Aim of lesson

To observe the behavior of light below the water surface, to learn how hyperspectral data is prepared for benthic cover classification and to make a benthic cover map of a coral reef.

Objectives

1. To learn how in-situ collected spectra, measured with the GER spectroradiometer, can be used to observe how light at different wavelengths is influenced by the water column.
2. To learn why and how hyperspectral data, which is already radiometric, geometric and atmospheric corrected, needs additional corrections for sun glint.
3. To perform a benthic cover classification on a part of a coral reef.

Background information

Practical issues

This lesson relates to Section 10 of the Hyperspectral Theory Syllabus. For further details about the instruments and techniques, it is recommended to read this Section. The measurements procedure for the GER spectroradiometer is described in the ANNEX of the Hyperteach Theory Syllabus.

Software

A PC with ENVI® software, and Excel and Word is required to carry out the lesson.

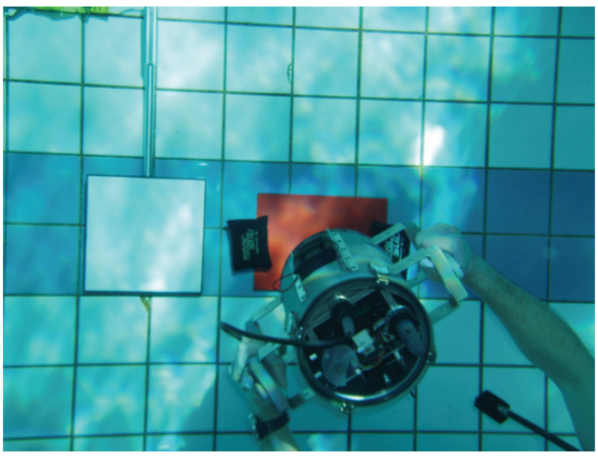
Lesson outline

Part 1: The behavior of submerged color

In this lesson you will learn how light at different wavelengths is influenced by the water column. For practical purpose ('not everyone feels happy dressed in a diving gear!' ☹) we will use existing data of a submerged blue, green and red target that were measured in a local swimming pool with the GER spectroradiometer (☺). These data can be found in the accompanying data directory (\Lesson12\Data\GER_raw*.*) as raw ASCII files. which were generated by the GER spectrometer.

Measurement protocol

Measuring spectra with the GER spectrometer in an underwater environment needs special precautions. First of all, the fragile mechanism of the GER spectrometer with its built-in electronics must be protected against the moist environment. Therefore, the instrument is placed in a specially developed underwater housing.
All functionality of the GER instrument can be operated from the outside of the housing. For underwater measurements, the GER is calibrated with a fore optic of 4°. This means that the field of view (FOV), when measuring from a height of 70 cm, is approximately 8 x 6 cm.



>> Figure 12.1: Measuring a red target with the GER spectrometer installed in the underwater housing.

Question 12.1: If you carefully observe the picture shown in Figure 12.1, especially the light conditions on the bottom surface, what do you think is a problem when measuring the reflected light with the spectroradiometer and how do you think the problem can be solved?

Because we are interested in the reflectance of a target, reference measurements need to be performed. For this purpose, a white reference panel is measured at regular times. All measurements are performed in the 'TAR' mode of the GER instrument and the data is read-out as ASCII files. More info on how to perform GER measurements can be found in Hyperteach Theory Annex 14.5 GER1500-measurements. The reflectance is calculated manually using the formula:

$$Target\ reflectance = \frac{Target\ reflected\ radiance}{Reference\ relected\ radiance} \quad (12.1)$$

Practically, measurements were performed on a blue, green and red plastic sheet located at a depth of 1 m and 3 m. For a certain target, e.g. the blue one, first a white reference measurement was performed at a depth of 1 m. This measurement is immediately followed by a measurement of the blue target at 1 m and at 3 m.

Question 12.2: Can you explain why no white reference measurement was performed at a depth of 3 m for calculating the reflectance of the deep target?

Building spectral libraries from GER data

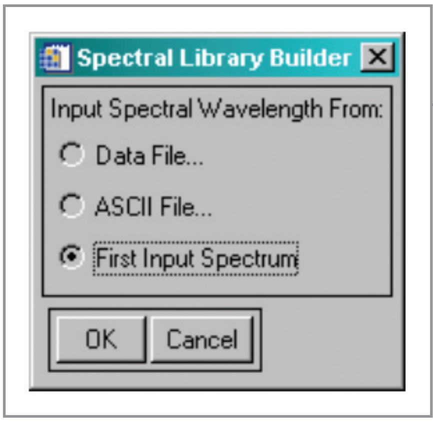
Data collected with the GER instrument is stored in ASCII files. Each individual measurement is stored in a separate file which can be read by ENVI.

Question 12.3: The ASCII files generated by the GER can be opened using a text editor e.g. 'Word' or 'Notepad'. Can you explain the content of these files? The files can be found in the data directory: \Lesson12\Data\GER_raw*.*.

The GER data files (raw data) can be used to create spectral libraries of the measured reflectance spectra. Because these files are the individual measurements performed on the reference panel and targets, additional processing is needed to obtain the target reflectance spectra. We will now use the ENVI Spectral Library Builder to create spectral libraries of the GER raw data.

Action: Build spectral libraries of the GER raw data.

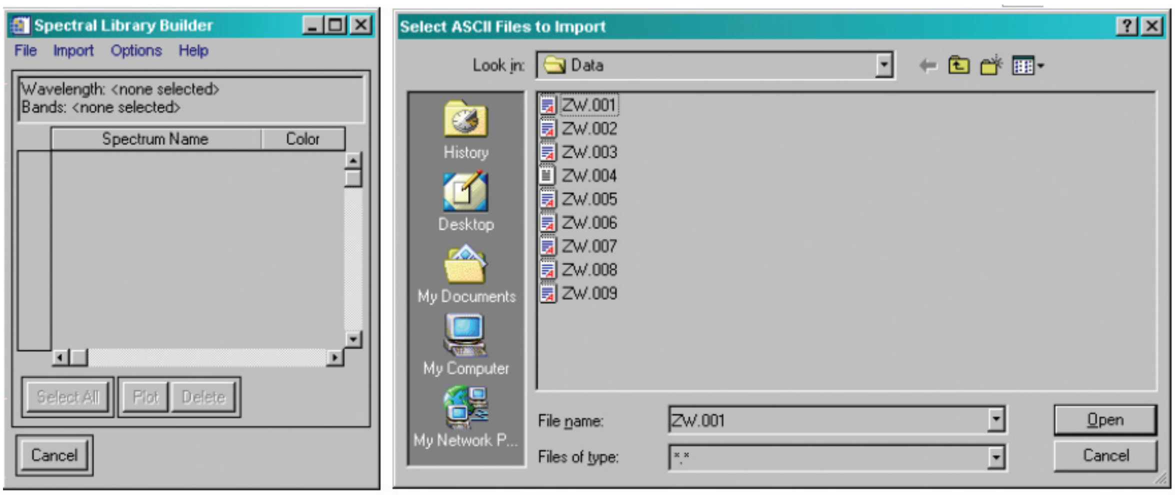
> **Hint**: In the ENVI main menu [ENVI] use <Spectral> <Spectral Libraries> <>Spectral Library Builder>; in the 'Spectral library Builder' window switch-on the 'First Input Spectrum' radio button as shown in Figure 12.2 and click 'OK'.



>> Figure 12.2: In the 'Spectral Library Builder' window, the 'First Input Spectrum' radio button has to be set when importing the raw GER data.

Action: Locate the first GER raw data file using ENVI Spectral Library Builder.

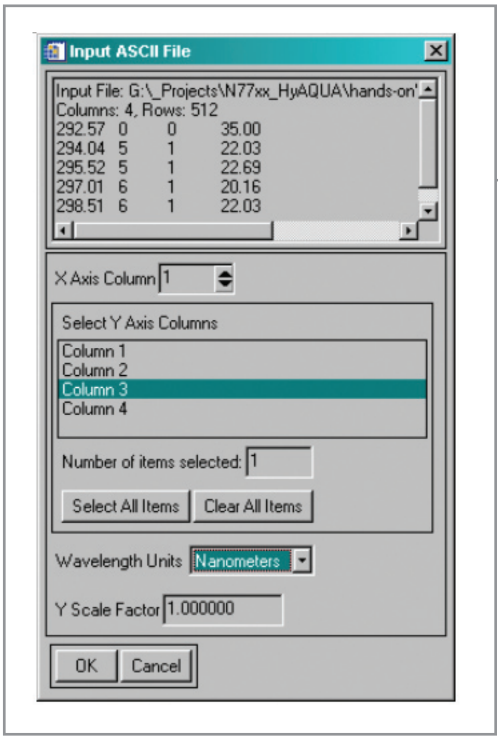
> **Hint**: After you got the 'Spectral Library Builder' window, use <Import> <from ASCII file…> to get a second window where you can browse to the directory where the GER raw data is located, i.e. \Lesson12\Data\. The two windows you get should look similar to those in Figure 12.3.



