MEASUREMENT OF THE DIP OF THE HORIZON

Lecture delivered by Captain E. MOLL.
at the Verein Deutscher Seeschiffer at Hamburg, 3rd. *October*, 1906.

The life of a seaman is a constant warfare with the forces of nature, which, partly in visible form and partly in invisible form, press in from all sides and make the exercise of his profession more difficult. Modern science and technique have provided us to-day with excellent weapons to combat this enemy successfully and to aid us to obtain victory in the great majority of cases; in spite of this there are, however, other natural phenomena against which we are comparatively helpless, since being unable to see them with the human eye, the detrimental influence which they exert can only be approximately determined at best, in spite of all scientific methods. It is a well-known fact that in war and in any other phase of the struggle for existence nothing is more dangerous than to underestimate the strength of the enemy. If we follow carefully the records of the maritime courts we find that a large number of marine disasters involving loss of life and property are to be attributed, apart from culpable neglect of the necessary precautionary measures, to an under-estimation of the hindrances which the natural phenomena prevailing at the time may impose upon the navigation of the ship. It seems proper, therefore, that we should examine more closely the nature of these invisible natural phenomena which, under certain circumstances, are capable of exerting such an extremely evil influence on navigation and to seek for means which will at least materially diminish these detrimental effects and, if possible, eliminate them altogether.

Since, in spite of all the experiments which have been made along these lines, it has been found impossible to construct an artificial horizon for use at sea which is reliable and by means of which it would be possible to measure the altitude of the heavenly bodies above the mathematical horizon, we are to-day, as before, reduced to the necessity of using the sea horizon for this purpose. Apart from the often disagreeable fact that this horizon is not visible at night or in a fog or is not defined with sufficient sharpness, there is the further drawback that as a result of the caprices of terrestrial refraction the horizon is slightly displaced from its normal position and appears raised or lowered by appreciable amounts to the eye of the observer. This is nothing new in itself since in practically every textbook on navigation, attention is directed to the fact that the altitudes observed above the sea horizon may easily be in error if the refraction of light is strongly influenced by abnormal atmospheric conditions, so that the actual dip of the horizon differs materially from the value obtained from tables. Unfortunately this subject has been treated by our scientists from a much too theoretical standpoint, as a result of which the impression has been created, among practical seamen, that the question involves trivialities which may be neglected in practice. It has been established from reliable observations, however, *that errors of* 10' *and more are not rare*, so that it becomes of the greatest importance to study the problem somewhat more thoroughly.

The values given in tables for the dip of the horizon are correct for average conditions of terrestrial refraction. The calculation is based on the experimentally determined fact that, under normal conditions, as a result of the atmospheric refraction, the observed object is elevated about 1/13th of its distance in nautical miles converted into minutes of a great circle. Since the light rays from the horizon reach the eye of the observer after passing through the lower strata of the atmosphere and since the density of these particular layers is greatly influenced by the prevailing meteorological conditions, it is evident that the values for the dip of the horizon given in the tables may differ materially from those obtaining in actual practice.

Everyone has probably noted that objects which are seen over a lamp or a warm stove appear to shimmer. The reason for this must be sought in the fact that the heated air rises through the colder layers and thus air strata of unequal temperature occur which refract the light rays differently. The apparent shimmering or twinkling of the stars, which is frequently observed as a harbinger of bad weather, may also be due to currents of warm and cold air in the atmosphere.

We are, therefore, justified in concluding that the abnormal rèfraction of the light rays which reach the eye of the observer from the horizon, is favoured also by unequal distribution of temperature in the lower atmospheric strata. This will be the case particularly in those instances where a material difference between the temperature of the air and the water exists.

If the water is colder than the air, then the lower layers of the air directly over the water become considerably cooled, and the cooling is slowly conducted to the higher layers so that strata of unequal temperature occur. Since in this cooler, denser medium the light rays reaching the eye of the observer from the horizon incline towards the vertical, the line of sight appears to be raised. Under such conditions the observed altitude may be too small, since the value of the dip of the horizon taken from the tables will be too large. Objects on the horizon, such as lighthouses, etc., will be seen from much greater distances than normally.

The opposite phenomenon occurs when *the water is warmer than the air* since then the lower layers of air become warmed and less dense. The ray of light will then be less refracted towards the vertical than under normal conditions and the line of sight appears to be lowered. The values for the dip of the horizon taken from the tables will then be too small and the observed altitude will be too great. Objects on the horizon such as lighthouses, etc., will then appear at less than the normal range of visibility.

Such irregular distribution of temperature in the individual strata of air, which is a condition of abnormal refraction, is naturally much favoured by a calm or light airs, whereas a stronger breeze tends to restore thermal equilibrium between the higher and lower strata of air.

A very excellent means with which to counteract the above mentioned detrimental conditions successfully is by observations of stars. In the twilight, in clear weather it will usually be possible to take observations of stars in rapid succession in different directions around the horizon, taking those for latitude in northerly and southerly directions about the meridian and for longitude those in easterly and westerly directions in the vicinity of the prime vertical. With a little practice in the proper selection of suitable stars the mean result of such observations will give a position which is very nearly correct, provided that the dip of the horizon, as a result of refraction, is uniform in every direction, which will usually be the case.

