5: REMOVING SUN GLINT FROM COMPACT AIRBORNE SPECTROGRAPHIC IMAGER (CASI) IMAGERY

Aim of Lesson

To learn how to remove sun glint from high resolution airborne and satellite imagery to reveal bottom features and improve classification.

Objectives

- 1. To understand the rationale underlying the method of sun glint removal developed by Hochberg *et al.* (2003) as modified by Hedley *et al.* (2005).
- 2. To choose a reference near infra-red (NIR) band and find out the ambient NIR signal in the absence of sun glint.
- 3. To select areas of deep water with varying sun glint intensities and find out the linear relationship (regression) between each visible band and the chosen NIR band pixels.
- 4. To use the information from 2 and 3 above to remove the component of visible band values that is due to sun glint and thus "deglint" each pixel of the visible bands.

Background Information

This lesson relates to recent research published by Hochberg *et al.* (2003) and developed by Hedley *et al.* (2005). You are recommended to consult these papers for further details of the techniques involved. This lesson uses the modified approach of Hedley *et al.* (2005) to show how to remove sun glint from Compact Airborne Spectrographic Imager (CASI) imagery flown in the vicinity of the island of St John in the US Virgin Islands.

The Bilko 3 image processing software

Familiarity with *Bilko 3* is required to carry out this lesson. In particular, you will need experience of stacking images and creating colour composites and of using Formula documents to carry out mathematical manipulations of images. Tutorials 2 and 10 in the *Introduction to using the Bilko 3 image processing software* are particularly relevant and provide a good grounding for this lesson. A familiarity with the Microsoft *Excel* spreadsheet package or the *Minitab* statistical package is also highly desirable. You will need access to one or other of these two packages to complete this lesson.

Image data

A Compact Airborne Spectrographic Imager (CASI) instrument was mounted on a light aircraft and flown at 4100 ft (1250 m) altitude over shallow coral reef areas off the coast of St John in the USVI at a speed of 130 nautical miles per hour (240 km.h⁻¹) in an East–West direction. An incident light sensor (ILS) was fixed to the fuselage so that simultaneous measurements of irradiance could be made and radiance measurements thus converted to reflectances. A Differential Global Positioning System (DGPS) was mounted to provide a record of the aircraft's flight path. Data were collected at a spatial resolution of 2 x 2 m (4 m²) in 19 wavebands (Table 5.1). The images were geometrically corrected using a UTM projection and WGS 84 spheroid/datum. The width of the groundtrack recorded by the CASI was approximately 1 km.

The final geometrically and radiometrically corrected images were stored in a 16-bit unsigned integer format. For the purposes of this lesson the coordinate information has been removed from the images. However, if you wish to replace this, the coordinates of the upper left pixel are Easting 322978.0 m

Northing 2032462.0 m (UTM zone 20 N). The pixel DX: = 2.0 m and DY: = 2.0 m. (If you correctly edit the coordinates you should find that the lower right pixel has an Easting of 326066.0 m and Northing of 2031302.0 m.) Each image consists of 581 rows and 1545 columns of pixels.

Band	Part of electromagnetic	Mid-wavelength (nm)	Width of waveband (nm)	Regions of peak sensitivity in eve
	spectrum	()		
01	Blue	442.4	13.1	Blue cones
02	Blue	465.6	10.4	Blue cones
03	Blue	488.0	12.3	
04	Green	507.6	7.6	
05	Green	519.7	4.8	
06	Green	530.0	5.8	
07	Green	540.3	4.9	Green cones
08	Green	549.7	4.9	Green cones
09	Green	560.1	5.8	
10	Green	570.4	4.9	
11	Green	579.9	4.9	
12	Yellow	589.3	4.9	Red cones
13	Orange	599.7	5.8	Red cones
14	Orange	618.6	5.8	
15	Red	639.4	5.8	
16	Red	668.9	6.8	
17	Near infra-red	698.4	5.9	
18	Near infra-red	756.6	8.8	
19	Near infra-red	809.3	11.7	

Table 5.1. Band settings used on the CASI. Bands 8-16 ha	ave not been included with the lesson data.
--	---

Geometrically and radiometrically corrected Compact Airborne Spectrographic Imager (CASI) data for 10 bands are provided for the purposes of this lesson as a set (*St_John_USVI_CASI.set*) of 10 *Bilko .dat* files (*St_John_USVI_CASI#01.dat – St_John_USVI_CASI#19.dat*). These files are unsigned 16-bit integer files (each pixel recording a reflectance value converted to an integer between 0 and 65535). This means that there are two bytes needed per pixel.

