ON THE DIP OF SEA HORIZON

by

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RESUMÉ. — *The Dip of Sea Horizon, with reference to the difference of temperature of the air and the sea water, is discussed. Tables by various authorities are given, and observations made by Mr.* A. SONE *on board H. J. M. S.* Mansyû *in the area of the "Kurosio" near the south coasts of Japan in January and February of* 1926 *are discussed. These observations were compared with the* KOHLSCHÜTTER-BREHMER'S *Table for the correction of the dip of sea horizon, and it was found that the difference sometimes amounts to* 4', *the mean of differences (tabular value — observed value) being* −1'.8 *and* 0'.0 *for high and low altitudes respectively.*

The most serious error in reducing the true altitude of a heavenly body from the observed altitude at sea arises from the uncertainty of the atmospheric refraction and of the dip of sea horizon. These quantities for a given altitude of a heavenly body and a given height of the eye are not constants, but vary considerably with the conditions of the temperature, pressure, and humidity of the air. If the altitude of a heavenly body be higher than a certain limit, say 6°, the variation of refraction produced by the variation of the conditions of the air is very small; but if the altitude be very low, the refraction varies considerably with the temperature and pressure. Therefore, for very low altitudes, it becomes necessary to apply corrections for the variations of these quantities. For instance, Table 2 *A* of the *Sin Kôdo Hôikaku Hyô* (*New Altitude and Azimuth Tables*) published by the Japanese Hydrographic Department gives such corrections to the observed altitude where it is lower than 6°. These corrections are for the variation of refraction under the normal conditions of the air, and are therefore subject to considerable errors where the conditions of the air are very abnormal.

The Tables of the dip of sea horizon and the values of the dip of sea horizon included in the Tables of the total correction of the observed altitude of a heavenly body, as given in the ordinary nautical Tables, are good for the normal condition of the air; but under abnormal conditions, especially when the difference in temperature between the sea water and the air is great, these Tables will be found subject to considerable errors.

In observations at sea based on the sea horizon, the uncertainty of refraction is great in low altitudes but very small in high altitudes, while the uncertainty of the dip of sea horizon gives rise to errors equally for low and high altitudes. I will here discuss the dip of sea horizon.

The variability of the dip of sea horizon had been known for hundreds of years; but the first systematic observations of the dip of sea horizon which took into consideration the meteorological elements and the temperature of the sea water were made by a French ship: *La Galisonnière*, in 1884, in the

TABLE I. — KOSS'S TABLE FOR THE CORRECTION OF THE DIP OF SEA HORIZON.
TABLE DE KOSS POUR LA CORRECTION DE LA DÉPRESSION DE L'HORIZON DE LA MER.

(I) Wind Force 2-3 and stronger : (Temperature of the air is measured at the height of the eye).
)I) *Vent de force 2 à 3 et au-dessus :* (*La température de l'air est mesurée à la hauteur de l'œil*).

H. E. *Hauteur de l'œil*	(Air Temperature) — (Water Temperature) C. (*Température de l'Air*) — (*Température de l'Eau*) C.							
	+ 8°	+ 6°	+ 4°	+ 2°	0	−2°	−4°	−6°
m.								
4	−2'.5	−2'.0	−1'.5	−0'.5	0'.0	−1'.0	−1'.5	−2'.5
6	−3'.0	−2'.0	−1'.5	−0'.5	0'.0	−0'.5	−1'.5	−2'.0
8	−3'.0	−2'.0	−1'.0	−0'.5	0'.0	−1'.0	−1'.5	−2'.5
10	−3'.0	−2'.5	−1'.5	−1'.0	0'.0	−0'.5	−1'.0	−2'.0
12	−3'.0	−2'.5	−1'.5	−1'.0	0'.0	−0'.5	−1'.5	−2'.0
14	−3'.0	−2'.5	−1'.5	−1'.0	0'.0	−0'.5	−1'.0	−2'.0
16	−2'.5	−2'.0	−1'.0	−0'.5	0'.0	−1'.0	−1'.5	−2'.5

(II) Wind calm or very feeble :
(II) *Vent calme ou très faible :*

H. E. *Elévation de l'œil*	(Temp. of the air at the H. E.) — (Temp. of the air on surface of the sea) C. (*Temp. de l'air à la hauteur de l'œil*) — (*Temp. de l'air à la surface de la mer*) C.												
	+ 6°	+ 5°	+ 4°	+ 3°	+ 2°	+ 1°	0	−1°	−2°	−3°	−4°	−5°	−6°
m.													
6	—	—	—	—	−4'.5	−2'.5	0'.0	+ 2'.5	+ 4'.5	—	—	—	—
8	—	—	—	−6'.0	−4'.0	−2'.0	0'.0	+ 2'.0	+ 4'.0	+ 6'.0	—	—	—
10	—	—	—	−5'.5	−3'.5	−1'.5	0'.0	+ 1'.5	+ 3'.5	+ 5'.5	—	—	—
12	—	—	−7'.0	−5'.0	−3'.0	−2'.0	0'.0	+ 2'.0	+ 3'.0	+ 5'.0	+ 7'.0	—	—
14	—	−7'.5	−6'.5	−4'.5	−3'.5	−1'.5	0'.0	+ 1'.5	+ 3'.5	+ 4'.5	+ 6'.5	+ 7'.5	—
16	−9'.0	−7'.0	−6'.0	−4'.0	−3'.0	−2'.0	0'.0	+ 2'.0	+ 3'.0	+ 4'.0	+ 6'.0	+ 7'.0	+9'.0

2 TABLE 2A. ⊙ CORRECTION OF THE OBSERVED ALTITUDE OF THE SUN'S LOWER LIMB FOR THE ALTITUDES 0°–6°.

Corr. 4. Mean Correction Temperature: 10°C(50°F) Barometer: 762mm(30 inches)

