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N6SP – Standards and Protocols

DN6.2.2 – Software test and comparison report Documentation on best practices

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2. Introduction

An important issue of N6SP is to support users and operators with recommendations on best practice and state-of-the-art software for airborne data pre-processing.
As a follow-up of DN 6.2.1, which provides a list of existing data-pre-processing software and algorithms for hyperspectral image processing and in-situ measurement processing, this deliverable concludes with a report on software test and comparison (where applicable). This study includes software performance results and information on the availability and adaptability of processing software, and covers the first part of the deliverable.
The second part of this report comprises a catalogue of best practices for the different steps of data pre-processing. This should be directly made available on the EUFAR website for users.

3. Software Test and Comparison Report

3.1. Data Pre-Processing of Imaging Spectrometer Data

System Correction Programs

The system correction is highly sensor-specific, and so is the processing software. Therefore any comparison of software is not reasonable as the procedures are significantly different. Furthermore the software is usually protected by intellectual property laws and thus provided as "closed source", so no insight is possible.

Atmospheric Correction Programs

A comparison between ATCOR and FLAASH

1 Background

FLAASH and ATCOR are both powerful and widely accepted software in the realm of atmospheric correction, which is a necessary step to remove atmospheric contributions and generate surface reflectance from air-borne or space-borne imaging spectrometer data. Both software have algorithms based on the radiative transfer modeling, and both use the same radiative transfer code, namely MODTRAN. However there are also some differences between these two software when it comes to the system requirements, correction capabilities and the amount of control users are allowed to have.

2 Comparison

This section reports the differences between the two software in detail.

2.1 System Requirements

Both ATCOR and FLAASH run on a number of operating systems, such as windows, Solaris and Linux. ATCOR also runs on MacOX while FLAASH does not. With regarding to base software required, ATCOR only requires IDL virtual machine, which is a runtime version of IDL without an IDL license and is thus free. However, FLAASH is available as an ENVI plug-in, thus it requires ENVI software as a prerequisite.

2.2 Radiative transfer modeling

Although both ATCOR and FLAASH use MODTRAN as the radiative transfer code to simulate the atmospheric contribution, they use it in a different way.

For a given scene with certain solar and viewing geometry, ATCOR interpolates radiation transfer properties from a database. The database is pre-calculated by MODTRAN offline. In the solar spectral region (0.35-2.5 µm) MODTRAN was run with variable wavenumber spacings (5 cm^{-1} for wavelengths below 2 µm, and 1 cm^{-1} for wavelengths above). The database is then resampled with an equidistant 0.6 nm grid of Gaussian filter function of FWHM=0.6 nm. So the final ATCOR database should be sufficient for instruments with bandwidths > 3nm covering the solar spectral region from 350 to 2500 nm.

While ATCOR uses an offline database pre-calculated by MODTRAN4.3R1, FLAASH incorporates the MODTRAN4+ radiation transfer code. Both MODTRAN versions are presumably the same but the official version number is named 4.3. For a given scene, users may choose any of the standard MODTRAN model atmospheres and aerosol types to represent the scene, and a unique MODTRAN LUT is computed for this scene. This capability enables FLAASH to correct scenes acquired with a large sensor tilt angle. The tailor-made LUT might also offer some advantages over ATCOR's interpolated LUT in terms of accuracy. However in the current version of FLAASH, the spectral resolution of the LUT has to be constant over the instrument spectral coverage and has several possible options (1, 5, 15 cm^{-1}). For a narrow-band (~10 nm) with central-wavelength above 2 µm, it is advisable to use the 1 cm^{-1} resolution in order to have a reasonable number of data points for resampling. For other bands on the same spectrometer with center-wavelength below 2 µm, a spectral resolution of 1 cm^{-1} is a waste of computing power to have too dense data points for resampling. It also slows down the program.

