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An Attempt of Hindcasting the High Waves Observed by the OWS "Weather Reporter" at Position "J" on 17 December 1959*

By H. Walden

Summary. The data for high wave conditions at position "J" on 16 December, 1959 were recently published in this journal (C. L. Bretschneider, H. L. Crutcher, J. Darbyshire et al. [1962]). With reference to this paper an attempt is made to hindcast those waves.

Versuch einer nachträglichen Berechnung des hohen Seeganges beim Ozean-Wetterschiff „Weather Reporter" auf der Position „J" am 17. Dezember 1959 (Zusammenfassung). Die Unterlagen zur Berechnung des hohen Seegangs auf der Position „J" am 16. Dezember 1959 wurden vor kurzem in dieser Zeitschrift veröffentlicht (C. L. Bretschneider, H. L. Crutcher, J. Darbyshire et al. [1962]). Unter Zugrundelegung dieser Arbeit wird versucht, den hohen Seegang aus den meteorologischen Gegebenheiten nachträglich zu berechnen (*hindcast*).

Essai de calculer ultérieurement les hautes vagues auprès du frégate météorologique «Weather Reporter» à la navirestation «J» le 17 décembre 1959 (Résumé). Les données pour le calcul de hautes vagues observées auprès de la navirestation «J» le 16 décembre 1959 ont été récemment publiées dans ce journal (C. L. Bretschneider, H. L. Crutcher, J. Darbyshire et al. [1962]). Partant de ce travail, on essaie d'estimer après-coup (*hindcast*) des conditions météorologiques cette forte mer.

Weather situation. A cyclonic system comprising various centres and approaching from the Nova Scotia region reached the North Atlantic Ocean near Newfoundland on 14 December. A triple point situation of air masses (M. Rodewald [1937, 1939]) developed, and the depression deepened considerably from 15 December, evening, moving approximately toward the north north-east with a speed of about 35 knots. In its south-eastern sector, it was accompanied by a large "field" of south-westerly winds, forces 6 to 8 Beaufort, which arrived at OWS "J" in the afternoon. The main cold front passed the ship between 15 and 18 GMT. However, the wind veered only a little behind the front, because a wide trough had been forming more to the W, i.e. in the south-western sector of the depression. At "J", winds became west south-west reaching full force 11 with gusts 75 knots at about midnight 16/17 December. As has been frequently observed, the trough then developed the characteristics of an eastward swinging cold front. It passed OWS "J" on 17 December between 03 and 06 GMT, so that the wind veered from west south-west to 280° (see table I in: Bretschneider, Crutcher, Darbyshire et al. [1962]) and also decreased to force 9. It is important to state also that the westerly to west north-westerly winds in this very air flow were blowing with force 10 to 11 Beaufort within a wide area more to the W of "J". This area was quickly travelling eastward.

Complex seas. It is remarkable that on December 17, from 15 to 21 GMT, two different wave systems have been broadcasted by OWS "J". A look at these reports shows that the main "wind sea" was following the change of the wind direction. One could take the other system, from the WSW, to be a new additional wave train, but it is much more likely to have already been present at "J". The WSW system was superposed on the higher waves from the W to WNW during a certain period of time in such a manner that it could not be perceived by the observers. Then, after the wind and the wind sea had turned far enough from the WSW, this wave system, having been generated to the WSW of "J" some time before, could again be distinguished from other wave trains. However, independently of which wave systems are mentioned in the weather log, it is, for hindcasting the sea, important to investigate both how

* See the paper by C. L. Bretschneider, H. L. Crutcher, J. Darbyshire et al. in: Dt. Hydrogr. Z. 15, 243.

many and what wave systems are assumed to have been present at the spot and time in question and also from which directions such wave systems came.

It is difficult to compute the total energy within a complex sea that has been formed by various wave systems; in fact, a way to add the partial energies that are contributed by each of these systems to the total, is not known.

Certainly, only such trains can be taken into account that are independent of each other. That means that they must originate from different fetches. A very rough estimate on how to add the "partial" wave energies has recently been tried (Walden [1961]). These provisional assumptions will also be utilized in this paper.