>> Figure 12.3: In the 'Spectral Library Builder' window the first GER raw data file can be located.

Action: Display from the GER raw data file, the first measured radiance as spectrum in ENVI.

Hint: Select the first GER raw data file and click 'Open'. Now the 'Input ASCII File' window appears where you get the columns listed that are found in the GER ASCII file. From the GER file description, which you have studied in question 12.2, you know that the third column contains the target radiance. Therefore, you select 'Column 3' in the 'Select Y Axis Columns' list box. Don't forget to select the correct wavelength unit! Wavelengths in the GER ASCII file are listed in nanometers as you know from the file description. Yes, now you may click 'Ok'.

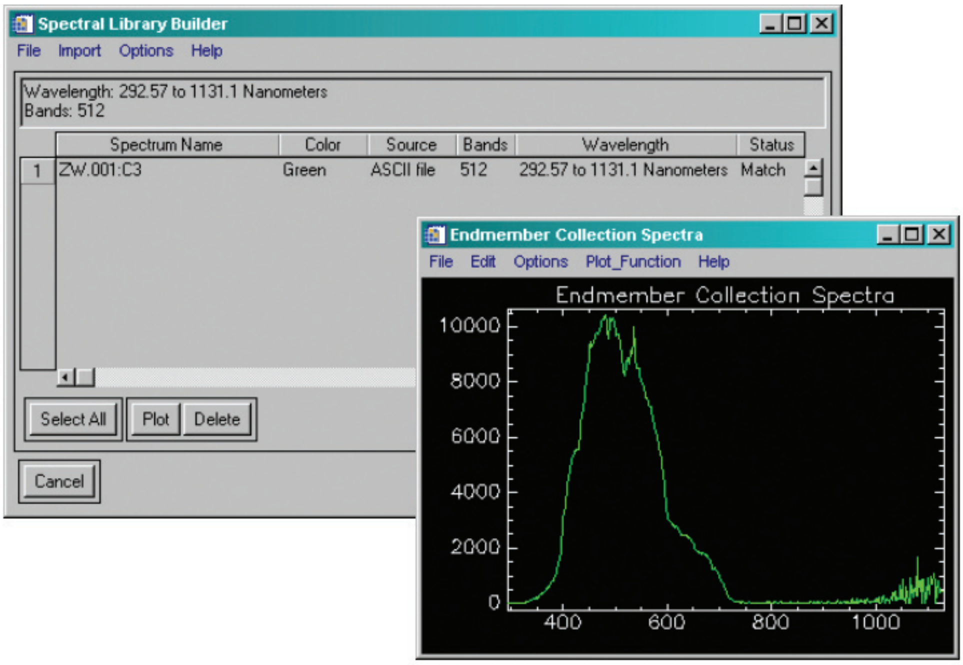


>> Figure 12.4: In the 'Input ASCII File' window you can select the column from which to build the spectrum. The wavelength unit has to be set to 'Nanometers' as we know from the GER ASCII file description.

Now, the first GER radiance spectrum is imported into ENVI. It is listed in the 'Spectral Library Builder' window. You can enlarge this window by grabbing its corner and dragging it to obtain a larger size. More information on the imported spectrum appears. You can use the 'Help' option to explore the meaning of the different parameters.

Action: Plot the imported GER radiance spectrum in a green color.

Hint: In the 'Spectral Library Window' click right on the entry under the parameter 'Color' where you find the value <none>. You get a drop down list where you can change the color of the spectrum as it appears in the plot window, i.e. use the color 'green'. Once you changed the color, you can plot the spectrum. Just click the 'Plot' button. You should get the windows, similar to those shown in Figure 12.5.



>> Figure 12.5: Detailed information of the imported spectrum is listed in the 'Spectral Library Builder' window. The spectrum can be visualized using the 'Plot' button. ZW.001 is the radiance measured on the white reference panel at a depth of 1 m.

Question 12.4: If you carefully look to the plot window in Figure 12.5, you notice that the values on the x- and y-axis are meaningless. Can you give this plot window a nice look, i.e. axis titles indicating the units for the values on x-axis and y-axis? Maybe you also want to change the plot title!

Question 12.5: Can you explain, using the plot window in Figure 12.5, why the measured radiance is very low in spectral range below 380 nm and above 720 nm.

Action: Import the remaining spectra.

Hint: In the 'Spectral Library Window' use <Import> <from ASCII file (previous template)…>. In the 'Select ASCII Files to Import' click left on the second file so it becomes highlighted. Hold the shift key and left click on the last file. All files, except the first one, are highlighted. Click the 'Open' button.

Now all spectra are imported into ENVI. You can visualize the different spectra using the 'Plot' button and change the appearance of the plot window using the <Edit> <Plot Parameters…> option in the 'Endmember Collection Spectra' window. Remember that all spectra are expressed in radiance values and reflectance values still need to be calculated. Therefore the spectral match function is used. However you also need to know for each measured spectrum, the type of target (white reference or other target). Table 12.1 gives an overview of the performed measurements and the type of target.

File	Target	Depth (m)	Name
ZW.001	WR	1	
ZW.002	Blue target	1	Blue_1
ZW.003	Blue target	3	Blue_3
ZW.004	WR	1	
ZW.005	Green target	1	Green_1
ZW.006	Green target	3	Green_3
ZW.007	WR	1	
ZW.008	Red target	1	Red_1
ZW.009	Red target	3	Red_3

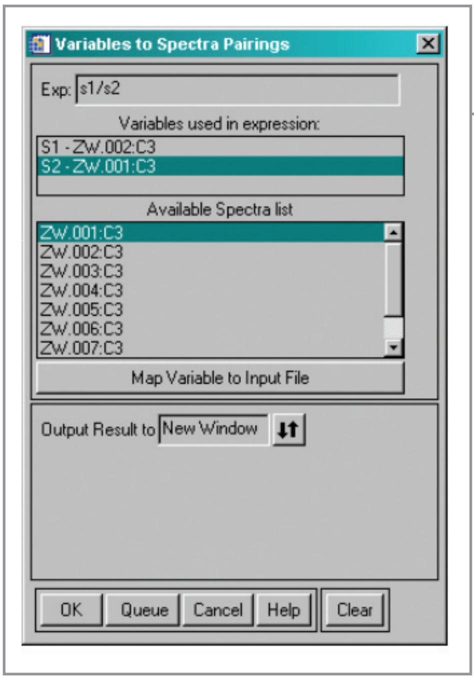
>> Table 12.1: When using the GER spectrometer you have to keep track of the performed measurements. This means writing down the type of target so you will know afterwards what was measured and how the different measurements need to be processed. WR is the White Reference.

Because we want to calculate reflectance values, we have to divide blue, green or red target radiance by white reference radiance.

Action: Enter the expression for calculating reflectance values.

> **Hint**: Before you start spectral calculations plot all spectra. Therefore click the 'Select All' button in the 'Spectral Library Builder' window followed by the 'Plot' button. This is the way how you tell ENVI you want to use these spectra in any further action. Now, in the ENVI main menu <ENVI> select <Basic Tools> <Spectral Math>. Enter in the 'Enter an expression:' field the expression "s1/s2" and click the 'Add to List' button followed by clicking the 'OK' button.

Now you obtain the window 'Variables to Spectra Pairings' as shown in Figure 12.6, where you can match a particular spectrum to a particular variable of the expression s1/s2 you have entered.



>> Figure 12.6: The 'Variables to Spectra Pairings' window allows linking of spectra to specific variables of the entered expression.

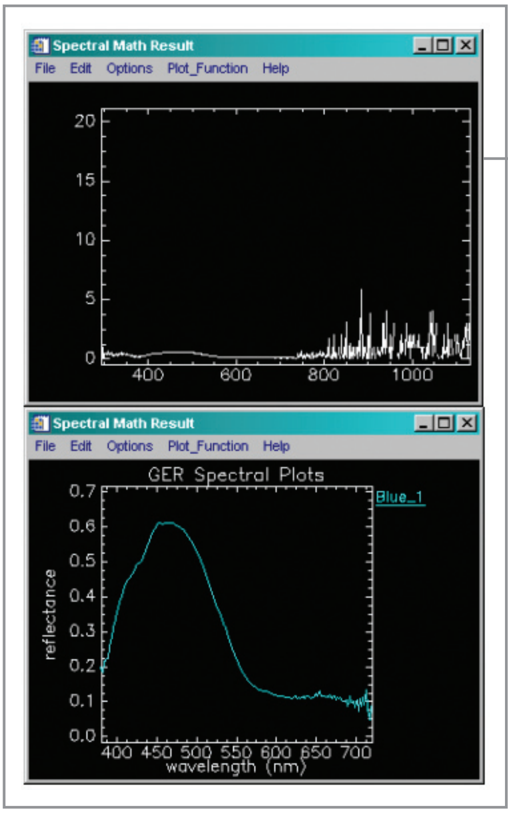
Action: Calculate the reflectance spectrum for the blue target located at a depth of 1 m.

