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DEPARTMENT OF TRANSPORT
METEOROLOGICAL BRANCH

THE ACCURACY OF UPPER LEVEL
WIND FORECASTS

BY

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CANADA - DEPARTMENT OF TRANSPORT - METEOROLOGICAL BRANCH

THE ACCURACY OF UPPER LEVEL WIND FORECASTS

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F. J. Mahaffy, D. S. Ross
and
Student Assistants at Montreal

Student Assistants participating in this study were:
S. Glickman, R. Vachon, G. Guerin and C. Marullo.

1. INTRODUCTION

The purpose of this study was to determine the accuracy of upper wind forecasts for various routes and levels as compiled from upper level prognostic charts prepared at the Main Meteorological Office at Dorval. The work was done by students from several Canadian universities under the supervision of meteorologists from Dorval during the summers of 1961-63 inclusive.

There are a number of previous studies on the errors in upper level winds. A paper by Major Elsaesser (1) provides a valuable summary of a number of previous studies and draws a number of conclusions as to the relative value of upper wind forecasts obtained using persistence, climatology and conventional techniques for various periods. An attempt is made in this study to verify his conclusions regarding the relative value of conventional versus persistence forecasts for 12 and 24 hours, but no comparison is made with climatological forecasts. Some of Elsaesser's paper was based on previous work discussed by Sutcliffe and Sawyer in 1953 (2).

There were several reasons for undertaking a new study of errors in upper level winds:

- (1) Few data were available on errors in Canadian forecasts.
- (2) Methods of preparation of prognostic charts have changed and since earlier studies there has been an increase in the number of basic data available.
- (3) In attempting to assess the value of future changes in forecasting methods and basic data, it is necessary to have some means of comparing and measuring the results achieved. Such a yardstick seemed to be lacking for Canadian forecasts.
- (4) It was hoped that such a study would give some indication of the value added to the basic data (the current analysed charts) or the results achieved, by the whole forecasting process.

The paper by Major Ellsaesser (1) suggested that for periods of 12 hours or less a persistence forecast was equal to or better than a forecast prepared by conventional forecast techniques. Since persistence represents the best information available before the application of any forecast techniques, the errors resulting from a persistence forecast for 12 and 24 hours are compared with the errors resulting from conventional methods.

Previous studies have tended to concentrate on the verification of spot-wind forecasts. In view of some of the objectives of this study as outlined above, it was felt that figures should be based on the mean vector error over a route. Ellsaesser found that this figure varied inversely with the length of the route.

2. TECHNIQUES USED IN UPPER LEVEL PROGNOSTIC CHARTS

The Dorval 500-mb and 300-mb prognostic charts used in this study were mainly based on the 500-mb barotropic prog as received from the U.S.W.B. NWP centre. The NWP prog was modified subjectively by the forecaster to conform with trends indicated by the latest analysis, especially in areas of development. The 300-mb prog was prepared from the 500-mb one using the Boville technique (3). A jet-isotach prog for 500 mbs was then prepared, having regard to the prognostic position of surface fronts and the historical relation between the jet axis and jet maxima and minima. A 300-mb jet-isotach prog was obtained using the 500-mb positions for jet axes and maxima except where current analysis indicated a horizontal separation.

3. DETERMINATION OF ERRORS

Direction of the forecast upper winds was determined by measuring direction of the contours on the prognostic chart. Speeds were interpolated from the isotach pattern.

To determine actual winds, observations were used from RAWIN stations spaced as equally as possible along the route. In those cases where the observation was missing, a geostrophic wind measured from the current chart was used.

The following are the observations used on the various routes:

- (1) Montreal-London: Maniwaki, Caribou, Stephenville, Ship Charlie, Ship Juliette, Valentia, London
- (2) Gander-London: Argentia, Ship Charlie, Ship Juliette, Valentia, London
- (3) Goose-Thule: Goose Bay, Fort Chimo, Frobisher, Clyde River, Thule
- (4) Montreal-Vancouver: Maniwaki, Sault Ste. Marie, International Falls, Glasgow, Spokane, Seattle
- (5) Toronto-Winnipeg: Buffalo, Sault Ste. Marie, International Falls.

Since stations were not evenly spaced along the route, a check was run initially to see whether they gave a good representation of mean winds along the route. To do this, a template with 10 equally spaced intervals was placed over the Montreal-London route and resultant mean east-west vectors were obtained using a geostrophic wind scale for both prognostic and actual 500-mb charts for 20 occasions in May 1961. This was then compared with the resultant vectors obtained using observations at the 7 stations. The average variation in the two methods was 7% for prog charts and 4% for actual charts. As a result it was felt that the 7 stations selected gave a good representation of actual resultant wind vectors.

Two measures of error distribution were obtained initially: (1) vector mean difference, or error denoted by \overline{VMD} and (2) the root mean square vector difference (or error) by ϵ . From ϵ it is possible to obtain the standard deviation (σ) if the VMD is different from zero, and also the mean vector error (MVE).

