COMBINATION OF GEOMETRIC AND ATMOSPHERIC CORRECTION FOR AVIRIS DATA IN RUGGED TERRAIN

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1. INTRODUCTION

In the past years, knowledge and general methodology for geometric and atmospheric correction has been extended continuously. However, these two important preprocessing steps for hyperspectral data have not been combined so far in a complete and efficient manner. Therefore, we implement and test a combination of the parametric geocoding application PARGE and the atmospheric correction software package ATCOR for airborne hyperspectral data in view of ESA's Airborne PRISM experiment (APEX). The effectiveness of this preprocessing chain is verified using 1998 AVIRIS data over a Ray Mine area in Arizona. First, both a low and a high altitude data set are orthorectified with respect to the USGS digital elevation model (DEM) of the area. For this purpose, the PARGE application is applied, using a set of about 20 ground control points (GCPs) combined with the instrument GPS/INS. We achieve an overall accuracy of about 10 m for the low altitude data, whereas results for the high altitude data are less precise due to a lack of accurate GPS airplane position measurements in 1998. Secondly, this geocoding output is used by ATCOR for terrain-dependent radiometric and atmospheric correction. Resulting reflectance spectra are compared between the scenes and evaluated with regard to the differences in processed reflectance and terrain influence.

1.1 The Data

An AVIRIS data set from Ray Mine (AZ), acquired in 1998, is chosen as a validation set for many reasons. First of all, AVIRIS data are renowned for reliability in terms of radiometric calibration and therefore suited for full radiometric correction. Second, an extensive set of five AVIRIS runs was carried out across the area, partly from the ER-2 at 20 km altitude, and partly from a NOAA Twin Otter aircraft at 4 km height above ground. This data set opens various possibilities to study scaling issues in time and space. For this study, two runs have been selected:

- f981003t01p01_r04: North-south flight, Ray Mine, flight altitude: 4 km, pixel size: 3.6 m
- f980605t01p02_r02: Flight from NW to SE across the same area, altitude: 21 km, pixel size: 20 m

Additional data included the separate GPS data streams for the low altitude data, the 7.5 Minutes USGS DEM, and a set of 23 ground control points measured in the field by a handheld GPS unit.

2. GEOMETRIC CORRECTION

Geometric correction has become increasingly important for many applications in hyperspectral remote sensing, and for the incorporation of data products into geographic information systems. Since airborne systems are never as stable in the air as satellite sensors, the platform movement has to be taken into account. Distortions caused by these instabilities can be readily removed by simple correction techniques, rendering the data suitable for further standard registration processes as applied to satellite imagery. The complexity of the problem increases dramatically as soon as spectra are to be located in relation to a known surface geometry, given by a DEM, ground control points, or digital maps. Most of the currently available imaging spectrometers have the equipment for measuring position and scan angle of the sensor quite accurately. In many cases though, content, calibration, and even simple formatting of this auxiliary information is poorly documented. Therefore, correct synchronization and recalibration of the auxiliary data to the image reference system is a major task of an ortho-rectification procedure.

2.1 The PARGE Application

PARGE is a parametric ortho-rectification package which has been developed in the past years specifically for application to imaging spectrometry data (Meyer, 1994; Schläpfer et al.,1998). It requires a set of auxiliary and DEM input data for its mathematical solution of the airborne image geometry. Additionally, GCP-based algorithms are available for recalibration of the auxiliary data streams whenever necessary. PARGE is currently available on a commercial basis from the author as standalone package, based on IDL and ENVI standards. It supports HyMap, DAIS and AVIRIS formats, but may also be adapted to other sensor types.

2.2 Co-Registration of High and Low Altitude Data

With increasing availability of optical remote sensing data, the issue of co-registration between individual scenes as well as from imagery to terrain becomes more important. A “clean” approach of co-registration has been pursued in this paper that does not refer either image to each other. In PARGE, the terrain model serves as master for the ortho-rectification procedure.

The following steps are performed for an exact geocorrection of the two images:

1) Import the AVIRIS data and associated data streams using standard settings for the sensor characteristics and special filters for the AVIRIS *.nav/*.eng and the non-standard *.gps files,
2) Synchronize the two data sets using the offset between the two master clocks (automatic),
3) Import a set of 10-20 ground control points,
4) Import a USGS standard DEM; resize DEM to the required output resolution,
5) Derive the heights of the GCPs and calculate the offsets for roll and pitch,
6) Offset the roll/pitch/heading values based on GCP offsets,
7) For high altitude data only: interpolate roll and pitch drifts over best-known GCPs,
8) Calculate pixels’ positions through intersection with DEM,
9) Geocode whole image cube.

