

Atmospheric / Topographic Correction for Airborne Imagery

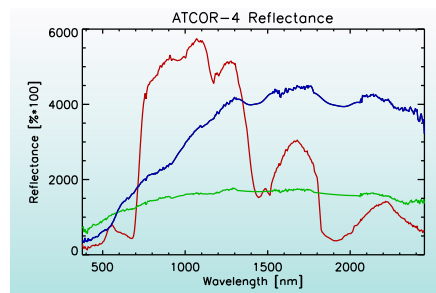
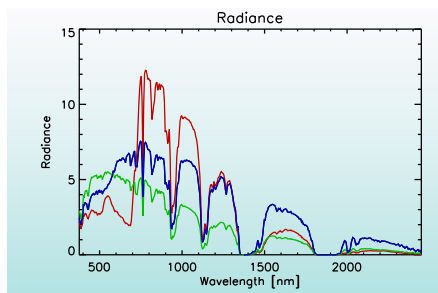
(ATCOR-4 User Guide, Version 7.5., August 2023)



Original Image (AVIRIS NG)



ATCOR and BREFCOR corrected



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The cover image shows atmospheric correction results for AVIRIS-NG imagery. The import functions and processing options for AVIRIS NG, Specim AISA and Itres CASI instruments have been improved in Version 7.5 (© data provided by Remote Sensing Laboratories, University of Zurich).

ATCOR-4 User Guide, Version 7.5, August 2023

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Chapter 1

Introduction

The objective of any radiometric correction of airborne and spaceborne imagery of optical sensors is the extraction of physical earth surface parameters such as spectral albedo, directional reflectance quantities, emissivity, and temperature. To achieve this goal, the influence of the atmosphere, solar illumination, sensor viewing geometry, and terrain information have to be taken into account. Although a lot of information from airborne and satellite imagery can be extracted without radiometric correction, the physical model based approach as implemented in ATCOR offers advantages, especially when dealing with multitemporal data and when a comparison of different sensors is required. In addition, the full potential of imaging spectrometers can only be exploited with this approach.

Although physical models can be quite successful in eliminating atmospheric and topographic effects they inherently rely on an accurate spectral and radiometric sensor calibration and on the accuracy and appropriate spatial resolution of a digital elevation model (DEM) in rugged terrain. In addition, many surfaces have a bidirectional reflectance behavior, i.e., the reflectance depends on the illumination and viewing geometry. The usual assumption of an isotropic or Lambertian reflectance law is appropriate for small field-of-view ($FOV < 30^\circ$, scan angle $< \pm 15^\circ$) sensors if viewing does not take place in the solar principal plane. However, for large FOV sensors and / or data recording close to the principal plane the anisotropic reflectance behavior of natural surfaces causes brightness gradients in the image. These effects can be removed with an empirical method that normalizes the data to nadir reflectance values. In addition, for rugged terrain areas illuminated under low local solar elevation angles, these effects also play a role and can be taken care of with an empirical method included in the ATCOR package.

The ATCOR software was developed to cover about 80% of the typical cases with a reasonable amount of coding. It is difficult if not impossible to achieve satisfactory results for all possible cases. Special features of ATCOR are the consideration of topographic effects and the capability to process thermal band imagery.

There are two ATCOR models available, one for satellite imagery, the other one for airborne imagery [104, 105]. The satellite version of ATCOR supports all major commercially available small-to-medium FOV sensors with a sensor-specific atmospheric database of look-up tables (LUTs) containing the results of pre-calculated radiative transfer calculations. New sensors will be added on demand. The current list of supported sensors is available in the ATCOR related web site on www.rese-apps.com. A simple interface has been added to provide the possibility to include user-defined instruments. It is mainly intended for hyperspectral sensors where the center wavelength of channels is not stable and a re-calculation of atmospheric LUTs is required.

An integral part of all ATCOR versions is a large database containing the results of radiative transfer calculations based on the Modtran®5 code [9, 10]. While ATCOR uses the AFRL MODTRAN code to calculate the database of atmospheric look-up tables (LUT), the correctness of the LUT's is the responsibility of ATCOR.

Historical note:

For historical reasons, the satellite codes are called ATCOR-2 (flat terrain, two geometric degrees-of-freedom DOF [87, 89]) and ATCOR-3 (three DOF's, mountainous terrain [91]). They support all commercially available small to medium FOV satellite sensors with a sensor-specific atmospheric database. The scan angle dependence of the atmospheric correction functions within a scene is neglected here.

The airborne version is called ATCOR-4, to indicate the four geometric DOF's x, y, z, and scan angle [95]. It includes the scan angle dependence of the atmospheric correction functions, a necessary feature, because most airborne sensors have a large FOV up to 60°- 90°. While satellite sensors always operate outside the atmosphere, airborne instruments can operate in altitudes of a few hundred meters up to 20 km. So the atmospheric database has to cover a range of altitudes. Since there is no standard set of airborne instruments and the spectral / radiometric performance might change from year to year due to sensor hardware modifications, a monochromatic atmospheric database was compiled based on the Modtran®5 radiative transfer code. This database has to be resampled for each user-defined sensor.

1.1 Organization of the manual

This manual describes how to use the ATCOR-2 and ATCOR-3 software whereas the theoretical background of ATCOR is described in the algorithm theoretical basis document (ATBD) which is distributed in parallel to this manual [106].

Chapter 2 of the manual gives details about installation and running ATCOR on various operating systems. Chapter 3 presents the workflow in ATCOR, and Chapter 4 contains a detailed description of the graphical user interface panels of the major modules. Chapter 5 describes the batch processing capabilities with ATCOR. It is followed by chapters on sensor simulation, implementation issues, and sensor specifics.

Further information about the IDL version of ATCOR described in here can be found on the ReSe home page on <https://www.rese-apps.com>

Processing parameters:

ATCOR processing is performed based on two input files, containing scene-dependent and independent parameters:

- The scene specific parameters are stored in the *"scene.inn"* containing the relevant data from the sensor meta file, and in case of hyperspectral sensors the specification of channels for the retrieval of the water vapor map.
- The other set of parameters is stored in file *"preference_parameters.dat"* located in the directory *.idl/rese/atcor3/*. It contains, among others, channel interpolation options and the spatial interpolation of the water vapor map. For most sensors, the default parameters of this file apply. Occasionally, a few parameters might have to be changed for a specific sensor,

but not on a per-scene basis. These parameters can be changed with an editor or with the ATCOR GUI ('File', 'Edit Preferences') and the corresponding pop-up menu.

What's new compared to the last major release:

- The default option of calculating the AOT(550nm) map is based on reference DDV (Dense Dak Vegetation) pixels and the average AOT is assigned to the non-DDV pixels. Now a spatial interpolation option of the AOT(550nm, DDV) is available using an inverse distance weighting. It requires a somewhat more execution time.
- If a scene does not have enough DDV pixels (minimum 2 percent of pixels), a DDVS algorithm (DDV Substitute) is automatically executed using relaxed vegetation conditions, see chapter 'Aerosol Retrieval' of the separate ATBD document [106]. If both algorithms (DDV and DDVS) fail, then a default visibility of 40 km, AOT(550nm)=0.20, is used instead of the previous visibility 23 km (AOT=0.32) to avoid overcorrection of surface reflectance spectra.
- The AOT map over water bodies is calculated independently with the assumption of a water surface reflectance of 0.01 in the near-infrared (around 850 nm) spectrum.
- The dehaze program contains an improved definition of the 'bright' pixels, where the haze thickness has to be spatially interpolated. For hyperspectral sensors a channel near 424 nm and 440 nm is used for the haze thickness map calculation (default). However, if the 424 nm channel is rather noisy, the keyword `b440=1` should be specified to employ the channels near 440 nm and 480 nm. Furthermore, the calculation of the spectral band correlation of haze thickness was improved.
Additionally, a new keyword `h_sigma` is available (default: `h_sigma = 0.3`) to specify the definition of 'haze pixels'. For `h_sigma < 0.3` the percentage of haze pixels is increased, otherwise decreased.
- The range-dependent adjacency correction (up to 5 adjacency zones) is now also supported for batch jobs. The corresponding parameter is included in the '*.inn' file, line 15, example:

1.000 5 Adjacency range [km] adj zones (max 5)

This feature is backward compatible: if adj zones is not specified then a single zone is assumed. The difference between both options, in terms of surface reflectance, is usually very small (0.005 reflectance units), but can be somewhat larger (0.01 to 0.02 units) for special geometries (land/water coastal region) and spectral regions with large albedo differences (e.g., NIR: high reflectance of vegetation, low water reflectance).

The range-dependent adjacency processing requires more execution time and is not necessary in most cases. The reason is that the land field pattern (low and high albedo fields) tends to repeat itself within patches of 2 km × 2 km (i.e., twice the adjacency range), yielding about the same average albedo in a patch.

- The calculation of the water vapor map with the option of band regression (parameter `iwv_model=2` in the '*.inn' file) now also supports the combination of bands from the 940 nm region and the 1130 nm region. Previously, it was only one of the two regions. It requires parameter `iwaterwv = 1` (only 940 nm bands), `iwaterwv = 2` (only 1130 nm bands), and `iwaterwv = 3` for both regions.
- Minor bugs in several programs were fixed.

- The documentation of the User's Manual is updated. The theoretical background of ATCOR is described in a separate document.
- The de-shadowing with the matched filter algorithm is improved for batch processing and includes some iterations and plausibility checks. So it usually performs better than the module with the graphical user interface. However, over-/under-correction of cloud shadow areas is still possible and this remains an interesting research topic for the future,
- Minor bug fixes were performed,
- Improved BREFCOR correction for better masking and generic model,
- New TELOPS Hyper-Cam LW import, updated ITRES CASI, AVIRIS-NG, and SPECIM AISA import functions,
- Consolidated and updated topographic correction methods,
- The documentation of the User's Manual is updated. The theoretical background of ATCOR is described in a separate document.

Programs to import airborne image data for

- CASI (ITRES)
- AISA (SPECIM)
- AVIRIS (JPL)
- Hyper-Cam (TELOPS)

Chapter 2

Installation Process

The following chapter will provide an overview over the installation of the software and give a short explanation as to how the licensing works. Furthermore, updates and a few tips and tricks are discussed as well.

2.1 Download and Licensing

First, the ReSe Software base installer package is to be downloaded from

<https://www.rese-apps.com/software/download>.

Upon downloading proceed as follows:

- Unarchive the zip file and place the unzipped directory to the location where the software should be installed (separate software packages will be installed within the ReSe Software directory).
- Windows: start the installer application ReSe_Software.exe
- Linux: (make sure csh/tcsh is installed) start the installer application shell script rese_software.sh
- Mac: (make sure X11 / Xquartz is installed) start the installer application ReSe_Software.app
- select the packages to be installed from the dialog and wait for the software to be downloaded and installed,
- startup the software by pushing the 'Start' button or by clicking the respective *.sav file or *.exe file contained in the installed software directory;
- this will start the software with the IDL virtual machine included in the distribution.

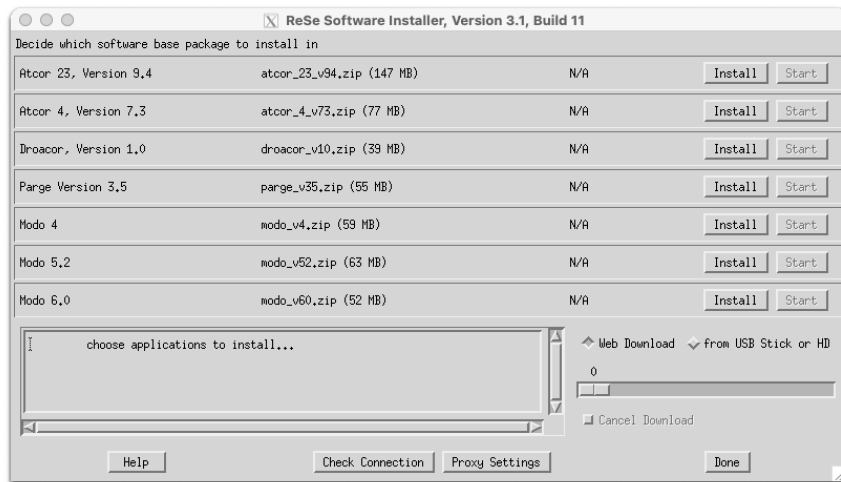


Figure 2.1: ReSe installer graphical interface

- Above is the main installer for ReSe Applications. Select the package to install, the package will be put in a directory within the main ReSe.Software_xxx. To uninstall a package, simply remove the respective subdirectory.
- After Installation, the software may be start from within this GUI or from the respective installation directory (using the operating-system depending startup applications). In unlicensed mode, three warnings appear which can be dismissed. Finally, a dialog will appear displaying the relative licensing information.

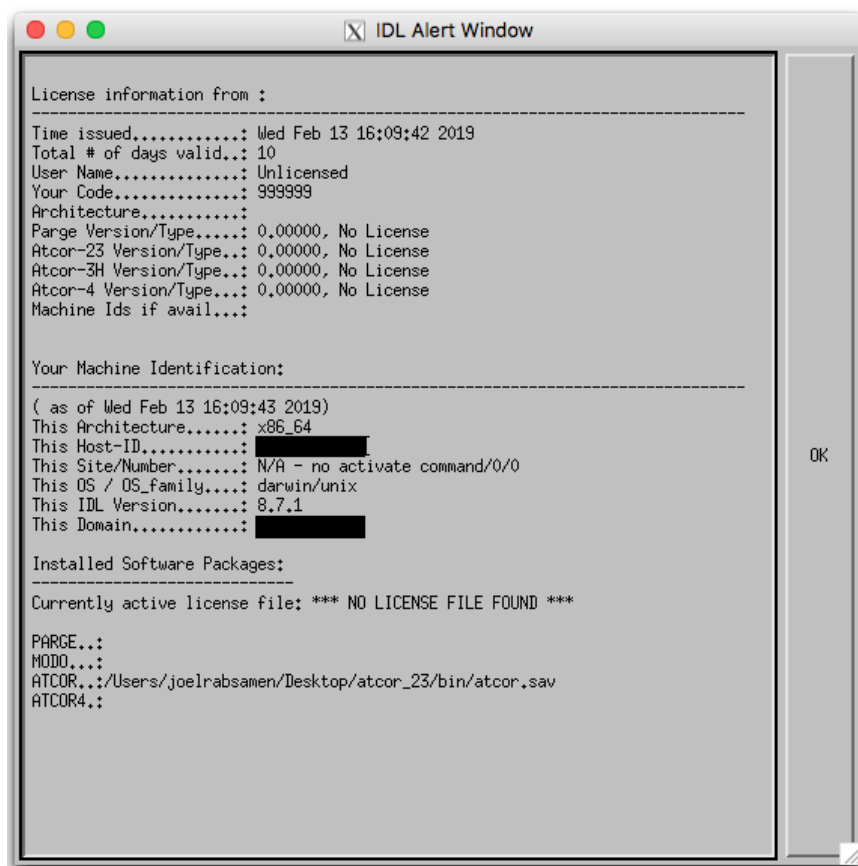


Figure 2.2: Output of licensing information dialog

- Please email the text outputs (do not take a screenshot, please) of this job together with your complete address and affiliation to info@rese-apps.com , mentioning the product. You then will receive a binary license key file within a few days.
- The license key `rese.license.pro` is to be put beneath the `*.sav` file after receipt. It is suggested to save the license key in the bin folder within the software (e.g. `atcor_23/bin` or the `atcor_4/bin` or `parge/`, respectively).

2.2 Application start-up

After installation, the software may be started directly using the 'Start' Button. *Note:* On Windows, this can only be done once per session due to technical limitations.

The once installed software may be started from within the software directories directly. For MODO and ATCOR, the Application binaries can be found in the `/bin/` directory of the distribution whereas for PARGE it is on the uppermost level.

On this level, system specific startup scripts are available which direct directly to the IDL87 virtual machine:

Windows an *.exe file with corresponding *.ini configuration file (containing the relative paths, self-configurable)

MacOSX a *.app file (may be unpacked from the terminal by removing the *.app extension)

Linux a *.sh script (may be adapted for specific needs)

The IDL binary used for starting up is found in:

Windows in IDL87/bin/bin.x86_64/idlrt.exe

Linux in idl87/bin/idl

MacOSX in ReSe_Software.app/idl87/bin/idl

The ReSe software binaries (i.e. atcor.sav, atcor4.sav, pargе.sav, modo.sav, modo4.sav, modo6.sav) may be started directly, opening them with IDL Virtual machine, or by clicking the respective starter program located beneath the idl binary. The startup binaries are open to the creation of added links.

2.3 Updates

ReSe Software is updated frequently based on user inputs without notification to end users. The following steps allow to check for the latest version and for an automatic update of your installed software by download of the latest binary.

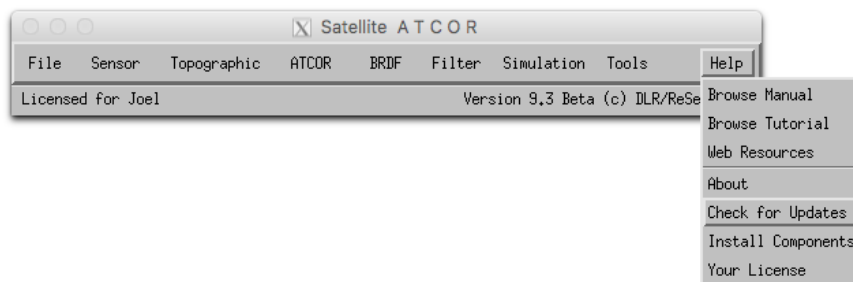


Figure 2.3: Update check-function of ATCOR

The above path lets the software check for a new update via an internet connection.

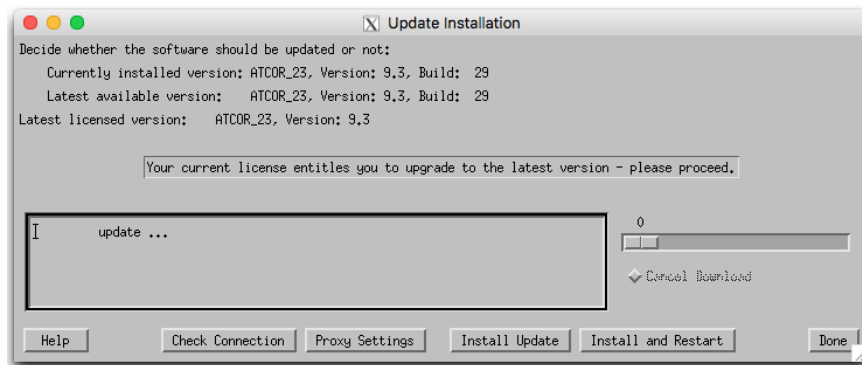


Figure 2.4: ATCOR update installation window

The above installation window provides following functions:

Check Connection Tries to download a dummy file from the ReSe Download server to check if settings are ok.

Proxy Settings This will allow to set a proxy server to allow internet connections behind a fire wall. Push 'Check Connection' after settings to make them active. Also see [2.4](#).

Install Update This will download the latest binary for the current version and replace the current binary (which will be overwritten)

Install and Restart Download the latest binary and restart the software after download.

Please note that the described update function only works for minor releases (x.x.x and new builds). Major releases (x.x) usually require a full reinstall.

2.4 ReSe Proxy Settings

Sitting behind a firewall sometimes requires to set the proxy server in order to allow floating licenses to work or for automatic updates to be installed.

The purpose of this program is to provide an interface for internet server proxy settings.

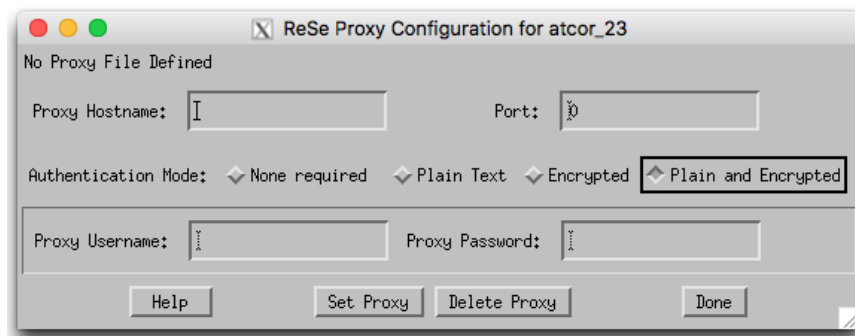


Figure 2.5: ATCOR proxy settings window

The proxy configuration window takes the following inputs (name in proxy file to the right):

Proxy Hostname internet name or IP address of the proxy host (PROXY_HOSTNAME)

Proxy Port port number for connection (often 8080) (PROXY_PORT)

Proxy Authentication Type of authentication (PROXY_AUTHENTICATION):

None No login is required. [0]

Plain Text login is performed in plain text. [1]

Encrypted login is encrypted before being sent to proxy server. [2]

Plain and Encrypted the system chooses whether the login shall be encrypted based on the server's properties. [3]

Proxy Username User name for proxy authentication (PROXY_USERNAME)

Proxy Password Password for proxy authentication (this is shown in plain text) (PROXY_PASSWORD)

The proxy configuration window provides the following actions:

Set Proxy This reads the current proxy settings and writes the proxy file `rese_proxy.txt` to the software installation

Delete Proxy This will delete the proxy file and settings.

The resulting proxy settings are stored in a file named `rese_proxy.txt` in the bin directory of the software installation; the currently active proxy file is displayed in the top row of the panel. The location of the file is usually in the bin directory, or where the `rese_license.pro` resides. The file may also be edited manually for configuration; editing the entries to the right of the equal signs only. A sample proxy file named `rese_proxy_sample.txt` is provided with the software distribution in the respective bin directory. It may be renamed to `rese_proxy.txt` to make it active.

2.5 Tipps and Tricks

GLIMPS Please take note that along with the ReSe Software distribution comes the free GLIMPS software for ENVI image viewing and analysis. The application can just be started and it is ready to check it out.

IDL Virtual Machine All ReSe software runs on the IDL virtual machine. This VM is included in the ReSe Software distribution and is used for start-up of the applications automatically.

Floating License With the new ATCOR and PARGE software there is the possibility to use floating licenses. The following restrictions apply:

- Floating licenses require a permanent internet connection to be active
- One license allows for one concurrent user
- The license is released immediately after quitting the software
- No checkout system is available for offline use of the floating license
- A floating license always includes a backup node locked license (for offline/field use)
- Floating licenses are only available on yearly subscription basis.
- The use of licenses is tracked on ReSe's license server by the local MAC-id, startup time, license identification and user's network domain

Chapter 3

Basic Concepts in the Thermal Region

Fig. 3.1 (left) presents an overview of the atmospheric transmittance in the 2.5 - 14 μm region. The main absorbers are water vapor and CO_2 which totally absorb in some parts of the spectrum. In the thermal region (8 - 14 μm) the atmospheric transmittance is mainly influenced by the water vapor column, ozone (around 9.6 μm) and CO_2 (at 14 μm). Fig. 3.1 (right) shows the transmittance for three levels of water vapor columns $w=0.4, 1.0, 2.9$ cm, representing dry, medium, and humid conditions. The aerosol influence still exists, but is strongly reduced compared to the solar spectral region because of the much longer wavelength. So an accurate estimate of the water vapor column is required in this part of the spectrum to be able to retrieve the surface properties, i.e., spectral emissivity and surface temperature.

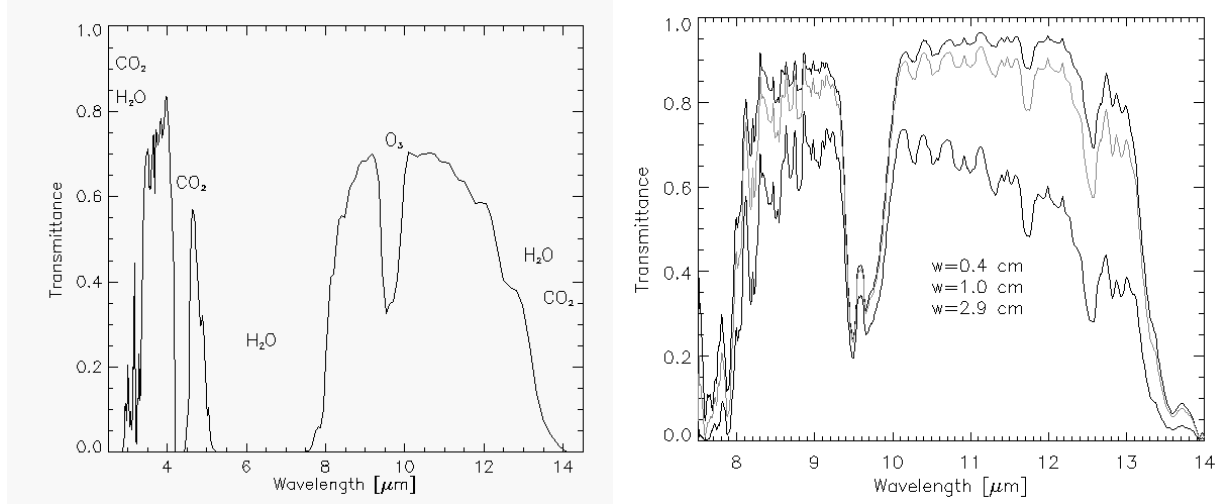


Figure 3.1: Atmospheric transmittance in the thermal region.

Similar to the solar region, there are three radiation components: thermal path radiance (L_1), i.e., photons emitted by the atmospheric layers, emitted surface radiance (L_2), and reflected radiance (L_3).

In the thermal spectral region from 8 - 14 μm the radiance signal can be written as

$$L = L_{\text{path}} + \tau \epsilon L_{\text{BB}}(T) + \tau(1 - \epsilon)F/\pi \quad (3.1)$$

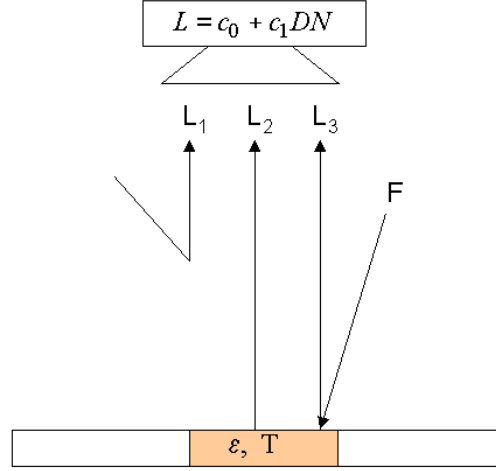


Figure 3.2: Radiation components in the thermal region.
 $L_1 = L_P$, $L_2 = \tau \epsilon L_{BB}(T)$, $L_3 = \tau (1 - \epsilon) F/\pi$.

where L_{path} is the thermal path radiance, i.e., emitted and scattered radiance of different layers of the air volume between ground and sensor, τ is the atmospheric ground-to-sensor transmittance, ϵ is the surface emissivity ranging between 0 and 1, $L_{BB}(T)$ is Planck's blackbody radiance of a surface at temperature T , and F is the thermal downwelling flux of the atmosphere, see Fig. 3.2. So the total signal consists of path radiance, emitted surface radiance, and reflected atmospheric radiation. The adjacency radiation, i.e., scattered radiation from the neighborhood of a pixel, can be neglected because the scattering efficiency decreases strongly with wavelength.

For most natural surfaces the emissivity in the 8-12 μm spectral region ranges between 0.95 and 0.99. Therefore, the reflected downwelling atmospheric flux contributes only a small fraction to the signal. Neglecting this component for the simplified discussion of this chapter we can write

$$L_{BB}(T) = \frac{L - L_{path}}{\tau \epsilon} = \frac{c_0 + c_1 DN - L_{path}}{\tau \epsilon} \quad (3.2)$$

In the thermal region the aerosol type plays a negligible role because of the long wavelength, and atmospheric water vapor is the dominating parameter. So the water vapor, and to a smaller degree the visibility, determine the values of L_{path} and τ . In case of coregistered bands in the solar and thermal spectrum the water vapor and visibility calculation may be performed with the solar channels. In addition, if the surface emissivity is known, the temperature T can be computed from eq. (3.2) using Planck's law.

For simplicity a constant emissivity $\epsilon = 1.0$ or $\epsilon = 0.98$ is often used and the corresponding temperature is called brightness temperature. The kinetic surface temperature differs from the brightness temperature if the surface emissivity does not match the assumed emissivity. With the assumption $\epsilon = 1.0$ the kinetic temperature is always higher than the brightness temperature. As a rule of thumb an emissivity error of 0.01 (one per cent) yields a surface temperature error of 0.5K.

For rugged terrain imagery no slope/aspect correction is performed for thermal bands, only the elevation-dependence of the atmospheric parameters is taken into account.

3.1 Thermal spectral calibration

The spectral calibration in the thermal region using atmospheric absorption features can be conducted in a similar way as for the solar region. A spectral mis-calibration will cause spikes and dips in the surface emissivity spectrum. An appropriate shift of the center wavelengths of the channels will remove these artifacts. This is performed by an optimization procedure that minimizes the deviation between the surface emissivity spectrum and the corresponding smoothed spectrum. However, in the thermal region one also has to account for the unknown surface temperature. Therefore, the merit function also has to be evaluated for a range of surface temperatures T_k and the calculated emissivity depends on the assumed temperature :

$$\varepsilon(i, T_k) = \frac{L(i) - L_p(i) - F(i)/\pi}{L_{bb}(i, T_k) \cdot \tau(i) - F(i)/\pi} \quad (3.3)$$

Here the index i indicates the channel, L is the measured at-sensor radiance, L_p the path radiance, L_{bb} the blackbody radiance, and F the downwelling thermal flux multiplied with the ground-to-sensor transmittance $\tau(i)$. The merit function to be minimized as a function of the wavelength shift δ is :

$$\chi^2(\delta) = \sum_{k=1}^m \sum_{i=1}^n \{\varepsilon(i, T_k, \delta) - \bar{\varepsilon}(i, T_k, \delta)\}^2 \longrightarrow Min ! \quad (3.4)$$

The moving average of the emissivity is performed over 5 channels. In the present version, only channels in the 8.5 - 13.5 μm region are taken into account to avoid strong atmospheric absorption regions. Since MODTRAN look-up tables are used, the resulting wavelength shift also depends on the accuracy of these LUTs. The default temperature range is 280 - 310 K, but the user can specify it with the keyword *trange*, e.g. *trange=[270,320]*. The temperature increment is fixed at 1 K.

Input to the spectral calibration is the thermal scene (ENVI band sequential format) in the original geometry (i.e. not geocoded). The program will select 10 pixels from 10 image lines in the image center (nadir), calculate the wavelength shift, and the mean and standard deviation. Additionally, there is an optional keyword *box* where the averaging over a specified box of pixels can be specified to reduce the influence of noise. The default is *box=1* (no pixel averaging, *box=3* performs an averaging over 3 x 3 pixels). A wavelength shift $< FWHM/30$ will have a negligible effect and usually does not require an update of the sensor response functions and sensor-specific atmospheric LUTs.

When starting the spectral calibration program (either in the GUI or batch mode, see chapters 5 and 6, respectively) for an image named 'scene.bsq' the corresponding 'scene.inn' must already be available, because the sensor name and atmospheric LUTs are taken from this file.

Note: this 'scene.inn' file contains the (sea level) water vapor column in its name, e.g. the string 'wv10' in 'h02000_wv10.tem'. The 'wv10' might not be the correct water vapor column, and for instance the 'wv04' or 'wv29' could be more realistic. However, this mainly influences the depth of the atmospheric absorption spectrum, it has a small influence on the wavelength shift calculated during the spectral calibration.

The spectral sampling distance SSD of the high-resolution thermal database (*.bt7 files) is $SSD = 0.4 \text{ cm}^{-1}$ in the 7 - 10 μm region, and $SSD = 0.3 \text{ cm}^{-1}$ in the 10 - 14.9 μm region. The full width at half max (FWHM) is always twice the sampling distance. This means we have a variable SSD

in wavelength, about 2 - 4 nm below 10 μm , and 3 - 5 nm in the 10 - 13 μm part of the spectrum. This is adequate for the processing of thermal band imagery with bandwidths greater than 25 nm.

Chapter 4

Workflow

This chapter familiarizes the user with ATCOR-4's workflow and with the program's basic functionality using the graphical user interface. A detailed description of all modules and user interface panels is given in the subsequent chapter 5.

ATCOR may also be used in batch mode for most of its functions. A description of the batch mode can be found in chapter 6.

4.1 Menus Overview

To start ATCOR-4, double click the file 'atcor4.sav'. It will be opened through IDL or the IDL virtual machine. Alternatively, type *atcor4* on the IDL command line after having added the atcor4 directory to the IDL search path. The graphical user interface of Fig. 4.1 will pop up. A large number of processing modules is available from this level as described in chapter 5. Most of them can be used without reading a detailed manual description because they contain explanations in the panels themselves. However, the next section guides the ATCOR newcomer during the atmospheric correction of a sample scene.

The functions in the "File" menu allow the display of an image file, the on-screen display of calibration files, sensor response curves etc, see Fig. 4.2. Furthermore it contains import functions for standard image data. More details about this menu are given in chapter 5.1.

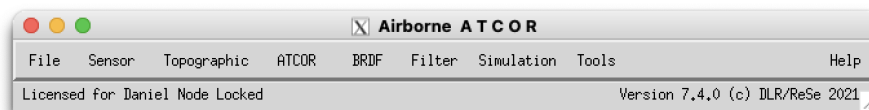


Figure 4.1: Top level graphical interface of ATCOR.

The "Sensor" menu of Fig. 4.1 contains routines to define and adjust sensor definitions, to create spectral filter response curves, to calculate atmospheric look-up tables (LUTs) for new sensors, and to compute the radiance/temperature functions for thermal bands; see Fig. 4.3 and chapter 5.2.

The "Topographic" menu contains programs for the calculation of slope/aspect images from a digital elevation model, the skyview factor, and topographic shadow. Furthermore, it supports the import and smoothing of DEMs and its related layers; see chapter 5.3.

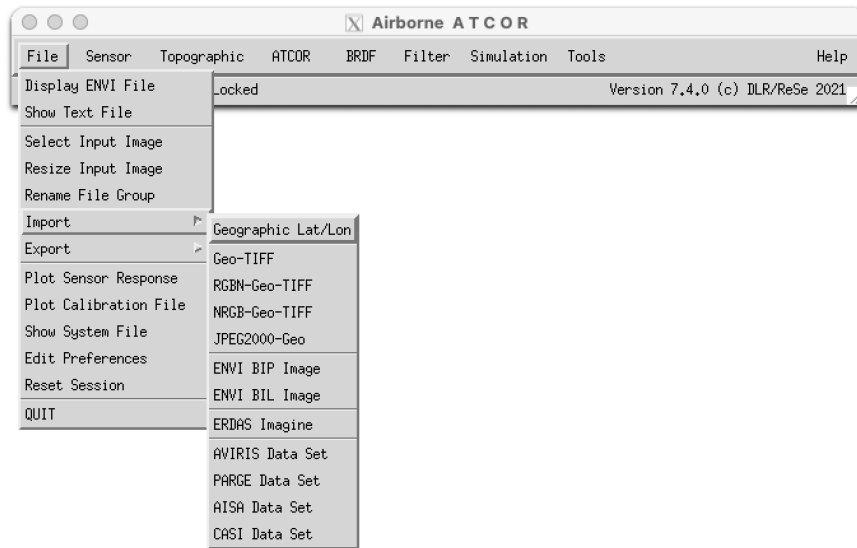


Figure 4.2: Top level graphical interface of ATCOR: "File".

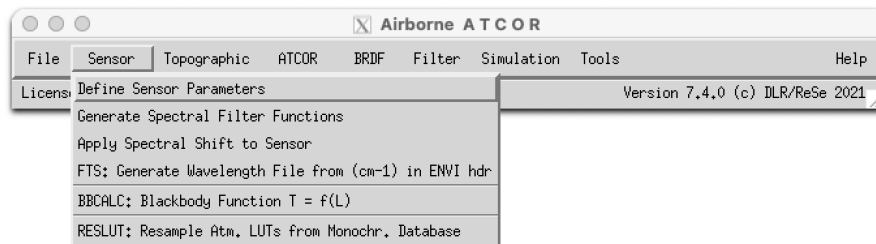


Figure 4.3: Top level graphical interface of ATCOR: "Sensor".

The menu "ATCOR" gives access to the ATCOR-4 core processes for atmospheric correction in flat and rugged terrain. It also includes functions for haze and cirrus removal and for SHAOT retrieval. It is further described in chapter 4.2 below and in chapter 5.4.

The "BRDF" menu provides access to the BREFCOR BRDF effects correction method and to the nadir normalization for wide field-of-view imagery as well as to mosaicking functions; see chapters 5.5 and 5.5.1.

The "Filter" menu provides spectral filtering of single spectra (reflectance, emissivity, radiance) provided as ASCII files, spectral filtering of image cubes, and various options for spectral polishing; see chapter 5.6.

The "Simulation" menu provides programs for the simulation of at-sensor radiance scenes based on surface reflectance (or emissivity and temperature) images and for at-sensor radiance validation; see chapter 5.7.

The "Tools" menu contains a collection of useful routines such as the calculation of the solar zenith and azimuth angles, spectral classification, nadir normalization for wide field-of-view imagery, spec-

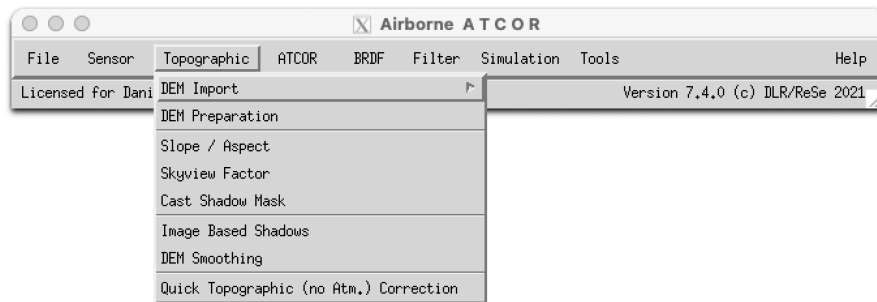


Figure 4.4: Topographic modules.

tral calibration, conversion of the monochromatic atmospheric database from one to another solar irradiance spectrum, scan angle file creation, and more; see chapter 5.8.

Finally, the "Help" menu allows browsing of the ATCOR user manual, provides a link to web resources, and displays license and credits information, and serves to update your software; see chapter 5.9.

4.2 First steps with ATCOR-4

The 'ATCOR' menu of Fig. 4.5 displays the choices 'ATCOR4f: flat terrain' and 'ATCOR4r: rugged terrain', compare Fig. 4.5. The last button starts the ATCOR processing in the image tiling mode, i.e., the image is divided into sub-images in x and y direction as specified by the user. This mode is intended for large scenes and the '.inn' file with the processing parameters must already exist.

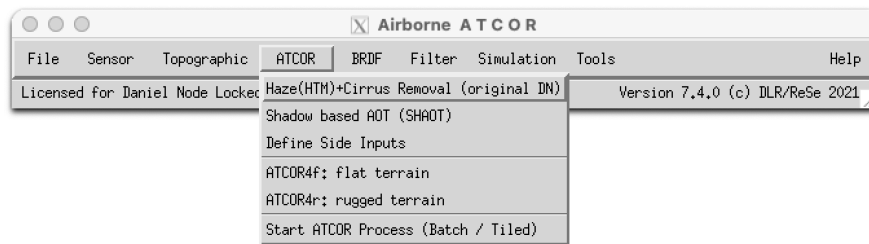


Figure 4.5: Top level graphical interface of ATCOR: "Atmospheric Correction".

Let us start with a scene from a flat terrain area where no digital elevation model (DEM) is needed. Then the panel of Fig. 4.6 will pop up. First, the 'INPUT IMAGE FILE' has to be selected. ATCOR requires the band sequential format (BSQ) for the image data with an ENVI header. Next the acquisition date of the image has to be updated with the corresponding button. We work from top to bottom to specify the required information. The scan angle file is only required if the image geometry does not correspond to the original geometry as specified in the '*sensor*.dat*' file which contains the number of pixels per line and the sensor field-of-view (FOV), see chapter 4.6. The scale factor defines the multiplication factor for surface reflectance (range 0 - 100%) in the output file. A scale factor of 1 yields the output as float data (4 bytes per pixel). However, a scale factor of 100 is recommended, so a surface reflectance value of say 20.56% is coded as 2056 and is stored as a 2 byte integer which means the file size is only half of the float file size with no significant loss of information.

If the input file name is "*image.bsq*" then the default output file name for the atmospherically corrected image is "*image_atm.bsq*". The user may modify the output name, but it is recommended to keep the "*_atm.bsq*" qualifier to facilitate the use of subsequent programs. Then the flight and solar geometry have to be specified as well as the sensor and the calibration file. The atmospheric file contains the look-up table (LUT) results of the radiative transfer calculations, separately for the solar and thermal region.

For a new user-specified sensor these LUTs have to be calculated once prior to the first call of ATCOR. This is done with the module RESLUT available under the 'Sensor' button of Fig. 4.1.

It is recommended to check the quality of the atmospheric correction before processing the image data. For that purpose, the SPECTRA module should be used where the surface reflectance of small user-defined boxes can be evaluated and compared with library spectra, compare chapter 5.5.1. In case of calibration problems, the spectral calibration module, available from the 'Tools' button of Fig. 4.1, and the radiometric (inflight) calibration may be employed before finally processing the image data.

The '*AEROSOL TYPE*' button provides an estimate for the recommended aerosol type (e.g. rural, maritime, urban) derived from the scene. This module also provides a visibility value for each

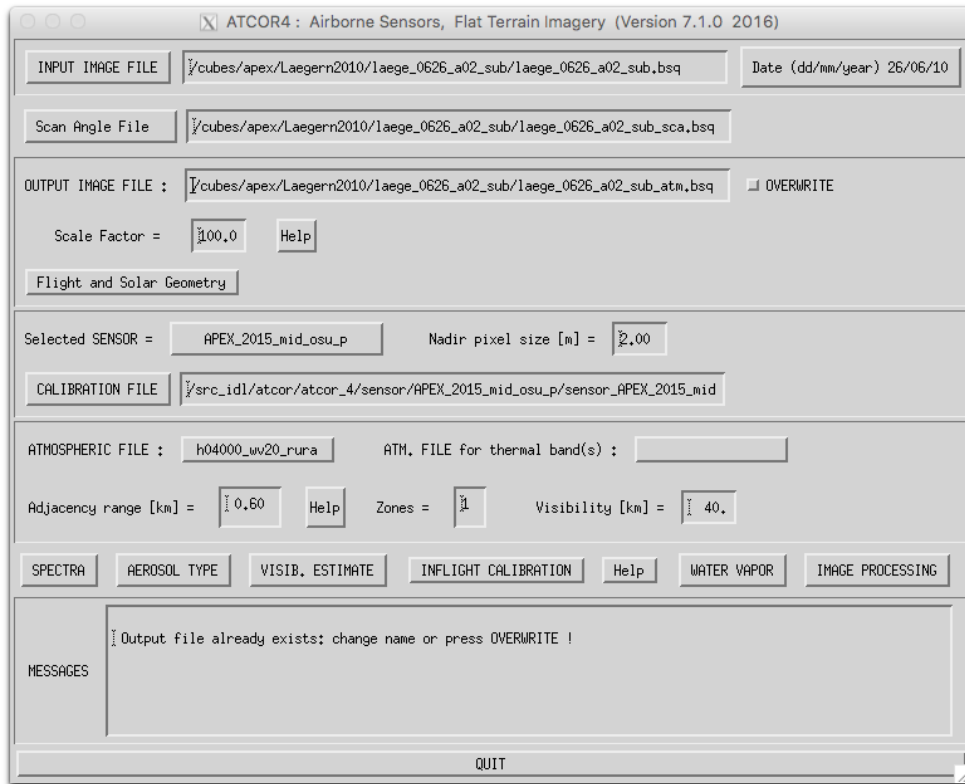


Figure 4.6: ATCOR panel for flat terrain imagery.

aerosol type based on reference pixels (dark vegetation) in the scene. The '*VISIB. ESTIMATE*' button provides a visibility value for the selected aerosol type by checking dark scene pixels in the red band (vegetation, water) and NIR band (water). It is assumed that the lowest reflectance in the red band is 0.01 (1 percent) and 0.0 in the NIR band. Therefore, the obtained visibility value usually can be considered as a lower bound. The higher visibility value (of '*AEROSOL TYPE*' and '*VISIB. ESTIMATE*') is recommended as a start visibility for the *SPECTRA* module.

The '*Inflight Calibration*' routine is described in chapter 5.4.10.

The '*WATER VAPOR*' button can be used to test the appropriate band combinations for the retrieval of a water vapor map without a calculation of the surface reflectance cube. Fig. 4.7 shows the panel with the image processing options. Some options may not be accessible, they are blocked if the required spectral bands are missing.

In case of a rugged terrain the ATCOR4r button has to be selected (Fig. 4.1, "ATCOR"). This panel is similar to Fig. 4.6, but an additional panel for the specification of the DEM files will appear (Fig. 4.8). The user has to provide the DEM file matched to the size of the input image. The slope and aspect files can be calculated from the corresponding module under "Topographic" (Fig. 4.1). These two files may need a special treatment as discussed in chapter 5.5.1. Therefore, they are not automatically created from the elevation file. The "skyview" file and cast shadow file are optional, only required in extremely steep terrain. The "skyview" calculation can also be found under the "Topographic" label of Fig. 4.1.

Depending on the selected image processing option some additional panels may pop up. Most

Blocked Options Are Not Available For The Selected Sensor
(Might also apply for a reduced set of bands)

Variable Visibility (aerosol optical thickness)	Yes	No
Variable Water Vapor	Yes	No
Haze or Sun Glint Removal	Yes	No
Shadow Removal (Clouds/Buildings)	Yes	No
Value Added Products	Yes	No
Solar Flux at Ground	Yes	No

Cancel OK

Blocked Options Are Not Available For The Selected Sensor
(Might also apply for a reduced set of bands)
(Either Haze or Cirrus Removal, not both)

Variable Visibility (aerosol optical thickness)	Yes	No
Variable Water Vapor	Yes	No
Haze or Sun Glint Removal	Yes	No
Shadow Removal (Clouds/Buildings)	Yes	No
Value Added Products	Yes	No
Cirrus Removal	Yes	No
Solar Flux at Ground	Yes	No

Cancel OK

Figure 4.7: Image processing options. Right panel appears if a cirrus band exists.

Update DEM Path Path = /auto_as/data7/atcor43/demo_data/gruber/

Mandatory Files

Elevation = jdpw10_hysens_ele DEM height (z) unit : [m] [dm] [cm]

Slope [degree] = jdpw10_hysens_slp

Aspect [degree] = jdpw10_hysens_asp

Optional Files

Sky View Factor [%] = jdpw10_hysens_sky

Cast Shadow [0,1] = 1

Use pre-calculated shadow file

Shadow map calculated "on the fly", requires more memory

--> Check "line2_geo_ilu" for possible DEM-related artifacts.

Message

Cancel OK

Figure 4.8: Panel for DEM files.

of them are listed in chapter 5.4.12. They are mostly self-explaining and are not discussed here. They also contain default settings which can be used in most cases. When the main panel (Fig. 4.6) is left and the SPECTRA or "IMAGE PROCESSING" sections are entered, all information is written to a processing initialization (.inn) file, e.g., "image.inn". When reloading the input file this information is read from the .inn file, so a new specification of all processing parameters is not necessary. Therefore, this .inn file can also be used for a batch processing, see chapter 6.

4.3 Survey of processing steps

Figure 4.9 shows the typical workflow of atmospheric correction. A detailed description of the corresponding graphical user interface for each module is given in chapter 5. First, the image is loaded with possibly some additional information (DEM files). Then the sensor has to be defined, the radiometric calibration file, and a basic atmosphere/aerosol type combination, e.g. a summer atmosphere with a rural aerosol. It is recommended to check the validity of the calibration and to estimate the visibility (and perhaps the atmospheric water vapor column wv) before processing

the image cube. The SPECTRA module can be employed for this purpose, see chapter 5.4.7. Reflectance spectra of scene targets can be displayed as a function of visibility and water vapor and compared with field or library spectra. If calibration problems exist in a few channels a copy of the calibration file can be edited in these channels to match the reference spectrum. If there are problems in many channels the inflight radiometric calibration module should be used to generate a calibration file as discussed in chapter 5.4.10.

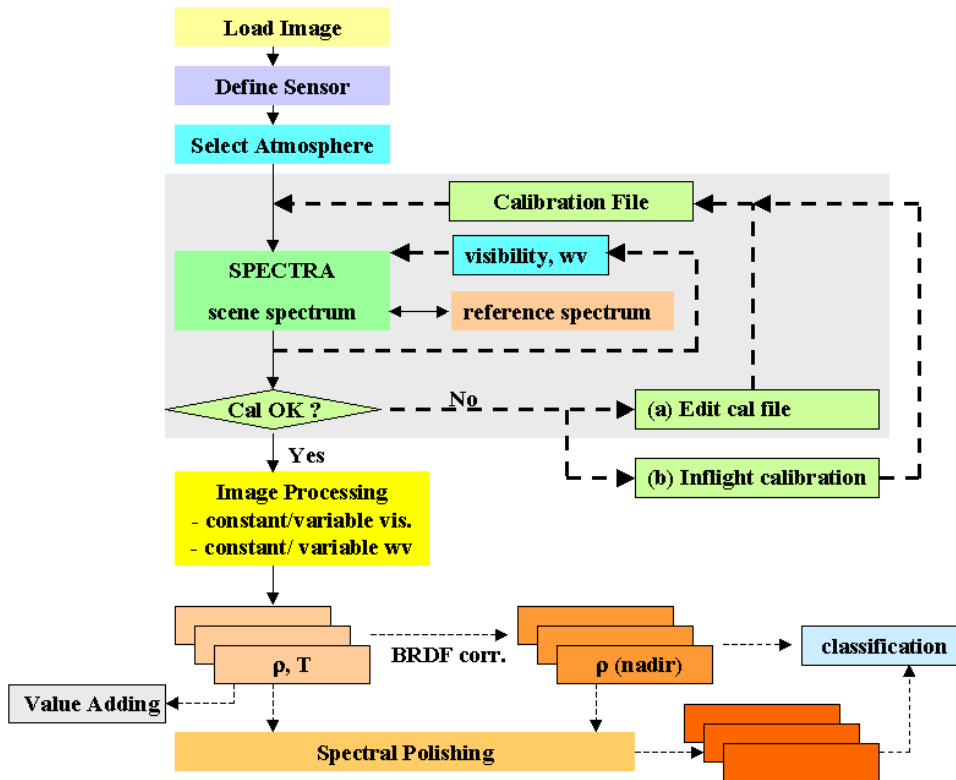


Figure 4.9: Typical workflow of atmospheric correction.

When the calibration file is OK the user can continue with the image processing. Depending on the available sensor channels there are options to process the imagery with constant or variable visibility and atmospheric water vapor. For large FOV sensors an option is available to correct for across-track illumination (BRDF) effects. This is especially useful if the image recording took place in the solar principal plane. In addition, a spectral polishing can be performed for the atmospherically and / or BRDF corrected data as indicated by the dotted lines of figure 4.9. The polishing requires hyperspectral imagery. Finally, a classification may be performed.

Figure 4.10 shows the input / output image files associated with ATCOR processing. On the left part the flat terrain case is treated, on the right part the rugged terrain case. If the image has the original scan geometry, i.e., the number of pixels per line corresponds to the number specified in the "sensor.dat" file, then the scan angle assignment for each pixel is calculated internally employing the total FOV and pixels per line. Otherwise, a scan angle file (created with PARGE) has to be provided.

In mountainous terrain, the DEM, DEM slope and aspect files are required. Optional input are

the skyview file and the shadow map, the latter can also be calculated on-the-fly. The slope and aspect files can be calculated from ATCOR's interactive menu, or run as a batch job (*slopasp_batch* see chapter 5). The skyview file has to be computed with the *skyview* program, see chapter 5.3.7.

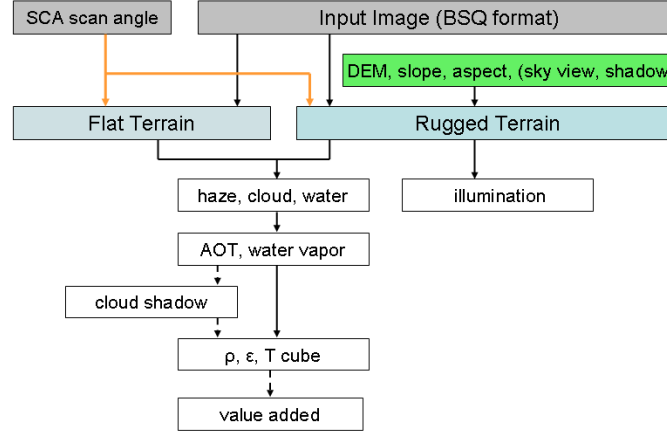


Figure 4.10: Input / output image files during ATCOR processing.

4.3.1 Shadow Based Data Processing Steps (SHAOT)

Alternatively to the processing workflow as given above, ATCOR may be used based on image derived shadows. This workflow is specifically suited for very high resolution imagery (resolutions 1cm to 5m). The core processing scheme is shown in Figure 4.11. It uses the outputs from a cast shadow detection procedure as described in [120, 121] including a skyview factor map which takes the reduced skyview factor within cast shadow areas into account. The SHAOT method is then used for aerosol retrieval. Finally, the atmospheric compensation is applied in conjunction with DEM information and water vapor retrieval.

1. Prepare meta data and calibration data for the sensor, also possibly prepare the DEM (see above)
2. Start *ATCOR:ATCOR4f* and define all parameters. Use the SPECTRA function to update the parameter and to check if the retrieved spectra are reasonable. This will write a **inn* file with all parameters.
3. Retrieve cast shadow distribution (*Menu: Topographic:Image based Shadows*) and write illumination file (**_ilu*)
4. Derive the height-dependent AOT map using the digital elevation model, the visibility index, and the MODTRAN-based relation between aerosol optical thickness and visibility, store output as **_aot550*. (*Menu: Shadow based AOT (SHAOT)*)
5. Define the layers required for data processing (*Menu:ATCOR:Define Side Inputs*). Deselect the **_ilu* file in case no cast shadow correction is to be applied.
6. Start *ATCOR4f* or *ATCOR4r*, start processing and select 'Variable Aerosols' The file **_aot550* will be used automatically for the processing.

7. Proceed with filtering and polishing routines as needed.

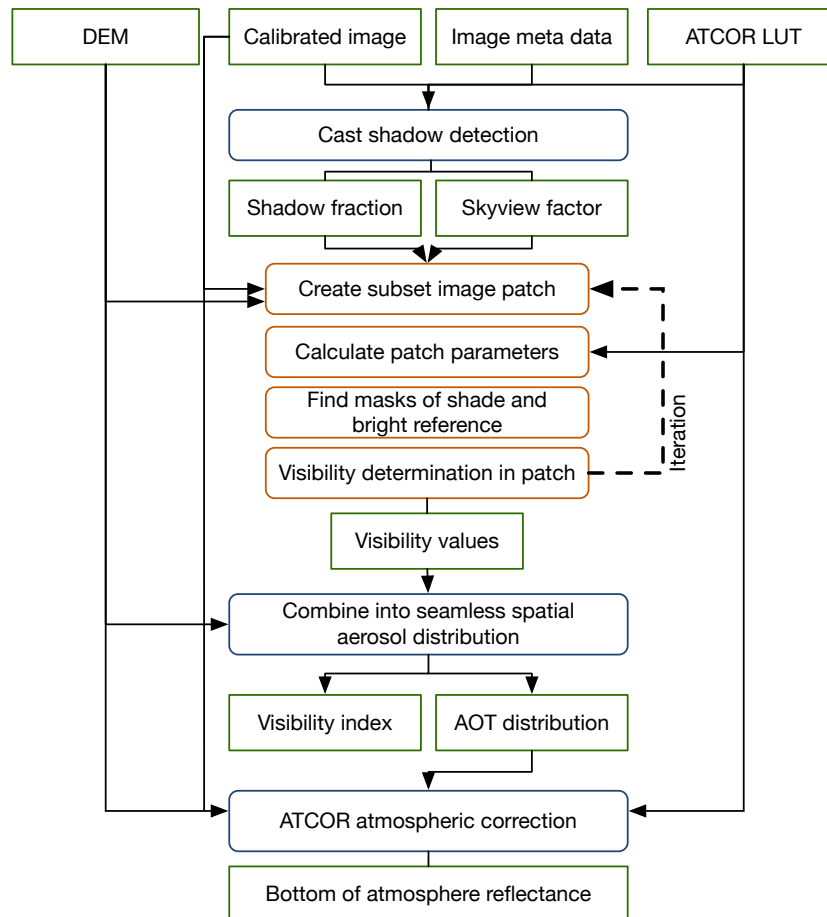


Figure 4.11: Cast shadow based workflow for aerosol retrieval and atmospheric correction (s. [121]).

4.4 Directory structure of ATCOR-4

Figure 4.12 shows the directory structure of the airborne version of ATCOR. There are a number of sub-directories with the following content: The 'bin' directory holds the ATCOR4 program with all modules as listed in chapter 5. The 'sensor' directory holds all supported airborne sensors in sensor-specific sub-directories.

As a possible convention, the last 2 digits indicate the year of calibration, e.g. hymap04 means the spectral and radiometric calibration of HyMap conducted in 2004. The "atm_database" contains the files of the monochromatic ATCOR database, see chapter 8.1. The "atm_lib" contains the results of the atmospheric database after resampling with the sensor-specific spectral response curves. The "spec_lib" is an optional subdirectory where the user can put field measurements of surface reflectance spectra resampled for the appropriate sensor. This is useful for inflight calibration or comparison of scene spectra with ground spectra. Finally, the "demo_data" contains some demo imagery to be able to run ATCOR-4 immediately.

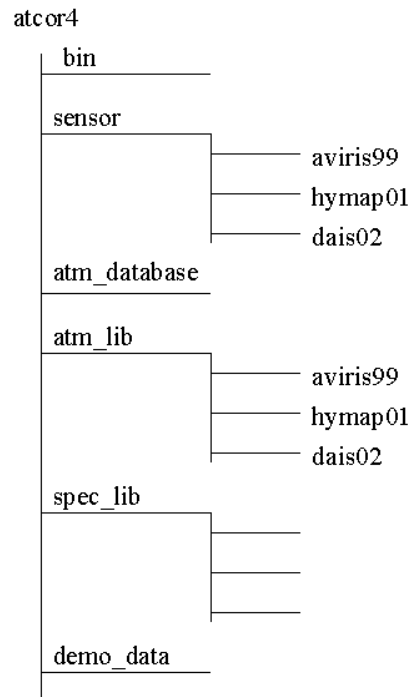


Figure 4.12: Directory structure of ATCOR-4.

4.5 Convention for file names

Although file names are arbitrary it is useful to agree on some conventions to facilitate the search of files, especially concerning the extensions of file names.

Input images to ATCOR must have the band sequential format (BSQ), therefore it is recommended to employ the '.bsq' as an extension, e.g. 'image1.bsq'. Then in this example the default output file name of ATCOR will be 'image1_atm.bsq' and a log report of the processing is available in 'image1_atm.log'.

Once an image is processed with ATCOR all input parameters are saved in a file *'*.inn'* that is automatically loaded should the image be processed again.

The recommended extension for the radiometric calibration files is *'cal'*. Other extensions are *'*_ele.bsq'* for the digital elevation file, *'*_slp.bsq'* for the DEM slope file, *'*_asp.bsq'* for the DEM aspect, *'*_sky.bsq'* for the sky view file, *'*_ilu.bsq'* for the solar illumination file in rugged terrain, and *'_cla.bsq'* for the classification map of SPECL. The interface to PARGE (Schläpfer and Richter 2002 [95]) uses a scan angle file *'_sca.bsq'*, where band 1 provides the scan view angle for each pixel, and band 2 the absolute scan azimuth angle. The visibility index map is named *'*_visindex.bsq'*, the aerosol optical thickness is *'*_aot.bsq'*, the cloud/building shadow map is named *'*_fshd.bsq'*, and the atmospheric water vapor map *'*_wv.bsq'*.

Thermal band imagery

In case of thermal band imagery the surface temperature and emissivity are stored in separate files. Surface temperature is appended to the reflectance cube, i.e. is included as the last channel in the *'*_atm.bsq'* file, e.g., *'image1_atm.bsq'*.

The surface temperature calculation is based on an assumption for the emissivity in *one* spectral band. Three options have been implemented:

- a constant scene emissivity of $\epsilon = 0.98$ in the channel used for the surface temperature calculation.
- a map of 3 emissivity classes (vegetation, soil, others) depending on surface cover. The surface cover class is calculated on the fly based on the vegetation index and red/NIR reflectance values for each pixel. Typical average emissivity values were assumed (vegetation $\epsilon = 0.97$; soil, asphalt, concrete $\epsilon = 0.96$; others $\epsilon = 0.98$). The file name of the 3-class emissivity map is *'image1_atm_emi3.bsq'*, the '3' indicating the 3 classes, if the file name of the scene is *'image1.bsq'*.
- a detailed map of up to 18 emissivity classes, compare [ATBD \(Appendix\)](#). The user has full control over the assignment of an emissivity value for each class, i.e. the file *emissivity.dat* can be edited by the user. This emissivity assignment pertains to the channel for which the surface temperature is calculated, compare the sensor definition file in chapter 4.6. The emissivity map for each scene can be calculated with program SPECL prior to the processing of the thermal bands, but after processing of the coregistered reflective bands.

