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# A comparison of shallow water wave predictions.

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Abstract: Predictions from two different wave models on wave height, low frequency wave height, wind speed and wind direction, are compared with observations. The comparison is made for the period December 1979 until April 1980 and for three different locations in the southern North Sea, and two northerly stations.

Note The time series mentioned in this report are contained in a seperate Supplement, which is available from the KNMI library on request.

## 1. Introduction.

In recent years interest in accurate wave predictions has been increasing steadily. This interest has been stimulated by demands from the off-shore industry. In the Netherlands a special stimulus came from the envisaged construction of a storm surge barrier in the Oosterschelde estuary.

At present a large number of wave prediction models is available (Favre and Hasselmann, 1978; Earle and Malahoff, 1979; Holthuijsen, 1980). Although many of these are used for hindcasting studies, few are actually used for operational forecasts on shallow water (depth < 0.2 wavelength). Two such models are the Met. Office model (Golding, 1978) and the KNMI model GONO (Klepper, 1975; Sanders, 1976; Saraber, 1980; Bouws et al, 1980; Bruinsma et al, 1980; Sanders, de Voogt and Bruinsma, 1981). The latter model has been extended to take certain bottom effects into account. The former considers refraction as well. The Met. Office model makes use of two different grids, a coarse one covering most of the North Atlantic and a finer 50 km grid for the North Sea (Fig. 1a). It gives wave predictions every 12 hours: a 12 and 24 hour forecast, as well as a calculation based on the analysed weather map. GONO gives similar predictions every 6 hours. Its 75 km (Fig. 1b) grid extends quite far to the North (75° N). It covers only a small part of the Atlantic Ocean.

In order to monitor the over-all quality of these predictions it was decided to compare the output of both models with each other and with available observational data. The comparison started on the first of December 1979, and continued until the end of April 1980. Preliminary results covering the month of December only, were given by Bouws et al (1980). Predictions for 5 different locations were selected for the comparison. These positions are

| | | | | depth |
|---|---|---|---|---|
| 0 | EURO | 51°59'N | 3°30'E | 20 m |
| 1 | IJMUIDEN | 52°34'N | 4°03'E | 25 m |
| 2 | PENNZOIL | 53°13'N | 3°13'E | 22 m |
| 3 | EKOFISK | 56°33'N | 3°13'E | 60 m |
| 4 | OWS MIKE | 66°00'N | 2°00'E | ∞ |

Wave data were obtained with the help of waverider measurements. The data from EURO and PENNZOIL came to us via Rijkswaterstaat, Directie Noordzee; the IJMUIDEN data have been taken with the KNMI waverider.

The models involved predict wave spectra. In principle, these, could be compared with the observed spectra. However, because of the large amount of data involved it was considered more useful to concentrate on a comparison of the significant wave height.

$$H_S = 4 \left( \int_0^\infty E(f)\, df \right)^{1/2} \qquad (1)$$

where E (f) is the variance spectrum whose integral over all positive frequencies f gives the mean square surface displacement. As there is a special interest in the low frequency part of the spectrum an additional comparison was made of the low frequency (period > 10 s) energy. To this end a "low frequency wave height"

$$H_{S,10} = 4 \left( \int_0^{0.1} E(f)\, df \right)^{1/2} \qquad (2)$$

was introduced.*

Since the atmospheric input to the models is important, we also made a comparison of calculated and measured wind vectors. Wind data for EURO were taken from the nearby light platform Goeree,** for IJMUIDEN from a nearby coastal station and from PENNZOIL from the oil rig itself.

It should be understood that the present comparison is mainly of interest as a test for the accuracy of the actual predictions. A search for weak points in the steps that lead to the predicted values would require a different approach.

The comparison is complicated slightly because at the end of February a new GONO version became operational. With this version, GONO-HI, December and January were rerun in order to compare with the older version. March and April were run operationally with GONO-HI only. If no confusion is possible we will denote the updated GONO version simply by the name GONO.

The plan of the present paper is as follows. In Sec. 2 a summing up is given of the differences between GONO and GONO-HI. Section 3 attempts to discuss the quality of the observational data. Section 4 gives a discussion of the observed time series, and in Section 5 statistical results are given. Our conclusions are presented in the last Section.

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* At KNMI the quantity $E_{10}$ has also been used as a measure of the low frequency energy. Its relation to $H_{S,10}$ is $E_{10} = (\frac{1}{4} H_{S,10})^2$.

** If missing, Hook of Holland data were used.

## 2. Improvements of the GONO-model.

A joint wave modelling project of KNMI and Rijkswaterstaat, led to several improvements of the GONO model, and resulted in a new version of GONO, denoted by GONO-HI. This version has been introduced in the operational service on March 1, 1980. In order to compare the new version of the model with the old one, a hindcast run has been carried out for the period December 1979 until the beginning of February 1980. The results of this comparison are included in this report.

In the hindcast run pressure analyses have been used which have been updated by including retarded observational data; also occasional errors have been corrected. This sometimes causes slight differences between the wind fields of the original real-time run and the hindcast run.

The improvements of the GONO model will be described in detail in a forthcoming paper by Sanders, de Voogt and Bruinsma (1981). In short they are the following:

(i) The windcalculation has been refined, with special attention to the effect of atmospheric stability as determined by the difference of air temperature and seawater temperature. In addition a problem with air pressure patterns when the isobars show a strong gradient and anticyclonic curvature, leading to singular results for the wind speed, has been overcome; This problem is intrinsic to the Hesselberg technique of calculating wind fields from pressure distributions (Hesselberg, 1915).

Also offshore windspeed is reduced near the coast, to account for lower surface wind speeds on land, with gradual transformation of the boundary layer to sea conditions.

(ii) Errors in the group velocity table for shallow water waves have been corrected.

(iii) The calculation of the advective part of the energy balance has been improved.

(iv) The spectral shape in extreme wave conditions on shallow water is now modelled more in agreement with empirical data.

(v) As to the +12 and +24 hours prediction the input of pressure data has been refined. However, the results could not be used yet because of a programming error.

## 3. Observational data.

Wave prediction models have been evaluated by comparing four elements of model data with observational data - wind direction and wind speed, significant wave height and low-frequency wave variance - at five locations:

- three in southern North Sea (west of Hook of Holland, west of IJMUIDEN, and in block K-13 (100 km west of the Frisian Isles),
- one in Central North Sea (north of Dogger Bank: AUK and/or EKOFISK),
- one in Norwegian Sea (Ocean Weathership Station MIKE).

This comparison requires a uniform quality of observational data. However, this requirement cannct be met fully, as will be illustrated by Table 1.

TABLE 1.

| locations: | wind sensor placed: | wave data from: |
|---|---|---|
| 0. EURO | on light platform GOEREE just on top of lighthouse at 30 m height (sometimes replaced by wind data from landstation at Hook of Holland). | waverider near Eurochannel |
| 1. IJMUIDEN | on southern pier of IJMUIDEN harbour at 18 m height | waverider at the ammunition dump-site approx. 40 km west of IJMUIDEN |
| 2. PENNZOIL | on platform on top of tower at about 80 m height | waverider near rig. |
| 3. EKOFISK | on platform AUK probably similar to 2. (EKOFISK wind data not available) | waverider near AUK altimeter om platform EKOFISK. |
| 4. OWS MIKE | in mast of weathership | visual estimates |

### Wind data.

Table 1 shows that - even for one location - conditions are not uniform at all. Wind data at station 1 are close to ideal for onshore wind directions; however it has been found that offshore winds are less representative for conditions at sea. Wind at coastal stations - depending on local conditions - is subject to diurnal variations in most cases, with the exception of strong onshore winds. Stations 0, 2 and 3 are located on tall structures at sea, with station 0 still rather close to shore and wind

sensors not so far from the water surface as at stations 2 and 3. It has generally been assumed that, approximately, there is a fixed proportion between wind speeds at higher levels (up to 100 m, say) and standard level of observation (10 m above mean water level) according to standard wind profiles. However, comparison of instrumental data with calculated data from air pressure distributions shows that wind speed data of K-13-A (PENNZOIL) and AUK are not proportional to surface wind speed for all wind speeds; it seems that - in the absence of reduction for height of observation - for gale wind speeds the reduction is very small for all heights whereas for light to moderate wind speeds the reduction is of the order of 15-30 percent, depending on the height of observation and the disturbance of the airflow. Wind speed of light platform Goeree and of platform K-13-A are reduced before they are included in the synoptical dataset (Meteo Holland). No reduction seems to have been applied to wind data at AUK; comparison of simultaneous wind data of AUK and EKOFISK platform since May 1980 (GTS - via Norway) reveals that the EKOFISK data are reduced to standard height. No detailed information is available so far about wind observations at these locations. Finally, wind data of weatherships are probably biased a little by the ship's speed; for safety reasons the ships are steaming when wind speed exceeds 6 Beaufort. In addition, the movement of the ship will cause a slight enhancement of wind speed. On the other hand, when wind and sea are moderate the ship may be drifting with speeds up to 2 knots, causing some decrease of wind speed.

To summarize (see Table 2), comparison of wind data must be carried out with sufficient caution also noting that the wind field near coasts is discontinuous (besides there is a strong impact of wind direction on fetch lengths near coasts!) and that reduction for height of observation (when applied) is sometimes too strong. The fact that model wind fields have been calculated according to the Hesselberg relation which implies the risk of singularities at high wind speeds does not seem to have caused any bias.

TABLE 2.

| Station | direction or location | speed moderate | speed gale |
|---|---|---|---|
| 0 | onshore (Goeree, Hook of Holland) | + | +(?) |
| | onshore (Goeree only) | | < |
| | offshore (Goeree) | + | << |
| 1 | onshore | + | + |
| | offshore | - | - |
| 2 | all | + | << |
| 3 | AUK | >> | > |
| | EKOFISK | + | (not known) |
| 4 | all | + | > |

+ : good.

- : less good.

> : observational data assumed to be greater than correct value.

< : idem, less than correct value.

Wave data.

The uniformity of wave data is much better: at locations 0, 1 and 2 waveriders are used. However, location 1 appears to be quite vulnerable for radio disturbance, due to the relatively large distance between the wave-rider at the ammunition dump-site, and the receiving station (approx. 40 km) in the vicinity of IJMUIDEN harbour, where walkie-talkies are operated rather frequently. The quality of wave data from location 3 was variable, but now and than just as good as from the southern locations. However, during the period of observation (Dec. 1979 - April 1980) wave data from EKOFISK through direct line to Rijkswaterstaat are not available for publication. So data points - with the exception of the second half of April which are from location AUK - should be ignored.