Obs. Alt. − Dip	Height of the Eye metre (m), foot (′) 0m 0′	3m 10′	4m 13′	5m 16′	6m 20′	7m 23′	8m 26′	9m 30′	10m 33′	11m 36′	12m 39′	13m 43′	14m 46′	15m 49′	Obs. Alt. − Dip
° ′	Correction to be added to or subtracted from the observed altitude														° ′
−0 10	20.7	23.8	24.3	24.7	25.1	25.4	25.7	26.0	26.3	26.6	26.9	27.1	27.4	27.6	−0 10
0 0	18.5	21.6	22.1	22.5	22.9	23.2	23.5	23.8	24.1	24.4	24.7	24.9	25.2	25.4	0 0
10	16.4	19.5	20.0	20.4	20.8	21.1	21.4	21.7	22.0	22.3	22.6	22.8	23.1	23.3	10
20	14.5	17.6	18.1	18.5	18.9	19.2	19.5	19.8	20.1	20.4	20.7	20.9	21.2	21.4	20
30	12.8	15.9	16.4	16.8	17.2	17.5	17.8	18.1	18.4	18.7	19.0	19.2	19.5	19.7	30
40	11.2	14.3	14.8	15.2	15.6	15.9	16.2	16.5	16.8	17.1	17.4	17.6	17.9	18.1	40
50	9.7	12.8	13.3	13.7	14.1	14.4	14.7	15.0	15.3	15.6	15.9	16.1	16.4	16.6	50
1 0	8.4	11.5	12.0	12.4	12.8	13.1	13.4	13.7	14.0	14.3	14.6	14.8	15.1	15.3	1 0
10	7.2	10.3	10.8	11.2	11.6	11.9	12.2	12.5	12.8	13.1	13.4	13.6	13.9	14.1	10
20	6.0	9.1	9.6	10.0	10.4	10.7	11.0	11.3	11.6	11.9	12.2	12.4	12.7	12.9	20
30	5.0	8.1	8.6	9.0	9.4	9.7	10.0	10.3	10.6	10.9	11.2	11.4	11.7	11.9	30
40	4.0	7.1	7.6	8.0	8.4	8.7	9.0	9.3	9.6	9.9	10.2	10.4	10.7	10.9	40
50	3.1	6.2	6.7	7.1	7.5	7.8	8.1	8.4	8.7	9.0	9.3	9.5	9.8	10.0	50
2 0	2.3	5.4	5.9	6.3	6.7	7.0	7.3	7.6	7.9	8.2	8.5	8.7	9.0	9.2	2 0
10	1.5	4.6	5.1	5.5	5.9	6.2	6.5	6.8	7.1	7.4	7.7	7.9	8.2	8.4	10
20	0.8	3.9	4.4	4.8	5.2	5.5	5.8	6.1	6.4	6.7	7.0	7.2	7.5	7.7	20
30	0.1	3.2	3.7	4.1	4.5	4.8	5.1	5.4	5.7	6.0	6.3	6.5	6.8	7.0	30
40	+ 0.5	2.6	3.1	3.5	3.9	4.2	4.5	4.8	5.1	5.4	5.7	5.9	6.2	6.4	40
50	+ 1.1	2.0	2.5	2.9	3.3	3.6	3.9	4.2	4.5	4.8	5.1	5.3	5.6	5.8	50
3 0	+ 1.6	1.5	2.0	2.4	2.8	3.1	3.4	3.7	4.0	4.3	4.6	4.8	5.1	5.3	3 0
20	+ 2.6	0.5	1.0	1.4	1.8	2.1	2.4	2.7	3.0	3.3	3.6	3.8	4.1	4.3	20
40	+ 3.5	+ 0.4	0.1	0.5	0.9	1.2	1.5	1.8	2.1	2.4	2.7	2.9	3.2	3.4	40
4 0	+ 4.3	+ 1.2	+ 0.7	0.3	0.1	+ 0.4	0.7	1.0	1.3	1.6	1.9	2.1	2.4	2.6	4 0
20	+ 5.0	+ 1.9	+ 1.4	+ 1.0	+ 0.6	+ 0.3	0.0	0.3	0.6	0.9	1.2	1.4	1.7	1.9	20
40	+ 5.6	+ 2.5	+ 2.0	+ 1.6	+ 1.2	+ 0.9	+ 0.6	+ 0.3	0.0	0.3	0.6	0.8	1.1	1.3	40
5 0	+ 6.2	+ 3.1	+ 2.6	+ 2.2	+ 1.8	+ 1.5	+ 1.2	+ 0.9	+ 0.6	+ 0.3	0.0	0.2	0.5	0.7	5 0
20	+ 6.7	+ 3.6	+ 3.1	+ 2.7	+ 2.3	+ 2.0	+ 1.7	+ 1.4	+ 1.1	+ 0.8	+ 0.5	+ 0.3	0.0	0.2	20
40	+ 7.2	+ 4.1	+ 3.6	+ 3.2	+ 2.8	+ 2.5	+ 2.2	+ 1.9	+ 1.6	+ 1.3	+ 1.0	+ 0.8	+ 0.5	+ 0.3	40
6 0	+ 7.6	+ 4.5	+ 4.0	+ 3.6	+ 3.2	+ 2.9	+ 2.6	+ 2.3	+ 2.0	+ 1.7	+ 1.4	+ 1.2	+ 0.9	+ 0.7	6 0
Dip	0.0	3.1	3.6	4.0	4.4	4.7	5.0	5.3	5.6	5.9	6.2	6.4	6.7	6.9	Dip

