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Meteorological and Oceanographic Observations on I. N. S. INVESTIGATOR (March-April 1952)

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ABSTRACT. This paper describes the observations taken on *I.N.S. Investigator*, during the ship's last survey season in the Andaman Islands. The work done during the voyage was (*a*) measurement of temperature, density and salinity in the surface waters of the Arabian Sea and Bay of Bengal, and (*b*) measurement of the humidity wind gradient in the lower layers of the atmosphere above the sea.

The observations of salinity during the voyage have been compared with the earlier work of Sewell (1938). In addition, attempts have been made to estimate evaporation from the observations of humidity gradient. The wind observations have also been analysed to see what agreement they give with Rossby's earlier results.

1. Introduction

The necessity of initiating meteorological and oceanographic observations on Indian waters has been long felt. However, it was only recently that an opportunity could be had for making a beginning, through the courtesy of the Indian Navy, who agreed, at the request of the Central Board of Geophysics, to take the personnel of the Meteorological Service on board the survey ship *I.N.S. Investigator* during its cruise from Bombay to Port Blair and back. The authors were deputed by the India Meteorological Department for meteorological and oceanographic work on the *I.N.S. Investigator* during this cruise. Useful experience was gained regarding the arrangements for recording the observations and the exposure of instruments, and it was possible to record some of the desired observations. This paper deals with the observations taken during this cruise.

The work done was as follows: (*a*) Measurement of temperature, density and salinity in the surface waters of the Arabian Sea and Bay of Bengal, (*b*) Measurement of the humidity and wind gradient in the lower layers over the sea.

The methods of observation and the results obtained in each of the above items are described below.

2. Surface Salinity

2.1. *Method of observation*—Samples of sea water were collected as a routine measure twice a day (0830 and 1730 IST); on some occasions when time permitted a third observation was also taken, usually at 1200 IST. The water was collected in a marine bucket of standard design and its temperature, as well as specific gravity, was measured as soon as the bucket was hauled on board. To avoid contamination the water samples were invariably collected from the fore end of the ship.

The salinity was determined by two methods; firstly, by measuring its specific gravity, and secondly, by titration against Silver Nitrate. The specific gravity of each sample was determined by a stem hydrometer capable of reading up to the fourth decimal place. In modern oceanographic work (Helland-Hansen and Nansen 1909, and Sewell 1938), more accurate hydrometers have been used, but such hydrometers were not available with us at the time of the expedition.

The specific gravity readings were converted to read salinity with the help of Knudsen's hydrographic tables (1901). In working up the data, the density of sea water at 17·5°C was evaluated after making necessary corrections for the expansion of the hydrometer glass. The corresponding values of salinity and σ_0 were then obtained from the tables. We have defined σ_0, in the usual notation, as the density of the water 'in situ', *i.e.*,

$$\sigma_0 = 1000\,(S_0 - 1) \qquad (2 \cdot 1)$$

where S_0 is the specific gravity of water at 0°C.

For chemical analysis, the water samples were stored during the voyage in rubber stoppered bottles, and later titrated against Silver Nitrate by using a few drops of Potassium Chromate (K_2CrO_4) as indicator. To eliminate the effect of sunlight on Silver Nitrate, the titration was done in a dark room. The Silver Nitrate was also standardised by titration against pure sodium chloride solution of known strength.

From the results of titration, the chloride content of each sample was evaluated in grams per litre at the room temperature. This was then corrected to give the chloride content at 20°C, and the chlorinity per kilogram was obtained from Thompson's (1928) relation,

$$Cl_W = 0 \cdot 008 + 0 \cdot 99980(Cl_V) - 0 \cdot 001228(Cl_V)^2 \qquad (2 \cdot 2)$$

(Cl_W — Chlorinity per kilogram,

Cl_V — Chlorinity per litre at 20°C).

Finally, the salinity was obtained from Knudsen's formula,

$$S^0/_{00} = 0 \cdot 030 + 1 \cdot 8050\ Cl^0/_{00} \qquad (2 \cdot 3)$$

The above formula is based on the assumption that this relation between the total halogen content and the total salt content is true for all sea water. The assumption is not strictly true, but departures from it have been shown to be very small.

2.2. *Discussion of results*—In all thirty five samples of sea water were analysed (*cf.* Appendix 1). In Table 1, the difference between the titration and specific gravity readings have been tabulated. It will be seen that measurements of salinity by both methods agree within $\pm 1 \cdot 0^0/_{00}$, except in one case. The comparatively large difference in one case was probably an experimental error; consequently, it has been neglected. The average difference between the titration and specific gravity values were $-0 \cdot 249^0/_{00}$ for salinity and $-0 \cdot 199$ for σ_0.

In 18 cases the hydrometer gave a higher value of salinity; while in 3 cases both methods gave identical values. In 6 of the remaining cases, the titration values were only slightly higher, the difference being less than 0·01.

The observations, therefore, showed that in a majority of cases the hydrometer recorded a higher value of salinity. This was in agreement with the observed results of Helland-Hansen and Nansen (1909) and Sewell (1938). In particular, Sewell (1938) analysed thirtyfour samples from the Andaman Sea and found that the hydrometer readings gave a higher value of salinity in 28 cases. The same tendency was also noticed in our observations.

2·3. *Geographical distribution of salinity*—In Figs. 1 and 2, we have also shown the salinity values obtained by titration and from measurements of specific gravity. For comparison, the isohalines of Sewell (1938) have been shown in Fig. 3. Although the present series of observations were rather few, some features of similarity, namely, the low salinity of the Andaman Sea and high salinity of the waters round Ceylon, were noticed.

