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A CLIMATOLOGICAL ANALYSIS OF WINTER PRECIPITATION EVENTS AT GREENVILLE-SPARTANBURG SC

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1. INTRODUCTION

Winter precipitation events are usually very complex in the foothills of the Carolinas. Winter storms are always a challenge for the operational forecaster, especially those new to the area and those with limited experience in forecasting in the lee of the Appalachians. Several studies (e.g. Keeter et al. 1995; Keeter and Cline 1991; Keeter, Cline, and Green 1989; and, Keeter and Green 1981) discussed valuable techniques for forecasting predominant precipitation type (p-type) in North Carolina. Many of those findings can also be applied to similar climatological regimes in South Carolina. This short paper is designed to address the characteristics of winter precipitation in the Upstate of South Carolina and to document what is climatologically normal for this region.

2. APPROACH

The present study began with an analysis of all winter weather events that occurred in the Greenville-Spartanburg, SC area over a 40-year period (January 1960-December 1999). Precipitation type, predominant precipitation type, precipitation amount, and the duration of precipitation were logged for each event. A review of the synoptic scale weather patterns was also conducted to relate heavy frozen (sleet and/or snow) precipitation events to a particular pattern. The goal was to develop climatic frequencies of common and rare winter precipitation events.

A winter precipitation event is defined by any occurrence of sleet, freezing rain, or measurable snowfall. Variable precipitation types did not necessarily have to fall at the same time. As long as a particular type was observed during the event, that type was counted as a part of the event. For the purposes of this paper, when discussing heavy snow and snow advisory events, 3.5 inches or more qualifies as heavy snow (rounded up to 4 inches) and 1.5 inches to 3.4 inches qualifies as the criteria for a snow advisory (National Weather Service 1996).

3. DATA

Surface observations from Greenville Downtown Municipal Airport (GMU) were utilized for the period of January 1960 to September 1962, before the official record keeping station was moved approximately 8 miles east to the Greenville-Spartanburg International Airport (GSP). Surface observations from GSP were used from October 1962 to December 1999. The surface observations and daily summaries for GSP were found by using a combination of locally archived hourly Surface Airway Observations (SAO) and METARs, and Local Climatological Data (LCDs) produced by the National Climatic Data Center (NCDC). Hourly surface observations and daily summaries for GMU were provided by NCDC as well. Gridded NMC Analyses (Jenne 1975) fields were extracted, plotted, and smoothed in order to study synoptic scale patterns which resulted in heavy snow events at GMU and GSP.

4. RESULTS

A total of 183 cases qualified as a winter precipitation event, stretching from November through April. As one might expect, January had the greatest number (70) (Fig. 1). A forecaster can assume with a high degree of certainty that any given winter weather event at GSP will consist of more than one p-type. Of the 183 cases, 158 (86%) were a combination of two or more p-types (Fig. 2). Only 25 cases (14%) consisted of entirely one type. Eighteen of those 25 cases were all snow. As would be expected near the latitude of GSP, the most frequent wintry mix event was rain, freezing rain and sleet (Fig. 2) which occurred most often in the months of December and January. The most frequent wintry mix in February was rain, sleet, and snow. Thirty-three cases were all frozen (snow and/or sleet), with 23 of those (70%) occurring during January and February. A mix of rain and freezing rain occurred on the most days (36), followed by all snow (34) (Fig. 3).

a. November

It is rare to experience measurable winter precipitation during the month of November. Freezing rain was never observed over the period of this analysis. This seems logical since seasonal patterns do not favor an extremely cold, shallow air mass as far south as South Carolina this time of year. There were a total of five winter p-type cases during this 40 year period. One was all sleet, two were a rain/sleet mixture, one was a rain/snow mixture and one was a mixture of rain, sleet, and snow (Fig. 4). All accumulations resulting from these events were one half inch, or less, except for 1.9 inches of snow which fell on the 11th in 1968 (Fig. 5).

b. December

December is a rather interesting month, with measurable snowfall occurring in only 8 of the 40 years of this study. There was an 18-year period between 1971 and 1989 when snow was not observed at the GSP Airport during December (Fig. 6). There were a total of 35 winter p-type cases from 1960 to 1999 of which 30 (86 %) involved some sort of mix (Fig. 7). Five events were all frozen, with four of those all snow. Events which were comprised of a mixture of rain, freezing rain, and sleet occurred 10 times, the most of any mixture. Eleven cases resulted in measurable snowfall. Heavy snow (4 or more inches) occurred only once; 11.4 inches on the 3rd in 1971. Advisory criteria were reached only three times. Six of the 11 snowfall cases measured less then one inch (Fig. 8).

c. January

January ranks first in terms of number of winter p-type events (70) and number of all frozen events (16). Sixty-one of the 70 events (87%) involved a mixture, of which rain and freezing rain or rain, freezing rain, and sleet events totaled 20 (Fig. 9). January was the only month to have exclusively freezing rain events (3).

Measurable January snowfall cases totaled 42, the most of any month (Fig. 10). Twelve of these cases (29%) satisfied heavy snow criteria and seven others reached advisory criteria (Fig. 11). Four events resulted in snowfall totals greater than six inches with the maximum of 12 inches occurring on the 7th in 1988. Only one event reaching heavy snow criteria was an "all snow" event.

d. February

As one might expect, February had the second highest number of winter p-type events (51) (Fig. 1). Forty-two of 51 events (82%) involved a mixture, with a mixture of rain, sleet and snow being the most frequent. Ten events were all frozen. Although January experienced the greatest number of wintry events, February had the most "all snow" events (7) (Fig. 12). Additionally, February had the most years with measurable snowfall for the month (26) (Fig. 13), followed by January with 24 cases (Fig. 14).

February also ran a close second to January regarding the total number of measurable snowfall events (36) (Fig. 10). Six of these events qualified as heavy snow and eight satisfied advisory criteria. Only one event was greater than six inches (8.2 inches on the 18th in 1979) and only one *heavy* snow event was characterized as an "all snow" event (Fig.15).

e. March

The month of March had a total of 20 measurable winter p-type events during the 40-year period, of which 19 involved a mix (Fig. 16). Three of these events were frozen (snow/sleet mixture). The most frequent mixtures however, were rain and sleet; rain, sleet and snow; and freezing rain, sleet, and snow (four each). An interesting note about March involves the measurable snowfall cases (15). Twelve of the 15 cases satisfied advisory (6) or warning criteria (6) (Fig. 17). Four of the heavy snow events were greater than or equal to 6 inches with the maximum (9.8 inches) occurring in 1993 during the "Storm of the Century" on the 12-13th. Heavy snowfalls in March appear to occur about every 10 to 12 years (Fig. 18). The only all snow event occurred on the 11th in 1960 and totaled 6.0 inches. March had the highest percentage of heavy snowfall events per month (40%) (Fig. 17).

f. April

It is very rare to have winter p-type events in April. There were only two events (both rain and snow mixtures) that occurred during the period of this study. Both events resulted in snowfall amounts of less than one half inch.

g. Addtional Comments

In order to illustrate the *infrequency* of winter precipitation at GSP, we will examine the daily numbers. There were 7250 days (November-April 1960-1999) on which winter p-type was considered. Of those 7250 days, snow was reported on 128 days (1.8% of the time), sleet was reported on 152 days (2.1% of the time) and freezing rain was reported on 128 days (1.8% of the time).

The mean recurrence interval (MRI) of a particular amount of snowfall can be calculated by dividing the years of record by the number of events. For example: the study at GSP covers a 40-year period. Snowfall greater than 4 inches occurred 19 times in those 40 years (Fig. 19). Simple division yields a MRI of 2.1 years. Schaeffer (1984) states that the MRI is the reciprocal of the probability that an event will occur in a given time span. Therefore, the annual probability that a greater than 4 inches snowfall event will occur at GSP is 48% (see Table 1).

Table 1. Annual Probability of Snowfall Events at GSP

Snowfall Amount (inches)	MRI (years)	Annual Probability (%)
Any measurable	0.4	~100
>1	0.7	~100
>2	1.1	90
>3	1.4	73
>4	2.1	48
>6	4.4	23
>8	6.7	15
>10	13.3	8

Almost all of the top ten snowfall events at GSP (5.9 inches or greater) had common meteorological patterns: 1) A single surface low track from the northern Gulf of Mexico, northeast to the North Carolina coast (Miller Type A) (Miller 1946), 2) An 850 mb baroclinic zone either across the Carolinas or to the south, 3a) A split 500 mb flow with a short wave trough moving east from the south-central U.S. in an initially zonal flow, and confluence over New England, or 3b) A high amplitude 500 mb long wave trough across the eastern third of the U.S.

