GCA-TR-73-2-N

FINAL REPORT

for

ATMOSPHERIC MOTION INVESTIGATION FOR VAPOR TRAILS AND RADIO METEORS

Contract No. NASW-2147

CASE FILE COPY

February 1973

Prepared by

GCA CORPORATION
GCA TECHNOLOGY DIVISION
Bedford, Massachusetts

Principal Investigator: J. Bedinger

for

National Aeronautics and Space Administration
Headquarters

TABLE OF CONTENTS

SECTION I

INTRODUCTION

The purpose of this contract is to investigate the dynamics of the lower thermosphere through comparison of optical observations of motions of ejected vapor trails with radar observations of motions of ionized meteor trails. In particular, the winds obtained from a series of vapor trail observations which occurred at Wallops Island, Virginia during the night of 14-15 December 1970 are to be compared with wind data deduced from radar observations of meteor trails during the same period.

The comparison of these data is considered important for two reasons. First, the most widely used methods of measuring winds in the lower thermosphere are the vapor trails and the radar meteors. However, the two techniques differ markedly and the resultant sets of data have been analyzed and presented in different formats. As a result, several theories have been developed to describe the sources and variations of the observed winds. It is expected that a careful, systematic comparison of simultaneously obtained results will aid in identifying and understanding the physical processes which control the dynamics of the region.

Secondly, and possibly of greater immediate concern is the fact that the radar meteor method appears to be an appropriate approach to the synoptic measurement of winds. It is generally accepted that the vapor trails which require rocket vehicles for deployment are too expensive to be acceptable as the only method for such a system. However, the radar meteor method has limitations in the useful altitude range and resolution which can be attained. It is anticipated that this study of the data from the coordinated vapor trail/meteor measurements will aid in developing procedures by which the radar data may be improved and extended through the judicious use of vapor trails and other techniques such as ionospheric drift measurements.

During the night of 14-15 December 1970, five vapor trails were ejected from Nike Apache rockets over Wallops Island, Virginia from 2208 EST through 0627 EST. The wind data which were obtained from these trails are presented in Section II of this report and features of the wind profiles which relate to the radar meteor trails results are discussed.

The radar meteor wind system was designed by the New Mexico State University who operated the system for the first time throughout the period in which the vapor trails were observed. The results which were presented in a letter report during March 1971 are summarized in Section III. The initial operation of the system encountered some difficulties which caused the validity of large portions of the data to be questioned. The data which are considered valid are compared to the vapor trail results in Section IV.

1

Due to the fact that the rate of influx of meteors is greater in the daylight hours, the radar system has greater sensitivity during the day than at night. However, vapor trail measurements have not yet been made in the daytime due to limitations of the currently used techniques. Thus the investigation of methods of obtaining vapor trail observations in the daytime was also an objective of this contract. The major emphasis was placed on evaluating the possibility of narrow band filter photography from a high flying aircraft. The results of this study are presented in Section V.

SECTION II

VAPOR TRAIL WINDS

During the night of 14-15 December 1970, a series of five Nike Apache rockets were launched from Wallops Island, Virginia in order to eject vapor trails for the observation of thermospheric winds. The firing times, payload type and apogee are given in Table I.

Winds down to about 90 km were obtained from all of the trails. The upper limit for the TMA trails varied from 146 to 165 km. The Na-Li trail allowed wind measurement up to 193 km. The hodographs of the winds obtained from the five trails are shown in Figures 1 through 5.

The winds in the region below about 120 km in which the meteor measurements may be obtained are shown to be highly variable throughout the period. The hodographs contain the major features which are typical of most of the observations from Wallops Island. High shears are present throughout the entire period and changes in speed or direction often occur in a small height interval. These features cause considerable difficulty in the meteor measurements which have height uncertainties of a km or so and must average the data over both space and time. There is also evidence of the typical spiral structure which rotates slowly with time and is indicative of a large scale variation which could be associated with tidal oscillations. These large scale changes would be more easily observed in the meteor data. However, the variable high shears dominate the wind profiles and adversely affect the resolution and accuracy of the meteor wind measuring system.

TABLE I

VAPOR TRAILS OF 14-15 DECEMBER 1970

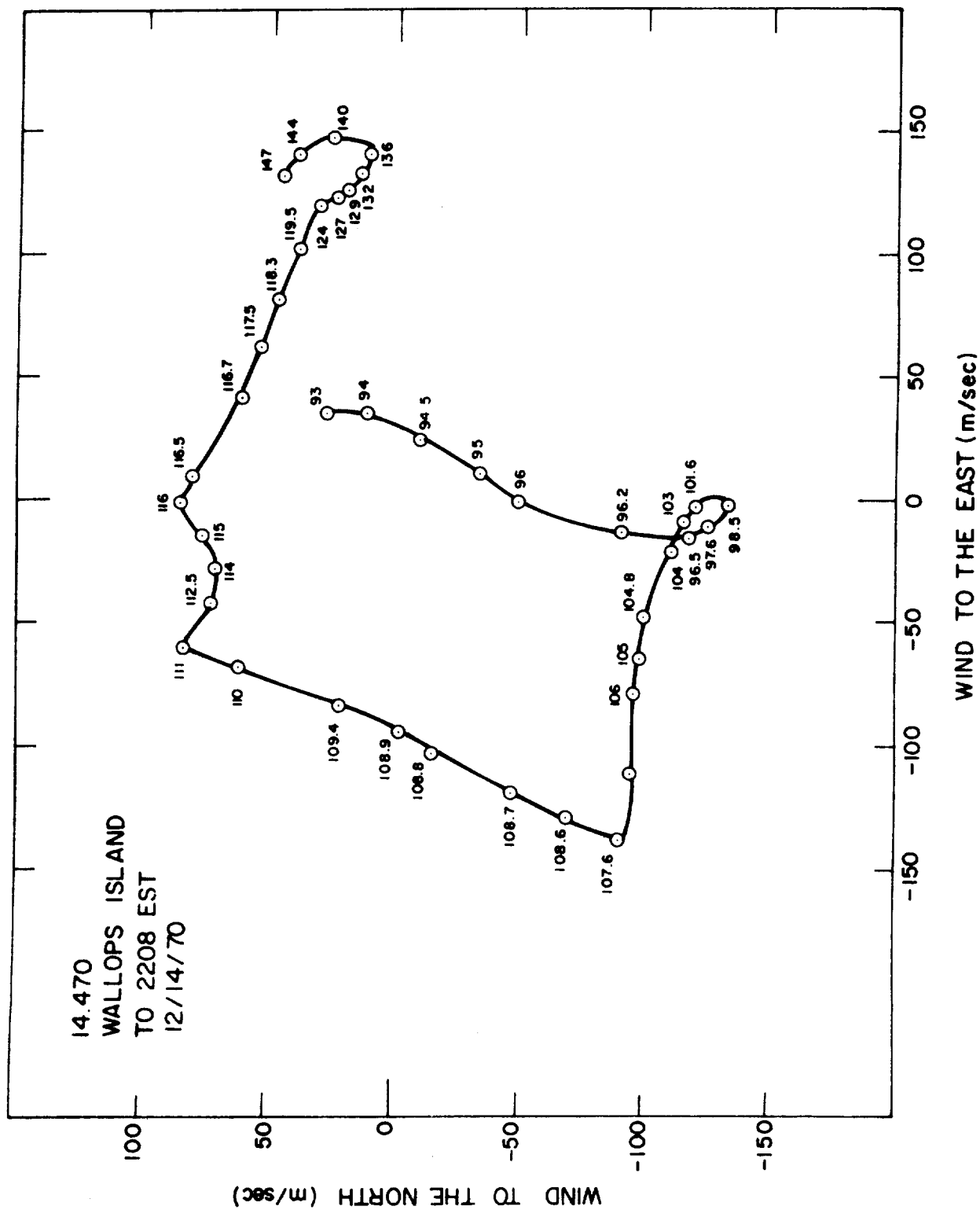| NASA No.	Firing Time (EST)	Payload	Apogee (km)
14.470	2208	TMA	207
14.471	0018	TMA	212
14.472	0200	TMA	210
14.473	0404	TMA	194
14.474	0627	Na-Li	213

