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REMOTE SENSING PORTFOLIO

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CHAPTER ONE:
Using colour composites and spectral signatures to analyse a landsat image

An important component of the use of satellite imagery is the ability to transform the ‘raw’ data or unprocessed image into an image that can be used as a definitive tool in the study of a particular region. This section focuses on the creation and enhancement of colour composites in order to identify certain features in terms of their reflectance/ absorbance and corresponding colour signal. As well as exploring the application and use of colour composites, a spectral signature (the degree of absorbance over a range of wavelengths) for each of three predominate features in the area was created. This is a very useful application as the signature can be used to identify similar features in the same image.

The image is an area of Cape Town that included a small part of the CBD, Devils Peak and UCT, with Table Bay Harbour just visible in the upper left-hand corner. The image encompassed a fairly large suburban area and, on the slopes of Devil’s Peak, an area sparsely populated and interspersed with more vegetation.

The image is from the Landsat 5 satellite and was taken on 14 December.

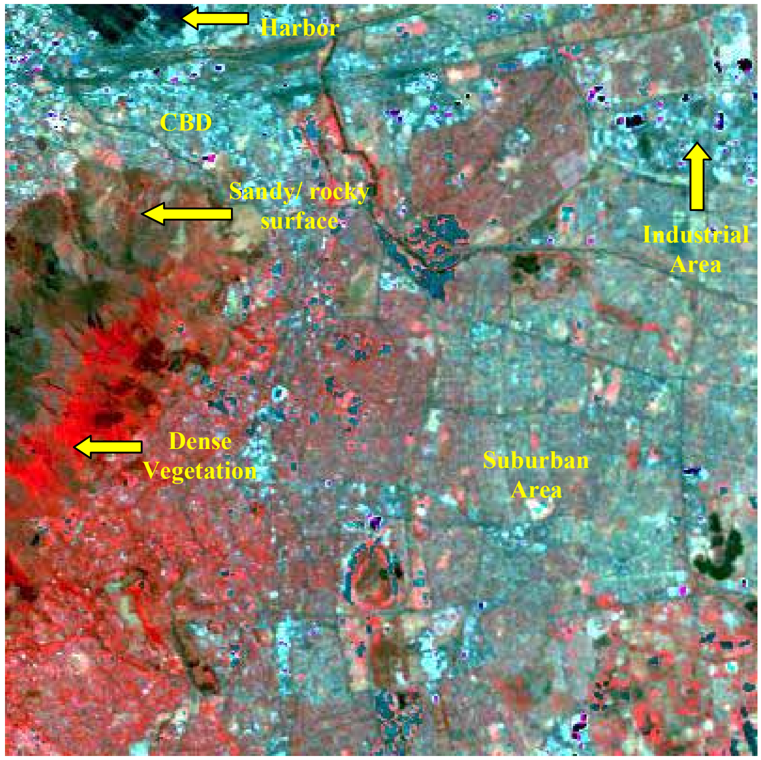
1.1 Landsat Background

Landsat is a US satellite used to acquire remotely sensed images of the lands surface and coastal region. The satellite is fitted with an enhanced thermal mapper (ETM), which contains sensors to detect the Earths radiation in three specific bands:

- Bands 1, 2, 3 & 4 are visible and near infrared and have a spectral range between 0.4µm to 1.0µm.
- Bands 5 & 7 are short wavelength near infrared (SWIR) and have a spectral range between 1.0µm and 3.0µm.
- Band 6 is thermal long wavelength infrared (LWIR) with a spectral range of 8µm to 12µm.

Landsats orbit has an inclination of 98.2° and is at an altitude of 705km. It has a repeat time of 16 days in 233 orbits and its swath width is 185km.

1.2 Creating Colour Composites



For this colour composite, I chose bands 4, 3 and 2 to be represented by red, green and blue respectively. This combination is commonly used to map vegetation. Band 4 is a near infrared band and reflects high concentrations of chlorophyll and is therefore a useful tool when investigating biomass content. Band 3 reflects any surface that has a red colour such as soil or rocky surfaces. Band 2 reflects green surfaces, but not necessarily the chlorophyll content.

The resulting image shows regions of fairly high chlorophyll values in red, sandy/rocky surfaces in green and in blue are the areas of high reflectance in the green band. Water absorbs all light in these bands it therefore appears black.

In order to enhance the image I sharpened it by 18% and applied a Gaussian stretch to the red and green bands. The filtering method of enhancement improved the contrast between vegetated areas and non-vegetated areas as well as highlighting features of the populated areas such as roads and rivers. The Gaussian stretch applied to the red and green bands improved the contrast between the shades and intensities of red.

The southern slopes of Table Mountain has a bright red signal, this is a result of the fact that it reflects in the near infrared as it is a highly vegetated area with high a high chlorophyll concentration. It is an area that receives a relatively large amount of rainfall, hence the elevated chlorophyll and biomass. Areas of red are also found in the suburban areas, though of a lesser intensity to that found on the mountain. This corresponds to more absorption and less reflection in the near infrared and is likely to be a result of less densely vegetated plots of land, more heavily interspersed with soil and rock. Another factor leading to a duller red signal could be the fact that the vegetation is less healthy in the suburbs than on the mountain. Interestingly, one can distinguish between suburbs and street layout when one looks at the red signal in the suburbs. Nearer the slopes of Table Mountain, the red signal is more intense and there appears to be dense vegetation between borders such as roads and walls. Towards the Cape Flats the red is not as intense and is, in places, partitioned into neat blocks. There are regions where the red signal is not at all visible.

The northern slopes of Table Mountain showed less reflection in the near infrared band. The red band (band 3) signal (green) dominates in places, possibly a result of exposed rock surfaces. There are places where the green seemed to interfere with the red signal, this could be a result of the sparsely vegetated rocky surfaces found on top and on the northern slopes of Table Mountain.

The city shows a very blue signal, whereas the suburbs to the east of Table Mountain show up predominately as green. The city has more reflective surfaces and less vegetation, it is also likely to reflect more heat than the suburbs. As a result, it is the reflected heat energy of the city that is picked up in the green band and is represented as blue on the image. The suburbs appear more green in the image as band 3 picks up more red, shown as green in the image. The red that is seen could be a result of closely spaced roofs or sparsely vegetated gardens.

Another interesting feature brought out by this choice of bands is a number of small bright purple 'blocks' interspersed throughout the image, but more dominant in the city. When creating a spectral signature, they seem to uniformly reflect band 4 and band 2 in equal amounts. These 'blocks' could correspond to recreational parks with an equal amount of reflected chlorophyll and the colour green. They appear to be more common in the city because they are in obvious contrast to the surrounding environment.

1.3 Spectral Signatures

Spectral signatures were created for three of the dominant land surface features: (1) the densely vegetated southern slopes of Table Mountain, (2) the top and northern slopes of Table Mountain and (3) the city.

A spectral signature shows the proportion of each band that is reflected by a particular feature. Similar spectral signatures would result from land surface features with similar properties.

(1) Southern slopes of Table Mountain

In the most intensely vegetated areas, where the red signal is brightest, band 4 reflects 100 %, band 3 20% and band 2 25%. All of band 4 is reflected because of the very high chlorophyll content. Band 2 has a fairly low signal because, though the area has a very green appearance, the green has been picked up by the near infrared (band 4) and is seen as red in the image. Band 3 only reflects 20% as there is little surface on the surface that has a red colour such as soil or rock.

(2) Top and northern slopes of Table Mountain

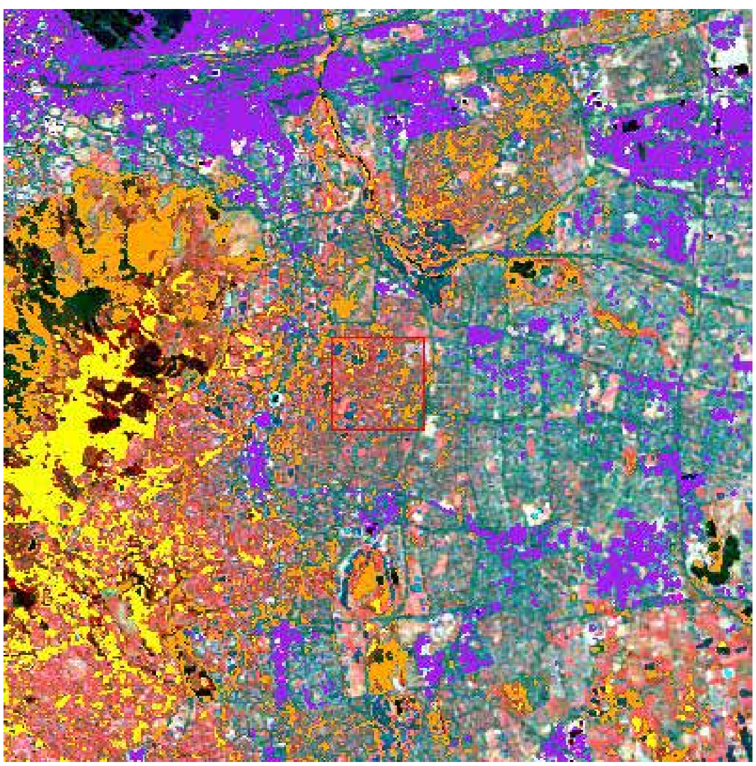
The spectral signal for this region shows band 2 and band 3 to be equal, while band 3 is only slightly lower. This is likely to be the result of a dominantly rocky or sandy surface with a sparse vegetation cover. The red colour of the surface reflects band 3. Band 2 reflects green vegetation, which is drier and therefore less prone to reflect in the near infrared (band 4) as it has less moisture content.

(3) Urban Areas: CBD

Band 4 has a very low reflectance, this is as one would expect, as there is little vegetation in the city and therefore very low chlorophyll. Band 2 reflects only slightly higher than band 4, again this relates to the lack of vegetation in the city. The peak of reflectance for this spectral signal is band 3, which relates to the red surfaces that dominate in the cities. A similar spectral signal is noted in the suburbs, although because of the varying degrees of vegetation cover, the reflectance of band 4 changes accordingly.

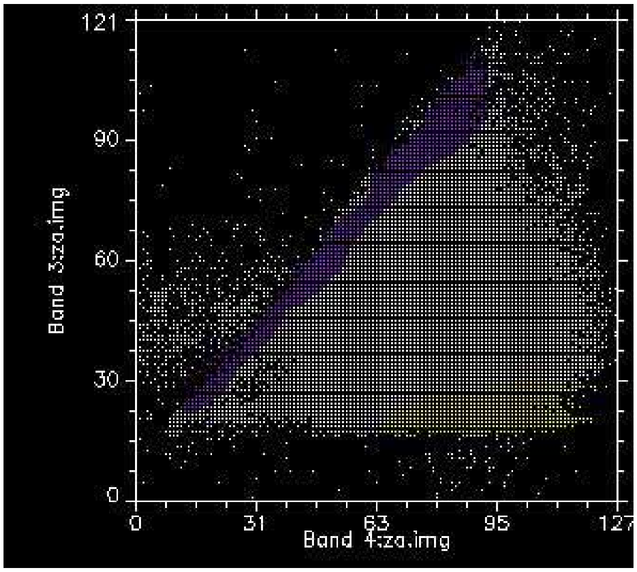
1.4 Scatter Plots

2-D scatter plots compare the reflectance of two bands of each pixel of the image. Envi software allows one to decide on the bands to be compared and then to highlight the area of interest on the scatter plot, the software will then highlight all areas on the map that correspond to the reflectance characteristics chosen on the scatter plot. In this way we can easily compare and identify regions of similar spectral characteristics in the area of interest.

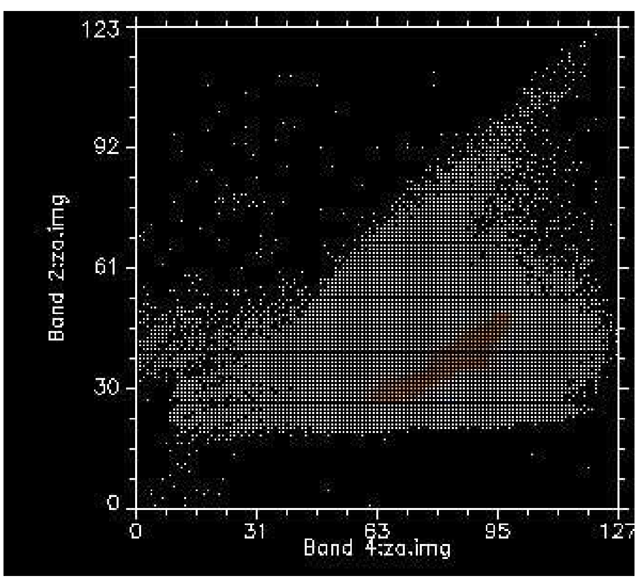


The image above has regions of similar spectral characteristics highlighted in the same colours. Urban areas are highlighted as purple, densely vegetated regions are yellow and more sparsely vegetated areas with more exposed rock or soil is shown as orange.

I used two scatter plots, one comparing band 4 with band 3 and the other comparing band 4 with band 2 (see plots below). The former clearly distinguished the urban areas and the densely vegetated areas, while the latter defined the sparsely vegetated regions more successfully.



From the scatter plot on the left, it can clearly be seen that high reflectance in band 4 and very little in band 3 (the area highlighted in yellow) defines regions of dense vegetation. The high reflectance in band 4 is a result of the high chlorophyll values, while the low reflectance in band 3 is due to very little exposure of sandy or rocky surfaces that reflect in band 3 due to the reddish hues. The purple represents the urban area, which reflects band 3 and band 4 in a roughly linear fashion, although it has a greater range of reflectance in band 3 and doesn't reach the peak band 4 reflectances. The high reflectance in band 3 could be due to the fact that man- made structures are often made of materials with a reddish hue and the great range of reflectances in band 3 is likely to be related to the relatively non-uniform surface of the city and the many contrasts between features.

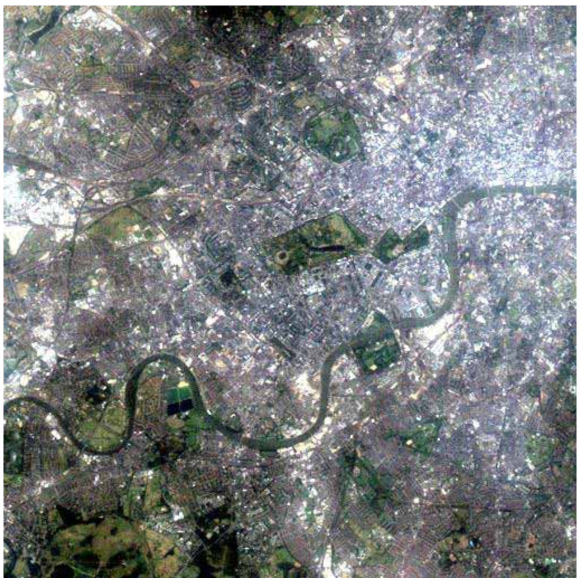


The scatter plot on the left has band 4 on the x-axis and band 2 on the y-axis. The orange area represents all regions on the image that are more sparsely vegetated and perhaps consist of a different class of vegetation than the vegetated area described above. The reflected chlorophyll (as represented by the reflectance of band 4) has a fairly limited, intermediate range. Band 2 is similarly limited in its extent of reflectivity, but in general has lower reflectance than band 4. This corresponds to areas that have less green in the visible spectrum.

CHAPTER TWO:
An in-depth investigation of London and the Mississippi River near New Orleans

2.1 Grey Scale Images and True Colour Images

LONDON (True Colour)



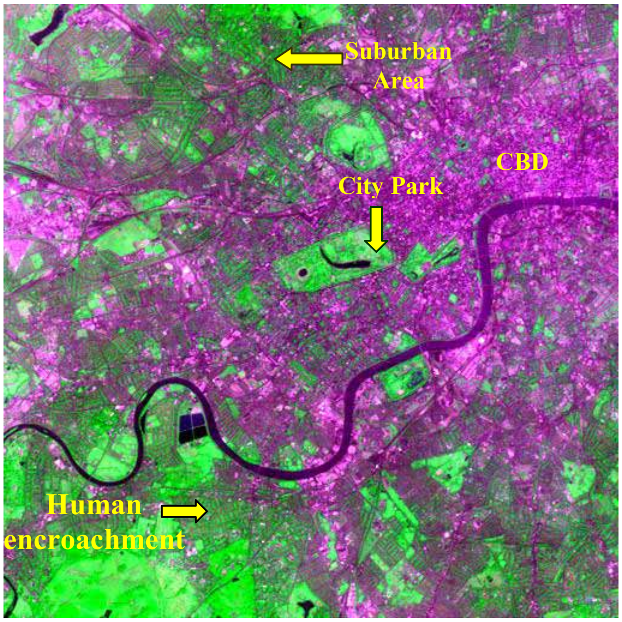
True colour images are produced by using visible bands: 1, 2 and 3, which reflect blue, green and red respectively. These bands are represented on the image by assigning them their 'true' colours, for instance, band 1 is represented by blue, band 2 by green and band 3 by red. The image produced is closest to what our eyes would see. On the right are true colour images for London (above) and for the Mississippi (below).

