus HyspIRI-Simulated 60m SWIR MTMF Mineral Map (Kruse, Unpublished)

AVIRIS (16m)

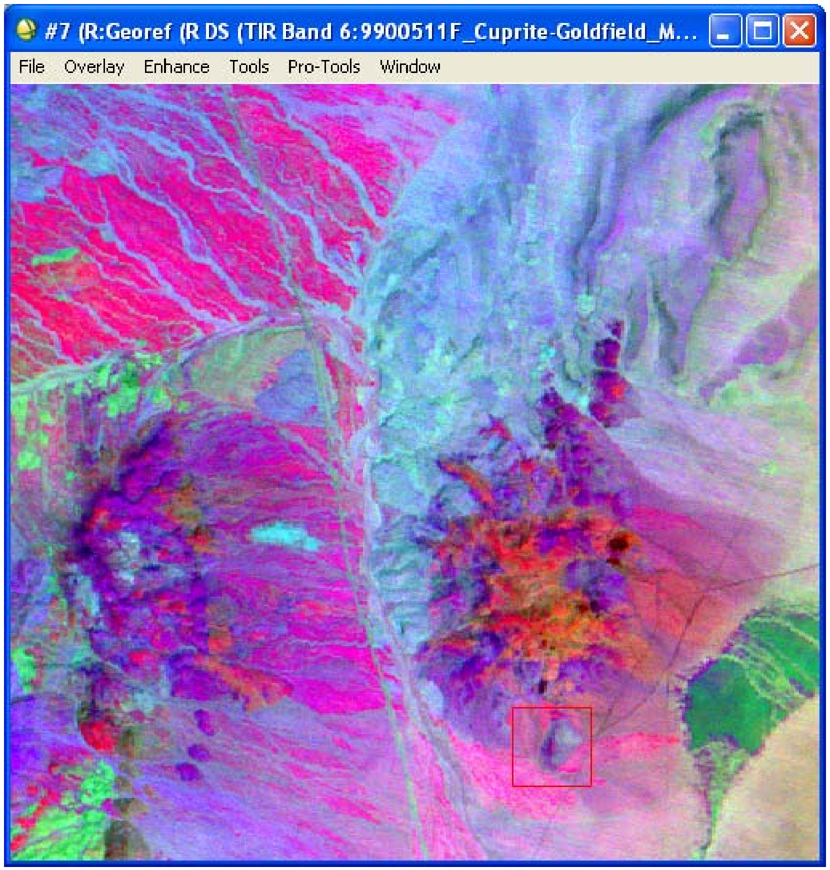


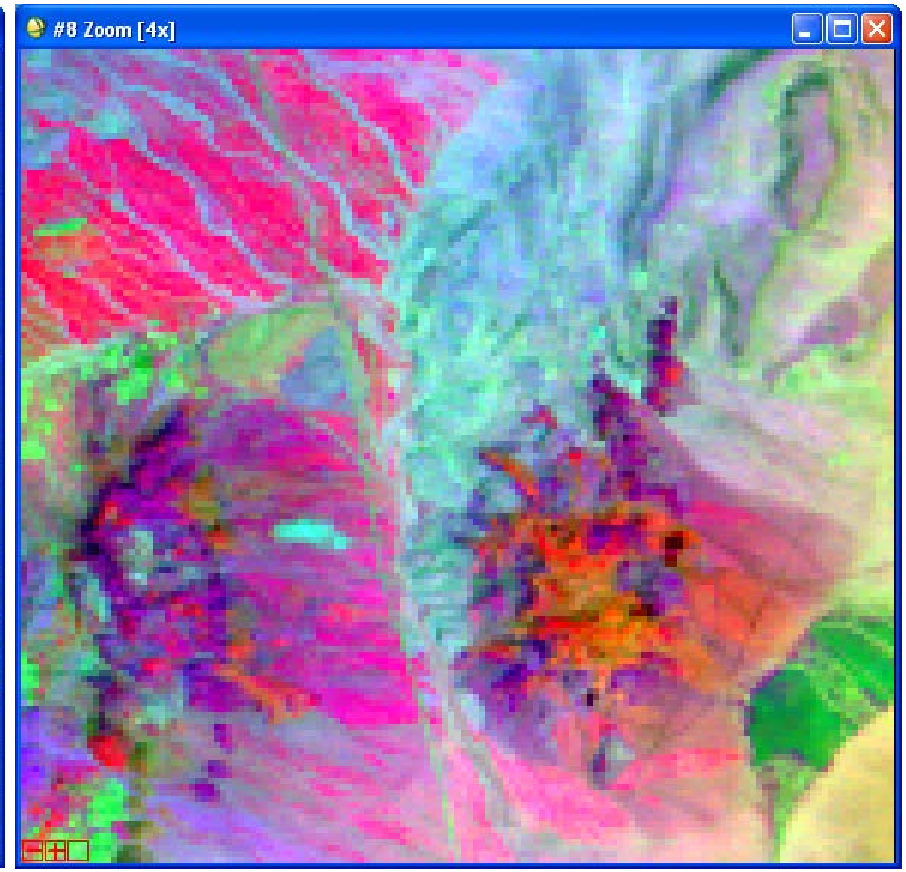


Simulated HyspIRI 60m



Cuprite, NV 1999 MASTER 6, 5, 3 (RGB)
Decorellation Stretch versus HyspIRI-Simulated 60m

