Aerial Triangulation in the Antarctic

DR. A. J. BRANDENBERGER,
Professor and Research Supervisor,
The Ohio State Univ., Dept. of Geodetic Science

ABSTRACT: *In the framework of the United States Antarctic Research Program considerable research is being done in the field of glaciology. Of particular interest are ice surface movements over extended areas. At present the National Science Foundation supports a research program of ice surface displacement measurements by aerial triangulation at The Ohio State University. This project is under the supervision of the author and Institute of Polar Studies, The Ohio State University. Field work for the aerial triangulation between Byrd Station and the Whitmore Mountains, Antarctica, started in the austral summer 1962–1963. The paper describes the scientific, technical and organizational aspects of the program as well as the photogrammetric operations conducted in the Antarctic.*

1. GENERAL ASPECTS AND INTRODUCTION

SUBSEQUENT to the International Geophysical Year the Antarctic, as the seventh continent on our earth, and one of the few remaining challenges of exploring unknown areas on our planet, became the subject of extensive research and exploration. The political aspect of research and exploration in the Antarctic is governed by the Antarctic Treaty of 1959 which declares the Antarctic to be used for peaceful purposes and in particular for scientific studies.

In this framework the United States Antarctic Research Program (USARP) plays an important part. This program is a continuation of the antarctic research and exploration of the International Geophysical Year and will be continued for years to come. USARP is under the direction of the National Science Foundation and the logistic support is provided by the U. S. Navy.

At present USARP is concerned with research in the fields of Meteorology, Physics of the Upper Atmosphere, Biology, Geophysics, Geology, Glaciology, Cartography, etc. For the photogrammetrist the research programs in Glaciology and Cartography are of special interest.

2. GEODETIC, PHOTOGRAMMETRIC AND CARTOGRAPHIC PROBLEMS IN THE ANTARCTIC

Since the Antarctic continent is about the size of the United States and Europe combined, the cartographic exploration of the Antarctic represents a sizeable task. This is further evidenced by 97 per cent of the area being covered by ice with depths of up to about 10,000 feet. This ice cap rises near the South Pole to an altitude of about 9,000 feet above sea level, and is interrupted by a few mountain chains rising up to about 17,000 feet above sea level. (See Figure 1.)

This means that the establishment of a relatively dense geodetic triangulation system would require the location of "fixed points" on the ice surface which cannot be considered as stable due to the ice flow. This inconvenience is further aggravated by the fact that many astronomic positioning methods are weak in the Antarctic, that no stable instrument positions can be found, and that the working conditions are extremely rough due to the cold and blizzards. All of these problems have to be overcome in the years to come since, at present, no continental geodetic triangulation network exists in the Antarctic, excepting a very few scattered local surveying systems of variable accuracy.

Similar difficult problems are found in the cartographic exploration of the Antarctic. It is natural that aerial photogrammetric methods are considered for this purpose, particularly with regard to the rough conditions encountered when ground surveying is performed; these conditions make it desirable to reduce the field work to a minimum. But even in applying aerial photogrammetric methods, many difficulties arise in the Antarctic which do not exist elsewhere. Examples are: navigation difficulties, increased

