Willow Run Laboratories

N73 - 11296

October 31, 1972
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CR - 129064

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt Road
Greenbelt, Maryland 20771

Attention: Mr. E. F. Szajna, Code 430

Contract: NAS5-21783

Subject: Second Bimonthly Report For Period Covering 1 September-31 October, 1972.

Dear Sir;

The enclosed material comprises the second Type I bimonthly technical
report for contract NAS5-21783, and reports progress on the ten tasks of
this program for the period 1 September-31 October, 1972. Financial reports
533M and 533Q are submitted separately from our Accounting Department.

Work on this contract is performed in the Infrared and Optics Division
(Tasks 1-3 and 5-10)directed by Mr. Richard Legault and in the Radar and
Optics Division (Task 4) directed by Dr. Leonard Porcello.

Principal Investigators for each task are listed on the report subsections
associated with those tasks.

Three important aspects of the effort at Michigan deserve general discussion.
First, a prototype computer based data management system is now running on the
IBM 360 computer on campus to catalog digital magnetic tapes. All pertinent
data about the tapes is stored for automatic retrieval. By use of an editing
retrieval program, only data of interest to the investigator may be listed on
page printer or time sharing station teletype. In addition to editing searches,
plans are to publish periodic lists of additions to the system.

Second, ERTS-1 CCT's of the San Francisco frame (1003-18175) were success-
fully processed to the color coded recognition map stage. This was done to
assess the state of readiness of the IBM-7094 software system. Problems
identified in this simulation run on real ERTS-1 data are now being addressed by

programmers. Because the processed results from the Sacramento Valley
have the potential of being significant results, some effort has been
expended checking the recognition map in the field. Based on Mr. Sadowski's
field trip to the site, a modified set of spectral signatures, each signature
representing a particular crop type, has been suggested. A second recognition
map will be prepared. Analysis of this map should yield useful results in
determining the ability to map important crops from ERTS-1 data and determine
their acreages.

Third, it is clear that the length of the first look data phase will
be longer than the three months originally anticipated. This extension is
caused by the fact that magnetic tapes ordered from Goddard have not yet
arrived. Investigators for tasks II, VI, VII, VIII, and X have ordered
magnetic tapes but only Wezernak (Task VIII) has obtained tapes to date.
Investigators for tasks I, III, IV, V, and IX have not yet received any imagery.

For tasks III, V, and IX cloudy sky conditions have precluded obtaining
any useful imagery. Task IV deals with lake ice and the standing order is not
in force as yet. Task I has not received data apparently becaused of tape recorder
priorities in the collection of data over Puerto Rico. The Lake Michigan
site for task I has been covered, but no imagery has been received to date.
Data from the first two orbital cycles are known to be unusable because of
100% cloud cover but status of data from the next 3 orbital cycles is unknown
at present.

Table I shows the tasks presently being pursued under contract NAS5-21783.
Reports by individual investigators follow in order of task number.

Respectfully submitted

Frederick J. Thomson
Associate Research Engineer

R. R. Legault
Associate Director
Willow Run Laboratories

FJT:RRL:cmk

ERTS PROGRAM SUMMARY
Under Contract NAS5-21783

TASK	PRINCIPAL INVESTIGATOR	MMC #	UN	SHORT TITLE
I	Polcyn	063	200	Water Depth Measurement
II	Thomson	077	621	Yellowstone Park Data
III	Thomson	137	636	Atmospheric Effects (Colorado)
IV	Porcello	072	201	Lake Ice Surveillance
V	Sattinger	086	225	Recreational Land Use
VI	Polcyn	114	635	IFYGL (Lake Ontario)
VII	Malila/ Nalepka	136	612 178	Image Enhancement
VIII	Wezernak	081	625	Water Quality Monitoring
IX	Horvath	079	606	Oil Pollution Detection
X	Vincent	075	422	Mapping Iron Compounds

Second Type I Progress Report - 1 September - 31 October 1972
Task I - Water Depth Measurements - 1388
F. Polcyn, UN 200

Since no data had been received, a request was made of the User Services at NASA Goddard for any data collected in the Virgin Islands. It was found that data over this test site must be tape recorded and data from only one pass was recorded. A request for any frames available was made and is pending.

Data over the second test site in Upper Lake Michigan is also missing. While there has been data collected in lower parts of Lake Michigan no data has been received. There appears to be some confusion in that useful data for one researcher over his designated site is being sent to other researchers whose area lies in a small geographical part of the frame.

Standing orders will be changed to extend the period of time designated for which useful space data can be collected at each test site because of season conditions.

Meanwhile work continues on completing the programming effort for using water depth subroutines on the 7094 computer.

Second Type I Progress Report - 1 September-31 October 1972
Task II - Yellowstone National Park Data - 1398
F. Thomson, UN 621

    Since the first bimonthly report, a number of excellent ERTS-1 frames have been received of the Yellowstone National Park area. These frames are summarized below and imagery content forms are attached. On 16 October, digital 7 track, 800 bpi tapes were ordered for frame 1015-17404 collected on 7 August. This frame covers the entire park, has less than 10% cloud cover, and essential park features are well portrayed. When the tapes are received and preliminarily processed, we should be able to prepare a data analysis plan.

    Harry Smedes concurs in the selection of the 7 August data for preliminary processing. Training sets for the recognition are now being summarized on maps. Processing is now planned for about 15 December. This starting date is based on the typically 2 month (from order date) delivery time for digital tape products. If digital tapes arrive sooner, processing will begin sooner.

    A considerable amount of time has been spent getting software in shape for processing the data. Based on our experience with the San Francisco frame, some modifications were made in a tape copy program.