Figure 1. Hodograph of winds obtained from Nike Apache 14.470. Height is in kms.
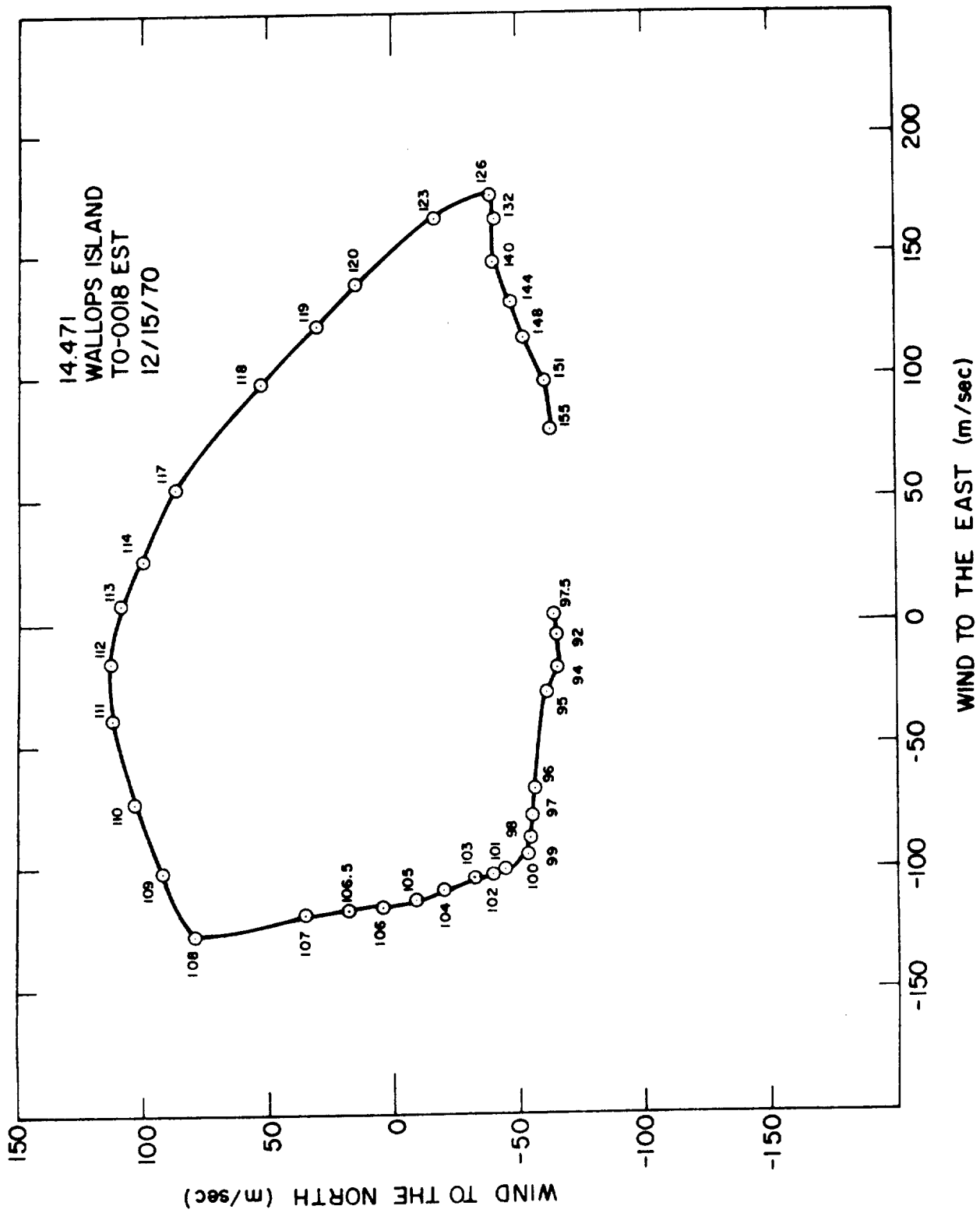
4

