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Recent Investigations with Drift Cards for Determining the Influence of the Wind on Surface Currents

by

G. Tomczak

The theory of the drift currents is just as old as the I.C.E.S. It was set up in 1902 by V.W. Ekman who was inspired by the observations made by Fridtjof Nansen on his polar drift in the "Fram". In the first instance it was valid for stationary currents in a homogeneous, unlimited sea and led to the well-known "Ekman-Spiral". According to this the direction of the surface current differs by 45° from the direction of the wind passing over the surface of the sea, the current being deflected to the right in the northern hemisphere. With increasing depth this angle of deflection, α, increases, while the velocity of the drift current decreases. At a certain depth, called by Ekman "frictional depth", α amounts to 180°, and the velocity to 1/23 of the velocity in the surface. It is not easy to confirm the theory by observations in the sea, even when taking into consideration the supplements made later on by Ekman, Fjeldstad, Thorade and others, with respect to the influence which changes of the wind, limited water depths, stratified water, etc. have. The test conditions and the technique for observing currents in the open sea are faced with great difficulties. In particular the values observed for the angle of deflection are differing very considerably, namely between 0° and 60°. But also the relation between the velocity of the drift current and the wind passing over the sea deviates.. For this relation Thorade set up the following formula:

$$V_o = \lambda W / \sqrt{\sin \varphi}$$

which indicates a dependence on the geographic latitude. $k = \frac{\lambda \cdot 10^2}{\sqrt{\sin \varphi}}$ is called the wind factor. It gives the velocity of the drift current expressed in percentage of the wind velocity. According to observational data by Mohn, Nansen, Witting, and Thorade 1.5 was considered probable for the value of k. However, as will be shown later, k does in fact - in agreement with more recent observations - vary between 1.4 and 4.3.

Investigations performed by the German Hydrographic Institute in connection with the contamination of the coasts by oil residues that drifted ashore rendered an opportunity for new determinations of the wind factor k. As drift matter we applied drift cards of the type developed in 1958 at the National Institute of Oceanography in Wormley by Dr. Carruthers, who kindly provided us with a sample card. The cards in question are post cards water-tightly wrapped in double plastic envelopes. They are liberated in the sea and returned by the finder, who states place and time of retrieval. The envelopes, the thickness of which amounts to 2 mm, swim perfectly in the top water layer. As they do not present any particular targets to the wind they reflect the movement of the uppermost millimetres of the surface layer of the sea. Within one year we released 5000 drift cards in the North Sea area, generally 30 in the same position. A little more than 50% were returned from Norway, Sweden, Denmark and Great Britain, as well as from places along the German coast. An interim evaluation made in March this year and about which is now being reported referred to 2000 cards released in 42 different positions, 948 of which had been returned. If for all cards retrieved within a zone of a radius of about 10nm we presumed only one position of retrieval then 133 different places of retrieval resulted for the 948 returned cards.

A preliminary, rough evaluation of the results is presented in the following table

Table 1. Wind factor k according to a rough evaluation of the observations.

Time of drift t = time between release and retrieval	Length of drift e = distance between place of release and place of retrieval	Minimum drift velocity v = e : t	k presuming a mean wind force of 3 Bft	5 Bft	7 Bft
10.5 days	152.7	14.5 nm/day	6.7	3.4	2.0
25.75	145.0	5.6	2.6	1.3	0.8
74.0	522.4	7.1	3.3	1.7	1.0
90.25	679.0	7.5	3.5	1.8	1.0

The third column of the table - v = e : t - contains minimum values of the drift velocity; the value would increase if instead of the direct distance between the place of release and retrieval the length of actual drift way could be inserted, because it probably is not a straight line but a meandering path. Along with this v would increase by introducing shorter drift times. As the cards are apt to have been driven ashore some time before they were found the true drift time must be regarded as being somewhat smaller than t. The values given in column 3 and the k-values resulting therefrom are consequently most probably too small. In the last 3 columns the respective values of k were computed by assuming different mean wind velocities during the time of drift. In case of high drift velocities, as in the first line, higher wind forces must have prevailed. The most probable value for k is therefore, in this case to be found between 2.0 and 3.4. The probable k-values of the remaining lines are also underlined. Yet, as we have seen that the underlined k-values are only minimum values we have to conclude that the wind factor k must result from our investigations as > 2.6. The analysis of the British observations, as carried out by the National Institute of Oceanography in 1958, roughly proceeded along this principle though somewhat more refined. As result Hughes gave the value k = 3.3.

