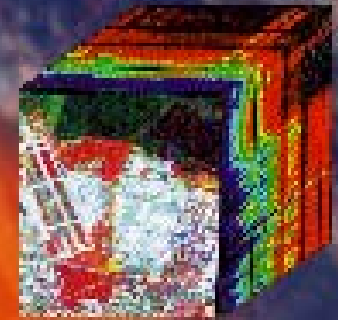


**Validating Hyperion in  
Yellowstone National Park  
Using AVIRIS, HyMap and  
Field Spectra**



**Joseph Boardman, AIG**  
**Don Despain, USGS BRD**

## **Presentation Outline**

- **YNP Study Site**
- **Previous Work and Validation Data**
- **Research Objectives and Topics**
- **Hyperion Data and Results**
  - **Hyperion data summary and overview**
  - **example ecological results**
- **Preprocessing Research Topics**
  - **orthorectification**
  - **destriping**
- **Conclusions and Summary**

# Yellowstone Hyperspectral Study Site

- NE corner of YNP
- Soda Butte Creek
- Cache Creek
- Lamar River

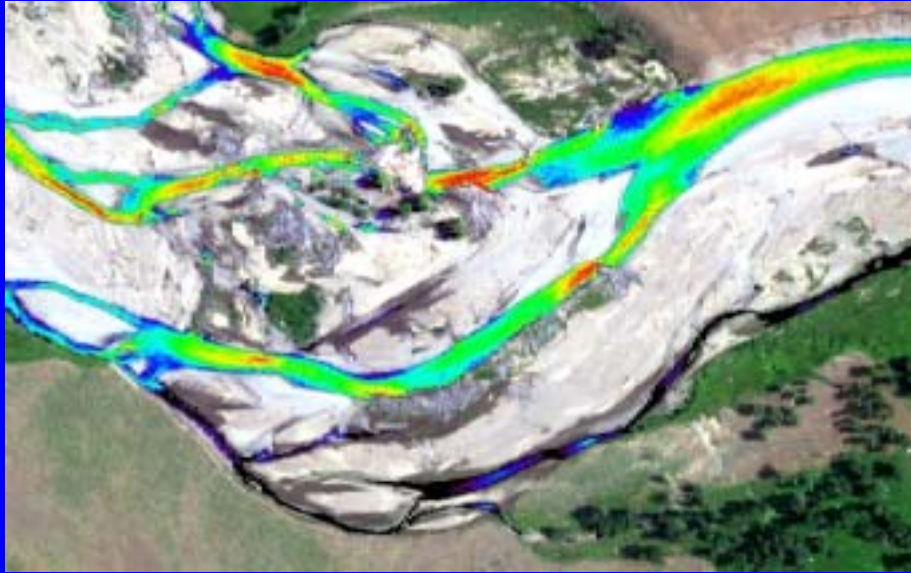


1996 AVIRIS data  
17 m resolution

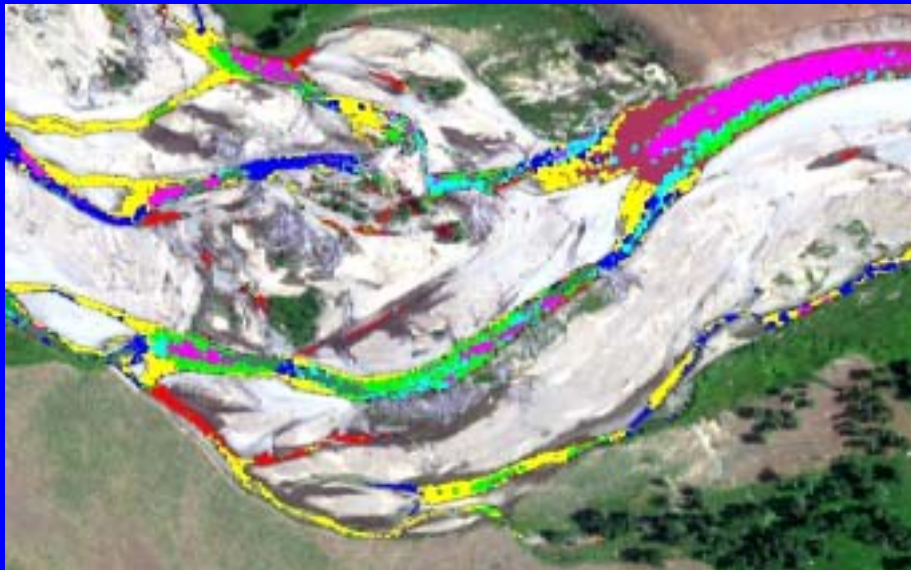
## **Leverages Yellowstone Hyperspectral EOCAP**

- **Collaborative project funded by NASA Stennis, explored potential of hyperspectral studies in the areas of riparian and in-stream ecology, project wrapped up in January 2001**
  - **YES - private non-profit science center with a focus on Yellowstone ecology (now YERC)**
  - **AIG - commercial company with hyperspectral expertise**
  - **MSU - Soda Butte fluvial geomorph and GIS/RS inputs**
  - **ISU - riparian ecology of Cache Creek drainage**
  - **USGS/BRD - Yellowstone vegetation mapping experience**

## In-Stream Mapping - Close Up



- Mapping both depth and stream flow morphology appears feasible using hyperspectral data