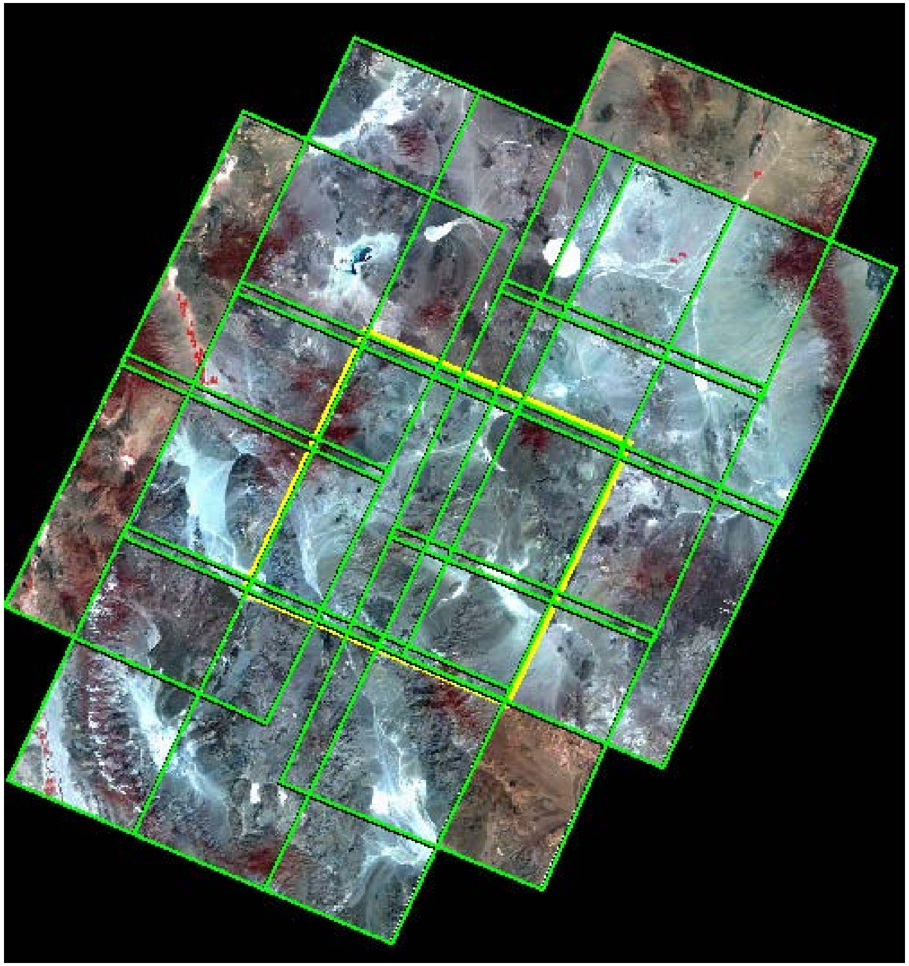


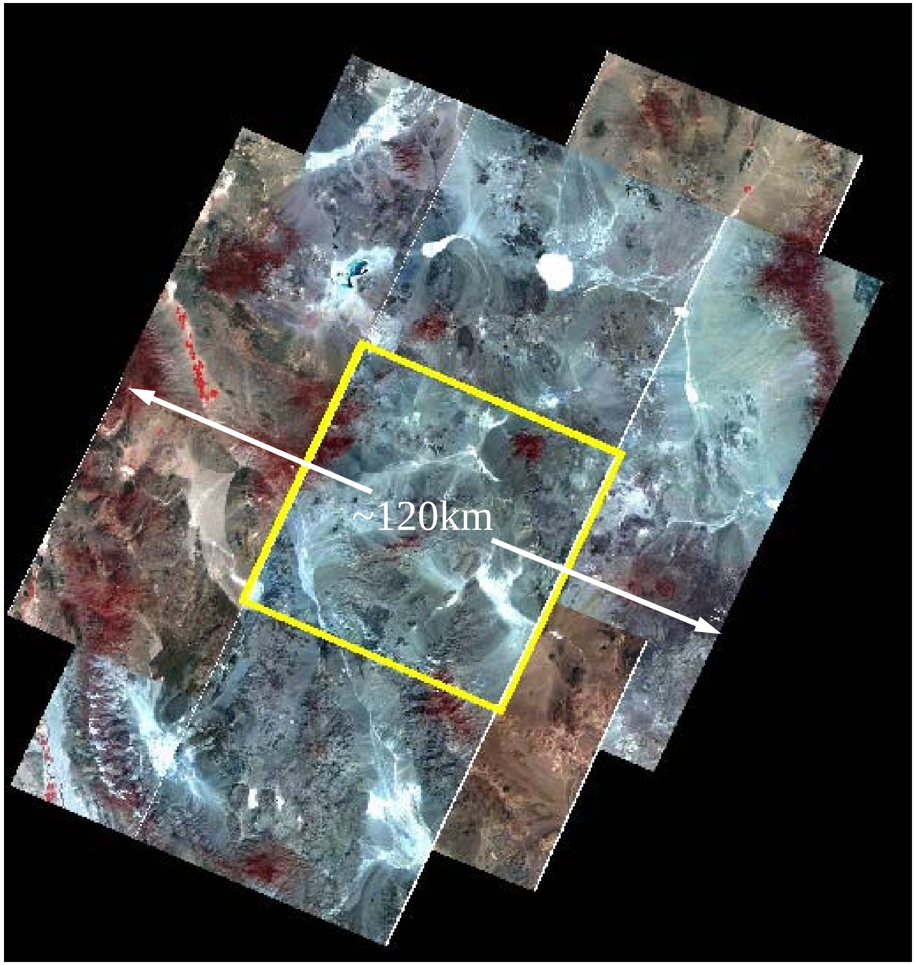


Proposed: Use spectral unmixing and modeling to create spatially extended simulated HSI data

- Geocorrect and co-register nested multispectral (ASTER) and HSI (AVIRIS) datasets (Cuprite, NV example – 2 scenes to start, 13 scenes total to get to ~HyspIRI VSWIR spatial scene
- Correct both datasets to reflectance
- Resample AVIRIS data to HyspIRI spectral response
- Extract HSI "endmember" signatures and model to ASTER wavelength centers and response
- Unmix ASTER modeled endmembers using ASTER reflectance data
- Use ASTER mixture fraction images and HSI endmember spectra to model full-resolution HSI signature for each ASTER pixel based on mixture analysis
  - Result is simulated HSI dataset with ASTER spatial coverage
  - Signature at each pixel has full HSI spectral resolution
  - Validate with other nested HSI datasets
  - Model to 60m HyspIRI spatial resolution