The energy density spectra of as many as 40 records taken by Tucker's ship-borne wave recorder have been determined in the scope of the whole of the above mentioned investigation (Bretschneider et al. [1962]). Although the present author considers it very valuable to have available such a series of spectra, he decided to confine his hindcasting to the highest sea observed in this storm period (17 December, 18 GMT) and additionally to a case in which only one wave system was observed, i. e. the state of the sea was essentially determined by the wind sea generated by the winds blowing at that time and in the corresponding fetch (17 December, 03 GMT).

17 December, 18 GMT. In the opinion of the writer, at least three wave systems were simultaneously present at the position of "J" on 17 December, 18 GMT. They were:

1. The "wind sea" running from about true 280⁰ (azimuth).
2. A kind of swell from approximately 250⁰. The waves were generated in the south-eastern to southern sector of the depression.
3. Swell-like waves from the northwest (about true 320⁰) having been generated at the rear of the depression.

It is assumed that these three wave systems will satisfactorily form the composite sea in question and that it is not necessary to consider wave trains from other azimuths. It is recognized, however, that, due to the rapid and fluent transitions between the various wind fields or fetches, other azimuths could be selected as the representative ones.

The great circle hitting position 53,1⁰N 17,5⁰W (OWS "J" on December 17, 18 GMT) with true 280⁰, passes near Newfoundland on the North American continent to the Atlantic Ocean (see fig. 1). Fig. 2 contains the distance-time or "fetch-duration" diagram for the distribution