The following procedure was used in obtaining these quantities:

- 3.1. (1) From actual maps, the resultant wind vectors were obtained by vectorial addition of observed winds at the various stations along the route. This was done by resolving each wind into X and Y components, and adding algebraically
- 3.2. (2) A similar process was followed for prognostic charts except that the winds were obtained from contour directions and isotachs.
- 3.3. (3) The following vector differences were then obtained for each occasion:
 - 3.3.1. Prog resultant vector - Actual resultant vector (24-hour prog)
 - 3.3.2. Actual resultant vector - Actual 12 hours later (Actual 00 - Actual 12)
 - 3.3.3. Actual resultant vector - Actual 24 hours later (Actual 00 - Actual 24)
- 3.4. (4) Dividing these vector differences by the number of stations along the route will give the vector mean error (VME) or difference for the route, - i.e. 3.1 will give the mean prognostic error while 3.2 and 3.3 give what may be called the persistence error or the 12- or 24-hour wind variation.
- 3.5. (5) Adding vectorially the VMD for each occasion and dividing by the total number of occasions in each month (N) gives the mean for the month (\overline{VMD}).
- 3.6. (6) The root mean square vector difference or standard error is defined as:

$$\epsilon = \sqrt{\frac{\sum (F - V)^2}{N}}$$

and is obtained by summing the squares of the differences as obtained in (3), dividing by N and obtaining the square root of the resultant.

- (7) The standard deviation is then defined as follows:

$$\sigma = \sqrt{\epsilon^2 - \overline{VMD}^2}$$

- (8) Assuming that the various vector differences or errors have a circular distribution, the scalar mean value of the vector differences (MVD) is given by $MVD = 0.88 \sigma$. In those cases where \overline{VMD} is close to zero this corresponds to $MVD = 0.88 \epsilon$. A test on one month showed this relation held almost exactly.

4.

DATA VERIFIED

Table 1 shows the months for which various levels and routes were verified.

The Gander-London route was done separately to permit comparison with an earlier study and also to determine the effect of route length on the verification score. The latter reason also applies to the Toronto-Winnipeg route.

5.

ANALYSIS OF RESULTS

5.1. The results obtained from this study are presented in Table 2. The annual mean given for each route is an average of the monthly means for January, May and September.

Vector Mean Deviations or Forecast Bias

Under the column headed \overline{VMD} are the vector means of the errors or deviations. If such deviations are equally distributed among all directions the \overline{VMD} should be zero. It will be noted that this is the case for 12 or 24-hour wind variations. On the other hand the \overline{VMD} for Prog-Actual shows a decided resultant from the west-southwest for all routes. Figures 3 and 4 illustrate the frequency distribution of such errors at 500 mbs and 300 mbs respectively over the Gander-London routes. Each of these diagrams covers a period of 5 months only but is fairly representative of the whole period studies. Since prevailing winds at these elevations in middle latitudes are westerly this might indicate that forecast winds on prognostic charts are too high. Alternatively, since the study is based on vectors, the forecast wind may have too great a westerly component. Specific explanations for this bias could be any one or all of the following:

- (1) Troughs and ridges may be unduly flattened in preparing prognostic charts.
- (2) In the absence of direct observations jet streams may be unduly extrapolated and given too high a maximum.
- (3) The actual winds may deviate appreciably from the geostrophic.

5.3. Scalar Mean Vector Error

Since the vector mean of equal errors in opposite directions is zero, this quantity gives little idea of the magnitude of errors or deviations. For this purpose the scalar mean is more suitable and this has been tabulated in Table 2 under "MVE".

The following points may be noted from the tabulation of the scalar mean of vector errors:

- (1) There is a seasonal variation with maximum values occurring in January and minimum values in May (18.8 knots at 300 mb on all routes in January vs. 14.4 in May). This corresponds roughly to the variation in average wind velocities but previous work by Ellsaesser indicates the relations are not linear.
- (2) The error decreases with route length. This is shown in Figure 3 where the scalar mean vector forecast error and the 24-hour wind variation have both been plotted against route length. Durst (4) has given figures for the decrease with route length of the mean 24-hour wind variation in terms of percent of spot winds. This is an average for a number of levels in the atmosphere. This curve has also been plotted on Figure 1. It will be noted that the rate of change with route length as given by Durst differs substantially from that obtained in this investigation. This relationship, however, is affected by the geographical location, the level in the atmosphere, and the direction of the route (north-south routes differ from east-west), and it is felt there is too small a variety of cases in this study to make any valid comparison.

5.4. Comparison with Other Studies

A number of previous studies on upper wind verification are summarized by Ellsaesser (1). Figures quoted in his report, however, are in terms of winds at a point, while this study is in terms of vector mean winds over a route. As indicated in 5.3, this study did not contain sufficient data to establish any general relationship between winds over a route and winds at a point, and it is therefore impossible to make any direct comparison on any given route over a 24-hour period.

One possible assumption, however, is that over any given route the MVE of a 24-hour persistence forecast decreases with distance at the same rate as a 24-hour conventional forecast,

$$\text{or } \frac{\text{MVE}(A \text{ } 00 - A \text{ } 24) \text{ rte}}{\text{MVE}(A \text{ } 00 - A \text{ } 24) \text{ point}} = \frac{\text{MVE}(\text{Prog} - A) \text{ rte}}{\text{MVE}(\text{Prog} - A) \text{ point}}$$

$$\text{or } \frac{\text{MVE}(A \text{ } 00 - A \text{ } 24) \text{ rte}}{\text{MVE}(\text{Prog} - A) \text{ rte}} = \frac{\text{MVE}(A \text{ } 00 - A \text{ } 24) \text{ point}}{\text{MVE}(\text{Prog} - A) \text{ point}}$$

This ratio might also serve as an index of forecast skill. A value of 1 would indicate no improvement over a straight persistence forecast, with increasing values indicating greater skill.

