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LANDSAT 4 AND 5 STATUS AND RESULTS FROM THEMATIC MAPPER DATA ANALYSES

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I. ABSTRACT

Landsat-4 was launched July 16, 1982. The Multispectral Scanner (MSS) and Thematic Mapper (TM) on Landsat-4 have performed very well. In the first year of operation the Landsat-4 flight segment and MSS Image Processing System (MIPS) were turned over to the National Oceanic and Atmospheric Administration (NOAA). Over 6000 TM scenes were acquired prior to February 1983. Several hundred of these TM scenes have been processed and are in the public archive at Sioux Falls, South Dakota. The higher spatial resolution, new spectral bands and better radiometric capability of the TM have been demonstrated to provide at least twice the observing capability of the MSS. Landsat-5 was launched successfully March 1, 1984. Early inspection of data from Landsat-5, including MSS and TM imagery, indicates that all Landsat-5 systems are performing well.

II. INTRODUCTION

In 1972, Landsat-1 was launched into a sun-synchronous orbit near 900 kilometers. Landsats 2 and 3 were launched in 1975 and 1978, respectively. All of these spacecraft functioned successfully well beyond their design lifetimes of one year. Landsat-1 operations terminated in 1978 and Landsat 2 and 3 operations terminated in 1983. Most importantly over 1,200,000 MSS scenes and 270,000 Return Beam Videcon (RBV) scenes were acquired by the United States and over 90 percent archived for analyses and application. Approximately 2.5 times the number of scenes acquired by the United States were acquired by the several ground receiving and processing stations operated by other countries. This very sizable collection of data from the Landsat 1-3 series, thus made a very significant impact in providing inventories and improved understanding of the characteristics of the land cover of the earth and associated resources. Evidences of the use of Landsat data products appear in numerous scientific and technical journal articles, magazines, handbooks and textbooks.

A second generation of Landsat satellite operations and earth observations began on July 16, 1982 with the successful launch of Landsat-4 from Vandenburg Air Force Base in California. Landsat-4 continued the type of observational capability provided by the MSS on Landsats 1-3 and provided an improved observational capability in the form of the Thematic Mapper (TM). The characteristics of the Landsat-4 systems and the TM, in particular, are described by Engel and Weinstein (1983). Some insight into the planning and evolutionary steps leading to the launch of Landsat-4 are provided by Salomonson and Mannheimer (1983).

III. Landsat-4

A. SYSTEMS STATUS (MARCH 1984)

Since the launch of Landsat-4 on July 16, 1982, the majority of systems in the flight segment (command and control, data processing, etc) have performed very well. The systems on the spacecraft including the MSS and supporting ground systems were turned over to NOAA in January 1983. The Landsat-4 and the pertinent ground - processing for the MSS have generally met product requirements requested by the user community up to the present time.

In the case of the new second generation, earth observing system called the Thematic Mapper, over 6000 scenes were acquired from Landsat-4 through 1983. 5000 of these scenes were acquired by the Transportable Ground Station (TGS) facility at Goddard Space Flight Center in Greenbelt, Maryland and another 1000 scenes over the United States were acquired for NASA by the Canadian ground station at Prince Albert, Saskatchewan. Another 2000 (approximately) TM scenes from Landsat-4 outside the U.S. have been acquired by Canada and 1200 scenes by the European Space Agency (ESA) station in Fucino, Italy (Fusco, 1984). Of the six thousand scenes acquired over the United States or nearby areas, nearly 300 of the best scenes were fully processed into film and Computer Compatible Tape (CCT) format and archived at the EROS Data Center in Sioux Falls, South Dakota. These scenes were largely processed by so-called "scrounge" system that was put together to process TM data prior to the operation of the Landsat-4 TM Image Processing System (TIPS). Near the end of 1983 and the beginning months of 1984 the TIPS was processing scenes from the available archive of 6000 scenes at a rate approximating 12 scenes per day or 60 per week processed into a 241 mm format and 2 scenes per day or 10 per week into standard CCT products. Masuoka (1984) provides more detail on the availability of Landsat-4 TM data.

More TM data would have been acquired had it not been for some malfunctions of equipment in the Landsat-4 flight segment. One key failure that occurrd in February 1983 was the loss of the X-band transmission capability that allowed direct-readout of TM data by the TGS and other stations in Canada, Italy and elsewhere that have the appropriate read-out capability. This failure occurred due to substrate cracks in the three-stage amplifier portion of the X-band frequency source. Another key problem was the failure in the interconnecting power cables for the solar panels. Due to thermal expansion differences in the cabling and potting compounds used, the power derived from two out of four panels was lost. In order to limit the thermal stresses causing the wiring failures, the solar array was tilted 37° away from perpendicular to the sun thus providing power sufficient to operate only the MSS and provide the user community requested data. To date this strategy has worked well but has precluded acquisition of any appreciable quantity of TM data. Other difficulties in the establishment of the Tracking and Data Relay Satellite (TDRS) capability have been limiting factors in acquiring TM data. However, the available quantities of TM data have permitted some substantive evaluations of the quality and utility of TM data.

