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The effect of route choice on aircraft wind observations over the North Atlantic

by

D. Lang and N.B. Ingleby

October 1988

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Introduction

The quantity and quality of observational data gathered over the North Atlantic ocean has important consequences for the accuracy of weather forecasts for the United Kingdom. Surface observations are made by drifting buoys (approx. 3000 per month) and ships (approx. 30000 per month). However, a large proportion of the observations in the upper troposphere are made by civilian aircraft (approx. 30000 per month). Over 85% of aircraft reports are made between 300 and 200 mb, and observations are mainly Mid-Atlantic as aircraft do not report during ascent or descent.

Considerable economy of time (and hence fuel) can be made by the choice of a suitable route and flight level. Airlines normally choose minimum time routes for their aircraft, within the constraints imposed by Air Traffic Control. According to Attwooll [Ref. 1] the bulk of peak time traffic is organised into set tracks - the Organised Track Structure - while the remainder follow so called random routes.

Tailwinds speed the flight, but headwinds and crosswinds slow the aircraft. The effects of crosswinds are generally small. This suggests that Eastbound flights will report a higher mean Westerly wind component than Westbound aircraft, and that areas of strong Westerlies, particularly jet streams, will contain more Eastbound than Westbound flights.

Aircraft over the North Atlantic tend to fly Westward during daylight and Eastward at night. Thus assimilations at different times of day will receive wind observations with different sampling biases. The effect on analyses and forecasts should be considered further but is not covered in this work.

Aircraft reports over the North Atlantic for the month of October 1987 were separated into Westbound and Eastbound flights, and their spatial and temporal distribution and their wind observations were investigated.

Procedure

The aircraft reports (AIREPs) used were extracted from the Observation Processing Database (OPD). The sample was taken from October 1987 and restricted to those reports with longitude between 90°W and 30°E and latitude between 30°N and 70°N. This was sufficient to cover the majority of the North Atlantic. In general aircraft do not report over land so the data mainly consisted of observations over the ocean. The 4th, 5th, 9th and 18th days of the month were excluded because of missing or conflicting data in the OPD.

All repeat observations (probably unique reports received by more than one collecting centre) and reports without wind observations were excluded from this study.

The observations were sorted into flights. (Each call-sign/day combination was considered a separate flight. The call-sign is unique to a particular airline, flight - departure and destination airports - and time of day.) A pair of consecutive reports from the same flight was used to determine the

direction of flight by inspection of the change in longitude with time. If there was only one report from a particular flight then it was excluded. The reports were divided into an Eastbound group and a Westbound group, these contained 10091 and 9545 observations respectively. The numbers of observations processed are summarised in Table 1. A few observations were ignored because of a minor programming error.

The majority of reports are made every 10° of longitude. The observations were 'binned' in intervals of 10° longitude by one hour. The longitude intervals are 95°W - 85°W to 25°E - 35°E, the time intervals are 00.00Z - 00.59Z to 23.00Z - 23.59Z; on the longitude-time tables the intervals are labelled with their mid-points. Mean and standard deviation (S.D.) values were also calculated for all Westbound flights and all Eastbound flights and are given in Table 2 - they will be mentioned in the appropriate sections.

Distribution of reports

Time-longitude diagrams of frequency are presented as Figures 1 and 2 for Westbound and Eastbound flights respectively (Tables 3 and 4 are tabulations of the same data). Figure 3 shows the net (Westbound plus Eastbound) frequency. Note that the longitude of the maximum frequency decreases (increases) with time for Westbound (Eastbound) flights - as expected.

These diagrams provide a clear indication that Eastbound and Westbound flights occur at quite distinct times. Westbound aircraft generally make reports between 11Z and 18Z and Eastbound between 01Z and 08Z. This is mainly due to practical constraints including time-zone differences, the total flight time and limitations on aircraft landing or taking off during the night. The main Westbound group has a maximum of 11.9 reports per day at 20°W, 12Z-13Z (Table 3). The main Eastbound group has a maximum of 14.7 reports per day at 20°W, 04Z-05Z (Table 4).

The Global analysis has assimilation times at 6 hour intervals from 00Z ± 3 hours through to 18Z ± 3 hours and the fine mesh analysis at 3 hour intervals from 00Z ± 1½ hours through to 21Z ± 1½ hours. Between 00Z and 09Z mostly data from Eastbound aircraft will be assimilated; while between 12Z and 21Z mostly data from Westbound aircraft will be assimilated. Figure 3 shows that there are very few AIREPs in the East Atlantic round 00Z, and very few in the West Atlantic at 12Z, this is unfortunate as these are the main analysis times.

In Figures 1 and 2 there are minor secondary maxima, up to about two reports per day, at about 04Z for Westbound flights and 18Z for Eastbound flights. These represent aircraft moving in the direction opposite to the main flow at those times.

Height of observations

Aircraft flight levels, while quoted in feet, are actually based on pressure; the height-pressure relationship is given by the ICAO standard atmosphere. In the pre-processing of observations for the analysis the pressures are re-calculated. Aircraft are separated in the vertical by a minimum of 2000 ft [610 m].

It was found that the mean pressure level for Westbound flights is 260.3 mb with an S.D. of 49.7 mb while Eastbound flights have a mean of 243.2 mb and an S.D. of 46.2 mb. Corresponding flight level statistics are: Westbound - mean 10.0 km with an S.D. of 1.3 km and Eastbound - mean 10.8 km with an S.D. of 1.4 km. This is in agreement with Attwooll [Ref. 1] who stated that Westbound aircraft aim to fly at 31000 - 35000ft [9.4km - 10.7km] while Eastbound aircraft prefer to fly at 33000 - 37000ft [10km - 11.3km].

A histogram of pressure reports was plotted and is shown in Fig. 4. The bin range is 200 to 320 mb in intervals of 10 mb and the extreme bins include all reports outside this range. This figure shows the difference in the use of flight levels which results in the difference in mean pressure. It also shows the discrete nature of the flight levels, for example there are almost no observations between 240 and 260 mb whereas there are large numbers in adjacent pressure intervals.

Mean winds

The winds are reported as wind speed and direction but are converted to Westerly (u) and Southerly (v) components for use in the analysis. The mean Westerly component is 21.9 knots with an S.D. of 35.2 knots for Westbound flights, for Eastbound flights the mean is 56.9 knots with an S.D. of 39.7 knots. Thus there is a substantial dependence on the direction of flight.