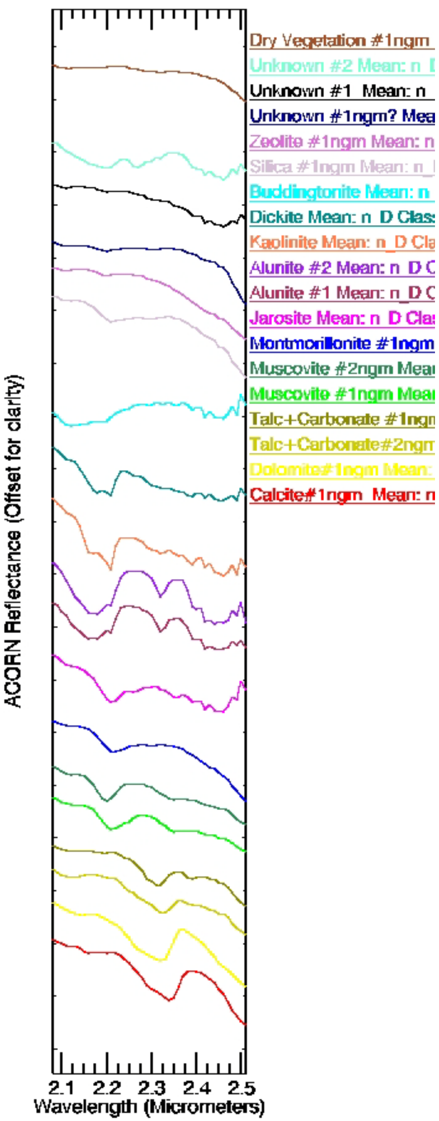
Extended HyspIRI Simulation Using Nested Datasets, Spectral Unmixing, and Spectral Modeling

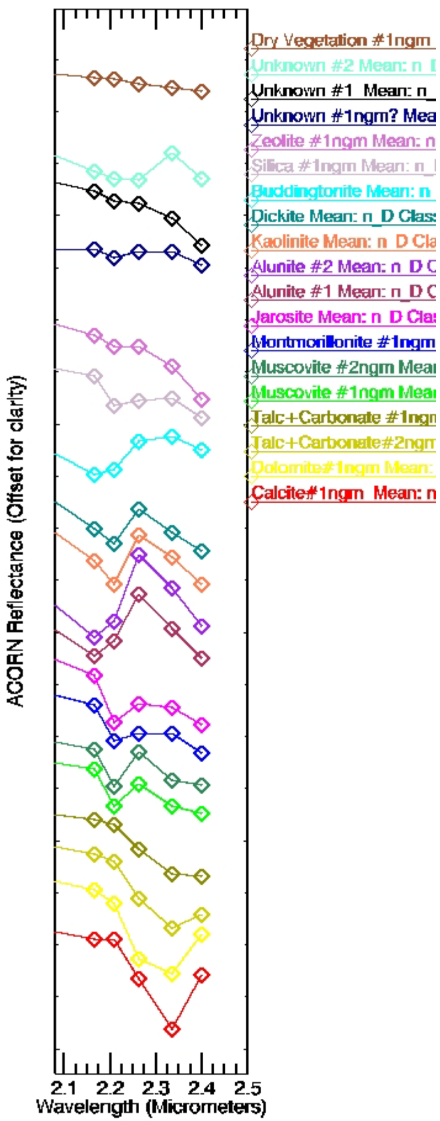


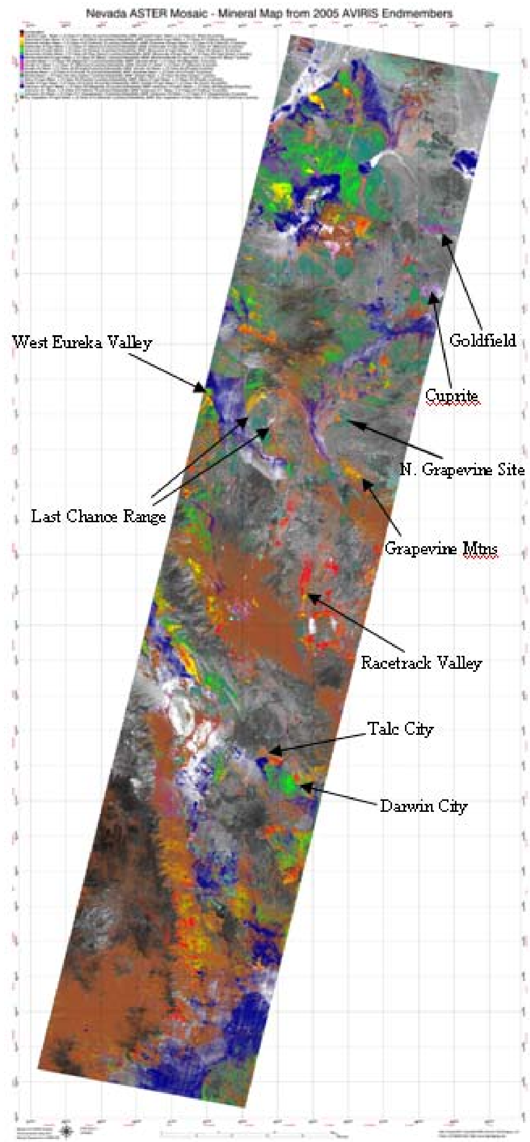


F. A. Kruse ♦ 303-499-9471 ♦ fkruse@unr.edu ♦ http://www/unr.edu/mines/able

Extended ASTER Mineral Mapping (Combined AVIRIS Endmembers)



