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Comparison between actual wind speeds and simulated wind speeds generated by a stochastic model developed by British Petroleum. By SMITH,S.G.,COLLISON,P. and GANGE,M.D.

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MET O 3 TECHNICAL NOTE NO. 10

Comparison between actual wind speeds and simulated wind speeds generated by a stochastic model developed by British Petroleum.

by

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CONTENTS

COMPARISON BETWEEN ACTUAL WIND SPEEDS AND SIMULATED WIND SPEEDS GENERATED BY A STOCHASTIC MODEL DEVELOPED BY BRITISH PETROLEUM

1. Introduction

O'Carroll and Williams (1981) describe a stochastic model for generating values representing wind speeds and directions, present weather and visibility for Sullom Voe in the Shetlands, about 35 km north of Lerwick. The treatment of wind speeds is of particular interest to the Climatological Research Group (part of the Climatological Services branch) because work is currently being undertaken within the group to formulate a statistical model which, it is hoped, will generate speeds for different areas of the United Kingdom. Although O'Carroll and Williams' model was designed only to simulate values for Sullom Voe it might be possible to apply it to other places by varying the values of the parameters.

The purpose of this note is to outline some of the statistical properties of the simulated speeds and to compare them with those of actual observations from Lerwick. Also considered is the relationship between Lerwick 10 minute mean and hourly mean speeds, since the model generates 10 minute means but hourly means are used for most climatological applications in the Meteorological Office.

2. The model

Details of the model and the methods used for its development and testing are given in O'Carroll and Williams (1981). Ten minute mean speeds and directions are simulated by a bivariate autoregressive moving average (ARMA) model of transformed speed and direction. The model was intended to "provide a basis for taking weather into account in the computer scheduling system being developed for Sullom Voe terminal". The authors believe it to be "adequate for practical purposes" although acknowledge that some weaknesses exist, which they suggest are attributable to defects in the data base.

3. Data and Notation

Five years of simulated 10 minute mean speeds and directions every hour were available on computer line-printer output. To facilitate the analyses, speeds for the first January and the first July were copied to a computer compatible medium. Ten minute and hourly mean speeds at Lerwick are available every hour for many years in machineable form. Simulated speeds for the first January and July will be denoted by JAN1 and JUL1 respectively. Lerwick January 10 minute and hourly means for 1980 will be referred to as JAN80T and JAN80H respectively with obvious extensions to July and other years.

The sites at Lerwick and Sullom Voe, besides being 35 km apart, have different exposures and their speeds are therefore not strictly compatible. In O'Carroll and Williams' paper they indicate that Sullom Voe speeds are on average about 4% less than Lerwick speeds, though the difference varies with wind direction. They give a formula to convert Lerwick speeds W_L to Sullom Voe values W_S. For some of the analyses in this note the formula has been applied but inverted to express W_L in terms of W_S:

$$W_L = (0.96 + 0.08 \cos D - 0.05 \sin D - 0.05 \cos 2D - 0.03 \sin 2D - 0.05 \cos 3D - 0.06 \sin 3D)^{-1} W_S \qquad (1)$$

where D is the wind direction at Sullom Voe.

Note that although the overall effect is to increase W_S by 4%, for directions between 270 and 340 degrees W_S is reduced, by a maximum of 16% for winds with direction 300 degrees. The simulated data used in sections 4.4 and 4.5 have been converted to equivalent Lerwick values but this is not the case for data used in 4.1 to 4.3.

4. Analysis and Results

4.1 Histograms

Figs 1.1, 1.2 and 1.3 show histograms for JAN1, JAN80T and JAN80H together with their means and standard deviations. There are 744 values in each sample (also true for the July speeds discussed below). The mean speed for Lerwick in January 1980 is approximately equal to the 1965-80 January average. There are obvious differences between the simulated and actual data but no inferences can be made since these are only one month's values. Comparing JAN80H with JAN80T, it is observed that there are fewer speeds in the 0/1 kn and more in the 2/3 kn category for the hourly means. The mean for the month is 0.3 kn greater for JAN80H, probably as a consequence of this, and its standard deviation is slightly less.

Figs 2.1, 2.2 and 2.3 shows histograms for JUL1, JUL80T and JUL80H. The mean for July 1980 at Lerwick is slightly lower than the July 1965-80 average. Again there are differences between the simulated and actual distributions. The simulated speed of 41 kn, which using (1) is equivalent to a Lerwick speed of 45 kn, is exceptional because the highest Lerwick hourly mean speed between 1961-80 for any month between May and August inclusive is only 42 kn. Differences between the 10 minute and hourly means are similar to those observed for January.

4.2 Hour-to-hour differences

The difference in speed from one hour to the next was calculated such that

$$d_i = \sum_{i=1}^{743} (x_{i+1} - x_i)$$

where d_i is the difference for hour i and x represents the wind speed. Values of d_i were ignored if either x_{i+1} or x_i equalled zero. The distributions of d_i for JAN1, JAN80T and JAN80H are displayed in Figs 3.1, 3.2 and 3.3. The number of observations, N, varies because the number of calms is different. There are considerably fewer hour-to-hour differences for changes of up to $\pm$ 3 kn for JAN1 compared to JAN80T and a correspondingly greater proportion of differences between $\pm$4 and $\pm$12 kn. This is reflected in the variance of the differences which is much larger for the simulated speeds. The hour-to-hour differences for JAN80H are less than those for JAN80T with a smaller variance.

Values of d_i for JUL1, JUL80T and JUL80H are shown in figs 4.1, 4.2 and 4.3 respectively. Similar relationships hold between the different samples as occurred for January data.

4.3 Autocorrelations

Autocorrelations for lags 0 to 50 hours were determined for JAN1, JAN80T, JAN80H and also for January 1979 10 minute means, JAN79T. These are shown in figs 5.1 to 5.4. There is a striking difference between the autocorrelation for JAN79T and JAN80T; the former reveal a diurnal cycle whereas the latter do not; in addition the values for JAN79T are considerably less in magnitude. The autocorrelations for the simulated speeds lie some way between these two, although for lags up to five hours the values are smaller than both those for actual speeds. The autocorrelations for the hourly means are greater than for the 10 minute means although differences are slight for the longer lags.

Autocorrelations for JUL1, JUL79T, JUL80T and JUL80H are displayed in figs 6.1 to 6.4. Again there are important differences between 1979 and 1980 values (figs 6.2 and 6.4). The negative values found for JUL80T after 28 hours (which fall to as low as -0.35 by lag 60 - not shown) are unexpected and probably justify a separate study. The diurnal peaks for the simulated data are more pronounced than for either of the actuals. The autocorrelations for the hourly means are higher than those for 10 minute means but differences are small.

4.4 Maximum speeds

The five years of available simulated speeds were examined to determine whether the maximum speeds for each month were significantly different from maxima over 10 years of actual Lerwick 10 minute data. The maximum speeds and associated directions were extracted for each month of simulated data and the speed converted to an equivalent Lerwick speed using (1). The highest of these five maximum values are shown in table 1 for each month of the year. Also given is the highest Lerwick 10 minute speeds for the two five year periods 1971-75 and 1976-80. The simulated speeds appear to be rather higher than the actuals.

For each season viz Winter (December to February), Spring (March to May), Summer (June to August) and Autumn (September to November) the means and standard deviations of all the highest monthly speeds (combined seasonally) were computed for the five years of simulated data and 10 years of Lerwick data for 1971-80. Student's t-test was then applied to these values to ascertain whether differences in the means were statistically significant. The results are shown in table 2. The highest simulated speeds are indeed significantly greater for each season except Spring. The largest mean differences are about 7 kn occurring in Winter and Summer.

4.5 Spells of winds above 20 kn

Frequencies of spells of different lengths were studied for occasions when the speed exceeded 20 kn. Results from five years of simulated January and July data, converted to equivalent Lerwick speeds, were compared with results from five years of actual January and July 10 minute means for 1976-80. The number of spells and total duration with speeds above 20 kn are presented in table 3 for different lengths of spell and for January and July separately.

In January three regimes are apparent corresponding to different lengths of spell:

i) Less than 10 hour spells when the spells of simulated winds are more frequent and the total durations longer than for actual winds. This is also borne out by the fact that the total number of spells from simulated speeds is greater (214 against 180) whereas the total duration summed over all spell lengths is less (889 against 1188) than for actual speeds.

ii) From 10 hour to 46 hour spells when the frequency of spells of simulated winds is less and total durations shorter than for actual winds.

iii) More than 52 hour spells when the frequency of spells of simulated winds again exceed those for actual winds. This is probably due to the fact that the maximum simulated speeds are in general greater than the maximum actual speeds (section 4.4).

The results for July are similar but not as marked since there are fewer occasions with speeds above 20 kn.

The three regimes are illustrated in fig 7 where the cumulative number of hours for all spells above each spell length is plotted and fig 8 which shows the differences in the cumulative values between the actual and simulated winds. Referring to the January curve in fig 8, the gradient is positive up to 10 hours (corresponding to regime (i)), remains negative up to 46 hours (regime (ii)) and then becomes positive again above 46 hours (regime (iii)). The curve crosses the zero line at 39 hours and this point represents the spell length above which there are equal numbers of simulated and actual winds. For the July curve in fig 8 only the first two regimes are evident. The second is not very significant and does not start until 14 hours. The third regime does not occur because the speed in July does not usually much exceed 20 kn.

5. Summary and Concluding Remarks

Any conclusions made on the basis of the above analyses can only be tentative because the data samples were small and because additional tests may be desirable. However the results suggest that

i) There is a tendency for the hour-to-hour variability of the simulated speeds to be too high. This is reflected in the larger hour-to-hour differences (section 4.2), the smaller autocorrelations at low lags (4.3) and the greater number of short spells with speeds above 20 kn (4.5).

ii) The highest speeds taken on a monthly time scale may be too large (section 4.4). This is possibly a consequence of the higher hour-to-hour variability.

Of course these differences, if they exist, may not be important for all practical applications.

The analyses also showed that there were differences in the hour-to-hour variability of hourly mean speeds compared to that of 10 minute means. The variability is less for the hourly means and as a result extremes are also usually lower for the hourly values. If the model were to be used for hourly means (which in the Meteorological Office are more readily available and more commonly used for climatological work than 10 minute means), then some adjustment of model parameters is probably necessary.

The model is designed to generate speeds for Sullom Voe. To adapt it for other areas, considerable effort may be required because it contains many terms and many coefficients, a large proportion of which may vary irregularly from area to area. The wind speed climate of Sullom Voe is unlikely to be representative of the wind speed climate elsewhere in the United Kingdom which could cause problems in the adaptation. A further difficulty is that in the model simulated speeds are related to the simulated wind directions and the latter are highly site dependent (as indeed are wind speeds to some extent).

A model is currently being formulated in the Climatological Research Group to simulate speeds above 20 kn (independent of wind direction) for different areas. This a less complex model than O'Carroll and Williams' and unlike their model the highest speeds are simulated explicitly. This may be important because the majority of wind speed enquiries received in the Meteorological Office relate to strong wind events.

6. Reference

O'Carroll, F.M. and Williams, Patricia M. 1981 A stochastic model for wind, weather and visibility at Sullom Voe. British Petroleum internal report (for private circulation only).

