DEVELOPMENT OF SPACE TECHNOLOGY FOR RESOURCE APPLICATIONS IN THE 1980's

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ABSTRACT

The resource observation program within NASA's Office of Space and Terrestrial Applications conducts research and develops technology for space related observations of the Earth. The program has three interrelated elements which address national and global needs. First, the Renewable Resources program is largely aimed at improving agricultural assessments through a program called Agristars which has evolved from the success of the Large Area Crop Inventory Experiment (LACIE) project. Second, the Non-Renewable Resources program is directed towards improving the effectiveness of global assessment and exploration for mineral and energy resources. Third, the Geodynamics program is focusing on global observations of crustal plate stability or deformation, earth rotation, and polar motion to better understand dynamic processes related to earthquakes. Research and development is phased to develop understanding of the scientific basis for earth observations through laboratory, field and aircraft experiments. Experimental space sensor and measurement systems will be tested in space either on board the Shuttle or on free-flying satellites. Remote sensing systems which transition to an operational status will be the responsibility of the U.S. Department of Commerce.

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INTRODUCTION - The Heritage of Earth Observations from Space

In the late 1960's and early 1970's the Gemini and Apollo programs of the United States National Aeronautics and Space Administration (NASA) demonstrated the importance of synoptic space photography for global resource observations. Photographs taken by astronauts using hand-held cameras showed landscape features of dimensions which had not been previously observed from aircraft or delineated from ground-based field studies. These spaceborn observations greatly assisted geoscientists in analyzing major crustal features in the context of the then-new theory of plate tectonics. A variety of land managers including geographers, land-use planners, foresters, and agricultural scientists recognized the importance of synoptic space-acquired data for development of resource information on not only regional, but continental and global scales. At the end of the 1960s' a landmark experiment was conceived by resource managers and space technologists to test the use of space-acquired data for global resource observations--the Earth Resources Technology Satellite (ERTS) program. This program has been such an unqualified success as an experiment that users of ERTS (now Landsat) data now demand that space-acquired data of land area be provided routinely on an operational basis not only for research, but for specific applications. Research conducted by NASA during the past decade has demonstrated the potential for new spaceborne data collection systems to a degree that has caused users to actively lobby for their development.

In light of the success of the Earth Observations Program which evolved during the past decade NASA reorganized its Office of Applications into an Office of Space and Terrestrial Applications and combined many of the elements within NASA in a manner which would allow more efficient management of Earth-oriented programs. The Earth Observations Program was organized into two divisions; the Environmental Observations Division dealing with the atmospheres and oceans and the Resource Observation Division which is concerned with observations related to the Earth's land surface and interior. The Resource Observations Division conducts research, develops technology, and demonstrates the applicability of space-related methods for renewable resources, non-renewable resources and geodynamics. The renewable resources program is aimed at improving global agricultural assessments, improving land use analyses, and evaluating surface water resources. The non-renewable resources program is directed toward improving the effectiveness of global evaluation of mineral and energy resources. The geodynamics program is focused on improving knowledge of the Earth's interior and on developing information about Earth motions for improved understanding of earthquake mechanisms.

THE LANDSAT PROGRAM

Landsat-1 and -2. The Landsat satellite program was developed as an experimental global earth resources observations data collection system. Landsat-1 (formerly ERTS-1) and Landsat-2 were launched into near-polar 918 kilometer orbits in 1972 and 1975 respectively. Both satellites carried an identical sensor payload consisting of a 4-band line-scanning system called the Multispectral Scanner (MSS) and a 3-band television camera system called the Return Beam Vidicon (RBV). Both sensors had 79-

meter ground resolution expressed in terms of instantaneous field of view (MSS) and in terms of line-pairs (RBV). These systems imaged a 185 kilometer wide swath on the ground and the data were formatted into scenes covering approximately 34,000 square kilometers. Landsat-1 stopped gathering data in early 1978. Landsat-2 ceased data collection in late 1979 but has now been reactivated. Both satellites collected a total of 655,728 MSS scenes and 4550 RBV scenes during the period 1972 to 1979, but much of the Earth still lacks repetitive multispectral data coverage at 80-meter ground resolution. During the period of Landsat-1 and-2 operations the master archival medium was film, although computer compatible tapes (CCTs') were produced on special request. Landsat data during this period were converted from wide-band video recordings to 70-millimeter film images by an electron beam recorder and Landsat-1 and-2 data were converted to CCTs' at Goddard Space Flight Center (GSFC). MSS data, which had an original ground instantaneous field of view(GIFOV) of 79-meters by 79-meters, were formatted at GSFC to picture elements covering 56-meters by 79-meters, on the ground.

Landsat-3. Landsat-3 was launched in the spring of 1978 and its sensor payload included an MSS with an additional thermal channel and a two-camera single-band RBV with twice the focal length of the previous version. The two RBV cameras were arranged to give sidelapped coverage of a 185-kilometer swath at 40-meter resolution. The Landsat-3 experiment was designed to test both the utility of these new sensors and the conversion to an all digital data handling system for Landsat data. Landsat-3 data are processed from wide-band video recordings to 20,000 bit-per-inch High Density Tape (HDT) at GSFC. When the HDTs' are created, radiometric corrections are applied to minimize the effects of variations in sensor response. The original HDTs' are processed at GSFC to geometrically fit the data to a Hotine Oblique Mercator (HOM) projection using cubic convolution resampling and ground control points (Digital MSS and RBV data are formatted to picture elements covering 56-meters by 56-meters on the ground during the cubic convolution resampling process). Standard corrected digital MSS and RBV data are transmitted to the Earth Resource Observations Systems (EROS) Data Center in Sioux Falls, South Dakota via domestic satellite link. At the EROS Data Center (EDC) the HDT data are converted to images on 241 millimeter wide film using a laser beam recorder and to CCTs'.

By the late 1970s' a sophisticated Landsat domestic user community had developed and had begun to demand that Landsat data be provided on a timely and routine basis. In the international sector Landsat data receiving stations were established by foreign countries around the world, with more to come for the future. In response to the wishes of the user community for an operational land remote sensing program the President of the United States in 1979 assigned the Department of Commerce the responsibility for management of all operational civilian remote sensing activities from space. The Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) was charged with preparing an implementation plan by June 1980 for establishing the land observing system based on the Landsat program. Ultimately a program will be developed which will lead to establishment of a fully operational land observing system within this decade. NASA will continue in its already established research and technological development role with its development of experimental satellite systems and the development of the prototype operational land observing systems.