Figures 5 and 6 are time-longitude diagrams of Westerly wind for Westbound and Eastbound flights respectively (the values are tabulated in Tables 5 and 6). All categories whose frequency was less than one per day per hour interval were masked out in order to remove contours of low statistical reliability. As expected the unmasked contours indicate little or no evidence of a diurnal variation in wind for each longitude. Fig. 7 is a histogram of u reports in 20 knot intervals. For all bins higher than 60 - 80 knots the frequency of Eastbound flights is greater than that for Westbound flights.

The mean Southerly component is -4.1 knots with an S.D. of 39.9 knots for Westbound flights, and -7.3 knots with an S.D. of 39.3 knots for Eastbound flights. Fig. 8 is a histogram of v reports (note the difference in range from Fig. 7). Most aircraft report a Southerly component of less than 40 knots. The bias is much smaller than for u. Note that aircraft will not travel due East or West because in general the airports will be at different latitudes. There will also be changes in bearing as the aircraft follow great circles.

Summary

The North Atlantic air traffic system is clearly tidal with the majority of Eastbound flights reporting between 01Z and 08Z and the majority of Westbound flights reporting between 11Z and 18Z. This will result in some assimilations containing predominantly Westbound reports and some containing predominantly Eastbound reports.

On average Eastbound flights are higher than Westbound flights by nearly 30 mb.

There is a bias in the reported Westerly wind. The mean Westerly component for the Eastbound reporting group is 56.9 knots while that for the Westbound group is 21.9 knots. The difference is due to the airlines choosing routes that minimise flight time.

Further work is required if the effect of the aircraft sampling biases on numerical analyses is to be assessed. The work here suggests that there may be systematic differences with time of day.

References

[1] Attwooll V.W., 1986, 'The Economics of the North Atlantic Air Traffic System', J. of Navigation 39, pp 103-109.

Observations discarded	
Number of duplicate observations	1255
Number of flights with only one observation	1612
Number of observations without reported wind	113
Observations used in this study	
Number of observations on Westbound flights	10091
Number of observations on Eastbound flights	9545
Total number of reports	22657

Table 1. Numbers of observations for 27 days in October 1987.

	Westbound		Eastbound	
No/day	**373.7**		**353.5**	
U (knots)	**21.9**	(35.2)	**56.9**	(39.7)
V (knots)	**-4.1**	(39.9)	**-7.3**	(39.3)
P (mb)	**265.6**	(48.2)	**237.8**	(45.2)
H (km)	**10.04**	(1.29)	**10.77**	(1.36)

Table 2. Results for all Westbound and Eastbound aircraft.
Number of reports per day, Westerly and Southerly wind components, Pressure and Height.
Numbers in bold are mean values, with standard deviations in brackets.

LONG HOUR(Z)	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30
0.5	0.0	0.0	0.0	0.0	0.1	0.6	0.3	0.9	1.0	0.0	0.0	0.0	0.0
1.5	0.0	0.0	0.0	0.0	0.5	0.4	0.9	1.3	0.6	0.0	0.0	0.0	0.0
2.5	0.0	0.0	0.0	0.1	0.4	1.1	0.8	1.1	0.7	0.0	0.0	0.0	0.0
3.5	0.0	0.0	0.0	0.0	0.3	1.0	0.7	2.2	1.1	0.0	0.0	0.0	0.0
4.5	0.0	0.0	0.0	0.1	0.1	0.7	2.3	1.0	0.6	0.0	0.0	0.0	0.0
5.5	0.0	0.0	0.0	0.1	0.4	1.4	1.0	0.9	0.6	0.0	0.0	0.0	0.0
6.5	0.0	0.0	0.0	0.0	0.6	0.8	0.9	0.9	0.4	0.0	0.0	0.0	0.0
7.5	0.0	0.0	0.0	0.1	0.7	0.7	0.9	0.5	0.4	0.0	0.0	0.0	0.0
8.5	0.0	0.0	0.0	0.5	0.4	0.7	0.7	0.4	0.8	0.0	0.0	0.0	0.0
9.5	0.0	0.0	0.0	0.1	0.4	0.5	0.6	0.9	1.3	0.1	0.0	0.1	0.0
10.5	0.0	0.0	0.0	0.1	0.4	0.5	1.2	1.8	4.3	0.4	0.0	0.1	0.0
11.5	0.0	0.0	0.1	0.1	0.5	1.4	3.1	6.8	10.6	1.3	0.1	0.0	0.0
12.5	0.0	0.0	0.0	0.0	1.1	2.9	8.2	11.9	10.9	1.6	0.1	0.0	0.0
13.5	0.0	0.0	0.0	0.8	3.5	8.1	11.6	11.6	9.6	1.5	0.0	0.0	0.0
14.5	0.0	0.0	0.1	2.0	5.8	9.6	11.5	10.0	10.6	0.7	0.0	0.0	0.0
15.5	0.0	0.0	0.1	2.1	7.6	11.3	10.2	9.2	6.4	0.1	0.0	0.0	0.0
16.5	0.0	0.0	0.1	2.7	8.4	9.9	7.9	5.5	3.7	0.1	0.1	0.0	0.0
17.5	0.0	0.1	0.3	3.6	7.1	6.0	5.1	3.2	2.0	0.1	0.0	0.0	0.0
18.5	0.0	0.0	0.5	2.4	3.9	4.0	3.2	2.3	1.8	0.0	0.0	0.0	0.0
19.5	0.0	0.0	0.1	1.3	2.4	2.9	3.4	1.8	1.0	0.0	0.0	0.0	0.0
20.5	0.0	0.0	0.2	0.6	2.0	2.5	1.5	1.4	0.6	0.0	0.0	0.0	0.0
21.5	0.0	0.0	0.1	0.6	1.3	1.4	1.1	0.7	0.6	0.0	0.0	0.0	0.0
22.5	0.0	0.0	0.1	0.1	0.9	1.0	0.6	0.9	0.6	0.0	0.0	0.0	0.0
23.5	0.0	0.0	0.1	0.3	0.5	0.7	1.0	0.4	0.5	0.1	0.0	0.0	0.0

Table 3. Frequency of reports by time and longitude, October 1987. Westbound flights.