Deep cold air was supplied to the area in most of these events by very strong arctic high pressure systems (>1032 mb) that were centered anywhere from the Great Lakes to the Mid-Atlantic coast. Several heavy frozen events were the result of prolonged isentropic lift, which was present in an otherwise benign-looking synoptic pattern (i.e., no well-defined short wave troughs). An example of a benign-looking synoptic pattern producing heavy snow at GSP occurred on January 7, 1988. On this date, GSP received its greatest single storm snowfall of the 40-year study (12 inches of snow and some sleet). Figure 22 shows only a minor ripple moving east at 500 mb at 1200 UTC on the 7th. However, Figure 21 shows an 850 mb pattern that would support substantial warm air advection/isentropic lift over GSP. Also, note the strongest part of the 850 mb baroclinic zone positioned just south of GSP. Figure 20 shows very cold air was supplied and held in place across the Upstate of South Carolina by 1040 mb high pressure centered over Maryland. A surface low did develop in the northern Gulf of Mexico during the day on the 7th, but remained well south, crossing the panhandle of Florida around 00Z on the 8th. The low turned to the northeast once it moved into the Atlantic Ocean in a typical Miller Type A track, but was well east of the immediate coast. In any event, accumulating snow was over by 0300 UTC on the 8th at GSP as the isentropic lift moved east.

5. CONCLUSIONS

If winter weather is anticipated, climatology heavily favors mixed winter precipitation events in the GSP area. This makes the performance of the forecaster all that more important. Between 80 and 90% of all cases each month result in mixed events (Fig. 23). Measurable snowfall events were most likely in January and February. If measurable snowfall is expected, climatology would suggest that there is a high likelihood of the snowfall reaching advisory or warning criteria. Overall, slightly less than one quarter of all snowfall events satisfied warning criteria (25 of 109; 23%), with 12 of those occurring in January. However, February had the most "exclusively snow" events.

Annual probabilities of particular single storm snowfall amounts occurring in a given year can be calculated from the mean recurrence interval. There is around a 100 percent chance that the GSP area will have a winter storm produce a snowfall of less than 1 inch in any given year. The annual probability drops to just less than 50 percent (MRI of 2.1 years) for a snowfall of greater than 4 inches. On average, a snowfall of greater than 10 inches can be expected every 13.3 years, but with an annual probability of only 8%. In summation, for any given year, there is a very high likelihood (90% chance) of receiving a snowfall of greater than 2 inches, but only a 50/50 chance of receiving a snowfall of greater than 4 inches.

It is apparent, and perhaps inherently obvious, that in order for the GSP region to receive heavy snow, a source of deep cold air and a strong or prolonged lifting mechanism must be present. The lifting mechanism can be in the form of a short or long wave trough, or isentropic lift. Although rapid cyclogenesis spurred by approaching short wave energy often gives birth to "mega" storms which steal much attention. Nontheless, the more passively developing isentropic flow over a deep and cold air mass can also lead to significant snowfalls, as evidenced by the largest single storm snowfall at GSP in this 40-year study.

6. ACKNOWLEDGMENTS

The author would like to thank Laurence Lee, SOO, WFO GSP for his untiring and patient supply of ideas, guidance and support throughout the evolution of this study. Dr. Joseph Pelissier, MIC, WFO GSP offered helpful insight into the calculation and definition of the mean recurrence interval.

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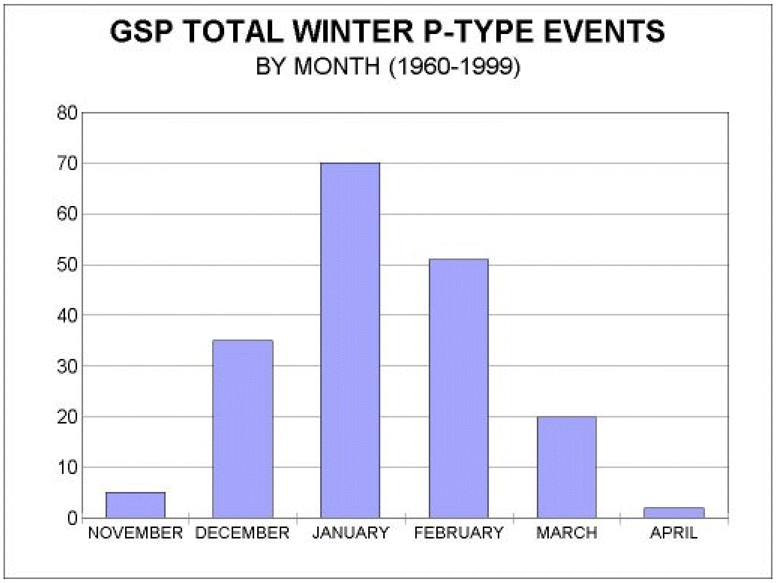

Figure 1. GSP total winter p-type events by month for the 40-year period.

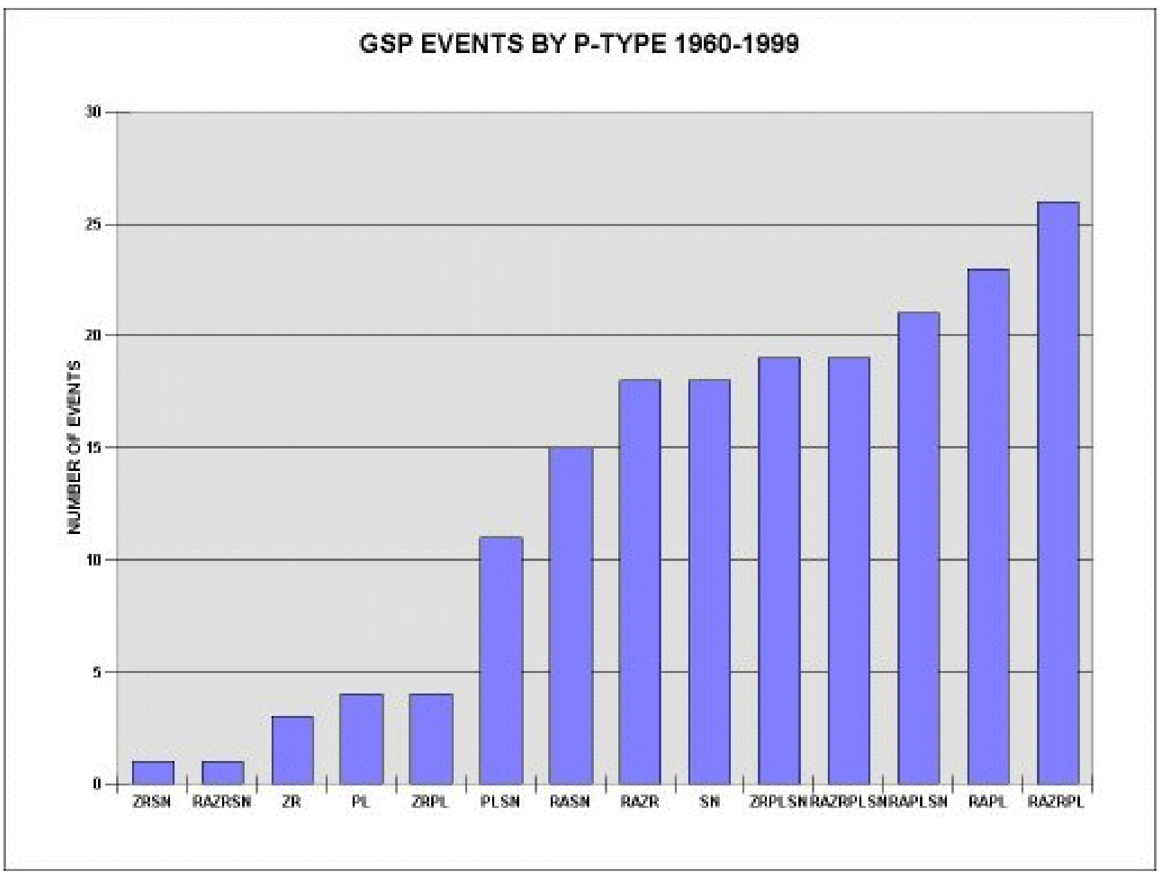

Figure 2. Number of events containing the specific combinations of p-type(s) for the 40-year period. See appendix A for acronym definitions.