The problem of sun glint

The mapping of benthic features can be seriously impeded by sun glinting on the water surface. When skies are clear and the water surface is rippled, specular reflection of the incident radiation occludes the benthic signal with bright 'sun glint'. Unfortunately the problem of sun glint is particularly acute under conditions when remote sensing might otherwise be most effective: clear skies, shallow waters (which, when wind-blown, form waves), and when images are collected at a high spatial resolution. Typically, sun glint forms bands of white along wave edges on the windward side of near shore environments (Figure 5.1). These white bands confound the visual identification of bottom features, and will confuse both supervised and unsupervised classifications (with the presence or absence of sun glint dominating the categorisation in affected areas).



Figure 5.1. A colour composite (if printed, this may be in shades of grey), showing the CASI image before sun glint removal. Specular reflection along wave edges is obscuring much of the image and sun glint is generally bad along the southern side of the ground-track. Three areas of deepish water showing varying sun glint are outlined by boxes.

Although in areas with sun glint the recorded signal appears almost entirely composed of the water surface specular reflectance signal, the component caused by water leaving radiance may be recoverable providing that the sensor remains spectrally unsaturated. A recent paper by Hedley *et al.* (2005) presents a conceptually simple method whereby sun glint can be removed from visible wavelength spectral bands of remotely sensed images using a spectral band in the near infra-red (NIR) part of the electromagnetic spectrum (around 700–910 nm). The method is particularly applicable to high-resolution imagery such as that obtained using airborne sensors such as CASI or satellite sensors such as IKONOS. Image pixels are adjusted to remove the sun glint component of the recorded signal, thereby leaving only the component derived from benthic reflectance and processes within the water column. This leads to a substantial visual improvement in the 'deglinted' images and can also lead to an increase in user accuracies on maximum likelihood classifications of such images.

Outline of the 'deglinting' method

The deglinting method relies on two simple assumptions:

- 1) That the signal in the NIR is composed only of sun glint and a spatially constant 'ambient' signal. In particular, there is no spatially variant benthic contribution to the NIR.
- 2) That the amount of sun glint in the visible bands is linearly related to the signal in the NIR band.

The first assumption is justified by the fact that water is relatively opaque to NIR wavelengths (700-1000 nm) (Mobley, 1994), so that even shallow waters (e.g. those only 1.5-2 m deep) have a low water-leaving radiance in the NIR regardless of bottom type. Although a minimum NIR signal over deep water might be expected to be zero, in practice the minimum NIR (Min_{NIR}) signal is usually greater than zero. In particular, if images are not atmospherically corrected this 'residual' or 'ambient' NIR signal corresponds to NIR backscatter in the atmosphere. The method assumes a constant 'ambient' NIR (Min_{NIR}) signal level, which is removed from all pixels during the analysis.

The assumption of a linear relationship between the NIR signal and the amount sun glint in the visible bands holds because the real index of refraction (which governs reflection) is nearly equal for NIR and visible wavelengths (Mobley, 1994). Therefore the amount of light reflected from the water surface in the NIR is good indicator of the amount of light that will be reflected in visible wavelengths, and a linear relationship exists between the two. The deglinting method proceeds by establishing the linear relationship between NIR signal and the amount of sun glint in each visible band. This information, combined with the NIR signal in each image pixel, is used to work out how much to reduce the signal in each band to remove the sun glint in each pixel.

Firstly a linear relationship is established between a NIR band and each visible band using linear regression. To do this one or more regions of the image are selected which provide a range of sun glint, but where the underlying signal would be expected to be consistent (areas of deep water are ideal for this, Figure 5.1). For each visible band all the selected pixels are included in a linear regression of the visible band signal (*y*-axis) against the NIR signal (*x*-axis) (Figure 5.2).