Table I-1

SUMMARY OF YELLOWSTONE DATA RECEIVED TO DATE

Frame No.	Date	Center Lat. & Long.	Area
1014-17350	Aug 6	N 44° 34' LAT W 109° 10' LONG	East Edge Yellowstone Cody, Wyo. Black streaks in MSS-5.
1015-17404	Aug 7	N 44° 48' LAT W 110° 35' LONG	Yellowstone, Henry's Lake, Ida.
1015-17410	Aug 7	N 43° 22' LAT W 111° 08' LONG	Jackson Lake, Grand Tetons, Snake River Valley
1032-17350	Aug 24	N 45° 06' LAT W 108° 54' LONG	N.E. Corner Yellowstone, Cody, Wyo, Montana 30% cloud cover Band MSS-7 missing
1050-17351	Sept 11	N 44° 33' LAT W 109° 05' LONG	East Edge Yellowstone Cody, Wyo. 10% cloud cover

ERTS IMAGE DESCRIPTOR FORM
(See Instructions on Back)

DATE ___11/2/72___

PRINCIPAL INVESTIGATOR ___F. Thomson___

GSFC ___UN 621___

ORGANIZATION ___University of Michigan___

NDPF USE ONLY
D _____
N _____
ID _____

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
	Geology	Forest	Agriculture	
1014-17350M	X	X	X	Rangeland, Snow
1015-17404M	X	X		
1015-17410M	X	X	X	
1032-17350M	X	X	X	Rangeland, Snow
1050-17351M	X	X	X	Rangeland, Snow

*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

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NASA GSFC
GREENBELT, MD. 20771
301-982-5406

GSFC 37-2 (7/72)

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Second Type I Progress Report - 1 September - 31 October 1972
Task III - Atmospheric Effects in ERTS-1 Data - 1410
F. Thomson, UN 636

No acceptable ERTS-1 data was obtained in the overpass of 9/6/72 and no data are listed in the September 30 catalog for the overpass of 9/7/72. Roland Hulstrom of Martin - Marietta made atmospheric measurements in the test site in this time frame. Had we obtained good ERTS data on this pass we probably could have conducted an assessment of the atmospheric effects and have written a data analysis plan.

A frame of data was ordered from the 25 September overpass. While this data is outside the range of the initial standing order, the frame was ordered to provide an introductory look at the test site.

Because snow now covers the test site, data collected from now until April 1973 will probably have limited utility to implementing the experiment as now planned. Thoughts will be crystallized in the next bimonthly period on possible alternative plans which will allow the experiment objectives to be fulfilled with alternative data sets. These plans will then be discussed with the scientific and technical monitors.

Second Type I Progress Report - 1 September - 31 October 1972
Task IV - Lake Ice Surveillance - 1406
L. Porcello, UN 201

The only problem which has arisen during this second two month period is the long delivery time for a few components of the instrument discussed in the 31 August 1972 Type 1 bimonthly report.

Plans are continuing to prepare for the aircraft underflights and ground truth operations during the ERTS-1 passes. It is tentatively planned to conduct these "earth based" portions of the project on 15 January 1973, 10 March 1973 and 15 April 1973, although these times are flexible as may be required by the conditions at the time. Flight and ground operations may be off by a day or two, but they must remain to be simultaneous with one another.

The flight lines have been tentatively identified to cover Douglas Lake and Whitefish Bay at the entrance of the St. Mary's River and the Straits area of Lake Michigan. It is noted that the number of flights has been reduced from 6 to 3. This reduction will not seriously hamper the study although it may reduce the variations in ice types which will be studied during the field period.

Initial efforts are being conducted to contact individuals and agencies which are presently involved in ice studies and reports on the Great Lakes. It is intended to try to coordinate their mesoscale reports with hour proposed microscale ground truth and the macroscale ERTS-1 imagery. This should cause no change in the program as written through the ERTS-1 contract, but should increase the amount of ground truth data to be correlated with the ERTS-1 imagery and thus increase the scope of ERTS imagery usefulness.

At this time, no "significant results" have been realized.

One paper: "The Utility of Imaging Radars for the Study of Lake Ice" was presented at the International Symposia on the Role of Snow and Ice in Hydrology held in September at Banff, Alberta, Canada. A xerox copy of the preprint of this paper is enclosed as Appendix I. A corrected version will be published in the Proceedings of the Symposia. Multiple copies of this paper are presently available. This report was generated on funds provided by the Director of Willow Run Laboratories. The information copy of the report is attached and is being sent to NTIS because of its pertinence to the Task IV ERTS-1 investigation.

Order forms for both test sites, submitted on 13 December 1971 under user ID UN 201, Proposal #MMC-072 show (p. 4 of 5) that we requested 1 copy Bulk B&W 70mm (ng. transparency) RBV (1, 2, 3) and MSS (4, 5, 6, 7), 4 copies Bulk B&W 9.5" Positive Paper Print (RBV 1, 2, 3) and MSS (4, 5, 6, 7) and 2 copies Precision B&W 4.5" Pos. Paper Print (RBV, 1, 2, 3) and MSS(4, 5, 6, 7) for each site. It was also indicated that we did not intend to order for all cycles marked on Section 3.2 of that form.

We now wish to change that request to have the above enumerated products delivered for all cycle which passes over the test sites as outlined on the ERTS-1 Product Order Forms.

Second Type I Progress Report - 1 September 1972 - 31 October 1972
Task V - Recreational Land Use - 1387
I. Sattinger, UN 225

Photographic results of RB57 Mission 205 flown over Southeast Michigan (Site 279) in June 1972 were received during September. Preliminary examination of the photography shows that coverage of parts of Oakland County was obtained, but that other parts could not be photographed due to developing cloud cover. However, coverage of other parts of Southeast Michigan was obtained which will be useful for some aspects of the investigation. It is understood that an attempt was made during Mission 211 in September to obtain additional coverage of the area, but this was again prevented by cloud cover. In the absence of complete coverage of Oakland County, the RB57 photography will be used as much as possible and supplemented where necessary by previous coverage obtained in 1969. If it appears by next spring that additional photography is needed to complete the work, a new request will be submitted at that time.

Full-scale analysis for this task must await receipt of ERTS-1 imagery for Southeast Michigan. At the end of this reporting period, no useful coverage of the test area had yet been obtained. However, preliminary study of RB57 photography and C47 scanner imagery is being conducted in preparation for the analysis of satellite data. The useful RB57 imagery of Oakland County and 9 in. x 9 in. color infrared imagery of the C47 test site taken during the C47 flight is being examined to determine the types of vegetation, water bodies, and residential areas to be identified in the ERTS-1 data.

