Exercises using MODIS 250-m bands

1 Introduction to MODIS

MODIS (Moderate Resolution Imaging Spectroradiometer) is an advanced multi-purpose NASA sensor. MODIS is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning (10:30 local time), while Aqua passes south to north over the equator in the afternoon (13:30 local time). Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands. MODIS has separate science teams and very many data products for land, atmosphere, cryosphere, oceans, and calibration. MODIS bands have resolutions of 250 m (bands 1-2), 500 m (bands 3-7) and 1 km (all the rest). The ocean color bands and products are similar to SeaWiFS and have the typical 1 km pixel size. Here we will be interested in the higher-resolution, 250-m and 500-m bands that were not designed for ocean applications. These bands are considered "land" bands because of their lower sensitivity. However, it is obvious that their sensitivity is sufficient to detect features in coastal ocean where their higher spatial resolution is crucial. For most applications in coastal areas 1 km resolution of typical ocean color sensors is not sufficient but the high-resolution sensors (e.g. Landsat ETM) have drawbacks such as a narrow swath, very infrequent overpasses and high price. That makes MODIS 250 and 500 m bands very promising for coastal monitoring applications. Some examples of this are provided at http://spg.ucsd.edu/Satellite_Projects/MODIS_250m_data/MODIS_250m_data.htm.

Table 1. MODIS BANDS and their PRINCIPAL AREAS OF APPLICATION

Primary Use	Band	Bandwidth (nm)	Central Wavelength (nm)	Pixel Size (m)
Land/Cloud/Aerosols Boundaries	1	620 - 670	645.5	250
	2	841 - 876	856.5	250
Land/Cloud/Aerosols Properties	3	459 - 479	465.6	500
	4	545 - 565	553.6	500
	5	1230 - 1250	1241.6	500
	6	1628 - 1652	1629.1	500
	7	2105 - 2155	2114.1	500
Ocean Color/	8	405 - 420	411.3	1000
	9	438 - 448	442.0	1000

Phytoplankton/ Biogeochemistry	10	483 - 493	486.9	1000
	11	526 - 536	529.6	1000
	12	546 - 556	546.8	1000
	13	662 - 672	665.5	1000
	14	673 - 683	676.8	1000
	15	743 - 753	746.4	1000
	16	862 - 877	866.2	1000
Atmospheric Water Vapor	17	890 - 920	904.0	1000
	18	931 - 941	935.5	1000
	19	915 - 965	935.2	1000
Surface/Cloud Temperature	20	3.660 - 3.840	3.785	1000
	21	3.930 - 3.989	3.960	1000
	22*	3.930 - 3.989	3.960	1000
	23	4.020 - 4.080	4.056	1000
Atmospheric Temperature	24	4.433 - 4.498	4.472	1000
	25	4.482 - 4.549	4.545	1000
Cirrus Clouds	26	1.360 - 1.390	1.383	1000
Water Vapor	27	6.535 - 6.895	6.752	1000
	28	7.175 - 7.475	7.334	1000
Cloud Properties	29	8.400 - 8.700	8.518	1000
Ozone	30	9.580 - 9.880	9.737	1000
Surface/Cloud Temperature	31	10.780 - 11.280	11.017	1000
	32	11.770 - 12.270	12.032	1000
Cloud Top Altitude	33	13.185 - 13.485	13.359	1000
	34	13.485 - 13.785	13.675	1000
	35	13.785 - 14.085	13.907	1000
	36	14.085 -	14.192	1000

		14.385		

*different saturation levels

In this course we will be using the following MODIS products. MODIS Terra and Aqua products have similar names except Terra product names start with MO and MODIS-Aqua product names with MY.