Corr. 2. Correction for Temperature of the Air

Obs. Alt. − Dip	Temperature −20°C −4°F	−15°C 5°F	−10°C 14°F	−5°C 23°F	0°C 32°F	5°C 41°F	10°C 50°F	15°C 59°F	20°C 68°F	25°C 77°F	30°C 86°F	35°C 95°F	Obs. Alt. − Dip
° ′	Correction to be added to or subtracted from the observed altitude												° ′
−0 10	− 8.5	− 6.7	− 5.2	− 3.8	− 2.5	− 1.2	0.0	+ 1.1	+ 2.2	+ 3.2	+ 4.3	+ 5.2	−0 10
0 0	− 7.5	− 6.0	− 4.7	− 3.4	− 2.2	− 1.1	0.0	+ 1.0	+ 2.0	+ 2.9	+ 3.9	+ 4.7	0 0
20	− 6.0	− 4.9	− 3.9	− 2.8	− 1.8	− 0.9	0.0	+ 0.8	+ 1.7	+ 2.5	+ 3.3	+ 4.0	20
40	− 5.1	− 4.2	− 3.3	− 2.4	− 1.5	− 0.7	0.0	+ 0.7	+ 1.5	+ 2.1	+ 2.8	+ 3.5	40
1 0	− 4.4	− 3.6	− 2.8	− 2.0	− 1.3	− 0.6	0.0	+ 0.6	+ 1.3	+ 1.8	+ 2.4	+ 3.0	1 0
20	− 3.8	− 3.1	− 2.5	− 1.8	− 1.2	− 0.6	0.0	+ 0.6	+ 1.2	+ 1.6	+ 2.1	+ 2.6	20
40	− 3.4	− 2.8	− 2.2	− 1.6	− 1.0	− 0.5	0.0	+ 0.5	+ 1.0	+ 1.4	+ 1.9	+ 2.3	40
2 0	− 3.0	− 2.4	− 1.9	− 1.4	− 0.9	− 0.4	0.0	+ 0.4	+ 0.9	+ 1.3	+ 1.7	+ 2.0	2 0
20	− 2.6	− 2.1	− 1.7	− 1.2	− 0.8	− 0.4	0.0	+ 0.4	+ 0.8	+ 1.1	+ 1.5	+ 1.8	20
40	− 2.3	− 1.9	− 1.5	− 1.1	− 0.7	− 0.3	0.0	+ 0.3	+ 0.7	+ 1.0	+ 1.3	+ 1.6	40
3 0	− 2.1	− 1.7	− 1.3	− 0.9	− 0.6	− 0.3	0.0	+ 0.3	+ 0.7	+ 0.9	+ 1.2	+ 1.5	3 0
4 0	− 1.7	− 1.4	− 1.1	− 0.8	− 0.5	− 0.2	0.0	+ 0.2	+ 0.5	+ 0.7	+ 0.9	+ 1.1	4 0
5 0	− 1.4	− 1.2	− 0.9	− 0.7	− 0.5	− 0.2	0.0	+ 0.2	+ 0.4	+ 0.5	+ 0.7	+ 0.9	5 0
6 0	− 1.2	− 1.0	− 0.8	− 0.6	− 0.4	− 0.2	0.0	+ 0.1	+ 0.3	+ 0.4	+ 0.6	+ 0.8	6 0

Corr. 4. Correction for Semidiameter

Jan. 1	Feb. 1	Mar. 1	Apr. 1	May 1	June 1	July 1	Aug. 1	Sept. 1	Oct. 1	Nov. 1	Dec. 1
+ 0.3	+ 0.3	+ 0.2	0	− 0.1	− 0.2	− 0.2	− 0.2	− 0.1	0	+ 0.1	+ 0.3

Note: For ⊙ subtract the Sun's Diameter (2 S.D.) from the values given for ☾.

TABLE 2A. ⊙ CORRECTION OF THE OBSERVED ALTITUDE OF THE SUN'S LOWER LIMB FOR THE ALTITUDES 0°–6° 3

Corr. 1. Mean Correction Temperature: 10°C(50°F) Barometer: 762mm(30 inches)