Figure 5.2. Graphical illustration of how the deglint method works. A regression is carried out between a sample of visible band (band *i*) pixels from areas of varying sun glint intensity and corresponding pixels in the chosen NIR band. The assumption is made that all the NIR pixels would have the 'ambient' NIR (Min_{NIR}) value in the absence of sunglint. Knowing the slope (b_i) of the regression and the value of Min_{NIR}, you can then work out the proportionate reduction in the visible band signal (R_i) required to remove the component of the signal that is due to sun glint; the magnitude of the glint being obtainable from the NIR band ($R_{NIR} - Min_{NIR}$). This allows you to calculate a 'deglinted' value (R'_i) for each visible band pixel.

If the slope of the regression line for band i is b_i , then all the pixels in the image can be deglinted in band i by the application of following equation:

$$R_i' = R_i - b_i \times (R_{\text{NIR}} - \text{Min}_{\text{NIR}})$$
 [Equation 5.1]

which simply means: reduce pixel signal in band i (R_i) by the product of regression slope (b_i) and the difference between the pixel's NIR signal (R_{NIR}) and the ambient NIR level (Min_{NIR}). Min_{NIR} essentially represents the NIR signal in a pixel with no sun glint and can be estimated by the minimum NIR found in the regression sample or alternatively as the minimum NIR found across the whole image. In general, the minimum NIR pixel is less prone to problematic outliers than the maximum NIR pixel.

If you find problems with understanding the derivation of equation 5.1, we can look at the diagrammatic interpretation of the method in Figure 5.2 and derive the equation step by step.

By definition, the slope (b_i) of the regression line is just the amount of change in the visible band value divided by the amount of change in the NIR band value, between any two points on the regression line. Thus if, between two points on the regression line, the visible band changed from 1000 to 4000 (change = 4000 - 1000 = 3000) whilst the NIR band changed from 1500 to 3000 (change = 3000 - 1500 = 1500) then the slope of the line would be (4000 - 1000)/(3000 - 1500) = 3000/1500 = 2.

For each pixel in the image we know its NIR value (R_{NIR}) and its value in the visible band *i* (R_i). We also know the 'ambient' NIR value (Min_{NIR}) and assume that all reflectance in the NIR above this value is due to specular reflection at the sea surface. After carrying out regression analysis between selected pixels in our visible band *i* and the corresponding pixels in the NIR band, we know the slope of the regression line b_i . This allows us to work out how much of the signal of each pixel in band *i* is due to specular reflection. From figure 5.2 we can see that:

$$\frac{(R_i - R'_i)}{(R_{NIR} - Min_{NIR})} = b_i \qquad \text{which translates as:}$$

 $\frac{\text{Amount of signal due to specular reflection in visible band}_{i}}{\text{Amount of signal due to specular reflection in NIR band}} = \text{Slope}$

The only value we do not know in the equation is the value (R'_i) of the deglinted pixel. We thus need to rearrange the equation so that it can be solved to give us R'_i . This can be done in 3 steps. Firstly, we must multiply each side by $(R_{\text{NIR}} - \text{Min}_{\text{NIR}})$. This gives:

$$(R_i - R'_i) = b_i \times (R_{NIR} - Min_{NIR})$$

Secondly, to isolate R'_i on the left-hand side of the equation, we next need to subtract R_i from each. This gives us:

$$-R_i' = b_i \times (R_{NIR} - Min_{NIR}) - R_i$$

Finally, to make R'_i positive, we need to multiply each side of the equation by -1. This gives us equation 5.1:

$$R_i' = R_i - b_i \times \left(R_{NIR} - Min_{NIR}\right)$$

Since the method relies on a user-based selection of a sample set of pixels it is not necessary to mask out non-submerged or cloud pixels prior to deglinting. It is prudent to ensure that the sample pixels do not contain any non-submerged objects, but the regression will nevertheless mitigate the impact of isolated invalid pixels. However, non-submerged areas will not contain valid data after deglinting since the algorithm is valid only for submerged pixels. Note also, that as the method operates purely on the relative magnitudes of values, the absolute units of the pixel values are unimportant. Therefore, there is no need to transform pixel values into radiance and deglinting can be applied to the original image digital numbers. It is however advisable to ensure floating-point arithmetic is used in order to correctly handle fractional values and negative numbers.