Table 2. MODIS PRODUCTS USED IN THIS EXERCISE

Short Name	**Long Name**	**Channel Data**	**Ancillary**	**Lat-lon**
MOD021KM	**MODIS/TERRA CALIBRATED RADIANCES 5-MIN L1B SWATH 1KM**	**1-36 @ 1 km**	**7 @ 5 km**	**5 km**
MOD02HKM	**MODIS/TERRA CALIBRATED RADIANCES 5-MIN L1B SWATH 500M**	**1-7 @ 500 m**	**none**	**1 km**
MOD02QKM	**MODIS/TERRA CALIBRATED RADIANCES 5-MIN L1B SWATH 250M**	**1-2 @ 250 m**	**none**	**1 km**
MOD03	**MODIS/TERRA GEOLOCATION FIELDS 5-MIN L1A SWATH 1KM**	**none**	**8 @ 1 km**	**1 km**

MODIS data is free of charge and all data products can be ordered from NASA. However, there are SO MANY of these datasets that finding the right one is a big problem. You need to know the date (or Julian day) and the time of a pass in order to order the products. Data are split into 5-minute granules. You can use the Terra and Aqua orbits from http://rapidfire.sci.gsfc.nasa.gov/realtime/ where you can find the date and time of a pass that is over your area of interest. This site has also the quasi-true color RGB image in JPG format. However, they are not mapped and are hard to manipulate. In order to produce images that you have full control over, you need the Level-1B data files. You can order these from NASA's LAADS Web at http://ladsweb.nascom.nasa.gov/data/search.html. You can select either *Terra* MODIS or *Aqua* MODIS. You need the following product types MYD03 (geo-location), MYD021KM (1 km dataset), MYD02HKM (500 m dataset), MYDO2QKM (250 m dataset). These product type names are for Aqua. For Terra the names are MOD03, MOD021KM, MOD02HKM, MOD02QKM, respectively. After that select *Temporal Selection* and *Spatial Selection*. Then click *Search*. You can preview the scenes but it is quite slow. For faster finding of cloud-free MODIS Aqua and Terra scenes over water I recommend locating the suitable passes with the Ocean Color browser at http://oceancolor.gsfc.nasa.gov (the Level 1 and 2 Browser). Select a date for MODIS-Aqua or Terra, pick search radius (e.g. 400 km) and click on your area of the interest on the map. Suitable passes can be downloaded by clicking on the corresponding Level-2 filename. Note the date (year and year-day) and time of the pass and order the specific scene by its date and time. If you want all good passes for a selected area then I recommend processing all available Level-2 ocean color data (see another exercise http://www.wimsoft.com/Exercises_Merging_L2_Chl_and_SST.pdf) into daily mapped images and then browsing through these images to find good Level-1B passes. You may have multiple passes per day but the good passes are easily recognized as passes with good coverage have large file sizes whereas bad passes (not centered on your selected area) have small file sizes. This applies to Level-2 data subset to your area of interest.

2 Prerequisites

We assume that you are familiar with the basics of the Windows or DOS command line, i.e. how to open the command window, change directory, issue a command, etc.

Before you can run the following examples, the executable programs used here should be available to the operating system, i.e. in the path. The Wimsoft folder (*C:\Program Files\Wimsoft*) is automatically added to the path. However, if you have a different location of the Wimsoft folder or for some other reason the Wimsoft folder is not in your path then you need to manually add it. You can define an environment variable WAMPATH and add it to the system variable PATH. Detailed instructions for that are given in the section "Installing WAM" in *WAM.pdf*.

3 Creating true-color images

True-color (actually, quasi-true color or RGB) images are a useful way to visualize multi-spectral data. A summary of the command sequence for generating RGB images is presented here. More details can be found below in the Examples section below. We assume that you use *C:\tmp* as your working directory. It is better to use a more informative directory names (e.g. C:\sat\MODISA\L1b\Dongsha\2007_113) but for brevity we assume here that your data files are in *C:\tmp* folder. It is a good idea to keep different sets of data in separate folders. You can name the folders by date or by year and Julian day, e.g. 2007_113 (2007, April 24, Julian day = 113).

