Terrestrial Magnetism

and

Atmospheric Electricity

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MAGNETIC DECLINATION AND LATITUDE OBSERVATIONS IN THE BERMUDAS.[1]

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At the wish of Prof. E. L. Mark, Director of the Bermuda Biological Station, the writer spent the three weeks from March 27 to April 17, 1905, in Bermuda for the purpose of making first, a general investigation of the distribution of the magnetic declination in the Islands, and second, a determination of the latitude at some station. Climatic conditions at that time of the year were very favorable for completion of the necessary work in a short space of time. Thanks are due to Mr. Goodwin Gosling, of Bermuda, for providing a horse and buggy and also charts of the Islands. Most of the instruments were the property of the writer.

PART ONE

Magnetic Declination

In 1873 observations for magnetic elements were made at Burmuda by members of the *Challenger* expedition. Intensity observations were obtained at seven, inclination at ten, and declination at seventeen stations. The results of the observations for declination are perhaps the most interesting, from a practical point of view, and remarks will be confined to this element. The *Challenger* was swung for a normal value of the declination fifteen miles south of the Dockyard at Ireland Island. The normal was found to be 7° 18′ west. The values for the declination at different parts of the islands, determined by the *Challenger* Expedition, show the presence of sources of considerable local disturbance.

[1] Contributions from the Bermuda Biological Station for Research, No. ~~11.~~ 13

Previous to 1873 various other determinations of declination had been recorded.

The results of the *Challenger* observations for declination were of such interest that arrangements were made by Prof. Mark for a series of observations for declination, which, though carried out only to tenths of degrees, should be of sufficient number and of even enough distribution to give a better idea of the general direction of the compass needle over the Islands.

Naturally, from the method employed and the instruments available, no precision was to be expected from separate observations. Still, it was thought that in a place where declinations varied several degrees each way from the normal, a greater number of rough observations, sufficiently well distributed over the Islands, would be of more value and interest than a few determinations made with precise instruments. No means were available for getting observations for intensity or dip. A complete investigation involving the three magnetic elements would be of great interest.[1]

The equipment for getting the observations was of the simplest nature. The watch was a Waltham "Riverside," the errors of which were obtained frequently by observations with the sextant and artificial horizon. The time observations were usually taken in the morning before setting out with the compass. The method was that of "Time by Single Altitudes." Generally five to seven altitudes were observed. The eccentricity of the sextant was known from previous testing, so that the time observations are believed to be correct to one or two seconds—which was sufficient for the accuracy to be obtained by shadow observations with a compass. Corrections of the watch were reduced to Ireland Island Mean Time, that of the meridian $4^h\ 19^m\ 18^s$ west of Greenwich.

The compass was the usual type of azimuth compass by Gurley provided with folding sight vanes, a needle of 4½ inches length, and two plate levels; the circle was divided to half degrees. Fig. 1 shows cross section of the compass to half scale. The errors of the instrument will be considered later.

The azimuth observations were recorded in a note book together with the time and a brief description of the locality. The points were generally situated on or near roads, so that the

[1] In July and August, 1907, Prof. H. W. Fisk, magnetic observer of the Department Terrestrial Magnetism of the Carnegie Institution of Washington, determined the three magnetic elements at 45 stations besides dips and intensities at 27 auxiliary stations.—[ED.]

identification was easily made with the help of the ordinance maps of the islands. Where possible, stations, somewhat uncertain, were further identified by bearings of known marks, as islands or lighthouses. The large ordnance maps, on a scale of six inches to the mile, which were furnished by Mr. Gosling, were of the greatest assistance in locating positions. These show the contours, elevations, bench marks, and practically all roads, paths, and buildings. All the stations, at which the azimuth observations were obtained, are shown on the accompanying map, Fig. 2. The positions were plotted by co-ordinates taken from the *small ordnance map, which, as will be shown later gave latitude 16″ too small.*

Care was taken to avoid, as far as possible, proximity to buildings, telegraph wires, iron fences, and other sources of possible

