# Using the NCEP Dynamical Seasonal Forecast Model To Predict the Number of Snowmaking Days at a Missouri Ski Resort

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## 1. Introduction

The most basic requirement for any ski facility is adequate snowpack, whether it be from natural snowfall or that produced by snowmaking machines. Depending on seasonal weather conditions, the financial costs associated with snowmaking can vary considerably from one year to another. Such financial concerns encompass a variety of aspects, including costs of operating the equipment and, more fundamentally, potential loss of revenue if the ski facility cannot operate due to lack of snowpack. These issues could have a significant impact on how long a ski facility can remain open for the season, as a warm early-winter could substantially delay a targeted open date, or likewise, a warm late-winter could prematurely close a facility for the season. Such logistical and financial concerns are no small issue for ski facilities or other recreational entities whose success depends heavily on the cooperation of seasonal weather.

Although many ski facilities are located in mountainous areas or northern latitudes that are more likely to receive an adequate amount of natural snowfall, seasonal forecast trends are likely an annual concern for facilities located in more "marginal" climate regions where snowfall totals might have more annual variability. This paper focuses on one of these more "marginal" areas as it examines how well the NCEP seasonal forecast model predicts the number of potential snowmaking days for Hidden Valley ski area, located about 30 miles west of St. Louis, Missouri, in an area not generally known for substantial annual snowfall (Hidden Valley webpage). Because Hidden Valley Ski Area is operational only during the peak winter months, this study focuses solely on the months of December, January and February (DJF).

## 2. Data

According to a chart of snowmaking temperature versus relative humidity (Figure 1), a temperature of 25ºF appears to be a good baseline temperature for ideal snowmaking conditions, assuming the relative humidity is below 80 percent (www.backyardblizzard.com/guide.htm). This value is toward the warmer end of the ideal snowmaking temperature spectrum, but for the "warmer" winter climate of Missouri compared to typical skiing locales, this value seems to be realistically attainable on a regular basis. Therefore, 25ºF was chosen as a threshold temperature in this study and was used to develop a relationship between monthly mean temperature (MMT) and the number of days per month that the temperature falls at or below 25ºF. This relationship will be discussed extensively in Section 3.

This study utilized two primary data sets, observed temperatures and NCEP model hindcast temperatures. The MMT was then calculated from each. For model hindcast data, the first step in data collection was to determine the particular gridpoint in the model that contained the area where Hidden Valley is located. The model gridpoints are approximately 1.9° by 1.9° of latitude/longitude and the hindcasts consist of 10 global spectral model ensemble members that each output a predicted MMT for the 20-year period from 1979-1999 (Kanamitsu et al., 2000). The average of the MMT from all 10 ensembles was designated as the hindcast MMT for each of the 60 months in the study beginning with Dec. 1979 and ending with Feb. 1999. A two-month lead-time was chosen for the hindcasts in this study, meaning that the hindcast data was initialized in October of each year. The two-month lead-time seemed to be a sufficient choice, as it not only allows the ski facility some time to make necessary plans or adjustments, but it also is close enough to the winter months to hopefully produce a more accurate prediction than earlier model runs might have. It should be noted that the fairly large geographical size of the model domain introduces a significant assumption into this study that the gridpoint output is representative of the entire domain.

To compare against the hindcast data and test the predictive ability of the model, a MMT climatology was constructed using observed MMTs at four weather stations within the model gridbox and all within approximately 30-50 miles of the ski facility in east-central Missouri. The four stations were: St. Louis (Lambert Field), Elsberry, Bowling Green and St. Charles. Calculating the climatology MMT involved a number of steps. First, the MMT for all four stations for all 60 months of the study period were obtained from NCDC data. This resulted in approximately 240 initial monthly observations, as only a few observations were missing. Next, for each month the median temperature out of these four stations was designated as the MMT for the overall domain (60 total values). Finally, each of these MMTs were combined and averaged over the 20-year period to produce the final climatological MMTs for the entire period (3 total values). These values were: Dec. (33.0 ºF), Jan. (29.2 ºF) and Feb.(34.5 ºF). The seasonal mean for the entire study period was simply an average of these monthly values (32.2 ºF).