Further, it has been found in practice that, in clear weather, it is advantageous to observe the altitudes from the highest suitable position on board ship, as experience has shown that, with a great height of eye, the abnormal depression of the horizon resulting from refraction is less noticeable and the horizon is more sharply defined. Also, an error in the height of the eye, which is easily possible when the ship is working heavily in a seaway, has less influence on the result, as may be readily seen by a glance at the tables and a comparison of the values for the increase in the dip of the horizon at various heights. In misty weather with low visibility, when the apparent horizon is possibly obscured by the state of the atmosphere, it is advisable to employ as small a height of eye as possible and thus take observations for altitude from as close to the surface of the sea as possible. At a height of 3 feet above the water the horizon is only two miles distant and consequently, when the visibility is from 2 to 3 miles, it is sometimes possible to take altitudes from the lowest step of the accommodation ladder. The results of such observations should always be used "*with caution*", and, particularly in the vicinity of land, other precautions such as slow speed and constant sounding should not be neglected.

Numerous scientists and practical seamen have sought, for a long time, to discover some definite law governing the deviation of refraction from its average values and, in recent times especially, some success has been obtained in this field of endeavour.

Based on observations on land (1) the geodetists BAEYER, BAUERNFEIND, and others, were able to prove a diurnal variation which bore a relation to the temperature of the air. However, the insulation of the ground plays a decisive part in the distribution of temperature. Since at sea, however, the temperature of the water differs but slightly from the temperature of the air and remains close to the daily mean temperature, there will be no such periodic variation as pointed out by OPPOLZER (2) ; a fact which has been confirmed by observation. Here also the temperature gradient, or temperature distribution in altitude remains the essential factor governing terrestrial refraction, while the other meteorological elements, such as barometric pressure, humidity, etc. play a subordinate role.

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(1) *Annalen*, 01, *IV*, *page* 163-64.

(2) Th. v. OPPOLZER : "*Ueber den Zusammenhang der Refraktion mit der Temperaturverteilung in der Atmosphäre. (On the connection between refraction and the temperature distribution in the atmosphere). Supplement to the May, 1884, vol. of the "Zeitschrift der österreichischen Gesellschaft für Meteorologie*".

From the most simple observations of the sea-horizon, particularly in the vicinity of coasts, BUDDE (1) came to the conclusion that measurements based on the sea horizon might introduce errors of several minutes in observed altitudes.

Prolonged observations of the horizon, on Starnberg Lake, by F. LINGG (2), resulted in refraction constants which lay between — 0.3 and + 0.3, when the height of eye was 2 metres above water level, while BAUERNFEIND, in the trigonometrical work carried out between Dobra and Kapellenberg, observed values of between 0.09 and 0.22 only. LINGG found also that, in the course of the day, the horizon lies higher in the early morning hours and gradually sinks from this high position with the increase in the temperature of the air, reaching its lowest level at various times, after which it again begins to rise. In this case it should be noted, however, that the observations were made over a small bay of water in which the air temperature is of great influence.

Humid air raises the horizon above its normal position while a dry atmosphere causes it to be depressed. The differences in the periodic variations of the horizon on different days led LINGG to the conclusion that it is occasioned less by differences in the absolute amounts of the air temperatures than differences in the periodic vertical distribution of temperature in those strata of air through which the light rays pass to reach the eye.

From this it is clear that LINGG correctly judged the cause of the apparent movement of the horizon, but his observations were not sufficiently accurate to permit serviceable values to be deduced therefrom for use in practice.

A comprehensive series of observations for the dip of the horizon, extending over several years (1863 to 1876), but which individually were not sufficiently systematic, was taken by E. KAYSER (3), who, from the observatory in Danzig, measured the difference in altitude between the lighthouse of Hela and the apparent sea horizon. In this case the height of the observation point was 78 Rhenish feet above sea-level while the height of the lighthouse, distant 29.7 kilometres, was 130'. He found an appreciable variation in the height which, in apparently normal atmospheric conditions, varied between 1'13" and 6'52", but which increased to as much as 8'24" when atmospheric mirage occurred. While at times extreme values remained practically unchanged over long periods, at other times the changes in the dip of the horizon were very rapid. From observations made in later years, in which an instrument different from the first was employed, KAYSER calculated the constant k of refraction for the lighthouse to lie between the limits of 0.36 and 0.07 and for the sea horizon between 0.55 and 0.14. On an average the observations for the lighthouse gave a value of $k = 0.1306$, that is, very nearly the value found by GAUSS and others. This was due to the fact that the line of sight to the lighthouse was relatively high and the strata of air through which the light rays pass were more nearly of an even temperature than the layers closer to the water level. Although KAYSER systematically recorded the meteorological data at the place of observation, the corresponding data for the sea horizon and the water is lacking. It is therefore impossible further to evaluate this otherwise rich mass of material.

The first practical measurements made in which account was taken of all meteorological elements and in particular of the data regarding water temperature, were initiated on board the French ship *La Galissonnière* in 1884 in the Red Sea, in the Indian Ocean and in the China Sea, the height of eye being 9 metres (4). PERRIN himself, however, did not discover the law which governs the change in the dip of the horizon. These observations furnish a welcome confirmation of the laws enunciated by Koss as a result of his measurements.

