PRECISION GEOCODING OF LOW ALTITUDE AVIRIS DATA: LESSONS LEARNED IN 1998

Joseph W. Boardman
Analytical Imaging and Geophysics, LLC
Boulder, Colorado
boardman@aigllc.com

1. INTRODUCTION

In the autumn of 1998 an experiment was conducted deploying AVIRIS on a relatively low-altitude platform. For several months AVIRIS was operated in a NOAA Twin Otter aircraft and typically flown at 12,500 feet above sea level. This experiment, the first airborne operation of AVIRIS not in the ER-2 aircraft, successfully achieved its objective: collection of high quality, high spatial resolution AVIRIS imagery. However, new methods had to be developed and implemented to achieve acceptable image quality for data collected on the low altitude platform.

While operating on the ER-2 platform, typically at 65,000 above sea level, AVIRIS benefited from the benign imaging environment at those altitudes and its built-in roll compensation system. The ER-2 provided a very stable, predictable platform and AVIRIS was designed specifically to match its velocity and flight altitude profiles. AVIRIS on the ER-2 typically produced imagery that was visually pleasing, if not exactly planimetrically correct. In moving to the Twin Otter, operating in more turbulent air, a more robust system of spatial rectification and geocorrection was needed. AVIRIS was bolted directly to the Twin Otter airframe and the roll compensation was disabled, so any aircraft motion or vibration would manifest as image distortion.

The AVIRIS team installed a state-of-the-art GPS/INS system developed by Boeing. This C-MIGITS II device provides real-time delivery of position and attitude with excellent accuracy and precision. It operates using combined Digital Quartz Inertial Measurement Units and a MicroTracker Global Positioning System receiver. The position information from the GPS system and the 3-axis attitude data from the INS accelerometers are combined in a tightly coupled Kalman filter approach to give real-time information on x, y and z position values as well as roll, pitch and true heading. The stated accuracy is 78 meters in position and 2.0 milliradians in coarse mode, and 4.5 meters and 1.0 milliradian when operated with differential GPS. The C-MIGITS II device was bolted directly to the AVIRIS frame, measuring its position and three axes of rotation at rate of 10 Hz, nearly matching the AVIRIS scan rate of 12 Hz.

By using the high accuracy position and attitude information provided by the C-MIGITS II system it was possible to create and employ a full photogrammetric camera model for AVIRIS for the low-altitude deployment. The raw imagery is usually grossly distorted by turbulence and aircraft roll, pitch and yaw. Our image rectification process has successfully geocoded these distorted data by ray tracing each pixel to the ground surface and implementing a nearest-neighbor resampling scheme. Figure 1 shows a low-altitude AVIRIS image in its raw and geocorrected forms. After geocorrection, not only is it planimetrically correct, but it is projected absolutely in the UTM map grid system giving precise coordinates for each pixel. This paper describes and demonstrates the data and methods used to perform this geocorrection. The next section shows typical data sets and describes the processing flow in detail. The following section gives a full description of the several types of standard products produced and distributed. Finally a summary and discussion section describes some of the conclusions and caveats that relate to these experimental data.