A portion of the C47 scanner data acquired during the August 29 flight is being processed. This portion covers a part of the Pointe Mouillee State Game Area at the mouth of the Huron River. Studies of this waterfowl habitat area being conducted under other projects will provide useful ground truth data on vegetation species for verification purposes when ERTS data becomes available.

During the next reporting period, study of RB57 photography and C47 scanner imagery will be continued for the purpose of further defining the plan for analyzing ERTS-1 data when it becomes available.

Second Type I Progress Report - 1 September - 31 October 1972
Task VI - IFYGL (Lake Ontario) - 1384
F. Polcyn, UN 635

        MSS images of the western and eastern ends of the Lake Ontario Basin
were received during this period. These frames were recorded on August 19 and
21 and appear to be of good quality. Unfortunately ERTS imagery of the central
portion of Lake Ontario was not collected by ERTS at that time. These frames
are being considered for automatic processing using multispectral discrimination
techniques.

        Two attempts were made to obtain supporting U of M aircraft data at
times of ERTS passes -- September 8th and October 13-14th. The September
mission was aborted due to technical aircraft problems after two flightlines
had been flown and poor weather conditions during the October mission prevented
any aircraft data collection on that date.

        Current plans include 1) continued attempts to obtain supporting aircraft
data, 2) obtaining ERTS imagery from passes over the Lake Ontario Basin
subsequent to the mid-August pass, and 3) continued coordination of ground
observation efforts with various IFYGL cooperating universities and agencies.
It is unfortunate that to date weather conditions have been generally
unseasonably poor during times of ERTS passes over the Lake Ontario Basin.

Second Type I Progress Report - 1 September-31 October 1972
Task VII - Image Enhancement - 1385
W. Malila, UN 612, and R. Nalepka, UN 178

Experience has been gained at WRL over the past decade in computer processing and extraction of information from airborne multispectral scanner data and in modeling atmospheric effects in received radiance signals. The general objective of Task VII is to adapt techniques existing at WRL for their application to ERTS-1 data, to assess the applicability of these techniques by applying them to selected ERTS-1 data, and to identify any additional problems that might be associated with such processing of satellite multispectral scanner data. Three areas are to be studied: (1) compensation for atmospheric effects in ERTS-1 data, (2) preprocessing for improved recognition performance, and (3) estimation of proportions of unresolved objects in individual resolution elements.

The principal activities prior to and during the current reporting period have been in planning data collection activities, providing ground support for aircraft and ERTS-1 overflights, making field observations in the test site area, and modifying computer software to handle ERTS data.

The intensive test site for this investigation is an agricultural area South-West of Lansing, Michigan, and the extensive test area also covers several other counties in South Central Michigan. Field data on the identity of crops planted in a large fraction of the fields in the extensive test area had been obtained through the cooperation of ASCS personnel of the USDA and coordination efforts of Michigan State University (MSU) personnel, although only data for the intensive area are presently at our disposal. In addition, extensive field checking and ground photography were carried out in the intensive test area by MSU personnel with assistance from WRL personnel. RB-57 camera coverage of the region was obtained during June, but was not available for use in this effort.

The intensive test area is in an overlap region covered by ERTS-1 on two successive days of each 18-day cycle. On 6, 7, and 24 August, there were heavy cloud overcasts, but skies were clear on 25 August. Simultaneous multi-altitude underflight coverage was obtained by the Michigan C-47 multispectral scanner aircraft, and ground-based measurements were made of spectral irradiance and sky radiance. No ERTS imagery was received prior to the current reporting period.

Imagery from the Aug. 25th pass over our test site was received on Oct. 18th. A preliminary analysis showed it to be cloud-free over the intensive test area and a majority of the remainder of the frame. Thus, it will serve as a major data base for the investigation. Computer-compatible tapes were ordered immediately for our analyses. Color-composite images also were ordered from ERTS User Services. A phone call was made to the Aircraft Program Office at the Manned Spacecraft Center, Houston, Texas, to confirm our immediate need for copies of photographs and imagery collected by the Michigan multispectral scanner aircraft.

RB-57 photography from June 10/11 was received on Sept. 22nd. A second RB-57 flight was made on Sept. 15th and copies of the photographs were received Oct. 27th.

Field observation data along a 10-mile segment of the test site were consolidated and preparations begun for analysis of the scanner data. Visual range measurements at 10:00, 11:00, and 12:00 (noon) on Aug. 25th were collected for all reporting weather stations in the ERTS frame.

In addition to that from Aug. 25th, imagery was received from Aug. 6, 7, 8, and 24 and Sept. 9, 11, 12, and 13. Most of these suffered from cloud cover in the test area. Image descriptor forms were forwarded for nine frames. The planned aircraft underflights on Sept. 11 and 12 were cancelled because of weather conditions.

Dr. Robert Fraser, GSFC, visited WRL on Oct. 19th to discuss plans and progress on the atmospheric portions of our study.

Plans for the next reporting period are to plan and begin analyses of ERTS-1 CCT data and supporting aircraft multispectral scanner data for the Aug. 25th frame.

Second Type I Progress Report - 1 September - 31 October 1972
Task VIII - Water Quality Monitoring - 1400
C. T. Wezernak, UN 625

Work during the reporting period consisted of:

1. Examination of available satellite imagery (70 mm positives and negatives) for the test sites included in this investigation
2. Review of available aircraft imagery
3. Preliminary analysis of satellite and aircraft data
4. Preparation of a plan for preliminary data analysis.

During the reporting period, data became available for the New York Bight. A preliminary analysis was made and results were reported at the ERTS seminar "Preliminary Findings From Analyses of ERTS Observations" held at Goddard on 29 September 1972. Digital tapes for the study area have been received and the data will be preliminary processed during the next reporting period.

Product order requests have been submitted for the other test sites. Data will be processed as it becomes available.