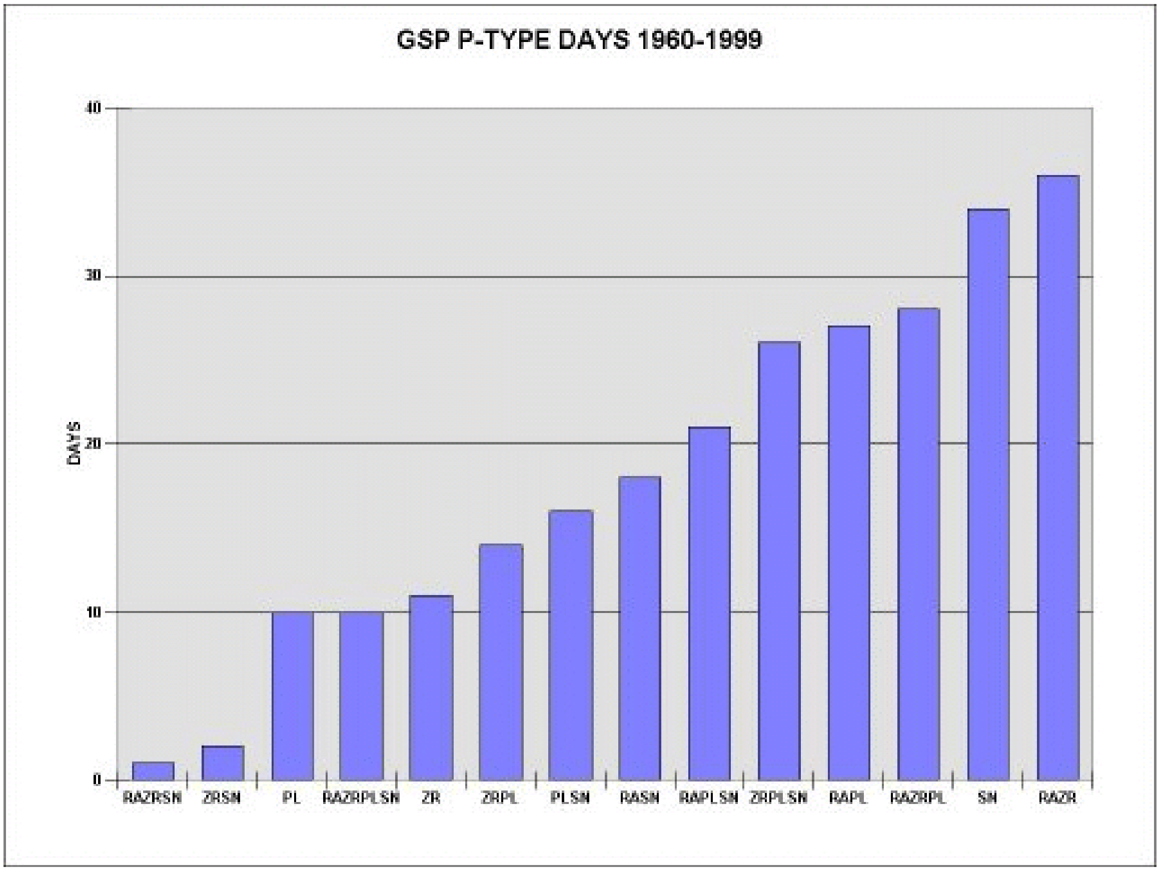

Figure 3. Number of days containing the specific combinations of p-type(s) for the 40-year period. See appendix A for acronym definitions.

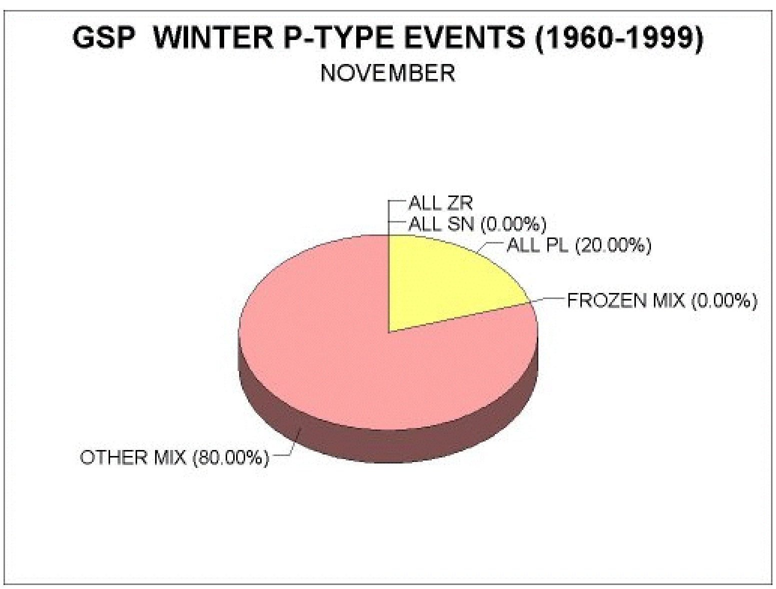

Figure 4. November p-type events at GSP shown by percentage.

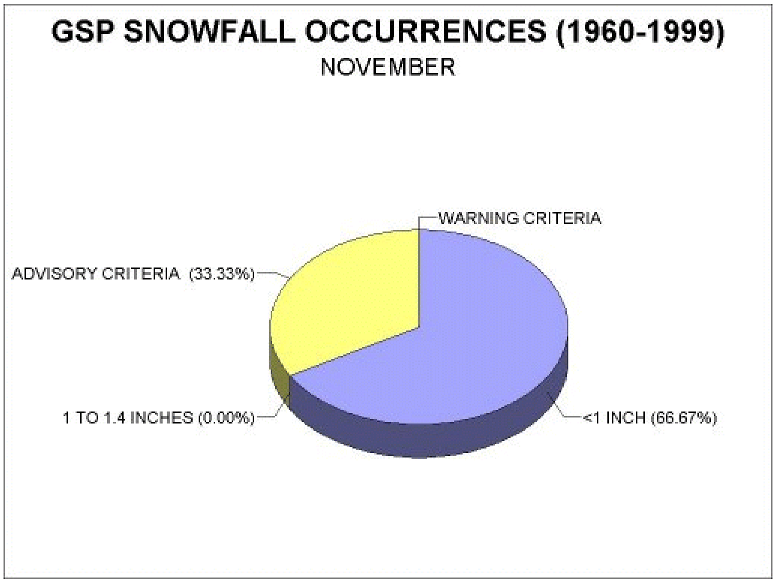

Figure 5. November snowfall occurrences shown by percentage. Advisory criteria is 2 to 3 inches. Warning criteria is 4 inches, or greater.

