

## Cooperative Station Snow Climatologies

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### ABSTRACT

The U.S. National Weather Service (NWS) began installing the Automated Surface Observing System (ASOS) at aviation weather stations in the early 1990's. ASOS instrumentation does not measure snowfall and snow depth amounts, thus requiring a greater reliance on the daily snowfall and snow depth observations of the voluntary Cooperative Network (COOP) stations. The National Climatic Data Center computed snow climatologies for 5525 COOP stations to support NWS operations in the ASOS era, and snowfall return period statistics for 7464 COOP stations to provide the Federal Emergency Management Agency with an objective basis for declaring federal snow disasters. This product represents the most comprehensive snow climatology ever computed for the United States.

Key words: Snow climatology, snowfall return period statistics, U.S. Cooperative Network stations.

### INTRODUCTION

The introduction, by the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) in the early 1990's, of the Automated Surface Observing System (ASOS) has improved meteorological observations by standardizing observational methodologies across the airport observing network and by creating the potential for increasing the number and geographical coverage of aviation stations. However, ASOS instrumentation does not measure snowfall and snow depth amounts. The nation will therefore now have to rely more heavily on the daily snowfall and snow depth observations of the voluntary Cooperative Network (COOP) stations.

Comprehensive snow climatologies were generated for 5525 COOP stations in the contiguous United States and Alaska to support NWS operations in the ASOS era and to enable NOAA to better respond to user requests for snow information for use in economic and engineering decision-making.

One of the users of this information is the Federal Emergency Management Agency (FEMA). When disaster strikes, state and local governments may request federal aid through a Presidential disaster or emergency declaration. FEMA is responsible for making the federal disaster assistance available. Previously, FEMA did not have an objective basis for declaring federal snow disasters. The National Climatic Data Center (NCDC) and the NWS provided FEMA with snowfall extremes and return period statistics, for 7464 COOP weather stations across the contiguous United States and Alaska, to meet this need.

This paper summarizes the data base, quality assurance, and methodology used to create the snow climatologies and return period statistics. This product represents the most comprehensive snow climatology ever computed for the United States.

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## DATA

Daily snowfall and snow depth data from NCDC's TD-3200 data base were analyzed over the digital period of record through 1996. Three levels of quality control were applied: (1) The daily snowfall values were put through NCDC's ValHiDD quality control process (Reek *et al.*, 1992), which is a rules-based method for detecting and correcting discrepancies due to digitizing errors and observer errors. (2) Additional checks were made for factor of 10 errors (snowfall checked against concurrent precipitation) and extreme outliers. (3) The TD-3200 data base included hail mixed in with the snow data for part of the data period. A snowfall value was identified as hail and set to zero if the concurrent minimum temperature was  $\geq 4.4^{\circ}\text{C}$  ( $40^{\circ}\text{F}$ ).

The properties of snow make it difficult to accurately and consistently measure snowfall and snow depth. Snow often melts as it lands or as it lies on the ground, snow settles as it lies on the ground, and snow is easily blown and redistributed. These properties can be affected by location, time of day the observations are taken, and how often they are measured (Doesken and Judson, 1997). For these reasons, it is important for observers to adhere to a standard methodology (National Weather Service, 1972) for observing and reporting snow. Unfortunately, stations change location, observers, and observation time. Such changes introduce inhomogeneities into the snow record. No acceptable adjustment algorithms exist to statistically adjust daily snow data for inhomogeneities. The alternative for creating a reasonably high quality set of snow statistics, therefore, is to use stations which have a low risk of having inhomogeneous data.

Several indicators were computed, based on the data and metadata, to enable the user to assess the quality of the stations. These include frequencies of station moves and observation time changes, number of missing values and breaks in the record, number of values failing the QC checks, and percentages indicating how complete the data record is.

### Data for the FEMA Snowfall Return Period Statistics

A subset of this data (i.e., data from the period 1948-1996) was analyzed to compute the return period statistics. Sequential values of seasonal (August-July) 1-day, 2-day, and 3-day extreme snowfall, and total seasonal snowfall amount, were generated for each year. If even one day was missing during a year, the seasonal total amount was not computed for that year.