LONG HOUR(Z)	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30
0.5	0.0	0.0	0.4	2.1	3.8	0.9	0.4	0.3	0.0	0.0	0.1	0.0	0.0
1.5	0.0	0.1	0.2	1.4	11.0	7.9	1.9	0.6	0.3	0.1	0.0	0.0	0.0
2.5	0.0	0.0	0.2	2.0	11.7	13.6	12.1	3.5	0.7	0.1	0.0	0.0	0.0
3.5	0.0	0.0	0.4	1.4	8.2	13.4	14.4	12.3	2.8	0.0	0.0	0.0	0.0
4.5	0.0	0.0	0.2	1.6	6.1	8.7	11.7	14.7	4.6	0.1	0.0	0.0	0.0
5.5	0.0	0.1	0.1	1.4	4.9	6.9	7.2	9.6	3.9	0.4	0.0	0.0	0.0
6.5	0.0	0.1	0.1	1.1	2.3	4.9	7.3	6.1	2.0	0.4	0.0	0.0	0.0
7.5	0.0	0.0	0.0	2.1	2.5	3.2	4.7	5.4	1.9	0.0	0.0	0.0	0.0
8.5	0.0	0.0	0.1	1.2	2.9	3.5	3.6	3.8	0.9	0.0	0.0	0.0	0.0
9.5	0.0	0.0	0.0	0.3	1.8	3.0	3.6	3.9	0.7	0.1	0.0	0.0	0.0
10.5	0.0	0.0	0.0	0.3	1.2	1.7	3.0	3.1	1.1	0.1	0.0	0.0	0.0
11.5	0.0	0.0	0.0	0.1	0.6	1.3	2.0	2.3	0.6	0.2	0.0	0.0	0.0
12.5	0.0	0.0	0.3	0.0	0.4	0.7	1.1	1.3	0.3	0.0	0.0	0.0	0.0
13.5	0.0	0.0	0.1	0.0	0.5	0.8	0.5	0.7	0.3	0.0	0.0	0.0	0.0
14.5	0.0	0.0	0.1	0.1	1.0	0.7	0.8	0.7	0.2	0.2	0.0	0.0	0.0
15.5	0.0	0.0	0.0	0.1	1.3	1.1	1.5	1.0	0.4	0.0	0.0	0.0	0.0
16.5	0.0	0.0	0.1	0.1	1.0	2.1	1.8	1.4	0.4	0.0	0.0	0.0	0.0
17.5	0.0	0.0	0.3	0.3	0.9	1.8	1.9	2.3	0.3	0.0	0.0	0.0	0.0
18.5	0.0	0.1	0.3	0.6	1.1	0.9	2.1	1.6	1.0	0.1	0.0	0.0	0.0
19.5	0.0	0.0	0.1	0.2	0.7	0.9	1.4	1.9	0.6	0.1	0.0	0.0	0.0
20.5	0.0	0.0	0.0	0.1	0.4	0.4	0.6	0.7	0.3	0.0	0.0	0.0	0.0
21.5	0.0	0.0	0.2	0.1	0.3	0.4	0.2	0.2	0.1	0.0	0.0	0.0	0.0
22.5	0.0	0.0	0.1	0.2	0.4	0.4	0.6	0.1	0.0	0.0	0.0	0.0	0.0
23.5	0.0	0.0	0.1	0.3	0.3	0.3	0.3	0.3	0.1	0.0	0.0	0.0	0.0

Table 4. Frequency of reports by time and longitude, October 1987. Eastbound flights.

LONG HOUR(Z)	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30
0.5	0.0	0.0	0.0	-12.5	47.5	10.2	32.5	38.8	38.4	20.0	0.0	0.0	0.0
1.5	0.0	0.0	0.0	12.5	33.8	30.1	29.8	39.5	40.8	-2.6	0.0	0.0	0.0
2.5	0.0	21.9	0.0	49.9	64.7	29.4	20.1	34.1	44.2	0.0	0.0	0.0	0.0
3.5	0.0	-9.6	0.0	24.1	9.9	22.1	27.8	29.6	31.5	0.0	0.0	0.0	0.0
4.5	0.0	0.0	58.2	44.1	19.1	10.6	14.7	39.7	37.4	0.0	0.0	0.0	0.0
5.5	0.0	0.0	0.0	18.1	48.8	9.4	29.8	24.0	26.2	28.3	0.0	0.0	0.0
6.5	0.0	0.0	4.3	59.1	29.3	11.9	18.6	28.2	5.3	0.0	0.0	0.0	0.0
7.5	0.0	0.0	37.3	16.5	24.3	29.9	10.9	10.6	3.4	0.0	0.0	0.0	0.0
8.5	0.0	0.0	80.0	51.4	39.2	44.5	16.4	23.8	27.8	0.0	0.0	0.0	0.0
9.5	0.0	0.0	43.7	85.7	46.5	26.9	42.3	29.9	14.6	1.3	0.0	8.6	0.0
10.5	0.0	0.0	0.0	47.7	25.7	43.1	34.2	19.2	14.6	-0.5	0.0	28.6	44.8
11.5	0.0	0.0	5.6	50.1	33.8	31.9	19.6	14.7	16.8	10.9	49.8	59.1	0.0
12.5	0.0	0.0	23.0	6.8	33.1	19.9	18.5	13.9	13.4	11.3	44.6	0.0	0.0
13.5	0.0	0.0	23.0	15.6	24.0	23.0	18.2	17.8	11.9	14.9	0.0	0.0	0.0
14.5	0.0	0.0	-1.6	17.1	29.0	28.9	19.4	14.9	16.9	30.5	0.0	0.0	0.0
15.5	0.0	0.0	3.3	24.2	33.6	18.4	15.6	14.7	18.0	1.6	25.7	13.7	0.0
16.5	0.0	0.0	30.3	27.6	30.1	28.4	17.0	17.5	24.3	38.0	27.3	0.0	0.0
17.5	0.0	53.7	20.7	32.6	34.4	26.1	20.1	15.5	19.6	0.8	0.0	0.0	0.0
18.5	0.0	0.0	39.4	39.5	36.2	19.9	25.2	21.5	13.9	-19.2	0.0	0.0	0.0
19.5	0.0	0.0	68.4	28.4	36.8	33.4	26.1	19.0	5.6	0.0	0.0	0.0	0.0
20.5	0.0	0.0	37.4	26.6	38.9	31.6	23.9	16.2	17.5	0.0	0.0	0.0	0.0
21.5	0.0	0.0	53.6	31.2	35.6	35.4	15.8	10.9	14.9	0.0	0.0	0.0	0.0
22.5	0.0	0.0	97.2	33.3	42.9	24.2	19.5	8.3	21.7	0.0	0.0	0.0	0.0
23.5	0.0	3.5	70.1	24.9	36.5	20 2	11.4	11.0	17.2	37.9	0.0	0.0	0.0

Table 5. Westerly wind component by time and longitude, October 1987. Westbound flights.