Landsat-D and-D'. Landsat-D is now planned for a 1982 launch with the MSS for data continuity with the previous Landsats. It may also carry a Thematic Mapper (TM). The TM is a seven-band high-resolution precision scanner designed to test the characteristics of a possible operational resource observations sensor. Landsat-D' will carry MSS and TM sensors and will be available for launch in late 1983 or early 1984. Landsat-D will be launched into a 705.3 kilometer orbit which will allow for both maximized ground resoultion and for 16-day repeat coverage (as opposed to 18-day coverage for previous Landsats). The TM will have greatly increased spectral resolution, because of the decreased GIFOV from 79 meters to 30 meters, the increase in spectral bands from 4 to 7, the decrease in bandwidth of several of the bands, and the increased quantization from 64 levels to 256 levels.

The Landsat-D spacecraft will also be a departure from the previous Nimbus design used with earlier Landsats. The multimission modular spacecraft (MMS) to be used for Landsat-D will utilize a more compact design and will achieve much greater stability because it will have an improved pointing accuracy of 0.01° and a greater stability of 10^{-6} degrees per second, compared to the pointing accuracy of 0.7° and stability of 10^{-2} degrees per second for Landsat 3. Landsat-D is also planned to have a receiver for the Global Positioning System (GPS) data from which the 3-dimensional position of the spacecraft can be computed to within 10 meters.

Landsat-D will also utilize an improved data handling system which will allow data received by the satellite to be transmitted in real time to the United States from most areas of the world. The data system will use two Tracking and Data Relay Satellites (TDRS) positioned in geosynchronous orbit at 41° and 171° West Longitude. Data transmission relay through the Tracking and Data Relay Satellite System (TDRSS) will be done using Ku-band down-linked to White Sands, New Mexico. Direct readout of the data will be possible using X-Band (8.1GHz) at a data rate of 85 megabits per second for both TM and MSS data. An S-Band link for MSS data will also be available. Once the data are received at White Sands, they will be transmitted at a slower rate through a domestic satellite link to a ground processing station, currently planned to be located at Goddard Space Flight Center (GSFC) in Greenbelt, Maryland. At GSFC the data will be received every eight hours and will be demultiplexed and preprocessed to apply radiometric and geometric corrections. Multispectral Scanner (MSS) data will be transmitted to EDC using the existing Landsat-3 data handling system. Thematic Mapper data will be processed to film and CCT images at GSFC within 48 hours and TM film data will be shipped by air to EDC for distribution to users. Users will request all data through EDC and all data will be shipped from EDC except the digital data which will be shipped directly to users from GSFC to allow more rapid dissemination of that data.

The TM to be utilized on Landsat-D will be a significant step forward in Landsat technology because it will allow improved detection, mapping, and classification of resources phenomena. The 2.2 micrometer band will allow discrimination of clay minerals which, when discriminated with the iron oxide minerals, will be a good indication of altered rocks that are often associated with mineralization. The potential of space multispectral data for agricultural applications that was demonstrated during the Large Area Crop Inventory Experiment (LACIE) will be more fully realized as TM data are utilized in a program of Agricultural and Resources Inventory Survey Through Aerospace Remote Sensing (AgRISTARS) being conducted jointly with the U.S. Department of Agriculture.

Future development in technology for the Landsat system. The TM will probably be the last optical-mechanical scanner employed in the Landsat satellite series. Developments in solid state imaging technology have demonstrated that multispectral linear arrays can achieve resolutions of 10 meters GIFOV from satellite altitudes. Technology now exists for use of linear arrays in the visible and near infrared (to 1.0 micrometers) and within a few years narrow band solid state imaging should be available for most of the visible and infrared portions of the spectrum. Developments in on board signal processing should allow focal plane radiometric correction, calibration and geometric registration on board satellites. Selectable data transformation techniques will be available allowing users to specify certain ratio combinations of acquired data. Data archives of the future will be digital and probably many users will probably be able to order data by the picture element and have those data delivered through domestic relay satellites to remote locations. Users should have available small portable data reception antennae and low-cost suitcase-sized computer processing terminals which will permit all but the most sophisticated image processing and analysis for rapid information extraction.

THERMAL MAPPING FROM SPACE

The apparent temperature of materials at the Earth's surface is mostly a function of the manner in which the materials absorb and re-radiate incident solar radiation, and also local atmospheric conditions. In unusual circumstances, heat from the Earth's interior may be concentrated at the surface by volcanic processes. Thermal mapping methods which focused only on analysis of apparent daytime or nighttime temperature were not very useful for mapping of materials at the Earth's surface. However these methods are now almost routinely used for mapping of thermal discharges in rivers and monitoring heat losses from buildings. When daytime and nighttime observations of temperature were combined to evaluate how materials conduct, store, and reradiate solar radiation on a diurnal basis, geologists and agronomists found that characteristics of different materials could be evaluated on the basis of their thermal inertia. The thermal inertia of materials has been defined as a function of the heat capacity, density, and thermal conductivity of materials. The utility of thermal inertia mapping form satellites was first demonstrated by geologists from the U. S. Geological Survey using Nimbus-III and-IV satellite data in 1975.

Heat Capacity Mapping Mission (HCMM). HCMM was launched on April 26, 1978 into a nearly sun-sychronous 620Km circular orbit that was inclined 97.6^{o} to the Equator. Local times of satellite equatorial crossing are 2:00AM and 2:00PM and the orbit allows for 16-day repeat coverage. The HCMM sensor is a modified Nimbus-5 Surface Composition Mapping Radiometer (SCMR) which has a total field of view of 60^{o} and thus acquires data over a 716Km swath. The ground instantaneous field of view (GIFOV) of the thermal band is approximately 600m by 600m and this allows a noise equivalent temperature difference (NEAT) of 0.4^{o}K over a 10.5 to 12.5

micrometer wavelength interval. The sensor also has a panchromatic band which measures reflectance in the 0.5 to 1.1 micrometer range in a 500m GIFOV and the data are registered to picture elements having a 481.5 meter size. HCMM has no tape recorder and data were received only in real time at stations. HCMM data are processed at the Image Processing Facility (IPF) at Goddard Space Flight Center where they are converted to images and computer compatible tapes. At GSFC radiometric corrections are applied and the data are geometrically fitted to a HOM projection. Data recorded on film are enhanced by an algorithm which truncates one-half percent of the brightness values on either end of the brightness range and linearly expands the remaining range. A variety of analysis products are produced primarily for the scientific investigations team. These products are:

1. Standard photographic products on 241mm wide black and white film and paper in both negative and positive form at 1:4,000,000 scale.

2. Temperature difference and relative thermal inertia photographic products on 241mm film and paper that were produced from registered day/night data.

3. Computer compatible tape in 800 or 1600 bit-per-inch format of standard or co-registered data.

HCMM data are now available to the general public from the National Space Science Data Center (NSSDC) at Goddard Space Flight Center, in Greenbelt, Maryland. NSSDC provides catalogs to assist users in ordering such data.

