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WEATHER BUREAU

METEOROLOGICAL SATELLITE LABORATORY
REPORT NO. 20

Conference on Satellite Ice Studies

WASHINGTON, D. C.
JUNE 1963

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U.S. Weather Bureau
F. W. Reichelderfer, Chief

METEOROLOGICAL SATELLITE LABORATORY

REPORT NO. 20

CONFERENCE ON SATELLITE ICE STUDIES

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National Oceanic and Atmospheric Administration
TIROS Satellites and Satellite Meteorology

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PREFACE

This report presents the transcript of the Conference on Satellite Ice Studies held June 14, 1962, in Washington, D. C.

Representatives from the fields of meteorology, oceanography, hydrology, geology, and photogrammetry were invited to discuss and review the satellite photography collected in conjunction with Project TIREC* and to present their thoughts and ideas on the use of satellite observations for ice reconnaissance.

These transactions are being distributed with the view of stimulating interest in satellite observations which might also be useful in associated fields.

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* A joint United States-Canadian program to investigate the application of weather satellites for ice reconnaissance.

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- Mr. J. F. Cronin

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- Mr. J. R. Longard
- W/C A. W. Armstrong

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- Mr. R. E. Moore

Department of Transport
- Meteorological Branch
  - Mr. W. E. Markham
  - Mr. D. C. Archibald

Department of National Defence
- Defence Research Board
  - Mr. T. A. Harwood
  - Miss I. M. Dunbar
- Joint Photographic Intelligence Centre
  - Maj. C. I. Taggart
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- Royal Canadian Air Force
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Mr. P. Clapp
Mr. R. R. Dickson

National Weather Satellite Center

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Mr. D. S. Johnson
Dr. D. Q. Wark
Mr. J. S. Winston
Mr. R. W. Popham

University of Alaska

Meteorology Department

Dr. H. Peyton

University of Wisconsin

Meteorology Department

Dr. R. Ragotzkie

Mr. B. Heathfield -- former RCAF liaison officer with Project TIREC.

AGENDA

June 14, 1962; 9:30 a.m.

1. Introductory remarks - David S. Johnson

2. Statement of requirements; discussion of specific areas where ice information from satellites might be applied, without regard to practical limitations of vehicle. Open discussion, individual contributions invited. 30 minutes

3. Review of future meteorological satellite program (continuation of TIROS series; Nimbus systems, data acquisition and utilization; other meteorological satellies). W. Bandeen 20 minutes

4. Review of satellite ice program through TIROS II. Remarks by USNHO Rep., NSRF Rep., B. Heathfield, and R. Popham. 30 minutes

5. Summary of Project TIREC operations and data collected. TIREC Working Group. 60 minutes

June 14, 1962; 1:00 p.m.

<u>Conference on Satellite Ice Studies Continued</u>

1. Proposed analysis of Project TIREC data and current status of work done.

   a. Defence Research Board (DND) and Joint Photographic Intelligence Center Representative
   b. Meteorological Branch (DOT) Representative
   c. U. S. Navy Hydrographic Office - USNHO Representative
   d. U. S. Weather Bureau - R. W. Popham 40 minutes

2. Areas of possible analysis of Project TIREC data. Discussion of analysis techniques. Open discussion. 80 minutes

3. Requirements for monitoring analysis. Open discussion. 20 minutes

4. Future programs in conjunction with proposed meteorological satellites. 60 minutes

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CONFERENCE ON SATELLITE ICE STUDIES

Mr. Johnson: We would like to welcome you to this conference on behalf of both the Weather Bureau and the Meteorological Satellite Activities. We, as you, have been interested in ice recently, primarily as a result of the TIROS meteorological satellite program and the obvious application of data from these satellites to studies of ice and, hopefully, ice reconnaissance. As Mr. Popham will point out, our interests have been limited primarily to serving as a catalyst and to helping those who are more directly concerned with ice studies and ice reconnaissance to make use of satellite data in their work. So it is indeed a pleasure on our part to welcome you as our guests and to invite you to use our facilities. I certainly hope that this conference proves to be mutually beneficial to all of you and that it may be a precursor to similar conferences as the satellite program progresses in the coming years.

We would like to assist you in every way during your stay here and subsequently to assist you in any way we can in using the data which will be available from satellites. At this time I would like to turn the conference over to Mr. Popham, who will chair the conference.

Mr. Popham: We have some items on our agenda which several people have indicated are worth spending more than the allotted time on; therefore, I will keep my remarks short in the beginning. Since the meeting is being recorded, it would be very helpful in writing the minutes if you would give your name and organization when you start to speak.

For those not familiar with the term, Project TIREC was a joint Canadian-United States effort to investigate the use of satellites for ice reconnaissance and surveillance. The purpose of this conference is to bring together those who could use such information, as well as those who could provide it, so that both requirements and capabilities can be made known.

For the past three days the people who were most closely connected with the planning and coordinating of the TIREC operation have been preparing an index and overall operations report on the Project. These people will discuss how the program was conducted, what analyses they are performing, and what they hope to gain from this.

We will start with Part II on the agenda, a Statement of Requirements - a discussion of specific areas where ice information might be applied without regard to practical limitations of the vehicle. Following this we will quickly review what the future satellite program will be so we will have some idea of how many of these requirements might be satisfied. We hope this

will help those who are analyzing Project TIREC data to concentrate on some specific areas of interest. Would someone, perhaps from the Navy Hydrographic Office or the Defence Research Board, care to start the discussion?

Mr. Clapp: My name is Clapp from the Weather Bureau's Extended Forecast Branch. We have a very obvious requirement and desire for data summaries of clouds, ice, and snow cover, by week, month, or season for use in synoptic climatology and long-range forecasting. Furthermore, these data must eventually be made operationally useful.

Mr. Popham: Might I invite comments from Mr. William Markham? Mr. Markham is Officer-in-Charge of the Department of Transport Ice Forecast Central in Halifax. He is one of the persons most closely connected with Project TIREC and with the ultimate use of satellite ice information.

Mr. Markham: Our requirements vary from season to season. In the fall we are interested in areas of ice formation so that we can determine the pattern of growth and also - indirectly perhaps - get some information about currents from the way the ice spreads. During the winter and spring our interest is divided; in Arctic areas it is somewhat less than at other seasons in that we are mainly interested in the formation of leads, but in the Gulf of St. Lawrence and Newfoundland waters full information is desired. In early summer, we are most interested in following the Arctic breakup pattern, while in late summer we are vitally interested in ice location, concentration, and to some extent in topography so that we can assist ships in their resupply missions.

LT Dotson: I'm LT Dotson of the U. S. Navy Hydrographic Office. Our Office has similar requirements as those expressed by Mr. Markham, except in the Arctic Ocean, where we have rather different interests. Perhaps Mr. Wittmann could express our interests more precisely.

Mr. Wittmann: In the Central Arctic we are most interested in the ice topography - pressure ridging, and the distribution of discrete sizes of water openings. We are interested in the physical processes which produce these features, one of the most important being wind stress. We are also interested in the stability of these features (e.g., maximal rates of closing). From satellites we hope to obtain time sequence photography and get control in time and space of the topographic features of the sea ice canopy. This may be discernible from smoothness considerations as well as tonal qualities.

Mr. Popham: By discrete, what size do you mean, say in terms of feet or miles?

Mr. Wittmann: At the moment, I would say 150 to 1,500 feet (in width, these may run for miles in length); this is the average size of discrete water openings in the Central Arctic. In some regions you get larger openings which would be measured in miles. The nuclear submarine, SEADRAGON, for example, steamed 13 miles on the surface when it was well within the Central Arctic ice pack in August 1960.

Dr. Peyton: Our primary interest at the University of Alaska is with the distribution of sea ice in the Polar Basin. Our interest is both one of predicting the ice cover and the more important meteorological aspects. We have looked into the things Walt has talked about, and quite important and quite obvious are the rather small leads and openings that occur in the Polar Basin throughout the year. In using satellite pictures, it would appear that we may have problems involving the resolution of the vidicon system.

Mr. Popham: Dr. Ragotzkie is here also. We have been talking about sea ice distribution. I know you are interested in lake ice. Would you care to express your interests?

Dr. Ragotzkie: Yes. I am Dr. Ragotzkie from the University of Wisconsin. We have been studying lake ice, particularly the breakup and freeze-up of the lakes of central and subarctic Canada. The usefulness of this has many facets. One of the more interesting is that ice formation in the lakes is apparently an indication of air mass trajectory and persistence. This is something we know very little about because of a lack of data. We need information on the time of freeze-up and breakup of lakes from latitude 45°N to as far north as we can get, preferably the Arctic Ocean. We would need a resolution that would let us see lakes of a mile in diameter or smaller. Also we need to tell the difference between snow-covered ice and bare ice, frozen lakes, and snow-covered terrain.

Observations to determine information on freeze-up or breakup dates would have to be frequent - at least twice a week - over our area or whenever cloud movement permitted. Some more of these ideas will be brought out later.

Mr. Popham: Is CDR King here?

CAPT Lanterman, Task Force 43: I haven't seen him here. I have spent a little time with Task Force 43. In the event you may have specific questions, I might be able to help.

Mr. Popham: Task Force 43 is the Antarctic Task Force and, obviously, a principal user of ice and weather information in this area. I thought we

might discuss requirements in that area with CDR King, who is Staff Aerologist with this Task Force.

CAPT Lanterman: I think Mr. Dotson may have some information on that. He spent a little time with CDR King last year.

LT Dotson: As far as Task Force 43 is concerned, their problems are similar to those which would be encountered in the Arctic. Air bases are few; ice reconnaissance coverage is inadequate. The use of satellites would provide systematic and wide-area coverage of ice conditions in the Antarctic. From such a vehicle the Hydrographic Forecasting and Ice Reporting Sections would have far better coverage than anything we have had up to this time, especially coverage of ice conditions which may be encountered in entering and leaving in certain seasons.

CAPT Lanterman: I think there is one other thing that might be brought out; the runway at McMurdo Sound is on ice. This last year they had to evacuate in a hurry. If there is any information that might be available to indicate the early breakup or the extent of the breakup, this would be a real help as far as determining when evacuation from the ice is necessary.

LT Dotson: Weather is another critical problem in the Antarctic, especially where aircraft operations are concerned. Perhaps weather requirements in this area should be considered before the ice requirements.

CAPT Lanterman: I believe you should also point out the increase in requirements for weather and ice data on the part of Task Force 43 which has resulted from their attempt to lengthen their period of operation in the Antarctic. They went in earlier this past year than ever before.

LT Dotson: Yes. Here is where continuous satellite observations could be extremely important.

Mr. Magnitzky: My name is Magnitzky from the Office of the Chief of Naval Operations. I am unfamiliar with Project TIREC and, as yet, have heard no mention whether there are sensors aboard TIROS which give some indication of heat exchange. I assume there are. Is this correct?

Mr. Popham: Yes, there are sensors aboard the satellite. While the TIREC operation was directed mainly toward collecting comparative data to interpret satellite ice photography; it will be brought out in discussing the data collected during TIREC that considerations were also given to obtaining meteorological data, such as surface and upper air temperatures, moisture, and other parameters which might be useful in interpreting satellite infrared observations.

However, this may constitute an area of separate study. If somebody here does become interested in the reduction of the IR data from the satellite, I would like to refer them to Dr. Wark or Dr. Fritz.

Mr. Harwood: My name is Trevor Harwood. I wear two hats - one as Chairman of the Working Group on Ice in Navigable Waters in Canada, Canadian Committee on Oceanography, and the other with the Defence Research Board of the Department of National Defence. Speaking in the civilian and mercantile side, it is quite obvious that as future satellites are launched technical advances will provide much better feature definition. For ice reconnaissance, resolution will have to improve; I do not at this moment know to what extent. Walt Wittmann is interested in resolution of the order of 100 feet. For ships operating in navigable waters under commercial conditions, I don't think this resolution is necessary. In routing ships into the Gulf of St. Lawrence, for example, sufficient large open water areas usually exist into which ships can be directed. At most times in the Gulf it is not deliberately necessary to route ships through leads in the ice until you actually get close to the port areas.

It is obvious to me that changes in density or color tone of the ice seen in these satellite pictures are indicative of real changes in the ice, produced, for example, by currents. This information appears to be certainly applicable to the Gulf of St. Lawrence and, within the next few years, could be used elsewhere in the Maritime Provinces. If it can be used here, it can also be used in other areas by other countries.

While better resolution is certainly desirable, another very important fundamental requirement is communications, i.e., getting these data into the hands of the users. This is a point which I am sure the Department of Transport is considering with regard to the readout station in Canada.

From the defence side, ice is certainly important in submarine operations. The submarine captain wants to know where ice-free areas are so that he may surface. He also would seek ice areas to prevent detection. Conversely, aircraft or maritime commands would want to search these areas for the submarine. Techniques for submarine searching in ice areas have hardly been explored. Since ice boundaries can be indicated by latitude and longitude coordinates, communications are greatly simplified. With improvements in satellite camera resolution largely a matter of time, the satellite can be very useful in observing these boundaries. Again, the important thing is to get this information into the hands of the ship captains and other users in a form which can be readily used.

Dr. Fritz: Is the resolution now available from TIROS IV adequate for civilian use or is it too poor?

Mr. Harwood: While I may stand corrected by Mr. Markham and others around me, I would say that had the TIROS photographs been continually available to Captain Kelso, who is with the DOT Marine Unit, he could have prepared ship routings into the Gulf of St. Lawrence. He would not have been able to prepare routings from the open water areas into the ports themselves. This would have been done by using aircraft observations.

LCDR McGary: I am Lieutenant Commander McGary of the U. S. Coast Guard Reserve. Our missions and needs in ice reconnaissance are very discrete and long standing. Our concern is the open ocean area just outside Mr. Harwood's area. We are interested in the movement of sea and glacial ice in the vicinity of the Grand Banks of Newfoundland since it is here that they threaten the shipping lanes of the North Atlantic. We are concerned with the ice movement into the area from the Greenland waters from February to early July.

We are also interested in high-resolution photographs since we have always had the danger that an isolated berg may get through our patrols.

Mr. Harwood: We might point out how much more serious this ice problem is becoming and of what immense value these photographs may be. Six years ago you could count on your hands the number of ships that were going up the St. Lawrence. This year some 270 ships actually entered the Cabot Straits going into the Gulf area; of that number probably 100 went up well into the Gulf, while the rest went around the New Brunswick and Nova Scotia coasts. So anything that assists us, e.g., in reducing insurance rates, and this is one of the things that could or might reduce rates, is an economic advantage.

Mr. Dickson: My name is Dickson, and I'm with the Extended Forecast Branch of the U. S. Weather Bureau. I think we might note here that back in the early days of meteorology a good deal of effort was put forth to relate ice conditions to long-time climatic fluctuations. The Extended Forecast Branch has been trying to follow these various ice and abnormal snow cover features of the earth's surface. One area in which data are hard to come by is that area north of Scandinavia and Iceland. Even historical data for this area are hard to come by. I think that current ice data in this area would provide useful information for long-range forecast purposes.

Miss Dunbar: My name is Moira Dunbar. I wear the same two hats approximately as Mr. Harwood, though perhaps of slightly different size. Most of the speakers thus far have been talking about the operational use of the satellite for ice reconnaissance. I would like to support the last speaker on its value for climatological studies. This is particularly true in the Arctic and Antarctic areas, where it has been pointed out that it is not always possible to have as much reconnaissance flying as you would like to have. In the Arctic the shipping season is very short. So far it has been practical to have full ice

reconnaissance only at the times and places where ships are going to operate. This is one area where satellites could fill a very real need, especially in following the freeze-up pattern. Again, however, we will need considerably better resolution than we had with TIROS IV.

Mr. Harwood: To more or less confirm what Miss Dunbar has said, we have two people from the Department of Meteorology at McGill University, Dr. Bird and Dr. Boville. Dr. Bird is the "Ungava-ite" around here and may want to comment on what I have to say. Professor Hare, who started the Meteorology Department at McGill, is well known for one of his original theses in which he explained how the climate in Ungava literally changes from maritime to continental when Hudson Bay freezes over. Few people fly across Hudson Bay; since observations are so scarce, it is difficult to predict when the Bay will actually freeze over.

Satellite observations would be extremely useful as an aid to forecasting ice freeze-up in this area, which in turn would aid the meteorologist in predicting, perhaps weeks in advance, when this climatic change would occur. Since this is an area where quite a bit of mining and industry is now taking place, there would most probably be some gains on the economic side.

Mr. Popham: I'm afraid we're not going to have time to pursue this subject any further, so I would like to summarize briefly some of the uses of satellite ice observations which have been brought out thus far. First, there are meteorological applications which include observing ice and snow because of their effect on long-range weather forecasting. The synoptic mapping of ice on a large scale is one possibility which might be realized using satellites. Second, there are ice reconnaissance and forecasting uses, including observing ice boundaries and concentration, discrete water openings, icebergs, and in general, observing and collecting data for predicting ice freeze-ups and break-ups in lakes, rivers, or oceans. Third, there are oceanographic applications such as measuring water current motion by observing ice movement.

As pointed out in the discussions there are both military and civilian applications of such observations. The major requirements seem to be for resolution and communication.

We will leave the subject there for now and go on to a discussion and review of the meteorological satellite program by Mr. William Bandeen of NASA.

Mr. Bandeen: Thank you, Bob. It's a pleasure for me to be here this morning on the part of NASA's Goddard Space Flight Center to discuss the meteorological

satellite program. I must plead to being the fifth choice this morning. We have an impending launch, and hence, the four top directors of the group for which I work are either in Florida or concerned with other activities having to do with that program. Not having personally been deeply involved in the planning, I will, after my talk, invite the comments of certain members of the audience I see who might be more familiar with later developments.

Before going into future meteorological satellite programs, I would like briefly to review the past. The satellite program as we know it began on April 1, 1960, with the launch of TIROS I. TIROS I, as everyone now knows, was injected into a nearly circular orbit about 450 statute miles above the earth, inclined to the equator by about 48.5°. It carried two cameras, one a wide-angle camera with an angle of view of about 104° and the other a narrow-angle camera with an angle of view of about 12.7°. There are always things that are learned in satellites that are not foreseen to begin with, and this morning I will just briefly touch upon these as we lead into future programs.

TIROS I was thought to be a spin-stabilized satellite before launch, but within hours after launch it was noted that it was not spin-stabilized or fixed in space but was indeed moving in an angular motion in inertial space. This led to the determination that the magnetic field of the earth primarily and secondarily the gravitational field of the earth were indeed exerting torques upon the satellite, causing an angular motion of its spin vector in fixed space (as differentiated from its revolution in orbit around the earth). This was a blessing in one way because it made photography possible throughout the life of the satellite, whereas, had the spin vector remained fixed in inertial space, there would have been blank areas throughout the nominal three-month lifetime when photography would have been very poor or impossible. Further, this led to a development for TIROS II; namely, the inclusion of a magnetic coil which could be programed from the ground with varying magnitudes and directions of current so that we could take advantage of the magnetic field and thereby steer, in effect, the satellite from the ground and cause optimum photographic conditions during its nominal three-month lifetime.

TIROS II was also different from TIROS I in that it was the first of the series to carry radiation experiments. One of these was a medium resolution 5-channel scanning radiometer. This radiometer had a field of view for each sensor of about 5°. It sensed various spectral regions of the earth and atmosphere; namely, two solar regions and three infrared. One of the solar sensors included practically the entire solar spectrum reflected and scattered from the earth and the atmosphere; the second one included a narrower range in the near infrared part of the visible spectrum, similar to the regions seen by the human eye and the television vidicon cameras.

Of the three infrared sensors, one included some 75% of the total IR radiation from the earth and the atmosphere, from about 7 to 30 microns. There were two other IR sensors which sampled narrower regions: one of them, a narrow region around the 6.3 highly absorptive water vapor band, and the other averting absorption as much as possible in the partial window between 8 and 12 microns. In addition to the medium-resolution radiometer, there was a low-resolution radiometer consisting of several cones subtending an angle of about 50°. One of these was essentially a black sensor, the other essentially a white sensor. By comparing the equilibrium temperatures of these two sensors, one can derive measurements of apparent earth black body temperatures and solar reflectances of the part of the earth viewed.

An outstanding feature of TIROS II was the poor performance of the wide-angle camera. Apparently it was out of focus or perhaps fogged by products from the third stage bottle. I don't believe this has been fully determined to the satisfaction of all. The quality of the pictures was indeed poor, although still useful, I hasten to add. Perhaps this inspired Dr. Wark and Mr. Popham to concentrate on the narrow-angle camera and therefore develop satellite ice photography somewhat more extensively than it would otherwise have been.

TIROS III was launched in July of 1961, and here again in the development of the TIROS series we find changes. The poor performance of the wide-angle camera on TIROS II led to the decision to include two wide-angle cameras on TIROS III, thereby eliminating the narrow-angle camera, perhaps to Dr. Wark's and Mr. Popham's regret. Meteorologists have shown that if there must be a choice it is much better, for weather forecasting purposes at least, to have a wide-angle camera as opposed to the 12.7° very narrow-angle camera. In TIROS III there was another marked improvement in the system. During the period July through November, the hurricane season over the Atlantic reached its peak, and it was decided that it would be very fine to use TIROS III to observe hurricanes. TIROS I and II could not observe hurricanes in the Atlantic because of constraints upon the remote camera clock in the satellite. Only five hours' capacity is included in the clock, and from the last contact in the western United States it is more than five hours until the satellite crosses over the hurricane belt in the Atlantic. Hence, it was proposed to establish a third station in South America at Santiago, Chile, whose only function would be to start the clock. The clock could be set over the western United States but not started and then started over Santiago. Therefore, we would effectively extend the time delay so that pictures could be taken over the Atlantic Ocean and the hurricane region.

TIROS IV was launched last February, and again it exhibited some improvements. It utilized, for the first time, a low-distortion, higher-resolution camera system, having an angle of view of about 78° in place of the

traditional wide-angle 104° camera. This gave greater resolution, with substantially wide coverage to satisfy the forecasting requirements of meteorologists. I am sorry that I failed to mention that on TIROS III for the first time a third radiation experiment, Professor Soumi's University of Wisconsin heat balance experiment, was included. It was also included on TIROS IV.

This brings us to the future; TIROS V is going to be launched shortly. It will have the same instrumentation as TIROS IV: three radiation experiments and the same two cameras, the traditional 104° wide and the new low-distortion 78° angle camera.

In the future we plan to add some additional experiments to TIROS. At this moment, I do not know what effect they will have on ice reconnaissance. One of these experiments will be the inclusion of a Langmuir probe to measure electron temperatures and electron densities at satellite altitudes. This experiment is similar to those flown by the University of Michigan during the IGY and recently by NASA. Also on a future TIROS we plan to substitute in one of the five channels of the medium-resolution radiometer, a sensor which will look into the 15-micron carbon dioxide absorption band. Looking forward to the stabilization of the second generation Nimbus meteorological satellites, it has been amply proven in recent months that the stabilization of an earth-oriented satellite is rather difficult. In a nongravity environment such as that in which a satellite finds itself, one must use some sort of sensing, e.g., the horizon of the earth or stars, to orient the satellite with respect to the earth. Unfortunately, the horizons, as far as horizon sensors are concerned, are variable as temperatures, gas compositions, and clouds vary. We feel that the carbon dioxide region is most suitable, as far as a constant horizon is concerned, because absorption takes place largely above the local weather.

The first slide (figure 1) shows TIROS. The transmitting antennas for the subsystems are located on the baseplate of the satellite. The receiving antenna accepts commands from the ground, programing for the readout of television pictures and radiation data and programing for remote pictures to be taken at a future time up to five hours after the clock is started. As I indicated earlier the clock need not be started at the west coast station. It may just remain in a ready condition until Santiago, Chile, starts it so the Atlantic Ocean can be covered. The power supply for the satellite consists of nickel cadmium cells - which are constantly charged by silicon solar cells covering the top and side of the satellite. Here we have indicated a wide-angle camera lens. Actually there are two of them; one does not show. The magnetic orientation coil is merely a coil of aluminum wire wrapped around the baseplate of the satellite. The infrared electronics are contained in this tall cylindrical canister.

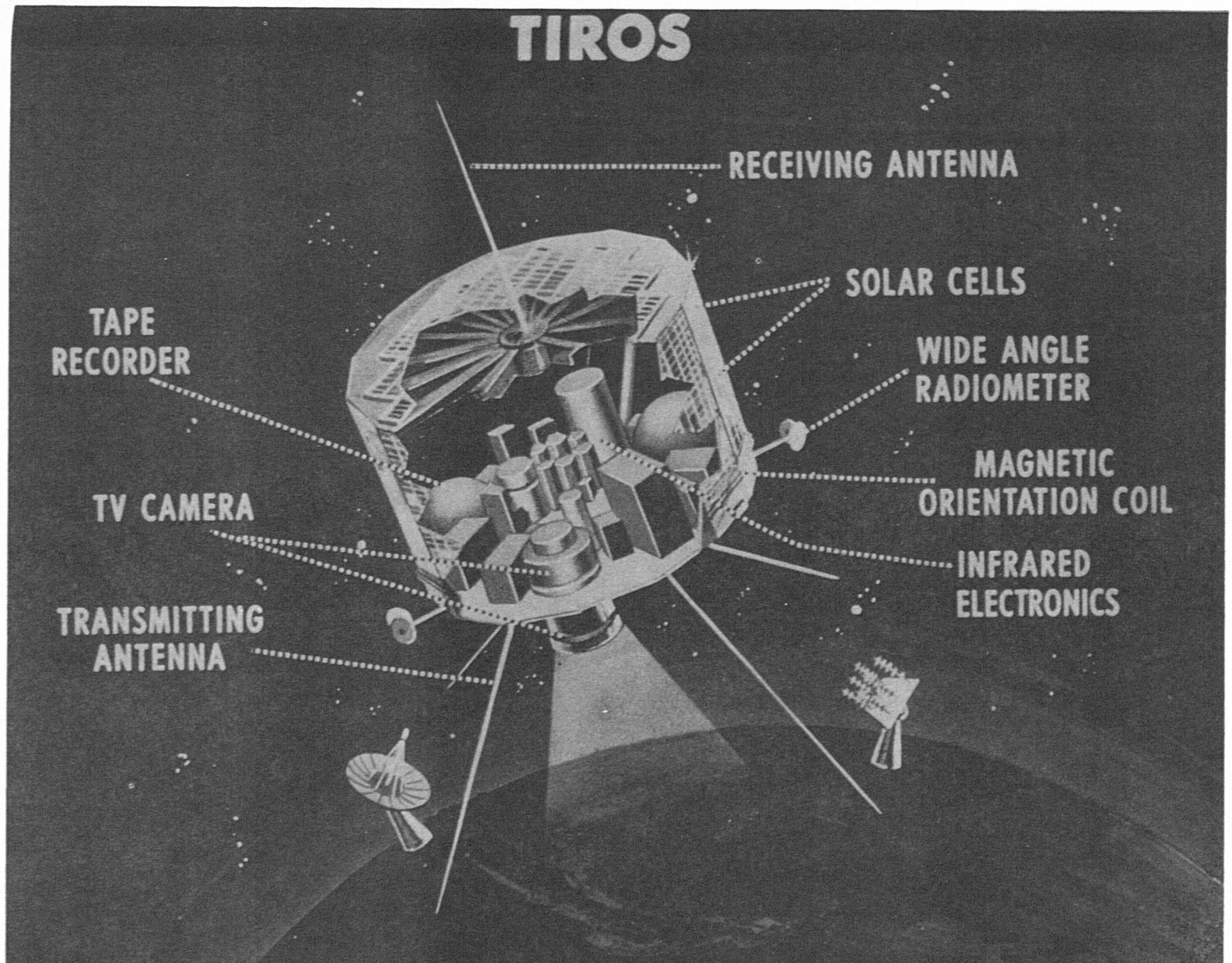

Fig. 1 Cross-section of TIROS meteorological satellite

I don't see in this artist's conception the medium-resolution radiometer, but it is positioned along the side so that it looks out at 45° through the side and, in the other direction, at 45° through the baseplate of the satellite. The 50° conical low-resolution radiometer is not in view, but is in the baseplate looking parallel to the television cameras.

