SECOND INTERNATIONAL CONFERENCE ON
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UNIVERSITY OF ICELAND
DEPARTMENT OF ENGINEERING AND SCIENCE

A REMOTE SENSING PROGRAM IN SEA ICE AND CURRENT STUDIES

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INTRODUCTION

The Ocean Engineering group of the Memorial University of Newfoundland is conducting extensive research to develop technology concerning the exploitation of resources of the ice-infested continental shelf of eastern Canada. At the present particular attention is being paid to the study of movement of sea ice and ice bergs. Accurate information on this is required for both navigational and operational purposes on and in the sea.

With the advancement of satellite technology and with the availability of sophisticated remote sensing systems for civilian use, a great deal of data on sea and ice state can be collected over large areas. However, because most of these systems became available only recently their usefulness for oceanographic data gathering is not fully understood. Each different types of imagery must be evaluated for specific purposes. In this study photographs obtained by various sensors mounted in satellite-borne and airborne platforms, are being used. Since the evaluation process commenced recently; only partial results are presented here.

BACKGROUND

From November 1972 pictorial data of the eastern seaboard, obtained by the ESSA-8, NOAA-2, and ERTS-A satellites were received in connection with various projects. This presented a unique opportunity to use the provided imagery for ice distribution and movement observations.

In August 1972 an iceberg research program was carried out along a coastal strip off Saglek Bay in Northern Labrador. The field investigation was conducted from the research vessel "C.S.S. Dawson" of the Bedford Institute of Oceanography. Three weeks were spent in a 50 kilometer wide and 100 kilometer long experimental area gathering data on various parameters of the sea (Allen, 1972)[1]. In connection with this investigation a remote sensing program was initiated for the following purposes:

1) to evaluate the usefulness of different remote sensing systems in obtaining various parameters of sea ice and water surface,
2) to provide iceberg census and hydrographical data for the experimental area,
3) to provide information on the physical dimensions of selected icebergs, and on the characteristics of water envelopes surrounding the bergs.

The acquisition of imagery was carried out by the Maritime Command of the Canadia Forces using an Argus Aircraft.

PLATFORMS, SENSORS, AND IMAGERY

Satellites

The ESSA-8 weather satellite was designed to provide photographs of clouds covering very large areas.[2] The average altitude of the space craft is 1300 kilometers. The only sensor, carried on board, is a 25.4 millimeter vidicon camera producing an instanteous picture. This picture is transmitted as A.M. modulated video signal to receiving stations. The Canadian Station is located in Malton, Ontario. The effective picture size is 284 square centimeters corresponding to an area of 4400 square kilometers on the ground (Figure 1).

The NOAA-2 is an improved version of the TIROS operational weather satellites.[3] The nominal altitude of this space vehicle is 1464 kilometers. This satellite carries various sensors from which two produce images: a scanning radiometer (SR) and a very high resolution radiometer (VHRR). Both radiometers have two channels. One is sensitive to energy in the visible spectr (0.5 to 0.7 microns) and the other to energy in the atmospheric infrared "window (1.05 to 12.5 microns). Data from the sensors are transmitted in real time to the receiving stations. In this study, imagery, produced by the very high resolution radiometer (VHRR) is being used (Figure 2). The ground resolution of the obtained pictures is 0.93 kilometer.

The ERTS-A satellite was designed to provide high resolution multichannel imagery of the earth surface that can be used for resources inventory and for efficient resources management.[4] This space craft was lunched into a near-polar sun-synchronous orbit with an altitude of 900 kilometers. Three return beam vidicon (RBV) cameras and a four channel multi-spectral scanner (MSS provide imagery of an approximately 185 kilometer wide strip of the earth surfac during each orbit. The satellite ground trace repeats its earth coverage at the same location every 18 days within 37 kilometers. At present only the multi spectral scanner (MSS) operates which has the following bands and spectral sensitivity:

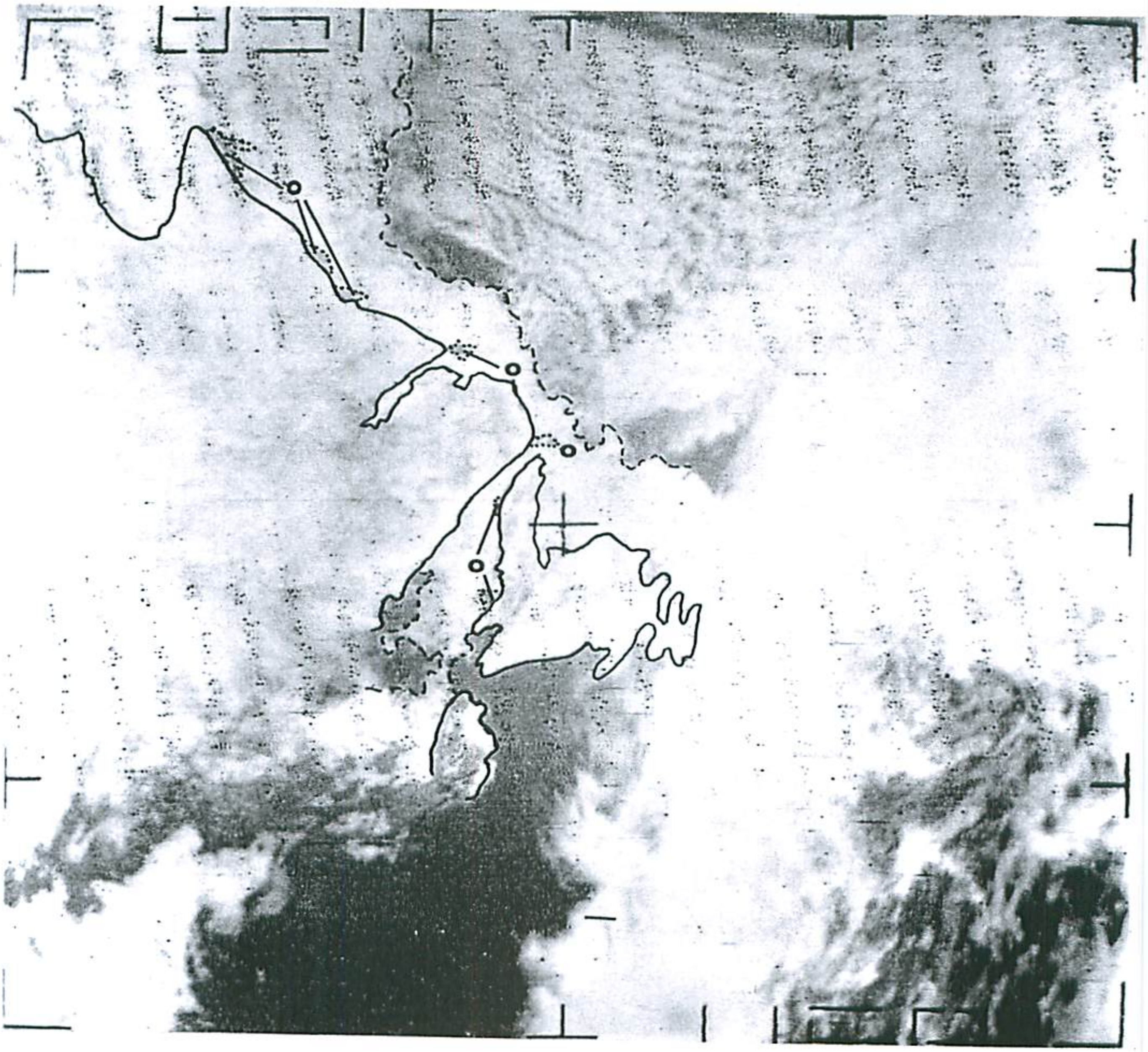

Figure 1. ESSA-8 Photograph of Newfoundland and Labrador (Orbit 14671).

