MEAN 700 MB CIRCULATION PATTERNS ASSOCIATED WITH THE SNOWIEST AND LEAST SNOWY WINTER MONTHS OVER THE EASTERN UNITED STATES

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ABSTRACT

Composite mean 700 mb circulation patterns and their anomalies were computed for the approximately 10 to 15 percent snowiest and least snowy winter months over the eastern United States, using data from January 1947 through March 1978 and snowfall records from 28 cities. Rather strong and consistent composite anomaly patterns covering much of the Northern Hemisphere were associated with the snowiest months. The patterns associated with the least snowy months were generally somewhat weaker and less consistent than the snowy ones.

Composite patterns were also computed for similar-sized groups of the coldest, warmest, driest, and wettest winter months. Comparison of patterns indicates that lower than normal temperature is a more important factor than copious moisture for heavy snow over the eastern United States. Snowy months sometimes tend to be drier than normal, whereas the patterns for the warmest and wettest winter months resemble those for the least snowy months.

1. INTRODUCTION

Recent severe winters over the eastern half of the United States characterized by exceptionally heavy snows as well as record cold (Wagner, 1977 and 1978) have had significant impact upon the lives and well-being of millions of people. In addition to the obvious effects of severe and extended cold upon fuel supplies and of major winter storms upon safety and transportation, there have been long-term economic effects as well. It is believed that it would be useful to identify the atmospheric circulation patterns associated with the snowiest months over the eastern portion of the United States, as well as the converse case.

Although a number of studies have been done relating circulation patterns to temperature and precipitation, only two previous studies relating large-scale atmospheric circulation patterns specifically to snowfall are known to the author. One of these (U. S. Weather Bureau, 1956) has not been published in the formal scientific literature, and dealt mainly with the prediction of individual storms at short or intermediate ranges of as much as 4 or 5 days. The other study (Namias, 1960a) examined both monthly and seasonal snowfall totals for winters from 1929-30 to 1958-59 at a fairly dense network of stations extending from New England westward to Ohio. The seasons and months were ranked in order of their respective departures from the mean snowfall for that period of record, and typical 700 mb height and anomaly patterns associated with light and heavy snow months and seasons were shown. A shift in the area of heaviest snow relative to normal from the coast to the interior from one decade to another was related to a corresponding change in the mean circulation and mean winter temperature.

The current study is an extension of the earlier work of Namias, using more recent data that partially overlaps Namias' sample. Only monthly mean snowfall data and circu-

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lation patterns are examined here. The beginning of the period considered was determined by the first year (1947) of generally reliable hemisphere-wide 700 mb data, and the last month included was March 1978. Thus this study does not include data from the most recent severe winter, 1978-79.

Months examined included November and March as well as the three traditional winter months, but due to the lack of officially compiled snowfall normals at most stations, the actual monthly snowfall amounts, rather than anomalies, were used. Since only one November (1950) was selected at just a couple of stations as an exceptionally snowy month, and many or even most Novembers fell into the least snowy category (often with zero or only a trace) at the southern and coastal stations, November snowfall was, to all practical purposes, not included in the data of this study. March had its share of heavy snow situations, and although it was represented significantly fewer times than January in the snowiest month group and significantly more often in the least snowy category, it was included along with the other three winter months in the results of this study.

2. SNOWIEST AND LEAST SNOWY PATTERNS

When the snowfall data were first compiled, they were averaged for several groups of three to five stations as shown in Table 1. Preliminary analysis of the 700 mb height anomaly patterns associated with the snowiest and least snowy months at these small station groupings did not show apparent significant differences between most of them, so the main emphasis was placed on larger groupings (Atlantic, Southern and Midwest). The snowfall data were also averaged over the entire area (all 28 stations listed in Table 1) and it is this result that is shown in Figure 1.

The mean 700 mb height pattern for the 11 snowiest months (Fig. 1A) displays an amplified system of planetary waves, with deeper than normal troughs over the central Pacific south of the Aleutians, over the eastern United States, and over western Europe. There is a tendency for blocking* at high latitudes, with the main band of westerlies south of normal over much of the Northern Hemisphere from the central Pacific to western Europe. The signs of the individual monthly anomalies making up the mean anomaly were at least 70% consistent over much of the hemisphere, rather than only in the eastern United States near the area for which the selection was made. The lack of sign consistency and relatively weak mean anomaly over Greenland and the Davis Strait may be related to the fact that a blocked pattern was only one of three different types associated with major east coast snowstorms (U. S. Weather Bureau, 1956).

A similarly derived mean 700 mb height pattern for the 9 least snowy months as averaged over the entire 28 stations listed in Table 1 (Fig. 1B) shows a generally zonal flow with positive anomalies in or near the mean troughs and negative anomalies associated with some of the ridges, indicating a weakening of the normal troughs and ridges at middle latitudes from the central Pacific to the Atlantic. Blocking is absent from high latitudes of the western part of the Northern Hemisphere, and the peak band of westerlies is generally north of normal due to a northward building of the subtropical ridges to the south. Areas of 70% or greater sign agreement with the mean are less extensive than with the composite of the snowiest months, however.

It should be noted at this point that composite mean 700 mb height and anomaly patterns were also computed for somewhat larger samples of the 22 snowiest and 18 least snowy months as averaged over the northeastern United States (the same months as are listed in Table 2). As might be expected, the patterns were not quite so strong and the areas of 70% or better sign agreement with the sign of the mean were somewhat less extensive. Nevertheless, the patterns were in good qualitative agreement with those shown in Figs. 1A and 1B.

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*Blocking has been defined as the obstructing, on a large scale, of the normal west-to-east progress of migratory cyclones and anticyclones. It is often characterized by one or more abnormally strong anticyclonic circulation centers at high latitudes and unusually strong cyclonic circulation at low latitudes. Blocking patterns usually evolve fairly slowly and last for at least a week and thus make a noticeable impression on monthly mean charts.

Table 1. Station Groupings Used in Compiling Snowfall Data.

ATLANTIC AREA

North Atlantic Coast

Portland Boston New York

North Atlantic Interior

Burlington Albany Avoca

North Mid Atlantic

Philadelphia Washington Roanoke

SOUTHERN AREA

South Mid Atlantic

Norfolk Richmond Raleigh-Durham

Tennessee

Knoxville Nashville Memphis

Lower Ohio Valley

Cincinnati Louisville Evansville

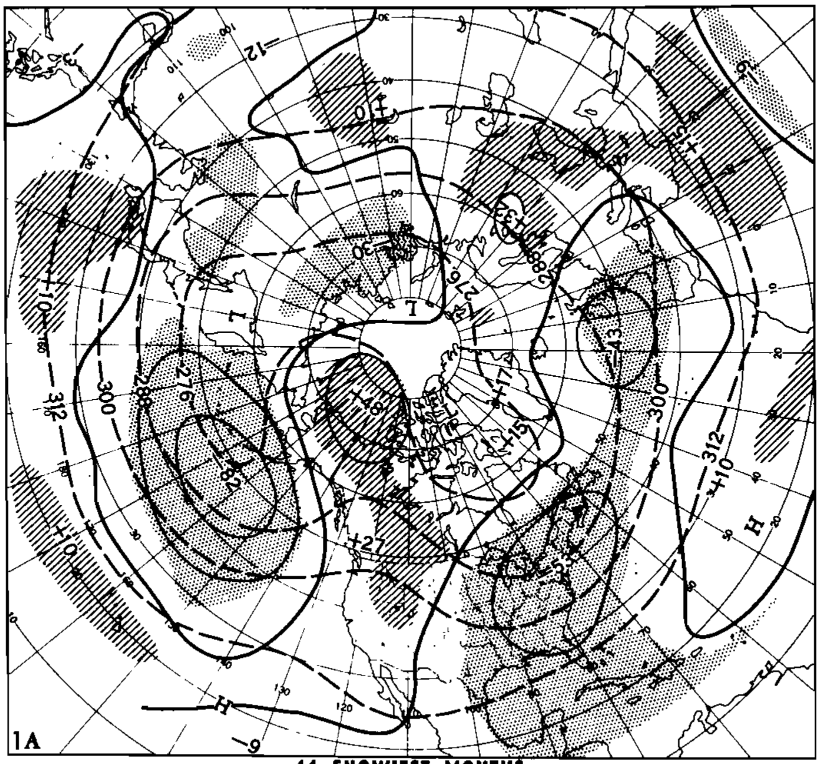
MIDWEST AREA

Lower Lakes (Strong Lake Effect Stations)

