Current observations at Horn's Rev, Varne and Smith's Knoll in the years 1922 and 1923.

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During the years 1922 to 1924 observations of currents in the North Sea were made at Horn's Rev, Varne, and Smith's Knoll, by the Jacobsen apparatus, and these were sent to the Tidal Institute for reduction and analysis. The methods of reduction previously used were lengthy and expensive, as graphical methods were recommended; though Dr. JACOBSEN had stated that a numerical process could be designed for the reductions, he does not appear to have published one. At the Tidal Institute graphical methods are not looked upon with much favour, and the process of reduction was arranged for numerical computation. In view of the relative ease and accuracy of this numerical method it is considered desirable to place it on record, while giving the results of the reductions and analyses.

It is sufficient to mention that the Jacobsen apparatus registers the current visually by the movement of a bubble of air on a portion of a spherical surface; the position of this bubble gives a measure of the velocity and direction of the current as affecting the suspended cylinder and the suspending wire. The observations have to be reduced to isolate the effect of the current on the cylindrical float. We shall take Dr. JACOBSEN's experimental data for granted, and simply describe what is required to reduce the observations. We must remark, though, that the numerical method gives exactly the same results as the graphical methods, being in fact the equivalent of that method in the sense that we take two components at right angles, instead of dealing vectorially with the currents. The components in any case are required for subsequent analysis.

Assuming that the observations of direction of movement of the bubble are corrected for magnetic deviation, bearing of ship's head, etc., and that the results are expressed in components to the true north and true east, let us call these quantities n' and e'; they are readily derived from the amount and corrected direction of deviation of the bubble by the help of simple tables of cosines and sines with deviations 0 to 32, at unit intervals, and angles at intervals of 10° from 0° to 180°, the entries being given to one decimal; thus this table would give, for deviation 13, the values

13.0, 12.8, 12.2 .... being 13 cos. (0°, 10°, 20°, ...)
0.0, 2.3, 4.4 .... being 13 sin. (0°, 10°, 20°, ...)

A very compact table is readily made up in manuscript for this purpose.

The results are placed on every third line of a form such as is illustrated in Table I, under n', e', for each depth of 2.5 m., 5 m., 10 m., ... Preferably they should be written in red ink, and they represent the fundamental unreduced observations. The effect of the current on a wire 5 m. long has been given by Dr. Jacobsen in the form of a table of corrections to the deviation of the bubble; the contributions (b_n, b_e) to the total bending of the wire will be computed and placed under n', e' and the cumulative bending effect will be denoted by $\sum b_n$, $\sum b_e$, and will be on the next lower line. Under n, e in the next two columns we shall place the corrected values of the deviations of the bubble, such as would have been obtained with an infinitely thin wire; these are then translated into true velocities N and E by tables obtained experimentally by Dr. Jacobsen. The conversion factors depend upon the shape and size of the cylinder and upon the velocity of the current. Let D be the deviation of the bubble, if the wire is infinitely thin, so that $D = \sqrt{n^2 + e^2}$; let B be the bending amount of the wire actually used, and let V be the true velocity of the current corresponding to D. Then Jacobsen's tables can be expressed as in Table III, of which one advantage is that the quantities B/D, V/D change very slowly with D, so that an exact value of D is not required. Now the quantities B/D, V/D represent the factors to be applied to D to give B and V, and therefore, when applied to the components of D (viz., n and e) they give b_n, b_e (the components of B) and N, E (the components of V), respectively. A simple table of $\sqrt{n^2 + e^2}$ against n vertically and e horizontally (or *vice versa*) should be used for integral values of n and e. Such a table is given in Table II; the use of odd integers horizontally and even integers vertically requires us to interpolate only in the column or in the row; it is immaterial whether the column or the row is used for n, if the other is used for e.

Instructions for computation (see Table I for example).

