REALISM IN CURRENT-MEASURING IN THE UPPER LAYERS OF THE SEA

by

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(A lecture delivered on the occasion of the Vth International Hydrographic Conference held at Monaco in April, 1947).

There is little need for me to state directly what I mean by " Realism " in connection with the observation of water-movements in the sea; what, to my mind, constitutes the realistic attitude on the part of an investigator will become sufficiently apparent from what I shall say.

I may preface my remarks by stating that I shall restrict my attention to the carrying-out of observations by means of instruments, i.e. with current-meters, and that I shall pay no regard to instruments of which it could *NOT* be confidently said, that, if used suspended from an anchored lightship for months on end in all seasons and all weathers (weedy and silty water and similar impediments taken as " all in a day's work "), the instrument would still be in good working condition, and be still producing acceptable data.

What I mean by " Realism " is largely implicit in that statement, and it is meant also to convey my firm personal belief that there can be no justification for remaining satisfied with data on water-movements which come from brief periods of observing carried on under fair weather conditions only. I am fully aware that such remarks require me to show good reason for the implied claim that particular value attaches to knowledge of how the water *can* move in the sea at times of wild weather.

I shall not deal here with the matter of observing currents at levels near bottom ; though such observations have their special value in specific connections, we will restrict present attention to the layers of interest to surface-vessel navigation. Moreover, certain modern techniques used in the observation of near-bottom water movements, are less dependent upon weather conditions than are measurements made in the upper layers—and it is in the question of bad weather observations that I am chiefly interested.

It is however, not to be assumed that the apparatus of which I shall speak could not be used for observing the water-movements near bottom where depth is not excessive.

Since what I shall say will be pointed with references to data collected in the course of a very extensive programme of work (" non-stop " observations in all weathers) carried out in the southern North Sea and English Channel, I must make one thing clear at the outset.

Though the waters named are sea areas in which tidal streams hold sway, I am not a specialist on Tides, and my present discourse is not to be regarded as devoted to them.

The data which I shall present, come from work done primarily in connection with problems of fishery research —— in which field of marine investigation, interest in questions of water-movement attaches mainly to overall water flow, i.e. to the net translocation of water over and above the runs of the streams in their varying directions.

Since I shall be speaking of continuous current measurements however, the water travel accomplished by the changing streams, will necessarily be contained within the data which I shall use to point my remarks.

It is useful when discussing researches on water movements, to take account of the different departments of interest so to speak.

The fishery researcher, concerned with the fortunes of fish eggs and larvae borne along by the moving water, is not necessarily greatly interested in the bulk of water which moves to and fro —— nor is he necessarily any more interested in how the water moves when deepest (at " High-Tide ") than when at its least deep stage.

Of the man who is interested in the maintenance of coasts, the same cannot be said; he may very well be much more concerned (because of erosion problems) with water movement at time of High Water —— though he may also have a special interest in the Low Water situation on account of the greater burden of silt which may then be carried by the water at times of wild weather.

The Coastal Engineer may also of course, have a special interest in water movements near bottom.

To the oceanographer who may wish to make inferences regarding currents (over a long period) from attention paid to the distribution of the usually-studied elements, volume transport will be a matter of concern.

What of the Navigator ? The man whose duties are performed in a well-found powerful vessel, will naturally be much less interested in the "run of the streams" (whether it be the most-usual regimen or the extreme conditions which may be produced by wind influence) than would be the Master of a low-powered ship who might have thoughts of one day finding himself fog-bound in an area with numerous hazards.

We will take it for granted that the Navigator *is* interested in knowing everything possible as to how the water *can* move under the influence of extremes of strong winds from various directions. We may readily assume there to be no difference of opinion as to the advisability that those whose job it is to prepare atlases and the like for the use of the seaman, should possess all the information which can be forthcoming.

The Navigator, will, of course, have information from which he can make his predictions as to how the water will move —— as to how he will be set, but the question which interests me particularly, is whether he would ever predict (be prepared to expect) such extreme conditions of water movement as are attested by certain observations on record within a collection of data at my disposal.

If it be later agreed that such extremes of experiences as I can show are outside expectation (beyond prediction), then point is given to my contention that it is not justifiable to generalise from data on water-movements which relate only to fair-weather observing.

In an area like Dover Straits, we have not only the tractive effect of wind on water to consider, nor even only this *plus* whatever consideration needs to be given to the push of the wind on big waves at times of wild weather; there are also the great complications which come from the materially-changed hydraulics of the situation when the Southern Bight of the North Sea becomes pooled up under the influence of winds from a N.W.'ly quarter.

I have said enough to convey my belief that we must, in this matter of current-measuring, refuse to rest content with data which relate to favourable weather only.

There are of course means available (the Current Pole is one) for prosecuting researches on currents independent of weather to a large extent, but we are here concerned with observations made with current-meters.

Observations made by current-pole have necessarily involved the immobilisation of a vessel which is a costly business; so too, generally, have done sporadic investigations made by current-meter.

The problem surely is this :—how can we arrange to get adequate data of the kind to which reference has been made ?

In the past, as much use as possible has been made of lightships, but they have become less in number, can necessarily serve only for a few places, and are nowadays nearly always constructed of steel.

In the case of lightships, the problem faced was that of all-weather observing, and an instrument was developed which could stand up to bad weather. This was the "Drift Indicator" as pictured in fig. 2., and of this instrument descriptions are available. (2)*.

Reference to it is made here, and an illustration of it given because of a proposal put forward elsewhere to effect the step mentioned in the legends to figs. 1 and 2 and referred to later.

The Drift Indicator was used continuously from a number of Trinity House lightships for many years on end; it stood up to bad weather satisfactorily enough, but, despite its greater suitability for the work needed than any other instrument existing at the time, it has

(*) Numerals in brackets refer to the List of References to be found at the end of this paper.

now been susperseded as being no longer the best all-weather instrument for making "non-stop" observations of the kind here under consideration.

