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SODIUM VAPOR EXPERIMENT

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1 July 1966 - 30 September 1966

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I. INTRODUCTION

The purpose of this contract is to investigate the dynamics of the upper atmosphere through analysis of the motion of sodium vapor trails ejected from sounding rockets. Data are taken photographically from several widely separated sites. Triangulation is used to determine winds from the rate of motion of the trail, and densitometry measurements determine the growth rate and small-scale structure of the trail. Complete descriptions of the experimental and analytical methods are given in reports covering NASA contracts NAS5-215 and NASw-396. Theoretical studies of the dynamics of the upper atmosphere are directed toward formulation of models based on the observations. The first series of rocket firings occurred during November 1964 from Wallops Island and simultaneously from a ship at selected distances from Wallops Island. The objective of the series was to investigate the variation of the vertical wind structure at two places separated by different distances.

The results of the first series were seriously limited by vaporizer malfunction, but one set of trails separated by 180 km showed the winds to differ significantly above 120 km. Previous analysis of several up and down trails separated by a distance of about 50 km have shown no wind variations over that distance. Continuation of the study of horizontal variation of the vertical wind profile was an objective of a series of flights from Wallops Island during June 1965. Two vapor trails were ejected from rockets fired nearly simultaneously on different azimuths during the evening twilight of 22 June and the morning of 23 June. A fifth rocket ejected a trail of TMA at 2300 EST on 22 June to allow observations of the time variations of the winds.

The spatial separation of the simultaneous trails in June was not large and the differences in the wind profiles were small. The evening trails were separated by only 25 km, and the wind speed around 100 km was only about 30 m/sec. The trail separation and wind speed of the morning trails were greater than those of the evening trails. The TMA trail, because of poor rocket performance, did not reach the predicted altitude and faded very quickly, causing some loss of data in the 100 to 125 km region and reduced the accuracy of the data below that height. Thus, the information on spatial variations is limited. Much more information was obtained from the time-spaced trails. The low wind speeds during evening twilight had increased by a factor of 2 to 3 by 2300 EST (about 3 hours later) and the familiar spiral pattern had begun to form. The clockwise spiral was even more apparent over much of the height region by morning twilight and the whole pattern had been continually rotated through the night, as has been previously observed in other time sequences in January and July 1964. The observations should be more closely spaced in order that the exact nature of the changes may be determined. Such closely spaced observations were the purpose of the series of firings at Wallops Island in January 1966.

During the night of 17-18 January 1966, five vapor trail payloads were successfully launched from Wallops Island. This series showed that observations spaced an hour or two apart provide much information concerning the manner in which the winds vary. Some of the initial observations were discussed in the Quarterly Report covering the period 1 January 1966 - 31 March 1966. It was shown that the large scale spiral pattern collapsed into an irregular low speed pattern in about 6 hours and that the entire pattern moved slowly downward.

During the period covered by this report, a series of vapor trail firings were conducted at Wallops Island, Virginia. The objectives of the series, description of the experimental program, and preliminary results are discussed in this report.

II. ROCKET FIRINGS

1. Objectives and Firing Schedule

The primary objective of the July series of firings at Wallops Island was to observe the temporal variations of the winds as evidenced by closely spaced vapor trails. The firings in January were grouped closely between evening twilight and midnight. The firings in the July series were grouped closely between midnight and morning twilight. Other specific objectives of the series were, (1) verification of the slow downward motion of the wind pattern which was observed in January 1966, (2) investigation of the "sunrise effect" reported by Spizzichino [1]*, and (3) conduct detailed observations of irregular structure on the trail at heights below 110 km.

The firing schedule, rocket apogee, and vapor type are given in Table I. In general all flights were successful and good data were obtained.