At the present time (March 1984) Landsat-4 is still operational. It was operated successfully to acquire MSS and TM data since the launch of Landsat-5. In particular, nearly coincident in space and time Landsat-4 and 5 data have been acquired so as to permit intercomparisons of TM and MSS data from the two spacecraft and attendant sensor systems. If another solar panel fails, the spacecraft will be commanded in such a way as to lower the orbital altitude to 500 kilometers. It will be then configured so as to remain at that altitude in the event that plans and resources are commensurate with repair and retrieval operations using the Shuttle at a a later date when it is operating from Vandenberg Air Force Base in California.

B. ANALYSIS OF LANDSAT-4 EARTH-OBSERVING SENSOR DATA

1. <u>Multispectral Scanner</u> (MSS)

The MSS on Landsat-4 was designed to provide the same observational capability as the Landsat 1-3 MSS instruments. Some modest changes were necessary to allow a 185 kilometer swath to be provided at the operating altitude near 705 kilometers used for Landsat-4 (Landsat 1-3 operated near 913 kilometers) and to accomodate the different spacecraft conditions afforded by the Multimission Modular Spacecraft (MSS).

Examination of data from the Landsat-4 MSS showed very little differences as compared to Landsat 1-3 MSS observations. Malila et al. (1984) provides a discussion of the Landsat-4 versus Landsat 2 and 3 MSS observations. A linear relationship can be applied to adjust for calibration differences between these instruments. The most noticeable artifact in the imagery of Landsat-4 MSS data is diagonal striping in the imagery associated with coherent noise. This noise exists in all MSS bands. This noise can be distracting and have a slight but negative impact on analysis over large uniform areas. The amplitude (RMS) of this noise is less than one digital count out of 64 and has a dominant wavelength between 3 and 4 pixels. An electronic filter has been placed on Landsat-5 to reduce this effect. Early results from Landsat-5 indicate this solution has been effective.

2. <u>Thematic Mapper</u> (TM)

The radiometric qualities of the TM have been shown to be quite good (Barker and Guenther, 1983; Malila et al., 1984; Anuta et al., 1984; Bernstein et al., 1984; Murphy et al., 1984; Dozier et al., 1984). The response is linear in all bands over the entire dynamic range. Striping or detector to detector differences do occur but can be effectively accounted for leaving data with very little striping, i.e. differences of 1-2 counts out of 256 are occasionally evident over large uniform areas with maximum excursions occasionally observed near 4 or 5 counts. Overall, the TM is providing data of very high relative radiometric quality. The absolute radiometric accuracy of TM data is still under study.

The geometric qualities of TM data have proven to be remarkably good given the complexities of data processing involved. The relative geometry within the scnes is particularly good. Early problems in achieving band to band registration near 0.1 pixel have generally been solved even for registration between the cooled focal plane bands (1.6, 2.2 and 10.4-12.5 micrometer bands) and the prime focal plane bands (visible and near infrared bands). Discussions of the TM geometry are given by Malila et al. (1984), Bernstein et al. (1984), Anuta et al. (1984), Wrigley et al., (1984), Walker et al. (1984 a,b), and Welch and and Usery (1984). Colvocoresses (1984) describes success in producing satellite image maps from TM imagery that meet national map accuracy standards at 1:100,000 scale. This is a substantial step forward in that MSS imagery or data would at best provide image maps meeting these standards at map scales no larger than 1:200,000. A substantial fraction of this improved performance is due to the improved altitude control and knowledge provided by the MMS spacecraft systems

Several investigators or investigator teams have examined the TM data for its application potential in various disciplines areas. The new spectral bands in the middle infrared (1.6 and 2.2 micrometers) have consistently been shown to be useful. An analysis of spectral band combinations done by Chavez, et al. (1984) shows that these bands consistently rank high when applied in producing imagery for a variety of scenes having differing land cover content. Pitts et al. (1984) demonstrate the utility of these bands for successfully delineating corn from soybeans. DeGloria (1984) shows a similar result for separating sugarbeets and alfalfa. In MSS data these crops often appear spectrally indistinguishable. Haas and Waltz (1984) and Anuta et al. (1984) provide results using multispectral classification procedures for scenes containing a wide variety of land cover classes showing the new TM shortwave infrared bands permit the objective a-separation of twice as many land cover classes as can be provided by the MSS. Thompson and Henderson (1984) describe some interesting results indicating that soil differences in grassland situations are delineatable when using the TM bands and making use of the short wave infrared bands, in particular.

