MEASUREMENTS OF DIP OF HORIZON FROM S. S. "ARUCAS" IN MAY 1933.

by

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(Extract from *Annalen d. Hydr. u. Marit. Meteor.*, Berlin, 15th May 1934, p. 208).

At the instance of the MARINELEITUNG, I carried out, during a run to the Canary Islands, observations of the dip of the horizon which, on the one hand, were intended for making comparisons with observations made with the bubble sextant, and on the other, were to be carried out systematically in view of the requirements of practical navigation on board merchant vessels.

The MARINELEITUNG placed at my disposal for this work a PULFRICH Dip-of-horizon meter, a sea water thermometer and an ASSMANN suction psychrometer, and the firm of C. PLATH very kindly lent me a sextant with dip-of-horizon prism devised by Dr. CASPAR. Unfortunately it was not possible to use this last analysing instrument on account of damage sustained which it was not possible to make good on board; all that could be done was to make a few methodical trial observations with it in order to compare it with the PULFRICH instrument from the point of view of ease of handling.

We must assume that the instrumental conditions of these appliances are known. In order that work with the CASPAR dip-meter be impeccable, considerable experience is necessary as well as a certain amount of bodily agility; when the ship is labouring the job becomes definitely difficult. It has the great advantage, however, that both the directly viewed horizon (through the simple reflecting prism) and the horizon at the rear, viewed by reflection in the small and large mirrors of the instrument, lose but little of their brightness and, further, a blindingly bright apparent horizon, particularly a sun-horizon, can be darkened to the necessary degree for observing by simply applying coloured glasses. Finally, by turning down the dip-prism, the instrument may be used at any moment as an ordinary sextant.

The PULFRICH instrument, on the other hand, is remarkable for its handiness and the actual taking of observations is very simple also, seeing that the two visible vertical and parallel horizons are brought into contact throughout the field of view. Yet it has a disadvantage due to its extreme sensitiveness and the practical impossibility of adjusting it onboard. The darkening of a too bright horizon by means of a diaphragm with a slit interferes considerably with the observation, for the horizon thus shaded is only visible in separate pieces. The difference in the brightness of the two images of the horizon is frequently so great that one cannot get an impeccably accurate contact. Under these circumstances to obtain results which were at least utilizable I adopted the following plan: both sea horizons are brought closely parallel to each other in the centre of the image field of the telescope of the instrument, so that the only faintly visible horizon is just recognizable by the side of the other one (Fig. 1). The instrument is then lowered and raised; the angles of intersection, despite the previously hardly perceptible horizon, are mostly fairly well recognizable (Fig. 2). Whilst slowly raising and lowering, the setting screw is then turned until the apices of the two angles of intersection coincide (Fig. 3). In this position, with the instrument horizontal, the accurate contact of the two sea horizon images is secured. With a little practice, good results may be obtained by this method, even with some swell on the sea.

The dip of the horizon was observed onboard the *Arucas* from the bridge and from *B* deck. The horizon right ahead and right astern of the ship was observed from the port and starboard ends of the bridge and this gave rise to no difficulty. Observation of the horizon athwartships was somewhat more complicated seeing that the wheel-house extended to the fore end of the bridge; consequently these observations had to be made through the wheel-house with the side doors open or, with a following wind, by leaning out of one of the wheel-house windows.

Later, the athwartships horizon was observed from the after bridge for there, though the cowls etc. interfere, it was much easier to work. From *B* deck the fore and aft horizon observations were taken from the starboard gangway platform. Unfortunately it was not possible to observe the athwartships horizon from the fore end of *B* deck at the same height of eye; they had to be taken at the after end of *B* deck at a height of eye 0.50 m. lower. The mean values found were corrected for this difference in order to make them utilizable with the values found for the fore and aft directions. It was possible to take observations from *B* deck on the outward voyage only; during the homeward trip no athwartship observations could be taken owing to interference caused by a deck cargo. It was materially impossible to take observations at 45° from the fore and aft line of the ship from *B* deck and even from the bridge these observations were seriously interfered with by cowls etc. Consequently such observations were taken only when fore and aft and athwartships horizons could not be used.

