White Christmas?

An Application of NOAA's 1981–2010 Daily Normals

By Imke Durre and Michael F. Squires

For many, Christmas is directly associated with snow. Christmas cards, carols, stories, and movies tend to depict a "white Christmas." Often these depictions portray a snow-covered landscape or falling snow. In most parts of the United States, however, a white Christmas is actually far from certain. Where, then, are the best places for experiencing snow on the ground or snowfall on Christmas Day? Where is there likely to be sufficient snow for skiing at that time? In which parts of the country might holiday travel be impeded by snow? These are the questions that this paper attempts to answer on the basis of NOAA's 1981–2010 U.S. Daily Climate Normals (Arguez et al. 2012).

For a number of years, NOAA's National Centers for Environmental Information (NCEI, formerly NCDC) has responded to requests for information about the odds of a white Christmas. An NCDC Technical Report from 1995 (Ross et al. 1995) provides probabilities of occurrence for snow depths equal to or exceeding various thresholds, using observations taken between 1961 and 1990 at several hundred cities across the continental United States. More recently, NCEI has issued a press release every December centered around a map of the probability of measurable (≥ 1 in., or 2.54 cm) snow depth across the country. Since 2011, the map has been based on the 1981–2010 Daily Normals, which include data from several thousand U.S. stations.

The purpose of this paper is to provide a more detailed assessment of the probability of a white Christmas than is possible in the annual press releases, and to document the methodology used to calculate the underlying daily climatological statistics.

METHODOLOGY. The results presented herein include two types of statistics taken from the 1981–2010 Daily Normals: probabilities of occurrence and medians of nonzero amounts. The statistics are computed empirically from once-a-day snow depth measurements as well as from 24-h totals of snowfall and precipitation at stations operated by the U.S. National Weather Service (Arguez et al. 2012; Durre et al. 2013). The Global Historical Climatology Network–Daily (GHCN-Daily) dataset (Menne et al. 2012) is the source of these data. Shown in this paper are results from the subset of stations where at least 25 of the years between 1981 and 2010 meet the relevant data completeness requirements (appendix A), and no more than three consecutive years fail to meet those requirements. The computational procedures are outlined here and described further in the appendices.

The climatological probability of occurrence for a calendar day is the percentage of years in which a particular event occurred on that day. For a 30-year period, however, using only the observations taken on exactly that day would yield a maximum sample size of 30 values, fewer when a station's record is incomplete. To increase the sample size, a 29-day window centered on the day of interest is used instead. Thus, the probability of a measurable snow depth on 25 December is based on measurements from 11–31 December and 1–8 January during 1981–2010. Once the probabilities have been calculated using the appropriate 29-day window for each day of the year, they are smoothed with a 29-day running mean in order to reduce random day-to-day variability (appendix A).

Medians of nonzero snow depth and snowfall amounts provide an indication of typical amounts

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when snow depth or snowfall are present. They are computed within the same moving 29-day windows that are used in the computation of probabilities. A median for a specific day and variable is calculated only when nonzero amounts account for at least 10% of the total sample across all years and days in the window. As a result, medians are available only at stations and times of year at which this threshold is met. Furthermore, when the sample size is too small for one or more days within the snow season, some additional processing steps are employed to eliminate the resulting gap in the annual cycle (appendix B).

The combination of a 29-day window and 29-day running mean was chosen after sensitivity tests with different window sizes and smoothing filters. Based on visual inspection of resulting annual cycles of the various statistics included in the 1981–2010 Normals, the chosen combination strikes the best balance between dampening day-to-day sampling fluctuations and resolving the climatologically significant features of the annual cycle. To test the sensitivity of the statistics for 25 December in particular, the analyses shown in this paper were repeated for the stations listed in Table 1 using a five-day window together with a five-day running mean, requiring at least four of the five possible values to be available in each of at least 10 years. All of the probabilities thus obtained were within 5% of those shown in Table 1, and differences were less than 1% when the probability itself was small. Similarly, medians based on the five-day window were often identical to, and never more than half an inch different from, those computed with a 29-day window. Thus, the climatological patterns of probabilities and medians for 25 December are retained even with the use of a window that is 29 days long.