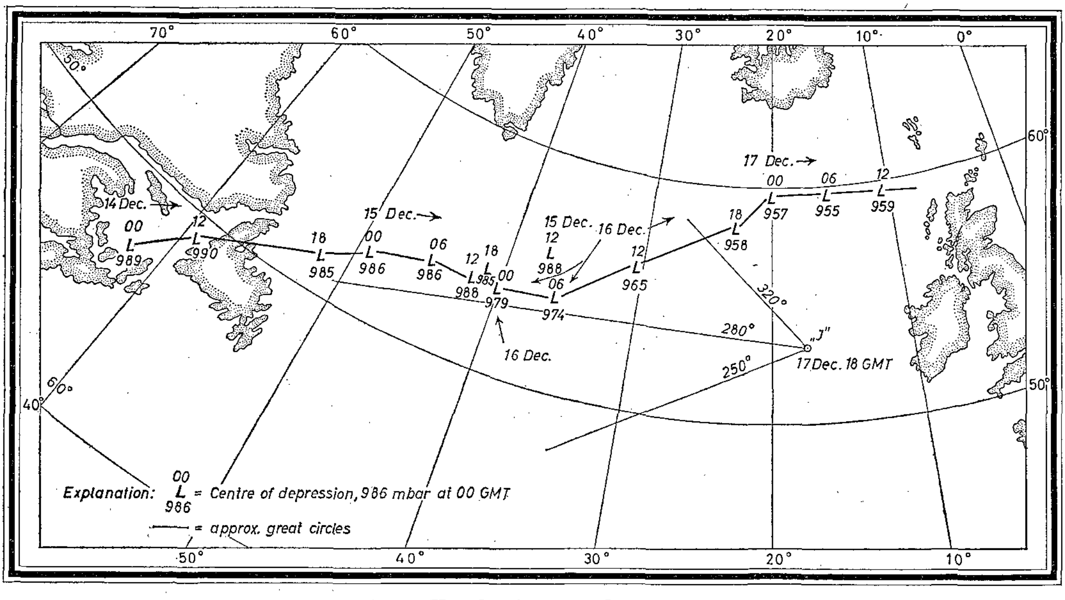

Fig. 1. Track of storm depression

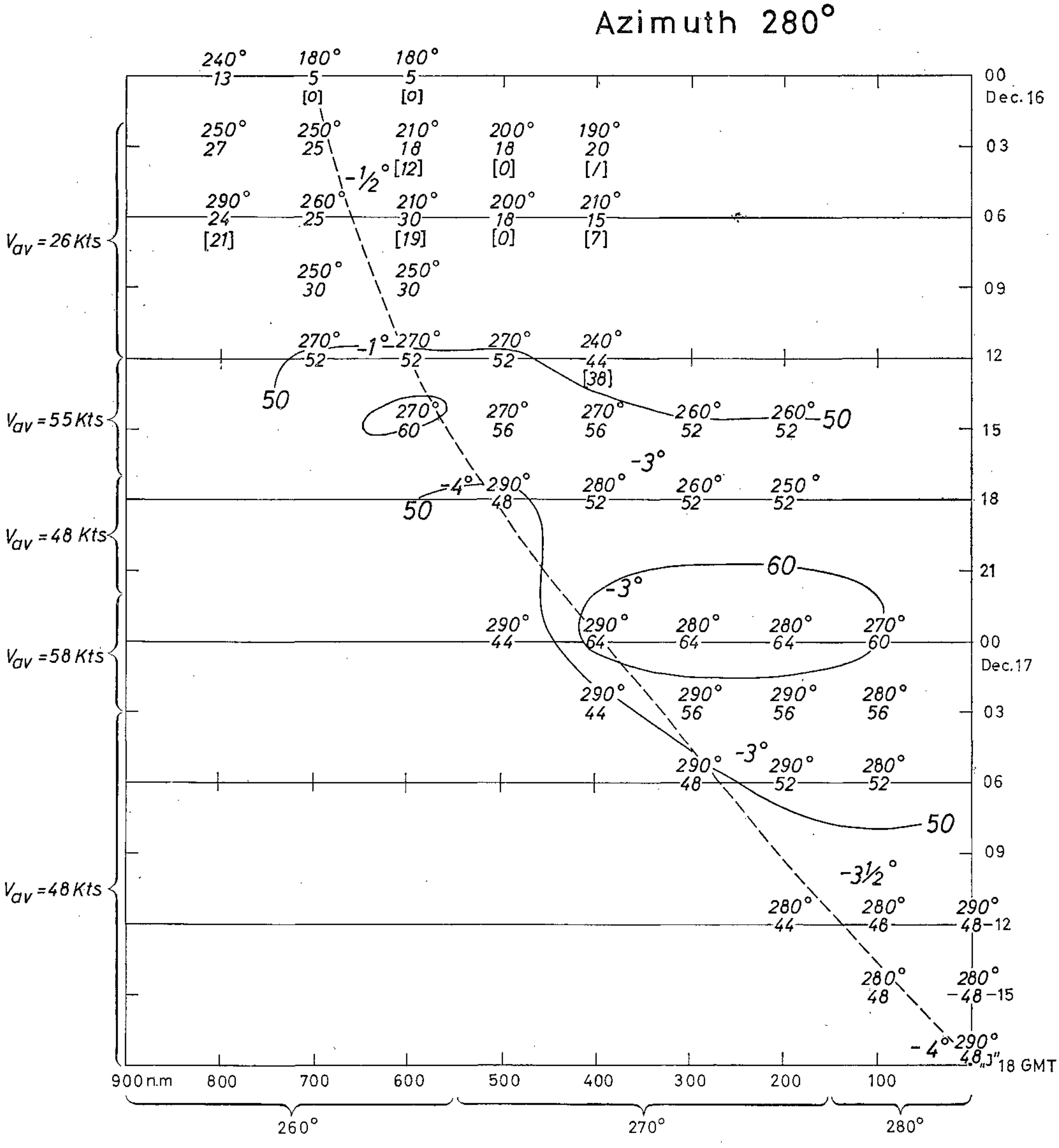

Fig. 2. Fetch-duration diagram along great circle 280°, 17 December, 18 GMT

of wind direction and wind velocity along this great circle for synoptic hours. The three-figure numbers give the azimuth of the wind; the number below is the estimated wind speed and the number in brackets represents the wind speed component related to the great circle azimuth at the position in question, but only for angles > 20° between great circle and wind direction. (The azimuth of the great circle changes with longitude; its approximate values are entered at the bottom of the diagram.) Some isolines for wind components along the great circle have been put in. The single larger numbers give the temperature differences air minus water surface ($T_a - T_w = \Delta T$). The dotted line is the "propagation line" (B. W. Wilson [1955]). It represents the movement of an "energy parcel" related to the assumed upper period T_u of the spectrum, and that for a "parcel" which arrived at "J" on 17 December, 18 GMT. For simplification, averages of wind speeds ($= v_{av}$) in some various sections along the propaga-