2.3 Correction capabilities

The basic functionalities in ATCOR and in FLAASH have a lot in common. Both software require as input: viewing and solar geometry (For FLAASH, the solar geometry is calculated from the image location and image acquisition time, the calculation is transparent to the users.), atmosphere type, aerosol type and boundary layer visibility. In addition to surface reflectance output, both ATCOR and FLAASH can generate pixel-by-pixel water vapor column map, provided that the sensor has water vapor bands with suitable band-width. If dark vegetated pixels exist in a scene, both ATCOR and FLAASH can estimate a scene-average visibility or aerosol optical thickness based on the same algorithm first proposed by Kaufmann. As by-product, ATCOR produces so-called haze-cloud-water mask. This mask has 17 tags. For a particular pixel, the surface reflectance retrieval algorithm takes a unique path according to the its tag. FLAASH has a cloud-mask with different tags. Spectral calibration using the absorption features is offered by both software. For the retrieved surface reflectance spectrum, both offer spectral polishing to remove the artificial spikes.
ATCOR's surface reflectance retrieval algorithm seems to be more sophisticated than FLAASH in that ATCOR can distinguish a variety of scene backgrounds and can carry out reflectance retrieval under some unfavorable conditions, such as cirrus, haze and shadow. This will increase the coverage of retrievable area.
While FLAASH assumes a Lambertian surface, ATCOR includes an empirical approach to correct the BRDF effect of the surface when the instrument Field-Of-View (FOV) is relatively large and when the measurement is taken close to the solar principal plane. The BRDF effect due to terrain effect can also be corrected provided that a DEM with appropriate spatial resolution can be used as input.
ATCOR offers a few more functions than FLAASH, such as the LAI, FPAR, albedo and surface energy balance calculation.
The website http://www.rese.ch/atcor/compare.html contains a detailed comparison between ATCOR and FLAASH copied here in Table 1.

	ATCOR-IDL (ReSe)	FLAASH
System Features		
supported operating systems	Windows, Solaris, Linux, MacOSX	Windows, Solaris, Linux
base software	none[1]	ENVI
airborne	yes (A-4)	yes
satellite	yes (A-23)	yes
hyperspectral	yes	yes
ultraspectral[2]	limited[3]	yes
extreme tilt angles	no	yes
batch processing	yes	no
Correction Features		
variable visibility	yes	yes
aerosol type detection	yes	no
adjacency effect	yes	yes
water vapor retrieval	yes	yes
haze removal	yes	no
cirrus cloud removal	yes	no

cloud shadow removal	yes	no
preview of spectra	yes	no
inflight calibration	yes	no
normalizing wide FOV imagery	yes	no
spectral polishing[4]	yes	yes
spectral calibration	yes	yes
spectral smile correction	yes	no
empirical line correction	no	yes (ENVI)
Thermal region		
surface temperature	yes	yes (ENVI)
surface emissivity	yes	yes (ENVI)
Rugged terrain		
terrain height (DEM)i	yes	no
DEM illumination effectst	yes	no
empirical BRDF correction	yes	no

Table 1: Comparison between ATCOR and FLAASH from website http://www.rese.ch/atcor/compare.html

[1]ATCOR from ReSe runs on the free IDL virtual machine.

[2]It's a true advantage of other atmospheric correction softwares (e.g. FLAASH or ACORN) that sensor-specific LUTs can be calculated directly through Modtran. This feature is particularly well suited for sensors at tilted angular conditions with large tilt angles. Also, "ultraspectral" sensors having resolutions below 2nm are not ideally sampled in the ATCOR LUT. On the other hand, our experience has shown that 99% of all currently relevant data acquisitions are within the range which is covered by the ATCOR pre-calculated LUTs

[3]The IDL version of ATCOR supports the inclusion of new (user defined) sensors. A resampling tool contained within ATCOR allows interpolation of virtually any multispectral or hyperspectral sensor from the database (at 0.6 nm resolution). Inaccuracies due to this interpolation become only relevant at spectral resolutions below 2 nm