- Copy the data files to your working directory, e.g. to *C:\tmp*.
- Open command window, e.g. with *Start-Run* type `cmd`
- Change directory to C:\tmp: `cd C:\tmp`
- Test that the WIM/WAM executable programs are accessible; type a name of any WIM/WAM executable, e.g. *wam_rgb_modis.* You should see the command syntax. If your response is: "'wam_rgb_modis' is not recognized as an internal or external command, operable program or batch file" then the path was not set correctly and you need to fix that now.
- If the data files are compressed, uncompress them.

- Edit the respective *crefl* control file with Notepad (*Bloka de notas* in Spanish) or another editor; change the location of the source files and the output file to your actual directory (e.g. *C:\\tmp*). Remember to use double backslashes (\\) in the pathnames.
- Perform atmospheric correction for the sets of bands, separately for each resolution (1 km, Half km = 500 m, Quarter km = 250 m). Edit the control file (*log_crefl*.txt*) with an editor to specify the resolution which you want to run. Specify with "1" to run the resolution and with "0" for the others. Do it separately for each resolution, i.e. ONLY ONE RESOLUTION AT A TIME! Run *crefl* three times: for 1 km resolution, for 500 m (H) and for 250 m resolution (Q), e.g.

  ```
  crefl log_crefl_MY_2007_113.txt
  ```

  Here *log_crefl_MY_2007_113.txt* is just the name of your control file. It is not really necessary to run *crefl* with 1 km resolution to get 250 m RGB data but it is useful to get a small RGB image first as an overview.
- Note: this step was useful with OLDER versions of the L1B files and is **not recommended** with recent data. It creates high-resolution geo-location datasets.

  ```
  DONOT USE WITH NEW DATA !!!  zoom_modis_lat_lon MYD03*.hdf
  ```

  For MODIS Terra you would use MOD03*.hdf.
- Create default, full extent 1-km RGB image(s) by typing:

  ```
  wam_rgb_modis *.1km_cref.hdf
  ```

  It may take several minutes to finish. After it is done, you can view the 1-km PNG image or load the 1-km RGB HDF image with WIM. Use the corresponding MOD03 or MYD03 file for geo-location. This is the basic form of running *wam_rgb_modis* with all the default options. To see all the options type the name of the command *wam_rgb_modis* without arguments. For example, the default option is to use the full range of 0 to 255 for each of the R, G and B bands. The full range is good for bright land features. To highlight darker ocean features you can stretch the RGB ranges and specify different ranges depending on what features you want to highlight. You can save all the bands and experiment with WIM to find the best color ranges.
- Create a new 1-km RGB image(s) by typing:

  ```
  wam_rgb_modis *.1km_cref.hdf 0 150 0 150 0 150 yes
  ```

  This specifies the color range from 0 to 150 for the Red, Green and Blue components. It also specifies ("yes") to save the 3-band file that you can use to tune the color range in the next step. After it is finished, load the 3 images from *_3bands.hdf* into WIM and find the best color range for each band with *Examine – RGB Image*. Use the MOD03 or MYD03 file for geo-location. Make sure that you load the correct bands for the R (band 1), G (band 4) and B (band 3) components.

- You can now create the full extent 250-m RGB image(s) by typing:

  wam_rgb_modis *.250m_cref.hdf 0 150 0 150 0 150

  We assume here that you want to use the color range from 0 to 150 for the three components.If you found another preferred set of range for the Red, Green abd Blue components in the previous step, please use those instead. The command may take several minutes to finish. After it is done, load the image into WIM and view it. Use the MOD03 or MYD03 file for geo-location.

- When studying a certain feature or area you will probably want to have multiple RGB images of the same area and in the same projection. You need to create a target projection file and then all the RGB images can be mapped to the projection in that file. For example,

  wam_rgb_modis *.250m_cref.hdf 0 130 0 130 0 130 no target.hdf

  will not save the individual bands (*no* option instead of *yes*) but will map the RGB image to the projection in *target.hdf*. Of course, you need to create your own target projection file. The easiest way to create the target projection is cut out your area of interest and do *Geo-Remap Projection-Create New Projection-Linear-Auto parameter Setting* and save it as your *target.hdf*.