Land boundary:
Ice boundary:
Open water in ice:
—0

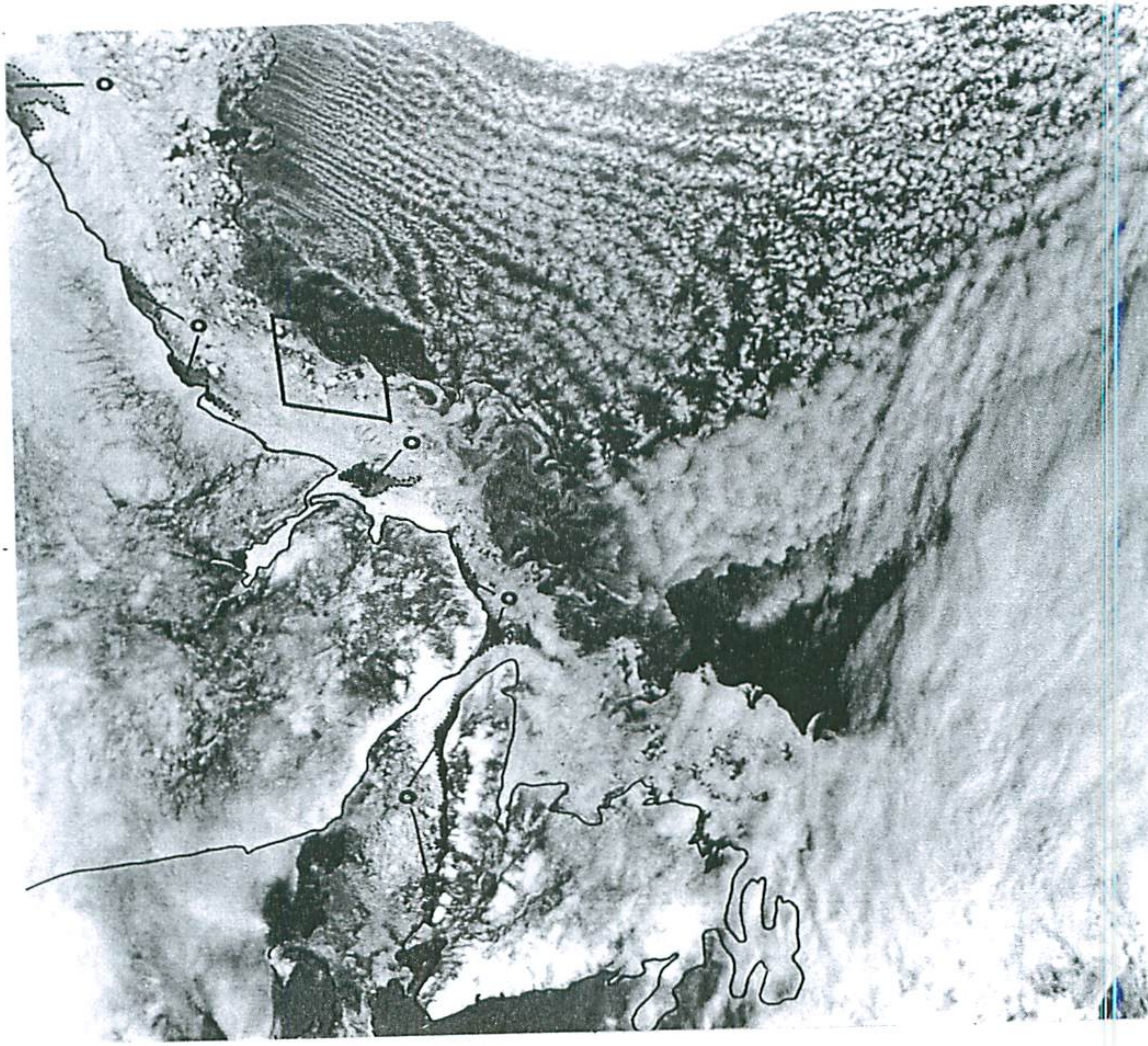

Figure 2. NOAA-2 Photograph of Newfoundland and Labrador (Revolution 2089, VHRR-Vis).

Land boundary:
Ice boundary:
Open water in ice: ——0
Area shown in Figure 3: A

Figure 3. ERTS Satellite Photograph of Ice Field (Orbit 3498, Band 2).

Close and very close pack:			A
Open pack	vast to small floes		B
Very open pack	vast to small floes		C
Brash and slush:			D
Open water:			O