This process can be very time-consuming, e.g. if some of the data is wrong defined or if the coordinate transformation and formats of the GPS systems are not precisely known. We therefore recommend to apply such a procedure with well-defined and calibrated systems and complete data sets only.

The results of the co-registration are shown in Figure 1. A subset of about 1500 lines of the low altitude data is overlaid on the high altitude image and the USGS shaded DEM, calculated at a resolution of 3.75 meters.

2.3 Accuracy Analysis

The quality of results is evaluated visually in comparison to the DEM and between the two images. Overall accuracy turns out to be stable throughout the high altitude and low altitude flightlines which consist of 1478 and 4487 contiguous scan lines, respectively. A relative accuracy of 1-2 high altitude pixels (20 - 40m) has been observed. This accuracy is within the accuracy of GCP measurement in the image, but is also caused by some problems in the high altitude auxiliary data streams. For the low altitude scene, the residuals of the GCPs indicate an error in the range of down to 10m. These residual geocoding errors can be attributed to various sources:

DEM

DEM resolution and positional accuracy are major error sources in the ortho-rectification process. Considering in addition vegetation height, matching problems increase since standard DEMs seldom represent the observable sur-

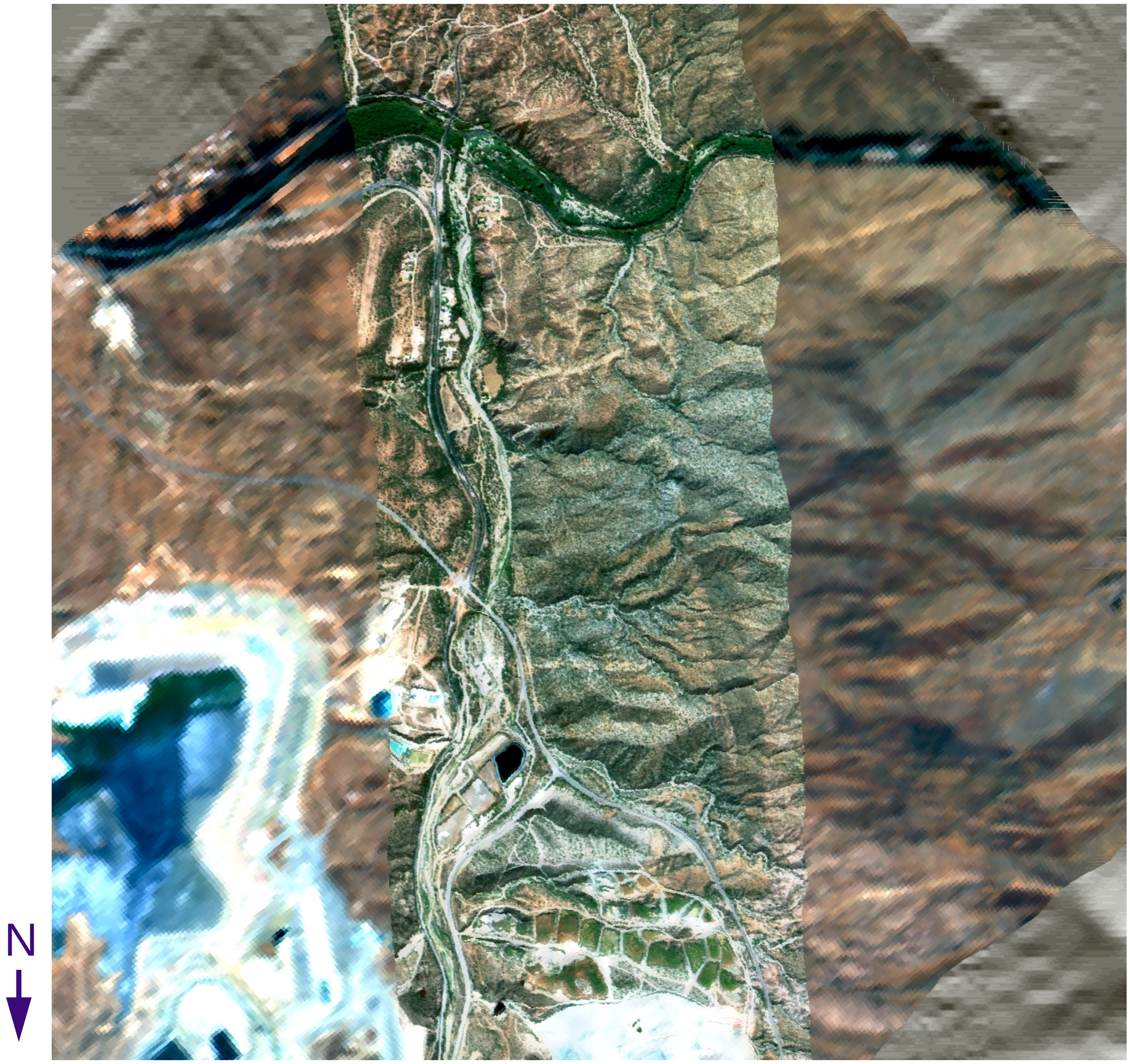

Figure 1: Co-registered AVIRIS data over the Ray Mine Area (AZ). Data from a shaded relief, the AVIRIS high altitude scene from June 1998, and the low altitude scene from October 1998 have been overlaid.

face. Vertical accuracy can be easily related to horizontal accuracy via the scan zenith angle. A short analysis of the DEM-related horizontal error is shown below (Table 1).

Table 1: Horizontal accuracy in relation to the scan zenith angle and the DEM vertical error.

Off-Nadir Scan Angle	Δh = 5m	Δh = 10m	Δh = 20m	Δh = 75m	Δh = 100m
10°	0.9	1.8	3.6	13.2	17.6
15°	1.3	2.7	5.4	20.1	26.8
20°	1.8	3.6	7.3	27.3	36.4
30°	2.9	5.8	11.5	43.3	57.7
40°	4.2	8.4	16.8	62.9	83.9

For AVIRIS having a FOV of ±15 degrees and high altitude data with 20 m resolution, Table 1 indicates critical DEM amplitudes of about 75m, at which pixel accuracy becomes affected. If considering low altitude data (3-4 m pixel size), this criterion reduces to below 20 m, the height of a typical building or a forest. Given these circumstances, the relatively poorly resolved USGS standard DEM did of course not yield optimal results for the low altitude data.

