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DYNAMICS OF COLD SEASON PRECIPITATION IN THE SOUTHWESTERN UNITED STATES

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ABSTRACT

The percentage frequency and spatial distribution of cold season precipitation in New Mexico during the 1972-73 fall, winter, and spring season are related to the intensity and path of 500 mb vorticity maxima for twelve-hour periods after Younkin (1). Although parameters describing the circulation characteristics near the surface and at 500 mb were not averaged over a set of grid points for these events as in Younkin's study, close examination of individual disturbances strongly supports his models. The climatological network of observation stations over Southern Colorado and New Mexico were utilized to better define the distribution of cold season precipitation. If favorable convergence of air near the surface does not exist or develop, precipitation may be localized only.

1. INTRODUCTION

Applications of Younkin's models which were used successfully by forecasters for the large number of heavy snow occurrences during the 1972-73 cold season convinced members of the staff at WSFO, Albuquerque that particularization of Younkin's study to New Mexico and adjacent areas should be pursued. And, since Younkin indicated that there were no heavy snow occurrences in the U.S. Southwest in his study, there was sufficient reason for evaluation and possible enlargement of his study. Repetitive storm tracks through the Southwestern U.S. during this season resulted in many new snowfall records. From October 31, 1972 to April 21, 1973 there was an average of one heavy snow event per 6.5 days. In total, 39 twelve-hour periods of heavy snow were documented in the state during this season.

2. PROCEDURE

Developmental data (see Table 1) comprise all heavy snow events (26 separate storms during the 1972-73 cold season) which occurred in New Mexico. Heavy snow as defined for this study is snowfall of 10 cm+(4 inches) or more which was reported by any of the synoptic or cooperative weather observing stations located throughout the state at altitudes at or below 2 km during the twelve-hour periods from 0000 GMT to 1200 GMT or 1200 GMT to 0000 GMT.

A Lagrangian coordinate system was used by locating the 500 mb vorticity maximum at the origin and orienting the twelve-hour forecast path of this maximum along the x-axis. All model frequency distributions of various parameters were determined for the twelve-hour forecast period following the placement of these vorticity maxima at the origin of the Lagrangian coordinate system. Geographical positions and numeric values of vorticity maxima were obtained from the coarse-mesh six-layer primitive equation model analysis transmitted by the National Meteorological Center on the National Facsimile Circuit. To supplement the reports of "heavy" snowfall during a twelve-hour period from regularly reporting stations, precipitation

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*Now at WSFO Honolulu

+Metric units(converted from English units)have been rounded for convenience.

TABLE 1.--1972-1973 Heavy Snow Events in New Mexico. Values of associated 500-mb vorticity maximum are in units of 10^{-5} sec.$^{-1}$

CASE NO.	TYPE	TIME AND DATE OF BEGINNING (GMT)	VALUE OF VORTICITY MAXIMUM AT BEGINNING OF 12-HOUR PERIOD OF HEAVY SNOW	12-HOUR CHANGE IN VORTICITY VALUE	REMARKS
1	I	1200 10/31/72	> 22	-4	
2	II	0000 11/09/72	> 16	0	
3	II	0000 11/12/72	> 16	0	
	II	1200 11/12/72	> 16	0	
4	II	0000 11/18/72	> 14	0	
5	I	1200 11/20/72	> 14	0	
6	II	0000 11/24/72	> 14	0	
7	III	1200 11/27/72	> 16	-2	Blizzard conditions NE New Mexico
8	I	0000 12/05/72	> 18	0	
9	II	1200 12/11/72	> 16	+2	
10	II	1200 12/14/72	> 16	-2	
11	I	1200 12/28/72	> 18	0	
	I	0000 12/29/72	> 18	0	
12	IA	0000 1/02/73	> 22	0	
	IA	1200 1/02/73	> 22	-4	
13	I	1200 1/17/73	> 14	-2	
14	I	0000 1/27/73	> 16	0	Blizzard conditions NE New Mexico
15	II	0000 1/31/73	> 16	-2	
	II	1200 1/31/73	> 14	0	
16	IA	0000 2/08/73	> 12	0	
17	II	0000 2/12/73	> 14	0	
18	I	1200 2/16/73	> 16	-2	
	I	0000 2/17/73	> 14	0	
	I	1200 2/17/73	> 14	-2	
19	IA	0000 2/21/73	> 12	+2	
		1200 2/21/73			No heavy snow reported
	II	0000 2/22/73	> 14	0	
	II	1200 2/22/73	> 14	0	
20	IA	0000 3/09/73	> 18	0	
21	II	0000 3/13/73	> 16	0	
	II	1200 3/13/73	> 16	+2	
22	IA	1200 3/14/73	>16	0	
23	II	1200 3/23/73	>16	0	Near blizzard conditions NE NM
	II	0000 3/24/73	>16	0	
24	I	1200 3/29/73	>18	-4	Blizzard conditions NE New Mexico
	I	0000 3/30/73	>14	0	
	II	1200 3/30/73	>14	+2	
25	I	1200 4/02/73	>18	+2	
26	III	1200 4/07/73	>18	-2	Blizzard conditions NE New Mexico
	III	0000 4/08/73	>16	0	

data from approximately 60 climatological network stations in New Mexico and 25 in Southern Colorado at or below 2 km msl are included in this study. All of these are equipped with recording gauges. The spatial distribution of percentage frequency of the occurrence of 0.6 cm (.25 inch) and 1 cm (.40 inch) of precipitation, Figures 1 and 2, rather than the occurrence of heavy snow has been derived in order to utilize the abundance of data from the climatological network and to obtain better definition; however, a method for rain vs snow determinations is included.

For types I and II, the occurrences and non-occurrences of the two amounts in a one degree latitude square were tabulated separately and then expressed in percentage frequencies before being analyzed, smoothed and displayed in graphical form. No percentage frequencies are derived for type III events since there were only three twelve-hour periods of heavy snowfall. Rather, occurrences and non-occurrences of 0.6 cm (.25 inch) and 1 cm (.40 inch) of precipitation and no data available are marked for each one degree latitude square, Figure 3. These models can be used by forecasters in the form of clear plastic overlays which are scaled to the various prognostic charts. These percentage frequencies indicate the most susceptible areas for the two categories of precipitation amounts.

The vorticity tracks were classified into three basic types with separate characteristics of heavy snow distributions. Type I, derived from 13 twelve-hour periods of heavy snow, is a "digging" storm characterized by a vorticity maximum moving south of east over land masses to the west of New Mexico during the twelve-hour heavy snowfall period. An example of this type is shown in Figure 4. A sub-type, 1A, of these digging storms which occurred during six twelve-hour periods of heavy snowfall includes those where the trajectories of the vorticity maxima were over the Eastern Pacific Ocean or the Gulf of California, as exhibited in Figure 5, with the implication that the downstream 500 mb ridge is at least east of the continental divide of New Mexico during the period. Also, a low-level cyclonic circulation having a significant easterly component is associated with this type.

The second type, Type II, occurred during 17 twelve-hour periods. It is a "coming out" storm, as described in Younkin's study, in which the vorticity maximum moves north of east from the long wave trough position. A typical example is shown in Figure 6.