FIG 1.1: JANUARY SIMULATED WIND DATA FOR SULLOM VOE

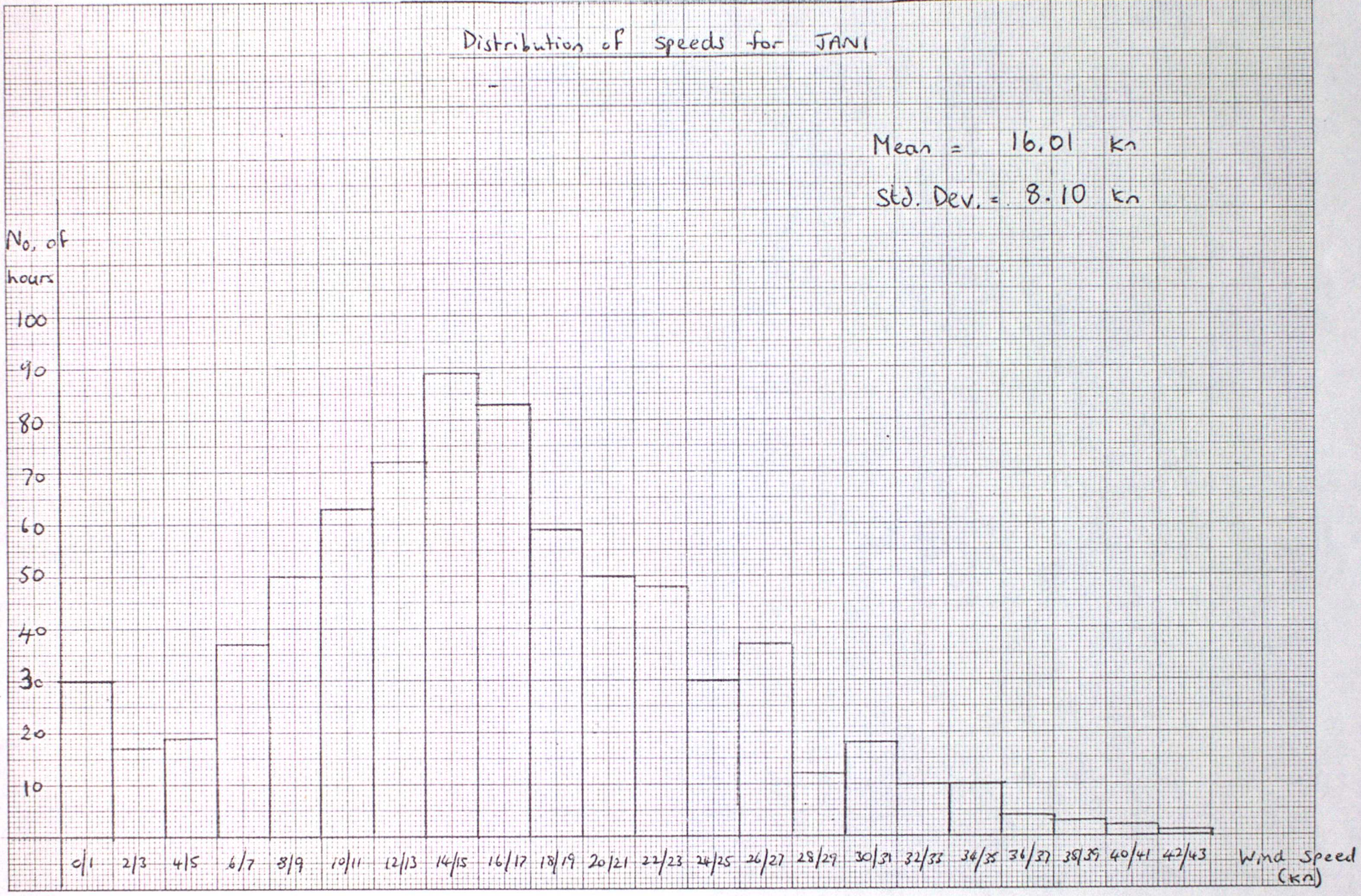


FIG 1.2 : JANUARY ACTUAL WIND DATA FOR LERWICK 1980

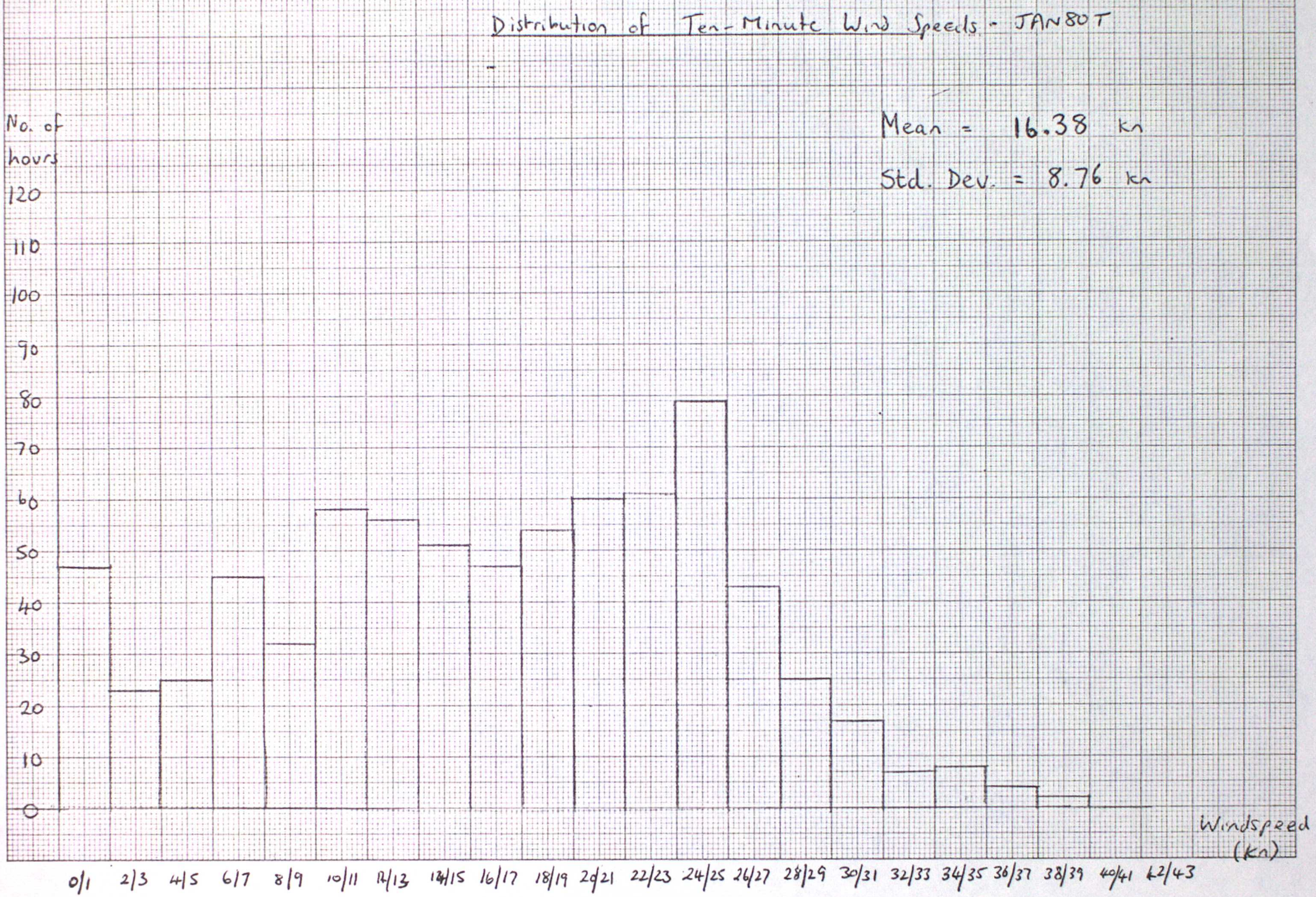


FIG 1.3: JANUARY ACTUAL WIND DATA FOR LERWICK 1980

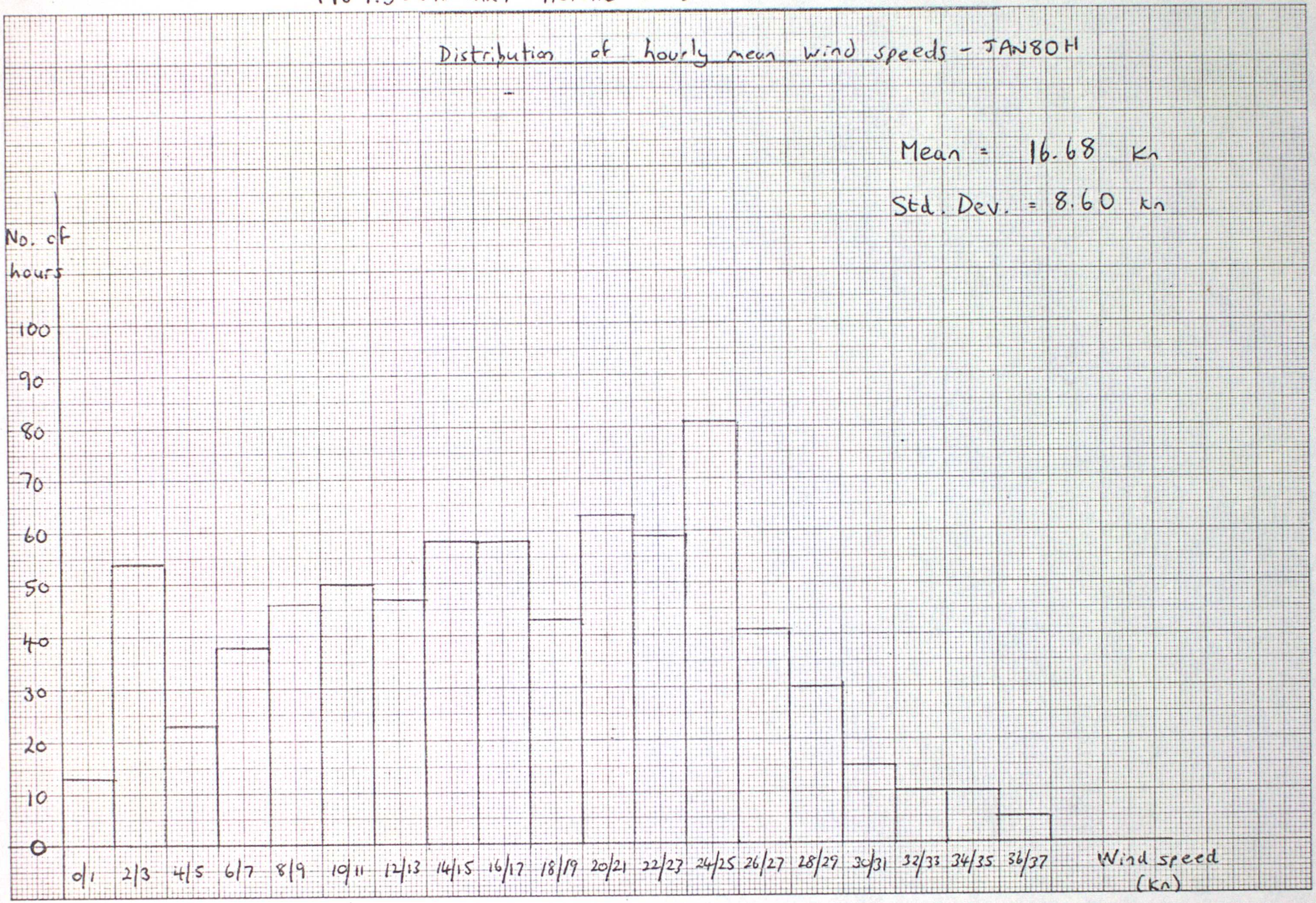


Fig. 2.1 : JULY SIMULATED WIND DATA FOR SULLOM VOE

Distribution of Wind Speeds. - JULI

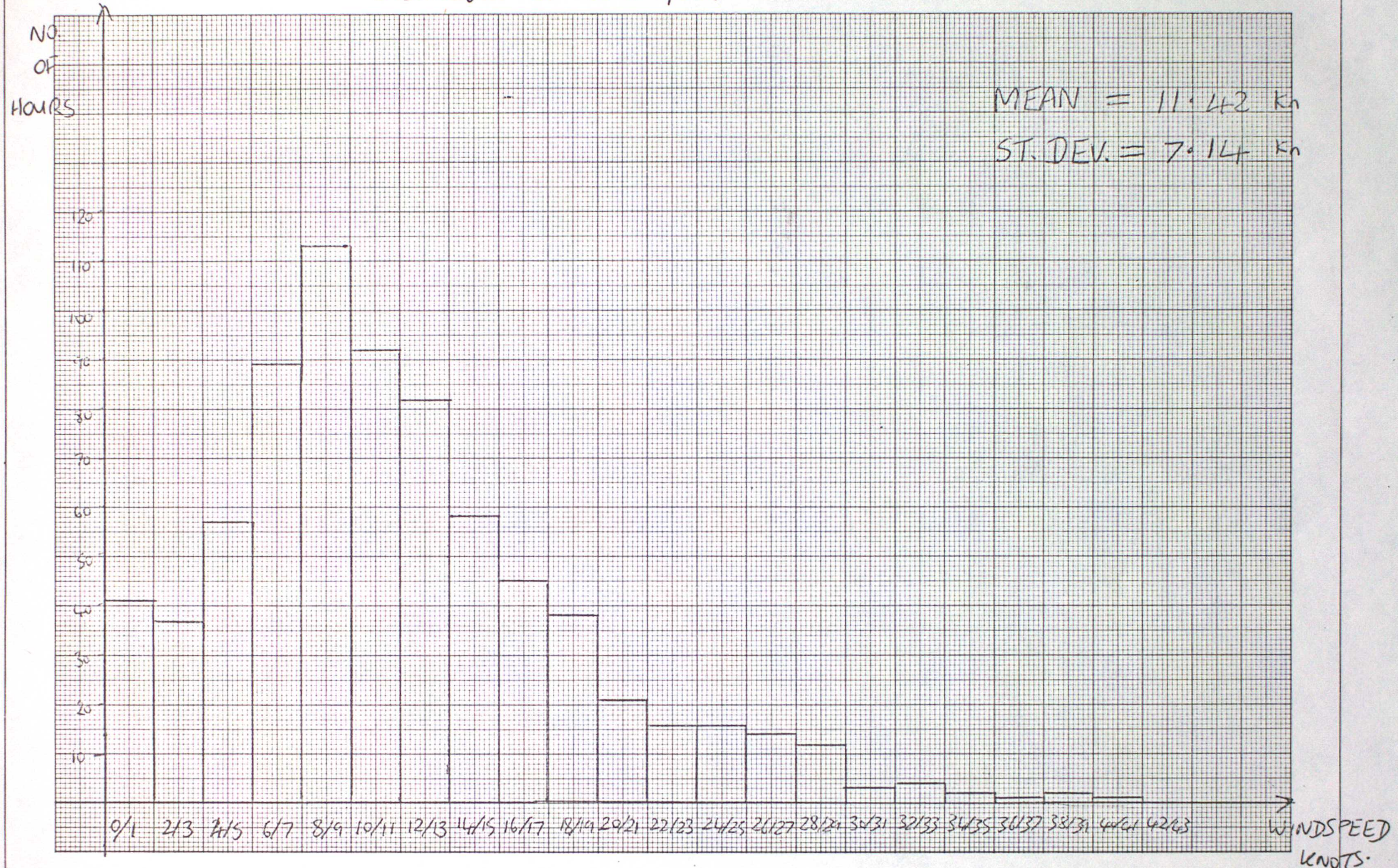