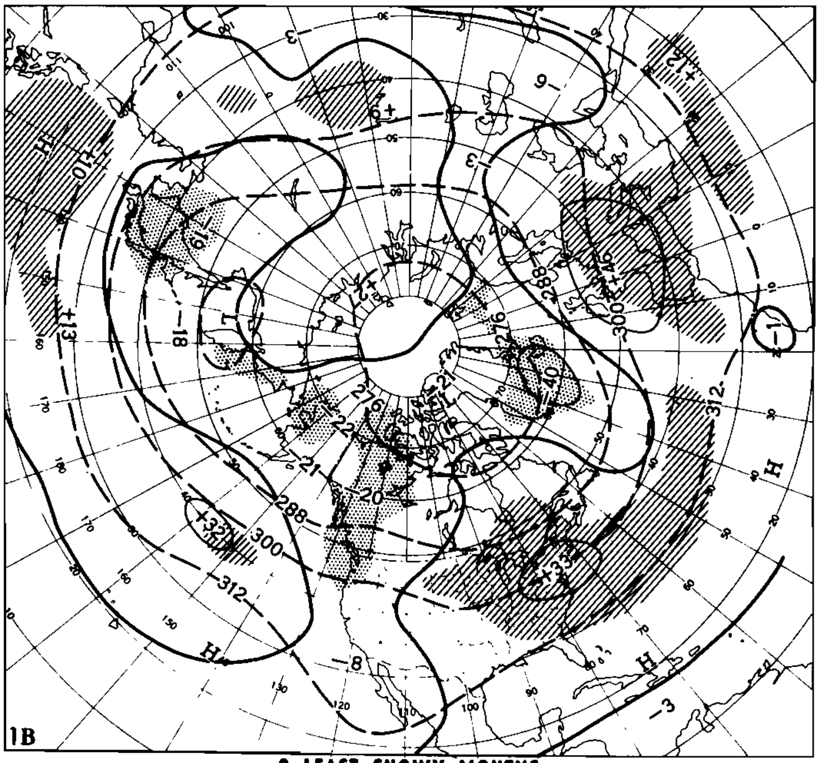
Syracuse Buffalo Cleveland Muskegon South Bend

Upper Ohio Valley (Weak Lake Effect Stations)

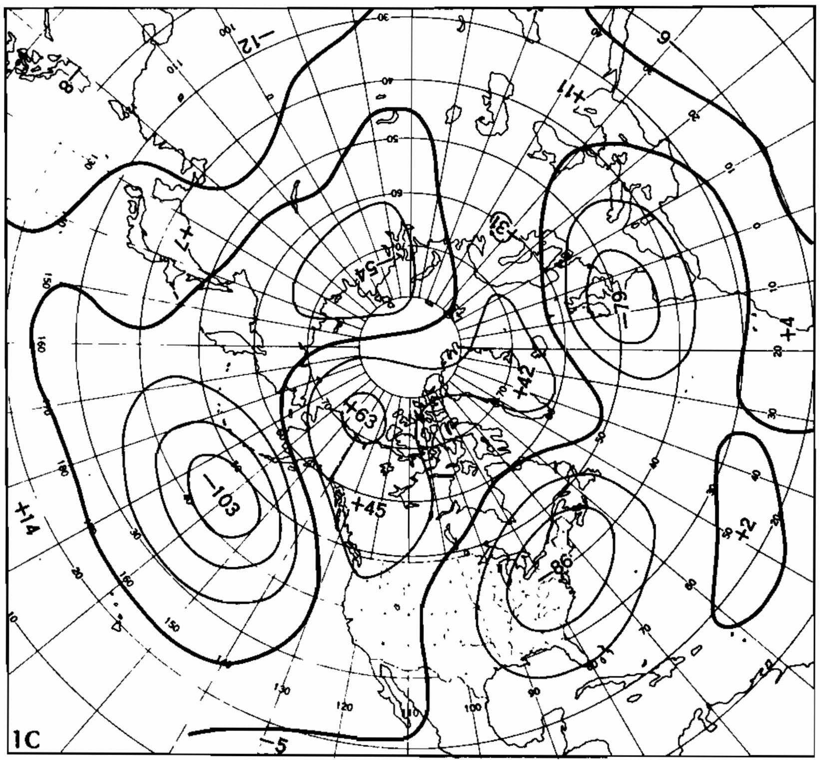
Pittsburgh Columbus Detroit Indianapolis Chicago



1A
11 SNOWIEST MONTHS



1B
9 LEAST SNOWY MONTHS



11 SNOWIEST MINUS 9 LEAST SNOWY

Figure 1. (A) Composite monthly mean 700 mb height pattern for the 11 snowiest winter months over the northeastern United States from January 1947 through March 1978. Dashed lines indicate the mean 700 mb height contours, labeled in decameters. Solid lines give the composite anomaly pattern at 30 m intervals, with the zero line heavy and anomaly centers labeled in meters. Areas of stippling and hatching show where the sign of the individual monthly mean anomalies was in agreement with the sign of the composite mean at least 70% of the time.

(B) As in (A) except for the 9 least snowy winter months from the period of record. In order to avoid selection of an excessive number of Nobembers, this and all least snowy composites were constructed from the months December through March only. Due to the similarity of these and subsequent height patterns, the actual height contours are shown only in Fig. 1 (A) and (B).

(C) Difference in the composite 700 mb height anomalies shown in (A) and (B), with the least snowy pattern subtracted from the snowiest pattern. Labeling and intervals as in (A) and (B).

The difference between the composite mean 700 mb monthly height anomalies for the 11 snowiest and 9 least snowy months is shown in Fig. 1C. The central magnitudes in the areas of greatest height differences over the Pacific and the Canadian Arctic represent about one and a half times the average standard deviation of winter monthly mean heights at those locations. The difference center over the middle Atlantic States was about two standard deviations, while the one near the English Channel was about one standard deviation. Except for the eastern Atlantic one, which was weaker, the height anomaly centers on the snowiest composite (Fig. 1A) were around one standard deviation over the Pacific and north of Alaska and one and a half standard deviations over the middle Atlantic States. The anomaly centers on the least snowy composite (Fig. 1B) were all less than one standard deviation. The results shown here imply that further studies should be conducted to learn whether 700 mb height anomalies in one or more of these key areas can be used to specify the probabilities of large monthly snow amounts over the eastern United States. If sufficiently strong relationships can be established, snowfall projections might be derived from predicted 700 mb height anomalies in the key areas. Such projections, even if only modestly accurate, could have considerable economic utility.

Perhaps the most impressive thing about Figure 1 is that the monthly snowfall over a relatively small percentage of the total area of the United States is evidently influenced by large and generally consistent changes in the mean circulation over at least half of the Northern Hemisphere. The overall atmospheric circulation patterns favorable (or unfavorable) for the development of significant winter snowstorms over the eastern United States are usually strong enough and/or in existence long enough to make a significant impression on monthly mean data. Although no additional means were computed with the actual daily maps during snowstorms removed as a further test, the fact that the height anomaly patterns and their differences were large and consistent not only over the eastern United States but for at least one full planetary wavelength both upstream and downstream indicates that there are preferred large-scale modes of Northern Hemisphere circulation in existence for a considerable length of time than are related to the occurrence of heavy snow or the relative lack of it over the eastern United States.