Obs. Alt. − Dip	Height of the Eye metre(m), foot(′) 15m 49′	16m 52′	17m 56′	18m 59′	19m 62′	20m 66′	21m 69′	22m 72′	23m 75′	24m 79′	25m 82′	26m 85′	27m 89′	28m 92′	29m 95′	Obs. Alt. − Dip
° ′	Correction to be added to or subtracted from the observed altitude															° ′
−0 10	27.6	27.8	28.0	28.3	28.5	28.7	28.9	29.1	29.2	29.4	29.6	29.8	30.0	30.1	30.3	−0 10
0 0	25.4	25.6	25.8	26.1	26.3	26.5	26.7	26.9	27.0	27.2	27.4	27.6	27.8	27.9	28.1	0 0
10	23.3	23.5	23.7	24.0	24.2	24.4	24.6	24.8	24.9	25.1	25.3	25.5	25.7	25.8	26.0	10
20	21.4	21.6	21.8	22.1	22.3	22.5	22.7	22.9	23.0	23.2	23.4	23.6	23.8	23.9	24.1	20
30	19.7	19.9	20.1	20.4	20.6	20.8	21.0	21.2	21.3	21.5	21.7	21.9	22.1	22.2	22.4	30
40	18.1	18.3	18.5	18.8	19.0	19.2	19.4	19.6	19.7	19.9	20.1	20.3	20.5	20.6	20.8	40
50	16.6	16.8	17.0	17.3	17.5	17.7	17.9	18.1	18.2	18.4	18.6	18.8	19.0	19.1	19.3	50
1 0	15.3	15.5	15.7	16.0	16.2	16.4	16.6	16.8	16.9	17.1	17.3	17.5	17.7	17.8	18.0	1 0
10	14.1	14.3	14.5	14.8	15.0	15.2	15.4	15.6	15.7	15.9	16.1	16.3	16.5	16.6	16.8	10
20	12.9	13.1	13.3	13.6	13.8	14.0	14.2	14.4	14.5	14.7	14.9	15.1	15.3	15.4	15.6	20
30	11.9	12.1	12.3	12.6	12.8	13.0	13.2	13.4	13.5	13.7	13.9	14.1	14.3	14.4	14.6	30
40	10.9	11.1	11.3	11.6	11.8	12.0	12.2	12.4	12.5	12.7	12.9	13.1	13.3	13.4	13.6	40
50	10.0	10.2	10.4	10.7	10.9	11.1	11.3	11.5	11.6	11.8	12.0	12.2	12.4	12.5	12.7	50
2 0	9.2	9.4	9.6	9.9	10.1	10.3	10.5	10.7	10.8	11.0	11.2	11.4	11.6	11.7	11.9	2 0
10	8.4	8.6	8.8	9.1	9.3	9.5	9.7	9.9	10.0	10.2	10.4	10.6	10.8	10.9	11.1	10
20	7.7	7.9	8.1	8.4	8.6	8.8	9.0	9.2	9.3	9.5	9.7	9.9	10.1	10.2	10.4	20
30	7.0	7.2	7.4	7.7	7.9	8.1	8.3	8.5	8.6	8.8	9.0	9.2	9.4	9.5	9.7	30
40	6.4	6.6	6.8	7.1	7.3	7.5	7.7	7.9	8.0	8.2	8.4	8.6	8.8	8.9	9.1	40
50	5.8	6.0	6.2	6.5	6.7	6.9	7.1	7.3	7.4	7.6	7.8	8.0	8.2	8.3	8.5	50
3 0	5.3	5.5	5.7	6.0	6.2	6.4	6.6	6.8	6.9	7.1	7.3	7.5	7.7	7.8	8.0	3 0
20	4.3	4.5	4.7	5.0	5.2	5.4	5.6	5.8	5.9	6.1	6.3	6.5	6.7	6.8	7.0	20
40	3.4	3.6	3.8	4.1	4.3	4.5	4.7	4.9	5.0	5.2	5.4	5.6	5.8	5.9	6.1	40
4 0	2.6	2.8	3.0	3.3	3.5	3.7	3.9	4.1	4.2	4.4	4.6	4.8	5.0	5.1	5.3	4 0
20	1.9	2.1	2.3	2.6	2.8	3.0	3.2	3.4	3.5	3.7	3.9	4.1	4.3	4.4	4.6	20
40	1.3	1.5	1.7	2.0	2.2	2.4	2.6	2.8	2.9	3.1	3.3	3.5	3.7	3.8	4.0	40
5 0	0.7	0.9	1.1	1.4	1.6	1.8	2.0	2.2	2.3	2.5	2.7	2.9	3.1	3.2	3.4	5 0
20	0.2	0.4	0.6	0.9	1.1	1.3	1.5	1.7	1.8	2.0	2.2	2.4	2.6	2.7	2.9	20
40	+ 0.3	+ 0.1	0.1	0.4	0.6	0.8	1.0	1.2	1.3	1.5	1.7	1.9	2.1	2.2	2.4	40
6 0	+ 0.7	+ 0.5	+ 0.3	0.0	0.2	0.4	0.6	0.8	0.9	1.1	1.3	1.5	1.7	1.8	2.0	6 0
Dip	6.9	7.1	7.3	7.6	7.8	8.0	8.2	8.4	8.5	8.7	8.9	9.1	9.3	9.4	9.6	Dip

Corr 3. Correction for Atmospheric Pressure

Obs. Alt. − Dip	Atmospheric Pressure mm 720 in 28.35	725 28.54	730 28.74	735 28.94	740 29.13	745 29.33	750 29.53	755 29.72	760 29.92	765 30.12	770 30.32	775 30.51	780 30.71	Obs. Alt. − Dip
° ′	Correction to be added to or subtracted from the observed altitude													° ′
−0 10	+ 2.3	+ 1.9	+ 1.7	+ 1.4	+ 1.2	+ 0.9	+ 0.7	+ 0.4	+ 0.1	− 0.2	− 0.5	− 0.7	− 1.0	−0 10
0 0	+ 2.1	+ 1.8	+ 1.6	+ 1.3	+ 1.1	+ 0.8	+ 0.6	+ 0.3	+ 0.1	− 0.2	− 0.4	− 0.6	− 0.9	0 0
20	+ 1.8	+ 1.6	+ 1.4	+ 1.1	+ 0.9	+ 0.8	+ 0.6	+ 0.3	+ 0.1	− 0.2	− 0.4	− 0.6	− 0.8	20
40	+ 1.6	+ 1.4	+ 1.3	+ 1.0	+ 0.8	+ 0.7	+ 0.5	+ 0.3	+ 0.1	− 0.1	− 0.3	− 0.5	− 0.7	40
1 0	+ 1.4	+ 1.3	+ 1.1	+ 0.9	+ 0.7	+ 0.6	+ 0.4	+ 0.2	+ 0.1	− 0.1	− 0.3	− 0.4	− 0.6	1 0
20	+ 1.3	+ 1.1	+ 1.0	+ 0.8	+ 0.6	+ 0.5	+ 0.4	+ 0.2	+ 0.1	− 0.1	− 0.3	− 0.4	− 0.5	20
40	+ 1.1	+ 1.0	+ 0.9	+ 0.7	+ 0.6	+ 0.5	+ 0.3	+ 0.2	0.0	− 0.1	− 0.2	− 0.3	− 0.4	40
2 0	+ 1.0	+ 0.9	+ 0.8	+ 0.7	+ 0.5	+ 0.4	+ 0.3	+ 0.2	0.0	− 0.1	− 0.2	− 0.3	− 0.4	2 0
20	+ 0.9	+ 0.8	+ 0.7	+ 0.6	+ 0.5	+ 0.4	+ 0.3	+ 0.2	0.0	− 0.1	− 0.2	− 0.3	− 0.4	20
40	+ 0.9	+ 0.8	+ 0.7	+ 0.6	+ 0.4	+ 0.3	+ 0.3	+ 0.1	0.0	− 0.1	− 0.2	− 0.3	− 0.3	40
3 0	+ 0.8	+ 0.7	+ 0.6	+ 0.5	+ 0.4	+ 0.3	+ 0.2	+ 0.1	0.0	− 0.1	− 0.2	− 0.3	− 0.3	3 0
4 0	+ 0.7	+ 0.6	+ 0.5	+ 0.4	+ 0.3	+ 0.3	+ 0.2	+ 0.1	0.0	0.0	− 0.1	− 0.2	− 0.3	4 0
5 0	+ 0.6	+ 0.5	+ 0.4	+ 0.4	+ 0.3	+ 0.2	+ 0.2	+ 0.1	0.0	0.0	− 0.1	− 0.2	− 0.2	5 0
6 0	+ 0.5	+ 0.4	+ 0.3	+ 0.3	+ 0.2	+ 0.2	+ 0.1	+ 0.1	0.0	0.0	− 0.1	− 0.1	− 0.2	6 0

