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USING LANDSAT 5 TM DATA TO INVESTIGATE FLOOD PHENOMENA

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13. ABSTRACT (*Maximum 200 words*)

This report was written based on a demonstrative analysis performed to describe to a potential user some digital processing techniques that may be applied to Landsat TM data to yield useful information regarding flood phenomena. Several techniques, such as linear data transformations, spectral ratio combinations, and density slicing may be employed individually or collectively to provide highly correlated spectral information.

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1.0 Introduction

Digital satellite data, such as Landsat 5 TM, can be extremely helpful in assessing disaster phenomena over large areas. They offer repetitive coverage which is transmitted as microwave signals to ground stations that receive and then process the data for dissemination in digital image formats to the EROS Data Center (EDC) (see Figure 1.1).

The land observation satellite number five (Landsat 5) carries a Thematic Mapper (TM), which is actually an improved version of the multispectral scanner (MSS), which was launched on the first Landsat systems (see Figure 1.2). TM is an earth-observation, across-track scanner, modeled heavily from MSS technology. The TM provides improved spatial resolution of 30-m for all bands, except band 6 (thermal-IR) which has 120-m resolution. It provides a greater detail of spectral information through the addition of four new spectral bands. Added bands include blue-green (0.45 - 0.52 µm), mid-IR (1.55 - 1.75 µm), thermal-IR (10.40 - 12.50 µm) and mid-IR (2.081 - 2.35 µm). The Landsat 5 platform was upgraded for improved geometric and positional accuracy.

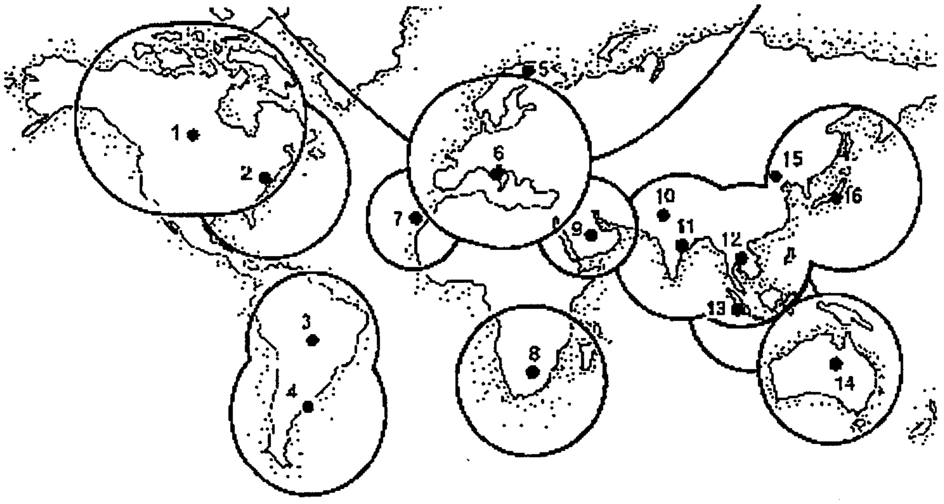

FIGURE 1. 1 Landsat Ground Stations. Each Circle Shows the Approximate Range for Direct Communications With the Satellite.

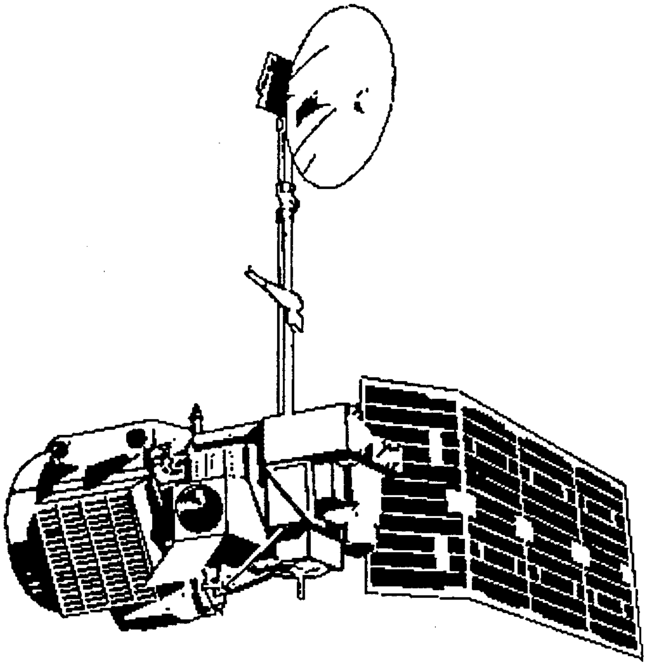

FIGURE 1. 2 Platform for Landsats 4 and 5. Diagram Based Upon Landsat *Data Users Notes*, No. 23, July 1982, p. 3.