NEW ORLEANS (True Colour)

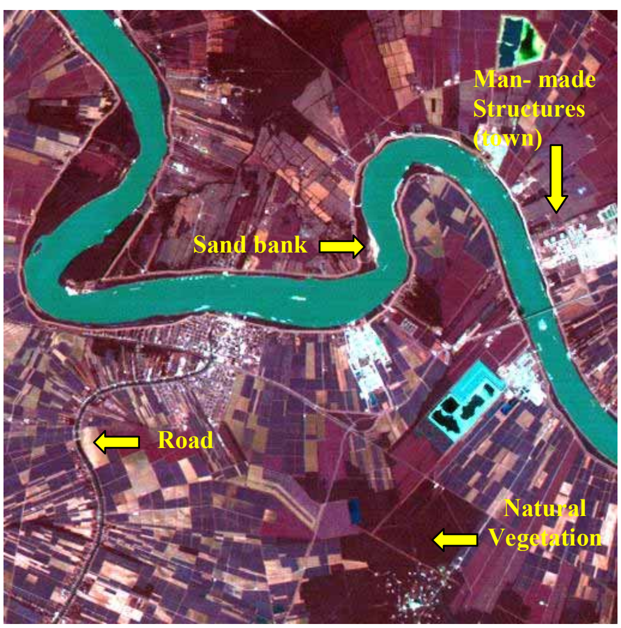
True colour images allow one to easily identify and interpret features within an image because the colours representing salient features on the image correspond to what our eyes expect to see. Although true colour images give a good overall idea of a region, grey scale images are often more successful at highlighting particular features of interest such as vegetation or lack there of, water content, reflective surfaces etc. Grey scale images are created using only one band, effectively highlighting features that reflect (or absorb) that band strongly. The thermal and infrared bands (particularly bands 4, 5 and 7) are more useful when creating grey scale images as they provide more contrast than bands 1, 2 and 3. The thermal band, band 6 results in a very blurred image due to the fact that it is a low resolution band.

2.2 Enhancement of Built Environment/ Vegetation

The spectral bands used in the images below have been specifically selected to enhance the vegetated vs. built environments in both scenes.



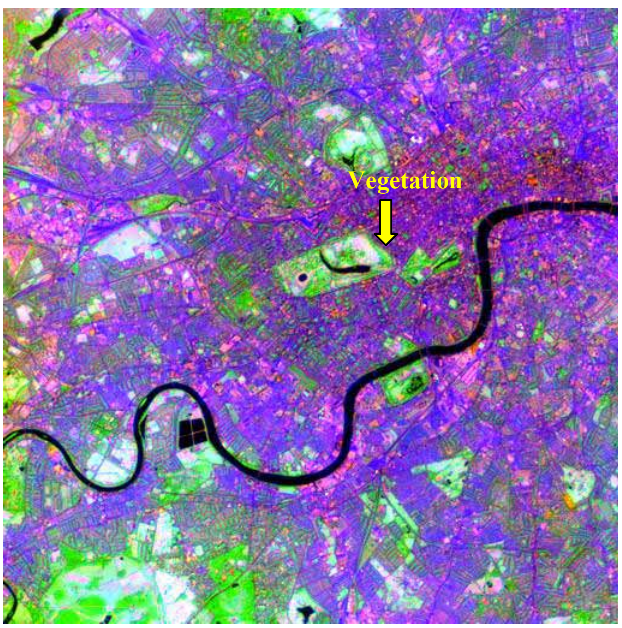
Using bands 3, 4 and 2 in red, green and blue respectively, the image on the right has highlighted vegetated regions of London in green, while urban areas are shown in various shades of purple. City parks are very clearly seen as bright green 'islands' within a predominantly purple 'sea'. Suburban areas have a distinct pattern of parallel green lines, which can be interpreted as a tree-lined street pattern that alternates with housing that has a more purple signal. The CBD and other highly reflective areas are seen as very bright purple. These areas therefore reflect bands 3 and band 2 in roughly equal amounts, which is indicative of city regions. The relatively large, bright green signal in the lower left of the image is a region that has not been developed for some reason; perhaps it is a protected natural environmental reserve. However, the outskirts of this region has a less bright signal, the green has a grey/purplish hue, this correlates with an area of less dense human habitation.



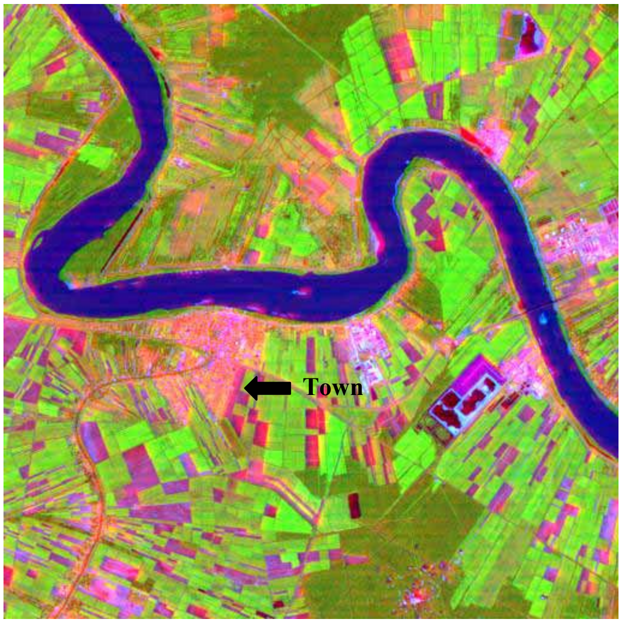
On the left is a false- colour image of New Orleans. I chose bands 7, 3 and 2 (represented by red, green and blue respectively) to best enhance the built and vegetated regions. Man- made structures and the built environment is clearly represented in this image as very bright white. It is the reflectance of band 7 that causes the built environments to appear white. Band 7 reflects very strongly in the built environment as more heat is emitted in those areas. Sand-banks in the river also appear white as they reflect heat, which is picked up by band 7. The road appears black as the tar absorbs heat and therefore does not reflect band 7. The river appears a turquoise colour as it reflects bands 2 and 3 in some proportion. It reflects in band 2 due to the green colour of the river and band three due to the high silt content of the water, which has a reddish colour. The vegetation is dominantly agricultural and in this composite the different types of fields can be very clearly distinguished by their specific colour signal in the image above. Fields that have been harvested and that have a sandy surface have a bright, orangey appearance due to the fact that they emit a small amount of heat that reflects band 7. Healthy, green fields (seen mostly to the south of the Mississippi) are blue-ish, because they reflect band 2, which is assigned blue as its colour signal. Fields with a redder hue, although found throughout the image, dominate to the north of the Mississippi. This colour signal could be due a vegetation type that reflects more in the mid-infrared (band 7) than the type of vegetation found to the south of the Mississippi. The region to the north of the Mississippi is therefore likely to be more conducive to a certain type of crop, with different spectral characteristics to the type of crop found to the south of the river. Non-agricultural, more densely vegetated areas appear very dark, almost black, but with a slightly red tone. These regions are likely to be natural forests, that are highly absorbant and that reflect only slightly in the mid-infrared due to the water content.

2.3 Thermal Structures

The false-colour images below use spectral bands that best represent the thermal structures of each image.



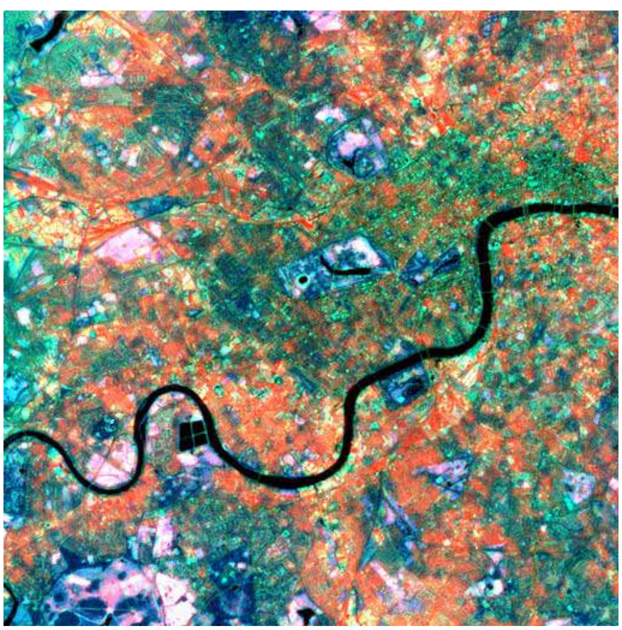
In order to enhance the thermal structure of the image of London, I used 3 infrared bands: 7, 4 and 6 represented by red, green and blue respectively. The vegetated regions are green as they predominantly reflect band 4, which has been assigned a green signal. Band 6 has a low resolution and reflects in the thermal infrared, therefore it is useful when investigating regions that emit a large amount of heat. In this image reflectance of band 6 is shown as blue and dominates the highly built-up regions. This follows with the fact that man-made environments tend to emit a large amount of heat. Band 7 highlights (in red) the very reflective regions in the CBD and other regions where there are highly reflective surfaces



New Orleans has been thermally enhanced using bands 6, 4 and 3 in red, green and blue respectively. The thermal band (band 6) shows up surfaces that emit a lot of heat in shades of red. Towns and populated areas appear in various shades of red and pink with purplish hues in places where sandy surfaces reflect some of band 3, for example, the harvested fields that have a sandy surface. The other vegetated areas all appear green as they all reflect band 4 to some degree due to the chlorophyll content. Sand banks in the river look pink/red due to the fact that they reflect heat from the sun and therefore have a fairly strong thermal signal. The river appears blue as it reflects almost completely in band 3, due to its high silt content.

2.4 Enhancement of Thermal Bands

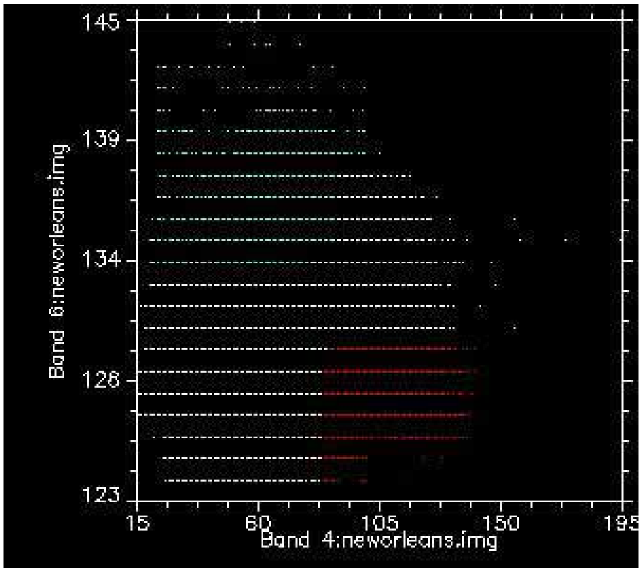
The enhancement of thermal bands using the interactive enhancement tool allows one to distinguish the more subtle thermal properties of a scene.



The image alongside uses bands 6, 7 and 5 in red, green and blue respectively to produce a thermal representation. An equalization stretch was applied to all three bands in order to produce greater contrasts between areas of differing thermal characteristics. Band 6, which reflects in the thermal infrared, has a red signal in this image. Areas that emit a lot of heat (man-made, built environments) are therefore seen as red. Roads can be seen very clearly in red when in a fairly contrasting environment such as the outskirts of the city. In the CBD however, reflection of band 7 and band 5 dominate with fairly clear contrasts visible between the two, due to the many contrasting surfaces in the city. Vegetated areas appear blue/purple as they reflect more in bands 6 and 5, the proportion of which depends on the vegetation type, health and density.

2.5 Using 2-D Scatter Plots to Separate the Built Environment from Vegetated Surfaces

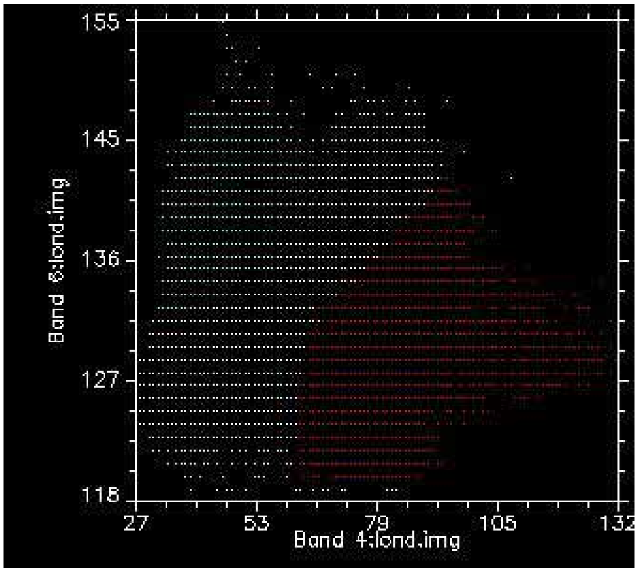
New Orleans

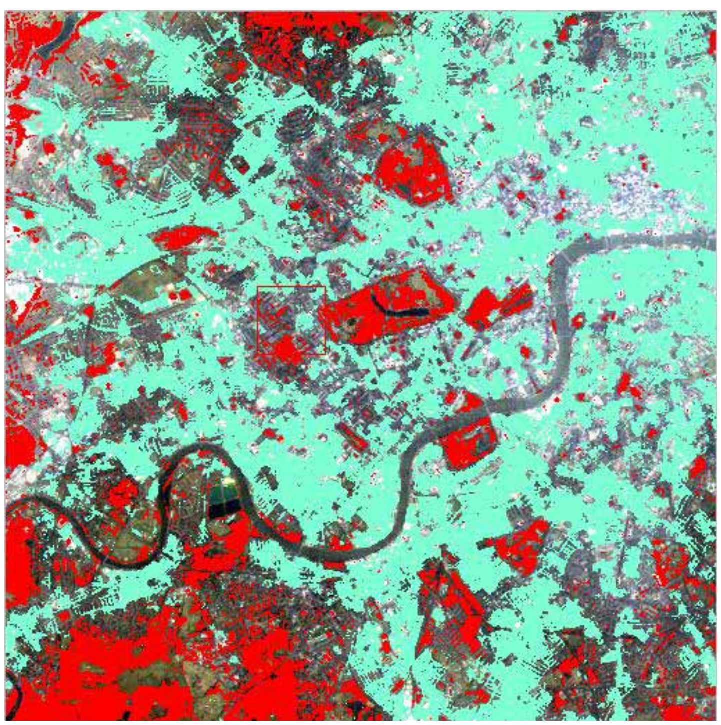


In order to best distinguish the built environment from the vegetated environment in the New Orleans image, I compared band 6 and band 4 in a 2-D scatter plot. I chose these bands because high reflectance in band 4 is found in regions of high chlorophyll content (i.e. vegetated areas), while high reflectance in band 6 is generally an indication of areas that emit a lot of heat (i.e. the built environment). Highlighting low reflectance values of band 4 and high reflectance values of band 6 (in blue) in the scatter plot on the left therefore corresponds to sparsely vegetated areas on the image (see the areas highlighted in blue on the image below). On the other hand, low reflectance values of band 6 and high values of band 4, highlighted in red on the scatter plot and on the image below, relate to the most vegetated regions.

London

Again, I compared band 4 and 6 in a scatter plot to distinguish the built environment from vegetation in the image of London. I chose these bands for the same reasons stated above, however the areas highlighted in the scatter plot differentiating regions of vegetation and the built environment differ from the regions highlighted in the scatter plot for New Orleans. This is a result of the fact that London has different thermal characteristics and, of course, very different vegetation to the agricultural region of New Orleans. A very small region of high reflectance values for band 6, highlighted in blue in the scatter plot above, corresponds to the very large populated region of London (see colour-coded image below). A much larger area of the scatter plot, encompassing high values of band 4 reflectance and a fairly wide range of band 6 (high values are associated with the highest values of band 4), represents the small 'islands' of vegetation in the London area (coded in red on the image). The vegetated areas in the London image below have a certain amount of reflectivity in band 6 due to the radiant heat from the city impacting on those areas.



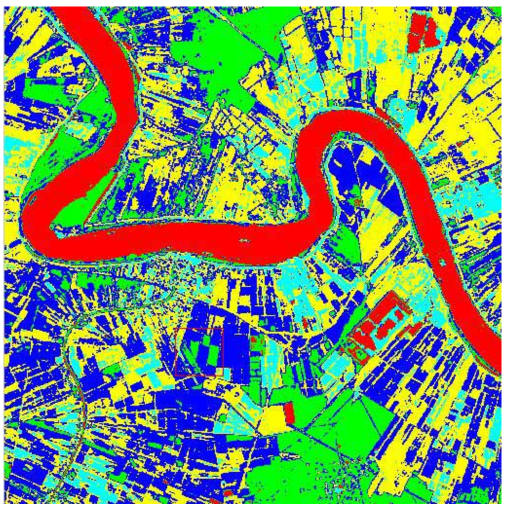


2.6 Unsupervised Classification

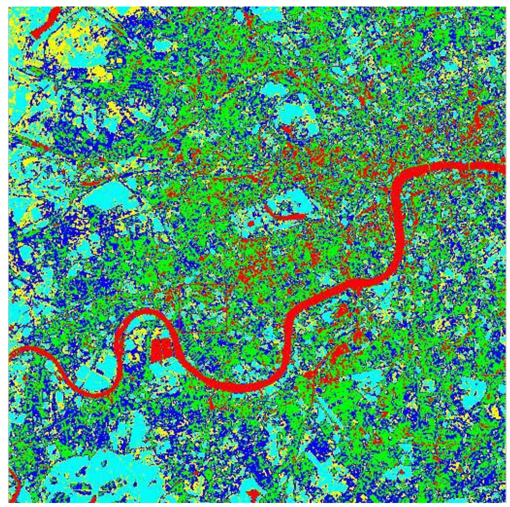
On both images, a K- means unsupervised classification was carried out. The objective of unsupervised classification is to group multiband spectral response patterns into clusters that are statistically separable. Each pixel in the image is assigned to a cluster on the basis of similarity of digital number (DN) combination value. Therefore, pixels in the same cluster generally relate to features on the ground that that are similar to one another. Each cluster of pixels is represented by a different colour on the image, allowing one to classify surface features in terms of their relation to different clusters.