The reasons for this suppression will be stated, but a remark should be entered at this stage for the consideration of those who would set out to undertake long-period observations on water-movements in the sea using instruments of a type which could not be described as robust.

It would be perfectly impossible to learn even a fraction of what we want to know, if there prevailed any disinclination to prosecute all-weather observations in "dirty water", i.e. in waters having a notable silt burden. The Drift Indicator is a very massive instrument, yet, even in the waters of Dover Straits, the erosion due to the continual bombardment of sand particles was most impressive after many months of constant use.

The lantern-type door of stout naval brass became worn down to razor-edge thinness, and the copper of the cups (stout enough when new to defy deformation from finger pressure) was eroded down to a state at which it could be easily poked through with a finger.

These remarks will serve to set certain standards of robustness for instruments designed to do the work I have in mind; quite clearly, any instrument of delicate type such as might appeal on grounds of sensitivity and accuracy (instruments using cups or propellers are referred to) could not stand up to the very exacting conditions.

There must, equally clearly, be a frank and completely realist attitude to considerations of "accuracy" and "sensitivity" when thought is given to carrying-out such programmes of work as are here being considered.

There would seem often to have been far too much attention paid to the beauties of various instruments, and to claims as to what they could do —— when the main consideration should surely be : "what will actual working conditions in the sea let the various instruments do towards the production of sheer practical utility ? "

This is the crux of the matter indeed, and my main theme is to urge yet once again, that only scant value can possibly attach to researches which last but for short periods, and relate only to fair weather conditions —— when it is current-measuring that is in question.

In another place (3) I have made "Practical Proposals for a continuous Programme of 'Thick Layer' Current-Measuring in all weathers, with Remarks on relevant Wind Observations and other related Matters."

To regard the desirability of such work as an ideal, would be to possess the attitude of "Realism" which concerns me here.

By the expression "Thick-Layer", I mean to advocate that the observations should relate to a "surface" layer of water thick enough for the data on its movements to apply directly to the draught of a ship.

As has been pointed out elsewhere, with the Vertical Log installed on lightships, the existence of radio signalling arrangements would make it simple for the Mariner to ask and be told how his ship was being set when he found himself fog-bound in the neighbourhood. Visual signals in clear weather (if considered useful) would be an easy matter to arrange. Such facilities would have no dependence upon weather.

What remains for me to say now, can be set down under a few heads :—

(a) To describe how such observations as I have dwelt upon, could, in my view, best be carried out ;

(b) To show that the water has, in the regions already named, been known to move in a manner which it would seem not possible to predict :

(c) To explain why it was necessary to abandon the use of the Drift Indicator. Even supposing that other self-contained instruments not using ship-board registration (instruments containing compass "needles" —— the entire instrument being suspended in the sea at the end of a line as is the case with Ekman-type meters) could stand up to exacting weather conditions, what I shall say will amount to ruling them out as well for the purposes in view.

It will be convenient to take point (b) last.

All existing current-meters of the self-contained type, i.e. ones whose rotor and registering mechanism, work at the end of a line let down from a ship, must inevitably put on many registrations due to being lifted, dropped, and towed through the water in response to movements of the ship —— particularly in bad weather. Not only must they do so, but the spurious currents so recorded are inevitably mechanically allotted at random to a wide spread of direction.

It was not seen that any instrument of pressure plate type would offer satisfactory escape from trouble, and one had to keep always in view the ultimate hope of working the finally-chosen instrument (or some derivative of it) from an unattended buoy to economise ship's time when observations other than from lightships came to be undertaken.

Since a buoys is but a ship in miniature, the problem of avoiding the registration of spurious current would then possibly be even greater using most existing instruments.

There was too, always the problem of observing from steel ships which required that an instrument like the Drift Indicator be kept always down at depths beyond the influence of the ship's magnetic field. German researches had shown that, working with an Ekman Meter from a vessel of length 46 metres, beam 9 metres, and draught 3 1/2 metres, falsification of direction due to the ship's magnetic field could occur down to depths of from 20 to 25 metres. This consideration alone makes the getting of reliable information by current-meter for " navigation depths " somewhat of a problem.

It became necessary to think along new lines, and the simple and very strong instrument known as the " Vertical Log " (see fig. 1) was designed, thoroughly tested, and taken into use to supersede the Drift Indicator (see fig. 2) after the latter had been in use for upwards of ten years.

This " Vertical Log " cuts down the registration of " adventitious current " to a minimum —— as is explained in published accounts of it (1), and there is no concern for the magnetic field of the observation ship when using it.

It was decided to give this very robust new instrument a long trial under all possible conditions, and then to proceed further along lines which would result in the production of a version of it which could work completely automatically.

That most exacting trials have been given in ample measure, is attested by published all-weather records coming from English, French, Dutch and Danish lightvessels. Of these, a few specimen examples are given in the various figures and tables used to illustrate this lecture.

As to the second stage of progress, i.e. the production of a version of the " Vertical Log " which would work completely automatically from an anchored vessel : to give any full account (for which see reference (3), would occupy too much of my time. Suffice it here to say that the proposal has been to arrange for the rotations of the " Measuring Unit " (see fig. 1, left) to be transferred by an overhead log line to a spot near the binnacle position of a lightship.

At that spot there would be a sort of small turntable fixed to the deck (like a ball-bearing spinning bollard). On this would be mounted a very simplified version of part of the Drift Indicator —— of which components very little indeed would need to be made by an instrument-maker, since there would be no call for quality such as was necessary for working under water.

For brevity of description here, it can be imagined that an entire Drift Indicator were secured atop the turntable in question, and that the log-line coming overhead from the outboard submerged measuring-unit of the Vertical Log, served to turn the Drift Indicator cups in correspondence with water-movement.