3. The vertical gradient of humidity in the lower layers of the atmosphere above the sea

3·1. *Theoretical considerations*—Measurements of the humidity gradient are required for estimating evaporation from the sea surface. Montgomery (1940) showed that if the distribution of water vapour was logarithmic, then the rate of evaporation was given by,

$$E = \rho \,.\, k_0 \,.\, \Gamma_b \,.\, (q_s - q_b) \,.\, \gamma_a \,.\, U_a \qquad (3 \cdot 1)$$

where:

E=flux of water vapour (gm cm^{-2} sec^{-1})

q_s, q_b = the specific humidities at the surface and at a height b cm

k_0 = Von Karman's constant (0·4)

U_a=Wind velocity at a height of a cm

and $\gamma_a = \frac{1}{U_a} \cdot \left(\frac{\tau_0}{\rho}\right)^{\frac{1}{2}}$

τ_0 represents the shear stress exerted by the wind on unit area of the sea. This has been assumed to be independent of height near the surface. The other non-dimensional co-efficient (Γ) is given by,

$$\Gamma = -\frac{1}{e_s - e_b} \cdot \frac{de}{d(\log z)} \qquad (3.2)$$

where e_s, e_b refer to the vapour pressures at the surface and at a height b cm.

The co-efficient Γ depends on the state of the sea surface, and on atmospheric stability. For a smooth surface in neutral equilibrium, it is generally agreed that two boundary layers exist near the surface. They are: a thin layer of laminar flow, having a thickness of about a centimetre, and, a turbulent layer above it. The wind velocity in the turbulent layer is assumed to follow a logarithmic profile given by,

$$\frac{1}{\gamma} + 5{\cdot}75 \log \frac{1}{\gamma} = 5{\cdot}5 + 5{\cdot}75 \log r \qquad (3{\cdot}3)$$

where, $r = \frac{U \,.\, z}{\nu}$

ν = kinematic co-efficient of viscosity.

The above equation was originally obtained from observed profiles over flat plates on a laboratory scale (Goldstein 1938), but Rossby (1936) found that it also fitted wind observations over a calm sea. The limiting wind velocity for 'smooth' flow was found from observation to be about 6 m sec^{-1}.

Sverdrup (1946) used the above equation and obtained the following values of Γ for flow over a smooth surface at 20°C.

	Wind velocity at 6 m (m sec^{-1})	Γ
1	2·0	0·087
2	4·0	0·083
3	6·0	0·080

At higher temperature the Γ values increase, but the variation with temperature is very small.

For evaporation over a rough surface, a number of authors have obtained values of Γ based on different boundary conditions (*cf.* references). The assumptions made have been recently reviewed by Sverdrup (1951) and will not be discussed here. In Fig. 4, however, we reproduce the different values of Γ that have been computed for a rough surface. The noteworthy feature of this diagram is that while Sverdrup, Norris and others claim a higher value of Γ for a 'rough' surface; Montgomery's value is much less.

3·2. *Observations of the humidity gradient*—The gradient of humidity can be measured from well exposed positions on a ship, or alternatively, from self-recording instruments fitted to a mast on a floating raft. In the former method the conditions may not always represent the undisturbed air, but on the other hand, the latter technique cannot be used in strong winds and rough seas.

In the present series the observations were made from three well exposed heights on the ship. The dry and wet bulb temperatures were recorded by observers equipped with Assman Psychrometers at 19·0 m, 11·8 m and 7·5 m above the sea surface. Each observer took a number of readings and the mean value was taken as the observed result. The sea surface temperature, and the wind at 11·8 m, was also measured at the same time. For computing the vapour pressure corresponding to the surface, it was assumed that the air in immediate contact with the sea was saturated. The lowering of saturated vapour pressure due to salinity was also taken into account by assuming a mean salinity of 35‰.

TABLE 1

Difference in values of salinity and σ_0 obtained by titration and measurement of specific gravity

Sample No.	Ship's position		By Titration		By Hydrometer		Difference (T—H) in $S^0/_{00}$	Difference (T—H) in σ_0
			$S^0/_{00}$	σ_0	$S^0/_{00}$	σ_0		
1	15° 36′ N	73° 21′ E	36·44	29·29	36·00	28·94	+0·44	+0·35
2	14° 00′ N	74° 02′ E	35·23	28·31	35·17	28·26	+0·06	+0·05
3	11° 11′ N	75° 16′ E	34·61	27·82	34·52	27·74	+0·09	+0·08
4	10° 00′ N	75° 48′ E	34·61	27·82	34·61	27·82	0	0
5	09° 24′ N	76° 04′ E	34·49	27·71	34·51	27·73	—0·02	—0·02
6	07° 18′ N	78° 03′ E	34·18	27·47	34·85	28·00	—0·67	—0·53
7	06° 10′ N	79° 30′ E	34·18	27·47	34·18	27·47	0	0
8	06° 06′ N	82° 12′ E	33·96	27·29	33·66	27·04	+0·30	+0·25
9	06° 26′ N	82° 50′ E	33·96	27·29	34·78	27·95	—0·82	—0·66
10	06° 42′ N	83° 48′ E	33·78	27·15	33·77	27·14	+0·01	+0·01
11	08° 25′ N	86° 31′ E	34·09	27·39	33·78	27·15	+0·31	+0·24
12	09° 24′ N	88° 16′ E	33·96	27·29	33·93	27·26	+0·03	+0·03
13	10° 26′ N	91° 25′ E	32·52	26·13	32·56	26·16	—0·04	—0·03
14	11° 05′ N	92° 10′ E	32·94	26·46	32·81	26·36	+0·13	+0·10
15	11° 17′ N	92° 32′ E	32·75	26·32	32·71	26·28	+0·04	+0·04
16	Port Blair		32·54	26·13	32·54	26·13	0	0
17	11° 40′ N	89° 54′ E	32·65	26·23	34·11	27·41	—1·46*	—1·18*
18	11° 28′ N	89° 11′ E	31·92	25·65	Values not available in Knudsen's tables			
19	11° 59′ N	87° 53′ E	33·78	27·15	34·64	27·84	—0·86	—0·69
20	12° 12′ N	85° 00′ E	32·54	26·14	32·38	26·01	+0·16	+0·13
21	12° 23′ N	84° 20′ E	32·94	26·46	32·80	26·36	+0·14	+0·10
22	12° 30′ N	82° 45′ E	32·63	26·22	33·48	26·90	—0·85	—0·68
23	12° 56′ N	80° 29′ E	34·31	27·57	35·28	28·35	—0·97	—0·78
24	09° 47′ N	81° 21′ E	33·84	27·19	33·61	27·01	+0·23	+0·18
25	08° 57′ N	81° 33′ E	34·16	27·45	35·16	28·26	—1·00	—0·81
26	07° 50′ N	81° 55′ E	33·82	27·18	34·76	27·93	—0·94	—0·75
27	05° 49′ N	80° 23′ E	33·95	27·28	34·27	27·54	—0·32	—0·26
28	06° 10′ N	79° 40′ E	34·16	27·45	34·76	27·93	—0·60	—0·48
29	06° 50′ N	78° 45′ E	34·79	27·96	35·05	28·16	—0·26	—0·20
30	08° 37′ N	76° 30′ E	35·10	28·21	36·09	29·01	—0·99	—0·80
31	09° 19′ N	76° 17′ E	34·47	27·70	34·85	28·00	—0·38	—0·30
32	10° 00′ N	75° 50′ E	34·79	27·96	35·50	28·53	—0·71	—0·57
33	13° 23′ N	74° 19′ E	35·73	28·72	35·44	28·48	+0·29	+0·24
34	14° 13′ N	73° 56′ E	35·73	28·72	36·72	29·51	—0·99	—0·79
35	15° 09′ N	73° 34′ E	36·36	29·23	36·38	29·24	—0·02	—0·01