Figure 2. Hodograph of winds obtained from Nike Apache 14.471. Height is in kms.
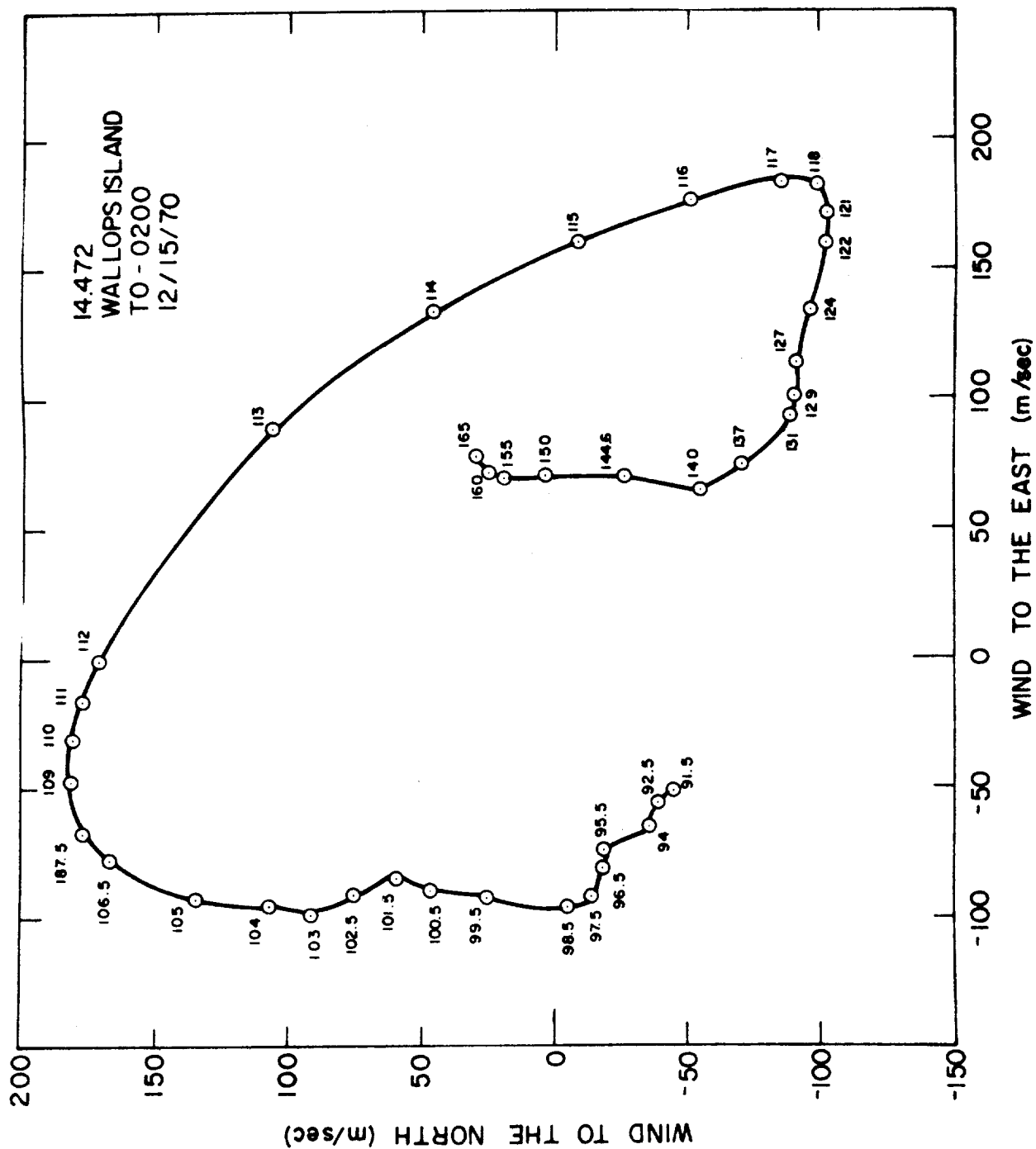
Figure 3. Hodograph of winds obtained from Nike Apache 14.472. Height is in kms.
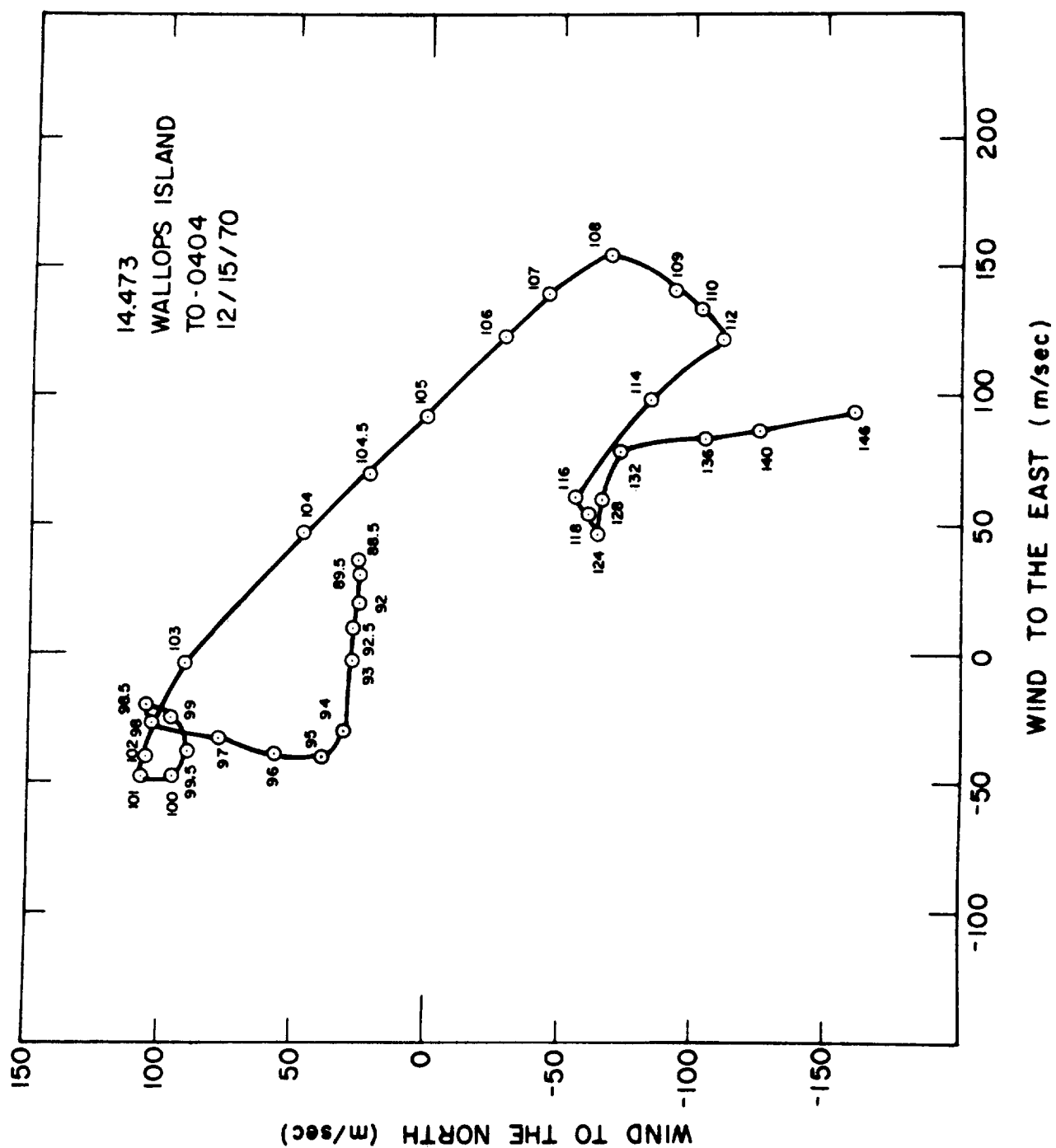
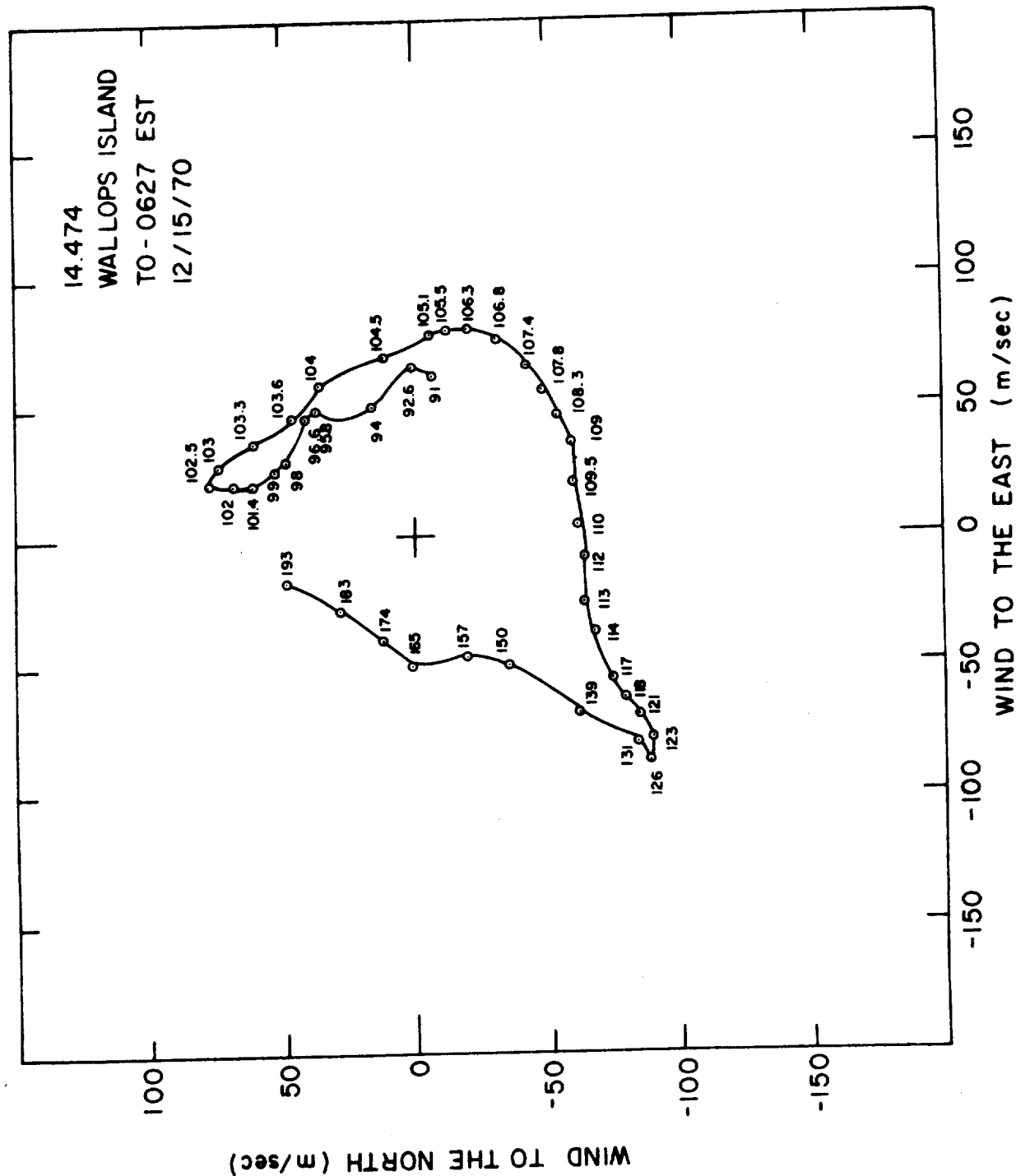Figure 4. Hodograph of winds obtained from Nike Apache 14.473. Height is in kms.

Figure 5. Hodograph of winds obtained from Nike Apache 14.474. Height is in kms.

8

SECTION III

RADAR METEOR WINDS

The radar meteor trail station was established and operated by the New Mexico State University. The station was still being tested when it was operated during the period of the vapor trail observations. The results of this operation were reported in a letter type progress report dated 9 March 1971. It was reported that the system recorded over 3300 events during a 13.5 hour period. However, many of the events were of a very short duration and were not considered to be proper for processing. After eliminating all events with a duration of less than 40 milliseconds, a total of 1660 remained. These were distributed in time as shown in the histogram in Figure 6. The time scale on the histogram is Greenwich Mean Time which is EST +5 hours. The times when the vapor trails were ejected have been marked. It is apparent that the influx rate during the time of the first two trails is very low but increases markedly after local midnight at 5 hours GMT.

The meteor trail data were processed to determine winds during three time intervals when observations of vapor trails were obtained from Nike Apaches 14.471, 14.472, and 14.473. It was determined that the results from most of the events which were processed were invalid for one or more of several reasons. The results of this validation process were reported in tabular form in Table II. The explanation of Table II was reported as follows.

'Events Processed' is the total number of events or meteor trails which were processed during the time intervals shown. 'Valid Events' are events which apparently gave reasonable answeres. There are two sets of entries in each column of the table. The first is the actual number of events and the second is the percentage of the total. There were several reasons for which a data point was rejected and these are itemized in the table.

During this test the gain of the Doppler channel was not constant in the frequency domain. For this reason, at least one complete Doppler cycle had to be present to compute Doppler frequency. If there was not a complete cycle present, the event was rejected for 'Insufficient Doppler'.

'Exceeded Tolerances for Range' means that the values obtained for range from the coarse range channel and the medium range channel did not agree to within one cycle of the fine range channel.