TABLE I

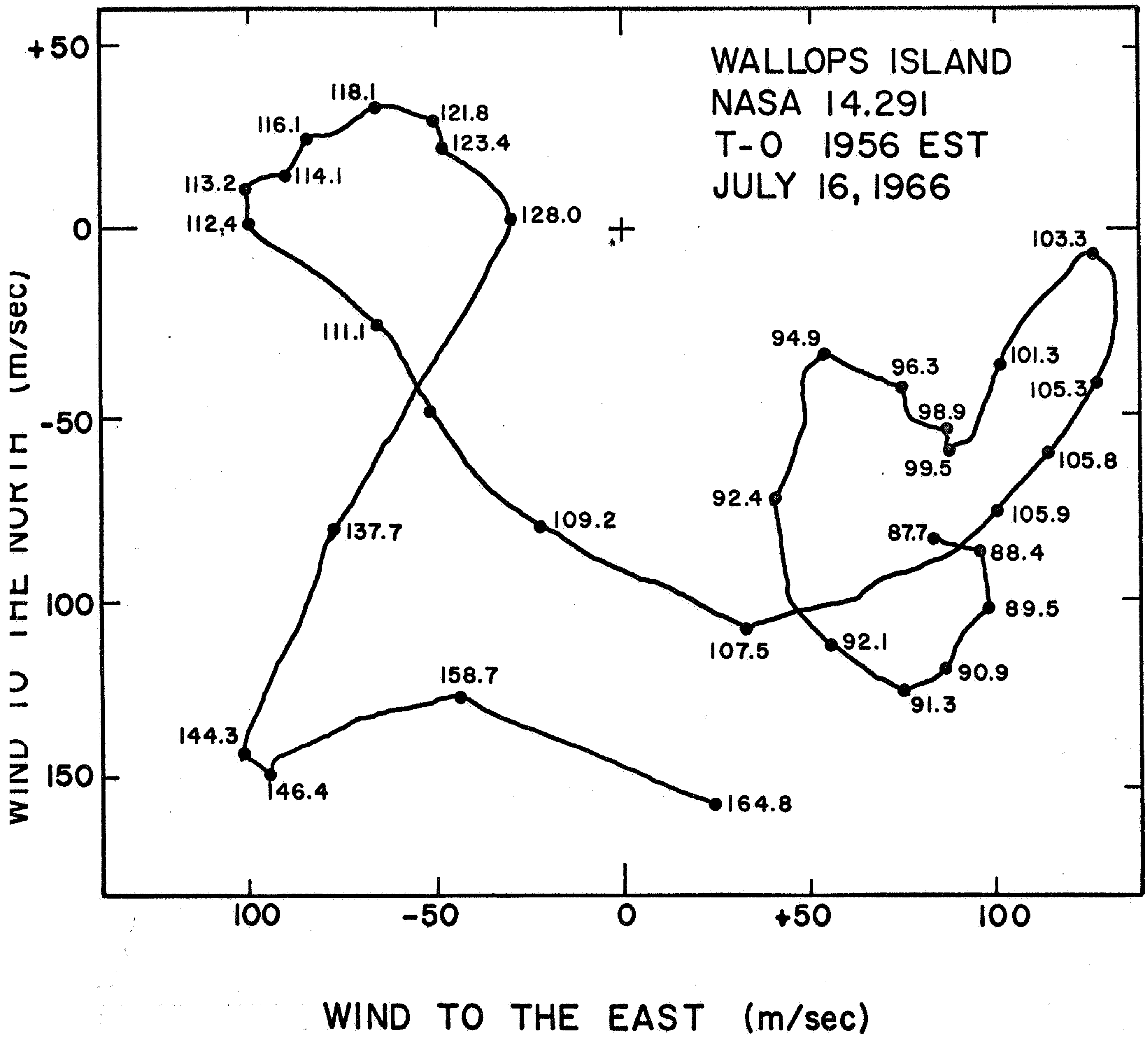
NASA No.	Firing Time EST	Rocket Apogee KM	Vapor Type
14.291 CM	1956 - 16 July	192	Na-Li
14.292 CM	0000 - 17 July	211	TMA
14.293 CM	0145	199	TMA
14.294 CM	0325	200	TMA
14.295 CM	0408	208	Na-Li

* Numbers in [ ] represent reference numbers.

III. WINDS

Hodographs of the winds obtained from the five vapor trails of 16 and 17 July are given in Figures 1 through 5. Individually, the wind patterns are similar to previous observations at Wallops. The time variation is also similar to that observed from other sequential firings, i.e., the often observed spiral pattern collapses and reforms during one night. Winds during evening twilight (Figure 1) exhibited the large spiral pattern below 125 km. The N-S component of the wind decreased until 0145 (Figures 2 and 3) while the E-W component remained large. At 0325 (Figure 4) the N-S component had again increased and at morning twilight (Figure 5) the spiral pattern was again evident. Thus, a large port of a cyclic pattern may have been observed during the 8-hour period. A complete cycle was not observed since the spiral pattern was not fully developed at either the beginning or the end of the observing period. As discussed in the last report, half periods of six hours were suggested by the data from January 1966 at Wallops Island and also at Eglin, Florida [2].

Differences in wind patterns just prior to and just after sunrise at the observing altitude are shown in Figures 4 and 5. Spizzichino has reported that winds obtained from observations of ionized meteor trails with a newly developed phase measuring radar suggest a sudden increase of E-W winds following morning twilight. It has not yet been determined if the differences shown in Figure 4 and 5 are due to a special sunrise effect or are only part of the cyclic variations.



WALLOPS ISLAND
NASA 14.291
T-0 1956 EST
JULY 16, 1966
WIND TO THE NORTH (m/sec)
WIND TO THE EAST (m/sec)
+50
0
-50
100
150
100
-50
0
+50
100
118.1
121.8
123.4
116.1
114.1
113.2
112.4
128.0
111.1
137.7
109.2
107.5
144.3
146.4
158.7
164.8
103.3
94.9
96.3
101.3
105.3
98.9
99.5
105.8
92.4
105.9
87.7
88.4
89.5
92.1
90.9
91.3