The visual observations of the weather ships at OWS MIKE seem to be of poor quality, in particular when the Norwegian ship "Polar Front" was at station (15 Dec. 1979 - 14 Jan. 1980, 9 February - 9 March and 4 April - 5 May 1980). This was concluded by comparing with other wave observations in same area during gales.

Conclusions.

- Wind speeds have been observed under very different conditions. Table 2 shows indications of the bias that was caused by e.g. the nearness of land, the extreme height of wind sensors above the water level and the ship's speed at OWS MIKE.

- Wave data from stations 0, 1 and 2 are of good quality (though some data at station 1 have been lost due to disturbances); the amount of data from station 3 is limited: wave measurements at AUK were only available in April; EKOFISK wave data were only available for restricted use, pending delivery of data system to Rijkswaterstaat. However, the Norwegian Met. Office has included the same station in the GTS-network since April. The visual estimates of wave height at station 4 seem of poor quality during periods that the "Polar Front" was at station.

## 4. Time series.

We give a qualitive description of the main features of the time series. It is meant too guide the eye while studying the plots which can be found in the Supplement of this report. Time will be indicated by date and time (GMT) as DDHH, or simply by date as DD. We will mainly concentrate on a comparison of calculations starting from the analysed weather data. Deviations in the forecast (if present) are obvious and are not normally commented on.

### DECEMBER 1979. (See Supplement, Figs. 1-15.)

The time series for this month was discussed by Bouws et al (1980). However, December has been rerun with GONO-HI (analysis only, cf. Sec. 2). Here, we will discuss the difference between GONO and GONO-HI results.

#### 0412-0612.

Southerly winds generated waves of 3 m significant wave height at EURO and of about 4 m at IJMUIDEN and PENNZOIL. GONO overpredicted by about 1 meter; with GONO-HI the overprediction was reduced to 0.5 m for EURO and PENNZOIL; IJMUIDEN was about right. The spuricus swell peaks occurring with GONO on 1$^{st}$, 3$^{rd}$ and 10$^{th}$ of December are suppressed in GONO-HI.

#### 0612-1400.

In this period several peaks occur. Again GONO tends to overpredict with too high winds. GONO-HI has somewhat better winds and a better $H_S$, although it is too low on 11$^{th}$, with winds too low at EURO. The behavior near IJMUIDEN is similar. At PENNZOIL GONO and GONO-HI have errors of compatible magnitude. For all three locations GONO and GONO-HI fail to give $H_{S,10}$ correctly.

1400-1900.

The main December storm occurred in this period with waves of up to 6 m significant wave height. The storm really consisted of two maxima separated by a sharp minimum on '618, when the westerly wind dropped from 40 to 15 knots and the significant wave height from 5 to less than 2 metres. GONO-HI follows $H_S$ quite well for the position considered, in fact, much better than GONO did. $H_{S,10}$ was well described at EURO by GONO; GONO-HI overestimates $H_{S,10}$ by nearly a factor of 2 on 10$^{th}$. IJMUIDEN was a special and interesting case, as both GONO and Model M underestimated $H_{S,10}$. In Bouws et al (1980) this was ascribed to the special shape of the observed spectrum, which was rather broad. GONO-HI was expected to give a better representattion of the spectrum on shallow water and indeed on comparing the GONO-HI results with the data we find better agreement. At PENNZOIL both GONO and GONO-HI give a good description of the observations.

20-25.

Falling sea with some swell. For EURO and IJMUIDEN GONO gave a fair description of the observed $H_S$. GONO-HI was always too low, but followed $H_{S,10}$ reasonable well. At PENNZOIL the description was reasonable.

26-29.

Winds reached 35 knots at all three stations. Unfortunately these winds were badly overestimated, with an estimated peak of 50 knots. This led to too much $H_S$ and $H_{S,10}$ for both GONO and GONO-HI at EURO and IJMUIDEN. Remarkably the GONO-HI wave results agreed well at PENNZOIL, despite the overpredicted winds. The remarks about the quality of the wind measurements (Sec. 3) should also be taken into account, however.

JANUARY 1980. (See Supplement, Figs. 16-30.)

For this month we compare GONO, GONO-HI and Model M with data.

01-0312.

During this storm, which started on 30$^{th}$ December, $H_S$ was overpredicted by GONO and GONO-HI at EURO with winds too strong. Agreement at IJMUIDEN and PENNZOIL was better. Particularly $H_{S,10}$ at PENNZOIL was followed well by GONO-HI. Model M gave too much low frequency energy at all locations. $H_S$ at EURO and IJMUIDEN were well described, at PENNZOIL it was overpredicted, the calculated wind being 5 knots too high on 0200.

0312-0512.

During a second storm GONO and GONO-HI overpredicted slightly at all locations, with winds too high, while Model M underpredicted mildly.

07-13.

This period is marked by easterly winds. At EURO and IJMUIDEN GONO gives better $H_S$ than GONO-HI, which might indicate that the reduction of wave growth with off-shore winds (cf. Sec. 2) has been too large.

15-18.

One of the most interesting events of this winter occurred during these days. A depression (970 mb) passed between Iceland an Norway (See Fig. 2), giving first a westerly gale at OWS MIKE, later on 1412-1418 a northerly gale with measured winds of 50 knots. In the southern North Sea wind speeds remained low. The gale off the Norwegian coast generated a wind sea with a significant waveheight calculated by GONO-HI to be 12.8 m. The visual estimate was 9 m, while Model M calculations were somewhat lower. It is however important that the Model M grid does not extend up to the polar ice. The wind sea produced swell with a period of 17 s, which reached EURO withing 24 hours with an estimated speed of the order of 50 km/h. The observed extreme swell period supports the validity of the GONO calculation for OWS MIKE. Both GONO and Model M wind input agree well with observations at MIKE, although the calculated maximum of the northerly gale is 6 hours too late in GONO. GONO wind-forecasts were poor, but this is irrelevant for the swell calculation in the southern North Sea. GONO used an incorrect group velocity for the propagation of the swell. As a result the calculated swell appears 18 hours late at EURO. The level at EURO is about right. PENNZOIL is underpredicted. GONO-HI, with corrected propagation speed, has better arrival times. At PENNZOIL it is about 6 hours late, but this may be due to the fact that the maximum of the generating storm was taken too late. At EURO, the same can be said about the arrival time; the predicted level is far too high implying an underestimate of the dissipation of waves of this extreme length ($\sim$ 500 m). A definite explanation for the observed weakening is not available. However, we conjecture that refraction may have contributed to the effective swell reduction at EURO.Model M, with time steps of 12 hours for the output, does not show the extreme waves at MIKE on 1418. The resulting swell at PENNZOIL started, as nearly always, too high, and failed to give the observed sharp peak in $H_{S,10}$. The same thing happened at EURO. In Fig. 3 the original swell registration at PENNZOIL is shown for illustration.

21-25.

Winds at EURO and IJMUIDEN were overpredicted by GONO. Model M had better winds. As a result GONO and GONO-HI overestimate the resulting wave height, while model M gives a quite accurate description of $H_S$. At PENNZOIL similar trends are observed. GONO-HI gives $H_{S,10}$ too high, as at EKOFISK.

FEBRUARY 1980. (See Supplement, Figs. 31-40.)

This month was a quiet period. The most striking features are the poor observations of OWS MIKE when the "Polar Front" is on duty. In the southern North Sea the most remarkable feature is the overprediction of $H_{S,10}$ on the first 6 days of the month, especially at PENNZOIL. It is not clear if this is the result of too high winds in the northern part of the GONO grid. The difference in $H_S$ calculation of GONO and Model M is striking.

MARCH 1980. (See Supplement, Figs, 41-50.)

GONO-HI became operational and is referred to as GONO in the following. GONO, and Model M results are compared.

02-05.

At EURO and IJMUIDEN GONO winds are a little low. As a consequence GONO has $H_S$ too low. $H_{S,10}$ is reasonably given by GONO. As usual Model M has $H_{S,10}$ too high. At PENNZOIL Model M overpredicts both $H_S$ and $H_{S,10}$. GONO underestimates $H_{S,10}$. The two metres swell observed on 0312 were generated by a storm at $60^{\circ}$N, with $H_S$ = 6 m, which, apparently, is poorly handled by GONO.

06-09.

GONO gives $H_S$ too high, with a spurious $H_{S,10}$ peak on 0718, at EURO and IJMUIDEN. For PENNZOIL better results were obtained. Model M performed well. EKOFISK data are available from 7$^{th}$ on. GONO is somewhat low, Model M is somewhat high.

12-17.

GONO has winds too high at EURO and IJMUIDEN. The resulting $H_S$ of over 3 m is twice the observed value. Model M has correct winds and correct $H_S$. At PENNZOIL both models perform well. At EURO the change in wind direction on 1406 is nicely following.

18-21.

GONO performs well at EURO, follows initial rise correctly; later winds are too high, but fall-off is well described. Model M is too low. At IJMUIDEN the GONO wind is too low initially, while the direction is also given incorrectly. At PENNZOIL both models behave well.

22-23.

Available spectra indicate the presence of several swell peaks. Model results are too high at EURO and IJMUIDEN. GONO behaves reasonably at PENNZOIL.

27-30.

All models behave reasonably as far as $H_S$ is concerned. $H_{S,10}$ is (much) too high at all three southern stations. $H_S$ is described very well by GONO at PENNZOIL. At EKOFISK GONO winds are much too low (15 knots instead of 35 observed on 2718).

APRIL 1980. (See Supplement, Figs. 51-60.)

02-06.

Winds of up to 25 knots (westerly first, later from the north) generate waves at EURO and IJMUIDEN, which are very well described by GONO. Agreement at PENNZOIL and with Model M was slightly poorer. $H_{S,10}$ of Model M was too high, especially on 3rd and 4th. At EKOFISK both GONO and Model M performed reasonably.

08-12.

At all three southerly stations Model M has $H_{S,10}$ too high. $H_S$ is good on the other hand, except in the tail where calculations remain too high. GONO overpredicts $H_S$ at the maximum and then decays too fast. This may be related to overcompensation for the off-shore wind reduction.

17-23.