'Exceeded Tolerances for Altitude' means that the computed value for the altitude was either less than 80 km or greater than 120 km. Some of
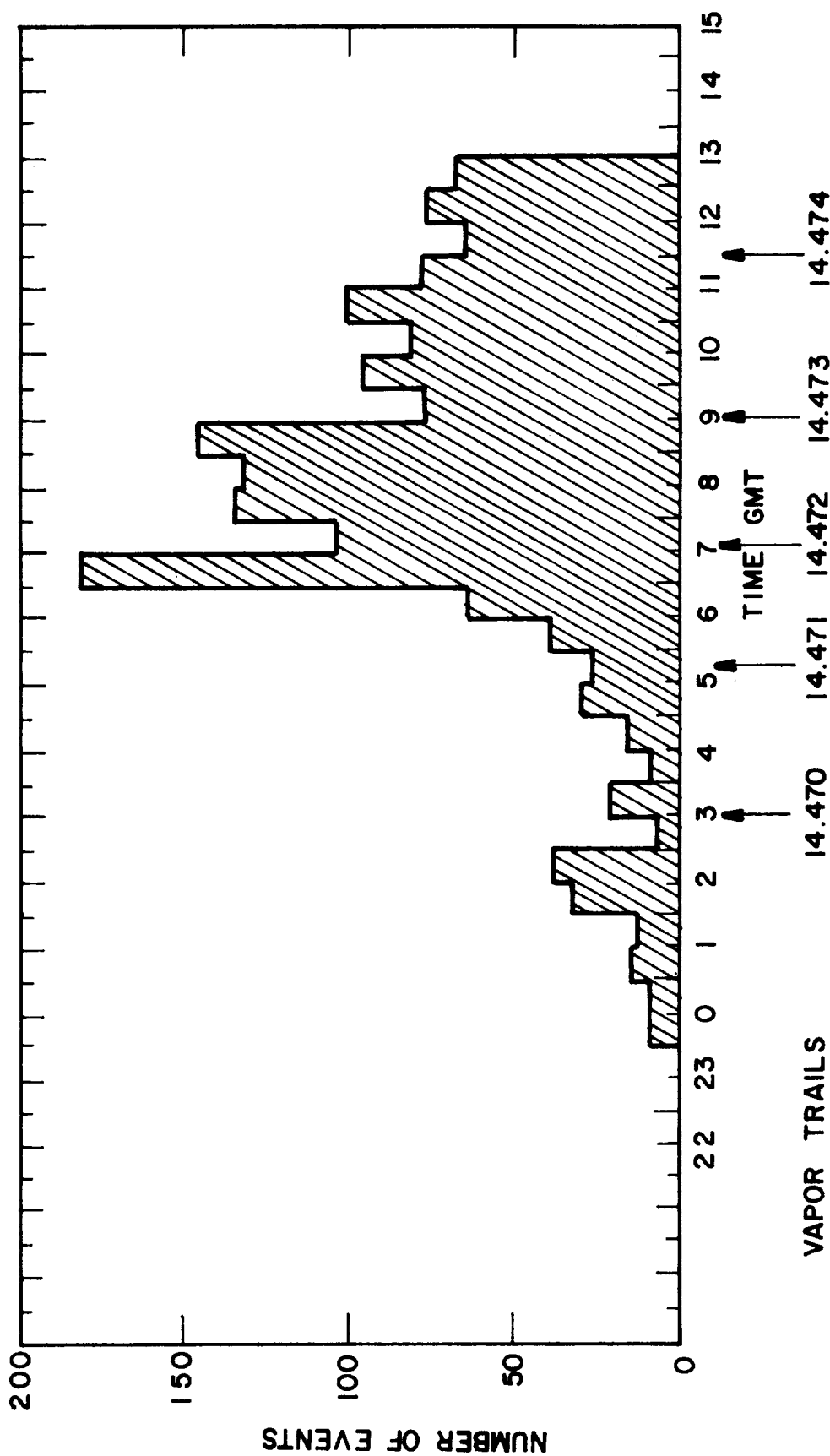
Figure 6. Number of recorded meteors in each half hour interval. Time is GMT. The times of associated vapor trail rocket launches are indicated by arrows.

TABLE II

EVALUATION OF RADAR METEOR DATA

| Time GMT | Events Processed | Valid Events | | Reasons for Rejection | | | | | | | | |
		#	%	Insufficient Doppler #	%	Exceeded Tolerances For Range #	%	Exceeded Tolerances For Altitude #	%	Doppler Sense Change #	%	Others #	%
0445-0630	193	20	10.4	118	61.4	3	1.6	42	21.9	9	4.7	0	0.0
0700-0740	178	14	7.8	124	69.7	9	5.1	20	11.2	8	4.5	3	1.7
0840-0955	233	15	6.4	178	76.4	1	0.4	17	7.3	19	8.2	3	1.3
Averages			8.2		69.2		2.4		13.5		5.8		1.0

11

these values were very low and were probably aircraft. A few values may be caused by an elevation angle at the very edge of the beamwidth where the elevation angle cannot be resolved.

'Doppler Sense Change' means that an apparent direction change was sensed during the event. This sometimes occurred when a very low Doppler frequency was measured or when the Doppler channel was noisy.

'Other' was usually due to noisy data.

The table indicates that most of the events were rejected for 'insufficient Doppler'. Methods of overcoming this problem were suggested in the report.