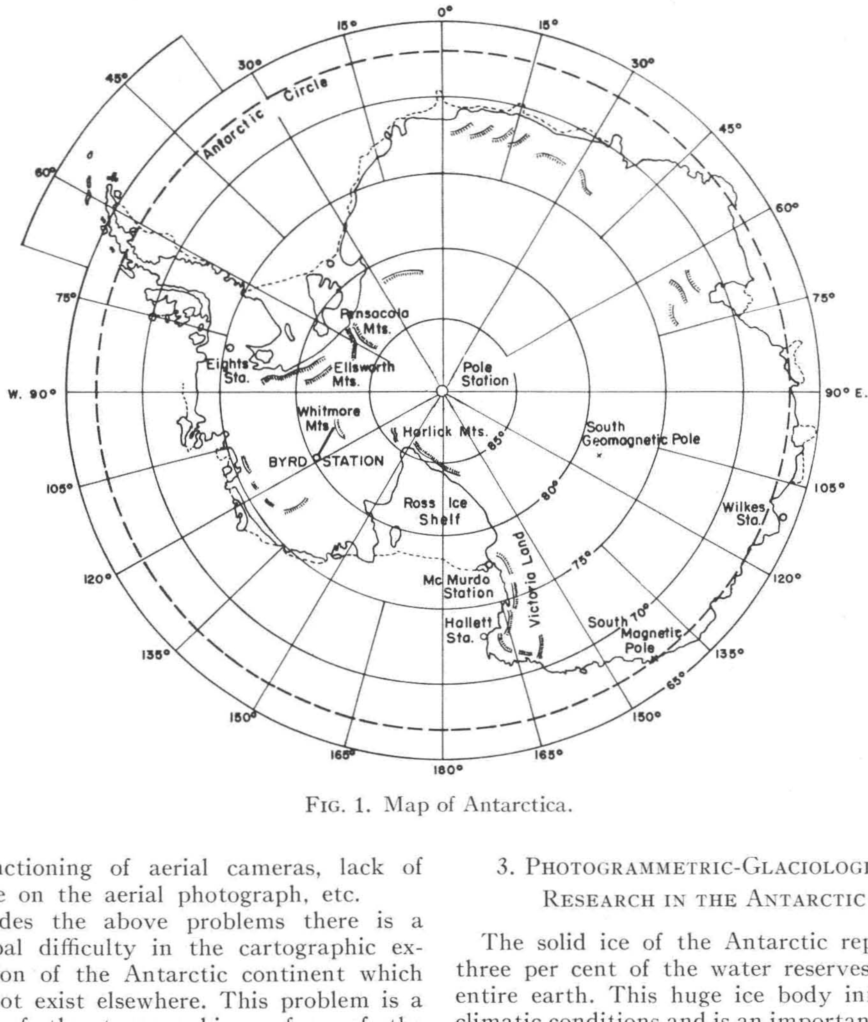

FIG. 1. Map of Antarctica.

malfunctioning of aerial cameras, lack of texture on the aerial photograph, etc.

Besides the above problems there is a principal difficulty in the cartographic exploration of the Antarctic continent which does not exist elsewhere. This problem is a result of the topographic surface of the Antarctic being not static due to the ice flow. Research at the University of Michigan and at The Ohio State University revealed that the ice flow produces annual horizontal displacement of surface points on glaciers of the Antarctic of 600 meters and more. Also, vertical displacements of ice surface points have to be considered. These phenomena cause contour maps becoming obsolete in a very short time; the time period is determined by the amount of the ice flow, the map scale, and the accuracy required for contour lines. This crucial problem of the cartographic exploration of the Antarctic continues to exist and at present it is difficult to say how this problem should be solved. The solution to this problem requires additional research and investigation and represents an interesting challenge to those who are concerned with the cartographic exploration of the Antarctic.

3. PHOTOGRAMMETRIC-GLACIOLOGICAL RESEARCH IN THE ANTARCTIC

The solid ice of the Antarctic represents three per cent of the water reserves of the entire earth. This huge ice body influences climatic conditions and is an important factor in the water inventory of our planet. Therefore, it is obvious that the glaciological studies, for determining volumetric variations of the Antarctic ice sheet, are of considerable interest. Also, a detailed knowledge of the surface velocity of the ice over wide areas is required in direct assessments of the mass balance of the ice sheet. From the same information, values of the surface horizontal strain rates can be obtained. Such data are required in interpreting the deformation of deep holes drilled into the ice sheet, and in evaluating the stress history and age of the ice recovered from the lower layers of the ice sheet.