Unsupervised classifications using all spectral bands.

New Orleans



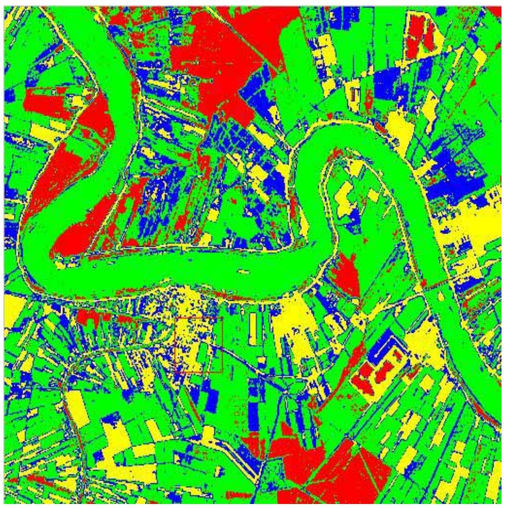
London



For both images, 5 classes are used and are sufficient in describing the salient features without 'smudging' too much detail. The use of 6 classes tends to clutter the images and make certain obvious ground features less discernable. In both images, the rivers and other bodies of water are red. Highly absorbant features of the city of London and just a few areas in the image of New Orleans also appear red. It is immediately noticeable that the image of New Orleans is coloured with much more yellow than the image of London. The yellow seems to correspond to healthy, green fields in New Orleans, this would explain why there is so little yellow to be seen in the image of London. The less green vegetated regions in London (parks and suburban areas) have a light blue signal. The light blue in both images also shows highly reflective surfaces: certain isolated features in London and, very obviously, the towns in the image of New Orleans (which are in very stark contrast to the fields) as well as the reflective ploughed fields. The CBD of London shows up speckled with dark blue and green. This is due to the highly contrasting surface of the city: absorbant tarred surfaces vs. buildings of various degrees of reflectivity. The dark blue in relates to regions that are slightly reflective, but with a green/blue hue when viewed in true colour while the green correlates to features that are more absorbant. The green and dark blue signal in the image of New Orleans looks quite different due to the fact that there is less contrast between the features they represent on the surface i.e. there is no ‘speckling’ effect as in the London CBD, the colours are present as larger areas of solid colour. The green relates to areas of very dark green, absorbant vegetation (perhaps natural forest) and the dark blue generally shows up fields and other regions of vegetation that are less green (in some instances, ploughed) and reflective to some degree.

Unsupervised Classification using a subset of spectral bands.

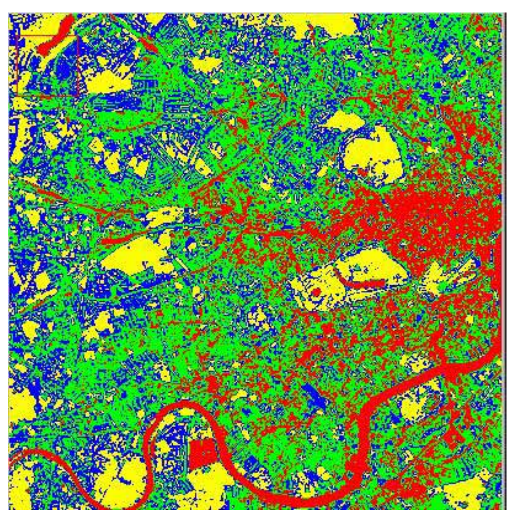
Below is an unsupervised classification of New Orleans in bands 7, 3 and 2, using 4 different classes. These bands were chosen in order to distinguish the different types of vegetation: more green vegetation reflects band 2 while vegetation or fields with a slightly redder appearance would reflect band 3. Band 7 picks up the heat energy of surface features, thereby distinguishing different vegetation types.



Yellow highlights reflected surfaces, in particular the towns and ploughed, dry fields. The sandbanks on the river are also seen in yellow.
Red shows up absorbant surface features such as the dark green and uncultivated vegetated areas and tarred roads.
Green represents healthy green fields and the river is very clearly situated in the same cluster.
Blue also shows up cultivated fields. The difference being that it highlights fields that are a lighter shade of green, perhaps fields that have less moisture.

An unsupervised classification of the city of London using bands 6, 4 and 2 with 4 classes appears below. These bands were chosen in order to distinguish regions that emit thermal energy (indicative of populated and built-up areas) from the more vegetated regions (that reflect band 4).

Red represents the heat radiating from the CBD as well as bodies of water including the river and tarred roads can also be seen in places.
Yellow shows up very green vegetated areas.
Blue shows up areas that have less of a green appearance in true colour and that are less intensely vegetated. These areas are fairly built- up (suburban-type areas).
Green corresponds to regions, particularly on the outskirts of the city that radiate less heat than the CBD, but are still very built-up and are interspersed with vegetation.



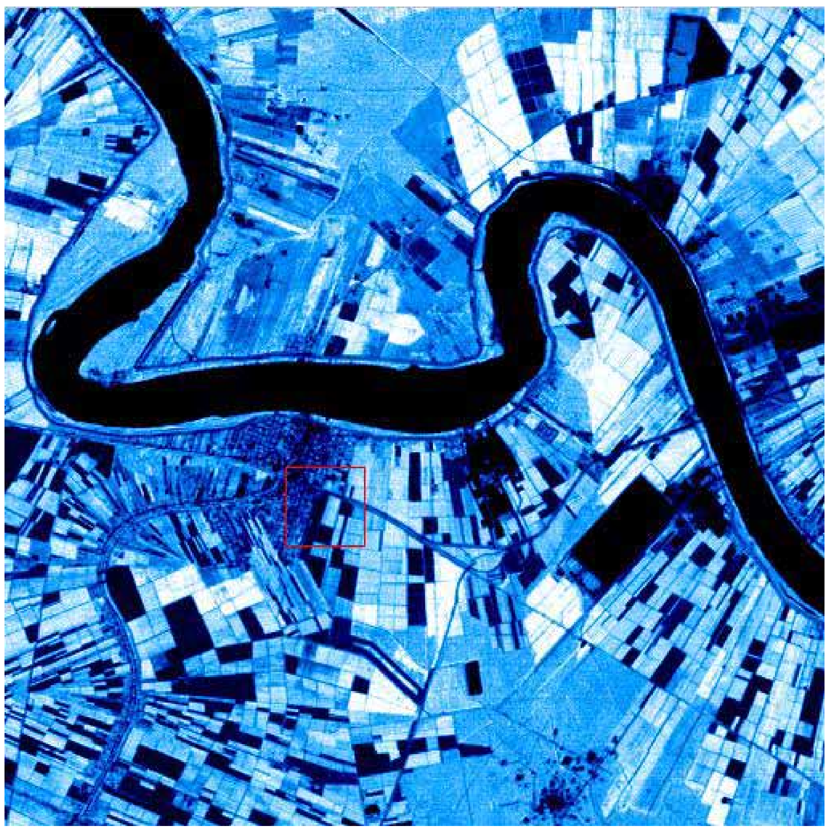
2.7 Normalized Difference Vegetation Index (NDVI)

NDVI transforms multispectral data into a single image band representing vegetation distribution. The NDVI values indicate the amount of green vegetation present in a pixel; higher values indicate pixels with a greater amount of green vegetation present. NDVI values lie between –1 and +1 and are calculated in the following way:

$$NDVI = (NIR - Red)/ (NIR + Red)$$

Where NIR = near infrared

Below is an NDVI image for New Orleans created using a blue/ white colour palette. In order to improve contrasts between vegetation types a stretch was applied, condensing the bottom half of the spectrum. The lighter shades are regions with more green vegetation present and very dark areas have very little or no green vegetation (such as populated regions and bodies of water).



The image above very clearly distinguishes fields in terms of their 'greeness' or, chlorophyll content. One can easily identify fields of similar vegetation type by comparing the shade of blue that represents it. From an NDVI image one could draw some conclusions relating to the state of vegetation, depending on its NDVI value (a high value corresponding to greener, healthier vegetation). Compared with enhancement images created previously, an NDVI image highlights vegetation features more precisely and includes detail more accurately, also an NDVI image makes it immediately obvious which areas are similar in terms of vegetation. It is not only a useful tool when investigating states of vegetation, towns and roads can also be clearly discerned by virtue of their lack of vegetation.

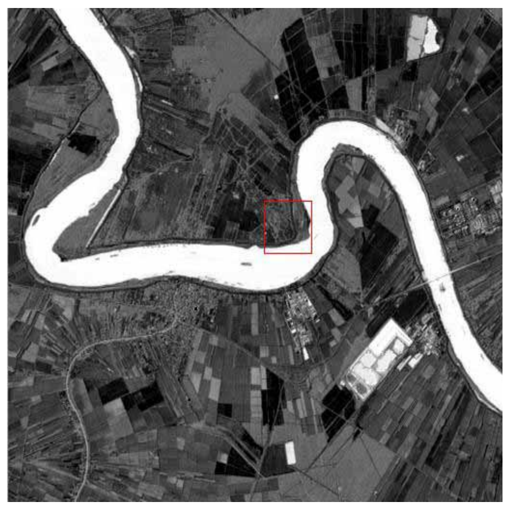
2.8 Principle Component Analysis (PCA)

PCA is a decorrelation procedure for transforming a set of correlated values into a new set of uncorrelated variables. This is done because certain thematic (TM) bands, especially bands 1, 2 and 3, are strongly correlated, resulting in tonal patterns that do not distinguish between features that have similar responses in each band. The decorrelation procedure shifts axes that show strong correlations to new positions that cause significant differences in grey levels, allowing for a greater discrimination between similar features.

Each principle component viewed as a grey scale image.

PC1

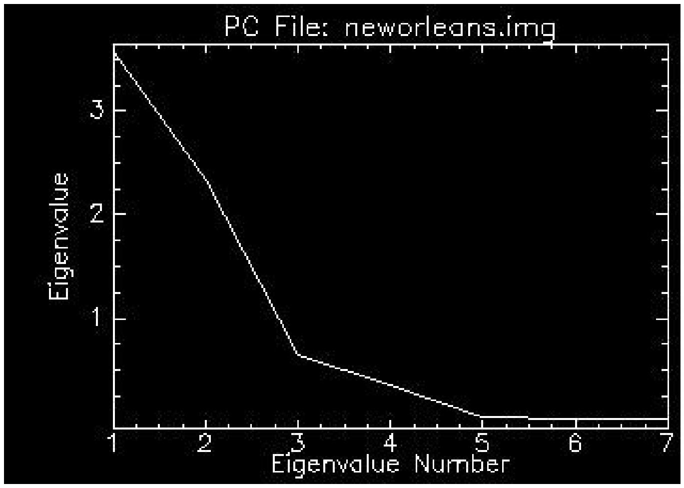
PC 2



PC 3

PC 1 (top right): Typically of PC 1 image, this image resembles an aerial photograph and highlights major features of the scene quite clearly. Bright, highly reflective areas are very well represented.
PC 2 (above): The contrasts in this image are not very clear, but absorbant surfaces and water appear as a very bright white.
PC 3 (left): Vegetation is clearly distinguished in tones of grey. Healthy green fields appear quite dark and sandy fields appear white to very light grey, while uncultivated vegetated land is an intermediate tone of grey.

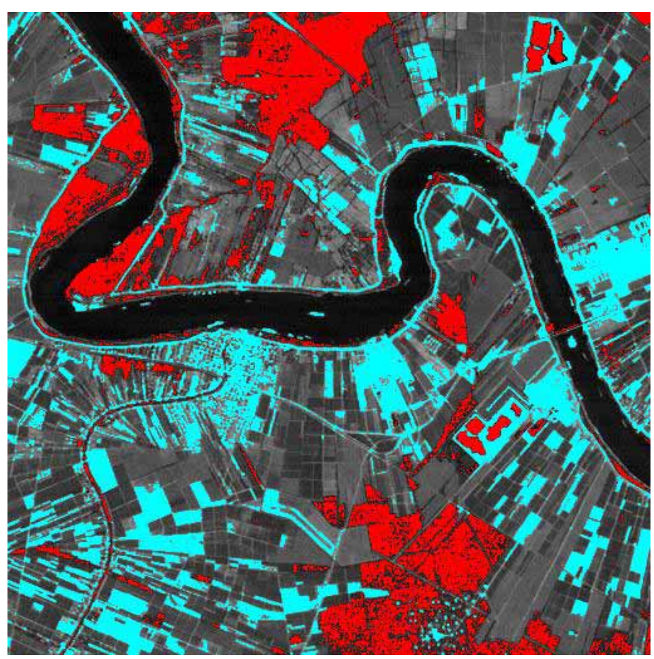
Principle Component Eigenvalue Plot.



The eigenvalue plot above shows that it is only PC bands 1, 2 and 3 that are useful in the analysis and interpretation of images. PC bands 4- 7 show very little variation in the 7-dimensional space defined by the 7 thematic bands. For this investigation therefore, only bands 1, 2 and 3 will be used in a PCA.

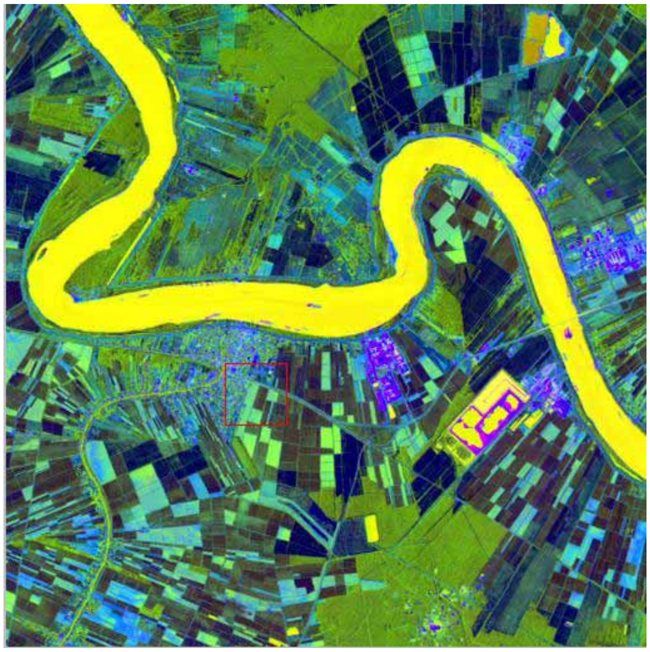
Class 1 and class 5 overlaid on PC 1 grey scale image.

In the image on the right selected categories (class 1 and class 5, red and blue respectively) have been overlaid on PC 1. The red highlights all highly absorbant areas such as the very dark green, natural vegetation and man-made structures, for example, the tarred roads. The blue relates to highly reflective areas: dry, ploughed fields, dirt track roads and, of particular interest, the towns. The features remaining are the cultivated fields of various vegetation types, as reflected by their tone of grey.



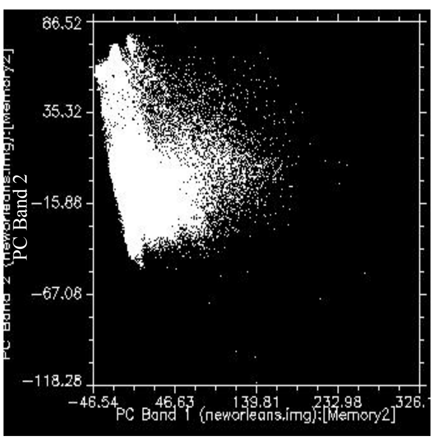
False colour composite using the 3 PC bands.

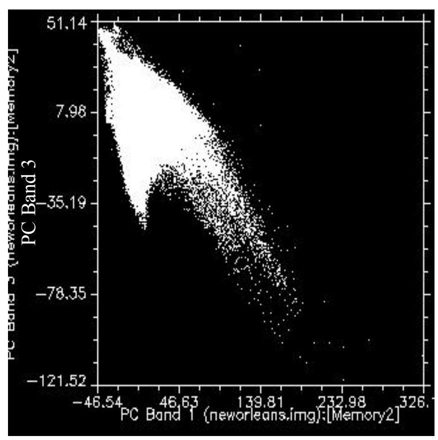
Below is a false colour composite created using the three PCA bands; PC 1, PC 2 and PC 3 in blue, red and green respectively.

