A Search for Necessary Conditions for Heavy Snow on the East Coast[1]

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ABSTRACT

An investigation into the synoptic conditions necessary for the occurrence of heavy snow on the east coastal plain of the United States has revealed no obvious characteristic antecedent patterns either 12 or 24 hr prior to the onset of snow. The contemporaneous association of heavy snow with east coastal secondary cyclogenesis and with certain synoptic features at the 850-mb level is found to be of limited predictive value.

1. Introduction

In the absence of reliable dynamical or other objective methods for quantitative prediction of heavy snowfall, weather forecasters at the present time are still dependent on synoptic methods for anticipation of these events. Quantitative guidance on the use of observed or predicted pressure and geopotential patterns for heavy snow prediction is therefore still needed.

While many forecasters would probably agree that characteristic synoptic patterns do exist both prior to and coincident with the occurrence of heavy snowfalls on the east coast of the United States, there is undoubtedly less agreement as to what these conditions are, how consistently they appear, and how far in advance of a heavy snowstorm they can be recognized. Objective data on this question appear to be scarce.

If such patterns exist and can be recognized 24 or even 12 hr in advance of a heavy snowfall, they would obviously be of significant value to forecasters. Even patterns coincident with the beginning time of heavy snowfall or shortly thereafter would be useful, if accurate pattern prognostications were available. Furthermore, because the prediction of the total snow depth in a city is still of vital importance even after the first flake has fallen, the identification of coincident synoptic patterns would be of value even in the absence of accurate pattern predictions.

The synoptic climatological approach to problems such as quantitative precipitation forecasting has been tried frequently in the past (see, e.g., Reiss, 1955). Recently the method has been applied at the 850-mb level, with a moving grid system, to identify areas of heavy snow associated with cyclones at that level (Spiegler and Fisher, 1970; Browne and Younkin, 1970). The technique adopted in the study reported here differs from these other approaches in that it does not employ a moving grid, but rather focusses on specific geographic areas. Presumably this should allow the effects of local influences to manifest themselves in the statistics.

An almost necessary condition for heavy snow in New York City has been described by Spar *et al.* (1967) in terms of the passage of a surface cyclone center through a sector southeast of the city. In the present study an attempt was made to find similar kinds of necessary conditions, both antecedent and coincident, that might be applicable to the entire eastern seaboard. A set of necessary conditions for heavy snow would clearly be of some value to a forecaster who must decide whether to issue or withold a heavy snow watch or warning. However, it must be emphasized that the existence of necessary conditions tells the forecaster nothing about the *probability* of heavy snow. The determination of heavy snow probabilities given necessary conditions would be an obvious sequel to the present study, if it proved successful.

The search for necessary conditions for heavy snow on the east coast has been pursued sporadically for many years. The work of Spiegler and Fisher (1970) and of Browne and Younkin (1970), referred to above, as well as previous studies, such as those of Bailey (1960), Brooks and Schell (1950), Donaldson and Shafer (1965), Hoover (1960), Penn (1948), and Whiting and Stakely (1958), are some examples of this continuing effort. Various synoptic approaches to the east coast snow problem were also discussed at the National Weather Analysis Center Conference of 21 October 1955 (Weather Bureau, 1956). However, the studies presented at that conference, like much of the work on this problem up to now, were based on relatively small samples of heavy snow cases at specific cities. In the present study the sample size was increased by collecting data for storms which produced heavy snow over specified areas, rather than at a specific city. The areas selected for the study were made small enough to keep the data sample homogeneous, but large enough to provide a reasonably large sample size.

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Two complementary techniques were applied in the search for characteristic weather patterns. First, composite charts were constructed by plotting on a common map the positions of synoptic features associated with all heavy snow events in the data sample, specifically, pressure centers and trough lines, in the hope that preferred positions of these features would become apparent. Second, mean charts were constructed from arithmetic averages of radiosonde data. The former technique exposes the dispersion or scatter in the data sample, while the latter suppresses it to reveal dominant features. Taken together, and accompanied by other measures of dispersion, such as the standard deviations of the radiosonde data, the two techniques may be used to determine whether or not necessary conditions and synoptic models associated with east coast heavy snowfalls can indeed be found.

2. Data

The Weather Bureau generally defines "heavy snow" as a fall of at least 4 inches in 12 hr or 6 inches in 24 hr. However, this definition is subject to local variations, and specific criteria for various geographical areas are given in the *Weather Bureau Operations Manual* of each region. For the purpose of the present study, heavy snow was defined as a total accumulation of at least 6 inches from one storm.

The east coastal plane was divided into three overlapping subregions, as shown in Fig. 1. The area south of latitude 40N is designated the southeast subregion, that north of 40N the northeast subregion, and the overlapping area from 38–42N as the middle Atlantic subregion. The use of subregions rather than individual cities to define heavy snow events not only provides a greater sample size, but also includes cases that may have "just missed" a city and yet at the time posed a heavy snow threat to that city.

A tabulation was made of all heavy snow occurrences recorded at all first-order Weather Bureau stations in these subregions during the period January 1946 through March 1969. A listing of the stations used is shown in Table 1.

A heavy snow event in a subregion was defined as the occurrence of heavy snow at any one or more of the reporting stations in the subregion. In the southeast subregion, with 12 reporting stations, 58 storms produced heavy snowfalls in the 24-year data period. At Wilmington, N. C., the southernmost station in the subregion, not one heavy snow was recorded during this period.

Of the 264 heavy snow events in the northeast sub-

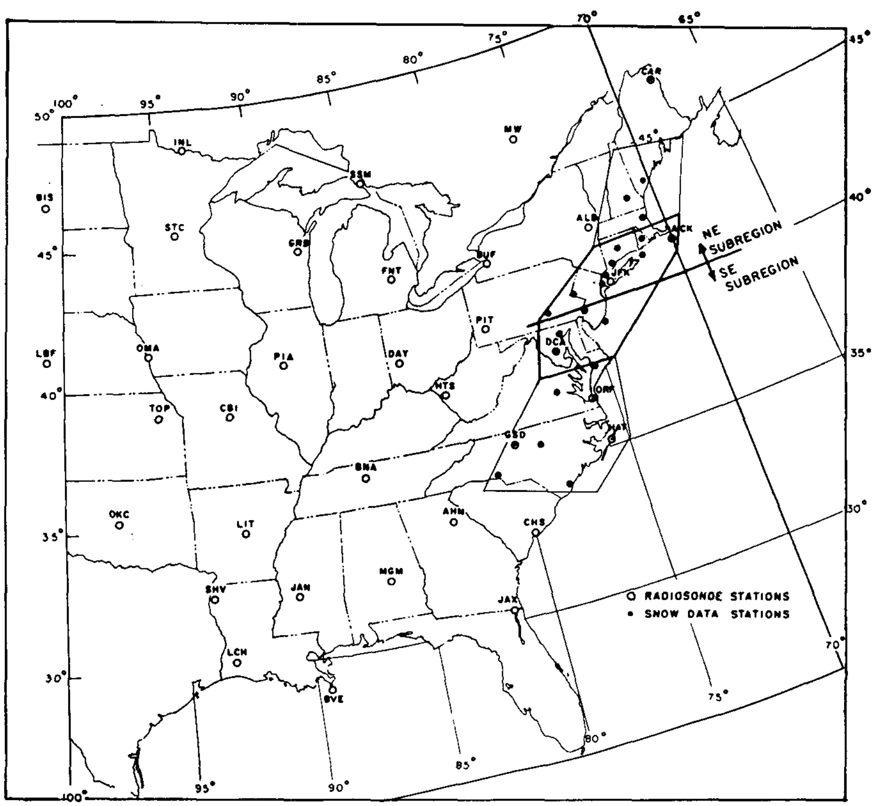

FIG. 1. Subregions, data collection area for composite map, and Weather Bureau stations for heavy snow identification. The heavily outlined area represents the middle Atlantic subregion, while the northeast subregion lies north of 40N, and the southeast south of 40N.