The wind measurements which are considered to be valid were presented in graphical form in Figures 7, 8, and 9. The system could determine only the zonal wind component. Due to the fact that the number of valid events was so small, it was decided that it would not be productive to continue the processing of data.
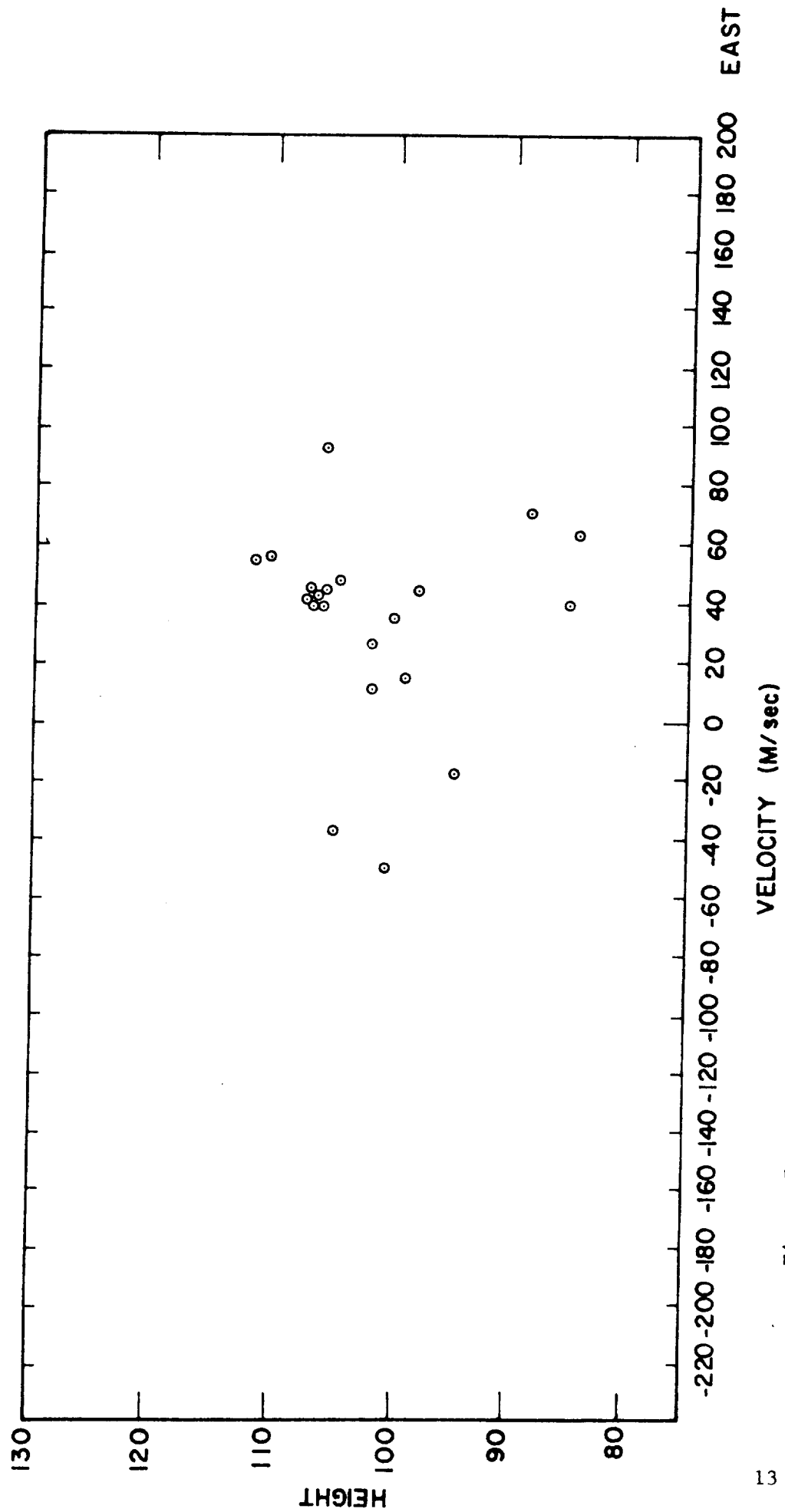
Figure 7. Reported zonal wind measurements from meteor trails during period 0445-0630 hrs. GMT. Coincides with the wind obtained from Nike Apache 141471 in Figure 2.
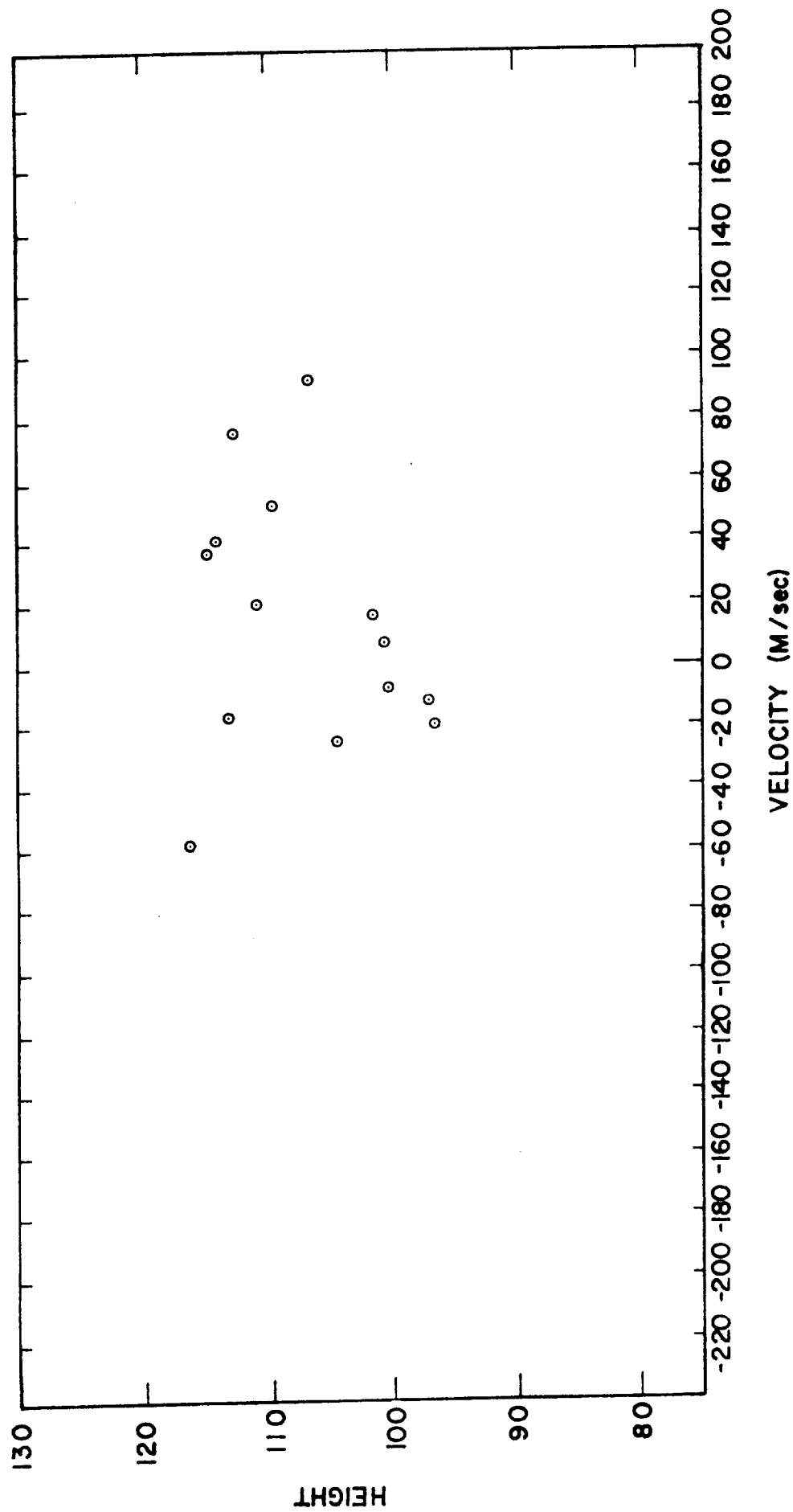
13

Figure 8. Reported zonal wind measurements from meteor trails during the period 0700-0740 hrs. GMT. Coincides with the wind obtained from Nike Apache 14.472, Figure 3.
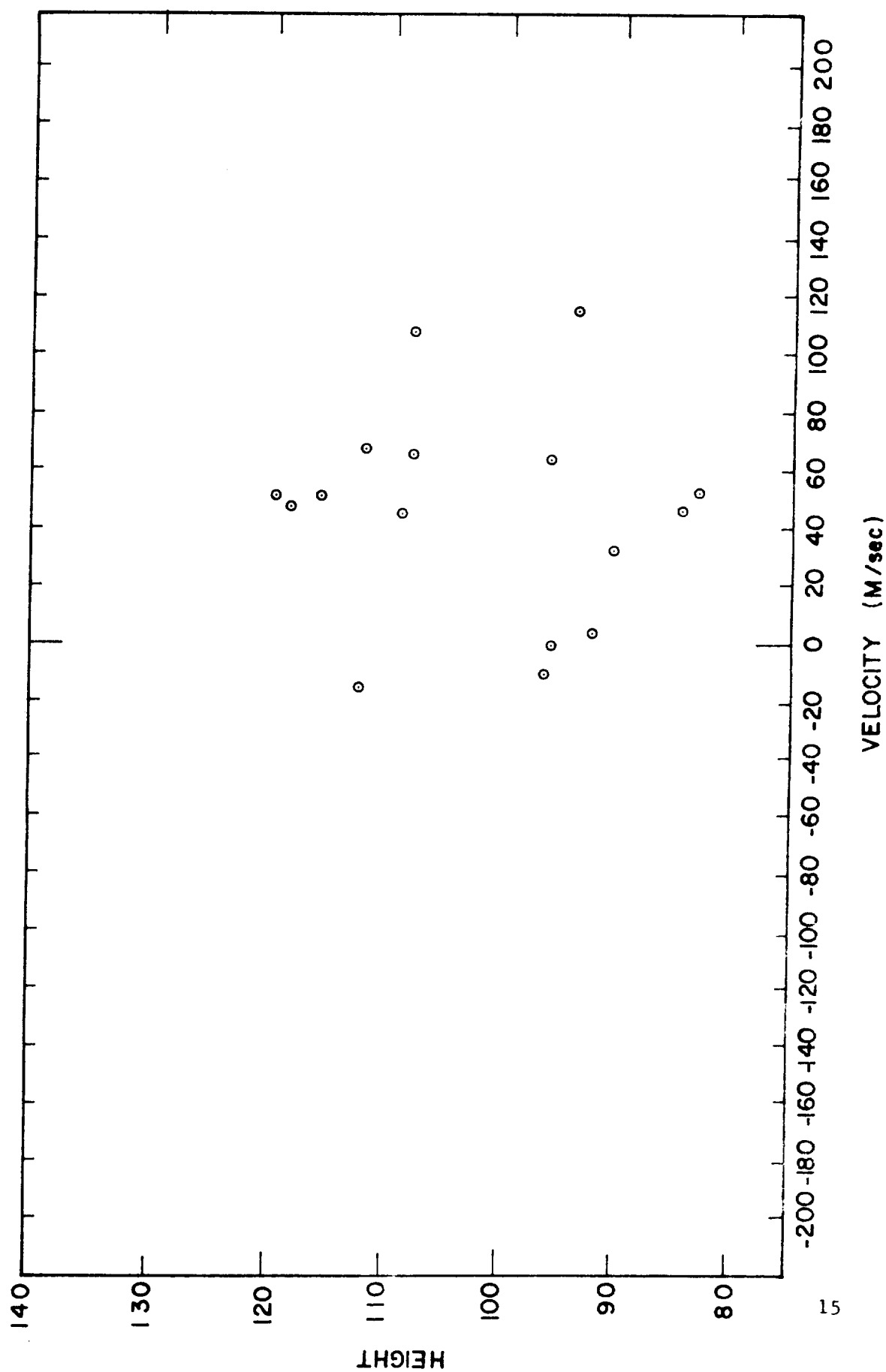
14

Figure 9. Reported zonal wind measurements from meteor trails during the period 0840-0955 hrs GMT. Coincides with wind obtained from Nike Apache 14.473, Figure 4.

