TERRESTRIAL MAGNETISM
AND
ATMOSPHERIC ELECTRICITY
AN INTERNATIONAL QUARTERLY JOURNAL

Conducted by
L. A. BAUER
Department Terrestrial Magnetism, Carnegie Institution
of Washington, D. C.

With the Assistance of

J. S. AMES
Johns Hopkins University, Baltimore

TH. MOUREAUX
Observatoire, Parc St. Maur

CHARLES CHREE
Kew Observatory, Richmond

H. F. REID
Johns Hopkins University, Baltimore

R. L. FARIS
Coast and Geodetic Survey, Washington

ADOLF SCHMIDT
Magnetisches Observatorium, Potsdam

J. A. FLEMING
Carnegie Institution of Washington

R. F. STUPART
Meteorological Service, Toronto

COUNCILORS

J. ELSTER AND H. GEITEL
Germany

A. ANGOT
France

M. RYKATCHEW
Russia

A. SCHUSTER
England

R. S. WOODWARD
United States, N. A.

VOLUME XXIII
MARCH—DECEMBER, 1918

THE JOHNS HOPKINS PRESS
BALTIMORE, MARYLAND
1918

TABLE OF CONTENTS

MARCH, 1918

JUNE, 1918

SEPTEMBER, 1918

DECEMBER, 1918

RESULTS OF DIP-OF-HORIZON MEASUREMENTS MADE ON THE *GALILEE* AND *CARNEGIE*, 1907-1917.[1]

BY W. J. PETERS.

The principal work of the Department of Terrestrial Magnetism on the oceans has been that of the magnetic survey. While it has been the desire to include other scientific investigations which might be made advantageously at sea, yet these have been necessarily restricted by the small personnel, and by the extensive program required for the daily magnetic and navigational work. Accordingly, only such additional observations could at first be undertaken that have an important bearing on the magnetic work, or such which would not conflict with the regular schedule. Among these are observations of atmospheric refraction as affecting the dip of the horizon.

Since all astronomic positions at sea depend upon Sun- or star-altitudes measured from the horizon, it is evident that the precision of the determinations of the geographic positions for the magnetic stations at sea will be affected by the error of that value of the refraction which is used in calculating the dip of the horizon. Experience shows that while the refraction for a star may be calculated with sufficient precision for ordinary altitudes, it will be quite uncertain for very low ones, and at the horizon it may even be found with opposite sign to that calculated. Fortunately for astronomic navigation, the path of the optical ray from the horizon passes through a very small portion of the atmosphere compared to rays from the Sun or stars. Thus while the refraction correction to the altitude of a star seen in the horizon may be over ½ degree, the correction to the altitude of the horizon, that is, the dip of the horizon, is ordinarily not more than 1′ or 2′, and its uncertainty is no doubt correspondingly small. While this may be fortunate for astronomic navigation, it is not so for the investigator who tries to ascribe its fluctuations to some physical law, for it is difficult to measure angles of less than 1′ at sea.

Although the atmosphere refraction is *usually* small, reports of extraordinary values from time to time have shown the desirability of extensive investigation, and a number of observations have been made, principally by German investigators, during the last

---

[1] Presented before the Philosophical Society of Washington, April 27, 1918.

30 years. Koss, who prepared the first tables of dip-of-horizon that have a temperature argument, has observed the horizon 10′ above its normal position and 3′ below. An interesting experience is given in "Tables of Calculated Hour Angles, etc.," by H. S. Blackburne,[2] who says:

> "A few years ago an old pupil of the writer, Captain W. H. Sweny, then commanding the P. & O. S. S. *Mooltan*, had a remarkable experience of exceptional refraction on the evening before making Rottnest Light. He took observations of four different stars at about 6 p. m., on April 11, 1910, and afterwards sent to the writer his own observations, asking him to work them out, and let him know what he made the resulting position, but without divulging what he made the result by his own calculations. This was done, and when Captain Sweny afterwards sent the results of his work, both observations were in agreement, and evidently not more than about 1′ in error in either latitude or longitude. The captain also sent the worked-out observations of the other two officers, and from all these observations the writer was able to deduce fairly accurate separate positions, and it was evident from these observations that refraction was excessive all round the horizon, but greatest to the northward, where it was about 11′.0, and in other parts of the horizon averaging about 6¾′, the altitudes being smaller by these amounts than they should have been by allowing the usual tabular corrections."

