Practical Session Instructions

Earth Observation of Water Resources (SEBS)

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Exercise 1

Introduction

The practical contains two exercises related to earth observation of water resources.

These exercises were developed originally for the ESA-MOST Dragon programme advanced training course in land remote sensing.

Exercise1 deals with the preparation of MODIS Level 1B data as input for SEBS, which includes preparing software for reading MODIS products, ordering and downloading the MODIS Level_1B data, and viewing and getting familiar with the MODIS data products in HDF format.

Exercise 2 will guide you through the different steps in processing satellite data (e.g. MODIS Level-1B data) in the ILWIS system (Integrated Land and Water Information System, an open source Remote sensing and GIS system developed by ITC, University of Twente, downloadable from http://52north.org/downloads/category/10-ilwis). In a step by step procedure, this exercise enables you to derive land surface geophysical parameters and energy balance components, including evaporation rate. The processes are similar to many sensors, so the steps apply to high to medium and low resolution imagery (NOAA-AVHRR, MODIS, LandSat, ASTER, and others). The process consists of four main sub-processes: **image (re)projection**, **image import**, **pre-processing**, and **the direct SEBS model application.** The user is warned that despite that the whole process sequences is similar for different sensors, the methodology of pre-processing is different and needs to be adapted. The SEBS model process remains practically unaltered.

Exercise 1

Exercise 1: Preparing MODIS data for SEBS

Exercise Steps:

- Preparing the software for MODIS products
- Ordering and downloading the MODIS Level_1B data
- Viewing and Getting familiar with the MODIS data products (HDF datasets) used in this exercise

1.1 Preparing software for using MODIS products

1.1.1 HDFView

HDFView is a tool for browsing and viewing the contents of HDF files. The software can be downloaded from http://www.hdfgroup.org/hdf-java-html/hdfview/

If not installed already, install the package as follows:

- Type hdfview_install_windows_novm.exe to install
- Start from Start -> programs -> HDFView 2.8 -> HDFView 2.8

Note: Before the installation of the software, Java JDK1.5.0 (or higher) must be installed on your machine.

1.1.2 ModisSwathTool

The Modis Reprojection Tool Swath allows you to reproject swath MODIS level-1 and level-2 data products. It is free and can be obtained from the internet link below:
https://lpdaac.usgs.gov/tools/modis_reprojection_tool

In this exercise, the software MRTSwath.zip has been downloaded and provided.

First unzip the MRTSwath.zip file to a folder, for example, D:\MRTSwath directory. Next you need to edit the ModisSwathTool.bat file in D:\MRTSwath\bin directory. You will need to update the MRTDATADIR to the MRTSwath data directory, the path to the Java executable, and the path to the ModisSwathTool.jar file. For example, the Java executable path is C:\Program Files\Java\jre1.5.0_11\bin, and the MRTSwath is installed in the D:\MRTSwath directory, the sample ModisSwathTool.bat file should look like as follows:

```
set MRTDATADIR=D:\MRTSwath\data
"c:\WINDOWS\system32\java.exe" –classpath
"D:\MRTSwath\bin\ModisSwathTool.jar" mrtswath.ModisSwathTool
mrtswath.ModisSwathTool
```

Note that the blue statement starting with "c\windows…" is all on one line. Do not break this statement into multiple lines!
Also note that The MRTSwath will not run correctly if the installation uses directory names that include **blank spaces**.

Start MRTSwath with ModisSwathTool.bat from the D:\MRTSwath\bin directory, or to create a shortcut to MRTSwath, and click on the shortcut.

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1.2 Ordering and downloading the MODIS data

For this exercise, you will be using the following MODIS products, covering the Naqu site on the Tibetan plateau, China:

MODIS calibrated L1B swath product named as:
MOD021KM.A2008186.0430.005.2010188194504.hdf
And its corresponding geolocation L1A product:
MOD03.A2008186.0430.005.2008186113434.hdf

Corresponding to an overpass on July 4, 2008 (Julian day186), recorded at 04:30 GMT.

You can order these products from the NASA's LAADS Web site:
http://ladsweb.nascom.nasa.gov/browse_images

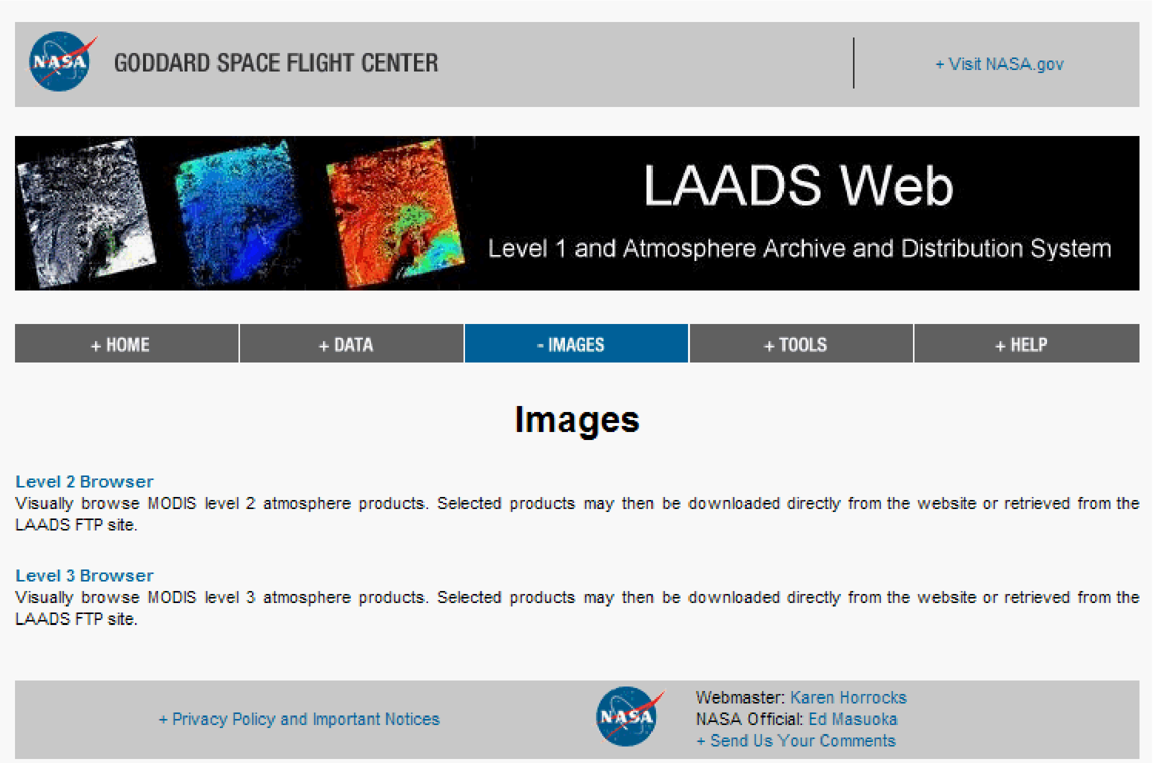

Figure 1.1 Overview of the web page for MODIS data downloads

For downloading MODIS L1B product, **c**licking on DATA field, then clicking on Search for MODIS level 1, atmosphere and land products.

The page that corresponds to this selection is shown in the picture below:

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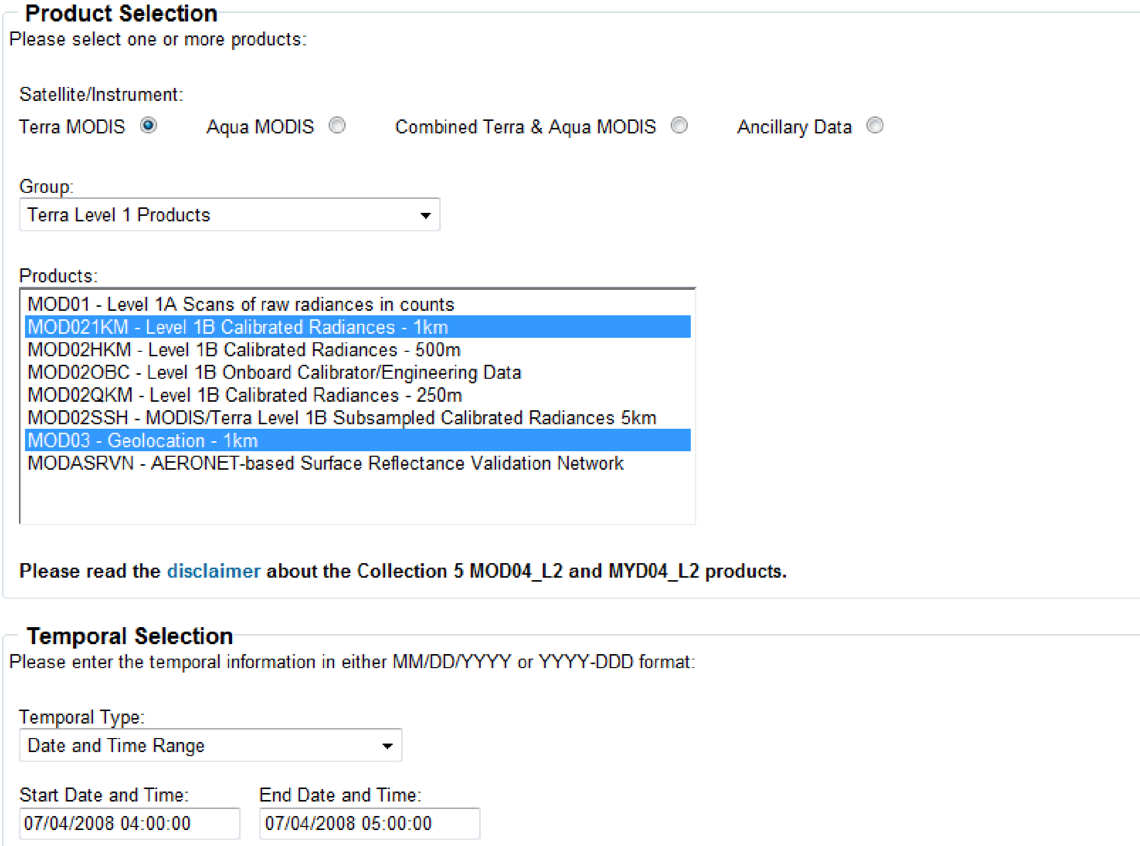

Figure 1.2 Overview of MODIS data search

Select the following options for:

Satellite/Instrument:
Terra MODIS

Group:
Terra Level 1 Products

Products
MOD021KM – Level 1B Calibrated Radiances – 1km
MOD03 – Geolocation – 1km

Search Date and Time
Start Date and Time: 04/07/2008 Time (UTC): 04:00:00
End Date and Time: 04/07/2008 Time (UTC): 05:00:00

Collection:
6 – Modis Collection 6 – L1, Atmos and Land

Special Selection
Latitude/Longitude

Search Area
Type in Lat/Lon range
Northern latitude: 35
Southern latitude: 27
West longitude: 86

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East longitude: 95

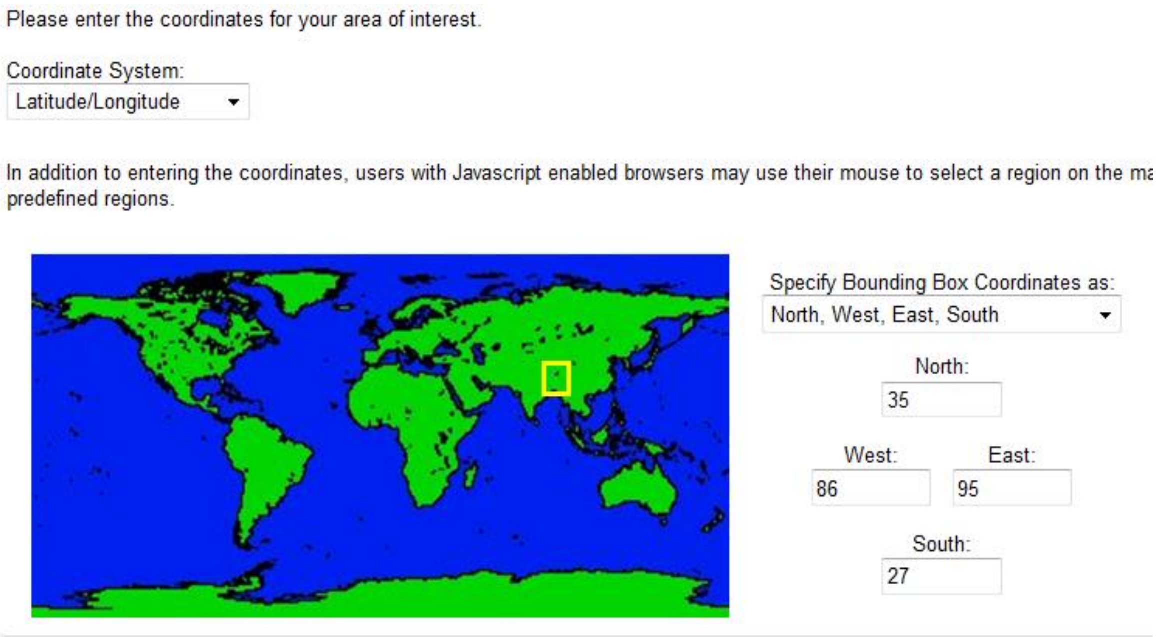

Figure 1.3 Overview of selected MODIS data coverage

Coverage Selection

Day (containing day data only)

Clicking on Search, the search should find two images having the following names on your screen after some time:

MOD021KM.A2008186.0430.005.2010188194504.hdf
MOD03.A2008186.0430.005.2008186113434.hdf

Note that July 4, 2008 is day-of-year 186.