An even more accurate statement will be possible when the exact length of drifting, e, and perhaps a better value for the time of drifting, t, is taken up into the calculations. The first is possible under certain conditions. For if both the direction and velocity of the wind prevailing over the relevant sea area are known then the way the drifting matter took can be composed out of small single parts. One proceeds from the position of release at time T_o and computes the way the drifting matter is to complete within the next 6 hours for instance, inserting fixed values for α and k respectively. In this way one obtains a position for time $(T_o + 6^h)$. In proceeding from this new position one determines for the following 6 hours a position for time $(T_o + 12^h)$ etc. by inserting into the calculation the wind then prevailing. At least after the entire time of drifting has expired the position calculated for $(T_o + t^h)$ must be identical with the position of retrieval, provided the values used for α and k were correct. Should such conformity not be achieved then the calculation can be repeated with different values of α and/or k until the calculated and observed places of retrieval agree with each other at time $(T_o + t^h)$ or earlier, since the card could already have lain there before it was discovered. The same calculations are accordingly to be made for all other places of release. Due to the uncertainties of the whole method it cannot be expected that in all cases the same α and k-values will lead to the best results. However, if a sufficient number of observations are avilable then the angles of deflection and the wind factors decisive for the drift currents will be easily recognized by supplying a dominating number of instances in which the computed and observed places of retrieval coincide. This calculation was carried out by us. We have simplified it, however, by taking into account only one parameter, namely the wind factor k. For the angle of deflection we put $\alpha = 0$. Thus we took as basis for our calculation the assumption that the uppermost 2 mm water layer moves in the direction of the wind. This is all the more appropriate as on account of the frequent changes of the wind fields prevailing over the North Sea we cannot speak of stationary conditions. The calculations were made by an electronic computer.

By applying the method described above the correct drift ways were calculated for 16 different k-values between 1.5 and 5.5. The distance between the place where the drift way touches the coast and the place of retrieval served as measure for the quality of the calculations. Whenever the drift way did not at all touch land it was the distance between the calculated position at the time of retrieval and the place of retrieval which served as measure. If the distance amounted to less than a certain value r, which stands for the "radius of the area of hit" then the calculation for the relevant k-value was regarded as a "hit". If the value was larger, then the calculation was looked upon as a "failure".

Table 2 gives the number of hits for several regions of hit, with the radius r, and different k. For the radii 20 to 80 nm an ajustment gave as the most favourable wind factor, that is the one which achieves the most hits, k = 4.2.

Table 2. Number of hits for different values of r (regions of hit) and k (wind-factor).

r \ k	1.5	2.0	2.5	3.0	3.5	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	5.0	5.5
20 nm	6	32	32	49	42	36	38	35	27	36	50	58	56	52	38	30
40 "	17	51	50	99	102	69	72	69	87	93	93	84	102	94	105	65
60 "	28	74	89	130	147				141					148	126	123
80 "	54	105	152	199	178				176					171	158	154
100 "	111	174	204	234	193				200					190	162	158

This value is almost three times that of the factor 1.5, assumed so far for drift currents, which is surprisingly high. An equally large value had already been determined in 1955 by the German Hydrographic Institute when tracing a large oil patch. The patch that developed in the mouth of the Elbe when the Danish tanker "Gerd Mærsk" run aground was observed by ships and planes. Its southern boundary could well be portrayed when the velocity of the oil drift was assumed to be 4.3% of the prevailing wind velocity.

The following table compiles the k-values determined by several authors, commencing with the low value of 1.44 by Thorade and ending up with the high values determined by us, 4.2 and 4.3. By regarding the manner in which the values were determined and by concluding from it the thickness of the water layer for which the value is valid it looks as if k increases the thinner the water layer observed became.

Table 3. Windfactor k determined by several authors.

Author	k	Method of determination	Valid for
Thorade	1.44	drift of ships	thick water layer; wind velocity > 4 m/sec
Ekman	1.85	current measurements at 5 m depth	surface up to 5 m depth
Rossby/ Montgomery	2.53	theory of hydrodynamics	"surface layer"
Stommel	~ 2.9	drifting buoys	surface up to about 1 m
Hughes	3.3	drift-cards	thin surface layer
van Dorn	→ 3.6	experiments in basins	thin surface layer (extrapolated)
German Hydr. Institute	4.2	drift-cards	thin surface layer
	4.3	drifting oil patch	thin surface layer

It is especially the agreement between the observed oil drift and the tests with our drift-cards which shows that the transfer of wind energy to the water surface does not immediately lead to turbulence in the water. Rather does the thin laminar layer seem to serve as a link between air and water masses.