There were only three twelve-hour periods of Type III heavy snow events. In Type III events the vorticity maximum moves southeastward over Colorado, Utah and/or New Mexico and is accompanied by a strong cold front moving southward over the Great Plains east and south of the vorticity maximum. This type deserves more documentation and is not classified as a Type I because the snowfall distribution can be quite

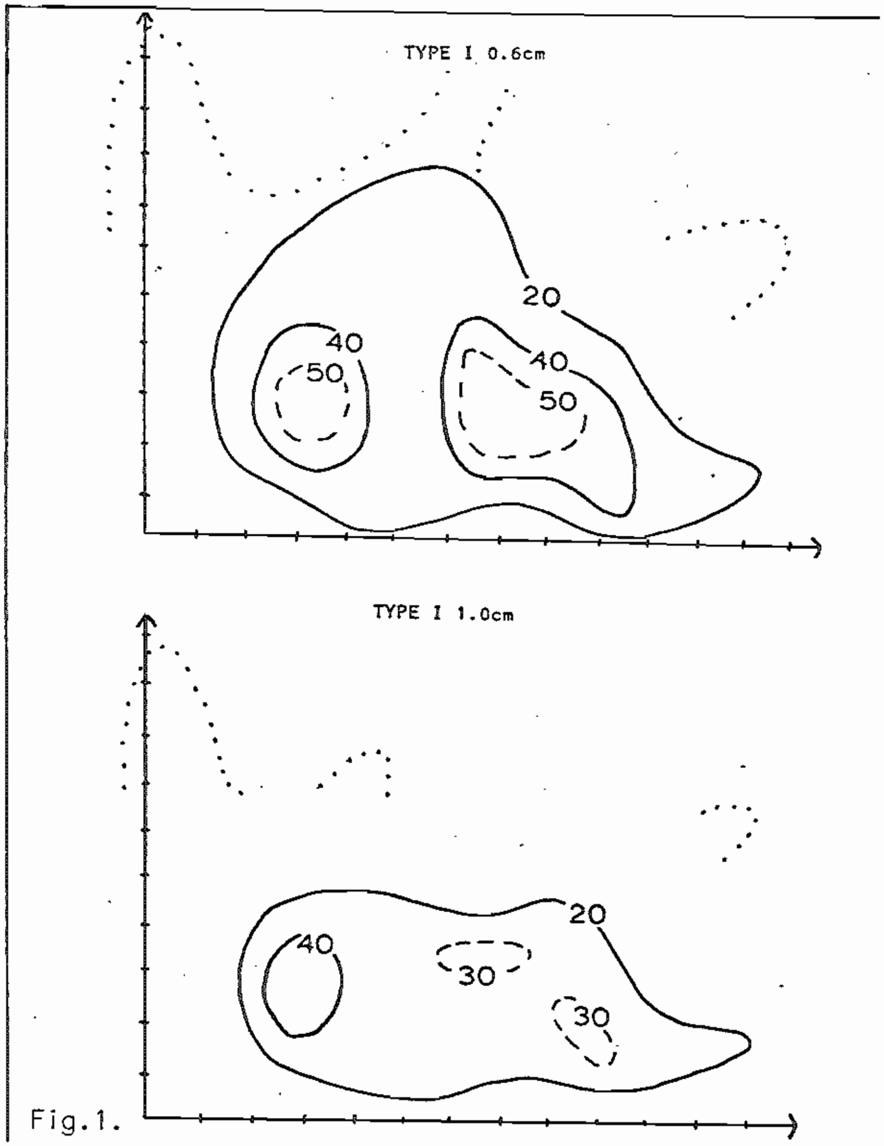

Fig.1.

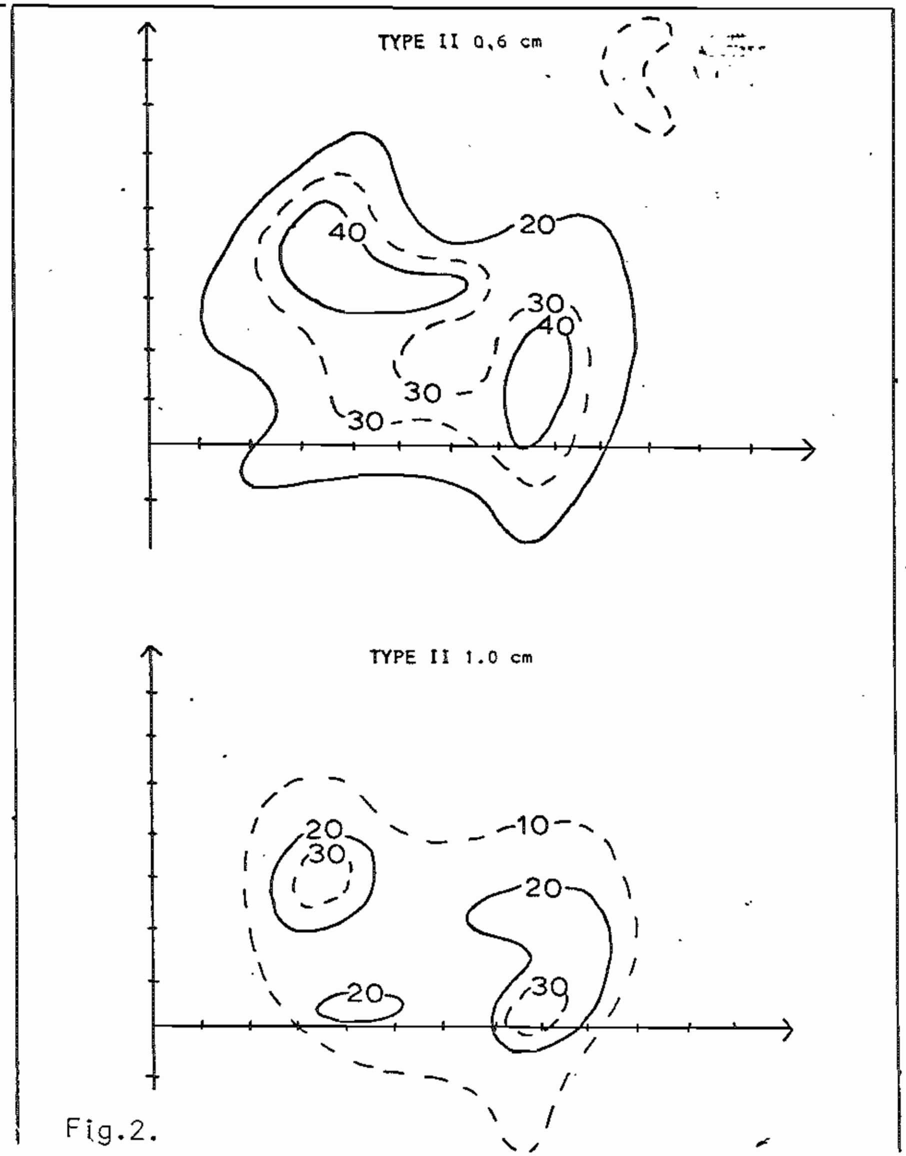

Fig.2.