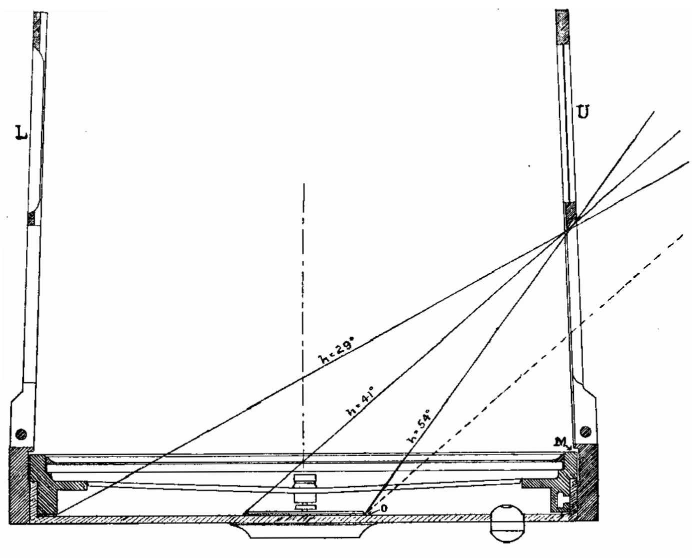


FIG. 1. CROSS SECTION OF COMPASS USED. (½ size.)

disturbance. The procedure in getting a bearing of the Sun was, after leveling to bring the bright line of sunlight, falling through the narrow slit in the lower part of the one vane (L, Fig. 1) into coincidence with the north and south line of the compass plate. The watch time of the coincidence was recorded. As the compass had no slow motion in azimuth it was found best to set the beam of light a little in advance of the position for coincidence so that the diurnal motion of the Sun would bring it to the north and south line without any handling of the compass. The needle was centered so accurately that it was found unnecessary to record the circle readings for both ends of the needle. Any difference noticed—it never amounted to over one-tenth of a degree—was allowed for mentally. As a rule, though, no splitting of tenths was practicable.

Disregarding the errors which will be considered later, the compass reading is the magnetic bearing of the Sun's center The watch times, corrected for error, are the Ireland Island mean times of the observations. These were reduced to the local mean time at the different stations by applying, with proper sign, the difference of longitude in time taken from the chart between the Ireland Island Meridian and that of the station. The local times of each sight were then reduced to apparent times by the equation of time.

From these data—apparent time, latitude, and declination—the corresponding true bearing of Sun was found from Burdwood's Azimuth Tables. The three interpolations necessary were rendered easier by tables, constructed for the occasion, giving the tabular differences in declination, latitude, and time. From these tabular differences the interpolations were made either mentally or by slide rule.

Some bearings were obtained with Sun higher than 60°. They were computed by the formulæ:

$$\tan X = \sin D \sec S \operatorname{ctn} \tfrac{1}{2}t,$$
$$\tan Y = \cos D \csc S \operatorname{ctn} \tfrac{1}{2}t,$$
$$\text{Azimuth} = X + Y \text{ (reckoned from the north);}$$

where S is the half sum of the latitude and declination of the Sun; D is half the difference of the same two quantities; t is the hour angle of the Sun or the apparent time. The magnetic declination is the difference between the true bearing of the Sun and the compass bearing corrected for various errors.

In the following sample tabulation of one day's observations are given first the station number, the watch time, the compass reading, the computed magnetic declination, the approximate altitude of the Sun taken from a celestial globe, and in the last column the magnetic declination, corrected for errors which were found to depend upon the altitude of the Sun. These instrumental errors will be considered later.