1) Enter the time of observation, and details of cylinder and weight used, if any.
2) Enter n', e' in red ink on every third line, against the depth.
3) Depth 2.5 metres:—
    a) There has been no cumulative bending effect on the wire, so we copy n' and e' under n and e.
    b) Refer to Table II and compute the approximate value of $D = \sqrt{n^2 + e^2}$; enter the result on the first line under D; obtaining 23 in example.
    c) Refer to Table III under the appropriate cylinder and weight, and take out values of B/D, V/D as given against the computed value of D, enter these under the value of D, obtained in (b), on the second and third lines, obtaining 0.05 and 1.4 in example.
    d) In general $b_n = n \times B/D$, $b_e = e \times B/D$, but for the special depth of 2.5 m. we have to take half these quantities; we enter them in square brackets to remind us of the exception. Thus in Table I we get $n \times B/D = 1.0$ and we enter [0.5] under b_n, [—0.3] under b_e.
    e) In this special depth there is only one contribution to the cumulative bend vector $(\sum b_n, \sum b_e)$ so that we copy b_n, b_e in the third line under $\sum b_n$, $\sum b_e$.
4) Depth 5 metres:—
    a) The value of n' must be corrected for the cumulative amount $\sum b_n$, appearing on the line just above it; therefore subtract $\sum b_n$ from n' and enter under n; thus in Table I we get $25.1 — 0.5 = 24.6$. Similarly obtain e.
    b) As in 3(b), obtaining 29 in example.
    c) As in 3(c), obtaining 0.05 and 1.3 in example.
    d) Multiply n, e by the value of B/D just obtained (0.05 in example) and enter under b_n, b_e on the second line for this depth, obtaining 1.2 and —0.7 in the example.
    e) Add these quantities to the values of $\sum b_n$, $\sum b_e$ given under depth 2.5 m., obtaining $1.2 + 0.5 = 1.7$ and $— 0.7 — 0.3 = —1.0$, respectively, in the example.
5) For remaining depths we proceed as under (4). Thus, in the example, depth 10 m., in the first column we subtract 1.7 from 25.7 and enter result 24.0 under n, similarly obtaining e; then $\sqrt{n^2 + e^2}$ gives $D = 28$, whence Table III gives 0.05 and 1.3, entered below D. Multiply 24.0 and —14.2, the values of n, e, by $B/D = 0.05$ and enter under b_n, b_e as 1.2 and —0.7. Add these to the previous values of $\sum b_n$, $\sum b_e$ in

Table I.

Example of reduction of current observations.

Time and Cyl.	Depth	n' b_n Σb_n	e' b_e Σb_e	n	e	D B/D V/D	N	E
66×33	2.5	19.9	—11.5	19.9	—11.5	23	28	—16
		[0.5]	[—0.3]			0.05		
		0.5	—0.3			1.4		
	5	25.1	—14.5	24.6	—14.2	29	32	—18
		1.2	—0.7			0.05		
		1.7	—1.0			1.3		
	10	25.7	—15.4	24.0	—14.4	28	31	—19
		1.2	—0.7			0.05		
		2.9	—1.7			1.3		
	15	27.9	—15.5	25.0	—13.8	29	32	—19
		1.3	—0.7			0.05		
		4.2	—2.4			1.3		
	20	27.4	—16.5	23.2	—14.1	27	30	—18
		1.2	—0.7			0.05		
		5.4	—3.1			1.3		
	25	27.7	—16.0	22.3	—12.9	27	29	—17
		1.1	—0.6			0.05		
		6.5	—3.7			1.3		

the same columns, giving 1.7 + 1.2 = 2.9 and —1.0 —0.7 = —1.7, respectively. Then proceed with the next depth.

6) Finally, we compute for each depth the values of N, E by multiplying corresponding values of n, e by V/D.

The multiplying factors B/D are so small that mental operations alone are necessary; the computations of N, E are readily performed to sufficient accuracy on a slide rule. After entering the values of n', e' on the sheets the remaining operations can be done in less than 5 minutes.

