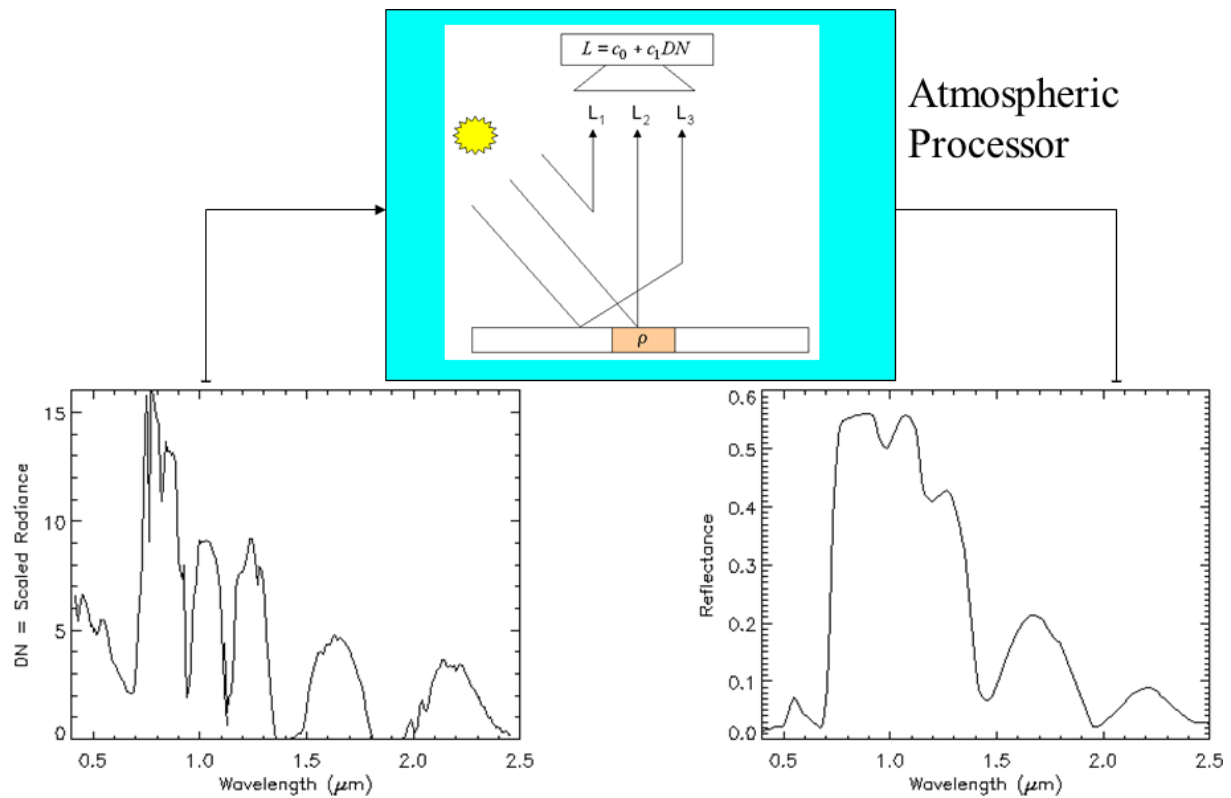


Atmospheric / Topographic Correction for Satellite Imagery

(ATCOR-2/3 Tutorial, Version 1.4, April 2019)



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The cover image shows the principal task of an atmospheric processor in the solar reflective spectrum: the input is a digital number (DN) or scaled radiance image with a certain number of channels, the output is surface reflectance, where the atmospheric influence has been removed.

The input signal consists of path radiance, transmitted radiance from the observed pixel, and radiation from the neighborhood (adjacency effect), schematically represented by the signal components L_1, L_2, L_3 , respectively.

The scaled radiance spectrum shows the influence of the additional path radiance L_1 , which has a strong influence in the blue-green part of the spectrum. In addition, regions with atmospheric absorption features can be observed. In the output surface reflectance spectrum these atmospheric features are eliminated.

ATCOR-2/3 Tutorial, Version 1.3, March 2019

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Chapter 1

Getting Started with ATCOR

This tutorial is a quick start guide for the satellite version of ATCOR. It covers the essential information about software installation and licensing as well as the basic steps to perform atmospheric correction. This tutorial is an addition to the extensive user manual provided with the software. Please refer to the manual [1] for details.

1.1 Installation

Please proceed as follows for a new installation of ATCOR:

1. download the software from the ReSe web site (<https://www.rese-apps.com/software/download>).
2. unzip the archive and put the created directory to any software installation path.
3. install the license file 'rese_license.pro' provided by email in the atcor_23 directory or any other valid idl-path location.
4. start IDL and type 'atcor' on the command line, then the save file 'atcor.sav' should be restored and the atcor GUI (graphical user interface) should appear.

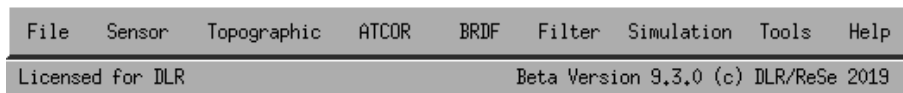


Figure 1.1: Top level menu of ATCOR.

Potential problems:

- IDL searches for the license file 'rese_license.pro', make sure such a file does not exist in several folders.
- IDL searches for the file 'atcor.sav', make sure only one file exists in all IDL paths (delete or rename older versions of 'atcor.sav').
- If licensing fails, ask for debugging instructions at info@rese.ch .

The next chapter describes the task of atmospheric correction with a pre-defined multispectral sensor for a flat terrain scene. It is recommended that beginners to ATCOR read this chapter first before moving to more difficult cases, e.g. scenes with mountainous terrain or hyperspectral (user-defined) sensors.

Chapter 2

Pre-defined or standard sensor

The input to an atmospheric processor is a grey level or digital number (DN) image for each channel. The digital number is proportional to the radiance L measured at the sensor:

$$L = c_0 + c_1 DN \quad (2.1)$$

where c_0 , c_1 are offset and gain of the radiometric calibration, respectively. Usually, all data providers deliver scenes with a meta file containing the offset and gain values for each channel. In addition, the meta file contains information on the solar and viewing geometry, on the geographic location, etc.

Since different radiance units are used by different data providers, these have to be converted into the unit employed by ATCOR, namely $mWcm^{-2}sr^{-1}\mu m^{-1}$.

ATCOR needs this basic information, then estimates the most important atmospheric parameters (aerosol and water vapor) to derive the surface reflectance. The schematic sketch on the title page shows that the total radiance signal L at the sensor consists of three components:

$$L = L_1 + L_2 + L_3 = c_0 + c_1 DN \quad (2.2)$$

- L_1 , path radiance: scattered radiation in the air volume between ground and sensor, consisting of all photons without ground contact.
- L_2 , ground reflectance radiation from a certain pixel.
- L_3 , radiation reflected from the neighborhood, scattered once or more times, being propagated into the direction of the viewed pixel.

After estimating the atmospheric parameters, ATCOR subtracts the radiance components L_1 and L_3 from the total at-sensor radiance L , and finally calculates the surface reflectance ρ from the component L_2 with a knowledge of the atmospheric transmittance as well as direct and diffuse solar flux on the ground. The corresponding atmospheric functions are pre-calculated with a radiative transfer code (MODTRAN-5) and stored in look-up tables (LUTs) for a large range of weather conditions and solar/view geometries.