A German epitome[3] states that the horizon has been observed 15′ above and 3′ below its normal position. Bowditch[4] says that reliable observations have frequently placed it 10′ above, and values as high as 32′ have been recorded. The significance of these figures will be realized when it is remembered that each minute of abnormal refraction means an error of one mile in the position of the ship.

Such extraordinary values of the refraction at the horizon, as cited in the previous paragraph, have not been found during 10 years of work at sea by the Department of Terrestrial Magnetism, covering all the oceans. Whether the large abnormal values may occur along the borders of equatorial and polar currents, shallows, and waters swept by very warm or very cold breezes blowing off land, regions in which the cruises of the *Galilee* and *Carnegie* have not been prolonged, requires further investigation.

In all the observations taken first on the Galilee, then continued on the Carnegie, amounting to 3,031 determinations, the refraction has not raised the horizon more than 2′.4 nor depressed it more than 2′.0 below the position in which it would be seen if no refraction

---

[2] Blackburne, H. S. Tables of calculated hour-angles and altitude azimuth table 30° N. to 30° S., second edition, p. xxvii.

[3] Lehrbuch der Navigation, herausgegeben vom Reichs-Marine-Amt., second edition, Berlin, 1906, p. 110.

[4] Bowditch, N. American Practical Navigator, Washington, 1914, p. 117.

existed. The observations were made mostly at heights above sea of 24 and 18 feet. The maximum raising of the horizon, + 2′.4, was found on two consecutive days, October 29 and 30, 1915, between New Zealand and Australia; there was a heavy sea at the time and the horizon was noted as "rough." The next maximum raising, + 2′.2, was also observed on two consecutive days, February 9 and 10, 1908, in latitude 41° S., longitude 111° W., when a very high sea, with clear, well-defined horizon, was noted. Values of + 2′.0 occur quite frequently, that is, about 1′ above the average refraction at sea. The maximum depression, − 2′.0, occurs only once in the 10 years, and was observed August 11, 1914, in latitude 71° N., longitude 5° W., with well-defined horizon and good conditions generally; the position is on the northern edge of the Gulf Stream, and not far from the ice floes of Greenland Sea, in a region where atmospheric conditions are subject to marked changes. Negative values are more rare than positive.

All *methods in use*, up to the present time, for measuring the refraction at the horizon, depend on one common principle—that of measuring the vertical angle between two diametrically opposite points of the horizon, or of measuring the difference between this angle and 180°. This principle, common to all methods, is objectionable because it must be assumed in general that the refraction is the same for opposite points of the horizon. It is possible that unusual values might be observed on occasions when the direction of the abnormal value might be assigned with some degree of plausibility, as, for example, when it is observed from near the edge of an ocean current that may be plainly traced from the vessel, or when mirages occur limited to a small part of the horizon, or by the adjustment of many observations taken about the same time well distributed around the horizon. Experience, however, on the *Galilee* and *Carnegie*, shows that the first two suggestions could only be used on very rare occasions, and the last is not practical on a sailing vessel, where the sails will always interfere with an uninterrupted view of the horizon at a height of 18 feet above water. Heights of less than 18 feet are not desirable in investigations of the refraction.