LONG HOUR(Z)	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30
0.5	0.0	28.2	51.3	51.9	79.2	64.1	27.8	41.3	0.0	0.0	20.3	0.0	0.0
1.5	0.0	19.6	39.6	51.1	80.6	78.7	63.5	64.6	14.5	-3.5	0.0	0.0	0.0
2.5	0.0	2.6	35.3	42.8	80.6	76.0	69.4	49.6	37.4	11.2	0.0	0.0	0.0
3.5	0.0	0.0	53.5	60.0	70.3	73.6	61.6	48.3	47.8	70.7	0.0	0.0	0.0
4.5	0.0	37.9	35.0	53.6	71.9	64.2	54.6	41.1	40.7	25.4	0.0	0.0	0.0
5.5	0.0	28.5	70.4	49.0	67.8	71.0	55.6	34.7	31.0	23.9	0.0	0.0	0.0
6.5	0.0	48.4	25.4	35.9	61.1	58.2	54.2	40.0	34.9	3.3	0.0	0.0	0.0
7.5	0.0	30.6	46.4	38.1	67.7	56.2	44.1	36.4	38.0	0.0	0.0	0.0	0.0
8.5	0.0	0.0	14.2	36.2	53.0	61.7	52.5	33.0	32.3	0.0	0.0	0.0	0.0
9.5	0.0	0.0	45.2	47.3	67.3	58.3	49.8	36.6	28.0	70.4	0.0	0.0	0.0
10.5	0.0	0.0	57.5	64.2	84.4	70.3	50.0	39.0	29.7	-0.8	51.6	0.0	0.0
11.5	0.0	-13.0	59.1	99.2	89.9	73.5	51.4	40.3	26.6	1.9	0.0	0.0	0.0
12.5	0.0	0.0	75.4	0.0	81.9	75.2	58.6	39.5	14.3	0.0	0.0	0.0	0.0
13.5	0.0	0.0	55.0	55.3	59.6	70.8	55.1	23.8	34.1	0.0	0.0	0.0	0.0
14.5	0.0	17.4	46.4	58.6	66.1	65.3	58.3	43.7	27.1	-14.4	0.0	0.0	0.0
15.5	0.0	0.0	0.0	55.5	88.5	67.1	50.3	28.4	8.4	0.0	0.0	0.0	0.0
16.5	0.0	0.0	37.9	67.5	84.6	68.8	55.9	38.7	33.8	31.7	0.0	0.0	0.0
17.5	0.0	73.9	56.1	43.1	78.2	81.2	58.3	37.7	53.9	0.0	0.0	0.0	0.0
18.5	0.0	62.8	47.9	51.0	49.9	72.8	58.7	45.3	29.0	8.5	0.0	0.0	0.0
19.5	0.0	0.0	62.6	40.0	48.0	51.3	42.7	37.8	30.7	21.7	0.0	0.0	0.0
20.5	0.0	0.0	30.3	51.4	56.8	54.2	33.5	36.5	25.2	0.0	0.0	0.0	0.0
21.5	0.0	0.0	40.0	74.7	70.0	76.7	69.4	28.2	27.4	0.0	0.0	0.0	0.0
22.5	0.0	22.9	25.3	50.9	80.7	66.3	63.9	18.0	79.9	0.0	0.0	0.0	0.0
23.5	0.0	27.0	50.9	40.0	44.2	64.0	52.4	53.9	73.6	0.0	0.0	0.0	0.0

Table 6. Westerly wind component by time and longitude, October 1987. Eastbound flights.

Figure 1. Time-longitude diagram of frequency of AIREPs, October 1987.
Contour interval is one report per day (in 10° longitude by 1 hour category).
Westbound flights: total = 373.7 reports/day.