GPS/DGPS
The flight path of the aircraft as well as ground control points are measured with GPS/DGPS systems. Their accuracy is nowadays good enough compared to the pixel size of AVIRIS. Anyhow, a number of problems has been encountered during processing: care has to be taken in the transformation of the GPS coordinates in order that all data (GCP, flightpath, DEM) be available in the same UTM coordinate system. Furthermore, the altitude measurement of the aircraft GPS systems frequently lacks absolute accuracy and may be affected by artefacts due to satellite configuration changes. Filtering and correcting of the aircraft GPS altitude data is therefore often required.

Heading
True heading, i.e. the angle between aircraft orientation and (map-)direction north, is used by the PARGE algorithm, and has therefore to be a known variable. The declination offset is found from the GCP analysis, resulting in a correction of heading data.

Roll/Pitch
A reference point for the roll and pitch data was unknown and had to be reconstructed using the GCPs. Both parameters may be affected by drifts, particularly within long image runs (i.e. > 2000 lines). A drift correction may lead to an improvement of results, but was only done for the high altitude data set. Another problem here is the standard roll compensation of the AVIRIS high altitude data: the provided roll parameters could not be used for processing. Anyhow, a significant residual roll could be reconstructed from the GCPs.

Sensor Description
A final error source is the description of the sensor itself. Exact knowledge of the FOV is crucial while an equally spaced scanning across track is assumed for whiskbroom scanners. Note that these intrinsic geometric parameters may be substantially different for pushbroom instruments.

3. RADIOMETRIC CORRECTION

In general, we talk about radiometric correction as a complete physical preprocessing of hyperspectral imagery including atmospheric properties, terrain influences, illumination, and scan angle dependencies, among others. The process applied to the geocoded AVIRIS imagery includes the correction for general BRDF properties of the ground and the solar incidence dependent illumination of each pixel. It therefore may be distinguished from a pure "atmospheric correction" that would only account for atmospheric scattering and absorption in relation to the terrain height and the scan angles.

The two AVIRIS data sets are radiometrically corrected in order to allow their comparison, for they have been acquired under completely different radiometric conditions.