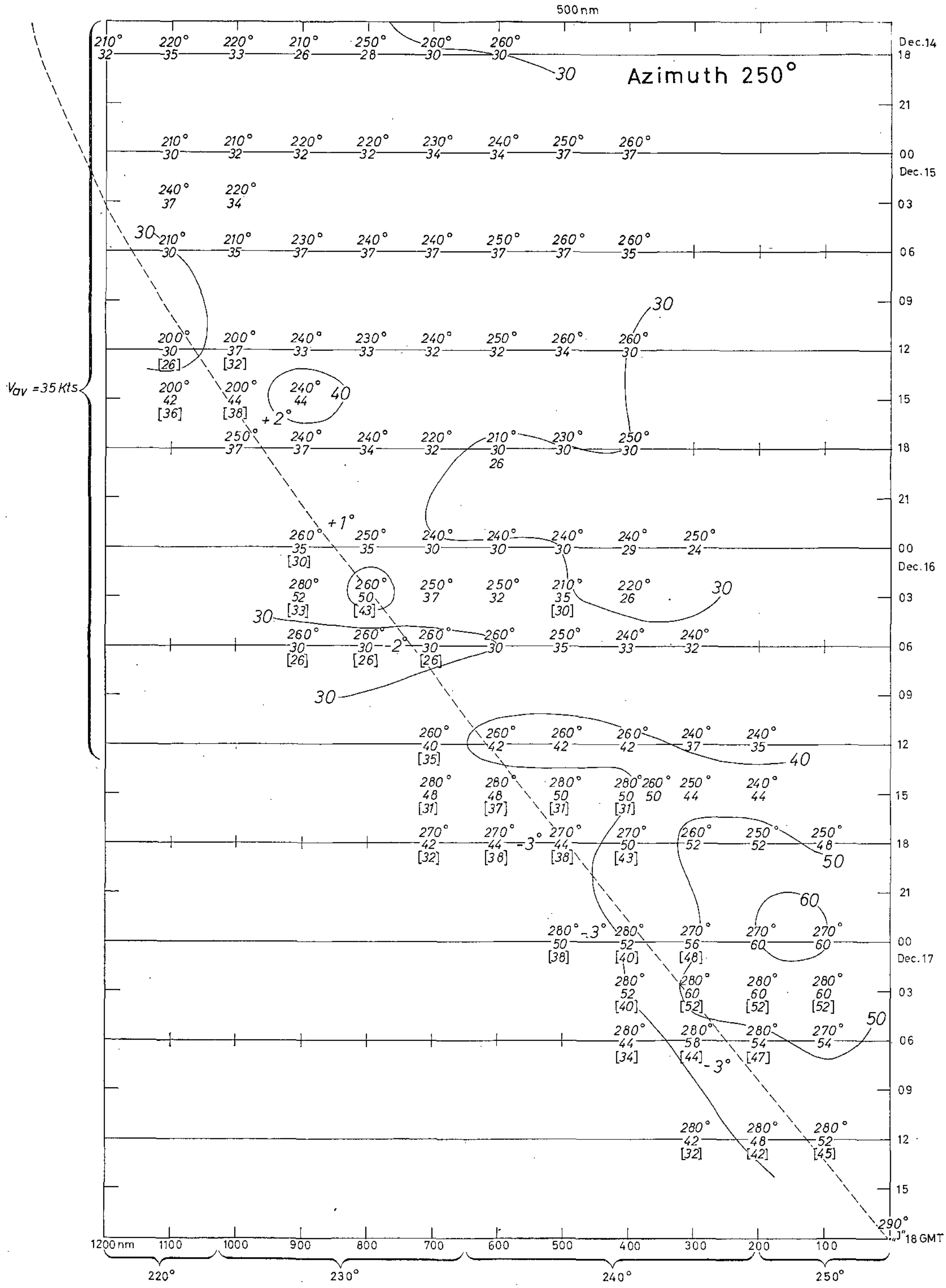

Fig. 3. Fetch-duration diagram along great circle 250⁰, 17 December, 18 GMT

tion line were estimated and marked at the left hand edge of the figure. The growth of the sea is determined by considering the development from section to section as described for example by Walden [1960] and by using diagrams after Walden [1958]. The successive steps are collated in table 1.