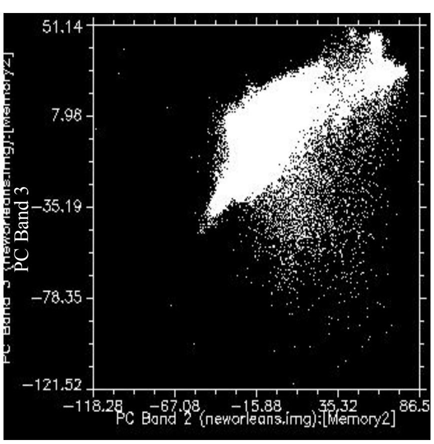


Very bright, reflective features as seen in the grey scale image of PC 1 as bright white and light grey are seen in shades of blue on the image alongside (the blue correlating to PC band 1). The vegetation is highlighted in green (PC band 3) and is different shades of turquoise in places depending on the brightness (and therefore, the influence of PC 1). PC 2, which has been assigned a red signal, seems to be related to thermal characteristics, as a hint of red is evident only in regions that are likely to emit a fair amount of heat such as in the towns.

2-D Scatter plots of each band against each other.







CHAPTER THREE:
Hyperspectral Imaging

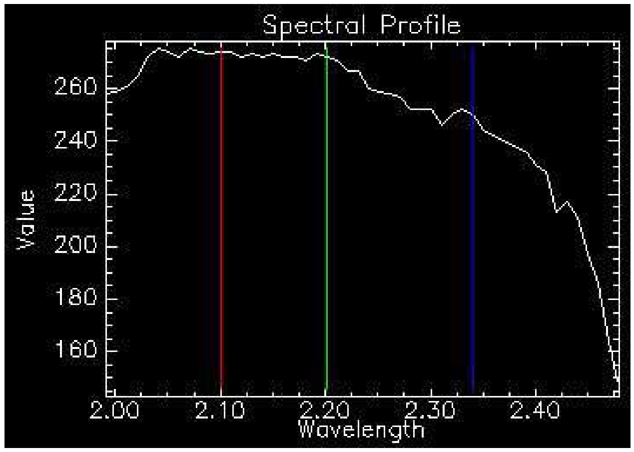
Hyperspectral Imaging is a useful method for continuous sampling of broad intervals of the spectrum. It covers narrower bands (10 nanometers) than Landsat (0.1 micrometers) sensors, which necessitated the intergration of spectral radiation within bands. From data required we are able calculate a spectral curve for any pixel or for a group of pixels that may correspond to an extended ground feature. The shape of the curve relates to, not only the major characteristics, but also to the 'purity' of the feature, thus providing a definitive index for identifying ground features.

Below left is a hyperspectral image, with 49 bands, 172- 221, loaded as a grey scale image in band 193.

Above right is the image loaded as a R, G and B image in bands 183, 193 and 207 respectively. Specific ground features are assigned a colour depending on their reflectance in the bands chosen. Similar colours relate to areas with similar ground feature characteristics.

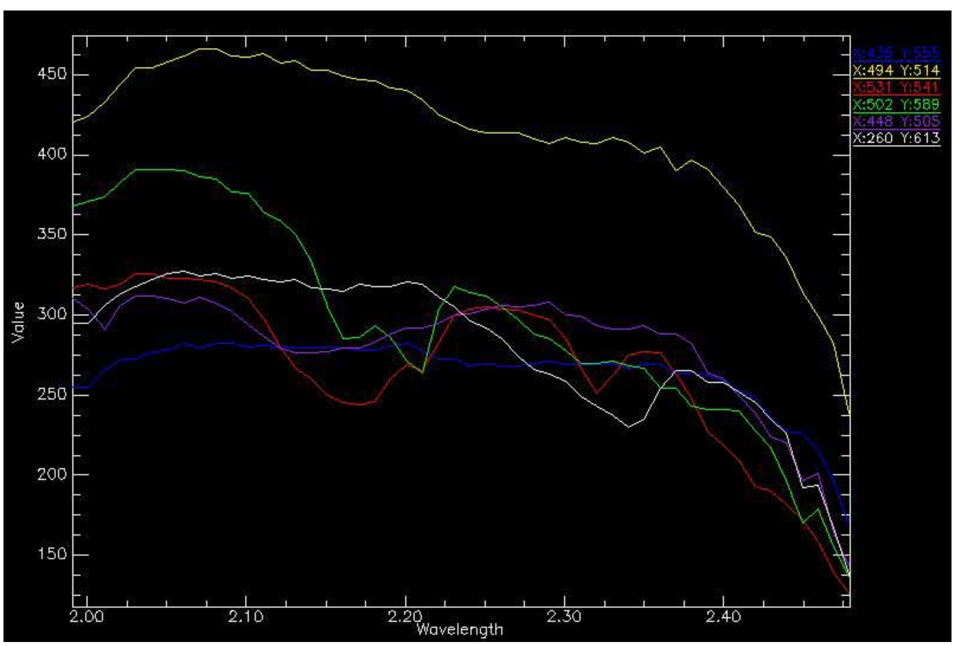
Linking the images above allows one to overlay the images by holding down the spacebar. The degree of transparency of the overlaid image can be selected by the user. This tool allows for easy comparison of two images created in different bands and produced in order to enhance different features. The red 'zoom-box' for each image is linked and move in unity thereby allowing identical areas to be highlighted for each image.

A spectral profile can be created (see over the page, top), which displays the spectral profile for the group of pixels of the current location. The spectral profile as the cursor is moved over the image. This is another tool that is useful in identifying ground features in terms of their spectral characteristics. As the location changes, not only does the curve change, the Y-axis also changes to suit the current profile. However, for spectral amplitude comparisons this function can be turned off. The red, green and blue vertical lines seen on the profile relate to the position of the bands assigned to those colours, the position of which can be changed by dragging the lines into another position.

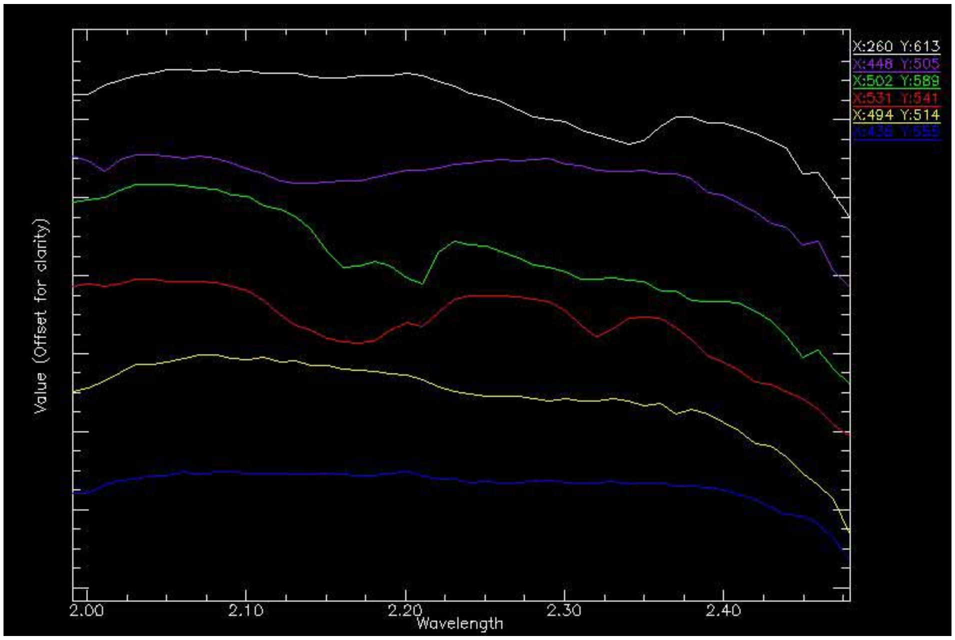


A spectral profile of a particular location on the image

The pixel locator is a tool that allows one to find a position accurately on the image using the pixel values. A variety of ground characteristics are given in terms of their pixel values (see table over page), this tool is was used in order to locate them. A spectral profile was created for each of them in the same window (below) by dragging each of the profiles into the same window. The profiles are then stacked, enabling comparisons to be made (over page).



Above are spectral profiles of 6 locations with very distinctly different surface features.

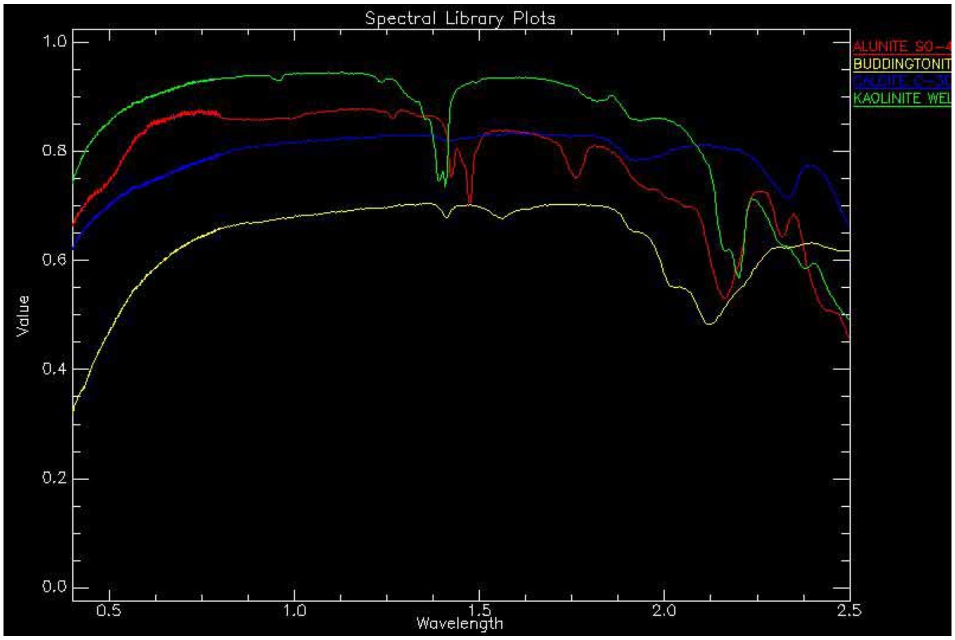


Above are the stacked spectral profiles for each of the locations listed below.

Ground Feature	x-pixel	y-pixel	Colour
Varnished Tuff	435	555	Blue
Silica Cap	494	514	Yellow
Opalite Zone with Alunite	531	541	Red
Strongly Argillized Zone with Kaolinite	502	589	Green
Buddingtonite	448	505	Purple
Calcite	260	613	White

ENVI has a library of spectral profiles determined in a lab. The spectral profiles from a number of ground features, particularly sandy and rocky surfaces, can be accessed and used for comparisons of spectral profiles obtained from an image. This database of spectral profiles for known minerals is very useful in surface geology investigations as it can be used as an index to identify minerals by virtue of their spectral profile. Spectral profiles for the following minerals have been obtained from the ENVI library and displayed in a single window (see over the page).

Mineral	Colour
Alunite SO_4A	Red
Buddingtonite fields TS-11A	Yellow
Calcite C-3D	Blue
Kaolinite well ordered PS-1A	Green



The four spectral profiles in the above image have been extrated from the ENVI library of spectral profiles for minerals.

CHAPTER FOUR:
Marine Remote Sensing

The objective of this section is to become familiar with the use of the free shareware package developed by UNESCO known as Bilko. Bilko is a useful tool for processing and displaying satellite data of the marine environment.

As an introduction to this package an image of the North Channel between Northern Ireland and Scotland has been used. Various stretches have been applied to the image, both automatically (such as the equalization and gaussian options) and manually. Different stretching procedures highlight certain features of the image differently, therefore a stretching approach has to be applied according to what information is required from the image.

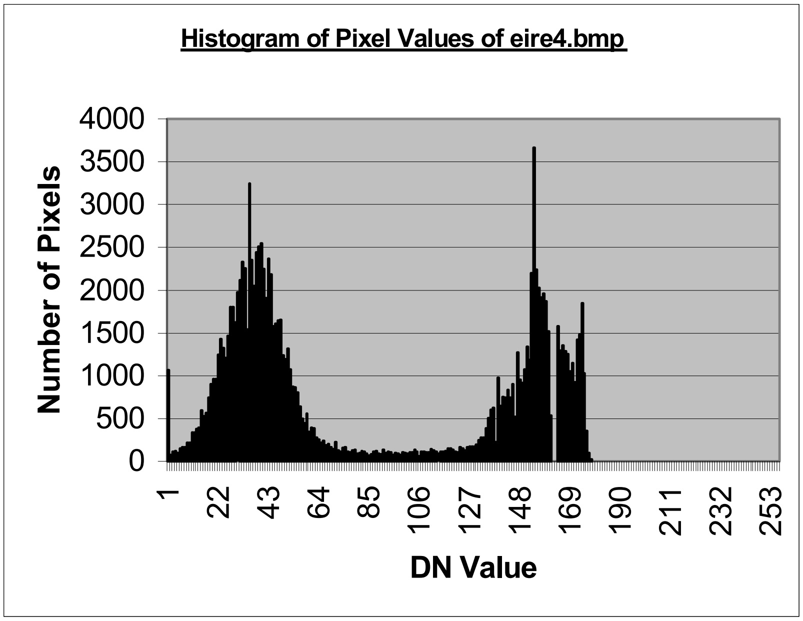
Before one can apply a sensible manual stretch to an image however, a certain amount of knowledge about the range and nature of pixel values is necessary. A histogram plot of the pixel values of the image is a useful way of gaining insight into the range of values the features on the image to which they are related.

4.1 Introduction

4.1.1 eire4.dat

This image has 512 columns and 256 rows, corresponding to 131 072 pixels each of which represents an area on the ground of 1.21km^2. The image was obtained from the band 4 Advanced Very High Resolution Radiometer (AVHRR) sensor on a US National Oceanographic and Atmospheric Administration (NOAA) satellite. Band 4 senses thermal infrared radiation and by convention warmer areas are represented by darker shades of grey.

The land is very clearly defined in very dark shades of grey to black. Within the landmasses very little can be distinguished other than inland bodies of water such as lochs. On the other hand, several shades of grey can be seen in the sea, the brightest areas relating to the coldest water. In order to examine the actual pixel values, represented by the shades of grey, more closely a histogram of the range of pixel values in the image above is created (see over page).



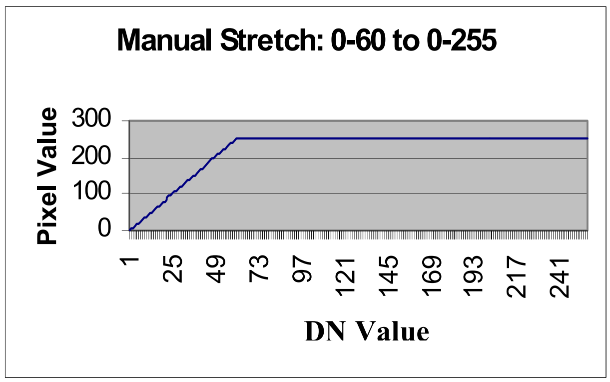
The two distinct peaks in the histogram above relate to the range of pixel values at sea (the peak on the right) and the range of values on land (the peak on the left). The DN (digital number) value is the pixel value that is related by a simple algorithm to an actual temperature. The sea has greater pixel values (121 to 178) relating to its colder temperatures than the land, which has values ranging between 9 and around 60. The flat region between the two peaks relates to features such as lochs, rivers and very high mountain peaks which have temperatures between that of the sea and land. The fact that the land looks an almost uniformly dark grey in the image, with very little contrast gives rise to the relatively smooth curve in its histogram representation. The peak representing the sea however consists of a number of 'subpeaks', relating to the various highly contrasting shades of grey (or, temperatures) highlighted in the sea.

Using the cursor to 'explore' the image allows one to investigate the actual DN number and precise location (in terms of pixel numbers) at particular points of interest. The program automatically reads the value and location of each pixel as the cursor moves over it. Using this function, the minimum and maximum values of the three most prominent features of the image were investigated:

Feature	Minimum DN Number	Maximum DN Number
Sea	121	178
Land	9	15
Loch	86	125

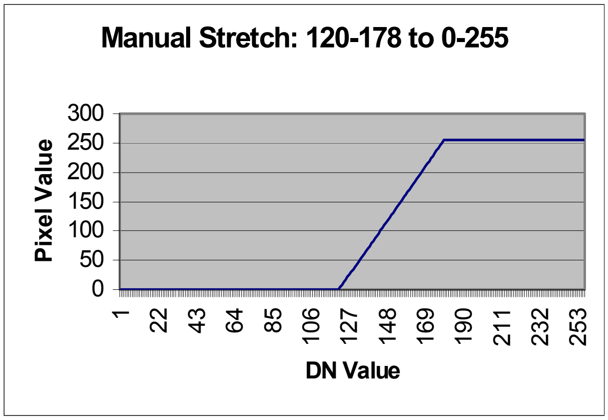
Enhancing/ Stretching the image
As previously mentioned, the application of stretches is an extremely useful technique in extracting 'hidden' information from an image. For example, if one wanted information about land features in the image above, a suitable stretch would be necessary in order to generate greater contrast of the land.

Manual Stretches
The first manual stretch takes values from 0-60 up to 0-255 (refer to the graph below for a visualization).