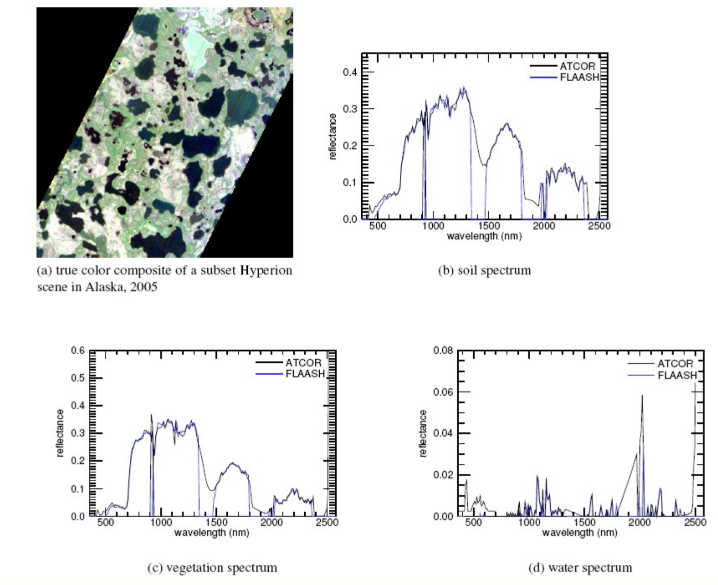
[4]The spectral polishing features within FLAASH and ENVI are very sophisticated. ATCOR also offers such a feature, but we acknowledge that this is less powerful.

2.4 User control

While the FLAASH has a relatively simple user's manual and straightforward functions, its algorithms are generally not explained in detail and a user has to dig into the literatures to find out the exact formulation of certain algorithms. In a way, FLAASH functions as a black box.
On the other hand, ATCOR's user manual has a detailed documentation about every algorithm applied in the software. Users can fine-tune many of the algorithms by changing the threshold values in a software preference file. To be able to use every function that ATCOR offers, a user must spend some time learning the user's manual.

