



5. PROCESSING OF THE REMOTELY SENSED DATA

All the data that were acquired by means of remote sensing such as the STS-DMSV images had to undergo specific and dedicated processing in order to be transformed into information layers and analysed within a Geographic Information and Database System

5.1. Image processing

The STS-DMSV is obviously best operated in cloudless conditions, and, in order to minimise illumination problems and maximise the spectral quality of the data, the best acquisition time ranges from two hours before to two hours after local noon and with an aircraft drift of less than seven degrees from the flight path (*Pinter et Al. 1987*). A number of parameters are taken into consideration to simulate the relative position of the plane with respect to the sun at any given time and account for the particular effects of sun angle on the image frames, especially the so-called 'Hot Spots'. These parameters are: day of year, solar declination angle, time, local standard time, local apparent time, zenith angle, azimuth angle, day length, and sunrise and sunset hours. (*Pinter et Al. 1987*)

However accurate the navigation and optimal the acquisition conditions, the images collected by the STS-DMSV sensor are affected by a number of disturbances and require pre-processing, radiometric correction and calibration. To do this, the images are imported in an 'image processing' software program ERDAS Imagine. This is done interactively for each frame. Usually all frames are imported, but only those falling within the limits of the target area are processed. Within the program, the images are geometrically corrected for projection distortions and georeferenced.

When the whole processing sequence has been accomplished, the resulting images can then be delivered as individual frames or can be mosaiced together to form a seamless overall 'picture' of the surveyed area. These processing phases are discussed in more detail in the following paragraphs.

5.1.1. Image pre-processing

The STS-DMSV system is based on a set of four separate digital video cameras and, accordingly, the data recorded are a combination of four separate video channels each representing a spectral band. These are: band 1, centred on the 0.45 μm wavelength recorded over a range 0.025 μm wide, band 2 centred around 0.55 μm , band 3 on 0.65 μm and finally band 4 (the near-infrared) at 0.75 μm .

In order to reassemble a homogeneous multi-spectral image, these bands require interlacing and alignment as well as the correction of flight influences such as linearity (alignment of the pixels) and pixel movement (pincushion effect¹⁴) caused by the shape of the lenses. Correction procedures for electronic noise sources, camera view angle and other environmental effects, are also needed in the pre-processing phase. A batch file that corrects each line that was flown drives the pre-processing operation and a specific program for the 'Cosine Lens Distortion' was implemented specifically for the STS-DMSV operations at the ARC-ISCW.

5.1.2. Radiometric corrections

The position of the camera and that of the platform, in terms of height above ground, geographical co-ordinates and direction of flight, influences the STS-DMSV data. This, combined with the sun angle, the time of acquisition, the illumination conditions and the topography of the ground being targeted, have significant effects on the image quality (*Pinter et Al. 1987*). A very immediate demonstration of these effects is the fact that most images have a colour difference in the overlapping area due to the different 'look-angle' at the same area. Radiometric corrections address all the anomalies and the distortions caused by these conditions.

The video of the STS-DMSV has an aperture setting that is adjusted at the beginning of every flight according to the level of illumination available

¹⁴ **Pincushion effect:** Lens aberration (distortion) causing parallel, straight lines at the edge of the image to curve inwards.

from sunlight and the brightness required for the characteristics of a specific target. The adjustment modifies the amount of light that hits the CCD array to make the picture.

If illumination conditions change in the course of the flight (common occurrence) and whenever images of the same target, but from a different acquisition date, need to be compared, the brightness conditions of the images themselves need to be equalised. This is necessary as the differing illumination may mask actual differences of the conditions and status of the target. Several solutions to this problem are possible but the so-called process of 'histogram matching' is the most direct, (*Pinter et Al. 1987*). This procedure is based on the fact that images can be represented as a distribution of pixels over a range of 256 colours, forming a histogram.