15

SECTION IV

COMPARISON OF VAPOR TRAIL AND METEOR RESULTS

The value of the comparison of these data is limited by the low rate of valid events reported from the meteors. From Table II, the rate per hour during the three periods which were processed was 11, 21, and 12. These occurred over the altitude region 85 to 120 km which is generally less than one measurement per two kilometers per hour. The change in the zonal wind during the observing periods is shown in Figure 10. The major feature of the profiles is a large shear which slowly drifts downward with decreasing maxumum winds speeds but with regions of high shear. The height uncertainty associated with the meteor observations causes a wide spread in wind measurements in a shear region and thus more observations must be averaged in order to accurately determine the profile. It is not expected, then that the small data samples from the meteors should produce accurately the profiles obtained from the trails.

The zonal wind profiles and the meteor data from the corresponding time interval are plotted together in Figures 11, 12 and 13. In all cases the maximum wind speeds on the trail profiles are several times those from the meteors. There appears to be some agreement in the region around 110 km in Figure 12 and below 100 km in Figure 13. However, this agreement may be fortuitous since the wind speeds are small in those regions and nearly all of the meteor measurements are small.

It is possible that the high wind speeds were not observed by the meteors due to their low influx rate and the random occurrence. In order to minimize the effect of the shears and high speeds, the trail data were averaged over a 20 km height interval. The circles in Figures 11, 12 and 13 are a running mean of these averages. No improvement in the agreement of the data was found.

It definitely appears that a higher rate of meteor measurements is required for a meaningful comparison within a limited time interval. Initial results from the radar system at Adelaide, Australia utilized a rate of about 10/hour but averaged over a period of 9 days. However, if the suggested modifications to the system are effective and a substantial increase in the number of measurements can be attained, a 12 or 24 hour period should be realistic. In that event, tidal components would be derived for comparison with similar analysis of the temporal variations of the vapor trail data. Until much time as the rate is increased, comparisons over short time periods do not appear meaningful.
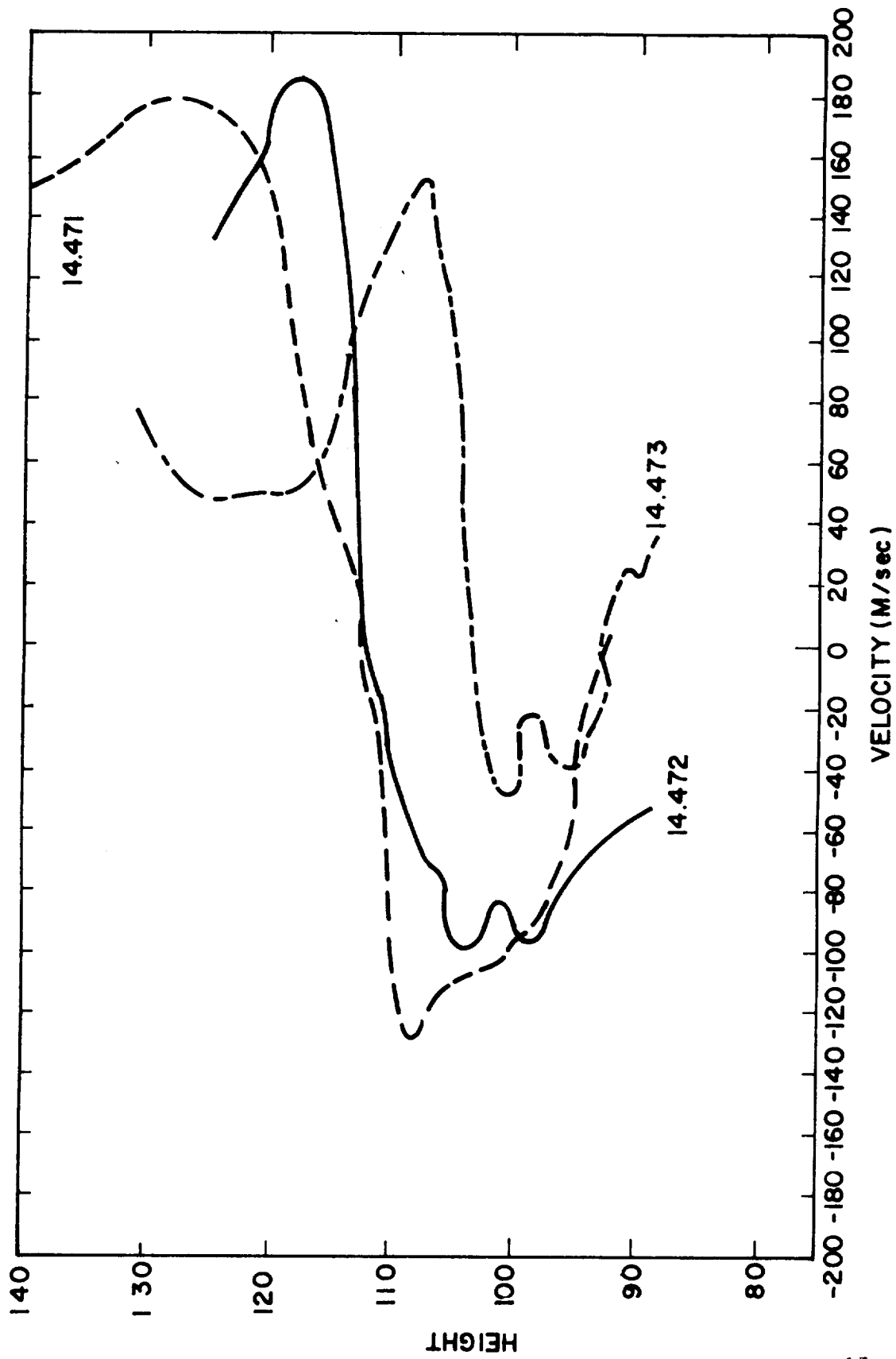
16

Figure 10. The zonal component of the wind in the altitude region below 130 km obtained from flights 14.471, 14.472, and 14.473.