As a way of internally testing the validity of the observational data, a comparison was made between the first 10 years of the study period (1979-1989) and the second 10 years (1989-1999). Averaging over all four stations for all years, the seasonal (DJF) temperature increased 2.1 ºF during the second 10 years over the first 10. Although this study does not address the significance of this increase, the warming trend is hard to ignore and is consistent with current hypotheses regarding global warming.

# 3. Analysis Procedures and Tools

*a . Monthly mean temperature relationship*

Because the seasonal model does not forecast the number of days that the minimum temperature falls below a certain value for any given month, a relationship was calculated between the MMT and the number of days the minimum temperature would fall to 25ºF or below. To do this, for each month of data, the number of days that the minimum temperature fell to 25ºF or below was counted. Because there are not an equal number of days in every month (DJF), the number of days were converted to a percentage of days. These percentages were then matched with the corresponding MMTs. Next, these two arrays were sorted by MMT, getting an array of ascending MMTs and their corresponding percentages. Then, the array was broken into MMT intervals (bins) of 2.9ºF starting with an interval of 17.0ºF – 19.9ºF and ending with 41.0ºF – 43.9ºF. After breaking the data into intervals, the median percentage value of each interval was found (the percentage of the number of days the minimum temperature falls to 25ºF or below in a given month). This relationship turned out to be rather good as shown in Figure 2. The percentages fell rather uniformly with increasing MMT and the standard deviation for each interval was only around 10%. Using this relationship, we were able to convert the hindcast MMTs to corresponding percentages for each month (DJF) from 1979 – 1999.

*b. Analyzing hindcast model performance*

To determine the performance of the model hindcast, an official observational percentage for each month was found for comparison. To do this, we took the four observational percentages (from our four sites) for each month, dropped the high and low values, and then took the mean of the remaining two values. By calculating the official percentage in this way, we were able to reduce the effect of outlying values.

After finding the official observational values, all percentages (both observational and hindcast) were converted to actual number of days for each month. For February, we used 28 days as the maximum, neglecting any leap years. The actual number of days for each season was also found by taking the sum of the three months each year.

To determine how well the hindcast performed, the error percentage for each month and season was calculated using the equation:

$$Error = \left( \frac{(hindcast) - (observation)}{(observation)} \right) * 100 \qquad (1)$$

In order to analyze the hindcast performance, the climatological MMT was calculated over the 20-year period by simply finding the mean of the MMTs for each month. The climatological MMTs were then converted to percentages according to the relationship described in Section 3a. Then, as for the hindcast, these percentages were converted to actual number of days ($T_{min} \leq 25°F$) for each month. Using Equation (1) above, the climatology error was calculated and compared to the hindcast error.

*c. Applying a bias correction to the hindcast*

In an attempt to increase the overall performance of the hindcast, a bias correction was applied. This was done by adding a correction value to the hindcast for each month separately (Table 1). This correction value was determined by taking the difference between the mean observational value and the mean hindcast value. This was done using the percentages which were then converted to days for performance evaluation. The seasonal correction was incorporated by taking the sum of the corrected monthly values for each year.

| Month | Correction Value |
|---|---|
| December | 1.8 |
| January | 5.8 |
| February | 5.1 |

**Table 1. Monthly correction values (in percent) applied to hindcast to get BCH.**

To determine whether the bias corrected hindcast (BCH) was an improvement, the error was calculated, using equation (1), and then compared with climatology and the uncorrected hindcast. The improvement (or lack thereof) between the hindcast error and the BCH error was found.