*This large difference was rejected

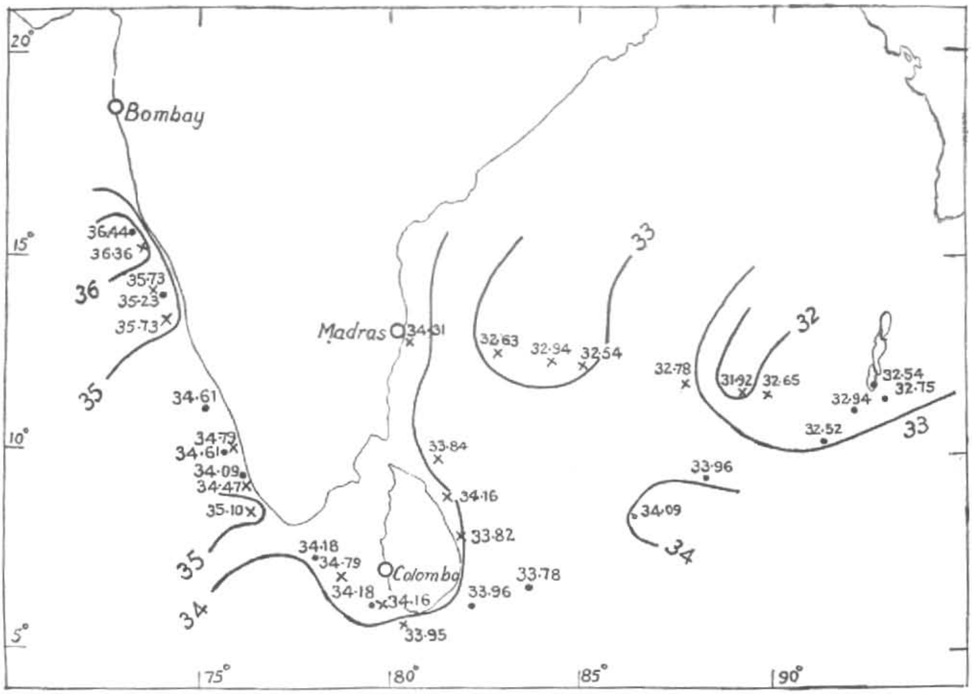

Fig. 1. Salinity ($^0/_{00}$) observations by chemical analysis (March-April 1952)

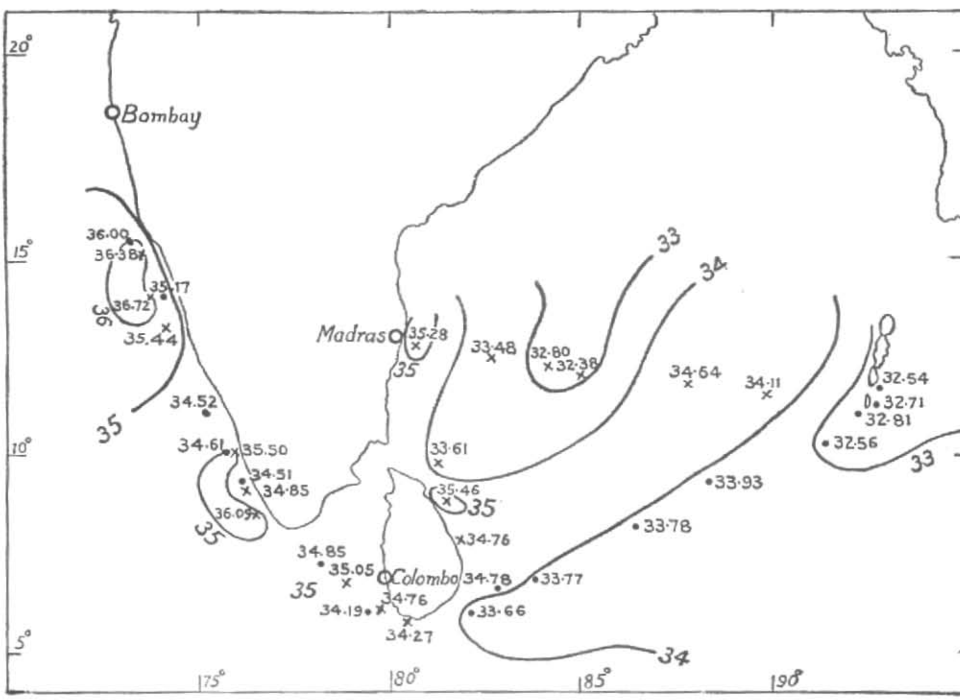

Fig. 2. Salinity ($^0/_{00}$) observations by measurement of sp. gravity (March-April 1952)

