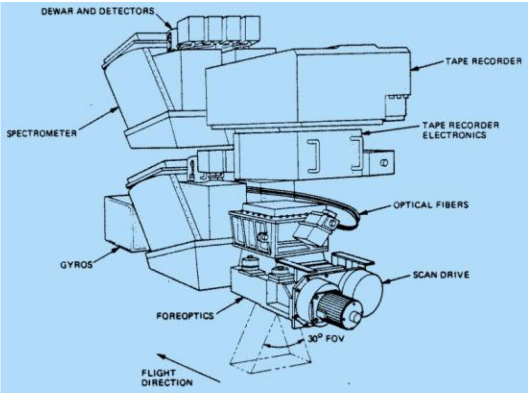
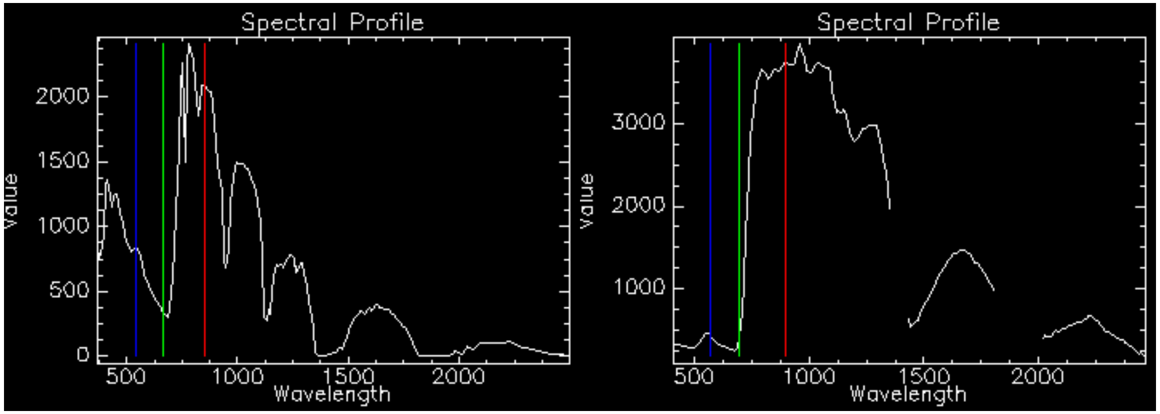
Three years, 150 AVIRIS images

Practical considerations for analyses of large imaging spectroscopy data sets for ecosystem studies





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Why does AVIRIS processing matter for HyspIRI?

- Imaging spectroscopy has enabled the retrieval of key canopy foliar biochemical and structural attributes over large scales.

- With the great volume of images that will come from HyspIRI, we will need to ensure that retrievals are consistent across time and space.

- Our biggest worry is having retrieval algorithms that can be applied "globally."

- AVIRIS imagery (and similar airborne data) will be critical to scaling and validation of canopy level estimates from HyspIRI.

- Multi-date, multi-location AVIRIS images are currently our best analogue for HyspIRI.

In order to apply algorithms "globally"….

- **We' ve been trying to figure out what steps in the processing stream are critical to ensuring consistent retrievals.**

- **At UW-Madison, we have worked with >150 AVIRIS scenes from WI, MD, WV, UT, CO, NY, MN and MI spanning 2008-2011.**

- **The scenes are not comparable off the shelf, even if the biological/physical attributes of the ecosystems in them are similar.**

- **All imagery has issues with:**
  - Occlusion by clouds, cloud-shadows,
  - Terrain effects,
- **Airborne images may have particular issues with:**
  - Along and across-track illumination gradients
  - Possible geo-location errors

Example: Baraboo Hills WI, 2008 AVIRIS campaign

The "best-case" scenario: Scenes from the same location, taken a short time interval apart, same flight geometry.

- Hypothesis: retrievals should match **exactly.**

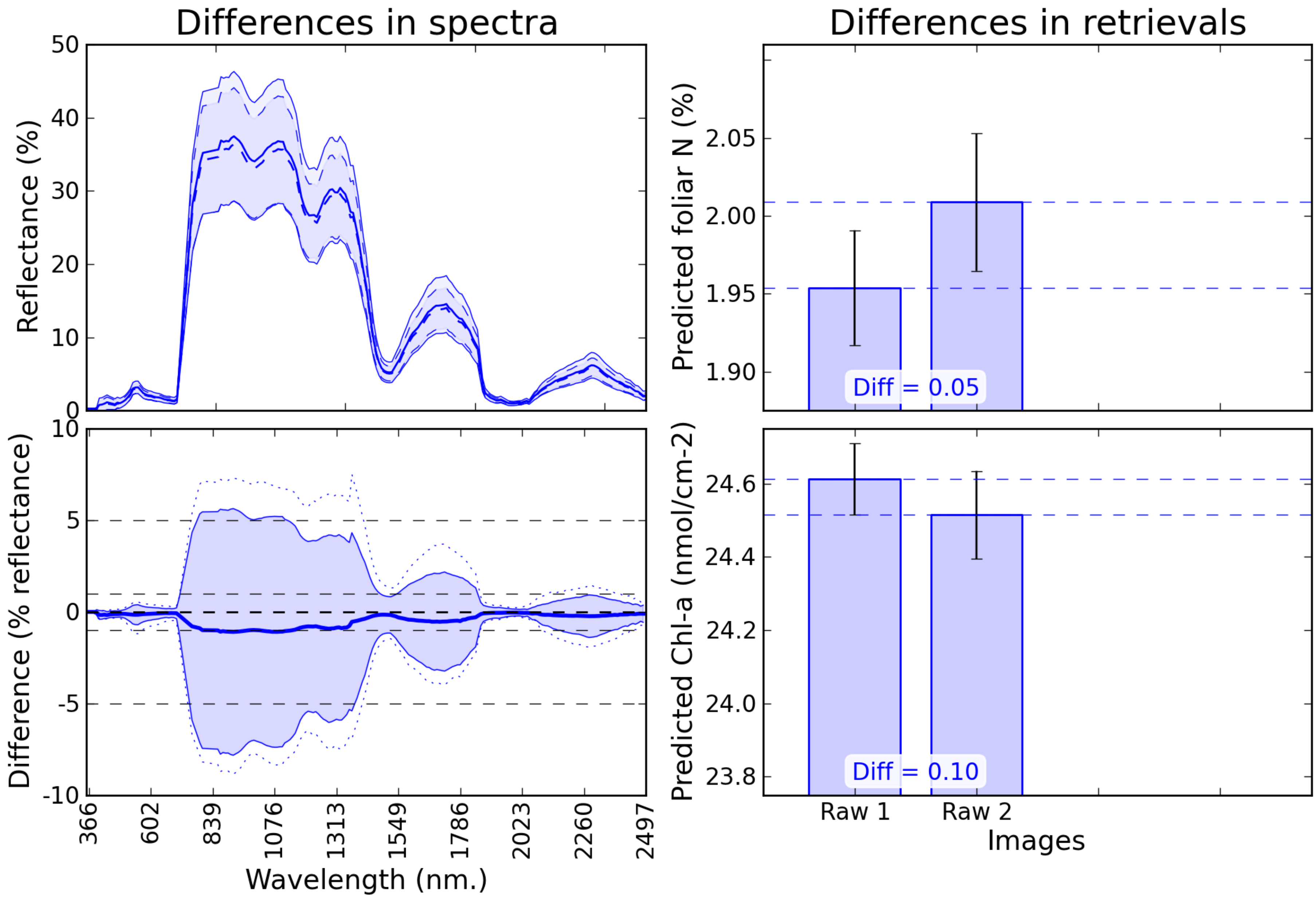
The data:

- Baraboo Hills, WI; Two images, acquired 13th July 2008.
- ~20min apart (UTC 16.099 – UTC 16.426)
- Same general coverage and flight orientation (77.12°)
- ~3° difference in solar elevation (57.03° – 59.92°)
- ~6° difference in solar azimuth (122.07° – 128.75°)

Spectra extracted from 30 forested sites

- Averaged in a 3X3 window to simulate a ~50m. Plot (17.8*3m.)
- Martin et al. (RSE 2008) coefficients applied to get canopy N%.
- Gitelson & Merzlyak (JPP 1996) for Chlorophyll-a.