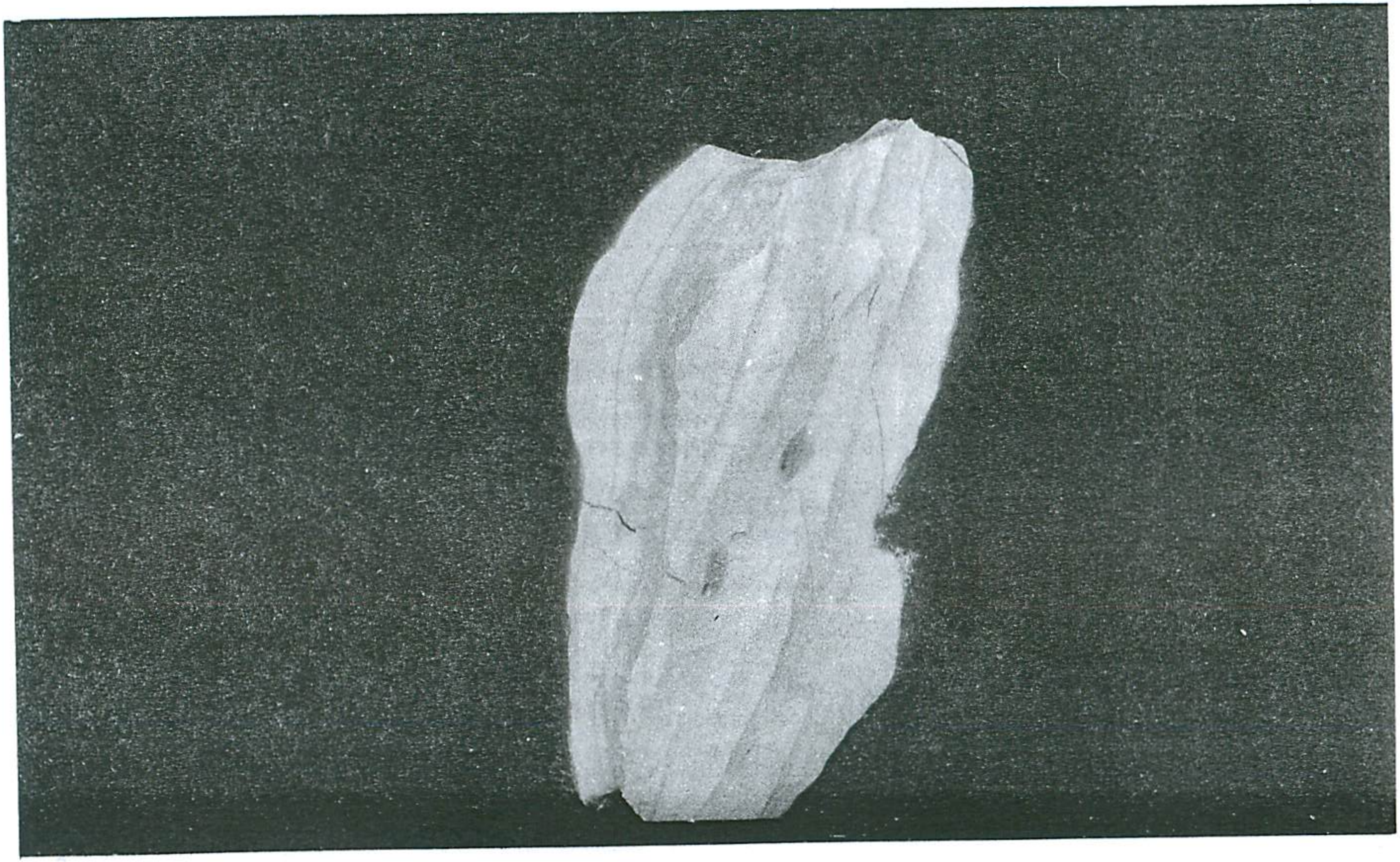

Figure 4. Panoramic Aerial Photograph of an Iceberg.

Band	Spectral Sensitivity
1	0.5 to 0.6 microns
2	0.6 to 0.7 microns
3	0.7 to 0.8 microns
4	0.8 to 1.1 microns

The ground resolution of the produced imagery is approximately 100 meters. Pictures of each band can be reproduced in paper print or positive transparency form. Besides these a color composit paper print or transparency can be produced combining three bands. In this study uncorrected paper print of band two with an approximate scale of 1:1,000,000 was used.(Figure 3). This kind of imagery covering Canada and Northern waters can be supplied to anyone within 24 to 48 hours after the imagery was acquired.

Airborne Systems

The following airborne remote sensing systems were available for this study: aerial photographic cameras, a thermal mapper, and a side looking radar mapper.

A KS-116-A pan/frame camera provided panoramic aerial photography to back up the thermal and radar mapping unit. This camera had a 304.8 millimeter focal length lens, a 90 degrees scanning angle, and a 11.4 by 47.75 centimeter picture format. The middle section of a panoramic picture showing an iceberg is included for illustration purposes (Figure 4). A vinten 70 millimeter camera with a 65.5 millimeter focal length lens was also used to obtain large scale vertical aerial photographs of specific icebergs (Figure 5).

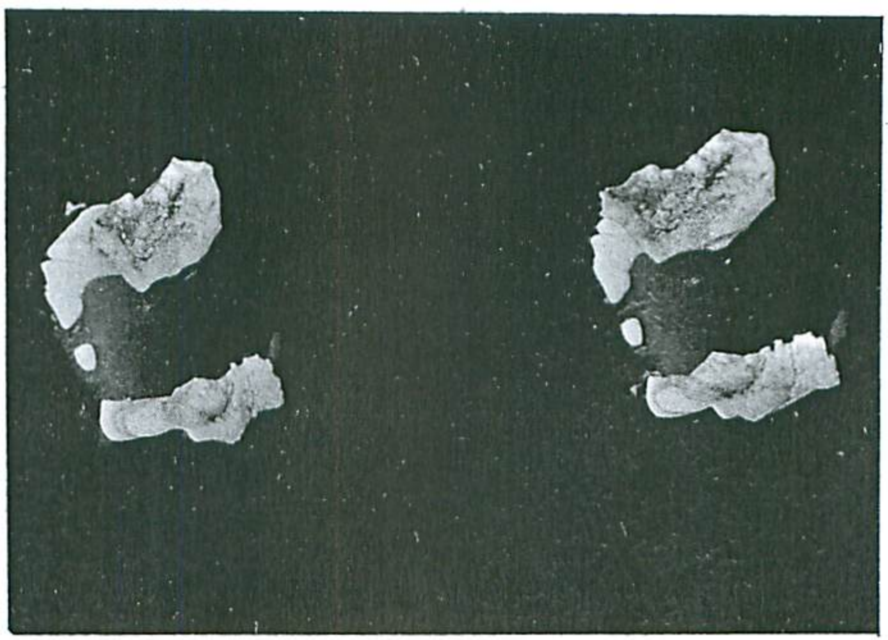

Figure 5. Stereogram of Vinten 70 Millimeter Vertical Aerial Photography.