Note: You can preview the scenes by clicking **View RGB**.

Clicking on Order Files Now, providing your e-mail address, and checking FTP pull option, and then clicking “Order”.

After this is done you will receive an e-mail informing you that your order has been received. Within some time (it may take several hours, or one or two days), you will receive an e-mail with FTP details, with which you can download the data.

Sometimes it can take quite some time to order the data. If you have no access to the Internet, use the files provided in the working directory during exercise, and go immediately to the exercise 1.3.

1.3 Getting familiar with the MODIS data with HDFView tool

- **Run HDFView**

You can run the HDFView from

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Start->Program Files->HDFView2.9

- **Open a file:**

You can either click the “open” button or select the “open” from the file menu. In the Open file pop up window, navigate to the directory containing the downloaded MODIS files, choose this file MOD021KM.A2008186.0430.005.2010188194504.hdf
After that, the structure of the file is displayed in the tree panel on the left side of the HDFView Window.

- **View data content:**

First double click on “MODIS_SWATH_Type_L1B”, and then double click on “Data Fields”, after that, a list of available data fields will appear (see picture below).

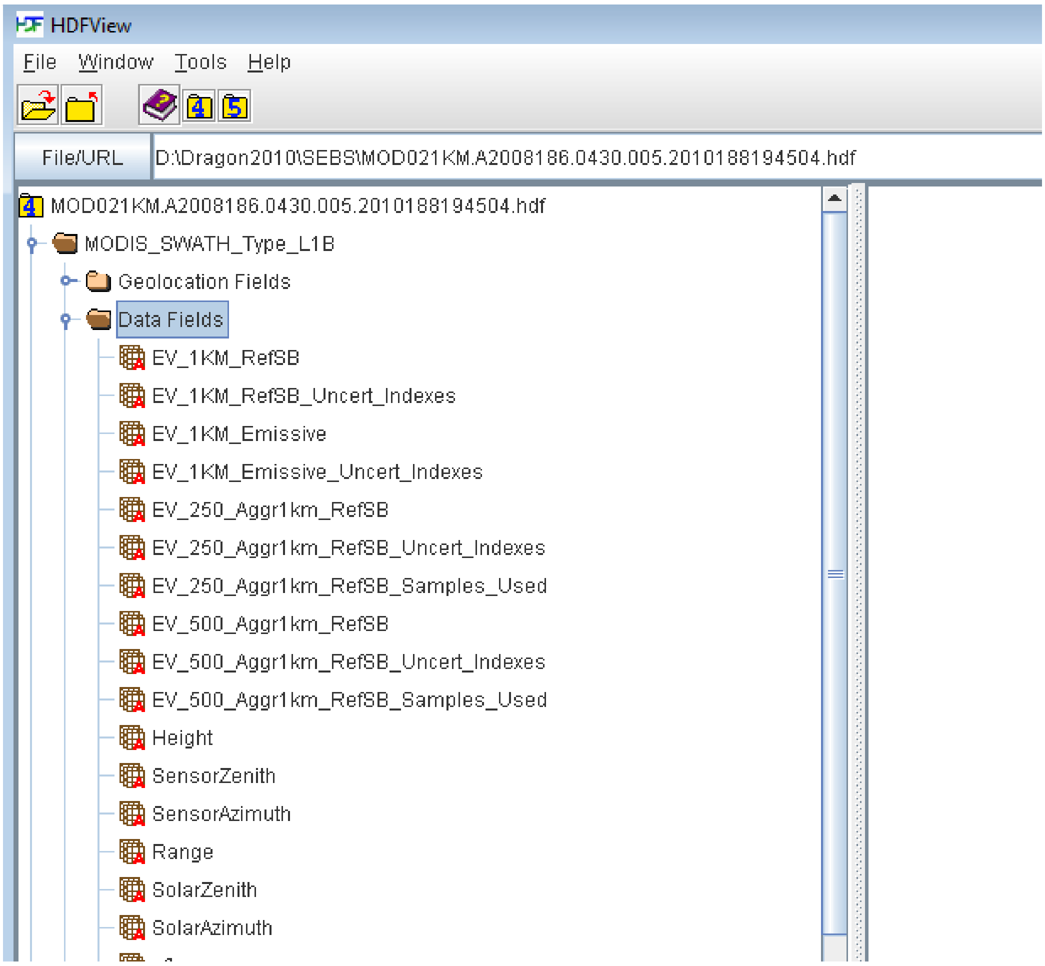

Figure 1.4 Overview of the tree panel of the Main Window

- **Obtain the calibration parameters from the HDF file:**

To view the attributes/metadata of the data fields, you can right click on an individual field e.g. EV_250_Agg1km_RefSB, in the context-menu, then select “Show Properties” menu, then in the pop up window, click on Attributes tab. The following figure shows an example of the information for the selected data field.

Exercise 1

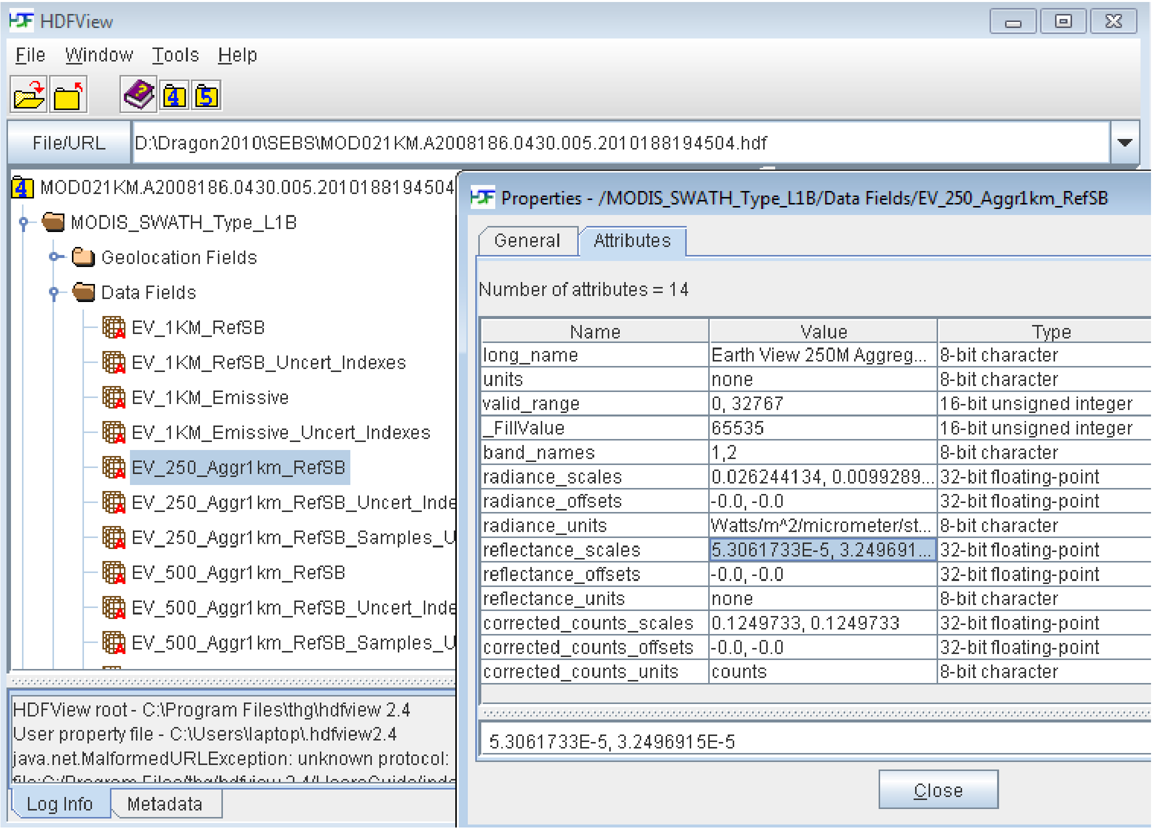

Figure 1.5 Overview of attributes of the selected data field

Take some time to examine the data attributes of the different data fields (e.g. band names, reflectance/radiance scales, reflectance/radiance offsets, valid range etc.).

There is very import information available in the header of the HDF file. This information is relevant for the processing of the MODIS images and need to be exacted.

⇒ Find out the calibration parameters (reflectance scale and offset) for the following bands in this table:

Band name	Reflectance scale	Reflectance offset
Band1		
Band2		
Band3		
Band4		
Band5		
Band6		
Band7		

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⇒ Find out the calibration parameters (radiance scale and offset) for the following bands in this table:

Band name	Radiance scale	Radiance offset
Band2		
Band17		
Band18		
Band19		
Band31		
Band32		

The calibration parameters will be used to calculate the reflectance and radiance products of the MODIS imagery in exercise 2.

Listing of the MODIS data fields and its corresponding MODIS bands used in this exercise in the MOD021KM product

Data Field	Band
EV_250_Aggr1km_RefSB	1,2
EV_500_Aggr1km_RefSB	3,4,5,6,7
EV_1KM_RefSB	17,18,19
EV_1KM_Emissive	31,32

- **View the Geolocation file:**

Click the “open” command button, in the Open file pop up window, choose this file MOD03.A2008186.0430.005.2008186113434.hdf
Follow the above steps to find out the scale factors for the SensorZenith, SensorAzimuth, Solarzenith, SolarAzimuth and Height bands.

Data Field	Scale	offset
SensorZenith		
SensorAzimuth		
Solarzenith		
SolarAzimuth		

- **Close the HDFview program.**

Exercise 2: Processing MODIS Level 1B data for SEBS in ILWIS

2.1 Introduction

SEBS for ILWIS provides a set of routine for bio-geophysical parameter retrievals. It uses satellite earth observation data, in combination with meteorological information as inputs, to retrieve a set of geo-physical parameters, evaporative fraction, net radiation, and soil heat flux parameters etc. This exercise will guide you through the process of estimation of land surface geophysical parameters and energy balance components, including evaporation rate. The process consists of four main sub-processes: **image reprojection**, **image import**, **pre-processing**, and **the direct SEBS model application**

It concerns the files over the Naqu site on the Tibetan plateau, China:

In this exercise, we will be using the following MODIS files:

- MODIS calibrated L1B swath product:
- MODIS L1B file MOD021KM.A2008186.0430.005.2010188194504.hdf

And its corresponding geolocation L1A product:
MOD03.A2008186.0430.005.2008186113434.hdf,

Corresponding to an overpass on July the 4th 2008 (Julian day186), recorded at 04:30 GMT.