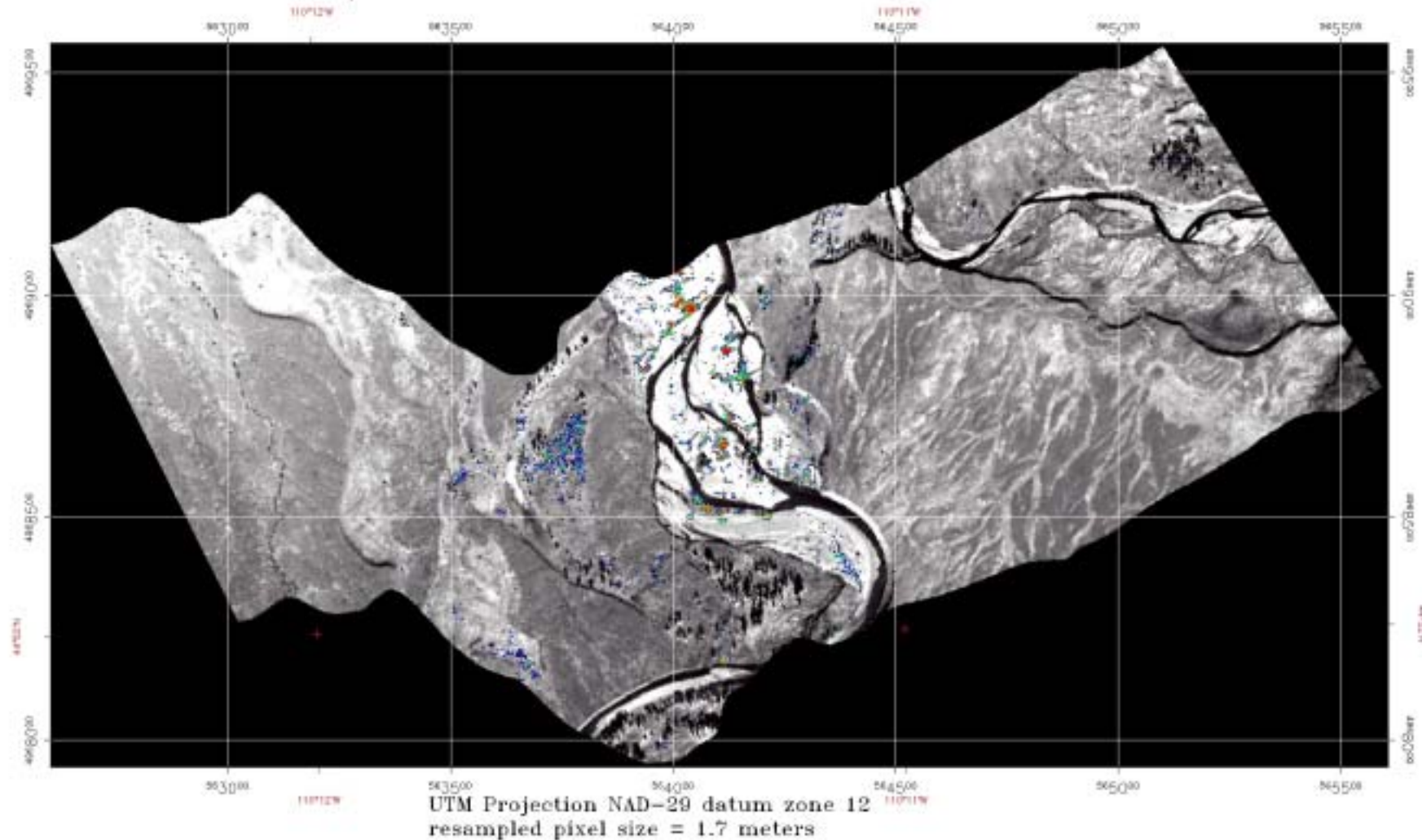


- Fine-scale HSI data prove their worth

# Low-Altitude AVIRIS LWD Mapping

Woody Debris Mapping Via AVIRIS Data

Lamar River / Soda Butte Creek Confluence October 20, 1998



# Example HyMap Imagery



## **EOCAP vs Hyperion Validation**

- **EOCAP** tasked with exploring the operational use of hyperspectral data for riparian and in-stream ecology studies including:
  - large woody debris mapping (log jams in & near streams)
  - stream flow morphology units (riffles, glides, pools, eddy drop zones, etc.)
  - stream depth, sediment loads, algae content, substrate
  - riparian vegetation community mapping (sedge, willows, aspen, cottonwood, etc.)
- **Hyperion validation can't address these small-scale issues directly, instead it leverages the accumulated airborne and field data to examine larger scale problems more suited to Hyperion's scaling**

## **Hyperion Validation Research Objectives**

- **Ecological Validation - Can Hyperion data be used to create meaningful and unique products with ecological value in YNP? **YES****
- **Algorithm Development – Can we use Hyperion data to explore and develop the suite of new algorithms that will be required for space-based, area-array imaging spectrometry? **YES****
- **Hyperion characterization – Can we use the Hyperion data in YNP, in conjunction with the supporting field and AVIRIS data to characterize Hyperion's on-orbit performance? **YES****

## Hyperion Validation Research Topics

- Demonstrate ecological products derived from Hyperion data (**forest mapping successes**)
- Explore multi-temporal leverage using spectral trajectories to exploit repeat Hyperion coverages and vegetation phenology (**orthorectification successes, cloud cover challenges**)
- Investigate improved methods for characterization and removal of Calibration and Reduction Accuracy Problems (C.R.A.P = vertical stripes) (**algorithmic success but application challenges**)

# Hyperion Validation Research Topics (cont'd)

- Use AVIRIS, HyMap and ground spectra as references to measure Hyperion performance (**fits in about ~1991 AVIRIS class data, right on spec**)
- Investigate problems inherent in making multi-swath large-area coverages (**cloud cover issues prevented significant progress**)
- Use our results to examine the spatial/spectral/radiometric design trade space for future space systems (**SNR, Uniformity, Stability and Calibration...plus more swath width please**)

# Hyperspectral and Field Data Sets

- **Hyperspectral data sets**
  - AVIRIS archival high-altitude, 8/96 and 7/97, 17m
  - AVIRIS experimental low-altitude, 10/98 and 7/99, 1.7m
  - HyMap low-altitude data, 10/00, 3.2 m
  - Valiant series of Hyperion collections in 2001:
    - Cache Creek 6/16 (lots of clouds)
    - Soda Butte Creek 7/2 (a few cumulus clouds)
    - Soda Butte Creek 8/3 (lots of clouds, no level 1 data)
    - Soda Butte Creek 9/4 (moderate cumulus)
    - Soda Butte Creek 10/6 (thin/thick cirrus)
- **Field data**
  - surveyed ground sites with detailed veg plot mapping
  - ASD and GER field spectrometry of veg and stream units
  - Accumulated USGS/BRD mapping results