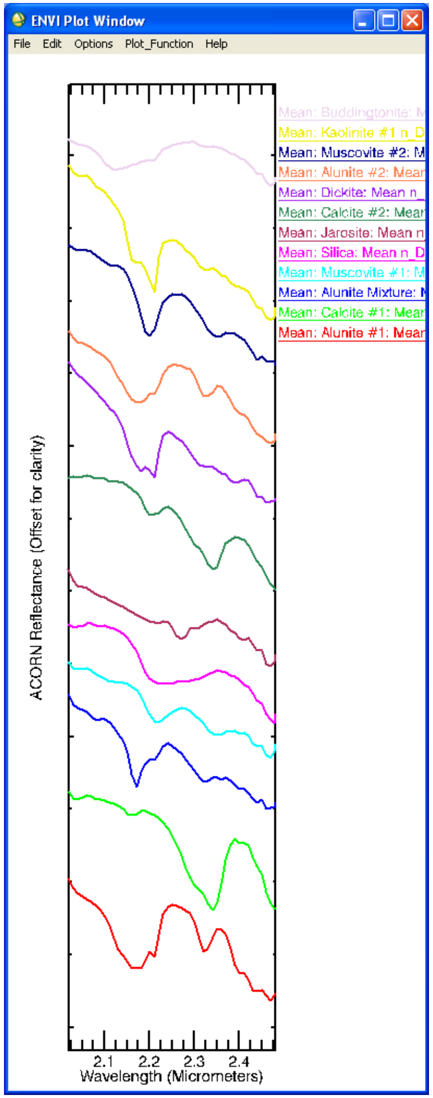


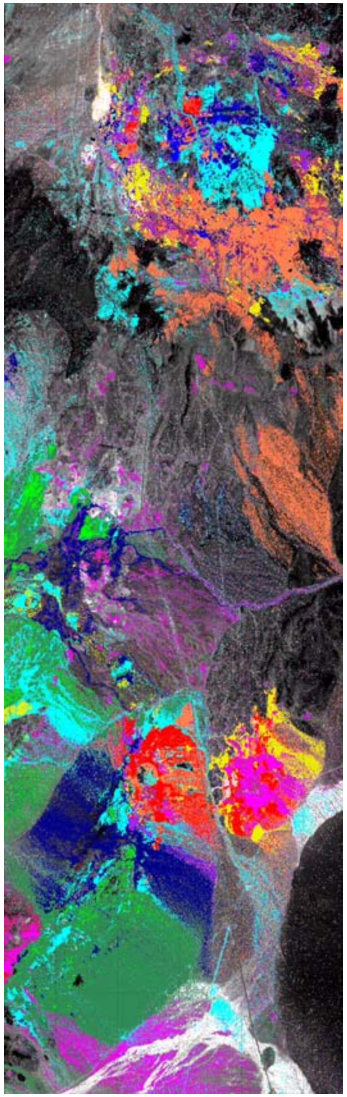


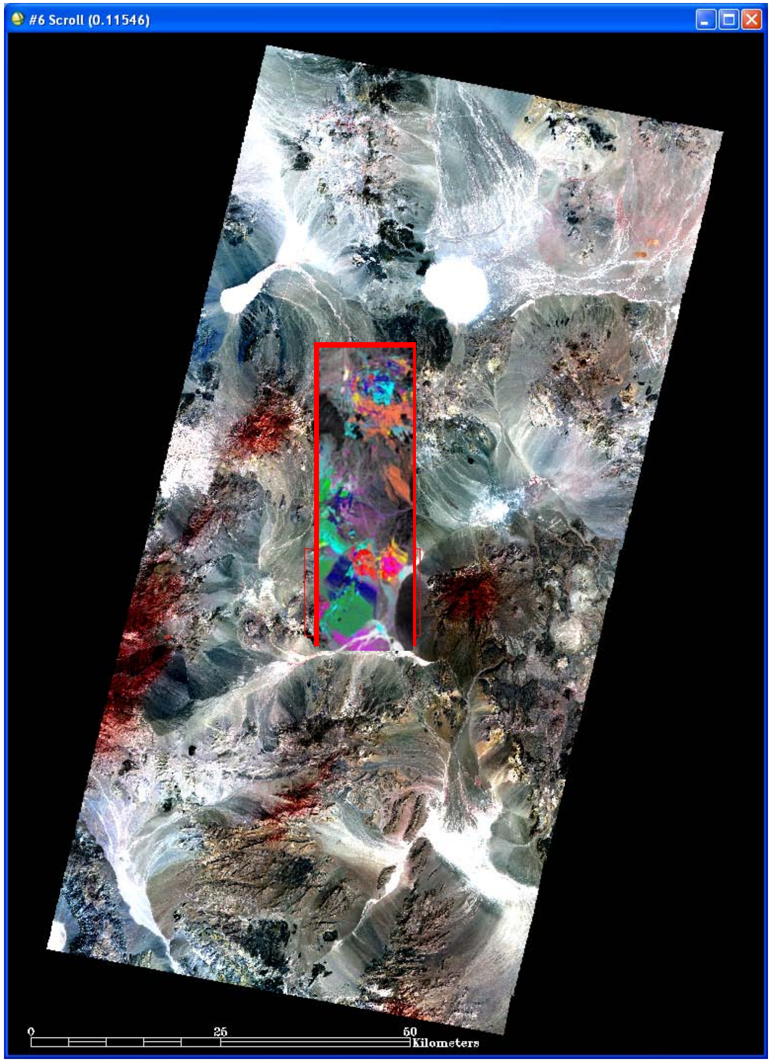
From Kruse and Perry, 2009

- •(1) **N. Grapevine Mtns, NV: Calcite vs Dolomite vs muscovite**
- •(2) **Goldfield, NV: Alunite vs kaolinite vs muscovite/illite**
- •(3) **Cuprite, NV: kaolinite vs alunite vs muscovite**
- •(4) **Grapevine Mtns, NV: Calcite vs Dolomite, muscovite**
- •(5) **Talc City, CA: Calcite vs dolomite vs Talc vs 2 varieties of muscovite**
- •(6) **Darwin City, CA: Calcite vs dolomite vs muscovite**
- •(7) **Racetrack Valley, CA: Calcite vs Dolomite vs altered (sericite-rich) granite**
- •(8) **Last Chance Range, CA: Calcite vs Dolomite**
- •9) **West Eureka Valley, CA: Two varieties of muscovite**