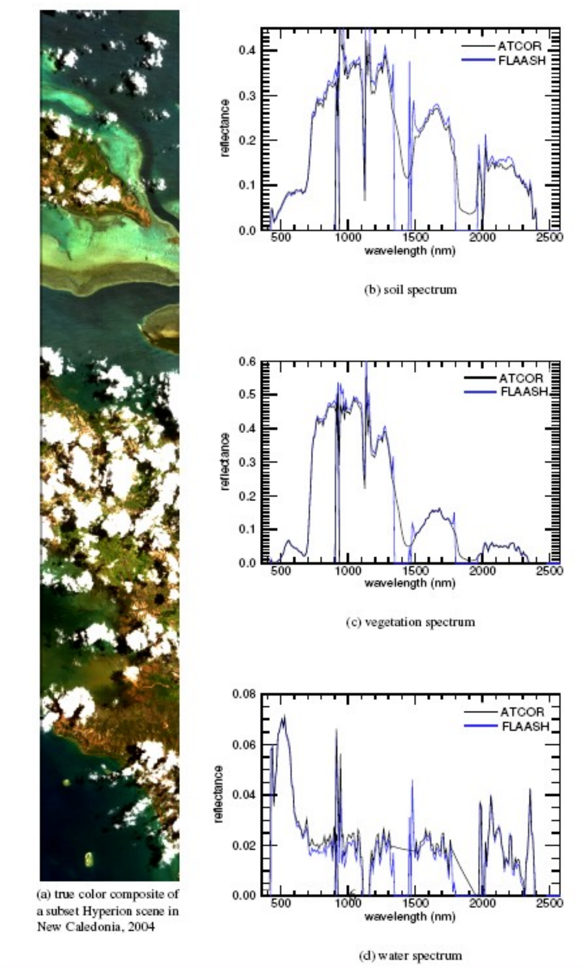
3 Two examples

In this section, ATCOR and FLAASH are used on two Hyperion scenes to illustrate that these two software produce similar outputs. The first scene was taken from Alaska on July 26, 2005. The second scene was taken from New Caledonia island on the south pacific ocean on Feb 12, 2004. Retrieved spectra from both software are plotted for three typical pixels, such as soil, vegetation and water. Visual inspection indicates ATCOR and FLAASH produce similar surface reflectance cubes as shown in Figure 1 and Figure 2. The major difference seen in the figures is due to interpolation of the fully absorbing spectral bands: ATCOR performs a spline interpolation of these bands which leads to a smooth spectrum (e.g. at 1800 nm), whereas FLAASH sets the unprocessed data to zero.
For the comparison of water vapor column retrieved from these two software, we selected for each scene a region of interest (ROI) with only clear land pixels. The average and standard deviation of water vapor column for the ROI in first scene is (1.33cm, 0.1cm) from ATCOR and (1.74cm, 0.096cm) from FLAASH, for the ROI in second scene, the numbers are (4.27cm, 0.27cm) from ATCOR and (5.10cm, 0.38cm) from FLAASH. The discrepancies in the average water vapor column are rather large. This is caused by the different water vapor algorithms and the different choices of absorption and window channels. An independent source (e.g. radiosonde) for validation was not available.



(a) true color composite of a subset Hyperion scene in Alaska, 2005
(b) soil spectrum
(c) vegetation spectrum
(d) water spectrum

Figure 1: Scene 1



(a) true color composite of a subset Hyperion scene in New Caledonia, 2004
(b) soil spectrum
(c) vegetation spectrum
(d) water spectrum

Figure 2: Scene 2

4 Conclusion

A comparison is carried out between ATCOR and FLAASH. The two atmospheric correction software tools are based on the same radiative transfer code MODTRAN, although

MODTRAN is used in a different way in FLAASH as in ATCOR. The two software produce similar surface reflectance cubes for two Hyperion scenes.

Geometric Correction Programs

A comparison between PARGE and ORTHO

1 Background

The two software packages PARGE and ORTHO have been described in DN6.2.1. Both software packages are used to geometrically correct the image data using the direct georefencing technique. ORTHO, so far, is only available for DLR-internal use. It is embedded as a batch process within the processing chain for airborne hyperspectral data. PARGE is a commercial software. It is used interactively for this comparison report, but it could also be run as batch process.

2 Comparison

This section reports the differences between the two software packages in detail.

2.1 System Requirements

PARGE runs on a number of operating systems, such as Windows, Unix, Linux and MacOSX. As underlying software, PARGE only requires IDL Version 6.2 or higher or the free IDL virtual machine. The ENVI license is recommended, but not a condition. ORTHO is a batch program written in C, and therefore it is platform independent. At DLR, ORTHO runs on Linux systems.

2.2 Correction capabilities

	PARGE (ReSe)	ORTHO
System Features		
supported operating systems	Windows, Solaris, Linux, MacOSX	platform independent
base software	none[1]	none
airborne	yes	yes
satellite	no	yes
hyperspectral	yes	yes
batch processing	yes	yes
output file format	standard ENVI file formats	XDIBIAS[2] file format
implementation of new sensors	yes	yes
Correction Features		
Resampling options	Nearest Neighbor, Bilinear interpolation, compromise solutions	Nearest Neighbor, Bilinear interpolation
DEM resizing/resampling	yes (interactive)	yes (automatically)
boresight calibration	yes	yes (ESTIMATE)
correction of attitude and position distortions	yes	no
Scan angle output for atmospheric correction	yes	yes
Output rotation	yes	yes (???)

Table 2: Comparison between PARGE and ORTHO

[1]PARGE from ReSe runs on the free IDL virtual machine, for unsupervised batch processing, a full IDL license is required.
[2]XDIBIAS is a DLR-internal image analysis software package.

2.4 User control

PARGE has a user-friendly interface for all functions and a extensive on-line help system. The user manual describes the theoretical background as well as the different functions used within the software in detail. PARGE also offers a programming interface (e.g., to set up a batch process) for which all variables and data structures are documented within the user manual. Before performing the final processing step, the input parameters are checked if the values are meaningful. Within PARGE it is always possible to store/restore the current progress of work, which eases the reprocessing of the data, e.g. using different interpolation algorithms. PARGE offers many options for interaction and fine-tuning of the different input data (e.g. navigation data transformation or synchronisation aids).
The ORTHO user handbook describes the function call and different start options of the image processor. The values are explained in detail. ORTHO requires a so called "control file" which includes all necessary parameters. The content of the control file can be edited by the user. All values are also described in the user handbook. To determine the boresight alignment angles, the additional tool ESTIMATE needs to be executed, where its call is explained in the user handbook as well.