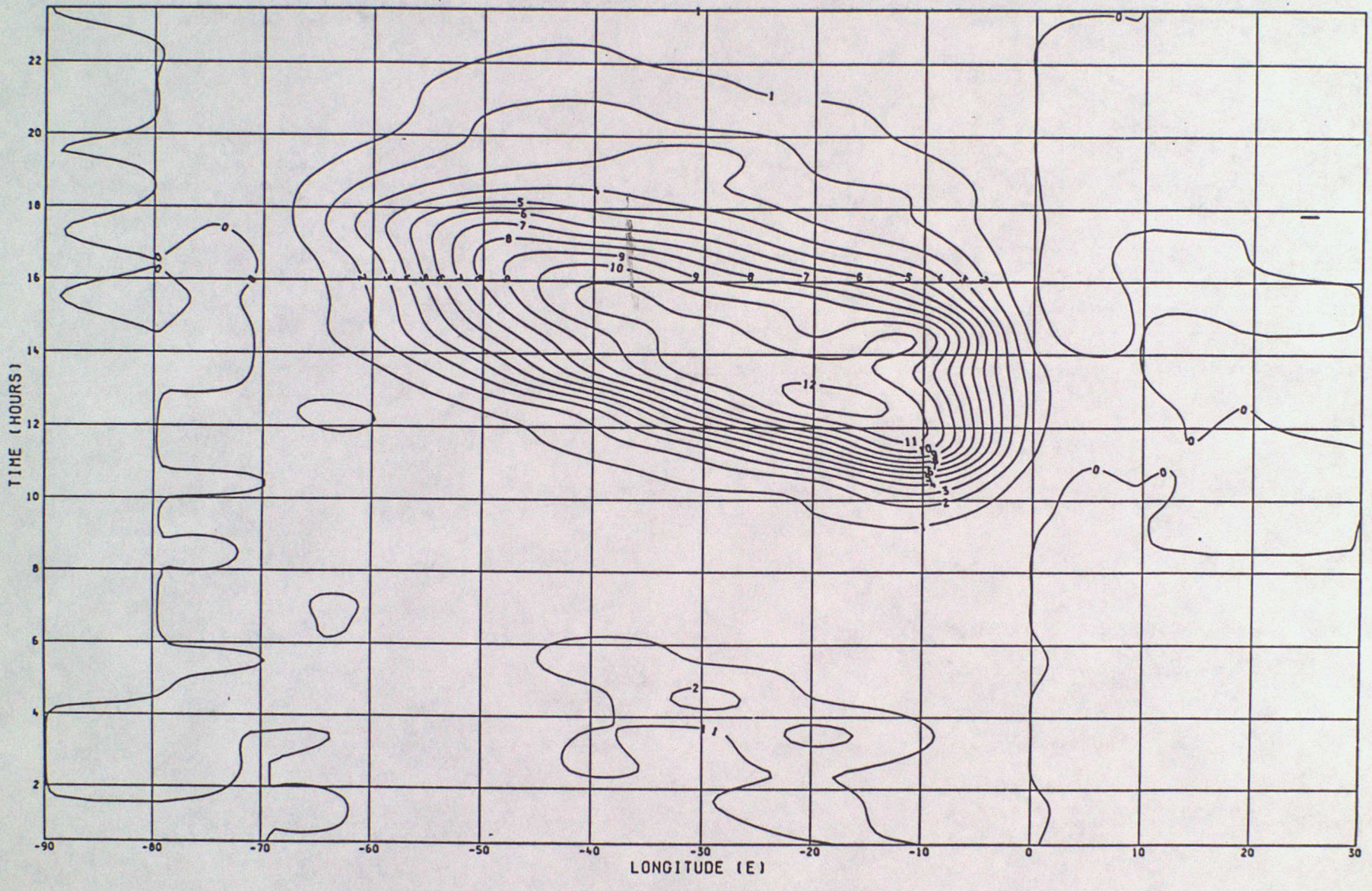

Figure 2. Time-longitude diagram of frequency of AIREPs, October 1987.
Contour interval is one report per day (in 10° longitude by 1 hour category).
Eastbound flights: total = 353.5 reports/day.

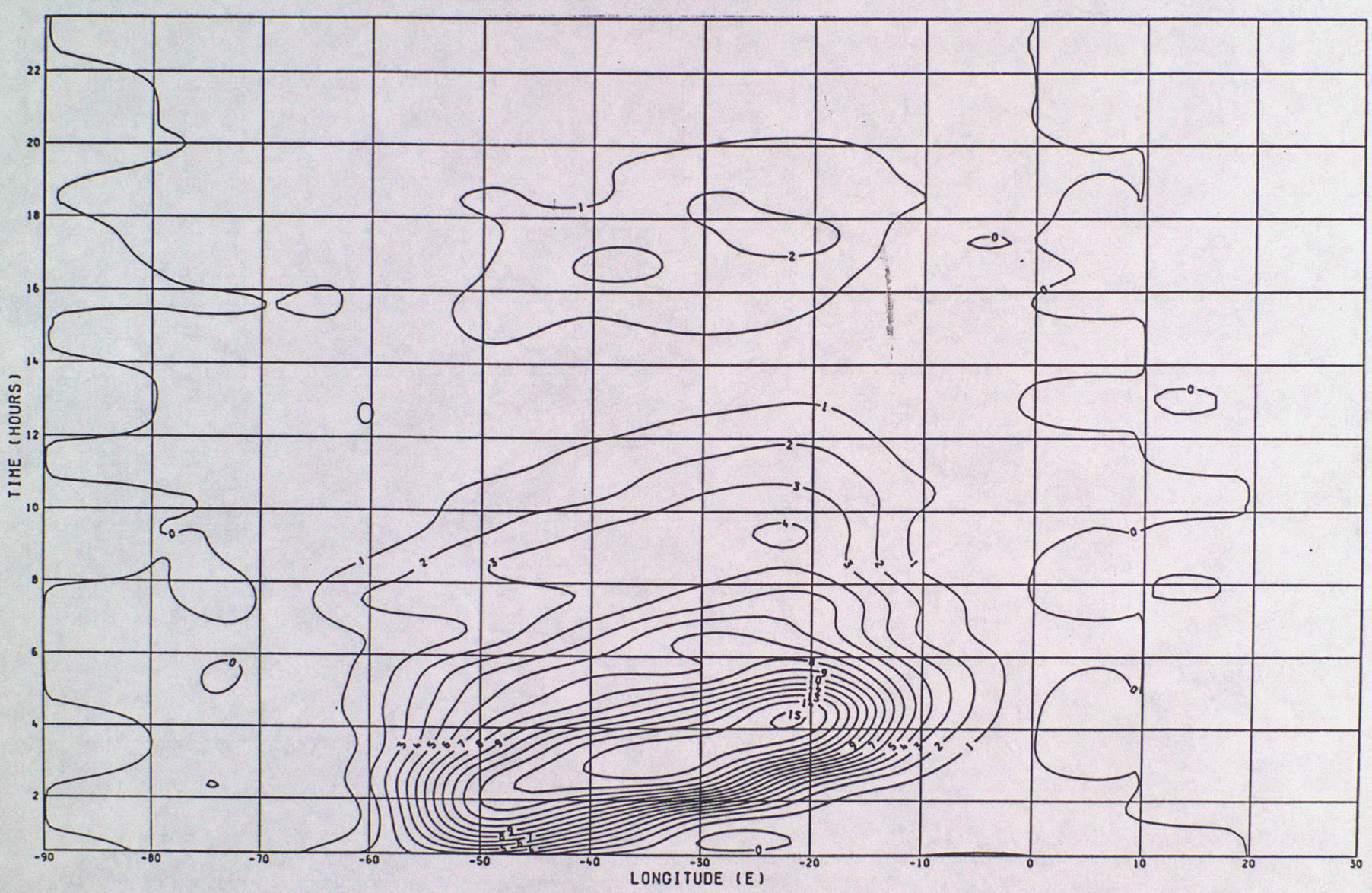

Figure 3. Time-longitude diagram of frequency of AIREPs, October 1987.
Contour interval is one report per day (in 10° longitude by 1 hour category).
Westbound and Eastbound flights combined: total = 727.3 reports/day.