2.1 Input files

The default image file format for ATCOR is the ENVI band sequential (BSQ) format. Other formats (e.g. BIL = band-interleaved by line, BIP = band-interleaved by pixel, TIFF) should be

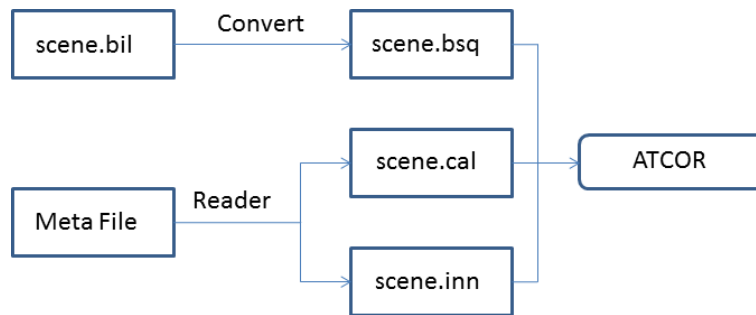


Figure 2.1: ATCOR input files.

converted, e.g. with ATCOR's File / Export options, see figure 2.2.

After the file format conversion into ENVI band sequential (example file name: 'scene.bsq'), the next step is the reading of the sensor meta file, which will create the calibration file ('scene.cal') and the ATCOR input parameter file ('scene.inn'), see figure 2.1. This completes the preparation phase and ATCOR can then be started.

It is recommended to start with the simplest case, namely atmospheric correction in flat terrain, see section 2.4, before moving on to the processing of scenes in mountainous terrain, where a digital elevation model (DEM) or digital surface model (DSM) is needed, see section 2.5.

Notes of caution:

1. SPOT imagery (SPOT, Kompsat, Formosat, Pleiades) are delivered in the DIMAP format, and often with the band sequence NIR, Red, Green. Make sure to convert the channels in the 'scene.bsq' with ascending wavelength.
2. Landsat-4/5 TM data: ATCOR allows a processing with or without the thermal band 6. If band 6 is included, it must be layer 6 in the band sequential file 'scene.bsq', and layer 7 is the $2.2\ \mu\text{m}$ band.
3. Landsat-7 ETM+ data is delivered with band 6 in the low gain ('band 61') and high gain ('band 62') modes. For consistency with Landsat-4/5 TM only one thermal band can be selected (either band 61 or band 62) and it must be layer 6 in the band sequential file 'scene.bsq'.
4. Landsat-8 data can be processed with or without the TIRS bands

These notes are automatically taken into account if the import for standard sensors is used, see chapter 2.3.

2.2 Read meta file information

The meta file reader provides two input files to ATCOR. When pressing the 'File' button of the ATCOR top level menu (see figure 1.1), the choices of figure 2.2 appear.

Select the button 'Read Sensor Meta Data' and a list of frequently used sensors appears (figure 2.3). The example selects a Worldview-2 metafile (*.IMD). Two input files for ATCOR are created:

- '*.cal', containing the radiometric calibration offset and gain per band.

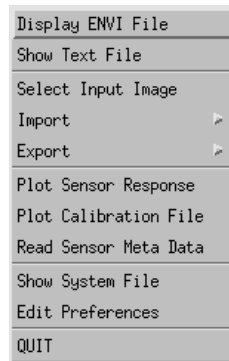


Figure 2.2: File selection of buttons.

- '*.inn', containing the input parameter file for ATCOR. It includes the name of the selected sensor, and the solar and view geometry for the current scene. Since the atmospheric visibility (VIS) and ground elevation (h) are not known at this time, they are assigned default values (VIS=23 km, h=0 km, i.e., sea level). These values can be updated with the ATCOR GUI (Graphical User Interface).

If the input scene is named 'scene.bsq', then the '*.inn' file has to be renamed as 'scene.inn' and all ATCOR input files are supplied.

Note

The meta file reader has no information on the appropriate atmosphere. Therefore, it sets the following defaults for the .inn file:

- US Standard atmosphere (concerning temperature, pressure, humidity profile). This choice selects the atmospheric water vapor column and it is not critical for most multispectral sensors, because their channels are not located in water vapor sensitive spectral regions.
- The elevation is set to zero (sea level). This value might be updated in the ATCOR GUI if necessary. Height differences up to 300 m have a negligible impact.
- rural aerosol, VIS=23 km. This visibility is only used if no dark reference pixels are found, see next bullet.
- Parameter npref = 1. This means the visibility is automatically calculated from the scene if dark reference pixels (dark vegetation, dark soil, water) are found in the scene. This 'variable visibility' flag can be disabled, i.e. npref = 0, in the ATCOR GUI by selecting the image processing option 'Variable Visibility No'. Then the specified constant visibility is used. If the visibility estimator calculates a lower or higher visibility (say VIS=15 km) then the default VIS=23 km will be overwritten. The meta file reader enables the visibility estimator flag to provide the necessary flexibility.
Of course, if the scene contains no dark reference pixels, the default visibility VIS=23 km is used, which might not be correct. However, the user can modify the VIS value (in the ATCOR GUI) and check its influence in the SPECTRA module, see chapter 2.4.

Unknown meta file

If the reading of a meta file format is not supported for a certain sensor, the user has to generate

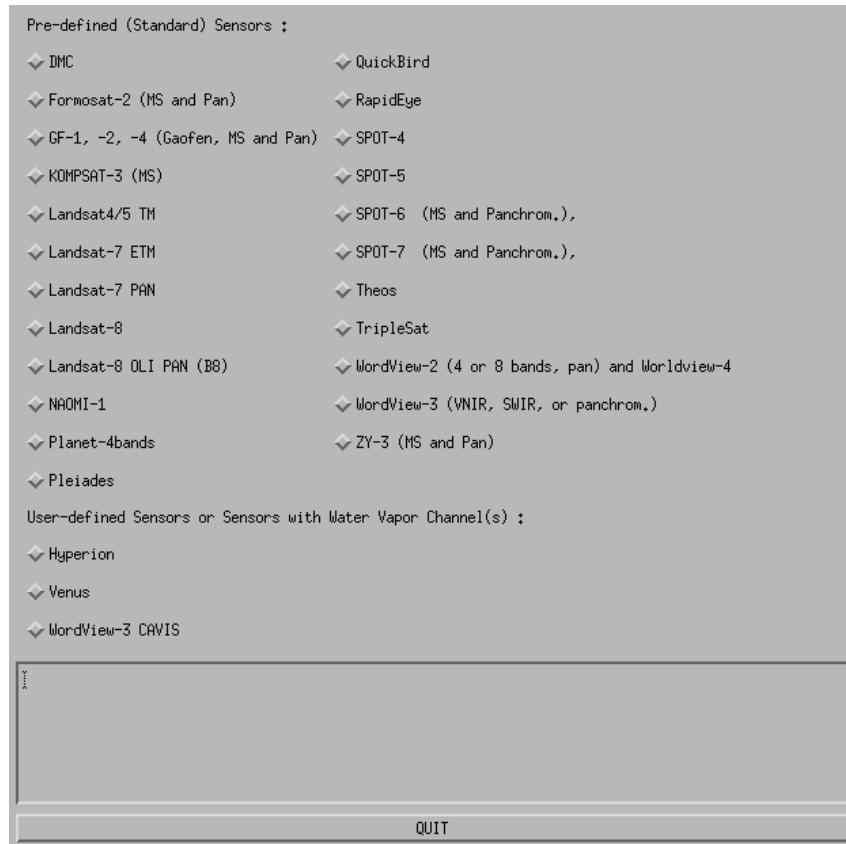


Figure 2.3: Sensor meta file selection.

the corresponding '.cal' file. Attention: when reading the offset, gain values from the meta file take care of the required ATCOR radiance unit ($mWcm^{-2}sr^{-1}\mu m^{-1}$).

However, the '.inn' file is also generated by the ATCOR graphical user interface (GUI), where widgets are provided for the solar / view geometry. The user has to take this information from the meta file.