The MODIS Level-1B and L1A Geolocation (the MOD03, for Terra, and MYD03, for Aqua) products are usually available through the GSFC DAAC website

http://ladsweb.nascom.nasa.gov/browse_images.

The following MODIS bands will be extracted and pre-processed for further SEBS sub-process.

From the MODIS L1b file (MOD021KM.A2008186.0430.005.2010188194504.hdf):

- bands 1 and 2 from the EV_250_Aggr1km_RefSB data field,
- bands 3, 4, 5, 6 and 7 from the EV_500_Aggr1km_RefSB data field,
- bands 17,18 and 19 from the EV_1km_RefSB data field
- bands 31 and 32 from the EV_1KM_Emissive data field.

From the Geolocation file (MOD03.A2008186.0430.005.2008186113434.hdf):

- Height,
- SensorAzimuth,
- SensorZenith,
- SolarAzimuth and,
- SolarZenith.

2.2 Install ILWIS and Sentinel-3 toolbox

We will need to install the **ILWIS** and **Sentinel-3** toolbox for further data processing and analysis.

ILWIS

ILWIS is a remote sensing and GIS software, which can be downloaded from
http://52north.org/downloads/category/10-ilwis/

If it is not installed already, install the package as follows:

Type setup.exe to install
Start from Start -> programs -> ILWIS

Sentinel-3 toolbox

Down and install the **Sentinel-3 toolbox** software (Please visit https://earth.esa.int/web/sentinel-tbx/)

2.3 Main Processing Steps

There are 4 main processing steps:

- Reprojecting & converting MODIS level-1B data using ModisSwathTool software
- Importing MODIS images into ILWIS
- Pre-processing for SEBS
  - Raw to radiance/reflectance
  - Brightness temperature computation
  - Water vapor content estimation
  - SMAC for atmospheric correction
  - Land surface albedo computation
  - Land surface emissivity, NDVI, and vegetation proportion difference computation
  - Land surface temperature computation
- Appling SEBS model for estimation of evapotranspiration
  - Input of the meteorological information
  - Input of the satellite observation data
  - SEBS computation
  - Verification the outputs and comment

Figure 2.1 below shows a simplified flowchart for these steps.

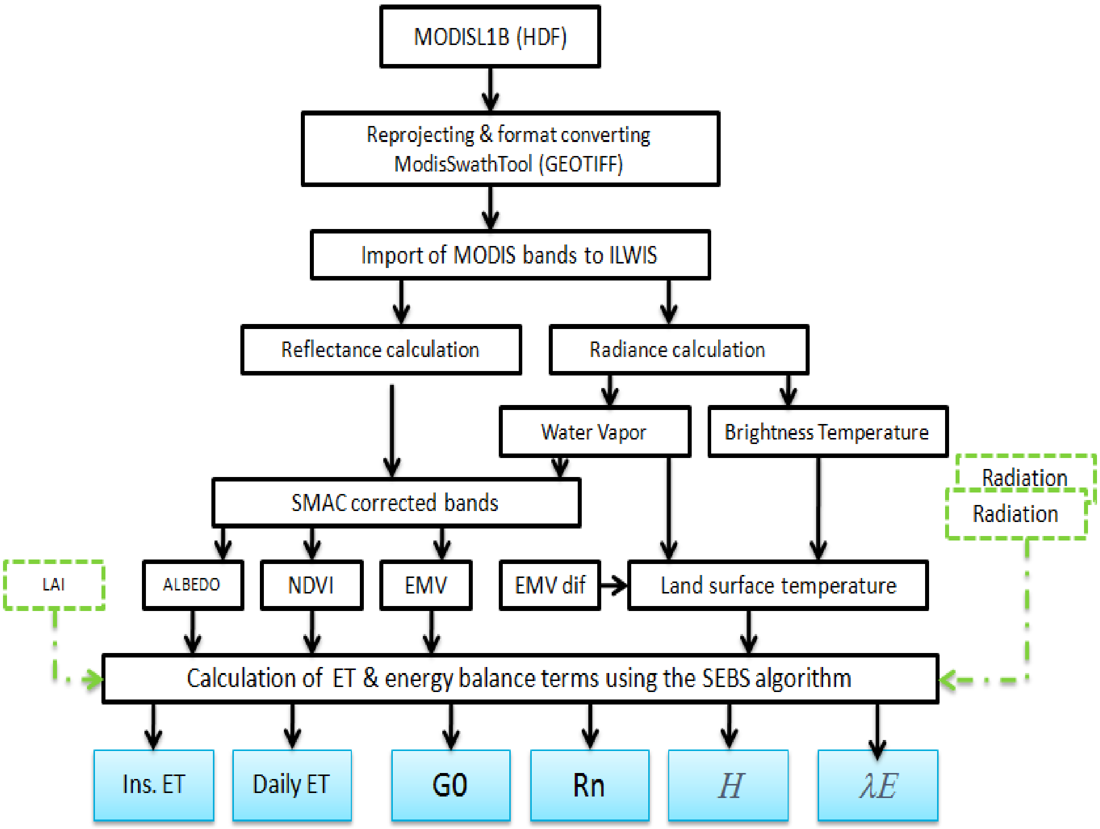


Figure 2.1 Simplified flowchart - Processing of MODIS L1B for SEBS

2.3.1 Step I: Reprojecting MODIS Level-1B Data

The MODIS L1B data are in swath (orbit based) format, therefore in this part, we need to reproject the data to a standard projection and format compatible with GIS software.
The MODIS Reprojection Swath Tool (ModisSwathTool) allows the user to transform MODIS L1B data from swath format to other widely supported projections and formats for GIS applications.

For the current exercise, both the MODIS Level-1B and geolocation products should be converted to TIFF/GeoTIFF format, and reprojected to the Geographic projection ready for importing into ILWIS.

The procedure with ModisSwathTool software is as follows*:*

Start MRTSwath program with ModisSwathTool.bat from the D:\MRTSwath\bin directory, or to create a shortcut to MRTSwath, and click on the shortcut

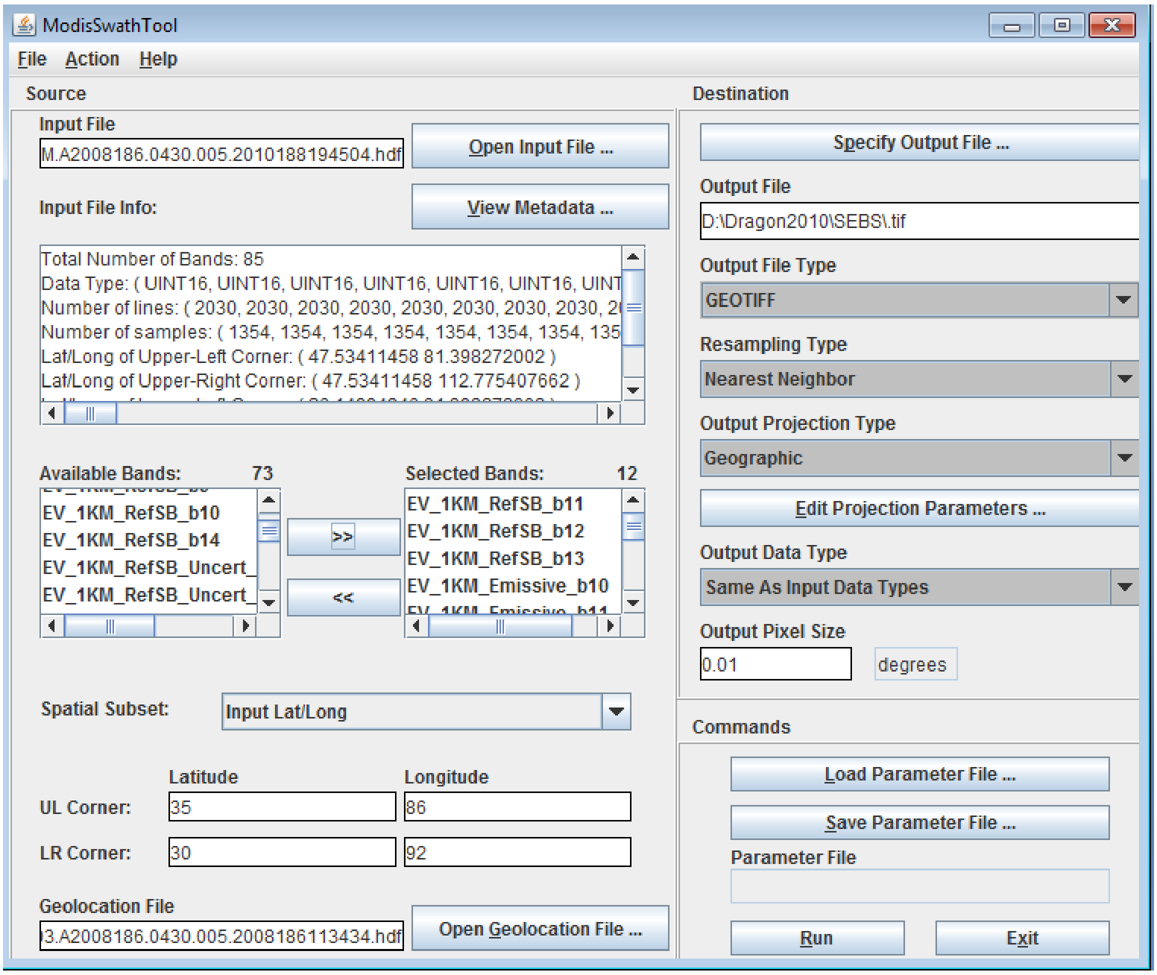


Figure 2.2 Example for the settings in the ModisSwthTool

a) Converting desired channels in the MODIS level-1B file into GeoTIFF

- Click on the "Open Input File" button to the right of the Input file field, and then select the desired input file, in this case, MOD021KM.A2008186.0430.005.2010188194504.hdf from the input file selection dialog box.
- Select the desired bands to process. By default, all the available bands in the input file are selected. In this exercise we wish to extract the following bands:
  EV_250_Aggr1km_RefSB_b0 - channel 1
  EV_250_Aggr1km_RefSB_b1 - channel 2
  EV_500_Aggr1km_RefSB_b0 - channel 3
  EV_500_Aggr1km_RefSB_b1 - channel 4
  EV_500_Aggr1km_RefSB_b2 - channel 5
  EV_500_Aggr1km_RefSB_b3 - channel 6
  EV_500_Aggr1km_RefSB_b4 - channel 7
  EV_1km_ RefSB_b11 - channel 17
  EV_1km_ RefSB_b12 - channel 18
  EV_1km_ RefSB_b13 - channel 19
  EV_1KM_Emissive_b10 – channel 31
  EV_1KM_Emissive_b11 – channel 32

- Select Input Lat/Lon from the spatial subset field.

- Enter the upper left and lower right corner coordinates in the Latitude and Longitude to cut the area of interest, in this case the coordinates are filled with following coordinates:
  UL Lat 19
  UL Long 97
  LR Lat 7
  LR Long 110
- Select the associated Geolocation file corresponding to the MODIS L1b swath file. Note: This file needs to be of the same date and time as the input MODIS swath file, otherwise the Geolocation data will be incorrect.
- Input the output file by clicking the "Specify output file" button. In the output file dialog box, type in .tif for the output file as shown right. Make sure the data is stored in the proper output folder.

Tip: The output band name is automatically appended to the base output file name, in this case, _EV_250_Aggr1km_RefSB_b0.tif for band1 and _EV_250_Aggr1km_RefSB_b1.tif for band2, respectively.

- Select GeoTIFF format from the output File Type.