In analysing, 100 all-round observations were used, consisting of fore and aft and athwartships observations; each of these was obtained by taking the mean of at least three observations in the positive position and of at least three in the negative position (axis of telescope turned through 180°). When conditions were unfavourable five distinct observations of each sort were often taken and thus the data available for analysis included, in round figures, some 1,600 separate observations.

Simultaneously with each all-round observation the temperature of the water was taken with the special thermometer which was always towed from the lee gangway platform for some minutes. The air temperature was determined by means of the ASSMANN suction psychrometer at the same height as the eye; the instrument was attached to a long gaff which, likewise, was held over the lee side. No temperature observations were taken quite close to the sea surface because no accurate thermometer was available and because the observations were to be taken with due consideration of practical conditions. During 12 of the 13 days of observation the wind-forces were from 3 to 6 on the BEAUFORT Scale but, usually, seldom below 4; on one day only was the force 1 to 2. An intense mixing of the atmospheric layers could thus always be assumed. The greatest difference found in the temperatures of the air and the water was 1.6° C. (2.9° F.) and therefore it was possible to omit taking the temperature near the sea-surface without prejudice to the results. Besides it would probably not have been possible to take such observations accurately on account of the swell which ran nearly every day of observing. It was decided, even, not to attempt to determine the influence of the relative humidity of the air on the dip of the horizon seeing that all previous observers reported, unanimously, that they had not been able to find that this factor had any noticeable influence.

Meteorological conditions were nearly the same during the various sets of observations and thus they could all be used collectively without leaving any out. They were divided into three groups according to the height of eye, namely:

1. Outward voyage, Bridge: H. E. 12.5 m. (41 ft.), ship rolling every day.
2. » » B. deck: H. E. 7.5 m. (24 ½ ft.), ship rolling every day.
3. Homeward voyage: Bridge: H. E. 13 m. (42 ½ ft.), ship pitching every day.

Continuous accurate determination of the height of eye had to be given up on account of the swell which ran all the time. The heights of eye given are mean values in which account has been taken of their gradual increase due to the consumption of coal (50 cm. — 1 ½ ft.) approximately on each voyage).

On observing days the observations for dip were spread over the whole day so as to be able to obtain from the results data as to a possible daily fluctuation of the dip. Each setting was read to a tenth of a minute for, with the micrometer drum marked in half minutes only, closer reading — e. g. to 5/100 — would have been more or less a speculative matter on account of the continual swell.

The personal error was checked regularly from time to time by observations taken by other observers; no discrepancy was found.

At Santa Cruz de Tenerife I was able to take a series of dip observations at a height of eye of 1 m. (3 ft.) only from a small steam boat kindly placed at my disposal by the DEUTSCHE KOHLENDEPOT GES. M. B. H. Unfortunately it was not possible to observe right round the horizon owing to the proximity of the land; we could not go further out to seaward for want of time.

Results. In order to obtain a determination as to the accuracy of the observations, the position of the mean zero of the instrument was obtained from 198 athwartships and fore and aft means; this placed the zero at + 0.55'. On land, and that from the roof of the Reichswehrministerium in Berlin, the zero was found to be at + 0.4' by Lieut. MARTINI (retired). The difference is doubtless due, firstly, to the difference in the reference points at sea and, secondly, to the very great sensitiveness of the instrument.