During the next reporting period, multispectral aircraft missions in support of the program have been authorized for the New York, S. E. Florida, and Tampa study areas. Accordingly, ground truth activities in support of these missions are planned.

The following talks and publications have been released during the reporting period:

1. "Barge Dumping of Wastes in the New York Bight" presented at Goddard ERTS seminar on September 29, 1972, Report No. 011229-6-S, NASA-CR 128099, E72-10084.
2. "Remote Sensing in the New York Bight", presented at the New York Bight Conference held at NOAA, Rockville, Maryland, on 12 September 1972. This was a meeting of government agencies which have programs in the New York Bight area. The ERTS program for the area was described and examples of aircraft data were shown.

The ERTS Image Descriptor Form which relates to the New York Bight analysis is attached. The standard vocabulary of image descriptors was used, except that the term pollution was added. In general this vocabulary is inadequate to describe image content.

The following Data Request Forms have been submitted:

1.	New York Bight	14 September 1972
2.	Tampa Bay	6 October 1972
3.	Lake Michigan	11 October 1972
4.	Santa Barbara Channel	12 October 1972
5.	Lake Erie	17 October 1972

These include requests for imagery and digital tapes. To date, only digital tapes for the New York test site have been received.

ERTS IMAGE DESCRIPTOR FORM
(See Instructions on Back)

DATE _1 November 1972_

PRINCIPAL INVESTIGATOR _C.T. Wezernak_

GSFC _UN 625_

ORGANIZATION _Willow Run Lab._

NDPF USE ONLY

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ID _____

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
1024150714 ⌉ 1024150715 ⊢ 1024150716 ⌋				Oceanography, river, sediment, slick, pollution, current
102415071M				Estuary, Coastline Harbor

*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

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GSFC 37-2 (7/72)

Second Type I Progress Report - 1 September - 31 October 1972
Task IX - Oil Pollution Detection - 1389
R. Horvath, UN 606

Work during the reporting period consisted primarily of finally
establishing the total geographic scope of the program which involves
complementary funding by NASA (this contract) and the U.S. Coast Guard
(Contract DOT-CG-24063-A). In addition to the Chesapeake Bay test area
defined in the NASA contract, U. S. Coast Guard interest has defined
additional sites in the Gulf of Mexico southwest of New Orleans and in
Santa Barbara Channel. These latter two areas represent concentrations
of offshore oil drilling activities as well as shipping lanes, and thus
complement the shipping and shoreline industrial nature of the southern
reaches of Chesapeake Bay. The Gulf of Mexico site is coincident with
an ecological test site being extensively investigated by Gulf Universities
Research Consortium (G.U.R.C.). Mr. C. Catoe, U.S. Coast Guard Co-investi-
gator (OT301) has arranged for access to ground truth data from the
G.U.R.C. area.

No satellite data have been received to date.

A revised ERTS1 Standing Order Form was submitted on 30 October
1972. This revision added the Gulf of Mexico and Santa Barbara channel
sites, and extended the time period of interest for the Chesapeake Bay
site.

Second Type I Progress Report-1 September through 31 October 1972
Task X- An ERTS Experiment for Mapping Iron Compounds - 1383
R. Vincent, UN422

During this reporting period a method for producing ratio images
from ERTS data was defined, a paper concerning the experimental plan
for this investigation was submitted for publication, computer programs
were begun, and an ERTS frame over the Wind River test site was selected
for quantitative examination.

The experimental plan presented here is more fully described in a
paper submitted this month to the Eighth Remote Sensing Symposium Pro-
ceedings entitled "An ERTS Multispectral Scanner Experiment for Mapping
Iron Compounds," by R. K. Vincent. The spectral radiance of Lambertian
targets measured by ERTS MSS scanner can be expressed as

$$L_\lambda = S \left(\frac{E_{sun_\lambda}}{\pi} \right) \tau_\lambda \rho_\lambda + L_{P_\lambda} \tag{1}$$

where L_λ = measured spectral radiance,

S = shadow or illumination factor (1.0 for no shadow in
instantaneous field of view),

E_{sun_λ} = spectral irradiance of the sun (impinging upon target),

τ_λ = atmospheric transmittance,

ρ_λ = spectral reflectance of target,

L_{P_λ} = path radiance (caused by atmospheric scattering).

The L_{P_λ} term contains path radiance from two sources: light scattered into
the beam between target _and_ detector, and light scattered off the sun-target
direction (diffuse illumination), then reflected off the target toward the
detector. Whenever the L_{P_λ} term is negligible, as with low-altitude scanner
data on a clear day, all of the environmental factors are multiplicative.
From satellite altitudes, however, L_{P_λ} is no longer negligible. To get
rid of most or all of this additive term, the purely empirical approach of
dark object subtraction can be taken. In a shadowed region, $S = 0$ because
there is no direct solar irradiance; hence $L_\lambda = L_{P_\lambda}$ whenever the shadow is
large compared with a spatial resolution element. Therefore, for a given
spectral channel, the value of the lowest radiance measured within the scene
will be subtracted from all other spatial resolution elements in the scene.
After dark object subtraction, the ratio of the ith and $(i + 1)$th channels
will be approximately

$$R_{i,i+1} \approx \frac{L_i}{L_{i+1}} = \frac{S\left(\dfrac{E_{sun_i}}{\pi}\right)\tau_i \rho_i}{S\left(\dfrac{E_{sun_{i+1}}}{\pi}\right)\tau_{i+1}\rho_{i+1}} = \frac{E_{sun_i}}{E_{sun_{i+1}}} \frac{\tau_i}{\tau_{i+1}} \left(\frac{\rho_i}{\rho_{i+1}}\right) \qquad (2)$$