region, which contained 13 stations, 91 occurred only at Caribou, Maine. Because the "Caribou-only" snowstorms appear to represent a different class of events from those affecting the remainder of the subregion, the northeast subregion was redefined to lie south of Caribou. This reduced the number of stations to 12, and the number of heavy snows in the subregion to 173. In the middle Atlantic subregion, with 12 stations reporting, 98 heavy snowstorms were recorded. Many of the storms were, of course, listed for more than one subregion.

For every heavy snow event the following data were recorded: beginning and ending times of snow, total snow depth, and total liquid equivalent precipitation at each station.

The onset time of a storm in the subregion was defined as the earliest time that snow began at any of the stations in the subregion which subsequently reported at least 6 inches of snow.

For the purpose of constructing composite and mean maps, onset time was converted into another reference time, designated "zero-hour" (0 hour). This was defined as the radiosonde observation time closest to onset time. The time expressed relative to 0 hour will be referred to as "map time."

Radiosonde data and microfilmed surface and upper air weather maps obtained from the National Weather Records Center in Ashville, N. C., were used to construct composite and mean maps for three map times: 0−24 hours, 0−12 hours, and 0 hour. Data were also composited for 0+12 hours, but no figures corresponding to this map time are reproduced. The area covered by these maps, which will be referred to as the "analysis area," is bounded by latitudes 25 and 50N, and longitudes 70 and 100W. Composite charts were constructed for the surface, and for the 700- and 500-mb levels, while maps were drawn for the 1000-, 700- and 500-mb levels. Separate composite and mean maps were prepared for each subregion.

The composite charts for each subregion were constructed from that portion of the total storm sample within the data period January 1946—February 1966. As shown in Tables 2 and 3, this reduced the total number of storms in the southeast, northeast and middle Atlantic subregions to 49, 145 and 79, respectively.

TABLE 1. Stations used for identification of heavy snow events.

Northeast subregion	
Caribou, Me.*	Block Island, R. I.
Portland, Me.	Hartford, Conn.
Concord, N. H.	Bridgeport, Conn.**
Boston, Mass.	LaGuardia Airport, N. Y.
Providence, R. I.	Central Park, N. Y.
Nantucket, Mass.	Allentown, Pa.
	Harrisburg, Pa.
Middle Atlantic subregion	
Providence, R. I.	Allentown, Pa.
Hartford, Conn.	Harrisburg, Pa.
Block Island, R. I.	Philadelphia, Pa.
Bridgeport, Conn.	Atlantic City, N. J.
LaGuardia Airport, N. Y.	Baltimore, Md.
Central Park, N. Y.	Washington, D. C.
Southeast subregion	
Philadelphia, Pa.	Wallops Island, Va.**
Atlantic City, N. J.	Hatteras, N. C.
Baltimore, Md.	Raleigh, N. C.
Washington, D. C.	Greensboro, N. C.
Richmond, Va.	Charlotte, N. C.
Norfolk, Va.	Wilmington, N. C.

* Caribou was later excluded from the northeast subregion.
** Observations began at Bridgeport, Conn., in 1948 and Wallops Island in 1965.

TABLE 2. Number of heavy snowstorms with surface low and high pressure centers in the analysis area for the period January 1946–February 1966.

Chart time	Lows	Highs
Northeast subregion (145 cases)		
0−24 hours	106	106
0−12 hours	134	103
0 hour	141	110
0+12 hours	124	99
Middle Atlantic subregion (79 cases)		
0−24 hours	53	61
0−12 hours	69	66
0 hour	79	56
0+12 hours	74	56
Southeast subregion (49 cases)		
0−24 hours	37	43
0−12 hours	40	39
0 hour	47	32
0+12 hours	47	35

TABLE 3. Number of heavy snowstorms with low centers or trough lines in the analysis area at each level for the period January 1946–January 1966.

Chart time	700 mb	500 mb
Northeast subregion (145 cases)		
0−24 hours	54/123	45/111
0−12 hours	61/137	57/129
0 hour	79/140	69/136
0+12 hours	83/139	65/132
Middle Atlantic subregion (79 cases)		
0−24 hours	25/69	20/61
0−12 hours	41/76	28/71
0 hour	50/77	34/75
0+12 hours	49/77	37/72
Southeast subregion (49 cases)		
0−24 hours	18/44	14/38
0−12 hours	22/48	24/46
0 hour	30/47	29/48
0+12 hours	31/49	26/47

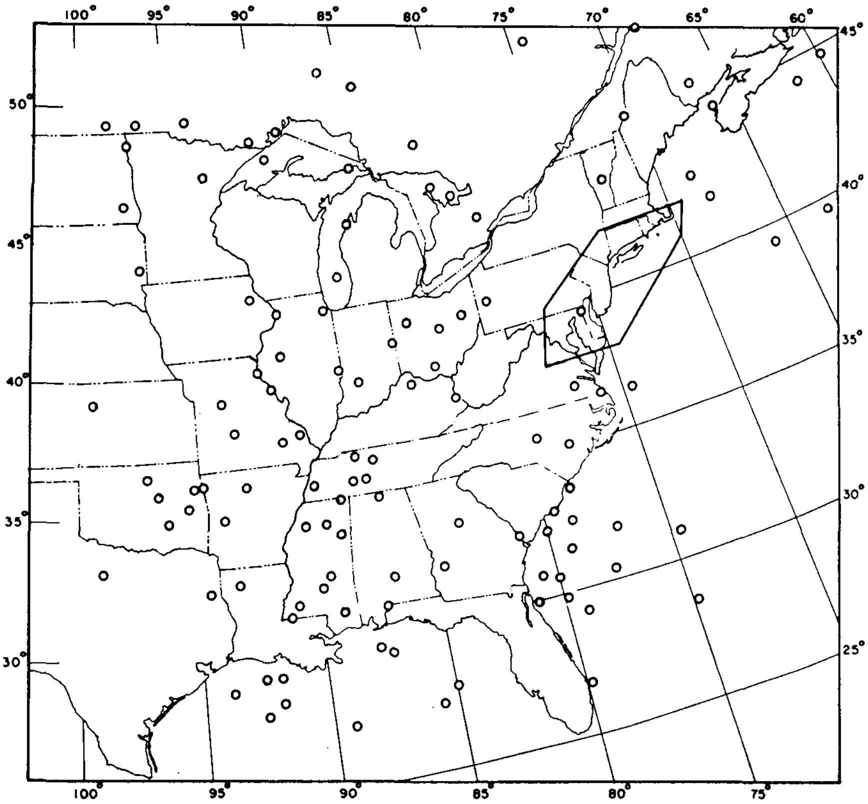

FIG. 2. Composite of surface low center positions 12 hr in advance (0–12 hours) of the beginning of heavy snowfall in the middle Atlantic subregion. (See text for explanation of 0 hour.)