In order to complete the record the observations undertaken by FOREL (5) on Lake

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(1) E. BUDDE : "*Ueber eine Eigentumlichkeit des Seehorizonts*". (*On a peculiarity of the sea horizon*). "*Oesterreichische Meteorologische Zeitschrift*", 1885, *page* 354.

(2) F. LINGG : "*Ueber die bei Kimmbeobachtungen am Starnberger See wahrgenommenen Refraktionserscheinungen*". (*On the refraction phenomena observed on the occasion of observations on the dip of the horizon over Starnberg Lake.*) *Nova Acta Acad. Leopold,* 1889.

(3) E. KAYSER : "*Beobachtungen über Refraktion des Seehorizontes und Leuchtturmes von Hela*". (*Observations on the refraction of the sea horizon and the Hela Lighthouse*). *Schriften der naturf. Ges. in Danzig, New Series, IV, Vol.* 2, 1877.

(4) E. PERRIN : "*Sur les Dépressions de l'horizon de la mer*" (*On the dip of the horizon at sea*). *Comptes-rendus,* 129, 1899, *pages* 495 *and* 597.

(5) F. A. FOREL : "*Les variations de l'horizon apparent*" (*The variations of the apparent horizon*). *Comptes-rendus,* 129, 1899, *page* 272.

of Geneva should be recalled; these, however, do not attain a degree of accuracy which would make them comparable with those of Koss. This is probably due in part to the fact that the temperature relations over the inland waters are much more complicated than those over the open sea and are therefore subject to greater variations.

The latest, and at the same time the most important and successful work, was undertaken by the Austrian Naval Officer (then Commander) Koss, and this gave results which won such high recognition in technical circles that Koss's initiative may be characterized as epoch-making, particularly as it encouraged navigators to devote much attention to this important question.

On the assumption that the majority of practical navigators (for whom this work is done) usually have neither the time not the inclination to read long scientific discussions, it will suffice to give the net result of the work done by Koss.

During the years 1887 and 1888, Koss accompanied the expedition of the *Pola* to the Red Sea and the Mediterranean, and he took this oppotunity to make a series of observations for the dip of the horizon. The results proved so interesting that they were an incentive for further systematic observations which were carried out in 1898 and 1899 by Koss with the co-operation of (then) Sublieutenant Graf THUN-HOHENSTEIN at a point, particularly suited for such observations, near Fort Verudella in the vicinity of Pola on the coast of the Adriatic. These were carried out in such a manner that the position of the horizon was observed from morning to evening by means of a theodolite and a levelling instrument from three different heights (10, 16 and 42 m.).

At the same time observations were made to determine the temperatures of the air and water in the vicinity of the instruments as well as near the horizon — these being recorded by a small steamer at sea — including also all other essential meteorological data. These results and those obtained by Koss during the *Pola* expedition, led Koss to the most important conclusion (1) that the depression of the horizon, even terrestrial refraction on land, depends on the difference of temperature between the point of observation and the position of the object observed.

The dip of the horizon may, therefore, be represented as a function of the difference between the air and water temperatures, while the barometric pressure, the humidity and nebulosity may be entirely neglected. Further, the actual height of the thermometer modifies the cœfficient of refraction to such a slight extent that the same results are applicable in all latitudes.

Further, Koss succeeded in establishing a law based on the difference in temperature between the water and the air, so that he was able to calculate tables from which the corrected values for the dip of the horizon (in which the differences in water and air temperatures were taken into consideration) could be taken. The tables in question were published in the "*Mitteilungen auf dem Gebiete des Seewesens*", Pola, in 1900, page 438, and were reprinted later in the "*Annalen der Hydrographie*", 1901, page 167, at the conclusion of an article on the same subject (written by Dr. MESSERSCHMIDT). These tables of the dip of the horizon were restricted to differences between the water and air temperatures up to 6 or 8 degrees, as a result of which they cannot be characterised as sufficiently comprehensive to cover all possible cases. Dr. KOHLSCHÜTTER, the Astronomer of the Reichsmarineamt, has fortunately devoted considerable study to the Koss Tables and published the results in an interesting article in the "*Annalen der Hydrographie*", 1901, page 553 and 554: *Conclusions drawn from the Koss Observations for the Dip of the Horizon at Verudella.* Since a thorough study of the article would lead us into realms of higher mathematics beyond the ken of the average practical navigator we will not go into the derivation of the formula established by Dr. KOHLSCHÜTTER, viz:

$$\text{Dip of horizon} = 1.82\sqrt{h} - 0.003\,h - 0.41\,\Delta$$

the third term of which served as the basis for the calculation of Table I which follows.

(1) *Annalen*, 1901, *IV*, *page* 165. *Mitteilungen auf dem Gebiete des Seewesens, Pola* 1900.

TABLE I. (1) — ALTITUDE CORRECTION FOR VARIATION IN DIP WITH TEMPERATURE.

Difference between water temperature and air temperature at height of eye.											
1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°
Air warmer than water.											
+ 0.4	+ 0.8	+ 1.2	+ 1.6	+ 2.1	+ 2.5	+ 2.9	+ 3.3	+ 3.7	+ 4.1	+ 4.5	+ 4.9
Air colder than water.											
— 0.4	— 0.8	— 1.2	— 1.6	— 2.1	— 2.5	— 2.9	— 3.3	— 3.7	— 4.1	— 4.5	— 4.9

TABLE II. — CALM OR VERY LIGHT AIRS.