AVIRIS Endmembers and Mineral Mapping

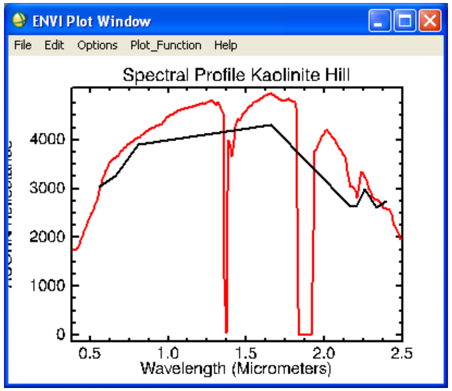


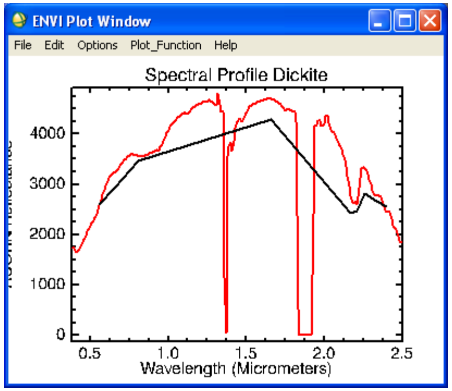


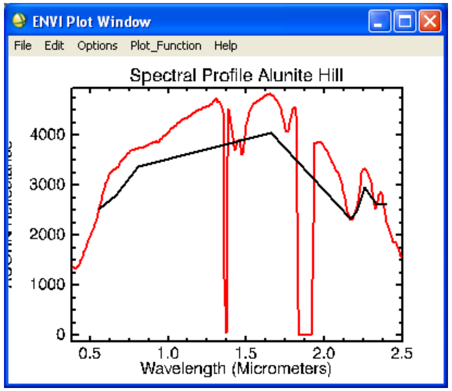


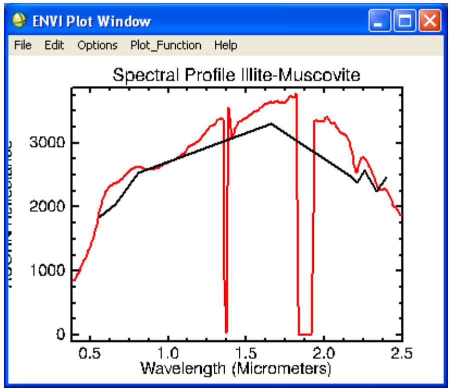
ASTER (2 scene test case)