Comparison of the position of the mean zero with the 198 means of observations gives the following discrepancies :

Discrepancy.	*Number of means of dips of horizon.*	*Percentage.*	*Discrepancy.*	*Number of means of dips of horizon.*	*Percentage.*
0.0' to 0.05'	132	66.7 %	0.35' to 0.45'	3	1.6 %
0.05' to 0.15'	37	18.6 %	0.45' to 0.55'	2	1.0 %
0.15' to 0.25'	16	8.1 %	0.55' to 0.65'	1	0.5 %
0.25' to 0.35'	7	3.5 %	—	—	—

(*The mean zero did not fall on a full tenth and thus the scale had to be made to half tenths*)

To get 169 mean dips of horizon (= 85 %) with discrepancies between 0 and 0.15', taking into account the accuracy of reading and the rounding off, both up and down, to the nearest tenth when striking the means, may be taken as normal. The remaining 15 % which have discrepancies greater than 0.15' must have mostly been affected by an undeterminable shift of the zero of the sensitive instrument (which fact has been noted by other observers) whereas in the rest the discrepancy must be due to an observational or some other error. It was not possible to infer from the few available values with more than 0.15' discrepancy any regularity in the shift of the zero. Further, the discrepancy of each individual observation was determined with reference to the corresponding mean.

The table shows the result expressed as percentages.

Discrepancy	0.0'	40.5 %
"	0.1'	43.9 %
"	0.2'	10.2 %
"	0.3'	4.1 %
"	0.4'	0.9 %
"	0.5'	0.3 %
"	0.6'	0.1 %

The mean error of the individual settings was found to be 0.08'.

In this connection the following is a brief statement of the discrepancies of the various mean dips of horizon with reference to the mean of the set of observations concerned :

Height of eye.		*General mean.*	*Discrepancy up to 0.2'*	*Mean discrepancy.*
1.	12.5 m.	+ 6.25'	77 %	± 0.2'
2.	7.5 m.	+ 4.6'	50 %	± 0.3'
3.	13.0 m.	+ 6.1'	96 %	± 0.1'
4.	1.0 m.	— 0.9'	100 %	± 0.1'

Comparison of the athwartships with the fore and aft horizon gave a value for the fore and aft 0.09' greater, on an average, than athwartships, but as the mean discrepancy reaches ± 0.18' it is scarcely possible to speak of a general difference ; the result agrees with that of other observers such as HESSEN, THORADE (1) and CONRAD (2). As percentages the differences are distributed between the athwartships and the fore and aft horizons as follows :

Athwartships dip	=	Fore and aft dip	23 %.
" "	>	" " "	28 %.
" "	<	" " "	49 %.

(1) Kimmtiefenmessungen an Bord von Schiffen der Reichsmarine, *Berlin*, 1930.

(2) Astronomische Ortsbestimmung und Kimmtiefenmessung auf See, *Berlin*, 1933.

Taking the state of the sea into account the same analysis gives the following :

Athwartships dip	=	Fore and aft dip	when pitching 47 %.
			when rolling 11 %.
" "	>	" " "	when pitching 18 %.
			when rolling 33 %.
" "	<	" " "	when pitching 35 %.
			when rolling 56 %.

It should be noted, here, that when pitching the discrepancy was never more than 0.3' whereas when rolling, when the athwartships dip was greater than the fore and aft dip, discrepancies as great as 0.5' occurred and when the athwartships dip was less than the fore and aft, discrepancies reaching even 1.0' were registered. In my opinion the larger discrepancies when the ship rolled may be attributed to erroneous heights of eye and, in part also, to less accurate individual observations on account of the shorter interval of time of the movements of the ship. But the pitching of the ship in a rough sea and swell, as occurred during the homeward voyage, must have had a certain reducing effect, for the mean of the observations, at H. E. 13 m. (42 ½ ft.), on the return voyage was + 6.1' whereas on the outward voyage, with the ship rolling almost continuously and H. E. 12.5 m. (41 ft.) only, the mean was + 6.25'. On account of the numerically few data no law could be deduced therefrom.

Under certain circumstances the observation may be greatly influenced by wave and swell horizons; in such cases the form of the horizon was observed as accurately as possible with a telescope before taking the observation, in order to keep the personal error as small as possible.