> **Hint**: According to Table 12.1 we know that the white reference radiance for the blue target at 1 m corresponds to the first spectrum, i.e. ZW.001 and the blue target radiance corresponds to the second spectrum, i.e. ZW.002. Therefore match the first spectrum to S2 and the second spectrum to S1. This is done by highlighting S1 in the 'Variables used in expression' box and clicking right on the spectrum ZW.002 in the 'Available Spectra list' box. A similar action is done for S2 and ZW.001. Before you click the 'Ok' button switch the 'Output Result to' choice to 'New Window'.

Now you get the 'Spectral Math Result' window as shown in Figure 12.7 (up)a. Again you can change the lay-out of the plot window and 'zoom-in' on a particular part of the calculated spectrum.

Action: Change the spectral plot to a nice lay-out with a plot title and axis titles. Give the spectrum the name and color specified in 'column 'Name' of Table 12.1.

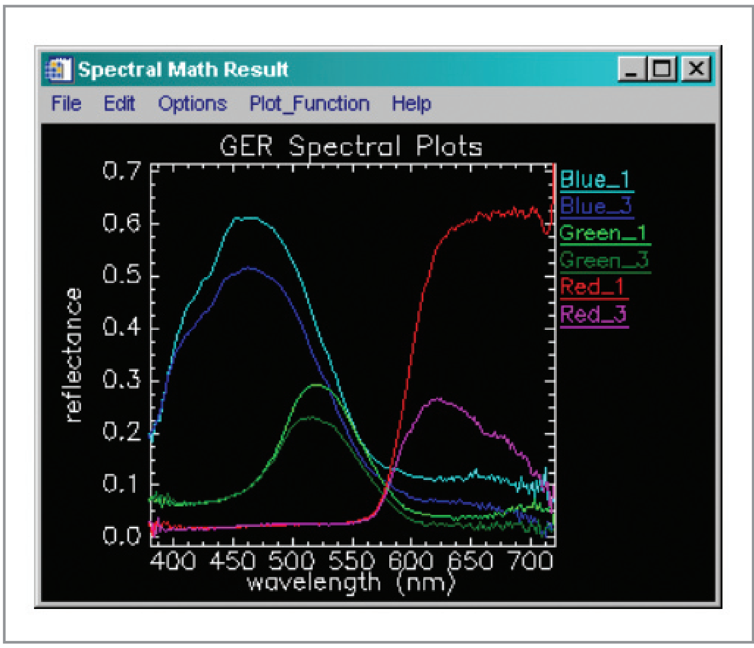
> **Hint**: In the 'Spectral Math Result' window use <Edit> <Data Parameters…> change the 'Name' edit box to "Blue_1". Right click on the 'Color' square and change the color to "Cyan". Click the 'Apply' button followed by the 'Cancel' button. Use <Edit> <Plot Parameters…> then enter the plot title, "GER Spectral Plots" in the "Plot Title" edit box. Make sure the X-Axis radio button is switched on. Enter in the 'Axis Title' edit box "wavelength (nm)" and change the "Range" edit box to '380' and the "To" edit box to '720'. Swith on the Y-Axis radio button. Change the "Axis Title" edit box to "reflectance" and the change the "Range" edit box to '0' and the "To" edit box to '0.7'. Click the 'Apply' button. Right click in the 'Spectral Math Result' window and click on 'Plot Key'.



>> Figure 12.7: Result of the spectral math function obtained for the blue target at 1 m (up). B. The same result after changing the 'Plot Parameters' and 'Data Parameters' (down).

Question 12.6: Can you explain in the left spectrum the high, unrealistic reflectance values which are calculated in the spectral range below 380 nm and above 720 nm?

The first reflectance spectrum is now calculated and displayed in a nice plot window. You can repeat the reflectance calculations for the remaining radiance measurements listed in Table 12.1 using the 'Spectral Math' function. The calculated reflectance spectra appear in the 'Same Window' or a 'New Window'. This is an option you can specify in the 'Variables to Spectra Pairings'. It doesn't matter, you can drag the newly calculated reflectance spectrum to the nice plot window you created by grabbing the spectrum by its name using the left mouse button. Just play around and try this out, you can't harm ENVI! Once you calculated all spectra your plot window should look similar to the one shown in Figure 12.8. The same spectra are stored in a spectral library 'GerReflectance' found in the data directory. This spectral library can be loaded and viewed using the 'Spectral Library Viewer'.



>> Figure 12.8: The six reflectance spectra calculated for the target measurements listed in Table 12.12.1.

Question 12.7: Can you explain the reflectance spectra in Figure 12.8?.

Part 2: Sun glint removal

In this lesson you will learn what causes sunglint and how it can be removed from hyperspectral imagery. The sunglint removal is based on the research published by Hochberg et al. (2003) and developed by Hedley et al. (2005) was used to remove sunglint from the airborne imagery according to:

$$VIS_{deglinted} = VIS_{initial} - NIR * slope \qquad (12.2)$$

Where $VIS_{deglinted}$ is the sunglint corrected image, $VIS_{initial}$ is the initial image, NIR is the near-infrared band which is - in this particular case - the average of six bands (band 25-30), and slope the regression slope between the blue band (average of band 1-3) and the NIR band (average of band 25-30). Averaging a number of bands is done to minimize noise affects.

Hyperspectral data

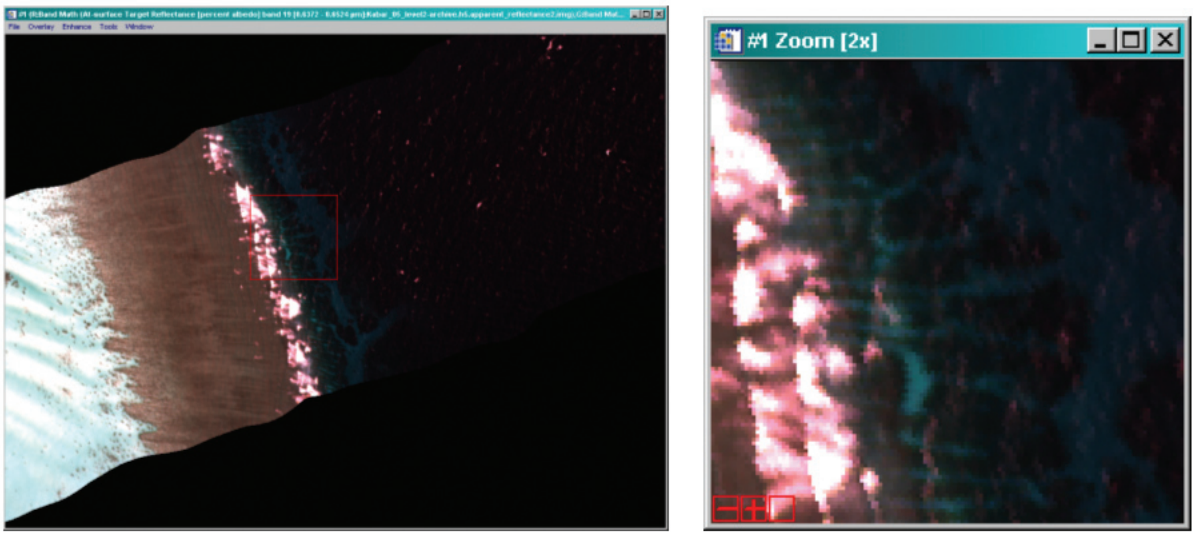
The coral reefs surrounding Pulau Fordata and Pulau Nukaha (7°05'S, 132°00'E), two small islands in the northeast of the Tanimbar archipelago, South-East Moluccas, Indonesia, have been selected as study area. On 1 September, 2005 between 7 and 11 AM local time, a CASI sensor was flown over the area. A full hyperspectral data set was recorded consisting of 16 flight lines with a ground resolution of 2.5 m. In total 30 spectral bands were recorded, covering the visible and near infrared part of the electromagnetic spectrum: 4 bands with a FWHM of 11.28 nm between 430 and 500 nm and 26 bands with a FWHM of 5.64 nm in a spectral range from 500 to 850 nm.

Performing sunglint correction

Now you have the chance to perform a sunglint correction yourself. Therefore you will use part of the hyperspectral dataset which was flown over the reefs of Pulau Nukaha. In the data directory: \Lesson12\Data\ you will find the file Kabar05_rag_p. This is a cut-out, '_p', from flight line '05' flown for the 'Kabar' project and is already radiometric, atmospheric and geometric corrected. Suffix '_rag' is an indication for these pre-processing steps.