Fig 2. 2 : JULY ACTUAL WIND DATA FOR LERWICK 1980

Distribution of Ten-Minute Wind Speeds. - JUL80T

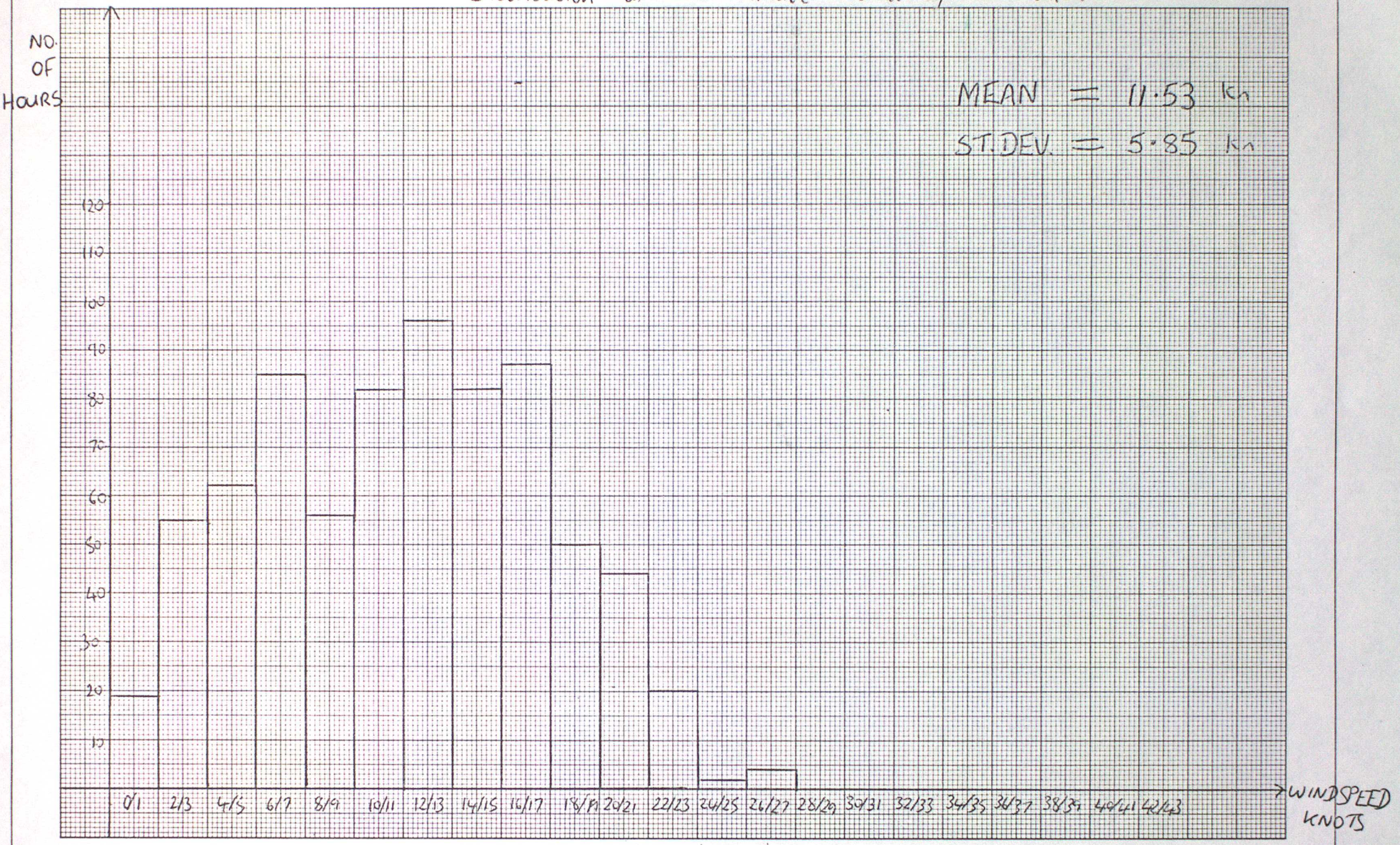


Fig 2.3 : JULY ACTUAL WIND DATA FOR LERWICK 1980

Distribution of Hourly Wind Speeds. - JUL80H

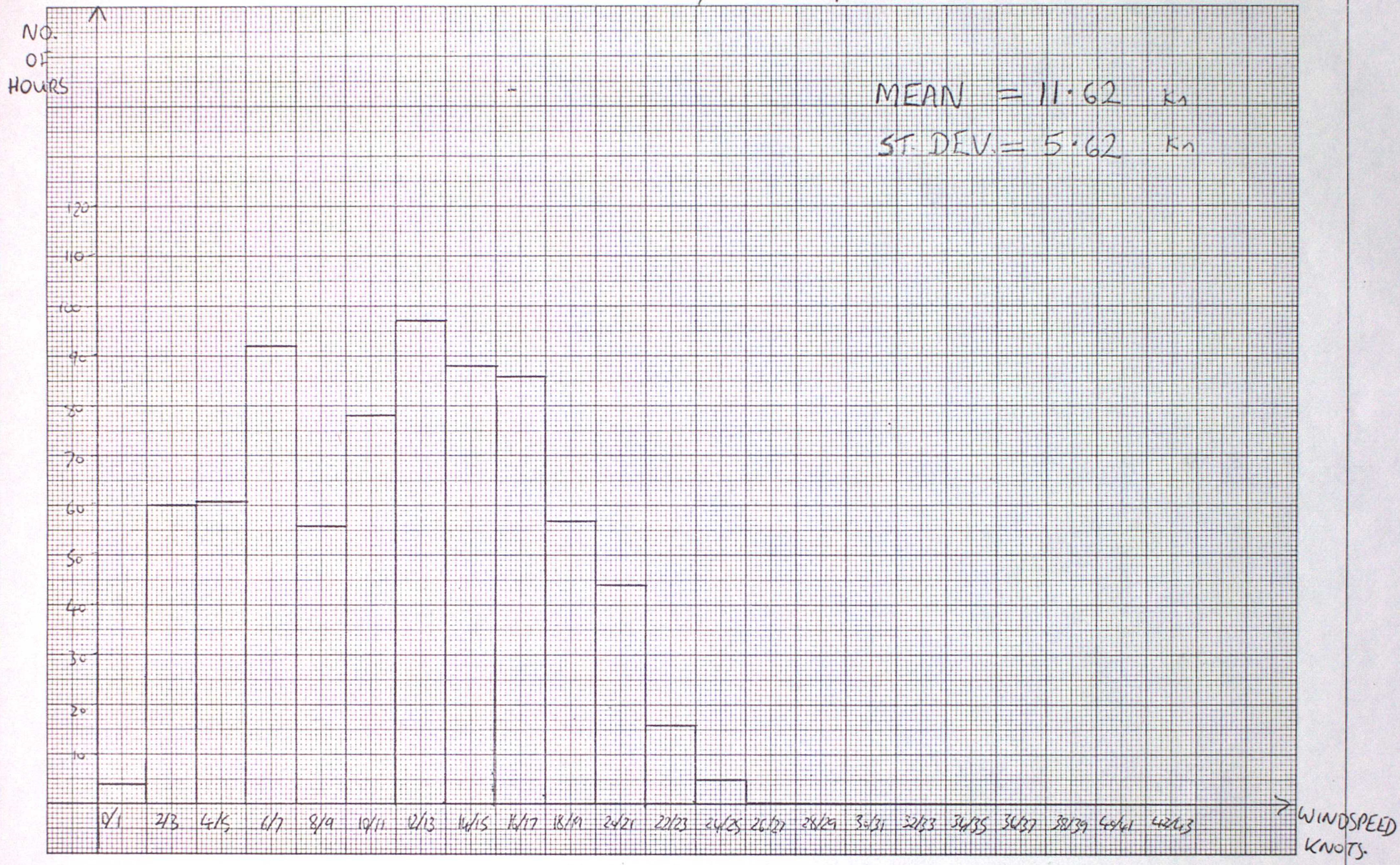


Fig 3.1 - JAN 1

Hour-to-hour differences in simulated speeds at Sullom Voe

N = 711

Mean = -0.007 Kn

Variance = 22.06 Kn^2