Also, with reference to the sun horizon, no regularity could be determined. Equal numbers of the observations gave results — dip of sun horizon equal to mean dip, dip of sun horizon greater than mean dip and dip of sun horizon less than mean dip; the greatest difference between the sun horizon and the mean was ± 0.3', the mean difference was ± 0.1'. On account of the difficulty, mentioned at the beginning, of obtaining sufficient protection from a dazzling horizon, these data as to the sun horizon should be taken with reserve. I suggested to the makers, Messrs. ZEISS of Jena, that in order to get better results the slit-diaphragm should be removed and that an anti-dazzle system consisting of light absorbing glasses of various thickness be added to the instrument. These glasses could and should be used, when taking ordinary observations for dip, to suppress the difference in the lighting of the opposite horizons whenever necessary.

A connection between the dip of the horizon and the azimuth of the sun was not expected, but, in order to satisfy a special request made by Prof. WEDEMEYER, research was made in this direction. As is shown in Fig. 4 the residual dips in the morning and evening lie below the mean value, shown as the axis of the abcissae, whereas the midday values lie above it, the culminating point being 180°.

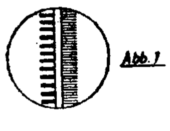
During the observations made on board the *Hunte* (1), CONRAD found exactly the same oscillation. This function, in the *Hunte* observations, cuts the zero about 30° before and after the culmination, with a maximum of 0.22', i. e. at practically the same values. In spite of these two results it is doubtful whether one can state that this is a case of conformity with a law, for insufficient observational data are available.

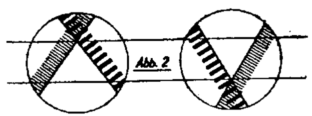
From two sets of observations the effect of atmospheric pressure on the dip of the horizon was examined; however the differences of atmospheric pressure of 7 and 5 mm. (0.28 and 0.20 in.) respectively are not sufficient on which to state a law though, as shown in Fig. 8, the mean, in each case, has the same slope. But the correction formula deduced therefrom : $C = + 0.03'$ (760 — Bar.), shows that, where the agreement is not merely fortuitous, the influence is but very small and of no importance to navigation. It is only when the difference of atmospheric pressure is 33 mm. (1.3 in.) that the dip of the horizon is affected to the extent of 1'.

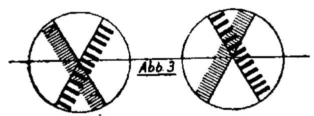
Even though no connection between dip of the horizon and geographical latitude was expected, the various sets of observations were examined from this point of view. The mean value of the dips given by the different sets, shown as the axis of the abcissae,

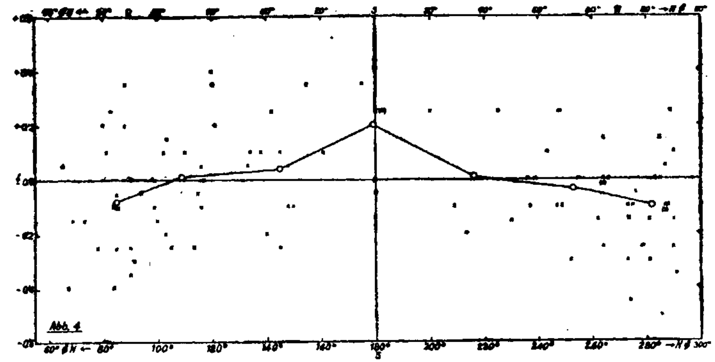
(1) Astronomische Ortsbestimmung und Kimmtiefenmessung auf See, *Berlin*, 1933.