4 Sample datasets

To create 250 m true-color images we need 4 files that are almost 500 MB (920 MB in the older, uncompressed version). You can download your own datasets but it will take long time. Some datasets are provided are for you for this exercise on a DVD or CDs but that will depend on a particular course. Make your selection and copy your favorite dataset to the work directory (e.g. C:\sat\MODISA\Dongsha) on your hard disk. The datasets may be compressed. To uncompress *.bz2 files you can use the *bwz2.exe* utility included with the WIM software, e.g. bzip2 –d *.bz2.

5 Exercises

5.1 An example of using *wam_rgb_modis*

In this exercise we will apply various procedures to create true-color RGB images from MODIS Level-1B (i.e. calibrated but not atmospherically corrected) products. The MODIS data files listed below cover southern Europe (Italy, the Mediterranean Sea, the Alps, etc.). If you selected a different dataset, please substitute the filenames with your respective MODIS filenames. The following products need to be available:

1 km radiances (MYD021KM*.hdf),

500 m (Half km) radiances (MYD02HKM*.hdf)

250 m (Quarter km) radiances (MYD02QKM*.hdf)

Geo-location product 03 (MYD03*.hdf)

The string "MY" stands for MODIS-Aqua and is replaced with "MO" for the respective MODIS-Terra products. The following files (or similar files of another area) need to be in your working folder on the hard disk:

MYD021KM.A2003359.1225.003.2003360215150.hdf

MYD02HKM.A2003359.1225.003.2003360215150.hdf

MYD02QKM.A2003359.1225.003.2003360215150.hdf

MYD03.A2003359.1225.003.2003360210518.hdf

It is possible to create 1-km and HKM (half-km) RGB images with just the single respective file (e.g. 1KM or HKM file) but for the best-looking, atmospherically corrected true-color images at 250 m resolution you need ALL 4 of the listed files.

You can create RGB images without atmospheric correction but the resulting images are hazy and bluish. For better looking results we will use atmospherically corrected data.

The 1st task is to perform (relatively simple) atmospheric correction using the MODIS Corrected Reflectance algorithm developed by Jacques Descloitres. The algorithm is currently implemented as a command line program *crefl.exe*. The *crefl* executable uses a control file to get filenames and other options. A sample control file looks like this:

```
C:\\tmp                                          ; data folder
MYD021KM.A2003359.1225.003.2003360215150.hdf     ; 1 km file
MYD02HKM.A2003359.1225.003.2003360215150.hdf     ; 500 m file
MYD02QKM.A2003359.1225.003.2003360215150.hdf     ; 250 m file
MYD03.A2003359.1225.003.2003360210518.hdf        ; geo-location file
1011000                                          ; bands 1-7 to process
C:\\tmp                                          ; output folder
0                                                ; output at 250 m resolution
0                                                ; output at 500 m resolution
1                                                ; output at 1 km resolution
Y                                                ; overwrite output file
y                                                ; verbose output
n                                                ; gzipped files
```

Here each line specifies either a filename or an option. You need to be able to edit that file with a text editor, e.g. *Notepad*. For example, unless you keep the data in *C:\tmp* you will need to change the data folder from *C:\\tmp* to your folder name. The same with the output folder name. Note that you need to use **double** backslashes as a separator. When you are creating the control file for your own image set, please note that the parameters are assumed to be at the fixed line in the file, e.g. the first line is always the data folder, the second line is the 1 km file, etc. To make a control file for a new dataset make a copy from an existing control file and replace the filenames. It is best to do that by listing the filenames and copying and replacing the old filenames with new filenames. Please note that the filename has to be followed by a space (e.g. before the semicolon in the example). You can include any explanatory text (as in the sample control file) but the parameter has to be separated by space from the rest of the line. To run atmospheric correction at 1 km (the line with "; output at 1 km resolution" starts with 1) type the following:

```
crefl log_crefl_sample.txt
```