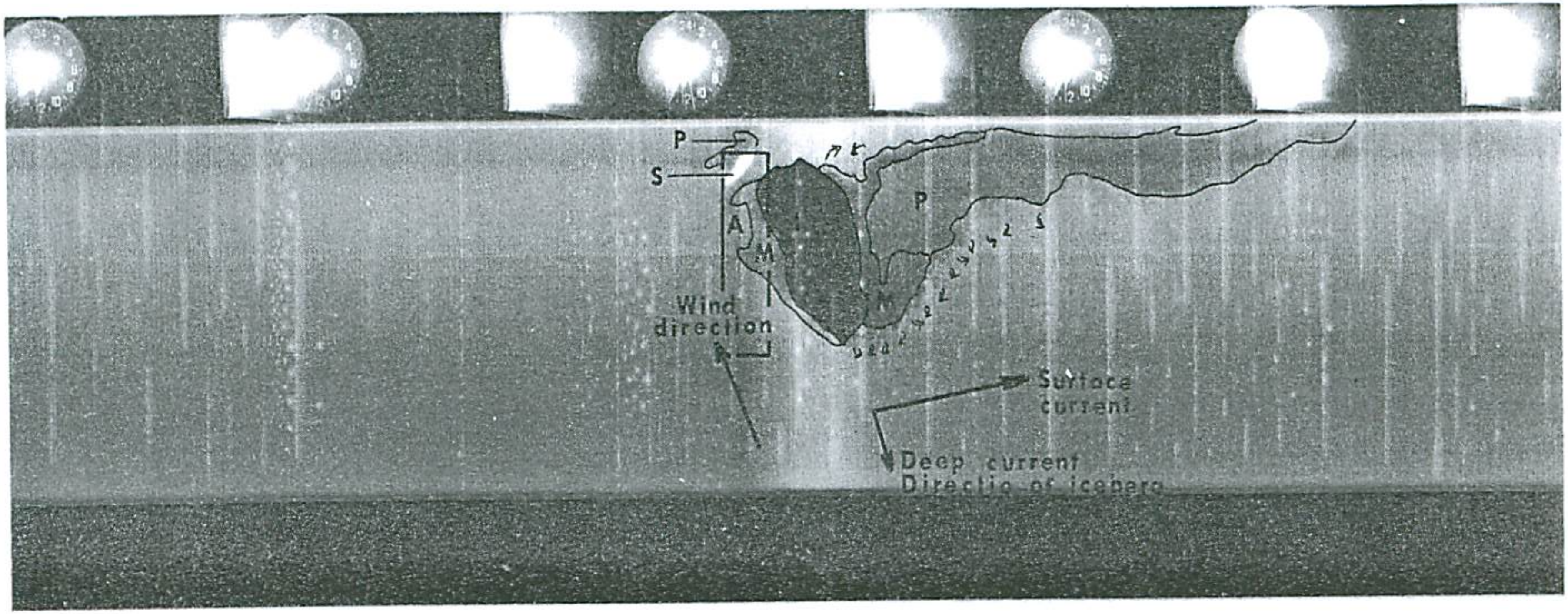

Figure 6. Infrared Line Scan Image of an Iceberg.

Ship:	S
Iceberg:	I
Area of melt water on surface:	M
Area of partially mixed water:	P
Eddies:	↲↙
Area illustrated by Figure 12:	[A]