Table 2 shows the total number of snowstorms in each subregion, and the total number of cases in which a sea level low or high pressure center (*not* necessarily a closed isobar) appeared in the analysis area (25–50N, 70–100W) at each of the four map times. Table 3 indicates the number of cases in which low centers and the number of cases in which trough lines (identified by subjective analysis) were found at 700 and 500 mb in the analysis area in each subregion at each of the four map times.

In each subregion, the number of cases with sea level low pressure centers (Table 2) in the analysis area increases from 0−24 hours to 0 hour, and then decreases from 0 hour to 0+12 hours. The decrease is undoubtedly due to the passage of low centers to the east of 70W, and out of the analysis area. It is noteworthy that, in ~30% of the cases, a surface cyclone did not even appear on the map in the analysis area 24 hr prior to onset of heavy snow on the east coast.

A similar pattern of behavior appears in the data in Table 3 where it is seen that again the frequency of identifiable characteristic features, in this case low centers and trough lines at 700 and 500 mb, increases with the approach of 0 hour. Clearly, the atmosphere arrives at the state corresponding to heavy snow on the east coast from a variety of initial states, and/or at a highly variable rate.

3. Composite analysis

Because the composite data are so similar for the three subregions, it will suffice to describe the results of the composite analysis for only the overlapping middle Atlantic subregion. Sample composite maps for this subregion are illustrated below.

a. 0–24 hours[3]

Twenty-four hours prior to the onset time of heavy snow in the middle Atlantic subregion, surface low pressure centers were found in the analysis area in only 68% of the cases, while high centers appeared there in 77% of the cases (Table 1). Furthermore, the low and high centers which did appear in the analysis area were very widely scattered. For these reasons, no composite surface maps are presented for this map time.

Of the 53 cases in which low centers were found in the analysis area, 43 (81% of the 53 cases and 54% of the total storm sample) were represented by a low center south of 40N. In only 15 cases (28% of the 53

[3] Figures omitted.

cases and 19% of the total storm sample) were these centers located in the vicinity of the Gulf of Mexico. Nor did any other area of the country contain a notably high concentration of low centers.

From these data, it appears that obvious characteristic antecedent conditions do not appear on the surface weather maps 24 hr prior to the beginning of heavy snow on the east coast. Undoubtedly cyclogenesis and rapid development play a dominant role in heavy storm production within this 24-hr period. Even in most of the cases when a cyclone did appear in the analysis area at 0−24 hours, the heavy snow on the east coast was associated with *secondary* cyclogenesis.

The trough lines and low centers identified on the analyzed 700- and 500-mb maps also exhibit wide scatter at 0−24 hours. Only 32% of the storms were preceded by low centers at 700 mb in the analysis area, although 82% were preceded by troughs at that level at 0−24 hours. In 54 cases (68% of the storms in the sample) the 700-mb trough line lay between 90 and 100W at 0−24 hours, and in 43 cases (54% of the storm sample) the trough line was found in the same zone at the 500-mb level. The remaining trough lines were widely scattered, frustrating any effort to formulate a simple model representing a necessary 24-hr antecedent condition for heavy snow on the east coast. Hence, no composite upper air maps are reproduced for this time.

b. 0−12 hours (*Figs. 2 and 3*)

Surface low pressure centers were found in the analysis area at 0−12 hours in 69 (87%) of the middle Atlantic heavy snow cases (Table 2). However, as shown in Fig. 2, the centers were still very widely scattered. Although concentrations of lows begin to appear along the South Atlantic and Gulf coasts, and in the central part of the country, the scatter of surface low centers 12 hr prior to the onset of heavy snow on the east coast indicates little likelihood of finding necessary antecedent conditions on the surface map.

An interesting feature of Fig. 2 is the almost blank area over the Appalachian Mountains. To the west are found the primary cyclones, which may or may not have spawned secondaries, while to the south and east are found the secondary lows. But, at least in this data sample, the two groups of lows appear to be separated by the mountains.

At the 700-mb level at 0−12 hours a trough was found in the analysis area in almost every case, as shown both in Table 3 and in Fig. 3. The same is true also at 500 mb, although at that level the trough lines appear a few degrees of longitude further to the west. In Fig. 3 it is seen that most of the 700-mb trough lines at 0−12 hours are concentrated in a fairly narrow NE–SW zone whose vertices are approximately at longitudes 90 and 100W at 30N, and at longitudes 80

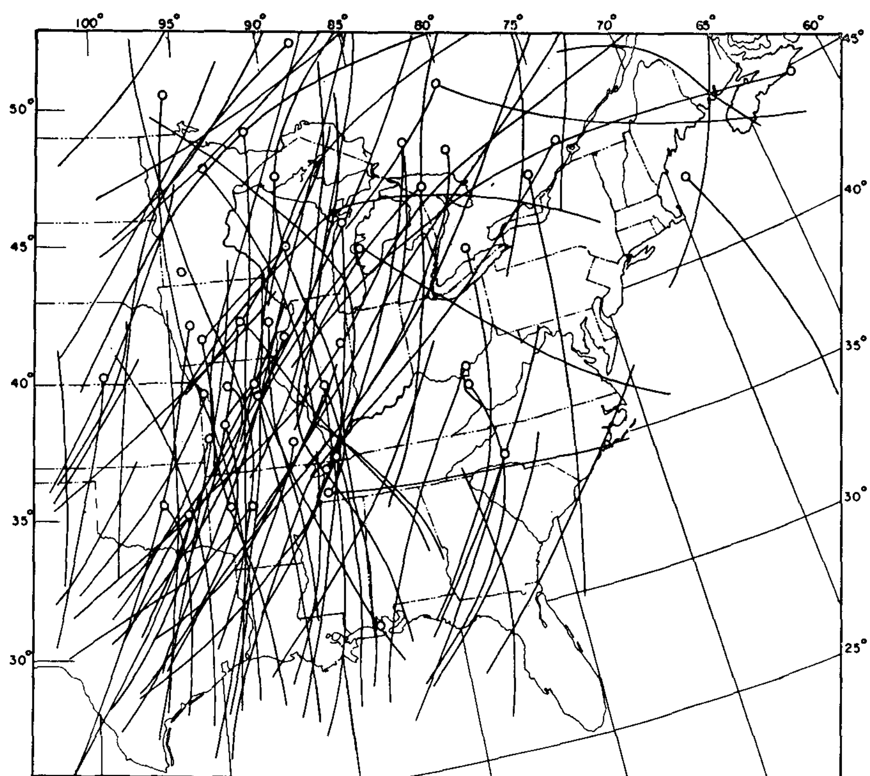

FIG. 3. Composite of 700-mb trough and low center positions 12 hr in advance (0–12 hours) of the beginning of heavy snowfall in the middle Atlantic subregion.