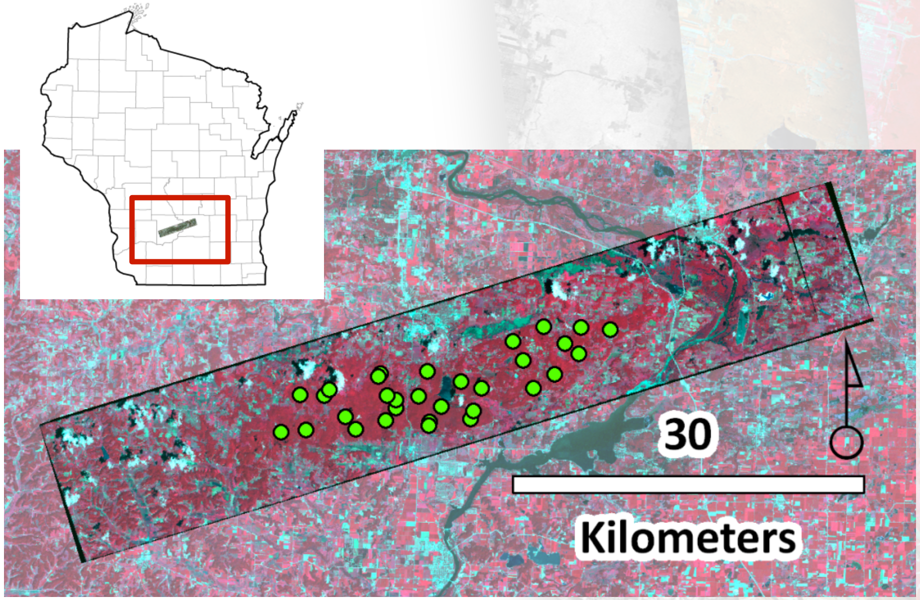
Example: Comparison of reflectance, no other corrections applied



AVIRIS Pre-processing: Steps

Raw image → Cloud, shadow, water mask

Raw image → Atmospheric correction → Cross-track correction → Terrain normalization → Precision georeferencing



AVIRIS Pre-processing: Atmospheric correction

1. **Atmospheric correction: one of the following…**
   - **ACORN5b**
   - **ATREM (TAFKAA)**
   - **ATCOR4 (explicit scan line geometry)**

AVIRIS Pre-processing: Cloud/Shadow mask development

2. **Cloud/Shadow mask development**
   - Important because other corrections depend on it

- **Band thresholding does not always work!**
  - All images need to have the exact radiometric behavior (… same for Image indices)

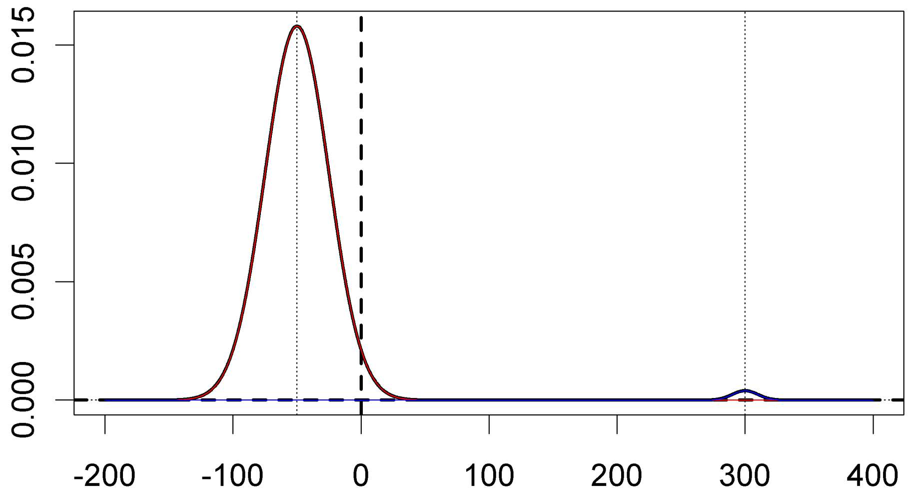
- **Gaussian mixture modeling** (of bands, indices, histograms)

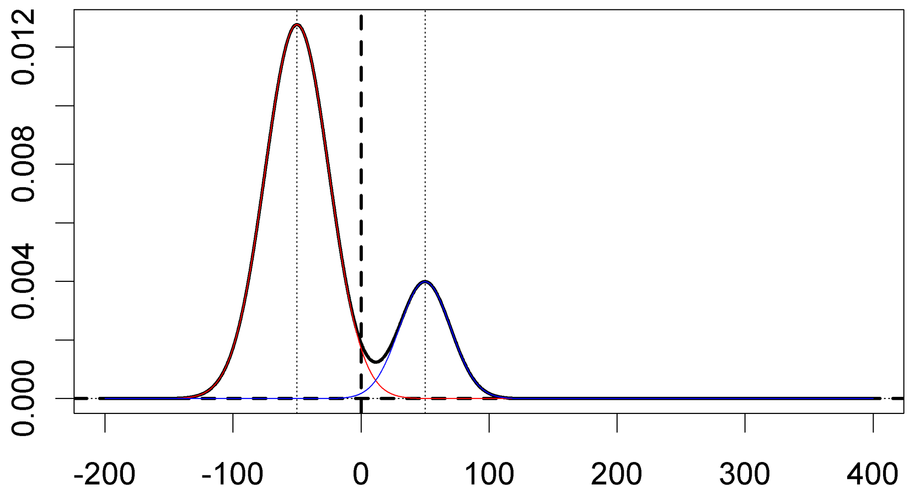
$$DN = \sum_{i=1}^{n} \pi_i\left(N(\mu_i, \sigma_i)\right) \quad \textbf{and...} \quad \sum_{i=1}^{n} \pi_i = 1$$

  - **Works as long as histograms have same number of peaks**
    - 2 peaks if bright clouds and dark background
    - 1 peak if only background (or no clouds, or all haze)
    - >2 peaks if clouds and haze (…etc.)
  - **…still need to find breakpoint to threshold**

AVIRIS Pre-processing: Cloud mask development

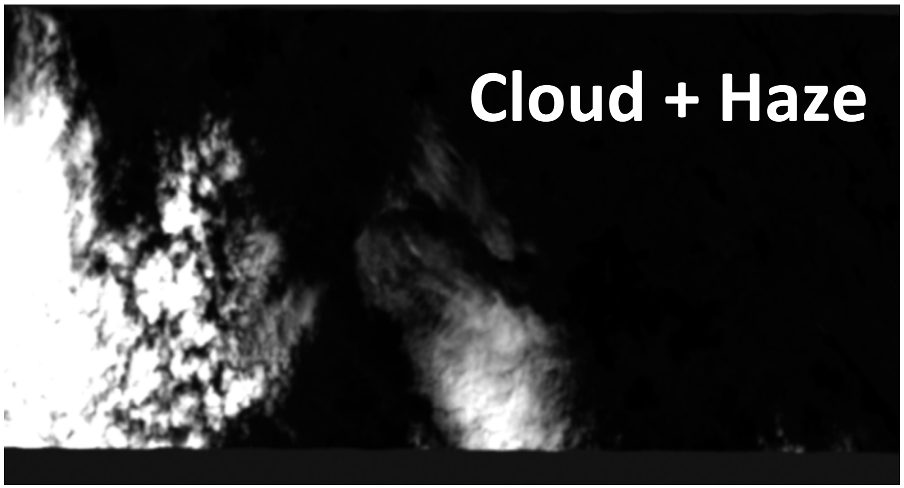
…Problems with Gaussian mixture modeling when number of histogram peaks indeterminate