Although the scientific results from the HCMM project are still being evaluated preliminary, results have already indicated that new and unique information, of a kind that cannot be derived from the analysis of reflectance data, can readily be extracted from HCMM data. In the Powder River Basin of Wyoming geologists from the U. S. Geological Survey are investigating a new linear trend which appears to be almost continuous from the Wyoming overthrust belt to the Black Hills of South Dakota. Soil scientists from the Remote Sensing Institute of South Dakota have shown that HCMM data can uniquely allow mapping of soil moisture-related phenomena which is not apparent on Landsat data acquired at the same time. Some recent HCMM data of Cape Cod, Massachusetts and Monterey Bay, California have shown large thermal circulation patterns related to the Gulf Stream and upwelling of cold water against the coastline of California, respectively. These striking examples of the new information that can be extracted from HCMM data suggest that this mission is the most significant step forward in spaceborn remote sensing technology since Landsat.

Research in spectral variations in apparent temperature. Early work by geologists ithe 1960s' and early 1970s' indicated that within the 8-14 micrometer range of the electromagnet spectrum many materials do not behave as ideal radiators. Instead many materials, have apparent temperatures that vary as a function of wavelength. Some of the most prominent spectral emission features are related to free silica contained in rock and soil materials. Scientists at the Jet Propulsion Laboratory of the California Institute of Technology recently were able to analyze multiband thermal data from the now-defunct Bendix 24-channel scanner that was acquired over the Tintic Mountains in central Utah. The analysis showed a strong correlation between rocks and soils rich in free silica, and apparent temperature in discrete wavelength intervals. This promising work has prompted the recent development of a multiband thermal mapping instrument for research with aircraft platforms

Future plans for research in thermal mapping from space. Based on laboratory, field, and aircraft investigations in the next few years a multiband sensor will be developed for Shuttle verification and demonstration flights in the mid-1980s'. The success of the HCMM mission has already demonstrated the importance of spaceborne repetitive diurnal observations of the thermal characteristics of the Earth's surface. A second thermal mapping satellite might incorporate a multiband sensor with increased temperature and spatial resolution, and would collect data diurnally.

SPACEBORNE IMAGING RADAR

The potential of imaging radar for global resource observations is great, but the interest in visible and near-infrared sensors for space applications has overshadowed developmental research in the radar area. Microwave methods allow all-weather, day or night imaging with selectable illumination geometries. Radar also detects roughness and electrical properties of surface materials that cannot be measured at other wavelengths.

Seasat-A. The Seasat program is managed by the Environmental Observation Division. Seasat was launched in June of 1978 into a nearly circular non-sun-synchronous orbit inclined 108^{o} with respect to the Equator. Seasat had a 800Km altitude and the orbital plane was allowed to precess through a day/night cycle in approximately 4 months. The coverage requirement for the system was 95% of the Earth's surface within 36 hours. The Seasat satellite included a complement of five main instruments for measuring ocean topography, surface winds, gravity waves, and ocean temperatures. The Seasat coherent synthetic aperature imaging radar utilized 10-meter L-band (23cm, 1.35GHz) antenna which was pointed at the ocean's surface to give an incidence angle of about 20^{o} from nadir (70^{o} depression angle). Coverage swaths with the imaging radar were approximately 100Km wide and 4000Km long. Data were acquired on both ascending and descending tracks so that different azimuths for illumination were possible for the same terrain. Seasat data were both digitally and optically correlated to give 25 to 35 meter ground resolution. Even though Seasat was primarily designed for oceanographic observations, much valuable data has been acquired over land. Seasat data over land are being optically correlated by the Jet Propulsion Laboratory (JPL) in Pasadena, California, and JPL is also producing digital scenes of Seasat data for The Resource Observation Division on request. Both digitally and optically processed products are available from NOAA's Environmental Data Service, in both film and CCT form. The 70^{o} depression angle showed that Seasat data could be used to evaluate soil moisture, agriculture and land use in areas of low relief. However, in areas having moderate to high relief, terrain layover made interpretation of topography related to drainage and landforms very difficult.

Shuttle Imaging Radar-A. The second engineering flight of the Space Shuttle will have six terrestrial observation experiments. Included is an imaging L-band radar constructed from Seasat spare parts and a surplus

Apollo-program optical recorder. The antenna will be pointed towards the Earth, with a depression angle of 40^o. This will give 50^o incidence on horizontal surfaces and the geometry will thus allow for much better detection and analysis of topography. Radar data will be recorded directly on film, and, following optical correlation, 40-meter ground resolution should be possible. The Shuttle will utilize a 235Km altitude with 30^o inclination of the orbital plane. The ground swath of the radar will be approximately 50Km. Data from this mission will be available from the National Space Science Data Center at GSFC.

Imaging radar research program. The success of the Seasat mission, the existence of an active radar research community, and operational use of aircraft imaging radar by the geoscience community, all prompted NASA to develop an aggressive radar research program. The program will undertake research and technological development to determine the potential of satellite radar and to define optimal microwave sensors for resource observations. An integral part of the program is tied to improvements in the Shuttle Imaging Radar (SIR) and experimentation with this system. After the first SIR flight in late 1981, the L-Band antenna system and electronics will be modified to allow for articulation of the antenna structure within the Shuttle bay. This modification will permit a range of depression angles to be utilized for analysis of the Earth's surface with L-Band radiation. The system electronics will also be upgraded to allow for preprocessing of the data and electronic recording of the data onboard the Shuttle. Experiments will be conducted to evaluate the effects of radar backscatter with incidence angles ranging from 20^o to 70^o and to evaluate the utility of stereoscopic radar image data. After the second shuttle radar mission the system will again be upgraded and a dual frequency antenna will be installed to allow data acquisition in X or C-Band and L-Band frequencies. The system electronics will again be upgraded to allow onboard processing to image form and real time data transmission of images through TDRSS or direct-to-ground. Experiments will be conducted at depression angles defined by the second experiment and L, X, and C-Band data will be evaluated for resource applications. Based on these Shuttle experiments and a comprehensive parallel program of laboratory, field, and aircraft research the need and parameters for operational spaceborn imaging radar systems should be well documented by the mid-1980s'.

POTENTIAL FIELD MAPPING FROM SPACE

Magnetic field observations. Near-earth satellite magnetic field data from Polar orbiting geophysical observatories (OGO-2,-4 and-6) were analyzed by NASA and U. S. Geological Survey scientists to produce an almost global magnetic anomaly map. These satellites were flown between 1965 and 1971 and they utilized alkali vapor scalar magnetometers which measured the magnitude of the total magnetic field at altitudes ranging from 400Km to 1500Km. Scientists at Goddard Space Flight Center have developed techniques to minimize the effects of varying external fields between subsequent satellite passes and to minimize the effects of high-latitude ionospheric fields, and they feel confident that the anomalies delineated from OGO scalar magnetometer data are crustal in orgin. Magnetic anomaly data were converted to equivalent bulk magnetization maps which assumed a constant thickness of magnetic crust of 40Km and assumed varying magnetization parallel to the ambient field. These studies have shown that the relative magnetization trends coincide with the Colorado Plateau, Basin and Range, Rio Grande Rift, Mississippi Embayment and Michigan Embayment. A major new magnetic feature in Kentucky is under active investigation by the U. S. Geological Survey and NASA Scientists.