Such large-scale circulation modes and their relationship to anomalies of temperature and precipitation at a given point or in a given area have been known for some time. The location of preferred areas of heavy or light winter precipitation were found to be related to the mean 700 mb flow pattern (Klein, 1948). Persistent and strong anomalous 700 mb circulation patterns were found to be associated with droughts or unusually wet spells (Namias, 1960b), and anomalous patterns that were recurrent or predominant enough could lead to substantial mean temperature anomalies over periods of several years up to a decade (Namias, 1970, and Wagner, 1977).

The 700 mb anomaly pattern for the snowiest winter months (Fig. 1A) bears considerable resemblance to the mean pattern for the relatively cold winters of the 1960's (Fig. 2 in Namias, 1970). This pattern is a basic mode of the hemispheric wintertime circulation, and has been derived by objective mathematical analysis procedures as the first eigenvector of January sea level pressure from a 70-yr data sample (Kutzbach, 1970). Patterns strikingly similar to Figs. 1A and 1B were found to be related to the coldest and warmest winter months in the southeastern United States (Dickson and Namias, 1976), while winter seasonal mean height difference patterns resembling Fig. 1C were found to be related to opposite extremes of objectively-derived second and third principal components of Pacific sea surface temperature patterns in the preceding Novembers (Harnack, 1979). This and earlier studies of possible predictive or causal links of winter 700 mb circulation with concurrent or antecedent Pacific sea surface temperature (Namias, 1978) suggest that there might be some hope of eventually predicting whether a winter month or season will be snowier or less snowy than normal over the eastern United States. Indeed, there was found to be a significant large-scale change in mean monthly snowfall not only over the Northeast, but also a concurrent change in the opposite sense over the Northwest related to temperature extremes over the Southeast (Fig. 5 in Dickson and Namias, 1976).

3. MEAN 700 MB ANOMALIES ASSOCIATED WITH COLDEST, MILDEST, DRIEST, AND WETTEST MONTHS

The similarity of the 700 mb height patterns of Figure 1 to patterns associated with temperature anomaly in some of the previously noted studies suggests that the relationship of cold and snow should be examined more closely. It is well known that at locations where wintertime precipitation is a mix of frozen and unfrozen types, the temperature of the lower troposphere is the main factor determining the amount of snow that will fall. The dividing line between rain and snow in individual winter storms as well as the normal limit of measurable snow on the ground (Dickson and Posey, 1967) are found somewhere in the northeastern United States throughout most of the winter and early spring.

The selection of coldest, mildest, driest, and wettest months was done somewhat differently from the selection of snowiest and least snowy months. Whereas the snowfall totals were carefully calculated for each of the 28 stations and selection was made on the basis of total amount rather than the departure from normal, the months of most extreme temperature and precipitation were chosen subjectively on the basis of strong anomalies. Generally speaking, at least half of the area covered by the 28 stations listed in Table 1 had to be in either the much above or much below normal temperature category (the class including the 10 or 12-1/2% most extreme temperature anomalies on each end of the distribution, depending on the date).

Nearly the entire area was required to be in either the approximately 30% heaviest or lightest precipitation class, with the additional requirement that a substantial number of stations have exceptionally light or heavy monthly totals (generally less than 30 mm or more than 150 mm). November was included along with March and the other three winter months. These selections resulted in samples of similar size comparable to the full lists of 22 snowiest and 18 least snowy months given in Table 2. Each of the composite means was thus made up of approximately 10 to 15% of the total months (November through March) in the 32-year sample.

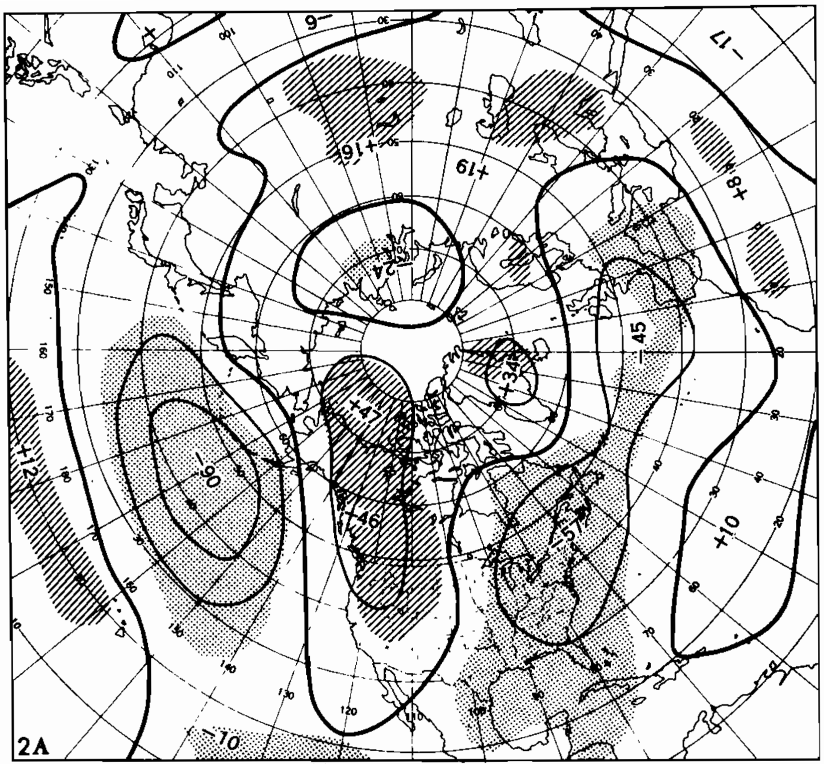
A. Coldest and Warmest Patterns

It can readily be seen (Figs. 2A and 1A) that the 700 mb height anomaly patterns for the coldest and snowiest months are quite similar, and the summary at the bottom of Table 2 shows that 8 of the 22 snowiest months were also among the 16 coldest months relative to normal. The main differences between Figs. 2A and 1A are that the anomalously strong ridge over western Canada is somewhat stronger for the coldest months, and the negative anomaly center on the east coast is displaced from near New York to northern New England. Both changes serve to increase the northerly anomalous flow from Canada into the United States for the coldest months, over that for the snowiest months.

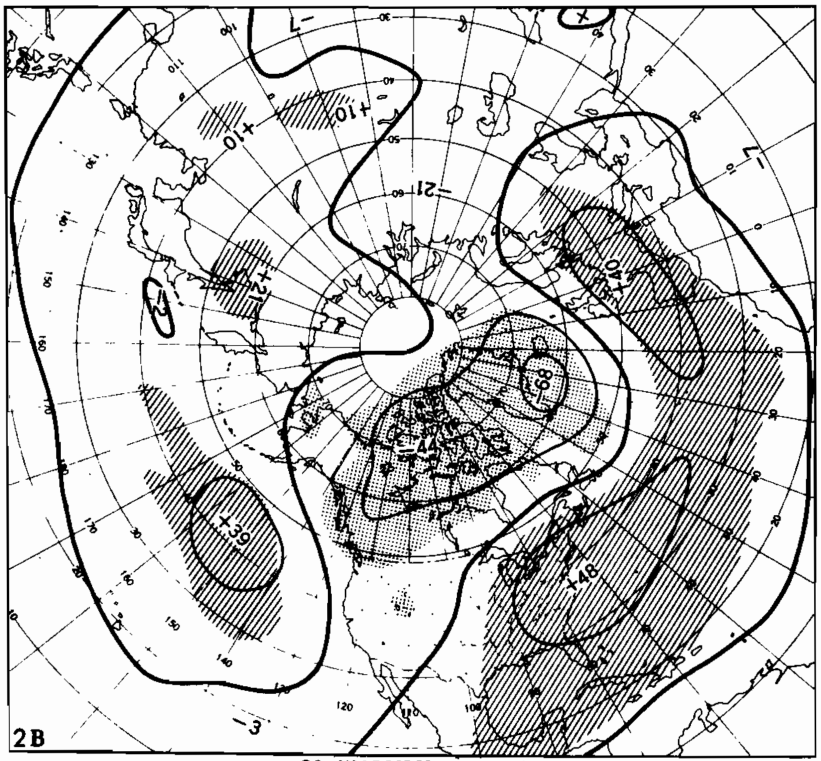
The composite 700 mb anomaly pattern for the 20 warmest winter months was similar to that for the least snowy months (Figs. 2B and 1B) and 7 of the 18 least snowy months were also among the 20 mildest months. The anomaly pattern was stronger and more consistent over North America and the Atlantic for the warm months than for the relatively snow-free months, and generally positive rather than negative height anomalies were the rule over northeastern Siberia and the Bering Sea.