Action: Open with ENVI, the file 'Kabar05_rag_p' located in the \Lesson12\Data\ directory and visualize the image on the screen (Figure 12.9)

> **Hint**: In the ENVI main menu [ENVI] use <File> <Open Image File> to import the hyperspectral file 'Kabar_rag_p' into ENVI. Therefore, highlight the file in the 'Enter Data Filenames' and click the 'Open' button. The file now appears in the 'Available Bands List'. To visualize the image click right the file in the 'Available Bands List' and click 'Load True Color'.



>> Figure 12.9: The hyperspectral image 'Kabar05_rag_p' shows part of the coral reefs at 'Pulau Nukaha'.

The hyperspectral image now appears on your screen in visual RGB colors. You can discover different reef structures when you examine it thoroughly. On the deep water part you clearly can see the effects of sun glint.

Question 12.8: Can you describe the different reef structures? (Don't panic, it's not essential to understand the sunglint correction.)

Question 12.9: Can you describe what causes sunglint? Do you have an idea how the sunglint effect can be minimized during the collection of the hyperspectral imagery?
In the sunglint correction algorithm, the average of the first three bands and last six bands is used.

Action: Calculate the average of the first three bands and the average of the last six bands.

Hint: Use <ENVI> <Basic Tools>, <Band Math> and type the following expression: (b1+b2+b3)/3. Click <Add to List> and click the 'Ok' button. In the 'Variables to Bands pairings' window, match the first band of the hyperspectral file to B1, the second band to B2 and the third band to B3. Save the result to 'File' on the work directory and choose as output filename 'Kabar05_AV_blue'. Repeat these steps for the last six bands, but use expression (b1+b2+b3+b4+b5+b6)/6 and as output filename 'Kabar05_AV_NIR'

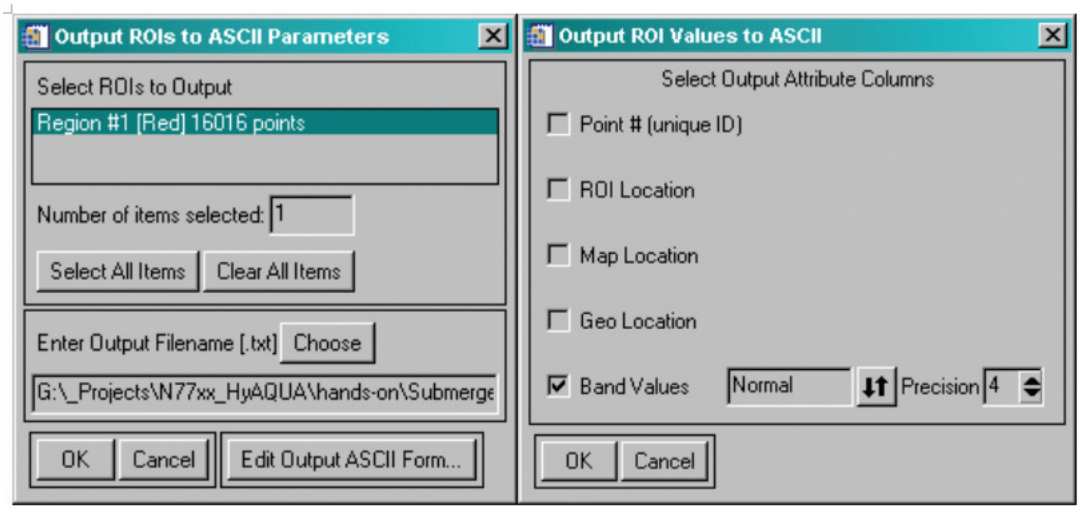
A statistical regression is used in the sunglint correction algorithm. Therefore, a statistically sufficient number of pixels needs to be collected from the 'average' images calculated in the previous step. For this purpose a Region Of Interest (ROI) is defined on an area above deep water where sunglint is present.

Action: Define a ROI on the hyperspectral image of approximately 16,000 pixels.

Hint: In the hyperspectral window, use <Overlay> <Region Of Interest…>. In the 'ROI Tool' window switch on <ROI_Type> 'Rectangle'. Make sure the 'Window: Image' radio button is switched on. In the hyperspectral image window, drag a rectangular ROI above deep water where sunglint is present. Make sure the size of the ROI is about 16,000 pixels. You can verify the size in the 'Roi Tool' window.

Action: Use the create ROI to extracted pixel values from the two calculated 'average' files. Save the extracted values in an ASCII text file.

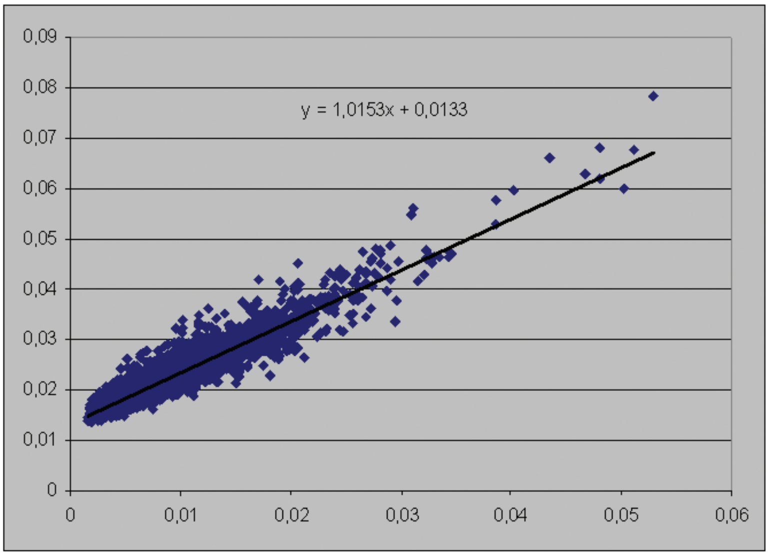
Hint: In the 'ROI Tool' window select <Output ROIs to ASCII…>. In the window 'Select Input File for ROI data' select the average file 'Kabar05_AV_blue' and click the 'Ok' button. In the 'Output ROIs to ASCII Parameters' click the 'Select All Items' button. Choose as output file 'Kabar05_AV_blue.txt' located in the work directory. Click the 'Edit Output ASCII Form…' button. In the 'Select Output Attribute Columns' switch off all options except the 'Band Values'. Your windows should look similar to those of figure 12.10. Click the 'ok' button in both windows to effectively write the ASCII file.



>> Figure 12.10: ROIs can be used to 'dump' pixel values from a certain file to an ASCII text file (right). The information written to the text file can be chosen via the attribute columns (left).

If everything went well, the first ASCII file containing the 'blue average' values is written. You should repeat the last action to extract pixel values from the 'NIR average' file. Use 'Kabar05_AV_NIR.txt' to store the values.

Now use Microsoft Excel to calculate the regression between the pixel values stored in both text files. These files can be easily imported in Excel via the 'Import External Data' utility. Make sure the NIR values are on the x-axis and the blue values are on the y-axis. A linear regression or trend line can now be calculated. The equation of the trend line can be displayed on the chart (Figure 12.11).



>> Figure 12.11: The linear regression calculated for the pixel values extracted from the average files (found on the data directory in the text files 'Kabar05_AV_blue.txt' and 'Kabar05_AV_NIR.txt') by the ROI defined by the ROI file 'Kabar05_rag_p_dg.roi'.

The slope of the trend line is now used for sunglint correction of the hyperspectral image. This is done according formula 12.2.

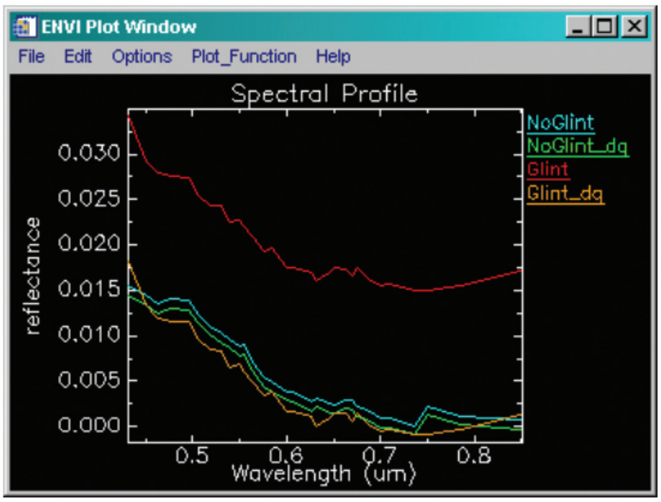
Action: Perform sunglint correction on the hyperspectral image using the slope calculated in the linear regression.