3.1 Link of PARGE to the Radiometric Correction

Special outputs of the geocoding application PARGE are scan zenith and azimuth angles per image pixel. After calculating the geometry for each pixel, they are stored as separate layers in the image cube. This output, together with the DEM-derived parameters, such as slope, aspect, and elevation, form one of the main inputs for subsequent radiometric correction. Consequently, a close alliance between PARGE and the atmospheric correction package ATCOR has been established for complete radiometric processing of airborne imaging spectrometry data. The overall processing scheme is shown in Figure 2. The same DEM is used in both processing steps. Radiometric standard products (e.g. FPAR, LAI, solar flux,...) can be created with ATCOR during radiometric processing, and be used directly for application oriented modeling.

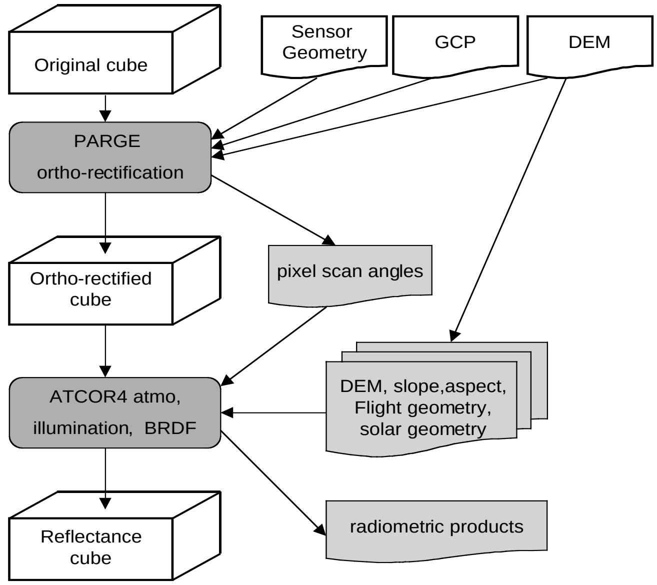

Figure 2: Process flow of the combined geometric/atmospheric processing chain, including PARGE and ATCOR applications.

3.2 The ATCOR4 Application

ATCOR 4 has been developed at DLR Munich in the last years as a complete hyperspectral atmospheric correction and in-flight calibration package (cf. Richter, 1996, 1997, 2000). The first step of the atmospheric correction algorithm employs the MODTRAN4 (Berk et al. 1989, 1999) radiative transfer code to calculate look-up tables (LUT) of the atmospheric correction functions (path radiance, atmospheric transmittance, direct and diffuse solar flux) that depend on scan angle, relative azimuth angle between scan line and solar azimuth, and terrain elevation. Results for the reflective wavelength range (0.35-2.55 µm) are stored in a spectral database. The second step performs the resampling with the channel-specific spectral response of the sensor. Thirdly, surface reflectances for flat or rugged terrain are calculated. In case of rugged terrain, information from a digital terrain model is employed to account for surface elevation, slope, and orientation. The ground reflectance calculation is based on the assumption that the scene consists of Lambertian surface elements. However, an interface to bidirectional reflectance models is provided for enhanced scene-dependent evaluations.

The generated LUTs depend on terrain altitude, scan zenith, wavelength and albedo. Other parameters have to be specified as input to the LUT generation module:

- MODTRAN-specific atmospheric parameters (standard atmosphere, aerosol model, ground visibility),
- Sensor geometry parameters (range of FOV, ground pixel size, flight altitude, ground altitude range),
- Illumination parameters (geographical coordinates, sun zenith and azimuth angles).

The LUT contains information on the different components of radiation. It is subsequently interpolated for each pixel using ground altitude and scan zenith angle.

The application is currently in operational use at DLR's hyperspectral processing facility and will be available soon as commercial product.

4. RESULTS

The processing chain described above is applied to the data, resulting in spatially and spectrally co-registered data sets from the two dates.