Using this index, a comparison was made with the previous studies quoted above with the following results:

<u>Study</u>	<u>LEVEL</u>	
	<u>500 MB</u>	<u>300 MB</u>
Present study (Montreal)	1.30	1.31
Sutcliffe	1.30	1.48
Ellsaesser (VS-7)	1.22	1.12

6. CONCLUSIONS

- (1) Taking the average of the MVE for all routes and all months it may be concluded that upper wind forecasts prepared from a 24-hour prog at Montreal are 3 knots better than a 24-hour persistence forecast at the 500-mb level and 5 knots better at the 300-mb level.
- (2) Forecasts at both 500 and 300 mb show a decided bias toward westerly or west-southwesterly winds.
- (3) Maximum errors were on the shortest routes in mid-latitudes at 300 mb with smaller errors on longer routes, at high latitudes and lower altitudes (500 mb).
- (4) The degree of skill at 500 mb is equal to the best of previous studies but at 300 mb is slightly below the best. Since 500-mb charts in the present study were based mainly on NWP Progs, it would appear NWP Progs are equal to the best subjective progs.

APPROVED,



J. R. H. Noble,
Director.

7.

REFERENCES

- (1) Ellsaesser, Major Hugh W.: "Errors in Upper-Level Wind Forecasts". AWS TR 105-140/1.
- (2) Sutcliffe, R. C. and J. S. Sawyer: "Forecasting Winds Up to the 100-mb Level by Contour-Chart Techniques". Proceedings of the Toronto Meteorological Conference 1953, Royal Met. Soc., 1954 pp. 155-159.
- (3) Bøville, B. W.: "300 mb Progs - A Short Method". Meteorological Branch, Department of Transport. Circular-2990, TEC-260, 27 Nov. 57.
- (4) Durst, C. S.: "The Accuracy of Dead Reckoning in the Air". Journal of the Institute of Navigation, Vol. VIII, No. 1, April 1955, pp. 91-116.

TABLE 1
MONTHS VERIFIED ON VARIOUS ROUTES AND LEVELS

<u>Routes</u>	1960	1961		1962		1963		
	Sept.	Jan.	May	Sept.	Jan.	May	Sept.	Jan.
			<u>500 mb</u>					
Montreal-London	X		X					
Gander-London		X		X	X	X	X	X
			<u>300 mb</u>					
Montreal-London		X	X	X	X	X	X	X
Gander-London		X		X	X	X	X	X
Goose-Thule		X		X	X	X	X	X
Montreal-Vancouver		X		X	X	X	X	X
Toronto-Winnipeg		X		X	X	X	X	X

TABLE 2

300 MBS

ROUTE	MONTH	PROG - ACTUAL					ACTUAL 00 - ACTUAL 12				ACTUAL 00 - ACTUAL 24			
		VMD		σ	ϵ	MVE	VMD		ϵ	MVE	VMD		ϵ	MVE
		Degs	Kts		(RMSVE)	(.88 ϵ)	Degs	Kts		(.88 ϵ)	Degs	Kts		(.88 ϵ)
MONTREAL	Jan 61	202	5.4	20.4	21.1	18.6	304	0.6	17.5	15.4	280	1.4	23.5	20.7
	Jan 62	259	3.8	20.3	20.7	18.2	168	0.3	21.7	19.1	082	0.7	26.8	23.6
	Jan 63	229	8.2	17.0	18.8	16.5	059	0.8	19.3	17.0	069	1.6	24.9	21.9
LONDON	Jan Mean	227	5.4	19.2	20.2	17.8	-	-*	19.5	17.2	-	-	25.1	22.1
	May 61	235	4.8	13.6	14.4	12.7	245	0.1	14.0	12.3	265	0.2	19.0	16.7
	May 62	240	4.1	12.7	13.4	11.8	070	1.3	16.2	14.3	070	1.8	21.0	18.5
	May Mean	236	4.4	13.1	13.9	12.2	-	-	15.1	13.3	-	-	20.0	17.6
	Sept 61	253	10.8	15.0	18.5	16.3	090	0.3	13.9	12.2	085	0.8	22.4	19.7
	Sept 62	289	3.9	15.0	15.5	13.6	073	0.2	15.0	13.2	180	0.5	17.8	15.7
	Sept Mean	262	7.1	15.0	17.0	15.0	-	-	14.4	12.7	-	-	20.1	17.7
	Annual Mean	244	5.4	15.8	17.0	15.0	-	-	16.3	14.3	-	-	21.7	19.1
GANDER-	Jan 61	196	5.5	19.9	20.7	18.2	350	0.5	21.4	18.8	320	1.15	25.3	22.3
	Jan 62	252	2.7	23.3	23.5	20.7	157	0.7	25.1	22.1	124	1.10	29.5	26.0
	Jan 63	196	5.1	24.3	24.9	21.9	139	0.5	22.5	19.8	146	0.80	26.4	23.2
LONDON	Jan Mean	210	4.1	22.5	23.0	20.2	-	-	23.0	20.2	-	-	27.1	23.8
	May 62	250	4.5	14.8	15.5	13.6	060	1.9	18.1	15.9	080	2.1	24.8	21.8
	Sept 61	254	13.2	15.5	20.4	18.0	090	0.4	16.9	14.9	065	0.9	22.9	20.1
	Sept 62	239	2.4	18.5	18.7	16.5	079	0.3	16.3	14.4	007	0.3	19.6	17.3
	Sept Mean	252	7.8	17.0	19.6	17.3	-	-	16.6	14.6	-	-	21.2	18.7
	Annual Mean	238	5.3	18.1	19.4	17.1	-	-	19.2	16.9	-	-	24.3	21.4

* Monthly and annual $\overline{\text{VMD}}$ for actual-actual are close to zero and have not been calculated - see Section 5.2.