This slide (figure 2) is an artist's conception of the second generation Nimbus meteorological satellite. We hope to launch the first Nimbus in the fourth quarter of 1963. It is the policy to have one operational satellite in orbit at all times. This means that the four remaining TIROS satellites will be launched in approximately five-month intervals so that the last TIROS will be in orbit and, hopefully, will reach its demise just as the first Nimbus goes up.

This slide (figure 3) shows a comparison between the TIROS and Nimbus systems. The TIROS orbit is at 450 miles high and inclined to the orbit at 48°. I must mention that for the four remaining TIROS satellites the inclination of the orbit is being raised about 10° to 58°. This will bring us about overhead at Churchill, Manitoba, and obviously will enhance ice research studies. The Nimbus orbit is going to be a near-polar orbit inclined to the equator by about 100° (or 80° in a retrograde direction) meaning that it will revolve in opposition to the rotation of the earth. This means that the orbit will - in accordance with precessional theory - regress toward the east in the same direction as the sun. The inclination of the orbit and its height, about 600 miles, is such that the regressional rate will be precisely that of the sun. Hence, the ascending node of the Nimbus orbit will always occur at the same local time and for the first one will presumably be local noon at the equator. The way the artist has drawn it here, I take issue with him, this is the descending node, and it should be nighttime because the ascending node will be in the sunlit part of the orbit.

The interrogation station for the first Nimbus will be at Fairbanks, Alaska. Obviously again, it is possible from a high-latitude acquisition station to interrogate more orbits per day. In the TIROS system at present, there are only eight orbits out of the daily 14 which can currently be interrogated. With the single station at Fairbanks, approximately ten out of 14 Nimbus orbits per day can be interrogated, leaving a gap of only four.

This slide (figure 4) shows the orbital tracks of a Nimbus satellite and shows the interrogational pattern around Fairbanks, Alaska. The two circles are nominal 5° and 10° elevation angles above the Fairbanks horizon. If you can see the orbits counting with number 1 here, we can interrogate orbits 1 through 9. The first one, which is missed is orbit 10; here 11, 12, and 13

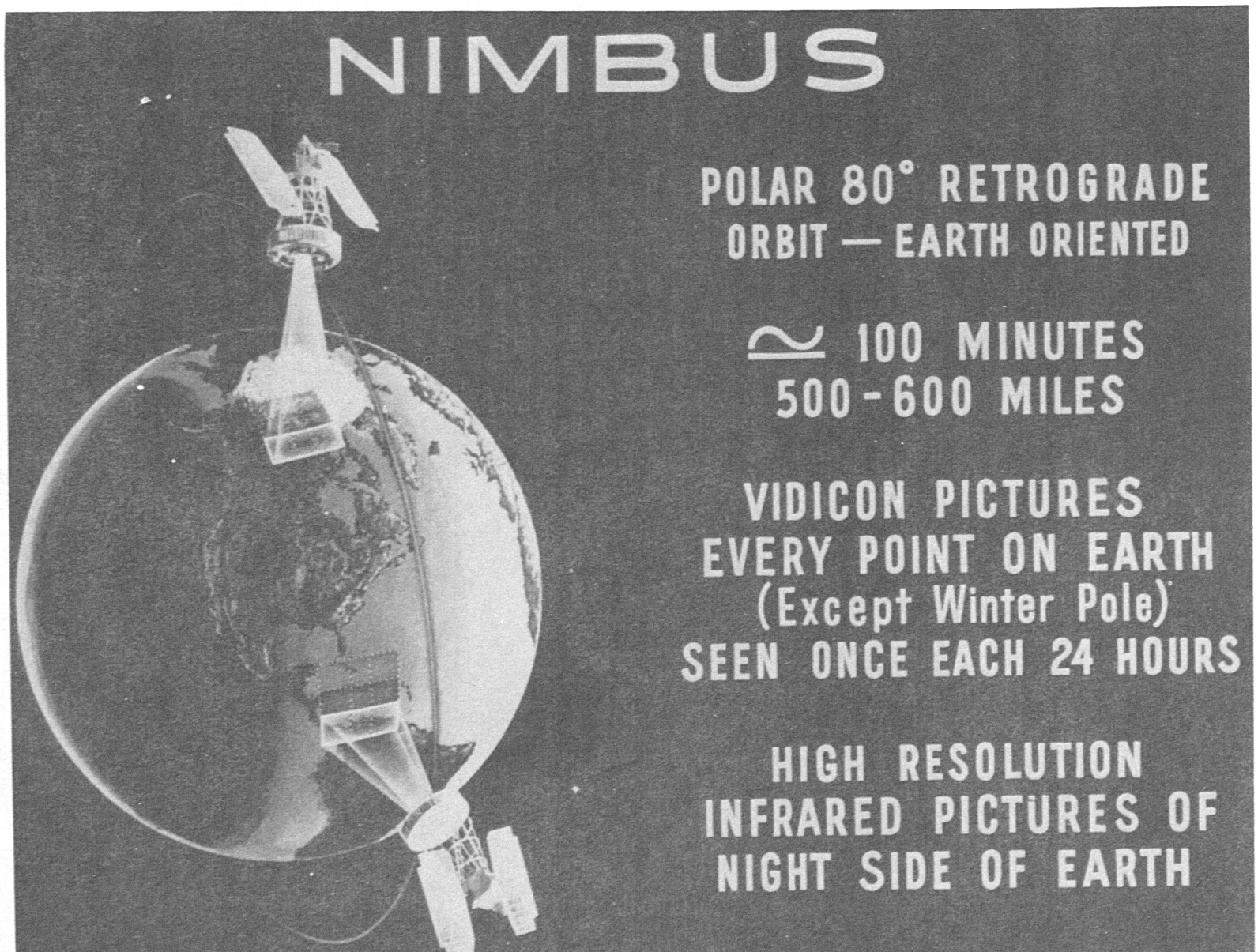

Fig. 2 Artist's conception of 2nd generaltion NIMBUS meteorological satellite

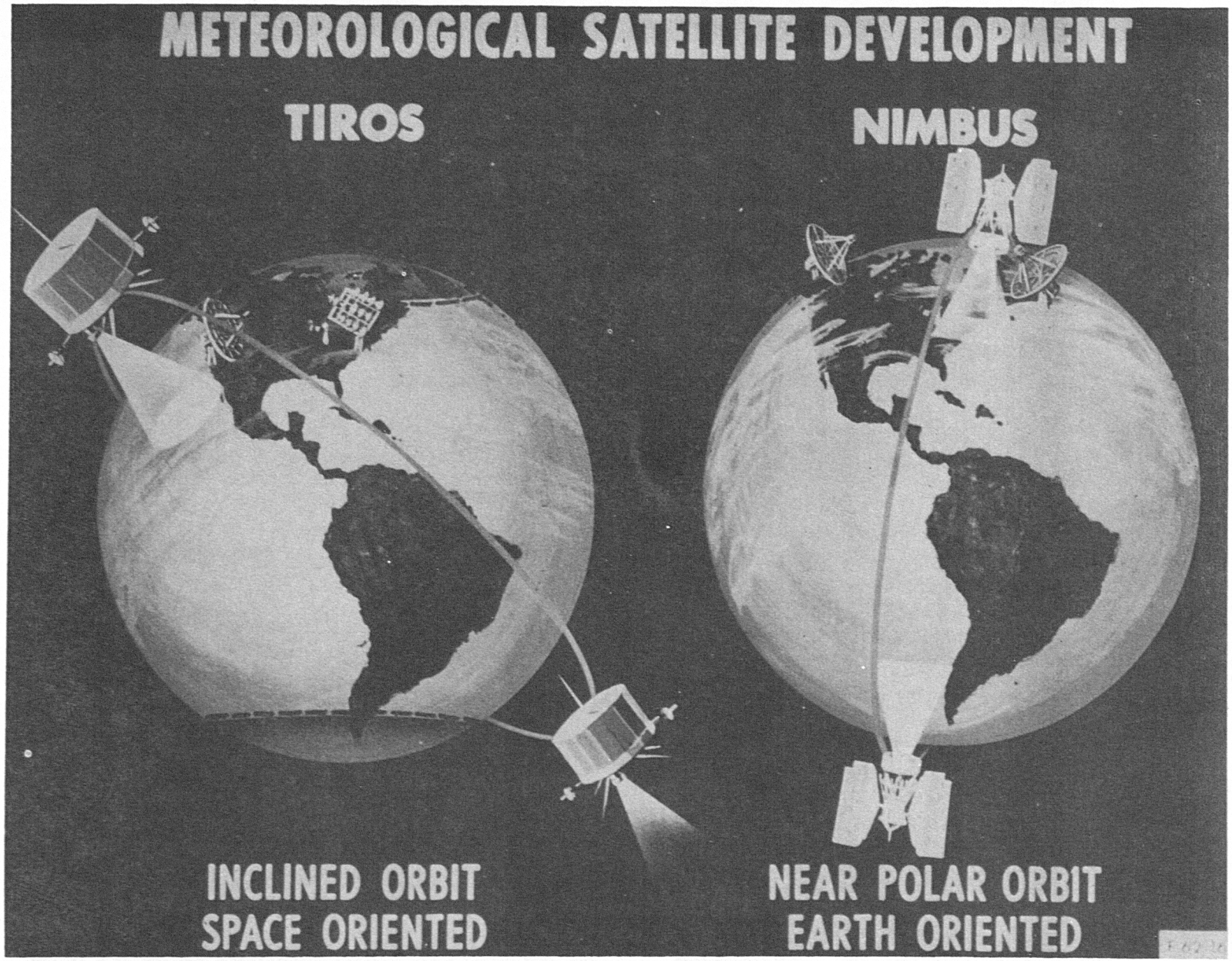

Fig. 3 Comparison of TIROS and NIMBUS orbital characteristics

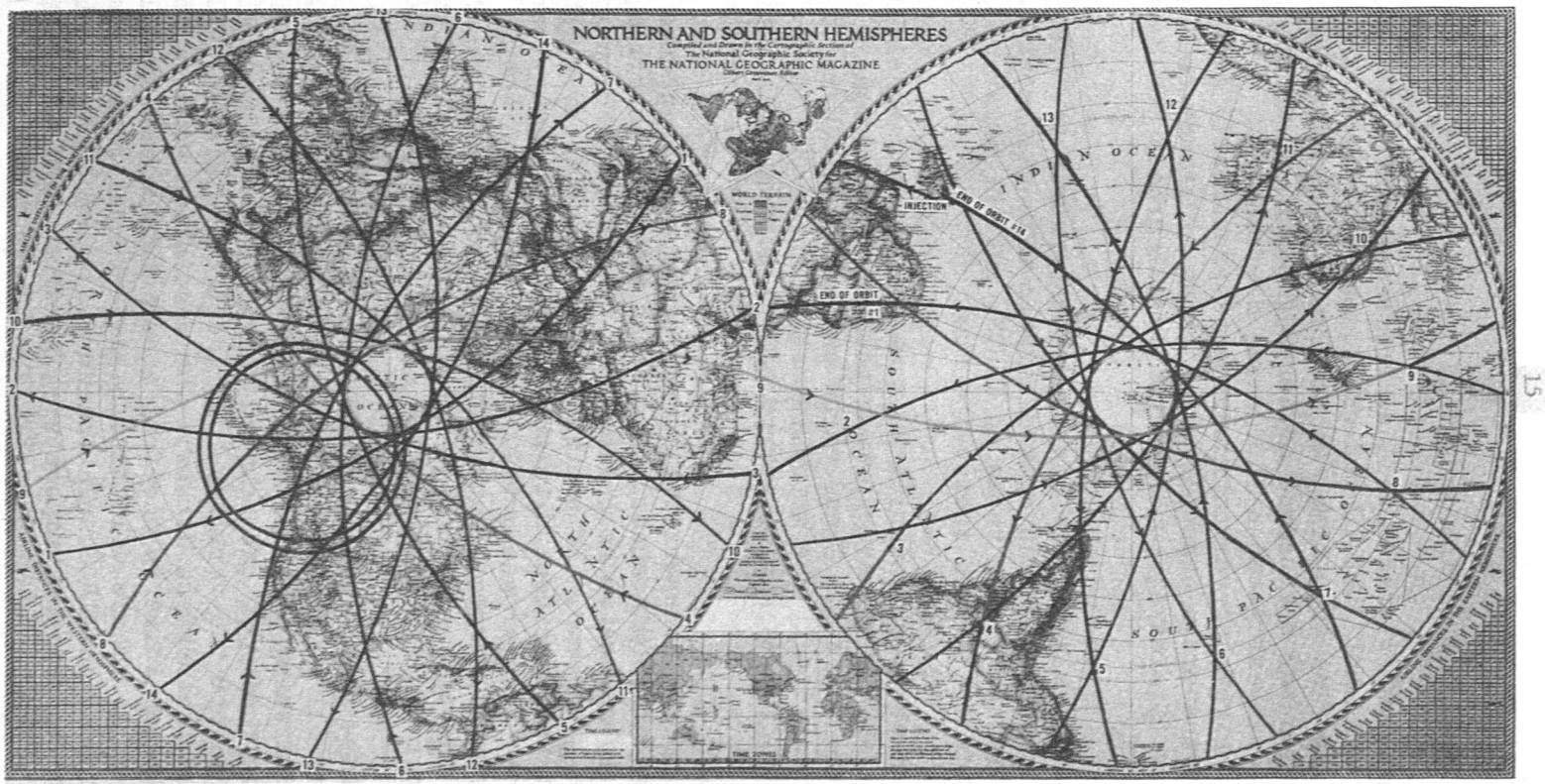

Fig. 4 Orbital tracks of a NIMBUS satellite and interrogational pattern around Fairbanks, Alaska

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are also missed, and once again 14 is interrogated.

Obviously meteorologists as well as ice reconnaissance people would like to interrogate all, not just 10 out of 14, orbits. To do this, a second station is required. At this time, we are looking into the possibility of a second station on the east coast of North America, in Canada or the United States. We have investigated a St. Johns, Newfoundland, site. With St. Johns as well as Fairbanks, we can interrogate practically every orbit based upon a two-orbit storage capability in Nimbus. Perhaps one orbit may be missed every four or five days, but essentially all orbits could be interrogated.

This (figure 5) is a picture of the Nimbus spacecraft. The upper part contains the stabilization and control system with the storage batteries. The solar cells are similar to those on TIROS, but the solar cells must now rotate so that they are always facing the sun.

To accomplish earth-orientation we must have error signals in all three axes. For this reason, we have horizon scanners which sweep a cone across the horizon both fore and aft. These earth swaths are the same if the vehicle is truly earth-oriented. If the satellite is pitched up or down, the swaths are different. This creates a pitch-error signal correcting the attitude of the satellite.

If a body axis of the satellite is not symmetrically placed with respect to the width of the horizon scanner, this means there is an error in roll, and an error-signal is generated to correct for the error. For purposes of yaw control, there is a gyroscope. If the satellite is moving as it should and if its velocity vector is coincident with the X-body axis - the gyroscopic axis being at right angles - the gyroscope will have no torque exerted on it as the satellite must necessarily rotate once in orbit going around the earth. However, if there is yaw, there is a component that exerts a torque on the gyroscope, thereby introducing a yaw error correction signal.

In the toroid - i.e., the lower part of the satellite - are the sensory subsystems. There will be a number of subsystems. One of these will be the camera subsystem comprising of three vidicon cameras, each with 800 scan lines and subtending an angle of 35°, one mounted vertically and the other two mounted on either side at 35° to the vertical. In addition, a high-resolution infrared radiometer will be included on Nimbus. The resolution will be about five miles in the vertical, sensitive in the four micron region, using a lead selenide radiation-cooled cell. There will also be a 5-channel medium-resolution radiometer similar to that used on TIROS. In the toroid there will also be the necessary telemetry systems to measure temperature, pressure, and attitude.

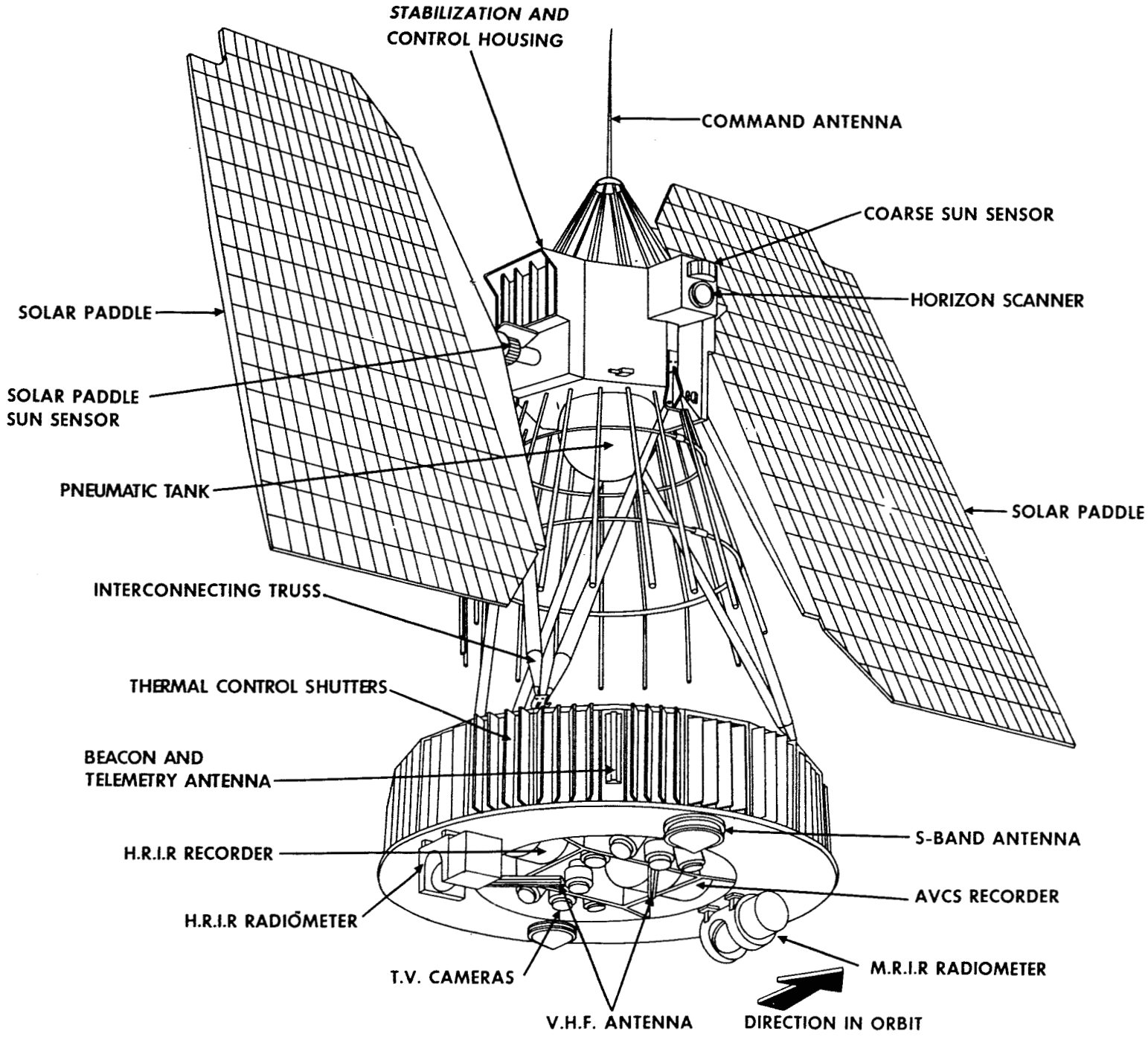

Fig. 5 Schematic of NIMBUS Satellite

Here (figure 6) we have a quick comparison of the Nimbus and TIROS systems. I have often been told at my agency that it is silly to read what the audience can already see, so I will just let you read it for a minute. Obviously for ice reconnaissance, it is important to note that Nimbus covers the entire earth as opposed to the TIROS satellite.

Prof. Cameron: With regard to skipping of orbits, is it always the same group of orbits that are skipped or do the orbits that are missed sort of precess around it?

Mr. Bandeen: In the case of Nimbus the orbits that are missed would always be the same ones relative to the earth.

Mr. Wittmann: Is the height of Nimbus different from that of TIROS?

Mr. Bandeen: Yes, approximately 600 nautical miles. This may possibly be revised to 500 nautical miles, but that is still higher than TIROS.

Here (figure 7) we have an artist's conception of a third generation synchronous meteorological satellite (AEROS). I point out that there is no existing program for this satellite. It is merely a conception to be concentrated on more fully after we lick the problem of Nimbus. But we are certain that in the future there will be a satellite of this design whose orbit has a height of 22,300 miles. This distance is such that the orbital period is equal to one sidereal day. Hence, to an observer on earth, the satellite remains fixed above him. The obvious advantage of such a system is the ability to observe time changes constantly over a given portion of the earth. For ice reconnaissance this would have obvious advantages.

To conclude then, this last slide (figure 8) shows the three meteorological satellites in being and contemplated by NASA and the U. S. Weather Bureau in a joint program. These are the TIROS satellites presently in orbit, the Nimbus satellite in development and the synchronous meteorological satellites, somewhat in the future.

Dr. Widger: I can perhaps add a few things that Bill was out of touch with. First of all, let me say that TIROS IV has essentially ended its useful picture-taking life. We are still getting IR data, but we are having problems. Fortunately, however, TIROS V isn't very far away. We are now within the period when the launch date is declassified, and I can say we plan to launch TIROS V next week. The earliest would be Tuesday.* Beyond there, we have a sixth and seventh scheduled for the fourth quarter calendar year 1962 and the second quarter of 1963, respectively, with some thought to another to overlap Nimbus.**

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* TIROS V was successfully launched June 19, 1962.

** TIROS VI was successfully launched September 18, 1962.

COMPARISON OF	TIROS	NIMBUS
HEIGHT (inches)	19	118
DIAMETER (inches)	42	57
WEIGHT (pounds)	300	650
ORBITAL ALTITUDE (nautical miles)	380	600
ORBITAL INCLINATION	48° EQUATORIAL	80° POLAR, RETROGRADE
STABILIZATION	SPIN-STABILIZED	3-AXES EARTH ORIENTED
EARTH COVERAGE (per cent)	10 TO 25	100
CAMERA RASTER	500 LINES/FRAME	800 LINES/FRAME
TV RESOLUTION (miles)	1	1/2
MAXIMUM POWER AVAILABLE (watts)	20	400
IR SENSORS (resolution, miles)	MRIR(30)	MRIR(30)-HRIR(5)

Fig. 6 Chart depicting a comparison of TIROS and NIMBUS characteristics

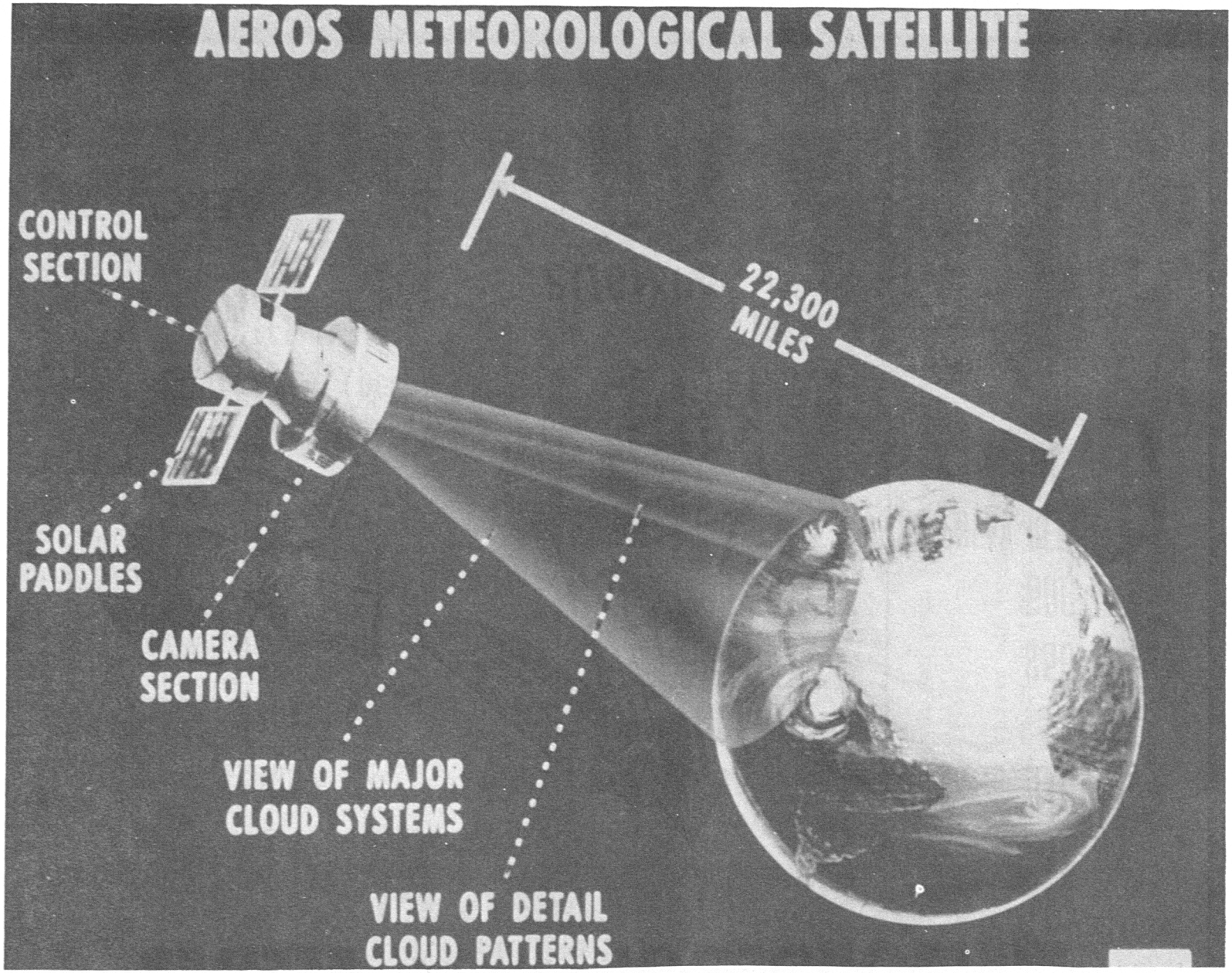

Fig. 7 Artist's conception of 3rd generation synchronous meteorological satellite (AEROS)

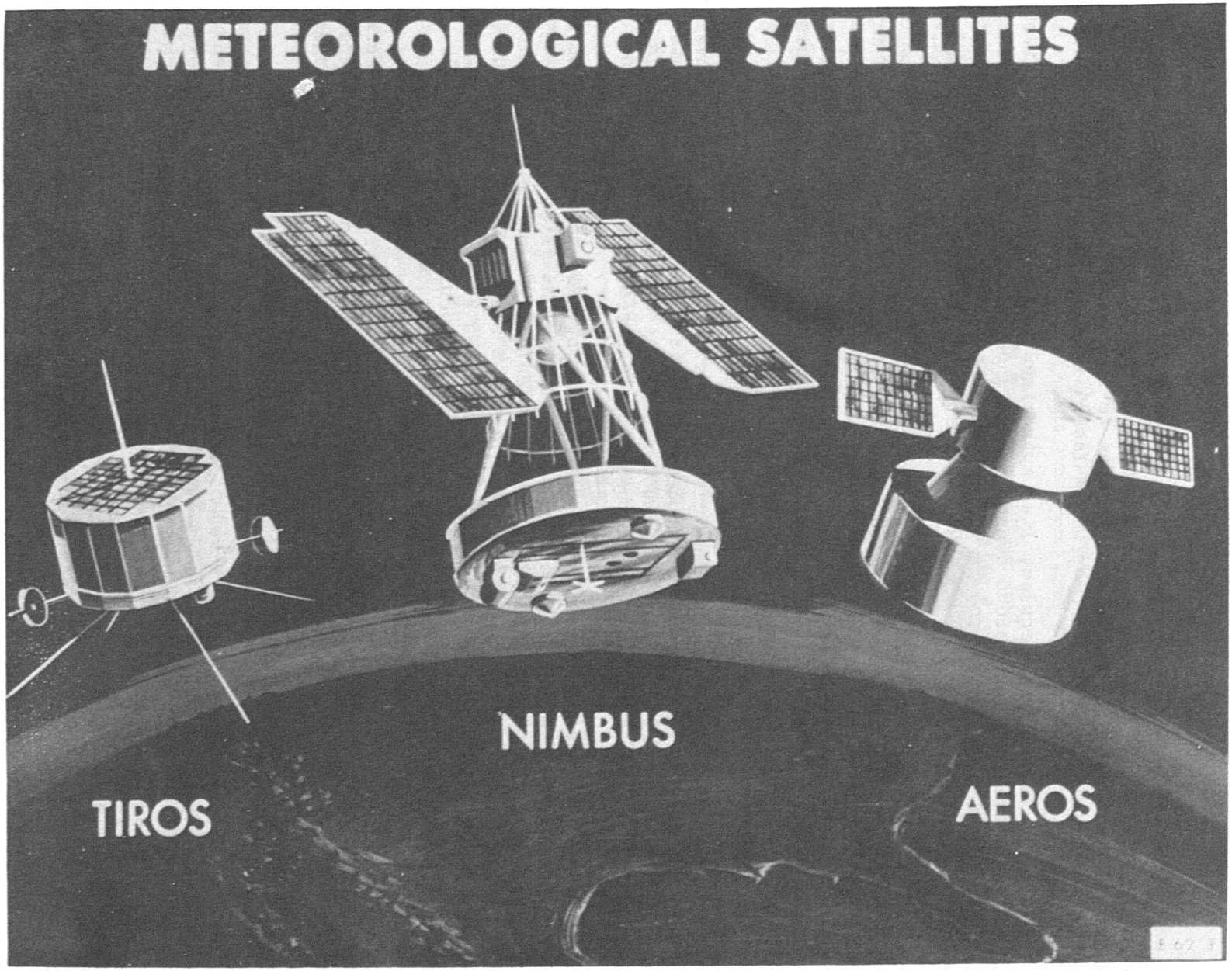

Fig. 8 Three meteorological satellites in existence and contemplated by NASA and USWB

With regard to Nimbus, the following comments may be worth noting. First, owing to weight limitations we do not intend to fly both radiometers on the first Nimbus but do plan to on later vehicles. We also plan to increase our coverage by placing later Nimbus at 750 nautical miles.