Date	Station number	Watch time	Compass reading	Magnetic declination	Sun's altitude	Corrected magnetic declination
		h m s	°	°	°	°
April 1, 1905,	93	9 12 25	S 53.6 E	10.6 W	42	10.4 W
	94	9 17 42	S 52.55 E	10.6	43	10.4
	95	9 22 50	S 51.1 E	10.9	44	10.6
	96	11 19 45	S 12.5 E	9.8	61	9.2
	97	11 26 55	S 7.6 E	11.4	61	10.8
	98	11 42 30	S 0.1 E	11.0	62	10.4
	99	11 51 05	S 4.0 W	10.6	62	10.0
	100	12 01 20	S 9.2 W	10.3	62	9.7
	101	2 43 50	S 72.6 W	10.6	44	10.3
	102	2 49 55	S 73.75 W	10.3	42	10.1
	103	2 54 35	S 75.05 W	10.6	42	10.4
	104	3 00 55	S 76.3 W	10.6	41	10.4
	105	3 07 20	S 77.8 W	10.8	39	10.7
	106	3 14 08	S 78.3 W	10.0	38	9.9
	107	3 19 55	S 81.25 W	11.8	37	11.7
	108	3 25 18	S 82.7 W	12.3	35	12.2
	109	3 30 55	S 83.5 W	12.0	34	11.9
	110	3 39 20	S 84.6 W	11.7	33	11.6
	111	3 48 15	S 85.6 W	11.1	31	11.0
	112	3 53 40	S 86.6 W	11.2	30	11.1
	113	4 30 40	N 89.3 W	9.6	22	9.5
	114	4 37 00	N 88.2 W	9.8	21	9.7
	115	4 44 10	N 86.05 W	10.9	19	10.8
	116	4 49 25	N 85.3 W	10.9	18	10.8
	117	4 53 45	N 85.1 W	10.9	17	10.8
	118	5 01 20	N 84.0 W	10.9	15	10.8
	119	5 11 28	N 82.5 W	10.6	13	10.5
	120	5 17 00	N 82.3 W	10.1	12	10.0

Compass Errors

No confidence can be placed in azimuth observations taken with an ordinary compass unless the Sun is low. Small defects in the compass cause a rapid increase in the errors when the Sun's altitude is over 30°. This applies of course only to shadow observations. Consequently, in 1906 and 1907, observations were taken at Castle Island, Boston Harbor, to furnish a table of errors of the compass at Bermuda. At Castle Island standard magnetic observations have been made by the United States Coast and Geodetic Survey. The station occupied by the Survey in 1905 was not marked, but a new station, marked by a stone post, within 60 feet of the old one, was established by the Survey in 1906. It was found that for the accuracy required of the Bermuda observations, the magnetic declinations at the two Coast Survey stations was the same. Hence, observations which were taken with the compass in 1906 before the establishment of the new station, were not discarded. About one-sixth of the total number of sights were taken at the old station. These observations showed that the compass had considerable error depending upon the altitude of the Sun. The sights were taken in the same manner as those at Bermuda.

A careful examination of the compass and an analysis showed the cause of these errors, and confirmed the system of errors obtained.

Observations for determining the magnetic declination, in order to get a table of errors for the Bermuda values, were made at Castle Island on eleven days between March, 1906, and May, 1907. These were made in the same way as the Bermuda observations.

Compass Correction

Altitude	Correction	Altitude	Correction
°	°	°	°
5	—0.1	45	—0.3
10	0.1	50	0.4
15	0.1	55	0.5
20	0.1	60	0.6
25	0.1	65	0.7
30	0.1	66	0.7
35	0 1	67	—0.8
40	—0.2		

