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WIND VELOCITY PROFILES MEASURED BY THE SMOKE-TRAIL METHOD AT WALLOPS ISLAND, VIRGINIA, 1965 THROUGH 1969

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16. Abstract

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SUMMARY

Thirty-nine detailed wind profiles measured by the smoke-trail method at the Wallops Island Test Range during the years 1965 through 1969 are presented as west-to-east and south-to-north velocity components at height intervals of 25 meters. The overall altitude range of the wind-profile data varies from about 1 to 23 km. The wind measurements, which were made under a variety of conditions, include velocities in excess of the annual 99-percent highest wind value (the wind value which will not be exceeded 99 percent of the time) for the Wallops Island Test Range. The report also includes a listing of the wind soundings and their maximum velocities and direction of the maximum velocities measured at Wallops Island from 1959 through 1969. Results of smoke-trail enhancement experiments are also indicated.

INTRODUCTION

A knowledge of winds aloft and their variation with altitude is required for the design of vertically rising rockets and space vehicles. Evidence indicates that the conventional balloon sounding, which has provided the bulk of such wind measurements, is not satisfactory for providing information at the shorter wavelengths, which can be of importance in design considerations such as vehicle structural response, fuel slosh, and control (ref. 1). Difficulties arise with the conventional balloon measurements at the shorter wavelengths because of self-induced balloon motions and large tracking errors. (Special-purpose balloons and other systems, refs. 2 to 6, have reduced but not totally eliminated these errors.) Also, balloons may travel a large distance horizontally in the altitude range of interest.

To provide accurate information on these small-scale variations, the smoke-trail wind-measurement technique described in reference 7 was developed. This technique not only provides information on small-scale wind fluctuations but also provides it along a typical missile trajectory.

Preliminary testing of the smoke-trail technique was begun at the NASA Wallops Station, Wallops Island, Virginia (lat. 37°50' N., long. 75°29' W.) in 1959 and the data collected through 1962 were published in reference 8. Additional data collected in 1963 and 1964 were published in reference 9. Results of similar tests at the Eastern Test Range, Cape Kennedy, Florida, for the years 1962 through 1964 are published in references 10 to 12.

The purpose of the present report is to present data collected during the years 1965 through 1969 at Wallops Island and to summarize in somewhat more comprehensive form all of the data collected by use of the smoke-trail technique at that location. Techniques to enhance the visual quality of the chemically produced smoke trails are also described. This report is the last of a series of NASA technical notes reporting wind profiles measured in the smoke-trail program and brings the total number of wind profiles reported to 105 for the Eastern Test Range and 107 for Wallops Island.

MEASUREMENT TECHNIQUE

Basic Technique

The method of measuring the details of the wind structure by means of smoke trails has been fully documented in reference 7, with later modifications to the method described in references 8 and 10. Only a brief review of the technique will be given here.

Basically, small rockets are used to eject a trail of chemical smoke over a nearly vertical flight path. The smoke then serves as a sensitive tracer of the winds. Ground-based aerial mapping cameras photograph the changing smoke pattern in time lapse to provide the data for wind-vector calculation. The triangulation needed to determine the position of the trail in space requires at least two ground installations, separated by sufficient distance to provide an adequate baseline. The camera sites employed at Wallops Island (designated Miona and Battle Point) were each located approximately 16 kilometers from the launch point on lines approximately 90° apart. Figure 1 is an example of a typical smoke-trail photograph taken from one of these camera sites.

The vehicles employed at Wallops Island to produce the smoke trails consisted of fin-stabilized Nike rocket motors with smoke-producing nose cones. (See ref. 13 for further details.) For most of the firings, the smoke-producing chemical ejected from the nose cone was titanium tetrachloride (chemical warfare symbol FM). This chemical, when introduced into the wake of the coasting rocket, reacts to induce condensation of atmospheric water vapor and generally produces a highly visible trail, as described in reference 14.

Trail-Enhancement Tests

After a number of firings, it was noticed that the smoke trail had a tendency to fade in the altitude region of 12 to 18 kilometers. The fading was attributed to a lack of moisture in that altitude region. A limited experiment (three launches) was then conducted in an attempt to enhance the trail in this region by expelling water into the atmosphere, in addition to the titanium tetrachloride normally employed. A system was designed for expelling the water. The system consisted of an air pressure chamber, a water chamber, a rubber bladder or seal to separate the water and air chambers, an electrical programer, and an explosive discharge valve. The only external change in the regular Nike smoke vehicle was the addition of a 17.8-cm-long (7-in.) section (containing the water-expulsion apparatus) between the regular smoke-producing payload and the Nike rocket motor, plus an additional discharge vent.

Results of these smoke-enhancement tests are shown in the smoke-trail photograph of figure 1. This figure illustrates one of three water-discharge tests, all of which clearly showed the faded portion of the trail followed by a more dense portion caused by the water discharge. It was thus concluded that the density of the smoke trail in the upper altitudes produced by the Nike smoke-system technique can be improved by the addition of water into the trail.

In addition to the trail-fading problem occasionally encountered, operational limitations were sometimes imposed by haze and/or cloud background. In an effort to increase the contrast between the smoke trail and the background under these conditions, laboratory experiments were conducted to determine whether the production of colored smoke was practical. (See ref. 15.) Colored oil smokes and colored pyrotechnic smokes, although possible to produce, would require much greater payload weight for a given volume of smoke; thus the approach was to determine whether the more efficient hygroscopic trails (as presently used) could be colored. The addition of many kinds of coloring agents, either mixed directly or as an aerosol, was tried with no success. A promising result was obtained with the addition of titanium tetrachloride to a flask containing acetic acid. In a laboratory experiment, a dense yellow smoke formed in the flask and "puffed" out the neck. As this smoke mixed with and dissipated into the atmosphere at surface pressure, however, the color disappeared and the normal white smoke appeared. Acetone and several other ketones produced similar results. However, tests under simulated high-altitude conditions in a vacuum chamber produced more persistent coloration. Therefore, reference 15 recommended field tests with a Nike smoke rocket employing both titanium tetrachloride plus acetone and titanium tetrachloride plus acetic acid.

Three experiments were therefore conducted, two employing acetone and titanium tetrachloride and one employing acetic acid and titanium tetrachloride. Essentially the same hardware previously used to discharge water into the atmosphere was used to discharge the acetone and the acetic acid.

The experiments involving the discharge of acetic acid and acetone into the trail in an attempt to color the smoke for contrast improvement did not produce either visual or photographic evidence of trail coloration. However, both the acetone and acetic acid increased the density of the white trail to about the same extent as the addition of water.

RESULTS AND DISCUSSION

Wind Profiles

West-to-east and south-to-north components of wind velocity as a function of altitude are shown in figures 2 to 40. Wind-velocity values are computed for every 25-meter altitude increment and connected with straight-line segments, thus giving an appearance of a continuous curve. The data contained in these figures and in references 8 and 9 are summarized in table I. The data presented in the tables are shown in chronological order with Langley identification, date and time of launch, altitude range of each profile, and the magnitude, direction, and altitude of the maximum wind velocity.

The wind-velocity data presented in figures 2 to 40 and in references 8 and 9 are available on request from the NASA Langley Research Center on punched cards or in tabular form as a supplement to this report.[1] A sample tabulation illustrating the format of these data is shown in table II. In the tabulation, each profile is identified by a trail number, date and time of launch, time increment over which the data were taken, and camera and picture (frame) identification.

The various measures of the wind shear, or rate of change of wind velocity with height, are evaluated over a height interval of 25 meters and apply to the 25-meter height interval immediately below the reported height. These wind-shear values have been included in the tabulation because of numerous requests. However, the user should be aware of the large errors involved in computation of shears over an interval as small as 25 meters. For example, rms velocity errors of 1.0 m/sec at both measurement points would result in an rms shear error of 0.056 sec^{-1}. (Actual shear values as large as 0.056 sec^{-1} are seldom encountered.) Of course, the magnitude of the error decreases in proportion to an increasing altitude interval; thus, some users may find it desirable to average several of the reported values or to compute directly the shears over larger altitude intervals.

To provide pressure, temperature, and humidity data, radiosonde measurements were made at the Wallops Island Range within 6 hours of each of the smoke-trail launchings. The results of these data are available from the National Weather Records Center, Federal Building, Asheville, North Carolina 28801.

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[1] Requests should be directed to the Langley Research Center, Hampton, Virginia 23365, and should include the author, title, and code number of this paper and the specific profiles desired.

The smoke-trail wind measurements presented in this paper exhibit characteristics similar to those of references 8 and 9. The two largest scalar wind values exceed the 99-percent highest wind (the value which has not been exceeded 99 percent of the time) for the months of October and February and for the year on the basis of data from reference 16. These values are 81.2 m/sec (trail 090, fig. 19 and table I(c)) measured at an altitude of 11.6 km, for the month of October; and 79.6 m/sec (trail 076, fig. 5 and table I(c)) measured at an altitude of 9.875 km, for the month of February. The maximum wind values for three additional profiles exceeded the 95-percent monthly value and those for another three profiles exceeded the 90-percent monthly value published in reference 16.

Table III shows the maximum resultant velocity, the altitude at which it occurred, and the cumulative percentage frequency of occurrence of the velocity at that altitude for the total sample, which includes previous data collected from 1959 through 1964 (refs. 8 and 9) of the smoke-trail wind data measured at Wallops Island. The maximum resultant velocity obtained with the Nike smoke-trail method for the total sample was 92.6 m/sec (trail 009, ref. 8), which exceeds the 99-percent highest velocity for both the year and month during which it occurred. A resultant wind velocity of 131 m/sec (trail 073, ref. 9) was measured at an altitude of 54.125 km by using an exhaust trail from a Scout rocket second stage. This large velocity is not included in the cumulative frequency of table III because the wind occurred well beyond the altitude range of the Nike smoke wind measurements and of the wind measurements of reference 16. In all months of the year, the median wind value (the wind velocity having a cumulative percentage frequency of 50) was exceeded at least once. The following discussion points out a few interesting features of the trails. In the profile of trail 076, figure 5, large shears in both wind components are found in the region of about 10 to 11 km as well as a large maximum west-to-east velocity component between about 8.3 to 10 km. The peak values exceed the 99-percent highest wind for February at 8 to 10 km.

In the profile of trail 090, figure 19(a), the largest maximum west-to-east wind of 79.5 m/sec occurring at 11.6 km exceeds the 99-percent highest wind for both the year and month at 11.6 km for Wallops Island. (See ref. 16.)

An unusual feature in trail 103, figure 31, is the large northerly wind maximum extending over about 4 km of altitude with a peak value of about 35 m/sec extending over about 1 km.

Consideration of Bias Effects

Because the use of the smoke-trail technique is limited to periods of good visibility, a question arises as to whether the wind data gathered by this technique are biased or unrepresentative of the general distribution of winds at the location. Since one of the uses of these data is in the design of launch vehicle systems in which wind loads are an important design parameter, there is particular concern that the experiments are possibly sampling relatively low-wind situations and not adequately sampling the high-wind cases, which are of particular importance for vehicle design.

To examine this possibility, averages of winds measured by the smoke-trail technique were compared with averages of balloon-measured winds at altitudes of 11, 12, and 13 km, which are often critical altitudes for launch vehicle loads. Figure 41, which shows such comparisons for an altitude of 11 km, is also typical of the results obtained for the other two altitudes. The balloon data shown are taken from references 16 and 17. Although the smoke-trail averages for individual calendar months show considerable variability, as might be expected from the smaller size samples, they are not systematically lower or higher than the balloon wind averages from references 16 and 17. Thus no bias is apparent from launching only during good visibility. This result is in agreement with results for earlier measurements reported in references 7 to 12.

CONCLUDING REMARKS

Thirty-nine detailed wind profiles measured by the smoke-trail technique at Wallops Island, Virginia, during the years 1965 through 1969 are presented. The wind-profile data presented include west-to-east and south-to-north velocity components at 25-meter height increments. The overall altitude range of the wind-profile data varies from approximately 1 to 23 km; however, the length of individual profiles varies from 3.5 to 20.6 km. The characteristics of these profiles are generally similar to those published in NASA Technical Notes D-2937 and D-4365. Although most profiles have low to moderate peak wind values and exhibit many small-scale variations, the data include wind velocities in excess of the statistical 99-percent highest value for the Wallops Island Test Range.

Experiments to increase the density of the smoke trails in the upper altitude regions by the addition of water were successful. Efforts to color the smoke and thus increase the trail contrast by the addition of acetone or acetic acid, however, did not produce either visual or photographic evidence of trail coloration.

This report is the last of a series of NASA technical notes reporting wind profiles measured in the smoke-trail program and brings the total number of wind profiles reported to 105 for the Eastern Test Range and 107 for Wallops Island.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., June 20, 1972.

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TABLE I. - LIST OF WALLOPS ISLAND WIND SOUNDINGS

(a) 1959 through 1962 (ref. 8)

Trail identification	Date	EST	Altitude range, km	Magnitude of maximum velocity, m/sec	Direction of maximum velocity, deg (a)	Altitude of maximum velocity, m
002	9/21/59	1500	2.4 to 11.6	10.0	316	8 230
[b]003	11/4/59	1040	1.5 to 10.5	[c]39.5	301	10 485
[b]004	12/4/59	1120	1.8 to 12.2	[c]26.0	360	9 905
005	9/8/60	1330	4.0 to 8.8	8.7	107	7 725
006	9/23/60	1110	3.4 to 13.4	19.9	293	12 850
007	2/15/61	1300	2.7 to 9.9	[c]51.2	270	9 625
[d]008	2/16/61	0807	2.8 to 16.5	61.4	289	12 650
009	4/6/61	1435	3.2 to 12.5	92.6	269	11 000
010	4/14/61	1030	4.6 to 10.2	[c]38.6	282	10 175
012	4/14/61	1435	3.2 to 12.4	39.1	275	11 175
014	7/14/61	1100	11.2 to 13.9	[c]26.4	325	12 475
015	7/14/61	1620	4.7 to 12.4	26.0	290	11 525
016	7/14/61	1620	11.2 to 13.9	25.8	250	13 900
018	10/24/61	1110	2.6 to 12.0	[c]22.9	273	11 475
019	11/22/61	1030	3.2 to 11.8	40.3	305	11 600
020	1/16/62	1610	3.1 to 15.8	72.1	268	10 225
021	2/6/62	1400	2.6 to 16.1	69.6	251	10 075
022	4/4/62	1550	3.0 to 11.4	[c]40.4	281	11 425
023	5/4/62	1530	4.0 to 8.9	[c]30.8	267	8 875
024	5/4/62	1530	2.8 to 12.3	44.0	257	11 350
025	5/4/62	1530	2.2 to 18.2	43.5	256	11 350
026	5/5/62	1340	2.9 to 14.8	19.7	179	7 925
027	5/25/62	1240	5.0 to 12.5	37.5	318	11 225

[a] Direction from which wind is blowing, measured clockwise from true north.
[b] Little Joe rocket system exhaust trail.
[c] Jet stream maximum velocity may not have been measured.
[d] Scout rocket first-stage exhaust trail.

TABLE I. - LIST OF WALLOPS ISLAND WIND SOUNDINGS – Continuéd

(b) 1963 through 1964 (ref. 9)

Trail identification	Date	EST	Altitude range, km	Magnitude of maximum velocity, m/sec	Direction of maximum velocity, deg (a)	Altitude of maximum velocity, m
028	4/25/63	1458	4.0 to 20.0	73.1	286	9 025
029	4/25/63	1458	4.0 to 11.4	73.2	286	8 900
030	4/25/63	1458	4.0 to 17.0	73.5	286	8 950
031	8/15/63	1811	3.6 to 19.5	48.9	245	12 275
032	9/19/63	1514	4.2 to 20.2	15.6	347	12 675
033	9/19/63	1648	4.2 to 20.2	17.8	345	12 500
034	9/23/63	1300	2.9 to 18.8	54.1	271	12 625
035	10/1/63	1634	5.6 to 20.0	27.3	230	13 925
036	10/4/63	1314	3.9 to 20.7	36.6	319	10 150
037	10/11/63	1309	5.5 to 22.0	22.8	278	14 800
038	10/15/63	1438	2.7 to 16.4	12.0	298	13 275
039	11/12/63	1520	4.2 to 19.2	61.3	243	10 875
040	1/22/64	1527	3.8 to 21.7	41.3	297	13 425
041	1/29/64	1419	3.5 to 20.1	53.9	299	10 350
042	2/4/64	1320	3.1 to 19.4	31.7	288	11 625
043	3/13/64	1336	4.7 to 20.5	43.4	305	11 250
044	3/17/64	1440	4.2 to 16.8	41.0	288	11 600
[b]045	3/27/64	1226	2.2 to 6.0	[c]46.7	257	6 000
046	3/27/64	1404	2.7 to 14.4	65.3	252	10 450
047	4/9/64	1629	2.9 to 18.9	48.9	267	10 800
048	4/17/64	1344	3.7 to 17.2	27.8	306	13 450
049	5/4/64	1315	3.3 to 17.9	17.7	320	11 625
050	5/5/64	1234	3.6 to 17.8	35.0	355	12 100
051	5/6/64	1318	3.7 to 18.6	33.0	22	10 925

See footnotes on p. 11.

TABLE I.- LIST OF WALLOPS ISLAND WIND SOUNDINGS – Continued

(b) 1963 through 1964 (ref. 9) – Concluded

Trail identification	Date	EST	Altitude range, km	Magnitude of maximum velocity, m/sec	Direction of maximum velocity, deg (a)	Altitude of maximum velocity, m
052	5/6/64	1343	3.7 to 14.4	35.1	359	12 450
053	5/19/64	1322	3.6 to 13.5	22.6	298	13 300
054	5/22/64	1443	5.2 to 15.1	16.1	334	14 750
055	6/11/64	1334	4.7 to 14.9	40.7	347	12 450
056	7/30/64	1617	5.7 to 16.3	27.3	253	12 000
057	8/14/64	1754	5.0 to 16.8	48.0	289	11 150
058	8/19/64	1311	4.0 to 16.5	51.0	250	12 075
059	9/3/64	1336	2.1 to 16.1	35.6	18	12 125
060	9/4/64	1201	2.9 to 15.5	19.3	303	10 725
061	9/9/64	1235	2.6 to 15.0	16.6	296	13 125
062	9/15/64	1258	5.6 to 18.9	36.8	260	13 050
063	9/25/64	1512	4.0 to 17.7	51.9	258	13 725
064	10/13/64	1426	4.2 to 18.4	49.5	273	12 325
065	10/22/64	1156	5.4 to 19.2	46.9	264	14 150
066	10/30/64	1328	4.2 to 15.4	26.2	248	12 700
[b] 067	11/6/64	702	0.6 to 1.4	[c] 17.8	343	625
[b] 067	11/6/64	702	16.9 to 23.5	[c] 15.4	323	17 500
[d] 067	11/6/64	702	40.3 to 48.1	60.3	261	48 075
068	11/13/64	1510	4.3 to 18.9	51.9	269	9 725
069	11/24/64	1310	2.9 to 18.0	57.3	269	13 400
070	12/1/64	1553	2.7 to 17.0	48.0	279	11 775
071	12/8/64	1313	2.8 to 19.9	58.2	243	10 000
[b] 073	12/15/64	1520	0.5 to 29.8	56.3	275	10 625
[d] 073	12/15/64	1520	39.3 to 57.9	131.1	265	54 125

[a] Direction from which wind is blowing, measured clockwise from true north.
[b] Scout rocket first-stage exhaust trail.
[c] Jet stream maximum velocity may not have been measured.
[d] Scout rocket second-stage exhaust trail.

TABLE I.- LIST OF WALLOPS ISLAND WIND SOUNDINGS – Concluded

(c) 1965 through 1969

Figure	Trail identification	Date	EST	Altitude range, km	Magnitude of maximum velocity, m/sec	Direction of maximum velocity, deg (a)	Altitude of maximum velocity, m
2	072	1/5/65	1500	2.0 to 16.5	32.4	299	11 975
3	074	1/14/65	1319	2.6 to 14.9	57.3	241	10 275
4	075	1/21/65	1311	2.6 to 17.9	46.5	273	12 775
5	076	2/2/65	1453	3.4 to 11.5	79.6	255	9 875
6	077	2/5/65	1529	2.7 to 16.8	43.0	291	14 100
7	078	3/11/65	1311	2.7 to 15.5	64.4	297	10 200
8	079	3/31/65	1331	2.3 to 12.0	59.2	264	11 775
9	080	4/30/65	1453	3.7 to 22.7	28.3	318	12 775
10	081	5/13/65	1313	3.7 to 11.5	[b] 26.5	292	7 550
11	082	5/14/65	1041	3.2 to 15.0	31.8	339	11 775
12	083	5/18/65	1330	4.3 to 13.9	42.7	278	10 525
13	084	6/1/65	1344	5.5 to 12.9	25.9	303	12 900
14	085	7/1/65	1240	2.5 to 19.2	33.4	276	13 850
15	086	7/14/65	1309	4.7 to 16.0	18.7	169	10 125
16	087	7/21/65	1208	4.4 to 14.9	25.2	336	13 700
17	088	8/12/65	1457	5.7 to 15.6	36.6	274	10 925
18	089	9/23/65	1431	6.0 to 17.6	14.0	334	17 175
19	090	10/5/65	1252	3.5 to 14.2	81.2	282	11 600
20	091	10/29/65	1323	2.6 to 13.4	33.6	287	13 400
21	092	11/2/65	1031	2.7 to 12.3	51.0	316	12 075
22	093	11/17/65	1542	3.7 to 14.5	50.8	268	10 050
23	094	11/18/65	1318	2.4 to 13.8	51.0	303	11 625
24	095	11/23/65	1424	4.0 to 12.1	39.6	281	5 575
25	096	11/30/65	1110	4.2 to 14.4	45.6	246	12 725
26	097	12/7/65	1312	3.0 to 15.7	28.2	002	6 275
27	099	1/11/66	1317	2.6 to 15.8	55.3	247	10 125
28	100	2/21/66	1354	2.9 to 21.7	53.9	273	10 175
29	101	3/16/66	1535	3.1 to 16.1	32.6	277	13 400
30	102	3/17/66	1302	2.4 to 13.5	28.2	17	9 000
31	103	7/22/66	1219	5.0 to 16.6	34.6	346	11 100
32	104	9/23/66	1251	2.2 to 16.4	47.8	271	5 725
33	105	10/7/66	1212	3.3 to 22.4	23.9	307	14 425
34	106	10/11/66	1317	2.4 to 23.0	59.6	291	11 025
35	107	10/28/66	1309	4.0 to 16.2	17.6	271	15 250
36	204	10/5/67	1344	1.0 to 4.5	[b] 19.8	271	3 950
37	205	10/5/67	1459	1.2 to 6.4	[b] 28.3	258	6 350
38	109	3/27/69	1405	4.1 to 17.0	66.8	239	10 825
39	110	3/27/69	1447	3.5 to 13.6	67.0	233	9 275
40	111	5/13/69	1250	3.4 to 17.8	50.4	280	11 600

[a] Direction from which wind is blowing, measured clockwise from true north.

[b] Jet stream maximum velocity may not have been measured.

TABLE II.- SAMPLE TABULATION

WALLOPS SMOKE TRAIL NO. 90 LAUNCHED 10/ 5/65 1252EST DELTA T 60 SECS
MIONA LEFT NEW BATTLEPOINTRIGHT FRAMES 8 AND 18

Z (METERS)	VX (MPS)	VY (MPS)	V	THETA (DEGREES)	SHEAR X (/SEC)	SHEAR Y (/SEC)	SHEAR V (/SEC)	SHEAR M (/SEC)
11375	76.5	-17.0	78.38	282.53	.016	.017	.023	.011
11400	77.1	-16.6	78.83	282.15	.022	.017	.028	.018
11425	77.5	-16.3	79.29	281.84	.021	.013	.025	.018
11450	78.1	-16.0	79.71	281.55	.020	.012	.023	.017
11475	78.5	-15.6	80.14	281.24	.020	.014	.024	.017
11500	79.1	-15.2	80.51	280.91	.018	.015	.024	.015
11525	79.2	-15.0	80.64	280.74	.007	.008	.011	.005
11550	79.2	-15.0	80.61	280.71	-.001	.002	.002	.001
11575	79.4	-15.7	80.95	281.19	.008	-.029	.030	.014
11600	79.5	-16.3	81.16	281.55	.004	-.022	.022	.008
11625	77.2	-15.4	78.67	281.27	-.094	.035	.101	.099
11650	77.3	-14.9	78.71	280.94	.005	.017	.018	.002
11675	77.5	-14.6	78.88	280.66	.009	.014	.017	.007
11700	77.9	-14.3	79.17	280.39	.014	.012	.019	.012
11725	78.1	-14.1	79.36	280.22	.009	.008	.012	.008
11750	78.3	-13.9	79.53	280.06	.008	.007	.011	.007
11775	78.5	-13.8	79.74	279.99	.009	.003	.009	.008
11800	78.5	-13.8	79.84	279.93	.004	-0.000	.004	.004
11825	78.3	-14.0	79.59	280.17	-.011	-.008	.014	.010
11850	78.1	-14.2	79.38	280.37	-.010	-.010	.014	.008
11875	77.5	-14.3	78.92	280.47	-.019	-.002	.019	.018
11900	76.5	-14.2	77.87	280.49	-.041	.007	.042	.042
11925	76.0	-14.2	77.34	280.61	-.022	-.003	.022	.021
11950	76.3	-14.5	77.62	280.75	.009	-.010	.013	.011
11975	76.3	-14.3	77.65	280.58	.003	.009	.009	.001
12000	76.4	-13.9	77.62	280.33	.001	.013	.013	.001
12025	76.5	-13.6	77.67	280.12	.004	.011	.012	.002
12050	76.7	-13.3	77.80	279.82	.008	.015	.017	.005
12075	76.8	-13.1	77.93	279.68	.006	.007	.009	.005
12100	76.7	-13.2	77.79	279.78	-.007	-.005	.008	.006
12125	76.5	-13.4	77.72	279.91	-.004	-.006	.007	.003
12150	76.3	-13.3	77.49	279.91	-.009	.001	.009	.009
12175	76.5	-13.6	77.71	280.09	.007	-.011	.013	.009
12200	76.7	-13.9	77.93	280.25	.007	-.010	.012	.009
12225	76.8	-14.2	78.11	280.46	.005	-.013	.014	.007
12250	76.4	-14.4	77.77	280.64	-.015	-.007	.016	.013
12275	76.0	-14.1	77.26	280.50	-.019	.011	.022	.021
12300	75.9	-13.8	77.19	280.30	-.001	.011	.011	.003
12325	76.2	-13.6	77.38	280.10	.009	.009	.013	.007

Z	altitude, meters
VX	west-to-east component of velocity, meters per second
VY	south-to-north component of velocity, meters per second
V	magnitude of resultant velocity, meters per second
Theta	direction from which wind is blowing, measured clockwise from true north, degrees
Shear X	$\delta VX/\delta Z$, per second
Shear Y	$\delta VY/\delta Z$, per second
Shear M	$\lvert\delta V/\delta Z\rvert$, per second
Shear V	$\sqrt{\left(\frac{\delta VX}{\delta Z}\right)^2 + \left(\frac{\delta VY}{\delta Z}\right)^2}$, per second

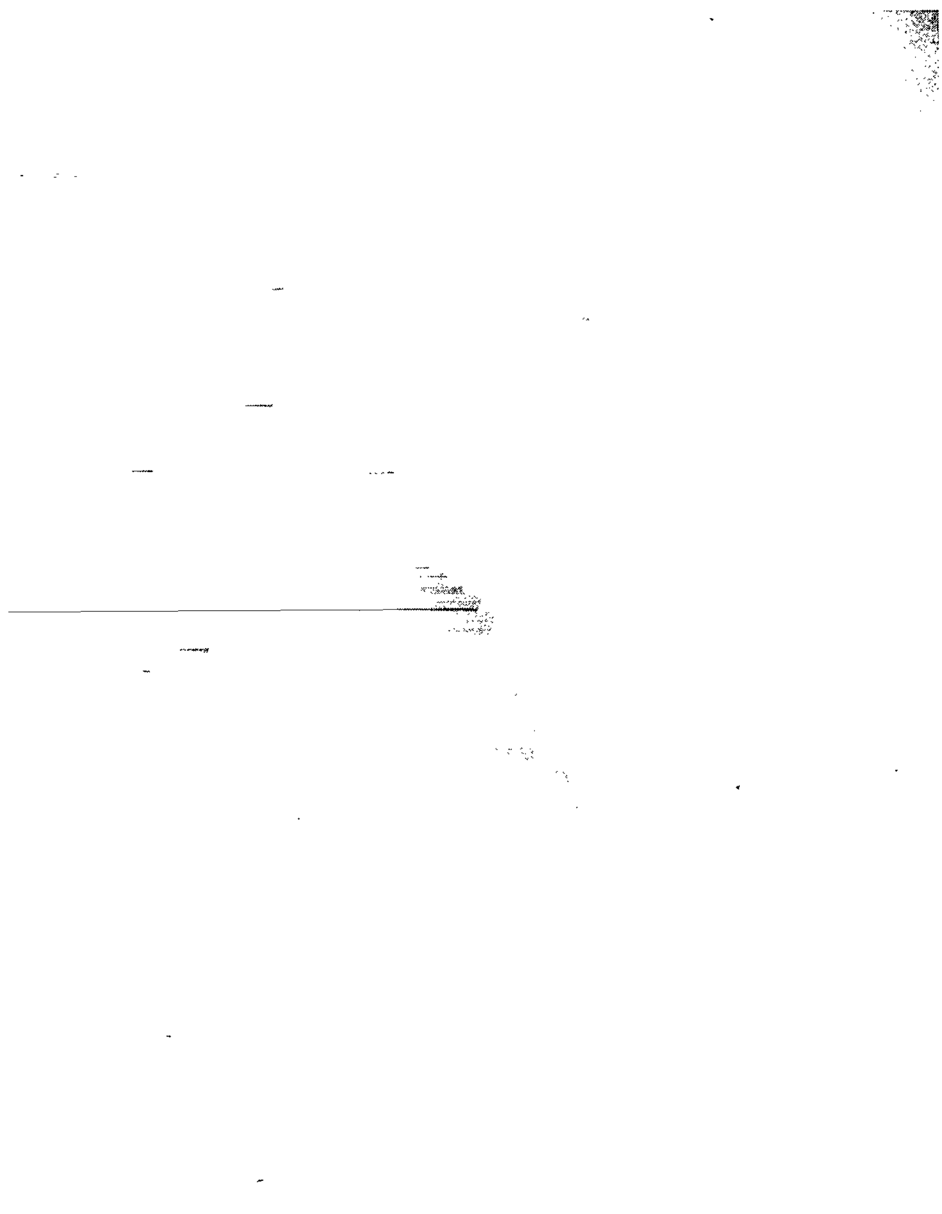
TABLE III. - MONTHLY MAXIMUM WIND VELOCITIES

[1959 through 1969]

Month	Number of cases	Maximum measured wind			CPF (a)
		Trail identification	Maximum velocity, m/sec	Altitude, m	
January	7	020	72.1	10 225	94.2
February	7	076	79.6	9 875	99.0
March	10	110	67.0	9 275	94.9
April	10	009	[b]92.6	11 000	99.0
May	15	111	50.4	11 600	95.4
June	2	055	40.7	12 450	91.0
July	8	103	34.6	11 100	80.9
August	4	058	51.0	12 075	99.0
September	13	034	54.1	12 625	98.2
October	15	090	81.2	11 600	99.0
November	11	039	61.3	10 875	94.2
December	5	071	58.2	10 000	84.5
Total 107					

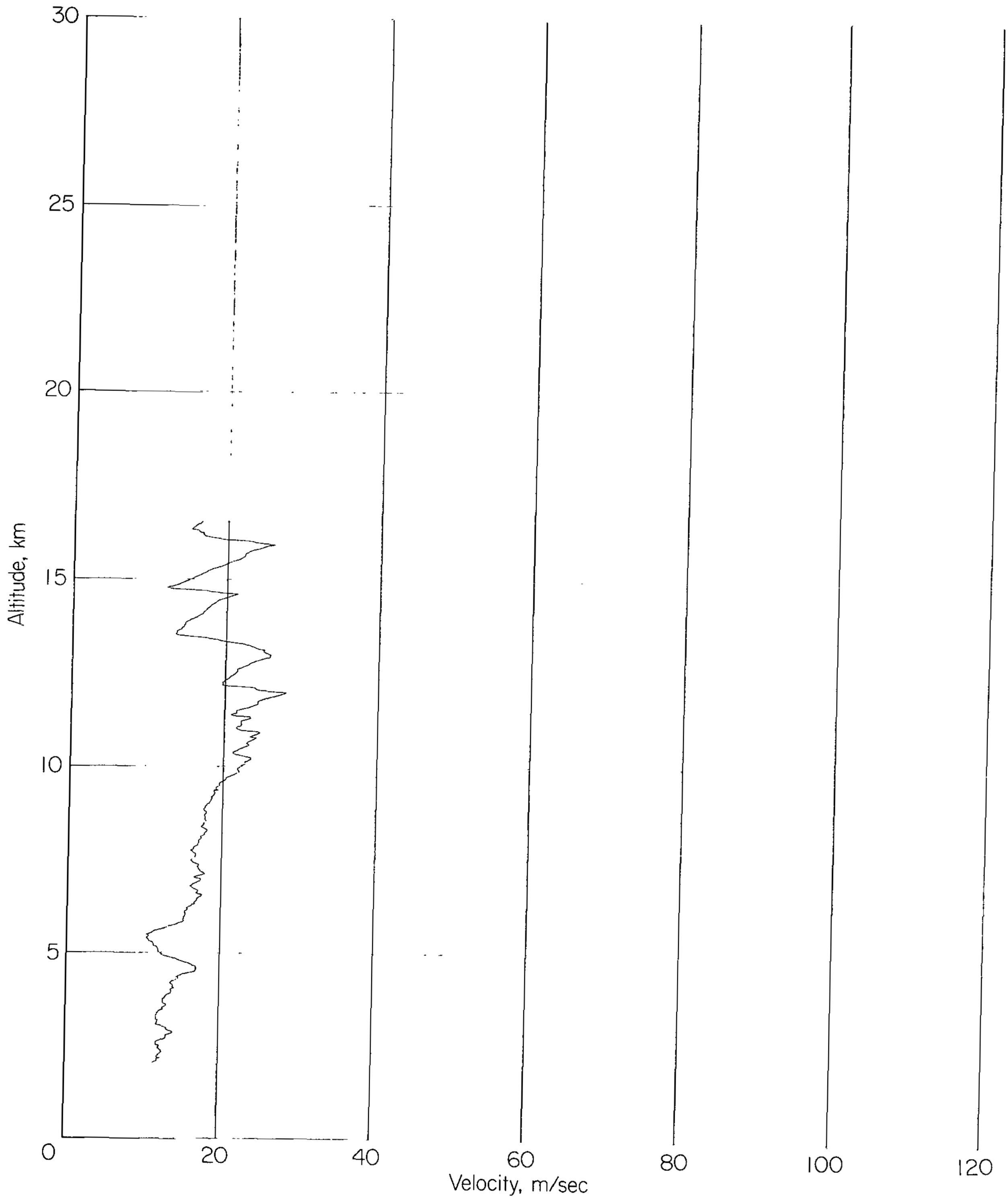
[a] Cumulative percentage frequency from reference 16.

[b] Maximum wind measured for the total sample.



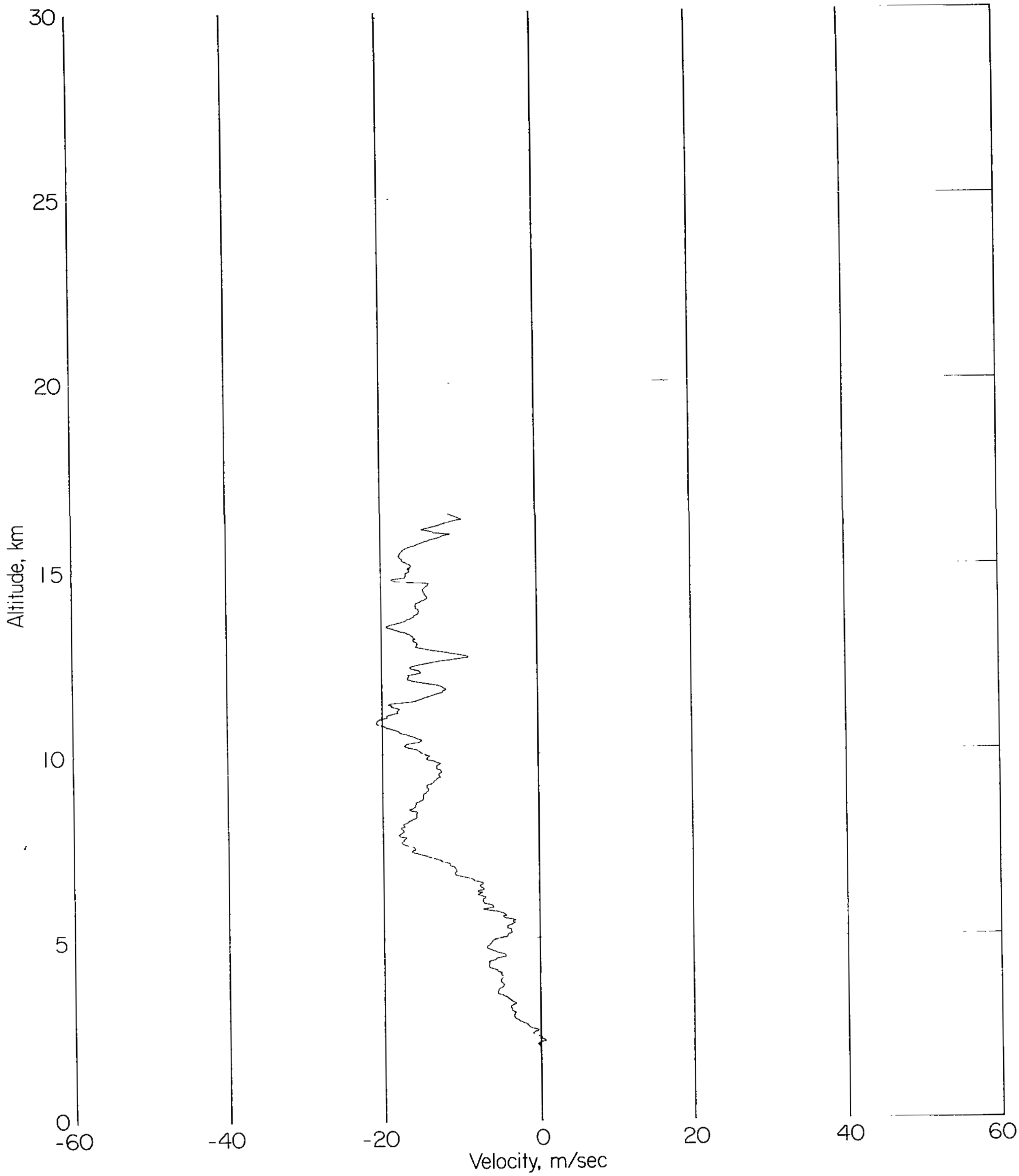
L-72-2450

Figure 1.- A smoke trail as photographed from one camera site at Wallops Island.



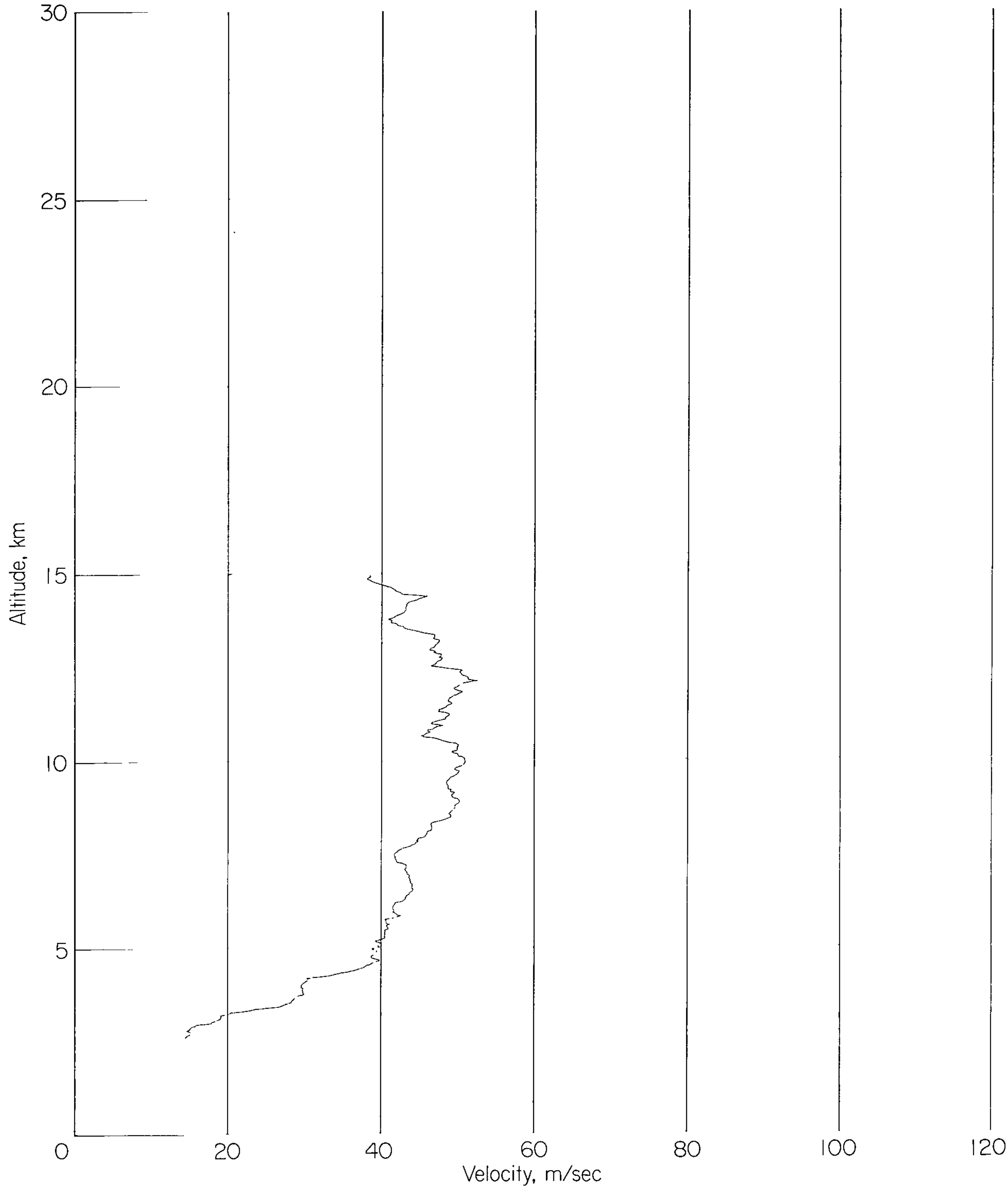
(a) West-to-east velocity component.