Regarding schedules, I am authorized to tell you that the first Nimbus is planned for the second quarter of calendar year 1963, i.e., between April and June. The second one is then expected to go up about six months later, with intervals of four months between that and successive launches.*

One development that is planned for a later Nimbus satellite, probably not before 1965 or 1966, is the Electrostatic Tape Camera. This may be of considerable interest to those of you who are concerned with detail, since we hope to have resolution on the order of one-tenth of a mile. However, in the initial stages, this camera would be used to photograph only one area 1,500 square miles per orbit. This could be programed whenever desired.

In connection with AEROS, I would like to point out that, because its position in space will be in the plane of the equator, most of its coverage will be of the lower and middle latitudes. I believe studies have indicated that the limits of effective coverage would be about 67° north and south, which may not be the most suitable for ice observing purposes.

Perhaps this is not the place to bring this up, but since it is not on the agenda I would like to suggest discussing the effect of cloud cover in meeting the photo requirements which have been brought out here. In a report by Dr. Arnold Glaser in 1957** he pointed out that as we approach the edge of the ice belts, in both northern and southern latitudes, the average cloud frequency is something of the order of .7 to .9. I would like to know how this might affect ice studies.

Mr. Popham: The problem of cloud cover versus ice observing is something we have been concerned with for the past two years. I think some of the approaches we have considered will be brought out later, and I would like to defer that discussion for the time being.

Although Mr. Bandeen's contribution ran over the twenty minutes allocated on the agenda, I'm sure we all benefited by it. The next agenda

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* As of the date of publication of these Conference Proceedings, the schedule for Nimbus launches is: second quarter fiscal 1964

** Glaser, A.H., 1957: "Meteorological Utilization of Images of the Earth's Surface Transmitted from a Satellite Vehicle," Final Report, Phase II, Contract No. AF19(604)-1589, Blue Hill Meteorological Observatory.

item, a discussion of TIROS I and II ice studies will be cut short to make up for some of this time, especially since much of this is covered in the two or three publications available to you around the room. After providing the background I will call on LT Dotson, Professor Cameron, and Mr. Heathfield, all of whom have made significant contributions to this work.

Shortly after TIROS I was launched Dr. H. Wexler noted in the satellite pictures what he thought was ice in the Gulf of St. Lawrence. These pictures, taken on April 1, 2, and 3, were analyzed by the Meteorological Satellite Activities and compared with Canadian Meteorological Office ice reconnaissance observations taken a week before and a week later. The early reconnaissance showed ice north of the area observed in the satellite pictures, while the later flight showed only a trace of ice but south of the area. One of the obvious conclusions made in this study was that clouds could be distinguished from ice on the basis of the persistence of this latter feature.

When TIROS II was launched in November 1960 we attempted to obtain pictures of the Antarctic but were unsuccessful.

In December 1960 the people who had performed the TIROS I ice analysis contacted the U. S. Navy Hydrographic Office requesting their cooperation in coordinating aircraft flights with TIROS II passes over Canadian east coast waters. This was done in January 1961. In March ,twelve very excellent series of TIROS II narrow-angle camera pictures were obtained, and two of these series were obtained concurrent with an aerial photo mission. This mission was flown through informal arrangements made between the Weather Bureau and a squadron stationed in Argentia, Newfoundland, and was most useful in determining how an operation such as TIREC might be coordinated.

The March series of pictures were compared with Canadian ice reconnaissance data obtained during this same period. This study is contained in Meteorological Satellite Laboratory Report #8 and in ARCTIC. Our conclusions were that we can observe ice concentrations and boundaries, but to see more detail would require both better resolution and more experience in interpreting these pictures.

Professor Cameron of the Nova Scotia Research Foundation performed a stereo analysis of TIROS II narrow-angle satellite pictures taken on two orbits on March 24; the same day aerial photos were taken by a USN P2V (Neptune). Mr. Battisfore stereo-analyzed the aircraft photos. I would like to call upon Professor Cameron to explain the details of this study.

<u>Prof. Cameron</u>: TIROS II pictures from successive orbits were treated as stereo pairs; the ice movement in the 101 minutes between these two passes recorded itself as a false parallax, and it was quite possible to measure the speed of the ice movement. We made it out to be 1.49 miles an hour.

I would like to point out that ordinarily any sequential photography can be used to determine velocities. I feel that it is very important to note that we did this with satellite pictures. It is also possible to do this with radar photography.

Mr. Popham: Since Mr. Battisfore is not here, do you recall his measurements?

Prof. Cameron: Yes, while I measured .49 miles an hour, he measured an even .50 miles an hour - a terrible error, I admit! Actually, for all intents and purposes these two checked exactly.

First, Mr. Battisfore tried to stereo successive prints taken along one flight line. There wasn't enough time lapse between photos, so he used adjacent prints from adjacent flight lines. Here, the movement showed up very nicely. He did this with three sets of prints and got considerable variation from set to set. I believe he was convinced that this was due to local movement, where a piece of the ice broke off and moved rather quickly. On two sets, however, the measurements checked exactly.

Mr. Popham: While you haven't discussed the direction of ice drift, actually both the speed and direction of motion of the ice determined from the stereo analysis of satellite pictures were in excellent agreement with measurements obtained by the analysis of the aerial photographs.

Now some comments from LT Dotson.

LT Dotson: From the ice observer's point of view, when you have observed ice for as many years as some of us here have, you know ice when you see it, almost without regard to its form. I was very satisfied with the resolution provided by TIROS II, and, while it may not have been good enough to observe topographic features, it did give us usable definition. I am prepared to go into this further this afternoon and explain what we have done and what we intend to do.

Mr. Harwood: TIROS II resolution is good enough for shipping.

LT Dotson: I agree.

Mr. Harwood: I think we might also point out that, although the theoretical resolutions may be of the order of a quarter of a mile with TIROS II, there is no doubt the eye may give better definition, perhaps even something on the order of 200 yards.

Prof. Cameron: We might also add that there is a lot of dissention among photogrammetrists. Some claim that according to the resolution of TIROS II you

should not be able to see topography if you stereo sequential pairs of satellite pictures taken at ten-second intervals. I consider this to be parallel to the case of the bumblebee. Mathematicians say they can't fly, but no one told the bumblebee. We have been able to see topography along the north shore of the Gulf of St. Lawrence and the Gaspe' very nicely. Most of this relief is of the order of 2-3,000 feet.

Mr. Kowalczyk: I would like to comment on the tests we ran on ice movement, which was a rather quick and dirty one. First we started with raw material which was not under laboratory control. We had very little data about the camera characteristics or the visual photography, and, as Professor Cameron has pointed out, the time lapse was not the greatest. Therefore, in consecutive series of photographs you are not going to get good measurements. We used no stereo instruments in making our measurements. We did use adjacent flights and came up with .50 as against .49. It's a question of techniques used and how well you control your measurements. We feel that with precision equipment such as a comparator, and with laboratory-controlled photography and complete camera data characteristics, there is no question that really good measurements can be made. It is no more difficult to make a measurement of ice movement when you have a complete line of demarcation than it is to make a topograph.

Height is another important factor. Neither with TIROS nor Nimbus can you get close measurement since this is not mapping photography. While you may talk about line resolution, when it comes down to close refinements it just can't be done. We have looked into it and we have been fairly close with Professor Cameron on this matter. Now that we have some comparators in the office we can make better measurements.

Dr. Fritz: Since Mr. Bandeen didn't have time to discuss data acquisition and utilization, and no opportunity was given to ask him questions, I would like to ask one which is uppermost in my mind, and one that I feel is an important part of the program. Mr. Harwood mentioned the importance of getting these data into the hands of the users. Since this is a meeting on ice, and since previous speakers indicated that TIROS IV observations could have been used by the marine routing officer to direct traffic into the Gulf, are there any plans on the part of the U. S. Navy to get these data to the ship captains using TIROS V or VI?

Mr. Popham: Under Item 4 on this afternoon's agenda, we have sixty minutes allocated to a discussion of further action in conjunction with proposed meteorological satellites. Perhaps this question could best be deferred until then.

Break

Mr. Popham: The next subject for discussion will be Project TIREC. We will attempt to follow, with minor exceptions, the outline of the Project TIREC Operations Report beginning with the Background, then the Operations, and, in general terms, the data collected. We will use one day, April 7, to illustrate the operation and data collected. The appendix to this report will contain maps and charts showing where and what data were obtained and the sources through which it will be available. The slides which will be shown and discussed are for the most part those which appear in the data folder presently being distributed among you now.

Previous experiments and small-scale pilot studies conducted with TIROS II indicated that very good use of polar satellite photography could be made in ice reconnaissance and surveillance. We felt that a much larger program than had previously been conducted would be needed to evaluate the ice surveillance capabilities of the satellite. Accordingly the Weather Bureau, in association with the Navy Oceanographic Office, planned such a program, designated Project TIREC.

In November 1961 the U. S. Weather Bureau for many reasons invited the Meteorological Branch of the Department of Transport in Canada to participate in this operation. In particular, we would be operating in an area which is especially significant to Canada---the Gulf of St. Lawrence---where ice is of direct economic interest. It was felt that their interest and knowledge of ice conditions in this area would be especially valuable in planning and conducting the operation, as well as in the interpretation of data collected.

The specific objective of Project TIREC was the identification and interpretation of sea ice features as seen in TIROS IV photographs. The emphasis is placed on the use of satellites for ice reconnaissance largely because it is in this area that the most direct economic advantages may be realized. The ultimate objective is to make maximum use of satellite data obtained in polar regions. It was brought out earlier that, to varying degrees, ice and snow distribution are of interest to oceanographers, meteorologists, and hydrologists. TIREC was designed around acquiring the type of information which would be most helpful in studying applications of satellite data to all these areas.

So much for the background. In discussing the operations we will begin with weather and ice conditions first, since these factors actually governed to a large extent how the operation was conducted. Then we will discuss the procedures used to acquire this information. Mr. Markham will brief us on weather and ice conditions.

Mr. Markham: Phase I of TIREC began immediately after the launch of TIROS IV on February 8. Weather was good for the first two days, but the long wave trough was approximately along the Atlantic seaboard. Several low pressure systems moved northeastward across Newfoundland during the last three days resulting in extensive cloud cover which interfered a great deal with operations on the 10th, 11th, and 12th. Consequently, most of our more successful operations were conducted in the northwestern sector of the Gulf.

Ice cover was nearly complete right down into the river, ranging upward from eight-tenths as indicated by the mosaic of aircraft pictures shown on the wall. There were some open leads around Stephenville, Newfoundland, (I don't think they extended as far up as Corner Brook) and some ice was flowing out through Cabot Strait. Off east Newfoundland, the ice extended roughly down to about 50°N, extending eastward about 100 miles, then swinging northward again. This was mostly young ice, whereas in the Gulf there was a higher percentage of winter ice.

In Phase II, which began on April 2, ice reconnaissance missions by Meteorological Branch chartered aircraft were increased. Except for the 2d, when a storm went through the area, the weather was very good during the initial stage. Between the 3d and 6th there was often nothing more than a few scattered cumulus clouds in the area. Good visual reconnaissance observations were obtained, and I believe these tie in well with the satellite data. When the operation got into full gear on the 7th, the weather was initially very good, but conditions deteriorated very rapidly so that poor flying weather was encountered on the 8th, 9th, and 10th. Conditions improved slightly on the 12th and 13th, then went sour again from the 14th to 17th with some flying but little photography done.

The following (figure 9) indicates the location of the ice at the beginning and end of this phase. The diagonal shading from northeast to southwest indicates the ice-covered area at the beginning of the operation, April 3, and the northwest-southeast lines show where it was at the end. There are quite significant motions of ice, clearing in the area from the Magdalen Islands to Chaleur Bay and actually increasing ice cover in the northern part of Cabot Strait. Although an area in the approaches to Sydney is shown as having ice both at the beginning and at the end of the operation, it was actually clear at one stage, for the ice first moved well to the east and melted while more floes moved southward along the Cape Breton coast into the initial area. In the northeast arm there was a large retreat with motion toward the northwest, and in East Newfoundland the ice drifted well to the east with an appreciable amount of melting. An additional surge of ice began to come down from the Labrador coast in the final few days.

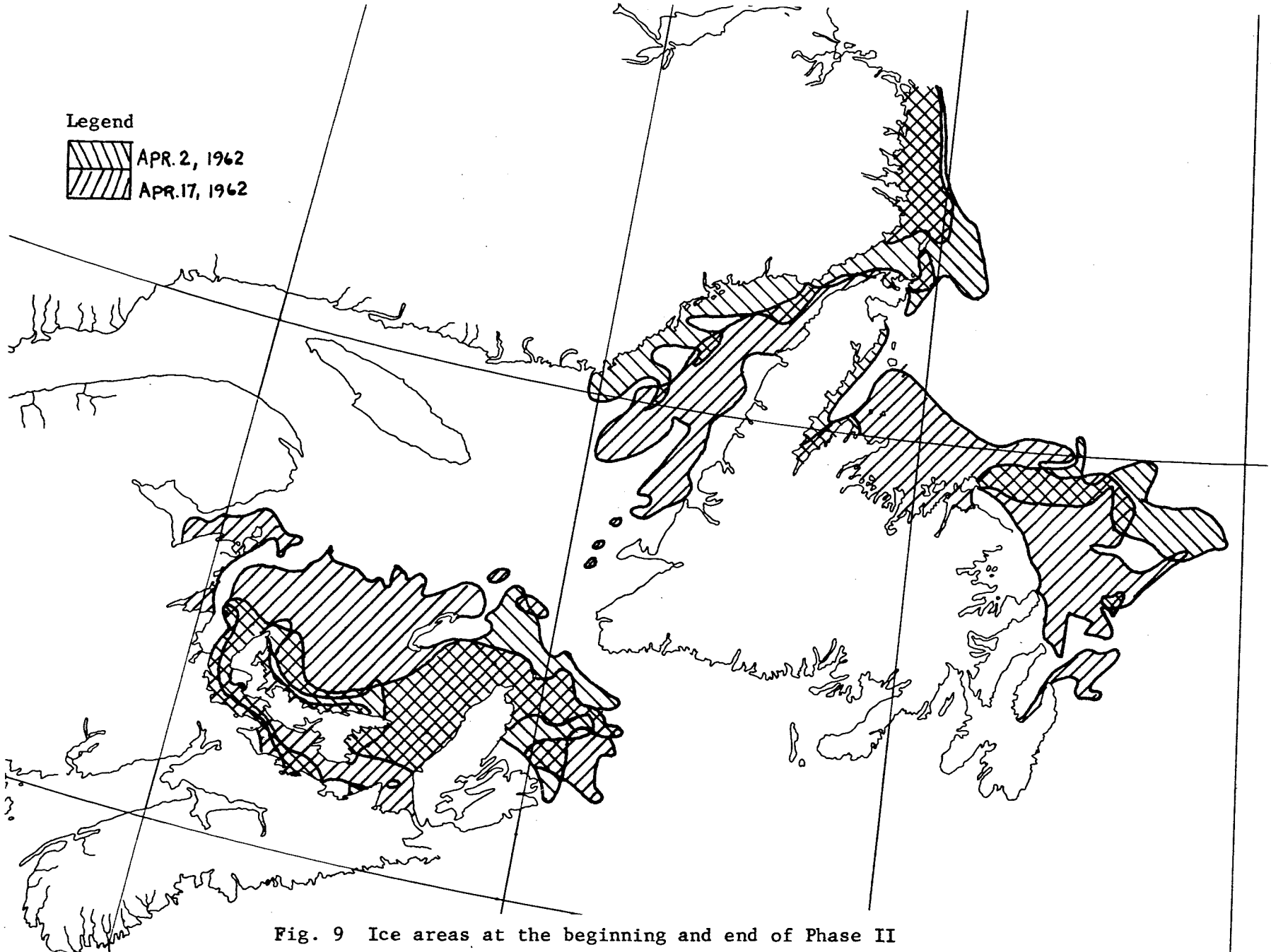

Fig. 9 Ice areas at the beginning and end of Phase II

Mr. Popham: Before F/L Meed begins I'd like to say that he had quite a job. In Phase II he was responsible for coordinating all aircraft operations, which involved U. S. Navy A3D's and P2V's, Canadian DOT Dakota's, RCAF Lancasters, CF-100's, Dakota's and Argus aircraft. Most of these aircraft operated at different altitudes taking different types of observations as required by four Control Group personnel. I think all of us connected with the project feel he is to be commended for an excellent job.

F/L Meed: I'm Flight Lieutenant Meed, RCAF Maritime Air Command (MAC), Halifax. I will try to give you a very brief run-down of the operations as they were conducted and the organization that we used to collect the photographs as well as other aircraft data. I will discuss the first and second phases, indicating very rapidly the changes that were made to improve it, and give you some idea of the scale of operations involved in a project of this size.

Phase I began February 8 and lasted to the 12th. It was run as a joint operation, although each agency controlled its own aircraft. MAC offered communications facilities and such air traffic control services as could be provided.

This chart (figure 10) shows the organization of Project TIREC. A representative of each of the four agencies shown at the top formed the Control Group. The Defence Research Board was Canadian Coordinator and issued the orders concerning the deployment of Canadian aircraft. The U. S. Navy Hydrographic Office essentially controlled United States aircraft. The U. S. Weather Bureau served as United States coordinator, was liaison with the Hydrographic Office on the deployment of United States aircraft, and in association with NASA, provided the satellite.

In Phase I, operational directives and other instructions were passed through several channels; Phase II was run as an integrated operation through a single coordinating agency, and the instructions were passed through a single channel. Aircraft consisted of one DOT Dakota operating out of Seven Islands in Phase I and two aircraft in Phase II, one based at Sidney, Nova Scotia, the other at Gander, Newfoundland. Two P2V's were at Argentia, one CF-100 at Chatham, New Brunswick, two Lancasters and one Dakota at Summerside, Prince Edward Island, and two A3D's and two Argus aircraft at Greenwood, Nova Scotia.

During Phase I, 62°W was chosen as an arbitrary dividing line for aircraft operations, with Canadian aircraft operating west of and United States aircraft operating east of this line. This did not work very well and was disregarded in Phase II when operations were integrated. This proved much more satisfactory.

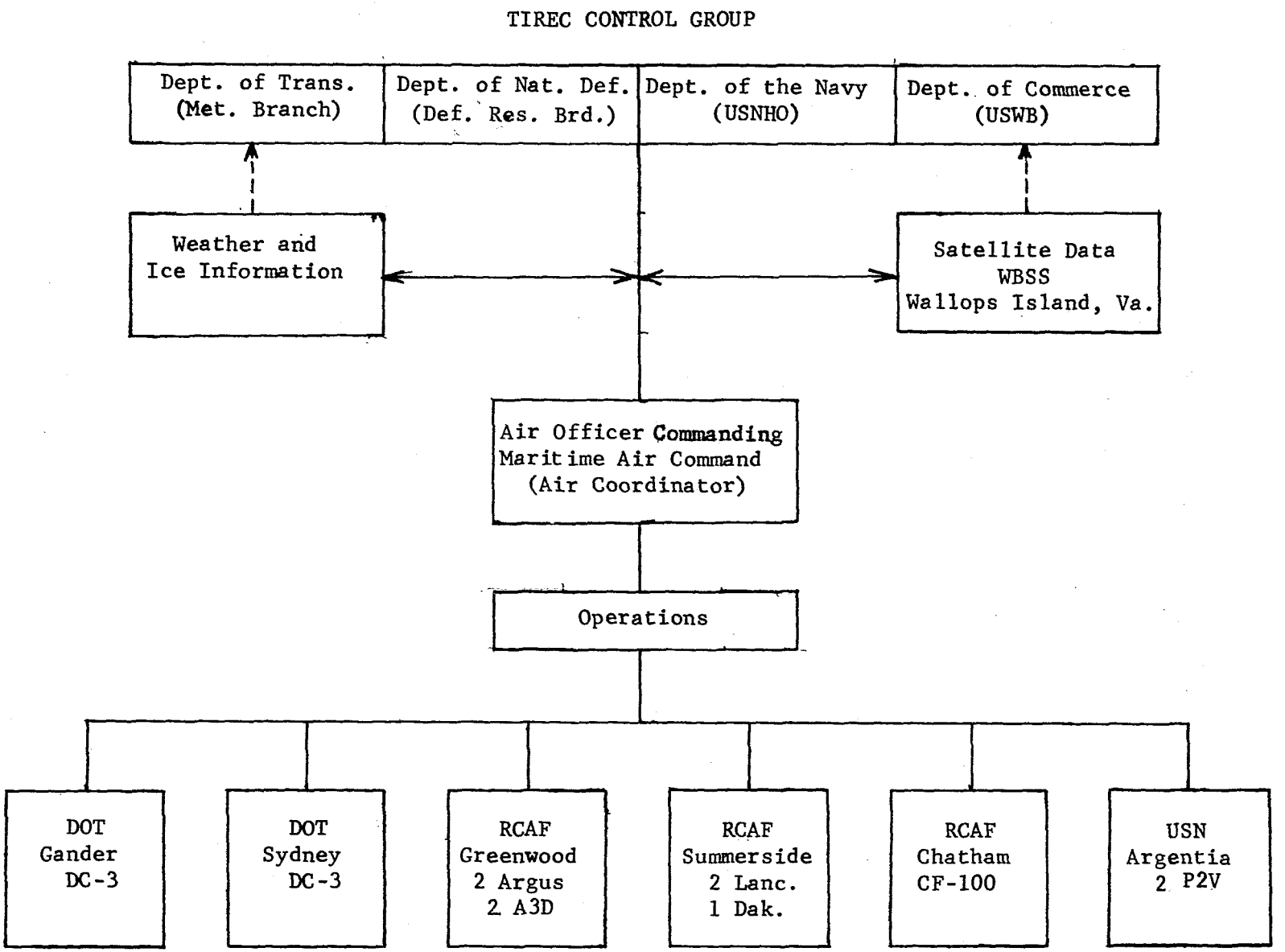

Fig. 10 Chart showing organization of Project TIREC

An example of photo flight lines for high-level A3D and CF-100 aircraft and medium-level Lancaster aircraft is shown in this slide (figure 11). The lines were prepared by the respective agencies.

This slide (figure 12) shows the basic tracks most frequently flown by Argus aircraft in Phase I taking radarscope photography and visual ice observations. One flew east, over the Newfoundland ice pack, through the Straits of Belle Isle and back to Greenwood; the second did a concentrated sweep in this (arrow) area.

This slide (figure 13) shows the normal tracks for DOT Dakota's operating from Sidney and flying in this area (1), Gander aircraft operated in this area (2), and RCAF Dakota's from Summerside flew in this area (3). P2V's based at Argentia normally flew in this area (4). Operations control of aircraft was established at MAC Headquarters, and all initial flight planning was done here. Complete records of most aspects of the operation were collected here.

Many lessons learned in Phase I helped make Phase II operations much more effective. Major items, such as changing radio crystals to improve communication, and relatively simple items, such as plotting flight tracks on the operations board using colored tape and photographing it in color instead of hand-plotting them using daily final aircraft operations messages, were improvements in procedures learned through Phase I operations.

This slide (figure 14)* illustrates both the type of records which were kept in Phase II and the air operations for April 7, the day on which pictures used to prepare the moasaic shown in your folder were obtained. The black lines show the track of the CF-100 which took the pictures; Argus flight lines are in red; Dakota tracks, in yellow; Lancaster, in green; and P2V, in orange.