The small turntable would be orientated in keeping with the lead-away of a device like the submerged portion of the Direction-Viewing-Unit of the Vertical Log (see fig. 1, right). How this would be achieved is easy enough to picture, but is described elsewhere (3).

It would result that we could get continuous onboard registrations of water movement quite automatically from such a hybrid instrument, and there would be no intermissions imposed by weather.

The registering could be by " ball-dropping " after the manner of the Ekman Meter, if the chief aim was to study overall water movements to serve such purposes as those of fishery research.

If however, there was a dual need —— for this latter, and for data to suit the needs of persons interested in the tidal streams, it would be easy to have say, thirteen radially-divided ball-receiving circular trays in use. Each of these could be labelled appropriately —— for H.W., for H.W + 1, for L.W. etc etc., and the proper one could be shipped and left in the instrument atop the turntable during the whole of the appropriate hour. Other modifications of observing technique will readily suggest themselves. Each day, the balls from the individual trays could be totalled, or put into suitably labelled bags destined to have their contents check-counted only each week perhaps.

It might well be preferred to effect the registering in some other way to suit specific needs, and attention is drawn again to the paper already cited (3) in this connection.

A method (one of two others) there outlined and referred to as "Typewriter Registration", will probably be used in the ultimate version of the "Vertical Log" destined to work in all weathers from an unattended buoy.

It is confidently thought that this problem will very soon have been satisfactorily solved ——— but that is a story for another time.

To be able to use a current-meter from an unattended buoy has very naturally always been the ultimate aim, but up to now, it has been little more than an aim so far as *non-stop* observations in all weathers irrespective of dirty water and the like troubles are concerned.

Good work has been done by current-measuring instruments buoyed up from "Submarine Stations" admittedly, but there has never (so far as is known) been any production of long-period data of the kind dwelt upon in this discourse for "navigation depths"; the "Submarine Station" records relate usually (and necessarily) to depths much too far down to be applicable in that connection.

All remaining for me to do now is to deal with point (b) above, and there is little need to do more than invite attention to the figures and tables provided to illustrate this talk (figs 1 to 5, and tables 1 to 4). I have purposely supplied all of these with legends adequate to make them more or less-sufficient, and I suggest that the specimen records presented suffice, of themselves, to give ample point to the remarks which I have made. For greater interest, I have chosen some examples which relate to the time when the North Sea made serious inroads on the Norfolk coast.

LIST OF REFERENCES

(Citing some papers by the Lecturer wherein accounts can be read of the Instruments and Methods discussed).

Reference No. 1

Concerning the Vertical Log Current-Meter, Work done with it, and Proposals for the Future.

(a) **Enregistreur de courant à loch vertical** ("Revue Hydrographique", vol. XII, No. 2. Monaco, November 1935, pages 63-79.)

(b) **A "Vertical Log" Current Meter.** "Journal du Conseil International pour l'exploration de la mer", vol. X, No. 2. Copenhagen, 1935 (pp. 151-168).

(c) **A "Vertical Log" Current Meter.** "Hydrographic Review", vol. XII, No. 2. Monaco, November 1935 (pp. 62-76).

(d) **Continuous current measuring in the Southern Bight.** (Journal du Conseil international pour l'exploration de la mer), R. et P.—V., vol. C (III-10.). Copenhagen, 1936, pp. 3-6).

(e) **Continuous current measuring from Lightvessels.** "Review of Progress, with Results for a third Winter", 1937-38. "Journal du Conseil international pour l'exploration de la mer", R. et P.—V., vol. C (III-3°). Copenhagen, 1936 (pp. 16-20).

(f) **Continuous Current Observations for Fishery Research Application.** "Journal du Conseil international pour l'exploration de la mer", R. et P.—V., vol. CV (III-6°). Copenhagen, 1937 (pp. 16-27).

(g) **The Horsey Floods of February, 1938. Current and wind at the time as observed aboard certain Lightvessels.** "Met. Mag." (M.O. 422) No. 868, vol. 73. May 1938 (pp. 86-93).

(h) **Exceptional Tidal Streams in the Southern North Sea and Eastern English Channel.** "The Marine Observer", vol. XVI, No. 133. H.M.S.O., London, January 1939 (pp. 18-19).

(i) **Water movements past certain Lightvessels in the Southern North Sea and Eastern English Channel under different wind conditions—Experiences of Winter, 1938-39.** "The Marine Observer", vol. XVI, No. 135. H.M.S.O., London, July, 1939 (pp. 104-106).

(j) **The Vertical Log Current Meter and its use.** "Min. of Agric. and Fish.", Fisheries notice: No. 26. August 1939 (30 pages).

(k) **First Annual Report on Vertical Log Observations in the Southern North Sea and Eastern English Channel.** "Journal du Conseil international pour l'exploration de la mer", R. et P.—V., vol. CIX (III-5°). Copenhagen, 1939 (pp. 37-45).

(l) **Instruments, Methods and certain Results relating to a scheme of continuous Current Observing in the North Sea and English Channel.** (Abstract of a communication made at the General Assembly of the International Association of Phys. Oceanogr., Washington, September 1939. Assoc. Océanog. Phys., Procès-verbaux, No. 3. Liverpool, 1940 (pp. 116, 117).

Reference No. 2

Concerning the Drift Indicator and Work done with it.

(a) **A New Current-Measuring Instrument for the Purposes of Fishery Research.** "Journal du Conseil international pour l'exploration de la mer", vol. I, No. 2. Copenhagen, 1926 (18 pages).

(b) **The Flow of Water through the Straits of Dover as gauged by continuous Current Meter Observations at the Varne Lightvessel (50°56' N.-1°17' E.).** Part I. Min. of Agric. and Fish., Fisheries Invest., ser. II, vol. XI, No. 1. London, 1928 (109 pages). Price 10/ - net.

(c) **The Water Movements in the Southern North Sea.** Part III : The Area off the Wash, (a) The Flow of Water past the Inner Dowsing Lightvessel. (Min. of Agric. and Fish., Fisheries Invest., ser. II, vol. XI, No. 6. London, 1929 (36 pages). Price 3/ - net.