From a somewhat different point of view, namely, through the use of principal component or eigenvector analyses, the TM data have been shown to have at least one more principal component or independent vector of information than the MSS when considering only the bands in the visible, near infrared and short wave infrared (1.6 and 2.2 micrometers). Crist and Cicone (1984) demonstrate this using the "tasselled-cap" approach. Anuta et. al (1984) and Bernstein et al (1984) show similar results and also show the thermal band makes a substantial contribution toward providing 4 significant independent vectors or components of information in the TM as opposed to two components in MSS data. Price (1984) uses information theory to show that the TM provides nearly twice as much information as the MSS.

A variety of analyses suggest that if one is too pick the most useful set of four bands out of the seven available from the TM, selecting one from the three bands in the visible part of the spectrum (TM bands 1, 2, or 3), the near infrared band (0.76 - 0.90 micrometers-TM band 4), one of the two middle infrared bands (1.6 or 2.2 micrometer bands - TM bands 5 or 7) and the thermal infrared band (TM band 6) would be the best set of bands. Specialized investigations in geology would place more emphasis on the short wave infrared bands (Chavez et. al, 1984); Everett et. al, 1984). Snowfield mapping also makes use of the shortwave infrared bands (1.6 micrometers, in particular) to objectively separate snow from clouds. (Dozier, 1984).

The uses of the thermal infrared still need to be studied in that distinctly different physics govern the emission of energy in this band as contracted against reflection of energy in the other infrared bands. Price (1984) and Anuta et. al (1984) illustrate results showing that it would appear that this band is clearly useful mapping water bodies and relative differences in temperature for water bodies much larger that the 120 meter pixel associated with this TM band. Potential also exists for assessing surface moistness and monitoring thermal features accompanying human activity (Price, 1984). DeGloria (1984) provides some preliminary results indicating the thermal band is helpful in separating agricultural and forest conditions that are not distinguishable using bands measuring reflected solar radiation.

The spatial resolution advantages of the TM are clearly useful and are illustrated in images from the TM. Street patterns, field boundaries, roads, etc. are much more visible in TM data. Williams et. al (1984) provide land cover classification results indicating that the higher resolution requires careful use of existing digital classification algorithms or the development of new approaches. The TM resolution provides more variability within classes and can, in fact, actually degrade classification results.

Overall from a wide variety of analyses and results, it appears that the TM can be described as being twice as effective in providing information as the MSS. This is based on its ability to provide twice as many separable classes over a given areas as the MSS, numerically provide 2 more independent vectors or components in the data or demonstrate through classical information theory that twice as much information exists in the TM. The caveats to these general conclusions that must be applied for specific situations will become more clear as investigations of TM data become more mature or are extended to wider varieties of situations.

IV. LANDSAT-5

Landsat-5 was launched successfully from Vandenberg Air Force Base in California on March 1, 1984. All of the problem areas associated with the flight segment of Landsat-4 had been extensively studied and modifications made to preclude similar problems occurring in Landsat-5 operations. These modifications included, in particular, changes in the solar panel wiring to reduce or eliminate problems due to thermal stresses and changes in the X-band transmitter systems to reduce the probability of failure of this spacecraft component as of the end of March 1984, these steps and others including the design and operations of the ground segment, appear to be successful in providing a system that are all functioning well.

The first Landsat MSS scene from Landsat-5 that was processed and made available to the public was acquired over Long Island, New York on March 4, 1984. The first Thematic Mapper (bands 1-4) scenes processed and made publicly available were acquired on March 6, 1984 over the Corpus Christi, Texas area and the area including Tulsa, Oklahoma and regions to the north. Successful acquisitions of data outside the United States using the TDRS were achieved over Europe and South America. Thematic Mapper scenes with all seven bands have also been acquired. Analyses of these scenes indicate that the data are very good. Landsat-5 should be in an orbit aligned with the World Reference System (WRS) by April 1984.

V. CONCLUSIONS

The results from Landsat-4 data analyses indicate that the technological capability provided by the Landsat 4 and 5 systems is a substantial step forward relative to the capability of the Landsat 1-3 systems. The spectral bands, in particular, of the TM provide a capability that will be unmatched for several years. The Landsat-5 systems all appear to be off to a good start in providing good performance that, hopefully, will persist over a long period so as to allow the excellent period of recorded observations spanning over a decade by Landsats 1-3 to be substantially extended. If this occurs, then Landsat 4 and 5 will have brought to practical reality a second generation of earth resources satellite observations that will enlarge our understanding of the processes occurring on the surface of the earth as well as our ability to monitor and judiciously utilize the increasingly valuable resources of the earth.

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