I will be available later this afternoon if anyone wishes to discuss any particular aspects of the operation. As a general summary of the overall operation, we feel that the amount of effective coverage obtained in Phase II was a direct result of experience in Phase I, which led to integrating Phase II operations using a single line of communications.

Mr. Popham: With regard to satellite coverage, photographs of the Great Lakes and/or Canadian east coast waters were obtained on four orbits during Phase I. On two of these orbits, pictures of the Gulf of St. Lawrence were of fairly high quality, and all were taken at a very oblique angle. During Phase II very excellent results were obtained. We had 79 passes on which satellite photographs of ice were obtained. Thirty-nine of these were over Canadian east coast waters; 15 of these 39 were of very high quality, and 7 were very good. Thirty-three passes showed the Great Lakes, and again about 15 of these appear to

*Not shown here due to poor reproduction quality. A print may be obtained by writing to the editors.

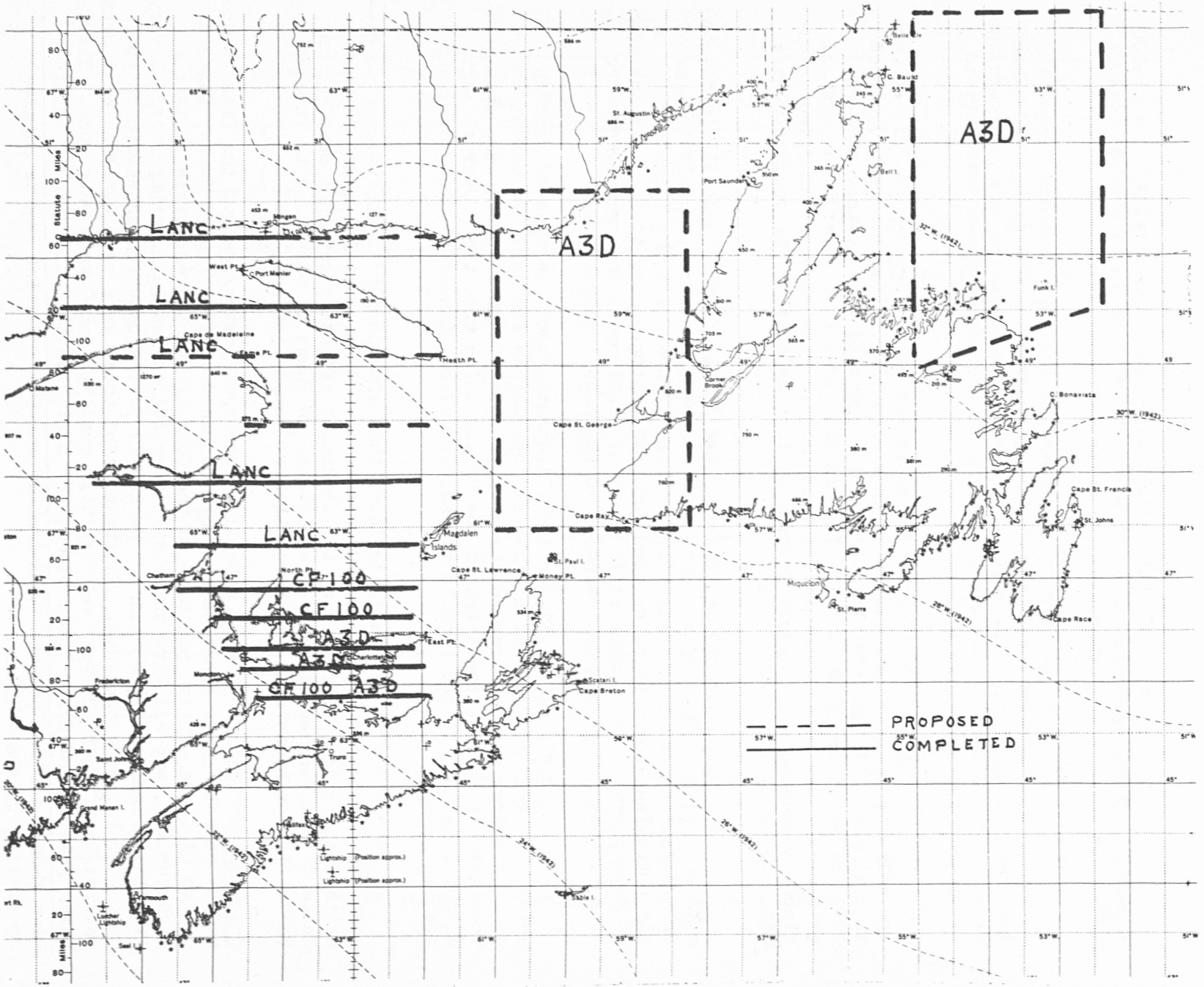

Fig. 11 Basic high and medium altitude tracks flown during Phase I.

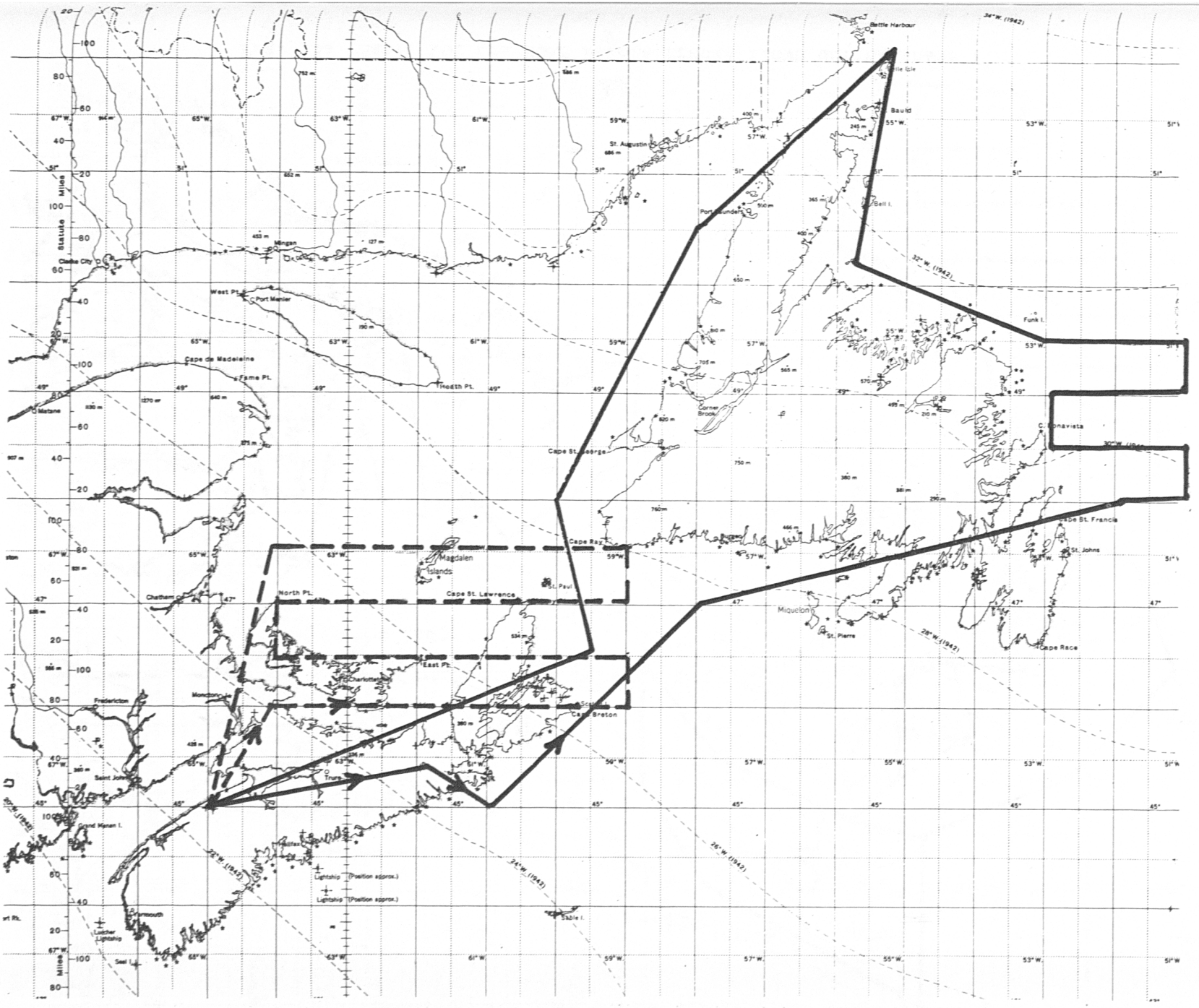

Fig 12 Basic Argus tracks flown during Phase I

Fig. 13a Basic DOT and RCAF Dakota tracks flown during Phase I

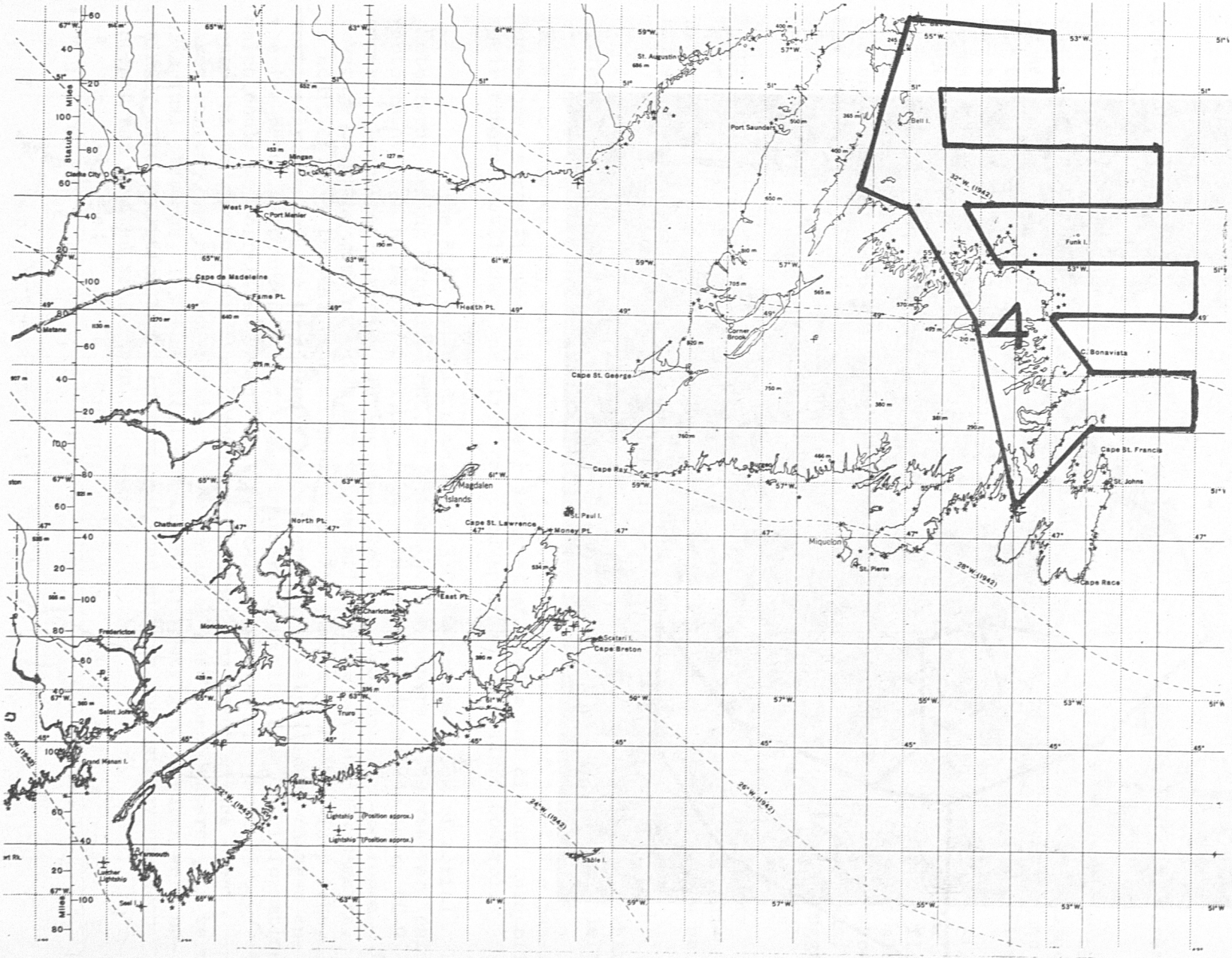

Fig. 13b Basic DOT and RCAF Dakota tracks flown during Phase I

SATELLITE: TIROS IV

ORBIT: 0835 DATE: 7 APRIL 1962

CAMERA: 2 MODE: DIRECT

FRAME SHOWN: 11 TIME: 16:46:39

HEIGHT: 767 KM. (477 STAT. MI.)

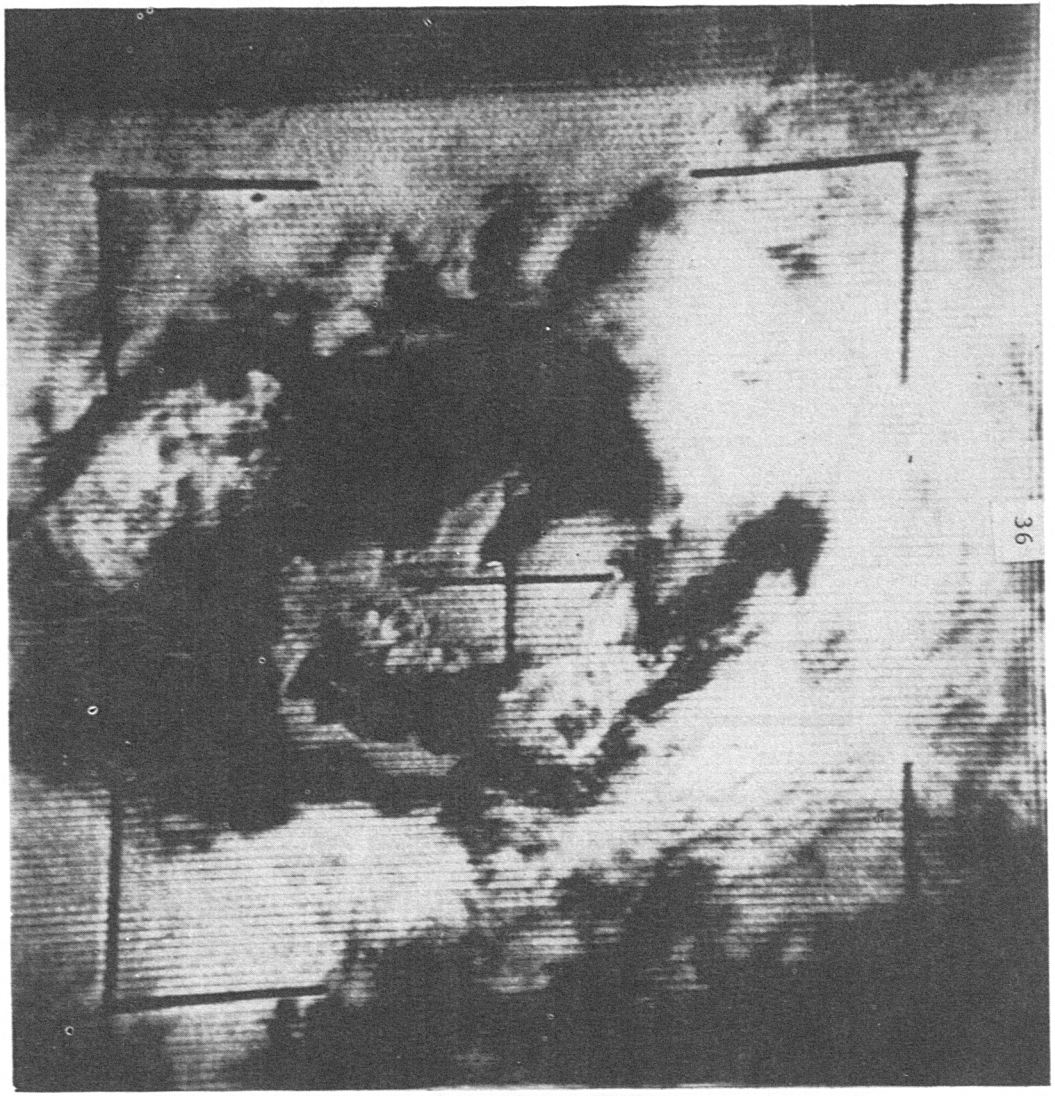

Fig. 15 TIROS IV picture showing ice around Prince Edward Island.

contain very useful information. Several passes, of course, showed both areas, and some still remain to be checked for quality.

This slide (figure 15) shows a picture from pass 835, one of the two picture-programed passes over this area on April 7. Prince Edward Island is seen in the lower part of the picture. Clouds cover most of Newfoundland and the Straits of Belle Isle, but the Gaspe' Peninsula and St. Lawrence River can be seen. The bright area around Prince Edward Island is ice; in the Northumberland Straits between PEI and Nova Scotia, the ice in places was over twenty feet thick. In particular, I would like to point out the fairly dark region in this ice "peninsula" near the Magdalen Islands, some of the ice floes which can be distinguished in the ice pack north of PEI, and the fast ice along the north coast of the island. You will see these features in the slide showing the mosaic of CF-100 pictures which Major Taggart will show during his talk. This is the picture shown in the folders which were distributed. Major Taggart will review RCAF photography obtained in Project TIREC.

Major Taggart: Before I begin I would like to explain briefly why an Army Major is talking about RCAF photography. I belong to a tri-service organization; therefore, the color of the uniform doesn't make any difference - we all wear the same "hat," and I speak on behalf of the RCAF.

The photographic phase of the TIREC operations was run somewhat differently from normal photographic operations in that the cameras were left on when flying over clouds. This was necessary for our purposes since we needed to know exactly what conditions existed at the time of satellite pass. Therefore, aircraft operated at their assigned altitudes and did not turn off their cameras until they had first received approval from TIREC Control.

The RCAF obtained a total of 370,000 square miles of aerial photography during Project TIREC, of which 150,000 square miles was vertical photography from a CF-100 at 41,000 feet using a 3-1/2-inch lens in an RC-9 camera. Lancaster aircraft, flying at 18,000 feet, obtained tri-metrogon coverage over the remaining 220,000 square miles using 6-inch F224 cameras. In addition, the Lancasters also carried an F52 camera with a 20-inch lens, vertically mounted, to take sample photography where significant changes in the ice details occurred. This was primarily to provide detailed information which could be correlated to the smaller-scale photography. About 13,000 square miles of the total photo coverage obtained was taken in the Great Lakes region; the rest was obtained over Canadian east coast waters. In terms of actual pictures, 1,300 vertical and 11,000 tri-metrogon pictures were obtained. The operation ended on April 18, and all the photography has been indexed and plotted since then.

It is our intention to use the high-altitude photos to prepare mosaics, such as those displayed on the wall, to compare directly with the TIROS pictures. Tri-metrogon photos will be studied to determine ice characteristics and to prepare ice concentration charts.

Again, using April 7 as an example, the following slide (figure 16) shows the ice area around PEI that Mr. Popham pointed out in the TIROS picture (figure 15). This is a mosaic made of CF-100 pictures. The tonal changes in the point of ice (ice "peninsula") near the Magdalen Islands is actually due to the broken ice floes through the center, which can be seen in this aerial photo. The large floes immediately north of the open water north of PEI can be seen, as well as the fast ice along the coast. According to the theoretical resolution of TIROS, this fast ice should not be seen, but it is.

The ice concentration chart, (figure 17), prepared from the Lancaster photography, is shown in your folders. In view of the time, I won't show the slide.

Mr. Popham: LT Dotson, would you give us a summary of USN photography?

LT Dotson: U. S. Navy A3D jet photo aircraft from VAP-62, Jacksonville, Florida, flew three sorties in the eastern, or United States sector, in Phase I and seven sorties off the east Newfoundland coast or PEI area in Phase II. Although it was initially planned to obtain photos from 30,000 feet, almost all of them were flown at altitudes between 35,000 and 41,000 feet. Approximately 175,000 square miles of tri-metrogon photography was obtained using CA-14, 6-inch focal length cameras. Selective low-level vertical photography was also obtained at or below 4,000 feet from U. S. Navy P2V's from Argentia using a CA-8, 6-inch focal length camera. Usually, this type of photography was obtained in strips of ten pictures each where ice conditions appeared to be changing rapidly. However, owing to the amount of film available, only six or seven strips could be obtained.

In obtaining the low-level photography, special emphasis was placed on observing both diffuse and well-defined ice pack boundaries, changes in tonal qualities, and ice floes or fields which exceeded 3,000 feet, since we assumed this to be the minimum floe size which might be resolved in TIROS IV photographs.

Some of this photography is on hand and is being indexed. We also plan to lay strip mosaics of the aircraft pictures to compare directly with the satellite photos.

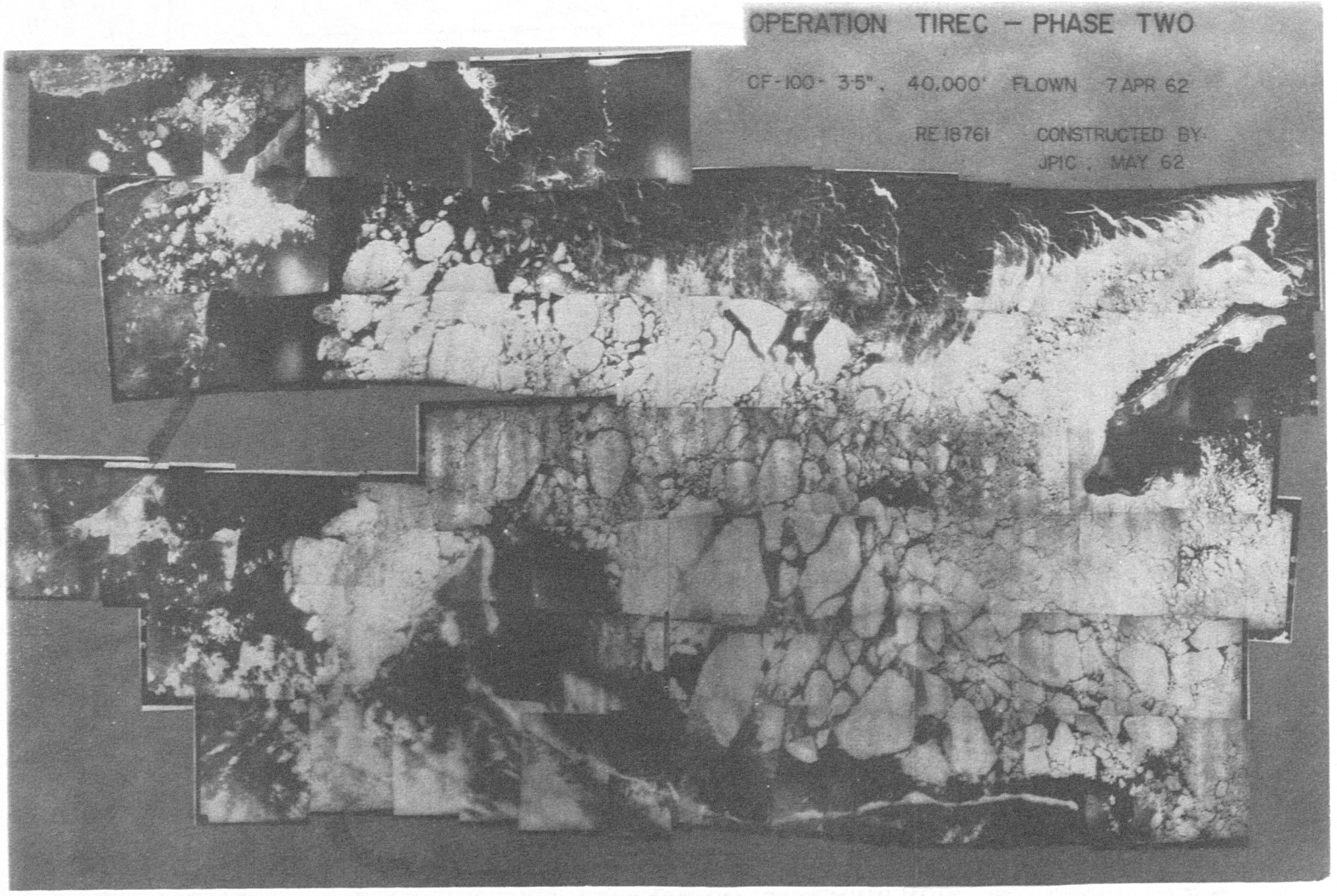

Fig. 16 Aircraft mosaic illustrating ice around Prince Edward Island

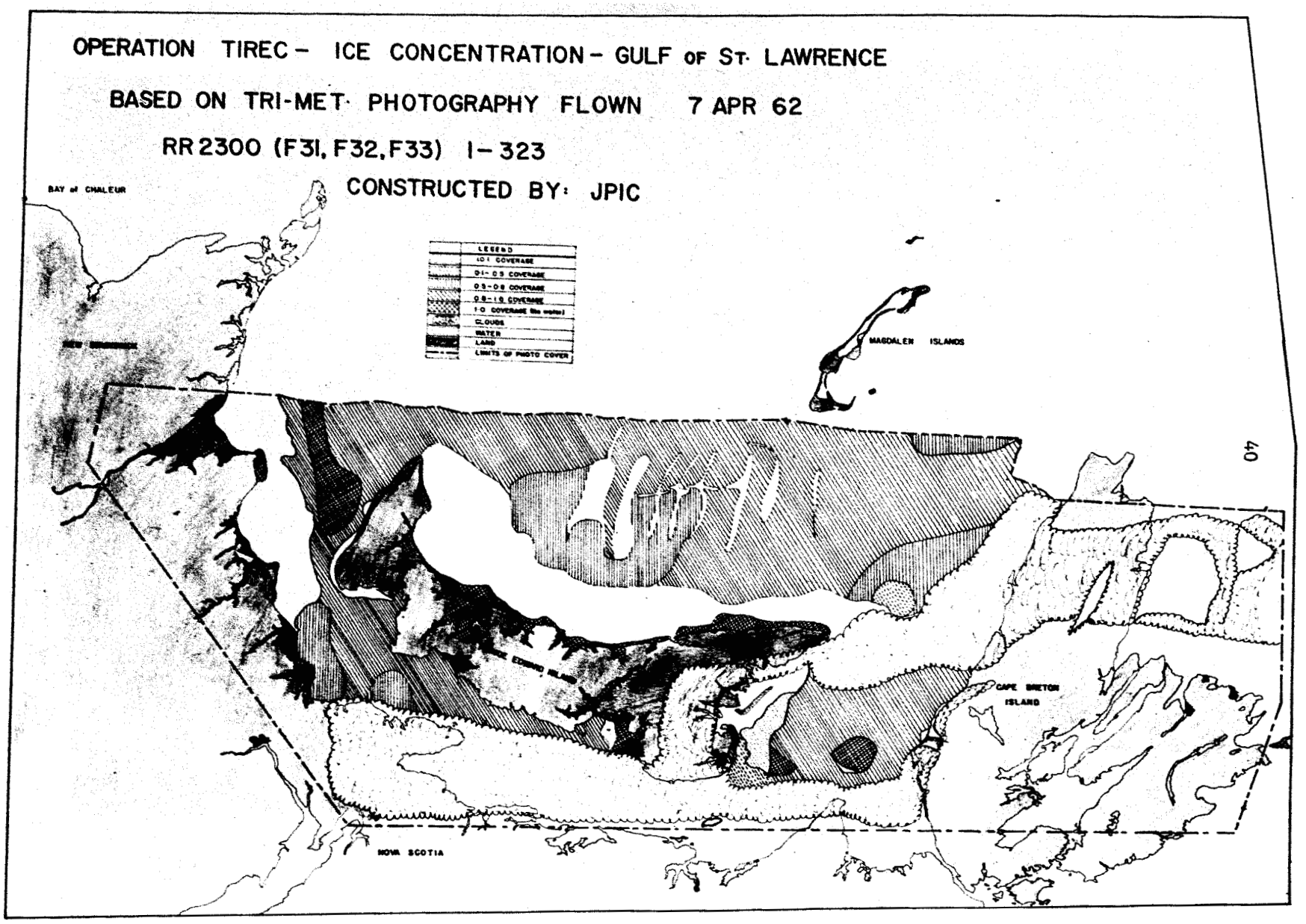

Fig. 17 Ice concentration chart for the Gulf of St. Lawrence

Major Taggart: I would like to say that, en toto, about 550,000 square miles of aerial photography, or roughly an area 13 times the size of the Gulf of St. Lawrence, was obtained by the combined Canadian and United States forces.