Figure 1

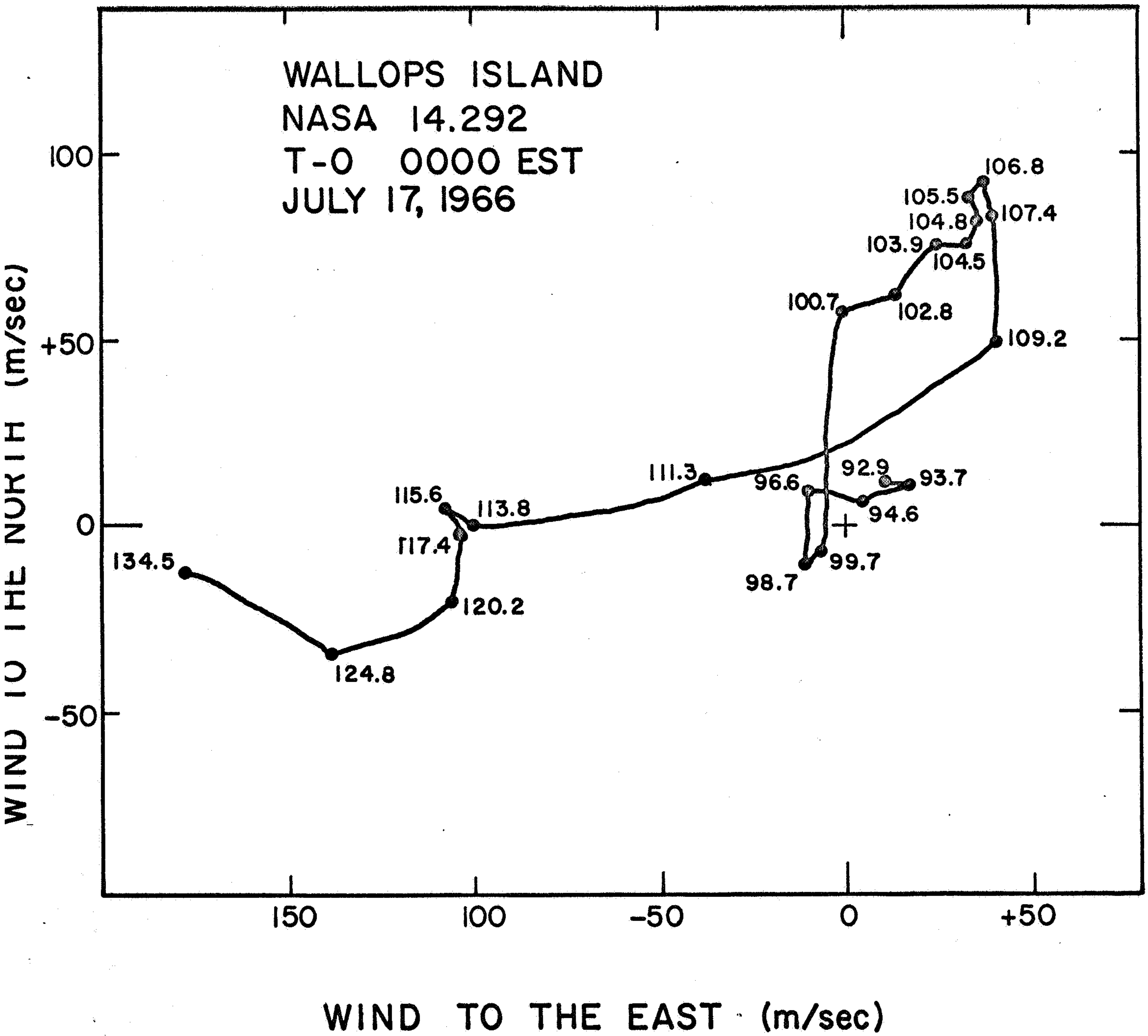
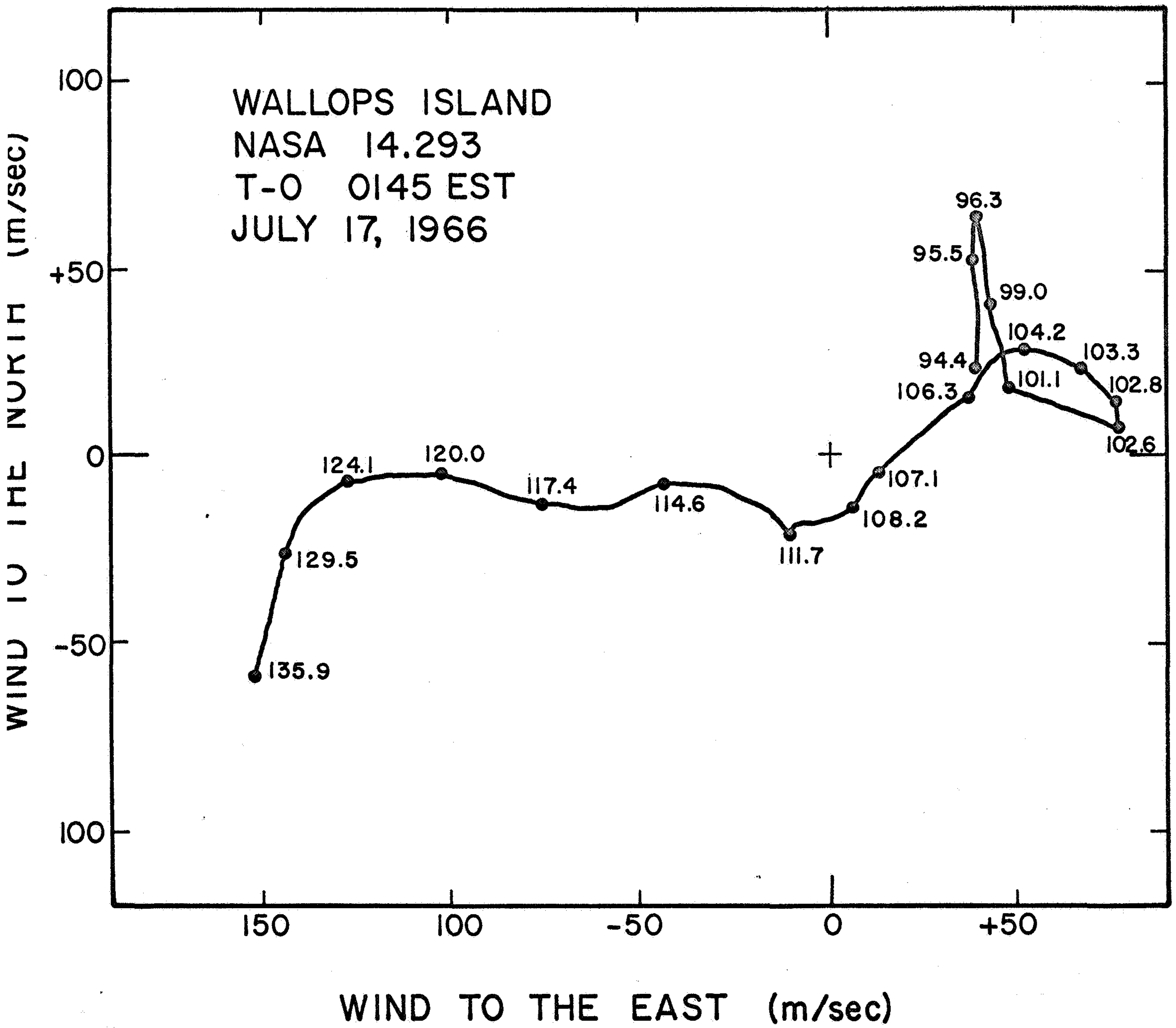