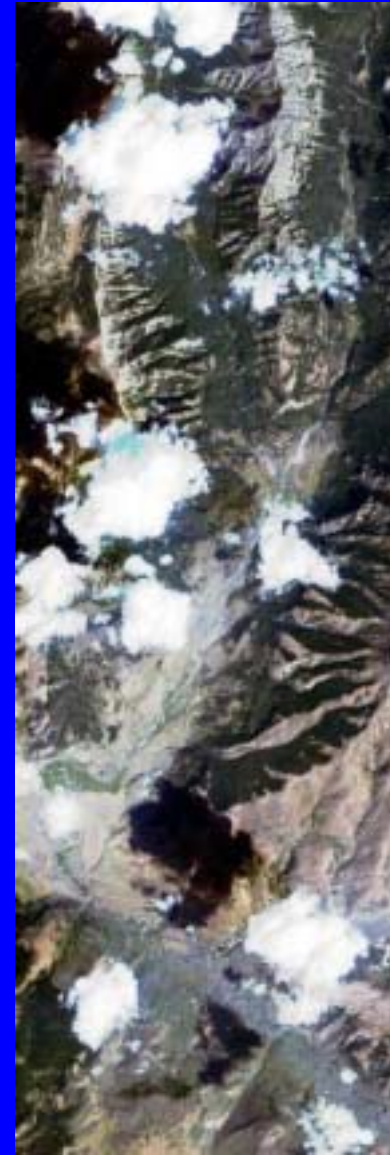
# Hyperion Image Subsets



CC 6/6/01



SBC 7/2/01



SBC 9/4/01

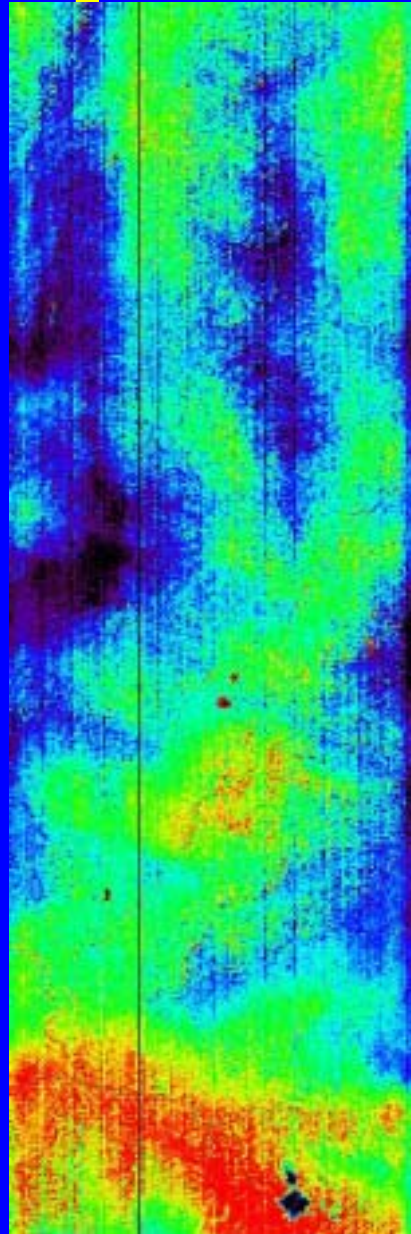


SBC 10/6/01

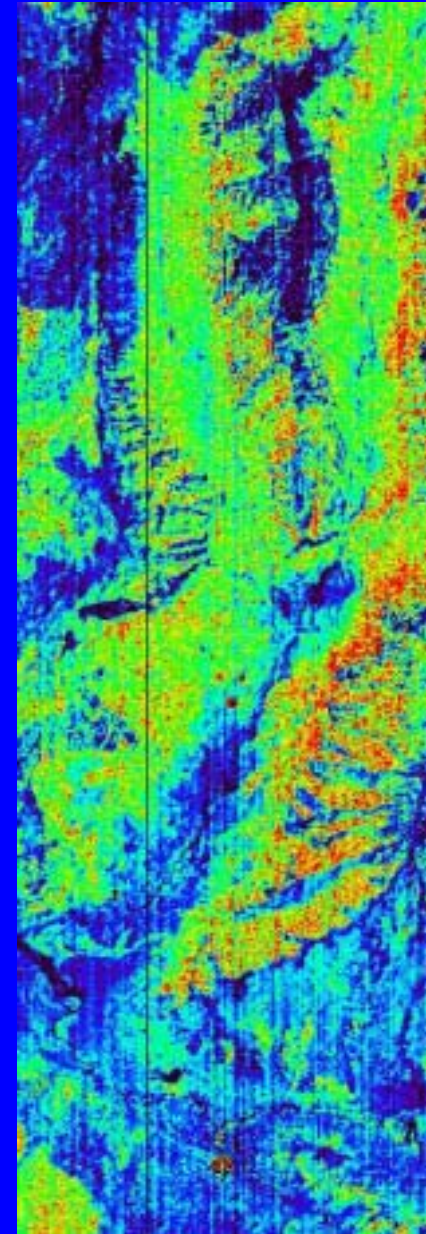
# Hyperion Example ACORN-4 Results



SBC 7/2/01

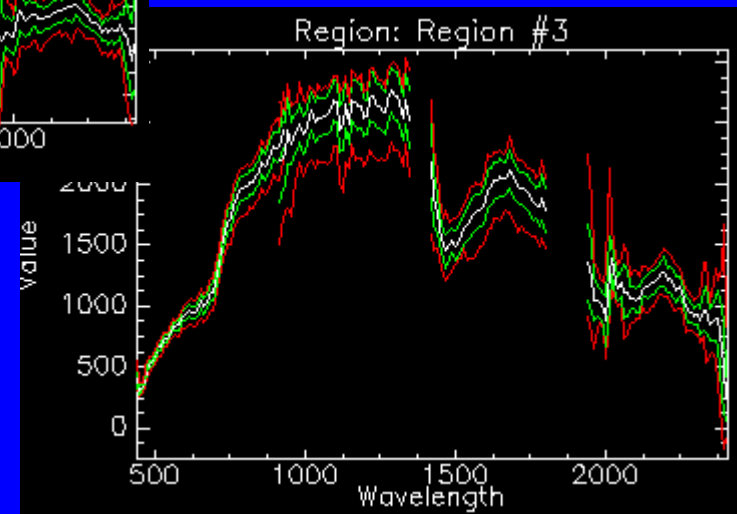
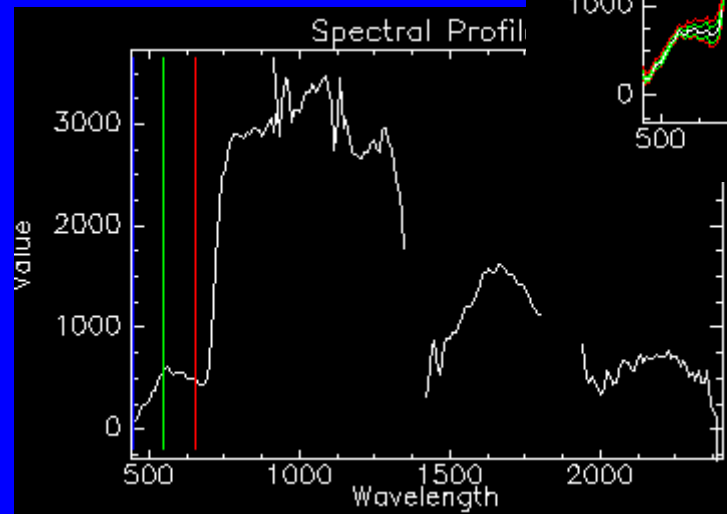
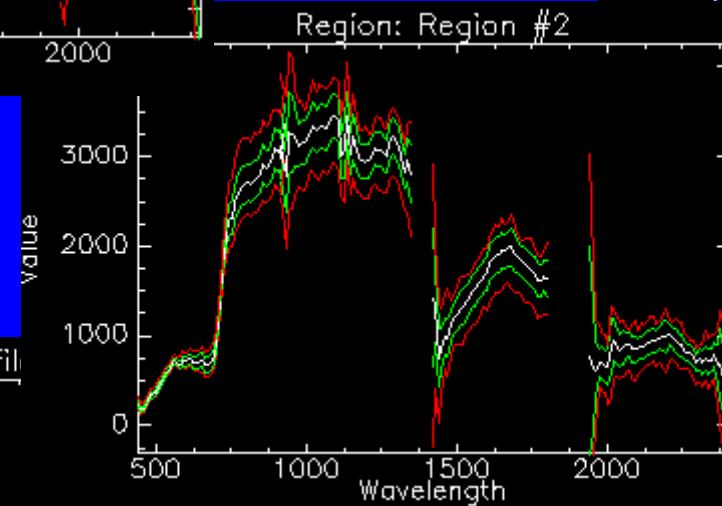
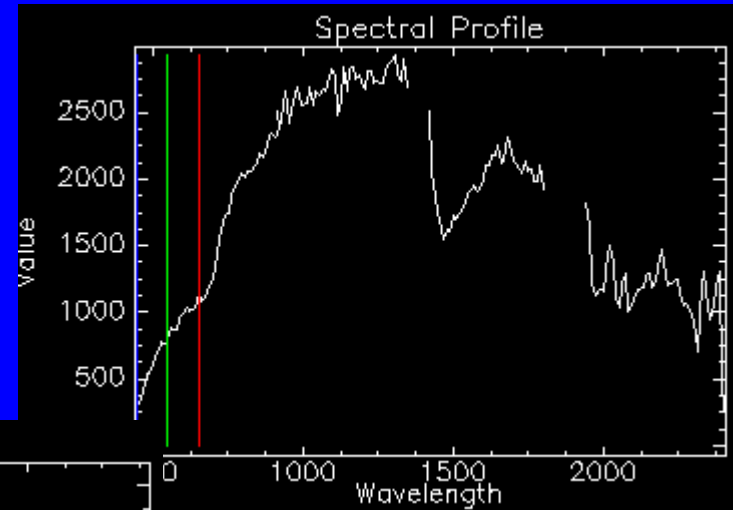
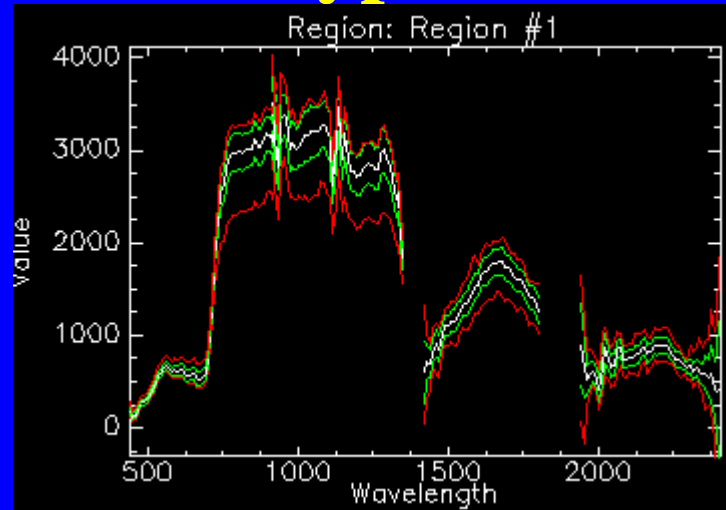