The main storm of April gave 5 m significant wave height at EURO, and over 9 m at EKOFISK. The generating wind field was exceptional because of its extremely long fetch (see Fig. 4). At EURO GONO reacted slowly, rising a little late and falling off too slow. The calculated maximum for both $H_S$ and $H_{S,10}$ agreed well with observations. At IJMUIDEN the same was found with respect to $H_S$. $H_{S,10}$ was underpredicted by 1 m. Model M performed very well at EURO; at IJMUIDEN it remained too low. At PENNZOIL GONO was slow again, while it underestimated the maximum $H_{S,10}$. Model M described

$H_S$ quite well. For $H_{S,10}$ comparison between GONO and Model M is difficult, because the descrepancy between GONO and the data was at 2006, a time not considered by Model M. At EKOFISK both models follow the data quite well.

24-28.

GONO has winds too low. $H_S$ is low and the small swell peak on 25$^{th}$ is missed. Model M performs better, but at EKOFISK, like GONO, it underestimates $H_S$ and $H_{S,10}$.

## 5. Statistics.

For each month summary tables of the errors are presented to compare the performances of the different models quantitatively. The interesting features of these tables are described in this chapter. Each table consists of: location, number of observations, average of the observations, average of the errors (calculated minus observed values), RMS error, number of cases overpredicted and number of cases underpredicted for each position. We treated wind speed and wind direction as independent statistical variables. The average direction is not given since it is not a meaningful quantity. For the calculation of the wind direction error, cases with a wind speed less than 10 knots are omitted. As before, the data of EKOFISK for the month of December and OWS MIKE for the whole period are not taken into account because of the unreliability of the data. There are tables for the Met. Office model, referred to as Model M, the original KNMI model, referred to as GONO, and the revised KNMI model, referred to as GONO-HI. (The latter also for the period March and April 1980 in contrast to the previous sections.) Analysis on a table means that for the calculations analysed data are used as input data. There are also tables for the +12 hour and +24 hour forecasts (GONO and Model M only). The tables are referred to by their numbers between brackets.

We shall successively discuss the wind direction, wind speed, significant wave height ($H_S$) and low frequency energy ($H_{S,10}$) while roughly using the following matrix scheme:

| Models | type | Period |
|---|---|---|
| 1. GONO, Model M | analysis | Dec. 79, Jan. Febr. 80 |
| 2. GONO-HI, Model M | analysis | Dec. 79, Jan. March Apr. 80 |
| 3. GONO, GONO-HI | analysis | Dec. 79, Jan. 80 |
| 4. GONO, Model M | +12, +24 h forecast | Dec. 79, Jan. Febr. 80 |

Because GONO-HI for Dec. '79 and Jan. '80 has been run in hindcast mode, a comparison is made between the results of GONO-HI for this period and for the period March, April '80. No significant differences are noted (3, 6, 15, 17).

At the eind of this chapter we will also look at the scatter-index, introduced by Holthuijsen (1980). The scatter-index is defined as the ratio of the RMS error and the average of the observations. The application of this index will be restricted to the significant wave height.

(i) Wind direction.

The wind analysis of Model M includes observations and so it is not valid to compare the errors at this time. The wind directions calculated by Model M systematically seem a little veered (4, 16, 18). No difference is noted between GONO and GONO-HI (3, 5, 6, 8). In GONO-HI the wind direction of PENNZOIL has backed during most of the time, compared with the observations (3, 6, 15, 17). For the +12 hour forecast Model M deteriorates more quickly than GONO, which results in errors of the same size (7, 8, 9, 10, 11, 12).

(ii) Wind speed.

The analysis by Model M again will not be compared because of the inclusion of observations in these data. The RMS error for Model M is about 15-20 dm/sec and for GONO and GONO-HI about 20-25 dm/sec. By comparing GONO with GONO-HI the latter shows a much smaller average error, but the RMS error remains of the same size (3, 5). For January a smaller change is noted (6, 8). The wind speeds for EKOFISK by GONO and GONO-HI are too low (6, 8, 15, 17). The wind speeds by GONO for April are also too low (17). Good wind speeds are calculated by GONO during February (14).

The longer the forecast period, the more the average of the errors deteriorates in GONO, with a tendency for much too low values (8, 10, 12). After a drop for the 12 hour forecast, the RMS error in Model M remains on the same level (7, 9, 11).

(iii) $H_S$.

Both GONO-HI and Model M give a better analysis than GONO (3, 4, 5, 6, 7, 8, 13, 14). GONO-HI equals Model M except in January, when Model M shows a remarkable small RMS error (3, 4, 6, 7). However, the average error in Model M widely differs for the different positions (4, 7, 13). By comparing GONO with GONO-HI we notice an important improvement of the average error and RMS error in GONO-HI (3, 5, 6, 8). The results for EKOFISK by GONO-HI are too low on average (15). This is in consistence with the average wind speed error noted above.

As to the forecast we see that the 12 hour forecasts by GONO are somewhat better than the values based on analysed data as to the average and RMS error (8, 10, 21)! Both the 12 hour and the 24 hour forecasts of Model M score better than GONO (9, 10, 11, 12). Model M overestimates a little (9, 11) but GONO tends to too low values in the 24 hour forecasts (10, 12).

(iv) $H_{S,10}$.

A comparison between GONO and Model M shows a smaller average error for GONO (4, 5). Model M overpredicts on average by 20 cm (4, 7, 13, 15, 17). During the first week of February GONO overestimates the low frequency, resulting in a high RMS error (even higher than Model M), especially when small values are excluded (13, 14, 19, 20). It occurs that $H_{S,10}$ equals zero for a long period, as we can see in the time-series for February and April. So low values have to be excluded from the statistical analysis. For a minimum height for observed and calculated values an arbitrary 30 cm is chosen. However, the tables constructed with a minimum height of 20 cm lead exactly to the same conclusions. GONO-HI also shows a smaller average error than Model M (3, 4, 5, 6, 15, 16, 17, 18). A comparison between GONO and GONO-HI shows that there is hardly any difference (3, 5, 6, 8). At EURO and PENNZOIL GONO-HI overpredicts swell (15, 21). The tables for April earn a closer look: those with all the values and those in which the small values are excluded (18, 22). The big difference between the averages of the observations is due to the fact that only a few cases are excluded in Model M because of the overpredicting of Model M.

The figures for the 12 hours and 24 hours forecasts hardly differ from the analysed data (7, 8, 9, 10, 11, 12).

Table 23 gives the scatter-indices for $H_S$, calculated from the tables 2 - 22. According to this criterion Model M scores better than GONO-HI, especially for EURO.

## 6. Conclusions and recommandations.

In accordance with the conclusions of Bouws et al (1980) we find that the operational GONO model performed rather well during the period December 1979 - April 1980. The wind data must be analysed with care because of the differences between the wind-measuring locations, as discussed in chapter 3.

With regard to the revision in the GONO model we notice that

1. Errors of the shallow water propagation of swell have been elimated. In this way a better timing of local swell ($H_{S,10}$) was obtained.
2. The spectral shape performance of GONO-HI is better than that of GONO, in the case of severe gale conditions in shllow water (cf. 17/18 December 1979, IJMUIDEN).

Due to a lack of information about the revisions in Model M and the analysis of the results for the whole period, the conclusion of Bouws et al (1980) for Model M is maintained.

For the period December 1979 - February 1980 the +12 and +24 hour wind forecasts of the GONO model show a systematic (increasing) discrepancy between observed and calculated wind speeds. The GONO winds are too low on average. This is probably due to smoothing of the forecasted pressure fields of the KNMI atmospheric model.

For further improvement of the GONO model a closer look should be taken at the different mechanisms in the model such as wind calculation, wave generation and dissipation and energy propagation. For example, $H_{S,10}$ in EURO and PENNZOIL has often been over-predicted. In one special case (Jan. 10, 1980) this might be attributed for EURO to the absence of refraction in the model.

## Acknowledgments.

We would like to thank Peter Janssen and Jan Sanders for discussions, and Brian Golding for making available the Model M data. The section ME was helpful in the handling of data. Arjan Baan wrote the plotting routines. This investigation is part of a joint wave modelling programme of KNMI and Rijkswaterstaat.

References.

Bouws, E., Golding, B.W., Komen, G.J., Peeck, H.H. and Saraber, M.J.M. (1980). Preliminary results on a comparison of shallow water wave predictions. Published in the series scientific reports of the Royal Netherlands Meteorological Institute. W.R. 80-5.

Bruinsma,J., Janssen, P.A.E.M.,Komen, G.J., Peeck, H.H., Saraber, M.J.M. and Voogt, W.J.P. de (1980). Description of the KNMI operational wave forecast model GONO. Published in the series scientific reports of the Royal Netherlands Meteorological Institute. W.R. 80-8.

Earle, M.D. and Malahoff, A. (1979). Ocean wave climate. Plenum, New York.

Favre, A. and Hasselmann, K. (1978). Turbulent fluxes through the sea surface, wave dynamics, and predictions. Plenum, New York.

Golding, B.W. (1980). A depth-dependant wave model for operational forecasting. In Favre and Hasselmann (1980), p. 593-606.

Hesselberg, T. (1915). Ueber einer Beziehung zwischen Druckgradient Wind und Gradientänderungen. Veröff. Geoph. Inst. Leipzig, Serie 2,1, S.207 - 210.

Holthuijsen, L.H. (1980). Vethoden voor golfvoorspelling. Technische adviescommissie voor de waterkeringen.

Klepper, F. (1975). Numerieke berekening van zeegang en deining op de Noordzee. Internal note. KNMI, De Bilt.

Sanders, J.W. (1976). A growth-stage scaling model for the wind-driven sea. D. hydr. Zts. 29 (1976), 136-161.

Sanders,J.W., Voogt, W.J.P. de and Bruinsma, J. (1981). To appear.

Saraber, M.J.M. (1980). Verifikatie van golfanalyses van het operationale GONO-model over de periode oktober 1978 t/m juni 1979. Published in the series "Verslagen" of the Royal Netherlands Meteorological Institute. V-343.

Figure Captions.

1.a. Grid of Model M.

1.b. Grid of GONO.

2 Weather map for 14 Jan. 1980, 0000 and 1200 GMT.

3. Swell registration on Jan. 15, 0900 GMT, at PENNZOIL.

4. Weather map for 19 April 1980, 1200 GMT.

The time series are given in a Supplement to this report.

Table Captions.

1. (In the text) Details of data collection.

2. (In the text) Estimated quality of wind measurements.

3-22. Summary tables, giving results for wind direction, wind speed, $H_S$ and $H_{S,10}$ (from top to bottom). Given are resp. location, number of observations, average of the observed values, average error, RMS error, number of cases overpredicted and number of cases underpredicted.

