Importance of Spatial and Radiometric Resolution of AVIRIS Data for Recognition of Mineral Endmembers in the Geiger Grade Area, Nevada, U.S.A.

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Abstract

In September 1998 NASA deployed the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) on a NOAA Twin Otter aircraft and acquired an approximately East-West line at 2000m above ground level over the Steamboat Springs - Geiger Grade area, Nevada. Data were acquired at a spatial resolution of 2.2 meters for the low-altitude data. A high altitude AVIRIS mission, flown on NASA ER-2 aircraft at 20,000m, provided data at approximately 20 meter spatial resolution. There are about 100 two meter spatial resolution elements in a 20 meter pixel. These data sets provided an excellent opportunity to evaluate the effects of linear mixtures of surface cover types on classification accuracy and the determination of end members. We found that high altitude data, for the most part, do not require extensive pre-processing and offer majority of the useful spectral content. Even though, high altitude data do not allow the mixture separation of low altitude data, they maintain an integrated data set, without the artifacts and line drops.

1.0 Geography and Geology

Geiger Grade (Figure 1) is situated on the southwestern slopes of Virginia Range, 10 miles south of Reno, NV, between the famous mines of Comstock Lode and the well-known thermal area of Steamboat Springs. The area is mountainous with elevation ranging between 4,400 ft and 6,500 ft and characterized by semi-arid climate. The exposed rocks are Tertiary andesite flows and breccias of the Alta and Kate Peak Formations. The Alta formation is most affected by hydrothermal alteration where the groundmass is devitrified and hyperstene replaced by secondary minerals indicative of propylitic and argillic alteration. (Thompson, 1956; Vikre, 1998). Geiger Grade exhibits the most spectacular evidence of alteration with bleaching, iron staining and widespread propylitization (Hudson, 1984, Vikre 1986). Predominant minerals found in/around Geiger grade are jarosite, illite, halloysite, quartz, alunite, minor biotite and iron oxides (Hudson, 1999).

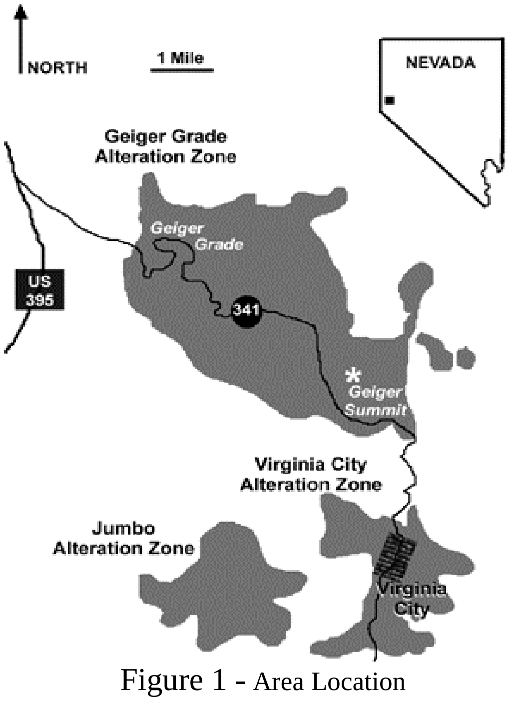

Figure 1 - Area Location

2.0 Spectral Characteristics of Alteration Minerals

The altered zones of Geiger Grade contain iron oxides, clay mineral assemblages and silicates (Hudson, 1999). Weathering of pyrite has produced heavy bleaching of the host rocks and alteration to jarosite while the propylitic and occasionally argillic alteration are characterized by chlorite, kaolinite and illite, respectively. The alteration to the host rock are visible even to the naked eye. Most iron minerals exhibit subtle spectral features in the 400-700 nm spectral range (Spatz, 1988; Taranik, 1989). The hydroxyl (OH) ion characteristic for clay minerals exhibits absorption features in 2200 – 2400 nm range (Figure 2).