I would also like to add to my earlier discussion the comment that the Lancasters involved in this operation were from the 408th Reconnaissance Squadron, while the CF-100 was from the Central Experimental Proving Establishment.

Mr. Popham: LT Dotson, would you review the U. S. Navy radar observations collected?

LT Dotson: No radarscope photography was obtained in Phase I. Six good sorties were flown in Phase II by P2V aircraft operating at or below 4,000 feet, and about 90,000 square miles of radarscope coverage was obtained. One very interesting point to bring out here is that the scales of the radarscope and TIROS pictures are very nearly the same, which should quite definitely bring in a brand new aspect to the interpretation of these data.

Mr. Popham: Mr. Heathfield, will you review the RCAF radar flights?

Mr. Heathfield: We operated two Argus aircraft out of RCAF Station Greenwood to obtain low-altitude radarscope observations using a 3-cm radar set. Radarscope photos were taken about one every ten miles. Our sorties were flown, as Mr. Meed has pointed out, either in the area adjacent to PEI or on long flights completely around Newfoundland. We had at least one and frequently two aircraft up on every day, regardless of weather. Almost all the radarscope photos have been prepared as mosaics.

I have also examined the P2V 3-cm radar and the high-altitude A3D 10-cm radar. I hope to discuss the analysis of radarscope photos this afternoon, but, in short, all three types of radar equipment have their own particular characteristics which should be helpful in comparing these photos with the TIROS photos. It is amazing how close they are, and they show some very interesting possibilities.

Mr. Popham: Mr. Archibald, would you review visual ice reconnaissance flights made by Canadian aircraft during TIREC?

Mr. Archibald: I should just like to take a moment to explain why the Meteorological Branch of Canada is so vitally interested in the project. We have been charged with the responsibility to provide ice observations for operational use and ice advisories and forecast services to all users in Canadian coastal waters from the Gulf up to about 81°N, including certain inland waters. Therefore, we are vitally interested in this project, and since it is a problem

of observation and forecasting, it fits well into the Meteorological program. In addition, we have trained and highly qualified ice observers to obtain aerial ice reconnaissance data. We welcomed the opportunity to participate in Project TIREC.

The detailed observations which the ice observers were asked to make included an emphasis on the gradation of the ice, its concentration, boundaries, and water openings. Over Canadian east coast waters we made optimum use of Decca navigation equipment aboard two Meteorological Branch-chartered Dakota aircraft. The Decca and Doppler navigation systems were very useful in precision mapping of the ice so that we would, within the space of the length of a ship, precisely locate the ice.

The combined United States and Canadian ice reconnaissance operations for Phase I covered the period February 4 through 12. We made 34 flights, including two over the Great Lakes (except Lake Michigan), and logged a total of 209 flying hours. In Phase II, which lasted from April 2 to April 18, we flew a total of 299 hours on 47 missions making a combined total for both phases of 81 flights and 509 hours.

In addition to the aircraft observers we also had observers stationed on icebreakers in Phase II. There were three Canadian icebreakers, one United States icebreaker and one U. S. Coast Guard survey vessel. In the Great Lakes, the research survey vessel Port Dauphine provided additional weather and ice data in Phase II.

Special supplemental weather observations were also desired. This slide (figure 18) shows the land stations in Canadian east coast waters which took special observations in Phase I. Observations were obtained from 29 stations or ships in this first phase.

We also solicited the cooperation of commercial airlines as well as private airline companies to take observations of cloud type above, at, or below flight level as well as observations of snow and ice coverage. These observations were reported on special forms which we supplied to forecast offices from Winnipeg through Montreal, Moncton, and New Brunswick. This slide (figure 19) shows the coverage obtained. As you can see, nine different agencies participated giving us additional information even over parts of Quebec and Laborador.

The last slide (figure 20) shows a map of stations which took supplemental weather observations in Phase II. As you can see, we added ten additional stations, mostly in the Great Lakes, giving us a total of 38 stations taking special observations in Phase II.

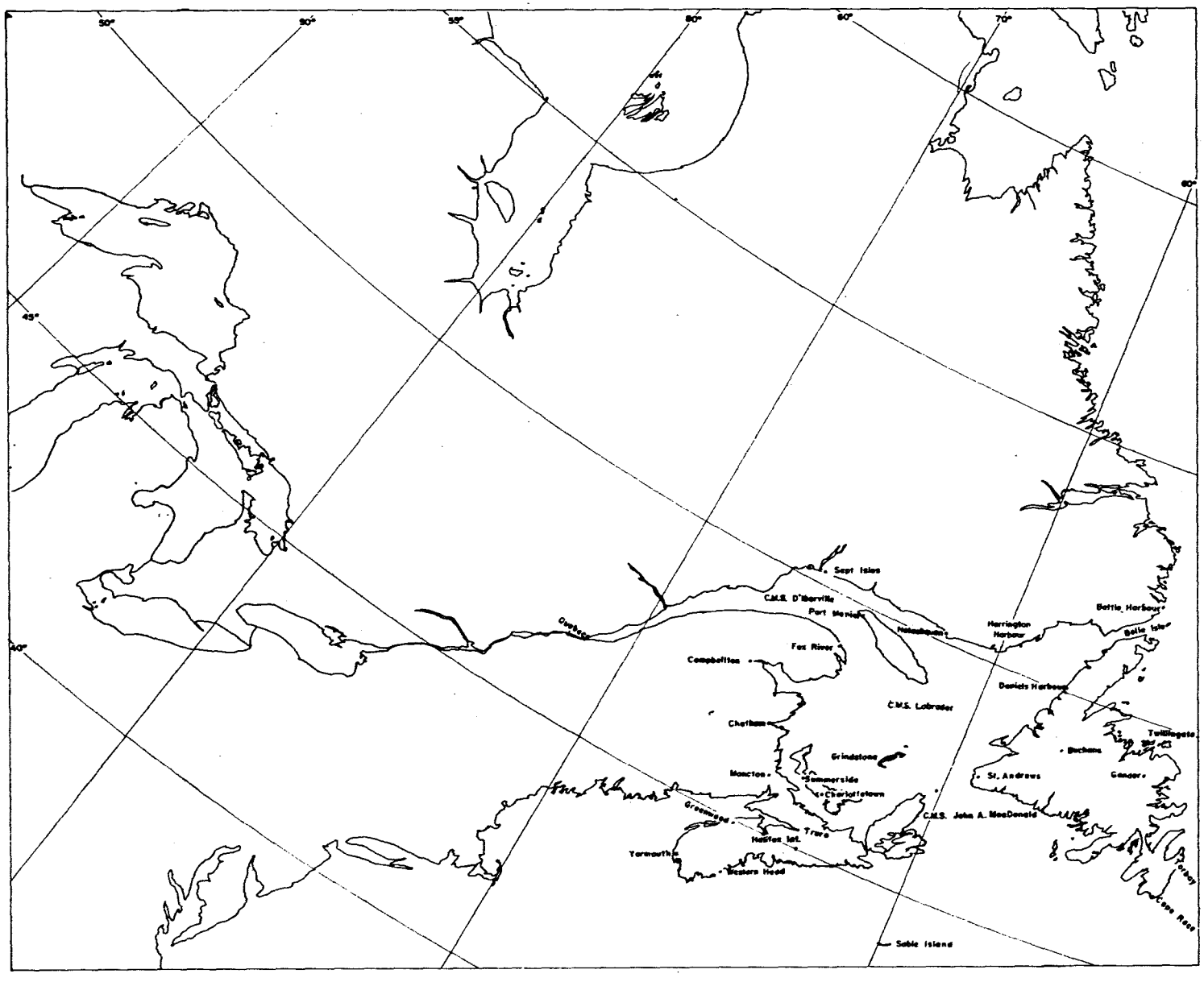

Fig. 18 Land stations around Canadian East Coast waters which took special observations during Phase I

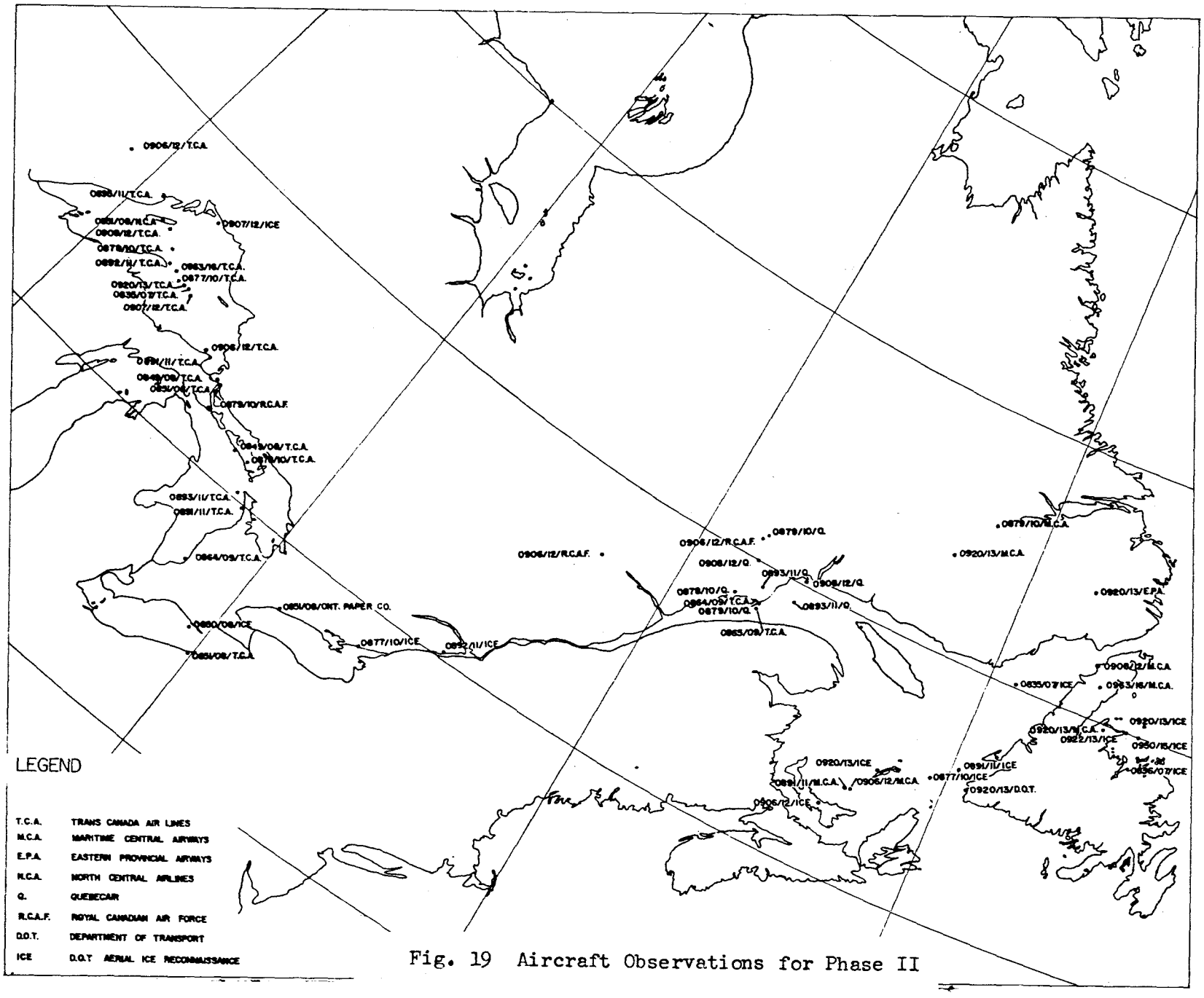

Fig. 19 Aircraft Observations for Phase II

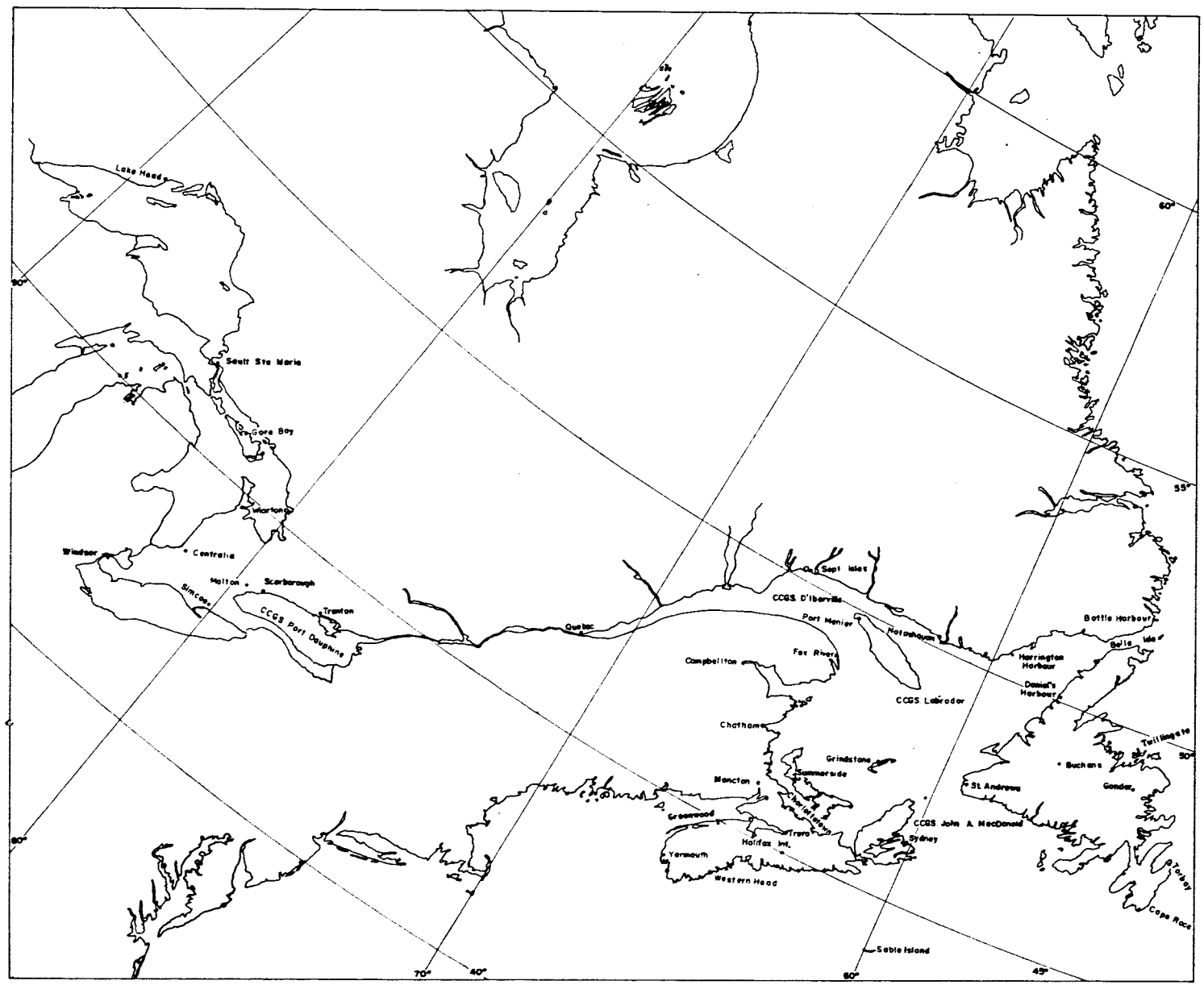

Fig. 20 Land Stations taking supplemental weather observations during Phase II

Mr. Popham: I would like to repeat here that satellite pictures of the Great Lakes region were obtained on 33 orbits with very good pictures obtained on 15 of these. Now, covering additional special observations, the U. S. Coast Guard obtained some aerial photographs with a hand-held camera along the northern and eastern shore of Lake Superior during Phase I. In addition representatives of the U. S. Army Corps of Engineers, Cold Regions Research Engineering Laboratory who participated as interested observers on this project arranged to have ground observations of snow depth in the Keweenaw Peninsula area of Lake Superior. In addition, low-level aerial photos were also obtained in this area, again arranged by these observers.

That concludes a general report on Project TIREC observations. We have asked Mr. Harwood if he would draw some conclusions now regarding the value of the Project TIREC operations.

Mr. Harwood: We've got one more aircraft to be accounted for. Since we have a member of the Department of Mines and Technical Surveys here, I might as well mention it. On the 4th and 5th of April we had an aircraft that did the Gulf visually for a somewhat different project which has been going on for about six years. That is, to have an aircraft over the Gulf on the same day at the same time to keep a series of geographical studies of ice. These have been going into the hands of the ship owners, and this has turned out quite successfully. That's probably the last aircraft that came back on the 5th.

I've been asked to draw some conclusions - this is purely the operational side. I'd like to go right back to the beginning and point out some of the conclusions one can draw from this. One is that you can go back fifteen years to the Marshall Plan and to the generosity of the American people that financed a defeated nation into recovery. I think most people in this world, with possibly the exception of the North Americans, realized what an act of generosity this was.

Here we see the same thing happening again. Here are a series of meteorological satellites being sent up. The cost is literally fantastic. It is out of the pocketbook of the United States taxpayer, and in the case of the results which are going to take place in the Gulf of St. Lawrence over the next five years, as I've mentioned, there will be a direct accrual to the Canadian economy which is, in a sense, in opposition to the United States economy (although if the various common markets get all mixed up together, we may end up in the American market). Whatever we do, there is one conclusion we can draw and that is that this open-handedness - this availability of satellite photographs - the open manner in which it's being given to the Canadians, the cooperation that we've received (and I presume that they would

say the same thing of us) is a direct gift to the Canadians of inestimable value. I think all the Canadians here will agree with this. That is the main conclusion I draw from this Operation TIREC. Of course, if things like this can go on elsewhere in the world, we'd like to think it would be a far better world to live in.

The second conclusion that one can draw from it is the immediate results that we get out of the photography. We have laid the groundwork, if we take advantage of it, for satellites that are to come. Even by just looking at the data you see around you, you know roughly what these future satellites can do for you. Everyone around this room, certainly on the Canadian side, has some idea as to how it's going to be used and how it can be used. We get that much out of it - that's the second conclusion.

The third conclusion I would like to draw is that I was not involved in it, but I've never been associated with an operation which was so highly complex - and this thing really is complex - as Flight/Lieutenant Meed pointed out to me a couple of days ago. It was just like coming up to a wartime emergency where you were drawing aircraft from the interior of the continent and bringing it toward the coast. Such a complex operation, where the pieces fell together so easily - and to me this is the amazing conclusion that one draws from this - is simply that everyone was interested in what was going to happen and what was going on. They all fell to it and really pulled together. My conclusion is, very simply, that everybody was highly intelligent and highly skilled and highly friendly.

There is one thing I would like to say on behalf of the Canadians, and I think on behalf of the Americans, which hasn't been said here yet. In Canada we have the Working Group on Ice in Navigable Waters, and, although the Department of Transport has the immediate operational program, as everyone realizes there are very wide areas where research can be done. For example, in using bubbling systems, we've had to face the problem, if you can keep the Lakes open, is it really worthwhile unless you can do something about the actual locks in the canals themselves. There is the relationship between ice and climatic changes and other peripheral items that are on the edge of the economic problem. So we have this particular group, and it is very fortunate that it is tied in with the Canadian Committee of Oceanography and equally fortunate that one of the members of this committee is a member of the Defence Research Board and is the Scientific Adviser to the Chief of Air Staff. I mentioned his name - Dr. Arnel - because this is where the Canadian aircraft came from, and if you work in Canada you'll find it very hard to pluck an aircraft out of the Air Force no matter what you want to do. He presented the case for

Canadian participation in the TIREC Operation to the Chief of Air Staff, and the Chief of Air Staff accepted it wholeheartedly. I therefore, in front of the audience here, give my thanks to Dr. Arnel and Air Marshall Campbell, Chief of Air Staff, for the magnificent support they gave to this whole operation. I think the Americans will second me on that. Thank you very much.

Mr. Popham: We do indeed. I think it would be hard to add to what Mr. Harwood has said so I think this would be a very good place to break for lunch.

AFTERNOON SESSION

Mr. Popham: This afternoon we will discuss general areas of proposed analyses as well as possible analyses which might not have been planned up to this point. Then we will discuss the requirements for monitoring these analyses and, ultimately, devote the last part of the afternoon to a discussion of areas other than ice where satellite polar photography might be of use. This again includes applications to Oceanography, Hydrology, as well as to other earth sciences which might be noted. Also during this session we will discuss possible operational applications of satellite ice information which might be made in conjunction with any of the proposed satellite systems.

I'd like to begin by asking the Defence Research Board to bring us up to date on any analysis they may have performed since the completion of Project TIREC. I should like to point out that thus far the agencies involved in TIREC have been mostly concerned with organizing the data rather than attempting any analysis. We'll start with the Defence Research Board. Perhaps Major Taggart or Miss Dunbar will begin.

Miss Dunbar: Mr. Johnson said this morning that the Met. Satellite Lab. was acting more as a catalyst than anything else in this particular field. The Defence Research Board very often finds itself in the same position. Our function in this has really been more coordinating than anything else, and I would like to refer this part to Major Taggart of the Joint Photo Intelligence Center, who has been doing tremendous work on organizing the photographic data. Quite a lot has already been accomplished by them on interpretation, and I think he is the one to talk about it.

Major Taggart: I could summarize our situation at JPIC by saying that we are up to our armpits in photographs. However, we do have some proposed lines of analyses along which we are working. One of our first considerations is to prove to ourselves and others that we are capable of differentiating between cloud and ice in satellite photography. We also hope to produce a paper showing that this can be done.

In investigating methods of distinguishing clouds from ice in satellite photographs we have been very fortunate in having ice observers and meteorologists loaned to us by the Department of Transport. With their knowledge of weather systems and ice and our knowledge of photo interpretation, we have formed a preliminary conclusion that, because of certain definite characteristics of ice and of various cloud types, we may not have difficulty in distinguishing between the two. The meteorologists have also indicated that the accuracy of interpretation may be enhanced if reasonably up-to-date weather information is available so that they may know what type of clouds they might expect to find in a given area.

To the ice observer, the brightness characteristics (of the ice, which may indicate differences in concentration of ice age) and the delineation of ice boundaries in these satellite pictures seem to be pretty apparent; once you have had some experience looking at several of these photographs and examining these characteristics, they are much more evident.

With regard to aerial photographs, we initially propose to make mosaics from pictures collected on each high-altitude sortie flown, for direct comparison with the satellite pictures.

Briefly if I may, I would like to comment on one interesting sidelight to this operation which occurred when we prepared a mosaic of some of this high-altitude photography. For all intents and purposes this was an entirely uncontrolled mosaic. However, we did have to form some kind of control, so we simply projected the coast line from a transverse Mercator projection at the same scale of the photos, and laid as much of the photography to that coast line as we could. This photo run started over the Gaspé Peninsula, near the mouth of the St. Lawrence River, across to Anticosti Island. By simply matching picture to picture detail, we found that when we should have been on Anticosti Island we were actually going south of the Island. At first, this caused some consternation; we had used GCI control of the aircraft along flight lines, so that we knew the aircraft flew in a straight line from Point A to Point B. Yet the pictures came out in a curve. We then examined these pictures stereoscopically, and as we suspected, shear planes were very evident in the photography. The exposure interval between pictures was approximately 50 seconds, which was enough to indicate that the ice between Gaspe and Anticosti Island was moving or flowing out from the St. Lawrence River at a fairly rapid rate. Because of this we had to offset our photographs a little bit in making our mosaic. If you looked at the mosaic which is on the wall, or at other pictures taken on consecutive days you can see evidence of this whirlpool action where the ice appears to hang on the shore and twist as the current stream carries the mid portion out into the open part of the Gulf.

We also plan to use the trimetrogon photography to prepare a complete analysis of the concentration of ice, the presence of open water leads and other features of the ice. In the meantime, we have been experimenting with stereo methods of differentiating ice from clouds in the satellite pictures. While it does not work out mathematically, in the stereo projection the ice and clouds do not appear at the same level. This was determined by looking at two frames from the same orbit placed in a stereo projector. Obviously, if we can exploit the stereo aspects of this photography, it is another tool in the hands of the interpreter. I would like to point out, however, that this stereo effect may only be true under certain conditions. At present, we haven't examined this in further detail but we intend to.

The Department of Mines and Technical Surveys has also indicated an interest in satellite photography and has ordered the photographic coverage and TIROS pictures from us. We will supply them this information and they will also be doing some analyses. The National Research Council has also expressed interest and has been supplied with certain basic publications. We will also be giving them pictures.

Mr. Popham: Would anyone like to ask Major Taggart any questions?

Mr. Poulin: My name is Poulin from the Cold Regions Research Engineering Laboratory, U. S. Army Corps of Engineers. I would like to ask Major Taggart whether he would be able to say at this point whether or not experienced ice observers or meteorologists have had better success at distinguishing clouds from ice.

Major Taggart: The preliminary assumptions that we made in our study were arrived at by an ice observer, a meteorologist and a photo-interpreter sitting down and examining the photographs. With this type of team work we can with few reservations say that this is ice and that is cloud. It becomes more a probability rather than a possibility using a team concept, and I think we can be 90% correct.

Mr. Popham: Partly in answer to your question, Mr. Poulin, I would like to point out that a year ago last January we coordinated visual ice reconnaissance flights over the Gulf of St. Lawrence with TIROS II passes over the same area. The TIROS II pictures were prepared in a mosaic form and presented to three or four people who had been working at the readout stations preparing nephanalyses. We asked them to identify the ice and clouds, note the cloud type and sketch their results on acetate laid over the mosaics. We then compared their analyses with the observations. For the most part, they had no idea where the ice was, or what type of ice it was; none of them had any background training in ice observing. They concluded they were looking at alto-stratus clouds, when actually the area was known from the reconnaissance to be cloud-free.

As a result of this and later exposure to satellite ice photography, these same people had little difficulty in differentiating between ice and clouds in TIROS IV pictures obtained along the eastern Asiatic coast. Perhaps this will serve to illustrate how experience in looking at satellite pictures of ice will help in the future.