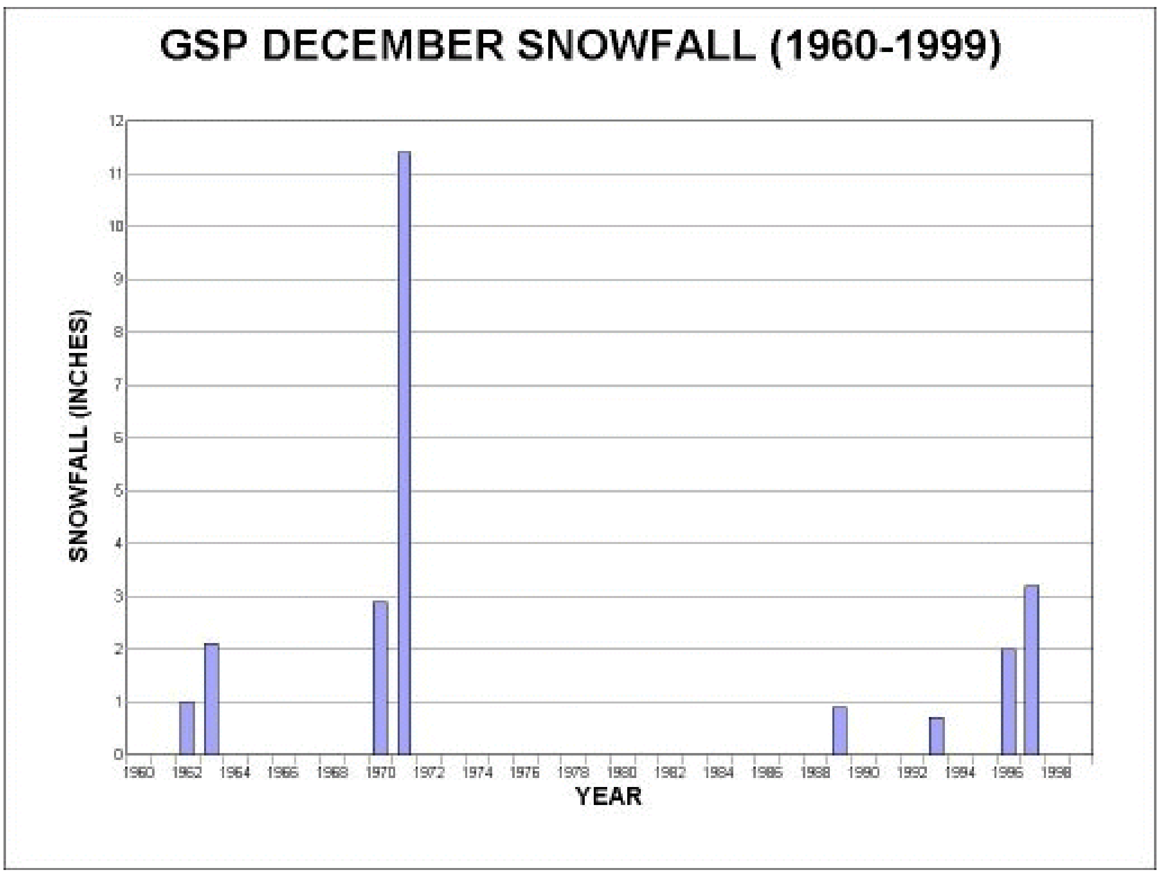

Figure 6. Total December snowfall each year.

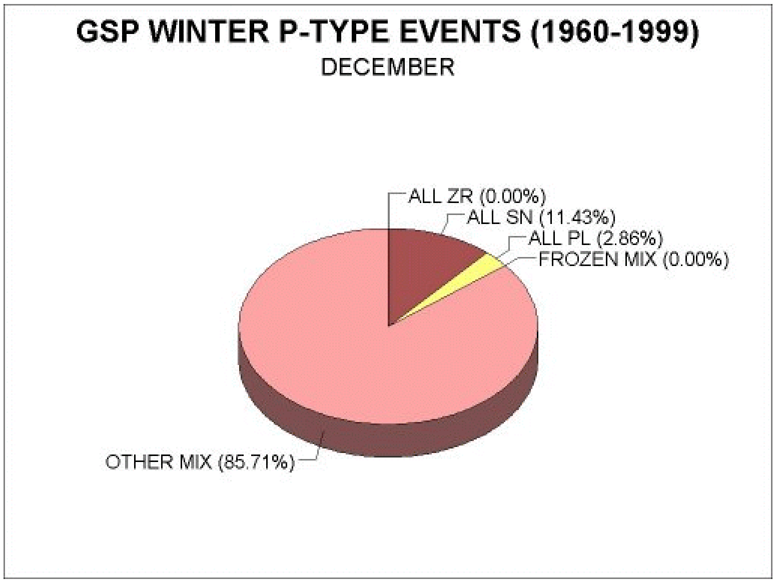

Figure 7. December p-type events at GSP shown by percentage.

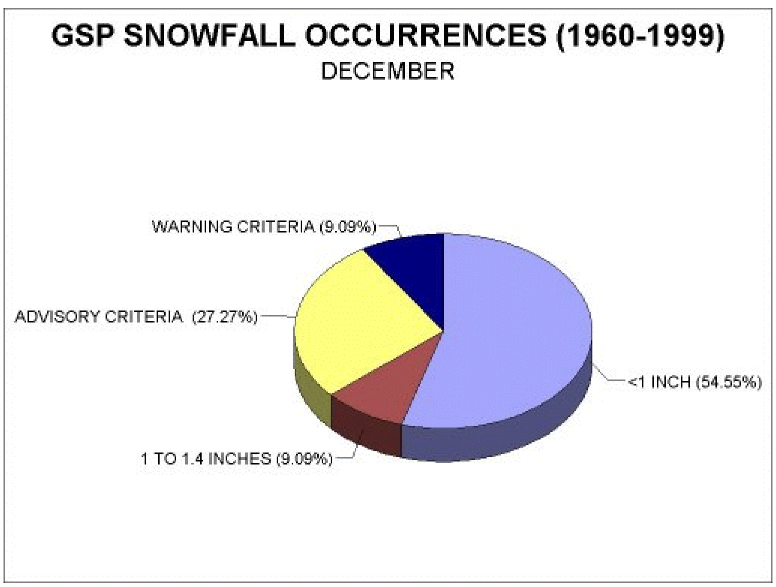

Figure 8. December snowfall occurrences shown by percentage. Advisory criteria is 2 to 3 inches. Warning criteria is 4 inches, or greater.

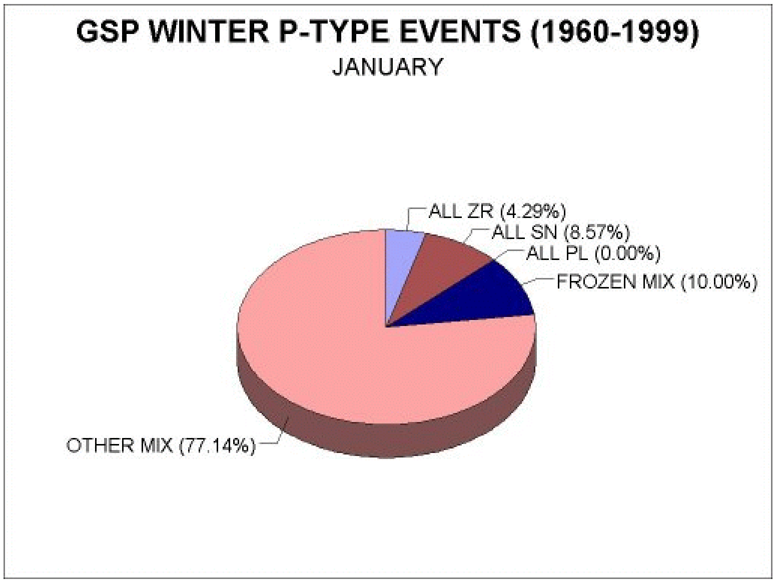

Figure 9. January p-type events at GSP shown by percentage.