Table 1

Length of time of the section (hours)	v_{av} (knots)	Effective wind duration of preceding section (hours)	Total of duration (hours)	New v_{av} (knots)	Corresponding wind duration (hours)	T_u at end of section (sec)	T_u averaged (sec)	$1{,}515 \cdot T_u$ (knots)	Number of hours	naut. miles
10	26	–	26	55	1	8,3	~5,5	8,3	10	83
5	55	1	6	48	11	11,6	9,95	15,1	5	76
5	48	11	16	58	7	13,1	12,35	18,7	5	93
5	58	7	12	48	27	13,6	13,35	20,2	5	101
15	48	27	43	–	–	15,8	14,7	22,3	15	334
									Total:	687 nm

One gets: $\tilde{H}_{1/3} \sim 9{,}8$ m; $\tilde{T}_{1/3} \sim 11{,}4$ sec; $T_u \sim 15{,}8$ sec. It has to be considered that ΔT was about $-3{,}5^0$ Celsius. After multiplying $\tilde{H}_{1/3}$ by 1,13 and the periods by the factor 1,06 (after H. U. Roll [1952] respectively H. Walden and H. U. Gerdes [1958]) we obtain the following quantities hindcasted for the sea that is coming from 280^0:

$\tilde{H}_{1/3} \sim 11{,}1$ m (~ 36,1 ft)
$\tilde{T}_{1/3} \sim 12{,}1$ sec
$T_u \sim 16{,}7$ sec
T_{max} between 13 and 16 sec
Total energy $E \sim 15{,}3$ [m²].

The hindcasting along the great circle 270^0 through OWS "J" renders very similar values.

Waves from true **250⁰** also were observed at "J" on 17 December, 18 GMT. The wind conditions along the great circle 250^0 through "J" were such (see weather maps and fig. 3) that an area of SW'ly to WSW'ly gales situated near OWS "D" (44^0N 41^0W) on December 14, was moving east northeastward. Waves generated by SW'ly winds in the environs of "D" were further (till 16 December about noon) affected by winds which favoured their growth. At a distance of 580 naut. miles WSW of "J" on 16 December, 13 GMT, the sea should have had the following characteristics:

$\tilde{H}_{1/3} \sim 6{,}1$ m (~ 20,0 ft)
$T_u \sim 13{,}6$ sec
$E \sim 4{,}6$ [m²].

ΔT was approximately zero so that corrections with regard to the temperature difference are not necessary.

During their further propagation, the waves constantly were under the effect of obliquely following winds. Thus, for most of the "wave components", it cannot be assumed that they decreased while running through this region; rather the sea may have become higher and longer. Probably, all longer portions of the original spectrum, as it was constituted 580 nm WSW to "J", would have reached OWS "J" on 17 December, 18 GMT. The short components (high frequency portions), however, may have lost a great deal of their energy or even completely disappeared. $\tilde{T}_{1/3}$, therefore, could be expected between 10 and 11 sec. But $\tilde{T}_{1/3}$ was reported between 13,5 and 15,4 sec.