The determination of ice flow vectors is best done by periodical determination of the position and elevation of a system of markers distributed over the area under study. This can be done by ground survey methods or by aerial triangulation. In selecting the appropriate method it is necessary to keep in mind that the ice sheet of the Antarctic is no static body. This makes necessary surveying and recording all markers of the network at a specific time, or at least in a time period as short as possible. If not done, i.e., if the surveying of the network takes considerable time, say several months, displacement of the markers due to ice flow can occur during the surveying period and can be easily a hundred times as large as the inherent errors of the surveying procedure applied. The result of this inconvenience is that the various periodical determinations of the position and elevation of the markers in the network to determine local flow vectors become inconsistent and unreliable.

This condition is evidenced by the experience of Hofmann in his Greenland traverse. After a period of several months, which was necessary to survey the traverse by tellurometer, he found at the termination of the field surveying work that the starting points of the traverse were already displaced about 10 meters due to local ice flow. At many places in the Antarctic the situation is possibly worse due to a much faster flow of ice.

At the Byrd Glacier a maximum ice flow of 850 meters per year was found. To eliminate this difficulty the surveying of the markers in the test area must be done as quickly as possible. Ground surveying methods by theodolite and tellurometers require considerable time also with respect to the extremely rough working conditions in the Antarctic. These methods are, therefore, not very suitable when a great number of markers in a large test area should be positioned in a very short period. A method which allows reduction of this time to a minimum is aerial triangulation since this method requires a minimum of ground surveying, and even a large test area can be photographed in a few hours. This is practically equivalent to a positional recording of all markers in the test area at the same time.

The disadvantage of the aerial triangulation method is that it does not permit the highest possible geodetic accuracy and standard position and elevation errors at the markers of several meters are to be expected depending on the available ground control, flight altitude, and number of bridged models However, it is considered that such an accuracy is sufficient to determine the ice flow in large test areas of the Antarctic where local flow vectors of up to 100 meters per year and even more might be expected.

The periodical measurement of marker positions and elevations by aerial triangulation is presently applied in the Byrd Station Traverse project of The Ohio State University.

4. The Byrd Station Traverse

This project is sponsored by the National Science Foundation. The scope is to determine the ice flow between Byrd Station and the Whitmore Mountains by means of a periodical aerial triangulation repeated annually for five years (see Figure 1). For this purpose approximately 140 permanent markers were placed between Byrd Station and Mt. Chapman in the Whitmore Mountains covering a strip area of about 375 km. by 8 km. (see Figure 2).

Each year the horizontal and vertical position of the markers are determined by aerial triangulation. From the differences of the marker's coordinates and elevations as determined each year, horizontal and vertical displacement vectors of the markers can be secured on the basis of which the ice flow vectors for the five year period are obtained. The method with independent geodetic control was chosen as aerial triangulation procedure, requiring base line, azimuth and slope measurements in the seven arrays of the strip.

Placement of the markers and the necessary field surveying for the first aerial triangulation took place during the austral summer 1962–1963. The field party consisted of Dr. Colin Bull, Assistant Supervisor (Glaciologist), Mr. Robert B. Forrest (Principal Investigator and Surveyor), Mr. Roy

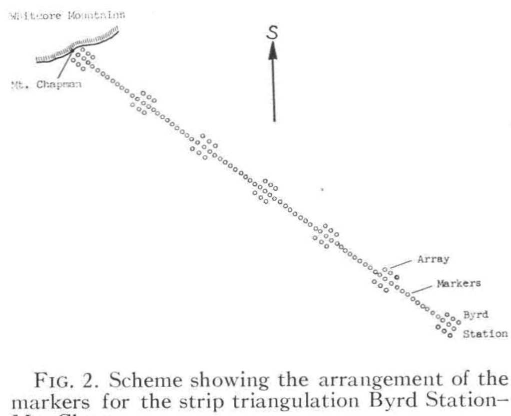

Fig. 2. Scheme showing the arrangement of the markers for the strip triangulation Byrd Station–Mt. Chapman.

FIG. 3. Members of field party at work.

Koerner (Assistant to Glaciologist), Mr. Don Dickson (Assistant to Principal Investigator), Mr. Graeme Johnstone (Mechanic), and the author of this paper as Project Supervisor. Figure 3 shows members of the field party at work.