NOTE—• Refers to the cruise from Bombay to Port Blair × Refers to the return voyage from Port Blair

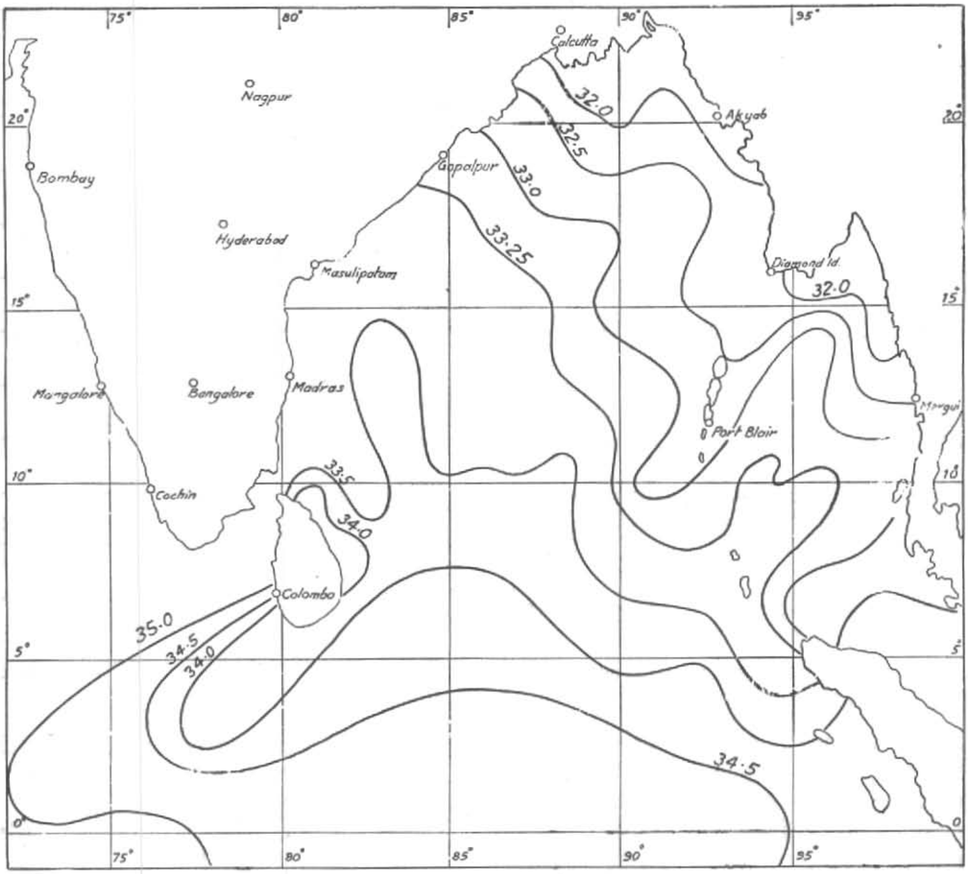

Fig. 3. The surface salinity ($^0/_{00}$) of the Bay of Bengal—March to May (after Sewell)

TABLE 2

Group	No. of observations	Wind speed (m sec⁻¹)		Average vapour pressure (mb)				Γ
		Range	Average	Surface	7·5 m	11·8 m	19·1 m	
For unstable layers								
I	10	0—1·5	0·8	42·78	29·28	28·92	29·01	0·059
II	8	1·5—4·1	2·8	41·86	28·93	28·39	28·62	0·093
III	6	4.1—7·7	5·9	42·13	31·49	30·09	29·57	0·1930
For stable layers								
IV	5	4·0 and above		39·88	31·99	30·77	30·19	0·2440

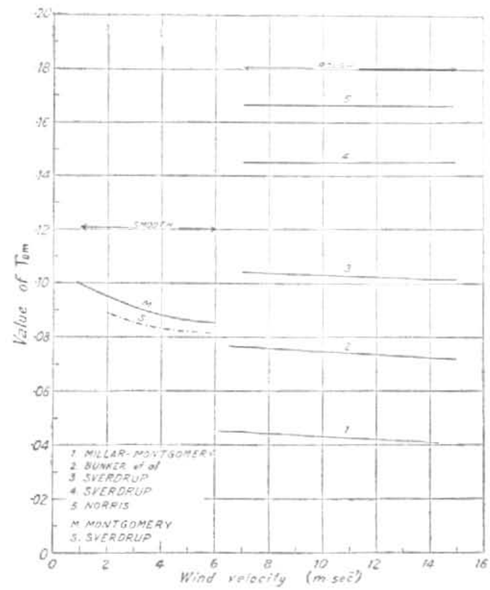

Fig. 4. Value of Γ_{8m} for smooth and rough surfaces (after Sverdrup)

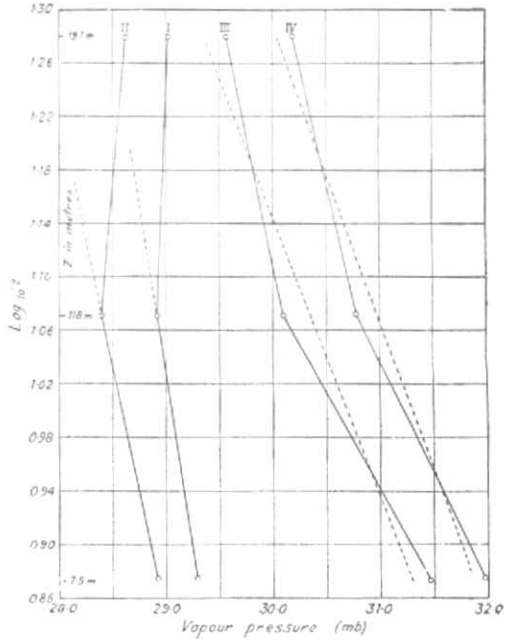

Fig. 5. Variation of vapour pressure with height

In all 31 sets of observations were taken. These are given in Appendix 2. Since Γ also depends on atmospheric stability, a column was added to indicate the stability of the layer. If the temperatures at two successive heights exceeded the sea temperature the layer was termed as 'stable'; otherwise it was called 'unstable'.