Major Taggart: May I add something to that, Bob? I don't think that initially any photo-interpreter, meteorologist or ice observer, when he sits down and looks at these photographs for the first time, can analyze them. By pooling their efforts, or in effect by picking each other's brains, they can effectively contribute to this analysis. What the brain comprehends the

eye can see, and conversely, what the brain doesn't comprehend the eye doesn't see. For anyone to start interpreting TIROS pictures without this type of correlating information, it's like asking someone to interpret air photographs for military information. They don't know what a gun looks like on the ground.

Mr. Poulin: That was admittedly a leading question on my part, because your results and what you say seem to indicate or verify our philosphy of photo interpretation.

Mr. Harwood: As Miss Dunbar has pointed out, the Defence Research Board is a catalyst and we do have some funds for both grants and contracts. Unfortunately, Professor Cameron is absent at the moment. We would like to bring him in and ask him what he would like to do.

Yesterday we telephoned McGill University because they have a Department of Meteorology and are obviously competing with Wisconsin and Alaska. Therefore,we thought we would ask them down here. Let's ask them if they have any ideas of what they would like to do with this material, having seen some of it this morning.

Mr. Popham: They were called down here rather quickly. Do you wish to add something now or would you rather wait until a little later on?

Professor Bird: Yes, I would like to leave it until a little later on. I do have some ideas, but I am not sure if they are totally relevant at this point.

Professor Boville: From my first impressions, I can visualize a number of research projects that could use these data, providing they are readily available and their interpretation is not misleading. If clouds, ice and snow can be clearly differentiated, the data would be of major importance in large-scale meteorological studies.

Major Taggart: I think you've got a harder problem differentiating snow from clouds than ice from clouds in the TIROS picture.

Mr. Hansen: I have a question for you experts who have been looking at TIROS pictures. Is there any kind of ice that is particularly easy to identify? Is there a type of ice that is hard to identify? I think we've been talking about pack ice. What about shelf ice, icebergs or melting pack ice? Does anyone care to comment on that?

Major Taggart: Well I'll just have a preliminary shot at that one. We haven't investigated this in any detail whatsoever but we think on one of the orbits we can see a little clump of ice setting off the northeast corner of Anticosti Island. We haven't as yet gotten into the aerial coverage of

that area to see if there is actually ice or not. I'm reasonably certain it is ice and not cloud because we've got sequential photography which shows this in the same spot on two different orbits; it is about the size of an iceberg.

Miss Dunbar: I think that as far as shelf ice goes, no problem exists. You know it's there; it doesn't move around and it's more or less a land feature. Very large icebergs I suppose might show up with the present resolution of photography. There were in fact a lot of icebergs off the east coast of Newfoundland at the time of this operation. Is this correct, Bill Dotson?

Lt. Dotson: No Miss Dunbar. There happened to be very few icebergs there at the time.

Miss Dunbar: Well, we saw some on the fifth.

Lt. Dotson: Still there were very few.

Miss Dunbar: Oh. Well in any case they didn't show up. I think most icebergs are too small.

Lt. Dotson: Can I answer Mr. Hansen's question about ice age? We have aerial visual reconnaissance over the area between Old Post Point and Anticosti Island, taken in conjunction with TIROS II. In the satellite photos we were able to detect tonal gradations in the ice; using this as a clue we may eventually be able to distinguish the type and tell basically what the age or stage of development of the ice is. I don't think this will be too much trouble. Eventually, we will be examining satellite pictures where we have visual reconnaissance showing large floes that are in various stages of puddling. This is already apparent in the TIROS II photographs.

Mr. Popham: We have been able to observe young and winter ice in the Gulf of St. Lawrence but as yet haven't observed any polar ice.

Mr. Harwood: I would like to step back in for a moment and rephrase my statement again now that Dr. Cameron is here. The DRB, as Miss Dunbar has said, is a catalyst in some of the studies that may go on in the sense that it can give grants and contracts. We've asked the McGill people behind you what they would like to do since this part of the agenda has to do with how the material could be analyzed. They said they may be able to stay to the end of the meeting and restate their case again, but I know you have some strong ideas which you'd like to put forward. You might present them on behalf of yourself or the DRB or anybody else you can get money from.

Professor Cameron: This is, I take it, how we use all the photographs? I feel very strongly that they should be worked up into a map showing, not only ice cover, but ice movement. The velocities of the ice movement can be determined and plotted. So much for the straight photography.

With regard to the radar photography the same thing can be done, though I must say that in radar photography the quality varies so much, even from plate to plate, that one of the things we should concentrate on would be, talking to the radar people and telling them to get straightened out. If they can give us consistently the quality of photography that they produce every fiftieth picture, we would be very happy to stick to the job of mapping the ice from the radar photography alone. A very broad statement, I know, but that's the way I feel about it.

From my own angle, our group down east would like to take on the job of converting some of this radar photography into maps which would figure it out. I think there is a definite relationship between the radar pattern -- what you see in the radar picture -- and the type of ice and the movements of the ice as shown in radar and in the vertical aerial photography. At the moment, I'd like to dig in my paddle backwards and say I may think of something else before the end of the meeting.

Mr. Popham: Kirby, was your question answered to your satisfaction?

Mr. Hansen: Yes, Bob, it was.

Mr. Popham: Next, I would like to call upon the Department of Transport to indicate what they have done or plan to do.

Mr. Archibald: I might just say that we agree very strongly with Major Taggart that this has to be initially a cooperative affair among the photo-interpreter, the ice observer, and the meteorologist. Essentially, it probably is mainly a meteorological problem to determine a sort of key, but we cannot do that without the assistance of all three. We've had just a preliminary study of this; one of the men from our research and training, Roy Lee, and Tom Kilpatrick, our senior ice observer, were part of Major Taggart's group. As a preliminary step, certain selected weather conditions have been taken with certain weather maps, for example when it's clear and when there is a certain amount of cloud. I think that right at the moment it's too early to say anything, definite, but you can see through the cirrus without any difficulty unless it's dense. The alto-stratus clouds present a barrier, but the meteorologists can usually distinguish cumuliform cloud types with their experience. The problem of establishing a key for identification is still in the making, but we feel that with careful selection and the supplementary

information contained in the upper air reports and upper air maps, perhaps the 700- and 500-millibar maps, we may be able to come closer to arriving at some relatively easier method of identification.

Mr. Popham: Would anyone care to ask Mr. Archibald any questions? If not, we'll ask a representative of the Navy Hydrographic Office to continue on this same subject.

Mr. Yotko: Our objectives are very much the same as those expressed by the Canadians. One of the things I want to bring out is that we are not too optimistic in that TIROS IV does not have the resolution of TIROS II, which demonstrated the potential of satellites and started us on this study. We accordingly had to downgrade our objective a little but we are shooting for establishing some key in recognizing ice versus clouds and delineating ice boundaries. Associated with the project, we obtained some radar information which in conjunction with the photography may be of value. We feel perhaps that a purely meteorologically inclined satellite does not provide us with data of sufficient accuracy of resolution to be utilized operationally and for ice research. I really feel that this may be one of the factors which will lead us to actually establishing the ice analyst's requirements in the satellite field. Our group's objective, of course, in the final analysis is to do two things: (1) provide operationally useful information immediately and (2) to do some more serious work which will provide data for developing prediction techniques. Basically, we are trying to school the ice analyst in prediction techniques where he can readily provide the operational data. The team concept, I believe, will have to be reserved for the more serious study. We are trying to school the ice analyst to adopt different ice interpretive techniques which will allow him to extract immediately data which can be sent to people who need it operationally.

Major Taggart: I hope no one took my remarks literally when I said we were quite happy with the type of photography that we were getting from TIROS because I concur with what you said. What we are using to date we are happy to get, but we also believe that we want a narrow-angle camera to give us more detail, increased resolution, etc. I would say, however, that we think it is feasible to do a certain amount of ice reconnaissance from even TIROS IV.

Mr. Poulin: Have you been doing much work, Major Taggart, with just a straight-forward delineation of cloud and ice from RC9 photography?

Major Taggart: Here I don't think there is any problem whatever. In the RC9 photography it's purely a matter of putting it under the stereoscope and what is up are clouds and what is down is ice.

Mr. Poulin: In every case?

Major Taggart: In every case! I don't think there is - and I think Professor Cameron will agree with me on this -- I don't think an experienced interpreter would even momentarily be confused with what was ice and what was cloud. There may be a reservation here where you have some crusting just starting; then he might confuse that with open water for a minute or two.

Mr. Heathfield: May I say something? We've been hedging around radar -- it's almost a dirty word. People have mentioned it but nobody has really shown or said much about it. We've also touched on interpretation. Perhaps we should diverge briefly from TIROS onto the problem of interpretation, the values of various intensities and shapes on a radar scope and the reliability of the operator who's looking at those shapes. Eventually, you're going to have somebody looking at the TIROS photographs who's not really a highly skilled or professional man -- how are you going to train him? How are you going to teach him to do this function? This, I think, is what we're gradually edging toward. Our primary function -- I speak historically -- was to try to train radar operators to find anything on radar while flying over the sea; cloud or any of our other little friends. I found, by subjecting a group of, say 200 operators, to standard phenomena, that out of 200 contacts one had 100 interpretation, i.e., 50% were missed. About 25% that were false were given as extra. It seemed that no matter how we ran the trial again, showing people small contacts, white contacts against a black background, with a noisy environment or just a white noisy environment the reliability of the operators who read this out was about one in four. So it looks as though somewhere along the line we've got to fall in and take very seriously Mr. Harwood's suggestion that we have to improve resolution techniques in order to boost our readout capability. I think that we should do it not only from the radar standpoint but also from the TIROS standpoint.

Professor Cameron: It seems like I've been on the pad and holding for five minutes. I think that Major Taggart put his finger on something that should be looked at very seriously, and that is the matter of trained interpreters. I heard the word "key" mentioned twice, and I winced each time. It is not possible in my opinion to take an untrained man who doesn't have any background in the science and train them by subjecting him to a "find it in the clutter" sort of technique. It is not merely a matter of improving resolution all along the line; we've got to improve the training of the people who are going to do the job if this is going to become a standard part of the technique of weather forecasting, ice forecasting or any other thing connected with this work. The people who are going to do this work have got to be trained; they have to do this work continuously until they become real experts.

I might just say there is one thing that hadn't been mentioned here yet -- it may come in later -- that is, the analysis of cloud movements from these photographs. It's going to take some real experts to carry this out.

Dr. Widger: I started out to say one thing; now I'd like to say two. About four years ago Mr. J. J. Aiken and I made some mathematical calculations about the possibility of deducing cloud movements from a satellite.* The results were rather discouraging, and I am not sure that they will be any better now. I mentioned this for the benefit of anyone who may be thinking about looking into this further.

However, what I am really interested in is representing the organization that will have at least part of the major responsibility for what sensors go on the satellites. I have been listening to this talk about improved resolution. I gather that there are times when you want sufficient detail to see breaks in the major ice packs, and times when you are not interested in the individual ice floe but rather what is representative of the gross area.

As I indicated earlier, we hope that within several years we will be able to resolve something on the order of a tenth of a mile, using the electrostatic tape camera. Obviously, it would appear to be very impractical to observe the whole world using this camera and resolution. In addition, every time we increase the resolution our problems go up by the factor of the square of the improvement. Therefore, we would like some real hard information as to what is really required rather than going ahead and building something which we would find out later we didn't need.

Therefore, we would certainly hope that the work which you have been doing would lead to some study whereby you would use your high-resolution photography and degrade it artifically to determine what an acceptable resolution would be.

Mr. Harwood: As you can see by the discussion so far there is a limited amount you can say with regard to ideas of what to do with these photographs. There is a very simple reason for this, this program was thrown together without a program. This is very odd but that, in effect, is what has happened. The opportunity to take these observations was presented, and you are obviously not going to turn down such an opportunity. The program therefore had to develop contemporaneously with the flying and satellite photography. Fortunately, since photography stores this, in the overall picture, this is not too detrimental for the future.

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*Aiken, J.J., and W.K. Widger, 1960: "On the Possibility of Measuring Cloud Velocities from a Satellite," in Contributions to Satellite Meteorology, GRD Research Note No. 36, pp. 47-62. Also summarized in Widger and Fowart, 1957: Bul. AMS, 38 (9) 521-523.

Mr. Winston: There is a lot of detail in the TIROS pictures (even wide-angle pictures) which could answer certain types of problems. You are going to have these pictures on a fairly regular basis even with TIROS, and it will be much better as we get into the Nimbus series. To what problems can you apply these data to? I haven't heard anything here for example, about keeping track of the ice limit across the Atlantic or Pacific.

Mr. Harwood: As far as we in Canada are concerned, I can almost guarantee that's one thing they will be doing once we start getting the Nimbus photographs in.

Mr. Winston: Is there an operational way of using it, that is of getting the data to the people who can use it right away?

Mr. Popham: We are planning on discussing operational applications later this afternoon.

Mr. Harwood: Now the second part of your question I'll share with Mr. Markham. Having actually pushed the throttles for nearly seven months on a U. S. Coastguard icebreaker as attached officer, I know something of the actual handling of convoys and moving ships. With the photographs that came from TIROS, and Mr. Markham can say either yes or no as to whether I might be right or not, the information that is now available from these is sufficient to be able to route ships into the Gulf on a 75% certainty that you will or you won't meet ice in these areas. It will not give you the 25% that you will require in specific refined approaches -- in other words -- if your transit route is 25 to 30 miles wide those photographs there would give you enough information to route into and out of the Gulf. When approaches have to be made to ports and harbors, or to channels which get narrower in going up the river, the information derived from these photographs is insufficient. This is the place where the detailed ice reconnaissance and the ice forecasting systems of DOT are, I think, going to be essential for a long time to come, because I don't think this type of information will be available from satellite pictures.

Mr. Winston: Yes, it is easier to use this aircraft reconnaissance near the harbors, and then you can cover the bigger areas over the ocean with satellite data.

Mr. Harwood: If, for example, next year the DOT Marine Routing Captain and DOT Ice Center will get those photographs, they can probably plot 75% of the shipping routes in and out of the Gulf.

Mr. Markham: I would like to discuss the matter of resolution a little more. I feel that the .5 mile resolution that Nimbus would provide is about what we need as far as ice is concerned.

In support of ship operations, however, we will still have to contend with clouds which would, of course, obscure the ice from satellite altitudes. If ships are moving through the Gulf of St. Lawrence on a cloudy day, we will still have to operate and to do this we will need aircraft.

Helicopters operating from icebreakers have been used very successfully for ice reconnaissance. It may therefore be practical to consider basing helicopters at the major ports. The range of the reconnaissance flights could be reduced, while the frequency could be stepped up.

With regard to picture quality, I have the impression that the quality of Nimbus pictures will fall in between TIROS II and IV. If this is right, then I think we should be able to direct shipping right up to the harbor on the basis of these data.

Mr. Popham: I think one of the points that we have made here is the fact that a satellite with a resolution such as that from TIROS IV could be used operationally to provide at least wide-scale surveillance, but not the close tactical support which might be required by ships at present -- is this right?

Mr. Harwood: Yes that is quite right. The economical importance is evident if you amortize the cost of one icebreaker and add on the operating costs. The savings amount to something on the order of 1.6 million per annum just by the reduction of this one icebreaker, and this certainly is an appreciable sum of money.

In addition the insurance companies are another factor to consider. Lloyds for example which insures most shipping has zoned the world. They put penalties upon certain of these zones and these penalties do increase from zone to zone. The penalty zone for North America starts south of Halifax in the wintertime and of course extends farther north. Twenty years ago I believe the penalty for Hudson Bay was ten shillings per hundred which is ½ of one percent. Just by putting icebreakers there, improving the service and for the last few years doing ice reconnaissance, the cost has dropped to one and six per hundred. So as you can see, there is an intangible which affects all the shipping companies which is not financed by the taxpayer, but nevertheless is there.

Mr. Popham: Dr. Widger?

Dr. Widger: A couple of comments -- (1) the question of what we will see on Nimbus relevant to what we see on TIROS. As far as resolution goes,

the statement is right in that the resolution will fall somewhere between TIROS II narrow angle camera and the IV wide angle camera resolutions actually a little closer to TIROS IV. However, let me point out that both absolutely and relatively we hope to have considerably better grey scale, for whatever this is worth, in the interpretation of ice type. Another factor which I think needs to be taken into account in discussing resolution is, I presume, a relation between the time scale of the phenomena, and the resolution distance you are concerned with. If you are only going to see a feature once a day, there is no point in getting down to the fine amount of detail that you might need if you were going to see this same feature once an hour, because the time rate of change then takes place so rapidly that the additional refinements aren't worth it.

Mr. Popham: Mr. Yotko wishes to add something, I believe.

Mr. Yotko: I just wanted to make a statement regarding the application of satellite data. People have been talking about the TIROS-type satellite, and so far as the U. S. Navy is concerned TIROS is practically nonfunctional. We are waiting for Nimbus, of course, in that our basic requirement at the present time is in the Polar Basin. The application to which we hope to put TIROS data is in perfecting prediction techniques which we feel are the most useful operational information you can give to a command or shipping organization in that you will be able to tell them what condition to expect in N number of hours or days. In order to develop predictions like this the analyst must understand the behavior of ice. Further, in order to be able to do this they must be able to synoptize it. We have never had sufficient data where we could adequately synoptize the ice conditions over a good portion of the earth in order to understand the relationships between the other environment and the ice. This is the major breakthrough that we hope to make utilizing satellite data. Again, it will do us no good to merely observe ice in the Polar Basin in that we know right now that ice is there, so this is no forecast. I must be able to see some of the qualities of ice to understand what goes on in the Polar Basin. That's why this pitch for resolution; I must see the details of the ice canopy and not just the fact that there is ice.

Professor Cameron: Some questions for the people who are going to put up Nimbus. Are the successive strips of pictures from the orbit going to overlap at all laterally?

Dr. Widger: They will, and particularly in the areas you are concerned with. We expect a slight overlap orbit to orbit even at the equator. Within a single orbit we will get overlap between the pictures forming a triplet of about ten percent, and also from picture to picture going forward. As you move up toward the Pole, I would guess at about 70°, you begin to get to the point where you almost see things every orbit, illumination permitting.

Professor Cameron: Well the point is -- will it be possible to stereo the successive passes of the same area? I have in mind particularly the Gulf Stream. From the pictures from one orbit to the next, will they overlap sufficiently to give you stereo?

Dr. Widger: I am not enough acquainted with the angular requirements on stereo to want to comment on that. This would have to be looked into more detail.

Dr. Glaser: Destabilization is going to give you some peculiar effects. You no longer have parallel lines to view.

Mr. Wood: I would like to make two or three comments. One, we've been discussing what Nimbus is going to do. I'd like to point out that Nimbus A, or the first one up, is going to be a little less than nominal. I would like to correct Dr. Widger I think there is going to be about 1° gap on the equator on A. It's going to be a 500 mile orbit until they change it rather than 600, so that most of the comments made here on Nimbus have been in connection with the nominal Nimbus rather than Nimbus A.

Knowing nothing about ice, I will very bravely make some comments on the discussion to date. My reaction to what you have presented is that with the results of the TIREC data observations, one thing you can come up with is to define a number of scales involved. I think we have discussed everything from the order of 100 feet or less up -- Polar Basin size.

Two, once you have defined the scale you could then specifically determine which of these scales could be observed with a Nimbus type satellite. With this you could determine what you can or cannot handle and what you need to handle by another method. With another method of observation you have two choices -- that of recommending a finer resolution camera that might be put aboard a Nimbus satellite, or taking it by some special aircraft observations in a local area. You would design your operations as the situation warrants it, timely and practically.

As far as Nimbus is concerned, when we start talking about Nimbus I -- correct me if I'm wrong here, Bill -- the first four "Nimbi" are going to be approximately the same because of the lag in development of equipment and so forth. If we start talking about new equipment aboard and modifications of existing systems on Nimbus, we are talking about something like Nimbus 5 or later. There will be modifications between now and launch on Nimbus A, I am positive, but this will only be the crash emergency type where a system fails and we can't get off the ground without modifying it. It takes a long time to redesign, put something

aboard and get it up, so we are talking about things now that are two to five years away when you are speaking about finer resolution. I just want to be a wet blanket in trying to bring things down to a practical level. I am inpressed with the details that you have gone into on this experiment. I think you will get a lot of valuable results out of the operation. Mr. Harwood's comments about the value of the observations and the practicality to the northern nations particularly impressed me. I think it is something that ought to be developed and I think we ought to keep the right time level or time sphere when we talk about what we should shoot for.

Dr. Widger: However, Paul, I think it is very important to keep this in mind. Admittedly you are right, in that the earliest we could expect any appreciable improvement in Nimbus i.e., such things as the electro-static tape camera with one-tenth mile resolution, is the latter part of 1964 or more likely 1966. This is for one picture per orbit. If you want to get global coverage or the large area over the Poles, than add another year or two beyond that. However, this very time lag which Paul has emphasized and I am re-emphasizing is a reason for needing the information as to what resolution you people want just as early as possible, so that it can be fed into the developments of the preprototypes and prototypes and finally into the flight models.

Mr. Harwood: That point is well made. The Chairman hasn't gone through all the people here but practically everyone has said something. The major point, as I see it, is simply this: you have piles of photographs and radar pictures at all levels and two years to analyze them. The things that ought to be considered have been stated very clearly by the NASA Meteorological Representative here, Dr. Widger, and that's simply to use the material to establish your criteria. Quite obviously the criteria that the U. S. Navy wants in the Polar Basin is going to be somewhat different from the requirements that are needed for the shipping groups. But we have two years to resolve it and get the ideas out. If everybody in this room sits down and uses the material that's available, you'll probably get your answer.

All of the material is available. You can get it straight from the U. S. Navy by asking, and all of the Canadian data by writing to the Photo Establishment at Rockcliffe or the Defence Research Board in Ottawa. It will all be in the report. Anyone can get all of these photographs to study.

Mr. Popham: This is precisely what this conference was called for -- to make the people who have been doing ice research aware of what future satellite developments will be, and conversely, to let NASA know that people

are interested in observing ice from satellites for several purposes. We realized that this would be a rather long-term program. We've gathered a lot of information during TIREC, and we realized that we would have to sit down and analyze this quite thoroughly before we could even attempt to make any recommendations to an organization such as NASA for any changes in existing or proposed satellite camera system. I think the exchange of information has been most valuable, even to this point.

Mr. Kowalczyk: We've heard from the research men, the geologist, the weather man and the ice man, but we haven't heard from the photogrammetrist. He has now entered into the picture. We mentioned TIROS photography, especially resolution. What can we do with resolution stereoscopically? I'd say that right now not too much. Instrumentwise, we cannot, because the photogrammetric gear is not on hand. In two years' time perhaps we would, if we were to put some effort, time and money into it. With visual photography we can make an orthographic projection which would give you straight line measurements. The equipment is available and on the market. We can use image enhancers, perhaps marrying image enhancing with visual photography and the TIROS pictures.

To answer Professor Cameron's question about stereoscopy -- no, you'd have to have a terrific instrument. I can visualize an instrument such as the M-2, enlarged maybe three or four times for the base-height ratio. Nimbus is almost a vertical shot, having it on the oblique would give better parallax.

These are the things we would like to be thinking about and upon which we will eventually make recommendations. I can't see any reason why your shot can't be put on the oblique for stereo, instead of a straight vertical, because you apparently have no parallax. You have only a five or ten percent overlap and there is not much you can do with that.

I would like to call on Mr. Helava to see if he would say something about this. He is the photogrammetrist on the Canadian side; let's see what he has to say.

Mr. Popham: Dr. Widger, could you add something to what Mr. Kowalczyk said?

Dr. Widger: I think that any immediate discussion about obliques on Nimbus other than what we have with the trimetrogon type of arrangement would not be worth talking about on such short notice. Most of the meteorologists seem to want to look straight down as much as they can. However, this is another requirement which should be looked into. It could guide future developments over the next decade if there is a real value to the stereo which

would justify the complexity of it. As we get into larger satellites and rockets with greater lifting power, perhaps we could consider adding cameras that would look 45° ahead and back, giving us a stereo capability. But here again you are talking in terms of millions of dollars of development and of operational spacecraft and you've got to know these requirements are really usable before we are apt to fly such a camera complex.

Mr. Helava: My name is Helava from the National Research Council of Canada. I'd like to start by saying that I agree completely with Mr. Kowalczyk, that is, the TIROS photographs as they are now are of very little value from a photogrammetric point of view. It's quite obvious that the quality will improve, and with improving quality we'll get photography which is much more useful for photogrammetry.

However, there is one question that I have been asking myself practically all day. Although the TIROS photographs are of very little photogrammetric value as we are accustomed to right now in photogrammetry, there is still some photogrammetric information on them. As soon as you can identify details on a photograph, potentially you will also be able to locate these details very accurately---at least to an accuracy which is compatible with the identification accuracy and scale of the photograph. The only thing that one has to do is to make sure that some basic photogrammetric requirements are met, and I don't think that this would involve very much money. It does involve knowing what kind of cameras we are dealing with. Not only the camera but the entire transmitting system should be calibrated so that we know at least to some degree what the distortions are, what the focal length is, and where the principal point is exactly on the photograph. We could then make full use of the photographs from the photogrammetric point of view There are some simple photogrammetric techniques that could be applied immediately. I'm thinking in terms of rectification--optical or electronic--which would make it possible to locate and identify these details. So my question is, are there any plans to have these cameras calibrated accurately?

Mr. Popham: I believe Dr. Glaser may be able to answer your question right now.

Dr. Glaser: I would like to speak about several things which have just been brought up. There has been a continuing attempt to improve the calibration. It is not an easy situation because of the fact that we have a satellite up there which can degrade as time goes by, and nobody can get up there to twist the knobs. Accordingly, calibrations have to take into account the fact that there is no point in very good initial calibration because it won't be preserved. Calibration techniques have improved, thanks to various people -- NASA, the Weather Bureau, our own efforts, and those of RCA who build the instrument.

Photogrammetry and photogrammetric techniques of specialized types have been constructed for meteorological purposes. Now there are some basic differences between the meteorological requirement and the ice requirement. In meteorology the cloud does not stay put very long, so that in the length of time it takes us to handle the data (there is usually about a 30-minute delay in the storage of the data on board the satellite from the time the picture is taken till the time it becomes available on the ground, and perhaps another hour before we have done everything to it that we want to do) an hour and a half or perhaps two hours have gone by. During that length of time the cloud will have dislocated itself by anywhere from 30 to 100 miles. This means that our accuracy of location does not need to be very great, but on the other hand it means that our speed of data handling has to be as great as it possibly can be.

And so, operational methods have been developed for crude photogrammetric techniques that work fast. Right now, in the TIROS operation at Wallops Island and Point Mugu, a digital computer draws overlay grids with latitude and longitude lines which are based on orbital elements and careful assessments of the attitude of the satellite. These grids are actually prepared in advance of picture taking, as we have that much confidence in our ability to forecast the orbit and the attitude of the satellite. The grids are drawn on a plain piece of white paper and the picture is simply projected down on the paper when it becomes available. If the picture was taken at the time it was supposed to have been, these grids fit surprisingly well. The characteristic error is about 20 miles. This error is not of any great significance to the meteorologist, while the ice observer might find it well outside acceptable limits.