TABLE 2
300 MBS (continued)

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ROUTE	MONTH	PROG - ACTUAL					ACTUAL 00 - ACTUAL 12				ACTUAL 00 - ACTUAL 24			
		VMD		σ	ϵ	MVE	VMD		ϵ	MVE	VMD		ϵ	MVE
		Degs	Kts		(RMSVE)	(.88 ϵ)	Degs	Kts		(.88 ϵ)	Degs	Kts		(.88 ϵ)
MONTREAL-	Jan 61	263	4.8	19.4	20.0	17.6	114	0.2	24.3	21.4	105	0.7	27.9	24.6
	Jan 62	258	6.1	20.4	21.3	18.7	154	0.7	23.6	20.8	153	0.9	30.8	27.1
VANCOUVER	Jan 63	253	8.9	17.0	19.2	16.9	050	0.8	18.9	16.6	055	1.8	24.7	21.7
	Jan Mean	257	6.6	18.9	20.2	17.8			22.3	19.6			27.6	24.3
	May 62	250	7.2	19.9	21.2	18.7	060	0.5	18.2	16.0	360	0.7	26.6	23.4
	Sept 61	250	9.6	18.6	21.0	18.5	053	0.1	16.3	14.4	209	0.3	21.3	18.7
	Sept 62	271	7.0	14.3	15.0	13.2	249	0.5	15.4	13.5	262	0.9	19.3	17.0
	Sept Mean	259	8.3	16.4	18.0	15.8			15.8	13.9			20.2	17.8
	Annual Mean	256	7.3	18.4	19.8	17.4			18.8	16.5			24.8	21.8
TORONTO -	Jan 61	045	2.2	25.0	25.2	22.2	175	1.9	25.7	22.7	166	3.1	37.6	33.1
	Jan 62	260	5.9	28.9	29.5	26.0	149	1.1	30.6	26.9	154	1.4	42.0	37.0
WINNIPEG	Jan 63	193	3.3	21.4	21.6	19.0	355	0.4	27.3	24.0	062	0.8	35.4	31.2
	Jan Mean	238	2.0	25.1	25.4	22.4			27.9	24.6			38.3	33.7
	May 62	220	9.0	14.7	17.3	15.2	090	0.4	14.5	12.8	120	0.4	18.2	16.0
	Sept 61	233	7.6	21.1	22.5	19.8	032	0.4	22.6	19.9	045	0.6	30.0	26.4
	Sept 62	279	6.7	21.1	22.1	19.4	228	0.8	21.6	19.0	225	1.8	28.7	24.2
	Sept Mean	255	6.7	21.1	22.3	19.6			22.2	19.5			29.4	25.9
	Annual Mean	237	5.7	20.3	21.7	19.1			21.5	18.9			28.6	25.2

TABLE 2

300 MBS (continued)

ROUTE	MONTH	PROG - ACTUAL					ACTUAL 00 - ACTUAL 12				ACTUAL 00 - ACTUAL 24			
		\overline{VMD}		σ	ϵ	MVE	\overline{VMD}		ϵ	MVE	\overline{VMD}		ϵ	MVE
		Degs	Kts		(RMSVE)	(.88 ϵ)	Degs	Kts		(.88 ϵ)	Degs	Kts		(.88 ϵ)
GOOSE -	Jan 61	328	3.8	18.3	18.7	16.4	171	0.5	17.6	15.5	202	1.4	23.3	20.5
	Jan 62	333	3.1	17.3	17.5	15.4	130	0.4	17.6	15.5	359	0.9	23.4	20.6
	Jan 63	250	1.0	17.9	17.9	15.8	224	0.5	17.5	15.4	257	0.8	23.1	20.3
	Jan Mean	322	2.4	17.8	18.0	15.8			17.6	15.5			23.3	20.5
	May 62	180	2.8	14.0	14.3	12.6	300	0.4	16.9	14.9	290	0.8	22.9	20.1
	Sept 61	257	3.7	16.7	17.1	15.1	158	0.3	19.8	17.4	256	0.3	27.6	24.3
	Sept 62	335	2.6	16.3	16.6	14.6	211	0.4	16.6	14.6	173	0.4	22.6	19.9
	Sept Mean	288	2.5	16.5	16.9	14.9			18.3	16.1			25.2	22.2
	Annual Mean	268	1.2	16.1	16.4	14.5			17.6	15.5			23.8	20.9