SPECL classifies the surface reflectance spectrum of each pixel by comparing it to a set of template surface cover spectra and assigns the class for which the best match is found. If no sufficient match is found, the pixel is assigned to 'not classified'. The file name is *"image1_atm_cla_emi.bsq"*. It is generated simultaneously with the classification file *"image1_atm_cla.bsq"*, see chapter 5.8.3.

One of the first two options is usually selected for sensors with a single thermal band. The last option can be selected in case of multispectral thermal bands. After the surface temperature has been calculated based on the provided emissivity map in one channel, the remaining emissivity channels are computed and put into the file *"image1_atm_emi.bsq"*. The multi-band emissivity file is coded with 16 bits per pixel scaled with the factor 1000.

label	description	emissivity
0	not classified	0.980
1	clear water	0.991
2	dark vegetation	0.980
3	average veget.	0.975
4	bright veget.	0.980
5	yellow veget.	0.980
6	mixed veg./soil	0.975
7	dark bare soil	0.970
8	bare soil	0.970
9	asphalt	0.955
10	sand / soil	0.970
11	bright sand/soil	0.970
12	dry veg./soil	0.975
13	sparse veg./soil	0.975
14	snow	0.980
15	cloud	0.980
16	turbid water	0.984

Table 4.1: Example of emissivity values for a 11 μm channel.

4.6 Definition of a new sensor

A few steps have to be taken to include a new airborne sensor in ATCOR, compare Fig. 5.18. These are :

- Using the routine *Define Sensor Parameters* as described in chapter 5.2.1, a new sensor and a calibration file with constant conversion factors for all bands may be defined. This process may also be done manually by copying and adapting an existing user-defined sensor directory. The routine *Define Sensor Parameters* defines a sensor parameter ('*.dat') file within the sensor directory. The entries in this file may be modified manually, according to the definitions in table 4.6 or 4.6.
- A calibration file has to be provided (e.g., "hymap2003.cal") in the new sensor sub-directory, containing the scaling factors from raw image DN to [mW/(cm² sr micron)]. This file is created automatically by the routine *Define Sensor Parameters*, but needs to be adapted in case the conversion factors are not constant for all spectral bands.
- The spectral response has to be provided as *band*.rsp'* files for each spectral band. These files can either be created by using the center wavelength and FWHM from the ENVI header file ('*.hdr') or by providing a wavelength file ('*.wvl'). The latter is a simple ASCII file with three columns (band number, center wavelength, and bandwidth), compare Fig. 5.18. Center wavelength and bandwidth may be given in the nm or μm unit. The first line of a *.wvl file may contain an optional header with text.

Eight analytical filter shapes can be selected from the top level graphical interface (Fig. 4.1 when selecting the menu 'Sensor', then choose 'Create Channel Filter Files' button. Then the menu of Fig. 4.13 will pop up, and one of these 8 filter shapes can be selected. Filter numbers 1 to 4 are of the Butterworth type, the slow drop-off for the Butterworth order 1

is truncated at the 0.05 response and set to zero. The filter type 9 (parameter *filter_type* in Table 4.3) is reserved for arbitrary user-specified channel filter functions.

- The RESLUT (*resample atmospheric LUTs*) program has to be run to generate the atmospheric LUTs for the new sensor employing the monochromatic atmospheric database in ".../atcor4/atm_database/". These resampled '*.atm' files will automatically be placed in a sub-directory of '.../atcor4/atm_lib/' with the name of the selected sensor. RESLUT will also create the resampled spectrum of the extraterrestrial solar irradiance in the appropriate ".../sensor/hymap2003/" folder, see chapter 8.2, e.g., "e0_solar_hymap2003.spc". In addition, the first use of RESLUT will create the "pressure.dat" file in the sensor-specific folder.

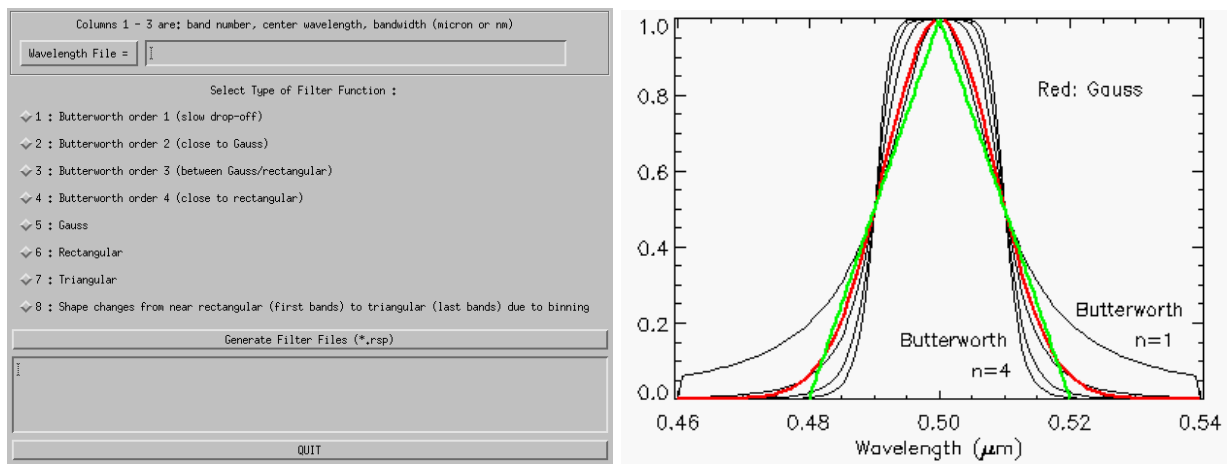


Figure 4.13: Supported analytical channel filter types.

Now you may start processing imagery of the just defined sensor. If the sensor has thermal spectral bands the program RESLUT will automatically calculate the coefficients of the temperature / radiance relationship. They will be stored in a "sensor*.bbfit" file in the appropriate sensor subdirectory. RESLUT will also create the resampled spectrum of the extraterrestrial solar irradiance, e.g. "e0_solar_hymap04.spc".

Two examples of the file "sensor_example.dat" are given below. The first table presents a sensor without thermal bands, and without gain settings. The second table defines a sensor with 79 bands (DAIS-7915), having 6 thermal channels. The mid-IR bands have to be specified separately, no atmospheric correction is performed for these bands. The input channels are included at the same position as output channels. In the ENVI header, they are labeled "DN".

60.0	512	across-track FOV [degree], pixels per line
1	128	first, last reflective band (0.35-2.55 μm)
0	0	first, last mid IR band (2.6 -7.0 μm)
0	0	first, last thermal band (7.0 -14 μm)
0		no tilt in flight direction
0		required dummy

Table 4.2: Sensor definition file: no thermal bands.

Line 5 of the sensor definition file is retained for compatibility with ATCOR-4 versions below 3.0. The tilt parameter is always zero, i.e., tilt sensors are not supported in the atmospheric database. In case of tilt sensors the old ATCOR-4 (version below 3.0) must be used which requires a MODTRAN® 5 license to calculate the atmospheric LUTs, because no database is available for tilt sensors. Line 6 is a required dummy to be compatible with previous versions.

60.0	512	across-track FOV [degree], pixels per line
1	72	first, last reflective band (0.35-2.55 μm)
73	73	first, last mid IR band (2.6 -7.0 μm)
74	79	first, last thermal band (7.0 -14 μm)
0		no tilt in flight direction
0		required dummy
77		temperature band (itemp_band=77)

Table 4.3: Sensor definition file: instrument with thermal bands.

4.7 Spectral smile sensors

Imaging systems can employ different techniques to record a scene: the whiskbroom design uses a rotating or oscillating mirror to collect an image line in across-track direction (with one or a few detector elements per spectral band). The forward direction is provided by the motion of the platform. Secondly, a pushbroom linear array can perform the same task without moving optical elements, but the number of array lines (each recording a certain spectral channel) in the focal plane is limited. The third imaging technique employs an area detector array where one direction collects the spatial information (across-track) and the orthogonal direction covers the spectral dimension. The advantage of the last two techniques is a longer pixel dwell time and a potentially improved signal-to-noise ratio (SNR). The drawback is a substantial increase in the spectral and radiometric characterization, i.e., a change of the channel center wavelength across the columns of the array (spectral "smile"), spatial misregistration ("keystone"), and detector non-uniformity problems [78], [27], [101].

Typical representatives of the whiskbroom type are Landsat TM/ ETM, HyMap, AVIRIS, and Daedalus. These instruments almost show no spectral smile, i.e., the channel center position and bandwidth do not depend on column pixel location.

Spaceborne hyperspectral instruments showing the "smile" effect are Hyperion and CHRIS/Proba, airborne instruments are for example CASI-1500 and APEX.

This section describes the ATCOR input files required for smile sensors. There are only two changes compared to the "non-smile" instruments:

- The sensor definition file, e.g., "*sensor_casi1500.dat*", needs one more line (see Table 4.3) containing the parameters *ismile* (=1 if smile sensor, otherwise 0) and *filter_type* (a number between 1 and 9 for the type of channel filter function) compare section 4.6 and Fig. 4.13. The filter types 1 to 8 are analytical functions, filter type 9 is reserved for arbitrary user-defined channel filter functions (the '*band*.rsp*' files). Center wavelength and bandwidth for each channel are defined in the wavelength file ('**.wvl*') pertaining to the center pixel=column of the detector array.
- For each spectral channel j the channel center wavelength $\lambda_c(j)$ depends on the image column or pixel position x . The absolute value of $\lambda_c(j)$ is specified in the wavelength file used to generate the spectral channel response functions, and it is also included in the sensor-specific solar irradiance file (e.g., "*e0_solar_casi1500.spc*"). If n is the number of image columns, the change $\Delta(x, j)$ of the center wavelength $\lambda_c(j)$ with the pixel position x can be described as a 4th order polynomial (using the nm unit):

$$\Delta(x, j)[nm] = a_0(j) + a_1(j) \cdot x + a_2(j) \cdot x^2 + a_3(j) \cdot x^3 + a_4(j) \cdot x^4 \quad (4.1)$$

$$\lambda_c(x, j) = \lambda_c(j) + \Delta(x, j) \quad (4.2)$$

The first left-hand image pixel is $x=0$, the last right-hand image pixel is $x=(n-1)$. The coefficients $a_i(j)$ have to be stored in an ASCII file, corresponding to the band sequence. The first column must contain the wavelength or band number, followed by the five channel-dependent coefficients (beginning with a_0 and ending with a_4), one line per channel. The fixed file name is *smile_poly_ord4.dat* and it has to be located in the corresponding sensor sub-directory. In the ideal case these coefficients should be derived from laboratory measurements.

Since an accurate description is only required for channels in atmospheric absorption regions, the 5 coefficients can be set to zero for the remaining regions, but they must be provided for each channel. If all 5 coefficients are set to zero for a certain channel, this channel is processed in the "non-smile" mode which will expedite the processing.

- Optionally, the spectral bandwidth (FWHM) might also depend on the image column. Again, a 4th-order polynomial is used to describe the bandwidth change depending on column position x and channel j :

$$\Delta_1(x, j)[nm] = b_0(j) + b_1(j) \cdot x + b_2(j) \cdot x^2 + b_3(j) \cdot x^3 + b_4(j) \cdot x^4 \quad (4.3)$$

$$FWHM(x, j) = FWHM(j) + \Delta_1(x, j) \quad (4.4)$$

The fixed file name is *smile_poly_ord4_fwhm.dat* and it has to be located in the corresponding sensor sub-directory. It is an ASCII file with 6 columns per channel, the first column is the channel number or wavelength, the remaining columns contain the polynomial coefficients starting with b_0 .

30.0	512	across-track FOV [degree], pixels per line
1	128	first, last reflective band (0.35-2.55 μm)
0	0	first, last mid IR band (2.6 -7.0 μm)
0	0	first, last thermal band (7.0 -14 μm)
0		no tilt in flight direction
0		required dummy
1	5	1=smile sensor, 5 = Gaussian spectral channel filter

Table 4.4: Sensor definition file: *smile* sensor without thermal bands.

Imagery from smile sensors must be processed in the raw geometry (IGM Image Geometry Map) to preserve the original image columns. During the surface reflectance retrieval the atmospheric / topographic correction is performed on a per column basis, i.e., to each image column its appropriate center wavelength /bandwidth is associated.

The per-column processing typically implies a factor of 8 increase in processing time. The following steps are to be performed:

1. Define a sensor (*wvl, *cal, *rsp files, RESLUT) using the original set of wavelengths (pre-launch values, as provided with the data from the data provider),
2. Run the smile detection tool (compare Section 5.8.4, using the sensor defined in 1 and appropriate absorption features, to derive the polynomial coefficients *smile_poly_ord4.dat* for smile correction in step 3; alternatively: enter the smile polynomial factors from laboratory calibration. *Note:* if two detectors are in the sensor system, this should be done separately for VNIR and SWIR, option 'repeat values', resolution 0.02 nm. Combine the two files for VNIR and SWIR manually into one file afterwards.
3. Using the same sensor as above, run the atmospheric correction with the smile correction option switched 'ON'; (after putting the new file *smile_poly_ord4.dat* into the sensor definition directory),

4. Apply the spectral polishing routine (see Section 5.6.3 and 5.6.4, and
5. Run the Spectral Smile Interpolation module (see Section 5.6.7 on the atmospherically corrected image.

4.8 Haze, cloud, water map

Although the surface reflectance cube (and temperature / emissivity for thermal channels) is the main result of the atmospheric correction, some additional products are often requested. One of these products is a map of the haze, cloud, water and land pixels of a scene. This map not only delivers a basic scene classification, but it may also contain information about potential processing problems. For example, if turbid water pixels are not included in the water mask, the haze mask may also be not appropriate and consequently, results of the haze removal over land might be of poor quality. Such a pre-classification as part of the atmospheric correction has a long history [32, 60, 88, 89, 90, 61, 70]. It is also employed as part of NASA's automatic processing chain for MODIS [1] using the classes land, water, snow/ice, cloud, shadow, thin cirrus, sun glint, etc.

Therefore, the calculated haze/cloud/water map is a useful optional output of ATCOR. It is enabled by setting the parameter $ihcw = 1$ in the *preference_parameters.dat* file (see chapter 8.4). If the file name of the imagery is *"image.bsq"* the corresponding map is named *"image_out_hcw.bsq"*. It is a 1-channel false-color coded ENVI file. In principle, if a certain mask of *"image_out_hcw.bsq"* (say haze pixels) contains artifacts, it may be edited, and if the edited file is named *"image_hcw.bsq"* it will automatically be used for the ATCOR processing. This means ATCOR can repeat the processing with an improved (edited) haze mask.

The file *"image_hcw.bsq"* can also be provided by an external (ATCOR-independent) source. In any case, if this file exists, ATCOR will skip its internal calculations of these masks and use the pre-calculated map.

Additionally, a compact classification map with seven classes (named *"image_out_csw.bsq"*) is also available, Table 4.6 contains the counterpart for the 'csw' file.

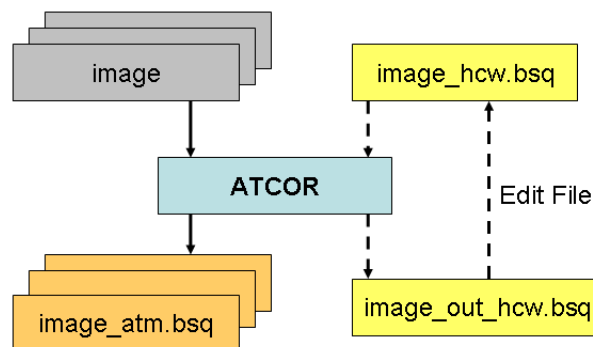


Figure 4.14: Optional haze/cloud/water output file.

The haze/cloud/water file contains the following classes (see Table 4.5):

- land
- water

label	definition	color coding
0	geocoded background	grey
1	shadow	dark black
2	thin cirrus (water)	light blue
3	medium cirrus (water)	medium blue
4	thick cirrus (water)	darker blue
5	land	brown
6	saturated	red
7	snow/ice	white
8	thin cirrus (land)	light yellow
9	medium cirrus (land)	medium yellow
10	thick cirrus (land)	darker yellow
11	thin haze (land)	yellow
12	medium haze (land)	darker yellow
13	thin haze/glint (water)	blue/yellow
14	med. haze/glint (water)	dark blue/yellow
15	cloud/land	bright grey
16	cloud/water	blue/grey
17	water	dark blue
18	cirrus cloud	green/yellow
19	cirrus cloud thick	dark green/yellow
20	bright surface	bright grey
21	topographic shadow	grey/black
22	cloud shadow	black

Table 4.5: Class label definition of "hew" file.

- boundary layer haze (two classes: thin-to-medium haze, and medium-to-thick haze)
- cirrus (three classes for thin, medium, thick; and cirrus cloud, thick cirrus cloud), provided a narrow channel around $1.38 \mu m$ exists.
- cloud over land, cloud over water
- snow (requires a $1.6 \mu m$ channel)
- saturated pixels using the criterion $T > 0.9 * DN_{max}$ where T is a threshold set at 0.9 times the maximum digital number. This criterion is only used for 8 bit and 16 bit (signed or unsigned) data, no threshold is defined for 32 bit (integer or float) data. As an example, for an 8 bit/pixel data encoding we obtain $T = 0.9 * 255 = 230$, and pixels with a grey value greater than 230 are flagged as (truly or potentially) saturated.

Although the saturation nominally starts at DN_{max} some sensors already show a non-linear behavior around $0.9 * DN_{max}$, so the factor 0.9 is a precaution to be on the safe side.

This saturation check is performed for two channels in the visible region (blue band around 470-500 nm, and a green band around 550 nm). For multispectral sensors, the blue band is usually the critical one concerning saturation. For hyperspectral sensors with many blue bands the one closest to 450 nm is taken. Although the haze/cloud/water file contains saturated pixels based on two visible bands, the percentage of saturated pixels for all bands

will be given in the corresponding ".log" file. However, the check of the blue and green channel normally captures all saturated pixels.

The thresholds for the cirrus class definition are described in the [ATCOR ATBD](#).

label	definition	color coding
0	geocoded background	grey
1	clear	brown
2	semi-transparent cloud	yellow
3	cloud	bright grey
4	shadow	black
5	water	dark blue
6	snow/ice	white
7	topographic shadow	grey/black

Table 4.6: Class label definition of "csw" file.

4.9 Processing of multi-band thermal data

Several options have been implemented to process multi-band thermal data, see [ATCOR ATBD](#) for details. Apart from the final products (surface temperature and emissivity) intermediate products are available such as surface radiance, at-sensor blackbody temperature, and surface blackbody temperature. The intermediate products might be useful to trace back spectral or radiometric problems. If *image.bsq* denotes the file name of the input image then the following products are available:

- *image_atm_emi3.bsq* : 3 or 4 emissivity classes obtained from an on-the-fly (in memory) pre-classification (vegetation, soil, sand, water). The pre-classification requires daytime data acquisition and spectral bands in the solar region. This file has one channel with the emissivity values for the specified thermal band, or in case of ANEM the pixel-dependent values assign the maximum emissivity of all available thermal bands.
- *image_atm_emiss.bsq* contains the spectral emissivity map for all thermal channels.
- *image_atm_emiss_lp3.bsq* is the same emissivity map but filtered with a 3-channel low pass filter to smooth spectral noise features (requires at least 10 thermal bands).
- *image_atm_emiss_lp5.bsq* is the same emissivity map but filtered with a 5-channel low pass filter to smooth spectral noise features (requires at least 30 thermal bands).
- *image_atm_isac_emiss.bsq* : emissivity cube for the ISAC algorithm.
- *image_at_sensor_channel_tmax.bsq* : map of channel numbers with maximum at-sensor temperature.
- *image_at_surface_channel_tmax.bsq* : map of channel numbers with maximum surface temperature.
- *image_at_sensor_tbb.bsq* : at-sensor brightness temperature cube

- *image_at_surface_tbb.bsq* : at-surface brightness temperature cube.

The last channel of *image_atm.bsq* contains the surface temperature map evaluated with the appropriate emissivity, the preceding thermal channels in this file contain the surface radiance.

In case of the ISAC algorithm an additional file *image_isac_lpath_trans.dat* contains the spectral path radiance and transmittance estimates for the scene. Fig. 4.15 shows an example of these spectra derived from a SEBASS scene.

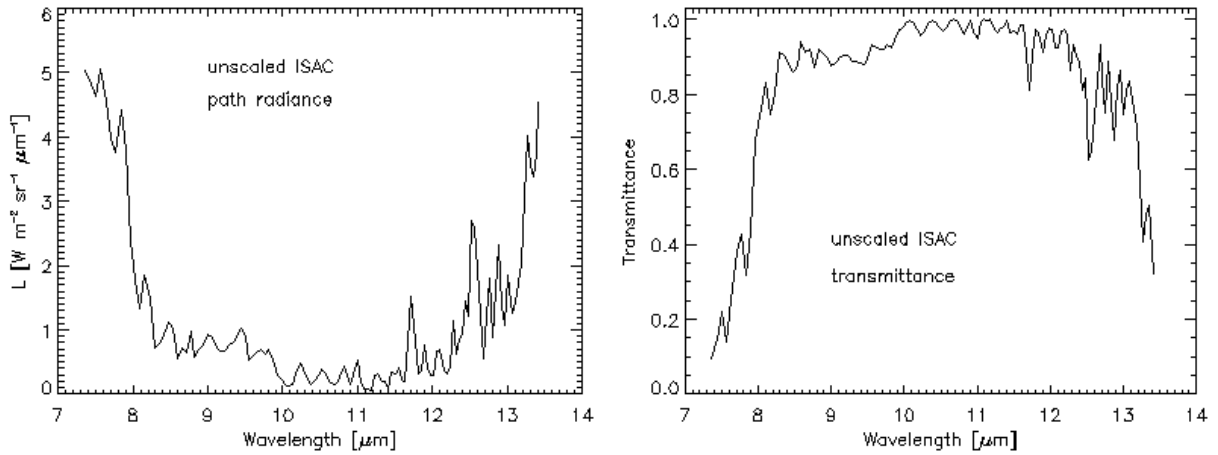


Figure 4.15: Path radiance and transmittance of a SEBASS scene derived from the ISAC method.

Fig. 4.16 presents the at-sensor/at-surface radiance and brightness temperatures. The at-sensor products clearly show the atmospheric absorption features which are removed in the at-surface quantities, apart from small residual effects. The bottom graphic presents the corresponding surface emissivity spectrum.

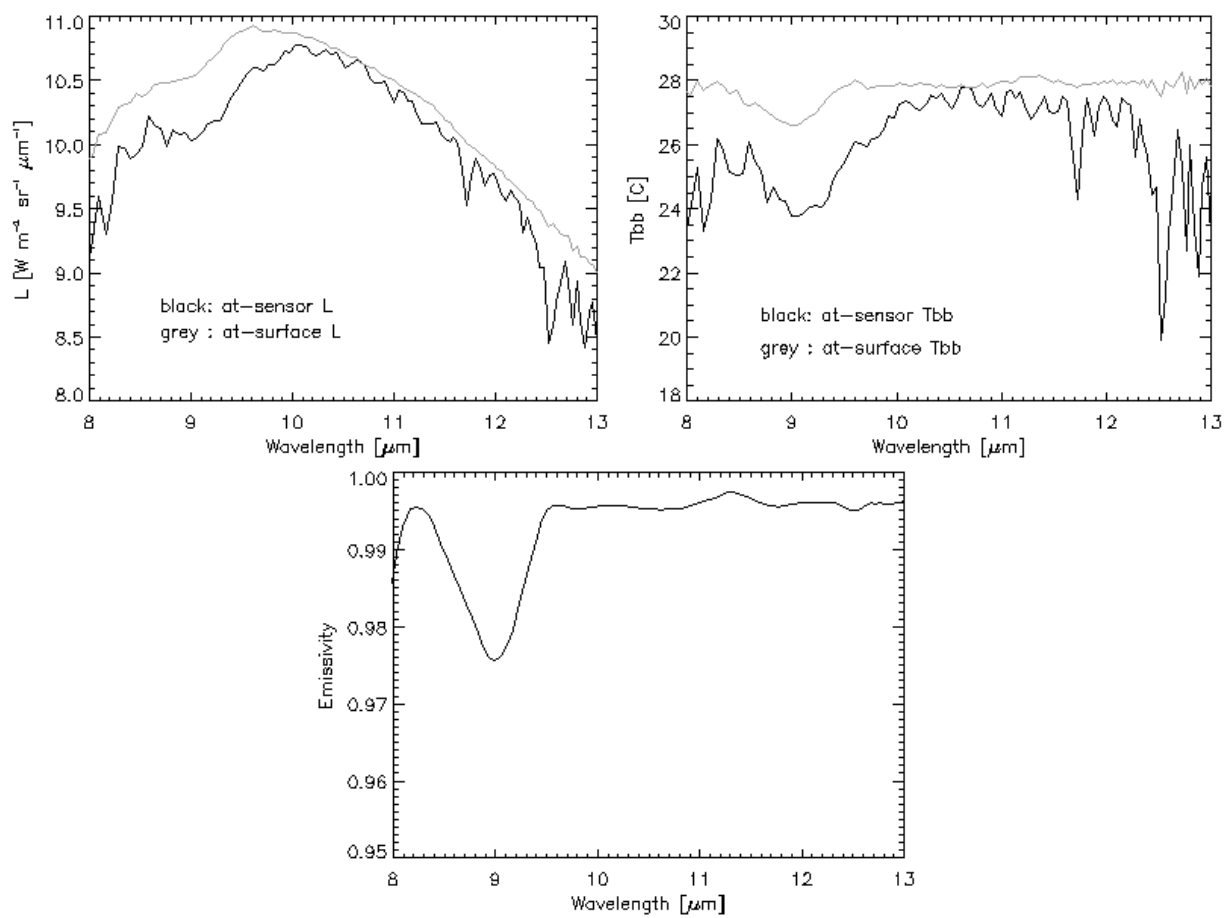


Figure 4.16: Comparison of radiance and temperature at sensor and at surface level.

4.10 External water vapor map

Sometimes, it is convenient to use an external water vapor map, even if this map could be derived from the scene. If the scene is named *"scene.bsq"* then the external map should be named *"scene_wv.bsq"* and it must have the same number of image lines and pixels per line as the scene. If this file is available in the same directory as the scene, it will be automatically used during the processing and the usage is also documented in the log file (*"scene_atm.log"*). Note: this feature is only supported for instruments that are able to retrieve the water vapor column with the intrinsic channels, because the prerequisite is the availability of the corresponding LUTs. The menu *ATCOR:Define Side Inputs* allows to select or deselect a water vapor map to be used as side input.

4.11 External AOT 550 nm map

Although ATCOR calculates the aerosol optical thickness map (at 550 nm) if the variable aerosol option is set (parameter npref=1 in the '*.inn' file), the import of an external AOT(550nm) map is also supported. This file should be located in the same folder as the scene. If the file name of the image is 'scene.bsq' then the corresponding AOT map should be named 'scene.aot550.bsq'. The size of this map should match the scene size (i.e. same number of columns and lines as the scene). If this map is stored as float data, then it contains the original AOT(550nm) values (i.e. without scale factor). This map can also be provided as 16-bit signed or unsigned integer with a mandatory scale factor of 1000. The menu *ATCOR:Define Side Inputs* allows to select or deselect an external aot550 map to be used as side input.

Note: The internal calculation of the aerosol optical thickness map is performed with DDV and water areas. Additionally, the path radiance in the blue-red spectrum is re-scaled to fit the surface reflectance of DDV pixels in the scene if required. However, for an external AOT550 map no re-scaling of the selected aerosol path path radiance is conducted. Therefore, if the internal AOT550 file is copied and used as an external AOT map both results may differ.

4.12 Filter for HySpex

HySpex is a suite of hyperspectral cameras developed and manufactured by Norsk Elektro Optikk, Norway (www.neo.no). There is a navigation file for each acquired airborne hyperspectral cube in the following format: an ASCII file with 8 columns separated by blanks, consisting of:

- line, longitude (deg), latitude (deg), ALT (meters), roll (deg), pitch (deg), heading (deg), UTCx

ALT is the flight altitude above sea level, and UTCx is the UTC time in seconds since midnight. The acquisition date is specified in the ENVI header. This information enables the automatic calculation of the solar zenith and azimuth angles evaluated for the center scan line of the scene. For this purpose, the nav ".txt" file must be in the same folder as the scene, named *"scene.txt"* if the scene name is *"scene.bsq"* or *"scene.img"*.

In addition, the ENVI header of each HySpex scene contains the radiometric scaling factor in the 'description' tag, and it is used to create the radiometric calibration file *"scene.cal"* with the gain $c1 = 100 / \text{scaling}$ (unit $mWcm^{-2}sr^{-1}\mu m^{-1}$). It is the same factor for all bands, and the offset $c0$ is zero.

4.13 Airborne FODIS instrument

Some airborne hyperspectral sensors are optionally equipped with an add-on instrument that can measure the downwelling hemispherical solar flux at the aircraft altitude. This add-on instrument is usually named FODIS (Fiber Optic Downwelling Irradiance Sensor). FODIS data could be useful for atmospheric correction, especially during adverse weather conditions. However, currently this information is seldom used for three reasons: atmospheric correction software usually does not support processing of FODIS data, the data must be corrected for the roll, pitch, yaw movements of the aircraft, and FODIS calibration can be a problem.

ATCOR now offers a tool to use FODIS data during the atmospheric correction. The general restrictions are:

- It can only be used in flat terrain processing, because the direct and diffuse solar fluxes (required for a rugged terrain processing) are no more available, as FODIS measures only the total downwelling solar flux at the aircraft level.
- FODIS data contain no information on the atmosphere below the flight level, so the precalculated atmospheric LUTs containing path radiance, direct and diffuse transmittances have to be used, only the global solar flux on the ground E_g is re-calculated based on the FODIS measurements.
- The hyperspectral scene must be processed in the original geometry, because FODIS measures one spectrum per original scan line. Geocoding can be performed later if required.

Without FODIS data the global flux at the ground is calculated as the sum of the direct and diffuse flux:

$$E_g = E_0 \tau_s \cos\theta_s + E_{dif} \quad (4.5)$$

where E_0 = extraterrestrial solar irradiance, τ_s = sun - ground (beam) transmittance, θ_s = solar zenith angle, and E_{dif} the diffuse flux on the ground. With FODIS data eq. (4.5) is replaced by:

$$E_g = E_f (\tau_{dir} + \tau_{dif}) \quad (4.6)$$

where E_f is the geometrically corrected spectral FODIS flux per scan line, and τ_{dir} , τ_{dif} are the direct and diffuse transmittances. E_f is calculated from the originally measured flux $E_f^{(0)}$ as

$$E_f = E_f^{(0)} \cos\theta_s / \cos\beta \quad (4.7)$$

where θ_s is the solar zenith angle and β is the incident solar angle (between FODIS normal and incident solar beam):

$$\cos\beta = \cos\theta_s \cos\theta_f + \sin\theta_s \sin\theta_f \cos(\phi_s - \phi_f) \quad (4.8)$$

The FODIS slope and azimuth angles θ_f , ϕ_f are computed from the FODIS attitude angles (roll: θ_{roll} , pitch: θ_{pitch} , yaw or heading: θ_{yaw}) :

$$\theta_f = \sqrt{\theta_{roll}^2 + \theta_{pitch}^2} \quad (4.9)$$

$$\phi_f = (\theta_{yaw} + 180 + \arctan(\theta_{roll}/\theta_{pitch})) \bmod 360^\circ \quad (4.10)$$

The last equation holds for the standard case of the aircraft nose up and the sign conventions are:

- roll angle is positive for the aircraft right wing up
- pitch angle is positive for the aircraft nose up
- yaw or heading ranges between 0° and 360° (90° = east)

The panel *"TOOLS"* contains a graphical user interface to process FODIS data in the Specim CaliGeo and NERC (Natural Environment Research Council, UK) formats. These are the currently supported formats and more will be added on demand.

Input to the GUI is the image file (example: *"scene.bsq"*), sensor, and FODIS format, see Fig. 4.17. The FODIS nav file(s) and irradiance file are included automatically if the mandatory file name conventions are kept, as described below. The output (example: *"scene_fodis.slb"*) is the geometrically corrected FODIS at-sensor flux in the ENVI spectral library format, stored as one reference spectrum per image line (unit $mWcm^{-2}\mu m^{-1}$). The data format is specified in the ENVI header: parameter 'lines' contains the number of image lines, 'samples' contains the number of bands, parameter 'bands = 1', and 'data type = 4', i.e. binary float data.

If the *"scene_fodis.slb"* file exists in the image folder, ATCOR(flat terrain) will automatically use this file during atmospheric correction, and this will be documented in the corresponding *"scene_atm.log"* file.

Mandatory name conventions apply for the FODIS processing:

- Specim CaliGeo format: if the scene file name is *"scene.bsq"*, then the navigation data must be named *"scene_nav.txt"*, and the FODIS data (coming in the binary ENVI BIP format) *"scene_fodis0.bip"*. These files have to be in the same folder as the scene. The angles in the nav file use the degree unit. The ASCII file *"*_nav.txt"* contains 9 columns separated with blanks:

scan line number, time, x, y coordinates, flight altitude, heading, roll, pitch, and aircraft speed.

Only data in columns 6 to 8 (heading, roll, pitch) is used. Heading is in the (-180,180) degrees interval and will be converted into the (0,360) interval.

The FODIS flux measurements in *"*_fodis0.bip"* are float data, and the ENVI header specifies the parameters 'samples = 1', 'lines = n' (where n is the number of image lines), 'bands = m', (where m is the number of bands), and 'data type = 4', i.e. float. All other ENVI header information is not used. The standard spectral flux unit is $(mWcm^{-2}nm^{-1})$, requiring a conversion factor of 0.001 for the unit $(mWcm^{-2}\mu m^{-1})$ which is used by ATCOR. However, the FODIS GUI (see Fig. 4.17) provides a flexible widget for re-scaling if necessary.

- NERC format: again, if the scene file name is *"scene.bsq"*, then the roll, pitch, yaw files must be named *"scene_COroll.txt"*, *"scene_COpitch.txt"*, *"scene_COhead.txt"* and the FODIS measurement file has to be *"scene_FODIS.txt"*. These files have to be in the same folder as the scene.

The angles in the roll, pitch, yaw files are in degrees times a scale factor 1,000. The *COroll*, *COpitch*, *COhead.txt* ASCII files contain one value per scan line, representing the corresponding angle times 1,000 stored as integer. The ASCII file *"scene_FODIS.txt"* contains the measured flux spectra with n columns (n = number of scan lines of scene) and m lines (m = number of bands). All flux values are in the unit $(mWcm^{-2}nm^{-1})$ stored as integer in the FORTRAN "I8" format.

Note: The capability of water vapor retrieval is switched off in case of FODIS processing, as it relies on the sun-ground-sensor radiation components and FODIS allows only the calculation of the sensor-ground-sensor radiation components. So the water vapor of the selected '.atm' LUT is taken. However, there is the possibility of providing an external water vapor map (see chapter 4.10), which can be calculated for the same scene in the non-FODIS mode (e.g. by moving the file "scene_fodis.slb" to another folder or renaming it temporarily in the same folder).

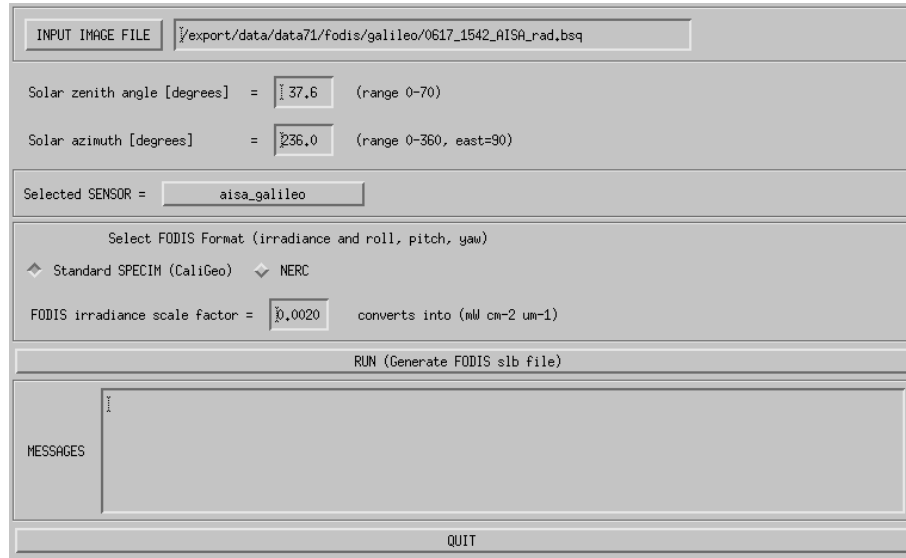


Figure 4.17: FODIS GUI supporting CaliGeo and NERC formats.

4.14 External float illumination file and de-shadowing

If the scene is processed with a DEM the additional files of slope, aspect (and optionally skyview and cast shadow) are used to calculate the solar illumination map (cosine of the local solar zenith angle), which is stored as byte data (range 0-100, scale factor 100) as side output. If the file name of the input scene is *scene.bsq* then the corresponding illumination file is named *scene.ilu.bsq*.

However, there is an option to process an external illumination map and skip the internal calculation. In this case the requested condition is a float-coded file (range 0 - 1) with the nomenclature *scene_raw_ilu.bsq* (first priority) or *scene.ilu.bsq* (second priority) to distinguish it from an internal calculation (if an internal calculation was performed previously). The image-based shadow detection routine *Topographic:Image Based Shadows* algorithm optionally stores results in a multi-layer file, and the first layer is the float-coded illumination, which will be read automatically for ATCOR processing upon availability. In case of a rugged terrain, the terrain illumination can be encoded in conjunction with the cast shadow information within the *_ilu file. The menu *ATCOR:Define Side Inputs* allows to select or deselect the illumination map to be used as side input.

Two de-shadowing methods are implemented in ATCOR: the matched filter and the illumination-based approach (see the theoretical background documentation [106]). The latter delivers a float-coded illumination file (range 0 - 1) containing the fractional shadow.

If a float-coded illumination file exists in the folder of the input scene, then it is used for de-shadowing, also for the flat terrain case (without DEM files). Therefore, it has always the first

priority. If the matched filter de-shadowing is intended, then the float-coded illumination file has to be renamed or temporarily removed from this folder.

Internally, the range 0 - 1 of the float illumination is then re-scaled to 0 - 1000 to be compatible with the matched filter de-shadowing case (only for the purpose of de-shadowing, not for the correction of terrain effects).

The menu *ATCOR:Define Side Inputs* allows to select or deselect an illumination file to be used as side input.

4.15 BRDF Correction

For the BRDF correction, including the BREFCOR approach, the following workflow is recommended:

1. Perform the atmospheric compensation using ATCOR-4. The indigence BRDF needs to be corrected in this step by selecting the BRDF option (for terrain correction). The observer BRDF correction is a step done subsequently to the atmospheric correction.
2. Apply spectral polishing routines (if required).
3. Prepare the inputs for the BREFCOR model calibration; i.e. check the scan angle file, specifically the second layer should be contained therein as absolute azimuth.
4. Select calibration data set: a number of 2-4 image scenes from a whole campaign should be used for the calibration. These scenes should have good statistical distribution of the objects of interest in across track direction and shouldn't contain too many clouds and cast shadows.
5. Start the model calibration with standard 5 levels on a 3-band image (RGB or NRG) first and select 'write ANIF outputs'. Check the BCI side output image and compare to the selected BCI level limits.
6. If level limits are not appropriate for the object types, the self defined level limits are to be set in the model calibration; redo the calibration again. Possibly you'll iterate this process and also you may need to increase the fitting accuracy threshold in order to get a BRDF model appropriate to your image.
7. Now, you're read to go for the full image, using the model you just created. Check the outputs, possibly do a mosaicking for the analysis.
8. If everything is correct, the whole campaign may be proceed using this calibrated model.

Chapter 5

Description of Modules

For most ATCOR modules a convenient graphical user interface is available, but batch jobs can also be submitted (see Section 6). If the atcor4 binary *atcor4.sav* is opened by the IDL virtual machine or when "atcor4" is typed on the IDL command line a menu with pull-down buttons pops up see Figure 5.1, with a thematic grouping of modules. A detailed discussion of the interactive panel-driven modules is given hereafter whereas a description of the batch commands can be found in chapter 6.

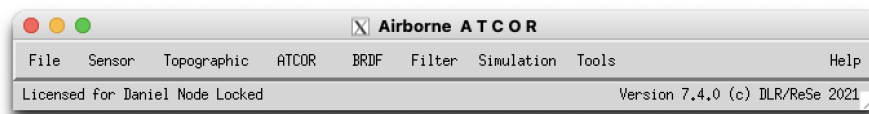


Figure 5.1: Top level menu of the airborne ATCOR.

5.1 Menu: File

The menu 'File' offers some tools for handling of the data and ENVI files. Below, a short description of the individual functions is given:

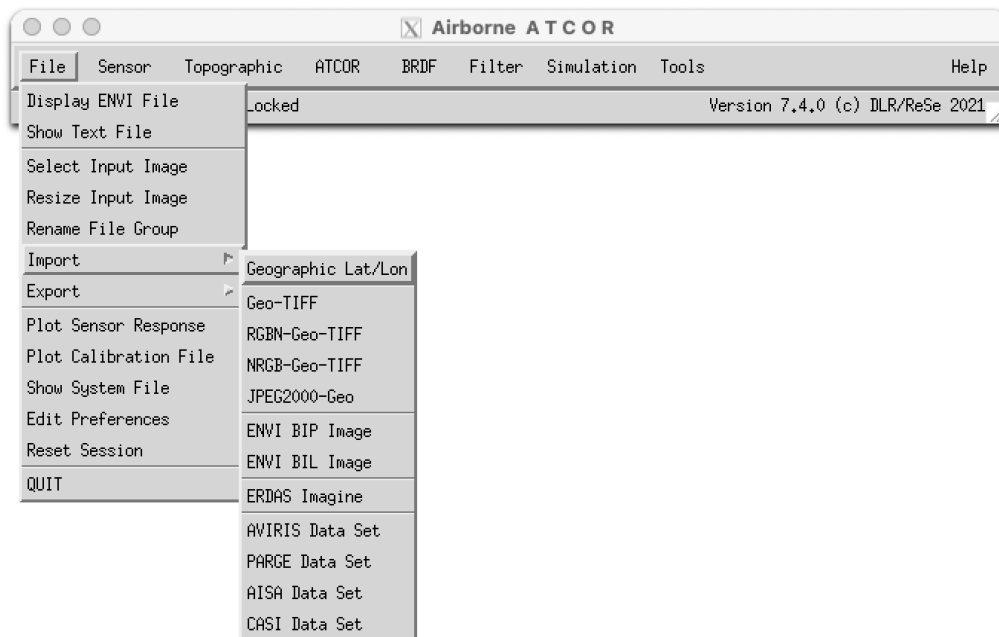


Figure 5.2: The File Menu

5.1.1 Display ENVI File

Use this function for displaying a band sequential ENVI-formatted file in a simple way. The functions of this panel are described in detail in the [Glimps Manual](#) which can be found in the docu directory of the ATCOR distribution.¹

An initial dialog allows to select the band(s) to display - either a true color, CIR color, or a single band mode may be selected.

After band selection, the following options are available within the file viewer from the menu:

File:Display Image Displays an ENVI or multi-band TIFF image in a new window.

File:Show ENVI Header Displays the ENVI header of the current image in a new editable window. This allows to make changes to the ENVI header. Note that the file needs to be loaded from scratch if changes have been made.

File:Band Selection Allows to select a new combination of spectral bands and updates the display.

¹The ENVI format is a raw binary file, accompanied by an ASCII header *.hdr; in ATCOR it should be stored in band sequential order. Note: this ENVI file display routine may be used separately using the GLIMPS software, available free of charge from ReSe Applications.

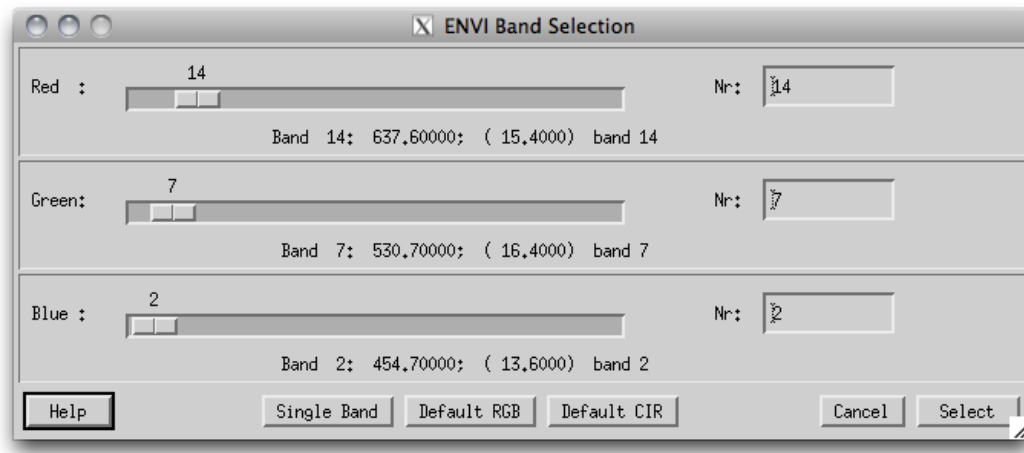


Figure 5.3: Band selection dialog for ENVI file display

File:Import:Image Reads a TIFF/GEOTIFF or JPEG image to ENVI file format.

File:Import:Micasense — FLIR Sensor-specific import filters.

File:Import:Spectrum Reads a columnar ASCII file to ENVI spectral library.

File:Show Specral Library Displays the spectra of an ENVI spectral library.

File:Show Text File Displays the contents of a text file.

File:Preview Image Displays the current image display as JPG in the native image file viewer of the operating system, useful for printing and adjusting images.

File:Close Closes the window.

Edit:Equalize Image Performs a histogram equalization on the three bands.

Edit:Scale Image Applies standard linear scaling on the imagery using 7 differing methods.

Edit:Scale Zoom Applies standard linear scaling on the imagery using 7 differing methods on the statistics of the Zoom Window.

Edit:No Scaling Reverts to unscaled display of the image.

Edit:Scale to Range Scales a single-band image linearly to a range entered as lower and upper limit (only applicable in single band displays).

Edit:Load Color Table Loads the standard color table (applicable for single band display only).

Edit:Flip Vertically Flips the image display vertically, e.g. for unrectified images.

Edit:Resize Image Allows to resize the currently displayed image to new spatial dimensions, optionally based on a reference image.

Profile:Horizontal Opens a window for a horizontal profile through the image (of the first band only). The profile is updated for the cursor location in the zoom window whenever the zoom window is clicked.

Profile:Vertical Opens a window for a vertical profile through the image (of the first band only).

Profile:Spectrum Opens a window for a spectrum of the image (for images with 4 and more bands only); use the middle mouse button to show the spectrum directly.

Calculate:Empirical Correction Allows to perform a white target or empirical line correction on the basis of one or two reference spectra.

Calculate:Dark Target Correction Allows to perform a simple dark target subtraction on the image, based on image statistics.

Calculate:Band Index Allows to calculate a spectral band index from the currently displayed image such as band ratio or NDVI-type of indices.

Calculate:Spectral Classification Allows to calculate a spectral quantification/classification using the spectral angle mapper or spectral fitting technique.

Calculate:Change Detection Calculates the difference between two image bands of the same spatial dimensions.

Calculate:Image Filter Three standard filters for smoothing and edge detection.

Calculate:Image Filter This routine filters a multispectral/hyperspectral image band-by-band. As a result a new file is created with the same dimensions as the input where each spatial layer is filtered by the chosen filter type and dimensions.

Calculate:Statistics Calculate the statistics per spectral band from the current image and stores the result as either an SLB or TEXT file.

Calculate:Scatterplot Analysis This function helps to understand spatial correlations between images of the same spatial dimensions.

Calculate:PARGE Trafo Tool to rectify imagery based on PARGE outputs (see [Glimps Manual](#) for details).

Export Allows to export the currently displayed image of either the zoom or the full image window to one of the given image data formats and ENVI file formats. The displayed image may be exported as a scaled 8bit/24bit image to the available standard image formats. Furthermore, the displayed color bar may be exported for use in publications (makes sense for single band images only).

Advanced:Spectral Validation compare and validate spectra of various files at same locations to spectral library spectrum.

Advanced:Image Filters This routine filters a multispectral/hyperspectral image band-by-band. As a result a new file is created with the same dimensions as the input where each spatial layer is filtered by the chosen filter type and dimensions. *A greater variety of filters is available for PRO-users*

Advanced:Shadow Detection This routine detects the fractional shadows in the image and saves a floating point fractional shadow (illumination) file. A floating point illumination map is created containing a quantitative estimate of the fractional cast shadow. Optionally, all indices used in the calculation are written in additional layers. Layer 1 always contains the illumination output, usable for atmospheric correction.

Note: when middle or right -clicking in the zoom window, the current image value and location is displayed, or a small plot of the spectrum at this pixel location is created (same as the function *Profile:Spectrum* of above). The menu in the such loaded window allows to save the spectrum to an ASCII table, to adapt the graph's properties and font size, configure the display and to output the graph to an appropriate graphics format.

The position field may be used to jump to a given coordinate by entering the coordinates manually and using the 'Enter' key on the keyboard. The button *Get Position* is used to get the currently stored coordinates from clipboard, whereas the button *Push Position* lets you push the currently shown coordinates to clipboard. Compare the [Glimps Manual](#) for further details about the image display and analysis routines.

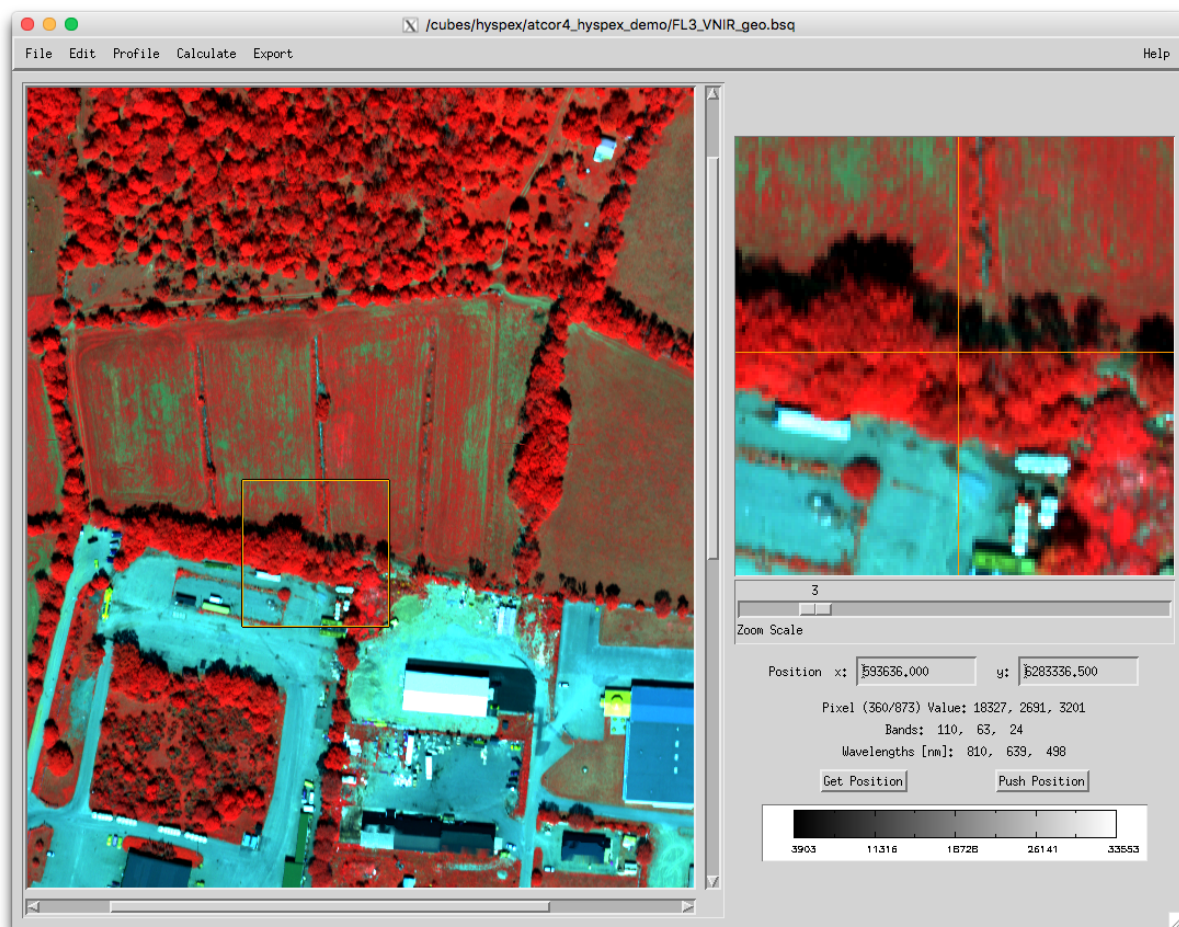


Figure 5.4: Display of ENVI imagery, details see in the [Glimps Manual](#).

5.1.2 Show Textfile

Use this function if you need to edit a plain text file which comes together with the data to be processed. The file is opened in a simple editor and may be changed and saved. Simple copy-paste is also enabled in this small editor. For opening and printing the file in an OS-native text editor, you may use the preview function. The function comes handy if an ENVI header needs to be checked or updated (e.g.). Selecting the 'Save' or the 'Save As' function in the submenu will allow to overwrite the file or to create a new one.

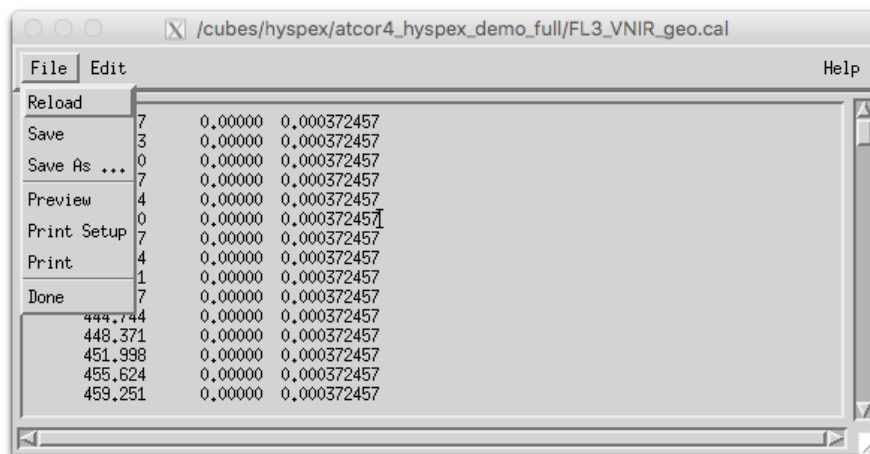


Figure 5.5: Simple text editor to edit plain text ASCII files

5.1.3 Select Input Image

This function allows to select the basis input image (i.e., the band sequential uncorrected image data in ENVI format). It is useful to define the starting point including the default paths of the images for further processing.

5.1.4 Resize Input Image

This tool allows to resize some georeferenced ATCOR input data to new spatial dimensions (without resampling).

The following inputs are necessary:

Inputs Files:

- Input Image Name: name of input data file to be resized
- Input DEM Name: name of input elevation data file (this line may be left empty if no DEM is available)

Dimensions:

- Upper Left corner: coordinates of upper left corner pixel (ENVI convention: lower left edge of upper left corner pixel is pixel 1/1) - the button "Get UL Position" may be used to get the upper left position of the image subset from a coordinate stored with the 'Push Position' button in an ENVI file display window
- Use Reference File: the coordinates of a reference file may be used
- Number of Pixels: size of output file in pixels in x and y direction (ncols, nrows) starting at upper left corner.
- Output name Basis: name of output main file; auxiliary files are stored according to ATCOR conventions, i.e. *_ele.bsq etc.

Output: Based on the output name (Basis) the auxiliary files are stored according to ATCOR conventions, i.e. *_ele.bsq etc. Possible outputs are:

- at sensor radiance image (ATCOR main input image)
- scan angle file (*_sca.bsq if available)
- illumination file (*_ilu.bsq if available)
- elevation file (if set)
- side layers of topography: *_slp, *_asp, *_sky.

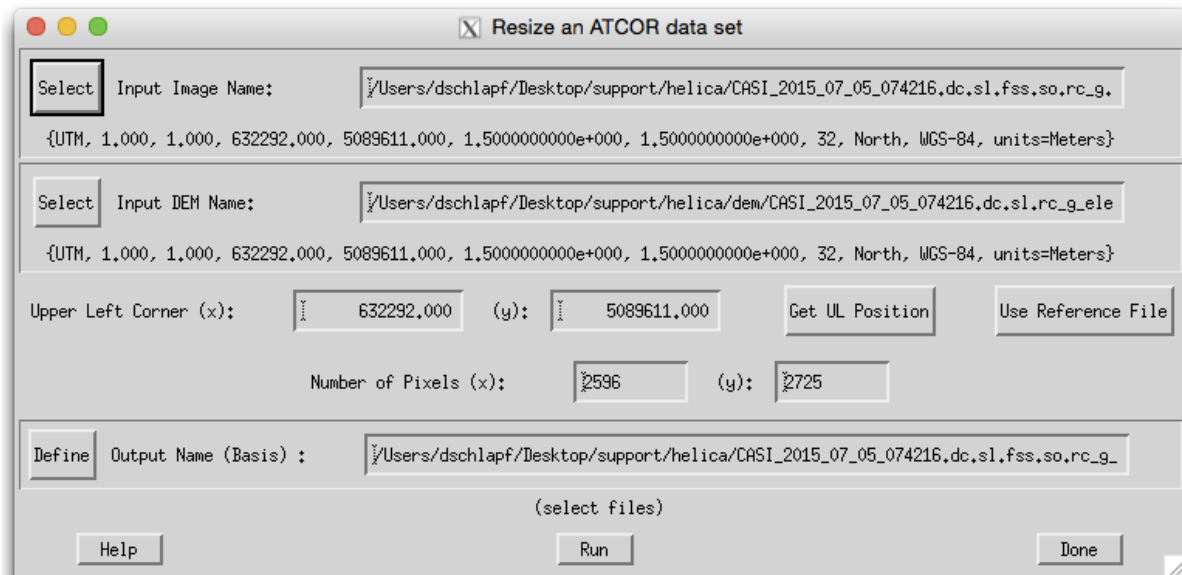


Figure 5.6: Resize ATCOR input imagery

5.1.5 Rename File Group

Use this function to rename a full group of ATCOR files. ATCOR processing relies on a significant number of files which can be renamed all at once, including the entries in the *.inn file. The such renamed data set is ready for further ATCOR processing.

5.1.6 Import: Geographic Lat/Lon

ATCOR requires that all input data are in cartesian metric coordinate systems. If data is provided in geographic coordinates (i.e. as latitude/longitude values) a conversion to a metric system is required at first.

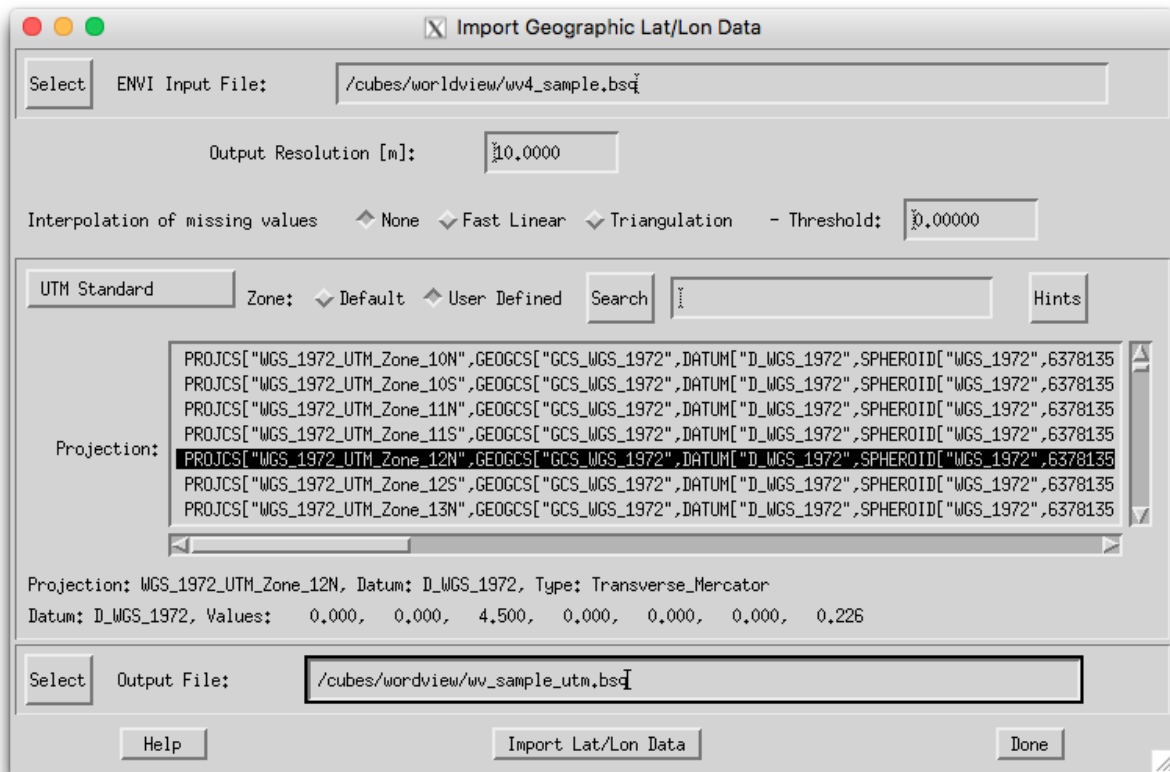


Figure 5.7: Import Geographic Lat/Lon image files

Inputs:

- ENVI or GEOTIFF Input File: Lat/Lon input file (in ENVI *.bsq or GEOTIFF format) - tiff files with *.tfw world file are to be imported by *Import:Geo-TIFF* first.
- Output Resolution: Size of one DEM pixel in meters (will be the same for x and y dimension).
- Interpolation of missing values: missing data in the Image (normally values below 0 or below -9000) are filled in by interpolation during the coordinate conversion process.
- Threshold: values equal or below the threshold value are interpolated. This parameter does not apply if no interpolation is selected.
- Coordinate conversion: select target projection/datum. For UTM the default zone may be selected to create a UTM WGS1984 projection.
- Output File: name of new file to be created.