Black-top markers were designed to be identifiable on the aerial photography. Fifty thousand pounds of marker material was shipped by U. S. Navy ships (traveling behind ice breakers) to McMurdo Station and from there to Byrd Station by LC-130F (Hercules) airplanes. The markers were placed on steel pipes 1.5 and 2 meters above the snow surface considering an average snow accumulation of 30 cm. per year. The marker type was designed on the basis of tests performed in the wind tunnel and of test markers placed at Byrd Station one year earlier (see Figure 4).

The southern end of the strip triangulation is tied to ground control on rock at Mt. Chapman. A rigid survey system consisting of seven independent base lines, sun azimuths, vertical angle measurements for slope determination, and barometric height measurements as well as horizontal angles measured between adjacent traverse legs should provide a sufficient accuracy at the north end of the strip triangulation at Byrd Station. It is expected that the errors of the adjusted strip triangulation at this end will be considerably less than one second in arc; this compares favorably with the present standard position error of Byrd Station which amounts to about one minute in arc.

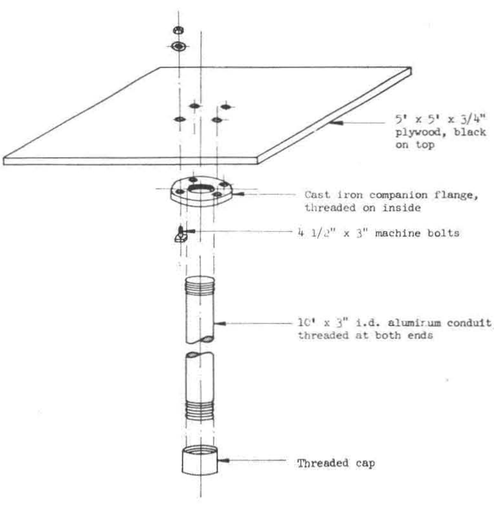

FIG. 4. Photographic marker.

A little more than one month was required for the work on ice. This operation included the placement of the markers and the survey work. For the performance of the field work one reconnaissance airplane, 2 Nodwells, one motor toboggan, and camping material were available. A detailed description of this field operation will be given in the technical reports to be published on the Byrd Station Traverse project.

Directly after the field work was completed four vertical photography strips were flown over the marker area with an overlap of 60 and 80 per cent from 6,000 and 3,000 meters above ice. In performing the aerial triangulation the high-altitude photography will be used. The low-altitude photography will serve as an emergency source in case a sufficient amount of markers cannot be identified on the high-altitude photography, or when the high-altitude photography will not provide sufficient texture for the performance of the relative orientation of certain models.

For the flight missions a T-11 Metrogon Camera was the only camera available for the project. Although this camera produced useful photography, it is recommended that for future missions of this type, a high-performance aerial camera be used with a practically distortion-free lens and a much higher optical resolution. Such cameras are now available.

The flight missions for the Byrd Station Traverse were performed by Navy Air Development Squadron Six. In preparing these missions valuable assistance was provided by Mr. McDonald, USGS who was stationed during the austral summer 1962–1963 at Christchurch, New Zealand.

Due to several delays the performance of the aerial triangulation at The Ohio State University could not be started up to now. Nevertheless, a first examination of the photography by means of a stereoscope has shown that markers are identifiable. It is planned to perform the aerial triangulation by using the Wild A7 of the Department of Geodetic Science, The Ohio State University. It is also planned to report in future papers and reports the results obtained with the repeated aerial triangulations over the five year period of this research program.

5. Future Phases in the Byrd Station Traverse Project

The aerial triangulation of the 1962–1963 photography will provide the reference system in terms of marker positions and elevations for the repeated aerial triangulations to be performed with annual intervals. This requires additional field work for each following aerial triangulation. This field work however, is considerably less extensive when compared with the initial phase of the research program, because future field parties will not have to be concerned with the placement of the markers. The operations of future field parties will be limited to checking the markers and the resurveying of the base lines, azimuths and slopes in the arrays of the traverse.