Analysis of current-components.

The observations of currents were made thrice a day at Varne and at Smith's Knoll, at or about 8 a.m., 2 p.m., and 9 p.m. Each set of observations from surface to bottom occupied about 4 to 6 minutes, and the time of the central observation is stated; there was very little variation in this time from day to day, and for analytical purposes the means of the times were taken for each of the three "series" of observations.

Table II.

To facilitate the computation of

$$D = \sqrt{e^2 + n^2}$$

Take *e* and *n* to nearest unit; if one is even and the other odd, take out the value of *D* direct; if both are even interpolate in the row; if both are odd interpolate in the column.

	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35
0	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35
2	2	4	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35
4	4	5	6	8	10	12	14	16	17	19	21	23	25	27	29	31	33	35
6	6	7	8	9	11	13	14	16	18	20	22	24	26	28	30	32	34	35
8	8	9	9	11	12	14	15	17	19	21	23	24	26	28	30	32	34	..
10	10	10	11	12	13	15	16	18	20	22	23	25	27	29	31	33	34	..
12	12	12	13	14	15	16	18	19	21	23	24	26	28	30	31	33	35	..
14	14	14	15	16	17	18	19	21	22	24	25	27	29	31	32	34	..	..
16	16	16	17	17	18	19	21	22	23	25	26	28	30	32	33	35	..	..
18	18	18	19	19	20	21	22	23	25	26	28	29	31	33	34	..	..	..
20	20	20	21	21	22	23	24	25	26	28	29	31	32	34	35	..	..	..
22	22	22	23	23	24	25	26	27	28	29	30	32	33	35	..	..	..	..
24	24	24	24	25	26	26	27	28	29	31	32	33	35	..	..	..	..	..
26	26	26	26	27	28	28	29	30	31	32	33	35	..	..	..	..	..	..
28	28	28	28	29	29	30	31	32	33	34	35	..	..	..	..	..	..	..
30	30	30	30	31	31	32	33	34	35	..	..	..	..	..	..	..	..	..
32	32	32	32	33	33	34	35	..	..	..	..	..	..	..	..	..	..	..
34	34	34	34	35	35	..	..	..	..	..	..	..	..	..	..	..	..	..

The observations for a single "series" were set out in 12 columns of 29 days each, certain days being ignored as in the author's method of analysing tidal observations[1]), and gaps in the series were interpolated both down and across the columns. A considerable amount of interpolation was necessary, but experiment showed that no other method of analysis without this interpolation could give equally satisfactory results. The observations were combined as in the paper referred to. It is not considered necessary to describe the special modification of

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[1]) "The Analysis of Tidal Observations", Philosophical Transactions of the Royal Society of London, Series A, vol. 227, pp. 223—279.

Table III.

Conversion factors for use with the Jacobsen meter.
D = Deviation of bubble. B = Correction to be applied for the bending of the wire. V = Velocity of current corresponding to corrected deviation.