Magsat. Magsat was launched on October 30, 1979 into a constantly sunlit, sun-synchronous polar orbit (it flies the terminator). The altitude of the initial orbit varied from 561 to 352 Km above the Earth's surface, and near the end of the mission in June of 1980 data should be collected well below 200Km. Magsat measures the Earth's magnetic field with a Cesium vapor magnetometer which detects variations in the total ambient magnetic field to an accuracy of 3-gammas. Also, a three-axis fluxgate magnetometer allows measurement of the magnetic vector (magnitude, direction, and location) to an accuracy of 6-gamma (root mean square error). Magsat data are being processed at GSFC the scalar magnetometer data being available to selected investigators for analyses within two months following acquisition. The vector magnetometer data are being processed in two stages: data with an attitude accuracy of 20 minutes of arc available within 2 months and final data with an accuracy of 20 seconds of arc available within 8 months after acquisition. In addition to the Magsat data, field models and charts are being developed including anomaly maps with a 300Km spatial resolution in both scalar and individual components, maps reduced to common elevation and inclination, and equivalent crustal magnetization maps. Magsat data products and some data analysis products will be placed in the National Space Science Data Center at GSFC for general distribution.

Future magnetic field missions. The possibility of a tethered magnetometer for Shuttle is currently being evaluated for future magnetic field mapping missions. One approach being considered would fly the Shuttle at a 270Km altitude and would tether a magnetometer to an altitude of 170Km for a 14-day mission. A follow-on tether mission might include two magnetometers, with one flown just 50Km below the Shuttle and the other at 100Km below. This latter configuration would allow analysis of the magnetic gradient between the two instruments and would permit better evaluation of the directions of the magnetic field. After Magsat data are thoroughly evaluated a follow-on Magsat mission could be flown to evaluate changes which have occurred in the Magnetic field within a period of 5 or 10 years. NASA is also evaluating the possibility of using high-altitude (higher than 40Km) platforms for national magnetic field surveys.

Gravity field observations. Although magnetic field measurements have been made directly from satellites, gravity measurements have not. Analyses of perturbations in satellite motion are the basis for extracting information on the gravitational field of the Earth. If the Earth were a sphere with a uniform density, the orbit of an artificial satellite would be an ellipse with the center of mass of the Earth at one focus. The Earth's gravity field is more complex and can be represented as the sum of a spherical harmonic series and a rotational potential. Satellites under the influence of this complex gravity field have orbits which depart from that of a simple ellipse. By observing the motions of satellites with ground-based optical, electronic and laser tracking systems scientists from GSFC have been developing gravity field models for the past decade. The geopotential model Goddard Earth Model-7 (GEM-7) was based upon over 560,000 observations of 27 satellites, contains 400 spherical harmonic coefficients and is complete to the 16th order.

The gravity field of the Earth can also be represented as a sum of the reference potential and a disturbing potential. The reference potential is an equipotential surface of a rotational ellipsoid while the disturbing potential can be represented as a spherical harmonic series which can be determined by satellite techniques. The disturbing potential represents the difference between the geopotential and the reference potential. This difference is usually mapped as the separation between the geoid, the equipotential surface of the geopotential which most nearly corresponds to mean sea level, and the surface of the reference ellipsoid at the same potential as the geoid. The separations are referred to as undulations of the geoid and can be represented as geoidal height variations relative to the reference ellipsoid. Altimeter measurements from the Geodynamics Experimental Ocean Satellite (GEOS-3) launched April 9, 1975 and Seasat have determined the global ocean geoid to about 1 meter or better. However, mean sea level is also influenced by movements of water related to currents, upwellings, and wind, and repetitive altimetric measurements are required to evaluate these effects. Gravity anomalies are defined by differences between gravity on the geoid and gravity on the reference ellipsoid. Free-air gravity anomalies can be related to the disturbing potential in a manner similar to the way in which geoid undulations are determined. Using combined satellite tracking with laser systems and altimetry from Seasat and Geos-3, 8-milligal gravity anomalies have been determined over 1° by 1° blocks, for some areas. The current GEM-10B model appears to be accurate to about 4-milligals for 5° by 5° blocks.

Gravsat. NASA is evaluating requirements for a dedicated gravity field mapping mission for later in this decade. The mission would evaluate internal variations in density deep within the Earth, probably in the mantle. A gravity mission might employ two satellites in a nearly polar orbit at 200Km altitude and approximately 300 to 400Km apart. The range rate-of-change between the satellites would have to be measured within 0.1 micron per second to detect 1-milligal gravity anomalies in 1° by 1° blocks and to allow mapping of a 10cm geoid for distances from 100 to 3000Km. If these accuracies are possible, then a Gravsat mission would allow for evaluation of the structural configuration and state of isostatic equilibrium of sedimentary basins and continental shields, the structure of plate boundaries, orogenic belts and continental margins, oceanic lithospheric features like trenches and island arcs, ocean circulation, and density differences in the mantle related to convection.

GLOBAL GEODESY

Several new space-related techniques for determining distances between points and elevations on the surface of the Earth are permitting key dynamic parameters to be evaluated, and are revolutionizing geodetic surveying on a global basis. Very long baseline microwave inferometry (VLBI) using extra-galatic radio sources and laser ranging to satellites (including the moon) have now made it possible to measure distances over several hundreds or thousands of kilometers to accuracies of 10 centimeters or more.

Fixed Geodetic Observatories. Fixed laser observatories are now in operation or are under development in the United States, France, West Germany, the United Kingdom, the Netherlands, Greece, and Japan. In addition, the United States maintains facilities in Brazil, Peru and Australia. The laser systems are capable of ranging to satellites with accuracies of ±10cm or better. Fixed VLBI facilities are under development in the United States, Sweden, West Germany, United Kingdom, Canada, Brazil, Australia, and Japan. Tests in the United States over continental distances have demonstrated VLBI baseline repeatability to 4cm. NASA is developing a coordinated international program to establish intercontinental baseline measurements using fixed facilities over the next decade.