It might thus be construed that much of the variability of monthly mean snowfall over the northeastern United States is related to the temperature variability, in agreement with other recent studies (Dickson and Namias, 1976). The anomaly patterns of Figs. 1 and 2 are also quite similar to those found to be related to a "seesaw" or opposition of winter monthly and seasonal temperature anomalies between Greenland and Northern Europe (van Loon and Rogers, 1978), in the sense that northern Europe has severe or mild winters more or less in phase with the eastern United States, but out of phase with Greenland. It is rather remarkable that the same characteristic anomalous circulation mode is responsible for extremes of weather over such a wide area of the Northern Hemisphere.

The 700 mb anomaly patterns shown in Figs. 1 and 2 are undoubtedly related to changes higher in the troposphere as well. A recent study (Angell and Korshover) related changes in the size and location of the 300 mb circumpolar vortex between 1963 and 1975 to changes in mean temperature over various parts of the Northern Hemisphere, including the United States. During winter, a contracted vortex (as implied by negative 700 mb height anomalies over the Canadian Arctic in Fig. 2B) was significantly correlated with relatively warm temperatures over the United States, and the converse was true for an expanded vortex, or one shifted toward Eurasia, as implied by Fig. 2A.



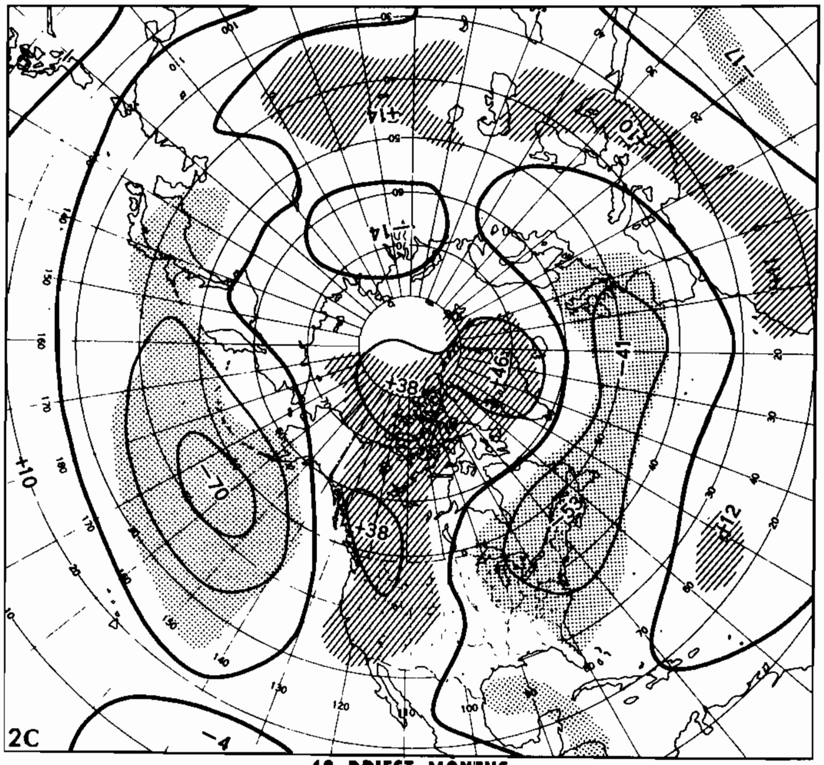
16 COLDEST MONTHS



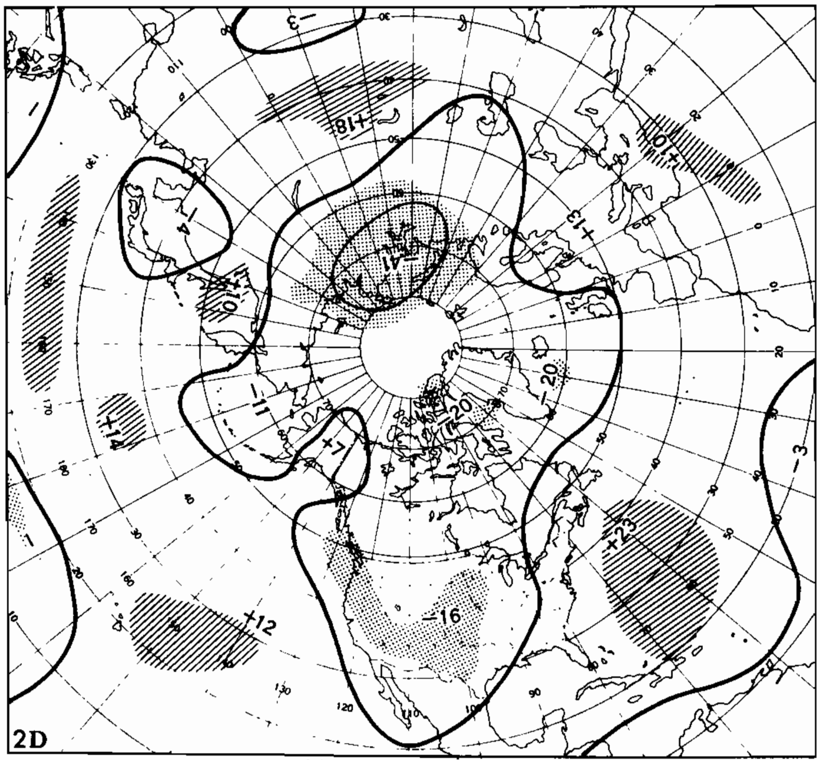
20 WARMEST MONTHS

Figure 2. (A) Composite monthly mean 700 mb height anomaly pattern for the 16 coldest winter months relative to normal from the period of record. Labeling, intervals, and shaded areas are as in Fig. 1.

(B) As in (A) except for the 20 warmest winter months relative to normal from the period of record.



18 DRIEST MONTHS



21 WETTEST MONTHS

Figure 2. (C) As in (A) except for the 18 driest winter months relative to normal from the period of record.

(D) As in (A) except for the 21 wettest winter months relative to normal from the period of record.

B. Driest and Wettest Patterns

Since moisture is required for snowfall, it was considered to be of interest to examine the composite mean 700 mb circulation anomalies associated with the driest and wettest winter months and compare these with the patterns associated with the snowiest and least snowy months. It is immediately obvious that the dry pattern (Fig. 2C) resembles the snowy and cold patterns (Figs. 1A and 2A) with the negative anomaly displaced a little farther northeast to the Gulf of St. Lawrence, while the wet pattern (Fig. 2D) bears a somewhat weaker similarity to the least snowy and mild patterns (Figs. 1B and 2B), with southerly anomalous flow over the Northeast the main feature. This result immediately points up one of the difficulties in predicting snow over the northeastern United States: the type of circulation patterns favorable for bringing in moisture for precipitation also bring milder air, thereby reducing the probability that the precipitation will occur as snow relative to the chances for rain.

This relationship is further illustrated by studies of the correlation between temperature and precipitation over the United States (Madden and Williams, 1978). Although much of the United States has a negative correlation between temperature and precipitation during winter, the largest area having a positive correlation extends from the Tennessee Valley northeastward through the Ohio Valley toward the eastern Great Lakes area and New England. This is just the area where most of the stations used in the current snowfall study are located.