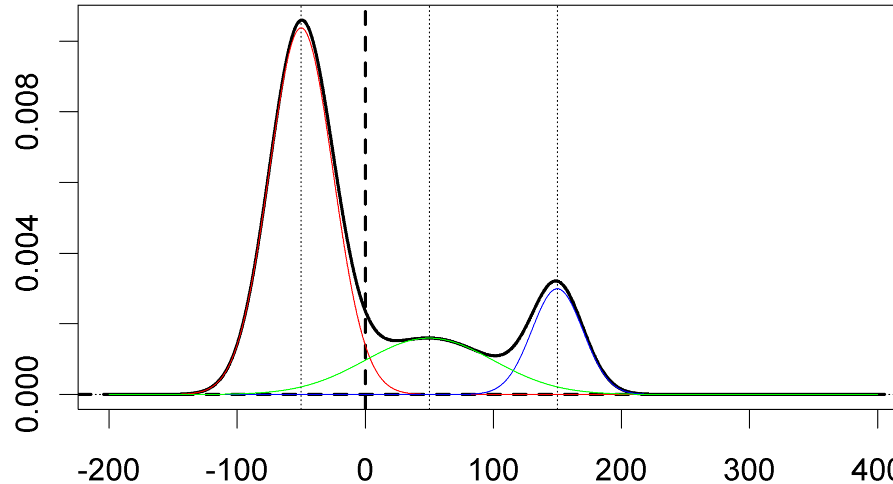


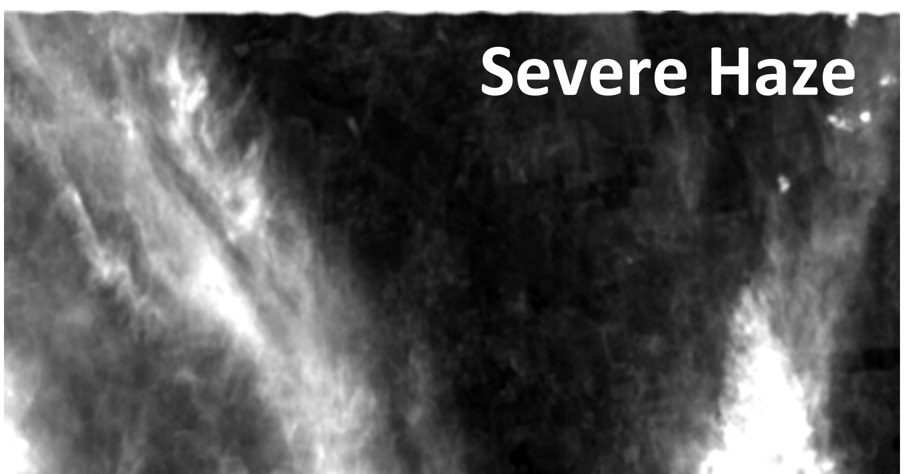


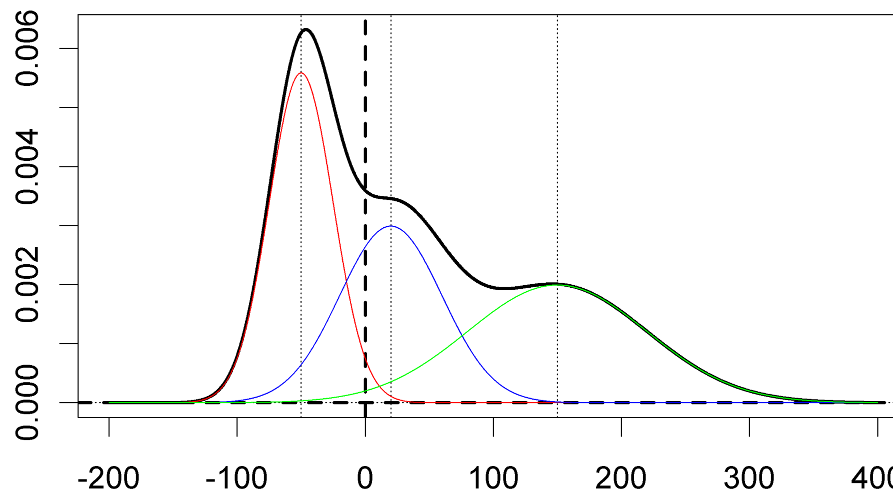
AVIRIS Pre-processing: Cloud mask development

Mixture modeling needs predetermined number of peaks to estimate parameters.





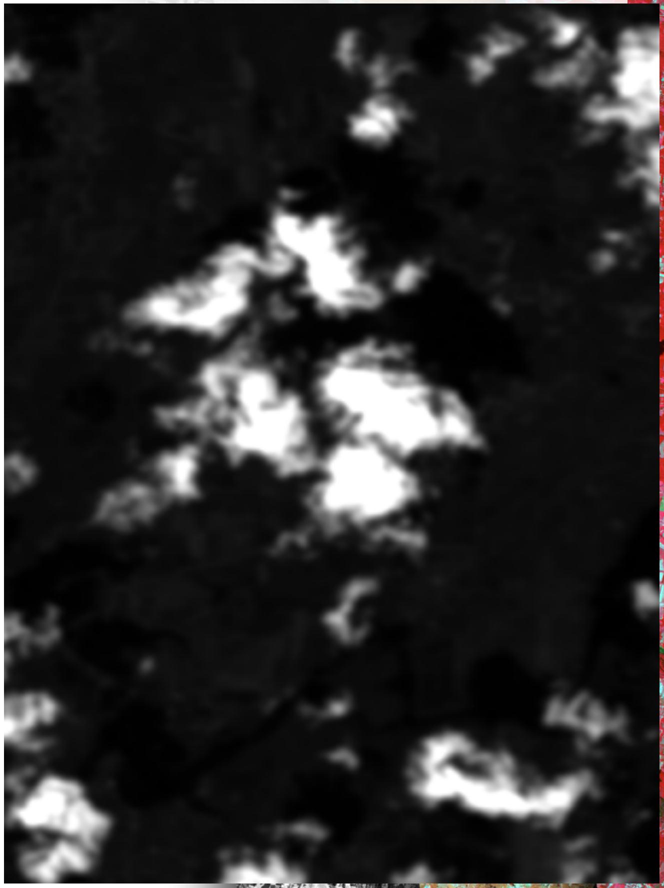




AVIRIS Pre-processing: Cloud mask development

Approach: Reflected Histogram Thresholding (RHT)

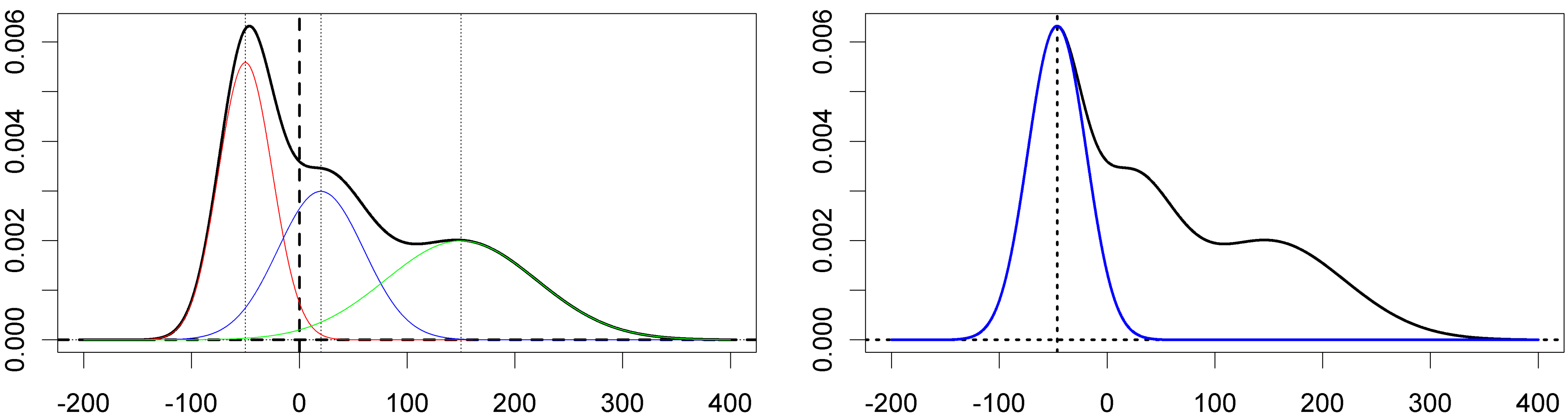
- **First, get "best estimate" of bright pixels:**
- Use a Mixture Tuned Match Filter (MTMF) to generate "abundance" images:
  - **Clouds:** 1.33nm^{B106}-1.38nm^{B110} and 1.77nm^{B149}-1.81nm^{B153} using *band maximum as target spectra.*
  - **Shadows:** 1.17nm^{B87}-1.30nm^{B102} *array of zeros as target spectra.*



AVIRIS Pre-processing: Cloud mask development

Reflected Histogram Thresholding:

1. Build histogram of MTMF abundance
2. Find peak of histogram in negative region (= background)
3. Get histogram to the 'left' of peak (this is the leading edge of the ideal 'background' histogram)
4. 'Reflect' it onto the other side to complete distribution



5. Calculate mean, stdev. from constructed histogram
6. Calculate Z-score of image, invert PDF, threshold by *P* ~> 0.95

AVIRIS Pre-processing: Shadow mask development

Shadow masking:

- Same as clouds, but easier because shadows are consistently dark:
  - Do MTMF using vector of zeros as reference spectrum.
  - Threshold resulting ‘shadow fraction’ image by 400.