6. Closing Remarks

It is believed that the Byrd Station Traverse aerial triangulation is the first long aerial triangulation performed in the Antarctic. The completion of the first phase of this research program has yielded valuable information on photogrammetric operations in the Antarctic and it is hoped that this research program will be the initiation for future photogrammetric activity on the last continent on our planet.

7. Acknowledgment

The organization of an expedition of the type of the Byrd Station Traverse requires a high degree of collaboration between the various organizations involved.

Besides the outstanding work by the members of the party (Mr. Robert B. Forrest, Dr. Colin Bull, and Associates), valuable help was given by Dr. A. P. Crary, Chief Scientist, Mr. R. W. Mason, Mr. K. N. Moulton, Mr. W. R. Seelig and Mr. P. M. Smith, all members of the NSF Office of Antarctic Programs; Mr. E. E. Goodale, USARP Representative in New Zealand, Mr. L. M. Martin, Station Scientific Leader, Byrd Station; Dr. R. P. Goldthwait, Director, Dr. Arthur Mirsky, Assistant Director, and Mr. H. Mehrling, all members of the Institute of Polar Studies, The Ohio State University; Mr. R. K. H. Adler and Mr. S. Weissman, Department of Geodetic Science, The Ohio State University; The U. S. Naval Support Force, Antarctica under the command of Rear Admiral Reedy; the Air Development Squadron Six, the AF Troop Carrier Squadron, the USGS with Mr. McDonald and Mr. Chapman, and many others.

The project was supported by the National Science Foundation under G-23006.

8. References

[1] "U. S. Antarctic Research Program, Manual for USARP Personnel, 1963," Office of Antarctic Programs, National Science Foundation.

[2] Brandenberger, Dr. A. J., "The Practice of Spatial Aerial Triangulation," Photogrammetric Inst., Federal Inst. of Technology, Zurich, 1951.

[3] Brandenberger, Dr. A. J., "Some Considerations About Error Propagation in Strip Triangulations. Attainable Accuracy," Publication No. 8, Institute of Geodesy, Photogrammetry and Cartography, The Ohio State Univ., 1958.

[4] Brandenberger, Dr. A. J., "Strip Triangulations with Independent Geodetic Controls, Triangulation of Strip Quadrangles," Publication No. 9, Inst. of Geodesy, Photogrammetry and Cartography, The Ohio State Univ., 1959.

[5] Brandenberger, Dr. A. J., "Aerial Triangulation with Auxiliary Data," Publication No. 10, Inst. of Geodesy, Photogrammetry and Cartography, The Ohio State Univ., 1960.

[6] Ghosh, S. K., "Strip Triangulation with Independent Geodetic Control," Reprinted from Photogrammetric Engineering, November, 1962.

[7] Brandenberger, Dr. A. J., and Dr. S. Laurila, "Aerial Triangulation by Least Squares," Report I, II, III, IV, and Final, ERDL, Fort Belvoir, 1955–1956.

[8] Brandenberger, Dr. A. J., "Mapping Glaciers in Western United States," Report RF Project No. 1227, The Ohio State Univ., 1962.

[9] Brandenberger, Dr. A. J., "Photogrammetric Glacier Mapping for Glaciological Studies in Yukon, Canada, Yukon Ice Field Ranges," Report RF Project 1391, The Ohio State Univ., 1962.

[10] Brandenberger, Dr. A. J., "Periodical Photogrammetric Mapping of Glaciers in Western United States for Glaciological Studies, Report RF Project 1278, The Ohio State University.

[11] Adler, R. K. N., "Photogrammetric Measurement of Ice Movement for Glaciological Studies of the Byrd Glacier, Antarctic Region," Report RF Project 1543, The Ohio State Univ., The results will be published by Dr. C. W. M. Swithinbank, Univ. of Michigan.

See announcement of International Congress on page 319.