PERCENTAGE FREQUENCIES OF 0.6 cm (.25 inch) AND 1 cm (.40 inch) OF PRECIPITATION FOR 12-HOUR PERIOD FOLLOWING INITIAL POSITION OF 500 MB VORTICITY MAXIMUM AT ORIGIN OF LAGRANGIAN COORDINATE SYSTEM. DOTTED LINES DELINEATE EXTREME LIMITS OF PRECIPITATION OF INDICATED AMOUNT. (Coordinates in degrees latitude)

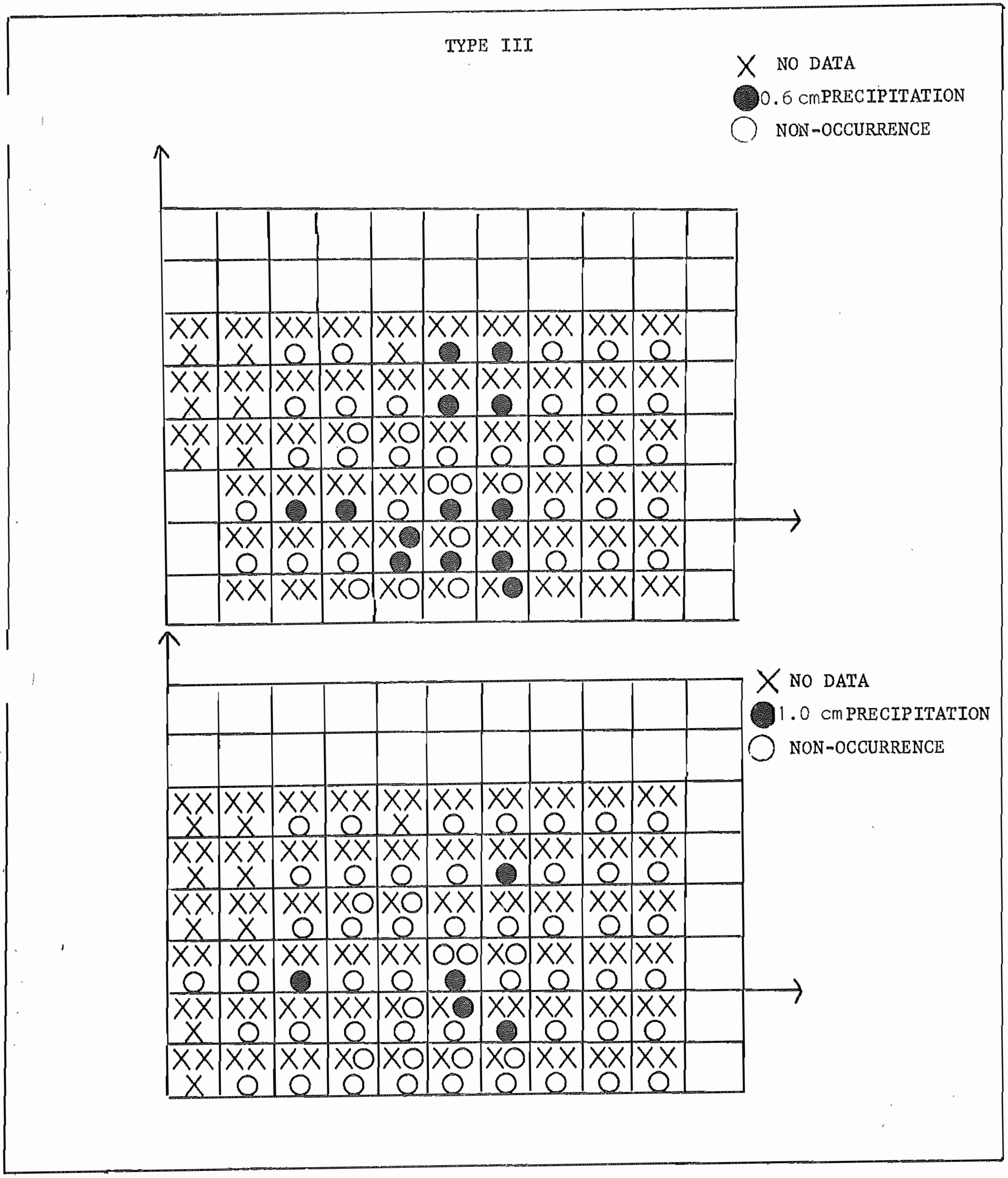

Fig. 3. OCCURRENCES AND NON OCCURRENCES OF 0.6 cm (.25 inch) AND 1 cm (.40 inch) OF PRECIPITATION AND NO DATA AVAILABLE FOR 12-HOUR PERIOD FOLLOWING INITIAL POSITION OF 500 MB VORTICITY MAXIMUM AT ORIGIN OF LAGRANGIAN COORDINATE SYSTEM.

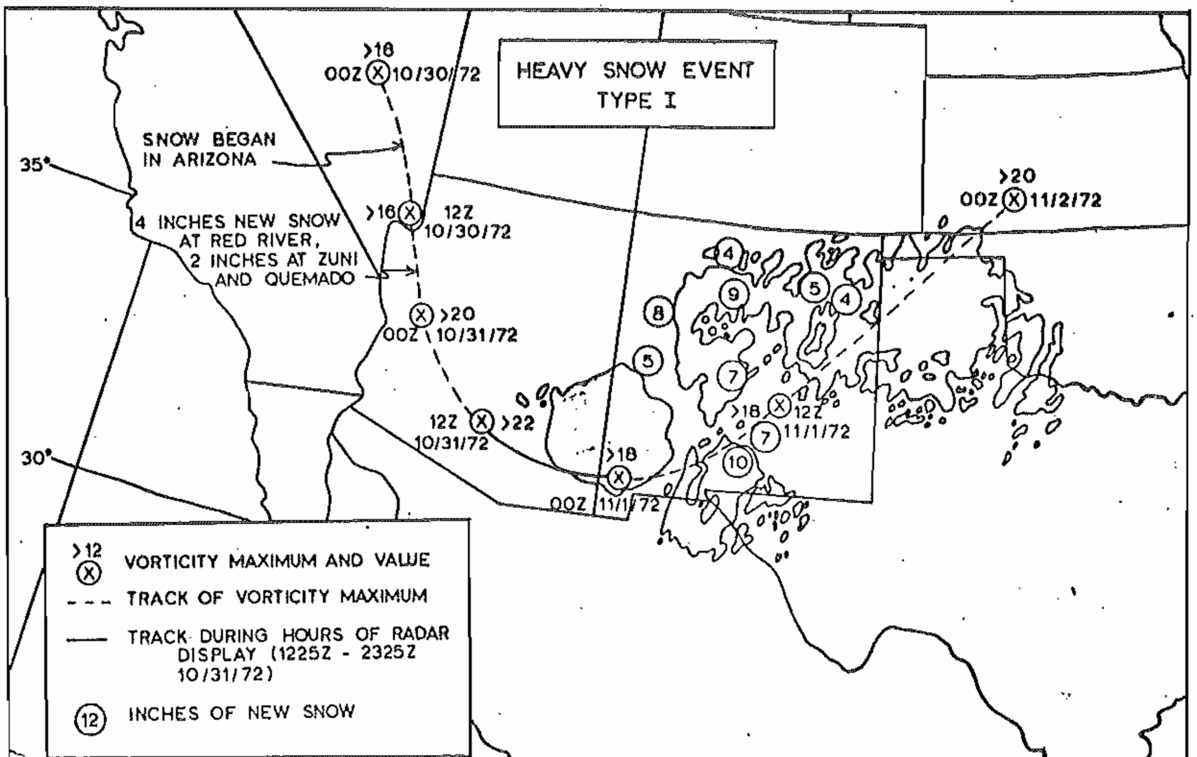
HEAVY SNOW EVENT
TYPE I
>18
00Z 10/30/72
SNOW BEGAN
IN ARIZONA
35°
4 INCHES NEW SNOW
AT RED RIVER,
2 INCHES AT ZUNI
AND QUEMADO
>16
12Z
10/30/72
>20
00Z 10/31/72
>20
00Z 11/2/72
12Z >22
10/31/72
>18
00Z 11/1/72
>18 12Z
11/1/72
30°
>12
VORTICITY MAXIMUM AND VALUE
TRACK OF VORTICITY MAXIMUM
TRACK DURING HOURS OF RADAR
DISPLAY (1225Z - 2325Z
10/31/72)
12 INCHES OF NEW SNOW