# 4. Results

*a. Uncorrected hindcast performance*

Overall, the results showed that the uncorrected hindcast struggled to outperform climatology on a monthly basis. In fact, climatology outperformed the hindcast more often for every month over the 20-year period of study. The hindcast did, however, outperform climatology on a seasonal basis. These results can be seen in Table 2 below.

| | December | January | February | Seasonal |
|---|---|---|---|---|
| Beat Climo | 3 | 4 | 6 | 12 |
| Lost | 7 | 6 | 7 | 8 |
| Tied | 10 | 10 | 7 | 0 |

**Table 2. Comparison (number of years) of uncorrected hindcast to climatology.**

*b. Bias corrected hindcast performance*

The BCH did show improvement in the sense that it was able to outperform climatology overall during one month (February). And unlike the uncorrected hindcast, the BCH was not able to demonstrate distinctively that it outperformed climatology on a seasonal basis (Table 3).

| | December | January | February | Seasonal |
|---|---|---|---|---|
| Beat Climo | 9 | 9 | 11 | 10 |
| Lost | 11 | 11 | 9 | 10 |

**Table 3. Comparison (number of years) of BCH to climatology.**

*c. Comparing the hindcast to the bias corrected hindcast*

As alluded to above, there are positives and negatives for both the uncorrected hindcast and the BCH. But looking closer, the error was compared between the two and Figures 3a-3d show when the BCH was actually an improvement and by how much. Overall, the BCH improved the December hindcasts 10 times, the January hindcasts 12 times, the February hindcasts 10 times, and the seasonal hindcasts 11 times. However, February was the only case in which the mean error (Table 4) improved from the uncorrected hindcast to the corrected hindcast. This indicated that the improved hindcasts were not as influential on error as the hindcasts that ended up being worse. This can also be seen in Figures 3a-3d.

| | Climatology | Hindcast | BC Hindcast |
|---|---|---|---|
| December | 24.0 | 26.5 | 27.5 |
| January | 21.9 | 22.1 | 22.4 |
| February | 60.8 | 37.9 | 43.9 |
| Seasonal | 18.1 | 15.9 | 16.2 |

**Table 4. Comparison of percent error between climatology and hindcasts.**

# 5. Conclusions

Neither the uncorrected or corrected hindcasts did a very good job forecasting snowmaking days on a monthly basis. Overall, climatology was able to outperform both the hindcast and BCH. The only exception was the month of February, when both the hindcasts and the BCH had mean percentage errors that were much lower than climatology. This is a bit deceiving, however, because even the hindcasts had relatively high error percentages as shown in Table 4 above. Also, climatology outperformed the uncorrected hindcast during February more often than not (Table 2). And even though the BCH outperformed climatology during February more often than not, this cannot justify its very high overall error for the month (Table 4).

The model shows much more potential for forecasting seasonal snowmaking days than monthly days. In this case the uncorrected hindcast was best, outperforming both climatology and the BCH. Over the 20-year period, the uncorrected hindcast outperformed climatology 12 years and its mean error was about two-percent lower (Tables 2&4). The BCH outperformed climatology only half of the time and likewise had a mean error about two-percent lower.

One reason the hindcasts may do a poor job on a monthly basis is that they cannot account for the interannual variability of the observations which is shown in Figures 4a-4c. There is substantial variability in the seasonal data as well, but it seems that the monthly hindcasts even-out somehow when put together for a seasonal forecast and thus do a better job seasonally.

The BCH did not show significant improvement over the uncorrected hindcast for forecasting snowmaking on a monthly basis, and the uncorrected hindcast performs as well or better than the BCH seasonally. Therefore, it does not appear necessary to apply a correction to the hindcast.

Overall, using the seasonal forecast model will not be useful to a ski resort for predicting monthly snowmaking days because of its poor performance compared to climatology. Even though, the hindcast does a better job during February, it is still not very useful because of its high error. However, the hindcast does have some value for predicting seasonal snowmaking days. It was able to outperform climatology 12 of 20 years and had an average error of about two percent lower than climatology.