2.3 Import for standard sensors

For selected standard sensors there is an import module which reads the meta file information and converts the native format (geotiff: '.tif', '*.TIF'; and jpeg2000: '.jp2', '.JP2') into an ENVI band sequential ('bsq') format. It is available with a GUI (Graphical User Interface) on ATCOR's main panel (use 'File', 'Import'). Currently, the following sensors are supported:

- Landsat-4/5, Landsat-7, Landsat-8
- Sentinel-2
- DMC (Disaster Monitoring Constellation)
- RapidEye
- SPOT-4 to SPOT-7

- Planetlabs
- Pleiades
- TripleSat
- Worldview-2, Worldview-3

The import function creates:

- an ENVI bsq file with all channels
- the radiometric calibration file ('.cal')
- the input parameter file ('.inn')

Then ATCOR can be started in case of a flat terrain. For a rugged terrain, the user has to supply the DEM file and resample it for the respective scene (use 'Topographic', 'DEM Preparation' on the main panel of ATCOR). The corresponding topographic files (elevation '*_ele.bsq', slope '*_slp.bsq', aspect '*_asp.bsq', and the optional skyview '*_sky.bsq') then have to be included in the '.inn' file using the ATCOR3 GUI.

The other possibility is a fully automatic batch processing. For a rugged terrain, the user has to provide the DEM file. Input to the batch processor is the file name of the input scene ('.tif', '.jp2', or '.bsq') and optionally the DEM file name. If the DEM file is specified, it is resampled to fit the scene, and the corresponding topographic files are calculated. If the DEM file is specified then ATCOR-3 is invoked else ATCOR-2. The sensor-specific modules for batch processing are:

- landsat5_batch (also applies to Landsat4 TM), landsat7_batch, landsat8_batch
- s2_batch for Sentinel2
- dmc_batch for DMC
- re_batch for RapidEye
- spot_batch for SPOT-4 to SPOT-7 (the SPOT mission ID is taken from the metafile)
- pla_batch for PlanetLabs
- ple_batch for Pleiades
- wv2_batch for Worldview-2, and Worldview-3

When typing the name of the batch module without any parameter, the optional keywords are displayed, e.g. the average scene ground elevation 'gnde' (default gnde=0, i.e., sea level) or 'dh' for dehazing.

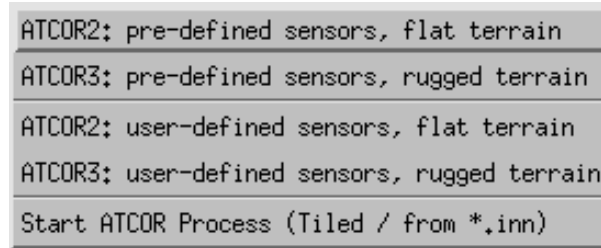


Figure 2.4: Choices in 'Atm. Correction'.

2.4 Flat terrain

The most frequent case is the processing of flat terrain imagery with pre-defined sensors, e.g. Landsat TM, ETM+, SPOT, RapidEye, Worldview-2 etc. The first prerequisite is the scene data in the ENVI band-sequential format ('scene.bsq'). In addition, a radiometric calibration file must exist ('scene.cal'). If the 'Read Sensor Meta Data' was used, it generated the 'scene.cal' and the input parameter file ('scene.inn') similar to the import of standard sensors in the last section. If neither option is employed and ATCOR is started from scratch, then the '.inn' file will be created from the ATCOR GUI, where the user has to fill out the required widgets.

Figure 2.4 presents the available choices when pressing the button 'Atm. Correction' of the top level menu. In this section we describe the option 'pre-defined sensors, flat terrain'. Figure 2.5 shows the corresponding menu.

The ATCOR2 main menu contains the widgets that have a counterpart for the parameters in the '*.inn' file. If a widget is changed (e.g. 'Visibility') and if one of the buttons directly above the 'MESSAGES' is pressed, then the '.inn' file is updated.

The task of the bottom line buttons is

- 'SPECTRA': calculates the surface reflectance spectrum for a small box in the scene, see figure 2.6. It allows a coarse check whether the visibility and radiometric calibration yield reasonable spectra. The example presents a vegetation and soil spectrum in two separate plot windows. A comparison with some typical library spectra (click button 'reference spectrum' in the upper right part of the SPECTRA panel) can also be conducted (green spectra in figure 2.6). More details are given in the User Manual.
- 'AEROSOL TYPE': proposes the suitable aerosol type (rural, urban, maritime, desert). Requires dark reference pixels in the scene.
- 'VISIBILITY': estimates the visibility for the currently selected aerosol type. Requires dark reference pixels in the scene.
- 'INFLIGHT CALIBRATION': calculates an updated set of calibration coefficients if ground reflectance spectra are available. See the corresponding chapter in the User Manual.
- 'HELP': provides a brief help on inflight calibration.
- 'WATER VAPOR': calculates the water vapor map (without surface reflectance cube) if the required spectral bands exists. Can be used to test the quality of this map for different channel combinations without having to compute the reflectance cube.

INPUT IMAGE FILE	<input type="text" value="/export/data/data7/atcor2+3/demo_data/tm_flat/tm_essen1000.bsq"/>	Date (dd/mm/year) 20/08/1989
OUTPUT IMAGE FILE :		<input type="text" value="/export/data/data7/atcor2+3/demo_data/tm_flat/tm_essen1000_atm.bsq"/> <input type="checkbox"/> OVERWRITE
Scale Factor = <input type="text" value="4.0"/>		<input type="button" value="Help"/>
<input type="button" value="Satellite / Sun Geometry"/>		<input type="button" value="Band selection"/>
Selected SENSOR =	<input type="button" value="Landsat-4/5 TM"/> <input type="button" value="Select M - Z"/>	Pixel size [m] = <input type="text" value="30.0"/>
CALIBRATION FILE	<input type="text" value="/export/data/data7/atcor2+3/cal/landsat4_5/tm_standard.cal"/>	
ATMOSPHERIC FILE :	<input type="button" value="aamsrura"/>	ATM. FILE for thermal band(s) : <input type="button" value="midlat_summer"/>
Adjacency range [km] =	<input type="text" value="1.00"/> <input type="button" value="Help"/>	Zones = <input type="text" value="1"/>
Visibility [km] =	<input type="text" value="19.1"/>	Solar zenith [degree] = <input type="text" value="43.0"/> Ground elevation [km] = <input type="text" value="0.1"/>
<input type="button" value="SPECTRA"/>	<input type="button" value="AEROSOL TYPE"/>	<input type="button" value="VISIB. ESTIMATE"/> <input type="button" value="INFLIGHT CALIBRATION"/> <input type="button" value="Help"/> <input type="button" value="WATER VAPOR"/> <input type="button" value="IMAGE PROCESSING"/>
MESSAGES	<div>Output file already exists: change name or press OVERWRITE !</div>	
<input type="button" value="QUIT"/>		

Figure 2.5: ATCOR2 main menu.