Lesson Outline

Before proceeding with the deglinting you should examine the CASI images to judge the magnitude of the sun glint problem.

Open the set St_John_USVI_CASI.set (select File, Open and then select SETS (*.set) Activity: from the **Files of type**: drop-down menu). Make sure the **Extract** checkbox is unchecked and in the **Redisplay Image** dialog box check the **Null Value(s)**: == 0 checkbox and select an and Auto linear stretch as the stretch to use, before clicking on All the button to apply the stretch to all of the images in the set. You should have a stack of 10 images displayed. Holding down the *Ctrl*> key, double-click on the top image to zoom out so that you can see the whole image. Then use the *Tab* key to look at each image in turn, noting how details of the seabed become progressively less distinct in bands #5–#7 and abruptly disappear when you move from band #7 to band #17 in the NIR. Note also that sun glint is concentrated on the southern half of the ground-track. For bands #17, #18 and #19 in the NIR part of the electro-magnetic spectrum, there should in theory be no return over deep (> c. 1 m depth) water and bright pixels should be due entirely to sun glint. In bands #17 and #18 note the series of parallel wave-fronts orientated in a south-west to north-east direction.

To see the extent of the sun glint more clearly and provide a reference image against which you can judge the success of the deglinting, you need to create a false colour composite image of bands #1, #3 and #5. [This combination was found to give a reasonable image and the final comparison will be with a composite made from deglinted bands #1, #3 and #5.]

St John USVI CASI#01.dat, Click Connect select Activity: on Image, and St_John_USVI_CASI#03.dat and St_John_USVI_CASI#05.dat as the three images to be connected. Do not check the Stacked checkbox and use the Selector toolbar to designate band #05 as image 1 (@1: red gun), band #03 as image 2 (@2: green gun) and band #01 as image 3 (@3: blue gun). [This is achieved by clicking each button in turn from right to left.] When you have done this, select **Image**, **Composite** to generate the colour composite. Zoom out so that you can see the whole image. Note the serious sun glint, which is obscuring the coral reefs along the southern part of the CASI groundtrack. Save this image for reference as a Windows .bmp image. [Note: a Windows bitmap (.bmp) image can be readily inserted into a Word document using Insert, Picture, From File menu in Word.]

Choosing a NIR band

Three CASI bands were recorded in the near infra-red (NIR): bands #17, #18 and #19. Of these, band #17 is on the border between the far red and NIR part of the spectrum but we would not expect any bottom reflectance for water more than c. 1.0 m deep for any of these wavelengths (see Table 5.1). You need to decide which of the three NIR bands will be best to use for deglinting. Normally you would need to check which NIR band gives best results in the deglining process. There appear to be at least two criteria for deciding this: (i) how good the deglinted visible bands look, and (ii) the goodness of fit of the regression lines between the sample(s) of pixels in the visible bands and the NIR bands; to find (i) out, you would need to carry out the whole deglinting process using all three NIR bands; to find (ii) out you can regress a couple of sample bands on each NIR band. This involves carrying out later parts of the deglinting process; thus to save you time this has been done for you for bands #2 and #7. The results are shown in Table 5.2.

Test bands for	Band 17 (698.4 nm)		Band 18 (756.6 nm)		Band 19 (809.3 nm)	
regression	Slope	R^2	Slope	R^2	Slope	R^2
Band 2 (blue)	1.2515	0.8928	1.6163	0.8481	1.6372	0.7293
Band 7 (green)	1.2760	0.9432	1.6681	0.9182	1.8247	0.8518

Table 5.2. Comparisons of linear regressions of visible bands #2 and #7 on each of NIR bands #17, #18 and #19. Slopes of regressions lines and coefficients of determination (R^2), which indicate the proportion of the variance accounted for by the regressions, are shown.