# 6. Study Improvement

The best way to improve this study would be to increase the period of study . This would increase the data sample size, leading to more solid statistical values for standard deviations, means and medians. Most importantly, it would help create a better relationship between MMT and the percentage of snowmaking days (Section 3a). It may even be possible, with more years of data, to make the temperature interval of the relationship smaller and more precise.

Based on the significant warming trend between the two 10-year periods noted in Section 2, it would be interesting to determine how using only the second 10 years for the MMT-percentage relationship would affect the results. Doing this would also affect our climatology values and may better reflect the current climate due to continued warming. It should also be noted that if average warming continues at roughly the same rate (a big assumption), it may only be about three more decades before snowmaking capabilities in this region are severely limited.

# 7. References

Hidden Valley ski area webpage. [Available online at http://www.hiddenvalleyski.com/index.asp]

Kanamitsu et al. 2002. NCEP dynamical seasonal forecast system 2000. *Bull. Amer. Meteor. Soc.,* **83,** 1019-1037.

National Climatic Data Center website. [Available online at http://www.ncdc.noaa.gov/oa/climate/stationlocator.html

Snowmaking temperature and humidity guide. [Available online at www.backyardblizzard.com/guide.htm]

# 8. Figures

**Snowmaking Temperature & Humidity Guide**

Snow Quality Key: Excellent, Poor, Rain

| Air Temperature °F | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 100% | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Wet Bulb Temperature °F | | | | | | | | | |
| 14.0 | 9.9 | 10.4 | 10.9 | 11.5 | 12.0 | 12.4 | 12.9 | 13.5 | 14.0 | Ideal Snowmaking Conditions |
| 15.8 | 11.3 | 11.8 | 12.4 | 12.9 | 13.5 | 14.0 | 14.7 | 15.3 | 15.8 | |
| 17.6 | 12.7 | 13.3 | 13.8 | 14.5 | 15.1 | 15.8 | 16.3 | 16.9 | 17.6 | |
| 19.4 | 14.0 | 14.7 | 15.4 | 16.0 | 16.7 | 17.4 | 18.0 | 18.7 | 19.4 | |
| 21.2 | 15.4 | 16.2 | 16.9 | 17.6 | 18.3 | 19.0 | 19.8 | 20.5 | 21.2 | |
| 23.0 | 16.9 | 17.6 | 18.3 | 19.0 | 19.9 | 20.7 | 21.4 | 22.3 | 23.0 | Marginal Snowmaking Conditions |
| 24.8 | 18.2 | 19.0 | 19.8 | 20.7 | 21.6 | 22.3 | 23.2 | 23.9 | 24.8 | |
| 26.6 | 19.6 | 20.5 | 21.4 | 22.1 | 23.0 | 23.9 | 24.8 | 25.7 | 26.6 | |
| 28.4 | 20.8 | 21.9 | 22.8 | 23.7 | 24.6 | 25.5 | 26.6 | 27.5 | 28.4 | |
| 30.2 | 22.3 | 23.4 | 24.3 | 25.3 | 26.2 | 27.3 | 28.3 | 29.3 | 30.2 | Snowmaking Not Possible |
| 32.0 | 23.7 | 24.6 | 25.7 | 26.8 | 27.9 | 28.9 | 30.0 | 30.9 | 32.0 | |
| 33.8 | 25.0 | 26.1 | 27.3 | 28.4 | 29.5 | 30.6 | 31.6 | 32.7 | 33.8 | |
| 35.6 | 26.4 | 27.5 | 28.8 | 29.8 | 31.1 | 32.2 | 33.3 | 34.5 | 35.6 | |
| 37.4 | 27.9 | 28.9 | 30.2 | 31.5 | 32.5 | 33.8 | 35.1 | 36.3 | 37.4 | |
| 39.2 | 29.1 | 30.4 | 31.6 | 32.9 | 34.2 | 35.4 | 36.7 | 37.9 | 39.2 | |
| 41.0 | 30.6 | 31.8 | 33.1 | 34.5 | 35.8 | 37.0 | 38.5 | 39.7 | 41.0 | |
| 42.8 | 31.8 | 33.3 | 34.7 | 36.0 | 37.4 | 38.8 | 40.1 | 41.5 | 42.8 | |

