New Era of Geodesy

W. A. Heiskanen

Institute of Geodesy, Photogrammetry and Cartography, Ohio State University, Columbus

GEODESY is an old science. Already by 220 B.C. Eratosthenes had determined the size of the earth. As science in the modern sense, however, geodesy began to develop only about 350 years ago. The principal tasks of geodesy are to measure the "waist line" of the earth and its general shape, brought about by its diurnal rotation, as well as its "shrinkage" (the undulations of the geoid), caused by the great age of the earth. In addition geodesy has to determine and compute accurate coordinates (latitude and longitude) of the control points, without which no adequate mapping would be possible.

In order to accomplish this mission, the geodesist has to carry out different types of accurate measurements and to struggle, perhaps more than any other scientist, against the effect of observation errors. These errors are brought about partly by the observers, partly by the measuring conditions, and partly by the measuring instruments. The finer and more accurate the measuring instruments, the better and more accurate the observations. The development of geodetic instruments is in close connection with the development of geodesy itself.

The 17th century gave geodesy the telescope, the logarithm tables, and triangulation, which has been the most important geodetic measuring method until now. Measurements made during the 18th century gave values for the size of the earth not far from the true value, and the flattened shape of our planet was discovered. The turn of the 19th century brought, through the genius of the 18-year old Gauss, the important adjustment computation as well as the definition and preliminary length of the meter by French scientists. The meter used to be 1/10,000,000 of the distance from the pole to the equator along the Paris meridian, but it has been found to be actually a little shorter. The 19th century brought the methodical basic triangulation works of Gauss and Bessel, the mathematical basis (Stokes' formula) of physical geodesy, and international geodetic cooperation.

Finally the 20th century opened a new era for geodesy. It had to do so, because geodesy faced new problems that could be solved only by new methods. Earlier all countries were satisfied to have their own geodetic control point system. For that purpose, even poor dimensions of the earth and the classic triangulation were sufficient. However, during this century geodesists have had to reconcile not only the geodetic systems of different countries but of different continents in a world system. In order to do this, we have to know very accurately the dimensions of the earth as well as its detailed shape. In other words, we must know the earth's ellipsoid along which we make the computations of the control points in different parts of the world and the distance of the geoid from the ellipsoid and its inclination as referred to the ellipsoid. In general, the geodesist speaks of the undulations of the geoid N and the deflections of the vertical components ξ and η (ξ is the meridian component, η the east-west component).

The symposium, *New Era of Geodesy,* sponsored by the Institute of Geodesy, Photogrammetry and Cartography, the Mapping and Charting Research Laboratory, and the Graduate School of Ohio State University, 12–13 November 1954, was concerned with how the new methods can solve the basic problems of geodesy as well as with the modern geodetic instruments that make these methods possible. The speakers for this symposium were 16 top-ranking scientists from the United States and abroad. It was attended by scientists from different parts of the United States who have worked with these problems for a long time.

Scientific evidences of this new era are the celestial methods, the electronic mensuration method, and the gravimetric method as well as the new types of measuring instruments that were brought to science during this century.

New types of geodetic measuring instruments devised and manufactured during the last four decades have become much lighter, smaller, and more convenient to use than the old-fashioned instruments, and they make observations 2 to 3 times faster. Cylindrical axes, glass circles, focusing lenses, coincidence spirit levels, optical micrometers, and particularly the possibility of reading directly the mean of two diametrically opposite points of circles are the most striking features of these new instruments, which were for the most part devised by Heinrich Wild, Sr., of Switzerland. The paper of Heinrich Wild, Jr. (Kern and Co., Ltd., Aarau, Switzerland) explained this development of geodetic instruments.

The Vening Meinesz pendulum apparatus for gravity measurements at sea devised three decades ago, the underwater gravity meters introduced by the Gulf Oil Company a decade ago, and the different types of gravimeters developed during the last three decades have brought a new epoch in the gravity survey of the globe.

The Vening Meinesz pendulum has opened the oceans for gravity surveys, and the underwater gravity meter can measure gravity in shallow waters along the coast lines. These two methods together permit gravimetric survey of the oceans and seas—that is, 70 percent of the whole area of the globe, which earlier was gravimetrically "terra incognita."

The gravimeters—spring balance principle—permit the measurement of gravity in 3 to 5 min with 20 to 50 times higher accuracy than the old-fashioned pendulum apparatuses were able to accomplish in 2 days. In fact, we need only relatively few pendulum gravity stations for calibrating the gravimeters. All other points (already several million stations) can be measured by the gravimeter. These new instruments, as well as the keen interest of the geodetic and geophysical institutions and universities of different countries and of the oil companies in gravity measurements, have essentially accelerated the gravity survey of the earth.