The actual corrections occasionally differ considerably from the tabulated values on account of abnormal refraction. Consequently, too much confidence must not be placed in the tables.

Note: For ⊙ subtract the Sun's Diameter (2 S.D.) from the values given for ☾.

TABLE 2 A extracted from the *New Altitude & Azimuth Tables*

Red Sea, the Indian Ocean and the China Sea. K. Koss of Austria made systematic observations of the dip of sea horizon on board the Austrian warship *Pola* in 1887-88, in the Red Sea and the Mediterranean Sea. Also, in 1898-99, he made systematic continuous observations from morning till evening at Verudella, near Pola, with theodolites at the heights of 10, 16 and 42 metres above sea-level, observing at the same time the meteorological elements and the temperature of sea water. These observations by Koss furnish the most important data for the investigation of this subject. Koss concluded from his observations that the dip of sea horizon is mainly affected by the difference between temperature of the air and of sea water, the effects of the pressure and humidity of the air being hardly perceptible. Theoretically he obtained from the same observations many important results, among which is Table I for the dip of sea horizon extracted from the *Nautischen Jahrbuch* of that period. All the Tables given below are corrections of the

TABLE II. — KOHLSCHÜTTER-BREHMER'S TABLE FOR THE CORRECTION OF THE DIP OF SEA HORIZON.
TABLE DE KOHLSCHÜTTER-BREHMER POUR LA CORRECTION DE LA DÉPRESSION DE L'HORIZON DE LA MER.

(I) For the Temperature 15° C. (Temperature of the air is measured at the height of the eye).
(I) *Pour la température* 15° C. (*La température de l'air est mesurée à la hauteur de l'œil*).

H. E. *Elévation de l'œil*	(Air Temperature) — (Water Temperature) C. (*Température de l'air*) — (*Température de l'eau*) C.											
	+ 12°	+ 10°	+ 8°	+ 6°	+ 4°	+ 2°	0	− 2°	− 4°	− 6°	− 8°	− 10°
m.												
6	−4'.0	−3'.4	−2'.7	−2'.0	−1'.4	−0'.7	0'.0	+ 0'.7	+ 1'.4	+ 2'.0	+ 2'.7	+ 3'.4
8	−4'.0	−3'.3	−2'.7	−2'.0	−1'.3	−0'.7	0'.0	+ 0'.7	+ 1'.3	+ 2'.0	+ 2'.6	+ 3'.3
10	−3'.9	−3'.2	−2'.6	−2'.0	−1'.3	−0'.7	0'.0	+ 0'.6	+ 1'.3	+ 1'.9	+ 2'.6	+ 3'.2
12	−3'.8	−3'.2	−2'.5	−1'.9	−1'.3	−0'.6	0'.0	+ 0'.6	+ 1'.3	+ 1'.9	+ 2'.5	+ 3'.2
14	−3'.7	−3'.1	−2'.5	−1'.9	−1'.3	−0'.6	0'.0	+ 0'.6	+ 1'.2	+ 1'.9	+ 2'.5	+ 3'.1
16	−3'.7	−3'.1	−2'.4	−1'.8	−1'.2	−0'.6	0'.0	+ 0'.6	+ 1'.2	+ 1'.8	+ 2'.4	+ 3'.1
18	−3'.6	−3'.0	−2'.4	−1'.8	−1'.2	−0'.6	0'.0	+ 0'.6	+ 1'.2	+ 1'.8	+ 2'.4	+ 3'.0
20	−3'.6	−3'.0	−2'.4	−1'.8	−1'.2	−0'.6	0'.0	+ 0'.6	+ 1'.2	+ 1'.8	+ 2'.3	+ 3'.0

(II). — Correction for the temperature higher or lower than 15° C.
(II). — *Correction pour les températures supérieures ou inférieures à* 15° C.

For every.....+ 5° (*Pour chaque*).	+ 0'.15	+ 0'.12	+ 0'.10	+ 0'.08	+ 0'.07	+ 0'.03	0'.00	— 0'.02	— 0'.05	— 0'.05	— 0'.88	— 0'.12
For every.....— 5° (*Pour chaque*).	— 0'.15	— 0'.12	— 0'.10	— 0'.08	— 0'.07	— 0'.03	0'.00	+ 0'.02	+ 0'.05	+ 0'.05	+ 0'.08	+ 0'.12

dip to the normal value, and therefore it is necessary to give opposite signs for the correction of the observed altitude.

E. KOHLSCHÜTTER deduced the following formulae from the data of Koss's observations (*Annalen der Hydrographie*, 1903, pp. 533-554):

Dip of sea horizon =

$$[+109''.3 + 0''.042\ (t - 15^\circ)]\sqrt{h} - [+22''.2 - 0''.151\ (t - 15^\circ)]\,\Delta \qquad (1)$$

and *Dip of sea horizon* =

$$+109''.3\ \sqrt{h} - 0''.37\ (h - 1) - 22''.2\ [1 - 0{,}0590\ (\sqrt{h} - 1)]\,\Delta \qquad (2)$$

where h is the height of the eye above sea-level in metres; t, temperature of the air in degrees of centigrade at the height of the eye; Δ difference between temperature of the air at 1 metre above sea-level and temperature of sea water, and Δ' difference between temperature of air at the height of the eye and temperature of sea water.