Output: Upon the action *Import Lat/Lon Data*, a new file is created, which is based on the given geometric coordinate system and saved to an output file in ENVI format. An ENVI formatted file is created and the coordinate system is updated. For TIFF files, a conversion to ENVI format is first executed, resulting in a file named [outfile]_latlon.bsq.

5.1.7 Import: Various File Formats

Some standard formats are supported for importing data layers to an ENVI band sequential format, vor efficient use with ATCOR-4:

Geo-TIFF Multi-Band GEOTIFF or TIFF file in band ascending order; for TIFF files, a tiff world file *.tfw is required for coordinates definition.

RGBN-Geo-TIFF Geotiff in 4-band configuration, storage order R-G-B-N (e.g. for photogram-metric data)

NRGB-Geo-TIFF Geotiff in 4-band configuration, storage order N-R-G-B

JPEG2000-Geo Import of JPEG2000 file (extension .jp2) with embedded georeferencing infor-mation in geotiff or gml format.

ENVI BIP Image Imports and transforms an ENVI image in BIP (band interleaved by pixel) format to the ATCOR default BSQ (band sequential) format.

ENVI BIL Image Imports and transforms an ENVI image in BIL (band interleaved by line) format to the ATCOR default BSQ (band sequential) format.

Erdas Imagine Imports an uncompressed image in ERDAS Imagine format to ENVI format (specifically suited for DEM data import).

5.1.8 Import: AVIRIS

Imports the orthorectified AVIRIS imagery and creates an appropriate DEM and scan angle file for atmospheric correction.

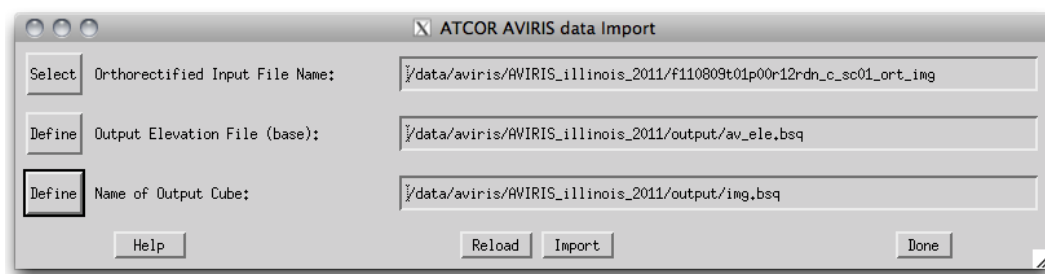


Figure 5.8: Import AVIRIS imagery from JPL standard format.

5.1.9 Import: PARGE Status

Imports the orthorectified PARGE imagery and reads all required information from the status file (*.gcs and ENVI image file header). A correct *.inn file for further processing is created. This option may be used to import Hypsax data.

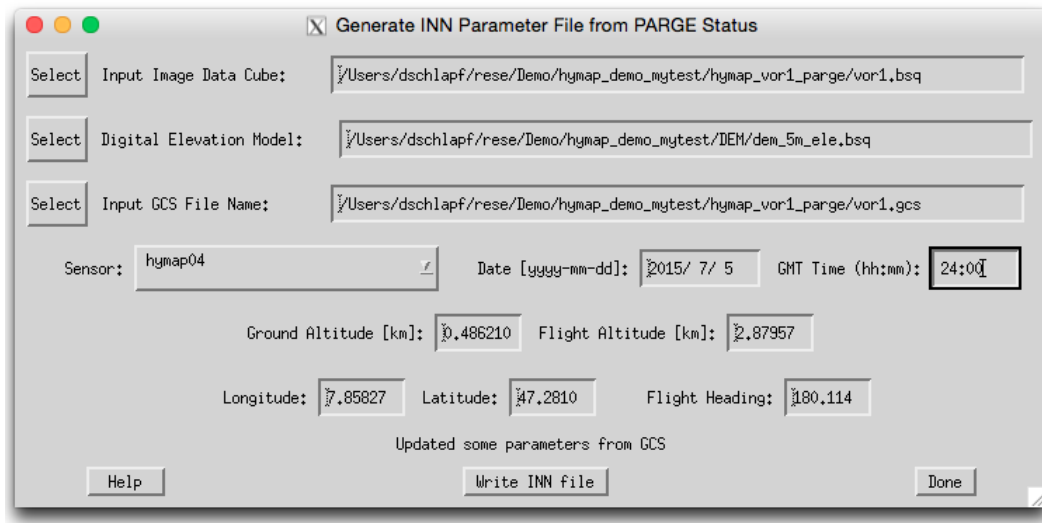


Figure 5.9: Import PARGE status and meta data information.

5.1.10 Import: AISA Data Set

Imports a Specim AISA data set based on CaliGeo outputs (*.opt and ENVI image file header) and optionally using an elevation model. A correct *.inn file for further processing is created.

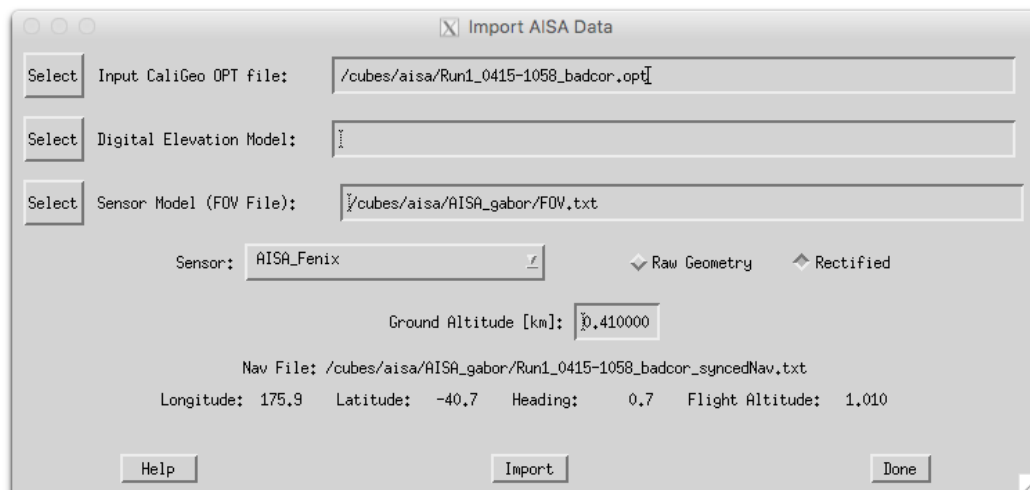


Figure 5.10: Import AISA data set and meta data.

5.1.11 Import: TELOPS Hyper-Cam Set

Program "imptelops" can be used to import TELOPS data from the IDL command line. This import can also be run from the ATCOR4 GUI, with "File", "Import", "TELOPS Data Set". Both options import a TELOPS Hyper-Cam LW data set after using the TELOPS software "Reveal Calibrate", which converts the raw data (*.raw) into ENVI *.sc data (in 'BIP' format).

The '*.sc' radiance (unit $Wm^{-2}sr^{-1}(cm^{-1})^{-1}$) file is input based on increasing wavenumbers, and the output file is '*_wvl.bsq' ('BSQ' format) with the radiance unit ($mWcm^{-2}sr^{-1}\mu m^{-1}$) and increasing wavelength (μm).

Additionally, a radiometric calibration file 'hypercam.cal' is created with $c_0 = 0$ and $c_1 = 1.0$ for all bands.

Note:

The wavenumber bandwidth is selectable and specified for recording TELOPS data. Please use the ATCOR-4 main GUI, "Sensor", then "FTS: Generate Wavelength File from (cm-1) in ENVI hdr" to specify the input (wavenumber) bandwidth. Use the ENVI file *"*radiance.hdr"* of the original *"*radiance.sc"* File.

Next select "Generate Spectral Filter Functions", "BBCALC: Blackbody Function $T = f(L)$ ", and "RESLUT" to obtain the sensor-dependent atmospheric LUTs. After these preparatory steps ATCOR4 can be executed.

=====

5.1.12 Import: CASI Data Set

Imports an Itres CASI data set based on standard processing outputs as multi-band tif or Geomagica-pix image and the corresponding meta data files. A correct *.inn file for further processing is created.

Supported image data formats:

img.bsq: ENVI BSQ format imagery

.tif (with *.hdr): Itres multiband TIFF File format

.pix (with *.hdr): Itres PCI file format (BIP)

Meta data files

.nad: auxiliary data layers (rectified)

- or - *.glu: auxiliary data layers (unrectified)

.geo: geocor auxiliary data file

.txt or *.asc: GPS/INS data stream (optionally)

Prerequisites: The sensor is to be defined before using this function. For terrain processing, the DEM is to be prepared first.

Geometry:

Raw Geometry: creates an input for raw geometry based atcor processing Rectified Geometry:

creates an input for rectified geometry based atcor processing

Outputs: - *.inn file for ATCOR processing - *_sca.bsq file fitting to the image data

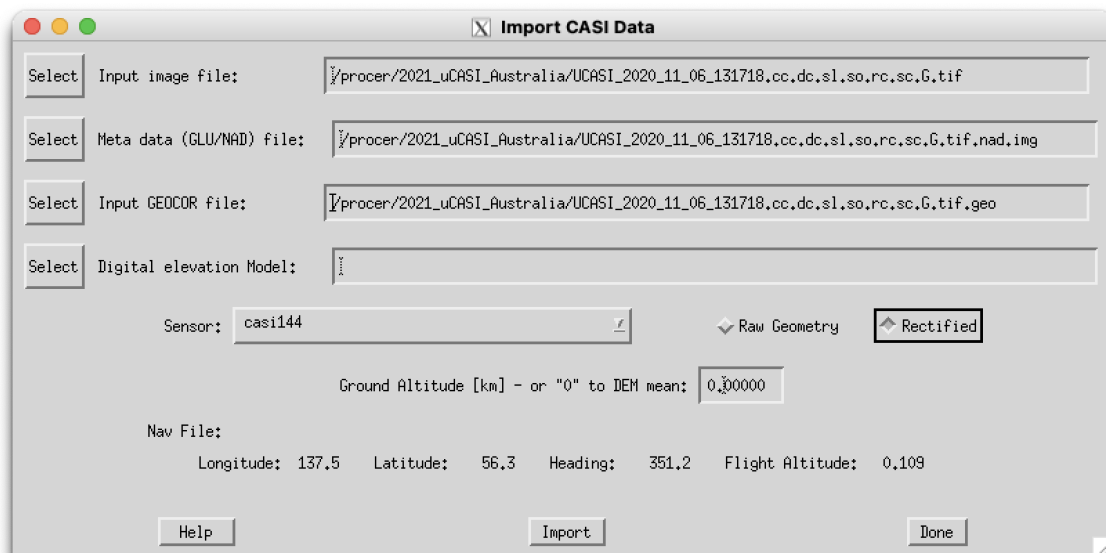


Figure 5.11: Import CASI data set and meta data.

5.1.13 Export

Transformation and export of standard ENVI format outputs to:

ENVI BIP Image Transforms and Exports an ENVI BSQ (band sequential) image to BIP format.

ENVI BIL Image Transforms and Exports an ENVI BSQ (band sequential) image to BIL format.

Multiband TIFF creates an universal multiband TIFF image from the input ENVI file.

Use the function 'Display ENVI file' (see section 5.1.1) to export JPG, PNG or TIFF imagery in RGB or grayscale for illustration purposes.

5.1.14 Plot Sensor Response

In the panel *Plot Sensor Response*, one may select the respective sensor response from within the available response functions in the ATCOR installation (or elsewhere). When selecting a response file, the related bands are loaded automatically and the total number of bands is displayed. The band range for display can be adjusted manually afterwards.

Normalization of the curves can be such that the area below the curves is constant (same weight of the functions) or the maximum is at 1 for all curves. The displayed graph may be adjusted in appearance and size and finally being exported to a standard graphics file for further use.

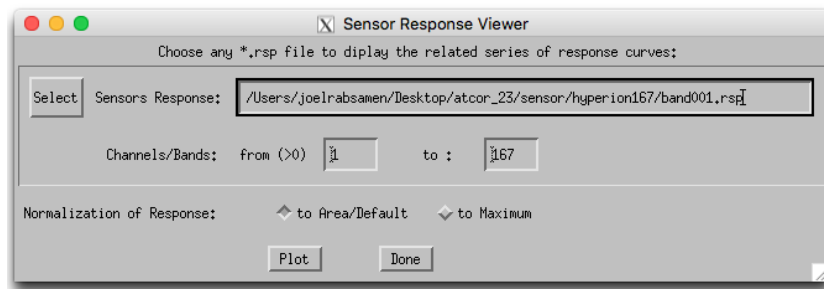


Figure 5.12: Sensor respons plot interface

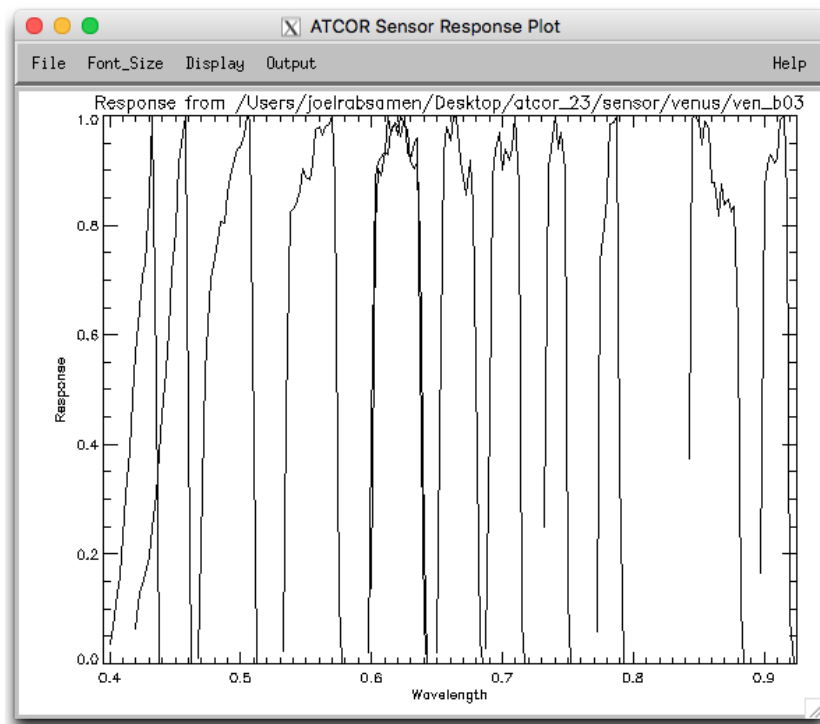


Figure 5.13: Sensor response plot

5.1.15 Plot Calibration File

When selecting this function, the dialog defaults to the atcor installation for the selection of a *.cal file to be displayed. Both, gain and offset are then plotted in the same graph to get an overview of their relative values.

5.1.16 Show System File

This is the same function as 'Show Textfile' but defaults always to the ATCOR installation in order to allow to select an ATCOR system file from within the installation, such as the cal-files, the solar reference files, the sensor definition files. The function then allows to adjust and save the respective text contents of the selected file.

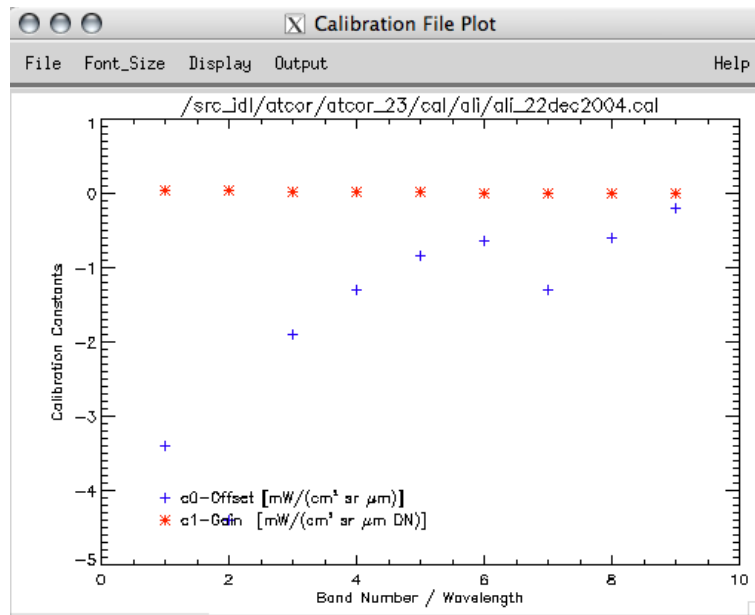


Figure 5.14: Plotting a calibration file

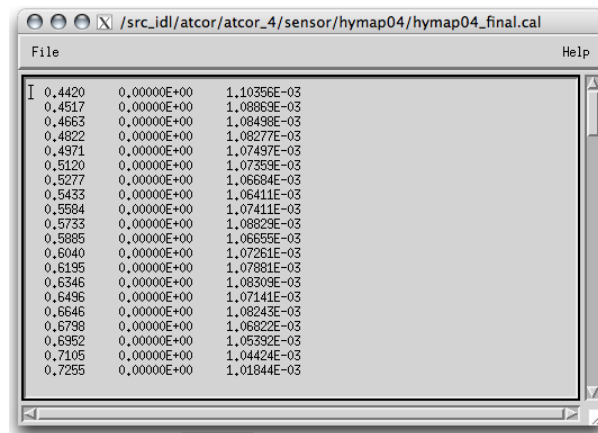


Figure 5.15: Displaying a calibration file (same file as in Fig. 5.14)

5.1.17 Edit Preferences

The default settings of ATCOR may be edited through this panel. The updated preferences are then written to the ASCII file as displayed at the top of the panel. The preferences persist for the user who started the ATCOR application the next time the system is started and also for batch processing.

NOTE: Preferences are set when one of the ATCOR modules has been opened. So, one should select one of the modules from within the menu 'ATCOR' before editing the preferences. For a description of the preferences, please refer to Section 8.4.

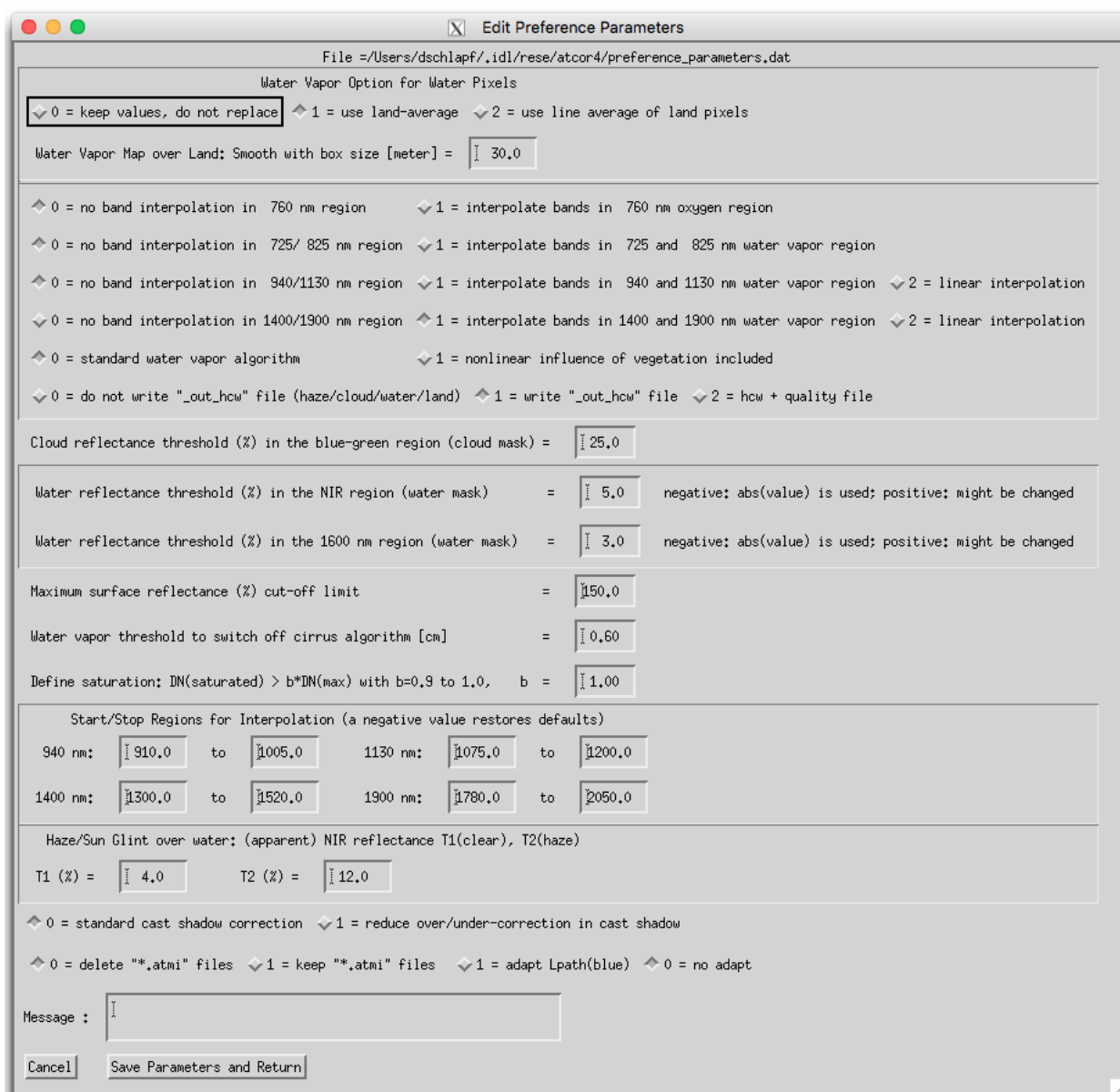


Figure 5.16: Panel to edit the ATCOR preferences.

5.2 Menu: Sensor

The menu 'Sensor' is used to create a new sensor from calibration information, if the sensor is not supported as standard sensor by ATCOR.

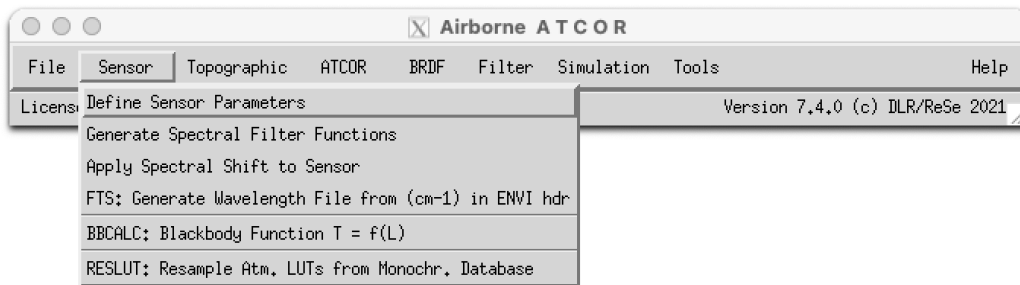


Figure 5.17: The 'New Sensor' Menu

Fig.5.18 shows the three required steps to include a new (hyperspectral) sensor to ATCOR. The example uses a sensor with 96 spectral bands, denoted as 'sensor_x96'. Using the function 'Define Sensor Parameters', the following steps are done in the background, which also could be done manually: a sub-directory of '.../atcor/sensor/' is created (named 'x96') and the three files as displayed in Fig. 5.18 are placed in this sub-directory. After execution of these steps, the new sensor will be automatically detected when ATCOR is started. Details about the sensor definition files are explained in chapter 4.6. Template files of several sensors are included in the distribution. After sensor definition, the module RESLUT (see section 5.2.6) is to be run.

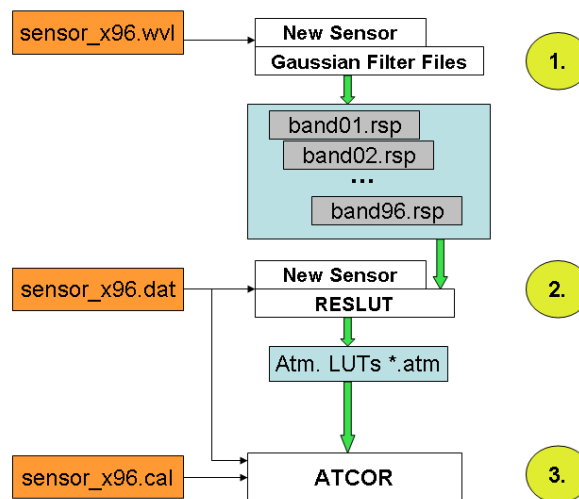


Figure 5.18: Sensor definition files: the three files on the left have to be provided/created by the user.

5.2.1 Define Sensor Parameters

This panel is the first step if a new sensor is to be defined. The panel as displayed in Fig. 5.19 allows the below options.

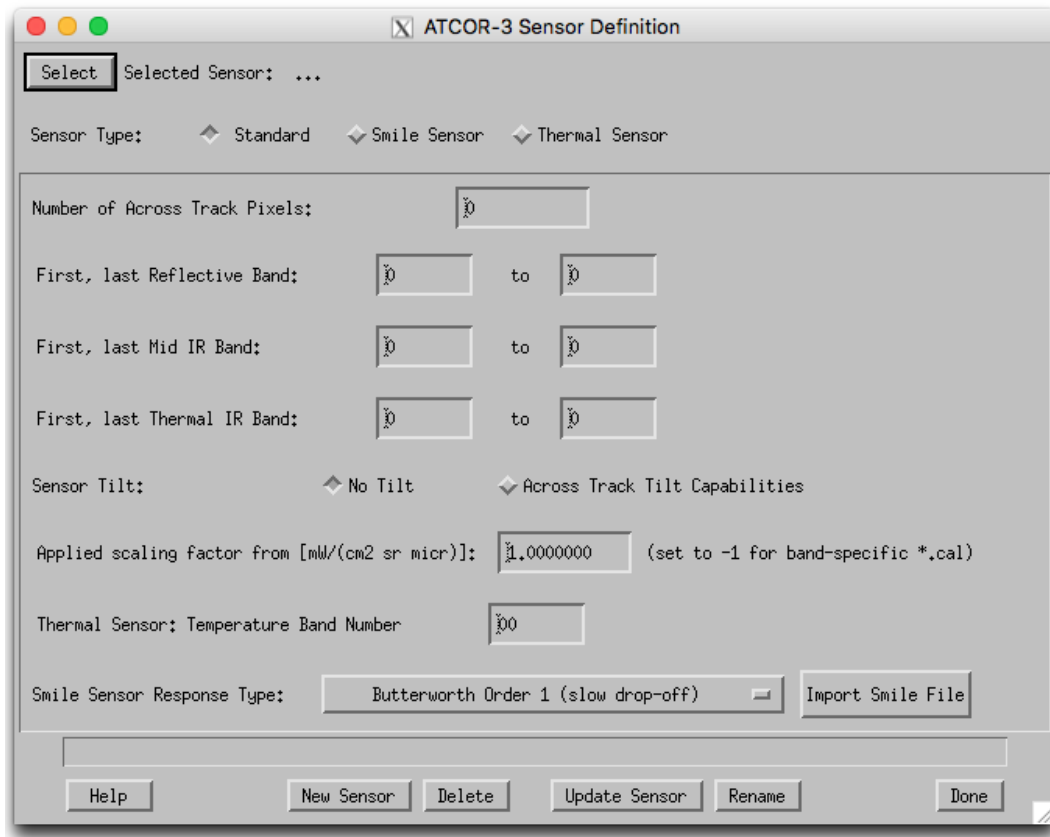


Figure 5.19: Definition of a new sensor

Sensor Selection Select any of the already defined sensors from within ATCOR - a sensor is selected by its sensor definition file (sensor*.dat) within a sensor directory. Use the function 'New Sensor' in case your sensor has not yet been defined.

Inputs

Sensor Type This is to be selected first, smile sensor and thermal sensors require additional inputs (as displayed in the panel).

Sensor Total FOV [deg] : edge to edge FOV in across track direction in degrees.

Number of Across Track Pixels: : Nominal number of pixels in the unrectified data.

First, last Reflective Band: Band numbers (starting at one) - none: 0

First, last Mid IR Band: Band numbers (starting at one) - none: 0

First, last Thermal IR Band: Band numbers (starting at one) - none: 0

Applied scaling factor: Enter the constant scaling factor which had been applied to the data to fit it to an integer data type from $mW/(cm^2 sr \mu m)$. Typical values are 100, 500 or 1000. The *.cal file will be created with constant values for all bands according to this value. If the scaling factor is not constant, the *.cal file is to be edited manually.

NOTE: a scale factor of zero or below inhibits to write a cal-file.

Calibration Pressure: absolute pressure in hPa of instrument during spectral calibration in laboratory.

Instrument Pressure: pressure of instrument during operations

'Absolute': pressurized instrument with constant pressure as of this value

'Relative': pressure difference to in-flight ambient pressure (in hPa; value of 0 hPa is ambient pressure)

Thermal Sensor: Temperature Band Number: Spectral band used for temperature retrieval algorithm (Optional -according to sensor type)

Smile Sensor: Smile Sensor Response Type , this selection may be required for convolution when sensor definition is not given explicitly: 'Butterworth Order 1 (slow drop-off)', 'Butterworth Order 2 (close to Gauss)', 'Butterworth Order 3 (between Gauss/Rect)', 'Butterworth Order 4 (close to Rectangular)', 'Gaussian', 'Rectangular', 'Triangular', 'Decreasing Binning (from Rectangular to Triangular)', or ' - Arbitrary - (as of *.rsp files) '. The last option is the recommended default for smile correction.

Button: Import Smile File : Use this button to import a smile file *.dat as created by the ATCOR smile detection routine into the sensor definition to the required file smile_poly_ord4.dat.

Actions

New Sensor : A new sensor is created within the ATCOR installation, which results in a new directory in the 'sensor' directory of the installation.

Delete : Allows to delete any sensor directory and all of its contents.

Update Sensor : The sensor parameters of the selected sensor definition are updated according to the settings.

Rename : The current sensor is renamed (both directory and sensor*.dat file)

Outputs A new sensor*.dat file, and possibly 'sensor' directory is created.

ATTENTION: this routine requires write-access to the sensor directory of the ATCOR installation.

5.2.2 FTS Generate Wavelength File from (cm-1) in ENVI hdr

ATCOR requires the spectral response of all bands of a sensor being present as a spectral filter file (response file) *.rsp in wavelength units, whereas Fourier Transform Spectrometers often use the cm-1 unit as a reference. Use this function to convert the cm-1 reference to band response files suited for ATCOR (compare Fig. 5.20).

Inputs

- Read the center wavenumber (cm-1) from the ENVI header
- Specify the bandwidth (cm-1), same for all channels
- Radiance scale factor c1 ($L = c1 \cdot DN$ with L in $mW \text{ cm}^{-2} \text{ sr}^{-1} \text{ um}^{-1}$) (same c1 for all bands)
- Sensor folder name

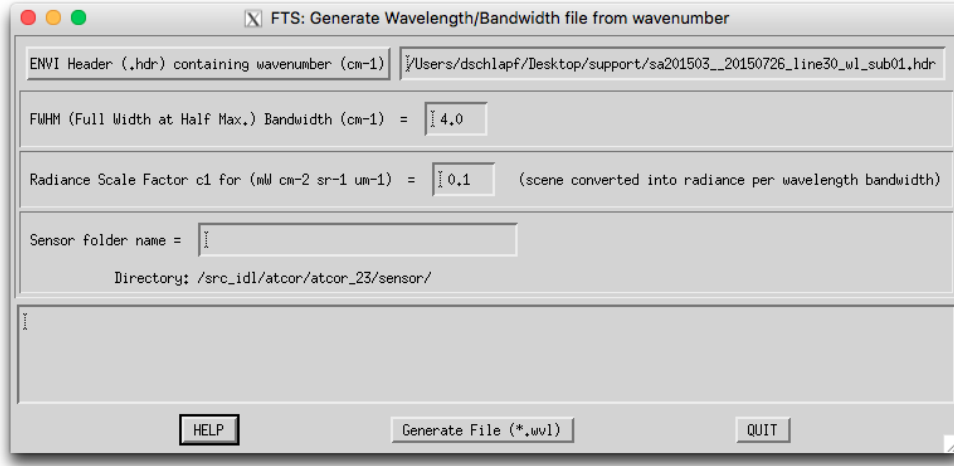


Figure 5.20: Spectral Filter Creation

Outputs File "*.wvl" in the sensor folder containing 3 columns:

- channel number
- channel center wavelength (micron)
- bandwidth (micron)

File "*.cal" in the sensor folder containing 3 columns:

- wavelength (micron)
- radiometric offset c0 (assumed as c0=0)
- c1 (radiometric gain)

Procedure The original FTS scene with the radiance bandwidth in (cm-1) and increasing wavenumbers per channel should be converted into a scene with increasing wavelength and radiance bandwidth in wavelength. The constant wavenumber bandwidth (bw_{wnu}) implies a variable wavelength bandwidth (bw_{wvl}). The radiance conversion from wavenumber to wavelength is based on the equations:

$$L(\lambda, bw_{wvl}) = \frac{L(wnu, bw_{wnu}) * \nu^2}{10000}, \quad (5.1)$$

where $\nu = wavenumber(cm^{-1})$ and $bw_{\nu} = bandwidth(cm^{-1})$ (same for all bands).

$\lambda = reverse(10000./\nu)$ (wavelength in micron) $bw_{\lambda} = (\lambda_1 - \lambda_2)/2.0$ (bandwidth in micron) with $\lambda_2 = reverse(10000./(\nu - bw_{\nu}))$ and $\lambda_1 = reverse(10000./(\nu + bw_{\nu}))$.

Next step: 'Generate Spectral Filter Functions (*.rsp)'

5.2.3 Generate Spectral Filter Functions

ATCOR requires the spectral response of all bands of a sensor being present as a spectral filter file (response file) *.rsp . For spectroscopic instruments, the band characteristics are often only available by band center and width at FWHM (Full width half maximum). This function creates the response curves from the latter information (compare Fig. 5.21).

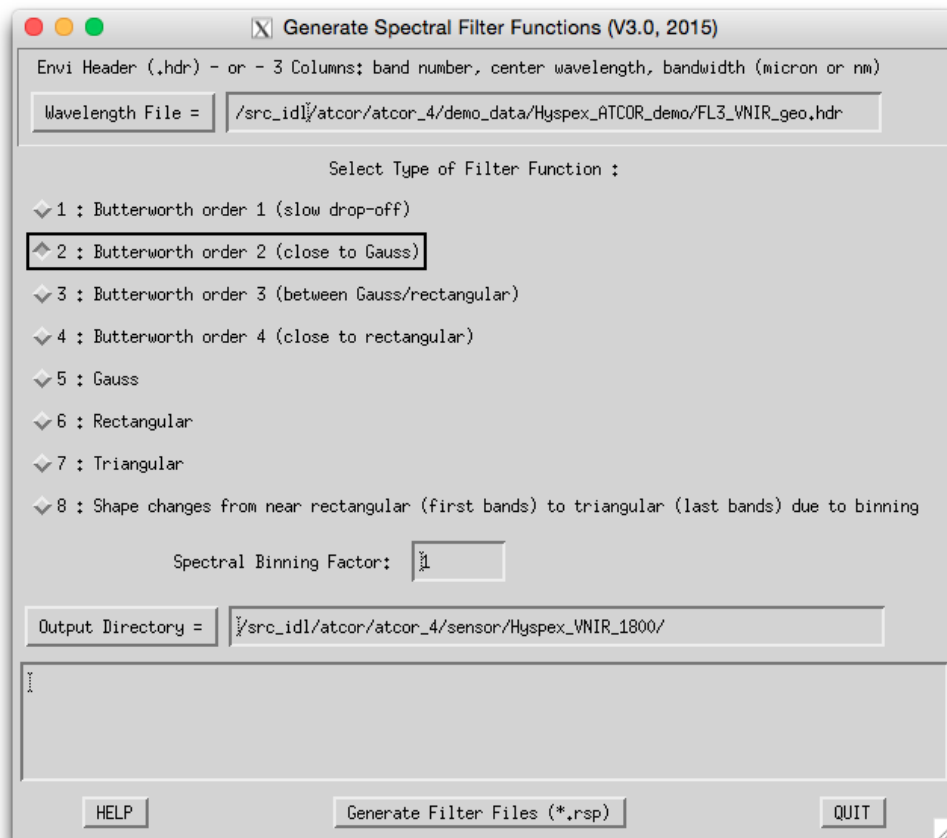


Figure 5.21: Spectral Filter Creation

Inputs

Wavelength File An ENVI header file (standard .hdr) or a wavelength reference file.

Format of ASCII File: 3 columns, no header; column 1: band number; column2: center wavelength; column 3: band width. Unit: [nm] or [μm] (same for columns 2 and 3).

Note: if the FWHM is not contained in the ENVI header or in the ASCII file, a bandwidth resolution is assumed which corresponds to 1.2 times the spectral sampling interval.

Type of Filter Function The type defines the basic shape of each of the created response curves.

Options are: Butterworth Order 1 (slow drop-off)

Butterworth Order 2 (close to Gauss)

Butterworth Order 3 (between Gauss/Rect)

Butterworth Order 4 (close to Rectangular)

Gaussian
 Rectangular
 Triangular
 Decreasing Binning (from Rectangular to Triangular)

Spectral Binning Factor This factor allows binning of channels, e.g., a factor 4 will combine four spectral response functions to produce the equivalent new channel filter function. This is a convenient feature for programmable instruments (e.g., HySpex or Specim AISA). For using this function, a wavelength reference file containing the unbinned spectral response is required as an input.

Outputs

A numbered series of band_*.rsp files are written to the path indicated by the output directory. The files contain wavelength reference and the relative response in two ASCII formatted columns.

5.2.4 Apply Spectral Shift to Sensor

This is a tool to shift the spectral response of a predefined sensor or to change the FWHM values of the sensor based spectral position and FWHM detection results from the ATCOR smile detection routine.

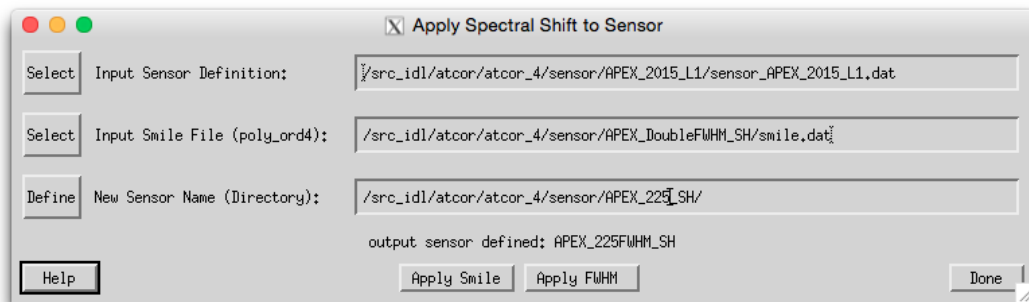


Figure 5.22: Application of spectral shift to sensor

Inputs

- input sensor definition file (sensor_*.dat)
- smile file (from smile detection routine) - or FWHM file (smile_poly_ord4.dat or smile_poly_ord4_fwhm.dat)
- New Sensor Name: directory name of new sensor.

Outputs

A new sensor definition is created which is shifted against the original sensor by the values given in the smile definition file. The shift is calculated as across track average of the band-wise polynomial. All components of old sensor other than the response files are copied to the new sensor directory. One may use this function for a constant offset by creation of a text file with the number of lines = number of bands and the second column containing the spectral offset to be applied.

5.2.5 BBCALC : Blackbody Function

This routine calculates the blackbody function [106], weighted by the spectral response curve of the thermal band used for the temperature retrieval (compare Fig. 5.23). This routine calculates the blackbody function as described in section about thermal data processing in the ATCOR ATBD [106]. It is weighted by the spectral response curve of the thermal band used for the temperature retrieval (compare Fig. 5.23).

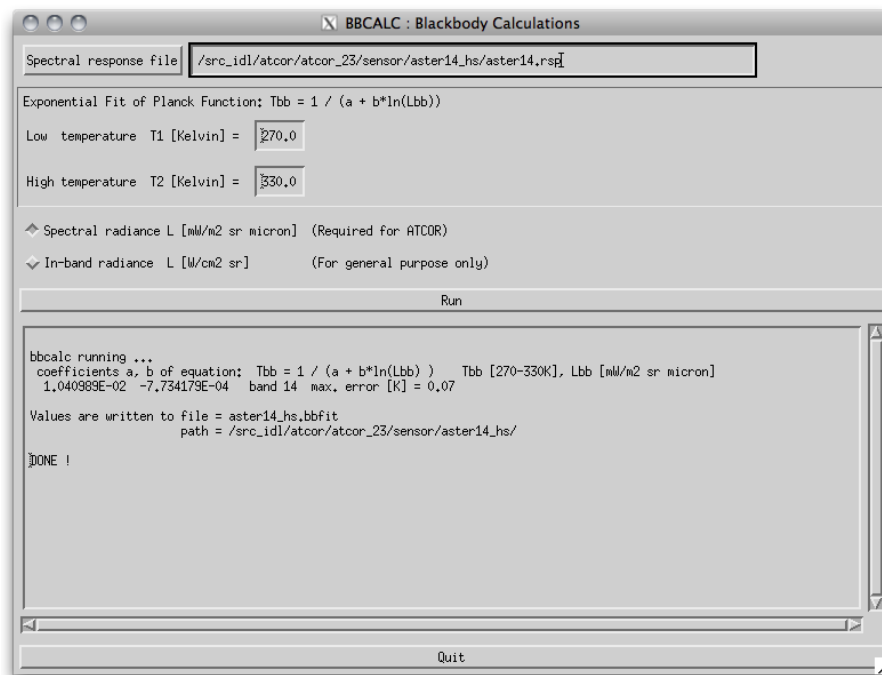


Figure 5.23: Black body function calculation panel

Inputs

Spectral response file Select the *.rsp file of the spectral band in the thermal IR to be used for temperature retrieval.

Exponential Fit - Limits The lower and the higher limit of the temperatures for which a fitting function should be created.

Unit of radiance output Select the unit either per micron or without normalization.

Outputs A file *_hs.bbfit is created containing the fitting parameters.

5.2.6 RESLUT : Resample Atm. LUTS from Database

The monochromatic database of atmospheric LUTs has to be resampled for the specific channel filter functions of each sensor. Details are given in chapters 4.6 to 8.2. Figure 5.24 repeats the panels of the LUT-resampling program RESLUT. The resampling has to be done separately for the

reflective and thermal region. Only the required range of flight altitudes and aerosol types should be selected.

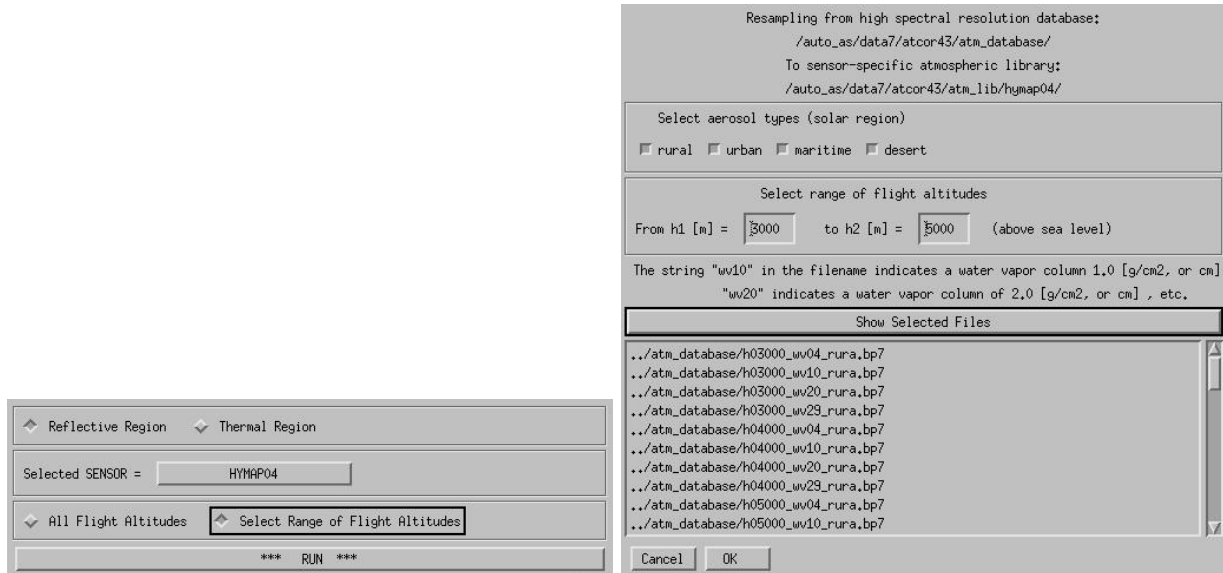


Figure 5.24: Panels of RESLUT for resampling the atmospheric LUTs.

5.3 Menu: Topographic

The "*Topographic*" menu contains programs for the calculation of slope/aspect images from a digital elevation model, the skyview factor, and topographic shadow. Furthermore, it supports the smoothing of DEMs and its related layers.

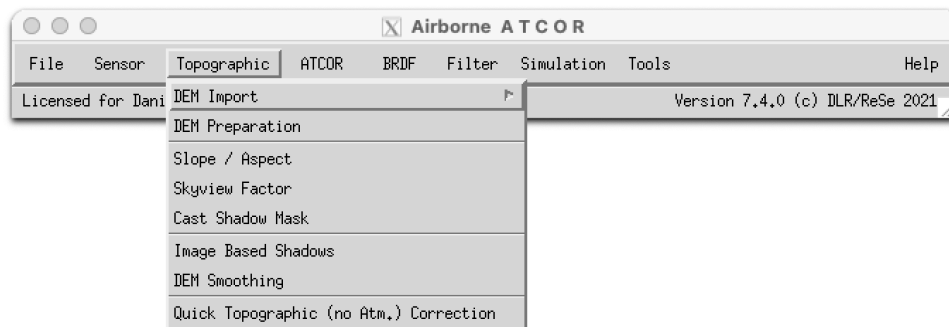


Figure 5.25: *Topographic modules.*

5.3.1 DEM Import: Import Global DEM

Import Global (Lat/Lon) DEM from SRTM or GMTED data to cartesian metric coordinates. The approx. 200m (0.5 arc min) resolution global DEM data is available for download through the help menu.

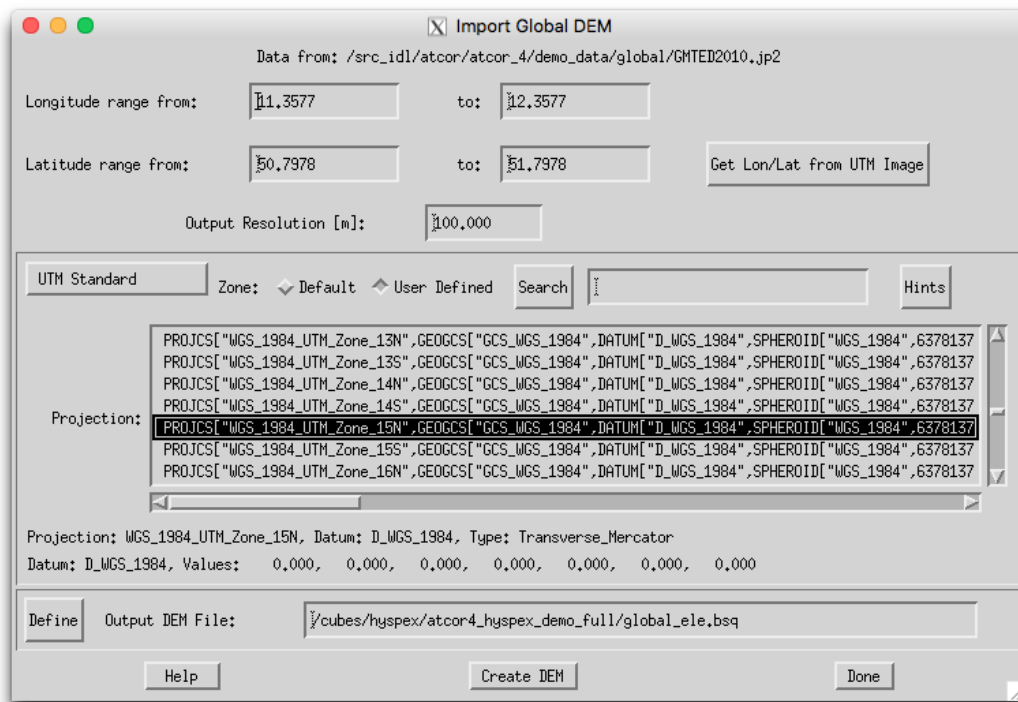


Figure 5.26: Import DEM from global elevation data.

Inputs:

- Longitude range: range in longitude direction; pixel edges - in decimal degrees only!
- Latitude range: range in latitude direction; pixel edges [deg]
- Output Resolution: output pixel size (default: 200m)
- Coordinate System: Select the appropriate projection string. For UTM, the 'Default' button will use WGS-1984 standard zone information.
- Output DEM : name of DEM (*_ele.bsq) to be written.

Action: Pushing the button 'Get Lon/Lat from UTM Image' will allow to select the target image (in UTM coordinates) in order to find the correct lon/lat range for global data extraction.

Restrictions: The DEM named DEM_SRTM30_WORLD.DEM or the 7.5 Arcsec GMTED 2010 dem (GMTED2010.jp2) have to be available in the *demo_data/global/* directory of the ATCOR installation. If both are present, the higher resolution data is taken automatically.

Output: converted DEM as ENVI file in UTM coordinates.

5.3.2 DEM Import: Geographic Lat/Lon DEM

This function imports an ENVI or GEOTIFF formatted DEM to a cartesian coordinate system. During datum conversion, the height values (z-value) in the DEM is also adjusted depending on the selected output coordinate system definition. More details about coordinate conversion can be found in Section 5.1.6.

5.3.3 DEM Import: Geo-TIFF

This function import a GEOTIFF file to an ENVI formatted elevation data file.

5.3.4 DEM Import: ARC GRID ASCII

This procedure reads a standard ARC GRID digital elevation model.

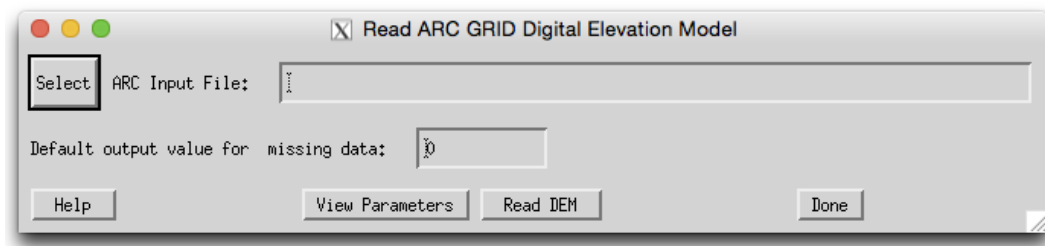


Figure 5.27: Import DEM from ARC GRID ASCII.

Inputs:

- Filename: Name of DEM to be read (usually extension *.asc)
- Default output value for found missing data: Value to be written to the pixels as defined by the NODATA keyword in the GRID file - if output value is less than zero, the mean of the read data is put to the missing pixels

Actions:

- View Parameters: Shows the header information of the GRID file.
- Read DEM]: Reads the DEM based on the given definition and stores it to a single channel ENVI formatted file (if required).

Output: converted DEM as ENVI file in arbitrary coordinates.

5.3.5 DEM Preparation

The purpose of this program is to provide a tool to resize a DEM to an image cube's dimensions. This menu function as depicted in Fig. 5.28 allows to calculate both layers in one step.

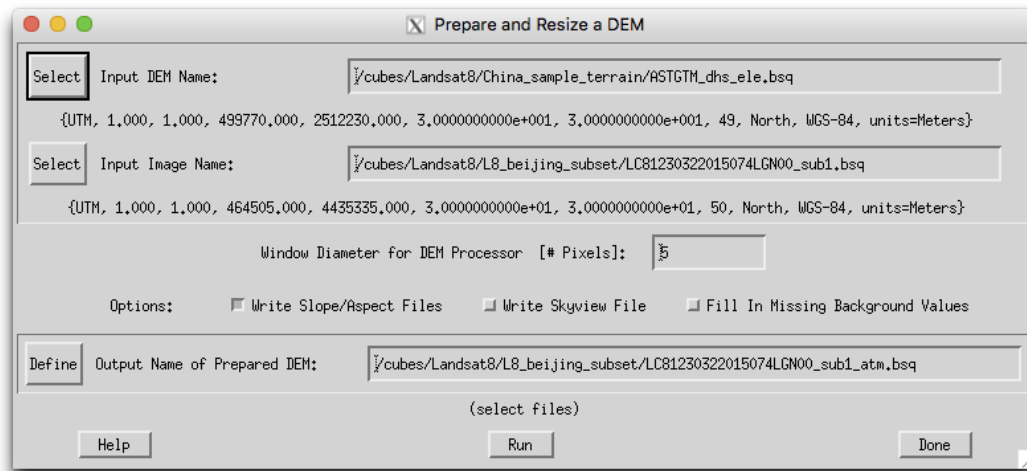


Figure 5.28: DEM Preparation

Inputs:

- Input DEM file] Input DEM (typically large than image).
- Input Image file] This is the target image (georeferenced). The DEM is automatically resized to its dimensions
- Window Diameter for DEM Processor] Size of the kernel in number of pixels; the slope and aspect and sky view side outputs are calculated using this kernel size and the output DEM is smoothed by this kernel size.
- Options] The writing of side outputs (i.e. `_slp` and `_asp` and `_sky` may be triggered by deselecting either of the first two options. The option "Fill in Missing Background Values" is used if the DEM is incomplete, the missing parts are filled with an average value from the DEM.

Outputs: An ATCOR elevation file `_ele.bsq` is written of the same size and location as the reference Image. Optionally, files of slope and aspect and sky view are created, same size as DEM. Attention: Both the DEM and the image should be represented in the same coordinate system and cover the same area. If the DEM is too small, the remaining parts of the image are filled with a zero value.

Note: this routine is only meant for rectified imagery. If working in raw geometry data format, the PARGE routine for inversion of DEM related layers to raw geometry is required.

5.3.6 Slope/Aspect

Slope and aspect are to be calculated from the DEM before ATCOR is run for rugged terrain. This menu function as depicted in Fig. 5.29 allows to calculate both layers in one step.

Inputs

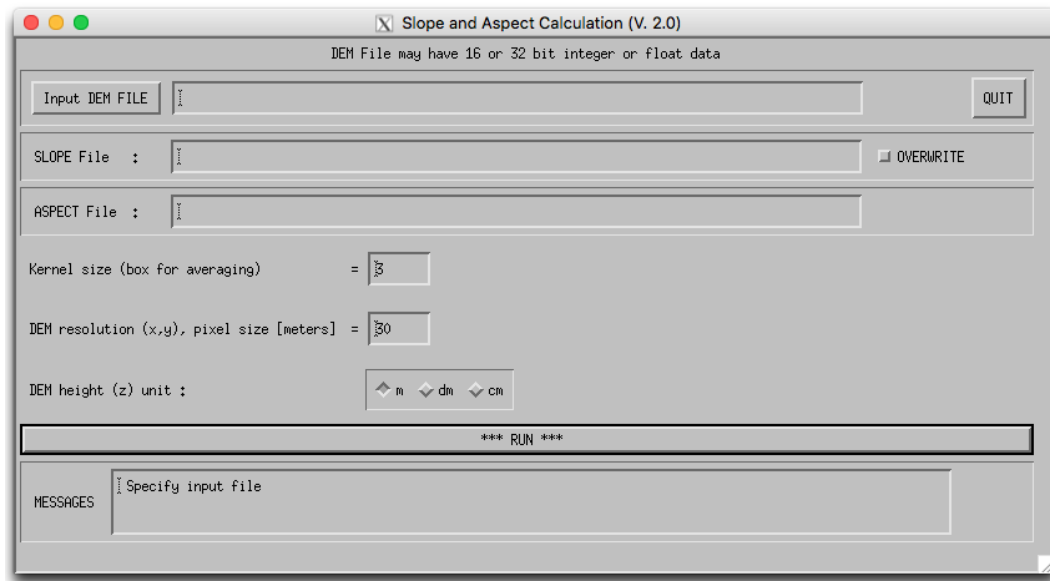


Figure 5.29: Slope/Aspect Calculation panel

- Input DEM file] The standard DEM file used for atmospheric correction. This DEM should be in meters.
- Output file names] The names for the output files are entered automatically and can't be changed as ATCOR asks these files to be named exactly according to the conventions.
- Kernel Size Box] Size of the kernel in number of pixels; the slope and aspect is calculated as gradient of the pixels at the edges of this box - the default value is 3 pixels (i.e. direct neighbors of center pixel).
- DEM resolution] This is the pixel size, a default of 30m is assumed. This needs to be entered manually.
- DEM height unit] The unit of the values in the DEM, usually a DEM is stored in meters, but sometimes an integer DEM is stored as dm or cm data in order to preserve disk space.

Outputs The two files of slope and aspect are created, same size as DEM, integer data.

5.3.7 Skyview Factor

The sky view factor of a DEM is calculated with a ray tracing program and ranges from $vsky = 0$ to 1, with 1 indicating a full hemispherical view. Data in the sky view file are scaled from 0 to 100% and coded as byte. The sky view factor determines the fraction of the hemispherical diffuse sky flux and $1-vsky(x,y)$ determines the fraction of radiation reflected from surrounding mountains onto the considered pixel, see [ATBD \(chapter Topography\) \[106\]](#). This program is also available in the batch mode, see chapter 6.3.

Input parameters besides the DEM file are:

- DEM horizontal resolution in meters: the x and y resolution must be the same.

- DEM height unit: supported units are m, dm, and cm.
- Angular resolution (degrees) in azimuth and elevation.
- The undersampling factor of the DEM in pixels. For large DEM's the skyview processing may be very time consuming unless an undersampling is chosen here.

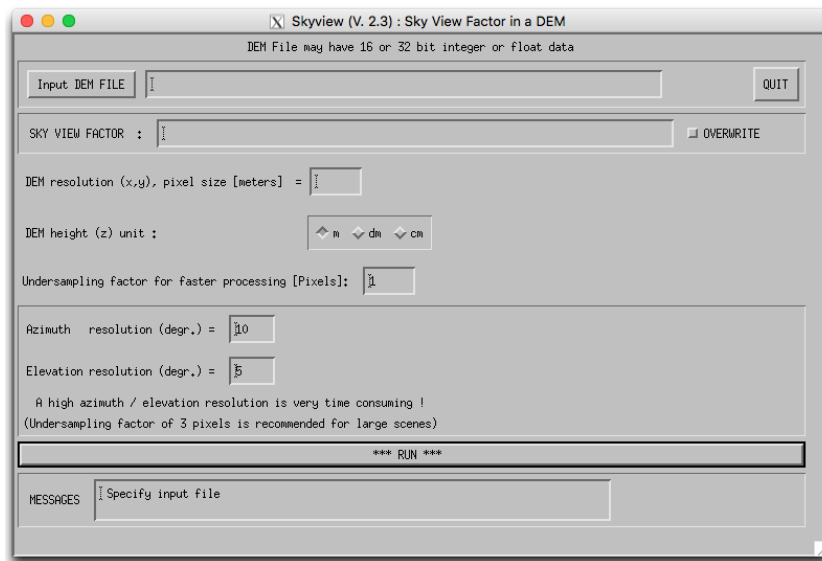


Figure 5.30: Panel of SKYVIEW.