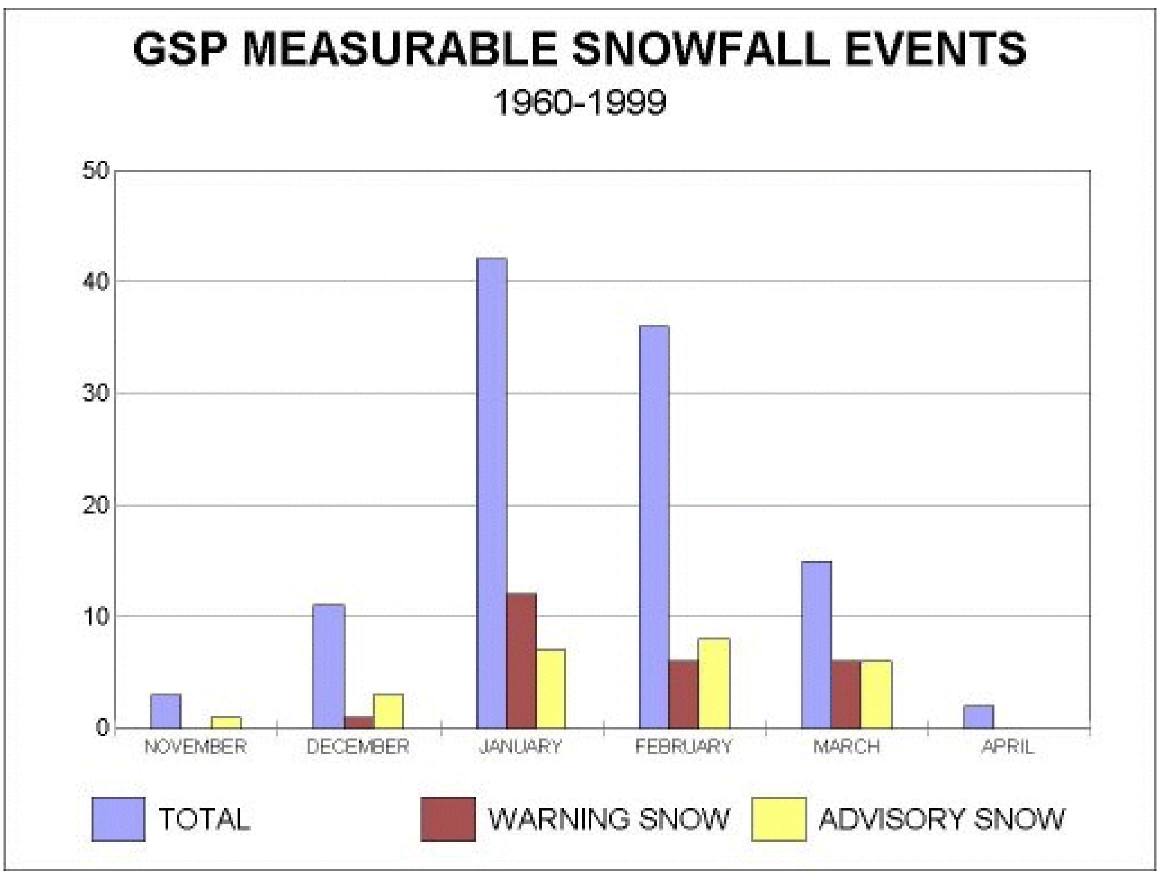

Figure 10. Number of snowfall events by category at GSP. Warning events are those of 4 inches, or greater, and advisory events are those of 2 to 3 inches.

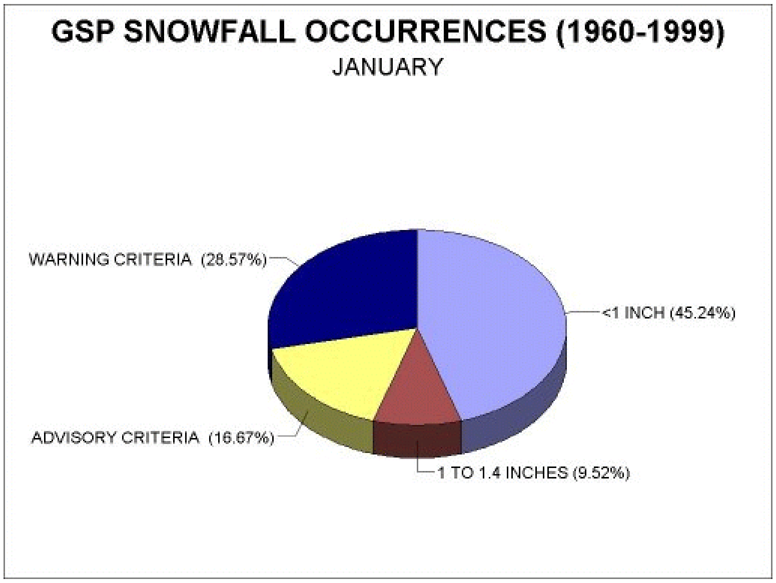

Figure 11. January snowfall occurrences shown by percentage. Advisory criteria is 2 to 3 inches. Warning criteria is 4 inches, or greater.

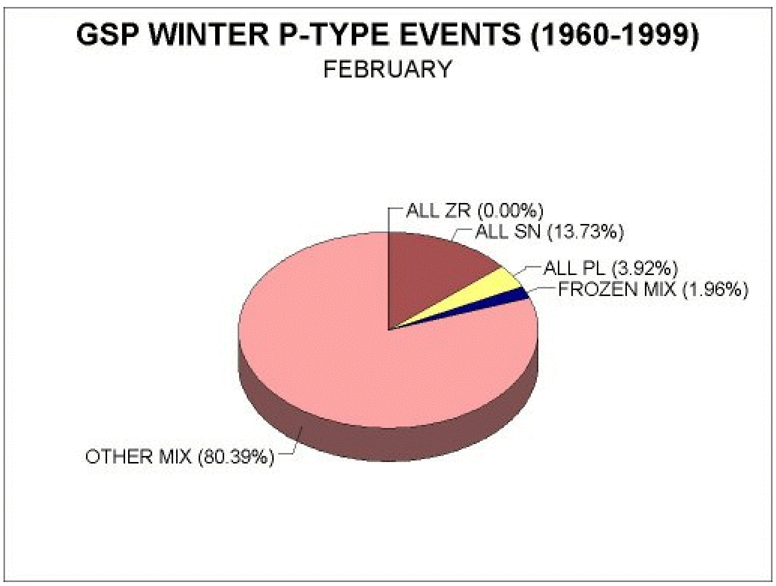

Figure 12. February p-type events at GSP shown by percentage.

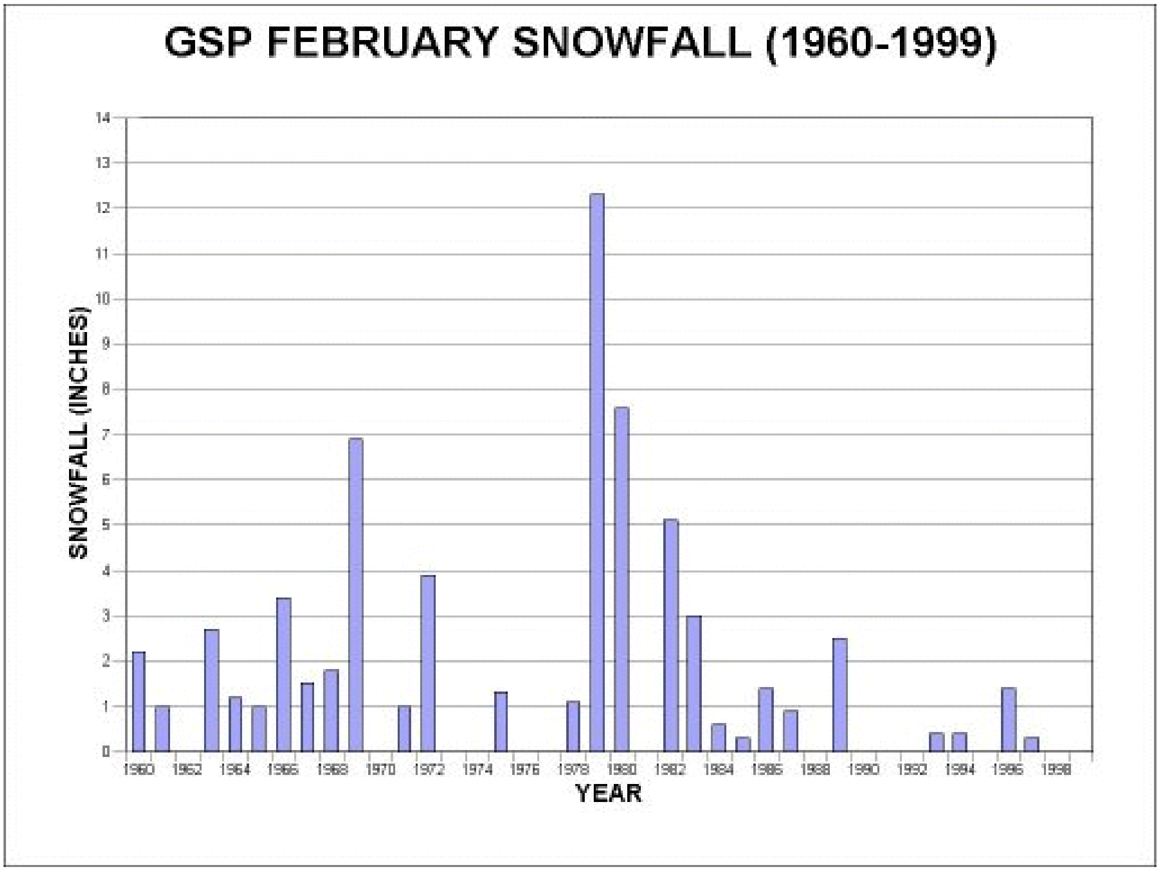

Figure 13. Total February snowfall each year.