2.0 Orbit and Earth Coverage

Landsats 4 and 5 were designed to travel in a sun-synchronous orbit which brings them over the equator at approximately 9:30 - 9:45 am (depending on ground location with respect to the equator; that is, north or south). This orbit was chosen to maintain similar integrity of solar illumination with imagery from the earlier satellites. Sun-synchronous orbits are designed to orient the plane of the satellite orbit in a position that maintains a consistent relationship with the solar time (see Figure 2.1).

The satellite track runs westward at ~15° of longitude each hour matching the rate of the earth's rotation with the solar beam. The satellite is propelled on this track by the earth's mass and rotation and passes over a fixed point on the ground at a constant local time. Sun-synchronous orbits produce similar seasonal illumination and shadowing of specific areas. This simplifies the spectral analysis and interpretation of the imagery. Landsats 4 and 5 have a lowered orbital altitude relative to all previous Landsats, of 705 km, which accounts for their finer spatial resolution.

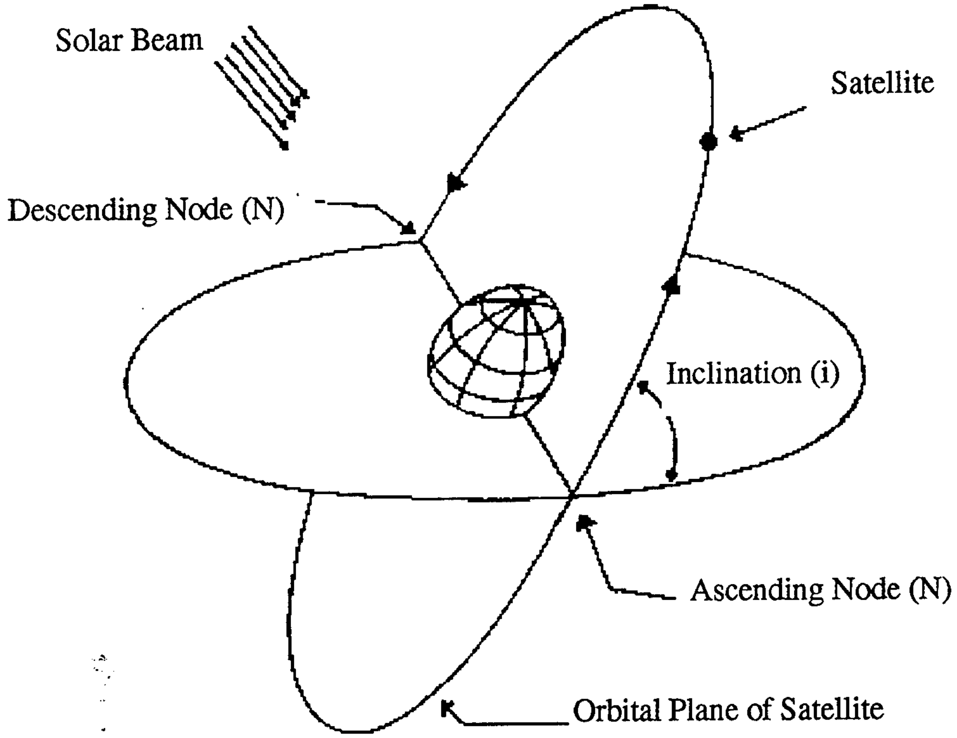

FIGURE 2.1 Inclination of Satellite Orbit (i). The nodes (N) are the points where the orbit crosses the equator. Here the ascending (south-to-north) track is shown.

The swath width of Landsat 5 is 185 km and its along-track length is 170 km. It collects coverage of adjacent swaths every seven days. Sequential passes are spaced at 2,752 km at the equator. The gaps between these passes are filled over a 16-day period. An entire image cycle is completed in 16 days or 233 orbits (see Figure 2.2). It is this collection cycle that is a major contributor to the untimeliness of gathering repeat coverage, required for disaster assessment.

