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EVALUATION OF THE AIRBORNE IMAGING SPECTROMETER FOR REMOTE SENSING OF FOREST STAND CONDITIONS

by

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EVALUATION OF THE AIRBORNE IMAGING SPECTROMETER FOR REMOTE SENSING OF FOREST STAND CONDITIONS

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ABSTRACT

In June-July 1983, five pairs of plots were established in forest stands with one of each pair trenched and covered to prevent precipitation from reaching the tree roots. High winds and falling limbs destroyed the covers on three of the plots. The two remaining plots were in a red pine (*Pinus resinosa* Ait.) plantation and in a natural stand of sugar maple (*Acer saccharum* L.). Trees in both plots developed levels of moisture stress more than nine bars higher than control trees on the dates of the overflights with the Airborne Imaging Spectrometer (AIS) and the Collins' Airborne Spectroradiometer (CAS), August 7 and 9, 1983, respectively.

Hemispherical reflectance from stressed and control trees was measured with a Beckman DK2A spectrophotometer. On the day of the AIS overflight, stressed maple foliage was less reflective than the control from 1000 to 1300 nm, but more reflective at wavelengths longer than 1300 nm. Pine foliage was less reflective than the control from 1000 to 1600 nm, but the difference was small at wavelengths longer than 1350 nm.

AIS data collected on August 7, 1983, showed brightness values for both maple and pine plots to be lower than for the controls from 1000 to 1300 nm. At wavelengths longer than 1300 nm, stressed maples became more reflective (brighter) than the controls, and stressed pines became almost indistinguishable from the controls.

CAS data collected on August 9, 1983, were used to determine the gain in species identification accuracy obtainable with high spectral resolution data. The Linear Discriminant Function provided better results than did Principal Components Analysis. With nine land cover types (eight forest types and water), the Linear Discriminant Function provided an accuracy of 80 percent in a supervised classification. The nine spectral bands which contributed most to species identification were 455, 459, 471, 486, 496, 513, 557, 1684, and 2222 nm. Of these, the best seven were all shorter than 600 nm.

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EVALUATION OF THE AIRBORNE IMAGING SPECTROMETER FOR REMOTE SENSING OF FOREST STAND CONDITIONS

INTRODUCTION

The utility of multi-band remote sensing was demonstrated more than twenty years ago with multiple camera arrays (Colwell, 1961), and fifteen years ago with optical-mechanical scanners (Lowe, 1968). Work with such systems provided the scientific foundation for the Landsat Multi-Spectral Scanner (MSS) and Thematic Mapper (TM). Although both instruments have resulted in important advances, their 100 and 60 nanometer (nm) band widths, respectively, are too wide to permit full exploitation of what is known about spectral reflectance differences between different terrain conditions (Goetz, et al., 1983), especially at wavelengths longer than 1.0 micrometer (um). Sensors with high spectral resolution at these longer wavelengths are now available (Collins, 1978; Vane, et al., 1983). Work with these sensors has been directed largely at agriculture and mineral exploration, with little attention to forestry. One of these sensors, the Airborne Imaging Spectrometer (AIS) developed at the Jet Propulsion Laboratory, appears to have meaningful forestry applications. This sensor has 120 spectral bands, 9.6 nm wide, in the wavelength range from 1.2 to 2.4 um (1,200 to 2,400 nm).

OBJECTIVES

The primary objective of the work described in this report was to evaluate the AIS for forestry applications. Specific objectives for the first year of work were to begin answering two questions:

1. To what extent can high spectral resolution, aircraft data in the 1.2 to 2.4 um spectral region improve the accuracy of identification of forest and wildland vegetation types?
2. To what extent can high spectral resolution, aircraft data in the 1.2 to 2.4 um spectral region facilitate determination of plant vigor or plant stress in forest and wildland ecosystems?

RATIONALE

Reflectance from plant foliage is largely controlled by plant pigments in the spectral region between 0.4 and 0.7 um, by internal leaf structure between 0.75 and 1.0 um, and by foliar moisture content between 1.2 and 2.4 um (Knipling, 1967; Olson, 1967; Rohde and Olson, 1971; Tucker, 1980). Any biologic or environmental factor resulting in a difference in the amount or nature of pigments present in the leaves, in the amount of cell-wall/air interface inside the leaves, or in the moisture content of the leaves can produce a change in reflectance of those leaves. Many investigators have identified differences between species in response to various biological and environmental factors. Such differences in reflectance have been used to distinguish between plant species (Krinov, 1947; Olson and Good, 1962; Olson, et al., 1964; Rohde and Olson, 1972; Roller and Thompson, 1972).

In the spectral region recorded by the 120 channels of the AIS, plant reflectance is largely controlled by the amount of liquid water in the leaves and morphologic changes in size and arrangement of leaves and branches which are associated with different levels of moisture availability (Olson, 1977). As moisture content decreases, foliar reflectance increases (Figure 1). Rohde (1971) developed a regression equation relating foliar reflectance to moisture content of broadleaved tree species. This equation was based on laboratory measurements in the 1.0 to 2.6 um spectral region, and had a multiple correlation coefficient of 0.93 with pooled data for three tree species.

Working from Rohde and Olson's beginnings, Roller and Thompson (1972) used an early multispectral scanner to separate broadleaved trees from conifers, and healthy conifers from those infected with *Fomes annosus*, an important root-rot of conifers, world-wide. Previous attempts to make similar separations from color-infrared aerial photographs had met with only partial success, with best results when the photographs were taken during the spring leaf-flushing period (Miller, 1972; Fox, 1974). Roller and Thompson were successful with a ratio-editing processing of their airborne multispectral scanner data, developing the discrimination matrix shown in Figure 2. The key spectral bands were those between 1.0 and 1.4, and 1.5 and 1.8 um.

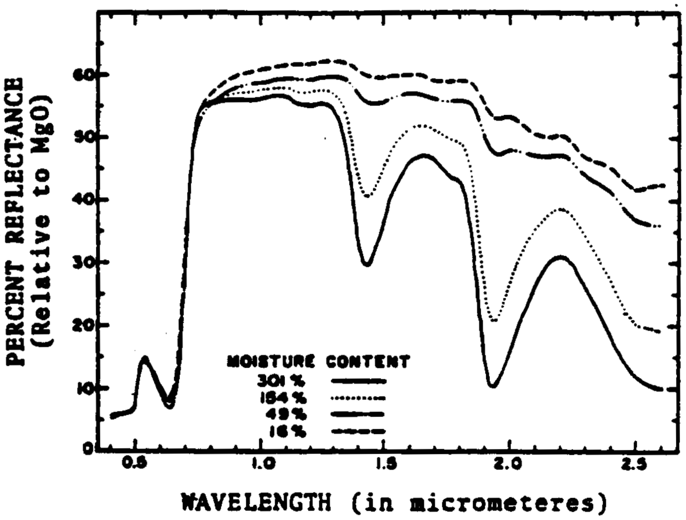


Figure 1. Changes in reflectance of a sycamore leaf at different oven-dry-weight moisture contents as it dried in air. (From: Olson, 1967)

Signal Level *		1.5 - 1.8 µm Channel		
Ratio		0 — 0.3711	0.3711 — 0.4883	0.4883 — 10.000
$\frac{1.5\text{-}1.8\ \mu m}{1.0\text{-}1.4\ \mu m}$	0.539	Healthy Conifers	Healthy Conifers	Broadleaved Trees & Brush
	2.000	Forest Litter	Diseased Conifers	Broadleaved Trees & Brush

*Signal levels in MW cm^{-2}ster^{-1}µm^{-1}.

Figure 2. Discriminant matrix for identifying diseased conifers based on level-slicing of merged and ratioed data from a multi-spectral scanner. (From: Roller and Thompson, 1972)

Responses of plants to environmental factors often result from complex interactions of several physiologic and morphologic changes. Laboratory work has shown root growth is inhibited when plants are grown in soils with high levels of heavy metals (Turner, 1973; Wainwright and Woolhouse, 1975). Reduction in root activity is accompanied by a reduction in cytokinin transport from roots to leaves, a change which promotes leaf senescence (Skene, 1975). Leaves undergoing senescence lose pigments, RNA, proteins and lipids, and become chlorotic; and several nutrients may be leached or re-translocated to branches. Leaf chlorosis is often observed in laboratory treatments of plants with toxic levels of heavy metals (Schwaller, et al., 1981). Abcisic acid (ABA) is one byproduct of the breakdown of carotenoid pigments in plant leaves (Burden and Taylor, 1976). The level of ABA in leaves is known to increase in response to water deficiency (Wright and Hiron, 1969; Livne and Vaadia, 1972) and other conditions of physiologic stress (Vaadia, 1976). ABA is a powerful antitranspirant, and plants treated with heavy metals have a lower transpiration rate (Bazzaz, et al., 1974). When transpiration decreases, water loss decreases and foliar moisture content does not decrease as much as when leaves are actively transpiring. Water stress may result from lack of water uptake by the plant in the absence of heavy metals. In such cases, severe stress leads to wilting of the foliage, a change in geometry which alters the nature of a tree crown as a reflector. Thus, both physiologic and morphologic changes may be present at the same time. Sorting out these several contributing effects to an overall plant response can be difficult.

Some types of plant stress result in the generation of various chemicals within the plant. Ethylene generation may be one response to treatment with herbicides, and ethylene is also produced as a precursor to flowering. When ethylene is produced with the plant under stress and many stomates closed, higher than normal concentrations of ethylene may accumulate within the air space of the spongy mesophyll. Reflectance of infrared light in the 1.0 to 1.4 um spectral region occurs primarily at the cell-wall/air interface in the mesophyll (Willstätter and Stoll, 1913). Ethylene has several strong absorption bands in this spectral region, and accumulations of ethylene in the mesophyll air space should result in a decrease in foliar reflectance. Ethylene absorption bands may be too narrow to be detected by broad-band sensors, such as the Landsat MSS or TM.

Until the development of sensors with high spectral resolution, it was not possible to fully exploit what is known about responses of plants to stress. The Collins' Airborne Spectroradiometer (Collins, 1978; Chiu and Collins, 1978) and the Jet Propulsion Laboratory Airborne Imaging Spectrometer (Vane, et al., 1983) provide data with greater spectral resolution (narrower spectral bands) than sensors previously available. The Collins instrument has a 2 nanometer band width and records between 0.4 and 1.0 um, and between 1.4 and 2.4 um. It is a non-imaging system providing a series of spectra for the line-trace beneath the aircraft. The AIS has a band width of 9.6 nanometers in 120 spectral channels within the spectral region between 1.2 and 2.4 um. Images may be produced in all 120 channels, if desired.

THE STUDY SITES

The work plan was designed to provide replicated and calibrated forest plots with different species and levels of moisture stress. Plots were established at two locations, the Sleeping Bear Dunes Test Site in northern lower Michigan, and at Saginaw Forest near Ann Arbor, Michigan. Both locations are sites of continuing remote sensing research being conducted from The University of Michigan, School of Natural Resources, Remote Sensing Laboratory.

The Sleeping Bear Dunes Test Site

The Sleeping Bear Dunes Test Site is located along the Lake Michigan shore in the northwestern quarter of Michigan's lower peninsula (Figure 3), including all of Benzie, Leelanau and Grand Traverse Counties. Within this nearly 900 square mile area, most complete documentation is centered in a 9 x 7 mile area surrounding Glen Lake and the Sleeping Bear Sand Dunes, in Leelanau County.

Terrain is generally flat to gently rolling. The area was extensively glaciated and areas of ground moraine, outwash plain, river channel, kettle holes, drumlins and sand dunes are present. Numerous lakes and wetlands are scattered across the site. Vegetation cover includes both broadleaved and coniferous forests; active agriculture with pasture, small grains, and orchards; abandoned fields at various stages of succession to forest; and bare dunes and gravel excavations. Traverse City, in the southeast part of the test site, is the largest urban area, but several small towns and villages are also present. The site includes part of the Niagara Reef, a trend of coral pinnacles some 4,000 feet below the surface with significant oil accumulations.

Several sets of vertical aerial photographs are available, the earliest taken in 1938. Complete coverage of the test site at a scale of 1:24,000 on color-infrared film is available for the summer of 1978, and

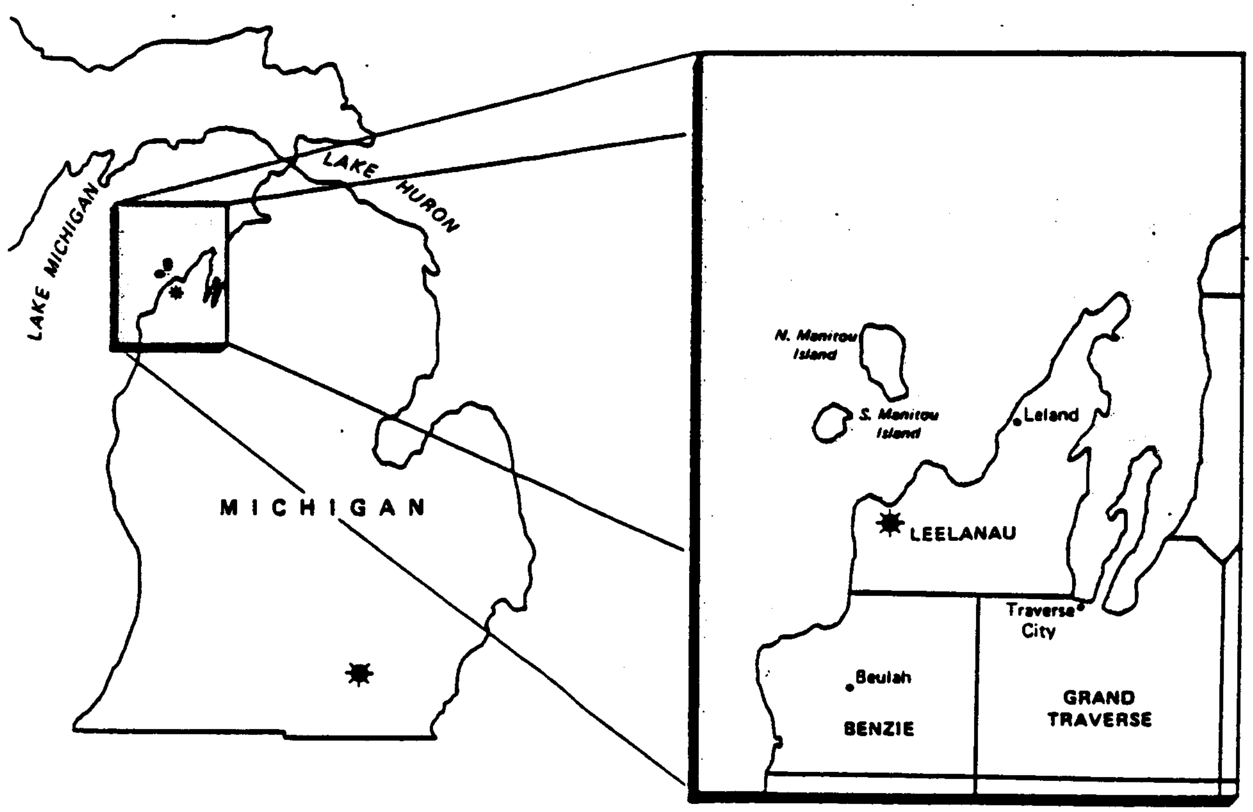


Figure 3. Location of the Sleeping Bear Dunes Test Site (expanded area) in the northwestern part of Michigan's lower peninsula, and the Saginaw Forest Test Site in southeastern lower Michigan.

leaf-off photographs were obtained under the National High Altitude Photo Program (NHAP) in the spring of 1983. The NHAP photographs were also obtained on color-infrared film, at a scale of 1:58,000.

The site is completely contained within Landsat MSS scenes for Path 024 Row 029, and in Landsat TM scenes for Path 022 Row 029. Excellent MSS data are available for May 5, 1973 and June 3, 1976, and TM data for October 18, 1982. Excellent MSS and TM data were obtained from Landsat-5 on July 11, 1984. Usable data may also exist for other dates, even though not currently held by the School of Natural Resources Remote Sensing Laboratory.

Map coverage of the test site is available on U.S. Geological Survey 15' Quadrangles: Empire, Maple City, Northport, and Traverse City provide coverage of all of Leelanau County. The new 7.5' Quadrangles are in final manuscript form with pre-editing field sheets available. Orthophotos are also available for each of the 7.5' Quadrangle areas at a scale of 1:24,000.

The 9 x 7 mile intensive study area includes the Crystal River on the north and Gilbert Lake on the south, two landmarks used to identify the area from the air and in aerial photographs. The Crystal River flows through the campus of The Leelanau Center for Education, and the Center owns an eighty-acre site at Gilbert Lake. Both of these controlled locations are important field locations for other remote sensing work. The Gilbert Lake parcel has both broadleaved and coniferous forest stands which can be manipulated to create varying conditions in different plots.

Field operations at the Sleeping Bear Dunes Test Site are headquartered at The Leelanau Center for Education, approximately two miles northeast of Glen Arbor. This cooperative arrangement makes laboratory facilities available within the test site, reducing the need to transport equipment or samples between Sleeping Bear and Ann Arbor.

The Saginaw Forest Test Site

Saginaw Forest is an 80-acre parcel given to the University of Michigan in 1903. The donor specified it be named Saginaw Forest and used as a test area to determine what species of trees could be used to reforest abandoned farms in Michigan. By 1920, most of the area had been planted to broadleaved or coniferous trees. Today, the site provides a variety of species, in pure stands, in a concentrated area. Stand records and soil data are more complete and detailed at Saginaw Forest than at Sleeping Bear.

Saginaw Forest was one of the target areas for many of the flight tests with multispectral scanners conducted from the Willow Run Laboratories of The University of Michigan from 1960 through 1972. Much of the early imagery for this site is now in the custody of the School of Natural Resources Remote Sensing Laboratory. Conventional aerial photographs are available for this site on several dates, beginning in 1940. Color-infrared aerial photographs are available from July 1974 at a scale of 1:8,000; from June 1978 at a scale of 1:24,000; and from May 1983 at a scale of 1:58,000. Landsat MSS and TM coverage is also available for several dates.

The U.S. Geological Survey Ann Arbor West 7.5' Quadrangle provides good map coverage of the site. The earlier 15' quadrangle was produced in the early 1900s may be of historical interest.

Field operations at the Saginaw Forest Test Site are headquartered in the Remote Sensing Laboratory on The University of Michigan Central Campus in Ann Arbor, five miles away.

METHODS

Field plots were established in five stands, two near Gilbert Lake in the Sleeping Bear Dunes Test Site, and three at Saginaw Forest near Ann Arbor. Plots were established in each stand by digging a trench 20 to 24 inches deep outlining a roughly rectangular area approximately 50 x 80 feet in size. Each plot was somewhat irregular in size and shape due to the need to avoid large trees when digging the trench. Trenched plots were covered with a nearly clear plastic material, sealed around the bole of each tree within the plot. The clear plastic cover was continued as a liner in the trench before the trench was filled with dirt, or extended well beyond the trench to prevent precipitation blowing into the plot under the edge of the cover. One plot at Gilbert Lake was located on a gentle slope and the cover laid on the ground. All other plots were located on nearly level ground and it was necessary to provide a peak near the center of the cover to prevent collection of water on the cover.

A. Nearing completion of the plastic cover on the plot in the red pine plantation on July 15, 1983.

B. Final stages of erecting the plastic cover over the sugar maple plot on July 27, 1983. This cover was elevated to minimize understory disturbance.

Figure 4. Views of the plastic covers used to prevent rain water from reaching the soil in two test plots at the Gilbert Lake Test Site in July-August 1983.

Experience showed it necessary to raise the peak of the cover approximately 12 feet above the ground to insure proper drainage off the cover. At this height, trees sway enough in high winds to make a rigid frame for the cover impractical. Instead, the cover was supported on 1/4-inch clothesline tied to the trees at appropriate heights. Approximately 2,400 feet of this line were needed to support the cover on each plot. The plastic material used in the covers was obtained in rolls 16 feet wide and 100 feet long. The rolls were cut to fit around each tree in the plot and all seams taped with 3-M brand strapping tape, 2-inches wide. Collars were made out of scraps and fitted around each tree bole. These collars were taped to the tree, and to the cover just below the collar, with the same type of strapping tape. The upper edge of each collar was also filled with caulking compound to insure a water-tight seal with the tree bole, despite irregular bark surfaces. Each cover required approximately six rolls of the plastic material, with a weight of nearly 160 pounds (Figure 4).

The purpose of the covers was to prevent precipitation from reaching the soil and roots within the plot, thereby developing abnormally high levels of moisture stress in the trees within the plot. Plans were made to water a similar sized plot in each stand to provide a control with little moisture stress. Precipitation was sufficiently well distributed during the 1983 growing season to make irrigation unnecessary at either site.