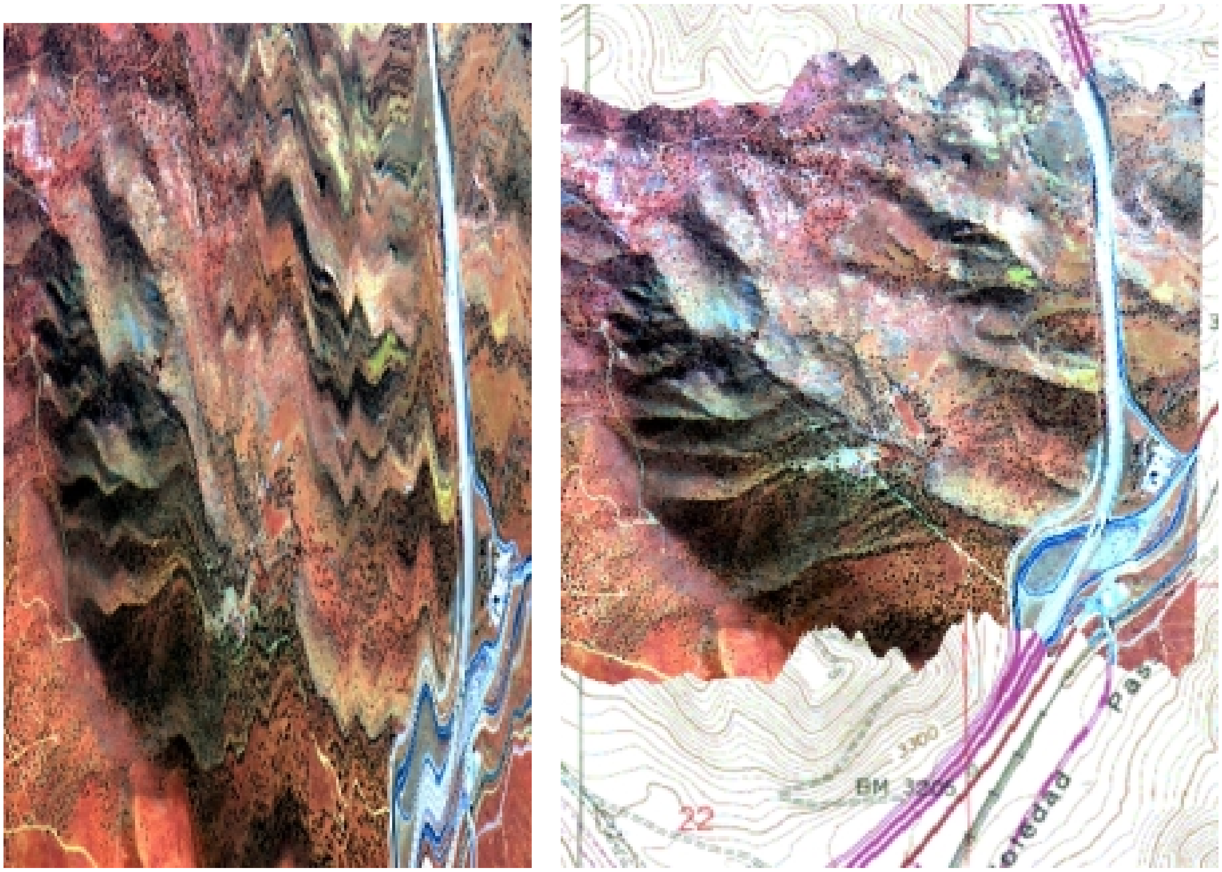

Figure 1. Raw and geocorrected AVIRIS imagery.

2. GEOCODING METHODOLOGY

The goal of the processing scheme was to employ a photogrammetric camera model for AVIRIS along with the C-MIGITS position and attitude information to provide precision geocoding of the low-altitude AVIRIS data. The AVIRIS camera model is well understood: whiskbroom scanner, 12 Hz scan rate, 30 degree FOV, 614 across-track-pixels and a 1.0 milliradian IFOV. The C-MIGITS data were used to recover the trajectory of AVIRIS as a function of scan line in both position and three axes of rotation: roll, pitch and true heading. Coupled with a global Digital Elevation Model (DEM), the AVIRIS camera model and the C-MIGITS data allowed direct recovery of the position and pointing vector for each AVIRIS pixel. Since the procedure must be robust and global in application, we chose to ray trace the pixels to a constant horizontal plane in each image (derived from the GTOPO-30 DEM) rather than performing a case-by-case orthocorrection. The method described here does not remove topography-induced image distortions. It does however remove the aircraft-induced and scan mirror-induced distortions that dominate AVIRIS low-altitude data.