Hint: Use <ENVI> <Basic Tools> <Band Math> and type the following expression: b1-slope*b2, where slope is the slope value from the equation. Click <Add to List> and click the 'Ok' button. In the 'Variables to Bands pairings' window, click the 'Map Variable to Input File' button, select the hyperspectral file 'Kabar_rag_p' and click 'Ok'. The hyperspectral file is now mapped to B1. Highlight B2 in the 'Variables used in expression:' list box and select the band from file 'Kabar05_AV_NIR' in the 'Available Bands List' list box. Save the result to 'File', choose as output filename 'Kabar_rag_p_dg' and save to the work directory.

Processing may take a few seconds. Afterwards you can load the sunglint corrected file into ENVI and display the file as described above.

Action: Observe the result of the sunglint correction. Both images can be linked and their spectra compared using the spectral profile (Z profile). Especially look at the geographic location 173780.24 E – 9217624.17 S where sunglint is absent and at 174067.84 E – 9217772.08 S where sun glint is present.

Hint: Link both images using the <Tools> <Link> <Link Displays…> option. Go to the specified geographic locations using the <Tools> <Pixel Locator..> option. Collect spectra from both images for both locations in one 'ENVI Plot Window'. This you have learned in the first part of the lesson. If everything went well your image should look like the one from Figure 12.12.



>> Figure 12.12: The effect of sunglint correction on pixel spectra where sun glint was present (Glint) and on pixel spectra were sunglint was absent. _dg indicates the sunglint corrected pixel spectra.

Question 12.10: Can you explain the spectra shown in Figure 12.12?

References

Hedley, J.D., Harborne, A.R. and Mumby, P.J., 2005, Simple and robust removal of sun glint for mapping shallow-water benthos, International Journal of Remote Sensing (in press).

Part 3: Benthic cover mapping

In this lesson you will learn how to produce a benthic cover map based on hyperspectral imagery and in-situ collected ground truth data.

Hyperspectral data

For this lesson you will use the sunglint corrected data from the previous Part 2. Common to hyperspectral image classification is a minimum noise fraction (MNF) transformation. This processing step is performed to compress and reduce noise in the data and to order the transformed bands by the variability represented in the new bands (Green et al. 1988). To exclude dummy pixels a data mask is produced.

Action: Mask out the non hyperspectral data dummy pixels.

Hint: Open and visualize the file 'Kabar05_rag_p_dg' as explained in Part 2the previous sections. Use <ENVI> <Basic Tools> <Masking> <Build Mask>. In the 'Mask Definition' window highlight the display where the hyperspectral image is displayed and click 'Ok'. In the 'Mask Definition' select <Options> <Import Data Range…>. In the 'Select input for Mask Data Range' window highlight the file 'Kabar05_rag_p_dg' and click 'Ok'. Now you get the window 'Input for Data Range Mask'. In both the 'Data Min Value' and 'Data Max Value' edit box enter 0 and click 'Ok'. In the 'Mask Definition' window enter the output filename 'Kabar05_rag_p_dg_mask' and save the file to the work directory. Also set the <Options> <Selected Areas "Off">, check and click 'Apply'.

It will take some time before the mask will appear in the 'Available Bands List'. If you visualize the mask you get a similar display as shown in Figure 12.13.

>> Figure 12.13: Mask image used in subsequent image processing steps.

Action: Perform an MNF transformation on the sunglint corrected hyperspectral image.

Hint: Use <ENVI> <Spectral> <MNF Rotation> <Forward MNF> <Estimate Noise Statistics from Data> to select the file 'Kabar05_rag_p_dg'. Don't forget to select the mask via the 'Select Mask Band' button. In the 'Forward MNF Transform Parameters' window, use the 'Shift Diff Subset' to select a homogenous area in the hyperspectral image for noise statistics calculation. Set 'Select Subset from Eigenvalues' to 'Yes'. Enter 'Kabar05_rag_p_dg_mnf' , located inon the work directory, as output file.

Processing can take some time. At a certain moment you get the 'Select Output MNF Bands' window (Figure 12.14). The information content shows that the first 3 bands of the MNF transformed data are sufficient to describe more than 99% of the information contained in the hyperspectral image. Set the 'Number of Output MNF Bands' to 3 and click 'Ok'.

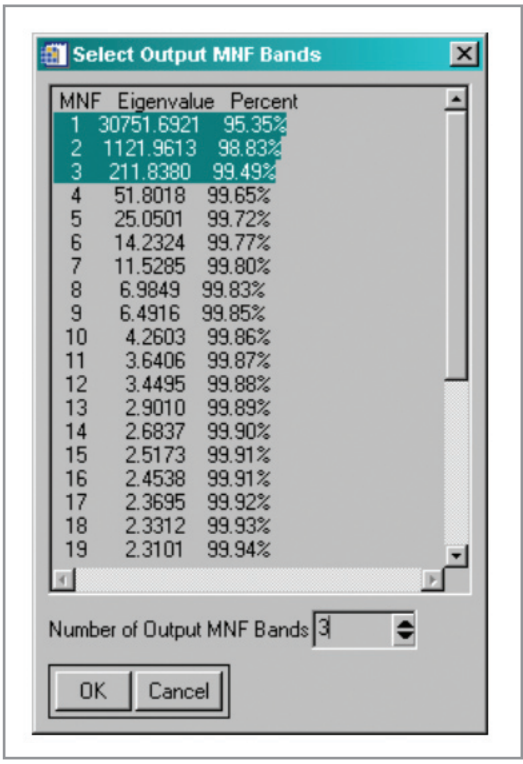
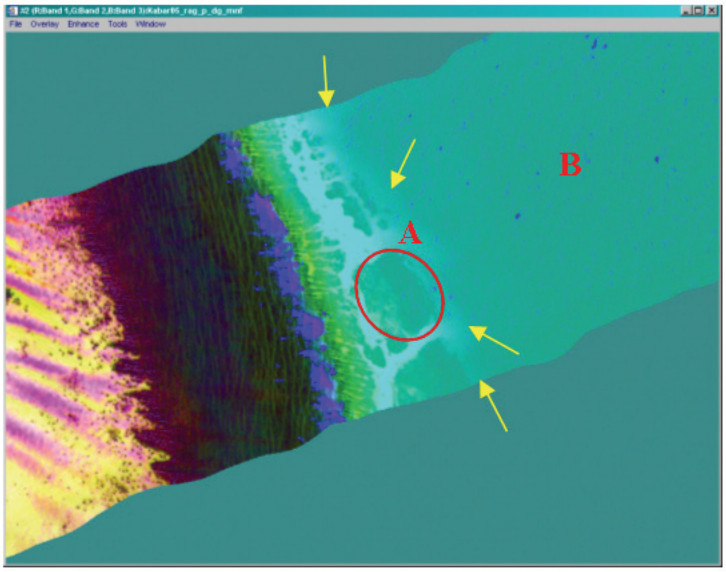


Figure 12.14: The calculated 'Eigenvalues' shown tells show that the first 3 bands of the transformed data are sufficient to describe the hyperspectral data.

Once processing has finished, the MNF image can be displayed (Figure 12.15). Now reef structures become clearly visible, especially on the fore reef.



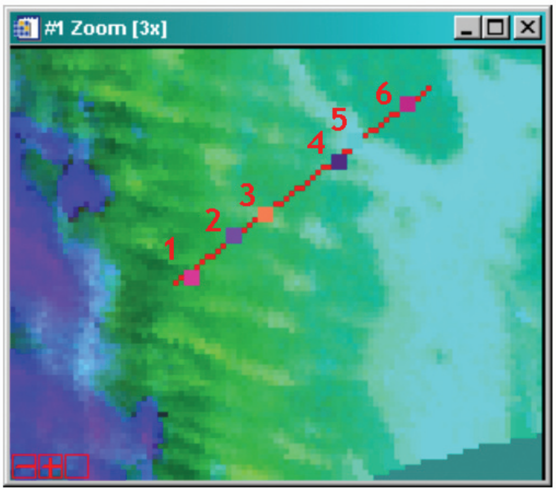
>> Figure 12.15: A visual representation of the first 3 MNF bands. The sandy bottom which is clearly recognized in the MNF transformed image and indicated by the yellow arrows are used to separate deep ocean water from deep corals.

Question 12.11: Can you describe the structure indicated by 'A'? Can you compare its spectra with the 'deep water' spectra collected in 'B'. What do you think the problem might be when classification is performed? How would you solve the problem?

As you carefully observe the image you will notice that deep corals are separated from deep ocean water by sandy bottom. This is indicated by the yellow arrows in Figure 12.15. This information can now be used to separate the deep ocean water from the deep corals.

Question 12.12: Can you perform the necessary actions to mask out the deep ocean water from the MNF transformed data?