Plots were completed in stands of sugar maple (*Acer saccharum*, Marsh.), red oak (*Quercus rubra*, L.), and Scots pine (*Pinus sylvestris*, L.) at Saginaw Forest by July 9, 1983. A red pine (*Pinus resinosa*, Ait.) plot was finished at Gilbert Lake on July 15th, and a sugar maple plot was finished nearly two weeks later, on July 28th. Several rains occurred during this two-week period, delaying work on the maple plot and showing need for strengthening the cover over the red pine plot. Heavy rains, accompanied by strong winds, also occurred at Saginaw Forest where falling limbs punched holes in the plastic covers over all three plots. The covers were repaired, to the extent possible, on July 29 and 30. Sufficient water had reached the soil in all three plots to effectively eliminate the developing difference in moisture stress between these plots and the surrounding stands.

Measurement of Moisture Stress

Internal xylem tension was used as the measure of moisture tension in the trees. Xylem tension was measured in a pressure cell after the method of Scholander, et al. (1965), based on a technique first reported by Dixon (1914). In this method the twig end of a freshly cut foliage sample is inserted through a rubber "O" ring fitted to the top side of a pressure chamber. The proximal end of the twig is exposed to atmospheric pressure while the foliage is placed inside a hollow cylinder and the two parts screwed tightly together. Inert nitrogen gas is slowly introduced into the cylinder until free water begins to exude from the cut end of the twig or leaf petiole (observed with a 10x hand lens). The pressure required to force water out of the cut end of the twig or petiole is considered to be the same as, although opposite in sign to, the negative hydrostatic pressure, or leaf water tension, existing in the plant at the time the sample was cut. Measurements were made for samples from two or more trees in each plot, and two or more trees in each surrounding stand, every second day. As the date of the overflight approached, tension measurements were made daily.

Reflectance Measurements

Foliage samples were collected from three trees in each plot, and three trees in each surrounding stand, and taken to the laboratory where spectral reflectance measurements were made for the upper surface of two leaves from each tree with a Beckman DK-2A spectrophotometer. Reflectance data were collected for the spectral range from 500 to 2,600 nanometers using a lead-sulfide detector and barium sulfate as the reference standard. In addition to measurements made several days before the overflight, samples were collected on the day of each overflight and measurements made representing conditions as close as possible to the exact time of the overflight.

The spectrophotometer was installed in the laboratory at The Leelanau Center for Education. Samples collected at Gilbert Lake were transported to the laboratory in zip-loc bags placed inside styrofoam chests. Samples collected at Saginaw Forest were handled similarly, but with a layer of dry ice covered by a layer of newspaper in the bottom of the chests. Previous experience had shown this procedure permitted storing samples for up to 48 hours without altering foliar reflectance properties.

Measurements of Foliar Moisture Content

Foliage samples were collected from both the maple and pine plots and surrounding stands on August 6, and 8, 1983. These samples were weighed, dried in a 95°F oven, reweighed, and the oven-dry-moisture content of the leaves calculated.

Support of Overflights

Flight lines were planned to provide readily identifiable ground check points to assist the air crew in locating the correct flight lines over the plots. On the day of each overflight, strips of the clear plastic cover material (appearing bright white from the air) were placed in open areas to provide "arrows" pointing to plot locations. The plot covers were removed on the morning of August 7th, the day of the overflight by the NASA C-130 carrying the AIS. Plot marker strips were checked and relocated on August 9th, the day of the overflight with the Collins Airborne Spectroradiometer (CAS).

Aircraft Sensor Packages

The AIS was carried by a NASA C-130 from Moffett Field, CA. The C-130 also carried a Thematic Mapper Simulator (NS-001), a 9x9 aerial camera with color-infrared film, and a 35-mm Nikon camera with black-and-white panchromatic film. All of these sensors were mounted with their optical axes vertical.

The Collins aircraft with the Collins Airborne Spectroradiometer also carried a 35-mm Nikon camera, bore sighted with the spectroradiometer. This camera provided an image record of the flight track of the aircraft, and was used to determine ground locations of the spectra recorded.

Analysis of the AIS Data

AIS data collected over the Sleeping Bear Dunes Test Site were analyzed at the Jet Propulsion Laboratory (JPL), Pasadena, California, in February 1984. Additional work was done with these data at JPL in April and July 1984. Based on the 35-mm Nikon photographs from the Nikon camera bore-sighted with the AIS, only Run 106 provided AIS data of both stressed plots at the Gilbert Lake site. This run was made with the AIS in grating position zero (GPOS-0) and data analysis was largely confined to the wavelength region between 1.0 and 1.6 um.

Plot locations were marked on aerial photographs on the basis of field measurements. Plot locations were transferred to the AIS image strips by intersection and resection from landmarks visible in both the aerial photographs and the AIS image strips. The specific AIS scan lines containing plot data were determined by counting scan lines in the AIS images from the first line of Run 106. The specific pixels containing plot information were determined by superimposing a scaled, transparent grid over the AIS images and reading the pixel number in the scan line from the grid.

Spectral curves were plotted from the AIS data with the JPL VICAR software. Curves were prepared for each plot and stand background. These were compared with the reflectance curves obtained with the Beckman DK2A spectrophotometer on August 7, 1983, the day the AIS data were acquired.

Analysis of Data from the Collins Airborne Spectroradiometer

Due to a communication error, data from the CAS were not received until late June 1984. Analyses of these data were begun in the Fall of 1984 and focused on determination of tree species. The Saginaw Forest data for August 9th were chosen as a starting point because most of the stands at that site are plantations containing only a single tree species.

Data were extracted for eight forest types and a lake within the forest boundaries (Table 1). A detailed description of this work was prepared by Zhu (1984). Using the MIDAS statistical package at the University of Michigan, Zhu compared species identification accuracies for different spectral bands and band combinations. Particular attention was given to the spectral bands of the Landsat TM sensor by comparing results obtained with sums of data for several Band Groups (Table 2). Data transformations included both Principal Components Analysis and the Linear Discriminant Function. The MIDAS clustering algorithm was used to group spectra into species groups on the basis of single spectral bands and Band Groups for both raw and transformed data.

Table 1. Number of spectra extracted for each of nine ground cover types at the Saginaw Forest Test Site.

Cover Type	Scientific Names	Number of Spectra
Red Oak	*Quercus rubra* L.	19
American Elm and Red Maple	*Ulmus americana* L. *Acer rubrum* L.	13
Black Walnut	*Juglans nigra* L.	13
Cottonwood	*Populus deltoides* Marsh.	3
Hickory	*Carya* spp.	4
Ponderosa Pine	*Pinus ponderosa* Laws.	13
Norway Spruce	*Picea abies* (L.) Karst.	15
Scots Pine	*Pinus sylvestris* L.	11
Third Sister Lake		14

All spectra were extracted from data collected on August 9, 1983, with the Collins Airborne Spectroradiometer.

Table 2. Spectral ranges of the Band Groups used in the data analyses and their equivalent Thematic Mapper channels.

Band Group	No. of Bands	Spectral Range (nm)	Equivalent TM Channel
1	48	450 - 520	1
2	54	520 - 600	2
3	42	630 - 690	3
4	136	760 - 960	4
5	14	1550 - 1750	5
6	18	2080 - 2350	7

The number of bands is the number of individual data points (wavelengths) from the Collins Airborne Spectroradiometer records used to represent the spectral range of each of the six reflective channels of the Landsat TM sensor.

RESULTS

Damage to the plot covers at Saginaw Forest allowed precipitation to reach the soil within the plots, essentially eliminating differences in moisture stress between the trees in the plots and those in the surrounding stands. This, plus heavy cloud cover on August 7th preventing AIS data acquisition of the Saginaw Forest plots, resulted in concentration of effort on data from the Gilbert Lake site.

Indicators of moisture stress in the Gilbert Lake plots are summarized in Table 3. Moisture tensions are shown in pounds per square inch, and the difference between a plot and its background is shown in bars (one bar is equivalent to 14.7 psi). The large increase in the moisture tension of the trees in the maple plot from August 6 to August 7 was the result of severe root pruning of the trees in the maple plot on the afternoon of August 6. All roots in the upper ten inches of soil, for approximately 100° around each tree, were cut about five feet back from the base of the tree. This action was taken to increase the level of stress in the trees in the plot in preparation for the overflight expected on August 7th or 8th.

Table 3. Indicators of moisture stress in the pine and maple plots at the Gilbert Lake Test Site in August 1983.

Moisture Stress Indicator and Cover Type	Date and Time of Sample Collection				
	8-5-83 1600	8-6-83 0900	8-7-83 1400	8-8-83 1300	8-12-83* 0800
Moisture Tension (from Scholander Cell)	psi	psi	psi	psi	psi
Maple - Control	50	80	102	84	20
Difference (in bars)	2.5	3.3	7.7	9.0	2.0
Maple - Stressed	87	99	215	217	49
Pine - Control	152	88	165	167	90
Difference (in bars)	9.4	9.6	9.2+	9.1+	1.4
Pine - Stressed	290	230	300+	300+	111
Foliar Moisture Content	-- as a percentage of oven-dry-weight --				
Maple - Control		170		168	
Maple - Stressed		155		153	
Pine - Control		106		102	
Pine - Stressed		68		57	

* Heavy rains occurred on August 10 and 11, 1983

The sharp drop in moisture tension for all trees following heavy rains on August 10th and 11th, indicated by the data for August 12th, indicate both the success of the treatments in producing higher than "normal" levels of moisture stress, and the effect of the rains in reducing moisture stress in the control trees which had not been covered.

Due to the difference in time of day at which the moisture tension data were collected, care must be taken in their interpretation. Moisture stress tends to peak each day at about 1400 hours (2 p.m.). Thus, only the data for August 7th and 8th represent times when moisture tension should be at, or close to the maximum for the day.

Although not as dramatic as the moisture tension differences, the foliar moisture content data also reveal some increase in moisture stress in trees within the covered plots. The greater difference between stressed and control trees in pine corresponds with the moisture tension data.

Stand tables summarizing the size-class distribution of trees in the two plots at Gilbert Lake are provided in Tables 4 and 5. The sugar maple plot was established in a natural forest stand. The red pine plot was established in a 30 year old plantation with an original spacing of approximately 6 x 8 ft. Both stands are on well-drained sites. Stocking levels, indicated by the basal areas of 99.8 ft^2 per acre in the maple stand and 155.8 ft^2 per acre in pine, are within the range of what is called "normal" for the area. The higher stocking in the pine stand should, however, result in greater water loss and contribute to the high levels of stress observed in pine than in maple. Also, the pine plot had been covered for a longer period than the maple plot and this would also contribute to the higher levels of moisture stress observed in pine.

Reflectance Measurements

Laboratory reflectance measurements made with foliage collected at the Gilbert Lake site on August 7, 1983 showed the stressed maple trees to be less reflective than the control maple trees at wavelengths from 1000 to 1300 nm, but more reflective than their controls between 1300 and 1600 nm

Table 4. Stand table for the stressed plot in the Sugar Maple stand at Gilbert Lake, Leelanau County, MI, as of August 17, 1983.

DBH (inches)	Number of Trees					Basal Area (square feet)		
	Sugar Maple	White Ash	Iron-wood	Black Cherry	Total	Sugar Maple	Other	Total
0.5- 2.9	6		5	1	12	0.102	0.100	0.202
3.0- 5.9	1				1	0.171		0.171
6.0- 9.9	2				2	0.730		0.730
10.0-13.9	4	1			5	3.213	0.785	3.998
14.0-17.9	3				3	2.540		2.540
18.0 +	2				2	3.920		3.920
Total	18	1	5	1	25	10.676	0.885	11.561
Per Acre	155	9	43	9	216	92.2	7.6	99.8

Table 5. Stand table for the stressed plot in the Red Pine plantation at Gilbert Lake, Leelanau County, MI, as of September 3, 1983.

DBH (inches)	Number of Trees				Basal Area (square feet)		
	Red Pine	Sugar Maple	Black Cherry	Total	Red Pine	Other	Total
0.5-2.9	8	1		9	0.275	0.029	0.304
3.0-3.9	9	1	1	11	0.604	0.142	0.746
4.0-4.9	36	1	1	38	4.106	0.218	4.324
5.0-5.9	50			50	8.141		8.141
6.0-6.9	29			29	6.426		6.426
7.0-7.9	2			2	0.566		0.566
Total	134	3	2	139	20.118	0.389	20.507
Per Acre	1018	23	15	1056	152.9	2.9	155.8

(Figure 5). The stressed pine were also less reflective than the control pine at wavelengths from 1000 to 1300 nm. Unlike the maple, the two reflectance curves for pine do not cross around 1300 nm, but continue to approach each other and then begin to separate at wavelengths longer than 1500 nm with the stressed foliage remaining somewhat less reflective than its controls (Figure 6). This difference does not increase with increasing wavelength in pine, but does with maple. In fact, the greatest absolute and relative differences in reflectance between stressed and control maple trees were observed at wavelengths between 2000 and 2400 nm (Figure 7).

Analysis of AIS Data

Locations of the AIS coverage for the several aircraft runs at the Sleeping Bear Dunes Test Site on August 7, 1983, are included in Appendix I. Only Run 106 provides data for both of the stressed plots at Gilbert Lake. Run 108 provides coverage of the red pine plot, but not the sugar maple plot.

Spectral curves plotted from the AIS data from Run 106 are shown in Figures 8 and 9, for the sugar maple and red pine plots respectively. The curves for maple show lower reflectance by the stressed plot than by the stand background from AIS Channel 1 through AIS Channel 15, but higher reflectance from AIS Channel 18 through AIS Channel 24. These intervals correspond to the spectral bands from 1145 to 1295 nm and from 1315 to 1385 nm. The differences recorded by the AIS, and the "cross-over" near 1300 nm, are quite similar to the results of the laboratory reflectance measurements (Figure 5).

The curves plotted from the AIS data for red pine show the stressed plot to be less reflective than the stand background from AIS Channel 5 through AIS Channel 24 (1185 to 1385 nm). These results are similar to those obtained with laboratory measurements (Figure 6).

Run 117 provided AIS data crossing several meanders of the Crystal River. In addition to present river meanders, the area also includes several abandoned river channels. Both present and former channels were confined between beach ridges formed during glacial retreat, some 13,000 years ago. These ridges are nearly concentric with the present shoreline of Lake Michigan. Although only two to five feet high, the ridges result in an alternating series of upland, transition, and lowland types.

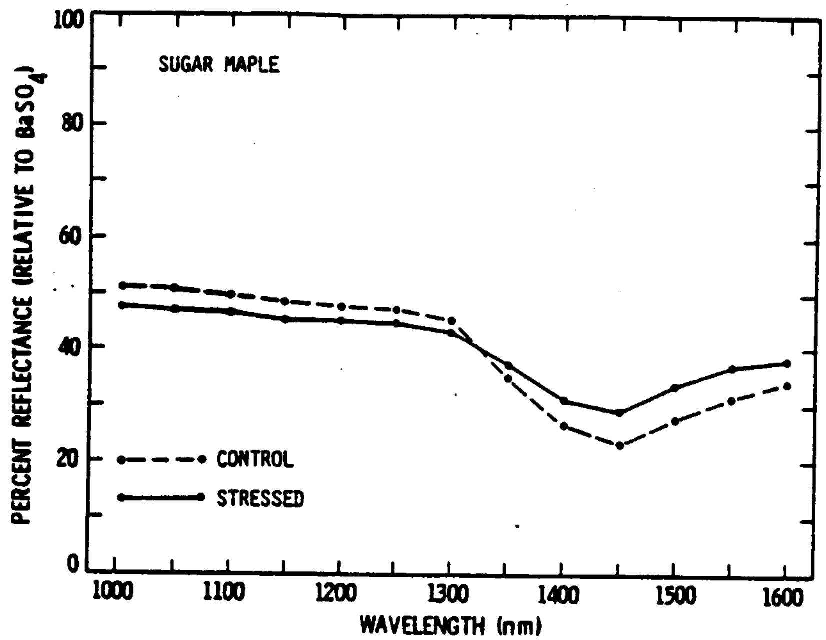


Figure 5. Hemispherical spectral reflectance from the upper surface of sugar maple leaves from both control and stressed trees at the Gilbert Lake Test Site, August 7, 1983.

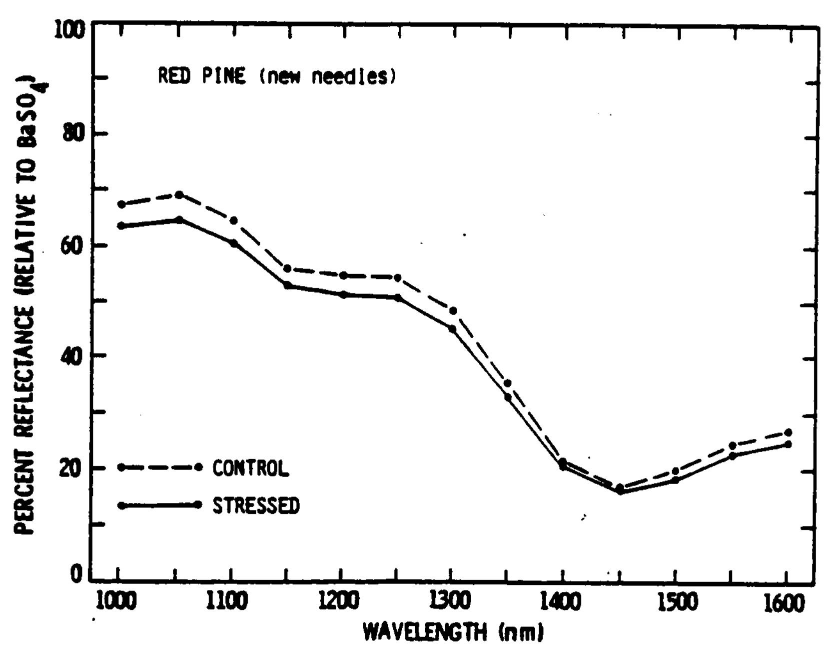


Figure 6. Hemispherical spectral reflectance from new needles from red pine from both control and stressed trees at the Gilbert Lake Test Site, August 7, 1983.

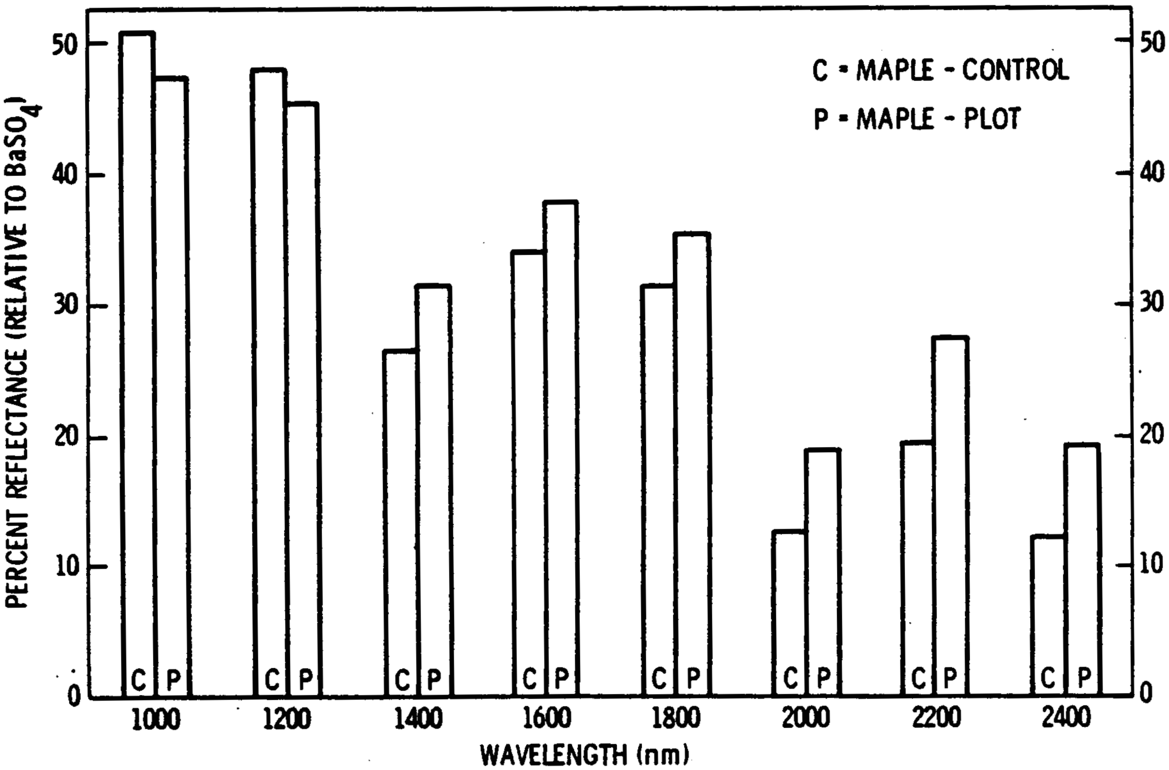


Figure 7. Histograms of reflectance from leaves from control and stressed [plot] sugar maple trees at the Gilbert Lake Test Site, August 7, 1983. The greatest absolute and relative differences observed are at the longer wavelengths: 2000, 2200, and 2400 nanometers.