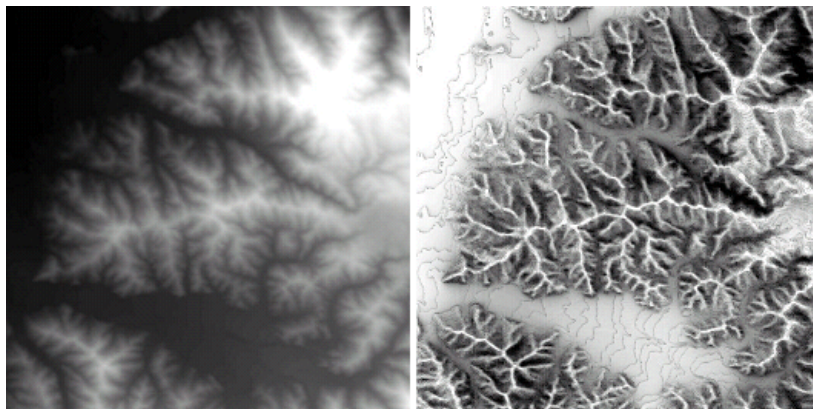


Figure 5.31: Example of a DEM (left) with the corresponding sky view image (right).

Figure 5.30 shows the GUI panel, and figure 5.31 presents a skyview image derived from a DEM image. An angular azimuth / elevation resolution of 10 degrees / 5 degrees is recommended. For large images it causes a high execution time which can be reduced by selecting an undersampling factor of 3 pixels. A high angular resolution is more important than a low undersampling factor.

5.3.8 Cast Shadow Mask

The calculation of the cast shadow map is done by ATCOR after reading the DEM files. If the shadow map is computed *"on-the-fly"* it is kept in memory, and it is not stored as a separate file. If the user wants to inspect the DEM shadow map the program *"shadow"* has to be started before running ATCOR. The program accepts float values of the solar zenith and azimuth angles. The output file name of the DEM cast shadow map includes the zenith and azimuth angles rounded to integer values.

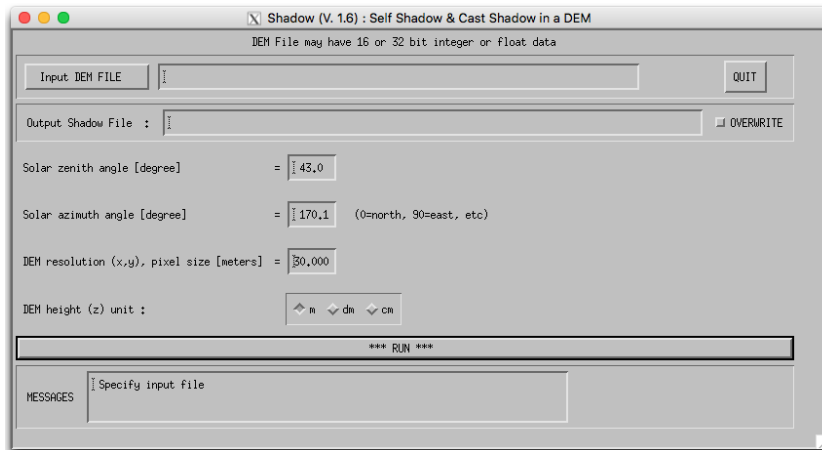


Figure 5.32: Panel of Cast Shadow Mask Calculation (SHADOW).

The DEM cast shadow map is a binary file where shadow pixels are coded with 0 and sunlit pixels with 1. It includes self shadowing and cast shadow effects. Self shadowing consists of pixels oriented away from the sun with slopes steeper than the solar elevation angle. The cast shadow calculation is based on a ray tracing algorithm and includes shadow regions caused by higher surrounding mountains. Figure 5.32 shows the GUI panel.

5.3.9 Image Based Shadows

This routine detects the fractional shadows in the image using a multi-index based approach as described in [121]. A floating point illumination file is saved to be used as input for atmospheric correction. Figure 5.33 shows the GUI panel. NOTE: this function is found in the menu 'Filter' for ATCOR versions without support for terrain correction.

Input Files:

- Input File: file to be analyzed, requires at least 4 bands (Blue, Green, Red, NIR)
- Calibration File: *.cal file for current input file (usually found in the sensor or cal directory of the ATCOR installation).
- Solar Reference File: e0_solar: solar irradiance file for current input, this file is also situated in the sensor or cal directory

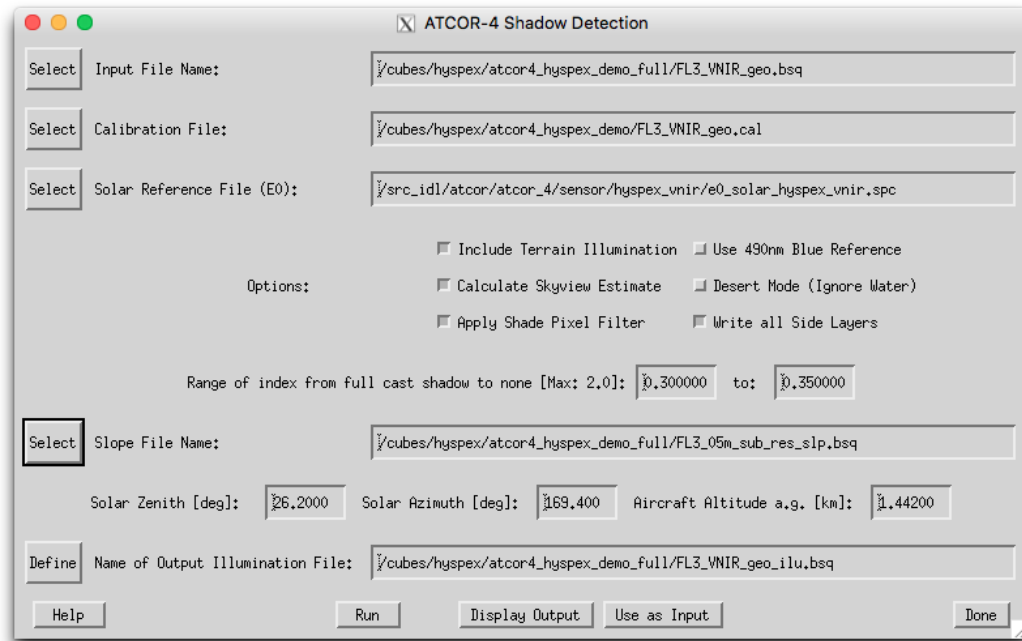


Figure 5.33: Panel of Image Based Shadows.

Options:

- Include Terrain Illumination - calculates the illumination based on slope and aspect files and the solar illumination angles as defined below
- Use 490 Blue Reference - use the band closest to 490nm as blue band instead of 430nm. this function is to be used if calibration in the blue is not accurate.
- Calculate Skyview Estimate - calculates an estimate of the local skyview fraction on the basis of a linear model.
- Desert Mode (Ignore Water) - does not try to find shadows over water bodies.
- Apply Shade Pixel Filter - filters single pixels within full cast shadow areas
- Write all Side Layers - creates a file containing all indices calculated during the processing in 5-7 layers. This function may be useful to find the appropriate range limits for a sensor system or imaging situation
- Limits of Index: - The lower and upper boundary can be set in order to derive a continuous fractional shadow from index. Larger values will result in large fractions of shadows being detected. The range can not exceed 0 to 2 in any case (default values are 0.5 to 1)

Parameters used for terrain illumination and skyview estimate:

- Slope File Name: Name of input Slope file to be used for illumination calculation (the corresponding .asp.bsq' file needs also to be present)
- Solar Zenith/Azimuth and Aircraft altitude above ground: solar angles (zenith/azimuth) for this data set and optionally the flight altitude above ground (airborne ATCOR version only)

Output: A combined index is created based on NIR brightness, and two red/blue and green/blue indices which results in a scaled number between 0 for full cast shadow and 1 for full illumination which is proportional to the cast shadow. The illumination layer is in the first band of the output file in case of multiband (all layers) output.s

5.3.10 DEM Smoothing

Smooth a DEM (or any other single-band image) in order to remove artifacts in the atmospherically corrected imagery. All related DEM-layers are automatically smoothed as well (e.g. slope / aspect / skyview). Alternatively, this task could be done with any image processing software.

Inputs:

- Input DEM/File Name] Usually a DEM *.ele.bsq is selected here; but any other single band ENVI image or the *_ilu.bsq file is also accepted. The routine searches automatically for related files (i.e. *_sky, *_slp, and/or *_asp) and smoothes them with the same parameters.
- Diameter of DEM Filter: Size of filter box in pixels (diameter)
- Output Name: Name of Elevation file output (auxiliary layer names will be derived from that)

Outputs: ENVI file(s) smoothed or filtered by the given factor and method:

Actions:

- Smooth: uses the standard smoothing (i.e., lowpass-filter) in the spatial domain.
- Median: uses a median filter for data correction, e.g., to remove noise or outliers from the DEM.

ATTENTION: The *_ilu file is not smoothed automatically by this routine. If the ilu has already been calculated before, it should be either removed or be smoothed separately.

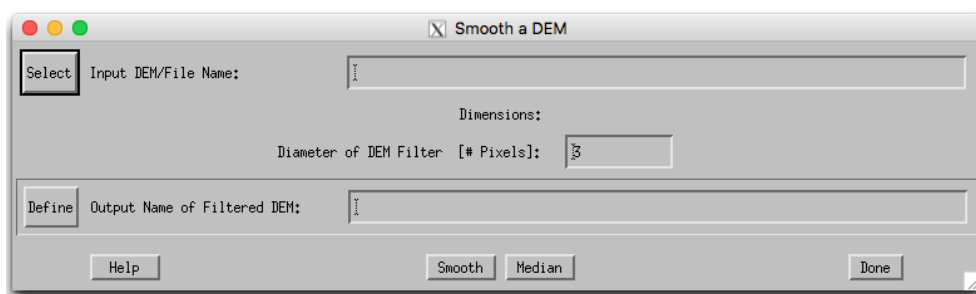


Figure 5.34: Panel of DEM smoothing

5.3.11 Quick Topographic (no atm.) Correction

The quick topographic correction routine (TOPOCOR) tries to eliminate the slope/aspect topographic effects and neglects the atmospheric influence. The program runs very fast and the output image contains the modified digital numbers. Processing with TOPOCOR can be done with or without display of images. The DEM slope and aspect files have to be specified on a separate panel that pops up after the input image has been specified. The topographic correction implemented here multiplies the DN value with a factor f that depends on the local solar zenith angle β and a weighting coefficient w . The wavelength-depending weighting w is based on a typical value of the ratio of the direct to total (direct + diffuse) solar flux on the ground.

$$f = 1 - (1 - \cos\Theta_S / \cos\beta)w \quad \text{if } \lambda < 1.1\mu m \quad (5.2)$$

$$f = \cos\Theta_S / \cos\beta \quad \text{if } \lambda \geq 1.1\mu m \quad (5.3)$$

Θ_S is the solar zenith angle of the scene. For $\lambda \geq 1.1\mu m$ the diffuse flux is neglected, i.e., $w=1$. The factor f is 1 for a flat terrain and some bounds were employed to prevent overcorrection. So for each pixel the new digital number is calculated as

$$DN(new) = DN * f \quad (5.4)$$

The method was compared with the standard Minnaert correction (eq. 5.5) and was superior in most cases. Figure 5.35 shows the GUI panel.

$$f = \left\{ \frac{\cos\Theta_S}{\cos\beta} \right\}^{\log(\cos\Theta_S / \cos\beta)} \quad (5.5)$$

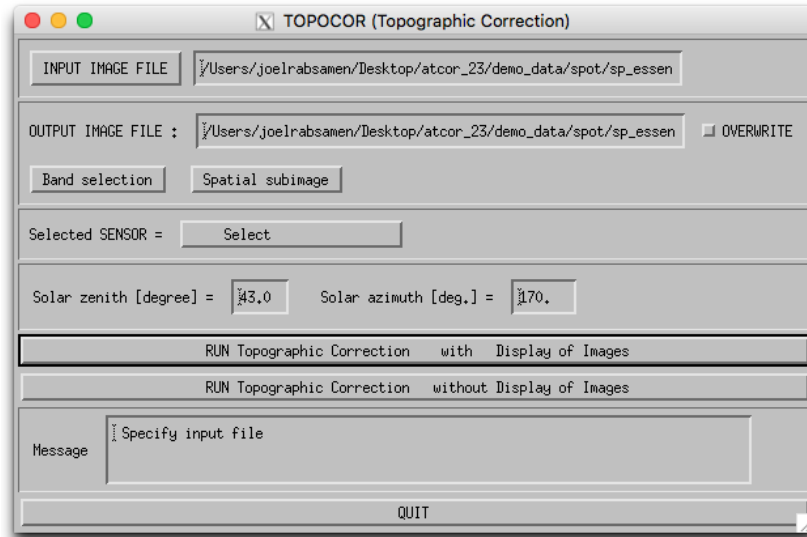


Figure 5.35: Topographic correction only, no atmospheric correction.

5.4 Menu: ATCOR

The menu 'ATCOR' contains the main processing modules of ATCOR, i.e., the panels for ATCOR4 for flat and rugged terrain.

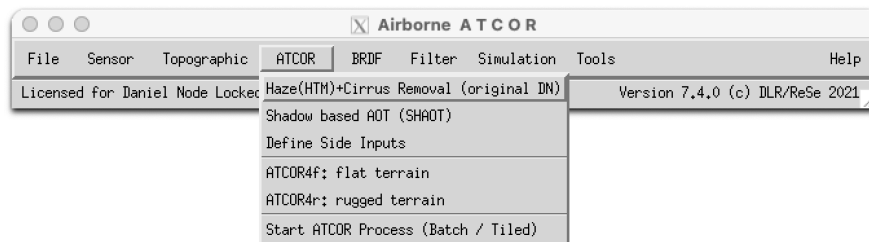


Figure 5.36: The 'Atm. Correction' Menu

5.4.1 Haze Removal

The atmospheric haze in imagery may be removed in a statistical procedure before going into atmospheric correction routines. More details about the procedure can be found in the theoretical background document [106]. Figure 5.37 shows the parameter settings which can be chosen for this procedure.

Inputs:

- **Input Image File:** this is a haze-affected input image in RAW DN or as calibrated at sensor radiance data. Note: haze removal is to be applied *before* running the main ATCOR process.
- **Sensor:** Select either a predefined sensor (ATCOR-2/3 only) or a user-defined sensor (all ATCOR versions).
- **Interpolation of the haze thickness map (HTM)** is required over bright objects. This option allows to select a spatial interpolation method. The very fast bilinear method is recommended, the time- and memory-consuming triangular method can only be used for small scenes. Usually, both methods yield very similar results.
- **Other options:**
 De-hazing of water surfaces may be switched off if overcorrections are observed.
 If a DEM is found (as defined in [input]*.inn), one may switch off de-hazing above 3000m ground altitude (to avoid confusion in snowy areas).
 If joint cirrus/haze removal is selected, cirrus and haze affected areas are processed in one step (only available for sensors with a 1.375 micron band).
- **Select Dehazing Module:** the standard 'dh1' module usually performs best, module 'dh2' performs a stronger dehazing, which might cause overcorrection in areas of very thick haze. It is possible to execute both modules in one run, check the results, and delete the inferior product. The decision to delete the inferior product can be tasked to the algorithm based on some statistical criteria. In this case, a message is issued which method ('dh1' or 'dh2') ranks best, and the final product is renamed as 'dh'.



Figure 5.37: ATCOR haze removal module.

Outputs: A dehazed image named [input]_dh1.bsq and/or [input]_dh2.bsq or [input]_dh.bsq is created. The *.inn file is copied to the new name to serve as an ATCOR input together with the dehazed image.

5.4.2 Shadow based AOT (SHAOT)

This routine uses the SHAOT [121] to retrieve a spatial aerosol optical thickness distribution from shaded pixels. The routine is best suited for high resolution airborne imagery with good dynamics in dark pixels. The output of the procedure may be used in ATCOR processing for improved aerosol correction which results in a better cast shadow removal and correction of adjacency effects. More details about the procedure can be found in the theoretical background document [106]. Figure 5.38 shows the parameter settings which can be chosen for this procedure.

Inputs:

- Input File Name: Name of at-sensor radiance input file. The process parameters should

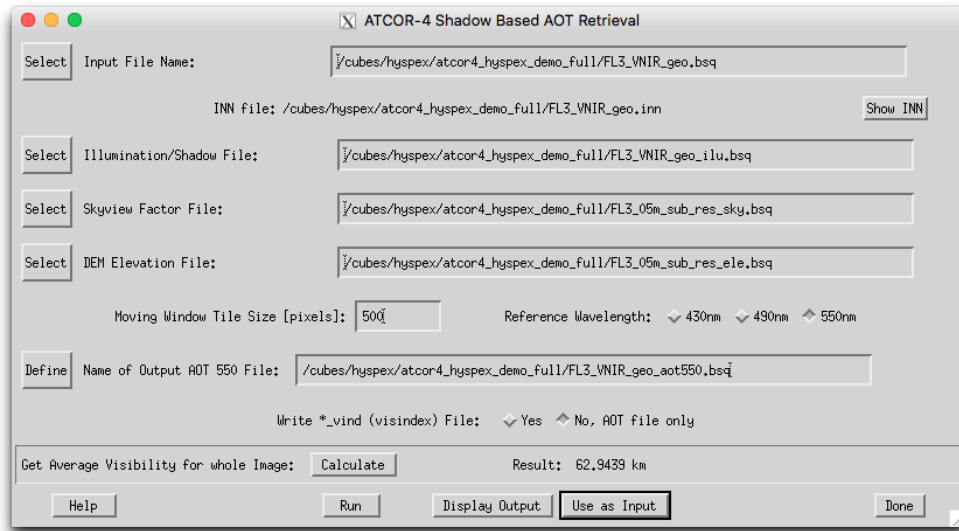


Figure 5.38: Shadow based AOT retrieval.

already be defined in an INN file before. (use the import function or the ATCOR-F menu to create the inn file)

- **Illumination/Shadow File:** *_ilu file containing mask of cast shadow pixels (coded as zero). The ilu file may be created using the function Topographic:Image based Shadows.
- **Skyview Factor file:** *_sky file with sky view factor. The skyview factor ideally considers the reduced view within cast shadow areas.
- **DEM Elevation File:** *_ele file of ground altitude; used for scaling of atmospheric parameters during retrieval.
- **Moving Window Tile Size:** Number of pixels length of quadratic tiles used for aerosol retrieval. The retrieval will be done in half the size of the tile distances in both image dimensions.
- **Reference Wavelength:** Wavelength used for aerosol retrieval. The output will always be written as AOT@550nm, however.
- **Output AOT 550 File:** file to be written for later use in ATCOR.
- **Write visindex file:** by default, no visibility index file is written. This file may be written for informational purpose.

Actions:

Get Average Visibility for whole Image Instead of applying a moving window technique, the best-fitting visibility is calculated using the complete image area and illumination mask.

Run Starts the aerosol retrieval process.

Display Output displays the just created aot550 map.

Use as Input renames the output such that it can be used as input together with the defined input file.

Outputs: The files *_aot550.bsq and a file *_visindex.bsq may be written. Additionally, an IDL save file *_aot550.sav with the original retrieval data is stored which may be used for further analysis, debugging or mosaicking.

5.4.3 Define Side Inputs

ATCOR may use side input files for its processing as long as they are available with the same name base as the input file for its processing. This GUI allows to define and rename the side inputs appropriately prior to the ATCOR processing.

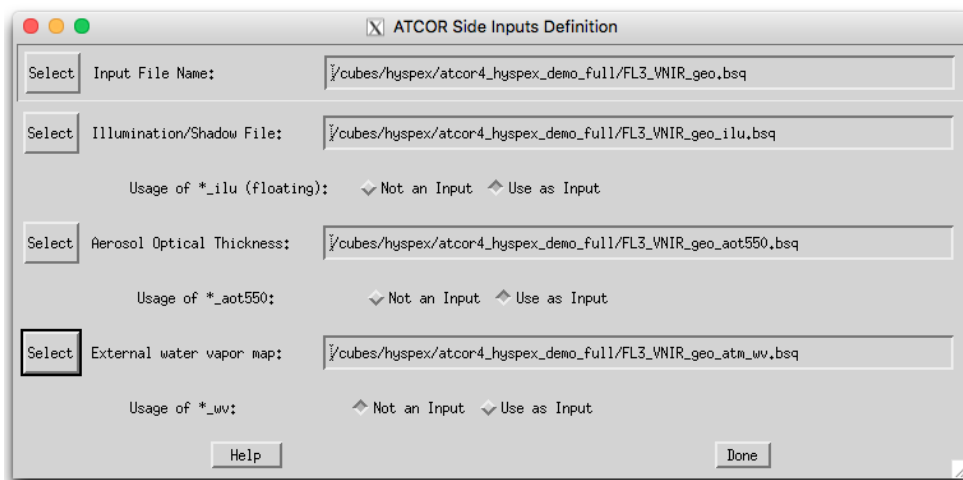


Figure 5.39: Define ATCOR side input files.

Inputs:

- Input file Name: [input]
this is the at-sensor radiance /scaled DN radiance file to be processed with ATCOR
- Illumination/Shadow File: Name: [input]_ilu.bsq, floating point
this file contains the terrain illumination possibly in combination with the shadow mask as created with the function: Topographic:image based shadows.
NOTE: an integer _ilu.bsq file is created as output of ATCOR processing in case no input is available. Such outputs have to be transformed to floating point data to serve as an input.
- Aerosol Optical Thickness: Name: [input]_aot550.bsq, scaled integer (aot*1000)
This file contains the terrain-normalized AOT as created by the SHAOT method. It will be used directly for processing while a visindex file may be created.
- Water Vapor Distribution: Name: [input]_wv.bsq, scaled integer (pw_cm*1000)
Note: an external water vapor map is only supported for instruments that are able to retrieve the water vapor column with the intrinsic channels, because the prerequisite is the availability of the corresponding LUTs

Actions: Using the toggle switches for the various input layers allows to rename the inputs, e.g. from [input]_ilu.bsq to [input]_img_ilu.bsq such that it will no longer be used automatically as an input, and vice versa.

5.4.4 The ATCOR main panel

Figure 5.40 shows the input parameters required for ATCOR. The lower part of the panel contains buttons for selecting SPECTRA, determining the aerosol type, employing inflight radiometric CALIBRATION, and starting the image processing. The processing options are shown in the separate panel as described in section 5.4.12. The trivial panels, e.g., band selection, spatial subimage etc. will not be shown here. The panels should be filled or clicked in the top-down direction. The message widget at the bottom will display hints, warnings, or errors.

Options that are not allowed for a specific sensor will appear insensitive. If the haze removal option is selected in combination with "Variable Visibility" the visibility index (proportional to total optical thickness) map is coded with the values 0-182. The value visindex=0 corresponds to visibility 190 km, each integer step of 1 corresponds to an AOT increase of 0.006. The array serves as a fast method of addressing the radiative transfer quantities (transmittance, path radiance etc) in case of a spatially varying visibility, i.e., in combination with the DDV algorithm. IF the "Haze or Sunlint Removal" button is selected the next panel will ask for haze removal over land (option 1), haze or sunlint removal over water (option 2), or haze removal over land and water (option 3).

In case of the rugged terrain version of ATCOR the panel for the DEM files has to be specified in addition (Figure 5.41). It pops up after the input file has been specified. A quick quality check is performed on the DEM files. The solar illumination file is calculated and if its standard deviation is large the panel of Figure 5.42 pops up with a warning. In this case the DEM elevation file (and the derived files of DEM slope, aspect etc) probably have a lot of large steps. The DEM resolution is often not appropriate for high spatial resolution imagery, and integer coded DEM's might have to be resampled and stored as float data. Appropriate action for resampling or low pass filtering is recommended in these cases, see the tips in chapter 8.6. Figure 5.43 shows an example in terms of the DEM illumination. The top image is obtained after low pass filtering the original elevation file,

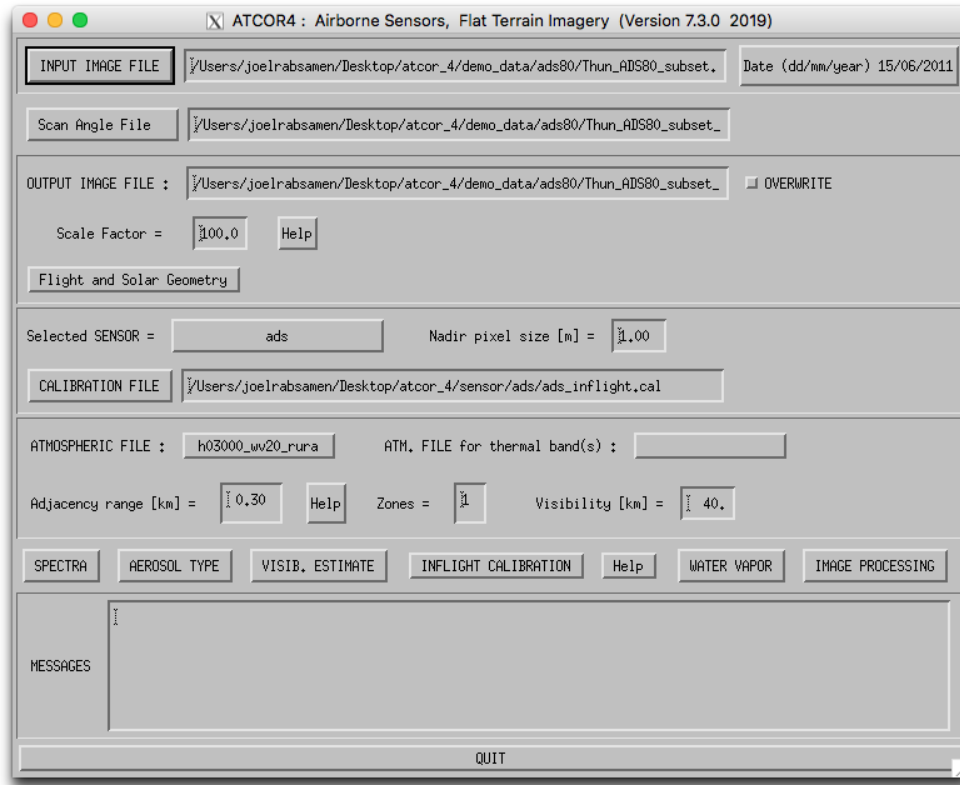


Figure 5.40: ATCOR panel.

the central image is the illumination based on the original DEM, and the bottom shows a 100 pixel transect of the original elevation data revealing the steps. The original DEM had a resolution of 30 m, was coded as 16 bit integer, and initially resampled to the 6 m pixel size of the image with integer arithmetic. After reprocessing the elevation file the other DEM derived files should also be reprocessed.

The pixel size of the DEM files must be the same as the image pixel size specified on the main panel, see figure 5.40. The physical units of pixel size (m) and adjacency range (km) are also used to calculate the equivalent number of pixels needed to cover the adjacency range.

5.4.5 ATCOR4f: flat terrain

The menus for ATCOR-4 share the same functionalities as described above in both flat and rugged terrain options. The ATCOR4f variant is recommended to speed up processing time and for fast checks as hyperspectral image processing may be very time consuming in rugged terrain.

5.4.6 ATCOR4r: rugged terrain

This routine is to be taken if highest accuracy is required in terrain for imaging spectroscopy instruments. The functionality is analogous as described for the other panels.

Update DEM Path Path = /auto_as/data7/atcor43/demo_data/gruber/

Mandatory Files

Elevation = jdpw10_hysens_ele DEM height (z) unit : [m] [dm] [cm]

Slope [degree] = jdpw10_hysens_slp

Aspect [degree] = jdpw10_hysens_asp

Optional Files

Sky View Factor [%] = jdpw10_hysens_sky

Cast Shadow [0,1] = 1

☒ Use pre-calculated shadow file

☒ Shadow map calculated "on the fly", requires more memory

--> Check "*line2_geo_ilu" for possible DEM-related artifacts.

Message

Cancel OK

Figure 5.41: Panel for DEM files.

*** Problem with illumination file "_ilu.bsq"

*** Reason: DEM has a lot of steps

*** Have a look at the "_ilu" file (with the artifacts)

Alternatives:

(1) Cancel this calculation

(A) Low pass filter DEM files (ele, slope, aspect)

(B) Load input image once again with filtered DEM files

(C) Are artifacts in "_ilu" gone ?

If not, increase low pass filter kernel size

(2) Continue and ignore this problem/warning: not recommended

CANCEL CONTINUE

Figure 5.42: Panel to make a decision in case of a DEM with steps.

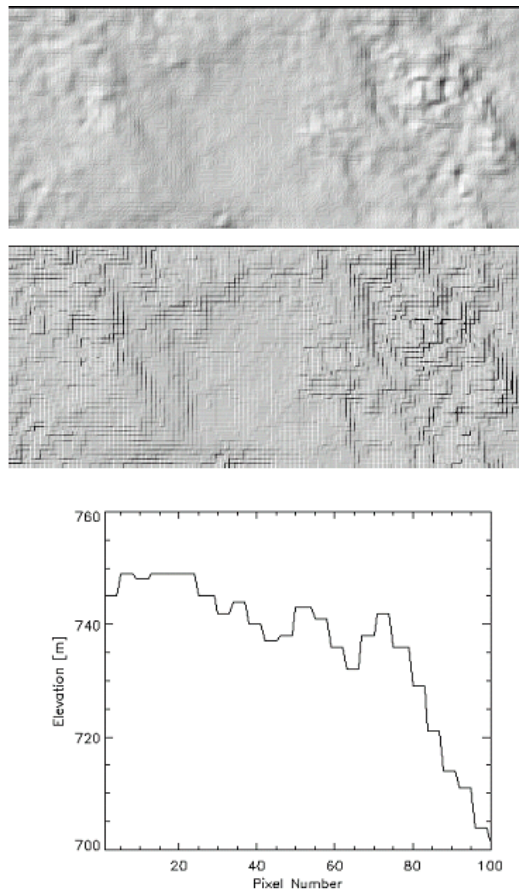


Figure 5.43: Influence of DEM artifacts on the solar illumination image.

Top: illumination with low pass filtered DEM; middle: illumination based on original DEM;
bottom: 100 m transect using original DEM, pixel size is 6 m.

5.4.7 SPECTRA module

The SPECTRA module (see figure 5.44) serves to extract spectra of different targets of the scene as a function of the visibility. These spectra can be compared to field spectra or library spectra to estimate the visibility. Scene-derived spectra also may indicate calibration errors in certain channels. In that case, a copy of the sensor calibration file can be edited to match the retrieved reflectance with the field / library spectrum or the inflight calibration module may be employed (see chapter 5.4.10).

In most cases it is useful to check some scene-derived target spectra, e.g. water, vegetation, or soils, before starting the processing of the image cube at the risk of "blind" processing and obtaining wrong results.

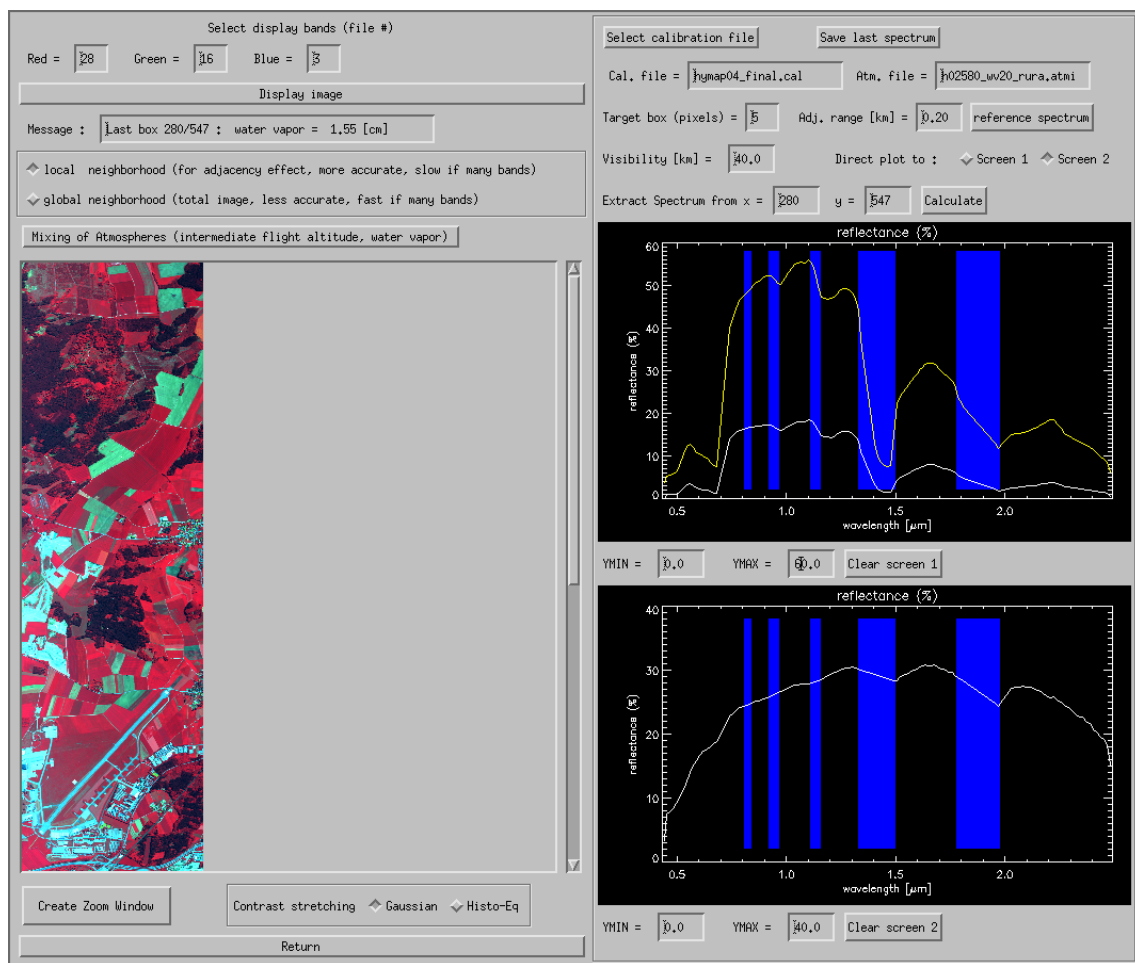


Figure 5.44: SPECTRA module.

To obtain a target spectrum of the scene click at any position in the image. In figure 5.44 the solid white-line spectrum at the top shows a meadow signature, the green line represents a reference spectrum taken from the *spec_lib* directory, already resampled for the HyMap sensor. A reference spectrum can be loaded when clicking the corresponding button at the top right of the panel. An exact match of scene spectra and library spectra cannot be expected when they are measured at different times and locations, but the trends (spectral shapes) should be similar. The bottom graphics shows an asphalt spectrum taken from the aircraft runway in the lower part of the image.

The parameter *Visibility* can be set in the corresponding widget near the center of the panel and its influence on the retrieved spectrum will be shown when placing the target box in the scene. For hyperspectral sensors, the water vapor column corresponding to the last spectrum is given in the "message" box (upper left of panel). In addition, there is the choice of selecting the global neighborhood (average over whole image) or the local neighborhood (adjacency range as specified on the main panel, see figure 5.40) for the correction of the adjacency effect. The "global" option is faster, because it has to be calculated only once per channel. The "local" option is more accurate and slower because it is always updated, but depending on the scene content, the difference between both options may be small.

The button "*Save last spectrum*" (upper right corner of figure 5.44) can be used to save the selected surface reflectance spectrum. A sequence of target DN spectra can also be generated here that is required as input to the spectral calibration module (see chapter 5.8.5). Up to 9 targets can be defined to be used in the spectral calibration. They have to be labeled consecutively, e.g. "*target1*", "*target2*", etc. These output file names (without file name extension) have to be specified after pressing the button "*Save last spectrum*". For each target name three files will be generated, e.g., "*target1.dat*" (surface reflectance spectrum), "*target1.txt*" (a description file), and "*target1_dn1.dat*" (the DN spectrum). The sequence of "*target*_dn*.dat*" files is used in the spectral calibration module.

5.4.8 Aerosol Type

The aerosol type is a parameter which is fixed for atmospheric correction. This routine searches automatically for the best suited aerosol type for the currently selected image. This type can then be used when selecting the atmospheric file.

5.4.9 Visibility Estimate

ATCOR uses the *Dark Dense Vegetation (DDV)* approach to calculate the best visibility for an image. This button allows to calculate the visibility estimate for the whole image without going into the image processing. Note, that for the 'Variable Visibility' option, the visibility map will be calculated anyway from the image during the image processing.

5.4.10 Inflight radiometric calibration module

This chapter presents the GUI for the inflight calibration, which may also be invoked from one of the four possible ATCOR main panels. The purpose is the calculation of the radiometric calibration coefficients for spectral bands in the solar region based on measured ground reflectance spectra. The user should be familiar with radiometric calibration as described in the ATCOR ATBD [106] before using this function.

Note: a ground reflectance spectrum from a field spectrometer has to be resampled with the channel filter curves of the selected sensor. The field spectrometer file format should be converted into a simple ASCII file containing the wavelength (*nm* or μm) in the first column and reflectance in the second column. The resampling can then be done with the sequence "Filter", "Resample a Spectrum" from the ATCOR main panel. The result is an ASCII file with 2 columns: the first contains the channel center wavelength (the *nm* and μm unit is allowed), the second contains the resampled reflectance value (either in the 0 - 1 or 0 - 100% range).

If "target1" is the name of the target, ATCOR provides three ASCII files with information on target / background properties and the derived calibration file. These are the output of the "c1" option of ATCOR's calibration module,

- File "target1.adj" contains the original target DN_1 , the adjacency corrected DN_1^* , and the ground reflectance data for each band.
- File "target1.rdn" (radiance versus digital number) contains the band center wavelength, target radiance L_1 and corresponding digital number. This file can be used as input to a regression program "cal_regress" that allows the calculation of the calibration coefficients with a least squares fit in case of multiple targets (more than two).
- File "target1.cal" contains three columns: band center wavelength, offset or bias set to zero ($c_0 = 0$), and c_1 according to the radiance conversion equation (compare the ATCOR ATBD [106]).

Remark: a bright target should be used here, because for a dark target any error in the ground reflectance data will have a large impact on the accuracy of c_1 .

Figure 5.45: Radiometric calibration: target specification panel.

At the top line of the menu of figure 5.45 the mode of calibration is specified: one or two targets can be employed by selecting the button 'c1' or 'c0 & c1', respectively. If a calibration is intended for $n > 2$ targets, each target has to be specified separately in the 'c1' mode, which creates a file 'target*i*.rdn' ($i=1, 2, \dots, n$) with the name 'target*i*' specified by the user. These files contain the radiance and corresponding digital number spectrum as a 2-column ASCII table, and they are employed in the batch module *cal_regress* (see chapter 5) to calculate a least squares regression

for the calibration coefficients. Next the target box size and the corresponding ground reflectance file have to be specified. The button for the file name of target 2 is insensitive, because the single target mode was selected here. Then the file name for the calibration results should be specified. The default name is *"test.cal"*. However, it is recommended to include the name of the ground target here. Now the target(s) can be clicked in the zoom window that pops up automatically. Target 1 has to be clicked with mouse button 1 (mb1, left), target 2 with mouse button 2 (mb2, center). The zoom window is moved in the main window by pressing mb1 (for target 1) and mb2 (for target 2). Alternatively, the target coordinates ($x / y = \text{column} / \text{line}$) can be specified.

In addition to the file *"xxx.cal"* the files *"xxx.rdn"* (radiance versus digital number), and *"xxx.adj"* (original and adjacency corrected DN's) are automatically created.

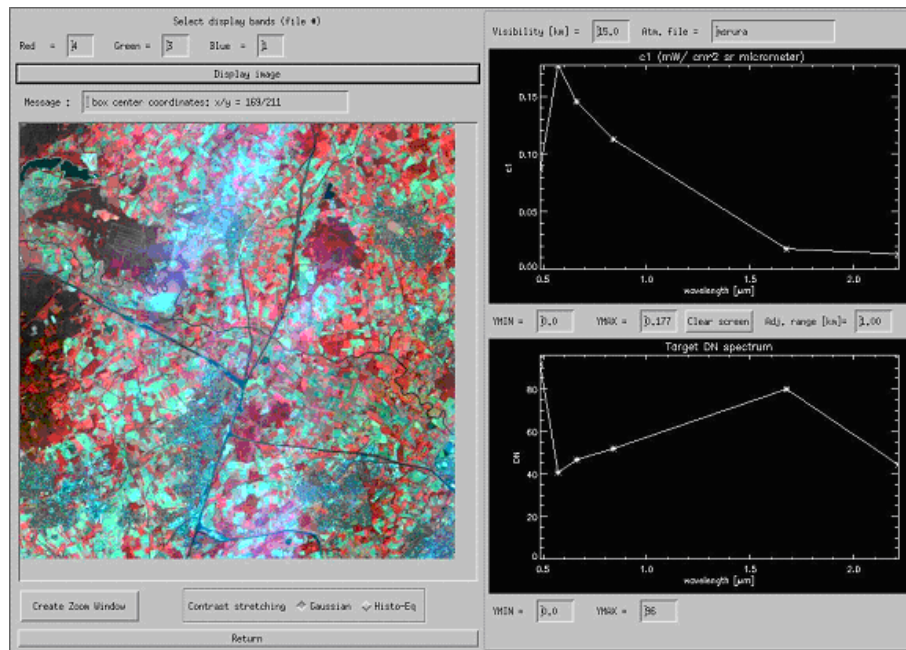


Figure 5.46: Radiometric CALIBRATION module.

The appearance of the inflight calibration module is similar to the SPECTRA module. In the left part the image is loaded. A zoom window can be created and two contrast stretching options (Gaussian and histogram equalization) are available. In the right part two windows are provided to display the *c1* spectrum and the box-averaged target DN spectrum. The *ymin* / *ymax* widgets allow the user to scale the graphical display. The parameters visibility and adjacency range can be varied and their influence on the calibration curve can be studied.

5.4.11 Shadow removal panels

The interactive session of the de-shadowing method enables the setting of three parameters that influence the results, compare Figures 5.47, 5.48:

1. a threshold Φ_T for the unscaled shadow function $\Phi = \text{PhiU}$ to define the core size of the shadow regions, see the theoretical background document [106] for details.
2. the maximum range Φ_{max} for re-scaling the unscaled shadow function $\Phi = \text{PhiU}$ into the (0,1) interval of the scaled shadow function.
3. the last parameter sets the minimum value of the scaled shadow function $\Phi^* = \text{PhiS}$, typically in the range $\text{PhiS}=0.02 - 0.10$, i.e., the darkest shadow pixels of the scene are treated as being illuminated with a fraction PhiS of the direct solar irradiance.

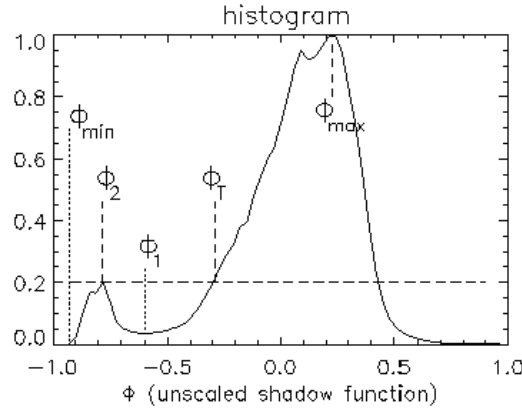


Figure 5.47: Normalized histogram of unscaled shadow function.

The first two parameters are most important. The last parameter is not very critical, and a default value in the range $\text{PhiS}=0.04 - 0.08$ covers most cases of interest.

The linear type of re-scaling of PhiU is recommended. The "exponential" option exaggerates the de-shadowing results, but it can be used to enhance the trends for a quick visual inspection.

When pressing the button "Run Interactive De-Shadowing", a reduced size image of the original scene, the shadow mask, and the de-shadowed image will pop up with the histogram of PhiU containing the threshold for core areas (point 1 of Fig. 5.48), the range of re-scaling of PhiU (point 2), and the current value for PhiS (point 3). Now these three parameters can be modified, and the results will again be shown as the corresponding quicklook image and histogram. When good results have been obtained the parameters can be saved and the final image processing can take place.

Figure 5.49 presents an example with two iterations. Results for iteration 1 contain too many shadow pixels (black areas in the central section of the image), therefore the threshold = -0.15 was decreased to -0.38 (parameter 1 of Fig. 5.48). After de-shadowing, most areas in the shadow mask were overcorrected in iteration 1, therefore the maximum range = 0.40 was decreased to 0.19 (parameter 2 of Fig. 5.48, see diagonal line from lower left to upper right in histogram of Fig. 5.49). The shadow mask for iteration 2 is appropriate, and no overcorrection effects can be observed.

1. PhiU unscaled shadow function, threshold (core areas) =

2. PhiU unscaled shadow function, max range for re-scaling =

(increase threshold to get more core shadow areas)
(increase max range to enhance de-shadowing)

3. PhiS scaled shadow function, min value (dark shadow) =

Type of re-scaling function : ☒ linear ☐ exponential

Run Interactive De-Shadowing and View Preliminary Results

File name (reflectance, without de-shadowing, Landsat TM comparable bands) = "preliminary_reflectance,bsq"

File name (reflectance, de-shadowed results , Landsat TM comparable bands) = "prelim_refl_de_shadowed,bsq"

Path = /auto_as/data7/cloud_shadow/etm_biota2001/

The preliminary files can be viewed in detail (e.g. with ENVI) to assess the results

They will be deleted when the interactive de-shadowing session is closed

Save Parameters and Continue with Image Processing

Figure 5.48: Panel to define the parameters for interactive de-shadowing.

Note: when leaving the panel of Fig. 5.48 it is possible to edit the cloud shadow map before continuing the scene processing, using any available image processing software. Then the edited map is employed for the processing. This provides some flexibility because it is difficult to calculate a satisfactory shadow map in all cases.

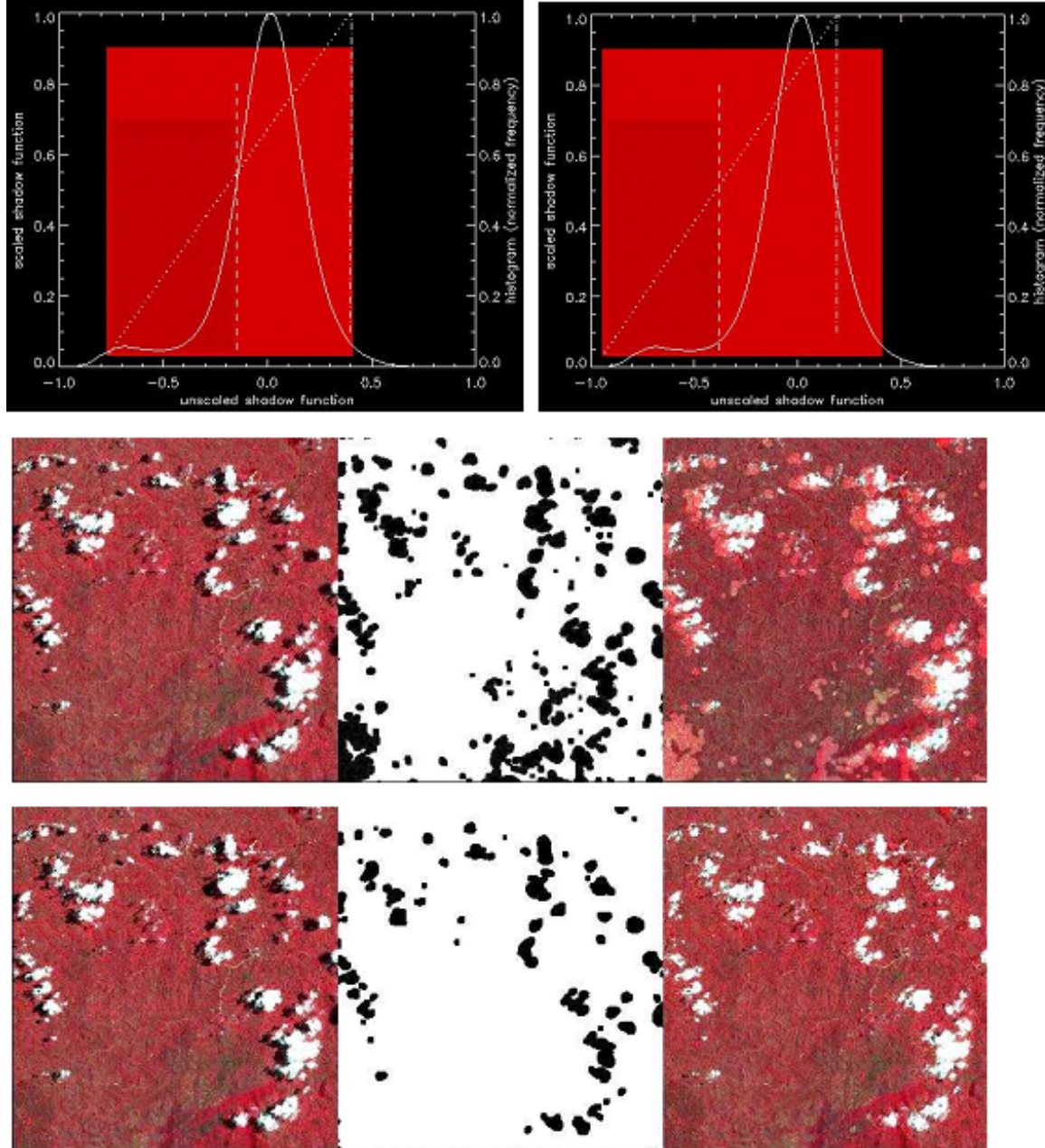


Figure 5.49: Quicklook of de-shadowing results.

Top left: histogram of PhiU (threshold=-0.15, range=0.40), iteration 1. Top right: histogram of PhiU (threshold= -0.38, range=0.19), iteration 2. Center: results for iteration 1, left-to-right: original, shadow mask, de-shadowed image. Bottom: results for iteration 2.

5.4.12 Panels for Image Processing

When pressing the button "IMAGE PROCESSING" in one of the main panel (figure 5.40) some additional panels will pop up. First, the processing options are to be selected (see figure 5.50).

Blocked Options Are Not Available For The Selected Sensor
(Might also apply for a reduced set of bands)

Variable Visibility (aerosol optical thickness)	<input checked="" type="radio"/> Yes	<input type="radio"/> No
Variable Water Vapor	<input checked="" type="radio"/> Yes	<input type="radio"/> No
Haze or Sun Glint Removal	<input checked="" type="radio"/> Yes	<input type="radio"/> No
Shadow Removal (Clouds/Buildings)	<input checked="" type="radio"/> Yes	<input type="radio"/> No
Value Added Products	<input checked="" type="radio"/> Yes	<input type="radio"/> No
Solar Flux at Ground	<input checked="" type="radio"/> Yes	<input type="radio"/> No

Cancel OK

Blocked Options Are Not Available For The Selected Sensor
(Might also apply for a reduced set of bands)
(Either Haze or Cirrus Removal, not both)

Variable Visibility (aerosol optical thickness)	<input checked="" type="radio"/> Yes	<input type="radio"/> No
Variable Water Vapor	<input checked="" type="radio"/> Yes	<input type="radio"/> No
Haze or Sun Glint Removal	<input checked="" type="radio"/> Yes	<input type="radio"/> No
Shadow Removal (Clouds/Buildings)	<input checked="" type="radio"/> Yes	<input type="radio"/> No
Value Added Products	<input checked="" type="radio"/> Yes	<input type="radio"/> No
Cirrus Removal	<input checked="" type="radio"/> Yes	<input type="radio"/> No
Solar Flux at Ground	<input checked="" type="radio"/> Yes	<input type="radio"/> No

Cancel OK

Figure 5.50: Image processing options. Right panel appears if a cirrus band exists.

Options that are not allowed for a specific sensor will appear insensitive. If the haze removal option is selected in combination with "Variable Visibility" the visibility index (proportional to total optical thickness) map is coded with the values 0-182. The value visindex=0 corresponds to visibility 190 km, each integer step of 1 corresponds to an AOT increase of 0.006. The array serves as a fast method of addressing the radiative transfer quantities (transmittance, path radiance etc) in case of a spatially varying visibility, i.e., in combination with the DDV algorithm. IF the "Haze or Sunglint Removal" button is selected the next panel will ask for haze removal over land (option 1), haze or sunglint removal over water (option 2), or haze removal over land and water (option 3).

In case of thermal bands, an emissivity selection panel will appear:

Constant scene emissivity = 0.9800 ; band 13 at 10.661 [micron]

Emissivities: water & vegetation e=0.98, dry veget. & soil e=0.97, sand & asphalt e=0.96 ; band 13 at 10.661 [micron]

Normalized Emissivity Method (NEM) : max emissivity specified below

Define constant scene emissivity =

Original NEM : all surface types have the same max emissivity
Adjusted NEM : surface types have different max emissivity

Adjusted NEM: max emissivity water =

Adjusted NEM: max emissivity green vegetation =

Adjusted NEM: max emissivity dry veget., soil =

Adjusted NEM: max emissivity asphalt, sand =

DONE

Figure 5.51: Emissivity selection panel.

The first two options are available for instruments with only a single thermal band, the NEM and ISAC options require multiple thermal bands and are not shown if there are less than 5 thermal

bands. The surface classes (water, vegetation, soil etc) are calculated on-the-fly employing the surface reflectance spectra from the reflective bands.

Figure 5.52 shows the panel with the two options for haze over land processing as explained in the ATCOR ATBD [106].

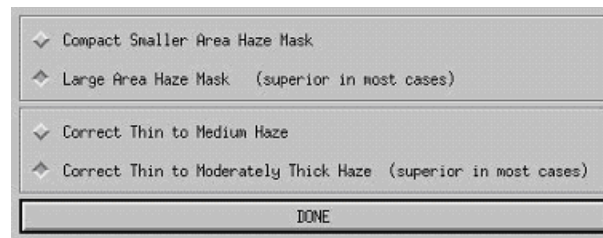


Figure 5.52: Options for haze processing.

The panel of figure 5.53 pops up when the spatially varying visibility option was selected and if the sensor has a $2.2\ \mu\text{m}$ (or $1.6\ \mu\text{m}$) band (or at least a red and NIR band) required for the automatic masking of the dark reference pixels, compare theoretical background document [106].

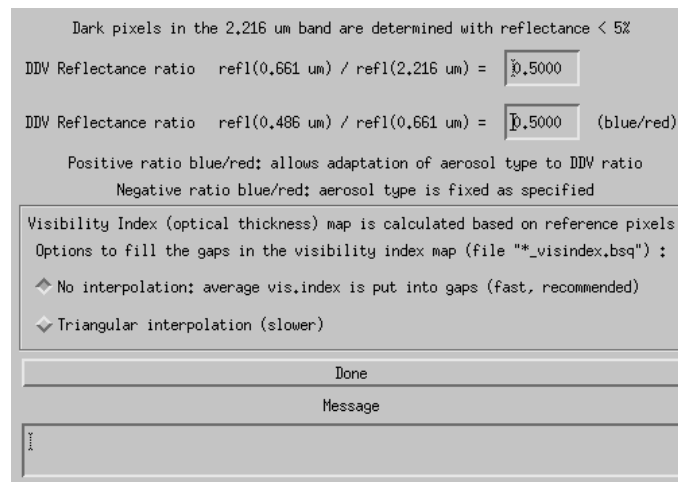


Figure 5.53: Reflectance ratio panel for dark reference pixels.

The panel of figure 5.54 pops up for rugged terrain and contains the input parameters to incidence BRDF compensation due to terrain variations as discussed in the section about topographic processing in the ATCOR ATBD [106].

☐ No BRDF correction
☐ (I) : Empirical BRDF correction (independent of surface cover)
☒ (II): Empirical BRDF correction (different for vegetation and non-vegetation)

i = local solar illumination angle
 t = illumination angle where BRDF starts ($>$ solar zenith angle of scene)
 $G = G1 = \{ \cos(i) / \cos(t) \}^b \geq g$
 where g is a user-defined lower cut-off value of G , exponent b : see below

☒ (A) $G = G1$ with exponent $b=1.0$ (linear)
☐ (B) $G = G1$ with exponent $b=1/2$ (sqrt) recommended standard

BRDF start angle (t) [degree] =

g = smallest value of G (range 0.1-1) =

BRDF correction for vegetation :
 (a) weak correction in NIR-SWIR (superior in most cases)
 (b) stronger correction in NIR-SWIR ($\lambda > 720$ nm)

☒ (a) $G = G1$ with $b=3/4$ ($\lambda < 720$ nm), $b=1/3$ for $\lambda > 720$ nm
☐ (b) $G = G1$ with $b=3/4$ ($\lambda < 720$ nm), $b=1.0$ for $\lambda > 720$ nm

Done

Figure 5.54: Incidence BRDF compensation panel.

Figures 5.55 and 5.56 are associated with the value added products as described in the corresponding chapter of the theoretical background document [106]. This value added file contains up to 10 channels if the sensor has thermal bands. In case of a flat terrain, the air temperature has to be specified. For a rugged terrain, air temperature at some base elevation and the air temperature gradient as well as water vapor have to be defined.

If the value added option is selected another panel pops up (Figure 5.57). It contains parameters for the leaf area index (LAI model) and FPAR model as described in the corresponding chapter of the theoretical background document [106].

Finally, a job status window indicates the processing progress.

Note:

The job status window of ATCOR shows the percentage of processed image data and the estimated remaining time. The time estimate is based on the processing time for the current band. The time per band increases for channels in atmospheric water vapor regions, it decreases in regions where interpolation is applied, e.g., around 1400 nm. However, the time also depends on other factors such as the overall CPU load in case of multi-user machines, or the traffic on net-worked machines. Accordingly, the estimate for the remaining time is not always continuously decreasing, but may increase sometimes.

☒ Constant Air Temperature, emissivity with Brutsaert eq. (user input)
☒ Constant Air Temperature, emissivity with Idso/Jackson eq. (no user input)
☒ Map of Air Temperature (external file)

Constant Air Temperature for the Scene

Air temperature [Celsius] T = ==> air emissivity (Idso eq.) =

Air emissivity (0 - 1) = (chapter 3 of "atcon_value_adding.pdf")

Coregistered Map of Air Temperature [Celsius]

Message:

DONE

Figure 5.55: Value added panel for a flat terrain.

☒ Constant Air Temperature
☒ Map of Air Temperature

Constant Air Temperature

Air temperature [Celsius] T = at elevation z0 = [km above sea level]

Air temperature gradient t_grad = [Celsius per 100 m height]

Water vapor partial pressure p [mbar] = (corresponding to T, z0)

Scale height for water vapor z_pvw [km] = (chapter 3 of "atcon_value_adding.pdf")

Coregistered Map of Air Temperature [Celsius]

Message:

DONE

Figure 5.56: Value added panel for a rugged terrain.

LAI (LEAF AREA INDEX) model

1 : $LAI = (-1/a2) * \ln \{ (SAVI-a0)/(-a1) \}$

2 : $LAI = (-1/a2) * \ln \{ (NDVI-a0)/(-a1) \}$

Parameters and Typical Examples

Cotton with various soils: a0=0.82, a1=0.78, a2=0.60

Corn : a0=0.68, a1=0.50, a2=0.55

a0 =

a1 =

a2 =

FPAR model: $FPAR = c * [1 - a * \exp(-b * LAI)]$

Parameters

c =

a =

b =

Message:

DONE

Figure 5.57: LAI / FPAR panel

Processing Band 2

28

Per Cent Done

Remaining time 15 min. 3 sec

Figure 5.58: Job status window.

5.4.13 Start ATCOR Process (Batch / Tiled)

This is a way to start a tiled or batch process of ATCOR from within the ATCOR GUI (instead of starting the process from console).

The process requires that an *.inn file has been created before by going through the atcor GUI or by editing a respective ASCII file manually or by using the routine *write_atcor_inn_file.pro* provided in the directory *docu* of the ATCOR installation.

The below parameters are to be entered for processing:

- Input file name: name of image data cube to be processed. The file must be accompanied by a valid *.inn file for processing.
- For DEM preparation: DEM to be used as input
- Name of output cube or elevation file to be created (Attention: outputs are overwritten).
- Number of tiles in X and Y dimensions - the total number of tiles to process is then X x Y tiles.
- ATCOR Method: Selection between:
 - DEM Preparation: resize of DEM and calculate slope/aspect/skyview
 - Rugged (ATCOR4-R): rugged processing based on INN parameters (Note: DEM is to be set manually in INN in case it is prepared here)
 - Flat (ATCOR4-F): flat processing based on INN parameters
- Kernel Size: Size of kernel in pixel to be used for DEM preparation
- Apply Dehazing First: Performs standard dehazing before applying flat or rugged ATCOR processing.

Functions

Run Starts the process (sorry, this may take some time)

Show Log Displays the Log file for the currently selected input image (if available..)

Display Output Displays the Currently selected output file in the ENVI fi

After starting the process using the 'run' button, the messages are printed to the prompt (or the console) if available. Error and status messages may also be found in the *.log file during and after processing.