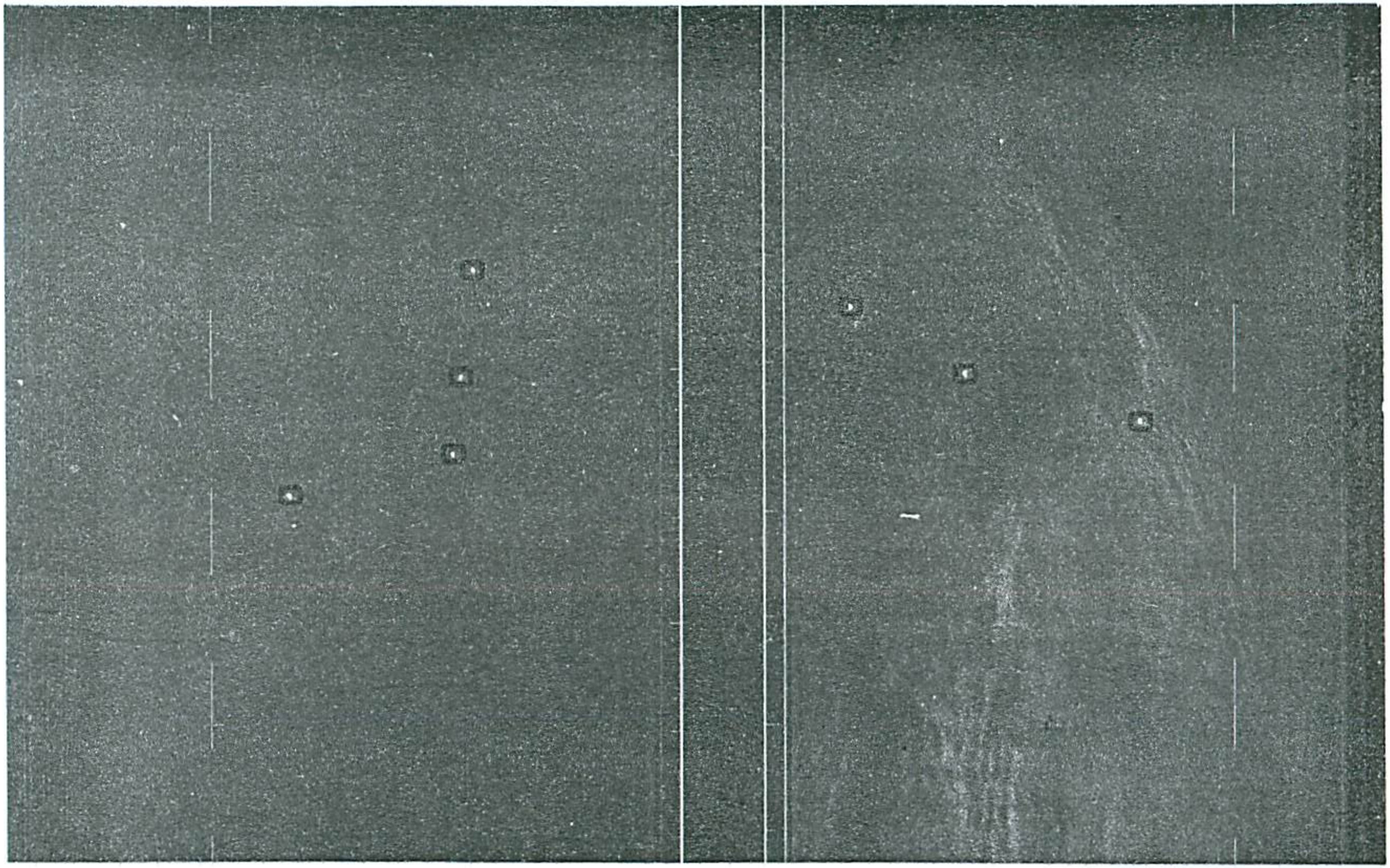

Figure 7. Side Looking Radar Image of Sea Surface
Icebergs: 0

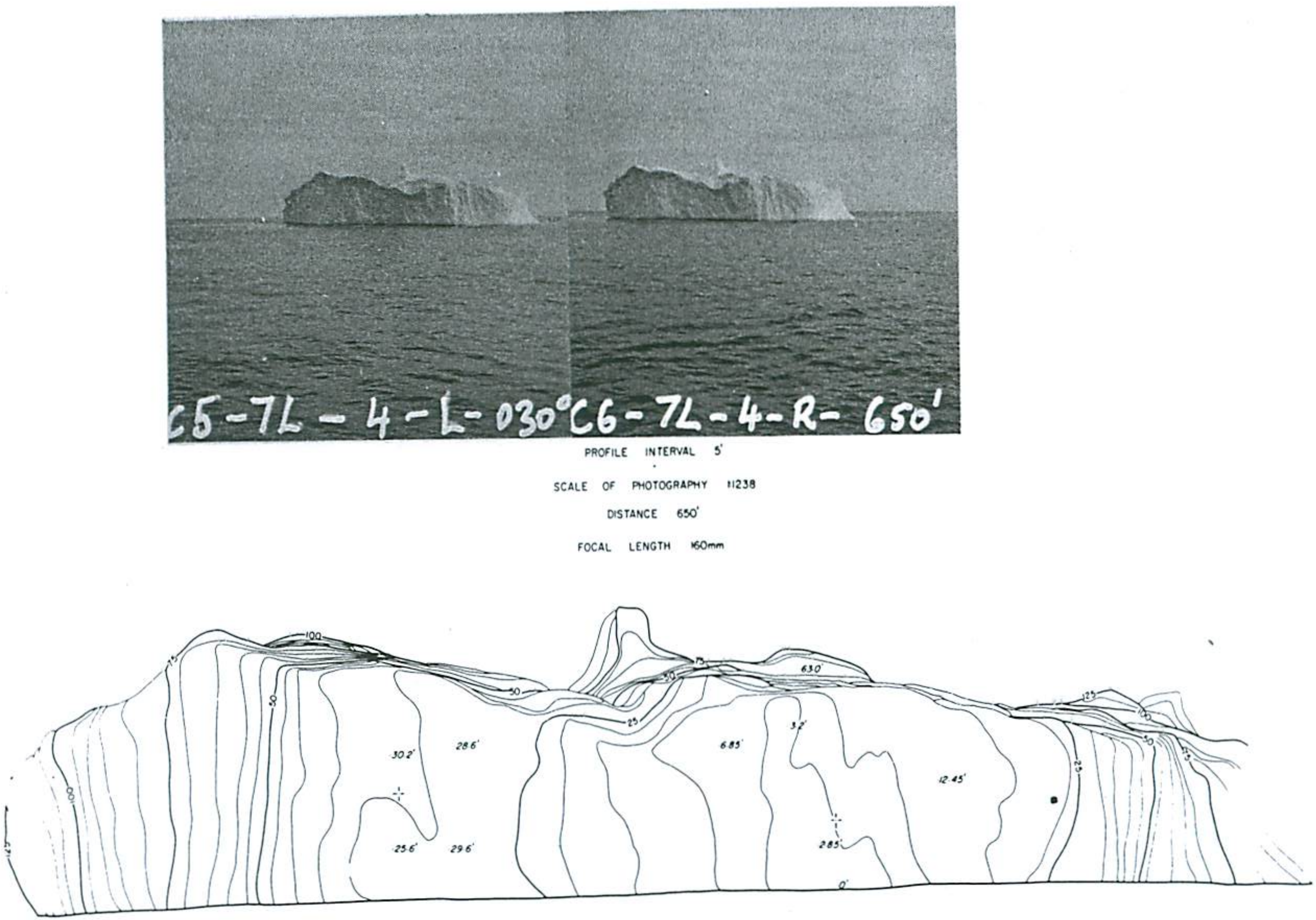

Figure 8. Stereogram and Profile Map of one Side of an Iceberg.

The thermal mapping unit consisted of a Reconoflax XIII-A infrared line scanner (JRLS). The detector of this instrument was sensitive in the 8 to 13 microns spectral region with a peak of 11 microns. This instrument had the following bands:

Band	Instantaneous Field of View	Thermal Sensitivity
1	1 milliradian	0.3^oC
2	2 milliradians	0.2^oC
3	4 milliradians	0.06^oC

During operation only one of the above bands can be used at a time for thermal mapping. The scanning angle of the optical unit was 120 degrees. The obtained imagery was reproduced in a 70 millimeter wide continuous strip form (Figure 6).

The radar mapping was carried out with a side looking airborne radar (SLAR) having real aperture system. The radar imagery was obtained from an altitude of 915 meters resulting in an image scale of 1:250,000. The range of the coverage was 25 kilometers each side of the plane with a loss of a 10 kilometer wide strip directly below the aircraft (Figure 7). However, the antennas could be set so that the ground is viewed only from one side of the plane resulting in a simultaneous double coverage.

Terrestrial Photography

Horizontal stereo photography of 11 icebergs was carried out using a dual Hasselblad 70 millimeter camera system. Two cameras 36.6 meters apart with parallel optical axis were mounted on the starboard side of the ship. The icebergs were circumnavigated on intersecting base lines. On each base lines the two cameras were exposed simultaneously once or twice to obtain a stereo pair of various sides of the icebergs (Figure 8).

AREA COVERAGE

Although ESSA and NOAA pictures of the coast of Labrador and of Newfoundland waters are produced every day their use for ice observations is limited due to weather conditions. On the average only one picture in a week shows enough ground details of land, ice, and water. It is even more difficult to obtain cloud free pictures of the ERTS satellite since any location is photographed only once in every 18 days. On March 31, 1973 the three satellites produced reasonably cloud free pictures of the shores of Labrador (Figure 1, 2 and 3). These photographs were taken approximately at the same time (forenoon).

The airborne sensing was designed to provide imagery for three different areas:

1) Five 220 kilometers long lines 20 kilometers apart were flown by the aircraft at an altitude of 915 meters using the panoramic camera and the thermal and radar mappers.

2) Three separate thermal maps were obtained from 300 meters altitude for a 25 kilometers long strip of ocean surface. For the first mapping band two and for the last two band three of the scanning instrument was used.

3) Thermal mapping and panoramic and 70 millimeter vertical aerial photography was carried out for selected icebergs. (Figures 4, 5 and 6). This imagery was obtained from an altitude of 150 meters. The produced photographs covered a one kilometer long strip of water surface. For each berg two lines with different directions were flown to determine iceberg rotation.

Navigational data relevant to the first program are given in Figure 9. The flight paths and the position of aircraft, icebergs, and of bathythermograph buoys are indicated. The area coverage of the side looking radar (SLAR), the thermal mapper, and of the panoramic aerial photography is shown by Figure 10.

GROUND TRUTHING

The various aceanographic data collected by the ship on three base lines will be used for ground truthing. In numerous stations of each line salinity, temperature, and density data (STD) of the water from the surface to the bottom were obtained.[1] Besides this, while cruising along the base lines surface temperatures were measured continuously using a Branes precision radiation thermometer model PRT-5. The instrument was mounted in the "crow's nest" looking at the water at an angle of 45 degrees. The recordings of this instrument must be corrected according to humidity and ambient temperature. For calibration purposes actual surface temperatures were obtained in each station using a sea bucket thermometer. On one of the base lines two Braincon thermographs, eight kilometers apart, were placed into the sea for the duration of the field work.

In each of the four corners of the experimental area the aircraft dropped an expandable bathythermograph during the remote sensing mission. In addition to this three bathythermographs were deployed 500 meters apart in the trail of an iceberg.

INTERPRETATION OF IMAGERY AND RESULTS

The photo interpretation commenced only recently because of difficulties occurred during the photographic reproduction and because of other commitments of the principal investigator. The preliminary results, presented here, are based on the enclosed imagery. However, final results will be published in due course. Most of the interpretation was confined to visual observations of photographs using a 2X magnifying glass. One positive transparency of the infrared line scan image was mechanically analysed.