The general method employed uses the standard Euler Angle approach to rotate the AVIRIS principal plane according to the roll, pitch and true heading data recorded by the C-MIGITS. By accounting for aircraft velocity and the scan cycle timing, a position and pointing vector is calculated for each AVIRIS image pixel. The average scene elevation is then calculated using the GTOPO-30 DEM, giving the elevation of the horizontal plane onto which the pixels are projected. The average flight altitude is used along with the average ground elevation to calculate the average ground clearance and thus the nominal pixel size. The pixel sizes were rounded to the nearest 0.1 meters. Typical low-altitude pixel sizes range from 3.5 to 1.7 meters, smaller for high-elevation sites like Yellowstone where the ground clearance was reduced.

The Universal Transverse Mercator (UTM) projection system was used to report the position information and for the framework of the geocorrected imagery. The North American Datum 1927 (NAD27) was employed for a horizontal datum. To minimize null border regions an optimal UTM system rotation was calculated that gave the narrowest-swath final geocorrected image. The rotation angles are integer degree values. The pixel size, UTM zone, scene elevation, and rotation angle information are reported in the header files that accompany the geocorrected products.

Since the Twin Otter has a velocity/height performance profile different from the ER-2, and AVIRIS has a fixed scan rate of 12 Hz, some undersampling did occur in the down-track direction in many scenes. Especially at high-altitude sites, where ground clearance was less than 1700 meters, there is a significant portion of the imagery that is “missing”. AVIRIS might move ahead 4 meters between scan lines, but each scan line only imaged a 1.7-meter swath, effectively skipping the remainder. At lower altitude sites, or when there was a significant headwind, little or no undersampling occurred. To provide continuous imagery, yet deliver an honest product depicting its undersampling and resulting spatial gaps, we implemented a nearest-neighbor resampling and a coded lookup table approach. The various products that form the geocoding results are discussed in the following section

3. DESCRIPTION OF STANDARD PRODUCTS

Three main types of images are produced as part of the standard geocorrection process. They are meant to provide useful tools for use of AVIRIS low-altitude data and to aid in the understanding of the data, their collection and limitations. Each of the three file types is described here.

3.1 Input Geometry File

Input geometry files (named with “_igm” file extensions) denote the UTM Easting and Northing values derived by the geocorrection process for each original image pixel. If a nominal AVIRIS scene is 614 samples, 1000 lines and 224 bands, then its corresponding input geometry file will be 614 samples, 1000 lines and 2 bands. The first band contains UTM Easting values in meters and the second band contains UTM Northing values in meters for each original pixel. The input geometry files have the same spatial size as the raw AVIRIS imagery. The file is double precision, binary data in a BIL format. The scene elevation, pixel size and UTM zone number information are given in an associated ASCII header file. The input geometry file itself is not geocorrected, but does contain the geolocation information for each original raw pixel. Figure 2 shows a portion of the two bands of a typical “_igm” file.