With long-range gravimeters like the Worden gravimeters, we can convert the gravity base stations of different countries, continents, and ocean islands to the same *world gravity system* relatively easily and accurately by using air transportation. This conversion—the ultimate prerequisite of the geodetic application of the gravity anomalies—has been carried out particularly by G. P. Woollard (University of Wisconsin) and his coworkers. As a result of these efforts, the world gravity base stations have been converted to the same system with an accuracy in most cases higher than 10^{-3} cm/sec^2. Through the efforts of F. A. Vening Meinesz (Delft University, Holland) and the Columbia University group led by M. Ewing and Lamar Worzel, more than 3500 gravity stations have been measured at sea. Some other nations have also contributed on a smaller scale in the gravity survey of the oceans.

The development of the gravimeters, the progress of the recent gravity measurements on the continents and at sea, and their significance for geodetic and geophysical purposes were presented to the symposium by Vening Meinesz, Worzel, G. P. Woollard, and S. P. Worden (Houston Technical Laboratories), inventor of the Worden gravimeter.

Besides the classic triangulation, we have new methods for measuring the geodetic "yardsticks," not only along the continents, but across the oceans as well. These yardsticks are needed to compute the size of the earth ellipsoid. Four types of celestial methods have been brought to science during this century.

Rocket-star triangulation was invented and developed by the Finnish geodesist Y. Väisälä a decade ago. In Väisälä's method, we have to photograph the rocket from several observation points simultaneously with the neighboring stars on the same plate or film. By measuring the small angular distances between the images of a rocket and the neighboring stars, the direction of the rocket and its distance from the observation point can be accurately computed. If the rocket is shot to an elevation of many hundred kilometers, the afore-mentioned method could give distances even across the oceans.

In the other three celestial methods, we use the moon as one triangulation point. In the solar eclipse method, developed by I. Bonsdorff, late director of the Finnish Geodetic Institute, for measuring distances across the oceans, we measure the exact moment when the totality of the eclipse begins and ends at three stations, *A, B,* and *C,* of which *A* and *B* are on the same continent and *C* on another continent. If we know the distance *AB,* we can compute the accurate distance of the moon and then use this distance for computing the accurate distance *BC* across the ocean. This method has been used three times; in 1945, 1947, and 1948, although only the distance between Brazil and Africa has been computed in this way by T. J. Kukkamäki on the basis of the observations of the Finnish expeditions during the total solar eclipse of 1947. The results of the eclipse observations on 30 June 1954 are not yet available. No less than 27 expeditions from different nations used this eclipse for geodetic purposes. The cloudy skies, however, hindered observations at most of the expedition's stations.

Similar to the eclipse method is the occultation method, in which the moments when a star disappears behind the moon's limb and again emerges from behind the limb of the moon are measured very accurately at several stations. When the distance of the moon is known, the distances between the observation points can be computed.

Best of the moon methods might be the moon-camera method, invented and developed by W. M. Markowitz (U.S. Naval Observatory). The idea behind it is to photograph from different observatories the moon with the neighboring stars. The moon-camera permits the photographing of the moon so that the stars and the moon limb will be stationary and their images will be distinct. In measuring the small angular distances of the different points of the moon limb from the neighboring stars, the direction to the moon and the distance between the observation points can be relatively easily computed. This method gives the geocentric distance of the observation points from the earth's center with an approximate accuracy of 40 to 50 m. In this way, the *general shape* of the earth can be determined. An international cooperation has been arranged among about 20 observatories in different parts of the world. After a few years, we hope to get results from this interesting cooperation.

The paper of R. C. Fitzpatrick (Cambridge Research Center of the Air Force) presented the solar eclipse observations of 30 June and Markowitz's paper explained the moon-camera method.

Quite different are the *electronic mensuration methods,* which allow accurate measurement of the propagation of the time of the electromagnetic impulses or light waves from the observation points to the target and back. The accuracy of these methods is dependent, of course on how effectively the disturbing elements of the atmosphere can be eliminated and how accurately the propagation time of the impulses can be measured. The accuracy of 1/15,000,000 of a second corresponds to the accuracy of 10 m in the measurement of distance.

Different types of electronic mensuration methods have been developed. The most important of these are the Shoran and its modifications, Hiran, and then Decca, and the geodimeter.