Figure 2.- Wind profile of smoke trail 072 obtained January 5, 1965. Time interval, 60 seconds; height interval, 25 meters.



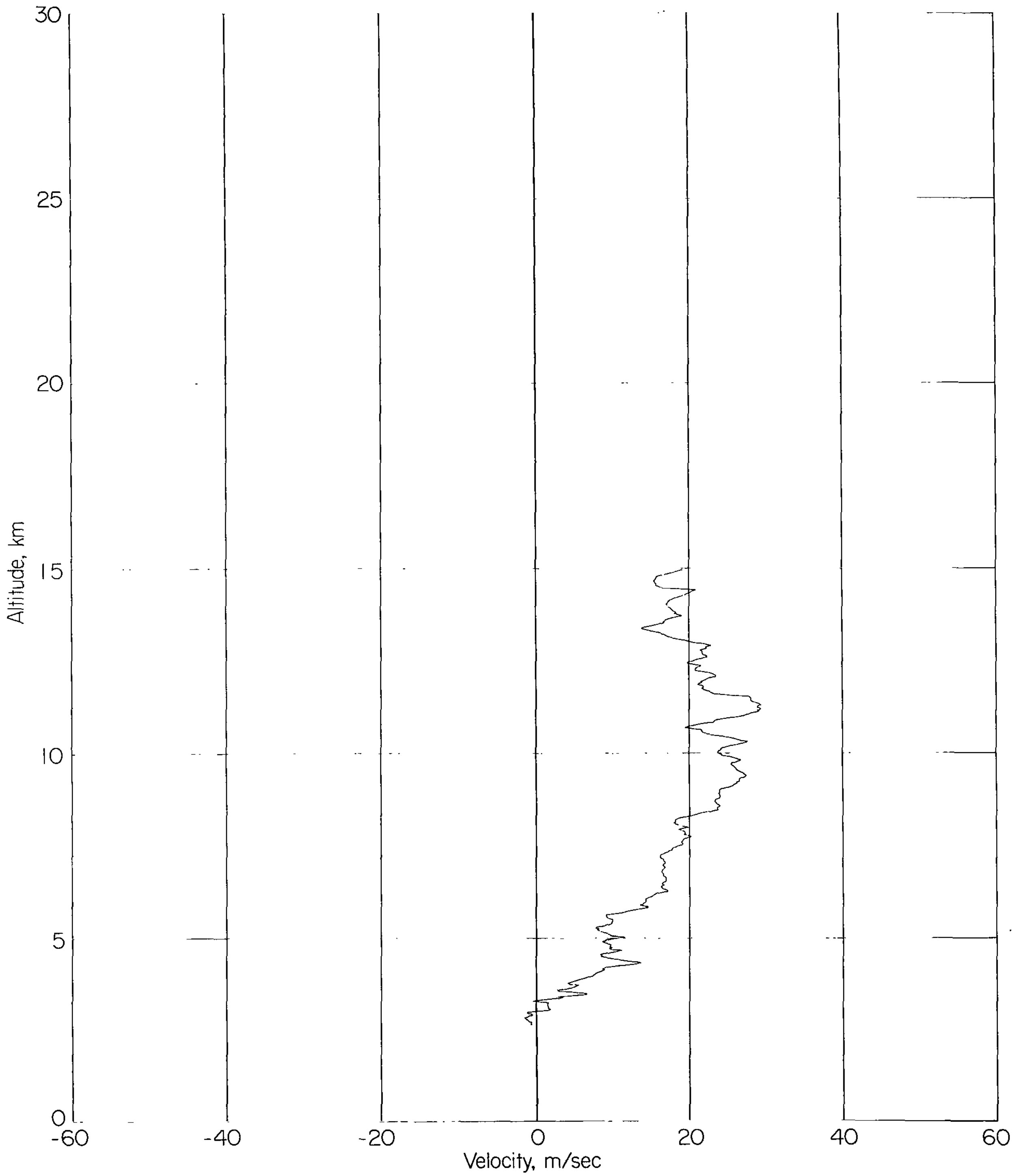
(b) South-to-north velocity component.

Figure 2.- Concluded.



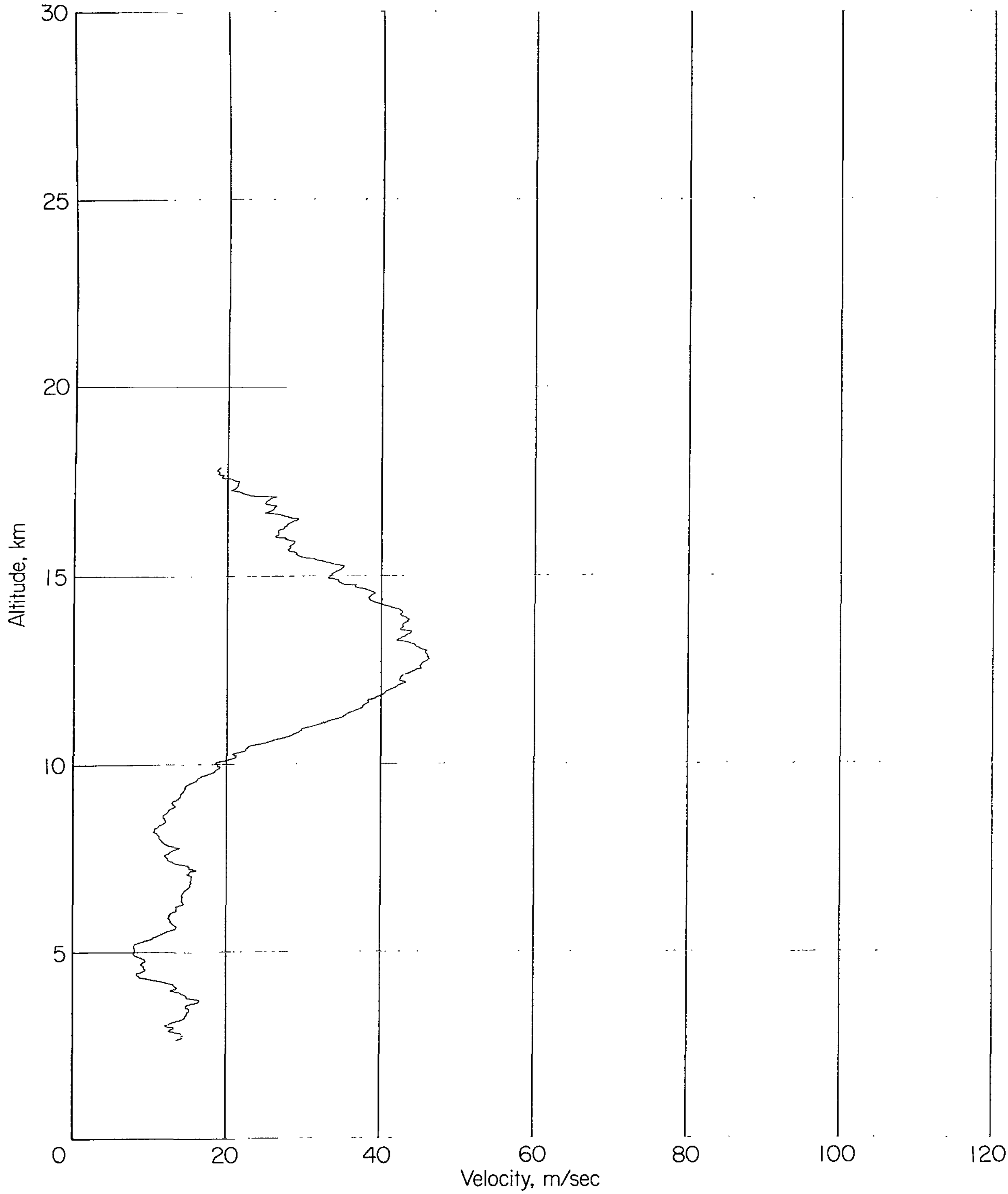
(a) West-to-east velocity component.

Figure 3.- Wind profile of smoke trail 074 obtained January 14, 1965. Time interval, 60 seconds; height interval, 25 meters.



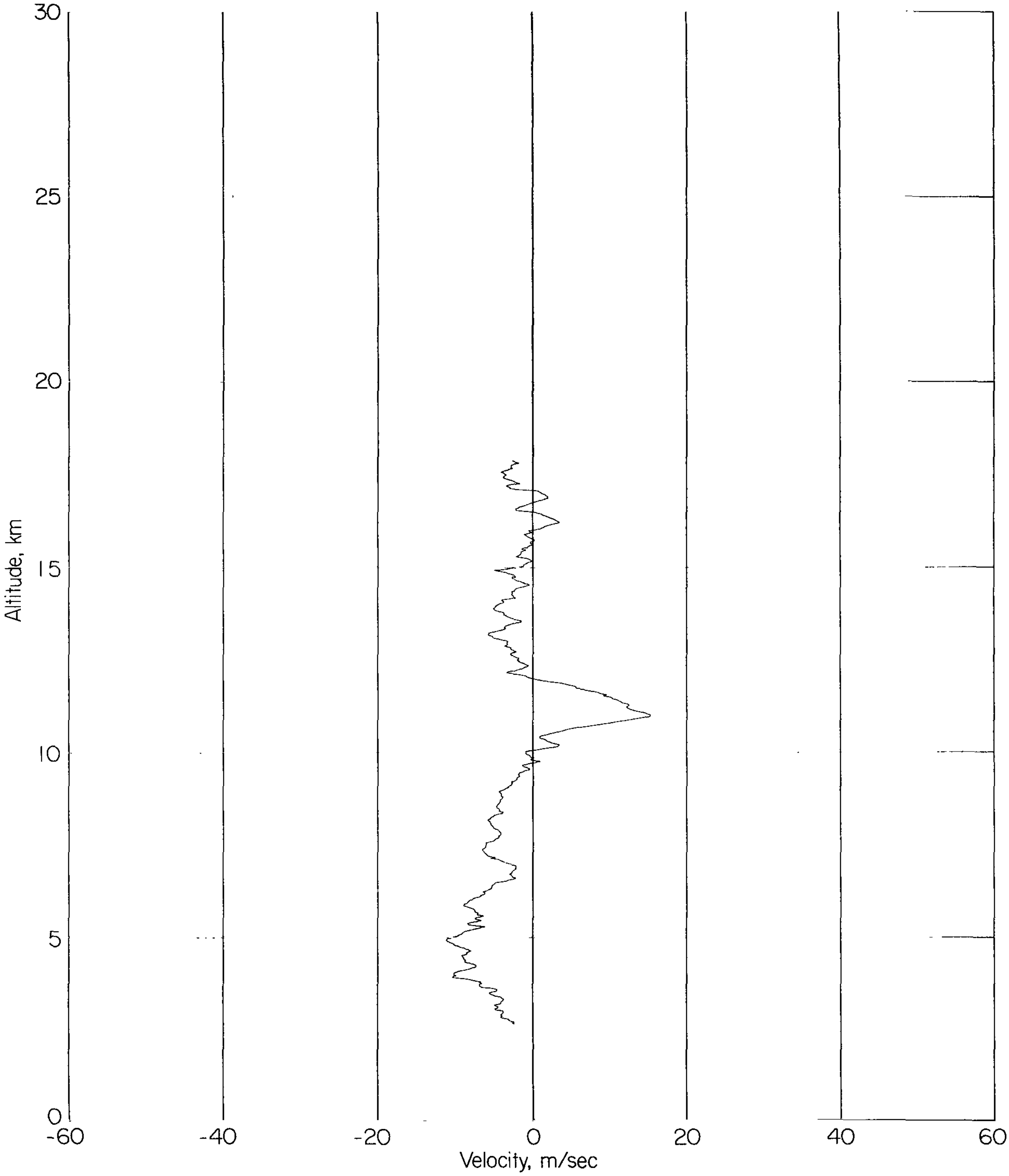
(b) South-to-north velocity component.

Figure 3.- Concluded.



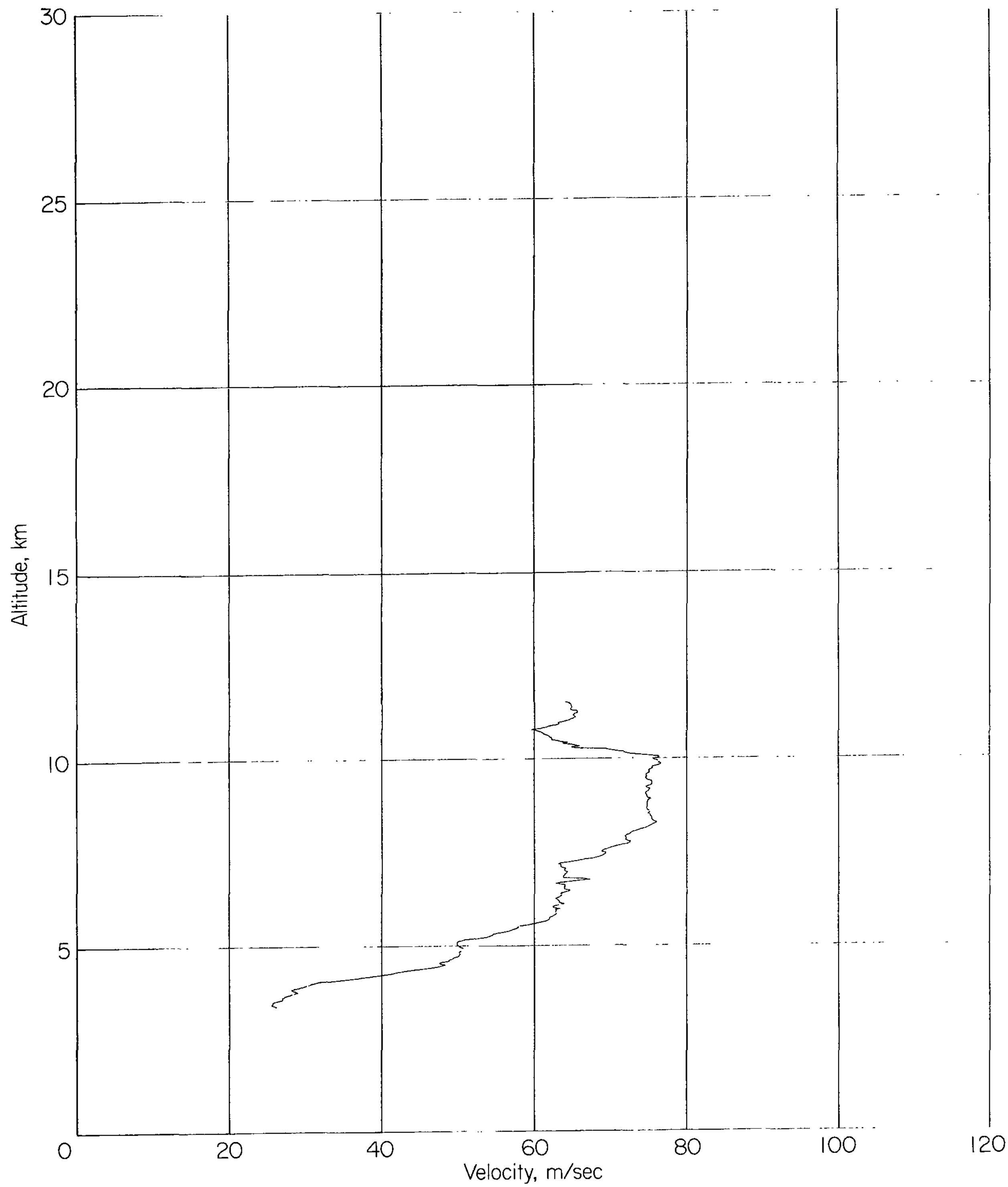
(a) West-to-east velocity component.

Figure 4.- Wind profile of smoke trail 075 obtained January 21, 1965. Time interval, 60 seconds; height interval, 25 meters.



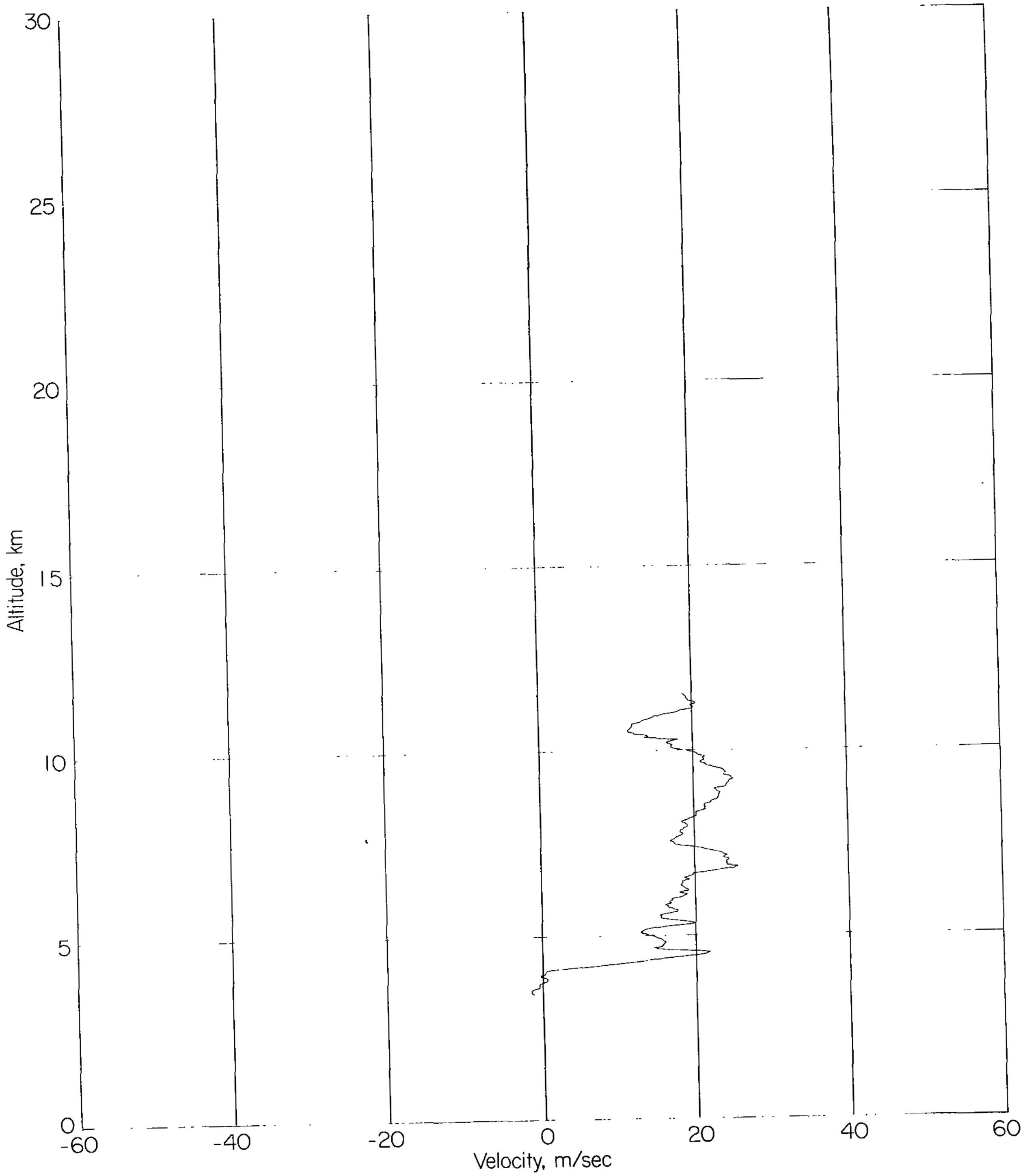
(b) South-to-north velocity component.

Figure 4.- Concluded.



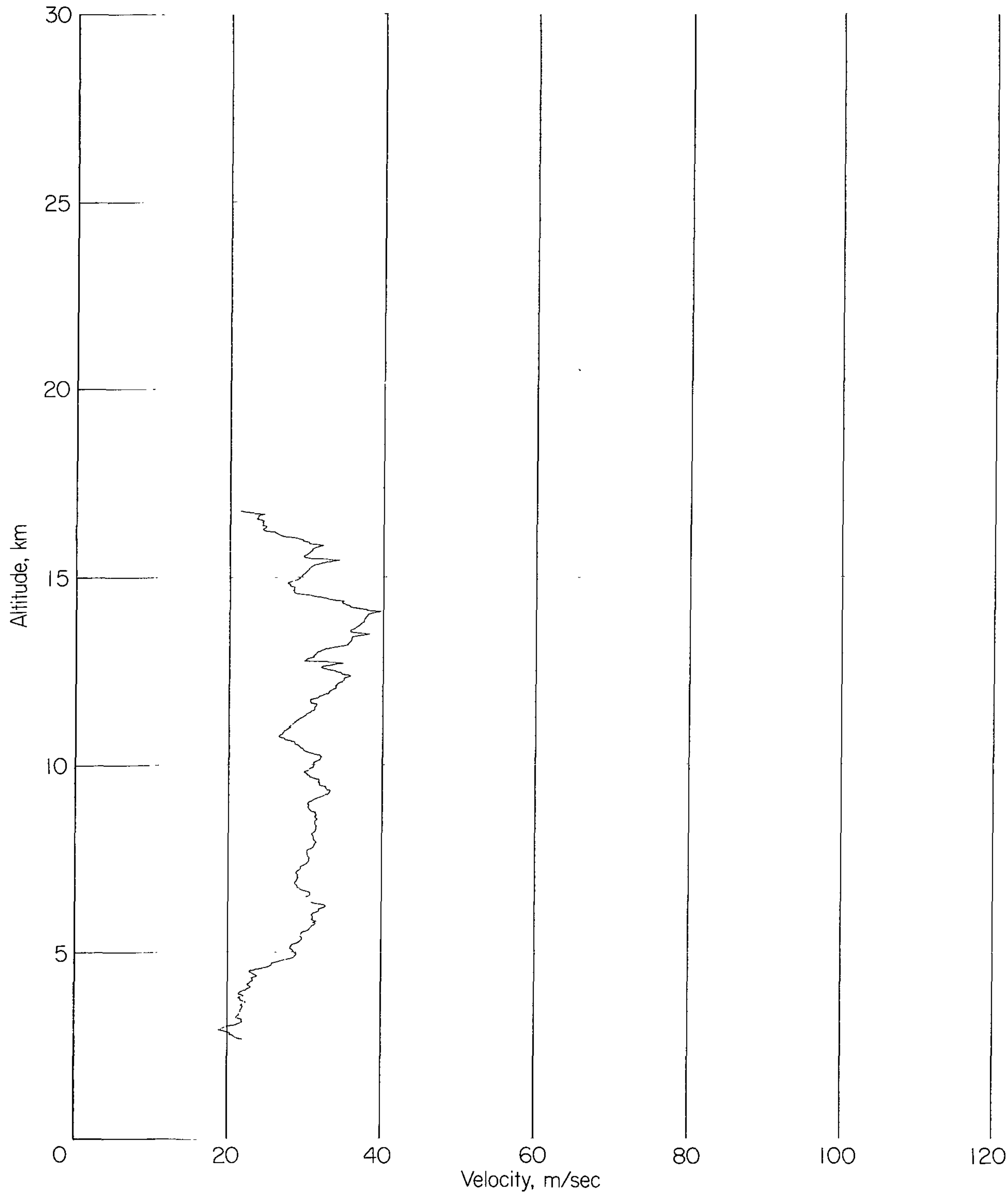
(a) West-to-east velocity component.

Figure 5.- Wind profile of smoke trail 076 obtained February 2, 1965. Time interval, 60 seconds; height interval 25 meters.



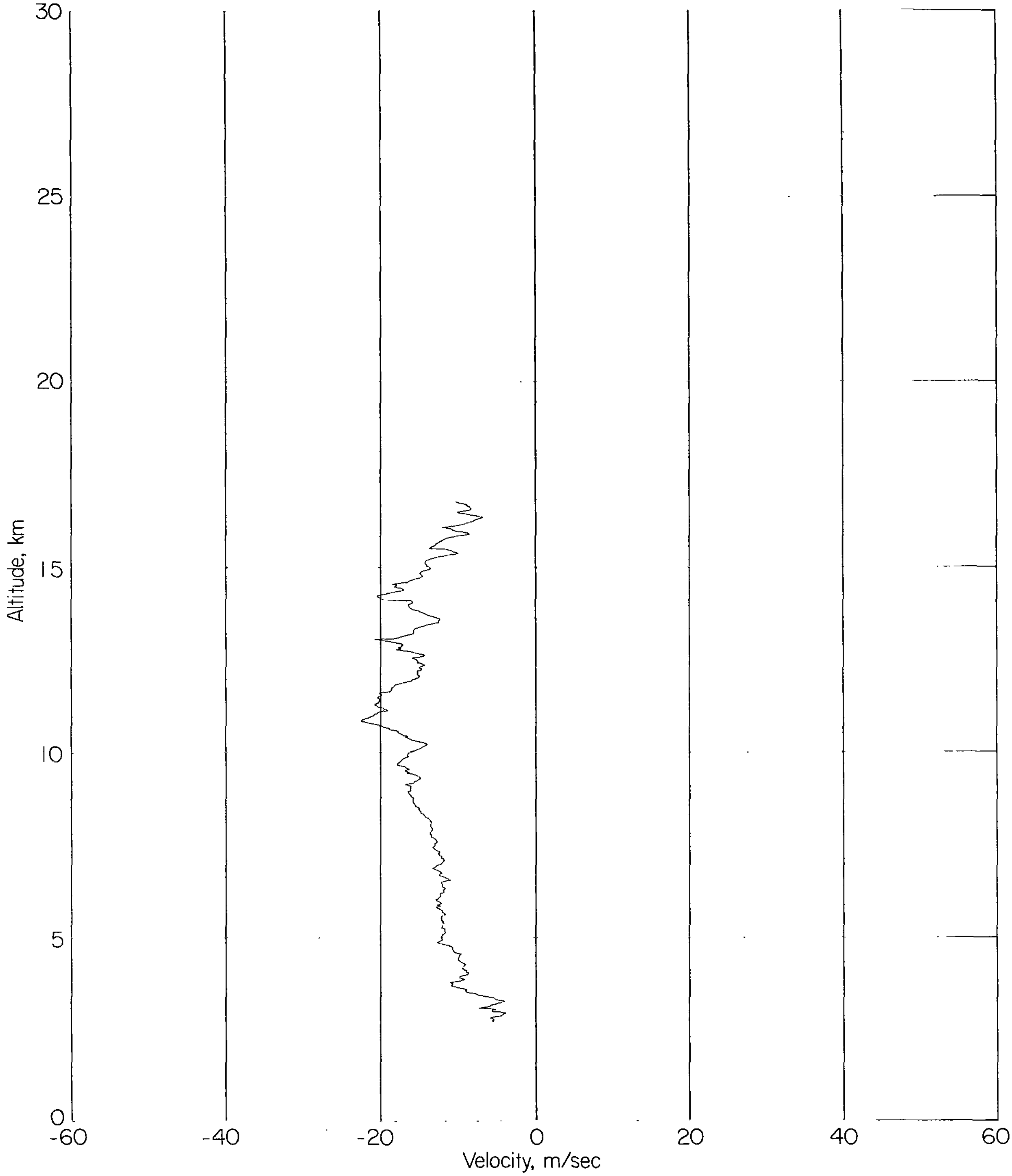
(b) South-to-north velocity component.

Figure 5.- Concluded.



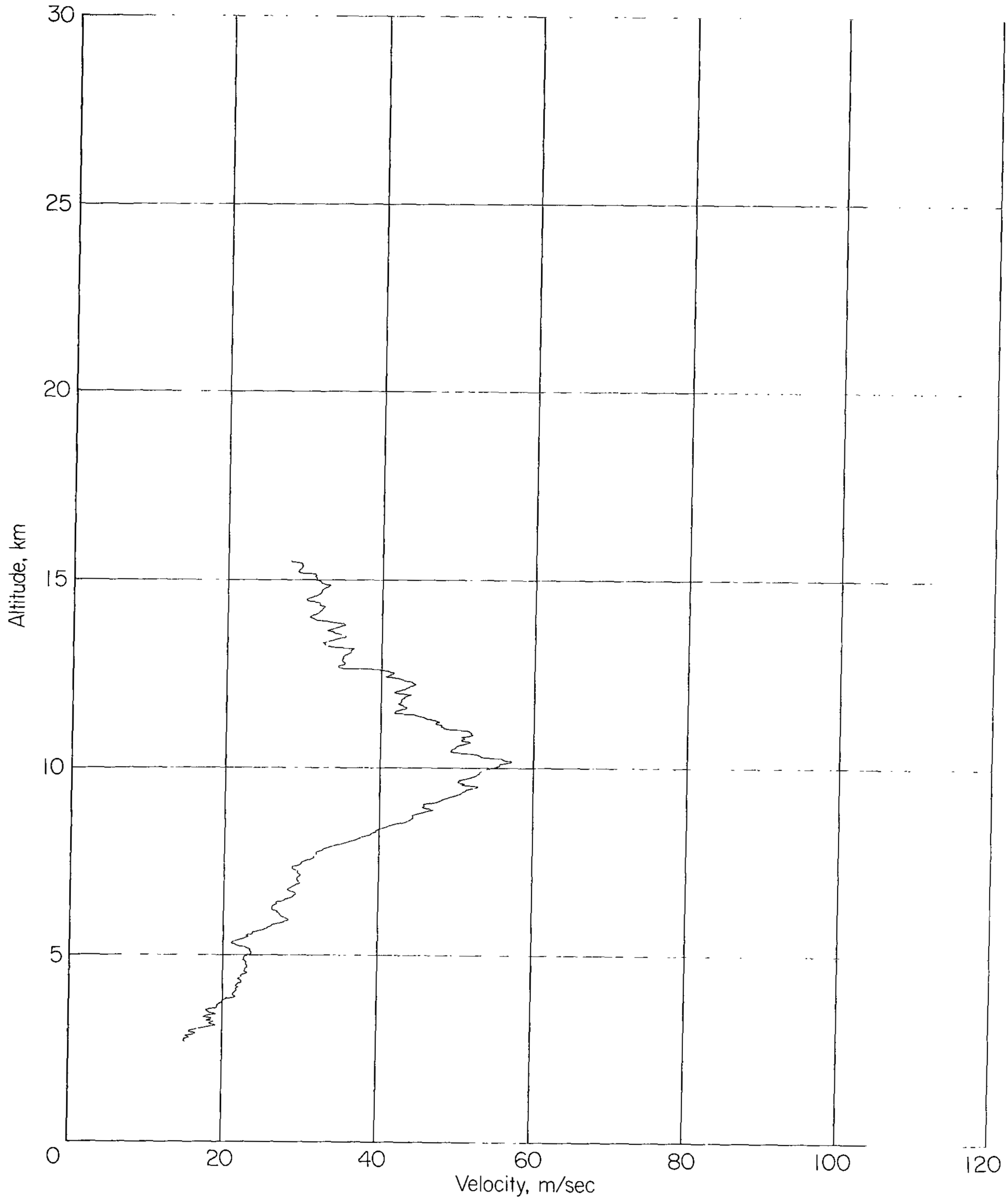
(a) West-to-east velocity component.

Figure 6.- Wind profile of smoke trail 077 obtained February 5, 1965.
Time interval, 60 seconds; height interval, 25 meters.



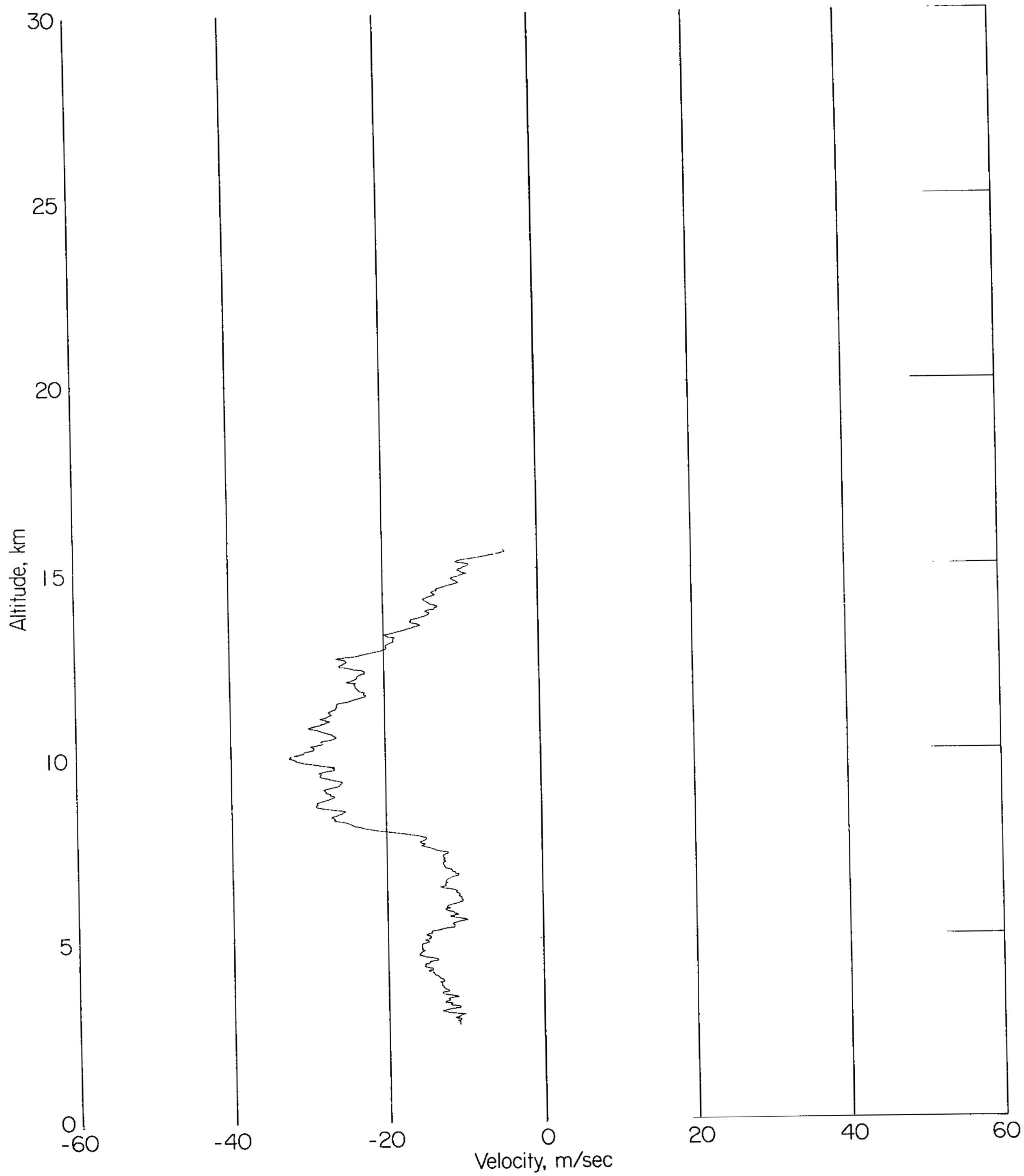
(b) South-to-north velocity component.

Figure 6.- Concluded.



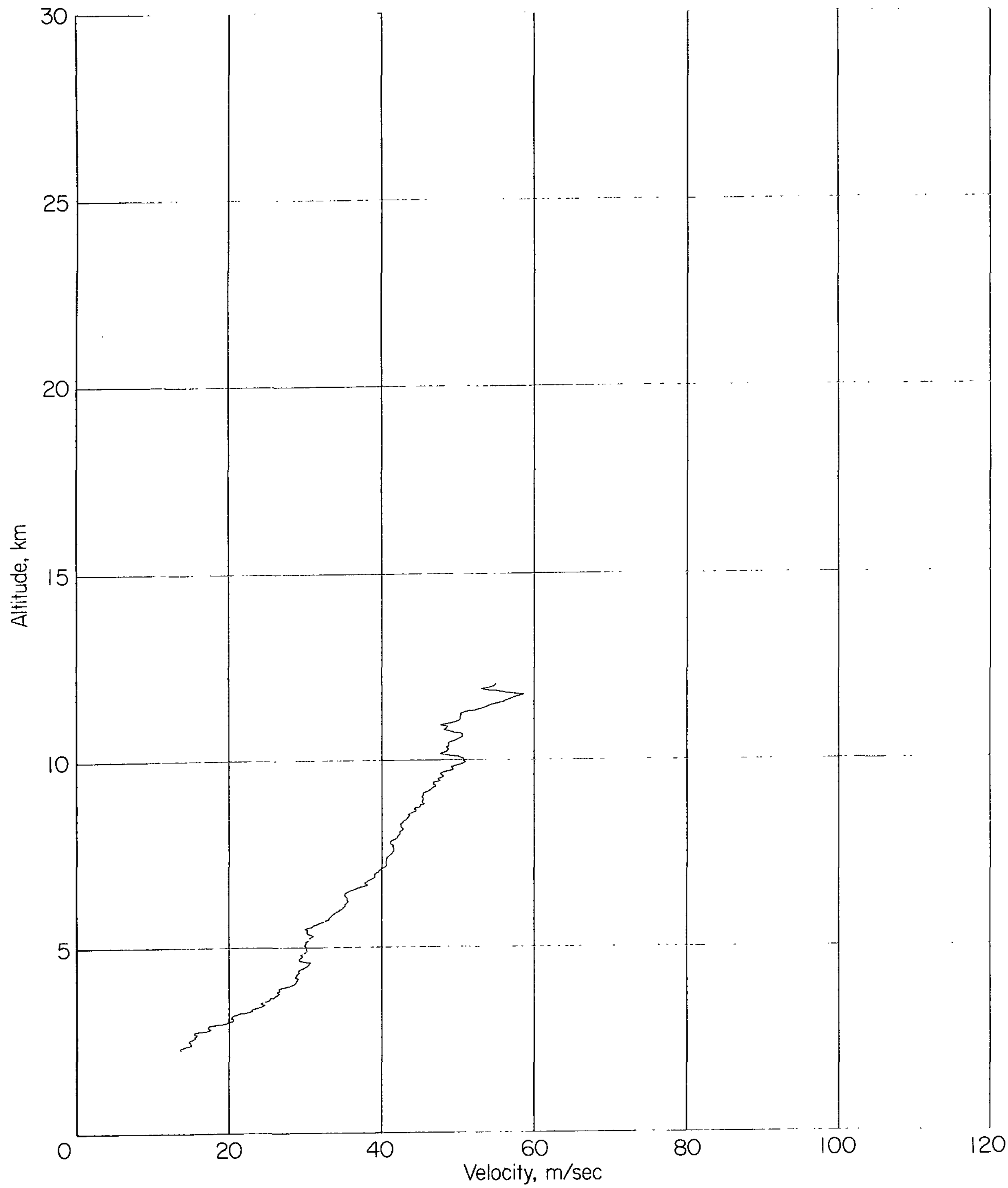
(a) West-to-east velocity component.

Figure 7.- Wind profile of smoke trail 078 obtained March 11, 1965. Time interval, 60 seconds; height interval, 25 meters.



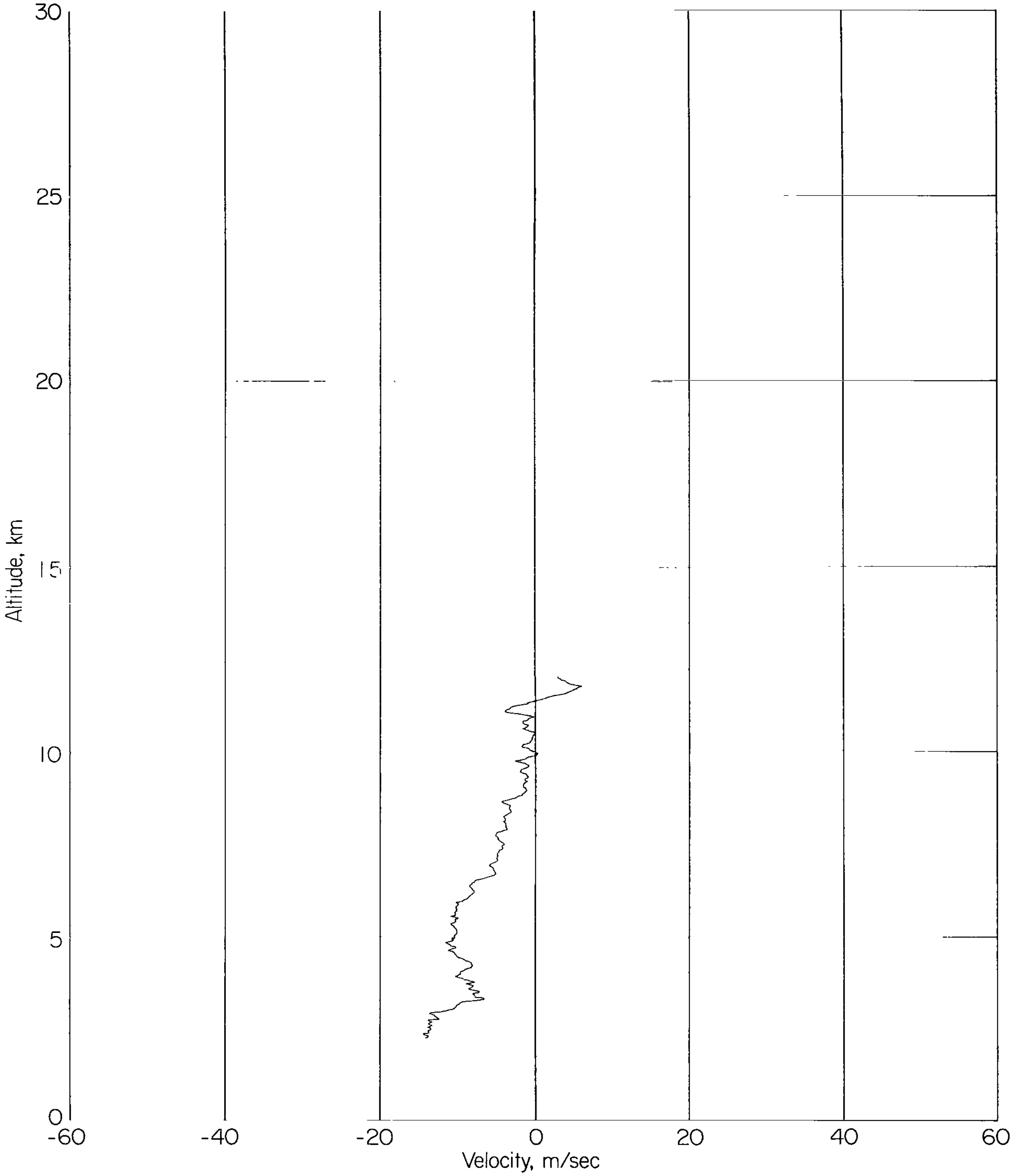
(b) South-to-north velocity component.