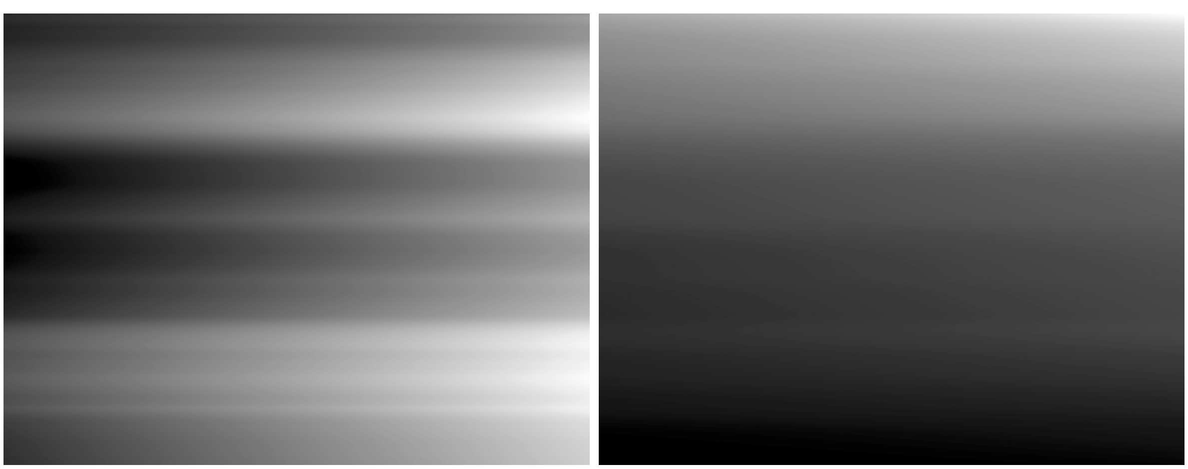

Figure 2. Typical IGM file (Easting values in band 1, Northing values in band 2)

3.2 Geometric Lookup Table File

The geometric lookup table files (named with "_glt" file extensions) represent much of the important information that is created in the geocorrection process. The "_glt" file contains the information about which original pixel occupies which output pixel in the final product. Additionally, it is sign-coded to indicate if a certain output pixel is "real" or a nearest-neighbor infill pixel. The "_glt" file is a geocorrected product, with a fixed pixel size projected into a rotated UTM system. The pixel size, scene elevation, UTM zone number and rotation angle information is reported in an associated ASCII header file. The "_glt" file itself is two-byte integer binary data in a BIL format. The two bands of the "_glt" file refer to original sample number and original line number respectively. The sign of the value indicates whether the pixel is an actual image pixel, located at its proper position (indicated by a positive value) or a nearest-neighbor infill pixel placed to fill an undersampling image gap (indicated by a negative value). The importance of the "_glt" image and its role in identifying image gaps and infill pixels must be stressed, especially for studies involving small targets. The geometric lookup table image, along with the raw imagery, can be used to geocorrect any band or derived product through a simple lookup table procedure. Figure 3 shows a portion of a typical lookup table image.