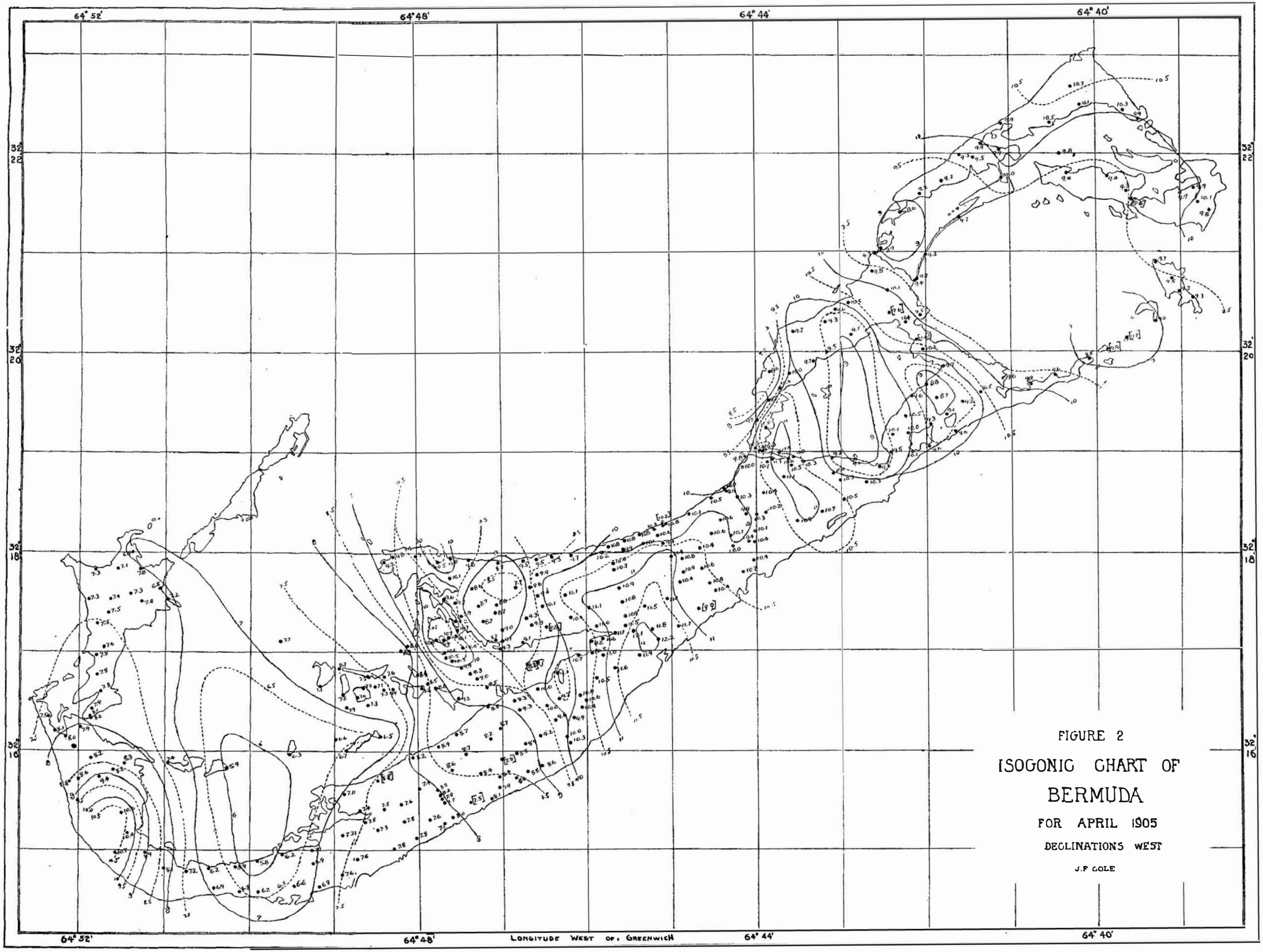
In the above no account is taken for diurnal variation in magnetic declination as this correction would, in general, be less than the error of observation, viz., $0^\circ.1$.

These were the values used to correct the observed magnetic declinations at Bermuda. The probable error of a correction for any altitude can hardly be more than one-tenth of a degree.

The isogonic lines of the map, Fig. 2, were drawn to conform as nearly as possible to the values obtained. The dotted lines are for the half degree curves. *It should be noted that the latitudes as shown on Fig.* 2 *require to be increased by 16″.* (See Part Two.)

For fourteen stations the declination values are decidedly anomalous; they are indicated by enclosure in brackets on the map. One-half of these differ by one degree from the values expected from the map. It is quite possible that in these cases, an error of an even degree or half degree may have been made. An examination of the values taken immediately before and after the suspected ones, with a knowledge of the change in azimuth of the Sun in the interval, shows in each case that this is very probable, since these cases happen to occur in regions where the declination does not change rapidly. The accidental errors due to imperfect levelling and imperfect setting of the beam of sunlight are believed to be, as a rule, less than three-tenths of a degree, even with the Sun at a high altitude.

The map shows in general a large area of declination below the normal around Great Sound. Another large area, above the normal, extends eastward from Hamilton Harbor. In the northeast part of Bermuda, the declinations, although in parts irregular, do not differ greatly from the normal. Rapid changes in the values



[N. B—*The Latitudes as shown on this Chart require to be increased by 16″.*]

occur south of Morgan and Tucker's Islands, and in the region southwest of Point Shares.