FIG. 4.

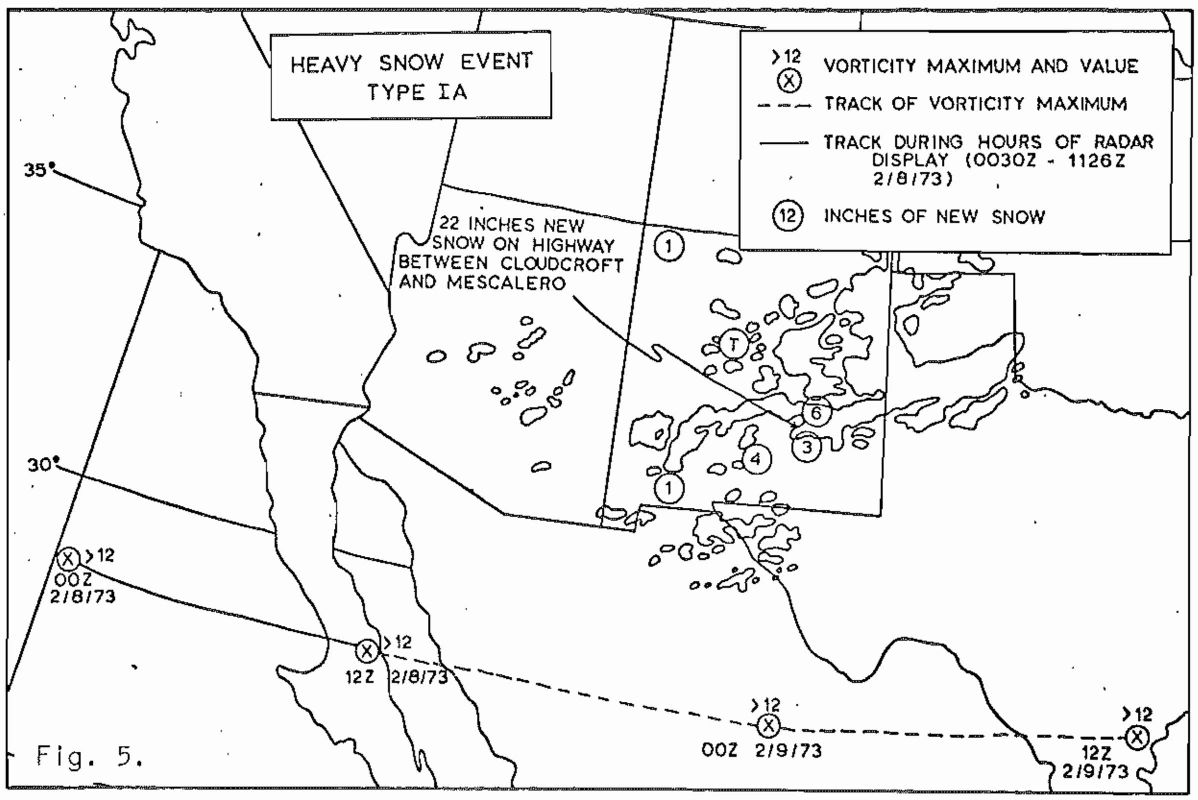
HEAVY SNOW EVENT
TYPE IA
>12
VORTICITY MAXIMUM AND VALUE
TRACK OF VORTICITY MAXIMUM
TRACK DURING HOURS OF RADAR
DISPLAY (0030Z - 1126Z
2/8/73)
12 INCHES OF NEW SNOW
35°
22 INCHES NEW
SNOW ON HIGHWAY
BETWEEN CLOUDCROFT
AND MESCALERO
30°
>12
00Z
2/8/73
>12
12Z 2/8/73
>12
00Z 2/9/73
>12
12Z
2/9/73

Fig. 5.