All further classification steps will use the file 'Kabar05_rag_p_dg_mnf_b'. During the field expedition from August and September 2005, in-situ data was collected consisting of photographs of transects and benthic cover type , accompanied by GPS measurements. For more info read Section 10.4 in the HyperTeach Theory Syllabus. One of the transects taken during the field expedition can be overlaid on the airborne image. This ROI is contained in the file 'Transect.roi' in the data directory. Using information derived from the in-situ data, several ROIs could be defined for which meaningful benthic cover data could be assigned (Figure 12.16). These ROIs were completed with manually defined ROIs for waves, lagoon floor, back reef and deep sand. All ROIs are contained in the file 'ReefGroundTruth.roi' located in the data directory.



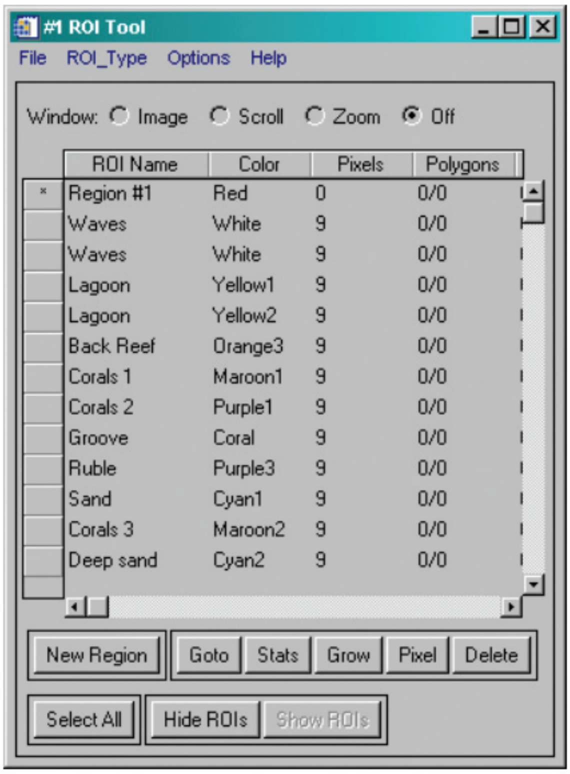
>> Figure 12.16: The transect taken during the field expedition together with in-situ collected data could be used to define ROIs which are used in a supervised classification.

Sampling point	Benthic cover
1	Coral Type 1
2	Coral Type 2
3	Grooves
4	Ruble
5	Sand
6	Coral Type 3

Action: Load the defined ROIs so they can be used for classification.

Hint: In the hyperspectral image click <Overlay> <Region of Interest…>. In the 'ROI Tool' window, use <File> <Restore ROIs…> to load the ROI-file 'ReefGroundTruth.roi'.

The ROI Tool window now looks like the one shown in Figure12.17. As you can see, two additional ROIs are defined for 'waves' and for 'lagoon'. This is done to cover the spectral variability within this class.

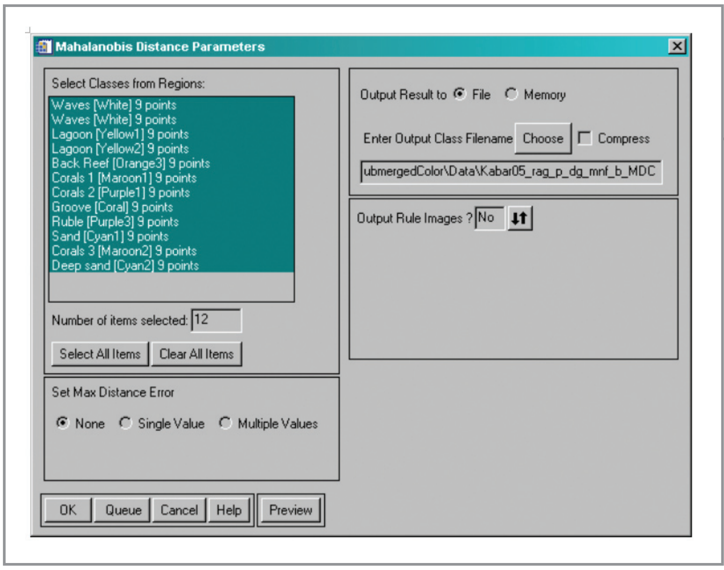


>> Figure 12.17: Ground truth ROIs used for supervised classification.

Within ENVI it is possible to run different types of supervised classification algorithms. The classification algorithm based on the 'Mahalanobis distance' is used here.

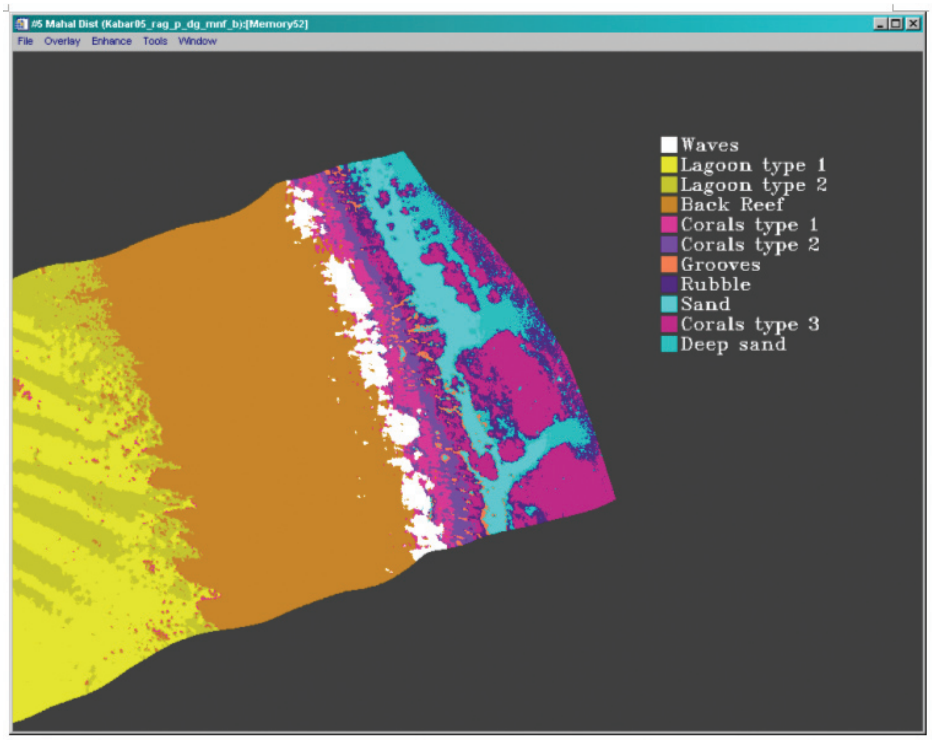
Action: Perform a supervised classification based on the Mahalanobis distance.

Hint: In <ENVI> click <Classification> <Supervised> <Mahalanobis Distance>. In the window 'Classification Input File' highlight the file 'Kabar05_rag_p_dg_mnf_b'. Click the 'Select Mask Band' button and highlight the mask file 'Kabar05_rag_p_dg_mnf_mask' and click 'Ok'. In the 'Classification Input File' window click 'Ok'. Now you get a window 'Mahalanobis Distance Parameters'. Click 'Select All Items' and make sure the 'Set Max Distance Error' is set to 'None'. Select as output file 'Kabar05_rag_p_dg_mnf_b_MDC' in the work directory and switch 'Output Rule Images?' to 'No'. Your window should look similar to Figure 12.18.



>> Figure 12.18: Setting the parameters for a supervised Mahalanobis classification.

When you now click 'Ok' the supervised Mahalanobis classification will start. This will take a few seconds. As soon as this is finished, the classification result is stored on the work directory and also it is placed in the 'Available Bands List'. Displaying the result will give a window similar to Figure 12.19. The colors of the classes may look different to those shown. You can adapt these via the window option <Tools> <Color Mapping> <Class Color Mapping…>. In Figure 12.19 a legend is shown which lists the different class colors and class names. You can set this via the window options <Overlay> <Annotation…> <Object> <Map Key>. Just try out these features. You also can run different supervised classification algorithms and compare the results.



>> Figure 12.19: Classification result of the Mahalanobis classification algorithm.

References

Green, A. A., Berman, M., Switzer, P., and Craig, M. D., 1988, A transformation for ordering multispectral data in terms of image quality with implications for noise removal: IEEE Transactions on Geoscience and Remote Sensing, v. 26, no. 1, p. 65-74.