Height of eye.	*Difference between air temperature at height of eye and that at water level.*					
	+ 6°	+ 5°	+ 4°	3°+	+ 2°	+ 1°
m.						
6					+ 4 ½	+ 2 ½
8				+ 6	+ 4	+ 2
10				+ 5 ½	+ 3 ½	+ 1 ½
12			+ 7	+ 5	+ 3	+ 2
14		+ 7 ½	+ 6 ½	+ 4 ½	+ 3 ½	+ 1 ½
16	+ 9	+ 7	+ 6	+ 4	+ 3	+ 2

In the formula Δ is the difference: air temperature at height of eye minus water temperature. The second term in the equation is not taken into consideration because it is very small. The first term represents the well-known formula employed for calculating the mean dip of the horizon due to refraction, in which a mean cœfficient of 0.11 is assumed for terrestrial refraction. The third term is taken from table I with the opposite sign to that given in the formula, since it is to be applied as a correction to the altitude and not to the dip of the horizon. The sign depends on whether the water or the air is the warmer. Therefore in making use of these tables, it is only necessary to apply the correction to the observed altitude, taking into account the sign due to the altitude, before applying the total correction. As is readily apparent, the observed altitude will be too small when the water is colder than the air. If the water is warmer than the air the opposite is to be expected.

Table II, which is extracted from the "*Mitteilungen auf dem Gebiete des Seewesens*", Pola, 1900, page 438, is valid for the case where a calm or very light airs prevail, so that the warmer air may collect in the higher strata without being mixed with the colder air currents of the lower strata by the action of the wind. Under these conditions an abnormal increase may result in the temperature in the upper strata, which, as may readily be seen from Table II, causes a considerable elevation of the horizon. For instance, Koss noted, in such circumstances in the course of the afternoon, a constant and rapid rising of the horizon until the sea horizon, which at a height of eye of 16 metres should have shown a dip of 7'40", appeared 1'7" above the eye's horizon, where it remained

(1) *Taken from Nautical Tables issued by the Reichsmarineamt and the Inspection des Bildungswesen der Marine.*

for one hour until sunset. At the same time, from a height of 10 metres, where the normal dip should have been 6'4", it was raised 3'19" above the level of the eye's horizon. *Under these conditions the observed altitude of the sun would have been 9' in error!!* In such cases, according to Koss ("*Mitteilungen*", 1900, page 437) additional consideration should be given to the fact that when the layers of warm air are stratified in this abnormal manner, the same conditions hold true in the layers above the level of the eye of the observer and, in addition to the abnormal raising of the horizon, the incident light ray from the observed body will also be subject to a certain amount of refraction in passing through the last few metres of its path above the eye of the observer.

Unfortunately, in making use of these tables for the dip of the horizon, it should be remembered that, on board merchant ships, it is quite impossible to take temperatures with the degree of accuracy required such as was actually obtained in the case of the Koss observations, since these necessitate the use of instruments of precision which are seldom, if ever, available. Further there may be a not inappreciable difference in the temperatures of the water at the horizon and at the position of the ship, which would also be a source of inaccuracy which it is impossible to avoid. Nevertheless it is advisable, on the occasion of every astronomical observation, to take the temperature of the water at the surface as accurately as possible as well as the air temperature somewhat above the water level and at the height of the eye (in the shade if possible) and to compare the mean values with the values obtained from Tables I and II. From this some indication can be obtained on which to base an estimate in which direction the error in the observed altitude above the horizon is to be sought as a result of abnormal refraction. It would, therefore, be fundamentally wrong to seek a universal panacea in these tables which would justify blind confidence in the data given therein. In spite of this *we must certainly grant that they are a very valuable aid which, when used with intelligent consideration of the prevailing conditions at the time of observation, is certainly to be preferred to the older procedure of applying the uncorrected dip to the altitude.* In this connection Dr. MESSERSCHMIDT, of the Deutsche Seewarte, makes the following remarks in the "*Annalen*", 1901, page 166:

"If we except the use of the above mentioned instruments (the respiration thermometer for air temperatures, and the aspiration thermometer for water temperatures), to the introduction of which in the Navy there are many objections, there will still be an appreciable increase in the accuracy of astronomical observations at sea due to the use of the Koss method of determining the dip correction, by which, even in the most unfavourable circumstances, the altitude can be obtained *within at most* 2 *minutes*; whereas by the employment of the usual tables for dip, *errors* of five times that amount, or as much as 10', are not impossible!» (I cannot fully subscribe to this assumption, particularly in the case of the use of Table II, the employment of which presupposes an accuracy of temperature determination which is practically unobtainable on board ship).

One particularly interesting and instructive fact deserving emphasis is that, in the course of the Koss observations for dip of the horizon, *elevations of the horizon of* 10' *and depressions of* 3' *from the normal position* were noted, which confirms the assumption of practical navigators that under certain circumstances, the altitudes observed from the sea horizon may be very considerably in error. In an article which appeared in the "*Annalen der Hydrographie*" (vol. IV, 1905, page 158-171) by a retired Captain of the Hamburg America Line, Freiherr v. SCHRÖTTER, entitled "*The Influence of terrestrial Refraction on Navigation*", the following very interesting tabulation is given showing the parts of the ocean in which strong and abnormal cases of refraction may be encountered. The remaining portions of the article, which is written by a seaman for seafaring men and is characterized by clearness and intelligibility, is also very well worth reading:

"Strong and abnormal cases of refraction may be encountered with great frequency in the following parts of the ocean:

1) *Constant throughout the entire year.*
   - *a*) In the vicinity of the Banks of Newfoundland, where the cold polar current comes into contact with the warmer waters of the Gulf Stream.
   - *b*) On the west coast of Africa from Cape Blanco as far as Mogador (where the cold current rises to the surface).
   - *c*) On the west coast of Africa from the Cape of Good Hope to the Congo (where the colder currents come to the surface).