The geodimeter, which is satisfactory for measuring base lines of the triangulation, as well as the sides of the triangles, was invented by the Swedish geodesist G. Bergstrand; a relative accuracy of 1/300,000 to 1/1,000,000 is possible to obtain in these measurements.

Decca was invented in England and has been used in Europe a great deal, particularly for hydrographic purposes. This method is convenient because we need only a few broadcasting stations to send the signals. By using these signals, every ship that has the receiving apparatus can determine its position with an accuracy of better than 10 m. Since the price of these receivers is only 4 percent of the cost of the broadcasting stations, this is an inexpensive method, too.

For long-range measurements, the Shoran method, invented in America and developed through the postwar years, particularly by Carl I. Aslakson (U.S. Coast and Geodetic Survey), has already reached the relative accuracy of 1/120,000, so that it can replace triangulation, especially in areas where the classic triangulation is very difficult to carry out. Shoran and Hiran were used in the Greater Antilles in 1950–52, as well as in the Lesser Antilles in 1954; it was also used to connect Norway and Scotland in 1953, Crete and Africa in 1953, and Scotland and Iceland in 1954. The advantage of this method is that very long distances can be measured, and the observation error will not increase with the distance, as it does in triangulation methods. We can agree with Aslakson when he says:

> It has been shown that Hiran can improve existing networks and make intercontinental connections which were heretofore impossible. Distances as great as 880 km have been measured. The next decade will see ever increasing use of this new technique.

The paper by John Williams (Battelle Memorial Institute, Columbus, Ohio) discussed the method and accuracy of the geodimeter. The paper by Simo Laurila (Mapping and Charting Research Laboratory, Ohio State University) presented the advantages and limitations of the Decca method. Aslakson's paper and the paper by C. E. Ewing (doctoral candidate at OSU) discussed the idea, development, accuracy, and achievements of the Shoran and Hiran methods.

During recent decades, the photogrammetric air triangulation method has been developed in different countries. The accuracy of this method is so high, particularly if one uses the statoscope and the horizon method, that it can be used for determining the control points for photogrammetric mapping. Bertil Hallert (Swedish Photogrammetric Institute, Stockholm; temporarily at OSU) discussed the obtainable accuracy of air triangulation.

Other evidences of the new era of geodesy are the facts that, in computation, we use numerical tables and calculating machines instead of logarithm tables. Of course, this makes the computations considerably faster and the tables shorter, as R. A. Hirvonen's "Nutshell Tables" show. Still more striking phenomenon of the new era is the use of high-speed computing machines, such as the I.B.M. and UNIVAC. It is possible to use these machines not only in the computations of the coordinates of the control points and in converting them to the same system but also in the isostatic reductions of the gravity anomalies and in computing gravimetric deflections of the vertical and the undulations of the geoid. These problems were discussed by Paul Herget (Cincinnati Astronomical Observatory).

The papers by Donald Rice (Department of Gravity and Astronomy, U.S. Coast and Geodetic Survey), Hirvonen (Institute of Technology, Finland; temporarily at the Mapping and Charting Research Laboratory, OSU), and W. A. Heiskanen (Institute of Geodesy, Photogrammetry and Cartography and supervisor of the World-Wide Gravity Project), show that the gravimetric method can, on the basis of the material already available, determine the undulations of the geoid in many places of the world with the accuracy of about 5 to 10 m and the deflection of the vertical components ξ and η with an accuracy of 0.5 sec. Accuracy of 3 sec can be obtained even when only few gravity observations are available. To compute the deflections of the vertical, we need detailed gravity station nets in the neighborhood of the computation point. The effect of the gravity field far from the computation point is small; in contrast to the computation of the undulation of the geoid in which the gravity field all over the world has considerable effect. Therefore, the additional gravity measurements in the continents and particularly in the southern oceans are very desirable.

The gravimetric method can also check the flattening value of the reference ellipsoid and convert the existing geodetic systems to the world geodetic system. In addition, it can give, in connection with the astronomical observations, control points for maps at a scale of 1/100,000 and smaller scale. When using the gravimetric deflections of the vertical, as well as the astrogeodetic deflections of the vertical, we can check the dimensions of the reference ellipsoid with very high accuracy.

The paper by Aslakson was read by Rice; the paper by Markowitz was read by Vernon Rybski (Mapping and Charting Research Laboratory); and the paper by Wild was read by Frederick Doyle (Institute of Geodesy, Photogrammetry and Cartography). The symposium was opened with a word of welcome by Frederic Heimberger, vice president of Ohio State University.