Table 5.2 shows that coefficients of determination are highest for band #17 and worst for band #19. If you study the band #19 image you will notice that it appears less focused (less sharp) than bands #17 and #18.

Activity: Use the *<Tab>* key to move between bands #17, #18 and #19 in the stack of CASI bands and *<Shift>+<Tab>* key to move back again. Note that the sun glint on band #19 appears less clearly delineated than that on bands #17 or #18.

Given both the relatively low coefficients of determination and slight blurriness of band #19, you should not consider it further but concentrate on band #17 as your first choice NIR band. Given the relatively short IR wavelength of band #17, you should, however, carry out deglinting using band #18 for comparison.

Determining the minimum NIR value over deep water

To determine the minimum NIR (Min_{NIR}) value of an image you need to select an area of water that is (a) relatively dark and (b) reasonably deep (≥ 2 m depth) so that there is no chance of bottom reflectance from coral or sand close to the surface. You want a representative sample of pixels with which to calculate the Min_{NIR} but can fit a maximum of 256 columns in an *Excel* spreadsheet. Thus the suggested sample size is 256 x 100 pixels from an area with top left coordinates at X: 1200 and Y: 5 which covers a substantial area of reasonably deep water on the north side of the ground-track in the darkest part of the image. You will now determine the Min_{NIR} for bands #17 and #18 using *Excel*.

Activity: Inspect bands #17 and #18 and note that the north-east of the images appears darkest. Start *Excel* and open the *Excel* workbook called **Lesson05_deglinting_St_John.xls**, making sure to click the Enable Macros button (if this appears). Select the **MinNIR** worksheet by clicking on its tab. Rows 2 to 101 are empty, ready to receive the sample of band #17 pixels needed to determine Min_{NIR} for band #17.

> Returning to *Bilko*, select band #17 (*St_John_USVI_CASI#17.dat*) as the active image in the stack and then select **Edit**, **Go To** from the menu. In the **Go To** dialog box, make sure **Selection Type:** is set to Box Selection and then set **X**: to 1200, **Y**: to 5, **DX**: to 256 and **DY**: to 100 and click OK. Copy the block of pixels using the Copy button or by pressing <Ctrl>+C. Switch to *Excel*, click on cell A2 of the **MinNIR** worksheet and paste the cells (using Paste button, <Shift>+<Insert> or <Ctrl>+V). Scroll down to row 103 and you will see that a formula in cell B103 has calculated the minimum NIR value for band #17. [Make a note of this as it will be needed later; it should be 208.] Note that rows 108 to 207 are empty and ready to receive the sample of band #18 pixels needed to determine Min_{NIR} for band #18.

> Returning to *Bilko*, press the $\langle Tab \rangle$ key to make band #18 the active image in the stack. The box selection should already be in place so you just need to copy the sample of band #18 pixels and paste it to cell A108.

Question: 5.1. What is the Min_{NIR} for band #18? [Consult the spreadsheet below where you pasted the band #18 sample.]

Selecting areas of varying sunglint to calculate regression of each visible band on the chosen NIR band

For the purposes of this lesson you will select a 50 \times 50 pixel area from each of three areas on the image; one from a low sun-glint area, one from an area with high sun glint and one from an area with intermediate sun-glint problems (Figure 5.1). The top left coordinates of each of these areas are given in Table 5.3.

Level of sun glint	Top left X: coordinate	Top left Y: coordinate	DX:	DY:
Low	490	150	50	50
Intermediate	450	300	50	50
High	400	500	50	50

 Table 5.3. Column and row coordinates for three areas of varying sun glint. (Settings for Go To dialog box.).

- *Question:* 5.2. What is the area in both hectares (ha) and m^2 of each of the areas of sun glint? How many pixels are in each area sampled?
- Activity: In the *Excel* workbook called **Lesson05_deglinting_St_John.xls** click on the tab labelled **Band samples** and you will see that for all bands <u>except band 5</u>, the 7500 pixels from the three areas of varying sun glint have already been entered. Your task is to enter those for band #5.