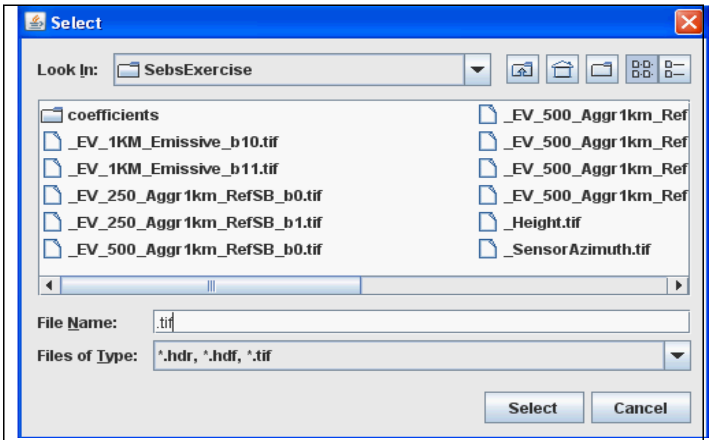


Figure 2.3: Output file selection dialog box, the extension you choose .tif (Tagged Image File Format TIFF) will determine the output file format.

- Change the resample method to Nearest Neighbor
- Select the Output Projection Type to Geographic
- Leave the default the same as input data types for the Output Data Type
- Set the output pixel sizes to 0.01 degree
- Press Run to complete the data conversion process. Note that a window will appear that shows the processing status of the process.

⇒ **Why do you think that the pixel size of 0.01 degree was selected?**

b) Converting satellite and solar zenith and azimuth angles into GeoTIFF

- Open the geolocation file MOD03.A2004186.1045.005.2007287062243.hdf. Select bands SolarZenith, SolarAzimuth, SensorAzimuth, SensorZenith and Height.
- Specify the file extension .tif for the output filename in the Select File dialog.
- Specify the other input parameters as same as those used for the MODIS L1B file (see figure 2.4 below).

After this processing finished, you will obtain GeoTIFF files:
_SolarZenith,
_SolarAzimuth
_SensorAzimuth,
_SensorZenith
_Height

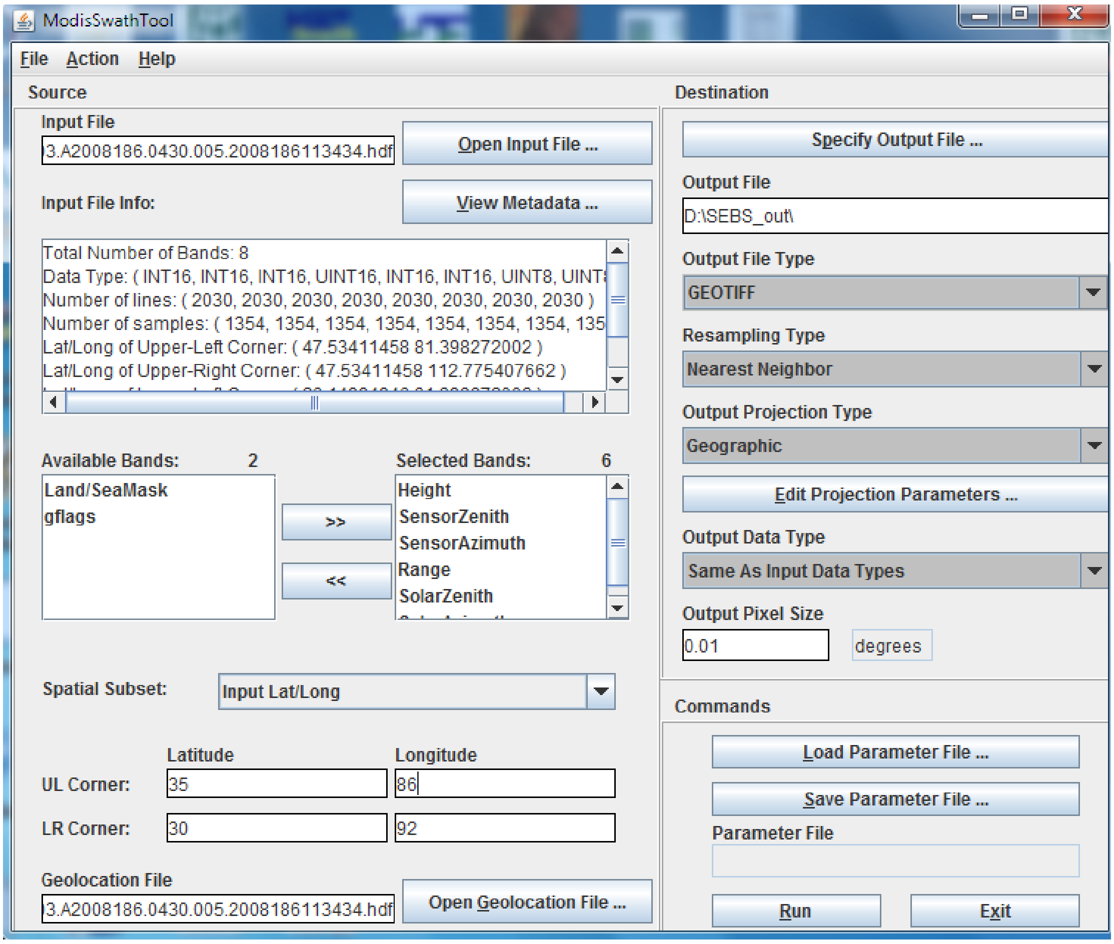


Figure 2.4 Example window for the setting to the Geolocation file

Upon completion the process of data processing, close the ModisSwathTool and start ILWIS.

At this point: ILWIS should be installed.

2.3.2 Step II: Importing MODIS files into ILWIS

a) **Start ILWIS and navigate to the directory where the MODIS GeoTIFF files are located.**

- Go to the ILWIS menu File-Import to open the ILWIS Import tool.
- Select Geospatial Data Abstraction Library (GDAL) option.
- Select raster->GEOTIFF format.
- Click on the “Open Input File” button to the right of the Input file field, and then select the desired input tif file, e.g. _EV_250_Aggr1km_RefSB_b0.tif from the input file selection dialog box.
- Uncheck the “Output name matches input” check box, input output filename (band1_dn).
- Clean the “Use as” check box to import as ILWIS raster files and proceed to import (see figure 2.5 below).

After that, you will find a new ILWIS collection (named band1_dn), which assigned automatically a name based on the output filename. The ILWIS collection contains the ILWIS objects.

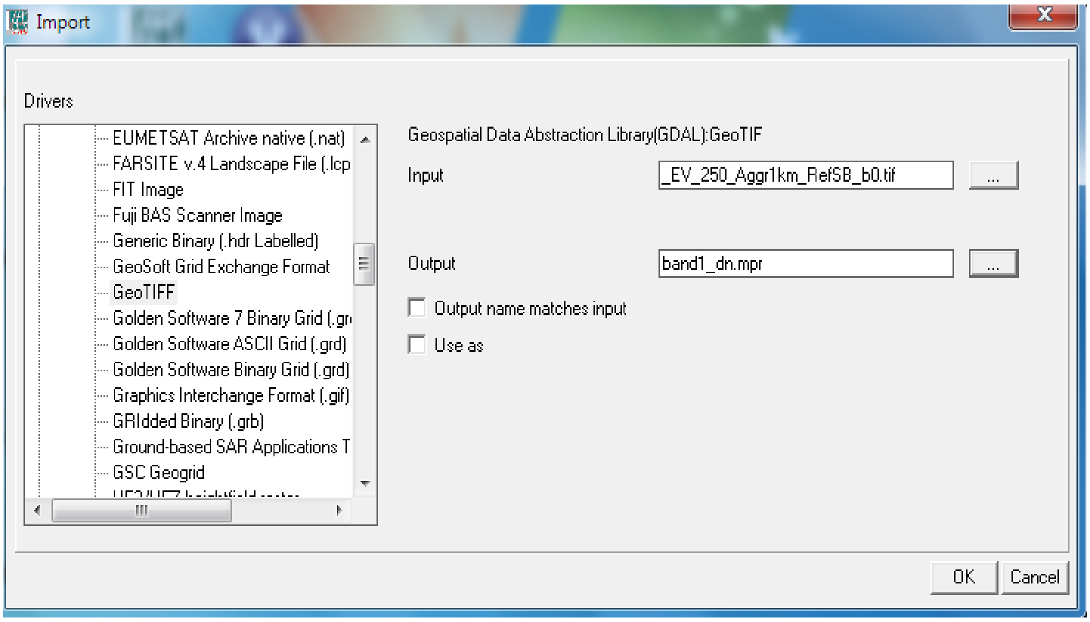


Figure 2.5 Import MODIS bands into ILWIS screen

Open the collection by double clicking on it (see Figure 2.6), Open the image to understand parameter value ranges, image size and resolution (right click on the map, select "Properties".

The raster map (named for example band1_dn) is assigned automatically a georeference and a coordinate system respectively. Check also the gereference and the coordinate system objects.

Repeat the import steps above for each of the MODIS files (in GeoTIFF format).

Verify that all images have been correctly imported (check the coordinate system and georeference)

Figure 2.6 Object collection after importing

Table 1: GeoTIFF files used in this exercise

Input GeoTIFF filename	Output Filename in ILWIS
_EV_250_Aggr1km_RefSB_b0.tif	Band1_dn
_EV_250_Aggr1km_RefSB_b1.tif	Band2_dn
_EV_500_Aggr1km_RefSB_b0.tif	Band3_dn
_EV_500_Aggr1km_RefSB_b1.tif	Band4_dn
_EV_500_Aggr1km_RefSB_b2.tif	Band5_dn
_EV_500_Aggr1km_RefSB_b3.tif	Band6_dn
_EV_500_Aggr1km_RefSB_b4.tif	Band7_dn
_EV_1KM_RefSB_b11.tif	Band17_dn
_EV_1KM_RefSB_b12.tif	Band18_dn
_EV_1KM_RefSB_b13.tif	Band19_dn
_EV_1KM_Emissive_b10.tif	Band31_dn
_EV_1KM_Emissive_b11.tif	Band32_dn
_SolarZenith.tif	sza_dn
_SolarAzimuth.tif	saa_dn
_SensorAzimuth.tif	vaa_dn
_SensorZenith.tif	vza_dn
_Height.tif	Height

⇒ Open some maps and check the values. What are the units?

b) **In order to import all the files in a faster way, you can create an ILWIS script and run it:**

- Select File menu > Create menu > Script …

A new script window will be opened.

- Go to the main ILWIS window, click on the arrow on upper right of the window to have a view on the command history.
- Look for the line starting with “open” and end with “-method=GDAL –import” (which is the ILWIS command to import data via GDAL). Click and copy the command line.
- Paste the command line in the new script window (as shown in Figure 2.7). Repeat this step 17 times in order to have 17 command lines in the new script.
- Change the name of input and output file in order to run the import command on all the MODIS GEOTIFF files. (See the red circles in Figure 2.7)
- Save the new script.
- To run the new script, click on “Run Script” button (see the red circle).

After these steps, you will see the complete list of output ILWIS collections in the Catalog shown in the main window of ILWIS.

Open images to understand parameter range, image size and spatial resolution. Identify how many images belong to the visible, near infrared, and thermal?