In this equation, the only term which will vary widely over an ERTS frame (for most geological test sites) is ρ_i/ρ_{i+1}, the target reflectance term. The ratio may not be invarient for a given type of target type in two ERTS frames collected at different times in different places, however. For a further suppression of environmental factors (S, E_{sun_i}, τ_i, and L_{P_i}), the spectral reflectance of a known target within the ERTS frame can be measured and used as a reference, for which the ERTS-measured ratio will be:

$$(R_{i,i+1})_{reference} = \frac{E_{sun_i}}{E_{sun_{i+1}}} \frac{\tau_i}{\tau_{i+1}} \left(\frac{\rho_i}{\rho_{i+1}}\right)_{reference} \qquad (3)$$

A division of equation 2 by equation 3 yields, after rearrangement,

$$\frac{\rho_i}{\rho_{i+1}} = \left(\frac{\rho_i}{\rho_{i+1}}\right)_{reference} \left[\frac{R_{i,i+1}}{(R_{i,i+1})_{reference}}\right] \qquad (4)$$

from which the term ρ_i/ρ_{i+1} can be calculated almost independent of environmental factors. The "almost" is included in the foregoing statement because the degree of environmental independence is dependent on how well the dark object subtraction succeeds in suppressing the path radiance term. It should be noted that the dark object subtraction is an approximation, because part of the L_{P_λ} term is dependent on target reflectance. However, it is assumed here that the target reflectance dependence of L_{P_λ} is negligible. Should the above procedure yield poor results, i.e., fail to suppress atmospheric effects, another approach will be attempted. The dark object subtraction method cannot be used to yield data from the darkest elements in the scene, however. These elements will be processed in a different manner, possibly as a straight radiance ratio.

Finally, dark object subtraction and ratio programs were begun and ERTS frame No. 1013-17294 (collected by ERTS on 5 August 1972) was selected for quantitative analysis. Tapes and images were ordered for this frame.

Appendix I

THE UTILITY OF IMAGING RADARS FOR THE STUDY OF LAKE ICE

by

M.L. Bryan

WMO - 4: Measurement and Forecasting Specific to River and Lake Ice

International Symposia on the Role of Snow and Ice in Hydrology

Symposium on Measurement and Forecasting

Banff, Alta. Sept. 72.   (PREPRINT)

THE UTILITY OF IMAGING RADARS FOR THE STUDY OF LAKE ICE

by M. Leonard Bryan

SUMMARY

Although several remote sensing systems are available for the surveil-
lance of ice and snow (e.g. aerial photography, multispectral scanners,
weather and earth resources satellites), they suffer from their present
restriction to the visible and infrared portions of the electromagnetic
spectrum. Sidelooking airborne radar (SLAR) is not so limited.

After a brief introduction to radar systems, the argument proceeds to
define system and ground parameters which affect the radar signal return.
Two of these, dielectric constant and surface roughness, are seen to be the
most important with respect to the final radar image. It is noted that
although SLAR has been used for surveillance of sea ice in the higher
latitudes, its usefulness for the study of fresh water lake ice in the
mid-latitudes is only now being intensively studied. Two images of X-Band
(3 cm) radar are presented, together with some comments concerning future
developments of radar imagery of lake ice.

L'UTILITE DE RADARS IMAGANTS POUR L'ETUDE DE LA GLACE SUR LES LACS

RESUME

Malgré la disponibilité de plusieurs systèmes sensitifs de contrôle
à distance pour la surveillance des glaces at des neiges (e.g. photographie
aérienne, scrutateurs multispectrales, satéllites de resources terrestres
et de conditions atmosphériques) ceux-ci souffrent tous présentement de
leurs restrictions aux portions visibles et infra-rouges du spectrum
électromagnétique. Le radar oblique aéroporté (SLAR) n'est pas aussi limité.

Faisant suite à une brève présentation aux systèmes de radar, l'argu-
ment procède à définir les paramètres de système et terrestre qui
influencent le retour des signaux de radar. Deux de ceux-ci, le diélectrique
constant et la rugosité sur la surface sont jugés les plus importants en
ce qui concerne l'image finale de radar. On note aussi que malgré l'emploi
de SLAR pour la surveillance de la glace océanique aux hautes latitudes,
son utilité pour l'étude de la glace sur les lacs d'eau fraiche aux
mi-latitudes, n'a jamais été étudié serieusement jusqu'à présent. Deux
images de X-Band (3 cm) sont présentées, avec commentaires touchant
aux dévèlopements futurs d'imageries de radar sur la glace des lacs.

INTRODUCTION:

In any of the earth sciences, a major problem is the collection of meaningful synoptic and real time data. Not only must the data often be quickly available but it must also be accurate and reliable, for, when dealing with a dynamic system (e.g. climate, hydrology, and to a lesser degree, glaciers, soils and sea or lake ice) we often do not have the opportunity to repeat our measurements. If that opportunity does arise, we are confronted with the problem of making assumptions concerning the rate of change of the items being investigated.

In addition to these difficult hurdles, we also must recognize that many of the important aspects of hydrologic studies, both in the frozen and the liquid states of water, are in relatively inaccessible regions where both intense and continuous research programmes are difficult and expensive. The Great Lakes are such an area.

Finally, much of the data we collect is point specific when indeed we are attempting to secure area data by summing the numerous points. As has often been observed: "Confronted by a situation as complex as the environment ... we are likely ... to attempt to reduce it in our minds to a set of separate, simple events, in the hope that their sum will somehow picture the whole." [1]

USE OF AIRCRAFT AND EARTH SATELLITES:

In some early, but recent attempts at approaching this problem of areal coverage using remote sensors, cameras were mounted in airplanes and flown over the ice/snow fields in question. This method has proven to be fairly useful both for defining the extent of the snowfield and also for determining the volume of the snowpack and glaciers, especially when a series of sequential photographs can be made to determine the changes in the snowpack mass. [2] However, in areas where there is little shadow, it is very difficult to contour the photograph in one of the early steps in the production of a contour map for mass balance studies.

The problem is not insurmountable, but the data retrieved through such a system are limited, primarily to the areal extent of the snow and also by the fact that only small areas could be covered in a given time. One solution was to change the focal length of the camera or, conversely, place the camera at a higher altitude. Ultimately, this led to the installation of cameras in earth satellites, and several (NIMBUS, TIROS, ITOS AND ERTS [A]) have been, or in the case of ERTS (A) will be used to produce excellent pictures of snow and ice covered regions of the world. Several published articles [3,4,5,6,7] have excellent examples of the imagery from such systems.