2) *Temporary, or particularly frequent or at certain definite seasons.*
   - *a*) In the ocean areas of the temperate zone in spring and summer.

b) In the cold zone, over ice-free water or water surrounded by ice.

c) On some coasts where high snow covered mountains exist in close vicinity to tropical waters, with offshore winds, for example :—
In the vicinity of the Sierra Nevada de Santa Maria, Colombia ; on the west coast of North and South America where the Andes are close to the sea (It is not certain whether these marked cases of refraction are due to the rising of deep cold currents or to other causes).

d) On the coasts of tropical seas, in which at times large rivers discharge quantities of cold water from the mountains or glaciers, for instance, in the Gulf of Mexico near the mouth of the Mississippi.

e) On coasts and bays past which strong currents flow at times as a result of which cold water is drawn to the surface from the depths, for example, in the Bay of Rio de Janeiro and Santos, to the westward of Cape Frio, as a result of the trade wind drift which is diverted to the southwest. On the African coast between Cape Palmas and Cape Three Points during the time of the S. W. monsoon, when the strongest Guinea Current is encountered, from June to September.

f) On the east coast of Africa to the north, east and south of Cape Guardafui as far as Ras Hafoun, from May to October.

According to other available reports, mirage and strong refraction phenomena may be observed : on the south coast of Australia, in the inland waters on the east coast of Asia, in the Sea of Okhotsk, in the Yellow Sea and in the China Sea, in the Mediterranean and in the Red Sea " (1).

Although on the basis of the above considerations, we are led to the conclusion that, even with a rational application of the Koss Method, there still remains a great deal of uncertainty with regard to the altitudes taken above the sea horizon, there still remains no doubt that in nautical practice, there is an urgent need for a simple apparatus which will permit the depression of the horizon to be determined by direct measurement. Various attempts in this direction have already been made. Among these the invention of the American Lieutenant Commander Blish deserves special mention. His attention was directed to the irregularities in the dip of the horizon by the fact that it was found impossible to locate the position of a cable steamer accurately by means of one side altitudes. The invention is called the "horizon prism" and consists of a truncated glass prism which is attached, by means of aluminium supports, to the hand grip of a sextant and is so constructed that one portion of the horizon is reflected through 180°, while the other side is viewed directly. If the reflected and direct images of the horizon are then brought into coincidence, the angle measured on the sextant corresponds to twice the dip of the horizon, from which all possible instrumental errors must naturally be deducted.

Further, Dr. Kohlschütter has invented a so-called prismatic telescope for measuring the dip of the horizon and Lieutenant Commander Koss has also invented a device for the same purpose. Complete descriptions of the instruments of Blish and Kohlschütter are to be found in the "*Annalen der Hydrographie*", 1904, vol. IX, pages 514 to 522. With regard to the Koss apparatus the author has no further information. It does not appear necessary to go further into the advantages and disadvantages of the above mentioned instruments, because that for measuring the dip invented by Dr. Pulfrich possesses great advantages over the others and therefore has a much greater probability of being introduced into nautical practice. Dr. Pulfrich, of the scientific staff of the well-known optical firm of Carl Zeiss of Jena, undertook the construction of an instrument for measuring the dip of the horizon at the suggestion of Dr. Kohlschütter and, after tedious experiments, succeeded in perfecting the instrument to such an extent that it can be put to practical use as fruit ripe for eating.

In the course of the various experiments which were made by various technical experts, including among others Dr. Kohlschütter himself, it developed that, contrary to the method of Blish, it is more advantageous to measure the dip of the horizon with an instrument which is independent of the sextant. In the tests which were subsequently made on board the Adlergrund Lightship in the summer of 1904 by Professor Stück at the instigation of the Reichsmarineamt, on the different types of instruments which were manu-

(1) *Annalen*, 1905, *page* 170.

factured for this purpose, it was found that the PULFRICH « horizon meter » provided a satisfactory solution of the problem and was superior to any of the other types. The favourable report on this instrument made by Professor STÜCK which was published in the "*Annalen der Hydrographie*", 1904, page 510, caused the author to request the Firm of Zeiss to supply him with one, for experimental use during the voyage of the Hamburg America Liner *Abessinia* to Philadelphia and back in June and July 1906, in order to ascertain whether the device should be recommended for general introduction in the merchant marine.

In courteous compliance with this request two types of the apparatus, *a* and *b*, Fig. 1, were placed at the disposal of the author. The principle of construction, in both types, is based on the determination of the dip of the horizon by measurements of the angular distance between two diametrically opposite sides of the horizon, the difference between which and 180°, as may be readily seen, equals twice the dip of the horizon. For this purpose use is made of the principle of the angle-mirror which consists of two separate mirrors placed cross-wise and which has the well-known property that two rays of light falling on the mirror from opposite directions are reflected back with a difference in direction which is independent of the position in which the instrument is held. A device may be included in the optical system of the instrument such that the difference in direction of the two rays may be measured directly or else may be varied by measurable amounts.