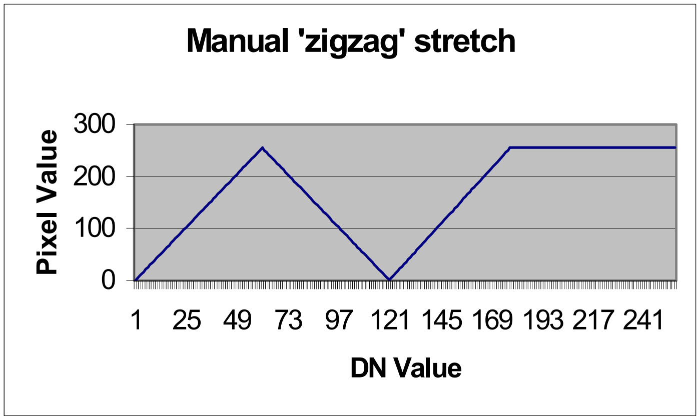
This stretch has spread the land values (+- 0- 60) over the full range of pixel values (the entire grey-scale range), thereby resulting in very fine contrasts on the land (see the image below). All DN values greater than 60 (such as the sea and lochs) are assigned the same shade (white). Land features can be observed in the image below that would have been totally overlooked without stretching the original image. This stretch is useful when doing studies of only the land features.

For the next stretch, values between 120 to 178 are mapped to 0 to 255 (see graph below).



This stretch has arranged the DN’s of the sea so that they spread across the entire grey scale. All DN’s that relate to regions that are not sea (i.e., numbers less than 120) appear black in the image. More subtle temperature differences in the sea can be made out in the image below that were not at all visible in the original image. This type of stretch is therefore beneficial to studies that are interested in only the sea.

One can include, in a single image, the benefits of both of the above stretches. The stretch below has mapped 0-60 to 0-255 and 120-178 to 0-255 in a ‘zigzag-like’ fashion.

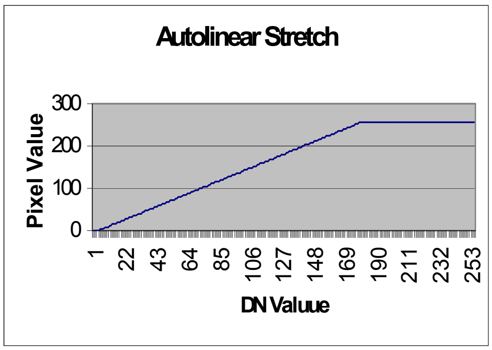


This stretch applies the full grey scale to sea and land values alike. Coastlines are very clearly defined using this stretch: a black line seems to define the landward border of the sea and a white line highlights the coastlines.

Manual stretching techniques are useful because they can be custom designed to highlight features according to the type of investigation being carried out. Many automatic stretches are available within the Bilko software that, although useful in improving contrast, apply the same stretch to all parts of the image so that particular regions of interest are not specifically highlighted. The stretches applied below are examples of the automatic stretches: autolinear, equalize and gaussian.

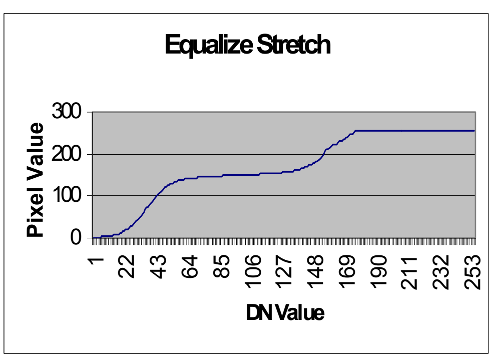
Autolinear Stretch

The highest DN is stretched to be represented by the shade of grey that correlates to the pixel value of 255 and the lowest DN is represented by 0, thus creating a linear plot between the lowest and highest values (see the plot below left). This type of stretch highlights subtleties in the ocean as more shades of grey are available for representation of the more subtle temperature differences. This stretch distinguishes only the coldest areas on land (perhaps high, cold mountain peaks and water bodies such as lochs).

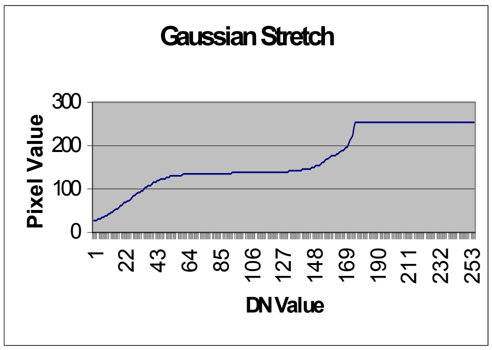


Equalize Stretch

Similar to the manual 'zigzag' stretch, the equalizing stretch provides good contrasts in both the sea and on land. Again, the highest DN value is stretched to 255 in order to make use of the full range of greys. The two peaks (land and sea) clearly identified previously on the histogram are represented in this stretch as curves (see graph on the bottom left), thereby the highly variable nature of both features are well recognized by this stretch. Despite the good contrasts within the land and sea, contrasts between the two are not very clear i.e. the coastlines are quite blurred.

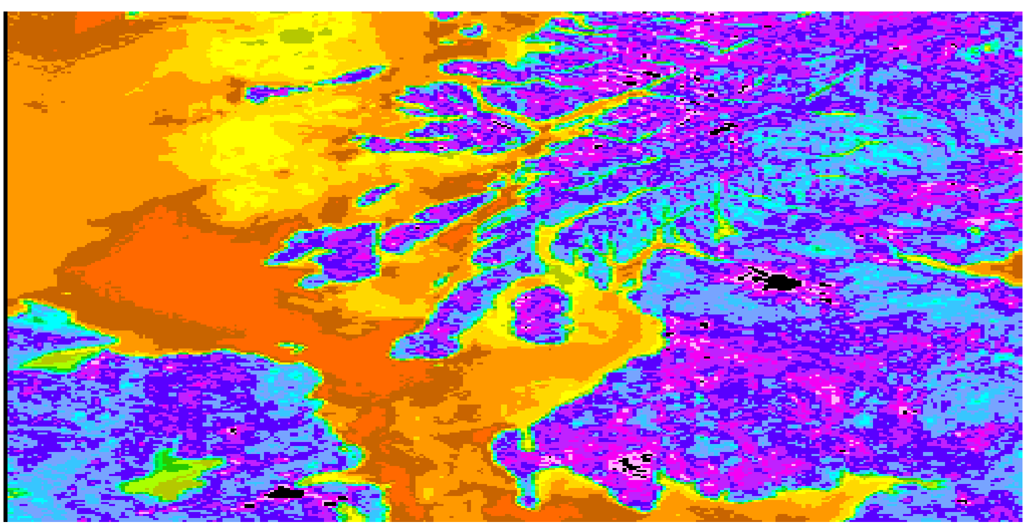


<u>Gaussian Stretch</u>
This stretch is similar to the equalize stretch in that it results in good contrasts in both the land and the sea, the method in which such contrasts are achieved is also very similar. The difference being that the lowest DN value in the image is not stretched to zero, it remains as the same (in this case, a land value of 9). This technique reveals finer detail on land as the predominantly low DN values, have a less dark signal and therefore more subtle shades of grey are distinguishable.



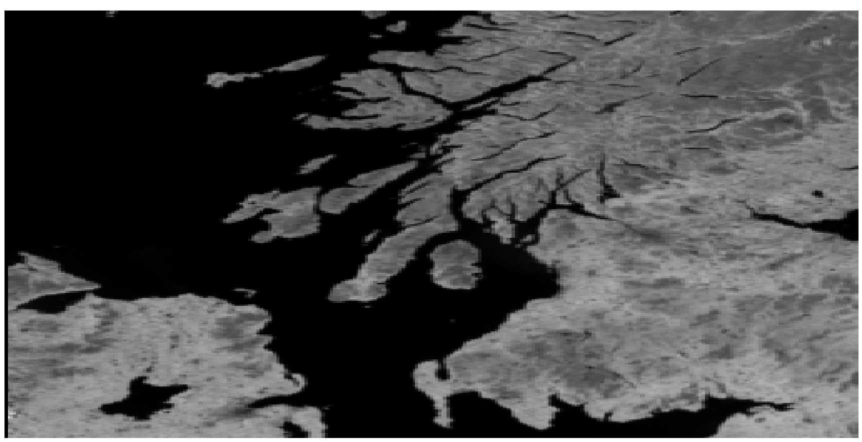
Colour Palettes
A colour palette can be applied to an image as a visualization tool, allowing one to easily get an idea of the distribution of DN values. Below is a colour palette has been applied to the image.

The reds in the image below represent the coldest temperatures (and highest DN's), while the purples and blues relate to the warmer temperatures (and lowest DN's). Green corresponds to values between land and sea such as lochs and certain coastal regions.



Filters
Filters are used, in conjunction with stretching techniques to extract particular signals from the data set. For example, the 'mean' filter function takes the average of a chosen matrix of pixels, while the 'median' extracts the middle value. This is useful because it 'smooths' small- scale features (eg., filaments) and allows one to clearly identify larger scale features such as upwelling fronts. Other filters such as the Roberts, Sobel and Laplacian explicitly highlight the borders between regions of very different properties.The borders that are revealed by these filters will depend on the stretch that is applied. For example, in the absence of any stretches, a Laplacian filter highlights only the coastline, but with an equalizing stretch the same filter also highlights the division between regions of major temperature differences.

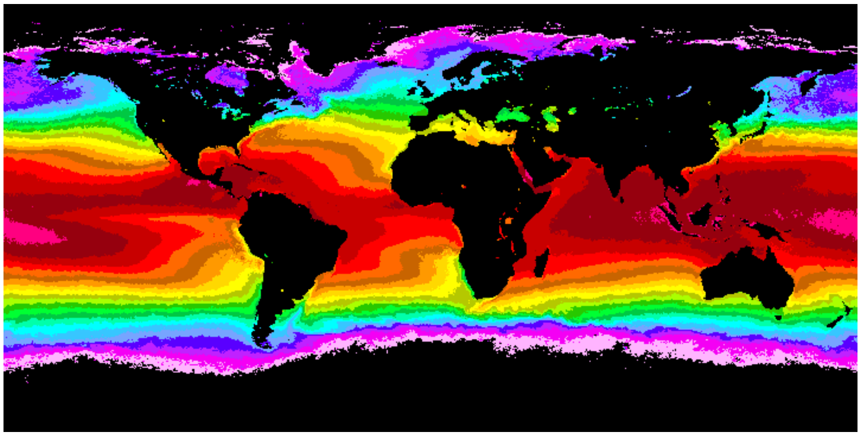
<u>4.1.2 eire2.dat</u>
This image is of the same area, but taken in band 2 of the same sensor. Band 2 senses electromagnetic radiation, which is in the near infra-red part of the spectrum. As a result, the sea appears almost black (it absorbs all near infra-red) while the vegetation on the land is seen as a wide range of greys (as vegetation reflects the near infra-red). Therefore, regions of dense vegetation will look brightest and more sparsely vegetated regions, such as the highlands, will appear darker.



4.2 Sea-surface temperature

4.2.1 gt93-mn.bmp

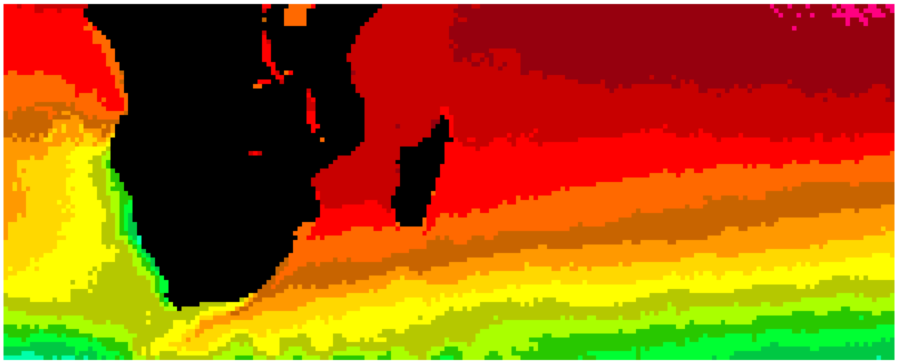
The image below has 720 columns and 360 rows, one degree of latitude and longitude is therefore made up of 8 pixels: 2 columns x 4 rows.



The colour image above was created using the globtemp.pal file. The reds in the colour image above are the warmest temperatures and the purples are coldest.

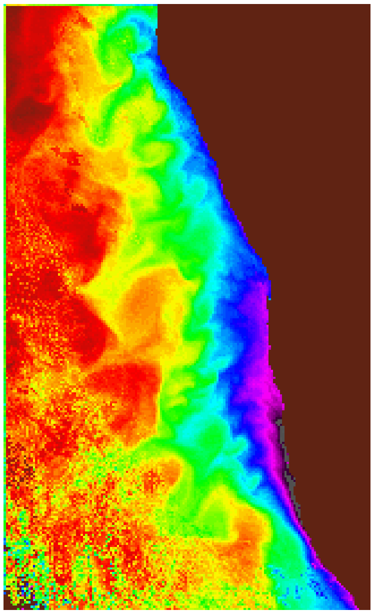
A zoom on Southern Africa

A region of Southern Africa was selected using the 'box' tool and was copied as a new image. The upper left-hand corner of the box is the intersection of the equator and the Greenwich meridian, 0°, 0°, which corresponds to a position 0360, 0180 on the image. The lower left-hand corner is -40°S, 50°E (0560, 0260).

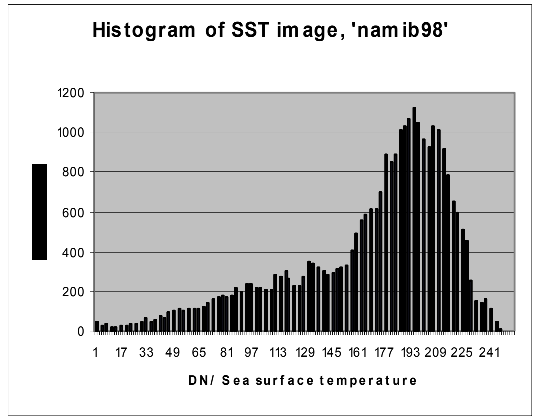


The image above clearly defines the upwelling region off the south west coast as a green margin. The Agulhas current can be seen as an orange tongue extending into the retroflection area. The front between the warmer, northerly waters (yellow/ orange) and the colder Sub-Antarctic waters (shades of green) is very clearly represented and, from this remote observation, it can be accurately deduced that it is a region of high mesoscale variability.

4.2.2 namib98.bmp

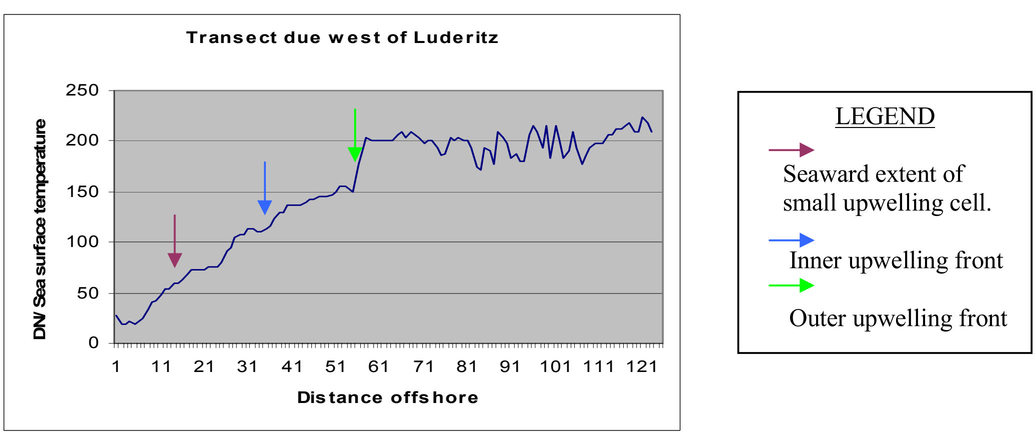


The image alongside is a five day composite of SST in May 1998 off the Namibian coast. It was obtained from the NOAA satellite and has a nominal ground resolution of 1km. The histogram below shows the range of the sea surface temperatures in the image.

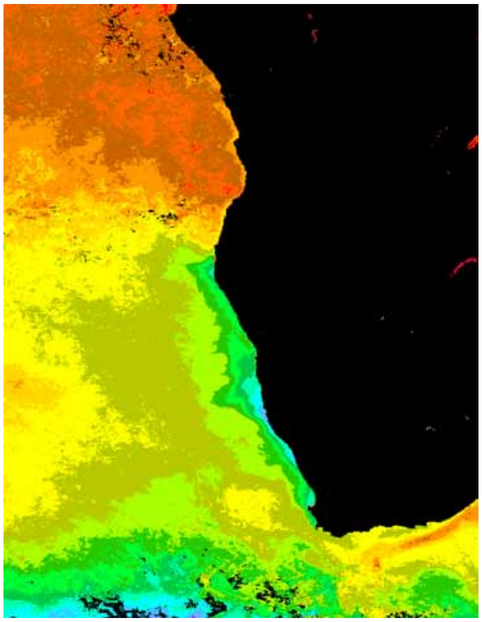


The SST colour image of the Namibian coast reflects a very prominent upwelling cell that has a purple/ blue signal. The dominant offshore temperature signal is relatively warm and is visualized in shades of red. The histogram of this image interprets this fairly large warm region as a very distinct peak of values at the higher temperatures. Smaller peaks, though less obvious, are visible at lower temperature values on the histogram. These peaks correlate to the cold regions of upwelling.