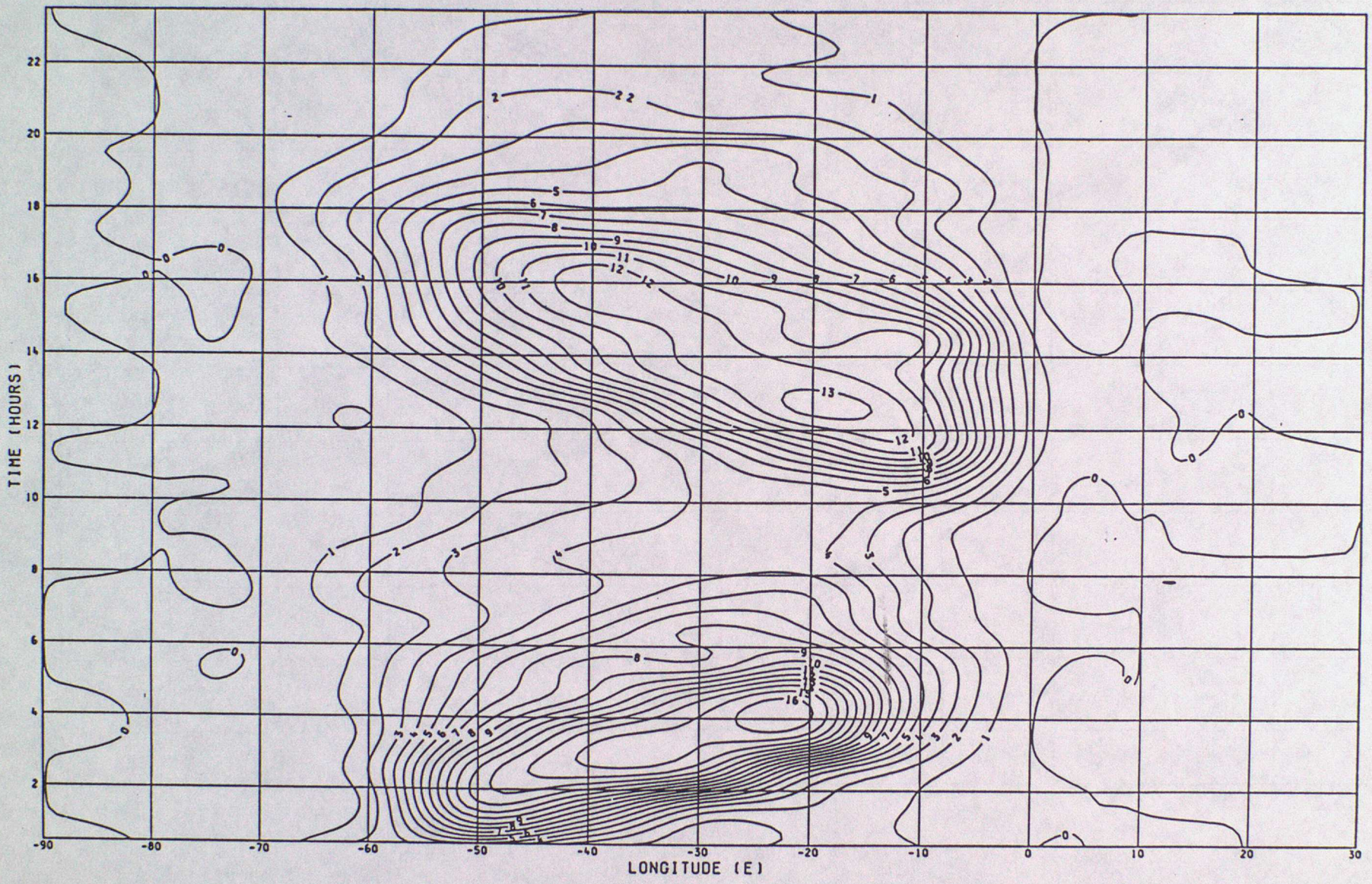

Figure 4. Histogram of AIREP pressures, October 1987.
The Y axis is percentage of reports processed.

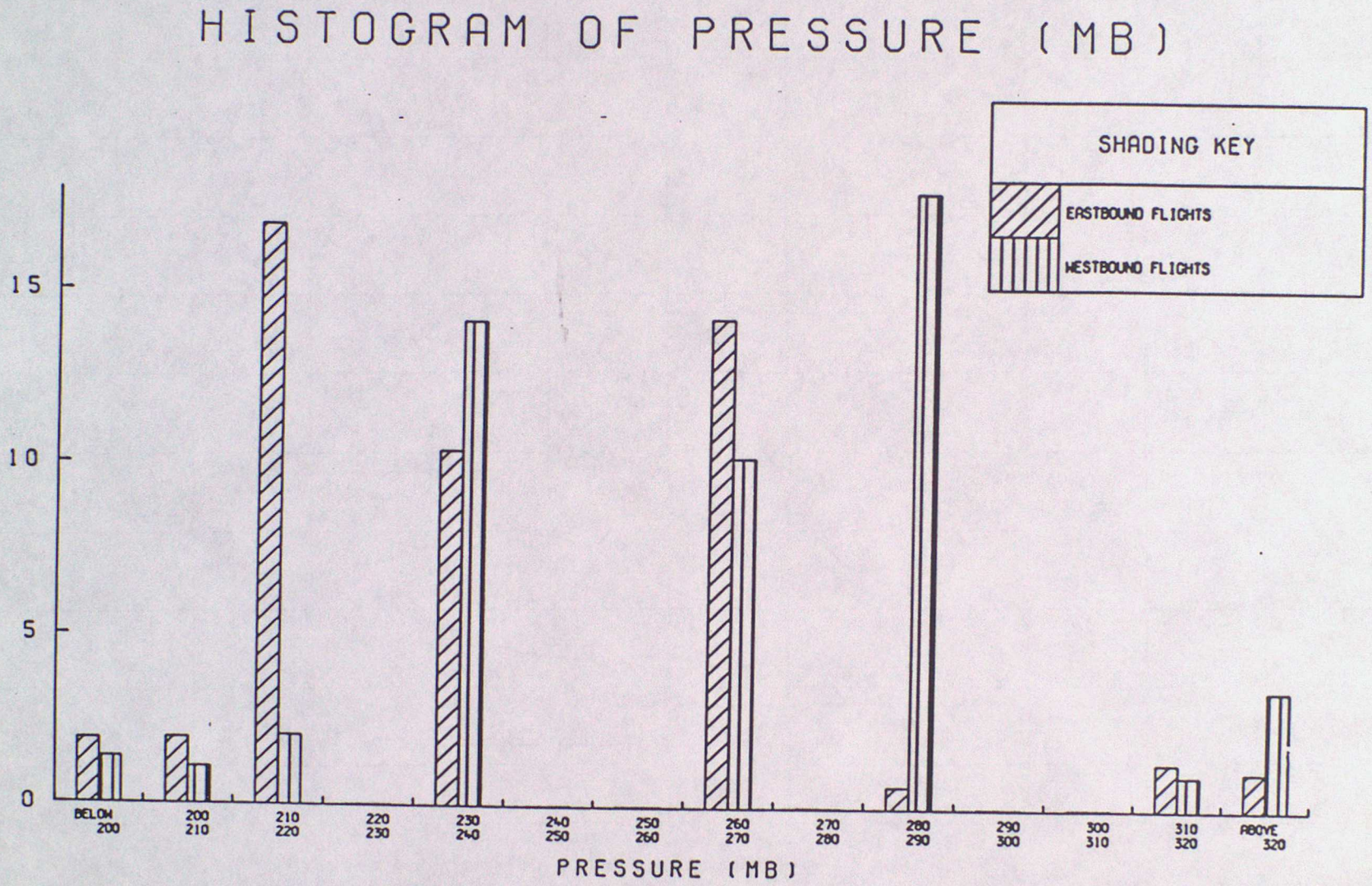

Figure 5. Time-longitude diagram of Westerly wind component, October 1987.
Contour interval is 5 knots.
Westbound flights: mean = 21.9 knots.