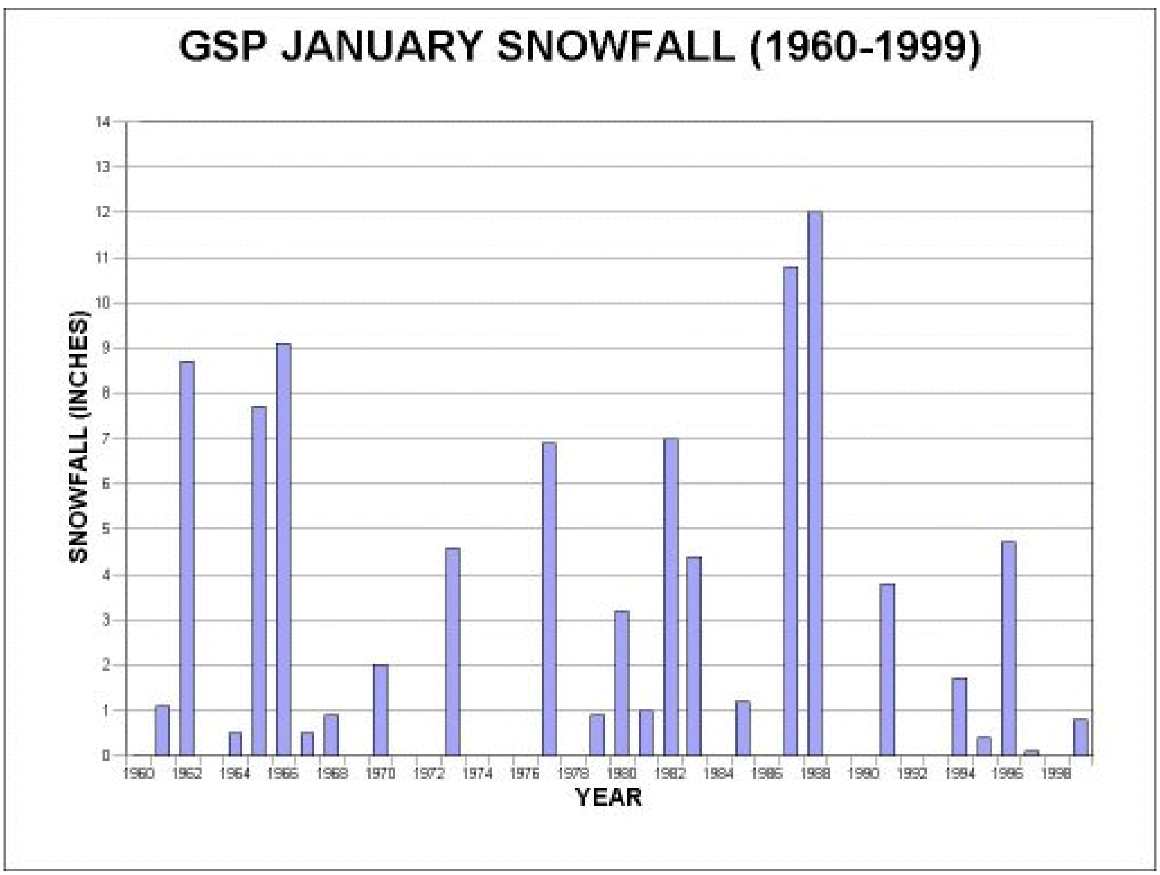

Figure 14. Total January snowfall each year.

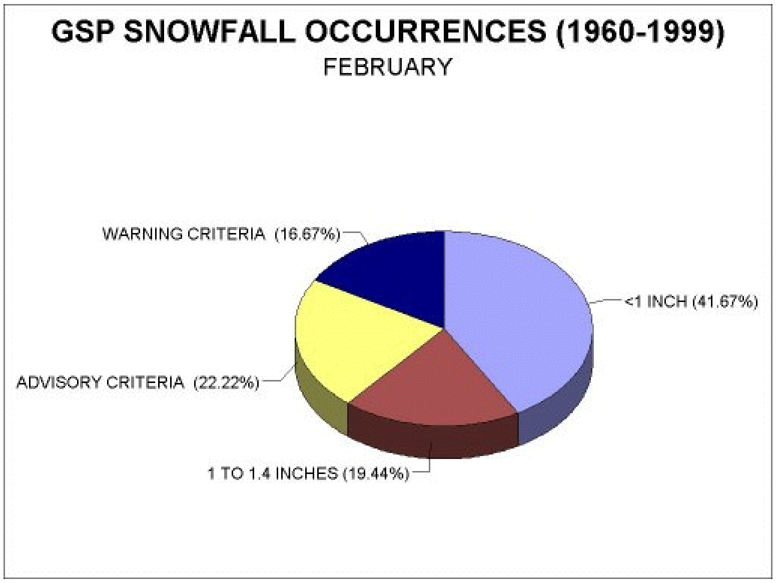

Figure 15. February snowfall occurrences shown by percentage. Advisory criteria is 2 to 3 inches. Warning criteria is 4 inches, or greater.

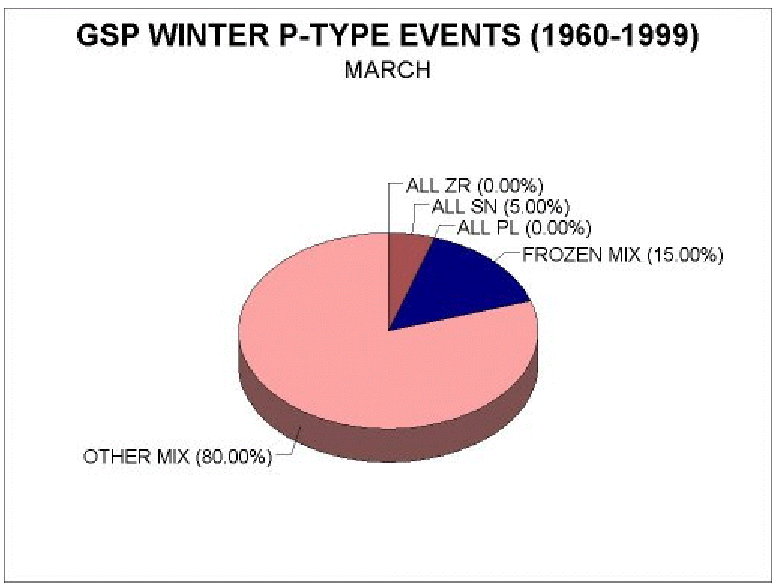

Figure 16. March p-type events at GSP shown by percentage.

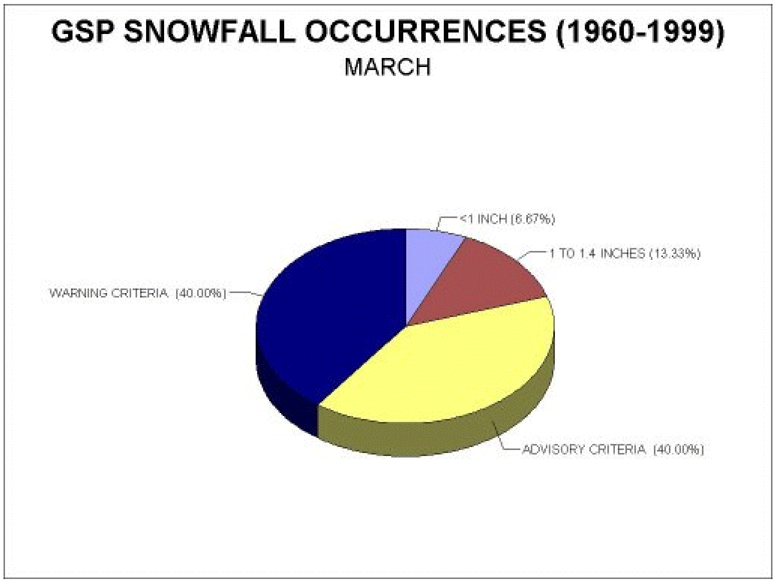

Figure 17. March snowfall occurrences shown by percentage. Advisory criteria is 2 to 3 inches. Warning criteria is 4 inches, or greater.