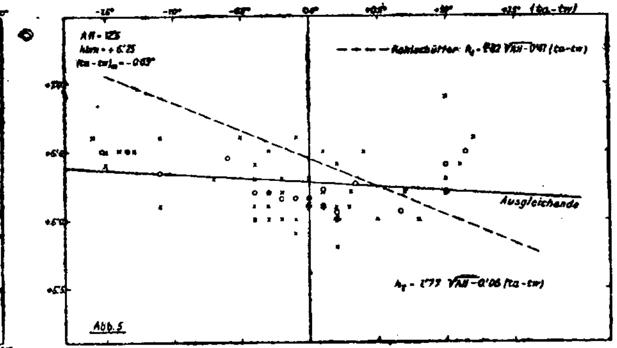
Herbert Michler: Kimmtiefenmessungen auf D. „Arucas" im Mai 1933.

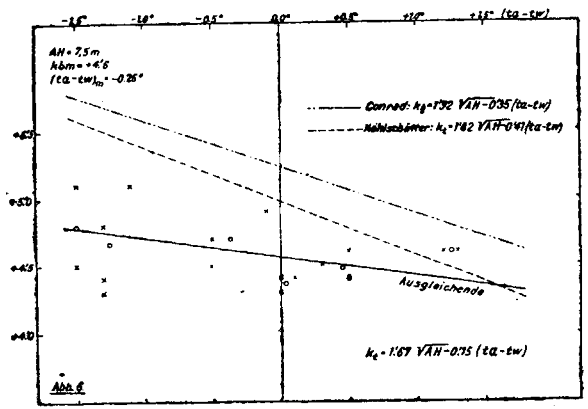


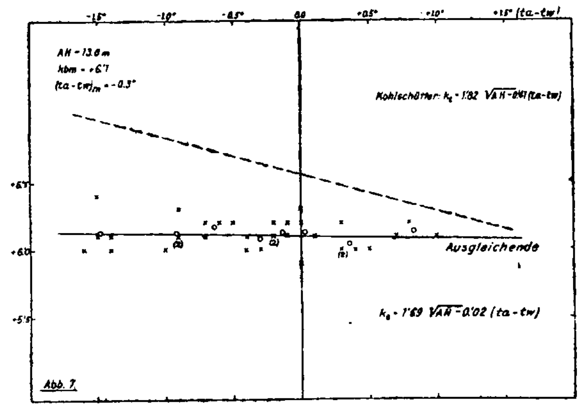


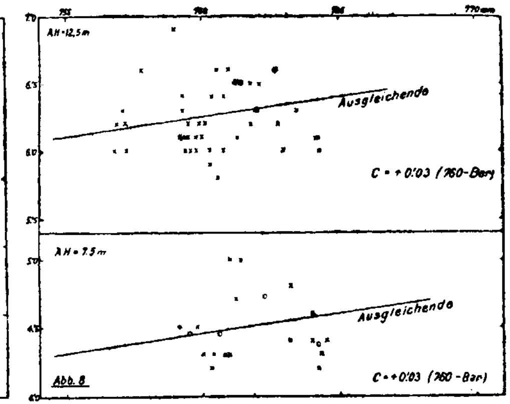












x = Wert einer Rundmessung ● $\underset{(2)}{x}$ = Zwei zusammenfallende Werte ○ = Gruppenmittel nearly coincides with the general mean obtained from the residuals of the dips of the horizon; the difference of latitude during the period of observation was but about 20°.

To determine the influence of the difference of temperature between the air and the water, which will be referred to as $(t_a - t_w)$ hereafter, on the dip of the horizon, the all-round observations of the three sets of observations are plotted graphically as functions of $(t_a - t_w)$ and compensated by striking the means of the groups. No attempt was made to compensate by the method of least squares on account of the small number of values resulting from each set of observations. Figs. 5 to 7 show clearly that $(t_a - t_w)$ has but trifling influence on the dip of the horizon which, incidentally, the earlier observations of HESSEN, HUBER and THORADE (1) had already shown. For purposes of comparison the graphic representation of the dip according to KOHLSCHÜTTER's formula, $k = 1.82' \sqrt{\text{H. E.}} - 0.41' (t_a - t_w)$ (2) has been plotted as has also the dip obtained from the sets with H. E. 7.5 m. (24.5 ft.) according to CONRAD's formula $k = 1.92' \sqrt{\text{H. E.}} - 0.35' (t_a - t_w)$. (3)