3 Two examples

The two software packages are applied to 4 different HyMap-scenes acquired in summer 2008 and 2009 over DLR's calibration site Kaufbeuren in Bavaria. As reference, a very accurate orthophoto of the Bavarian Survey agency is available. Based on this orthophoto, Ground Control Points have been selected for all four scenes. The integrated GPS/IMU system used for HyMap is the Boeing CMIGITS II system for both dates. The digital elevation model (DEM) is retrieved from the digital elevation database W42 at DLR, where the DEM is derived from SRTM data with a spatial resolution of 1 arc second and a relative vertical accuracy of 8m.
In 2009, there has been a failure of the differential GPS, which reduces the quality of the position data.
As resampling option, the bilinear interpolation method has been chosen for ORTHO and PARGE. Boresight alignment angles have been determined for all 4 scenes with the tool ESTIMATE as input for ORTHO and separately within the PARGE auxiliary data offset estimation. PARGE offers also the opportunity to correct for distortions within the navigation data. This means, the preparation of input data before the actual geocorrection process is more elaborate in PARGE and therefore better results can be expected. But this is only true when comparing the interactive mode of PARGE with the batch process ORTHO.
The results of the geometric correction of the four scenes are displayed in Figure 3 and 4. Control points have been placed to compare the results with each other. The relative geometric accuracy of the orthorectified images is shown in Table 3, where the orthophoto has been used as reference. As already assumed, the PARGE results are slightly better than the ORTHO results, which is due to the interactive treatment and examination of the different input data. For the data of 2009 the high standard deviation in X-direction of the ORTHO result is caused by the failure of the DGPS and the resulting inaccuracy of the position data. The quality of the position data could be improved in PARGE, which leads to the better standard deviation.

	Standard deviation X		Standard deviation Y	
	PARGE	ORTHO	PARGE	ORTHO
KB 2008 - 1	1,19	1,91	0,62	1,34
KB 2009 - 1	0,75	3,11	0,60	1,35