Figure 7.- Concluded.



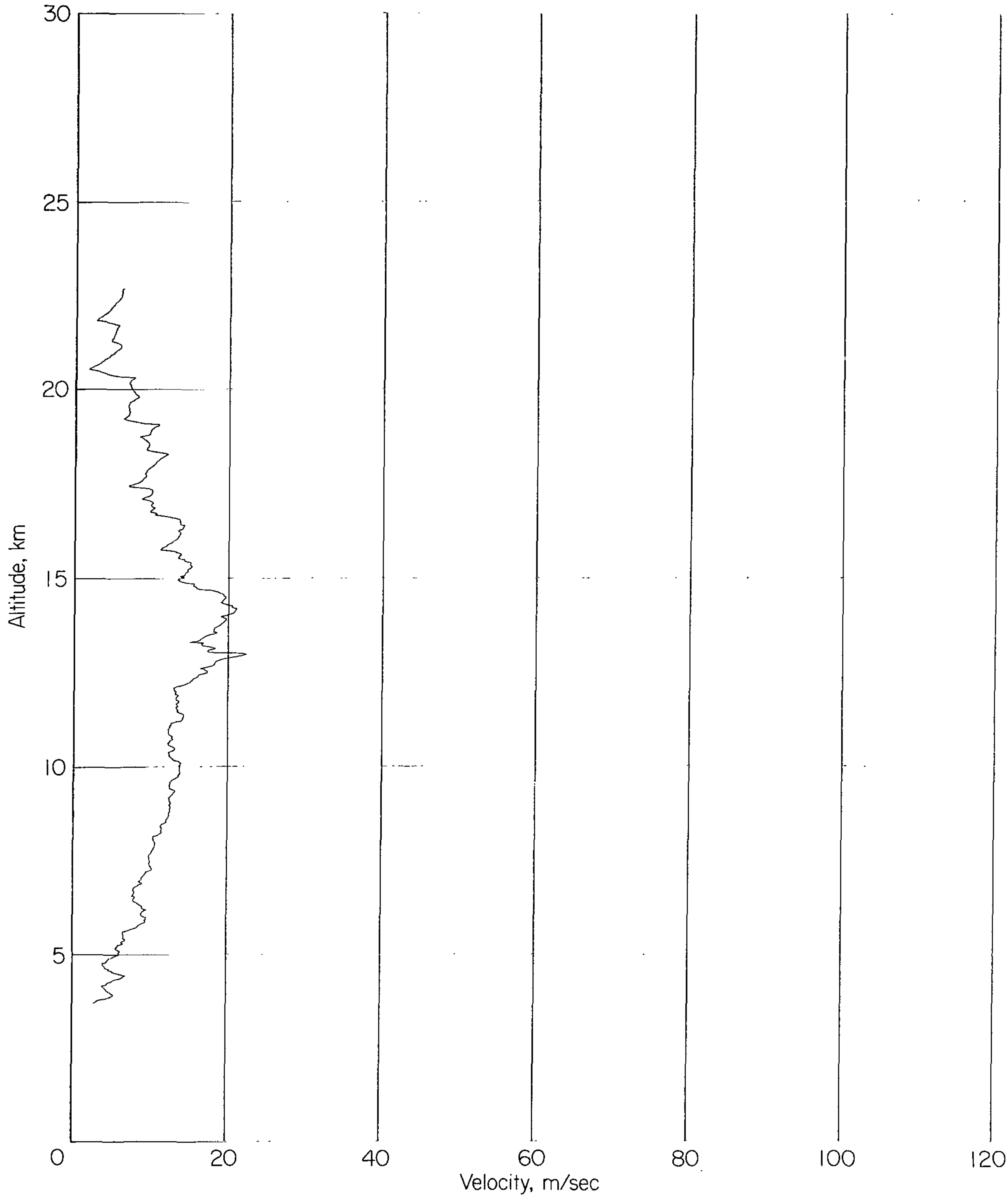
(a) West-to-east velocity component.

Figure 8.- Wind profile of smoke trail 079 obtained March 31, 1965. Time interval, 60 seconds; height interval, 25 meters.



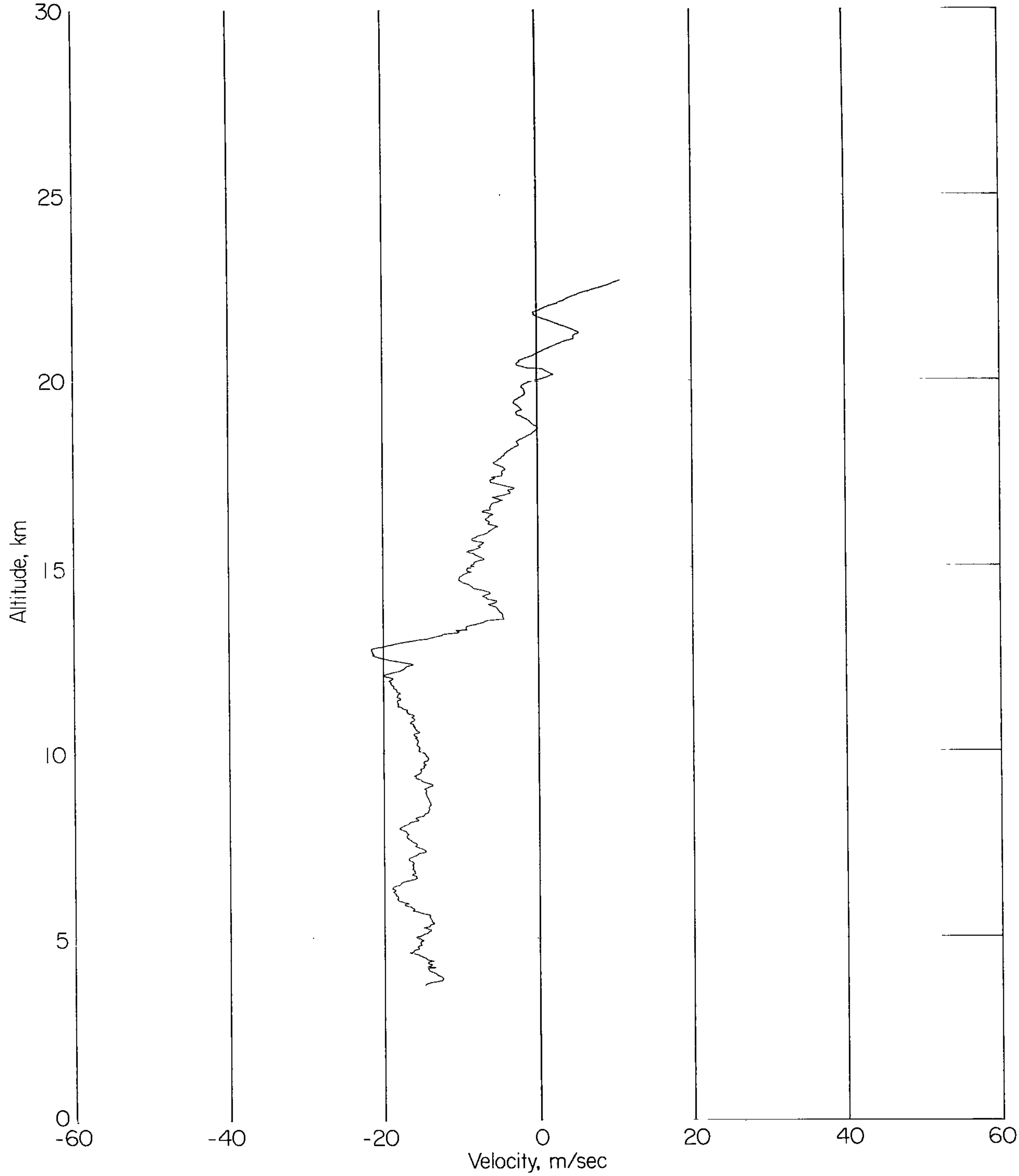
(b) South-to-north velocity component.

Figure 8.- Concluded.



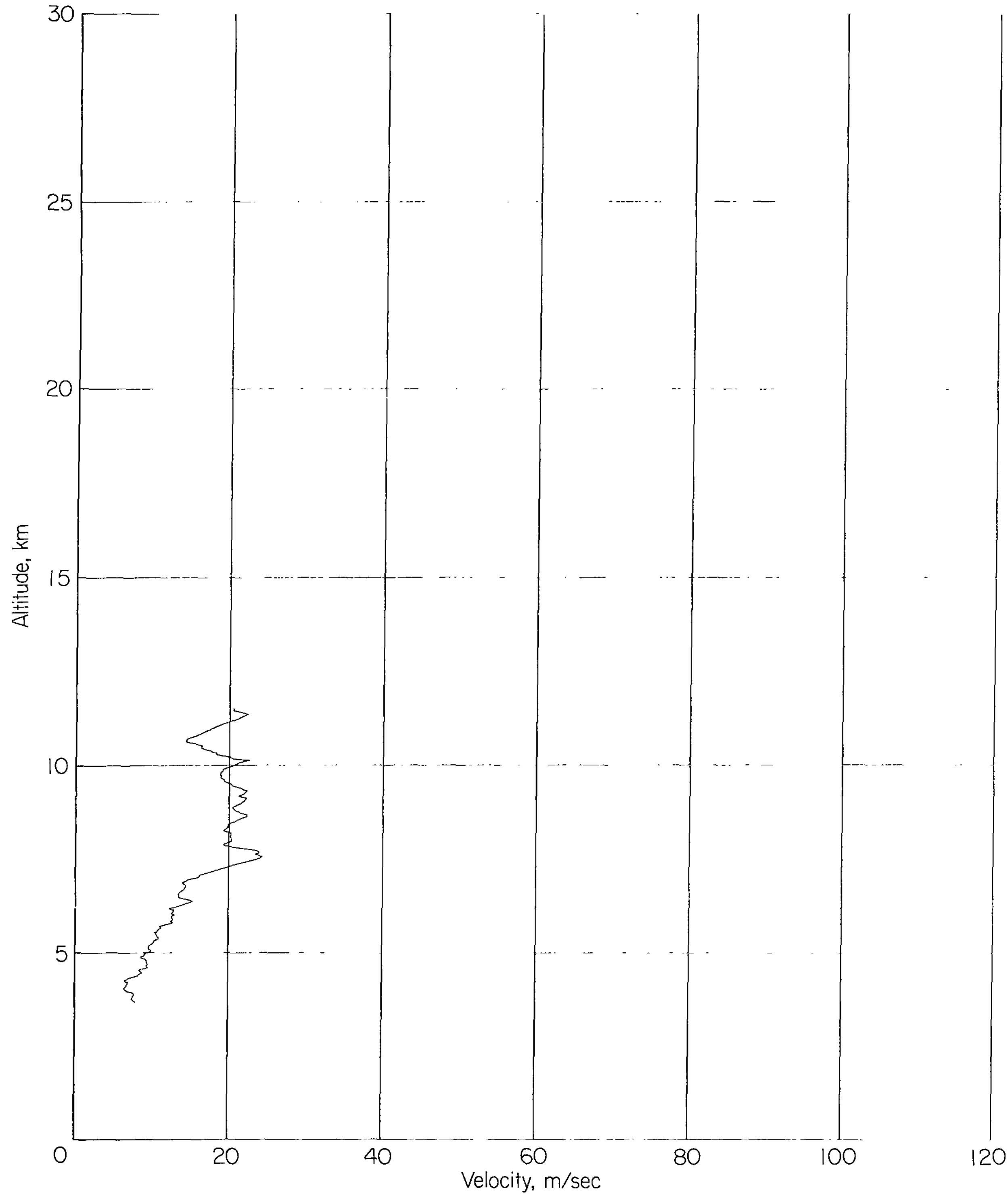
(a) West-to-east velocity component.

Figure 9.- Wind profile of smoke trail 080 obtained April 30, 1965. Time interval, 60 seconds; height interval, 25 meters.



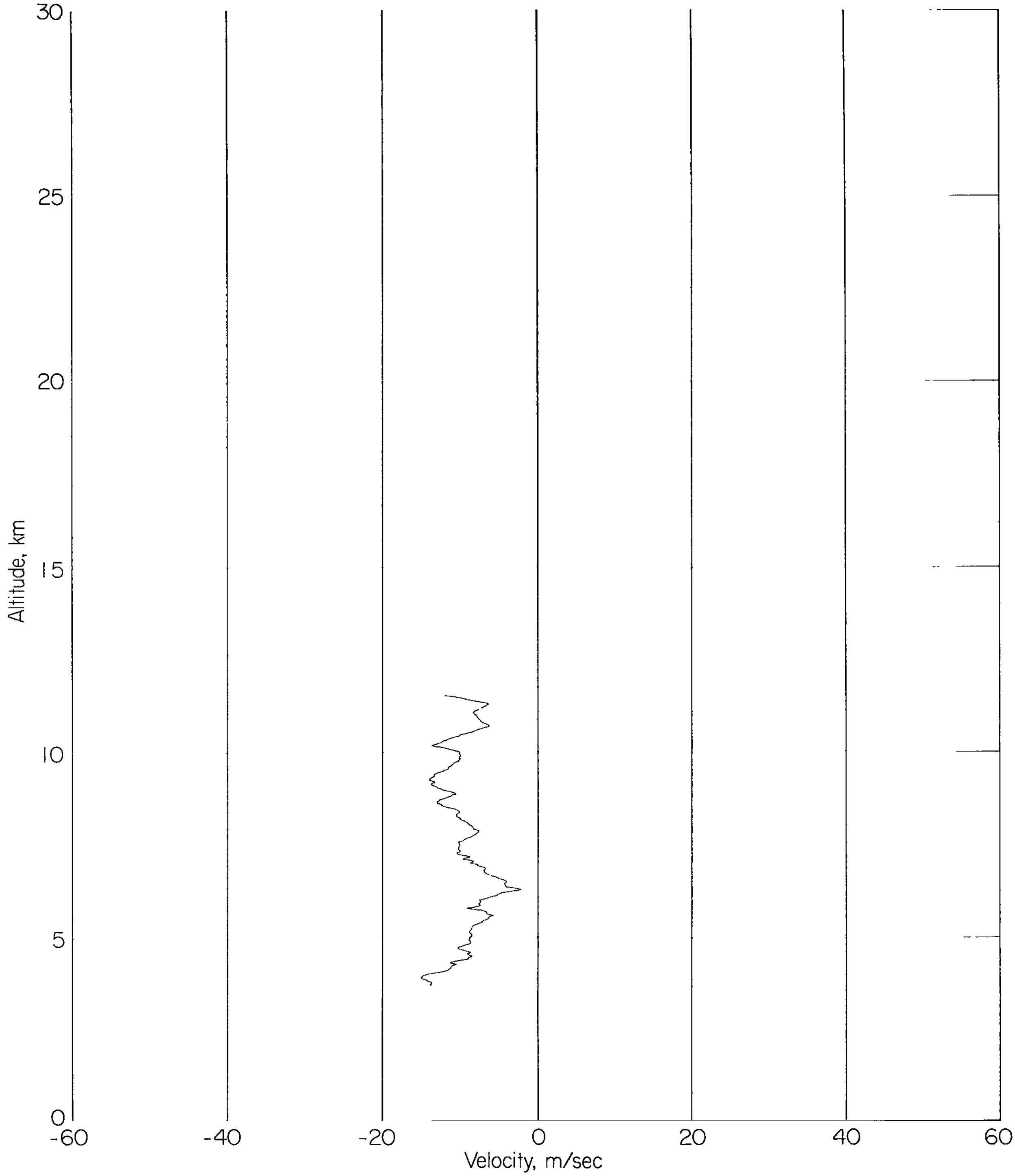
(b) South-to-north velocity component.

Figure 9.- Concluded.



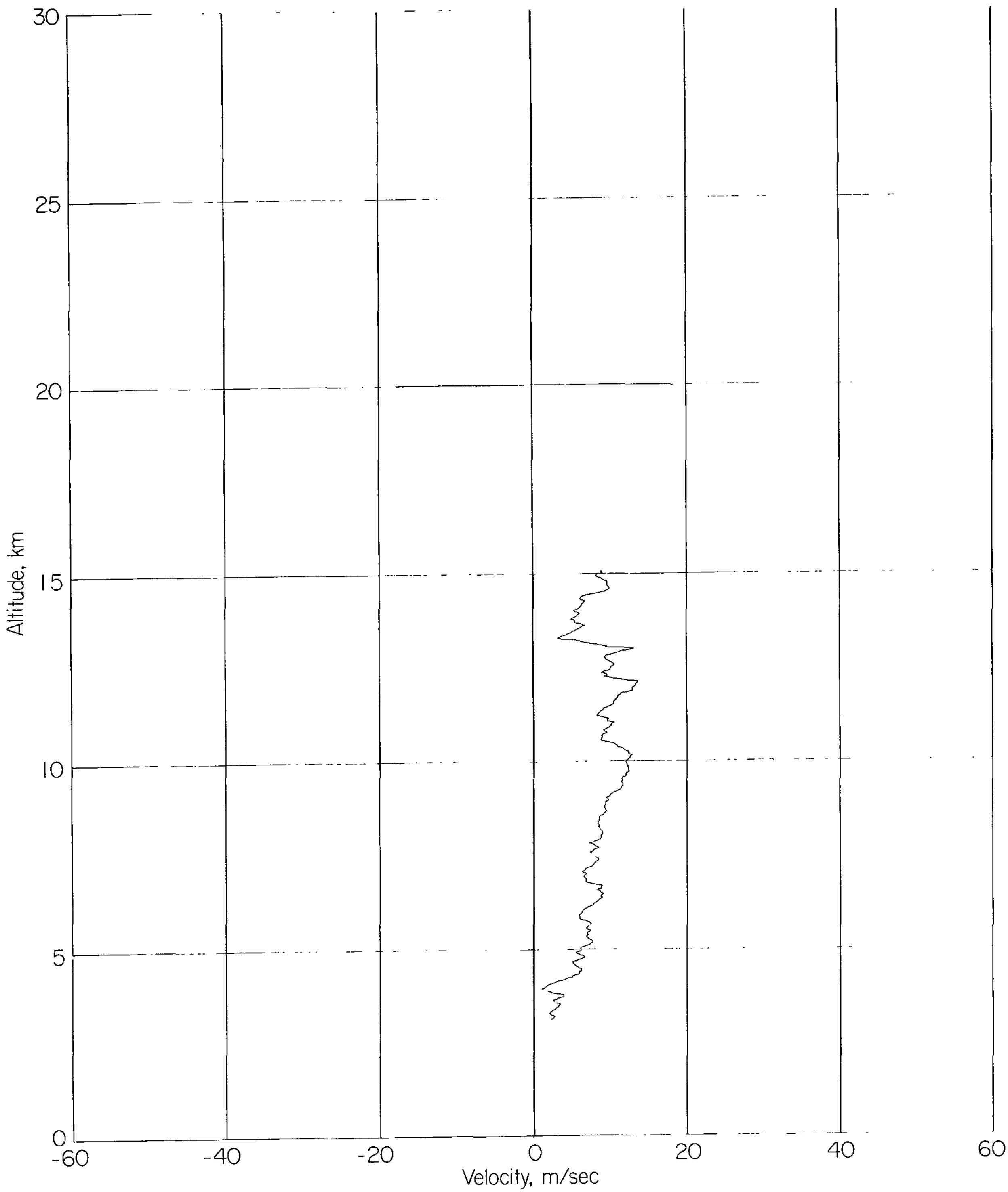
(a) West-to-east velocity component.

Figure 10.- Wind profile of smoke trail 081 obtained May 13, 1965. Time interval, 60 seconds; height interval, 25 meters.



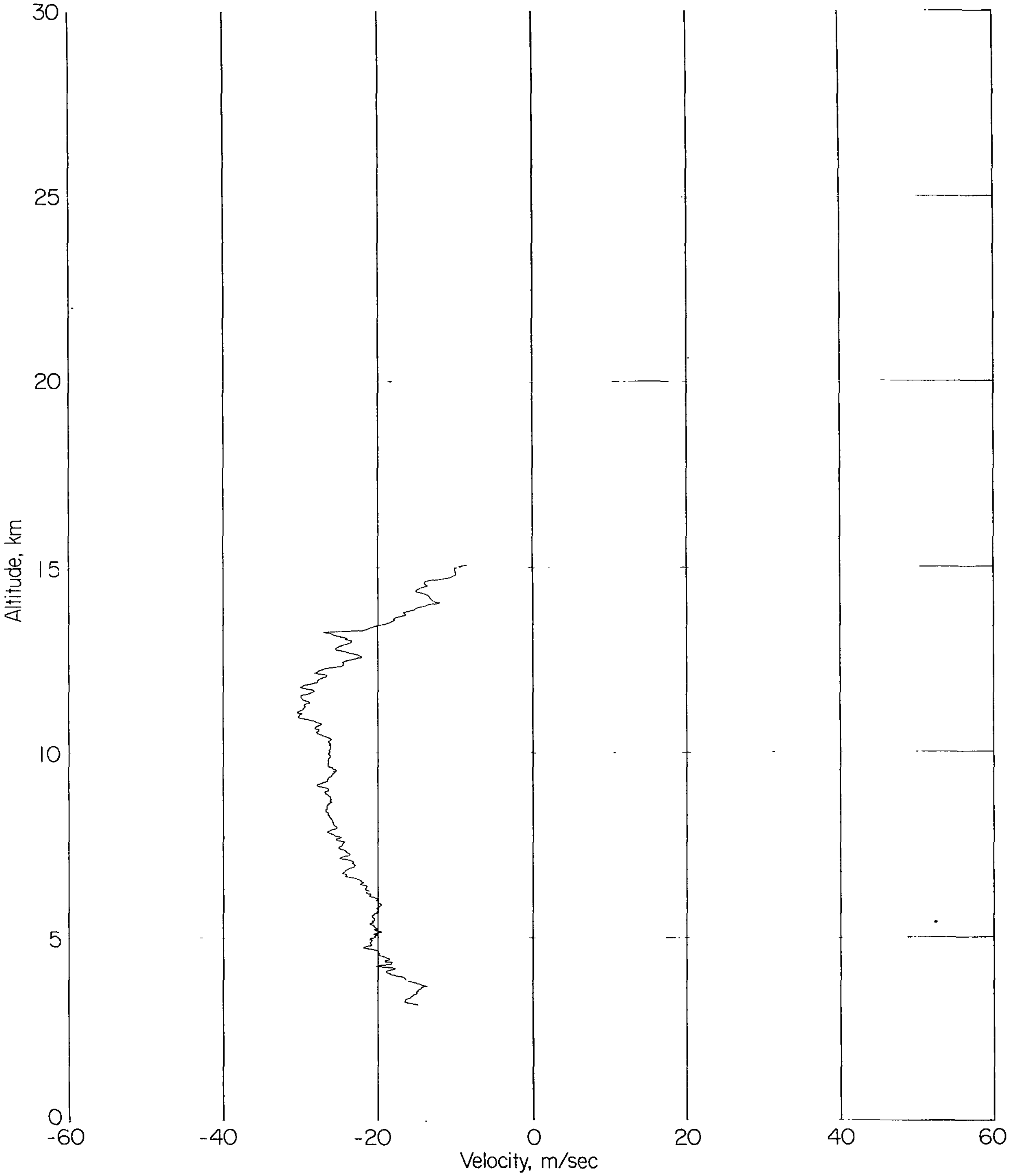
(b) South-to-north velocity component.

Figure 10.- Concluded.



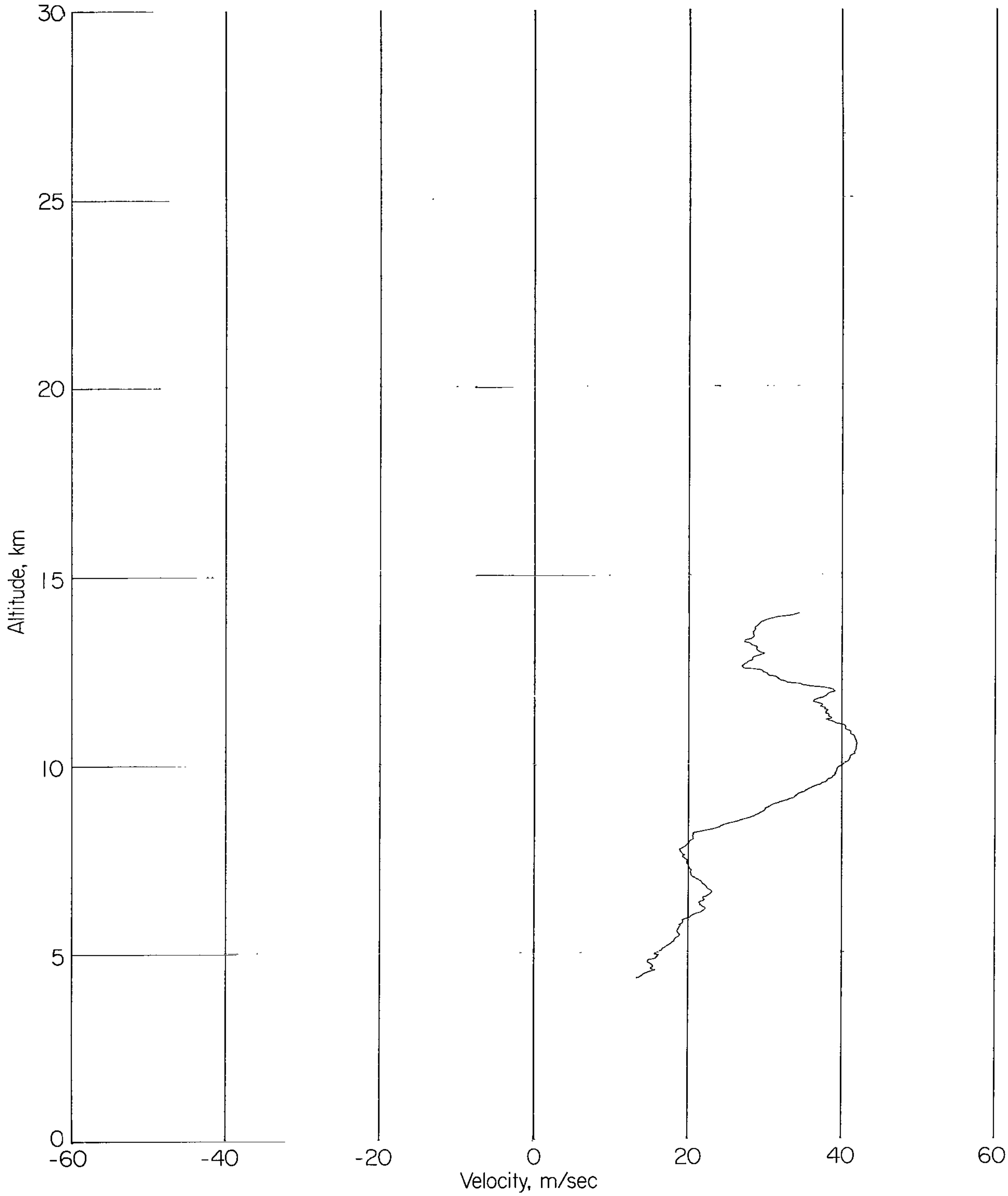
(a) West-to-east velocity component.

Figure 11.- Wind profile of smoke trail 082 obtained May 14, 1965.
Time interval, 60 seconds; height interval, 25 meters.



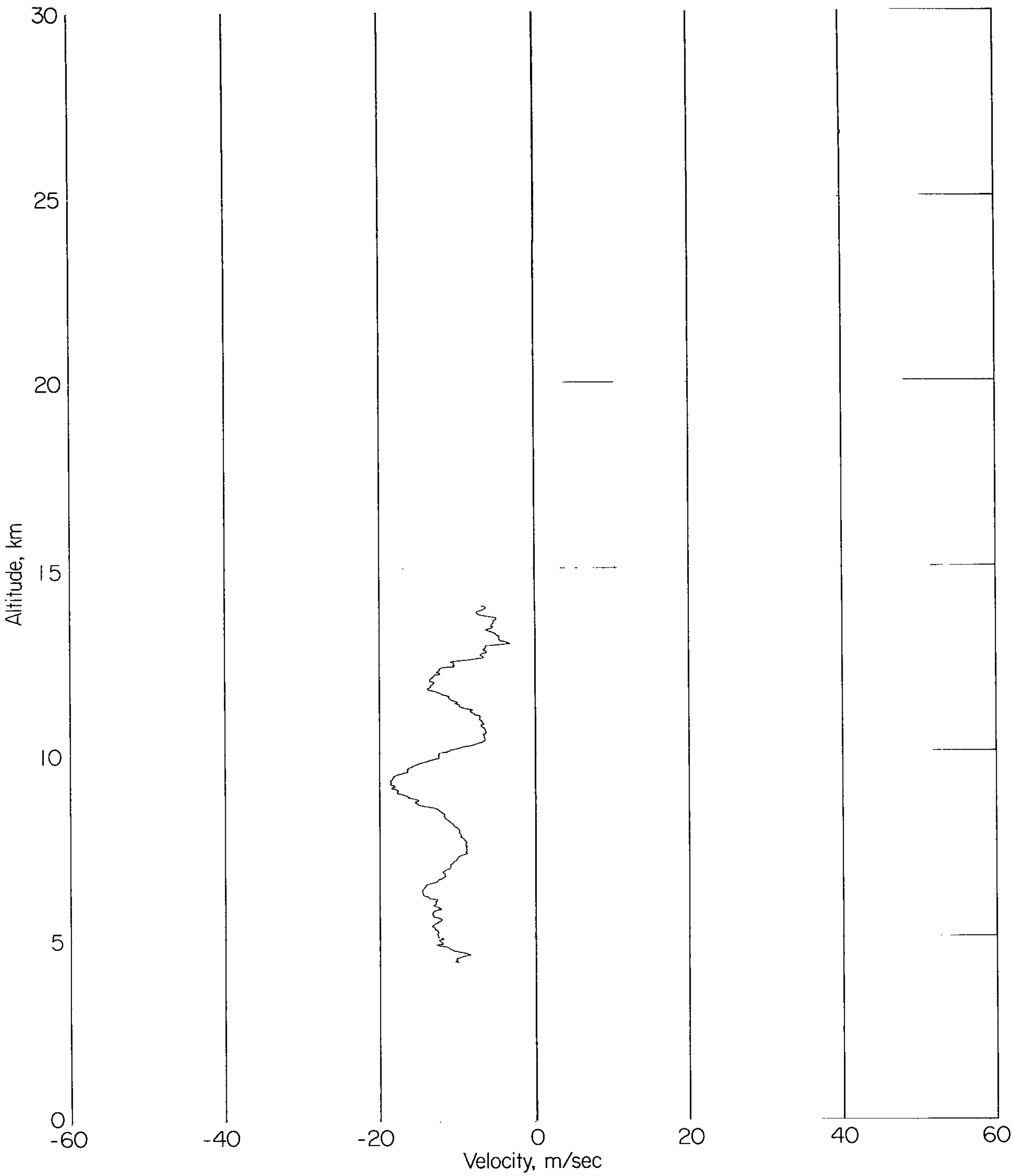
(b) South-to-north velocity component.

Figure 11.- Concluded.



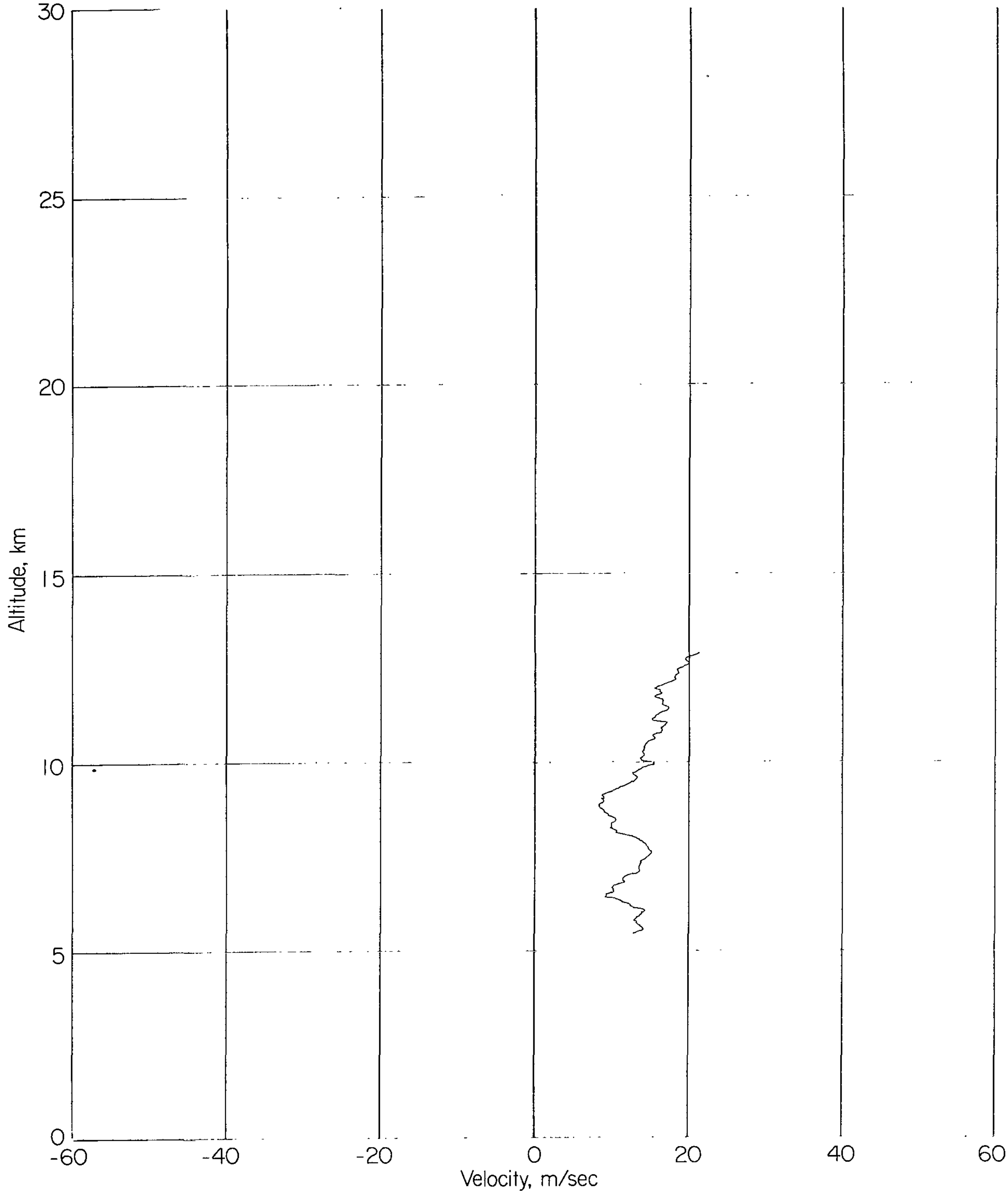
(a) West-to-east velocity component.

Figure 12.- Wind profile of smoke trail 083 obtained May 18, 1965. Time interval, 60 seconds; height interval, 25 meters.



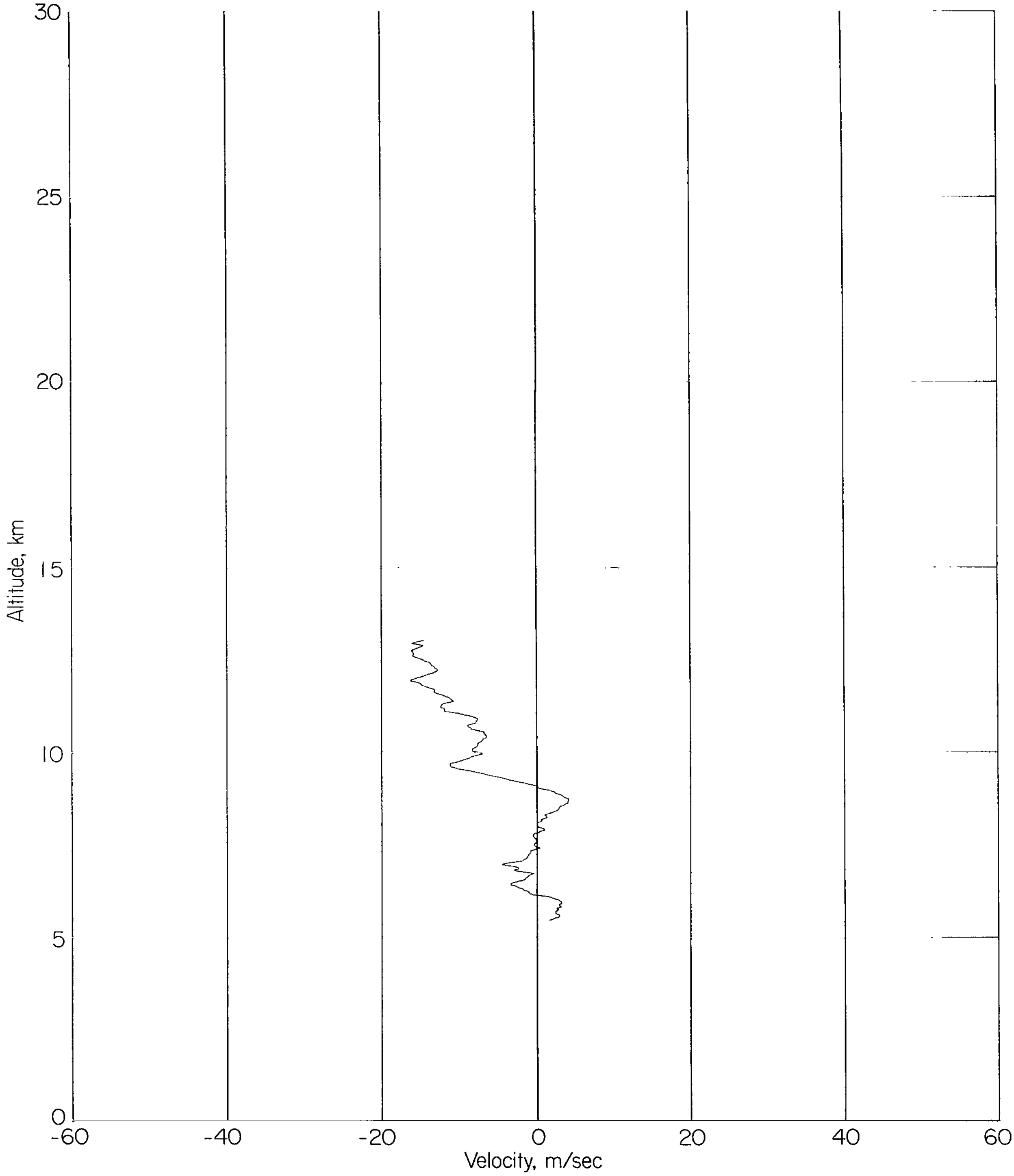
(b) South-to-north velocity component.

Figure 12.- Concluded.



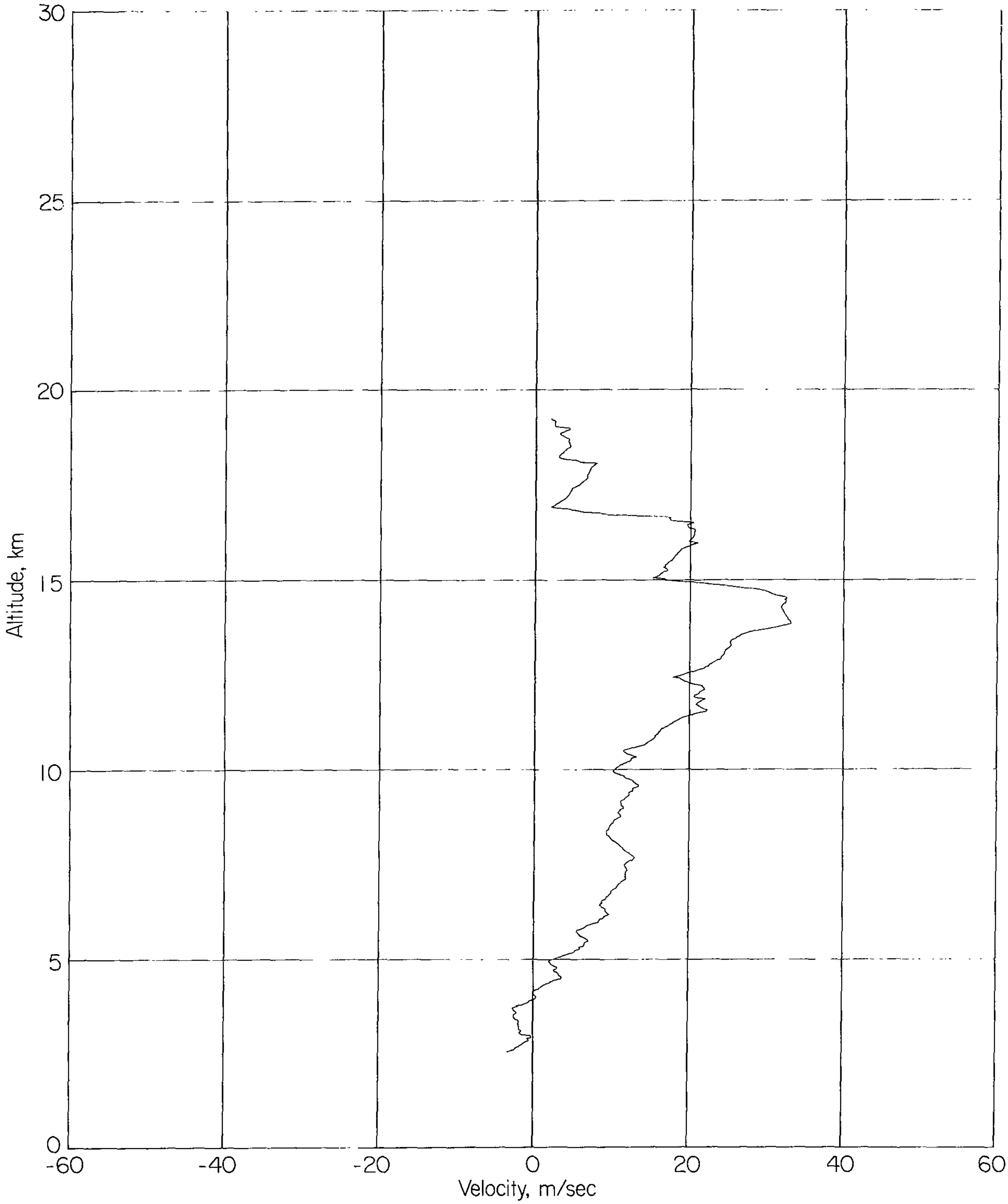
(a) West-to-east velocity component.