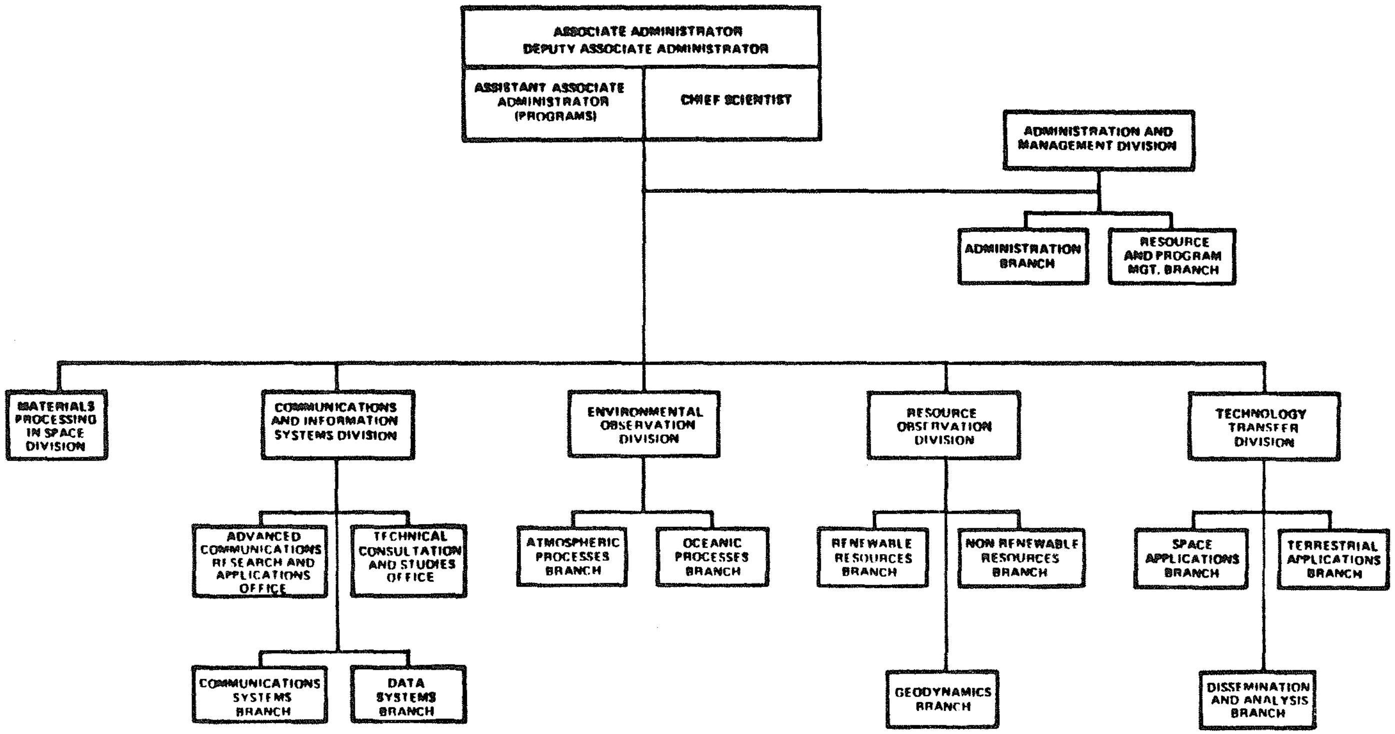
Mobile geodetic observatories. The United States mobile laser and VLBI facilities include four-and nine-meter VLBI systems at the Jet Propulsion Laboratory in Pasadena, California; mobile laser systems (MOBLAS) at Goddard Space Flight Center in Greenbelt, Maryland; and a highly mobile satellite laser ranging system, the Transportable Laser Ranging System or TRLS, which is under development by the University of Texas. The MOBLAS systems are capable of ranging to satellites in low orbit to accuracies of 10cm. The TRLS is capable or ranging to Lageos (Laser Geodynamics Satellite) to ±3cm and can visit 30 sites per year. Mobile VLBI has demonstrated an accuracy of ± 6cm for baselines less than 1000Km and improved VLBI systems should allow accuracies of 3cm over separations of 500Km.

Importance of global geodetic measurements. Laser ranging to satellites and Very Long Baseline Inferometry provide an inertial reference frame for very precise determination of vector baselines, polar motion, earth rotation, and crustal plate motion. Changes in the orientation of the body of the Earth relative to its instantaneous axis of rotation (Polar Motion) and changes in the angular velocity of the Earth about its axis of rotation (Earth Rotation) are thought to be related to the movement of air and water masses, and perhaps long-term climatic variations. Global VLBI and laser ranging will allow these Earth motions to be evaluated over long periods of time and perhaps correlated with temporal phenomena like earthquakes. Repeated verification of the vector distance between points on the Earth's surface to 10cm will be a major contribution to the establishment and monitoring to control reference points for transcontinental and intercontinental geodetic grids. Although horizontal and vertical crustal movements are thought to be only 1 to 2cm per year, systematic VLBI and laser measurements on a global basis over a decade or more should confirm rates of crustal plate motion proposed by the theory of plate tectonics and should aid in the evaluation of fault motion, earthquake mechanisms, intra-plate stress and strain, and subsidence in areas where crustal movements exceed normal rates.

THE FUTURE OF RESOURCE OBSERVATIONS FROM SPACE

Beyond the next decade the development of the Space Shuttle as an operational system will allow routine research and development in a space environment. Complementary sensors will be assembled on Shuttle pallets for short-duration Shuttle flights to accomodate intensive resource surveys over particular areas. The Shuttle will make possible the development of large space structures; thus power requirements and the physical size of sensors will not be technological limitations in designing new systems for Earth surveys. The Shuttle will also make possible the development and routine servicing of manned Earth observatories in geosynchronous orbit for continuous monitoring of dynamic phenomena on the Earth's surface.