4.1 Low Altitude Scene

After synchronizing external GPS and AVIRIS data, the low altitude image strip (4487 lines) is geocoded with satisfying accuracy, although time synchronization remains an issue. It took a number of attempts to finally obtain well fit-

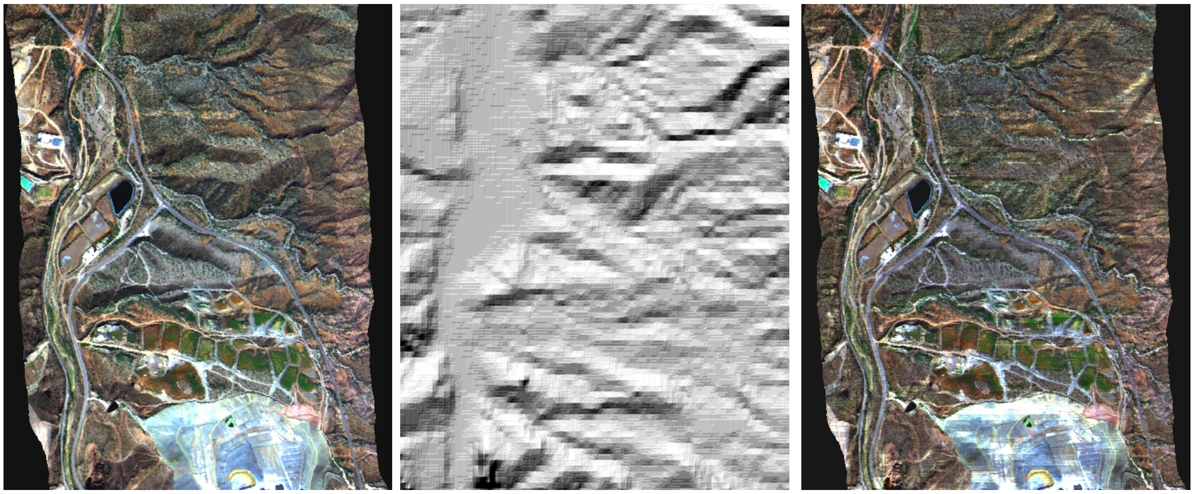

Figure 3: Atmospheric/radiometric correction result for the low altitude image data. Terrain shading has almost been eliminated; artefacts still occur due to terrain changes in the mining district, and coarse DEM resolution.

ting offset values for pitch and heading from the set of 18 ground control points available for this scene, mainly due to some erroneous GCPs.

The 30m horizontal resolution of the available USGS 7.5 Minutes DEM is almost an order of magnitude worse than the image resolution of 3 - 4 meters. Nevertheless, it still enhances overall accuracy compared to a flat terrain assumption, because in this scene altitude ranges from 500 to about 800 meters.

The atmospheric correction is based on an average flight heading of 190 degrees, a solar zenith angle of 38.5 degrees, and a solar azimuth of 162.8 degrees; according to the data acquisition date in the first days of October. We assumed a US standard atmosphere with water vapor scale being 0.9 times the standard amount, and with a clear desert aerosol model (80 km visibility).

The results of the processing are depicted in Figure 3: The radiometric processing removes the terrain shading effects significantly. Some residuals can be observed for fine terrain structures, which have not been represented by the DEM. Some overcorrections occur within the mining district itself, since the DEM obviously does not represent the actual shape of the terrain. The profiles in Figure 4 depict the improved comparability of spectra on slopes of varying exposition after radiometric correction.