(d) **The Water Movements in the Straits of Dover : Exceptional Currents in Winter 1929-30.** "Journal du Conseil international pour l'exploration de la mer", vol. V, No. 2. Copenhagen, 1930 (pp. 167-191).

(e) **Current Meter Work.** Min. of Agric. and Fish. Fisheries notice: No. 17, July, 1932 (29 p.).

(f) **The Flow of Water past the Seven Stones Lightvessel.** "Journ. Mar. Biol. Assoc. of the U. K.", vol. XIX, No. 2. May, 1934 (pp. 921-930).

(g) **The Flow of Water through the Straits of Dover,** as gauged by continuous Current-Meter Observations at the Varne Lightvessel (50°56' N.-1°17'E.). Part II. (Min. of Agric. and Fish., Fisheries Invest., ser. II, vol. XIV, No. 4. London 1935 (67 pages). Price 3/ - net.

(h) **Drift through the English Channel as shown by Current-Meter Observations.** Abstract of a communication made at the General Assembly of the Internat. Assoc. of Phys. Oceanogr., Edinburgh, September 1936. Assoc. Océanogr. Phys. Procès-verbaux, No. 2. Liverpool, 1937 (pp. 135, 136).

Référence n° 3

Practical Proposals for a continuous Programme of Thick Layer Current-Measuring in all weathers, with Remarks on Relevant Wind Observations and other Related Matters. In the Press: will appear in the first 1947 issue of the "Journal du Conseil international pour l'exploration de la mer" (Copenhagen).

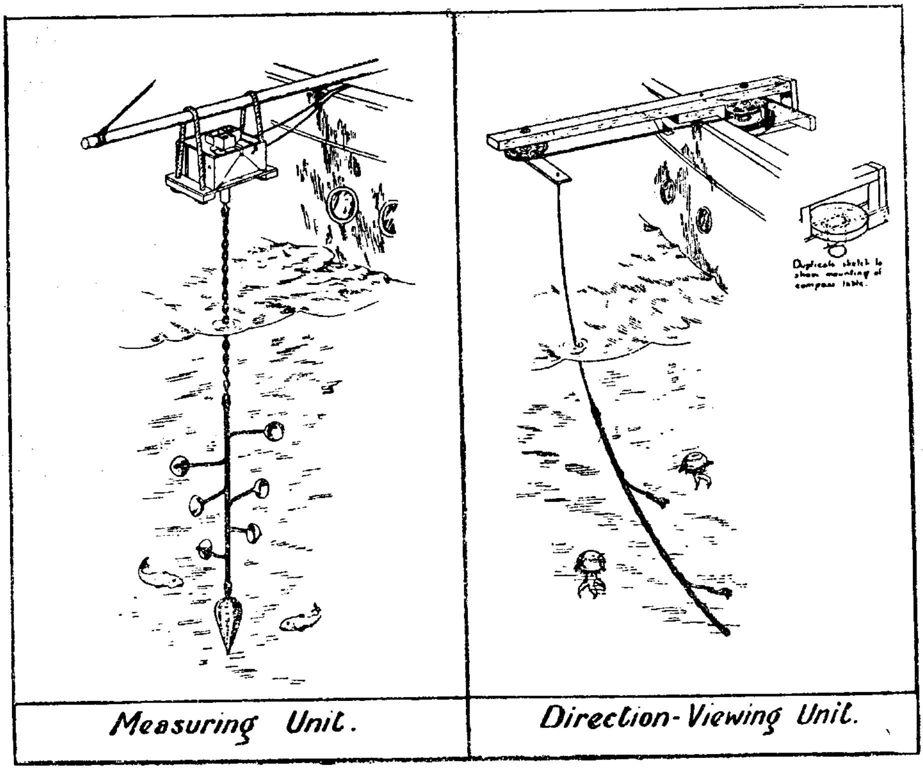

Fig. 1

The Vertical Log Current-Meter.

With this extremely robust (but not automatic) instrument, a very large body of data indeed on water-flow past lightvessels has been amassed. The observations have been carried on without any intermissions imposed by wild weather, and, throughout the entire winter of 1938-39, " non-stop " observations were made with this instrument from ten lightships (English, French, Dutch, and Danish) in the southern North Sea and eastern English Channel .... also from the Seven Stones lightship near Lands End. Proposals are made in the text for the " marrying " of part of this instrument (the submerged " cups " portion) with part of the Drift Indicator (see fig. 2 and its legend) to provide for a fully-automatic and continuous registration of water flow past anchored ships in all weathers. No considerations of magnetic disturbance arise to prohibit the use of this instrument from steel vessels other than at " safe " depths, and there is a virtual absence of registration of spurious current from revolutions put on in response to ship movements. It is intended to adapt this instrument to use from an unattended buoy.

(For descriptions see under reference (1) in the " List of References ").