Cylinder Weight	90×28 none		50×20 none		66×33 none	
D	B/D	V/D	B/D	V/D	B/D	V/D
1	0.03	9.0	0.08	15.0	0.02	4.0
2	,,	7.5	,,	12.0	,,	3.0
3	,,	6.3	,,	10.0	,,	2.3
4	,,	5.8	,,	9.2	,,	2.2
5	,,	5.2	,,	8.6	0.03	2.2
6	,,	4.8	0.10	8.0	,,	2.1
7	,,	4.6	,,	7.6	,,	2.0
8	,,	4.3	,,	7.4	,,	2.0
9	,,	4.1	,,	7.0	,,	1.9
10	0.04	3.9	0.11	6.7	0.04	1.9
11	,,	3.8	,,	6.5	,,	1.8
12	,,	3.7	0.12	6.3	,,	1.7
13	,,	3.5	,,	6.2	,,	1.6
14	,,	3.5	,,	6.0	,,	1.6
15	,,	3.4	,,	5.9	,,	1.6
16	,,	3.3	,,	5.8	,,	1.6
17	,,	3.2	0.13	5.6	,,	1.5
18	,,	3.2	,,	5.5	,,	1.5
19	,,	3.1	,,	5.4	,,	1.5
20	0.05	3.0	,,	5.3	0.05	1.5
21	,,	3.0	,,	5.1	,,	1.5
22	,,	2.9	,,	5.0	,,	1.5
23	,,	2.9	,,	5.0	,,	1.4
24	,,	2.8	,,	4.8	,,	1.4
25	,,	2.7	,,	4.7	,,	1.4
26	,,	2.7	,,	4.7	,,	1.3
27	,,	2.7	,,	4.6	,,	1.3
28	,,	2.7	,,	4.4	,,	1.3
29	,,	2.6	,,	4.3	,,	1.3
30	,,	2.6	,,	4.2	,,	1.3

the general methods in detail, but for the easterly components E for each series we deduced quantities

E_{00}, magnifying chiefly the constitutent S_2 and the residual current S_0;
E_{01}, E_{0a} magnifying chiefly the constituents K_1, P_1, T_2, and S_a;
E_{02}, E_{0b} — — — — K_2 and S_{sa};
E_{20}, E_{b0} — — — — M_2, MS_4, and $2\,SM_2$;
E_{21}, E_{b1}, E_{ba}, E_{2a} magnifying chiefly the constituent O_1.

Table IVa.

Currents at Horn's Rev — 55°34′ N. 7°20′ E.
Central days for analyses:— August 1st, 1922, and May 1st, 1923.

	Depth m.	S_o	S_a		S_{sa}		K_1		P_1		O_1		S_2		M_2		MS_4	
		H	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$
E 1922	2.5	−0.9	1.6	97°	1.7	146°	2.6	321°	0.7	317°	2.0	133°	5.4	325°	18.8	265°	2.0	146°
	5	−3.2	1.6	118	2.0	97	2.4	310	0.7	334	2.3	135	6.1	330	23.5	265	2.6	149