Now edit the *log_crefl_sample.txt* file and change output from 1 km resolution (change 1 to 0) to 500 (change 0 to 1 at the corresponding line). Run the same command again. Now edit the *log_crefl_sample.txt* file and change output from 500 m resolution (change 1 to 0) to 250 (change 0 to 1 at the corresponding line). You must have created 1 km, 500 m and 250 m corrected files (**1km_cref.hdf*, **500m_cref.hdf* and *250*m_cref.hdf*). If you are using more than one data set you will probably want to name your configuration files according to the set of files, e.g. *log_crefl_MY_2003_359.txt*.

Now create a simple RGB image from the atmospherically corrected 1 km data with a command like that:

```
wam_rgb_modis MYD021KM.*.hdf
```

Please note that you don't have to type the full filename and can use wildcard characters such as * and ?. All matching files will be used. If you have more than one matching files, then all the matching files will be processed with a single command. However, be careful with the matching filenames as you don't want to match with different kinds of files that happen to be in your data folder. If the command finished successfully it produced a *.*PNG* and a *.*RGB_0_255_0_255_0_255.hdf* files. The string "0_255_0_255_0_255" in the filename shows the stretching limits of the R, G, and B components, respectively. You can issue a similar command for the H resolution. You can view the *.*RGB_*.hdf* file by opening it with WIM (use the corresponding MY03* or MOD03* for geo-location).

The next step of creating high-resolution geo-location dataset is NOT RECOMMENDED any more:

```
DO NOT USE THAT: zoom_modis_lat_lon MYD03*.hdf
```

For MODIS Terra you would use MOD03*.hdf. This command will produce corresponding *.*Lat_Lon.hdf* files for each matching MOD03 or MYD03 file.

Creating RGB images at 250 m resolution is more complex as only the red band is available at 250 m resolution while the green and blue bands are measured at 500 m resolution and need to be "sharpened" to 250 m.

Now you are ready to create the 250 m true color image with a command like

```
wam_rgb_modis MYD02QKM.*.250m_cref.hdf
```

It may take several minutes to finish. After it is done, load the image into WIM and view it. This is the basic form of running *wam_rgb_modis* that uses all default options. To see all the options type the name of the command (*wam_rgb_modis*) without arguments. For example, the default option is to use the full range of 0 to 255 for each of the R, G and B bands. You can specify different ranges depending on what features you want to highlight.

To highlight less bright ocean features you can stretch the RGB ranges uniformly from 0 to 130 and use, for example,

```
wam_rgb_modis *.250m_cref.hdf 0 130 0 130 0 130
```

In order to interactively find the best RGB combination, you can save the three individual bands (*yes* argument after the three sets of limits), load them to WIM and create RGB interactively with *Examine-RGB Image*. After you have found the best combination for your application you can use these RGB limits in the command (e.g. instead of the *0 130* limits used previously).

When studying a certain feature or area you will probably want to have multiple RGB images of the same area and in the same projection. You need to create a target projection file and then all the RGB images can be mapped to the projection in that file. For example,

```
wam_rgb_modis *.250m_cref.hdf 0 130 0 130 0 130 no target.hdf
```