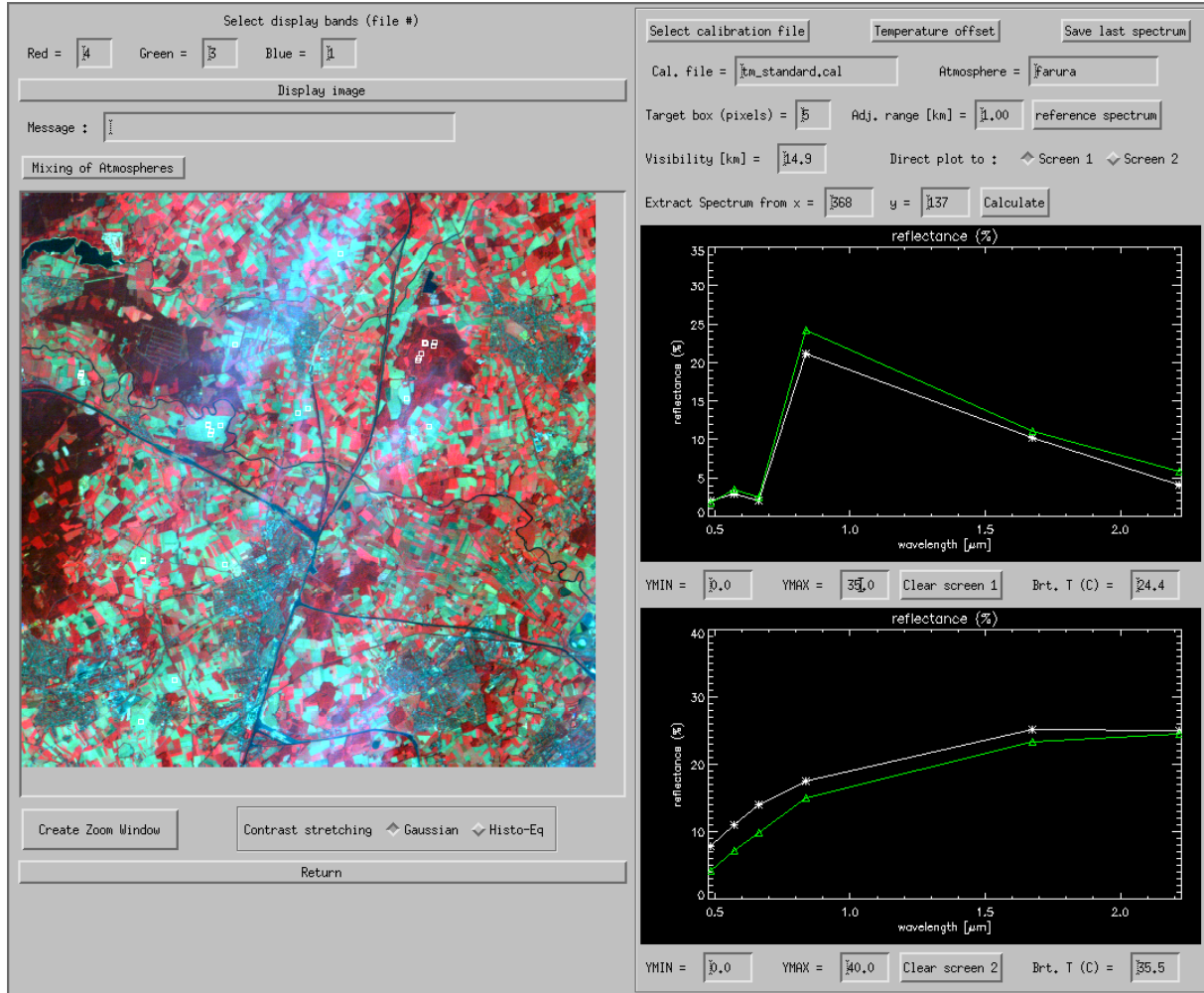


Figure 2.6: Spectra module.

- 'IMAGE PROCESSING': starts the image processing in the interactive mode. In case of very large scenes an error might appear: 'not enough memory to allocate array'. Then start ATCOR in the 'Tiling' mode, see last button in figure 2.4.

It is recommended to select an appropriate 'ATMOSPHERIC FILE' (e.g. mid-latitude summer, rural aerosol), then press the 'VISIBILITY' button to obtain the proposed scene visibility. Next, try the SPECTRA module to check if the proposed visibility yields expected surface reflectance spectra. Then continue with 'IMAGE PROCESSING'. Here a number of options exist (figure 2.7). It is recommended to start with the simplest option (everything 'No') before enabling more elaborate options.

Standard output files after atmospheric correction are:

- A map of pre-classification ('scene_out_hcw.bsq'), containing haze, cloud, water, land, shadow etc. The generation of this file can be suppressed if the parameter ihcw in the preference settings is set to zero, see chapter 5.1.
- A map of employed dark reference pixels ('scene_atm_ddv.bsq'), which is used to calculate

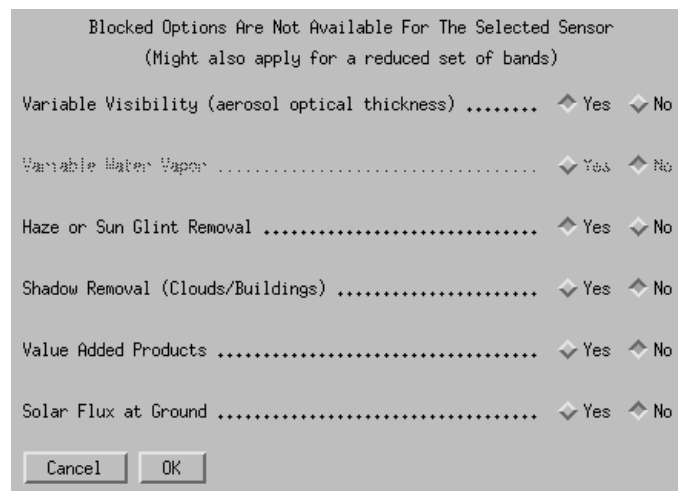


Figure 2.7: Image processing options.

the visibility / aerosol optical thickness. It is not available if the scene is processed with a constant visibility specification.

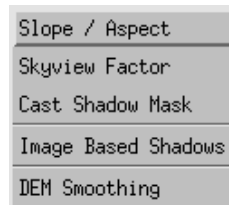
- A map of aerosol optical thickness at 550 nm ('scene_atm_aot.bsq'), not available if the scene is processed with a constant visibility specification.
- A map of columnar water vapor, if the required spectral bands exist ('scene_atm_wv.bsq').
- The surface reflectance cube ('scene_atm.bsq').

2.5 Mountainous terrain

Compared to the flat terrain three additional input files are necessary:

- the digital elevation model (DEM)
- the derived slope map
- the derived aspect map

The first step is to provide a DEM file and to orthorectify the scene with this DEM. The next step has to compute the mandatory derived files of terrain slope and aspect (unit degrees). This can be done with the 'Topographic' functions of ATCOR (or with other software tools): With the buttons 'Topographic', 'DEM Preparation' a user-supplied DEM file will be resampled to fit the scene.



The following nomenclature is used by ATCOR: the DEM elevation file should have an arbitrary name (say 'xxx') followed by '_ele.bsq', i.e. 'xxx_ele.bsq'. Then the slope and aspect files are named 'xxx_slp.bsq' and 'xxx_asp.bsq', respectively. The skyview and cast shadow files are optional because they are only needed for scenes in very steep terrain.

The next two figures show the panels of the slope/aspect and skyview calculations. These files are automatically calculated when using the 'DEM Preparation' module.

Concerning the generation of the '*.inn' and '*.cal' files from the sensor meta data the reader is referred to the previous sections 2.2, 2.3.

Now the 'Atm. Correction' button can be pressed, selecting the option 'ATCOR3: pre-defined sensors, rugged terrain'. The menu is very similar to the panel in figure 2.5, the only difference is that the solar azimuth angle is also specified on this graphical interface.

Additionally, another panel appears for the specification of the DEM related files, see figure 2.11. As a default, the program searches for the DEM files in the same folder as the scene. IF they are placed elsewhere, press the button 'Update DEM Path' to specify the appropriate folder. When processing the scene, the average elevation is extracted from the '*_ele.bsq' file and put into the '*.inn' file. In addition, the file names of the DEM files are automatically included in the '*.inn' file. The action of all other buttons (e.g. 'SPECTRA', 'VISIBILITY' etc) is described in the previous flat terrain section.

2.6 Output files

For a flat terrain processing, the standard output files after atmospheric correction are:

- A map of pre-classification ('scene_hcw.bsq'), containing haze, cloud, water, land, shadow etc. The generation of this file can be suppressed if the parameter ihcw in the preference settings is set to zero, see chapter 5.1.

