THE VARIATION OF THE COMPASS FOR THE YEAR 1960

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The United States Coast and Geodetic Survey, under a working agreement with the United States Navy Hydrographic Office, completed in September 1959 the compilation of the 1960 edition of an isogonic chart of the world. One of the authors (A. M. W.) was in charge of the execution of the work, and the other collaborated through technical consultations and by devising certain new procedures as explained below. The chart has been published by the Hydrographic Office as chart H. O. 1706, under the title *Magnetic Variation, Epoch 1960.0.* World isogonic charts are compiled at five-year intervals, and charts of magnetic inclination, horizontal intensity, vertical intensity, and total intensity are compiled at ten-year intervals. For the year 1960, only the isogonic chart and the related north and south polar isogriv charts were compiled.

All available world-wide data observed during the interval from 1900 to 1960 were used, amounting to some 150 000 observations. Since the Coast and Geodetic Survey first undertook the construction of the chart for 1950, the number of available observations of magnetic declination (variation of the compass) has steadily increased from 80 800 in that year, through 110 000 in 1955, to the present number. The data may be divided into three categories as follows : land observations, ship observations, and aeromagnetic observations. Only land and ship observations were available for the 1950 chart. In 1955 a few aeromagnetic observations were also used. In 1960 a considerably larger number of airborne observations were available, largely over ocean areas. They supplied fairly accurate data over vast regions in which interpolation and estimation had been necessary, thus improving the accuracy of the chart in previously doubtful areas. The U. S. Hydrographic Office is currently engaged in a project which will ultimately result in the coverage of all ocean areas with magnetic observations taken aboard long-range aircraft.

Basic processes devised for the compilation of the 1950 isogonic chart were repeated for the 1960 version. An outline of the procedures used in 1950 is available (WEBER and ROBERTS, 1951). It may be useful to give here a brief résumé of these procedures as applied to the 1960 chart.

A rigid completion date and limitations on personnel, usually to a staff of only four or five, dictated use of a processing method easily described and understood — one permitting joint work by a small group, and so far as possible reducing the amount of routine computational work to be performed by hand. This indicated recourse to automatic computing machines. The following unique method permitted the successful completion of the 1960 chart compilation project on schedule.

A permanent IBM file of field-data cards containing all observed values from 1900 onward was established in 1950. All available declination observations were collected in the period 1950 to 1959 and added to the file. Thus there was established a convenient store of material which could be readily sorted by machine according to location, date, or any desired scheme.

Curves of magnetic declination plotted against time were constructed for all observatories yielding data for the period 1900-1959 or a substantial portion thereof. The slopes of these curves represented the rates of secular change of declination. The curves exhibited a general tendency to undergo changes in their slopes at common times. The changes of slopes, or increments of rate, were termed *impulses,* and dates of observed impulses were selected at intervals of some two to six years. The compiled impulses had a sufficiently broad distribution to control the drawing of world *iso-impulse charts* one for each impulse epoch. This facilitated the quick graphical determination of impulse at any place for any such epoch.

For each of about 1 200 available repeat stations, the time and declination values for the two best observations were listed, as well as the impulses at all epochs, scaled from the iso-impulse charts. This information permitted a quick and simple hand computation, yielding a separate evaluation of the rate of annual change for each interval between epochs for each of these stations.

A world map of curves of equal annual change for each interval was drawn, to accord with a position plot of the annual-change values so derived for all observatories and repeat stations. From these maps the annual-change rates for each interval were scaled and tabulated, at a selection of points chosen to facilitate machine interpolation. The meridians defining the selected points were spaced at ten-degree intervals from 0.5 to 180.5 degrees east and from 0.5 to 180.5 degrees west; and the parallels similarly from 0.5 to 80.5 degrees north and south. These values of annual change were punched into master cards for controlling subsequent reductions, involving machine interpolation of values for the centres of one-degree quadrangle areas.

The processing from this point to obtain declination values for epoch 1960.0 from all observations of record since 1900 was a matter of simple arithmetic, but with individual operations numbered in the millions. Here was the province of the automatic computer, which rapidly disposed of the large numbers of repetitive computations.

In brief, this is what was accomplished with no hand work except that of machine operators :

The station cards were sorted by ten-degree quadrangles; annual-change rates for each of the applicable intervals between impulses were interpolated from the master-card values; the total change (rate multiplied by time) was computed for each interval; these total changes per interval were summed; and the resulting total reduction was applied to each station value. Within each one-degree area, all reduced station values were grouped, and mean declination, latitude, and longitude were derived and automatically tabulated. The foregoing steps involved many *runs* of the cards and a variety of operations, during which checks of several kinds were possible, with occasional limited re-runs and machine rejection of disturbed or apparently erroneous values — those differing from the average quadrangle value by more than two degrees.

The final preparation of the chart involved the plotting of mean declination values for 1960.0 at mean position within each one-degree quadrangle; the drawing, justifying, and smoothing of the isogonic lines to suit the plotted values; and the addition of the isoporic or equal-annual-change lines for 1960.0, previously prepared in one of the construction steps.

Several new features or methods are of interest in the 1960 world isogonic chart, as follows : (a) the inclusion of a south-polar isogriv chart, which had not heretofore been a part of the regular charting program; (b) the development and execution of a method of locating the position of the north magnetic pole and simultaneously deriving declination and horizontal-intensity lines and isopors within the 5000-gamma horizontal-intensity contour about the pole, in the Canadian Arctic; and (c) the maintenance of close liaison with the office of the Astronomer Royal of Great Britain, where a 1960 world isogonic chart was also being prepared.