It might be noted that even though the snowy and dry patterns are similar, 4 of the 22 snowiest months were also among the 21 wettest, while only 2 of the snowy months were among the 18 driest (Table 2). Of the least snowy months, only 1 was among the 21 wettest while 3 were among the 18 driest. Although these distinctions are probably not significant, it appears that the snowiest months are not representative of the driest months, even though many of the large-scale circulation anomalies are similar.

An example of the moisture variability occurring within a sample of cold and snowy months can be seen from the fact that January 1978, which ranked first of all the snowiest months, and January 1977, which ranked third, were among the wettest and driest winter months respectively even though both were also among the coldest months (Table 2). These two Januaries were typical of their respective winters, which had widely contrasting precipitation regimes over the whole country (Wagner, 1978). One of the main differences in the circulation was that during the dry winter the strong ridge over western North America extended down to low latitudes, effectively blocking cyclonic impulses approaching the United States from the Pacific. During the wet winter, the southern portion of the ridge was weak, allowing disturbances to cross the southern United States, where they triggered major snowstorms originating near the Gulf or south Atlantic coasts. It is worth noting that the southern portion of the anomalously strong western United States 700 mb ridge is somewhat broader on the driest composite pattern (Fig. 2C) than on the coldest or snowiest patterns (Figs. 1A and 2A), and the negative anomaly area over the subtropical eastern Pacific is weaker also.

As a final note in this section, January 1978, the snowiest month over the northeastern United States in the 32-year period studied in this paper, was the only snowy month to rank simultaneously in both the coldest and wettest groups. The average snowfall over the 28-station network was 750 mm, far above the second-ranked January 1966 with 569 mm and third-ranked January 1977 with 556 mm. The least snowy month, March 1973, had a 28-station average snowfall of only 56 mm.

4. SECULAR VARIATION OF EXTREME WINTER MONTHS

Irregularities in the time distribution of the occurrence of snowy months were obvious from Table 2. Fluctuations in the incidence of least snowy months were also evident, although not quite so marked. Particularly noteworthy were the over 6 year hiatus from December 1951 to February 1958 and the nearly 5 year gap from February 1972 to January 1977 in which there were no months falling into the snowiest category. Such

Table 2. Chronological listing of the 22 snowiest and 18 least snowy cold-season months selected from January 1947 through March 1978. Numbers preceding the month give the rank and the monthly snowfall in mm averaged over the 28 stations listed in Table 1. The lowest ranking number in each column indicates either the snowiest or least snowy month. Letters C, M, W, and D following a month indicate that month was also among the approximately 10% coldest, mildest, wettest, or driest months relative to normal, respectively. The summaries at the bottom of each column show how many of the months fell into the other extreme categories of temperature and precipitation anomalies.

22 Snowiest Months

17	318	Feb 47	
8	394	Jan 48	C
15	330	Dec 51	
7	402	Feb 58	C
22	307	Jan 59	
6	404	Feb 60	W
4	452	Mar 60	C
20	313	Dec 60	
16	328	Feb 62	
13	338	Dec 62	C
11	366	Dec 63	C, D
14	338	Jan 65	
2	569	Jan 66	C
21	313	Dec 66	
9	394	Feb 67	
5	411	Dec 69	W
12	353	Dec 70	
19	315	Mar 71	
10	358	Feb 72	
3	556	Jan 77	C, D
18	318	Dec 77	W
1	750	Jan 78	C, W

8 of 16 coldest
None of 20 mildest
4 of 21 wettest
2 of 18 driest

18 Least Snowy Months

15	119	Mar 48	
11	109	Feb 49	M
13	114	Mar 49	
4	84	Dec 49	
12	112	Jan 50	M
18	125	Mar 52	
14	114	Feb 53	
5	84	Mar 53	W
7	94	Dec 53	
2	66	Feb 57	M
8	99	Mar 57	D
17	122	Mar 61	
3	74	Dec 65	M, D
6	89	Mar 66	D
9	102	Dec 71	M
16	119	Jan 73	
1	56	Mar 73	M
10	107	Feb 76	M

None of 16 coldest
7 of 20 mildest
1 of 21 wettest
3 of 18 driest

secular changes in snowfall and temperature have already been studied for earlier periods (Namias, 1960a and 1970).

As an aid to concisely displaying the variability of different elements of the winter climate over the northeastern United States during the period January 1947 through March 1978, a bar graph was constructed showing the number of winter months from each of the past 32 seasons falling into any of the extremes of temperature, precipitation, or snowfall. The results, shown in Fig. 3, clearly show the predominance of relatively snow-free mild and wet months in the late 40's and first half of the 50's, followed by a 10-year period from 1957-58 through 1966-67 during which every season had at least one notably snowy month, with frequent cold and wet months as well. During the late 1960's there were more dry months, although occasional cold and/or snowy months occurred. A short period of predominantly mild, wet, and relatively snow-free months intervened in the early and middle 1970's, followed by a sudden change to cold and snowy winter weather beginning with the 1976-77 season. The sharp contrast between the predominantly dry winter of 1976-77 and the unusually wet winter of 1977-78 also shows clearly. The relatively large total number of months falling into various extreme categories during the last few seasons is undoubtedly related to a popular opinion that the climate has recently become more variable and less "favorable" with more harmful extremes.

5. SOME 700 MB COMPOSITE HEIGHT ANOMALY MAPS RELATED TO REGIONAL SNOWFALL

Although space limitations preclude examination of all the subtle and probably often insignificant variations in 700 mb height anomaly related to snowfall in some of the smallest regional groupings of stations shown in Table 1, a few of the more interesting patterns will be discussed in this section. The 14 snowiest months over the Atlantic area (Fig. 4A) have a somewhat weaker but qualitatively similar pattern to the overall composite (Fig. 1A). The stronger positive anomaly over northeastern Canada suggests that stalling or relatively slow movement of storms is a relatively more important factor for heavy snowfall in this area. The pattern for the 14 least snowy months (Fig. 4B) is again similar to the overall pattern(Fig. 1B) but somewhat weaker overall. The difference patterns are also similar and weaker in the case of the regional composite (Figs. 1C and 4C).

The composite for the 17 snowiest months in the Southern area (Fig. 5A) was again qualitatively similar to the other snowy patterns. Surprisingly, the negative anomaly center was farther north along the Atlantic coast for this composite than for the Atlantic area (Fig. 4A). Perhaps this is indicative that a relatively greater percentage of heavy snow situations over the Northeast are related to blocking, while storms are rarely blocked in the South during the winter. The somewhat stronger positive anomaly over British Columbia and the Pacific Northwest suggests that the southward movement of cold air from Canada into the South is more crucial for snow in this area. Also, the 70% or greater consistently negative height anomalies southwest of Baja California suggest that low latitude impulses originating in the subtropical eastern Pacific may be important for snow over the Southern area.

The pattern for the 21 least snowy months (Fig. 5B) was again qualitatively similar to the others (Figs. 1B and 4B), although rather weak and with few areas having 70% or better agreement of individual monthly anomaly sign with the mean. Perhaps this is related to the fact that all the months in the Southern area's least snowy class had zero or trace monthly total snowfall, so there was no way to select really extreme cases of light snowfall since the normal monthly average over this area is also quite small, even in the midwinter. The anomaly difference pattern (Fig. 5C) is again similar to the others (Figs. 1C and 4C).

The composite 700 mb height anomaly patterns for the snowiest months in two sub-groups of stations in the Midwest area are included because of what is believed to be a significant difference in their principal snow-producing mechanisms shown by the two patterns. There was no significant difference between the least snowy patterns (not shown), which were both similar to the others (Figs. 1B, 4B and 5B).