	10	−3.7	1.8	136	2.2	60	2.5	298	0.7	333	2.2	139	5.9	328	23.8	267	2.5	165
	15	−2.9	1.4	142	2.3	65	2.0	308	0.6	329	3.0	158	5.6	330	22.4	268	2.4	184
	20	−2.3	2.1	131	3.3	51	2.5	319	0.6	300	3.5	156	5.0	331	19.7	272	2.3	181
	25	−1.7	2.7	123	2.8	44	3.0	313	0.1	262	3.3	152	4.6	334	17.2	275	2.1	185
N 1922	2.5	6.8	3.6	306	4.8	227	4.0	103	1.4	103	4.3	289	5.8	157	25.2	95	1.2	247
	5	7.7	3.3	300	5.9	225	4.5	101	1.2	99	4.4	286	6.7	159	27.1	95	0.9	266
	10	7.8	4.1	299	5.8	223	4.7	95	2.0	103	4.7	289	7.0	162	27.9	95	0.8	310
	15	7.2	3.9	299	5.7	217	4.7	97	1.2	103	5.0	283	7.0	162	27.3	92	0.9	340
	20	6.6	3.8	303	5.2	216	4.5	92	1.6	103	4.5	289	6.7	159	26.4	88	0.6	354
	25	6.2	3.4	303	5.4	216	3.7	91	1.4	111	4.5	289	6.1	158	24.7	84	0.4	35
E 1923	2.5	−2.3	5.9	162	3.2	135	1.2	306	0.6	314	0.4	142	4.0	342	18.6	263	0.5	149
	5	−4.5	4.0	160	3.4	132	1.7	288	1.0	335	1.8	134	5.5	344	22.2	264	0.6	147
	10	−5.0	2.3	150	2.3	115	1.9	309	0.7	323	1.8	155	4.9	345	23.1	266	1.3	162
	15	−4.3	1.4	144	2.1	98	1.5	294	0.7	304	2.4	159	4.6	344	20.6	265	0.5	229
	20	−3.2	1.3	109	1.7	50	2.0	306	0.7	309	2.4	153	3.7	338	18.8	268	0.7	209
	25	−2.9	1.5	95	1.7	37	2.1	303	1.0	307	2.7	149	3.3	343	17.0	271	1.0	199
N 1923	2.5	10.7	2.1	299	4.0	309	3.5	93	1.2	97	4.1	278	4.7	181	24.6	97	0.7	112
	5	11.4	1.9	277	3.3	300	4.0	95	1.2	98	4.2	274	5.0	183	26.6	92	0.2	200
	10	11.0	1.7	248	2.8	276	3.8	85	1.9	95	5.4	276	4.3	178	27.4	91	0.4	202
	15	9.8	2.8	224	2.4	247	4.1	89	1.4	95	5.4	283	4.4	174	26.8	88	0.1	58
	20	8.5	3.5	217	2.5	241	4.1	87	1.2	100	5.0	287	4.2	168	25.8	84	0.4	204
	25	8.0	3.9	215	2.4	223	4.0	90	1.2	74	4.6	281	3.8	161	23.7	80	0.5	220