Figure 13.- Wind profile of smoke trail 084 obtained June 1, 1965. Time interval, 60 seconds; height interval, 25 meters.



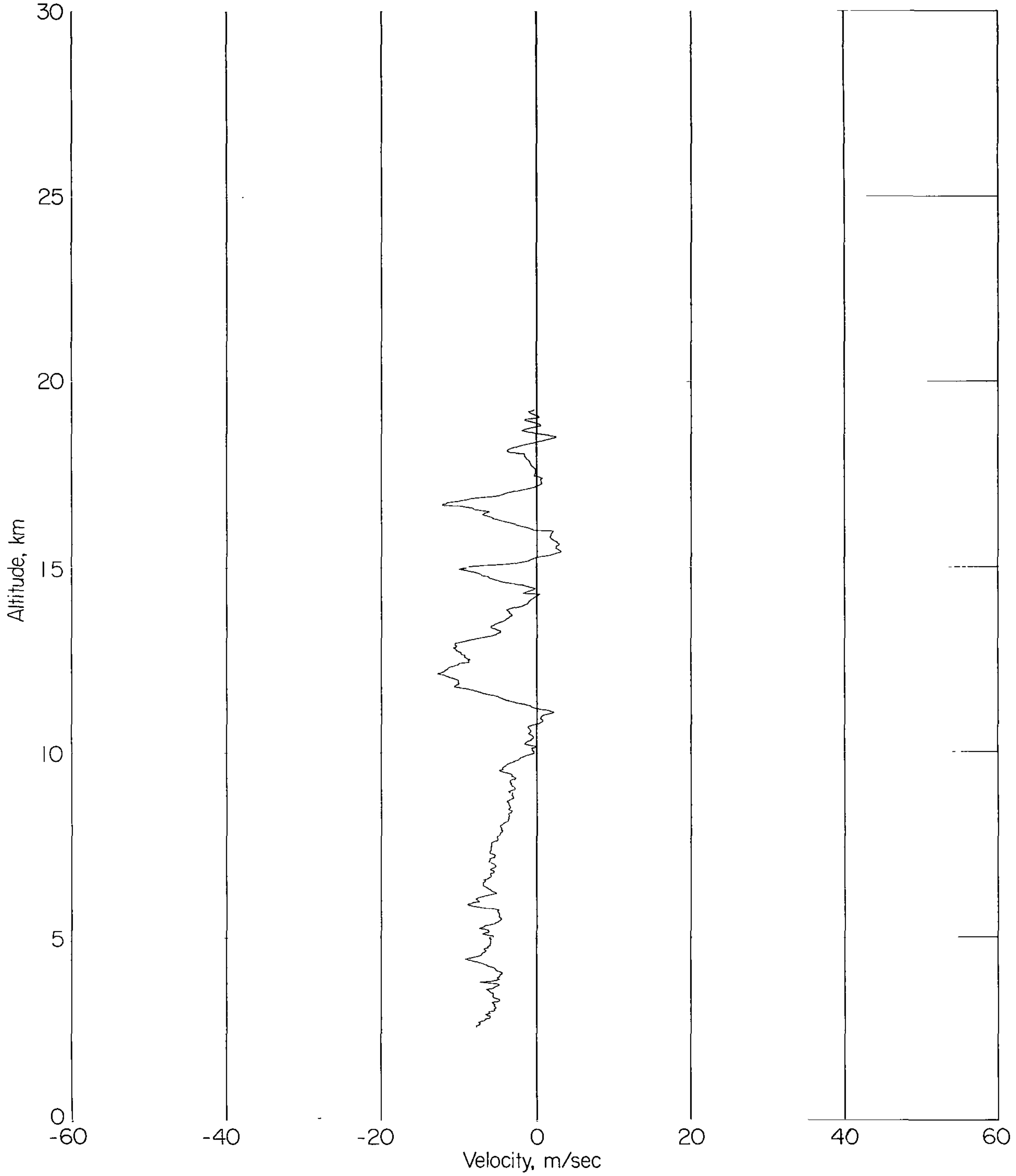
(b) South-to-north velocity component.

Figure 13.- Concluded.



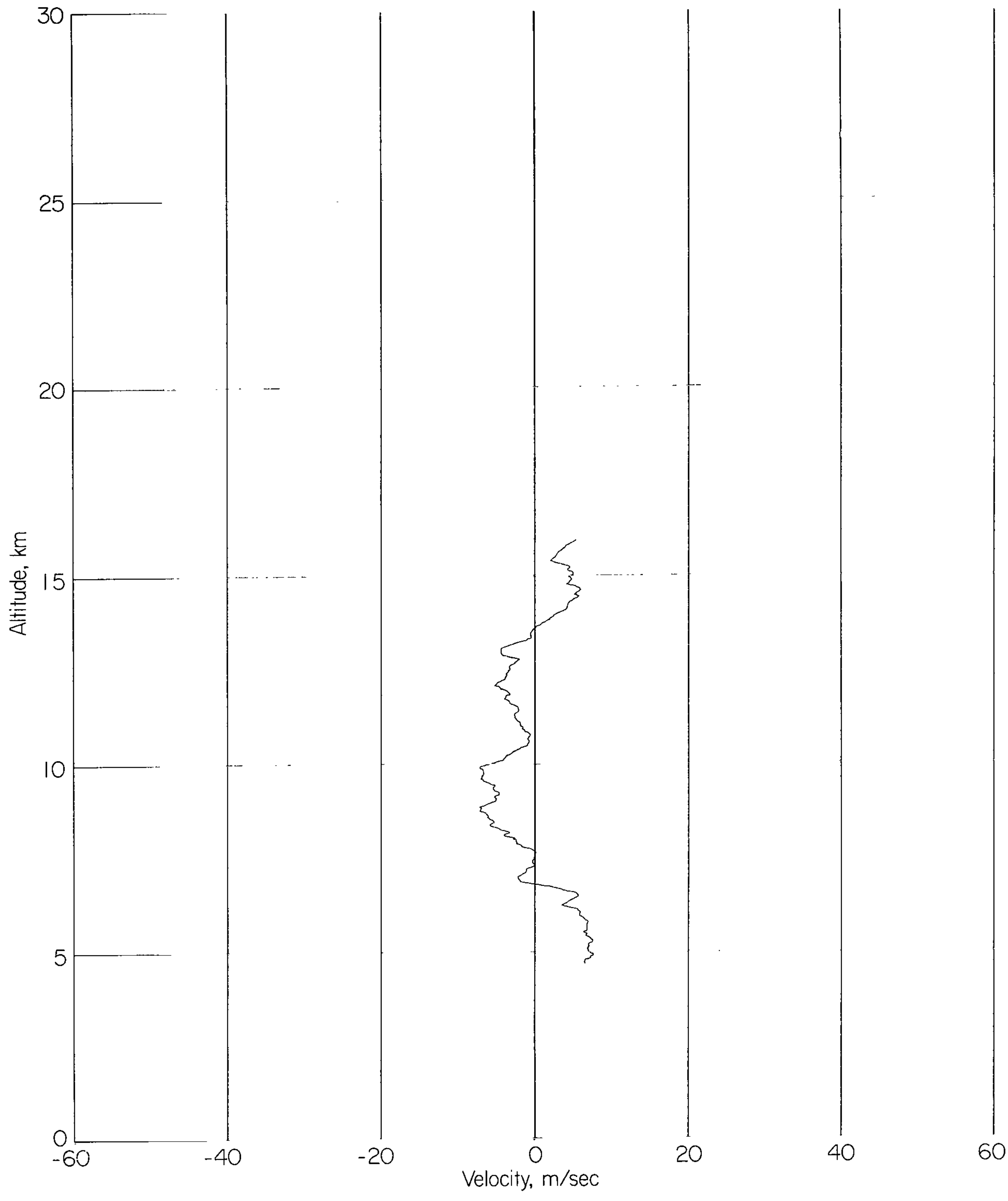
(a) West-to-east velocity component.

Figure 14.- Wind profile of smoke trail 085 obtained July 1, 1965. Time interval, 60 seconds; height interval, 25 meters.



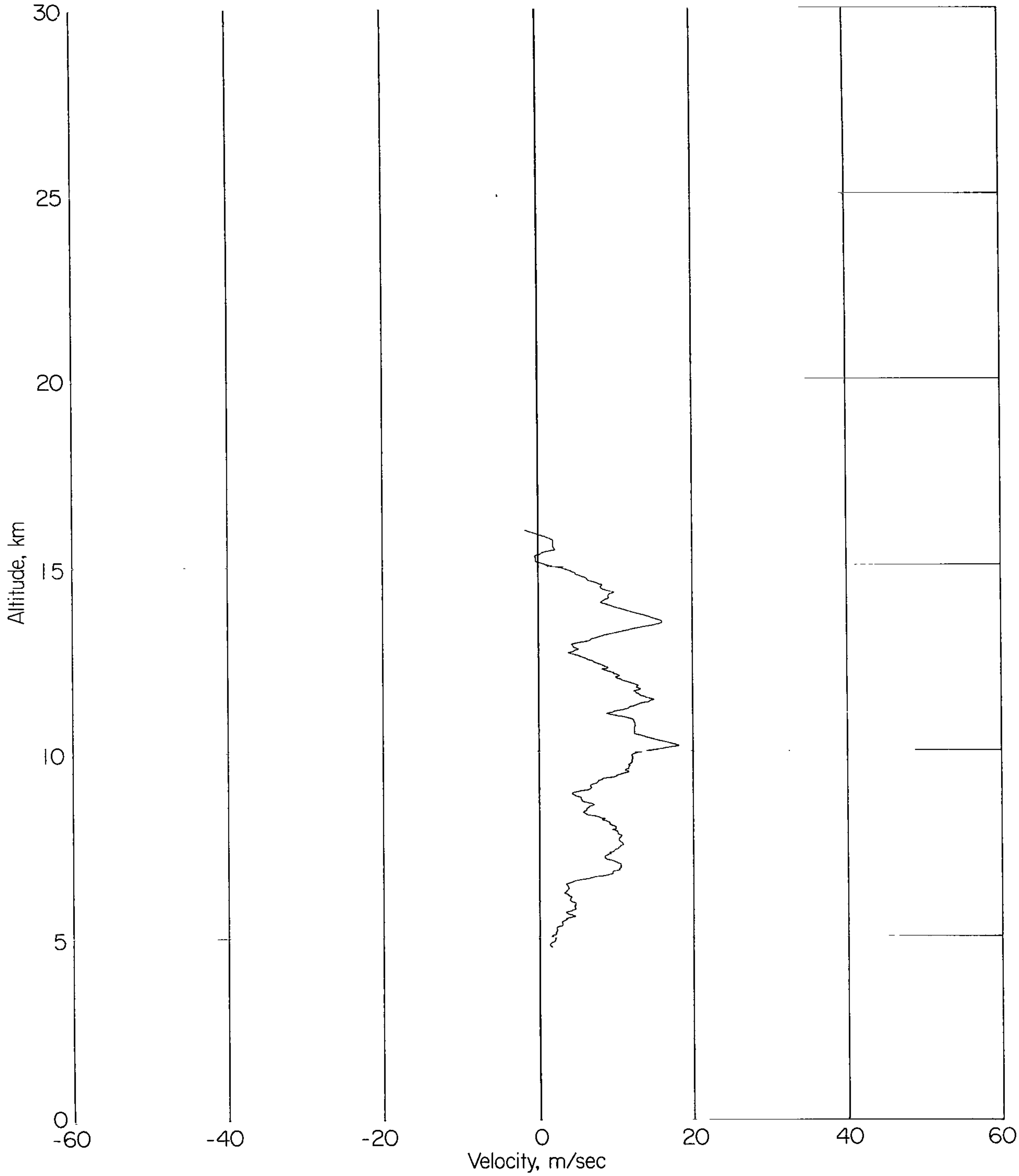
(b) South-to-north velocity component.

Figure 14.- Concluded.



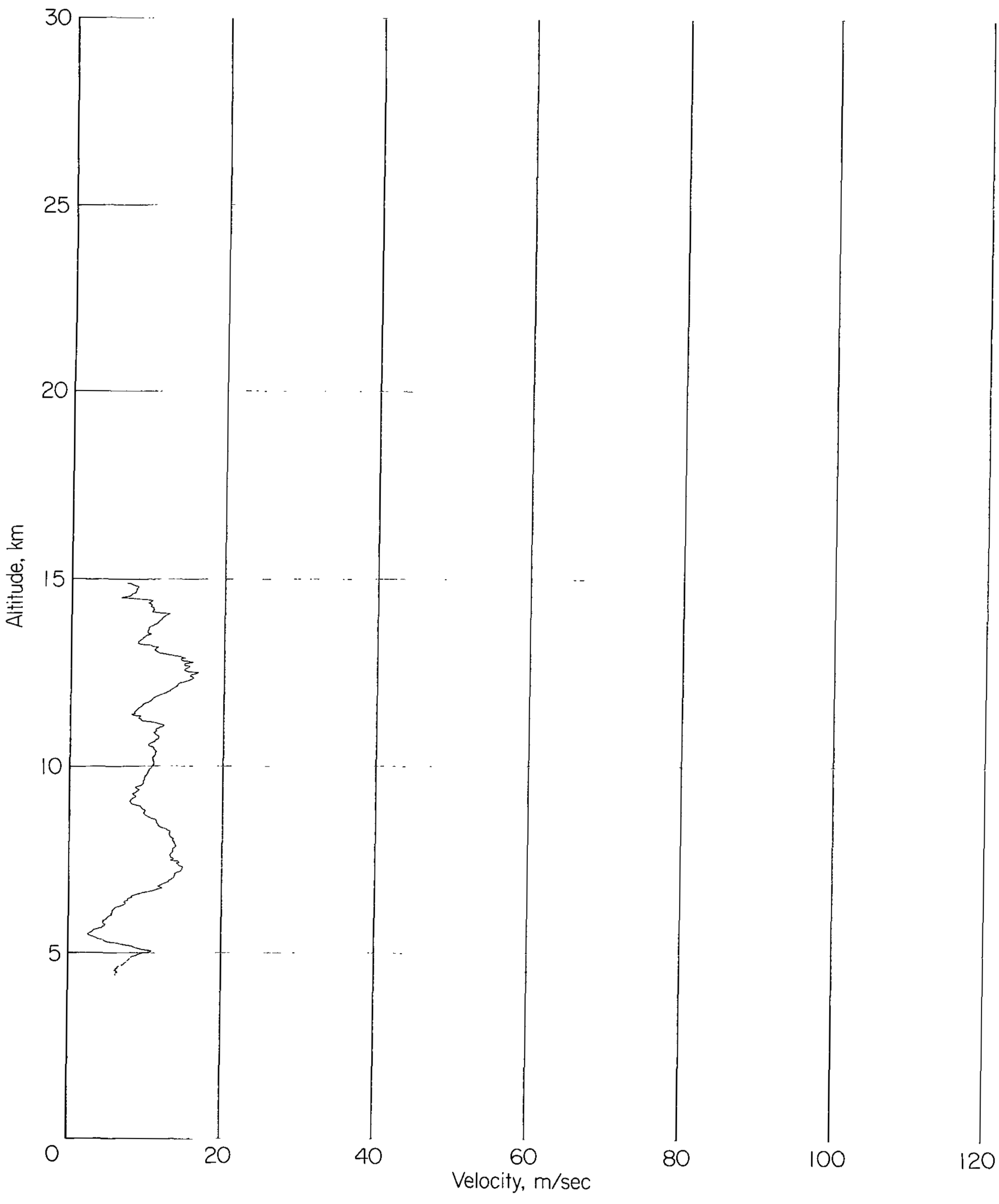
(a) West-to-east velocity component.

Figure 15.- Wind profile of smoke trail 086 obtained July 14, 1965. Time interval, 60 seconds; height interval, 25 meters.



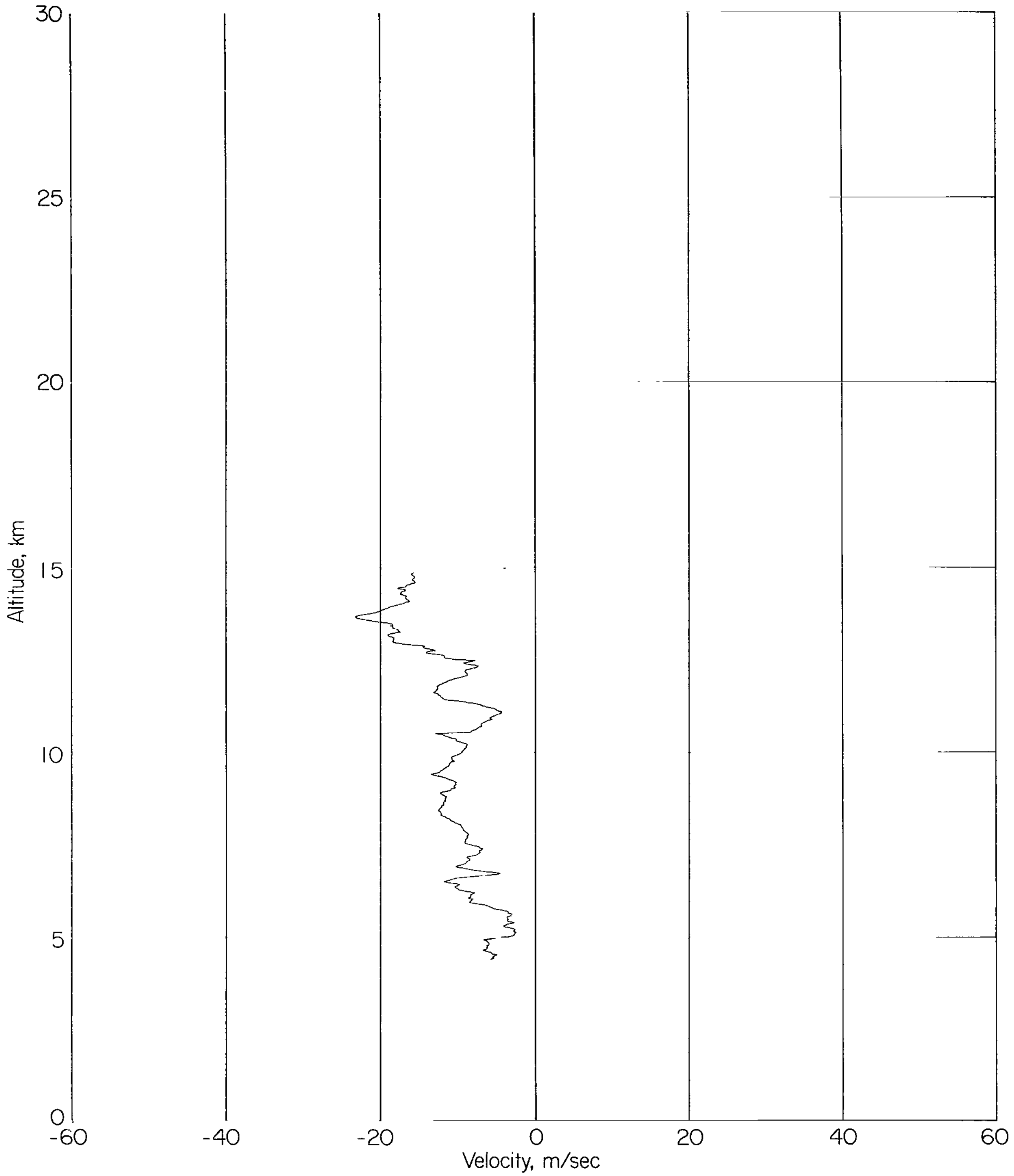
(b) South-to-north velocity component.

Figure 15.- Concluded.



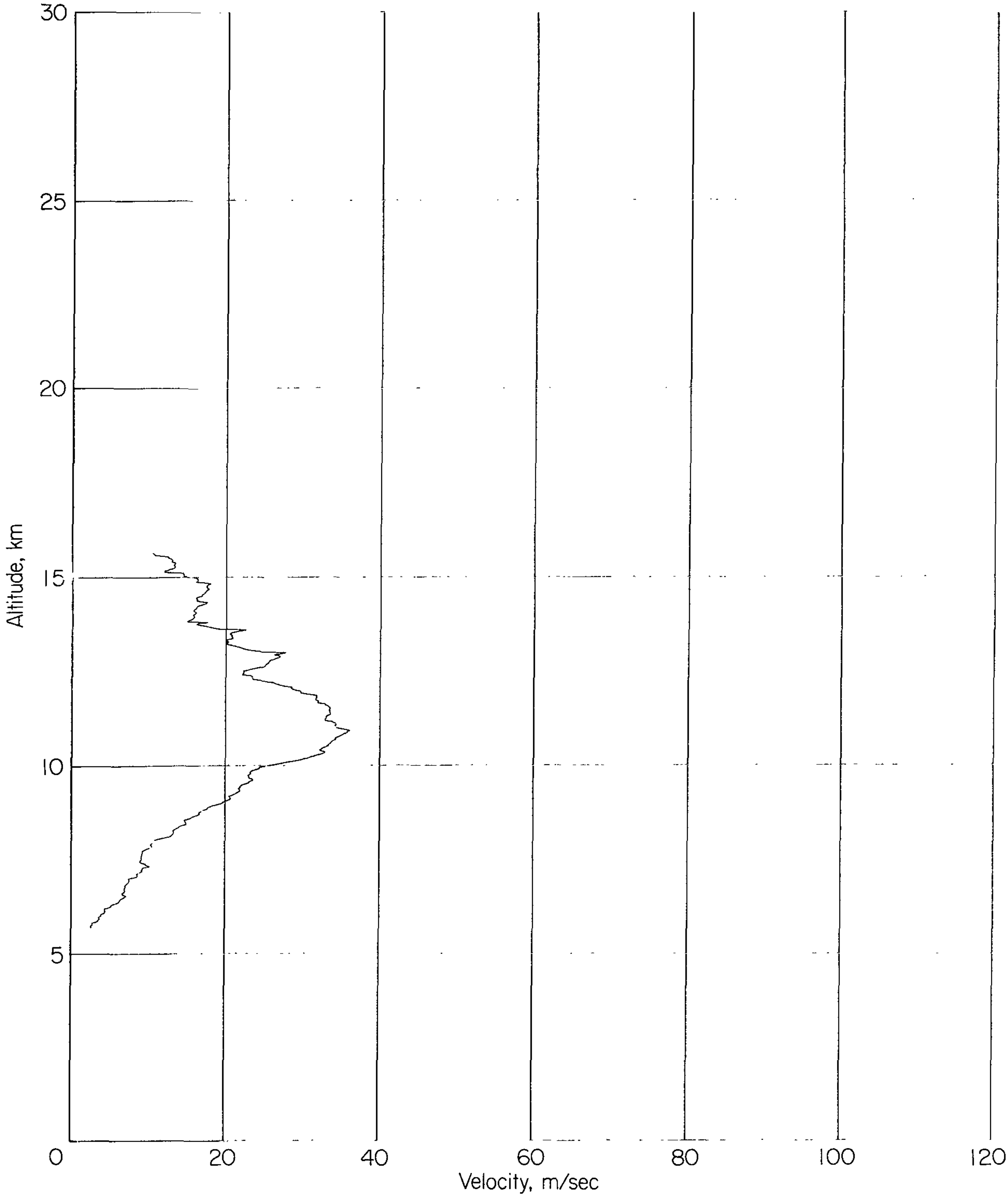
(a) West-to-east velocity component.

Figure 16.- Wind profile of smoke trail 087 obtained July 21, 1965. Time interval, 60 seconds; height interval, 25 meters.



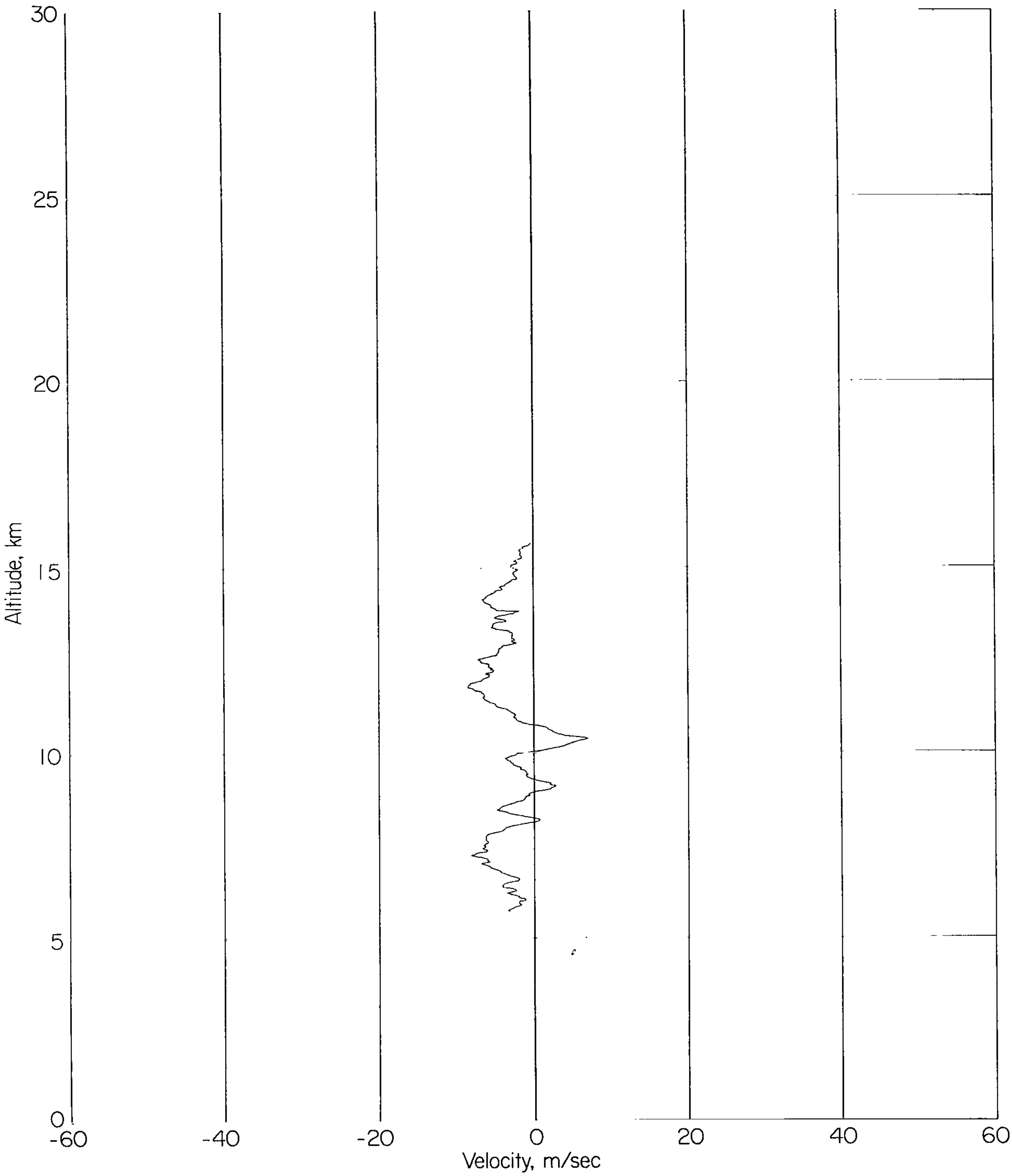
(b) South-to-north velocity component.

Figure 16.- Concluded.



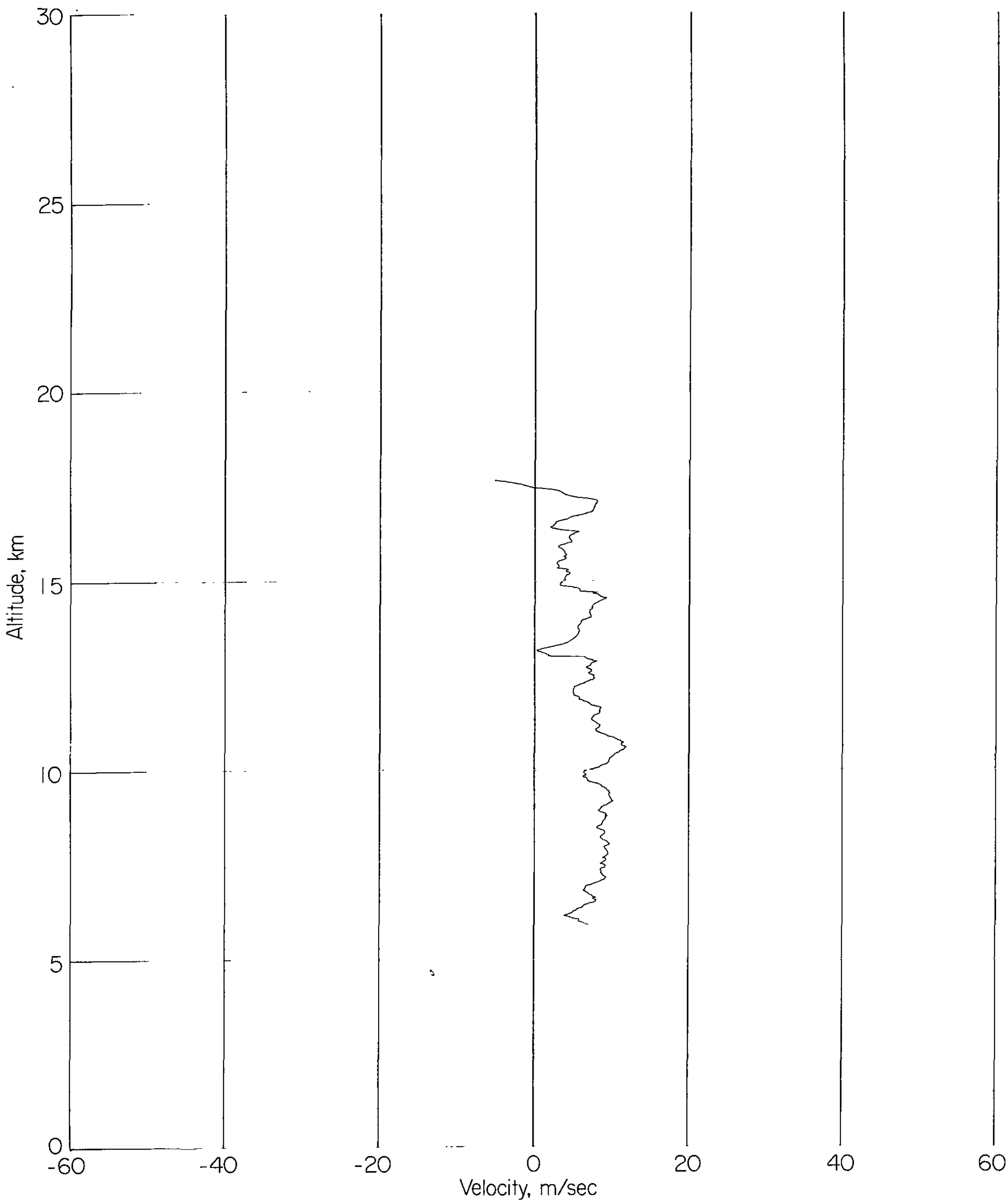
(a) West-to-east velocity component.

Figure 17.- Wind profile of smoke trail 088 obtained August 12, 1965. Time interval, 60 seconds; height interval, 25 meters.



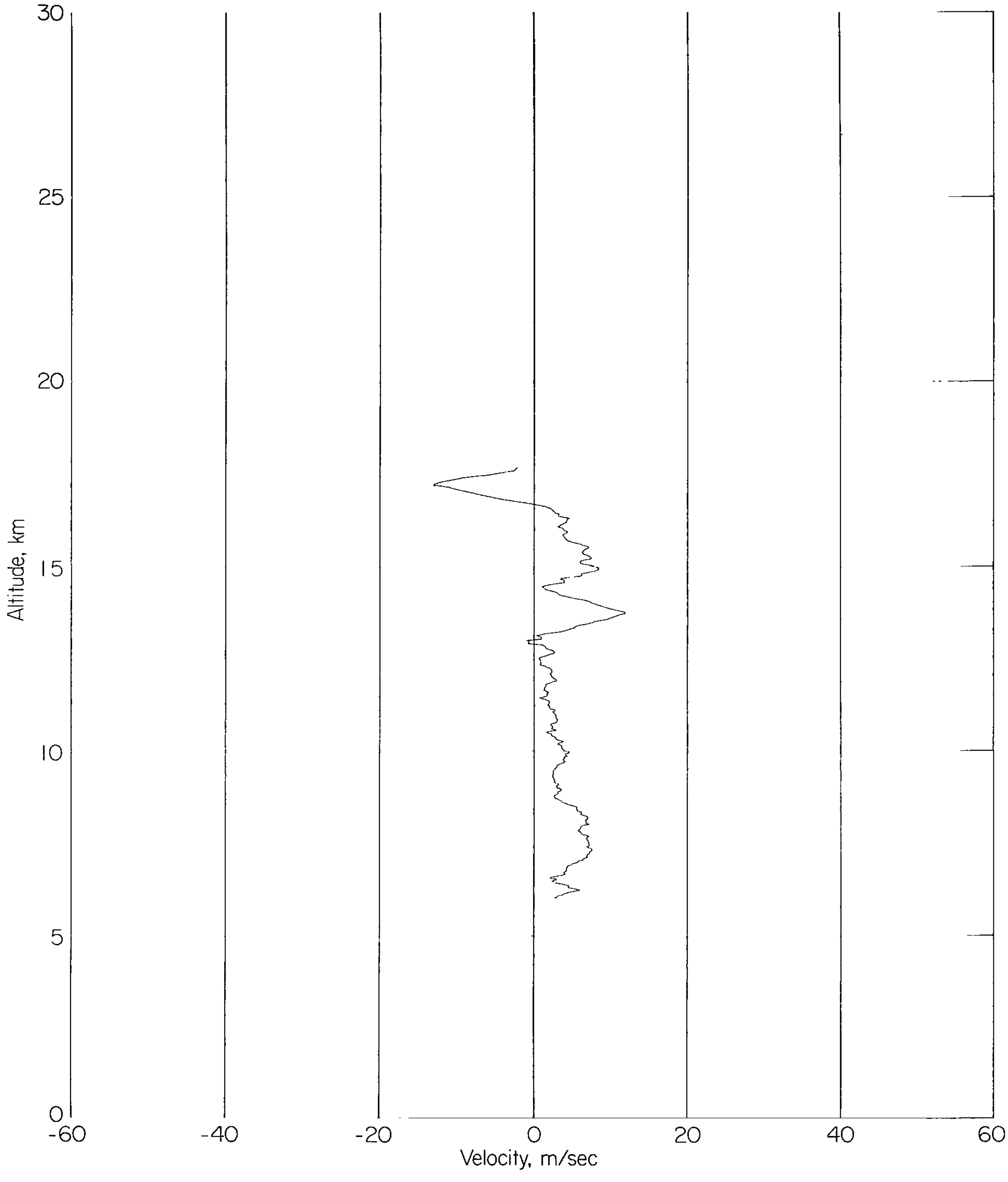
(b) South-to-north velocity component.

Figure 17.- Concluded.



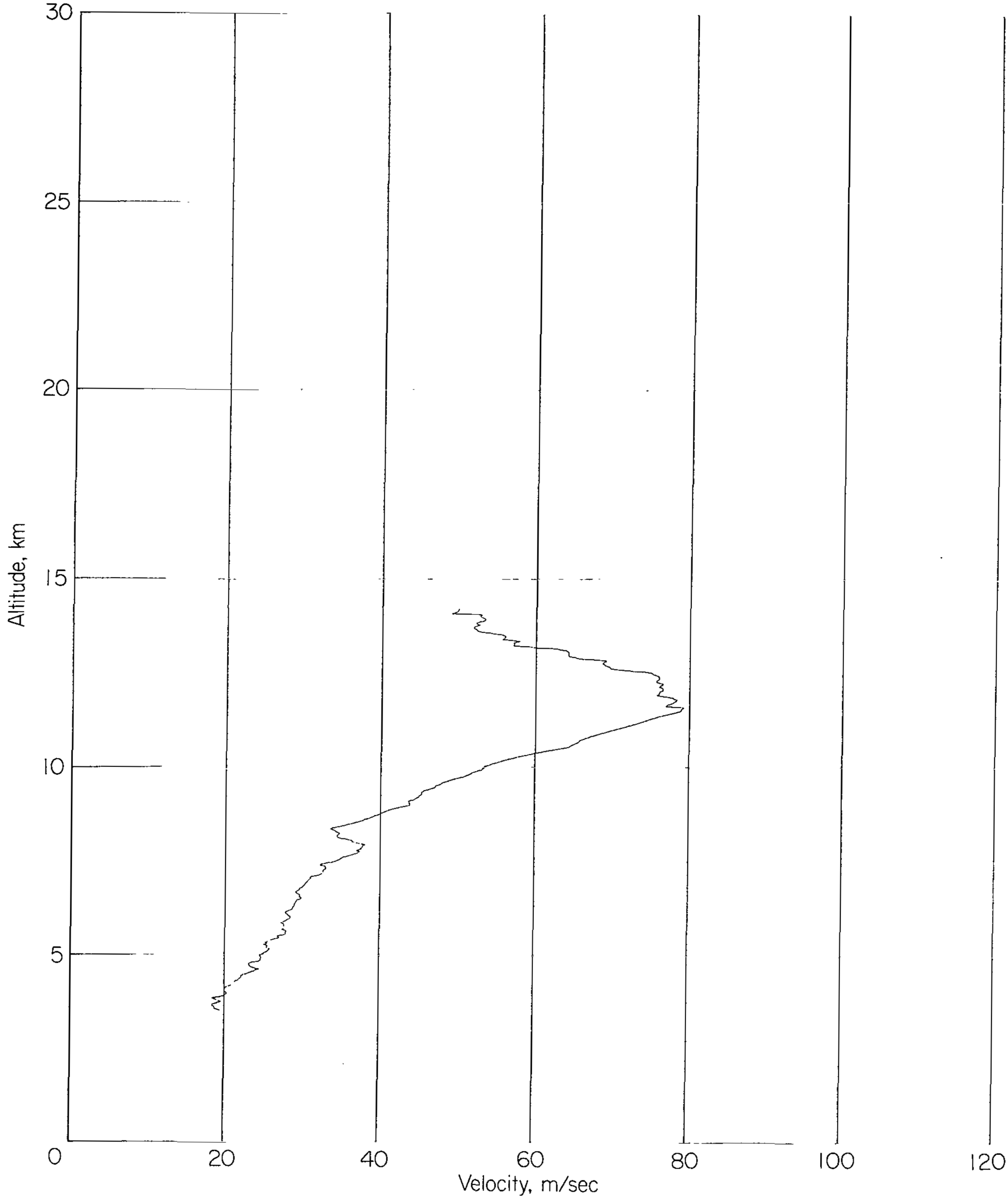
(a) West-to-east velocity component.

Figure 18.- Wind profile of smoke trail 089 obtained September 23, 1965. Time interval, 60 seconds; height interval, 25 meters.



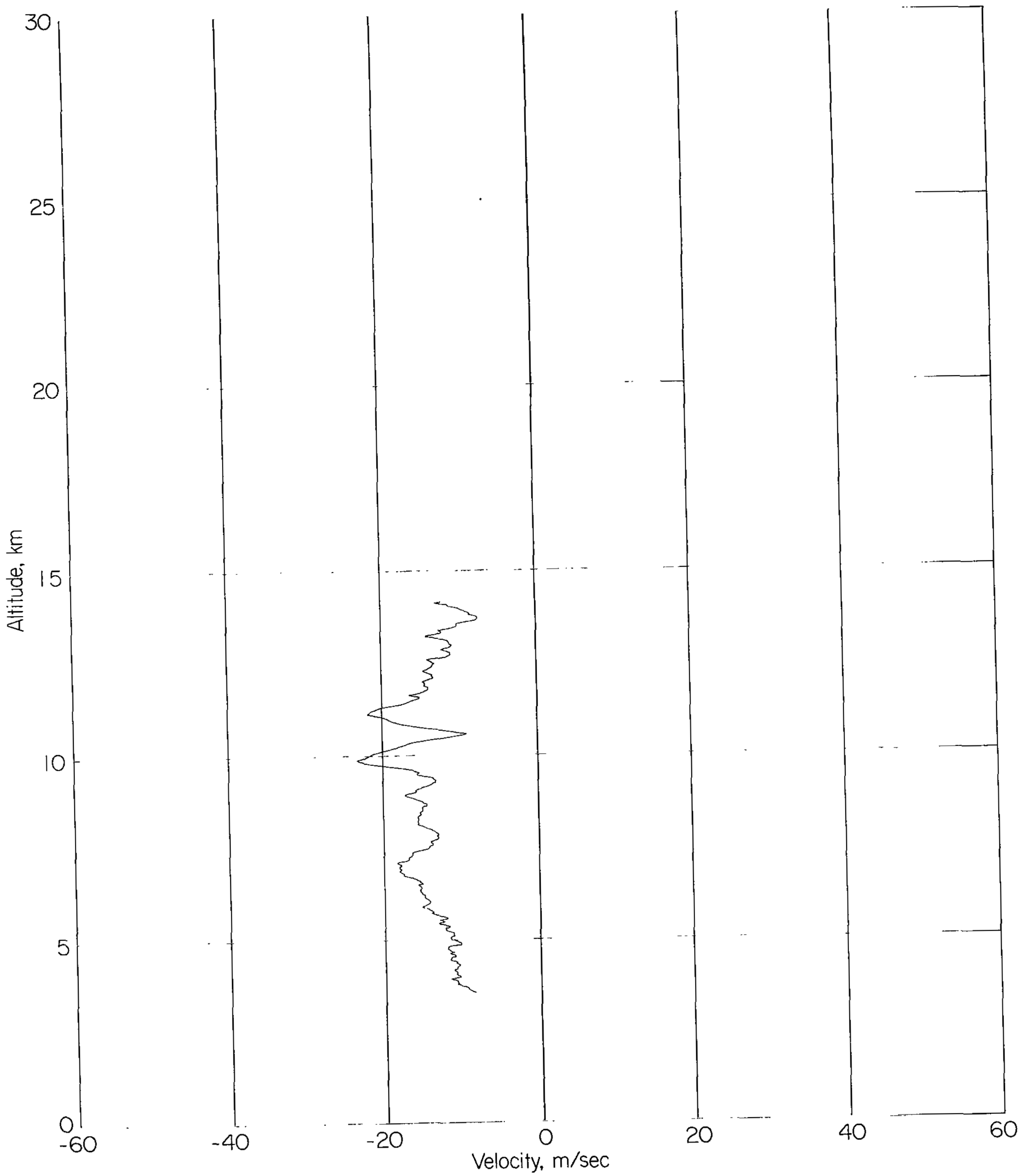
(b) South-to-north velocity component.

Figure 18.- Concluded.



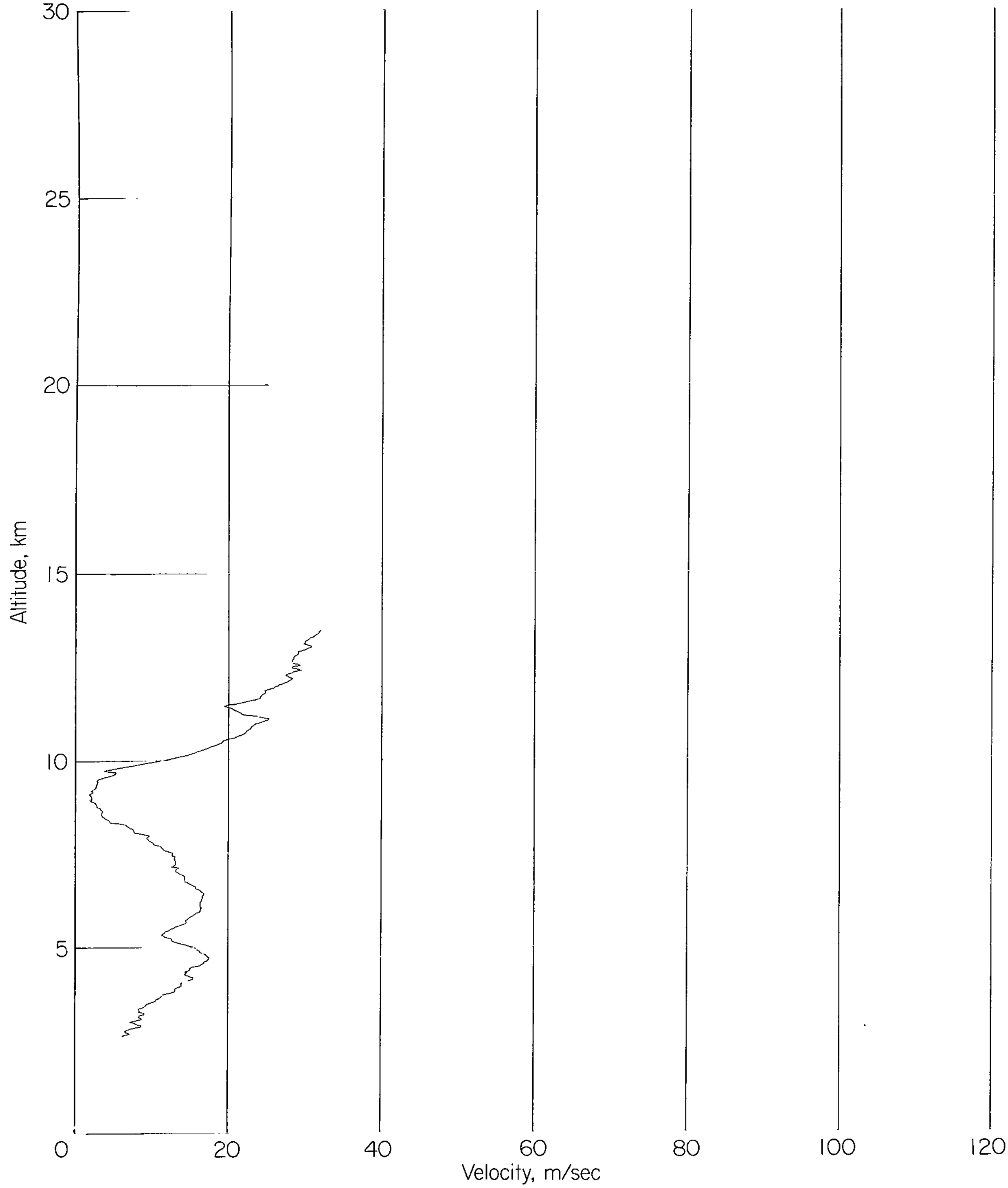
(a) West-to-east velocity component.

Figure 19.- Wind profile of smoke trail 090 obtained October 5, 1965. Time interval, 60 seconds; height interval, 25 meters.



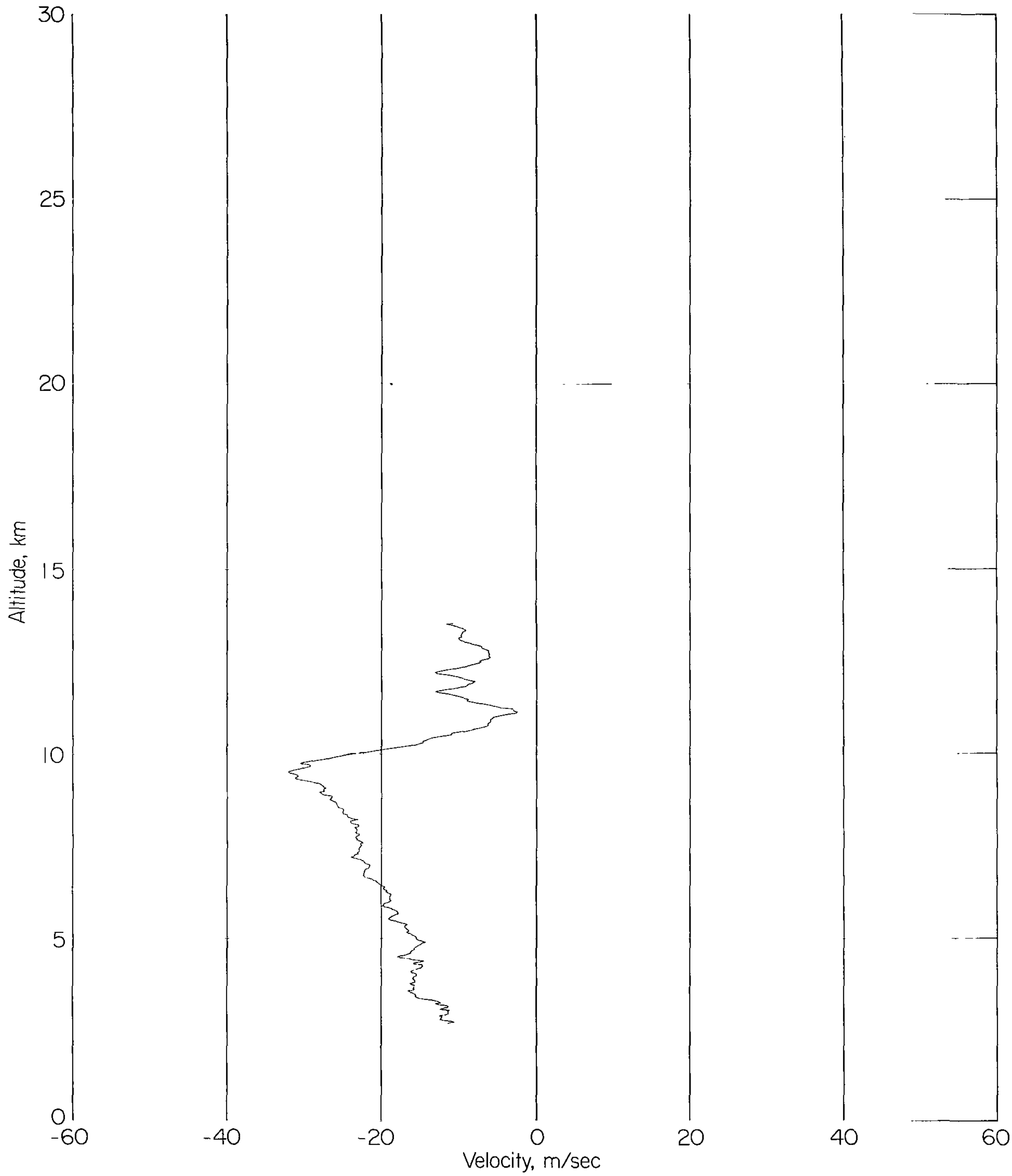
(b) South-to-north velocity component.

Figure 19.- Concluded.



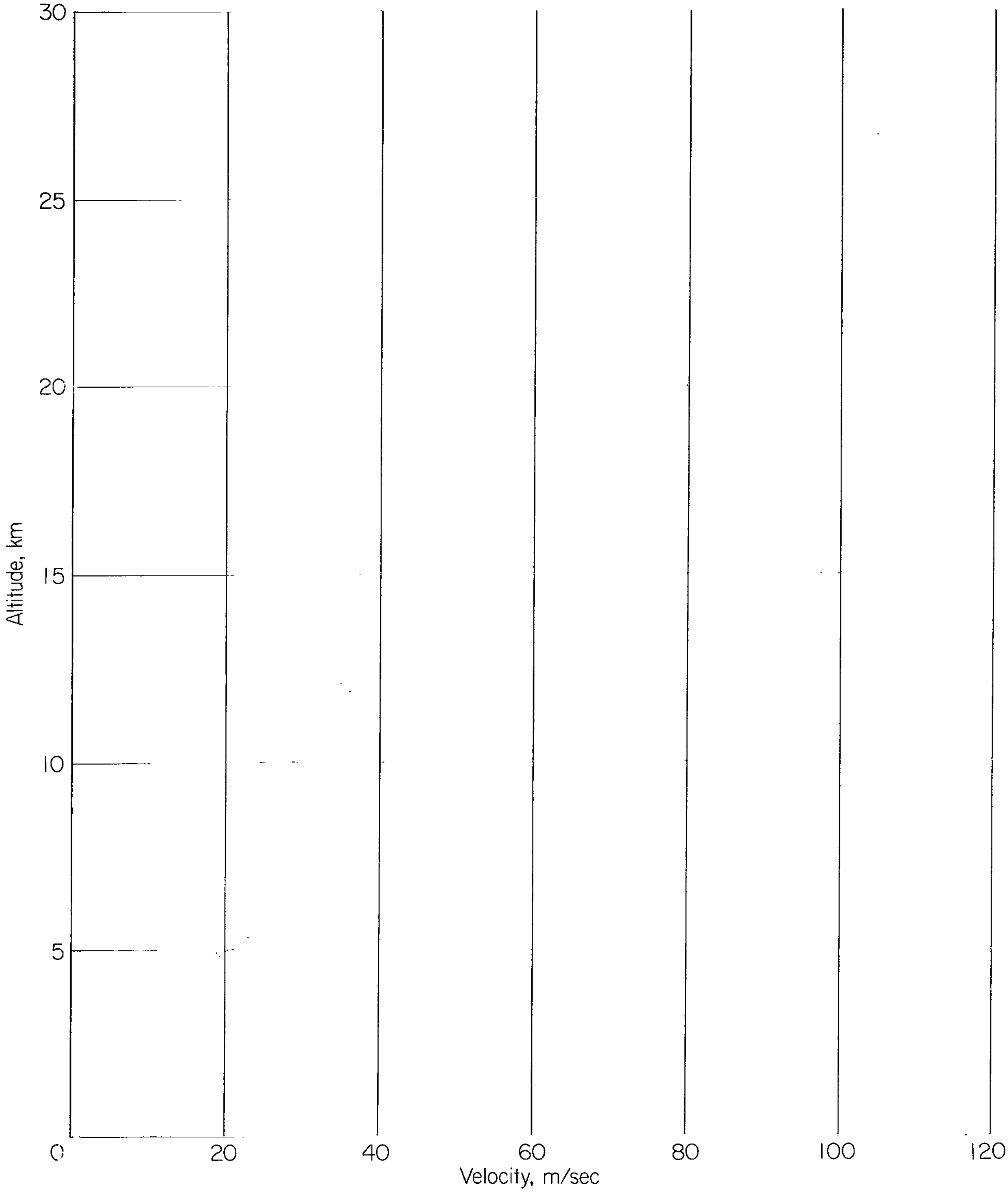
(a) West-to-east velocity component.

Figure 20.- Wind profile of smoke trail 091 obtained October 29, 1965. Time interval, 60 seconds; height interval, 25 meters.



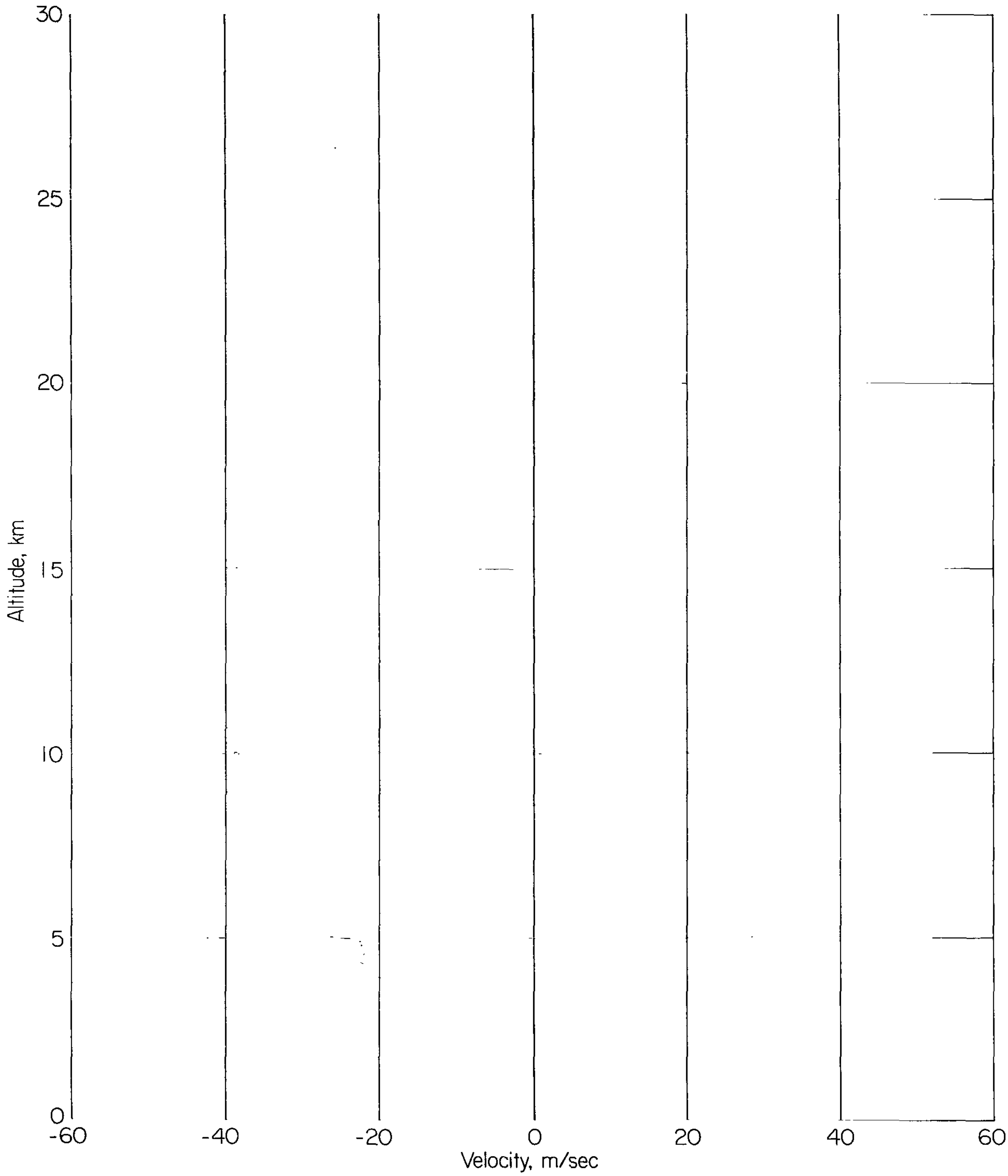
(b) South-to-north velocity component.

Figure 20.- Concluded.



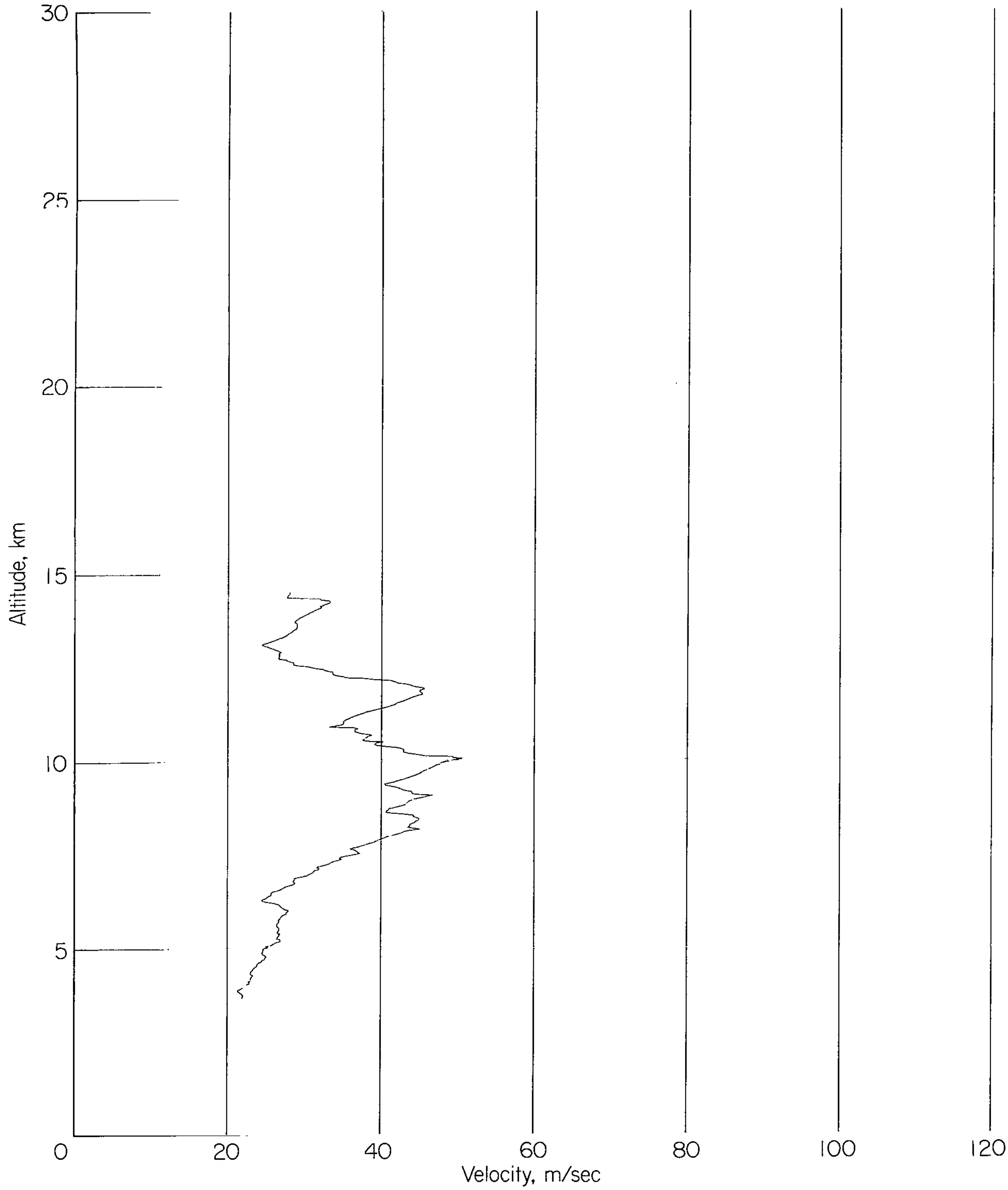
(a) West-to-east velocity component.

Figure 21.- Wind profile of smoke trail 092 obtained November 2, 1965. Time interval, 60 seconds; height interval, 25 meters.



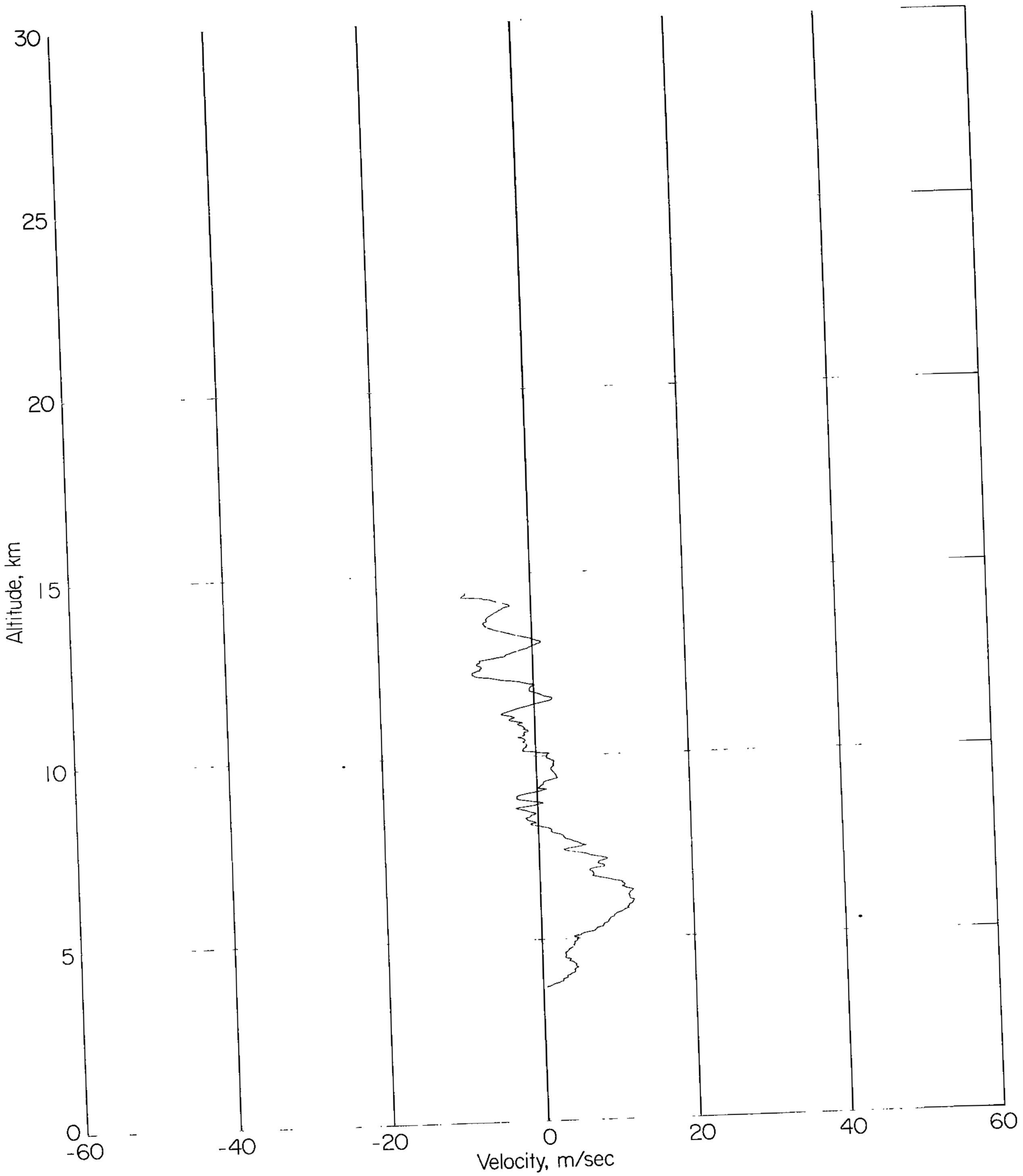
(b) South-to-north velocity component.

Figure 21. - Concluded.



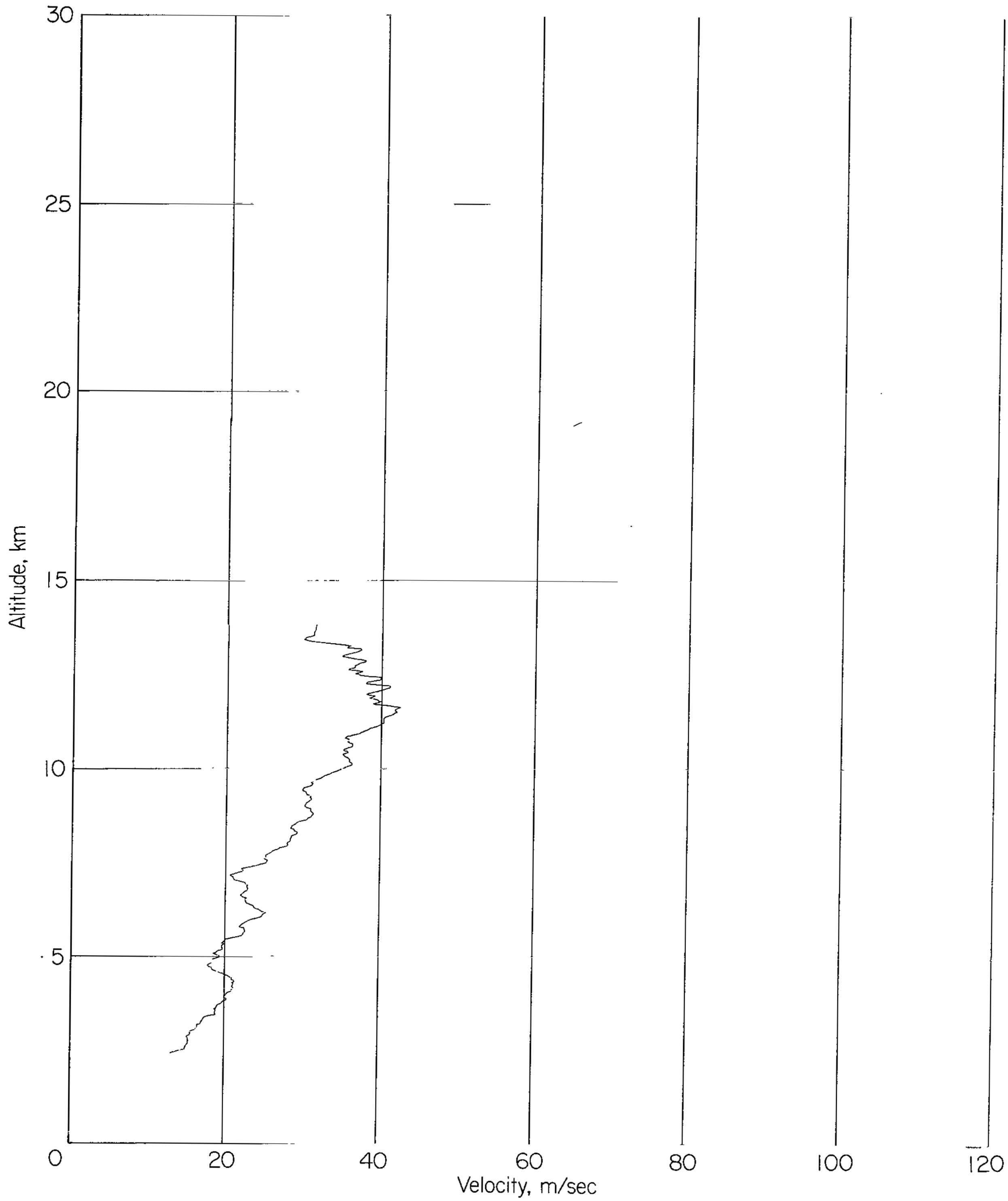
(a) West-to-east velocity component.

Figure 22.- Wind profile of smoke trail 093 obtained November 17, 1965. Time interval, 60 seconds; height interval, 25 meters.



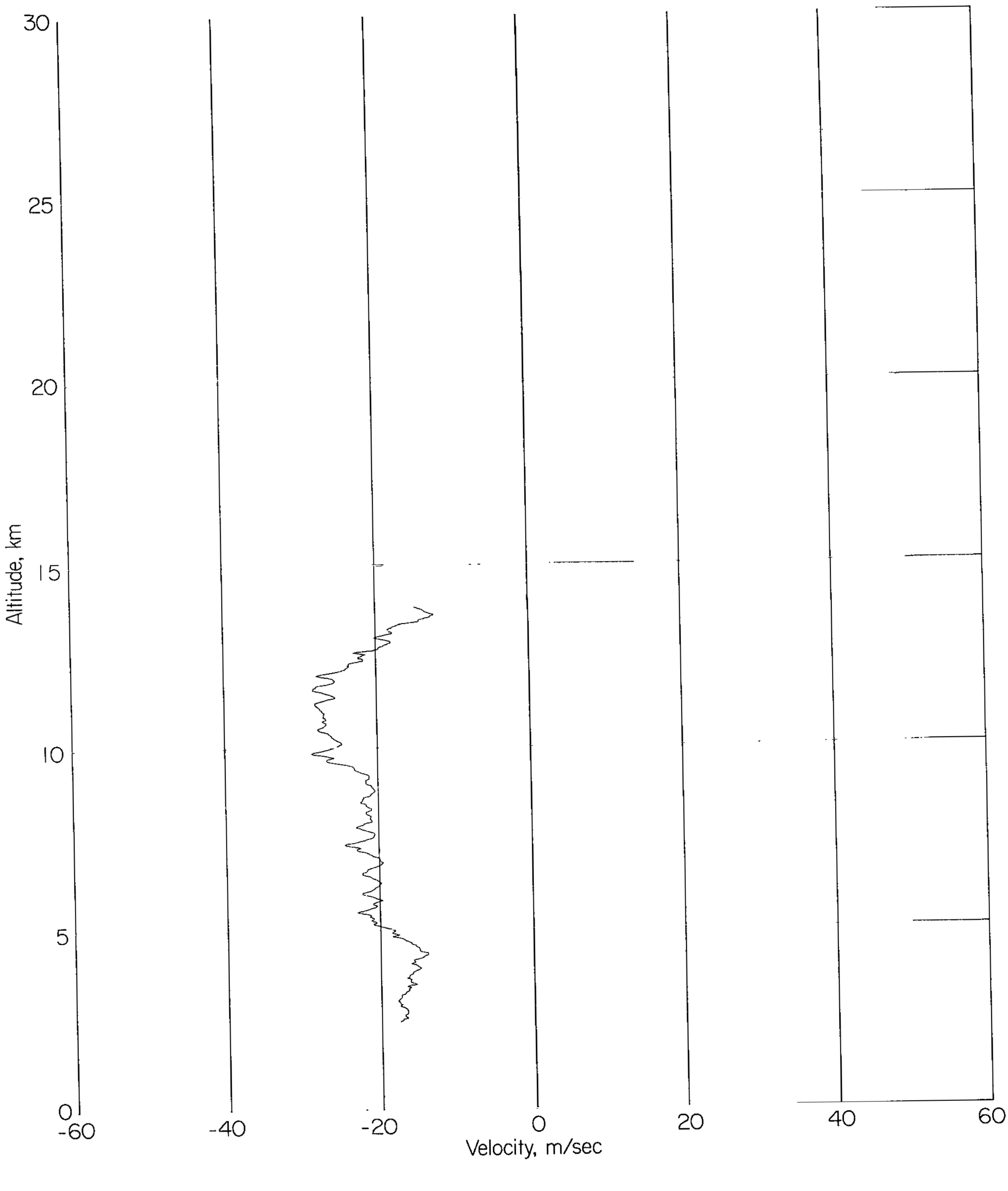
(b) South-to-north velocity component.

Figure 22.- Concluded.



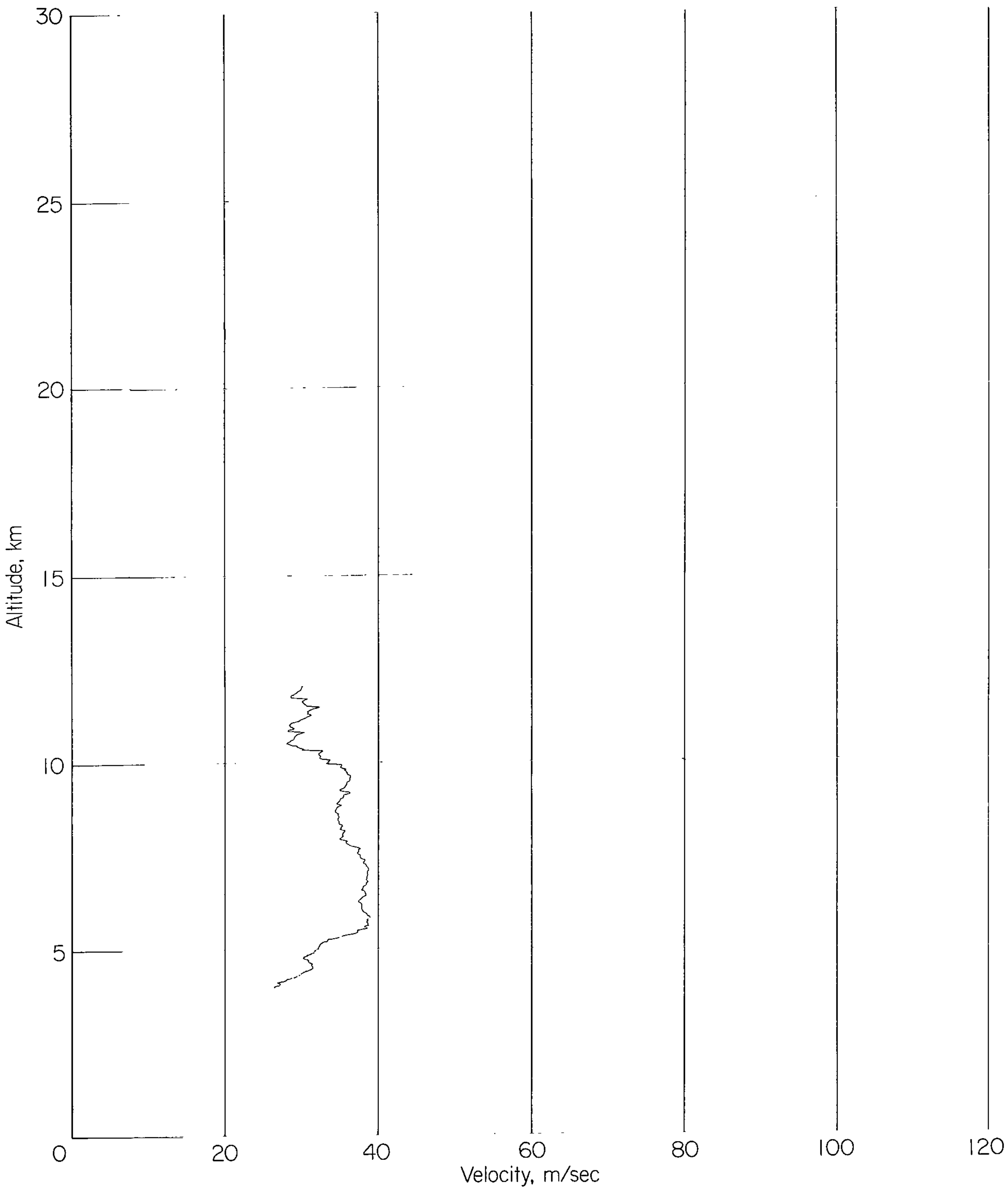
(a) West-to-east velocity component.

Figure 23.- Wind profile of smoke trail 094 obtained November 18, 1965. Time interval, 60 seconds; height interval, 25 meters.



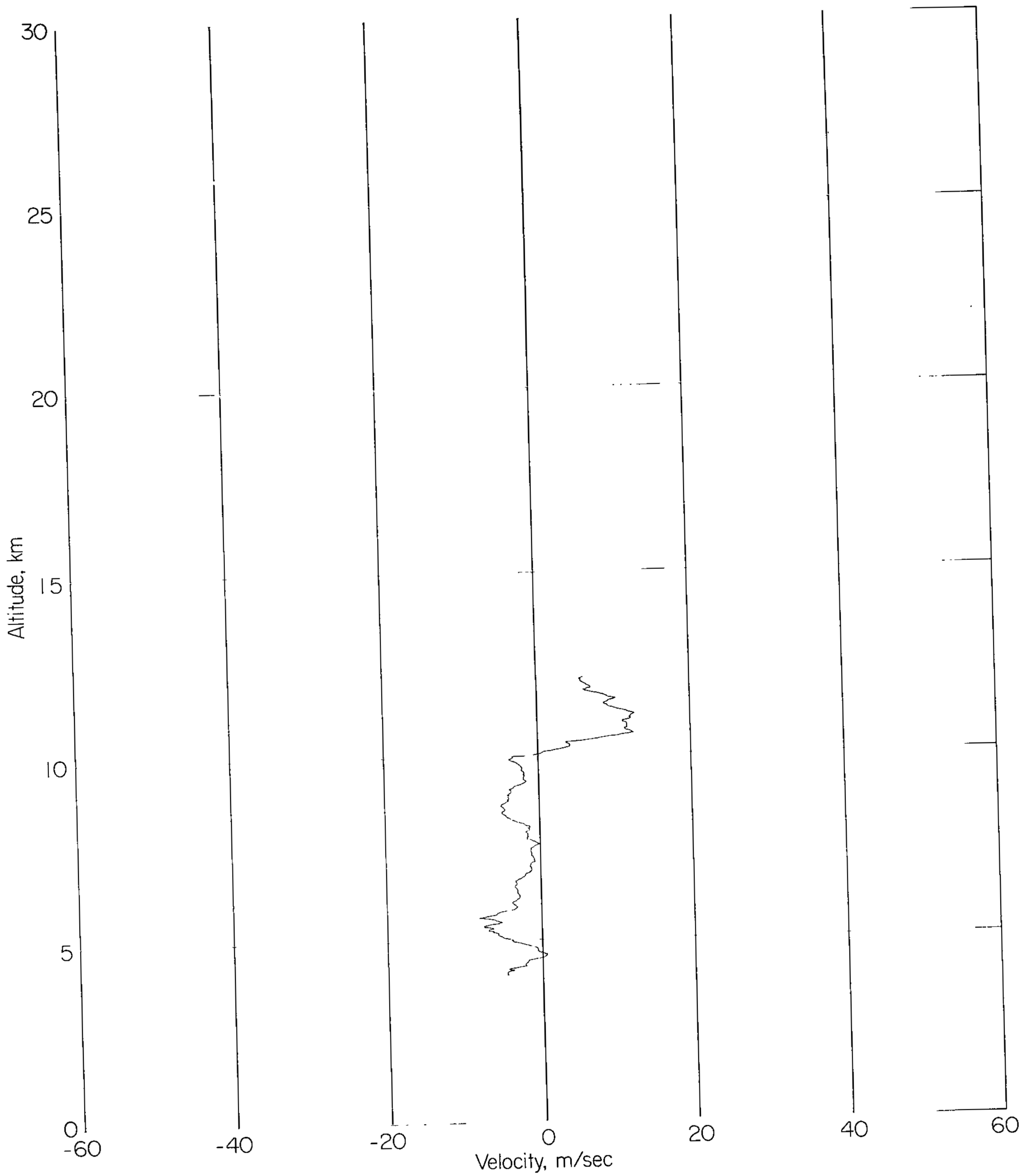
(b) South-to-north velocity component.

Figure 23.- Concluded.



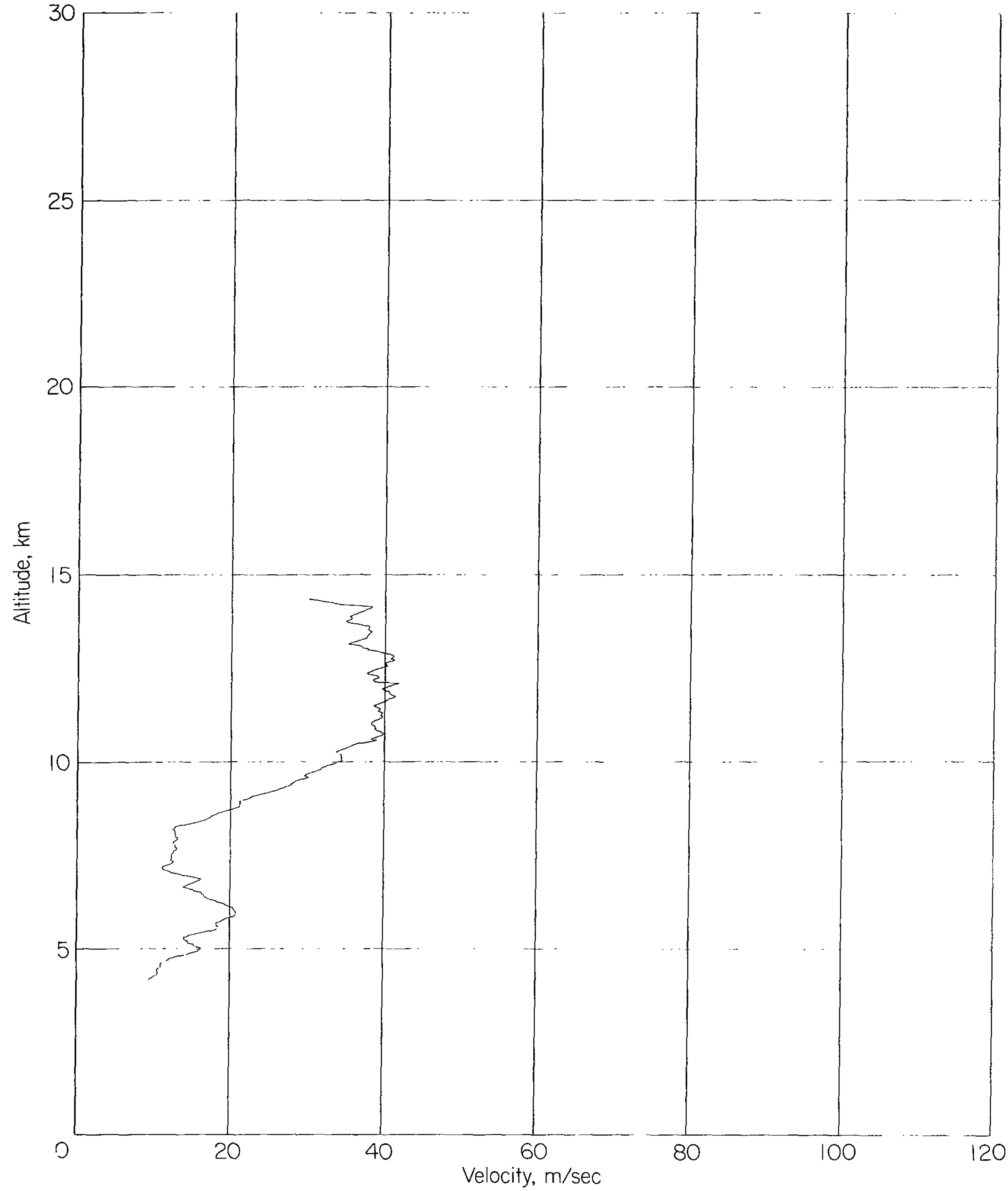
(a) West-to-east velocity component.

Figure 24.- Wind profile of smoke trail 095 obtained November 23, 1965. Time interval, 60 seconds; height interval, 25 meters.



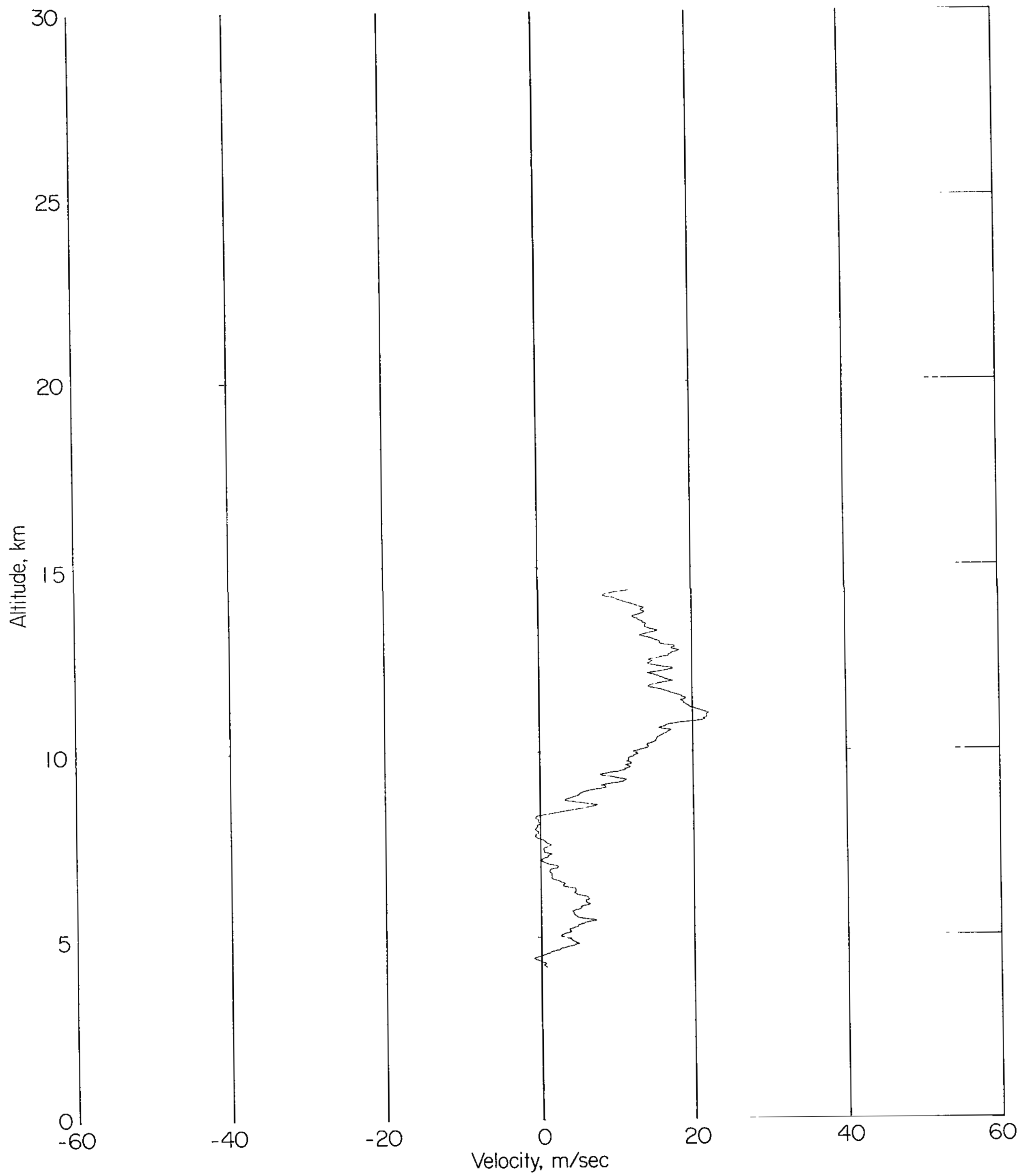
(b) South-to-north velocity component.

Figure 24. - Concluded.



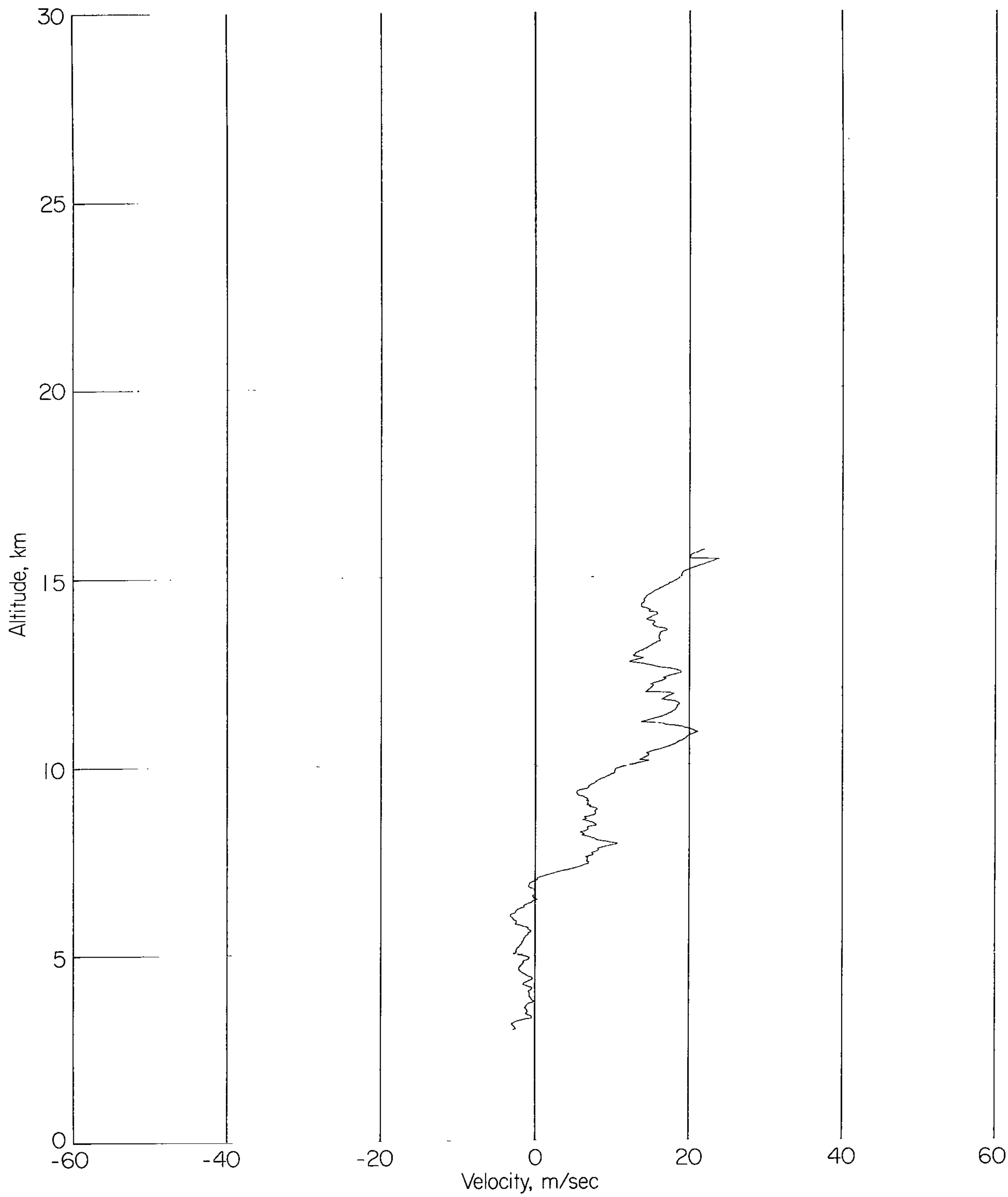
(a) West-to-east velocity component.

Figure 25.- Wind profile of smoke trail 096 obtained November 30, 1965. Time interval, 60 seconds; height interval, 25 meters.



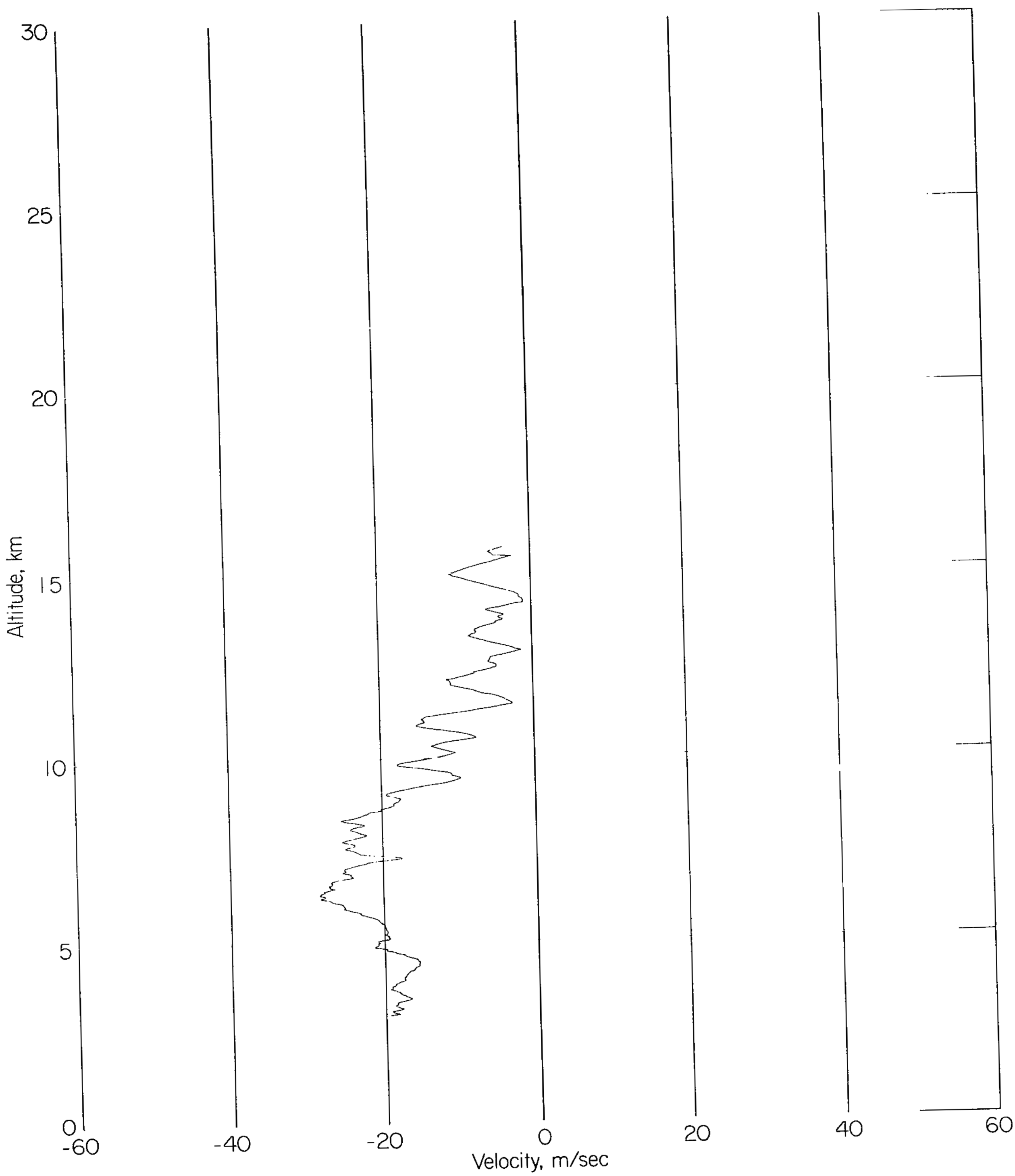
(b) South-to-north velocity component.

Figure 25.- Concluded.



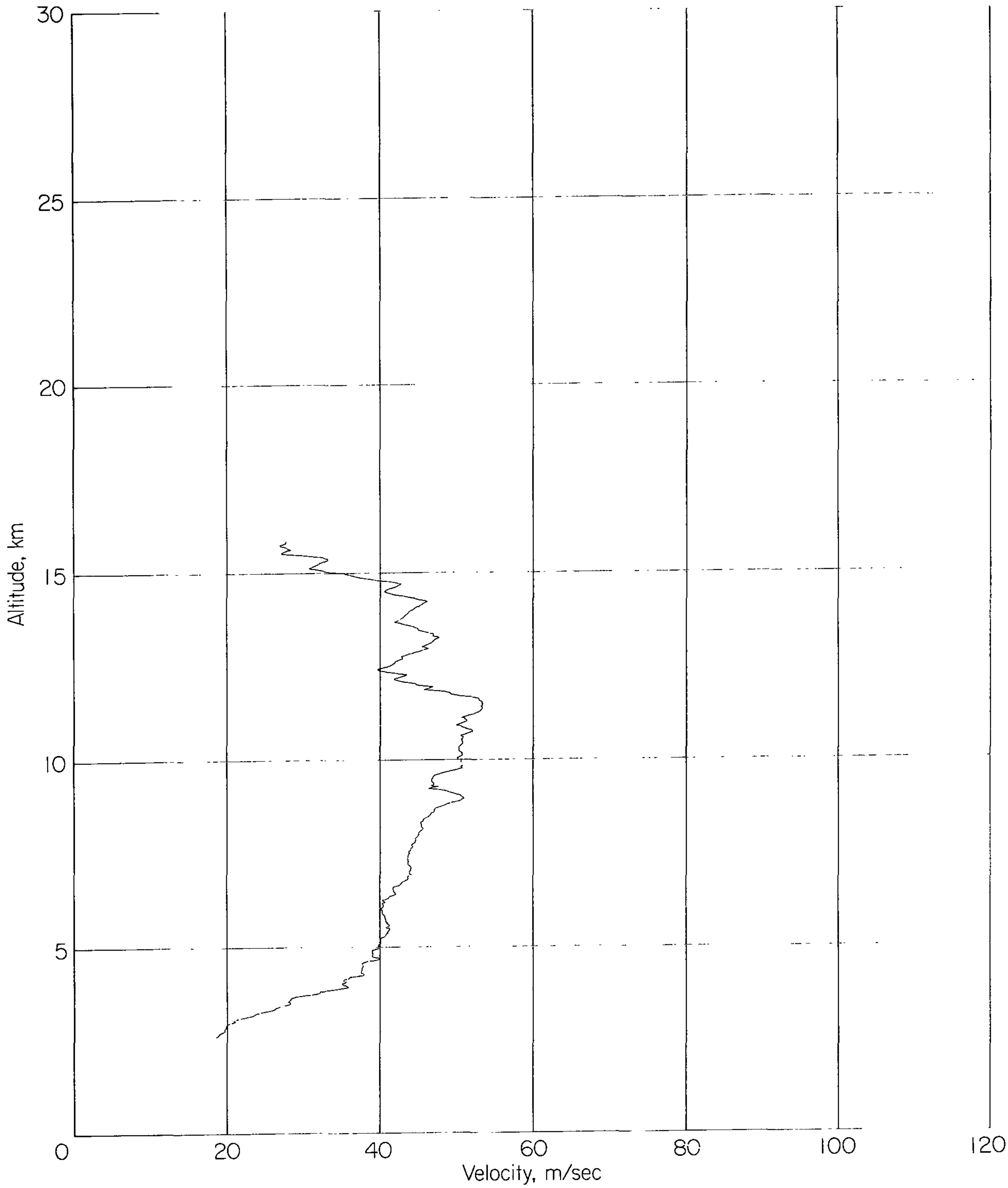
(a) West-to-east velocity component.

Figure 26.- Wind profile of smoke trail 097 obtained December 7, 1965. Time interval, 60 seconds; height interval, 25 meters.



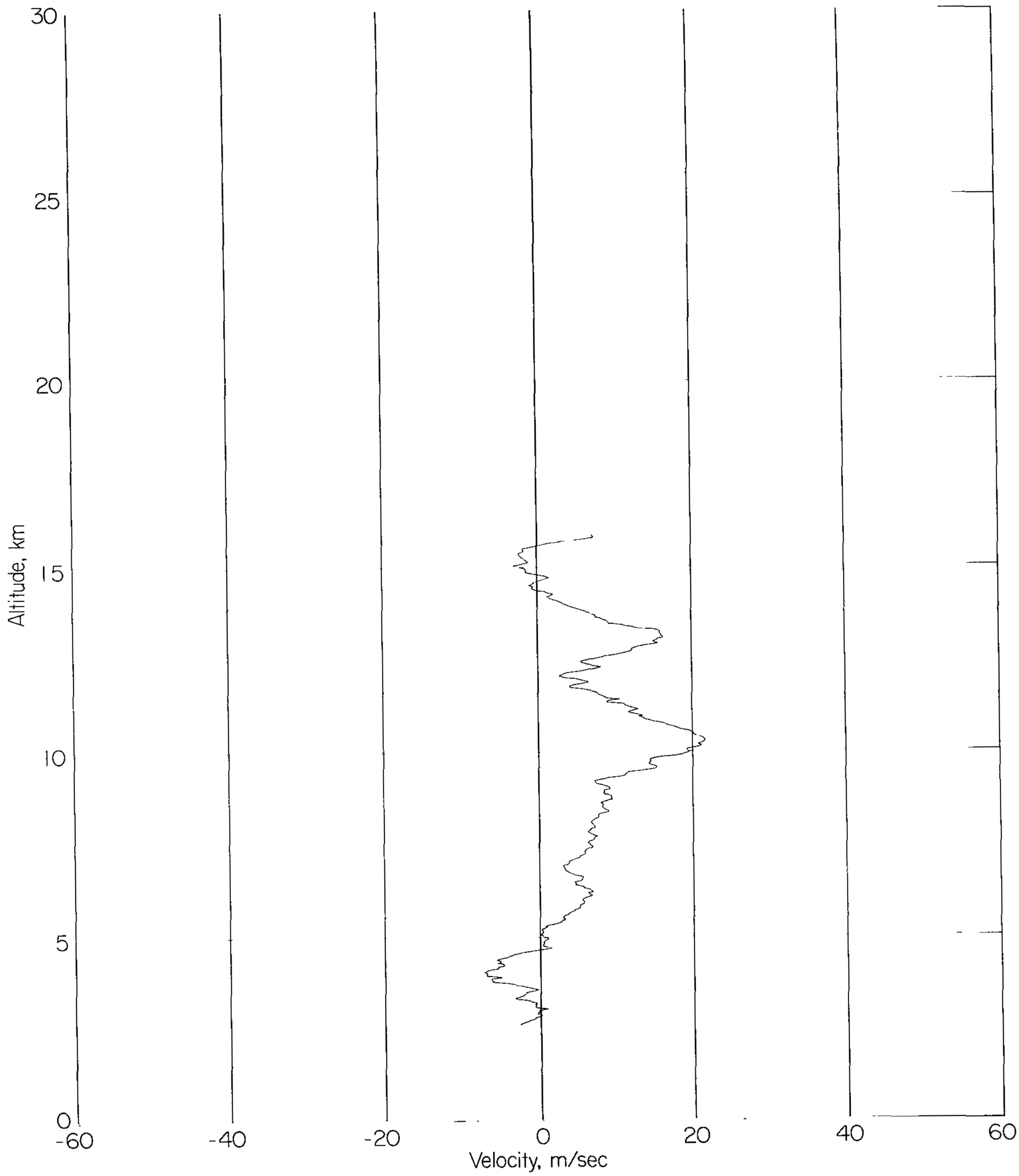
(b) South-to-north velocity component.

Figure 26. - Concluded.



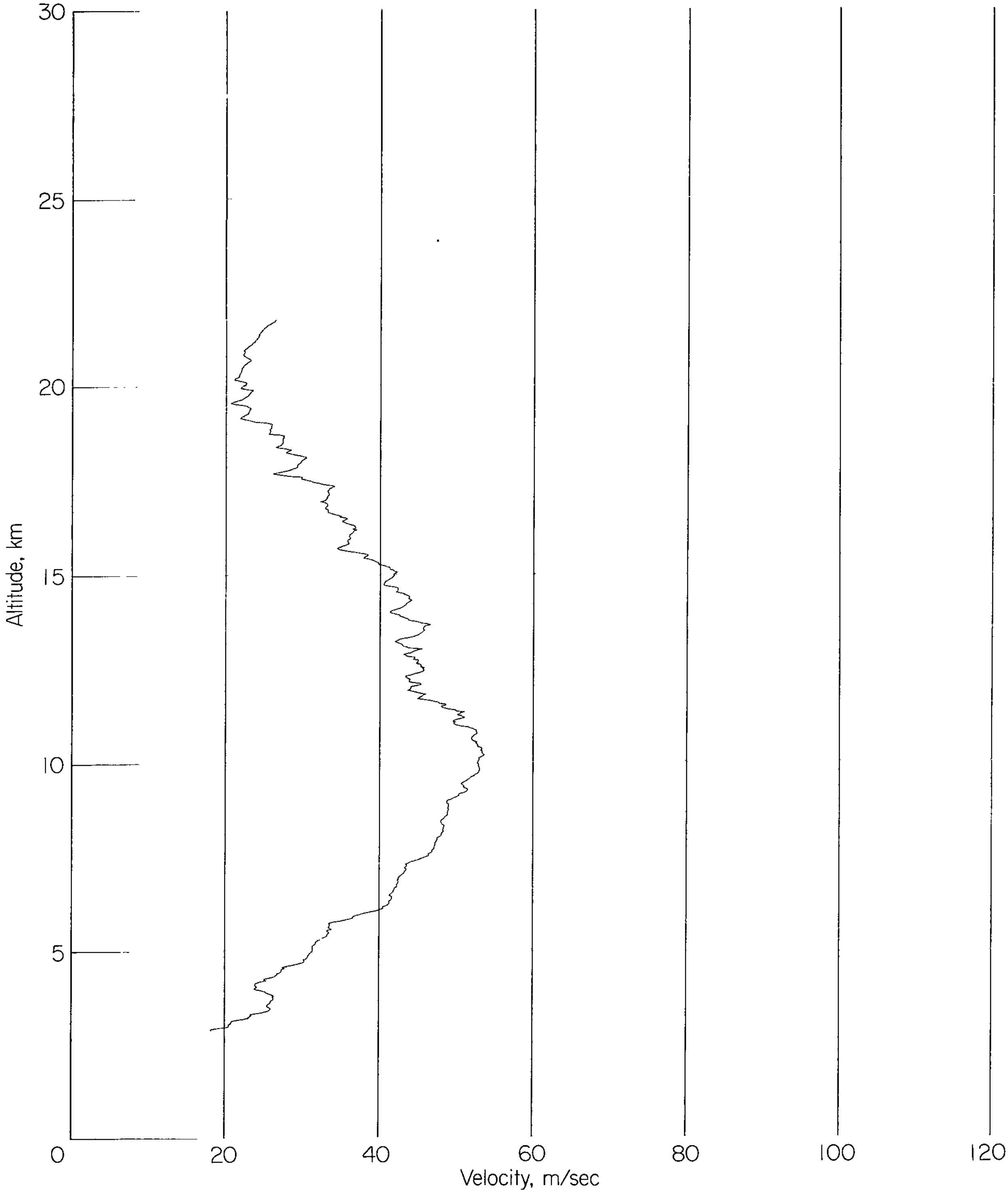
(a) West-to-east velocity component.

Figure 27.- Wind profile of smoke trail 099 obtained January 11, 1966. Time interval, 60 seconds; height interval, 25 meters.



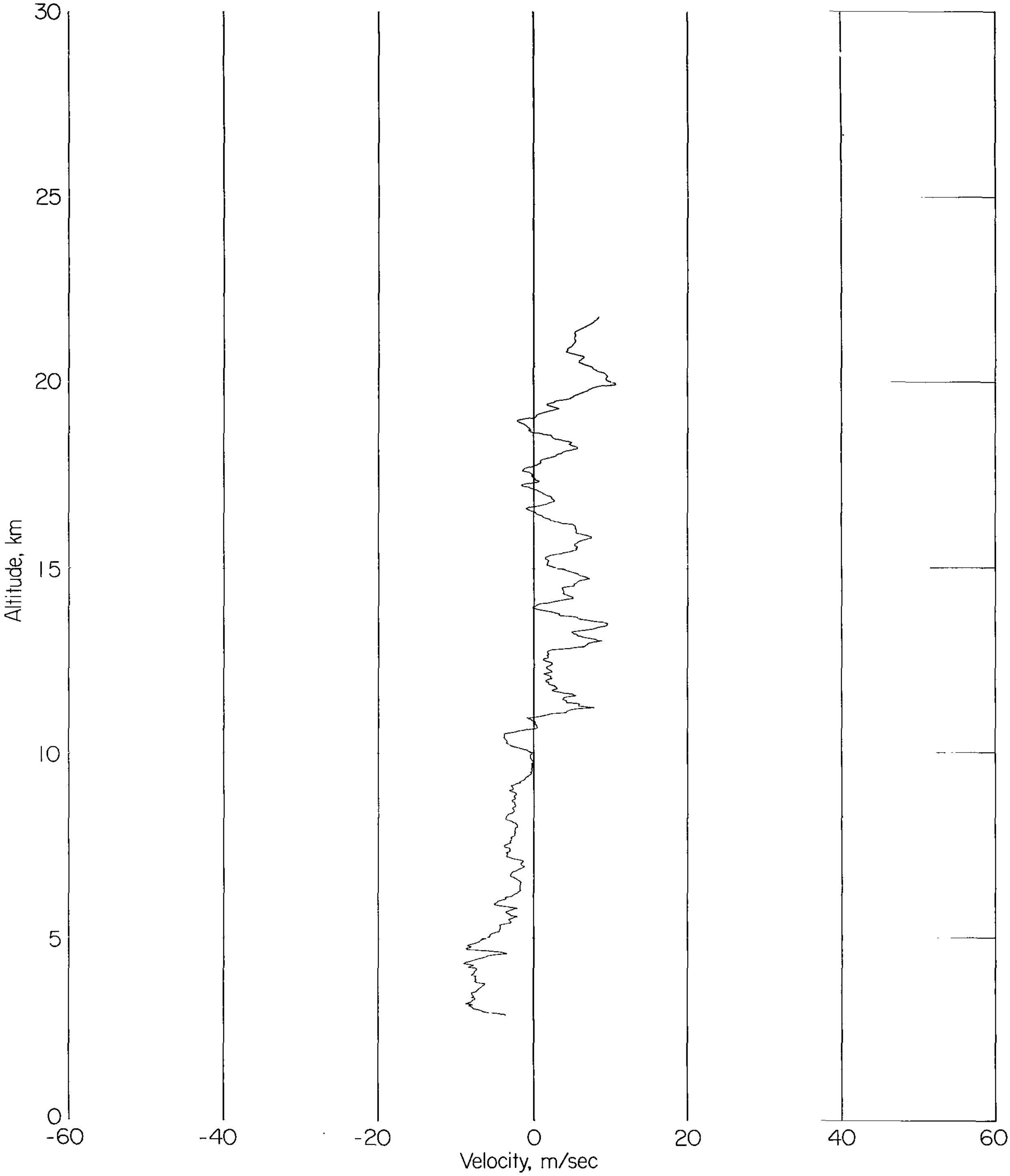
(b) South-to-north velocity component.

Figure 27.- Concluded.



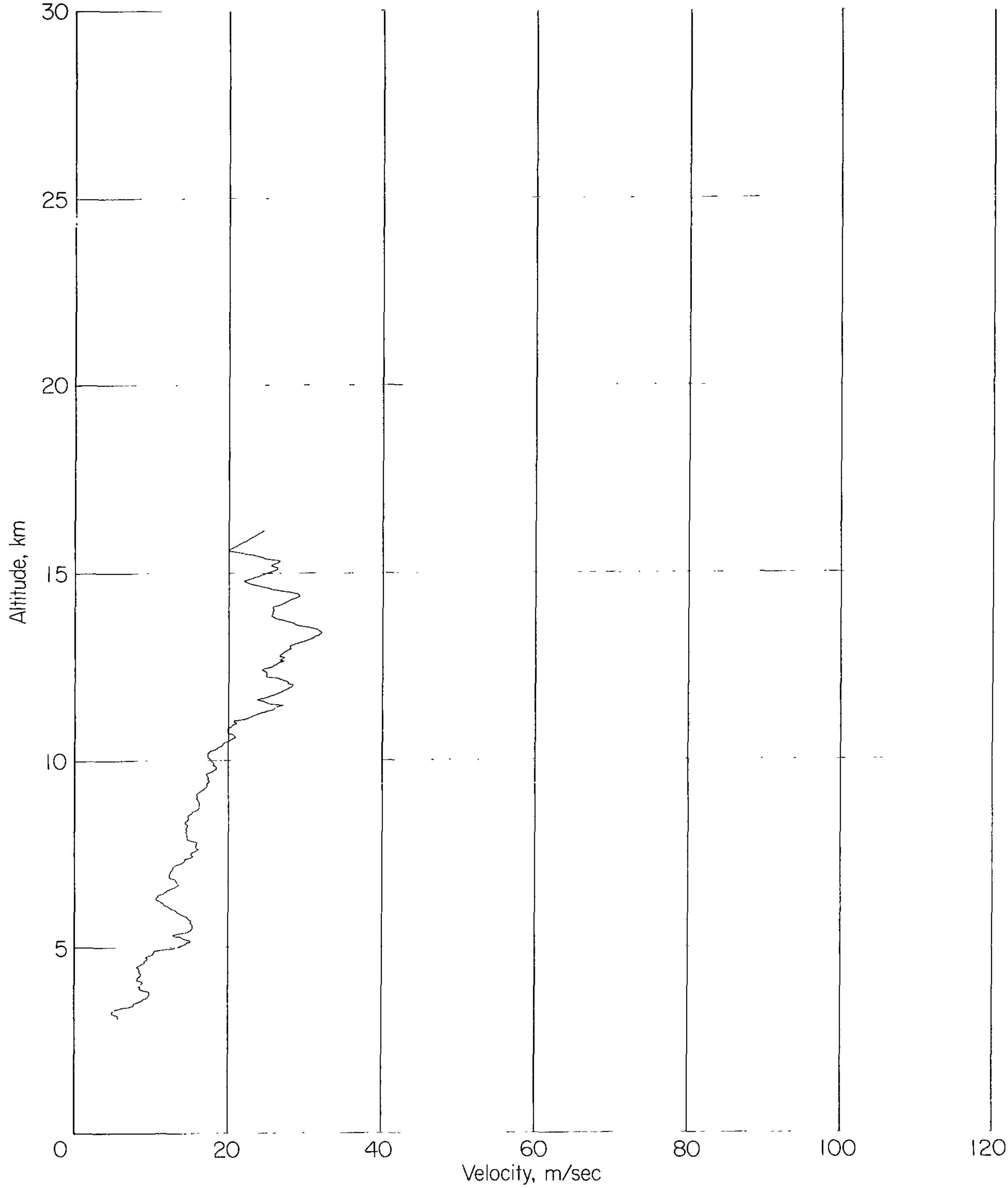
(a) West-to-east velocity component.

Figure 28.- Wind profile of smoke trail 100 obtained February 21, 1966. Time interval, 60 seconds; height interval, 25 meters.



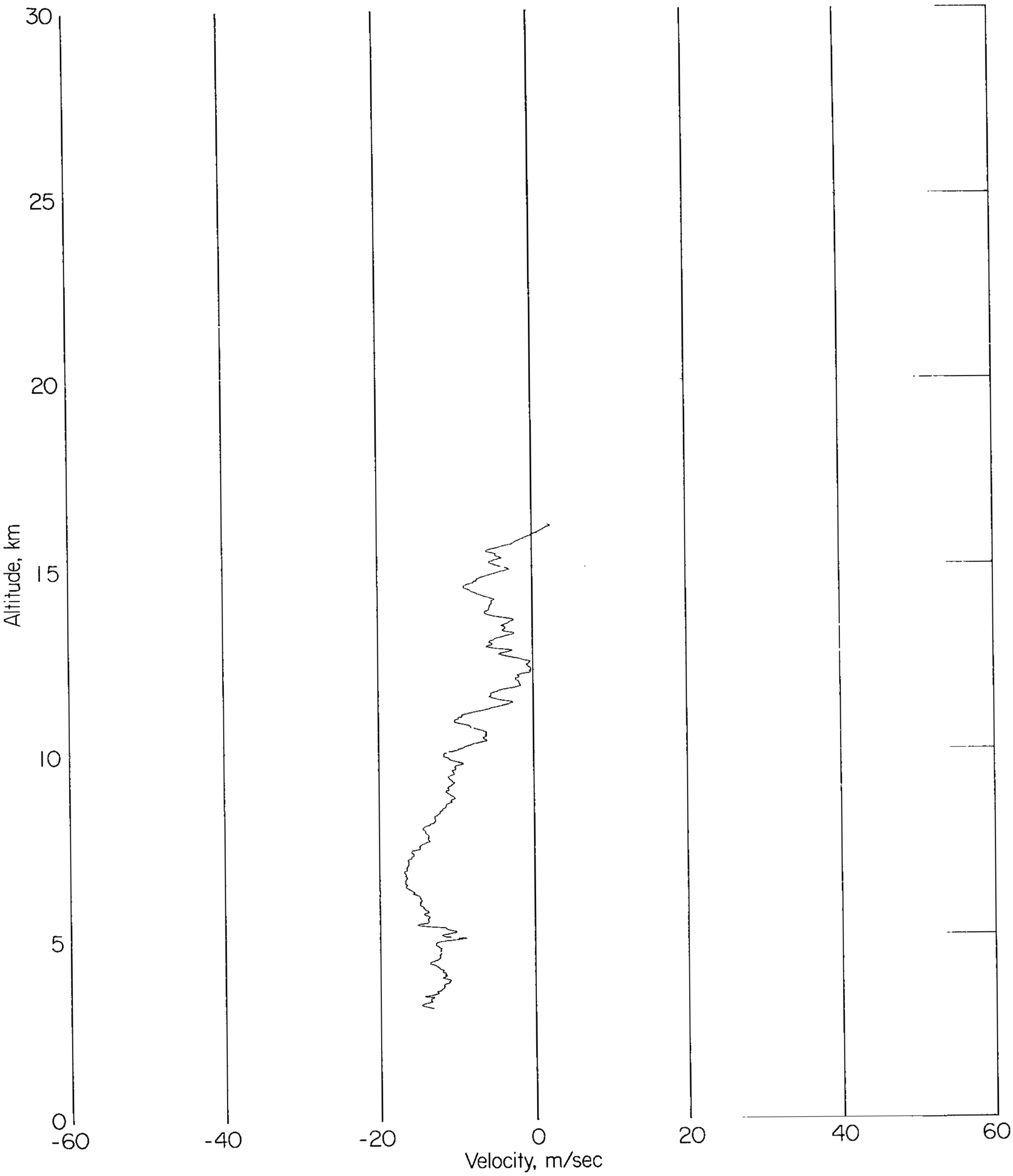
(b) South-to-north velocity component.

Figure 28.- Concluded.



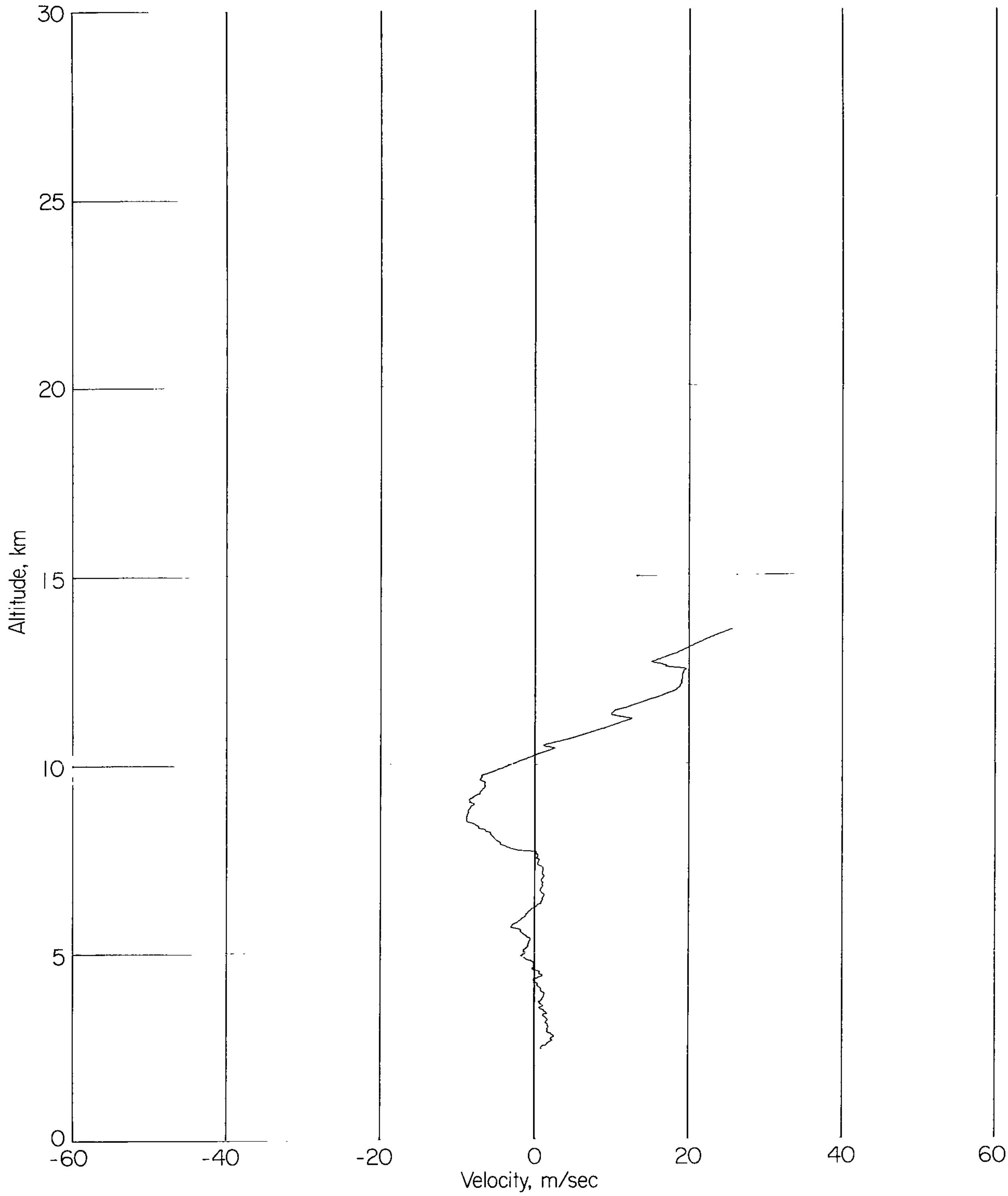
(a) West-to-east velocity component.

Figure 29.- Wind profile of smoke trail 101 obtained March 16, 1966. Time interval, 60 seconds; height interval, 25 meters.



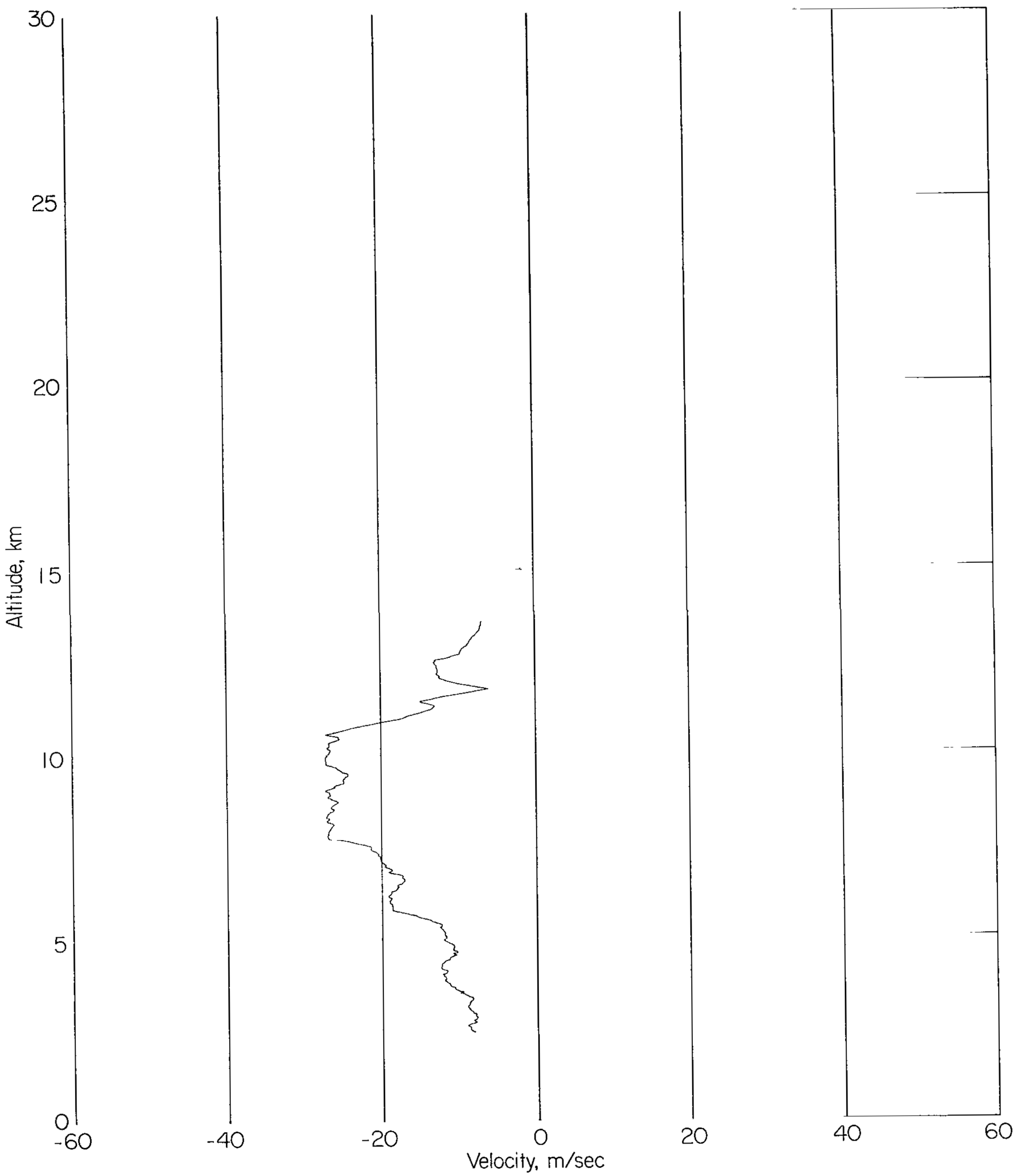
(b) South-to-north velocity component.

Figure 29.- Concluded.



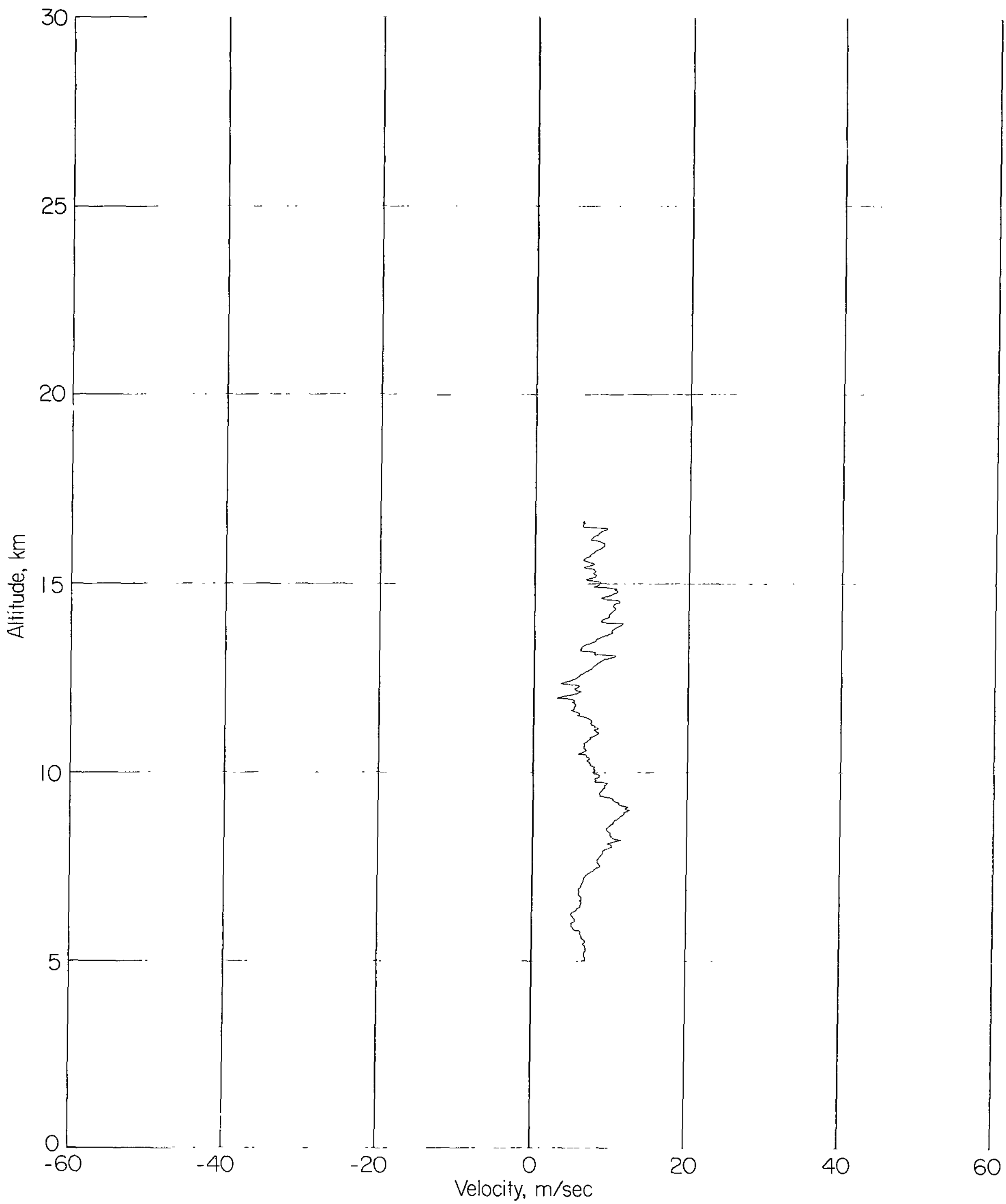
(a) West-to-east velocity component.

Figure 30.- Wind profile of smoke trail 102 obtained March 17, 1966. Time interval, 60 seconds; height interval, 25 meters.



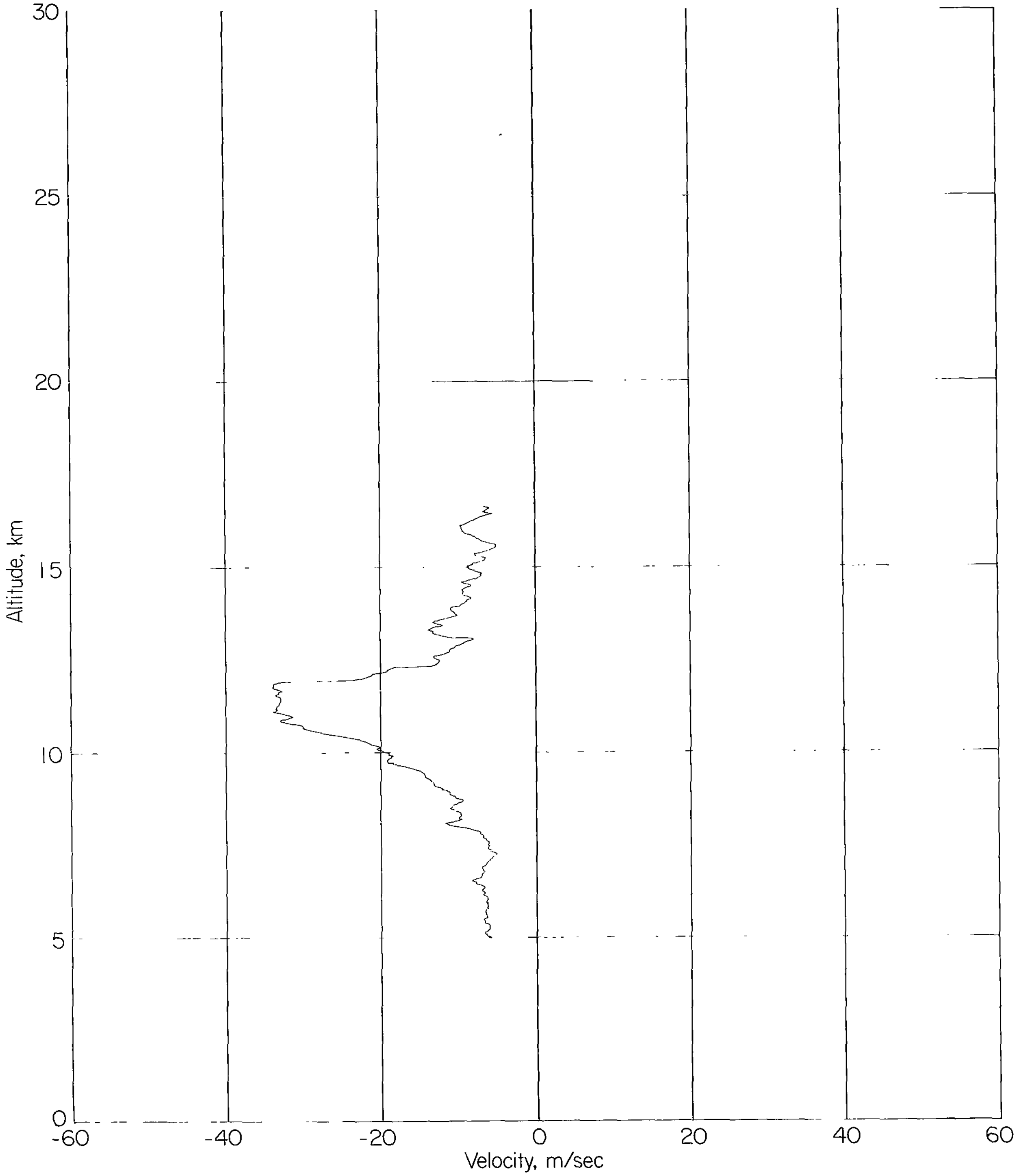
(b) South-to-north velocity component.

Figure 30.- Concluded.



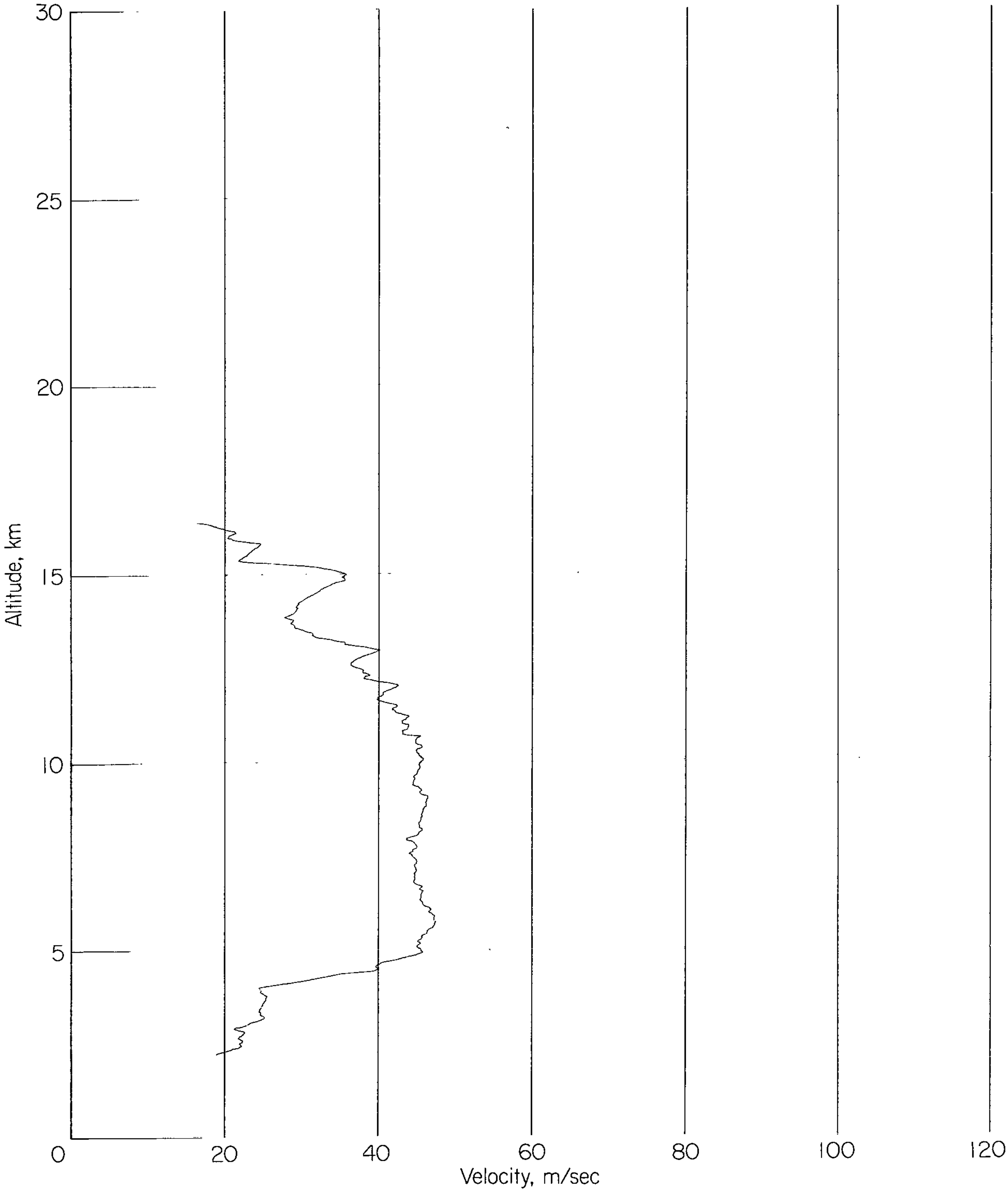
(a) West-to-east velocity component.

Figure 31.- Wind profile of smoke trail 103 obtained July 22, 1966. Time interval, 60 seconds; height interval, 25 meters.



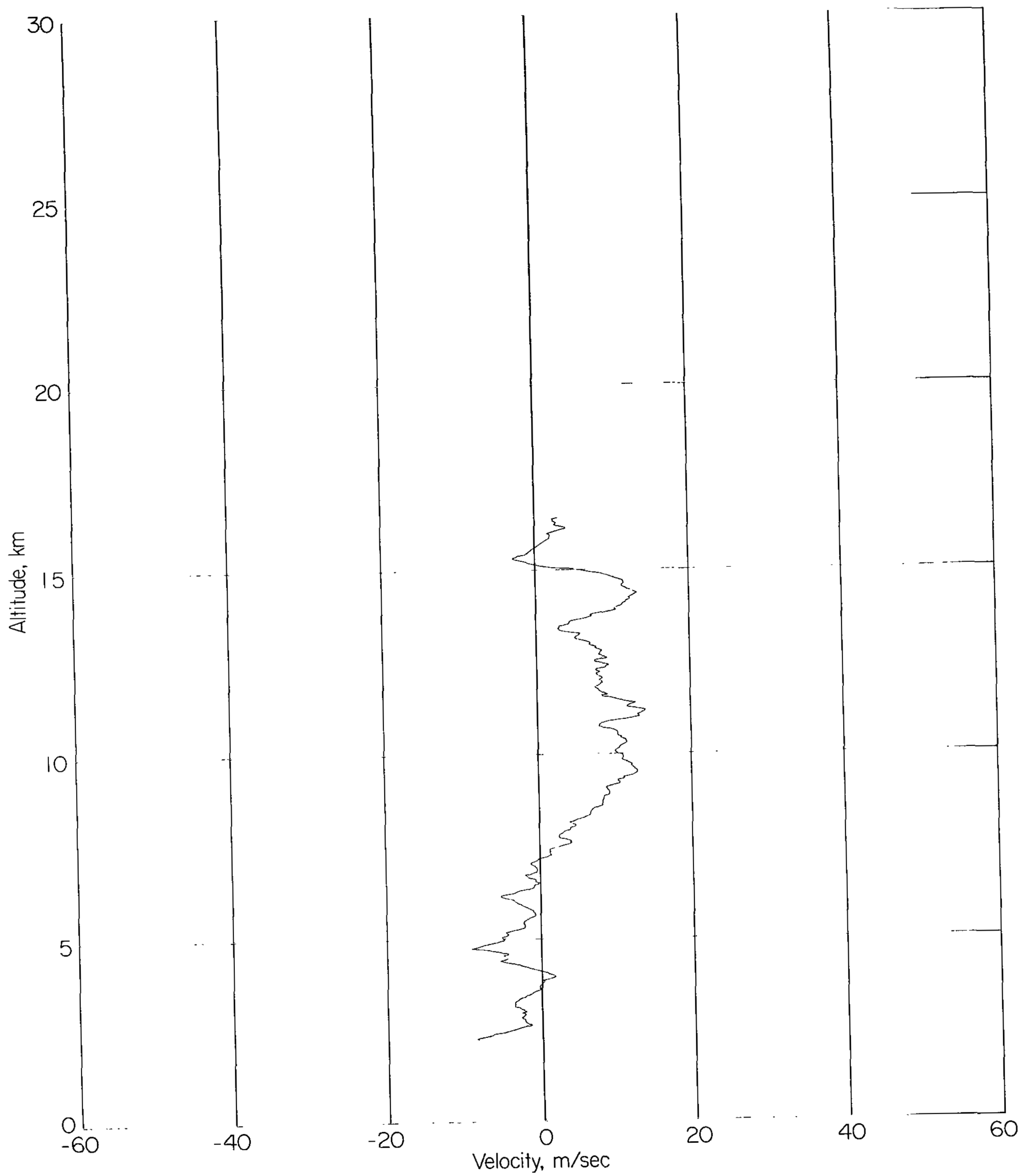
(b) South-to-north velocity component.

Figure 31.- Concluded.



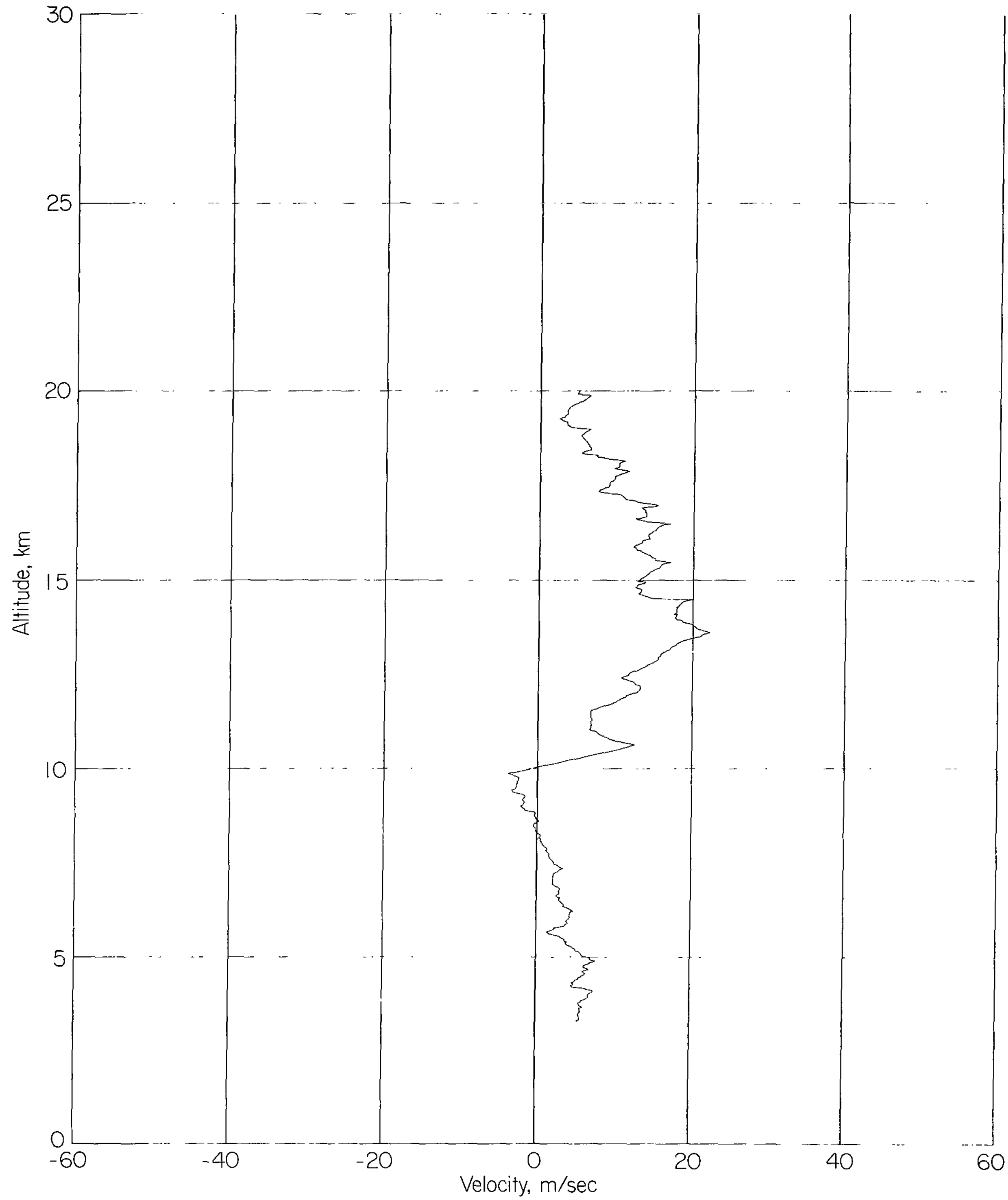
(a) West-to-east velocity component.

Figure 32.- Wind profile of smoke trail 104 obtained September 23, 1966. Time interval, 60 seconds; height interval, 25 meters.



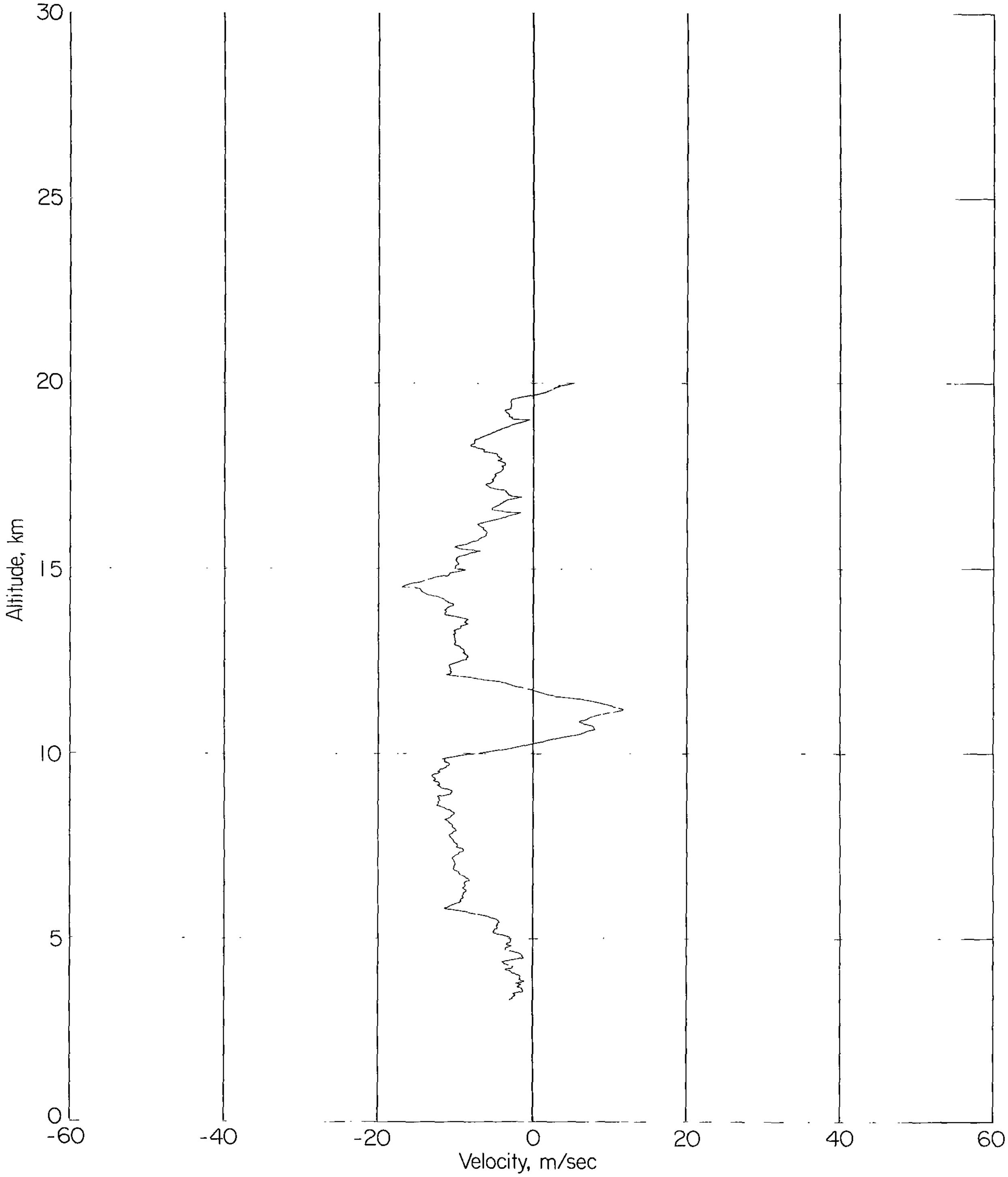
(b) South-to-north velocity component.

Figure 32.- Concluded.



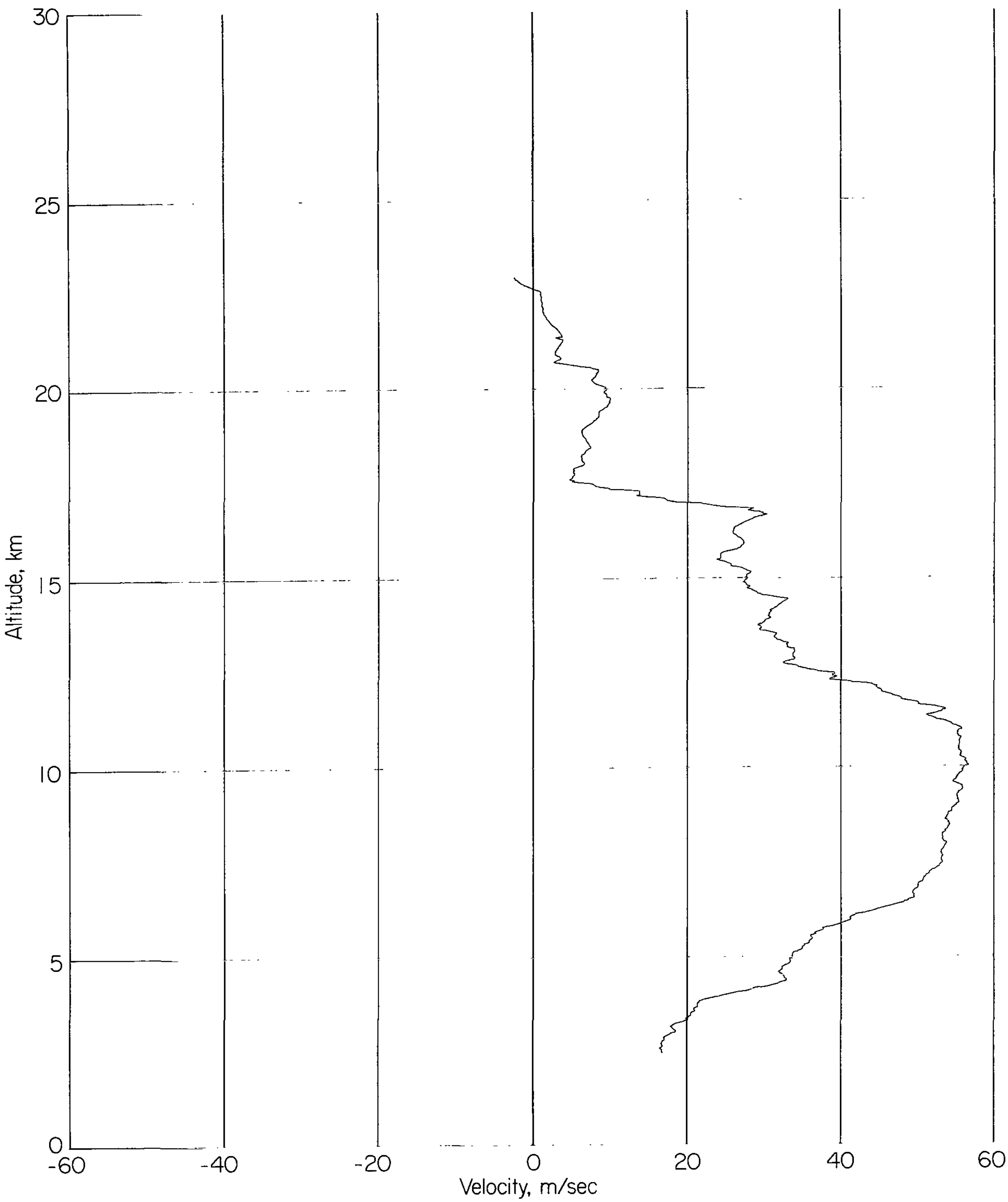
(a) West-to-east velocity component.

Figure 33.- Wind profile of smoke trail 105 obtained October 7, 1966. Time interval, 60 seconds; height interval, 25 meters.



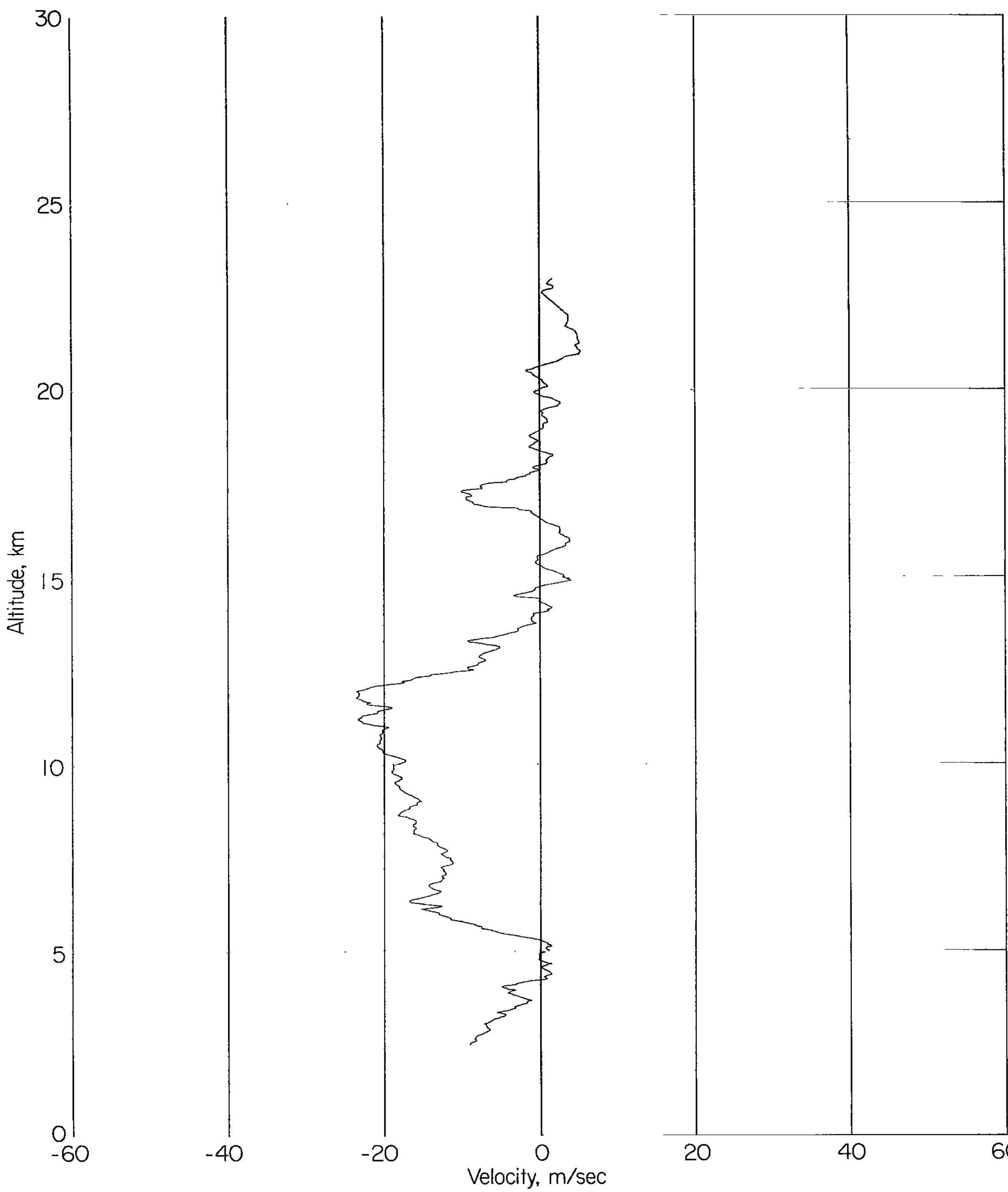
(b) South-to-north velocity component.

Figure 33.- Concluded.



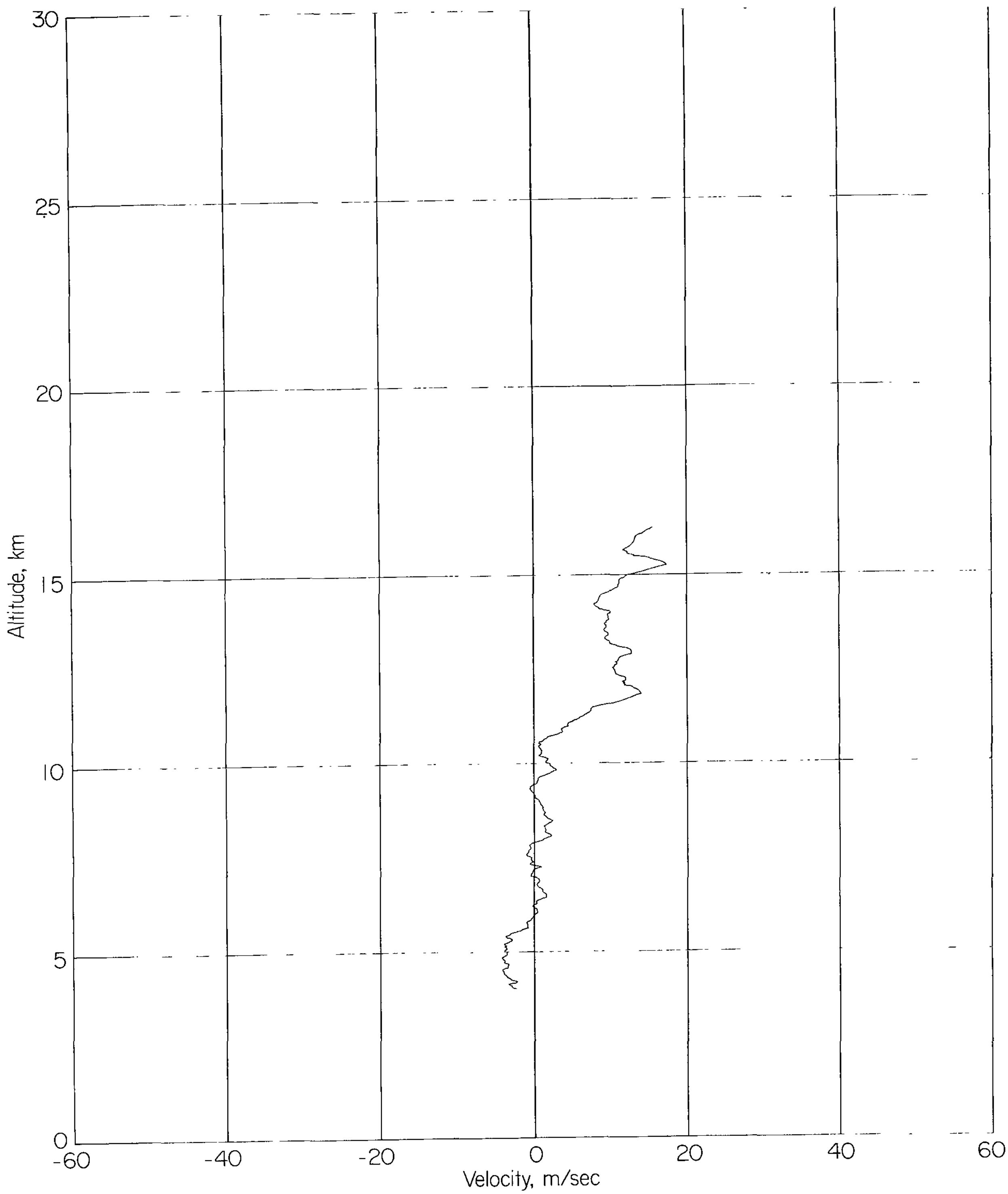
(a) West-to-east velocity component.

Figure 34.- Wind profile of smoke trail 106 obtained October 11, 1966. Time interval, 60 seconds; height interval, 25 meters.



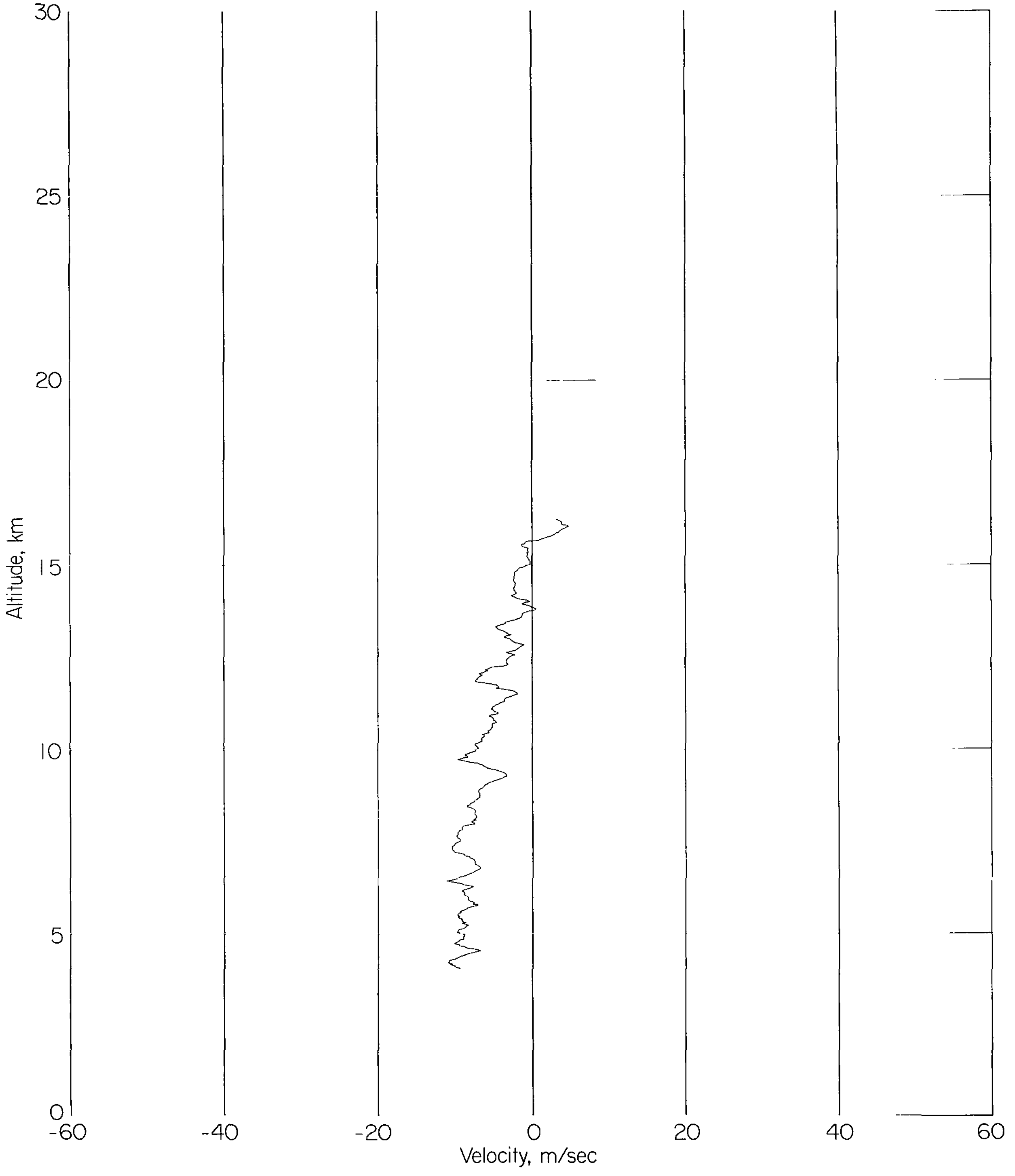
(b) South-to-north velocity component.

Figure 34.- Concluded.



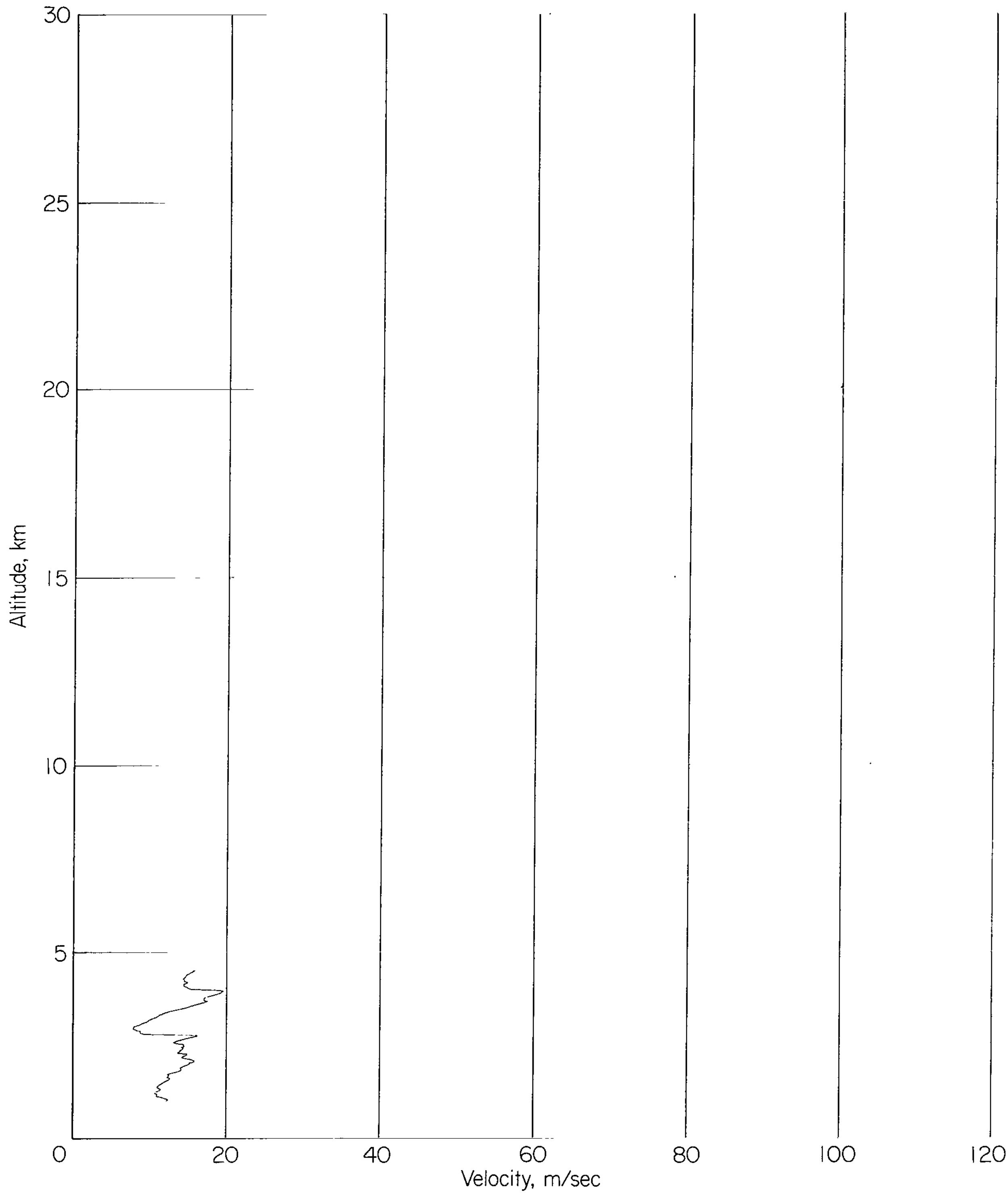
(a) West-to-east velocity component.

Figure 35.- Wind profile of smoke trail 107 obtained October 28, 1966. Time interval, 60 seconds; height interval, 25 meters.



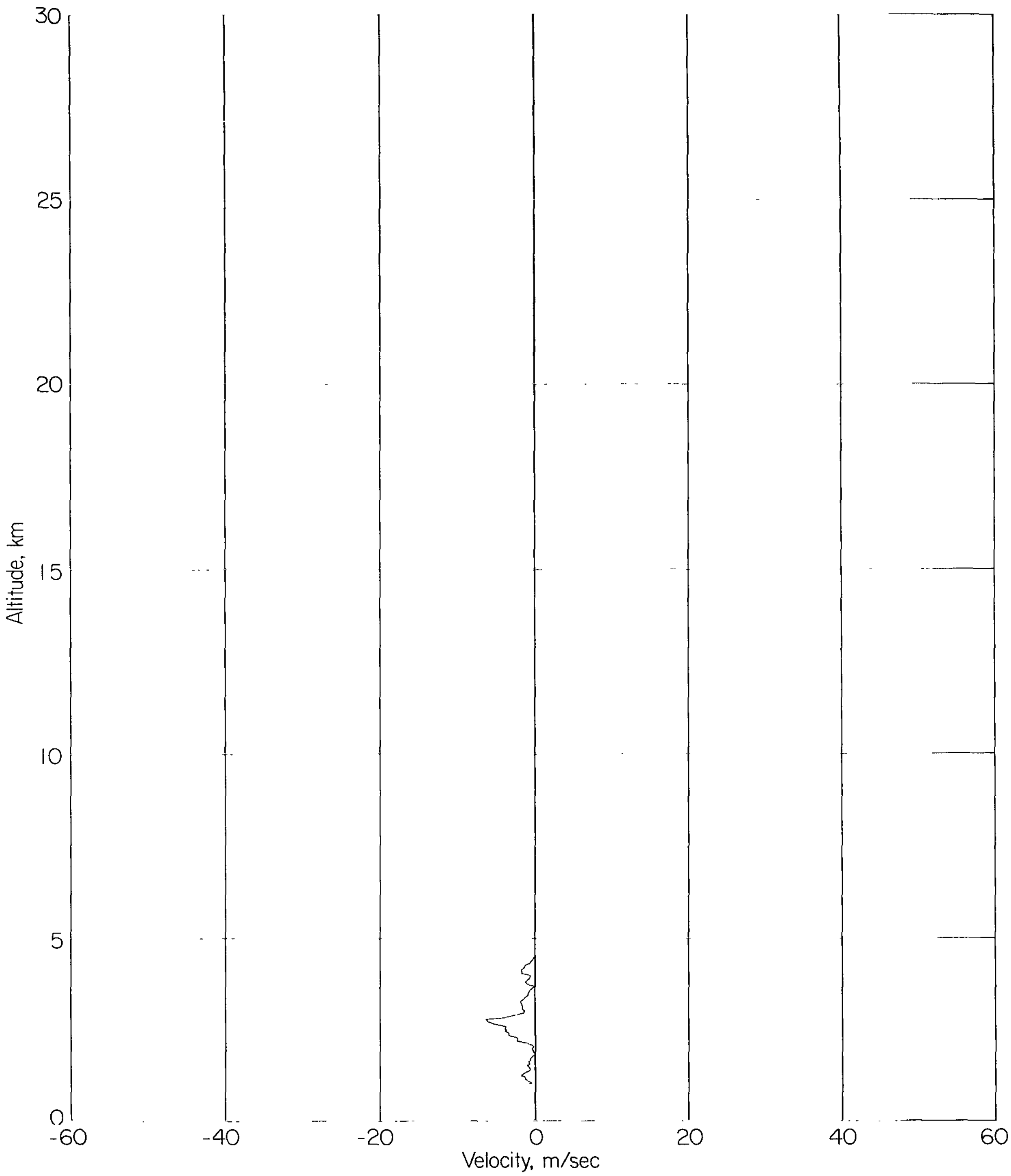
(b) South-to-north velocity component.

Figure 35. - Concluded.



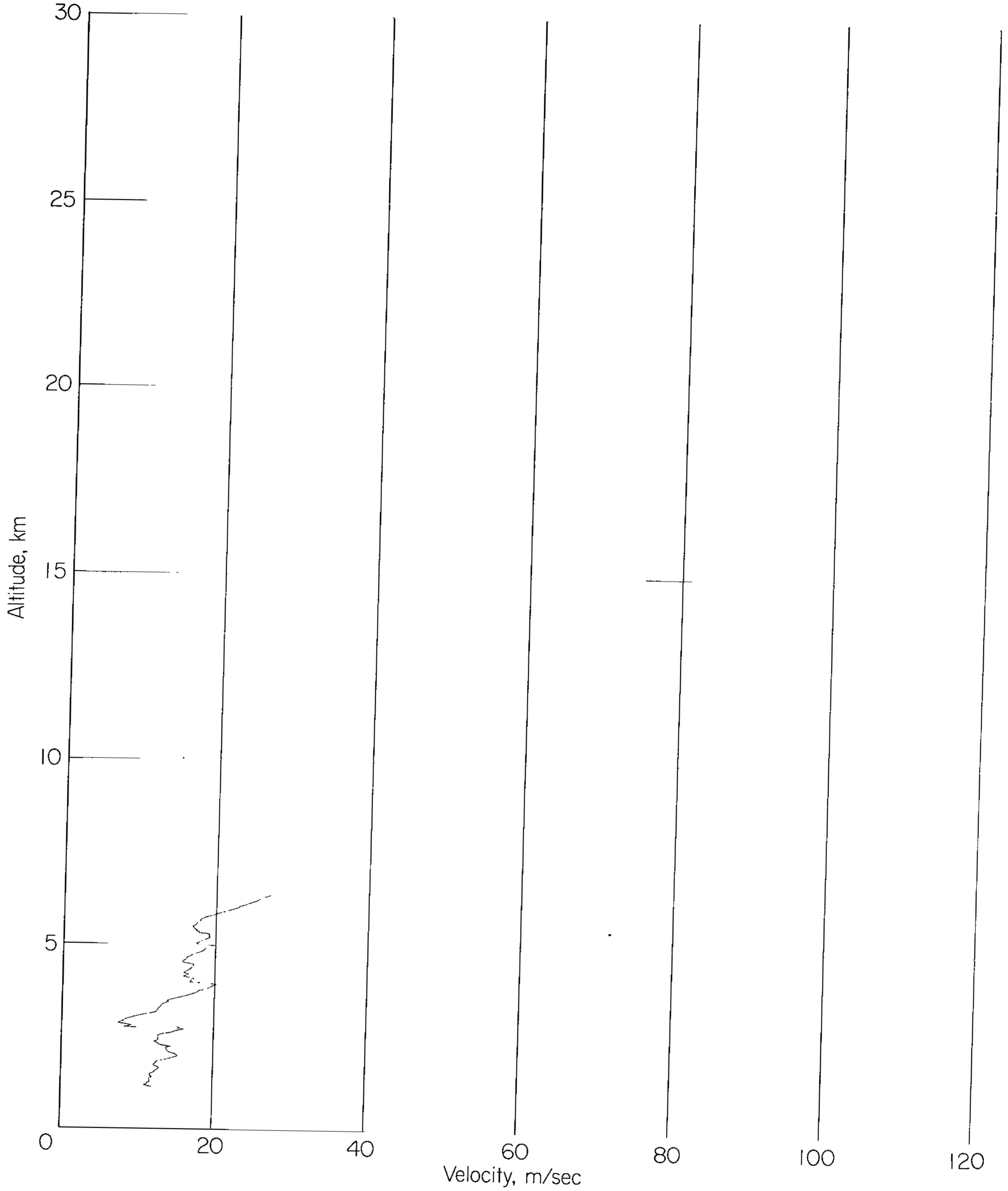
(a) West-to-east velocity component.

Figure 36.- Wind profile of smoke trail 204 obtained October 5, 1967. Time interval, 60 seconds; height interval, 25 meters.



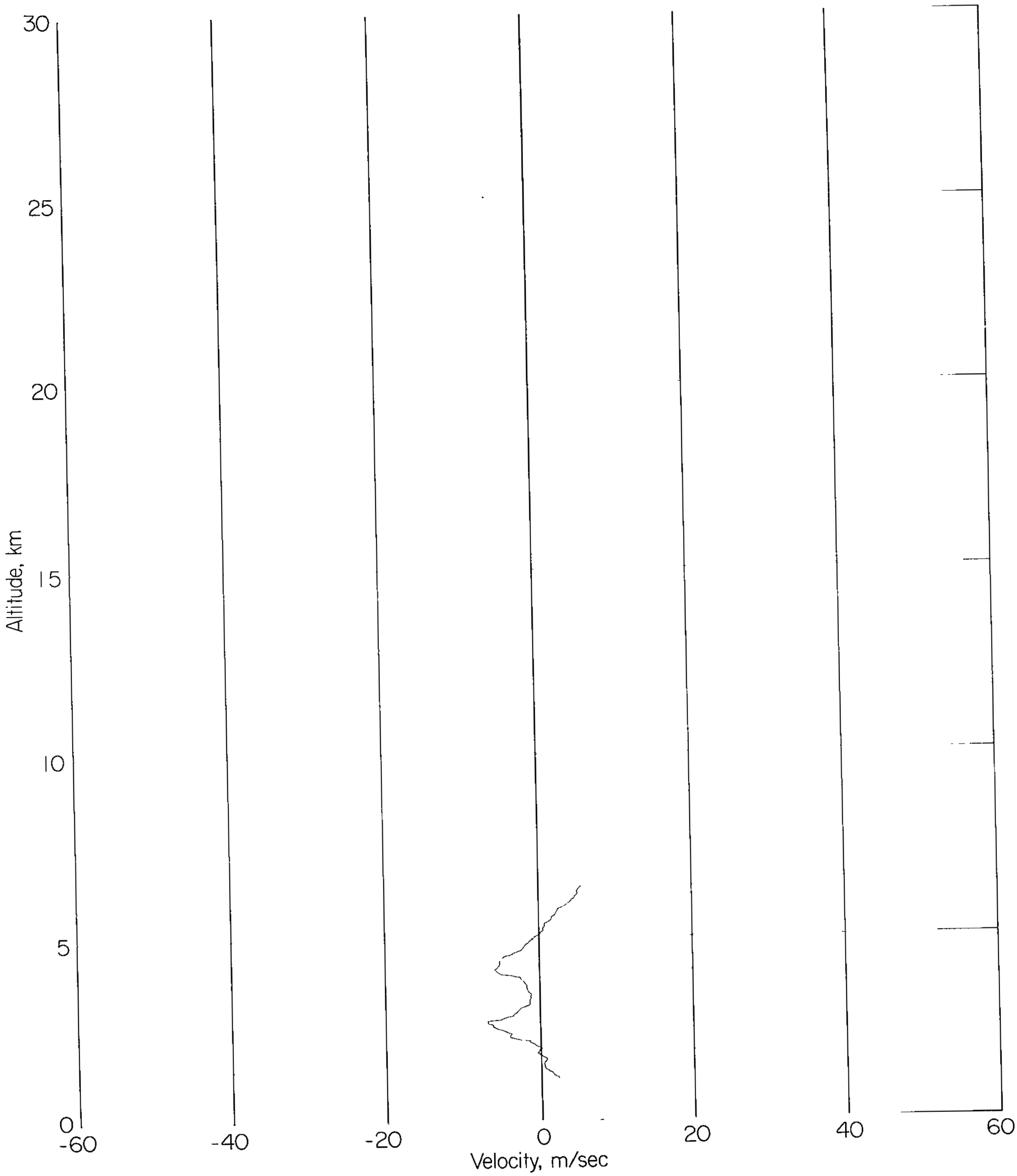
(b) South-to-north velocity component.

Figure 36.- Concluded.



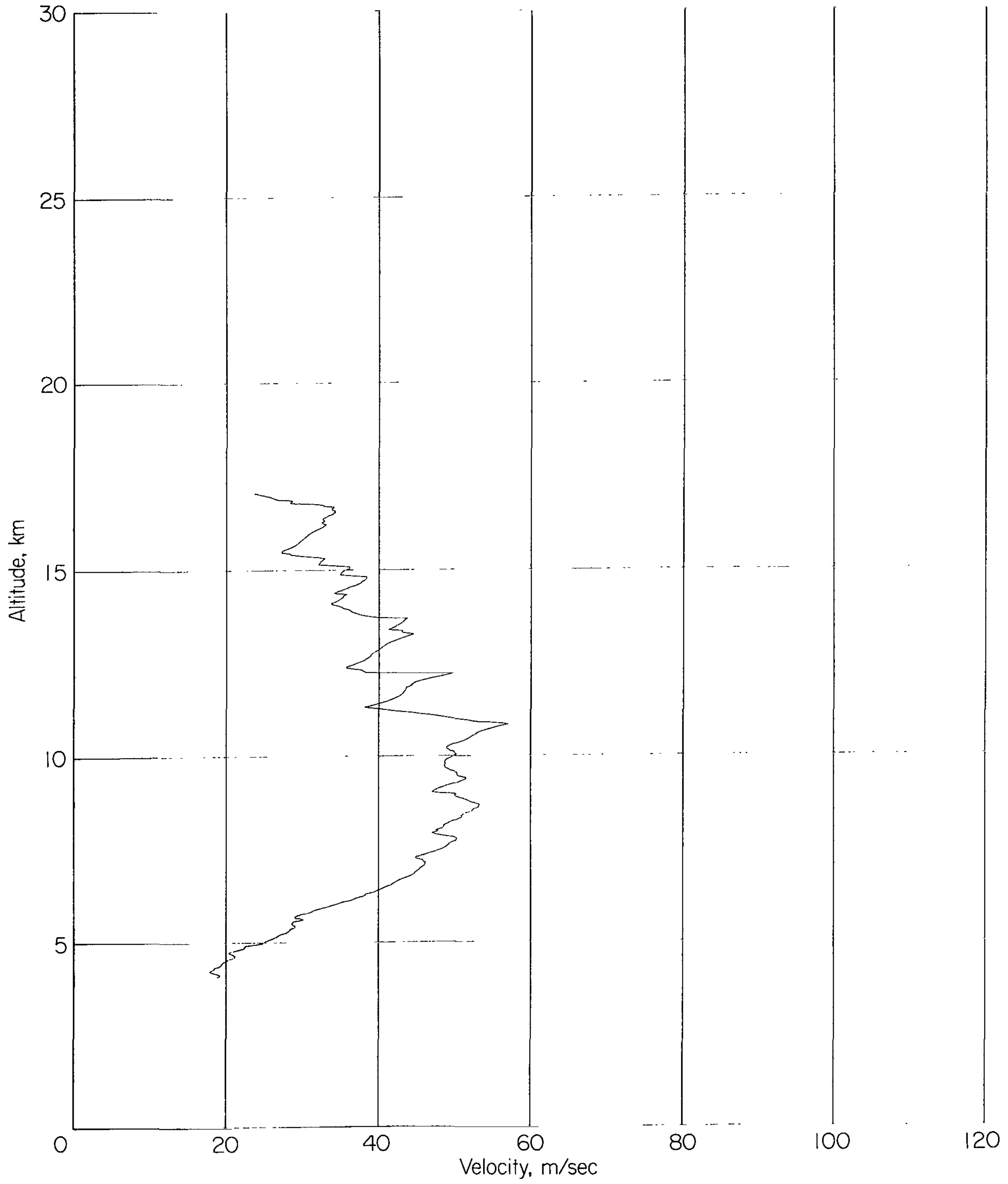
(a) West-to-east velocity component.

Figure 37.- Wind profile of smoke trail 205 obtained October 5, 1967. Time interval, 60 seconds; height interval, 25 meters.



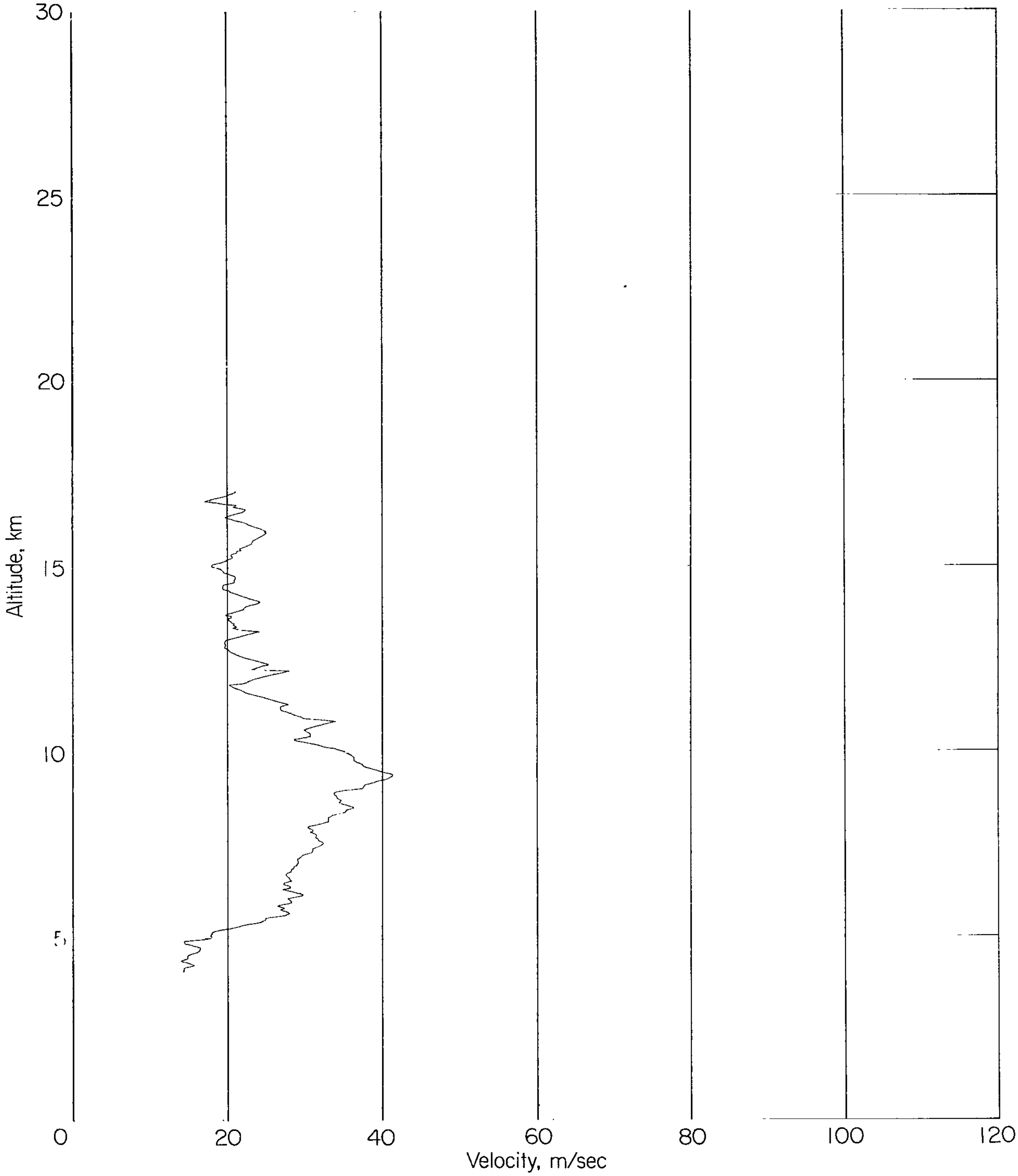
(b) South-to-north velocity component.

Figure 37.- Concluded.



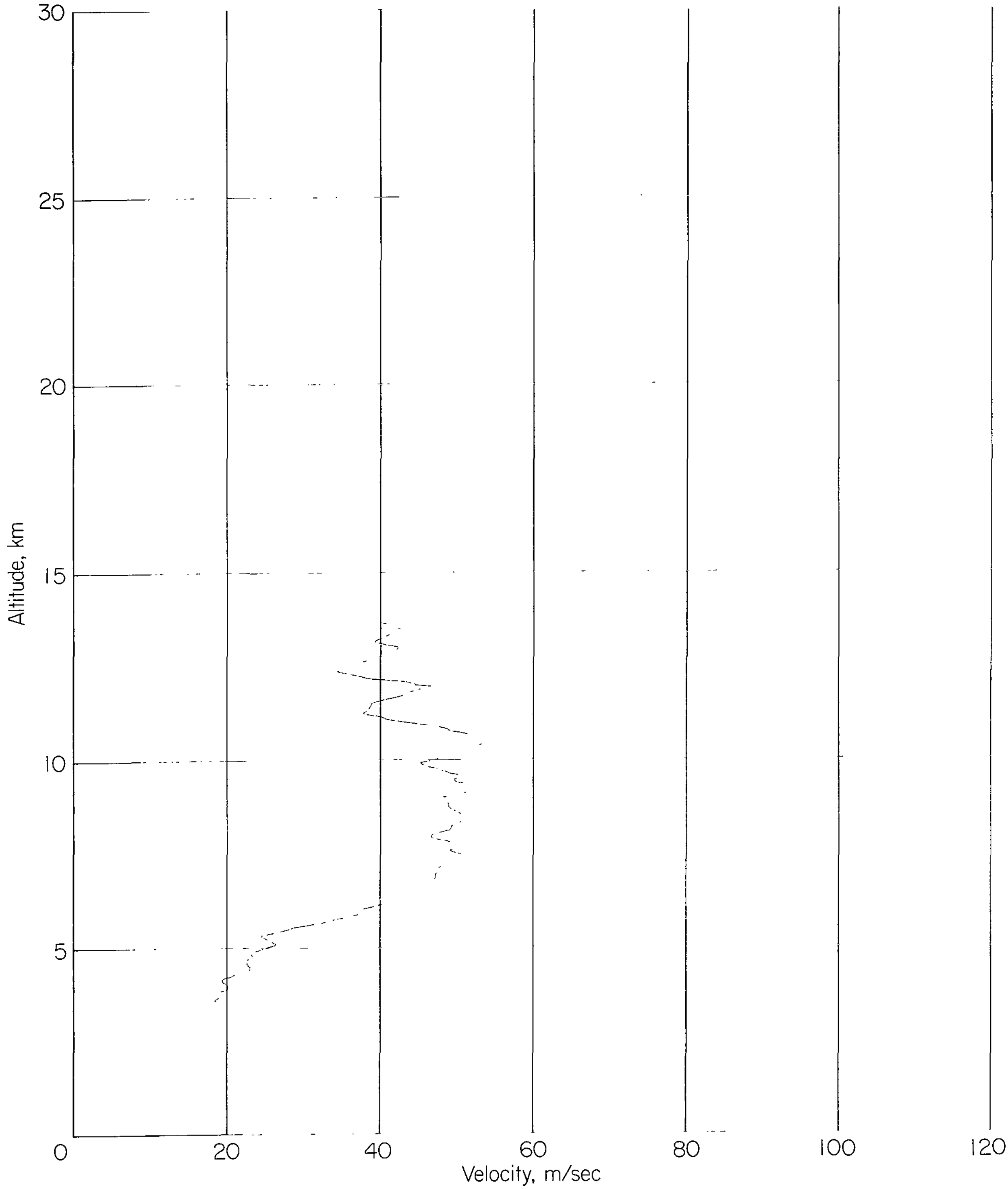
(a) West-to-east velocity component.

Figure 38.- Wind profile of smoke trail 109 obtained March 27, 1969. Time interval, 60 seconds; height interval, 25 meters.



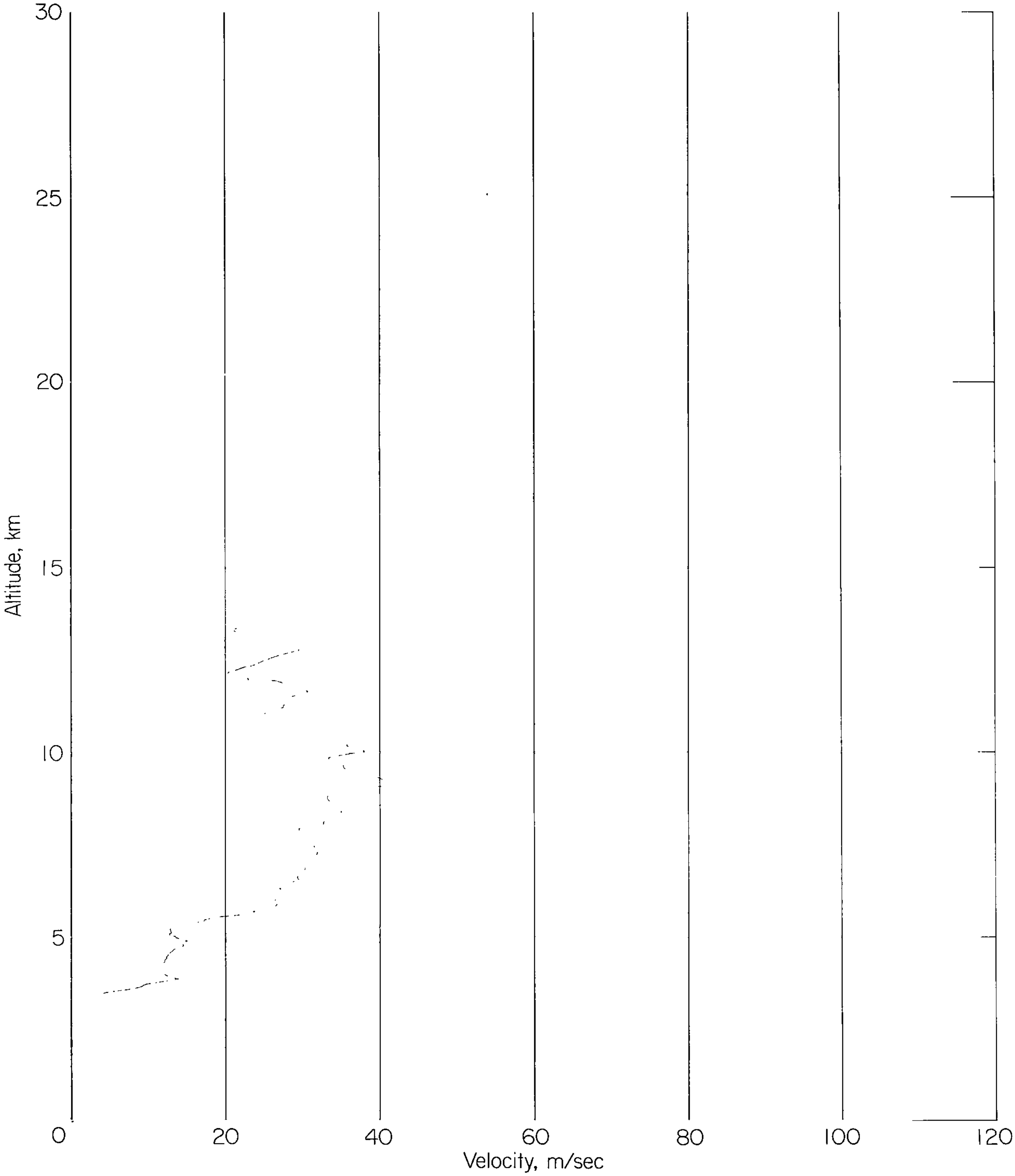
(b) South-to-north velocity component.

Figure 38. - Concluded.



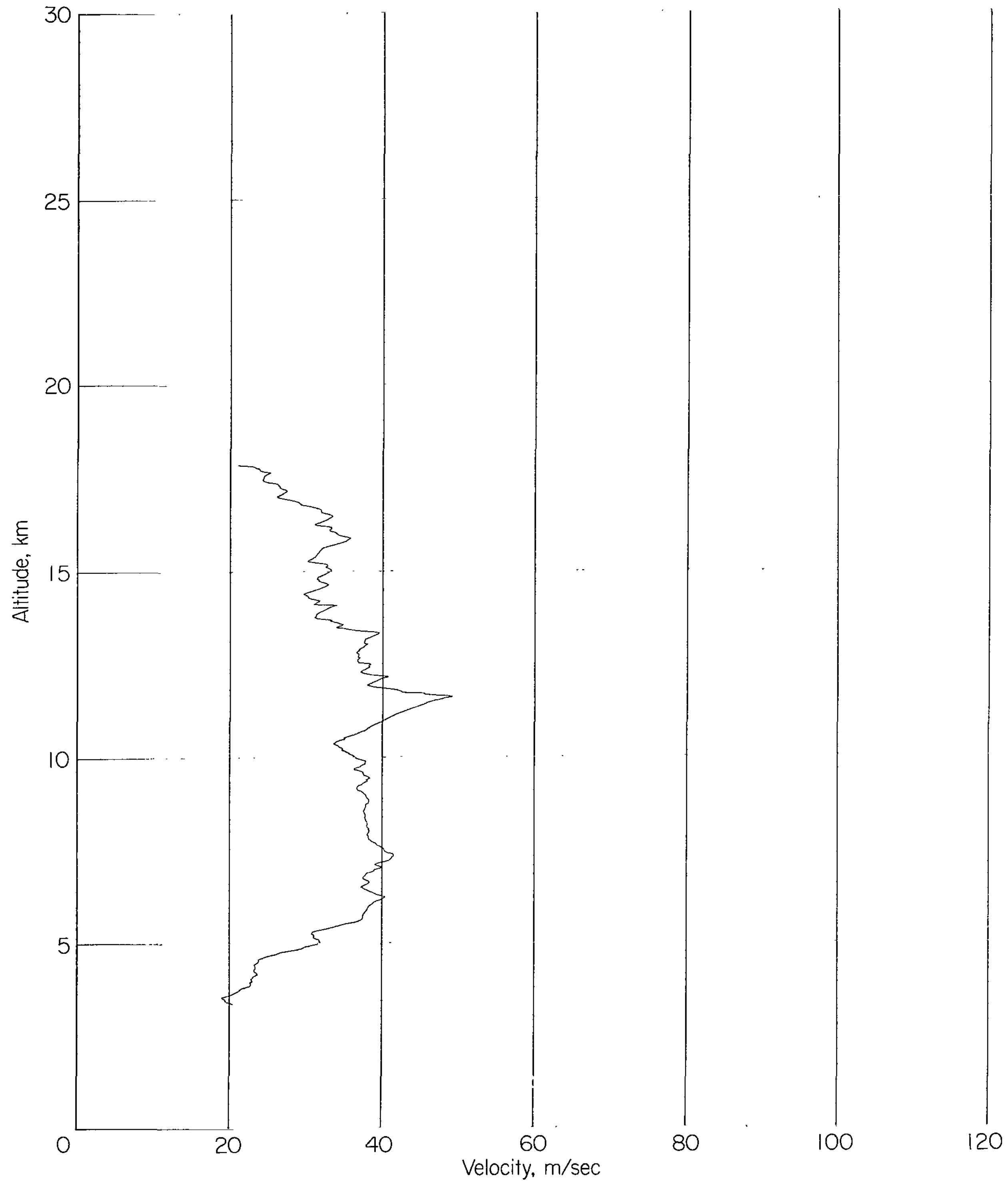
(a) West-to-east velocity component.

Figure 39.- Wind profile of smoke trail 110 obtained March 27, 1969. Time interval, 60 seconds; height interval, 25 meters.



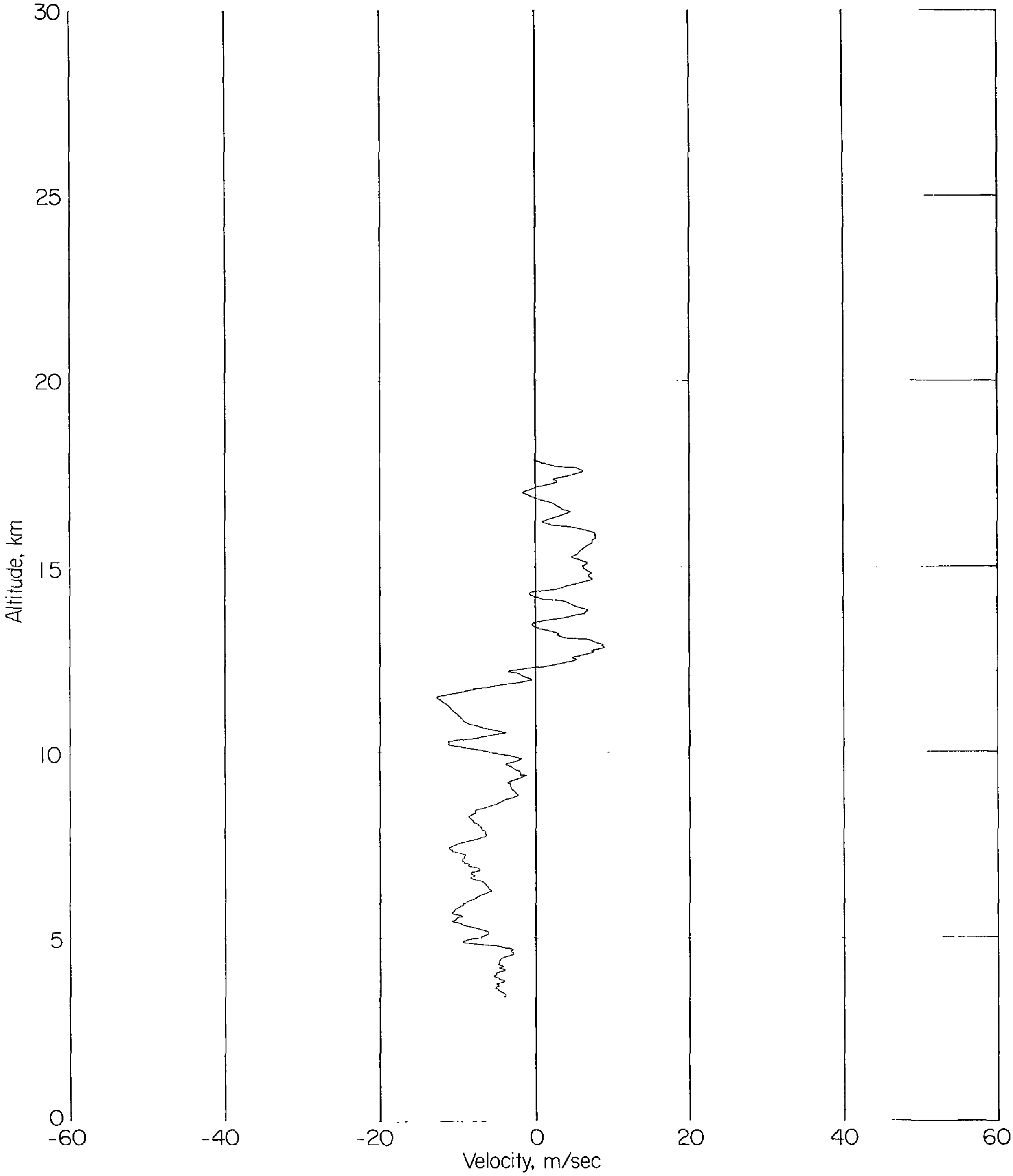
(b) South-to-north velocity component.

Figure 39.- Concluded.



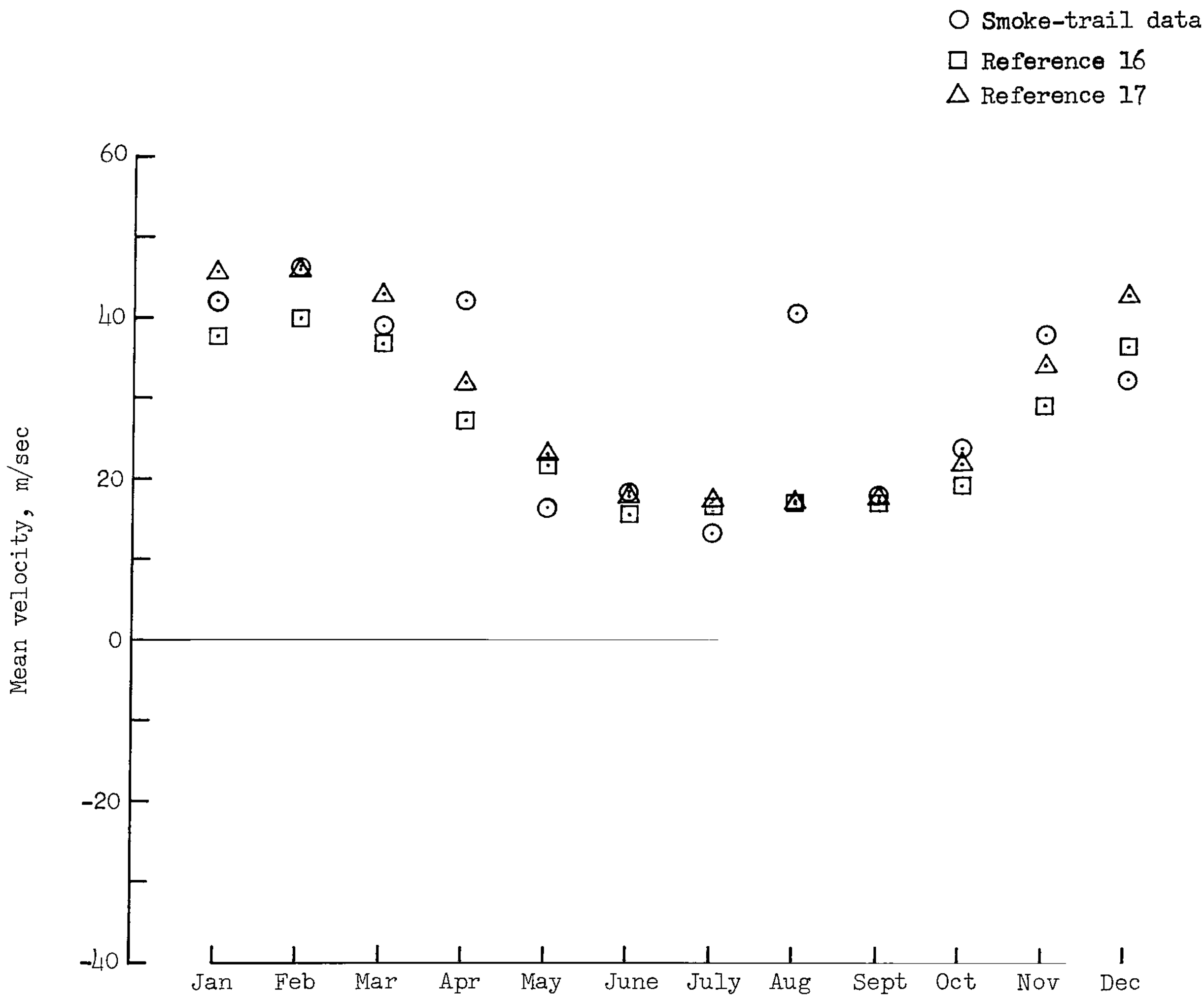
(a) West-to-east velocity component.

Figure 40.- Wind profile of smoke trail 111 obtained May 13, 1969. Time interval, 60 seconds; height interval, 25 meters.



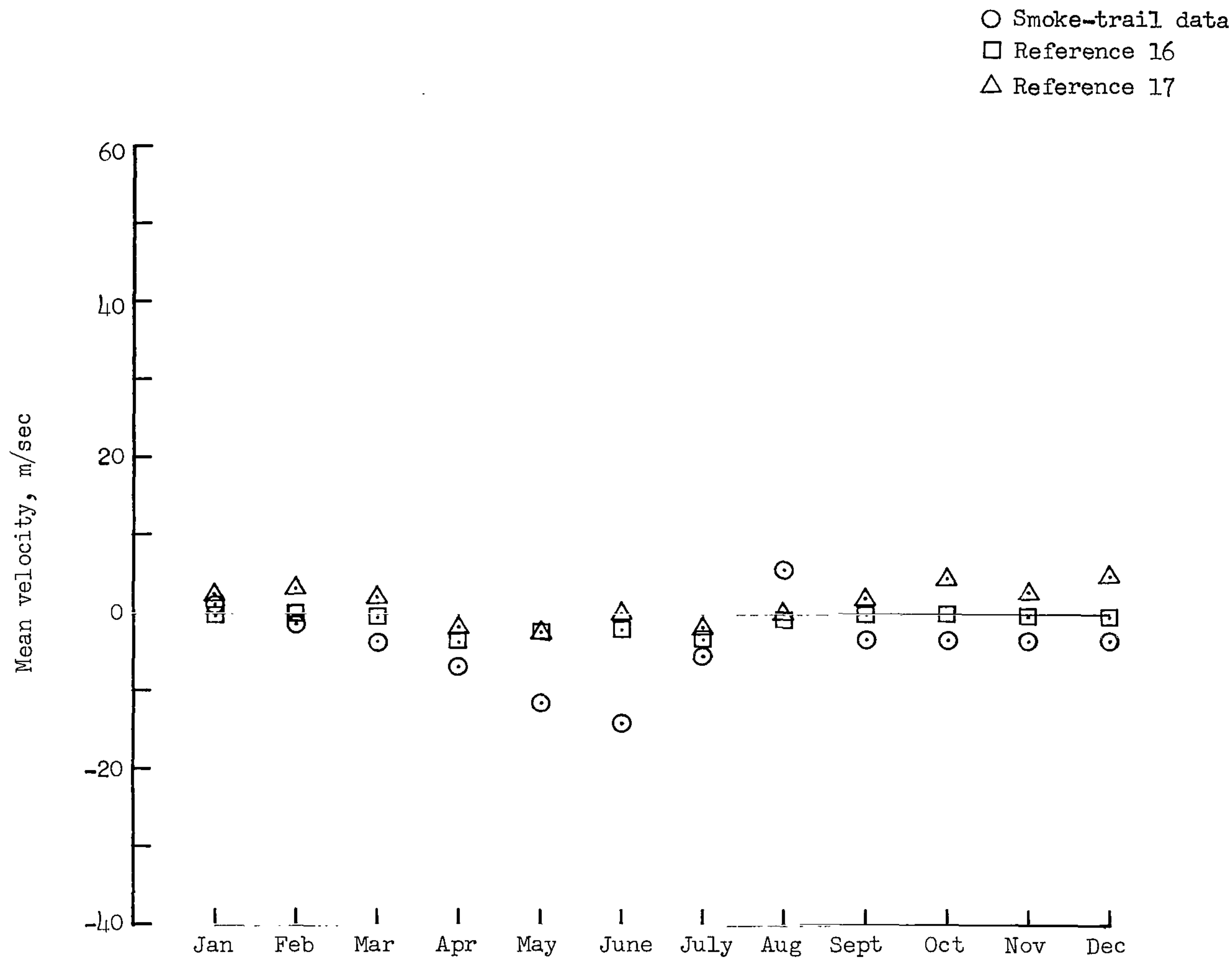
(b) South-to-north velocity component.

Figure 40.- Concluded.



(a) West-to-east velocity component.

Figure 41.- Mean wind velocity measured at an altitude of 11 km at Wallops Island.



(b) South-to-north velocity component.

Figure 41.- Concluded.

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