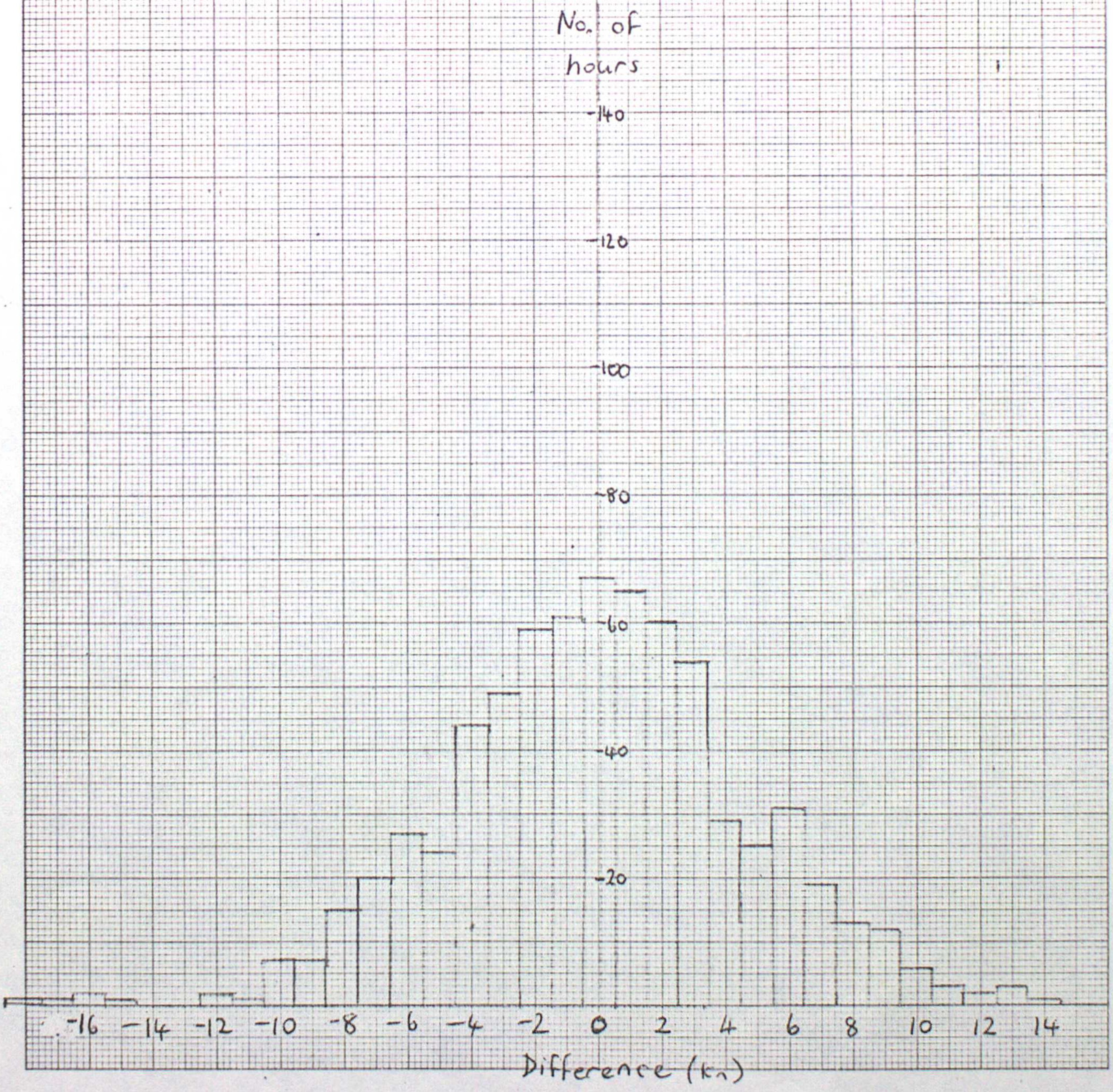


Fig 3.2 - JAN80T

Hour-to-hour differences in ten minute mean speeds at Lerwick, Jan. 1980

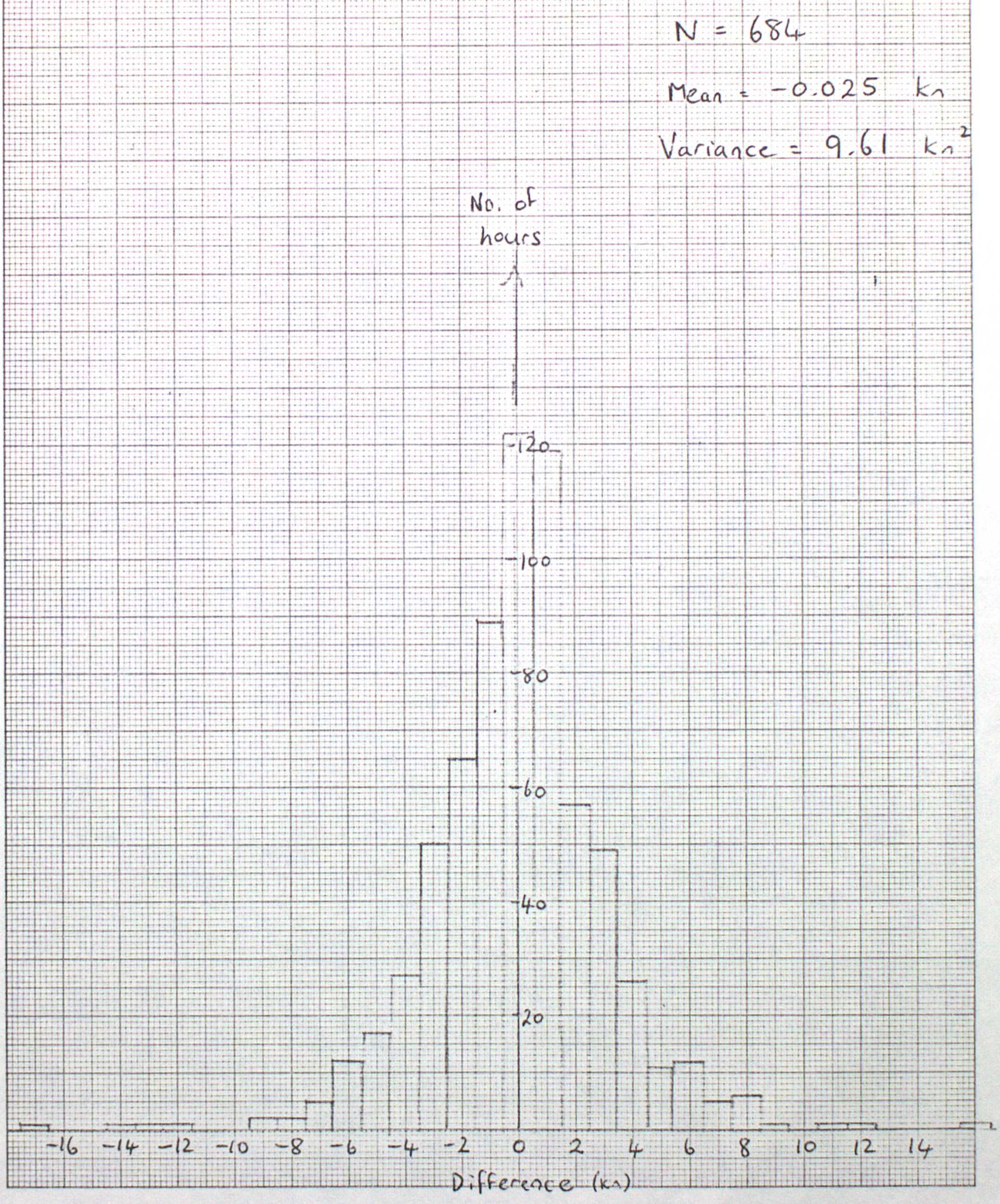


Fig 3.3 - JAN80H

Hour-to-hour differences in hourly mean speeds at Lerwick, Jan. 1980

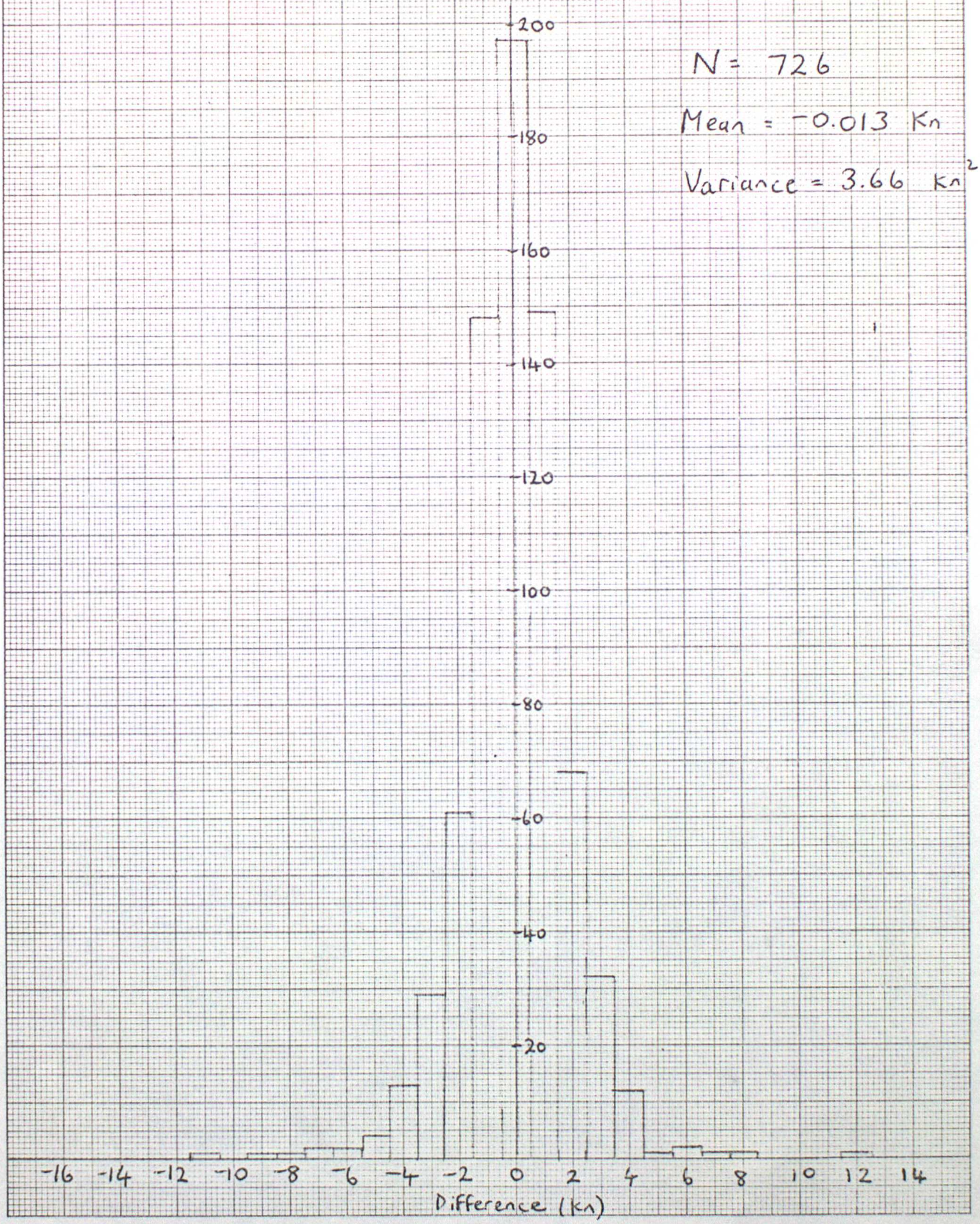


Fig. 4.1: JULY

HOUR-TO-HOUR DIFFERENCES IN SIMULATED WIND SPEEDS AT SULLOM VOE, JULY

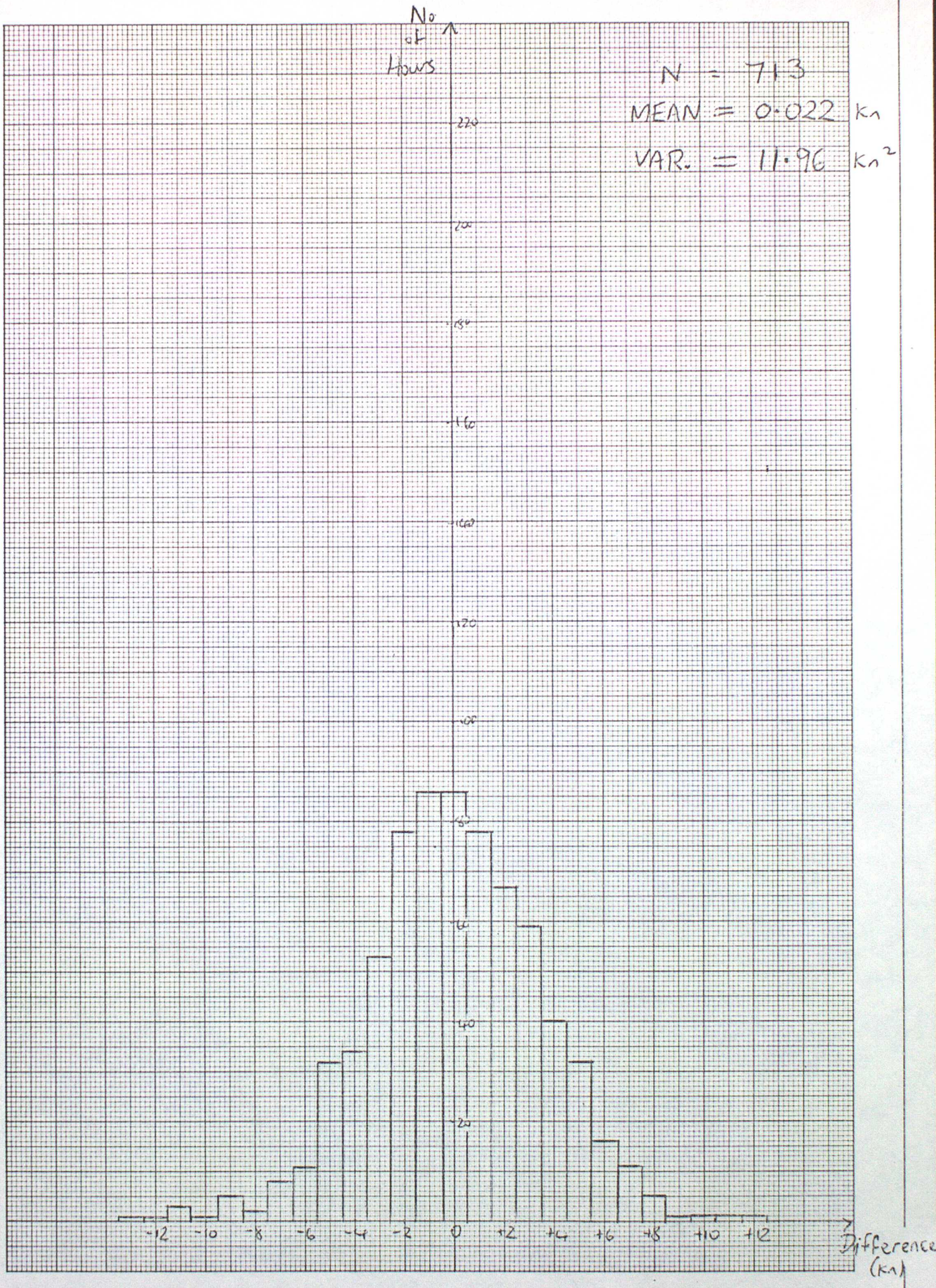