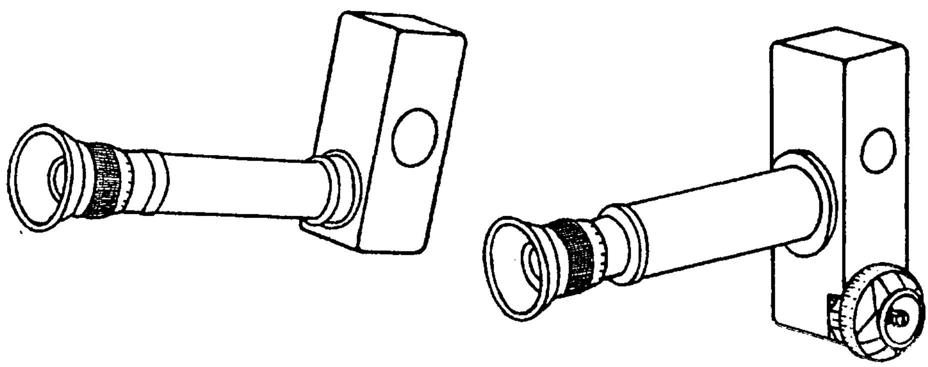

Fig. 1. — *Pulfrich's Instrument for measuring the dip of the horizon*

a) *With scale in the eye-piece* b) *With micrometer screw*

This principle was employed in the construction of the instrument which consists of a telescope, which should be held approximately horizontal and a cruciform mirror made up of the mirror *ab* and the three prisms *bcd*, *bde*, and *edff* (see figure 3, front elevation and figure 4, side elevation). In this manner opposite portions of the horizon, to the left and right of the observer, are brought into the field of vision of the telescope simultaneously. Between the first two prisms *bcd* and *bde*, is the silvered surface *bd*, half the silvering of which is removed in strips, so that not only is the light falling on the upper surface reflected as in any mirror, but the light rays coming from the rear can pass through the prism as through a transparent glass plate. This arrangement of the prisms was adopted at the suggestion of Professor STÜCK (1) who found, in the experimental instrument in use on board the Adlergrund Lightship, the drawback that the so-called "double exit pupil" made itself objectionably noticeable. This trouble, which is present also in the ordinary sextant, may be easily noted if the observer attempts to bring two terrestrial objects in coincidence with the sextant and moves his eye back and forth near the eye-piece. In this case it will be found that one of the objects becomes clear and distinct while the other disappears and vice versa, the second becomes clear while the first disappears. In order to bring the two objects into coincidence, therefore, the eye must be in a mean position in which both objects are faintly visible. This objectionable disappearing of one of the portions of the horizon has been eliminated by Dr. PULFRICH by placing the prisms one behind the other and not alongside each other and by covering one with a partially transparent silvered surface.

(1) *Annalen*, 04, *IX*, *pages* 520-21.

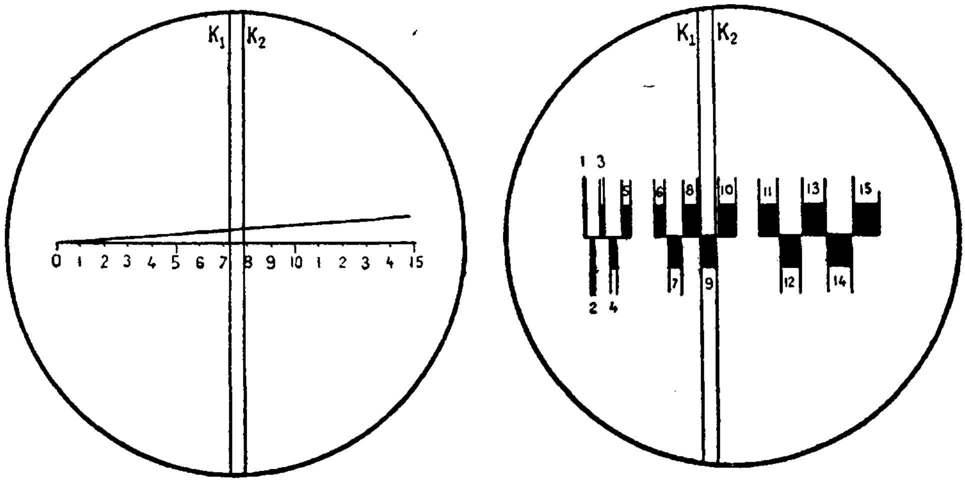

Fig. 2. — *Wedge scale*

The two sides of the horizon *when the telescope is held horizontally* then appear in the field of vision as two vertical parallel lines ($K1$ and $K2$ in Fig. 2), the distance between which is equal to twice the dip of the horizon, regardless of the position in which the instrument is held. The sign of the dip (— when the sea horizon is below and + when it is above the mathematical horizon) is readily determined by observing whether the strip between the lines is air or water.