23. Scatter indices, for various periods, models and positions.

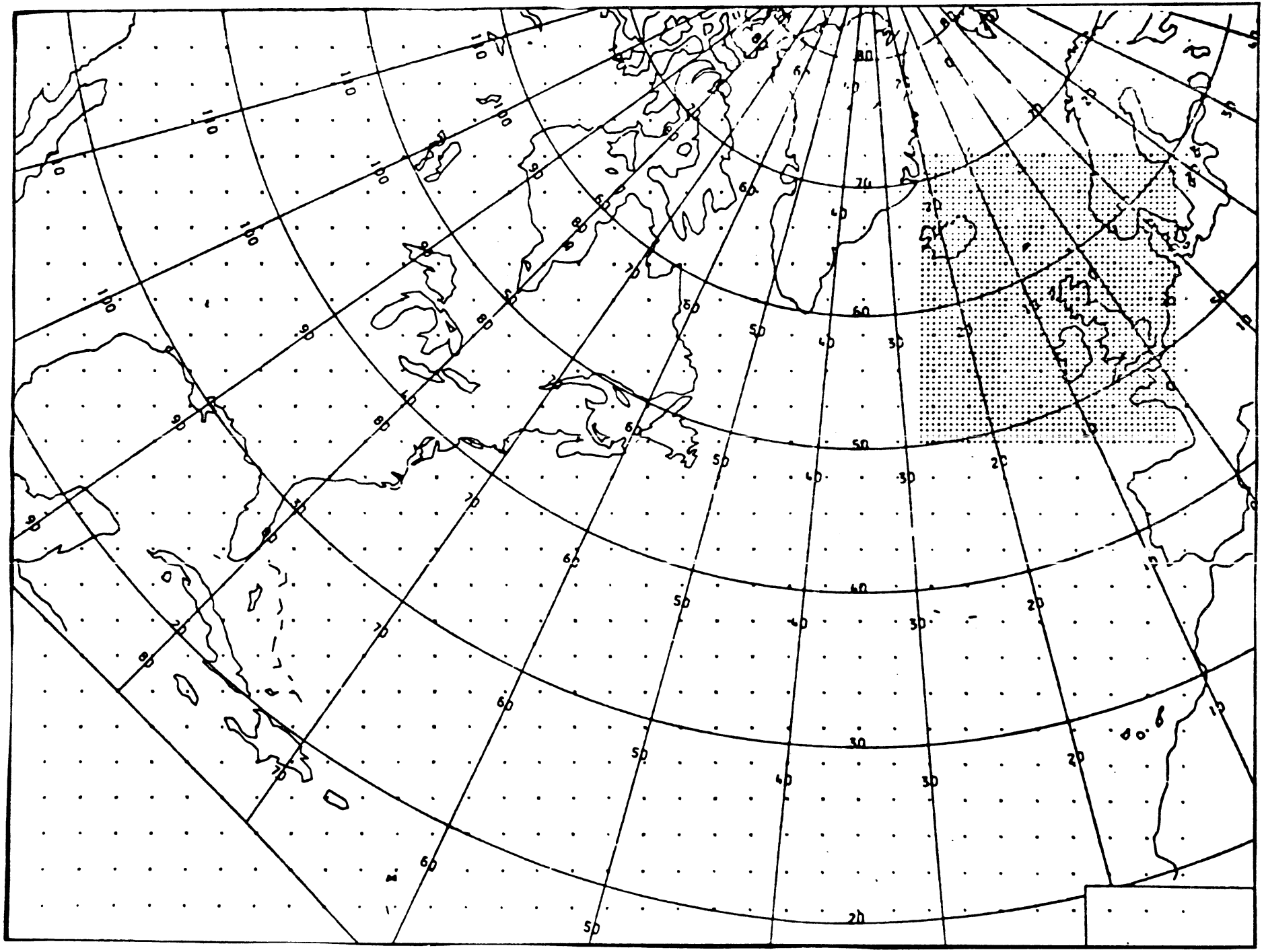


Fig. 1a

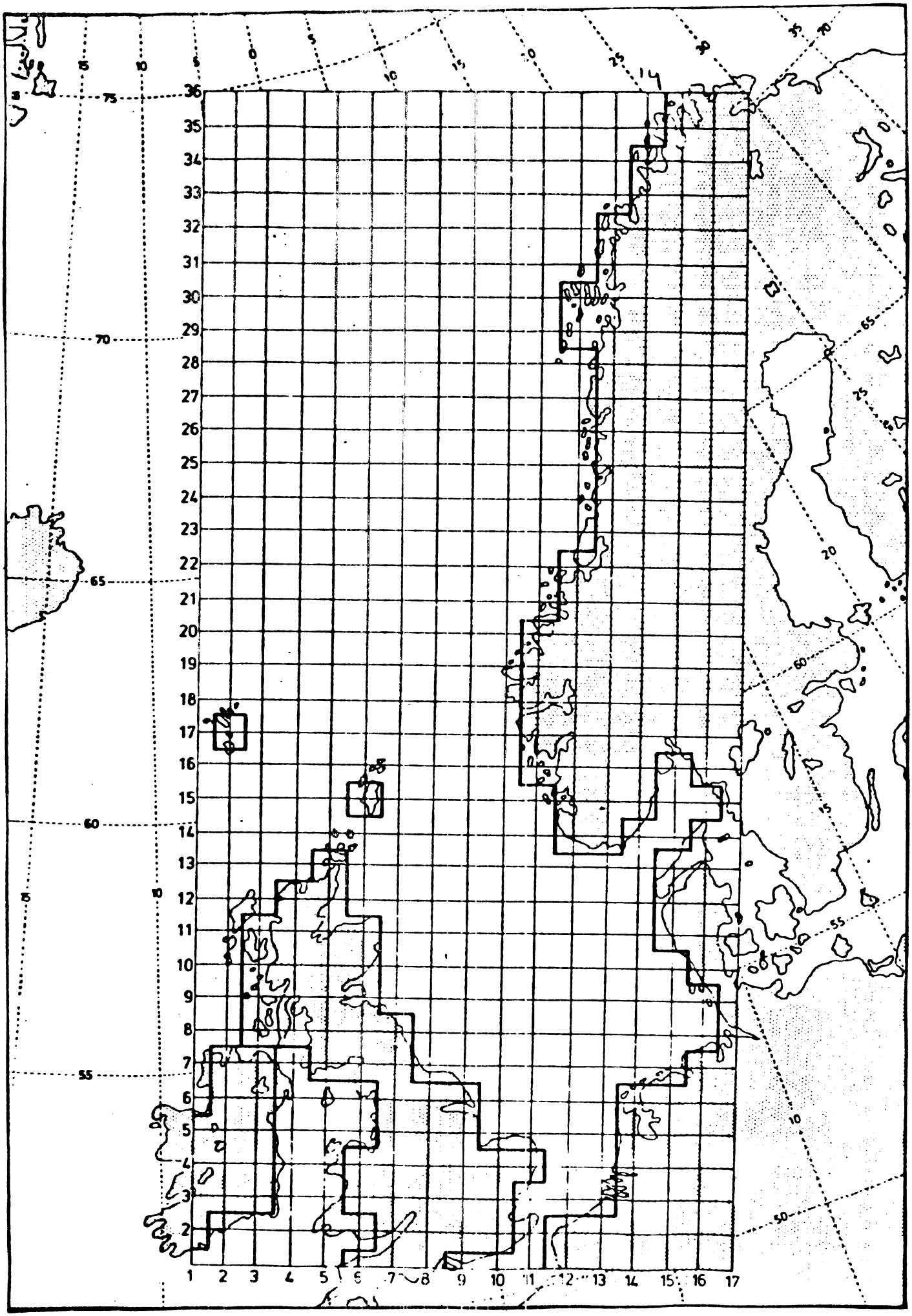
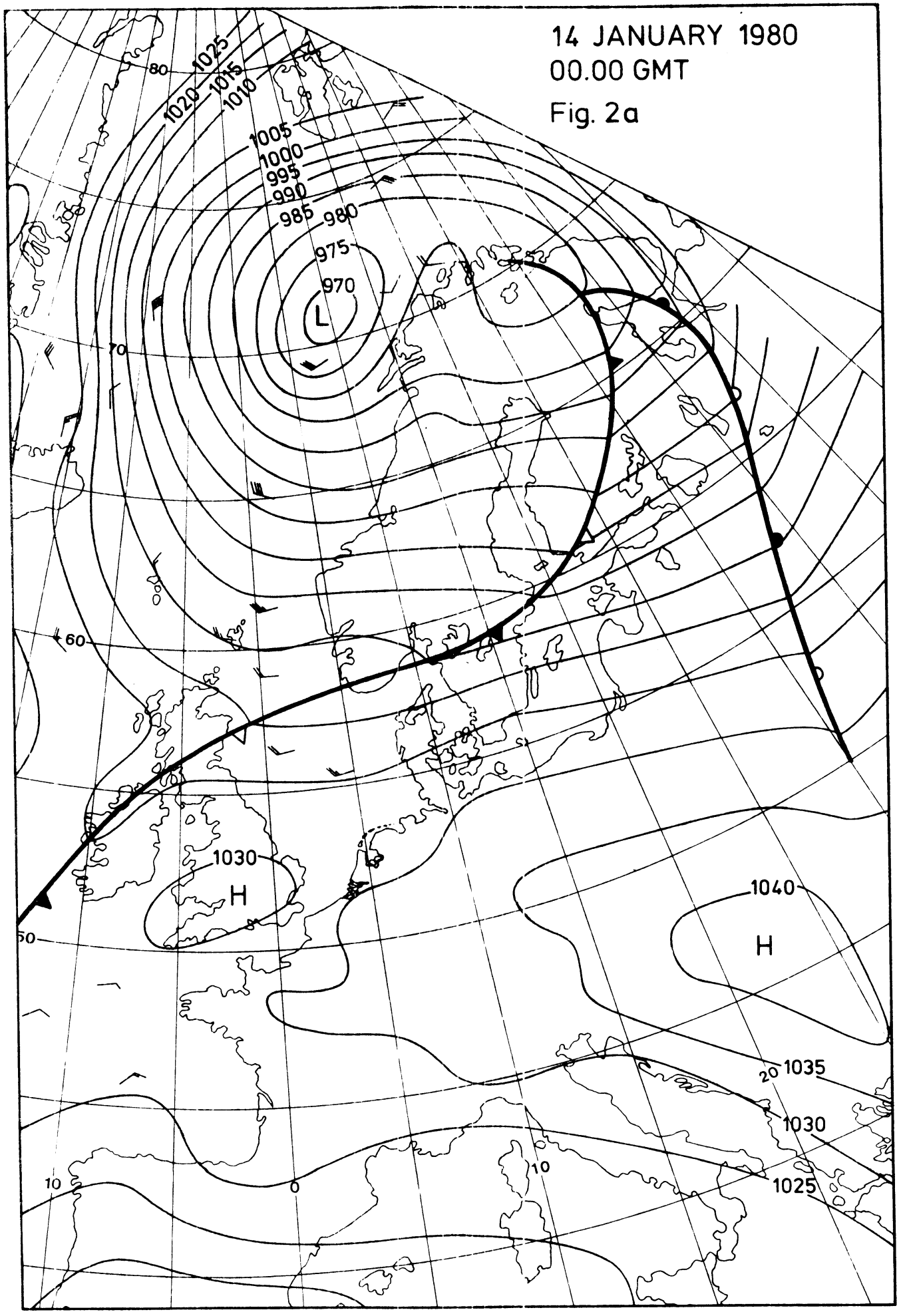