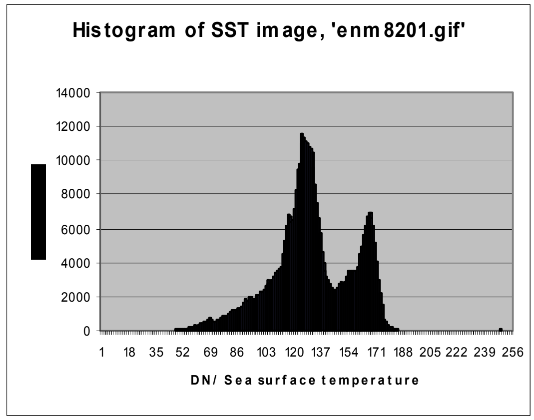
A relatively small, but very distinct upwelling cell is situated in the vicinity of Luderitz and extends to about 13km offshore (it is seen in the image as purple). The ‘inner’ upwelling front however, is situated further offshore at a position of roughly 35km from the coast and can be identified in the image as the very sharp gradient between the green and blue signals. The ‘outer’ upwelling front is situated at roughly 60km offshore and includes older upwelled water that has moved offshore and become warmer (i.e. the green/yellow signal). A transect due west from Luderitz, see below, clearly shows the position of these fronts.



4.2.3 enm8201.bin



The image on the left is a corrected sea surface temperature image for January 1982. The reds and oranges correspond to higher temperatures, while the blues to the coldest temperatures. The histogram below represents the range of temperatures.

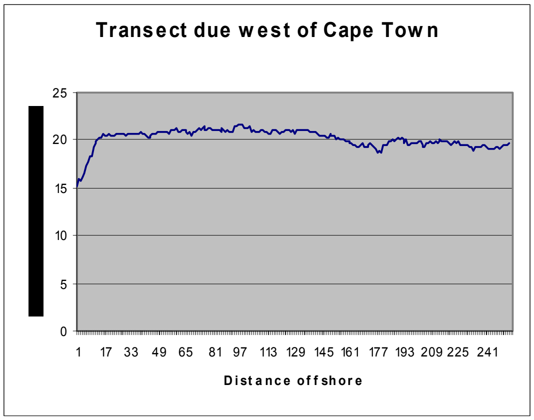


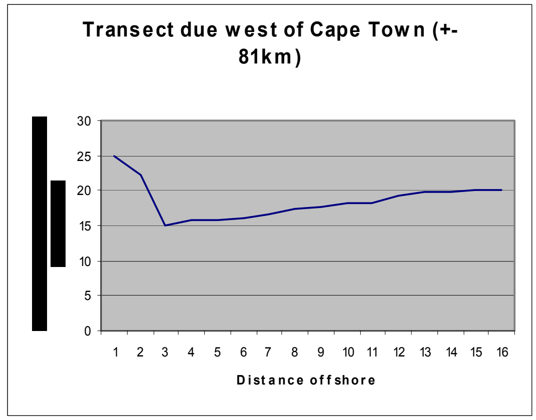
The tallest peak in the histogram refers to the most common range of temperatures in the image: these exist some distance offshore on the west coast and very close in shore on the east coast. These temperatures lie between about 18°C and 21°C[1] and are represented in shades of yellow and light green. The smaller, but equally distinct peak is situated in the region of warmer temperatures. This peak corresponds to the warm tongue of the Agulhas current extending into the colder waters of the Benguela and the very warm waters off the Angolan coast. Both of these warm bodies of water contrast very strikingly to the colder waters into which they penetrate hence the very apparent peak represented in the histogram plot.

Over the page are sea surface temperature transects due west of Cape Town. The transect on the left extends to 2°W, while the transect on the right extends only about 80km seaward. In order to convert pixels into distances, I used a nominal ground resolution of 4.5 km, however this is not accurate at the more southerly latitudes as it applies to the resolution at the equator. The distances in this section should therefore be regarded as an estimate only.

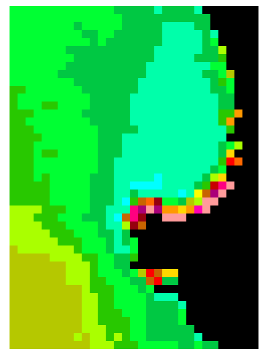
The transect on the left shows a very clear upwelling event at the coast i.e. the temperatures there are up to 5° colder than temperatures about 75km offshore. The temperature stays quite stable at around 20-21°C until about 14°E when it drops slightly to about 16-18°C. This colder water seems to be part a cold intrusion from the sub- Antarctic. The transect on the right only extends to about 80km offshore. A very warm region is found at the coast, which appears to have a very small area (see zoom of image). This warm water could be a result of outflow or runoff from the land. Beyond this warm body of water though, the water drops and then increases as one moves offshore (indicative of upwelling).

[1] The following relation is used to convert the DN's into temperatures: SST (°C) = (DN/10) + 8

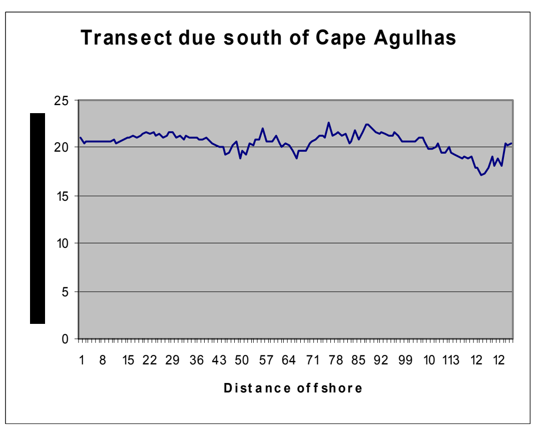




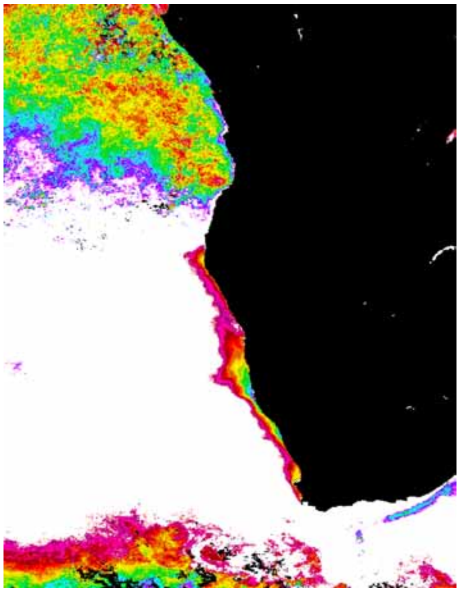
The zoom image on the right shows the warm water close inshore and the colder upwelled water further offshore.



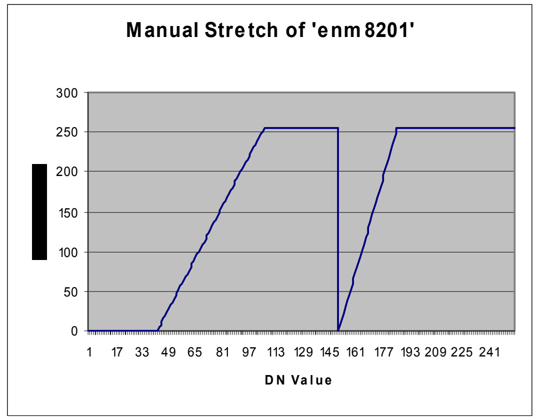
The transect below is due south from Cape Agulhas. The general trend is for the temperature to increase gradually until about 37°S and then to decrease more rapidly. This signal is of the warm tongue of the Agulhas current. Witihn in this general picture though, there are smaller peaks that might correspond to the highly variable nature of the Agulhas current, giving rise to meanders and filaments.



From the analyses above, two major points of interest in this image are the region of upwelling and the warm water of the Agulhas current and off the Angolan coast. Below, a manual stretch has been applied to the image in order to enhance these areas.



On the left, the upwelling regions, the warm Agulhas and Angolan waters have been enhanced. Below is the manual stretch that was applied.

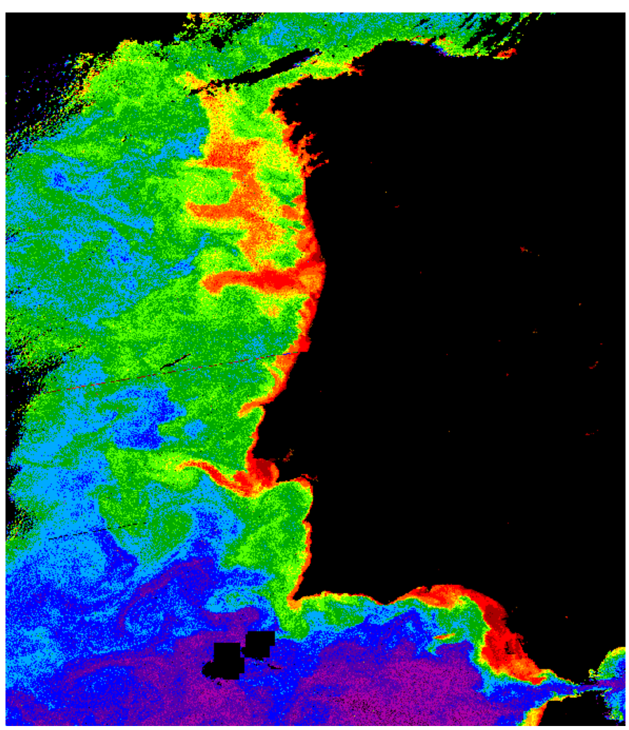


Values of between 0 and 255 were assigned to the areas of interest in order for them to be represented by the complete colour scale. Areas not of interest, were stretched to 255 and are thus seen on the image as white.

4.3 Chlorophyll

4.3.1 ib-chlor.bmp

Satellite observations of chlorophyll in the oceans are made in the visible part of the spectrum and is measured as a ratio of green and blue light leaving the water. The image below is of the coastal regions off the Iberian Penninsula. It is a two channel, chlorophyll concentration image from the Nimbus coastal zone colour scanner (CZCS). A pre-created colour palette, chlor2.pal has been applied to the grey-scale image.

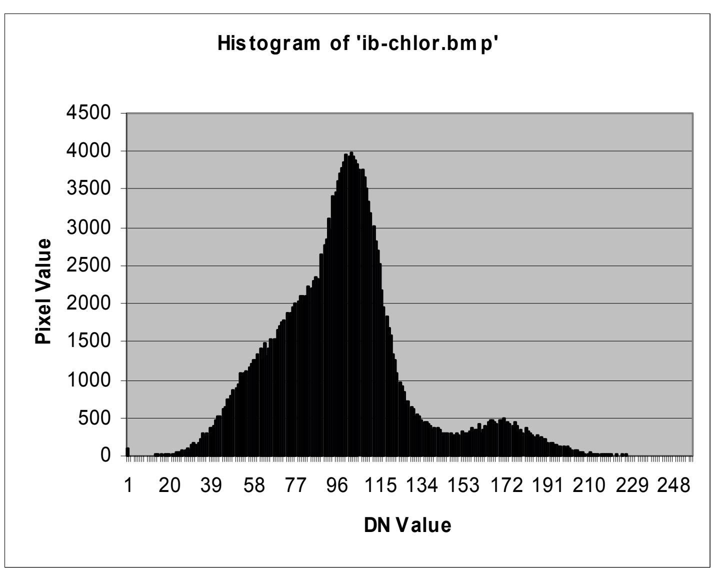


The palette represents the highest chlorophyll values as red and the lowest chlorophyll values as purple. The highest chlorophyll values are clearly evident as being at or very near to the coast. The reason for this is that coastal waters are generally enriched with nutrients from either upwelling or runoff from the land, thus leading to enhanced phytoplankton productivity. From the image above, regions of high chlorophyll concentration seem to move offshore in filaments, due to local wind forcing. A very intense 'chlorophyll bloom' is present in a bay on the south coast of the peninsula. This could be a result of the fact that the bay shelters the plankton community and allows it to grow before being dispersed by currents. On the other hand, the intense red signal could be the result of a large sediment load from a river entering into the bay.

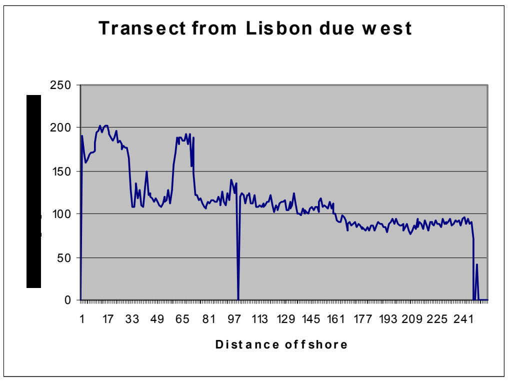
To the south, the chlorophyll concentration is very low, this is represented by the dark blue/ purple colour signal. This low concentration seems to be related to the water entering the Mediterranean through the Straits of Gibraltar. Cool North Atlantic surface water enters the Mediterranean on the surface above the warm, highly saline exiting Mediterranean water. It is therefore the North Atlantic water that is seen in the above image as the major body of water to the south and the water entering the Mediterranean.

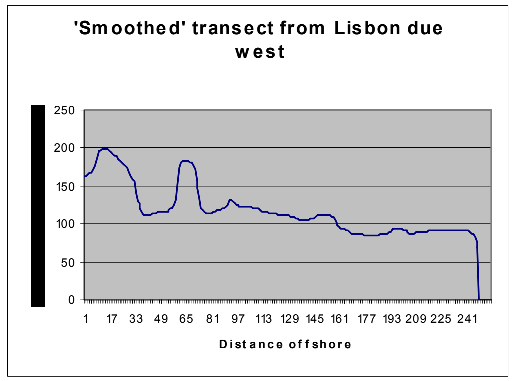
The green signal highlights regions of intermediate chlorophyll concentrations. These regions are found a fair distance offshore and have probably been advected there from the highly productive coastal regions. As they move offshore, the chlorophyll tends to dissipate and become less concentrated.

The histogram below shows the 'spread' of chlorophyll concentrations within the image. The most common value of chlorophyll corresponds to the peak and is 102. The highest value of chlorophyll is 227. The small peak on the right represents the relatively small region of very high chlorophyll on the coast. The dominant peak encompasses the most commonly occurring chlorophyll concentration in the image (the green signal in the image). The region between the peaks represents the least common concentrations and has a yellow/ light orange signal in the image.



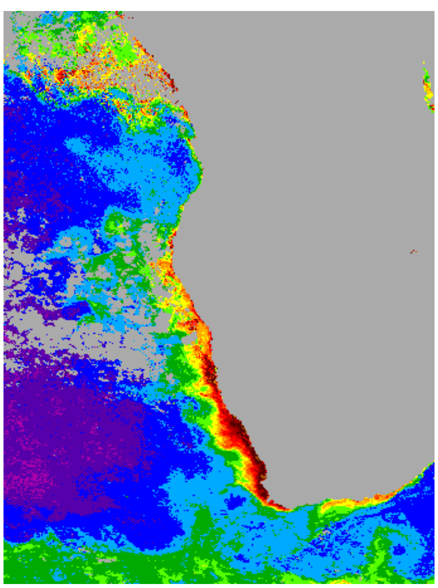
The transects below show the variability of the chlorophyll concentration as one moves offshore due west of Lisbon. The second transect has been ‘smoothed’ using the median function. Both transects show that the major chlorophyll peak occurs some distance offshore. Inshore, recent upwelling is likely to have created an environment of high nutrient content (due to the deep, cold and clear nutrient rich water), but little phytoplankton productivity. Slightly offshore a chlorophyll peak exists that is likely to be a result of a phytoplankton bloom some time after an upwelling event and which has subsequently moved offshore. Apart from one very distinct peak, the chlorophyll concentrations tend to decrease offshore due to the lack of a nutrient source for phytoplankton growth and due to dissipation of the highly concentrated bloom that originated near the coast. The distinct peak is part of the ‘meandering’ filament of high in chlorophyll coastal waters. The smoothed transect tells the same story, but does not include superfluous detail and is therefore a useful tool when studying features of relatively large spatial and/or temporal scales.



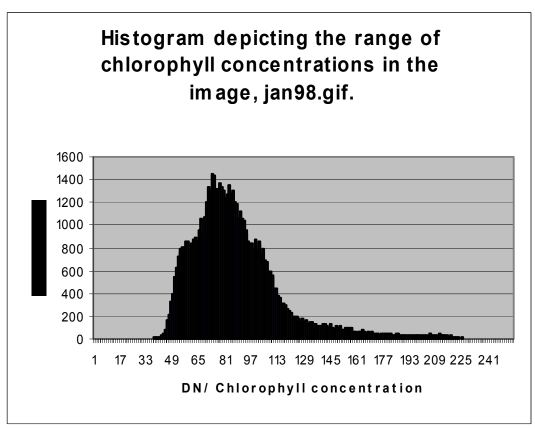


4.3.2 jan98.bmp

Below is a SeaWiFS chlorophyll image for January 1998. To this image, a colour palette, chlor2.pal, has been applied.