Annex: File description

- Files used in part 1

ZW.xxx:	GER raw data files
GerReflectance:	Spectral library of GER collected spectra

- Files used in part 2

Kabar05_rag_p:	Hyperspectral file; part of flight track 5; radiometric, geometric and atmospheric corrected
Kabar05_rag_p_dg.roi:	ROIs above deep water, used for sunglint correction
Kabar05_rag_p_dg:	Sunglint corrected hyperspectral file
Kabar05_AV_blue:	File containing the average of the first 3 bands (blue)
Kabar05_AV_NIR:	File containing the average of the last 6 bands (NIR)
Kabar05_AV_blue.txt:	Text file containing the pixel values of the blue average file
Kabar05_AV_NIR.txt:	Text file containing the pixel values of the NIR average file

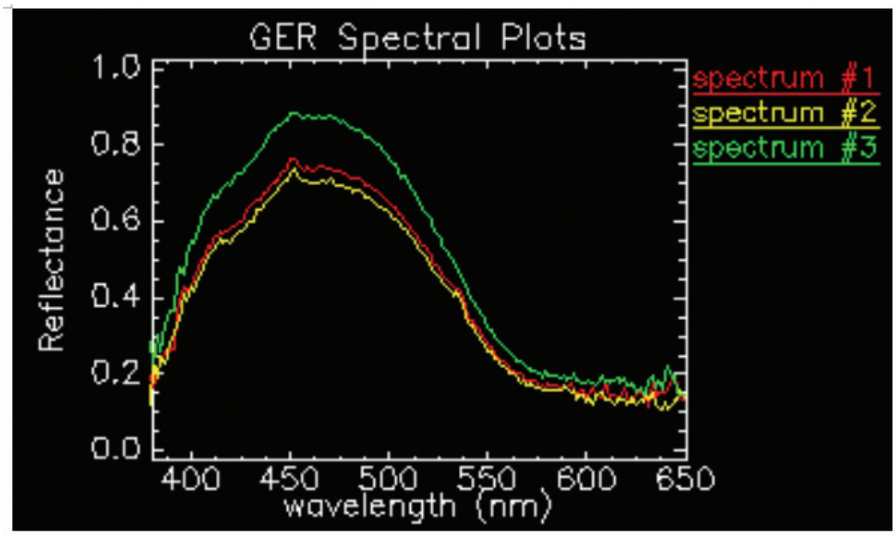
- Files used in part 3

Kabar05_rag_p_dg:	Sunglint corrected hyperspectral file
kabar05_rag_p_dg_mask:	Mask separating hyperspectral data from background
Kabar05_rag_p_dg_mnf:	MNF transformed hyperspectral file
Kabar05_rag_p_dg_mnf.roi:	ROIs above deep water, used to separating deep water
Kabar05_rag_p_dg_mnf_mask:	Mask file, separating deep water
Kabar05_rag_p_dg_mnf_b:	MNF transformed hyperspectral file containing benthic data only

Answers to questions

Answer 12.1: If you carefully observe the picture shown in Figure 12.1, especially the light conditions on the bottom surface, what do you think is a problem when measuring the reflected light with the spectroradiometer and how do you think the problem can be solved?

Due to wave focusing, the intensity of the light reflected at a certain location at the bottom varies continuously. This is clearly seen in Figure 12.1. Figure 12.20 shows the influence of wave focusing on the calculated reflectance spectra for a particular target. Remember that reflectance values are calculated as the ratio between the target radiance and the white reference radiance. At the time spectrum #1 and #2 were measured, light conditions for both, target and white reference, were more or less the same. However when spectrum #3 was measured, the target was exposed to full light conditions while the white reference was in a shady condition. This caused the calculated reflectance signal to increase considerable. To avoid this kind of problem, both target and white reference are always measured in a shady condition. It is the diver operating the GER instrument who can force a shady condition using his own floating body. Measurements are always performed in the shadow of the divers body and in this way he prevents wave focusing.



>> Figure 12.20: Wave focusing causes considerable variations in measured reflectance values.

Answer 12.2: Can you explain why no white reference measurement was performed at a depth of 3 m for calculating the reflectance of the deep target?

The white reference panel measurement is supposed to measure the incoming light. Therefore this measurement must be performed in shallow water. The influence of the water column is eliminated when measuring a white reference panel at a depth of 3 m. In this case, the calculated reflectance is identical to the reflectance calculated for the target in shallow water.

Answer 12.3: The ASCII files generated by the GER can be opened using a text editor e.g. 'Word' or 'Notepad'. Can you explain the content of these files?

The ASCII files generated by the GER consist of two parts, a header and the actual data. The content of such a file is shown in Figure 12.21. Note that only the first part of the file is listed as the size is rather large. When you study the file description, you can see that the third column of the data contains the target radiance.

```
///GER ASCII FILE///
name= Zw.001
instrument= 1500: 2068
time= 07-03-2005 10:29:35
long=
lati=
comm=
memory slot = 17,1
averaging= 4,4
integration Speed= 6,6
optic= 2,2
data=
292.57  0   0   35.00
294.04  5   1   22.03
295.52  5   1   22.69
297.01  6   1   20.16
298.51  6   1   22.03
300.01  7   2   25.64
301.53  11  2   22.13
303.05  16  4   22.95
304.57  20  5   23.77
306.11  24  6   24.59
...
```

File description:

1. The GER proprietary file format contains a header that includes:
   1. File Format specifier
   2. Title of file
   3. Instrument Model and Serial Number
   4. Date and Time of Acquisition
   5. Longitude data
   6. Latitude data
   7. Comments
   8. Memory slot of target, reference if required in stand alone mode
   9. Averaging parameter of target, reference
   10. Integration speed of target , reference
   11. Optic used

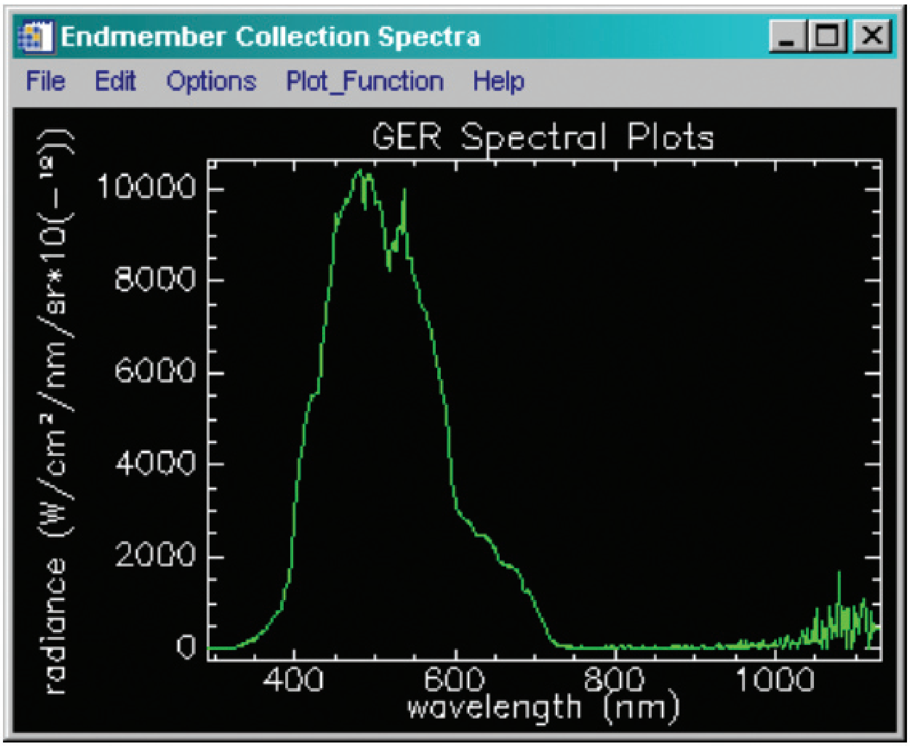
2. There are four columns of data:
   1. Wavelengths in nanometers (nm)
   2. Reference Radiance in W/cm²/nm/sr*10(-¹⁰)
   3. Target Radiance in W/cm²/nm/sr*10(-¹⁰)
   4. Percent Reflectance

>> Figure 12.21: The contents of an ASCII file generated by the GER spectroradiometer and its description.

Answer 12.4: In the ‘Endmember Collection Spectra’ window, use the <Edit> <Plot Parameters…> option to change some of the plot characteristics. You get the ‘Plot Parameters’ window where lots of parameters can be changed. Firstly, change the ‘Plot Title’ to “GER Spectral Plots”. Secondly, give the x-axis the correct title, i.e. “wavelength (nm)”. Thirdly, give the y-axis the correct title, i.e. “radiance $W/cm^2/nm/sr*10(-^{19})$”. Click the ‘Apply’ button to see the effect on the plot window.

Note: if the y-axis title is not visible, you can adapt the ‘Left Margin’ indent, i.e. change to 11. You can find this when you select the X-Axis radio button.

Your ‘Endmember Collection Spectra’ window should now look similar to this from Figure 12.22.



>> Figure 12.22: The new look of the ‘Endmember Collection Spectra’ window shows the axis titles with the correct units.

Answer 12.5: Can you explain, using the plot window in Figure 12.5, why the measured radiance is very low in spectral range below 380 nm and above 720 nm.

The reason for the low radiance values measured on submerged targets, in the spectral range below 380 nm and above 720 nm, is explained in Section 10 of the Hyperspectral Theory Syllabus.