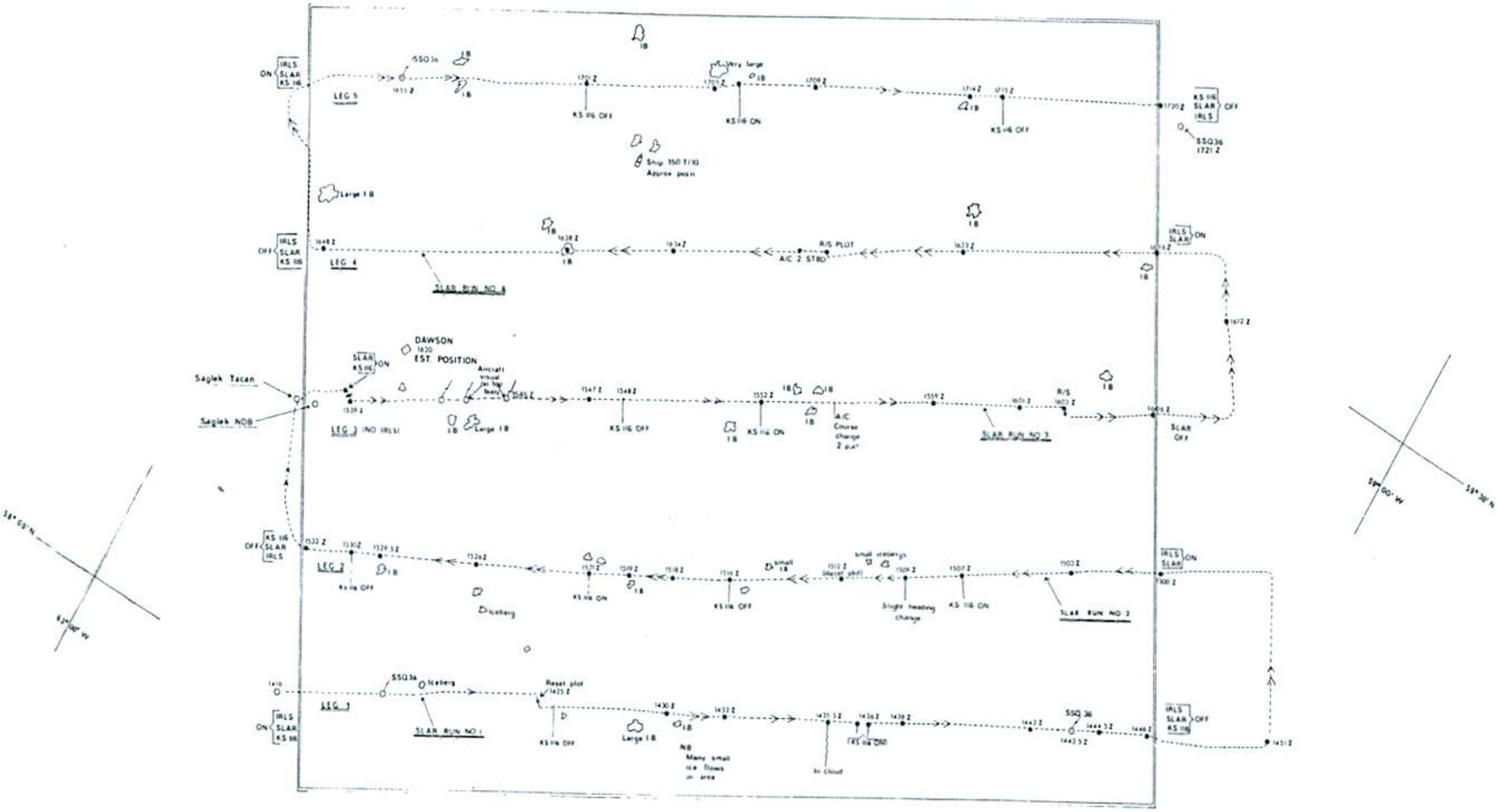

Figure 9. Navigational Chart and Data of Airborne Remote Sensing.

Date: August 14, 1973
Mission: SLAR - IRLS - K116
Bathymeter buoys: ⊙↙
Iceberg: ⬡ (I.B)