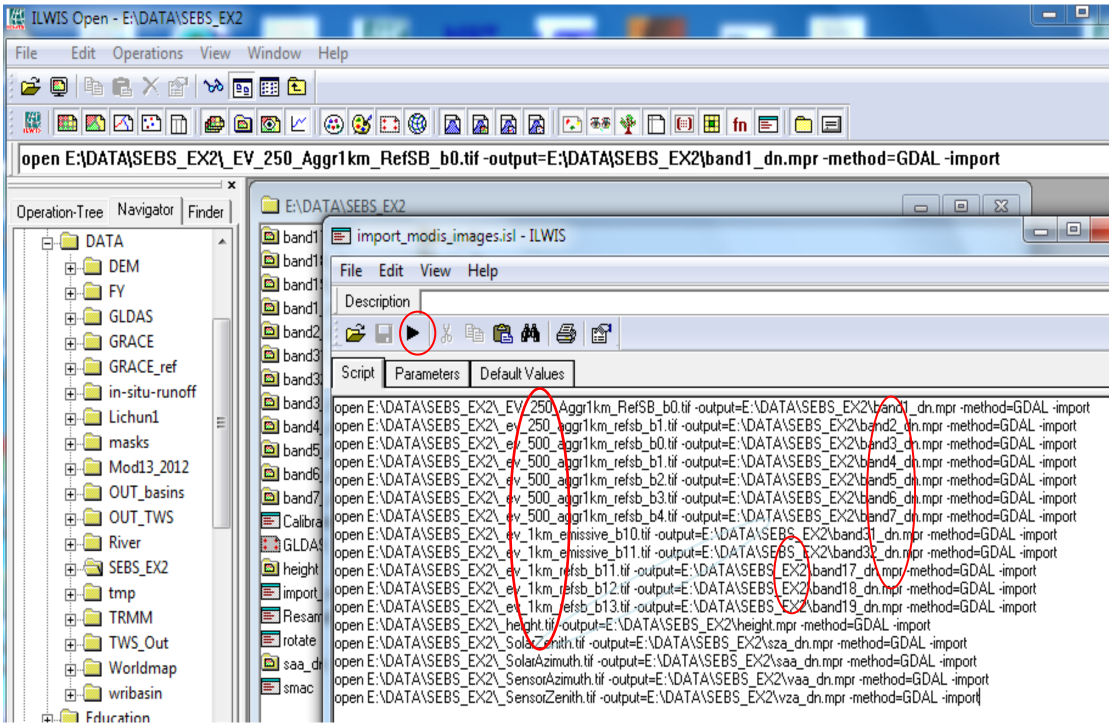


Figure 2.7 How to create a script to import MODIS GEOTIFF files used in this exercises

2.3.3 Step III: MODIS Pre-processing for SEBS

Raw to radiances/reflectance (MODIS)

The MODIS Level 1b data are given in digital numbers, therefore, once imported into ILWIS, DNs bands must be converted to reflectances (for bands 1 to 7) and radiances (for bands 2, 31,32, 17,18 and 19). The SEBS for ILWIS provides the tools to convert the imported MODIS bands in the digital numbers to the radiances and the reflectance.
The process is similar for all bands. Calibration coefficients (scale and offset) are provided in the HDF header file and are extracted in the previous exercise for each band. Please use them.

- Select Operations-SEBS Tools- Pre-processing - Raw data into radiances/reflectance (MODIS)
- Select input data file
- Provide the scale and offset values for radiance/reflectance correction
- Assign a proper name for the output file.
- Click on Show, an ILWIS raster file in radiance/reflectance will be created and opened.
- Have a look at it, and then close it.
- Repeat the same procedure for the other bands.

Note: bands 1 to 7 need to be corrected by the reflectance scales and offsets; while bands 2, 17, 18, 19, 31 and 32 need to be converted by applying radiance scales (8.40022E-4, 7.296976E-4) and offsets (1577.3397, 1658.2212) respectively in this case.

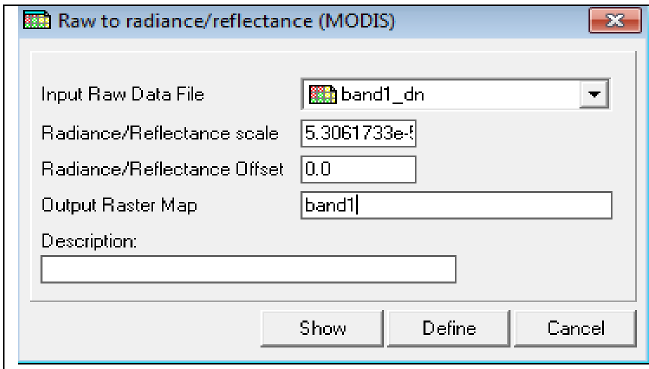


Figure 2.7 Example for converting band1 into reflectance dialog box

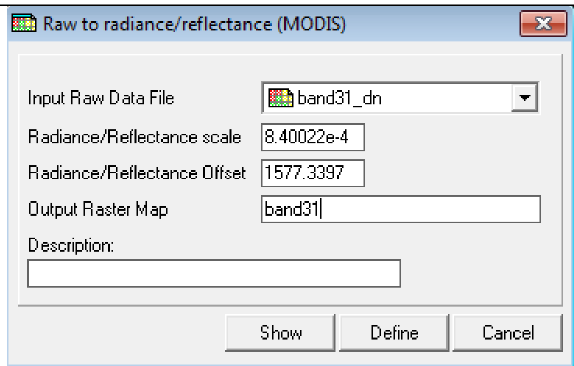


Figure 2.8 Example for converting band31 into radiances dialog box

The equation for calculation of reflectance and radiance as follows:
reflectance = reflectance_scale (DN – reflectance_offset)
radiance = radiance_scale (DN – radiance_offset)

The calculation also can be done using the ILWIS map calculator or command line. You could use a script to do it.
The following script in ILWIS will calculate the reflectance and radiance of all MODIS bands:

band1_ref.mpr := MapSI2Radiance(band1_dn,5.6184363E-5,0.0000000000)
band2_ref.mpr := MapSI2Radiance(band2_dn,3.371625E-5,0.0000000000)
band3_ref.mpr := MapSI2Radiance(band3_dn,5.6763303E-5,0.0000000000)
band4_ref.mpr := MapSI2Radiance(band4_dn,4.6312645E-5,0.0000000000)
band5_ref.mpr := MapSI2Radiance(band5_dn,4.110393E-5,0.0000000000)
band6_ref.mpr := MapSI2Radiance(band6_dn,3.6677564E-5,0.0000000000)
band7_ref.mpr := MapSI2Radiance(band7_dn,3.031405E-5,0.0000000000)

band2_rad.mpr := MapSI2Radiance(band2_dn,0.010334734,0.0000000000)
band17_rad.mpr := MapSI2Radiance(band17_dn,0.0037166378,316.9722)
band18_rad.mpr := MapSI2Radiance(band18_dn,0.003564576,316.9722)
band19_rad.mpr := MapSI2Radiance(band19_dn,0.001125143,316.9722)
band31_rad.mpr := MapSI2Radiance(band31_dn,8.40022E-4,1577.3397)
band32_rad.mpr := MapSI2Radiance(band32_dn,7.296976E-4,1658.2212)

The next step is the re-scaling of the zenith and azimuth angle maps:
Note: in this case all solar and satellite zenith and azimuth angles need to be re-scaled by multiplying maps with a scale factor 0.01; this operation can be done 4 times, one for each map, using the ILWIS map calculator or applying the following formulas in the command line. e.g.:
sza = sza_dn * 0.01
saa = saa_dn * 0.01
vza = vza_dn * 0.01
vaa = vaa_dn * 0.01

Open the SZA and the SAA maps and verify the minimum and maximum values and fill the following table. Units should be in degrees

	SZA	**SAA**
Min		
Max		

Brightness temperature computation

This procedure provides the option to convert the bands 31 and 32 of MODIS from radiance to blackbody temperatures. The conversion is done by applying the well-known Planck equation

$$T_c = \frac{c_2}{\lambda_c \log\left(\frac{c_1}{\lambda_c^5 \pi L_s} + 1\right)}$$

where:

T_c = brightness temperature, from a central wavelength

λ_c = the sensor's central wavelength

c1 and c2 are blackbody constant.

- Select Operations -> SEBS Tools -> Pre-processing > Brightness temperature computation
- Select MODIS sensor
- Select input radiance bands 31 and 32
- Specify a proper name for the output files, for example btm31 and btm32 for bands 31 and 32 respectively.
- Click on Show to start computing.

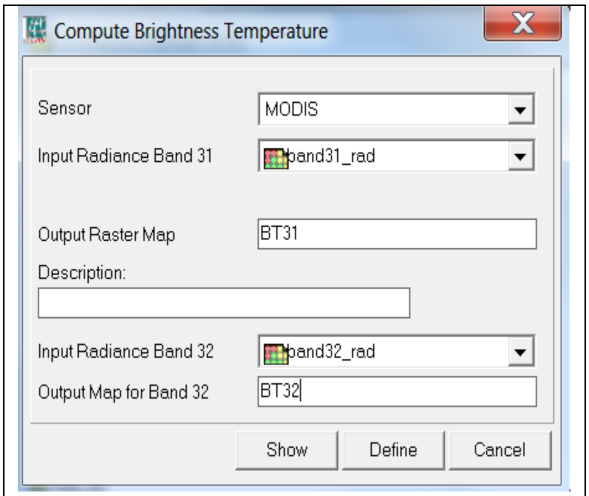


Figure 2.9 Computing brightness temperature for band 31 and 32 user interface

Open the reflectance map in channels 1 to 7 and select a water, a soil and a vegetated pixel and fill the following table with reflectances:

	Water		Vegetation		Soil	
Lat, long:						
Channel 1						
Channel 2						
Channel 3						
Channel 4						
Channel 5						
Channel 6						
Channel 7						

These will be the reflectance before atmospheric correction.
For the same pixels find out the Brightness temperature in channels 31 and 32.

	BT 31	BT32
Water		
Soil		
Vegetation		

Water vapour content estimation

Water vapour content is estimated using the radiance values of MODIS bands 2, 17, 18, and 19.

The procedure for water vapor estimation is as follows:

- Select Operations-SEBS Tools-Pr
- e-processing-Water vapor computation
- Select input radiance bands
- Specify a proper name for the output file
- Click on Show to start computing

At the end of this step all input maps are ready for the atmospheric correction process.

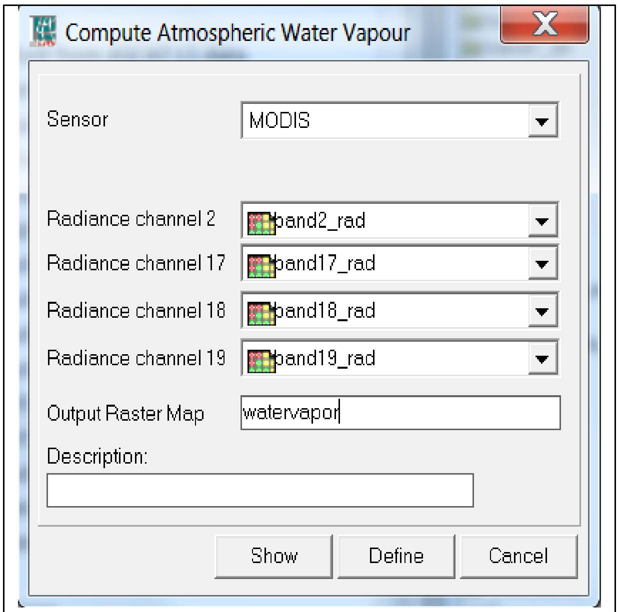


Figure 2.10 Example settings in Water Vapor computation

Atmospheric Correction (SMAC)

The correction of the atmospheric absorption and scattering in the visible channels is essential for any approach dealing with the energy balance equation. If atmospherically corrected maps are already available they can be imported into the ILWIS and this step can be skipped.

SMAC is a tool for the atmospheric effect correction of the visible and near visible bands of different sensors e.g. MODIS, ASTER, MERIS, NOAA, SPOT, and AATSR. The algorithm by Rahman H., Dedieu G. (1994). **i**s used.

SMAC requires information of the atmospheric composition at the moment the satellite passes and information of the geometry of the satellite and sun.

IMPORTANT NOTE: According to the authors of SMAC, the model can't be applied for solar zenith angles greater than 60 degrees and/or satellite zenith angles greater than 50 degrees. So be aware on the use of MODIS images in winter time. SEBS4ILWIS is able to accept atmospherically corrected maps from external sources, in case other algorithm is used.

The set of input required by SMAC is described below:

Aerosol optical thickness (AOT evaluated at 550 nm wavelength): The value ranges from 0.05 to 0.8. Aerosol in the atmosphere has an extreme dynamic behaviour. As a reference aerosol conditions may change in time scales less than an hour with high spatial variation. At such it is difficult to get accurate information on the aerosol optical thickness.

Use could be made of the aeronet service http://aeronet.gsfc.nasa.gov/ (that might help to evaluate a reasonable value of aerosols in case that a station is located close to the area of interest).