DEM File may have 16 or 32 bit integer or float data

Input DEM FILE :

SLOPE File : ☐ OVERWRITE

ASPECT File :

Kernel size (box for averaging) =

DEM resolution (x,y), pixel size [meters] =

DEM height (z) unit :

*** RUN ***

MESSAGES

Figure 2.8: Menu for slope/aspect calculation.

DEM File may have 16 or 32 bit integer or float data

Input DEM FILE :

SKY VIEW FACTOR : ☐ OVERWRITE

DEM resolution (x,y), pixel size [meters] =

DEM height (z) unit :

Undersampling factor for faster processing [Pixels]:

Azimuth resolution (degr.) =

Elevation resolution (degr.) =

A high azimuth / elevation resolution is very time consuming !
(Undersampling factor of 3 pixels is recommended for large scenes)

*** RUN ***

MESSAGES

Figure 2.9: Menu for skyview calculation.

INPUT IMAGE FILE: Date (dd/mm/year) 11/09/1999

OUTPUT IMAGE FILE: ☐ OVERWRITE

Scale Factor =

Selected SENSOR = Pixel size [m] =

CALIBRATION FILE:

ATMOSPHERIC FILE: ATM. FILE for thermal band(s):

Adjacency range [km] = Zones =

Visibility [km] = Solar zenith [degree] = Solar azimuth [deg.] =

MESSAGES

Figure 2.10: ATCOR3 main menu.

Update DEM Path Path =

Mandatory Files

Elevation = DEM height (z) unit:

Slope [degree] =

Aspect [degree] =

Optional Files

Sky View Factor [%] =

Cast Shadow [0,1] =

☐ Use pre-calculated shadow file (if existing)

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

--> Check "*etm_11_09_99_sub_ilu.bsq" for possible DEM-related artifacts.

Message

Figure 2.11: Panel for DEM files.

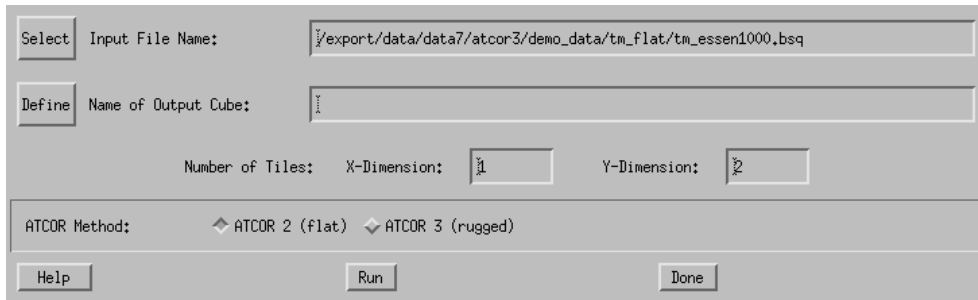


Figure 2.12: Panel for tiling of scenes.

- A map of employed dark reference pixels ('scene_atm_ddv.bsq'), which is used to calculate the visibility / aerosol optical thickness. It is not available if the scene is processed with a constant visibility specification.
- A map of aerosol optical thickness at 550 nm ('scene_atm_aot.bsq'), not available if the scene is processed with a constant visibility specification.
- A map of columnar water vapor, if the required spectral bands exist ('scene_atm_wv.bsq').
- The surface reflectance cube ('scene_atm.bsq').

For a rugged terrain, an additional file is provided containing the illumination map. This is the cosine of the local solar zenith angle multiplied with a scale factor of 100 and byte coded. The name is 'scene_ilu.bsq'.

2.7 Tiling for very large scenes

For very large scenes a processing may fail with the error message (on the IDL command line)

'Not enough memory to allocate array'.

In this case, the tiling option should be used, see figure 2.4. Figure 2.12 presents the corresponding menu. The number of tiles (sub-images) in x and y direction can be specified. Then the processing is performed separately for each tile, and finally all tiles are merged to the original scene size. The number of tiles should be as small as possible, because the result might depend on the tile definition (since some steps evaluate statistical properties of tiles which can vary with size). The required size depends on the memory resources of the machine and the operating system, so it has to be tested for each machine.

If no output name is specified, the default name is the same as the input file name plus the '_atm' appended (i.e. 'tm_essen1000_atm.bsq' in this example).

Chapter 3

User-defined or advanced sensor

In principle, the same preparation steps apply as for a pre-defined standard sensor. Please read chapter 2. However, some additional steps are needed to define the sensor and to calculate the corresponding look-up tables for the atmospheric correction. The required additional steps are listed below the 'New Sensor' entry of the top level ATCOR menu:

Define Sensor Parameters
Create Wavelength File .wvl from Image Header
Create Channel Filter Files
BBCALC: Blackbody Function $T = f(L)$
RESLUT: Resample Atm. LUTs from Monochr. Database

Figure 3.1: Steps to define a new user-defined sensor.

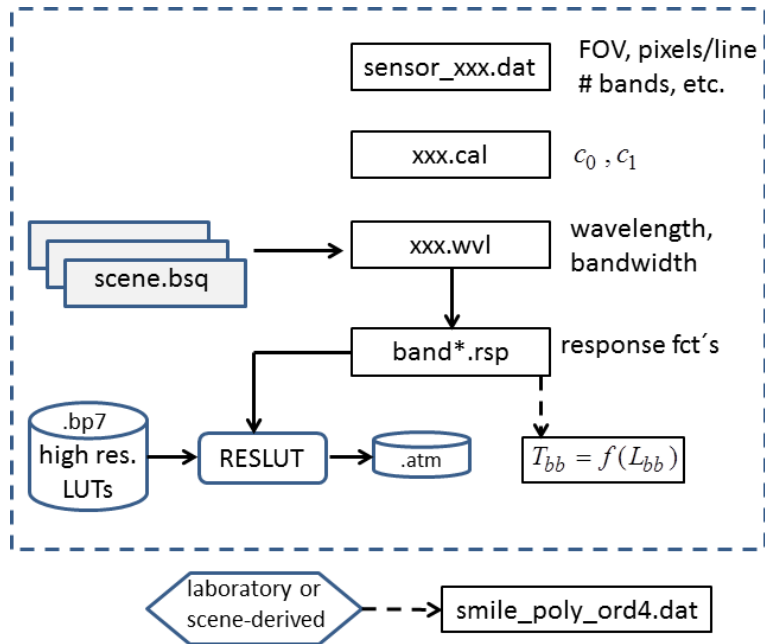


Figure 3.2: Sketch of sensor preparation files.

Figure 3.2 presents a sketch of the required preparation files. The part outside the dashed rectangle is only required for spectrometers affected by spectral smile. Details are described in the next section.

3.1 Preparation phase

1. Definition of the sensor field-of-view (FOV), number of bands in different spectral regions, etc. Example: a hyperion sensor with 191 bands shall be created, containing a subset of the original 242 bands without the very noisy bands. All user-defined sensors are located in the './atcor/sensor/' folder. Therefore, the new 'hyperion191' sensor description has to be defined in the folder './sensor/hyperion191/' and the file name must be 'sensor_hyperion191.dat' or 'hyperion191.dat'. The file can be created by copying the '.dat' from another sensor and editing it to update the FOV, number of bands etc.

The file 'sensor_hyperion191.dat' can also be created with a GUI: press the button 'Define Sensor Parameters' and fill out the required widgets, see figure 3.3. The next table presents an example for 'sensor_hyperion191.dat'. The last line is only required if the spectral smile characterization is included, i.e. if the file 'smile_poly_ord4.dat' is provided.

0.6	256	across-track FOV [degree], pixels per line
1	191	first, last reflective band (0.35-2.55 μm)
0	0	first, last mid IR band (2.6 -7.1 μm)
0	0	first, last thermal band (7.1 -14 μm)
1		flag for tilt capability (1=yes, 0=no)
0		required dummy
1	5	ismile (0=no, 1=yes), 5 = Gaussian spectral filter function

Table 3.1: Example of a sensor definition file (no thermal bands).