One of the major problems confronting these systems which deal with the visible and near-visible portions of the electromagnetic spectrum is that they are completely useless when persistent cloud cover overlie the area of

interest. It is recalled that many of the early spectacular pictures from both manned and unmanned satellites were from areas of little cloud cover (e.g. Egypt, southwestern United States, Persian Gulf, Australia). This problem of persistent clouds has not been totally solved. However, in areas where cloud cover is aperiodic, a technique known as Composite Minimum Brightness (CMB) has been used to discriminate cloud from snow cover. [6,8] Because snow generally has a fairly high albedo in the visible portion of the EM spectrum (i.e. reflectivity), it is readily seen against darker natural backgrounds. However, when it is obscured by cloud cover which has a reflectivity similar to that of the snow cover, the two cannot be distinguished from one another. In the CMB technique, the reflectance of each point over the area of interest is measured and stored in a geographic matrix. At intervals during several days these measurements are retaken from a new image and the minimum value for each point is stored in the matrix. After the period of study is completed, the minimum values measured for each of the several points are displayed, thus forming a composite map of the minimum brightness for each point in the geographic matrix. It is assumed that during the study period the cloud cover is variable while the snow cover is essentially stable. Minimum brightnesses would represent the darker natural background (e.g. forests, vegetated land, bare ground, or, in the case of lake ice, open water or relatively young ice) while the maximum brightness would be areas of snow (or older ice) cover.

Using this and similar methods, based upon imagery from the several meteorological satellites, the boundary of the snow could be mapped to an accuracy of $\pm$ 10 nautical miles, and in mountainous basins, the areal measurement of snow was determined to be $\pm$ 5% of the measurements taken using conventional aerial photography. [8] Although effective in removing the water clouds from the scene, the CMB method may prove to be of little help in the discrimination of ice clouds, although other techniques applied over Greenland question this supposition. [9] This method of using visible wavelengths in cloud and snow discrimination on satellite imagery could be of little use in areas which are: (a) completely snow covered, as the arctic deserts or the great plains in winter or (b) areas which are periodically covered with ice clouds. In each case, several passes of the sensor are required to make the complete map.

Finally, we must recognize the question of resolution when dealing with the staellite imagery. Using an ITOS image representing 90 miles (145 km) on a side and having 10 gray scales for the entire sensing range, it has been reported [10] that the lowest detectability for lake ice in the eastern portion of Lake Superior was approximately 25% cover. Even at this coverage, there were several questionable interpretations.

USE OF INFRARED:

In another portion of the electromagnetic spectrum (Table 1), infrared, both near and far, have been reported to be useful for the determination of

the surface temperature of ice and snowfields. Such work is quite helpful, especially for monitoring the advance of the firn line through the glacier season, detecting outflows from glacial lakes, the identification of snow bridges and crevasse areas in glaciers, and to a certain degree, the identification of ice/land interfaces. Thermal imagery (8.0μ to 13.5μ) of sea ice [11,12,13] can be used for the determination of ice thickness. It is assumed in this work that the water under the ice is of a constant temperature and the ice acts as an insulator. Hence, thicker ice being a better insulator, will appear cooler than will thinner ice. Highly stippled areas indicate something of the history of the ice pack through the variation of temperature, and by inference, variations in ice thickness. Recently frozen leads and polynyas are also clearly visible.

Still, such a system suffers from problems of attenuation by the atmosphere and even for areas in which there is an atmospheric window, there is always the problem of obscuration by weather and cloud systems.

TABLE 1. Wavelength Ranges of Remote Sensors		
Spectral Region	Wavelength	Frequency (Hz)
Visible	$0.380 - 0.780\mu$	$7.89 \cdot 10^{14}$ to $3.85 \cdot 10^{14}$
Infrared:		
Near	$0.780 - 3.000\mu$	$3.85 \cdot 10^{14}$ to $1 \cdot 10^{14}$
Intermediate	$3.000 - 8.000\mu$	$1 \cdot 10^{14}$ to $3.75 \cdot 10^{13}$
Far	$8.000 - 1000\mu$	$3.75 \cdot 10^{13}$ to $3 \cdot 10^{11}$
Microwave		
Millimeter	$0.1 - 1.0$ cm	$3 \cdot 10^{11}$ to $3 \cdot 10^{10}$
Centimeter	$1.0 - 10$ cm	$3 \cdot 10^{10}$ to $3 \cdot 10^{9}$
Decimeter	$10 - 100$ cm	$3 \cdot 10^{9}$ to $3 \cdot 10^{8}$
		(after [14], p. 75)

THE MICROWAVE REGIONS:

The longer wavelengths ranging from 0.1 cm to 1.0 m are generally termed microwaves. These waves lie between the most familiar EM waves, that is, between the visible and the radio wave lengths. One of the more important features of these 'radar waves' is their ability to retain both their strength and their form while propagating through the atmosphere of the earth. [15] In addition, in an active system (e.g. radar) which is transmitting a signal of known strength and measuring the strength of the reflected (i.e. returing) signals, the measurements are independent of available light or other (natural) radiated energy. Thus radar, compared to

the visible and IR portions of the spectrum, while suffering very little attenuation by the atmosphere or cloud cover and in combination with the independence of natural light sources, is virtually an all weather day/ night system.

Radar is a scanning device, that is, it scans orthogonally to the aircraft flight path over an area of several miles width. The samples of backscattered energy (i.e. the reflection of the transmitted signal) are easily measured and converted into a gray-tone series for the production of hard copies. The information can also be readily stored on computer compatible tape. This is an additional advantage radar has over conventional aerial photography. Although this advantage is also recognized for other line scan devices (as the multi-spectral scanner), the width of swath covered by radar is much greater thus affording more ground coverage per aircraft pass and hence less time per unit area of ground coverage for data collection.