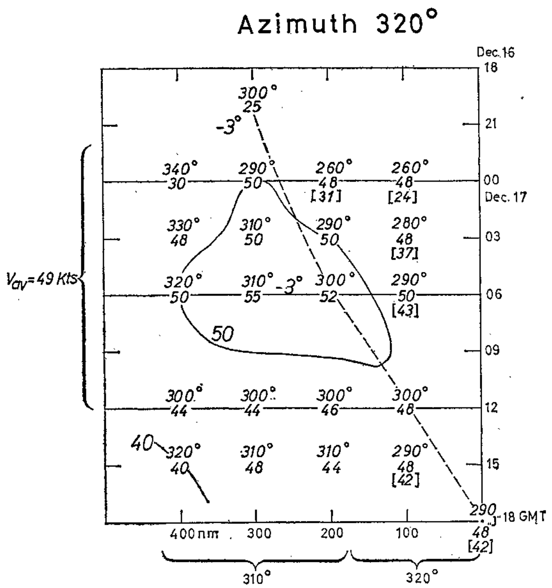

Fig. 4. Fetch-duration diagram along great circle 320⁰, 17 December, 18 GMT

It has to be considered as certain that the essential components also of a wave system from the NW **(320⁰)** were present at "J" at the time in question. These waves had been generated by northwesterly gales and storms at the rear of the storm depression in a rather wide area round 57⁰N 25⁰W on December 17 before 18 GMT. Fig. 4 gives the fetch-duration diagram along the great circle 320⁰ through "J" with the propagation line and other details. With the above mentioned procedure and $\Delta T = -3^0$ C, we get for the wind sea at a position 100 nm northwest of "J" and six hours before arriving at "J":

$\tilde{H}_{1/3} \sim$ 7,5 m (~ 24,6 ft)
$T_u \sim$ 13,8 sec
$\tilde{T}_{1/3} \sim$ 10,3 sec
T_{max} between 11 and 13 sec
$E \sim$ 6,9 [m²].

The addition of the energies, E, is problematical. The writer recently published some thoughts on how to compose the various wave systems (Walden [1961]). He provisionally assumes a procedure in which the energy of a wave system meeting the main wave train in an acute angle is to be multiplied by a factor p before being added to the energy of other systems. p is supposed to range between 0,6 and 1,0.

For simplification, we consider the three squared significant heights, $\tilde{H}_{1/3}{}^2$:

	Azimuth	$\tilde{H}_{1/3}{}^2$	Angle	p	$p \cdot \tilde{H}_{1/3}{}^2$
Main sea	280⁰	123	—	—	123
swell-like systems	250⁰	37	30⁰	0,77	28 ½
	320⁰	56	40⁰	0,83	46 ½
				Total:	198

$\tilde{H}_{1/3} = \sqrt{198} = 14{,}1$ m or 46,2 ft is found to be the significant height of the composite sea at "J" on 17 December, 18 GMT.

A comparison of the hindcasting results with the spectrum as computed from the record with the ship-borne wave recorder (see also Bretschneider, Crutcher, Darbyshire et al. [1962]) is given on table 2.

Table 2

	$\tilde{H}_{1/3}$ ft	$\tilde{T}_{1/3}$ sec	T_{max} sec	T_u sec
Hindcast 280⁰	36,1 } 46,2	12,1	13–16	16,7
250⁰	20,0	10–11	12–13	13,6
320⁰	24,6	10,3	11–13	13,8
Broadcast weather report 280⁰	31 } 46	14–15		
250⁰	28	14–15		
320⁰	—			
Spectrum (ship-borne wave recorder)	39,7		15,0	~20,0 (~19)*

* Longest period of "practical significance" (estimated).