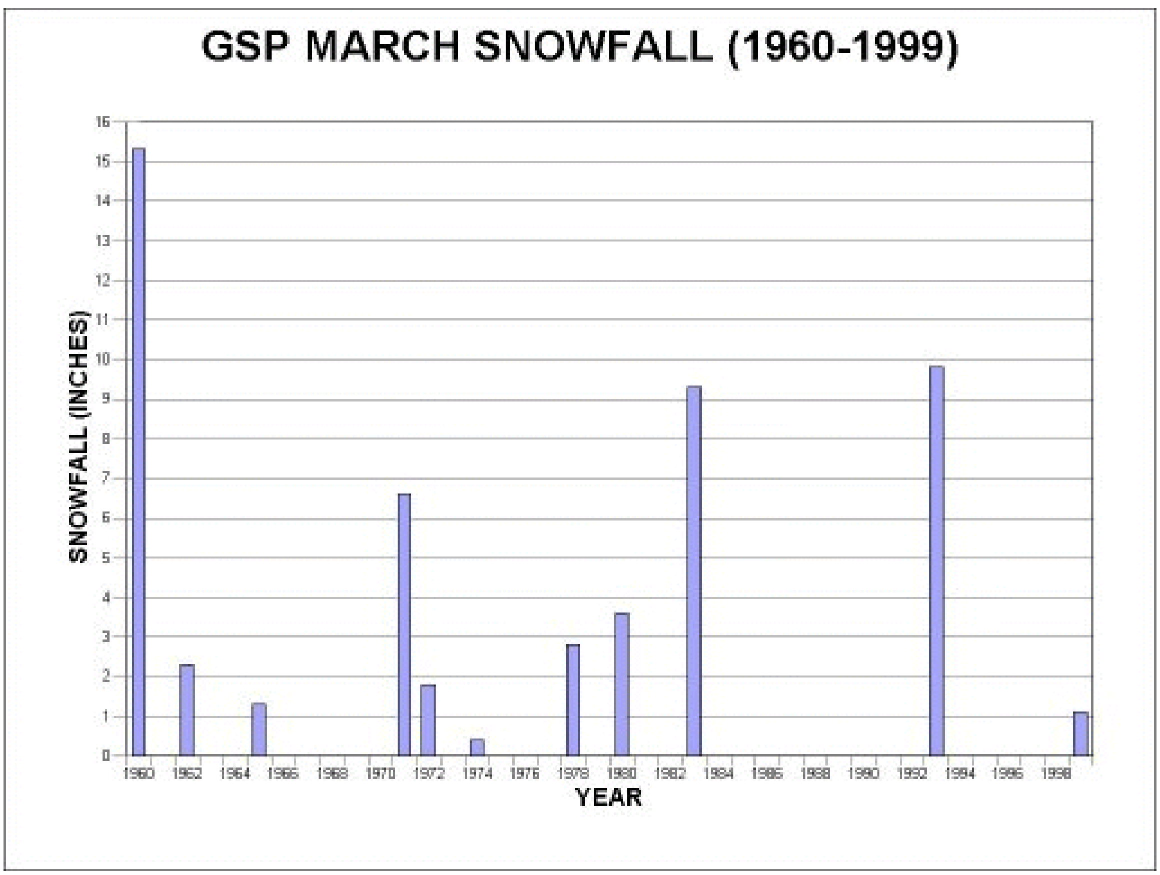

Figure 18. Total March snowfall each year.

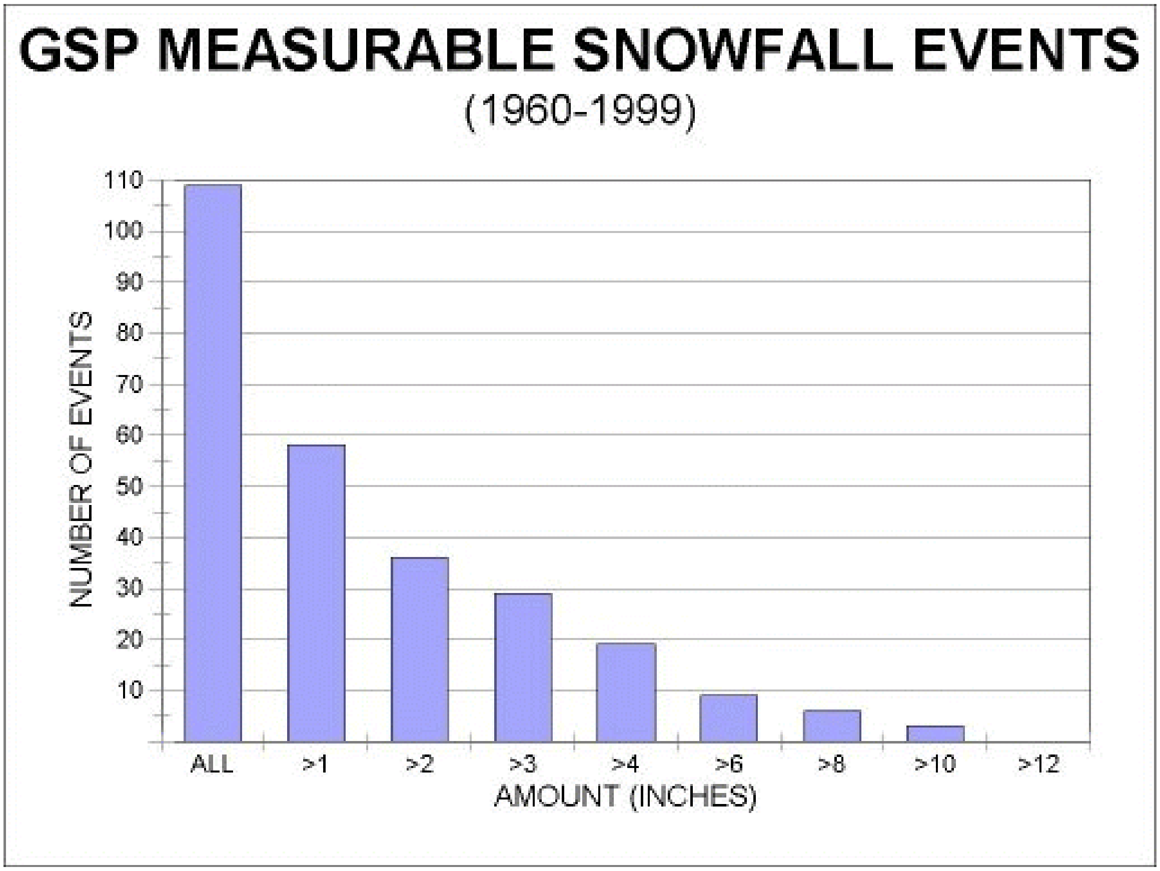

Figure 19. GSP measurable snowfall events.

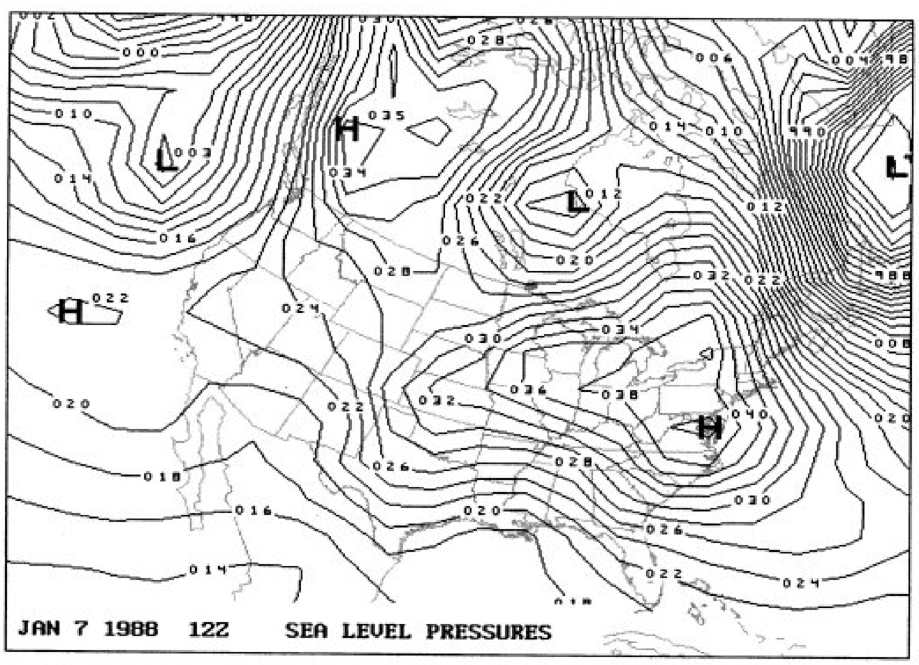

Figure 20. North American sea level pressures 7 Jan 1988 at 1200 UTC.