water vapor

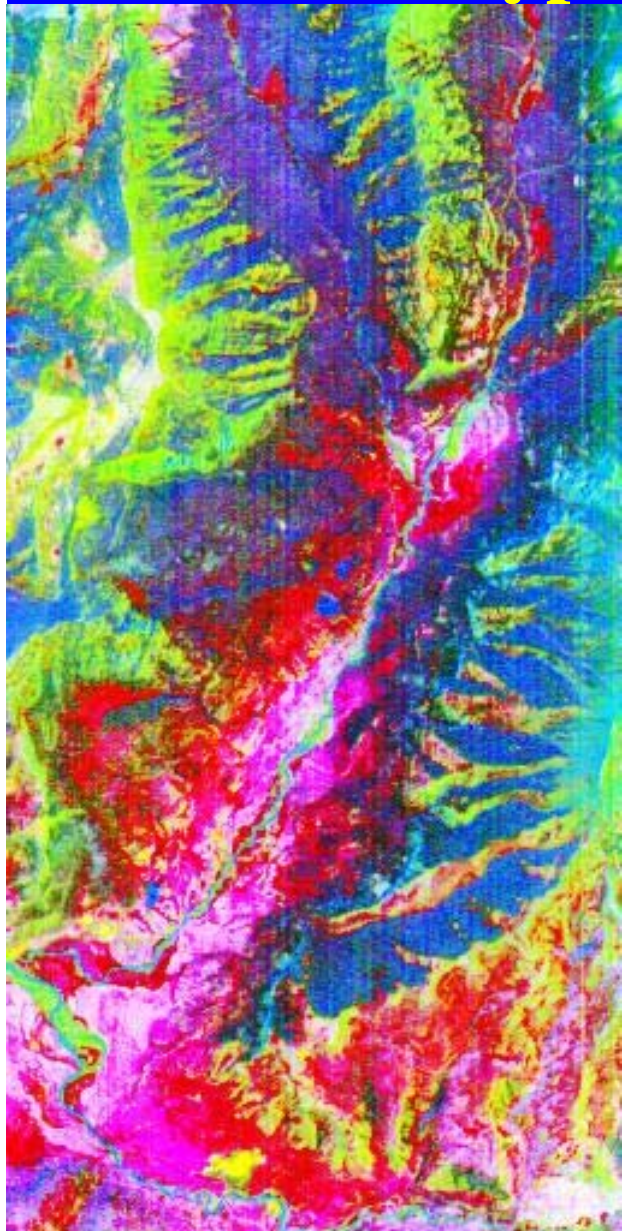


veg. liquid water

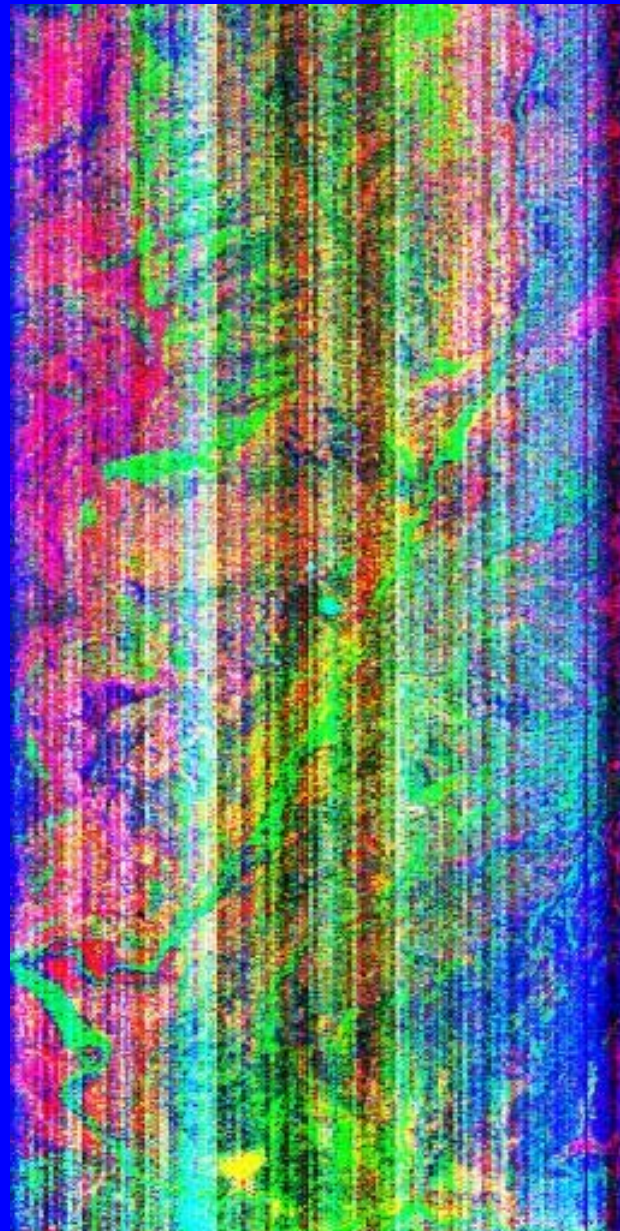
# Hyperion Example ACORN-4 Results



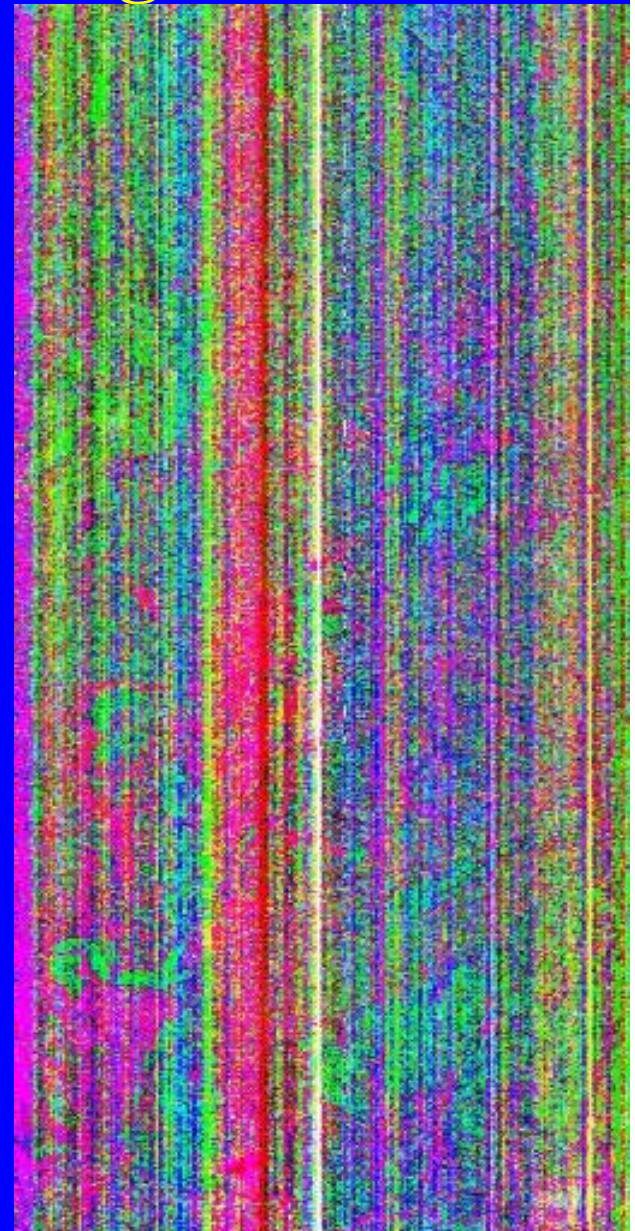
# Hyperion SWIR MNF Images



MNF 1,2,3



MNF 4,5,6



MNF 7,8,9

# Hyperion Coarse Vegetation Mapping



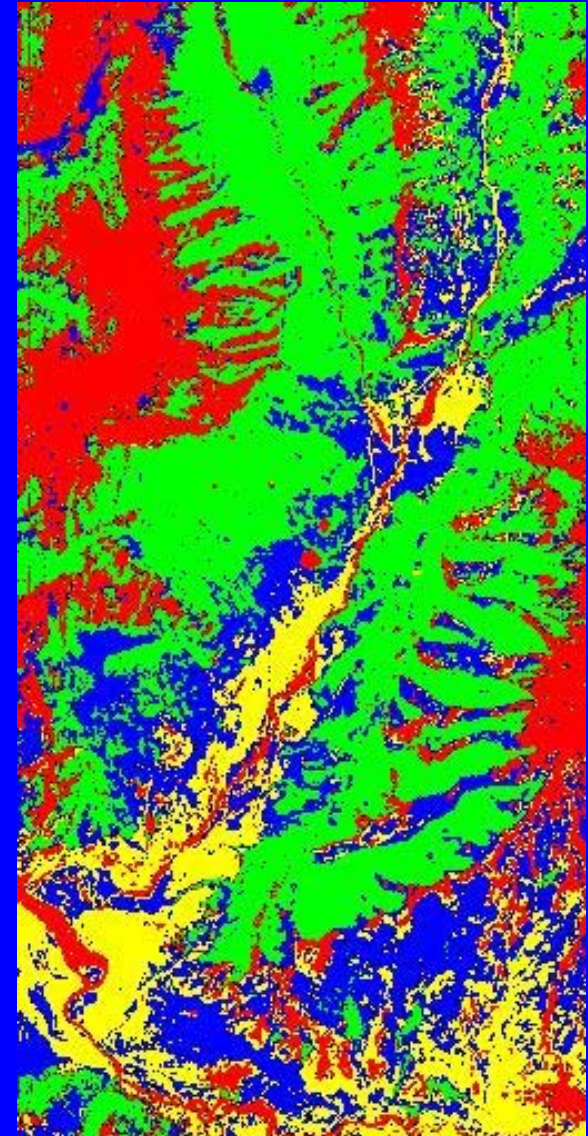
SBC 7/2/01

mineral soil

coniferous  
forest

wetter  
grasslands

dryer  
grasslands



Coarse Veg. Class Map

# Hyperion Forest Community/Species Level Vegetation Mapping

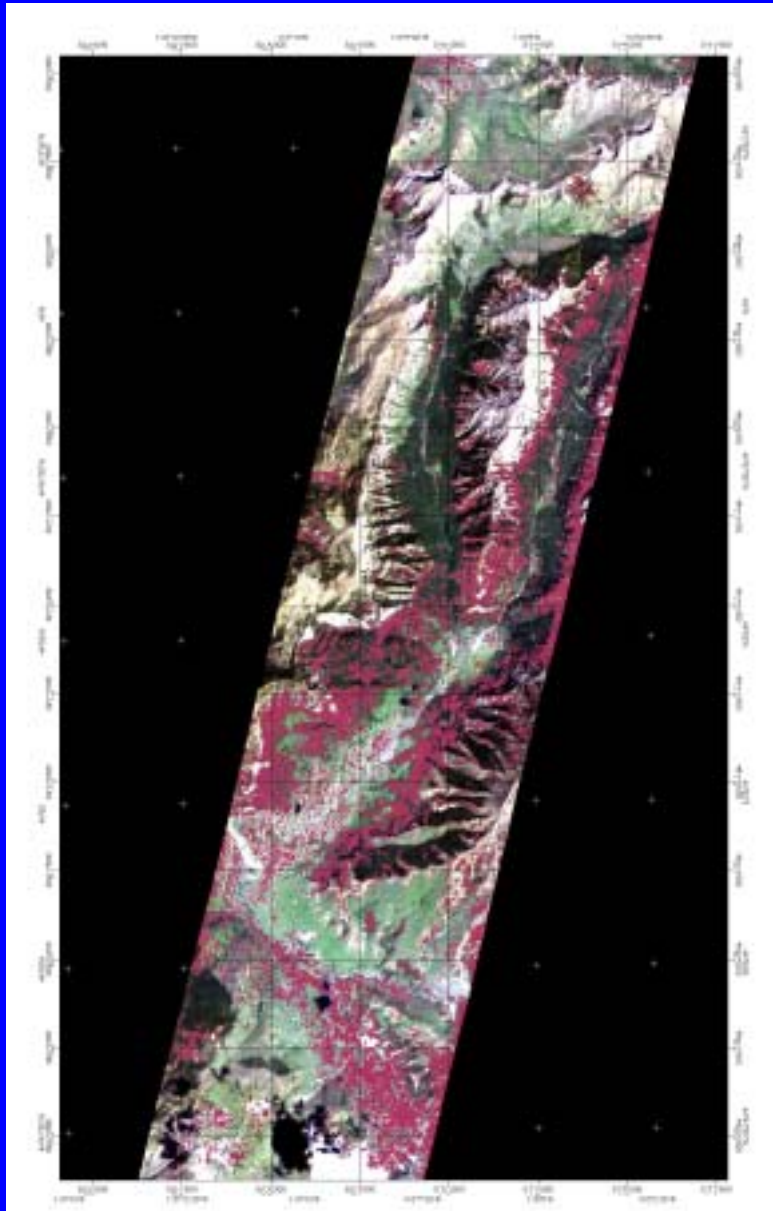


Left  
TM  
base  
image

Right  
Hyperion  
base  
image

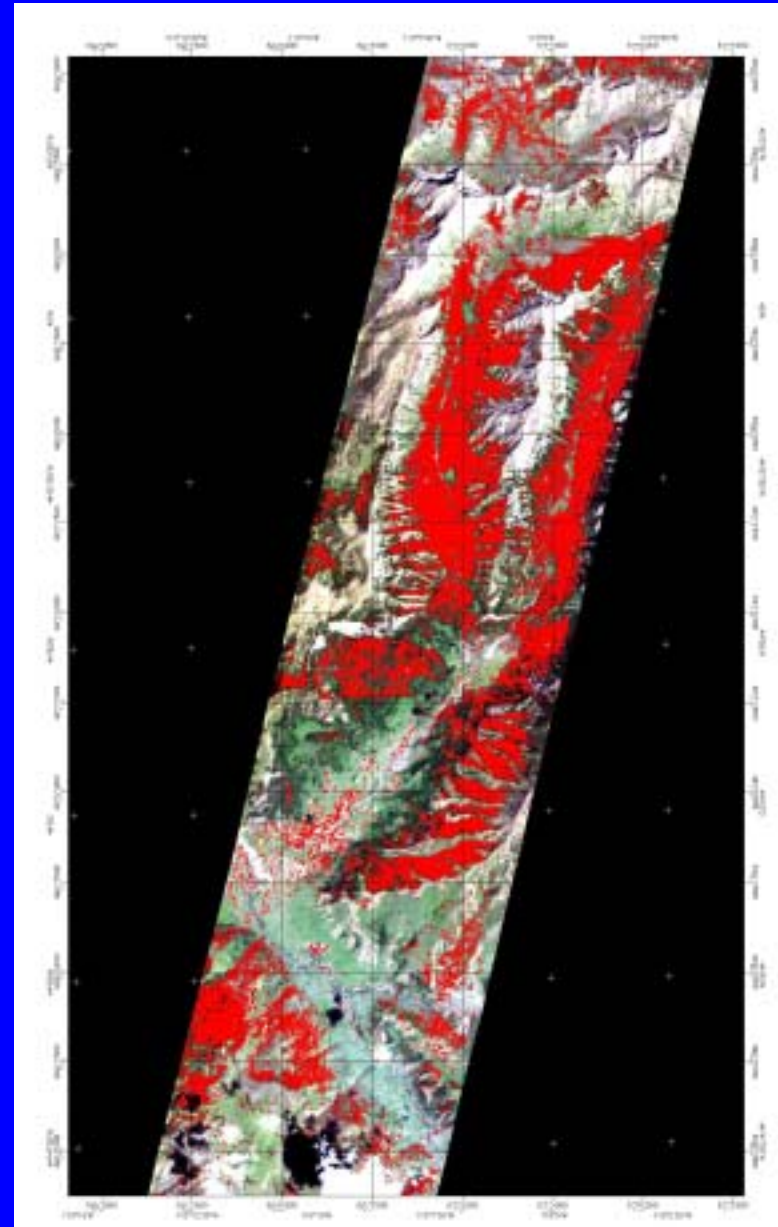


# Hyperion Forest Community/Species Level Vegetation Mapping



Left  
Douglas  
fir

Right  
Lodgepole  
pine



## **Hyperion Data “Issues”**

- **Area-array non-uniformity leads to serious vertical striping in MNFs and processed results**
- **<100:1 SNR limits suitable applications and results**
- **Misregistration between VNIR and SWIR is a real problem in areas of high spatial frequency**
- **Narrow swath width poses serious problems for “operational” uses**
- **Clouds are a real problem, even in Wyoming**
- **Focal plane “funnies” lead to echo and smear**
- **VNIR spectral smile leaves us to do resampling or else totally invent a new suite of software?**