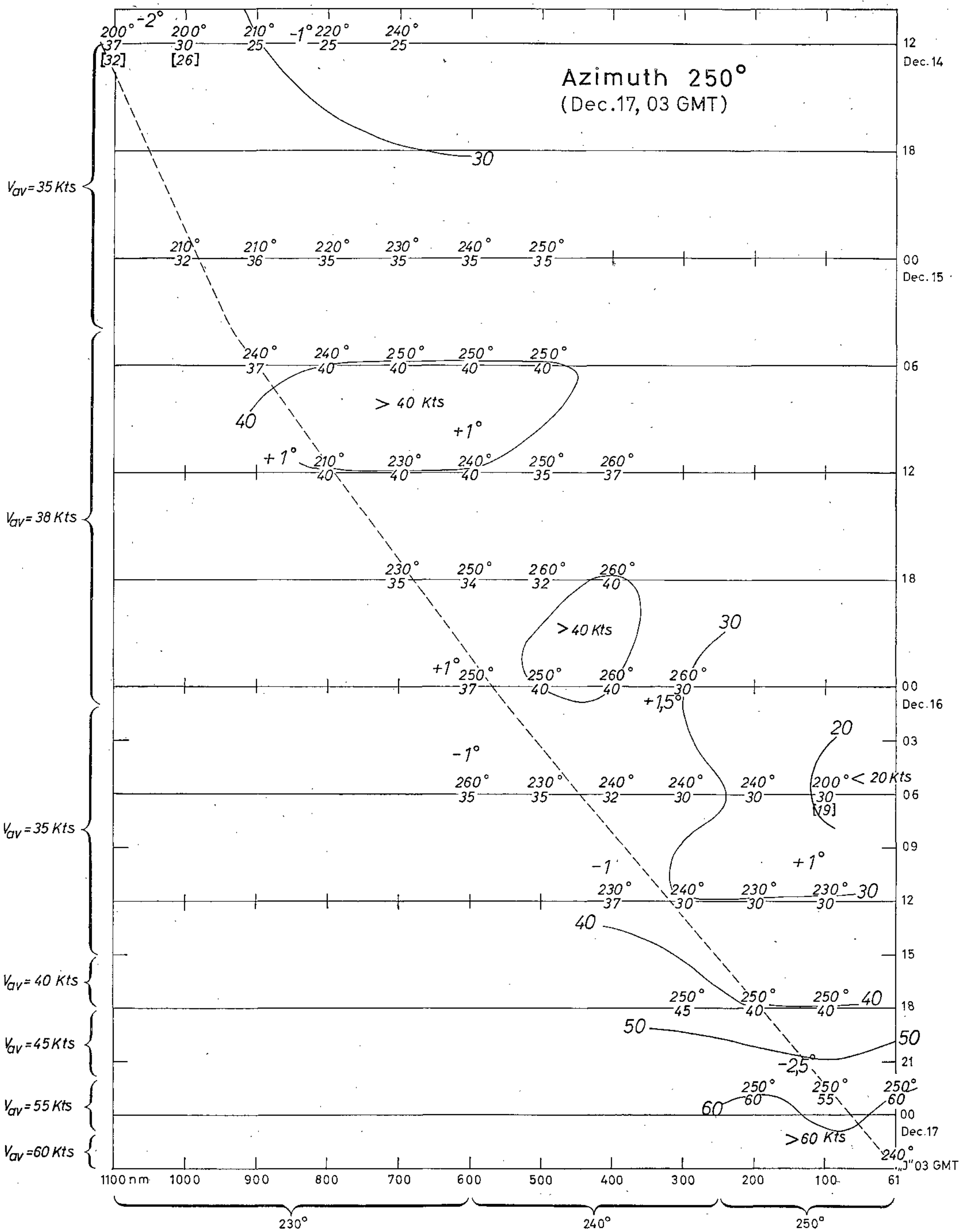

Fig. 5. Fetch-duration diagram along great circle 250°, 17 December, 03 GMT

The differences are considerable in some ways. There is some evidence that the periods given in the diagram after Walden [1958] are too short. Concerning T_u, Walden defined: T_u = longest period "of practical significance"; this value should be assumed in the observed spectrum near 19 sec. There is only one peak and not several ones, as could have been expected with regard to the hindcasting results. However, with 60 lags, the distance between two computed ordinate values is so large in the range of long periods that secondary peaks are likely to disappear.

It is rather surprising that the spectrum is so narrow and is confined to the band between 10,5 sec and 20 sec. This fact will be discussed later.

17 December, 03 GMT. On 17 December, 03 GMT, the storm depression was centered near 59^0N $17^1/_2{}^0$W. The cold front had crossed Ireland, but the following trough still was situated west of OWS "J". The ship reported storm winds from the WSW (240^0) force 11 with average gust-speeds of 75 knots. A widespread "field" of WSW'ly storm winds covered the area WSW of "J" the day before. The distance-time diagram (fig. 5) shows the distribution of the winds along the great circle 250^0 through the position of OWS "J" at 17 December, 03 GMT. No other wave system is present at "J".

The propagation line of fig. 5 runs through some "areas" of various wind speeds. It begins at a position near OWS "D" (44^0N 41^0W), approximately 1100 nm distant from OWS "J", on 15 December, 12 GMT. Until December 16, about 15 GMT, the "energy parcel" was affected by following winds with velocities between 32 and 40 knots. Then, it was influenced by a steadily increasing air flow. The determination of the "propagation line" and of the characteristic properties of the sea at "J" is presented in table 3.