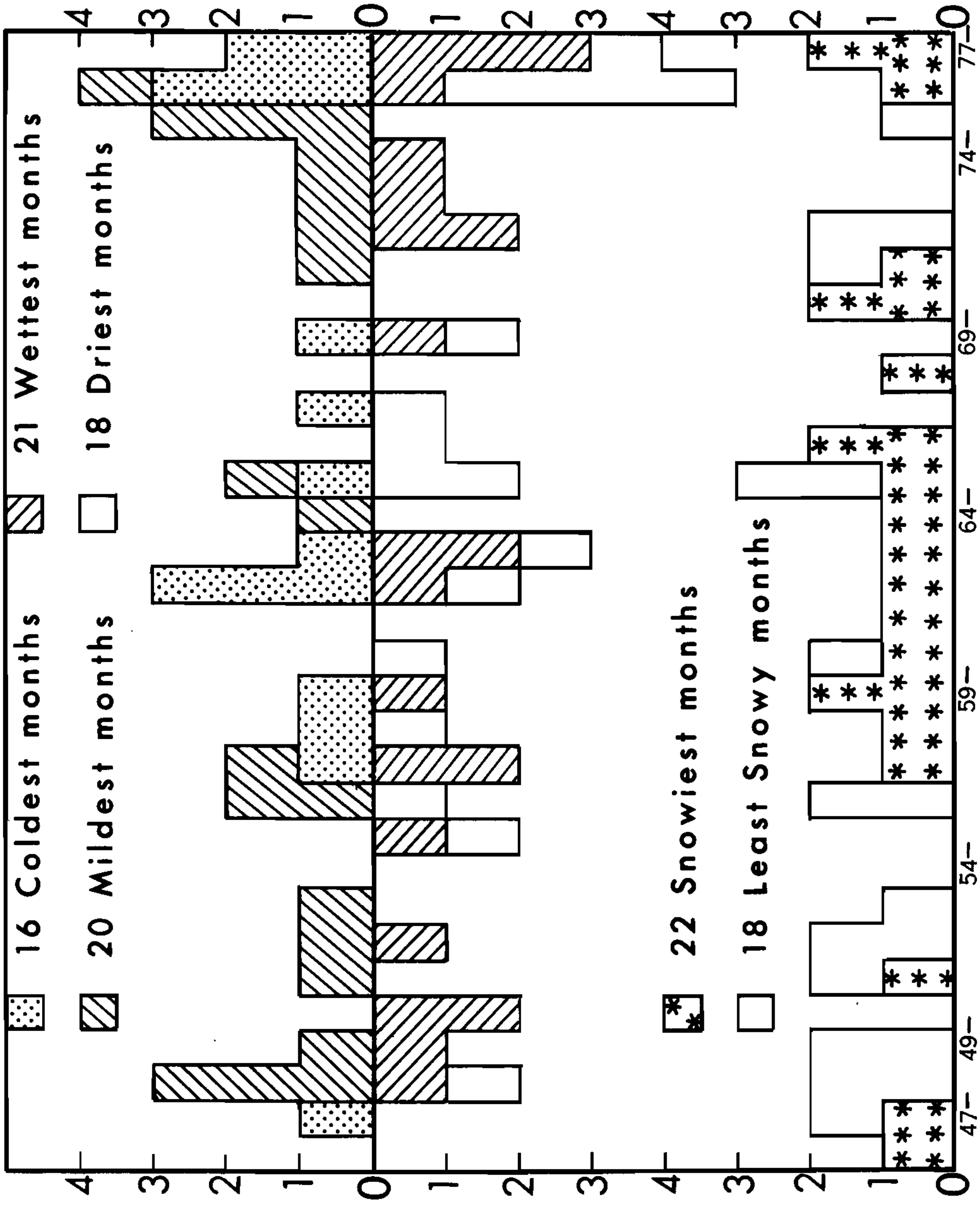
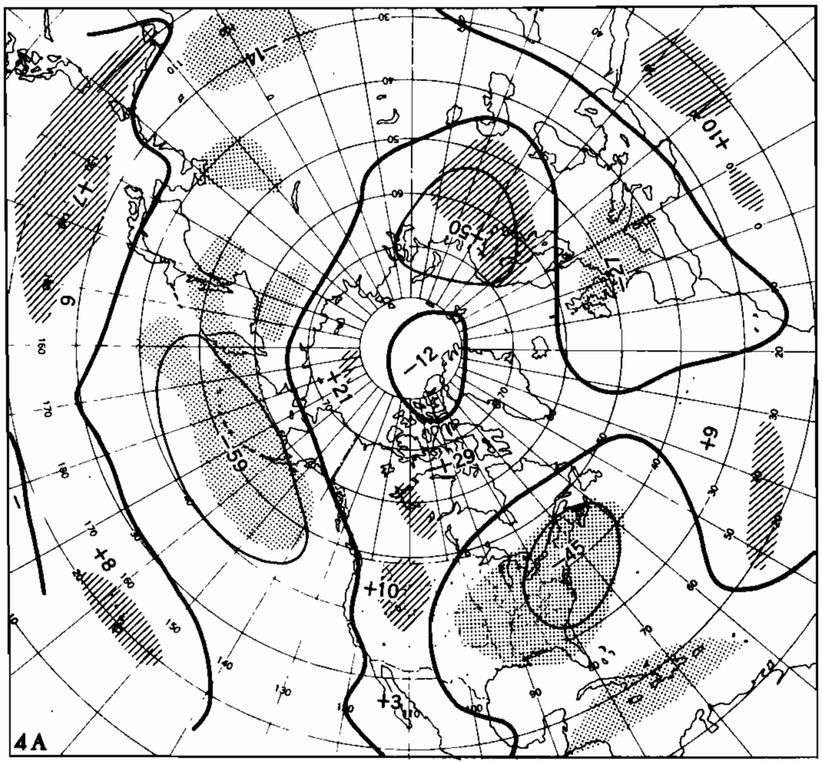
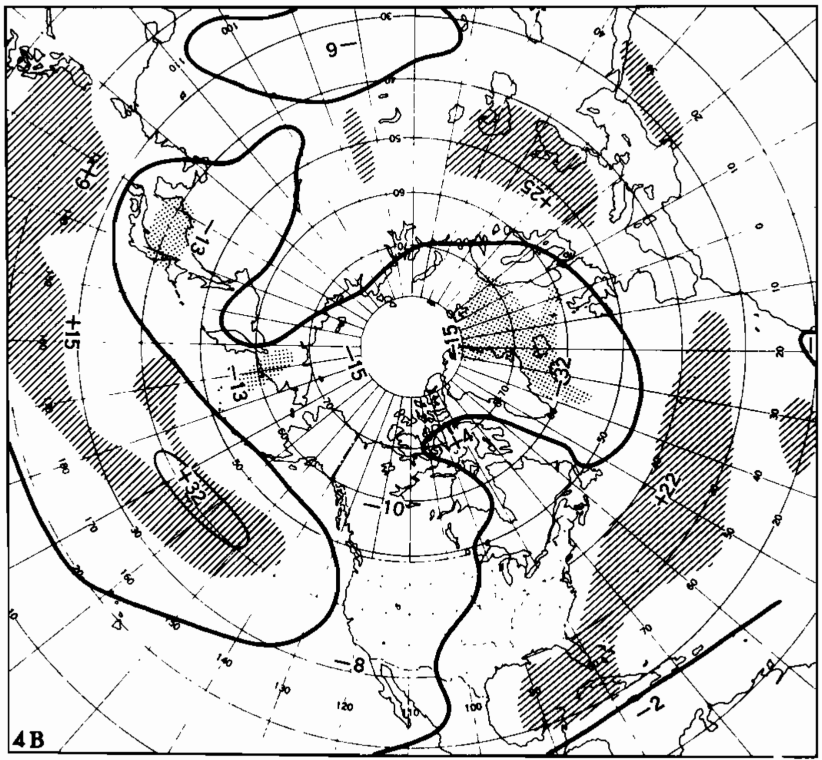