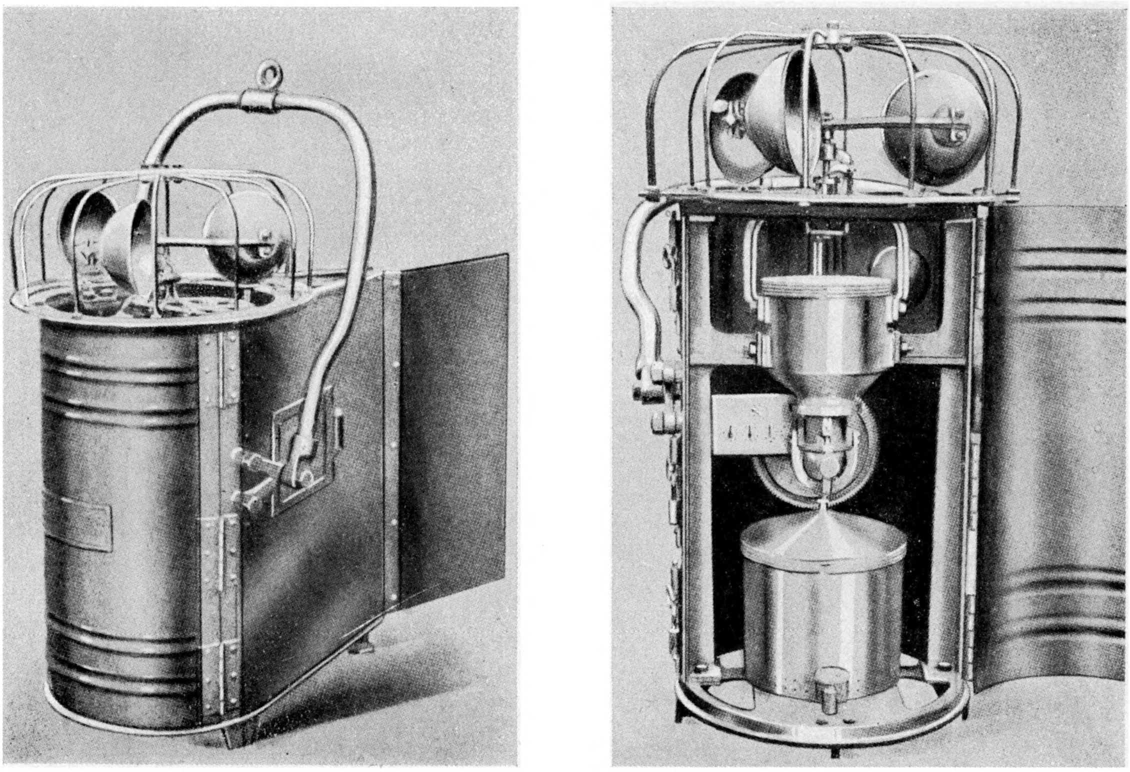

Fig. 2

The Drift Indicator Current-Meter.

This instrument has been used for many years in all weathers in the investigation of water-movements past lightvessels, but has now been superseded because, being self-contained, it necessarily puts on revolutions which are not "current" in response to ship movements. It is a totalising ball-dropping instrument (cf.: the Ekman Current-Meter), and has to be employed at depths beneath the influence of a ship's magnetic field. It has been proposed to "marry" the ball-dropping part of this instrument (mounted inboard at the binnacle position of a lightship) to the submerged part of the Vertical Log, to provide a completely-automatic instrument for use from anchored ships in all weathers. This would be achieved by log-line connection as described in the text.

(For descriptions see under reference (2) in the "List of References").

Observations with the "Vertical Log" Current Meter.

Place : Varne Lightvessel. Observer(s): Eaton & Everitt.

Number of Instrument A.2 Depth of top of cups at Slack Water Abt. 9 feet

Counter Number	1 N	2 NE	3 E	4 SE	5 S	6 SW	7 W	8 NW
Readings at 1600 on 8. 7.38	08418	07524	07398	01904	02768	17289	18746	01831
(24 hours 50 mins. later) Readings at 1650 on 9. 7.38	08418	13730	07398	01904	02768	17931	18746	01831
Differences (revolutions)		6206				642		
= Sea-Miles		20.7 NE				2.1 SW		

Net flow:- 18.6 miles NE

Counter Number	1	2	3	4	5	6	7	8
Readings at ... on ...								
(24 hours 50 mins. later) Readings at ... on ...								
Differences (revolutions)								
= Sea-Miles								

ABOVE A vertical log current-meter observation revealing a very strong overall water flow from English Channel to North Sea.

Counter Number	1	2	3	4	5	6	7	8
Readings at ... on ...								
(24 hours 50 mins. later) Readings at ... on ...								
Differences (revolutions)								
= Sea-Miles								

BELOW A marked contrast; a very strong overall water flow from North Sea to English Channel.

Counter Number	1 N	2 NE	3 E	4 SE	5 S	6 SW	7 W	8 NW
Readings at 2200 on 16. 4.38	06358	10245	04782	00846	02136	07170	17413	00908
(24 hours 50 mins. later) Readings at 2310 on 17. 4.38	06530	11308	04782	00863	02229	12649	17660	00908
Differences (revolutions)	172	1063	0	17	93	5479	247	
= Sea-Miles	0.6	3.5		0.1	0.3	18.3	0.8	

Net flow:- 14.7 miles SW.

NOTES.—The first time and date of an observation will usually be the same as the second time and date of the Previous one; Observers are to leave blank the spaces for "Differences."

The Moon was Full on 12th July and 14th April, 1938

Remarks :-

Form No.

Wind and Sea Particulars during the time of the Observations.

(Please send in a full record on these forms, even though the instrument be not working.)

DAY & DATE.	HOUR.	WIND STRENGTH.	WIND DIRECTION.	SEA.
8. 7.38 day	3 a.m.			
	6 a.m.			
	9 a.m.			
	Noon	7 to 8	S	
	3 p.m.	6 to 7	SW	
	6 p.m.	6 to 7	SW	The wind conditions
	9 p.m.	5 to 6	SW	associated with the
	Mid. Nt.	5	SW	particularly strong
9. 7.38 day	3 a.m.	5	SW	NE - going overall
	6 a.m.	5	SW	water flow through
	9 a.m.	5	W	the Straits of Dover.
	Noon	5	W	(upper record across)
	3 p.m.	4	W	
	6 p.m.	4	W	
	9 p.m.			
	Mid. Nt.			
16. 4.38 day	3 a.m.			
	6 a.m.			
	9 a.m.			
	Noon			
	3 p.m.			
	6 p.m.	4	NE	The wind conditions
	9 p.m.	4	NE	at the time of the
	Mid. Nt.	4	ENE	very outstanding
17. 4.38 day	3 a.m.	4	ENE	reversal of the most
	6 a.m.	4	ENE	usual NE-going overall
	9 a.m.	5	ENE	water flow from
	Noon	5	ENE	Channel to North Sea.
	3 p.m.	5 to 6	ENE	(lower record across)
	6 p.m.	5 to 6	ENE	

Fig. 4

Two highly-contrasting whole-day Vertical Log records from the Varne Lightvessel, to show how pronounced can be the effect of Wind on Water-Movement in Dover Straits. It is not to be assumed that either of these records is the most extreme which the collection of data could furnish.