By exploring the Aeronet site information of the kind showed in the graph below can be retrieved for the sunphotometer stations closest to the area of interest and at the time of the image.

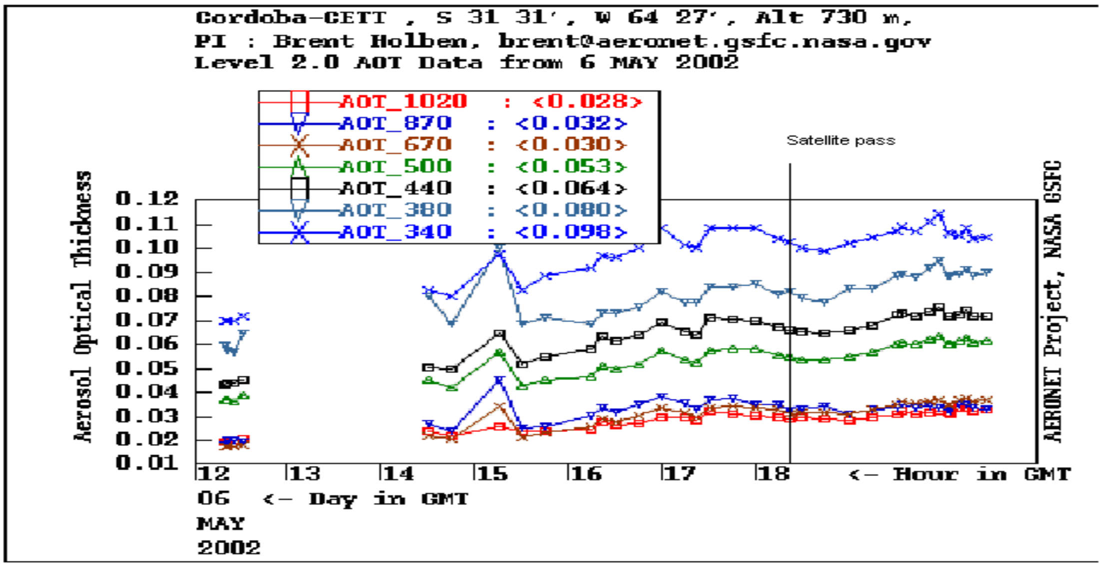


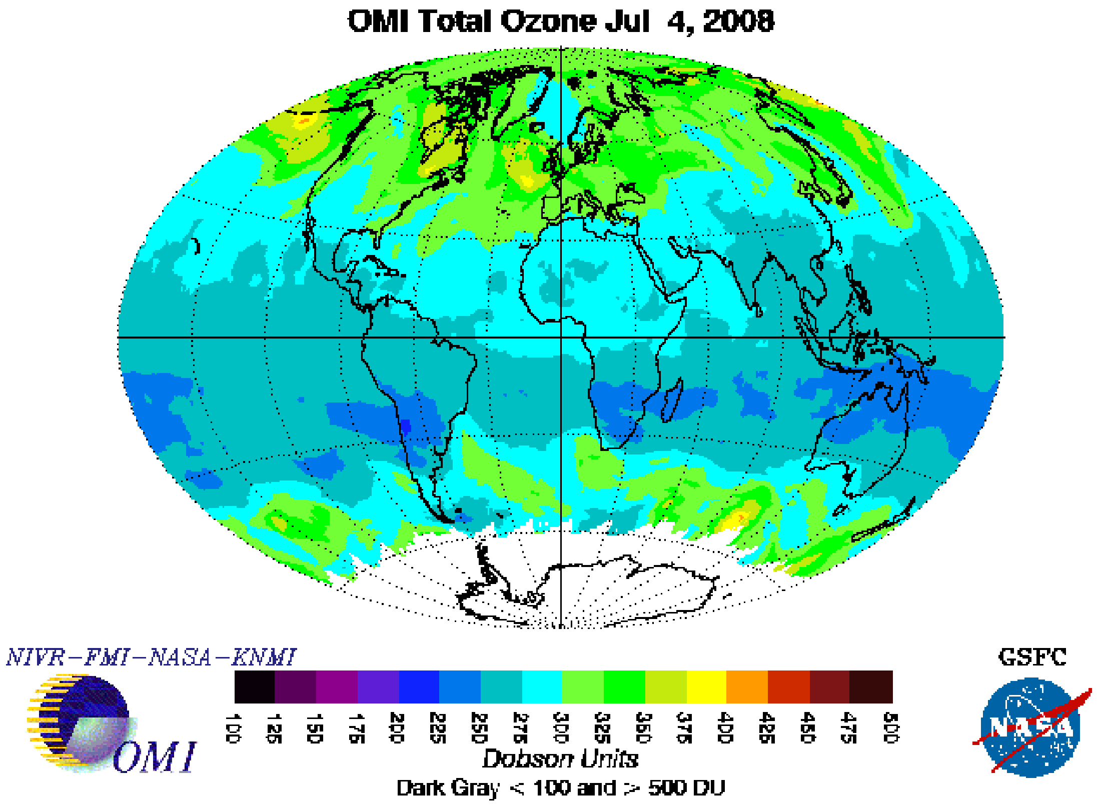
Figure 2.11 AOT is evaluated from sunphotometers at different wavelengths. The vertical line in the previous figure indicates the satellite pass

⇒ Go to the study area (Naqu site on the Tibetan plateau, China), derive the AOT value

Tip: in case you do not have enough time to complete the exercise, please use the AOZ provided you in the table below.

Ozone content: Ozone can be also measured in DU (Dobson Units. 1000 DU = 1 g.atm.cm). Ozone content is less dynamic than the AOT component (changes during days or weeks).

Ozone is monitored quite intensively from satellites and other ground resources.
A good source of ozone on the internet is http://macuv.gsfc.nasa.gov/. Use TIFF high resolution on the same date. Earth-Probe sensor.



In this exercise, we will use some fixed values, but it is important to realize that these atmospheric composition has to be evaluated by the time, site and conditions of the imagery.

AOT 550 nm	0.3
Ozone content [atm.cm]	0.288
Surface pressure [HPa]	592
Water vapour(grams. cm^{-2})	map

The procedure for SMAC is as follows:

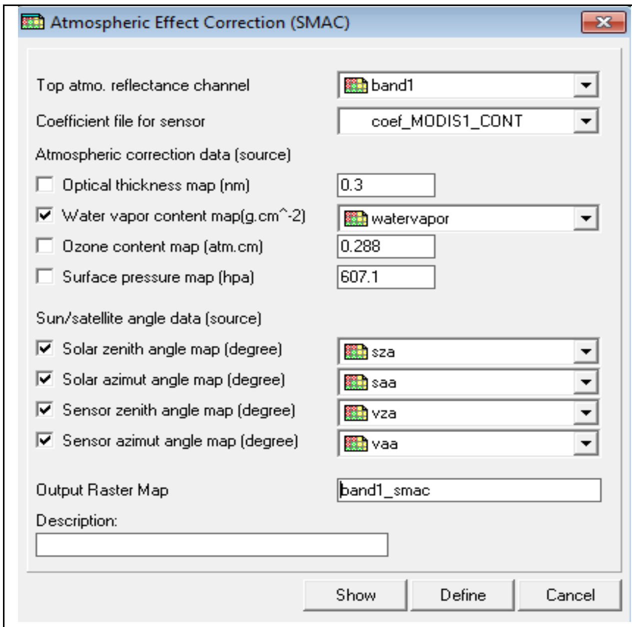


Figure 2.12 Example settings in Atmospheric correction for MODIS band1

- Select Operations -> SEBS Tools -> Pre-processing –> SMAC
- **Top atom. reflectance channel**: Select an input reflectance in VIS or NIR as it was calculated above. The process will be repeated for all VIS and NIR maps.
- **Coefficient file for sensor:** Select a coefficient file that contains calibration needed for the SMAC algorithm. The coefficients are calculated for only two atmospheres: desert and continental. SMAC model has in-built standard coefficients for different sensors e.g. MODIS, AATSR, MERIS, NOAA, SPOT and two atmospheres (desert and continental). SMAC for ILWIS allows the user to select from a list.
- **Optical thickness map**: Check the option when you wish to use a map that contains optical thickness (depth) values. Otherwise type a constant value that will be applied to all pixels. The value range is between 0.05 to 0.8. The value of the optical depth at 550nm is needed in SMAC.
- **Water vapor content map:** It refers to the total column of water. Check the option when you wish to use a map for water vapor values. Otherwise type a constant value that will be applied to the entire image. The unit of the value is grams. cm^{-2}, and the value range is between 0.0 to 6.0
- **Ozone content map:** Check the option when you wish to use a map containing ozone content values. Otherwise provide a constant value that will be applied to the entire image. The unit of it is gram. atm. cm, and the value range is 0.0 to 0.7.
- **Surface pressure map:** Check the option when you wish to use a map that contains surface pressure values. Otherwise provide a constant value for all pixels. The unit of the value is hpa (Hecto Pascal or millibars).
- **Solar zenith angle map:** Check the option when you wish to use a map that contains solar zenith angle values. Otherwise type a value for all pixels. Unit is degree.
- **Solar azimuth angle map:** Check the option when you wish to use a map that contains solar azimuth angle values. Otherwise type a value for all pixels. Unit is degree.
- **Sensor zenith angle map:** Check the option when you wish to use a map that contains satellite azimuth angle values. Otherwise type a value for all pixels. Unit is degree.
- **Sensor azimuth angle map:** Check the option when you wish to use a map that contains satellite azimuth angle values. Otherwise type a value for all pixels. Unit is degree.
- **Output raster map:** Type a name for the output raster map.

In this exercise, the procedure of atmospheric correction needs to be repeated seven times (one for each visible channel). In the end the interface should look like as shown in Figure 2.12 **(values are only example in there, you need to use your own data)**

Note that in order to correct all the images in a faster way, you can create an ILWIS script to do so. None of the atmospheric or geometric parameters change when doing all other bands. You must change the reflectance map and the coefficient file for the sensor and band in question!!

Land surface albedo computation

The surface albedo can be computed as follows:
Using MODIS reflectance bands 1, 2, 3, 4, 5 and7, the formula by Liang et al., 2001, 2003 is used:

albedo = 0.160*r1 + 0.291*r2 + 0.243*r3 + 0.116*r4 + 0.112*r5+0.018*r7 – 0.0015

Where, r1, r2, r3, r4, r5, r7 are the MODIS surface reflectance bands.

The procedure for land surface albedo calculation is as follows:

- Select Operations -> SEBS Pre-processing –> Land Surface Albedo Computation
- Select sensor type MODIS
- Provide the input bands. (surface reflectance maps that are the output of a previous SMAC operation)
- Assign a proper name for the output file
- Click on Show to start computing.

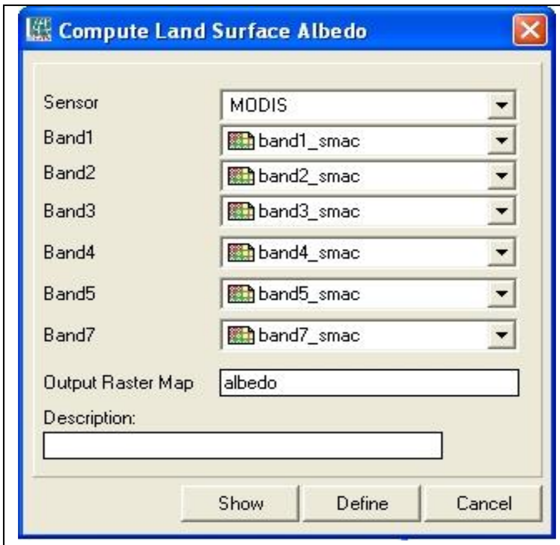


Figure 2.13 Computing surface albedo

Tip: A second way of calculating the albedo is type the equation directly in the Map Calculation or ILWIS command line

⇒ Display the albedo map and check the values for the same pixels as before:

	Albedo
Water	
Soil	
Vegetation	

Land surface emissivity computation

The Land surface emissivity computation operation is used to produce the surface emissivity using the atmospherically corrected surface reflectance in the red and NIR bands (Sobrino et al, 2003).
This method is restricted to land pixels. The emissivity for water pixels has been assigned a value of 0.995. Here assume that an albedo value < 0.035. You can try other discretization methods.