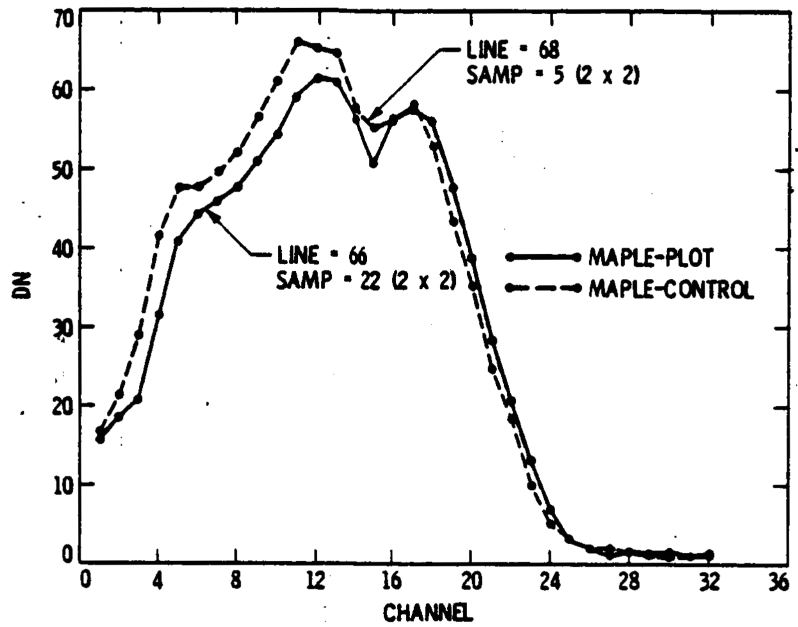


Figure 8. Brightness [DN] recorded in 32 channels of the Airborne Imaging Spectrometer for a stressed maple plot and the surrounding stand as a control. Data taken from the August 7, 1983, overflight of the Gilbert Lake Test Site.

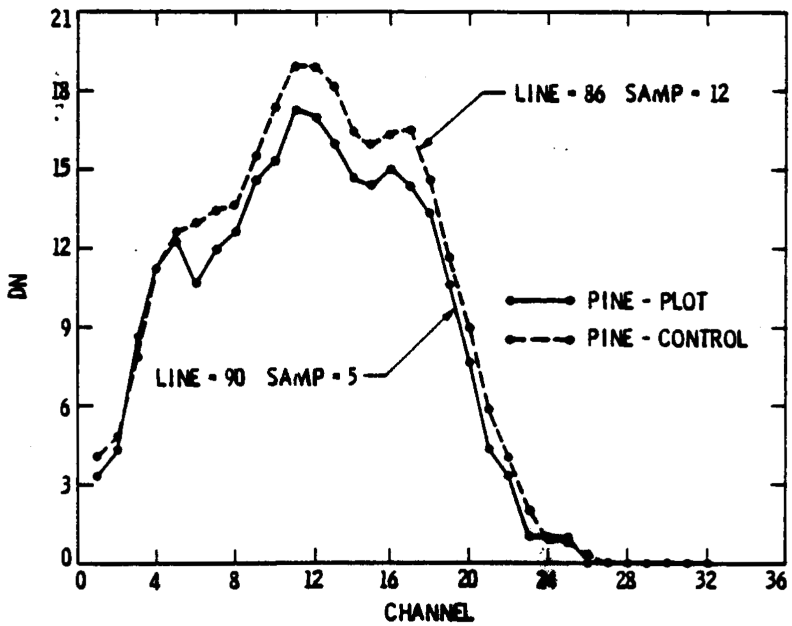


Figure 9. Brightness [DN] recorded in 32 channels of the Airborne Imaging Spectrometer for a stressed red pine plot and the surrounding stand as a control. Data taken from the August 7, 1983, overflight of the Gilbert Lake Test Site.

A linear enhancement of AIS Channels 2 through 17 from Run 117 produced detectable differences in a pattern similar to the known pattern of ridges and low channels. Within the larger lowland types, differentiations within the type in Channels 8 through 11 (1215 to 1255 nm) appear to be species related. In upland areas, similar differentions are evident in Channels 9 through 13 (1225 to 1275 nm). A 60 nm wide band encompassing both of these narrower spectral bands would include cross-overs which could mask the narrow band information.

Analysis of the CAS Data

Examples of spectral curves from the CAS data collected over Saginaw Forest on August 9, 1983, are shown in Figure 10. The most obvious differences between species occur in the near-infrared between 700 and 1000 nm, where broadleaved trees are typically more reflective than conifers. Cottonwood was the exception to this general rule, probably because the fall color change had already begun in this species.

The MIDAS clustering algorithm was used to make an unsupervised classification of the spectra. Clusterings were completed for each Band Group, for optimal bands selected from each Band Group by principal components analysis, for each of the first six principal component axes, and for optimal bands selected from each Band Group with the linear discriminant function. One set of analyses considered only three cover classes: water, broadleaved forest and conifer forest. A second set of analyses considered five cover classes: water; oak, hickory and walnut; elm and maple; pines; and spruce. Classification accuracy exceeded 80 percent in the three-class tests only for Band Group 4, PCA selected bands from Band Group 4, and LDF selected bands from Band Groups 4, 5, and 6. In the five-class test, no Band Group or combination of selected bands provided an accuracy above 75 percent.

PCA showed the first principal component accounted for more of the variance in Band Groups 1 through 4 than in Band Groups 5 and 6 (Table 6). When all Band Groups were considered together, the first component accounted for a much lower proportion of the total variance. In every case, however, the first two components accounted for over 95 percent of the variation in the data set.

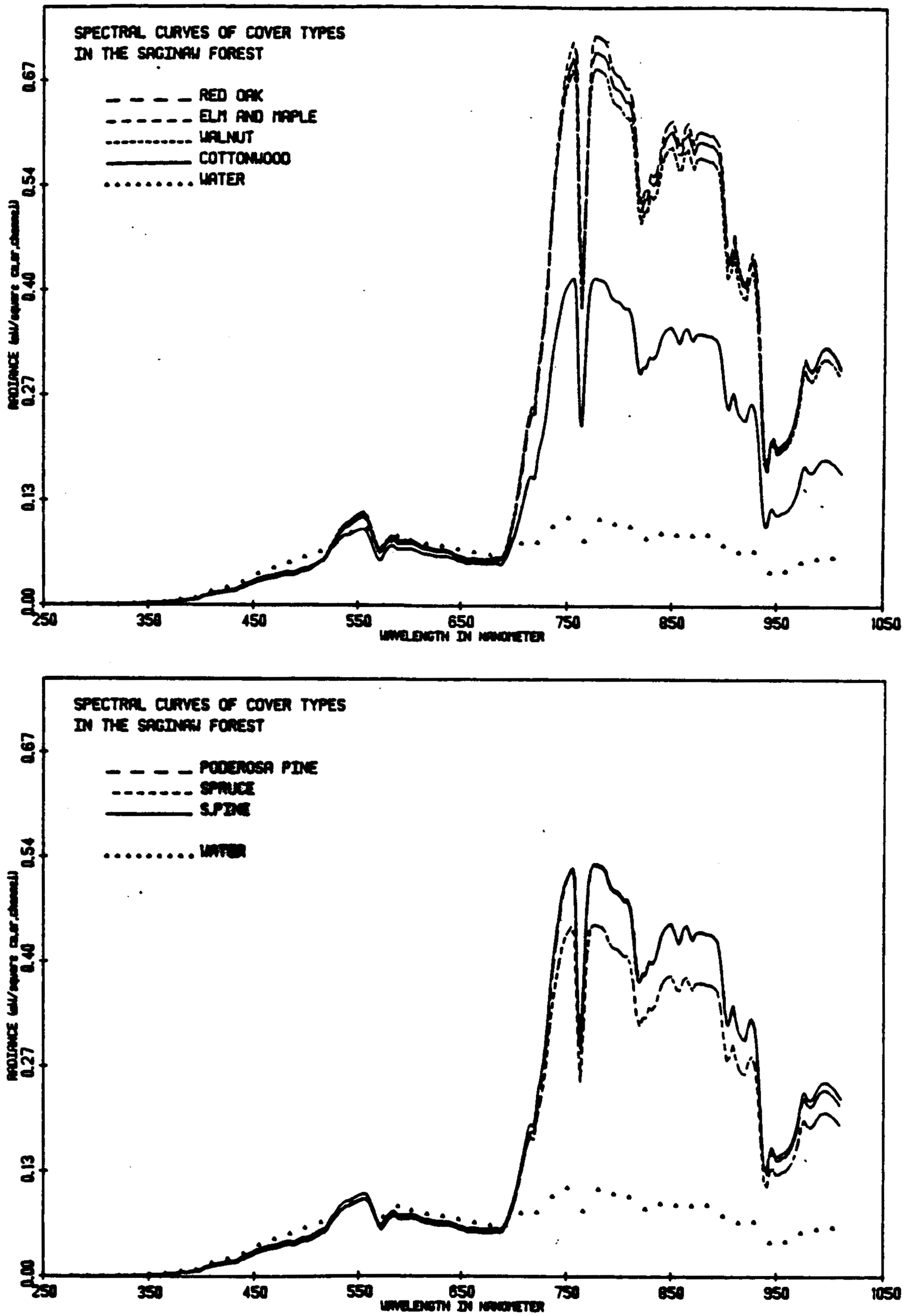


Figure 10. Spectral curves for eight land cover classes at the Saginaw Forest Test Site extracted from data collected with the Collins Airborne Spectroradiometer on August 9, 1983.

Table 6. Cumulative variance (in percent) associated with the first two Principal Components axes for Band Groups and the combined bands. (From: Zhu, 1984)

Data Subset	PC axis 1	PC axes 1 + 2
Band Group 1	97.72	99.74
Band Group 2	91.72	98.49
Band Group 3	97.61	98.95
Band Group 4	99.86	99.98
Band Group 5	77.43	99.87
Band Group 6	74.52	99.44
Combined Bands	58.85	96.00

Table 7. Classification accuracy using the linear discriminant funtion in a supervised classification of land cover types based on data from the Collins Airborne Spectroradiometer for the Saginaw Forest Test Site, August 9, 1983.

Band Group	Nine Cover Types			Hardwoods/Conifers		
	Subset 1	Subset 2	All	Subset 1	Subset 2	All
Group 1	91.1	61.2	77.0	83.7	88.1	85.8
Group 2	87.6	51.0	70.4	83.7	90.5	86.8
Group 3	85.7	48.8	68.7	75.5	92.9	83.6
Group 4	87.5	55.0	72.3	79.6	90.5	84.6
Group 5	51.8	40.8	46.6	81.6	90.5	85.7
Group 6	51.8	47.0	49.5	83.7	81.0	82.4
Combined	94.7	63.2	80.0	89.8	*	90.1

* Accuracy not available

Because better results had been obtained with the LDF, it was decided to attempt a supervised classification with the LDF. Spectra for each cover type were divided into two groups. One group became the training set for that class, and the second group was kept for testing classification accuracy. Analyses were made for a two-class case (broadleaved and conifer forests) and for all nine cover classes. Results for the combined bands from all Band Groups showed an accuracy of 80 percent when all nine classes were considered (Table 7). Band Group 1 provided almost as good results as the combination of all Band Groups. When the LDF was used to identify the nine best individual CAS bands from among the 312 bands considered in the analysis, six came from Band Group 1 (455, 459, 471, 486, 496 and 513 nm), one from Band Group 2 (557 nm), one from Band Group 5 (1,684 nm) and one from Band Group 6 (2,222 nm).

DISCUSSION

Specific objectives of the work covered by this report were to begin determining the extent to which high spectral resolution, aircraft data in the 1.2 to 2.4 um spectral region could improve accuracy of identification of forest and wildland vegetation types, and facilitate determination of plant vigor or plant stress in forest and wildland ecosystems.

Identification of Forest and Wildland Cover Types

Data processing and image generation which should have permitted determination of the accuracy of cover type identifications from the AIS data of the Sleeping Bear Test Site were nullified when queueing problems at JPL prevented printing of the results. Manual analyses of AIS data from Runs 106 (Gilbert Lake) and 117 (Crystal River) provided some information. Separation of broadleaved from coniferous forest, and forest from all other cover types, was not difficult. Spot checks produced accuracies in identification of the two forest classes above 90 percent in upland areas, and above 85 percent in the undulating upland/wetland areas along the Crystal River meanders.

Results with the CAS data of Saginaw Forest indicate there is a great deal of species information in the short wavelengths of TM Band 1 (450 to 520 nm) if it can be separated from atmospheric noise. Increasing knowledge of atmospheric scattering and modelling of atmospheric transmission make it increasingly likely that ways can be found to separate the terrain reflectance from the atmospheric noise. This liklihood makes inclusion of several shorter wavelength bands in an enhanced AIS-type sensor at least desirable.

The flightline covered by Run 117 was deliberately chosen to provide a severe test of the utility of AIS data in discriminating between wildland cover types. Cover type information from the Michigan Resource Information System (MIRIS) was used as ground reference data for initial determinations of classification accuracy. This map, compiled from 1:24,000 scale color-infrared aerial photographs and field checked, was used by Ma (1985) in comparing the accuracy of forest cover classification from Landsat MSS and TM data. Ma reported lower accuracies with TM data than with MSS data, and attributed this to the greater spatial resolution of the TM. The ground reference data were compiled with a five-acre minimum type size, and classifications from TM data were breaking up mixed cover types into their component parts. The even greater spatial resolution of the AIS data made it necessary to conduct additional ground work to identify cover type on a nearly pixel by pixel basis. This work was incomplete at the end of the 1985 field season.

Preliminary results of the pixel by pixel comparison of the AIS data with ground information on cover type appear to reveal narrow spectral band information unattainable with a broad-band system such as the Landsat TM. More importantly, there is no spectral band in the Landsat TM which records in the 1200 to 1300 nm region where species information seems apparent.

Analysis of the 1983 data set included preparation of several enhanced images of the Crystal River area from the NS-001 Thematic Mapper Simulator records. Channel 5 of the NS-001 records the 1000 to 1300 nm band. Best results for discrimination of forest and wildland cover types were achieved with a color-composite prepared from the 630 to 690, 1550 to 1750, and 1000 to 1300 nm bands, color-coded blue, green, and red, respectively. This result adds weight to the conclusion that the 1200 to 1300 nm spectral band contains important information related to species differences.

Determination of Plant Vigor/Stress

Results of the moisture stress experiment at Gilbert Lake indicate reflectance differences related to moisture stress can be detected with AIS data. Because notification of the date of the overflight was received only 90 minutes before the C-130 aircraft arrived over the test site, it is possible the plastic cover had not been removed from the maple plot before the first run was made. This was Run 106, the only run providing data of the maple plot. Careful interpretation of the 9x9 color-infrared aerial photographs taken during this, and all subsequent runs, reveal no indication of the cover at the plot location. Markers pointing to the pine plot, placed after the cover was removed from that plot, are clearly evident in the photographs. Markers pointing to the maple plot were placed after the cover had been completely removed, but are not visible in any of the photographs.

The possibility of anomalous reflectance from the maple plot as a result of the plastic cover remaining in place was explored. Reflectance data were collected for litter from the forest floor within the maple plot, and reflectance and transmission determined for the plastic cover material (Figure 11). In the spectral region between 1000 and 1600 nm, reflectance and transmission of the plastic cover are nearly constant at 10 and 90 percent, respectively. Reflectance of the two litter samples was essentially 50 percent. Modelling of total reflectance from the plot, with and without the cover in place, revealed the presence of the cover might increase reflectance from the forest floor by two percent; from 50 percent without the cover to 52 with the cover in place (Figure 12). Adjustment of the spectral curve for the maple plot derived from the AIS data showed no change in the basic relationship between stressed and control trees reported earlier, other than a one channel shift towards shorter wavelengths of the cross-over near 1300 nm.

All other data collected during Run 106 were studied to see if the reflectance differences between the stressed plots and their stand backgrounds could be detected. These attempts were unsuccessful, even with extensive manipulation and enhancement of each of the spectral bands of the NS-001 Thematic Mapper Simulator. A distinct information gain when using high spectral resolution data, is indicated.

Unfortunately, the storm which destroyed the covers on the stressed plots at Saginaw Forest also destroyed the replications of the stress conditions. Corroborating results from the Saginaw Forest plots would have greatly enhanced conclusions which seem appropriate from the work at Gilbert Lake. Without this corroboration, additional tests are needed before conclusions can be drawn with assurance.

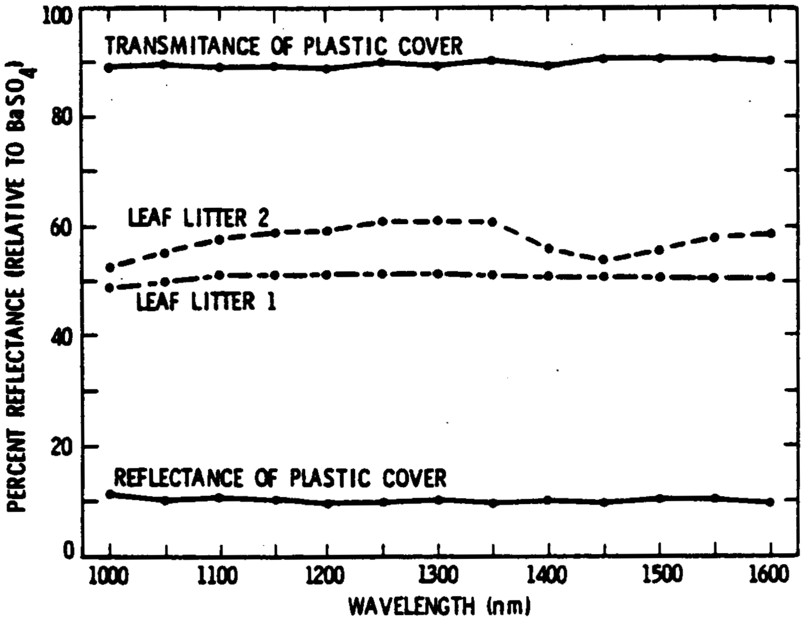


Figure 11. Hemispherical reflectance curves for two samples of leaf litter on the ground in the sugar maple plot at the Gilbert Lake Test Site, August 7, 1983, and reflectance and transmittance curves for the plastic material used in the plot cover.

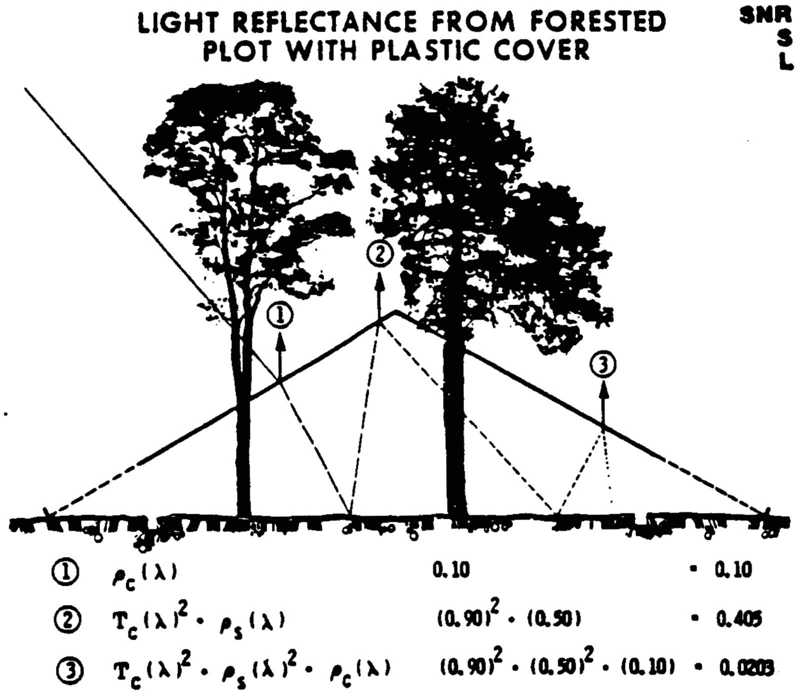


Figure 12. Schematic diagram of the modelling of reflectance from the maple plot with the plastic cover in place. Reflectance of the leaf litter alone was 50 percent, and total upwelling from the forest floor with the cover in place would be approximately 52 percent.

RELATED STUDIES

Two studies which were not part of the original work plan have resulted from the work already described. One utilized the August 1983 9x9 inch aerial photographs for an analysis of the effects of changing bi-directional reflectance from forest canopies on accuracy of species determination. The second is using NS-001 data to analyze underwater habitats related to snail colonies which are the alternate host for the "swimmers' itch" parasite.

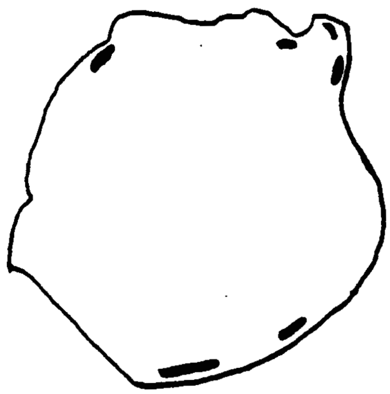
Bi-directional Reflectance

Aerial photographs taken during the several runs over the Gilbert Lake site provided repeated coverage of several forest stands with the stands in different parts of the photographs on each run. These different photo locations represent different bi-directional reflectance angles for these stands. Measurements from the photographs with a Carlson T/R-400 densitometer revealed changes in apparent brightness of the several stands are predictably related to the compound angle between the incident solar energy and the outgoing reflected light to the camera (the bi-directional reflectance angle). This information was used to improve accuracy of forest type identification from color-infrared aerial photographs (Laverne, 1984).