The top 2500 rows below the headings contain the pixels from the low sun glint area (Table 5.3 and Figure 5.1), the next 2500 rows contain those from the intermediate sun glint area, and the final 2500 rows contain those from the high sun glint area. In each case the rectangular sample of pixels has been copied and pasted into a *Minitab* worksheet and then "stacked" into one column. If you have access to the *Minitab* statistical package you can do the same. If you only have access to the *Excel* spreadsheet package, a "macro" is provided to allow you to do the stacking in the worksheet labelled **Stacking_sheet**. Instructions will be given to assist you to prepare the band #5 sun glint samples in both *Excel* and *Minitab*. Choose which package you will use and follow the appropriate set of instructions below. Instructions for *Excel* are given first, followed by those for *Minitab*.

Stacking the band 5 sun glint samples for regression analysis using Excel

Activity: In the Excel workbook Lesson05_deglinting_St_John.xls click on the tab labelled Stacking_sheet. This worksheet should be empty. Switch to *Bilko* and select the image stack. Use the Selector toolbar to select @5 St_John_USVI_CASI#05.dat as the active image. Now use Edit, Go To to select the low sun glint area, referring to Table 5.3 for the coordinates. When the box selection is in place, Copy the selection. Switch to *Excel* and paste the values to cell A1 (i.e. make sure cell A1 is highlighted when you click on the Paste button).

Checkpoint: You should see the value 1534 in cell A1 of the **Stacking_sheet** worksheet. If you press *<Ctrl>+<End>* you should find the cell AX50 highlighted and this cell should contain the value 1305. If all is well, congratulations! If not, undo the paste and check that (i) you have the right image in the stack and (ii) the box selection is correctly positioned. Then try again.

 Activity:
 With Stacking_sheet as the active worksheet in *Excel* select Tools, Macro, Macros.

 Select the macro called Stack_columns and click the sum button. The macro

takes each column of 50 pixels in turn and stacks them in column A of the worksheet. The next step is to transfer the 2500 stacked cells to the Band#05 column in the **Band** samples worksheet.

Activity: To do this select cell A1 in the Stacking_sheet worksheet and press <Ctrl>+<Shift>+<Down arrow>. This will select the whole column of cells. (You should see that cell A2500 now has the value 1305.) Click on the Cut button (or Edit, Cut) and then click on the Band samples tab to make this the active worksheet. Now click on cell E3 at the top of the blank part of the Band#05 column and click on the Paste button to paste the stacked cells. Before doing anything else press <Ctrl>+<Down arrow> which should take you to cell E2502 which should have the value 1305. Note the thick horizontal line through neighbouring columns, which marks the end of the low sun glint pixel sample. If you now click on the band#5_17 tab you will see that these pixels now feature on the graph.

In order to complete the graph and obtain the regression equation and hence slope for band #5, you need to repeat this procedure for the intermediate and high sunglint samples, adding the stacked pixel values to the Band#05 column until all 7500 pixels are present.

- Activity: Make **Stacking_sheet** the active worksheet again. Then switch to *Bilko* and select the intermediate sun glint sample in band #5 using Table 5.3 for guidance. Copy and paste the cells to the **Stacking_sheet** (making sure that the first value is pasted in cell A1) and then run the macro again to stack the values into one column. Select the column with *<Ctrl>+<Shift>+<Down arrow>* and cut and paste it to cell E2503 in the **Band samples** worksheet. If you now click on the **band#5_17** tab you will see that these intermediate sun glint pixels now feature on the graph.
- *Checkpoint:* The value of E2503 should be 1572 and the value of E5002 (press *<Ctrl>+<Down arrow>* to move to bottom of column) should be 1676.
- Activity: Repeat the exercise for the high sun glint sample area (Table 5.3). This time the stacked column of pixel values will be pasted to cell E5002 in the **Band samples** worksheet. If you now click on the **band#5_17** tab you will see that these high sun glint pixels now feature on the graph.

Checkpoint: The value of E5003 should be 2034 and the value of E7502 should be 1296.

If all is well, congratulations! You can now progress to the section headed *Deglinting the visible bands*.