Effect of modulating *P* cutoff, or shadow threshold

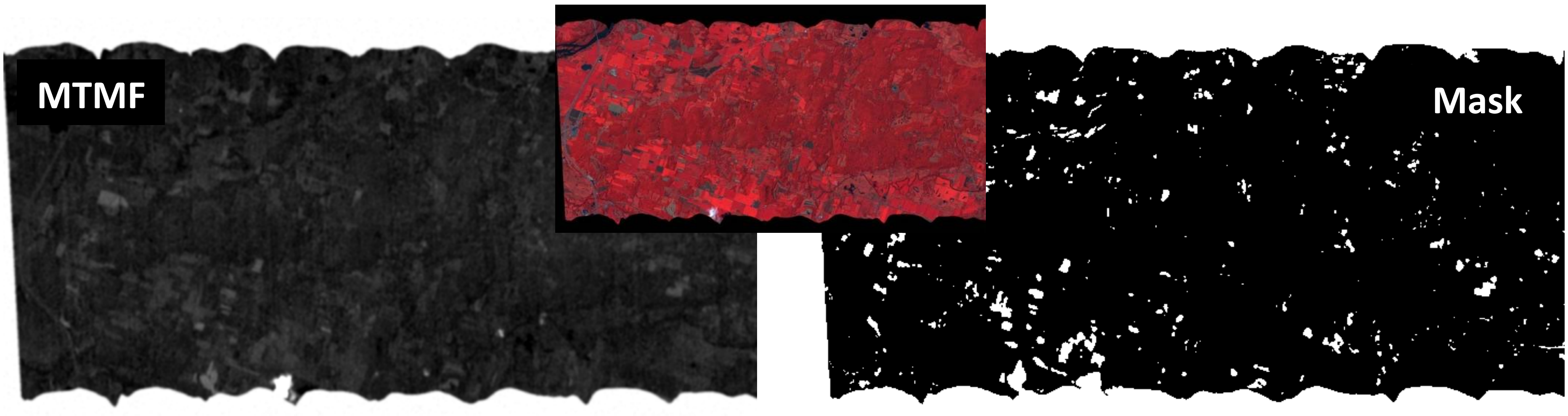
- Low *P* misses clouds.
- High *P* includes most Urban areas, bright soil, some bright Veg.
- Low shadow threshold includes deeply shaded terrain.

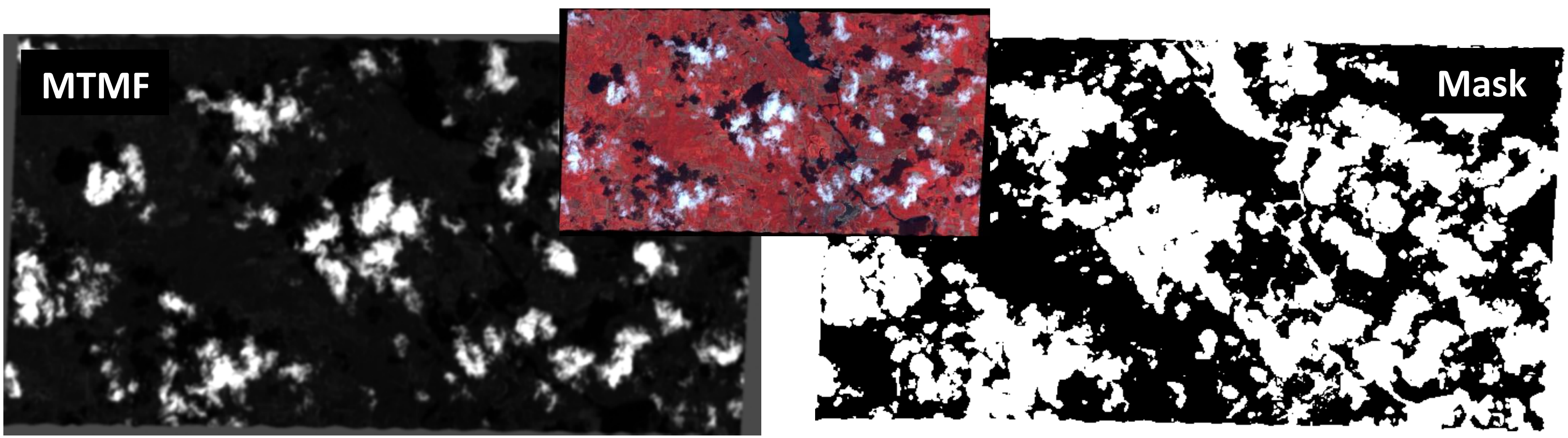
“Features” not “Problems”

- Rather than clouds or shadows, we are more interested in anomalously bright or dark objects that may affect overall image radiometry.

AVIRIS Pre-processing: Cloud/Shadow mask development

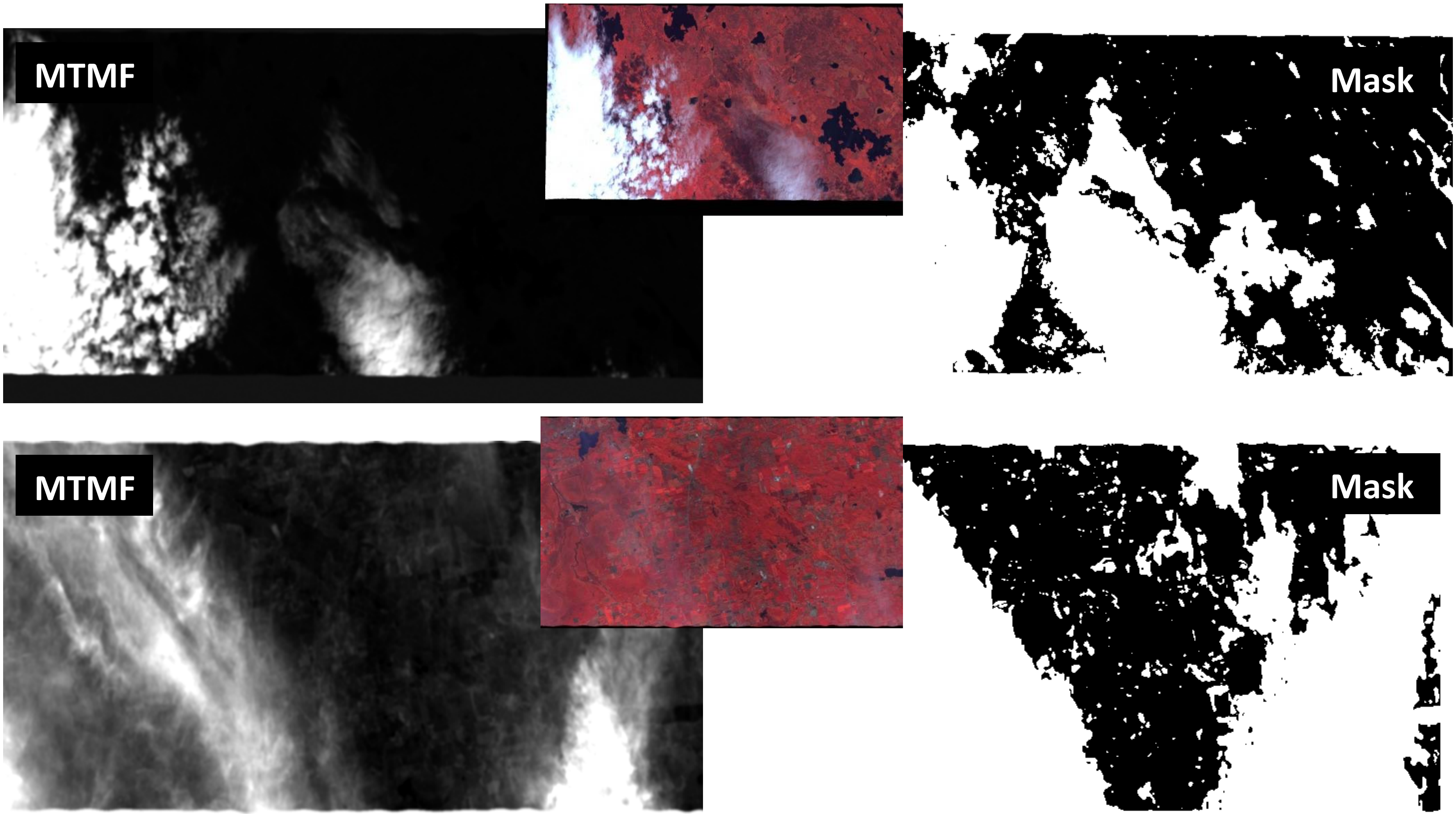
RHT results: Combined cloud/haze + shadow/water masks