and 90W at 45N. If a trough line lies east of this zone, the precipitation on the coast is probably already underway, while if it lies west of the zone, precipitation will probably not begin within the next 12 hr. Although Fig. 3 provides some information that may be of use to a forecaster, the scatter of trough positions is still too large for a necessary condition.

c. 0 hour (*Figs. 4 and 5*)

Close to the onset time of snow in the middle Atlantic subregion, the sea level cyclone positions, shown in Fig. 4, begin to organize into two main groups: a swath of primary cyclones along the western side of the Appalachian Mountains, and extending to the Great Lakes, and a band of secondary lows extending northeastward from the Gulf coast, with a major concentration south of the subregion. At this time (0 hour) there is, of course, at least one low center in the analysis area for every heavy snow case, and in many cases both primary and secondary cyclones are found. The high pressure centers (not illustrated) are less frequent, and do not exhibit preferred locations.

The notable scatter of surface low centers at 0 hour seen in Fig. 4 seems to be at variance with the almost necessary condition for heavy snow for New York City found by Spar *et al.* (1967). However, in the latter study the condition described (a low center in the southeast quadrant and within 300 mi of New York, at its closest approach to the city) referred to the total life history of the snow-producing cyclone, whereas Fig. 4 refers only to conditions close to onset time. Before almost every snowstorm in the present data sample ended, a coastal cyclone did indeed appear within 300 mi of the middle Atlantic subregion. Thus, the passage of a coastal cyclone within ~300 mi of any locality on the east coastal plain at some time during the life of the cyclone may still be considered to be an almost necessary condition for heavy snow at that locality, although the technique employed in the present study does not permit this condition to be demonstrated clearly.

The 0 hour 700-mb trough positions shown in Fig. 5 (as well as the corresponding 500-mb trough lines, which are not reproduced) are found, in general, about 5° of longitude eastward of the positions 12 hr earlier. The scatter of the 700-mb trough lines is at least as great at 0 hour as it was 12 hr prior to onset time. This fact, together with the equally large scatter found at 0+12 hours (not shown), suggests that a wide variety of degrees of baroclinicity are associated with heavy snow events on the east coast. Thus, even though the surface lows may tend to cluster near the coast during most heavy snowfalls, the horizontal temperature gradient, and, hence, the "tilt" of the trough with

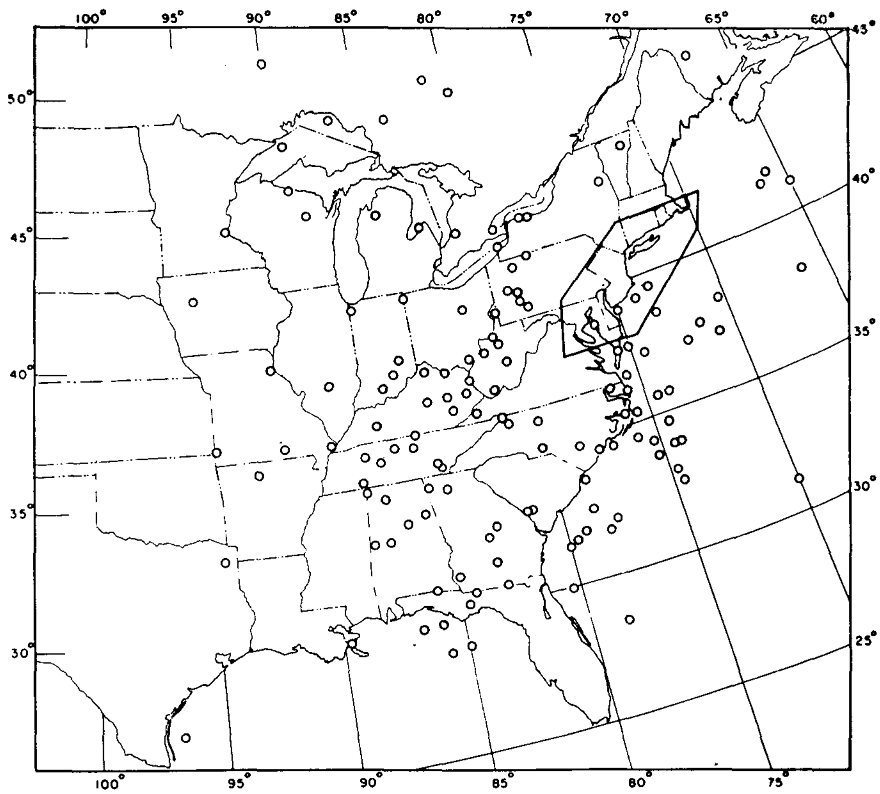

FIG. 4. Composite of surface low center positions at the beginning time (0 hour) of heavy snowfall in the middle Atlantic subregion.

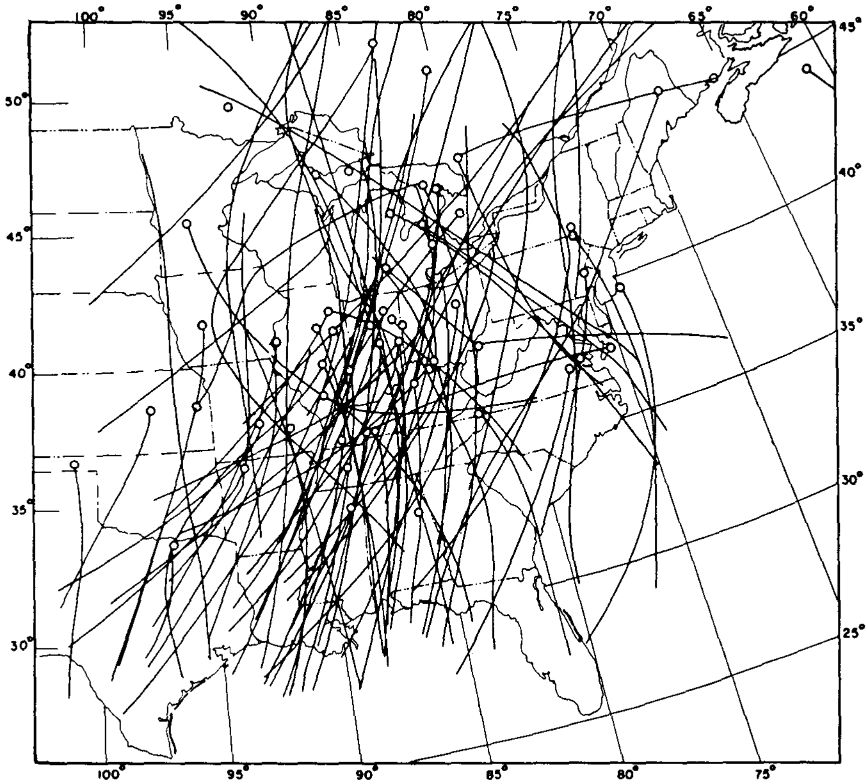

Fig. 5. Composite of 700-mb trough and low center positions at the beginning time (0 hour) of heavy snowfall in the middle Atlantic subregion.

height, varies from case to case, thus producing a scatter of 700-mb trough line positions. This scatter appears to be somewhat smaller for the southeast subregion and somewhat larger for the northeast subregion, suggesting the possibility that southeast snowstorms constitute a more homogeneous class than do those of the northeast. Apparently, the low temperatures required at low latitudes for a southeast subregion snowstorm limit the scatter of the upper trough positions, whereas in the northeast, where the temperatures are more frequently cold enough for snow, a wider variety of synoptic conditions may accompany heavy snowfalls.