Among the *instruments available for measuring the dip-of-horizon at sea* are prismatic and reflecting circles, sextants, Troughton's dip sector, the Blish attachment and Kohlschütter's device for sextants, and the dip-of-horizon measurer by Pulfrich. The prismatic circle, sextant, and dip-of-horizon measurer have been tried on the *Galilee* first, subsequently on the *Carnegie*, but none of these instruments has been found entirely satisfactory. The prismatic circle was acquired primarily for land observations, and was found to be so unwieldy at sea that only a few experiments were attempted. The principal objections to using sextants are the restriction imposed by the limits of their arcs, the much computing usually required to obtain the dip, and the periodic errors of the instrument, which are difficult to control; these errors, of no importance in navigation, are likely to be quite serious in attempts to measure fluctuations in refraction no larger than a fraction of a minute.

The most promising instrument at first seemed to be *Pulfrich's dip-of-horizon measurer*,[5] made by Zeiss, of Jena (Fig. 1). It consists of a low-power telescope, at the object-end of which is attached a box containing a system of 3 reflecting prisms. Rays from opposite points of the horizon enter through perforations or windows, one on each side of the box. They are reflected by the 3 prisms into the telescope. The images of the two opposite portions of the horizon appear as vertical lines. The dark portions of the field represent the sea, and the light band between represents the sky. The dip-of-the-horizon is one-half the angular width of this band, provided, of course, that the instrument is in perfect adjustment. Two methods are used to measure the width of the band; one is a micrometer screw arrangement which moves one of the prisms and enables the observer to bring the two horizons into contact; the other is a fixed-scale arrangement in the focus of the objective. It consists of 2 lines intersecting at a very small angle, on one of which a scale is laid off so that each number of the scale represents the number of minutes or one-half the number of minutes of angular space included between the lines. Fig. 2 shows, for example, that at the point of the scale marked 15 there are 30 minutes of arc between the two diverging lines. A small rotation of the instrument about the horizontal axis of the telescope will bring the images of the two horizons to any part of the scale, so that the trapezoid formed by the horizons and the scale has one of the parallel sides equal to the side formed by the scale. The intersection on the scale of this one of the sides indicates the reading.

The observations with the Pulfrich measurer are made first

---

[5] Pulfrich, C. Ueber einen Apparat zur Messung der Kimmtiefe, *Zs. Instrumentenk., Berlin*, 1904, Heft 8, pp. 225-229. Moll, E. Der Pulfrich'sche Kimmtiefenmesser, *Hansa*, Hamburg, 1906.

Fig. 1.

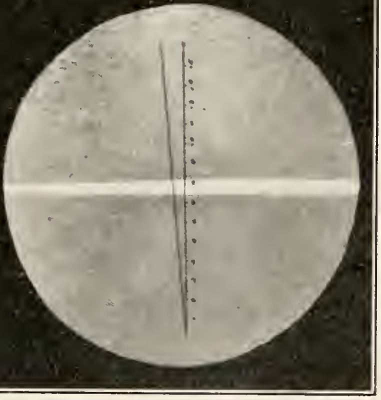

Fig. 2.

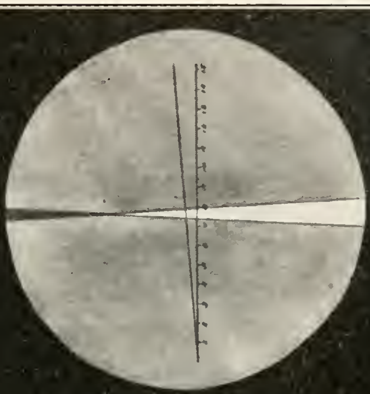

Fig. 3

with one end of the box up, or erect (*E*), and then, after rotating the instrument 180° about the horizontal axis of the telescope, the set is completed by a second reading inverted (*I*). The mean of the two readings is free from errors of maladjustment of the prisms and lack of parallelism in the window glasses. Half of the difference of the two readings, ½ (*E-I*), is the combined error of maladjustment and lack of parallelism of window glasses, and should remain constant. In the instrument numbered 4048, ½ (*E-I*) varied from 7′.1 to 7′.8; this change has been attributed to personal error, since careful inspection has not revealed any looseness of the optical parts. The personal error is largest for No. 4048, and might be explained by the fact that the observer has to estimate two trapezoids of quite different aspects. When the instrument is used erect, the trapezoid-area is the sky; when it is inverted, the images of the sea overlap and the trapezoid area becomes a small dark figure. No. 4048 was used on the *Galilee* and the *Carnegie*.