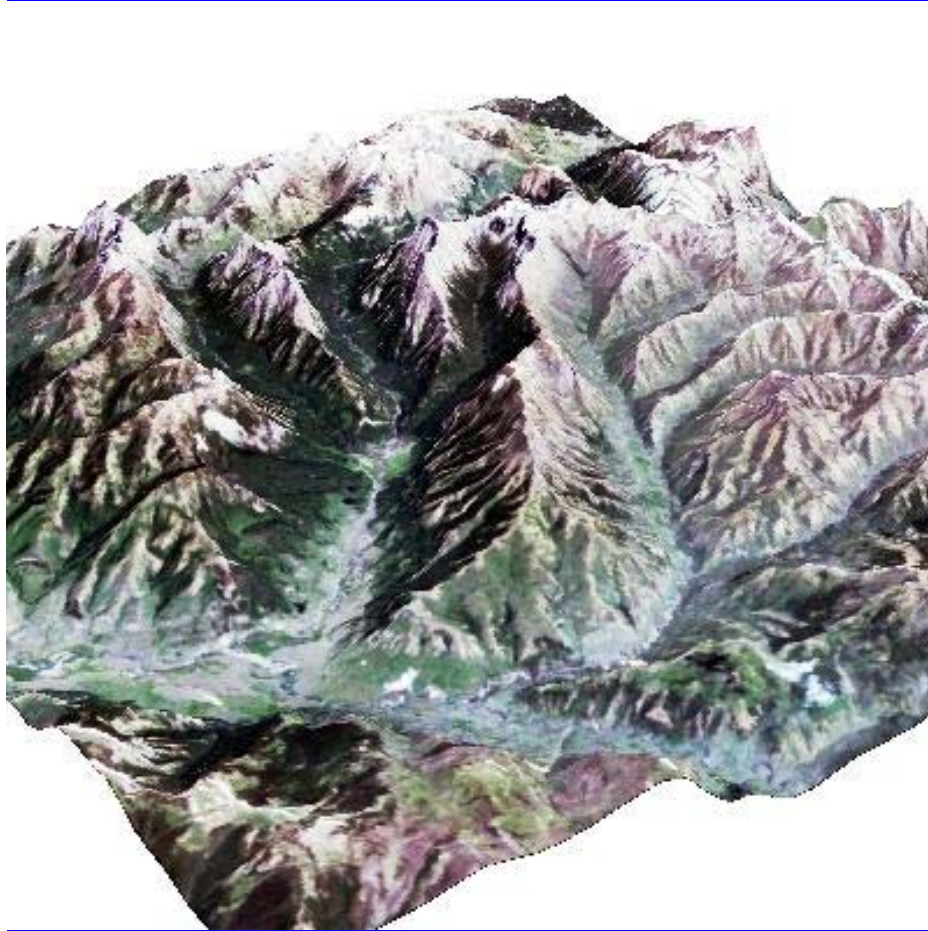
## Preprocessing Research and Results

- Orthorectification capability for Hyperion to allow time-series modeling and inter-instrument and integration of field spectra and other ground truth (now operational with typical RMS errors of ~10m depending on ground truth accuracy, subpixel locations better than the inter-spectrometer alignment)
- Area-array version of EFFORT “polishing”, leveraging both spectral and spatial regularizations (general concept and specific implementations proven on simulation data, but SNR level of Hyperion has prevented real success in application Hyperion data sets)

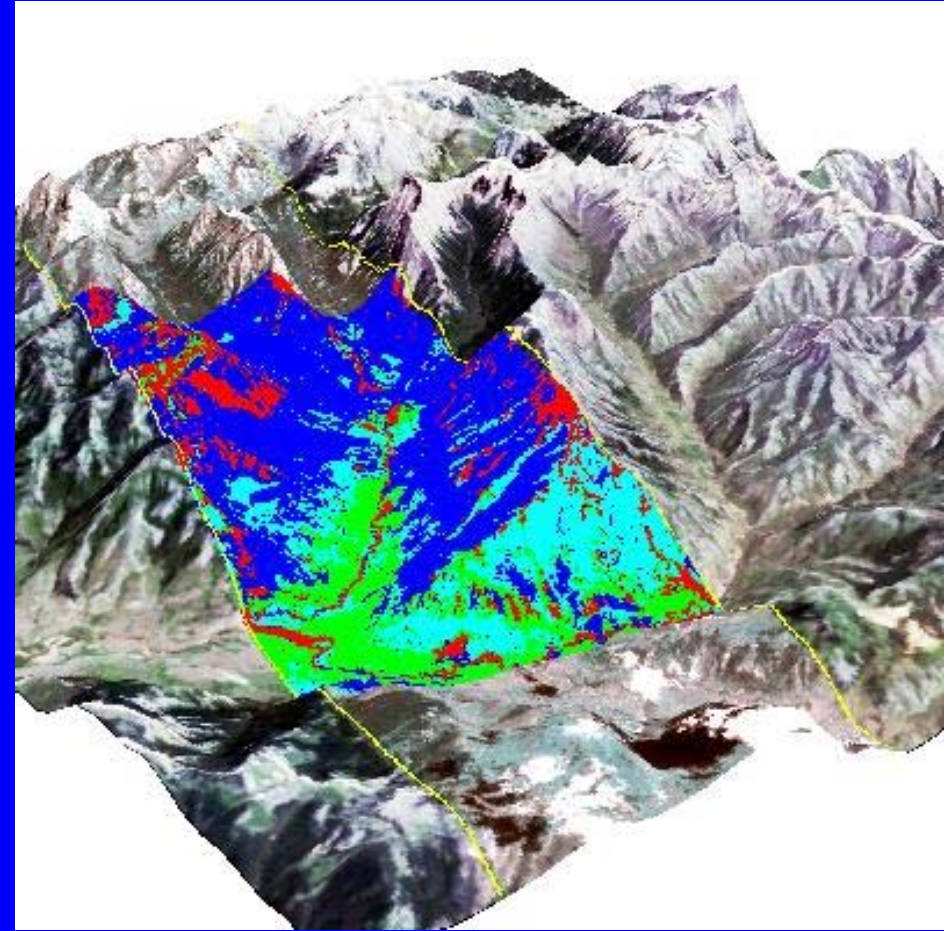
## **Orthorectification of Hyperion**

- **Extreme topography in YNP, combined with multi-angle, multi-look data, require full photogrammetric solution for Hyperion**
- **ACS file, timing coordination and Hyperion camera model allow ephemeris recovery from Level1 data**
- **IDL-based model is now complete and tested, requires a series of GCPs (picked from DOQQ?) and a high-quality DEM**
- **Inversion optimization solves for roll, pitch, yaw biases as well as an “orbit scale” factor, YNP yields ~33m rms errors (+/- 1 pixel accuracy)**
- **ENVI-compatible NN-resampled GLT files created**
- **Can be made available to other SVT members**

## Orthorectification Accurate to 1/3 of a Pixel Permits Direct Integration with a GIS and Ground Truth



Landsat 7 ETM+ 3-d view



orthorectified Hyperion swath and vegetation community mapping, superimposed on ETM+ 3-d view

## **Joint Spatial/Spectral Regularization or Polishing (an Area Array Version of EFFORT)**

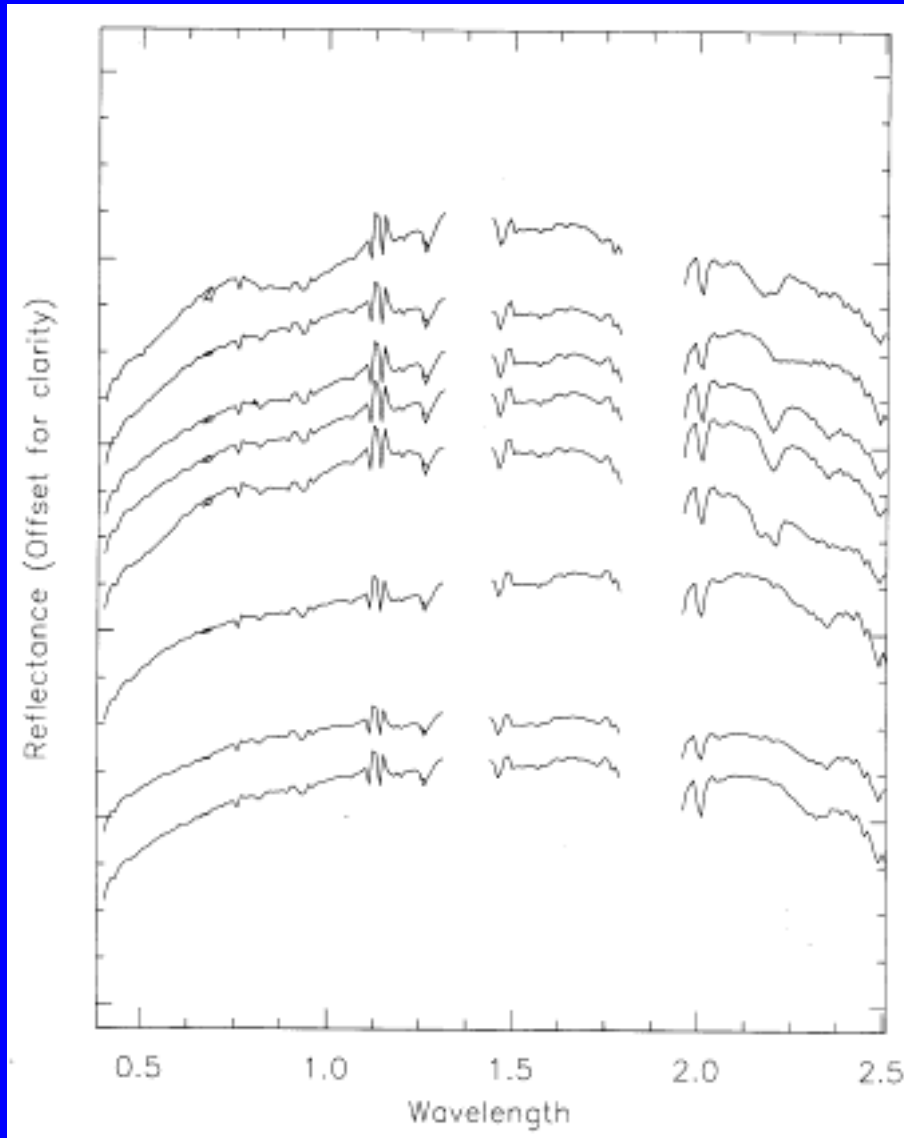
- **Calibration and Reduction Accuracy Problems are a fact of life in HSI data and their processing**
- **Area array instruments let this issue “leak” into the image signal and the spectral variance, while linear array sensors hide the same problems in their absolute calibration errors**
- **All proposed space systems are, and will be, area array based and we need to crack this nut, it will be the use-limiting barrier on an AVIRIS-class space platform and is often the high hurdle in Hyperion data**