Of course, part of the scatter in all the maps shown above is probably due also to the analysis technique used, and specifically to the definitions of "onset time," "zero hour," and "map time," which may result in time discrepancies as large as 6 hr.

4. Mean maps

Data from the 36 radiosonde stations plotted in Fig. 1 were used to construct *mean maps* for 0−24 hours, 0−12 hours, 0 hour, and 0+12 hours, for the 1000-, 850-, 700- and 500-mb levels, and for the storm samples of each of the three subregions. However, only a limited number of these maps are reproduced here.

A sample of 109 separate snowstorms in the period January 1956–November 1967 was selected for the construction of the mean maps. Within the northeast, middle Atlantic and southeast subregions, however, the sample sizes were only 77, 51 and 39, respectively.

At all levels, geopotential heights were tabulated to the nearest geopotential meter. Temperature, to the nearest degree Celsius, and relative humidity, to the nearest percent, were listed for the 850-, 700- and 500-mb levels, but are shown in the following maps only for the 850-mb level. Mean values and standard deviations of each of these quantities were computed at each station for the storm samples corresponding to each subregion and map time. The maps of standard deviations, however, are not shown here.

Because of the large scatter noted in the composite maps for 0−24 hours, it is felt that mean maps for that map time would be of little significance and are thus not shown or discussed. The maps for 0+12 hours are also not reproduced here, although they are referred to briefly.

Most of the following discussion is confined to the middle Atlantic subregion. However, for comparison, mean 1000-mb maps for 0 hour are also included for the other two subregions.

a. 0−12 hours (*Figs. 6, 7 and 8*)

Twelve hours prior to the onset of heavy snow in the middle Atlantic subregion, the geopotential contours on the mean 1000-mb map (Fig. 6) show a high center over the subregion and a low center over Mississippi. At the same time the mean 850-mb map (Fig. 7) exhibits a trough west of the surface low, moist air (relative humidity >70%) over the surface low, and dry (relative humidity <60%) cold air (temperatures, −1 to −7C) over the subregion. At 700 mb (Fig. 8) the mean contours, drawn for an interval of 30 gpm, indicate a broad trough only slightly west of the 850-mb trough line. At 500 mb (not illustrated) an area of maximum relative humidity (56% over Pittsburgh) is found well to the northeast of the 850-mb humidity maximum, indicating moist advection aloft from the cyclone area over Mississippi, where water vapor is apparently being " pumped" upward.

At the 1000-mb level the difference in height between the high and low centers at 0–12 hours is about 50 gpm, while the standard deviation at any station at that level for the data sample lies between about 45 and 70 gpm. Thus, the 1000-mb mean map can hardly be considered representative of typical conditions 12 hr prior to onset of heavy snow on the coast. On the other hand, the standard deviations at the upper levels, although slightly larger in absolute magnitude, are somewhat smaller relative to the larger gradients found there, so that the mean upper air maps may be slightly more meaningful.

b. 0 hour (Figs. 9, 10 and 11)

The evolution of the mean synoptic patterns as onset time approaches in the middle Atlantic subregion can be seen by comparing Figs. 9, 10 and 11 with Figs. 6, 7 and 8, respectively.

At 1000 mb (Fig. 9) the primary mean low has deepened and moved northeastward, a secondary center has developed over Cape Hatteras, and a characteristic ridge east of the Appalachians separates the two. However, the height range along the coast is only about 50 gpm, while the standard deviations along the coast are between 50 and 65 gpm. Thus, once again, considerable variability in the synoptic patterns constituting the mean pattern is indicated.

On the 850-mb mean map (Fig. 10), the trough has amplified perceptibly, and a low center has formed north of the 1000-mb low. Temperatures have warmed slightly in the middle Atlantic subregion, and are now between 0 and −5C. The dry area (relative humidities <60%) has moved northward (over New England); and the moist area, now with maximum relative humidities >80%, has spread over a larger region, and has reached the coast south of the subregion.

At the 700-mb level (Fig. 11) the mean trough has moved eastward, and its amplitude has increased to produce a more southwesterly flow along the coast.

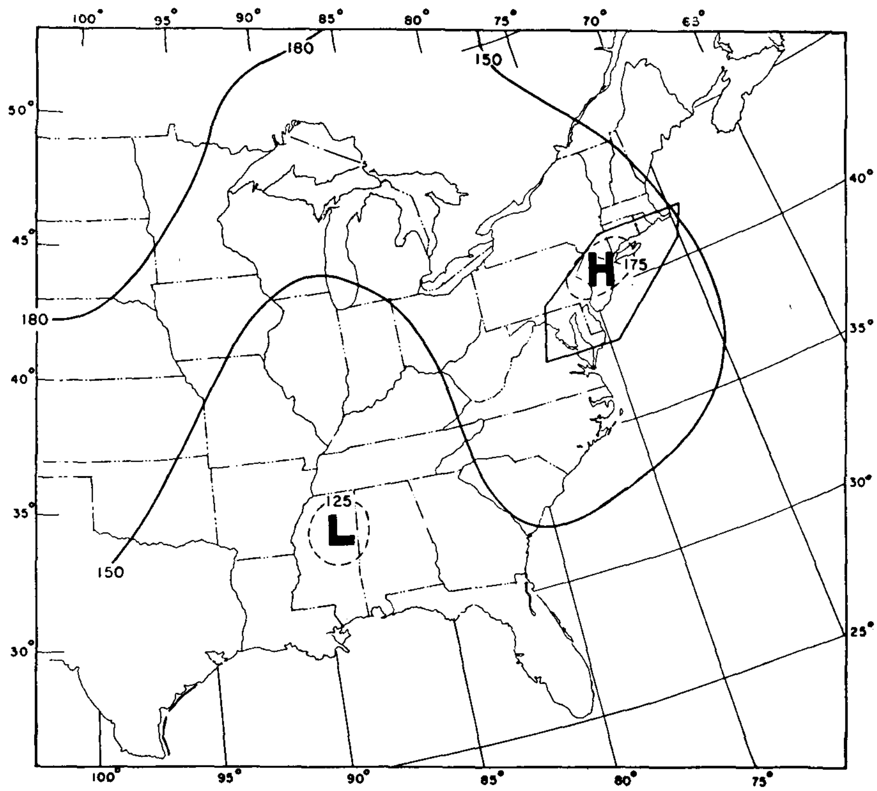

FIG. 6. Mean 1000-mb chart 12 hr in advance (0–12 hours) of heavy snowfall in the middle Atlantic subregion. Contours are labelled in geopotential meters.