RADAR IMAGERY:

Although the resulting radar imagery appears similar to aerial photographs, there are several subtle differences. One of the major differences is in the projection. For an optical projection, all points from the imaged surface to the imaging surface are projected through a common point in the lens, via straight lines. Thus both azimuth and range points are simultaneously recorded. In the radar projection, on the other hand, the imaged surface is transformed to the imaging surface through a series of constant range (i.e. constant distance from the antenna) arcs. For recording in the azimuth direction, the film is advanced in the recorder at a rate proportional to the speed of the aircraft and each line of points (in the azimuth direction) is plotted next to the previous one. Thus, there is a uniformity of scale in the along-track direction (that is, parallel to the aircraft line of flight). However, in the range direction (perpendicular to the line of flight), the scale is continually changing and is therefore similar to, but reversed, when compared to an oblique aerial photograph. (N.B. In radar the scale decreases at near range, for oblique photographs, at far range.)

Hence, the two resulting images are different and should be viewed quite differently. Radar images and oblique photos also show a similar relief displacement, with points of high elevation displaced toward the radar set, a feature termed 'layover' These and similar comparisons of SLAR and aerial photographic imagery are discussed in the literature. [15,16] Early radar imagery consisting of photographs of PPI-scopes, showing ice in the Gulf of St. Lawrence is also available. [17]

THE RADAR EQUATION:

What exactly does the radar measure? For this brief discussion, we must

return to the basic considerations of the radar equation, the equation which describes the interaction of the surface (i.e. the 'target') with the emitted microwave signal and its return to the radar antenna.

The radar equation, as defined in [18], is:

$$S = \frac{P_t \; G^2 \sigma \lambda^2}{(4\pi)^3 \; R^4}$$

in which: S is the received power
P_t is the transmitted power
λ is the wave length of the emitted EM wave
σ is the echoing (scattering) cross-section
R is the range.

Within this equation, the scattering cross-section[1] is a function of many conditions, and it is essentially the only term which is target dependent. When this is briefly considered, we note that by determining the controlling factors of the scattering cross-section, we would be able to approach the identification of the variables on the ground and hence the identification of the imaged items.

These controlling factors in the scattering cross-section are: (1) SYSTEM PARAMETERS: (a) wavelength; (b) polarization; (c) illuminated area; and (d) direction of illumination (azimuth and elevation) and (2) GROUND PARAMETERS: (a) complex permitivity; (b) surface roughness; and (c) roughness of the subsurface to depth where attenuation reduces the wave to negligible amplitude. [20,21]

The geometry of the target in terms of surface roughness has a very important role in the strength of the radar echo. For example, a smooth surface will provide no radar return because all signals reaching the surface will be reflected specularly, that is, in accordance with the Fresnel-reflection law (i.e. angle of incidence equals angle of reflection). The only occasion when such a smooth surface would produce a signal return would be when the impinging radar signal is orthogonal to the target surface. Hence, in many radar images, water areas appear black or, if covered with small waves, speckled. A surface which would appear rough at X-Band (3 cm) may appear smooth at S-Band (5.8 - 19 cm) or L-Band (19 - 77 cm).

In sea ice, roughness is often correlated with the age of the ice, with the older ice being increasingly rougher. By measuring roughness, as has been done using both scatterometers and radar imagery, a very good indication of the ice age, and by inference, the ice thickness has been developed. [22] Roughness as it affects the gray scale was also an important contributing factor in the analysis of JOHNSON & FARMER. [23]

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[1]The scattering cross-section is the measure of the ability of a target to produce a return. It is equivalent to the area of an isotropic scatterer which would produce a radar echo at a sensor equal to that from a given target. [19]

However, for lake ice on the mid-latitude Great Lakes, we do not have this advantage. Ice is generally very young with the oldest being possibly four months, and consequently the surface roughness has not had sufficient time to develop. Surface roughness is rather the result of drifting snow or pressure within the ice body.

If we take an ideal case, that of a homogeneous plane and if we assume that the radar looks at this plane from a single angle and has constant system parameters, we have reduced the number of unknown terms in the scattering cross-section to essentially one, that is, the complex permitivity or dielectric constant of the target. This is, of course, an abstraction for much of the real world, but may not be too far from reality with respect to some snow and ice studies.

The dielectric constant of ice is quite low (in the neighborhood of 3) and for snow is almost equally low. EVANS [24] has noted that dielectric variations are dependent upon: (a) density of the snow and ice; (b) wavelength; (c) temperature of the target; (d) Formzahl number[2]; (e) impurities in the snow or ice; and (f) free water content. Although laboratory work needs to be done concerning the dielectric constant of snow and ice, little work has been conducted using samples of natural materials. The relative importance of these variables in determining the dielectric constant is unknown, and the relative importance of the dielectric constant in determining the scattering cross-section is almost certainly unknown.

It has been previously suggested [25] that the sea ice/glacier ice interface should be easily determined by electromagnetic means because there is a distinct change in the dielectric constant across this interface. This is probably one of the best examples where imaging radars will be useful. Likewise, bergs in a pack of frozen sea ice could conceivably be easily spotted using the same logic. An exceptionally good paper dealing with imagery of sea ice is presently available. [23]

IMAGERY OF GREAT LAKES ICE:

Our experience at Willow Run Laboratory has shown, however, that X-Band radar imagery can be very helpful in distinguishing clearly and definitively, several types of Great Lakes ice. [26,27] Figures 1 and 2 clearly show several types of ice, classed generically, which were observed in the southeastern portion of Lake Superior during the 1967-1968 winter season. In Figure 1 brash ice, open water, large floes and thrust features are clearly

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[2]Formzahl is defined as a single parameter used to show how one medium is dispersed in another; essentially it is related to crystal orientation and structure of the snowpack with $F = 0$ when crystals are all oriented normal to the electric field and $F = \infty$ in the other extreme (i.e. orientation normal to the field) case. Hence, when dealing with snow, the structure of the snow pack is of extreme importance. [23]

seen. Also, easily identified are shore ice ridges which have developed along the entire portion of Whitefish Point which has a northern exposure. In Figure 2 several additional features of ice breaker channels, snow drifts on older ice, open water resulting from the parting of a large floe and recently refrozen ice are seen. The linear feature labeled "refrozen leads/cracks" is very white, signifying a high radar return and may have been a misinterpretation of a large pressure ridge. To a degree, ice thickness can be inferred in some areas, for example, in the area identified as "thrust features" (Figure 1). These highly irregular cracks are common features in thin ice, whereas the possible pressure ridges in Figure 2 are experienced on thicker and older ice. However, at this time we are unable to state quantitatively the ice thickness indicated by such features.