Swimmers' Itch

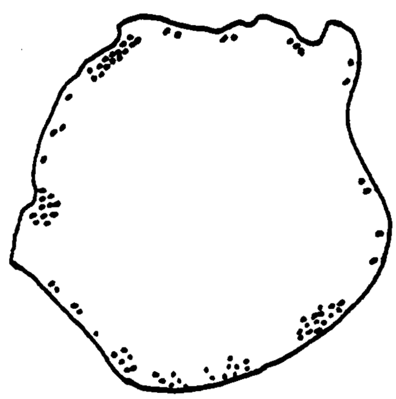
In August 1983, a study of the life history of the parasite (*Shistosoma dermatitus*) responsible for "swimmers' itch" in humans was being conducted in Glen Lake. The study was led by Dr. Harvey Blankespoor of Hope College, and based at The Leelanau Center for Education.

The August 7, 1983 flight program included a run across Glen Lake with the NS-001 operating. Data from Channel 1 (0.45 to 0.52 um), Channel 2 (0.52 to 0.60 um) and Channel 3 (0.63 to 0.69 um) show underwater detail with several anomalous, dark-toned areas in the shallow, near-shore zone. Discussion of these observations with staff from the swimmers' itch study revealed a close correlation between these anomalous areas and known locations of colonies of the snails (*Lymnea catascopium* and *Physa integra*) which are the alternate hosts for *Shistosoma dermatitus* (Figure 13). The reason(s) for this correlation have not been adequately explained, but the anomalous areas are also detectable, at the same locations, in Landsat TM data from October 1982.

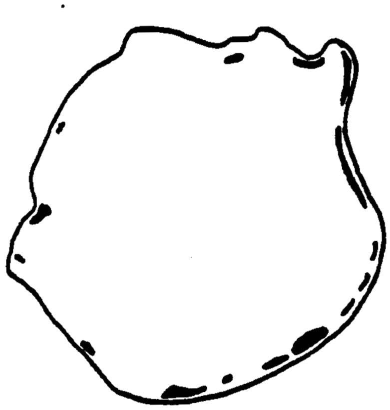


a. Locations of areas treated with copper sulfate during the second week of June 1983.

b. Locations of live colonies of snails (*Lymnea catascopium* and *Physa integra*) serving as alternate hosts for the "swimmers' itch" parasite (*Shistosoma dermatitus*). Locations based on surface reconnaissance during the third and fourth weeks of July 1983.



c. Locations of reported cases of "swimmers' itch" during the 1983 summer season.



d. Locations of brightness anomalies in shallow water areas observed in Thematic Mapper Simulator (NS-001) data collected on August 7, 1983.

Figure 13. Summary of information related to "swimmers' itch" in Big Glen Lake for the summer of 1983.

A POSTSCRIPT

On July 19, 1984 the NASA-Ames C-130 obtained additional AIS data for the Crystal River sub-area of the Sleeping Bear Dunes Test Site. Analysis of the 1984 data was begun at JPL in April 1985 using the SPAM software. Images to be field-checked during the 1985 field season were queued to the printer but lost when the queueing tape was accidentally erased before being printed. Some images were regenerated from records of the initial analysis session, but prints were not received in time to be field-checked in 1985. Some interpretations have been possible by comparing 1984 data with that obtained in 1983.

Run 404, flown from south to north, provided excellent AIS data crossing the ground track of Run 117 from August 7, 1983. In the area common to both Run 117 and Run 404, species distinctions observed in 1983 were also apparent in 1984. Some of the features detected appear to be former channels of the Crystal River not previously identified as such.

Logs of some of the analysis sessions include "HARDCOPY" records of spectral curves derived from the AIS data and displayed on the monitor screen at the work station. The spectral curves shown in Figure 14 are from Run 404. The curves for alder, (*Alnus* sp.), spruce (*Picea mariana* (Mill.) BSP), and aspen (*Populus grandidentata* Michx.) are three of the species being discriminated from the AIS data. Large differences between these species are evident in the 1.2 to 1.4 um and 1.55 to 1.85 um spectral bands. This latter band ~~is~~ represented in the Landsat TM as Channel 5, but the former is not include~~d~~ in any TM channel.

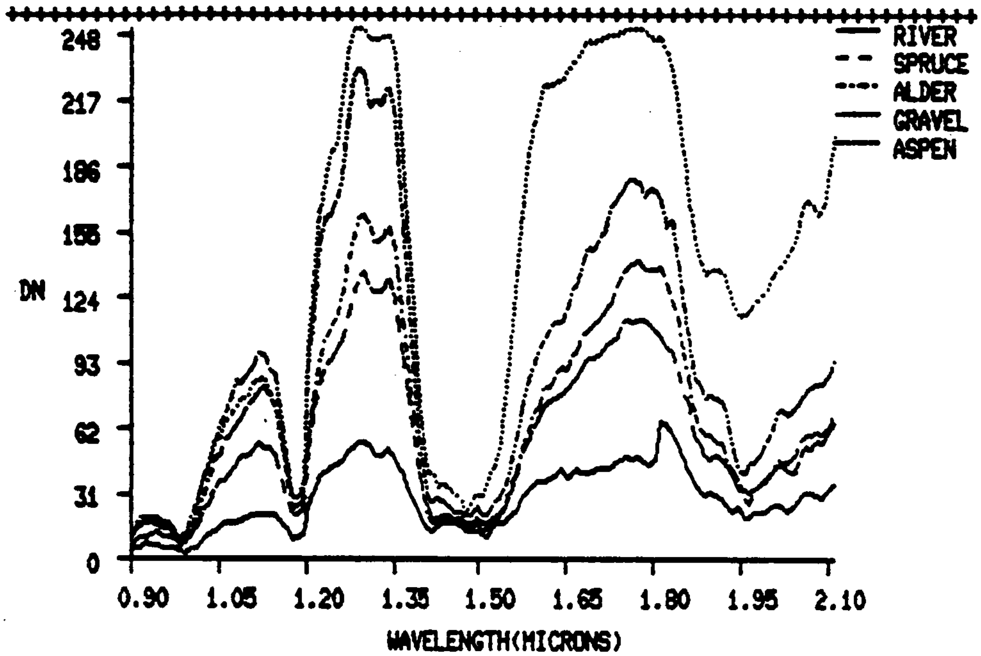


Figure 14. Sample spectral plots of brightness [DN] over wavelength for five ground cover classes at the Crystal River Test Site, July 11, 1984. Data are from Run 404.

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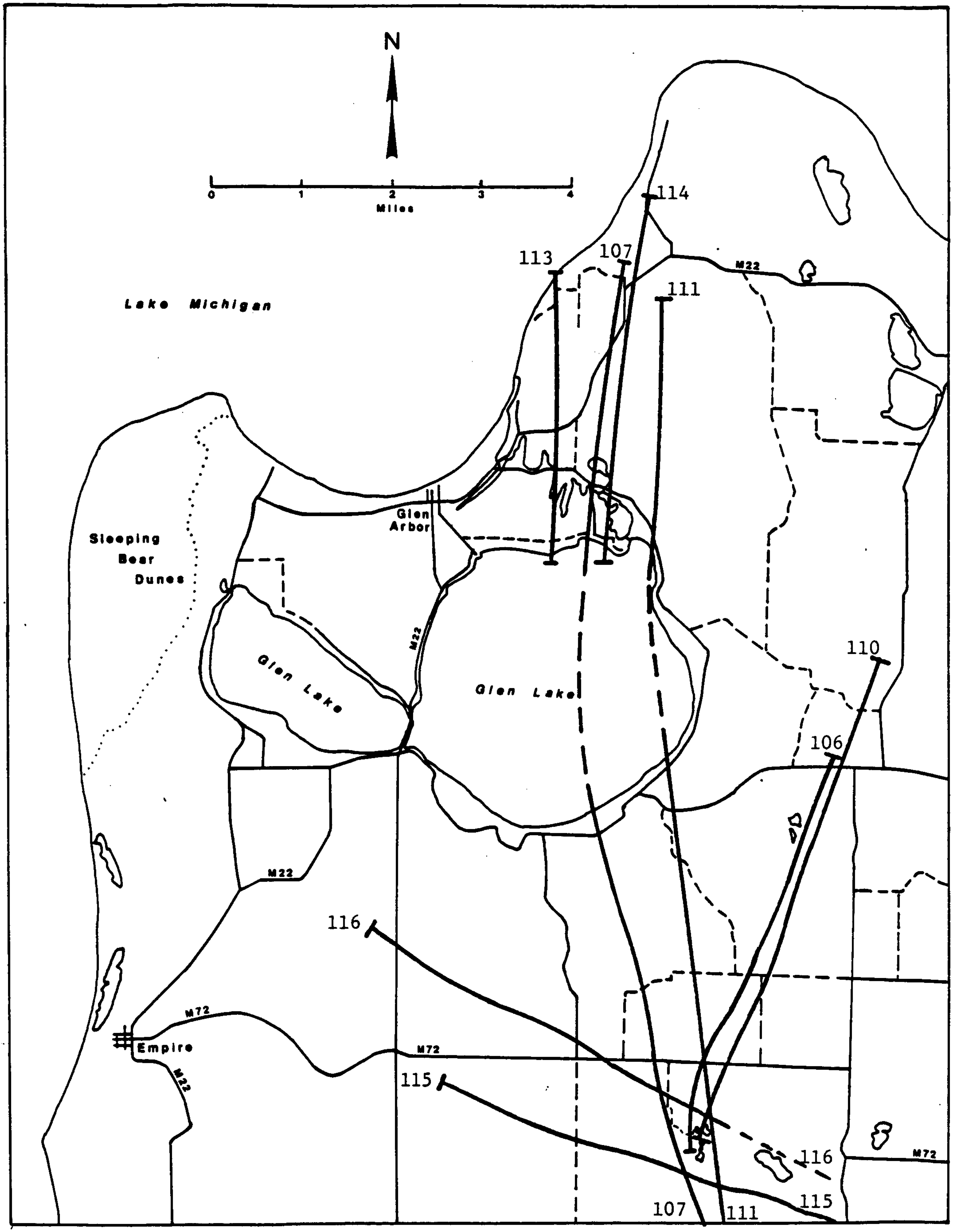
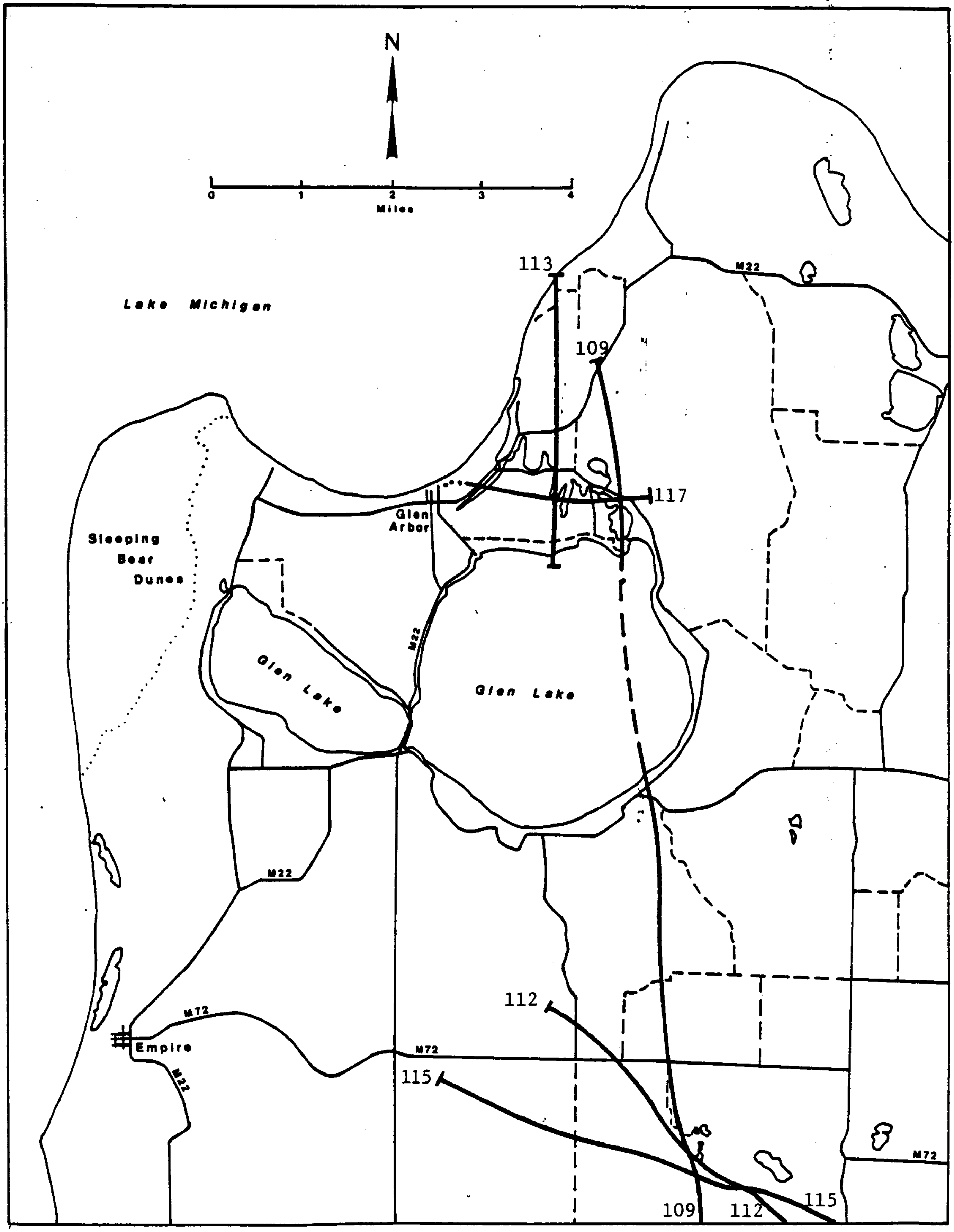
APPENDIX I. GROUND COVERAGE MAPS FOR SEVERAL FLIGHT LINES OVER THE SLEEPING BEAR DUNES TEST SITE, AUGUST 7, 1983

NASA-AMES C-130 Flight Number 83-008-03

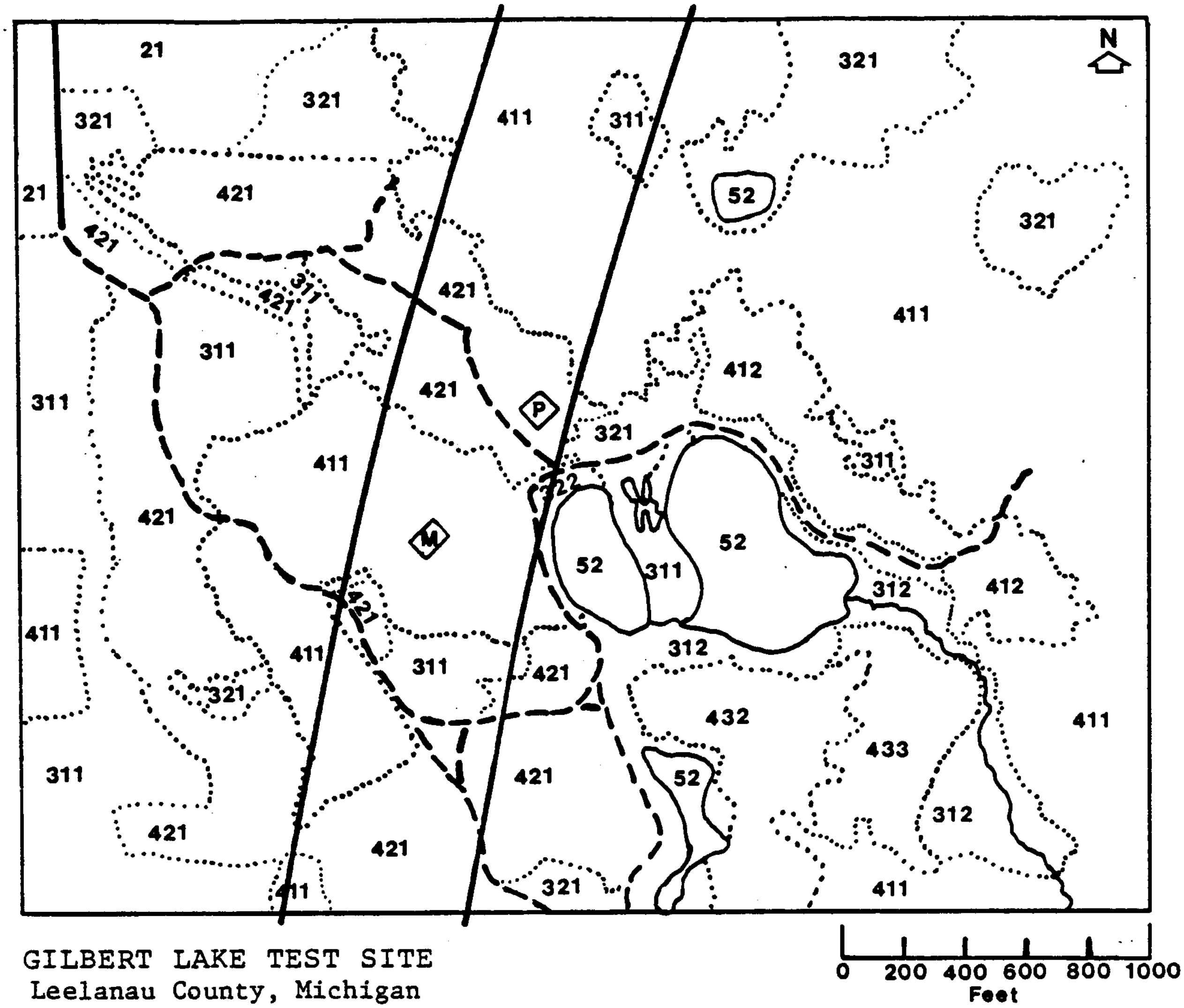
* This run was part of NASA-AMES C-130 Flight Number 84-006-02



APPROXIMATE FLIGHT TRACKS FOR SEVERAL RUNS BY THE NASA-AMES C-130, AUGUST 7, 1983, FLIGHT NUMBER 83-008-03.



APPROXIMATE FLIGHT TRACKS FOR SEVERAL RUNS BY THE NASA-AMES C-130, AUGUST 7, 1983, FLIGHT NUMBER 83-008-03.