## **EFFORT Spectral Polishing or Regularization**

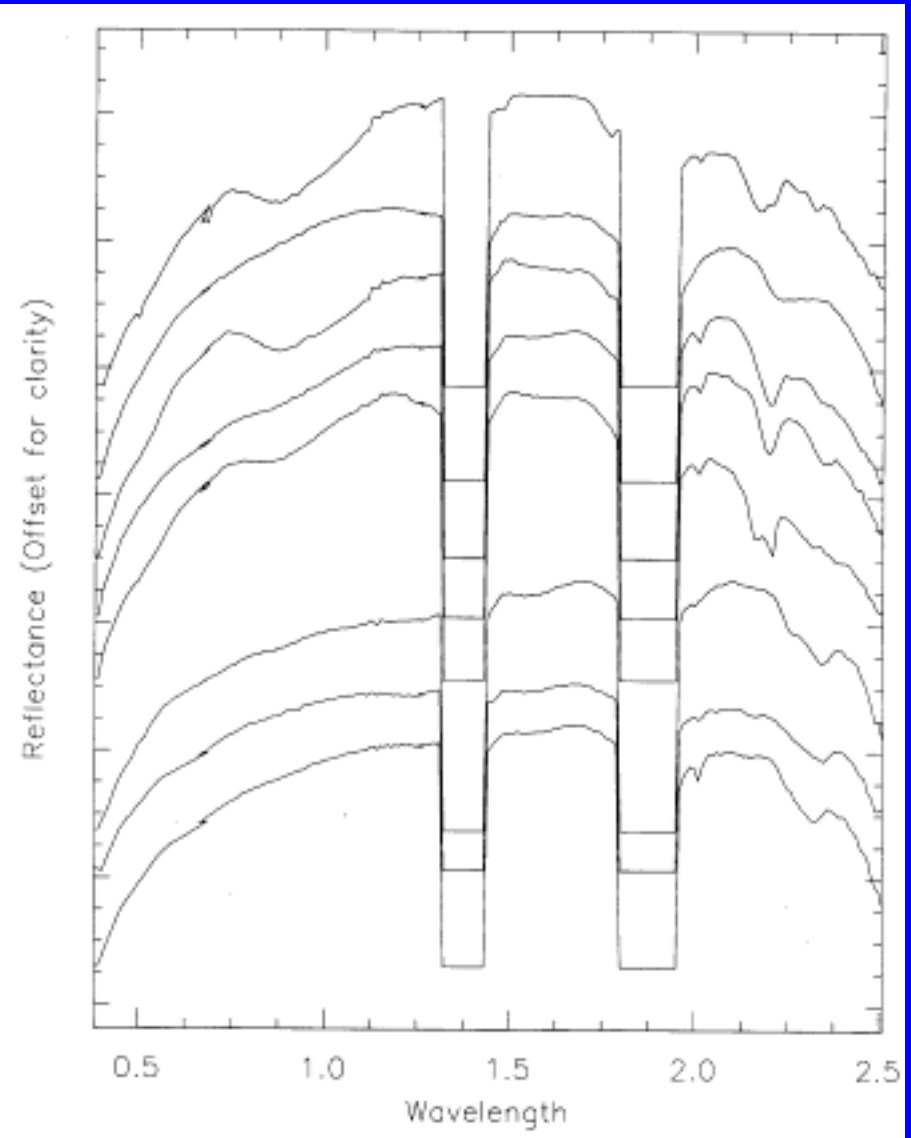
- **Atmospherically corrected spectra exhibit coherent sawtooth “noise”, apparently correlated with brightness**
- **These data are the end product of a long chain of absolute calibrations, measurements and models, each with its own error and uncertainties**
- **AVIRIS/HyMap now have a precision that exceeds the accuracy of any current or future absolute calibration and radiative transfer models**
- **Is all this precision for naught, if we can't match it with accuracy? No, but we must be pretty tricky to bootstrap an estimation of the lost accuracy, leveraging the precision**

## Oatman, AZ, 1995 EFFORT Gains and Offsets

# Oatman, AZ, 1995 EFFORT



ATREM

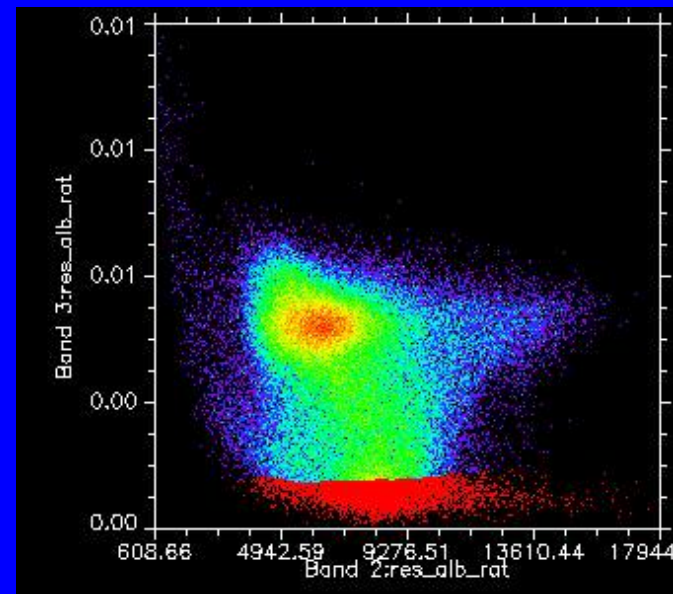
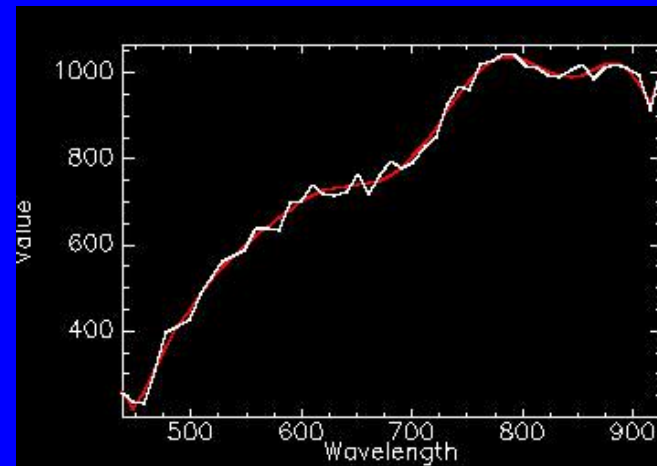
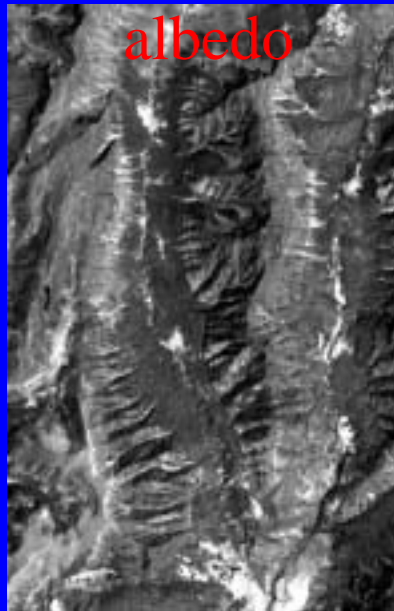