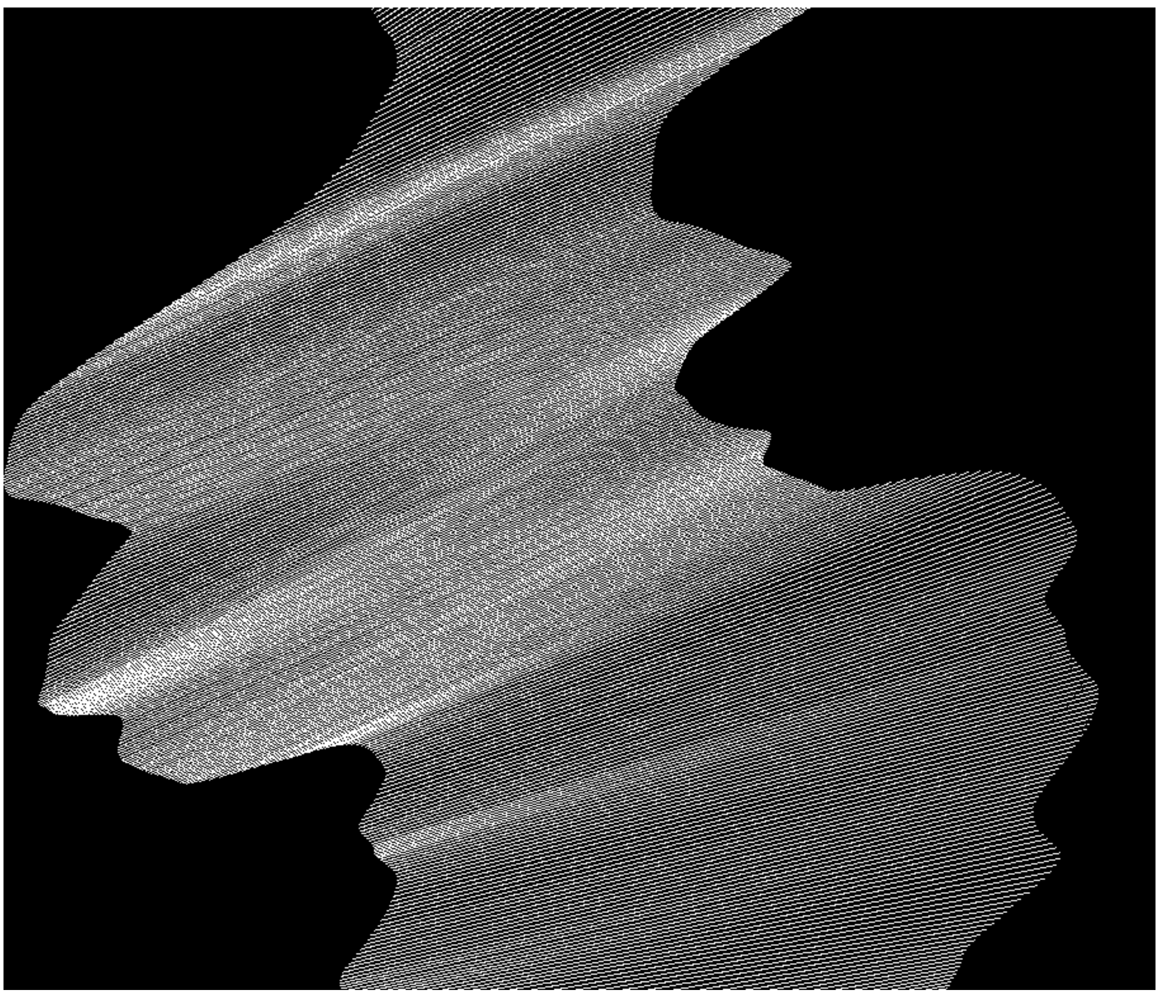

Figure 3. Typical GLT file.

3.3 Geocorrected Imagery

Applying the geometric lookup table to the full AVIRIS data set creates a fully geocorrected image cube. These files (named with "_geo" file extensions) represent the final product of the geocorrection process. While these images are visually pleasing and map-correct, they do have several practical drawbacks. First they have null values around their edges that must be masked in processing. Secondly they are often inflated in size by replicate pixels, as discussed above, and as indicated in the "_glt" files. These two complications lead to our suggestion to acquire and process the AVIRIS imagery in its raw spatial format, then apply the geocorrection to several bands for a reference image and to the derived products. The "_geo" files match the "_glt" files exactly in sample and line number as well as geocoding information. The accompanying ASCII header file has the map information, matching the "_glt" file. Figures 4 and 5 show a comparison of raw and corrected imagery, demonstrating the power and robustness of the process.

Figure 4. Raw imagery.

Figure 5. Geocoded version of imagery in Figure 4.

4. SUMMARY AND DISCUSSION

The geocoding results from the 1998 AVIRIS low-altitude experiment were very encouraging. The resulting imagery is quite useful and appears in most cases to have high spatial fidelity and to match ground truth well. Nevertheless, several problems unique to the 1998 experiment compromised some of the data and limited their ultimate accuracy. There was a problem in the orientation of the C-MIGITS device on AVIRIS, resulting in initialization and stability problems. Essentially the Kalman filter did not expect to be flying "sideways". As a result some data sets were unusable and others showed attitude errors. In the 1998 deployment, differential GPS was not used so all the data sets suffer from the error introduced by Selective Availability. Our experience with 1998 data has shown that a constant offset of up to 100 meters in Easting and Northing may be needed to align the geocorrected data sets with absolute ground control. The undersampling problem, a combined effect of ground speed, scan rate and ground clearance, is worst for high altitude scenes and virtually nonexistent for some lower altitude scenes. Clearly AVIRIS, on the Twin Otter with a C-MIGITS and proper geocorrection processing can collect excellent data with pixel sizes ranging from 1.7 to 4 meters. AVIRIS data collected in 1999, from both high and low altitude platforms, will be accompanied by C-MIGITS data and similar geocorrection.