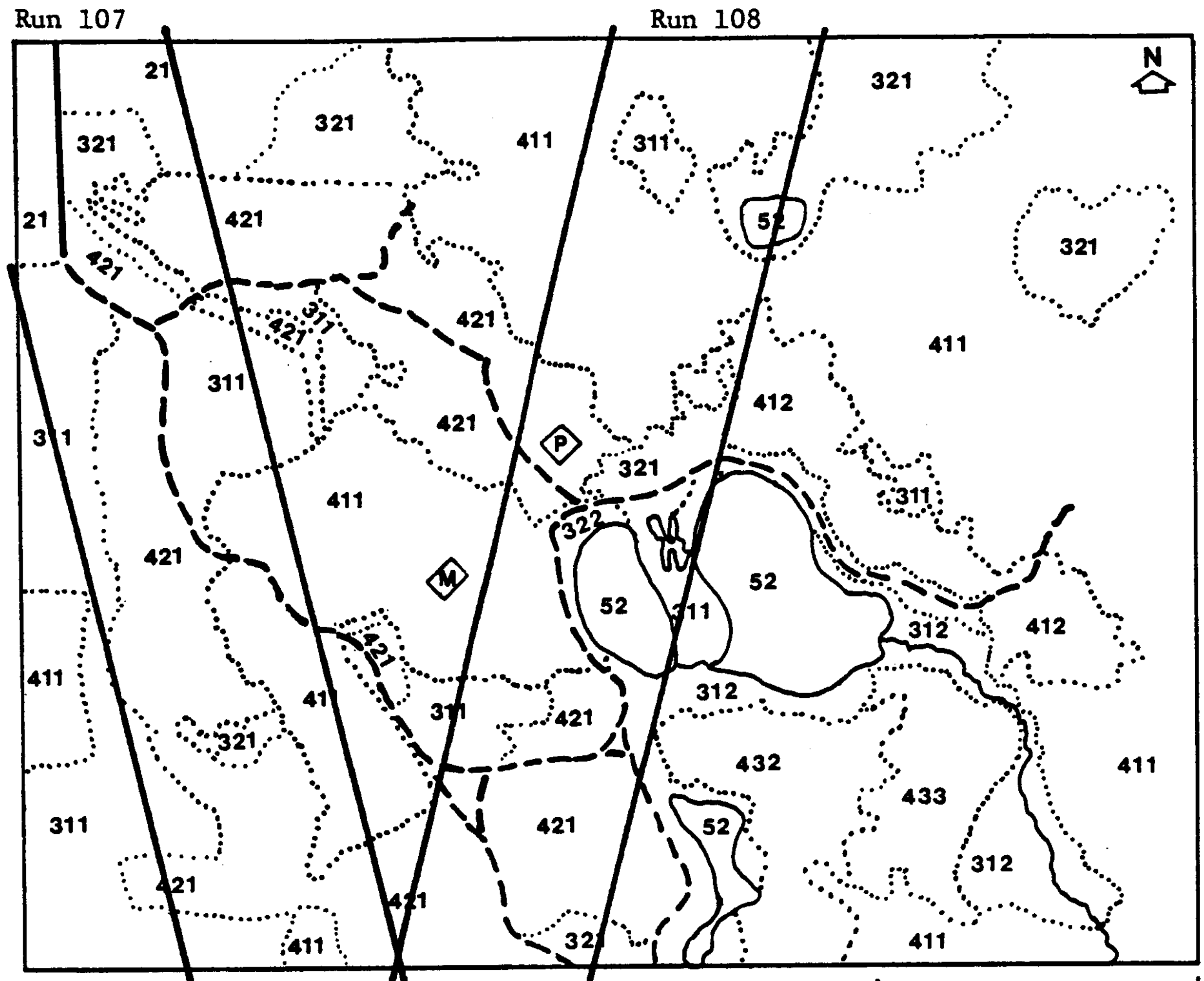


GILBERT LAKE TEST SITE
Leelanau County, Michigan

<u>Cover Type Legend</u>

21	Cropland	421	Upland conifers [plantation]
311	Upland herbaceous rangeland	432	Aspen-balsam association
312	Lowland herbaceous rangeland	433	Red maple, ash, and balsam
321	Upland shrub rangeland	52	Lakes and ponds
322	Lowland shrub rangeland	M	Maple plot [stressed, 1983]
411	Upland hardwoods	P	Pine plot [stressed, 1983]
412	Upland aspen association		

APPROXIMATE AIS GROUND TRACK: Run 106
August 7, 1983



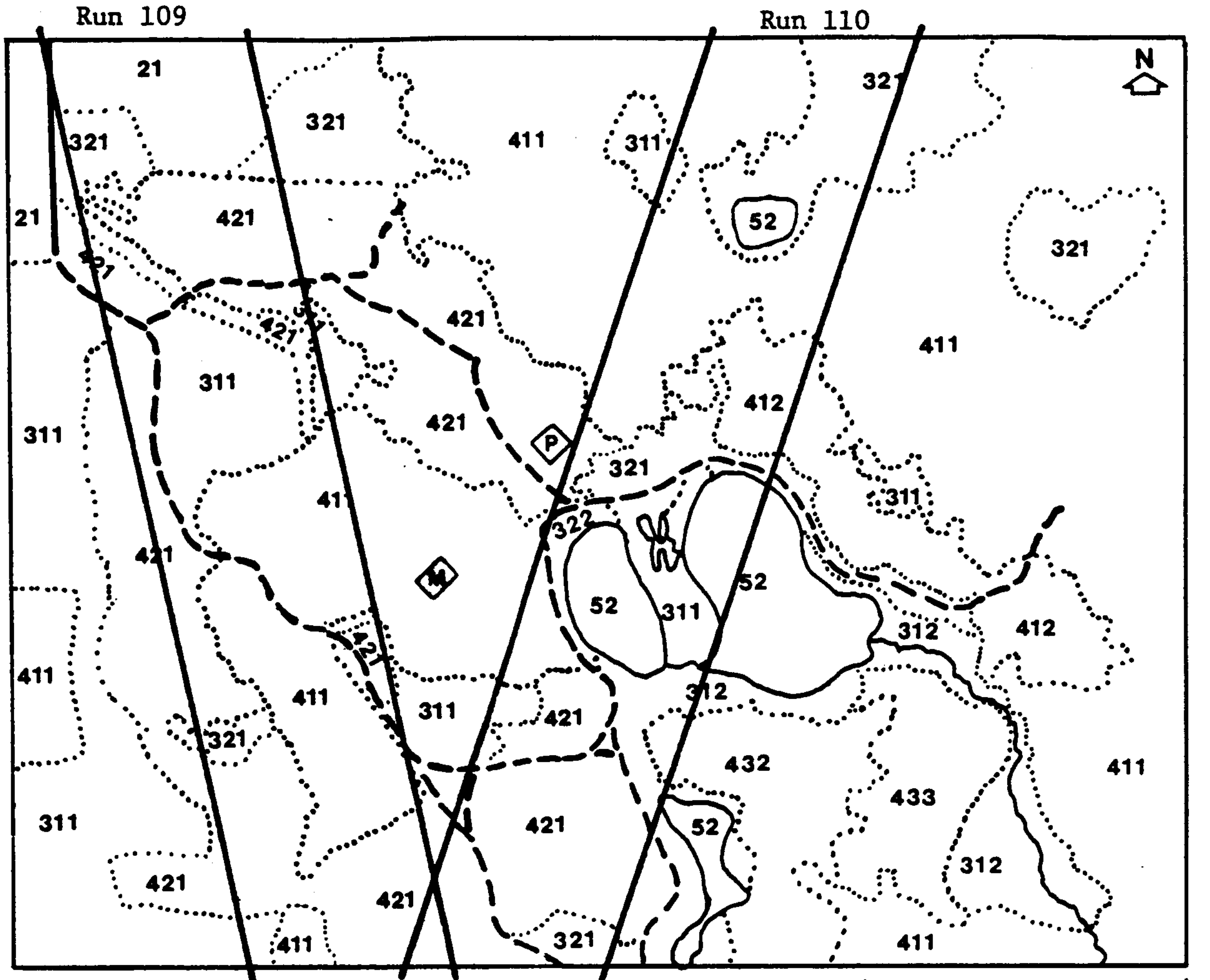
GILBERT LAKE TEST SITE
Leelanau County, Michigan

0 200 400 600 800 1000
Feet

Cover Type Legend

21	Cropland	421	Upland conifers [plantation]
311	Upland herbaceous rangeland	432	Aspen-balsam association
312	Lowland herbaceous rangeland	433	Red maple, ash, and balsam
321	Upland shrub rangeland	52	Lakes and ponds
322	Lowland shrub rangeland	M	Maple plot [stressed, 1983]
411	Upland hardwoods	P	Pine plot [stressed, 1983]
412	Upland aspen association		

APPROXIAMTE AIS GROUND TRACKS: Runs 107 and 108
August 7, 1983



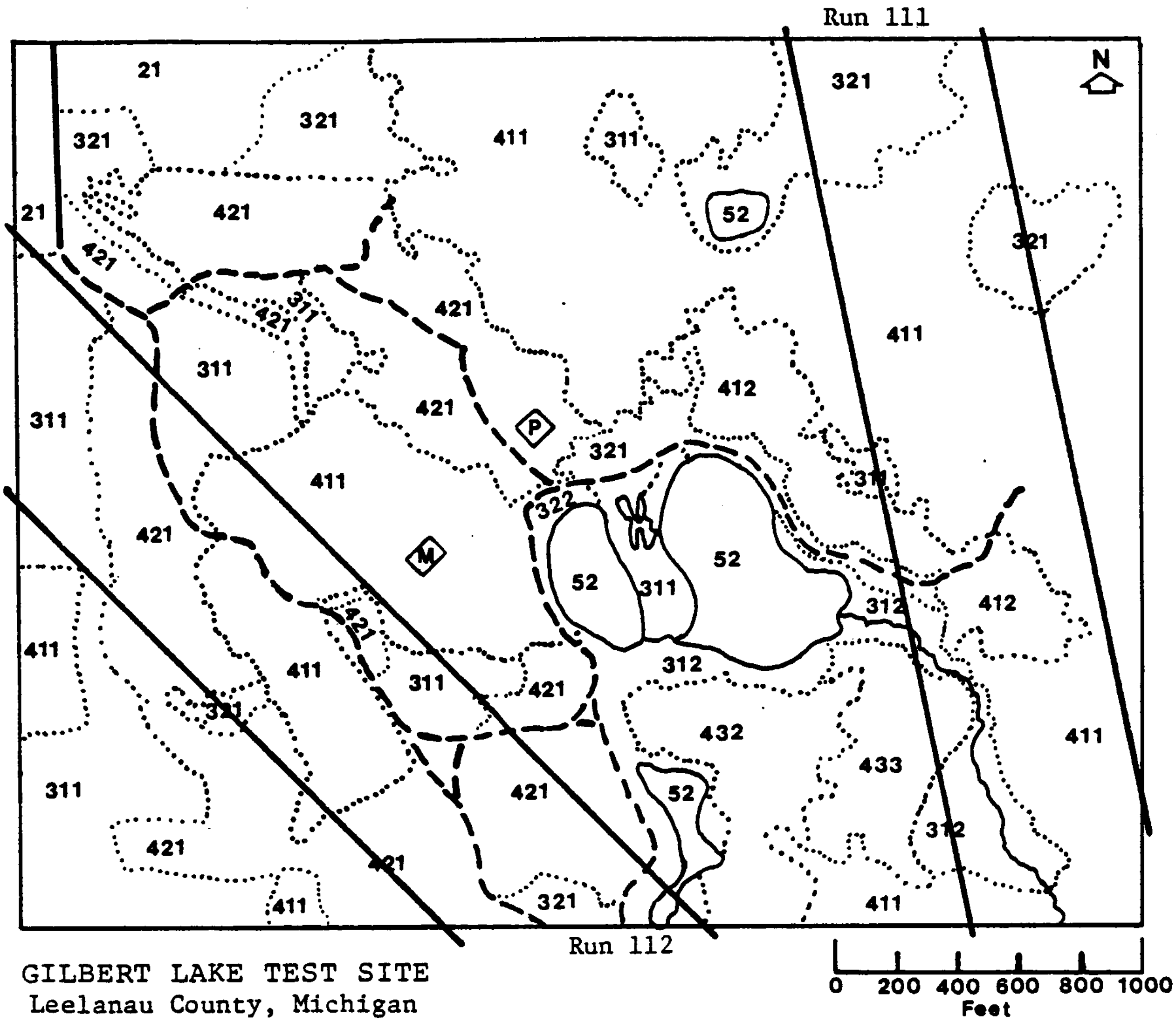
GILBERT LAKE TEST SITE
Leelanau County, Michigan

0 200 400 600 800 1000
Feet

Cover Type Legend

21	Cropland	421	Upland conifers [plantation]
311	Upland herbaceous rangeland	432	Aspen-balsam association
312	Lowland herbaceous rangeland	433	Red maple, ash, and balsam
321	Upland shrub rangeland	52	Lakes and ponds
322	Lowland shrub rangeland	M	Maple plot [stressed, 1983]
411	Upland hardwoods	P	Pine plot [stressed, 1983]
412	Upland aspen association		

APPROXIMATE AIS GROUND TRACK: Runs 109 and 110
August 7, 1983

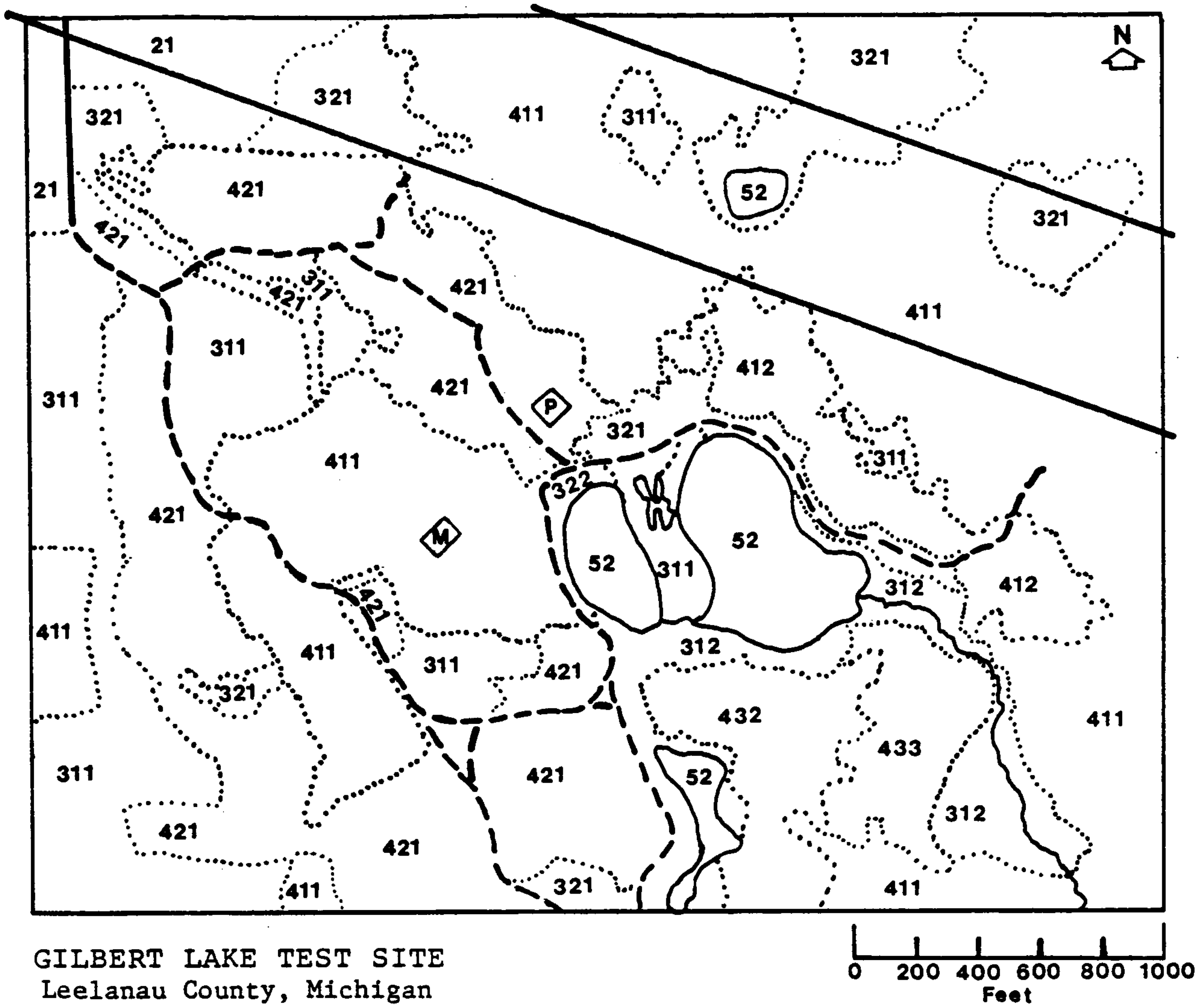


GILBERT LAKE TEST SITE
Leelanau County, Michigan

Cover Type Legend

21	Cropland	421	Upland conifers [plantation]
311	Upland herbaceous rangeland	432	Aspen-balsam association
312	Lowland herbaceous rangeland	433	Red maple, ash, and balsam
321	Upland shrub rangeland	52	Lakes and ponds
322	Lowland shrub rangeland	M	Maple plot [stressed, 1983]
411	Upland hardwoods	P	Pine plot [stressed, 1983]
412	Upland aspen association		

APPROXIMATE AIS GROUND TRACKS: Runs 111 and 112
July 7, 1983



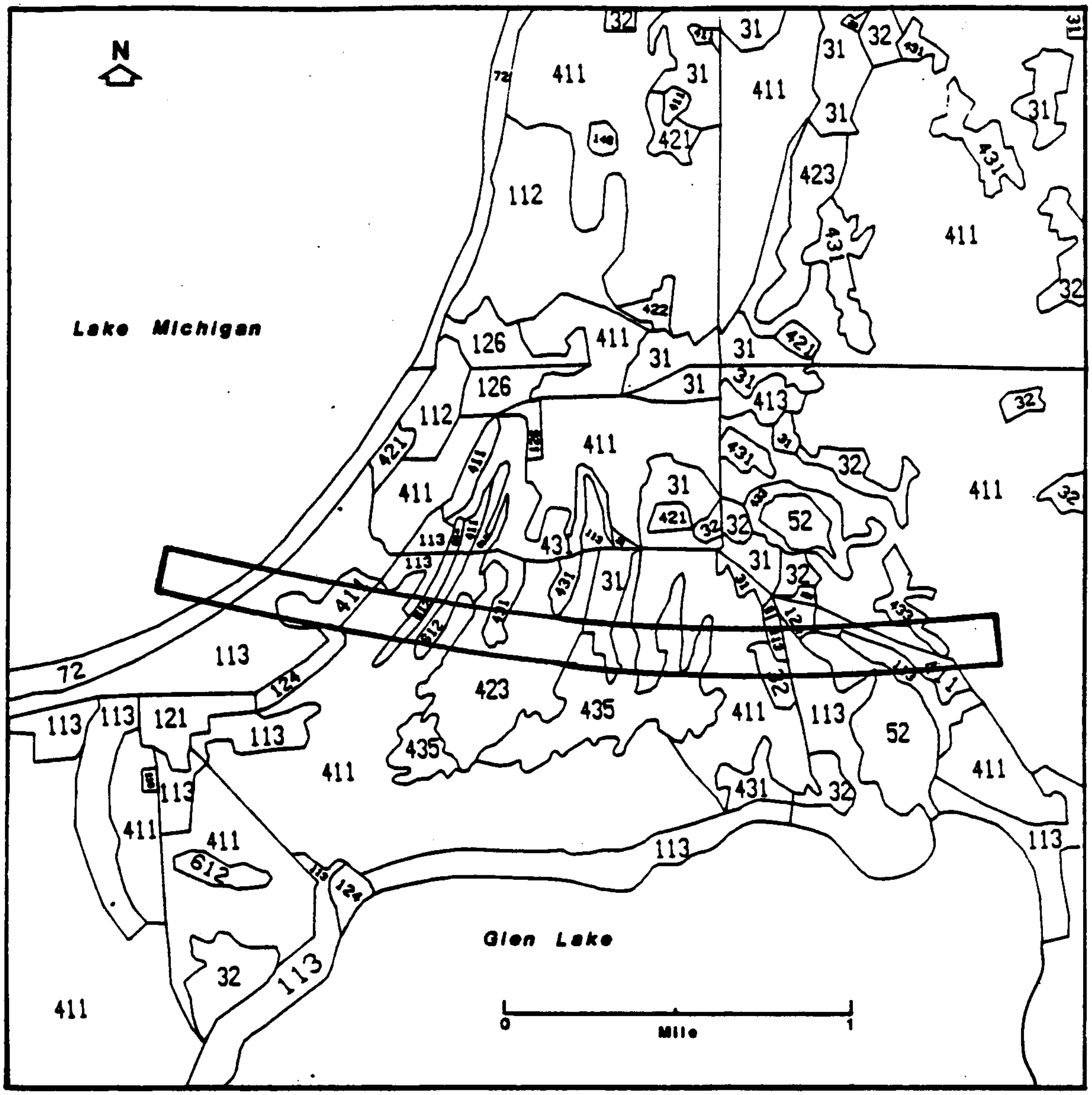
GILBERT LAKE TEST SITE
Leelanau County, Michigan

Cover Type Legend

21	Cropland	421	Upland conifers [plantation]
311	Upland herbaceous rangeland	432	Aspen-balsam association
312	Lowland herbaceous rangeland	433	Red maple, ash, and balsam
321	Upland shrub rangeland	52	Lakes and ponds
322	Lowland shrub rangeland	M	Maple plot [stressed, 1983]
411	Upland hardwoods	P	Pine plot [stressed, 1983]
412	Upland aspen association		

APPROXIMATE AIS GROUND TRACK: Run 116
August 7, 1983

Run 115 passed south of the area shown



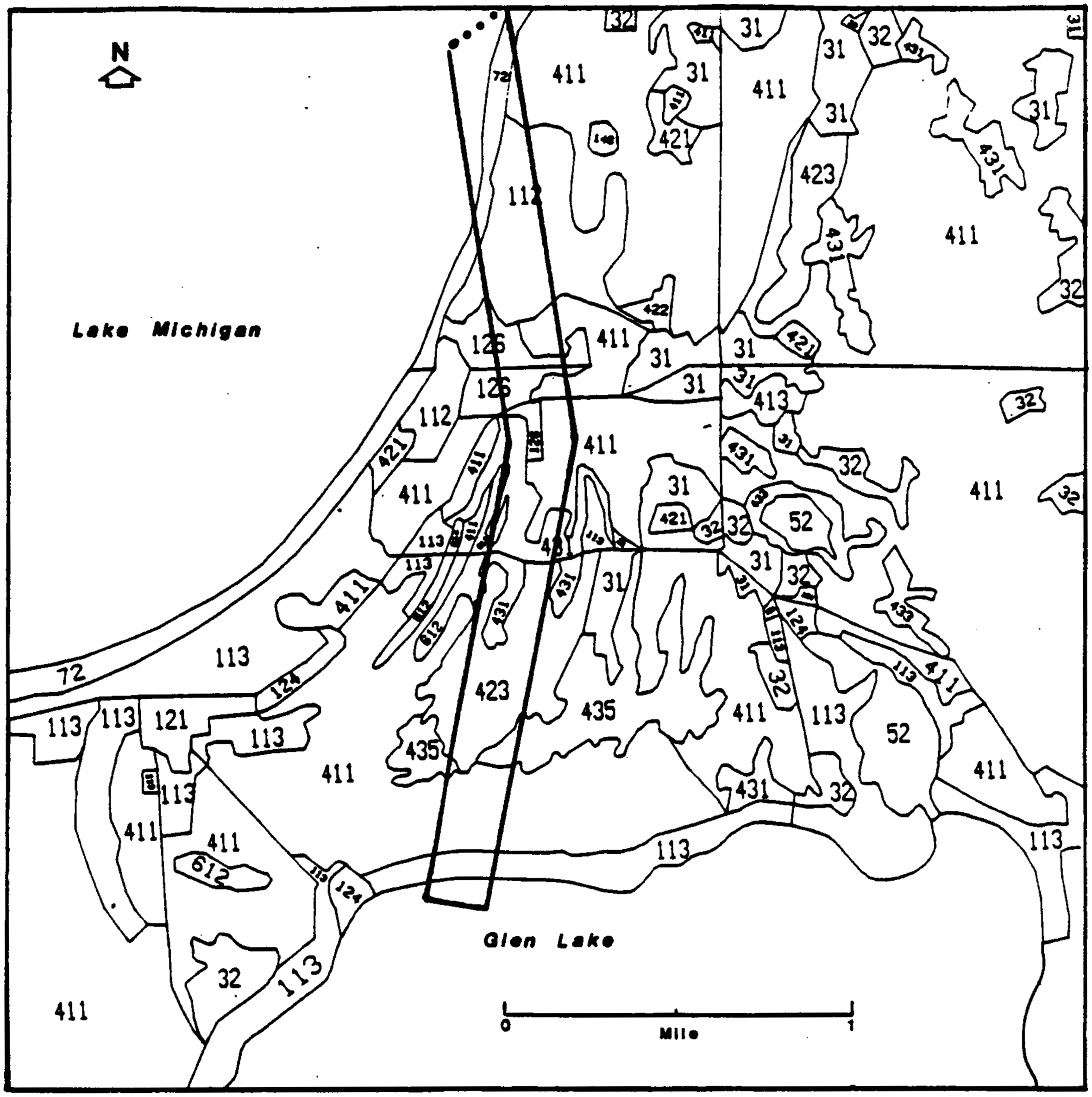
CRYSTAL RIVER TEST SITE
Leelanau County, Michigan

APPROXIMATE AIS GROUND TRACK
Run 117 August 7, 1983

Cover Type Legend

11x	Residential Use	411	Upland hardwoods
112	Multi-family, low rise	413	Aspen, white birch assoc.
113	Single family, duplex	421	Upland conifers
12x	Commercial, Institutional Use	423	Lowland conifers
121	Central business district	431	Upland hardwoods with pine
124	Neighborhood business district	433	Red maple, ash, balsam
126	Institutional [school]	435	Lowland conifers & hardwoods
146	Utilities	52	Lakes and ponds
31	Herbaceous rangeland	612	Shrub, scrub wetland
32	Shrub rangeland	72	Beaches and riverbanks

Cover type information from the Michigan Resource Information System supplied by the Michigan Department of Natural Resources, Lansing, MI.