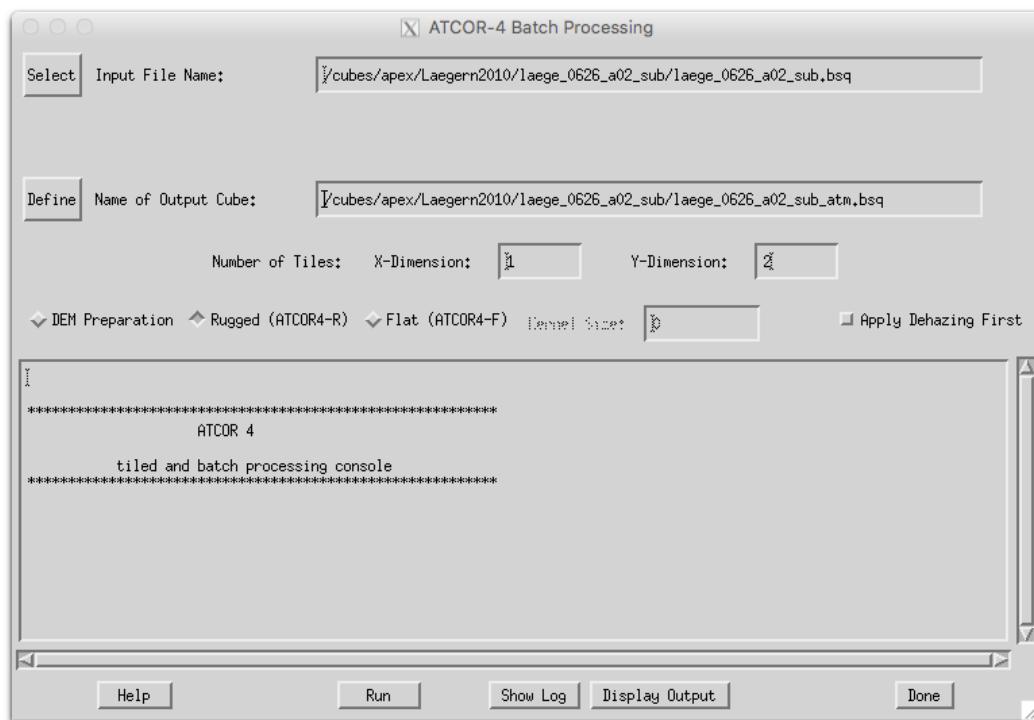


Figure 5.59: ATCOR Tiled Processing

5.5 Menu: BRDF

The "BRDF" menu provides access to the simple nadir normalization method and the more advanced BREFCOR BRDF correction.

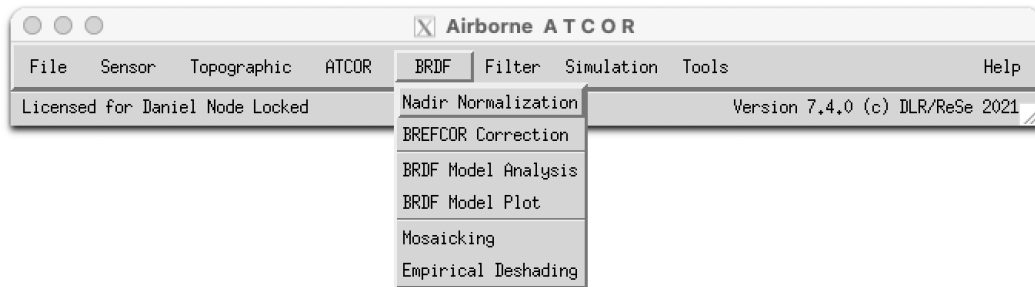


Figure 5.60: BRDF top Menu.

5.5.1 Nadir Normalization (Wide FOV Imagery)

This module (NADIR_REFL) performs an empirical BRDF correction by normalizing the across-track radiance gradients to the nadir brightness value (see [ATBD \(chapter BRDF\)](#) [106]). Figure 5.61 shows the corresponding GUI panel.

The statistical nadir normalization works best for wide FOV airborne data and requires a minimum field-of-view of 20°.

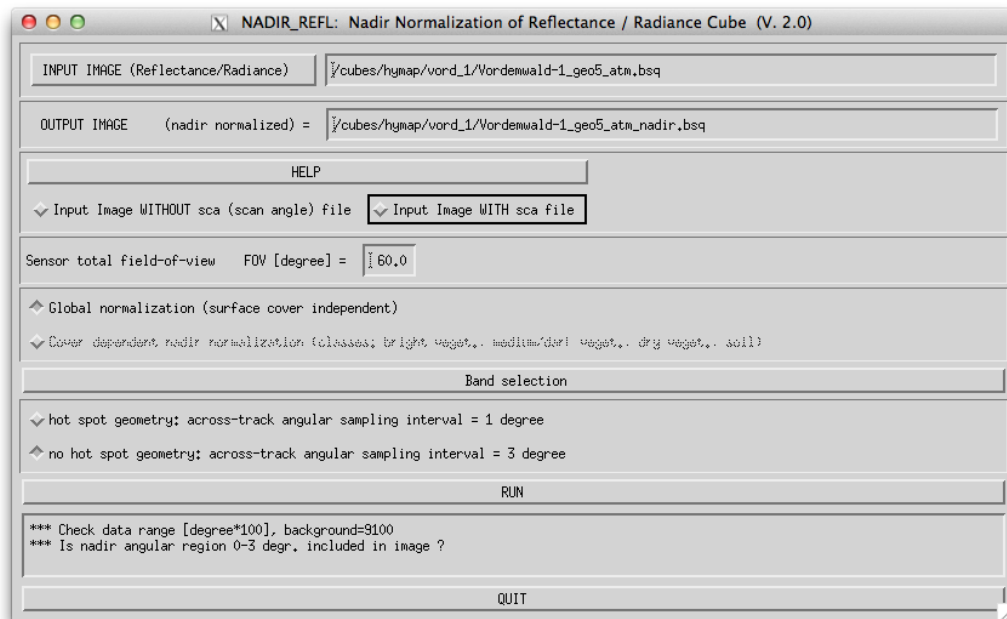


Figure 5.61: Nadir normalization.

5.5.2 BREFCOR Correction

This module calculates an observer BRDF correction using a model based approach, see the corresponding chapters in the theoretical background documentation [106]. Figure 5.62 shows the corresponding GUI panel.

This module calculates an observer BRDF correction using a model based approach. see ([ATBD \(chapter BRDF\)](#)). Figure 5.62 shows the corresponding GUI panel.

The BREFCOR is implemented for the airborne version of ATCOR for sensors with a large FOV. It works best if a number of scenes can be taken for model calibration, but it may also lead to good results for single scenes as long as the statistics are uniform within scene.

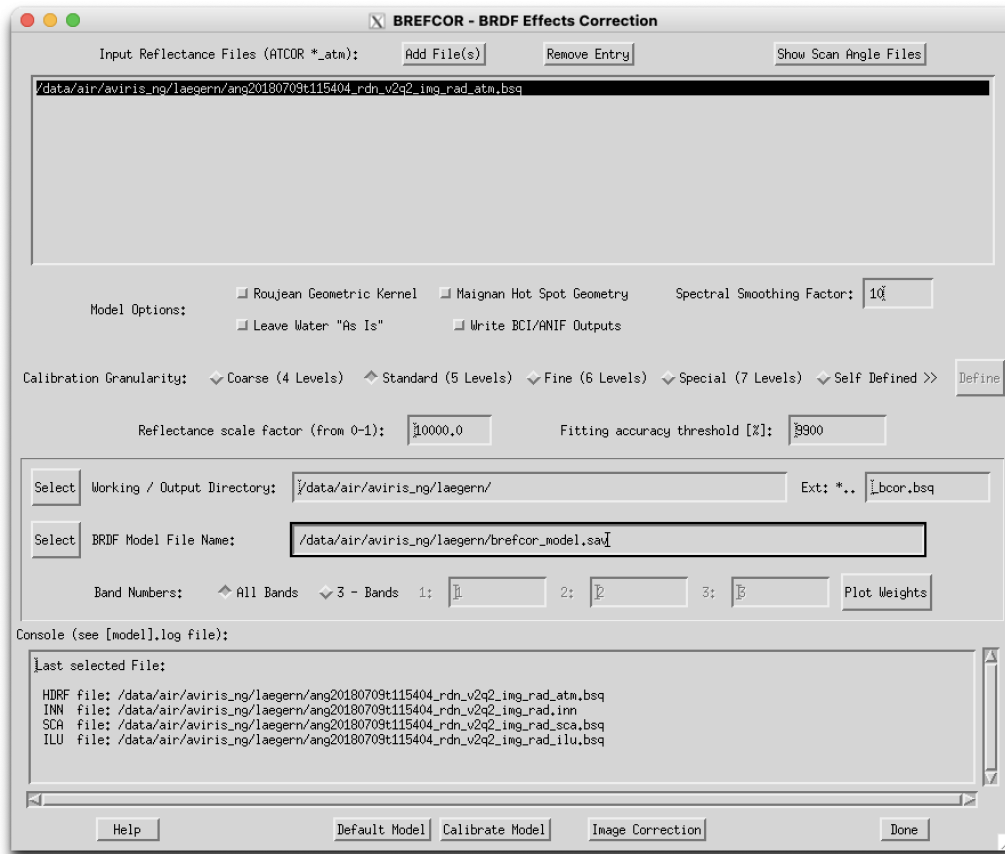


Figure 5.62: BREFCOR correction panel (airborne version).

The Ross Thick-Li-Sparse reciprocal BRDF model kernels are used for correction of the imagery. The various viewing angles of the individual images provided are used as reference points to calibrate the kernel weighting factors and the isotropic component of the BRDF models. This model requires a sufficient number of images for good calibration as a variety of incidence and viewing angles are required. The following inputs are necessary:

Inputs Files: A list of atmospherically corrected input file is to be compiled (*.atm.bsq). The ATCOR *.inn file is used for the meta data information. It should be named according to the

ATCOR convention and situated at the same place as the *_atm bottom of atmosphere reflectance file. Additionally, the viewing angles are read from the scan angle file, which should be named *_sca.bsq. Files are added using the 'Add File(s)' Button on top, while entries may be removed by the 'Remove Entry' Button. Further files considered are:

*_ilu file is used to exclude shadow pixels (if floating point ilu file is available according to ATCOR conventions)

*_hew file is used to exclude hazy/cloudy pixels from calculation.

Model Options:

- Roujean Geometric Kernel: the Roujean Kernel is used for the geometric part of the model (instead of the Li Sparse model).
- Maignan Hot Spot Geometry: use the improved hot spot geometry for the volumetric kernel as proposed by Maignan (RSE, 2003).
- Spectral Smoothing factor (number of bands): Smooth the weighting functions in the spectral dimension - this option is useful for hyperspectral instruments only to avoid spectral artifacts. A spectral smoothing in a range of 20-30nm is recommended. NOTE: this is NOT a spectral polishing but rather a smoothing of the correction function.
- Leave water 'as is': The first level (water) is not touched by the BRDF correction, i.e. the kernel weights are set to zero for both geometric and volumetric kernel; this may be useful because water can not be easily modeled by the Ross-Li formulation.
- Write ANIF outputs: By default, the corrected image is written. Use this option to get the side outputs; i.e. the files *_anif (anisotropy map) and the *_bci which is the BRDF correction index used to discriminate the BRDF levels.

Calibration Granularity: For calibration of the model, the image is stratified in a number of BRDF levels. The number of pre-defined levels can be selected; calibration on a bigger number of levels leads to better accuracy of the correction, while it requires good image statistics. A smaller number of levels leads to higher stability of the results.

The stratification thresholds for the calibration may be tuned manually by the 'Self Defined λ_i ' option - use the define button to adjust the levels. Please check the BCI image to find suited calibration limits.

Reflectance scale factor: This is a constant factor which is to be applied to the input image (which has to be directional reflectance HDRF) to convert the image DNs to absolute reflectance values (between 0 and 1), i.e. if the reflectance in [%] is scaled by 100 to store the data, the factor is 10'000.

Fitting accuracy threshold [%]: Limit to fitting accuracy to make an across track fitting function accepted. Increasing the limit will lead to more correction functions. For large FOV instruments, the threshold may be increased to up to 30% in certain cases.

Output Definition: The directory for all outputs, and the file name appendix can be defined here. If the directory is not given, the outputs are stored together with the input imagery using the given extension.

The Ext field is the extension which will be added to all input files to store the output of the calculation.

The BRDF model file name can be defined or selected here. The latter applies if the option 'Use precalculated Model' is selected above. It will be stored in the directory defined above

Band Numbers: By default all bands are corrected. For hyperspectral imagery, it may be useful to check the performance on an RGB sample first.

The button 'Plot Weights' allows to show the found kernel factors in relation to the BCI.

Actions:

- **Default Model:** A default model is created by interpolation to the sensor characteristics. The default model reference file (brefcor_defaults.txt) is defined in the bin directory of the atcor distribution.
- **Calibrate Model:** the model calibration file is created without applying a correction to the images.
- **Image Correction:** the model based BRDF correction is performed. If the selected model file is available, it is used for the correction.

5.5.3 BRDF Model Analysis

This tool is to analyze the model parameters which have been derived by best-fit approach from the imagery. An example is shown in Fig. 5.63. The top section shows the meta parameters of the currently selected model file (i.e., the output from the model calibration procedure).

Actions:

Export Plot: Exports the current plot as EPS image file.

Export Table: Exports the current parameter table to an ASCII file.

Plot Fit: Opens a new panel to show the current fitting results (see Fig. 5.64).

The displayed data in the fitting plot may be adjusted in various ways: the input file which had been used for model fitting may be changed, the two displayed spectral bands may be changed, and the range of BRDF cover index (BCI) levels may be selected.

5.5.4 BRDF Model Plot

This tool is to plot a BRDF model as it has been used for BREFCOR correction. An example is shown in Fig. 5.65.

Sliders and Inputs:

Select: This lets you select a model file (IDL save file) which has been created by the BREFCOR model calibration procedure.

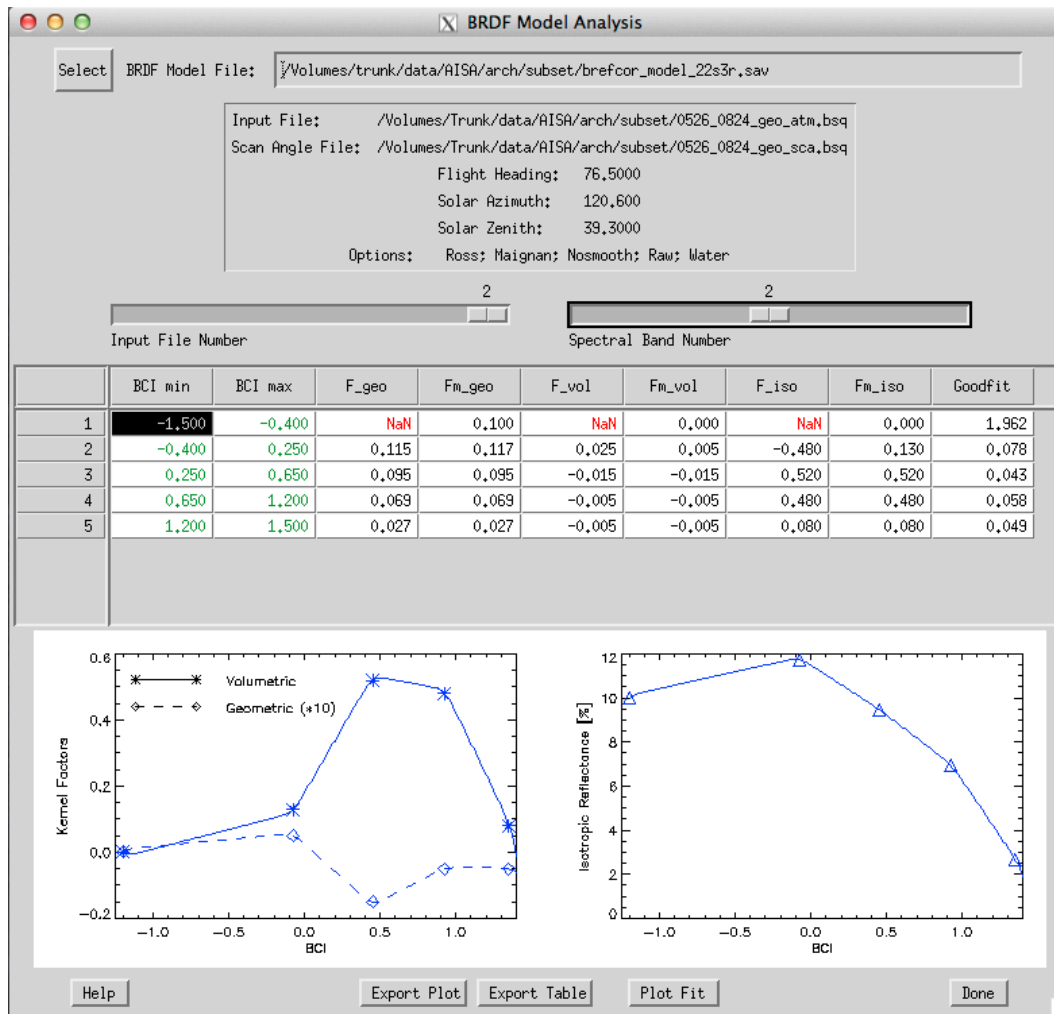


Figure 5.63: BRDF model analysis panel.

Input File Slider: If calibration has been done on multiple files at once, the files may be selected here. Setting this slider to '0' displays the averaged results from all files.

Spectral Band/BCI Levels Slider: Lets you select the respective band number and BCI level number.

BRF Range: Defines the scaling of the graphics in absolute BRF values or in ANIF values (if selected in the model Options below). The button 'AutoRange' will reset to the min/max of the available data.

Max Zenith: Maximum sensor zenith angle to be displayed (default: 45 degrees off nadir)

rho_iso/f_geo/f_vol : Factors of 3-parameter BRF-model to be plotted (these factors may be edited for test purposes; on return, the plot is updated)

Solar Zenith: Solar zenith angle for the plot in degrees.

Options: Allows to select variations of the BRDF model and to plot Anisotropy instead of BRF values.

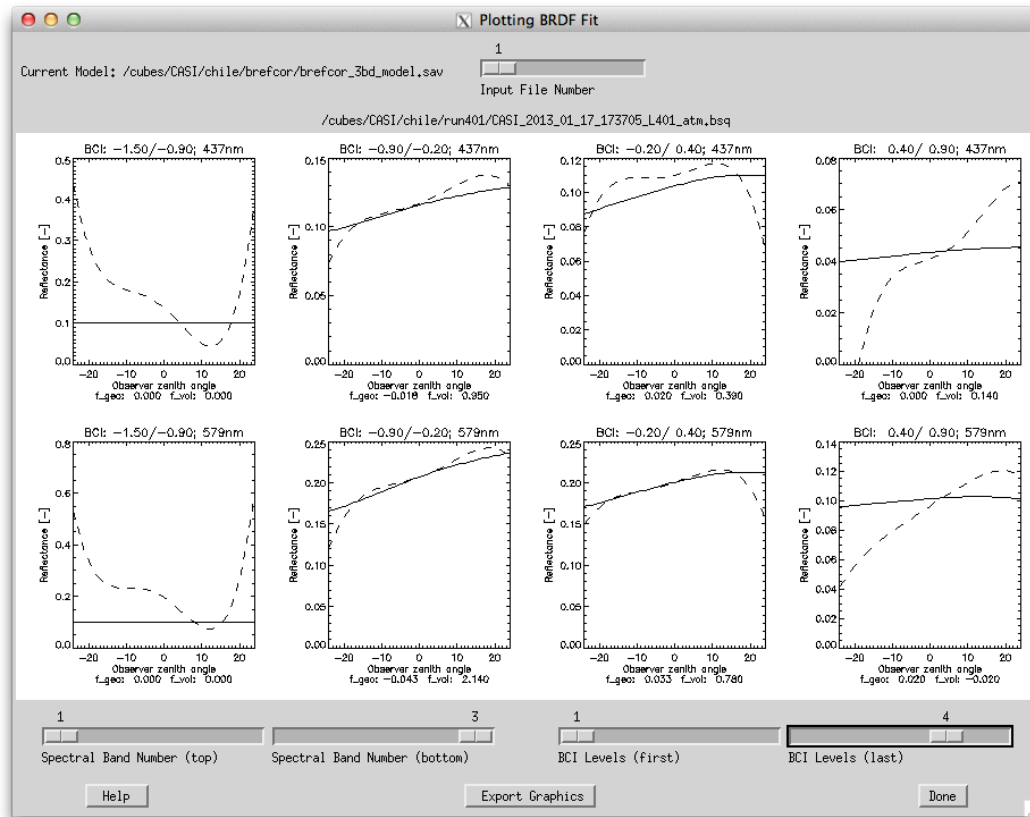


Figure 5.64: BRDF model fitting analysis panel.

The currently displayed graphics can be exported to an EPS file using the 'Export Graphics' button.

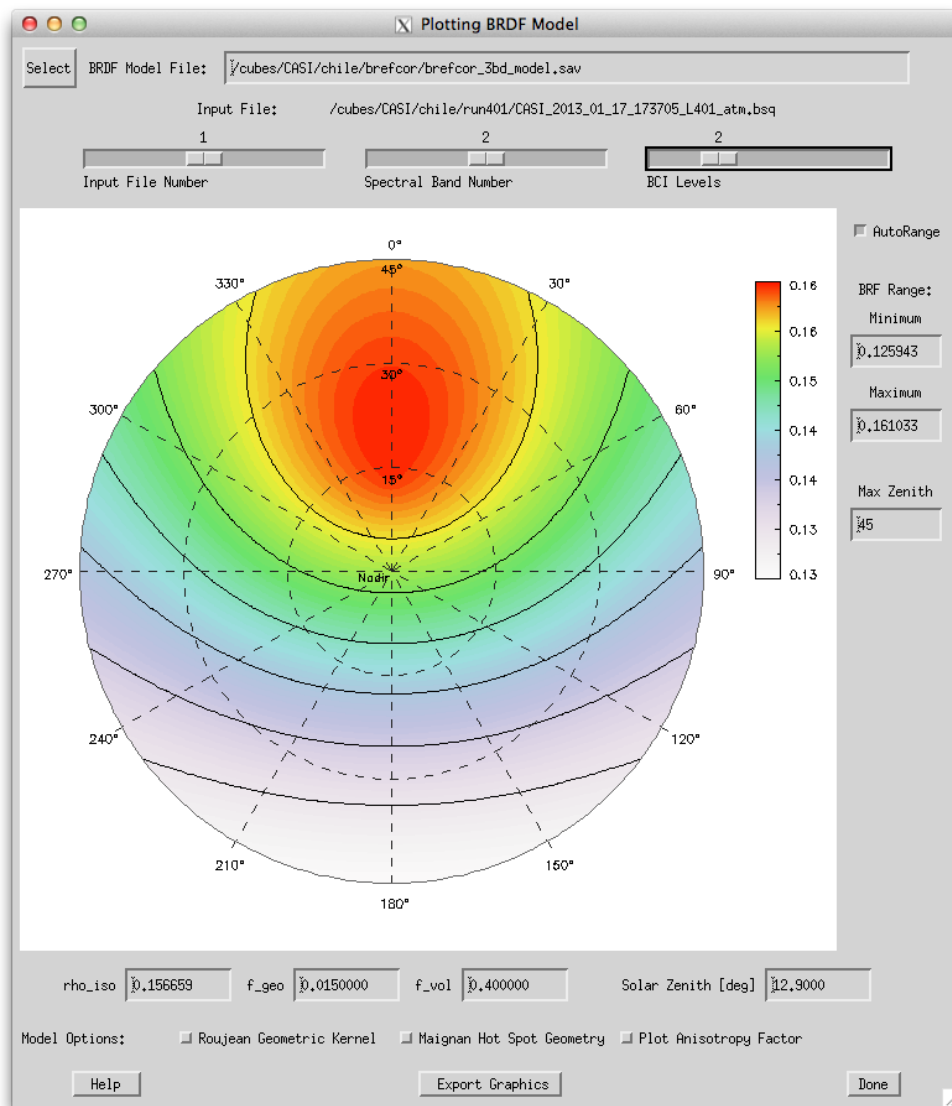


Figure 5.65: BRDF model plot.

5.5.5 Mosaicking

Mosaic a number of georectified scenes into one (in an efficient way...). Figure 5.66 shows the parameter settings which can be chosen for this procedure.

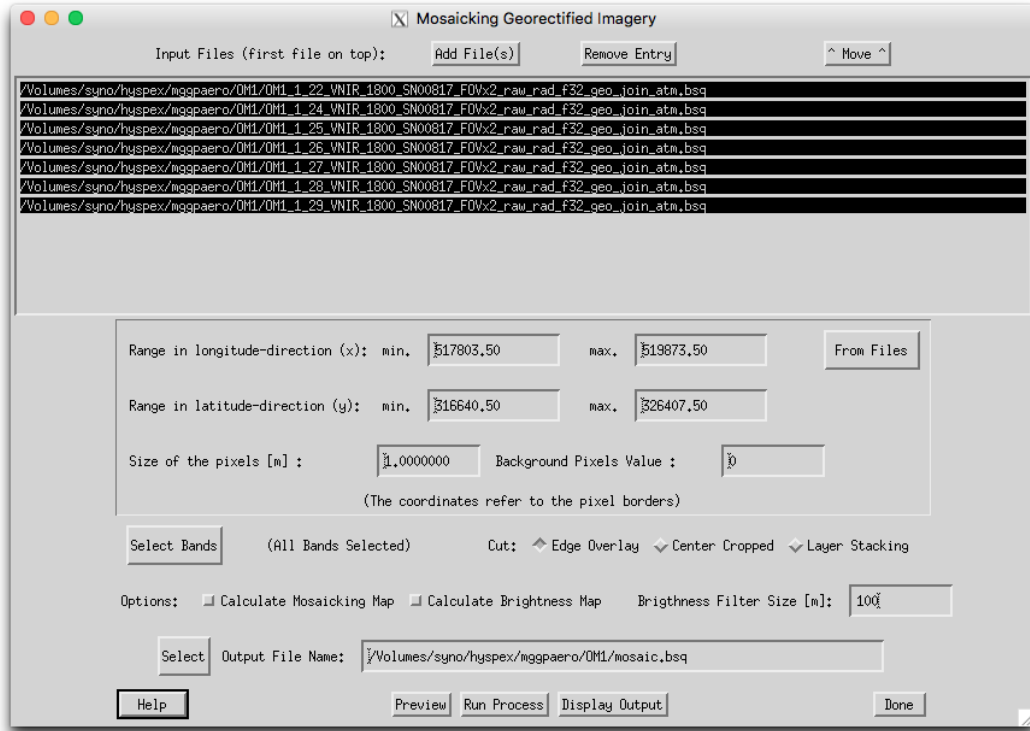


Figure 5.66: Mosaicking Tool.

Inputs

- **Input Files (first file on top):** list of files to be mosaicked. The files are stacked in the order of appearance (i.e the first file in the list is on top of the mosaicked output)
Buttons:
Add File(s): adds one or more new files
Remove Entry: removes the selected file(s)
Move: moves the file one position up (or rotates if already at top)
- **Range:** range in x and y direction to edge of pixels of the mosaicked product should be entered. The coordinates refer to the pixel borders (edges) on either side of the image.
- **Button *From Files* :** reads the maximum extend of all selected files as of the list (make sure to select the files in the list to be considered before pressing this button).
- **Size of the pixels [m]:** Pixel size of quadratic pixels
Note: the mosaicking uses a bilinear interpolation; no aggregation is done.
- **Button *Select Bands* :** Allows to select/deselect the spectral bands to be considered for mosaicking. NOTE: this option is void, if the number of bands does not agree between images. The number of currently selected bands is displayed beneath the button

- **Cut:** treatment of overlapping images, by
Edge Overlay: The mosaicking is such that the first file in the list is strictly on top
Center Cropped: While mosaicking, the routine tries to find the middle of the overlap area between the new image and all the images mosaicked so far as a cut line.
Layer Stacking: The files are stacked in band sequential order on top of each other. The first image in the list rules the output dimensions. All bands are used in any case.
- **Options:**
 Calculate Mosaicking Map: A file named `_mosmap.bsq` is written in parallel to the output, containing an integer map with numbers starting at 1 to n (number of input files) which shows for each pixel the used input file.
 Calculate Brightness Map: A file named `_bright.bsq` is written which contains the relative brightness for all mosaicked bands (for hyperspectral images, a subset of bands at 450, 600, 805, 1190, 2020nm is written)
 Brightness Filter Size: Smoothing filter size in meters to use for relative brightness determination.
- **Output File:**
 name of output file to be written.

Actions

Preview : the first of the selected bands is mosaicked at a resolution reduced by a factor of 2 and the result is displayed.

Run Process : The mosaicking is performed.

Restrictions

This routines requires georeferenced data with:

- same coordinate system
- no rotation in ENVI header
- background coded with 0
- all files should have the same number of bands for mosaicking (except for layer stacking)

The input resolutions of the imagery may vary.

5.5.6 Empirical Deshading

This routine applies an empirical cloud deshading (i.e spatial brightness adjustment) of images or image mosaics based on the relative brightness.

Inputs:

- **Input File:**
 File to be corrected; typically a mosaicked output file, usually in reflectance units.
- **Brightness File:**
 File containing smoothed brightness of the imagery, at least for the blue and the NIR spectral band. The size and data type of the brightness map for up to 10 bands is the same as the image; for more than 10 bands, a subset of 2 to 5 bands at [450, 600, 805, 1190, 2020] nm

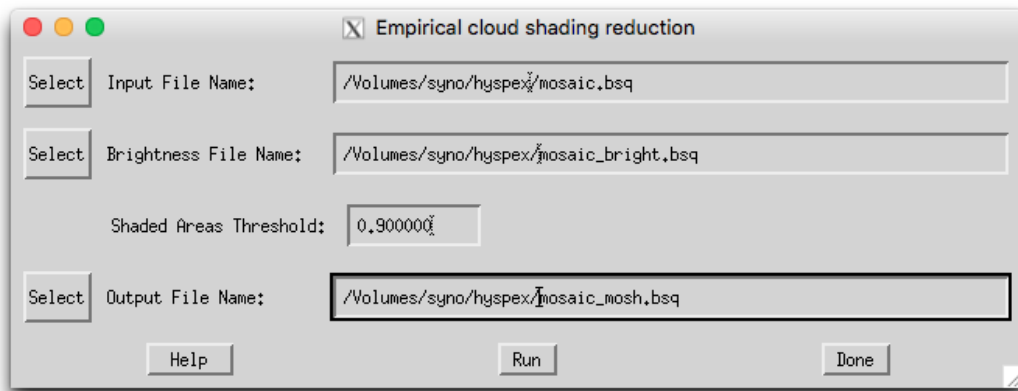


Figure 5.67: *Deshading/Brightness Adjustment Tool*

wavelength are used for brightness calculation; bands in between get interpolated brightness. This file can be created by the ATCOR mosaicking routine (see above) as side output.

- **Shaded Areas Threshold:**
relative brightness upper limit to image mean; i.e. only pixels darker than this factor from image mean are corrected.
- **Output File:**
name of output file to be written.

Action: **Run** Runs the brightness adjustment ('deshading').

Procedure: The routine reads the brightness in the blue spectral band and searches for the maximum relative brightness for the same pixels in the near infrared spectral bands. These two reference points are used to derive the coefficients for wavelength dependent correction. Using an Angstrom function of form $k \cdot \lambda^{-\alpha} < 1$, a wavelength dependent correction factor is then applied to the pixels below threshold.

Restrictions: This routine is still in development ... please approach us with sample data if results are not as expected.

A sample output of the empirical deshading is given in Figure 5.68

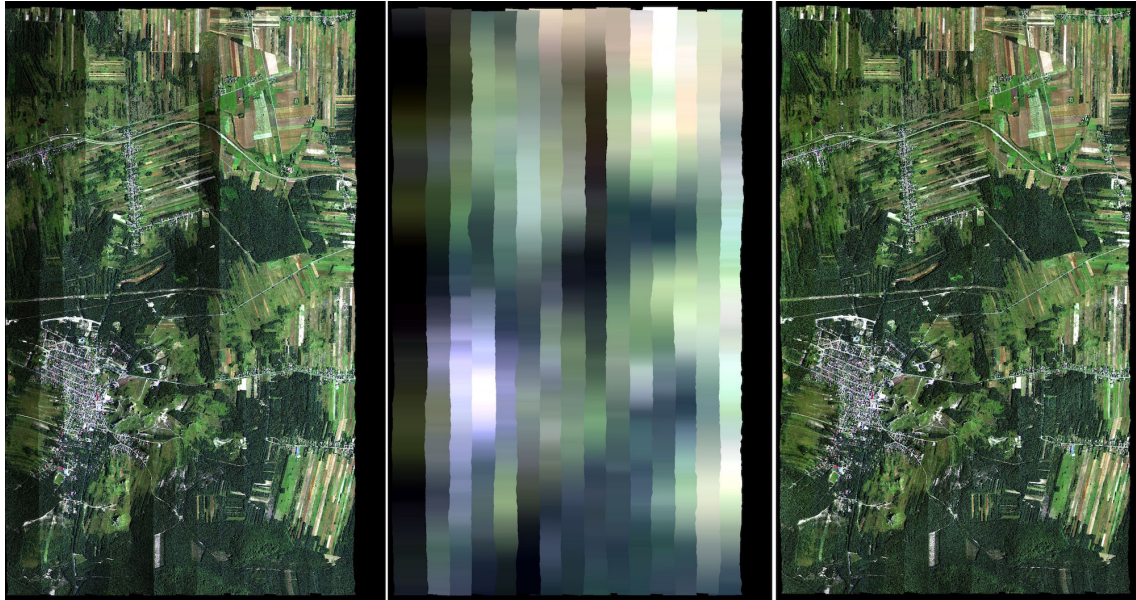


Figure 5.68: Sample result of empirical mosaic deshading of Hypex data (data courtesy of MGGP-Aero Poland)

5.6 Menu: Filter

The "Filter" menu provides spectral filtering of single spectra (reflectance, emissivity, radiance) provided as ASCII files, spectral filtering of image cubes, and spectral polishing.

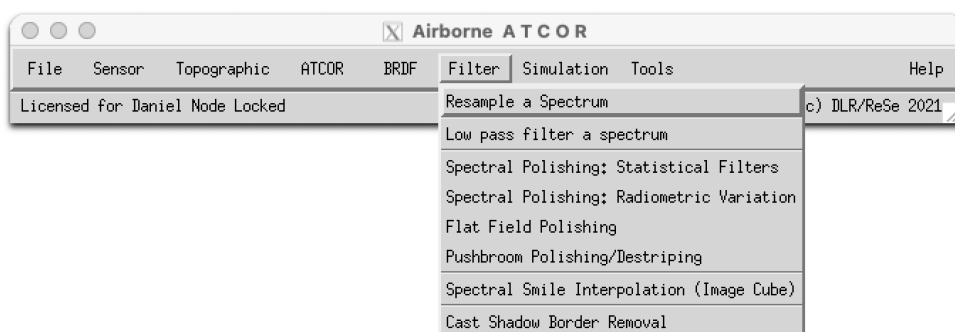


Figure 5.69: Filter modules.

5.6.1 Resample a Spectrum

This program serves for the general purpose of resampling. It requires an ASCII file with two columns as input. The first column is wavelength (nm or μm unit), the second is reflectance, or

emissivity, or something else, e.g. spectral radiance. The reflectance range can be 0 - 1 (the intrinsic reflectance unit) or the percent range (0 - 100). Figure 5.70 shows the graphical user interface. The input spectrum is high spectral resolution data. After specifying the first band of the sensor the resampling is performed for all spectral bands, and the result is written to an output file, again with two columns (wavelength and resampled spectrum).

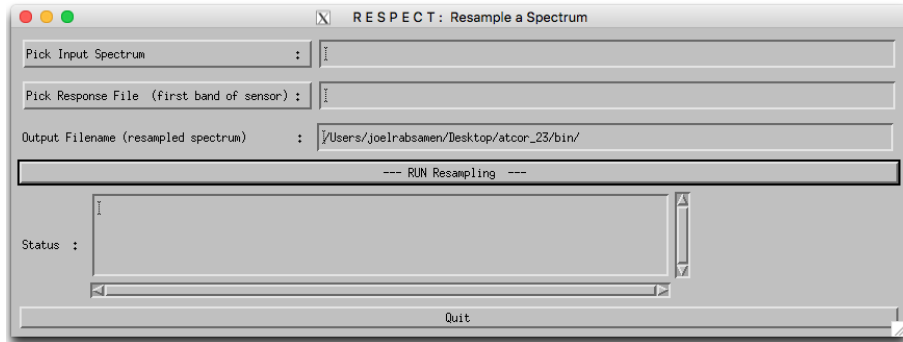


Figure 5.70: *Resampling of a (reflectance) spectrum.*

5.6.2 Low pass filter a Spectrum

This program serves to prepare target reference spectra for IFCALI inflight calibration. Unwanted spectral noise is removed by lowpass filter (i.e., spectral smoothing). It requires an ASCII file with two columns as input. The first column is wavelength (nm or μm unit), the second is reflectance, or emissivity, or something else, e.g. spectral radiance. The reflectance range can be 0 - 1 (the intrinsic reflectance unit) or the percent range (0 - 100). Figure 5.71 shows the graphical user interface. The input spectrum is high spectral resolution data. The result has the same format and dimensions as the input file.

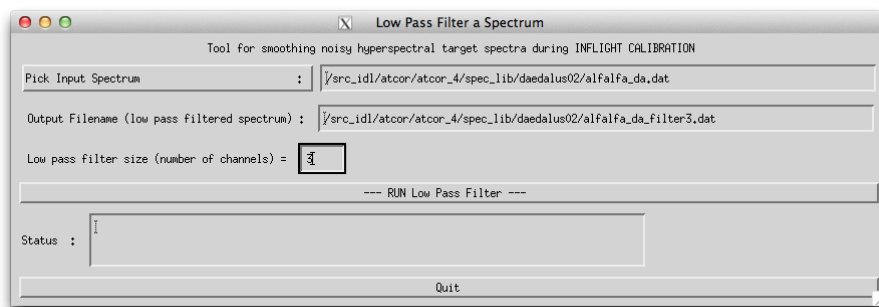


Figure 5.71: *Low pass filtering of a (reflectance) spectrum.*

5.6.3 Spectral Polishing: Statistical Filter

Remove spectral artifacts in high spectral resolution imaging spectroscopy data.

Inputs:

Input file name A hyperspectral image cube, usually the output of atmospheric correction *.atm.bsq

Sensor Spectral Response Defines the first band of the sensor response *.rsp. This field may be left empty - in that case, the wavelength information from the ENVI header is used if the wavelengths tag is properly given. if no wavelength reference is there, a spectrally equidistant succession of the spectral bands is assumed.

Note: the Savitzky-Golay filter is not wavelength-aware and uses always the assumption of equidistant, constantly increasing bands.

Number of polishing bands on each side Adjacent bands to be used for calculation on each side of the target band; e.g. factor 3 uses 7 bands for polishing (3 on each side plus central band).

Smoothing Factor smoothing applied stand alone or in combination with the derivative filter:

- 0: no smoothing
- 1: slight smoothing (filter: 1/4/1)
- 2: moderate smoothing (filter: 1/2/1)
- 3: standard smoothing (filter: 1/1/1)
- 4 and more: standard smoothing with moving average

Polishing Filter Type Four options are available for statistical spectral polishing: *Derivative Filter*: all spectral bands of the given window size are taken into account to calculate derivative used to reconstruct the value of the center band.

Neighbour Derivative: all spectral bands except for the center itself are taken into account to calculate derivative used to reconstruct the value of the center band.

Lowpass Filter: Only the smoothing is performed, no derivatives are calculated.

Savitzky-Golay: Filter to perform a numerical polynomial fit of 4th degree through the selected total window size.

Output:

A cube containing the spectrally filtered copy of the original image data cube is generated (compare Paper Earsel, SIG-IS Workshop, Edinburgh, 2011).

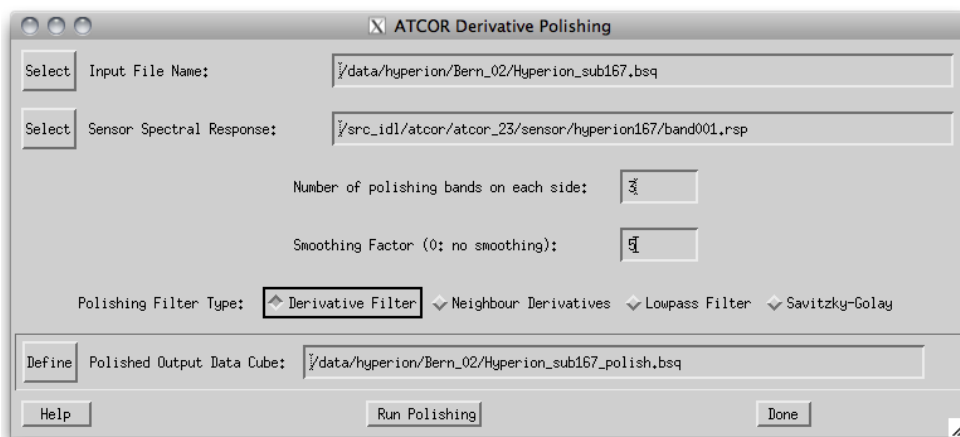


Figure 5.72: Statistical spectral polishing.

5.6.4 Spectral Polishing: Radiometric Variation

A module that was originally developed for the airborne version of ATCOR is the spectral polishing. The algorithm is only intended for hyperspectral imagery.

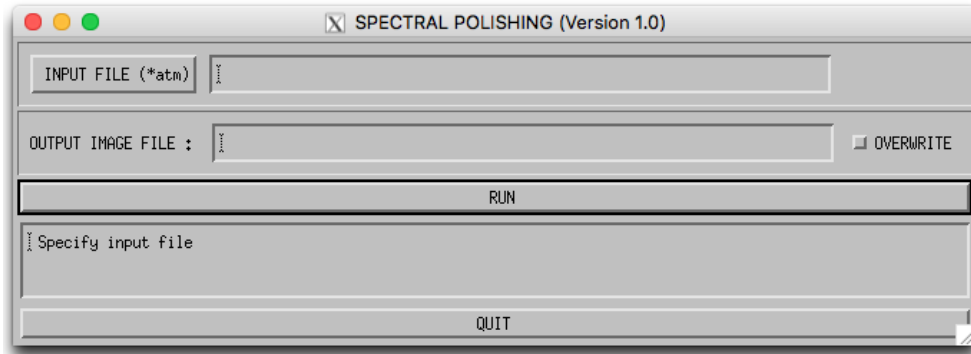


Figure 5.73: Radiometric spectral polishing.

Input to the spectral polishing program is the reflectance cube calculated with ATCOR. It employs the vegetation index ($0 < NDVI < 0.33$, $NDVI = (\rho_{NIR} - \rho_{RED})/(\rho_{NIR} + \rho_{RED})$) to mask soil pixels. A soil spectrum is a slowly varying function of wavelength, therefore a spectral smoothing will only remove spikes without disturbing the spectral shape. Then the average reflectance spectrum over all soil pixels is calculated and smoothed with a 5-channel filter except for the atmospheric water vapor regions where a linear interpolation is performed. The ratio of the filtered to the original soil spectrum is the spectral polishing function applied to all image pixels. If "xxx_atm.bsq" is the atmospherically corrected input image, then "xxx_atm_polish.bsq" is the polished output reflectance cube, and the spectral polishing function is stored in "xxx_atm_polish.dat", an ASCII file with two columns containing the center wavelength of each channel and the polishing factor. Figure 5.73 shows the GUI panel.

5.6.5 Flat Field Polishing

This routine is to remove spectral artifacts from atmospherically corrected imaging spectroscopy data. Average residual gains and offsets are calculated by comparison of assumed flat field data values to the measured values for each spectral band to find a gain correction factor. The flat field is searched automatically within an image as the spectrally least variable part of the image.



Figure 5.74: Flat field radiometric polishing.

Inputs:

Input file name (usually output of atmospheric correction `_atm.bsq`), can be any kind of image.

Type of Correction Function:

- Gain and Offset: calculate average residual gain and offset for each pixel and apply them as correction function
- Gain only: constrain the residual gain to an offset of 0; this is the typical situation.

Output:

A cube containing the spectrally filtered copy of the original image data cube is created.

5.6.6 Pushbroom Polishing / Destriping

This routine treats each detector pixel of a pushbroom imaging spectrometer separately and derives gain and optional offset values in comparison to its direct neighbors. The routine may be used for both, spectral polishing of residual gain/offset errors and for destriping of pushbroom imagery.

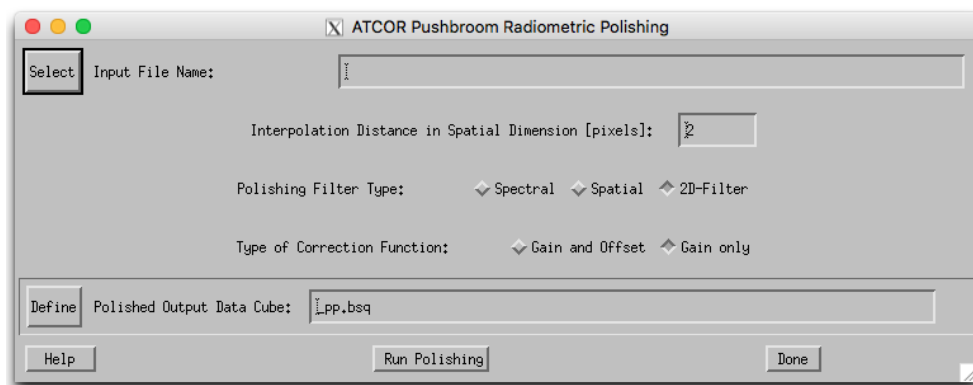


Figure 5.75: Pushbroom radiometric polishing.

Inputs:

Input file name A hyperspectral image cube, usually the output of atmospheric correction `*_atm.bsq`

Interpolation Distance Number of pixels from center pixel, i.e., a factor of 2 uses 2 pixels on each side for calculation of residual gains. The distance should be in a range of the width of visible striping artefacts.

Polishing Filter Type Three options are available for pushbroom spectral polishing: *Spectral*: Polishing is done in spectral dimension only; one adjacent band on each spectral side is taken for residual calculation.

Spatial: Only the spatial filter is applied; use this option for destriping of imagery.

2D Filter: Do both dimensions (spatial/spectral) simultaneously the filter size only applies to the spatial dimension, however..

Type of Correction Function For each detector pixel, correction parameters are generated:

Gain and Offset: Calculate average residual gain and offset for each pixel and apply them as correction function.

Gain Only: Constrain the residual gain to an offset of 0; this is the typical situation.

Output:

A cube containing the spectrally filtered copy of the original image data cube is created. As a side output, a gain file is written (name: `_gain.bsq'`), containing the following three layers: 1: offset of linear recalibration offset function

2: gain of linear recalibration offset function

3: gain of linear recalibration offset function if function is constrained to zero offset

such that the corrected spectral band is: $L_{polish} = L_{ori} - [L_{offs} + gain * L_{ori,smooth}$

5.6.7 Spectral Smile Interpolation

For sensors affected by "spectral smile" the surface reflectance cube is calculated accounting for the smile shift function in the column (across-track) direction of the detector array. The smile shift is specified as a 4th-order polynomial function, i.e. the file "*smile_poly_ord4.dat*" in the corresponding sensor folder, see chapter 4.7. Due to the smile shift the wavelength values of a spectral channel vary slightly in across-track direction. The "smile interpolation" function allows the specification of a common center wavelength for each channel. Then for each channel all pixel reflectances are interpolated to this new reference wavelength. Since the smile shift between adjacent bands does not vary significantly, a linear interpolation can be applied. If $\lambda_j(i)$ denotes the center wavelength of band i and column j, and $\rho_j(i)$ the surface reflectance of a column j pixel, then the new interpolated reflectance is

$$\rho_j^{(new)}(i, \lambda_{ref}(i)) = \rho_j(i) + \frac{(\lambda_{ref}(i) - \lambda_j(i)) (\rho_j(i+1) - \rho_j(i-1))}{\lambda_j(i+1) - \lambda_j(i-1)} \quad (5.6)$$

where $\lambda_{ref}(i)$ is the user-defined reference center wavelength for band i. There are three options for the reference wavelength grid:

1. use wavelength corresponding to the center of the detector array,
2. use average wavelength over all detector columns (per band),
3. use nominal wavelength specified in the (ENVI) header of the reflectance cube.

This tool is available in the interactive mode (main menu, then "Filter", then "*Spectral Smile Interpolation (Image Cube)*") and in the batch mode ("*smile_interp3_batch*", see chapter 6.3).

This routine is used after smile-dependent atmospheric correction. It applies a linear interpolation on the reflectance data in order to bring the spectral bands to a common reference in across track direction. The inputs are as follows (see Fig. 5.76):

Inputs:

Input Image A hyperspectral image cube, usually the output of atmospheric correction in smile mode `*_atm.bsq`

Smile polynomial file The file '*smile_poly_ord4.dat*' as of the sensor definition used for the smile-aware atmospheric correction.

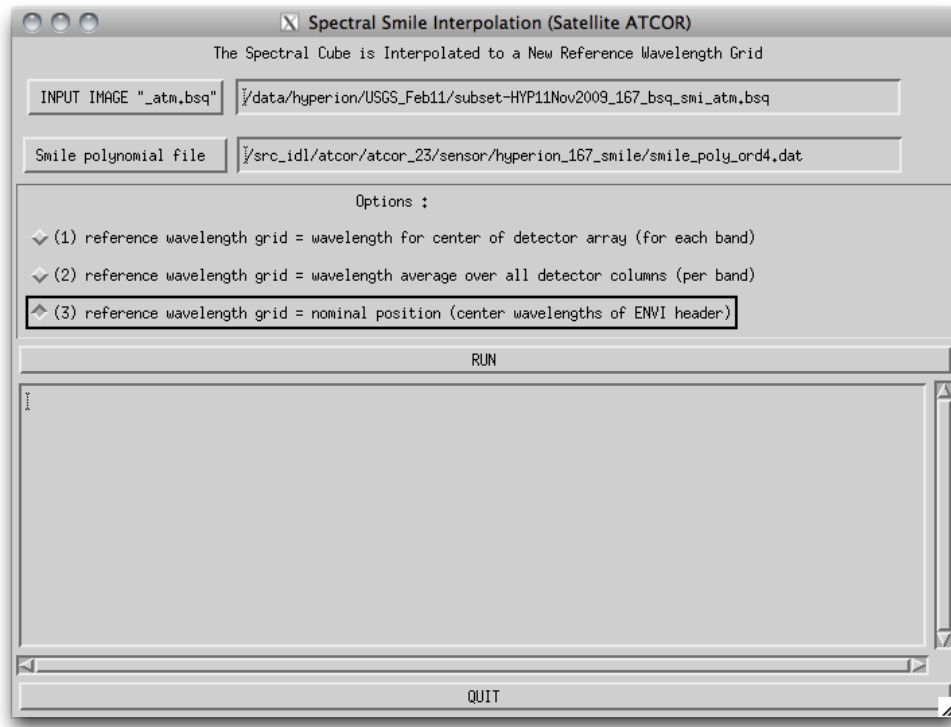


Figure 5.76: Spectral smile interpolation

Options Three options for the spectral reference wavelength grid to be used for interpolation may be selected:

center of detector array: The spectral position of the center pixel in across track direction of the detector is taken as the reference wavelength for each spectral band.

average over all detector columns: For each spectral band, the average of all (smiled) center wavelengths is calculated and used as the new reference wavelength.

nominal position (ENVI header) the nominal position as provided in the ENVI header file is taken as the reference.

Output:

A cube containing the spectrally interpolated image data is generated and the ENVI header is updated (for options 1 and 2).

5.6.8 Cast Shadow Border Removal

This routine is used after cast shadow correction in case the borders of the shadows show dark or bright artifacts. It corrects the imagery by adjusting the brightness to the direct neighbor pixels. Using the illumination file, all pixels at the cast shadow borders are first identified and a buffer along the borders is calculated using the border width. Secondly, a brightness correction factor is calculated for each pixel in the border lines using the relative brightness in comparison to its neighbours. The pixels are then corrected using this relative difference in a multiplicative way.

The inputs are as follows (see Fig. 5.76):

Inputs:

Input File A hyperspectral image cube, usually the output of atmospheric correction *_atm.bsq

Illumination/Cast Shadow File illumination file containing a shadow mask which had been applied to the image during atmospheric correction.

Options Two options for alternate processing are available (try those in case the artifacts are not well removed):

adjust spectral mean: An average additional correction factor is applied to the border pixels in order to correct for spectral variation of the brightness difference.

Interpolate Borders: The border pixels are interpolated from their neighbours, overwriting the original values.

Shadow Border Width: the width of the border to be corrected/interpolated..

Output:

A cube containing the filtered image data is generated and the ENVI header is copied to the new file.

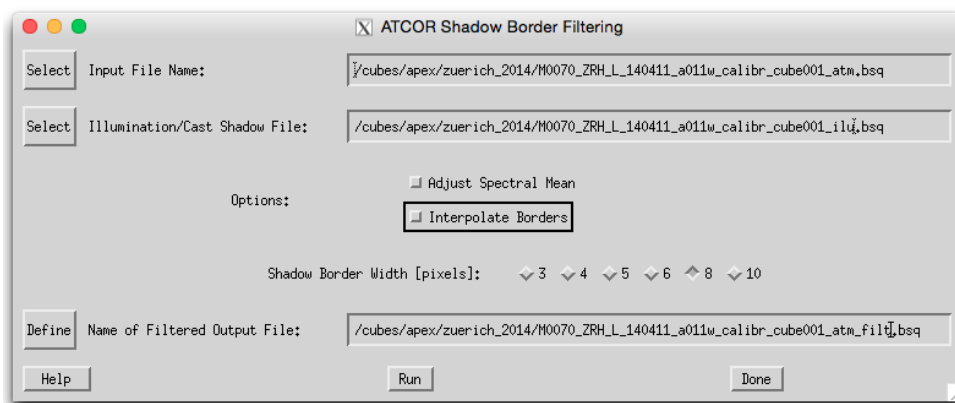


Figure 5.77: Shadow border removal tool

5.7 Menu: Simulation

The "Simulation" menu provides programs for the simulation of at-sensor radiance scenes based on surface reflectance (or emissivity and temperature) images.

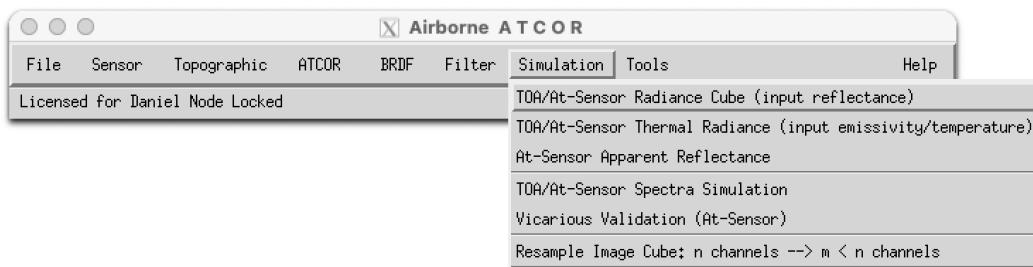


Figure 5.78: Simulation modules menu.

5.7.1 TOA/At-Sensor Radiance Cube

This routine 'toarad' calculates an At-Sensor Radiance Cube from a surface reflectance image cube. All parameters used for the processing are taken from the 'example.inn' file of the input cube 'example.bsq'. After the ATCOR run the name of the reflectance cube is 'example_atm.bsq'. If 'toarad' is called, the reflectance cube is opened, the 'example.inn' file is read, and the corresponding TOA / at-sensor radiance cube 'example_toarad.bsq' is calculated. If the adjacency range in the 'example.inn' is greater than zero, then the adjacency effect is included. If 'toarad' is executed as a batch job, the IDL command line should specify the reflectance cube and at least one of the simulation parameters, e.g.

- toarad, input='/data1/example_atm.bsq', vza=30, sname='vza30'

The output file is 'example_toarad_vza30.bsq'. All processing parameters are taken from the corresponding '/data1/example.inn', however, some can be overwritten with keywords. Valid keywords are:

- sz: solar zenith angle (degr.)
- vza: off-nadir view zenith angle (deg.)
- vis: visibility (km)
- elev: average ground elevation (km), only used if the .inn file contains no DEM files
- atmf: e.g., water vapor LUT atmf='h99000_wv10_rura' OR atmf='h99000_wv40_rura', sea level water vapor column wv=1.0 (cm) or wv=4.0 (cm). It specifies the atmospheric LUT. If no name is given, then the LUT in the ".inn" file is taken.
- sname: user-specified string, e.g., if vza=30, sname='vza30_wv40', to identify the simulation case in the output file name. In this case the output file will be 'example_toarad_vza30_wv40.bsq'. An empty string is allowed, but then every simulation overwrites the previous simulation.
- sa: solar azimuth angle (degr.) , less important, only available for a batch job

- vaa: view azimuth angle (deg.) , only for a batch job

The list of keywords can be obtained by typing 'toarad' (without parameters) on the IDL command line.

This module can also be started from the ATCOR GUI, 'Simulation', next button 'TOA/At-Sensor Radiance Cube (input reflectance)'. Then a reflectance cube 'scene_atm.bsq' has to be specified and the simulation parameters.

5.7.2 At-Sensor Apparent Reflectance

This routine calculates an at-sensor apparent reflectance from a calibrated at-sensor radiance image cube. This routines alculates for each image band the following output:

$$\rho_{app} = (DN * c_1 + c_0) * \pi * d^2 / (E_0 * \cos(\theta_0)) \quad (5.7)$$

where:

DN : stored data values

c_1 : gain for conversion of DN to at sensor radiance

c_0 : offset for conversion to at sensor radiance

d : relative sun-earth distance (average:d=1)

E_0 : solar irradiance, top of atmosphere (NOT at aircraft altitude)

θ_0 : solar zenith angle

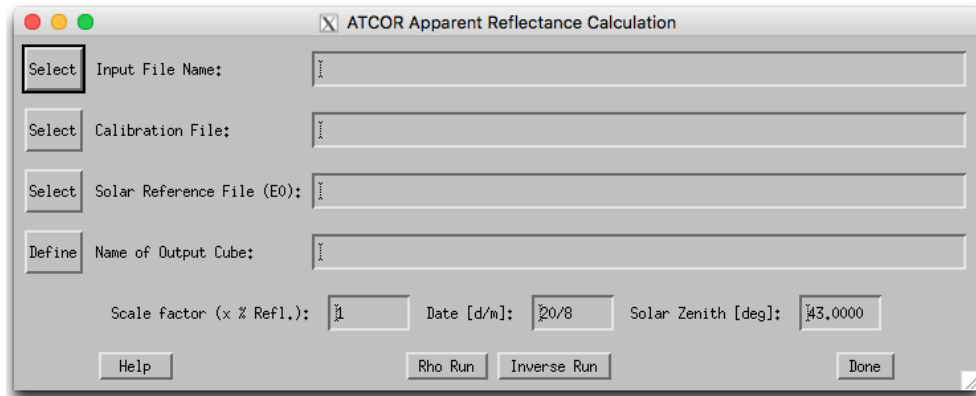


Figure 5.79: Apparent Reflectance Calculation

Inputs:

- input file name
- calibration file name (*.cal)
- solar radiation file (e0_solar_*.spc)
- output file name
- scale factor (see below)

- date of the year, given exactly as 'day/month', eg. 26/7 for July, 26th, used for sun-earth distance calculation
- solar zenith angle (use 'Tools : Solar Zenith and Azimuth' for its calculation)

Output: A cube containing the scaled apparent reflectance in [%] is stored. The data format is driven by the scaling factor as follows:

- scale < 10 : byte
- scale >= 10 : integer
- scale >= 500: unsigned integer
- scale <= 1. : floating point (effective value, unit: [%]) (wavelength reference and FWHM are taken from the file e0_solar_*.spc)

5.7.3 TOA/At-Sensor Spectra Simulation

This routine allows to calculate at sensor signals from spectral measurements of bottom of atmosphere reflectance under consideration of irradiance measurements.

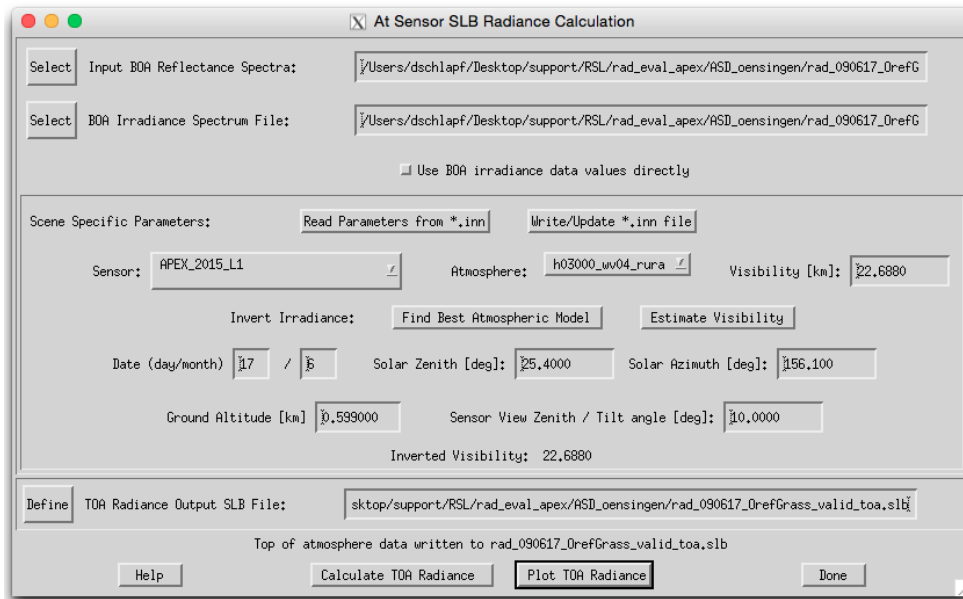


Figure 5.80: TOA radiance calculation from ground reference reflectance spectral library

Inputs:

- BOA Reflectance Spectra:
ENVI spectral library containing the bottom of atmosphere reflectance. All spectra in the file are used for TOA Radiance calculation

- BOA iWhite Reference Radiance:
ENVI spectral library containing the irradiance on the ground in $W/(m^2 \text{ sr nm})$
- Option: Use BOA irradiance data values directly: for TOA radiance calculation, one may use the BOA irradiance instead of modeled irradiance.