2. Create the wavelength and bandwidth file 'sensor_hyperion191.wvl': press the button 'Create Wavelength File .wvl from Image Header'. The the menu of figure 3.4 will pop up. Specify the ENVI image file (already with the subset of 191 bands) and the sensor name 'hyperion191'. Then an ASCII file with 3 columns is created containing the band number, center wavelength, and bandwidth for each channel.
3. Create the spectral response files for each band using the 'sensor_hyperion191.wvl', see figure 3.5. Here, different shapes of the channel filter functions can be selected: these correspond to simple analytical functions, number 5 (Gaussian) is the likely choice for spectrometers. Then for each channel a normalized spectral response ASCII file with 2 columns (wavelength in μm , response from 0 to 1) is created, including a header line specifying the number of spectral points.

These files are later used during the resampling of the high-resolution ('monochromatic') spectral database of atmospheric correction functions to obtain sensor-specific LUTs.

If no simple analytic function is able to describe the filter shape, then each channel has to be defined as tabular data. This information can usually be taken from laboratory measurements. Again, the response function of each band has to be defined in the same way as for the analytic functions, i.e., one ASCII file per band with a header line containing the number of spectral points, then two columns of data (wavelength, spectral response). The files must be named 'band001.rsp', 'band002.rsp' etc. In case of less than 100 bands, the numbering is 'band01.rsp',

'band02.rsp', etc. In case of less than 10 bands, the file numbering is 'band1.rsp', 'band2.rsp', etc.

The spectral binning option allows the binning of spectral response functions of the selected type. This is of interest for sensors with programmable binning of channels, e.g. HySpex. A binning factor of 2, for example, means that two neighboring bands are combined into a new band, weighted with their filter functions, and the new sensor has a factor 2 less bands than the non-binned version.

4. The blackbody functions for each band are only required in case of thermal bands, see figure 3.6. Here the first response file ('band001.rsp') is selected, and for all thermal bands a least squares fit of $T_{bb} = f(L_{bb})$ is performed using the corresponding channel filter files ('band*.rsp'). Results are written to a '*.bbfit' file in the pertaining sensor folder.
5. Sensor-specify atmospheric correction functions (LUTs) have to be calculated from the high-resolution spectral database. This is performed by resampling the high-resolution data with the spectral filter function of each band, see figure 3.7. Different resampling steps are required for reflective and thermal bands.

Figure 3.3: Definition of sensor parameters.

Figure 3.4: Generation of wavelength / bandwidth file.

Envi Header - or - 3 Columns: band number, center wavelength, bandwidth (micron or nm)

Wavelength File =

Select Type of Filter Function :

- ◆ 1 : Butterworth order 1 (slow drop-off)
- ◆ 2 : Butterworth order 2 (close to Gauss)
- ◆ 3 : Butterworth order 3 (between Gauss/rectangular)
- ◆ 4 : Butterworth order 4 (close to rectangular)
- ◆ 5 : Gauss
- ◆ 6 : Rectangular
- ◆ 7 : Triangular
- ◆ 8 : Shape changes from near rectangular (first bands) to triangular (last bands) due to binning

Spectral Binning Factor:

Output Directory =

Generate Filter Files (*.rsp)

Filter files ("band*.rsp") created !

QUIT

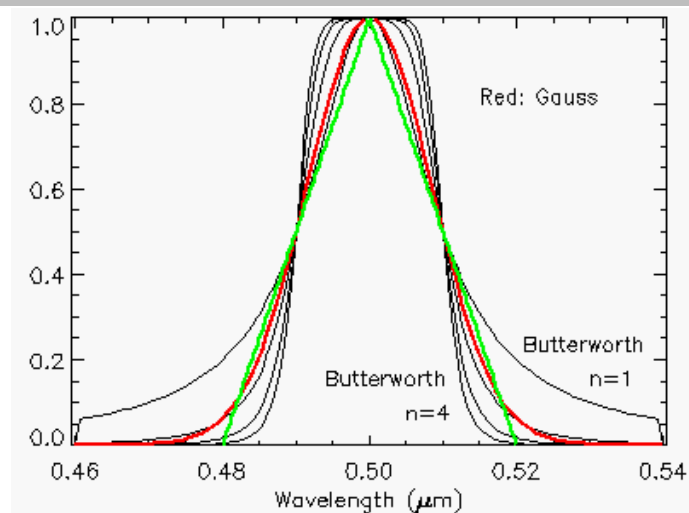


Figure 3.5: Choices for spectral response functions.

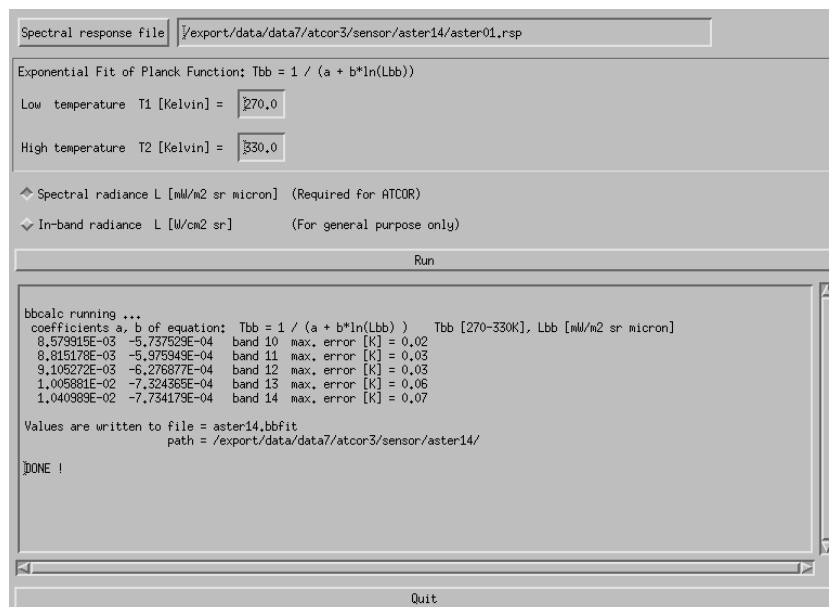


Figure 3.6: Blackbody temperature for thermal bands.



Figure 3.7: Resampling of atmospheric LUTs.

3.2 Radiometric calibration file

A radiometric calibration file is needed to convert the scaled image data (digital numbers, DN) into a physical radiance unit L at the sensor. ATCOR requires the unit $mWcm^{-2}sr^{-1}\mu m^{-1}$, i.e. $L = c_0 + c_1 DN$. The corresponding offset and gain values for each band are provided by the manufacturer. ATCOR requires an ASCII file with 3 columns (wavelength or band number, offset, gain), and the number of lines corresponds to the number of bands. The recommended extension of the file name is '.cal', e.g. 'hyperion191.cal'. Example: the first spectrometer of Hyperion has the gain $c_1=0.0025$, the second spectrometer $c_1=0.00125$, and the offset is 0 for all bands.

3.3 Spectral smile characterization

In case of a spectrometer instrument with spectral smile aberrations, the characterization can be described by a polynomial function. ATCOR uses a 4th-order polynomial for each band to describe the wavelength shift across the detector array. The smile shift is usually measured in the laboratory. It can also be determined from the image data for certain spectral regions containing atmospheric absorption features. ATCOR requires the smile description as an ASCII file with 6 columns: The first column contains the channel center wavelength, the remaining columns contain the 5 coefficients of the 4th-order polynomial, starting with the constant term. For details, read the corresponding sections in the ATCOR user manual. The file name has to be 'smile_poly_ord4.dat', located in the corresponding sensor folder.