CRYSTAL RIVER TEST SITE
Leelanau County, Michigan

APPROXIMATE AIS GROUND TRACK
Run 404 July 11, 1984

Cover Type Legend

11x	Residential Use	411	Upland hardwoods
112	Multi-family, low rise	413	Aspen, white birch assoc.
113	Single family, duplex	421	Upland conifers
12x	Commercial, Institutional Use	423	Lowland conifers
121	Central business district	431	Upland hardwoods with pine
124	Neighborhood business district	433	Red maple, ash, balsam
126	Institutional [school]	435	Lowland conifers & hardwoods
146	Utilities	52	Lakes and ponds
31	Herbaceous rangeland	612	Shrub, scrub wetland
32	Shrub rangeland	72	Beaches and riverbanks

Cover type information from the Michigan Resource Information System supplied by the Michigan Department of Natural Resources, Lansing, MI.

APPENDIX II. FLIGHT RECORDS FOR NASA-AMES C-130 FLIGHT NUMBER 83-008-03

FLIGHT SUMMARY REPORT

Flight No: 83-008-03

Date: 7 August 1983

FSR No: 1819

Julian Date: 219

Sensor Package: Zeiss/NSØØ1 Multispectral Scanner

Aircraft No: 707

Purpose of Flight: #0788 Support
Requestor: Goetz/Martin

Area(s) Covered: Saginaw Forest, Ann Arbor, Michigan
Sleeping Bear Forest, Michigan

SENSOR DATA

Accession No:	03293	-----
Sensor ID No:	075	072
Sensor Type:	Zeiss	NSØØ1
Focal Length:	6" 153.16mm	-----
Film Type:	Aerochrome Infrared 2443	-----
Filtration:	Wratten-12	-----
Spectral Band:	510-900nm	See NSØØ1 write-up
f Stop:	4.0	-----
Shutter Speed:	1/200	-----
No. of Frames:	116	-----
% Overlap:	60	-----
Quality:	Good	-----
Remarks:	-----	Tape data only

NSØØ1 Calibration Data
83-008-03

Thermal Data (Channel 8)

Flight Line	Reference Sources BB #1 (°C)	BB #2 (°C)	Channel 8 Response BB #1 (Counts)	BB #2 (Counts)
1	-----	-----	-----	-----
2	15.6970	35.9017	64.40	208.73
3	15.6000	35.8891	64.39	208.93
4	16.2000	37.1077	37.42	182.47
5	16.1460	37.0884	37.31	182.22
6	16.2000	37.1038	37.16	182.73
7	16.1640	37.0981	37.27	181.85
8	16.2000	37.0981	37.17	182.14
9	16.2000	37.0952	37.17	181.72
10	16.2000	37.1027	36.89	181.39
11	16.2109	37.1006	33.60	177.93
12	16.2371	37.1141	33.20	177.92
13	18.2000	38.5061	33.44	176.04

Optical Data *

Flight Line	Channel 1	Ch. 2	Ch. 3	Ch. 4	Ch. 5	Ch. 6	Ch. 7
1	-----	-----	-----	-----	-----	-----	-----
2	38.94	55.52	74.02	96.35	51.94	14.96	5.00
3	39.22	56.00	74.55	96.19	52.05	14.49	5.00
4	39.65	56.58	70.98	96.54	52.43	14.34	5.00
5	39.70	56.86	71.00	95.72	52.33	14.04	5.00
6	39.72	56.90	71.00	95.47	52.53	14.01	5.00
7	39.84	56.96	71.02	95.51	52.46	14.01	5.00
8	39.83	57.01	71.12	95.54	52.64	14.00	5.00
9	39.73	56.99	71.16	96.02	52.43	14.01	5.00
10	39.56	56.97	71.07	96.21	52.73	14.01	5.00
11	39.67	56.95	71.10	96.20	52.41	14.03	5.00
12	39.45	56.81	71.09	96.28	52.61	14.03	5.00
13	39.48	56.84	71.08	96.03	52.68	14.04	5.00

* Radiance units are microwatts per square centimeter per micron per steradian per count. Tare value (word 19) must be subtracted from video before multiplying by these values to obtain absolute radiance. These values are averages over a flight-line, in which there may be variation. Check individual scanline header data for more exact information.

NSØØ1 Calibration Data

83-008-03

Thermal Data (Channel 8)

Flight Line	Reference Sources BB #1 (°C)	BB #2 (°C)	Channel 8 Response BB #1 (Counts)	BB #2 (Counts)
14	18.2000	38.5087	33.65	176.21
15	16.5000	37.9747	33.98	175.96
16	16.5000	37.9062	33.58	175.76
17	16.5000	37.9237	33.41	175.78
18	16.5000	37.9183	33.98	175.86
19	16.5000	37.9026	33.65	175.88
20	16.5000	38.2234	33.73	178.16
21	16.5000	40.3003	33.82	193.13
22	16.4960	40.1889	34.04	192.26
23	16.4909	40.1849	33.70	192.36
24	16.4037	40.1400	34.08	192.02
25	16.4437	40.1822	34.16	192.71

Optical Data *

Flight Line	Channel 1	Ch. 2	Ch. 3	Ch. 4	Ch. 5	Ch. 6	Ch. 7
14	39.38	56.78	71.06	96.00	52.57	14.06	5.00
15	42.73	56.20	70.83	98.61	52.82	15.00	5.00
16	42.47	55.70	70.60	96.83	52.54	14.59	5.00
17	42.60	55.80	70.60	96.40	52.71	14.22	5.00
18	42.81	55.95	70.80	96.79	52.74	14.20	5.00
19	42.71	55.86	70.73	96.54	52.65	14.02	5.00
20	43.03	56.88	70.88	96.50	52.63	14.02	5.00
21	42.78	55.95	70.83	97.01	52.85	14.14	5.00
22	43.08	56.00	70.92	96.68	52.88	14.00	5.00
23	43.07	56.55	70.90	96.50	52.80	14.00	5.00
24	43.00	56.35	70.96	96.74	52.93	14.00	5.00
25	43.57	58.86	71.12	96.39	52.89	14.06	5.00

* Radiance units are microwatts per square centimeter per micron per steradian per count. Tare value (word 19) must be subtracted from video before multiplying by these values to obtain absolute radiance. These values are averages over a flight-line, in which there may be variation. Check individual scanline header data for more exact information.

FLIGHT SUMMARY

83-008-03

This flight was flown under Flight Request #0788 (Goetz/Martin, JPL) under the FY 1983 Airborne Instrumentation Research Program (AIRP) plan. Photographic and NSØØ1 multispectral scanner data were acquired over selected sites in Sleeping Bear Forest, Michigan and Saginaw Forest, Ann Arbor, Michigan with the NASA C-130 aircraft. No Track Map is provided for this flight.

Moderate cloud cover was encountered over the Saginaw Forest Site. No camera or processing malfunctions were noted and the quality of the data is rated as good. The times on the scanner data are approximately 5 minutes ahead of those on the corresponding photography.

NSØØ1 Multispectral Scanner

The NSØØ1 Multispectral Scanner used on the C-130B aircraft contains the seven Landsat-D Thematic Mapper bands plus a band from 1.0 to 1.3 micrometers. The specific bands are:

Band	Spectral bandwidth, um
1	0.45 - 0.52
2	0.52 - 0.60
3	0.63 - 0.69
4	0.76 - 0.90
5	1.00 - 1.30
6	1.55 - 1.75
7	2.08 - 2.35
8	10.4 - 12.5

Sensor specifications are:

IFOV	2.5 mrad
Total scan angle	100°
Pixels/scan line	699

The format of the flight data consists of 838 8-bit words per frame (data for one wavelength band throughout a scan line). Of these, 699 are the video information and the remainder are information on Greenwich time, scan line number, calibration lamp voltage and current, blackbody temperatures, etc.

Computer compatible tapes (CCTs) are produced from the flight tapes, and consist of header information followed by scanner video data.

FLIGHT LINE DATA

FLIGHT NO. 83-008-03

Sensor#	Check Points	Frame Numbers	Time (GMT—hr, min, sec) START	Time (GMT—hr, min, sec) END	Altitude, MSL feet/meters	Cloud Cover/Remarks	Line#
75		004-009	14:24:13	14:25:36	10,600/3212	Clear — Frames 004-092 are 14 lines	1
		010-022	14:36:34	14:38:24	10,900/3323	" — flown over Sleeping Bear	2
		023-028	14:49:25	14:50:45	10,700/3262	" — Forest, Michigan. The approx-	3
		029-039	15:00:14	15:02:39	10,800/3293	" — imate central location for	4
		040-046	15:10:36	15:12:06	10,700/3262	" — all of these lines is 44°50'W-	5
		047-056	15:20:05	15:27:19	10,800/3293	" — 85°56'N.	6
Abort		057-060	15:36:16	15:37:01	10,600/3212	" — Frames 096-119 are 11 lines	7
		061-065	15:47:48	15:48:47	10,900/3323	" — flown over Saginaw Forest,	8
		066-068	15:54:40	15:54:54	10,900/3323	" — Ann Arbor, Michigan. The	9
		069-073	16:01:24	16:02:24	10,600/3212	" — approximate central location	
		074-079	16:07:35	16:08:49	10,500/3201	" — for all of these lines is	
		080-085	16:16:14	16:17:28	10,800/3293	" — 42°17'N-83°48'N.	
		086-090	16:21:41	16:22:34	10,900/3323	"	
		091-092	16:24:06	16:24:11		"	
		093-095	16:58:02	16:58:15		30% cumulus cloud cover; Portage Lake, MI 42°26'N-83°55'W	
		096-098	17:09:55	17:11:24	10,500/3201	40-50% cumulus cloud cover	14
		099-100	17:19:57	17:20:12	10,500/3201	40-50% cumulus cloud cover	15
		101-102	17:26:17	17:26:31	10,500/3201	40-50% cumulus cloud cover	16

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FLIGHT LINE DATA

FLIGHT NO. 83-008-03

Sensor #	Check Points	Frame Numbers	Time (GMT—hr, min, sec) START	Time (GMT—hr, min, sec) END	Altitude, MSL feet/meters	Cloud Cover/Remarks	Line #
075		103-108	17:29:02	17:30:05	10,500/3201	30-40% cumulus cloud cover	17
		109-110	17:32:17	17:32:32	10,500/3201	30-40% cumulus cloud cover	18
		111	17:35:39	----	10,500/3201	Clearing frame; 30% cumulus cloud cover	19
		112	17:38:22	----	10,400/3171	Clearing frame; 30% cumulus cloud cover	20
		113-114	17:41:58	17:42:13	10,400/3171	20% cumulus cloud cover	21
		115-116	17:47:11	17:47:25	10,400/3171	20% cumulus cloud cover	22
		117	17:52:35	----	10,400/3171	40% cumulus cloud cover	
		118-119	17:53:50	17:53:57	10,400/3171	30% cumulus cloud cover	23

SENSOR FLIGHT DATA
FLIGHT NO. 83-008-03

Check Points	Time-GMT (hr, min, sec)	Altitude, MSL feet/meters	Event: Scanline Number	Event: Scan Speed	Remarks
072	~~14:29:41~~	~~10,600/3232~~	~~0001~~	13.0 rps	~~Begin Line #1~~ No Data
	~~14:31:10~~	~~"~~	~~1037~~	"	~~End " "~~
	14:41:00	10,900/3323	8850	13.0 rps	Begin Line #2
	14:43:47	"	11019	"	End " "
	14:54:51	10,700/3262	19577	12.0 rps	Begin Line #3
	14:56:16	"	20591	"	End " "
	15:05:41	10,800/3293	27463	13.0 rps	Begin Line #4
	15:08:00	"	29280	"	End " "
	15:16:10	10,700/3262	35648	13.0 rps	Begin Line #5
	15:17:36	"	36760	"	End " "
	15:25:31	10,800/3293	42932	13.0 rps	Begin Line #6
	15:27:51	"	44752	"	End " "
	15:41:16	10,600/3232	55220	13.0 rps	Begin Line #7
	15:42:30	"	56190	"	End " "
	15:52:51	10,900/3323	64256	13.0 rps	Begin Line #8
	15:54:14	"	65337	"	End " "
	15:59:21	10,900/3323	69388	15.0 rps	Begin Line #9
	16:00:26	"	70362	"	End " "

SENSOR FLIGHT DATA
FLIGHT NO. 83-008-03

072

Check Points	Time-GMT (hr, min, sec)	Altitude, MSL feet/meters	Event: Scanline Number	Event: Scan Speed	Remarks
	16:06:50	10,600/3232	75905	13.0 rps	Begin Line #10
	16:08:03	"	76849	"	End " "
	16:13:00	10,500/3201	80785	16.0 rps	Begin Line #11
	16:14:16	"	81991	"	End " "
	16:21:41	10,800/3293	88664	14.0 rps	Begin Line #12
	16:22:51	"	89641	"	End " "
	16:27:06	10,900/3323	93219	14.0 rps	Begin Line #13
	16:28:00	"	93975	"	End " "
	17:15:46	10,500/3201	133689	12.0 rps	Begin Line #14
	17:16:56	"	134531	"	End " "
	17:25:21	10,500/3201	140621	13.0 rps	Begin Line #15
	17:26:12	"	141294	"	End " "
	17:31:40	"	145556	13.0 rps	Begin Line #16
	17:32:33	"	146239	"	End " "
	17:34:25	"	147699	"	Begin Line #17
	17:35:20	"	148419	"	End " "
	17:37:46	"	150310	"	Begin Line #18
	17:38:22	"	150776	"	End " "

SENSOR FLIGHT DATA
FLIGHT NO. 83-008-03

Check Points	Time-GMT (hr, min, sec)	Altitude, MSL feet/meters	Event Scanline Number	Event Scan Speed	Remarks
072	17:40:10	10,500/3201	152190	13.0 rps	Begin Line #19
	17:41:36	"	153299	"	End " "
	17:43:16	10,400/3171	154583	12.0 rps	Begin Line #20
	17:44:16	"	155312	"	End " "
	17:47:31	"	157652	"	Begin Line #21
	17:47:50	"	157876	"	End " "
	17:52:00	"	160382	"	Begin Line #22
	17:53:01	"	161604	"	End " "
	17:59:25	"	166300	"	Begin Line #23
	17:59:41	"	166489	"	End " "
	18:05:00	"	170405	"	Begin Line #24
	18:05:26	"	170713	"	End " "

C-130

FLIGHT LINE REQUIREMENTS

PROJECT NO. 0788 P.I. A. Goetz / T. Martin ORGANIZ. JPL

LOCATION: Sleeping Bear Forest, Mich. SITE NO. 25

MISSION NO. 83-08 FLT. DATES: Aug. 5-19, 1983

LOCATION	LINE #	RUN	ALT (K FT) MSL	ALT (K FT) AGL	LINE NMI	RUN TIME	GND SPEED (KNOTS)	REMARKS
	1	1		15	3.7	1.0 min	200 MAX	WPT 1 → 2
	2	1		"	6.9	2.0	"	3 → 4
	3	1		"	2.5	1.0	"	5 → 6
	4	1		"	1.8	0:30	"	7 → 8
	5	1		"	1.9	0:30	"	1′ → 2′
								EACH LINE To Be Run 3 Times

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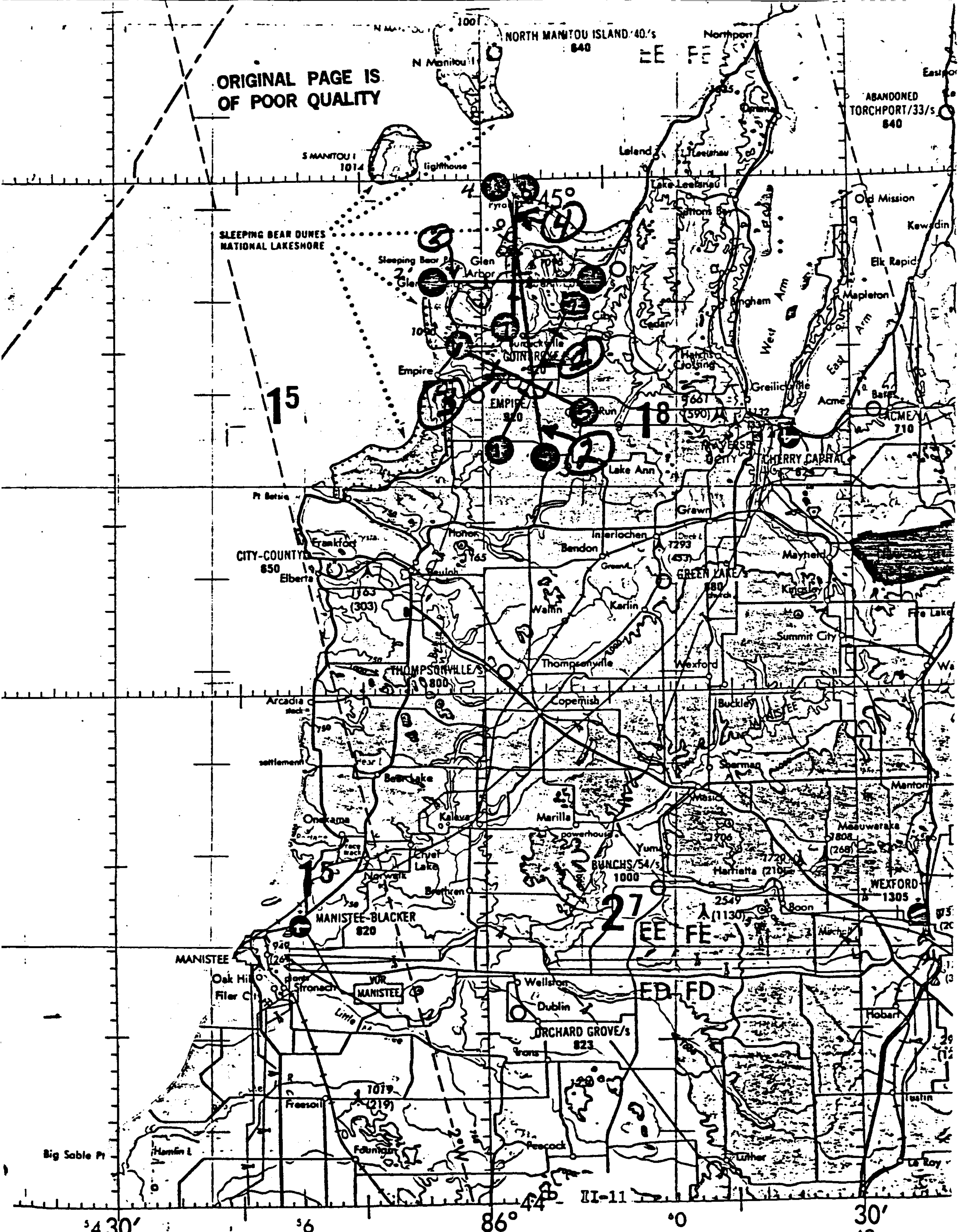
NOTES: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NORTH MANITOU ISLAND 40/s
640
N Manitou I
Northport
ABANDONED
TORCHPORT/33/s
640
S MANITOU I
1014
lighthouse
Leland
Lake Leelanau
SLEEPING BEAR DUNES
NATIONAL LAKESHORE
Sleeping Bear Pt
Glen Arbor
45°
Old Mission
Kewadin
Elk Rapids
Mapleton
West Arm
East Arm
Cedar
Bingham
Empire
EMPIRE/S
820
Burdickville
Greilickville
Acme
ACME
710
18
15
Lake Ann
TRAVERSE CITY
CHERRY CAPITAL
Pt Betsie
Frankfort
CITY-COUNTY
850
Elberta
Honor
Beulah
765
Bendon
Interlochen
7293
GREEN LAKE/S
880
Mayfield
Kingsley
Karlin
Wallin
Thompsonville
THOMPSONVILLE/S
800
Summit City
Wexford
Buckley
Copemish
Arcadia
settlement
Bear Lake
Sherman
Kaleva
Marilla
Onekama
Mesick
Manton
Yuma
BUNCHS/54/s
1000
Harrietta
WEXFORD
1305
Norwalk
Brethren
Boon
MANISTEE-BLACKER
820
27
MANISTEE
Oak Hill
Filer City
Stronach
VOR MANISTEE
Wellston
Dublin
ORCHARD GROVE/s
823
Hoxeyville
Freesoil
1079
(219)
Big Sable Pt
Hamlin L
Fountain
Peacock
Luther
Le Roy
86°
30′
44°