The micrometer form of the Pulfrich measurer seemed to be more satisfactory while using it. The observers state that the observations are more easily made, but the values of the constant, ½ (*E-I*), show little improvement over those of the fixed-scale form. Error probably occurs when the observer has to decide when the two images of the horizon are in contact and yet not overlapping. A somewhat similar difficulty is found in the determination of index error of a sextant by the sea-horizon method. The result is not so precise as when the sun or stars are used.

The difficulties of observing with the Pulfrich mesaurer *at sea* are increased by the motions of the images as the observer tries to hold the instrument steady. The chief objection is a scissors-like motion which no amount of practice apparently will eliminate; it is caused by changes in the inclination of the telescope to the horizontal. Fig. 3 represents an instantaneous view of the field as the motion is taking place. While the dark and light wedges are continually shifting from top to bottom the observer must decide when the horizons are parallel and must bring the trapezoid to the proper point of the scale at the same instant. He can only do this by a series of approximations. Besides the obstacles to precision which are inherent in this instrument, there are others which affect all instruments.

The actual conditions of visibility, etc., of course are taken care of by the observer's remarks, and these observations may be weighted or rejected, as desired.

One constant source of error is in the height of instrument adopted. Did no refraction exist, the dip-of-the-horizon could be computed for a given height of instrument with more precision than it could be measured. The difference between this computed dip and the dip observed being regarded as the refraction for the given height, it will be in error by the same amount as the computed dip, if the latter is in error. Supposing the given height of about 18 feet to be in error by one foot, the refraction deduced will have an error of 0′.12.

The *height of instrument* is measured in smooth water, as it is not practical to measure it at sea, and it changes with the draft of the vessel, with her rolling and pitching and as she rides the waves and drops into the troughs. Changes in draft are caused by the consumption of water, fuel, and stores, and may be allowed for by assuming a linear change from port to port, where the draft can be accurately read. The *Carnegie's* draft changes about 1½ feet during a long passage. As to the ship's rolling and pitching, it is most probable that observations for dip of horizon are never made on the *Carnegie* when she is inclined as much as 5° to the vertical, since care is taken to make them only on even keel as nearly as can be determined. This precaution was also taken on the *Galilee*.

The error in the height caused by an inclination of 10° is 0.3 foot for a height of 24 feet on even keel, and would cause an error less than 0′.1 in the deduced refraction. An error of this size is not likely to occur, as one can estimate even-keel position closer than 10°, but errors caused by the rolling and pitching of the vessel will always be in the same direction, and can not be entirely eliminated by the mean of many observations. It is more likely to be present on a sailing vessel heeled over by the wind, but even then, if she is on the open sea, she will frequently roll to an upright position. The necessity of precaution is confirmed by notes made on the passage of the *Carnegie* from Port Lyttelton to South Georgia, December, 1915, to January, 1916, in which the observer remarks:

> "When the vessel rolled heavily, as was nearly always the case, the width of light or dark band (that is, double the dip) would increase or diminish 50 per cent of the ordinary value."

As the ship rides the waves and drops into the troughs of the sea, the vertical height of the instrument above mean sea-level changes. The visible horizon is delineated as a straight line by the crests of the distant waves, if the sea is not too high and irregular. *Accordingly, observations are made only when the vessel rides the waves, on the supposition that the waves are all of the same height and that the instrument will be raised a like amount.* This precaution, however, does not eliminate the whole error, for when the vessel rides the waves, her load water-line is not tangent to the crests of the waves, but always below them. The adopted height therefore, is too high by the vertical height of the waves above the load water-line. The magnitude of the error will depend upon the relative lengths of the ship and the waves, and the angle at which she crosses them. If, for example, long swells reach her broadside on, she will ride them practically at her load water-line.