CONCLUSION:

From the several images shown here, it is noted that there is a great potential for expanded usefulness of radar imagery in the field of ice hydrology. It is theoretically possible for some very subtle features to be identified using radar imagery. This would give us a remote sensor capable of acquiring both area and point data of a nature which is at present only available on a point sample basis, or, if aerial photography is used, when weather and lighting conditions would permit. Radar will not, however, solve all data acquisition problems for the snow and ice hydrologist, even when the present problems of relating the scattering cross-section to the target parameters are solved and we develop a more extensive interpretation key.

Ice thickness data, for example, are not presently discernible using existing airborne imaging radars and even with longer wave microwave instruments, water layers in the ice together with variations of the dielectric constant through the ice sheet are problems which must be more thoroughly understood in order to develop a reasonable model of the ice body. When this model is available, we can return to our interpretation of radar ice imagery and possibly extract additional information concerning other important parameters of fresh water lake ice.

It is expected that as shipping interests continue to search for methods of expanding the shipping season in the upper Great Lakes, quick, efficient and reliable ice information collection systems will be required as an input for their daily decision making. Radar flights over the proposed shipping routes can collect these data, independent of the weather, and at a scale and resolution sufficiently fine to be an important aid to navigation. Likewise, the scientist interested in area and location, together with types, of ice cover can expect to find radar to be a useful field tool for his work.

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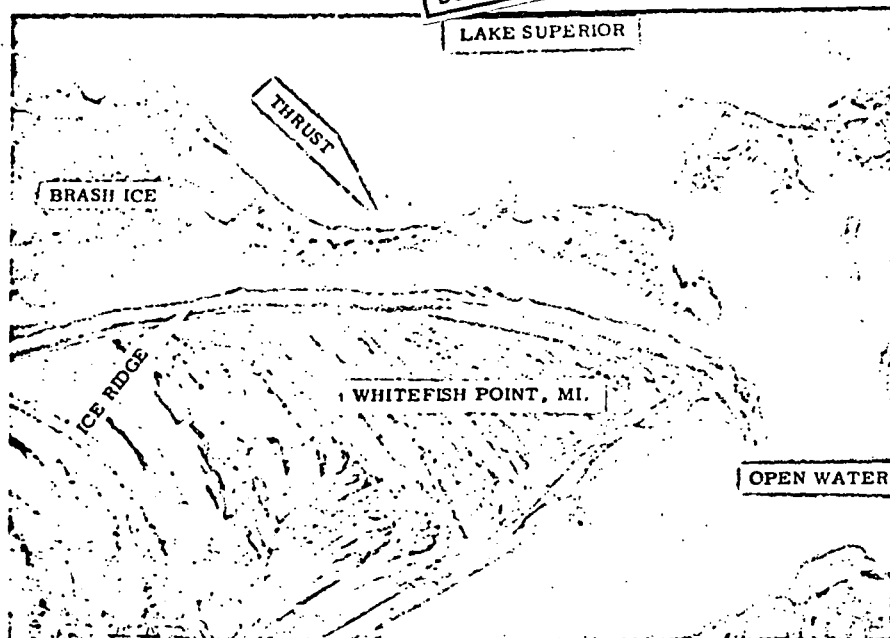
FIGURE 1.   X-BAND (3 cm) RADAR IMAGE OF GREAT LAKES ICE.
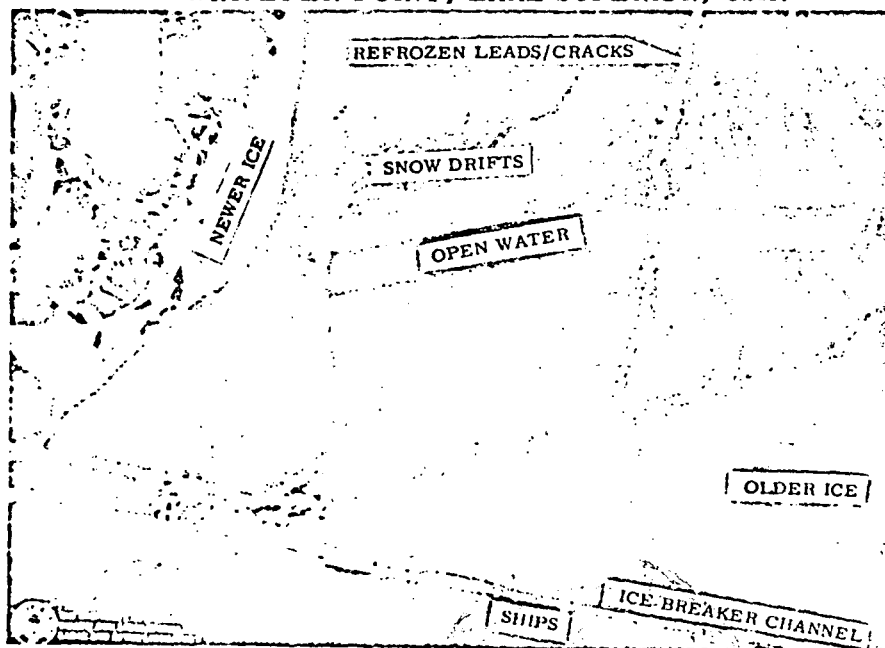WHITEFISH POINT, LAKE SUPERIOR, USA.

FIGURE 2.   X-BAND (3 cm) RADAR IMAGE OF GREAT LAKES ICE.
WHITEFISH POINT, LAKE SUPERIOR, USA.