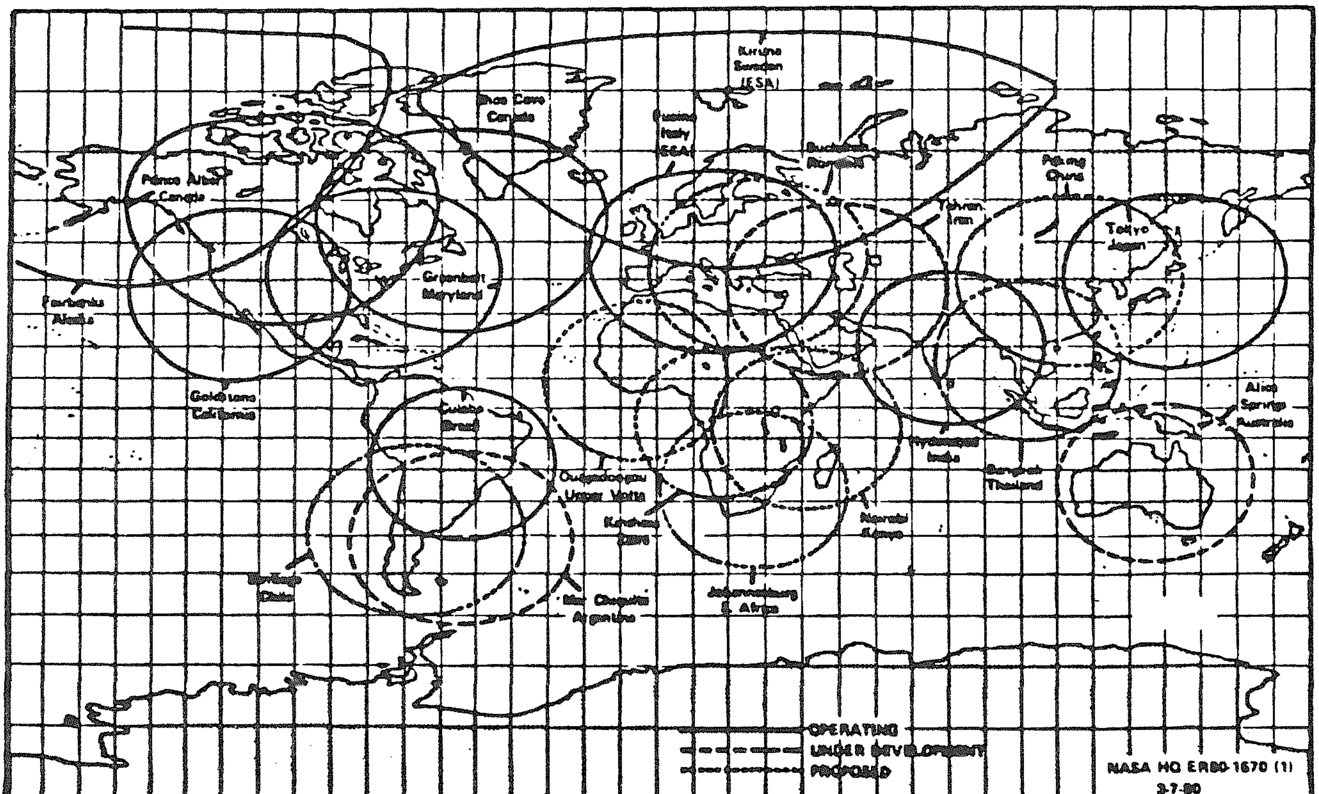
OFFICE OF SPACE AND TERRESTRIAL APPLICATIONS



LANDSAT PROGRAM STATUS

SATELLITE	LAUNCH	STATUS
LANDSAT 1	JULY 23, 1972	CEASED DATA COLLECTION JAN. 10, 1978
LANDSAT 2	JAN. 22, 1975	CEASED DATA COLLECTION NOV. 5, 1979
LANDSAT 3	MAR. 5, 1978	IN OPERATION
LANDSAT D	PLANNED FOR 1982	UNDER DEVELOPMENT
LANDSAT D'	AVAILABLE FOR LAUNCH 6 MONTHS AFTER D	APPROVED

CURRENT AND PROBABLE LANDSAT GROUND STATIONS



NOTE: COVERAGE CIRCLES BASED ON LANDSAT 3 RECEPTION (ALTITUDE 917 km)

LANDSAT SATELLITE SENSOR PAYLOADS

LANDSATS 1 AND 2	MULTISPECTRAL SCANNER (MSS) 4 BANDS RETURN BEAM VIDECON (RBV) 3 BANDS*
LANDSAT 3	MSS 4 BANDS PLUS 1 THERMAL* BAND HIGHER RESOLUTION SINGLE BAND RBV
LANDSAT D	MSS WITH 4 BANDS THEMATIC MAPPER (TM) 7 BANDS
LANDSAT D'	SAME AS D

* NOT MUCH DATA OBTAINED
  MULTIBAND RBV
  THERMAL MSS

LANDSAT D SYSTEM REQUIREMENTS

ORBIT
- ALTITUDE: 705.3 KM
- DESCENDING EQUATORIAL CROSSING: 9:30 - 10:00 AM
- REPEAT CYCLE: 16 DAYS

INSTRUMENTS
- MULTISPECTRAL SCANNER (MSS)
- THEMATIC MAPPER (TM)

GLOBAL COVERAGE (SCENES/DAY)
- TDRSS TO NASA (200 MSS, 100 TM)
- DIRECT READOUT (460 MSS, 150 TM)

PRODUCTS THROUGH DMS WITHIN 48 HOURS
- HDT'S
- CCT'S
- FILM

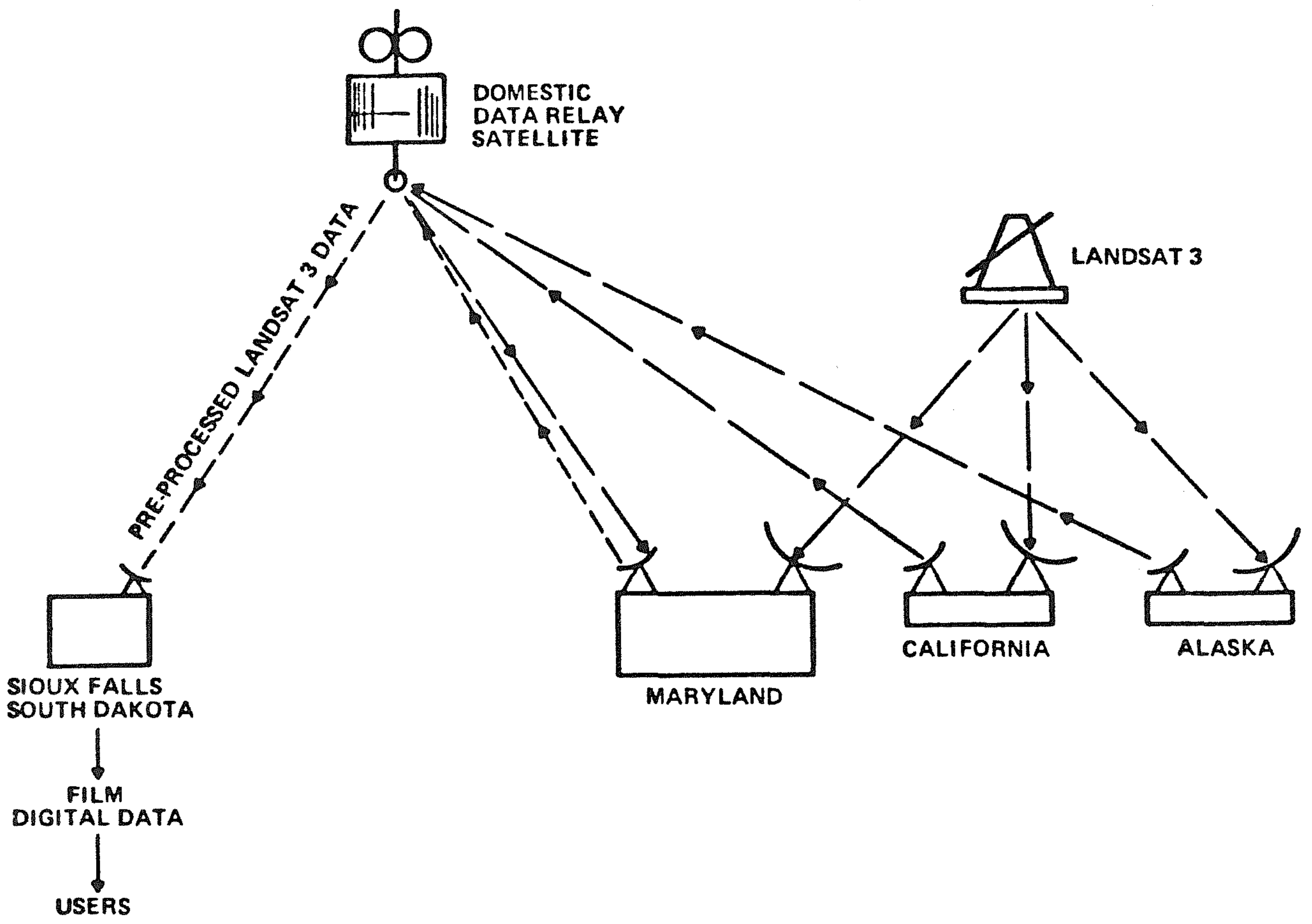
COMPARISON OF LANDSAT MULTISPECTRAL SCANNERS