Observations.—Those on the *Galilee* were made by one observer, using dip-measurer No. 4048. Two readings were always made, sometimes 4, 6, and 8, one-half with instrument erect, the other with inverted position. Those made on the first three cruises of the *Carnegie* were obtained with the same instrument (No. 4048) by different observers. Another instrument, No. 4031, was courteously loaned by the United States Coast and Geodetic Survey during the first two passages of the fourth cruise, after which it was replaced by instrument No. 5490. Every determination of the dip-of-horizon on the fourth cruise of the *Carnegie*, therefore is the result of 2 instruments, and observers were changed every passage or every two passages.

The *data recorded* include the date, latitude, longitude, approximate local time, height of instrument above sea, aspect or definition of the horizon, wind direction and force, air and water temperatures, barometer reading, the directions sighted, cloud notes, and direction of the Sun.

In the adjustments that have been made only those observations were used that were obtained under good conditions of the horizon. In the last few years German investigators of the refraction of the horizon have introduced a temperature coefficient in the adjustment of their observations. The temperature of the air can be measured on the ship, but there is no means of measuring the temperature of the air in contact with the sea at the horizon, so it is assumed that this temperature is the same as the surface of the water at the ship. Both temperatures as ordinarily observed may be subject to errors resulting from the methods used. The water temperature is obtained by immersing a thermometer in a bucket of sea water immediately upon hauling it aboard. This is a rather crude procedure, but more precise methods are not likely to give better results in the adjustment until larger systematic errors are eliminated.

The temperature of the air as usually measured on board ships has been questioned by Dr. Brehmer[6], who has found errors of 4° C., depending upon the location of the thermometer. Von Karl Willy Wagner[7], after some experiments made on a cable steamer, probably of steel, concluded that errors due to ordinary fixed locations on steamers might amount to 1° and more, and that they usually indicate a temperature higher than the actual air temperature. Exceptional errors of 2° and more were easily explained by heated air rising from a steamer in a calm or traveling with the wind.

The *Carnegie* is built of wood, as was also the *Galilee*. The *Carnegie* is seldom driven by her engine, and the only other sources of heat are the 2 galleys, both of which are well forward of the thermometers. In calm weather this heat, and possibly the heat of the vessel, may raise the temperature slightly, and this may account for some of the large temperature differences found, but it will not account for many. The largest one observed, $-7°.7$ C., is the difference between air of a blizzard blowing at the time, February 11, 1910, and the warm waters of the Gulf Stream. The temperature of the ship could have had little effect, if any, and that would have been to decrease rather than increase this difference.

In attempting to adjust the observations by using a temperature-difference term, the *Galilee* observations were taken up first and a preliminary adjustment was made to determine from them the temperature-difference coefficient which Chauvenet[8] deduces from theoretical considerations and gives in the formula

$$D - D' = 400 \frac{t_a - t_w}{D}$$

in which D is the dip-of-the-horizon (expressed as seconds in the first term and as minutes in the last term), computed on the supposition of no atmospheric refraction, D' the dip affected by refraction, and t_a and t_w the air and water temperatures, respectively,

---

[6] BREHMER. Nachtrag zur Genauigkeit von Kimmtiefenbestimmungen, *Ann. Hydrogr., Berlin*, v. 39, No. 3, 1911, p. 143.

[7] WAGNER, K. W. Ueber systematische Fehler bei der Messung der Lufttemperatur auf Schiffen, besonders in den Tropen und einige andere Beobachtungen, *Veröff. Met. Inst., Berlin*, No. 244, 1912, pp. 83-95.