The instrument acts as follows (1) :

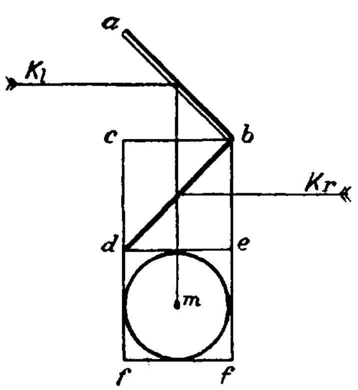

Fig. 3

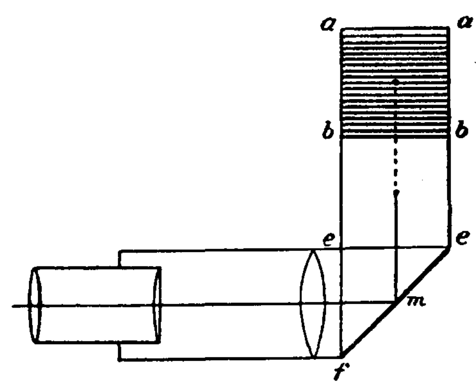

Fig. 4.

" The light ray coming from the right, *Kr*, impinges on the prism from the side *be* is reflected downward by the silvered strips *bd* to *m* where it is again reflected into the optical axis of the telescope in a horizontal direction, but at an angle of 90° to the original direction.

The ray coming from the left, *Kl*, is reflected downward by the mirror *ab*, passes through the prism *bcd* and through the gaps between the silvered strips on *bd*, then passes through the prism *bde* and reaches the point *m* where it is reflected into the optical field of the telescope together with the light ray coming from the right. Thus the observer sees in front of him the images of the two portions of the horizon lying to his right and left, as in Fig. 2.

If the mirror *ab* be placed perpendicular to the half-reflecting silvered surface *bd*, then the distance between the two images of the horizon corresponds to the sum of the dips of the horizon on the right and on the left".

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(1) *Text book on navigation issued by the Reichsmarineamt.*

The two types *a* and *b*, which were made available, differ from each other principally in the manner of measuring the angle. Type *a* is fitted with a device which permits the dip of the horizon to be read off directly on a wedge shaped scale which appears in the field of vision of the telescope (see Fig. 2). In order to measure the dip of the horizon the observer has only to note in which position on the scale the quadrilateral formed by the two legs of the wedge scale and the two sections of the sea horizon *appears practically square*. The second type *b* is not provided with a scale but is fitted with a micrometer screw which turns one of the prisms, by which means the space between the two images of the sea horizon is made to disappear. When this coincidence has been obtained the angle of dip may be read off on the drum attached to the micrometer screw. The tests made aboard the *Abessinia* were carried out in the following manner :— In so far as weather conditions permitted, the dip of the horizon was measured three times daily from various positions between 7 and 16 metres above sea level and the results of these measurements compared with the values taken from the Koss tables after taking the water and air temperatures into consideration.

In the course of these experiments it was found that type *b*, with the micrometer screw arrangement, was much less suitable for use on board ship than type *a*, since it was very difficult to bring the two parallel images of the horizon into exact coincidence. If the ship has much motion in a seaway I consider this operation quite impossible. Further, in the construction of this type there is the grave objection that the micrometer device may very easily get out of adjustment and therefore has to be constantly checked, this may be done by turning the apparatus through 180° about the axis of the telescope.

On the other hand type *a* was found to be eminently suitable for use on board ship and was extremely easy to handle. Even when there was considerable motion on the ship the apparatus could be moved very easily to bring the two portions of the horizon approximately parallel and visible simultaneously in the position on the scale at which the quadrilateral formed by the two legs of the scale and the parallel lines appears very nearly square. *The parallelism between the two portions of the horizon indicates also whether the telescope is being held in an approximately horizontal position.* Naturally, in this type of scale there can be no great mathematical accuracy, but in my opinion it is fairly easy for an average observer to estimate the correct position of the small square along the scale with an accuracy of within 0.3', which is adequate for all practical purposes.

The eye-piece of the telescope must naturally be focussed to suit the eye of the observer, however, once the position of the prism has been properly adjusted there is nothing to get out of order in this type.

In the early use of this instrument a disadvantage was discovered in that the illumination of the two images of the horizon in the field of the telescope differed and thus made accurate reading of the scale more difficult. As may be readily understood from a glance at the path of the rays shown in Fig. 3 the image reflected from the left side of the horizon appeared to be considerably brighter than the other. This drawback was overcome by Professor PULFRICH by attaching an adjustable device on one side of the instrument which made it possible, by partially cutting off the rays impinging from that side, to regulate the illumination of the two images as necessary.