3.0 Data Output

The TM device is a scanner, scanning in both directions normal to the ground track. A 16-element detector array is used for achieving 30-m resolution for bands 1-5 and 7, and a 4-detector array is used for the thermal-IR band to achieve 120-m resolution. As a result, each scan of the TM mirror generates 16 lines of data for bands 1-5 and 7, and 4 lines of data for band 6. The detectors are positioned in an array in a focal plane. Because of this positioning, the bands may be misaligned or misregistered slightly. These inaccuracies can be corrected with additional image processing that changes the geopositions of pixels to form a geometrically accurate image.

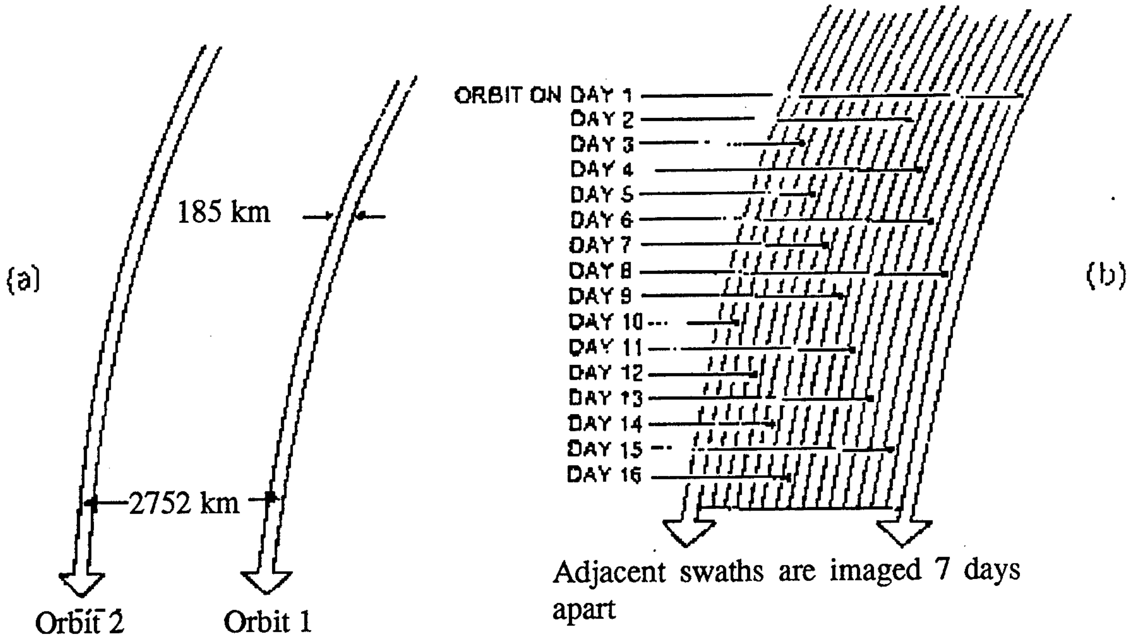

FIGURE 2.2 Coverage for Landsat 4 and 5. (a) Successive passes are spaced at 2,752 km at the equator. (b) Gaps between successive passes are filled in over a 16-day interval (based upon NASA diagram).

4.0 Significance of Spectral Bands

TM simultaneously records radiation responses in seven spectral bands (see Table 1.0). The seven bands, as well as the pixels (finer resolution) equate to an exceedingly large image for the analyst. A typical image consists of all seven bands which form a single scene, an estimated 250,000,000 pixels. It is best that the analyst narrow the scope of the analysis and choose only those TM bands that exhibit spectral information typical to the type of subject investigation under study. It would also be prudent for the analyst to choose a subset image from the overall TM scene, if possible. This will further narrow the amount of data required for adequate analysis.

TABLE 1. 0 Sensitivity Ranges of Landsat 5 TM

Band	Wavelength Region (μm)	Spectral Region	Spatial Resolution	Specific Sensitivity
1	0.45 -0.52	Blue-green	$(30)^2$	separate soil and vegetation
2	0.52 -0.60	Green	$(30)^2$	vegetation reflectivity
3	0.63 - 0.69	Red	$(30)^2$	chlorophyll absorption
4	0.76 - 0.90	Near - IR	$(30)^2$	delineation of water bodies
5	1.55 - 1.75	Mid - IR	$(30)^2$	vegetation moisture
6	10.40 - 12.50	Thermal IR	$(120)^2$	hydrothermal mapping
7	2.08 - 2.35	Mid IR	$(30)^2$	heat stress on vegetation

* Band 7 was added after band 6 during TM system design

These seven spectral bands are more narrowly defined so that each one relates to a specific surface spectral response. This design decreases the number of bands the interpreter will require for analysis.