AVIRIS Pre-processing: Cloud/Shadow mask development

RHT results: Combined cloud/haze + shadow/water masks

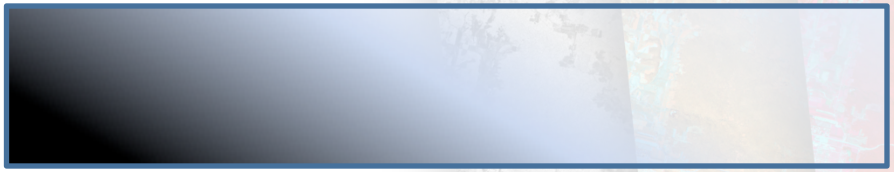


AVIRIS Pre-processing: Cross-track illumination correction

3. Bilinear cross-track illumination correction:

…because images can have brightness gradients in any direction

- **For each band…**



1. **Regress (masked) pixel DNs against pixel locations**

$$DN_{\lambda m} = \beta 0_\lambda + (x_m \cdot \beta 1_\lambda) + (y_m \cdot \beta 2_\lambda) + (y_m \cdot x_m \cdot \beta 3_\lambda)$$

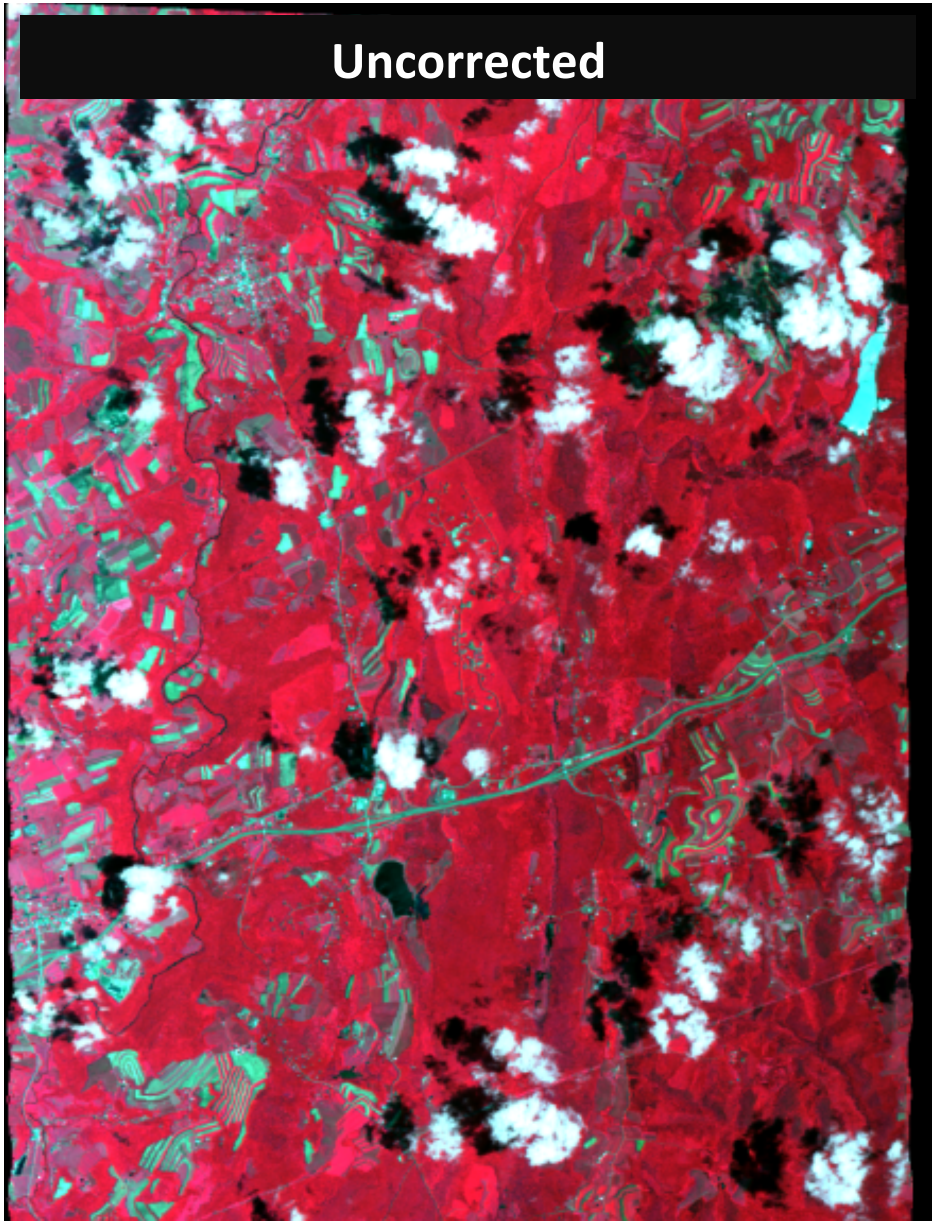
2. **Estimate the brightness 'plane'** (gradients in ***x, y, x*y*** directions)

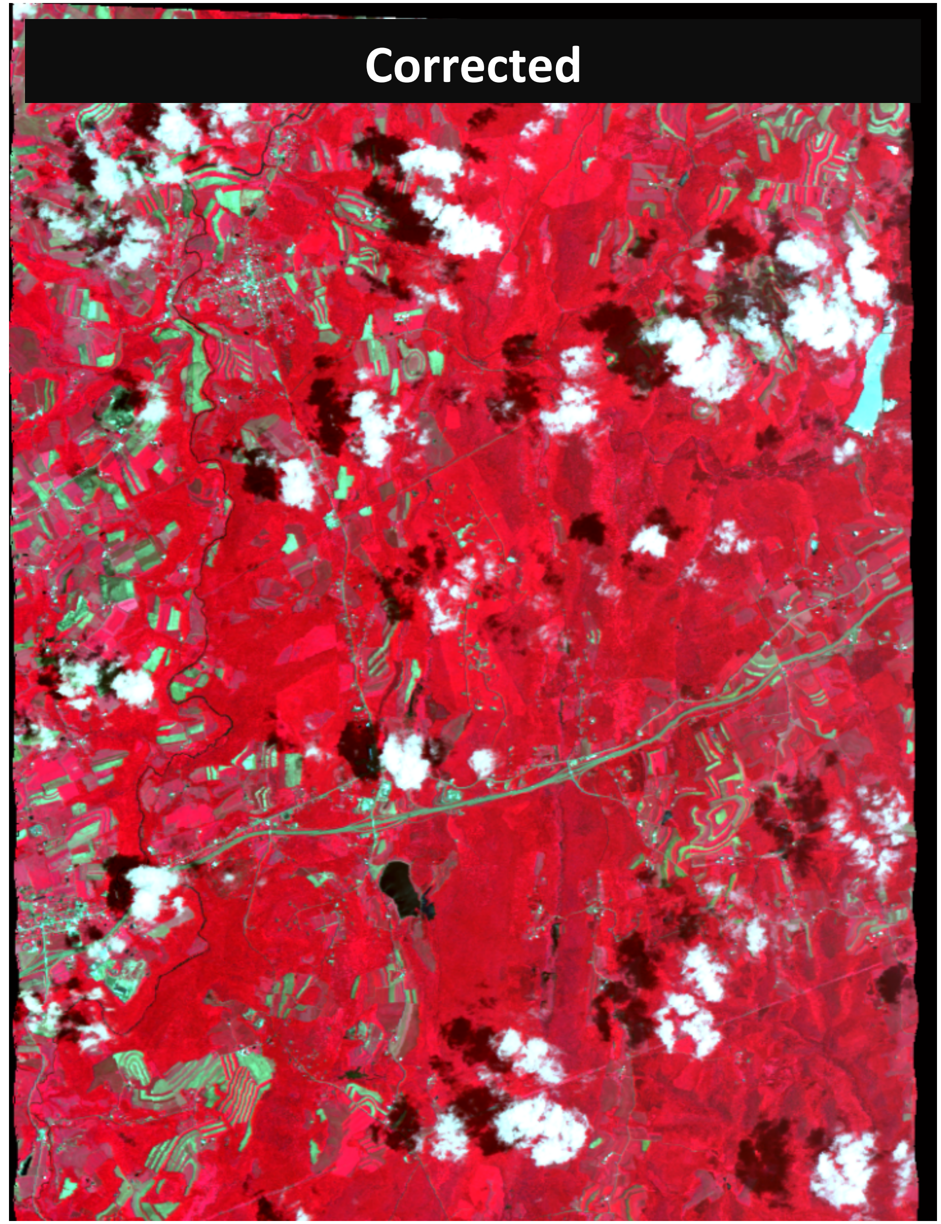
$$IL_\lambda = \beta 0_\lambda + (x \cdot \beta 1_\lambda) + (y \cdot \beta 2_\lambda) + (y \cdot x \cdot \beta 3_\lambda)$$