[8] CHAUVENET, W. Manual of spherical and practical astronomy, Philadelphia, 1863, v. 1, p. 176.

expressed in Fahrenheit degrees. Chauvenet gives no table for this formula, and evidently has no great confidence in it, for he says:

> "I know of no observations sufficiently precise to determine whether this simple formula deduced from theoretical considerations accurately represents the dip in every case."

The results of the adjustment of the *Galilee* observations show conclusively that the formula will not represent the dip.

The same *Galilee* observations, and also those of the fourth cruise of the *Carnegie* were then adjusted to Koss's equation,[9] which, for a constant height of eye, may be written:

$$D - D' = x + y\,(t_a - t_w)$$

The results are given in Table 1.

The adjustments of the observations of first, second, and third cruises of the *Carnegie* were deferred, pending the results of the adjustment of the fourth cruise, since the observations on this cruise having been made with two instruments with frequent changes of observers might indicate some improvement in methods of observations or adjustment.

The values of x for the *Galilee* are not strictly comparable with those of the *Carnegie*, for a different height of instrument was used. On the *Galilee* it was usually 23.8 feet, while on the *Carnegie* it is 18 feet. However, the difference, about 6 feet, makes very little difference in the value of x, as might be expected.

The range in the values of x might be explained partly by personal or instrumental error, the existence of which *is* suggested by different values that different observers get for the instrumental constant of maladjustment, that is, one-half the difference of reading erect and inverted. The existence of this error appears to be confirmed by the two pairs of values given for the period March 11 to May 21, 1915. The observations during this period and also subsequently were made with two instruments. One was used immediately after the other, so that all conditions, motion, height of instrument, visibility, temperature, etc., were practically identical for each instrument. The difference for the second pair, April 12 to May 21, is unusually large. Its magnitude might be due to the inexperience of the observer, especially as it has not been repeated since, and also as the probable error is about twice as large as the average.

[9] Meyer, H. Kimmbeobachtungen, *Ann. Hydrogr., Berlin*, v. 34, Heft 9, 1906, p. 438.

TABLE 1.—*Results of the adjustment of refraction observations made on board the Galilee, 1907-08, and the Carnegie, 1915-17, according to the equation:* $D-D'=x+y\ (t_a-t_w)$.

(Height of instrument above sea: For the *Galilee*, 23.8 feet, or 725 cm.; for the *Carnegie*, 18 feet, or 549 cm.)

Vessel	Date Interval	x	y	No. of Ob'sns	Probable Error	Average Range in Temp. Diff.	Measurer No.	Observers
	1907	′	′		′	°C.		
Galilee	Mar. 14-Apr. 29	+0.8	+0.1	26	0.09	0.7	4048	W. J. P.
	Apr. 30-June 23	+0.9	+0.1	27	0.17	0.6	"	
	June 24-Aug. 25	+1.0	+0.1	28	0.19	0.4	"	
	Aug. 26-Oct. 15	+0.9	+0.1	26	0.24	0.7	"	
	Oct. 15-Nov. 23	+0.7	+0.1	32	0.18	0.4	"	
	Nov. 24-Dec. 8	+0.8	0.0	24	0.13	0.7	"	
	Dec. 8-Jan. 19	+0.8	+0.1	33	0.21	0.8	"	
	1908							
	Jan. 22-Feb. 13	+1.1	+0.1	28	0.16	0.6	"	
	Feb. 13-Mar. 1	+0.7	−0.1	32	0.13	0.5	"	
	Mar. 1-Apr. 12	+0.6	+0.1	27	0.15	0.5	"	
	Apr. 13-Apr. 25	+0.8	0.0	30	0.11	0.8	"	
	Apr. 26-May 20	+0.6	+0.1	38	0.15	1.2	"	
Galilee	Cruises, 1907-08	+0.81	+0.09	357	....	0.7	4048	
	1915							
Carnegie	Mar. 11-Mar. 24	+0.5	−0.1	31	0.17	1.8	4048	I. A. L.
	Mar. 11-Mar. 24	+0.2	0.0	31	0.21	1.8	4031	I. A. L.
	Apr. 12-May 21	+0.1	+0.1	90	0.31	0.8	4048	H. E. S.
	Apr. 12-May 21	+0.7	0.0	87	0.30	0.9	4031	H. E. S.
	July 3-July 19	+0.7	0.0	34	0.14	1.3	4048 & 5490	I. A. L.
	Aug. 6-Nov. 2	+1.0	0.0	164	0.13	0.9	" "	H. E. S.
	Dec. 6-Jan. 10	+0.9	+0.2	39	0.22	1.1	" "	I. A. L.
	1916							
	Jan. 15-Mar. 31	+1.0	+0.1	111	0.18	1.0	" "	F. C. L.
	May 18-June 6	+1.0	0.0	40	0.11	0.8	" "	F. C. L.
	June 19-July 16	+0.6	0.0	72	0.08	0.8	" "	I. A. L.
	Aug. 8-Sep. 20	+0.7	+0.1	55	0.11	0.7	" "	I. A. L.
	Nov. 2-Dec. 24	+0.8	−0.1	120	0.16	1.1	" "	A. D. P.
	1917							
	Jan. 2-Mar. 1	+0.6	+0.1	107	0.18	1.1	" "	L. L. T.
Carnegie	Cruises 1915-17	+0.79	+0.02	863	....	1.0		