RESULTS. Figure 1 depicts the climatological probability that a snow depth of at least 1 in. (2.54 cm) was observed at locations across the contiguous United States on Christmas Day during 1981–2010. In addition, snow cover probabilities and related statistics for that calendar day at some specific locations are presented in Tables 1 and 2. A better than 50% chance of measurable snow on the ground was limited to the northern tier of states and higher elevations of the West. Values exceeded 75% at high mountain locations, in parts of North Dakota and Northern Minnesota, in the lee of the Great Lakes, and across northern New England. Crater Lake, Steamboat Springs, and Marquette are examples of locations where snow cover on Christmas Day was a virtual or complete certainty (Table 1).

Table 1. Probabilities of occurrence and medians of measurable snow depth and snowfall for selected U.S. cities where the probability of measurable snow on the ground on 25 Dec exceeds 20%. Entries are sorted in order of decreasing probability of snow on the ground. Medians are based on nonzero values only. By convention, measurable snowfall is defined as snowfall ≥ 0.1 in., measurable snow depth as snow depth exceeding 1 in.

City	Probability of Snow depth > 0	Median of Snow depth > 0	Probability of Snowfall > 0	Median of Snowfall > 0
Crater Lake, OR	100%	53"	52%	4.1"
Steamboat Springs, CO	98%	15"	44%	2.1"
Marquette, MI	97%	12"	61%	1.1"
Tahoe City, CA	87%	14"	23%	3.2"
Caribou, ME	86%	7"	42%	0.9"
Red Lodge, MT	85%	7"	17%	2.0"
Minot, ND	80%	3"	23%	1.0"
Burlington, VT	65%	4"	42%	0.8"
Los Alamos, NM	54%	5"	16%	1.5"
Salt Lake City, UT	53%	3"	28%	1.0"
Milwaukee, WI	48%	3"	26%	0.6"
Yankton, SD	47%	4"	11%	1.0"
Pittsburgh, PA	32%	2"	30%	0.6"
St. Louis, MO	21%	3"	13%	0.6"

Table 2. Probabilities of occurrence of measurable snow depth, snowfall, and precipitation for selected U.S. cities where the probability of measurable snow on the ground on 25 Dec is less than 10%. Entries are sorted in order of decreasing probability of snow on the ground and decreasing probability of precipitation. Measurable snowfall and snow depth are defined as in Table 1; measurable precipitation includes amounts ≥ 0.01 in.

City	Probability of Snow Depth	Probability of Snowfall	Probability of Precipitation
Oklahoma City, OK	8%	5%	17%
Portland, OR	4%	2%	68%
Raleigh, NC	1%	1%	29%
Birmingham, AL	<1%	1%	34%
San Antonio, TX	<1%	<1%	24%
Berkeley, CA	0%	0%	34%
Orlando, FL	0%	0%	21%
Tempe, AZ	0%	0%	13%