3.4 Post-processing: spectral filtering

In many cases hyperspectral imagery require some post-processing, e.g. a spectral filtering due to small errors in the spectral band center location, accuracy to the radiative transfer code, interpolation in the LUTs, or assumed extraterrestrial solar irradiance spectrum. Figure 3.8 shows the post-processing options offered by ATCOR.

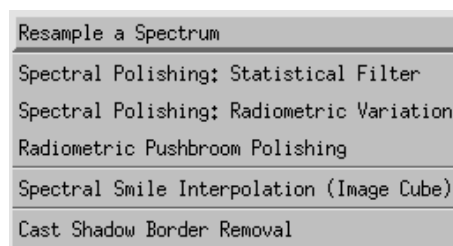


Figure 3.8: Post-processing filter modules.

Two options are presented here: the statistical filter and the smile interpolation.

3.4.1 Statistical filtering

Figure 3.9 shows the GUI for polishing hyperspectral data with statistical filters. Four filter types are offered, but the best choice depends on the sensor performance. Therefore, some trial and error is necessary to obtain the best results.

The different filters work as follows:

- Derivative Filter: all spectral bands of the selected window size are taken into account to calculate derivatives used to reconstruct the value of the center band.
- Neighbor Derivative: the derivatives of all bands except the center band are used to reconstruct the value of the center band.
- Lowpass Filter: only smoothing is performed, no derivatives are calculated.
- Savitzky-Golay: a 4th-order polynomial fit is performed for the total window size. Note: this filter does not account for the wavelength-spacing of bands, i.e. it assumes equidistant bands.

The input file is usually the reflectance product after atmospheric correction. For the spectral response the first channel is selected ('band001.rsp'). The default number of polishing bands on each side of the center band is 3, i.e., the total number is 7 (3 on each side plus the center band). The smoothing factor is defined as:

1. slight smoothing, weighting of bands (left/center/right) = (1/4/1)
2. moderate smoothing, weighting of bands (left/center/right) = (1/2/1)
3. standard smoothing, weighting of bands (left/center/right) = (1/1/1)
4. and higher: same as standard smoothing.

More details are described in reference [3].

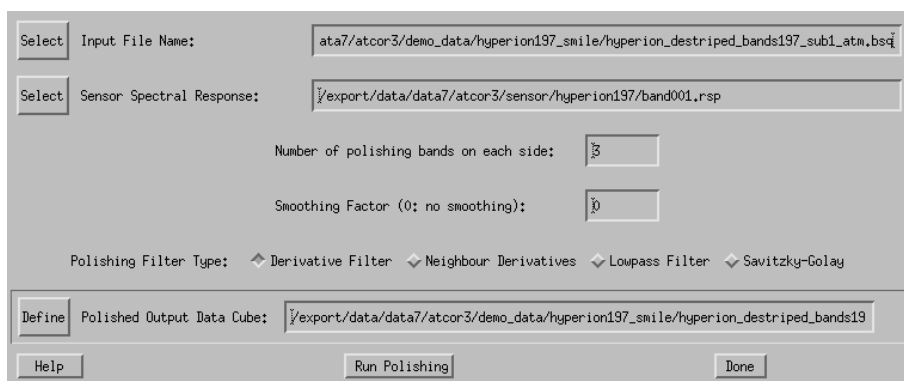


Figure 3.9: Statistical filter menu.

Figure 3.10 presents examples of polishing reflectance spectra using a statistical filter, see [3].

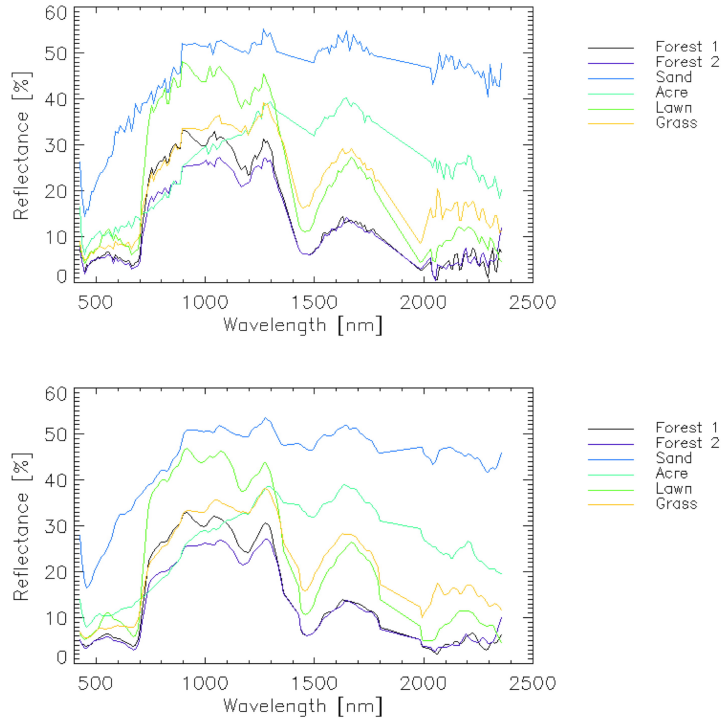


Figure 3.10: Example of polishing reflectance spectra of Hyperion data after atmospheric correction incl. smile (top) and using a statistical filter (bottom).

3.4.2 Smile interpolation

Figure 3.11 presents the GUI for a smile interpolation. Three options for resampling are offered as described in this GUI. The selected option indicates: the spectral surface reflectance cube (after atmospheric correction) is resampled to a new reference wavelength grid using the wavelength average over all detector columns (per band).

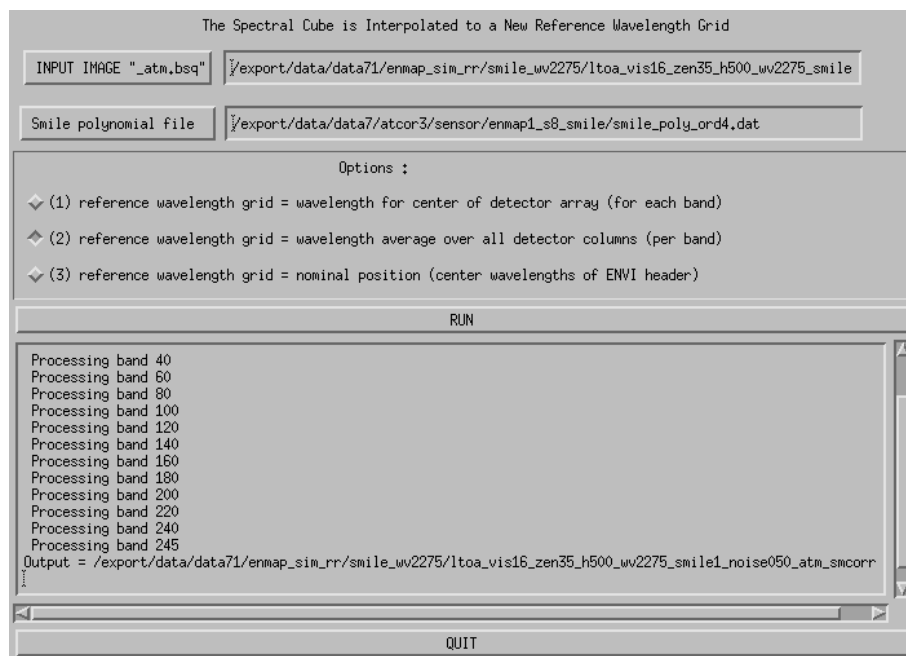


Figure 3.11: Smile interpolation.

Chapter 4

Advanced options

Some of the advanced options are briefly described here or a reference is given to the User Manual. The reasons for the reference are twofold: this tutorial is intended to present only the basic options, and the User Manual already covers the more complex subjects. On the other hand, a quick reference is useful where the material can be found.

4.1 Haze removal

This topic is covered extensively in the theoretical background document [4].