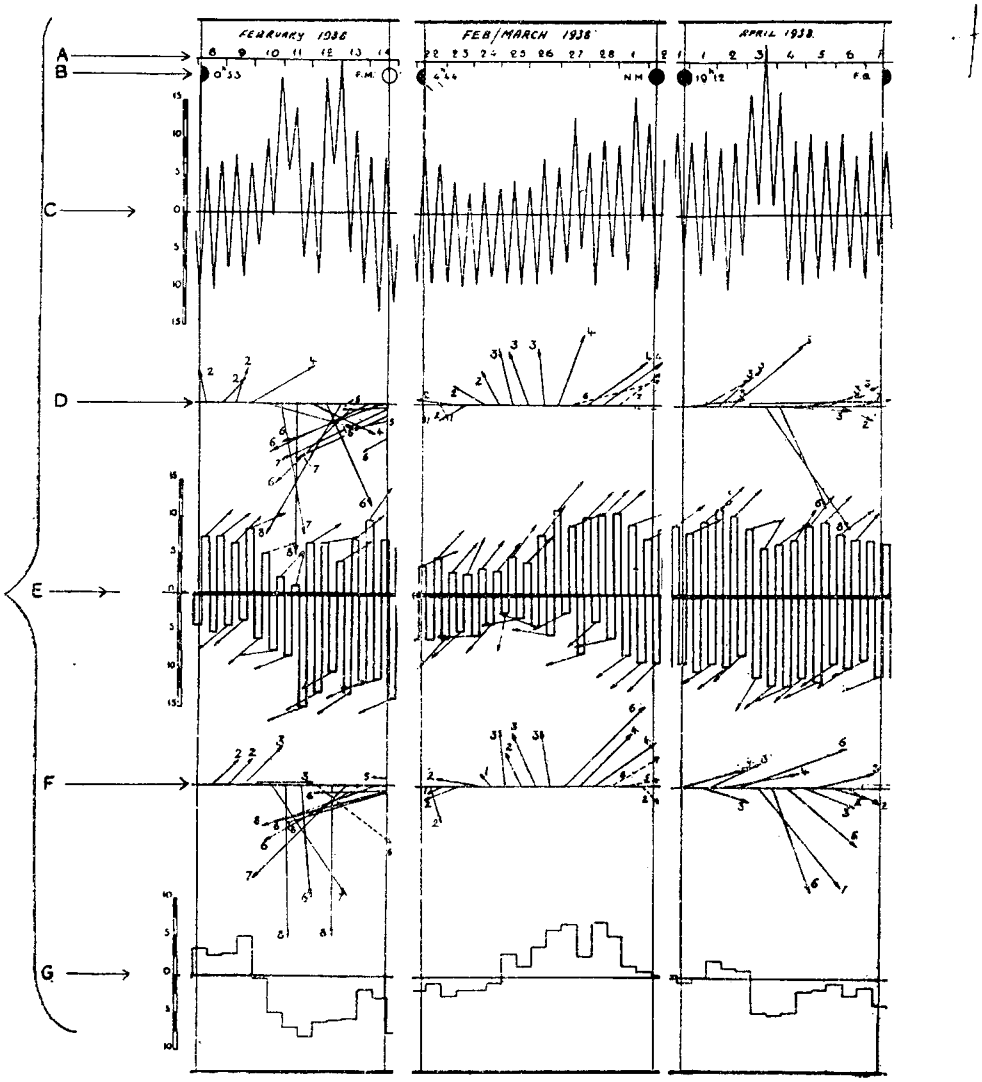

Fig. 3

Three small cut-out portions from a nine-foot long graphical presentation of wind and water movements (with certain other relevant elements) past the Maas lightvessel in 1938. The parent figure comprehended all days of the year, and one like it exists for some other years .... as also for other Dutch lightvessels. The continuous all-weather data on water movements here concerned (see lines E and G) came from the employment of a Vertical Log Current-Meter, and these "cut-outs" are to show how potent is wind influence in ruling water movement within a layer (some 34 feet thick) representative of ship draught.

Key.—A : Date ; B : Moon's phase ; C : Tide level at the Hook of Holland, decimetres above and below M.S.L.; D: Wind during Flood-wards water movement (NE-going), Beaufort numbers and true directions; E : Water travel in kilometres per half Lunar Day (add 8 per cent to scaled readings to get Sea-miles per Lunar Day). Flood-wards movement above the zero line and Ebb-wards below. The arrows at the column ends show the precise directions concerned ; F : As D but during Ebb-wards water movements ; G : The Excess-Run of the water in the one direction or the other, N.E. excesses above the zero line and S.W. excesses below it. Scaled for kilometres per half Lunar Day —— see remarks under E. (Acknowledgements to Dr. J. van Veen.)