TABLE 3

500 MBS

ROUTE	MONTH	PROG - ACTUAL					ACTUAL 00 - ACTUAL 12				ACTUAL 00 - ACTUAL 24			
		VMD		σ	ϵ	MVE	VMD		ϵ	MVE	VMD		ϵ	MVE
		Degs	Kts		(RMSVE)	(.88 ϵ)	Degs	Kts		(.88 ϵ)	Degs	Kts		(.88 ϵ)
GANDER - LONDON	Jan 61	237	4.2	13.4	14.0	12.3	342	0.1	14.1	12.4	323	0.6	15.6	13.7
	Jan 62	197	1.8	10.5	10.6	9.3	078	1.2	14.6	12.8	090	2.3	17.3	15.2
	Jan 63	245	5.3	13.2	14.2	12.5	135	0.3	14.0	12.3	125	0.8	16.8	14.8
	Jan Mean	235	3.6	12.4	12.9	11.4			14.2	12.5			16.4	14.6
	May 62	270	5.0	9.4	10.7	9.4	090	0.7	11.0	9.7	060	0.9	17.4	15.3
	Sept 61	257	7.3	9.0	11.6	10.2	109	0.5	9.3	8.2	094	1.0	12.3	10.8
	Sept 62	250	3.6	10.1	10.7	9.4	321	0.1	7.5	6.6	276	0.1	10.3	9.1
	Sept Mean	254	5.5	9.6	11.2	9.8			8.4	7.4			11.3	10.0
	Annual Mean	254	4.5	10.5	11.6	10.2			11.2	9.9			15.0	13.3
	MONTREAL- LONDON	Sept 60	270	4.7	8.5	9.7	8.5	335	0.4	10.1	8.9	340	0.5	13.8
May 61	215	1.7	7.3	7.5	6.6	205	0.1	7.4	6.5	215	0.2	10.2	9.0	
MEAN	254	3.0	7.9	8.6	7.6			8.8	7.7			12.0	10.6	

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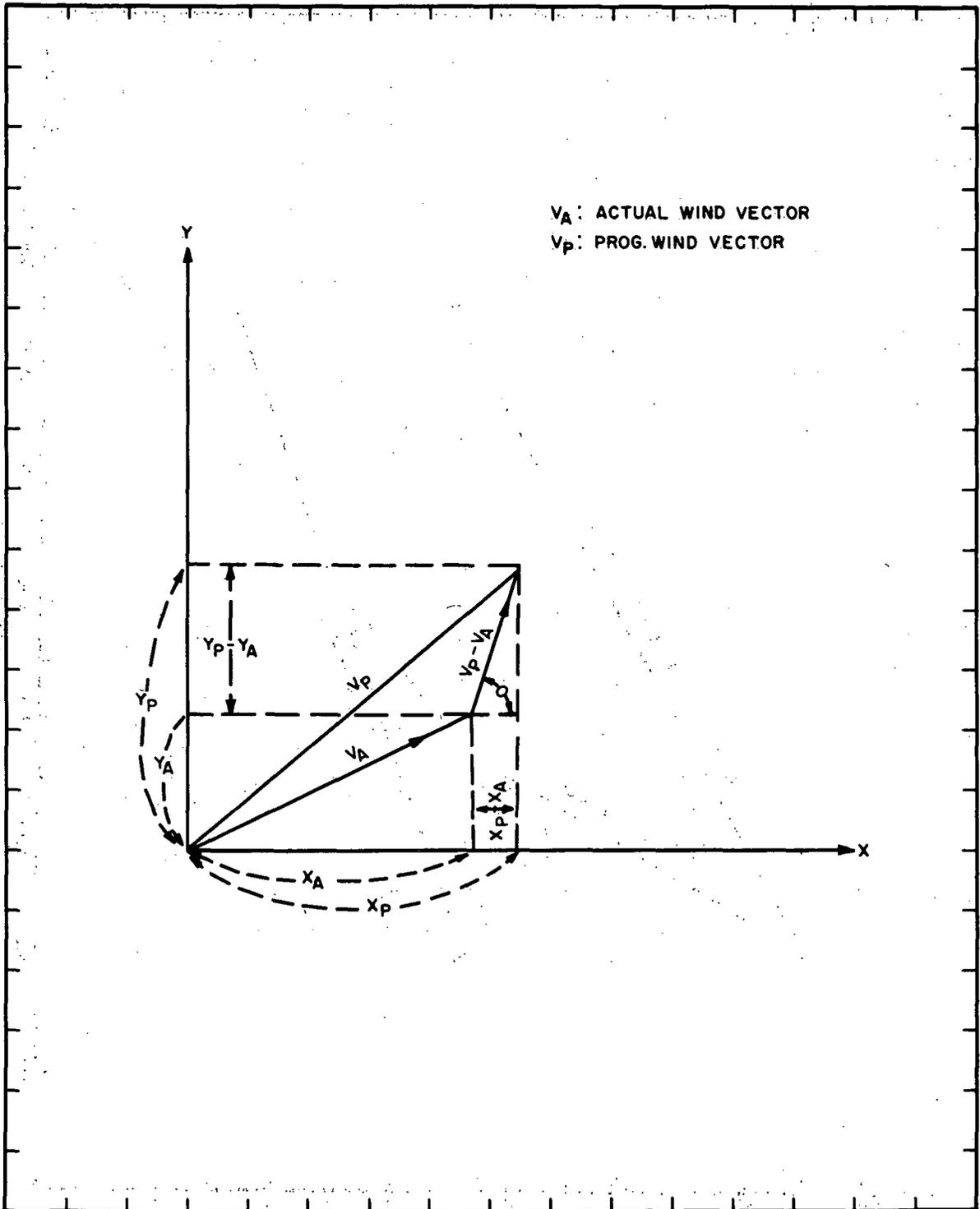