3. **…tness plane**

$$DN_{c\lambda} = DN_\lambda - IL_\lambda + (\overline{DN_{\lambda m}})$$

AVIRIS Pre-processing: Cross-track illumination correction





AVIRIS Pre-processing: C-factor terrain normalization

4. Terrain normalization: C-Factor correction (Teillet et al. 1982)

$$L_H = L_T \left(\frac{cos(z) + c}{cos(i) + c} \right)$$

Where: L_H = Reflectance from horizontal surface; L_T uncorrected reflectance

$$c = b/m$$

b and *m* determined by regressing each band with the *cos(i)* image

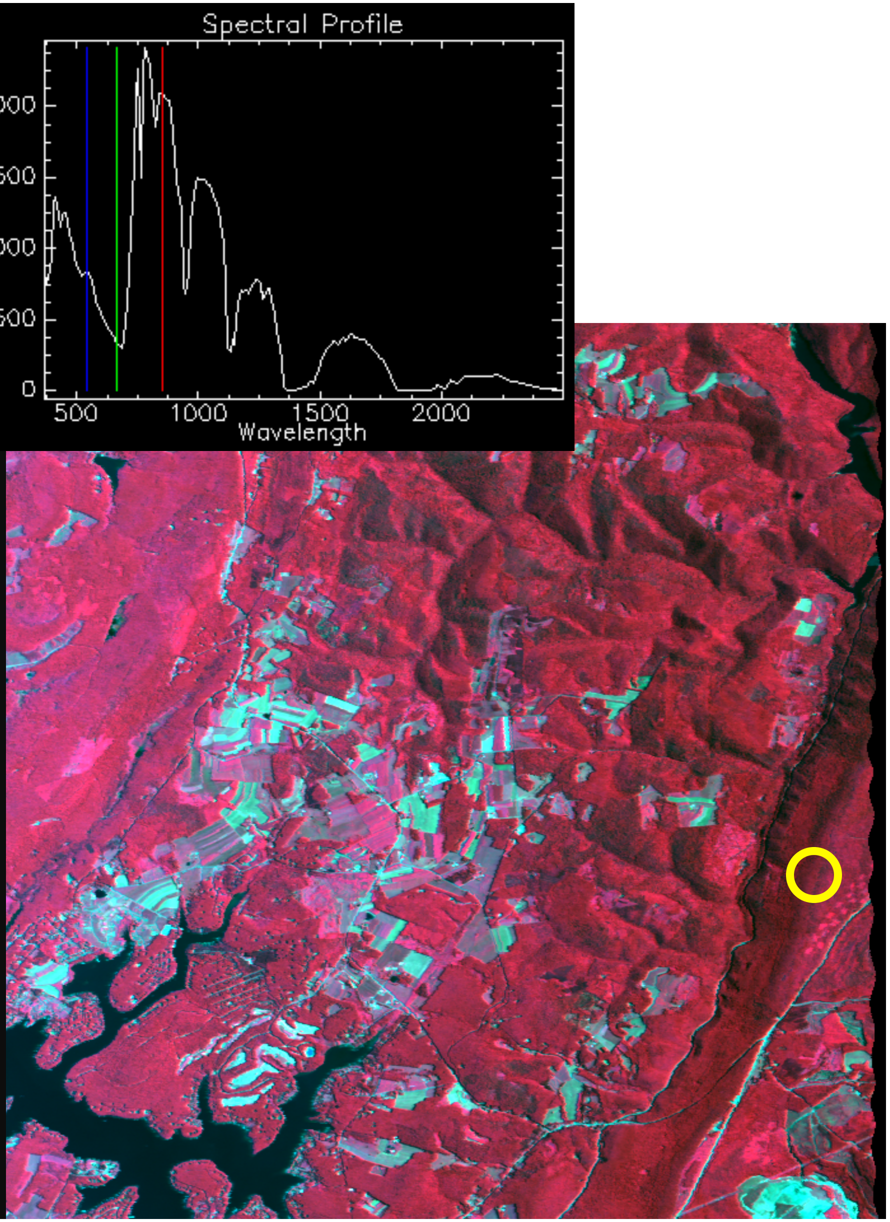
$$L_T = m \cdot cos(i) + b$$

$$cos(i) = cos(e) \cdot cos(\Phi_z) + sin(e) \cdot sin(\Phi_z) \cdot cos(\theta - \theta')$$

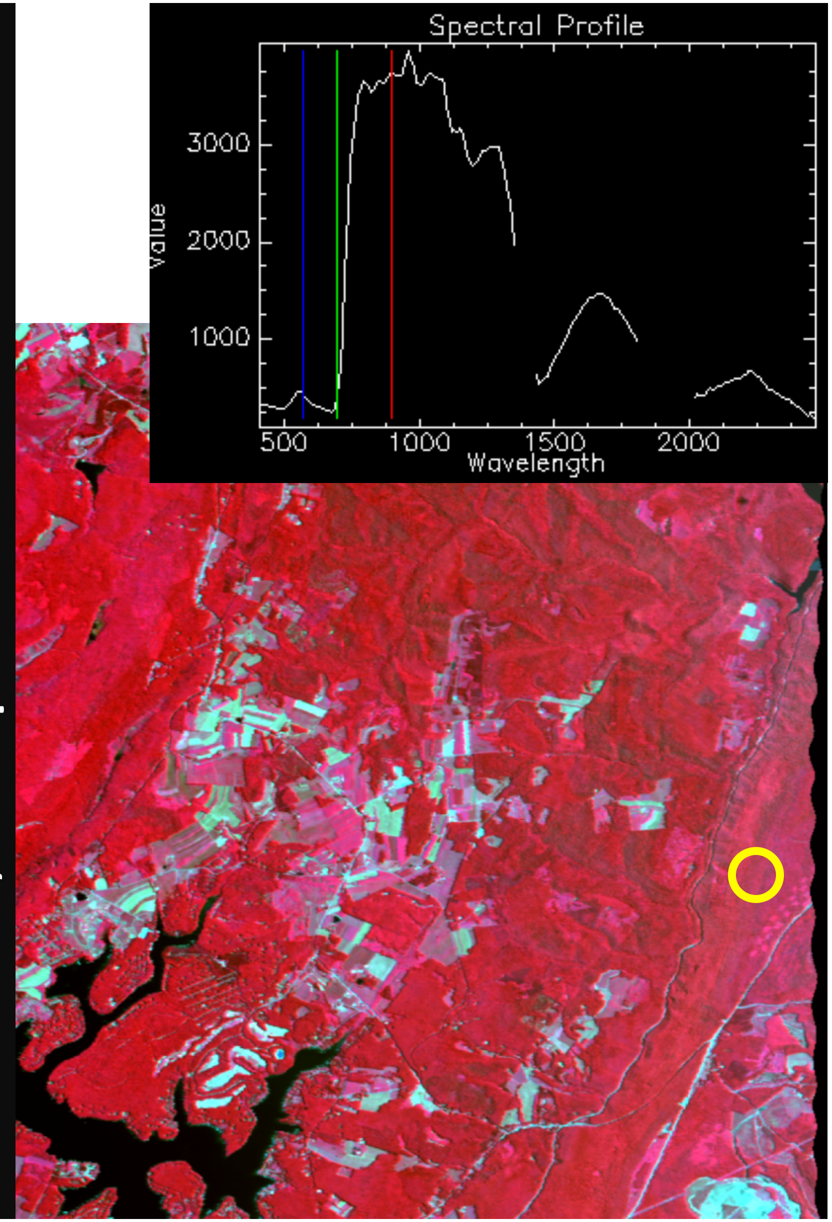
Where: *e* = terrain slope, ϕ_z solar zenith angle, θ = solar azimuth, θ' = terrain aspect

•**Note**: *cos(i), z,* images included with AVIRIS data product.