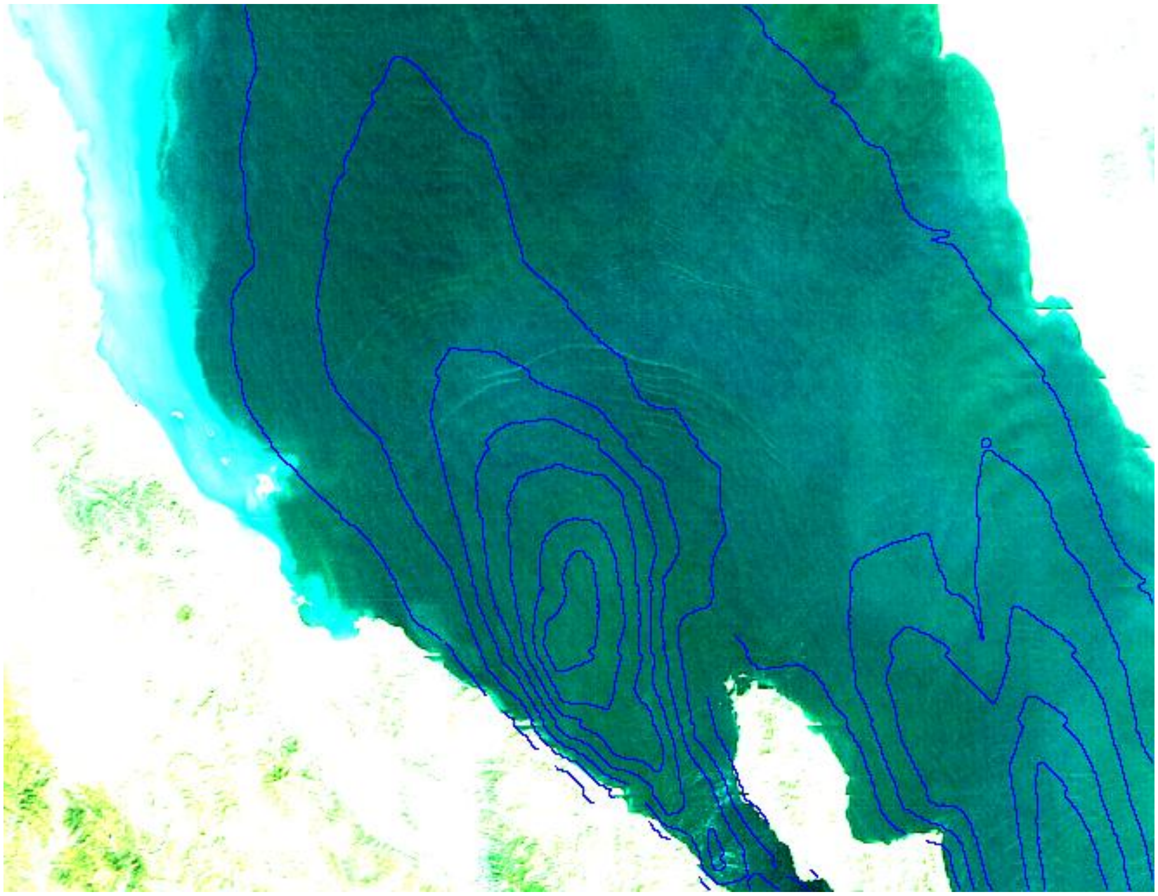
will not save the individual bands (*no* option instead of *yes*) but will map the RGB image to the projection in *target.hdf*. Of course, you need to create your own target projection file.

As you have probably realized by now, MODIS files are big and you need a fast PC with lots of disk space. Hopefully the command will finish successfully and you can enjoy the amazing features of our planet Earth!

When you look at the MODIS images, e.g. those you have just created, you can notice some geometric distortions, e.g. straight broken lines instead of smooth coastlines. This is the so-called "bow-tie" effect and is caused by the overlap effect of consecutive scans near the edges of the swath. The distortions are stronger near the edges and invisible near the center of the swath. The bow-ties can be corrected by remapping the image. Remapping is also needed if you want to create a consistent series of images of the same area in the same projection. The Level-1 data that we use here are in the sensor (swath) projection and look different for each pass. To remap the images and remove the bow-tie effects you need a target projection. The easiest way to create a target projection is to cut out a rectangular area of interest with *File-Cut* (the icon on the toolbar) in WIM and use *Geo-Remap Projection*, select *Create new projection* with *Auto parameter setting* to create a new *Linear* projection for the cut area. This creates a new *Linear* projection image of the same size as the source image. **Please do not try to remap the whole image to Linear projection in WIM**! That may take a very long time!