He also obtained the following formula for the change of temperature with the height:-

$$t - t_1 = -0.0167\ (h - h_1) + 0.0590\ (t_0 - t_w)\ (\sqrt{h} - \sqrt{h_1})\ 6 - 42 \text{ metres} \qquad (3)$$

where t, t_1 and t_0 are the temperatures of the air (C) at the heights h, h_1 and 1 metre respectively, and t_w is the temperature of sea water.

BREHMER further examined KOHLSCHÜTTER'S formulae and compiled his Table of the dip of sea horizon, as reproduced in Rear-Admiral YONEMURA'S *Text Book of Navigation* (published by the Japanese Navy), Vol. 2, p. 82. This Table is Table II below.

On page 144 of the *Lehrbuch für den Unterricht in der Navigation an der Kaiserlichen Marine Schule*, published by the German Navy in 1917, the following formula which, it is stated, is reduced from Koss's observations, occurs:-

$$\text{Correction of the dip of sea horizon} = 0'.37\ (t - t_w)$$

where t and t_w are the temperatures (C) of the air at the height of the eye and of sea water, both in degrees of centigrade. From this formula we obtain the Table III below.

In the *Tafeln und Formeln aus Astronomie und Geodesie* by C. WIRTZ, a Table for the correction of the dip of sea horizon calculated by the same formula as above is given.

In the *Nautical Tables* published by the German Navy a Table calculated by the following formula, also deduced from Koss's observations, is given:-

$$\text{Correction of the dip of sea horizon} = -0'.33\ (t - t_w)$$

This Table IV is included in the *Nautical Tables* published by the Japanese Naval College.

Table V is given in the *Nautical Tables* published in 1925 by the Italian Hydrographic Office, but no authority is assigned to it. It does not

TABLE III. — CORRECTION OF THE DIP OF SEA HORIZON BY THE FORMULA GIVEN IN THE TEXT BOOK ON NAVIGATION BY THE GERMAN NAVY,

CORRECTION DE LA DÉPRESSION DE L'HORIZON DE LA MER D'APRÈS LA FORMULE DONNÉE DANS LE TRAITÉ DE NAVIGATION PUBLIÉ PAR LA MARINE ALLEMANDE.

(Temperature of the air is measured at the height of the eye). (*La température de l'air est mesurée à la hauteur de l'œil*).

	(Air Temperature) — (Water Temperature) C.							(*Température de l'air*) — (*Température de l'eau*) C.						
	+ 12°	+ 10°	+ 8°	+ 6°	+ 4°	+ 2°	0	−2°	−4°	−6°	−8°	−10°	−12°	−14°
Correction	−4'.4	−3'.7	−3'.0	−2'.2	−1'.5	−0'.7	0'.0	+ 0'.7	+ 1'.5	+ 2'.2	+ 3'0.	+ 3'.7	+ 4'.4	+ 5'.2

TABLE IV. — CORRECTION OF THE DIP OF SEA HORIZON IN THE NAUTICAL TABLES PUBLISHED BY THE GERMAN NAVY.

CORRECTION DE LA DÉPRESSION DE L'HORIZON DE LA MER D'APRÈS LES TABLES NAUTIQUES PUBLIÉES PAR LA MARINE ALLEMANDE.

(Temperature of the air is measured at the height of the eye). (*La température de l'air est mesurée à la hauteur de l'œil*).

	(Air Temperature) — (Water Temperature) C.							(*Température de l'air*) — (*Température de l'eau*) C.						
	+12°	+10°	+8°	+6°	+4°	+2°	0	−2°	−4°	−6°	−8°	−10°	−12°	−14°
Correction	−4'.0	−3'.3	−2'.6	−2'.0	−1'.3	−0'.7	0'.0	+0'.7	+1'.3	+ 2'.0	+2'.6	+3'.3	+4'.0	+4'.6

TABLE V. — CORRECTION OF THE DIP OF SEA HORIZON IN THE NAUTICAL TABLES PUBLISHED BY THE ITALIAN HYDROGRAPHIC OFFICE.

CORRECTION DE LA DÉPRESSION DE L'HORIZON DE LA MER D'APRÈS LES TABLES NAUTIQUES PUBLIÉES PAR LE SERVICE HYDROGRAPHIQUE ITALIEN.

(Temperature of the air is measured at the height of the eye). (*La température de l'air est mesurée à la hauteur de l'œil*).

	(Air Temperature) — (Water Temperature) C.							(*Température de l'air*) — (*Température de l'eau*) C.						
	+12°	+10°	+8°	+6°	+4°	+2°	0	−2°	−4°	−6°	−8°	−10°	−12°	
Correction	−4'.8	−4'.0	−3'.2	−2'.4	−1'.6	−0'.8	0'.0	+0'.8	+1'.6	+2'.4	+3'.2	+4'.0	+4'.8	—

give the height at which the temperature of the air is measured, but presumably a height equal to the height of the eye is understood. The Table is inserted in Rear-Admiral YONEMURA'S *Text Book of Navigation* (Table 2 *B*, appended to Vol. 2).

On page X of *Imman's Nautical Tables* (1922) is given the Table for the correction of the dip of sea horizon by Rev. W. HALL, Royal British Navy, but no statement is made as to how the Table is derived. In this Table, the temperature is given in degrees of FAHRENHEIT, and by interpolation the Table VI below in which the temperature is given in degrees of centigrade is obtained. The height at which the temperature of the air is measured is not given in this Table.