EFFORT

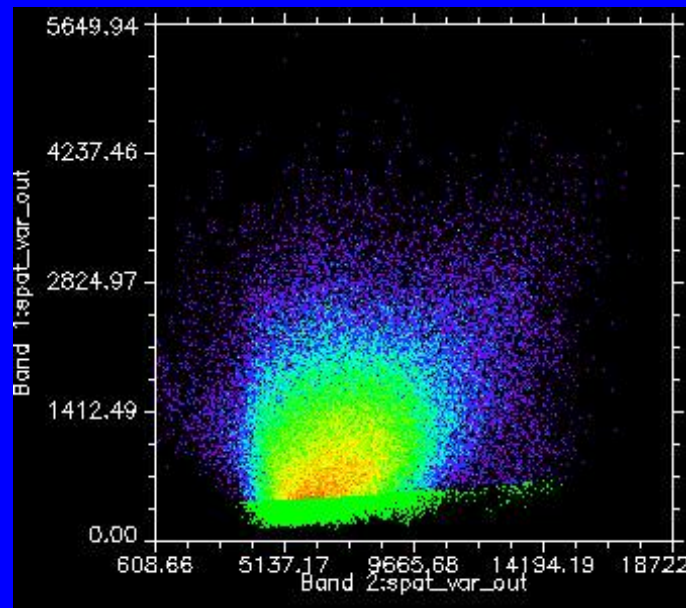
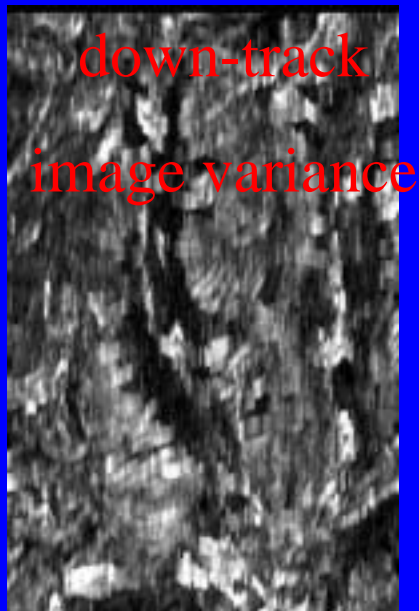
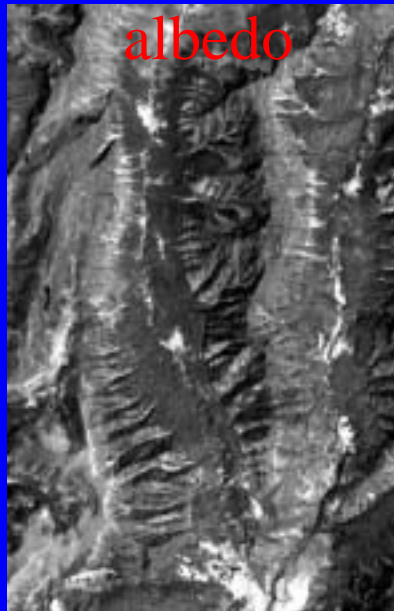
## **Area Array EFFORT Concept**

- **The gain/offset errors that cause the spectral “jaggies” are the same ones that cause the stripes!**
- **We have both spectral AND spatial leverage on their retrieval from the data with Hyperion**
- **Joint solution is attractive but intractable as full model (~102,400 unknowns)...but is band-separable**
- **Special pixels selected for spectral-EFFORT, other special pixels selected for spatial-EFFORT**
- **Band-by-band solution solves for 512 unknowns (256 gains and 256 offsets) per detector array lines (spectral band)**
- **Proof of concept with simulated data shows it works, but Hyperion is still a problem for the method**
- **SNR limits the utility/feasibility of the method with Hyperion, but follow-on sensors will NEED this technique**

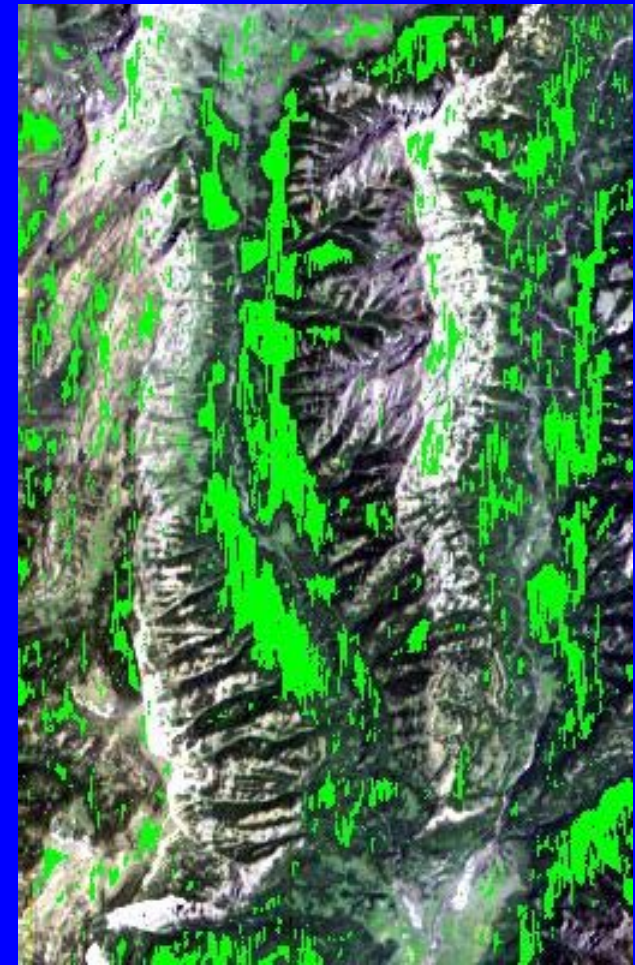
# Development of Spectral-Based Leverage



# Development of Spatial-Based Leverage



albedo vs. down-track  
image variance



spatially-derived  
mask of pixels for  
joint regularization

## Area Array EFFORT Concept



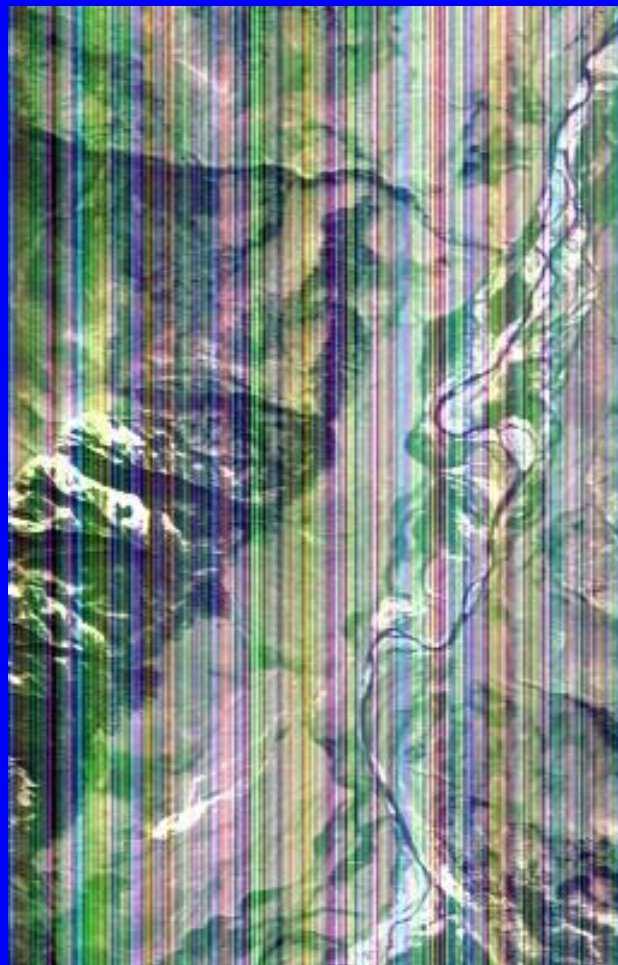
- With dual masks and EFFORT spectral fit models, the problem can be solved band-by-band
- Spectrally, regress against smooth models
- Spatially, regress against model-adjusted left and right neighbors
- Develops ~60,000 equations in 512 unknowns
- Direct least-squares solution is available

# Area Array Polishing Proof of Concept

AVIRIS data

contaminated

corrected



Simulation using “CRAP contaminated” AVIRIS data works!

Hyperion application is not successful, due to similar scale of errors and noise. Method adds more CRAP that it removes!

## **Hyperion in Yellowstone Conclusions**

- **Hyperion works as well, or better, than expected and can be used for HSI investigations including conifer species and community mapping**
- **Its SNR places it at about “1991” in the AVIRIS evolution, but other limitations must be considered**
- **Its area-array non-uniformity and other artifacts are serious and impact its suitable applications**
- **On-orbit data have some advantages, but they also have certain limitations, keep flying aircraft**
- **SNR, Uniformity, Stability THEN Calibration**
- **Swath width, area-array data uniformity, SNR and calibration must improve in the next generation**
- **YNP work clearly validates Hyperion performance and value of space-based HSI to ecological studies**