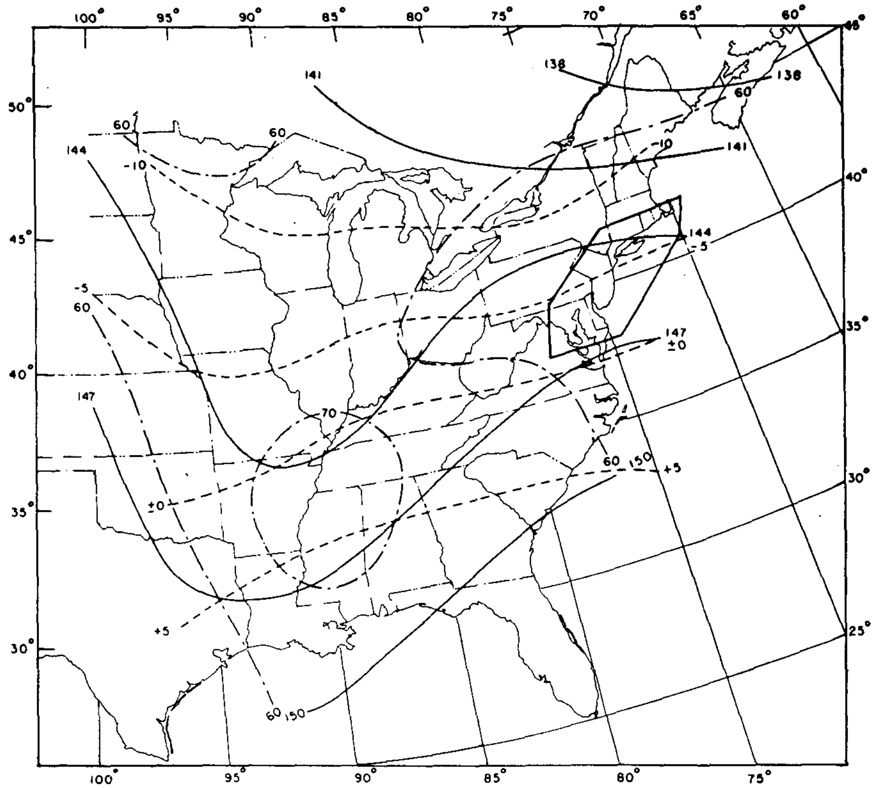

FIG. 7. Mean 850-mb chart 12 hr in advance (0–12 hours) of heavy snowfall in the middle Atlantic subregion. Solid curves are contours labelled in geopotential decameters; dashed curves are isotherms, labelled in degrees Celsius; dash-dot curves are isopleths of relative humidity, labelled in percent.

The mean relative humidity at 500 mb (not shown) exhibits a maximum over the coastal plain (69% at Washington, D. C.) at onset time. Together with the humidity pattern at 850 mb, this again indicates a column of moist air tilting northeastward with increasing height.

Again, however, caution must be exercised in interpreting the mean maps too literally in view of the large variances indicated. For example, at 850 mb the ranges of mean height, temperature and relative humidity on the 0 hour mean map (Fig. 10) are about 70 gpm, 15C and 30%, respectively, while the standard deviations at the individual radiosonde stations for the data sample average about 55 gpm, 5C and 25%. Thus, of the three fields, only the temperature pattern appears to be "representative" of the sample.

It is of some interest to compare the mean 0 hour 1000-mb maps for the southeast (Fig. 12) and the northeast (Fig. 13) subregions with that for the middle Atlantic subregion (Fig. 9). In the case of the southeast snowstorms, both primary and secondary mean cyclones are found much farther to the south (over Georgia), and a well-defined mean high appears over the middle Atlantic states. The mean chart for the northeast subregion heavy snow events, on the other hand, resembles the middle Atlantic mean map more closely, except that both primary and secondary lows are slightly farther north.

c. 0+12 hours[4]

Twelve hours after onset of heavy snow anywhere along the east coastal plain, a well-developed mean cyclone center appears off the coast, and its circulation dominates the eastern third of the country. For the southeast, middle Atlantic, and northeast subregion snowstorms, the approximate mean low center positions are, respectively: 35N, 75W (Cape Hatteras); 37N, 73W; and 39N, 71W.

Although this feature comes closest to representing a necessary condition for heavy east coast snows, there is still considerable scatter of the center positions on the individual maps comprising the mean. This is indicated both by the composite maps and by the standard deviations. The latter vary between 40 and 90 gpm along the coast, compared with a range of 90 gpm for the mean values in the coastal region.

5. Conclusions

In general, the following conclusions appear to be indicated by the composite and mean map analyses:

[4] Figure omitted.

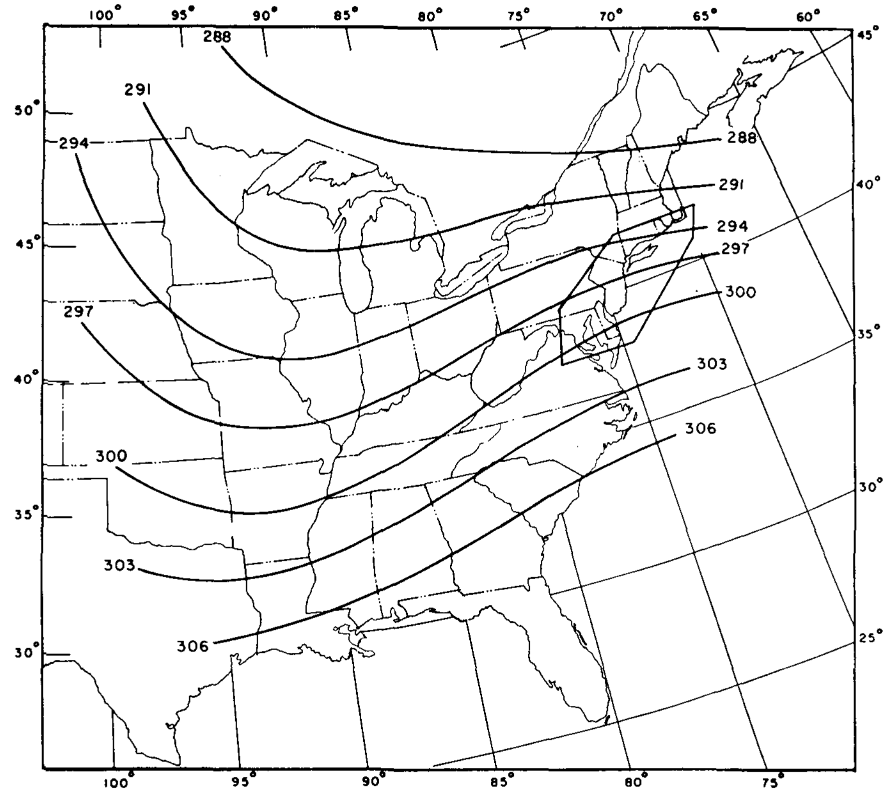

FIG. 8. Mean 700-mb chart 12 hr in advance (0–12 hours) of heavy snow in the middle Atlantic subregion. Contours are labelled in geopotential decameters.

