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 13\textsuperscript{th} 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%.
Example: Comparison of reflectance, no other corrections applied
AVIRIS Pre-processing: Steps

- Raw image
- Atmospheric correction
- Cross-track correction
- Terrain normalization
- Cloud, shadow, water mask
- Precision georeferencing
1. Atmospheric correction: one of the following...
   - ACORN5b
   - ATREM (TAFKAA)
   - ATCOR4 (explicit scan line geometry)
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)

\[
DN = \sum_{i=1}^{n} \pi_i(N(\mu_i, \sigma_i)) \quad \text{and} \quad \sum_{i=1}^{n} \pi_i = 1
\]

- 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:** $1.33 \text{nm}^{B106} - 1.38 \text{nm}^{B110}$ and $1.77 \text{nm}^{B149} - 1.81 \text{nm}^{B153}$ using *band maximum as target spectra.*
- **Shadows:** $1.17 \text{nm}^{B87} - 1.30 \text{nm}^{B102}$ *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 $P \sim 0.95$
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
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

   \[ DN_{\lambda m} = \beta_0 + (x_m \cdot \beta_{1\lambda}) + (y_m \cdot \beta_{2\lambda}) + (y_m \cdot x_m \cdot \beta_{3\lambda}) \]

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

   \[ IL_\lambda = \beta_0 + (x \cdot \beta_{1\lambda}) + (y \cdot \beta_{2\lambda}) + (y \cdot x \cdot \beta_{3\lambda}) \]

3. De-trend image by brightness plane

   \[ DN_{c\lambda} = DN_\lambda - IL_\lambda + (DN_{\lambda m}) \]
AVIRIS Pre-processing: Cross-track illumination correction
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

\[ c = \frac{b}{m} \]

\( b \) 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, \( \phi_z \) solar zenith angle, \( \theta \) = solar azimuth, \( \theta' \) = terrain aspect

• **Note:** \( \cos(i) \), \( z \), images included with AVIRIS data product.
AVIRIS Pre-processing: Radiometric corrections

Uncorrected

Cross-track, atmospheric and terrain corrected

Spectral Profile

Value

Wavelength

500 1000 1500 2000

0 500 1000 1500 2000 2500 3000 3500

0 500 1000 1500 2000

Value

Wavelength

500 1000 1500 2000
• 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.
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 <$\sim$13.0m, accuracy ($R^2$) > 0.99999
Test data: Comparisons with pre-processed imagery

Differences in spectra

Differences in retrievals

Reflectance (%)

Predicted foliar N (%)

Predicted Chl-a (nmol/cm²)

Wavelength (nm.)
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, δ^{15}N) from physically-based and statistical models at the upcoming HySpIRI workshop.
Thank you. Questions?
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