WALLOPS ISLAND
NASA 14.292
T-0 0000 EST
JULY 17, 1966
106.8
105.5
104.8
107.4
103.9
104.5
100.7
102.8
109.2
111.3
92.9
93.7
96.6
94.6
115.6
113.8
117.4
134.5
99.7
98.7
120.2
124.8
100
+50
0
-50
150
100
-50
0
+50
WIND TO THE NORTH (m/sec)
WIND TO THE EAST (m/sec)

Figure 2



WALLOPS ISLAND
NASA 14.293
T-0 0145 EST
JULY 17, 1966
WIND TO THE NORTH (m/sec)
WIND TO THE EAST (m/sec)
100
+50
0
-50
100
150
100
-50
0
+50
96.3
95.5
99.0
104.2
103.3
94.4
101.1
102.8
106.3
102.6
124.1
120.0
117.4
114.6
107.1
108.2
111.7
129.5
135.9

Figure 3

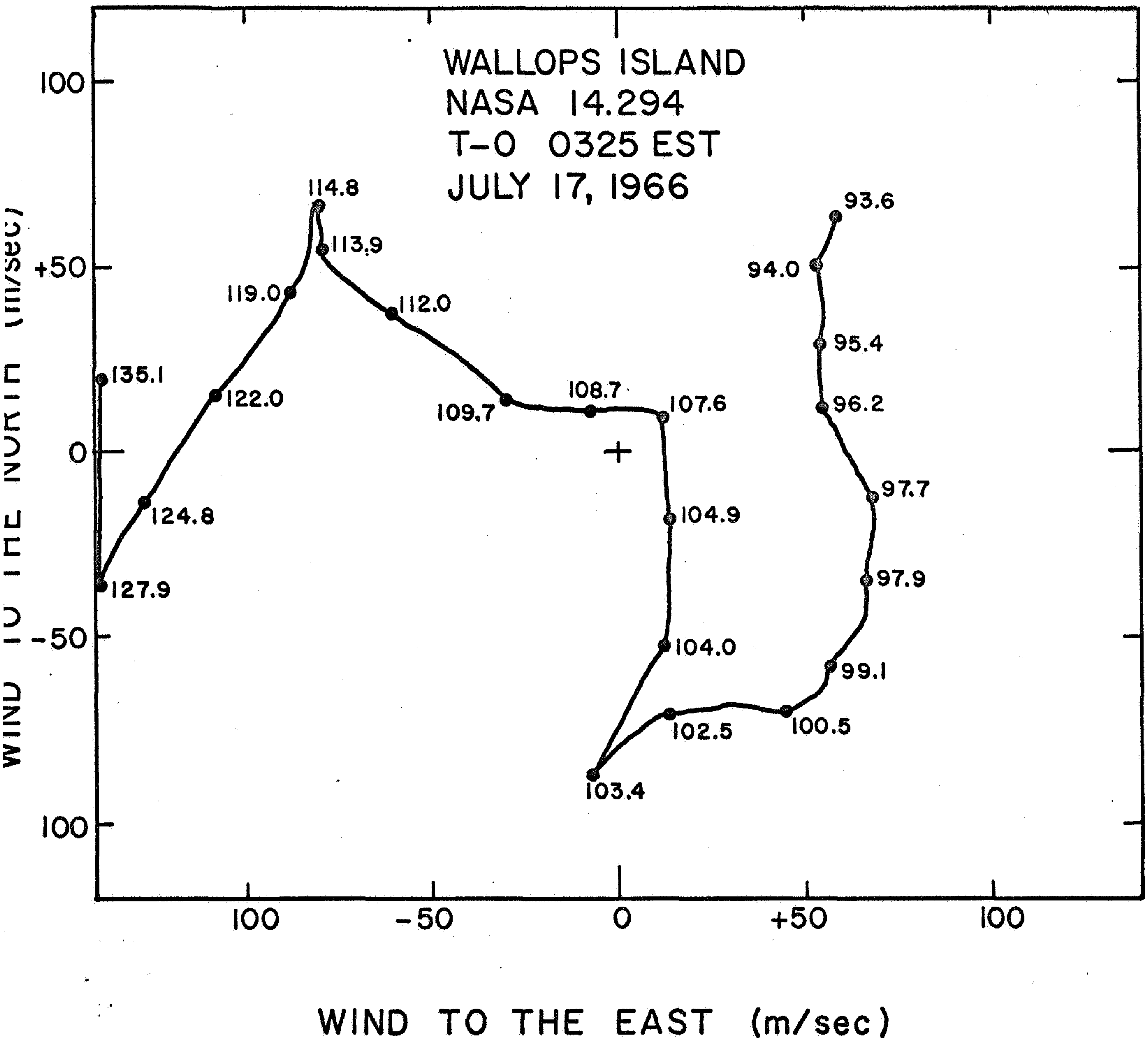

WALLOPS ISLAND
NASA 14.294
T-0 0325 EST
JULY 17, 1966
100
+50
0
-50
100
WIND TO THE NORTH (m/sec)
100
-50
0
+50
100
WIND TO THE EAST (m/sec)
114.8
113.9
119.0
112.0
135.1
122.0
109.7
108.7
107.6
124.8
127.9
104.9
104.0
102.5
103.4
93.6
94.0
95.4
96.2
97.7
97.9
99.1
100.5