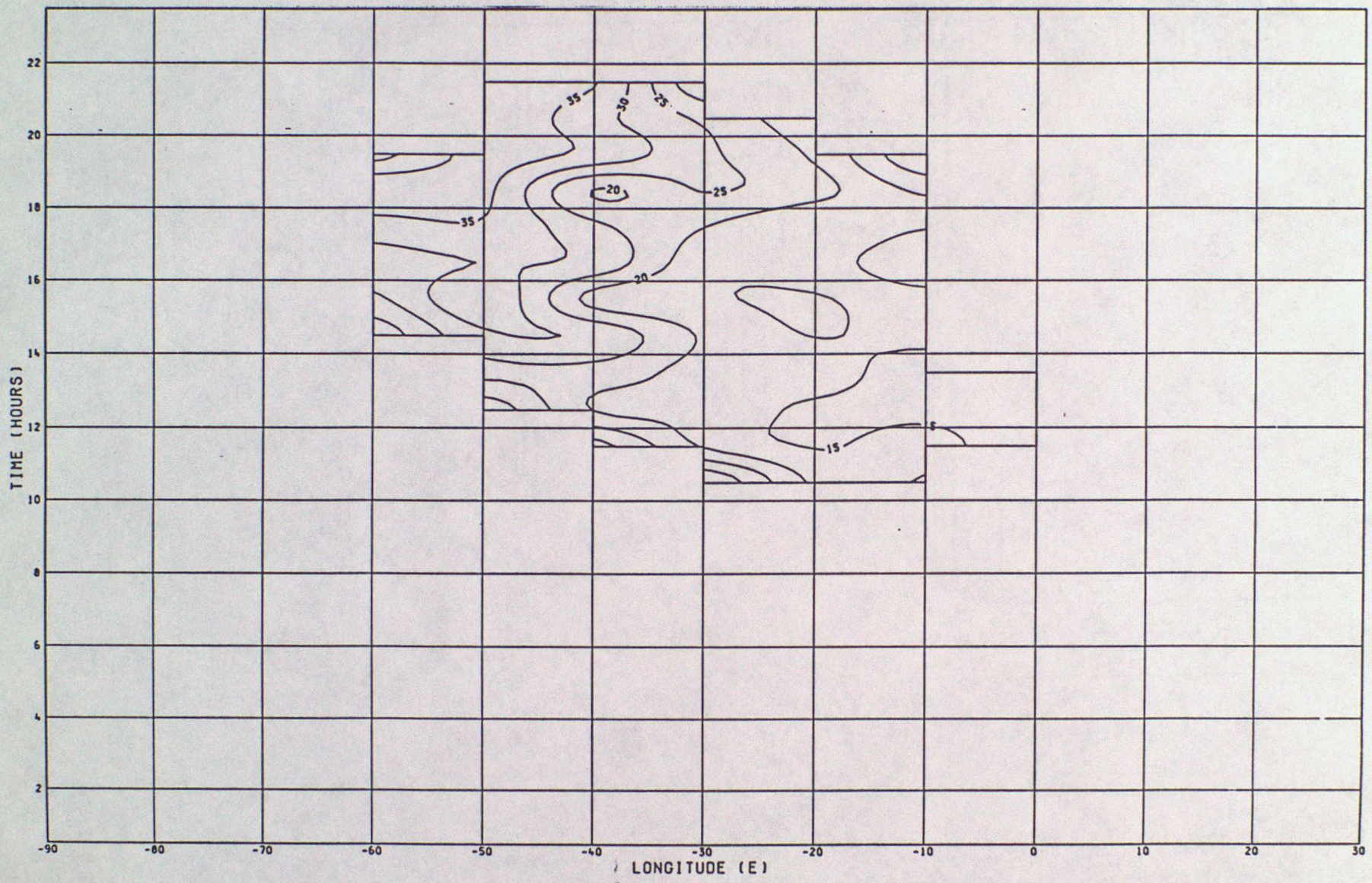

Figure 6. Time-longitude diagram of Westerly wind component, October 1987.
Contour interval is 5 knots.
Eastbound flights: mean = 56.9 knots.