AVIRIS Pre-processing: Radiometric corrections



Uncorrected



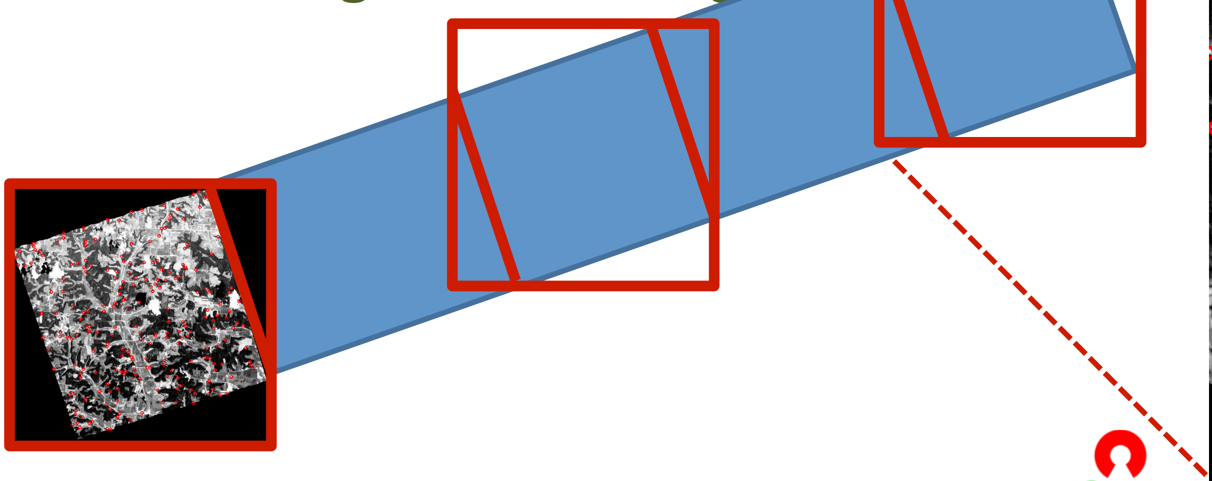
Cross-track, atmospheric and terrain corrected

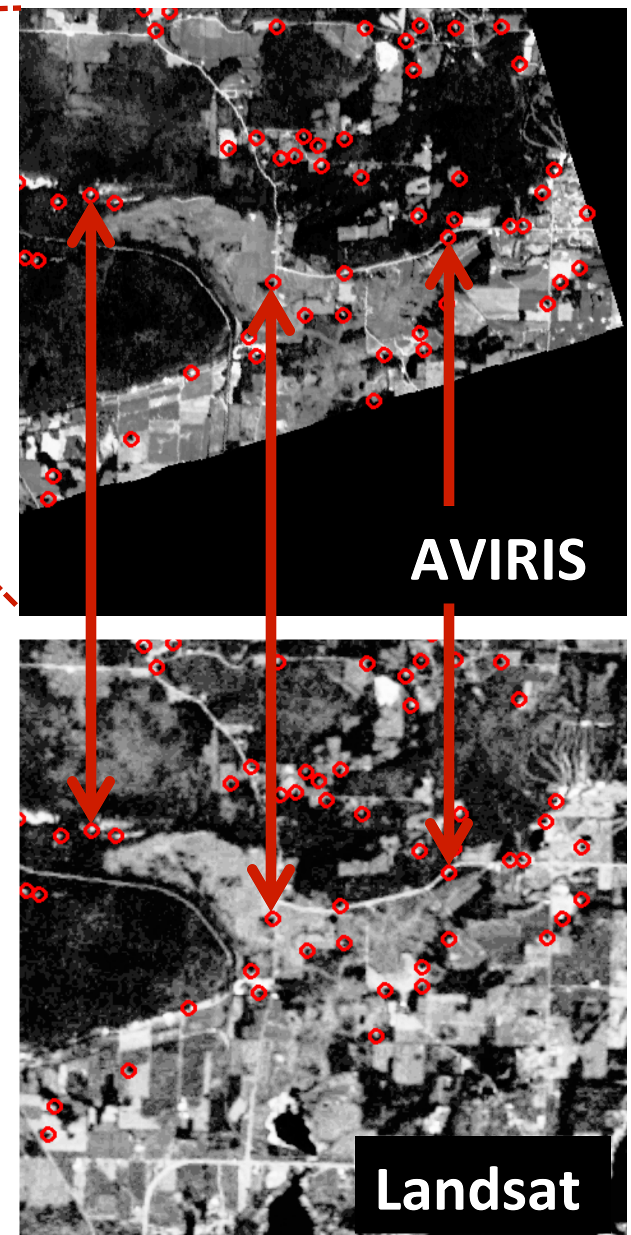
AVIRIS Pre-processing: Precision georeferencing

- **Some (orthorectified) AVIRIS images can be off by 1-5 pixels!**
  - Will cause errors when extracting spectra.
  - …pixels should be locatable to within Landsat resolution (ultimately HyspIRI), the usual reference for our plot sizes
- **Manual georeferencing possible,** time consuming, error-prone;
  - Need for a fast, automated technique (>150 images!)
- **Approach:** Use **Landsat Geocover** imagery as reference, use capabilities of the open computer vision (**OpenCV**) library to automate feature finding.

AVIRIS Pre-processing: Precision georeferencing

5. Precision georeferencing:

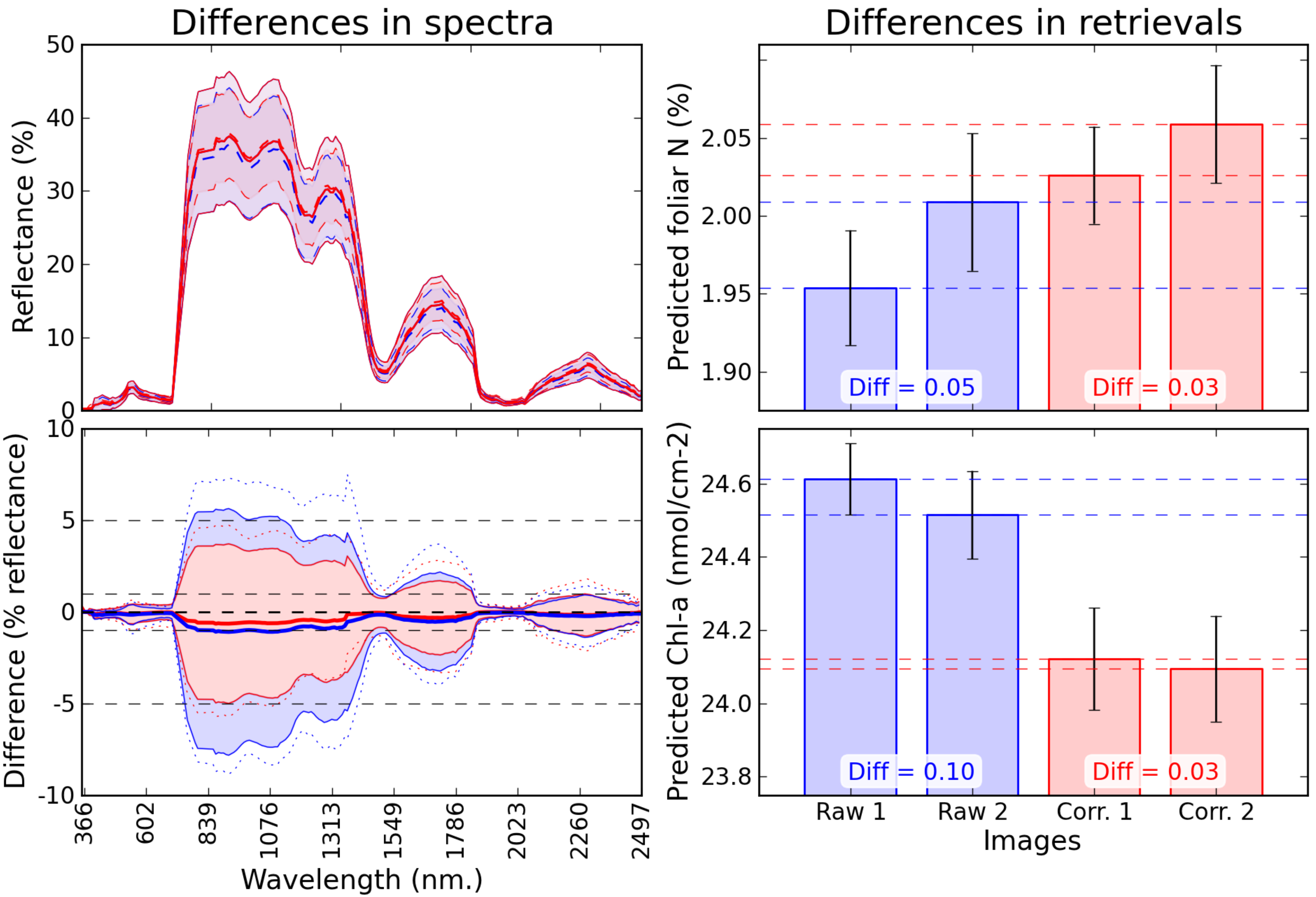




1. Get 3 chunks from AVIRIS imagery,
2. …same coverage from resampled Landsat,
3. Use **OpenCV** to find locations, match,
4. Store forward and inverse affine matrices.