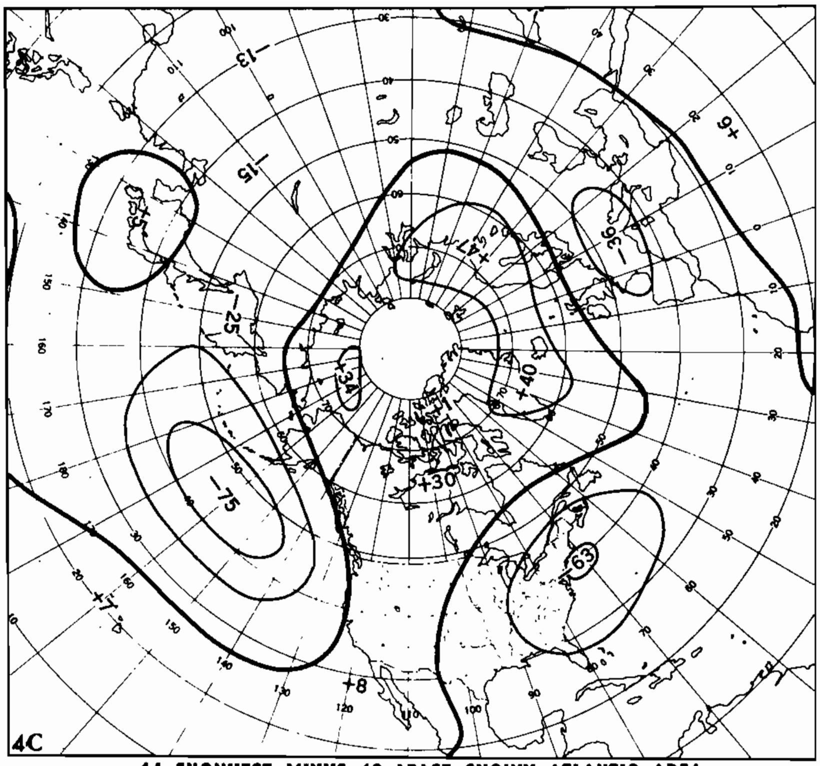
Figure 3. Bar graph displaying the number of months in each winter season having extremes of temperature and precipitation (upper portion) and snowfall (lower portion) over the northeastern United States. A given month in a particular season could fall into more than one extreme category, as shown in Table 2. Selection of months for the upper portion includes November, while the bottom portion is taken from December through March only.



14 SNOWIEST ATLANTIC AREA



12 LEAST SNOWY ATLANTIC AREA

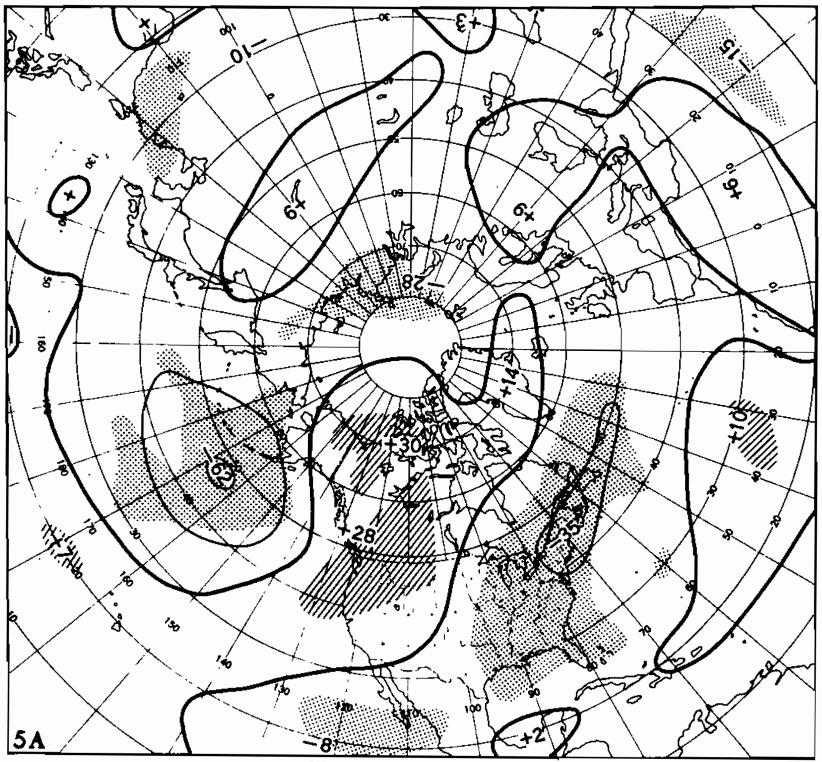


14 SNOWIEST MINUS 12 LEAST SNOWY ATLANTIC AREA

Figure 4. (A) As in Fig. 1 (A), except for the 14 snowiest winter months at stations in the Atlantic area.

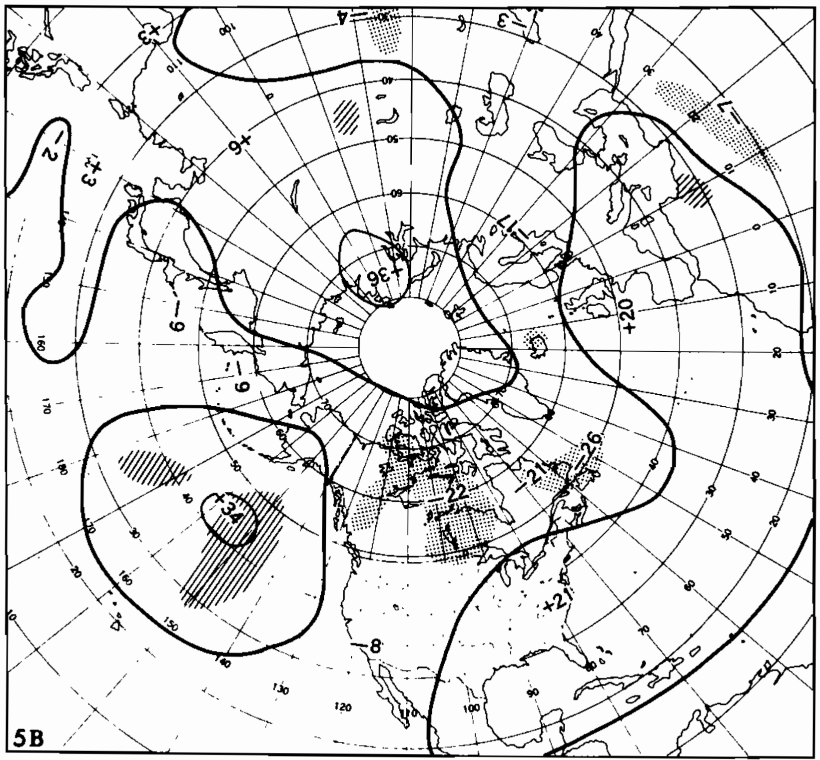
(B) As in Fig. 1 (B), except for the 12 least snowy winter months at stations in the Atlantic area.

(C) As in Fig. 1 (C), except for stations in the Atlantic area.