'Histogram matching,' means balancing the range of colour levels across the images that have to be compared, to a common variation range. However, in altering the histograms of images, some of the spectral resolution may be lost, and in addition, there can be 'flooding' or, the opposite, 'under-exposure' of the images.

Flooding occurs when there is a distortion towards values in the highest range (255), implying that there could be higher values but these cannot be represented. The phenomenon of 'under exposure' results in the presence of many pixels with values near to or at 0 on the histogram and can take place in parts of the same frame or across the whole series of frame belonging to the same flight. Also this implies a loss of information.

These problems become more complex in the case where frames have actual peaks on the histograms caused by objects that either absorb (peaks near to 0), or reflect a lot of radiation (peaks near to 255).

All these occurrences demand that the histogram matching process be conducted in a recursive manner to achieve the best possible compromise

between 'readability' and 'comparability' of the image frames.

Other radiometric disturbances may occur due to topography of the surface, causing the so-called 'hot spots' on the images, which are areas (usually of round shape) of intense brightness caused by the convergence of reflected light on the lenses. These can become significant if the direction of flight is not planned according to the sun angle, trying to keep, as far as possible, a high angle of incidence between the source of the illumination (the sun), the target and the lenses. These problems are common to all airborne imaging sensors that operate in daytime. However, for digital systems, which produce images with greater contrast than analog systems, these problems are more severe.

Specific formulas and procedures are available to address these problems (*Sabins, Jr., 1978*). These formulas were transferred into code for the removal of the effects of sun angle and hot spots from the frames. The technical staff in charge of pre-processing carried out this programming work. The whole pre-processing program is structured as a batch procedure that is routinely applied for each and every image acquisition of the STS-DMSV.

5.1.3. Calibration

The images of the STS-DMSV are, as the name suggests, digital. They are composed of a grid of cells (pixels), each of which is characterized by a numeric value. The number characterizing the single pixel, however, is just an indirect indication of the amount of reflected radiation hitting the cell of the CCD array. In order to convert these numbers into radiance¹⁵ values, the image needs to be calibrated. A dedicated calibration would have required the setting up of a ground-truthing procedure based on the use of targets of known reflectance¹⁶. The nature and requirements of the present project did

¹⁵ **Radiance:** A measure of the amount of radiant energy emitted or received per unit area of a surface over a specified time.

¹⁶ **Reflectance:** Ratio of the radiant energy reflected by a body to the energy incident on it. Spectral reflectance is the reflectance measured within a specific wavelength interval

not necessitate for such activity and so, this transformation was conducted according to pre-defined conversion tables provided by the sensor manufacturer.

5.1.4. Geometric correction

Having completed the pre-processing phase, the radiometric processing and the calibration procedures, the STS-DMSV images are imported to an image processing software package (ERDAS-Imagine®, in the case of this project). Usually all the frames are imported, but only those falling within the boundaries of the target area, as defined by a vector block, are processed.

The single frames are georeferenced to a topographic base. This base is provided by the digital ortho-photo of the target area or by a topographic digital map of adequate scale. The ortho-photos of the target area were acquired from the Kleinkopje Mine offices; they were scanned and imported into the image processing software together with the raw STS-DMSV images.

The process consists of comparing common features on each image to a set of ortho-photos. Up to 12 ground-control-points on each image are placed on common features in each of the photos. Each ground control point is programmed with a map value that corresponds to the real position on the ground.

The relative size of the STS-DMSV frames compared to the ortho-photos is very small and to place the first frame on the ortho-photo can take up to four hours. Thereafter it takes between 6 and 25 minutes to geographically reference a single frame. (*Sabins, Jr., 1978*)

Georeferencing is completed by the process of mosaicing and map composition, this consists of assembling the single frames to create the full seamless picture of the target area.



5.2. Image enhancement

Image enhancement is the process of making an image more interpretable for a particular application. Enhancement can make important features of digital images and aerial photographs, more comprehensible to the human eye. Enhancement techniques are often used for extracting useful information from images. This information can be contained either within the individual bands or in a combination of bands.