RMSE <~13.0m, accuracy (R^2) > 0.99999

Test data: Comparisons with pre-processed imagery



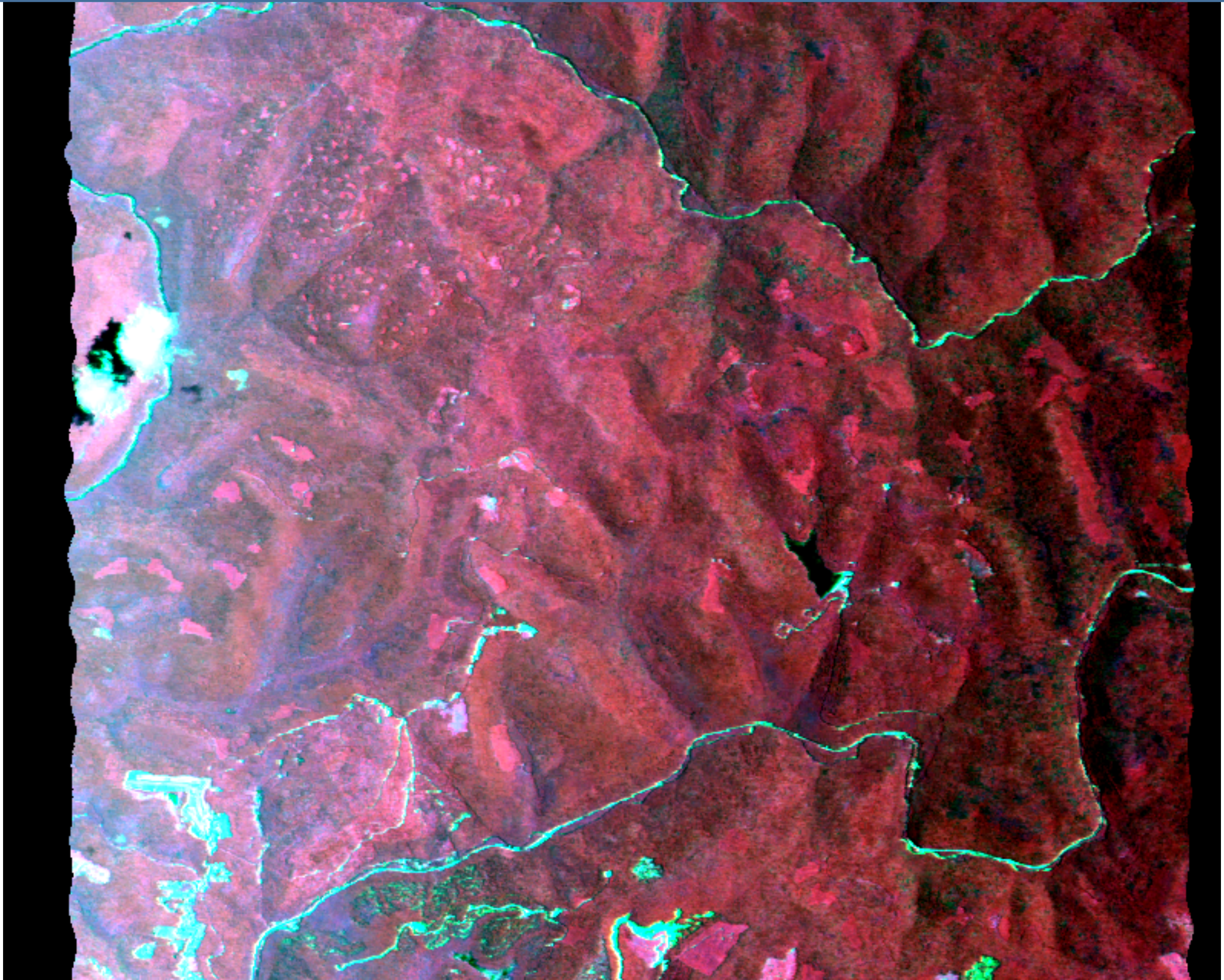
In conclusion:

- **Evidence that following a consistent pre-processing protocol may be instrumental in making ecosystem-scale predictions comparable across space and time.**

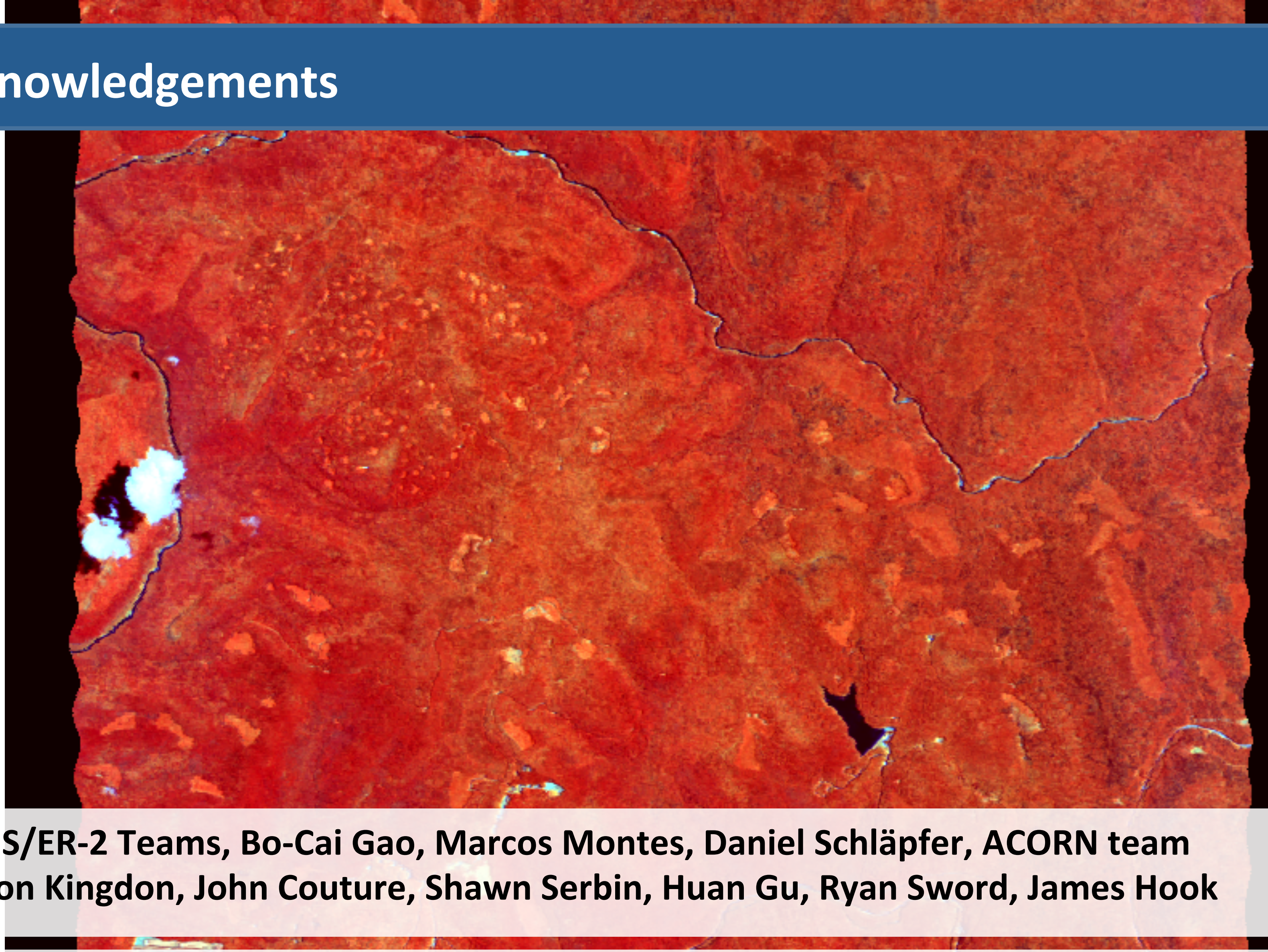
- **The tool-chain is mostly automated (using Python/IDL)**

- **We will present results comparing retrievals of key foliar biochemical and structural traits (%N, %C, %Lignin, %Cellulose, LMA, $\delta^{15}N$) from physically-based and statistical models at the upcoming HyspIRI workshop.**

Thank you. Questions?



Acknowledgements



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