Answer 12.6: Can you explain in the left spectrum the high, unrealistic reflectance values which are calculated in the spectral range below 380 nm and above 720 nm?

As already learned from the previous question, radiance values measured on submerged targets are very low in the range below 380 nm and above 720 nm. The radiance signal in these spectral ranges largely exists of noise. Therefore, calculating the reflectance in this spectral range can result in extreme reflectance values. It’s obvious that for submerged reflectance calculation the spectral range below 380 nm and above 720 nm is not considered.

Answer 12.7: Can you explain the reflectance spectra in Figure 12.8?

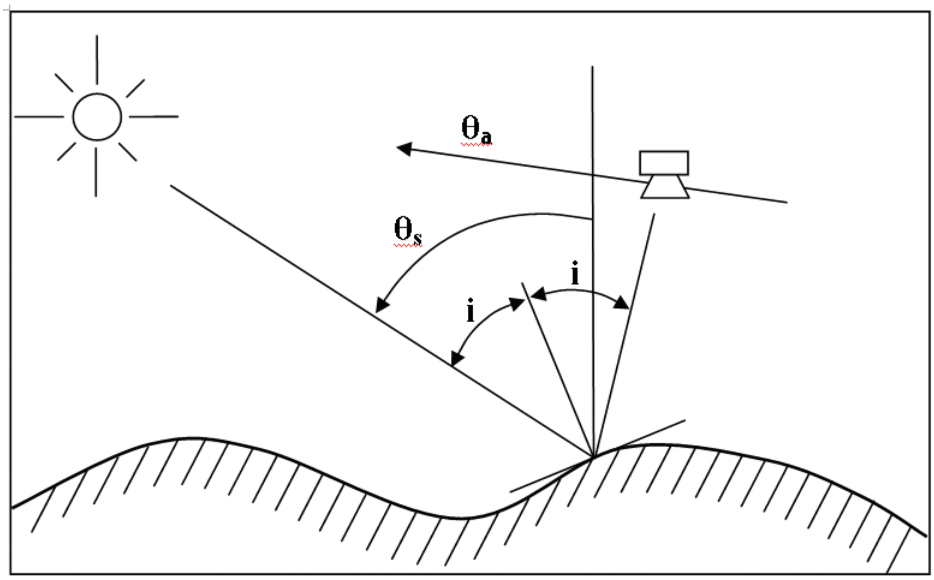
The wavelength at the maximum reflectance corresponds to their colour, i.e. for the blue target 466 nm, for the green target 520 nm and for the red target ± 655 nm. The maximum reflectance value for the blue and red target is ± 0.61. This means that these targets are rather bright, i.e. their albedo is high. The maximum reflectance value for the green target is ± 0.29, i.e. its albedo is much lower. The maximum reflectance values measured on the targets located in deep water drops considerable. The maximum reflectance value for the blue target is 0.52, for the green target 0.23 and for the red target 0.22. This means a decrease of respectively 16%, 22% and 65%. Therefore, we can conclude that water column has an influence on the absorption of the electromagnetic radiation. The absorption increases considerable for the longer wavelengths, i.e. red and near infrared.

Answer 12.8: Can you describe the different reef structures?

In the visualized image, which is part of flight track 5 over Pulau Nukaha, different reef structures can be distinguished. On the left side you can see part of the shallow lagoon. The depth at this location is ± 2 m, the bottom is covered with white coral sand. Next to the shallow lagoon the back reef is located. This reef part, which also has a depth of ± 2 m, consists of rubble, encrusting algae and minor hard coral patches. On the open ocean side of the back reef, the breaking waves at the reef crest can clearly be seen. The reef crest is the most shallow reef part, its depth varies around 1 m. From the reef crest on, in the direction of the open ocean, the fore reef is situated. The fore reef is the most biological diverse part of the reef, it ranges in depth from ± 1 m to ± 35 m. Here, different associations of hard and soft corals can be found. Sandy bottom (lighter structure in the image) alternates with coral patches (darker structure in the image) in different gradation. On the open ocean the bottom is not detectable anymore, however, waves and sunglint can clearly be seen.

Answer 12.9: Can you describe what causes sunglint? Do you have an idea how the sunglint effect can be minimized during the collection of the hyperspectral imagery?

Sunglint is caused by specular reflection of solar radiation on non-flat water surfaces (12.23). It is clearly present in the airborne imagery. Especially in images with a spatial resolution less than 10 m it is a serious confounding factor for benthic remote sensing. Specular reflection means mirror like reflection. Sunglint depends on solar zenith (θ_s) and sensor azimuth (θ_a) angles. To minimize the effect of sunglint the solar zenith angle should be between 30° and 60°. The flight azimuth, relative to the solar azimuth should be 0° or 180°, i.e. directly in the direction of the sun or away from the sun. Also wind speed and direction is an important factor, therefore image acquisition should take place above calm water.



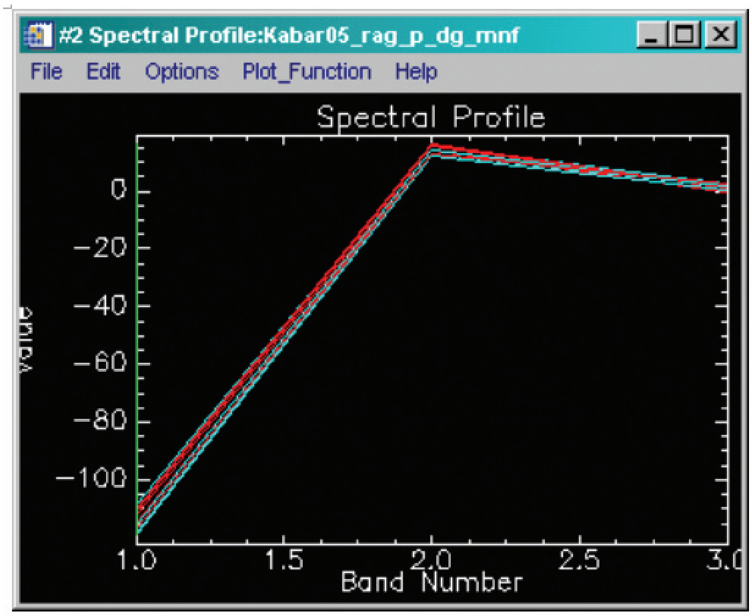
>> Figure 12.23: Sunlight is specular reflected on the water surface. To avoid sunglint, the solar zenith angle θs should be between 30° and 60°, sensor azimuth θa should be 0° or 180° relative to the solar azimuth.

Answer 12.10: Can you explain the spectra shown in Figure 12.12?

The blue 'NoGlint' spectrum comes from the uncorrected image where sunglint is absent. Notice that reflectance values above deep water are very low. The green 'NoGlint_dg' spectrum is the same spectrum obtained after the sunglint correction algorithm. You can see that it is quasi identical to the uncorrected spectrum. The red 'Glint' spectrum is taken at a location were sunglint is present. The orange 'Glint_dg' spectrum shows the same spectrum after the sunglint correction algorithm. You can see that the reflectance level is corrected to the reflectance level of pixels were no sunglint is present.

Answer 12.11: Can you describe the structure indicated by 'A'? Can you compare its spectra with the 'deep water' spectra collected in 'B'. What do you think the problem might be when classification is performed? How would you solve the problem?

The structure indicated by 'A' are corals located at a depth of ± 15 to 20 m. As you know from Part 1 of this lesson, red and green colors have almost completely disappeared at this depth, leaving only the blue colour. If you compare their spectra with spectra of deep water, see Figure , you will see that they are identical. All classification algorithms will be unable to separate both. Therefore, the only way to separate deep corals from deep water is by masking out the deep water part.



>> Figure 12.24: Spectra of corals (red) at greater depth (± 15 a 20 m) are confused with spectra of deep water (blue). Notice that these spectra are MNF transformed spectra.

Answer 12.12: Can you perform the necessary actions to mask out the deep ocean water from the MNF transformed data?

Use the <Overlay> <Region of Interest…> to get the 'ROI Tool' window. In this window, set <ROI_type> to 'Polygon'. In the image, draw a region of interest similar to the one shown in Figure12.25 (up). Use <ENVI> <Masking> <Build Mask> to select the window where the MNF image is displayed. In the 'Mask Definition' window use <Options> <Import ROIs…> to import all pixels contained in the created ROI. Make sure you set 'Selected areas "Off"' in the <Option> menu. Now you can output temporary to memory. Use <ENVI> <Masking> <Apply Mask> to apply the mask to the previous generated mask file 'Kabar05_rag_p_dg_mask'. Output the result to the work directory, use filename 'Kabar05_rag_p_dg_mnf_mask'. Now you can apply this mask to the MNF image. Output the result to the work directory, use filename 'Kabar05_rag_p_dg_mnf_b' (_b from benthic). Now the image should look like the one shown in Figure12.25 (down), it only contains benthic cover information.