Scene Specific Parameters:

The parameter may be read from an ATCOR *.inn file as far as they are available.

- Buttons:
Read Parameters from *.inn: opens the corresponding *.inn file and sets all parameters for the simulation.
Write/Update *.inn file: reads the parameters from the GUI and updates the respective parameters to a new/updated *.inn file.
- Sensor: current sensor definition (directory name)
- Atmosphere: current atmospheric file (for ATCOR-4: be aware to select the correct flight altitude)
- Visibility: current visibility.
- Date, Solar Zenith, Azimuth, and Ground Altitude, should be entered. The values are read from the *.inn file if available.
- Sensor View Zenith: this value is to be entered manually; zero degrees corresponds to nadir view.
- TOA Radiance Output SLB File:
Output file containing the TOA radiance data for each spectrum in spectral library.

Actions: Upon availability of irradiance spectra, the atmospheric parameters may be inverted from the irradiance spectra (first two actions):

Find Best Atmospheric Model searches for the applicable atmospheric file (i.e. aerosol model and water vapor content)

Estimate Visibility searches for the best visibility fitting to the irradiance spectrum.

Calculate TOA Radiance Performs the calculation and creates the output library.

Plot TOA Radiance Starts the internal spectral library viewer for plotting the outputs.

Outputs: Output File: An ENVI spectral library file is written which contains all spectra as of the input file transformed to at-sensor radiance. all relevant information is written to the ENVI file header.

Note: Use the tool *Simulation: Vicarious Validation (At-Sensor)* for validation of the such created spectral libraries in comparison to the ENVI at-sensor radiance imagery.

5.7.4 Vicarious Validation (At-Sensor)

This routine allows to validate imagery in comparison to simulated at-sensor radiance spectra.

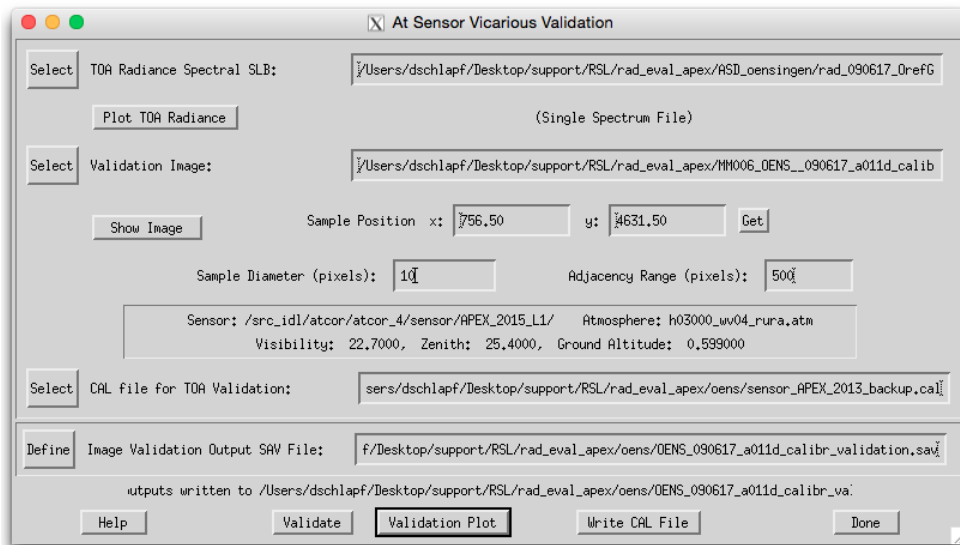


Figure 5.81: TOA radiance validation against calibrated image spectra

Inputs:

- Validation Image: Calibrated at sensor radiance image (ATCOR input image) to be used for cross validation
 - using the button 'Show Image' starts an image display of the currently selected image file.
- Sample Position: Coordinates of sample spectrum in image (may be either pixel coordinates or geographic coordinates)
 - using the 'Get' button transfers the position coordinates from the ATCOR file viewer (after 'Push' has been pressed there).
- Sample Diameter: diameter of square sample in pixels around the sample position (uneven numbers). Statistics for the validation are taken from this sample. NOTE: the sample size should be at least 3x3 clean pixels; this means that the total size of the target should be at least 7x7 pixels (compare [91]).
- Adjacency Range: The adjacency range is given in image pixels. The default is the adjacency range in km divided by the standard pixel size.
- TOA Radiance SLB: ENVI spectral library containing the TOA of atmosphere radiance (as created by the tool 'Simulation:TOA Radiance')
 - using the button 'Plot TOA Radiance' allows to plot the currently selected file
- Parameters: sensor, atmosphere, visibility, solar zenith, and ground altitude are read from slb ENVI header at first. If selecting an image file; the values are read from the *.inn file if available.
- CAL file for TOA Validation: This file can be selected, specifically for analysis using the 'Validation Plot' tool.

- **Image Validation Output SAV File:** Name of IDL save dump to be created containing all validation information. In parallel, an ASCII *.txt file is created containing the relevant data.

Actions:

Validate Calculates both the validation spectra including adjacency correction and writes an ascii report of the calculations.

Validation Plot Creates a plot of the sample statistics and the corresponding reference spectrum, scaled by the parameters from the currently selected *.cal file.

Write CAL File Lets you select a number of validation output files and will create a new *.cal file by linear regression of image data to simulated data for all selected files.

Outputs: Output File: an idl save dump is written upon pressing the 'Validate' button; in parallel a validation report with all spectra is written named [out]_eval.txt. The calibration reports may be used for derivation of CAL file by linear regression.

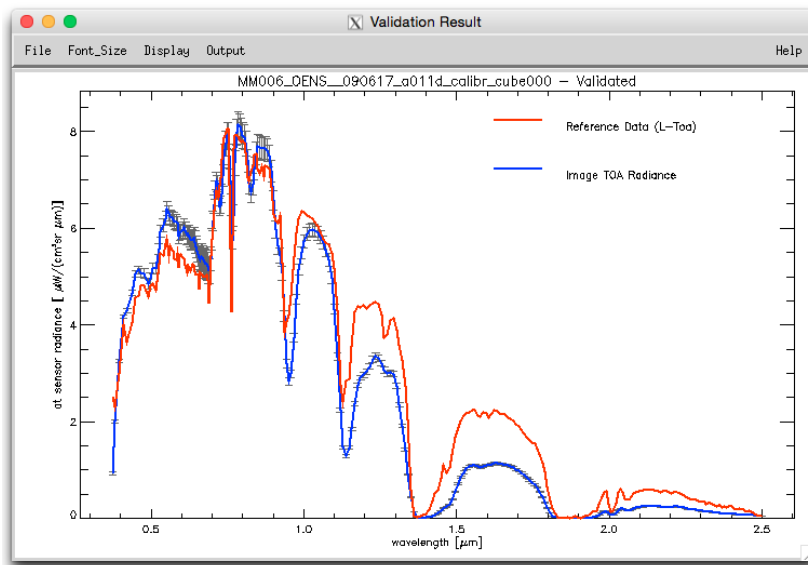


Figure 5.82: Plot sample of validation against calibrated image spectra

5.7.5 Resample Image Cube

This routine allows to simulate a multispectral image from imaging spectroscopy data. A detailed description of this routine is given in chapter 7.

5.8 Menu: Tools

The "Tools" menu contains a collection of useful routines such as the calculation of the solar zenith and azimuth angles, spectral classification, nadir normalization for wide field-of-view imagery, adding of a synthetic blue channel for multispectral sensors with a blue band (e.g. SPOT) which is done for the atmospherically corrected surface reflectance image, spectral calibration, conversion of the monochromatic atmospheric database from one to another solar irradiance spectrum, and BIL to BSQ conversion.

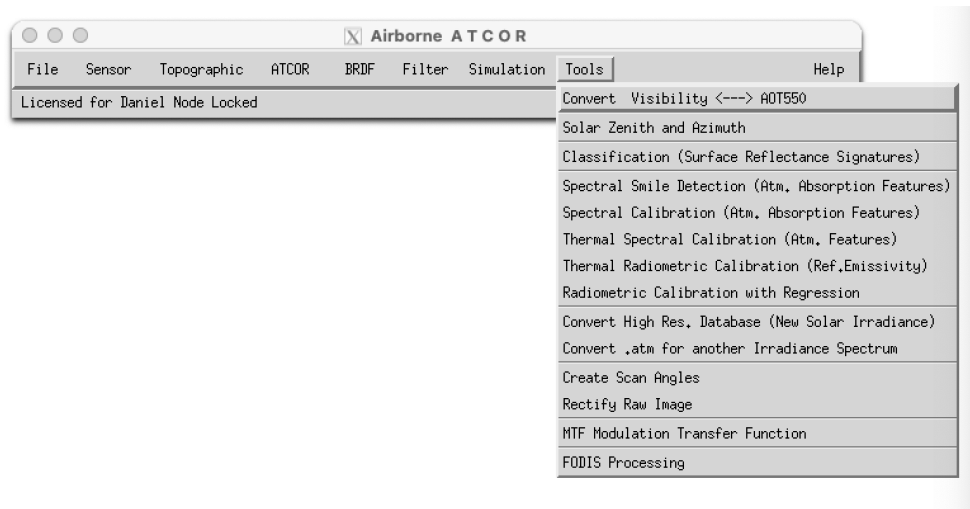


Figure 5.83: The tools menu.

5.8.1 Convert Visibility \longleftrightarrow AOT550

This tool provides simple conversion from Visibility in Kilometer to AOT (550nm) and vice-versa. Further it takes an input specifying the elevation above sea level in Kilometer.

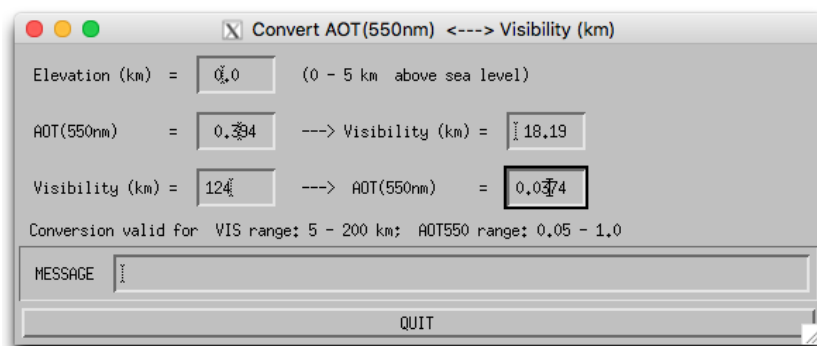


Figure 5.84: Visibility conversion.

5.8.2 Solar Zenith and Azimuth

The routine SOLAR_GEOMETRY is used to calculate the zenith and azimuth angle for the image location and acquisition time. All explanations concerning the definition of angles are included in the panel (Fig. 5.85).

Figure 5.85: Calculation of sun angles.

5.8.3 Classification of Surface Reflectance Signatures

The spectral classification (SPECL) is a hierarchical classifier based on surface reflectance data employing the Landsat Thematic Mapper (TM) wavelengths. It is not a land use classification, but a classification into certain spectral categories, e.g. dark and bright bare soil, and different vegetation classes, see figure 5.86. The following set of rules is used where b_1 , b_2 , b_3 , b_4 , b_5 and b_7 indicate the surface reflectance in the TM bands 0.48, 0.56, 0.66, 0.84, 1.65, 2.2 μm , respectively, or the nearest corresponding channel:

- snow: $b_4/b_3 \leq 1.3$ and $b_3 \geq 0.2$ and $b_5 \leq 0.12$
- cloud: $b_4 \geq 0.25$ and $0.85 \leq b_1/b_4 \leq 1.15$ and $b_4/b_5 \geq 0.9$ and $b_5 \geq 0.2$
- bright bare soil: $b_4 \geq 0.15$ and $1.3 \leq b_4/b_3 \leq 3.0$
- dark bare soil: $b_4 \geq 0.15$ and $1.3 \leq b_4/b_3 \leq 3.0$ and $b_2 \leq 0.10$
- average vegetation: $b_4/b_3 \geq 3.0$ and $(b_2/b_3 \geq 0.8$ or $b_3 \leq 0.15)$ and $0.28 \leq b_4 \leq 0.45$
- bright vegetation: $b_4/b_3 \geq 3.0$ and $(b_2/b_3 \geq 0.8$ or $b_3 \leq 0.15)$ and $b_4 \geq 0.45$
- dark vegetation: $b_4/b_3 \geq 3.0$ and $(b_2/b_3 \geq 0.8$ or $b_3 \leq 0.15)$ and $b_3 \leq 0.08$ and $b_4 \leq 0.28$
- yellow vegetation: $b_4/b_3 \geq 2.0$ and $b_2 \geq b_3$ and $b_3 \geq 0.08$ and $b_4/b_5 \geq 1.5$
- mix veg/soil: $2.0 \leq b_4/b_3 \leq 3.0$ and $0.05 \leq b_3 \leq 0.15$ and $b_4 \geq 0.15$
- asphalt/dark sand: $b_4/b_3 \leq 1.6$ and $0.05 \leq b_3 \leq 0.20$ and $0.05 \leq b_4 \leq 0.20$ and $0.05 \leq b_5 \leq 0.25$ and $b_5/b_4 \geq 0.7$

- sand/bare soil/cloud: $b_4/b_3 \leq 2.0$ and $b_4 \geq 0.15$ and $b_5 \geq 0.15$
- bright sand/bare soil/cloud: $b_4/b_3 \leq 2.0$ and $b_4 \geq 0.15$ and ($b_4 \geq 0.25$ or $b_5 \geq 0.30$)
- dry vegetation/soil: ($1.7 \leq b_4/b_3 \leq 2.0$ and $b_4 \geq 0.25$) or ($1.4 \leq b_4/b_3 \leq 2.0$ and $b_7/b_5 \leq 0.83$)
- sparse vegetation/soil: ($1.4 \leq b_4/b_3 \leq 1.7$ and $b_4 \geq 0.25$) or ($1.4 \leq b_4/b_3 \leq 2.0$ and $b_7/b_5 \leq 0.83$ and $b_5/b_4 \geq 1.2$)
- turbid water: $b_4 \leq 0.11$ and $b_5 \leq 0.05$
- clear water: $b_4 \leq 0.02$ and $b_5 \leq 0.02$
- clear water over sand: $b_3 \geq 0.02$ and $b_3 \geq b_4 + 0.005$ and $b_5 \leq 0.02$

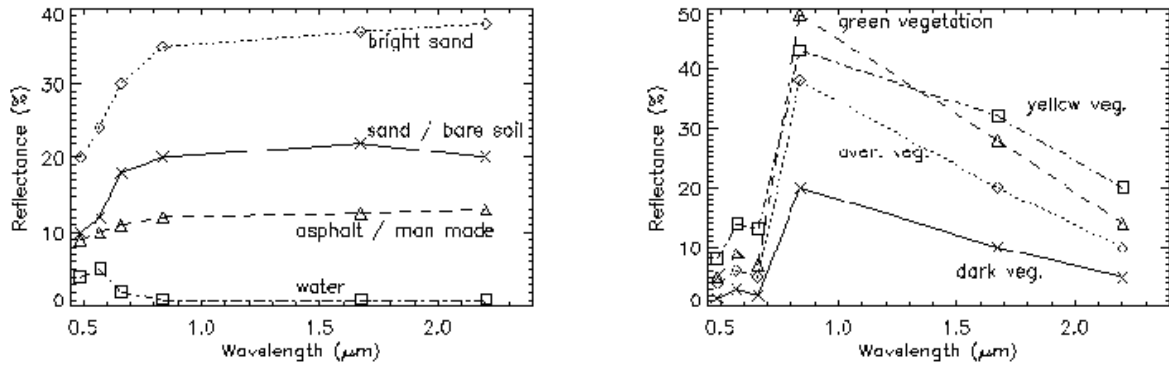


Figure 5.86: Examples of reflectance spectra and associated classes.

Figures 5.87, 5.88 show the panel of the SPECL program and a sample output. When the button "emissivity classes" is selected, the emissivity classes are assigned the emissivity values as defined in file "emissivity.dat" in the atcor4 directory (compare ATBD). So this file can be edited to modify the emissivity values for the 15 classes.

5.8.4 Spectral Smile Detection

This routine uses sharp atmospheric absorption features and Fraunhofer lines for inflight smile (i.e., spectral across-track non-uniformity) detection. The calculation is done by correlation analysis of a number of spectral bands in the vicinity of selected absorption features. The outputs may be used for smile-aware atmospheric correction.

Initially, the smile characterization for each spectrometer channel is derived from laboratory measurements. From such data, the wavelength shift with respect to the center pixel of the detector array can be parametrized using a 4th order polynomial fit. However, in case of instrument changes during the mission, a spectral re-calibration might be necessary from the image data or from on-board calibration facilities using well-defined absorption features. Onboard spectral calibration devices such as interference or rare earth filters would be well suited for this purpose. However, such devices are often not available in sensor systems. Therefore, atmospheric gas absorption features or solar Fraunhofer lines have to be taken as a reference from the imagery itself. The processing steps are:

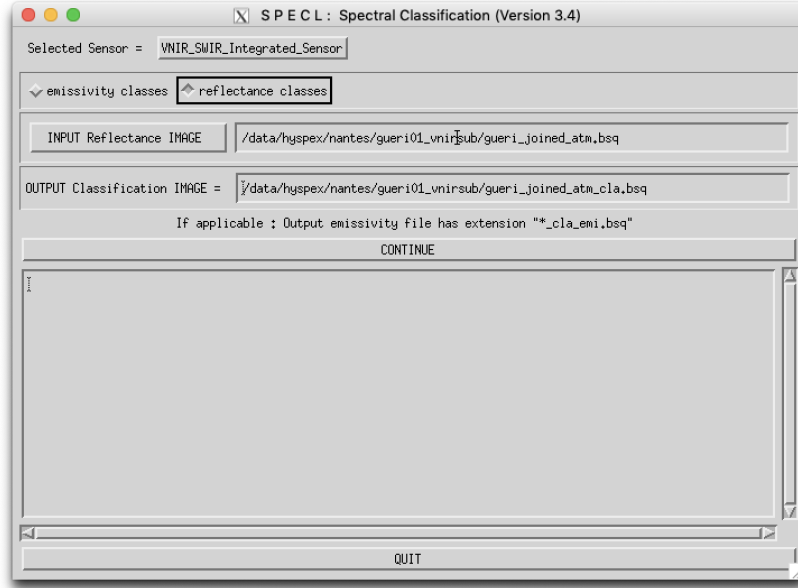


Figure 5.87: *SPECL: spectral classification of reflectance cube.*

1. A calibrated image is averaged in along track direction, leading to a signature image of the size of the detector array.
2. The surface reflectance is calculated (atmospheric correction) and smoothed.
3. The spectral bands within the spectral matching range are selected.
4. Spectral shifts with intervals between 0.01-0.05 nm are calculated and applied to the selected spectral band response functions.
5. An appropriate pre-calculated fine-spectral resolution atmospheric LUT is selected which serves for the calculation of at-sensor radiance values for the series of spectrally shifted response functions using the surface reflectance spectrum from step (2).
6. The derived spectral signatures are then correlated to the observed column-averaged signal in the image, such that the best fitting spectral shift $\Delta\lambda_j = \Delta_j$ can be found for each image column j , i.e., the Δ_j with the highest Pearson's correlation coefficient is selected. This is equivalent to minimizing the merit function

$$\chi^2(\Delta_j) = \sum_{\Delta_j = \lambda_k - 5nm}^{\lambda_k + 5nm} [L_I(j, k) - L_R(\lambda_k + \Delta_j, k)]^2, \quad (5.8)$$

where $L_I(j, k)$ is the average at-sensor radiance of the image for column j and channel k , and $L_R(\lambda_k + \Delta_j, k)$ is the corresponding reference radiance for a wavelength shift Δ_j within a 5 nm interval around λ_k . By using the continuum removed scaled radiances, the stability of the routine is enhanced.

7. A 4th order polynomial is fitted through the calculated spectral points and the respective polynomial parameters of eq. 4.1 are stored.



Figure 5.88: *Example of classification with SPECL.*

Left: true color image of HyMap, right: result of classification.

8. The polynomial parameters are interpolated and optionally extrapolated to all other bands within the same detector or spectrometer unit. Optionally, the polynomial coefficients can be set to zero in atmospheric absorption regions to expedite the processing.

The same approach is used for FWHM detection, with the difference that not the position of the spectral bands is varied, but the FWHM of the spectral bands is scaled in a systematic way. Once the coefficients have been determined, they are converted into the required file format and are placed in the respective sensor folder for a subsequent fully automatic radiometric and atmospheric processing. Fig. 5.89 shows the panel of the smile detection module.

Inputs:

Input file : calibrated ENVI image file. The file should be statistically as uniform as possible in order to get valid averages.

Atmospheric Database File: non-resampled atmospheric database file most appropriate for the selected image; take care of the flight altitude and aerosol model.

Sensor spectral response: First band of sensor spectral response file(s) *.rsp. The corresponding pressure definition file (pressure.dat) is selected automatically from the same directory as the *.rsp files, if available.

Output smile coefficients: file name of ASCII file which is written and contains the 4th order polynomial coefficients. This file may be copied to the sensor definition as 'smile_poly_ord4.dat' for use as smile definition with a sensor.

Detection resolution: finest spectral resolution used for correlation analysis - results will be resolved by this resolution.

Search range: maximum total spectral range used for smile detection (ie., 20 nm is ± 10 nm search distance). For FWHM detection, it is the maximum factor to be applied. A factor of 2, e.g. means to search between FWHM scaling from 0.5 to 2.

Band range: bands which shall be used for smile detection and for which the coefficients are written to the output file.

Split band: First band of second detector for sensor having more than one detector (starting numbering at 1). NOTE: for imagers with more than two detector it is recommended to derive the smile separately for each detector to avoid artefacts in the transition range.

Visibility: horizontal visibility as of modtran conventions [km]

Solar Zenith: angle measured from zenith to sun

Mean Ground Elevation: Ground altitude in km.

Flight Altitude: in km a.s.l.

Feature wavelength: 15 selectable features used for smile detection. the per-band smile is interpolated from these feature wavelengths.

Interpolation type: interpolation used to expand the feature wavelength results to all spectral bands

Extrapolation type: specifies how the bands outside of the selected features are treated. Repeat: repeats the last value toward the borders. 'to zero': gradually decrease to zero at border of detector.

Actions:

Detect Smile The module will perform the smile detection calculation.

Detect FWHM The FWHM variations are calculated instead of smile variations by the same technique.

Plot Smile Starts a plotting window to check the smile and lets you select suitable features for calibration.

Save Report Saves an informational report about the smile detection.

Outputs:

An ASCII-file which may be used as smile (or FWHM) description file in the respective sensor directory. Note that this file should be named *"smile_poly_ord4.dat"* or *"smile_poly_ord4_fwhm.dat"* in order to be automatically recognized by ATCOR.

As a side output, an IDL save dump (*.sav) is written in parallel which contains all used parameters and the effectively calculated smile results in array *"smileresult(4,ncols,12)"*. Here the first dimension (4) contains the center wavelength (nm), smile shift (nm), atmospheric transmittance, and correlation coefficient. The second dimension (ncols) refers to the number of image columns, and the last dimension (12) contains results for the 12 feature wavelengths. For example, the center wavelengths for all across-track pixels and the 760 nm feature are stored in *smileresult[0,*,2]*, because this feature is the third one and IDL arrays start with index 0.

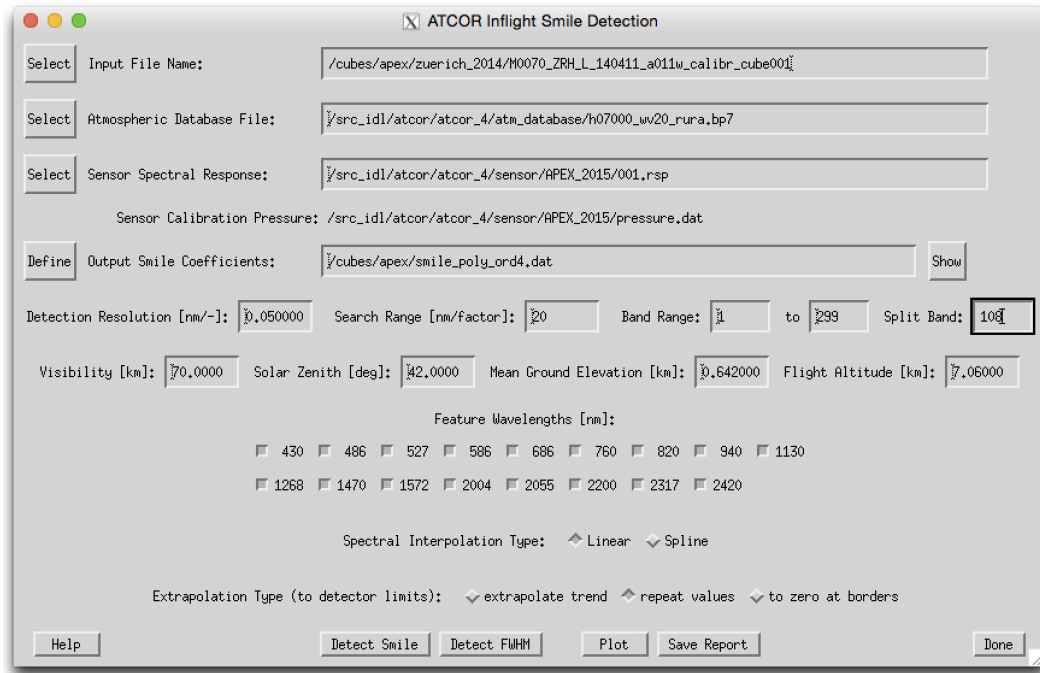


Figure 5.89: Spectral smile detection

5.8.5 Spectral Calibration (Atm. Absorption Features)

The program (SPECTRAL_CAL) is only intended for hyperspectral sensors and employs atmospheric absorption features to detect and remove possible wavelength calibration errors (see the details about spectral calibration in the ATCOR ATBD [106]). For this purpose, a certain number of target spectra have to be selected in the SPECTRA module.

NOTE: Alternatively to this routine, the spectral calibration can be done by first using the spectral smile detection routine (see section 5.8.4) and then applying the shift to the sensor as described in section 5.2.4.

Input to the spectral calibration module are the DN spectra of selected fields saved as ASCII files in the SPECTRA module by pressing the button "Save last spectrum". The files should be numbered consecutively, starting with a name such as "location_target1", without extension. The next target has to be named "location_target2" etc. For each target field three files will be generated, for example:

- "location_target1.dat" : contains surface reflectance spectrum,
- "location_target1.txt" : contains target coordinates, and processing parameters (visibility, water vapor column, etc.),
- "location_target1_dn1.dat" : contains the DN spectrum.

For a given location (scene) up to 9 targets can be extracted and used for the spectral calibration. The geometry, scene visibility and average water vapor content of the targets enter as parameters to the spectral calibration, see Fig. 5.90. The water vapor content has to be averaged from the values found in the "location_target*.txt" files. The first target DN file has to be selected by the user, the remaining target files are automatically found provided the nomenclature with a consecutive numbering is applied. The result of the spectral calibration are files with the spectral shifts per

spectrometer and the new center wavelengths of all channels. The spectral bandwidth of channels is not modified.

The DN spectra will be employed in an optimization procedure that minimizes the spikes of the derived surface reflectance spectra in the atmospheric absorption regions.

The first target DN file has to be entered at the top left button of the GUI panel (Figure 5.90). The other target files are automatically searched and employed if the targets are numbered continuously as described above. Further input data are the sensor definition, the range of bands per spectrometer, solar geometry and atmospheric parameters. Output is a file with the spectral channel center wavelength shifts per spectrometer, and a new wavelength file containing the updated wavelengths for each channel.

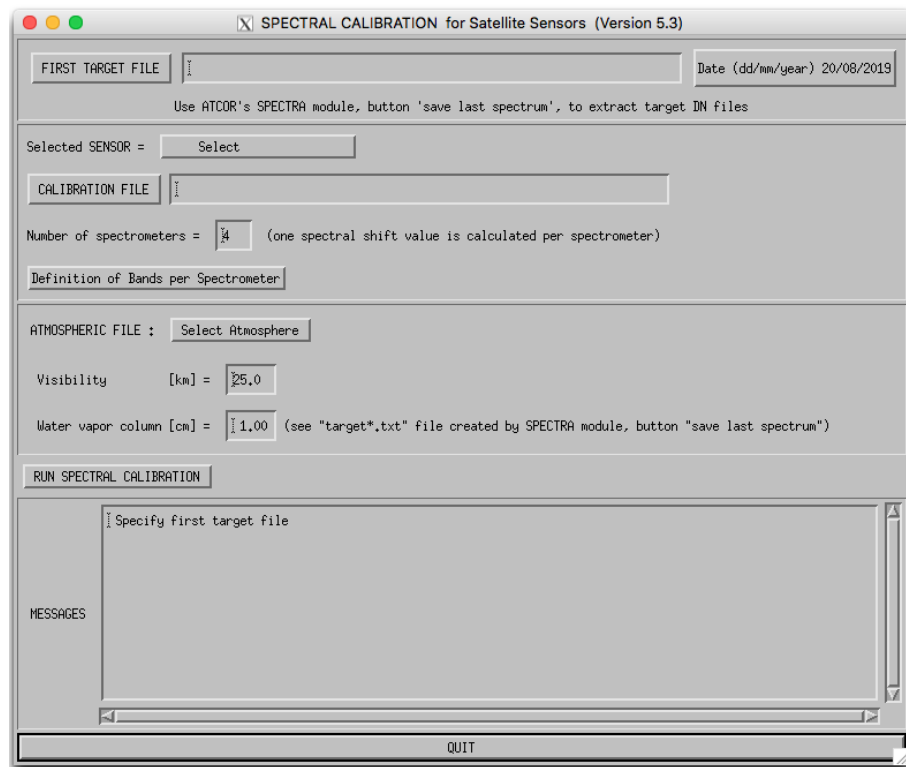


Figure 5.90: *SPECTRAL-CAL.: spectral calibration*

The results of the spectral shift are summarized in a file *"spectral_calibration_results*.txt"* where the wavelength shift is listed for each spectrometer and each target. The final shift is taken as the average of all target wavelength shifts. In addition, a new wavelength file *"sensor_new.wvl"* is created containing the channel center wavelengths and the FWHMs (bandwidth as full width at half maximum). A copy of the original radiometric calibration file (e.g., *"xxx.cal"*) is provided for convenience (e.g., *"xxx_new.cal"*) which contains the original radiometric calibration coefficients and the updated channel center wavelengths.

In case of originally non-Gaussian filter curves, the output FWHM values of *"sensor_new.wvl"* represent the equivalent Gaussian FWHM values, even though the spectral re-calibration is based on the original (non-Gaussian) filter curves. The corresponding sensor with the new spectral calibration has to be added to the list of existing sensors (see chapter 4.6) to process imagery

with the updated spectral calibration. In case of non-Gaussian filter curves, the original channel response files ("*band*.rsp*") should be copied to the new sensor directory applying the appropriate wavelength shifts. For sensors with Gaussian filter curves the '*gauss_rsp*' module (see chapter 5) can be applied to the "*sensor_new.wvl*" file to generate the corresponding "*band*.rsp*" files. Note that a change of the spectral calibration usually requires a radiometric re-calibration.

5.8.6 Radiometric Calibration with Regression

This routine employs the "**.rdn*" files obtained during the single-target calibration (the "*c1*" option" of ATCOR's calibration module to create a calibration file by rlinear regression.

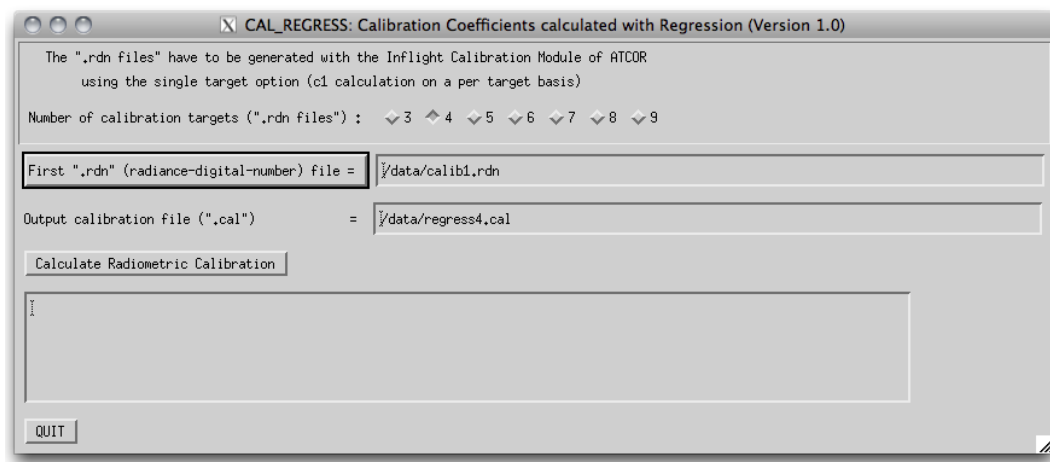


Figure 5.91: *CAL_REGRESS.: radiometric calibration with more than one target*

So for $n > 2$ the single-target calibration is to be performed n times and the resulting "**.rdn*" files (radiance versus digital number) are offered as input to the "*cal_regress*" program.

Inputs:

Number of calibration targets: A maximum of 9 calibration targets may be selected. The files **.rdn* should having been calculated beforehand and the need to be calculated consecutively, e.g., *calib1.rdn*, *calib2.rdn*, ...

First **.rdn* file: Name of the first **.rdn* file of the series to be used for regression

Output Name" Name of the calibration output to be created.

Output: The output of this program is an ASCII file "*name.cal*" with three columns (center wavelength, c_0 , c_1) where "*name*" is specified by the user.

Note: If several calibration targets are employed, care should be taken to select targets without spectral intersections, since calibration values at intersection bands are not reliable. If intersections of spectra cannot be avoided, a larger number of spectra should be used, if possible, to increase the reliability of the calibration.

5.8.7 Thermal Spectral Calibration (Atm. Features)

This program is intended for hyperspectral thermal sensors and employs atmospheric absorption features to detect and remove possible wavelength calibration errors. It is the counterpart to the spectral calibration in the solar reflective region. At least 20 channels in the 8.5 - 13.5 μm region are required.

Input to the thermal spectral calibration module is the original (non-geocoded) scene and its '*.inn' file from which the necessary parameters (sensor name, atmospheric LUTs etc) are taken. Then 10 spectra are evaluated from 10 image lines located at the image center (nadir) and the corresponding wavelength shifts are calculated for the specified surface temperature range. In addition, an averaging pixel box size can be specified to reduce noise.

Figure 5.92 presents the interactive GUI. Output is a file with the new shifted channel center wavelengths. This feature is also available for batch processing ('sp_calth'), see chapter 6.3.

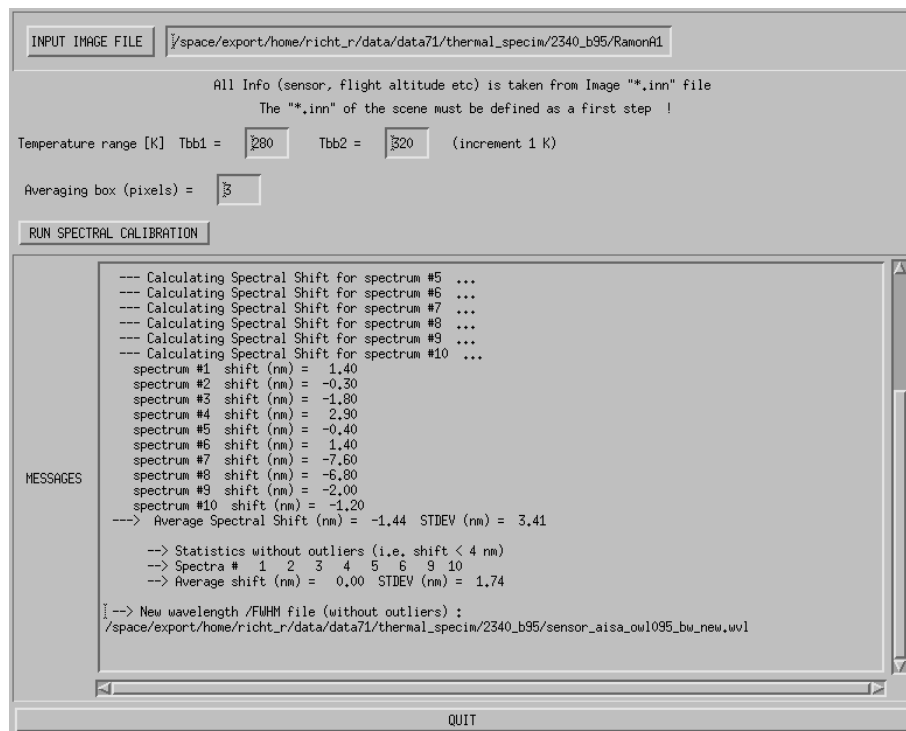


Figure 5.92: Thermal Spectral Calibration

Another module provides the capability of radiometric calibration for thermal band imagery ('thermalcal') if the scene contains water bodies. In this case the theoretical spectral water emissivity is used and the user has to specify the file name of the input scene, the water target pixel coordinates (xpos, ypos) and the box size. Output is the new calibration gain (c1), assuming that the offset (c0) is zero for all bands, see chapter 6.3.

A related subject is the estimation of the water vapor column from purely hyperspectral imagery. Here the water vapor is estimated by automatically selecting 10 pixel spectra from the scene covering a temperature interval (Tmin, Tmax), but avoiding extreme temperatures. Then the difference between measured and simulated at-sensor radiance spectra for these 10 pixels is calculated and the water vapor LUT which minimizes the difference is recommended for the processing, see chapter

6.3.

5.8.8 Thermal Radiometric Calibration (Emissivity Reference Spectrum)

This program is intended for hyperspectral thermal sensors with at least 30 thermal bands. The radiometric calibration is performed with a user-supplied reference emissivity spectrum (ASCII file with 2 columns, wavelength in μm vs emissivity). If no user emissivity file is given, then a water body is assumed, and a high spectral resolution water emissivity is stored in `'eps_water_7-14um.dat'` in the ATCOR4 folder. The water emissivity is automatically resampled with the channel spectral response functions. A user-supplied emissivity should (i) cover the spectral range of the image, and (ii) either match the number of image bands or should have a much finer spectral resolution to allow resampling with the channel response functions.

The input image should have the original sensor geometry and all parameters not specified in the graphical user interface (GUI) are taken from the image `'*.inn'` file. The GUI parameters are the target pixel coordinates (xpos, ypos), the box size, and optionally the scene average water vapor column. The latter parameter can be left out, in which case it is calculated from the image using the original calibration file and the other parameters in the `'*.inn'` file. This option is only recommended if the original radiometric calibration is reasonably accurate.

Figure 5.93 presents the interactive GUI. Output is the new radiometric calibration file, which can subsequently be updated in the `'*.inn'` file for the following ATCOR processing.

This module calculates the radiometric gain (c1) per band, assuming that the offset (c0) is zero.

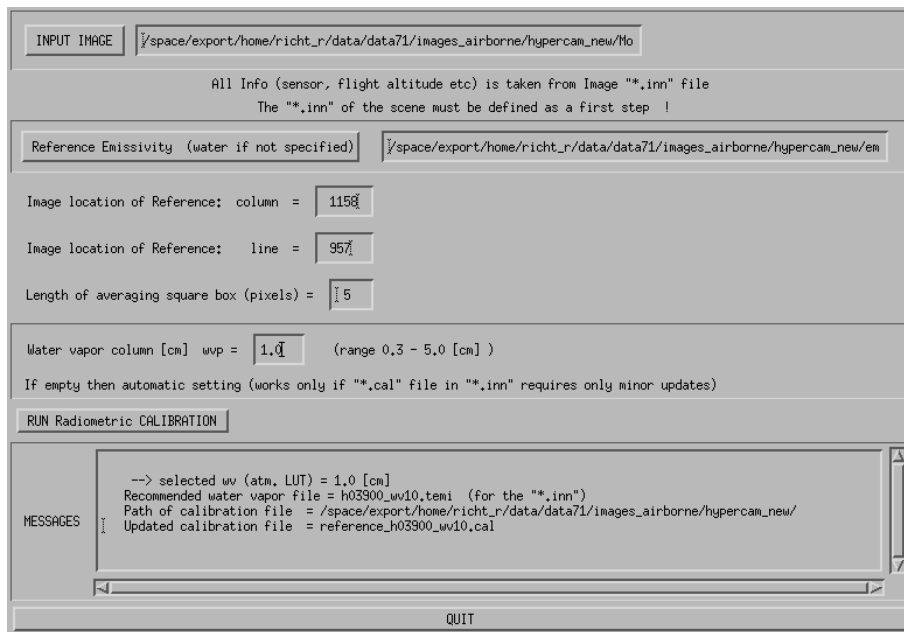


Figure 5.93: Thermal Radiometric Calibration

This feature is also available for batch processing (`'thermalcal'`), see chapter 6.3.

5.8.9 Convert High Res. Database (New Solar Irradiance)

The standard solar irradiance curve used with ATCOR is the Fontenla database (2011). However, there's some uncertainty about the solar irradiance and people may want to use ATCOR with a different solar reference function. This module (CONVERT_DB3) converts the complete high resolution atmospheric database from the current definition to a new irradiance function. Normally, the standard database is converted (this function does not apply to the thermal IR), but also the specific CHRIS database may be selected. In the panel (see Fig. 5.94), the two databases may be selected on the basis of the directory (f1) and the new reference function e0_solar*.dat.

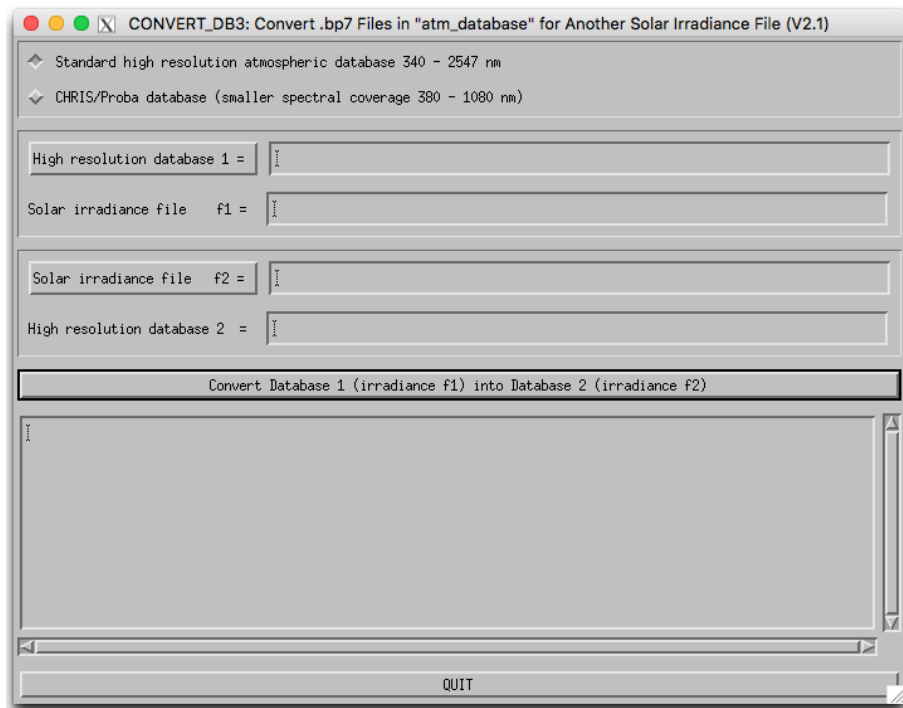


Figure 5.94: Convert monochromatic database to new solar reference function

5.8.10 Convert .atm for another Irradiance Spectrum

The conversion as described in module 5.8.9 can be applied to a sensor-specific atmospheric library of a self-defined sensor using this function. In the panel as of Fig. 5.95, the sensor has first to be entered and the new solar function e0_solar*.dat is to be selected before the conversion may be applied.

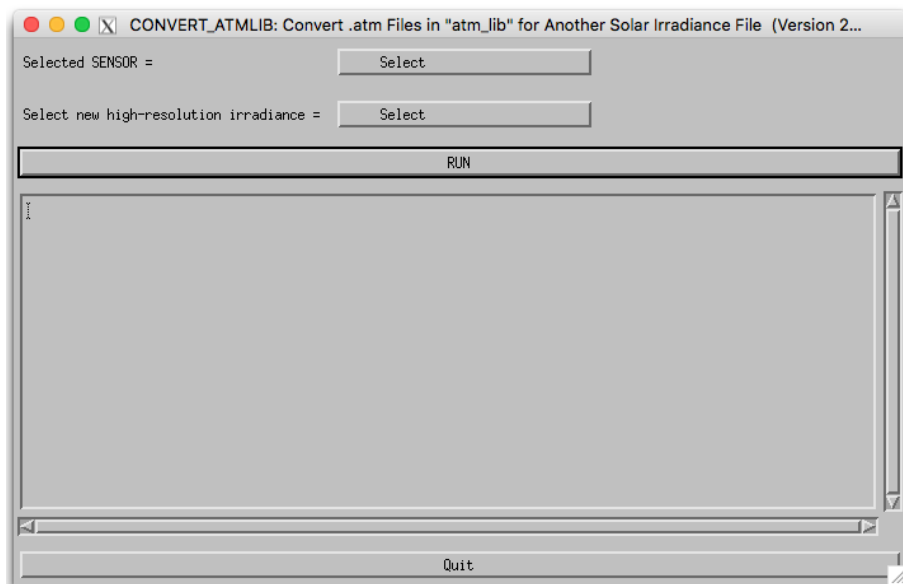


Figure 5.95: Convert atmlib to new solar reference function

5.8.11 Create Scan Angles

Creates a scan angle file from input geometry. Two procedures are supported:

- (a) (Preferred) If a MAP file or an ENVI GLT file is available for the imagery, the scan angle file may be created from the geometric information contained in that file. This results in a pixel accurate scan angle files.
- (b) If no MAP/GLT is available, the file is to be created from scratch on the basis of the flightpath direction. The given parameters are used to to interpolate a guess of the scan angle file under assumption of stable and straight flight conditions between (and beyond) a given starting point and ending point.
- (c) For frame camera imagery, a scan angle file can be created based on nadir pixel coordinates and two-dimensional FOV data. Such information is currently only partially supported in the ATCOR workflow.

Accepted Inputs:

- Create SCA file...: select either option (a), (b), or (c) from above
- Name of Reference File: File which defines the spatial dimensions of the output scan angle file to be created. - this is the GLT/MAP file if the respective option is selected, but may also be the Input image or a DEM of output resolution if flight path parameters are used.

OPTION (a):

- Flight Heading: direction of the flight path with respect to north, east is 90 degrees.
- Flight Altitude: average flight altitude in meters.

OPTION (b):

- Starting Point:
one initial point in pixel coordinates and meters altitude of nadir line the pixel coordinates are the row and column numbers as of the reference file selected in this window.
- Ending Point:
one final point in pixel coordinates and meters altitude of nadir line.

NOTE: the two points may be anywhere on the flight path, they are just used to find the nadir line within the imagery. The y coordinates are entered in bottom-up system, ie. the lower left pixel of the image is pixel number 0/0. Use the function *File:Display ENVI file 5.1.1* to find the correct coordinates.

OPTION (c):

- Starting Point:
the central (nadir) point in pixel coordinates and meters altitude. The pixel coordinates are the row and column numbers as of the reference file selected in this window.

- FOV:

The FOV has to be provided in both dimensions of the image (x and y FOV)

NOTE: Use the function *File:Display ENVI file* [5.1.1](#) to find the correct coordinates.

(END OPTION c)

- Sensor total Field of View:
total across track FOV of the sensor in degrees (default: as defined in sensor model)
- Scan Angle Output:
output file name (to be created):

The routine creates a standard 3 layers scan angle file (ENVI format) as it is used by ATCOR for radiometric processing, containing:

- pixel zenith (angle in degrees * 100)
- pixel azimuth (angle in degrees from north towards east * 10)
- sensor altitude (meters asl.)

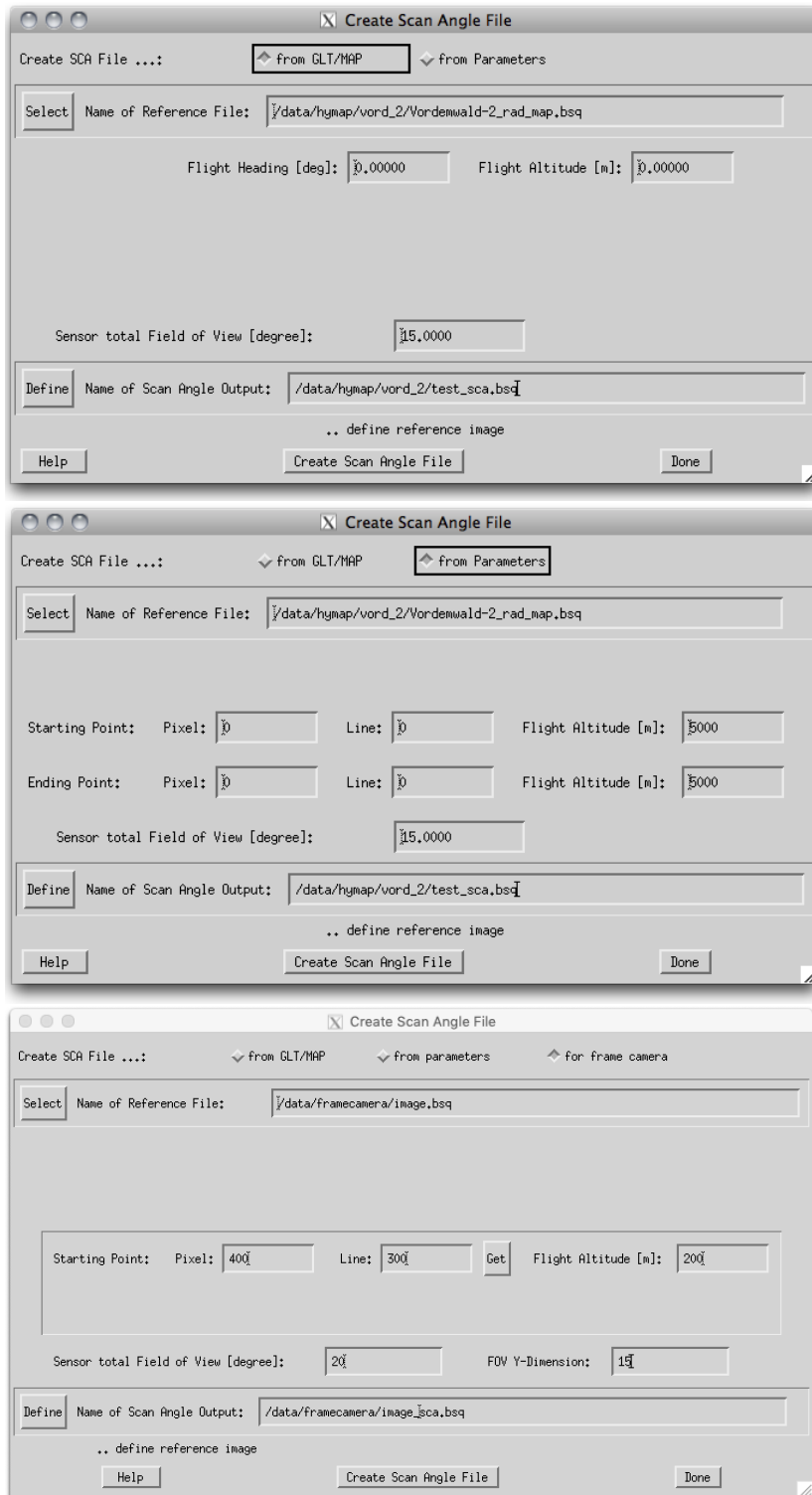


Figure 5.96: Scan angle creation panel; option (a): top, option (b): middle, option (c): bottom.

5.8.12 MTF, PSF, and effective GIFOV

A useful representation of the spatial resolution of a sensor is the transfer function, describable in terms of a modulation transfer function (MTF) and a phase transfer function. The transfer function describes how the system modifies the amplitude (MTF) and shifts the phase of the input spatial frequencies. Usually, only the MTF is given as a figure-of-merit or its counterpart, the point-spread-function (PSF). The MTF is the 2-D Fourier transform of the PSF [124].

Fig. 5.97 presents the GUI for the MTF / PSF evaluation. The image is loaded in the left part. The user should click with the left mouse button in the area where the MTF evaluation is intended. This area will be shown in top middle part of the GUI. Then the MTF can be evaluated for a line or an edge, yielding the line-spread function (LSF) or edge-spread function (ESF), respectively. The user is responsible to select an appropriate feature by clicking the start and end points of the line with the left and center mouse buttons, respectively.

After clicking "Calculate MTF", the MTF is plotted below for up to four fixed channels as well as the effective GIFOV (Ground Instantaneous Field-of-View) defined as one half of the reciprocal of the spatial frequency at which the MTF is 0.5. The effective GIFOV is also called effective instantaneous field-of-view EIFOV and it is specified in pixels. Low values of the EIFOV represent a good capability at resolving high spatial frequencies. The slider "Line averaging" can be adjusted between 3 and 9 to evaluate up to 9 parallel lines (centered on the user-defined line) to average the phase effect.

Results (MTF, LSF, DN_profile, Effective GIFOV) for all bands can be saved as ENVI spectral library files ("*.slb"). The "Status" widget indicates the mode of calculation (LSF or ESF).

5.8.13 FODIS Processing

The reader is referred to chapter 4.13 for the description and presentation of the graphical user interface for FODIS (Fiber Optic Downwelling Irradiance Sensor) data processing.

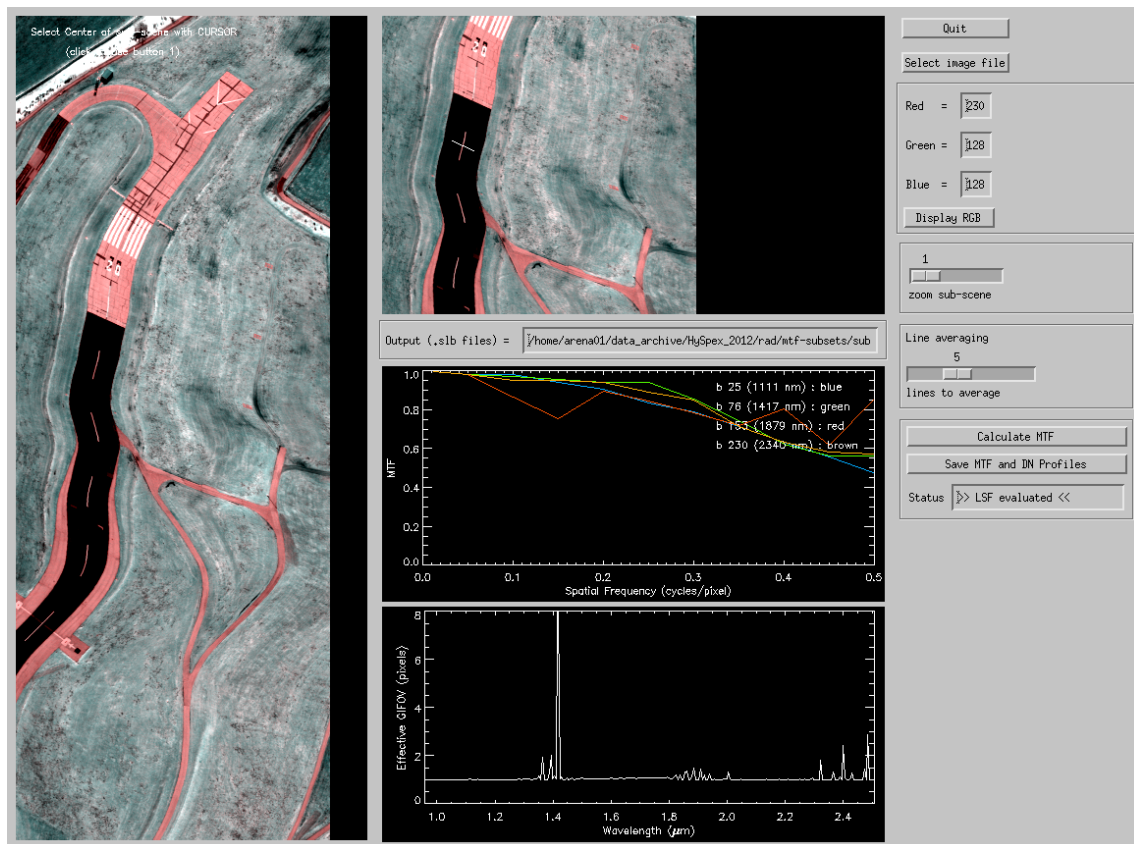


Figure 5.97: MTF and effective GIFOV.

5.9 Menu: Help

Finally, the "Help" menu allows browsing of the ATCOR user manual, provides a link to the web resources, contains the software update center, and displays license information.

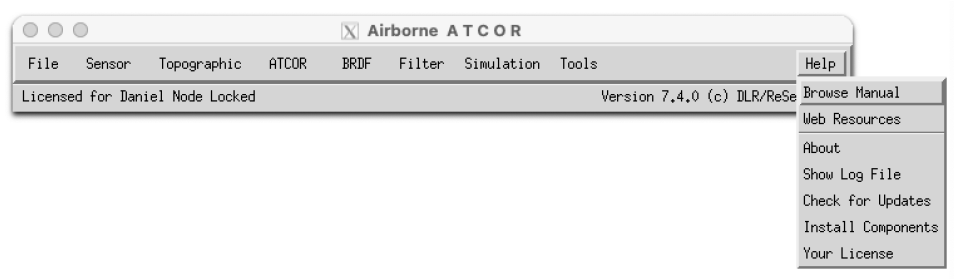


Figure 5.98: The help menu.

5.9.1 Help Options

The options of the *help* menu are listed below:

Browse Manual Opens this manual in the default PDF display application of your machine.

Web Resources Opens the html document *atcor3_webresources.htm* in the systems default applications for viewing HTML-documents.

About Provides basic information about the copyright and also displays the build-number of the software (please provide the build-number for debugging purposes in case the ATCOR support is contacted).

Check for Updates Connects to the ReSe Web server to check if a new build/release of the software is available. The software update is downloaded automatically if available and may be installed thereafter.

Install Components This is your software update center - atmospheric database files may be downloaded and updated directly through this update tool upon availability.

Your License Provides information about the licensed features in your license key and also displays which license key is currently active.

Chapter 6

Batch Processing Reference

For most ATCOR modules a convenient graphical user interface is available, but batch jobs can also be submitted. A detailed discussion of the interactive panel-driven modules is given in chapter 5. Running ATCOR in batch mode can be done in two ways: either from the operating system console directly or from within IDL. The latter provides a higher flexibility whereas the first is well suited for integration of ATCOR in a processing environment.

6.1 Starting ATCOR from console

ATCOR can be started directly from a console or from a different processing environment using the standard call to IDL run time environment. This call will show a splash screen when starting IDL unless an IDL RT or a full IDL license is installed on the processing computer. RT licenses can be acquired from Harris Geospatial (<https://www.l3harris.com>) at a significantly reduced price than full IDL licenses. This makes this method useful for operational processing with ATCOR.

The call in a windows environment is:

```
[idlpath]\idlrt.exe -rt="[atcorpath]\bin\atcor4.sav"  
-args input R|F|E [output] [logfile] [elefile] [factor]
```

where [idlpath] is the path to the idl installation, typically something like ..\idl87\bin\bin.x86_64\

On a unix/macOSX system, the call syntax is as follows:

```
[idlpath]/idl -rt="[atcorpath]/bin/atcor4.sav"  
-args input R/F/E [output] [logfile] [elefile] [factor]
```

The [idlpath] in this case is something like ../harris/idl87/bin/.

Arguments:

input: Input file to be processed or input reference file, respectively

R/F/E: Flag for processing option;

DH: dehazing (dehaze)

R: rugged terrain processing (atcor4r_batch)

F: flat terrain processing (atcor4f_batch)

E: elevation data preprocessing (at_prepele)

output: Name of output file to be created.

logfile: name of log file to be used or created.

elefile: input elevation file for at_prepele

factor: interpolation distance in number of pixels and smoothing factor for elevation data processing.