There are many enhancement techniques available. They can range from a simple contrast stretch, where the original values are stretched to fit the range of the display device, to a principal component analysis, where the number of bands is either reduced and new bands are created to account for most of the variance in the data (*Sabins, F. Jr., 1978*). A combined use of all four bands is usually performed through a 'classification' process. Image processing allows further analyses through the identification and enhancement of geometric features such as specific shapes or patterns, which may identify anomalies in plant health, irrigation or other characteristics (*Sabins, F. Jr., 1978*).

Images can only be viewed on a computer screen or on a print, using the three primary colours (red, blue and green) and for this reason, two visual reference images are usually produced:

- True Colour - A combination of band 3 (0.65 μm) as red, band 2 (0.55 μm) as green and band 1 (0.45 μm) as blue. These images appear as natural colour.
- False Colour Infrared - A combination of band 4 (0.75 μm) as red, band 3 (0.65 μm) as green and band 2 (0.55 μm) as blue. As vegetation appears very bright in the 'NIR' range (0.75 μm), these images highlight healthy vegetation in the image.

Other enhancements can be achieved by combining data sets of the same area acquired on different dates (but at similar solar angles). Each image can be precisely registered at the time of mosaicing and apply simple image

(pixel for pixel) subtractions to gain difference images that show areas of change and, over time, show vegetation trends and cycles.

For the requirements of this study, a number of 'True' and 'False Colour' compositions were produced. See Fig. 13 and 14.

Fig. 13: False colour composite of Major (left) and Tweefontein (right) Pivots, February 1999.

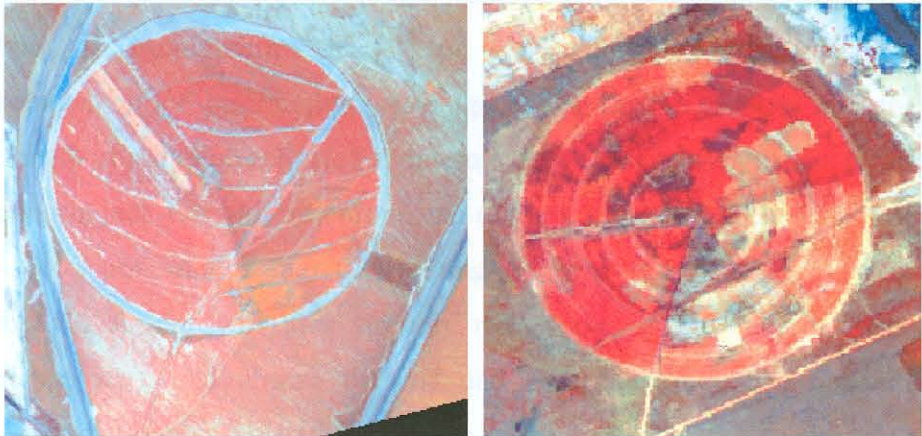
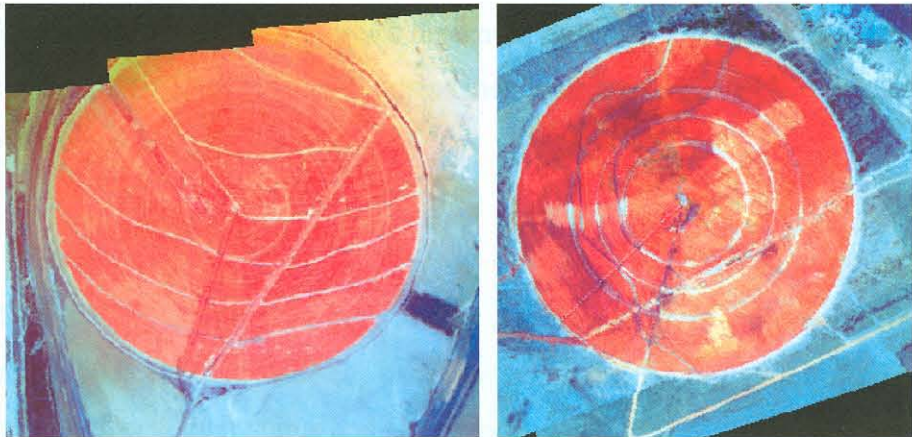


Fig. 14: False colour composite of Major (left) and Tweefontein (right) Pivots, September 1999.