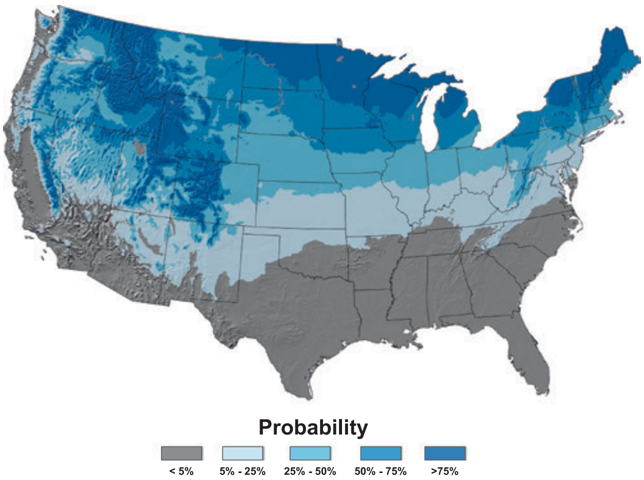

Fig. 1. Map of the climatological probability of at least 1 in. (2.54 cm) of snow on the ground on 25 Dec across the contiguous United States, derived from NOAA's 1981–2010 U.S. Daily Climate Normals. For this and all subsequent figures, station values are interpolated to a grid using thin plate splines (Vose et al. 2014).

East of the Rocky Mountains, the snow cover probability decreases from the high values in the North to values near zero in an area extending from Texas (excluding the panhandle) east to the Carolinas (Fig. 1, Table 2). In between these regions, there is a wide band with probabilities between 5% and 50%, as exemplified by Milwaukee, Yankton, Pittsburgh, and St. Louis (Table 1). From the Rockies westward, the influence of topography is apparent, with little or no chance of snow cover across southern Arizona and most of California, and probabilities below 50% at low elevations as far north as Oregon and Washington (e.g., 4% at Portland, Oregon).

The 1981–2010 25 December medians of nonzero snow depth observations are shown in Fig. 2. Not surprisingly, the large-scale spatial patterns in Figs. 1 and 2 roughly correspond to each other. The highest median values, exceeding 9 in. (22.86 cm), are found in the lee of Lake Superior and at high elevations in the Rockies, Sierras, and Cascades. Examples of such locations include Steamboat Springs and Tahoe City (Table 1), where the typically deep snow has led to the establishment of popular ski areas. Among the 1981–2010 Normals stations, the largest median snow depth on 25 December is 53 in. (134.62 cm) at Crater Lake, Oregon. East of the Rockies, a band of 1-to-3-in. (2.54-to-7.62-cm) snow depth medians extends eastward from the Colorado plains to the East Coast. Medians of 4 to 9 in. (10.16 cm to 22.86 cm) are found north of that region between the Rockies in the West and Maine in the East.

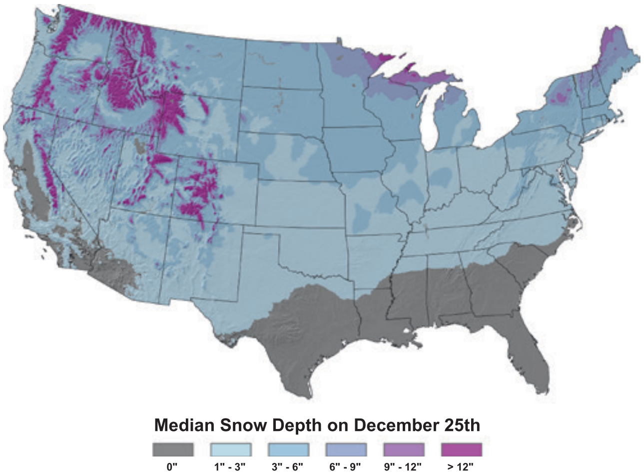

Fig. 2. Map of median snow depth when snow is on the ground on 25 Dec. For consistency with the original measurement units, medians are provided in inches. (1 in. = 2.54 cm).