Relative Humidity %

**Figure 1. Snowmaking Temperature and Humidity Guide.**

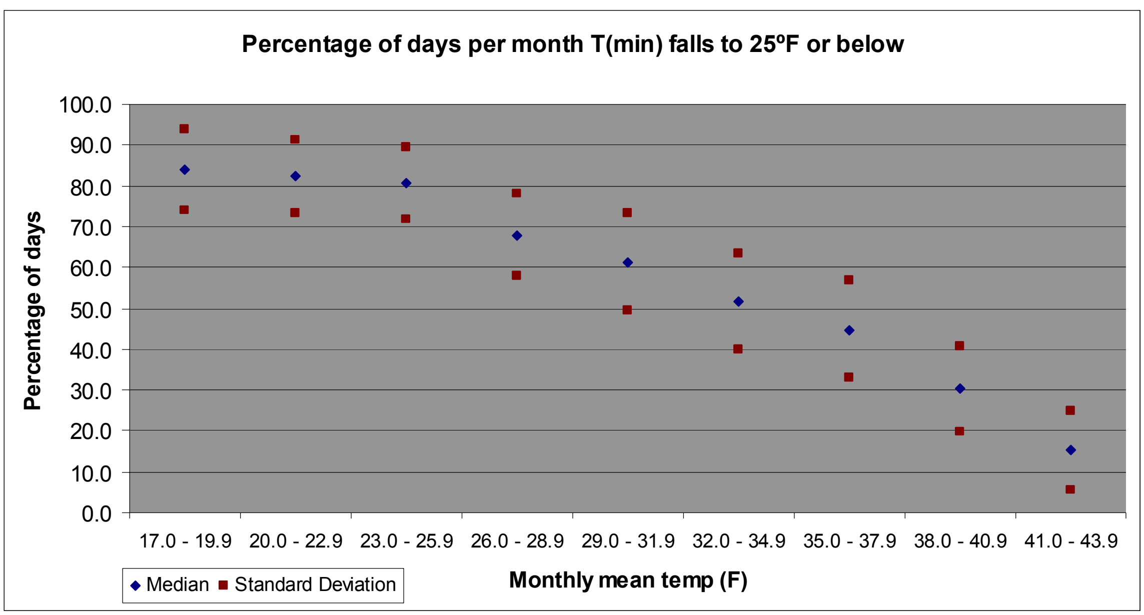


**Figure 2. Relationship between MMT and percentage of snowmaking days