Figure 1
Graphical Representation of Wind Vector

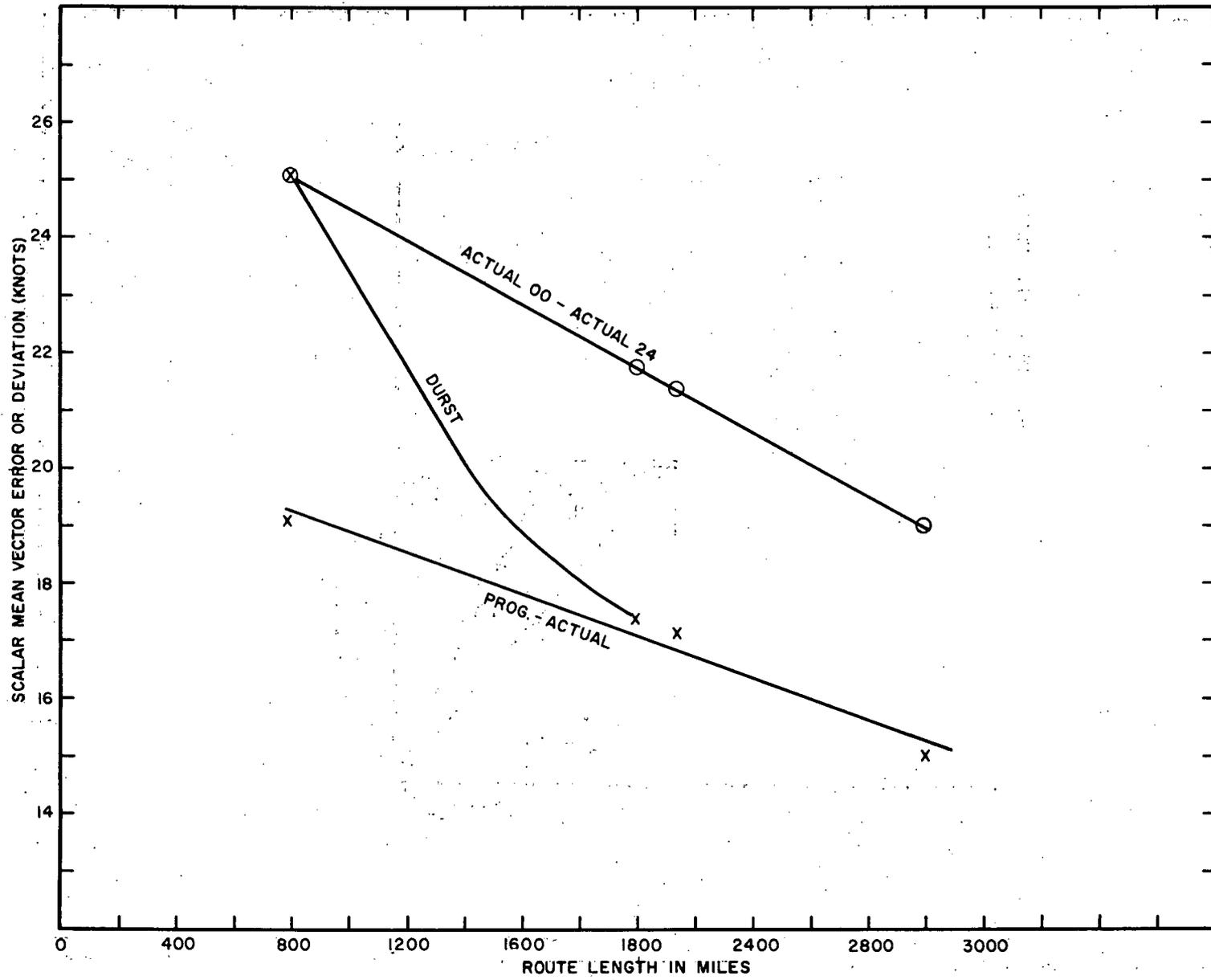


Figure 2
Scalar Vector Deviation VS Route Length (E-W Routes)