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C-130

FLIGHT LINE REQUIREMENTS

PROJECT NO. ______ P.I. Terry Martin ORGANIZ. JPL

LOCATION: Saginaw Forest, Ann Arbor, Mich. SITE NO. #26

MISSION NO. 83-08

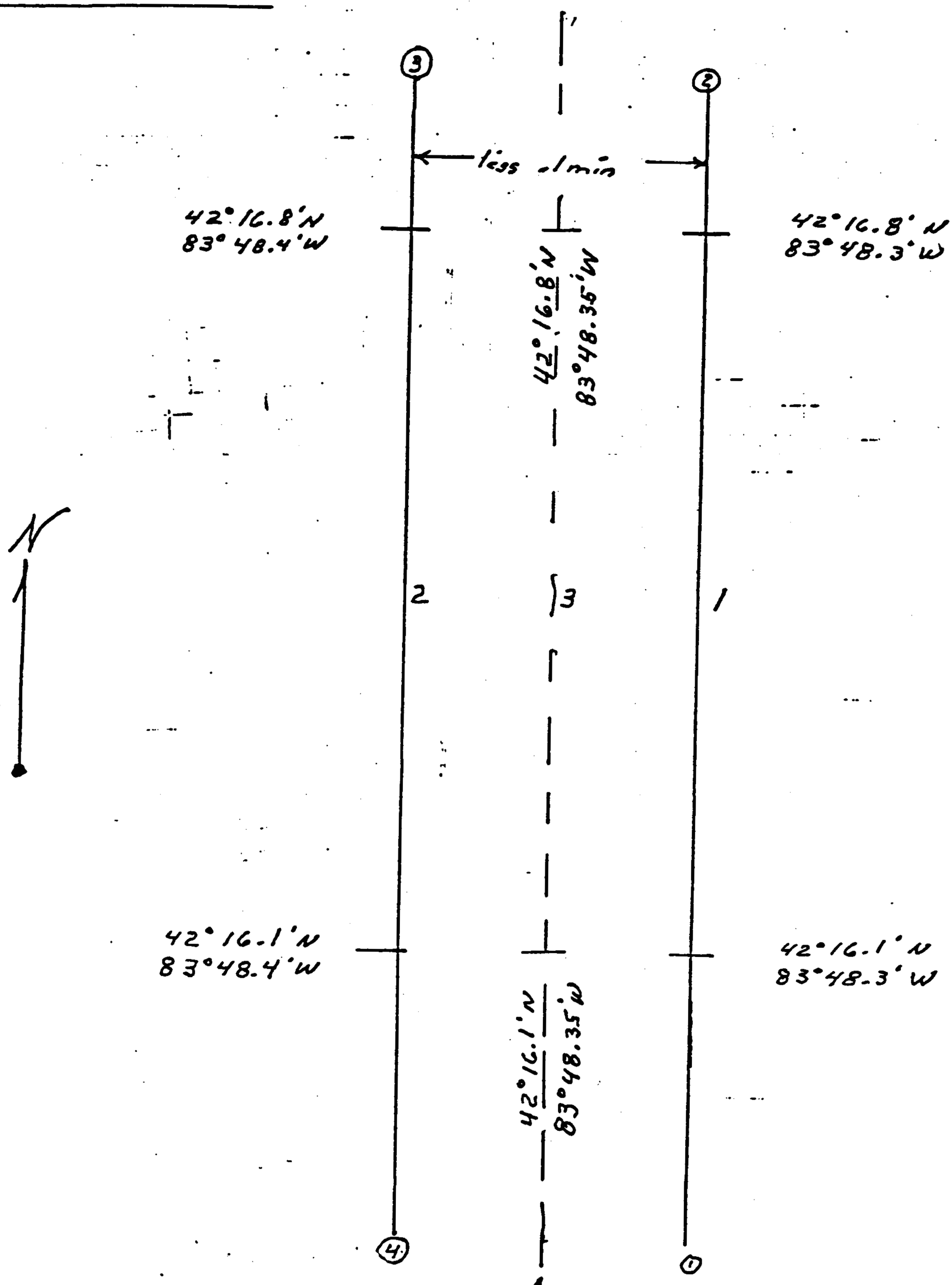
FLT. DATES: Aug. 5-19, 1983

LOCATION	LINE #	RUN	ALT (K FT) MSL	ALT (K FT) ~~ABS~~ AGL	LINE NMI	RUN TIME	GND SPEED (KNOTS)	REMARKS
	1	1		10	1	20 sec	~200	
	2	1		10	1	"		WPT #1 → #2
								#3 → #4
OPTIONAL	3	1		10	1	20 sec	~200	Visual Flt. between
								above lines ~ If Time Permits
						EACH	LINE	TO BE RUN 3 TIMES

TES:


FLINT TRSA
FREQ INFO. ON ATIS
Henderson
OWOSSO CITY
Owosso
Corunna
Bennington
LENNON
DURAND
GAINES
SWARTZ CREEK
BISHOP
FLINT
DALTONS
Flushing
DAVISON
LAPEER
DUPONT-LAPEER
Elba
Attica
Hadley
GOODRICH
Hunters Creek
Metamora
WOODWORTH
Thomas
Ortonville
OXFORD
LAKE ORION
Grand Blanc
COLE FIELD
LINDEN
PRICES
FENTON
HOLLY
PERRY
DYSINGER (Pvt)
Shaftsburg
MAPLE GROVE
MAIDEN
WILLIAMSTON
Webberville
Fowlerville
Cohoctah
Argentine
MERGER
GUDENBORT
Hartland
HOWELL
LIVINGSTON CO
Highland
RENCHIK LAKE
CZ eff 0600 - 2400
Drayton Plains
ROCHESTER
OAKLAND PONTIAC
PONTIAC
Milford
TROY-OAKLAND
BIRMINGHAM
ORIGINAL PAGE IS OF POOR QUALITY
Dansville
BUURMA FARMS (Pvt)
Brighton
SPENCER
Wixom
Plainfield
CARRIAGE LANE
NEW HUDSON
Novi
FARMINGTON
Stockbridge
RICHMOND
Gregory
Unadilla
Pinckney
Lakeland
Hamburg
SALEM
114.3 Ch 90 SVM
DETROIT
SMITH FARM
Munith
CACKLEBERRY
DETROIT FLYING B (Pvt)
Northville
SALEM
DETROIT
GOON (Pvt)
PLYMOUTH
METTETAL
DETROIT METRO
WAYNE CO CT - 118.4
ATIS 124.55
DETROIT DET
Dexter
Chelsea
ZLINES
See NOTAMs/Directory
ANN ARBOR
WILLOW RUN
CT - 120.0
VOR
WILLOW RUN
110.0 YIP
YPSILANTI
WAYNE
Romulus
Francisco
Grass Lake
ROSSETTIE
Napoleon
BELFORD
MAULE
Manchester
Saline
LARSEN
Belleville
SURFACE
New Boston
DOWNWIND ACRES
Willis
Whittaker
REVUP
SHAMROCK
Clinton
MYERS
Macon
TECUMSEH (Pvt)
Milan
CARLETON
Ch 104 CRL
DETROIT
Flat Rock
Rockwood
GROSSE
Onsted
TECUMSEH
BRABLEC FARMS (Pvt)
LOARS
Rome Center
CALHOUNS INTL
Britton
Dundee
Scofield
WICKENHEISER (Pvt)
MARSHALL
MONROE
GRADOLPH
Stony Pt

Basic Flt. Lines



Optional visual Flt. between Basic Lines

Ames Research Center

NASA 707 NSOOIMS INFLIGHT LOG

MISSION 83-003 (1-3)

PAGE 2 OF [illegible]

A/C NO. 707 (10-12)

FLIGHT DATE 8-7-83 (4-9) (MMDDYY)

OPERATOR Higgins

PROJECT NO. 0788 (15-22)

OBJECTIVE: SLEEPING BEAR FOREST SAGINAW FOREST

FLT 13-14	DATA FLT 26-27	SITE 28-30	LINE 31-32	RUN 33-34	TAPE 23-25	TIME, gmt hr:min:sec START	STOP	GND SPD, kts	MEAN RAD ALT, k ft	SCAN RATE, rps 60-61	SCAN LINE COUNT START	STOP	BLACKBODY TEMP, °C #1 LO	#2 HI	LAMP, hr	REMARKS GYRO S/N H-25 INS GYRO USED
3	3	25	~~1~~	~~1~~		~~14:29:40~~	~~14:31:00~~	~~195~~	~~10.6~~	~~13~~	~~0~~	~~1037~~	~~15.7~~	~~36.2~~		(1) CH 3 A/D IS
			2	1		14:41:00	14:43:46	207	10.9	13	8850	11019	15.6	35.8		NOW SHIELDED.
			1	2		14:54:50	14:56:15	194	10.7	12	19577	20591	16.2	37.0		
			2	2		15:05:40	15:08:00	212	10.8	13	27463	29280	16.1	37.0		(2) SCANNER IS
			3	3		15:16:10	15:17:35	204	10.7	13	35648	36760	16.2	37.1		SECONDARY DATA TO
			2	3		15:25:30	15:27:50	217	10.8	13	42932	44752	16.2	37.0		JPL/AIS.
			~~3~~	~~4~~		~~: :~~	~~: :~~	~~ABORT~~			~~RUN~~		16.2	37.1		OFF LINE!!
			3	2		15:41:15	15:42:30	205	10.6	13	55220	56190	16.2	37.0		30° ROLLS @ 1 MIN PAIR
			4	1		15:52:50	15:54:09	196	10.9	13	64256	65337	16.2	37.1		
			4	2		15:59:20	16:00:25	251	10.9	15	69388	70362	16.2	37.1		
			3	3		16:06:50	16:08:00	209	10.6	13	75905	76849	16.2	37.1		
			3	4		16:13:00	16:14:15	246	10.5	16	80785	81991	16.2	37.1		
			5	1		16:21:40	16:22:50	221	10.8	14	88614	89641	18.2	38.5		
			5	2		16:27:05	16:28:00	228	10.9	14	93219	93975	18.2	38.5		
						: :	: :									
		26				17:05:45	: :	→	NO		DATA	←				
			3	1		17:15:45	17:16:55	197	10.5	12	133689	134531	16.5	38.0		NO GOOD
			3	2		17:25:20	17:26:10	202	10.5	13	140621	141294	16.5	38.0		NO GOOD
			3	3		17:31:40	17:32:30	204	10.5	13	145556	146239	16.5	38.1		
			3	4		17:34:24	17:35:20	193	10.5	13	147699	148419	16.5	37.9		
			3	5		17:37:45	17:38:21	195	10.5	13	150310	150776	16.5	37.9		
			3	6		17:40:10	17:41:35	179	10.5	13	152190	153299	16.5	37.9		HARD ROLLS
			3	7		17:43:15	17:44:15	203	10.4	12	154583	155312	16.5	37.9		

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Ames Research Center

NASA 707 NSOOIMS INFLIGHT LOG

MISSION 63-003 (1-3)

PAGE 3 OF ____

A/C NO. 707 (10-12)

FLIGHT DATE 8-7-83 (4-9) (MMDDYY)

OPERATOR Higgins

PROJECT NO. 0788 (15-22)

OBJECTIVE: SAGINAW FOREST

FLT 13-14	DATA FLT 26-27	SITE 28-30	LINE 31-32	RUN 33-34	TAPE 23-25	TIME, gmt hr:min:sec START	TIME, gmt hr:min:sec STOP	GND SPD, kts	MEAN RAD ALT, k ft	SCAN RATE, rps 60-61	SCAN LINE COUNT START	SCAN LINE COUNT STOP	BLACKBODY TEMP, °C #1 LO	BLACKBODY TEMP, °C #2 HI	LAMP, hr	REMARKS
	3	26	3	8	2	17:47:15	17:47:50	185	10.4	12	157652	157876	16.5	40.2		INS GYRO USED HARD ROLLS
			3	9		17:52:00	17:53:00	184	10.4	12	160882	161604	16.5	40.2		
			3	10		17:59:10	17:59:40	188	10.4	12	166300	166487	16.5	39.9		
			3	11		18:05:00	18:05:25	188	10.4	12	170405	170713	16.5	[illegible]		

SEM-94

FOR Chuck Olsen

OPERATOR C. Mahoney

LOGGER R. Steinkraus

SCIENCE T. Martin

AIS TAPE LOG

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Sh 1 of 2

TAPE NUMBER AIS 18

DATE 8/6/83

LOCATION Multiple

RUN ID	FRAME # START / STOP	GMT T.O.D. START / STOP	GROUND SPEED KTS	ALTITUDE (x1000ft)	GPOS	OFFSET X=ON	SLOPE X=ON	CAMERA X=ON	GAIN H=HIGH L=LOW	COMMENTS	
104	251:100 / 252:100	18:31:24 / 19.32:24	254	24.00	0	X	X	■	L	Boreal Forest — SLOPE CORR TEST — AIR TEMP = -9.7°C — Line 9, Run 2	8/6
105	255:120 / 257:680	18:35:30 / 18:38:15	253	24.14	0	X		X	L	Boreal Forest — AIR TEMP = -9.9°C — Line 9, Run 2	8/6
	—	—									
	—	—								Weather clear 104 : line start → 1m duration	
	—	—								105 : Jeannette Lake → line stop SE → NW	
	—	—								Good tracking ; very steady Sun elev. ~ 55° ; sun time ~ 1230	
106	073:560 / 075:100	14:29:40 / 14:30:59	196	10.62	0	X		X	L	Sleeping Bear Forest — WPT 1→2 S→N — AIR TEMP = +15.8°C — Line 1, Run 1	8/7
107	085:080 / 087:660	14:41:00 / 14:43:45	214	10.94	0	X		X	L	Sleeping Bear Forest — WPT 4→3 N→S — AIR TEMP = +13.0 — Line 2, Run 2	8/7
108	098:700 / 100:300	14:54:50 / 14:56:15	196	10.70	1	X		X	L	Sleeping Bear Forest — WPT 1→2 S→N — AIR TEMP = +15.3°C — Line 1, Run 2	8/7
109	109:580 / 112:120	15:05:40 / 15:08:00	212	10.96	1	X		X	L	Sleeping Bear Forest — WPT 4→3 N→S — AIR TEMP = +12.9°C — Line 2 Run 2	8/7
110	120:200 / 121:540	15:16:10 / 15:17:35	202	10.66	2	X		X	L	Sleeping Bear Forest — WPT 1→2 S→N — AIR TEMP = +15.8 — Line 1, Run 3	8/7

Sh 2 of 2

OPERATOR C. Mahoney

LOGGER R. Steinkraus

SCIENCE T. Martin

AIS TAPE LOG

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TAPE NUMBER AIS 18

DATE 8/7/83

LOCATION Multiple

RUN ID	FRAME # START / STOP	GMT T.O.D. START / STOP	GROUND SPEED KTS	ALTITUDE (x1000ft)	GPOS	OFFSET X=ON	SLOPE X=ON	CAMERA X=ON	GAIN H=HIGH L=LOW	COMMENTS
111	129:480 / 132:000	15:25:30 / 15:27:50	216	10.97	2	X		X	L	Sleeping Bear Forest WPT 4→3 N→S AIR TEMP = +13.6°C Line 2 Run 3
112	145:280 / 146:460	15:41:15 / 15:42:30	203	10.76	0	X		X	L	Sleeping Bear Forest WPT 5→6 SE→NW AIR TEMP = +15.7°C Line 3, Run 2*
113	157:320 / 158:200	15:53:17 / 15:54:09	197	10.76	0	X		X	L	Sleeping Bear Forest WPT 7-8 S→N AIR TEMP = +16.3 Line 4, Run 1
114	163:400 / 164:360	15:59:30 / 16:00:25	252	10.76	1	X		X	L	Sleeping Bear Forest WPT 8-7 N→S AIR TEMP = +16.2°C Line 4, Run 2
115	170:680 / 172:140	16:06:50 / 16:08:00	210	10.65	1	X		X	L	Sleeping Bear Forest WPT 5→6 SE→NW AIR TEMP = +16.2°C ** Line 3, Run 3
116	177:100 / 178:300	16:13:00 / 16:14:15	243	10.63	1	X		X	L	Sleeping Bear Forest WPT 6→5 NW→SE AIR TEMP = +16.2°C Line 3, Run 4
117	185:580 / 186:680	16:20:40 / 16:22:50	220	10.58	0	X		X	L	Sleeping Bear Forest WPT 1'→2' E→W AIR TEMP = +16.3°C Line 5, Run 1
118	191:200 / 192:140	16:27:05 / 16:28:00	229	10.98	1	X		X	L	Sleeping Bear Forest WPT 2'→1' W→E AIR TEMP = 16.0°C Line 5, Run 2
	—	—								
	—	—								
	—	—								

** Line 3 Run 4 was ~~on~~ auto off

AIS TAPE LOG SUPPLEMENT Aug. 7 ~~1985~~
T. Martin

Notes on Sleeping Bear Forest Data Acquisition

Weather clear, very little haze. Runs begin ~0930 sun time.

RUN ID

106 Most of line OK. Off ~450' at North end.
107 Started early. Target OK. Went R over Glen Lake, then turned back L.
108 Aircraft steady. Just to R of target.
109 Just to R at start. Off at end by few 100' to R.
110 Made 2° L turn in middle of line.
111 Just L of Gilbert Lake. Dead on track at N. of Glen Lake.
112 Crossed southernmost lake of cluster of 3 near Gilbert. Some rolls.
113 OK at start. Angling off to ~1 mile L at end of line.
114 Big roll at start. Went L, corrected R, OK at end.
115 Way off track. Where?
116 Good tracking.
117 " "
118 Bad roll ~20 s after start. Other rolls present.

Line 107 crossed Burdickville at S. end of Glen Lake.

Run out of Nikon film sometime during this series.