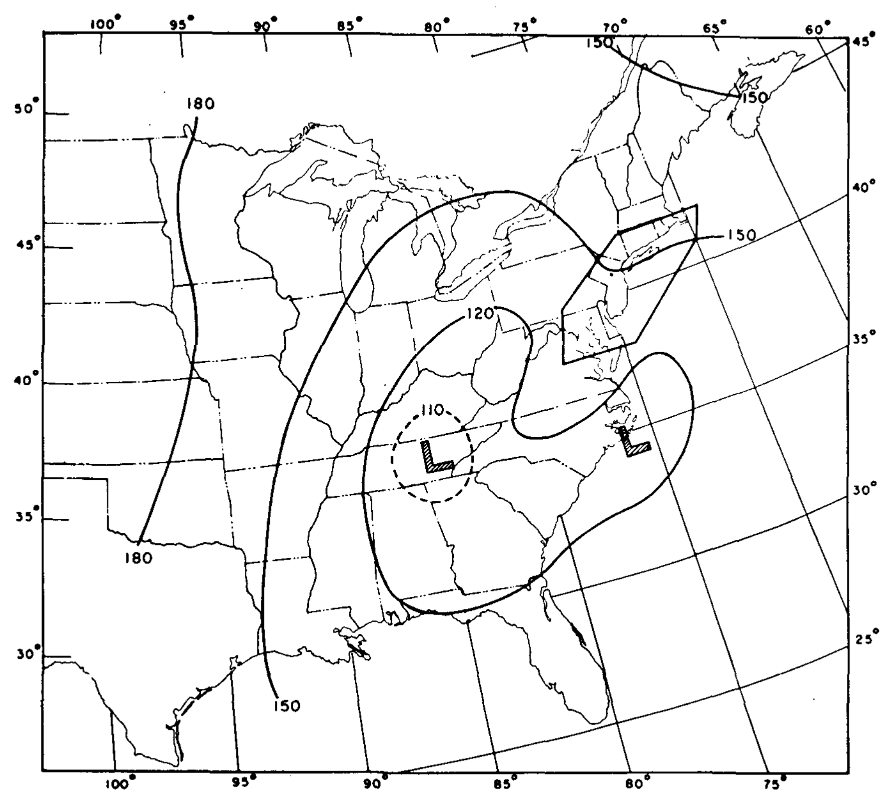

FIG. 9. Mean 1000-mb chart at the beginning time (0 hour) of heavy snowfall in the middle Atlantic subregion.

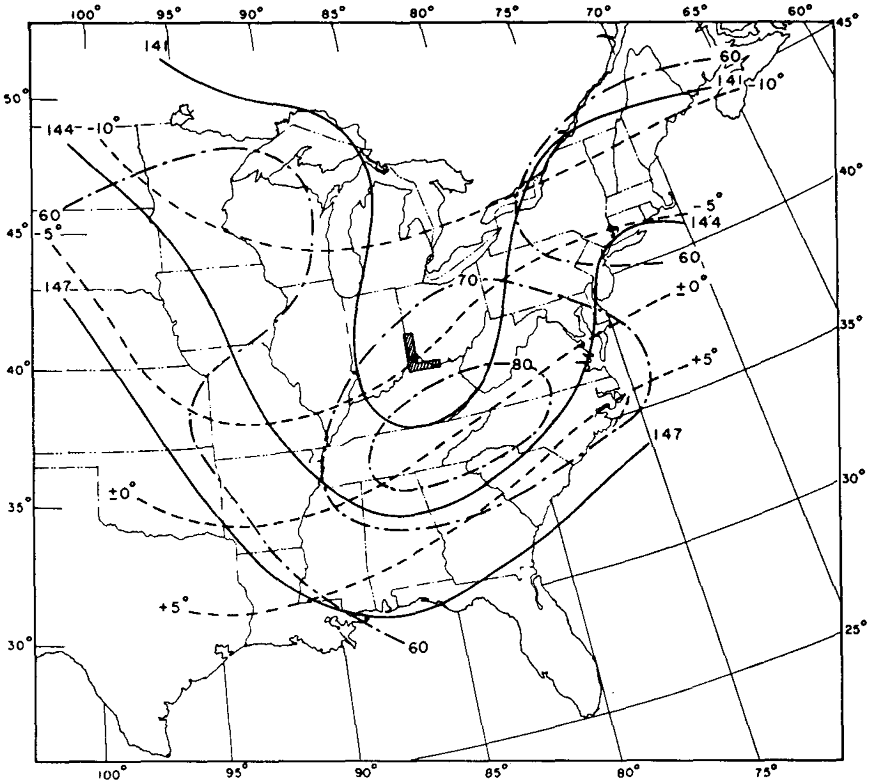

Fig. 10. Mean 850-mb chart at the beginning time (0 hour) of heavy snowfall in the middle Atlantic subregion.

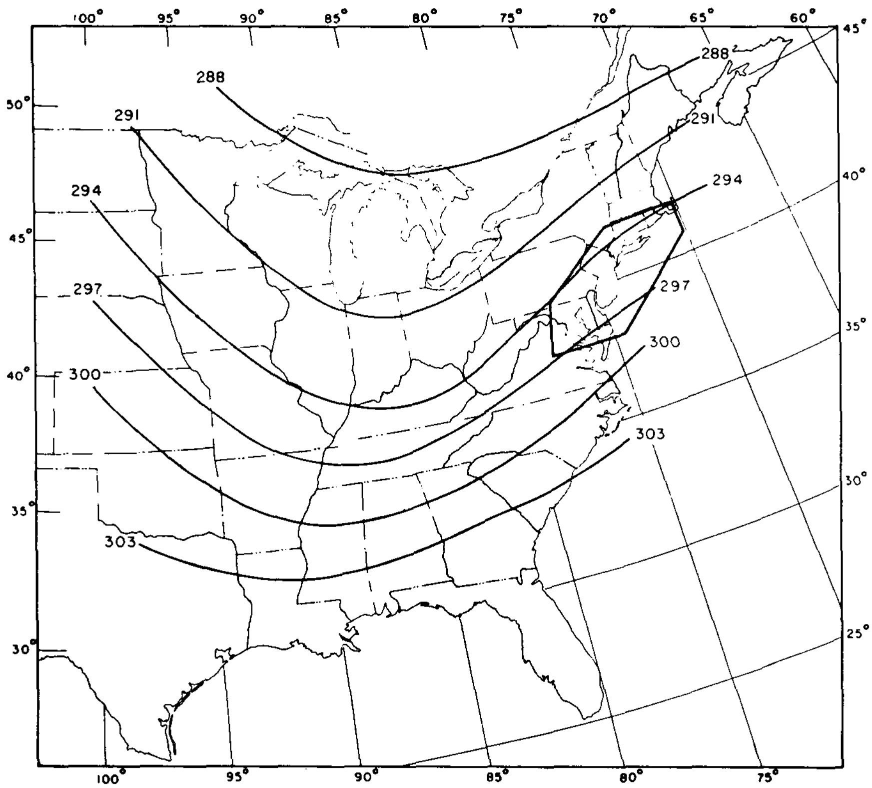

Fig. 11. Mean 700-mb chart at the beginning time (0 hour) of heavy snowfall in the middle Atlantic subregion.