5.0 TM Data and Flood Phenomena

For monitoring damage, some reference data is needed as a way of establishing conditions prior to the damage. Data collected after damage occurs is also needed as a way of assessing post-damage conditions. When these conditions are compared, damage can be assessed.

After these data sets are geographically co-registered, information concerning damage can be extracted in a variety of ways. One way to extract information is by the utilization of "spectral features" that give information about certain kinds of terrain features. Some of these may already have been developed (e.g., for vegetation indices, or tasseled cap features). Other spectral features might have to be developed for particular types of information.

5.1 Vegetation Indices

Vegetation indices are quantitative measures, based upon digital values that attempt to measure biomass or vegetation vigor (Campbell 1987). Vegetation indices come in several forms, from the very simple to the most complex. Normally, a vegetation index is created through mathematical manipulation (i.e., for addition, multiplication, division) of combined spectral bands, to produce a single value that will represent the amount of vegetation vigor within a single pixel. Consequently, a high index value represents healthy, living vegetation, and a lower index value represents low amounts of vigor in healthy vegetation.

The most common and least complex form of a vegetation index is found in band ratios. A band ratio is merely the value of a pixel, which was found by dividing two digital values, each from a separate spectral band. It is most important to remember that this ratio must be found by using two spectral bands whose reflectance measures reside in different locations of the visible spectrum.

Before using/creating a vegetation index, much should be known about the reflection and absorption properties of the targeted vegetation, as well as the atmospheric effects that may have altered the digital values in the original image. Preprocessing may remove some of these errors, but may also introduce new ones. Band ratios should be calculated using true values only. The commonly used vegetation index, and the one used in this analysis is called a *Normalized Difference Index.*

5.2 Tasseled Cap Features

The *Tasseled Cap Transformation* is a linear transformation of Landsat MSS or TM data that projects soil and vegetation information into a single plane in a multispectral data space - a plane in which the major spectral components of an agricultural scene are displayed in two dimensions (Kauth et al. 1976). The transformation consists of linear combinations of four bands, which can be applied to as many bands as are available. This transformation was originally developed for multispectral scanner data (MSS), but has been extended to Thematic Mapper (TM) data by researchers at ERIM.

The definition of the four new variables/bands for TM Tasseled Cap features are:
Tasseled Cap 1 (TC1) - Brightness
Tasseled Cap 2 (TC2) - Greenness
Tasseled Cap 3 (TC3) - Wetness
Tasseled Cap 4 (TC4) - No haze or undefined
*TC4 varies with the number of data types, and type of analysis.

Tasseled caps in general allow the analyst to examine agricultural scenes in a more scientific and in-depth manner. The transformation also allows the analyst to view the major spectral components of an agricultural image in a two-dimensional plot.

6.0 Panel 1, Four Up Composite

Certain criteria exist for the analysis of a natural disaster. The more ephemeral and the shorter the duration of a natural disaster event, the closer the temporal interval should be for damage assessment. For example, data acquisitions as close as possible to the event (before and after) are best. For longer-term events such as an entire flood season, a time series approach and associated caveats may be appropriate. These types of series are typically used for long-term monitoring of pollution and global change, facilitated by the use of anniversary dates to aid in normalization and trend analysis.

This panel (see Figure 6.1) of images shows some of the original data and selected spectral features created from this data which were subsequently used to generate the information concerning flood damage. The area shown is approximately 25 km x 25 km.

The bottom two panels show spectral features that indicate standing water on each of the two dates. This information comes from the short-wave infrared (SWIR) bands of the TM data which have sensitivity to water absorbing. Therefore, standing water areas appear dark in the two images. By level slicing these spectral features, a binary image showing water and non-water areas can be developed (not apparent in Panel 1).

6.1 Feature Extraction

Feature Extraction is one of several preprocessing operations that occur prior to the primary analysis. Feature extraction will help improve image quality for later analysis. Features in remotely sensed data cannot be visually identified. They are the statistical characteristics/components within multispectral data that are most useful for isolating specific items of interest.

A very common approach to feature selection searches for duplicated values within a correlation matrix. The analyst identifies high-correlation areas across bands and then discards one or more (in case of TM) of each duplication, thus reducing the number of bands required for analysis.