The ranges in x might also be explained by changes in draft of the vessel, and by the height and length of waves. These sources of possible error were not considered until after the adjustments had been made, and so far as known they have not been considered in any previous work. There is a tendency for all low values of x to group themselves in the equatorial regions and high values to occur in the high latitudes, but this distribution, which might be significant, requires further confirmation.

The value of the temperature coefficient, y, changes sign in both series, and the final values which result from including all the observations in one adjustment for each cruise are $+0'.09$ and $+0'.02$, the weighted mean of which is $+0'.04$, if double weight be given to the *Carnegie* value on account of more observations, and that there were two instruments and various observers. This value is practically negligible, for it will not amount to ½ a minute for a temperature difference of 10° C., a larger difference than has been found on our vessels. Koss[10] gives $+0'.33$ for the temperature coefficient, as determined on the Mediterranean and Red seas, where conditions are different from the oceans.

The four largest temperature differences, for the *Galilee* or the *Carnegie*, $t_a - t_w$, are $-7°.7$, $-6°.2$, $-5°.6$, and $+5°.6$, for which the "Nautische Tafeln," based on Koss's temperature coefficient, give the respective dips $7'.7$, $6'.4$, $6'.2$, and $2'.4$, whereas the observed dips were, respectively, $5'.5$, $5'.2$, $5'.8$, and $5'.2$, while the usual tables give the one value $4'.2$ for all temperatures.

From these comparisons it may be concluded that the dip tables based on a temperature difference argument, as published in the "Nautische Tafeln" and the "Nautisches Jahrbuch" are no improvement over those which ignore the temperature, at least for practical use on the deep waters of the ocean.

Table 2, which is an extension of one published in "Annalen der Hydrographie" for 1906,[11] shows the values of x and y as given by various observers. Again these are not strictly comparable, on account of the difference in height of instrument. There is also a big variation in the number of observations. The observations by Koss extend over a year. Meyer's results are from about 287 observations, the *Albert* from 15 equations, each one depending on 1 to 8 observations, the *Carnegie* sextant from 27, and the dip-

---

[10] Meyer, H. Kimmbeobachtungen, *Ann. Hydrogr., Berlin*, v. 34, Heft 9, 1906, p. 438. See also: Resultate neuerer Kimmtiefenbeobachtungen u. s. w., *Ann. Hydrogr., Berlin*, v. 29, Heft 4, 1901, pp. 164-165.