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
75
70
65
60
55
50

Fig. 1b


14 JANUARY 1980
00.00 GMT
Fig. 2a
1025
1020
1015
1010
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1000
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985
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80
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H
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20
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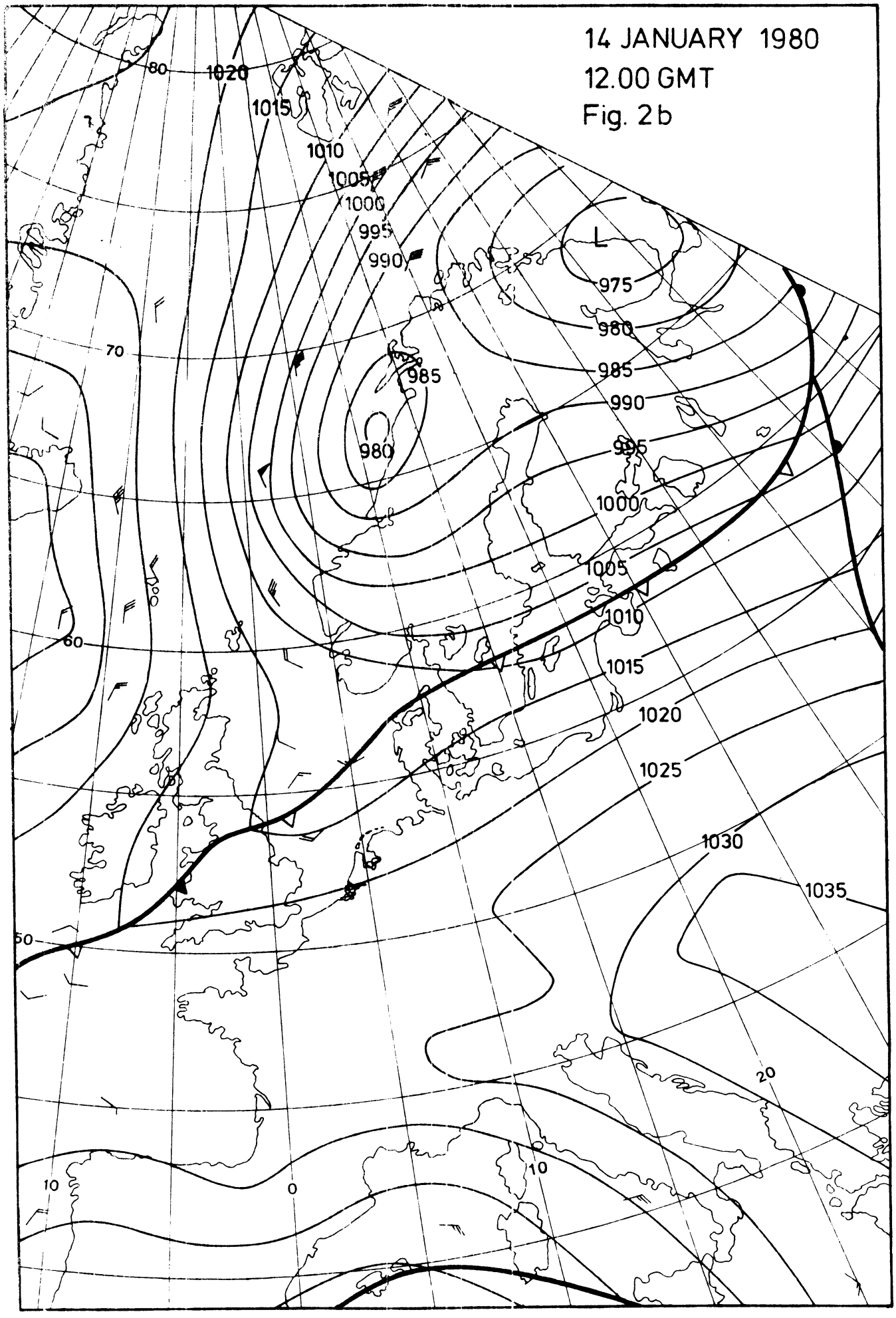
0
10


14 JANUARY 1980
12.00 GMT
Fig. 2b
80
70
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1005
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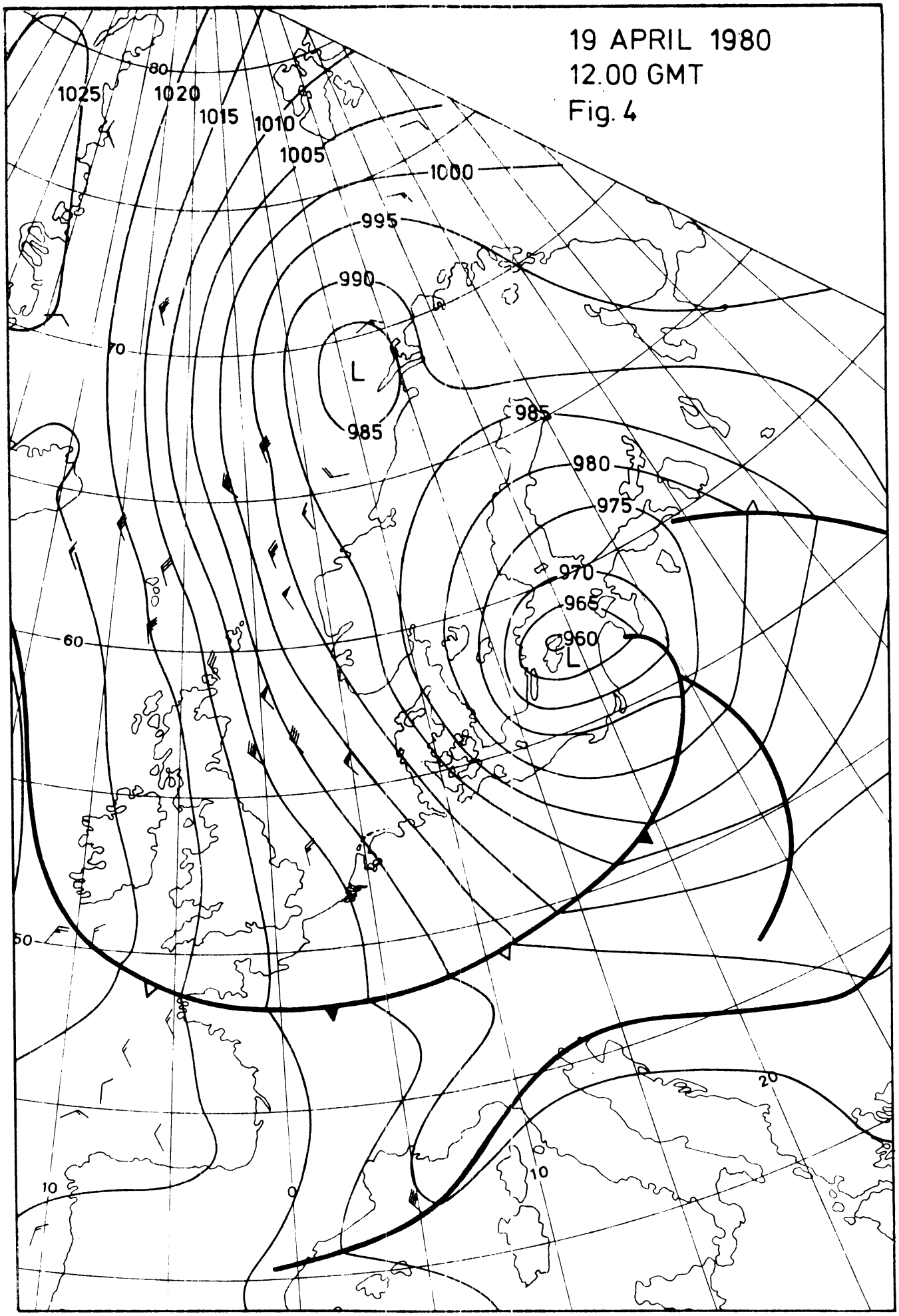
20


19 APRIL 1980
12.00 GMT
Fig. 4
80
1025
1020
1015
1010
1005
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70
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985
980
975
970
965
960
L
60
50
20
10
0
10

PERIOD 79120100-79123112

| WIND DIRECTION ( DEGREES ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS RMS | GONO HI PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 108 | *** | C08 | 017 | 078 | 028 |
| IJMUIDEN | 105 | *** | C14 | 026 | 082 | 023 |
| PENNZOIL | 106 | *** | -C06 | 016 | 031 | 072 |
| EKOFISK | 077 | *** | -C00 | 013 | 042 | 033 |
| STATION M | 099 | *** | -C09 | 025 | 031 | 064 |

| WIND SPEED ( DM/SEC ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS RMS | GONO HI PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 124 | 106 | C01 | 027 | 063 | 060 |
| IJMUIDEN | 124 | 106 | C01 | 029 | 056 | 067 |
| PENNZOIL | 123 | 099 | C06 | 028 | 084 | 039 |
| EKOFISK | 106 | 114 | -C29 | 037 | 008 | 098 |
| STATION M | 119 | 120 | -C24 | 041 | 024 | 095 |

| HS SIGN. WAVE HEIGHT( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS RMS | GONO HI PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 124 | 205 | -C04 | 055 | 053 | 069 |
| IJMUIDEN | 089 | 215 | -C01 | 053 | 044 | 045 |
| PENNZOIL | 123 | 229 | -C03 | 055 | 051 | 070 |
| EKOFISK | 018 | 192 | C93 | 169 | 015 | 002 |
| STATION M | 118 | 283 | C45 | 142 | 073 | 045 |

| H S,10 ( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS RMS | GONO HI PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 124 | 023 | C01 | 024 | 049 | 075 |
| IJMUIDEN | 081 | 044 | -C09 | 028 | 028 | 053 |
| PENNZOIL | 122 | 046 | -C03 | 030 | 047 | 075 |
| EKOFISK | 018 | 104 | C44 | 125 | 009 | 009 |
| STATION M | 000 | | | | | |

TABLE 3.