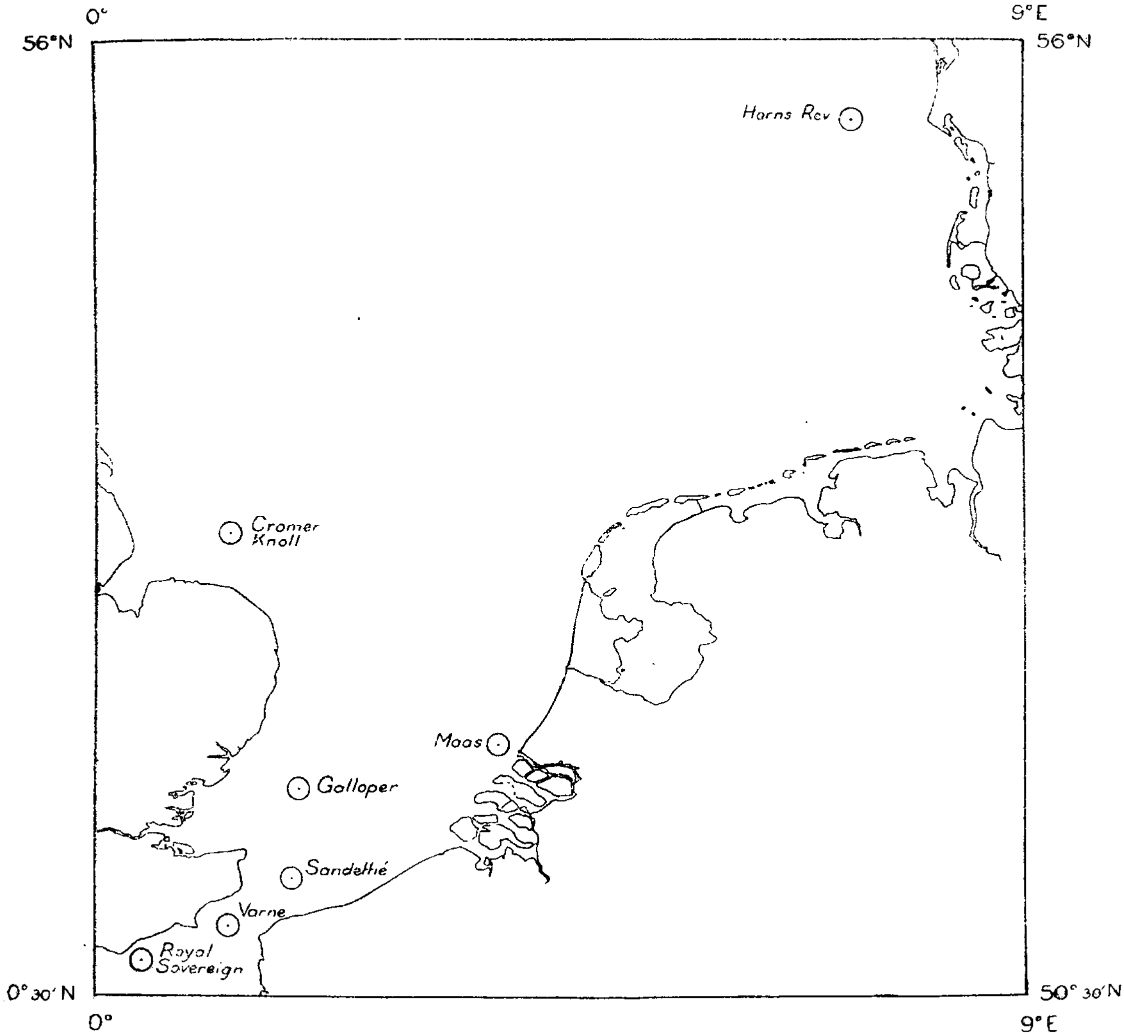

Fig. 5

Showing the Positions of the various lightvessels from which continuous observations on water-movements were in train (by Vertical Log Current-Meter) at the time of the Break-Through of the Sea on the Norfolk Coast referred to in the text as the "Horsey Flooding" (of February, 1938).

TABLE I.

Showing, for the time of the serious Break-through of the Sea on th Norfolk Coast (the Horsey Flooding of February, 1938), what were the Water Movements past certain Lightvessels of interest. In columns A and B, the entries denote Miles of Water Movement towards the stated Directions the Numerator values relating to a day relevant to the time of the Break-through (Central Times given in Column A), and the Denominator values relating to the best daily averages available (see 5th column).

The entries in Column C show the corresponding amounts of Net Water Travel.

Lightship.	A (Flood-wards (Water Travel	B (Ebb-wards (Water Travel	C (Net Water (Travel	Basis of Means used for Comparison	Remarks as to Preceding and/or Following Day or Days
Cromer Knoll	SE. 11.3 / 10.4 12.2.38 - 1515	NW. 6.5 / 9.9	SE. 4.8 / SE. 0.5	Average for the Whole Year 1937.	
Galloper	SW. 14.8 / 12.3 12.2.38 - 0645	NE. 10.6 / 11.0	SW. 4.2 / SW. 1.3	Average for the last three Entire Winters	Preceding Day - SW. excess was 9.8 miles. Following Day - SW. excess was 12.1 miles.
Sandettie	NE 4.9 / 13.2 12.2.38 - 2345	SW. 20.3 / 11.6	SW. 15.4 / NE. 1.6	Average for the last three Entire Winters	
Maas	N. 71° E. 6.6* / N. 52° E. 9.8 12.2.38	S. 50° W. 13.6* / S. 58° W. 8.1	ca. SW. 7.0* / ca. NE'E. 1.7	Average for period July, 1937, to February, 1938, inclusive.	Preceding Day - Flood-wards ca. 1.1 miles. ≠ Ebb-wards ca. 13.1 miles. ≠ Excess - about 12 miles towards SW approx.
Horns Rev	NNW. 5.0 / 7.6 12.2.38 - 0955	SSE. 4.9 / 4.2	NNW. 0.1 / NNW. 3.4 -/-	Average for Winter 1937/38 = Dec., 1937 + Jan., 1938 + Feb., 1938.	Following 3 days - SSE. excess was 3.7, 5.0, and 6.8 miles respectively.
Royal Sovereign	E. 6.8 / 9.6 12.2.38 - 0845	SW. 9.2 / 8.0	SW. 2.4 / E. 1.6	Average for the Whole Year 1937.	Preceding Day - SW. excess was 3.1 miles. Following Day - SW. excess was 6.5 miles.