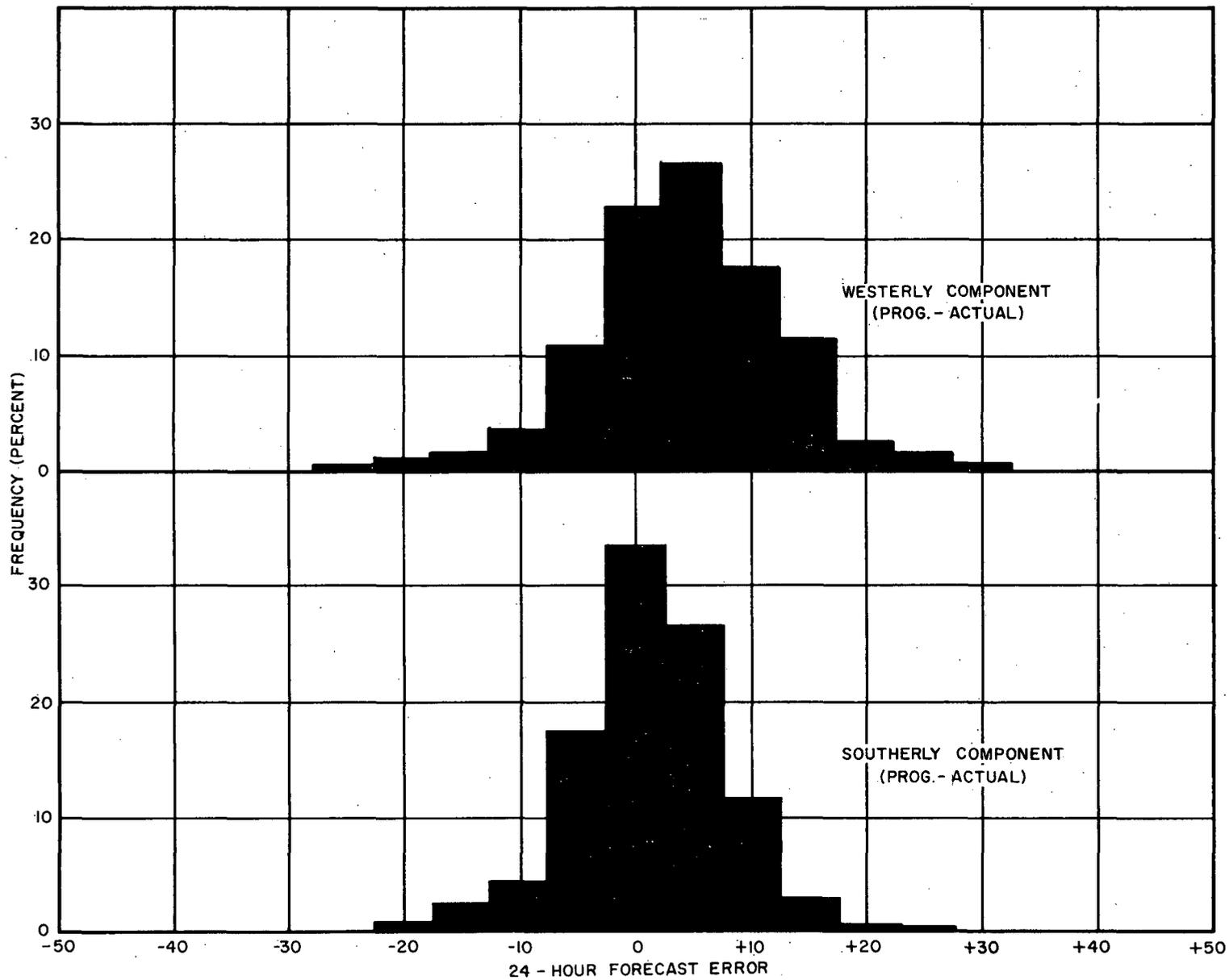


Figure 3
 Frequency of 24-Hour Forecast Errors in Vector
 Mean Winds at 500 MBS - Gander to London