The NDVI values will be calculated with the equation based on the atmospherically corrected surface reflectances as shown below:

NDVI = (Bnir-Bred)/(Bred+Bnir)

The algorithm considers three different types of pixels depending on the NDVI value:

for bare soil pixels, NDVI < 0.2
Emissivity **e** = 0.9832 – 0.058 * Bred
Emissivity difference **de** = 0.0018 – 0.06 * Bred

for mixed pixels 0.2 =< NDVI < = 0.5
Emissivity **e** = 0.971 + 0.018 * Pv
Emissivity difference **de** = 0.006 * (1 – Pv)

for vegetation pixels NDVI > 0.5
Emissivity **e** = 0.990 +de
Emissivity difference **de** = 0.005

A vegetation proportion Pv is given by:

Pv = (NDVI – NDVImin)^2 / (NDVImax – NDVImin)^2
Where, NDVImax = 0.5 and NDVImin = 0.2.

Optionally, you can also obtain the following surface parameters as outputs

- NDVI
- Spectral emissivity difference
- vegetation proportion

⇒ Display the emissivity and NDVI maps and check the values for the same pixels as before:

	NDVI	Emissivity
Water		
Soil		
Vegetation		

The procedure for land surface emissivity calculation is as follows:

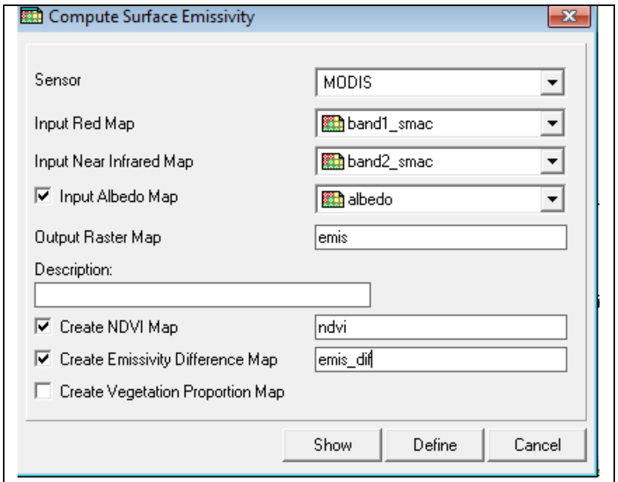


Figure 2.14 Computing surface emissivity dialog box

- Select Operations -> SEBS Pre-processing –> Land Surface Emissivity Computation
- Select Sensor type MODIS
- Select the visible and near infrared atmospherically corrected reflectance bands, which are derived from the previous SMAC operation for MODIS bands 1 and 2.
- Optionally, select an albedo map, if available.
- Assign a proper name for the output file
- Optionally, select Create NDVI map check box to obtain a NDVI map

- Optionally, select Create emissivity difference map check box to obtain an emissivity difference map.
- Optionally, select Create Vegetation Proportion map check box to obtain the vegetation proportion map.
- Click on Show to start computing.

Land surface temperature computation

This operation computes the land surface temperature using a split window method. The equation is shown below:

$$LST = btm31+1.02+1.79*(btm31-btm32) +1.2*(btm31 - btm32)^2+ (34.83-0.68*W) *(1-e)+ (-73.27-5.19*W)*de$$

Where:

LST – Land surface temperature
btm31 – brightness temperature obtained from MODIS band 31 using a previous Brightness temperature computation operation
btm32 – brightness temperature obtained from MODIS band 32 using a previous Brightness temperature computation operation
W – Water vapor content
e – Surface emissivity
de – Surface emissivity difference

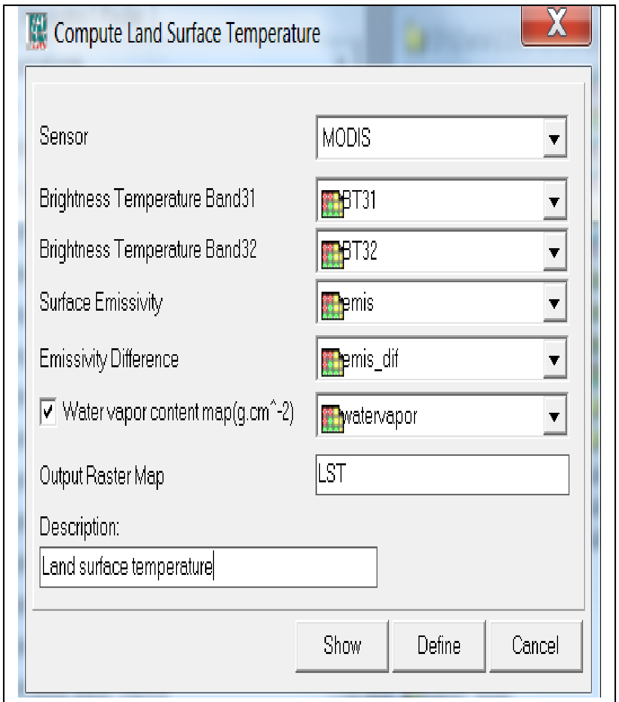


Figure 2.15 Land surface temperature calculation dialog window

If the water vapor map is not available, the simplified formula as shown below will be used:

$$LST = btm31+1.02+1.79*(btm31-btm32) +1.2*(btm31 - btm32)^2$$

The procedure for land surface temperature (LST) calculation is as follows:

- Select Operations -> SEBS Pre-processing –> Land Surface Temperature Computation
- Select Sensor type MODIS
- Select brightness temperature bands 31 and 32 of MODIS obtained from a previous Brightness computation operation.
- Optionally, select a map that contains water vapor content values.
- Assign a proper name for the output file
- Click on Show to start computing.

⇒ Display the surface temperature map and check the values for the same pixels as before:

	LST
Water	

Soil	
Vegetation	

2.3.4 Step VI: SEBS (Surface Energy Balance System)

The SEBS (Su, 2002) operation estimates the radiation balance components, atmospheric turbulent fluxes, surface evaporative fraction, and daily evaporation etc. using remote sensing observation in combination with the meteorological measurements.

In this exercise, you will be using the land surface parameter maps (e.g. land surface temperature, land surface albedo, NDVI, land surface emissivity) derived from the previous exercise and the meteorological data (specific humidity, wind speed, air temperature, and air pressure) will be extracted from GLDAS (Global Land Data Assimilation System) for forcing the SEBS model. Meteorological data from other analysis and prediction systems, e.g. ECMWF, NCEP, can be used equally.

GLDAS data can be accessed via NASA DISC Hydrology Data and Information Services Centre (HDISC) from the internet at the following address:

http://disc.sci.gsfc.nasa.gov/hydrology/data-holdings

It concerns the file: GLDAS_NOAH025SUBP_3H.A2008186.0300.001.2008296215855.nc

3 hourly 0.25 degree Experiment 1 GLDAS-1 Noah data, recorded at 03:00, on July the 4th 2008 (Julian day186) in netCDF format.

For the current exercise, the GLDAS file with global coverage has been already downloaded and provided to you in the same folder of the other data.

We will need to extract the following bands and import them into ILWIS:

Air temperature (K))

Air pressure (Pa)

Specific humidity (kg/kg)

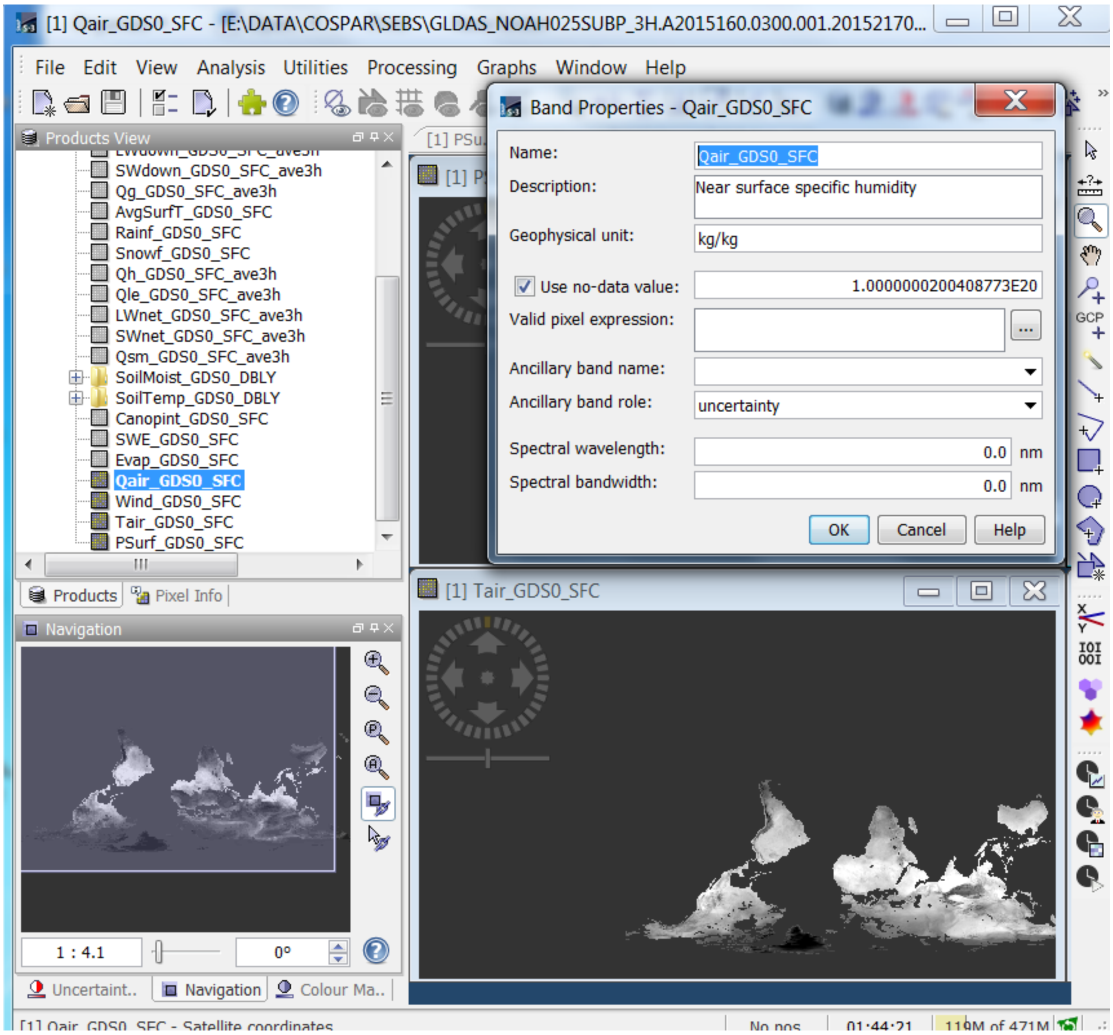
Wind speed (m/s)

First, Sentinel-3 toolbox will be used to convert the HDF images into the GEOTIFF files:

Sentinel-3 toolbox -part:

- Go to the menu File -> Open Products... to open the GLDAS file
- After that, a list of available bands will appear, double click at least one of the listed images.
- Check the description and unit of the bands: Qair, Wind, Tair, PSurf
- What are the units for the above bands?
- After that, go to menu File -> Export->Export to GEOTIFF Product...
- Close the toolbox.

Note that you can keep the default settings in the output dialog box.



ILWIS-part:

Import the GLDAS files to ILWIS

- Import the TIFF files into ILWIS. After this step you will obtain a new maplist for all GLDAS bands, and the band names are automatically numbered from 1 to 28.
- Note that the bands from 25 to 28 will be used for the present exercise, which correspond to the specific humidity (kg/kg), the wind speed (m/s), the air temperature (K) and the surface pressure (Pa) maps respectively.
- Change the maplist georeference to GLDAS provided.

- Mirror/Rotate maps: Reflect line numbers in a horizontal line.