Here E_2 is the result of applying "daily multipliers" (d_2) to the 29 values in a month, and E_{21} is the result of applying "monthly multipliers" (m_1) to the 12 values of E_2. Thus, the notation for the suffixes is similar to that of the paper quoted, but the effects of the operations on constituents of unit amplitudes had to be evaluated specially for this work, though all the necessary data are to be found in the paper referred to. The true values of E_{00}, etc. obtained from the three series were then combined to isolate the constituents required. Similar operations were carried out with the north-components.

Table IVb.

Currents at Varne — 50°56′ N. 1°17′ E.
Central days for analyses:— August 1st, 1922, and August 1st, 1923.

	Depth m.	S_0	S_a		S_{sa}		K_1		P_1		O_1		S_2		M_2		MS_4	
		H	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$
E 1922	2.5	—3.8	0.8	94°	2.0	299°	6.5	223°	3.0	228°	9.0	86°	14.0	70°	41.8	13°	5.2	254°
	5	—4.7	2.0	70	3.4	310	7.8	220	3.4	221	8.2	88	14.6	67	43.6	13	5.5	253
	10	—5.2	2.6	65	2.9	305	7.5	219	3.0	250	6.9	70	14.1	64	41.7	13	4.3	264
	15	—4.4	1.7	47	3.0	281	6.9	212	2.2	234	5.2	92	14.1	77	40.8	14	5.2	251
	20	—4.5	2.7	84	2.5	314	7.6	219	2.6	216	6.6	101	12.7	76	38.1	14	5.2	255
	25	—5.4	3.7	104	1.7	30	7.8	216	3.6	235	6.3	72	12.9	77	36.5	14	5.5	236
N 1922	2.5	9.7	1.6	260	1.8	306	4.5	240	3.8	143	8.2	91	19.2	48	60.3	355	0.3	104
	5	10.0	0.5	342	1.8	272	5.9	210	3.0	157	8.0	89	20.0	50	63.6	354	0.8	342
	10	9.4	0.9	239	2.0	293	4.5	211	3.1	154	8.8	85	19.0	47	63.2	352	1.6	189
	15	9.6	1.0	170	1.7	319	5.7	223	2.4	165	7.8	69	18.3	46	61.6	353	0.8	143
	20	9.1	0.3	159	3.5	312	5.6	203	2.2	194	7.0	85	17.7	50	60.5	354	0.6	128
	25	9.0	1.2	90	3.9	308	6.0	209	2.2	206	8.6	79	17.1	48	57.0	354	1.8	99
E 1923	2.5	2.4	5.0	186	2.0	217	5.7	212	2.4	179	6.3	34	16.0	34	49.3	358	1.5	33
	5	3.5	5.0	198	3.5	224	6.3	207	2.3	183	6.4	33	15.9	38	50.3	0	0.1	45
	10	2.2	3.9	200	3.1	227	5.2	203	1.5	199	5.7	36	13.2	48	45.7	0	1.2	220
	15	3.0	4.6	203	2.5	208	4.4	198	2.0	162	4.2	27	13.2	44	42.6	2	1.2	231
	20	2.9	3.4	213	2.9	206	4.1	193	1.9	152	4.0	348	13.9	48	40.4	1	1.4	164
	25	3.0	3.9	204	2.0	192	3.4	213	2.1	144	2.2	35	15.0	26	39.8	1	0.4	255
N 1923	2.5	6.6	4.3	350	3.7	300	4.9	214	5.6	185	2.3	2	23.6	23	66.6	343	1.6	118
	5	7.2	4.2	349	4.7	313	3.5	204	4.2	187	3.3	7	24.2	23	69.0	343	0.6	196
	10	7.2	3.6	347	4.1	306	3.1	206	3.5	170	4.0	12	22.4	25	68.0	342	0.9	213
	15	6.8	3.8	340	3.7	310	4.2	190	3.8	157	3.6	11	20.4	25	64.8	342	1.5	181
	20	6.1	2.9	335	2.8	317	3.6	204	4.0	145	4.0	14	20.1	21	62.4	342	2.1	161
	25	5.5	3.0	349	1.2	303	2.9	196	3.5	151	4.1	17	20.9	17	59.2	342	3.1	220