VELOCITY (M/sec)
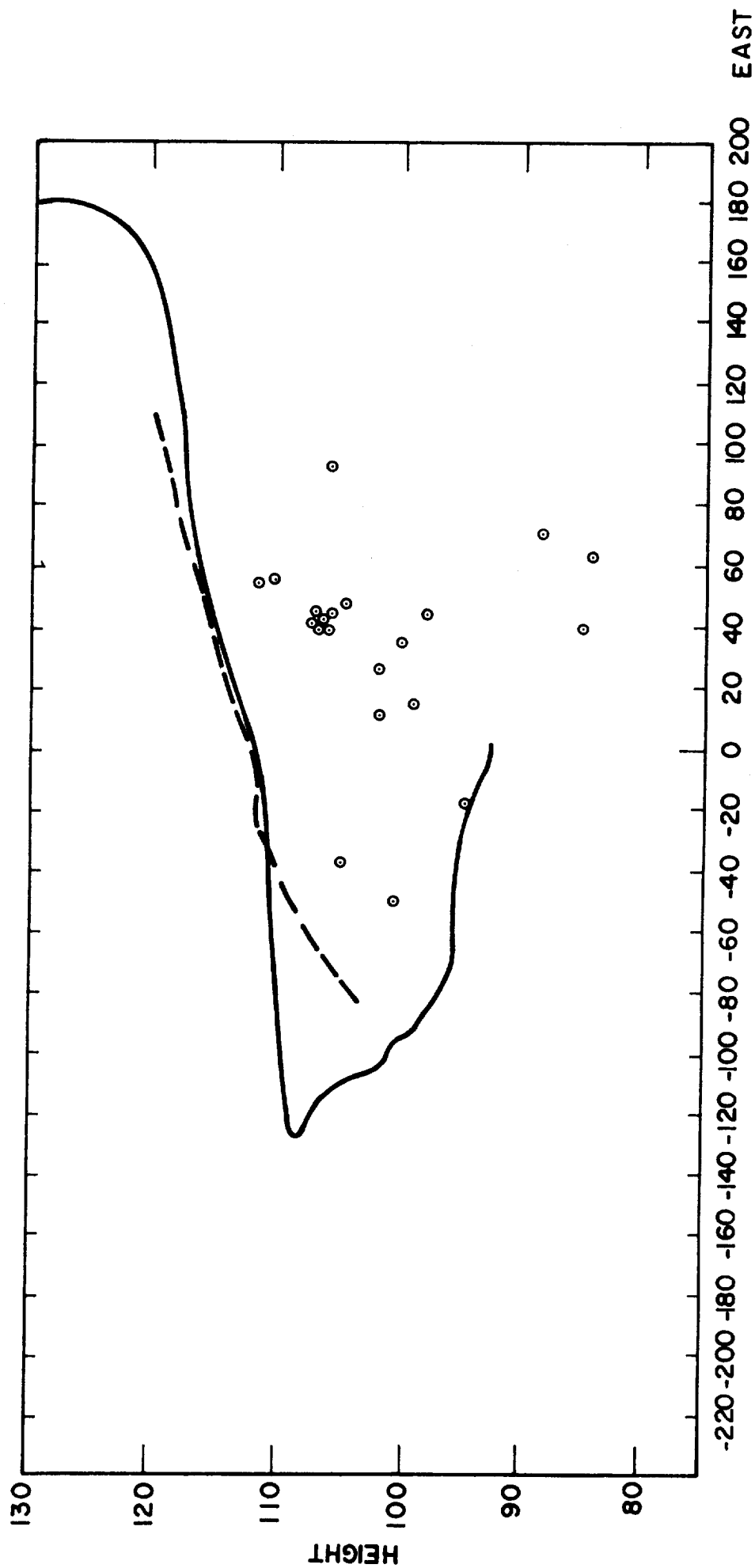
HEIGHT

14.471

14.473

14.472

17

Figure 11. Comparison of zonal component of vapor trail data from 14.471 (solid line) and meteor data during interval 0445-0630 hrs GMT (dots). The broken line is the 20 km running means of the vapor trail data.
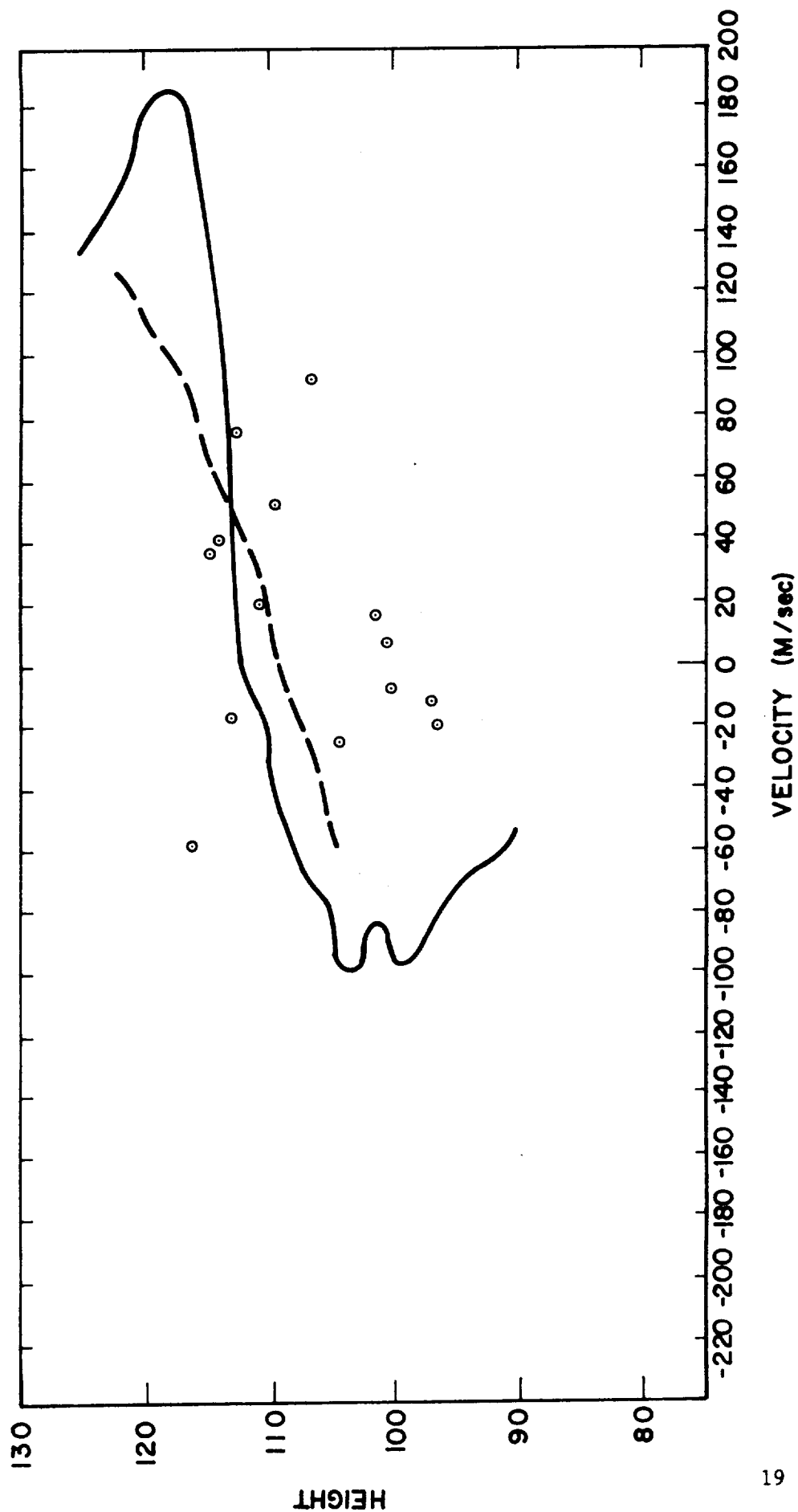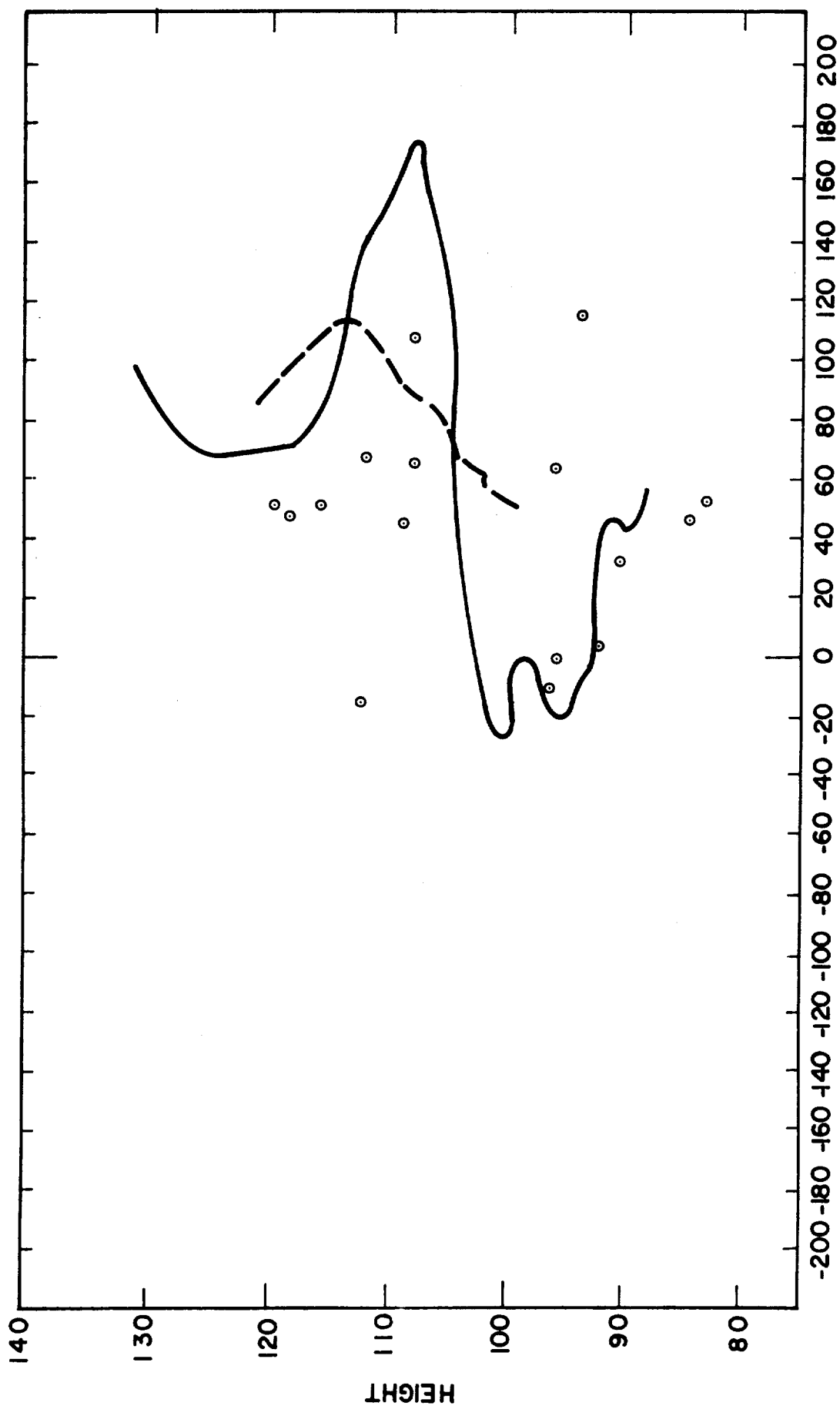
Figure 12. Comparison of zonal component of vapor trail data for 14.472; (solid line) and meteor data during interval 0700-0740 hrs GMT (dots). The broken line is the 20 km running means of the vapor trail data.