The multi-day extremes were more tolerant of missing data. As each day in each year was examined, a 2-day total was not computed if one of the two consecutive days was missing. Likewise, a 3-day total required all three consecutive days to have data. The 2-day and 3-day totals computed from non-missing data formed the basis for the sequential seasonal extreme multi-day values.

## ANALYSIS

### Variables and Statistics Computed for the Snow Climatologies

The NOAA and operational NWS needs included daily and monthly statistics for several snow variables. Statistics on snow *storms* were desired, but these could not be computed because the temporal resolution of the data was not to snow storm events. Snowfall from a given storm could fall on more than one day. As a surrogate for snow storm information, statistics were generated to a multiple-day resolution (two-day to seven-day periods), where the criteria was: snow had to fall on each day of the multiple-day period.

Several statistics were computed for several climatic variables using several snowfall and snow depth thresholds. The statistics include mean, median, first and third quartiles, extremes, and probabilities. The elements include number of days with snow (snowfall or snow depth) beyond various thresholds, monthly and seasonal total snowfall, number of consecutive days with snow, dates of the first and last occurrence of snowfall, daily and multiple-day extreme snowfall amounts, and daily snow depth amount.

Stations included in the final data set had to have a minimum of 15 years of non-missing data for each of the 12 months (for the monthly statistics) and each of the (non-leap year) 365 days (for daily

statistics). The period of record and the amount of missing data varied from station to station. The number of years with non-missing data for each month and day are included in the computed statistics to enable the user to evaluate any inter-station comparisons.

Figures 1-3 illustrate some of the statistics and variables included in this snow climatology.

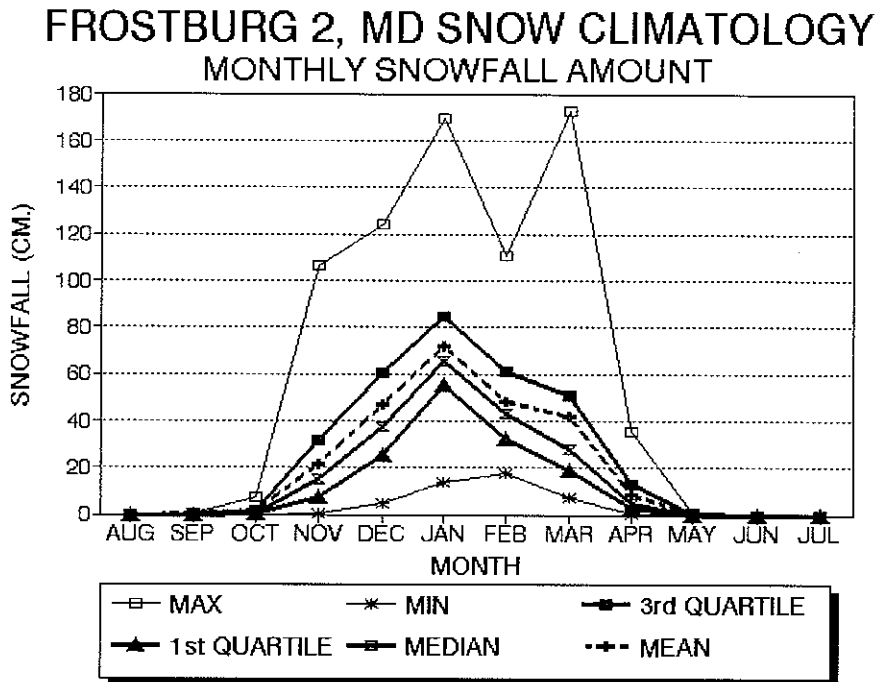


Figure 1. Mean, extremes, and quartiles of monthly total snowfall. Based on data from 1972-1996.