A small subset of the true-color RGB image created from a sample Aqua pass of December 25, 2003 is shown below. You can see smoke from a fire (upper left corner), haze tracks south from the city of Genoa (top), highly reflective (due to suspended particles) features in the Mediterranean Sea south of the city of La Spezia (a small bay near the center) and north of the city of Livorno (in the lower right corner), and snow in the mountains.

In the next example you can see surface manifestations of internal waves in the Gulf of California (Terra dataset from 2003, day 299). The following image was created with RGB stretch ranges 40-95 for Red, 21-55 for Green and 30-67 for Blue. After creating a suitable RGB image, cut out a rectangular area with the internal waves and create a bathymetry (depth) image of the area with *Geo-Bathy Image*. Stretch the colors with *View-LUT Stretch*. Using *Examine-Contour Lines* create depth isolines between 100 and 1000 m with a step of 100 m. Overlay the depth isolines on the RGB image showing internal waves. The internal waves are created at certain bottom slopes. The result should be something like that:



5.2 wam_turbidity

This WAM program calculates relative water turbidity from MODIS 250 m bands 1 and 2. Before that we need to apply the atmospheric correction to MODIS bands 1 and 2. We use the same program *crefl* used in the previous exercise but with a modified control file. The basic difference is that we specify bands 1 and 2 (and nothing else) to be corrected, i.e. the line in the control file with "bands 1-7 to process" should have "1100000" instead of the "1011000" that is used for creating the true-color RGB images. You can name your control file as *log_crefl_M*_12.txt*. Edit the file and specify where the data files are and where the output should go. As a simple example, we use use *C:\tmp* for both but you should use a more informative pathname.

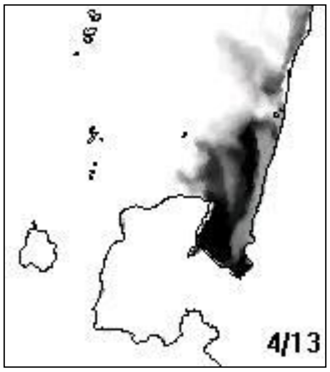
As step 1, perform the atmospheric correction by running *crefl* with the control file, e.g.

```
crefl log_crefl_MY_2004_104_12.txt
```

You can calculate turbidity for the whole scene or just a target area. The target projection must be specified it in the command. For example,

```
wam_turbidity C:\tmp\MYD02QKM.*.250m_cref.hdf C:\tmp\paracas_albers_200m.hdf
```

Note that you can use wildcard characters and process multiple files with a single command (all necessary files have to be in the same folder). In fact, the *wam_turbidity* program can process many datasets at once by looking into subdirectories and processing matching files in all the subdirectories. For example, if you have multiple subdirectories for individual days, e.g. “2004_104”, “2004_105”, “2004_06”, etc. then if you run *wam_turbidity* in the top directory then *wam_turbidity* will find all subdirectories and find matching files in the top directory as well as in ALL subdirectories. However, in this exercise we will run *wam_turbidity* for a single dataset. To see the command options issue the command without arguments.



The following output files are created: HDF file (**1minus2.*.hdf*) and a PNG file (**1minus2.*.png*). You can load the HDF file and view it in WIM. It is convenient to represent turbidity as a grayscale image with turbid areas dark (black) and clear areas light (white). Use *Settings* (icon) and set palette to *Grayscale*. Note using the *Color Definition* icon that *Start* and *End* are reversed, for example, *Start* = 200 and *End* = 28.

The examples below show the Mekong River delta off Vietnam in quasi-true color and the turbidity plume gray-scale (Aqua scene on April 23, 2007, day 113).