PERIOD 79120100-79123112

WIND DIRECTION ( DEGREES ) ANALYSIS MODEL M

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 049 | *** | 006 | 011 | 035 | 010 |
| IJMUIDEN | 045 | *** | 010 | 019 | 035 | 009 |
| PENNZOIL | 052 | *** | 003 | 014 | 030 | 019 |
| EKOFISK | 040 | *** | 004 | 012 | 028 | 010 |
| STATION M | 052 | *** | 015 | 021 | 051 | 001 |

WIND SPEED ( CM/SEC ) ANALYSIS MODEL M

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 057 | 109 | -007 | 018 | 023 | 032 |
| IJMUIDEN | 057 | 108 | -011 | 020 | 013 | 043 |
| PENNZOIL | 056 | 099 | 018 | 026 | 047 | 006 |
| EKOFISK | 050 | 109 | -006 | 021 | 018 | 030 |
| STATION M | 055 | 121 | 003 | 017 | 028 | 024 |

HS SIGN. WAVE HEIGHT( CM ) ANALYSIS MODEL M

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 057 | 211 | -017 | 041 | 017 | 039 |
| IJMUIDEN | 034 | 218 | -013 | 058 | 015 | 018 |
| PENNZOIL | 056 | 230 | 023 | 054 | 035 | 021 |
| EKOFISK | 009 | 204 | 176 | 213 | 009 | 000 |
| STATION M | 054 | 281 | 162 | 193 | 050 | 004 |

H S>10 ( CM ) ANALYSIS MODEL M

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 057 | 025 | 023 | 032 | 048 | 009 |
| IJMUIDEN | 029 | 050 | 020 | 048 | 024 | 005 |
| PENNZOIL | 055 | 049 | 035 | 051 | 049 | 006 |
| EKOFISK | 009 | 109 | 119 | 181 | 009 | 000 |
| STATION M | 000 | | | | | |

TABLE 4.

PERIOD 79120100-79123112

WIND DIRECTION ( DEGREES ) ANALYSIS GONC

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 110 | *** | 008 | 017 | 077 | 029 |
| IJMUIDEN | 104 | *** | 014 | 026 | 081 | 023 |
| PENNZOIL | 107 | *** | -005 | 016 | 035 | 070 |
| EKOFISK | 078 | *** | -002 | 023 | 040 | 035 |
| STATION M | 098 | *** | -009 | 025 | 031 | 063 |

WIND SPEED ( DM/SEC ) ANALYSIS GONC

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 123 | 106 | 006 | 030 | 073 | 048 |
| IJMUIDEN | 123 | 106 | 006 | 028 | 067 | 054 |
| PENNZOIL | 122 | 099 | 010 | 027 | 089 | 033 |
| EKOFISK | 105 | 114 | -025 | 035 | 010 | 095 |
| STATION M | 118 | 120 | -023 | 041 | 024 | 093 |

HS SIGN. WAVE HEIGHT( CM ) ANALYSIS GONO

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 123 | 205 | 037 | 071 | 085 | 036 |
| IJMUIDEN | 088 | 215 | 040 | 069 | 067 | 020 |
| PENNZOIL | 122 | 229 | 028 | 061 | 084 | 038 |
| EKOFISK | 018 | 192 | 150 | 198 | 018 | 000 |
| STATION M | 117 | 281 | 088 | 156 | 092 | 025 |

H S*10 ( CM ) ANALYSIS GONO

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 123 | 023 | 001 | 022 | 046 | 076 |
| IJMUIDEN | 080 | 045 | -012 | 041 | 024 | 056 |
| PENNZOIL | 121 | 046 | -006 | 030 | 044 | 076 |
| EKOFISK | 018 | 104 | 052 | 116 | 010 | 008 |
| STATION M | 000 | | | | | |

TABLE 5.

PERIOD 80010100-80013112

| WIND DIRECTION ( DEGREES ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS RMS | GOND HI PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 085 | *** | 010 | 021 | 066 | 018 |
| IJMUIDEN | 085 | *** | 021 | 030 | 071 | 014 |
| PENNZOIL | 069 | *** | -005 | 020 | 023 | 045 |
| EKOFISK | 032 | *** | -001 | 015 | 017 | 012 |
| STATION M | 060 | *** | -010 | 019 | 015 | 044 |

| WIND SPEED ( DM/SEC ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS RMS | GOND HI PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 124 | 073 | 002 | 021 | 065 | 056 |
| IJMUIDEN | 124 | 072 | 003 | 026 | 060 | 063 |
| PENNZOIL | 117 | 069 | 004 | 023 | 066 | 046 |
| EKOFISK | 049 | 095 | -021 | 026 | 004 | 045 |
| STATION M | 084 | 104 | -017 | 035 | 023 | 061 |

| HS SIGN. WAVE HEIGHT( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS RMS | GOND HI PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 122 | 128 | -011 | 051 | 042 | 079 |
| IJMUIDEN | 076 | 160 | 002 | 052 | 033 | 042 |
| PENNZOIL | 122 | 162 | -011 | 055 | 046 | 074 |
| EKOFISK | 041 | 200 | -033 | 083 | 006 | 035 |
| STATION M | 083 | 258 | 053 | 141 | 050 | 033 |

| H S.10 ( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS RMS | GOND HI PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 122 | 015 | 005 | 018 | 051 | 065 |
| IJMUIDEN | 074 | 029 | -003 | 022 | 026 | 048 |
| PENNZOIL | 121 | 035 | 005 | 027 | 049 | 072 |
| EKOFISK | 040 | 068 | -022 | 056 | 005 | 035 |
| STATION M | 000 | | | | | |

TABLE 6.

PERIOD 80010100-80013112

| WIND DIRECTION ( DEGREES ) | | | | ANALYSIS MODEL M | | |
|---|---|---|---|---|---|---|
| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
| EURO | 045 | *** | 005 | 012 | 030 | 015 |
| IJMUIDEN | 038 | *** | 010 | 014 | 032 | 004 |
| PENNZOIL | 040 | *** | -003 | 010 | 013 | 025 |
| EKOFISK | 022 | *** | 002 | 015 | 015 | 007 |
| STATION M | 035 | *** | 011 | 014 | 031 | 004 |

| WIND SPEED ( DM/SEC ) | | | | ANALYSIS MODEL M | | |
|---|---|---|---|---|---|---|
| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
| EURO | 062 | 072 | -002 | 013 | 027 | 034 |
| IJMUIDEN | 062 | 071 | -007 | 016 | 015 | 044 |
| PENNZOIL | 058 | 069 | 010 | 016 | 043 | 012 |
| EKOFISK | 025 | 095 | -005 | 017 | 010 | 014 |
| STATION M | 042 | 104 | 003 | 015 | 026 | 014 |

| HS SIGN. WAVE HEIGHT( CM ) | | | | ANALYSIS MODEL M | | |
|---|---|---|---|---|---|---|
| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
| EURO | 060 | 132 | -005 | 026 | 026 | 034 |
| IJMUIDEN | 038 | 168 | -011 | 037 | 013 | 025 |
| PENNZOIL | 060 | 167 | 016 | 046 | 037 | 023 |
| EKOFISK | 020 | 203 | 034 | 061 | 016 | 004 |
| STATION M | 041 | 266 | 115 | 174 | 033 | 008 |

| H S>10 ( CM ) | | | | ANALYSIS MODEL M | | |
|---|---|---|---|---|---|---|
| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
| EURO | 060 | 017 | 023 | 030 | 060 | 000 |
| IJMUIDEN | 036 | 032 | 014 | 019 | 030 | 006 |
| PENNZOIL | 060 | 039 | 027 | 044 | 053 | 007 |
| EKOFISK | 020 | 069 | 020 | 067 | 017 | 003 |
| STATION M | 000 | | | | | |

TABLE 7.

PERIOD 80010100-80013112

| WIND DIRECTION ( DEGREES ) | | | | ANALYSIS GONO | | |
|---|---|---|---|---|---|---|
| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
| EURO | 087 | *** | 011 | 022 | 068 | 018 |
| IJMUIDEN | 087 | *** | 022 | 031 | 075 | 011 |
| PENNZOIL | 072 | *** | -005 | 020 | 026 | 046 |
| EKOFISK | 033 | *** | -009 | 015 | 019 | 014 |
| STATION M | 050 | *** | -010 | 019 | 015 | 044 |

| WIND SPEED ( DM/SEC ) | | | | ANALYSIS GONO | | |
|---|---|---|---|---|---|---|
| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
| EURO | 124 | 073 | 006 | 023 | 068 | 051 |
| IJMUIDEN | 124 | 072 | 007 | 026 | 070 | 053 |
| PENNZOIL | 117 | 069 | 008 | 024 | 076 | 039 |
| EKOFISK | 049 | 095 | -019 | 025 | 006 | 042 |
| STATION M | 084 | 104 | -017 | 036 | 023 | 061 |

| HS SIGN. WAVE HEIGHT( CM ) | | | | ANALYSIS GONO | | |
|---|---|---|---|---|---|---|
| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
| EURO | 122 | 122 | 020 | 062 | 075 | 047 |
| IJMUIDEN | 076 | 151 | 040 | 070 | 055 | 021 |
| PENNZOIL | 122 | 152 | 012 | 063 | 070 | 051 |
| EKOFISK | 041 | 230 | -016 | 077 | 013 | 028 |
| STATION M | 083 | 254 | 109 | 165 | 070 | 013 |

| H S.10 ( CM ) | | | | ANALYSIS GONO | | |
|---|---|---|---|---|---|---|
| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
| EURO | 122 | 013 | 002 | 018 | 046 | 070 |
| IJMUIDEN | 074 | 023 | -003 | 024 | 030 | 044 |
| PENNZOIL | 121 | 033 | 001 | 032 | 048 | 071 |
| EKOFISK | 040 | 068 | -022 | 048 | 005 | 035 |
| STATION M | 000 | | | | | |

TABLE 8.