Table 3: Relative geometric accuracy (standard deviation) in pixel

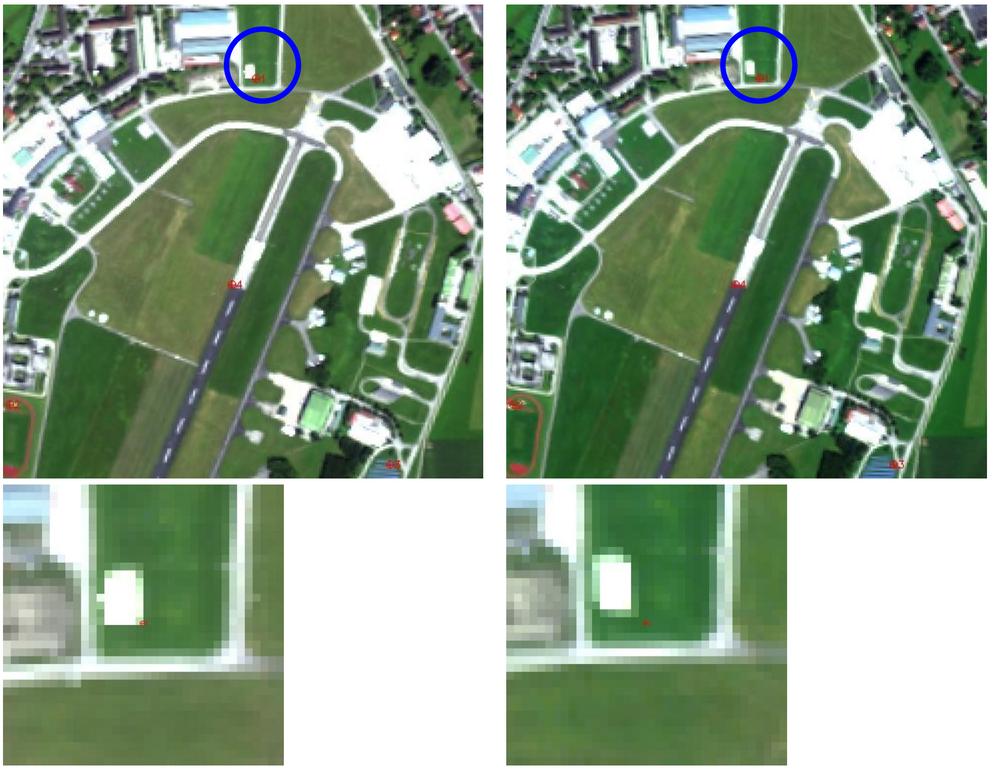


Figure 3: Results of geometrically corrected HyMap data (Kaufbeuren 2009) with PARGE (left) and ORTHO (right): Direct comparison.

Figure 4: Results of geometrically corrected HyMap data (Kaufbeuren 2008) with PARGE (left) and ORTHO (right): Direct comparison.

4 Conclusion

Both software packages for geometric correction ORTHO and PARGE have been compared with each other and produce similar results for the four selected data sets. ORTHO runs as a batch process, whereas PARGE offers a user-interface. Within PARGE, the possibility to check and prepare all input data is given. Therefore, the results of PARGE are slightly better, than the results of ORTHO.

Until now ORTHO is not commercially available. PARGE is distributed by ReSe Applications Schläpfer.

Note: Since ORTHO fulfils the requirement of geometric accuracy, it has been embedded into the processing chain for airborne hyperspectral data years ago. PARGE is only used within DLR, when the input data is corrupt, to cross-check results, or a different resampling method - apart from Nearest Neighbour or bilinear interpolation- is requested.

3.2.Data Pre-Processing of In-Situ Data

Programs for processing in-situ data tend to be very specialized and vary widely in scope. Many in-situ data pre-processing codes are developed by individual users or institutions for internal use and are not widely available. Public and commercial codes, such as those developed by probe manufacturers, deal with specific instruments, while broader data manipulation programs tend to be created for specific formats, tasks or institutions. The result is a heterogeneous mix of software designs and purposes and therefore, it is not feasible to do a comparison between these programs.

4. Best Practices

4.1. Data Pre-Processing of Imaging Spectrometer Data

System Correction Programs

There are certain points related to system correction where the sensor operator can ensure the data quality. In addition, the end user can be provided with documentation on the processes. Therefore best practice shall include:

- ensure that the newest calibration file is used, or - when re-processing - that the calibration file corresponds to the data
- analysis of sensor log file for error messages
- analysis of DC for stability and nominal function
- analysis of on-board calibration sources for stability and nominal function (if applicable)

Also most sensor operators do carry out test flights with corresponding ground measurements in order to validate the laboratory calibration, and - if required - to adjust this calibration by in-flight calibration procedures. If applicable, this shall be communicated to the end user.

An agreed set of metadata to be provided to the user is documented in EUFAR JRA DJ2.2.1 and DN6.1.2. For system correction, it is agreed to provide

- date of radiometric / spectral calibration
- calibration laboratory
- calibration file used
- radiance unit and scaling
- processing steps during system correction (e.g., if additional de-striping was applied)

Depending on the sensor, it was proposed to also provide

- parameterization of the spectral smile
- parameterization of keystone
- mask of bad detectors on the sensor ("bad pixel map")

Atmospheric Correction

A newcomer or occasional user of atmospheric correction methods often has problems to decide which is the best technique to apply to a certain hyperspectral scene. The following list summarizes the most important issues.

Guidelines for the selection of a method:

- Make sure the spectral coverage and spectral resolution of the selected code comply with the acquired hyperspectral scene.
- The method should be able to calculate the atmospheric water vapor column from the scene, and retrieve surface reflectance in the 940 nm and 1130 nm regions, if applicable.
- For imagery from airborne instruments and high spatial resolution (< 100 m) spaceborne sensors the selected method should account for the adjacency effect, i.e., it should remove the influence of reflected and scattered radiation from the neighborhood.
- In mountainous regions the influence of topography should be taken into account, i.e. a DEM and its derived products (terrain slope and aspect) have to be considered. It is

preferable to have a DEM of about the same spatial resolution as the scene itself. Note: results of a combined atmospheric/topographic correction will strongly depend on the DEM quality, resolution, and accuracy of the orthorectification.