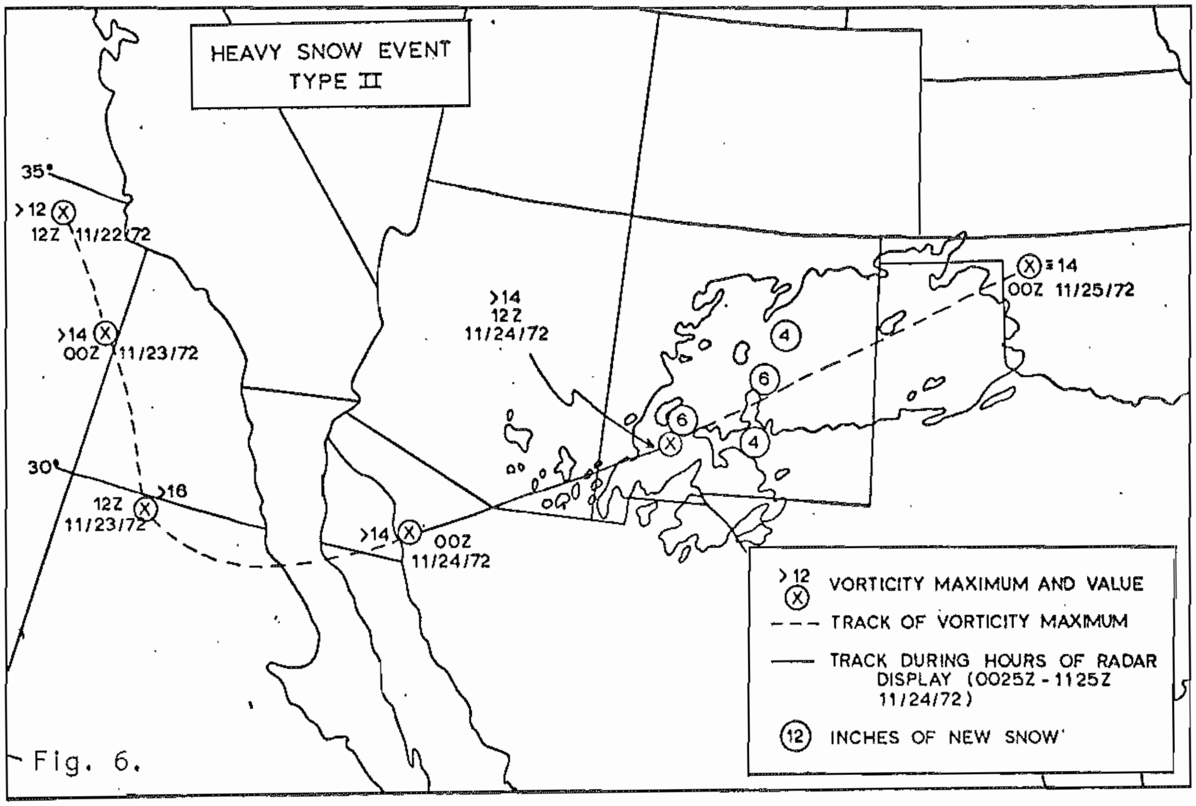
HEAVY SNOW EVENT
TYPE II
35°
>12
12Z 11/22/72
>14
00Z 11/23/72
30°
12Z
11/23/72
>16
>14
00Z
11/24/72
>14
12Z
11/24/72
00Z 11/25/72
≥14
>12 VORTICITY MAXIMUM AND VALUE
TRACK OF VORTICITY MAXIMUM
TRACK DURING HOURS OF RADAR DISPLAY (0025Z - 1125Z 11/24/72)
(12) INCHES OF NEW SNOW

Fig. 6.

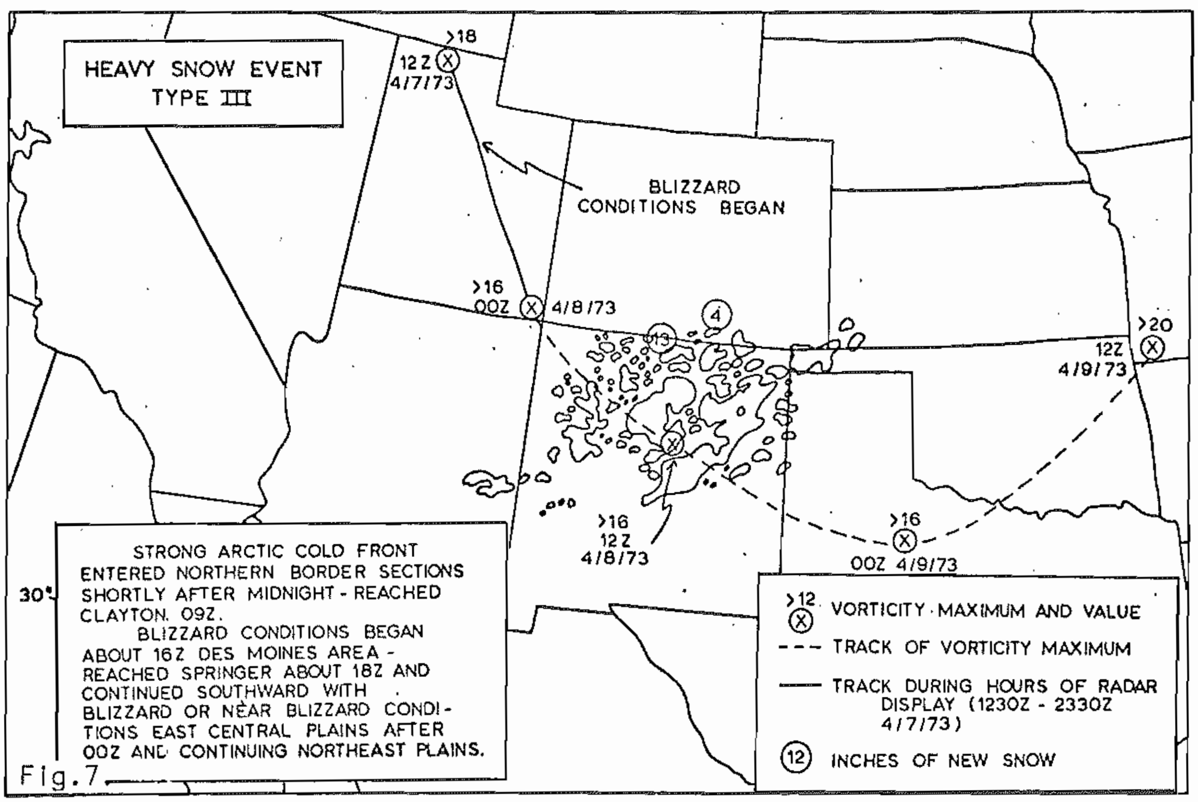
HEAVY SNOW EVENT
TYPE III
>18
12Z
4/7/73
BLIZZARD
CONDITIONS BEGAN
>16
00Z 4/8/73
>16
12Z
4/8/73
>16
00Z 4/9/73
>20
12Z
4/9/73
30°
STRONG ARCTIC COLD FRONT ENTERED NORTHERN BORDER SECTIONS SHORTLY AFTER MIDNIGHT - REACHED CLAYTON. 09Z.
BLIZZARD CONDITIONS BEGAN ABOUT 16Z DES MOINES AREA - REACHED SPRINGER ABOUT 18Z AND CONTINUED SOUTHWARD WITH BLIZZARD OR NEAR BLIZZARD CONDITIONS EAST CENTRAL PLAINS AFTER 00Z AND CONTINUING NORTHEAST PLAINS.
>12 VORTICITY MAXIMUM AND VALUE
TRACK OF VORTICITY MAXIMUM
TRACK DURING HOURS OF RADAR DISPLAY (1230Z - 2330Z 4/7/73)
(12) INCHES OF NEW SNOW

Fig. 7

different. In all three periods the heavy snowfall was confined to an area comprised of the northeast quarter of New Mexico, southeastern Colorado, the panhandles of Texas and Oklahoma and/or southwestern Kansas. Blizzard conditions also existed in these areas. Figure 7 relates to these occurrences.

Radar composites for twelve-hour periods compiled by the Albuquerque WSMO at the Albuquerque Air Route Traffic Control Center helped to assess the areal extent of snow occurrences. Certain modifications due to radar capability as described by May (2) and depicted in Figure 8 were weighed in these evaluations.