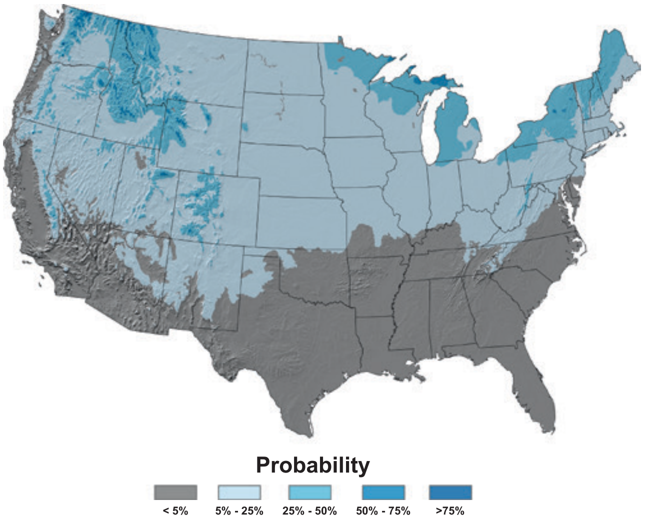

Fig. 3. Same as Fig. 1, but for the climatological probability of at least 0.1 in. (0.254 cm) of snowfall.

While the most popular definition of a white Christmas is the presence of significant snow cover, it is also instructive to consider the climatological probability of snowfall on 25 December since many cultural references to Christmas invoke an image of snowflakes, and travel is more likely to be impacted by new snow than by snow already on the ground. As shown in Fig. 3, the probability of measurable (≥ 0.1 in.) snowfall on 25 December is less than 25% for most of the country outside of mountainous regions and the Great Lakes. From central Texas to the Carolinas, it was essentially zero during 1981–2010. The only places where the probabilities exceeded 50% were isolated mountain locations in the West, some stations on the lee side of Lake Superior and Lake Ontario, and some stations in northern New England.

Over many parts of the United States, the probability of measurable snowfall (Fig. 3) is considerably less than the probability of measurable (≥ 0.01 in.) total precipitation, shown in Fig. 4, indicating that precipitation in these regions frequently falls as rain. Locations where more than half of the precipitation events involve snowfall are found in the mountains of the West as well as north of a line arching from New Mexico through western Kansas and northern Illinois into interior New England (Fig. 4). When snow does fall, it is often relatively light, as reflected in the median snowfall amounts in Table 1. Only some mountain locations in the West experienced snowfall in excess of 3 in. (7.62 cm) more than half of the time when snow fell on 25 December during 1981–2010.

SUMMARY. Although the 1981–2010 statistics in no way represent a forecast for future conditions, they can nevertheless serve as a guide for setting expectations regarding which parts of the contiguous United States are most likely to experience a white Christmas. They suggest, for example, that the places where one is most likely to experience both snow on the ground and falling snow are in the Sierras and Cascades, on the leeward side of the Great Lakes, and in northern New England. At high elevations of the Rocky Mountains and at most locations between the northern Rockies and New England, the probability of measurable snow depth is greater than 50%, while the probability of snowfall is generally less than 25%. By contrast, snow is at best extremely rare on 25 December in Southern California, the lower elevations of the Southwest, and Florida (Table 2).

While the results presented here focus solely on 25 December, they are generally representative of conditions during the last half of December and early January. Therefore, they are relevant not only to those concerned about snow on Christmas Day, but also to those planning a vacation or family visit during this popular travel season. Readers interested in probabilities of occurrence or median values for other times of year or for specific locations other than those shown in Tables 1 and 2 are referred to the full set of NOAA's 1981–2010 U.S. Climate Normals available

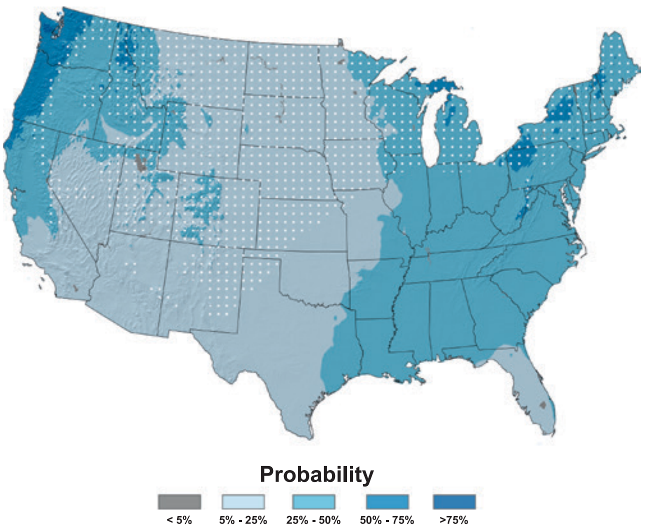

Fig. 4. Same as Fig. 1, but for the climatological probability of at least 0.01 in. (0.0254 cm) of precipitation. Stippling indicates regions where more than 50% of precipitation falls as snow.

on NCEI's website (www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/climate-normals/1981-2010-normals-data). Since conditions in any specific year may differ significantly from the climatological norm, however, those with flexibility in the short term may wish to also consult NOAA's real-time snowfall maps at www.weather.gov.

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APPENDIX A: CALCULATION OF DAILY CLIMATOLOGICAL PROBABILITIES OF OCCURRENCE. For a particular station and variable, the daily probabilities are calculated according to the following four-step procedure.

1) *Sample selection:* For each day of the year except 29 February, the sample used includes data from within +/–14 days of the day in question and from all years that have values on at least 20 calendar days within that 29-day window. A minimum of 10 such years is required for each window (Durre et al. 2013).
2) *Calculation:* The climatological probability of occurrence is then equal to the percentage of nonzero values within the pool. Due to the limited sample size for 29 February, the probability for that day is set to the average of the probabilities for 28 February and 1 March.
3) *Smoothing:* To reduce fluctuations from one calendar day to the next that are associated with sampling variability, the empirical probabilities are smoothed with a 29-day running mean. After several other types of filters had been tested, this particular filter was found to yield the desired level of smoothing while retaining variations on the time scale of weeks.
4) *Synchronization:* The use of the 29-day window and subsequent smoothing can result in small nonzero probabilities for snowfall or snow depth in months during which snow was never reported in the underlying observations. In such cases, the affected probabilities are set to zero. Similarly, at the beginning of the snow season, another check sets to zero any nonzero probabilities of snow on the ground that appear before the probability of snowfall has increased from zero.

As an example, consider the probability of snow on the ground on 25 December during 1981–2010 at Milwaukee (Table 1). For this calculation, observations were available on all of the 29 days in the window in 28 of the 30 years and on 27 of the 29 days in another year, yielding a total of 839 observations. Of these, 392 were nonzero values, resulting in an empirical probability of 46.8%, which was transformed to 47.7% by the subsequent smoothing of the raw probabilities.

APPENDIX B: COMPUTATION OF DAILY MEDIANS OF NONZERO AMOUNTS. The procedure for calculating daily medians of the nonzero amounts of one element at one station is described below.

1) *Sample selection:* The median of a particular day is calculated from the same sample of values used to compute the probability of occurrence (see #1 in appendix A).
2) *Calculation:* If at least 10% of the values in the sample for a particular calendar day are nonzero, these nonzero amounts are sorted from lowest to highest, and the median is identified (Durre et al. 2013). Otherwise, the median is set to missing. The median for 29 February is set to the average of the corresponding medians for 28 February and 1 March.
3) *Smoothing:* The resulting daily medians are smoothed with a 29-day running mean. To allow for the smoothing of even those medians that directly precede or follow a time of the year during which medians are missing, the running mean is calculated whenever medians are available on at least 15 of the 29 days. Medians that cannot be smoothed in this manner are set to missing.
4) *Interpolation:* Gaps in the resulting medians that are shorter than 15 days are filled in using linear interpolation between the corresponding medians immediately preceding and following the gap. At locations in the northern Great Plains, midwinter gaps in snowfall medians that extend over more than 15 days are also filled in since the medians before and after the gap typically do not differ significantly from each other.
5) *Cleanup:* To avoid fragmented annual cycles, continuous stretches of medians shorter than 15 days are removed, and all medians are set to missing if there is no continuous stretch of (empirical and interpolated) medians that is at least 30 days long.

FOR FURTHER READING

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