5.2.1. Band values

The selection of the band frequency centres for the STS-DMSV cameras was guided by the general rule provided by the reflectance curve of green vegetation. The scope of this set-up is to use each band as an independent gauging tool in a determined fraction of the electromagnetic spectrum.

From the diagram, in Fig. 4, one can easily see that, for a common feature, the four bands measure the reflectance responses in different portions of the spectrum. In simple terms, each band carries in itself a specific and autonomous bit of information. As a general rule, the amount and the wavelength of radiation reflected is determined by the physical nature of the reflecting object. For vegetation one can observe a dip in the curve around $0.4 - 0.45 \mu\text{m}$, this is due to a strong electromagnetic absorbance by chlorophyll. A leaf will thus strongly reflect the 'green radiation' (the colour we see), and absorb the red and blue radiation. The opposite phenomenon is observable in the near-infrared portion of the spectrum ($> 0.7 \mu\text{m}$), where most radiation is reflected ($> 50\%$) and the rest absorbed as a direct function of the moisture contained in the biomass, (Guyot, 1990). Temperature levels in the leaves are measured by much higher frequencies, in the order of $10-12 \mu\text{m}$, however these measurements can also be referred to moisture contents (Guyot, 1990).

5.2.2. Vegetation indices

The STS-DMSV bands can be variably combined to produce specific vegetation indices that can be used to highlight subtle variations in vegetated surfaces, their status and abundance. A wide array of indices have been tested and studied, ever since Multi-Spectral imaging has been applied to vegetation studies and the most widely used combine the visible red and near-infrared bands, (Jackson and Heute, 1991).

The principle behind such vegetation indices is that the levels of visible red and near-infrared radiation reflected by a vegetation canopy, is related to

photosynthetic activity. Photosynthesis is itself a function of chlorophyll contents and moisture availability in the canopy, the greener and wetter the canopy, the healthier and more abundant the vegetation.

As stated in the previous chapter, chlorophyll absorbs red radiation (while reflecting green), so the lower the level of red reflectance the higher the overall chlorophyll contents. At the same time, water reflects the most part of the near-infrared radiation, thus indicating moisture contents in the canopy. So the combination of low reflectance in the visible red and high in the near infrared is indicative of high chlorophyll contents and high moisture contents, consequently emphasizing high photosynthetic activity and thus healthy vegetation. On the same basis, vegetation indices can be related to biomass and to LAI.

Indices can vary significantly in terms of complexity and sophistication. The selection of the most appropriate index, however, is strongly dependent on the type of vegetation cover, its density and also the scope of the analysis. In the present study, the TVI (Transformed Vegetation Index) (Deering *et al.* 1975) was used:

$$TVI = \sqrt{\left(\frac{B4 - B3}{B4 + B3}\right) + 0.5}$$

Where:

B4: Radiance of Band 4 (NIR, 0.75 μm)

B3: Radiance of Band 3 (Visible red, 0.65 μm)