The observations were further divided into three groups in order of increasing wind speed, and all observations under 'stable' conditions were collected together separately in a fourth group (*cf.* Table 2).

The mean vapour pressure at each height was computed for the different groups, and in Fig. 5 they are shown against the logarithm of height. The observed values indicate a steep gradient of vapour pressure from the surface to 7·5 m, the difference being of the order of 10 mb. From 7·5 to 19·1 m, the observations approximately fit a logarithmic profile (shown by dashed lines), except in groups I and II. In these groups the observations at 19·1 metres did not fit in with a logarithmic profile.

Assuming, however, a logarithmic distribution of vapour pressure, we have,

$$\Gamma = \frac{e_a - e_b}{e_s - e_a} \cdot \frac{1}{\ln(b/a)} \qquad (3\cdot4)$$

(the suffixes a, b refer to two different heights above the sea surface)

The Γ values obtained from (3·4) are shown in Table 2. The computations were based on the average vapour pressures at 19·1 m and 7·5 m, except in groups I and II. In these groups the vapour pressure at 11·8 m was used instead of the higher value, as the latter showed a rather large discrepancy from the logarithmic profile. Two individual observations (Nos. 9 and 25 in Appendix 2) were also rejected because they gave abnormally high values of Γ probably due to experimental errors.

The values, 0·059 and 0·093, in groups I and II were of the same order as obtained by Sverdrup and others on theoretical grounds. For higher wind speeds (group III), when the sea acts as a rough surface, the value of Γ was more than double that for a smooth surface. This supports the theoretical result of Sverdrup and Norris. In 'stable' conditions, the value of Γ (observed) was higher than that for a rough surface, but theoretical work has not yet been extended to take account of stable conditions.

The above values of Γ were also used to compute the total evaporation from the sea surface with the help of equation 3·1, and the results are shown in Table 3.

TABLE 3

Group	No. of observations	Mean wind velocity at 11·8 m (m sec^{-1})	E (gm cm^{-2} sec^{-1})
I	10	0·8	0·60 × 10^{-6}
II	8	2·8	2·80 ,,
III	6	5·9	11·10 ,,
IV	5	4·0	11·20 ,,

For groups I and II, the stress coefficient (γ_a) was deduced from equation 3·3, and for the remaining groups, the coefficient corresponding to a 'rough' surface was used. This value of γ_a is given by

$$\gamma_a = k_0 \left(\ln \frac{a+z_0}{z_0}\right)^{-1} \qquad (3\cdot5)$$

where z_0 = the roughness parameter of the sea surface (0·6 cm).

4. Measurement of the wind gradient in the lower layers of the sea

4·1. *Theoretical considerations*— The importance of wind measurements over the sea arises from the fact that the sea can act both as a hydrodynamically 'smooth' or 'rough' surface depending on the wind speed.

Rossby (1936), using the wind measurements of earlier workers, had found that the transition from a 'smooth' to a 'rough' surface took place at 6 m sec^{-1}. For lighter winds he claimed good agreement between the observed profiles and equation

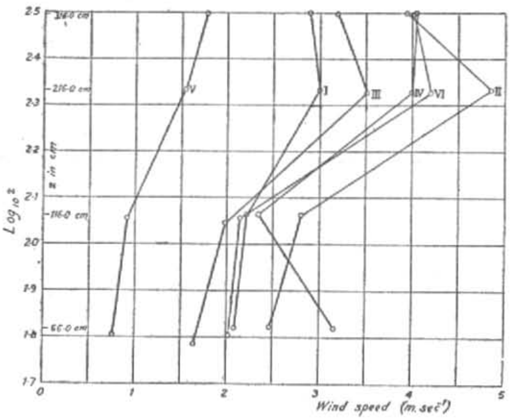

Fig. 6. Variation of wind with height

3·3, which was only true for flow on a laboratory scale. At higher wind speeds, Rossby found that the observed velocity profiles were also logarithmic, and indicated a roughness parameter equal to 0·6 cm under conditions of equilibrium between the waves and the wind. The existence of a discontinuity at winds of 6–7 m sec^{-1} was also supported by Munk (1947) from theoretical considerations.

In the present voyage, the wind observations were undertaken to see what agreement the actual observations give with Rossby's results.

4·2. *Observations of the wind gradient*— The wind observations were made with sensitive vane anemometers. The range of these instruments varied from 200—300 ft min^{-1}, and, each anemometer was also provided with a calibration curve giving a correction for the observed velocity. At high wind speeds the corrections varied linearly, but there was a sharp increase in the corrections at low wind speeds. Therefore, the instruments were not suitable for measuring very low winds.

The anemometers were mounted at approximate heights of 0·5, 1·0, 2·0 and 3·0 metres on a mast, and the mast was fitted to an open boat. While taking observations, the anemometers were read at the beginning and end of three minutes intervals, and the

TABLE 4

Date	No. of observations	a (cm)	U_a (m sec^{-1})	b (cm)	U_b Computed (m sec^{-1})	U_b Observed (m sec^{-1})
22.3.52	5	216	3·01	66·0	2·71	2·08
25.3.52	4	216	4·86	66·0	3·41	2·45
30.3.52	6	212	3·51	62·0	3·09	1·63
3.4.52	6	214	4·21	64·0	3·69	2·01

experiment was repeated several times. By operating a system of wires, it was also possible to start, as well as stop, all the instruments simultaneously, but the main difficulty with vane anemometers was experienced in conditions of gustiness and changing wind direction.