	MULTISPECTRAL SCANNER (MSS)	THEMATIC MAPPER (TM)
SPATIAL RESOLUTION	80M	30M/120M
SPECTRAL RESOLUTION NUMBER OF BANDS	4	7
BAND PASSES	2 VISIBLE 2 SOLAR INFRARED	3 VISIBLE 3 SOLAR INFRARED 1 THERMAL INFRARED
QUANTIZATION	64 LEVELS	256 LEVELS

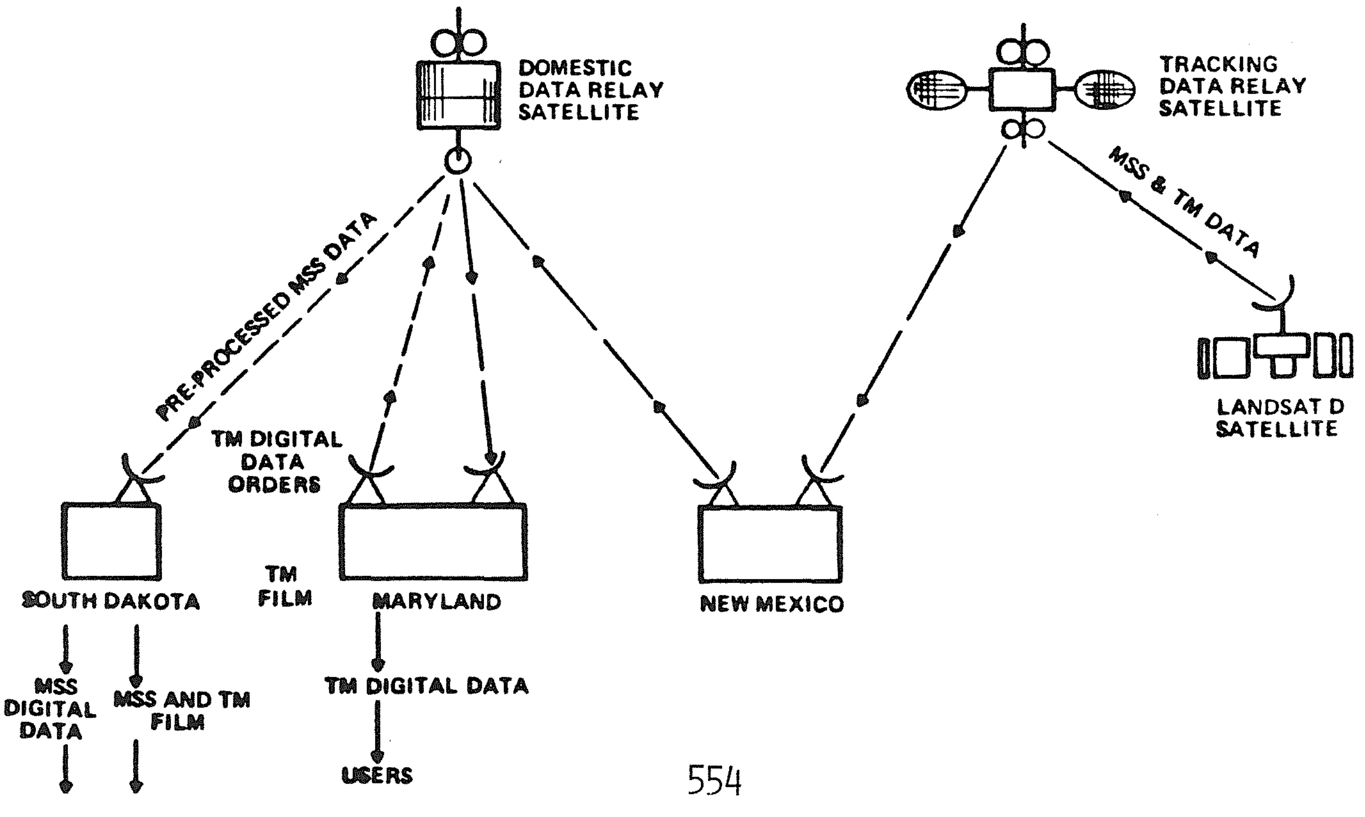
UTILITY OF SPECTRAL REGIONS

MSS	THEMATIC MAPPER	
	0.45 - 0.52 UM:	SENSITIVE TO CHLOROPHYLL AND CAROTINOID CONCENTRATIONS GOOD WATER PENETRATION (SEDIMENT LOAD AND BATHYMETRY)
0.5 - 0.6	0.52 - 0.60 UM:	VEGETATION GREEN PEAK (REDUCED CHLOROPHYLL ABSORPTION) DISCRIMINATION OF IRON CONTENT IN ROCKS AND SOILS
0.6 - 0.7	0.63 - 0.69 UM:	SENSITIVE TO CHLOROPHYLL
0.7 - 0.8 0.8 - 1.1	0.76 - 0.90 UM:	SENSITIVE TO VEGETATION DENSITY OR BIOMASS
	1.55 - 1.75 UM:	SENSITIVE TO LEAF WATER CONTENT SEPARATES CLOUDS FROM SNOW
	2.08 - 2.35 UM:	SENSITIVE TO ALTERED (MINERALIZED) ROCK
	10.4 - 12.5 UM:	THERMAL PEOPERTIES - ROCK DISCRIMINATION, PLANT STRESS, SOIL MOISTURE