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Sh 1 of 2

OPERATOR C. Mahoney

LOGGER R. Steinkraus

SCIENCE T. Martin

AIS TAPE LOG

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TAPE NUMBER AIS 19

DATE 8/7/83

LOCATION Multiple

RUN ID	FRAME # START / STOP	GMT T.O.D. START / STOP	GROUND SPEED KTS	ALTITUDE (x1000ft)	GPOS	OFFSET X=ON	SLOPE X=ON	CAMERA X=ON	GAIN H=HIGH L=LOW	COMMENTS
119	022:500 / 023:500	17:15:45 / 17:16:55	197	10.52	0	X		X	L	Saginaw Forest N→S MISSED TARGET AIR TEMP +14.2 Line 1 Run 1
120	032:180 / 032:620	17:25:20 / 17:26:10	206	10.49	0	X		X	L	Saginaw Forest N→S under cloud AIR TEMP Line 1 Run 2
121	038:400 / 039:300	17:31:40 / 17:32:30	205	10.47	0	X		X	L	Saginaw Forest missed N→S AIR TEMP +14.2°C Line 1, Run 3
122	041:320 / 042:140	17:34:24 / 17:35:30	approx 200	approx 10.4	0	X		X	L	Saginaw Forest west to east caught South end AIR TEMP = Line 1, Run 4
~~123~~	? / 045:140	17:37:45 / 17:38:21	195	10.47	0	X		X	L	Saginaw Forest AIR TEMP Line 1, Run 5
123	047:000 / 048:360	17:40:10 / 17:41:35	183	10.50	0	X		X	L	Saginaw Forest ~S→N AIR TEMP +14.1°C LINE 1, Run 6
124	050:140 / 050:620	17:43:15 / 17:44:06	199	10.56	0	X		X	L	Saginaw Forest W→E AIR TEMP +14.3°C Line 1, Run 7
125	054:140 / 054:520	17:47:15 / 17:47:50	Approx 190	Approx 10.5	0	X		X	L	Saginaw Forest SE→NW AIR TEMP +14.3°C Line 1, Run 8
126	058:700 / 058:640	17:52:00 / 17:53:00	184	10.42	1	X		X	L	Saginaw Forest IN Shadow SE→NW AIR TEMP +14.3°C Line 1, Run 9
127	065:600 / 066:340	17:59:10 / 17:59:40	188	10.4	1	X		X	L	Saginaw Forest SE→NW AIR TEMP +14.3°C Line 1, Run 10
128	071:700 / 072:280	18:05:00 / 18:05:45	189	10.5	2	X		X	L	Saginaw Forest IN Shadow SE→NW AIR TEMP +14.9 Line 1, Run 11

T. Martin

Notes on Saginaw Forest Data Acquisition

Weather clear above, but many cumulus below, ~ 2000' AGL. Forest obvious, but target area within not evident visually. Markers on ground not seen by photo operator.

RUN ID	
119	Missed forest. Lots of cloud beneath.
120	Much cloud over target again.
121	Site clear but went just West of it.
122 "A"	Abandoned N→S approach. W→E. Crossed S. end of forest. Clear.
122 "B"	No new run ID. Dead on at line start, clear; may not be on tape.
123	Clear. A little to R of target.
124	Crossed N. end of forest. Clear.
125	Very close, a little N. of site. Clear.
126	Site in shadow. Very close.
127	Clear. Targeting apparently OK.
128	Some clouds. " " ", but LN₂ going.

Initial strategy of flying by INS abandoned due to abundance of cloud cover. Instead did "bombing runs" using visual targets when site appeared clear.

APPENDIX III. FLIGHT RECORDS FOR NASA-AMES C-130 FLIGHT NUMBER 84-006-02

FLIGHT SUMMARY REPORT

Flight No: 84-006-02

Date: 19 July 1984

FSR No: 1946

Julian Date: 201

Sensor Package: Zeiss Camera
NS001 Multispectral Scanner

Aircraft No: 707

Purpose of Flight: #1005 Support
Requestor: Tucker

Area(s) Covered: Sleeping Bear Dunes

SENSOR DATA

Accession No:	03370	---
Sensor ID No:	077	072
Sensor Type:	2443	NS001
Focal Length:	6" 153.40mm	---
Film Type:	Aerochrome Infrared 2443	---
Filtration:	W-12	---
Spectral Band:	510-900nm	see write-up
f Stop:	40	---
Shutter Speed:	1/400±	---
No. of Frames:	28	---
% Overlap:	60%	---
Quality:	Good	Good
Remarks:	---	Tape Data only

FLIGHT SUMMARY

84-006-02

This flight was flown in support of Flight Request #1005 (Tucker, JPL) under the FY 1984 Airborne Instrumentation Research Program (AIRP) plan. Photographic and NS001 multispectral scanner data were acquired over Sleeping Bear Dunes, Michigan (see Track Map).

Some cloud shadows were encountered over some of the frames. The clocks on the NS001 and the camera are not working. Times for the NS001 data and the photography were taken from the flight log.

NSØØ1 Multispectral Scanner

The NSØØ1 Multispectral Scanner used on the C-130B aircraft contains the seven Landsat-D Thematic Mapper bands plus a band from 1.0 to 1.3 micrometers. The specific bands are:

Band	Spectral bandwidth, um
1	0.45 - 0.52
2	0.52 - 0.60
3	0.63 - 0.69
4	0.76 - 0.90
5	1.00 - 1.30
6	1.55 - 1.75
7	2.08 - 2.35
8	10.4 - 12.5

Sensor specifications are:

IFOV	2.5 mrad
Total scan angle	100°
Pixels/scan line	699

The format of the flight data consists of 838 8-bit words per frame (data for one wavelength band throughout a scan line). Of these, 699 are the video information and the remainder are information on Greenwich time, scan line number, calibration lamp voltage and current, blackbody temperatures, etc.

Computer compatible tapes (CCTs) are produced from the flight tapes, and consist of header information followed by scanner video data.

NSØØ1 Calibration Data
84-006-02

Thermal Data (Channel 8)

Flight Line	Reference Sources BB #1 (°C)	BB #2 (°C)	Channel 8 Response BB #1 (Counts)	BB #2 (Counts)
1	10.39	38.80	50.7	175.1
2	10.30	33.05	50.7	149.0
3	10.20	32.93	50.7	149.5
4	10.20	33.01	50.7	149.9
5	10.20	33.08	50.8	150.0

Optical Data *

Flight Line	Channel 1	Ch. 2	Ch. 3	Ch. 4	Ch. 5	Ch. 6	Ch. 7
1	44.04	46.46	67.23	94.41	51.06	13.64	3.97
2	52.44	55.47	67.42	93.64	51.18	13.49	4.03
3	52.76	55.89	67.66	92.91	51.46	13.36	4.07
4	59.50	70.78	68.08	92.17	51.59	13.23	4.10
5	60.04	71.68	68.47	91.79	51.89	13.13	4.12

* Radiance units are microwatts per square centimeter per micron per steradian per count. Tare value (word 19) must be subtracted from video before multiplying by these values to obtain absolute radiance. These values are averages over a flight-line, in which there may be variation. Check individual scanline header data for more exact information.

NS001 SCANNER DATA
LOGICAL RECORD FORMAT

16-BIT WORD NUMBER	CONTENTS
1-25	Channel Scanline Housekeeping Information
1	Data frame status 0 Good frame 10-16 Interpolated data 20-26 Repeated data 30-36 Zero-fill for data
2	Radiance per count calibration values: —Visible channel (1-7) flight calibration values modified for gain: integer, tens of nanowatts per square centimeter per nanometer per steradian per count. —Thermal channel is not used.
3-4	Scanline number (32-bit integer)
5	Black body 1 (BB1) reference thermistor count (low)
6	Black body 2 (BB2) reference thermistor count (high)
7	BB1 (low) thermal reference temperature (degrees C * 100)
8	BB2 (high) thermal reference temperature (degrees C • 100)
9	Scan speed (* 100)
10	GMT hours
11	GMT minutes
12	GMT seconds (* 10)
13	Demagnification value (* 100)
14	Filler
15	Gain Value (* 1000): —Visible channel (1-7) gain value is defined as as 1000 times (word 24 minus word 19) divided by (the laboratory value of reference lamp less tare). —Thermal channel (8) is not used.
16	Channel number
17-18	Time expressed as a 7-digit number in the form HHMMSST
19	BB1 (low) radiance count
20	BB2 (high) radiance count
21	Reference lamp voltage
22	Reference lamp current
23	Reference lamp state: 16 bits 000000000ab00000 a = 1 means reference lamp selected as visible high-level calibration source b = 0 means lamp has degraded below predetermined level of 12.8V b = 1 means lamp has not degraded below predetermined level
24	Reference lamp radiance count
25	Filler
26-375	Digitized Video Pixel Information (see note below)
26	Digitized video pixel no. 699 and no. 698
27	Digitized video pixel no. 697 and no. 696
•	•
•	•
•	•
375	Byte 1 is digitized video pixel no. 1 Byte 2 is filler

NOTE: Housekeeping information consists of 16-bit integers, unless otherwise noted. Video pixel data consist of two 8-bit samples packed into one 16-bit word. Geometrically corrected data contains 953 pixels, expanding the logical record format to 502 words. Digitized video pixels are reversed to compensate for the fact that the NS001 scans right to left; pixel no. 1 is the leftmost pixel, and pixel no. 2 is the rightmost.

NS001 SCANNER DATA TAPE FORMAT

The Applications Aircraft Data Management Facility converts scanner data recorded on 14-track high-density tape to standard 9-track computer-compatible tapes (CCT) for the user. Density of CCTs can be 6250, 1600, or 800 bpi, depending on the user's preference. The logical record length is fixed at 750 8-bit bytes for raw data and 1004 bytes for geometrically corrected data. The first 50 bytes for all records are house-keeping information; the next 699 (or 953 for geometrically corrected data) are digitized pixel data. A single "filler" byte is added at the end of each logical record to maintain even-numbered lengths.

All channels for a particular flight segment are written in a single tape file in line-interleaved format, as follows:

record 1 = scanline 1, channel 1
record 2 = scanline 1, channel 2
record 3 = scanline 1, channel 3
•
•
•
record 8 = scanline 1, channel 8
record 9 = scanline 2, channel 1
etc.

Users can request that tapes be blocked to contain all channels of a single scanline sequentially in one record. In such cases physical record length equals the number of channels multiplied by the logical record length (750 or 1004 bytes).

SCANNER FLIGHT LINE DATA
FLIGHT NO.

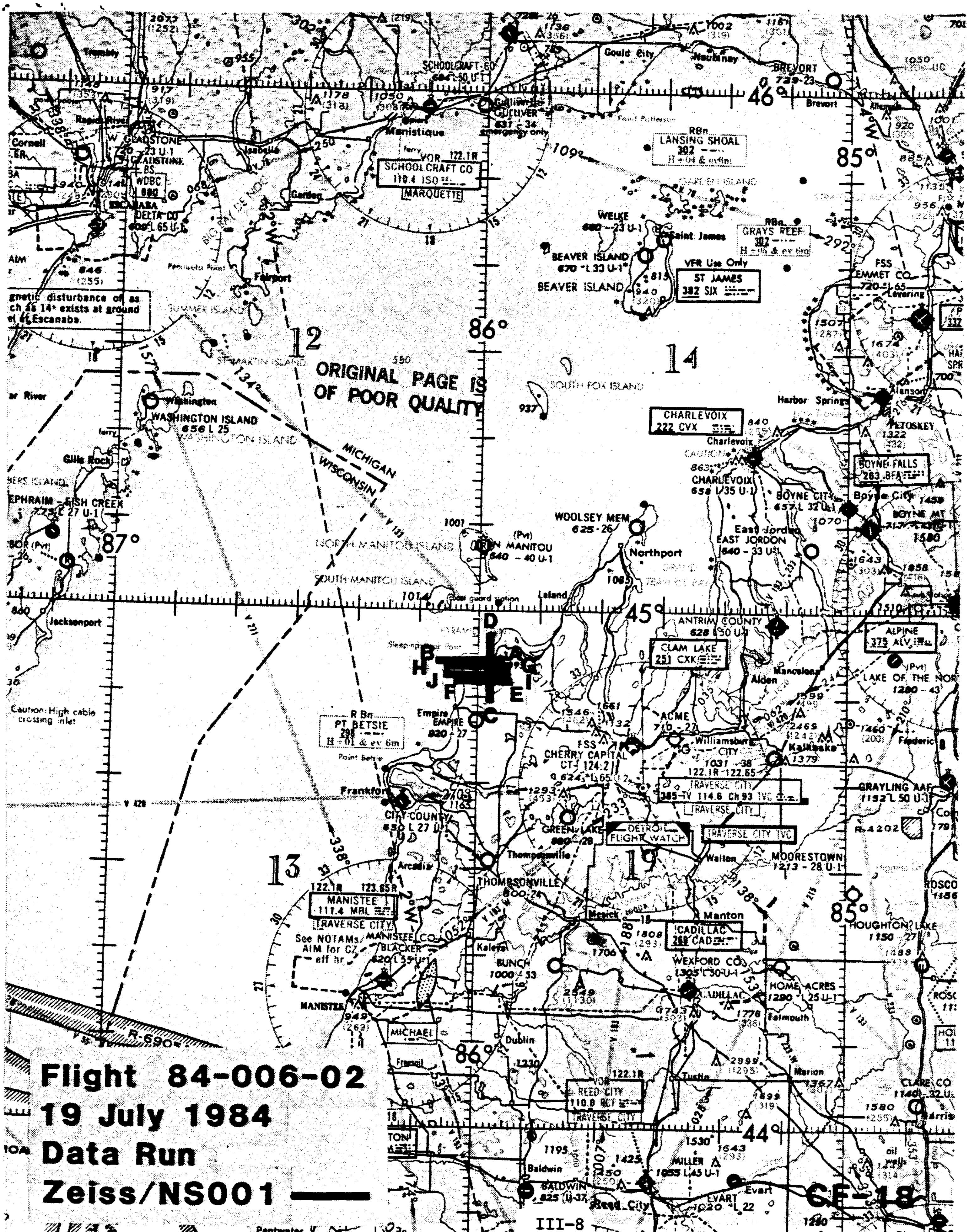
NS001 FLIGHT DATA
FLIGHT NUMBER: 84-006-02

Check Points	flightline number	Actual time begin	Actual time end	Actual scanline begin	Actual scanline end	Altitude feet/meter	Scan Speed (rps)	total Good scanlines	total Interpolated scanlines	total Repeated scanlines	total Zero-fill scanlines
A-B	1	20202	20202	306	2255	13600/ 4145	15.0	1938	0	12	0
C-D	2	20202	20202	7653	10000	13700/ 4175	15.0	2344	0	4	0
E-F	3	20202	20202	15005	17580	14000/ 4267	15.0	2572	0	4	0
G-H	4	20202	20202	23821	26321	13500/ 4114	15.0	2499	0	2	0
I-J	5	20202	20202	32412	35173	13700/ 4175	15.0	2648	0	114	0

FLIGHT LINE DATA

FLIGHT NO. 84-006-02

Sensor #	Check Points	Frame Numbers	Time (GMT—hr, min, sec) START	Time (GMT—hr, min, sec) END	Altitude, MSL feet/meters	Cloud Cover/Remarks
077	A-B	185-190	17:43:57	17:46:24	13600/4146	Frames 185-190 cloud shadows; S25L1R1
2443	C-D	191-196	17:52:32	17:55:00	13700/4177	Frames 191-196 cloud shadows; S25L3R1
	E-F	197-201	18:00:47	18:03:17	13900/4238	Frames 197-201 cloud shadows; S25L2R1
	G-H	202-206	18:10:43	18:13:05	13500/4116	Frames 202-206 cloud shadows; S25L1R2
	I-J	207-212	18:20:16	18:23:11	13700/4177	Frames 207-209 clear frames 210-212 cloud shadows; S25L2R2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OF POOR QUALITY
Flight 84-006-02
19 July 1984
Data Run
Zeiss/NS001
CF-18
MICHIGAN
WISCONSIN
BEAVER ISLAND
WASHINGTON ISLAND
CHARLEVOIX
TRAVERSE CITY
CHERRY CAPITAL
MANISTEE
THOMPSONVILLE
CADILLAC
EMPIRE
FRANKFORT
PT BETSIE
GRAYLING AAF
REED CITY
Manistique
SCHOOLCRAFT CO
ESCANABA
GLADSTONE
ST JAMES
LANSING SHOAL
GRAYS REEF
PETOSKEY
BOYNE FALLS
ANTRIM COUNTY
CLAM LAKE
WEXFORD CO
HOUGHTON LAKE
Caution: High cable crossing inlet

C-130

FLIGHT LINE REQUIREMENTS

PROJECT NO. ~~AIS~~ P.I. VANE ORGANIZ. JPL

LOCATION: SLEEPING BEAR DUNES SITE NO. 25

MISSION NO. 84-05 FLT. DATES:

LOCATION	LINE #	RUN	ALT (K FT) AGL	ALT (K FT) ASL	LINE NMI	RUN TIME	GND SPEED (KNOTS)	REMARKS
	1	1	13.	14.1	6	2.2	160	*
	2	1	13.	14.1	6	2.2	160	
	3	1	13.	14.1	8.5	3.2	160	
								AIS - PRIME
								PHOTO: CIR
								NS001 - ALL CHANNELS

NOTES: * MAINTAIN FLIGHTLINES AS STRAIGHT AS POSSIBLE EVEN IF THEY ARE OFF TRACK SOMEWHAT. DO NOT CORRECT AIRCRAFT HEADING WHILE ON LINE.

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AIS TAPE LOG

OPERATOR Mahoney

LOGGER Tucker

SCIENCE Tucker

TAPE NUMBER 34

DATE 7/18/84

LOCATION Boreal Fores[t] Sleeping Bear MI

NIKON DIDN'T WORK NO FILM AVAILABLE

RUN ID	AIS FRAME # START / STOP	T.O.D. START / STOP	GND SPEED KTS	ALTITUDE (x1000')	GRATING MODE	OFF-SET Y/N	SLOPE Y/N	CAMERA FRAME # START / STOP	AIR TEMP °C	LINE # / RUN #	SITE NAME (DATE)	COMMENTS
401	144:40 / 149:68	16:29:45 / 16:35:10	204	17.88	ROCK	Y	N	244 / 209	-6°	8 / 1	Boreal forest MINN.	Good line
402	157:14 / 158:18 [illegible]	16:42:52 / 16:43:5_	—	—	ROCK	Y	N	— / —	+8°	— / —	line source calibration data	Krypton lamp warmed up 30 sec
403	013:30 / 015:62	17:43:57 / 17:46:24	157	13.82	TREE	Y	N	203 / 185	3.2°	1 / 1	Sleeping Bear MI	~~3370~~' cabin altitude 3200 Good line - attempted to stay
404	022:08 / 024:34	17:52:32 / 17:55:00	162	13.71	"	Y	N	185 / 168	2.0°	3 / 1	"	3700' cabin altitude Sod a little off, N end great shadow first 10 sec, rest clear
405	030:16 / 032:54	18:00:47 / 18:03:17	161	13.99	"	Y	N	168 / 151	3.0°	2 / 1	"	3750' cabin altitude line a little to left
406	040:12 / 042:40	18:10:43 / 18:13:05	162	13.55	"	Y	N	151 / 134	3.0°	1 / 2	"	3650' cabin altitude
407	049:54 / 052:48	18:20:16 / 18:23:11	162	13.75	"	Y	N	151 / 113	2.8	2 / 2	"	3650' cabin altitude 6000 LINE
408	003:26 / 004:26	18:29:12 / 18:30:_	—	—	TREE	Y	N	(113) / (111)		— / —	LINE SOURCE CALIBRATION	KRYPTON LAMP WARMED UP 30 SEC

AIS SCIENCE LOG

SCIENCE Tucker

DATE 7/19/84

RUN ID	SITE NAME/EXPTR	EXPTR'S LINE #/RUN #	START WPT/LAT	START WPT/LON	END WPT/LAT	END WPT/LON	FLIGHT DIRECTION	WEATHER	COMMENTS
403	Sleeping Bear, MI Olsen	1/1	44 54.8	85 47.8	44 53.6	86 04.8	E to W	clouds above dunes clearest (high thin cirrus)	Good line sun angle 64°
404	"	3/1	(9) 44 49.5	85 58.1	(3) 44 56.0	85 58.0	S to N	a little clearer less shadowing 1st 10 sec shadowed the rest clear	S end a bit off line N end great
405	"	2/1	(6) 44 52.3	85 55.4	(E) 44 51.4	86 04.7	E to W	clear!	line a little to left 2000' left
406	"	1/2	(2) 44 54.3	85 55.9	(1) 44 54.0	86 [illegible]4.8	E to W	clear!	Repeated since weather improved LINE very close
407	"	2/2	(6) 44 52.5	85 54.5	(5) 44 52.3	86 05.5	E to W	clear over 1st part. " shadow over Dunes	Repeated to get closer to line. GOOD LINE
408	" LINE SOURCE CALIBRATION	—	—	—	—	—	—	—	KRYPTON LAMP

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JET PROPULSION LABORATORY California Institute of Technology • 4800 Oak Grove Drive, Pasadena, California 91109

JUNE 26,1984

Dr. Charles Olsen
School of Natural Resources
University of Michigan
Samuel Trask Dana Bldg
Ann Arbor, MI 48109

Dear Chuck,

The wavelength calibration for Airborne Imaging Spectrometer data flights from July through September is as follows:

GPOS	Lower Wavelength	Upper Wavelength	Dispersion
0	not measurable	1141.6 nm	---
1	1151.8 nm	1440.8	9.21 nm/pixel
2	1452.8	1740.0	9.26
3	1748.0	2036.0	9.29
4	2048.0	2336.8	9.32

These wavelengths are about 60 nm lower than planned. We received a new spectroradiometer about one week before we needed to calibrate AIS. , During shipping, the grating had slipped on its mount in the monochromator thereby shifting the wavelength calibration by about 60 nm. The discrepancy was not found in time to correct the AIS wavelength endpoints. The above values were measured after the September data flights when we returned AIS to JPL.

If you had requested and received the light cannon calibration data, it too was off by the 60 nm. A post-flight calibration was performed after the monochromator was re-calibrated.

If you have any questions, please call me at (818) 354-2466 ,FTS 792-2466.

Sincerely,

Deanne Tucker

Deanne Tucker
AIS Experiment Representative
MS 11-116

Telephone (213) 354-4321 Twx 910-588-3269 Twx 910-588-3294