Figure 4

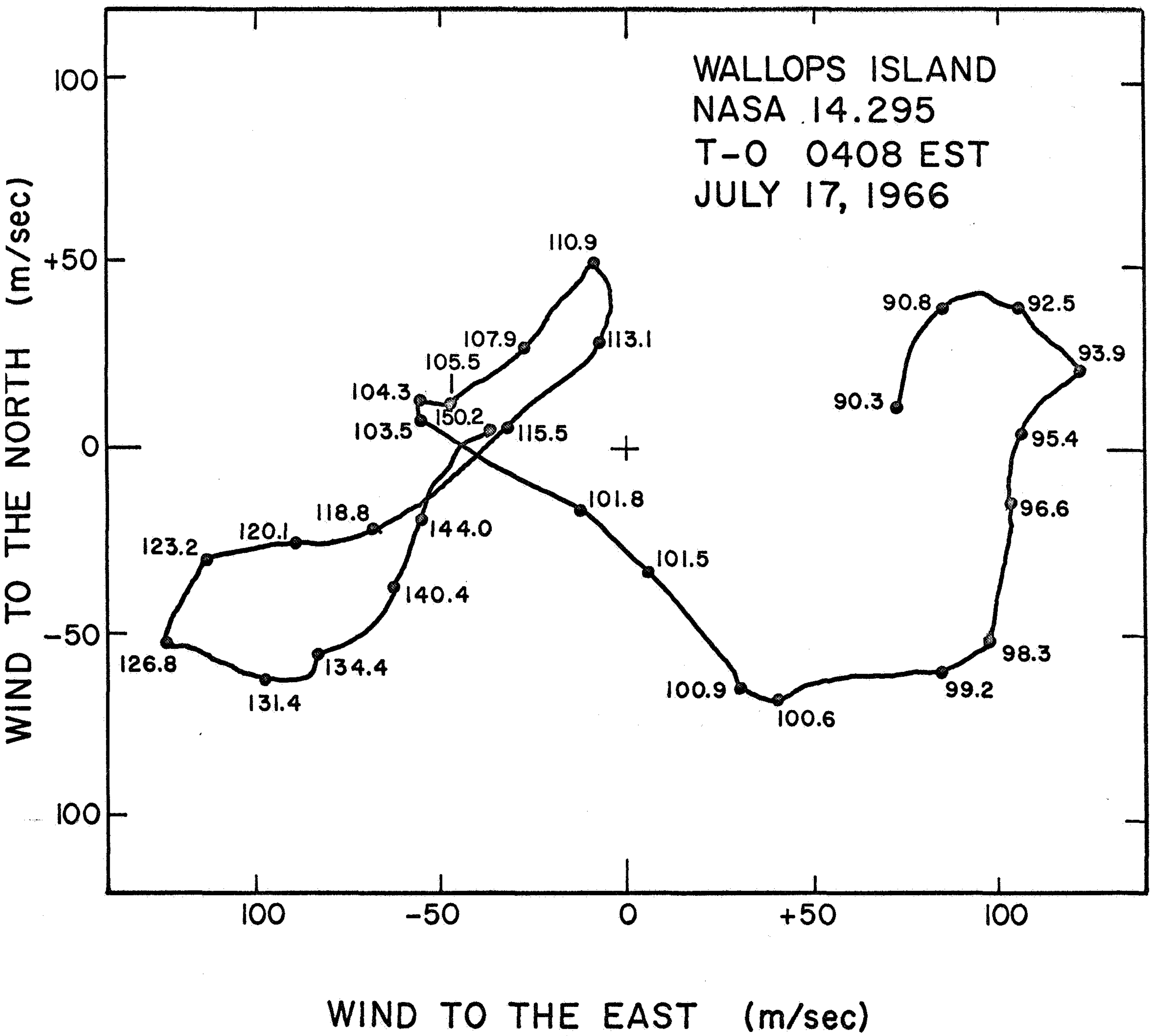

WALLOPS ISLAND
NASA 14.295
T-0 0408 EST
JULY 17, 1966
WIND TO THE NORTH (m/sec)
WIND TO THE EAST (m/sec)
100
+50
0
-50
100
-50
+50
90.3
90.8
92.5
93.9
95.4
96.6
98.3
99.2
100.6
100.9
101.5
101.8
103.5
104.3
105.5
107.9
110.9
113.1
115.5
118.8
120.1
123.2
126.8
131.4
134.4
140.4
144.0
150.2

Figure 5

The sequential vapor trails, in January 1966, revealed a slow downward motion of the entire wind pattern during the early part of the night. The large and small scale structure apparently moved together at a rate which decreased with decreasing height. One of the objectives of the July series was to determine if the downward motion continues throughout the night as would be expected of a traveling wave or if the rate decreases toward dawn as would be expected of a mass motion due to cooling during the night. Although a detailed study has not been made, the downward motion apparently was present throughout the July observing period in much the same manner as in January. The boxed points in Figure 6 were obtained from the July data. Both the magnitude and height dependence of the downdrift are comparable during the two observing periods. Such a motion could be due to the phase velocity of a traveling wave.