Stacking the band 5 sun glint samples for regression analysis using Minitab

Activity: Leave the *Excel* workbook open at the worksheet labelled **Band samples**. Start *Minitab* and make sure you have a blank worksheet showing as the active window. Switch to *Bilko* and select the image stack. Use the **Selector** toolbar to select @5 St_John_USVI_CASI#05.dat as the active image. Now use **Edit, Go To** to select the low sun glint area, referring to Table 5.3 for the coordinates. When the box selection is in place, Copy the selection. Switch to *Minitab* and paste the values to row 1 of column C1 (i.e. make sure this cell is highlighted when you click on the Paste button).

Checkpoint: You should see the value 1534 in the first cell of the worksheet. If you press *Ctrl>+<End>* you should find the row 50 cell in column C50 highlighted and this cell should contain the value 1305. If all is well, congratulations! If not, undo the paste and check that (i) you have the right image in the stack and (ii) the box selection is correctly positioned. Then try again.

Activity: Select Manip, Stack/Unstack, Stack Columns from the *Minitab* menu. In the Stack Column dialog box enter C1-C50 in the Stack the following columns: text box and C1 in the Store the stacked data in: text box and click on OK. All the data is now stacked in column C1 so you can delete the data in columns C2-C50. To do this, select Manip, Erase Variables and enter C2-C50 in the Columns, constants, and matrices to erase: text box. You are now left with just a single column of the data you want. The next step is to transfer the 2500 stacked cells to the Band#05 column in the Band samples worksheet in *Excel*.

To do this click on the first cell in column C1 and press <Ctrl>+<Shift>+<End> to select the whole column of 2500 cells. Click on the Cut button (or Edit, Cut Cells) and switch to the Band samples worksheet in the *Excel* workbook. Click on cell E3 at the top of the blank part of the Band#05 column and click on the Paste button to paste the stacked cells. Before doing anything else press <Ctrl>+<Down arrow> which should take you to cell E2502 which should have the value 1305. Note the thick horizontal line through neighbouring columns, which marks the end of the low sun glint pixel sample. If you now click on the band#5_17 tab you will see that these pixels now feature on the graph.

In order to complete the graph and obtain the regression equation and hence slope for band #5, you need to repeat this procedure for the intermediate and high sunglint samples, adding the stacked pixel values to the Band#05 column until all 7500 pixels are present.

Activity: Switch to Bilko and select the intermediate sun glint sample in band #5 using Table 5.3 for guidance. Copy and paste the cells to the *Minitab* worksheet (making sure that the first value is pasted in row 1 of column C1). Stack the contents of columns C1-C50 in C1 as before, and then erase columns C2-C50. [Note that your previous settings are preserved in the two dialog boxes, which makes life easier the second time round!] With the first cell of C1 highlighted, select the stacked column with *<Ctrl>+<Shift>+<End>* and cut and paste it to cell E2503 in the Band samples *Excel* worksheet. If you now click on the band#5_17 tab you will see that these intermediate sun glint pixels now feature on the graph.

Checkpoint: The value of E2503 should be 1572 and the value of E5002 (press *<Ctrl>+<Down arrow>* to move to bottom of column) should be 1676.

Activity: Repeat the exercise for the high sun glint sample area (Table 5.3). This time the stacked column of pixel values will be pasted to cell E5002 in the **Band samples** worksheet. If you now click on the **band#5_17** tab you will see that these high sun glint pixels now feature on the graph. Well done! – that was the hardest part of the practical. You can now close *Minitab*.

Checkpoint: The value of E5003 should be 2034 and the value of E7502 should be 1296.

Deglinting the visible bands

You now have the full sample of 7500 band #5 pixels in column E of the **Band samples** worksheet. This is plotted against the corresponding pixels in the NIR band #17 (in column I) in the **band#5_17** chart. A linear regression (trendline) has been fitted to the data and the slope and intercept of the regression are automatically displayed on the chart.

Question: 5.3. What is the slope and intercept for the regression of band #5 pixel values on the corresponding NIR band 17 pixel values?

You now have the necessary information to carry out the deglinting of the 7 visible bands using band #17 to estimate the amount of specular reflection in each pixel. This is done using Equation 5.1:

$$R_i' = R_i - b_i \times (R_{\text{NIR}} - \text{Min}_{\text{NIR}})$$

expressed in a Formula document. To save time most of the formula document has been written for you. You only need to enter the Min_{NIR} value and the slope values for bands #5-#7 (b_5 , b_6 or b_7 in the equation).

Activity: Open the formula document **Deglinting_band17.frm**. Study the formula document and note how the b_i and Min_{NIR} values are set up as a series of constants in the CONST = statements. You need to fill in the Min_{NIR} value for band #17 and also the regression slope values for bands #5, #6 and #7, which can be found on the relevant charts in the **Lesson05_deglinting_St_John.xls** spreadsheet. Do this, remembering that each statement must end with a ';'. Note that there is a separate formula for each band.

Let us briefly examine the first of the formulas.

IF (@1 == 0) 0 ELSE (@1 - Band01_Slope * (NearInfraRed - MinNIR)) ;

The background in each image (areas outside the CASI groundtrack) have been set to zero and thus should not be processed. Thus the first part of each formula says that <u>if</u> the visible band pixel value is equal to zero then the output image pixel will be 0. <u>Else</u> (otherwise) for all other pixels Equation 5.1 is applied. Thus each pixel (R_1) of the @1 (= band#01) image has the Band01_Slope (b_1) multiplied by the difference between the corresponding band#17 (@8 image) pixel (R_{NIR}) and the Min_{NIR} value for band #17 (= 208). This effectively removes the component of the signal due to specular reflection. The formula just mimics Equation 5.1.

Activity: When you have completed the formula document, save it. Then select Options! from the menu, set the Output Image Type: to Floating point 32-bit, and uncheck the Use special handling for Nulls checkbox (if checked) because the formula deals with these already. Copy the formula and paste it to the stack of connected images. You should get 7 deglinted images produced. Connect the first (deglinted band#01), third (deglinted band#03) and fifth (deglinted band#05) of the output images (using Image, Connect) but do not stack them. Use the Selector toolbar to designate the deglinted band#05 as image 1 (@1: red gun), the deglinted band#03 as image 2 (@2: green gun) and the deglinted band#01 as image 3 (@3: blue gun). When you have done this, select Image, Composite to generate the false colour composite. Save the deglinted composite as either a Bilko .set or Windows .bmp file. When you have done this, you should close the individual deglinted images, leaving only the composite open, in order to reduce clutter.

The deglinted composite should look similar to Figure 5.3. Zoom out to 50% and compare the deglinted composite with the original raw composite you saved as a Windows .bmp image at the start of the lesson.

Question: 5.4. In what specific ways has the deglinted composite image improved compared to the raw composite?



Figure 5.3. A colour composite (if printed, this may be in shades of grey), showing the CASI image after 'deglinting'.

At this point you have seen the effectiveness of the deglinting method and hopefully understood the concepts underlying it. If you are feeling ambitious or curious or both, you may wish to discover whether band #18 is a better NIR band to choose for deglinting. As we noted earlier, band #17 is only just into the near infra-red part of the electro-magnetic spectrum and one might achieve better results with band #18, despite the coefficients of determination (R^2) in the test regressions being less than for band #17 (Table 5.2). To allow you to test this fairly easily, the formula **Deglinting_band18.frm** is included. All you need to add is the Min_{NIR} value for band #18, which you calculated earlier, into the CONST statement at the start.

Activity: Either finish by closing all documents (Window, Close All) or deglint the stack of images using the *Deglinting_band18.frm* formula with the CONST MinNIR = ; statement completed. Create a colour composite of deglinted bands #1, #3 and #5 and compare with the one you created using band #17 as the NIR band. When you are finished, close all documents.

You will find that there is little to choose between deglinting with band #17 or band #18.

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).
- Hochberg, E.J., Andréfouët, S. and Tyler, M.R. 2003. Sea surface correction of high spatial resolution Ikonos images to improve bottom mapping in near-shore environments. *IEEE Transactions on Geoscience and Remote Sensing* **41** (7): 1724-1729.

Mobley, C. D. 1994. Light and Water. Academic Press.