NOTE: files names other than the input file may be set to 'dum' in order to process default file names. After execution, the idl session quits and throws an error status of '1' if an error occurred during processing.

ATTENTION: These routines are overwriting existing outputs.

6.2 Using the batch mode from within IDL

ATCOR can process scenes in the batch mode. For large scenes the tiling option is also available which splits a big scene into a number of smaller sub-scenes, processes the sub-scenes, and finally merges them into one file. A prerequisite for the tiling is that enough IDL memory is available to keep one image channel and the sub-scene channel in memory.

The batch mode can be accessed after the processing parameters have been specified in the interactive graphical user interface (GUI) panel, i.e., after the SPECTRA module has been accessed or after one of the image processing options has been selected. Thus, the GUI panel creates an '*.inn' file containing all input parameters.

The batch mode can be started after quitting the interactive session, using the same IDL window. It can also be started in a new IDL session after typing 'atcor4' on the IDL command line. Then continue with:

```
>atcor4f.batch, input='/data1/examples/example_image.bsq'      (case of flat terrain) or
>atcor4r.batch, input='/data1/examples/example_image.bsq'      (case of rugged terrain)
```

At this stage, all required input parameters are already available in the '*.inn' file, in this specific case 'example_image.inn'.

The submitted job is a 'quasi batch' job, the corresponding IDL window is used for error and status messages and it may *not* be closed during the run time of the job. A log file is created during processing, e.g. 'example_image_atm.log', which contains information about the job status. It contains three message levels (I=Info, W=Warning, E=Error) followed by a two digit number (between 0 and 99) and a space, e.g. 'W19 ', followed by the appropriate information. These three message levels can easily be parsed by a separate user program if desired. Other information in the log file is marked with the hashmark symbol in the first column.

In the tiling mode the user has to specify the number of tiles in x=column direction (ntx) and in y=line direction (nty), e.g.,

```
>atcor4f.tile, input='/data1/examples/example_image.bsq', ntx=3, nty=2
```

In this case the image is split into $3 \times 2 = 6$ tiles, each tile is processed separately, finally all tiles are merged into one output file, and the sub-scenes are deleted. The maximum size of each tile

depends on the available memory for a specific machine because ATCOR performs most calculations in memory loading one or two complete bands of the scene. A typical tile size for modern machines is 3000×3000 pixels = 9 Mpixels to 5000×5000 pixels = 25 Mpixels. The user has to try and find out the appropriate tile size. As an example, with a 9 Mpixel tile size and a 30 Mpixel scene the image has to be split into 4 sub-scenes. Assuming that the number of image columns and lines is approximately the same, one would choose the keywords 'ntx=2, nty=2' in this example. Of course, processing of much smaller tiles is also possible, e.g., 'ntx=20, nty=10', but this is not recommended because of potential image border effects, i.e., larger visibility differences for the small tiles might lead to seams at the tile borders.

An optional keyword *output* can be used to define the output directory and name of the output reflectance file. If the keyword specifies only the output path, which is recommended, then all output files are written to the specified output directory, and the reflectance output file name is the name of the input file with ".atm.bsq" appended.

The optional keyword 'vis' can be used to overwrite the visibility value in the ".inn" file. For a constant visibility per scene (npref=0 in the "*.inn" file), the input 'vis' value is the start value that will be iterated as described in the [Atcor ATBD \(Chapter Reflectance Retrieval\)](#) [106]. In case of a variable scene visibility (npref=1) the 'vis' parameter is ignored if the scene contains enough dark reference pixels. If not, the program switches to the constant visibility mode and 'vis' is used as a start value.

An IDL routine called 'write_atcor4_inn_file' is available to users who want to generate the '*.inn' file without the ATCOR GUI.

Note: :

On the IDL command line, the command 'atcor4' has to be typed first to load the 'atcor4.sav' file. Then the 'atcor4f_tile' or 'atcor4r_tile' commands will execute the tile processing. A simple trick can be used to start the 'atcor_tile' programs directly on the IDL command line without having to type 'atcor4' first: just copy the 'atcor4.sav' file to 'atcor4f_tile.sav' and 'atcor4r_tile.sav'. The same can be done for 'atcor4f_batch.sav' and 'atcor4r_batch.sav'. For the Linux/Unix operation systems a symbolic link is sufficient, e.g., `ln -s atcor4.sav atcor4f_batch.sav`.

For Linux/Unix users with a full IDL license a batch job can be started directly from the shell, e.g.: `idl -e "atcor4f_batch, input='/export/data/data7/atcor4/hymap07/flight71.bsq' "`

Most of the modules are available in both modes (interactive and batch). If the 'atcor4.sav' file is copied to 'atcor4f_batch.sav' and 'atcor4r_batch.sav', a batch job can be started immediately from the IDL command line, otherwise 'atcor4' has to be typed first. We begin with a description of the batch modules and keyword-driven modules.

6.3 Batch modules, keyword-driven modules

A number of modules can also immediately be started as batch jobs. You have to type "atcor4" on the IDL command line, then the ATCOR GUI selection panel pops up. Disregard this panel and continue on the IDL command line with the name of the batch job module where all the input parameters have to be specified via key words. Current batch programs are:

- *slopasp_batch*, *input=filename*, [*pixelsize=10.0*, *kernel=3*, *dem_unit=0*]

The 'filename' should have the last four characters as "_ele" and the extension ".bsq". Two output files (slope and aspect) are generated from the elevation file, e.g., "example_DEM25m_slp.bsq" and "example_DEM25m_asp.bsq". The values are coded in degrees. The keyword *pixelsize* is not required if this information is included in the map info of the ENVI header. The keywords *kernel* and *dem_unit* can be omitted if the default values *kernel=3*, and *dem_unit=0* are used. The unit of *pixelsize* is 'meter'. For the elevation height unit three options exist: *dem_unit=0* : height unit is 'meters', =1 for 'dm', =2 for 'cm'.
 Note: Before running ATCOR with a DEM, please check the results of the slope image. We often encounter severe horizontal and vertical striping in the slope image in case of low quality DEMs or if coarse DEMs of 25 m have to be resampled to say 5 m. Additional appropriate filtering is required in these cases! A simple way might be to try a larger kernel size, e.g., *kernel=5* or *kernel=7*. A simple quality check on the derived DEM solar illumination file is also performed at the start of ATCOR, see the discussion below.
- *skyview_batch*, *input=filename*, *pixelsize=10.0*, [*dem_unit=0*, *unders=unders*, *azi_inc=azi_inc*, *ele_inc=ele_inc*]

'filename' is the full file name including the path, 'filename' should have the last four characters as "_ele" and the extension ".bsq" to indicate a digital elevation file and to enable an automatic processing, e.g., "example_DEM25m_ele.bsq". 'pixelsize' is specified in meters, 'dem_unit' is the integer code for the DEM height unit (0 represents [m], 1 means [dm], 2 means [cm]). The option *dem_unit=0* is default and can be omitted. The keyword "unders" specifies the undersampling factor (in pixels) to reduce the execution time for very large files. The default angular azimuth resolution is *azi_inc=10* degrees and the default elevation increment is *ele_inc=30* degrees. However, the recommended resolution is 10 degrees for azimuth and 5 degrees for elevation. In case of large files, an undersampling factor > 1 can be specified to reduce the execution time. Usually an undersampling factor of 3 is sufficient. A high angular resolution is more important than a low undersampling factor. The output file replaces the ending "_ele" with the ending "_sky", e.g., "example_DEM25m_sky.bsq".
- *shadow_batch*, *input=filename*, *pixelsize=10.0*, *solze=30.5*, *solaz=160.8*, *dem_unit=0*,

The keywords have the same meaning as for *skyview_batch*, 'solze' is the solar zenith angle [degr.], and 'solaz' is the solar azimuth angle [degr.]. In particular, 'filename' should have the last four characters as "_ele" and the ".bsq" extension. The output file replaces the ending "_ele" with the ending "_shd" e.g., "example_DEM25m_zen31_azi161_shd.bsq". The rounded zenith and azimuth angles will be included in the "*shd" file name.
Note: The shadow and skyview calculations can be omitted in gently undulated terrain. Example: for maximum slopes of 25° and a solar zenith angle of 40° no DEM shadow is possible. Also, the local trigonometric sky view factor, employed if the "_sky.bsq" file is missing, is sufficiently accurate, compare [ATBD \(Chapter Topography\)](#) [106].
- *atcor4f_batch*, *input=filename* [, *output=file*, *vis=vis*] or *atcor4f_tile*, *input=filename*, *ntx=3*, *nty=2* [, *output=file*, *vis=vis*]

The 'f' in *atcor4f_batch* means the code for flat terrain, i.e. no DEM is employed. The 'filename' must be fully qualified, i.e. it includes the path, e.g., "/data2/project1/image1.bsq". The file should have the band sequential (BSQ) file structure. A corresponding "*.inn" file, e.g., "/data2/project1/image1.ini" must be available that contains all processing parameters. This file will be generated during the interactive session. It may be also be created by the user, e.g. employing the program "write_atcor4_inn_file.pro" that is available on request. The

default output file name without the output keyword specification is the input name with an "_atm.bsq" appended, e.g., "/data2/project1/image1_atm.bsq".

The keyword *output* can be used to specify the full output name, or only the output path, the latter option is recommended. In that case, all output files are written to the specified output directory, and the reflectance output file name is the name of the input file with "_atm.bsq" appended. Example: *output="/data4/project1/"* then the output reflectance file will be "/data4/project1/image1_atm.bsq".

The corresponding tile program *atcor4f_tile* in this example is called to split the image into 3 sub-images in x direction, and 2 in y direction, compare chapter 6.2.

The optional keyword 'vis' can be used to overwrite the visibility value in the ".inn" file. For a constant visibility per scene (*npref*=0 in the "*.inn" file), the input 'vis' value is the start value that will be iterated as described in the ATBD [106]. In case of a variable scene visibility (*npref*=1) the 'vis' parameter is ignored if the scene contains enough dark reference pixels. If not, the program switches to the constant visibility mode and 'vis' is used as a start value.

A negative vis value means the value *abs(vis)* is used for processing even if it causes a large percentage of negative reflectance pixels.

- *atcor4r_batch*, *input=filename* [, *output=file*, *vis=vis*] or *atcor4r_tile*, *input=filename*, *ntx=3*, *nty=2* [, *output=file*, *vis=vis*]

The "r" in *atcor4r_batch* means the code for rugged terrain, i.e. a DEM is employed as well as other DEM related files, e.g., slope, aspect, skyview. Otherwise, the same explanations hold as for the "flat" terrain ATCOR.

The corresponding tile program *atcor4r_tile* in this example is called to split the image into 3 sub-images in x direction, and 2 in y direction, compare chapter 6.2. The keywords *output* and *vis* are described in *atcor4f_batch* above.

- Note: optional keywords for *atcor4f_batch*, *atcor4r_batch*, *atcor4f_tile*, *atcor4r_tile*. There are four keywords concerning spectral interpolation to overwrite the interpolation settings in file "*preference_parameters.dat*":

- *i725=-1*: no interpolation for 725/820 nm channels, *i725=1*: interpolation.
- *i760=-1*: no interpolation for 760 nm channels, *i760=1*: interpolation.
- *i940=-1*: no interpolation for 940 nm channels, *i940=1*: nonlinear interpolation, *i940=2*: linear.
- *i1400=-1*: no interpolation for 1400/1900 nm channels, *i1400=1*: nonlinear interpolation, *i1400=2*: linear.

- *toarad*, *input=filename*, [*pixelsize=pixelsize*, *sz=solar_zenith*, *atmfile=atmfile*, *elev=elevation*, *vis=visibility*, *adjrange=adjrange*, *scalef=scalef*]

The keywords in brackets are optional, the meaning of all keywords is described in chapter 7. Information on all missing keywords is taken from the corresponding ".ini" file. If the keyword *elev* is missing and the corresponding "*.inn" file contains the DEM files (elevation, slope, aspect) then the simulation is performed for a rugged terrain, otherwise for a flat terrain, compare chapter 7.

- *toarad2*, *input=filename*, [*pixelsize=pixelsize*, *atmfile=atmfile*, *elev=elevation*, *vis=visibility*]
Similar to program *toarad*, but for thermal channels, compare chapter 7.
- *cal_regress*, *ntargets=4*, *outfile='regression4'*
This program uses the "*.rdn" files to calculate a regression for the c0, c1 radiometric calibration, see [Atcor ATBD \[106\]](#), 5.4.10. The above example is for the case of n=4 targets, and the output file will be "regression4.cal" in the directory of the "*.rdn" files which are prompted with a dialog pickfile panel. A graphical user interface for this program is available in the "Tools" pull-down menu of ATCOR labeled "Calibration Coefficients with Regression".
- *reslut_batch*, *sensor='xxx'*, [*aero=aero*, *h1s=h1s*, *h2s=h2s*, *ith=ith*]
Here 'xxx' is the sensor name corresponding to the './atcor4/sensor/xxx/' folder. The keyword *aero* can have the values 'rura', 'urba', 'mari' or 'dese'. If not specified *aero='rura'* is the default. The keywords *h1s* and *h2s* specify the lower and upper flight levels in (km), e.g. *h1s=3* and *h2s=5*. For the processing of thermal band LUTs the keyword *ith=1* has to be set.
- *sp_calth*, *input=filename*, *trange=[280,320]*, *box=3*
Spectral calibration in the thermal region, the temperature range (Kelvin) and box (pixels) parameters are optional. Ten emissivity spectra in nadir direction are evaluated, evenly spaced between the image lines. Spectral shifts smaller than FWHM/30 usually can be neglected and do not require an update of the calculation of the sensor-specific atmospheric LUTs. This module can also be started from the main menu of ATCOR: 'Tools', 'Thermal Spectral Calibration (Atm.Features)'.
- *thermalcal*, *input=filename*, *xpos=xpos*, *ypos=ypos*, *box=box*, *ref_emi=ref_emi*, *wvp=wvp*
Radiometric calibration for thermal band imagery if the scene contains water bodies or a non-water reference emissivity spectrum (ASCII file *ref_emi* with 2 columns: wavelength (μm) vs emissivity). If keyword *ref_emi* is not specified, then a water target is assumed, and the theoretical spectral emissivity of water is used (file 'eps_water_7-14um.dat' in the ATCOR4 folder). *xpos*, *ypos* are the user-specified pixel coordinates, *box* is the window size for averaging over *box*box* pixels centered around *xpos*, *ypos*. If *box* is not specified, then *box=1* is taken. The input thermal image should have the original sensor geometry. This module calculates the radiometric gain (c1) per band, assuming that the offset (c0) is zero.
- *estimate_wv*, *input=filename*
This module estimates the water vapor column from purely hyperspectral imagery. It automatically selects 10 pixel spectra from the scene covering a temperature interval (Tmin, Tmax), but avoiding extreme temperatures. Then the difference between measured and simulated at-sensor radiance spectra for these 10 pixels is calculated and the water vapor LUT which minimizes the difference is recommended for processing.
- *specl_batch*, *input=filename*, *sensor='xx'* or
specl_tile, *input=filename*, *sensor='xx'*, *ntx=ntx*, *nty=nty*
The spectral classification based on template reflectance spectra is also available in the batch mode and with the tiling option. The 'xx' is a keyword for the sensor type, e.g., 'xx'='hymap04'. The complete list of sensor keywords is shown when typing *specl_batch* on the IDL command line without the sensor specification. The *ntx*, *nty* keywords have the meaning explained for the ATCOR tile programs above.

- *smile_interp4_batch*, *input=filename*, *fpoly=fpname*, *option=number* [, *silent=silent*]
Purpose: The atmospheric correction accounts for the column-dependent smile shift as specified in the "*smile_poly_ord4.dat*" of the corresponding sensor folder, but the image columns of each band belong to slightly different wavelengths.
This function interpolates the pixel reflectance values for each band to a specified reference wavelength. Three options exist for the reference wavelength grid:

1. use wavelength corresponding to the center of the detector array,
2. use average wavelength over all detector columns (per band),
3. use nominal wavelength specified in the (ENVI) header of the reflectance cube.

The new reference center wavelengths are included in the header of the output file. If the input filename is *"/path1/image_atm.bsq"* the output name is *"/path1/image_atm-smcorr.bsq"* indicating the "*smile corrected*" common wavelength grid.

Function parameters are: "filename" is the full name of the surface reflectance file, "fpname" is the full name of "*smile_poly_ord4.dat*", i.e., including the path, 'number' is the above option number (1 - 3), and if the keyword 'silent' is set the progress about the band processing is not issued to the command line.

This module is also available in the interactive mode (see main menu, 'Filter', "*Spectral Smile Interpolation (Image Cube)*", chapter 4).

- *decirrus*, *input=input* [, *dem=dem*] This module performs the cirrus removal for the file input. This means, the apparent cirrus band reflectance is calculated, and related to the apparent reflectance at the visible bands, see [ATBD \(Chapter Haze and Cirrus removal\)](#) [106]. Finally, the cirrus-removed apparent reflectances are converted into the corresponding DN values. If the optional keyword is set (*dem=1*) and if a digital elevation file (*'*_ele.bsq'*) exists in the folder of the input scene, then decirrus is switched off for high mountains above 3000 m. This module can only be applied to high-altitude airborne sensors such as 20-km AVIRIS scenes.
- *dehaze*, *input=filename* [, *water=iw*, *ipm=ipm*, *ihm=ihm*, *keep=keep*, *dem=dem*, *ihaz = ihaz*, *nocirrus = nocirrus*, *fraction_haze = fh*]

Here the filename is the name of the image (level 1 data, original DN, stored as ENVI bsq, band-sequential) including the path. The sensor name is read from the scene 'inn' file, e.g. sensor='ads40'. If keyword *water=0* (or not keyword set) then only land pixels are dehazed, with *water=1* also water pixels will be dehazed. Keyword "ipm" specifies the interpolation method:

ipm = 1 is default and uses bilinear interpolation for the bright areas (very fast)

ipm = 2 uses triangulation (very slow)

ihm = 0, 1, 2 specifies the dehazing option, ihm=1: standard dehazing, ihm=2: stronger dehazing, ihm=0: both options are executed, the results contain the identifier 'dh1' and 'dh2', respectively. Afterward, the better result is renamed with 'dh' and the inferior result is deleted if keep=0 or if this keyword is not specified.

If 'scene.bsq' is the name of the input image, then the output file name is "scene_dh_bilin.bsq", and "scene_dh_trian.bsq" for ipm=1, 2, respectively. The 'dh' indicates the dehazing and the interpolation method is also included. Additionally, a file *'*_haze_map.bsq'* is created containing the classes haze/land, haze/water, clear, water, and geocoded background. IF the keyword *water=1* is specified, then the corresponding names are 'dhw', 'dh1w' etc. Typing

the name of the module without parameters will yield the list and description of the parameters. This program can also be invoked from the ATCOR main panel.

If a DEM file is in the folder of the input scene with the name ending '*_ele.bsq*' and if the keyword *dem=1* is set, then the haze and cirrus removal are switched off for mountains higher than 3000 m. Keyword *nocirrus=1* may be set to ignore the cirrus channel info. The default is *nocirrus=0*, i.e. the cirrus channel is included and a joint cirrus / haze removal is performed.

If the keyword *fraction_haze* is not specified, then *fh=0.01* (1 percent of scene), i.e. the program will not perform the dehazing, if the fraction of haze pixels is less than *fw*.

Several dehazing options exist if a cirrus channel is available.

1. The default is a joint cirrus / haze removal (keywords *ihaz=0*, *nocirrus=0*, i.e. both keywords not set). The decirrus algorithm is run first (see the 'decirrus' description), followed by the dehaze. The 'decirrus' handles the cirrus affected part of the scene, and the dehaze handles the hazy (cirrus-free) part. In addition, the dehaze algorithm also treats overcorrected cirrus areas to a certain extent and reduces the amount of overcorrection. This option usually ranks best.
 2. With *ihaz=1* (and *nocirrus=0*) the dehazing is performed in cirrus affected regions and (non-cirrus) hazy regions. Normally, without a cirrus band, cirrus clouds are labeled as bright objects and the haze thickness map (HTM) in these regions has to be spatially interpolated. However, with the cirrus band information, the calculated HTM values can be retained to achieve a better haze removal, because the spatial interpolation is avoided. This option usually ranks second.
 3. With *ihaz=1* and *nocirrus=1* the dehazing is performed without the information of the cirrus channel. This option ranks last.
- *at_derpolish, infile, outfile, nbin, respfile $\bar{*}$.rsp, smooth τ ., /lowpass, /adj*
Derivative polishing routine.

PARAMETERS:

infile: file of reflectances to be filtered

outfile: name of output file to be created

nbin: number of adjacent bands to use for filtering (*nbin=1*)

KEYWORDS:

respfile: response file used for wavelength reference (default: ENVI header values) *lowpass*: perform lowpass filtering only

smooth: smooth the outputs by a lowpass filter of size '*smooth*' after derivative filtering

adj: use only adjacent bands (excluding current) for derivatives

- *at_evalcali, filelist, outcal, /gainonly*

Write calibration output based on vicarious validation results.

PARAMETERS:

filelist: list of ASCII files used to derive calibration file.

outcal: name of *.cal file to be written.

KEYWORDS:

/gainonly: only get gain and no offset in cal file

- *at_evaluate, ifile, geopos, slbfile, output, selspc = selspc, calfile = calfile, zen = zen, vis = vis, gndalt = gndalt, adj = adj, atmfile = atmfile, sample = sample, dark = dark, group = group*

Perform at-sensor radiance evaluation of spectra based on at sensor radiance spectral library.

PARAMETERS:

ifile: input image file

geopos: geometric position of spectrum sample center

slbfile: file of toa radiance spectra corresponding to sample

output: name of output save and txt file

KEYWORDS:

selspc: index of selected spectrum from within SLB (starting at 0)

zen: sensor zenith angle

vis: visibility

gndalt: ground altitude

calfile: calibration file for scaling of image

adj: range of adjacency window (pixels)

atmfile: atmfile used for validation

sample: size of sample window (diameter in pixels,uneven numbers only)

/dark: exclude bright pixels of sample (for water/sun glint)

OUTPUT:

variables in save file:

sdev: standard deviation of sample spectrum

avgspc: average spectrum from image sample

corpc: corrected spectrum for adjacency from image

n_spc: number of sampled spectra in image

sdevsm: standard deviation of adjacency sample

avgspcsm: average spectrum of adjacency window

m_spc: slb spectra

m_spc_Scl: slb spectra scaled to at sensor using calfile

selspc: currently selected spectrum index

q: q factor for adjacency correction

As a further output a text file with the spectra is created (.eval.txt).

- *at_evaluate_batch, ifile, slbfile, output, selspc = selspc, calfile = calfile, vis = vis, gndalt = gndalt, adj = adj, at3=at3, sample = sample*

Perform at-sensor radiance evaluation of spectra based on ground reference spectral library.

PARAMETERS:

ifile: input image file

slbfile: file of BOA reflectance spectra corresponding to sample; should contain additionally

ENVI header tags POS_X and POS_Y containing coordinates of sample spectrum
 output: name of output save and txt file

KEYWORDS:

selspc: index of selected spectrum from within SLB (starting at 0)
 zen: sensor zenith angle
 vis: visibility
 gndalt: ground altitude
 calfile: calibration file for scaling of image
 adj: range of adjacency window (pixels)
 atmfile: atmfile used for validation
 sample: size of sample window (diameter in pixels,uneven numbers only)
 /dark: exclude bright pixels of sample (for water/sun glint)

- *at_flatpoli, infile, outfile, gainfile, [/zero_offset]*

Spectral polishing using an extended flat field approach..

PARAMETERS:

infile: file of reflectances to be filtered
 outfile: name of output file to be created
 gainfile: optional output file containing gains and offsets (will be stored)

KEYWORDS:

zero_offset: apply linear function through zero (no offset)

- *at_impgeogr, infile, cord, resol, thresh = thresh, /s_bilin, expand = .., /interp, /autoutm, /altioff, outfile = , /overwrite, logfile = ..*

Program to convert an ENVI image or GEOTIFF in geographic coordinates to metric system.

PARAMETERS:

infile: input file in geographic Lat/Lon format (ENVI or TIFF)
 cord: Projection name (e.g. 'WGS_1984_UTM_Zone_1N')
 resol: horizontal/vertical resolution of output image

KEYWORDS: /interp: interpolate the missing values (see keywords below, default by triangulation)

thresh: threshold value above which pixels should be interpolated (default: -1)
 /s_bilin: use fast nereast bilinear resampling (note: s_bilin and expand can not be used at the same time)
 /expand=.: use fast nearest neighbor expansion by the given amount of pixels
 outfile: name of ENVI file to be written
 /altioff: apply z datum offset for DEM data.
 /autoutm: convert to UTM data using the default UTM zone for the given longlat location.

- *at_prepele, infile, demfile, ofile, [kernelsize= .., /fillzero, log=.., /slopasp, /skyview]*

Program to resize and prepare a DEM and all its layers for ATCOR processing..

PARAMETERS:

infile: ENVI formatted BSQ file (to be processed with ATCOR)

demfile: ENVI DEM covering the area of ifile (same coordinate system, can be different resolution/extent)

ofile: name of primary elevation file

KEYWORDS:

kernelsize: size of kernel to calculate slope/aspect (default: 5)

fillzero: fill in zero values at edges of image (shrink image)

slopasp: set to calculate slope/aspect files

skyview: set to calculate skyview factor file

- *at_pushpoli, infile, outfile [, gainfile, spatial= .. , /nospectral , /zero_offset]*

Spectral polishing and post-calibration/destriping on the basis of pixel wise deviations from local average.

PARAMETERS:

infile: file of reflectances to be filtered

outfile: name of output file to be created

gainfile: optional output file containing gains and offsets (will be stored)

KEYWORDS:

spatial: use the spatial dimensions with a filter size of the keyword for filtering

nospectral: don't apply spectral interpolation (by default, spectral interpolation with 3 bands is used to get systematic offsets)

zero_offset: apply linear function through zero (no offset)

- *at_rdglobdem, globdem, longrange, latrange, cord, outdem, log = log, psize = psize, /overwrite*

PARAMETERS:

globdem: input Lon/Lat DEM

longrange: range in longitude direction; pixel edges

latrange: range in latitude direction; pixel edges

cord: coordinate structure (use cord=ll.getcord(projname) to get this structure.

outdem: name of dem to be written

KEYWORDS:

psize: pixel size in meters of output

- *at_rhoapp, infile, calfile, e0solar [,outfile, scale= .., zen=.., date=..]*

Apparent reflectance calculation.

PARAMETERS:

calfile: ATCOR calibration file to be used for conversion of the cube

e0solar: File containing the solar irradiance for the sensor (atcor file)

outfile: name of output

KEYWORDS:

scale: scale for processing (same convention as for ATCOR, scale=1.0 is floating point output)

zen: solar zenith angle (default: 0 degrees), in degrees

date: date as two-elemt array [day,month]

- *at_shadowdetect, infile, calfile, e0solar [outfile, solangles= .., slopefile= .., /skyview, min= .., /all_layers, /pixfilter, range= ..,*

Image based shadow detection/classification.

PARAMETERS:

infile: file to be analysed

calfile: calibration file for current input file

e0solar: solar irradiance file for current input

outfile: output file of the processing

KEYWORDS:

castshadow: if keyword is set, an existing cast shadow file is provided in order to find the shadows through this keyword.

slopefile: use slope and aspect and include them in the illumination.

solangles: solar angles [zenith/azimuth]; only required for slopefile option

skyview: calculate additional skyview layer (based on illumination) requires keyword solangles and slopefile being set

range: range of index (default 0.5-1.0)

min: minimum value of output (default:0)

pixfilter: set to filter single pixels from dark areas (to avoid artifacts in full cast shadows)

all_layers: write all layers instead of the illumination file only.

- *at_shadowfilter, infile, ilufile, outfile[, smfact .., /interp,/meanadjust, min=..*

Filter dark/bright borders of shadows after cast shadow correction.

PARAMETERS:

reffile: file to be filtered (reflectance file)

ilufile: illumination file containing a shadow mask which had been applied to the image.

outfile: output file of the processing

KEYWORDS:

smfact: width of shadows to be corrected

interp: shadow borders are replaced by interpolations (instead of brightness adjustment)

meanadjust: The mean brightness across all spectral bands is adjusted (not only band wise)

min: minimum threshold for border pixel detection (default: 0.02)

- *at_scalefwhm, sensorin, sensout_dir, fwhmdat, meanshift=..*
- *at_shiftresp, sensorin, sensout_dir, smiledat, meanshift=..*

Apply FWHM or smile detection results to a sensor.

PARAMETERS:

sensorin: input sensor definition file sensor*.dat

sensout_dir: output sensor name; to be created, path to directory in sensor directory of atcor installation

fwhmdat/smiledat: files smile_poly_ord4.dat to be applied to sensor

- *at_shadowvisibility, infile, skyviewfile, ilufile, elefile = elefile, outfile = outfile, tilesize = ..., tiledist = .., refwvl = .., /at3, /getvis, vis = vis, log = logfile*

Derive aerosol distribution from image using the SHAOT method.

PARAMETERS:

infile: input file for visibility determination; the input file should be provided together with *inn file containing all parameters

skyviewfile: file containing skyview factor

ilufile: file to be used to identify shaded areas (as created with *at_shadowdetect*)

KEYWORDS:

elefile: elevation file (default: ground altitude from inn)

outfile: output aot550 file name (default: *infile_aot550.bsq*, and *infile_visindex.bsq* will be created)

visindex: optional name of visindex file to be written (if keyword outfile is set)

tilesize: default 400 pixels (tile size for calculation of moving window)

tiledist: default 200 pixels (distance between tiles, default *tilesize/2*)

refwvl: reference wavelength for AOT calculation (default 550 nm)

/at3: use atcor 3 formats

/getvis: calculates one value for the whole image - tilesize gets irrelevant here

vis: side output of visibility if /getvis keyword is set.

log: log file name

/savedump: only save parameters without creating the aot/visindex file

- *at_fwhmdetect, incube, dbfile, respfile, resol, outfile, featureflags=[..], vis=..., zen=..., ele=..., alti=..., chlist=..., results=..., /spline, zeroborder=[0/1/2], range=..., splitband=..., /overwrite*
- *at_smiledetect, incube, dbfile, respfile, resol, outfile, featureflags=[..], vis=..., zen=..., ele=..., alti=..., chlist=..., results=..., /spline, zeroborder=[0/1/2], range=..., splitband=..., /overwrite*

Smile detection routine.

PARAMETERS:

incube: input data cube

dbfile: raw database file to be used for convolution (no height interpolation)

respfile: response file (e.g., *band001.rsp*)

resol: internal resolution for the calculation

outfile: name of output file for smile coefficients

KEYWORDS:

featureflags: bytarr(*n_feat*), 15 feature regions, *featureflags[i] = 1* if feature is set, else 0;

vis: visibility [km]

zen: solar zenith angle [deg]; zenith at 0 deg.

ele: average ground elevation [km]

alti: flight altitude elevation [km] for pressure compensation

chlist: list of bands which are used for smile detection and for interpolation of the results numbering starting at 0.

results: write idl save dump of all results in a file named *.sav together with the regular output

spline = 1, spline channel interpolation, =0 linear channel interpolation of smile coefficients

zeroborder : 2 set smile coefficients to 0 at spectral borders
 (first, last channel) 1 repeat smile coefficients outside of interpolated values
 range : search range, default =20 nm
 splitband: splitchannel index between two detectors (starting at 0) - first band of second detector. overwrite: silently overwrites the older output

- *at_smoothdem, infile, dist, outfile, /median*

DEM smoothing routine.

PARAMETERS:

infile: input data cube (single band ENVI image)
 dist: size of smoothing filter
 outfile: name of output file

KEYWORDS:

median: use median filter instead of default low pass filter.

- *bil_2_bsq, infile[, outfile]*

- *bip_2_bsq, infile[, outfile]*

Conversion of ENVI band interleaved by line (BIL) or by pixel (BIP) to ATCOR standard band sequential storage order (BSQ).

PARAMETERS:

infile: input data cube in BIL or BIP format (ENVI image)
 outfile: name of output file to be created (optional; default *_img.bsq).

- *env_mosaic, filelist, outfile, [psize, xr, yr, [/brightness, /middle, /mosmap, background = ..., chlist = ..., /overwrite]]*

Create a mosaic of a series of images.

PARAMETERS:

filelist: list of files to mosaic
 outfile: name of output file to be created
 psize: pixel size of output
 xr: range in x dimensions (edges of pixels, two elements [xmin,xmax])
 yr: range in y dimensions (edges of pixels, two elements [ymin,ymax])

KEYWORDS:

chlist: list of bands to mosaic (starting at zero 0).
 background: value of background pixels (in and out)
 overwrite: overwrites the output without asking...
 middle: search for cutline in the middle of the overlap area
 mosmap: write mosaicking map instead of the mosaicked file, indicating the file numbers.
 brightness: calculate brightness map; this may also be the smoothing factor

If yr is not set correctly, the full extent is taken for both xr and yr. If psize is not set, the minimum pixel size of all images is used.

- *env_mosshades, envifile, brightnessfile, outfile, [thresh=., /horizontal,/vertical,/overwrite]*

Correct large scale shadowing/cloud shadow effect in envi mosaics.

PARAMETERS:

envifile: mosaiced envifile to be corrected

brightnessfile: brightnessfile to be used for correction; created by env_mosaic,/brightness

outfile: corrected file

KEYWORDS:

horizontal: horizontal flight strips, ie. vertical averages are normalized (by default vertical strips are assumed)

vertical : vertical flight lines (N-S), horizontal averages are done.

thresh: threshold value for correction (maximum percentage of 1)

overwrite: overwrite the output

- *multires, sensor=sensor, psens=psens, pspec=pspec*

Resampling of multiple spectra stored as separate ASCII files ('*.dat') in the path *pspec*. The spectral channel response functions ('*.rsp') are stored in the path *psens*, and the keyword *sensor* specifies the sensor name. The ASCII files ('*.dat') contain 2 columns: wavelength (μm or nm), spectral value. Empty lines (in between or at the end) are not allowed. The spectrum can have any unit (radiance, reflectance, emissivity, ...)

Example:

multires, sensor='xxx', psens='/data7/sensor/xxx/', pspec='/data7/spectra/'

The resampled spectra are written to a new folder '/data7/spectra/xxx/' .

- *multires_slb, sensor=sensor, psens=psens, slbfile=slbfile*

Same as multires, but all input spectra are stored in a single ENVI spectral library file (.slb) and the keyword *slbfile* specifies this file (with path).

Example:

multires_slb, sensor='xxx', slbfile='/data7/spectra/field1.slb'

The resampled spectra are written to file '/data7/spectra/field1_xxx.slb'

- *spect_xx, input=input, xc=xc, yc=yc, box=box, spnam=spnam*

Extraction of a reflectance spectrum from a Level-1 image (DN image), file name=input. The spectrum is taken from the center coordinates xc, yc, and averaged over a square box of box*box pixels. The name of the spectrum is specified with the keyword *spnam*. The corresponding '*.inn' file must exist and all parameters for the calculation of the surface reflectance are taken from this file. If *box* is an even number it is replaced with the next higher odd number to uniquely define the box center. If *box* is not specified then box=1 is taken.

NOTE: The above *spect_xx* is a symbolic placeholder. There are four implementations (flat and rugged terrain, satellite and airborne ATCOR)

- spect_a2 : satellite version, flat terrain
- spect_a3 : satellite version, rugged terrain
- spect_4f : airborne version, flat terrain
- spect_4r : airborne version, rugged terrain

So an example of invoking this feature is:

```
spect_4r, input='/data1/mission2/scene15.bsq', xc=500, yc=600, box=3, spname='target15_n1'
```

Two ASCII output files will be created in the folder '/data1/mission2/' :

- 'target15_n1.dat' : the surface reflectance spectrum, 2 columns: wavelength, reflectance (%)
- 'target15_n1.rdn' : 4 columns: wavelength, at-sensor radiance, DN, standard dev(DN).
Radiance is in ($mWcm^{-2}sr^{-1}\mu m^{-1}$). The standard deviation indicates the spatial uniformity within the box.

- *angles=sun(month=..,day=.., hour=..,minute=..,lat=..,lon=..)*

Calculate solar position from parameters; the keyword are self-explanatory. The output 'angles' is an array containing [zen,azi,doy], Zenith angle and azimuth angle in degrees and day of the year as a number.

- *at_cresca, reffile, startpoint, endpoint, fov, [rawdims, scafile = ..]*

Create scan angle file from parameters.

PARAMETERS:

reffile: Reference file for output dimensions

startpoint: first point of flightpath (x,y,z)

endpoint: last point of flightpath (x,y,z)

fov: total FOV of image in degrees

rawdims: n_pixels/n_lines of raw image as two element array

KEYWORDS:

scafile: name of output scan angle file (default [input]_sca.bsq)

- *at_impaisa, imgfile, [optfile, sen_dir, /raw demfile = demfile, gndalt = gndalt, fovfile = fovfile, gltfile = gltfile, navfile = navfile, logfile = logfile]*

Aimport Specim AISA data set. Side inputs: [optfile]_GLT.dat, [optfile]_synded_Nav.txt, [imgfile]_GLT.dat, [imgfile]_sca.bsq. In case no optfile is available, the base from imgfile is used.

PARAMETERS:

imgfile: orthorectified Specim AISA image data cube

optfile: options file

sen_dir: sensor definition directory name (name only, no path)

KEYWORDS:

raw: unrectified data input

demfile: name of DEM file, will be converted to [imgfile]_ele.bsq for processing

logfile: name of log file to be written

navfile: name of synced_Nav.txt file

gltfile: name of GLT mapping file

fovfile: FOV file (default: FOV=31.5 deg)

gndalt: ground altitude to be used (default to average dem nadir height)

- *at_impaviris, imgfile, obsfile, gltfile, locfile, gndalt = gndalt, demfile = demfile, outele = outele, logfile = logfile, /reload, outfile = outfile*

Import AVIRIS NG imagery. Side inputs: the files: *_glt, *_obs_ort, and *_igm are to be available at the location of the ortho image file if not specified by keywords.

PARAMETERS:

imgfile: orthorectified AVIRIS image data cube

obsfile: observation file (default: *_obs)

gltfile: GLT location file (default *_glt)

locfile: location file (default *_loc)

KEYWORDS:

demfile: name of DEM file

outele: name of elevation (DEM) and related layers to be created; no DEM creation if left empty.

logfile: name of log file to be written

reload: make sure that all data are re-created (even if the are already available on disk)

gndalt: ground altitude to be used (default to average dem nadir height)

outfile: name basis of output file and all side outputs

- *at_impacasi, imgfile, [glufile, geofile, sen_dir, /raw, demfile = demfile, gndalt = gndalt, logfile = logfile, ofile = ofile, /overwrite]*

Import Itres CASI imagery. Side inputs: the files: *_sca *_glu or *_nad, are to be available at the location of the ortho image file if not specified by keywords.

PARAMETERS:

imgfile: orthorectified AVIRIS image data cube

glufile: GLU or NAD file with auxiliary data layers

geofile: file *.geo with some meta data

sen_dir: sensor definition directory name

KEYWORDS:

raw: unrectified data input

demfile: name of DEM file, will be converted to [imgfile]_ele.bsq for processing

logfile: name of log file to be written

gltfile: name of GLT mapping file

ofile: name of output image

overwrite: overwrite existing outputs

gndalt: ground altitude to be used

- *br_calmodel, filelist, outfile, rfact = .., inpath = .. /roujean, /maignan, /interp, /constrain, /anifwrite, smooth = .., scalist = .., chlist = .., accuracy = .., config = .., logfile = ..*

Do BRDF model calibration based on a list of files.

PARAMETERS:

filelist: list of files to process; convention: the following files should be present for each file in

file list:

infile = [*]_xxx.bsq (usually *_atm.bsq)

scaang = [*]_sca.bsq (path may be changed using inpath keyword)

inn = [*].inn (path may be changed using inpath keyword)

outfile: name of output file to be created (default brdf_model.sav)KEYWORDS:

roujean: calculate Roujean/Ross-Li Model Kernels for geometric kernel

maignan: Use improved hotspot geometry for volumetric kernel

chlist: list of bands to process

rfact: scaling factor to reflectance [-]

accuracy: fitting accuracy threshold [%] anifwrite: write BCI side output (*_bci.bsq)

interp: perform interpolation on incomplete BCI levels (not recommended)

smooth: spectral smoothing of BRDF model (factor to be given as number of bands)

config: standard configurations or array of BCI limits (only required if no brdf model is given)

inpath: path of side inputs (SCA/INN) if different from file.

scalist: list of scan angle files to be used; same order as filelist

logfile: write log to that file

- *br_brefcor, infile, scafile, outfile,*

brdfsav = .., /anifwrite, /constrain, /roujean, /maignan, /anif

Perform BREFCOR brdf correction.

PARAMETERS:

infile: input file

scafile: scan angle file *_sca.bsq

outfile: name of output file

KEYWORDS:

brdfsav: use save set of brdf parameters (default: calculate from this image only)

constrain: constrain correction to vegetation only such that no correction is done for BCI LE -1.2

anifwrite: write anif and BCI side output (*_anif.bsq and *_bci.bsq)

roujean: calculate Roujean/Ross-Li Model Kernels for geometric kernel

maignan: Use improved hotspot geometry for volumetric kernel

chlist: list of bands to process

rfact: scaling factor to reflectance [-]

config: standard configurations or array of BCI limits (only required if no brdf model is given)logfile: write log to that file

- *gc_glttosca, gltfile, fov, heading, alt, scafile = ..*

Create scan angle file from GLT.

PARAMETERS:

gltfile: GLT reference file in BIL format (or MAP file in BSQ format)

fov: total FOV of image in degrees

heading: average heading to direction north of flight (north: 0; east: 90)

alt: altitude of aircraft for first and last line (two element vector; if only one value is provided

it is assumed to be constant)

KEYWORDS:

scafile: name of output scan angle file (default [input]_sca.bsq)

Chapter 7

Sensor simulation of hyper/multispectral imagery

After atmospheric correction the surface reflectance and temperature/emissivity cubes can be used to simulate new products which might be of interest:

- at-sensor radiance cubes in the solar region ($0.4 - 2.5 \mu m$) for different solar geometries and atmospheric conditions,
- at-sensor radiance cubes in the thermal region ($8 - 14 \mu m$) for different atmospheric conditions, e.g. for satellite sensor studies,
- resampling of the surface reflectance cube to an existing or new multispectral sensor,
- resampling of the surface emissivity cube to an existing or new multispectral sensor.

This is a convenient way to simulate realistic data for a spaceborne version of an airborne instrument, to obtain radiance data at different flight levels, or to compare hyperspectral (hs) data with broad-band multispectral (ms) data. As a restriction, the TOA (top-of-atmosphere) or at-sensor radiance calculated with the *"TOARAD"* program assumes a nadir view. The *"HS2MS"* (hyperspectral-to-multispectral) program requires the hs and ms center wavelengths and the ms channel filter curves for resampling. In addition, noise of the ms sensor can be included as Gaussian noise with a specified amplitude, either as noise-equivalent radiance (NER) or as noise-equivalent reflectance ($NE\Delta\rho$). The hs contribution to a certain ms band is weighted with the value of the ms response curve at the corresponding hs wavelength, compare Fig. 7.1.

After summing all contributions the result is normalized with the sum of the hs filter values

$$L_{ms}(i) = \frac{\sum_{k=1}^{n_i} L_{hs}^{(k)} R_{ms}^{(i)}(\lambda_{hs}^{(k)})}{\sum_{k=1}^{n_i} R_{ms}^{(i)}(\lambda_{hs}^{(k)})} \quad (7.1)$$

where L denotes at-sensor (or TOA) radiance, $R_{ms}^{(i)}$ the ms response function of channel i , and n_i is the number of hs channels covered by the i -th ms filter function. A similar equation is used for the resampling of surface reflectance or emissivity. The weight factors w_k for each hs channel are calculated with eq. 7.2, and they are documented in the corresponding *".log"* file created by program *"HS2MS"*.

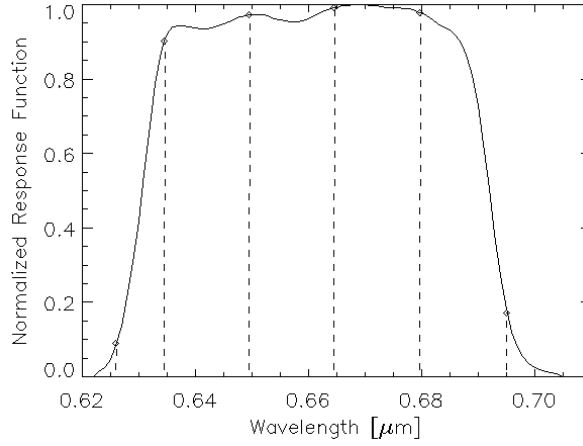


Figure 7.1: Weight factors of hyperspectral bands.

The solid curve shows the response function $R_{ms}^{(i)}$ of a ms channel, and the dashed lines indicate the hs center wavelengths $\lambda_{hs}^{(j)}$.

$$w_k(i) = \frac{R_{ms}^{(i)}(\lambda_{hs}^{(k)})}{\sum_{j=1}^{n_i} R_{ms}^{(i)}(\lambda_{hs}^{(j)})} \quad (7.2)$$

Fig. 7.2 describes the sequence of processing for the sensor simulation in the solar region. After atmospheric correction with ATCOR the *"image_atm.bsq"* contains the surface reflectance cube. Program *"TOARAD"* then calculates the at-sensor radiance for a different flight altitude, solar geometry, or atmospheric parameters. All parameters not specified as keywords (see list of keywords below) are taken from the *"image.inn"* file created by ATCOR.

The program *"HS2MS"* can be started to resample the radiance cube to a ms image by specifying the ms sensor (i.e., channel filter functions) and the ms noise equivalent radiance (NER). $NER = 0$ is allowed, so the resampled image product will only include the noise of the hs scene, which will be reduced due to the inherent integration over several hs bands. A channel-constant NER or a file with channel-dependent NER values may also be employed.

Figure 7.3 shows the GUI panel of program *"HS2MS"*. Although the input image will usually be a hyperspectral scene with $n > 50$ channels and the output a multispectral scene with $m \ll n$ channels, this program can also be employed for the case of a multispectral input image with $n < 10$ channels and a panchromatic sensor with $m=1$ band. The program supports the four cases of resampling mentioned above, i.e., solar or thermal at-sensor radiance, surface reflectance, or emissivity.

Fig. 7.4 describes the sequence of processing for the sensor simulation in the thermal region. The file *"image.bsq"* consists of thermal band data and possibly also reflective band data. After atmospheric correction, the file *"image_atm.bsq"* starts with the surface reflectance channels (if existing), continues with the surface radiance for the thermal channels, and contains the surface temperature as the last channel. The corresponding emissivity data is stored as a separate file (*"image_atm_emiss.bsq"*, 16 bit integer) which is scaled with a factor of 1,000. Program *"TOARAD2"* corresponds to *"TOARAD"*, but calculates thermal at-sensor radiance imagery. Again, program *"HS2MS"* converts the hyperspectral imagery into multispectral scenes. However, the noise is now

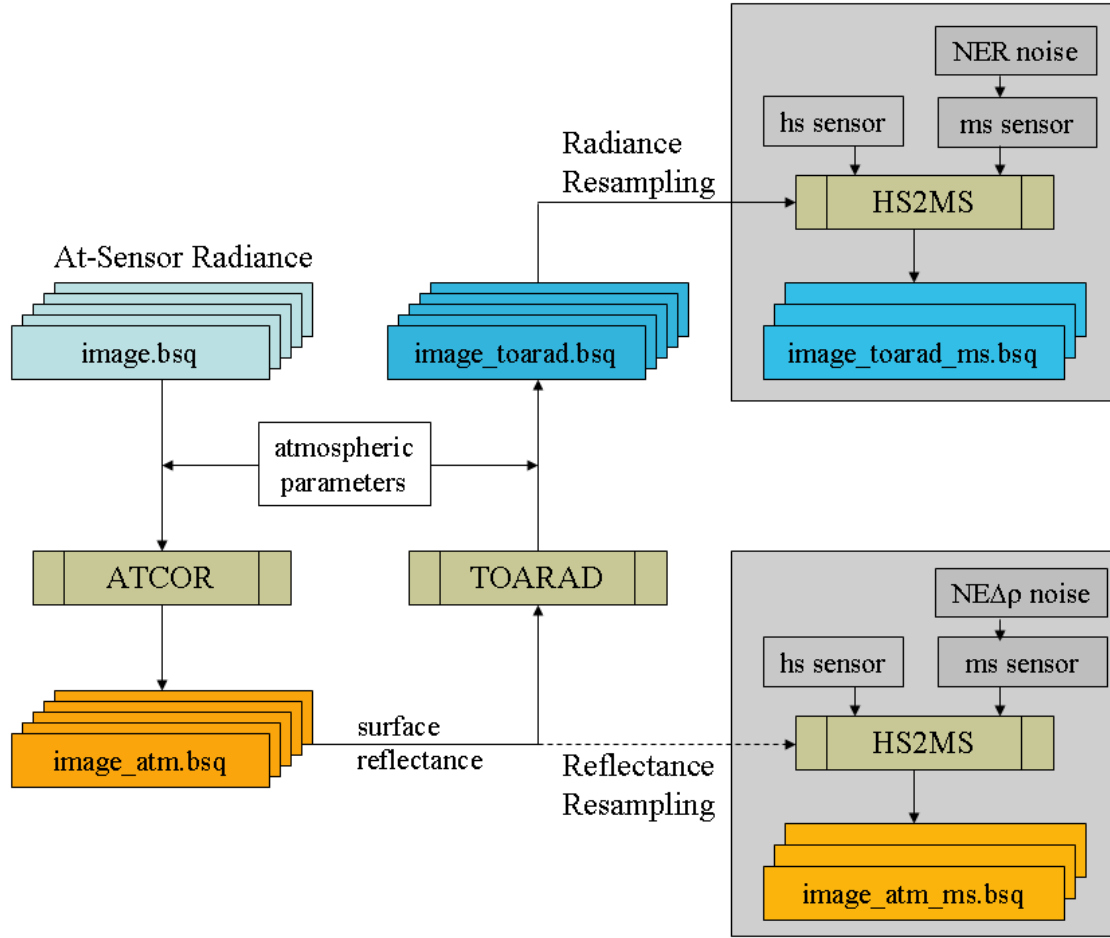


Figure 7.2: Sensor simulation in the solar region.

specified in terms of $NE\Delta T$ (noise equivalent delta temperature) which is specified in [K=Kelvin]. For the emissivity resampling, the noise equivalent emissivity $NE\Delta\epsilon$ is internally computed from the $NE\Delta T$:

$$NE\Delta\epsilon = NE\Delta T \frac{\partial L_{bb}/\partial T}{L_{bb}} \quad (7.3)$$

Since the temperature-radiance relationship for thermal bands is calculated with an exponential fit equation (compare [ATBD \[106\]](#)).

$$L_{bb} = \exp[(\frac{1}{T} - a)/b] \quad (7.4)$$

we can express $NE\Delta\epsilon$ (using $T=300$ K) as

$$NE\Delta\epsilon = \frac{NE\Delta T}{b T^2} = \frac{NE\Delta T}{b 300^2} \quad (7.5)$$

where b is a channel-dependent coefficient.

Keywords for batch programs *"toarad, toarad2"*

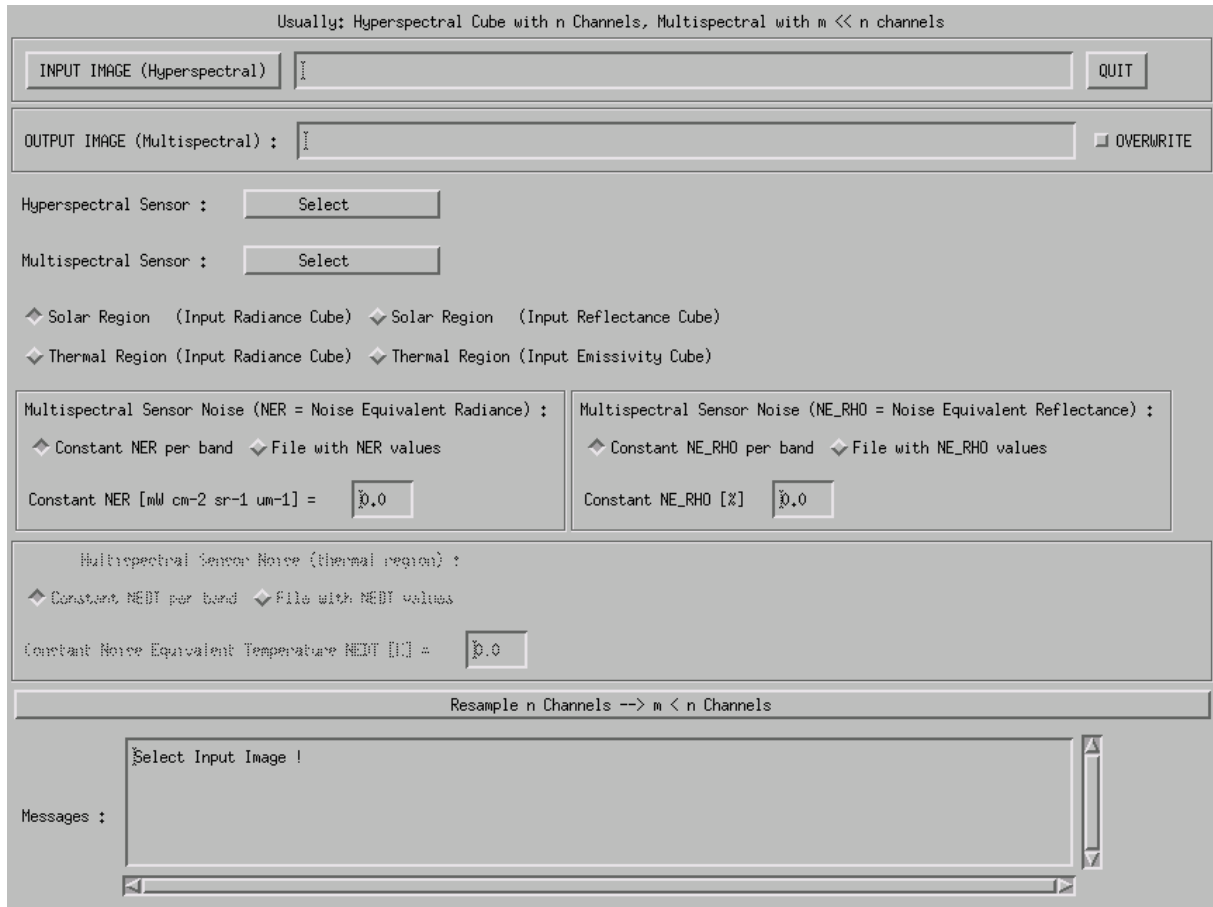


Figure 7.3: Graphical user interface of program "HS2MS".

On the IDL command line, program names can be written in lower case letters, so as an example "toarad" instead of "TOARAD" is used synonymously in this context. If "toarad" or "toarad2" is submitted as a batch job, the following keywords can be specified:

- *toarad*, *input=filename*, [*pixelsize=pixelsize*, *sz=solar_zenith*, *atmfile=atmfile*, *elev=elevation*, *vis=visibility*, *adjrange=adjrange*, *scalef=scalef*]

The input file name must include the path, and the keywords in brackets indicate optional parameters. A detailed description is given below.

- *toarad2*, *input=filename*, [*temfile=temfile*, *elev=elevation*, *vis=visibility*]

Similar to "toarad", *temfile* is the atmospheric LUT file name for the thermal region. The solar zenith angle is not required in the thermal region. In addition, the pixel size and adjacency range are missing, because the adjacency effect can be neglected. The output thermal radiance is in the unit $mW m^{-2} sr^{-1} \mu m^{-1}$. For ambient surface temperatures the radiance range is from about 5,000 to 15,000 in this unit, and data is always stored as float, i.e., the scale factor is *scalef*=1. Besides the input "*image_atm.bsq*" the file "*image_atm_emiss.bsq*" is automatically loaded as well and all processing parameters will be taken from the "*image.inn*" generated by the ATCOR run. If the keyword *temfile* is not specified, the file "*h99000_wv10.tem*" is used. The default visibility is 23 km.

If a keyword is set, it will overwrite the corresponding parameter from the ".inn" file, compare

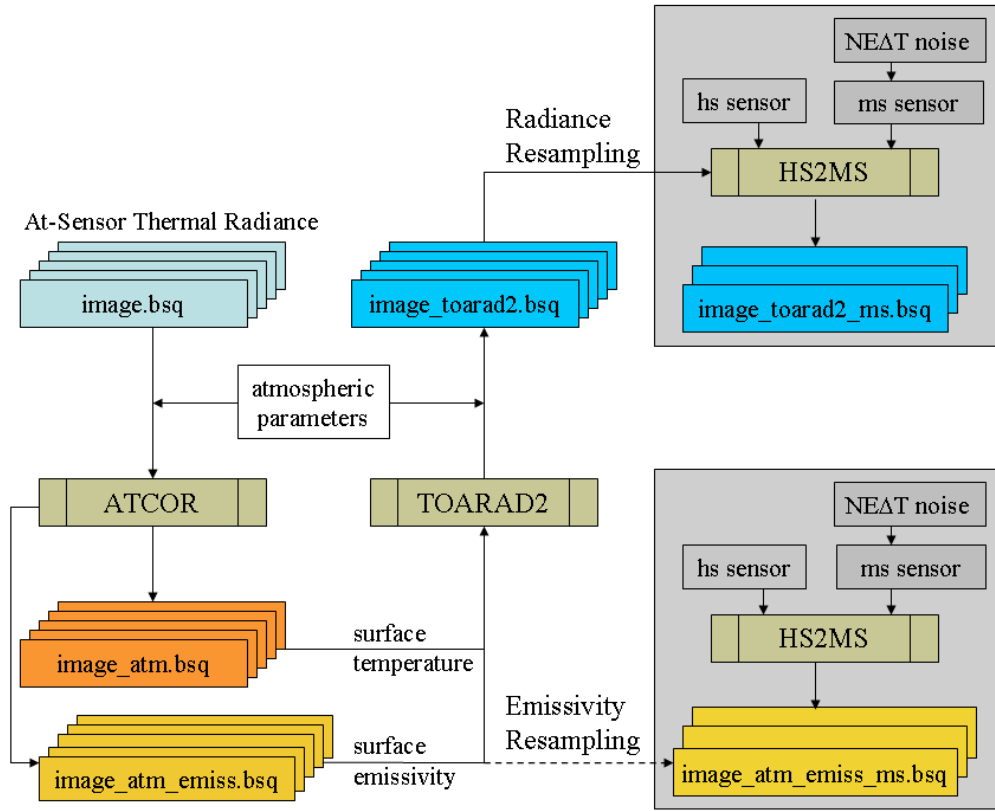


Figure 7.4: Sensor simulation in the thermal region.

chapters 6.3 and 8.5. To perform a TOA/at-sensor radiance simulation for a given airborne scene and sensor, the user has to resample files from the monochromatic atmospheric database:

- for the chosen new airborne altitude to be simulated (if not already available),
- for the altitude 99,000 m that serves as "flight" altitude for space sensors, see chapter 8.1.

After running ATCOR4 for a certain scene and sensor, a surface reflectance cube is obtained which is input to the TOA/at-sensor simulation that can be performed for a flat or a mountainous terrain. A detailed description of the "toarad" keywords follows:

- *input*='data1/image_atm.bsq', the '_atm.bsq' indicates a surface reflectance file which is the output of an ATCOR run. The input file to ATCOR was 'data1/image.bsq', and *toarad* extracts some information from the corresponding file 'data1/image.inn', for example the sensor name. The output file name is 'data1/image_toarad.bsq'.
- *atmfile*='h99000_wv29_rura', this is an example of an atmospheric look-up-table file with a rural aerosol and a water vapor column of 2.9 gcm^{-2} , see chapter 8.1. If the keyword *atmfile* is not specified, then 'h99000_wv10_rura' will be taken.
- *elev*=500, an example of a ground elevation at 500 m above sea level. If *elev* is not specified, then *elev*=0 is assumed. However, if the keyword *elev* is not specified and the 'data1/image.inn' file contains file names for the DEM elevation, slope, and aspect, then the DEM files are taken,

and the TOA calculation is performed for a rugged terrain. If the keyword *elev* is specified the simulation is always performed for a flat terrain regardless of any possible DEM file names in the *'*.inn'* file.

- *sz=35.5*, an example of a solar zenith angle of 35.5° (not used for *"toarad2"*).
- *vis=25*, an example of a visibility of 25 km.
- *pixelsz=4.5*, an example of a pixel size of 4.5 m.
- *adjrange=500*, an example of an adjacency range of 500 m.
- *scalef=10,000*, scale factor for the TOA radiance. The default is *scalef=1.0* which provides the output file as float data of TOA radiance in units of $[mWcm^{-2}sr^{-1}\mu m^{-1}]$. If *scalef* > 1, e.g. *scalef=10,000*, the output TOA radiance is stored as 16 bit unsigned integer multiplied with the scale factor. The advantage is a smaller output file (compared to the 32 bit float), the drawback is that radiances will be truncated at 65,000 which might happen for bright surfaces (e.g., snow, vegetation in the NIR) with *scalef=10,000*, see Figure 7.5. Therefore, the easiest way to avoid scale problems is to use the default *scalef=1.0* and have a float radiance output cube.