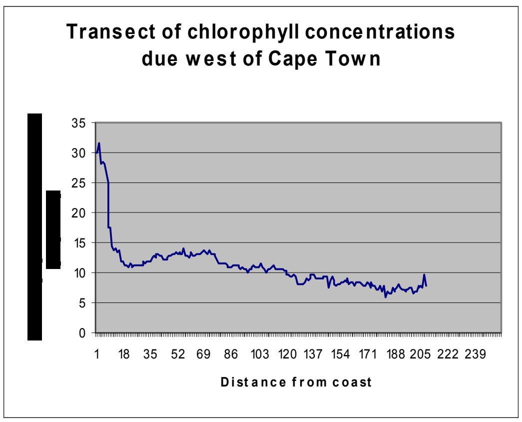


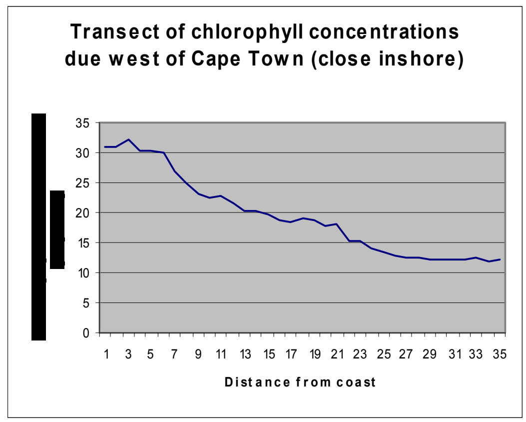
Below is a histogram depicting the range of chlorophyll concentrations in the image alongside.



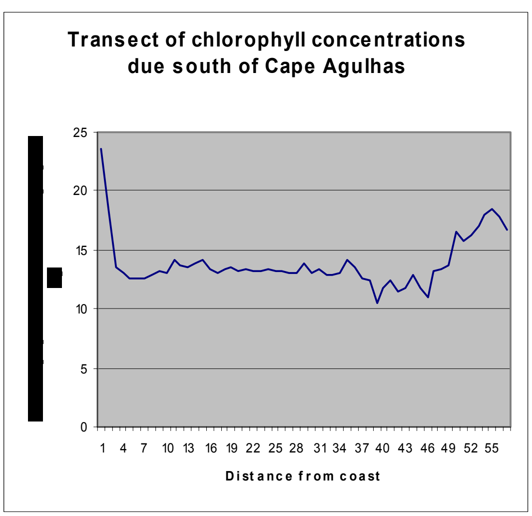
The chlorophyll concentrations are highest on the west coast, extending from Cape Agulhas to roughly the border of Namibia and Angola. An isolated cell of high chlorophyll exists on the south- coast, this cell is likely to be upwelling- induced as it is probably a bit large to be a result of runoff. The chlorophyll concentrations are also high in the waters off the west coast of central Africa due to the warm tropical waters there. The histogram depicts these centers of upwelling and high chlorophyll as a 'shallow slope' extending over a wide range of values from about 133 to 255. The peak in the histogram represents the large region offshore that has low chlorophyll concentrations.

Below are transects from Cape Town offshore, the transect on the left extends well offshore, while the one on the right depicts chlorophyll variability close inshore.





Both transects show that the chlorophyll concentration at the coast is highest and it decreases with distance offshore. The high chlorophyll concentrations at the coast would have been preceded by an upwelling event, bringing nutrient-rich water up to the surface. The chlorophyll concentrations[2] at the coast are about 30mg.m^{-3}, while the values offshore range between 13mg.m^{-3} and 6mg.m^{-3}.



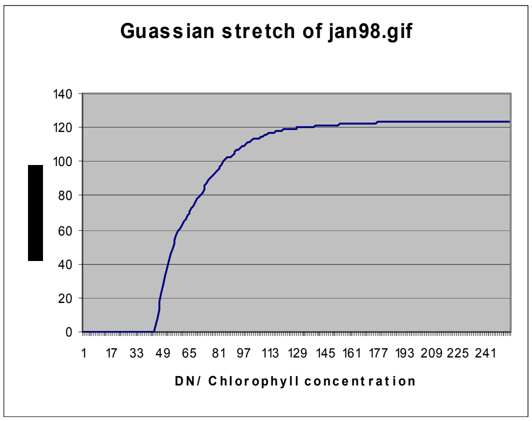
On the left is a transect of the chlorophyll concentration off Cape Agulhas. Although the values are higher (+- 23 mg.m^{-3}) at the coast than offshore, they are lower than the values off the west coast. The lower values could be due to the fact that there is less upwelling off Cape Agulhas. The high values observed there could be from the high concentrations on the west coast that have been advected south-eastwards. The chlorophyll concentrations are consistently low until a drop at about 35°S and a fairly sudden increase at about 47°S. This

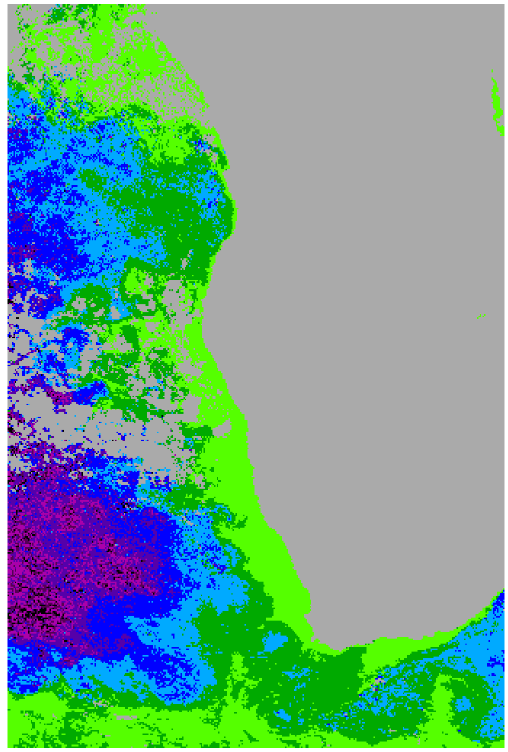
[2] The digital number is converted into an actual chlorophyll concentration by the following equation: Chl. Conc. = 10**(0.015*DN-2)

region of high variability could relate to the position of the Subtropical Convergance, the region between the colder Sub-Antarctic waters and the warmer Sub-tropical waters.

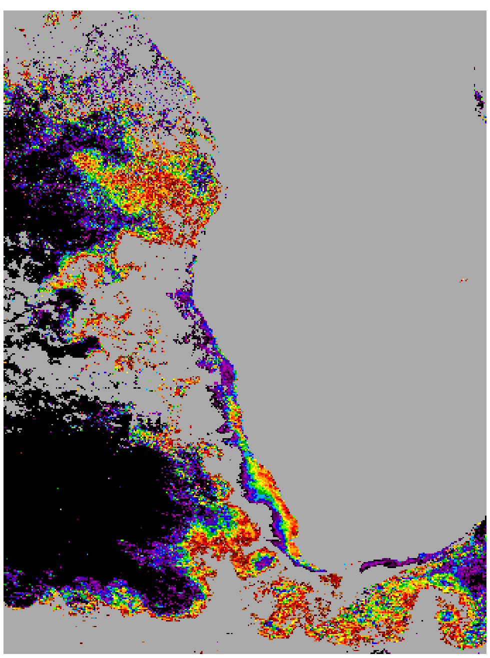
Gaussian Stretch

A Gaussian stretch (see below) was applied to the image. The results can be seen in the image on the right. No distinction is made between regions of intermediate to high chlorophyll and both are shown in green. A Gaussian stretch compresses the highest DN values into a very small range of pixel values and assigns the lower concentrations the full range of pixel values below this.

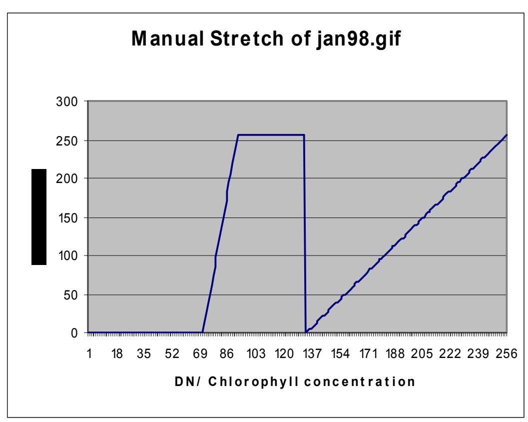




Enhancing the upwelling regions and the warm waters



A manual stretch was applied (see below) to the image in order to highlight certain regions (see image on the left) of interest such as the upwelling/ high chlorophyll regions and the warm waters of the Agulhas and Angolan currents.



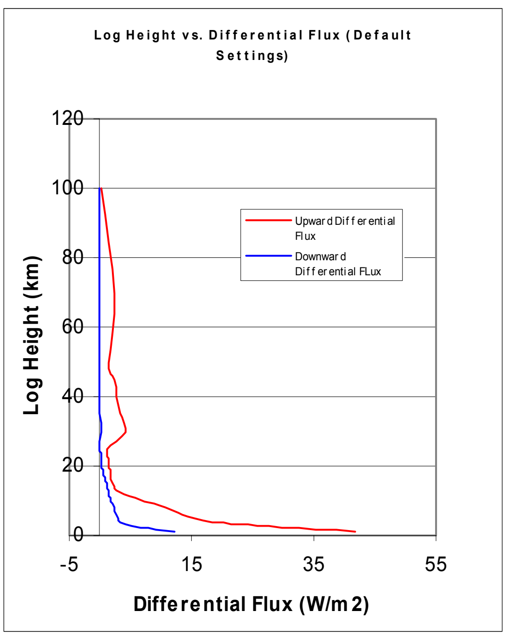
In order to enhance the upwelling regions/ regions of high chlorophyll, DN values ranging between 133 and the maximum value, 256, were ‘stretched’ to 0 and 255 respectively. The regions of highest chlorophyll concentration were thereby assigned the full colour scale, resulting in greater detail of the distribution of chlorophyll in these areas. The warmer waters tended to have an intermediate concentration of chlorophyll. In order to include only these areas and to ignore the major water mass offshore to the west, the stretch assigned all values that corresponded to the peak of the histogram (i.e. the most common chlorophyll concentrations) a value of 255. A very steep gradient was created on either side of the ‘peak of values’ to represent the warm water regions namely, the Agulhas and Angolan currents.

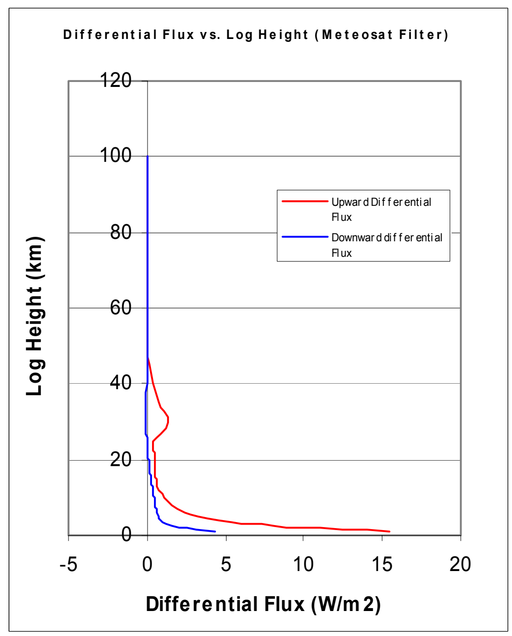
CHAPTER FIVE:
Atmospheric Remote Sensing

5.1 Investigating Radiative Transfer

The SBDART (Santa Barbera DISTORT Atmospheric Radiative Transfer) modelling program was used to investigate radiative transfer in the atmosphere. The model is capable of taking into account solar geometry, seasonal differences, aerosol factors, surface albedo characteristics, trace gasses and cloud parameters. It can be set to apply one of a number of filters characteristic of a particular viewing platform such as Meteosat.

Below are plots of the upward and downward differential fluxes versus log height for the default setting (left) and of the Meteosat filter results (right).



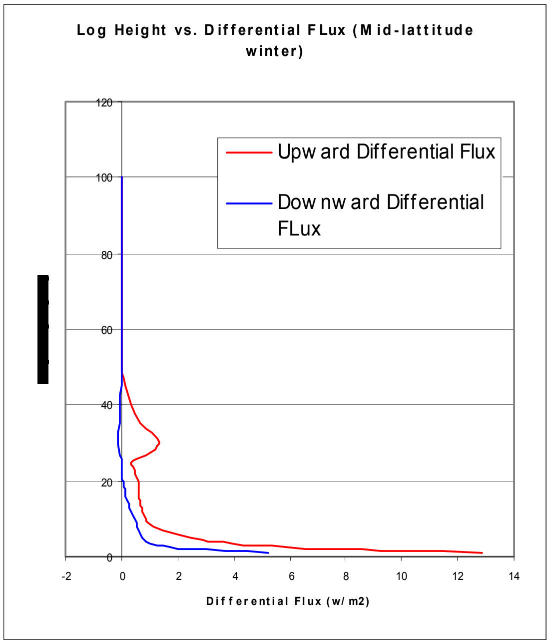


The profiles above show that the Meteosat satellite filters the upward radiation flux in such a way that it effectively ‘sees through’ the thermosphere and mesoshpere. It therefore, only sees atmospheric features up to an altitude of about 50km. The downward radiative flux has a similar profile after applying a Meteosat filter , but is slightly shallower.

Over the page are profiles of the upward and downward radiative fluxes for

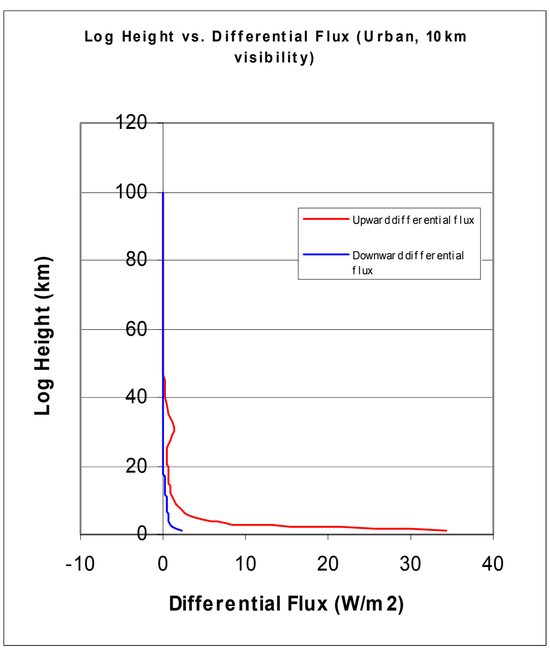
- Mid-lattitude winter seasonal profile.
- An aerosol model of an urban Area with a visibility of 10km
- An albedo model for sea water

Mid-lattitude Winter



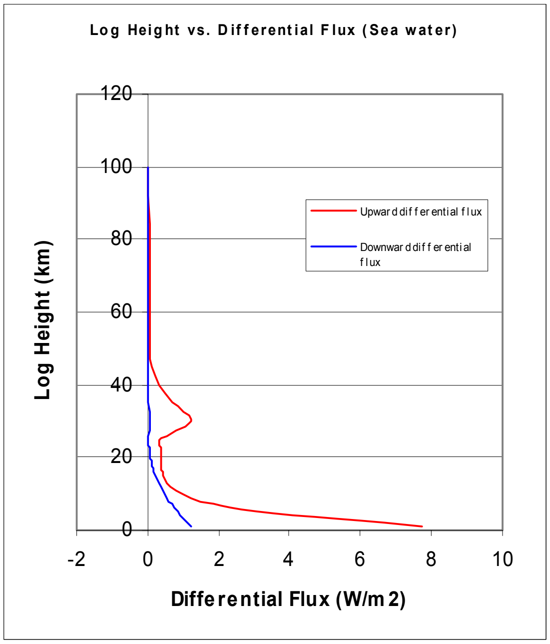
The profile on the right is for mid-lattitude winter, whereas the default setting was set as mid-lattitude summer. The seasonal differences are fairly evident. The upper atmosphere (50- 100km) has upward radiative fluxes of close to zero during winter (see figure on the left), whereas in summer the upward radiative fluxes are fairly significant in the upper atmosphere. This disparity is due to the fact that less heat is radiated from the Earth during winter than in summer. The profile of downward flux is similar is similar, but is characterized by lower values due to the fact that the sun is not directly overhead. Between an altitude of about 30km and 45km the downward flux is negative, but the upward flux peaks quite distinctly. This implies that the outgoing radiation exceeds the incoming solar radiation.

Aerosol Model of an Urban Environment with a visibility of 10km



The profile on the left shows the upward and downward radiative fluxes for a polluted urban area with a visibility of 10km. The upward differential flux is very high in the troposphere, but drops quite markedly above the troposphere. This is a result of the fact that the particles in the lower atmosphere (0-10km) absorb the longwave radiation emitted from the Earth. Above the polluted zone of the troposphere, the upward differential radiative flux drops suddenly because the long wave radiation is no longer trapped by pollution and is emitted. The downward radiative flux is lower in the troposhpere than it is for an unpolluted surface because the incoming solar radiation is hindered by the polluted zone.

Albedo Model of Sea Water.