[11] Meyer, H. Kimmbeobachtungen, *Ann. Hydrogr., Berlin*, v. 34, Heft. 9, 1906, p. 448.

TABLE 2.—*Various determinations of the constant part of refraction, x, and the temperature coefficient, y, in the equation:* $D-D'=x+y\ (t_a - t_w)$.

Height of Instrument	x	y	Observer
ft.	′	′	
21.2	+0.25	+0.35	Koss.
33.3	+0.30	+0.36	
20.0	+0.33	+0.34	Meyer.
20.5	+0.44	+0.30	
29.5	+0.47	+0.29	
22.6	+0.44	+0.47	U. S. S. *Albert.*
23.8	+0.81	+0.09	*Galilee.*
18.0	+0.79	+0.02	*Carnegie.*
18.0	−0.20	−0.06	*Carnegie* (sextant).

measurer results from both *Galilee* and *Carnegie* are deduced from over 1,000 observations. Koss's results are from theodolite observations on a point of land. Meyer's come mostly from prismatic-circle observations. The instrument used on the U. S. S. *Albert* is not known.

The sextant observations on the *Carnegie* were made by an observer of unusual skill with this instrument. Index errors were determined for each day's set, and periodic errors were controlled by shore observations at the close of the series. The result differs very much from all others. The explanation might be that the periodic errors were not stable, or that the magnifying power was too low.

Comparisons with the dip-of-horizon tables ordinarily used, that is to say, with tables in which the temperature difference is disregarded, is most conveniently made by referring to the equations on which these tables are constructed, as shown in Table 3.

Conclusions.

1. The dip-of-horizon tables in common use which ignore air-water temperature differences are sufficiently accurate for the navigator.

2. Extraordinary values such as quoted in the beginning of this paper may possibly occur occasionally in certain regions, where one should be ready to detect them either by observing stars in different azimuths or by special instruments or attach-

TABLE 3.

Table	Equation for dip-of-horizon	Dip	
		16 ft.	50 ft.
	′	′	′
Chauvenet,[12] Bowditch[13], Inman[14]........	$0.980\sqrt{h}$ ft.	3.9	6.9
Martin[15]............................	$0.984\sqrt{h}$ ft.	3.9	7.0
Nautisches Jahrbuch[16]................	$1.005\sqrt{h}$ ft.	4.0	7.1
Nautische Tafeln[17]....................	$0.978\sqrt{h}$ ft.	3.9	6.9
Galilee, II, III; *Carnegie*, IV...........	$0.89\sqrt{h}$ ft.	3.6	6.3

ments to the sextant. Even if the direction of the abnormal value is uncertain, the knowledge of its existence is a factor of safety.

3. During the 10 years of observations of atmospheric refraction made aboard the *Galilee* and the *Carnegie*, in all the oceans, amounting to 3,031 determinations, the observed values of refraction have not raised the horizon more than 2′.4, nor depressed it more than 2′.0 below the position it would be seen, if no refraction existed.

4. If aerial navigation across the oceans is eventually realized, which seems quite likely, and astronomic methods are used, then simple means of measuring the dip-of-the-horizon might be very desirable, if not absolutely essential. At present the aviator determines the height of his ship by the aneroid, which has not the precision necessary for computing the dip.

---

[12] CHAUVENET, W. Manual of spherical and practical astronomy, Philadelphia, 1863, v. I, p. 177.

[13] BOWDITCH, N. American Practical Navigator, Washington, 1914, p. 509.

[14] INMAN, J. Nautical tables designed for the use of British seamen, London, 1906, p. ix.

[15] MARTIN, W. R. A treatise on navigation and nautical astronomy, third edition, London, 1899, p. 147.

[16] Lehrbuch der Navigation, herausgegeben vom REICHS-MARINE-AMT., second edition, Berlin, 1906, p. 111.

[17] Nautische Tafeln der K. und K. Kriegs-Marine, Pola, 1902, p. xvi.

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON.