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WIND VELOCITY PROFILES MEASURED BY THE SMOKE-TRAIL METHOD AT THE EASTERN TEST RANGE, 1963

by Robert W. Miller, James C. Manning, and Robert M. Henry

Langley Research Center
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SUMMARY

Fifty-four detailed wind velocity profiles measured by the smoke-trail technique at the Eastern Test Range during 1963 are presented. The altitude range covered is from approximately 2 to 22 kilometers and the maximum velocity measured exceeds the 99-percent highest value. The persistence of the wind profile shape, under some conditions, for periods up to 2 hours is demonstrated and illustrations are given of the accuracy of the smoke-trail method.

INTRODUCTION

The investigation of the dynamic response of vertically launched missile and space systems has indicated the necessity for considering the small-scale variations of the wind velocity with altitude. It is, therefore, essential that the wind measurements define these small-scale variations in wind velocities at the various missile ranges. The smoke-trail wind measurement technique described in reference 1 was developed and used by the NASA Langley Research Center to make these measurements.

The preliminary testing of the smoke-trail technique was begun at the NASA Wallops Station, Wallops Island, Va., in 1959 and fairly comprehensive data collection programs were begun in 1962 at both the Wallops Station and the Eastern Test Range. Data collected at the Wallops Station through 1964 were published in references 2 and 3. Data collected at the Eastern Test Range during 1962 were presented in reference 4. It is the purpose of this report to publish the smoke-trail measurements made at the Eastern Test Range during 1963.

MEASUREMENT TECHNIQUE

The basic technique for obtaining wind velocity profiles by the smoke-trail method consists of photographing a visible trail formed by releasing a suitable chemical from a rocket during its flight. The motion of the trail is determined from measurements of its

image on successive pairs of simultaneous photographs from any two camera sites. The fundamental procedures for reducing the data are described in reference 1 and later modifications are described in references 2 and 4.

The photographs at the Eastern Test Range were taken with four cameras. These were located at three camera sites; thus five camera pairs were available in case of camera failure or clouds at any site. The camera sites were at False Cape, Williams Point (2 cameras), and Patrick Air Force Base, which were, respectively, 15 kilometers NNW, 23 kilometers W, and 26 kilometers SSW of the launch point. Further details of the camera network are given in reference 4.

Figure 1 shows three photographs taken simultaneously from the three camera sites. The apparent tilt of objects in the photographs is due to camera tilt and the wide angle lens used and is taken into account in the data reduction.

The data in this report are mainly derived from smoke trails produced during the coasting portion of flights of Nike smoke vehicles. These vehicles, described in reference 5, are fin-stabilized Nike booster rocket motors (M5) with smoke-producing nose cones. The smoke-producing chemical used in most of the firings was titanium tetrachloride (FM), reference 6. One profile was also included which was derived from photographing the exhaust trail of a Saturn vehicle.

Discussions of the technique of data preparation are given in references 2 and 4, and the machine processing of the data is discussed in an appendix of these references. Briefly, the process consists of (1) the selection of simultaneous photographs taken at successive 30-second intervals, (2) redundant reading and plotting of smoke-trail images for minimization of errors, and (3) computation and final plotting of velocity profiles.

RESULTS AND DISCUSSION

Plots of west-to-east and south-to-north components of wind velocity as a function of altitude are shown in figures 2 to 55. Values of wind velocity are computed for every 25-meter altitude increment and connected with straight-line segments; this gives the appearance of a continuous curve. Table I shows the figure number, Langley smoke-trail identification number, date and time of launching, altitude range covered, and the maximum resultant velocity, its altitude of occurrence, and the direction from which the wind is blowing.

The data shown in the 54 profiles presented herein plus wind speed and direction and wind-shear values are available on request from the NASA Langley Research Center

on punched cards or in tabular form.[1] The format of the data and the units used are illustrated by the sample tabulation in table II. In tabular form, each profile is identified by a trail number, date and time of launch, time increments over which the data were taken, and camera and picture (frame) identification.

To provide pressure, temperature, and humidity data, radiosonde measurements were made at the Eastern Test Range within 6 hours of each of the smoke-trail firings. The results are not included in this report but are available from the National Weather Records Center, Federal Building, Asheville, North Carolina 28801.

As shown in table I, the measurements were obtained during all months of the year. The characteristics of these profiles are generally similar to those in references 2, 3, and 4. The profiles varied in length from 8.0 to 18.9 kilometers with a minimum altitude of 2.2 kilometers and a maximum altitude of 22.3 kilometers.

Since use of the smoke-trail technique is restricted to periods of good visibility the question arises as to whether high-wind conditions are encountered during this type of survey. The results of wind distribution surveys based on radiosonde and rawinsonde observations at the Eastern Test Range (refs. 7 and 8) were compared with the results of the present test to answer this question. The maximum resultant velocity and the altitude at which it occurred for each monthly period and for the annual period are given in table III along with the cumulative percentage frequencies (CPF) of occurrence for each of the velocities at its own altitude as obtained from reference 7.

Table III shows that the maximum resultant velocity of 88.7 m/sec in trail 340 exceeds the 99-percent highest velocity (the value which would not be exceeded 99 percent of the time) for both the year and the month during which it occurred. In all months of the year, the median wind value (the wind velocity having a CPF of 50) was exceeded at least once. Similar results were obtained by use of reference 8. Therefore, the profiles in this report appear to include examples of high-wind conditions, even though the smoke-trail technique is limited to days with good visibility.

Two comparisons of profile shape over a lapse of time are presented in figures 56 and 57. Figure 56 compares the profiles obtained from two Nike smoke vehicles launched about 1 hour apart. Figure 57 compares the profile obtained from a Nike smoke trail with that obtained from the exhaust trail of a Saturn vehicle launched approximately 2 hours later. The similarity of the profiles demonstrates the persistence of the profile shape over a considerable lapse of time within the same air mass.

Two illustrations of the overall accuracy of the smoke-trail method are presented in figures 58 and 59. Figure 58 presents a comparison of the five profile measurements

[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 specific profiles desired.

obtained by reducing the data from all five of the camera pairs available. The profile which shows the largest deviations from the general shape was obtained from the False Cape, Patrick camera pair. This camera pair has the least favorable geometry and therefore the largest theoretical error. It was used for the reduction of data only when unfavorable conditions prevented obtaining any data from the Williams Point camera station.

Figure 59 presents two completely independent profile measurements using the most suitable camera pair. One profile was obtained from frames 14 and 26, the other from frames 15 and 27. The profiles, therefore, have a time difference of only 6 seconds and, since the wind variations over that time interval can be considered almost negligible, the profiles should be essentially the same. The degree of similarity of the profiles indicates that reading error, difficulty of identifying the trail at some points, and other errors involved in measurement and reduction of the data had no large effects on the results. A more complete discussion of smoke-trail accuracies with root-mean-square errors for several cases is presented in reference 4.

CONCLUDING REMARKS

Fifty-four detailed wind profiles measured by the smoke-trail technique at the Eastern Test Range during the year 1963 are presented. The characteristics of these profiles are generally similar to those in NASA Technical Notes D-2937, D-4365, and D-3289. The altitude ranges of the individual profiles vary but the overall range is from approximately 2 to 22 kilometers. The wind profiles include a variety of seasonal conditions and include velocities in excess of the 99-percent highest value. The persistence of the wind profile shape, under some conditions, for periods up to 2 hours is demonstrated.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., July 10, 1968,
709-05-00-02-23.

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TABLE I.- EASTERN TEST RANGE WIND PROFILES FOR 1963 LAUNCHINGS

Figure	Trail identification	Date	EST	Altitude range, km	Maximum velocity, m/sec	Wind direction, deg	Altitude of maximum, m
2	326	1/3/63	1458	3.1 to 13.9	42.8	308	11 950
3	327	1/3/63	1600	3.3 to 11.7	[a]39.8	307	11 700
4	328	1/4/63	1500	3.0 to 14.8	44.9	292	12 225
5	330	1/9/63	1300	4.1 to 14.7	46.8	272	12 975
6	331	1/10/63	1430	2.8 to 20.6	50.4	256	10 975
7	332	1/11/63	1442	5.1 to 15.8	52.0	251	13 150
8	333	1/17/63	1617	3.7 to 15.2	53.0	275	12 875
9	334	1/18/63	1717	2.8 to 15.0	50.2	271	14 175
10	335	1/22/63	1446	2.9 to 14.9	52.3	281	13 425
11	336	1/28/63	1300	4.5 to 16.1	49.4	259	13 125
12	337	1/31/63	1500	5.6 to 15.0	38.7	287	14 375
13	338	2/7/63	1245	3.4 to 22.3	53.0	267	14 625
14	339	2/13/63	1315	4.2 to 15.8	70.2	252	10 800
15	340	2/20/63	1430	4.1 to 18.4	88.7	231	10 450
16	341	2/27/63	1430	5.0 to 13.9	[a]46.2	256	13 875
17	342	3/8/63	1420	4.3 to 20.5	51.2	256	13 900
18	343	3/11/63	1630	4.1 to 14.4	[a]32.9	277	14 375
19	344	3/12/63	1425	4.7 to 14.5	35.3	290	12 400
20	345	3/18/63	1430	3.3 to 14.7	40.6	306	12 000
21	346	3/21/63	1410	3.6 to 15.1	70.0	265	11 525
22	347	3/22/63	1330	3.8 to 16.1	60.7	259	11 450
23	348	3/28/63	1302	9.0 to 21.3	45.9	267	14 500
24	408	3/28/63	1510	11.1 to 19.2	46.0	260	14 175
25	349	4/2/63	1423	4.9 to 13.3	[a]30.0	14	13 350
26	350	4/3/63	1420	5.9 to 14.0	[a]27.6	17	11 500
27	351	4/5/63	1403	4.6 to 14.7	20.5	281	13 400
28	352	4/11/63	1535	3.7 to 14.6	39.7	325	10 450
29	353	4/12/63	1425	3.7 to 11.7	[a]46.5	280	11 650
30	354	4/15/63	1430	4.8 to 15.8	46.4	282	13 000
31	355	4/16/63	1430	4.7 to 21.5	29.6	293	14 250
32	356	4/17/63	1430	3.5 to 16.0	25.6	294	14 700
33	357	4/22/63	1430	4.1 to 12.5	[a]39.9	309	12 400
34	358	5/7/63	1530	6.5 to 15.5	30.4	300	12 625
35	359	5/8/63	1430	4.5 to 13.5	[a]27.8	320	13 325
36	360	5/14/63	1635	5.3 to 16.6	19.6	290	11 900
37	361	6/7/63	1400	3.4 to 13.3	23.5	203	12 725
38	362	6/19/63	1545	4.4 to 16.0	14.4	205	10 025
39	363	7/1/63	1300	2.2 to 16.7	17.6	126	14 200
40	364	7/17/63	1430	5.1 to 14.3	12.1	35	13 750
41	365	7/26/63	1430	5.4 to 19.9	13.4	85	18 225
42	366	7/31/63	1430	2.3 to 17.0	19.9	83	12 425
43	367	8/7/63	1430	2.3 to 19.4	16.0	161	12 925
44	369	9/30/63	1430	8.9 to 20.2	18.5	207	10 050
45	370	10/1/63	1512	8.0 to 20.3	21.7	228	11 075
46	371	10/9/63	1530	3.7 to 12.8	41.8	271	11 875
47	372	10/22/63	1417	7.5 to 15.9	19.8	344	11 300
48	374	10/30/63	1430	4.0 to 18.0	39.5	268	12 175
49	373	10/31/63	1530	4.4 to 18.6	26.3	275	14 825
50	375	11/6/63	1430	3.2 to 18.6	43.8	278	10 175
51	376	11/13/63	1511	3.6 to 20.2	75.5	251	11 475
52	377	11/15/63	1433	5.4 to 20.3	57.0	245	12 900
53	378	11/21/63	1430	3.9 to 19.4	42.0	331	12 850
54	379	12/5/63	1525	4.9 to 15.5	40.3	266	12 950
55	380	12/20/63	1230	5.0 to 16.4	68.7	277	11 475

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

TABLE II. – SAMPLE TABULATION

CAPE SMOKE-TRAIL NO. 376 LAUNCHED 11/13/63 1511EST DELTA T 60 SECS
WILLIAMS POINT NORTH PATRICK FRAMES 18 AND 30

Z (METERS)	VX (MPS)	VY (MPS)	V	THETA (DEGREES)	SHEAR X (/SEC)	SHEAR Y (/SEC)	SHEAR V (/SEC)	SHEAR M (/SEC)
10475	61.0	22.6	65.05	249.70	.012	.024	.026	.019
10500	61.1	23.2	65.36	249.70	.004	.024	.024	.012
10525	61.2	23.7	65.63	249.20	.004	.020	.020	.010
10550	61.3	24.1	65.87	248.70	.004	.016	.016	.009
10575	61.4	24.4	66.07	248.70	.004	.012	.012	.008
10600	62.0	24.5	66.67	248.70	.024	.004	.024	.024
10625	62.6	24.5	67.22	248.70	.024	0.000	.024	.022
10650	63.2	24.3	67.71	249.20	.024	-.008	.025	.019
10675	63.7	24.1	68.11	249.70	.020	-.008	.021	.016
10700	64.4	23.8	68.66	250.21	.028	-.012	.030	.022
10725	65.2	23.7	69.37	250.21	.032	-.004	.032	.028
10750	66.2	23.6	70.28	250.71	.040	-.004	.040	.036
10775	67.1	23.7	71.16	250.71	.036	.004	.036	.035
10800	67.8	24.0	71.92	250.71	.028	.012	.030	.030
10825	68.2	24.2	72.37	250.71	.016	.008	.017	.018
10850	68.6	24.3	72.78	250.71	.016	.004	.016	.016
10875	68.9	24.4	73.09	250.71	.012	.004	.012	.012
10900	69.2	24.9	73.54	250.71	.012	.020	.023	.018
10925	69.5	25.4	74.00	250.21	.012	.020	.023	.018
10950	69.9	26.1	74.61	249.70	.016	.028	.032	.024
10975	70.1	26.2	74.84	249.70	.008	.004	.008	.009
11000	70.4	26.4	75.19	249.70	.012	.008	.014	.014
11025	70.5	26.4	75.28	249.70	.004	0.000	.003	.003
11050	70.4	26.3	75.15	249.70	-.004	-.004	.005	.005
11075	70.1	26.1	74.80	249.70	-.012	-.008	.014	.014
11100	69.6	25.9	74.26	249.70	-.020	-.008	.021	.021
11125	69.3	25.5	73.84	250.21	-.012	-.016	.019	.016
11150	69.3	25.1	73.71	250.21	0.000	-.016	.016	.005
11175	69.8	25.3	74.24	250.21	.020	.008	.021	.021
11200	69.8	25.5	74.31	250.21	0.000	.008	.007	.002
11225	69.4	25.3	73.87	250.21	-.016	-.008	.017	.017
11250	69.4	25.2	73.83	250.21	0.000	-.004	.003	.001
11275	69.5	25.2	73.93	250.21	.004	0.000	.003	.004
11300	69.5	25.2	73.93	250.21	0.000	0.000	0.000	0.000
11325	69.8	25.5	74.31	250.21	.012	.012	.016	.015
11350	70.0	25.4	74.47	250.21	.008	-.004	.008	.006
11375	70.3	25.4	74.75	250.21	.012	0.000	.012	.011
11400	70.7	25.4	75.12	250.71	.016	0.000	.016	.014
11425	70.9	25.4	75.22	250.71	.004	0.000	.003	.004

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, degrees
SHEAR X	$\delta VX/\delta Z$, per second
SHEAR Y	$\delta VY/\delta Z$, per second
SHEAR M	$\delta V/\delta Z$, 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

Month	Number of cases	Maximum measured wind			CPF (a)
		Trail	Maximum velocity, m/sec	Altitude, km	
Jan.	11	333	53.0	13	72.9
Feb.	4	340	88.7	10	99.7
Mar.	8	346	70.0	12	90.1
Apr.	9	353	46.5	12	62.6
May	3	358	30.4	13	65.4
June	2	361	23.5	13	79.3
July	4	366	19.9	12	89.2
Aug.	1	367	16.0	13	76.6
Sept.	1	369	18.5	10	91.4
Oct.	5	371	41.8	12	90.4
Nov.	4	376	75.5	11	98.6
Dec.	2	380	68.7	11	97.4
Annual	54	340	88.7	10	99.7

[a]Cumulative percentage frequency from reference 7.

(a) Camera site I (False Cape). L-68-5681

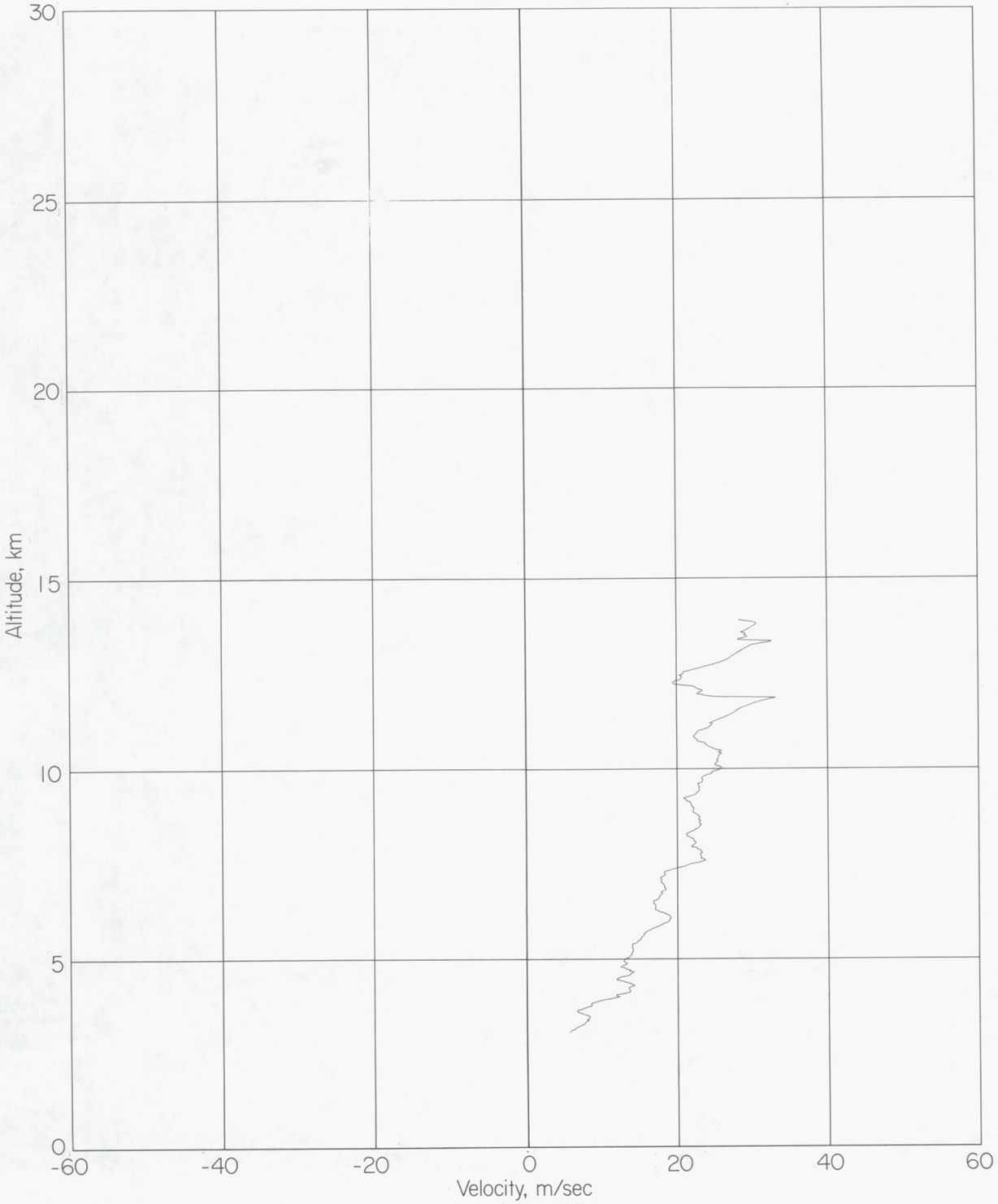
Figure 1.- A smoke trail as photographed from the three camera sites at the Eastern Test Range.

(b) Camera site 11 (Williams Point). L-68-5682

Figure 1.- Continued.

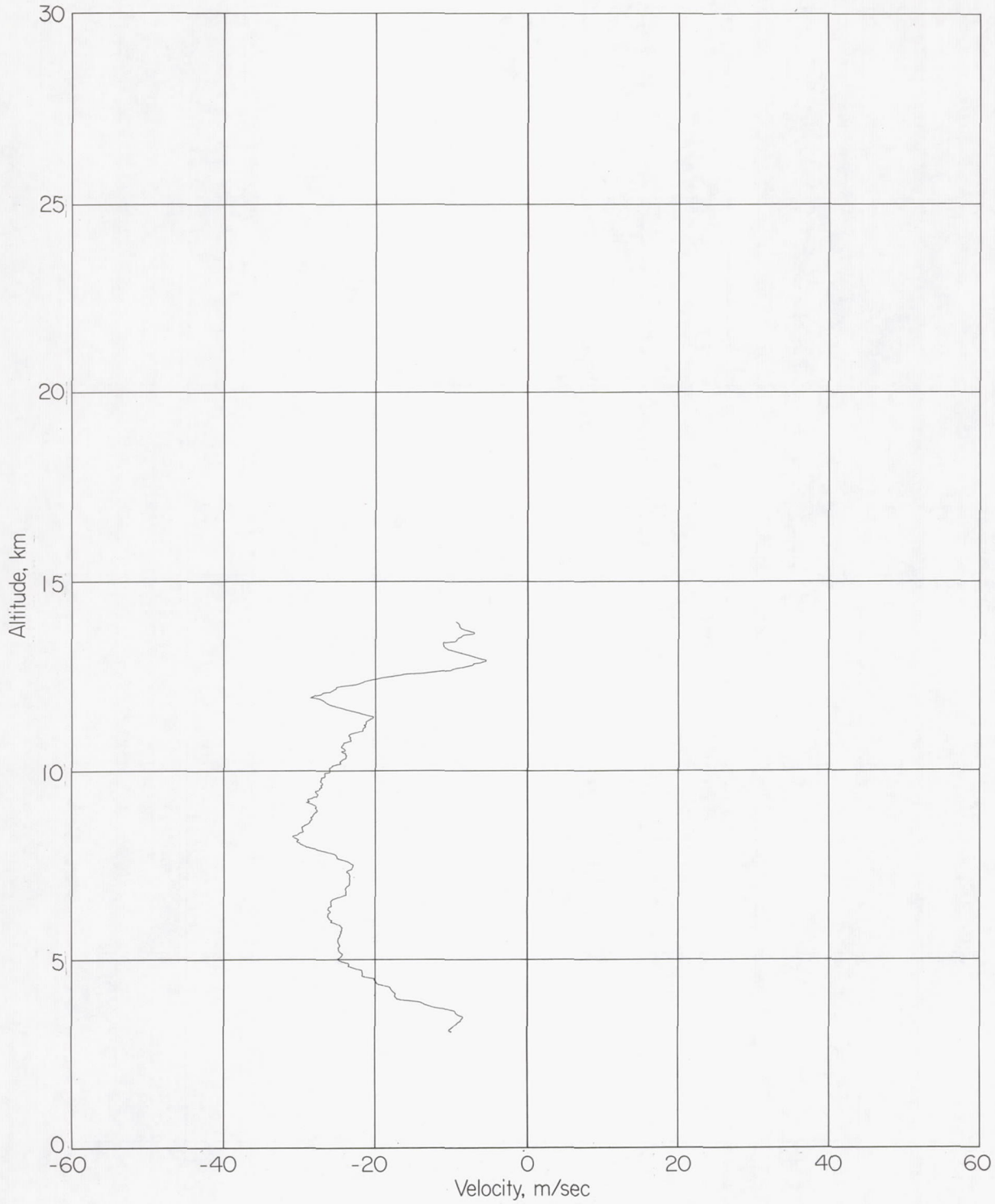
(c) Camera site III (Patrick AFB). L-68-5683

Figure 1.- Concluded.



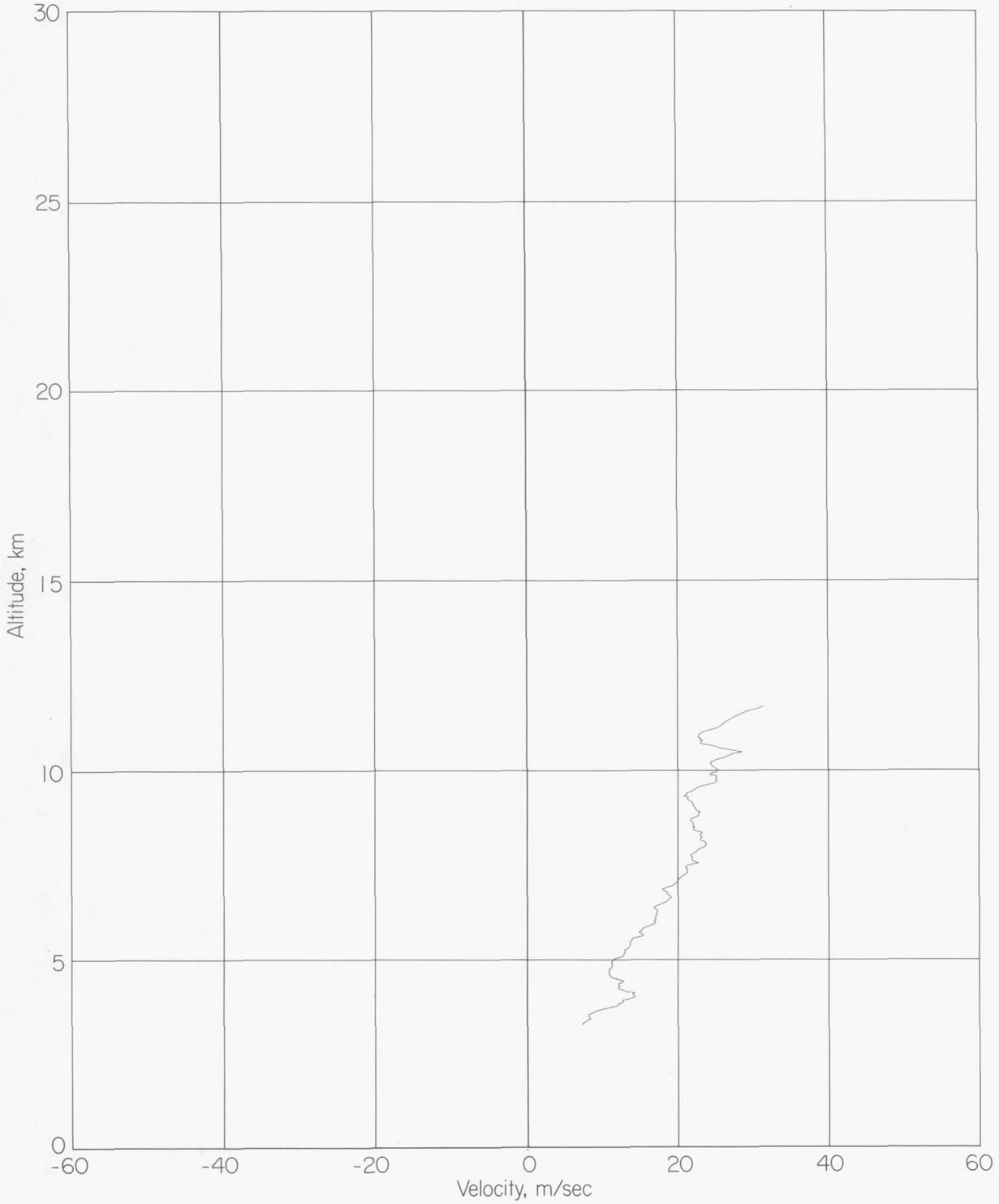
(a) West-to-east velocity component.

Figure 2.- Wind profile of smoke trail 326 obtained January 3, 1963. Time interval, 60 seconds; height interval, 25 meters.



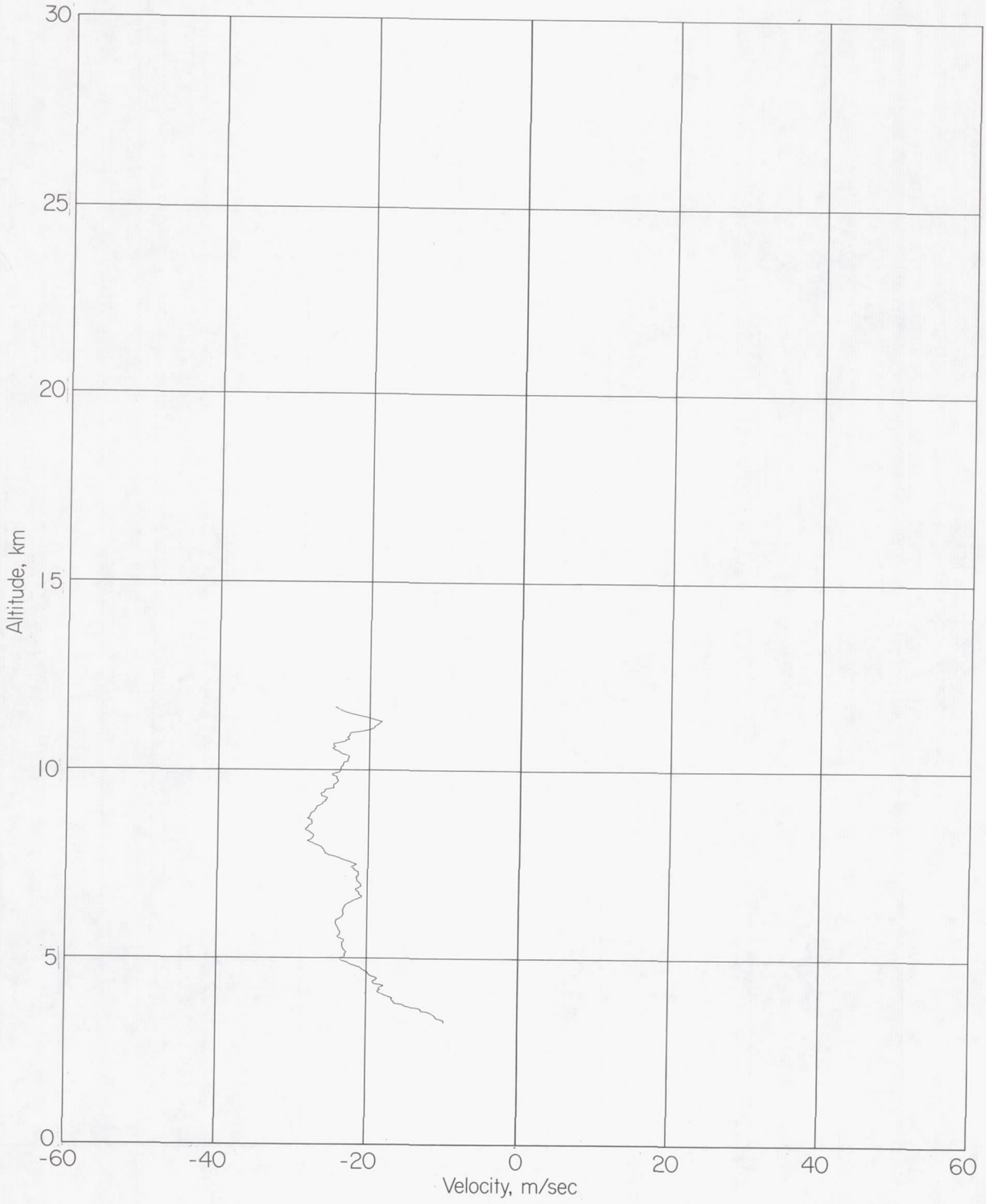
(b) South-to-north velocity component.

Figure 2.- Concluded.



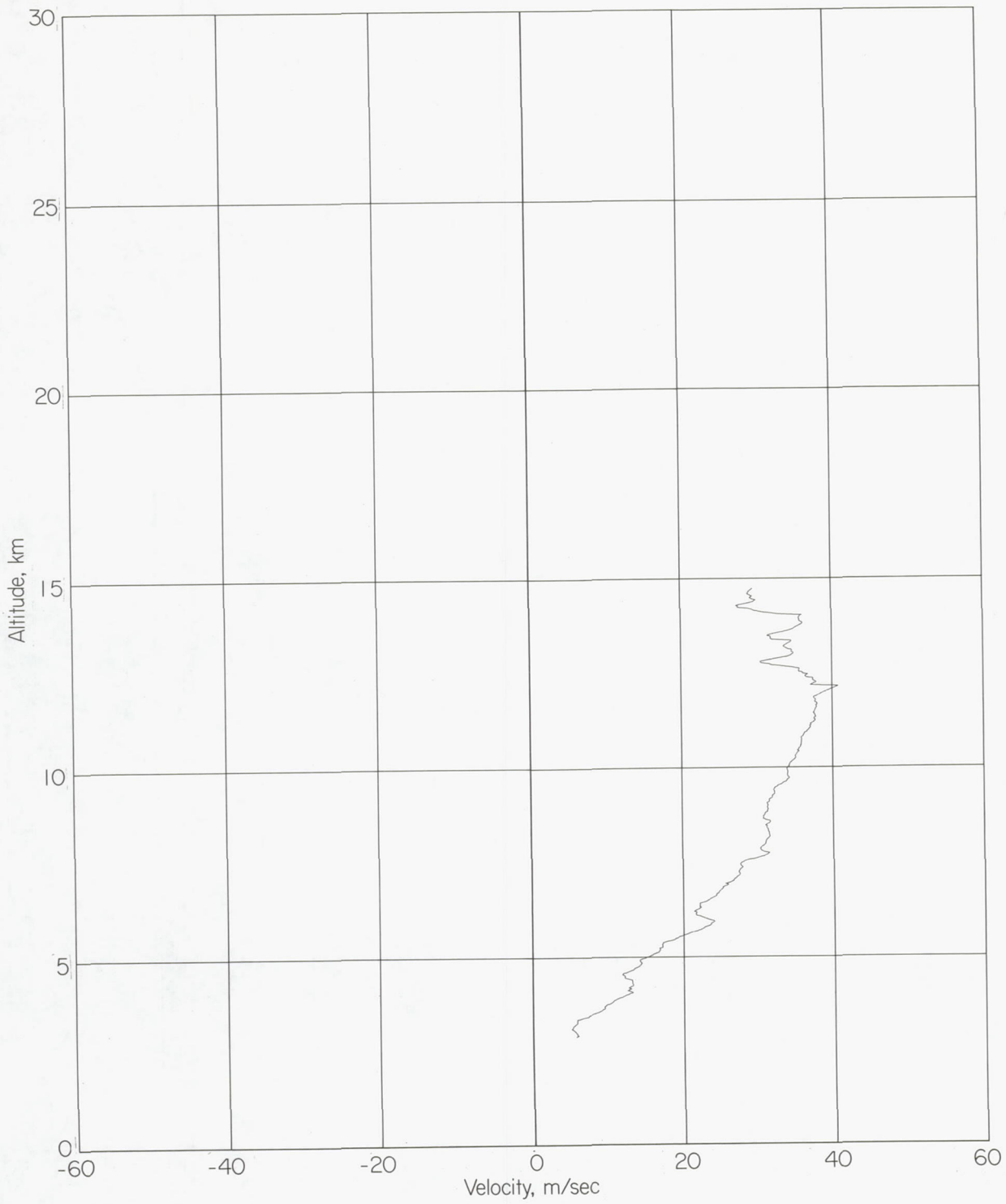
(a) West-to-east velocity component.

Figure 3.- Wind profile of smoke trail 327 obtained January 3, 1963. Time interval, 60 seconds; height interval, 25 meters.



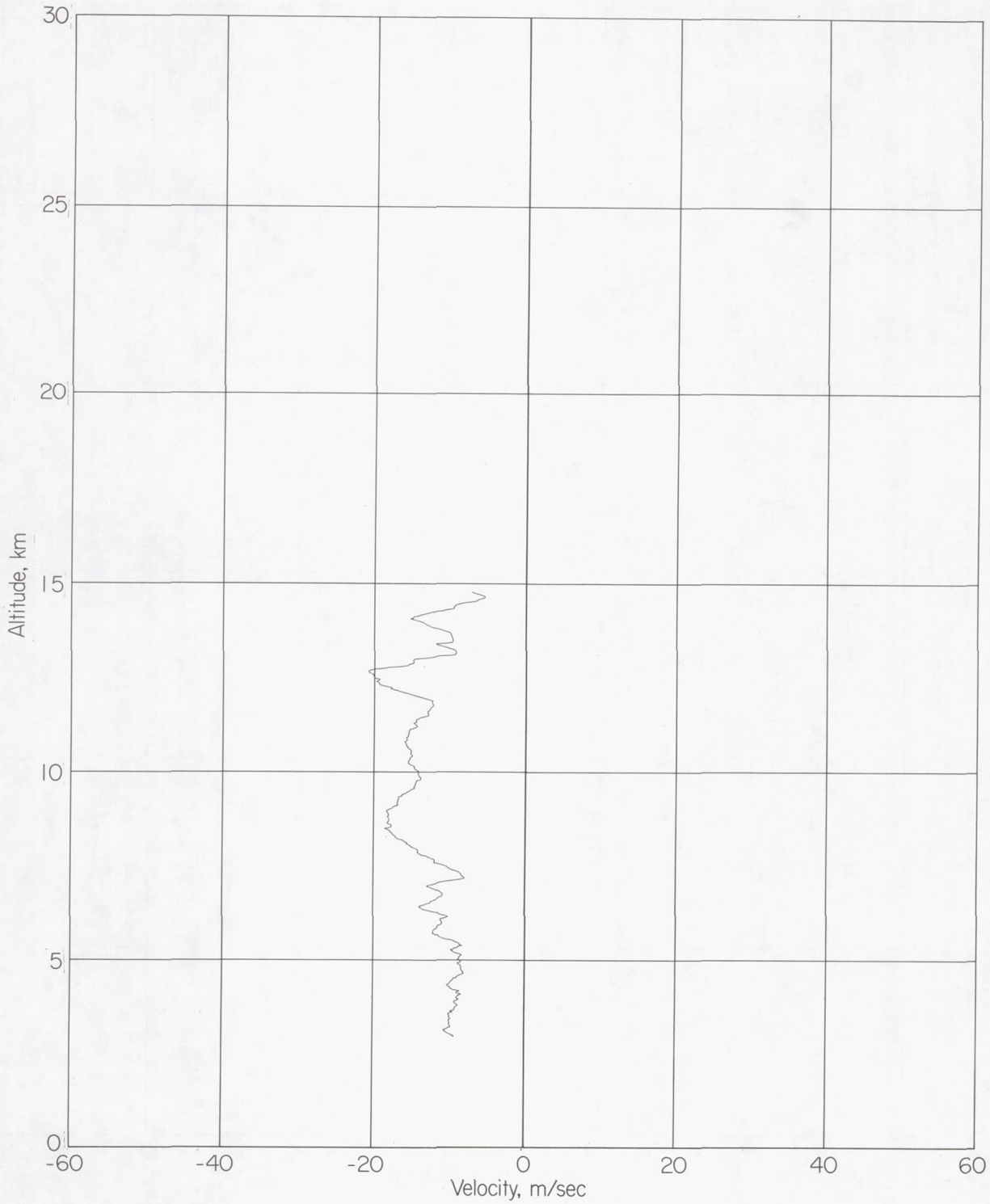
(b) South-to-north velocity component.

Figure 3.- Concluded.



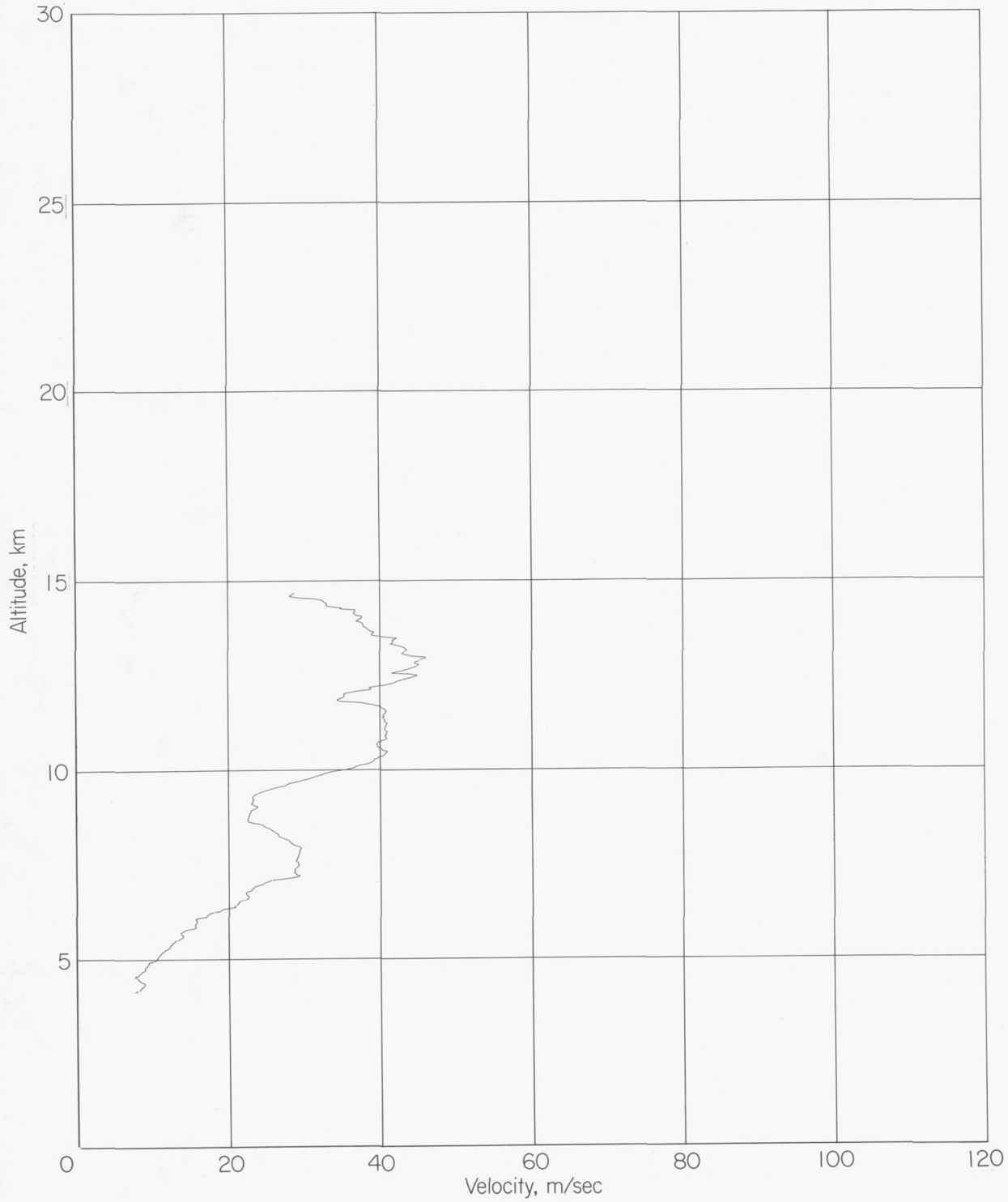
(a) West-to-east velocity component.

Figure 4.- Wind profile of smoke trail 328 obtained January 4, 1963. Time interval, 60 seconds; height interval, 25 meters.



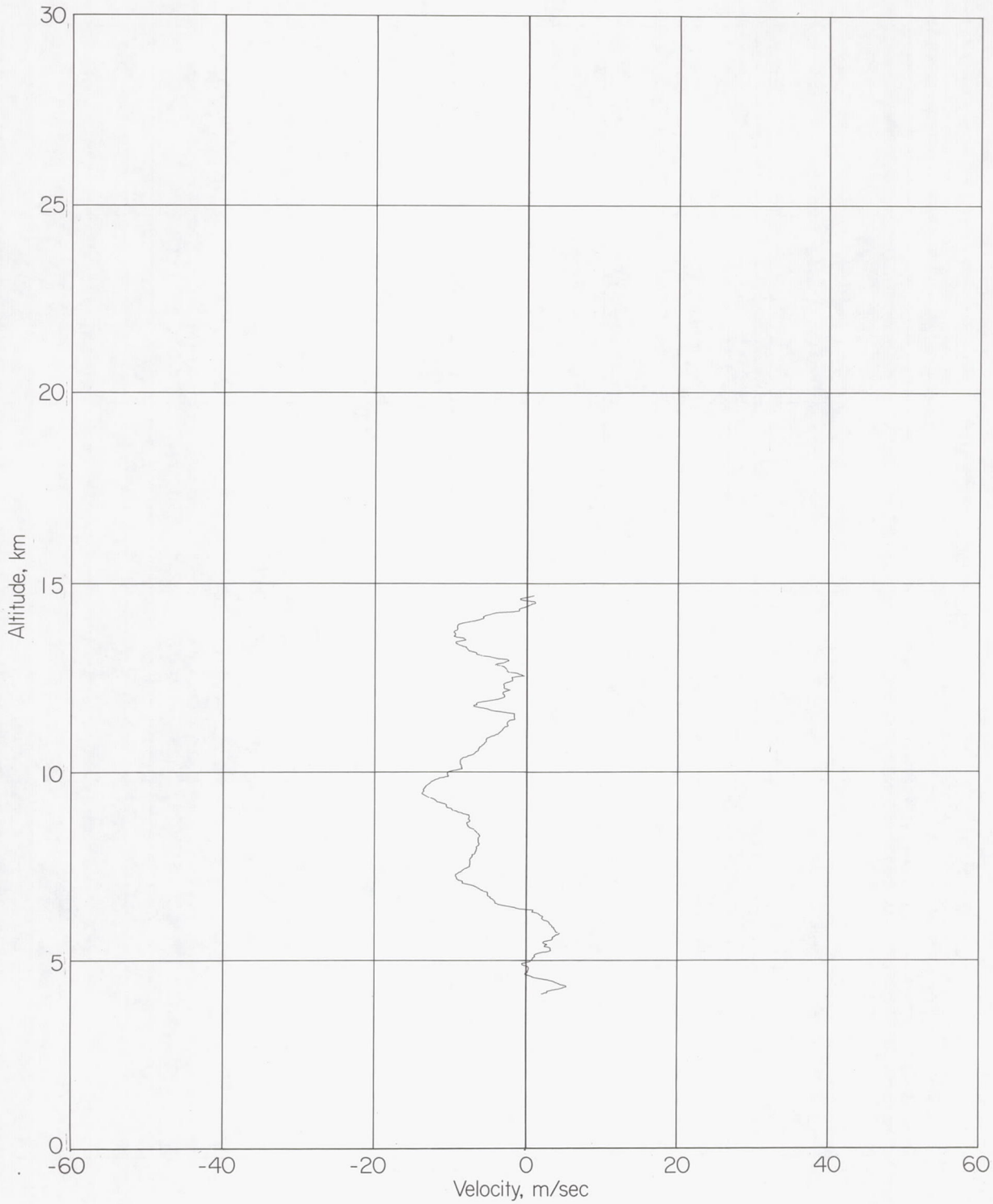
(b) South-to-north velocity component.

Figure 4.- Concluded.



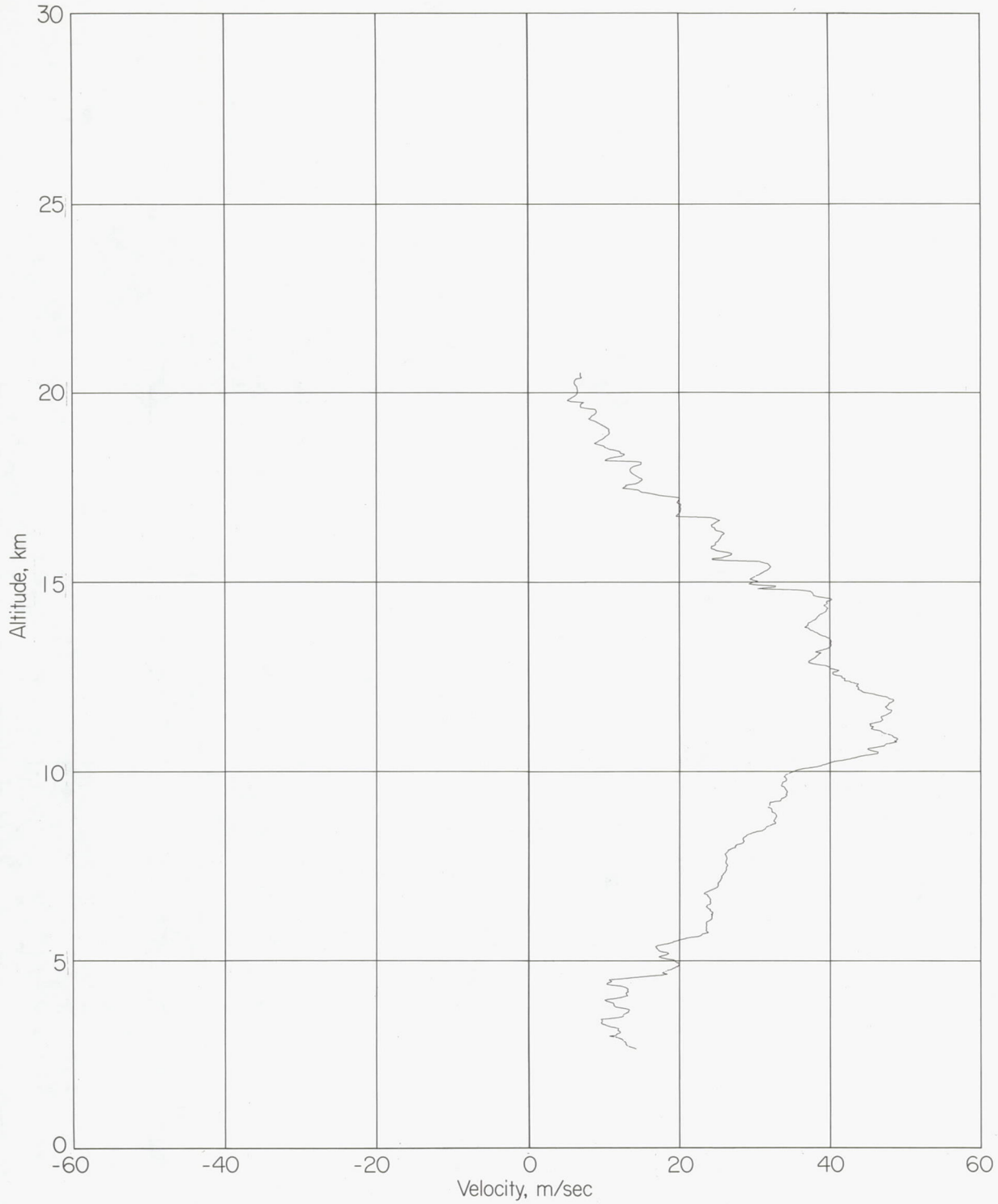
(a) West-to-east velocity component.

Figure 5.- Wind profile of smoke trail 330 obtained January 9, 1963. Time interval, 60 seconds; height interval, 25 meters.



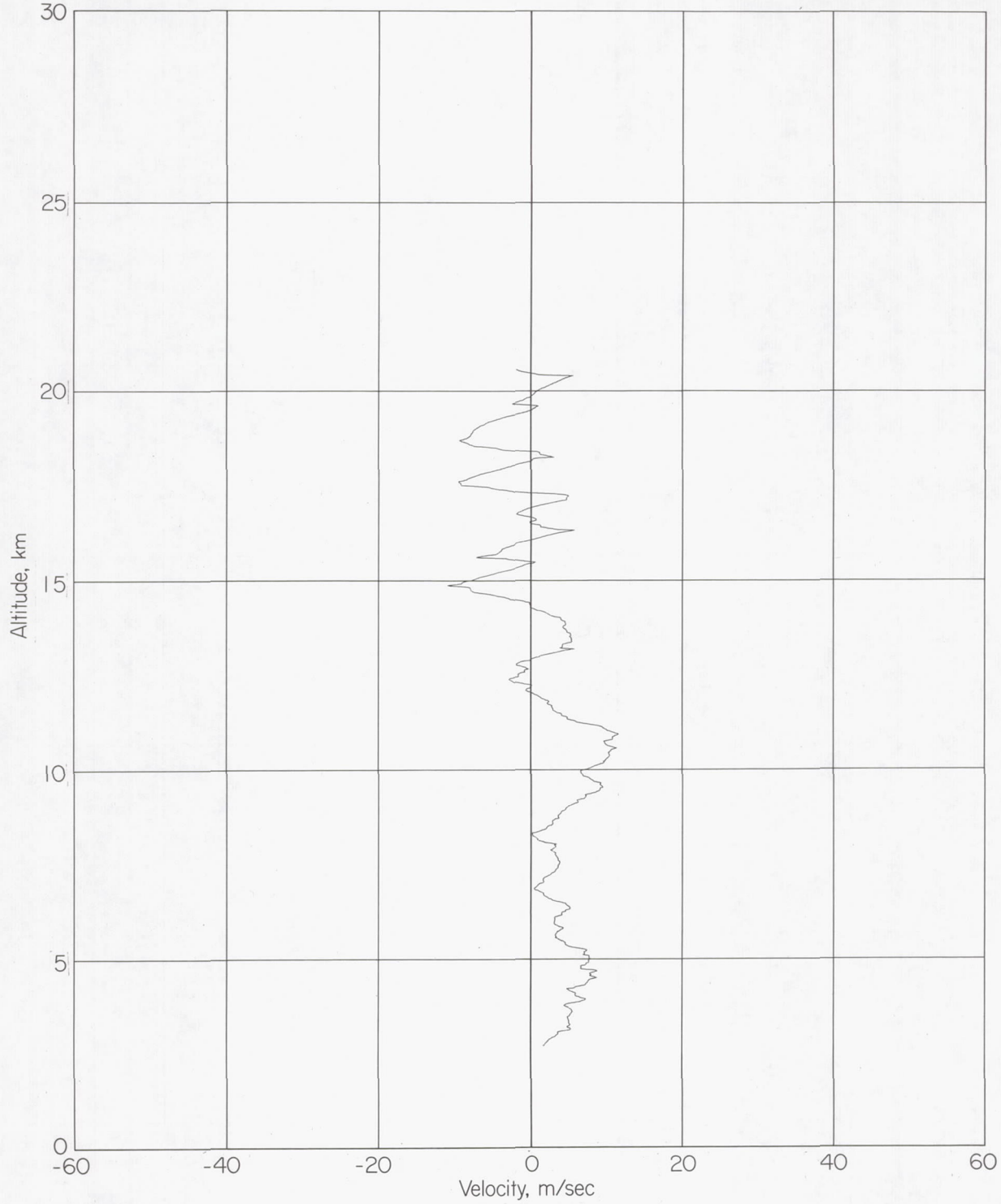
(b) South-to-north velocity component.

Figure 5.- Concluded.



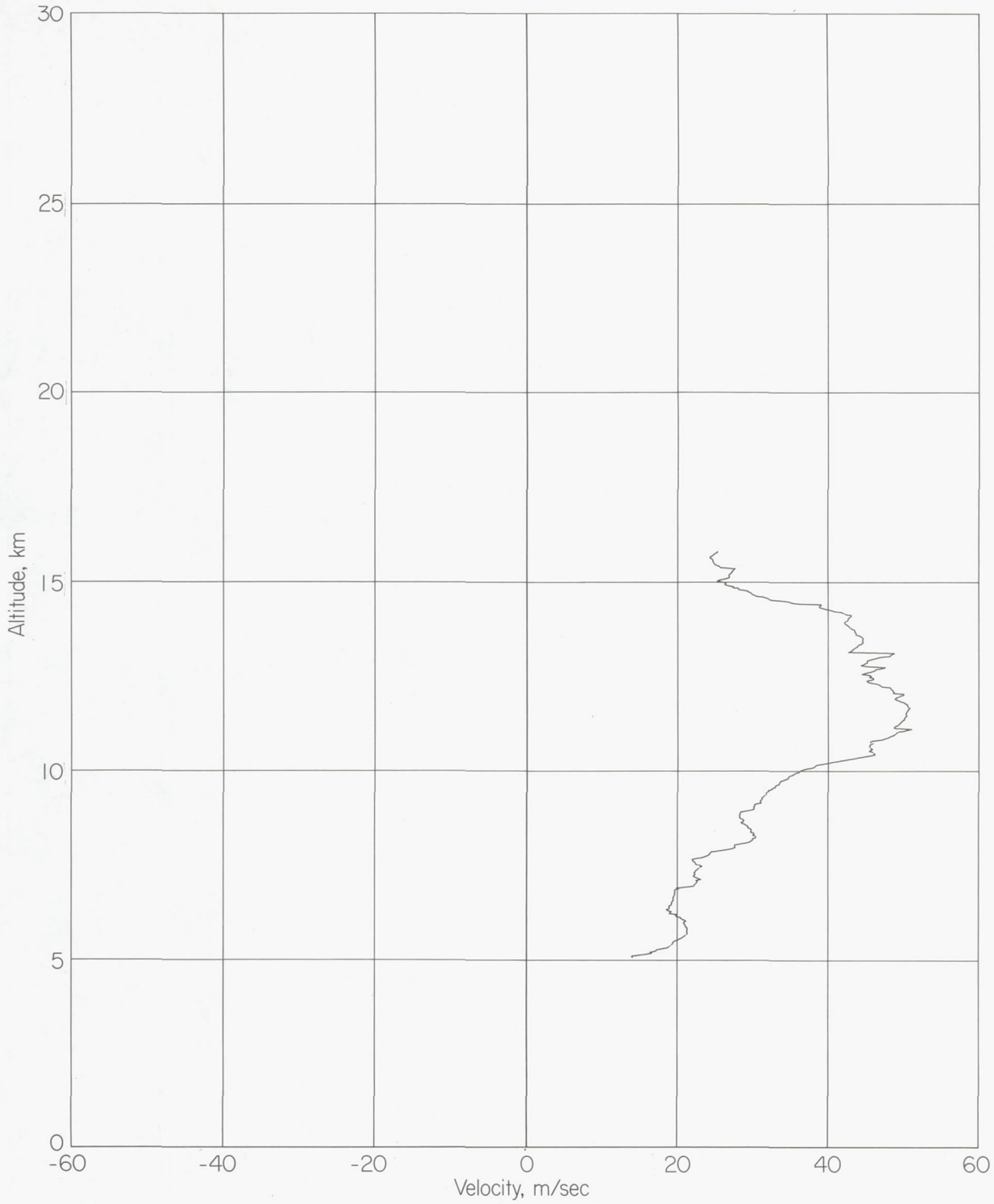
(a) West-to-east velocity component.

Figure 6.- Wind profile of smoke trail 331 obtained January 10, 1963. Time interval, 60 seconds; height interval, 25 meters.



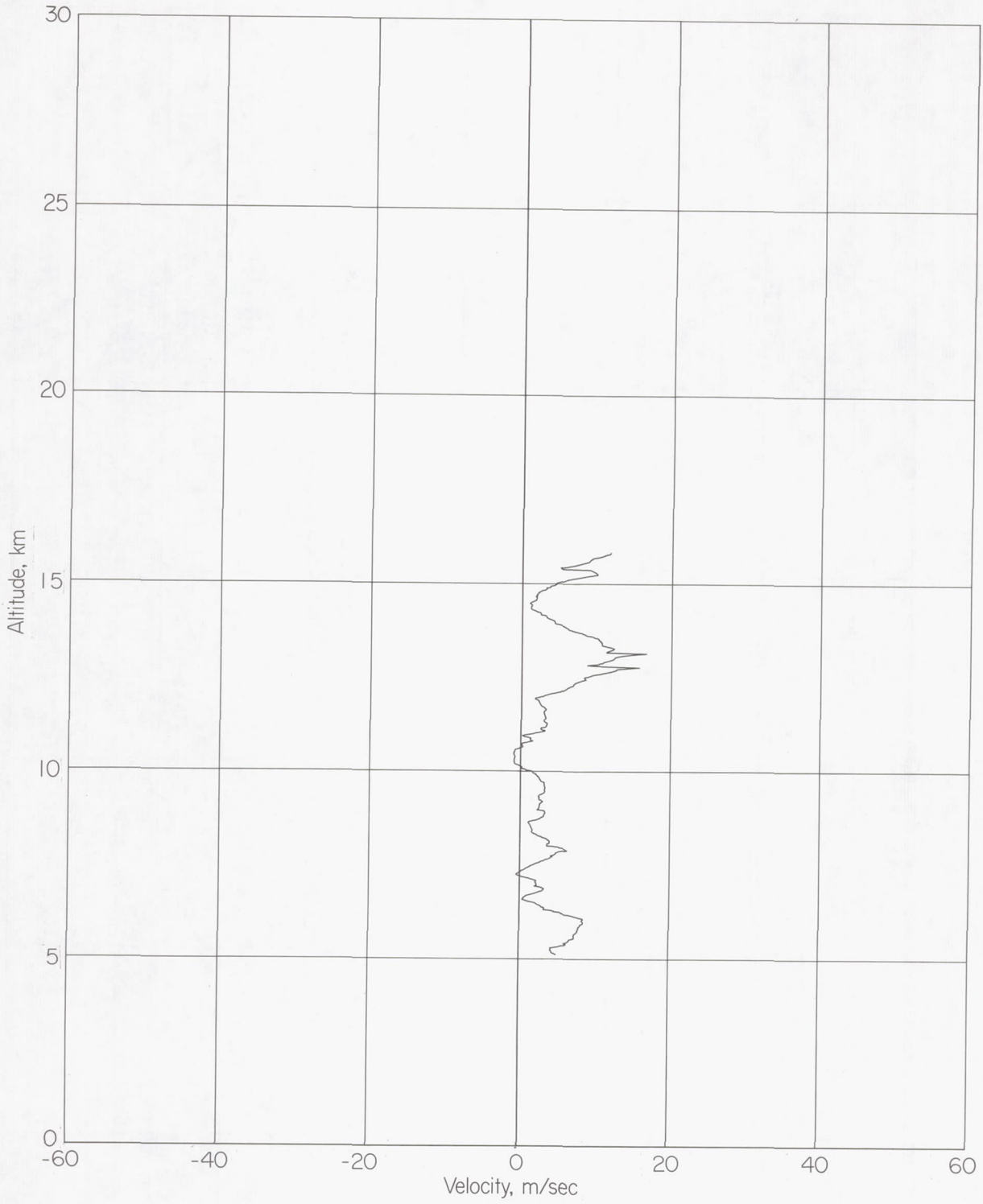
(b) South-to-north velocity component.

Figure 6.- Concluded.



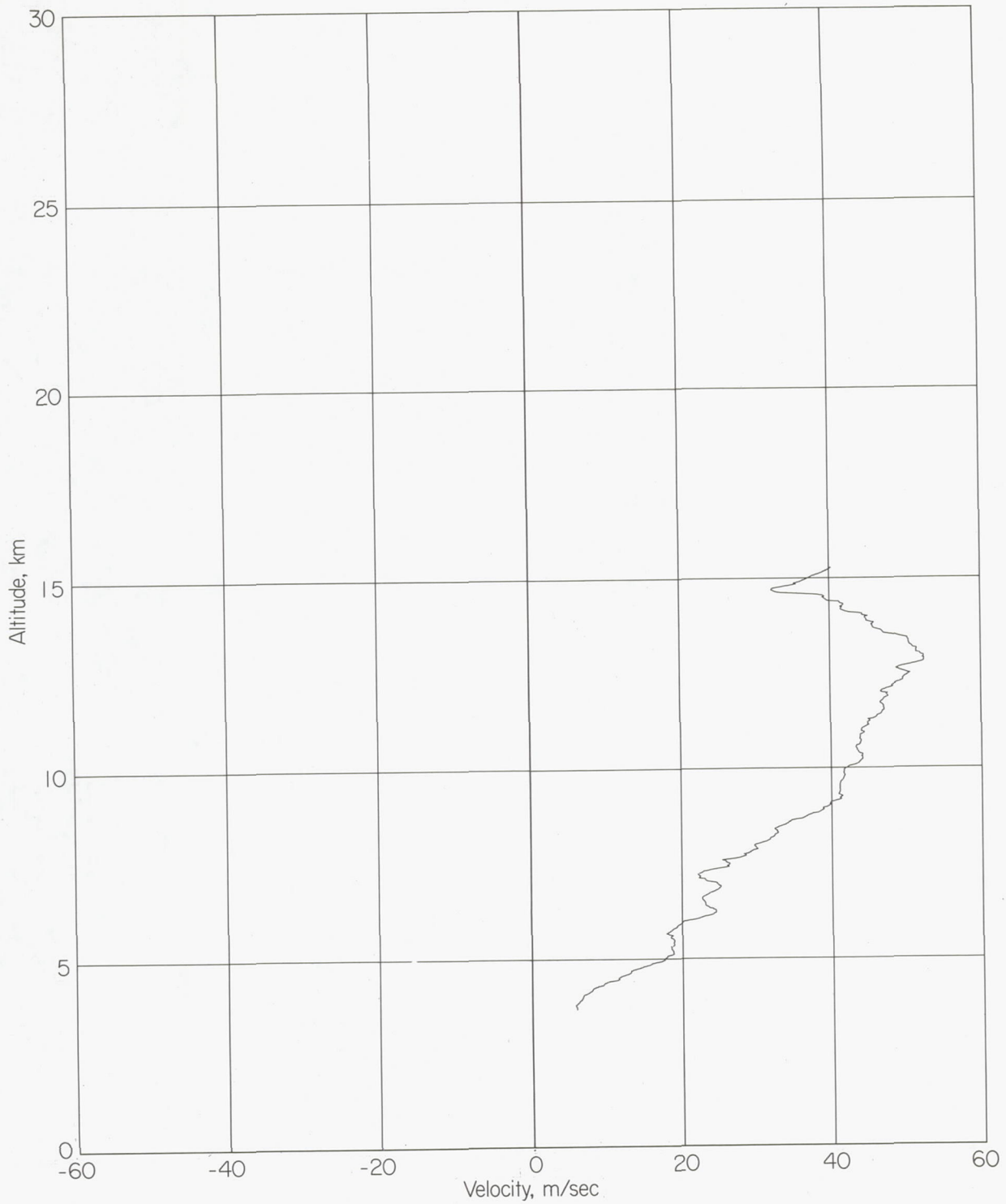
(a) West-to-east velocity component.

Figure 7.- Wind profile of smoke trail 332 obtained January 11, 1963. Time interval, 60 seconds; height interval, 25 meters.



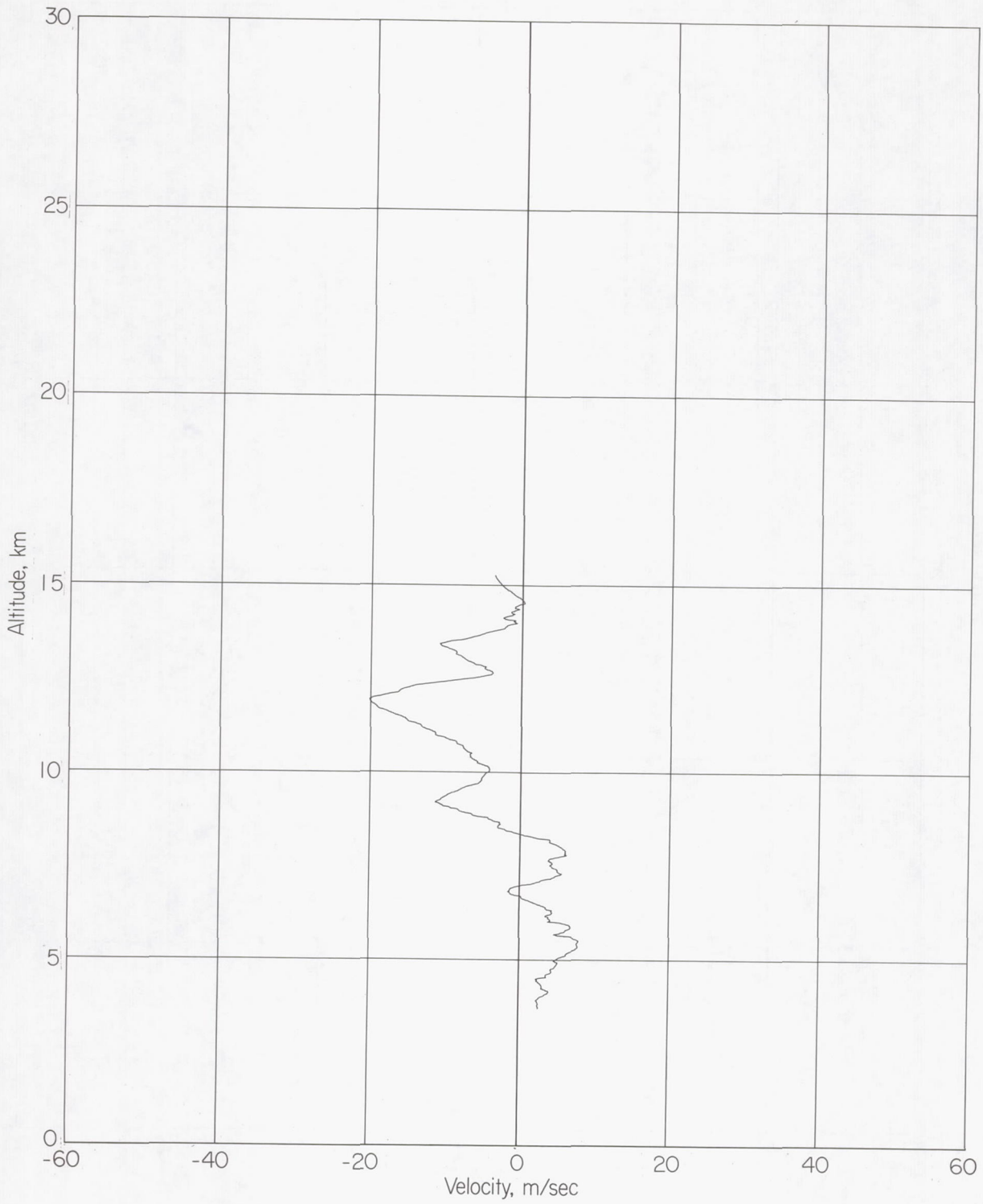
(b) South-to-north velocity component.

Figure 7.- Concluded.



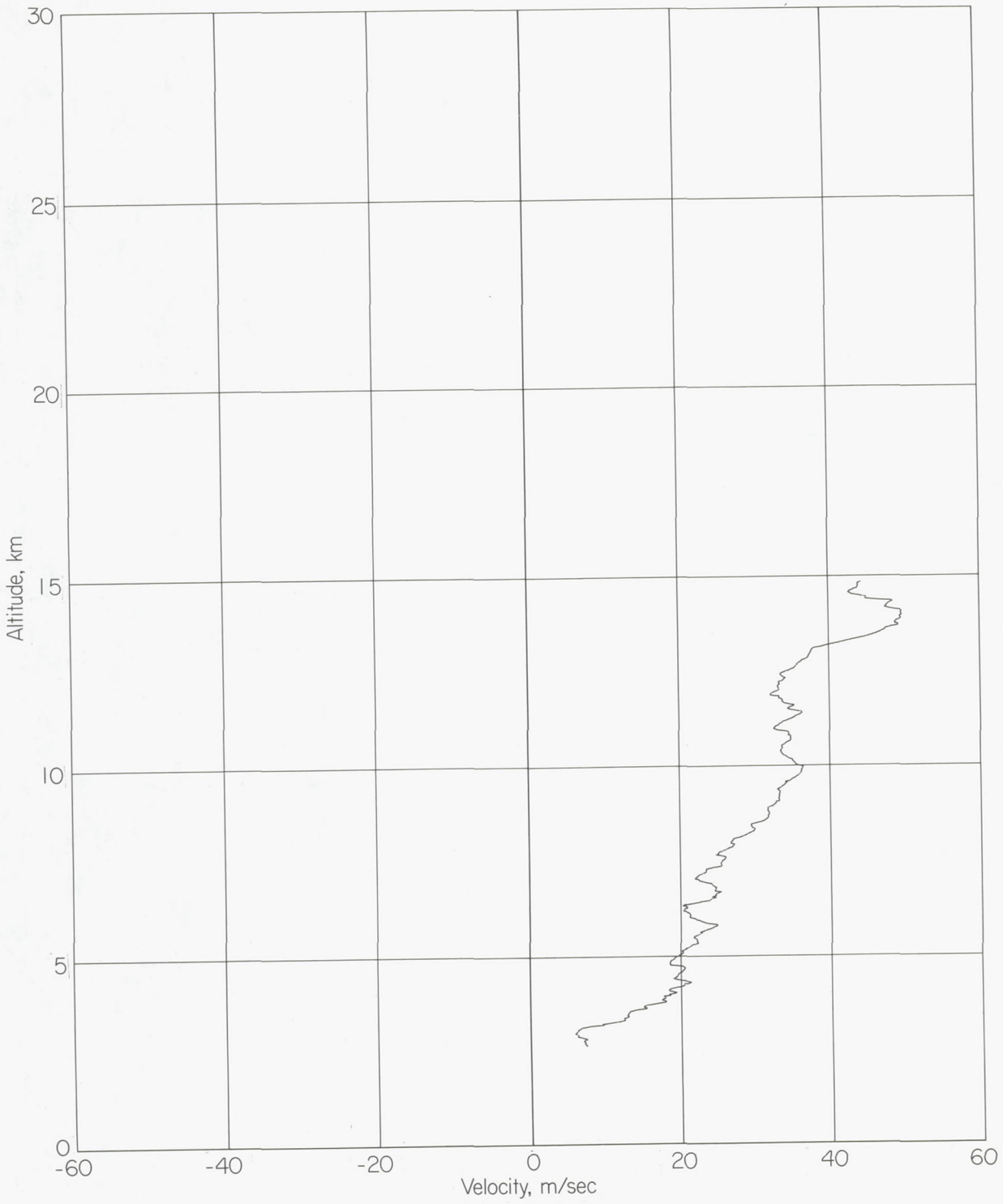
(a) West-to-east velocity component.

Figure 8.- Wind profile of smoke trail 333 obtained January 17, 1963. Time interval, 60 seconds; height interval, 25 meters.



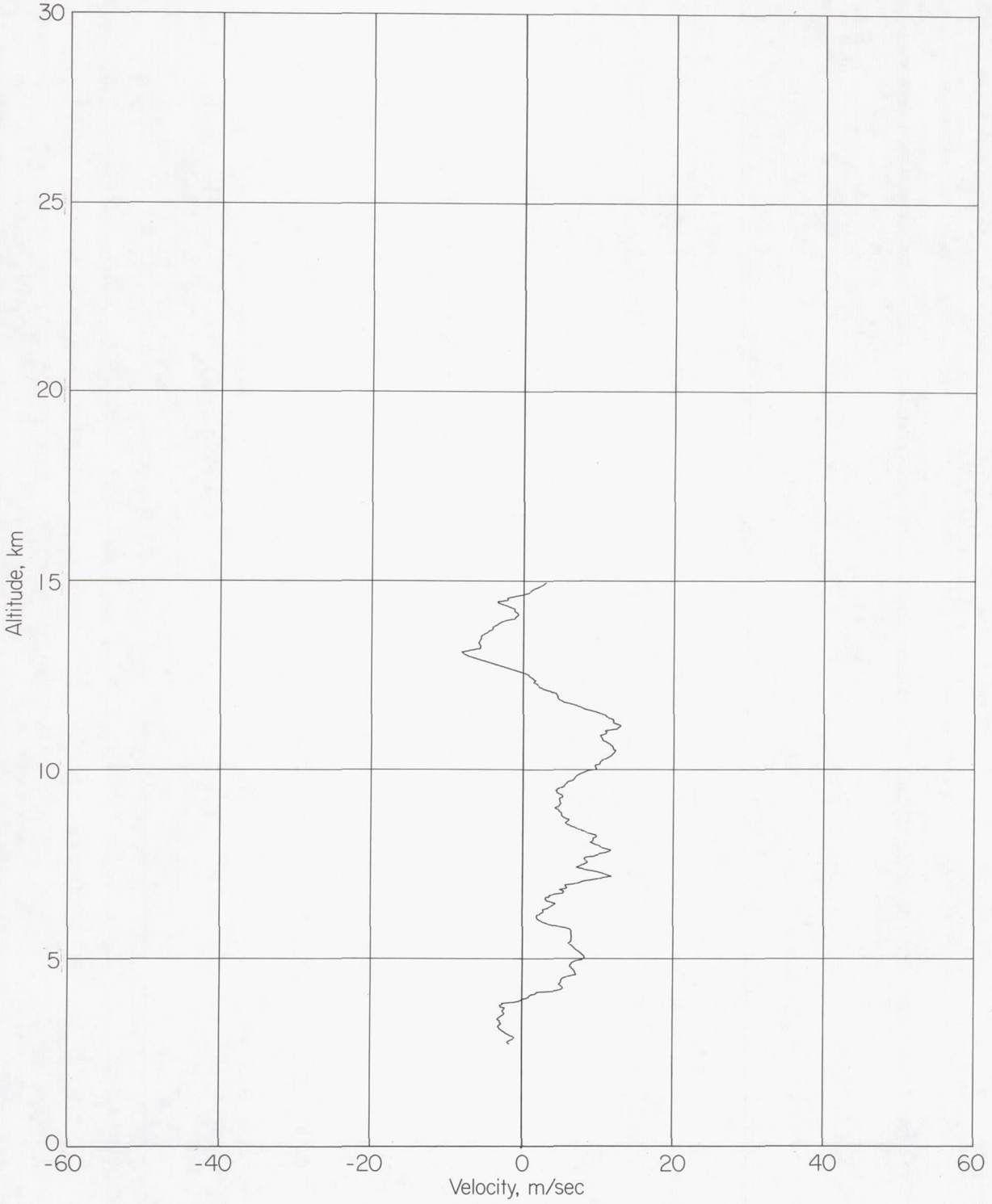
(b) South-to-north velocity component.

Figure 8.- Concluded.



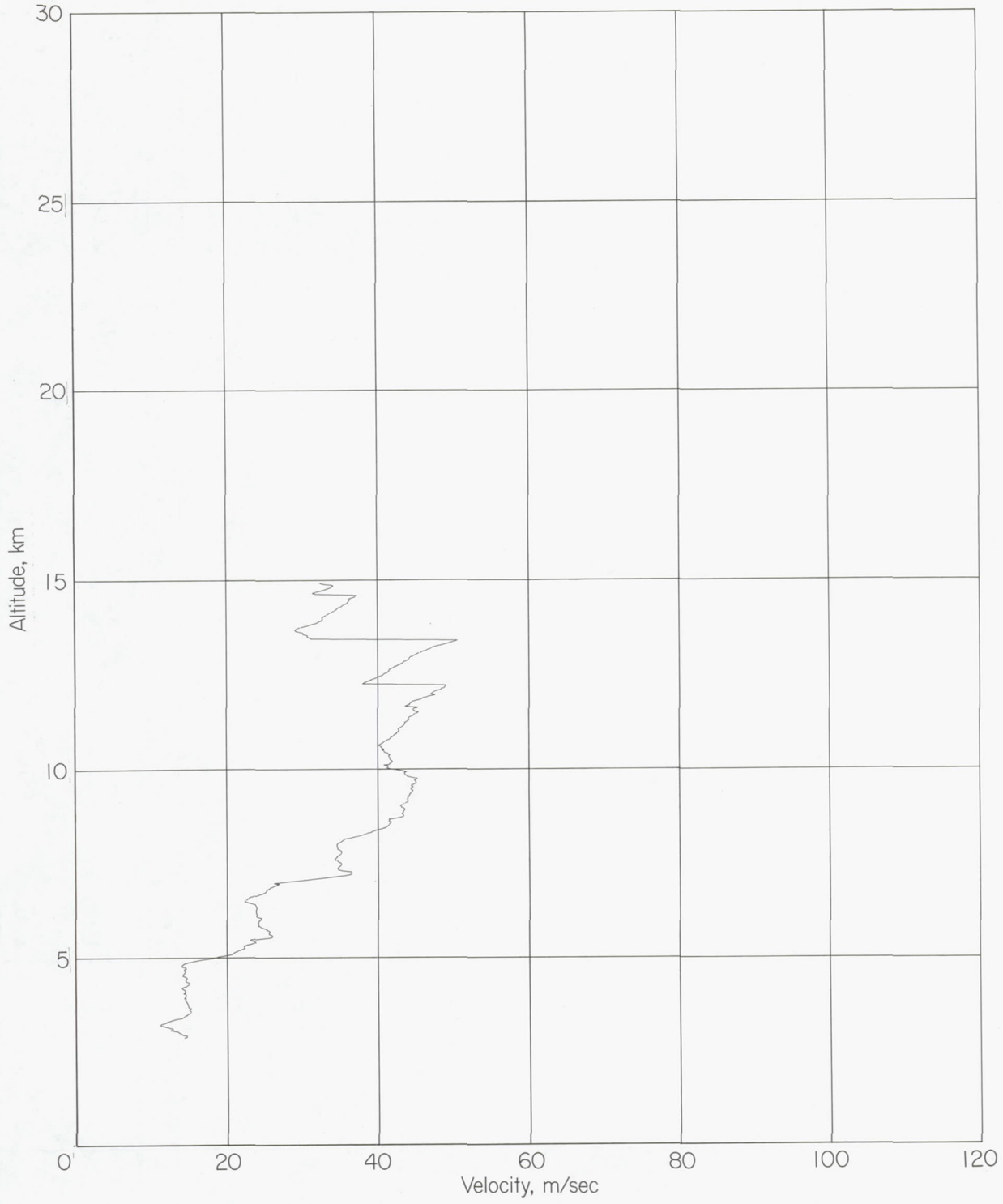
(a) West-to-east velocity component.

Figure 9.- Wind profile of smoke trail 334 obtained January 18, 1963. Time interval, 60 seconds; height interval, 25 meters.



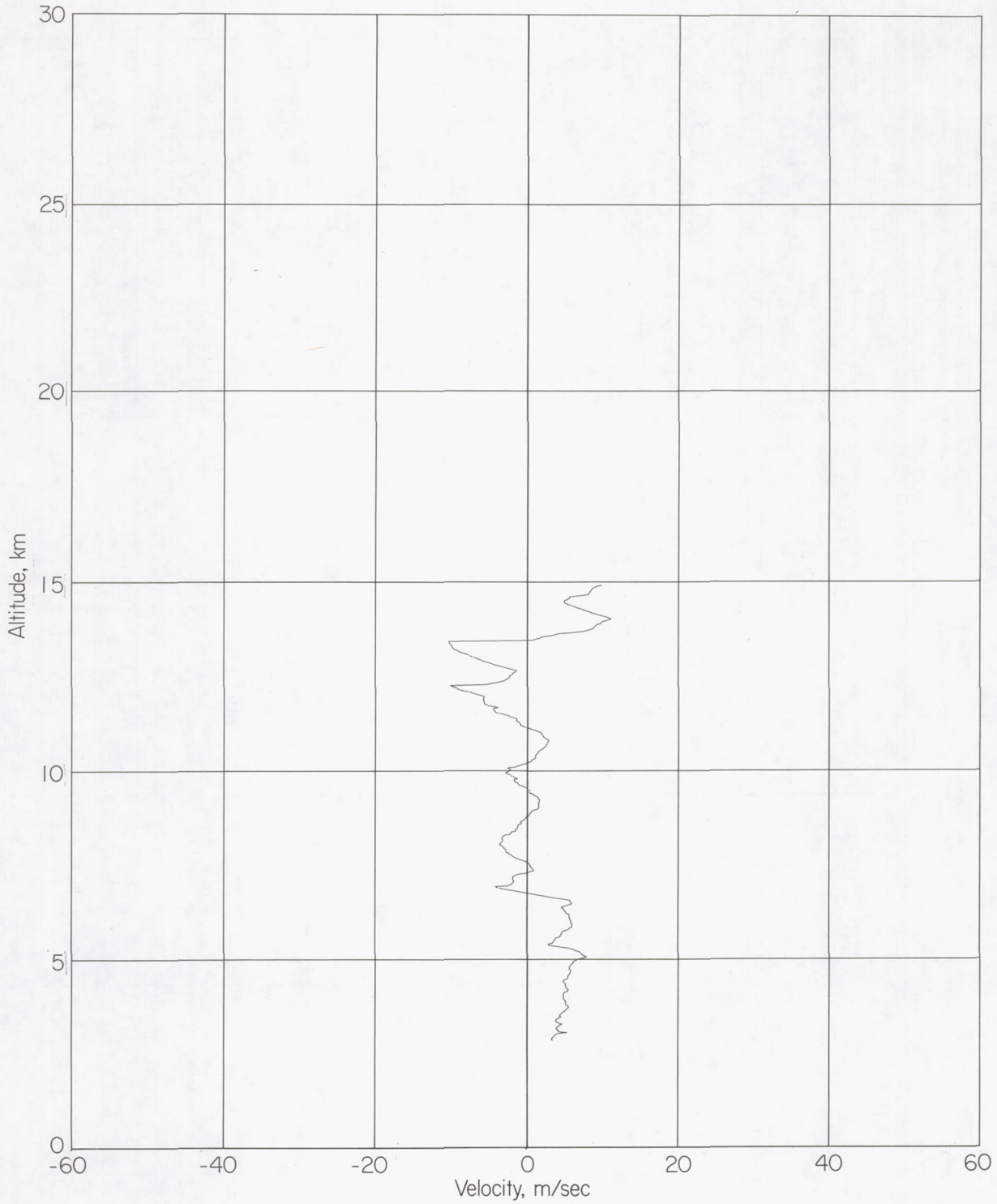
(b) South-to-north velocity component.

Figure 9.- Concluded.



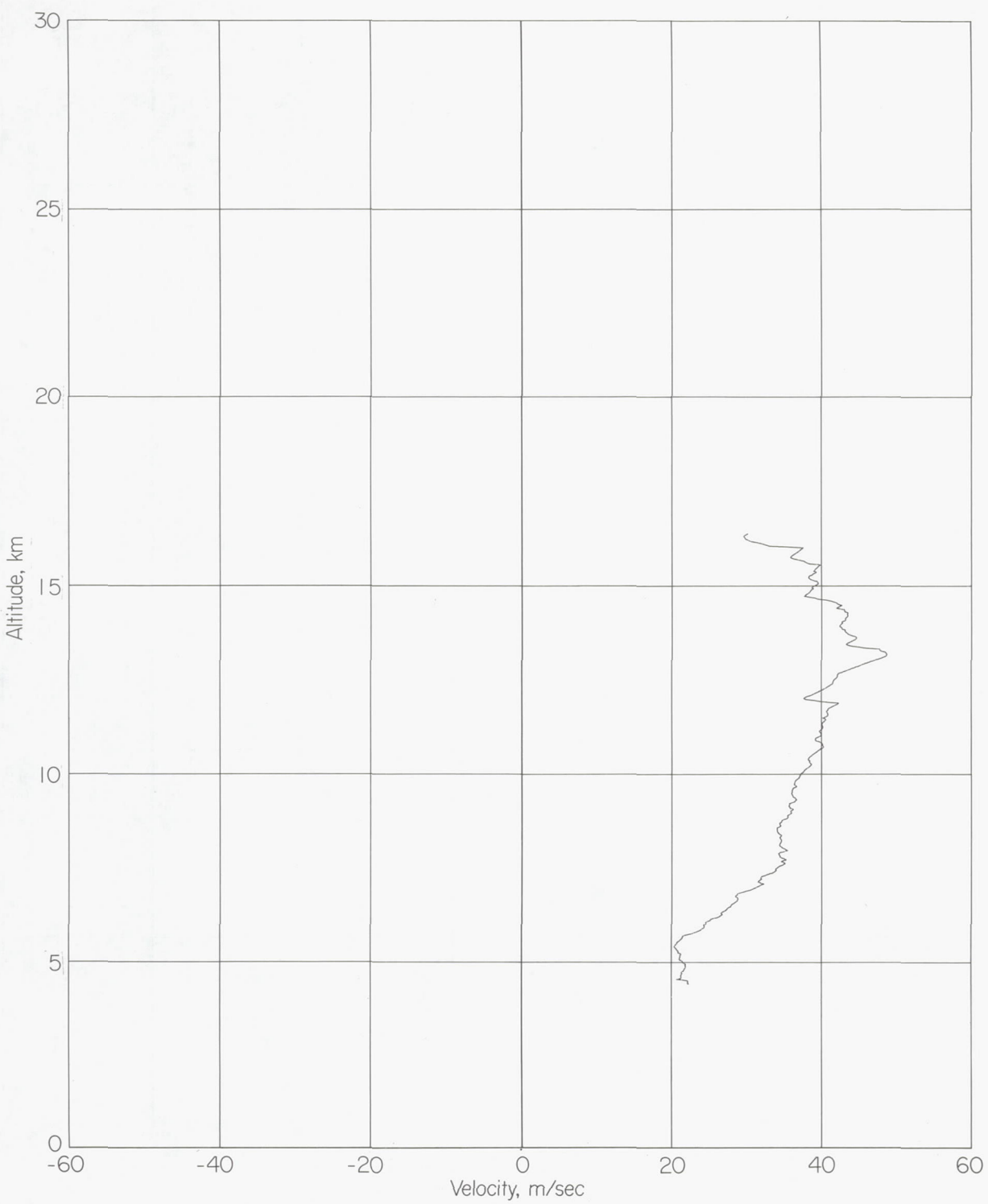
(a) West-to-east velocity component.

Figure 10.- Wind profile of smoke trail 335 obtained January 22, 1963. Time interval, 60 seconds; height interval, 25 meters.



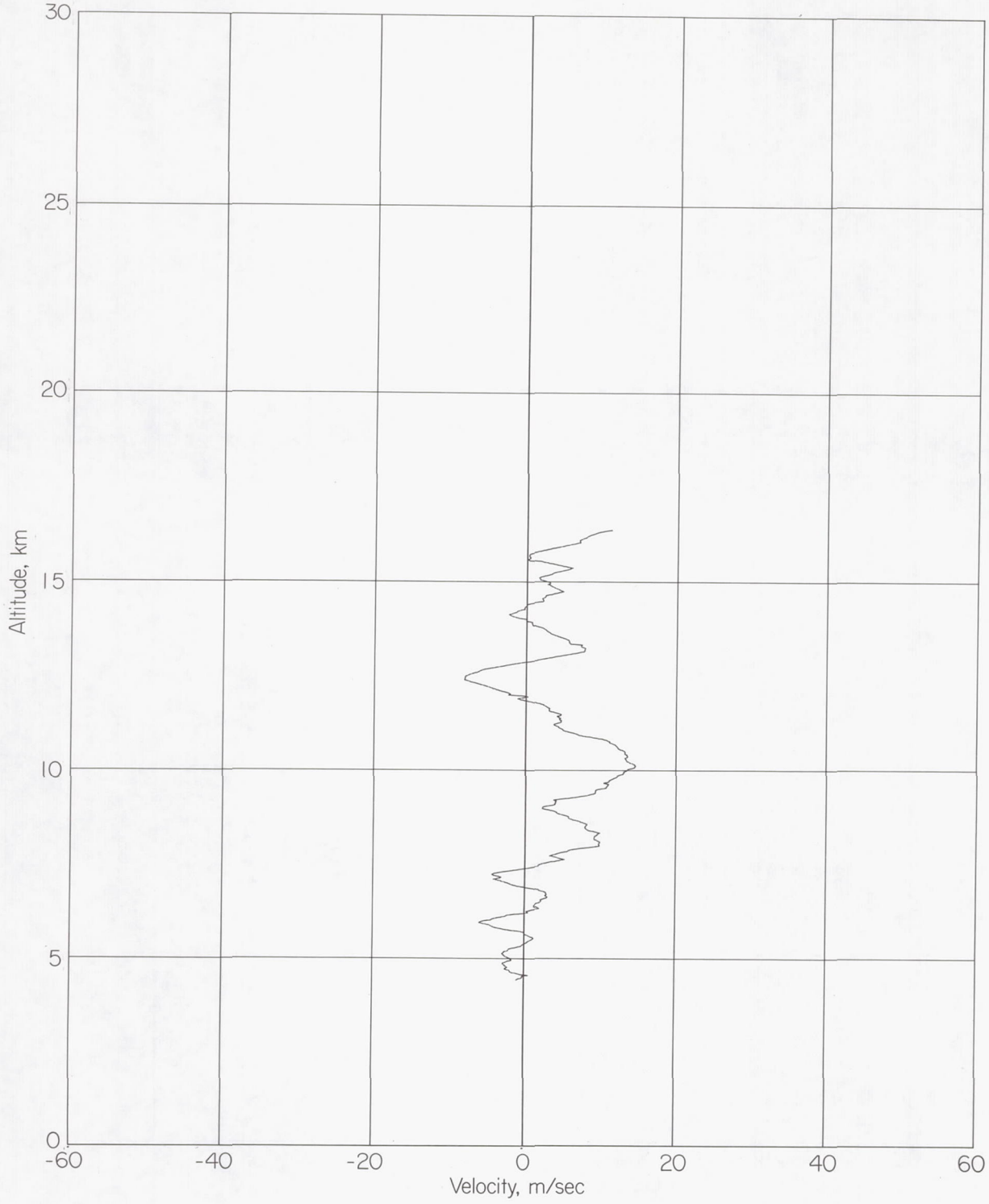
(b) South-to-north velocity component.

Figure 10.- Concluded.



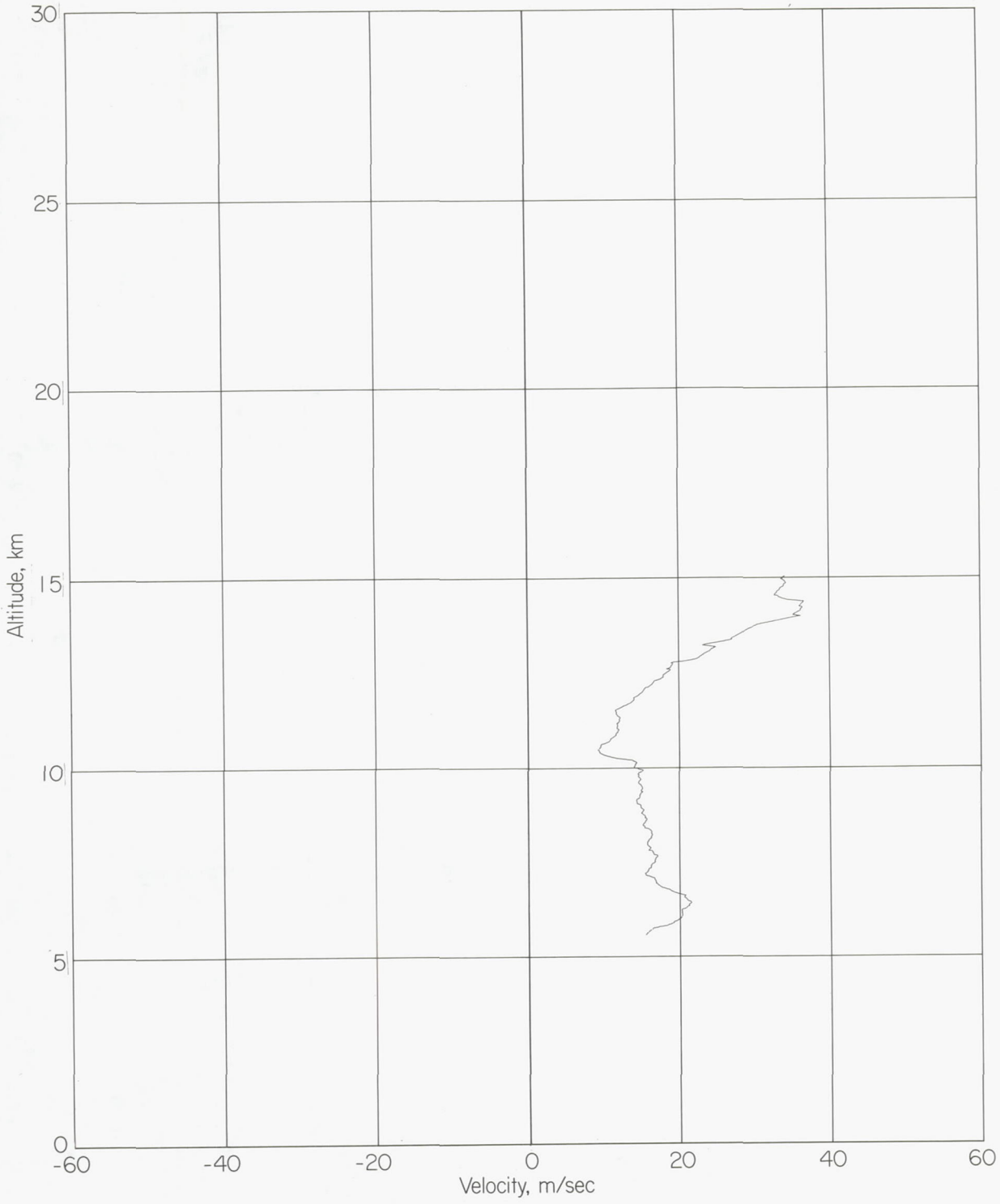
(a) West-to-east velocity component.

Figure 11.- Wind profile of smoke trail 336 obtained January 28, 1963. Time interval, 60 seconds; height interval, 25 meters.



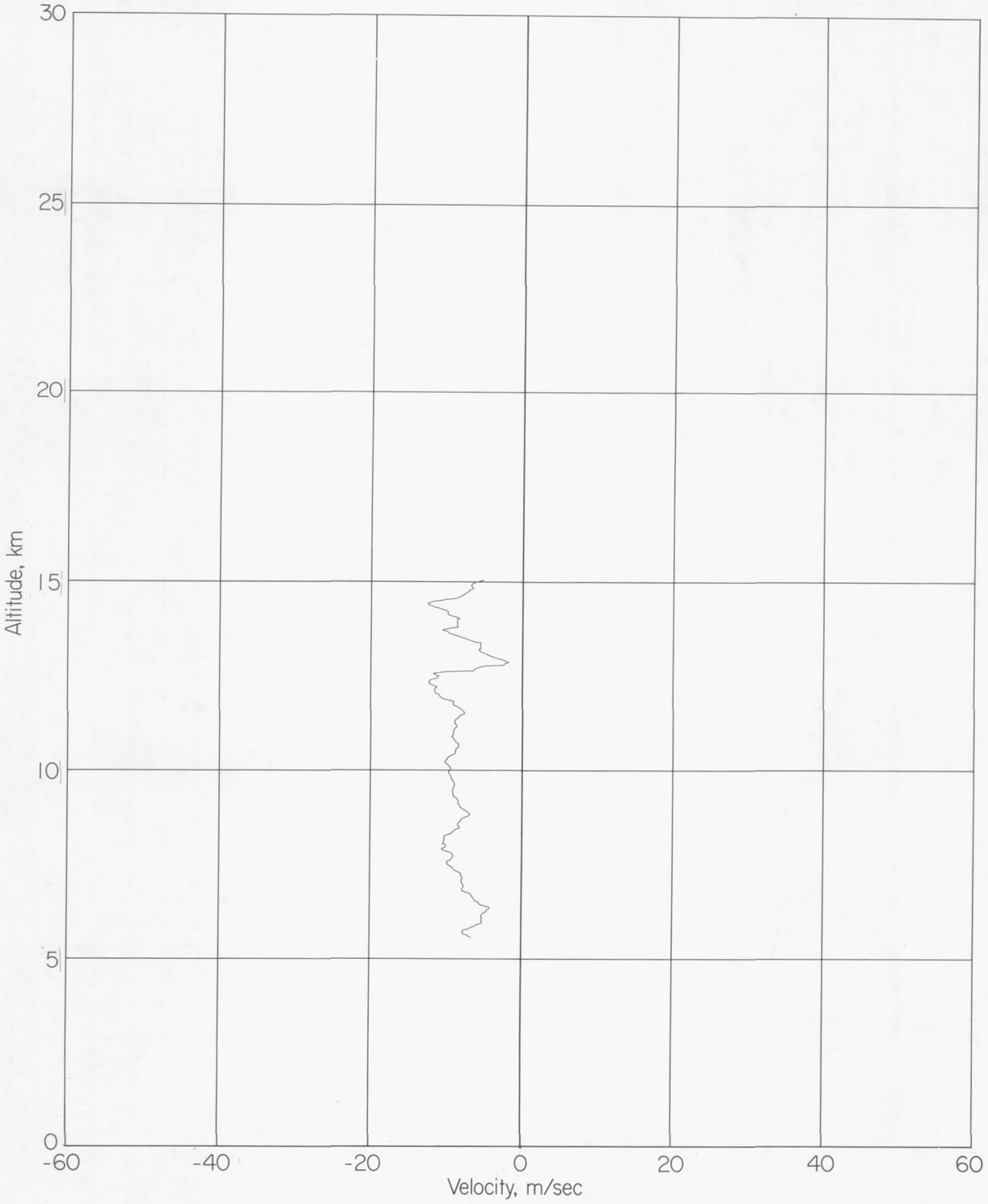
(b) South-to-north velocity component.

Figure 11.- Concluded.



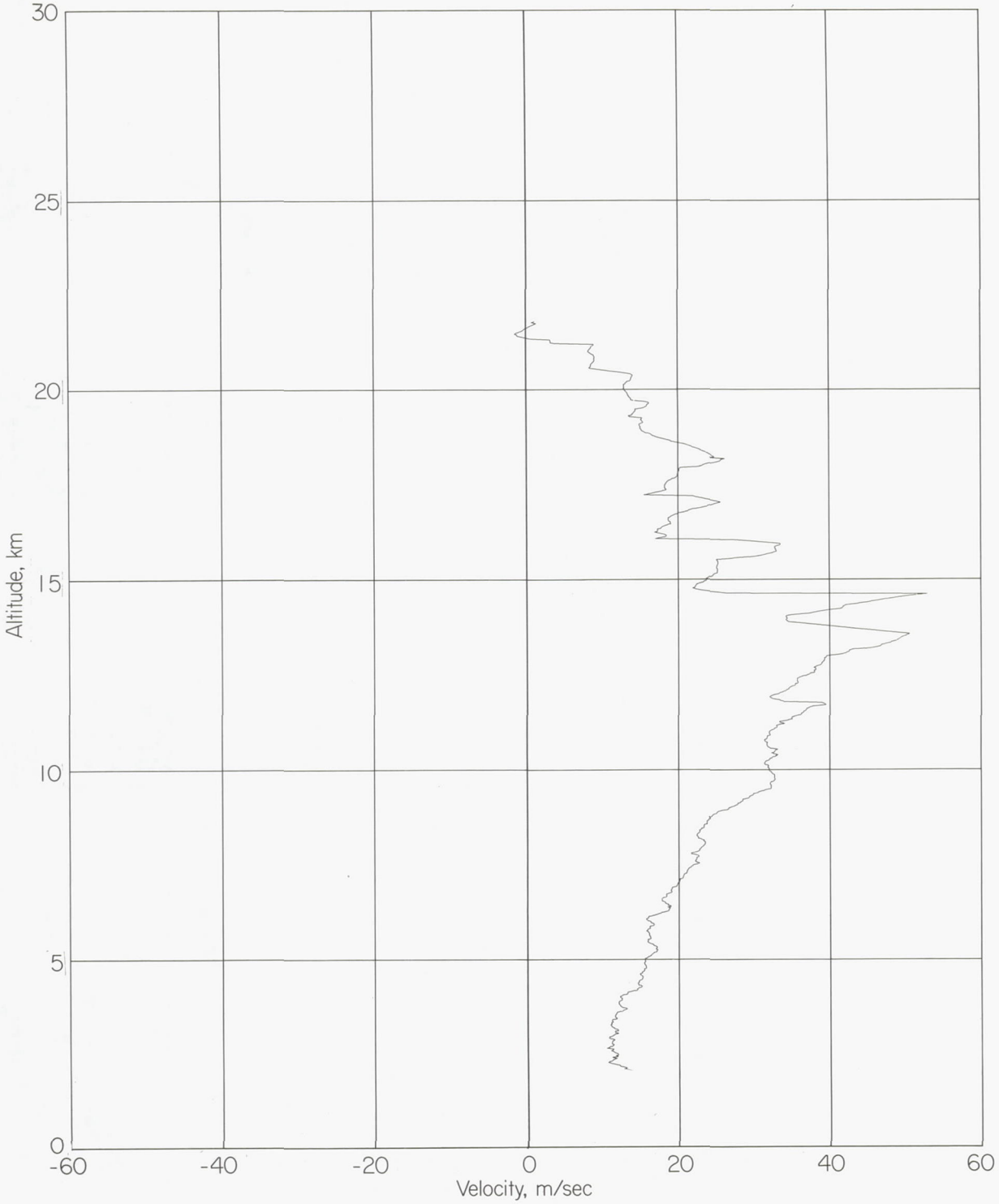
(a) West-to-east velocity component.

Figure 12.- Wind profile of smoke trail 337 obtained January 31, 1963. Time interval, 60 seconds; height interval, 25 meters.



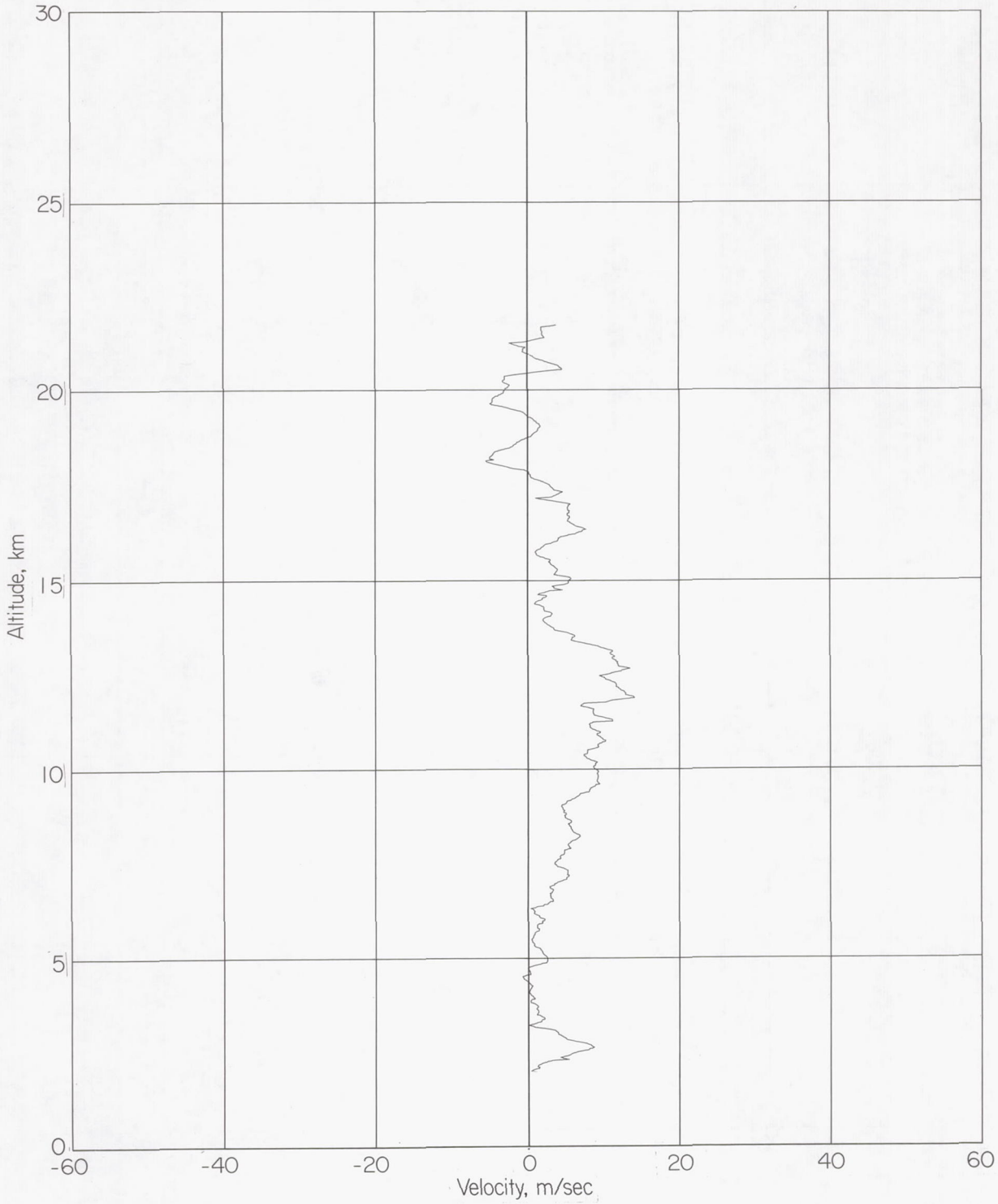
(b) South-to-north velocity component.

Figure 12.- Concluded.



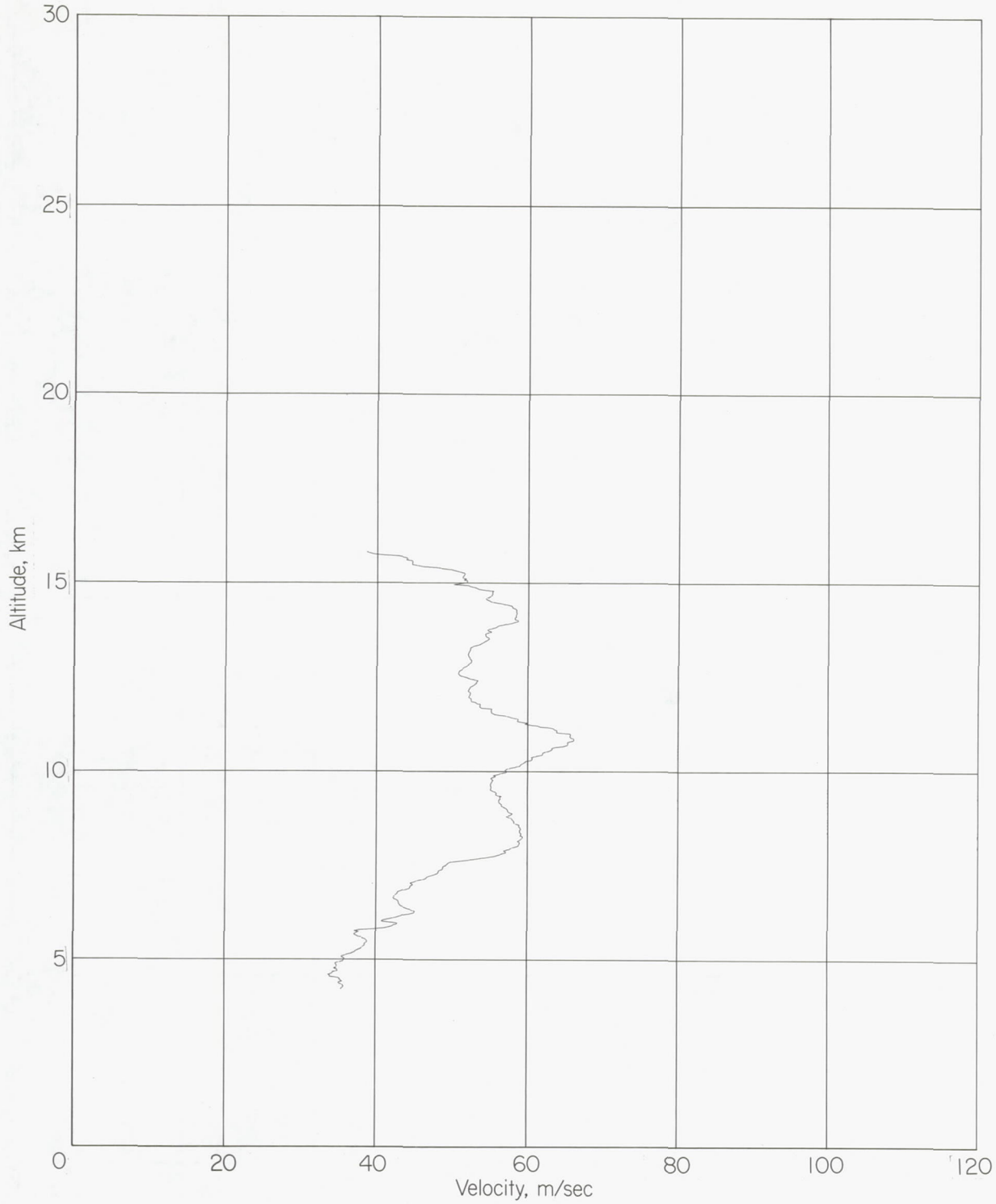
(a) West-to-east velocity component.

Figure 13.- Wind profile of smoke trail 338 obtained February 7, 1963. Time interval, 60 seconds; height interval, 25 meters.



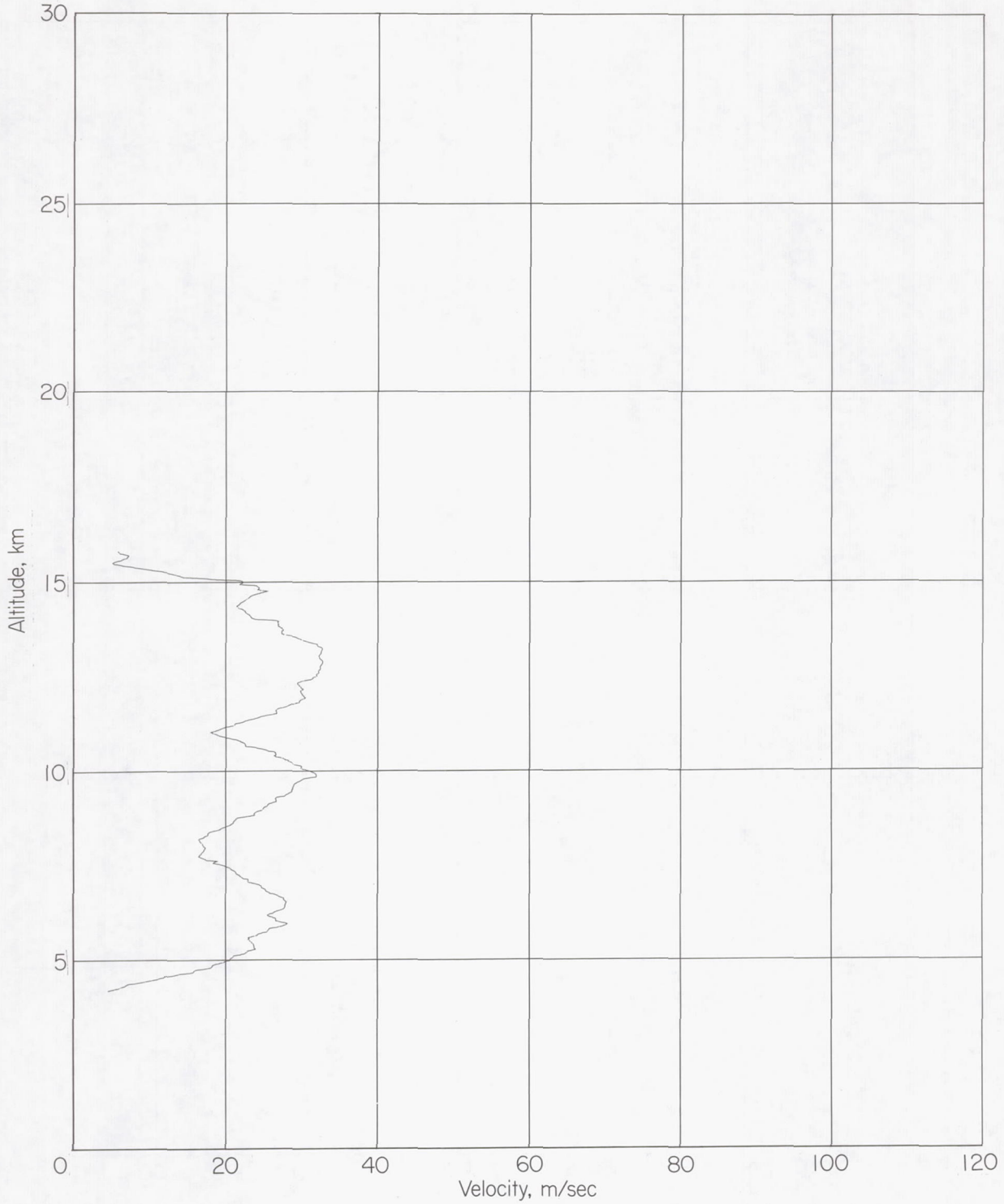
(b) South-to-north velocity component.

Figure 13.- Concluded.



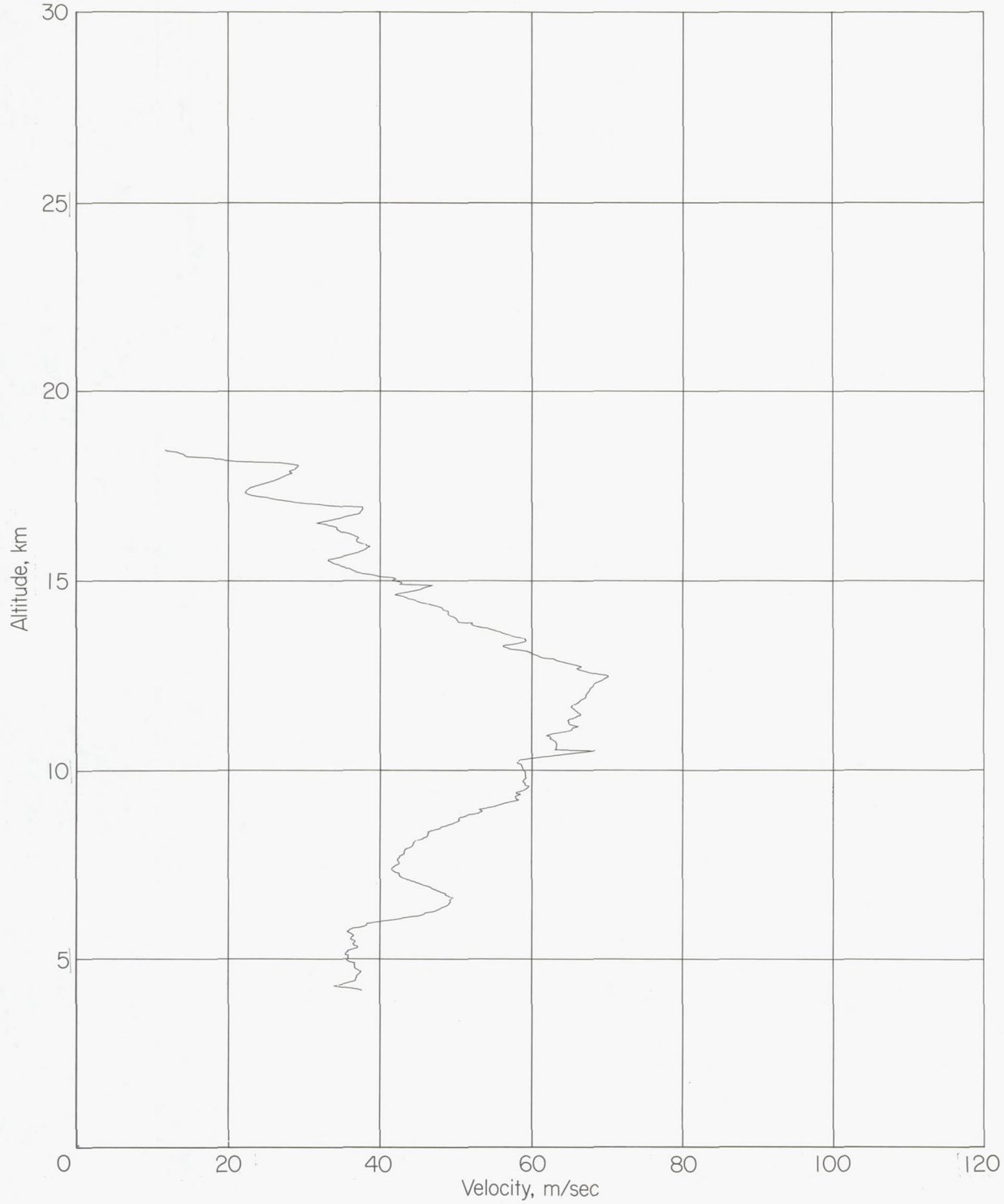
(a) West-to-east velocity component.

Figure 14.- Wind profile of smoke trail 339 obtained February 13, 1963. Time interval, 60 seconds; height interval, 25 meters.



(b) South-to-north velocity component.

Figure 14.- Concluded.

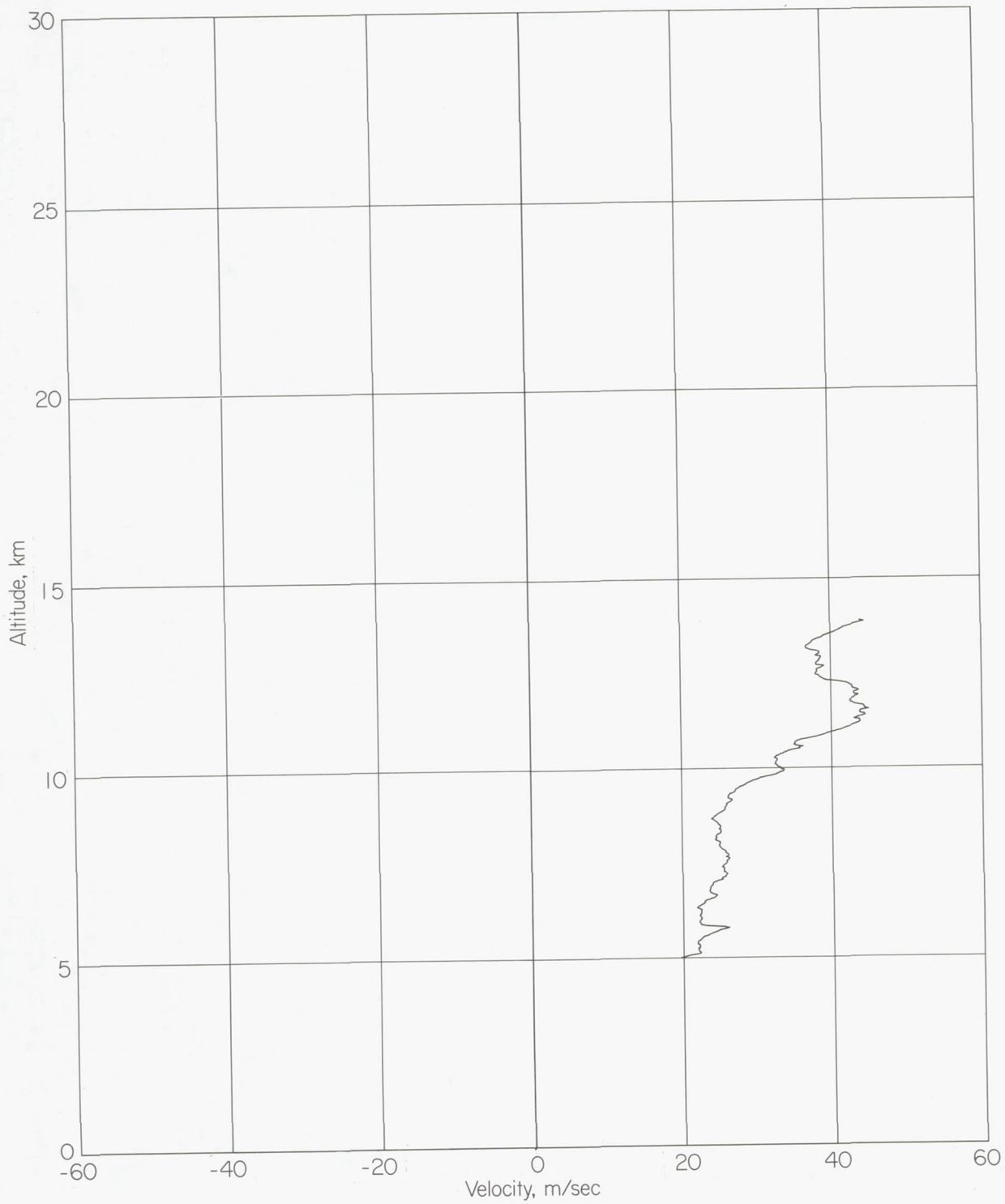


(a) West-to-east velocity component.

Figure 15.- Wind profile of smoke trail 340 obtained February 20, 1963. Time interval, 60 seconds; height interval, 25 meters.

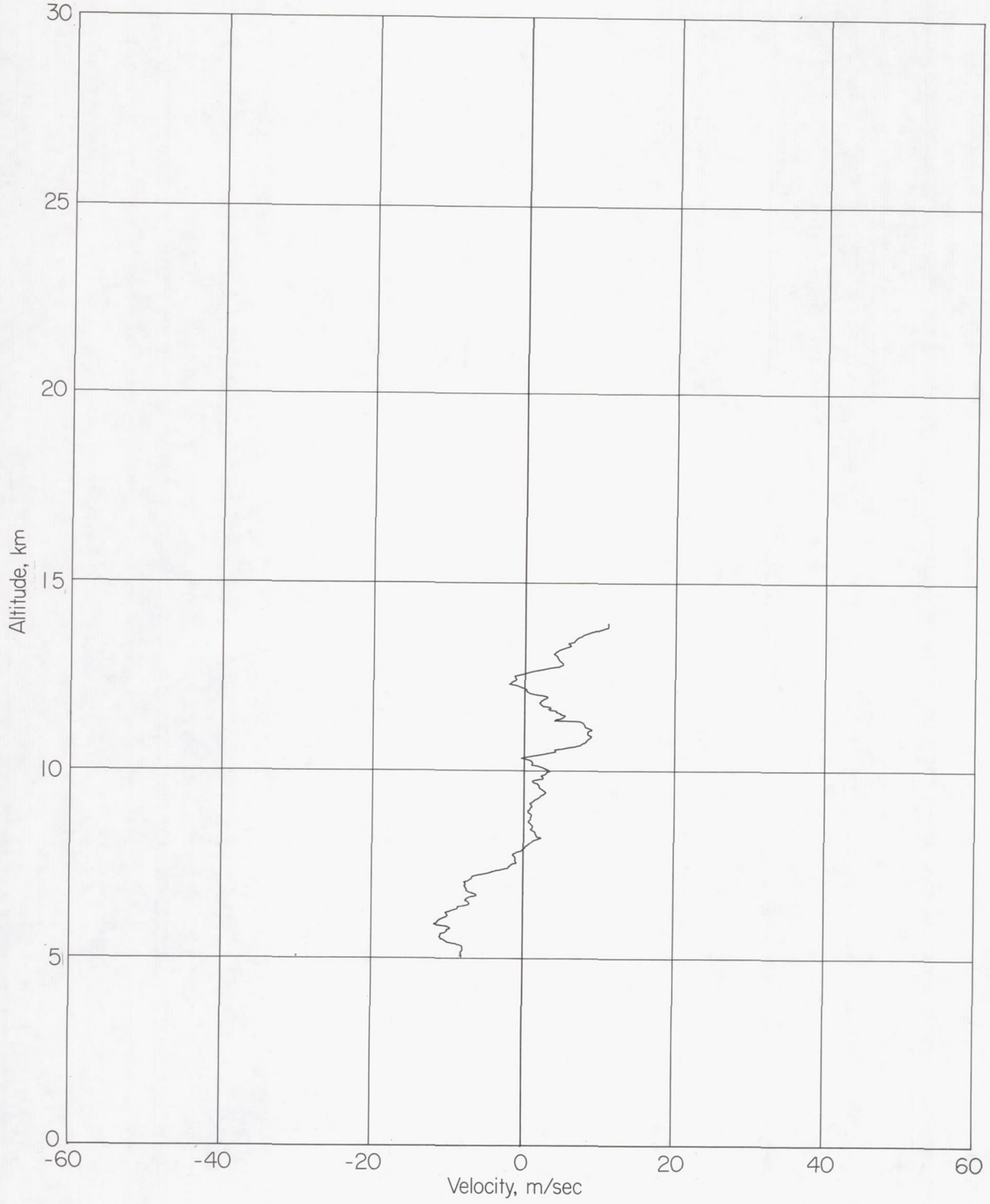
(b) South-to-north velocity component.

Figure 15.- Concluded.



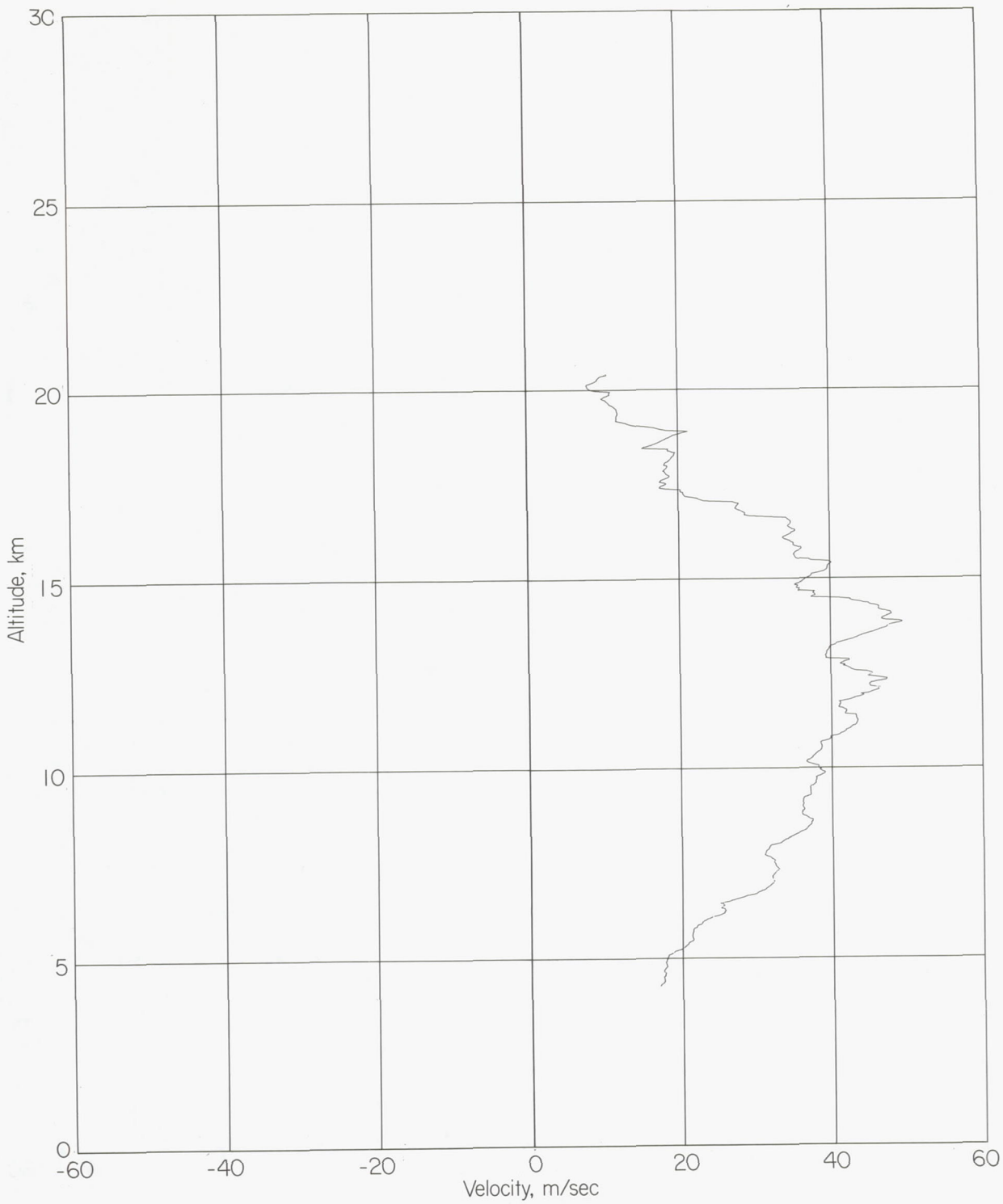
(a) West-to-east velocity component.

Figure 16.- Wind profile at smoke trail 341 obtained February 27, 1963. Time interval, 60 seconds; height interval, 25 meters.



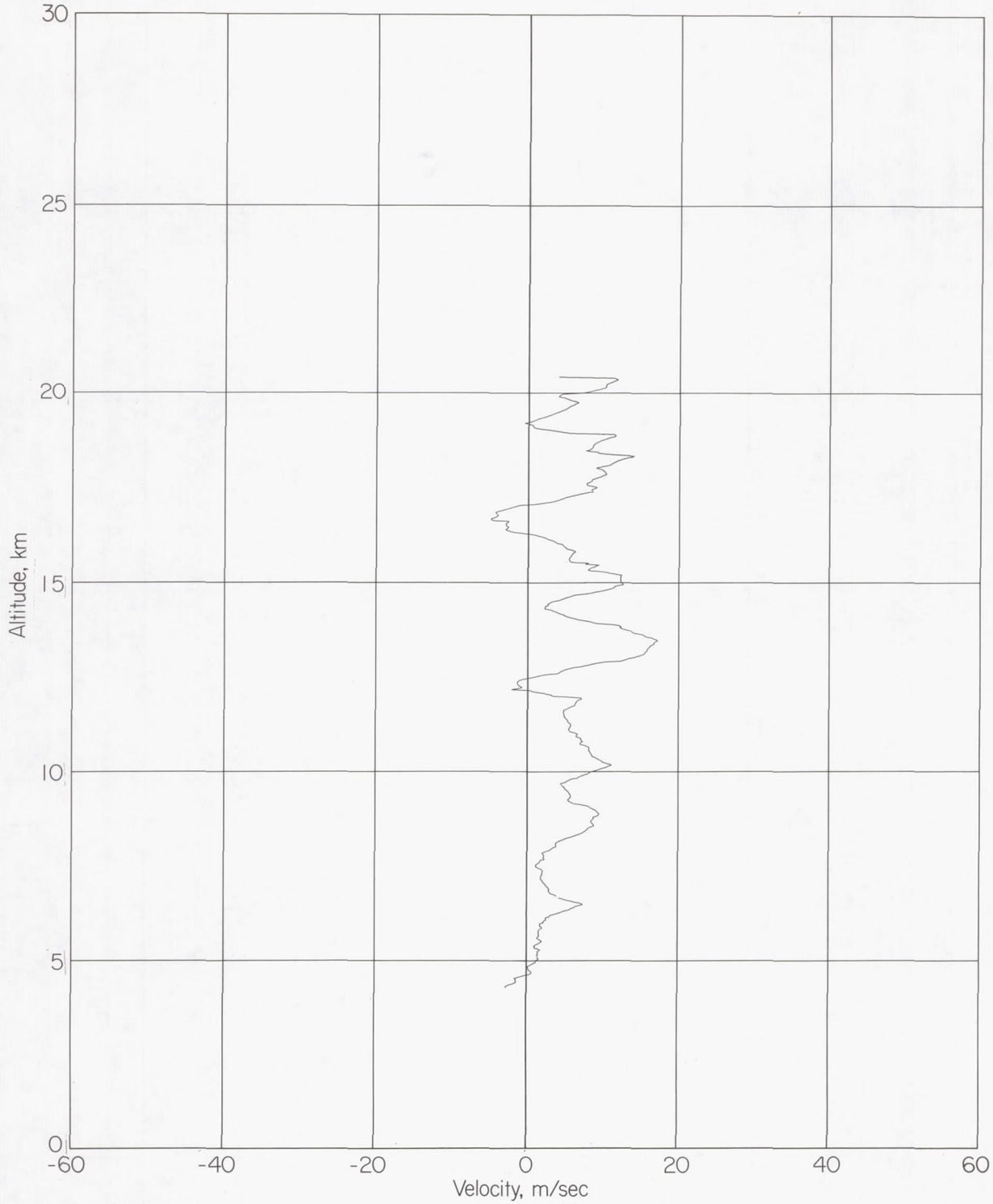
(b) South-to-north velocity component.

Figure 16.- Concluded.



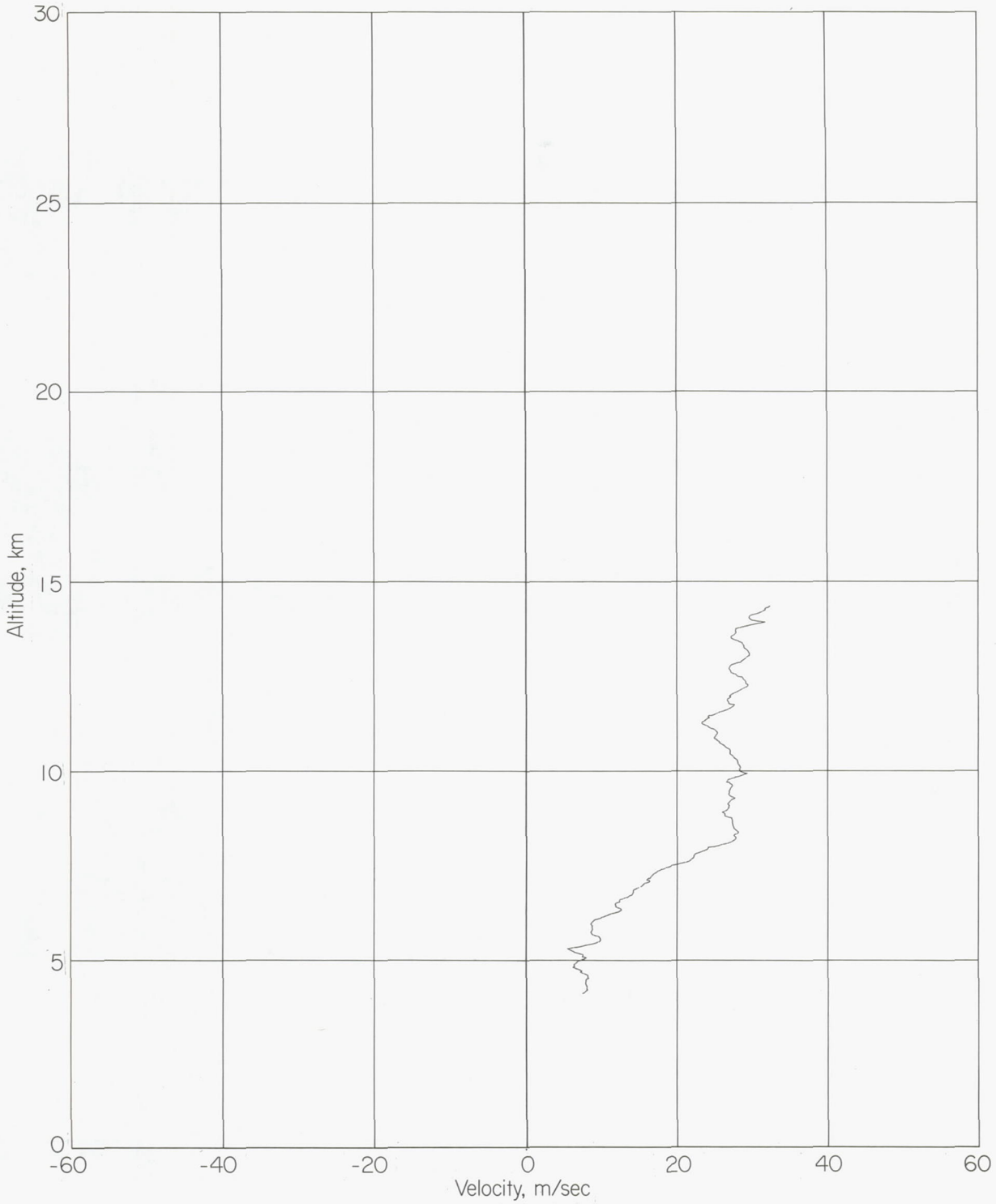
(a) West-to-east velocity component.

Figure 17.- Wind profile of smoke trail 342 obtained March 8, 1963. Time interval, 60 seconds; height interval, 25 meters.



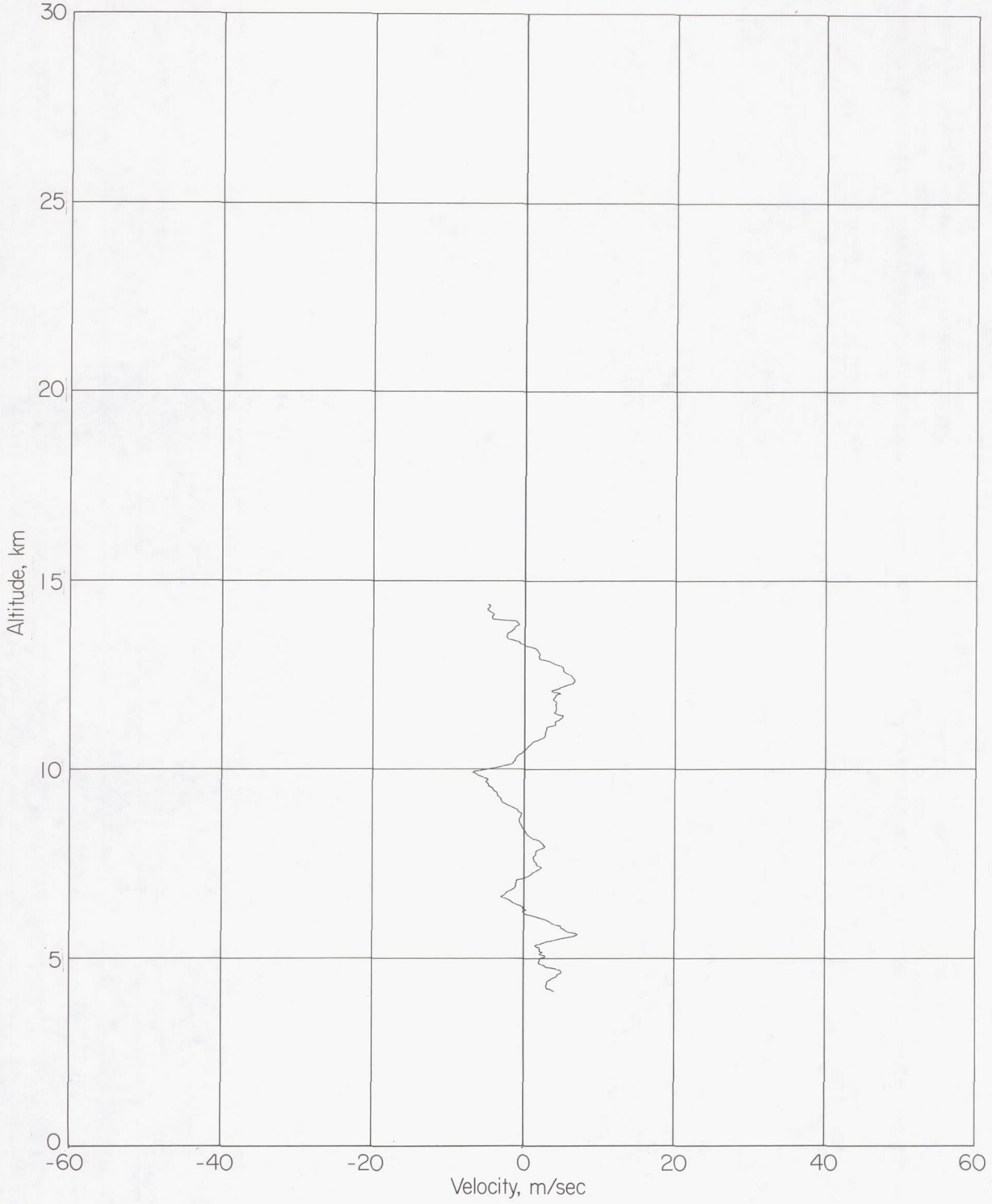
(b) South-to-north velocity component.

Figure 17.- Concluded.



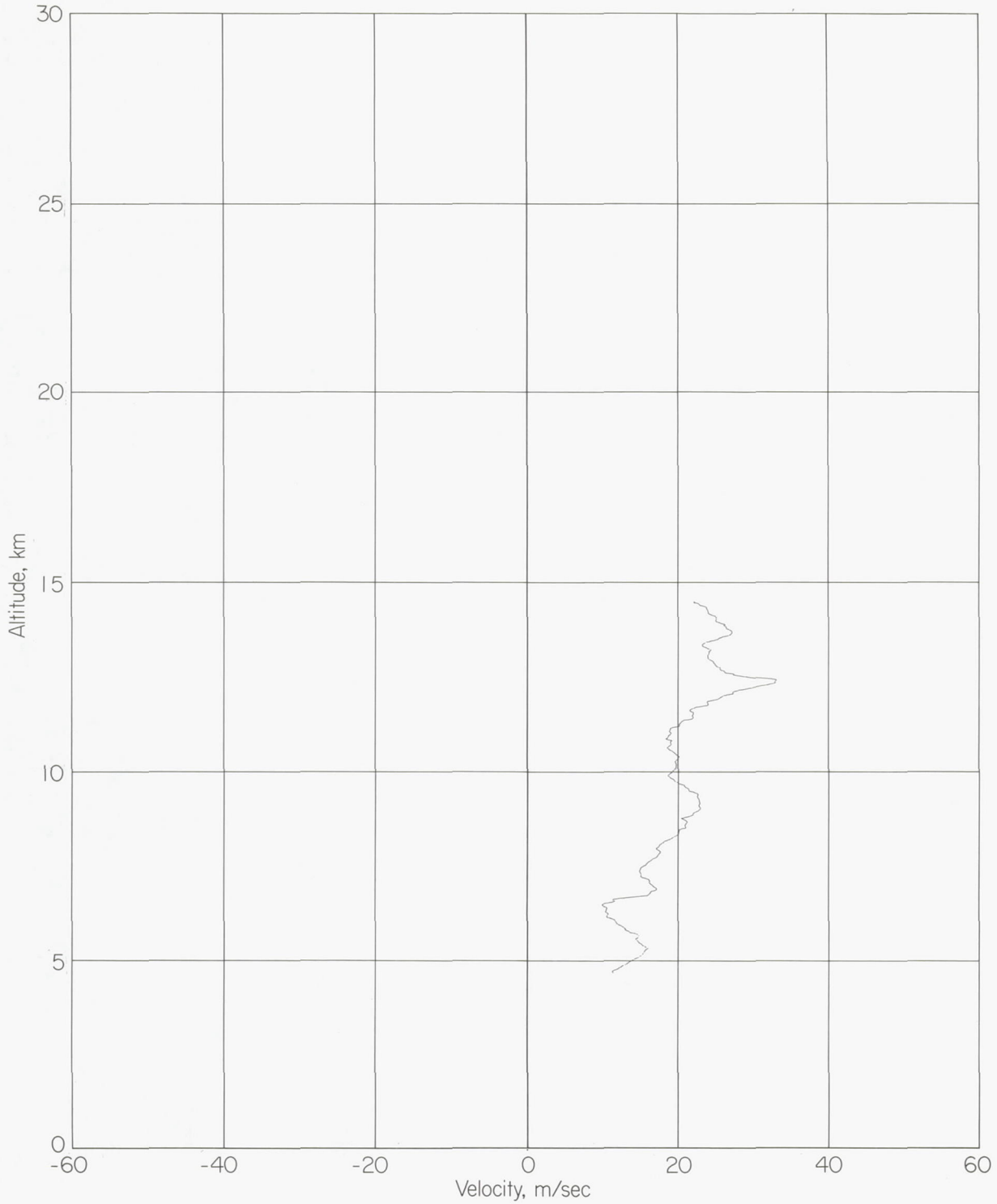
(a) West-to-east velocity component.

Figure 18.- Wind profile of smoke trail 343 obtained March 11, 1963. Time interval, 60 seconds; height interval, 25 meters.



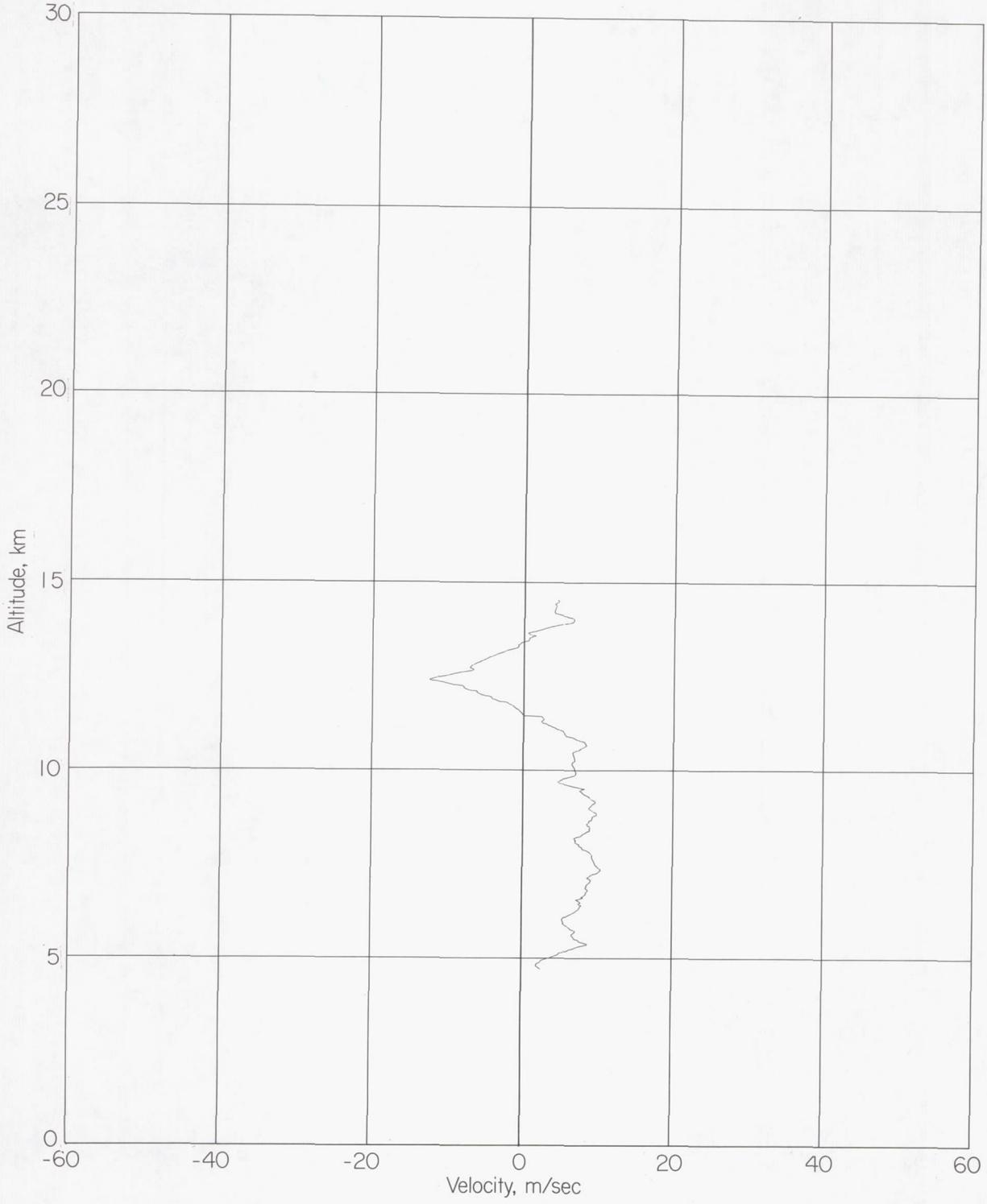
(b) South-to-north velocity component.

Figure 18.- Concluded.



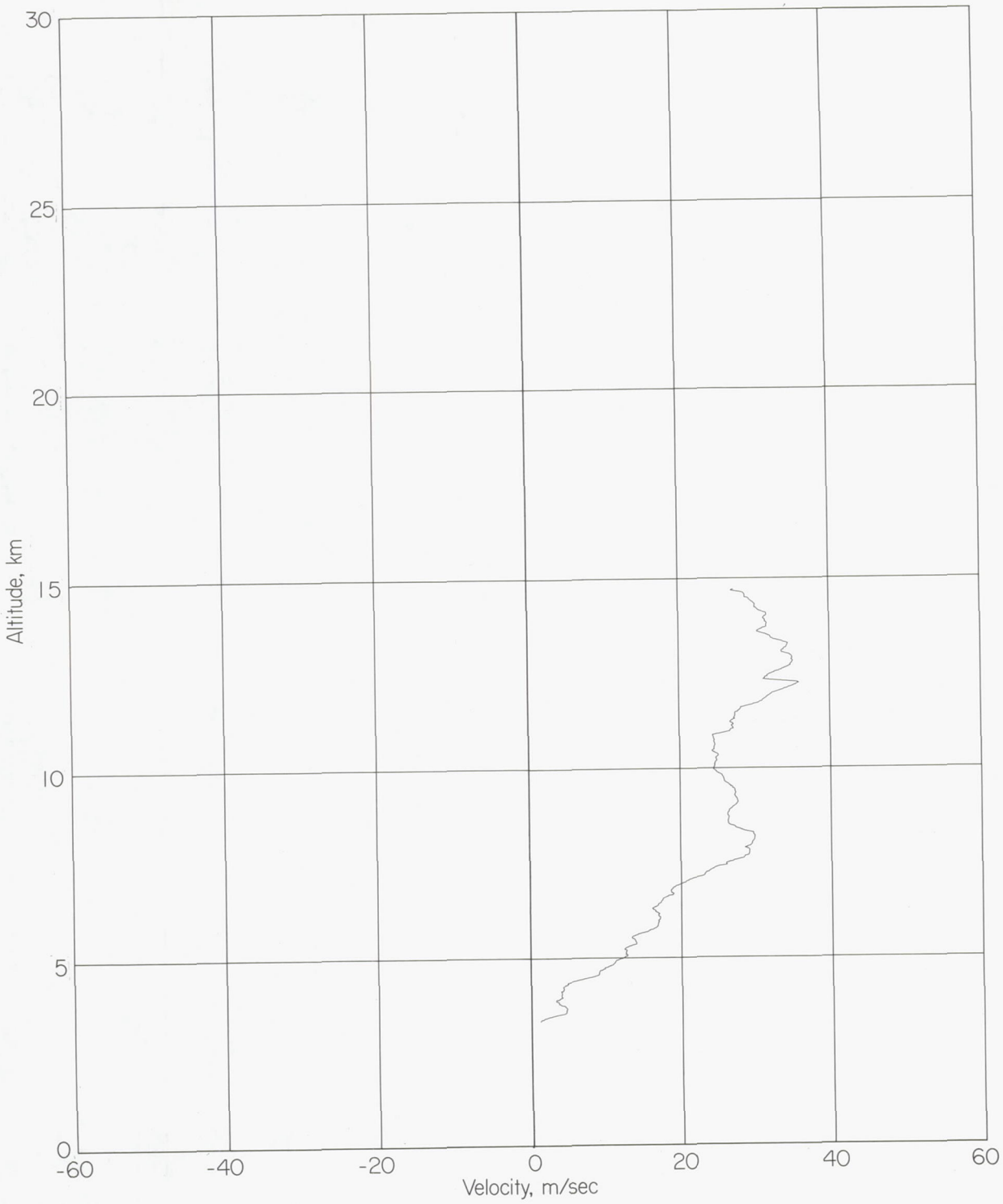
(a) West-to-east velocity component.

Figure 19.- Wind profile of smoke trail 344 obtained March 12, 1963. Time interval, 60 seconds; height interval, 25 meters.



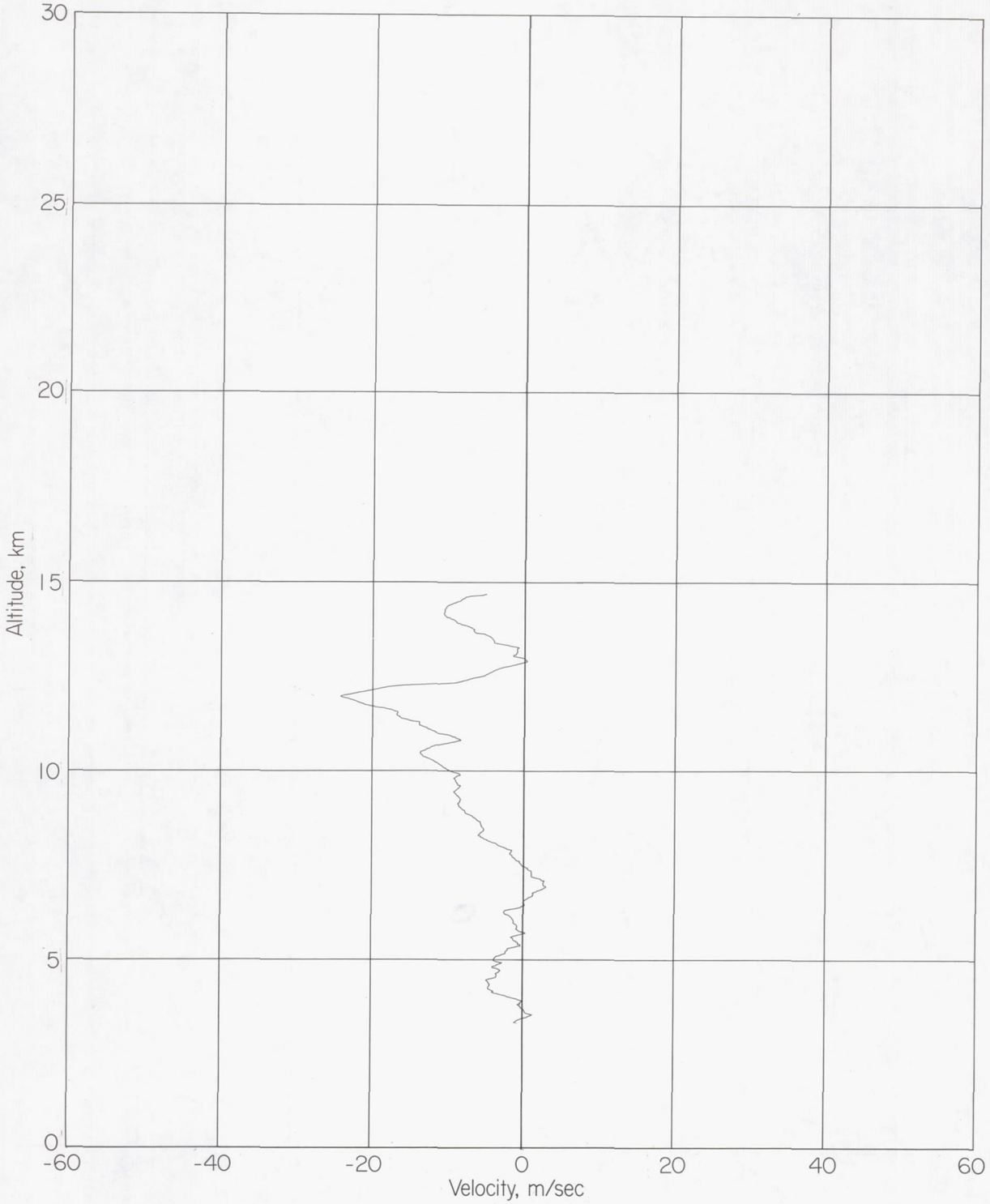
(b) South-to-north velocity component.

Figure 19.- Concluded.



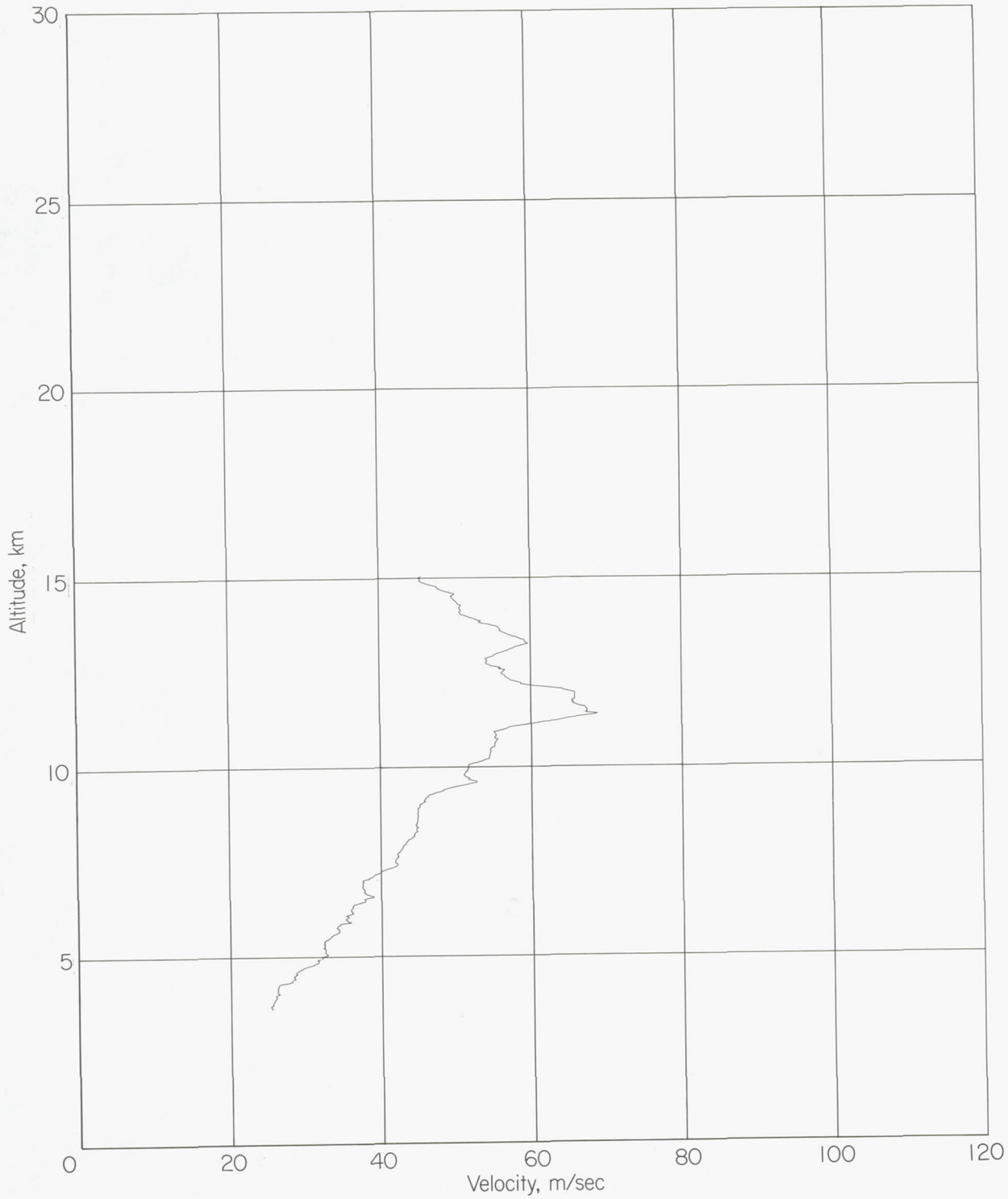
(a) West-to-east velocity component.

Figure 20.- Wind profile of smoke trail 345 obtained March 18, 1963. Time interval, 60 seconds; height interval, 25 meters.



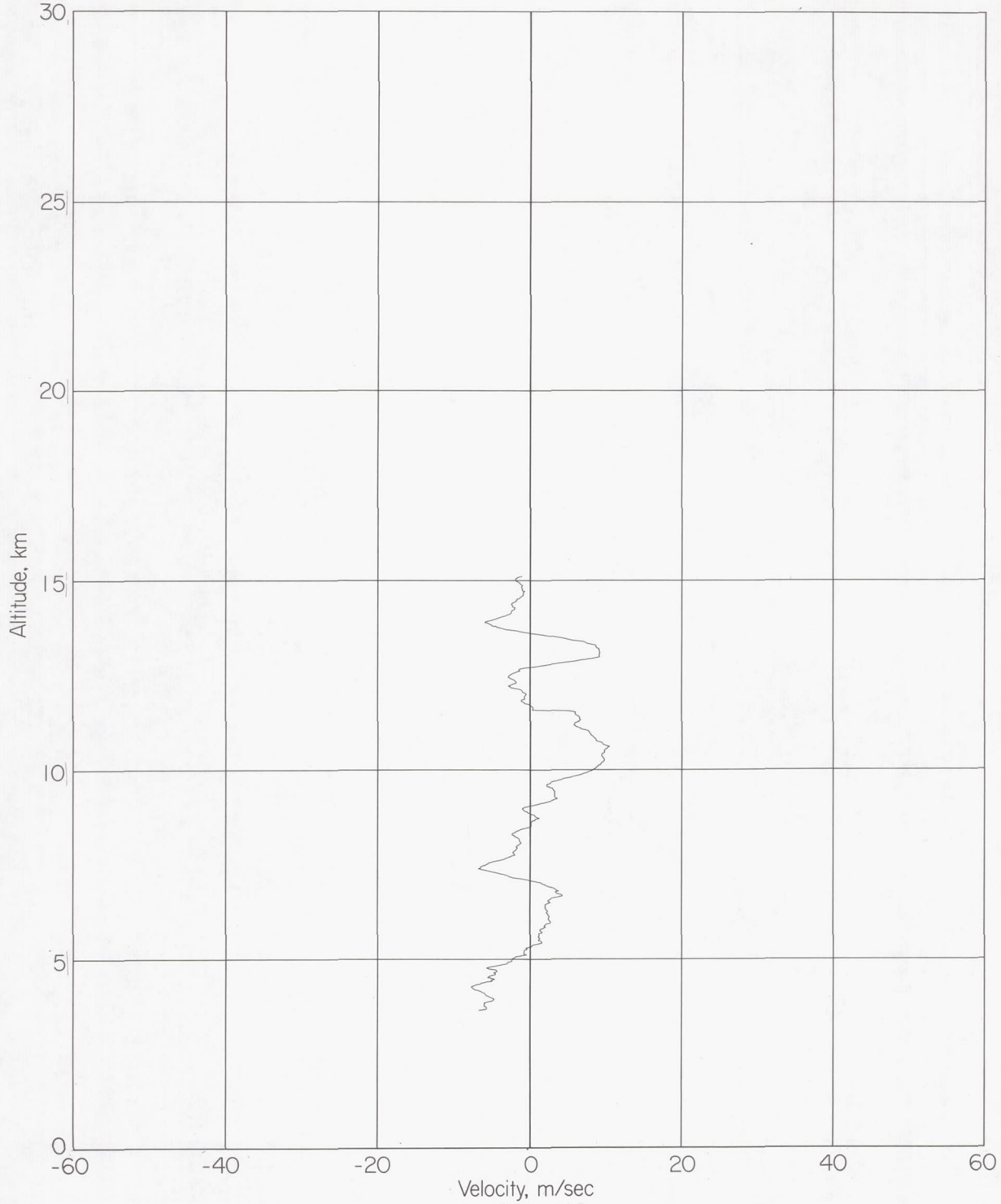
(b) South-to-north velocity component.

Figure 20.- Concluded.



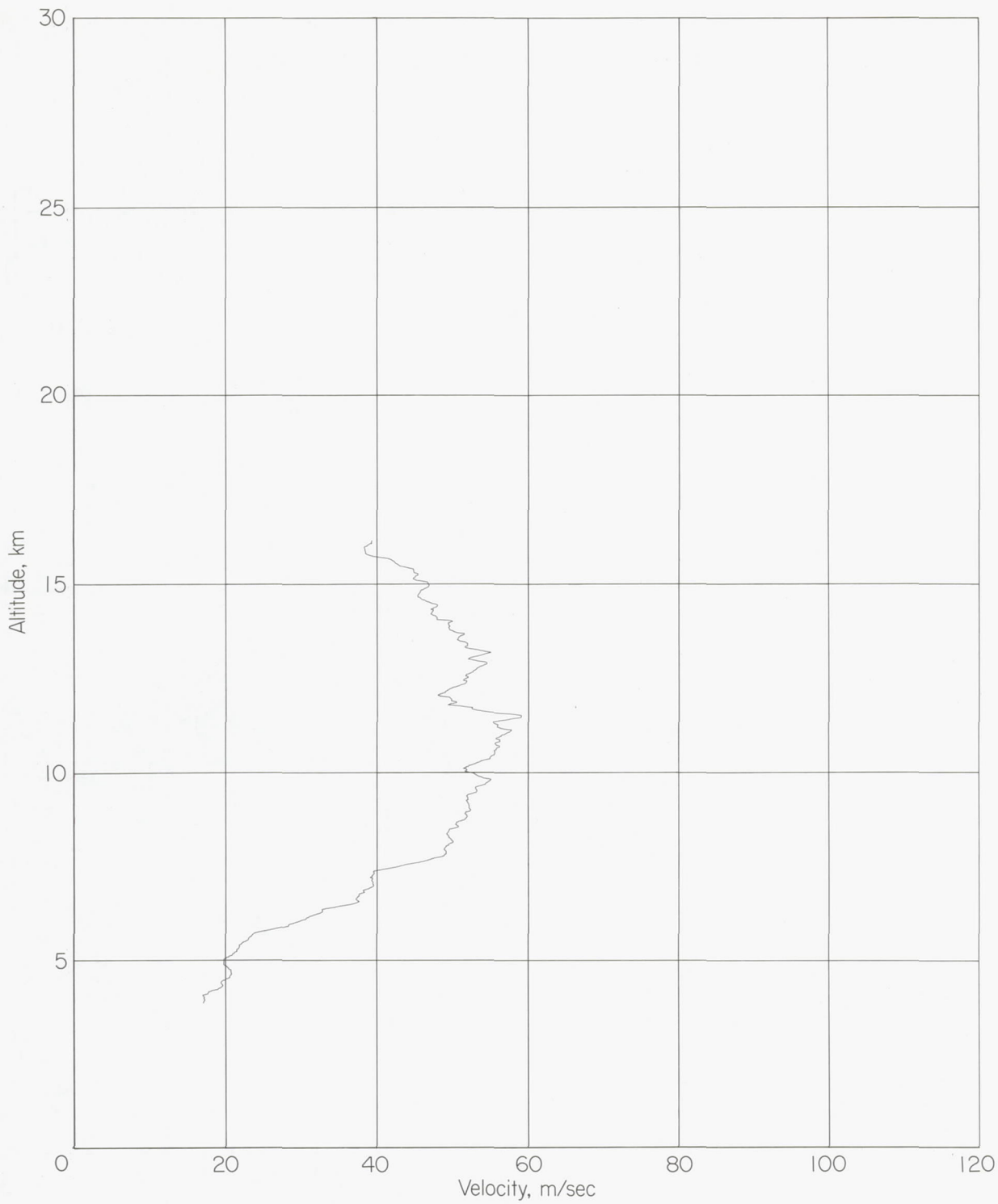
(a) West-to-east velocity component.

Figure 21.- Wind profile of smoke trail 346 obtained March 21, 1963. Time interval, 60 seconds; height interval, 25 meters.



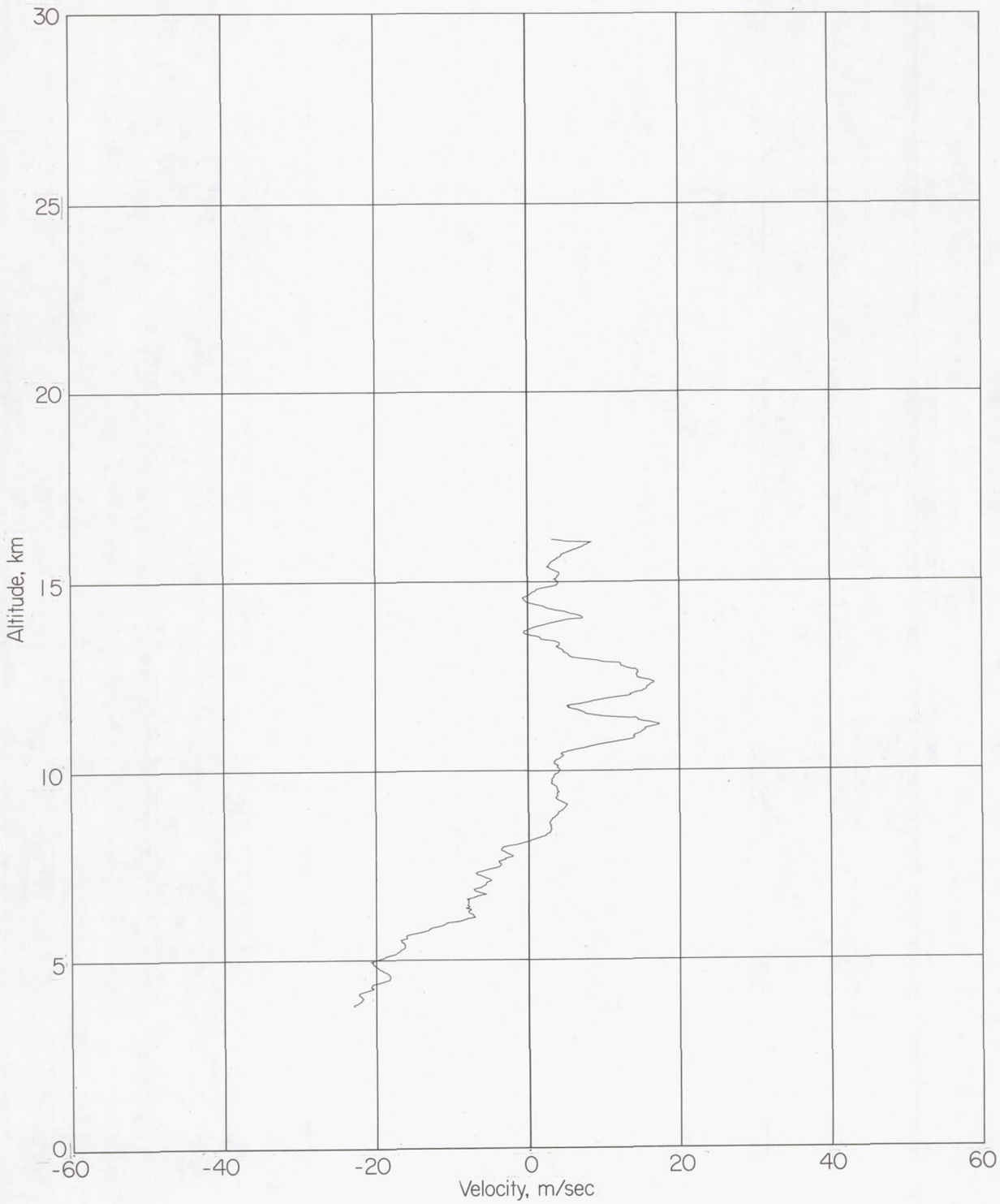
(b) South-to-north velocity component.

Figure 21.- Concluded.



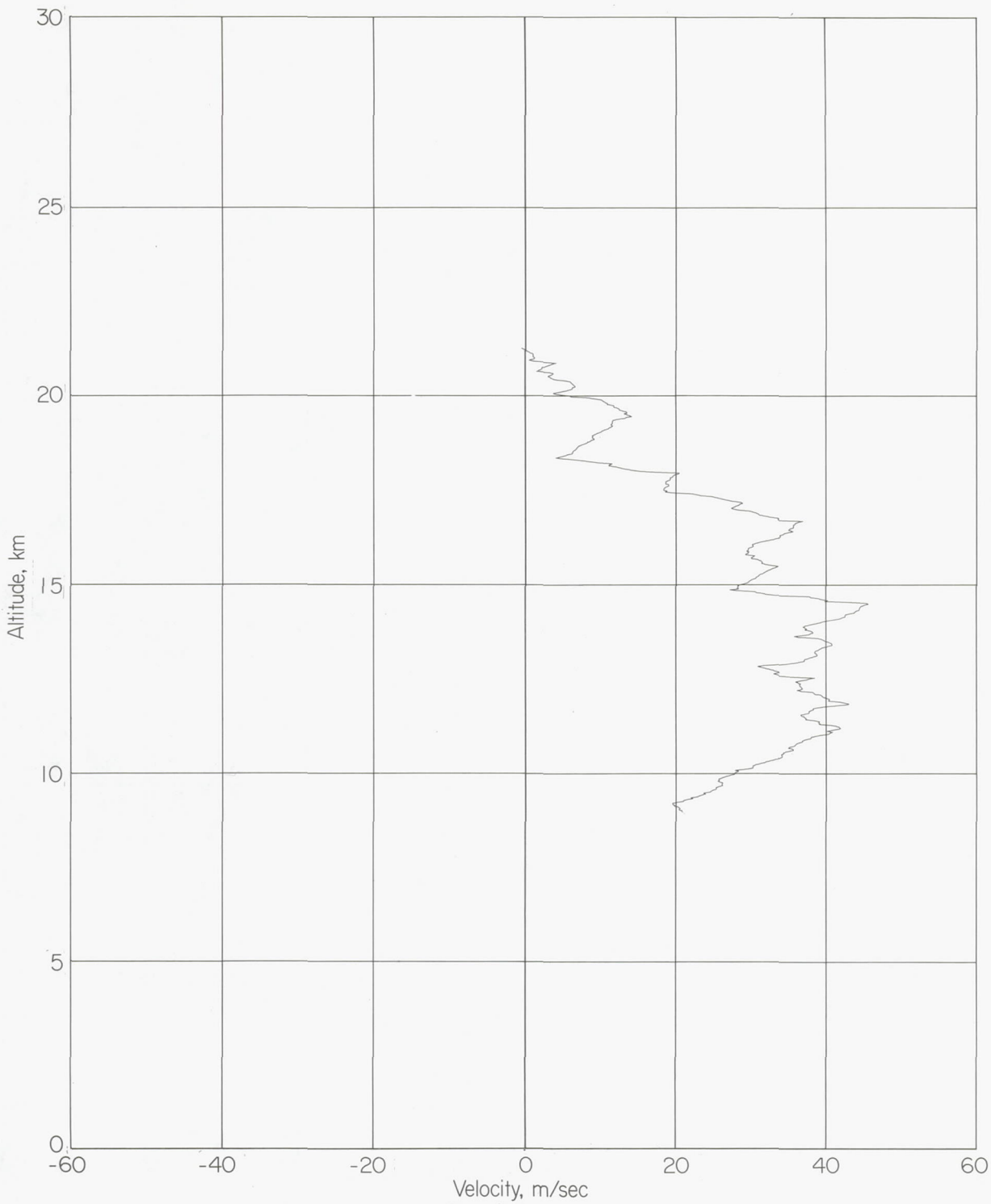
(a) West-to-east velocity component.

Figure 22.- Wind profile of smoke trail 347 obtained March 22, 1963. Time interval, 60 seconds; height interval, 25 meters.



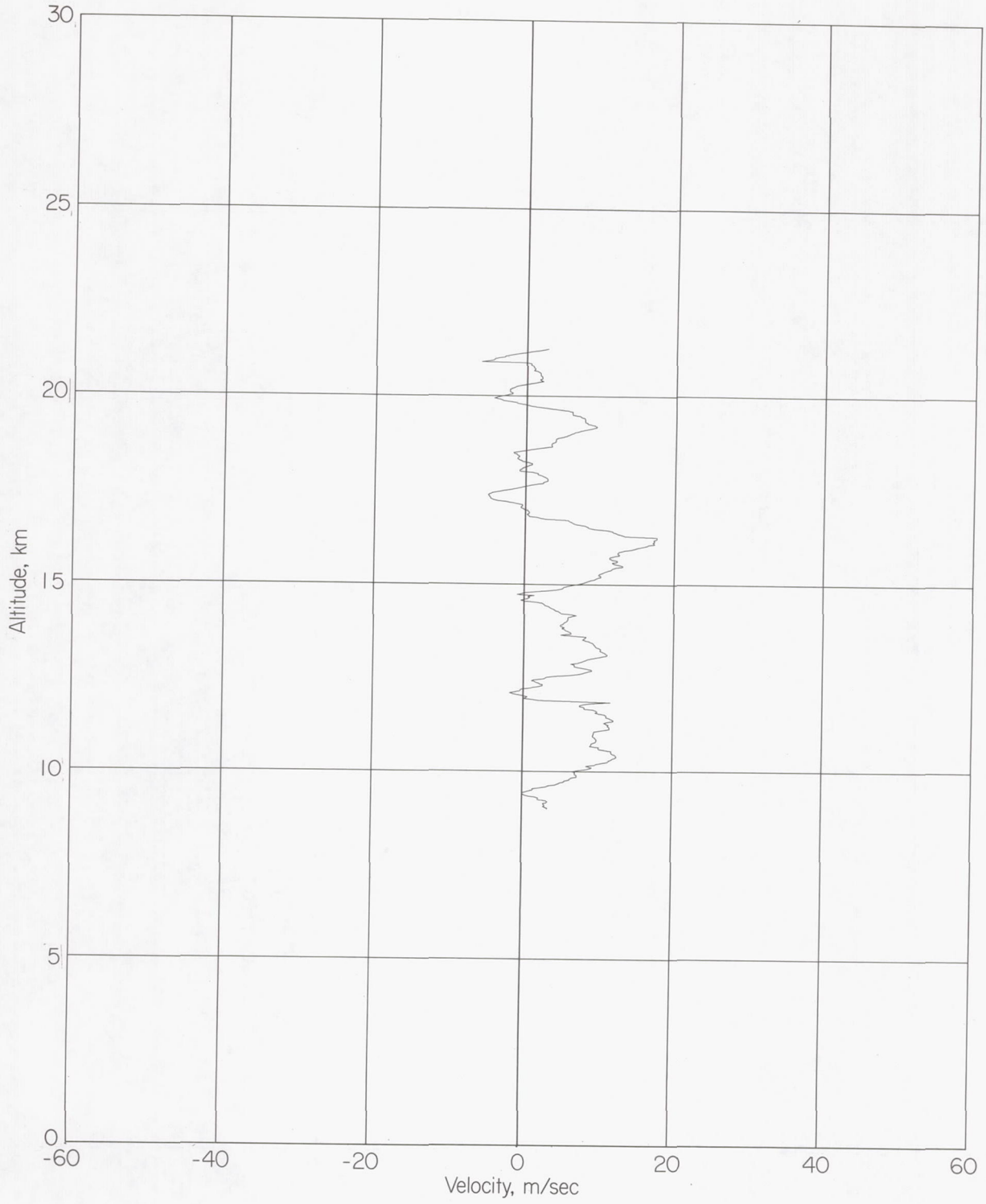
(b) South-to-north velocity component.

Figure 22.- Concluded.



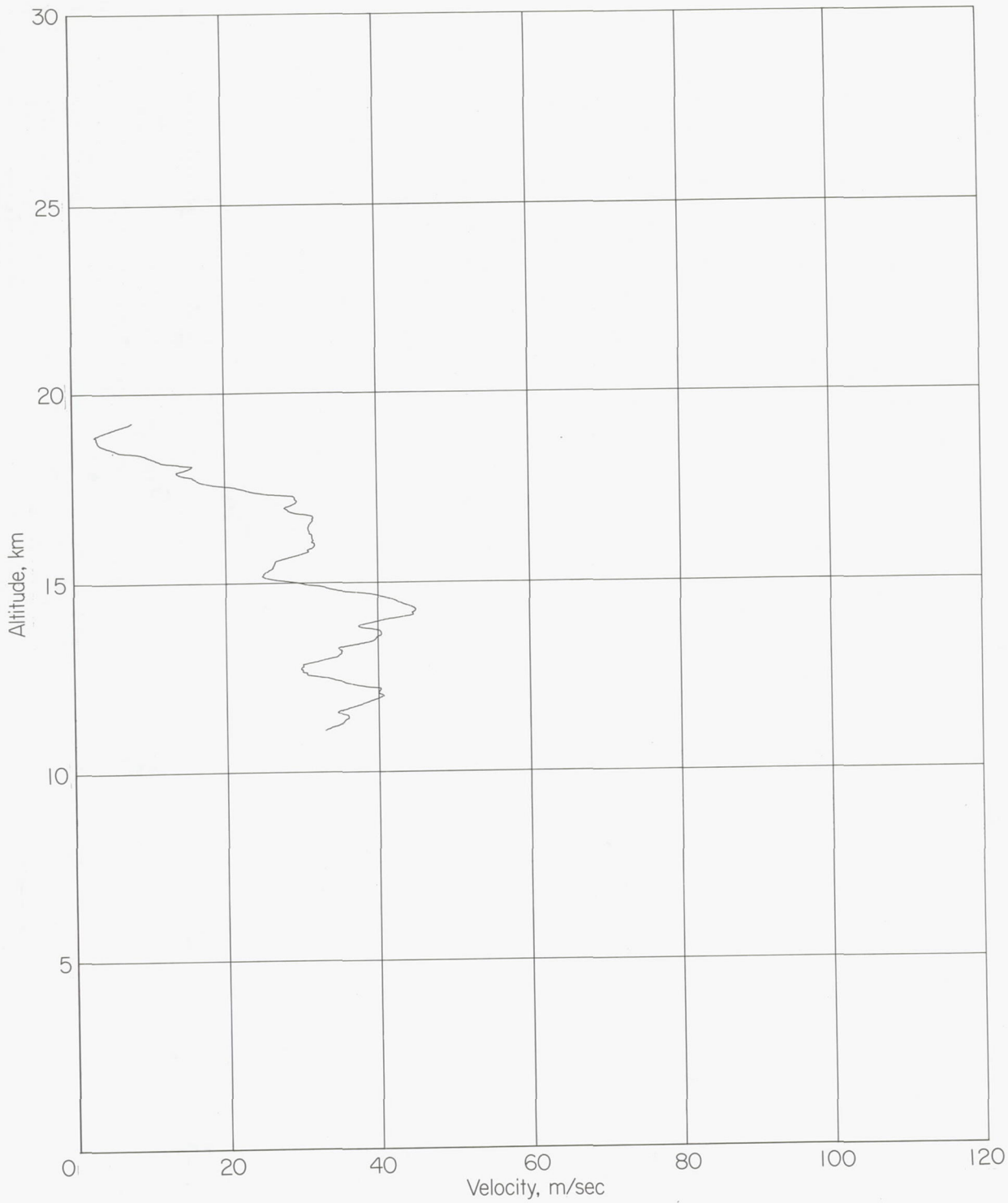
(a) West-to-east velocity component.

Figure 23.- Wind profile of smoke trail 348 obtained March 28, 1963. Time interval, 30 seconds; height interval, 25 meters.



(b) South-to-north velocity component.

Figure 23.- Concluded.

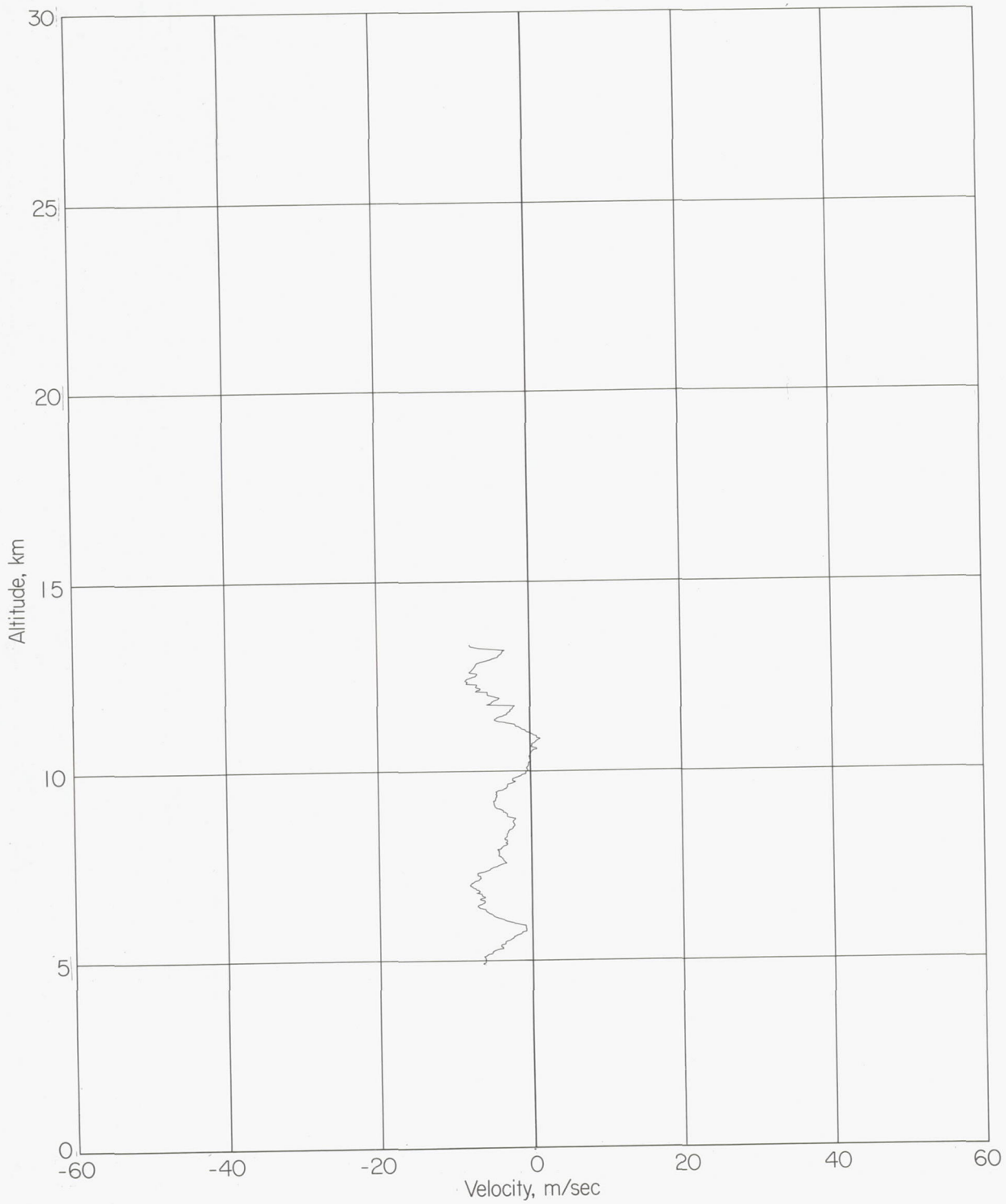


(a) West-to-east velocity component.

Figure 24.- Wind profile of smoke trail 408 obtained March 28, 1963. Time interval, 60 seconds; height interval, 25 meters.

(b) South-to-north velocity component.

Figure 24.- Concluded.

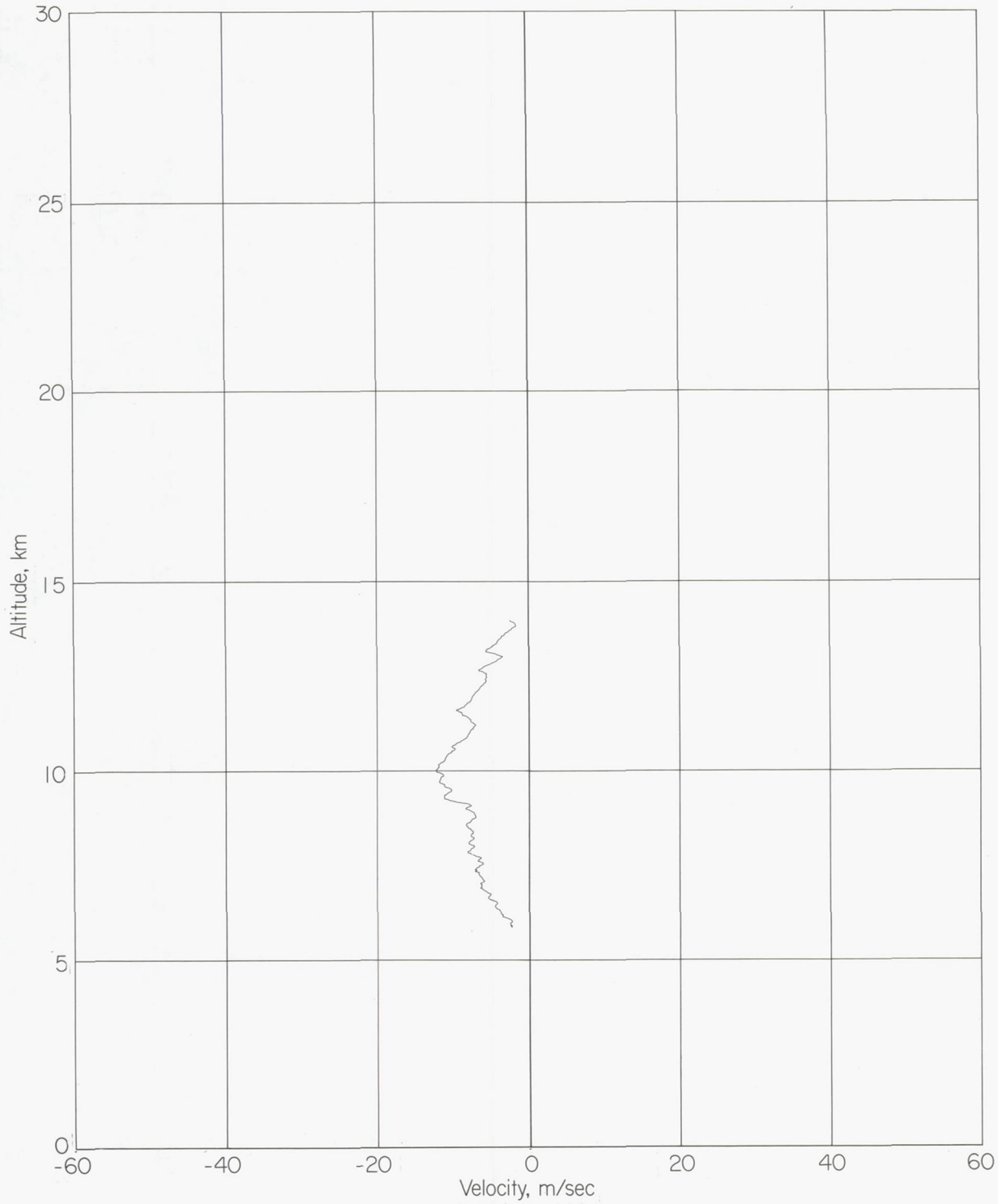


(a) West-to-east velocity component.

Figure 25.- Wind profile of smoke trail 349 obtained April 2, 1963. Time interval, 60 seconds; height interval, 25 meters.

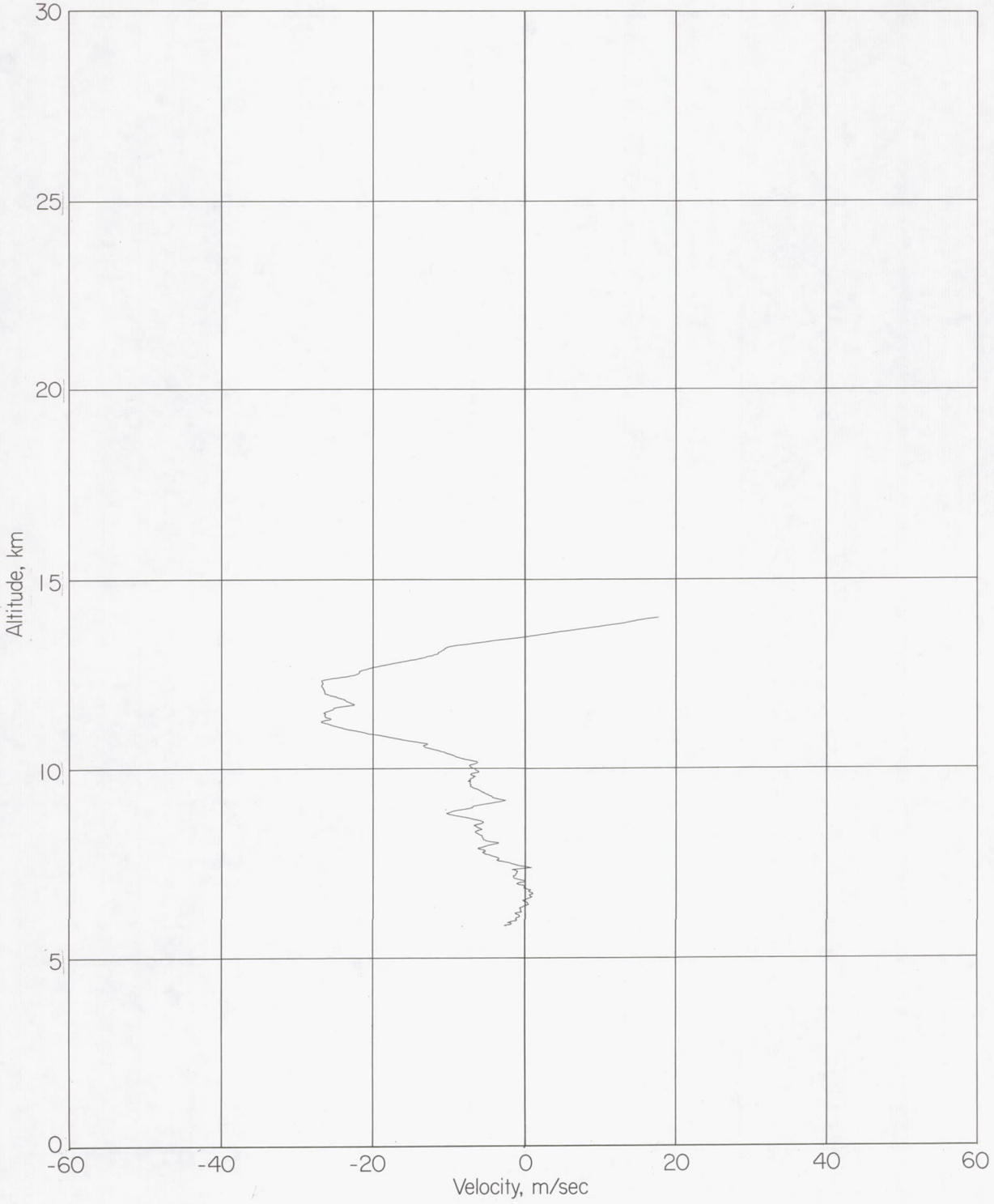
(b) South-to-north velocity component.

Figure 25.- Concluded.



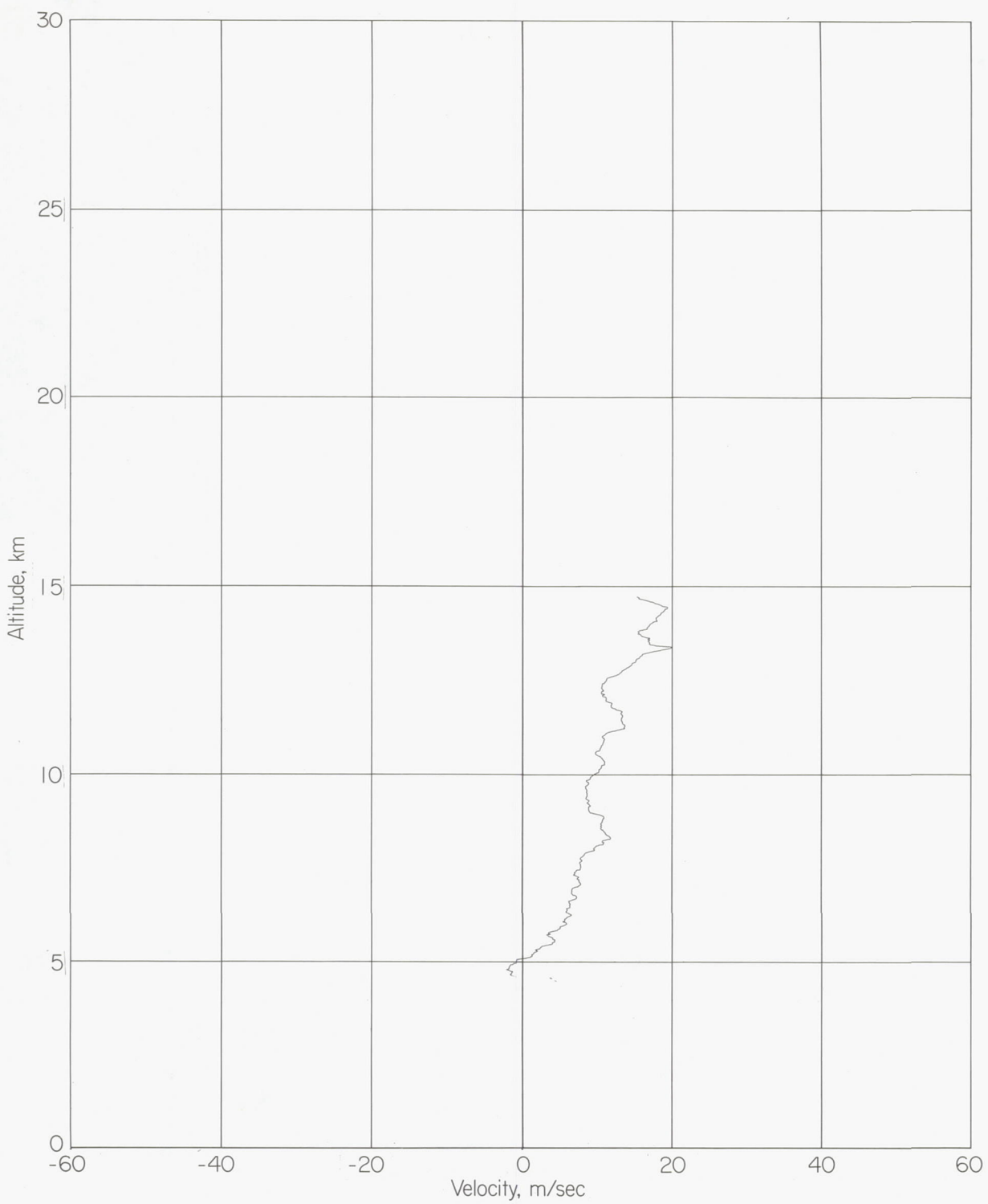
(a) West-to-east velocity component.

Figure 26.- Wind profile of smoke trail 350 obtained April 3, 1963. Time interval, 60 seconds; height interval, 25 meters.



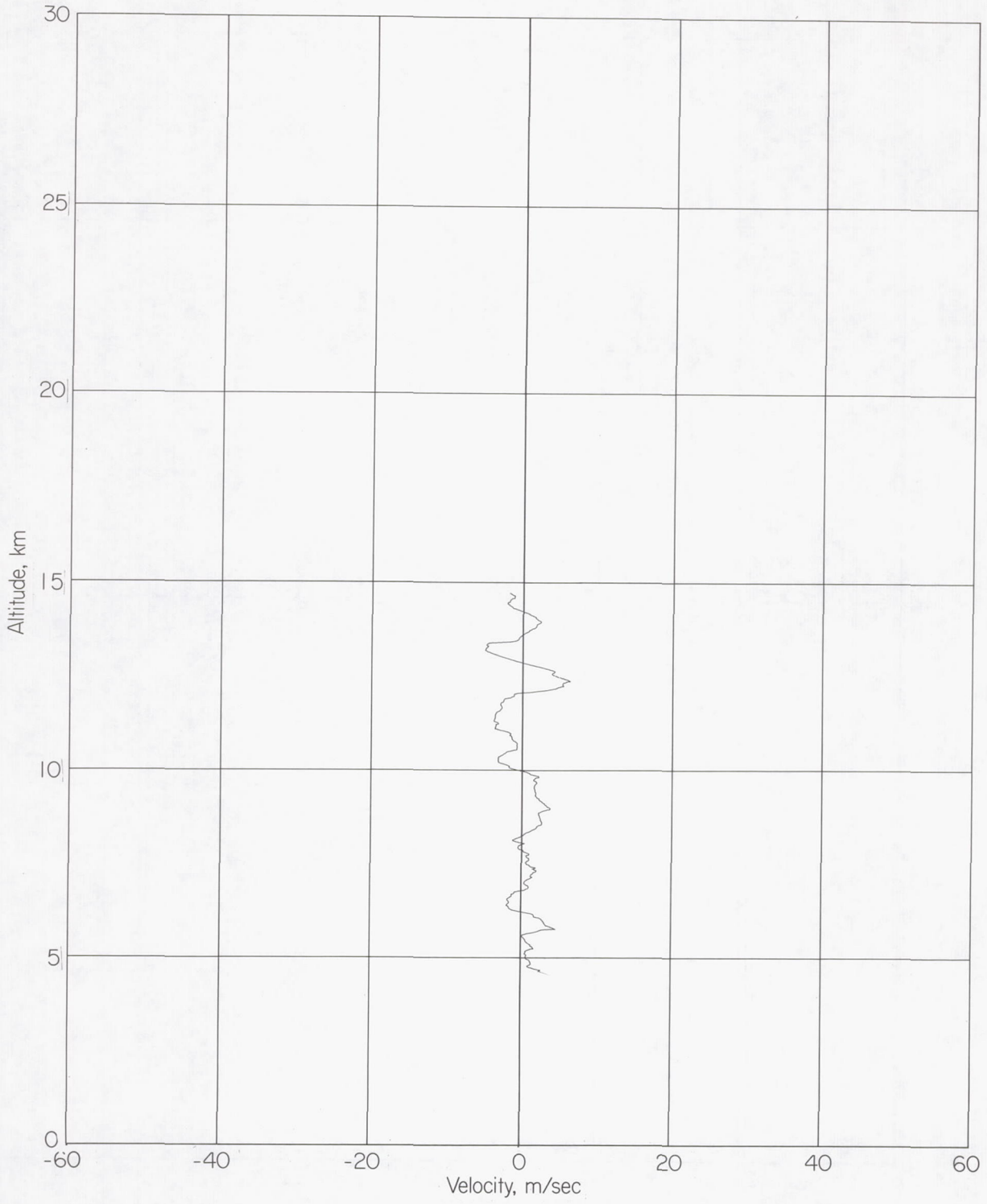
(b) South-to-north velocity component.

Figure 26.- Concluded.



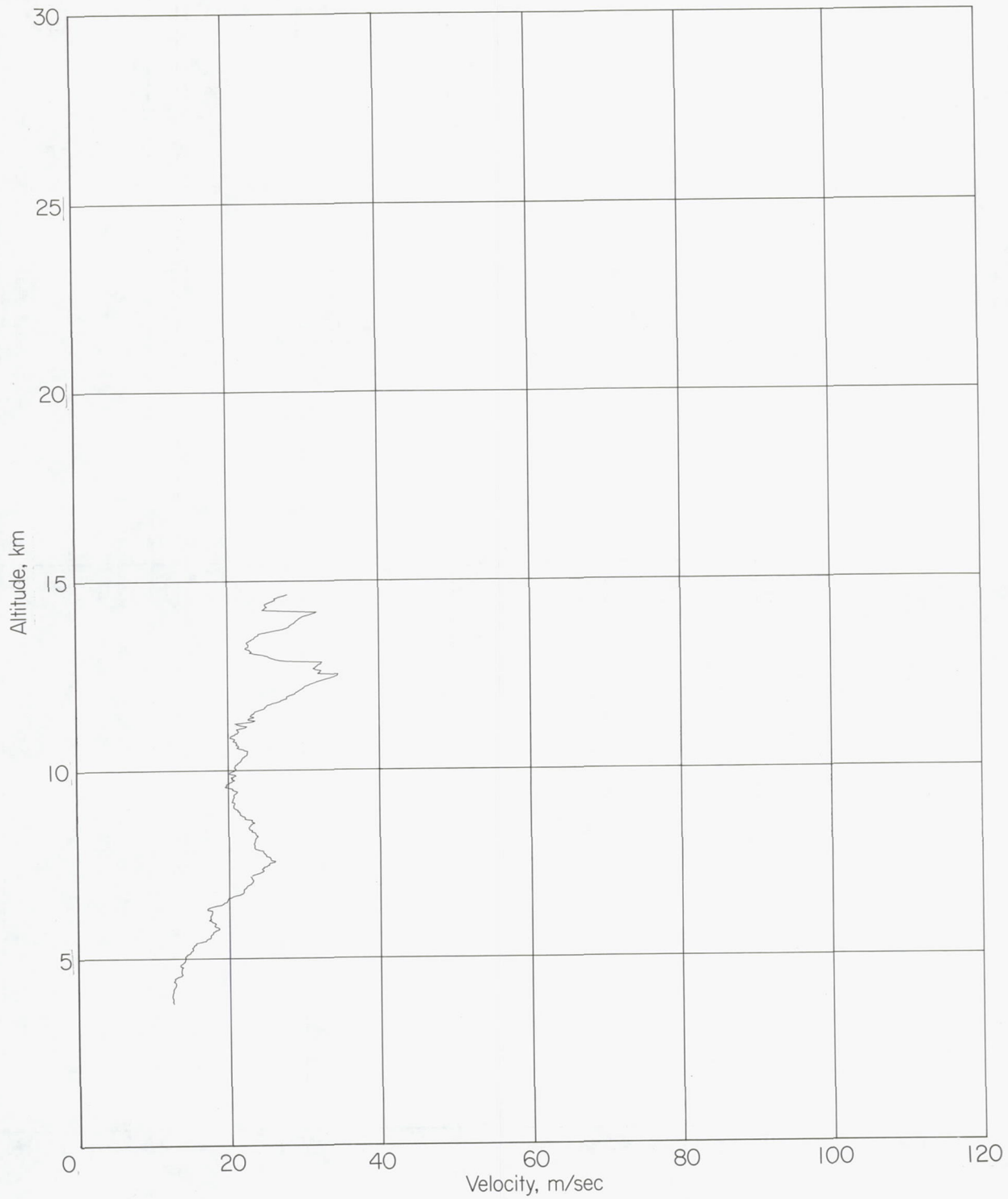
(a) West-to-east velocity component.

Figure 27.- Wind profile of smoke trail 351 obtained April 5, 1963. Time interval, 60 seconds; height interval, 25 meters.



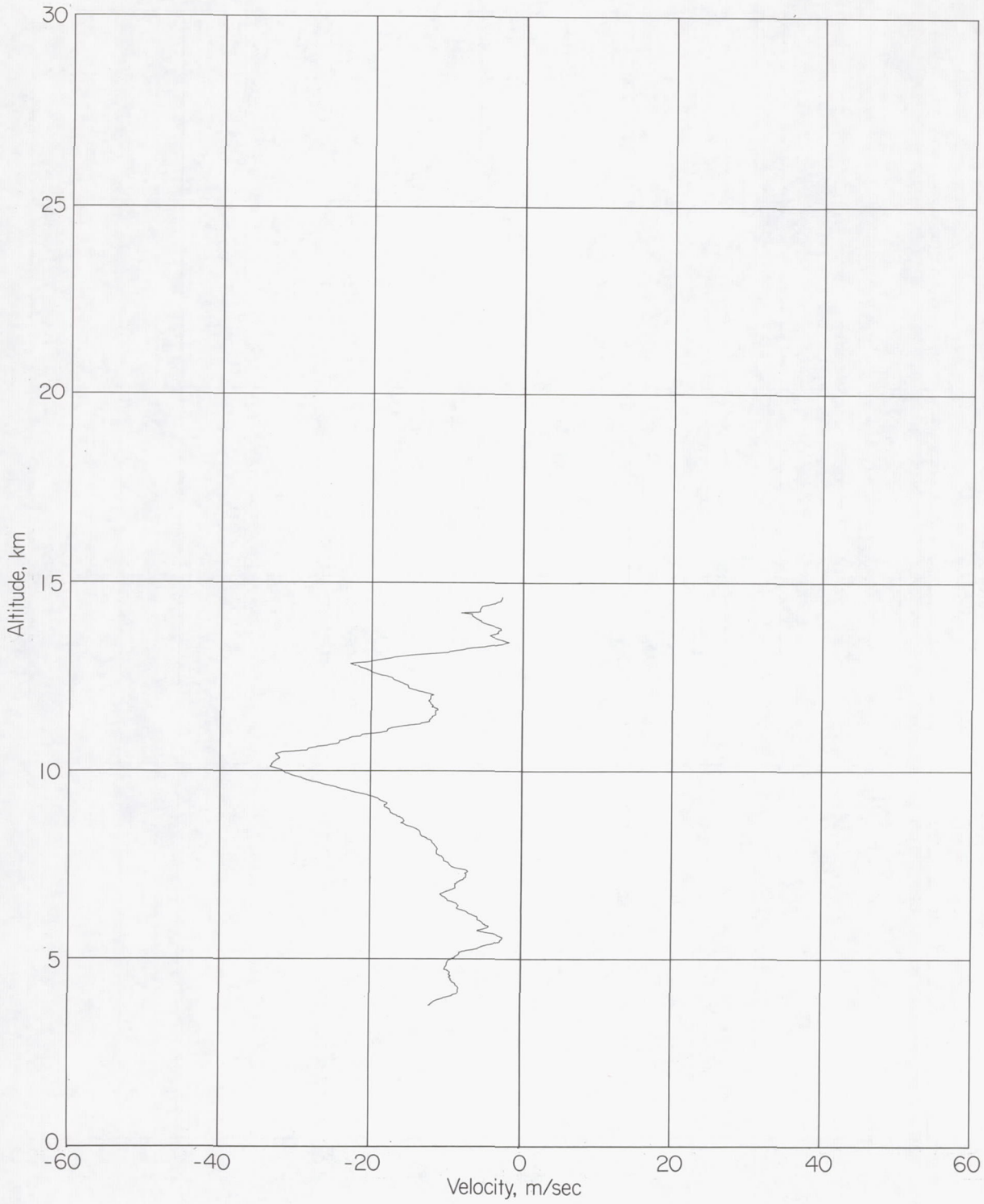
(b) South-to-north velocity component.

Figure 27.- Concluded.



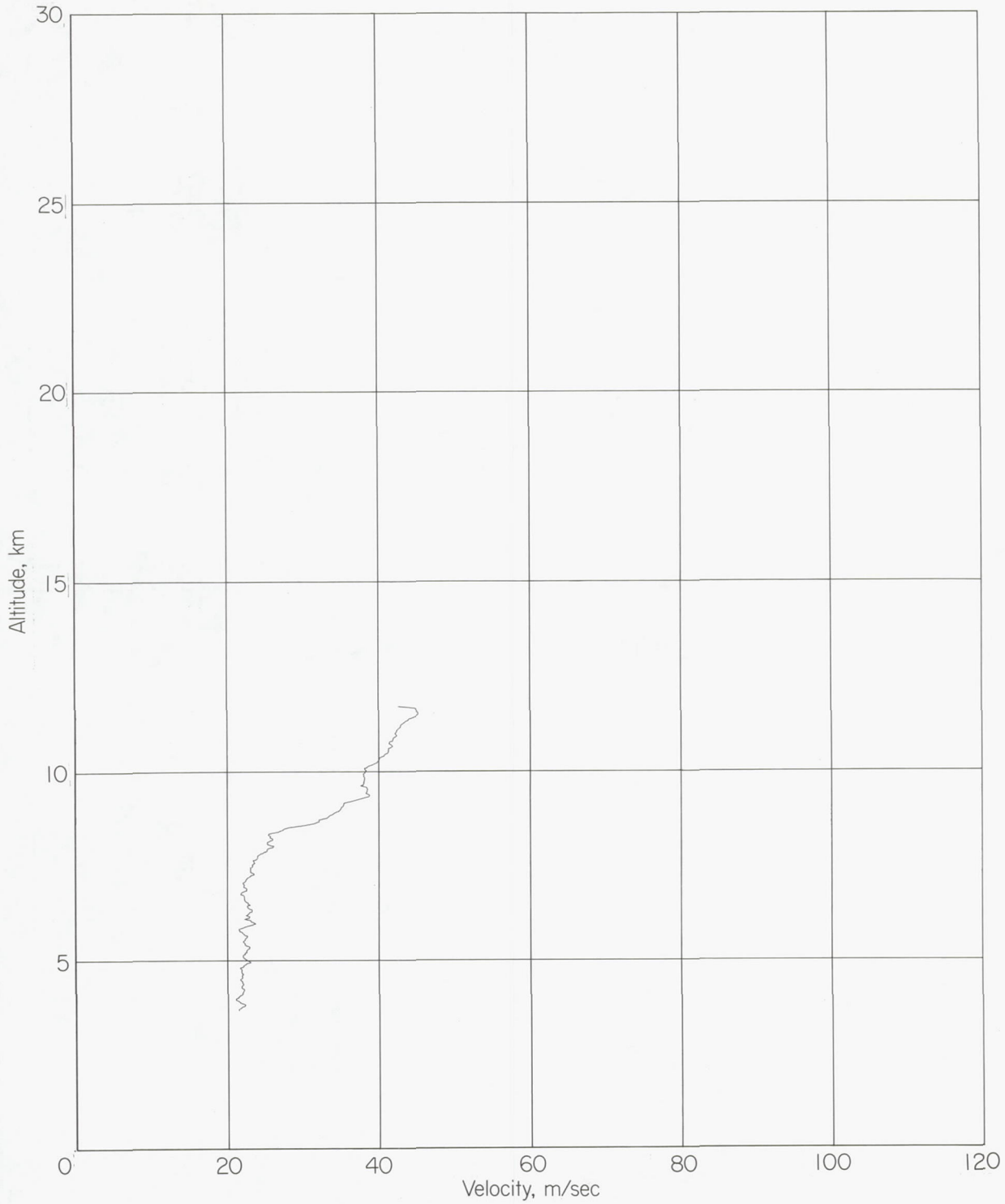
(a) West-to-east velocity component.

Figure 28.- Wind profile of smoke trail 352 obtained April 11, 1963. Time interval, 60 seconds; height interval, 25 meters.



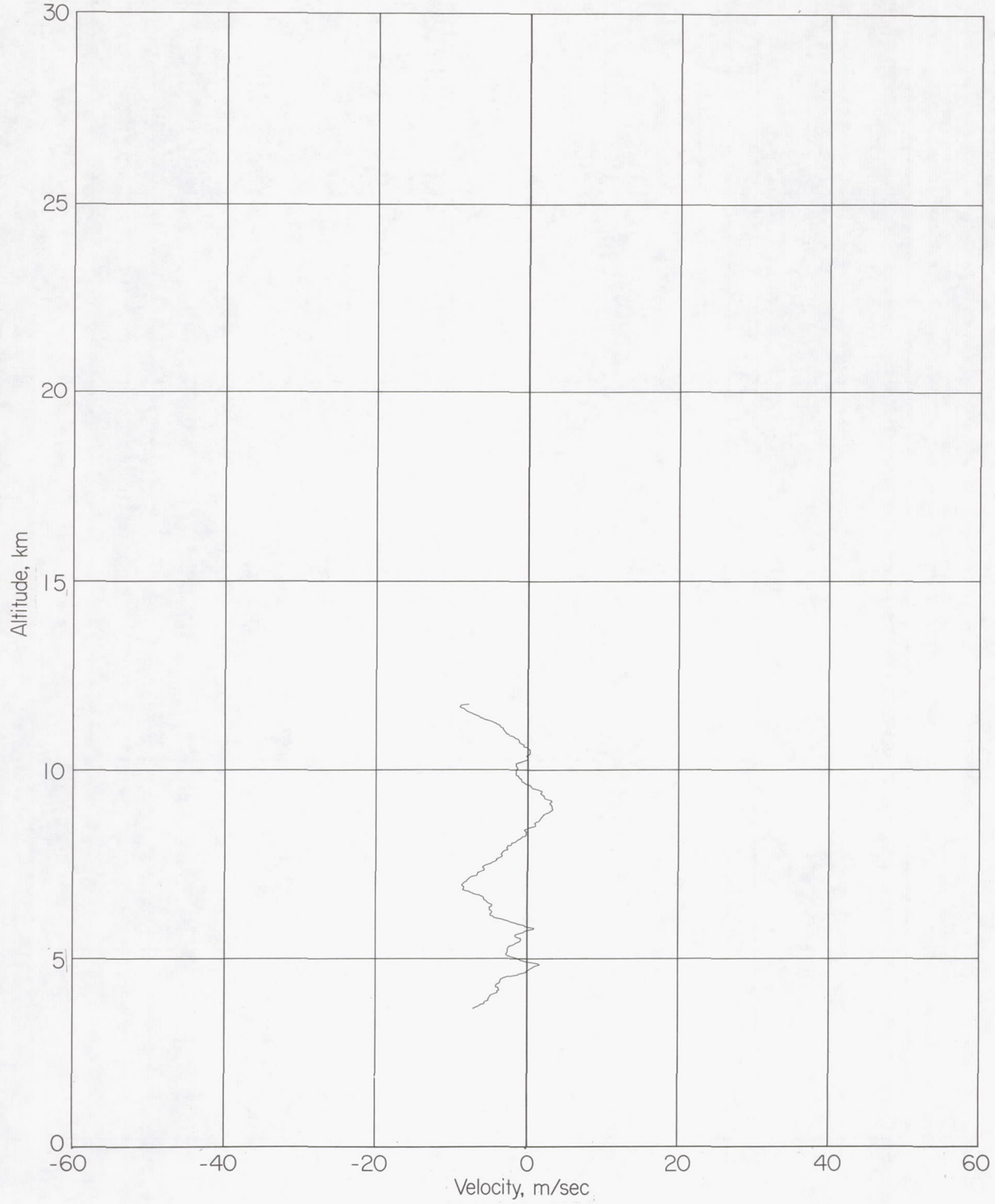
(b) South-to-north velocity component.

Figure 28.- Concluded.



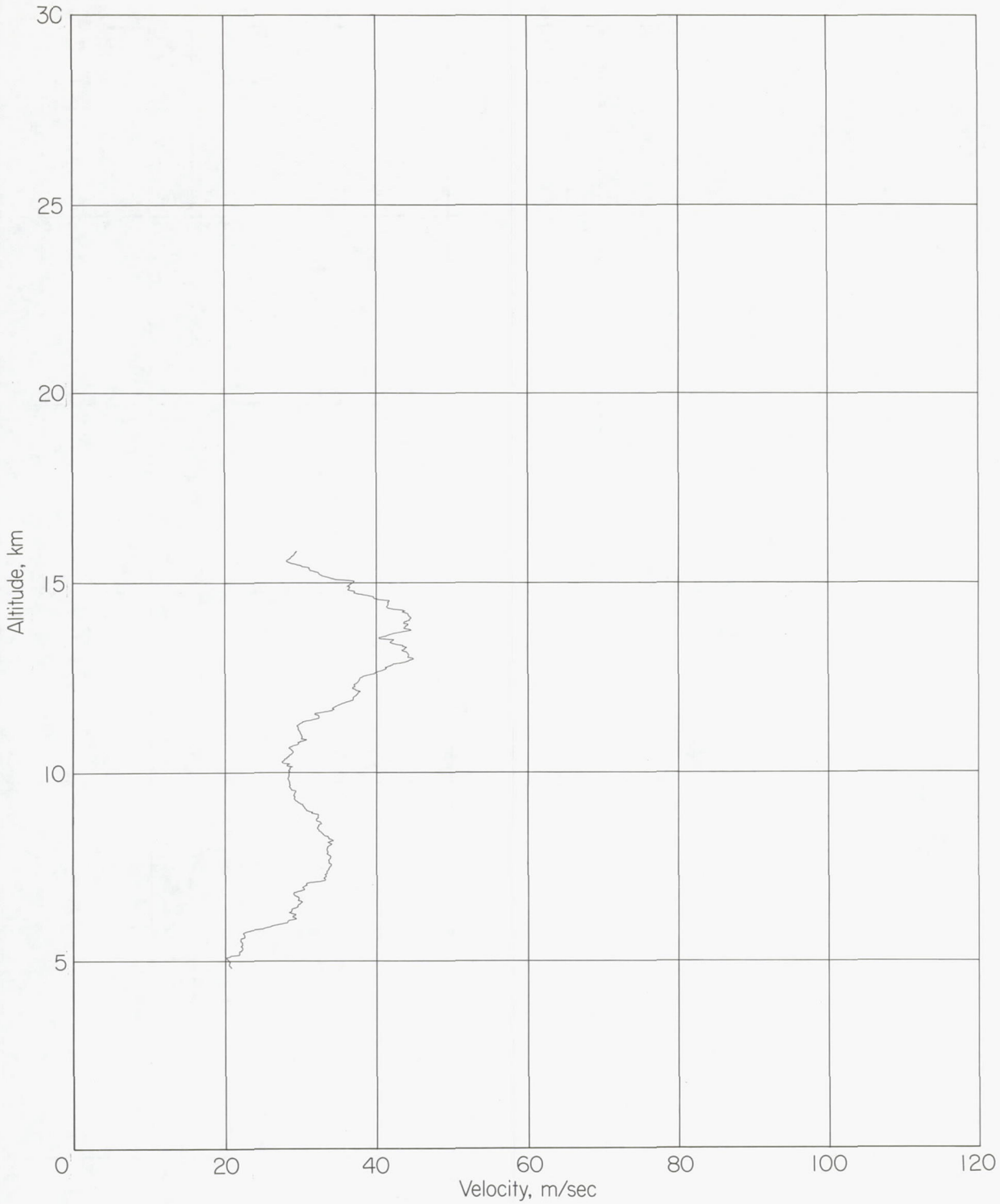
(a) West-to-east velocity component.

Figure 29.- Wind profile of smoke trail 353 obtained April 12, 1963. Time interval, 60 seconds; height interval, 25 meters.



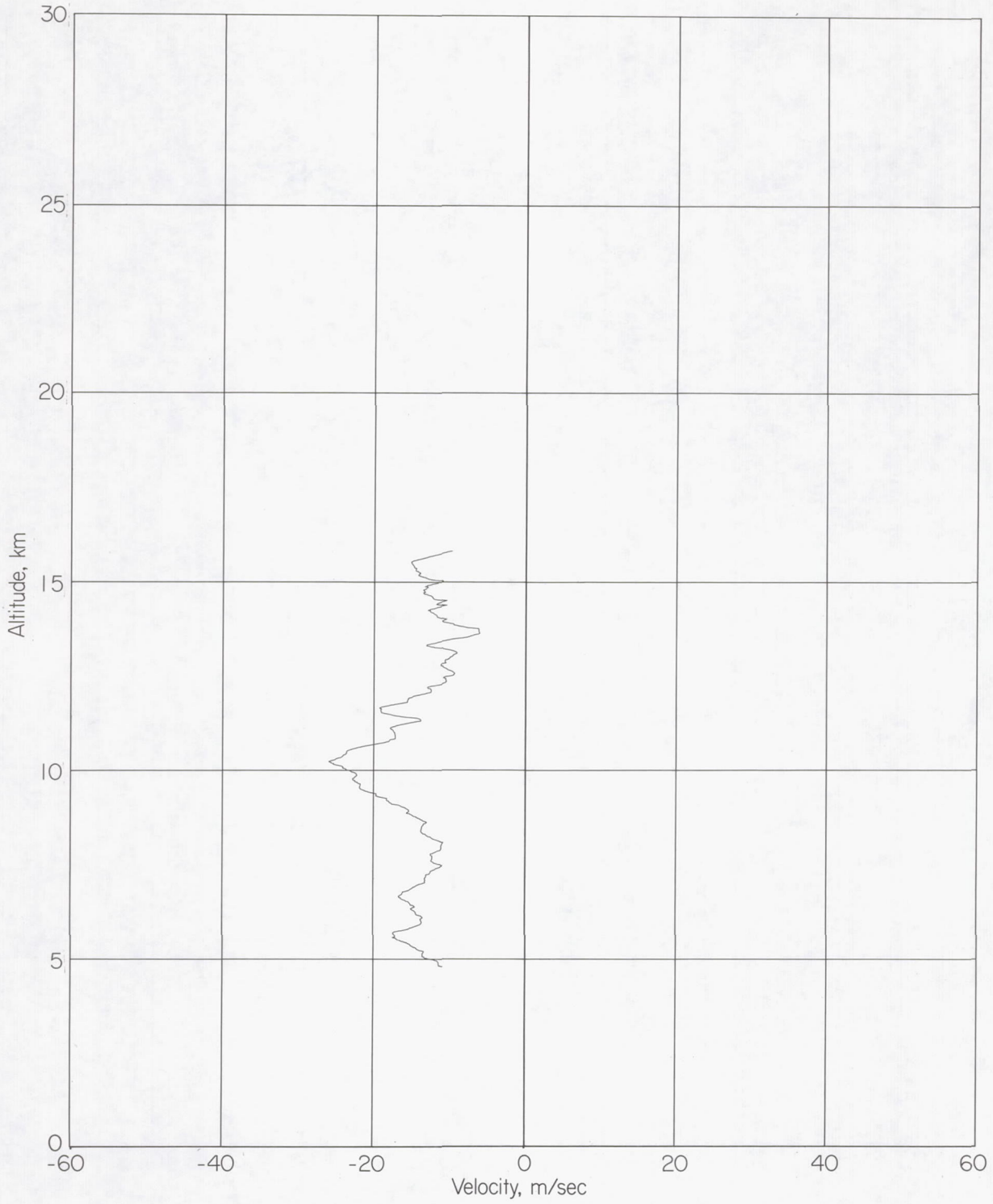
(b) South-to-north velocity component.

Figure 29.- Concluded.



(a) West-to-east velocity components.

Figure 30.- Wind profile of smoke trail 354 obtained April 15, 1963. Time interval, 60 seconds; height interval, 25 meters.

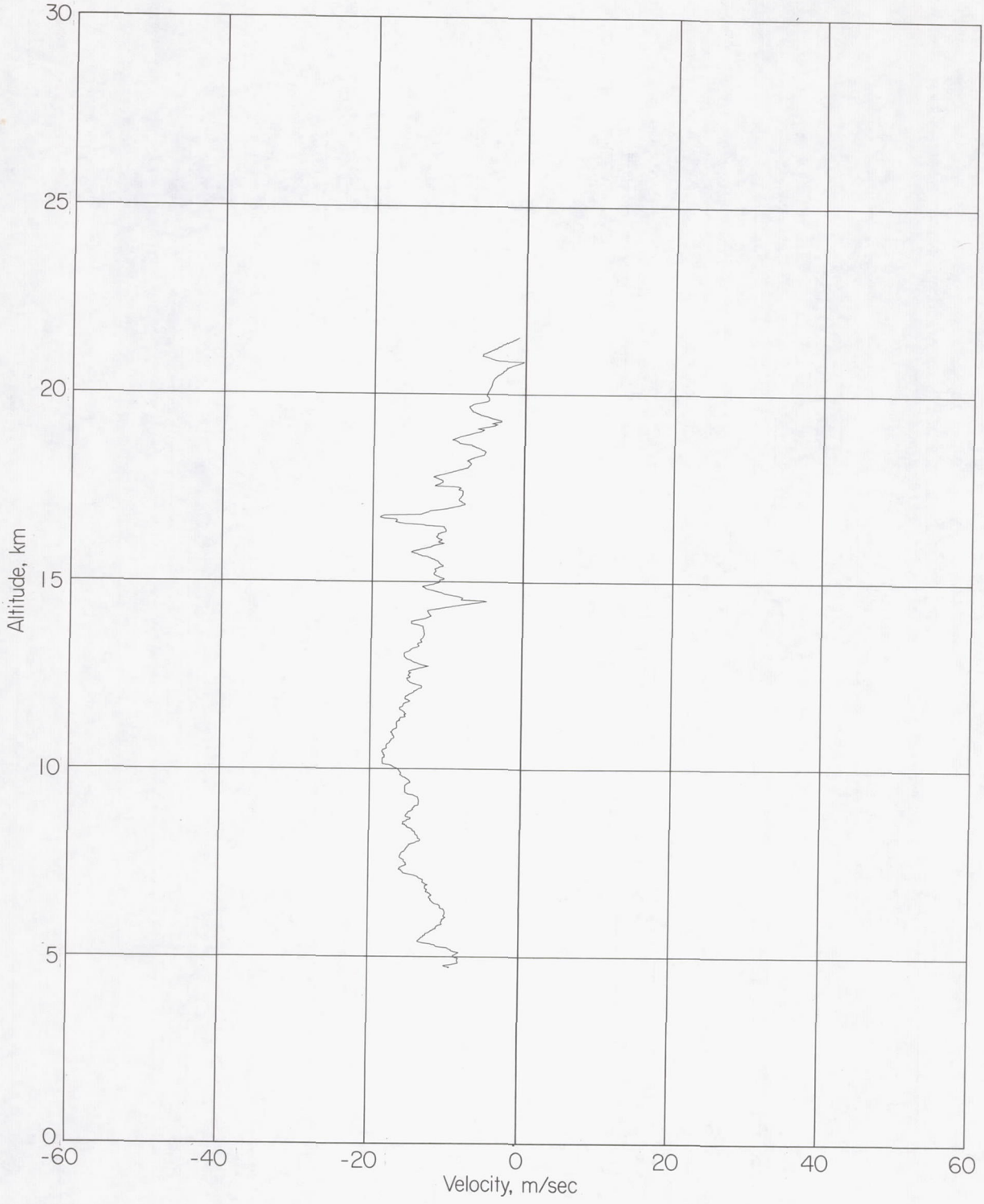


(b) South-to-north velocity component.

Figure 30.- Concluded.

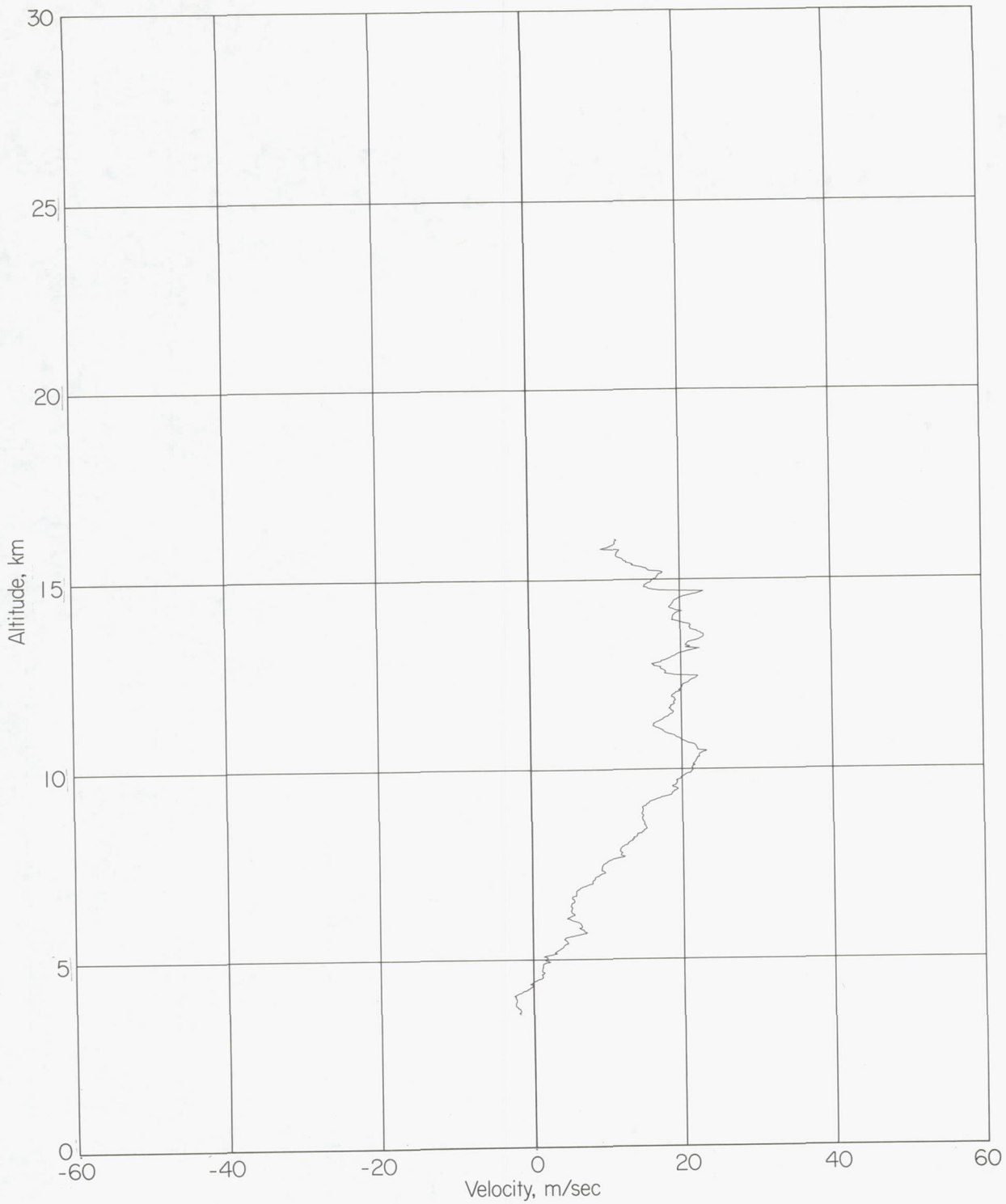
(a) West-to-east velocity component.

Figure 31.- Wind profile of smoke trail 355 obtained April 16, 1963. Time interval, 60 seconds; height interval, 25 meters.



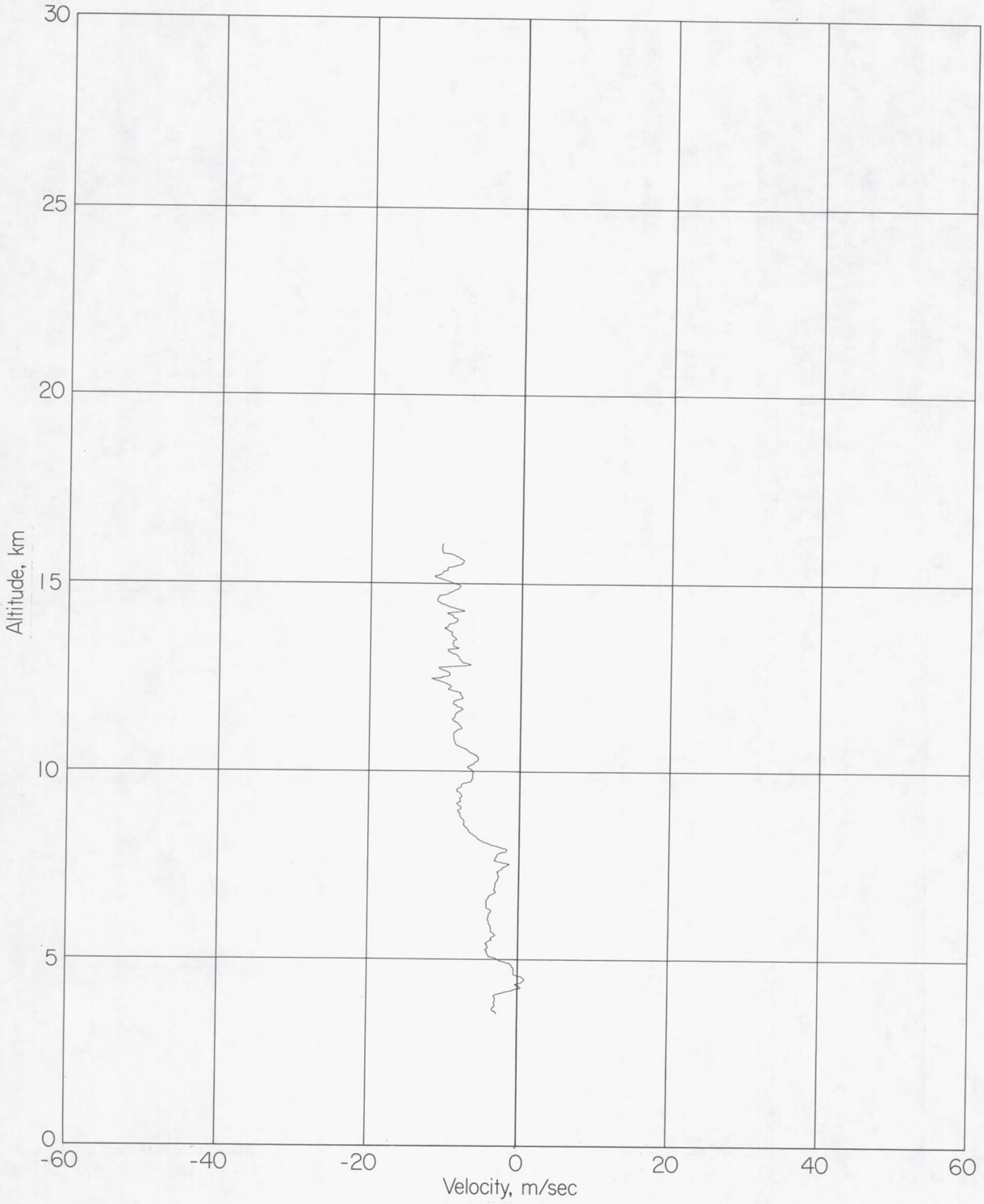
(b) South-to-north velocity component.

Figure 31.- Concluded.



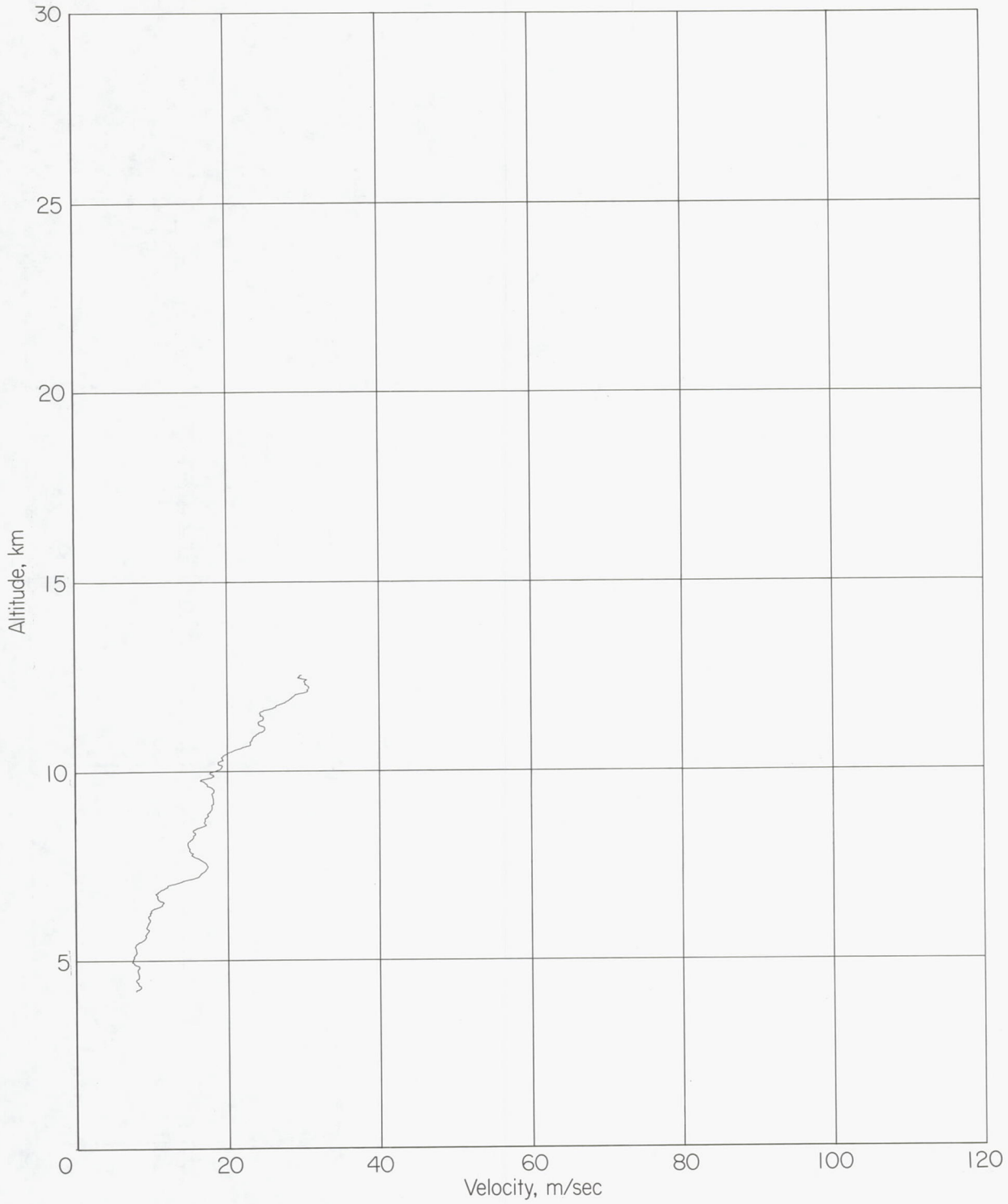
(a) West-to-east velocity component.

Figure 32.- Wind profile of smoke trail 356 obtained April 17, 1963. Time interval, 60 seconds; height interval, 25 meters.



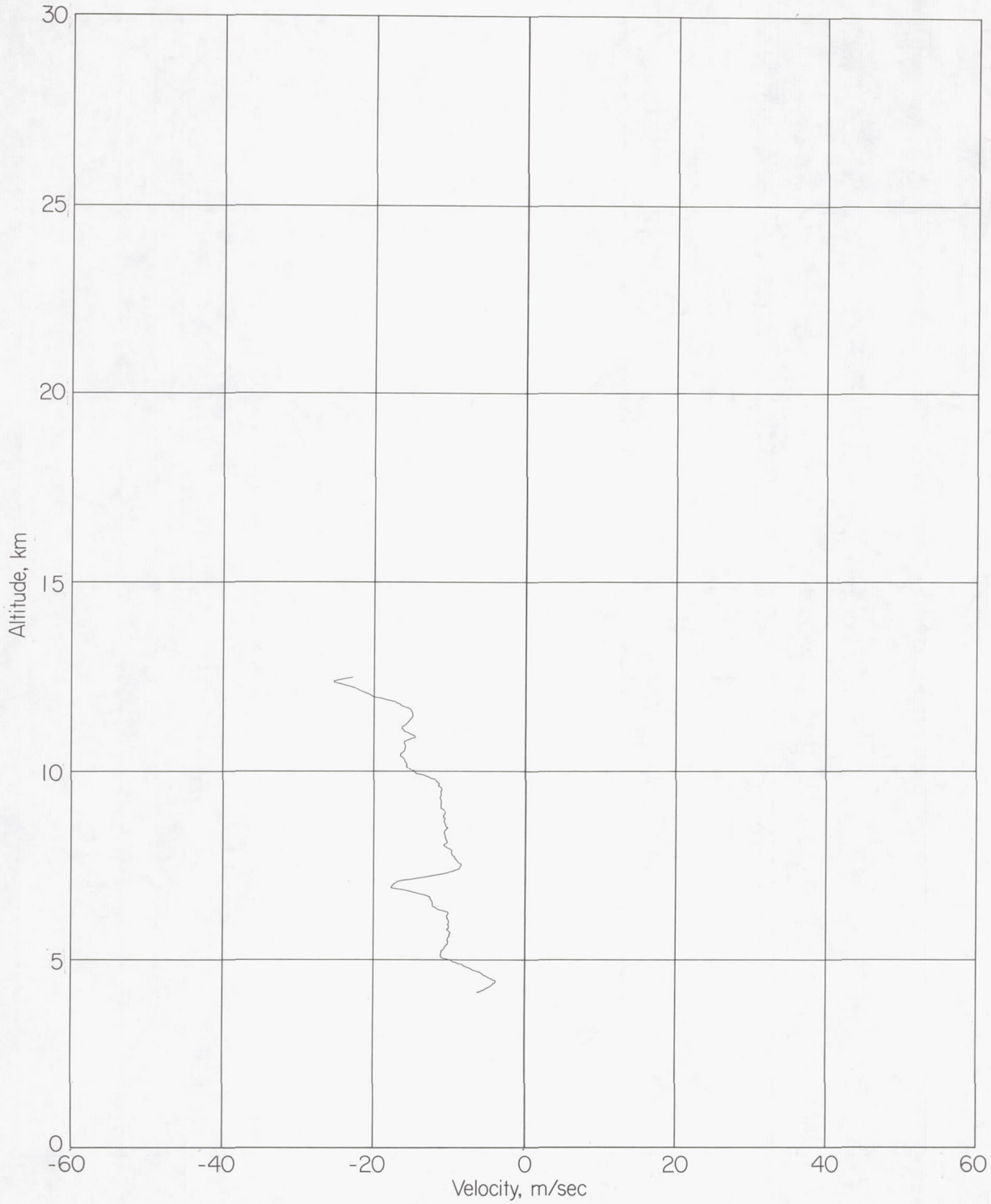
(b) South-to-north velocity component.

Figure 32.- Concluded.



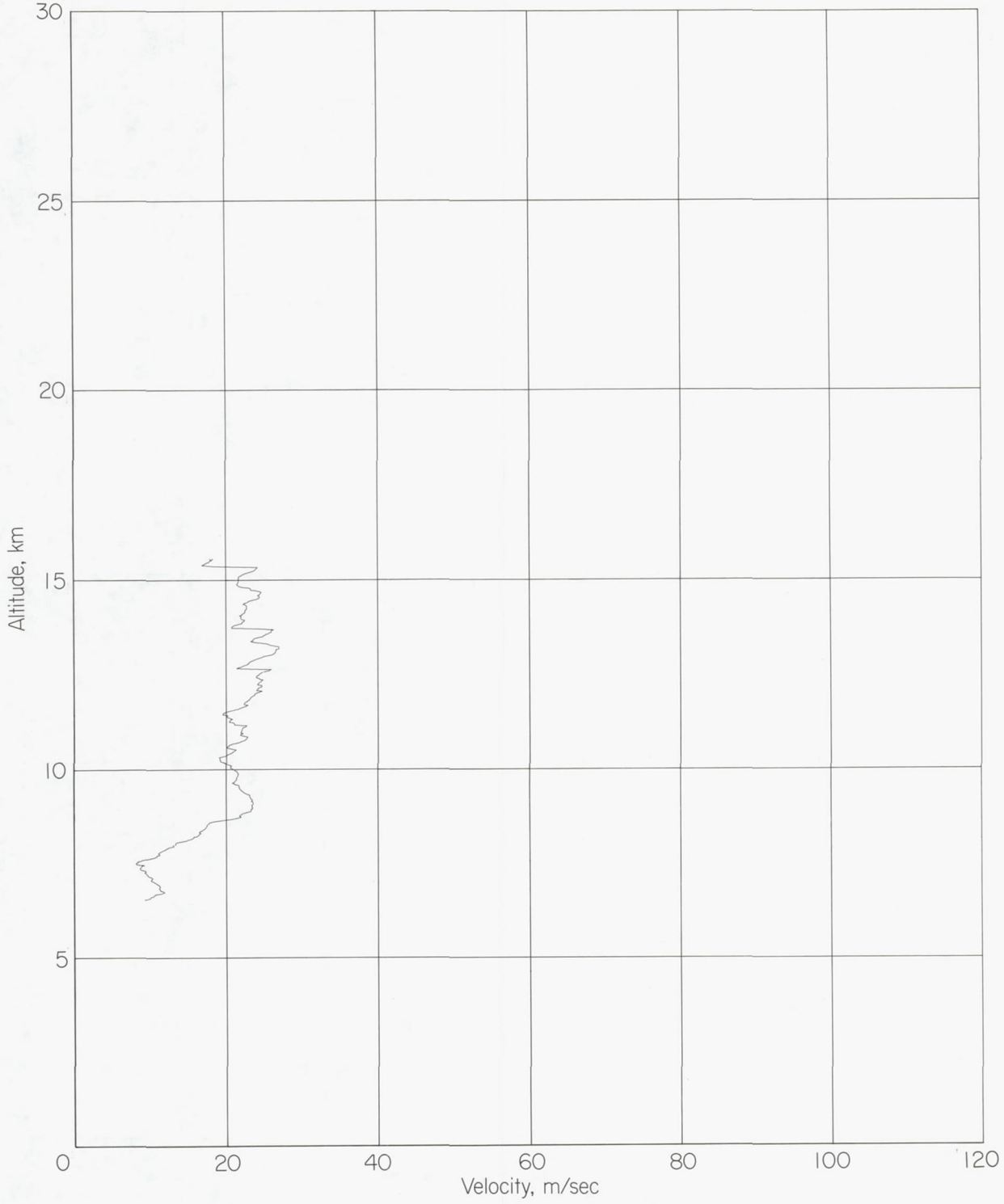
(a) West-to-east velocity component.

Figure 33.- Wind profile of smoke trail 357 obtained April 22, 1963. Time interval, 60 seconds; height interval, 25 meters.



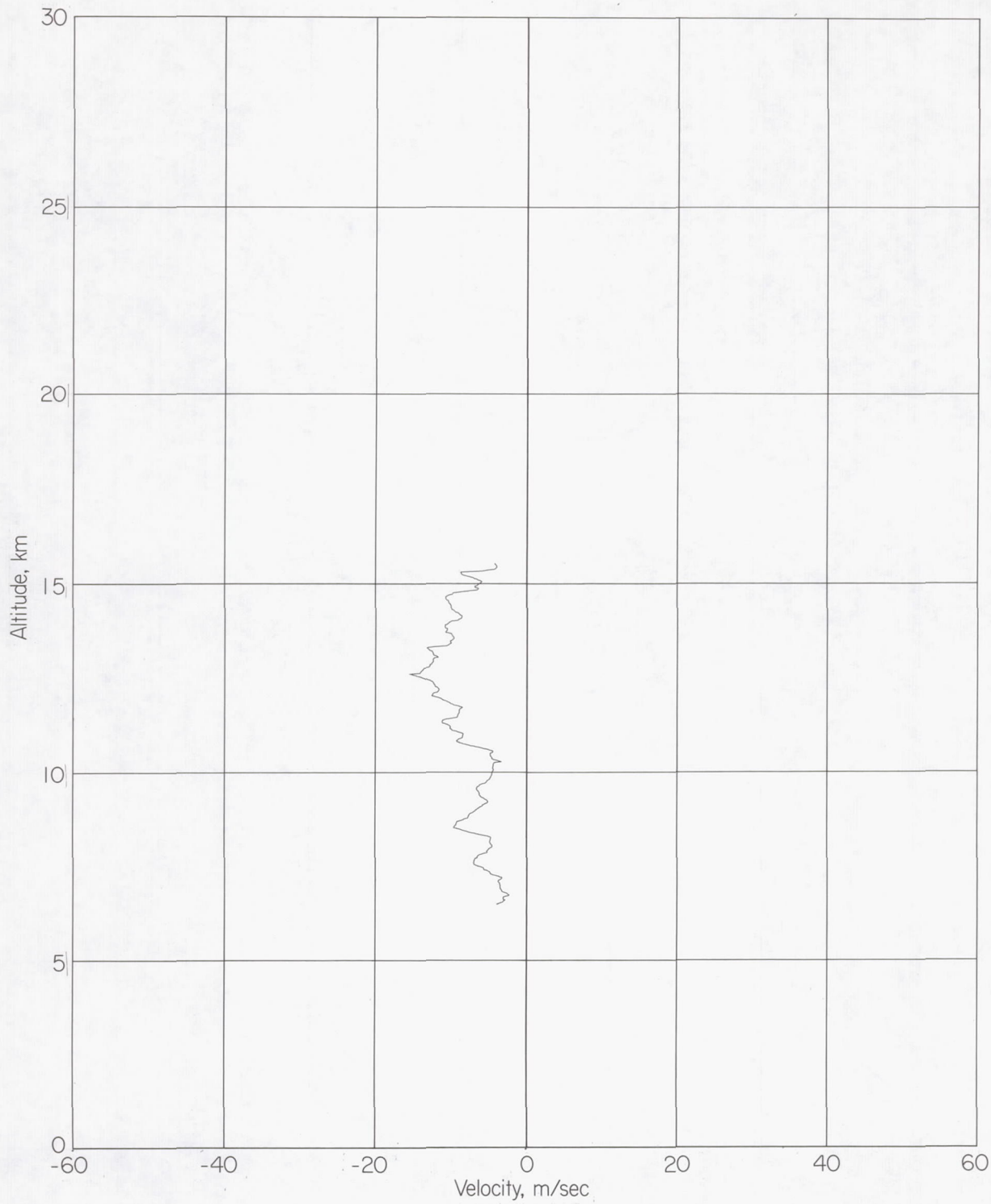
(b) South-to-north velocity component.

Figure 33.- Concluded.



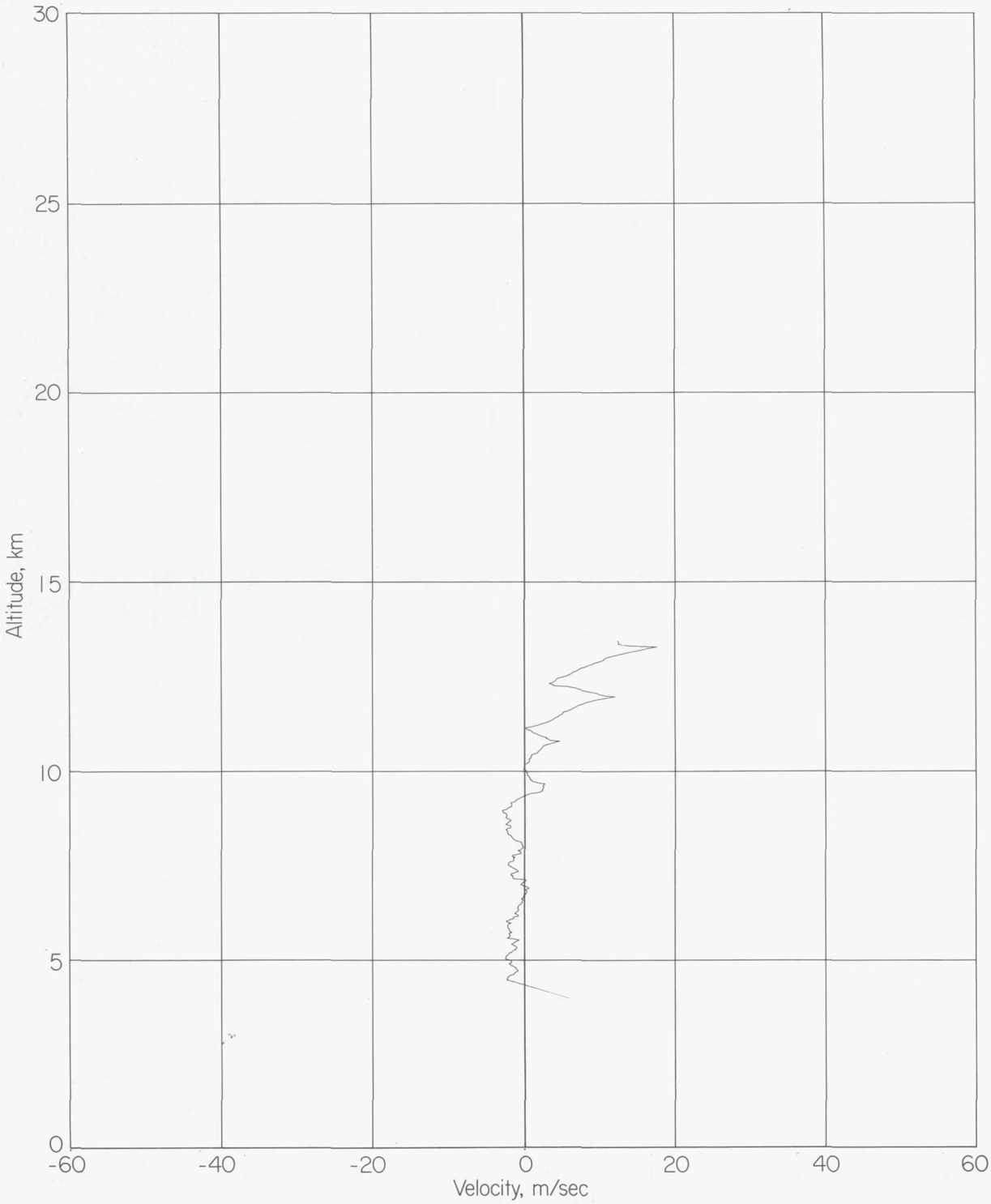
(a) West-to-east velocity component.

Figure 34.- Wind profile of smoke trail 358 obtained May 7, 1963. Time interval, 60 seconds; height interval, 25 meters.



(b) South-to-north velocity component.

Figure 34.- Concluded.

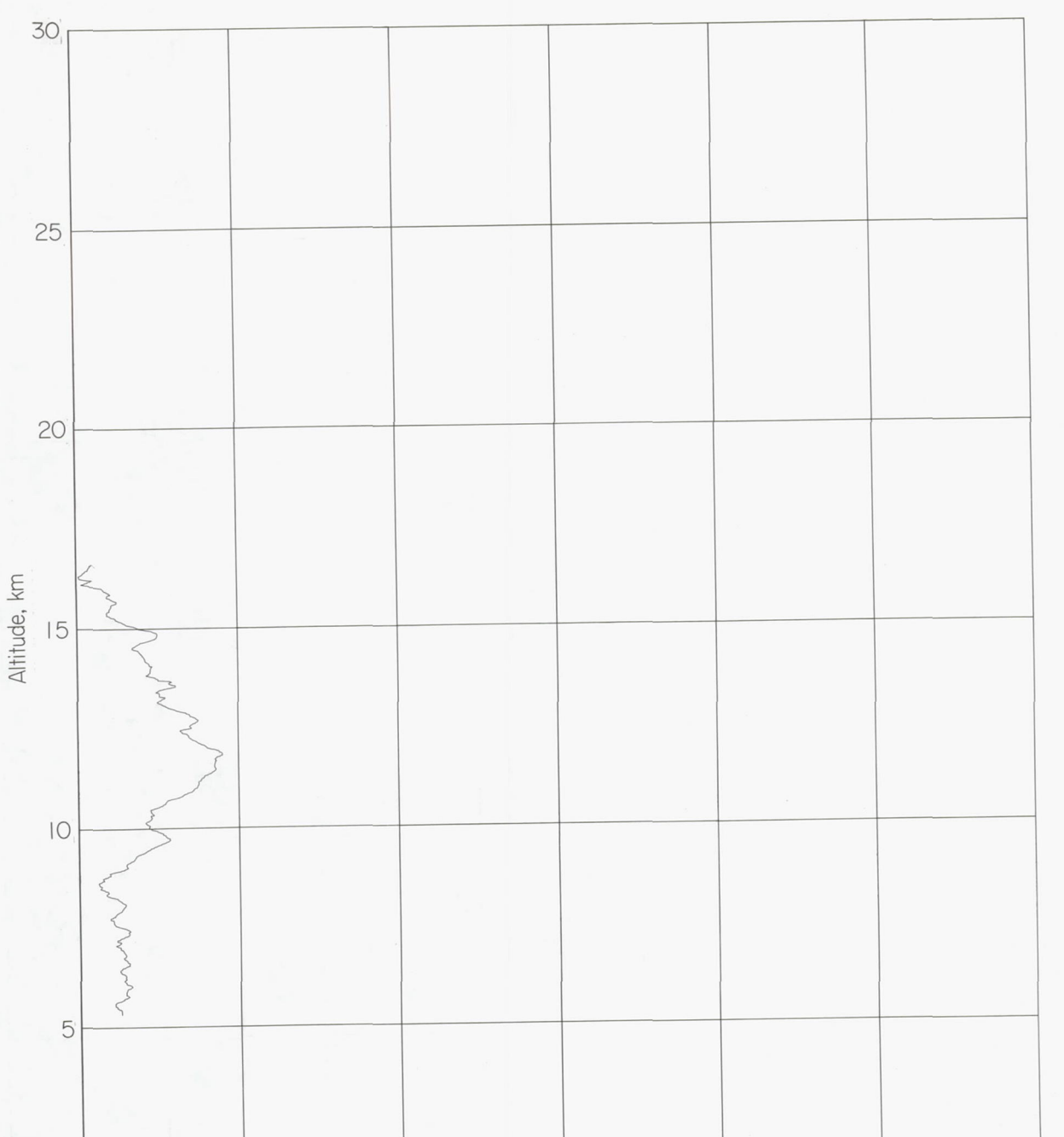


(a) West-to-east velocity component.

Figure 35.- Wind profile of smoke trail 359 obtained May 8, 1963. Time interval, 60 seconds; height interval, 25 meters.

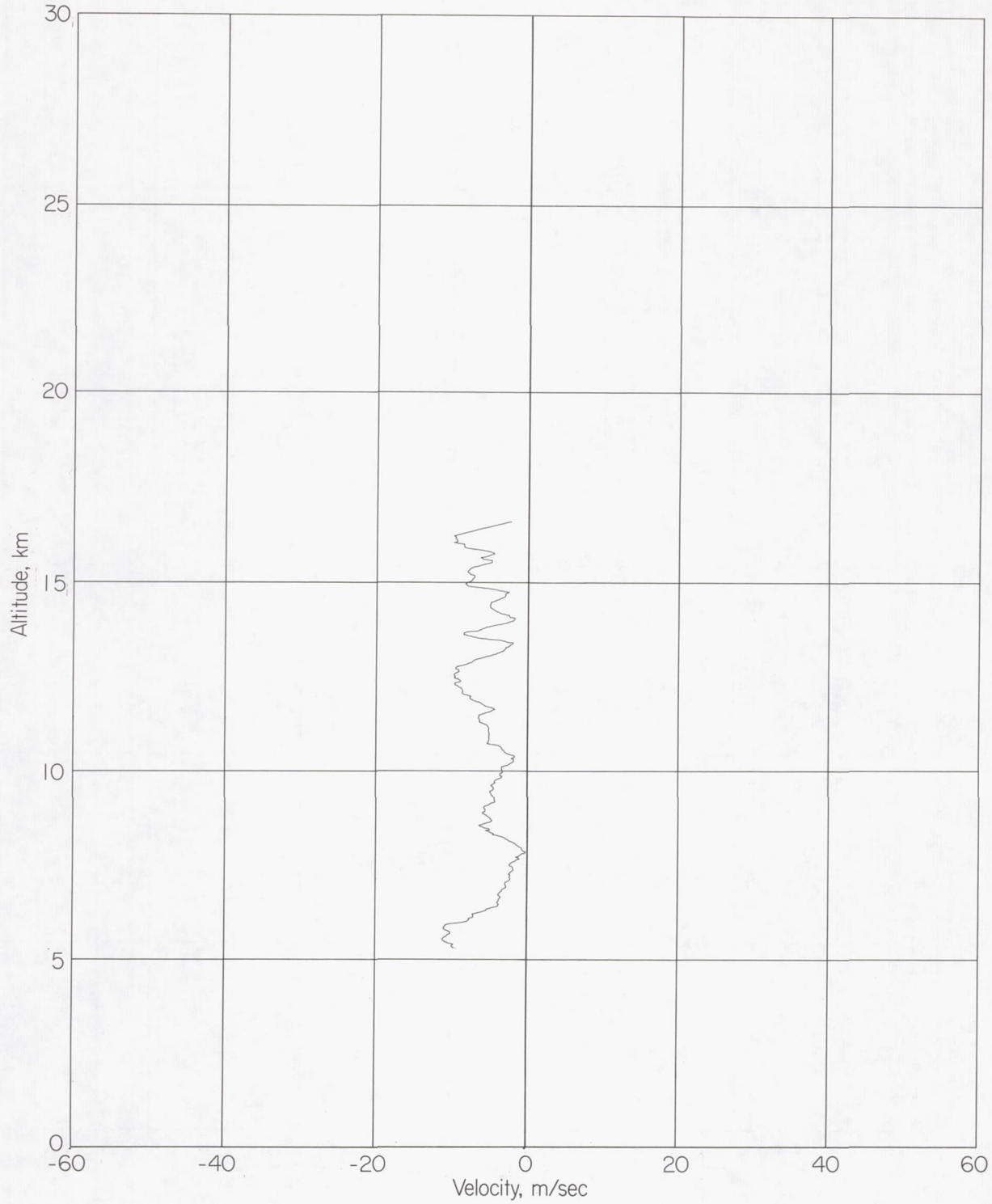
(b) South-to-north velocity component.

Figure 35.- Concluded.



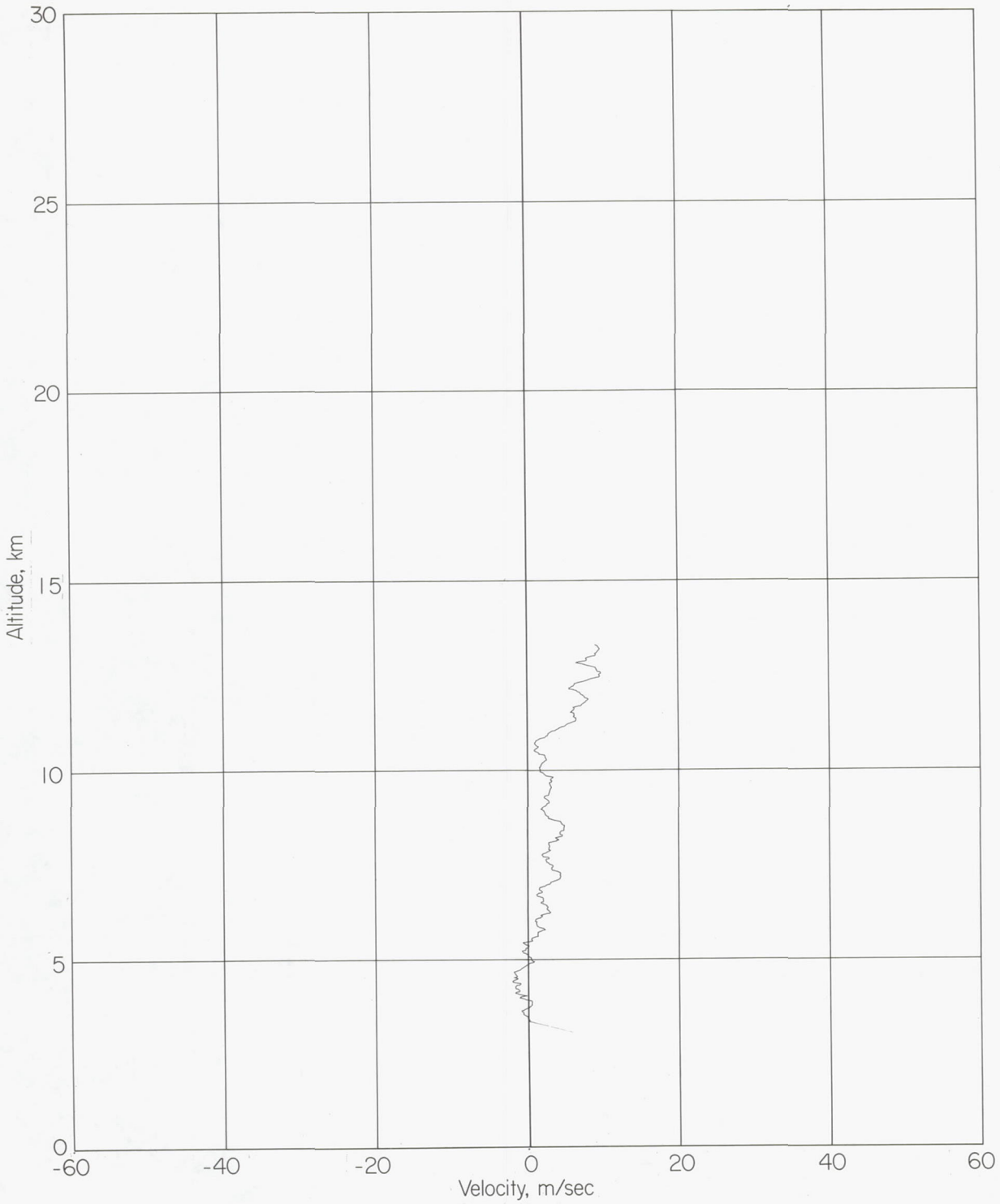
(a) West-to-east velocity component.

Figure 36.- Wind profile of smoke trail 360 obtained May 14, 1963. Time interval, 60 seconds; height interval, 25 meters.



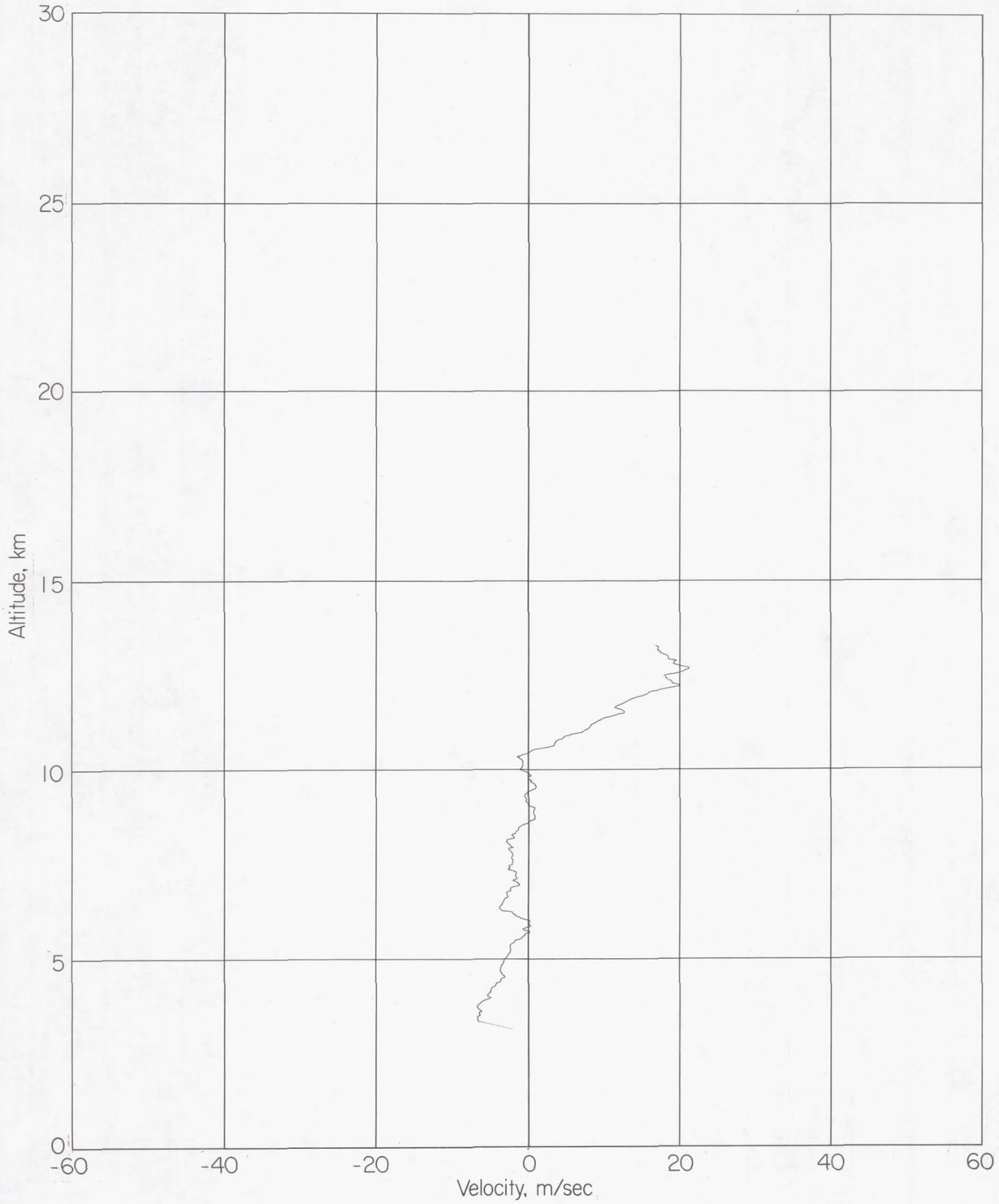
(b) South-to-north velocity component.

Figure 36.- Concluded.



(a) West-to-east velocity component.

Figure 37.- Wind profile of smoke trail 361 obtained June 7, 1963. Time interval, 60 seconds; height interval, 25 meters.

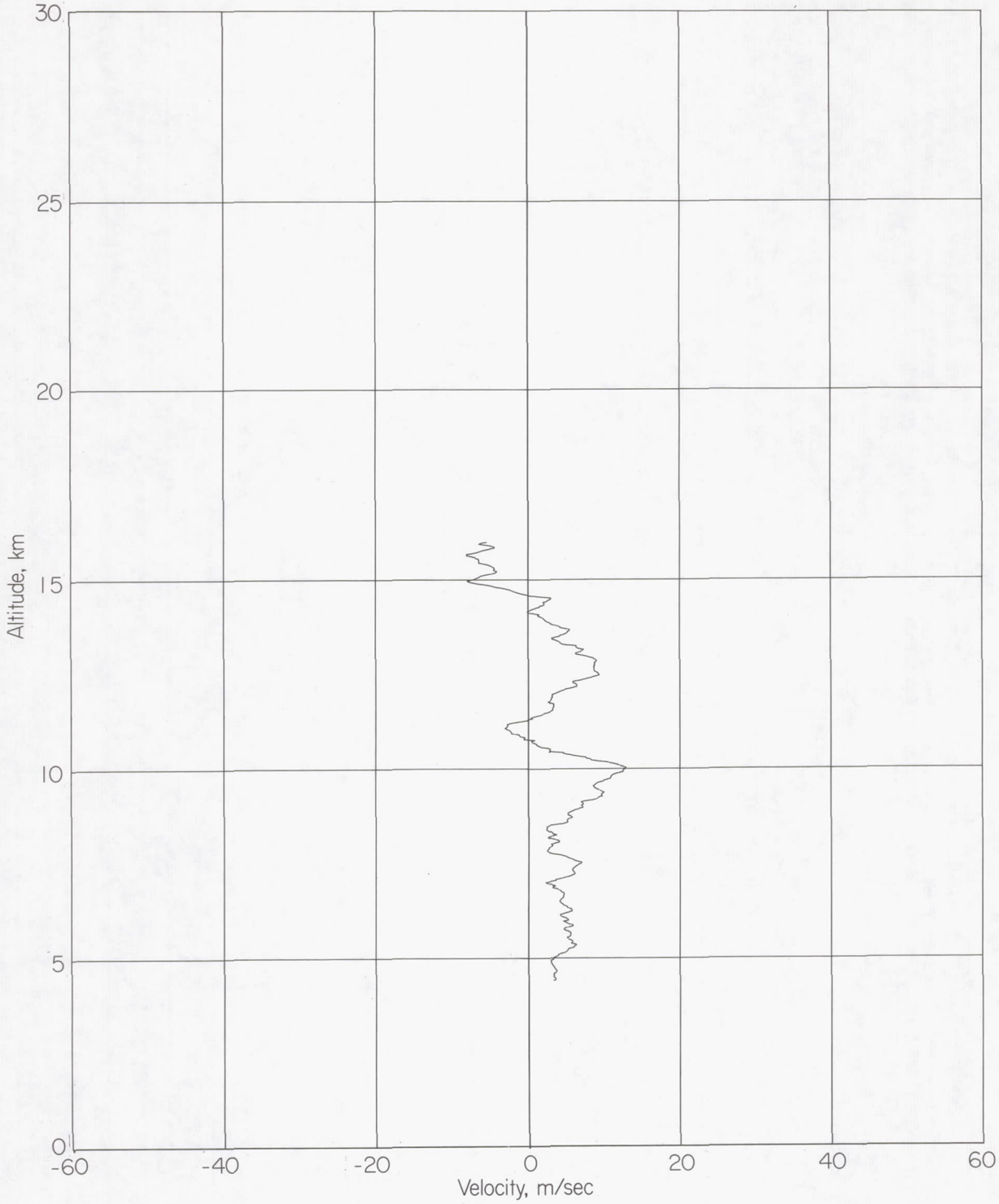


(b) South-to-north velocity component.

Figure 37.- Concluded.

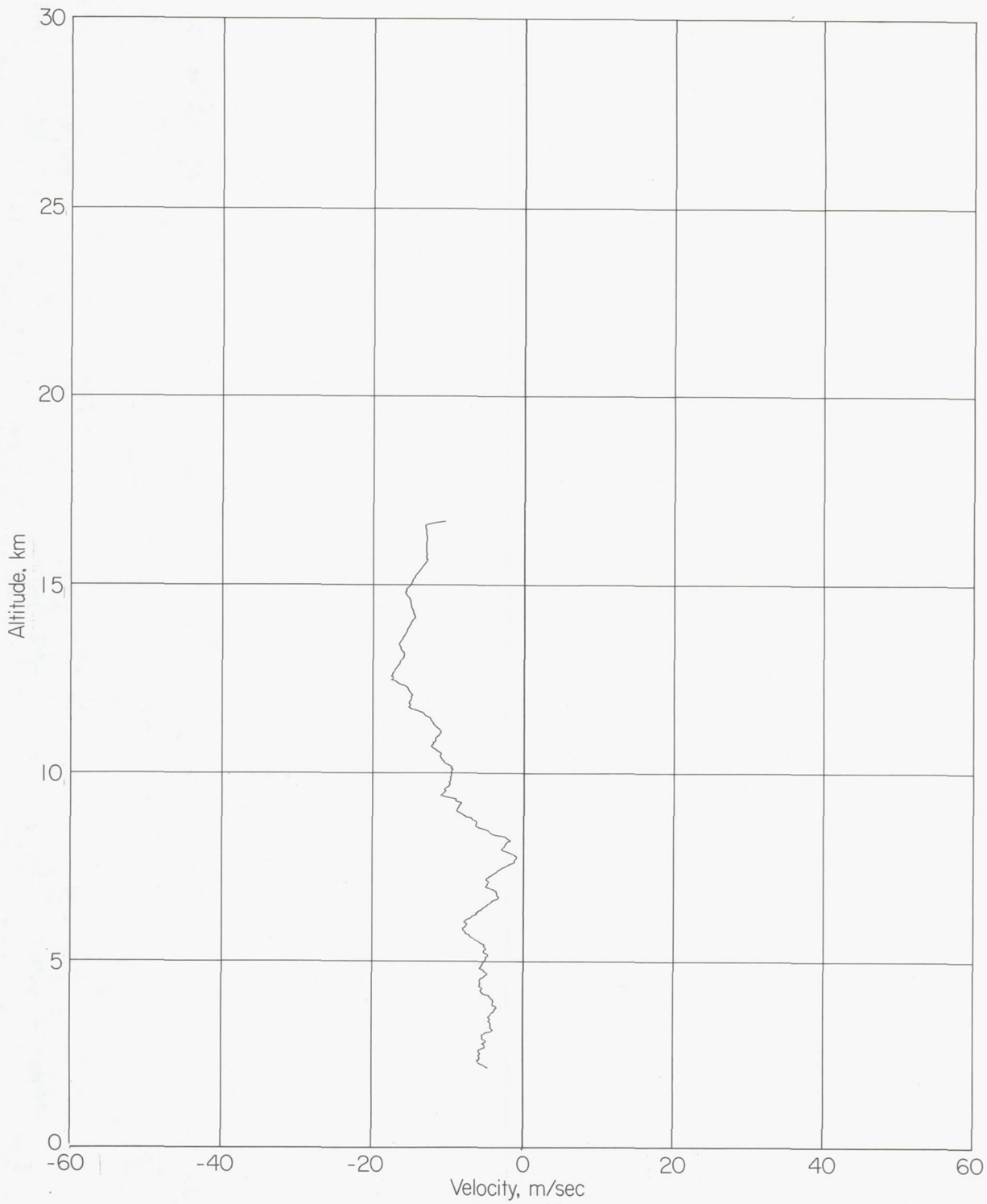
(a) West-to-east velocity component.

Figure 38.- Wind profile of smoke trail 362 obtained June 19, 1963. Time interval, 60 seconds; height interval, 25 meters.



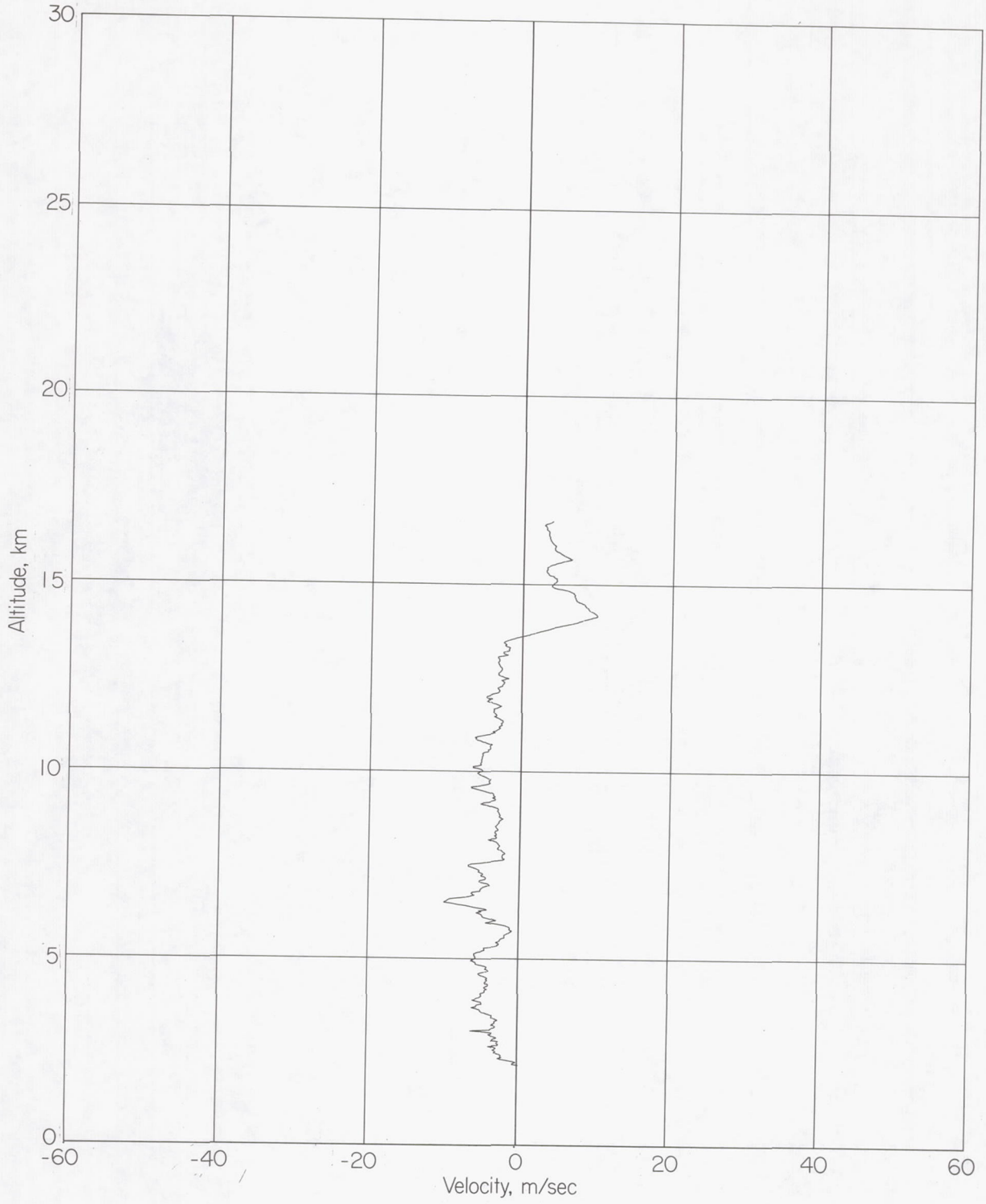
(b) South-to-north velocity component.

Figure 38.- Concluded.



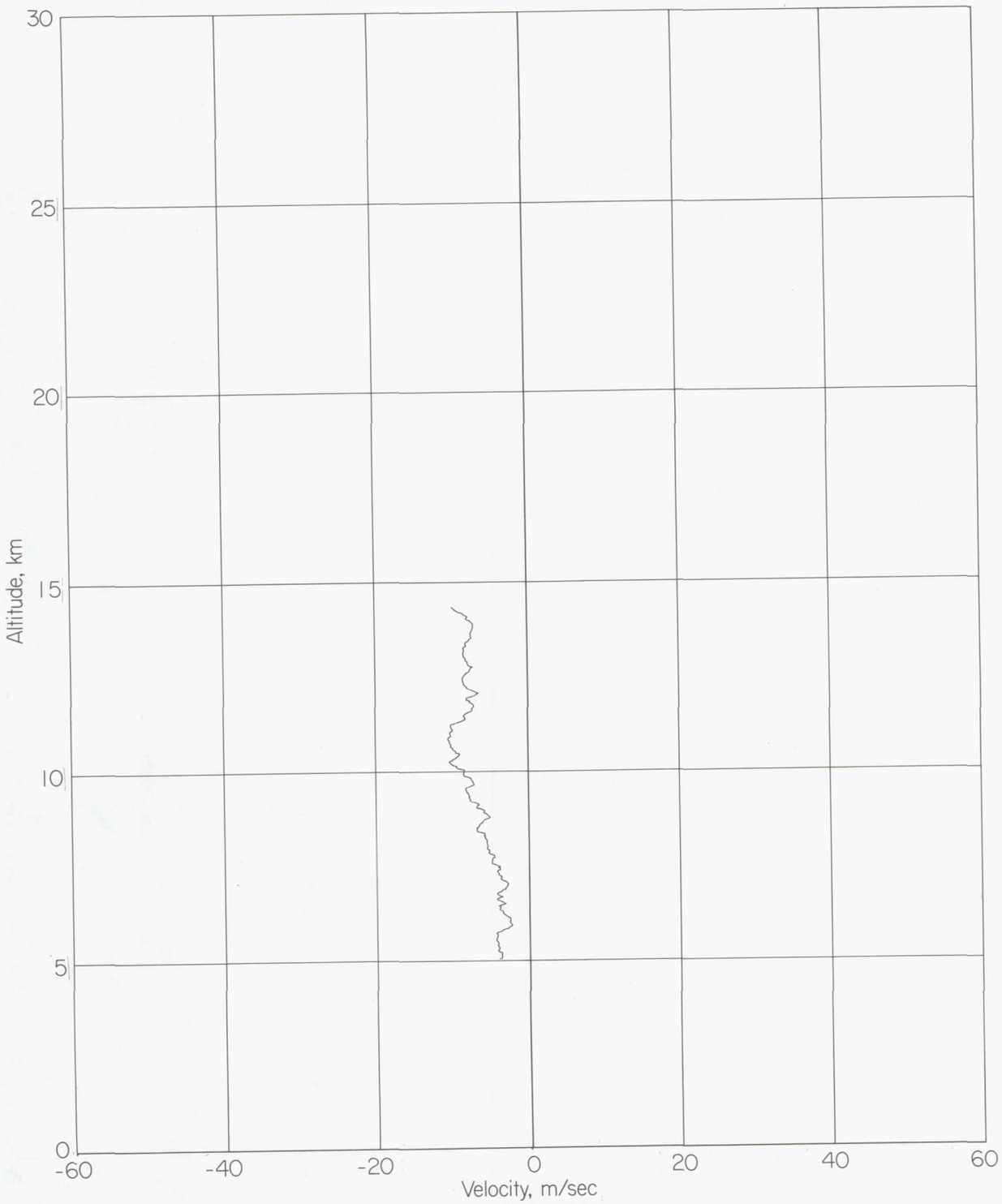
(a) West-to-east velocity component.

Figure 39.- Wind profile of smoke trail 363 obtained July 1, 1963. Time interval 60 seconds; height interval, 25 meters.



(b) South-to-north velocity component.

Figure 39.- Concluded.

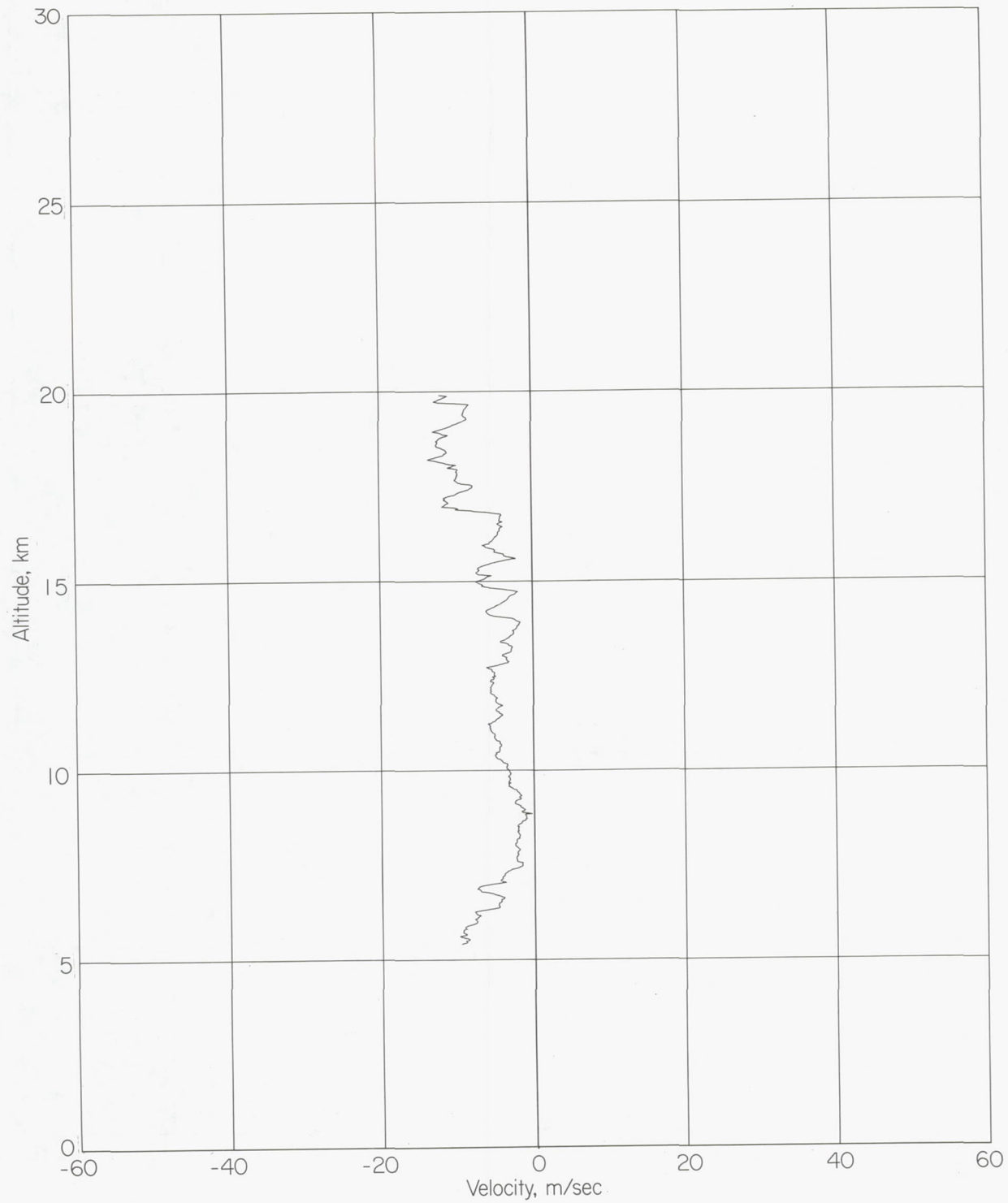


(a) West-to-east velocity component.

Figure 40.- Wind profile of smoke trail 364 obtained July 17, 1963. Time interval, 120 seconds; height interval, 25 meters.

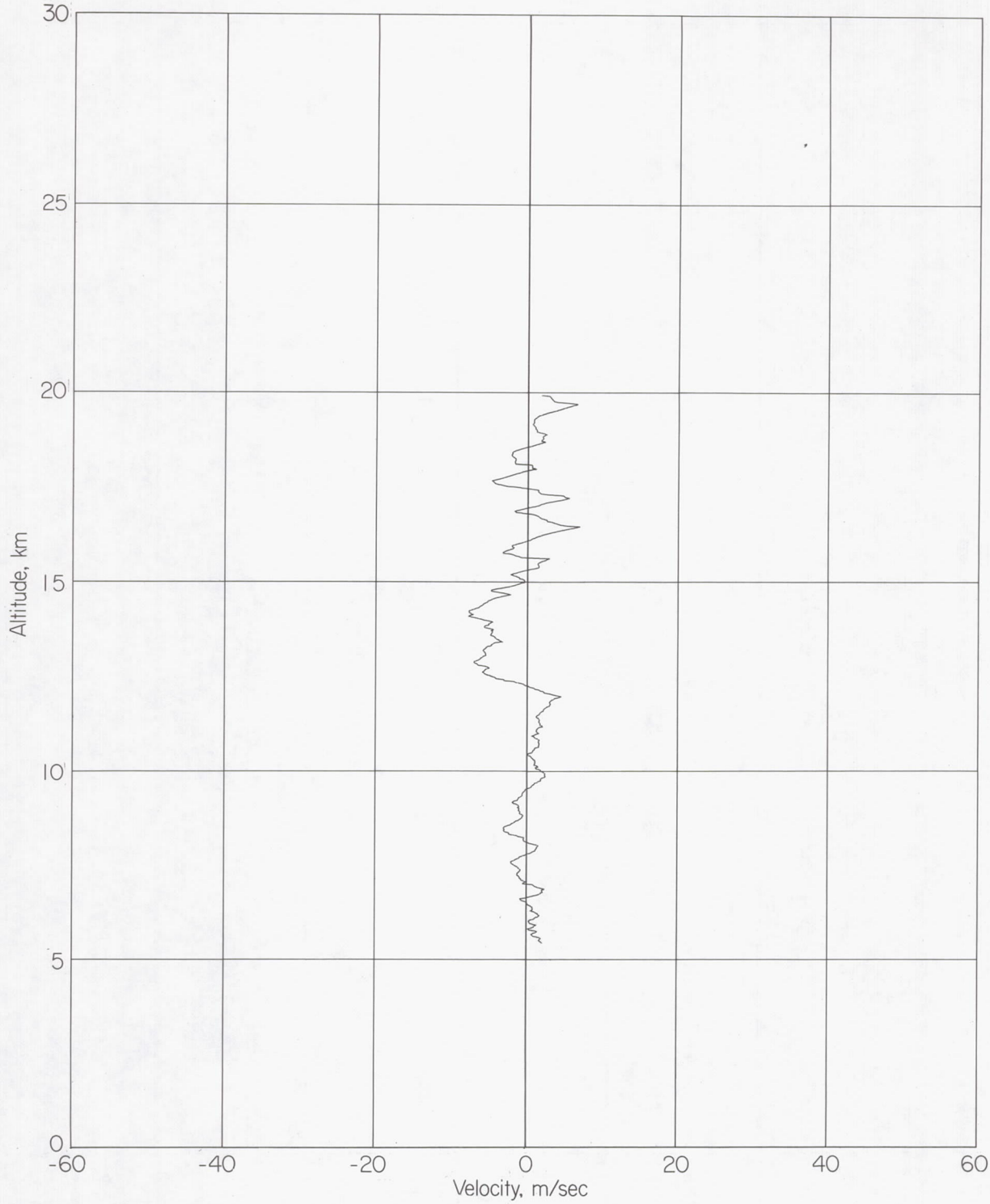
(b) South-to-north velocity component.

Figure 40.- Concluded.



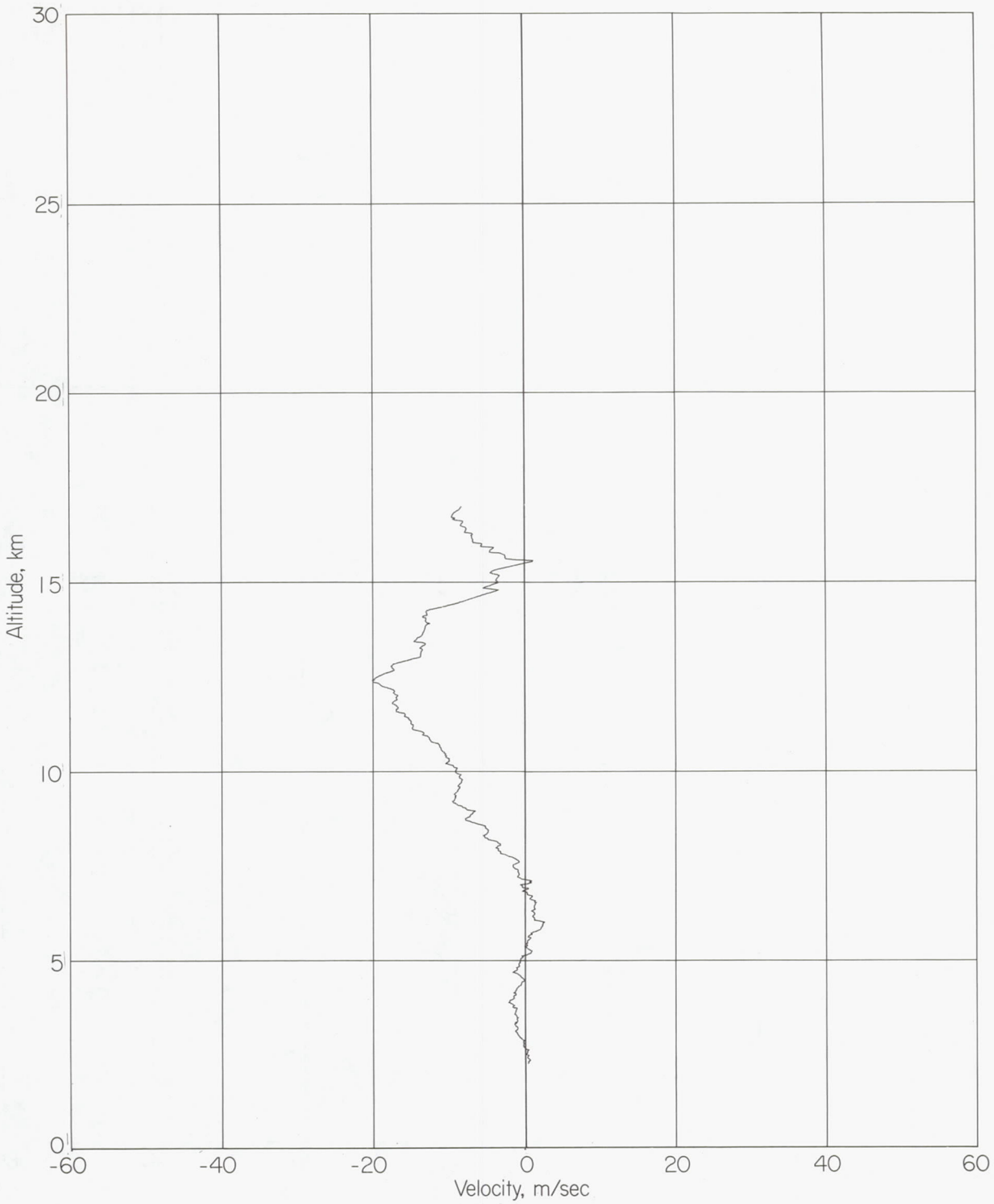
(a) West-to-east velocity component.

Figure 41.- Wind profile of smoke trail 365 obtained July 26, 1963. Time interval, 60 seconds; height interval, 25 meters.



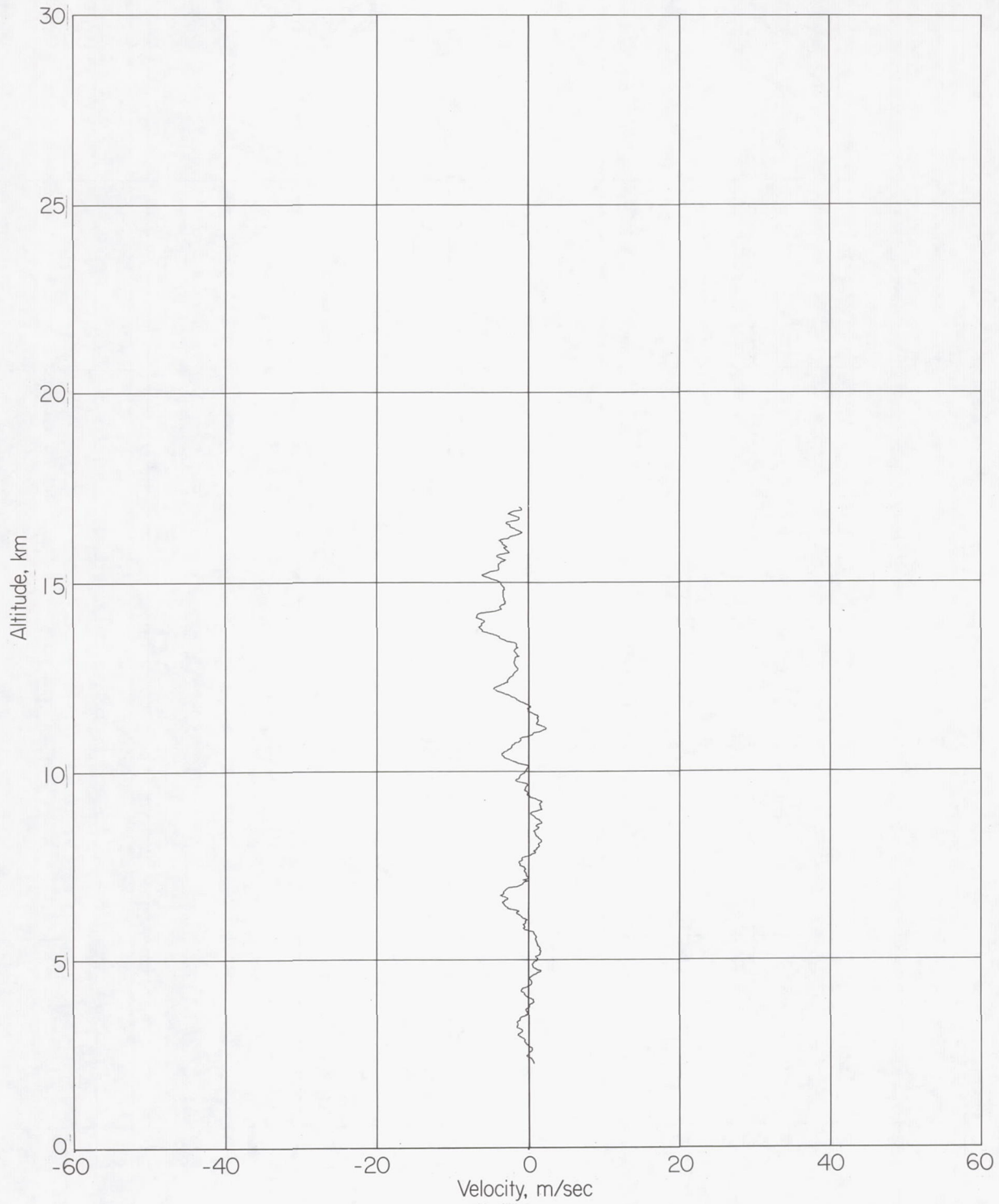
(b) South-to-north velocity component.

Figure 41.- Concluded.



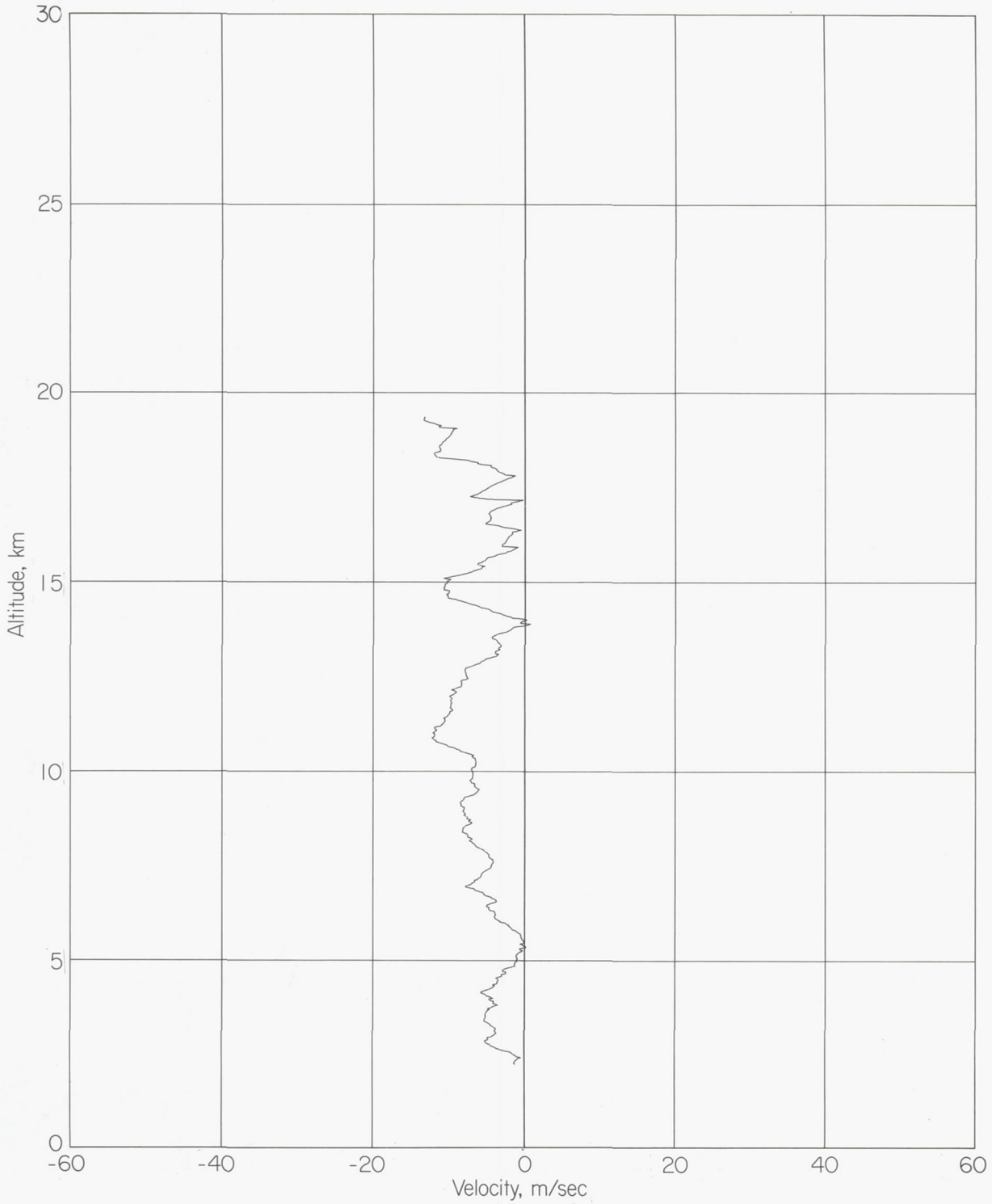
(a) West-to-east velocity component.

Figure 42.- Wind profile of smoke trail 366 obtained July 31, 1963. Time interval, 60 seconds; height interval, 25 meters.



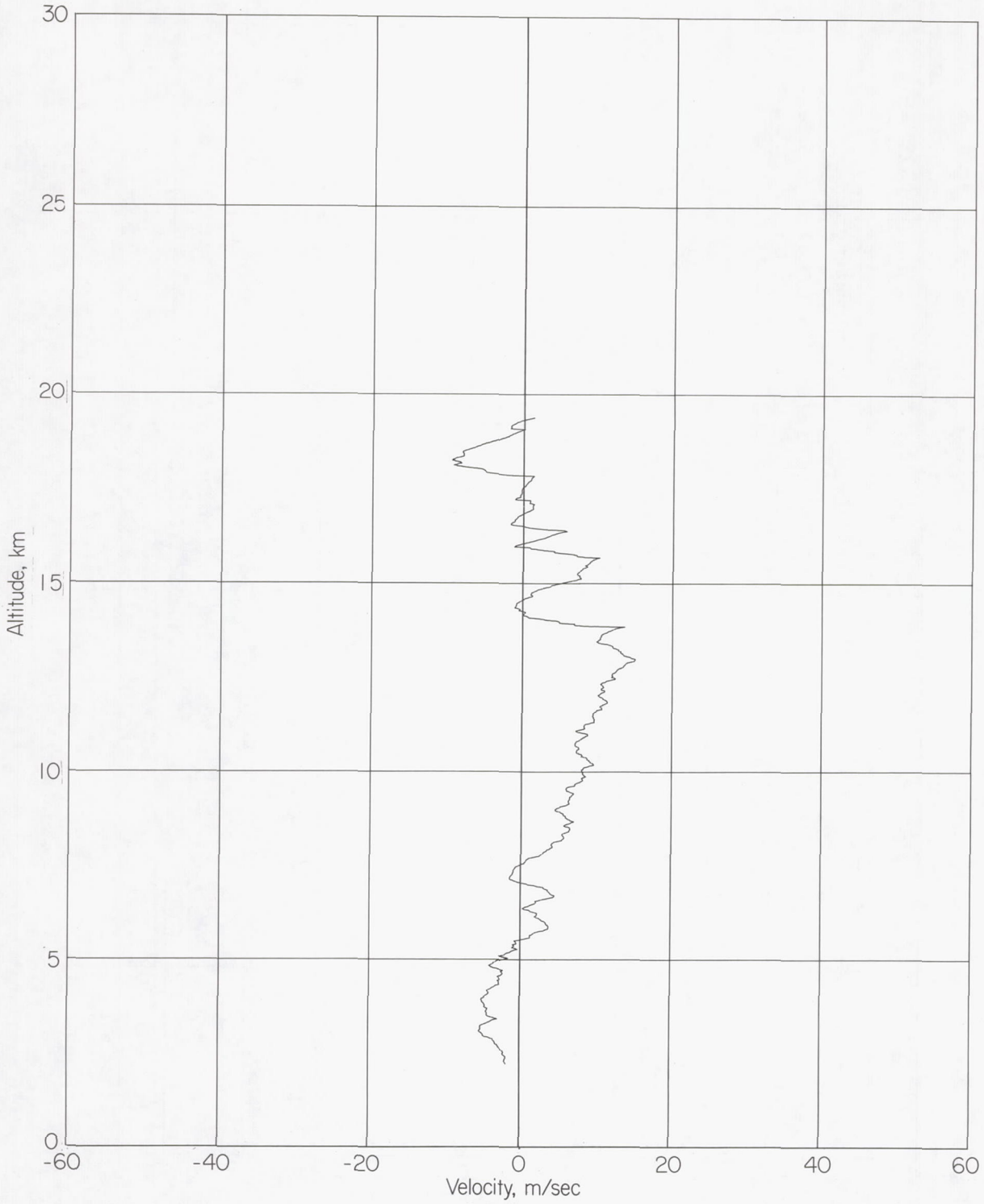
(b) South-to-north velocity component.

Figure 42.- Concluded.



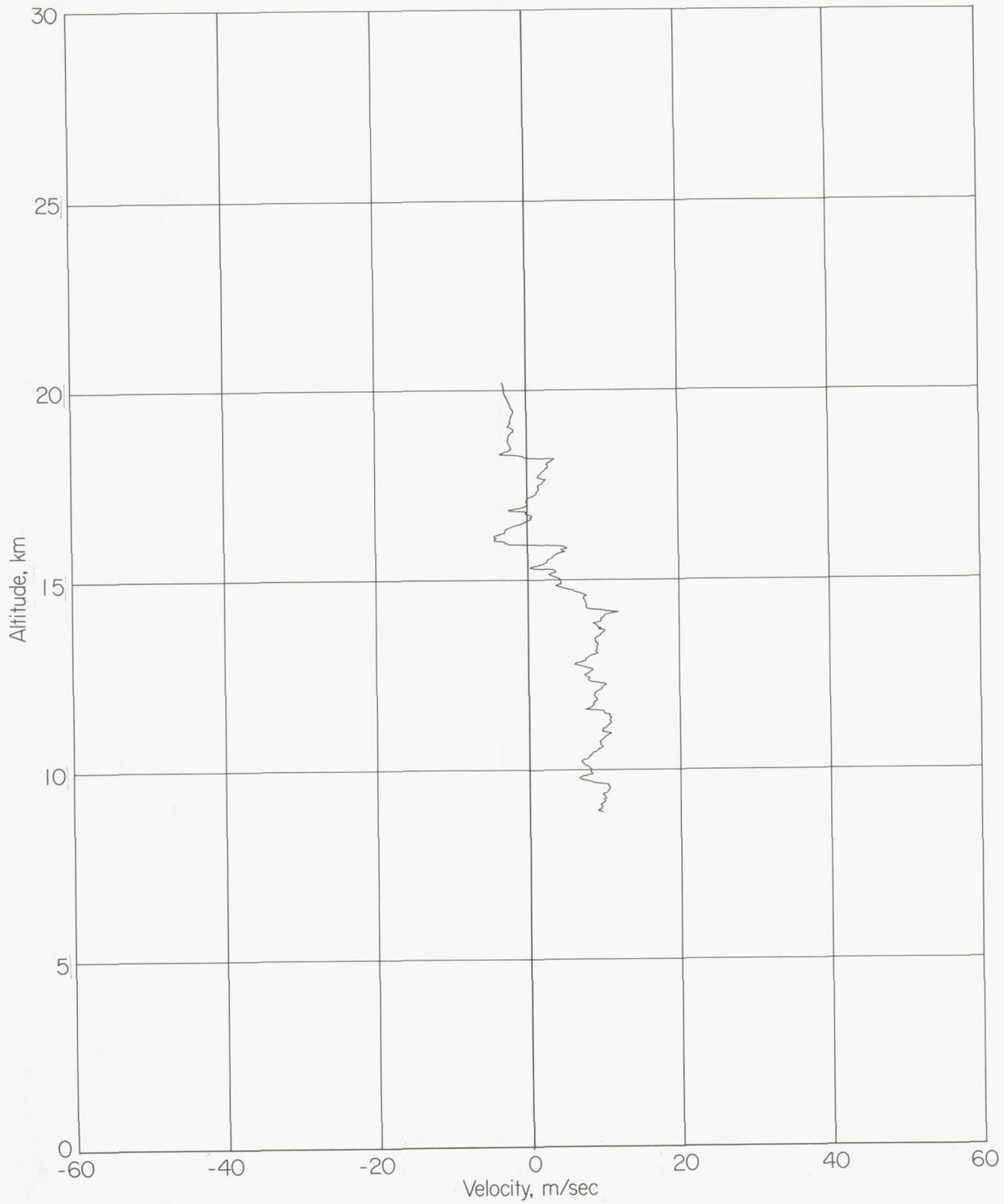
(a) West-to-east velocity component.

Figure 43.- Wind profile of smoke trail 367 obtained August 7, 1963. Time interval, 60 seconds; height interval, 25 meters.



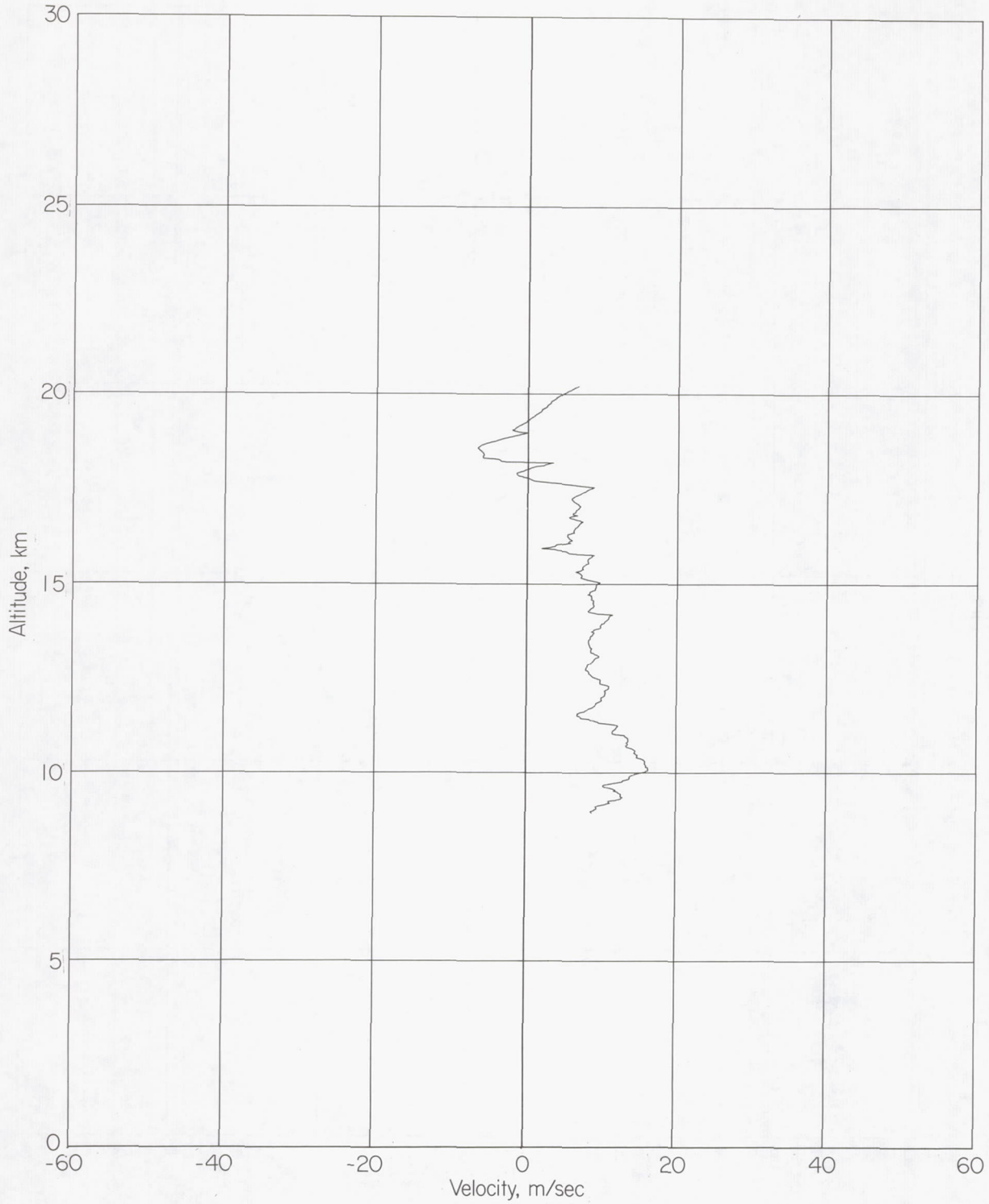
(b) South-to-north velocity component.

Figure 43.- Concluded.



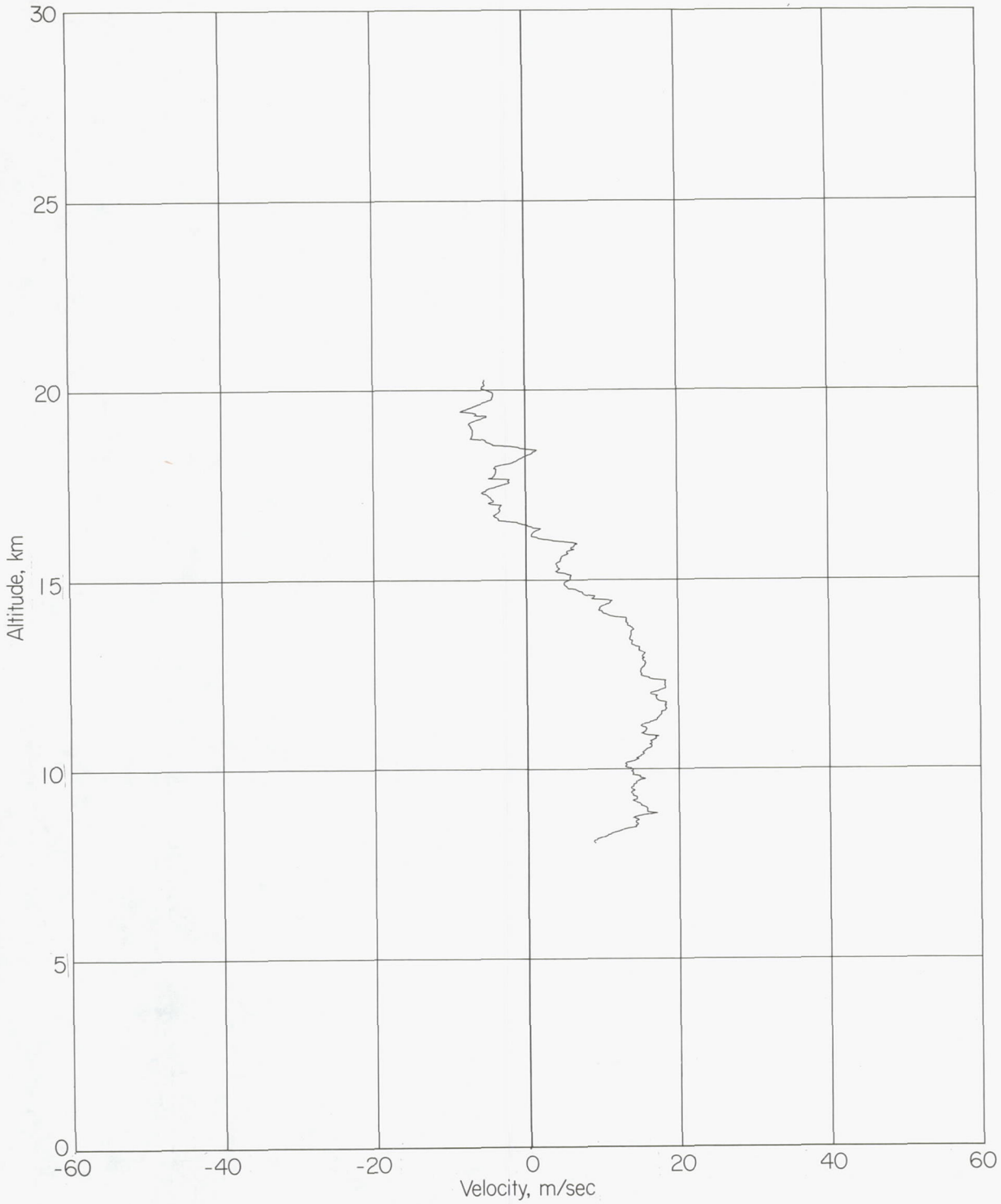
(a) West-to-east velocity component.

Figure 44.- Wind profile of smoke trail 369 obtained September 30, 1963. Time interval, 60 seconds; height interval, 25 meters.



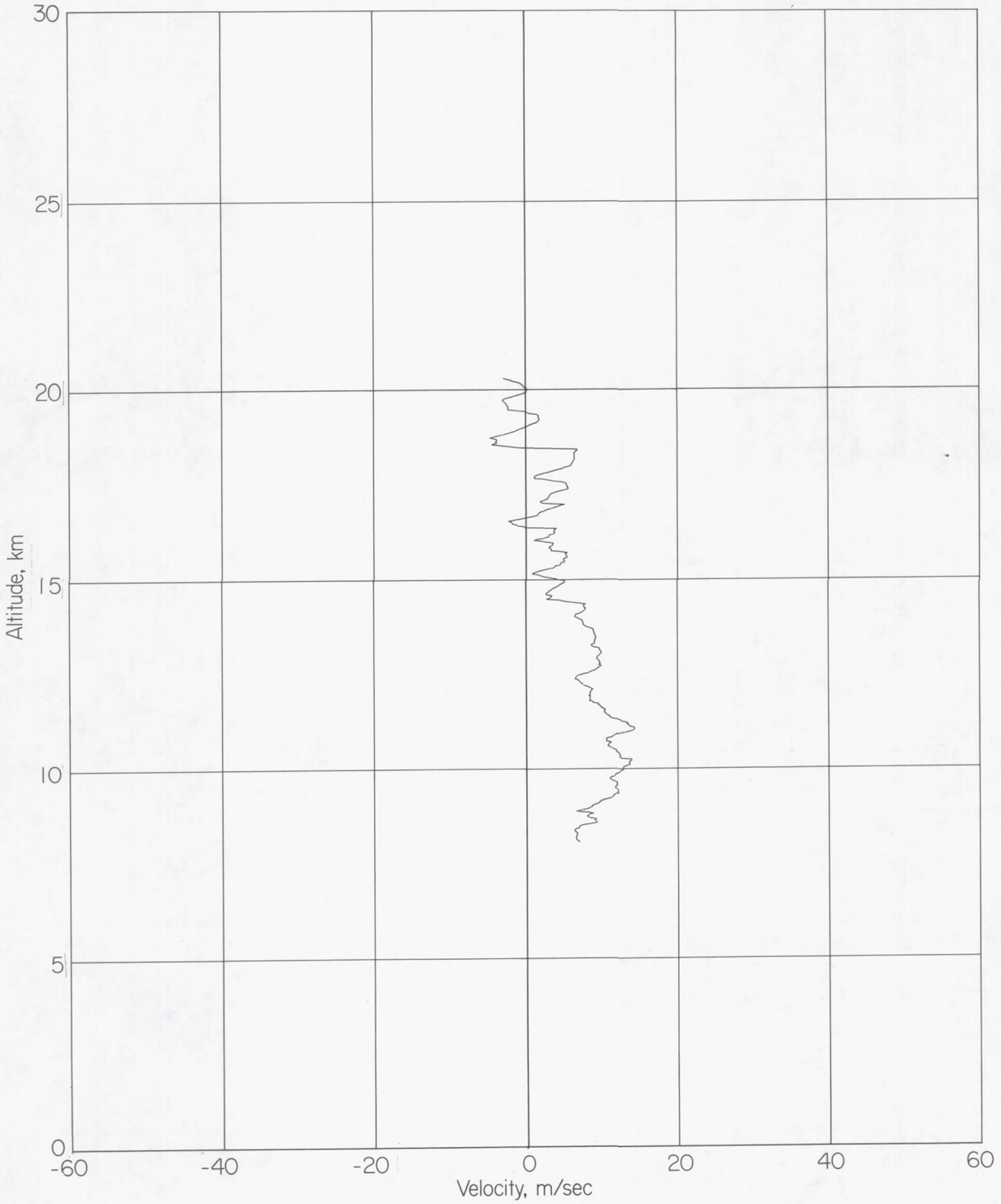
(b) South-to-north velocity component.

Figure 44.- Concluded.



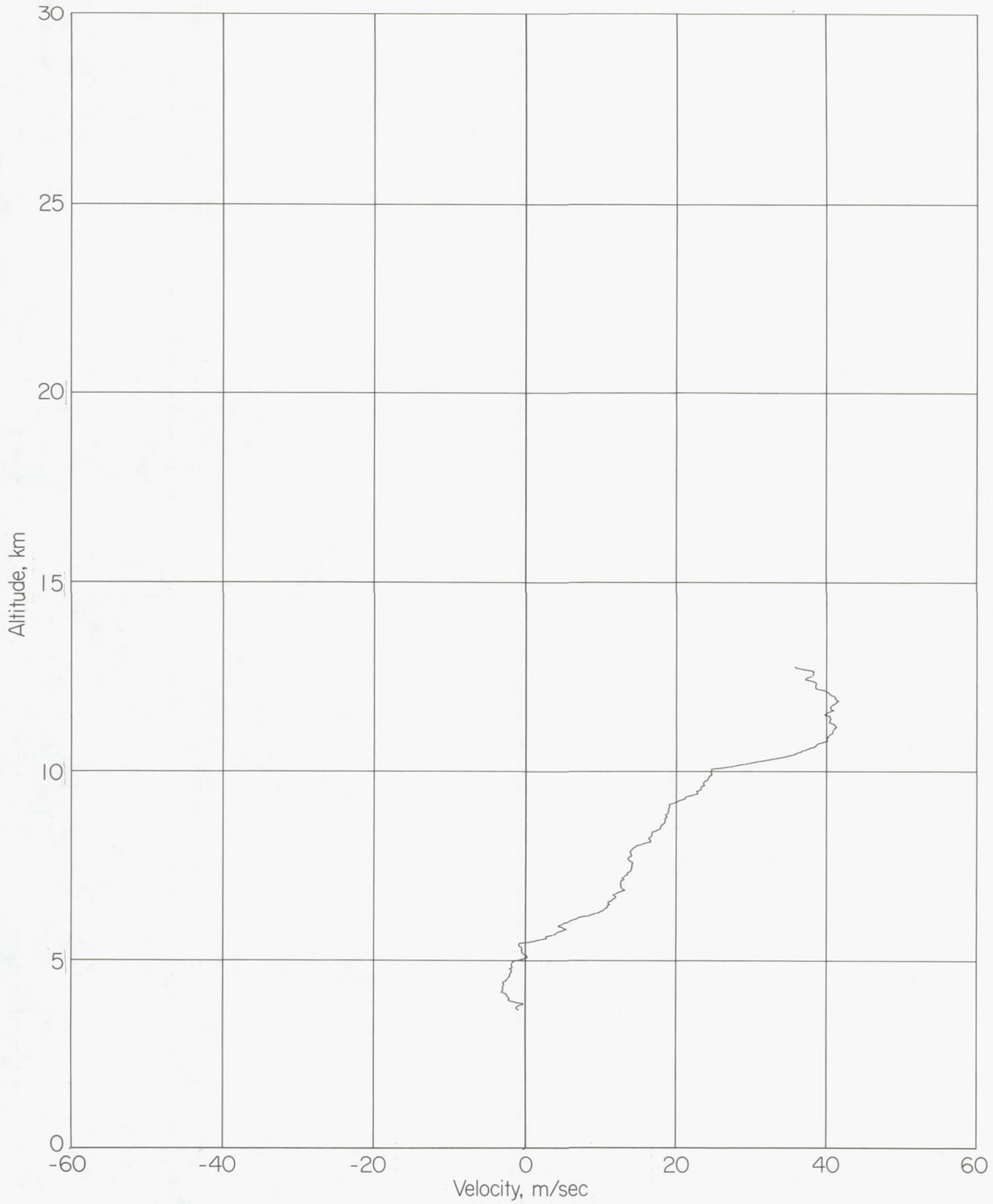
(a) West-to-east velocity component.

Figure 45.- Wind profile of smoke trail 370 obtained October 1, 1963. Time interval, 60 seconds; height interval, 25 meters.



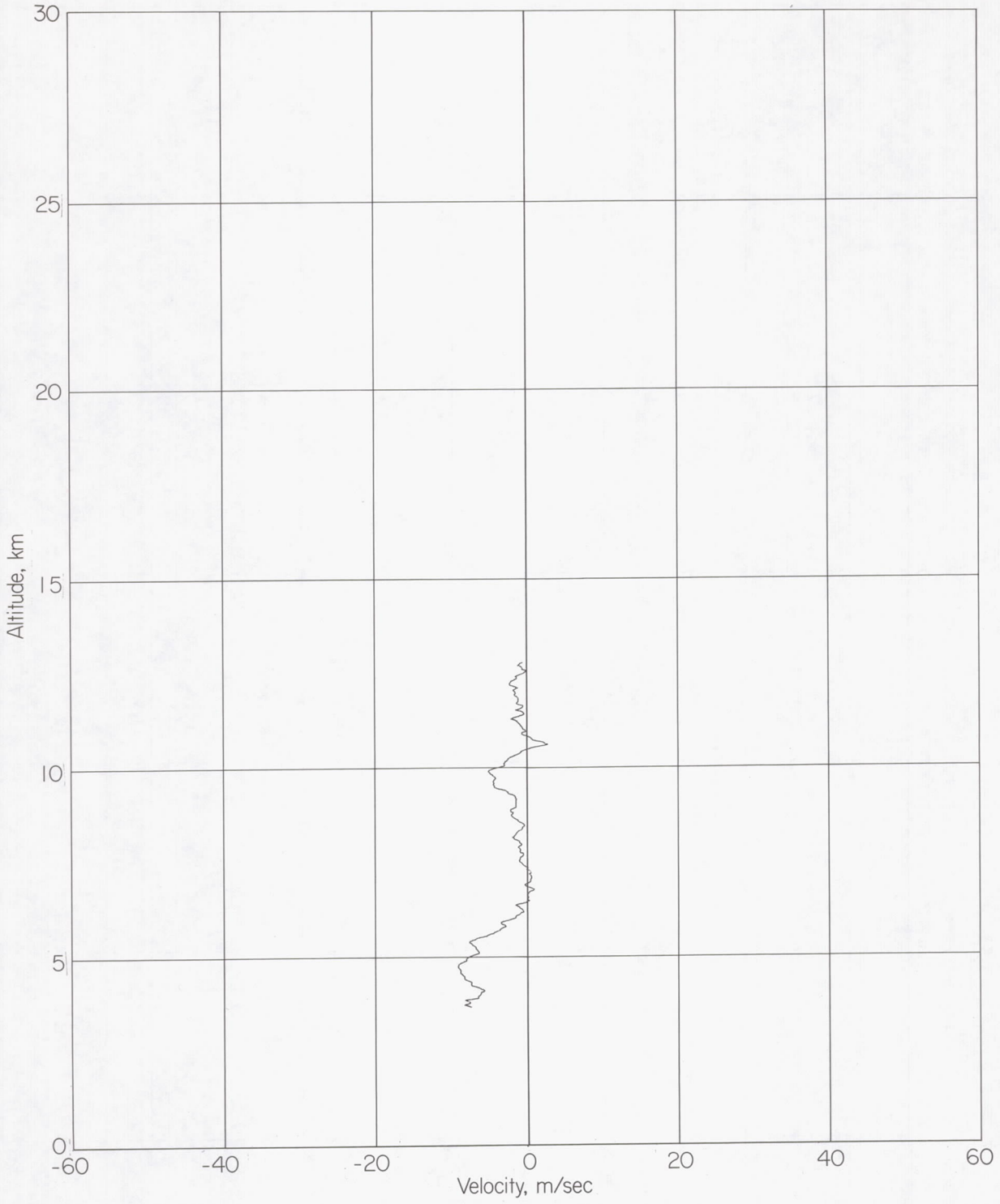
(b) South-to-north velocity component.

Figure 45.- Concluded.



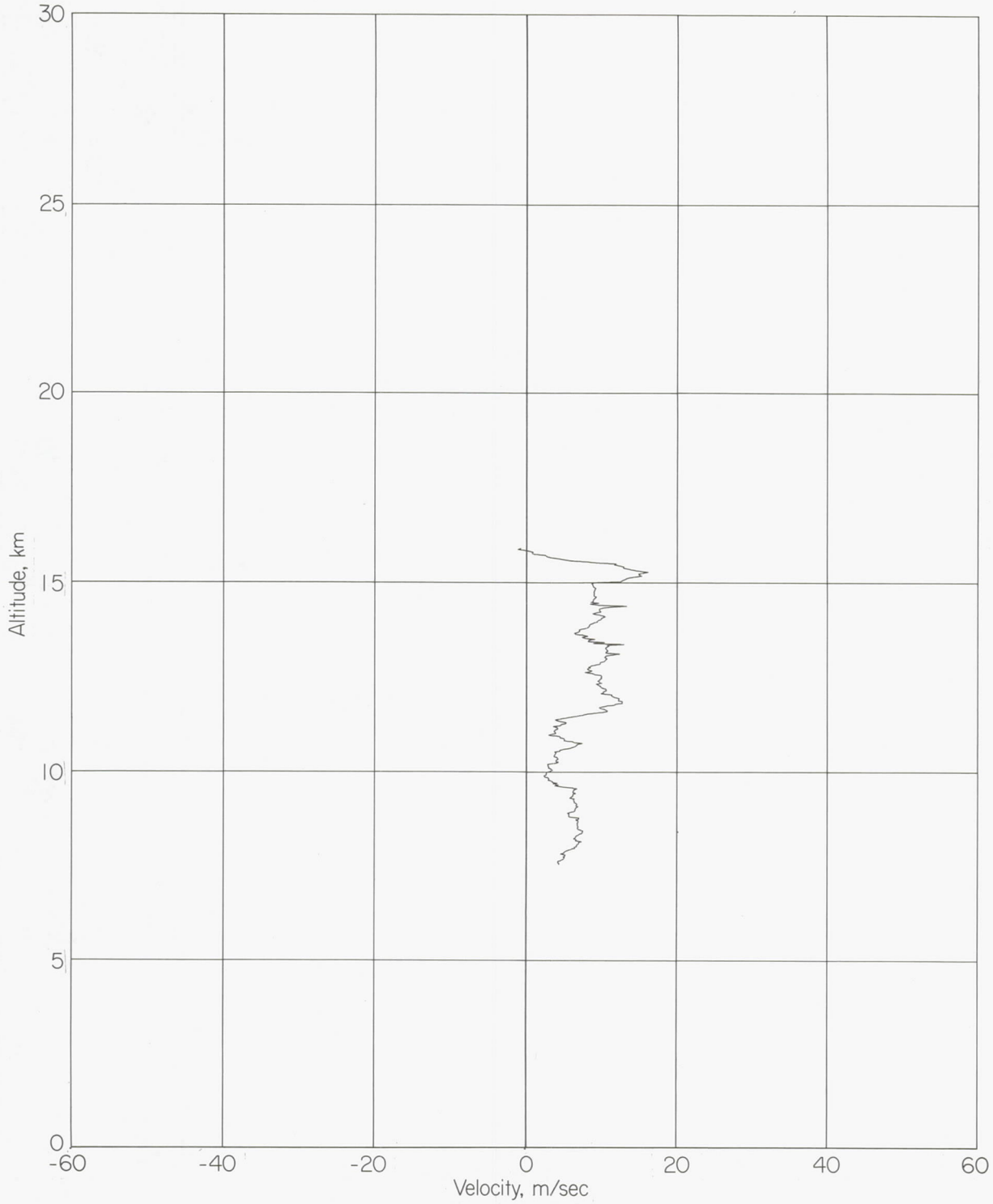
(a) West-to-east velocity component.

Figure 46.- Wind profile of smoke trail 371 obtained October 9, 1963. Time interval, 60 seconds; height interval, 25 meters.



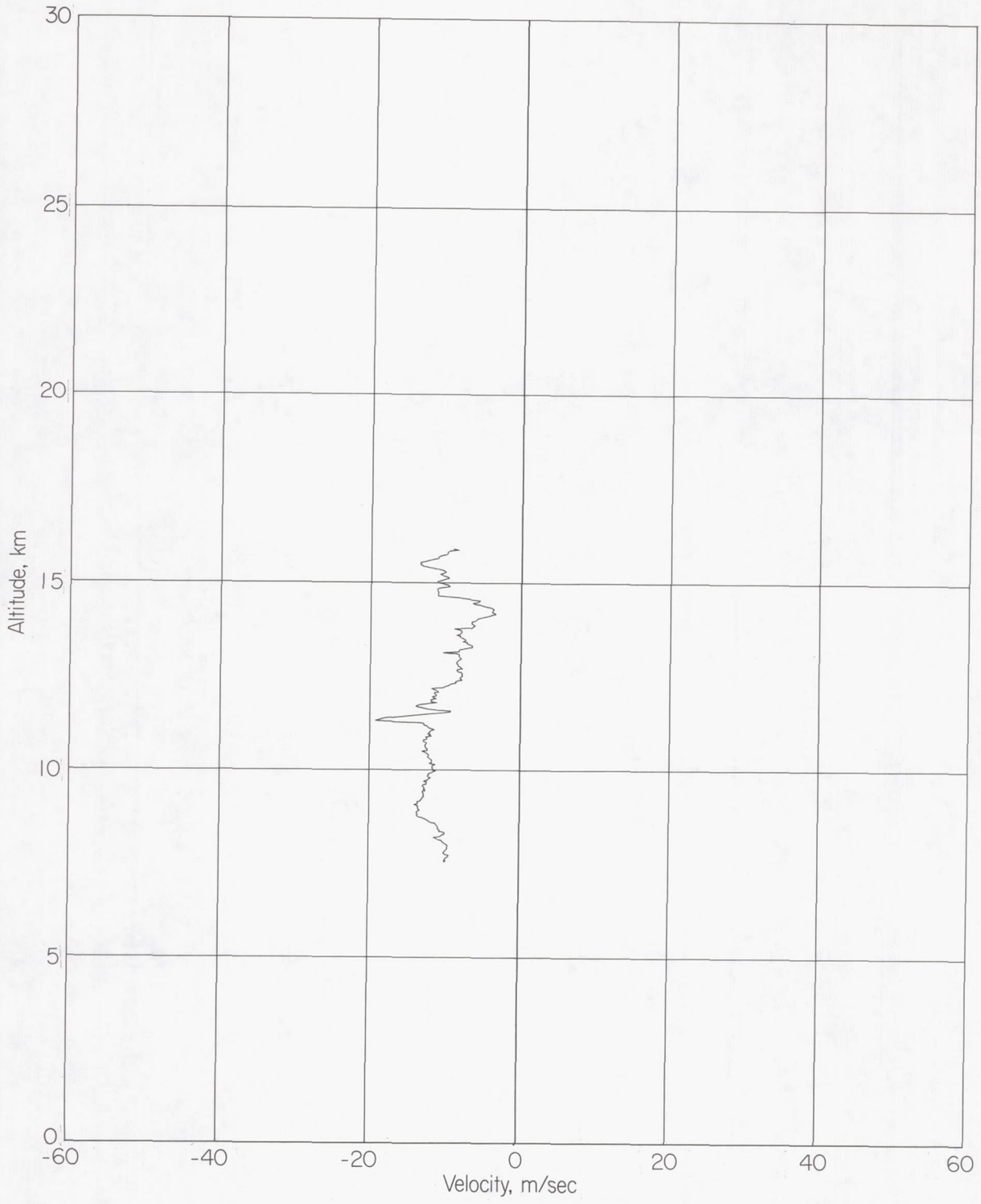
(b) South-to-north velocity component.

Figure 46.- Concluded.



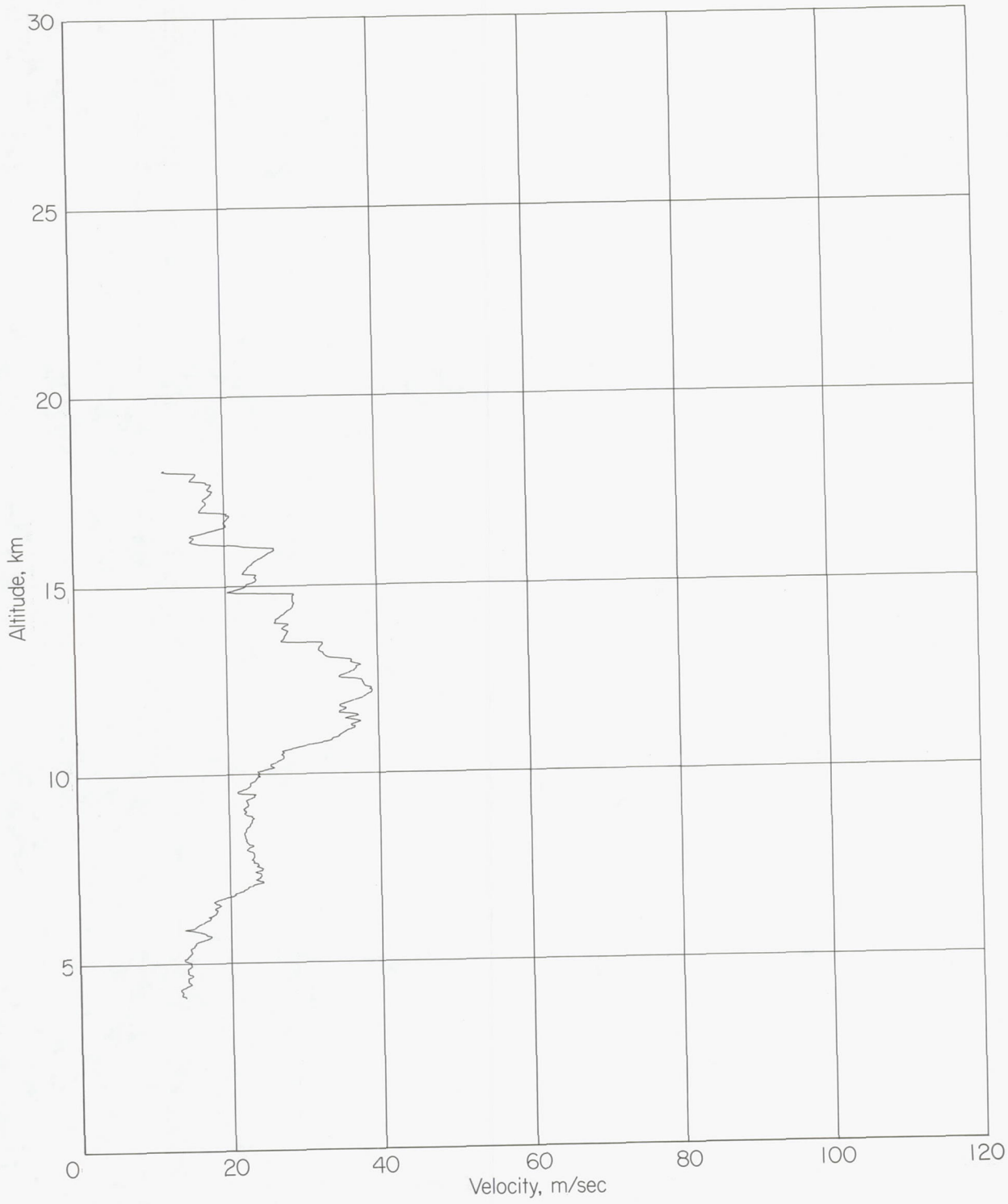
(a) West-to-east velocity component.

Figure 47.- Wind profile of smoke trail 372 obtained October 22, 1963. Time interval, 30 seconds; height interval, 25 meters.



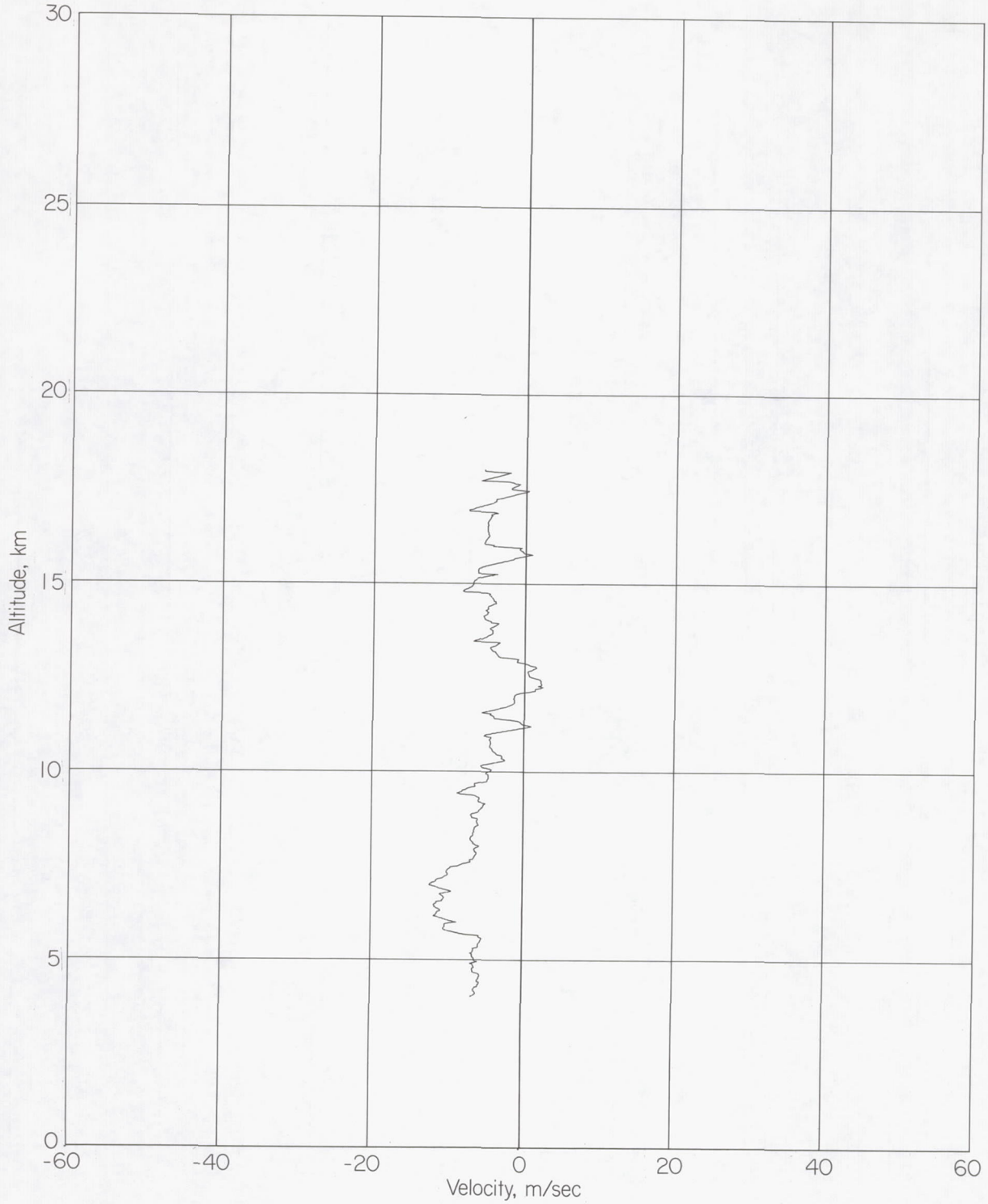
(b) South-to-north velocity component.

Figure 47.- Concluded.



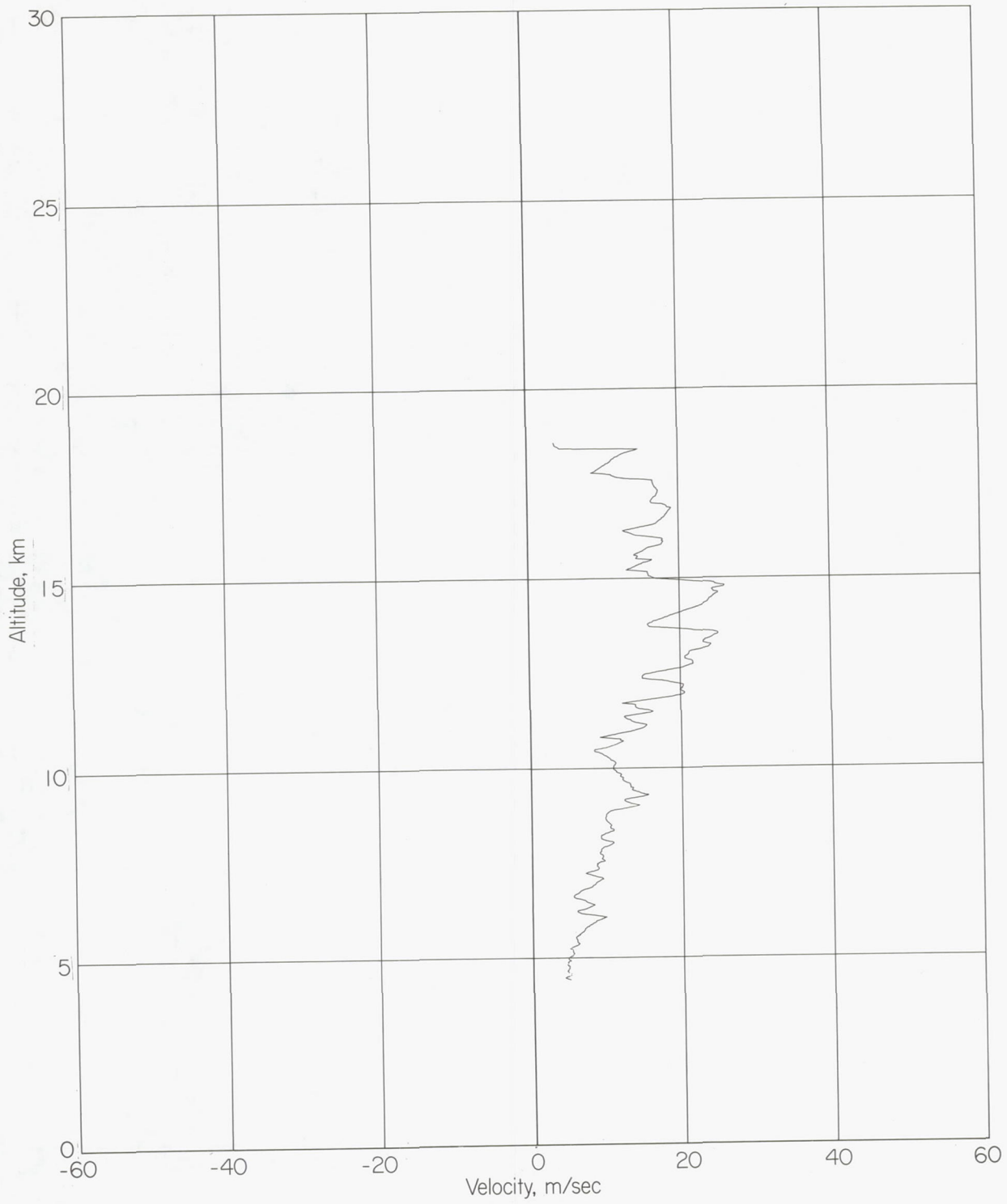
(a) West-to-east velocity component.

Figure 48.- Wind profile of smoke trail 374 obtained October 30, 1963. Time interval, 60 seconds; height interval, 25 meters.



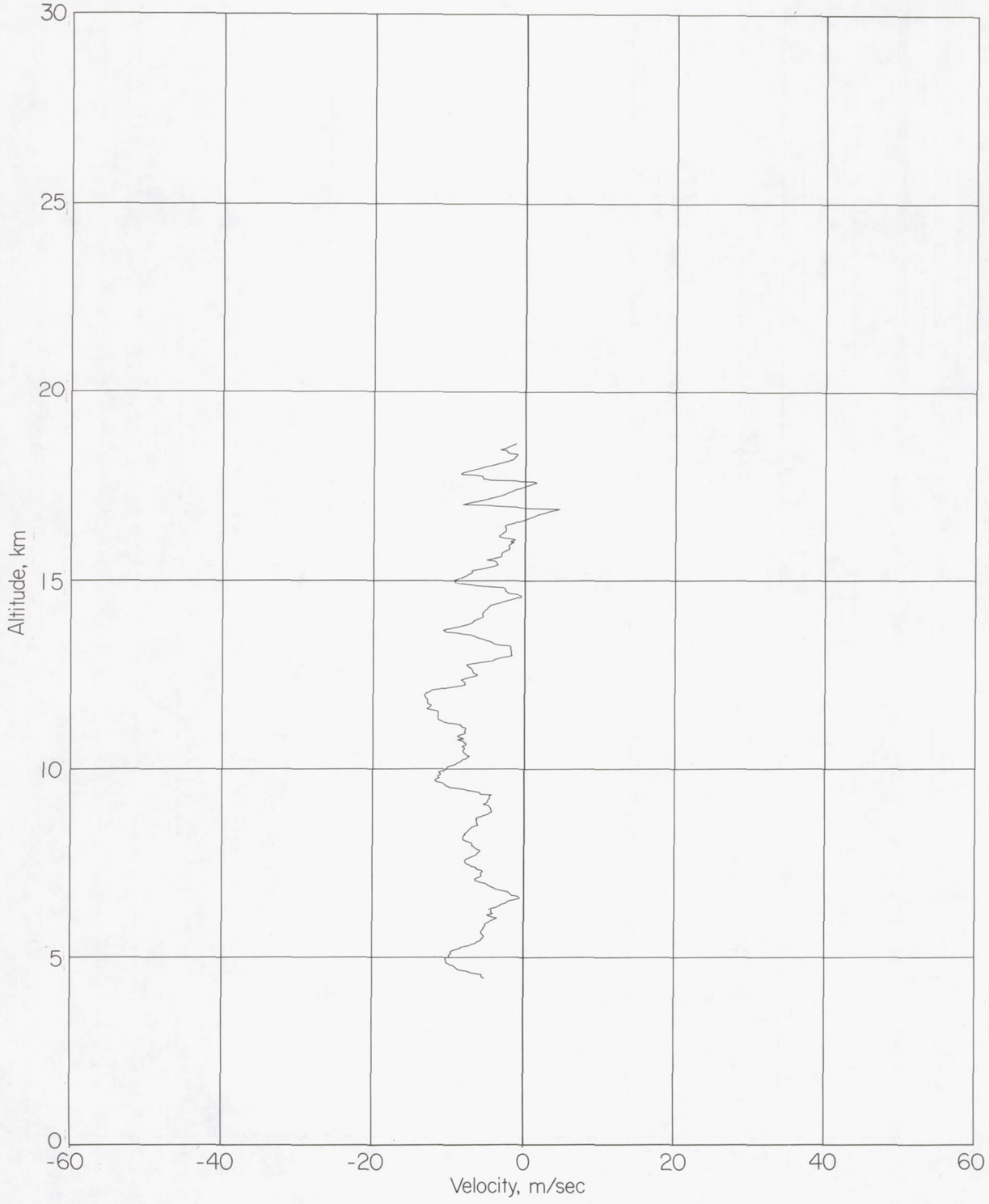
(b) South-to-north velocity component.

Figure 48.- Concluded.



(a) West-to-east velocity component.

Figure 49.- Wind profile of smoke trail 373 obtained October 31, 1963. Time interval, 60 seconds; height interval, 25 meters.

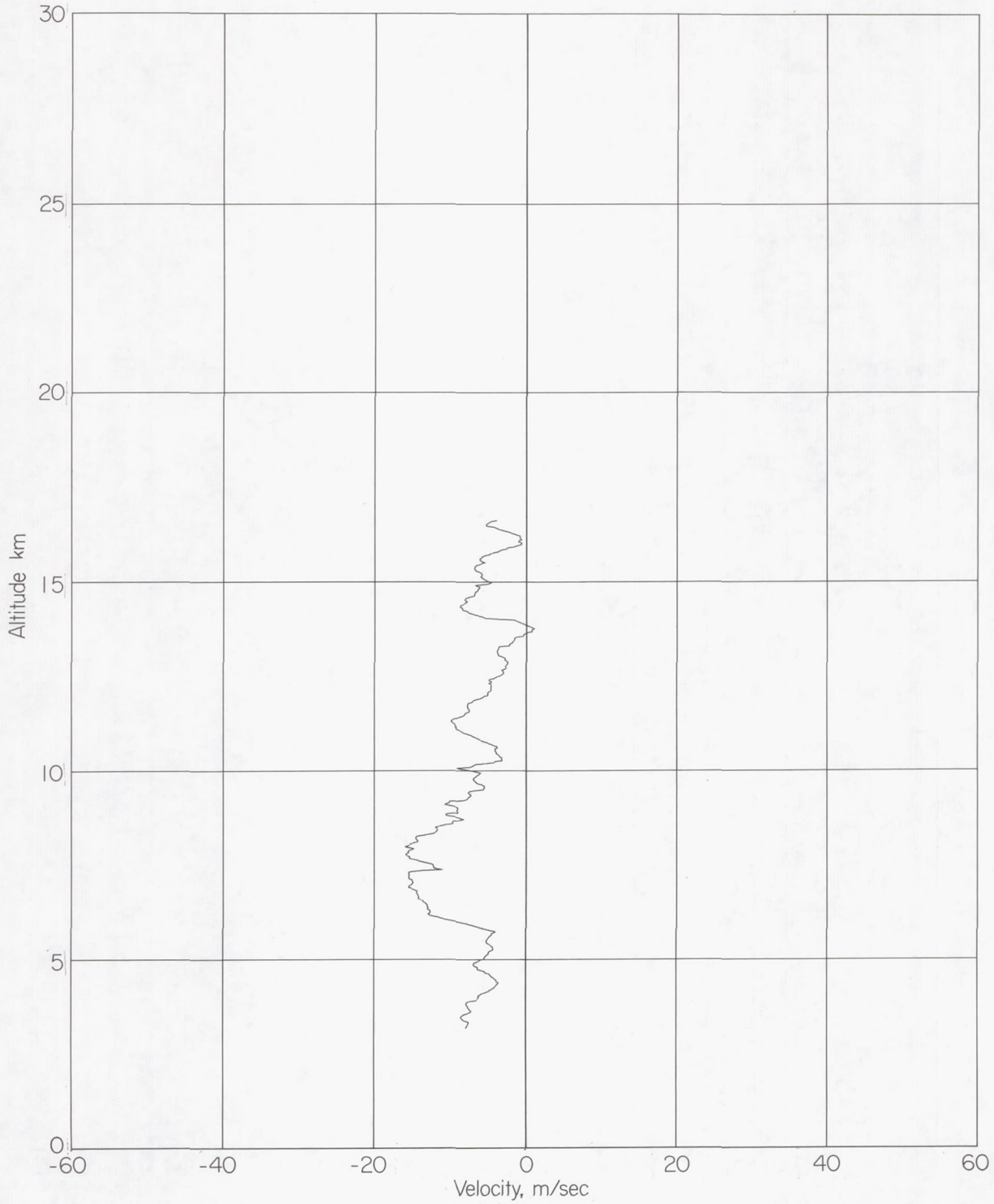


(b) South-to-north velocity component.

Figure 49.- Concluded.

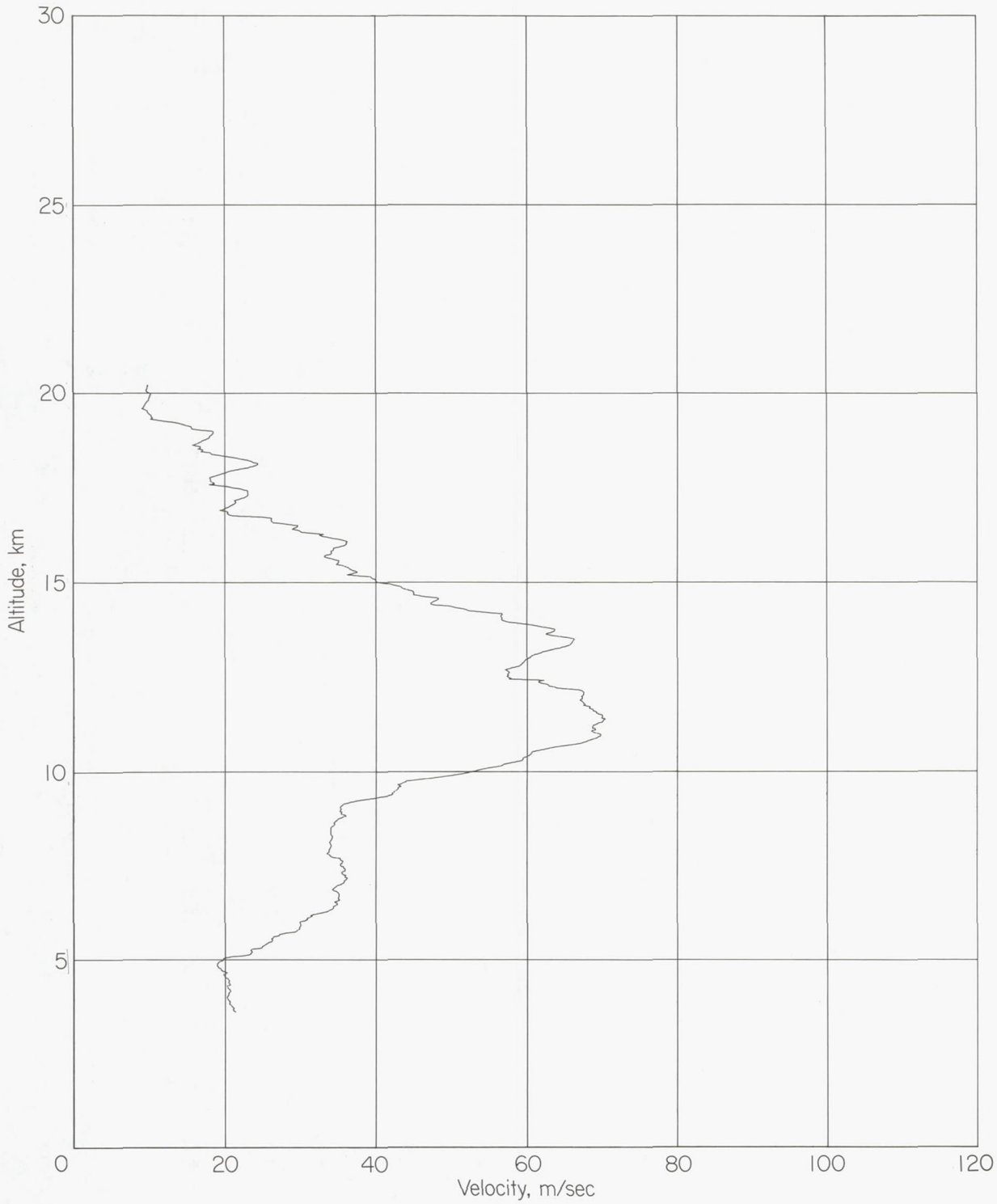
(a) West-to-east velocity component.

Figure 50.- Wind profile of smoke trail 375 obtained November 6, 1963. Time interval, 60 seconds; height interval, 25 meters.



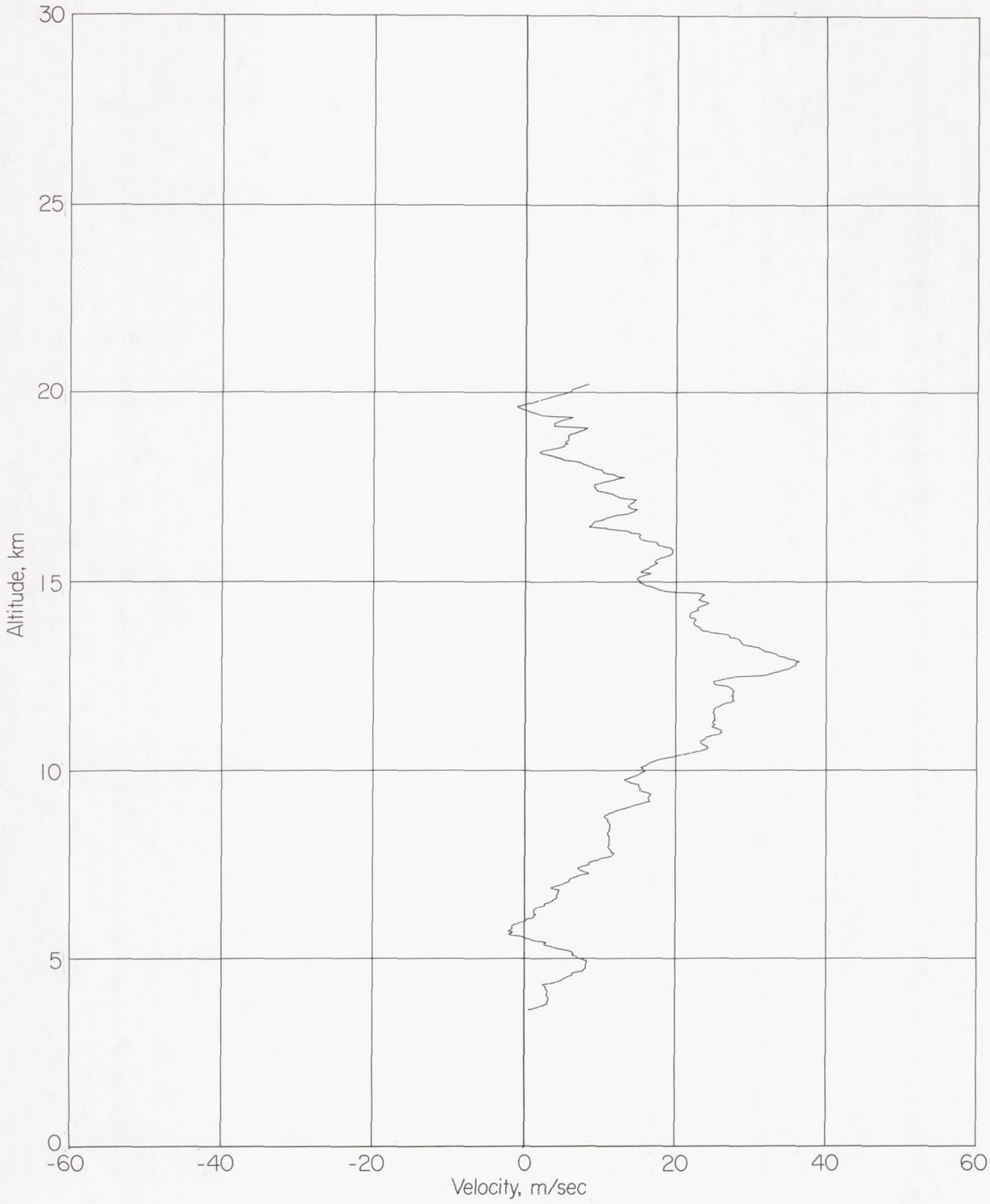
(b) South-to-north velocity component.

Figure 50.- Concluded.



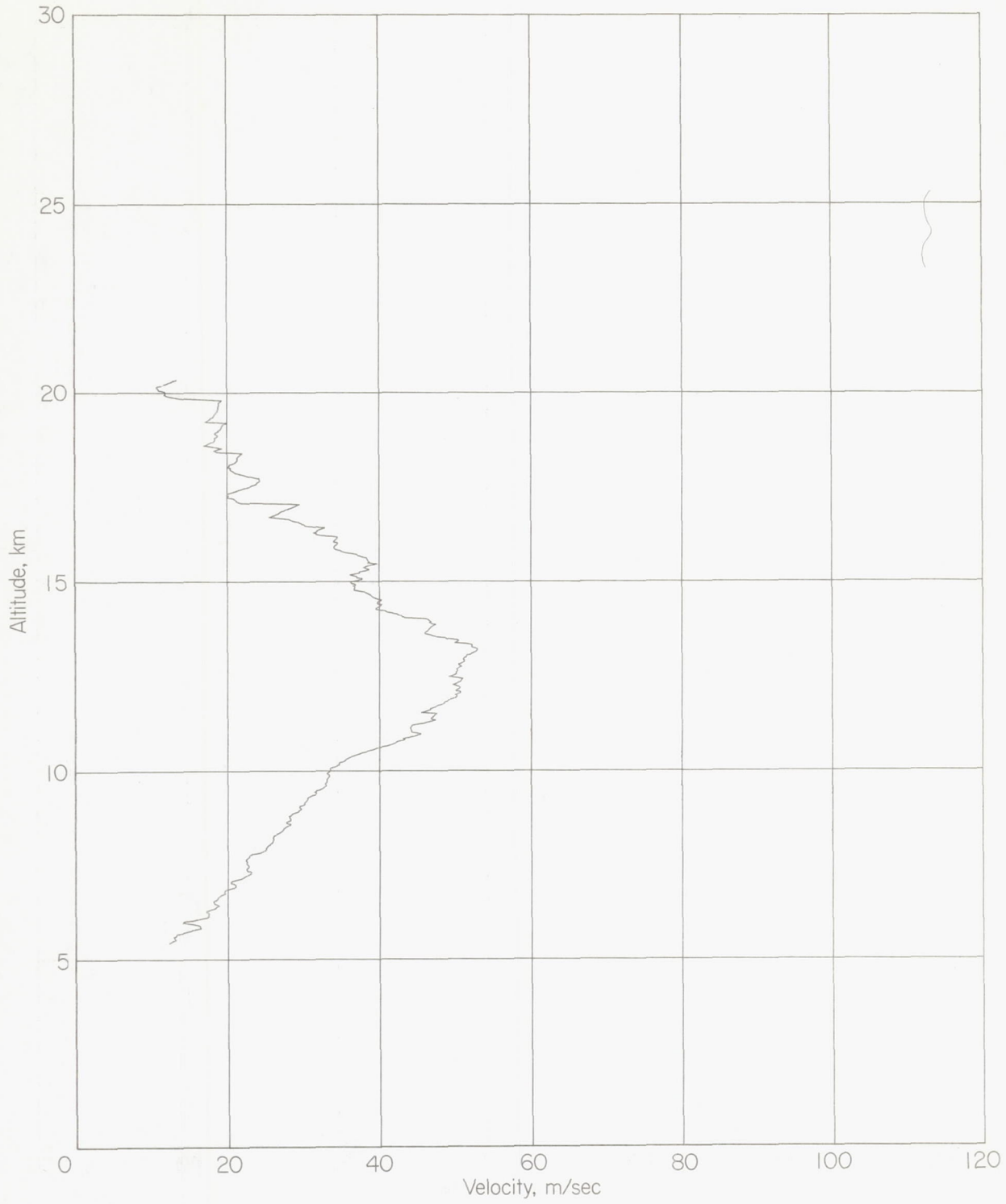
(a) West-to-east velocity component.

Figure 51.- Wind profile of smoke trail 376 obtained November 13, 1963. Time interval, 60 seconds; height interval, 25 meters.



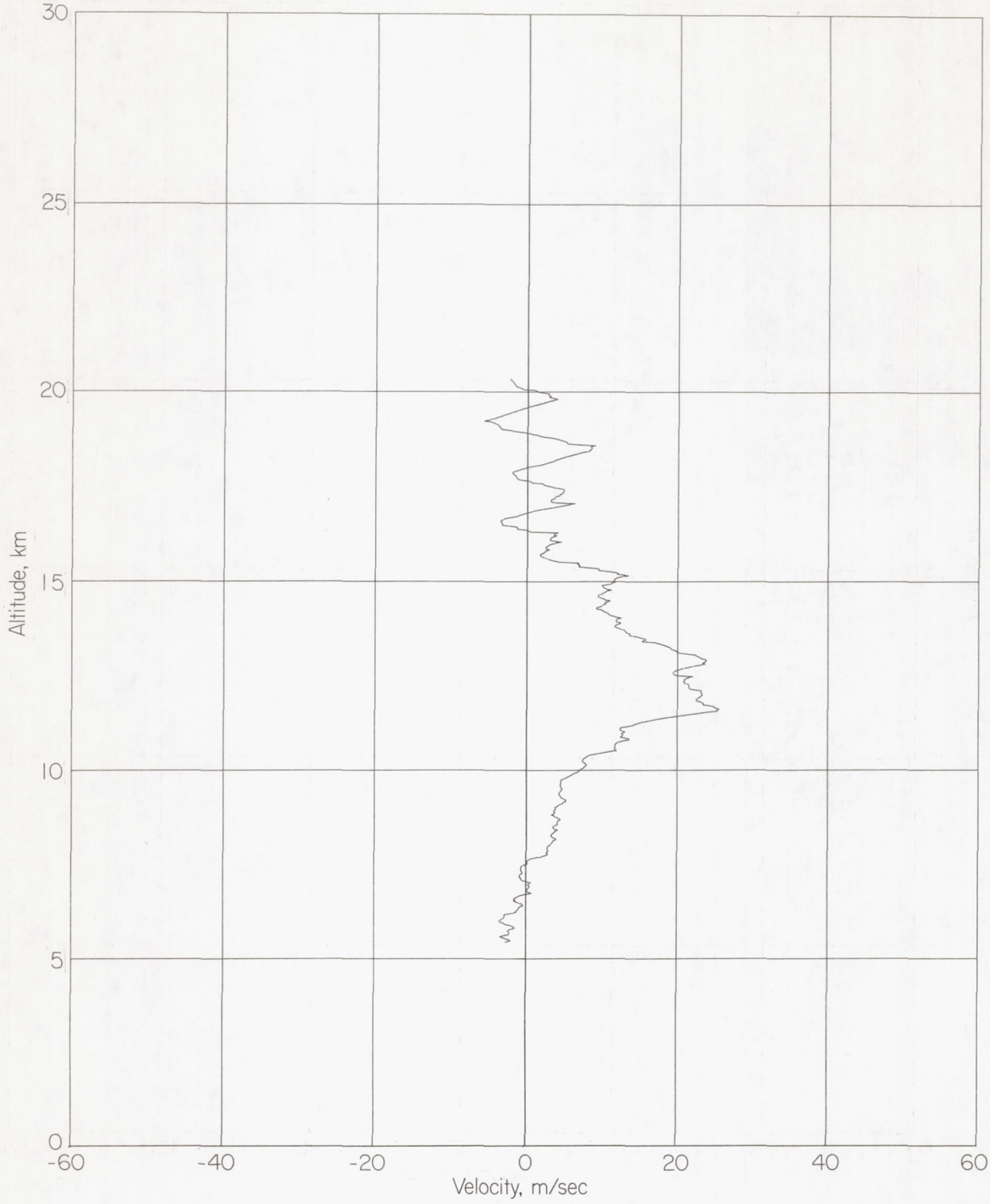
(b) South-to-north velocity component.

Figure 51.- Concluded.



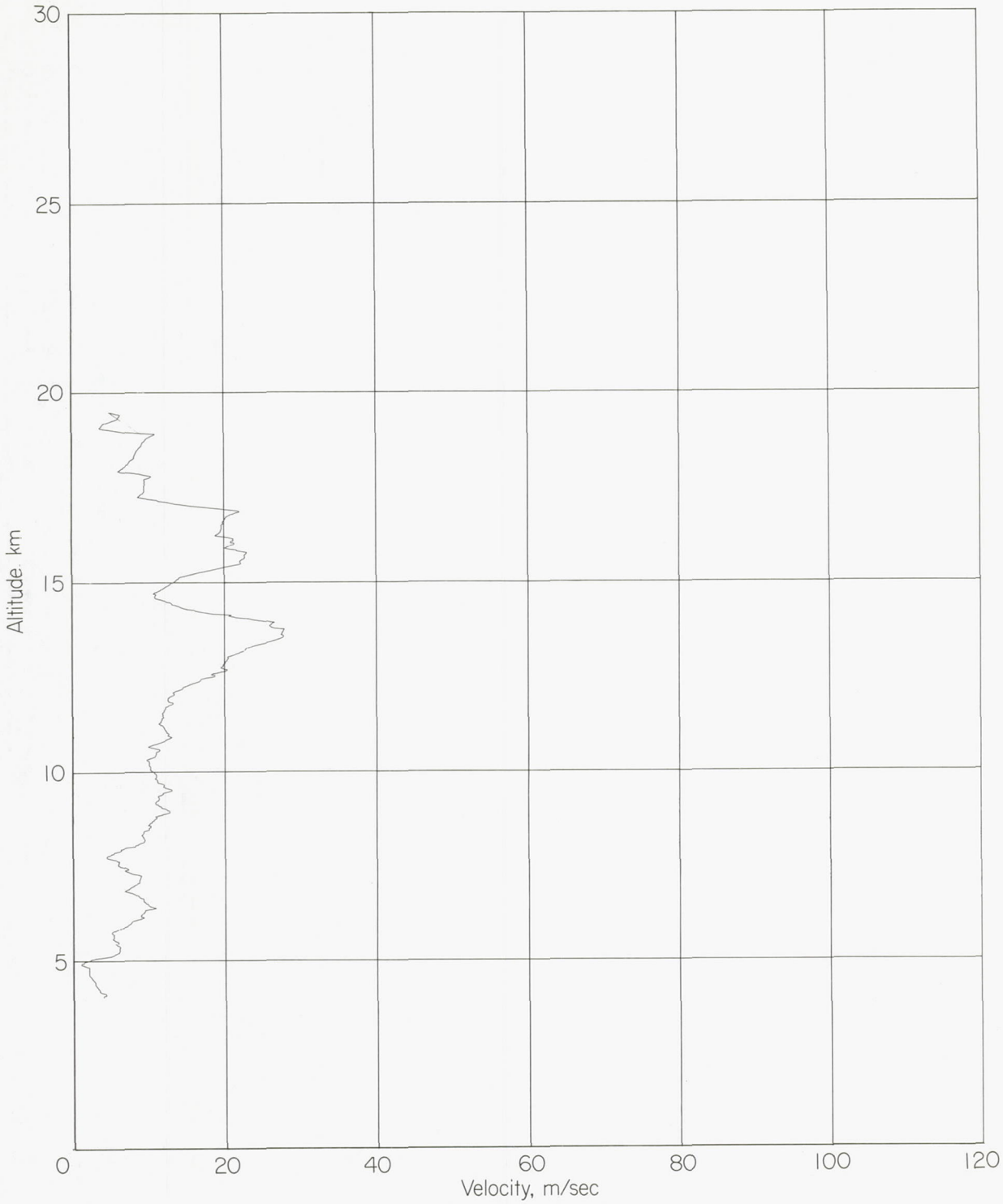
(a) West-to-east velocity component.

Figure 52.- Wind profile of smoke trail 377 obtained November 15, 1963. Time interval, 60 seconds; height interval, 25 meters.



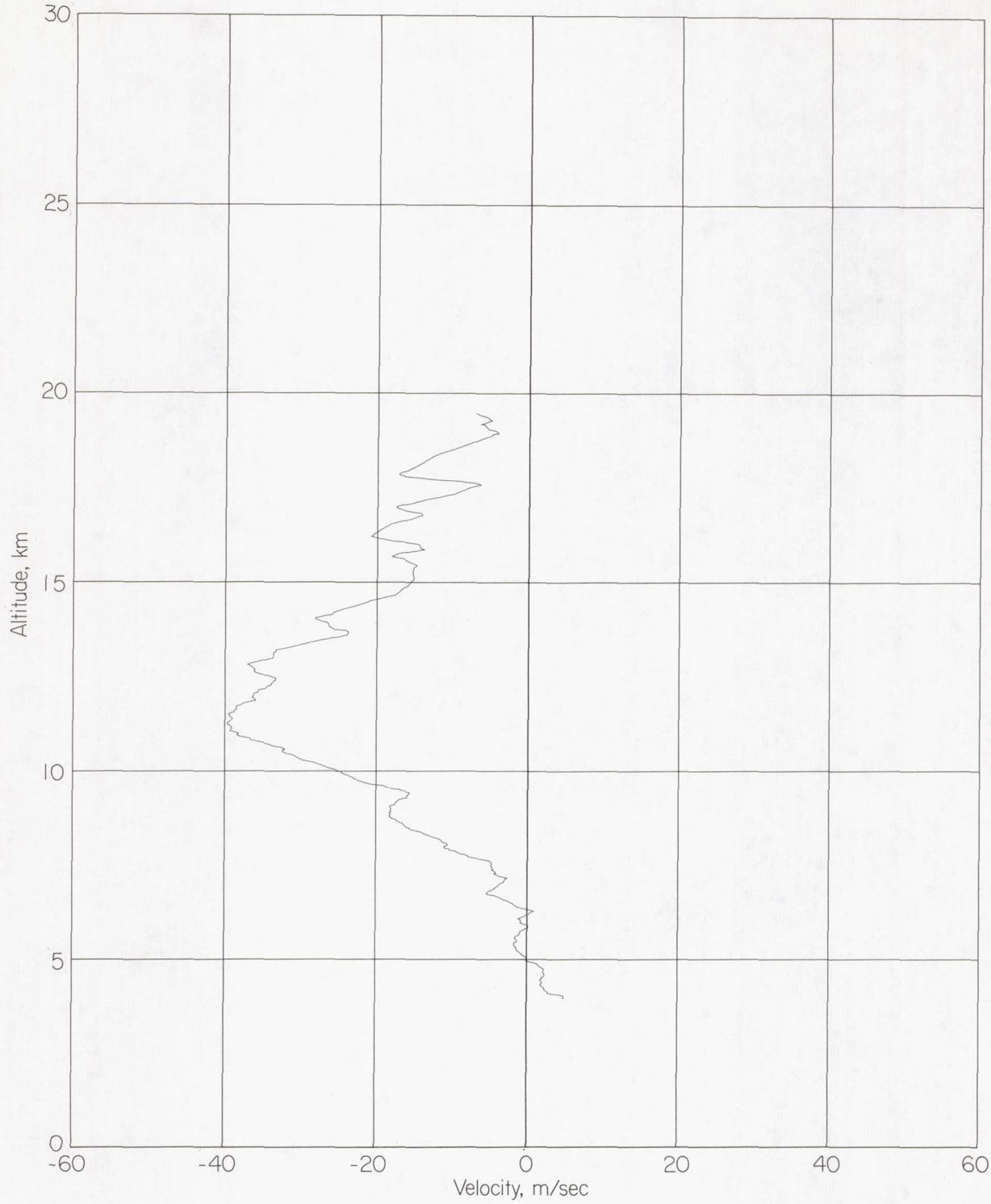
(b) South-to-north velocity component.

Figure 52.- Concluded.



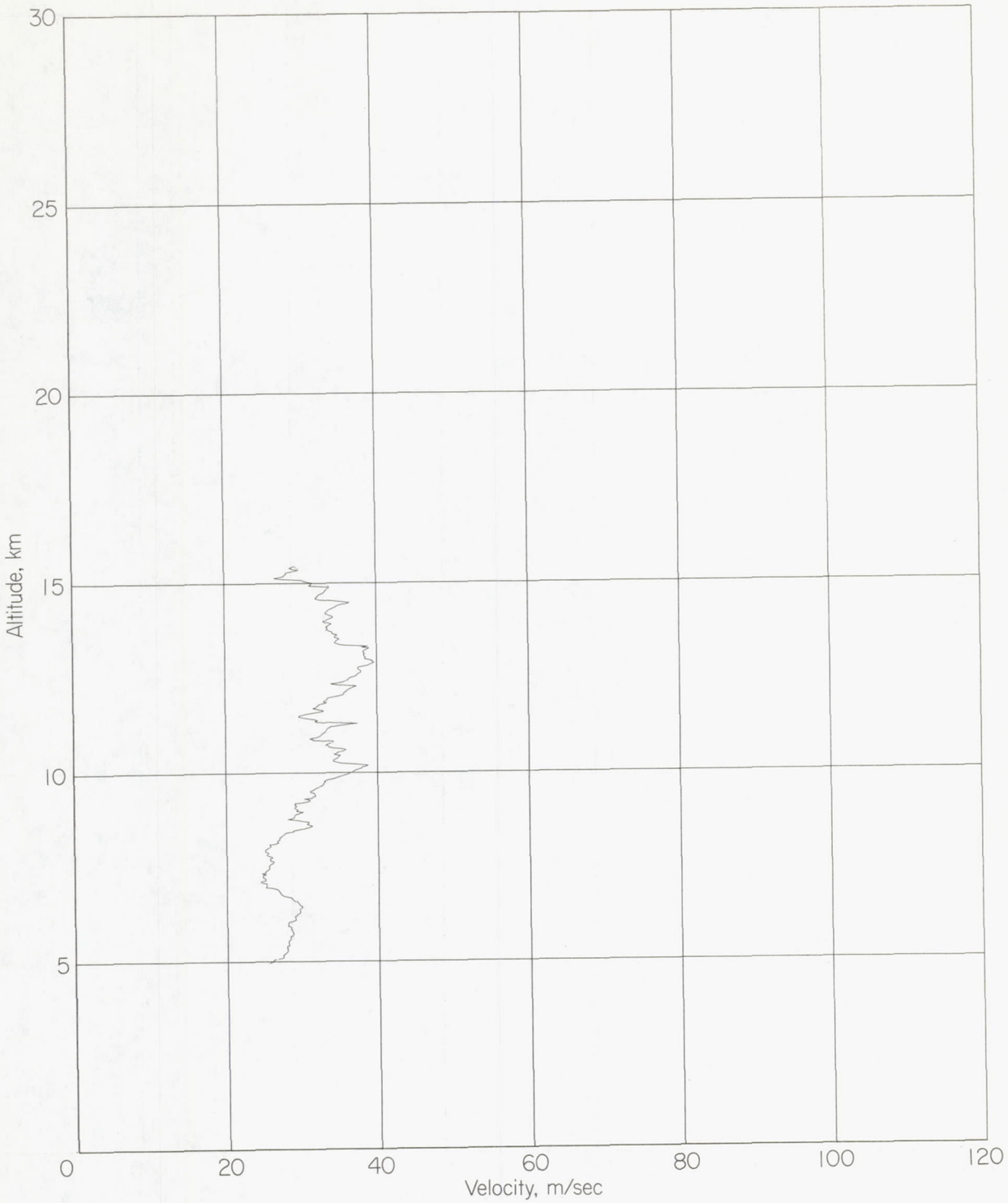
(a) West-to-east velocity component.

Figure 53.- Wind profile of smoke trail 378 obtained November 21, 1963. Time interval, 60 seconds; height interval, 25 meters.



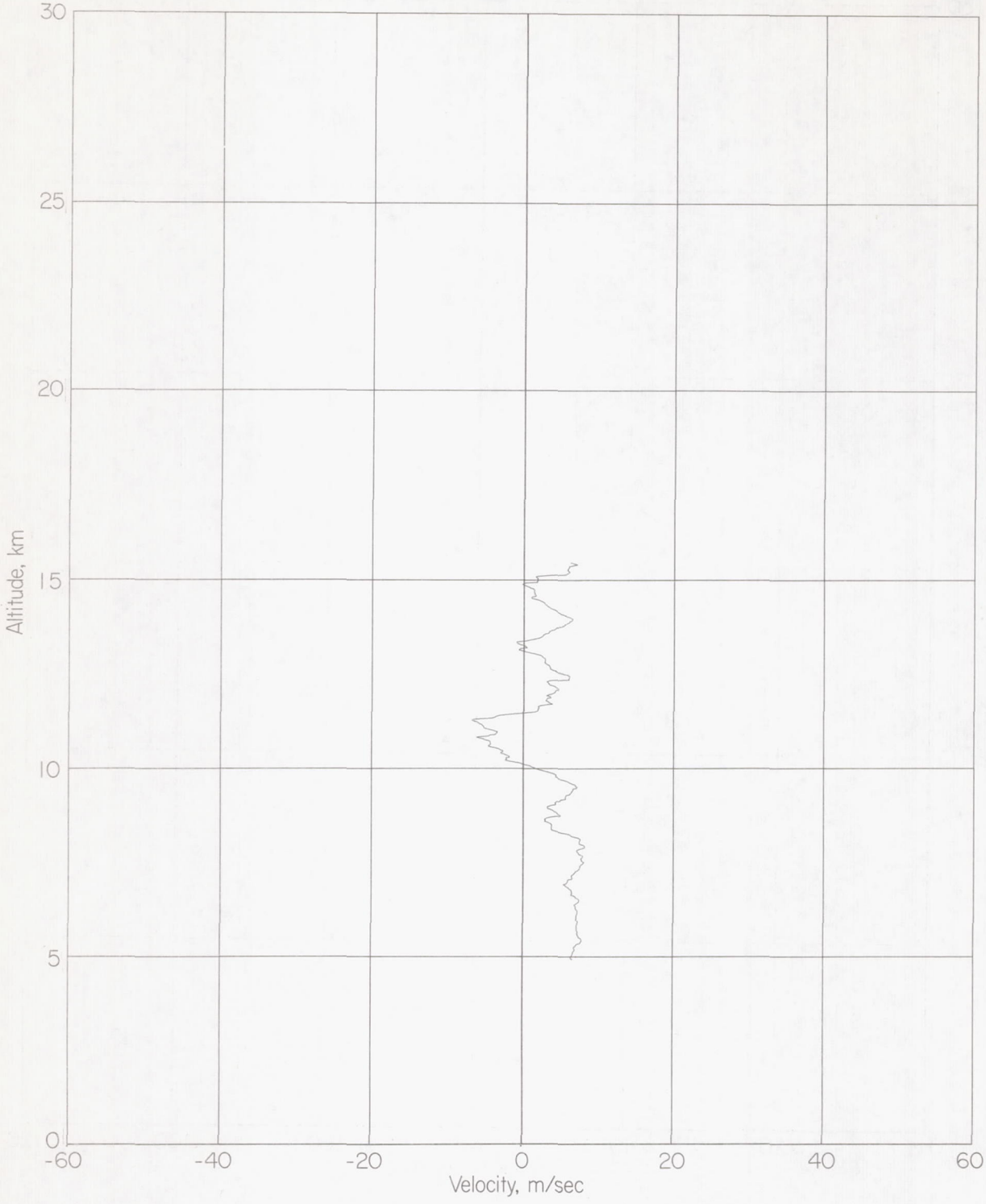
(b) South-to-north velocity component.

Figure 53.- Concluded.



(a) West-to-east velocity component.

Figure 54.- Wind profile of smoke trail 379 obtained December 5, 1963. Time interval, 60 seconds; height interval, 25 meters.

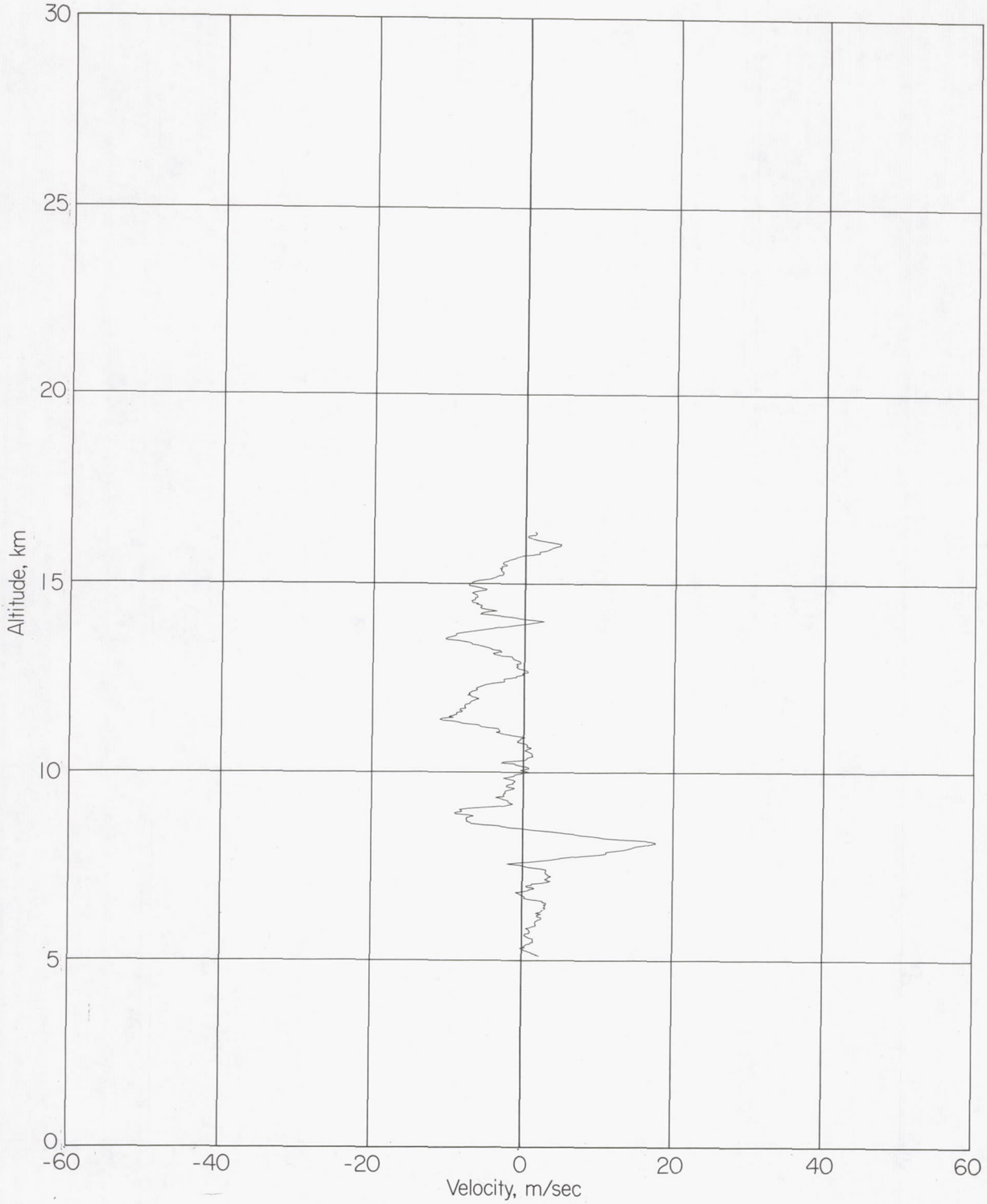


(b) South-to-north velocity component.

Figure 54.- Concluded.

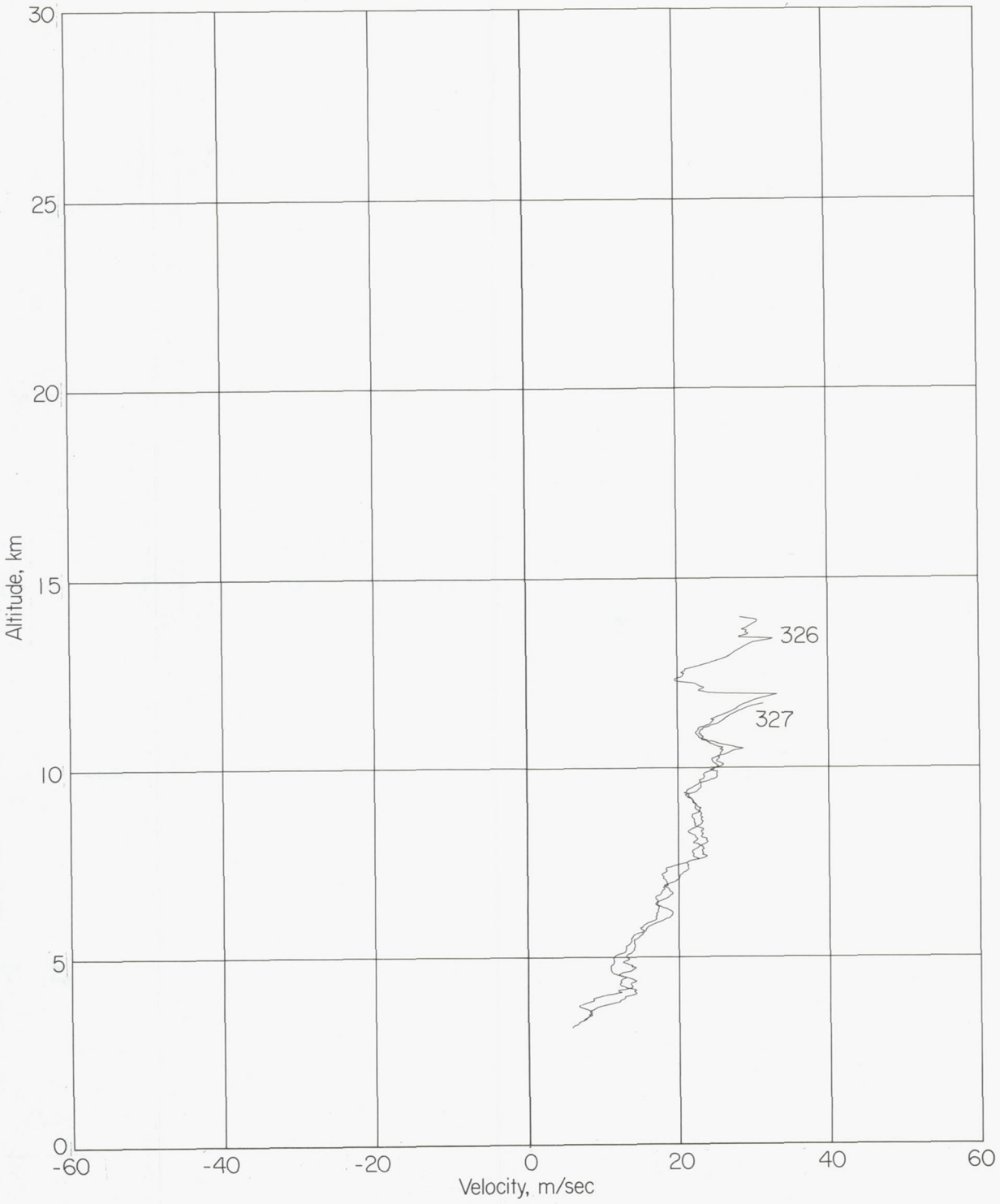
(a) West-to-east velocity component.

Figure 55.- Wind profile of smoke trail 380 obtained December 20, 1963. Time interval, 30 seconds; height interval, 25 meters.



(b) South-to-north velocity component.

Figure 55.- Concluded.

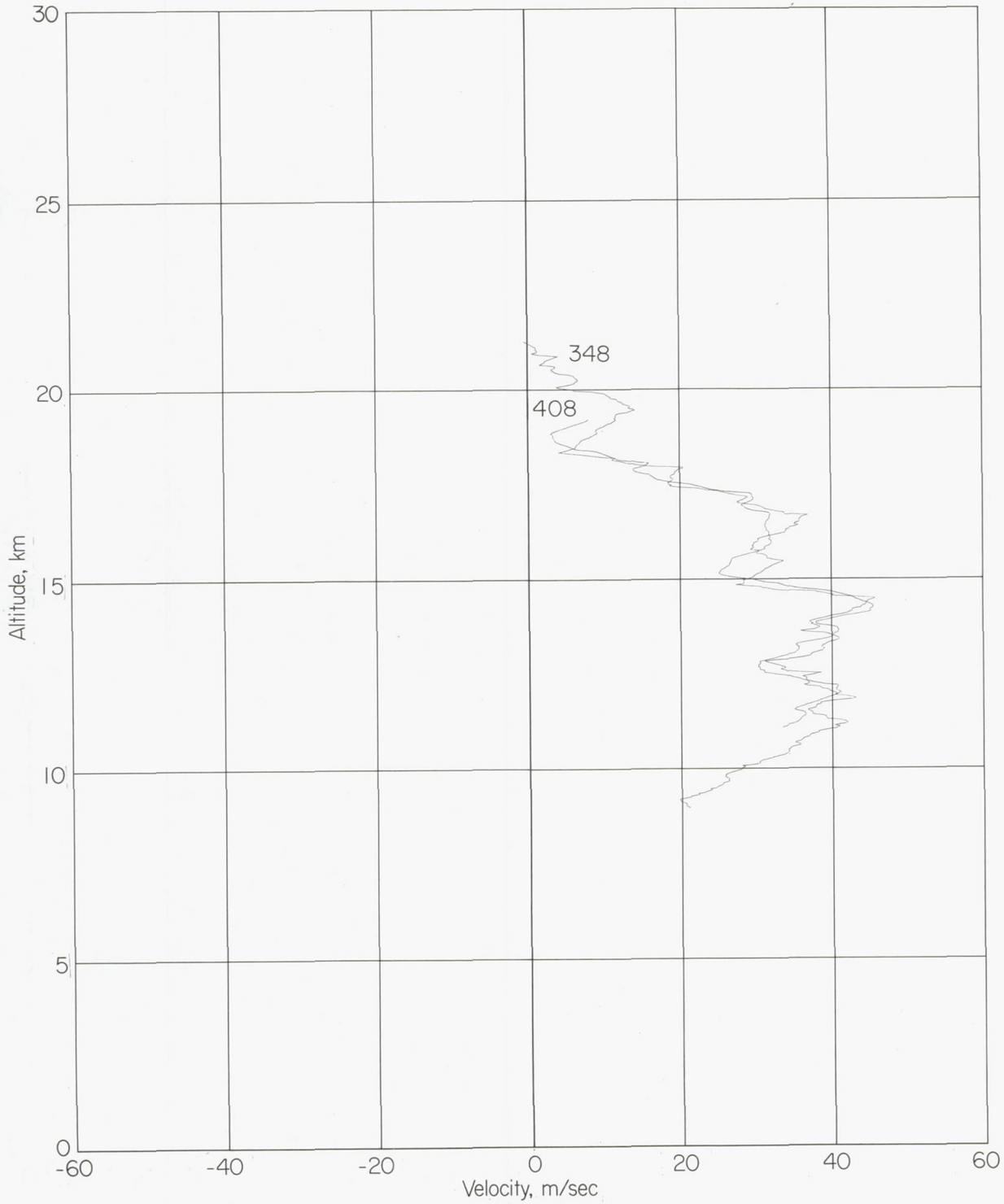


(a) West-to-east velocity component.

Figure 56.- Wind profiles of smoke trails 326 and 327 obtained January 3, 1963, at 1458 and 1600 EST.

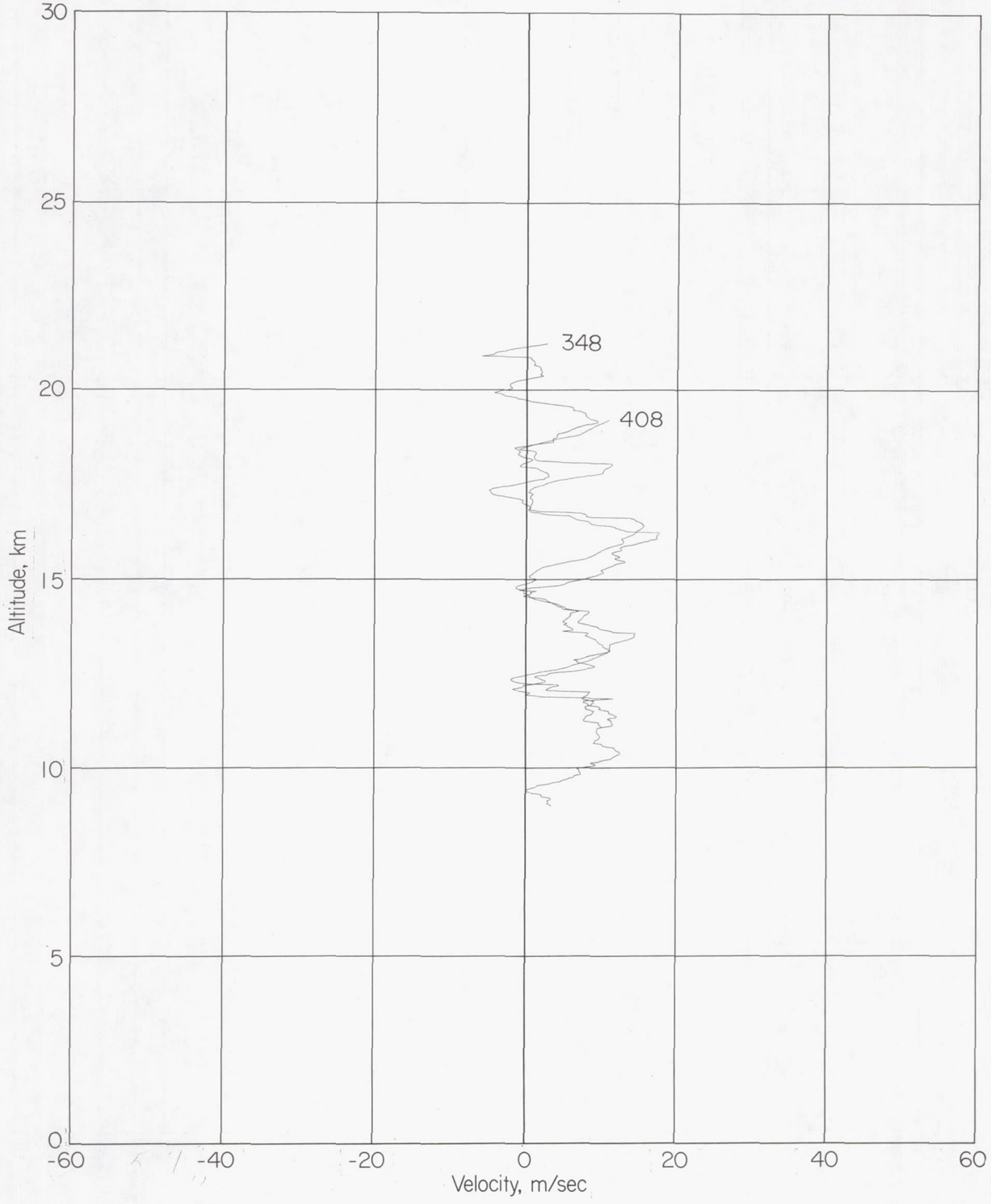
(b) South-to-north velocity component.

Figure 56.- Concluded.



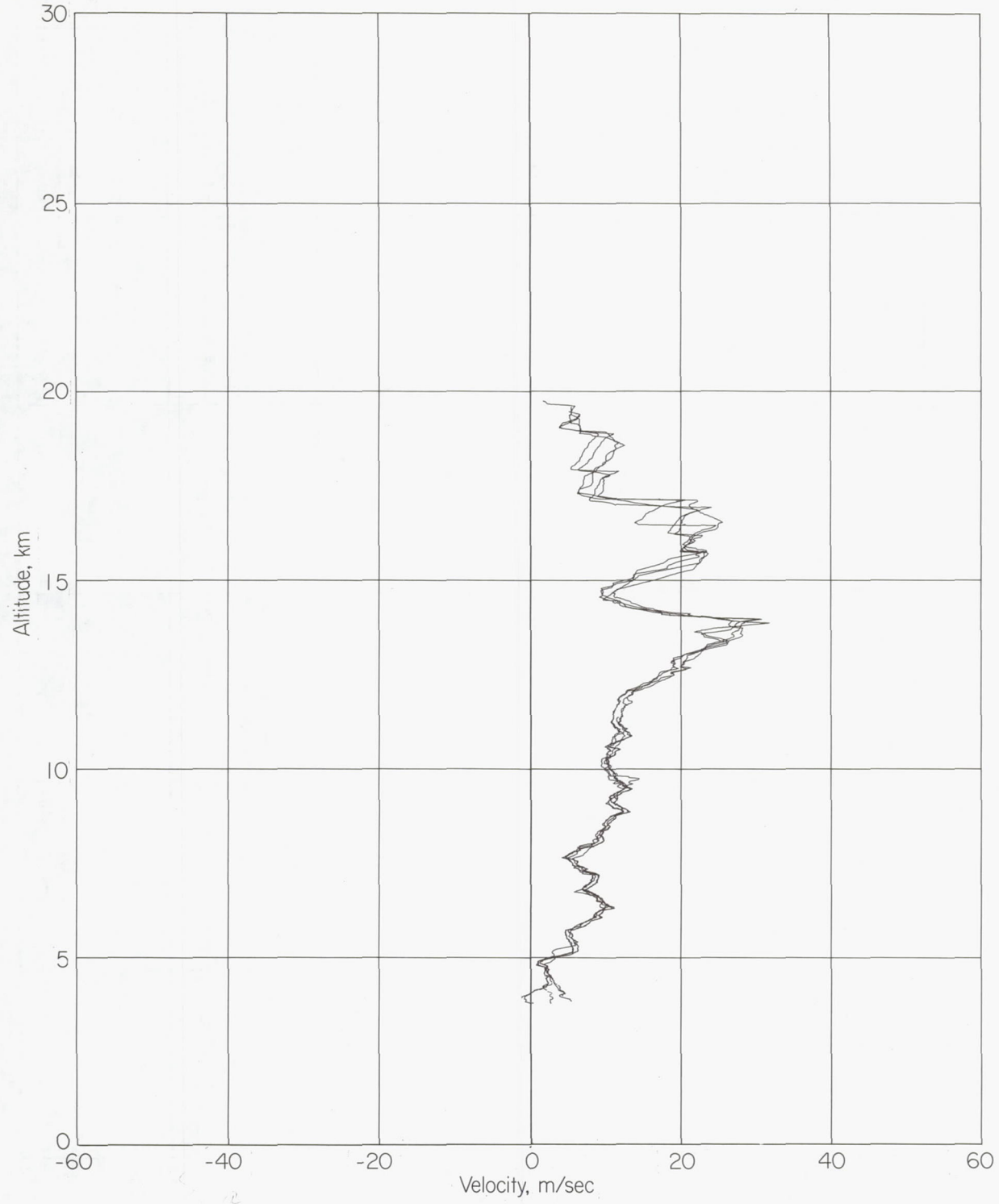
(a) West-to-east velocity component.

Figure 57.- Wind profiles of smoke trails 348 and 408 obtained March 28, 1963, at 1302 and 1510 EST.



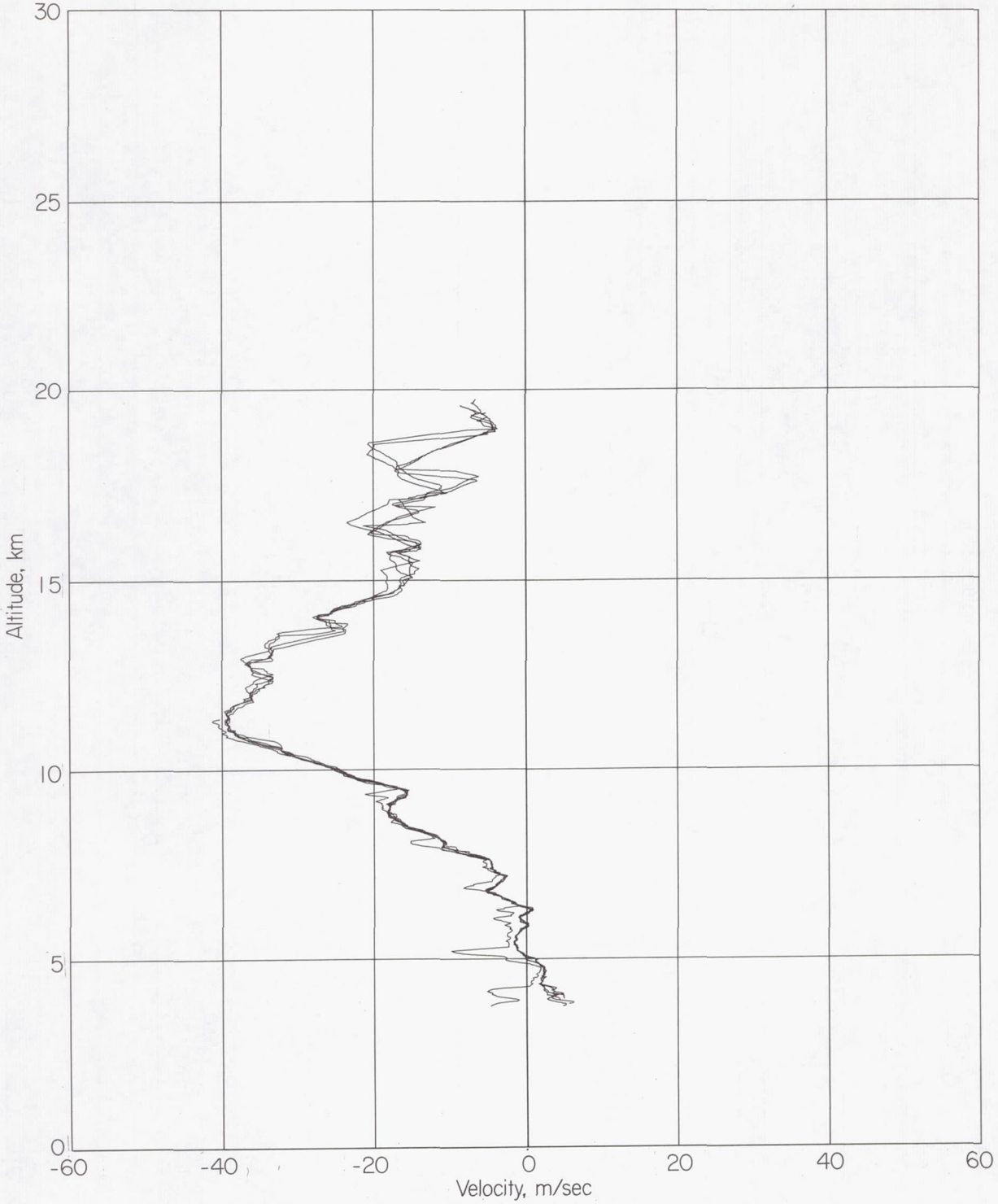
(b) South-to-north velocity component.

Figure 57.- Concluded.



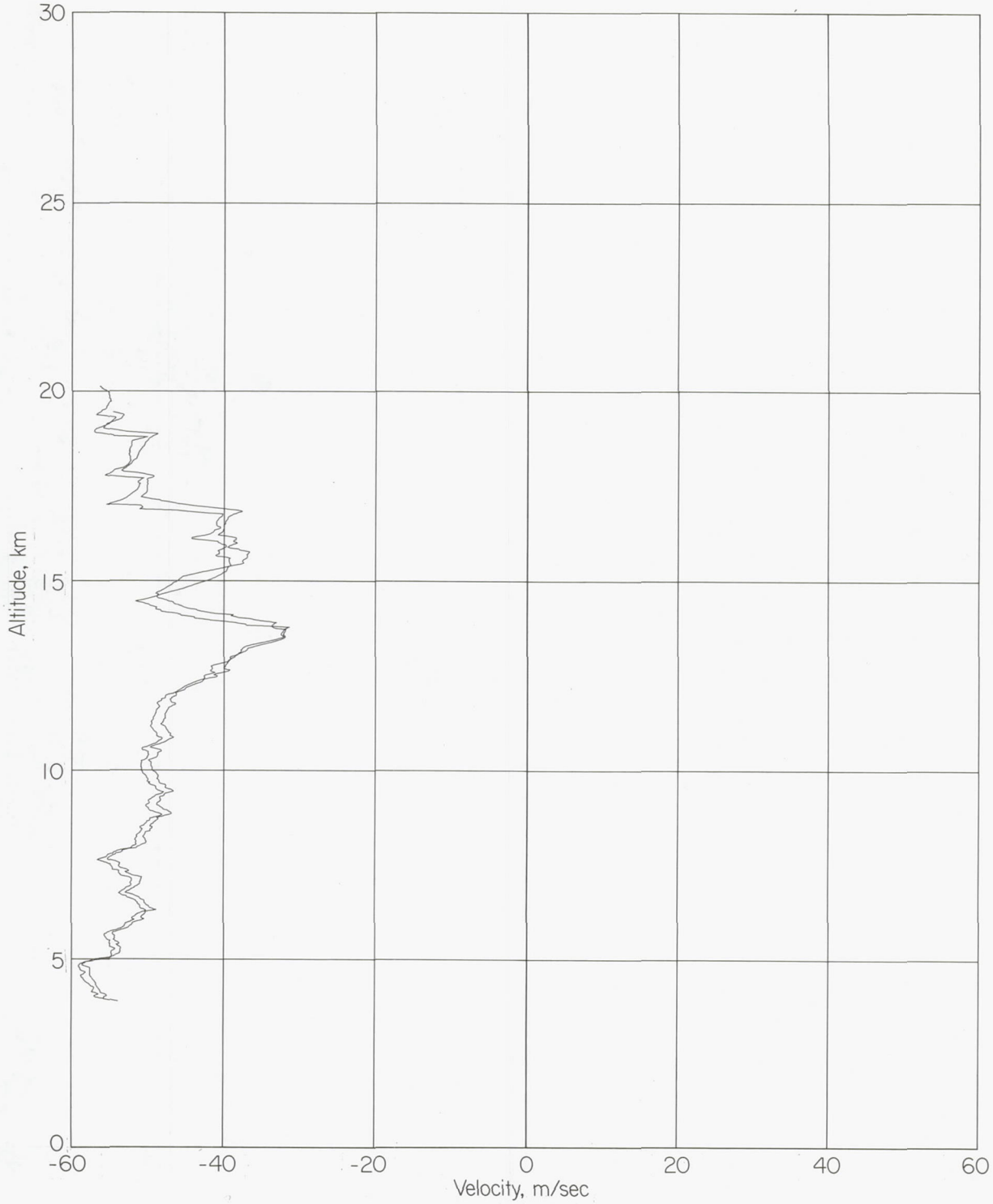
(a) West-to-east velocity component.

Figure 58.- Comparison of smoke trail 378 velocity profiles obtained by using all five of the camera pairs.



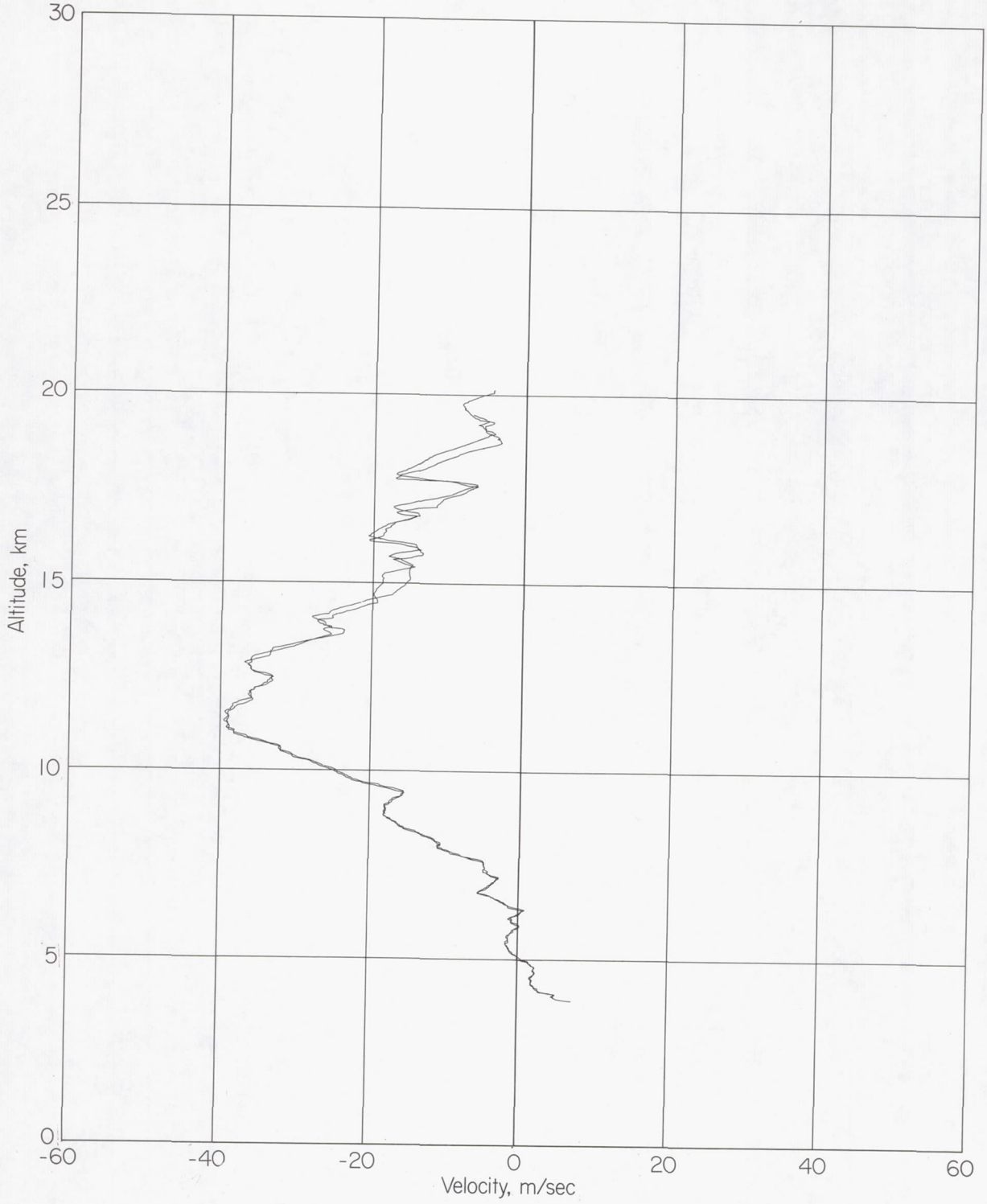
(b) South-to-north velocity component.

Figure 58.- Concluded.



(a) West-to-east velocity component.

Figure 59.- Comparison of smoke trail 378 velocity profiles having a 6-second time difference.



(b) South-to-north velocity component.

Figure 59.- Concluded.

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