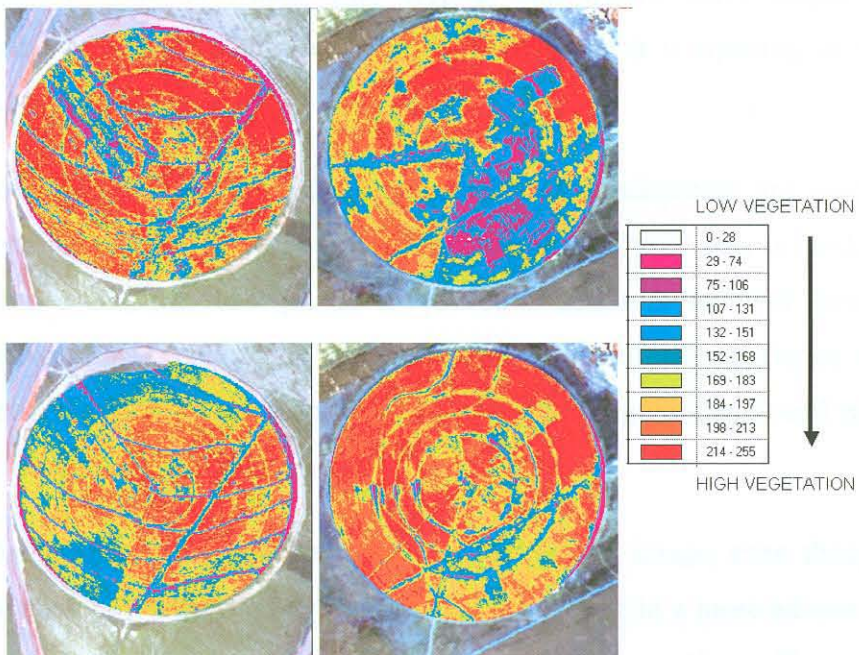
The TVI is derived from the commonly used NDVI (Normalised Differences Vegetation Index) (Rouse *et al.* 1974):

$$NDVI = \left(\frac{B4 - B3}{B4 + B3}\right)$$

The NDVI has the ability to minimize topographic effects while producing

a linear measurement scale. This measurement scale ranges from -1 to 1 with 0 representing the approximate value of no vegetation; thus negative values represent non-vegetated surfaces. The TVI modifies the NDVI by adding an empirical constant of 0.5 and taking the square root of the results. The constant 0.5 is introduced in order to avoid operating with negative NDVI values. The square root is intended to correct NDVI values that approximate a Poisson distribution¹⁷ and introduce a normal distribution. The TVI vegetation index was applied to the Multi-Spectral images of the Major and Tweefontein pivots collected in the course of the third and fourth flights. These enhancements are shown in Fig. 15 for the February 1999 and September 1999 flights. The index enhancement was applied to the round surface of the pivots only. For image editing purposes, these enhancements were subsequently re-applied over a common background chosen from the February 1999 flight. This is true for all the images shown in the rest of this document.

Fig. 15: Vegetation Index maps of Major (left) and Tweefontein (right) pivots, during the second (top) (February 1999) and third flight (bottom) (September 1999).



¹⁷ The **Poisson Distribution** is a probability distribution that represents the number of random events occurring over a fixed period of time

The TVI ranges between 0 and 1, and when these values need to be represented in graphical form, the colour resolution permitted by 8 bit computers ranges between 0 and 255. A grey scale could well represent this range, but 255 levels of thematic detail would be difficult to grasp by the human eye and even more difficult to interpret.

Conventionally the '0-255' range is grouped in equal intervals, the number of which is at the discretion of the analyst or is a function of the variability of the index on the image itself. The range can also be divided as a function of the standard deviation from average or even with a specific clustering.

In the figure above (Fig. 15) the range has been divided in 10 equal intervals and the colours assigned to each interval ranges from magenta to red. Magenta represents the lowest levels of the index and consequently the lowest levels of vegetation activity. On the opposite side of the range, red represents the highest levels of vegetation activity.

The change in the condition of the vegetation cover can be clearly seen in these pictures where we are looking at two different stages of the phenological cycle of wheat. The crop is still in the early stages of development in the first image (August 1999) while it is ripening in the September scene.

Some obvious differences in the homogeneity of development are visible over both pivots. For Major, a general decline in the "red" area is evident which is probably the consequence of reduced irrigation in the outer sectors of the pivot. For Tweefontein, there is a marked overall irregularity in the development pattern of the crop that may be due to irregularities in soil type or soil compaction.