Fig. 4.2: JUL80T

HOUR-TO-HOUR DIFFERENCES IN TEN-MINUTE WIND SPEEDS AT LERWICK, JULY 1980

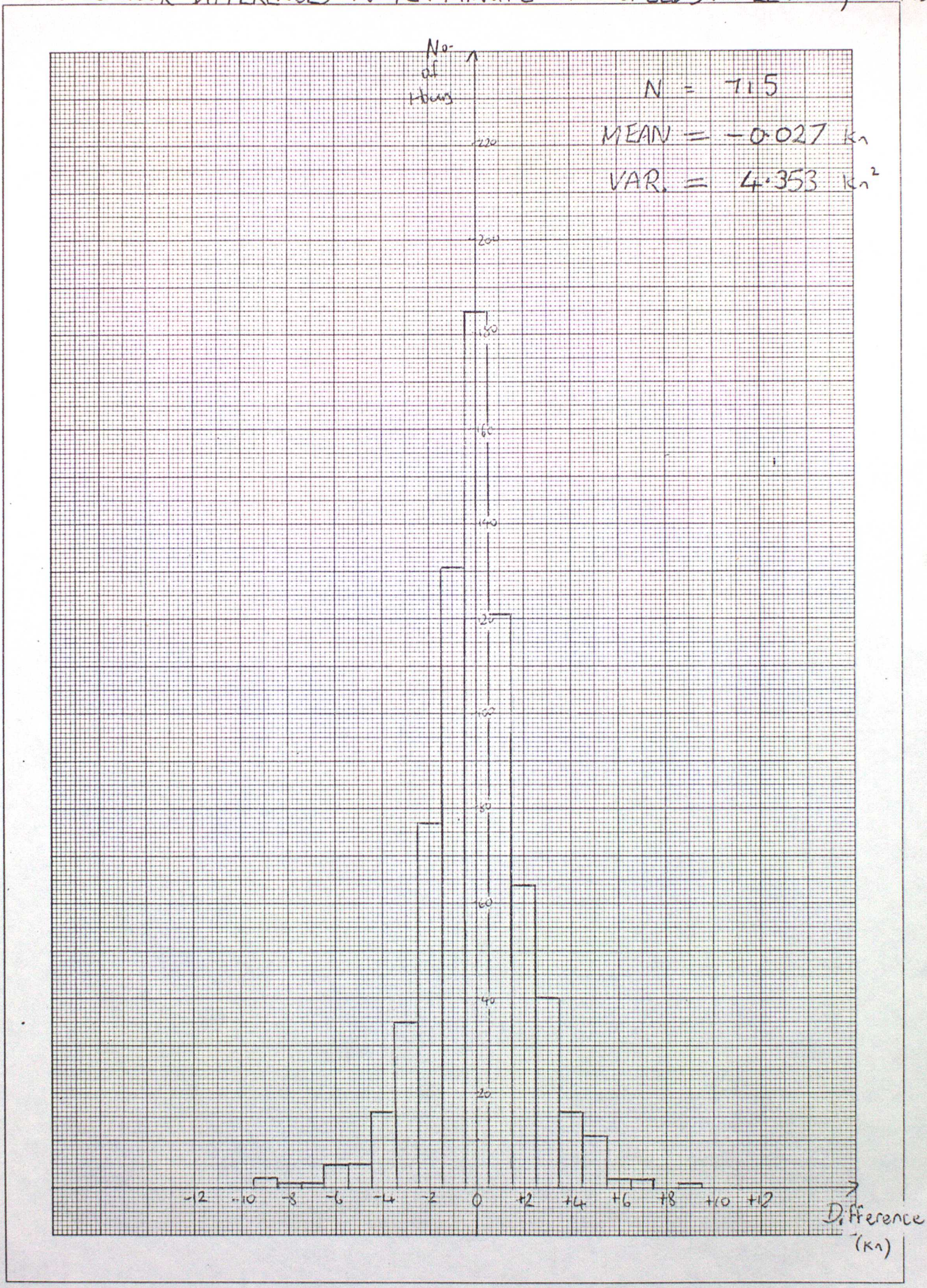
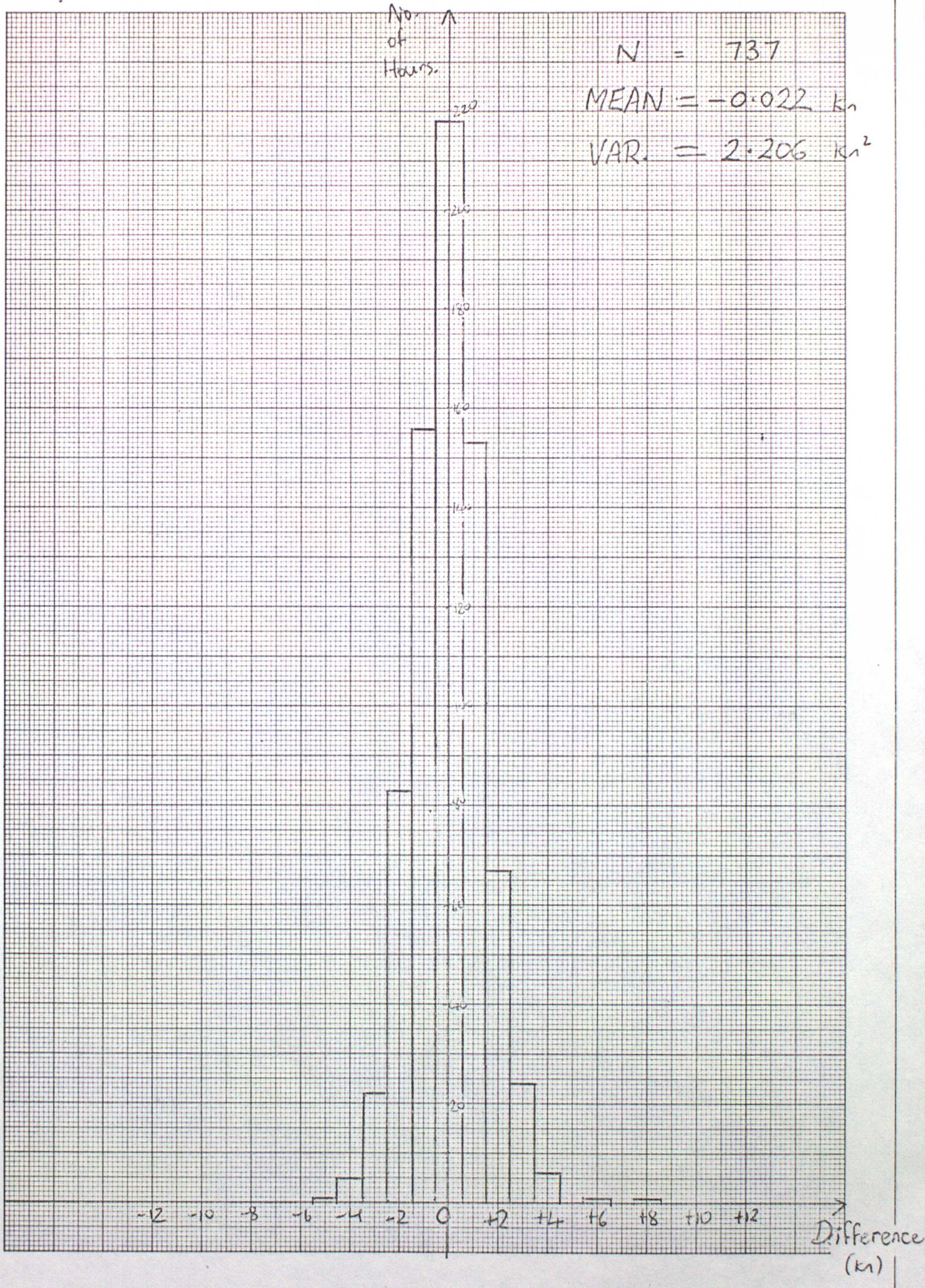


Fig. 4.3: JUL80H

HOUR-TO-HOUR DIFFERENCES IN HOURLY WIND SPEED AT LERWICK, JULY 1980



AUTOCORRELATIONS - JANUARY

Fig 5.1 - JAN1

SULLOM VOE SIMULATED DATA.

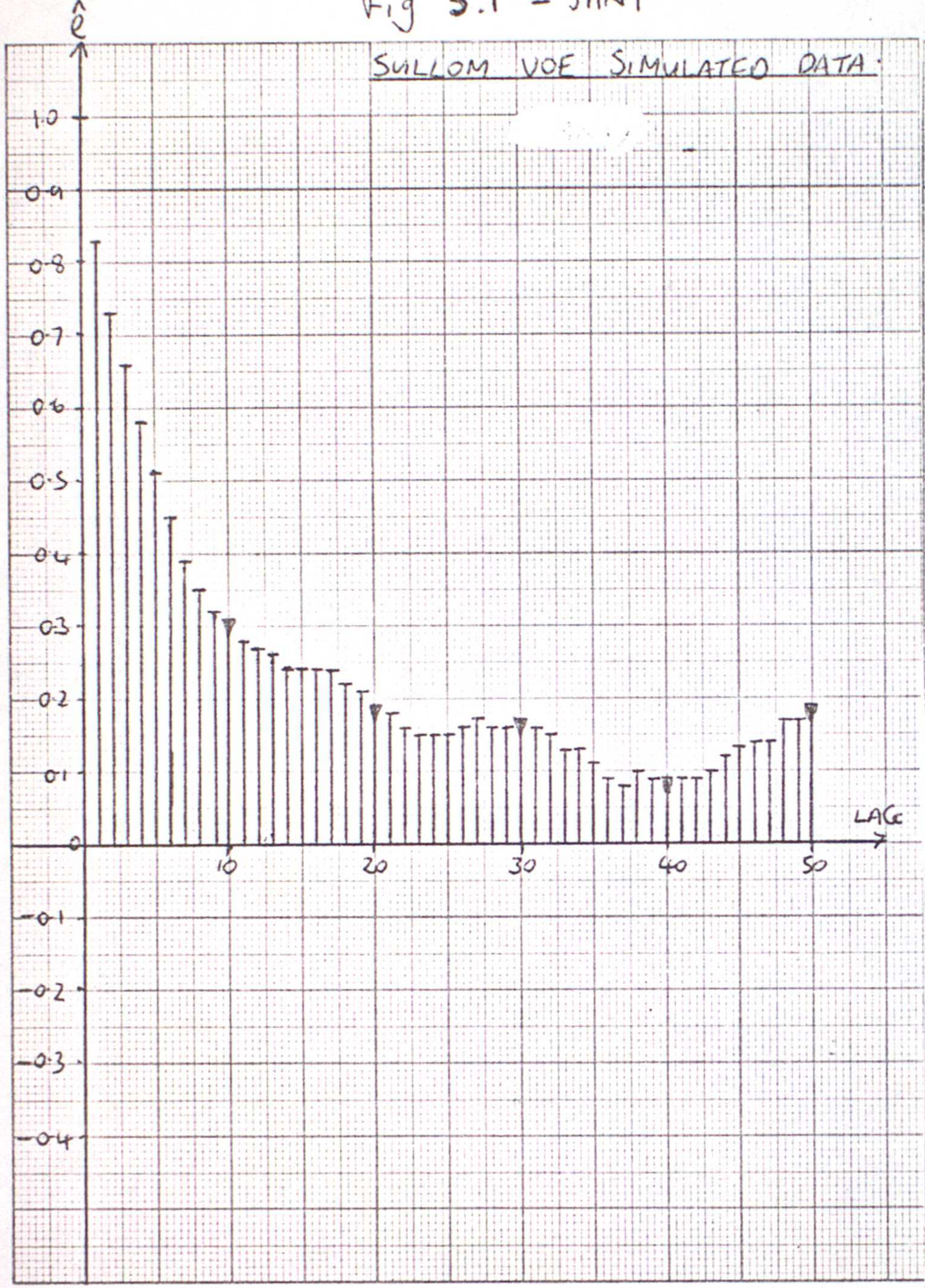
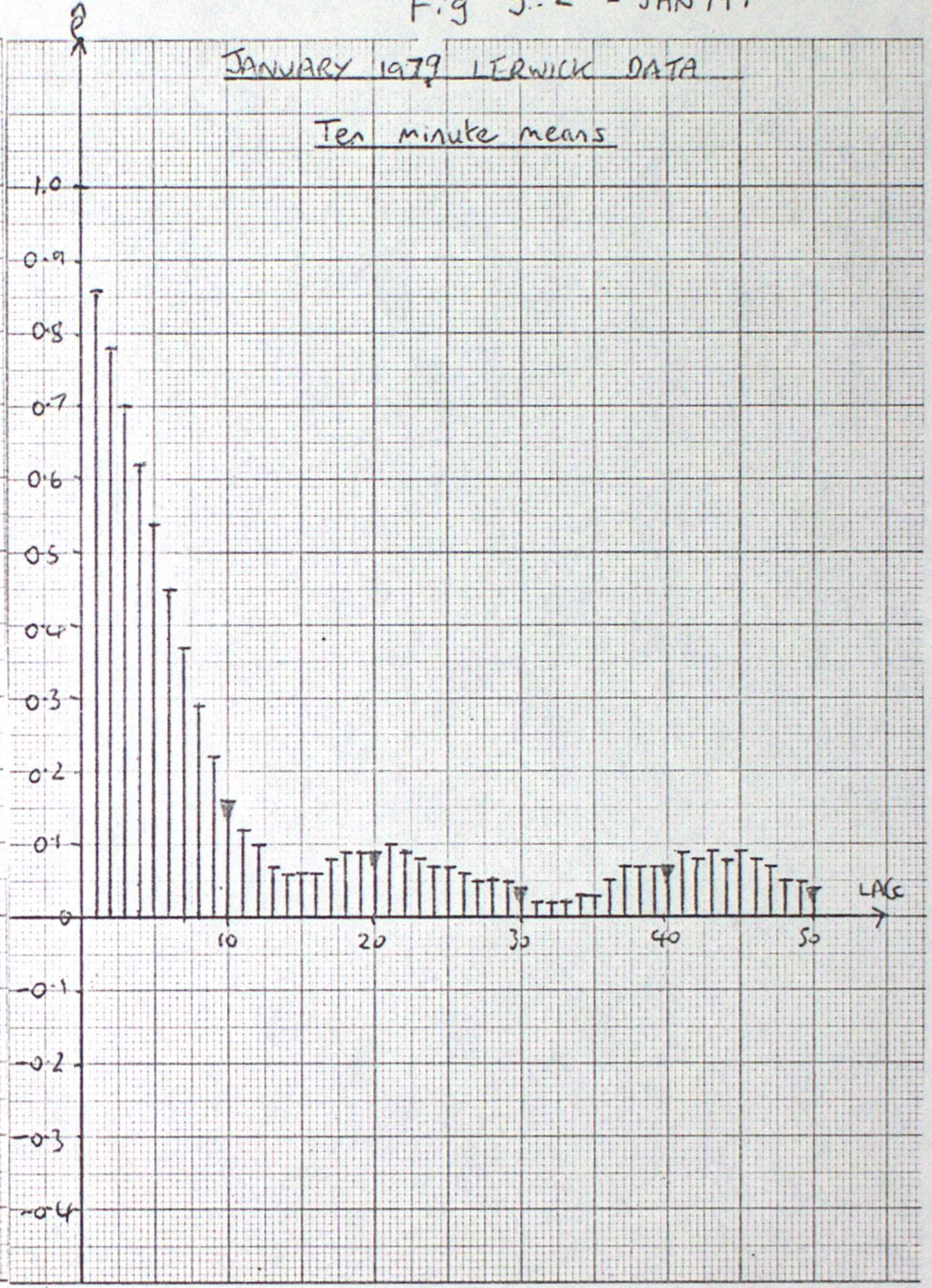