Select Mirror Rotate operation. The input raster map is the GLDAS band e.g. LDAS_files_band25 (specific humidity, see figure 16). **After the map is rotated, change the georefference of the mirrored map to GLDAS.** Repeat the Mirror Rotate operation for other 3 GLDAS files.

- Resample the GLDAS images from 0.25 degree spatial resolution to MODIS (1km) scale.

Go to Spatial Reference Operations -> Resample. This step needs to be repeated 4 times (one for each required GLDAS file)

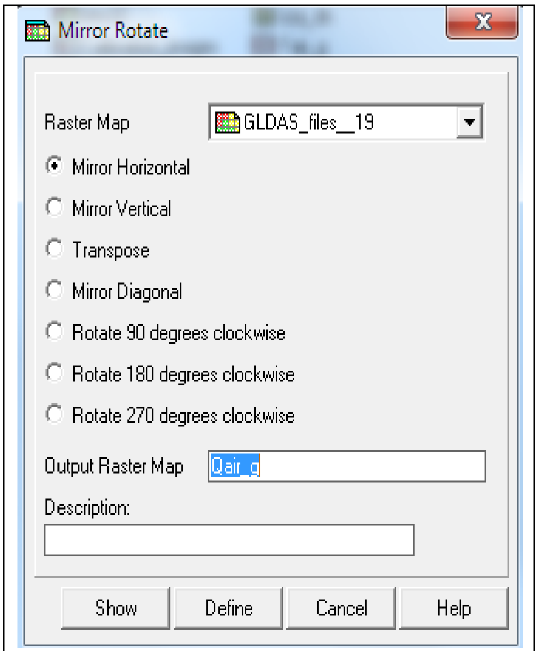


Figure 16: Mirror Rotate map

You could use a script to do it. The following script in ILWIS will carry out the Rotate operation.

```
Qair_g.mpr := MapMirrorRotate(GLDAS_files__25,MirrHor)
calc Qair_g.mpr
setgrf Qair_g.mpr gldas.grf
Qair:=iff(Qair_g.mpr<=1.00000e20,Qair_g,?)
Wind_g.mpr := MapMirrorRotate(GLDAS_files__26,MirrHor)
calc Wind_g.mpr
setgrf Wind_g.mpr gldas.grf
Wind:=iff(Wind_g.mpr<=1.00000e20,Wind_g,?)
Tair_g.mpr := MapMirrorRotate(GLDAS_files__27,MirrHor)
calc Tair_g.mpr
setgrf Tair_g.mpr gldas.grf
Tair_K:=iff(Tair_g.mpr<=1.00000e20,Tair_g,?)
Tair:=Tair_K-273
Psurf_g.mpr := MapMirrorRotate(GLDAS_files__28,MirrHor)
calc Psurf_g.mpr
setgrf Psurf_g.mpr gldas.grf
Psurf:=iff(Psurf_g.mpr<=1.00000e20,Psurf_g,?)
```

The following script in ILWIS will carry out the Resample operation.

```
Qair_rs.mpr:= MapResample(Qair,band1_dn.grf,bilinear)
Tair_rs.mpr:= MapResample(Tair,band1_dn.grf,bilinear)
Wind_rs.mpr:= MapResample(Wind,band1_dn.grf,bilinear)
Psurf_rs.mpr:= MapResample(Psurf,band1_dn.grf,bilinear)
calc Qair_rs.mpr
calc Tair_rs
calc Wind_rs.mpr
calc Psurf_rs.mpr
```

After that, the following maps will be created:

Map	Description
Tair_rs	Air temperature (K)
Wind_rs	Wind speed (m/s)
Qair_rs	Specific humidity (kg/kg)
Psurf_rs	Air pressure (Pa)

SEBS estimates roughness height either using field observations and literature values from a look-up table associated to a land-use map, or using empirical equations with NDVI values, when the filed observations/literature values are not available.

You can start SEBS from Operation –> SEBS Tools -> SEBS

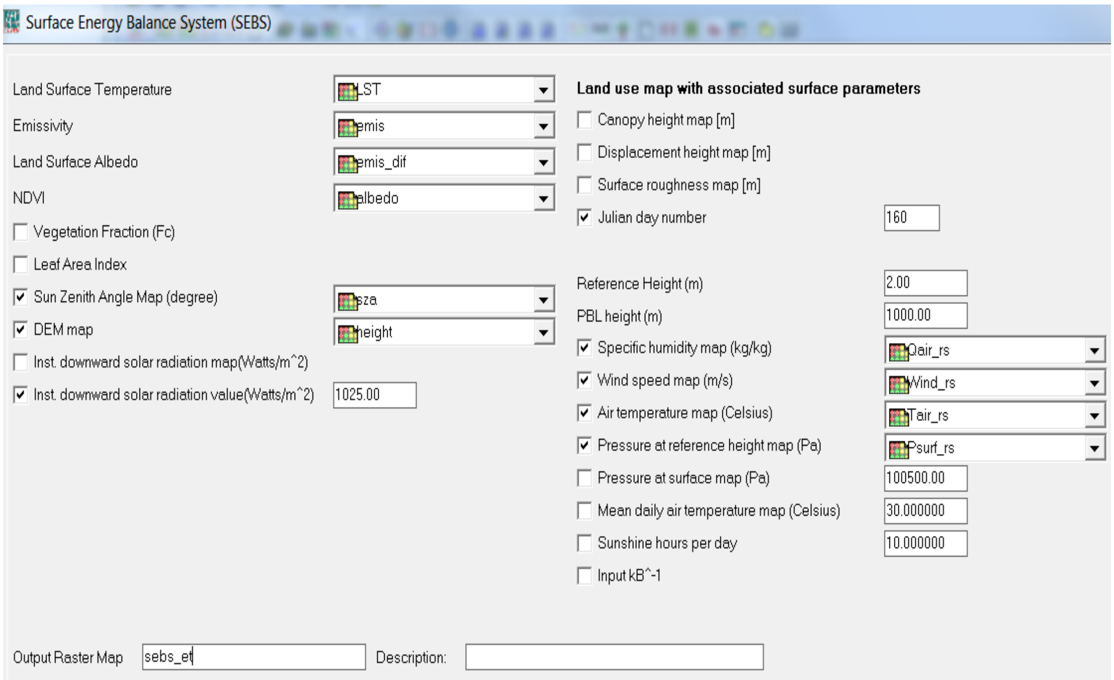


Figure 2.16 Example: SEBS operation user interface.

Land surface temperature map: Select an input map that contains land surface temperature values; In this case, select lst derived from a previous <u>Land surface temperature computation</u> operation.
Emissivity map: Select an input map that contains land surface emissivity values.
Land Surface Albedo map: Select an input map that contains surface albedo values.
NDVI map: Select an input map that contains NDVI values.
Vegetation fraction map: Select this option when you wish to use a map containing vegetation fraction (proportion) values.
Leaf Area Index map: Select this option when you wish to use a map containing leaf area index values, if this is not available, empirical equation with NDVI values is used to estimate the LAI. MODIS products also contain LAI product. The data is almost compulsory for a real case because the validity of empirical equations is mostly site limited. For the exercise leave the data blank.

Sun zenith angle map: Check the option when you wish to use a map containing sun zenith angle (Select sza in this case). Otherwise type a sun zenith angle value that will be applied to all pixels.
DEM map: Check the option when you wish to use a digital elevation map (Select height in this case). Otherwise type a height value that will be applied to all pixels.
Downward Solar radiation map: Select this option if you wish to use a map containing downward solar radiation. The user is entitled to build the map, which uses the same georeference to all other maps.
Downward Solar radiation: Select this option to type a downward solar radiation value to be applied to the whole study area;
The solar radiation is a very important variable and it is highly recommended for its direct input with a map or an actual value. If both a map and a actual value are not available, the horizontal visibility will be used in SEBS as surrogate for the calculation of the incoming shortwave radiation needed in the SEBS equation.
Horizontal visibility: Type a value for the horizontal visibility in kilometers. Enter 39.20. The user interface will not use this value if the shortwave radiation map/value is entered.
Canopy height map: Select this option to calculate SEBS results with the canopy height values (hc) from the attribute table associated to a land-use map. Otherwise, empirical equations for the calculation of canopy height values are used. For additional information over the attribute table, refer to the figure below.
Displacement height map: Select this option when you wish to calculate SEBS results with the displacement height values (d0) from the attribute table associated to a land-use map. Otherwise, empirical equations for the calculation of the displacement height values are used.
Roughness height map: Select this option when you wish to calculate SEBS results with the roughness height values (z0m) from the table associated to a land-use map. Otherwise, empirical equations for the calculation of the roughness height values are used.
For options 11, 12 and 13, leave the uncheck box. For the sake of time concerns, we will not calculate the landuse map (normally very much needed). Leaving the uncheck boxes will trigger a routine to calculate these values. This is not adequate for a proper real case!!!
Julian day number: Select this option to type a Julian day number. Unselect the option if you wish to use the routine in SEBS to obtain it.
Reference height: Type a value for the reference height in meters (at which the meteorological variables are measured or computed from a model). Enter 2 m.
PBL height: Type a value for the PBL (Planetary Boundary Layer) height in meters. Enter 1000 m.
Humidity map: Select the Check box if you wish to use a map containing humidity values. Otherwise type a value for the specific humidity at reference height in kg per kg.
Wind speed map: Select the Check box if you wish to use a map containing wind speed. Otherwise type a wind speed value in meters per second.
Air Temperature map: Select the Check box if you wish to use a map containing air temperature measurements. Otherwise type a value of air temperature at reference height in degree Celsius..
Pressure at reference height map: Select the Check box if you wish to use a map containing pressure at reference height. Otherwise type a value for the pressure at reference height in Pa.

Pressure at surface: Select the Check box if you wish to use a map containing pressure at surface. Otherwise type a value for the pressure at surface in Pa.
Mean daily air temperature map: Select this option to provide a map containing mean daily air temperature. Otherwise type a value for the mean daily air temperature.
Sunshine hours per day: Select this option to provide a sunshine hours/day map. Otherwise type a value for the sunshine hours per day.
kB^-1: Where B^-1 is the inverse Stanton number, a dimensionless heat transfer coefficient. Select this option to type a value for kB^-1, otherwise, use the model output for the estimation of the kB^-1 in SEBS.
Output Raster Map: Type a name for the output raster map containing evaporative fraction.

	hc (m)	Z0m(m)	d0 (m)
Bare soil	0.0000	0.0050	0.000
Stubble	0.1500	0.0150	0.100
Forest nursery	0.3500	0.0600	0.228
Vineyard	1.2500	0.1500	0.813
Grassland	0.0200	0.0025	0.013
Sunflower	1.0000	0.1250	0.650
Corn	2.0000	0.2500	1.300
Waterbody	0.0000	0.0004	0.000
Crops	0.2500	0.0313	0.163

Figure 2.17 Look-up table associated to a land-use class map containing field observations/literature-based surface parameters for canopy height (hc), roughness length for momentum transfer (Z0m) and displacement height (d0)

Outputs of SEBS

After the successful completion of the SEBS operation in ILWIS, you should see the following main raster maps in the Current Catalog:

sebs_ evap: Evaporative fraction
sebs_daily_evap: daily evaporation
sebs_evap_relative: relative evaporation
sebs_G0: Soil heat flux
sebs_H_dry: Sensible heat flux at the dry limit
sebs_H_i: Sensible heat flux
sebs_H_wet: Sensible heat flux at the wet limit
sebs_Rn: Net radiation
sebs_LE: Latent heat flux

For this exercise, a special version of SEBS4ILWIS is available that also allows seeing some intermediate maps like:

Sebs_LAI: Leaf area index
Sebs_z0m: roughness height for momentum transfer (m)
Sebs_C_i: Stability corrections
Sebs_z0h: scalar roughness height for heat transfer (m)
Sebs_T0ta: Difference between LST and air temperature
Sebs_kb: kB^-1 value

⇒ Evaluate the results and comment.

By now you have successfully completed this exercise. Congratulations!

2.4 References:

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