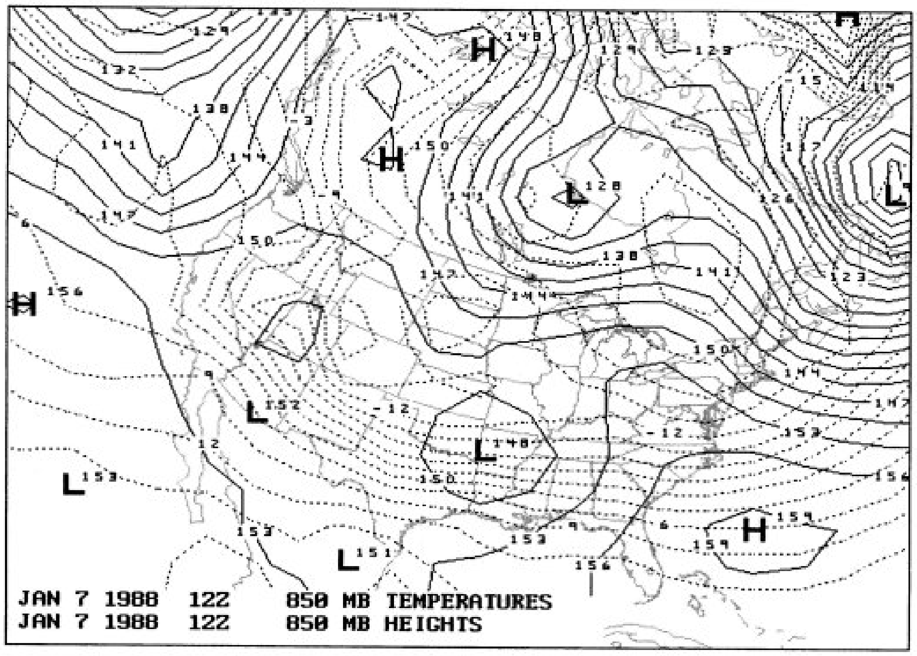

Figure 21. North American 850 mb heights and temperature 7 Jan 1988 at 1200 UTC.

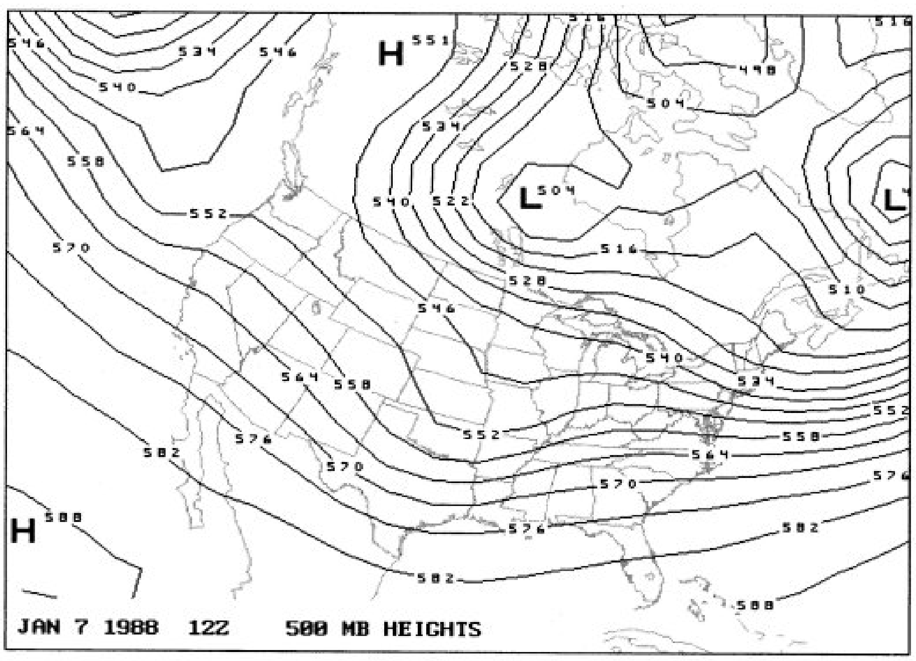

Figure 22. North American 500 mb heights 7 Jan 1988 at 1200 UTC.

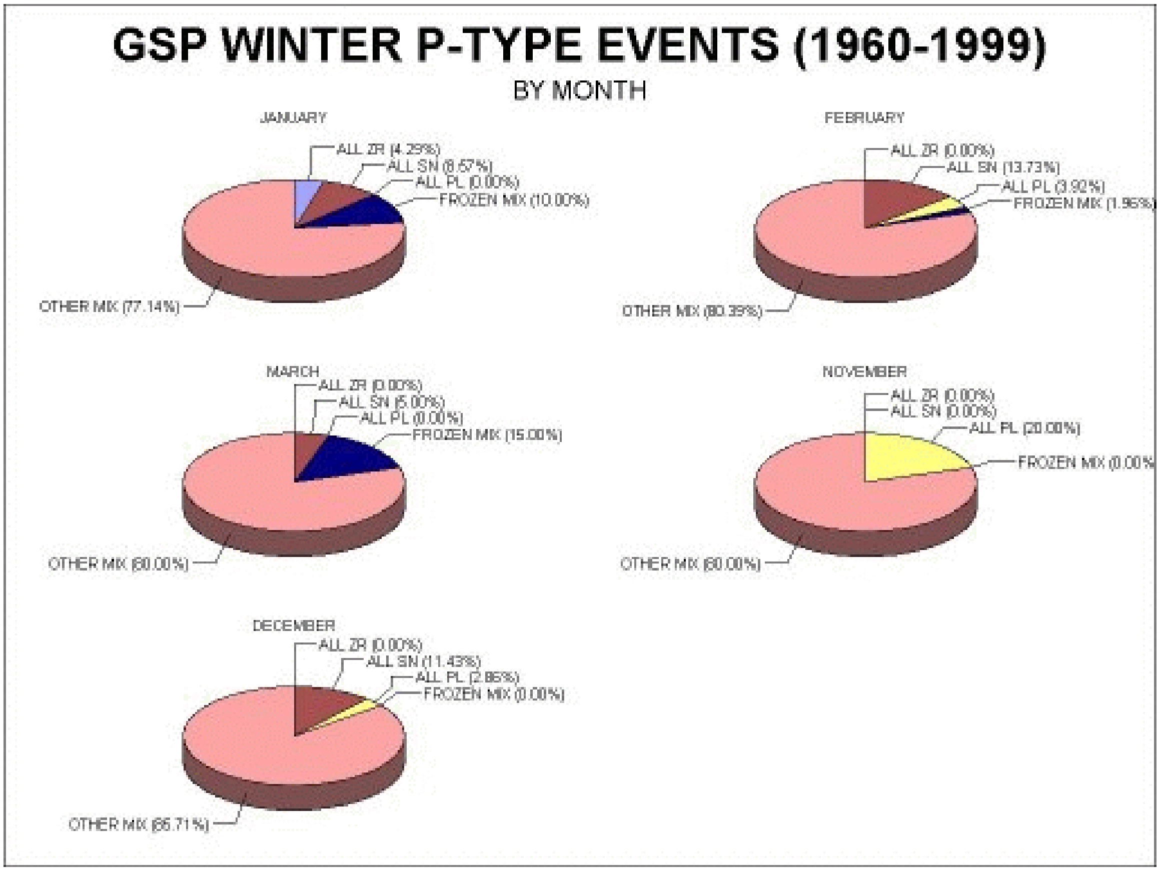

Figure 23. P-type events shown by percentage for November through March. Events composed of a mixture of precipitation were by far the most common at GSP.

Appendix A. P-Type Acronym Definitions

PL	Sleet (or Ice Pellets)
RA	Rain
SN	Snow
ZR	Freezing Rain
PLSN	Sleet and Snow
RAPL	Rain and Sleet
RASN	Rain and Snow
RAZR	Rain and Freezing Rain
ZRPL	Freezing Rain and Sleet
ZRSN	Freezing Rain and Snow
RAPLSN	Rain, Sleet, and Snow
RAZRPL	Rain, Freezing Rain, and Sleet
RAZRSN	Rain, Freezing Rain, and Snow
ZRPLSN	Freezing Rain, Sleet, and Snow
RAZRPLSN	Rain, Freezing Rain, Sleet and Snow