4.2 De-shadowing

This topic is also discussed in detail in the theoretical background document [4]. Two de-shadowing algorithms are available: the matched filter approach and the illumination based approach. The last method requires a DEM and the subsequent calculation of the illumination map. However, as a special case, a float illumination map can also be generated based on scene-derived spectral indices, with or without the topography files. The image scene derived illumination map is stored as the first band of a multi-layer file, coded in float. Use the 'Topographic', 'Image Based Shadows' module of the ATCOR main panel to create such a file. If the scene is named 'scene.bsq', then the corresponding illumination file is named 'scene_ilu.bsq'. And if the de-shadowing option is specified, then the de-shadowing with this file has the first priority. If the matched filter method is selected, then the 'scene_ilu.bsq' has to be (temporarily) renamed, e.g. as 'scene_iluq.bsq' or it has to be moved to a different folder.

4.3 Cast shadow border removal

This routine can be 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 neighbors. The pixels are then corrected using this relative difference in a multiplicative way.

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.

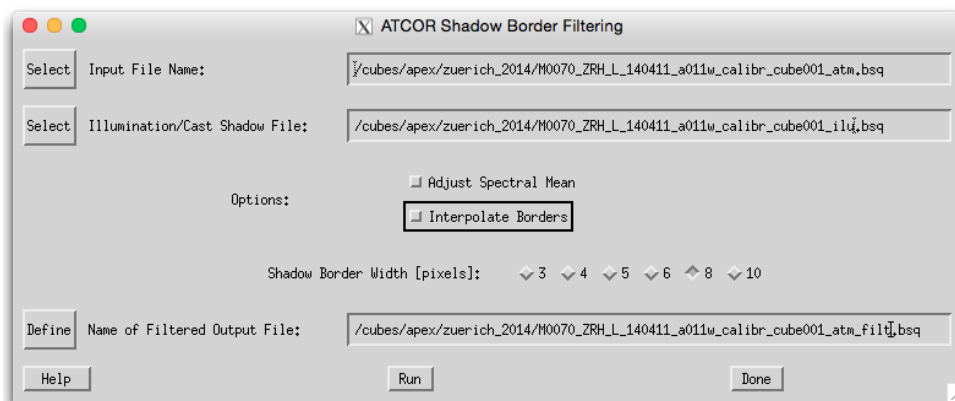


Figure 4.1: Shadow border removal tool

Chapter 5

Miscellaneous

5.1 Default preference parameters

In addition to the processing parameters of the ".inn" file there are a number of default settings (e.g. thresholds for cloud and water masking, definition of atmospheric absorption regions etc) which usually are kept constant. However, if necessary they might be edited (activate button 'Edit Preferences', see figure 2.2.) A detailed description of these parameters is given in the User Manual. Figure 5.1 shows the user interface for the preference parameters.

5.2 Cloud and water mask

The cloud mask for an input file "scene.bsq" is included in the file "scene_out_hcw.bsq", which also contains the haze (if the haze option is set) and water pixels. The calculation is solely based on a spectral threshold criterion with the default reflectance threshold $T=25\%$ in the blue/green band. All pixels with reflectance higher than this threshold are labeled 'cloud'. Bright soils, sand, or roofs might exceed this threshold. Therefore, a more realistic cloud mask may need an adjustment of this threshold (in the preference parameter file, see figure 5.1, depending on scene content).

A better cloud threshold usually also improves the haze removal (if set).

The water mask is also included in the file "scene_out_hcw.bsq". Again, it is exclusively calculated with spectral criteria set in the preference parameter file. Depending on the available spectral bands and the turbidity of water bodies in the scene, these default thresholds might have to be modified.

5.3 Spectral classification

After atmospheric correction the surface reflectance image ("scene_atm.bsq") can be fed into a fully automatic spectral classifier (top level menu 'Tools', then 'SPECL: Spectral Reflectance Classifier'). The output file ("scene_atm_cla.bsq") contains a number of fixed spectral classes (e.g. bright and dark vegetation, soil, water) which might be useful as a first orientation. However, these are not land use classes. An example is given in figure 5.2.



Figure 5.1: Panel for preference parameters.

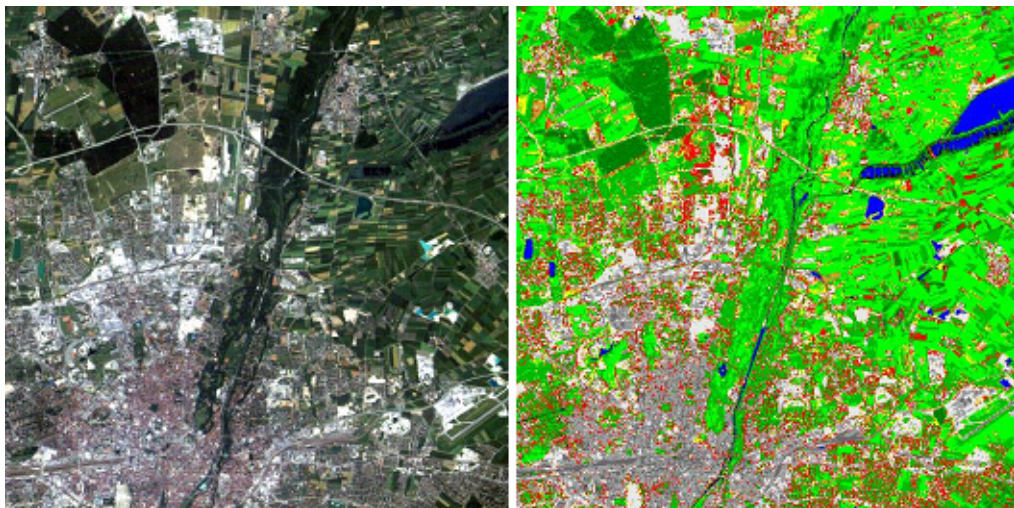


Figure 5.2: Spectral classification of a Landsat TM subset.

5.4 DEM smoothing

Spatial artifacts often occur in case of processing mountainous terrain data, especially for high spatial resolution imagery. These artifacts are clearly visible in the slope and illumination maps, and therefore also in the output surface reflectance product. There are several options to improve the situation:

- smooth the digital elevation model and the derived products (slope, aspect) using the function *DEM Smoothing* of the '*Topographic*' top level menu. The default kernel size is 3 (pixels), but larger kernels might be necessary depending on the spatial resolution of the image. This will reduce the high spatial frequency content.
- Better results can sometimes be obtained by using a larger kernel size for the slope / aspect maps than for the elevation.
- The slope / aspect maps often achieve a better quality if they are expanded, then smoothed, then shrunk to the original size. Then the following steps may be tried to improve the results:
 - FLOAT (elevation file) if integer coded
 - Calculate slope and aspect with a low pass filter of 5x5 pixels
 - Resize slope / aspect file: factor 4 larger
 - Apply a low pass filter (7x7 pixels)
 - Resize with factor 0.25 using nearest neighbor to obtain the original size.
- Switch off the cast shadow correction (by leaving the field empty where the cast shadow map is defined in the DEM panel).
- Use the empirical BRDF correction for rugged terrain.

Bibliography

- [1] Richter, R. and D. Schlöpfer, "Atmospheric / topographic correction for satellite imagery: ATCOR-2/3 User Guide", DLR IB 564-01/19, Wessling, Germany (2019).
- [2] Richter, R., and D. Schlöpfer, "Atmospheric / topographic correction for airborne imagery: ATCOR-4 User Guide", DLR IB 564-02/19, Wessling, Germany (2019).
- [3] , D. Schlöpfer, and R. Richter, "Spectral polishing filters of high resolution imaging spectroscopy data", Imaging Spectroscopy (2011).
- [4] Richter, R., and D. Schlöpfer, "Atmospheric and topographic correction (ATCOR Theoretical Background)", DLR IB 564-03/19, Wessling, Germany (2019).