This analysis involved a more complex feature extraction method, called *Principal Components Analysis*. This method involves a process which calculates optimum coefficient values that will provide maximum variation in a single band of data. In general, feature selection using principal components analysis allows us to find sets of coefficients to be used in linear combination, to concentrate maximum information into a single TM band.

In summary, feature extraction was originally developed for Landsat 4 (MSS) analysis, but has regained significant use by TM data users. Feature extraction reduces the size of the data set required for analysis and can increase the speed of the analysis, which infers reducing the overall cost as well.

6.2 Level Slicing

A single band of digital data, in this case TM (any one of seven bands), is displayed as a continuous range of brightness values. White represents the highest digital values and black represents the lowest digital values. In between these extremes are many shades of gray. All gray and white levels represent objects that have some degree of reflectance.

Level slicing assigns a color to a certain range of DN values. These colors should ultimately produce a natural representation of color (i.e., maybe grass = green, H_2O = blue), so that the scene content appears normal. Sometimes odd colors may be chosen to promote an item of interest in the image.

7.0 Panel 2, Flood Extent

The area that was flooded in 1993 is assumed to be the area which was covered with water in 1993, but which was not covered with water in 1986. This area was determined by comparing a binary water mask from each date. The resulting "flood mask" can then be displayed in a background image for context (see Figure 7.1). This panel shows the flood mask overlaid on a natural color image, and color coded red. A natural color composite can be made by projecting bands 1, 2, and 3 positive images through blue, green, and red light respectively. Note that the pre-existing river channels are not shown as flooded.

The total amount of flood area can be assessed by calculating the area indicated by the flood mask. For the area shown in red, 20,577 ha were flooded. That number is representative of approximately 31.4 percent of the total image area shown.

8.0 Panel 3, Flooded Cultural Features

The human-made features that are flooded can be located by judicious comparison of spectral features from both dates (see Figure 8.1). For this panel three spectral features were used; 1) a water spectral feature from 1986, 2) a human-made spectral feature from the first date, and 3) a water spectral feature from the second date. The human-made spectral feature used was "Tasseled Cap" feature number four, which has previously been found to be somewhat effective at showing human-made features such as roads, parking lots, and buildings. The water features used are shown in Panel 1 and Panel 2.

These three images were used to prepare a three-band color composite. The water features from the first and second dates were color-coded blue and green respectively. The human-made feature was color-coded red. Colors in the resultant image can be interpreted as follows:

Dark blue - areas that are flooded

Magenta- roads and parking lots that have been flooded

White - areas surrounded by blue and/or magenta are flooded buildings (i.e., roofs above water levels)

9.0 Panel 4, Flooded Agriculture

The agricultural land that was flooded can be located by judicious analysis of spectral features from both dates (see Figure 9.1). For this panel, the cultivated agricultural land from the first date was selected using the Tasseled Cap "Greenness" (TC2) spectral feature from the first date. In the spectral feature, most cultivated agricultural land is brighter than all other scene constituents. This was compared with the water spectral features from both dates. As a result of this comparison, we determined the amount of flooded, cultivated agricultural land. This was done by the comparison of cultivated agriculture land from the earlier data set and flooded agriculture land on the second date. Note that flooded agriculture on the second date that was not cultivated on the first date was not included in the comparison. A binary image showing the flooded agriculture area was then superimposed on a second date Tasseled Cap "Brightness" (TC1) feature to give context to the flooded agriculture. In the brightness image, water is dark grey, and urban areas and bare fields are light toned.