4·3. *Observed features of the wind profile*—The data collected has been tabulated in Appendix 3, and the velocity profiles observed on six different days are shown in Fig. 6. The wind speeds shown in the figures represent mean values, obtained from a number of individual observations.

The wind observations show a discontinuity at about 2 m. This feature had also been observed by other workers (Charnock 1951), but it is possible, in these measurements from a boat, that the wind field in the lower layers was distorted by the presence of the boat itself.

The observations were made in light winds and an attempt was made to see how they fit in with equation 3·3, but the results were not satisfactory. In each case, the velocity at 2·16 m (just below the discontinuity) was used to compute the velocity at the lowest level (0·6 m) but no agreement was found between the observed and computed velocities (Table 4).

The above result does not agree with Rossby but, as mentioned earlier, the discrepancy may have been due to limitations of the experimental technique.

5. Acknowledgement

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Appendix 1

S. No.	Date	Time (IST)	Position		By Titration			By Hydrometer			
					Cl_w	$S^0/_{00}$	σ_0	Sea Temp. (°C)	Sp. Gravity	σ_0	Salinity $^0/_{00}$
1	12-3-52	0830	15°36′N	73°21′E	20·17	36·44	29·29	27·78	1·0248	28·94	36·00
2	12-3-52	1700	14°00′N	74°02′E	19·50	35·23	28·31	29·33	1·0237	28·26	35·17
3	13-3-52	0830	11°11′N	75°16′E	19·16	34·61	27·82	29·44	1·0232	27·74	34·52
4	13-3-52	1430	10°00′N	75°48′E	19·16	34·61	27·82	30·20	1·0230	27·81	34·61
5	13-3-52	1730	09°24′N	76°04′E	19·09	34·49	27·71	30·00	1·0230	27·73	34·51
6	14-3-52	0830	07°18′N	78°03′E	18·92	34·18	27·47	29·17	1·0235	28·00	34·85
7	14-3-52	1730	06°10′N	79°30′E	18·92	34·18	27·47	31·67	1·0222	27·47	34·18
8	15-3-52	0830	06°06′N	82°12′E	18·80	33·96	27·29	28·89	1·0227	27·04	33·66
9	15-3-52	1200	06°26′N	82°55′E	18·80	33·96	27·29	30·56	1·0230	27·95	34·78
10	15-3-52	1730	06°42′N	83°48′E	18·70	33·78	27·15	29·78	1·0225	27·30	33·77
11	16-3-52	0845	08°25′N	86°31′E	18·87	34·09	27·39	29·17	1·0227	27·15	33·78
12	16-3-52	1730	09°24′N	88°16′E	18·80	33·96	27·29	29·17	1·0228	27·26	33·93
13	17-3-52	0830	10°26′N	91°25′E	18·01	32·54	26·13	29·44	1·0217	26·16	32·56
14	17-3-52	1630	11°05′N	92°10′E	18·23	32·94	26·46	30·06	1·0217	26·36	30·81
15	18-3-52	0830	11°17′N	92°32′E	18·13	32·75	26·32	29·83	1·0217	26·28	32·71
16	18-3-52	1630	Port Blair		18·01	32·54	26·13	29·44	1·0217	26·14	32·54
17	22-4-52	0830	11°40′N	89°54′E	18·07	32·65	26·23	30·56	1·0225	27·41	34·11
18	22-4-52	1200	11°28′N	89°11′E	17·67	31·94	25·65	32·50	1·0208	Values not available in Knudsen's tables	
19	22-4-52	1700	11°59′N	87°53′E	18·70	33·78	27·15	31·23	1·0227	27·84	34·64
20	23-4-52	0830	12°12′N	85°00′E	18·01	32·54	26·14	30·00	1·0214	26·01	32·38
21	23-4-52	1200	12°23′N	84°20′E	18·23	32·94	26·46	29·67	1·0218	26·36	32·80
22	23-4-52	1700	12°30′N	82°45′E	18·06	32·63	26·22	29·44	1·0224	26·90	33·48
23	27-4-52	1630	12°56′N	80°29′E	18·99	34·31	27·57	29·33	1·0238	28·35	35·28
24	28-4-52	0830	09°47′N	81°21′E	18·73	33·84	27·19	29·44	1·0225	27·01	33·61
25	28-4-52	1300	08°57′N	81°33′E	18·91	34·16	27·45	30·00	1·0235	28·26	35·16
26	28-4-52	1730	07°50′N	81°55′E	18·72	33·82	27·18	30·56	1·0230	27·93	34·76
27	29-4-52	0830	05°45′N	80°23′E	18·79	33·95	27·28	29·44	1·0230	27·54	34·27
28	29-4-52	1230	06°10′N	79°40′E	18·91	34·16	27·45	30·56	1·0230	27·93	34·76
29	29-4-52	1730	06°50′N	78°45′E	19·26	34·79	27·96	30·00	1·0234	28·16	35·05
30	30-4-52	0830	08°37′N	76°30′E	19·43	35·10	28·21	30·56	1·0240	29·01	36·09
31	30-4-52	1200	09°19′N	76°17′E	19·08	34·47	27·70	31·11	1·0229	28·00	34·85
32	30-4-52	1520	10°00′N	75°50′E	19·26	34·79	27·96	31·67	1·0232	28·53	35·50
33	1-5-52	0900	13°23′N	74°19′E	19·78	35·73	28·72	30·56	1·0235	28·48	35·44
34	1-5-52	1245	14°13′N	73°56′E	19·78	35·73	28·72	31·39	1·0242	29·51	36·72
35	1-5-52	1740	15°09′N	73°34′E	20·13	36·36	29·23	30·00	1·0244	29·24	36·38