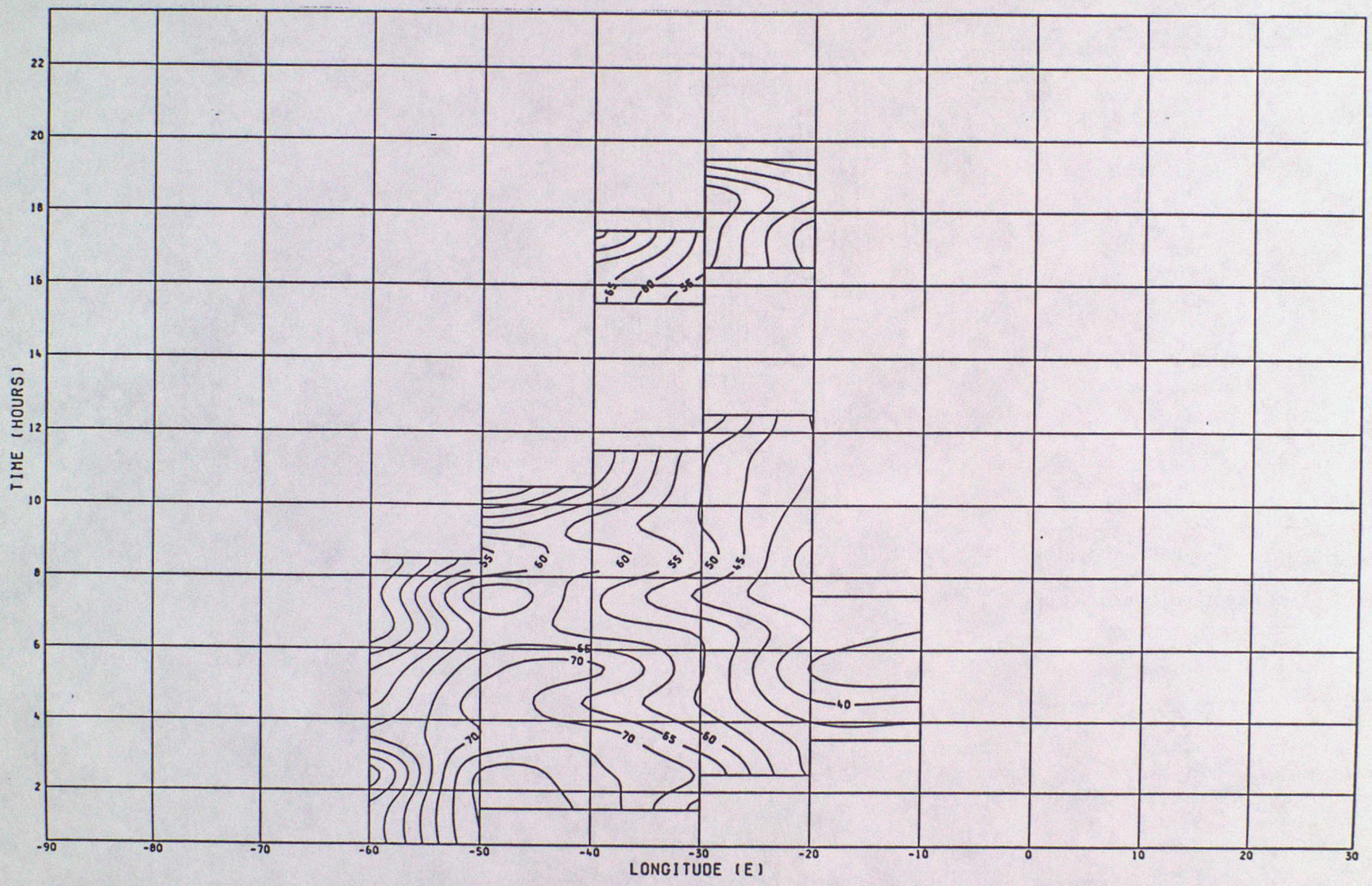

Figure 7. Histogram of Westerly wind component, October 1987.
The Y axis is percentage of reports processed.

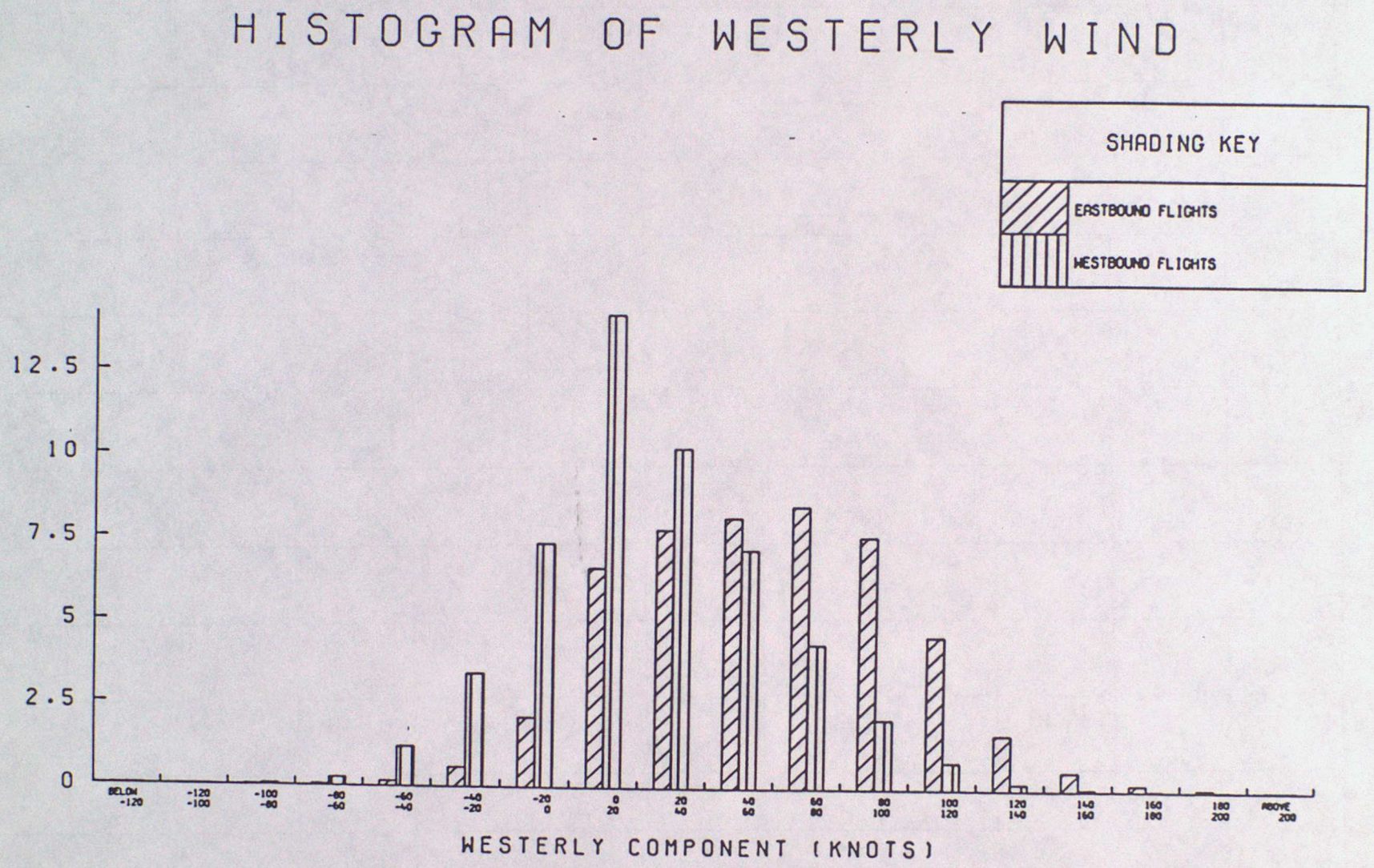

Figure 8. Histogram of Southerly wind component, October 1987.
The Y axis is percentage of reports processed.