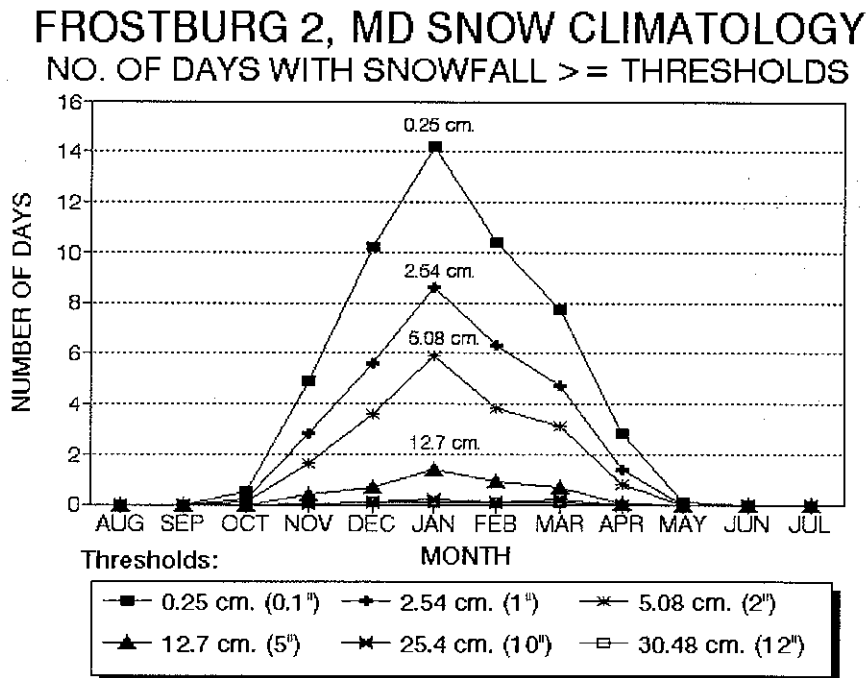


Figure 2. Number of days with snowfall beyond six specified thresholds. Based on 1972-1996 data.

## FROSTBURG 2, MD SNOW CLIMATOLOGY DAILY SNOW DEPTH PROBABILITY

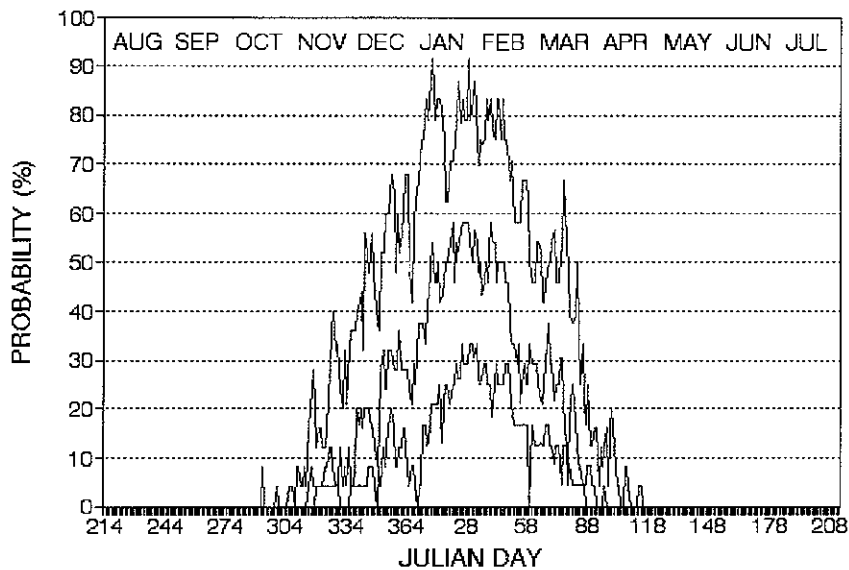


Figure 3. Top: for snow depth  $\geq 2.54$  cm. (1 in.). Middle: for snow depth  $\geq 12.7$  cm. (5 in.). Bottom: for snow depth  $\geq 30.48$  cm. (12 in.). Based on 1972-1996 data.

### Methodology for the Snowfall Return Period Statistics

The greatest seasonal snowfall total and 1-, 2-, and 3-day extreme snowfall amounts were extracted from the sequential data for 7464 stations (7320 in the contiguous U.S., and 144 in Alaska). Maximum values for these four variables were also computed for return periods of 10, 25, 50, and 100 years for a subset (4946) of these stations (4855 in the contiguous U.S., and 91 in Alaska).

The return period analysis was done using the generalized extreme-value distribution estimated using the method of L-moments and L-moment ratios described by Hosking and Wallis (1997). A statistical distribution can be determined only from nonzero values. If too many values are zero (which will happen, for example, in warm climate regions such as the Gulf Coast states, southern New Mexico, southern Arizona, and coastal and southern California, where it rarely snows), then a statistical distribution cannot be determined and return period statistics cannot be computed. Hosking and Wallis (1997) note that at least 20 nonzero values are needed in order to determine the statistical distribution, but a study by Guttman (1994) indicates that at least 30 nonzero values are needed for stable return period statistics. In this study, return period statistics were computed if at least 20 nonzero values were available, in order to generate return period statistics for as many stations as possible. The number of years with nonzero data were included in the output to enable the user to assess each station's statistics.