including +/- one standard deviation.**

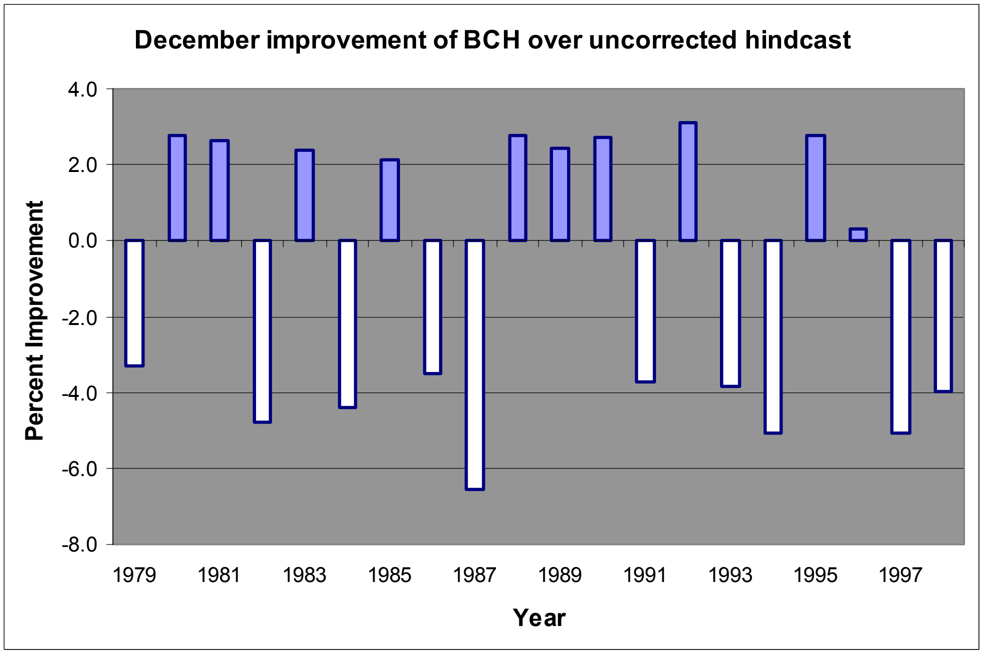


**Figure 3a. December BCH improvement.**

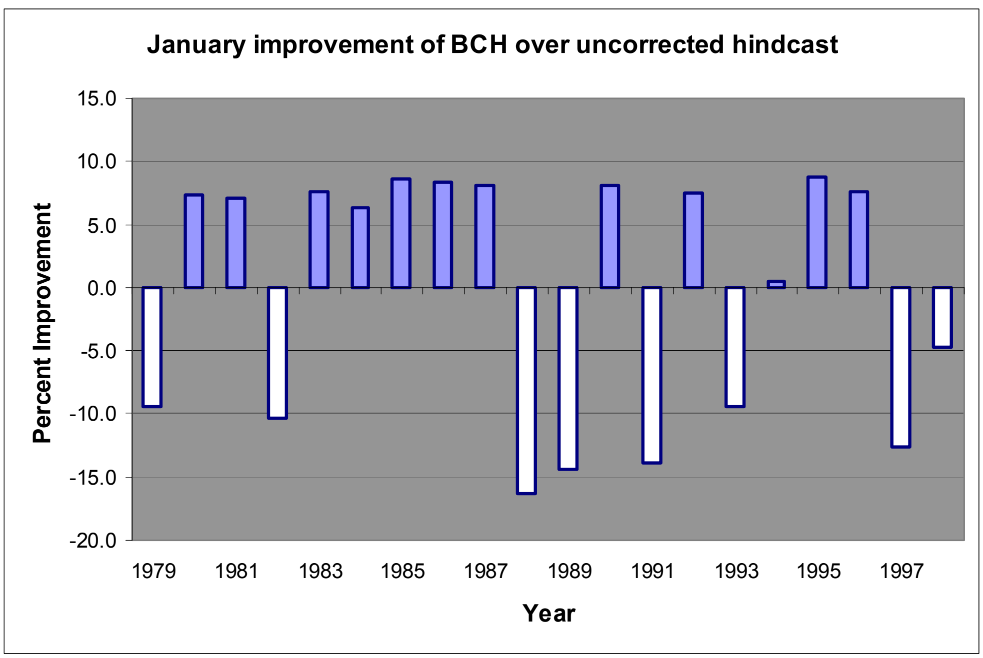