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a) An isogriv chart depicts lines of equal *grivation;* that is, lines for each of which the angle between an arbitrarily selected grid north and magnetic north has the same value throughout. Any convenient direction may be chosen for grid north. This direction then remains identical over the entire chart; that is, a grid-north vector at one point on the chart is parallel to the grid-north vector at any other point. The relation between grid-north vector at any other point. The relation between grid north and true north at any given point, and likewise the value of grivation at that point, will depend on the projection used. Such charts may be constructed for any part of the globe. However, because of the rapid convergence of meridians as the geographic poles are approached, the charts become particularly advantageous in such areas. Isogriv lines combine the corrections of both declination and convergence. Consequently, the navigator, after laying his course and computing his initial magnetic direction, may correct his magnetic direction from time to time by use of the grivation increment. A commonly used grid-north direction is the northerly direction of the Greenwich or zero meridian, and this was used on the 1960 north and south polar isogriv charts. As the charts are constructed on the polar stereographic projection, grivation (plus for east, minus for west) is equal

(A) In the northern hemisphere, to declination (plus east, minus west) *minus* longitude (plus east, minus west);

(B) In the southern hemisphere, to declination (plus east, minus west) *plus* longitude (plus east, minus west).

b) The polar techniques referred to in item (*b*) above were developed by one of the authors (D.G.K.). A complete explanation of the theory and methods properly belongs in a separate paper, but a brief résumé of the process is given here. The objective was to transform the elements declination, horizontal intensity, rate of change of declination, and rate of change of horizontal intensity (hereinafter referred to as D, H, $\dot{D}$ and $\dot{H}$ respectively) into elements having the possibility of a smooth distribution, with no singularity in the area of either the geographic or the magnetic pole. The elements adopted in lieu of D and H were P and Q, where P is the projection of the H vector on the northerly direction of the Detroit meridian, 83° West, and Q is the projection of the H vector on a line normal to that used for P. Meridians other than the 83rd might readily have been used without appreciably affecting the results of the study. It was believed that the position of the Detroit meridian offered the greatest possibility of leading to P and Q isoline patterns that would intersect at right angles in the vicinity of the dip pole, a condition to be desired. Available 1955 values of D and H for the pertinent area were used to compute epoch-1955 values of P and Q for each station. To obtain the annual-change function from 1955 to 1960, observatory data giving values of the north and east components of the magnetic field were used to compute E, the magnitude of the horizontal annual-change vector, and Ψ, its azimuth. A third function δ was introduced by subtracting the longitude from Ψ, thus obtaining freedom from polar singularity. Charts of the annual-change elements E and δ were drawn, and for each station the annual changes P and Q were determined, multiplied by the time interval of five years, and the results applied to the 1955 P and Q values. Charts of the resulting 1960 P and Q were then drawn. Scalings from the four charts of P, Q, E, and δ yielded data for computations of 1960 D, H, $\dot{D}$, and $\dot{H}$ at any desired point in the area. The intersection of the zero P and Q lines for epoch 1960 assisted in fixing the position of the north magnetic pole at 74.9° north and 101.0° west, which was adopted after consultation with the Dominion Observatory of Canada and the Royal Greenwich Observatory, and was substantially in agreement with the result of an independent study along similar lines by the former organization [WHITHAM, LOOMER, and DAWSON, 1959].

c) During the preparation of the 1955 world charts, copies had been exchanged with the Royal Greenwich Observatory with a view to avoiding any large inconsistencies. In the course of work on the 1960 chart, further consultations led to a plan to attempt agreement of isogonals within one degree on the respective charts. The original manuscript copies were compiled independently and then exchanged. Comparative declination scalings were made on a five-degree latitude and longitude grid. Where scaled values agreed within one degree, as was true over a considerable part of the world, neither compilation was altered. After review of the data, it seemed advisable in certain areas, where discrepancies of more than one degree existed, for one or the other version to prevail, with the concurrence of both agencies. In all other areas where agreement was not obtained within one degree, average grid values were computed and plotted, and lines redrawn using the average values as control, thus obtaining a balanced compromise between the British and United States versions. Minor differences between the two versions were permitted to remain, as the time required to remove them would have unduly delayed publication.

Charts are published by the United States Hydrographic Office in the following form :

1. A series of twelve Mercator isogonic charts, covering the world area between latitudes 84° north and 70° south at a scale of 1/12 233 000 at the equator.
2. *a*) A Mercator isogonic chart, covering the world area between latitudes 84° north and 70° south at a scale of 1/39 000 000 at the equator.

   b) A north and a south polar isogonic chart, and a north and a south polar isogriv chart, each covering the area between latitude 55° and the geographic pole. These charts are on a polar stereographic projection at a scale of 1/10 000 000 at latitude 71°.

BIBLIOGRAPHY

WEBER, A. M., and E. B. ROBERTS : The 1950 world isogonic chart. *J. Geophys. Res.*, v. 56, pp. 81-84, 1951.

WHITHAM, K., E. I. LOOMER, and E. DAWSON : Recent studies of the north magnetic dip pole. *Arctic,* v. 12, pp. 28-39, 1959.