3. DISCUSSION OF RELATIONSHIPS

It was noted early in this study that the magnitude of the absolute vorticity was a basic indicator of precipitation amount. Almost invariably central vorticity values equaled or exceeded 14×10^{-5} sec^{-1} at some time during a twelve-hour heavy precipitation occurrence. This is not so for cases 16 and 19, but these were digging sub-types in which the vorticity maximum moved in rapidly from well offshore over sparse data areas of the Eastern Pacific where basic analyses and hence vorticity calculations are often questionable. The circulation in the lower levels (first two thousand meters above ground) cannot be overemphasized; i.e., both the low-level circulation and the vorticity maximum at 500 mbs should be considered in forecasting the extent and intensity of heavy snowfall, as in Younkin's study. If favorable convergence near the surface does not exist or develop, precipitation may be localized only. Also, in case 16 the vorticity track continued slight digging nearly parallel to latitude 28N, to the vicinity of Corpus Christi where it began a coming-out track over the Gulf of Mexico. The subsequent dramatic heavy snowfall in Georgia on the night of February 9 and the morning of February 10, 1973, almost exactly fit Younkin's coming-out model. The heaviest twelve-hour snowfall report recorded in New Mexico during this season was 56 cm (22 inches) during the night of February 8 and the morning of February 9, 1973, in association with this same storm.

There were 35 instances of vorticity maxima $14 \times 10^{-5} sec^{-1}$ or greater passing over or near the state during this season. Heavy snowfall occurred over New Mexico in 26, or approximately 75 percent, of these cases. On one occasion when heavy snowfall did not occur the event was characterized by an exceptionally fast-moving storm. Heavy snowfall, as much as 20 cm (8 inches) did occur in this case in the Grand Canyon and Flagstaff areas of Arizona, in Southern Utah and in Southwestern Colorado before loss of circulation intensity. Only 7.6 cm (3 inches) of snow occurred at Chama in extreme north central New Mexico, 2370m (7800 feet) msl, as the track accelerated to a speed of nearly 60 knots. An updated graph, Figure 9, as described by Gregg et al (3) used in conjunction with NMC forecast 850-500 mb thickness values has proven very useful in snow/rain determinations.

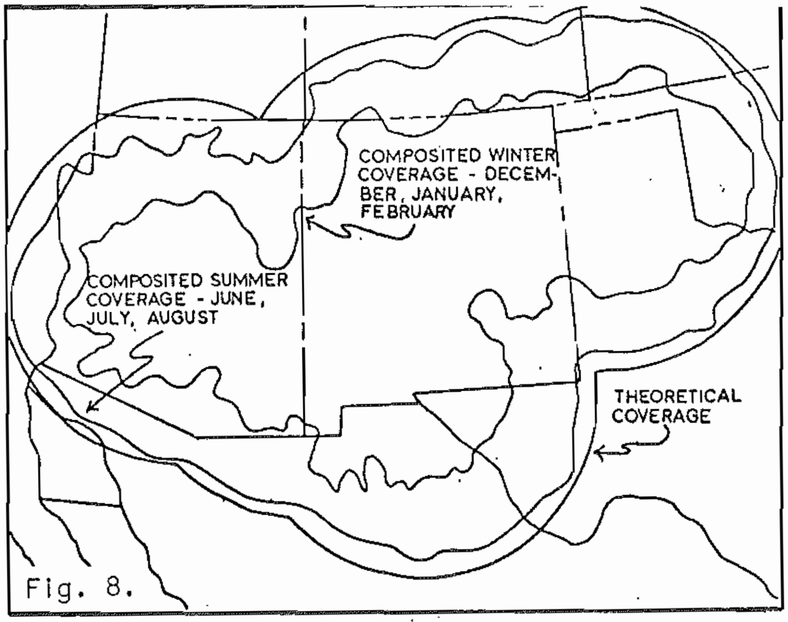
COMPOSITED WINTER COVERAGE - DECEMBER, JANUARY, FEBRUARY
COMPOSITED SUMMER COVERAGE - JUNE, JULY, AUGUST
THEORETICAL COVERAGE

Fig. 8.

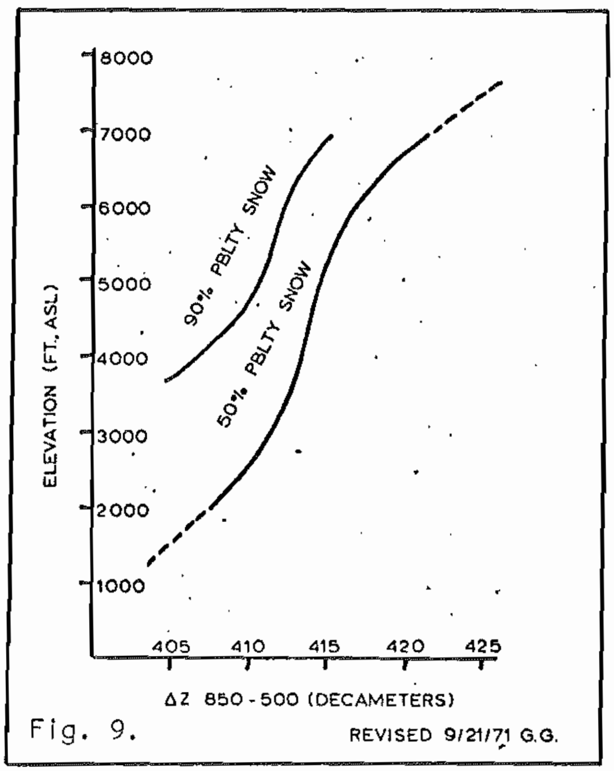
8000
7000
6000
5000
4000
3000
2000
1000
ELEVATION (FT. ASL)
90% PBLTY SNOW
50% PBLTY SNOW
405
410
415
420
425
ΔZ 850-500 (DECAMETERS)
REVISED 9/21/71 G.G.

Fig. 9.