In CHAUVENET'S *Manual of Spherical and Practical Astronomy* (1874), Vol. I, p. 176, the following formula for the dip of sea horizon is given :-

$$D' = D - \frac{24021\ (t - t_0)}{D}$$

where D is the dip of sea horizon expressed in seconds, supposing there is no refraction, t and t_0 are the temperature of the air at the height of the eye and the temperature of sea water, both expressed in degrees of FAHRENHEIT. As the dip under the normal state of the air is equal to $D - 0.0784D$, as given by the same manual, the following formula can be obtained :-

$$\textit{Correction to be applied to the dip of se a horizon} = 0.0784D - \frac{24021\ (t - t_0)}{D}$$

The corrections calculated by this formula are shown in Table VII. CHAUVENET'S formula is derived from the theory of refraction and not from actual observations of the dip. It appears that considerable errors occur in constants and in hypotheses used in the formula.

These Tables show that the values of the corrections of the dip of sea horizon by different authorities do not differ much from one another; in the Tables of Koss (Table II.) and CHAUVENET, the values are nearly equal. We will not consider CHAUVENET'S values, since they are derived from the theory of refraction and not from observations of the dip. Most of the other Tables are derived from Koss's observations. KOHLSCHÜTTER-BREHMER'S Table seems to be the most accurate. In this last Table it is presumed that the temperature of the air at the surface of the sea is equal to that of sea water, and that the variation of the temperature of the air with the height is subject to a regular law. But these presumptions are scarcely borne out by actual occurrences. It can be observed from Table I (II) that the corrections of the dip for a very weak wind differ very much from those for a stronger wind. On board a ship at sea it is possible to measure the temperature of sea water at the ship's own position only, and not at the visible horizon. Therefore, where the temperature of the sea differs considerably from place to place, as is often the case in the area of an ocean current, the actually-observed correction of the dip of sea horizon may differ greatly from the tabular value.

BREHMER compared the observations of the dip of sea horizon by navigators in 1906-1910, over 1000 in number, with the values given in KOHLSCHÜT-

TABLE VI. — HALL'S TABLE FOR THE CORRECTION OF THE DIP OF SEA HORIZON.
TABLE DE HALL POUR LA CORRECTION DE LA DÉPRESSION DE L'HORIZON DE LA MER.

H. E. (*Elévation de l'œil*)		(Air Temperature) — (Water Temperature) C. (*Température de l'air*) — (*Température de l'eau*) C.													
		+14°	+12°	+10°	+8°	+6°	+4°	+2°	0	−2°	−4°	−6°	−8°	−10°	−12°	−14°
m.	*m.*															
0	36.6	−4'.8	−4'.1	−3'.4	−2'.8	−2'.1	−1'.4	−0'.7	0'.0	+0'.7	+1'.4	+2'.1	+2'.8	+3'.4	+4'.1	+4'.8
6.1	30.5	−5'.1	−4'.4	−3'.7	−3'.1	−2'.4	−1'.6	−0'.9	0'.0	+0'.9	+1'.6	+2'.4	+3'.1	+3'.7	+4'.1	+5'.1
12.2	24.4	−5'.3	−4'.6	−3'.9	−3'.2	−2'.5	−1'.7	−1'.0	0'.0	+1'.0	+1'.7	+2'.5	+3'.2	+3'9.	+4'.6	+5'.3
18.3		−5'.5	−4'.8	−4'.1	−3'.3	−2'.6	−1'.9	−1'.1	0'.0	+1'.1	+1'.9	+2'.6	+3'.3	+4'.1	+4'.8	+5'.5

TABLE VII. — CHAUVENET'S TABLE FOR THE DIP OF SEA HORIZON.
TABLE DE CHAUVENET POUR LA DÉPRESSION DE L'HORIZON DE LA MER.

(Temperature of the air is measured at the height of the eye). (*La température de l'air est mesurée à la hauteur de l'œil*).

H. E. (*Elévation de l'œil*)	(Air temperature) — (Water Temperature) C. (*Température de l'air*) — (*Température de l'eau*) C.												
	+12°	+10°	+8°	+6°	+4°	+2°	0°	−2°	−4°	−6°	−8°	−10°	−12°
m.	'	'	'	'	'	'	'	'	'	'	'	'	'
6	−30	−25	−20	−15	−10	−5	0	+5	+11	+16	+21	+26	+31
8	−26	−22	−17	−13	− 8	−4	0	+5	+ 9	+14	+18	+22	+27
10	−23	−19	−15	−11	− 7	−3	0	+4	+ 8	+12	+16	+20	+24
12	−21	−17	−14	−10	− 7	−3	0	+4	+ 8	+11	+15	+18	+22
14	−19	−16	−13	− 9	− 9	−3	0	+4	+ 7	+11	+14	+17	+20
16	−18	−15	−12	− 9	− 6	−3	0	+4	+ 7	+10	+13	+16	+19
18	−17	−14	−11	− 8	− 5	−2	0	+3	+ 6	+ 9	+13	+15	+18
20	−16	−13	−10	− 8	− 5	−2	0	+3	+ 6	+ 9	+12	+14	+17

TER-BREHMER's Table (*Annalen der Hydrographie*, 1910, pp. 120-132, 160-171). The difference between the temperatures of air and of sea water was generally smaller than 5°C. But at some places much greater differences were observed, the maximum being 13°.6 in the area of the Gulf Stream near Newfoundland, in winter. In most cases the observed value of the dip coincided with the tabular value within 1', but sometimes a difference of 3'-4' was found. BREHMER concluded that, except for the places where the temperature of the sea water changes very rapidly from place to place, the KOHLSCHÜTTER-BREHMER Table of the dip is sufficiently accurate for practical purposes.