The constituent M_4 could have been obtained by evaluating quantities E_{40}, E_{d0}, N_{40}, N_{d0}, but it was considered that MS_4 would sufficiently represent the characteristics of the quarterdiurnal tides.

For Horn's Rev, the observations at 2.5 m. were commenced on the average, at 3.35, 7.35, 11.35, a.m. and p.m., in time one hour fast on Greenwich, and the bottom observations were made on the average at 3.52, 7.52, 11.52, a.m. and p.m. There was very little interpolation necessary with these observations.

The resulting harmonic constants are given in Table IV a, b, c for

Table IVc.

Currents at Smith's Knoll — 52°44′ N. 2°15′ E.
Central days for analyses:— August 1st, 1922, and August 1st, 1923.

	Depth m.	S_o	S_a		S_{sa}		K_1		P_1		O_1		S_2		M_2		MS_4	
		H	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$	H	$\varkappa$
E 1922	2.5	13.3	3.6	239°	4.7	181°	2.1	355°	2.2	63°	4.4	162°	8.0	204°	17.6	202°	0.6	112°
	5	12.2	2.0	215	3.3	158	1.4	320	1.6	58	1.7	113	6.1	236	19.0	198	2.0	117
	10	9.9	3.0	192	1.9	135	1.2	317	1.2	45	2.8	100	5.4	256	18.5	201	2.1	107
	15	8.3	2.6	171	1.2	130	2.1	309	1.0	126	2.7	101	4.6	246	17.1	195	1.8	65
	20	6.1	1.6	212	2.1	226	0.9	357	0.3	239	3.6	147	5.6	283	11.7	191	0.9	42
	25	5.7	0.6	209	1.6	60	0.3	333	2.6	241	1.3	304	3.4	244	10.7	195	2.1	58
	30	3.7	1.1	118	0.5	323	0.9	353	2.0	248	0.8	210	3.3	287	9.0	185	3.1	79
N 1922	2.5	—3.2	2.4	81	3.1	181	8.0	136	1.9	82	10.2	356	26.1	117	91.3	81	0.7	243
	5	—3.8	4.0	67	1.2	151	8.8	136	0.6	95	10.5	347	28.6	117	99.0	81	1.3	77
	10	—4.5	3.2	62	0.3	79	7.9	135	1.0	38	6.9	337	26.4	118	95.9	81	1.4	53
	15	—5.3	2.0	58	0.7	104	7.3	127	2.3	84	6.4	354	23.2	115	91.6	80	0.8	49
	20	—5.8	2.6	76	1.0	331	7.0	136	2.1	93	5.5	7	21.6	111	85.6	79	1.9	93
	25	—5.0	3.7	44	0.4	266	6.3	143	0.7	96	5.0	333	21.0	114	80.2	80	3.4	98
	30	—5.1	3.7	42	2.5	325	6.0	143	1.1	58	4.6	16	20.2	114	71.8	78	3.9	122
E 1923	2.5	11.2	6.5	151	3.0	135	1.1	268	0.3	311	3.0	226	5.6	219	18.6	221	2.4	181
	5	10.8	4.1	143	3.0	146	2.0	315	0.9	114	2.5	258	5.0	255	19.7	211	3.1	167
	10	10.0	2.9	130	2.6	127	1.4	310	1.2	165	2.8	217	4.4	254	17.3	217	1.9	124
	15	7.8	2.6	140	1.9	127	1.9	303	1.4	125	3.0	265	5.4	211	16.7	212	2.0	112
	20	6.0	0.8	65	1.3	217	1.8	315	1.8	138	1.9	184	4.1	262	13.4	220	2.9	100
	25	6.9	0.8	52	0.5	151	0.3	69	0.9	109	1.2	32	5.3	200	13.1	209	5.2	91
	30	5.6	1.9	339	0.7	183	0.9	39	2.2	150	4.4	46	5.0	209	12.7	214	3.7	69
N 1923	2.5	3.2	2.5	119	0.9	8	5.7	157	2.2	54	1.8	300	31.5	130	87.5	79	3.3	121
	5	0.6	2.0	70	2.2	254	6.9	155	1.0	61	5.3	292	32.1	127	98.0	79	2.0	117
	10	—0.6	2.4	60	1.6	247	7.1	148	0.8	131	3.5	291	29.3	125	94.1	79	0.9	119
	15	—0.9	2.7	8	1.3	279	6.8	131	1.8	69	3.9	286	30.2	129	90.1	78	0.8	90
	20	—1.9	2.8	335	1.5	239	6.8	130	1.6	101	3.3	307	24.9	123	85.0	78	2.1	36
	25	—1.9	2.7	0	0.8	238	6.5	137	0.9	99	2.0	341	24.1	123	78.8	77	2.5	85
	30	—1.4	2.5	350	1.1	287	6.7	143	0.2	143	2.7	314	22.2	125	70.3	76	1.7	69

the years 1922 and 1923. The central day of the observations is given in each case. Owing to a shortage of observations, for some reason or other, it was necessary to have a short overlap in the two "years" for Horn's Rev. H is given in cms. per sec.

The elliptical components for M_2 are tabulated in Table V. The

Table V.

M_2— ellipses at Horn's Rev, Varne, and Smith's Knoll.

Depth	Horn's Rev, 1922				Horn's Rev, 1923			
	Direction of Flood	u	v	$\varkappa$	Direction of Flood	u	v	$\varkappa$
2.5	N. 53° W.	31.4	—2.7	91°	N. 53° W.	30.7	—3.7	92°
5	N. 49° W.	35.8	—3.1	91°	N. 50° W.	34.5	—2.4	89°
10	N. 50° W.	36.7	—2.5	92°	N. 50° W.	35.8	—1.5	89°
15	N. 51° W.	35.3	—1.2	90°	N. 52° W.	33.8	—0.9	87°
20	N. 53° W.	33.0	1.1	89°	N. 54° W.	31.9	1.1	85°
25	N. 55° W.	30.0	2.7	88°	N. 54° W.	29.1	2.6	84°