Appendix 2

No.	Date Time (IST)	Ship's position	Height (m)	T°C	T'°C	(T–T')°C	e (mb)	Wind velocity (m sec⁻¹)	Lapse rate
1	12-3-52 (0900)	15°36′N 73°21′E	19·1	27·0	23·0	4·0	27·74	6·0	Stable
			11·8	27·8	23·8	4·0	29·15		
			7·5	27·9	23·9	4·0	29·32		
			Surf	27·8	—	—	37·12		
2	12-3-52 (1200)	15°00′N 73°35′E	19·1	26·5	23·7	2·8	26·75	2·0	Unstable
			11·8	27·0	23·8	3·2	26·56		
			7·5	27·3	24·2	3·1	27·37		
			Surf	28·8	—	—	38·85		
3	12-3-52 (1700)	14°00′N 74°02′E	19·1	27·7	23·6	4·1	26·30	1·8	Unstable
			11·8	28·2	24·2	4·0	26·55		
			7·5	28·7	24·0	4·7	25·54		
			Surf	29·9	—	—	41·39		
4	13-3-52 (0900)	11°11′N 75°16′E	19·1	28·0	24·0	4·0	26·18	1·9	Unstable
			11·8	28·3	24·3	4·0	26·54		
			7·5	28·2	24·5	3·7	27·37		
			Surf	29·4	—	—	40·22		
5	13-3-52 (1430)	10°00′N 75°30′E	19·1	28·5	24·8	3·7	27·92	1·5	Unstable
			11·8	28·5	24·7	3·8	27·65		
			7·5	29·2	25·4	3·8	28·97		
			Surf	30·3	—	—	42·35		
6	13-3-52 (1730)	09°24′N 76°04′E	19·1	28·5	25·5	3·0	29·90	1·0	Unstable
			11·8	28·7	25·5	3·2	29·72		
			7·5	29·2	26·0	3·2	30·70		
			Surf	30·0	—	—	41·63		
7	14-3-52 (0830)	07°18′N 78°03′E	19·1	28·3	25·2	3·1	29·23	6·0	Unstable
			11·8	28·4	25·8	2·6	29·52		
			7·5	29·6	26·1	3·5	30·62		
			Surf	29·2	—	—	39·75		
8	14-3-52 (1730)	06°10′N 79°30′E	19·1	29·5	26·1	3·4	30·72	2·1	Unstable
			11·8	29·3	26·1	3·2	30·90		
			7·5	30·0	26·4	3·6	31·14		
			Surf	31·7	—	—	45·86		
9	15-3-52 (0830)	06°06′N 82°12′E	19·1	29·5	25·2	4·3	28·13	Calm	Stable
			11·8	28·7	25·4	3·3	29·43		
			7·5	29·4	26·1	3·3	30·81		
			Surf	28·9	—	—	39·07		
10	15-3-52 (1230)	06°30′N 82°30′E	19·1	28·8	25·3	3·5	29·06	0·9	Unstable
			11·8	28·8	25·6	3·2	29·91		
			7·5	30·4	26·0	4·4	29·60		
			Surf	30·6	—	—	43·08		
11	15-3-52 (1730)	06°42′N 83°48′E	19·1	28·5	24·6	3·9	27·37	0·9	Unstable
			11·8	28·7	24·9	3·8	28·02		
			7·5	28·9	24·4	4·5	26·45		
			Surf	29·6	—	—	40·68		
12	16-3-52 (1200)	08°30′N 85°30′E	19·1	28·6	24·9	3·7	28·11	4·1	Unstable
			11·8	28·6	25·0	3·6	28·39		
			7·5	29·9	25·8	4·1	29·48		
			Surf	30·0	—	—	41·63		
13	16-3-52 (1730)	09°24′N 88°16′E	19·1	28·5	24·9	3·6	28·80	1·3	Unstable
			11·8	28·8	24·7	4·1	27·37		
			7·5	29·2	25·0	4·2	27·84		
			Surf	29·2	—	—	39·75		

Appendix 2 *(contd)*

No.	Date Time (IST)	Ship's position	Height (*m*)	T°C	T'°C	$(T-T')$ °C	*e* (*mb*)	Wind velocity (m sec⁻¹)	Lapse rate
14	17-3-52 (0900)	10°36′N 91°25′E	19·1	29·3	25·0	4·3	27·75	6·0	Stable
			11·8	29·7	25·4	4·3	28·51		
			7·5	29·8	26·0	3·8	30·15		
			Surf	29·4	—	—	40·22		
15	17-3-52 (1200)	10°57′N 91°57′E	19·1	28·5	24·9	3·6	28·20	6·0	Unstable
			11·8	30·2	25·8	4·4	29·19		
			7·5	30·3	26·4	3·9	30·86		
			Surf	30·2	—	—	42·11		
16	17-3-52 (1730)	11°05′N 92°10′E	19·1	28·6	25·0	3·6	28·39	Calm	Unstable
			11·8	28·7	25·0	3·7	28·30		
			7·5	29·2	25·2	4·0	28·40		
			Surf	30·1	—	—	41·87		
17	18-3-52 (1630)	11°87′N 92°32′E	19·1	27·8	25·5	2·3	30·55	1·9	Unstable
			11·8	28·3	25·4	2·9	29·80		
			7·5	28·3	25·8	2·5	30·95		
			Surf	29·4	—	—	40·22		
18	20-3-52 (1630)	11°15′N 92°30′E	19·1	27·4	23·8	3·6	26·19	4·4	Unstable
			11·8	28·2	27·7	3·5	27·73		
			7·5	28·1	24·7	3·4	28·01		
			Surf	30·1	—	—	41·87		
19	22-4-52 (0830)	11°40′N 89°54′E	19·1	29·0	26·0	3·0	30·88	Calm	Unstable
			11·8	29·5	25·7	3·8	29·56		
			7·5	29·8	26·4	3·4	31·32		
			Surf	30·6	—	—	43·08		
20	22-4-52 (1215)	11°50′N 88°30′E	19·1	29·0	25·0	4·0	28·02	Calm	Unstable
			11·8	30·0	25·7	4·3	29·10		
			7·5	30·6	26·0	4·6	29·41		
			Surf	32·5	—	—	47·99		
21	22-4-52 (1700)	11°58′N 87°58′E	19·1	29·0	25·3	3·7	28·87	Calm	Unstable
			11·8	30·4	25·8	4·6	29·02		
			7·5	30·6	25·8	4·8	28·83		
			Surf	31·1	—	—	44·33		
22	23-4-52 (0930)	12°12′N 85°00′E	19·1	28·5	26·0	2·5	31·34	5·5	Stable
			11·8	30·0	26·5	3·5	31·43		
			7·5	29·9	27·1	2·8	33·32		
			Surf	29·7	—	—	40·92		
23	23-4-52 (1200)	12°30′N 84°00′E	19·1	29·0	26·3	2·7	31·76	5·5	Stable
			11·8	30·2	26·7	3·5	31·84		
			7·5	29·9	27·3	2·6	83·93		
			Surf	29·7	—	—	40·92		
24	23-4-52 (1700)	12°36′N 83°18′E	19·1	29·0	26·5	2·5	32·35	4·4	Stable
			11·8	30·0	27·0	3·0	32·93		
			7·5	30·0	27·1	2·9	33·23		
			Surf	29·4	—	—	40·22		
25	27-4-52 (1745)	12°56′N 80°29′E	19·1	28·0	26·4	1·6	32·98	4·0	Stable
			11·8	29·7	26·4	3·3	31·41		
			7·5	29·7	26·8	2·9	32·60		
			Surf	28·9	—	—	39·07		
26	29-4-52 (1215)	06°10′N 79°40′E	19·1	29·0	26·0	3·0	30·88	1·2	Unstable
			11·8	30·0	26·2	3·8	30·55		
			7·5	29·9	26·4	3·5	31·23		
			Surf	30·6	—	—	43·08		