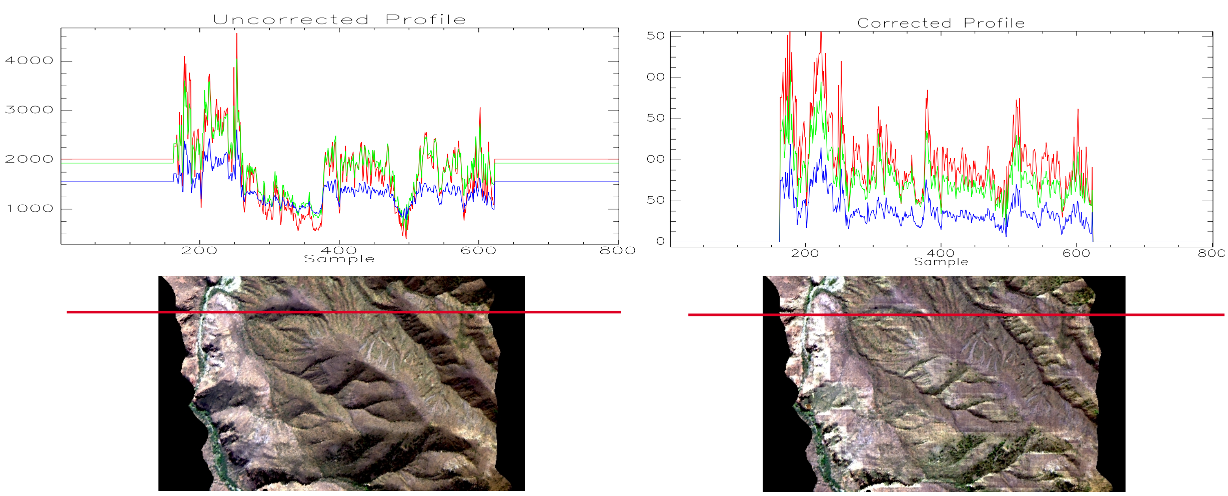

Figure 4: Arbitrary profile through the image data, left: uncorrected (scaled at-sensor radiance), right: corrected (surface reflectance).

4.2 High Altitude Scene

As already mentioned above, the high altitude data acquisition has not been supported by high precision GPS and attitude measurement and was stored using the AVIRIS standard roll compensation procedure. It therefore was necessary to adaptively interpolate the roll and pitch values over the whole run using the best of the 25 available GCPs. The such interpolated residual roll was significantly different from a stable data take; variations corresponding to up to 5 mrad (5 pixel errors) have been reconstructed and applied.

The radiometric processing has been based on a sun zenith angle of 11.8°, an azimuth of 153.8° and an average heading of 140°. The US standard atmosphere, having 0.5 times the water content, and a rural aerosol model has been derived as best suited. It was possible to correct for the radiometric influence in almost the same accuracy as for the low altitude scenes. Only in image line ranges without any GCPs, the accuracy was down to about 3 pixels what resulted in residual over/under corrections along the terrain structures.

4.3 Inter-Scene Comparison

The final goal of any radiometric correction is the achievement of comparability between scenes taken under differing environmental conditions. We thus compare the co-registered images on the basis of example spectra (compare Figure 5). The water reflectance is almost constant at 1-2% for both scenes, while the agreement between vegetation

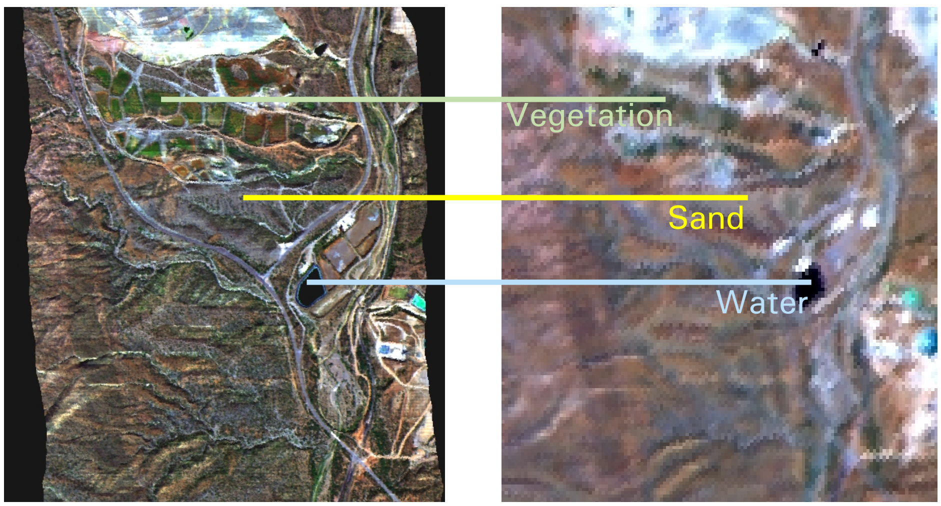

Figure 5: Spectral test areas in the radiometrically corrected and co-registered low altitude data (left) and the high altitude data (right).