Well-advanced techniques are also available for a much closer refinement. They take much more time, but Dr. Fujita of the University of Chicago has developed a technique which will permit the location of items and reconstruction of a map to one scan line or perhaps two scan lines. I put the accuracy measure in that form because of the variable size on earth of scan lines depending on the angle of obliquity at which you are looking. This means you are dealing with errors now down to three miles if you happen to be looking straight down. These techniques are available right now to any of the ice researchers who are willing to put in the time and the effort. They are totally dissimilar from classical techniques of photogrammetry because we are taking advantage of the dynamics of the satellite itself. The satellite flies in an orbit that has certain specified physical characteristics and can't bob up and down or wiggle around as an aircraft can. Space resection has been quite unsuccessful. Space resection mixed with the fact that the satellite has to follow in some sort of a definite orbit is considerably more successful. Techniques which accept the orbital position of the satellite are supposed to be by far the most successful. They are available right now.

Mr. Popham: Mr. Helava.

Mr. Helava: Just one comment -- you said the calibration doesn't keep. Is it possible to add a reseau (network) in the camera so that it would superimpose a grid on the photograph? On that grid you could then see what kind of calibration changes you've got.

Dr. Glaser: In TIROS there are certain practical problems associated with this. You're aware of the crude fiducial pattern we have in the TIROS pictures now. It has to be appreciated that the active surface of the vidicon is a quarter-inch square. The pattern has to be etched on the surface of the vidicon. Any mistake in the pattern calls for the discarding of the vidicon, and mind you, trying to etch down to those sizes is an extremely difficult operation. Accordingly, we've had to settle for what we can get.

Now the technique that Dr. Fujita has developed is very interesting in that it makes use of the accidental calibration marks caused by imperfections in the vidicon screen in the quarter-inch square. He uses the pictures that were taken on the ground, of the calibration target, locates every one of these tiny little blips, which always reproduce themselves very nicely, and keeps track of where they should be with respect to the original focus chart. It's not an easy operation but one which can be learned and operated by someone who is willing to put in the time and effort. Frankly, I haven't been.

Dr. Widger: I wonder if maybe Paul could give us an idea of what they are planning regarding the fiducial marks on the Nimbus. I'm not up on it myself.

Mr. Wood: There will be twenty-five rather than the five that are currently on TIROS. There will be a five by five matrix.

Dr. Widger: Right.

Mr. Popham: If there are no more questions at this point, I would like to begin with Part D under Agenda Item 1.

From the ice standpoint -- I speak for MSA alone -- we have, as Dave Johnson indicated this morning, only served as a catalyst. We particularly do not have any obligations or commitments to do extensive research in MSA on ice. We will function mainly by providing whatever assistance or information we can to the people who are doing ice research and assist those people who may be concerned with the operational utilization of TIROS and Nimbus ice data.

We do have people here from other branches of the Weather Bureau; Hydrologic Surveys, Extended Forecast, the Polar Meteorological Branch--this is perhaps their first major introduction to the satellite ice program as it has been conducted at MSA. We've been trying to present to them, as well as to others, the type of information that is available from TIREC, and indicate what is proposed in the meteorological satellite program so that they may analyze these data in their respective offices and come to their own conclusions relative to the operational or research value of satellite observations. Our part in the TIREC program will now consist largely in compiling the data collected during the project, and putting it in a useful form so that further research can be conducted.

Dr. Glaser: Is there any geographical referencing on those pictures?

Mr. Popham: Yes, there is. Most of these pictures were obtained very nearly from the vertical. It would appear that gridding these pictures by hand, using the geographical points for location, may be the best gridding procedure to use initially. The ice distribution can then be plotted.

Mr. Poulin: Are the grids going to be magnified?

Mr. Popham: They can be.

Mr. Poulin: Those will be available, won't they?

Mr. Popham: They'll be available. Right now, however, they are only available for TIROS I, which stopped taking pictures about 78 days after launch on April 1, 1960. It will be a little time before we catch up for TIROS IV. I'm speaking now of the most accurate grids that can be prepared. For analysis of TIREC information I don't believe it's necessary to wait for a grid, with the good landmarks which are present.

Mr. Poulin: Would it be possible to get certain selective grids?

Mr. Popham: Yes, once the grid code has been prepared.

(BREAK)

Mr. Popham: The rest of this afternoon will be devoted primarily to discussing two subjects: possible operational applications of data which may be obtained in conjunction with existing or proposed meteorological satellites, and other areas of interest where research might be done using either Project TIREC data or data to be collected. I'd like to start with operational applications first and ask Dr. Fritz and LT Dotson in particular for their comments.

Dr. Fritz: I've been following with a great deal of interest the work that Dr. Wark, Mr. Popham and others have been doing over the past few years starting with TIROS I, II, and now IV. It seems to me that it was quite clearly demonstrated this morning, I believe by Mr. Harwood, that to a certain extent we already have the capability to utilize satellite ice pictures for practical problems. In my association with the program, I've had the uneasy feeling all along that, while everybody agrees to this and realizes it, nobody is actually doing anything to bring this utility into such a position that people could actually do something with the data.

Now, the case of TIROS I, Dr. Widger was very influential in emphasizing, even before the satellite was launched, the need to be prepared to actually utilize the data which might be acquired from the satellite, in order to get it distributed to the people who might be using it, even though we really didn't know what was going to happen. As you know, this has grown steadily until now it is practically a well-established worldwide procedure, although there are still many things to work on to improve methods of data dissemination. This very important step has to be taken in the case of the ice pictures, and my question is -- who is going to go down to the readout station to analyze the pictures and interpret the ice information which is available to an ice expert and to arrange for getting that information into the hands of at least one center which is responsible for the utilization of ice information? It seems to me that we have already reached the stage where that could be done. It should be done, and the responsibility there would lie in the hands of the United States and Canadian services who have the capability to interpret pictures and to get the ice information which is required. Those people should send representatives to readout stations, and mechanism should be set up to relay that information at least to one or two key centers, and then those centers might perhaps relay them further. The important thing is to get started. I think that one shouldn't wait for Nimbus, which would give you daily coverage, but utilize what is available now in those times and places when it is available. What I would really like to see is a discussion, perhaps even here, of who would do what to realize this program.

Mr. Popham: May I call on Mr. Yotko?

Mr. Yotko: I think it's worth commenting that we have several problems that deter the application of this information in an operational way. The basic problem is revealed by Project TIREC, which indicates that we don't know what we are looking at. There is a danger in transmitting data when even the environmentalist doesn't know what it is. It's hard to give this to an operator and say use it. It is presumed that after TIREC or some subsequent series of experiments that the environmentalist or the photo-interpreter will understand what he is looking at. Then you may have some operationally useful data that you could transmit to the operator. The other problem is that essentially the TIROS series doesn't get us very much ice information. It views only a very small portion of our area of interest. It may be useful for St. Lawrence Seaway operations for a short period of time, but it covers very few areas of interest to the U. S. Navy. As I recall, with TIROS IV we initially had to wait for a favorable period of light. We began obtaining data in March and ran out of ice sometime in April, a very short period of time. Accordingly, we have begun thinking about utilizing the data operationally but as yet we have not started implementing the idea since the usefulness of data and the sources of the information are quite slim.

Mr. Popham: Mr. Harwood?

Mr. Harwood: I go back into past history to answer Dr. Fritz, and I I may have drawn on Mr. Markham. We said the history of ice in Canada is relatively short, as Mr. Markham, Mr. Archibald and Miss Dunbar sitting in the room know. You will remember that five years ago, to set up the organization of the D. O. T. that we have now in Halifax took a great deal of persuading. Some of the tasks that they were given and their terms of reference were then the only sources available, and these looked almost hopeless. Gradually, a program has been developed in Canada which is a cooperative one, involving all sorts of people. It involves the oceanographers, actually the East Coast Working Group, the D. O. T. on the climatological and meteorological side, bits and pieces of the Air Force, Mines and Technical Surveys and so forth. This task of research into ice conditions of the Gulf of St. Lawrence at this stage of the game was broken down into bits and pieces so it could be picked up by various departments. As a point of fact, it has been picked up at a great speed, and in a sense the capabilities of the D. O. T. Meteorological Branch, the capabilities of the oceanographers in the East Coast Working Group and all the other people have increased so rapidly that they are rather in a sense overwhelmed by the material available. We now have another technique thrown on top of us. One

of the things that we have to do is to survey ice through clouds and darkness. We are now getting into a joint operation, partly with D. O. T. and the D. R. B. on infrared. We've put up the ideas of side-ways-looking radar, and the Air Force has been looking at that. We have to start to sort them out, and now we have this one on top of us. As has been pointed out further down the room,at the moment you get data for four days and then it disappears for five weeks and then it comes up again. My own personal feelings are that we should aim for Nimbus, because more than likely there will be a readout station in Canada for Nimbus. The techniques of actually getting these data into the Maritime provinces and to the ships would probably be a good deal easier. At the same time, I would also like to recommend that Mr. Archibald support Dr. Fritz's idea that somebody should be down at the readout station next winter when the next satellite goes over this area, even if he's down there only five to seven days at a time. At least you've got one man with an idea of what he can get out of the readout station. He would be able to give ideas to the D. O. T. and help them in plans to use the material they are going to set out of it at the Nimbus readout station at Newfoundland and just outside Fairbanks, Alaska.

I would like to take issue on one point. I don't think we are going to get too much data out of TIROS because of the interval between them. I would join with you on the other part -- let's get somebody down there to find out how we are going to process these data when we finally do get continuous records coming through. It's a step-by-step operation, and since in this case it only involves one man in periods of about ten days, seven to eight weeks apart during the winter, I think, though I don't know even with the depreciated Canadian dollar, I think the Canadian taxpayer could probably bear that load.

Mr. Archibald: I hope so!

Mr. Popham: Might I raise a point here, Mr. Harwood, that TIROS V will also be looking at the James Bay and Hudson Bay areas for a short period of time.

Mr. Harwood: This is another interesting point. One of the extraordinary things about Canada is that we know a good deal more about the areas north of 60° than we do actually about Hudson Bay. We have a great big gap in the middle of the country that ships sail through and they say this is a terrible

bay, horrible bay, cold bay and that's about all that has been done, although the oceanographers have spent one and one-half seasons in there now. The ice conditions in the bay, the breakup, and the path of the breakup, are only barely known. We've no ideas of how it does break and where it goes, and there has been no real research or help given to this. There has been a little bit more research on the actual pattern of freeze-up but very little on the actual breakup, and where the ice disappears. Any information from the TIROS series over James Bay would be very useful. I believe James Bay is the heat sink in this area, and I think people will agree with me that in effect the shallow part in the bay warms up and the ice comes down with the prevailing wind which blows into this basin. It melts down at the bottom and the speed of the melt up depends on the surface water temperature. If we could get the TIROS photographs to show that pattern which does exist we have a start in making some predictions about when the bay breaks up and the condition of ice in the bay -- and it does some strange things.

Miss Dunbar: I quite agree with Mr. Yotko that this technique is very young and that it's far too soon to take ice information right off the TIROS V picture and throw it operationally at an operator who might use it. But I think it would be very valuable to go through the motions of doing this, not for the sake of the operator but for the sake of the ice forecaster, for comparison with the data he's getting to see, in fact what you do get, and I think that an experienced interpreter can get enough out of these pictures to be of some interest. It would be very interesting to check the accuracy of what you can get.

Mr. Popham: In effect, you would suggest a pilot study?

Miss Dunbar: Yes, provided someone was available to be at the readout station. I think a pilot study of that nature would be very valuable, and it is not too soon to do that.

Mr. Popham: Dr. Fritz.

Dr. Fritz: I would like to comment briefly on a point that previous speakers have made in regard to the inability to interpret the material on an operational basis now. I would go along with Mr. Harwood's statement made early this morning in which he said that if the TIROS IV pictures had been available to the proper official in the Gulf of St. Lawrence, he could have used those pictures at that time to direct shipping. This to me means that it would have been operationally useful had it been available then. I don't understand these recent remarks which say that one could not interpret ice in the larger sense.

Mr. Popham: I believe he was referring to the fact that if it were available throughout the winter it could be very valuable operationally, but

since it is available for only a short period of time it is not.

Mr. Harwood: You understood me correctly, but perhaps you misunderstood the fact I was making the assumption that you knew when these things would be over the Gulf for five to seven days separated by six weeks.

Dr. Fritz: In other words, for a five-day period it would have been of use?

Mr. Harwood: If you look at the pictures in the folder that was passed out, the satellite is seeing in effect what the ice people draw, and what the CF-100 and Lancaster saw in different degrees of detail. That aircraft picture on the wall shows that the limits of the ice are quite clearly organized. It is good enough for a man forming a convoy, for routing ice breakers, or routing ships into the Gulf, to steer them clear of the main pack. It is not good enough, as I have pointed out, for the last 25% of the trip when the channel gets narrow and ice fills the approaches.

Dr. Fritz: In other words you use it where you can and you don't use it where you can't. Here is a place where you can use it operationally.

Miss Dunbar: I think perhaps I did not make myself quite clear either. I didn't mean to say that you couldn't get anything from them; I was saying it was too soon to use this to replace other techniques. All you could do now is make a pilot study.

Mr. Markham: I am very keen to see something like this started for TIROS V, because ice reconnaissance in the Hudson Bay is much different from ice reconnaissance in the Gulf of St. Lawrence. You can make a comparison of the difference in area between the Gulf and Hudson Bay by looking at the map on the wall, even though Hudson Bay is only half shown. If we can get anything at all that will assist in the reconnaissance of ice in the Bay, I am all for it. To get good aerial coverage, one would have to base several aircraft in the area and this is not economical. Because of the weather factor, we are very often working with a little less than the minimum amount of data when considering the shipping route across to Churchill. The critical factor is one of timing for the period when observations are vital; it lasts from mid July to the second week of August. After that the ice has usually retreated sufficiently to allow ships to get into Churchill without any trouble. If the five days that TIROS is viewing Hudson Bay doesn't happen to match this very well, I am afraid we had better wait for Nimbus, but if they do, I would like to be getting a long distance phone call from Wallops.

Mr. Popham: Would you like these to be pictures on a facsimile?

Dr. Fritz: This means you would have to send a man to Wallops who could send you the telephone call.

Dr. Glaser: I would simply like to review the meteorological experience on this. Before TIROS I went up the attitude was rather similar, i.e., here is something which is going to be taking essentially scatter gunshots here and there over an earth which is already well populated with observing stations, so let's just wait and see what it does. I think Dr. Forsythe organized a team to work at the two readout stations for TIROS I, as if the world is going to be listening to us. We were rather startled to find that people were listening at the other end of our extremely crude communications. In my case I was sitting in Hawaii for the TIROS I activities. One day a major storm came between Los Angeles and Hawaii causing total consternation to the normal forecasting procedure. We were looking at it and were able to give concise instructions as to what was going on and what was going to happen next and a minor meteorological catastrophe was partially averted, giving us and, of course, anyone that had anything to do with the exercise great hope for the future.

But more important it gave us experience on what we were supposed to be doing at the end where the signals were first interpreted and finally experience at the other end giving these interpretations some meaning. You can only acquire experience by doing; contemplation is not enough. When Nimbus becomes available you will want trained personnel, and they can only be trained by action. If the meteorological experiences are any guide, the earliest opportunity to get this training is the proper opportunity.

Dr. Widger: We have heard a lot of comments here about the fact you are only going to view the St. Lawrence for about five days at a time roughly two months apart. Perhaps you may be thinking in terms of the last four satellites, which were placed in a 48° orbit. TIROS V will be placed in a 58° orbit. This means that you will be able to see north or south to 65° latitude, or roughly to obtain coverage at one time or another from the Arctic Circle to the Antarctic Circle. In addition, at the peak of the orbit, for example, over the upper part of James Bay, you may be able to get periods of coverage perhaps three to four weeks in duration. As a rough estimate, I would say about 25% of the time, the satellite will be able to observe ice, either in the northern or southern hemisphere, not just 10% of the time.

Perhaps it isn't worth while keeping an ice observer at the readout station all the time, but if you could at least send one down there part of the time he could receive some training. In addition, the meteorologists who are there full time may profit by his being there in that his experience may help meteorologists in distinguishing ice from clouds.

Mr. Popham: Several people here seem to feel that we would only view these ice areas for a period of five or six days. If you recall our experience with Project TIREC we obtained TIROS IV pictures over the Gulf of St. Lawrence for a period of approximately 23 days.

Mr. Yotko: I would just like to clarify my statement and maintain the controversy a little. I believe in exercising the analyst. I believe he should be schooled, and should try to discern from the satellite pictures whether there is or is not ice. That's what we are trying with TIREC, as a matter of fact. But I am wholeheartedly against providing what we consider information operationally unless the analyst is sure what he is giving out. I would rather give no information at all than information that is inherently risky. I feel that the quality of TIROS IV at the present time does not provide the analyst with any certainty of what he is seeing. It took something like 20 planes, 100 men, and many dollars to get us situated with TIROS IV. I hear these statements about how the photography and the radar and all these other parameters agree with TIROS IV, but it took a lot of additional effort to find out what TIROS was reading out. I still don't think we have the capability of looking at a satellite readout and saying truly that this is ice and that this is the limit. I think that we would be giving out information with a high degree of risk and perhaps the operator would develop lack of confidence in this information if we disseminate it prematurely. I am not against schooling the analyst; I believe that this should be done and we should run practice sessions. But we shouldn't be premature in delving out this information directly to operational units until we develop a degree of confidence in it.

Professor Cameron: You can't get started in training these people too soon. Let us get a man down to Wallops as soon as possible and make a dry run to find out what can be done. He could put out some material with a note on the bottom saying, don't place too much reliance on this information. Following that line I think that the sooner a man gets started reading these things the more practice he is going to get and the more expert he will be when Nimbus is launched.

Mr. Wood: I think it would be very smart to set up the mechanism whereby the information is disseminated to major sea-ice analysis centers. If you have the mechanism for the transfer of information from the readout site to the centers, you can at least start evaluating what can be produced, whether it is ultimately used operationally or not.

Getting back to the comments made before about TIROS IV experiments, right now the photography from TIROS IV is essentially useless as far as dissemination to the field is concerned. However, they are still reading out the photography and trying to analyze it locally to see what significance, if any, is there. I think the mechanism is worthwhile pursuing whether or not it is disseminated.

Mr. Harwood: You have to remember one thing -- if you have someone down there analyzing photography or ice conditions, for example in the Gulf, it's going through a filter system which would consist of Mr. Markham and his crew.

Dr. Widger: This is the same thing we are doing with the meteorological interpretation of these TIROS photos; the nephs that come up from Wallops are filtered through NMC and MSA to determine whether it looks sufficiently reliable to justify sending it out.

Mr. Cronin: My name is Cronin from Allied Research. I have been holding back several points, and I'll take the immediate one first. My background is geology and geophysics, with some experience in the Arctic. When the satellite ice pictures were being obtained in April, I was at Wallops Island and worked with Jack Woods, who represented the Hydrographic Office. He did a marvelous job. We had no difficulty whatsoever identifying ice even in some of the small areas, except where the cloud cover was very dense. When this happened, we were able to call upon a meteorologist to help us in our identification. We generally agreed on what should be indicated on the nephanalysis as ice. It was also not too difficult to distinguish between clouds and snow.

I had been doing this type of work for the last four months for the Air Force Geophysical Research Directorate, in association with John Conover. Working in adjoining offices we taught each other how to identify these features. At one time a lake covered by clouds was identified as a

frozen lake. This type of mistake isn't being made anymore, at least by John and the people working with him. (Perhaps this indicates how valuable experience is in interpreting these pictures.)

My second point has to do with picture gridding. The Fujita method may take a day or a day and one-half to learn. After learning this method an entire series of 32 pictures could be gridded in one day. If you have just one geographical point of reference and four or five frames with horizons, you can get remarkably precise, gridding these pictures to within one degree with an accuracy down to one-tenth of a degree.

My next point has to do with resolution. Because of the high reflectivity of some of these ice features, some of the ice objects, even though they are small appear to be large. Therefore, I believe you can see objects smaller than three-quarters of a mile.

Dr. Glaser: When we first started looking at TIROS I pictures we could not tell clouds from ice; we could not tell clouds from the sands of the Sahara Desert. Many of the newer people still make these errors.

The only way to get over this was to have these people looking at picture after picture. After a while they learned the geography of the world and also learned that certain features which appear to be clouds don't ever seem to move. We persuaded the photographers to change gray scale of the pictures so that white sand would not appear as white clouds.

The present system is still far from perfect, for the simple reason that we don't have really good communications between the readout stations and the consumer.

Mr. Wittmann: I would like to ask Mr. Cronin a question, and invite additional comments from others here; in conducting preliminary work, what ice features would be analyzed? Would you cover the whole Arctic? What would be the nature of the pilot study? Would you just be moving the boundaries around or would you attempt to delineate areas of great and small concentration?

Mr. Cronin: I think that the abundance of satellite ice photos already available, showing such areas as the St. Lawrence and the Great Lakes, could be analyzed as a preliminary study.

I am all in favor of sending someone to Wallops and Point Mugu to observe photos as they come in. I believe Jack Woods did send out photos that he thought were interesting.

Mr. Wittmann: Would this be in the nature of a nephanalysis?

Mr. Cronin: Exactly. There is no reason this couldn't be done in the same fasion as it is done for cloud study. Surely there will be mistakes made, but working together you will narrow the errors down so that you are making only one or two percent errors at the most.

Dr. Glaser: One point that may not have been made clear about the desirability of doing work, even if it is only research work, at the readout station, as opposed to doing it at home, is simply that at the readout station one has the complete spectrum of information at one's finger tips required to handle the pictures. One has a large staff of people who are concerned with nothing more than handling the photogrammetry and the attitude determination of the satellite. If one man attempts to handle all these things by himself back in his own laboratory, he gets bogged down with the mechanics of managing the pictures, and has practically no time left for the job of worrying about what's really in them.

Lt. Dotson: I think this might be an appropriate time to discuss what the Hydrographic Office proposes to do from TIROS I, II, and IV. We have several thousands of pictures of ice. In analyzing pictures there are two primary considerations; research applications and operational applications. Before we can develop operational uses we will have to do a lot of initial research.

First we will be attempting over a period of about six months to bring together the type of people who could best assist us in analyzing the satellite and other ice observations taken during TIREC. Our approach will be to start with the ice observers concept of what he sees using data selected from the best period of observations. Then we will let the ice forecaster make his forecast and compare this with the data obtained a couple of days later in the same area. We will then do a similar study using the TIROS observations.

By determining what our capabilities and requirements using satellite data would be, we hope to be able to answer some of the questions that NASA has asked regarding the refinements to the satellite that would be required to satisfy our needs.

I am very much interested personally in developing operational capabilities using satellite data, hopefully before Nimbus goes up. I also agree that we should conduct some pilot studies. Perhaps the group that we hope to form in the near future will serve as the nucleus for conducting some of these pilot studies. I believe that the Canadians are attacking this problem about the same as we will be doing. The Hydrographic

Office is aware of many of the problems which have been stated here, and we have already taken steps to come up with the answers.

Mr. Popham: With one exception, all of the people here who have spoken on this subject seem to feel that some sort of a pilot project to interpret and transmit satellite ice information should be attempted. The next objective would appear to be to establish specifically who would do this study. Perhaps a small working group or organization, could put this into practice. Perhaps the Meteorological Branch of the Department of Transport might be interested in having somebody at the readout station to conduct a rather limited pilot study in connection with the interpretation and dissemination of satellite information. Would you care to discuss this now, or would you suggest some group be set up to look into this further?

Mr. Archibald: I might say that we would be very happy indeed to send someone down to the readout stations, but before we can do that we would have to get the necessary approval. For our part, I should think this is one thing we would like to take under consideration for the next few weeks, especially until we know definitely about the proposed readout station in Canada. I think that as soon as that decision is made we would immediately feel the requirement to send someone down to the readout station.

While I am on my feet, there is one other thing I would like to inject here. I am not sure whether this is quite the right place or not, but we have been talking entirely about ice, it seems to me that this has some applications other than ice, for example, applications to forestry to record forest fires. In our country the forest fire problem is quite a serious one. There is a great deal of time, effort and money spent on forest patrols. It seems to me that this is one experimental phase that we might try to see what we can get out of it, perhaps in conjunction with TIROS V.

Mr. Popham: Mr. Yotko appears to have some comments to add on possible operational procedures in conjunction with TIROS. Perhaps we can conclude the discussion of operational applications with his remarks, and then begin discussing other research areas.

Mr. Yotko: I wanted to make a remark regarding the establishment of a working group. I speak for the Hydrographic office and concur with Mr. Archibald that this conference is not the proper vehicle for setting it up. In order to take it into consideration, some formal exchange will be necessary before we commit ourselves to a group.

Mr. Popham: We have been talking specifically about the operational aspects of the program and also the ice analysis from the Project TIREC stand-

point. I know there are other people here who are interested in doing some research with the TIROS and Nimbus vehicles other than in those areas which we have specifically discussed so far today. Bob, I know you have something to begin with.

Dr. Ragotzkie: (University of Wisconsin) I asked that I could say a few words about this particular subject because this seems to be the place for it. We have been talking mostly about operations up to now. Coming from the University arena we are less concerned with operations and more concerned with research of course. I would like to make a small plea for a little more elasticity in the use of satellite data for research work. Today we are talking about ice. These satellites have opened up sources of information which up to now meteorologists, oceanographers, mineralogists, and geographers have not had. Since they do not have this kind of information -- information that is global -- they have, for the most part, ignored problems which could only be solved by this kind of data. Some of us are beginning to work with these problems of climate and other problems which are ideally adapted to satellite investigation and which could never be examined before.

Mr. Harwood mentioned Professor Hare's work on Hudson Bay's effect on climate. This was one of the first qualitative stories about the effects of ice and water on climate. I would like to add to that, giving, strictly as an example, our own work on the Central Canadian Arctic. Here we do not have a continent in the true sense, since the surface is usually about 25% water. This is not continental, it is maritime. As soon as this surface freezes, however, it becomes continental. But, we don't know when it freezes. I have searched for these data for two years now and only last fall had an opportunity to get it. We surveyed part of this area for three weeks with a U. S. Navy P2V just to find out more about the lakes in this area and when they freeze. As it turned out we found a great deal more. When all lakes in an area are frozen, the character of the air mass has changed. Whether it is because the lakes froze when the air mass moved in, or the air mass character changed because the lakes were frozen, I am not sure. Nevertheless, the line dividing the zone from all lakes frozen to some lakes frozen also divides the area of cloudiness and the area of clear air. Also, there is a very sharp line between rough air and smooth air, as any observer can tell you who has flown this area. There is another line south of which the weather is apt to be more clear than north of it.

So we have two lines between which we find a zone where some lakes are frozen and some lakes are not. In this zone it is almost always cloudy, largely cumuliform clouds, and the air is very rough. We also measured albedo, and we find that in this zone the albedo is extremely variable,

whereas north of this line the albedo is uniformly high, while south of this line the albedo is jumping up and down twenty to ninety percent depending upon what terrain feature you are over.

I will not prolong this example, but with one aircraft we found these things which before we could only speculate about. It seems to me that TIROS V and future satellites are going to give us photography and perhaps radiation data and will give us an area view rather than a transect observation of such phenomena. We would certainly like to pursue this.

We think also that we have requirements for satellite data, and we don't look on this as taking what we can get; rather, we would like to present our requirements. These are more modest than many of the operational requirements but if our requirements are compatible with operational needs it is fine; if not we would certainly like to express our views in some way.

There was some mention of sending a man to the Wallops Island readout station to see what is coming in, screen it and determine what was most useful. If someone were to ask us to send a man to Wallops he would be there tomorrow. We are ready, because we want to look at weather as it happens.