PERIOD 80010100-80013112

| WIND DIRECTION ( DEGREES ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +12 MODEL M RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 048 | *** | 015 | 034 | 033 | 014 |
| IJMUIDEN | 044 | *** | 025 | 040 | 034 | 009 |
| PENNZOIL | 038 | *** | -002 | 020 | 019 | 018 |
| EKOFISK | 018 | *** | -005 | 035 | 010 | 008 |
| STATION M | 033 | *** | 009 | 025 | 025 | 008 |

| WIND SPEED ( DM/SEC ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +12 MODEL M RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 062 | 072 | 013 | 026 | 045 | 016 |
| IJMUIDEN | 062 | 071 | 011 | 027 | 040 | 021 |
| PENNZOIL | 058 | 069 | 013 | 023 | 045 | 012 |
| EKOFISK | 025 | 095 | -029 | 037 | 002 | 023 |
| STATION M | 042 | 104 | -007 | 027 | 017 | 025 |

| HS SIGN. WAVE HEIGHT( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +12 MODEL M RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 060 | 132 | 010 | 036 | 036 | 024 |
| IJMUIDEN | 038 | 168 | 011 | 042 | 024 | 014 |
| PENNZOIL | 060 | 167 | 014 | 048 | 036 | 024 |
| EKOFISK | 020 | 203 | 008 | 051 | 013 | 006 |
| STATION M | 041 | 266 | 108 | 177 | 033 | 008 |

| H S.10 ( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +12 MODEL M RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 060 | 017 | 023 | 029 | 060 | 000 |
| IJMUIDEN | 036 | 032 | 014 | 021 | 030 | 006 |
| PENNZOIL | 060 | 059 | 024 | 037 | 052 | 008 |
| EKOFISK | 020 | 069 | 009 | 042 | 016 | 004 |
| STATION M | 000 | | | | | |

TABLE 9.

PERIOD 80010100-80013112

| WIND DIRECTION ( DEGREES ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +12 GOND RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 073 | *** | 015 | 029 | 048 | 024 |
| IJMUIDEN | 066 | *** | 026 | 038 | 054 | 009 |
| PENNZOIL | 051 | *** | -001 | 021 | 028 | 021 |
| EKOFISK | 028 | *** | 007 | 025 | 019 | 009 |
| STATION M | 058 | *** | -007 | 025 | 022 | 034 |

| WIND SPEED ( DM/SEC ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +12 GOND RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 123 | 073 | -009 | 027 | 044 | 078 |
| IJMUIDEN | 123 | 072 | -011 | 026 | 042 | 080 |
| PENNZOIL | 116 | 069 | -013 | 025 | 030 | 085 |
| EKOFISK | 048 | 093 | -036 | 044 | 003 | 044 |
| STATION M | 084 | 104 | -026 | 042 | 016 | 067 |

| HS SIGN. WAVE HEIGHT( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +12 GOND RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 121 | 124 | -002 | 058 | 050 | 071 |
| IJMUIDEN | 076 | 160 | -008 | 058 | 029 | 046 |
| PENNZOIL | 121 | 162 | -026 | 057 | 038 | 083 |
| EKOFISK | 041 | 209 | -038 | 078 | 006 | 035 |
| STATION M | 083 | 253 | 095 | 154 | 065 | 017 |

| H 3*10 ( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +12 GOND RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 121 | 015 | 001 | 018 | 043 | 070 |
| IJMUIDEN | 074 | 029 | -006 | 026 | 028 | 046 |
| PENNZOIL | 120 | 035 | -004 | 031 | 042 | 075 |
| EKOFISK | 040 | 063 | -030 | 041 | 004 | 036 |
| STATION M | 000 | | | | | |

TABLE 10.

PERIOD 80010100-80013112

| WIND DIRECTION ( DEGREES ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +24 MODEL M RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 045 | *** | 019 | 037 | 033 | 012 |
| IJMUIDEN | 040 | *** | 032 | 045 | 033 | 006 |
| PENNZOIL | 033 | *** | 005 | 024 | 020 | 013 |
| EKOFISK | 018 | *** | -005 | 047 | 010 | 008 |
| STATION M | 035 | *** | 008 | 024 | 026 | 008 |

| WIND SPEED ( DM/SEC ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +24 MODEL M RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 062 | 072 | 008 | 024 | 042 | 019 |
| IJMUIDEN | 062 | 071 | 006 | 026 | 034 | 027 |
| PENNZOIL | 058 | 069 | 007 | 027 | 039 | 017 |
| EKOFISK | 025 | 095 | -021 | 037 | 005 | 019 |
| STATION M | 042 | 104 | -011 | 036 | 014 | 027 |

| HS SIGN. WAVE HEIGHT( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +24 MODEL M RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 060 | 132 | 015 | 041 | 037 | 023 |
| IJMUIDEN | 038 | 168 | 017 | 048 | 023 | 015 |
| PENNZOIL | 060 | 167 | 017 | 053 | 040 | 020 |
| EKOFISK | 020 | 203 | -016 | 066 | 009 | 010 |
| STATION M | 041 | 266 | 087 | 158 | 032 | 009 |

| H S*10 ( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +24 MODEL M RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 060 | 017 | 021 | 028 | 058 | 002 |
| IJMUIDEN | 036 | 032 | 013 | 021 | 031 | 004 |
| PENNZOIL | 060 | 039 | 023 | 039 | 052 | 008 |
| EKOFISK | 020 | 069 | 003 | 034 | 014 | 006 |
| STATION M | 000 | | | | | |

TABLE 11.

PERIOD 80010100-80013112

| WIND DIRECTION ( DEGREES ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +24 GONO RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 067 | *** | 020 | 035 | 050 | 017 |
| IJMUIDEN | 059 | *** | 030 | 046 | 047 | 011 |
| PENNZOIL | 045 | *** | -000 | 030 | 024 | 021 |
| EKOFISK | 022 | *** | 002 | 029 | 014 | 007 |
| STATION M | 053 | *** | -005 | 029 | 024 | 029 |

| WIND SPEED ( DM/SEC. ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +24 GONO RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 123 | 073 | -014 | 033 | 033 | 089 |
| IJMUIDEN | 123 | 072 | -016 | 034 | 032 | 089 |
| PENNZOIL | 116 | 070 | -019 | 033 | 025 | 088 |
| EKOFISK | 048 | 094 | -039 | 048 | 005 | 043 |
| STATION M | 084 | 104 | -035 | 056 | 018 | 066 |

| HS SIGN. WAVE HEIGHT ( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +24 GONO RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 121 | 123 | -020 | 060 | 044 | 077 |
| IJMUIDEN | 076 | 160 | -037 | 067 | 020 | 055 |
| PENNZOIL | 121 | 163 | -045 | 072 | 030 | 091 |
| EKOFISK | 041 | 200 | -061 | 106 | 001 | 040 |
| STATION M | 083 | 258 | 038 | 127 | 049 | 034 |

| H S,10 ( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | +24 GONO RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 121 | 015 | -001 | 017 | 036 | 076 |
| IJMUIDEN | 074 | 029 | -010 | 025 | 022 | 052 |
| PENNZOIL | 120 | 035 | -006 | 032 | 036 | 081 |
| EKOFISK | 040 | 068 | -049 | 077 | 003 | 037 |
| STATION M | 000 | | | | | |

TABLE 12.

PERIOD 80020100-80022912

WIND DIRECTION ( DEGREES ) ANALYSIS MODEL M

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 030 | *** | 005 | 010 | 022 | 008 |
| IJMUIDEN | 034 | *** | 007 | 011 | 025 | 007 |
| PENNZOIL | 039 | *** | -002 | 012 | 015 | 020 |
| EKOFISK | 004 | *** | -002 | 014 | 001 | 003 |
| STATION M | 041 | *** | 016 | 019 | 041 | 000 |

WIND SPEED ( CM/SEC ) ANALYSIS MODEL M

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 058 | 064 | -009 | 017 | 010 | 047 |
| IJMUIDEN | 057 | 061 | -006 | 016 | 015 | 040 |
| PENNZOIL | 057 | 064 | 003 | 015 | 037 | 018 |
| EKOFISK | 005 | 094 | -018 | 026 | 001 | 004 |
| STATION M | 044 | 121 | 002 | 013 | 031 | 012 |

HS SIGN. WAVE HEIGHT( CM ) ANALYSIS MODEL M

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 058 | 087 | 003 | 024 | 033 | 025 |
| IJMUIDEN | 042 | 099 | 009 | 037 | 028 | 012 |
| PENNZOIL | 058 | 123 | 013 | 032 | 040 | 017 |
| EKOFISK | 008 | 209 | 115 | 123 | 008 | 000 |
| STATION M | 044 | 248 | 207 | 223 | 044 | 000 |

H S*10 ( CM ) ANALYSIS MODEL M

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 058 | 009 | 022 | 030 | 057 | 001 |
| IJMUIDEN | 042 | 021 | 018 | 029 | 040 | 002 |
| PENNZOIL | 058 | 022 | 025 | 035 | 056 | 002 |
| EKOFISK | 008 | 033 | 049 | 055 | 008 | 000 |
| STATION M | 000 | | | | | |

TABLE 13.

PERIOD 80040100-80043012

WIND DIRECTION ( DEGREES )

| LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS MODEL M RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 037 | *** | 008 | 013 | 029 | 007 |
| IJMUIDEN | 036 | *** | 003 | 011 | 023 | 013 |
| PENNZOIL | 041 | *** | 001 | 009 | 023 | 016 |
| EKOFISK | 042 | *** | 005 | 010 | 029 | 009 |
| STATION M | 048 | *** | 010 | 022 | 045 | 003 |

WIND SPEED ( CM/SEC )

| LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS MODEL M RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 060 | 089 | -006 | 015 | 019 | 038 |
| IJMUIDEN | 060 | 071 | -005 | 014 | 018 | 041 |
| PENNZOIL | 060 | 067 | 008 | 016 | 046 | 014 |
| EKOFISK | 057 | 095 | -012 | 019 | 017 | 040 |
| STATION M | 052 | 115 | -002 | 014 | 025 | 025 |

HS SIGN. WAVE HEIGHT( CM )

| LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS MODEL M RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 060 | 124 | 007 | 028 | 041 | 019 |
| IJMUIDEN | 056 | 132 | 015 | 042 | 039 | 016 |
| PENNZOIL | 047 | 148 | 034 | 045 | 044 | 003 |
| EKOFISK | 006 | 183 | 043 | 047 | 006 | 000 |
| STATION M | 052 | 221 | 077 | 113 | 041 | 010 |

H S*10 ( CM )

| LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS MODEL M RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 060 | 021 | 021 | 032 | 055 | 005 |
| IJMUIDEN | 056 | 042 | 013 | 049 | 040 | 015 |
| PENNZOIL | 047 | 049 | 027 | 045 | 043 | 004 |
| EKOFISK | 006 | 057 | 012 | 029 | 004 | 002 |
| STATION M | 000 | | | | | |

TABLE 18.