During the voyage no great discrepancies were noted between the values for the dip obtained by direct measurement and the mean values obtained from the ordinary tables, which is to be attributed to the fact that, generally, the air and water temperature differed by very small amounts (at most 5° C.). The greatest discrepancy was noted on 23rd. June when, in bright clear weather at 8 o'clock in the morning, in 40°43' N., 57°09' W., air temperature 17.3° C., water temperature 21.5° C., the dip of the horizon measured at a height of eye of 16 metres was 8.2' and at 7 metres height of eye it was 5.7'. The corresponding mean values should have been 7.1' and 4.7' and those to which the Koss correction had been applied 8.5' and 6.5' respectively. At 2000 on the same day, in 40°23' N., 60°14' W., air temperature 14° C. and water temperature 16° C., the dip of the horizon observed, at height of eye 16 metres, was 6.7' and at 7 metres, 5' ; *thus, between morning and evening, at a height of eye of 16 metres, a difference of 1.5' was found.* According to Koss the corresponding values, which should have obtained with this difference between water and air temperature, are 8' and 5.5' respectively. It is noteworthy that on several days, in spite of a difference of from 3° to 4° between the water and air temperatures, the dip of the horizon, as measured, corresponded with the mean values obtained from the ordinary tables, and therefore in these instances, the application of the Koss corrections would have made the results worse. The explanation of the difference between the values of the dip measured by the PULFRICH apparatus and those obtained from the Koss tables probably lies in the fact that the temperatures were taken according to the general practice on board ship. The dry-bulb thermometer was in an ordinary wooden psychrometer screen, at the after end of the wheel-house on the bridge, at a height of 13 metres. For taking the water temperature the ordinary sailcloth bucket and water thermometer were employed.

On the basis of a subsequent comprehensive study of these results, the impression was gained that the air temperature readings, taken in this particular manner, cannot be considered reliable. It appears advisable therefore, in taking readings for this purpose, to remove the thermometer from the screen, where it probably is not sufficiently shielded from the sun, and to set it in a favourable place in the shade where the air temperature may be read, not only at the height of the eye, but as closely as possible to water level.

The results lead also to the indubitable conclusion that it is better to measure the dip of the horizon by means of the PULFRICH apparatus than by using the Koss method for this is based upon requirements which, in ordinary practice on board merchant vessels, are very difficult to fulfil. Further, by direct measurement, the observer is independent of errors due to a mistake in the height of the eye, which under certain circumstances is an advantage which is not to be underestimated. The assertion, made earlier in this article (page 210) that it is better to measure altitudes above the sea horizon from great heights *in clear weather*, was confirmed by the experiments made with the dip of horizon instruments in that the two sides of the horizon were generally more sharply defined in the field of the instrument from 16 metres than from 7 metres. Another striking fact is that on several occasions, in making measurements at 7 metres small variations from the mean values of the dip were noted (about 0.3' to 0.5') which disappeared at 16 metres. Since this became particularly noticeable in those cases where a fresh breeze and equality in air and water temperatures made it probable that normal dip values would obtain, it must be assumed that a higher point of observation is more favourable than a lower. Further, in the case of measurements with the PULFRICH apparatus, consideration should be given to the fact that the two parallel lines of the horizon in the field of the telescope are further apart at a greater height of eye and that consequently it becomes easier to estimate the proper position of the small square along the wedge scale than from a lower observation point, when the square must be moved closer to the tip of the wedge scale.

The objection may be raised in connection with this prescribed method of measuring the dip of the horizon, that dip to the left and to the right of the observer may not necessarily always be the same. In actual fact instances have been observed in practice where the dip has varied at different points of the horizon, but systematic investigations along these lines are not yet available. Since, however, this possible source of error must always be taken into consideration, it is very advisable to measure the dip several times on different bearings. On board the *Abessinia* this was done on more than 50 occasions but no appreciable variation in the results was noted. Should this occur in practice, then the careful navigator, who understands how to combine theory with practice, will place a larger note of interrogation than usual after the results of his astronomical observations.

When we consider that experience has shown that abnormal raising or lowering of the horizon usually occurs in bright clear weather when the sea horizon is so distinct and sharply defined that the inexperienced observer would not suspect anything wrong, it must be characterized as a decidedly progressive step that in this instrument the navigator is given a means whereby the invisible enemy may be driven into the open and prevented from sailing under the false colours of "unusual currents" or inexplicable phenomena which make their appearancee later on or even "too late".

In coastal navigation the influence of the refraction due to the land must also be taken into consideration. Primarily the cases to be considered are those in which a bearing of a lighthouse is taken at night, on or above the horizon, the distance being determined in accordance with data from the chart or light list, taking the height of eye of the observer into account. As already explained elsewhere, the apparent distance from the eye of the observer increases or decreases as the line of sight appears to be raised or lowered in consequence of meteorological conditions. For these reasons, therefore, the results of such determinations of position from objects on the horizon must be used with great caution. The same applies to distances determined by estimation, especially in those places where abnormal refraction is to be expected. There are seamen who pride themselves upon their great experience in estimating distances from the shore and who are inclined to place confidence in this ability, a fact which, under certain circumstances, may lead to grave consequences. It cannot be too strongly recommended that the ship's position when near the shore should be checked, whenever an opportunity occurs, by bearings, angles and soundings and that no dependence should ever be placed upon estimates. An old English saying has it that it is "Better to be safe than sorry".

This lecture was followed by a lively discussion in which, in particular, Lieutenant Commander RÜDIGER, Inspector of Navigation of the Hamburg America Line, took part; he pointed out that observations for dip of the horizon were of great value where error of chronometer determinations were made by altitudes above the sea horizon, in cases where no opportunity has arisen to ascertain the error from a time ball or from observations on shore with an artificial horizon. From the very great number of chronometer-logs which passed through his hands, he found that, with this method of determining the chronometer error at sea, serious mistakes occurred on numerous occasions which, in most cases, could probably be attributed to a false horizon resulting from abnormal refraction. Commander RÜDIGER's explanations were extremely instructive and indicated furthermore how important it is that this material should be given the consideration, by practical navigators, which it so richly deserves.