Turbulence

The question of existence of turbulence in the atmosphere based on the visual appearance of vapor trails in the region around 100 km was summarized in the last quarterly report. It was suggested that much of the irregular structure observed on the trails may be due to effects of the rocket passage and the vapor ejection method. An effective system to eliminate the disturbance produced by the passage of a ultrasonic rocket has not yet been devised. Some slight modification in the manner in which the vapor is ejected were made during the July series. The standard sodium canister ejects the vapor

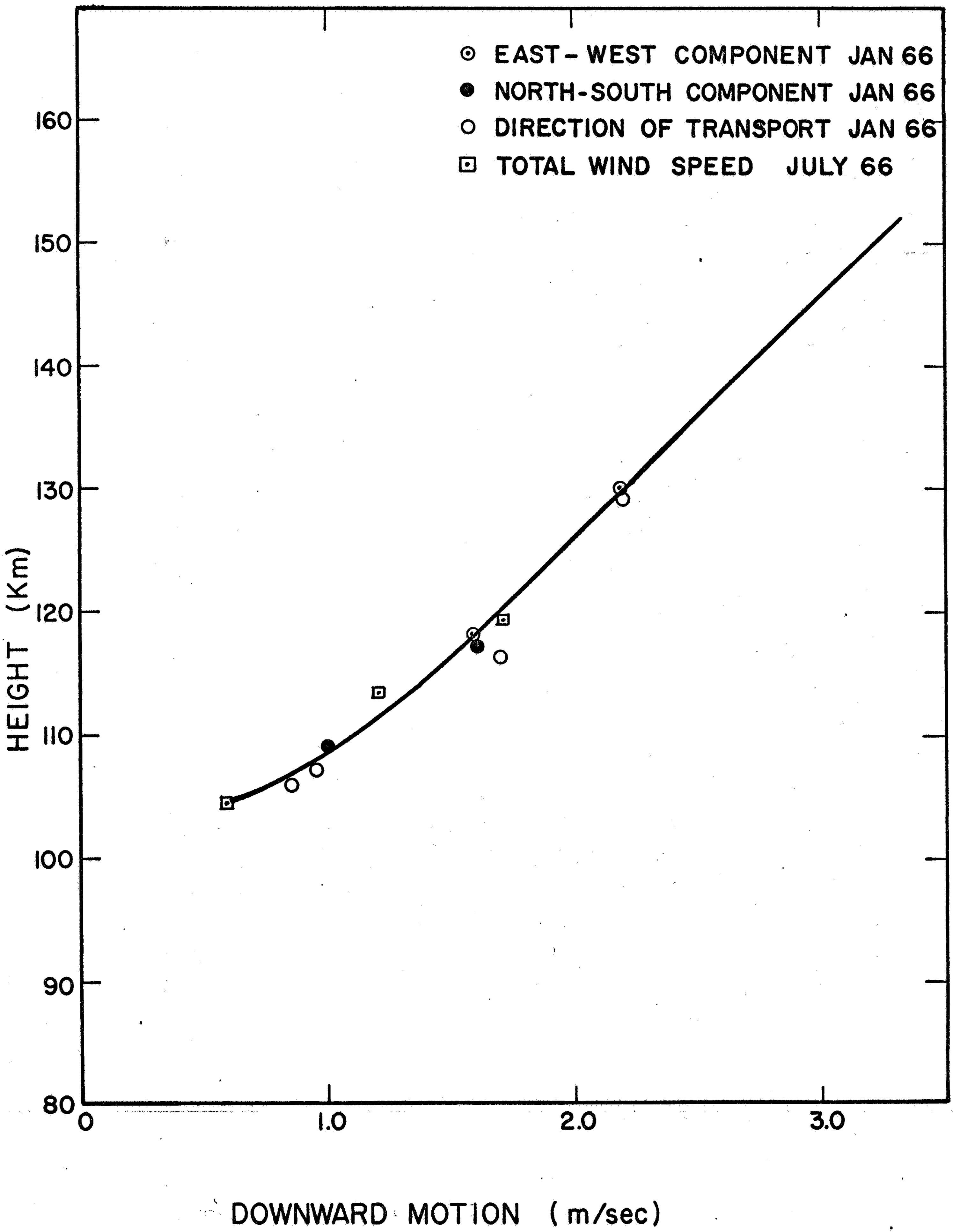

EAST-WEST COMPONENT JAN 66
NORTH-SOUTH COMPONENT JAN 66
DIRECTION OF TRANSPORT JAN 66
TOTAL WIND SPEED JULY 66
160
150
140
130
120
110
100
90
80
HEIGHT (Km)
0
1.0
2.0
3.0
DOWNWARD MOTION (m/sec)

Figure 6

radially through three circular ports equally spaced around the canister circumference. It has been suggested that this "three-jet" system together with a spinning rocket produces an irregular or sometimes "corkscrew" pattern of vapor along the rocket trajectory. One of the canisters in the July series (14.291 CM fired at 1956 EST, 16 July) was fitted with deflectors over the three exit ports in order to direct the vapor backwards along the rocket body and thus reduce the effects of forward motion of the rocket as well as the "corkscrew pattern". This canister is shown in Figure 7. The other canister, shown in Figure 8, with 8 ports, 45° apart was designed to give a more uniform distribution of ejected vapor and thus reduce effects of rocket spin. This canister was flown on NASA 14.295 at 0408 EST on 17 July 1966. A photograph of the vapor trails from each of these canisters is shown in Figure 9. Initial inspection of the photographs might lead one to assume that the wind patterns are very similar at the two times and that one trail is much more "turbulent" than the other. After data reduction was completed, it was seen that the upper boundary of the irregular trail structure is at about the same height at both times, but the large wind shear is at a lower height during the morning twilight. The section on the evening trail, 14.291, between 103 and 113 km appears to be smaller in diameter than most trails in this height region. This effect could be due to the vapor being deflected backward instead of radially, or it could be caused by the large wind shear.