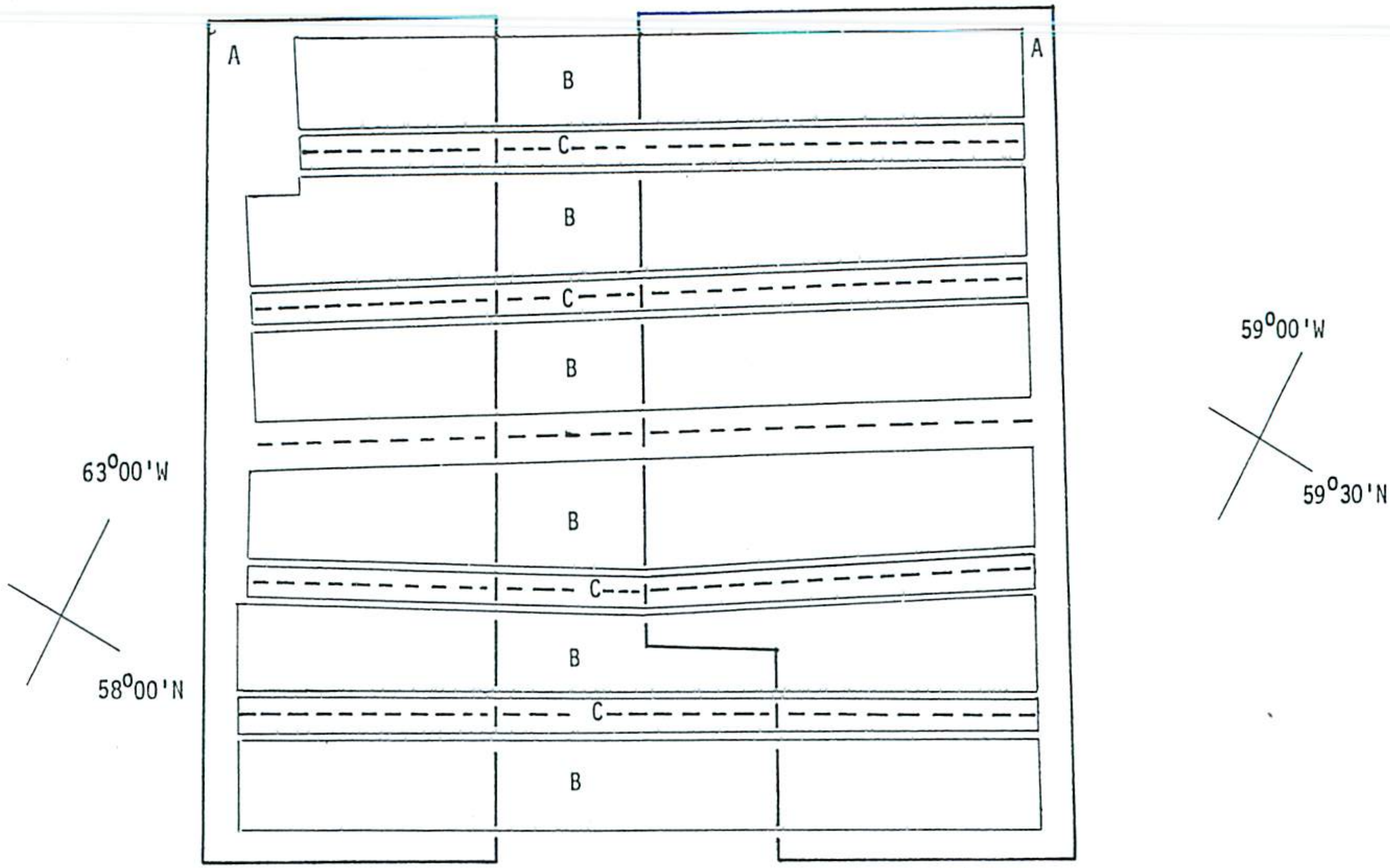

Figure 10. Area Coverage of Airborne Remote Sensing.
Flight path: -----
Aerial Photography (KS116): A
Side Looking Radar (SLAR): B
Infrared Line Scan (IRLS): C

Satellite Photography

Although the resolution and quality of the ESSA pictures is poor the boundary of ice cover can be recognized on them (Figure 1). Large open water-bodies between ice and land and within ice is also distinguishable.

The NOAA satellite provides excellent high resolution photography of extensive ice cover (Figure 2). On this photograph the ice boundary can be mapped out with high accuracy, the number and distribution of large size ice pieces can be determined, and valuable information can be obtained on ice cover structure and on the pattern of large channels. This type of imagery is the most useful to monitor the movement and position of large ice bodies during the whole season.

Photographs produced by the ERTS satellite are the best suited to obtain data on ice characteristics and movement. A simple ice cover structure classification was applied to the area shown by Figure 3. This classification could be refined by identifying the number and distribution of ice pieces having different sizes. The area of ice and open water could be determined accurately on this kind of imagery if it is precision processed. Over northern areas there is considerable overlap between imagery obtained during consecutive days. This allows the observation of the daily movement of large and medium size ice pieces. In turn this movement can indicate the direction of major currents.[5]

Airborne Sensing

A mozaic will be prepared using the panoramic aerial photgraphy. This mozaic will be used to detect various sea states and larger currents if possible. The large scale panoramic pictures of icebergs could be used to study the structure and erosion pattern of the berg, and the pattern of melt water channels on its surface (Figure 4). The Vinten 70 millimeter aerial photography will be used to produce a horizontal contour map of the imaged iceberg.

The thermal infrared imagery will provide a surface temperature distribution map. Figure 6 shows such a map for a short strip of sea surface surrounding an iceberg. The delineated units represent areas having different surface temperatures. These differences are due to the uneven mixing of melt water and surface water. Using a calibrated gray scale actual temperature figures could be attached to a particular gray tone of a delineated area.

The thermal infrared images can be digitized using a scanning micro densitometer. This instrument can distinguish 256 shades of densities of a photographic negative or positive transparency. Since the various levels of densities on the film are proportional to the emitted energy of the corresponding target surface actual temperature values can be attached to these values. A section of the picture of Figure 6 was digitized using an aperture and scanning distance of 200 microns and printed out by a computer (Figure 11). The points in the digitized field were separated manually into classes according to their

133	132	130	128	126	120	112	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
132	131	129	126	124	112	80	52	41	38	36	35	35	36	36	38	43	53	79	95	109	113	114	115	117	113
129	128	128	125	120	96	48	43	38	36	35	34	34	35	37	41	50	63	91	101	110	113	114	115	116	112
129	126	125	122	114	88	48	41	37	34	35	34	35	37	39	47	63	89	98	105	111	114	114	114	114	112
128	126	123	118	108	80	48	41	36	35	36	35	37	41	47	59	87	95	103	110	113	113	113	114	114	112
122	122	116	110	96	64	42	40	37	37	37	37	41	46	55	87	99	103	109	111	113	114	113	112	113	110
120	116	112	100	64	44	39	41	40	38	39	42	47	55	79	95	103	109	113	112	113	114	112	112	113	112
117	112	104	72	44	38	39	51	48	39	42	47	59	83	98	105	112	114	113	112	115	114	113	114	114	114
12	104	80	44	38	36	39	55	40	40	45	59	87	103	111	113	116	114	115	114	116	114	112	115	117	116
02	80	48	37	36	35	37	40	41	45	59	87	106	113	117	118	118	116	116	115	115	114	114	116	118	118
68	48	39	35	36	36	37	42	45	55	79	103	113	118	118	119	120	118	118	116	117	117	116	118	121	121
44	39	37	35	37	37	41	47	59	79	102	108	118	122	119	120	122	120	121	121	123	121	119	119	123	125
38	37	36	37	39	41	46	61	87	99	107	115	121	122	120	120	122	120	123	124	125	124	124	121	125	126
37	37	37	39	43	47	63	87	102	107	114	119	123	121	118	120	123	123	124	123	124	123	125	124	127	130
39	40	41	45	55	71	95	107	111	119	122	122	124	124	124	126	127	127	125	124	124	126	127	128	132	135
41	43	47	63	83	95	105	115	121	123	125	126	126	127	128	129	130	128	126	126	127	130	131	133	138	150
47	58	75	91	99	107	115	123	124	125	126	127	128	130	129	129	131	128	127	127	127	133	133	137	143	163
71	87	95	101	107	113	119	126	126	126	125	127	127	126	125	127	129	128	127	123	127	132	135	141	151	166
95	101	103	109	115	119	123	129	128	128	128	126	127	126	126	128	128	125	125	125	131	135	138	143	159	168
106	108	110	113	119	124	126	127	129	128	126	124	127	125	125	128	128	128	126	126	131	134	139	143	164	168
111	115	116	119	123	126	125	129	131	129	127	124	127	127	124	125	126	129	128	127	132	134	139	151	165	168
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120	122	123	125	127	127	127	129	130	128	124	122	123	124	124	124	125	125	124	125	127	135	142	159	167	168
120	124	125	126	127	127	128	130	131	128	122	120	122	121	124	124	125	124	123	123	127	133	141	159	167	168
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128	130	129	129	129	131	130	131	128	120	109	113	117	119	120	124	126	124	126	127	134	137	141	149	163	167
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131	131	132	132	132	131	129	129	128	121	114	115	118	118	118	122	126	125	125	129	132	136	141	147	154	163
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131	132	132	134	133	133	132	130	130	122	116	117	121	120	120	123	127	127	125	126	131	136	136	139	145	149
132	132	133	134	133	133	132	132	131	128	118	116	119	120	119	122	126	126	126	126	131	135	134	137	140	146

Figure 11. Digitized Infrared Line Scan Image.