Table 3

Length of time of the section (hours)	v_{av} (knots)	Effective wind duration of preceding section (hours)	Total of duration (hours)	New v_{av} (knots)	Corresponding wind duration (hours)	T_u at end of section (sec)	T_u averaged (sec)	$1{,}515 \cdot T_u$ (knots)	Number of hours	naut. miles
15	35	—	35	38	9,8	10,9	~8	12,1	15	182
21	38	9,8	30,8	35	43,3	13,4	12,15	18,4	21	387
14	35	43,3	57,3	40	30,0	14,6	14,0	21,2	14	297
3	40	31,3	34,3	45	22,0	14,1	14,05	21,3	3	64
4	45	22,0	26,0	55	10,6	14,0	14,0	21,2	4	85
3	55	10,6	13,6	60	8,8	13,4	13,7	20,8	3	62
2	60	8,8	10,8	—	—	13,4	13,4	20,3	2	41
									Total:	1118

From the diagrams of Walden [1958] one gets $\tilde{H}_{1/3} \sim 8{,}8$ m; $\tilde{T}_{1/3} \sim 10{,}1$ sec. The temperature difference ΔT was near $-2{,}5^0$ C from 16 December, 15 GMT onward. We take this fact into account by multiplying $\tilde{H}_{1/3}$ by 1,09 and the periods by the factor 1,06. The results are compared with the broadcast reports and with the corresponding quantities derived from the record taken with the ship-borne wave recorder:

	$\tilde{H}_{1/3}$ ft	$\tilde{T}_{1/3}$ sec	T_{max} sec	T_u sec
Hindcasting	31,5	10,7	11,5–13,5	14,2
Broadcast	31	12–13	—	—
Ship-borne wave recorder	32,9		13,9	20 (17,5)

The heights agree within a tolerable range, the periods are hindcasted considerably too short.

Some final critical remarks. There is an essential difference between the observed and the hindcasted periods. Evidently the values for $\tilde{T}_{1/3}$ as well as for T_u as given in the diagrams of Walden [1958] are too small, at least for the wind speeds and durations in question.

But also the spectra do not look too reliable. Both spectra considered here possess a rather symmetrical shape. Other spectra of ocean waves, for example that of SWOP, show a steep cut-off at the long-period tail, whilst a slow decrease of the energy density is observed toward the short-period end. As the seas of our two cases are not fully developed, the sharp cut-off should be expected. One could get the impression that some energy is missing near frequencies of 0,10 cps. On the other hand, it is astonishing that it is possible to determine the energies in the upper period tail, when the ship-borne wave recorder only records accelerations to 0,02 g.

The wind velocities on which the hindcasting is based have been taken from ships' reports or estimated from the pressure gradients on the weather maps. Both methods include some uncertainties: The wind observations are estimates based on the appearance of the water surface, so that they – at least partly – are not too accurate. The relation between pressure gradient and wind speed depends on a series of factors and also on the temperature conditions, which are not known precisely enough. Moreover, the various air flows possess very different gust characteristics. It is not known at present how to take into account squalls and gusts. To make allowance for ΔT is only a provisional and expedient procedure.

Another severe handicap arises from our lack of knowledge of how the energies of various wave systems are to be superimposed.

On the whole, an investigation such as the present one shows not only the difficulties which exist in hindcasting waves but also the necessity of intensifying efforts to gain satisfactory ocean wave records for deep water and the needed information on the meteorological factors influencing the properties of the waves.

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Empirische Untersuchung zur Frage der Beziehung zwischen durchschnittlicher und kennzeichnender Wellenperiode im Seegang

Von Jürgen Piest

Zusammenfassung. Als Zusammenhang zwischen der kennzeichnenden Wellenperiode $\tilde{T}_{1/3}$ und der durchschnittlichen Periode $\bar{\bar{T}}$ im Seegang wird die Formel $\tilde{T}_{1/3} = c\bar{\bar{T}}$ angesetzt. Mit Hilfe empirischer Unterlagen wird nachgewiesen, daß c eine Funktion des von D. E. Cartwright und M. S. Longuet-Higgins [1956] eingeführten Spektralparameters ε ist. Es wird eine vorläufige quantitative Beziehung zwischen c und ε abgeleitet.