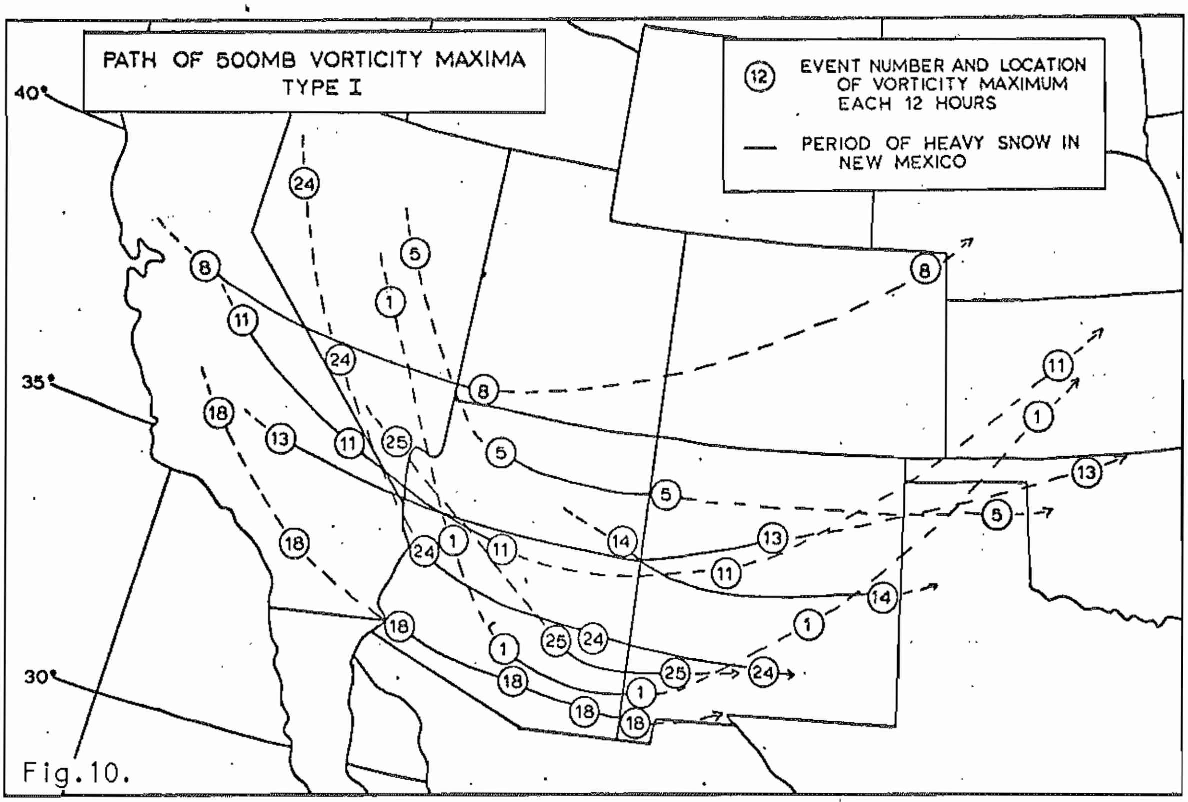
PATH OF 500MB VORTICITY MAXIMA
TYPE I
EVENT NUMBER AND LOCATION OF VORTICITY MAXIMUM EACH 12 HOURS
PERIOD OF HEAVY SNOW IN NEW MEXICO
40°
35°
30°

Fig.10.

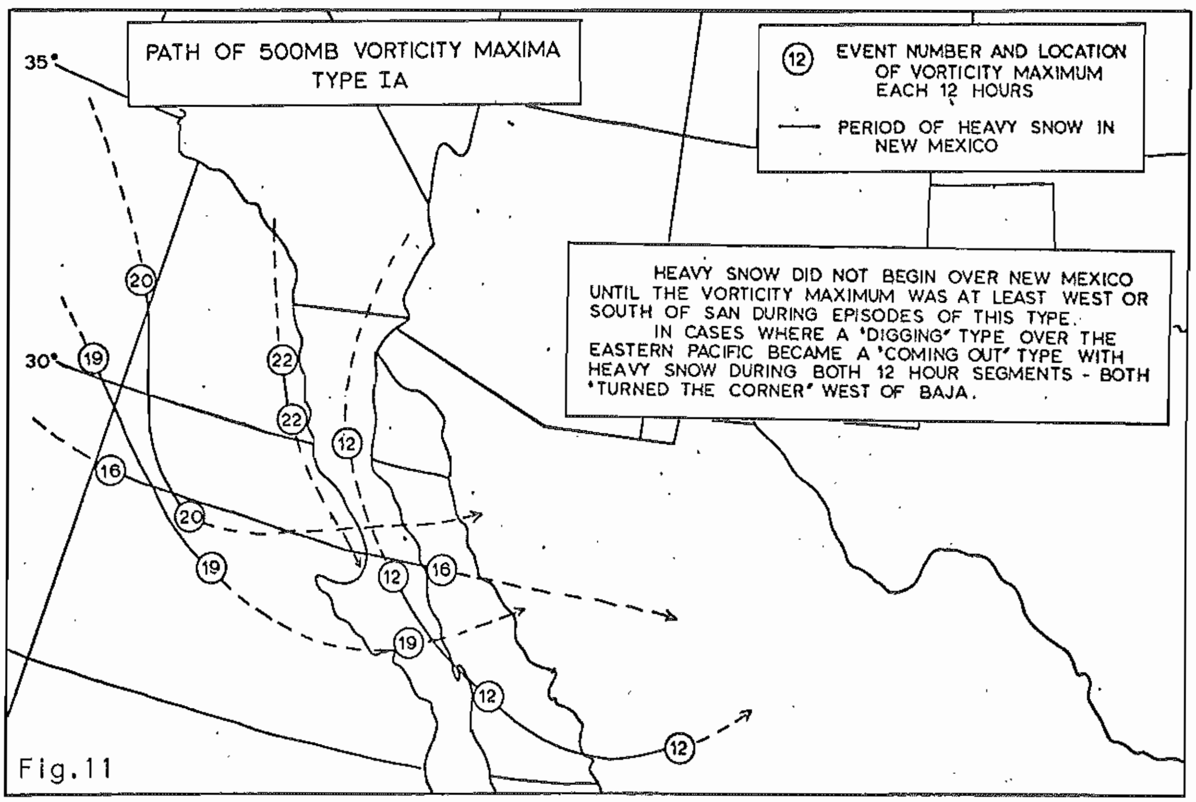
PATH OF 500MB VORTICITY MAXIMA
TYPE IA
EVENT NUMBER AND LOCATION OF VORTICITY MAXIMUM EACH 12 HOURS
PERIOD OF HEAVY SNOW IN NEW MEXICO
HEAVY SNOW DID NOT BEGIN OVER NEW MEXICO UNTIL THE VORTICITY MAXIMUM WAS AT LEAST WEST OR SOUTH OF SAN DURING EPISODES OF THIS TYPE.
IN CASES WHERE A 'DIGGING' TYPE OVER THE EASTERN PACIFIC BECAME A 'COMING OUT' TYPE WITH HEAVY SNOW DURING BOTH 12 HOUR SEGMENTS - BOTH 'TURNED THE CORNER' WEST OF BAJA.
35°
30°