The affect of the albedo of sea water is shown in the profile on the left. The downward radiative flux is relatively low. Although the sea receives as much direct sunlight as a polluted surface, it is a highly reflective surface so much of the direct sunlight is immediately reflected back into the atmosphere, ultimately lowering the downward radiative flux. Beacause of the reflection of solar radiation, the corresponding long- wave radiation emitted from the Earths surface is lower resulting in a particularly low upward radiation flux, lower even than the situation over land during mid-latitude winter

The distinct peak of upward radiative flux at an altitude of about 50km is common to all of the profiles. This corresponds to the temperature maximum at the base of the mesosphere.

Inversion of Fluxes and the Dependency on Radiative Transefer Parameters.

Remote sensing of the atmosphere is slightly more complex as the parameters of interest change markedly with altidude and it is the entire 3-D structure that is of interest to meteorology and forecasting. The vertical sructure of the atmosphere can be remotely sensed because of the wavelength dependance of the emmission of radiation from the Earths surface, clouds and layers in the atmosphere. Emitted radiation is a function of Planck's law and by intense absorption ovre narrow wavelength intervals due to absorption by gasses such as CO_2 and ozone and by water vapour.

Regions of extreme absorption, known as absorption bands, are key components of remote sounding of the atmosphere. Radiation measured by satellite in the centre of an absorption band where absorption is strong will be from the upper atmosphere. On the other hand, at wavelengths where absorption is weak, radiation in the lower atmosphere will be the greatest contribution. At wavelengths of moderate absorption, the upper atmosphere will appear transparent and the satellite will 'see' radiation in the middle troposphere instead.

The highly selective absorption (and re-emittance at characteristic temperatures) of gasses is therefore an integral component of atmospheric remote sensing. A gas such as CO_2, which is uniformly mixed through the atmosphere can be used to construct temperature profiles because of its re-emmission at known temperatures.

Radiative Transfer Equation

The transfer of radiation to space from the Earth- Atmosphere system can be written in terms of wavelength in the following equation:

$$I(v) = \varepsilon_v B_v(T_s)\tau_v(O\rho_s) + \int_o^{\rho s} B_v(T)W_v(\rho)\, dp/p$$

Where:

- $I(v)$ is the emission from the earth's surface at a given height,
- $\tau_v(O\rho_s)$ is the vertical transmittance from a given height to space,
- (T_s) is the vertical temperature profile,
- $B_v(T)$ is the corresponding Planck function profile,
- and $W_v(\rho)$ is the weighting function.

The equation describes the outgoing radiation as two terms, the first describes the spectral radiation emitted by the Earths surface and attenuated by the atmosphere. The term on the right is the spectral radiance emitted by the atmosphere and attenuated by the atmosphere above it.

Orbiting meteorological satellites using thermal infrared emission for atmospheric sounding make use of the inversion of the radiative transfer equation. The measured outgoing radiance is the sum of a surface term and an atmospheric emmission term.

The weighting function (W_v) in the equation is necessary to identify different amounts of radiance emitted at different layers of the atmosphere. In the infrared region of the spectrum, the weighting function is reduced to the vertical derivative of the atmospheric transmittance function. In the microwave region however, the weighting function is slightly complicated because of its reliance on emissivity.

Despite this complication, using microwaves for sensing non-raining clouds is preferable due to the relative transparency of non-rain clouds. The disadvantage of microwave remote sensing is that it results in a lower spatial resolution than the infrared sensors.

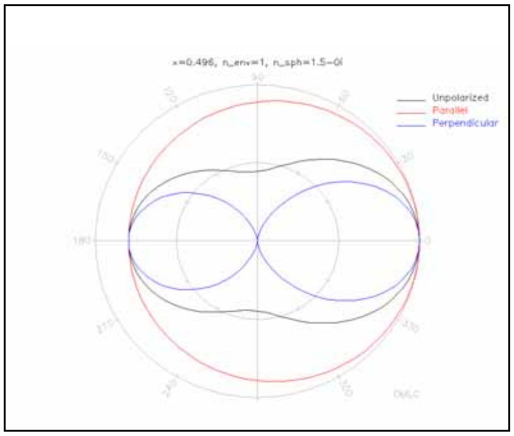
5.2 Investigating Scattering as a Function of Particle Size

Mie Scattering

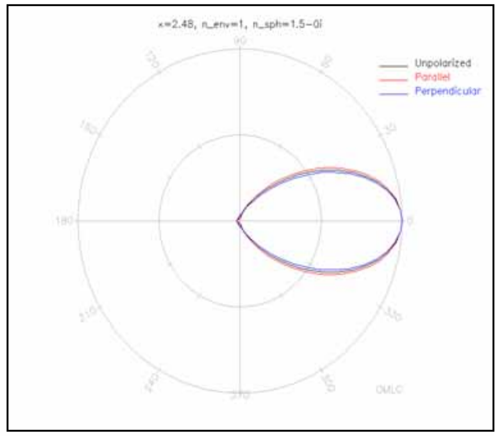
Mie scattering occurs when the radius of the scattering particles is of a similar size to the wavelength of incident radiation such as cloud droplets, dust and pollution particles. Mie scattering causes all wavelengths to be scattered therefore, resulting in a white- grey sky rather than blue. Mie scattering occurs primarily in the forward direction, but can be omnidirectional with smaller particle sizes. Mie scattering is significant to atmospheric remote sensing as it strongly affects what the satellite ‘sees’.

Over the page are plots of the direction and intensity of Mie scattering for particles of progressively larger radii.

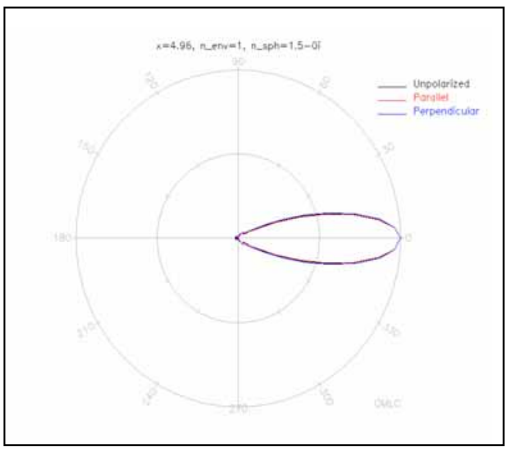
0.1 micron radii particle



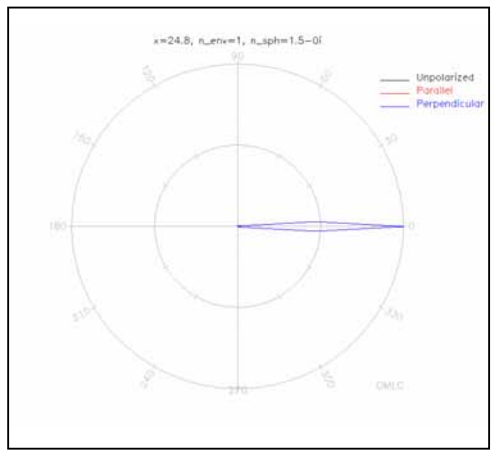
0.5 micron radii particle



1.0 micron radii particle



5.0 micron radii particle



The polar diagrams above show that the intesity of the scattered beam inceases in intensity as the particle size increases. An angle of 0° relates to scattering in the backward direction and an angle of 180° is scattering in the forward direction. A relatively small particle size (e.g. 0.1 micron) causes omnidirectional scattering, but most intensly in the forward and backward directions. As the particle size increadses, scattering occurs only in the backwards direction and becomes more intense.

Heavy rain clouds appear dark from the ground as much of the incident radiation from the sun is being refelcted directly back into the atmosphere. This is due to the fact that the droplet size in heavy rain clouds are quite large and, by virtue of Mie scattering, reflect radiation intensly and predominantly in the backwards direction.

The implications of Mie scattering on remote sensing is obvious. The satellite would see bright cloud as a result of the intense backscattering. This brighter the cloud, the larger the droplet sizes within it. From an understanding of the relationship between particle size and scattering, the droplet size and the liklihood of rain can be established. In order to ‘see’ through the intense backscattering of the cloud a number of wavelengths would have to be used. It is not only the large particle sizes within clouds that result in Mie scattering, pollution in cities and dust particles in desert regions would have the same effect.

Because Mie scattering occurs primarily in the backwards direction, it is a process that must be considered when making calculations of radiation transfer. Because Mie scattering causes solar radiaton entering the Earth-Atmosphere system to be effectively 'bounced' back into space, an inversion of radiation occurs. This radiation inversion needs to be considered for successful atmospheric sounding.

5.3 Investigating Profiling: Tropical Rainfall Measuring Mission (TRMM)

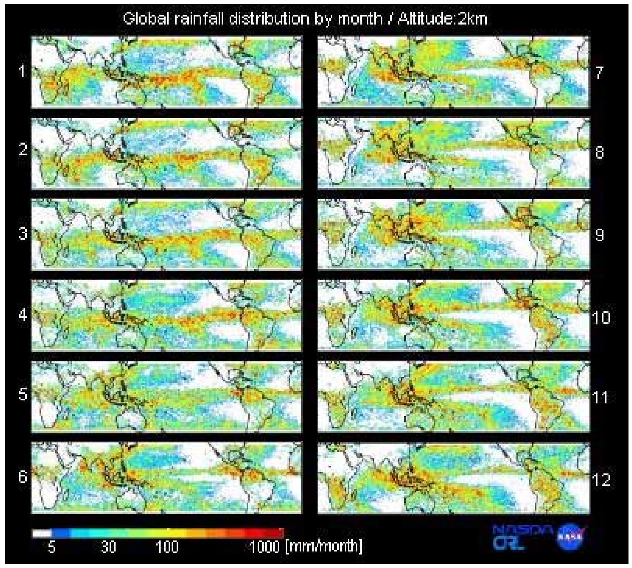
TRMM, the first satellite designed to monitor rainfall over the tropics, was launched in Tanegashima in Japan in 1997 and is a joint venture of the National Space Development Agency of Japan (NASDA), Communications Research Laboratory (CRL) and the Natioanl Aeronautics and Space Administraion (NASA). It is placed in low Earth orbit (350km) and fitted with the first precipitation radar (PR) to be flown in space as well as a 9-channel passive microwave imager (TMI), a visible- infrared radiometer (VIRS), a lightning and cloud sensor. The orbit ranges between 35°N and 35°S of the equator, allowing TRMM to fly over each position on the Earths surface at a different local time each day.

The precipitation radar (PR) measures the echo backscattered from rain. The strength of the echo is proportional to the square of the volume of falling water, allowing the PR to produce very accurate estimates of rainfall profiles. The vertical distribution of rainfall is therefore obtained by measuring the 'radar reflectivity' of the cloud system and the weakening of the signal as it passes through a rain cloud.

The microwave imager (TMI) is a multichannel radiometer whose signals in combination can measure rainfall quite accurately over oceans and slightly less accurately over land. TMI distinguishes the rain and ice by using its various channels.

The Visible Infrared Scanner (VIRS) measures radiance in five bandwidths from the visible through the infrared spectral regions. Infrared data are used to make rough estimates of total tropical rainfall.

Microwave sounding of rainfall is possible because of microwave emission from rain and the fact that it is significantly different for rain and oceans. For this reason, passive microwave measurements from satellites can be used to estimate rainfall rates, with particular success over the oceans. The satellite can pick out an electromagnetic signature from rain in a known background radiation from land or ocean. In the 10 to 50 GHz region, microwave emission can be refelcted from rain, but is transparent to non-raining clouds. Microwave sounding therefore provides a more direct method of rainfall measurement than visible or infrared methods, which rely on indirect relationships such as rainfall and cloud top heights.



Above is an example of a TRMM rainfall product. It is annual monthly rainfall from 35°N to 35°S.

5.4. Meteosat

The Meteosat system provides images of meteorological observations in three channels (visible, infrared and water vapour) from space every 30 minutes. It is an optical system with its telescope comprised of two moveable mirrors, one with an aperture of 400mm and the other with an aperture of 140mm). The image is produced line-by-line, east to west using the satellite rotation of a hundred revolutions per minute. The line scanned changes as a result of a step by step shift in the angle of the telescope. For the two channels most used for meteorological observations, namely the infrared and visible channels, a 5.5km resolution is achieved.

The first Meteosat satellite was launched in 1977 in Cape Canaveral and within 6 months reliable meteorological data was obtained. In May 1991, the Meteosat Transition Program (MTP) was initiated in order to phase out the existing Meteosat system and to replace it with the improved Meteosat Second Generation (MSG). The need for improvement is crucial, because the definition of the requirements and the performance of the existing Meteosat system dates back to technology of the 70's.

The MSG is due to be launched early in 2003 and aims at achieving more frequent and reliable data from space. It will serve the requirements of nowcasting and forecasting and will supply data for climate monitoring and research.

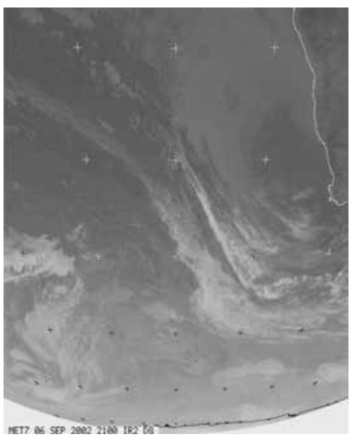
MSG contains the following improvements that will make it more useful to the end user than the existing system.

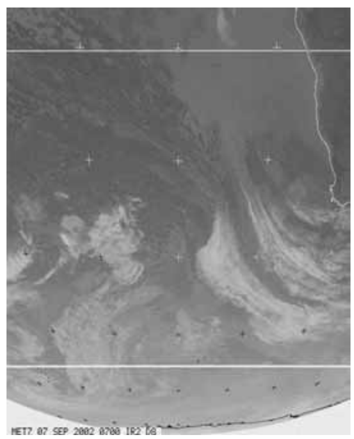
- It has 12 spectral channels as opposed to the 3 of the current system. This will provide more precise data.
- An improved periodicity of 15 minutes, giving rise to improved temporal resolution and more accurate forecasts of severe weather.
- Improved resolution: 1km vs. the 2.5km of the current system.

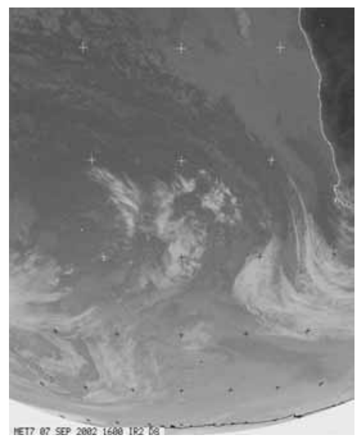
- It is fitted with an instrument called the Geostationary Earth Radiation Budget (GERB), which will provide important data for climate research.
- A Search and Rescue Transponder will relay distress signals from ships, aircraft and others.
- Digital transmission will improve performance and simplify maintenance.
- MSG will be in orbit for 7 years, 2 years longer than the former systems.

Below is a sequence of Meteosat infrared satellite images for 6 September 2002 at 21h00, 7 September 2002 at 7h00 and at 21h00. A double cold front is evident in all three images and moved eastwards fairly rapidly over the 24 hour period. From a visual analysis of the images below, the frontal system seems to have had an approximate eastward velocity of 1.3 m.s^{-1}.

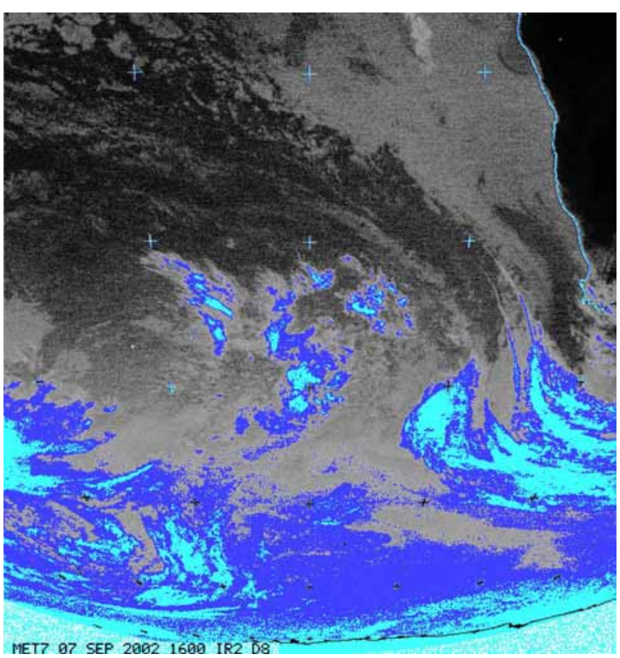
7 September 2002, 21h00 **8 September 2002, 07h00** **8 September 2002, 21h00**







Below is a false colour rendition of a Meteosat image for the 7 September 2002 at



16h00. It was created using Paintshop Pro. Firstly, an equalization stretch was applied in order to enhance the regions of cloud and to provide better all round contrasts. The 'replace colour' tool was used to replace very bright white regions, corresponding to rain clouds, with a light blue colour. The slightly less bright shade of grey/white was replaced with a dark blue and these regions correspond to cloud that is relatively high, but that has less water vapour than the clouds highlighted in light blue. The light blue colour also corresponds to clouds that extend fairly high into the atmosphere. The dark grey relates to extensive cloud cover that does not extend particularly high up in the atmosphere and does not contain a large amount of water vapour.