As soon as the plotting had been done on board, the means of each athwartships and of each fore and aft observation were compared with the value given by BREUSING's Nautical Tables ($k = 1.779' \sqrt{\text{H. E.}}$). As CONRAD, during his researches, reached the conclusion that $(t_a - t_w)$ has considerable influence on the dip of the horizon, account was taken of the temperature correction in BREUSING's old Nautical Tables by working out $B - R$; in only 12 % of the observations was $B - R$ positive.

In the observations taken on board the *Arucas*, the factor for Height of Eye, which, according to CONRAD, nearly reaches the value of the geodetic dip of the horizon (1.93'), nearly agrees in two sets of observations, with the values found by PRZYBYLLOK (4) and HESSEN (5); in the third set it nearly reaches the magnitude of BREUSING's value. This third set seems to have been more greatly affected by the ship's movements as is set out above in greater detail. Thus, according to the results obtained by various observers, the factor for Height of Eye given by Nautical Tables seems to be too large; anyway, for practical navigation, the difference is negligible.

The temperature factor is so small that only a very considerable difference of temperature, such as is probably but rarely experienced in practice, is likely to have any noticeable influence on the dip of the horizon. To sum up, it may be said, therefore, in full accord with other observers, that in normal conditions it is not worth while to take $t_a - t_w$ into account in practical navigation as the value of the correction is quite insignificant. The difference, nearly always, would probably constitute but a fraction of the error which it is necessary to expect in astronomical observations taken for navigation in the mercantile marine. Also, in most ships, there is no means of making the accurate observations of t which are necessary for taking $t_a - t_w$ into consideration, for suction instruments, which are the only ones suitable for determining with certainty the temperature of the air, are unfortunately not yet included in the prescribed outfit of vessels. (6) It is justifiable, therefore, in practice, to neglect the correction of dip for $t_a - t_w$, and IMMLER (7) confirms this. In most cases the Tables containing the precalculated total reduction are used for reducing the horizon distances of stars and, in these consequently, $t_a - t_w$ is not considered. Nevertheless this should not be taken to suggest that no signification whatever should be given to the factor $t_a - t_w$; if this difference be great a considerable anomaly in the apparent horizon is to be expected particularly in light winds or calms. Thus, for instance, during the *Meteor* Expedition (1925 to 1927) in the tropics in relatively normal conditions discrepancies reaching as much as 3' were found. (8)

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(1) Kimmtiefenmessungen an Bord von Schiffen der Reichsmarine, *Berlin*, 1930.

(2) Folgerungen aus den Kosschen Kimmtiefenbeobachtungen zu Veradella, ***Ann. d. Hydrogr.***, 1903.

(3) Astronomische Ortsbestimmung und Kimmtiefenmessung auf See, *Berlin*, 1933.

(4) Kimmtiefenmessungen auf der Deutschen Antarktischen Expedition, *Königsberg*, 1925.

(5) Kimmtiefenmessungen an Bord von Schiffen der Reichsmarine, *Berlin*, 1930.

(6) *Cf. also Harries*: Schiffsraum-Meteorologie, *Ann. d. Hydrogr.*, 1932, *pp.* 113 & 220, *and* Seewart, 1932, *p.* 149; *see also* Handbuch für den Rote Meer und den Golf v. Aden, 2nd *ed.*, *Berlin*, *p.* 5.

(7) Kimmtiefenmessungen, *Ann. d. Hydrogr.*, *July* 1927.