Ship:: 35 to 99 density level
Water: 100 to 159 density level
Iceberg: 160 to 180 density level

numerical values by 20 density levels starting with 100. This provided a contour map of surface areas having different temperatures. The same digitized image was stored in an electronic computer in an X-Y matrix form. Then a contour map was produced by the computer using the same density classes as for the manual contouring (Figure 12). With this kind of image evaluation contour maps of large areas can be produced rapidly.

The side looking radar imagery will be used for iceberg count. On this kind of pictures the ice bergs are well defined (Figure 7). Major disturbances of sea surface are also detectable. The great advantage of the radar sensing system is that it operates in almost any weather conditions therefore imagery can be obtained through clouds.

Terrestrial Photography

The terrestrial stereo photography is being used to provide vertical contour profiles of icebergs. The stereo pair is mounted in a Wild 10-A autograph and after orientation contours are drawn by desired intervals. Figure 8 presents the profile map of one side of the iceberg shown by Figures 4 and 5. Two profile drawings of opposite sides of an iceberg can be combined to determine the volume of the berg. This work also supplemented the underwater profiling carried out on the same iceberg.[6]

CONCLUSIONS

Although the presented results were based on preliminary interpretation of selected images they give indication on the merit of remote sensing in oceanographic data collection. On the basis of these results the following conclusions can be made:

1) The NOAA and ERTS satellite pictures are very useful to obtain information on large ice bodies covering extensive areas.
2) The horizontal and vertical stereo photography is adequate for the contouring of various icebergs.
3) Iceberg census can be conducted over a large area in almost any weather conditions using a side looking radar mapping system.
4) The infrared thermal imagery provides a relative surface temperature map, however, considerable testings have to be carried out before actual temperature figures can be attached to these maps.

Finally it is emphasized that during any remote sensing mission various atmospheric conditions and instrument malfunctions can cause "noise" in detecting the incoming energy. This causes irregularities in the obtained imagery which is very significant in the case of thermal mapping. Such "noises" can be observed on the image presented in Figure 6 (light spots and streaks).

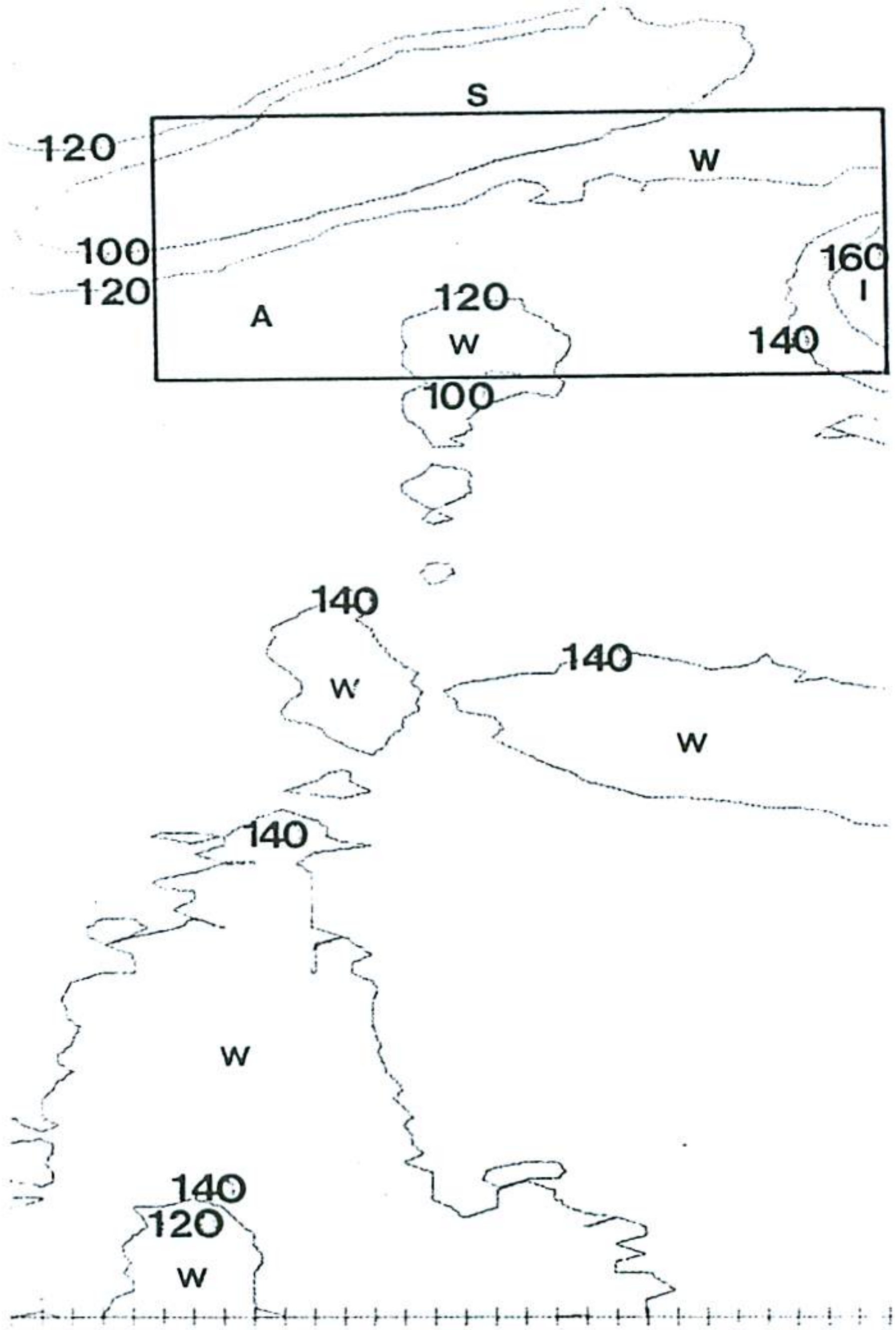

Figure 12. Computer Contour Map of Part of Infrared Line Scan Image.

Density contour: 120
Ship: S
Part of iceberg: I
Melt water: W
Area shown by Figure 11: A

REFERENCES

1) Allen, J.H., 1972. Iceberg Study, Saglek, Labrador. Initial Report. Memorial University of Newfoundland, St. John's, Newfoundland.

2) Taggart, C.I., 1973. Personal Correspondence. Atmospheric Environment Service, Environment Canada, Malton, Ontario.

3) Schwalb, A., 1972. Modified Version of the Improved TIROS Operational Satellite. NOAA Technical Memorandum NESS 35. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite Service. Washington, D.C.

4) Goddard Space Flight Center., 1973. Data Users Handbook. Document No. 715D4249. NASA. New Carrollton, Maryland.

5) Anonymous, 1973. Ice Motion in the Gulf of Boothia. Information Bulletin. Canada Center for Remote Sensing. Ottawa, Ontario.

6) Benedict. C.P., 1973. Underwater Profiling of Icebergs. Paper presented at the Second International Conference on Port and Ocean Engineering under Arctic Conditions. August 1973. Reykjavik, Iceland.