Rear-Admiral YONEMURA, the Director of the Hydrographic Department of the Imperial Japanese Navy, who has always been interested in the problem of the dip of sea horizon, gave orders to the Captain of H. J. M. S. *Mansyû* to observe the dip of sea horizon in winter in the area of the "Kurosio". Lieutenant SONE, the navigating officer of the *Mansyû*, made observations and sent in his report (*Suiro Yôhô*, 1926, pp. 155-158). These observations were made in January and February of 1926 in the area of the "Kurosio", near the south coast of Japan. The exact position of the ship was determined by terrestrial objects. The observed altitude of the Sun was first corrected by the *Sin Kôdo Hôikaku Hyô*, the corrections for the variations in refraction being applied for altitudes lower than 6°; and then corrected for the variation of the dip for the difference between temperatures of air and of sea water by KOHLSCHÜTTER-BREHMER Table. The position line was drawn on the chart and the distance of the position line from the ship's position, determined by terrestrial objects, was taken as the error of the observed altitude. The temperature of the air was measured at the height of 9 metres above sea-level. To reduce it to the temperature at the height of the eye, KOHLSCHÜTTER'S formula (3) was used. This formula was found to be nearly correct by laboratory experiments (*Annalen der Hydrographie*, 1909, pp. 306-324). The correction of the temperature was less than 0.4°. The temperature of the air given in Table VIII is that corrected in this way.

The number of observations made is too limited to enable us to arrive at any definite conclusion from these data. Assuming that the correction of the dip is equal to $a\ (t - t_w)$, we find from this table, by the method of least squares, the constant a to be 0.32 for high altitude, 0.15 for low altitude, and 0.23 for all observations. The error of the observed altitude for a low height of the eye is greater than for a high height. However, it is needless to say that these values are subject to considerable errors: we require more ample observation data.

This at least may be asserted with certainty, that, where the difference in temperature between the air and the sea water is great, as in the area of the "Kurosio", the correction of the dip for the difference of temperature is correspondingly great, and therefore the required correction must be made. For all practical purpose, the simpler Tables such as Tables IV and V seem to be quite sufficient.

In conclusion I wish to express my best thanks to Rear-Admiral YONEMURA, who ordered me to make investigations in connection with this subject and gave me much valuable advice with many equally valuable suggestions.

TABLE VIII — ERROR OF THE OBSERVED ALTITUDE OF THE SUN IN THE AREA OF THE "KUROSIO".
ERREUR SUR LA HAUTEUR OBSERVÉE DU SOLEIL DANS LES PARAGES DU "KUROSIO".

1926	TIME. *HEURE*	H. E. *Elévation de l'œil*	Altitude *Hauteur* ° '	Air *Air* ° C.	Water *Eau* ° C.	Diff. *Diff.* ° C.	Error *Erreur Cal. - Obs.*	REMARKS. REMARQUES
Morning : *Matin :*	h. m.	*m.*	Low Altitude.	*Petites Hauteurs*				
January 24.....	7 15	11.6	3.59	0.7	13.0	12.3	—0.8	Horizon not good.
Janvier 24.....								*Mauvais horizon.*
January 21.....	7 25	11.6	4.12	2.8	11.0	8.2	+2.0	Horizon worse than the above.
Janvier 21.....								*Horizon encore plus mauvais.*
January 24.....	7 15	6.0	4.26	1.4	13.0	11.6	—0.2	Horizon not good.
Janvier 24.....								*Mauvais horizon.*
January 22.....	7 30	11.6	5.45	5.7	18.8	13.1	—0.2	Horizon very bad.
Janvier 22.....								*Horizon très mauvais.*
Evening : *Après midi :*								
February 2.....	17 30	6.0	0.48	12.2	19.5	7.3	+1.4	Horizon not good.
Février 2.....								*Mauvais horizon.*
February 2.....	" "	11.6	1. 5	11.8	19.5	7.7	+1.4	Horizon not good.
Février 2.....								*Mauvais horizon.*
January 21.....	17 0	11.6	3.12	4.7	17.0	12.3	—3.9	Horizon good.
Janvier 21.....								*Bon horizon.*
			High Altitude	*Grandes Hauteurs*				
January 21.....	8 30	11.6	14.35	2.8	11.0	8.2	+0.9	Horizon not good.
Janvier 21.....								*Mauvais horizon.*
January 21.....	10 0	11.6	27.28	3.8	11.0	7.2	+0.1	Horizon not good.
Janvier 21.....								*Mauvais horizon.*
January 21.....	15 0	11.6	23.55	4.7	17.0	12.3	—2.0	Horizon not good.
Janvier 21.....								*Mauvais horizon.*
January 23.....	8 50	11.6	18.37	5.2	18.5	13.3	—2.0	Horizon not good - hazy.
Janvier 23.....								*Mauvais horizon - brumeux.*
January 23.....	11 20	11.6	35.53	6.7	19.3	12.6	—2.2	Horizon not good.
Janvier 23.....								*Mauvais horizon.*
January 29.....	10 30	11.6	33.20	12.7	18.0	5.3	—0.4	Horizon rather good.
Janvier 29.....								*Horizon assez bon.*
January 23.....	8 50	6.0	18.50	5.9	18.5	12.6	—4.0	Horizon not good - hazy.
Janvier 23.....								*Mauvais horizon - brumeux.*
January 23.....	11 20	6.0	35.56	7.4	19.3	11.9	—3.9	Horizon not good.
Janvier 23.....								*Mauvais horizon.*
January 29.....	11 0	6.0	35.40	13.0	18.0	5.0	—1.0	Horizon rather good.
Janvier 29.....								*Horizon assez bon.*

MEAN ERROR For high altitude *Pour grandes hauteurs* – 1'.8 For H. E. *Pour Elévation de l'œil* 11.6 m.– 0'.8
ERREUR MOYENNE. For low altitude. *Pour petites hauteurs* 0.0 For H. E. *Pour Elévation de l'œil* 6.0 – 1'.5

In seas where the difference between temperatures of air and of sea water is very great, as in the area of the "Kurosio", the problem of dip is very important, and observations in such seas supply very important data for the study of the dip. It is earnestly requested that navigators in general make observations and send their reports to the Hydrographic Department.