Fig 5.2 - JAN79T

JANUARY 1979 LERWICK DATA

Ten minute means



AUTOCORRELATIONS - JANUARY

Fig 5.3 - JAN80H

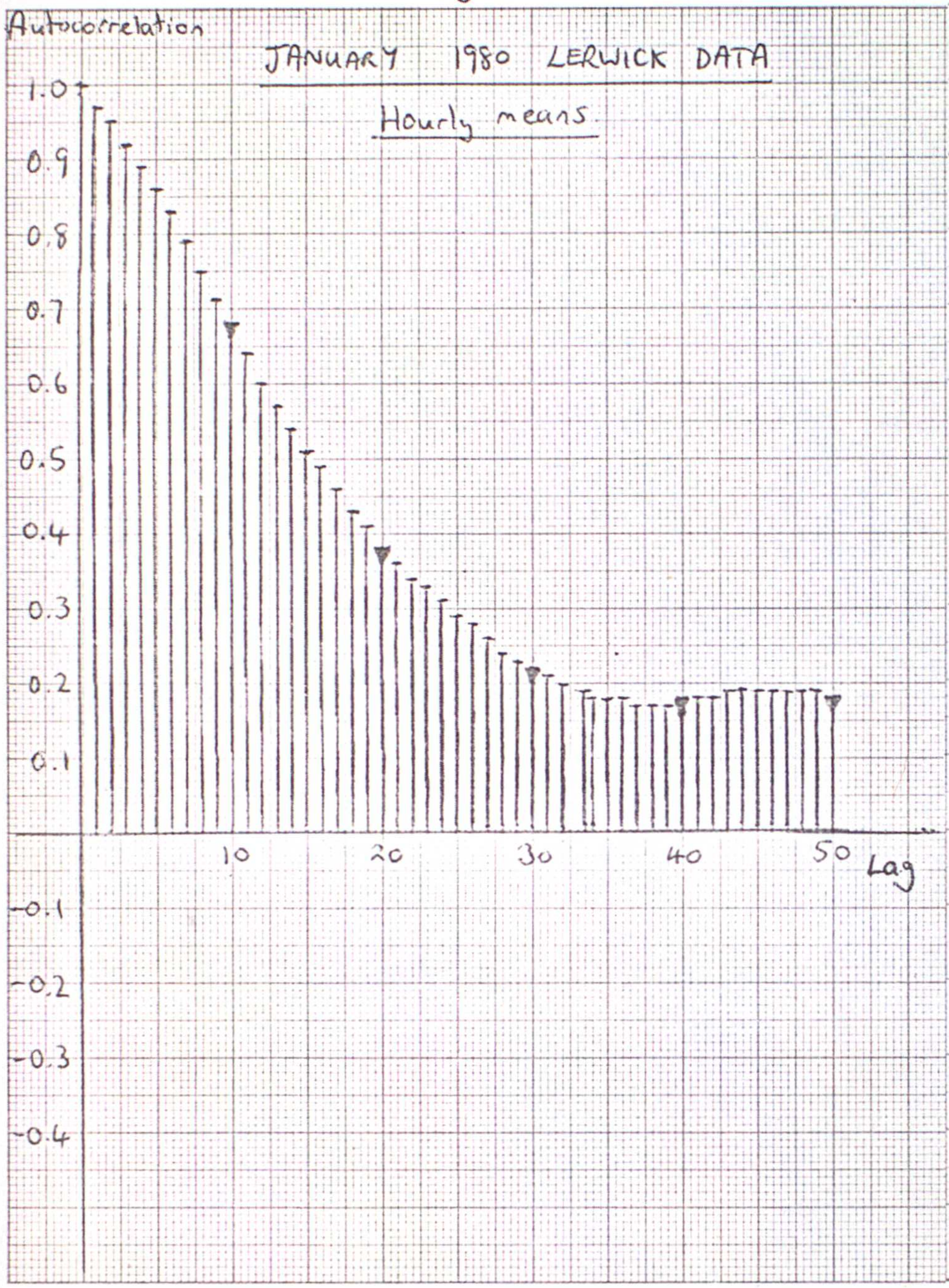
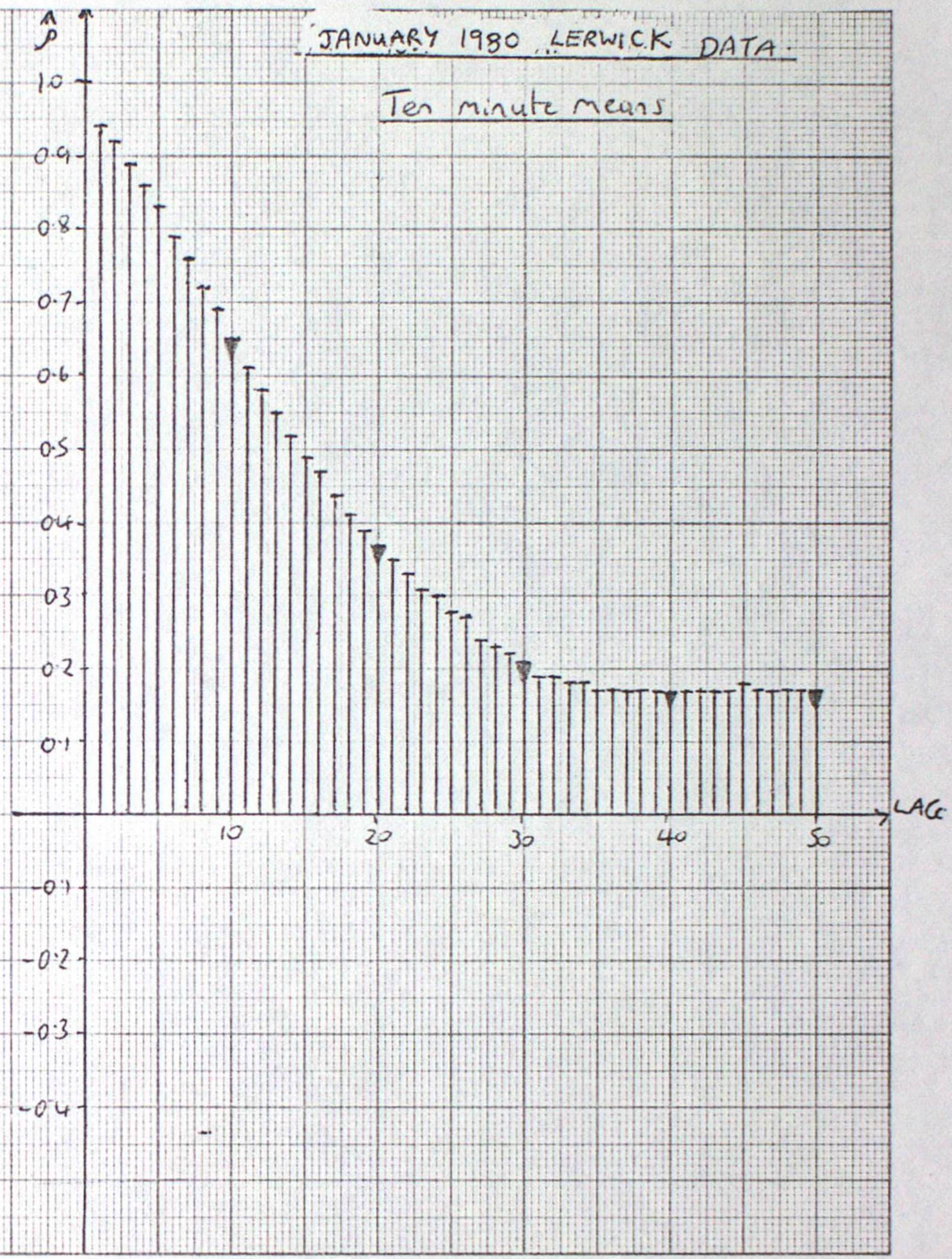