* The observing technique was somewhat different at this ship. These values were obtained by vector-averaging 22 equally-spaced observations within the day.

≠ These values were obtained on vector-averaging 23 equally-spaced observations made on February 11th. The flood-wards water movement was mainly towards a N. by E.'ly point and the ebb-wards towards a WSW.'ly point.

-/- The least amount of net NNW.-going water movement at this vessel during the whole Winter.

TABLE II.

Winds at the Various Lightvessels during days appropriate to the Horsey Flooding.

(The Entries are Vector-Averages based upon (n) observations, and are expressed in miles per hour from a true direction)

Ship	Thursday, 10.2.38	Friday, 11.2.38.	Saturday, 12.2.38.	Sunday, 13.2.38
Cromer Knoll	21.6 N.57°W. (8)	25.6 N.36°W. (8)	32.8 N.38°W. (8)	32.8 N.11°E. (8)
Galloper	22.8 N.72°W. (8)	28.6 N.40°W. (8)	32.9 N.40°W. (8)	39.2 N. 3°E. (8)
Sandettie	25.1 Due W. (8)	42.2 N.37°W. (8)	31.5 N.27°W. (8)	49.0 N.10°E. (8)
Maas		34.7 N. 2°W. (24)	24.6 N.25°W. (24)	
Horns Rev		37.9 N.20°W. (6)	11.2 N.22°E. (6)	
Varne	17.7 N.87°W. (8)	22.6 N. 8°W. (8)	25.8 N.32°W. (8)	33.8 N.26°W. (8)
Royal Sovereign	19.3 S.88°W. (8)	17.2 N. 3°E. (8)	27.6 N.27°W. (8)	33.6 N.34°E. (8)

TABLE IV.

Another Presentation of Data on Water-Movements past various Lightvessels at the time of the Horsey Flooding of February, 1938. This table presents the information in a less-summarised form than does Table 1. The central times of the "Exceptional Days" concerned are given, and the entries denote Miles of Water Movement in a day towards the Octants specified. The wind data of Table 2 relate.

Lightvessel	Average and Exceptional.	Between N.N.W. and N.N.E.	Between N.N.E. and E.N.E.	Between E.N.E. and E.S.E.	Between E.S.E. and S.S.E.	Between S.S.E. and S.S.W.	Between S.S.W. and W.S.W.	Between W.S.W. and W.N.W.	Between W.N.W. and N.N.W.
Cromer Knoll ...	Average for whole year 1937	0·19	0·14	0·21	10·00	0·19	0·17	0·21	9·49
	Exceptional, 1515 (12.2.38) ...	1·72	0·21	0·39	10·69	0·21	0·12	0·18	4·60
Galloper ...	Average for Winter 1937-38...	0·20	10·91	0·11	0·05	0·21	11·04	0·14	0·18
	Exceptional, 0735 (13.2.38) ..	—	6·50	—	1·33	—	18·48	0·08	—
Sandettie ..	Average for Winter 1937-38...	0·03	12·34	0·18	0·13	0·18	12·68	0·06	0·03
	Exceptional, 2345 (12.2.38) ...	—	3·55	1·34	0·54	9·04	11·22	—	—
Royal Sovereign	Average for whole year 1937...	—	0·02	9·57	0·01	0·00	7·95	0·01	—
	Exceptional, 0935 (13.2.38) ..	—	—	9·15	—	—	15·68	—	—

TABLE III.

Showing (from Vertical log records) how the overall Water Movements well below surface (2 fathoms and more) past various lightvessels in the southern North Sea and English Channel, have been known to vary in dependence upon the Direction of Strong Winds. (To this table could now be added comparable information for the Seven Stones lightvessel near Lands End).

Lightvessel . N. Long. E.	Average Current True Direction and Sea-Miles per Lunar Day.	Direction of Strong Wind and resultant current in sea-miles per lunar day.							
		N	NE	E	SE	S	SW	W	NW
oyal Sovereign ° 43' 0° 27'	132° 6.8	225° 2.4	201° 10.5				096° 14.7	096° 14.7	
Varne ° 56' 1° 17'	032° 2.8	225° 7.2	225° 14.0	V A R I O U S			045° 18.0	045° 18.0	225° 7.2
orth Goodwin ° 20' 1° 34'	045° 3.0		225° 9.8	225° 11.9	225° 4.1		045° 10.5		225° 6.7
Sandettie ° 13' 1° 54'	045° 2.5	225° 16.0					045° 18.0	045° 18.0	225° 16.0
North Hinder ° 38' 2° 34'	066° 3.1	225° 4.0				045° 16.2	045° 16.2		
Maas ° 01' 3° 54'	019° 1.8	225° 9.5				045° 12.2			
Haaks ° 58' 4° 19'	004° 2.3		225° 6.5	225° 6.5		045° 21.6			
Terschelling ° 27' 4° 47'	032° 5.2				225° 11.9		055° 23.7		
Borkum Riff X ° 46' 6° 04'	097° 2.0	270° 1.7	270° 4.5	270° 4.5	270° 1.7		097° 6.0	097° 6.0	
Horns Rev ° 34' 7° 20'	338° 3.5	158° 6.8	158° 5.0	158° 5.0			338° 17.0	338° 17.0	
Cromer Knoll ° 16' 1° 18'	120° 0.8				300° 5.3				120° 7.0
Smiths Knoll ° 43' 3° 17'	135° 2.6	135° 10.0		225° 2.0	315°. 6.0	345° 10.0			
Galloper ° 44' 1° 58'	225° 1.3	045° 10.0	045° 10.0				225° 20.0		045° 10.0

Reservation.—The data for the Borkum Riff lightvessel (the only exception) did not come from observation made with a Vertical Log Current-Meter, but were taken from a paper by Hugo Mandelbaum (Aus dem Arch. der Deutschen Seewarte, Bd. 53, No. 4, 1934-35).