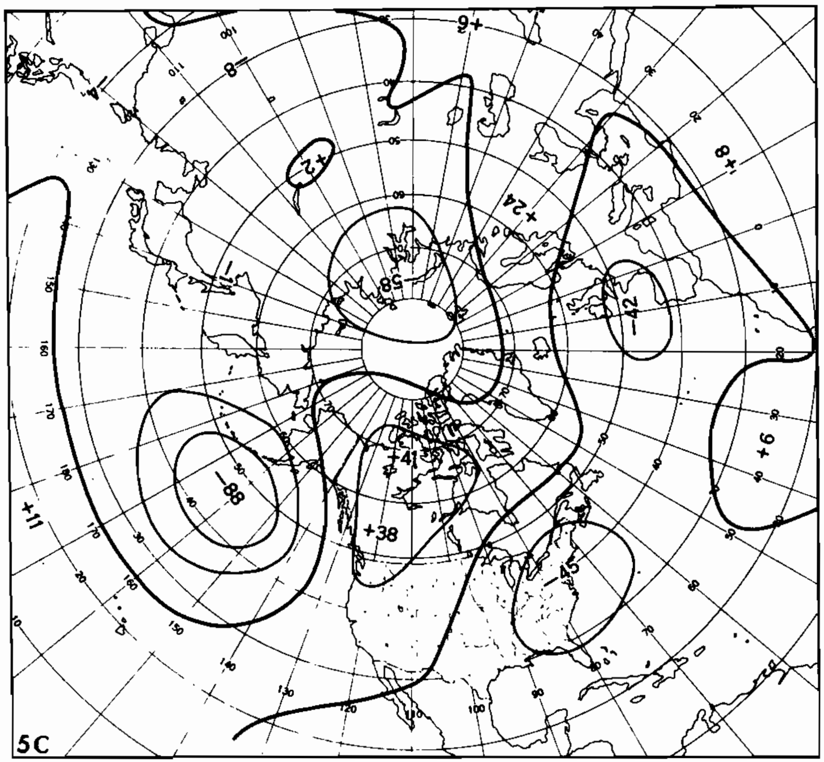
5A

17 SNOWIEST SOUTHERN AREA



5B

21 LEAST SNOWY SOUTHERN AREA

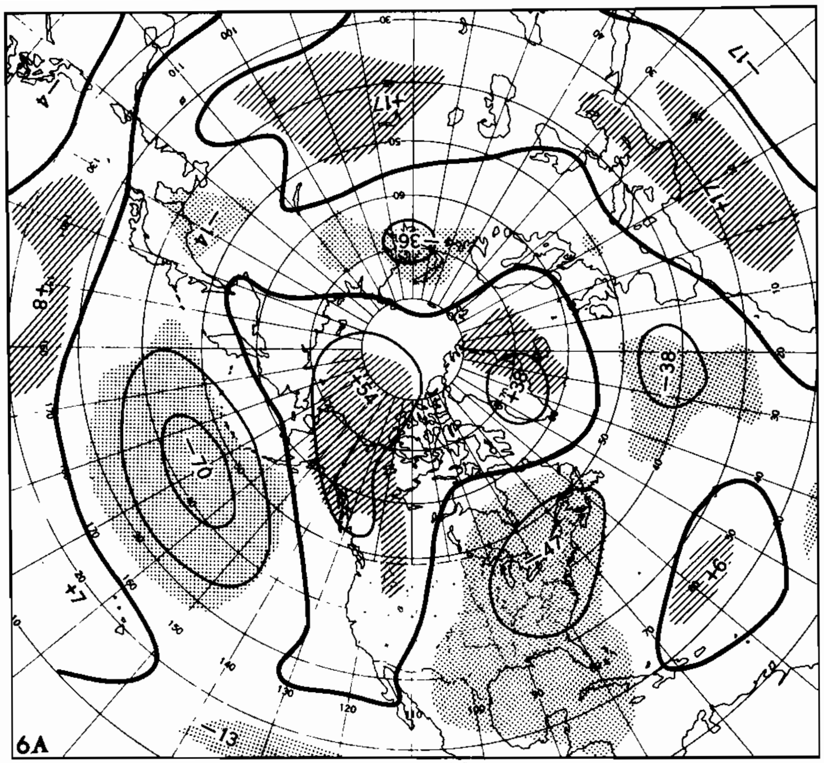


17 SNOWIEST MINUS 21 LEAST SNOWY SOUTHERN AREA

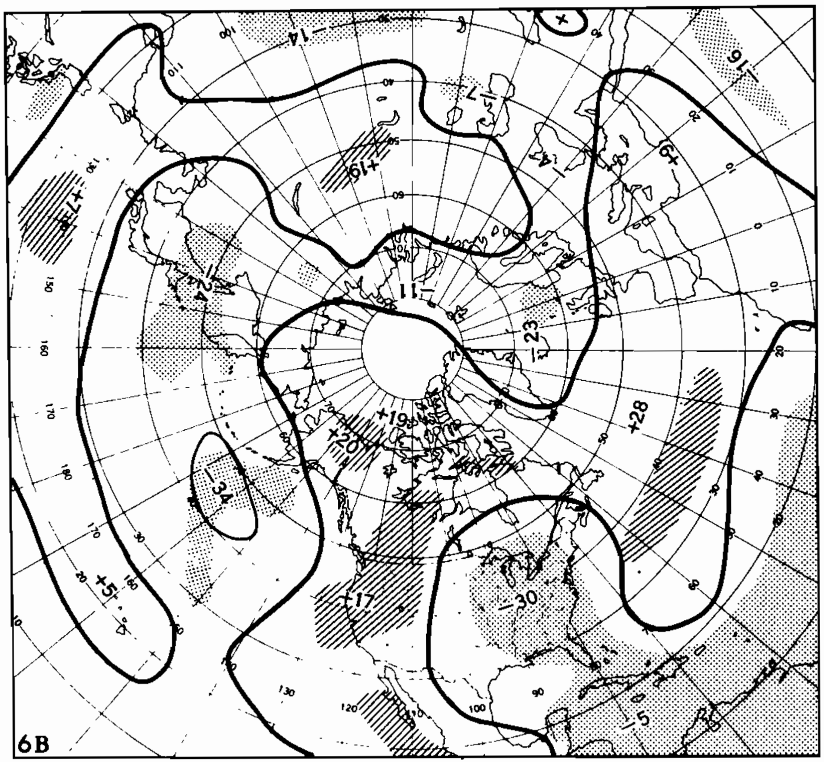
Figure 5. (A) As in Fig. 1 (A), except for the 17 snowiest winter months at stations in the Southern area.

(B) As in Fig. 1 (B), except for the 21 least snowy winter months at stations in the Southern area.

(C) As in Fig. 1 (C), except for stations in the Southern area.



14 SNOWIEST LOWER LAKES



14 SNOWIEST UPPER OHIO VALLEY

Figure 6. (A) As in Fig. 1 (A), except for the 14 snowiest winter months at stations in the Lower Lakes area. Although including two stations from the upper Lakes area, these cities generally have substantial or frequent Lake-effect snows.

(B) As in Fig. 1 (A), except for the 14 snowiest winter months at stations in the Upper Ohio Valley area. Although including two stations on the Great Lakes, these cities generally have relatively weak or infrequent Lake-effect snows.

The pattern for the 14 snowiest months (Fig. 6A) at Lower Lakes stations (considered to have the most pronounced Lake-effect snows) resembles the overall composite for the coldest months (Fig. 1A). The concurrent close juxtaposition of the negative anomaly center over Lake Ontario agrees with the results of many other studies, too numerous to reference here, that a plentiful supply of Arctic air and local cyclonic curvature in the lower troposphere are the principal ingredients for heavy snow squalls over the Great Lakes lee shores.

The pattern for the 14 snowiest months over the neighboring upper Ohio Valley stations (Fig. 6B) where Lake-effect snows are a relatively less important factor in winter snowfall, suggests that stalling and slow movement of lows, perhaps associated with deepening of 700 mb troughs in the Midwest, is the principal factor in heavy snow there. The composite pattern over the Atlantic is quite different from the other heavy snow patterns, and the Pacific and Arctic anomalies are much weaker and less consistent.

6. SUMMARY OF PRINCIPAL RESULTS

The occurrence of heavy monthly snowfall over the eastern United States appears to be related to a relatively important and large-scale mode of variation in Northern Hemisphere circulation during winter or cold-season months.

This circulation mode is also strongly correlated with the variation of temperature over the eastern United States, and monthly mean temperature anomaly at the ground or lower troposphere is probably the most important climatological variable related to the occurrence of heavy snow in the area investigated.

There is little qualitative difference in the composite anomaly patterns related to snowfall for smaller regional groupings of stations. The relatively small quantitative differences that occur are synoptically and climatologically consistent with shifts in prevailing storm tracks or the relative importance of cold air or moisture in each subregion.

The consistent and large-scale nature of the composite patterns, considered in relation to numerous other studies cited in the references, suggests that after further research, moderately reliable statements of the risk of heavy winter snowfall over the eastern United States as a whole at monthly or seasonal ranges may eventually be possible. It would likely not be possible to distinguish between smaller subregions, such as New England, the Appalachians, or the Midwest in such projections, however.

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