Depth	Varne, 1922				Varne, 1923			
	Direction of Flood	u	v	$\varkappa$	Direction of Flood	u	v	$\varkappa$
2.5	N. 34° E.	72.9	—10.7	1°	N. 36° E.	82.4	—10.3	348°
5	N. 34° E.	76.3	—11.9	0°	N. 36° E.	84.6	—12.0	349°
10	N. 33° E.	74.6	—12.6	358°	N. 33° E.	81.1	—11.8	348°
15	N. 33° E.	72.9	—12.3	359°	N. 33° E.	76.6	—12.3	348°
20	N. 32° E.	70.6	—11.2	0°	N. 32° E.	73.4	—11.1	347°
25	N. 32° E.	67.0	—10.6	0°	N. 33° E.	70.6	—10.9	348°

Depth	Smith's Knoll, 1922				Smith's Knoll, 1923			
	Direction of Flood	u	v	$\varkappa$	Direction of Flood	u	v	$\varkappa$
2.5	S. 06° E.	91.8	—15.0	260°	S. 10° E.	88.7	—11.3	258°
5	S. 05° E.	99.4	—16.8	260°	S. 08° E.	98.9	—14.4	258°
10	S. 06° E.	96.4	—15.9	260°	S. 08° E.	95.0	—11.5	258°
15	S. 05° E.	91.9	—15.4	259°	S. 08° E.	91.0	—12.0	257°
20	S. 03° E.	85.7	—10.8	259°	S. 07° E.	85.7	—8.2	257°
25	S. 03° E.	80.3	—9.7	260°	S. 06° E.	79.3	—9.7	256°
30	S. 02° E.	71.9	—8.6	258°	S. 08° E.	70.9	—8.4	255°

The flood is defined as that maximum current which occurs within a quarter-period of high water, either before or after, or else exactly a quarter period before high water.

direction of the "flood" is given according to a definite rule. These elliptical components may be compared with those obtained in the years 1911, 1912, 1913 from fortnightly sets of observations[1]); the mean current (from top to bottom) is given below for comparison:—

Place	Year	Direction of flood	u	v	$\varkappa$
Horn's Rev	1911	N. 25° W.	38.9	—3.9	115
	1912	N. 42° W.	33.8	—0.5	73
	1913	N. 31° W.	38.7	—0.4	91
Varne	1911	N. 46° E.	95.1	—14.3	348
	1912	N. 44° E.	86.2	—6.7	336
	1913	N. 20° E.	79.7	—10.8	358
Smith's Knoll	1911	S. 26° E.	70.0	—6.6	254
	1912	S. 10° E.	89.5	—7.4	251
	1913	S. 4° E.	84.9	—11.3	253

The component u is given in the direction of the flood, and the component v is given in the direction 90° in advance of the flood in the mathematical sense (that is, in a counter-clockwise direction). The negative sign to v therefore indicates clockwise rotation.

On the whole the agreement between the new results and the averages for the three years 1911—1914 is quite good. The change in sign of rotation of the current at a depth of 15 to 20 metres at Horn's Rev is shown by all the analyses. There are fairly large differences in the degree of variation of H and $\varkappa$ with depth, but this was to be expected.

The "residual current" as given by S_0 is considerably different from that obtained for the years 1911—1914, but a fortnight's observations could not be expected to yield accurate values. The agreement between the annual and semiannual components of current for the two years 1922 and 1923 is not very good.

In conclusion, the difficulties attending the taking of observations of currents at all depths are so great that no other sets of observations comparable in length with these have been available for scientific purposes, and it is likely that the present results will form for many years a basis for scientific investigations of the dynamics of currents in open seas. A beginning has already been made, and valuable results have been published by Dr. S. F. GRACE in a paper on "Internal Friction in certain Tidal Currents", published in the Proceedings of the Royal Society of London, Series A., Vol. 124, 1929.

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[1]) "Bulletin Hydrographique", 1911—12, 1912—13, 1913—14.