Fig 5.4 - JAN80T



AUTOCORRELATIONS - JULY

Fig 6.1 - JULI

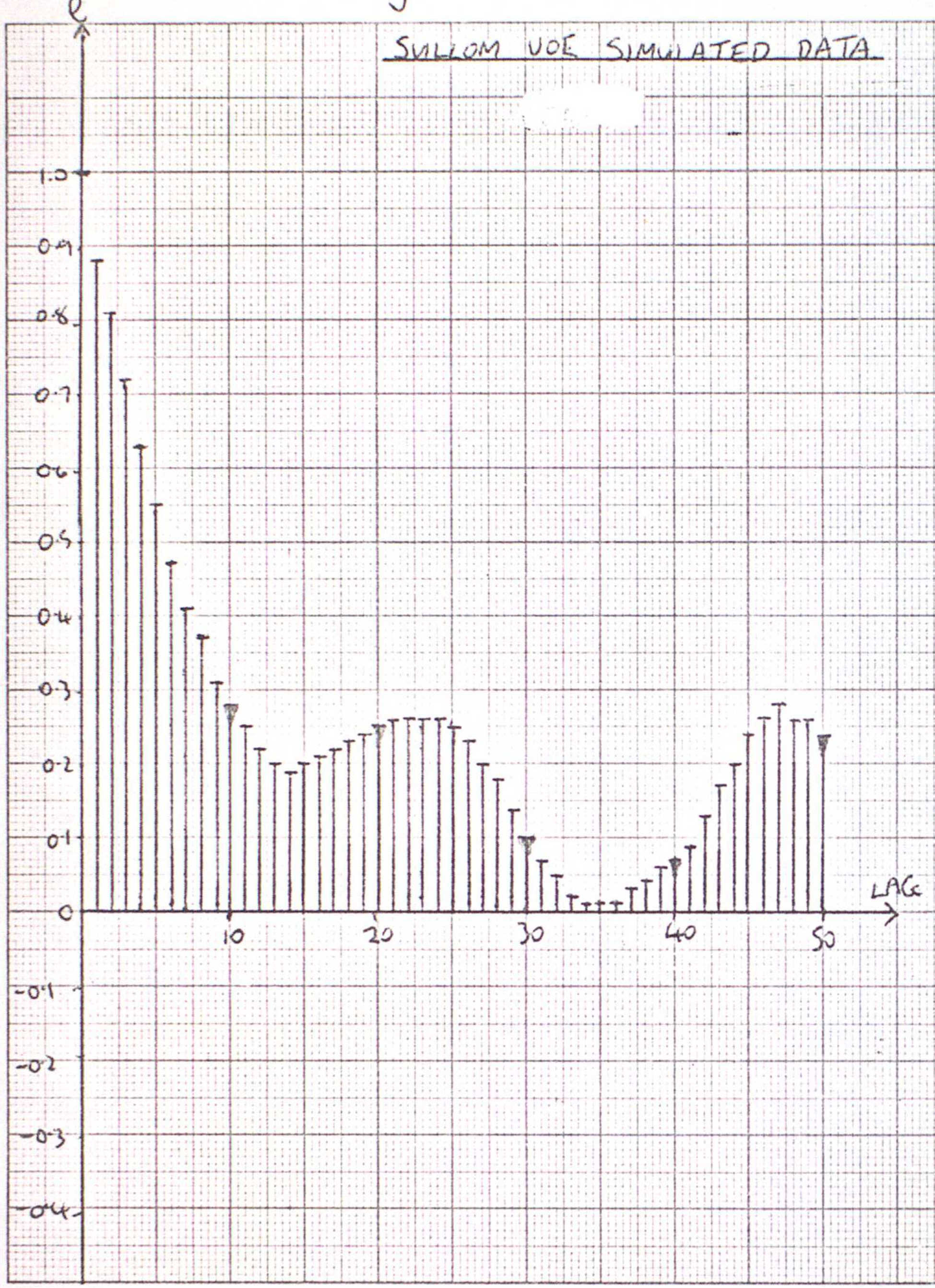
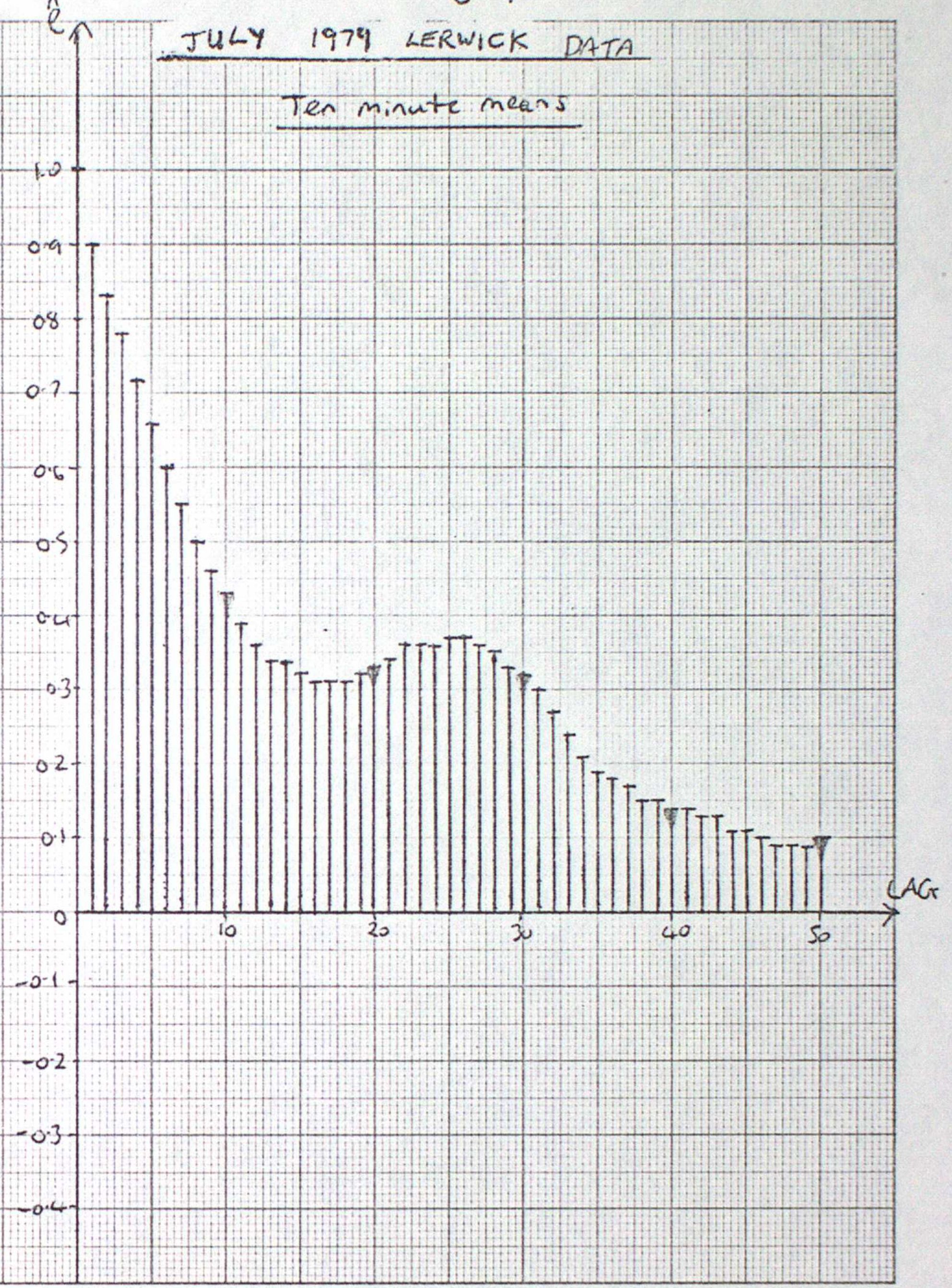