- For pushbroom instruments with a strong "spectral smile" effect the selected method should be able to account for "smile" during the surface reflectance retrieval.
- Other considerations include the capability of batch processing and image tiling.

Geometric Correction

The direct georeferencing technique is used for the geometric correction of airborne scanner data. The mandatory input data for this type of geometric correction is the knowledge of

- Interior orientation: specified by the sensor's manufacturer
- Exterior orientation: Position and attitude for each moment of the data acquisition derived from the combined GPS and IMU measurements

To improve the geometric accuracy of the position data, differential GPS is used. The processing of the data (e.g. Kalman filtering) is done with the corresponding software, or has been already done in-flight. One has to be aware of the different reference systems, the GPS and IMU measurements do refer to. To relate all measurements to one system, leverarms and boresight angles must be taken into account. Leverarms can be determined using conventional surveying methods, whereas boresight angles can be calculated from Ground Control Points (GCP). The data of the exterior orientation needs to be synchronised to the image data. Usually, one set of parameters (position and attitude data) is given by scanline. The assignment per image pixel can be done by interpolation.

For rugged terrain and to further improve the results, a digital elevation model is also necessary. The quality of the elevation data directly influences the quality of the georeferenced image data.

One necessary step during the geometric correction process is the resampling of the data to generate a regular grid. Depending on the resampling method, artificial interpolated spectra can be introduced. Before choosing the resampling method, the user has to decide, if the preference should be towards geometric or radiometric accuracy.

The software which can be used for geometric correction is described in DN6.2.1.

4.2. Data Pre-Processing of In-Situ Data

Due to the differences in probes, aircraft and data systems used in airborne research, processing chains of airborne in-situ data are unique to institutions and operators. As such, it is difficult to impose strict practices on in-situ data processing. In this section we will give broad recommendations for data pre-processing, data formats and probe intercomparisons, with the aim to facilitate data exchange and accuracy.

Data Pre-Processing

The wide range of different probes, hardware, aircraft and data systems makes it common practice for users and operators to develop their own solutions for processing in-situ probe data. Manufacturers of some probe types provide software packages designed to capture and process data from a specific probe. For probes with manufacturer software available, it will be considered best practice for results from custom software to be compared against the manufacturer software. Otherwise, the best source for comparison and code validation will be the common processing toolbox currently under development by EUFAR N6SP. This free toolbox will be open-source, and cross platform and will incorporate algorithms considered 'best-practice' by the EUFAR EWG community. This will provide a benchmark for custom software accuracy and will help reduce errors.

Data/Metadata Formats

Due to differences in existing data systems and probe types, we will solely make recommendations for final, published data. Raw and internal data formats are left up to the users based on their needs, but the recommendations provided here can be applied internally if desired.

Data guidelines:

- Preferred format – NetCDF format (http://www.unidata.ucar.edu/software/netcdf/)
- Alternate format – NASA Ames (http://badc.nerc.ac.uk/help/formats/NASA-Ames/)
- Metadata should follow EUFAR protocols outlined in DN6.1.2 Draft version of common protocols, or DN6.1.3 Version 1.0 of common protocols, whichever is available

For more information on data format recommendations, please see the common protocol documents (DN6.1.2 or DN6.1.3) available on the EUFAR website.

Probe Intercomparison

The best practice for probe comparisons will be the common processing toolbox currently under development by EUFAR N6SP. By using this toolbox, any differences between processing chains and algorithms will be eliminated, and a standard baseline for aircraft data processing can be established. Input/output modules for the recommended data formats listed above will be included in the toolbox, and users will be able to add custom scripts to read other data formats.

5. Conclusion

This report has provided comparisons of processing codes where applicable to aid users' selection of data processing codes for their needs. Several hyperspectral correction programs were compared for various tasks. Unfortunately, there was no similar overlap for in-situ processing programs, and no comparison was done. Recommendations were made for best practices for the different steps of hyperspectral and in-situ data processing. It is hoped these will guide EUFAR users in their use of aircraft data.