VELOCITY (M/sec)

HEIGHT

Figure 13. Comparison of zonal component of vapor trail data for 14.473 (solid line) and meteor data during interval 0840-0955 hrs GMT (dots). The broken line is the 20 km running means of the vapor trail data.

20

SECTION V

INVESTIGATION OF METHODS OF DAYTIME OBSERVATIONS OF
A VAPOR TRAIL

The possibility of the daytime use of the vapor trail method was realized about two years ago when very narrow band interference filters became available. It was demonstrated by Bedinger (Ref. 1) and also by Best (Ref. 2) that a differential radiometer employing a 2Å interference filter could track a lithium trail in the daytime. This method requires more specialized and expensive equipment than has previously been required for the vapor trail observations, and to date no operational system is available. The scanning photometer method is necessary because the narrow band interference filter required to isolate the lithium trail against the bright day sky has a small usable field of view.

The interference filters were originally called Fabry-Perot interference filters because their operation is identical to that of the classical Fabry-Perot interferometer. The conditions for transmission in the filter are illustrated in Figure 14.

The condition for constructive interference and thus transmission at wavelength λ is that the optical path through the spacer layer is an integral number of half wavelengths. Thus, $n\lambda/2 = \mu d \cos \alpha$; where μ is the refractive index of the layer of thickness, d.
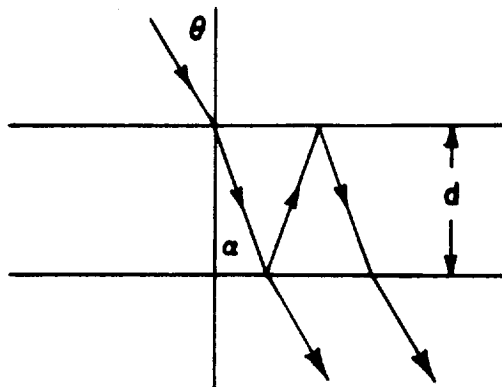

Figure 14.   Interference in a thin film of thickness, d, and refractive index, μ.

This may be written as:

$$\lambda = \lambda_o \cos \alpha; \quad \lambda_o = 2\mu d/n$$

The transmission of radiation from an angle, θ, is of interest in this application, thus it is useful to write:

$$\lambda = \lambda_o (1 - \sin^2\alpha)^{1/2} = \lambda_o \left(1 - \frac{\sin^2\theta}{\mu^2}\right)^{1/2}$$

since $\sin \theta = \mu \sin \alpha$.

Also, for small angle, $\sin \theta = \theta$ and

$$\lambda = \lambda_o \left(1 - \frac{\theta^2}{\mu^2}\right)^{1/2} = \lambda_o \left(1 - \frac{\theta^2}{2\mu^2}\right) - 1$$

If we define

$$\Delta\lambda = \lambda - \lambda_o = \lambda_o \left(1 - \frac{\theta^2}{2\mu^2} - 1\right)$$

then

$$\Delta\lambda/\lambda_o = \theta^2/2\mu^2$$

or

$$\theta = \mu \left(\frac{2\Delta\lambda}{\lambda}\right)^{1/2}$$

This equation defines the useful half angular field of view for transmission of a radiation of wavelength, λ, by a filter with band width $\Delta\lambda$. It is noted that the useful angular field is directly proportional to the index of refraction of the spacer layer of the filter. The substances most generally used for the spacers at wavelengths in the visible portion of the spectrum are sodium aluminum fluoride (cryolite) with a refractive index of 1.35 and zinc sulfide having an effective index of 2.25. The index of zinc sulfide is usually quoted as 2.4, but apparently

22

is some what less when evaporated into thin films. The angular field of view, 2θ, for filters at $\lambda6708\overset{o}{A}$ with spacer of zinc sulfide and varying band widths are given in Table III.

TABLE III

ANGULAR FIELD OF VIEW OF INTERFERENCE FILTER
TRANSMITTER AT $\lambda = 6708\overset{o}{A}$; $\mu = 2$

$\Delta\lambda$	2θ
2	5°
5	9°
10	13°
15	16°
20	18°

It is apparent from Table III that the narrow band width required to isolate the lithium radiation from the ground in the daytime would allow only a small portion of a vapor trail to be photographed. Even if a band width as large as as $2\overset{o}{A}$ were used, it would require at least 16 cameras (4 x 4) to cover a 20 x 20 degree field of view which is the minimum field size required to photograph a complete lithium trail. The formation of a mosaic type photograph of a vapor trail from such a bank of cameras would require careful alignment and precise angular calibration of the fields of view as well as skillful preparation and control of the filters. Nevertheless, it would be less expensive than the scanning radiometer method which requires accurate mechanical measurement of angles. The photograph would contain more information on small scale structure, also. However, both of the methods if used on the ground are restricted by weather and logistics. These restrictions may be removed by observations from an aircraft as discussed previously. The scanning radiometer method becomes quite complicated because of the time required for the scan and the rapid motion of the aircraft. This could result in a serious degrading of the data. On the other hand, the use of the aircraft greatly improves the photographic method. The background sky brightness at an altitude of 40,000 feet is reduced by an order of magnitude as compared to the ground values. Thus, the bandwidth of the filter can be increased to 10 or $20\overset{o}{A}$, which decreases the number of cameras required to no more than four and possibly only two.

The maximum angular field for a particular transmitted wavelength is obtained by designing the filter passband such that the peak trans-

mission is at a wavelength which is given by $\lambda_1 + 1/2 \ \Delta\lambda$. Thus, for normal incident light, the filter transmits the desired wavelength, λ_1 in passband A in Figure 15. For light incident at angles other than normal the passband of the filter is shifted to lower wavelengths. For light entering at the maximum usable field angle, θ, the passband has shifted so that λ_1 is transmitted as in passband B. Thus, the transmission of the desired wavelength, λ_1, is at least 50 percent of the maximum transmission over the field angle, 2θ.

Filters with passbands similar to those in Table III are available. However, most standard types are constructed for photometric rather than photographic usage. Thus methods of improving image quality, rejecting wide angle light and decreasing the thickness of blocking materials must be investigated.

The small effective field angle of the filters also suggests some investigation of camera characteristics. In particular, a film size smaller than the 70 mm or 5 in. width are usually employed from the ground may be used. This implies smaller instrumentation which may be desirable for observations from a small window of an aircraft.

Likewise, the distance from the cloud to the plane may be substantially increased and the image size can be retained by using a lens of larger focal length. This approach may be of interest in future possible photography of trails from on-board manned satellites.
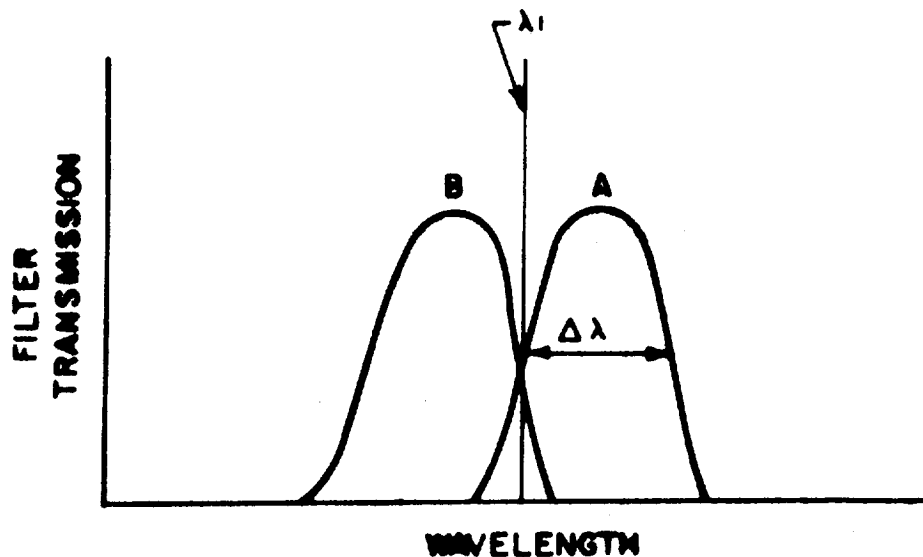

Figure 15. Dependence of field angle on passband of an interference filter. Filter passband A is for normal incidence light. The passband, $\Delta\lambda$ is shifted to B for light incident at angle θ.

REFERENCES

1. J. F. Bedinger, Rev. Sci. Instr. 41, No. 8, 1234 (1970).

2. G. T. Best, J. Atmos. Sci. 27, 979 (1970).