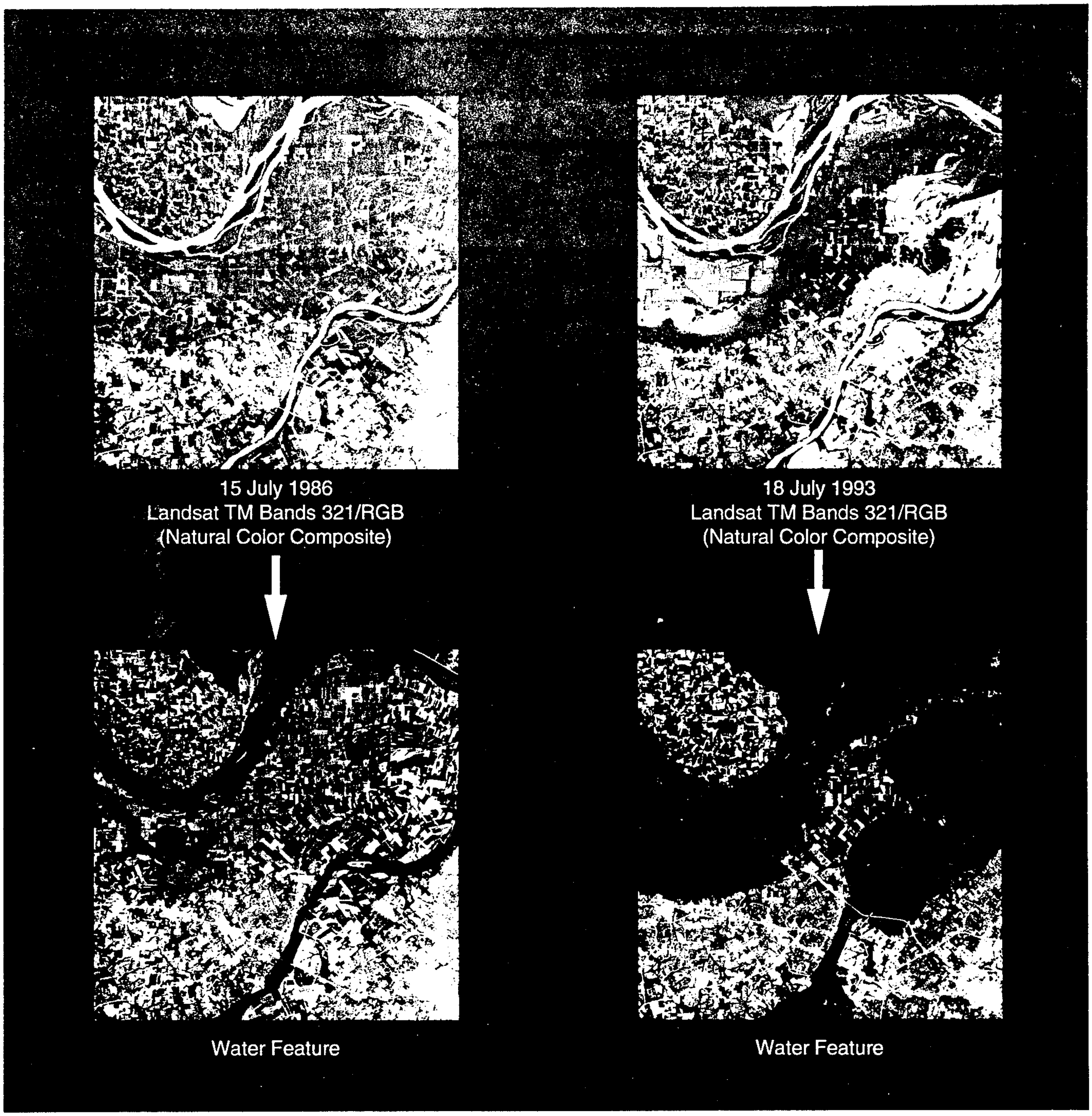

FIGURE 6.1 Panel 1, Original Data and Selected Spectral Features

FIGURE 7.1 Panel 2, Flood Extent

FIGURE 8.1 Panel 3, Flooded Cultural Features

FIGURE 9.1 Panel 4, Flooded Agriculture

10.0 Summary

This demonstrative analysis was performed to describe to a potential user some digital processing techniques that may be applied to Landsat TM data, to yield useful information regarding flood phenomena. Several techniques, such as linear data transformations (Principal Components Analysis), spectral ratio combinations for vegetation indices (Normalized Difference Vegetation Index), and density slicing may be employed individually or collectively to provide highly correlated spectral information.

To study specific phenomena, such as floods, multitemporal processing is required. Temporal information for a given area can be extracted from coregistered images that were collected at different times. The multitemporal images provide change detection information, which enables the analyst to quickly estimate the total area affected, as well as the magnitude of the situation.

Again, this was only a demonstrative analysis. A more in-depth and concise analysis is possible with ancillary information or with merging the TM with other imagery, such as Spot Panchromatic XS. Ancillary data could provide pertinent topographic information like elevation, locations of streams, highways, and water bodies; soil information; and census data. Line data defines features such as pipelines or power lines. Areal data contains distributions of soil, land cover and vegetation classes. This auxiliary information merged with remotely sensed imagery (i.e., Landsat 5, TM imagery) information would prove invaluable to disaster management agencies for mapping and responding to natural disasters.

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