Dr. Peyton of the University of Alaska I think has other problems and I would certainly like to hear his needs and requirements for satellite data.

Dr. Peyton: I represent, from the University, a rather small group interested primarily in polar problems. Others couldn't come, or have other problems. I am a Civil Engineer who has gotten into geophysics, and I have worked for several years at the Arctic Research Laboratory in sea ice physics, mechanical properties, etc., and of course, have become very much interested in the mechanisms of sea ice distribution and the interrelationship with oceanography and meteorology. When we view the problems which are highly significant in understanding the Arctic and Polar regions, we see in the satellite a new tool which is at least an order of magnitude more powerful than anything we have had in the past, particularly in the broad aspects.

In observing some satellite pictures very casually, not having had the opportunity to look at them in detail, many things become immediately obvious; they are much more obvious than when you are on an ice island, or crashing through ice in an icebreaker, or flying 300 to 400 miles north of the coastline in the wintertime. This seems to be a beautiful tool to use.

We have a very good man who has been all over the world studying snow problems. His name is Carl Benson, and he is vitally interested in the entire water shed of the Yukon River, particularly upstream from Rampart. It appears as if the dam is going to be built and the hydrology is unknown. We planned to study the immense hydrology problem exclusively from the ground or with aircraft. It may be possible to see satellite data to determine some of the gross hydrologic features of the area.

The better the pictorial quality, the better use we can make of the data. Thus if recommendations are in order, I recommend rather high priority be given to resolution.

Professor Bird: The spread of sea ice as the winter approaches -- and conversely the retreat of the boundaries of the sea ice in the summer is clearly of great interest. The distribution of ice off the Labrador coast immediately comes to mind.

There is another aspect that I think should be considered. The earth's surface reveals different patterns depending on the scale on which we look at it. It may be that there are geographical patterns on a continental scale that nobody has recognized. We try to do this with mapping techniques but I know from studies we have made in the Arctic that mechanical reduction in scale of large-scale analysis from air photographs does not show the same patterns as high altitude, small-scale photographs. The surface of the Arctic. . . It may well be that they show something very different when seen from a satellite than from a detailed study of the ground. Of course, there are already the Mercury capsule films which can be examined. It is obvious that there are very peculiar patterns in parts of the world. I doubt whether we are going to see these from TIROS or Nimbus, but sooner or later we are going to see it.

It may be that the geographer, like the photogrammetrist, is going to require a film that can be retrieved from outer space at some time. He is dealing with a phenomena that is essentially static, therefore, time sequence photography does not seem as important a requirement as it does to other areas mentioned here.

Therefore, I would like to suggest that a program be started in which TIROS photographs of cloud-free areas would be examined, to see what geographical features can be identified. Then as resolution improves, there

may be a point reached where the synoptic patterns disappear, and we eventually get into something we recognize from our aerial photographs.

Dr. Glaser: There actually are several research enterprises under way at the moment with this in mind, to make use of TIROS and other photography that is available. Allied Research is doing one under Air Force sponsorship, in which the concern is more specifically the background of the earth as something one sees clouds against. There will necessarily be a fair amount of fallout in the form of large-scale structural geology and large-scale geography. It becomes quite obvious that large-scale changes in the reflectivity of the surface of the earth are robbed by the cumulative effects of climate or climatic aberrations. I am sure that if one performed an analysis of the drought areas of China, the reflectivity would show these changes.

All these things are available so that you have both a static picture and non-static. What started us off on this was the discovery of the San Andreas Fault which showed up very clearly in the TIROS pictures. Similar faults then were hunted down in Africa and other places, and some of these were found in the pictures to extend beyond what the geologists thought their extent was.

So it's a fascinating business. It gets even more fascinating from the point of view of NASA, since after all this is the way we are first going to take a look at other planets. It might be a good idea if we understood the relationship between our conventional geography and geology as we know it, and that which is seen from TIROS, in order to better understand the geography and geology of the other planets when we get sufficiently close.

Mr. Harwood: This is a very important point. We can't just sit on this continent and develop a pattern of structural geology which is purely North American. For example, we think of the core of the continent and the geosyncline around it, while the Europeans think of platforms in the interior of the continent and the geosyncline between them. When you start looking at the globe it starts to dawn on you that North America and Eurasia are one; they comprise the major land masses of the whole earth, everything else is stuck around it. This is essentially what it amounts to.

One of the things you notice about European structural geology, particularly Russian structural geology, is their global concept, whereas in North America the geology has been aimed at the mining and oil industry in training at the universities. The North Americans and Canadians tend to look at structural geology on a rather parochial basis, and it is very difficult to get any connection.

If you study a geological map of the United States, which stops right at the border, and then try to match this with a similar map of

Canada, which begins at the border, they don't match, because people have a different idea of the structure and in addition they are not necessarily on the same scale. This is even worse when you get to Alaska, and when you get to Eurasia nothing fits together because of the same philosophy.

The satellite is going to look at the structural geology of the interconnection between Eurasia and North America, and it's this interconnection at which the geotechtonicist is eager to look at. This is going to begin the first steps in establishing the geological relationship between Eurasia and North America in a manner which has never been done before. The only people who have thought very much about this interconnection are the Soviets, who have for example come up with various ideas of what the Arctic Ocean bottom is. They range from pure oceanic structure into a step structure. The only persons that I know in North America who has given this very much thought and written really serious papers on it is Ostenso and Woodward, in Wisconsin, who postulate a step structure from Eurasia through Alaska into the North American continent. The geotechtonic structures are things you can actually see. This satellite photography, I think is going to present an ideal method and opportunity to get started.

When you look at the Arctic islands, you get linears and aggregates there which are basically tectonic.

There is the other point in the Arctic which is obvious since the prowandering; it has kept its geotechtonic forms without too much geomorphology modifying it. You will see the old structure much easier from the satellite.

Mr. Cameron: Getting back to specific projects, I would like to examine the Gulf Stream, and perhaps also take on all the other ocean currents of the world. I think we have a field of endeavor here where Nimbus in particular might be able to give us a very good pattern of the oceanic currents. If we had narrow angle pictures of the Gulf Stream off Nova Scotia we might be able to nail down some of these wierd meanders that some people claim exists in the stream. I know that the oceanographers will immediately say you are just getting the surface. Well, they can go after the deep stuff with their hooks if they want to, but let's get the surface also.

The second field is exactly the one that's been mentioned twice now, geomorphic studies. I would also like to inform the gentlemen at the back that there is one project already under way. I have been studying the Atlas Mountains in Mercury pictures and there is a very interesting structure there. The only thing I can find that closely resembles it anywhere is a model that I have seen on exhibit in front of the meetings in Washington showing the mid-Atlantic ridge with its accompanying rift. This may not be a

rift, it may be something else, but the very fact that I could think of such a thing from such pictures gives you some idea of how this type of photography broadens your outlook.

I feel that if we had the whole world covered with vertical photographs -- real photographs -- not transmission-type things--we would be well on the way. The old statement that we know more about the moon than we do about the bottom of the sea I think could be extended; there is a great deal about the surface of the earth about which we don't know anything. I would like to stake a claim on ocean currents, if, as and when we get the pictures.

Mr. Harwood: Who is going to dye them for you?

Mr. Cameron: We don't need a dye. There has been a great deal of discussion on the technique of measuring water current. The pessimists say you have to mark them with ice or dye; nobody told the water about it, and we have been measuring perfectly good currents in the Rideau River in Ottawa and elsewhere. The water is not only clear, it is almost black; and yet you can see the pattern of the currents. We have also done it down in Nova Scotia -- we can be accused of having muddy water there -- but nevertheless it works.

Mr. Harwood: There are two other things I would like to mention. I don't know whether Dr. Tulley has been down here, but Dr. Tulley is very familiar with the oceanography of the West Coast. He produced both for the Fisheries people and for the services what he called an ocean system. It is rather complex but in effect it postulates a pool of fresh water in the North Pacific which he calls a sub-arctic lake. This is where the salmon go and they play around in this pool of fresh water. The actual structure that dominates the current system on the west coast of Vancouver northward, a total amount of fresh water that gets in there and the sea surface temperatures are dominated by the Aleutian low over the Pacific. He has done sufficient work for the Fisheries Research Board in Canada that they can now forecast with some (more than 50%) certainty the route of the salmon north or south of Vancouver Island. Of course, economically in Canada, this means a great deal because if they all go over on the north side of Vancouver Island, Canada gets all the salmon and the Americans get none, and if they go on the southside you share it 50-50 with your neighbors.

So it has a great deal of interest to them, but it also has a great deal of interest to the services. The satellite, both through its photography and infrared, gives you some idea of the total amount of clouds over the surface of that area of the Pacific which actually dominates what Dr. Tully called his ocean system, and the Fisheries Research Board system which predicts salmon.

Now on the eastern side of North America the Greenland current is in some years stronger than others. If you consider the Arctic Ocean as a great desert getting a spring freshet for a period of six weeks, produced by 10% of its ice volume melting, you put on the surface of the Arctic Ocean something of the order of 2-1/2 to 3 feet of fresh water and probably more. In effect, the Arctic Ocean then has a slope towards the Atlantic of 2 feet over 3 to 4 thousand miles. Thus, superimposed on the Greenland Current is this spring freshet, which must, and obviously does affect the volume of the current in some way. The speed or the volume of the Greenland Current is what brings the ice around the Greenland coast and takes it up toward Disco Island. If you can get any system at all, such as a good satellite, which would give the total volume of ice that has melted off the Arctic Ocean (you might be able to do this even with just totals) you could make some kind of prediction of what the Greenland Current is going to do.

One final point. Part of the Greenland Current meets with and again affects the Labrador Current. This is the one which brings icebergs southward along the Labrador and Newfoundland coasts. Any change in the Greenland Current thus may affect the numbers of bergs in the shipping lanes.

Mr. Magnitzky: Has anyone attempted to take radiation data from TIROS and establish a relationship between it and observe sea surface temperature to determine if it was possible to map the sea surface too?

Mr. Harwood: No, but this is exactly what I was asking.

Mr. Popham: Mr. Poulin has a question first. Then we will come back to this, because I know there are other people in the Hydrographic Office who are interested in this subject.

Mr. Poulin: When you talk of using meteorological satellites for such things as geomorphic studies, the exposure for which the camera is set is for high reflectant surfaces such as clouds and ice. I wonder whether there is any possibility of getting another exposure built in, one that is selective on command, for land studies?

Mr. Wood: As far as TIROS is concerned, I think we are at the stage in its life where the only modifications to the TIROS program would be the emergency type where we have a consistent failure. In other words, it has been developed as far as it is going to go.

As far as Nimbus is concerned, the exposure time I believe is fixed. They are going to have a variable iris which will be controlled by the solar panels, which are directly related to the illumination of the surface below. In addition to this there is a command position of the iris in

case the automatic feature fails. You would have some possibility of getting what you want of this type of operation.

Mr. Popham: Getting back to Mr. Magnitzky's question about the radiation measurements of sea surface temperatures, Dr. Wark has done much of the work with the TIROS IR data; perhaps he could give a review of what has been done thus far.

Dr. Wark: We have the same problem of getting sea surface temperatures from the satellite you have in trying to observe ice, except it is worse because our resolution is so much poorer. In addition, one can see ice through thin or scattered clouds, while they completely destroy information from radiation sensors. You must have completely clear skies before you can get any reliable surface information at all. Therefore, in regions of persistent cloudiness this is a very poor technique.

Haze can also effect things, but probably more important is that you have to know how much water vapor is present. Here again the absorptions in the atmosphere give an uncertainty to the final value by several degrees, and this might be intolerable to somebody trying to use sea temperatures. I don't know what the limitations are since it probably varies from one area to another. But to get to 1° is extremely difficult. I am very pessimistic; other people like Mr. Winston are more optimistic than I am. Would you care to comment on this?

Mr. Winston: The one thing you didn't mention was the temperature gradient. Aside from just getting absolute values I think there is more chance of getting the gradient. So far I don't believe we have identified any sea surface temperature discontinuities using TIROS radiation data although I don't know whether we have really made an extensive search.

We have one case, a winter case where we have a very clear outline of the Florida coast. This was a dry situation; there was a cloud mass over the land, while the Gulf of Mexico on one side and the Atlantic on the other were clear. The temperature gradient was concentrated sharply along the coast. Therefore, you might be a bit optimistic about observing very sharp gradients of sea surface temperature.

Now as to whether you get the absolute value, there might be some question. Even here I think with enough data you might be able to do this by statistical means after a long time. You can't make all the corrections by physical equations and a lot more could be gained by summarizing the data statistically. Therefore, I think there is some hope in observing the Gulf Stream or other currents which have rather sharp gradients.

Dr. Wark: If you can get enough clear skies for the purpose.

Dr. Glaser: I think the greatest hope, not only from the point of view of sea surface temperatures but also ice reconnaissance, is going to be the high-resolution infrared radiometer observations presented in pictorial form. Here we are talking about resolutions not far different than current TIROS resolutions and a picture created by the self-emission of the material. A lot of the uncertainties as to the nature of the ice and snow at the surface will be resolved by thermal effects, in the sense that snow-covered ice is a better insulator than just plain snow. As a result you will get either colder or warmer readings, depending on what the ambient air temperatures are. You will be able to see contrasts of a different nature, which, I think, when one once learns to interpret these unfamiliar pictures it will be quite helpful. Similarly the Gulf Stream and features like that will show up very nicely in their own pictures, complete with all their eddies, something we have been unable to see before. This is something we have been looking forward to sort of on the edge of our chairs, because it is going to open a whole new world that is unavailable to us now.

Dr. Wark: I should mention, in regard to this type of instrument, that the present development does not give us resolution comparable with the vidicons. It is an order of magnitude lower.

Dr. Glaser: This may not be bad because as we have already discovered in the vidicon pictures we can stand a degradation by an order of magnitude without suffering very badly.

Mr. Wood: We have had a lot of trouble with the IR data reduction program, a fact which has held up the exploitation of much of these data. Hopefully, we are in the final stages of ironing out some of the major errors. We hope the bottleneck will soon be removed.

The other comment I have is just what Dr. Wark started to talk about. Unfortunately on Nimbus the IR sensor had to be wide because of the failure of the development of the sensor. My understanding is that the resolution is something of the order of 5 miles in the vertical.

Dr. Wark: Yes, we still hope that in the future, perhaps, with other cooling techniques, that we can get down to something comparable to the vidicon.

Dr. Glaser: Is there an intent for a pictorial presentation?

Dr. Wark: I think the best way of doing this is by an analog system. I don't particularly like the digital system because it's so much slower. I do not know what NASA's plans are.

Mr. Wood: They are still developing a facsimile with anticipation that it will be ready by launching.

Mr. Poulin: What is the angle.of view of your IR sensor?

Dr. Wark: I don't have the figures at hand right now. Is this the high resolution you are talking about?

Mr. Poulin: Yes, any of them actually.

Dr. Wark: The medium resolution radiometer has an angle of view of 5°, which is about 50 miles on a side, so the other one would be about 1/2°.

Dr. Boville: McGill University. I have just a couple of comments. The general discussion on satellite ice observing appeared to be concerned with looking at it from a very small-scale point of view. This is essentially the approach of the physicist, where fine detailed observations are required.

Most of the people associated with this program are well aware of the meteorologist's approach which is usually concerned with a much larger scale. Meteorologists must interpret data on many different scales and may have little control over the observations. Again there are two different approaches here; one, the physicist's approach where individual measurements are made to determine fine-scale accuracy. Then there is the general circulation approach where he is interested only in utilizing the measurement in some sort of a system, and integrating it on a very large scale.

I think the same is very much true of ice. If the general circulation, or synoptic dynamic meteorologist, is given information on ice and cloud coverage over certain areas at specific times he can then do research on this particular material. If he has to go through a set of a thousand pictures and sort these parameters, he is automatically discouraged from this type of research and he waits until someone with the approach of a physicist extracts the data and codes it for a systems approach.

I think it is very necessary that these minute approaches be taken, that one gets a lot of experience at interpreting these pictures so that one may readily say what is ice, what is snow and what are clouds and the approximate information is then available for general research on the broader problem. I think that this is what the general circulation man is really waiting for. This, of course, does not solve the problem of the man who wants to forecast a given lead in a given river,but I think here again we will have to take initially a broader scale approach to the problem. Certainly, when Nimbus has given us very large-scale coverage, knowing the ice coverage on a planetary scale is going to be a very fine tool in general circulation research. There again the people who are using the output don't want to go back through all of the individual bits of collected data. They want some kind of printout that is useful to them.

I think that in this initial stage in the ice program some very fine work can be done since there is an operational requirement. In meteorology an operational requirement has often provided the impetus to obtain new observational data which provides a basis for further research and as it gets going the research follows along. So, I am very well pleased to see that the Meteorological Branch in Canada is interested in this from an operational point of view as this points toward a new area.

Now with regard to the infrared problem, I was wondering if the infrared temperature does give an integrated temperature, for instance, the temperature that irradiates the ozone layer.

Dr. Wark: In the TIROS radiometer there is a sensor covering the 8 to 12 micron region which includes the ozone. In Nimbus, however, this will be narrowed to the region from 10 to 11 microns which will avoid the ozone, so there will be no ozone contribution. Water vapor, however, is the big problem.

Dr. Boville: I am not trying to get the ozone temperature, I am trying to find out if this will give the temperature which is irradiating the ozone layer from below. This gives an indication of the black body temperature below, regardless of whether its the water surface, land surface or cloud top.

Dr. Wark: I don't quite see the connection with the ozone.

Dr. Boville: The ozone band is irradiated from below and in the radiation budget for this layer, it is presumably the important factor. What is irradiating the ozone from below surely isn't known. We don't know what temperature in the mean is irradiating the ozone layer over the Pacific, for instance.

Dr. Wark: The radiometer is sensing probably quite accurately the radiation coming to the ozone layer. To measure the flux at the ozone level it would be better to use infrared because this is what mainly comes up to this layer; most of the radiation comes from below, even that emitted by water vapor. However, the radiation absorbed by the 9.6 micron band itself can best be estimated from measurements in the nearly 10 to 11 micron interval; even with the TIROS 8 to 12 micron radiometer, good adjustments can be made to account for emission by the ozone layer itself.

Dr. Boville: This then could come out of the infrared data.

Dr. Wark: Yes.

Mr. Popham: I would like to invite our visitors on a short tour of the laboratory after this meeting if they wish. I think we have a few more minutes left; if there are any other areas that people are interested in discussing any points we haven't covered which you feel should be raised.

Dr. Boville: Can we now tell the cloud cover, ice cover, or amount of open water over say, the Hudson Bay, from TIROS? I get the impression that this could be done, even at the present stage of resolution.

Dr. Wark: Do you mean from radiation measurements?

Dr. Boville: No, from the television cameras.

Dr. Wark: No, not in every case. We have been fooled on occasions. For example, we thought we were looking at some ice in one of the TIROS IV pictures. The next day we received a picture of the same area, and there was no ice there. We were misled by a bit of cloudiness.

It's only through experience, both by ice observers and by meteorologists, and through persistence that we can differentiate between ice and clouds. When you have daily observations in the area, then much of this uncertainty is swept away unless there is persistent cloudiness. At the time when Nimbus is fully operating, I think we will be able to say that we have snow, ice or clouds. From the radiation data we can get further information on the presence of clouds because they are generally colder than the ground, except in certain cases in the Arctic where they might be warmer. But at least we distinguish between cold and warm, and we can use this as an aid in deciding whether there are clouds, snow or ice.

Mr. Popham: I would like to show a composite of six pictures from TIROS IV. (Figure 20). The pictures were taken on April 3, 4, 5, 6, 7 and 12. This first picture was sent to Halifax during TIREC; Mr. Markham, Miss Dunbar, Major Taggart, Mr. Meed and I examined it. We knew the bright area around Prince Edward Island was ice, but we couldn't determine how much of the bright area north of the major ice area was cloud and how much was ice. Major Taggart attempted a stereo analysis of these April 3rd photos. He wasn't willing to say it was all cloud or that part of it was ice. However, he was positive most of it was cloud cover. Also, he said there were some clouds over ice around Prince Edward Island. Of course, with the April 4 photo which arrived a couple of days later, it was evident that the questionable area was all cloud, essentially verifying Major Taggart's analysis.

Perhaps I should also mention that the rest of us were divided in our opinions of which was which.

This shows that, on the basis of persistence, we can distinguish between clouds and ice, where sufficient background contrast exists. This is obviously the easiest way.

On April 7 we obtained a substantial amount of aerial photography over the ice around Prince Edward Island. This was pointed out earlier this morning. The weather was mostly clear, with a few clouds and some ice up in the Straits of Belle Isle, and ice in Chaleur Bay. The bright

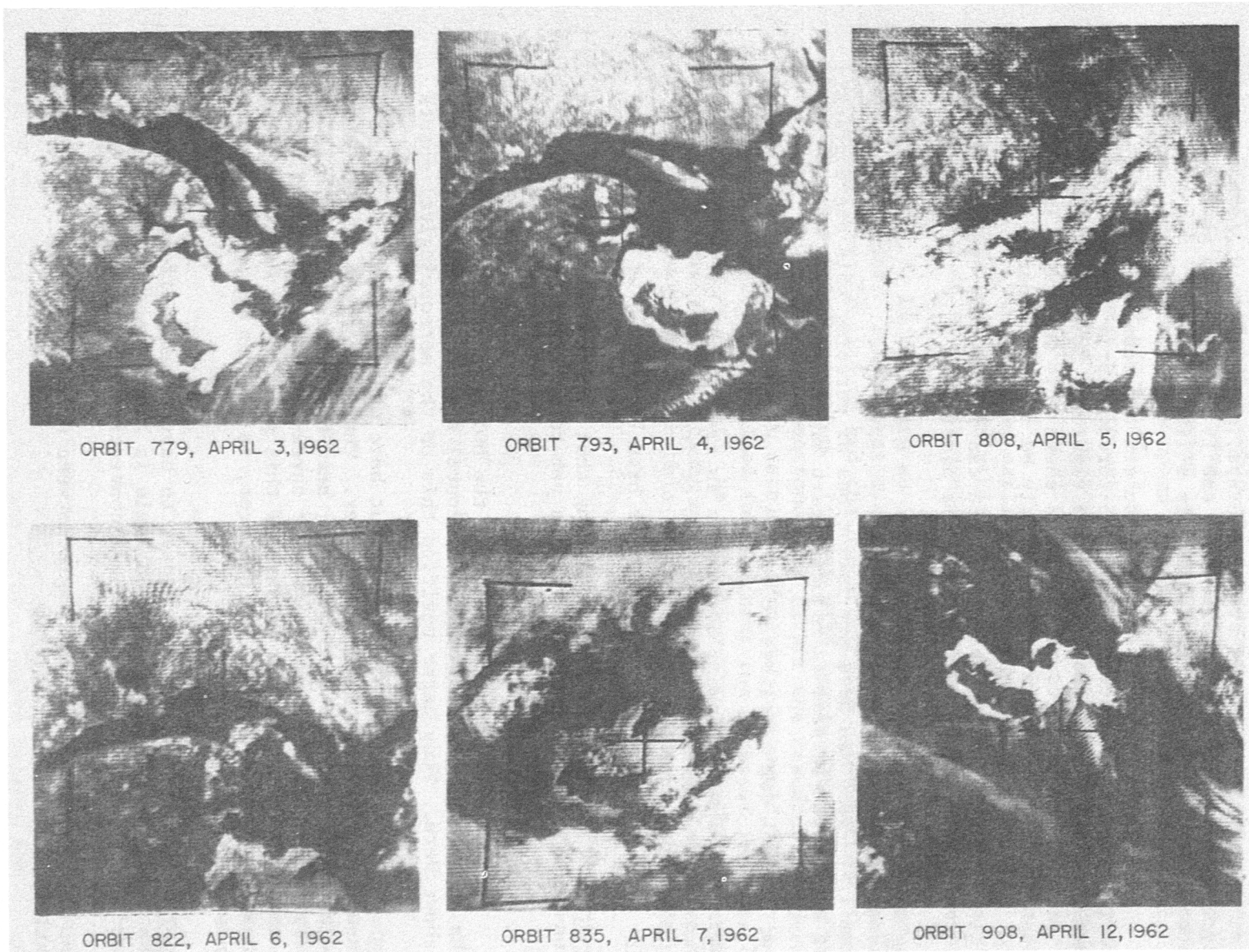

Fig. 21: Composite of TIROS IV pictures depicting ice around Prince Edward Island.

spot on Anticosti Island, tentatively identified as snow covering a 1957 forest fire burn, and the bright areas on Gaspé, probably snow cover, have repeatedly been observed from TIROS I, II, and IV. On the 8th we have clouds moving into the area, and picture quality is a little poorer.

In a regular sequence, you see the substantial changes in the ice which have taken place from April 3 through April 12. I thought this slide would best illustrate what we can see regarding ice in satellite pictures better than the one picture which was shown this morning. In the James Bay - Hudson Bay area pictures would probably be of this order.

Mr. Poulin: I think in these cases you can distinguish between clouds and ice from successive pictures of the same pass.

Mr. Popham: Right.

Mr. Markham: Does MSA have any intentions of pursuing this stereographic viewing of alternate pictures as Major Taggart has described?

Mr. Popham: I don't believe so.

Mr. Markham: I was thinking of this on an operational basis, to help distinguish clouds from snow-covered ground or ice.

Mr. Popham: At present, no such plans have been made.

Major Taggart: We think we have something that can be used operationally. However, we haven't done enough analysis as yet to really prove it to ourselves.

I would like to add that the DOT personnel examining these photographs felt they had identified two frontal systems in the satellite pictures shown here. They later verified this on the meteorological charts.

Mr. Popham: Perhaps we could point out here where the meteorologist would be useful in interpreting ice pictures. The lower right picture shows parallel cloud bands, or lee wave patterns, near Cape Breton Island. If we had pictures from only one pass in a two or three day period we would not be likely to call this ice, largely because of this parallel or banding orientation of these features. The ice in this area, as you can see, has a rather sharp boundary.

Major Taggart: These clouds also appear to have a lumpy effect in addition to the broken pattern. If the sun angle is right, you may also get very marked cloud shadow on the edges of these convective type clouds.

Mr. Poulin: The relative sun angle between different pictures may be significant.

Major Taggart: Perhaps I could add another example of the meteorologists' part in analyzing these pictures. We decided to follow up the movement of this cloud system to see whether it disappeared or moved in some particular direction. We estimated the speed of movement of this cloud, based on the upper wind data, and projected it across Newfoundland. At the time of the satellite pass, Gander was reporting high cirrus clouds. Our projection placed this heavy cloud area over Newfoundland within an hour, and within an hour Gander was reporting snow flurries.

I mentioned earlier that I don't feel the photo interpreter can work properly and get everything out of a satellite photograph without the help of others with a meteorological and ice observing background.

Mr. Popham: If there are no more questions I think we can bring this meeting to an end. I hope that everyone has found this meeting mutually profitable, and I'm glad we had the opportunity to get together like this to exchange ideas and information. The MSA will continue to do everything we can to help those who are concerned with either the research or operational aspects of the meteorological satellite program. We would like to extend our appreciation to those who helped in preparing the material for this conference, and we hope we have laid the foundation for a more thorough understanding of the potential applications as well as the capabilities of weather satellite observations. With this I would like to adjourn the meeting.

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