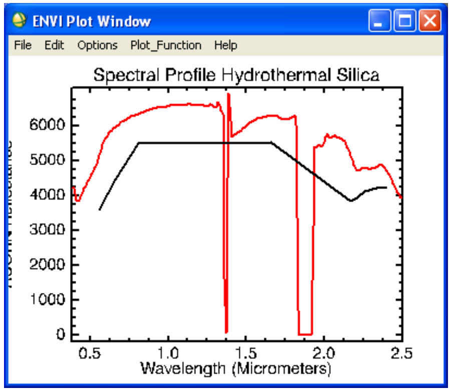
ASTER vs AVIRIS Reflectance

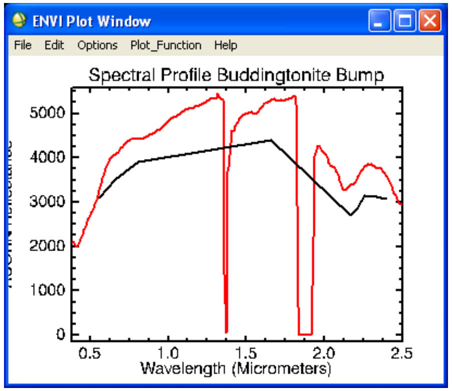


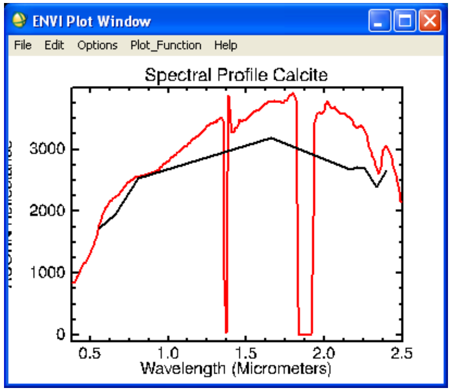




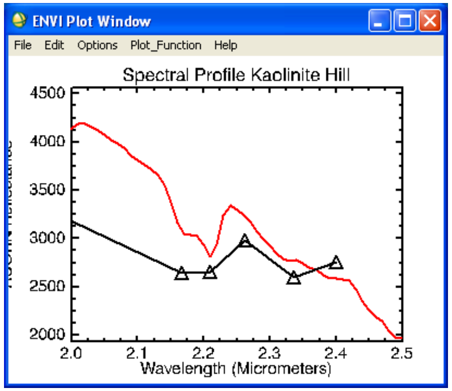


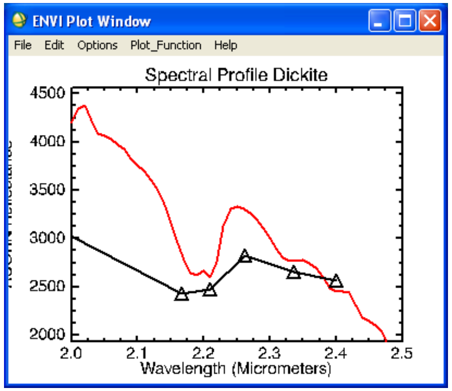


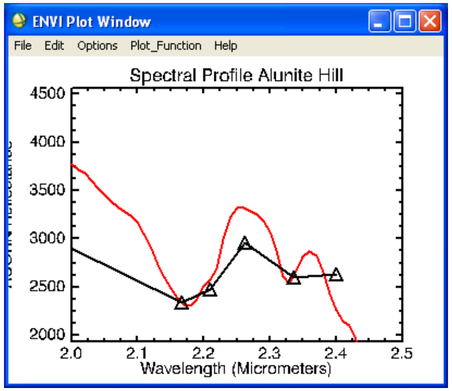


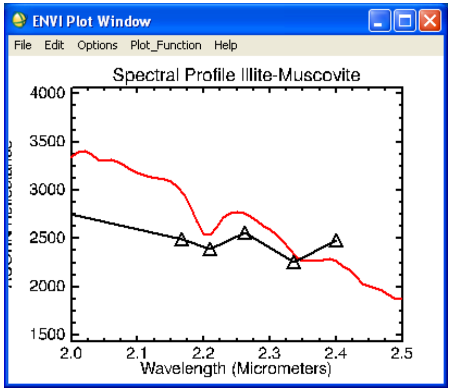


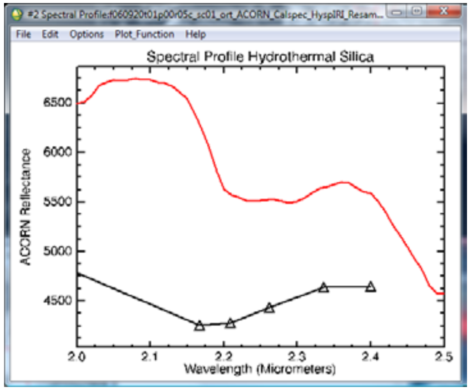
ASTER vs AVIRIS Reflectance

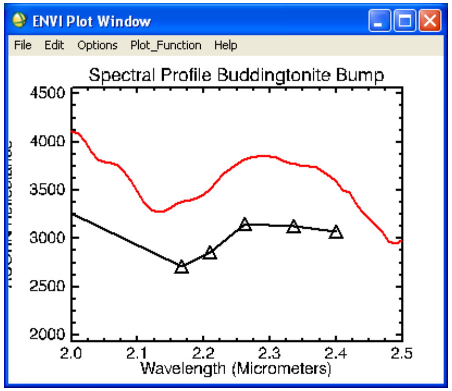


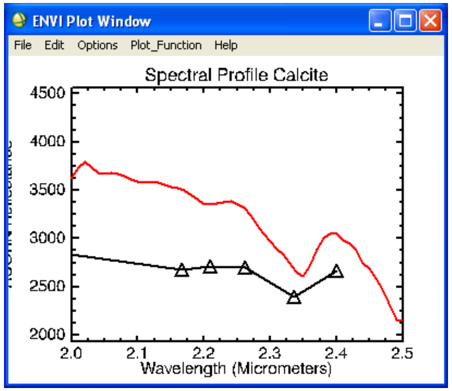












ASTER, HSI Modeling Next Steps

- Unmix ASTER modeled endmembers using ASTER reflectance data
- Use ASTER mixture fraction images and HSI endmember spectra to model full-resolution HSI signature for each ASTER pixel based on mixture analysis
  - Result is simulated HSI dataset with ASTER spatial coverage
  - Signature at each pixel has full HSI spectral resolution
  - Validate with other nested HSI datasets and field spectra (Goldfield, N. Grapevine Mtns)
  - Model to 60m HyspIRI spatial resolution

HyspIRI Simulation Status

- All datasets in-hand
- ASTER orthorectifiction completed for all sites
- VSWIR and TIR registration to ASTER completed for all but Yellowstone and some day-night datasets
- HyspIRI spectral response modeling and spatial resolution modeling in progress
- SNR modeling pending
- Selected SWIR and LWIR spectral analysis performed
- Combined analysis pending
- Day/Night temperature analysis pending

Last Words

- What does HyspIRI give us for "classical" geology that we can't get by other means?
  - Global remote sensing coverage at scale that will allow development of an "inventory" – a geographic database of hydrothermal systems
  - Worldwide simultaneous VSWIR hyperspectral and TIR multispectral at 60m spatial resolution
  - Large-scale multi-band LWIR Temperature determination at 60m spatial resolution
  - Temporal monitoring (of active geothermal systems and other dynamic geologic systems) on a timescale of days
  - Possibility of global synergism with NRC decadal survey instruments and others