(8) *Cf.* Handbuch für das Rote Meer und den Golf von Aden, *Berlin*, *p.* 8 *at top*, as well as *pp.* 21 *et seq.* (*Refraction of rays*).

The influence appears to be the greater the smaller the height of eye, which is confirmed by the observations for dip of the horizon made at Santa Cruz de Tenerife from a boat with H. E. 1 metre. Fifty separate observations were taken, the difference of temperature remaining unchanged at + 5.8°, wind N. E. 2 to 3, swell 2, during the hour of observation. These 50 observations were reduced to 8 mean dips, the general average of which (with a mean error of ± 0.1) came out at — 0.9'. The considerable raising of the horizon observed here should in no way be attributed to abnormal meteorological conditions, for with wind-force 2 to 3 a sufficient mixing of the atmospheric layers may be expected. The influence of the proximity of the land may also be discarded seeing that the apparent horizon was fairly free of land over 180° and, besides, a sea breeze prevailed. Likewise, the swell could not have had so great an influence since the mean error was found to be ± 0.1'. The greater number of the dip formulae so far found fail herein. For purposes of comparison the dip of the horizon in this case, calculated according to various formulae, is given:

Calculated dip.	*According to*	*Formulae.*
+ 1.5'	HESSEN	$k = 1.70'$ H. E. $- 0.04'$ $(t_a - t_w)$.
+ 0.38'	PRZYBYLLOK	$k = 1.71'$ H. E. $- 0.23'$ $(t_a - t_w)$.
— 0.11'	CONRAD	$k = 1.92'$ H. E. $- 0.35'$ $(t_a - t_w)$.
— 0.14'	BREUSING	$k = 1.779'$ H. E. $- 0.33'$ $(t_a - t_w)$.
— 0.56'	KOHLSCHÜTTER	$k = 1.28'$ H. E. $- 0.41'$ $(t_a - t_w)$.
— 1.50'	BREITFUSS	$k = 1.81'$ H. E. $- 0.57'$ $(t_a - t_w)$.

These formulae were all deduced from observations made with the eye at a considerable height and it is to this, I believe, that the differences should be mainly attributed. On the basis of BREUSING's height-of-eye factor the following formula is obtained from the observed dips: $k = 1.779' \sqrt{\text{H. E.}} - 0.46' \; (t_a - t_w)$. The factor for temperature correction is much greater here compared with those found for larger H. E.'s in approximately the same conditions. For 13 m. (42 ½ ft.) and 12.5 m. (41 ft.) the respective factors are 0.02' and 0.06', at 7.5 m. (24 ½ ft.) it reaches already 0.15' and at 1 m. (3 ¼ ft.) it is 0.46'. Thus the influence of $t_a - t_w$ increases as the H. E. diminishes. In observations taken from low heights of eye $t_a - t_w$ alone may, in otherwise normal circumstances, produce divergencies which are appreciable in practical navigation. In the Merchant Marine one is not likely to have to deal with observations taken at very small height of eye except when, perhaps, in the case of a calm sea and insufficient visibility, an attempt be made to observe the altitude of the sun from a stage rigged just above the water line. It is quite another matter in the Navy; it is necessary only to recall the long overseas journeys of submarines to show how important this question is and particularly to the Navy.

Further researches should extend more than has so far been done to checking the influence of $t_a - t_w$ on the dip at lower heights of eye. So long as formulae have not been found which can be applied with proper results, which, in view of the variety of the influences which may affect the dip of the horizon, appears unlikely, whenever it is a case of obtaining accurate values, it will be necessary to have recourse to dip measuring instruments. However, in mercantile navigation, when reducing altitudes above the horizon, it will suffice (as is the present practice) to use a mean dip of the horizon, for this, generally speaking, will fall within the degree of accuracy required. In spite of this, the greatest attention should always be given to the nature of the horizon and to the influences likely to produce anomalies so that, in any given circumstances, the degree of accuracy of one's astronomical observations may be judged.