CIR-4096
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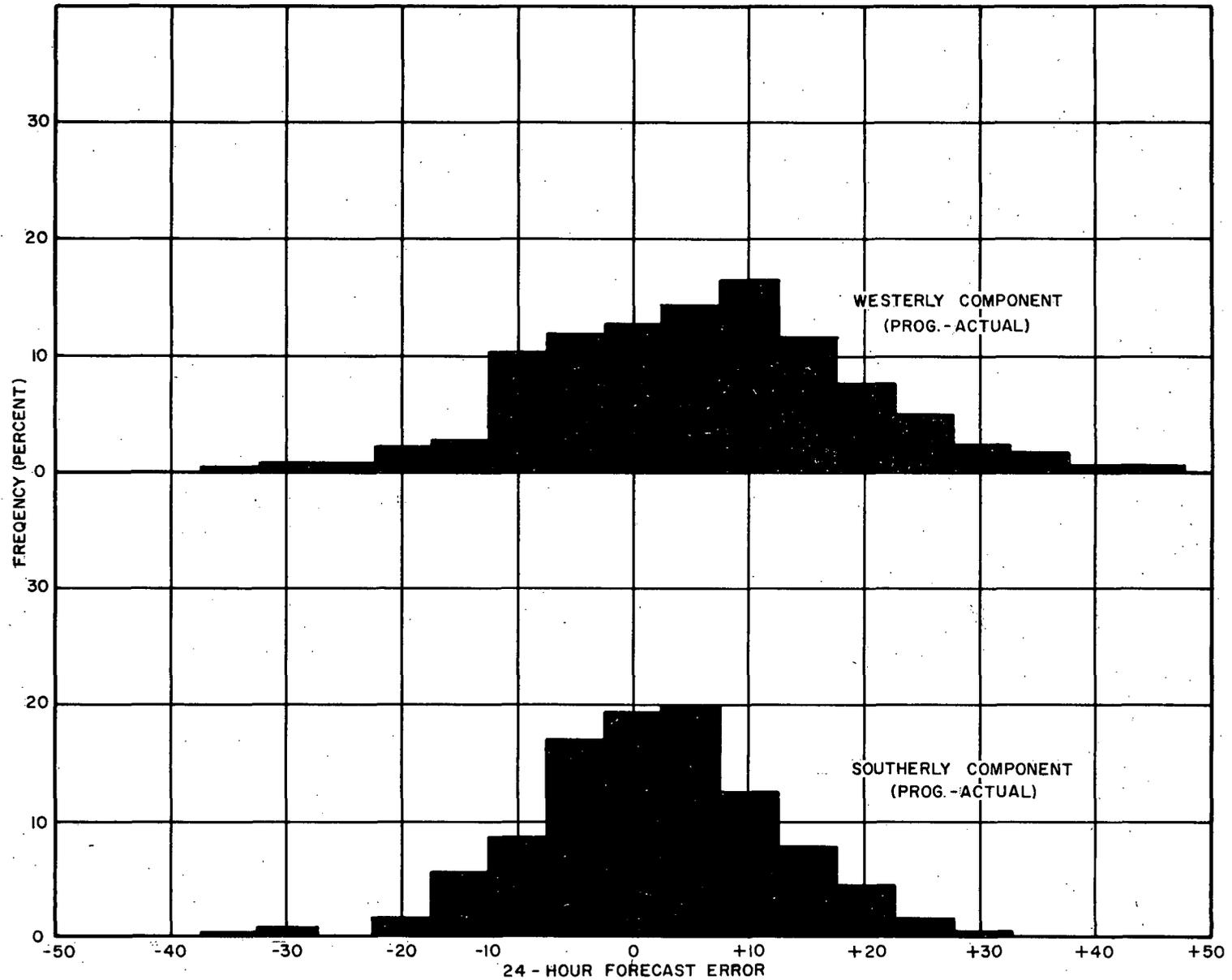
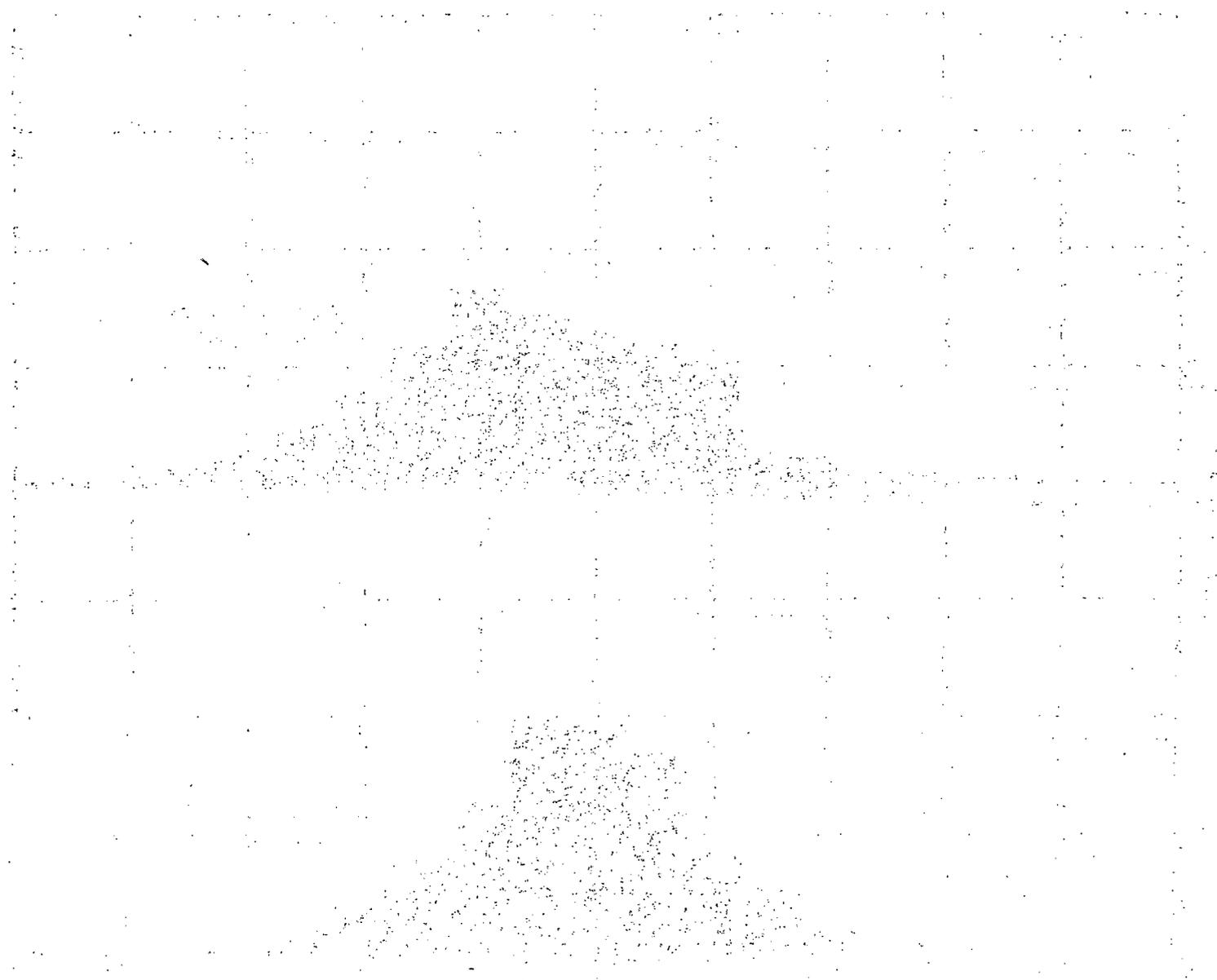


Figure 4
Frequency of 24-Hour Forecast Errors in Vector
Mean Winds at 300 MBS - Montreal to London



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6 pps. 4 figs. 4 refs. 5 tables.

Subject reference: Forecast Verification:
Forecasting of Upper Level Winds.

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Forecasting of Upper Level Winds.

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