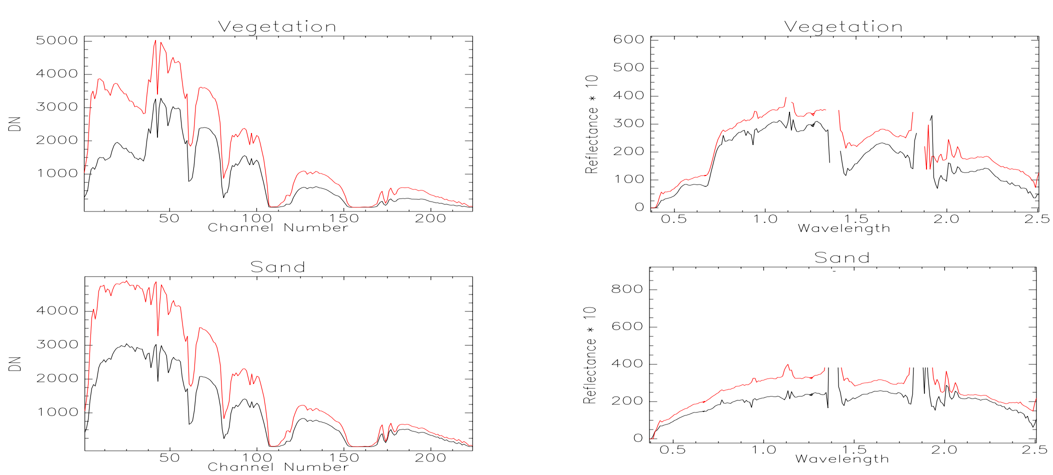

Figure 6: Comparison of multitemporal and -resolution radiometric correction results. Upper curve: 5.6.1998, high altitude, lower curve: 10.3.1998, low altitude.

and sand spectra is in the range of about 20% as depicted in Figure 6. These almost systematic offsets have been attributed to BRDF effects due to the difference in solar zenith angle, but may also represent real changes of the surface reflectance between the two dates of data acquisition.

5. CONCLUSIONS

A complete geometric and atmospheric processing chain has been proven to provide valuable results for radiometric processing of AVIRIS data for low altitude data as well as for high altitude data. This type of processing is required for many applications including multi temporal analysis and vegetation coverage study in rugged terrain. It also prevents users from errors due to misregistration and radiometric offsets.

A number of error sources are identified for the geometric processing whose influence will be reduced for future instruments (e.g. APEX) and processing efforts. Given these errors, the AVIRIS co-registration is possible to about 10 - 40m, depending on the DEM and the number of GCPs employed. Pixel accuracy seems only to be in the reach if higher precision DGPS, attitude gyros, and DEMs are employed with the AVIRIS data.

The link between the preprocessing applications PARGE (geometric correction) and ATCOR4 (radiometric correction) is now established and an integral processing of hyperspectral data to normalized reflectance images based on a DEM is possible and available on a commercial basis. This option is of specific interest for people who have to deal with hyperspectral data in mountainous terrain.

To address remaining radiometric differences in time and scale, BRDF correction algorithms are currently under development for later integration into the system. A further operationalization of the processing chain is planned for implementation with ESA's APEX system.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Berk A., Bernsten L.S., and Robertson D.C., 1989: *MODTRAN: A Moderate Resolution Model for LOWTRAN7.* Air Force Geophysics Laboratory, Hanscom AFB, MA, GL-TR-89-0122, pp. 38.

Berk, A., Bernstein, L.S., Anderson, G.P., Acharya, P.K., Robertson, D.C.,Chetwynd, J.H., and Adler-Golden, S.M., 1998: MODTRAN cloud and multiple scattering upgrades with application to AVIRIS, *Remote Sens. Environ.*, 65:367-375.

Meyer P., 1994: A Parametric Approach for the Geocoding of Airborne Visible/Infrared Spectrometer (AVIRIS) Data in Rugged Terrain. *Remote Sens. Environ.*, 49(2):118 - 130.

Richter R., 1996: Atmospheric Correction of DAIS Hyperspectral Image Data. Im. Spec. of the Terrestrial Environment, Orlando, *SPIE Vol. 2758*:390-399.

Richter R., 1997: Correction of atmospheric and topographic effects for high spatial resolution satellite imagery. *Int. J. Rem. Sens.*, 18(13):1099-1111.

Richter, R., 2000: *Atmospheric / Topographic Correction for Wide FOV Airborne Imagery: Model ATCOR4.* DLR Internal Report, DLR-IB 552-05/00, pp. 62.

Schläpfer D., Meyer P., and Itten K.I., 1998: Parametric Geocoding of AVIRIS Data Using a Ground Control Point Derived Flightpath. Summaries of the Seventh JPL Airborne Earth Science Workshop, JPL, Pasadena (CA), 97-21, Vol. 1:367-372.

Schläpfer D., Schaepman M., and Itten K.I., 1998: PARGE: Parametric Geocoding Based on GCP-Calibrated Auxiliary Data. Imaging Spectrometry IV, *SPIE Vol. 3438*:334-344.