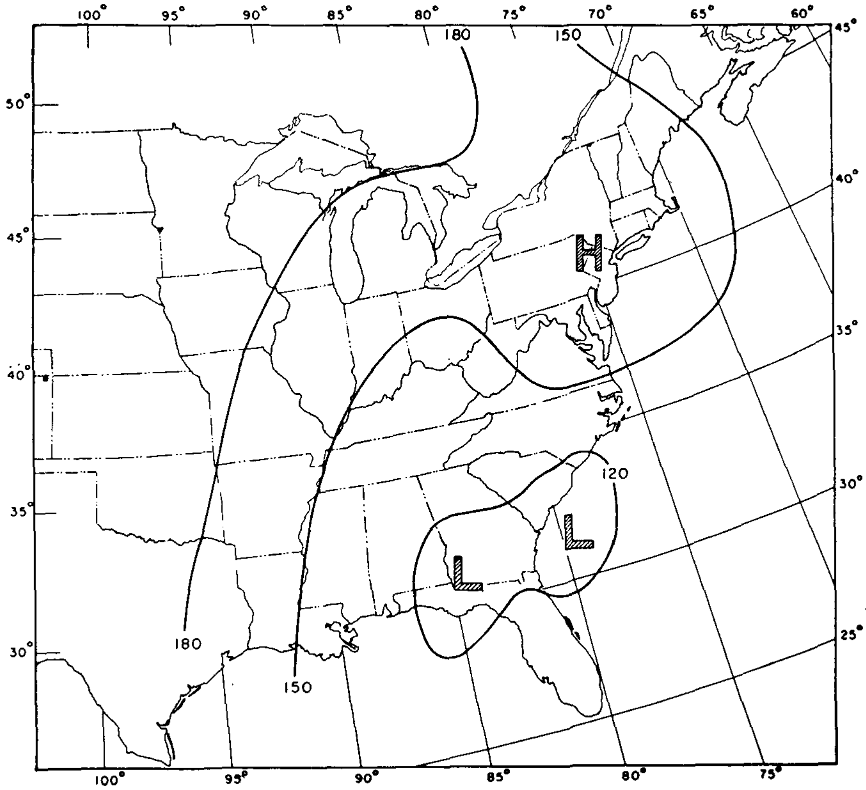

FIG. 12. Mean 1000-mb chart at the beginning time (0 hour) of heavy snowfall in the southeast subregion.

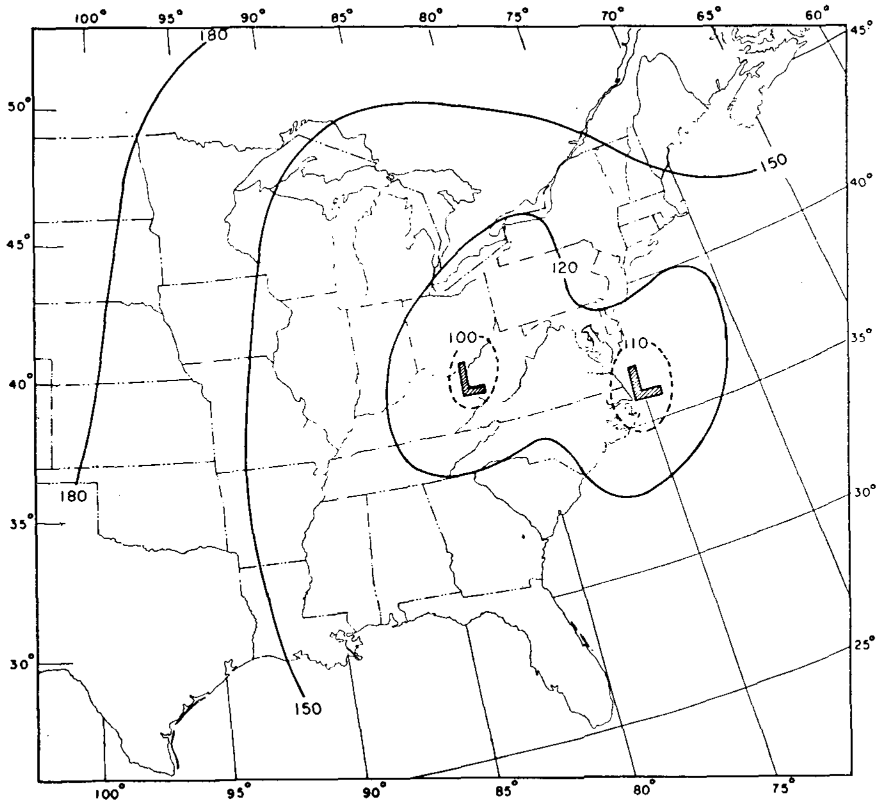

FIG. 13. Mean 1000-mb chart at the beginning time (0 hour) of heavy snowfall in the northeast subregion.

1) No obvious antecedent conditions are apparent either 24 or 12 hr prior to the onset of heavy snow on the east coast.

2) East coastal heavy snows are associated with coastal secondary cyclogenesis, and begin with little or no lag behind the formation of the secondaries.

3) Onset time of heavy snow on the east coast is generally accompanied by the appearance at 850 mb of (i) a low center, (ii) a pool of high humidity spreading to the coast, and (iii) temperatures between 0 and −5C in the coastal area of heavy snow. This result is in agreement with the ideas of Spiegler and Fisher (1970) and other investigators, and lends support to their suggestion that 850 mb is the level of greatest utility for heavy snow prediction. However, even this result provides, at best, only a weak "necessary" condition, for the standard deviations of all variables are quite large.

4) A column of high humidity tilting northeastward with height from 850 to 500 mb is characteristic of heavy snow events on the east coast.

5) Except for the obvious requirements of an east coastal cyclone, there appear to be no useful synoptic analogue patterns for anticipation of heavy snow on the east coast. This suggests that the problem will be solved only through improved dynamical and/or statistical quantitative precipitation and temperature forecasts.

Finally, it should be noted that our failure to find a set of necessary conditions for the occurrence of heavy snow on the east coastal plain does not prove that such conditions do not exist. We have investigated only a small set of simple parameters. It is, of course, possible that other quantities might prove more useful.

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