Each variable was analyzed separately. Missing data may result in a 2-day total being less than a 1-day total, or a 3-day total being less than a 2-day total. In parts of the country where snowfall is an uncommon event, missing data may result in the multi-day extremes being greater than the seasonal total snowfall extreme.

### UTILITY OF THE SNOWFALL RETURN PERIOD OUTPUT STATISTICS

The data set developed here provides a comprehensive nationwide picture of extreme snowfall events in a variety of locales, and comprises the most representative national return period snowfall

## FLAGSTAFF, AZ SNOWFALL, 1950-1995 RETURN PERIODS & EXTREMES

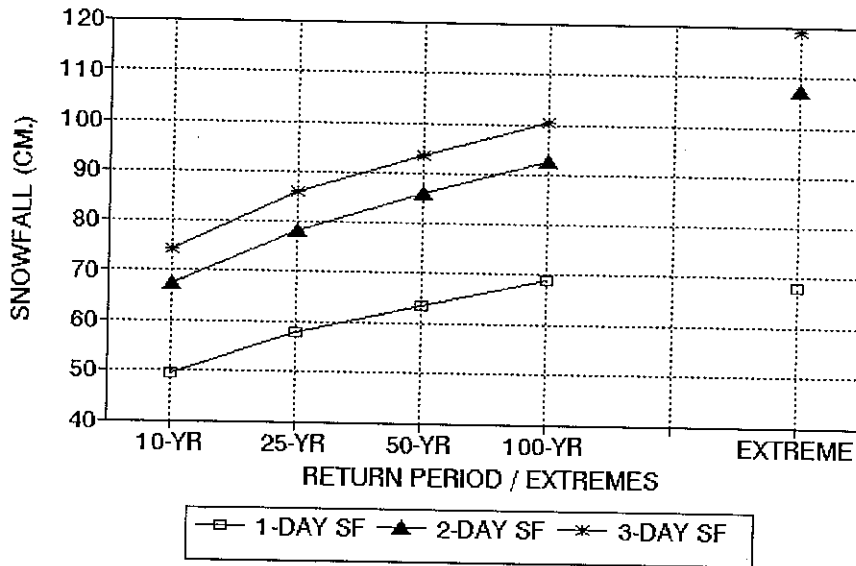


Figure 4. Example of snowfall return period statistics and observed extreme values.

statistics ever computed for non-airport locations. The snowfall extremes and return period statistics are useful for assessing how rare a snowfall extreme is on a station-by-station basis (see Figure 4).

Caution should be used, however, if stations are compared to one another, for the following reasons:

- (1) The properties of snow make it difficult to accurately and consistently measure snowfall. As noted earlier, snow often melts as it lands or as it lies on the ground, snow settles as it lies on the ground, and snow is easily blown and redistributed. These properties can be affected by location, time of day the observations are taken, and how often they are measured.
- (2) The synoptic weather patterns that generate snow can result in snowfall amounts that vary greatly over small distances (e.g., snow bands).
- (3) Local topography can have a major effect. Snowfall amounts can vary greatly depending on elevation and on slope aspect, steepness, and orientation (especially with regard to the prevailing wind patterns and the wind patterns associated with any given storm).
- (4) The data period is an important factor. Ideally, the same data period (with no missing data) would be desired for all stations if any inter-station comparisons were to be made. In reality, the stations have varying data periods with differing amounts of missing data.
- (5) The results of a statistical analysis partly depend on how much data are analyzed (sample size). A bigger sample size (60 or 70 years of nonzero data) would provide more stable results for this type of analysis (Guttman, 1994). Unfortunately, this amount of data was not available. The preferred minimum sample size is 20 to 30 years of nonzero data.
- (6) Even if two stations have the same number of years with nonzero data, the history of snowfall at a location can affect the shape of the statistical distribution, which determines the snowfall amounts corresponding to the selected return periods.

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