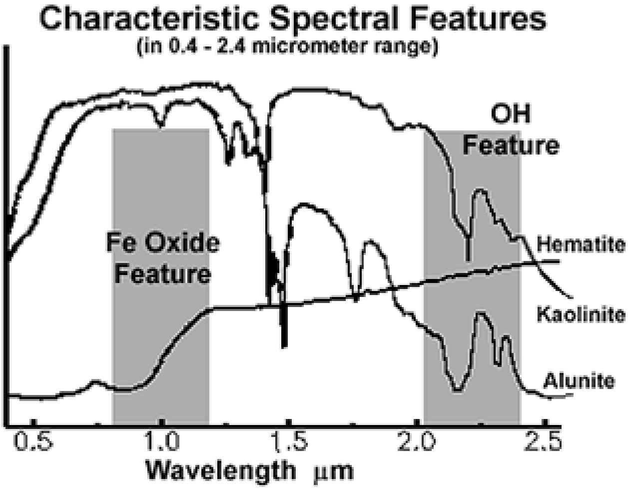

Figure 2 – Characteristic mineral spectral features in 400-2500nm range

3.0 AVIRIS Data Collection and Processing

AVIRIS Instrument is usually flown on NASA ER-2 aircraft at an altitude of 20,000 meters. This imposes certain limitations on data collection: the ER-2 has a narrow operational altitude range, fixing the AVIRIS ground pixel at 20 meters. In 1998, JPL began experimenting with a different platform (Twin Otter aircraft) and lower flight altitudes (3000 – 10,000 meters) to improve spatial resolution (down to <3 meters) (Sarture et. al, 1999). Low altitude data acquistion requires special pre-processing. Because AVIRIS is a whisk-broom type scanner, aircraft preturbations and scanner undersampling introduce geometric distortions in the data (Boardman, 1999). Furthermore, low altitude AVIRIS flight-line require greater computer processing memory than the high altitude data, and could introduce additional computer processing problems (6 Gigabytes per flightline).

4.0 Low-Altitude Issues

Even though the spatial resolution of the sensor has improved, the low altitude acquisition creates geometric distortions and undersampling in the down-track direction, particularly at ground elevations less than 6000 ft (Figure 3). In order to make coherent imagery, JPL has requested that the data be geo-rectified and undersampling gaps be “filled” with the nearest neighbor replicates. The data are filled using a 7x7 kernel, which means that up to 12-line gap in sensor measurements can be spanned in especially bad conditions. The locations of actual and “artificial” pixels are then recorded to a file (*.glt file), in which the actual pixels have positive values and artificial pixels have negative values (Boardman, 1999).

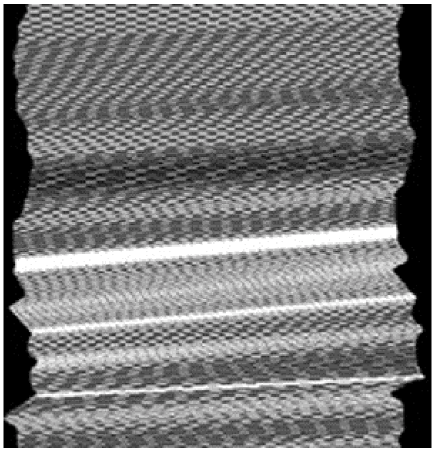

Figure 3 – Geo-rectification image map of actual pixels (white) and artificial pixels (black). Note jagged edges caused by kerneling.

5.0 Data Analysis

5.1 High-Altitude AVIRIS Data

The AVIRIS data over Geiger Grade are a subset of a larger AVIRIS scene acquired in 1995 over Steamboat Springs and Virginia City. The dataset analyzed in this paper was provided by Dr. Fred Kruse, AIG – Boulder, CO. The AVIRIS data were corrected for atmospheric effects using ATREM (Atmospheric Removal Emulation Model) (Gao et. Al 1993) and calibrated to relative reflectance using the IARR (Internally Averaged Relative Reflectance) routine (Kruse, 1988). Noise-free bands were collected for the reflectance data using MNF (Minimum Noise Fractionation) routine by estimating the noise statistics from the AVIRIS data. Twenty-five noise free bands resulting from MNF were used to calculate the PPI (Pixel Purity Index) and define “spectrally pure pixels” for the dataset. Ultimately, 5 spectral endmembers were selected to define “spectral classes” when the “pure pixels” were analyzed in the n-dimensional space. The spectral endmembers were classified using several routines:

- MTMF – Mixture Tuned Match Filtering (Boardman, 1998).
- LSU – Linear Spectral Unmixing (Boardman, 1998)
- SAM - Spectral Angle Mapper, using 2.25 radian spectral angle.(Kruse, 1988).
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5.2 Low-Altitude AVIRIS Data

The low altitude data analyzed in this paper are from scene number 8 along the flight line. The scene was cropped to remove the jagged edges caused by geo-rectification process. Because, the low-altitude the data were acquired on the altitude of 2000m, ATREM routine had to be modified for different atmospheric parameters, chiefly because ATREM default assumptions and calculations (water vapor, atmospheric gasses)are based on a 20,000m atmospheric column (high altitude data). Data processing routine used for high altitude data (MNF, PPI, MTMF, LSU and SAM) was also used for the low altitude data, resulting in selection of 5 endmembers. The scene was then co-registered to the *.glt file (file containing information on actual and artificial pixels) to locate the pixels containing original spectral measurements. Great care had to be applied to make sure that a “true” pixel was selected. Using an image mask, derived from the geo-rectification file, we were able to eliminate the artificial pixels and classify only the actual spectral measurements.

5.3 High- and Low-Altitude Data Co-Registration

High and Low altitude scenes, and a “glt-file” were co-registered using Ground-Control Points. Pixel by pixel identification then took place. Single high altitude pixel contains approximately 100 low altitude pixels and not all of the low altitude pixels may represent complete, ground instantaneous measurements (Figure 4). Thus, dismembering a high altitude pixels in a sub-pixel analysis using a low altitude data is an extremely challenging task.

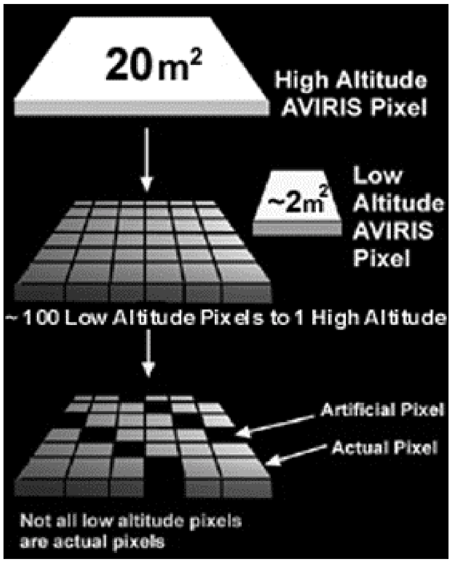

Figure 4 – High and low altitude pixel comparison.

6.0 Results

Analysis of the high altitude and low altitude data yielded comparable results in selected locales (Figure 5). The low altitude AVIRIS data better resolved mineralogic boundaries (it was easier to delineate contacts between altered, bleached and unaltered rock units). Mixtures of minerals could be more easily resolved into endmembers at smaller spatial resolution. Several spectrally unique areas were identified from the high altitude data. When the same areas were observed in the low altitude data set, the areas exhibited more spectral diversity than originally observed. Data acquired from high altitude AVIRIS measurements, at larger resolution, can detect subpixel distributions of minerals if they are spectrally dominant, but the patterns may be distributed over a larger area than is actually present on the ground (linear mixing). Thus, an area within the scene that was identified as predominantly kaolinite rich, from high altitude data, in low altitude data was found to consist of not only kaolinite, but also illite and jarosite abundant zones. Furthermore, the low altitude data indicated that the kaolinite-abundant zone is not as spatially extensive and spectrally “pure” as high altitude data may have initially suggested (Figure 5). Again a single high altitude data pixel contains roughly 100 low altitude pixels and the spectral response from the ground is thus averaged for the 20 x 20 meter area. Using averaged spectral measurement from 100 low altitude pixels, co-registered to a single high altitude pixels, it was possible to improve signal-to-noise ratio above that acquired by the high altitude data. The improved signal-to-noise ratio is evident in “deepening” of kaolinite absorption feature (Figure 6). It is important to mention, however that while the area covered with a single high altitude pixel would contain 99.9% actual spectral information, the same area covered with the low altitude pixel would be, at best, only 70% actual spectral measurement because of the undersampling (Table 1).