Fig.11

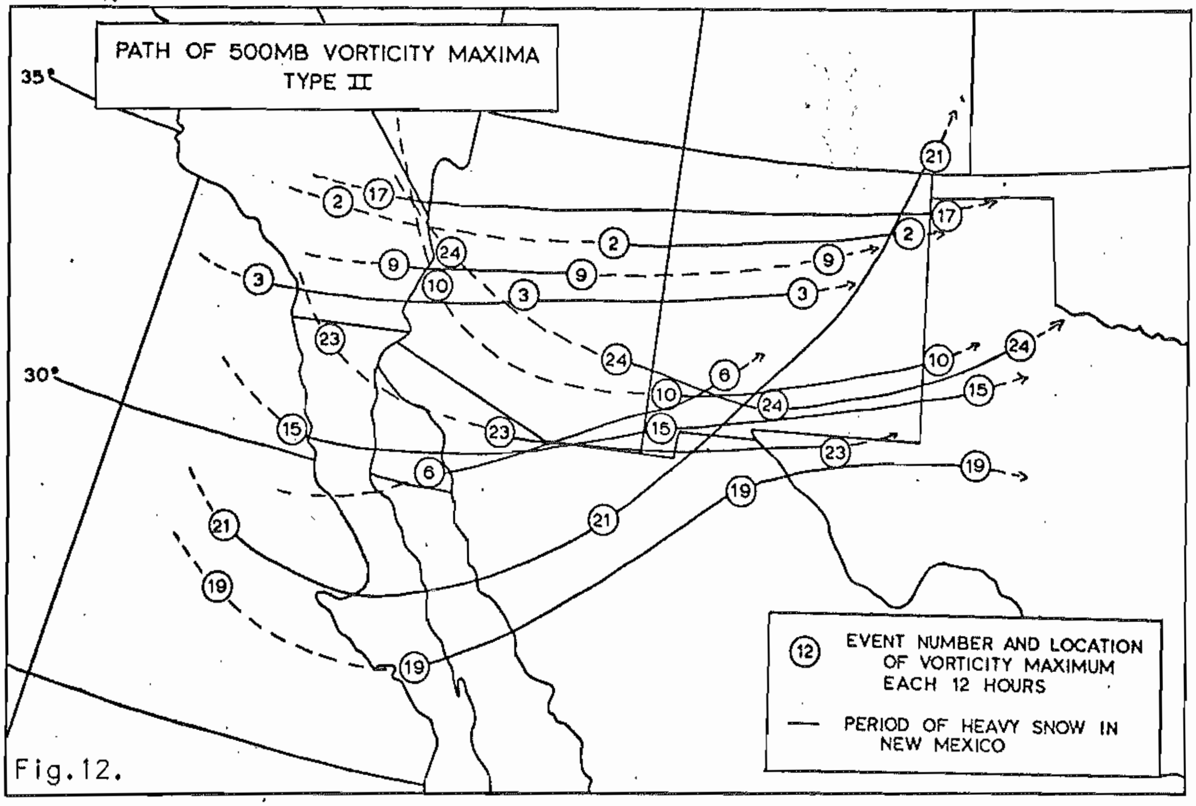
PATH OF 500MB VORTICITY MAXIMA
TYPE II
35°
30°
EVENT NUMBER AND LOCATION OF VORTICITY MAXIMUM EACH 12 HOURS
PERIOD OF HEAVY SNOW IN NEW MEXICO

Fig.12.

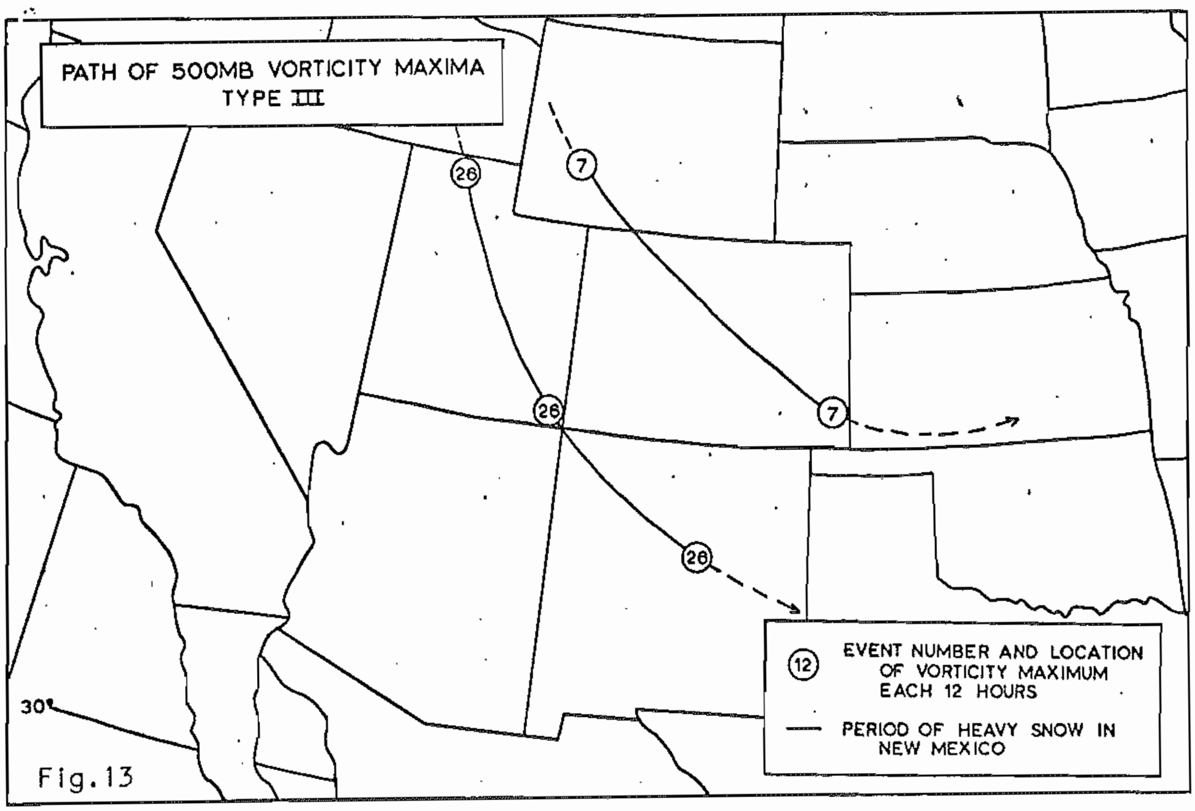
PATH OF 500MB VORTICITY MAXIMA
TYPE III
30°
EVENT NUMBER AND LOCATION OF VORTICITY MAXIMUM EACH 12 HOURS
PERIOD OF HEAVY SNOW IN NEW MEXICO

Fig.13

Figures 10 through 13 show all of the various tracks followed by each of the types which resulted in heavy snow in New Mexico. Examination of these figures points up the following general considerations:

1. Two of the heavy snowfall cases continued for more than 12 hours involving a transition from "digging" to "coming-out". Areas of heavy snowfall during these events correspond to the model which describes the net latitudinal movement of digging or coming-out storms.

a. In case No. 24 heavy snowfall was observed over New Mexico during a combination of digging and coming-out. A relatively small radius of curvature of the path of the vorticity maximum occurred rather than the usual slightly curved trajectories observed during coming-out cases.

b. In case No. 19 an eastern Pacific sub-type combined with a coming-out type with resultant heavy snowfall. The track recurved and changed from Type IA to Type II west of Baja California (also with small radius of curvature).

2. During Eastern Pacific maritime digging events, heavy snow did not begin over New Mexico until the vorticity maxima were immediately west or south of San Diego.

3. Heavy snow ended over New Mexico after the vorticity maxima reached the continental divide in most digging Type I cases.

ACKNOWLEDGEMENTS

We wish to thank Mrs. Beverly Riese for the preparation of the many charts and Mr. David McLaughlin for analyses of data.

REFERENCES

1. R. J. Younkin, "Circulation Patterns Associated with Heavy Snowfall Over the Western United States", Monthly Weather Review, Vol. 96, No. 12, December 1968, pp. 851-853.

2. H. T. May II, "Some Insights into ARTCC Radar Observations at Albuquerque", unpublished.

3. G. T. Gregg, et al, "Note on 850-500 Layer Temperatures as a Rain/Snow Discriminator", Technical Attachment B, Southern Region Topics and Personnel, November 1969.