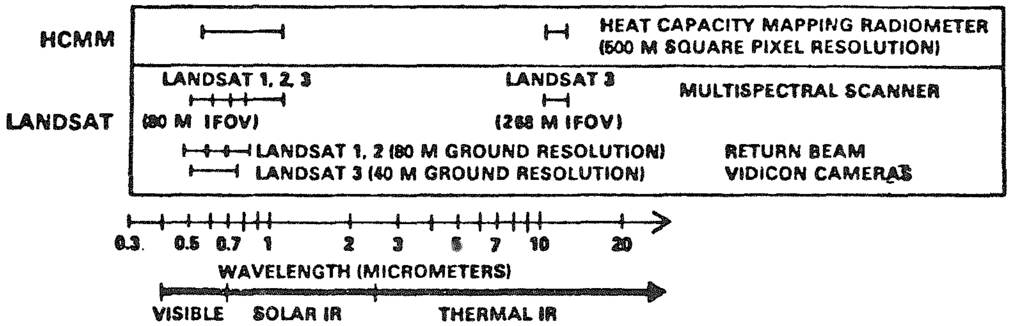
LANDSAT 3 DOMESTIC DATA FLOW

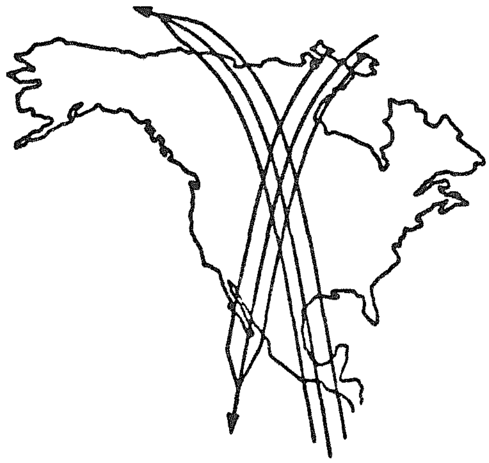


PROPOSED LANDSAT D DOMESTIC DATA FLOW



HCMM: SPECTRAL AND SPATIAL RESOLUTION

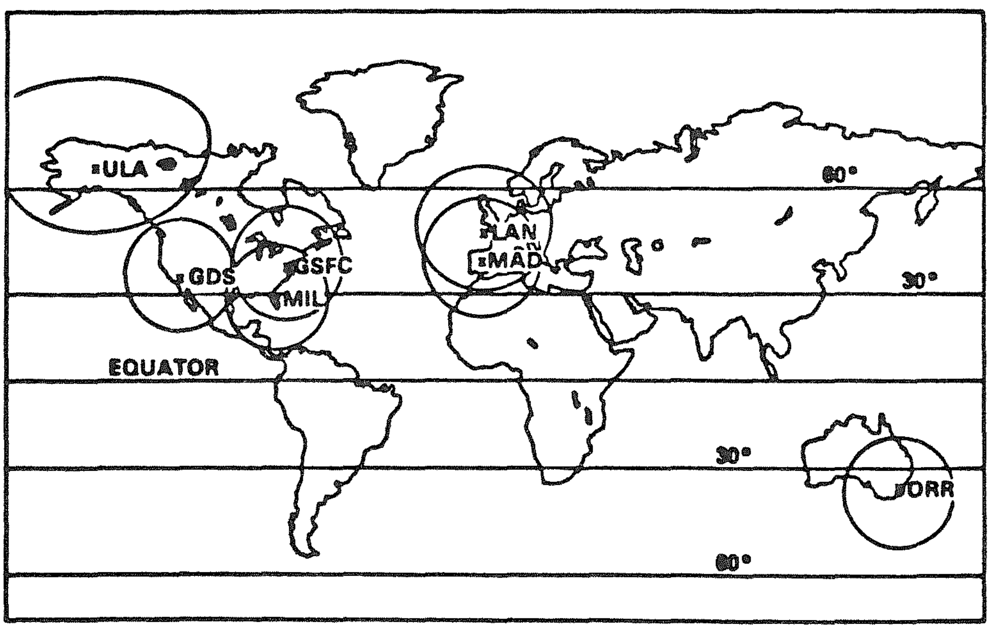




DIURNAL COVERAGE

CROSSING TIMES AT 40° N
1:30 PM - 2:30 AM
LOCAL TIME

HCMM REAL TIME DATA ACQUISITION STATIONS

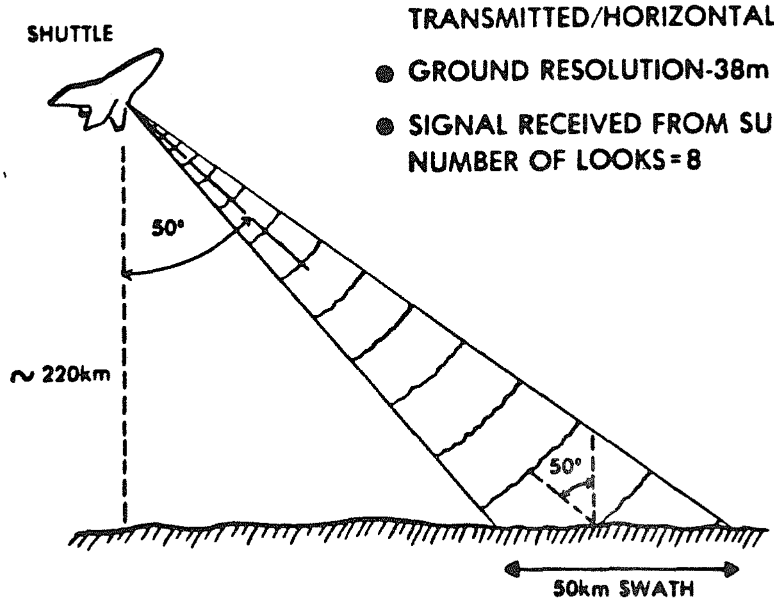


COMPARISON OF SEASAT SAR AND SIR-A CHARACTERISTICS

	SEASAT	SIR-A
WAVELENGTH	23cm	23cm
INCIDENCE ANGLE (FROM VERTICAL)	20°	50°
POLARIZATION	H H	H H
SWATH WIDTH	100km	50km
GROUND RESOLUTION	24m	38m
NUMBER OF LOOKS	4	8

SHUTTLE IMAGING RADAR-A (SIR-A)
TECHNICAL CAPABILITIES

- L-BAND (1.278 GHz/23cm WAVELENGTH)
- HH POLARIZATION (HORIZONTAL TRANSMITTED/HORIZONTAL RECEIVED)
- GROUND RESOLUTION-38m
- SIGNAL RECEIVED FROM SURFACE-NUMBER OF LOOKS=8



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