Recent values of the normal declination at Bermuda are found on the sailing charts. Hydrographic chart No. 1411 of the Atlantic Coast, 1894, shows the normal for the region of Bermuda to be about 8°.6 west, and that the normal curves run N 44° W. On Hydrographic chart 1495 of Great Sound, taken from the Admiralty, is a statement that the normal 8°.4 (1895) was found at Grassy Bay; that the declination was 2½° greater at Clarence Cove, and 1¼° less at the Cemetery of Ireland Island. Hydrographic chart No. 27 of the Bermudas, gives values of the declination from 8°.5, west of the Islands, to 8°.75 east of the Islands. The average of all the values on the map, Figure 2, is 9°.3 W, though in such a disturbed region this can hardly be taken as representing the normal.

Part Two

Determinations of Latitude, Flatts Village, Bermuda

Latitudes and longitudes on Chart No. 27 of the Bermudas, published by the United States Hydrographic Office, are taken from Admiralty data, probably the best source. A small ordnance map of Bermuda on a scale of one inch to the mile is provided with longitude and latitude lines. Although it is claimed that these are inserted from Admiralty data, the latitudes differ by 16″ from the Admiralty values. Thus, the latitude of Bastion C, Ireland Island, taken from the ordnance map is 32 19′ 21″. The Admiralty latitude is 32 19′ 37″. The longitudes from the two charts agree very well. In view of the discrepancy in the latitudes, which is great enough to be determined readily by accurate portable instruments, the Bermuda Biological Society desired a set of latitude observations.

The instrument with which the latitude observations were taken was a Wegener prismatic circle, No 1948, ten inches diameter, graduated on silver to 10′ with two opposite verniers reading to 10″. This type of sextant gives very bright images, enabling a power of 10 to be used with ease for star work. The horizon glass is a 90° prism. All the back-lash in the tangent screw is taken up by a spring; this fact contributes much to the accuracy of a setting.

The artificial horizon was a wooden block upon which a strip of heavily tinned sheet iron was held. Mercury poured over this amalgamated with the tin, enabling a very small amount of mercury to cover the whole surface of the tin—about 1¾ inches by 4¾ inches in extent. The effect of the amalgamation is to lessen the quivering of the mercury when disturbed, as a very thin film is all that is required to give a true level plane.

In order to get as careful observations as possible I made a stand, permitting slow motions of altitude and azimuth and swinging. The circle could be taken off the stand quickly for reading the verniers by means of a cylindrical stud, firmly screwed to thg center leg of the circle. This stud slipped into the correspondine socket of the stand where it could be clamped, permitting only slow motion in altitude by a lever and tangent screw. Time observations of the Sun and stars were frequently taken.

Polaris was observed for latitude on the evenings of March 29, 31, April 4, 7, 8, 1905, at the Frascati Hotel.

The index readings were taken at the close of each evening's work. Temperature conditions were so steady that it was thought unnecessary to observe twice each night for index.

The instrumental double altitudes were reduced to true altitudes by properly correcting for index and refraction. The mean of the two vernier readings was in each case used. The latitude corresponding to each sight is obtained finally by applying to the true altitude the correction:

$$x = +p \cos t - \tfrac{1}{2} p^2 \sin^2 t \tan h + \tfrac{1}{3} p^3 \cos t \sin^2 t - \tfrac{1}{8} p^4 \sin^4 t \tan^3 h$$

where p is the polar distance of Polaris, t its hour-angle, and h its true altitude. The work was carried to even seconds of arc.

The average of the 68 observations made, uncorrected for, graduation errors, is: 32° 19′ 22″.5 N.

The graduation errors of the circle were determined by meridian observations of the Sun at Marblehead, Mass., from September to November, 1906. *By means of the corrections so determined the finally adopted value of latitude is:*

32° 19′ 13″.2 N.

The probable error of a single observation, account being taken of probable error of graduation correction determination, is: 4″.7, and of the result adopted, 0.″5.

By carefully measuring on the large ordnance map of Bermuda the differences of latitude between the Frascati Hotel and prominent points, the latitudes of which are published as representing Admiralty values, the Admiralty latitude of the place of observation is found to be 32° 19′ 13.″1, with perhaps an uncertainty of 0.″4 from the measurement. The accordance of the circle observations, taken in 1905 and corrected as described above, with this Admiralty value makes it highly probable that the latitudes published on the small ordnance map of Bermuda were erroneously inserted.