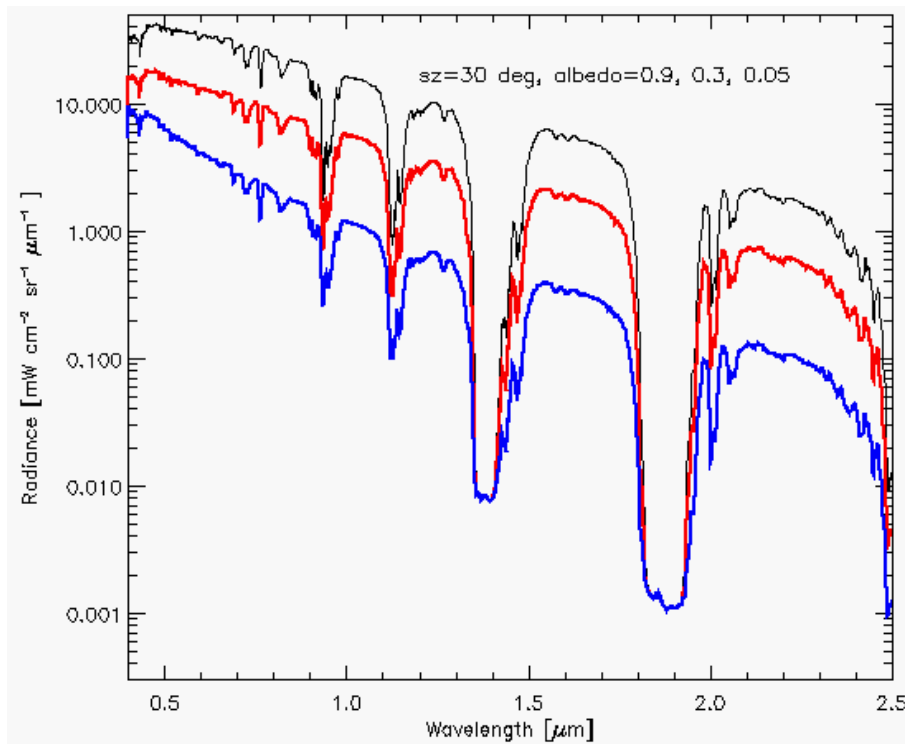


Figure 7.5: TOA radiances for three albedos and a solar zenith angle of 30° .

MODTRAN calculation for a mid-latitude summer atmosphere, rural aerosol, visibility 15 km, ground elevation 500 m above sea level.

For convenience, a *"*.log"* and an *"*.inn"* file are created for the documentation of the processing parameters, e.g., *'/data1/image_toarad.ini'*. In addition, the corresponding sensor calibration file

will be created. Example: sensor='casi96', scalef=1000, then file '*casi96_scalef1000.cal*' will be created on the '*../atcor4/sensor/casi96/*' directory with the radiometric calibration coefficient $c_1 = 0.001$ for each band.

Chapter 8

Implementation Reference and Sensor Specifics

This chapter discusses miscellaneous topics associated with the current implementation of ATCOR. First the user is acquainted with the structure and handling of the atmospheric database. Second, the supported input/output file types are given.

The next item discusses the preference parameters, e.g. the definition of thresholds employed for the masking of cloud and water areas, and options for interpolating certain spectral regions. Then the parameters of the `*.inn` file are described which is employed for the interactive and batch processing. Last but not least a section on problems and tips is included.

8.1 Monochromatic atmospheric database

This chapter presents the technical details of the atmospheric database.

To be capable of handling typical hyperspectral sensors with arbitrary spectral bands in the solar and thermal spectral regions a large database of atmospheric LUTs was compiled with the MODTRAN® 5 (version 5.4.0) radiative transfer code in 2016, which uses resampled HITRAN2013 files. The database is called "monochromatic" because of its high spectral resolution, compare figure 8.1. The size is currently about 6.2 GB. After resampling with the spectral response functions of any sensor a typical size of the sensor-specific database is 10-50 MB. Chapter 8.2 contains a description of the resampling program RESLUT.

In the solar spectral region (0.34 - 2.56 μm) MODTRAN® was run with different wavenumber spacings to achieve a wavelength grid spacing of approximately 0.4 nm (except for the 1400 nm and 1800 nm regions). This required the use of MODTRAN®'s `"p1_2008"` database (i.e., 0.1 cm^{-1}) in the 2.1 - 2.5 μm region. In addition, different RT algorithms were used: in atmospheric window regions the scaled DISORT algorithm with 8 streams (SD-8) was employed, in absorption regions the more accurate SD-8 with the correlated k algorithm was selected [43]. Since the wavenumber grid is not equidistant in wavelength, the LUTs were resampled with an equidistant 0.4 nm grid of Gaussian filter functions of FWHM=0.4 nm to speed up subsequent calculations. So the new LUT database should be sufficient for instruments with bandwidths > 2 nm covering the solar spectral region from 340 to 2540 nm.

The thermal high-resolution database employs a spectral sampling distance of SSD=0.4 cm^{-1} for the wavelength region 7 - 10 μm , i.e. corresponding to a wavelength SSD=2 - 4 nm, and SSD=0.3 cm^{-1} for the wavelength region 10 - 14.9 μm , i.e. corresponding to a wavelength SSD=3 - 5.5

nm. A triangular weight function is used with a spectral bandwidth of twice the SSD. The Isaacs's 2-stream method is employed including the correlated k algorithm. The Isaacs's algorithm is much faster than DISORT, and yields the same results for our cases in the thermal region. All files (*.bt7") are calculated for view or scan angles from 0° (nadir) to 40° off-nadir with a 5° increment to enable an accurate interpolation.

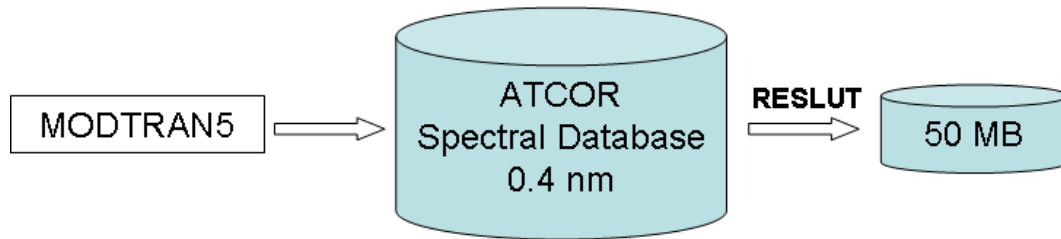


Figure 8.1: Monochromatic atmospheric database.

The database comprises the flight altitudes 0.1, 1, 2, 3, 4, 5, 10, and 20 km above sea level, and the aerosol types rural, urban, maritime, and desert. In the altitude regime 1 - 5 km the increment is 1 km. A larger increment is adequate for the high altitudes of 10 and 20 km because of the lower optical depth increment. For flight altitudes in between ATCOR will interpolate if requested by the user. In addition, the database contains LUTs for the 99 km altitude which can be used for satellite sensors.

Imagery of the commercially available standard satellite sensors such as Landsat TM, SPOT, or IRS-LISS are already treated in the satellite ATCOR environment.

For each flight altitude and aerosol type files with five water vapor columns are available ($W = 0.4, 1.0, 2.0, 2.9, \text{ and } 4.0 \text{ cm or g cm}^{-2}$, sea level-to-space values). These represent dry to humid atmospheric conditions [89, 8]. They are needed for the water vapor retrieval to create interpolated / extrapolated values for the range $W = 0.3 - 4.5 \text{ cm}$. In spectral regions where water vapor absorbs, the accuracy of the surface reflectance retrieval depends on the number of water vapor grid points and the interpolation method (full range of W or sub-interval pertaining to a pixel [99]). The CO_2 mixing ratio of the atmosphere is set at 400 ppmv, the ozone column is fixed at 330 DU (Dobson Units, equivalent to the former 0.33 atm-cm) for a ground at sea level.

The file names for the solar region include the altitude, the aerosol type, and the water vapor content. They have the extension ".atm". Example: "h03000_wv04_rura.atm" represents a file with flight altitude 3000 m (above sea level), water vapor column 0.4 cm, and the rural aerosol. Each ".atm" file contains the look-up tables for the visibility range 5 - 120 km, solar zenith angles 0 - 70°, and ground elevations 0 - 4000 m (increment 500 m). If the flight altitude is lower than 4000 m the maximum ground elevation is set to 100 m below flight altitude.

In the solar spectral region the database was compiled for a nadir view. However, the atmospheric transmittance will be calculated in ATCOR depending on the actual scan angle for each image pixel employing the nadir value. For the path radiance, the nadir value is not sufficient to predict the off-nadir values. Therefore, the scan-angle dependence of the path radiance was approximated by 2nd order polynomials obtained by a least squares fit. The polynomial coefficients depend on the aerosol type, view and illumination geometry, and wavelength. In general, they are different for the left and right part of a scanline.

The extension of the files for the thermal spectral region is ".tem". Since the aerosol type is of negligible influence in the thermal region, these files do not include an aerosol type identifier in their name. They were compiled for the rural aerosol. So, the file name corresponding to the 3000 m altitude and the 0.4 cm water vapor column is called "h03000_wv04.tem". The thermal LUTs were compiled for the scan angle range 0 - 40° with an increment of 5° to keep the interpolation error of the radiance and transmittance values smaller than one percent. Transmittance and path radiance values for scan angles above 40° will be extrapolated.

8.1.1 Database update with solar irradiance

In the solar region any high spectral resolution database of LUTs is based on the specification of an extraterrestrial spectral solar irradiance, because the values of path radiance, direct and diffuse solar fluxes depend on solar irradiance. Other quantities (direct and diffuse atmospheric transmittances and spherical albedo) are independent of the solar spectrum. ATCOR's standard atmospheric database is calculated for a certain irradiance $E_1(\lambda)$, and the corresponding file 'e0_solar_XXX.dat' is included in the directory 'atm_database'.

Beginning with the ATCOR-2011 release there is an option to switch from one extraterrestrial solar irradiance source $E_1(\lambda)$ to another one $E_2(\lambda)$. The delivered high spectral resolution database of atmospheric LUTs is based on the Fontenla-2011 solar irradiance spectrum (Fontenla et al. 2009, 2011 [29, 30]). It represents the solar irradiance for a quiet or "low activity" sun and is recommended as the standard spectrum. The original 0.1cm^{-1} resolution spectrum is convolved with Gaussian filter functions (FWHM=0.4 nm) and mapped on an equidistant 0.4 nm grid. The file name of this spectrum $E_1(\lambda)$ is 'e0_solar_fonten2011_04nm.dat'. If R_1 denotes the set of quantities (path radiance, direct, diffuse solar flux) based on $E_1(\lambda)$, then the new set R_2 with the irradiance spectrum $E_2(\lambda)$ is calculated as:

$$R_2(\lambda) = R_1(\lambda) E_2(\lambda)/E_1(\lambda) \quad (8.1)$$

Figure 8.2 presents a schematic sketch of this conversion. The folder 'sun_irradiance' contains a number of solar irradiance files that can be selected. The folder of the atmospheric database DB_1 pertaining to $E_1(\lambda)$ includes the corresponding irradiance file (e.g. 'e0_solar_fonten2011_04nm.dat') and the calculated new database DB_2 includes the $E_2(\lambda)$ file (e.g., 'e0_solar_kurucz2005_04nm.dat'). The standard or "active" database is named 'atm_database', while the new database includes 10 characters from the E_2 file name, e.g. 'atm_database_kurucz2005'.

The ATCOR "tools" panel contains the program to convert from one to another spectral irradiance database (see Figure 8.3). It enables an update of the "monochromatic" atmospheric database without the need to repeat the time-consuming MODTRAN® 5 computations (involving the correlated k algorithm in some spectral regions). Figure 8.3 shows an example for a reduced height set of files, the complete conversion for all height levels requires about 3 minutes. The user can also provide additional solar irradiance files to the 'sun_irradiance' folder provided the spectral range, increment, and irradiance unit agree with the template spectra.

Attention: ATCOR will always work with files in the "active" folder 'atm_database', therefore the old 'atm_database' has to be renamed (or deleted) and the folder with the new database has to be renamed as 'atm_database' before applying the sensor-specific resampling program (RESLUT). Since each 'atm_database' folder contains its corresponding solar irradiance spectrum a unique identification is always possible. In addition, the directory of the sensor-specific "*.atm" files contains an ASCII file named 'irrad_source.txt' identifying the solar irradiance file.

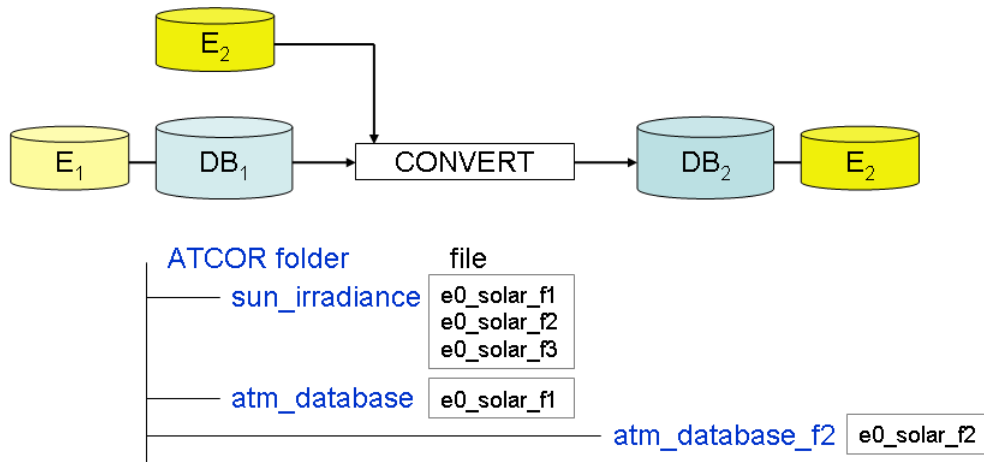


Figure 8.2: Solar irradiance database.

8.2 Sensor-specific atmospheric database

This database is created by resampling the files of the monochromatic database with the sensor's spectral response functions employing program RESLUT, see figure 8.4. Usually, only a subset of the total number of files of the monochromatic database is needed for a new sensor. The sensor-specific database will contain the altitudes and aerosol types that were specified during the resampling with program RESLUT. There are 6 water vapor files per altitude and aerosol type that have to be resampled. The folder with the ".atm" files also contains a file "irrad_source.txt" identifying the underlying solar irradiance spectrum.

Attention: Do not resample all flight altitudes and aerosol types contained in the monochromatic database, because the program might run an hour, but restrict the resampling to the cases you need. If you want to resample a larger number of files let the program run over night.

Example: A sensor operates exclusively in the altitude region from 1 - 3 km in areas where rural and maritime aerosols are likely to occur. In this case, it makes no sense to resample the atmospheric files for the altitude regions above 3 km. Also, a restriction to the files with rural and maritime aerosols will reduce the computation time of the RESLUT program considerably.

In case of sensors with solar and thermal bands the option "Thermal Region" on the first GUI panel of RESLUT has to be selected as well. The second GUI panel will look slightly different, because the aerosol type selection is missing. In the thermal region, the aerosol type can usually be neglected. Therefore, all files in the monochromatic database were calculated with the rural aerosol, but the aerosol identifier is not included in the file name, because only the rural aerosol is available.

Note: Any altitude-interpolated files that were created by ATCOR will be deleted as soon as the user exits the program. This is done intentionally to avoid "garbage collection". Any interpolated file is generated again within a few seconds if necessary. Interpolated "*.atm" files for the solar region have the extension "*.atmi", for the thermal region the interpolated "*.tem" files have the extension "*.temi".

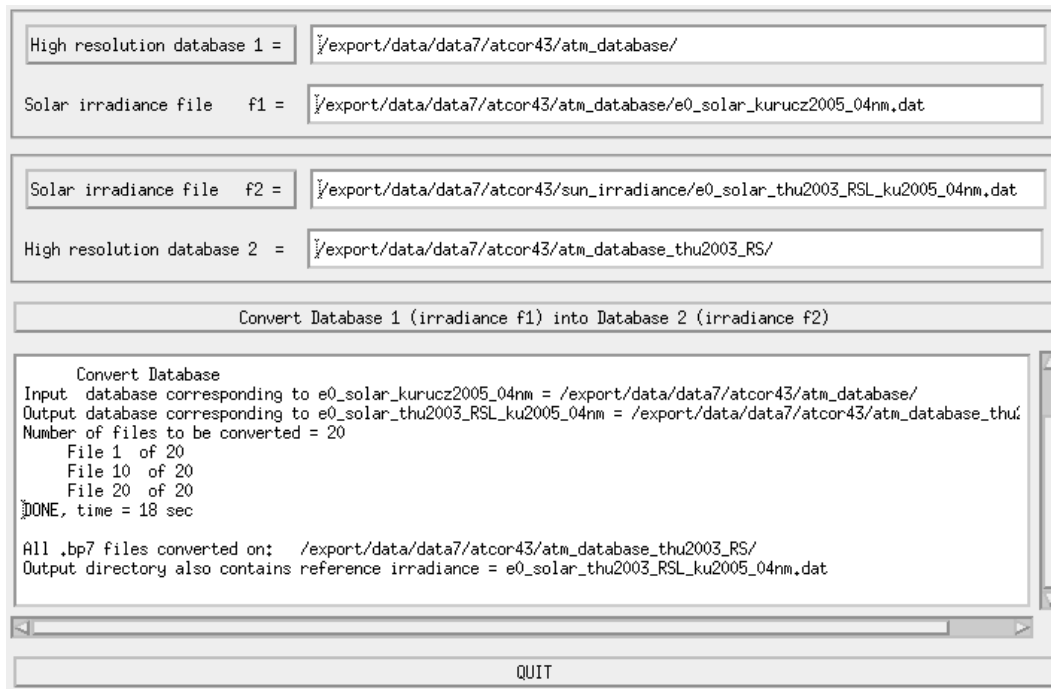


Figure 8.3: User interface to convert database from one to another solar irradiance.

8.2.1 Resample sensor-specific atmospheric LUTs with another solar irradiance

It is also possible to resample existing sensor-specific LUTs (".atm" files) with another solar irradiance spectrum. Input is a sensor from the "atcor/sensor/" folder (example name 'xxx') with the corresponding spectral response files (".rsp") and a high-resolution solar irradiance file from the "atcor/sun_irradiance/" directory (example: 'e0_solar_kurucz2005_04nm.dat').

Output is a new sensor subdirectory (example: "sensor/xxx_kurucz2005/") where the first 10 characters of the 'e0_solar_kurucz2005_04nm' (starting after the 'e0_solar_') are appended to the input sensor name. The contents of the input 'atcor/sensor/xxx/' are copied to the output directory, 'e0_solar_xxx.spc' is deleted (in the output directory) and replaced by the new 'e0_solar_xxx_kurucz2005.spc'. A comparison of 'e0_solar_xxx.spc' with 'e0_solar_xxx_kurucz2005.spc' shows the influence of the change of the irradiance spectrum. In addition, a new 'atm_lib/xxx_kurucz2005/' is created where all the LUTs '.atm' from the input 'atm_lib/xxx/' are replaced with the resampled selected irradiance spectrum. This new folder also contains a file "irrad_source.txt" identifying the selected irradiance source.

8.3 Supported I/O file types

Below, a list is compiled of all input and output files to the atcor main process.

8.3.1 Main Input

The input image to ATCOR-4 must have the band sequential (BSQ) ENVI format. Several data types exist for the encoding. The following data types of an input image are supported:

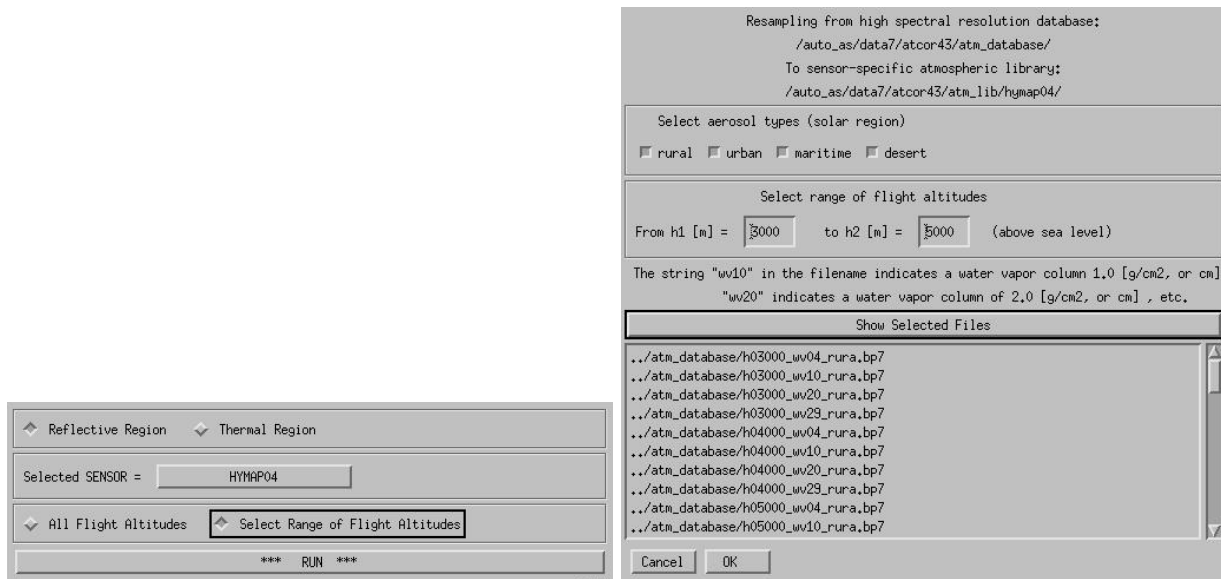


Figure 8.4: GUI panels of program RESLUT.

- byte, or unsigned 8 bit integer, ENVI data type = 1;
- signed 16 bit integer, ENVI data type = 2;
- unsigned 16 bit integer, ENVI data type = 12;
- signed 32 bit long integer, ENVI data type = 3;
- float (32 bit), ENVI data type = 4.

8.3.2 Side inputs

Before running the main processor, certain files have to be provided (the DEM derived files are not required for a flat terrain):

Parameter file extension: *.inn

This file is written automatically while using the graphical user interface. It may also be written externally for use in batch processing. See Section 8.4 for a detailed description.

Scan angle file extension: [image]_sca.bsq

Data layers defined in map geometry or in raw geometry with scan zenith, scan azimuth angle, and the absolute distance from aircraft to the pixel for each geocoded pixel. The first band of this image is used as standard input for ATCOR-4 radiometric processing whereas the second band is only required for a potential future BRDF correction. Only band 1 is mandatory for use with ATCOR-4.

Format: 3 bands 16-bit integer ENVI image.

1: Sensor zenith angle (degree * 100), 0 deg. is downward looking (nadir),

- unknown/invalid/background values are greater than 9000 (assigned value: 9100),

- pixels to the right* with respect to the flight direction have negative values

this is sometimes confusing in raw data formats as it depends on the scan direction of the

instrument...

2: Absolute azimuth angle to direction north (degree * 10, unknowns are lower zero)

3: Height of airplane above ground for each pixel [meters], unknowns are 0

4: Optional: pixel distance: distance in meters from aircraft to each pixel.

Optional: Relative azimuth angle to flight direction (would be in channel 2 while shifting channels 2/3 to 3/4)

Elevation file (DEM) extension: [dem]_ele.bsq

Elevation file containing the digital terrain model used for processing.

Format: single band ENVI file in either integer, unsigned integer, or floating point format.

Default unit: meters.

Slope file extension: [dem]_slp.bsq

Slope angle for each image pixel.

Format: single band ENVI file byte or 16-bit integer or float data type. Unit: degrees.

Aspect file extension: [dem]_asp.bsq

Aspect angle for each image pixel with respect to north.

Format: single band ENVI file 16-bit integer or float data type. Unit: degrees.

Skyview factor file extension: [dem]_sky.bsq

Skyview Factor

Format: single band ENVI file byte data type. Unit: % (percentage 0-100)

Cast shadow mask extension: [dem+angles]_shd.bsq

Shadow flag (0: cast shadow, 2: no shadow, 1: border region) for each image pixel.

Format: single band ENVI file byte data type.

Illumination file extension: [image]_ilu.bsq

External Illumination file, Format: ENVI floating point data file - external illumination files are only read if they are in floating point format and if they are in the same size as the imagery. Contents: a value of zero is a complete cast shadow whereas a value of 1 is in full illumination, corresponding to the definition of the $\cos(\beta)$ of the incidence angle, where $\beta = 0$ deg is a 90 degree incidence direction.

Calibration file extension: [sensor].cal

Calibration file, containing wavelength, c0 and c1 for each spectral band for conversion of image data to calibrated radiance $L = c0 + c1 * DN$, units $mW/(cm^2 sr \mu m)$

Format: 3 column ASCII, one header row

Response Function extension: [bandxxx].rsp

Spectral response function for one spectral band with wavelength reference and relative response

Format: 2 column ASCII, no header

Sensor Description extension: sensor_[type].dat

Sensor description file as created by the Function 'File:New Sensor' Format: ASCII.

Solar Reference extension: e0_solar_[type].dat

Solar reference function for the sensor as created when compiling the atmospheric LUT for a sensor. Format: ASCII, three columns: center wavelength, bandwidth, extraterrestrial solar irradiance.

8.3.3 Main output

The default output image data type is byte if the input is byte data. Then a scale factor $s=4$ is employed, i.e., the per cent reflectance value of each pixel is multiplied with $s=4$ and rounded to byte. As an example, a surface reflectance value of 20.2% will be coded as 81. However, the user can modify the scale factor (on ATCOR's main panel). A value of $s=10$ to $s=100$ causes the output file to be coded as signed 16 bit integer, i.e., with two bytes per pixel. The specification $s=1.0$ produces a float output image, i.e., with 4 bytes per pixel.

Attention: The float output could be used for testing on small images. For large files and an input data type of 2 bytes per pixel the output float image would require twice the disk space of the input image.

The default output data type is signed 16 bit integer for all integer (and float) input data employing the scale factor $s=100$. The scale factor is always included in the output ENVI header file.

Note: Any positive value of the scale factor s is accompanied with a truncation of surface reflectance values at 0 in the output cube. So a negative reflectance, e.g., caused by a wrong choice of visibility or inaccurate radiometric calibration, will be reset to zero in the output image. In the "SPECTRA" module no truncation is applied. If a user wants the output reflectance cube without zero-truncation, the scale factor s should be specified with a negative value, e.g., $s=-1$ will provide a float output surface reflectance retaining negative reflectance values, $s=-100$ will provide a 16 bit integer output file. The byte scale ($-10 < s < -1$ and output data range 0-255) cannot be used to represent negative values. The negative scale factor should only be used for test purposes, since the results do not make a physical sense, and some further processing options or modules are excluded in this case, e.g. the value added calculation of surface energy balance components, the automatic spectral classification (SPECL), BRDF corrections, or top-of-atmosphere radiance (TOARAD).

Summary of output data types :

- byte (default surface reflectance scale factor = 4.0)
- 16 bit signed integer (scale factor ≥ 10.0 , typically 10 or 100)
- float (scale factor = 1.0)

8.3.4 Side outputs

A number of side outputs is written by default after successful execution whereas some outputs are optional (marked with an '*').

Log file Name: [outputname].log

Standard log file containing all necessary information about the data processing.

Format: ASCII

Error log file Name: atcor_error.log

An error log file is written whenever an uncaught error occurred. Please send this file to the software supplier in case of malfunction.

Format: ASCII

Aerosol optical thickness* Name: [outputname]_atm_aot.bsq

Aerosol optical thickness map (scale factor 1,000).

Format: 1 channel, binary, 16-bit signed integer

DDV classification* Name: [outputname]_atm_ddv.bsq

Classification of dark dense vegetation, cast shadows, and water pixels map used for aerosol retrieval.

Format: 1-band ENVI byte file containing the three classes

Visibility index* Name: [outputname]_atm_visindex.bsq

Index of Visibility used for atmospheric correction (if variable aerosol distribution has been selected as processing option).

Format: 1-band ENVI byte file containing the indices

Water vapor* Name: [outputname]_wv.bsq

Columnar amount of water vapor calculated from image

Format: ENVI single band file, 16-bit signed integer; unit: cm (i.e., g/cm²)*1,000, i.e. scale factor 1,000.

Illumination Name: [outputname]_ilu.bsq

Illumination file created during processing (in case no external floating *.ilu has been provided).

Format: Scaled illumination in byte format from 0 to 100%, single band.

Haze/cloud/water* Name: [outputname]_out_hcw.bsq

Haze, cloud, and water mask.

Format: ENVI byte image; classes.

Fractional shadow* Name: [outputname]_fshd.bsq

Fractional cloud/building shadow (optional)

Format: ENVI Integer image; Scaled shadow between 0 and 1000.

Diffuse irradiance* Name: [outputname]_edif.bsq

Diffuse irradiance component, 1 band, 16-bit signed integer, unit ($Wm^{-2}nm^{-1}$).

Direct irradiance* Name: [outputname]_edir.bsq

Direct irradiance component, 1 band, 16-bit signed integer, unit ($Wm^{-2}nm^{-1}$).

Global irradiance* Name: [outputname]_eglo.bsq

Global irradiance (sum of edir and edif).

1 band, 16-bit signed integer, unit ($Wm^{-2}nm^{-1}$).

Value Added Vegetation* Name: [outputname]_atm_flux.bsq

Multi Layer file containing side outputs for vegetation, i.e. flux, fapar, savi, etc..

Format: ENVI signed 16-bit integer with scale factors as specified in the header.

8.4 Preference parameters for ATCOR

The preference parameters are located in a user specific HOME directory `"~/idl/rese/atcor4/"`, so multiple users of the same license can retain their personal preference settings. The settings of the last input image is saved separately together with GUI-related parameter settings in a save file called `"atcor4_settings.sav"`. In addition, the file `"preference_parameters.dat"` contains a number of default parameters that can be adjusted to scene properties. This file contains the parameters with a short description; a graphical view of the preferences can be found from the menu *File>Edit Preferences* 5.16.

More details are given here.

line 1	<p>A choice to set the water vapor values for water pixels:</p> <p>1 = average water vapor value of land pixels is assigned to water pixels, Option available for <i>iwv_model</i> = 1 and <i>iwv_model</i> = 2, see section 8.5.</p> <p>2 = line average of water vapor of land pixels is assigned to water pixels. Option only available with <i>iwv_model</i> = 1, see the job control parameter section 8.5.</p>
line 2	<p>A cloud reflectance threshold T_c (%) in the blue-green region to define a cloud mask. Pixels belong to the cloud mask if :</p> <p>(a1) $\rho^*(blue) > T_c$ or (a2) $\rho^*(green) > T_c$ (asterisk: apparent reflectance) Typical values for T_c range from 15 - 35% . If the cloud reflectance threshold is too high, clouds will be included in the haze mask. This will reduce the performance of the haze removal algorithm.</p>
line 3	<p>A surface reflectance threshold ρ_{w1} (%) for water in the NIR band. Pixels belong to the water mask if $\rho(NIR) < \rho_{w1}$, for details see the theoretical background document</p>
line 4	<p>A surface reflectance threshold ρ_{w2} for water in the 1600 nm region (if band exists). Pixels belong to the water mask if $\rho(NIR) < \rho_{w1}$ and $\rho_{1600} < \rho_{w2}$. The defaults $\rho_{w1} = 5\%$ and $\rho_{w2} = 3\%$ allow some margin for turbid water.</p>
line 5	interpolate bands in 760 nm oxygen region (0=no, 1=yes)
line 6	interpolate bands in 725 / 825 nm water region (0=no, 1=yes)
line 7	interpolate bands in 940 /1130 nm water region (0=no, 1=nonlinear, 2=linear)
line 8	<p>smooth water vapor map (box 50m*50m) (0=no, 1=yes)</p> <p>The water vapor map is calculated on a pixel-by-pixel basis, a moderate spatial smoothing (50m*50m or at least 3*3 pixels) reduces the noisy appearance.</p>
line 9	interpolate bands in 1400/1900 nm water region (0=no, 1=yes)
line 10	cut-off limit for max. surface reflectance (default 150%)
line 11	"_out_hcw.bsq" file (haze/cloud/water/land) (0=no, 1=yes, 2=hcw + quality file)
line 12	water vapor threshold to switch off the cirrus algorithm, unit [cm]
line 13	define saturation with factor b: $DN(saturated) \geq b DN(max)$, b=0.9 to 1.
line 14	<p>include non-linear influence of vegetation in water vapor calculation (yes/no)</p> <p>Only for water vapor retrieval with regressein (<i>iwv_model</i>=2)</p>
line 15	start/stop wavelengths for interpolation in the 940 nm region
line 16	start/stop wavelengths for interpolation in the 1130 nm region
line 17	start/stop wavelengths for interpolation in the 1400 nm region
line 18	start/stop wavelengths for interpolation in the 1900 nm region
line 19	haze/sun glint over water: (apparent) NIR reflectance $T_1(clear)$, $T_2(haze)$
line 20	reduce over/under-correction in cast shadow (0=no, 1=yes)
line 21	keep '*.atmi' files in sensor-specific 'atm.lib' (0=no, 1=yes)
line 22	adapt path radiance for blue bands (<i>visib</i> > 0, no DDV pixels) (0=no, 1=yes)

Note on the non-linear influence of vegetation in water vapor calculations:

This option applies to the APDA-regression algorithm and only if the 940 nm region is selected for the water vapor retrieval. The retrieval is based on a linear interpolation across the absorption region, and errors can occur due to the non-linear behavior of the reflectance of vegetated surfaces in this region. A simple empirical correction to the water vapor map W is applied using the NDVI calculated with the apparent reflectances in the red/NIR channels:

$$W(new) = W(old) - 0.1 (NDVI/0.7) \quad (cm) \quad (8.2)$$

The correction is only performed for pixels with $NDVI \geq 0.25$ and values $NDVI > 0.7$ are reset to 0.7.

Note on cut-off limit for surface reflectance

The default limit is set to a high value (150% reflectance) to avoid a truncation in spectra of high reflectance surfaces, e.g. snow and/or surfaces with specular reflectance. The previous default cut-off (before 2012) was set to 90%.

Note on factor b:

Factor b is a relative saturation factor applied to the maximum radiometric encoding, e.g. for 8 bit data and $b=1$ all pixels with $DN=255$ will be marked as saturated in the "_out_hcw.bsq" file (color coding: red). Setting $b=0.9$ implies pixels with $DN > 230$ will be considered as saturated or in the non-linear radiometric range close to saturation. This factor is only used for 8 and 16 bit (signed or unsigned) data, not for float or 32 bit data.

Note on the cloud mask:

The criterion (a1) or (a2) is also coupled with the conditions: $\rho^*(NIR)/\rho^*(red) < 2$ and

$\rho^*(NIR)/\rho^*(SWIR1) > 1$ and $NDSI < 0.7$,

where NDSI is the normalized difference snow index. A quality or probability mask for clouds is generated with the above three conditions and different apparent reflectance thresholds T_c in the blue/green spectral region. For $T_c = 15\%$ we define a low probability cloud, $T_c = 25\%$ a medium probability, and $T_c = 35\%$ a high probability cloud. The result is put into a cloud map file named "image-quality.bsq" if the input scene is named "image.bsq". The cloud mask in the "image_out_hcw.bsq" file is based on the user-defined threshold T_c (in the preference parameter file) and the above three conditions.

The band interpolation options are only intended for hyperspectral imagery. Linear interpolation is employed in the 760, 725, and 825 nm regions. Non-linear interpolation as a function of the vegetation index is applied in the 940 and 1130 nm parts of the spectrum to account for the leaf water content in plants. Interpolation in the strong atmospheric water vapor absorption regions around 1400 nm and 1900 nm is recommended because of the low signal and large influence of sensor noise. However, interpolation can be disabled if required, i.e., for test purposes. If enabled, non-linear interpolation is performed in the 1400 / 1900 nm regions by fitting the surface reflectance curves with a hull of a template vegetation or soil spectrum. All interpolated channels are marked with an '*' in the ENVI header of the output reflectance cube.

Haze or sunglint removal over water: the default apparent reflectance thresholds in the NIR channel for clear water and haze are $T_1(clear) = 0.04$ (or 4%) and $T_2(haze) = 0.12$ (or 12%), respectively. Pixels with values less than $T_1(clear)$ are defined as clear water, pixels with values between the thresholds $T_1(clear)$ and $T_2(haze)$ are assigned as haze (or sun glint). A lower value (i.e., $T_1(clear) < 0.04$) can be specified, but might cause a wrong classification of bright coastal water (sandy bottoms and bleached coral waters). If the threshold $T_1(clear)$ is too high, haze pixels might erroneously be put into the clear water category.

Cast shadow areas (mountainous terrain): these may contain over- and/or undercorrected pixels during the standard empirical BRDF correction. A reduction of these pixels is tried with the following steps:

- bright pixels in the NIR with $DN > DN(mean) - \sigma$, σ =standard deviation, are removed from the list of shadow pixels.

- a 7 x 7 pixel convolution filter is being applied to the shadow mask.
- a transition region shadow/sunlit is introduced.
- already dark pixels ($DN < DN(\text{mean}) - \sigma$ in the NIR) are not reduced in brightness during BRDF correction. The threshold is evaluated for a NIR channel, but the non-reduction of brightness (reflectance) is applied to all channels.

Note on keeping the '.atmi' files*

In the interactive mode, the temporary '*.atmi' files in the sensor-specific sub-directory of the 'atm_lib' are deleted to avoid an accumulation of these temporary files. However, in the batch mode it might be necessary to keep these files if subsequent runs with the same flight altitude exist: these need the files and they might have been deleted by the previous run. Then, the user should delete the '*.atmi' files after processing the imagery of the flight campaign. The GUI 'Edit Preferences' should be used to change the default setting.

Note on "adapt path radiance for blue bands"

This flag is set to 1 (enabled) as a default. It is only used if the option of constant scene visibility is selected, and if the visibility in the "*.inn" file is positive. Then the program might change the input visibility if negative reflectance pixels (in the red and NIR bands) occur, while a negative visibility in the "*.inn" file will not be changed even in case of negative surface reflectance values. Therefore, if this flag is set and the constant (positive) visibility is selected, the following steps are executed:

- Iteratively increase the visibility in the shortest wavelength blue band (up to vis=120 km), if negative surface reflectance pixels occur.
- Re-scale the path radiance using the shortest blue band and the red band ($0.66 \mu m$) as tie bands, using exponential interpolation.
- If no negative surface reflectance pixels occur (in the shortest blue band, for the selected input visibility) then search for dark pixels with ($NDVI > 0.4$, $\rho(NIR) > 0.1$).
- If the percentage of dark pixels is less than 4% of the scene, then terminate, else continue:
- Calculate the surface reflectance $\rho(\text{blue})$ and $\rho(\text{red})$ for these dark pixels.
- If $\rho(\text{blue}, \text{average}) > \rho(\text{red}, \text{average})$ then increase the visibility iteratively (until vis=120 km).
- Re-scale the path radiance with the final visibility using the shortest blue band and the red band ($0.66 \mu m$) as tie bands, using exponential interpolation.

8.5 Job control parameters of the "inn" file

If the file name of the input image is "example_image.bsq" then a file "example_image.inn" is created during the interactive ATCOR session. When all image processing parameters have been defined by the user this "inn" file is written to the directory of the corresponding image. When the image is re-loaded during a later session, or when a batch job is submitted, all input parameters are read from this file. It is suggested not to edit this file, because it might create inconsistent input data. The file might contain empty lines when input is not required for a specific case. The IDL routine

for writing this file is available on request for users who want to run ATCOR batch jobs without employing the interactive GUI panels. The contents of an *"inn"* file are:

line 1:

20/08/1989 Date (dd/mm/year) i.e., 20/08/1989 occupies the first 10 columns.

line 2:

100.0 ; scale factor reflectance (0-100% range)

The default reflectance scale factor in the output file is $s=100$ for 16 bit data and $s=4$ for 8 bit data, i.e. a reflectance value of say 21.75% is coded as 2175 and 87 for $s=100$ and $s=4$, respectively. For 8 bit input data and $s=4$ reflectance values above 63.75% are truncated at 255. If higher values are expected, a scale factor of $s=100$ should be selected. For $s=1$ the output file will be coded as 32 bit (float) data requiring twice the disk storage as for $s=100$. With $s > 0$, negative reflectance values are truncated to 0. With $s=-100$ or $s=-1$ the negative values are not truncated. This option may sometimes be useful to identify areas in the scene where overcorrection exists. This is usually caused by a too low visibility or in shadow areas.

line 3:

5.0 ; pixel size [m]

line 4:

casi04, casi04, ; name of *"../atcor4/sensor/casi04"* sub-directory, twice, separated by a comma and space

line 5:

1.0 ; gain setting

Any positive value is accepted, this gain setting g is used to replace the c_1 in the corresponding *".cal"* file with c_1/g , where g is the same for all channels.

line 6:

calfile ; calibration file name

line 7:

fscapix ; scan angle file *"*_sca"*, empty line, if image is not geocoded

line 8:

0.9500, 0 ; iemiss, dem_unit (surface emissivity, DEM height unit)

iemiss = surface emissivity option or value, disregarded if no thermal band exists.

iemiss = 0 invokes $\epsilon = 0.98$ to be consistent with the definition of earlier ATCOR versions.

Since iemiss=1 is reserved for the cover-dependent emissivity setting below, $\epsilon=1.0$ has to be approximated as iemiss=0.999 or iemiss=0.9999.

In case of multiple thermal bands this ϵ holds for the thermal band *itemp_band* employed for the surface temperature evaluation, see chapter 8.2. Further details are described in the thermal data processing chapter of the [Atcor ATBD](#) [106].

iemiss = 1 : fixed values of surface emissivity = 0.98 (water), 0.97 (vegetation), 0.96 (soil).

iemiss = 2 : surface emissivity map calculated with SPECL.

iemiss = 3 : NEM or ANEM method [106], requires multiple thermal bands.

iemiss = 4 : ISAC method, requires multiple thermal bands [106].

iemiss = 5 : both NEM and ISAC, but ISAC is currently only supported for flat terrain imagery.

dem_unit : 0 = [m], 1 = [dm], 2 = [cm] DEM height unit

line 9:

fele ; DEM elevation file name (empty line for a flat terrain calculation)

line 10:

fslp ; DEM slope file name (empty line for a flat terrain calculation)

line 11:

fasp ; DEM aspect file name (empty line for a flat terrain calculation)

line 12:

fsky ; DEM skyview file name (empty line for a flat terrain calculation)

line 13:

fsld ; DEM cast shadow file name (empty line for a flat terrain calculation, rugged terrain: empty if calculated "on-the-fly")

line 14:

atmfile ; atmospheric LUT file name (reflective region)

- If the automatic aerosol type retrieval is intended for batch jobs, the usual aerosol identifier in the file name (e.g. 'rura') has to be replaced with 'auto'. Example: file name (without path) is 'h03000_wv10_rura.atm', replace it with 'h03000_wv10_auto.atm'. The program then uses all aerosol types for the 3000 m altitude in the aerosol type estimate, and selects the one with the closest match, see the theoretical background documentation [106]. Of course, the user has to provide the desired aerosol types using the RESLUT program. altitude in the aerosol type estimate, and selects the one with the closest match, compare compare the [Atcor ATBD](#)[106]. Of course, the user has to provide the desired aerosol types using the RESLUT program. If only one aerosol type is available for the specified altitude, the program will use this atmosphere and quit the automatic aerosol mode. The automatic aerosol type retrieval requires the parameter npref=1 (variable visibility, see line 20 below). If npref=0, it is reset to npref=1.

In the interactive mode the user can just press the 'Aerosol Type' button on ATCOR's main panel to execute the aerosol type retrieval, irrespective of the '*.atm' name in the '.inn' file.

line 15:

temfile ; atmospheric LUT file name (thermal region, empty if no thermal band)

line 16:

1.0 ; adjacency range [km]

line 17:

35.0 ; visibility [km]

line 18:

0.7 ; mean ground elevation ([km asl] not used in case of rugged terrain, where elevation file applies

line 19:

33.0, 178.0 ; solar zenith, solar azimuth angle [degr.]

line 20:

4.2, 230.0 ; flight altitude [km asl], heading [deg. north]

line 21:

0, 0, 1, 0, 0, 0, 1 ; npref, iwaterwv, ihaze, iwat_shd, ksolfux, ishadow, icl_shadow

seven parameters controlling the processing options:

`npref = 0` : constant visibility

`npref = 1` : variable visibility, based on dark reference areas in the scene

`npref = -1` : variable visibility for each sub-image during batch job with tiling

`iwaterwv = 0` : no water vapor correction or no water vapor bands available

`iwaterwv = 1` : water vapor correction using bands in the 940 nm region

`iwaterwv = 2` : water vapor correction using bands in the 1130 nm region

`iwaterwv = 3` : 940 and 1130 nm bands are employed

- Haze removal with the HOT method is enabled by setting the parameter `ihaze > 0`, no haze removal is specified with `ihaze = 0`. Separate parameter values define haze removal over land, haze/sunglint removal over water, and the combination. Some criteria exist to check whether the haze/land removal is likely to yield good results. The haze/land algorithm is switched off if those criteria are not passed (`ihaze = 1`). However, as these criteria might fail in certain cases, there is the option of setting `ihaze = -1` which enforces the haze removal disregarding the termination criteria. The parameter `ihaze` enables the HOT haze removal. Better results are usually obtained with the HTM method to be used as a preprocessing step, see [Atcor ATBD\[106\]](#)..

`ihaze = 0` : no haze correction

`ihaze = 1` : haze/land correction, might be switched off if quality check criteria are not passed

`ihaze = 2` : haze over water removal (requires clear water pixels)

`ihaze = 3` : haze/land and haze/water removal

`ihaze = 4` : sun glint removal over water

`ihaze = -1` : haze/land correction is executed disregarding quality checks

`ihaze = -2` : is treated as `ihaze = 2`

`ihaze = -3` : haze/land removal is forced, haze/water removal needs clear water pixels

Haze removal is performed for the visible bands, sun glint removal for all bands.

`iwat_shd = 0` : water pixels are excluded from de-shadowing (land), default

`iwat_shd = 1` : water pixels are included in de-shadowing (land)

The option `iwat_shd = 1` might be useful if the internal water classification based on purely spectral criteria fails, and dark land pixels are classified as water (which is excluded from de-shadowing). So this flag is only used if the de-shadowing option is set and if no external water map is supplied. Example: scene is `"image1.bsq"`, and a file `"image1_water_map.bsq"` or `"image1_hcw.bsq"` exist in the same folder, then the flag `iwat_shd` is ignored because an external water map always has the first priority.

`ksolflux = 0` : file with value added channels not calculated

`ksolflux = 1` : value added channels are calculated (*.flx file)

`ishadow = 0` and `fshd=""` (empty string): no DEM cast shadow map is used

`ishadow = 0` and `fshd="valid file name"`: pre-calculated DEM cast shadow file is used

`ishadow = 1` : DEM cast shadow mask is calculated "on-the-fly"

The pre-calculated map avoids repeated on-the-fly calculations.

`icl_shadow = 0` : no cloud/building shadow correction

`icl_shadow > 0` : cloud/building shadow correction is performed

`= 1` : de-shadowed output as DN image corresponding to input DN scene

`= 2` : de-shadowed output as surface reflectance image

= 3 : de-shadowed output as surface reflectance and DN image

If a float '*_ilu.bsq' file exists in the scene folder, then the de-shadowing is performed with this file, i.e. the matched filter algorithm is not applied. Otherwise this '*_ilu.bsq' has to be renamed (temporarily) if the matched filter method shall be executed.

line 22:

0, 0.5, 0.5 : itriang, ratio_red_swir, ratio_blu_red

itriang = 0 : average vis. index of reference areas is employed for non-reference pixels

itriang = 1 : triangular interpolation of visibility index of reference areas

ratio_red_swir : ratio of surface reflectance of red to 2.2 μm band for the reference pixels

If no 2.2 μm band exists, but a 1.6 μm band, the ratio holds for the red-to-1.6 μm band.

If only VNIR bands exist (400 - 1000 nm) the ratio holds for the red-to-NIR band.

ratio_blu_red : ratio of surface reflectance of blue band to red band for the reference pixels.

line 23:

0, 65.0, 0.25 ; ibrdf, beta_thr, thr_g, parameters for BRDF correction in rugged terrain

For a flat terrain, these parameters are not used.

- ibrdf = 0 : no empirical BRDF/topographic correction (only Lambert correction)
- ibrdf = 1 : correction with cosine of local solar zenith angle (see [Atcor ATBD\[106\]](#)).
- ibrdf = 2 : correction with $\sqrt{\cos}$ of local solar zenith angle
- ibrdf = 11 : correction with cosine of local solar zenith angle, different for soil/sand and vegetation. Soil: \cos has exponent $b=1$. Vegetation has exponent $b=3/4$ and $b=1/3$ for $\lambda < 720$ nm and $\lambda > 720$ nm, respectively, i.e., option (a) in the BRDF panel, see Figure 5.54 ("weak" correction),
- ibrdf = 12 : correction with cosine of local solar zenith angle, different for soil/sand and vegetation. Soil: \cos has exponent $b=1$. Vegetation has exponent $b=3/4$ and $b=1$ for $\lambda < 720$ nm and $\lambda > 720$ nm, respectively, i.e., option (b) in the BRDF panel, see Figure 5.54 ("strong" correction).
- ibrdf = 21 : correction with $\sqrt{\cos}$ of local solar zenith angle, i.e., \cos has exponent $b=1/2$ for soil/sand. Vegetation has exponent $b=3/4$ and $b=1/3$ for $\lambda < 720$ nm and $\lambda > 720$ nm, respectively, i.e., option (a) in the BRDF panel, see Figure 5.54 ("weak" correction). This is the recommended standard yielding good results in most cases.
- ibrdf = 22 : correction with $\sqrt{\cos}$ of local solar zenith angle, i.e., \cos has exponent $b=1/2$ for soil/sand. Vegetation has exponent $b=3/4$ and $b=1$ for $\lambda < 720$ nm and $\lambda > 720$ nm, respectively, i.e., option (b) in the BRDF panel, see Figure 5.54 ("strong" correction).
- ibrdf = 30 : IRC topographic correction, see the theoretical background documentation [106].
- ibrdf = 40 : topographic compensation with C-correction method, see [Atcor ATBD\[106\]](#).
- ibrdf = 41 : topographic compensation with SE (statistical empirical) method, see [106]
- ibrdf = 50 : topographic compensation with LA + C (Lambert + C, see [106]),
- ibrdf = 51 : topographic compensation with LA + SE(standard), see [106],

- `ibrdf = 52` : topographic compensation with LA + SE(variant), see [106],
- `beta_thr` : threshold local solar illumination angle β_T where BRDF correction starts. If `beta_thr=0` (and `ibrdf > 0`) then the angle β_T is calculated in ATCOR depending on the solar zenith angle and its value can be found in the corresponding `"*_atm.log"` file. This threshold is only used for $0 < ibrdf < 30$.
- `thr_g` : g, lower boundary of BRDF correction factor, see the [Atcor ATBD\[106\]](#), only used for $0 < ibrdf < 30$.

The modified Minnaert method G is defined as:

$$G = \{\cos\beta/\cos\beta_T\}^b \geq g \quad (8.3)$$

where the angle β_T is the parameter `beta_thr` defined above. Further details can be found in the topography correction section of the [Atcor ATBD\[106\]](#).

line 24:

1, 0.820, 0.780, 0.600 ; `lai_model`, `a0_vi`, `a1_vi`, `a2_vi`

Parameters for the LAI model to be used if `ksolflux > 0`, see chapter "value added products" in [106]

line 25:

0.900, 0.950, 0.380 ; `c_fpar`, `a_fpar`, `b_fpar`

parameters for the `fpar` model to be used if `ksolflux > 0`, see [106]

line 26:

20.0, 0.83 ; air temperature (C), air emissivity, see [106]

Parameters for the net flux calculation (used for flat terrain, ignored for rugged terrain)

line 27:

20.0, 0.50, 0.65, 15.0, 6.3 ; `t_air`, `z0_ref`, `tgradient`, `p_wv`, `zh_pwv`, see [106]

`t_air` : air temperature (Celsius) at elevation `z0_ref`

`z0_ref` : reference elevation for `t_air` [km asl]

`tgradient` : air temperature gradients (Celsius per 100 m height)

`p_wv` : ([mb or hPa], default, water vapor partial pressure at `z0_ref`)

`zh_pwv` : ([km], scale height of water vapor, exponential decrease falls to 1/e value)

Parameters for the net flux calculation (rugged terrain, `ksolflux > 0`)

These are dummy values (not used) if `ksolflux=0`, or for a flat terrain.

line 28:

2, 2 ; `ihot_mask`, `ihot_dynr` , parameters for haze correction

`ihot_mask = 1` : small area haze mask

`ihot_mask = 2` : large area haze mask

`ihot_dynr = 1` : thin to medium haze levels are corrected

`ihot_dynr = 2` : thin to thick haze levels are corrected

line 29:

2, -0.500, 0.12, 0.08, 1 ; `iclshad_mask`, `thr_shad`, `phi_unscl_max`, `phi_scl_min`, `istretch_type`

Parameters for correction of cloud/building shadow effects, if `icl_shadow > 0`

Default values are put in this line even if `icl_shadow=0`.

For definitions and details about the parameters compare the shadow correction description in the [Atcor ATBD\[106\]](#).

iclsHAD_mask = 1,2,3 : small, medium, large cloud shadow mask
thr_shad = -0.500 : threshold for core shadow areas, -999 means threshold is calculated from image histogram
phi_unscl_max : max of unscaled shadow function Φ_{max} phi_scl_min : min of scaled shadow function Φ_{min}^* , see [106].
istretch_type: 1=linear stretching, 2=exponential stretching of Φ into Φ^* .

line 30:

ch940(1:6) vector with 6 channel numbers for the 940 nm water vapor retrieval
ch940(1) : left window channel (850 - 890 nm)
ch940(2) : right window channel (850 - 890 nm)
ch940(3) : left absorption channel (920 - 970 nm)
ch940(4) : right absorption channel (920 - 970 nm)
ch940(5) : left window channel (1000 - 1040 nm)
ch940(6) : right window channel (1000 - 1040 nm)

The left and right channel numbers for each window or absorption region may be the same. Put in a zero channel number if not applicable. If the 820 nm water vapor region is selected the vector ch940 holds the corresponding window and absorption channels for this region.

line 31:

ch1130(1:6) vector with 6 channel numbers for the 1130 nm water vapor retrieval
ch1130(1) : left window channel (1050 - 1090 nm)
ch1130(2) : right window channel (1050 - 1090 nm)
ch1130(3) : left absorption channel (1110 - 1155 nm)
ch1130(4) : right absorption channel (1110 - 1155 nm)
ch1130(5) : left window channel (1200 - 1250 nm)
ch1130(6) : right window channel (1200 - 1250 nm)

The left and right channel numbers for each window or absorption region may be the same. Put in a zero channel number if not applicable.

line 32:

chth_w1, chth_a1, chth_a2, chth_w2 bands for thermal water vapor retrieval (10 - 12 μm)
chth_w1 : left window channel (SWCVR method, [Atcor ATBD](#)[106])
chth_w2 : right window channel
chth_a1 : left absorption channel
chth_a2 : right absorption channel

line 33:

e_water, e_veget, e_soil, e_sand surface emissivities (adjusted NEM, channel with Tmax)

line 34:

0 iwv_model (water vapor retrieval: 1=no band regression, 2=band regression)

The choice iwv_model = 0 indicates the water vapor retrieval is disabled. Option 1 means the water vapor retrieval is performed for the selected bands, and in case of several measurement bands the one with the smallest standard deviation is selected (per 940 and 1130 nm region). Finally, if both regions are active, the average of the water vapor maps of both regions is taken. Option 2 employs a linear regression of bands which yields better results for the water vapor map if the data is noisy or not accurately calibrated. If iwv_model = 2 and channels in the 940 nm and 1130 nm regions are specified, then only the 940 nm region is evaluated with a linear regression of bands. If the regression is intended for the 1130 nm region, then the 940 nm channels (all channels in line 30) have to be specified as 0.

line 35:

0 icirrus flag for cirrus removal (0=disabled, 1=enabled, -1=forced))

The value icirrus = -1 enforces cirrus detection and removal, i.e., termination criteria are ignored.

line 36:

0 irradi0 flag for solar flux on ground (0=disabled, 1=enabled)

For *irradi0=2* the surface reflected (leaving) radiance is calculated additionally.

For a flat terrain, ASCII spectra of the direct, diffuse, and global flux on the ground are provided in the folder of the input scene, see [Atcor ATBD\[106\]](#) In case of a flat terrain the global (i.e. direct plus diffuse) flux image is calculated. For a rugged terrain the images of the direct and diffuse fluxes are calculated. Note: as the flux files have to use a float encoding (32bits/pixel) the file size is twice or four times the size of the input scene for a 16bit/pixel and 8bit/pixel input scene, respectively.

Notice concerning visibility iterations:

ATCOR will automatically iterate the initial visibility (parameter *visib* set in the *.inn* file) if the number of negative reflectance pixels is larger than 1% of the scene for the red band (around 650 nm, vegetation is checked here) or the NIR band (around 850 nm, water is checked here). The specified visibility is always kept if the visibility is set to a negative value, i.e., *visib=-20* means the program performs the calculation with *visib=20 km* and does not iterate even if a large number of negative reflectance pixels occurs.

If the parameter *npref* is set to 1 the program computes the visibility map based on dark reference pixels in the scene and *npref=1* overwrites the initial value of the *visib* parameter. With *npref=1* the program still iterates the average visibility of the visibility map by checking for water pixels in the NIR band unless the specified *visib* is negative. A constant scene visibility is employed for *npref=0*. In case of scene tiling and *npref=0* or *npref=1* the iterated visibility obtained for sub-scene 1 is also applied to all other sub-scenes to avoid brightness steps for the merged sub-scenes caused by potentially different visibilities.

Attention : If scene tiling has to be performed and the aerosol map is requested for each sub-image then specify *npref=-1*, but this could cause different average visibilities in the sub-scenes and potentially brightness steps at the sub-scene borders.

8.6 Problems and Hints

- *Distinction of haze and cloud, when can the haze removal algorithm be applied ?*

Ground surface information under haze areas can still be recognized in the 600-900 nm region, but the brightness contrast is low. The haze removal is only applied for channels in the 400 - 800 nm region. However, for cloud areas no ground information can be observed. If in doubt whether a certain area should be assessed as haze or cloud covered, take a look at the scene in the NIR (around 850 nm) channel: if surface features can be seen in this area, the haze algorithm might be applied. If not, the area is cloud covered and a haze removal run will not be successful.

- *The cloud mask is not appropriate.*

The cloud mask might contain too few pixels: then decrease the cloud reflectance threshold in the *../atcor/preferences/preference_parameters.dat* file. The default threshold is 25% reflectance in the blue-green spectrum. The opposite case can also happen: if the cloud mask comprises too many pixels the threshold has to be raised.

- *The haze mask is not appropriate.*

This problem may be connected with the setting of the cloud threshold. If the cloud threshold is too high, cloud pixels are counted as haze, and the results of the haze removal are bad because the haze algorithm is applied to clouds.

- *The water mask is not appropriate.*

This might lead to problems for the haze removal as well as the cloud/building shadow removal, i.e., water is erroneously counted as land and included in the land mask. Check the two water reflectance thresholds (NIR, SWIR region) in the *preference_parameters.dat* and modify them appropriately. Enable the output of a haze/cloud/water map, compare Fig. 4.14, to check the water mask. Read chapter 4.8. If necessary, modify the NIR/SWIR1 reflectance thresholds for water, an increase/decrease of the thresholds will increase/decrease the number of water pixels.

- *Rugged terrain: the slope and illumination maps show strong horizontal and vertical stripes.* Strong artifacts in the DEM files will immediately be visible in the atmospherically / topographically corrected surface reflectance image. This problem frequently occurs for resampled DEMs, e.g. the original DEM resolution is 30 m, which is resampled to a 5 m pixel size. Artifacts will be enhanced, especially if the stepsize of the original DEM (height resolution) is coded as integer. Float data would have smoother transitions. A simple way to get better results is the use of a larger kernel size for the slope/aspect calculation, e.g., kernel=5 or kernel=7 instead of the default kernel=3 (pixels), but this approach causes a reduction of the high frequency spatial information.

Attention: in addition to using float data before resampling, it is recommended to calculate the slope/aspect maps on the original (coarse spatial resolution) data, followed by the high-resolution resampling step for all DEM files (elevation, slope, aspect). Do not employ the sequence of resampling the elevation, followed by a slope/aspect calculation of the high-resolution elevation map, because this approach enhances artifacts!

Steps to reduce slope/aspect striping:

1. FLOAT(ELEVATION file) (if it is stored as integer)
2. Calculate SLOPE (and also ASPECT) with a low pass filter of 5x5 pixels
3. Resize SLOPE (ASPECT) file: factor 4 larger
4. Apply a lowpass filter (7x7 pixels)
5. Resize with factor 0.25 using nearest neighbor to obtain original size.

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