Fig 6.2 - JUL79T



AUTOCORRELATIONS - JULY

Fig 6.3 - JUL80H

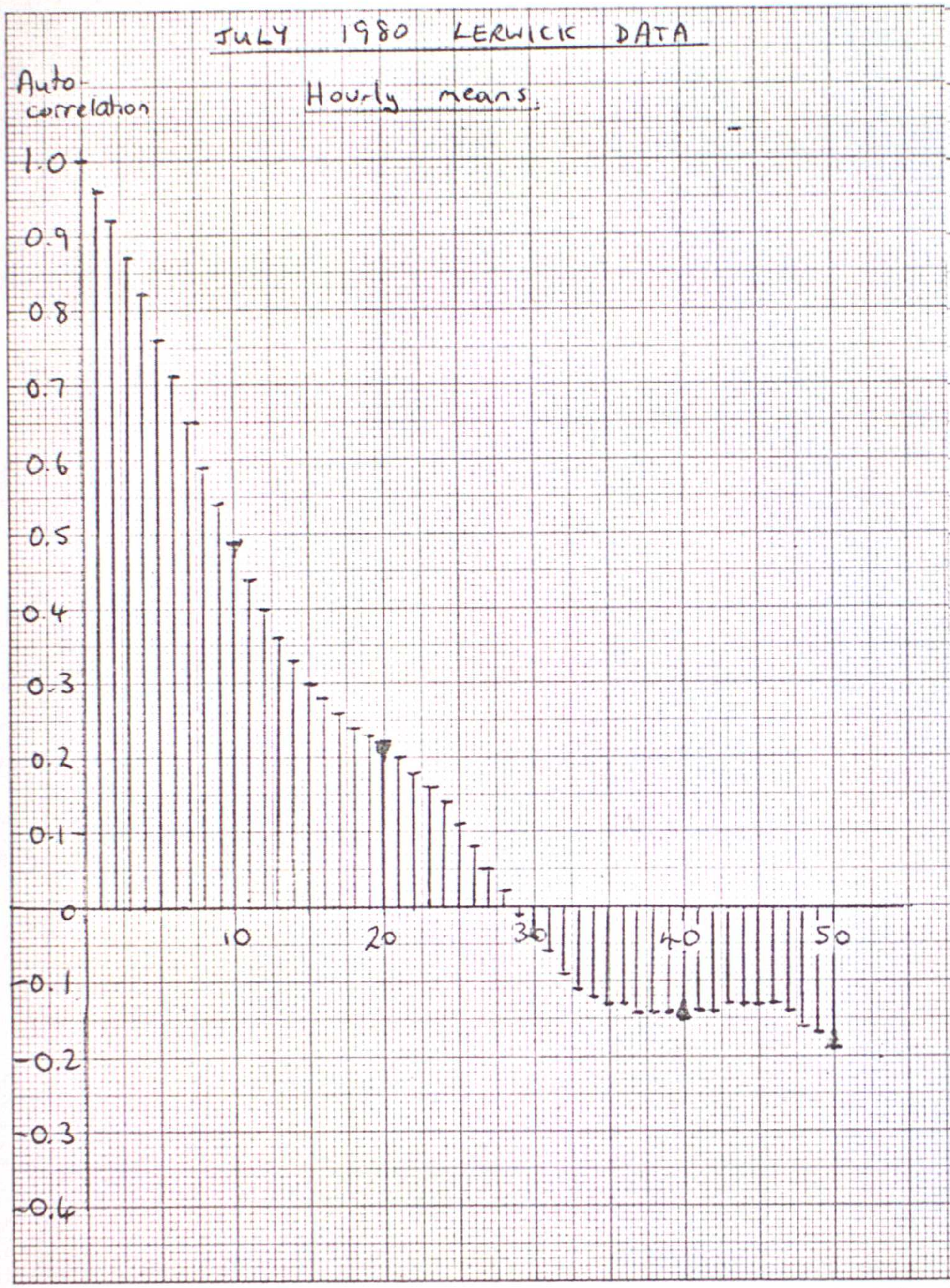


Fig 6.4 - JUL80T

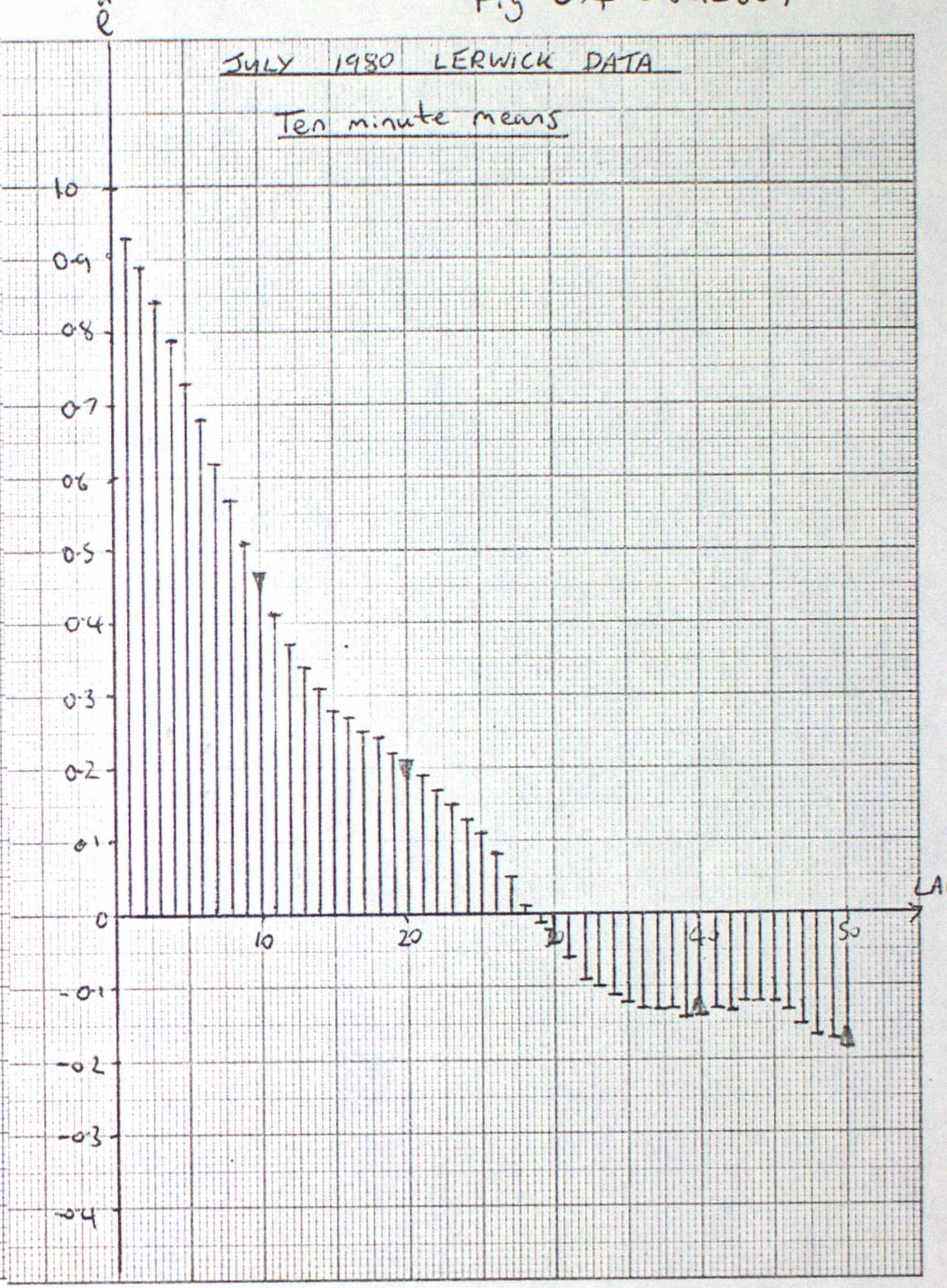


Fig 7

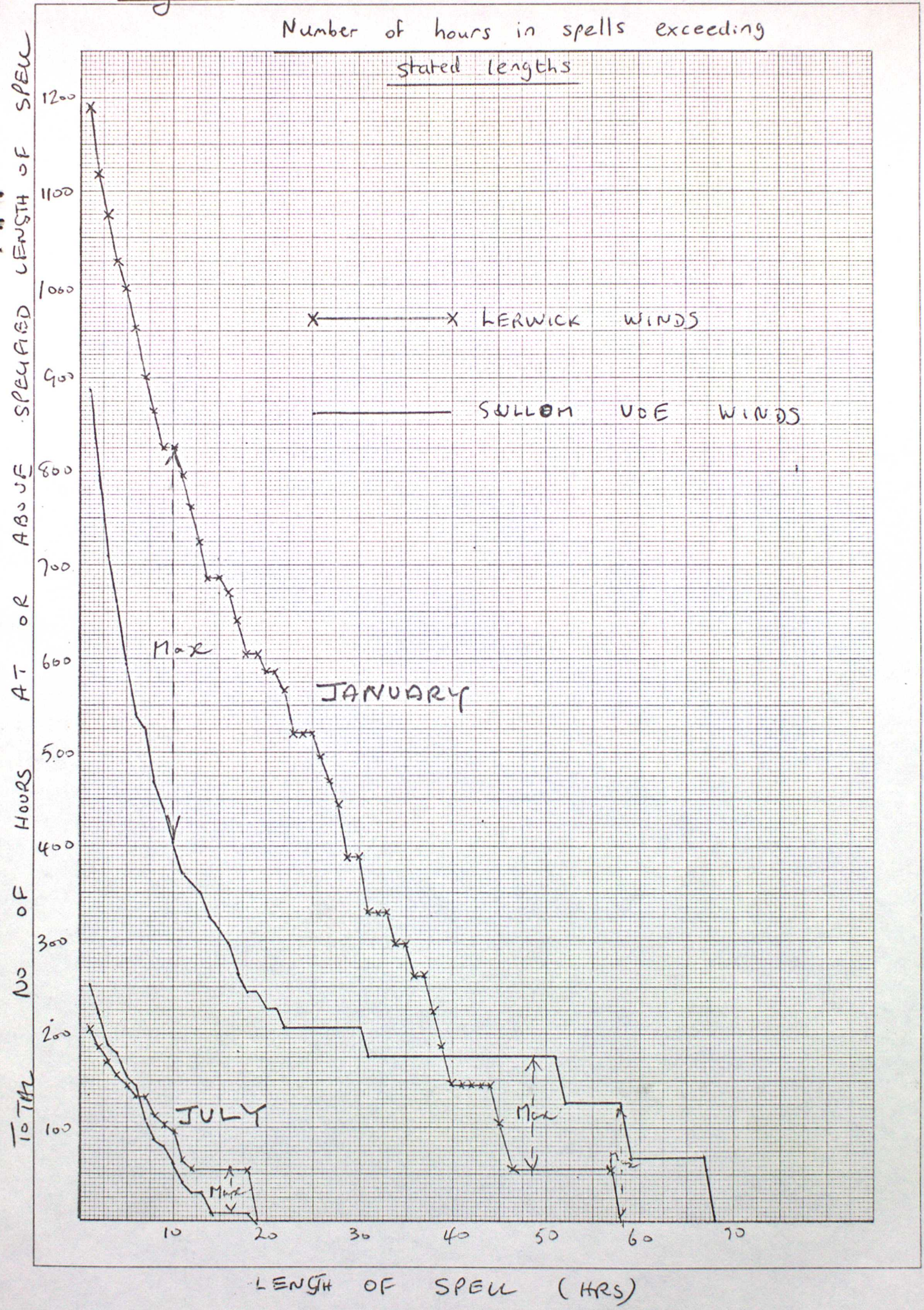

Number of hours in spells exceeding stated lengths
LERWICK WINDS
SULLOM VOE WINDS
JANUARY
JULY
Max
Max
Max
TOTAL No OF HOURS AT OR ABOVE SPECIFIED LENGTH OF SPELL
1200
1100
1000
900
800
700
600
500
400
300
200
100
10
20
30
40
50
60
70
LENGTH OF SPELL (HRS)

Fig. 8.

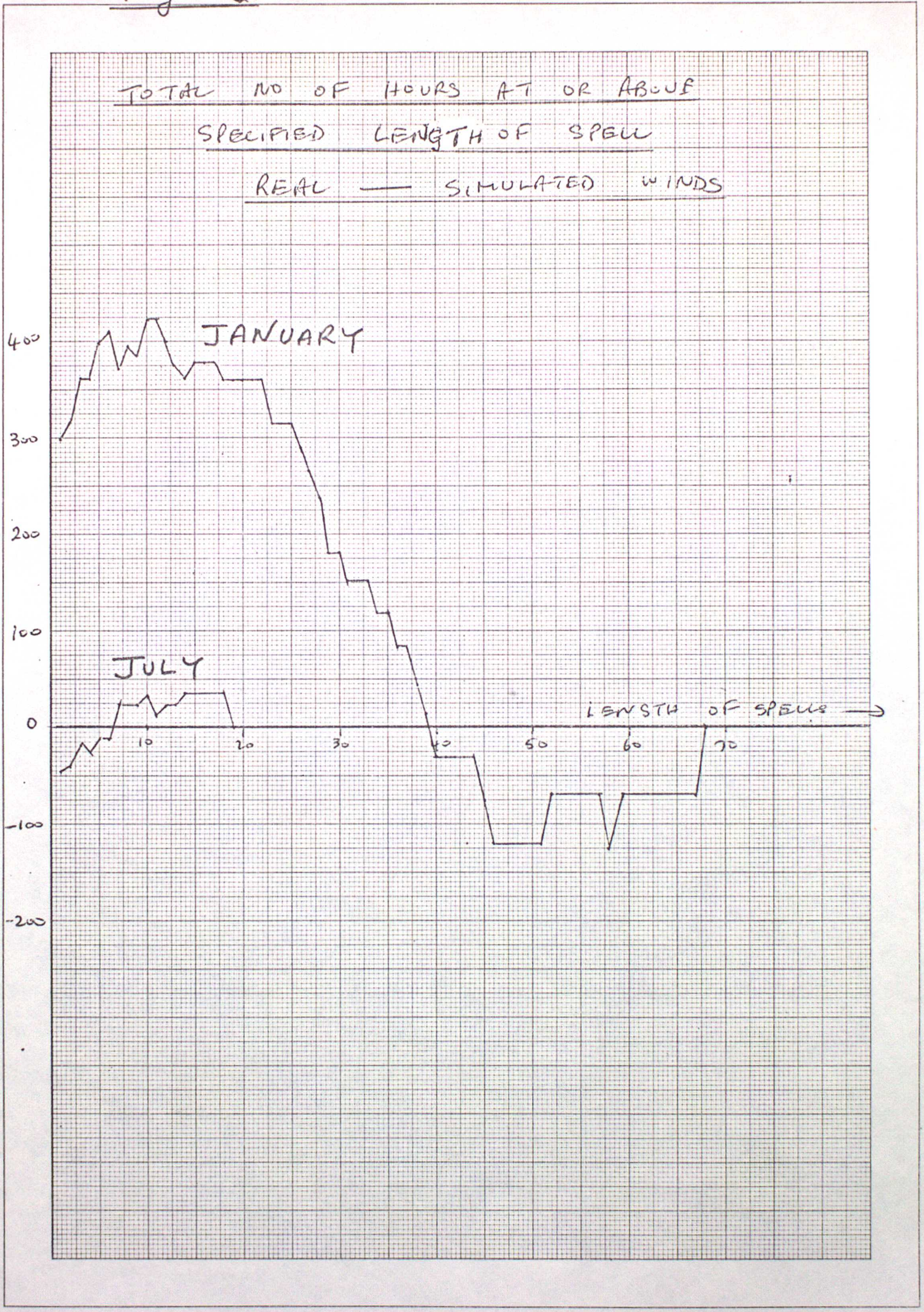

TOTAL NO OF HOURS AT OR ABOVE
SPECIFIED LENGTH OF SPELL
REAL — SIMULATED WINDS
JANUARY
JULY
LENGTH OF SPELLS
400
300
200
100
0
-100
-200
10
20
30
40
50
60
70

Table 1

Highest simulated speed in 5 years and highest actual speeds in two 5 year periods for each month of the year

	Simulated (Kn)	Actual 1971-75 (Kn)	1976-80
JAN	61	56	48
FEB	50	42 (twice)	51
MAR	45	45	48
APR	45	47	40
MAY	38	37 (twice)	37
JUN	35	29	37
JUL	45	29	33
AUG	38	38	35
SEP	50	42	60
OCT	47	44	58
NOV	52	52	50
DEC	62 (twice)	54	54

Table 2

Comparison of highest monthly simulated and actual speeds for different seasons (Kn)

SEASON	Mean of simulated	s.d	Mean of actual	s.d.	Degrees of freedom	t	Significance level.
Winter	49.5	7.67	42.2	7.13	43	3.16	1 %
Spring	36.9	4.60	35.0	6.73	43	0.98	not sig.
Summer	35.9	4.30	28.4	3.81	43	5.95	0.1 %
Autumn	45.5	3.14	40.6	7.23	43	2.50	5 %
YEAR	41.9	7.72	36.6	8.38	178	4.18	0.1 %

RANGE OF LENGTH OF SPELL	JANUARY				JULY			
	NO OF SPELLS		TOT. DURATION		NO OF SPELLS		TOT. DURATION	
	SIMULATED	REAL	SIMULATED	REAL.	SIMULATED	REAL.	SIMULATED	REAL.
1 - 5	177	125	344	234	58	38	108	72
6 - 10	22	22	172	159	14	8	103	68
11 - 15	6	10	78	123	2	1	24	11
16 - 20	4	5	68	85	1	3	18	54
21 - 25	1	4	21	90	0	0	0	0
26 - 30	1	6	30	169	0	0	0	0
31 - 35	0	2	0	68	0	0	0	0
36 - 40	0	3	0	114	0	0	0	0
41 - 45	0	2	0	89	0	0	0	0
46 - 50	0	0	0	0	0	0	0	0
51 - 55	1	0	51	0	0	0	0	0
56 - 60	1	1	58	57	0	0	0	0
61 - 65	0	0	0	0	0	0	0	0
66 - 70	1	0	67	0	0	0	0	0
TOTAL	214	180	889	1188	75	50	253	205

TABLE 3 SPELLS OF WINDS > 20 KTS (HRS)