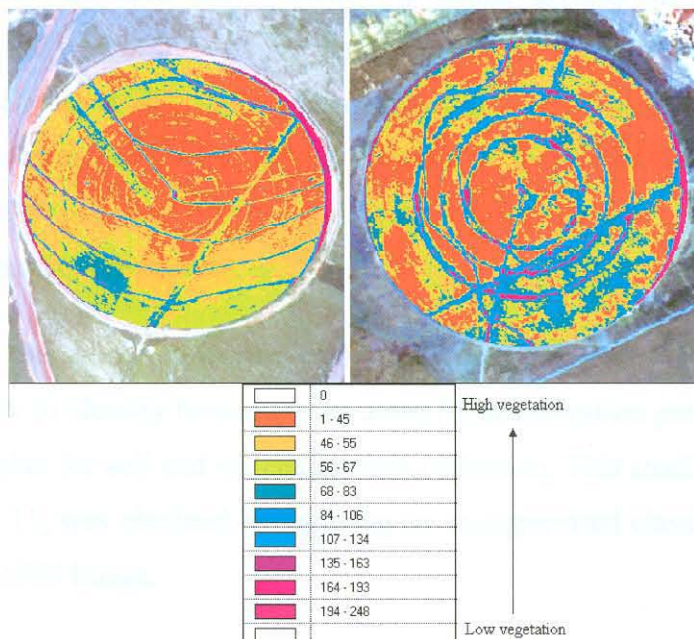
These irregularities are also very clear in the August image, even though they are somehow mitigated by the fact that the crop is in a more advanced phase of development, and probably by the compensating effects of irrigation.

5.2.3. Principal components

The Principal Component Analysis (PCA) is a transformation technique of an n-dimensional image (e.g. Multi-Spectral image) that produces a new set of images (components, or bands in our case) that are uncorrelated with one another and ordered with respect to the amount of variation they represent from the original image set. PCA is typically used to uncover the underlying dimensionality of multi-variate data by removing redundancy. In the context of remotely sensed images, the first component typically represents albedo, while the second component most often represents variation in vegetation cover. For example, component 2 has positive loadings on the near-infrared bands and negative loading on the visible bands. As a result, the green vegetation pattern is highlighted in this component (*Erdas Field Guide, 1997, Fung and Le Drew, 1987*).

As a direct consequence of this, the PCA enhancement was tested in the course of the study as a potential alternative to the Vegetation Index. This can be seen in Fig. 16.

Fig. 16: Principal component maps of Major (left) and Tweefontein (right) pivots for the third flight (September 1999)



Also the first principal component is represented here in the 0 to 255 range of values, grouped in 10 equal intervals. Because the lower levels of the PC1 (First principal component) account for vegetation in better conditions, the scale is reversed with respect to the TVI. Red, whilst representing vegetation in better condition, is placed at the beginning of the scale and magenta at the bottom. The information provided, however, is totally comparable to the one that can be seen in Figure 15.

5.2.4. Classification

The classification process uses the spectral information represented by the digital data in one or more of the bands, and attempts to identify as a specific ‘thematic class’ each individual pixel based on this spectral information. Multi-Spectral classification is the process of sorting pixels into a finite number of classes, or categories of data, based on their data values. If a pixel satisfies certain set criteria, it is assigned to the class that corresponds to those criteria. This process is also referred to as image segmentation.

Classifications can either be supervised, where training sites are provided, or unsupervised where spectral classes are grouped first, based solely on their value, and are then later matched to actual ground information. Depending on the type of information that the user wants to extract from the original data, classes may be associated with known features on the ground, or may simply represent areas that look different to the eye of the analyst. An example of a classified image is a land cover map, showing vegetation, barren land, pasture, urban areas, etc.

In this study, the most noteworthy example of ‘classification’ is the one applied in order to identify homogeneous areas for stratification purposes in the sampling plan for soil and vegetation data collection. This stratification, shown in Fig. 11, was obtained by applying an un-supervised classification to the August 1999 image.