PERIOD 80020100-80022912

| WIND DIRECTION ( DEGREES ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS MODEL M RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 030 | *** | 005 | 010 | 022 | 008 |
| IJMUIDEN | 034 | *** | 007 | 011 | 025 | 007 |
| PENNZOIL | 039 | *** | -002 | 012 | 015 | 020 |
| EKOFISK | 004 | *** | -002 | 014 | 001 | 003 |
| STATION M | 041 | *** | 016 | 019 | 041 | 000 |

| WIND SPEED ( DM/SEC ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS MODEL M RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 058 | 064 | -009 | 017 | 010 | 047 |
| IJMUIDEN | 057 | 061 | -006 | 016 | 015 | 040 |
| PENNZOIL | 057 | 064 | 003 | 015 | 037 | 018 |
| EKOFISK | 005 | 094 | -018 | 026 | 001 | 004 |
| STATION M | 044 | 121 | 002 | 013 | 031 | 012 |

| HS SIGN. WAVE HEIGHT( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS MODEL M RMS | PLUS | MINUS * |
|---|---|---|---|---|---|---|
| EURO | 048 | 097 | 001 | 025 | 024 | 024 |
| IJMUIDEN | 042 | 099 | 009 | 037 | 028 | 012 |
| PENNZOIL | 058 | 123 | 013 | 032 | 040 | 017 |
| EKOFISK | 008 | 209 | 115 | 123 | 008 | 000 |
| STATION M | 044 | 248 | 207 | 223 | 044 | 000 |

| H S,10 ( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS MODEL M RMS | PLUS | MINUS * |
|---|---|---|---|---|---|---|
| EURO | 019 | 018 | 038 | 047 | 018 | 001 |
| IJMUIDEN | 019 | 030 | 029 | 042 | 017 | 002 |
| PENNZOIL | 030 | 033 | 038 | 047 | 028 | 002 |
| EKOFISK | 008 | 033 | 049 | 055 | 008 | 000 |
| STATION M | 000 | | | | | |

* SMALL VALUES EXCLUDED RESP. <56, <30

TABLE 19.

PERIOD 80020100-80022912

WIND DIRECTION ( DEGREES ) ANALYSIS GONO

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 064 | *** | 014 | 023 | 056 | 007 |
| IJMUIDEN | 065 | *** | 021 | 029 | 056 | 009 |
| PENNZOIL | 064 | *** | -003 | 014 | 029 | 034 |
| EKOFISK | 010 | *** | -002 | 016 | 004 | 006 |
| STATION M | 063 | *** | -003 | 017 | 029 | 033 |

WIND SPEED ( DM/SEC ) ANALYSIS GONO

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 104 | 065 | -000 | 017 | 051 | 049 |
| IJMUIDEN | 103 | 060 | 005 | 019 | 053 | 047 |
| PENNZOIL | 103 | 065 | 001 | 017 | 056 | 044 |
| EKOFISK | 014 | 101 | -024 | 028 | 001 | 013 |
| STATION M | 077 | 111 | -021 | 035 | 016 | 059 |

HS SIGN. WAVE HEIGHT( CM ) ANALYSIS GONO *

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 080 | 100 | 031 | 052 | 059 | 020 |
| IJMUIDEN | 069 | 107 | 029 | 048 | 049 | 018 |
| PENNZOIL | 094 | 130 | 012 | 041 | 060 | 034 |
| EKOFISK | 016 | 213 | 011 | 059 | 009 | 007 |
| STATION M | 077 | 232 | 065 | 108 | 061 | 016 |

H S>10 ( CM ) ANALYSIS GONO *

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 018 | 024 | 029 | 042 | 016 | 002 |
| IJMUIDEN | 017 | 039 | 040 | 058 | 015 | 002 |
| PENNZOIL | 024 | 046 | 040 | 060 | 019 | 005 |
| EKOFISK | 011 | 037 | -022 | 033 | 002 | 009 |
| STATION M | 000 | | | | | |

* SMALL VALUES EXCLUDED RESP. <56 , <30

TABLE 20.

PERIOD 80040100-80043012

| WIND DIRECTION ( DEGREES ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS RMS | GOND HI PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 066 | *** | -001 | 014 | 030 | 035 |
| IJMUIDEN | 064 | *** | -005 | 017 | 018 | 044 |
| PENNZOIL | 069 | *** | -013 | 017 | 007 | 060 |
| EKOFISK | 064 | *** | 002 | 011 | 037 | 026 |
| STATION M | 083 | *** | -009 | 023 | 025 | 058 |

| WIND SPEED ( DM/SEC ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS RMS | GOND HI PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 120 | 071 | -010 | 020 | 029 | 088 |
| IJMUIDEN | 120 | 072 | -008 | 019 | 036 | 083 |
| PENNZOIL | 119 | 068 | -002 | 019 | 048 | 066 |
| EKOFISK | 113 | 097 | -028 | 035 | 008 | 104 |
| STATION M | 103 | 112 | -025 | 037 | 013 | 090 |

| HS SIGN. WAVE HEIGHT( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS RMS | GOND HI PLUS | MINUS | * |
|---|---|---|---|---|---|---|---|
| EURO | 095 | 145 | -003 | 045 | 031 | 064 | |
| IJMUIDEN | 091 | 159 | -006 | 051 | 028 | 061 | |
| PENNZOIL | 079 | 174 | 004 | 053 | 033 | 046 | |
| EKOFISK | 055 | 244 | -024 | 060 | 014 | 040 | |
| STATION M | 099 | 231 | 021 | 112 | 056 | 043 | |

| H S>10 ( CM ) LOCATION | NUMBER | AV. OBS | AV. ERROR | ANALYSIS RMS | GOND HI PLUS | MINUS | * |
|---|---|---|---|---|---|---|---|
| EURO | 023 | 078 | 018 | 047 | 020 | 003 | |
| IJMUIDEN | 036 | 104 | -015 | 065 | 020 | 016 | |
| PENNZOIL | 038 | 112 | -007 | 065 | 019 | 019 | |
| EKOFISK | 036 | 178 | -015 | 076 | 009 | 027 | |
| STATION M | 000 | | | | | | |

* SMALL VALUES EXCLUDED RESP. <56 , <30

TABLE 21.

PERIOD 80040100-80043012

WIND DIRECTION ( DEGREES ) ANALYSIS MODEL M

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 037 | *** | 008 | 013 | 029 | 007 |
| IJMUIDEN | 036 | *** | 003 | 011 | 023 | 013 |
| PENNZOIL | 041 | *** | 001 | 009 | 023 | 016 |
| EKOFISK | 042 | *** | 005 | 010 | 029 | 009 |
| STATION M | 048 | *** | 010 | 022 | 045 | 003 |

WIND SPEED ( DM/SEC ) ANALYSIS MODEL M

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 060 | 069 | -006 | 015 | 019 | 038 |
| IJMUIDEN | 060 | 071 | -003 | 014 | 018 | 041 |
| PENNZOIL | 060 | 067 | 008 | 016 | 046 | 014 |
| EKOFISK | 057 | 095 | -012 | 019 | 017 | 040 |
| STATION M | 052 | 115 | -002 | 014 | 025 | 025 |

HS SIGN. WAVE HEIGHT( CM ) ANALYSIS MODEL M *

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 051 | 140 | 006 | 030 | 033 | 018 |
| IJMUIDEN | 050 | 145 | 015 | 044 | 033 | 016 |
| PENNZOIL | 044 | 156 | 035 | 047 | 041 | 003 |
| EKOFISK | 023 | 235 | 027 | 059 | 020 | 008 |
| STATION M | 052 | 221 | 077 | 113 | 041 | 010 |

H S.10 ( CM ) ANALYSIS MODEL M *

| LOCATION | NUMBER | AV. OBS | AV. ERROR | RMS | PLUS | MINUS |
|---|---|---|---|---|---|---|
| EURO | 027 | 040 | 032 | 045 | 025 | 002 |
| IJMUIDEN | 034 | 061 | 021 | 062 | 028 | 006 |
| PENNZOIL | 031 | 071 | 036 | 054 | 029 | 002 |
| EKOFISK | 023 | 142 | 024 | 073 | 015 | 008 |
| STATION M | 000 | | | | | |

* SMALL VALUES EXCLUDED RESP. <56, <30

TABLE 22.

$H_S$ : SCATTER-INDEX

PERIOD 79120100-79123112

| | GONO-HI | Model M | GONO |
|---|---|---|---|
| EURO | 27 | 19 | 35 |
| IJMUIDEN | 25 | 27 | 32 |
| PENNZOIL | 24 | 23 | 27 |

PERIOD 80010100-8013112

| | GONO-HI | Model M | GONO | +12 Model M | +12 GONO | +24 Model M | +24 GONO |
|---|---|---|---|---|---|---|---|
| EURO | 40 | 20 | 48 | 27 | 45 | 31 | 47 |
| IJMUIDEN | 33 | 22 | 44 | 25 | 36 | 29 | 42 |
| PENNZOIL | 34 | 28 | 39 | 29 | 35 | 32 | 44 |
| EKOFISK | 42 | 30 | 39 | 25 | 39 | 33 | 53 |

PERIOD 80020100-80022912

| | Model M | GONO | Model M* | GONO* |
|---|---|---|---|---|
| EURO | 28 | 53 | 26 | 52 |
| IJMUIDEN | 37 | 46 | 37 | 45 |
| PENNZOIL | 26 | 33 | 26 | 32 |
| EKOFISK | 59 | 28 | 59 | 28 |

PERIOD 80030100-80033112

| | GONO-HI | Model M |
|---|---|---|
| EURO | 35 | 24 |
| IJMUIDEN | 37 | 35 |
| PENNZOIL | 25 | 29 |
| EKOFISK | 36 | 27 |

PERIOD 80040100-80043012

| | GONO-HI | Model M | GONO-HI* | Model M* |
|---|---|---|---|---|
| EURO | 33 | 23 | 31 | 21 |
| IJMUIDEN | 34 | 32 | 32 | 30 |
| PENNZOIL | 33 | 30 | 30 | 30 |
| EKOFISK | 28 | 23 | 25 | 25 |

* SMALL VALUES EXCLUDED.

TABLE 23.