Table 1 – Summary of High- and Low-Altitude Data Characteristics

Data Type	Swath	GIFOV	Results:	Drawbacks:
High-Altitude AVIRIS	11km	20m	Can detect individual mineral suites, if spectrally dominant.	Dominant spectral features tend to obscure others. Spectral patterns may be distributed over larger area than actual.
Low-Altitude AVIRIS	1.8km	~3m	Ability to detect features in greater detail.	Undersampling, distortions and narrow swath.

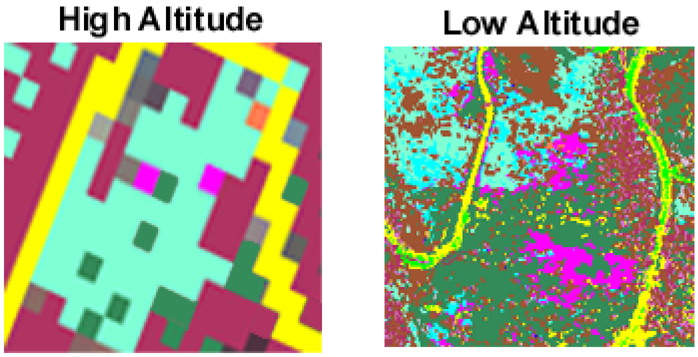

Figure 5 - Comparison between the high-altitude and low-altitude data for an area of interest.

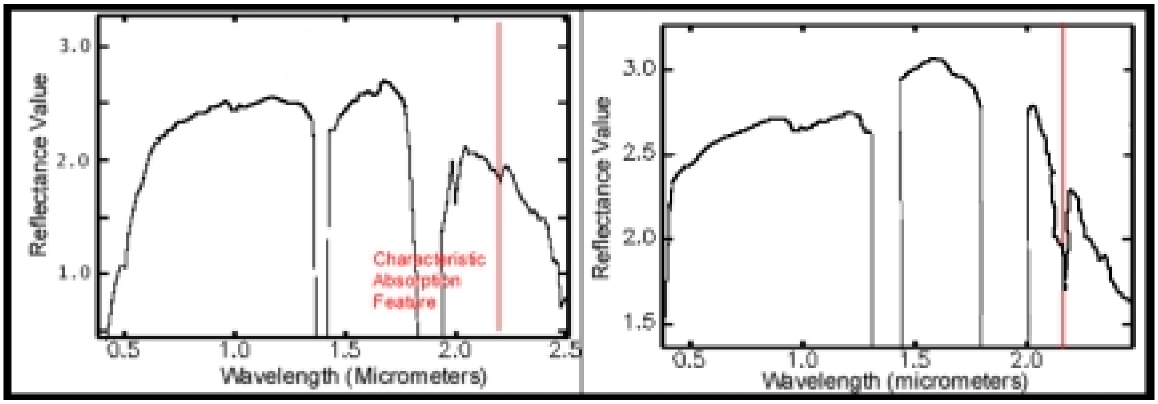

Figure 6 – Comparison of spectra acquired from a single high altitude pixel (left) and averaged spectra of 100 low-altitude pixels (right). Note deepening of kaolinite absorption feature.

7.0 Conclusion

The low altitude data may greatly enhance the spatial resolution and to some extent radiometric resolution by increasing signal-to-noise ratio when compared with high altitude data set. Averaged spectral measurements contained in low altitude pixels may aid sub-pixel analysis of conventional AVIRIS data. High altitude AVIRIS data covers approximately 11 square kilometers, while low altitude data cover about 1.8 square kilometers in a typical AVIRIS scene. Image processing, however, for the low altitude scene data is at least tripled. The low altitude data set has to be geo-rectified first, to create a coherent picture, the actual and artificial pixels have to be discriminated to classify only the actual spectral measurements Only after these pre-processing steps can the low altitude measurements successfully merged with the conventional data set. We found that high altitude set, for the most part, does not require the pre-processing steps and it offers majority of the useful spectral content. Even though high altitude data do not allow the mixture separation of low altitude data, they maintain an integrated data set, without the artifacts and line drops.

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