Figure 7

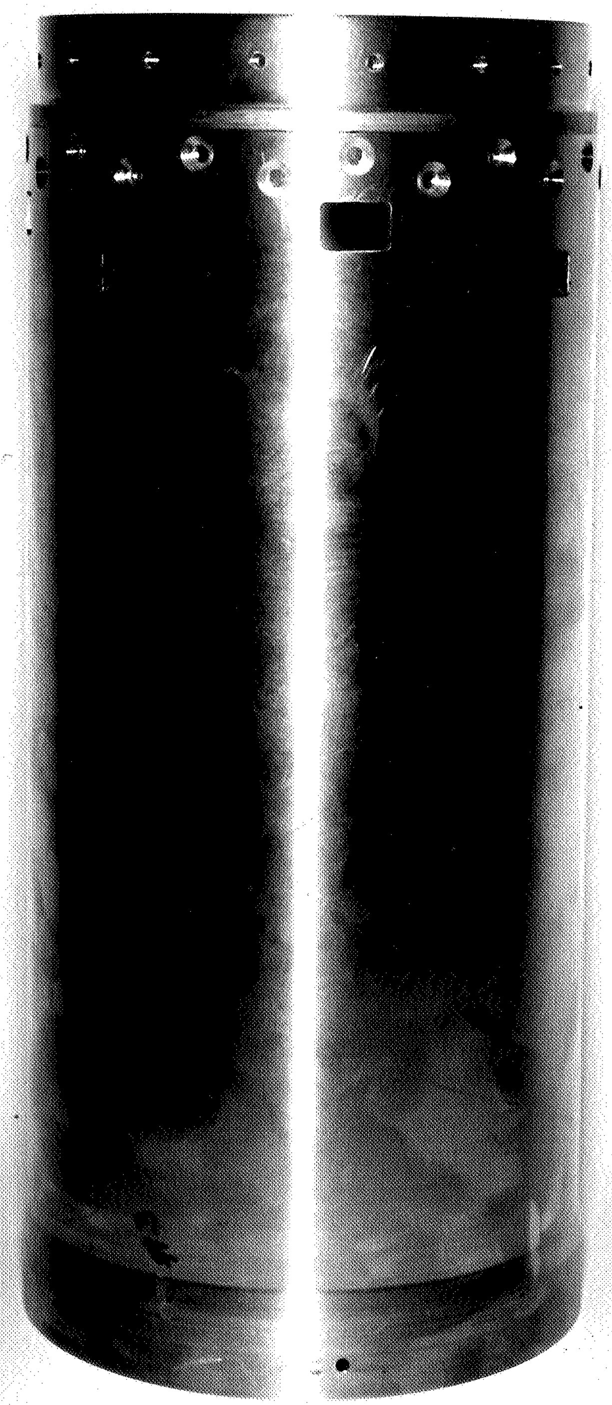
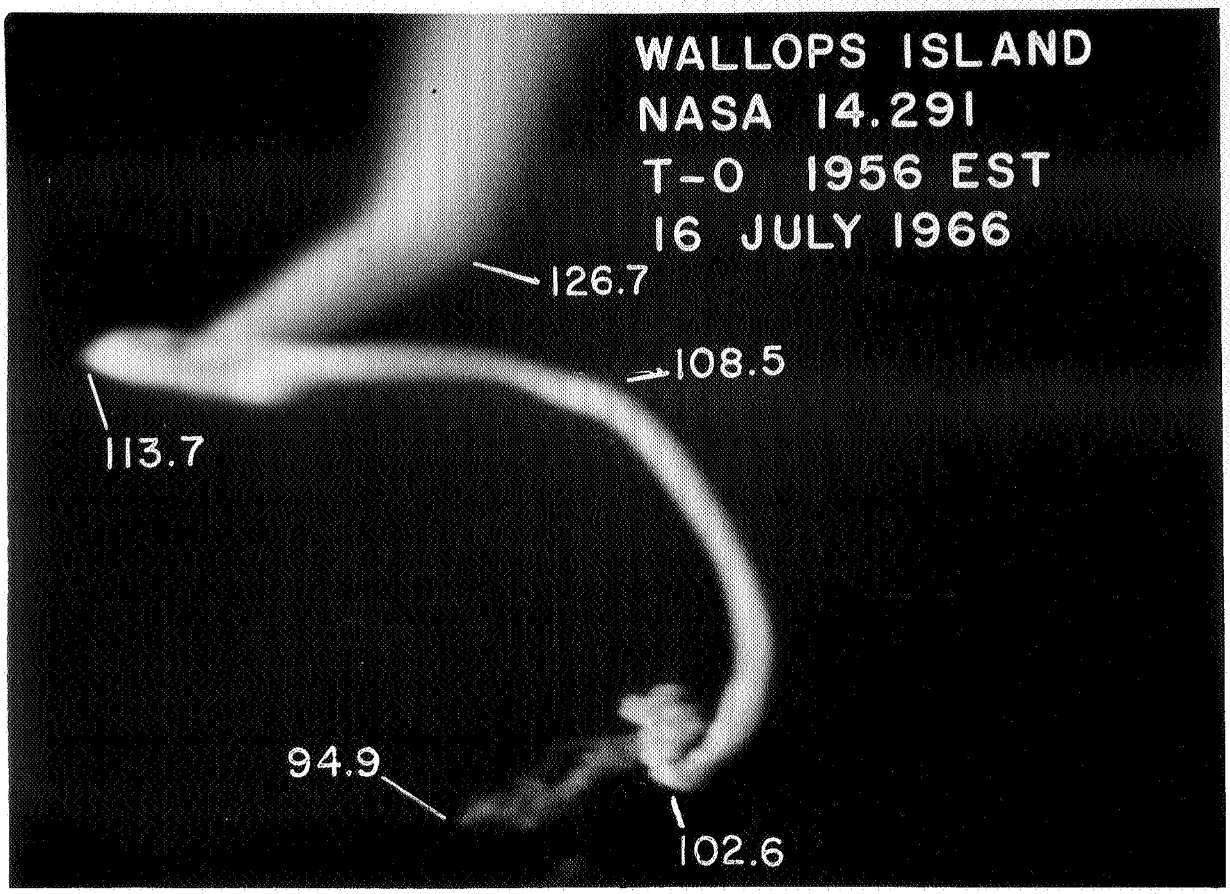
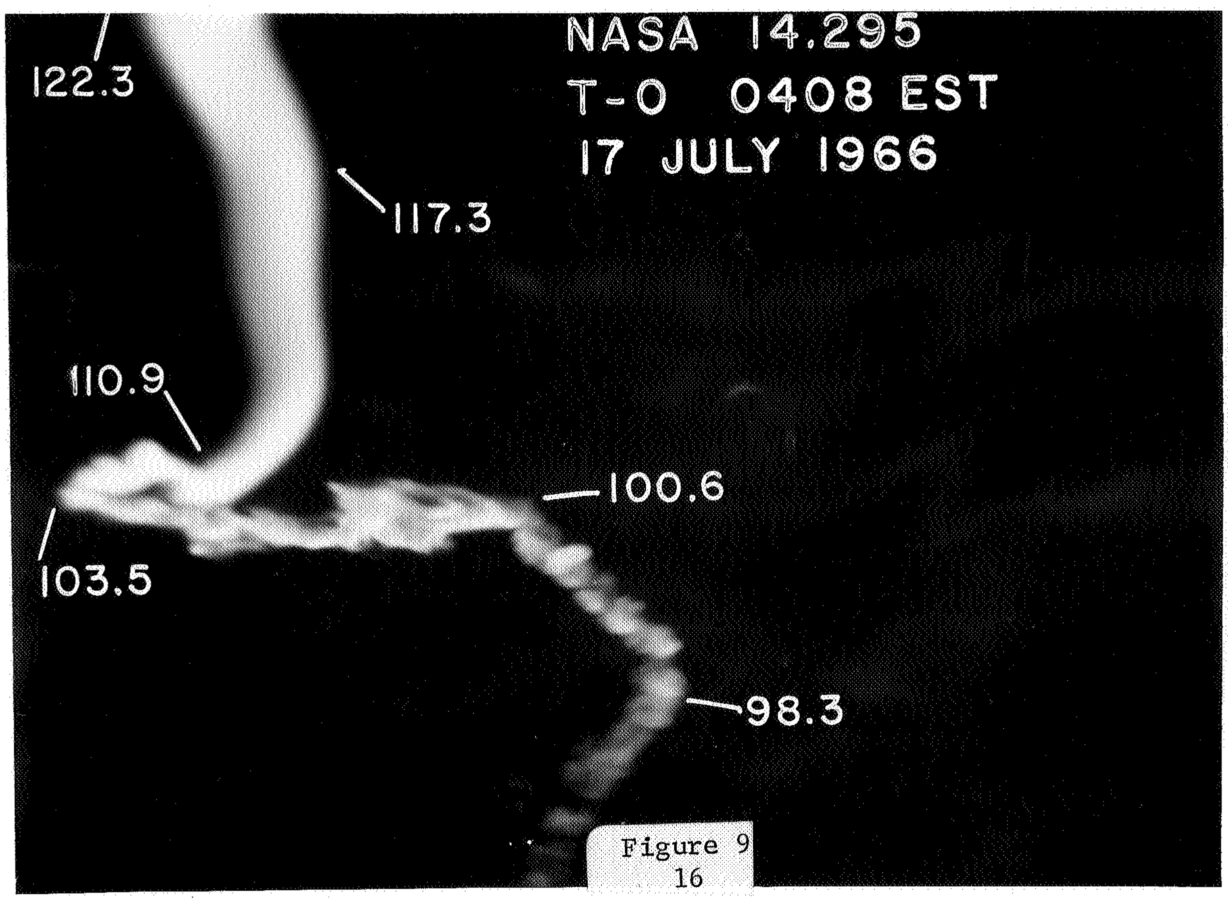