Appendix 2 (*contd*)

No.	Date Time (IST)	Ship's position	Height (*m*)	T°C	T'°C	$(T-T')$°C	e (*mb*)	Wind velocity ($m\ sec^{-1}$)	Lapse rate
27	29-4-52 (1730)	06°50′N 78°45′E	19·1	28·5	26·2	2·3	31·93	5·6	Unstable
			11·8	29·7	26·8	2·9	32·60		
			7·5	29·7	27·1	2·6	33·51		
			Surf	30·0	—	—	41·63		
28	30-4-52 (1200)	09°19′N 76°17′E	19·1	29·8	26·5	3·3	31·62	5·8	Unstable
			11·8	30·0	26·7	3·3	32·00		
			7·5	30·4	27·4	3·0	33·77		
			Surf	31·1	—	—	44·33		
29	1-5-52 (0900)	13°23′N 74°19′E	19·1	30·0	26·1	3·9	30·24	5·8	Unstable
			11·8	30·5	26·0	4·5	29·50		
			7·5	30·8	27·0	3·8	32·19		
			Surf	30·6	—	—	43·08		
30	1-5-52 (1245)	14°13′N 73°56′E	19·1	30·1	25·6	4·5	28·72	2·2	Unstable
			11·8	30·2	25·5	4·7	28·33		
			7·5	30·9	26·1	4·8	29·43		
			Surf	31·4	—	—	45·09		
31	1-5-52 (1730)	15°09′N 73°34′E	19·1	28·2	26·0	2·2	31·62	2·1	Unstable
			11·8	29·6	25·9	3·7	30·04		
			7·5	29·8	26·0	3·8	30·14		
			Surf	30·0	—	—	41·63		

Appendix 3

	Date	Height (*cm*)	V (m sec⁻¹) 1	2	3	4	5	6	7	8	Mean (m sec⁻¹)
I	22-3-52 (1100 IST)	66·0	2·24	2·23	1·98	1·86					2·08
		116·0	1·50	3·13	2·21	2·02					2·22
		216·0	2·69	3·04	3·25	3·05					3·01
		316·0	2·79	3·03	3·02	2·71					2·89
II	25-3-52 (1100 IST)	66·0	1·97	2·82	2·51	2·49					2·45
		116·0	2·65	2·94	2·85	2·79					2·81
		216·0	4·15	5·10	5·31	4·88					4·86
		316·0	3·15	—	4·76	—					3·96
III	30-3-52 (1100 IST)	62·0	2·10	1·50	1·35	1·48	—	1·71			1·63
		112·0	2·10	1·92	1·63	1·66	1·60	3·00			1·99
		212·0	4·89	3·11	2·78	3·10	2·59	4·58			3·51
		312·0	3·21	2·99	2·58	3·09	3·05	4·20			3·19
IV	31-3-52 (1100 IST)	66·0	2·14	3·46	3·74	3·02	—	2·69	3·78	3·32	3·17
		116·0	2·35	2·25	2·86	2·21	2·29	2·12	2·37	—	2·35
		216·0	3·77	3·79	4·25	4·10	3·96	3·95	4·18	3·91	3·99
		316·0	4·21	4·10	4·25	4·05	3·98	3·90	—	3·90	4·06
V	2-4-52 (1700 IST)	64·0	0·81	0·83	1·02	0·53	0·87	0·51	0·73	0·82	0·76
		114·0	0·83	1·06	0·97	0·71	1·35	0·74	0·85	0·83	0·92
		214·0	1·56	—	1·72	0·84	2·14	1·45	1·78	1·23	1·53
		314·0	1·84	1·81	1·94	1·38	2·31	1·53	1·90	1·47	1·77
VI	3-4-52 (1000 IST)	64·0	2·27	1·91	1·76	1·86	2·17	2·11			2·01
		114·0	2·45	2·01	1·89	2·14	2·32	2·11			2·15
		214·0	4·92	4·10	3·58	4·14	4·25	4·24			4·21
		314·0	4·72	3·82	3·57	3·89	4·13	4·12			4·04