Figure 8



WALLOPS ISLAND
NASA 14.291
T-0 1956 EST
16 JULY 1966
126.7
108.5
113.7
94.9
102.6



NASA 14.295
T-0 0408 EST
17 JULY 1966
122.3
117.3
110.9
100.6
103.5
98.3

Figure 9

Diffusion

The rate of growth of artificial vapor trails in the upper atmosphere can be used to obtain information about local properties such as the diffusion coefficient and the temperature. To fascilitate the interpretation of observational data we have formulated a general solution of the equation governing the diffusion of a trace fluid of low concentration through a homogeneous and isothermal ambient fluid. We find that the process of diffusion is affected considerably by the initial conditions and by the presence of wind shears. (The term "wind-shear" is used to denote the vertical gradient of the horizontal wind). Specific examples demonstrate the following conclusions:

(1) An accurate determination of local diffusion coefficients must take into account initial conditions and wind shears.

(2) The growth of the diameter of a vapor trail may be proportional to the square root, the first power, or the 3/2 power of the time, depending on the wind shear and the time of observation.

(3) The lifetime of irregularities of a given size in the trail depends strongly on the local diffusion coefficient.

The applicability to the upper atmosphere of the formulae used and of the conclusions derived from them is discussed. A detailed account of this material will be presented in a technical report.

IV. FUTURE PLANS

During the next reporting period analysis of the sequential wind measurements will continue. Although the number of observations is still small, it is thought that some statistical analysis may be informative.

Preparation for a series of firings in January will begin. Six vapor trail payloads will be constructed and camera equipment will be prepared for cold climate operation.

REFERENCES

1. Spizzichino, A., Cospar, Vienna, 1966.

2. Rosenberg, N. W., Edwards H. P., Wright, J. W., Space Research IV, North Holland Publishing Co.