**Figure 3b. January BCH improvement.**

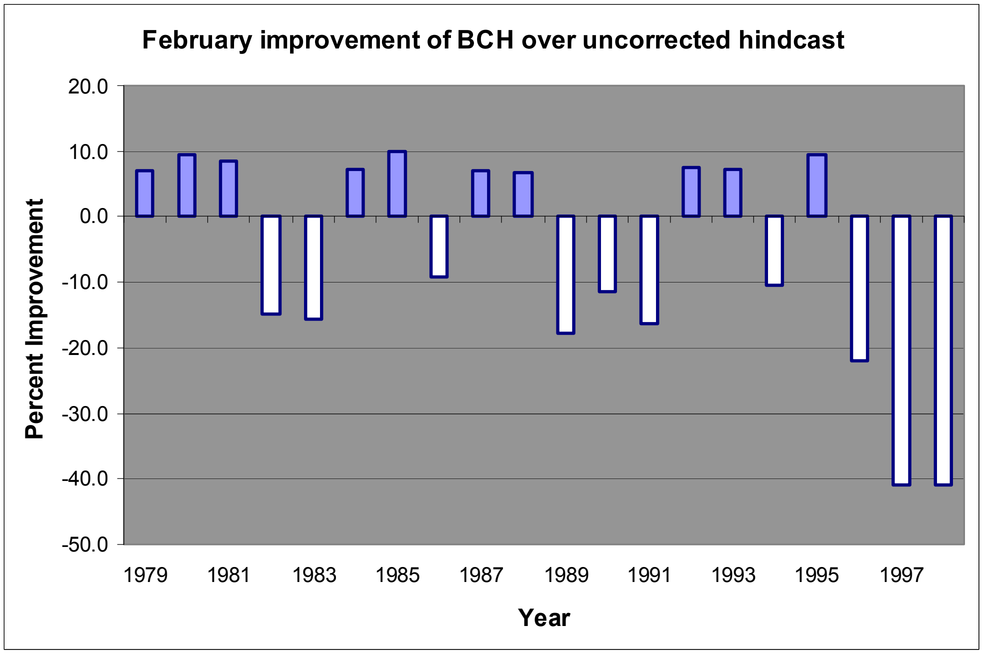


**Figure 3c. February BCH improvement.**

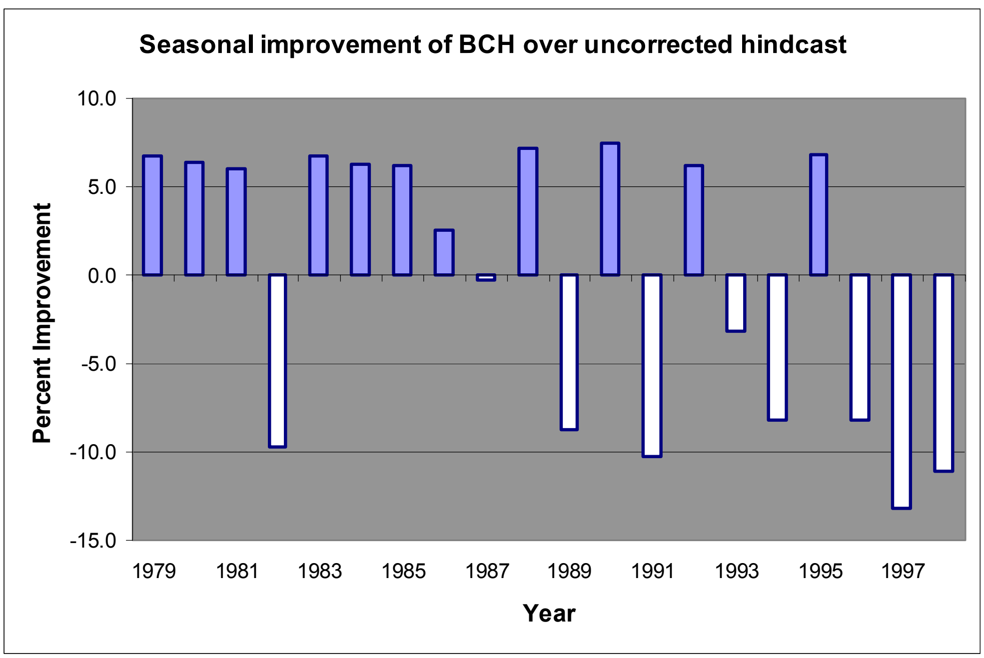


**Figure 3d. Seasonal BCH improvement.**

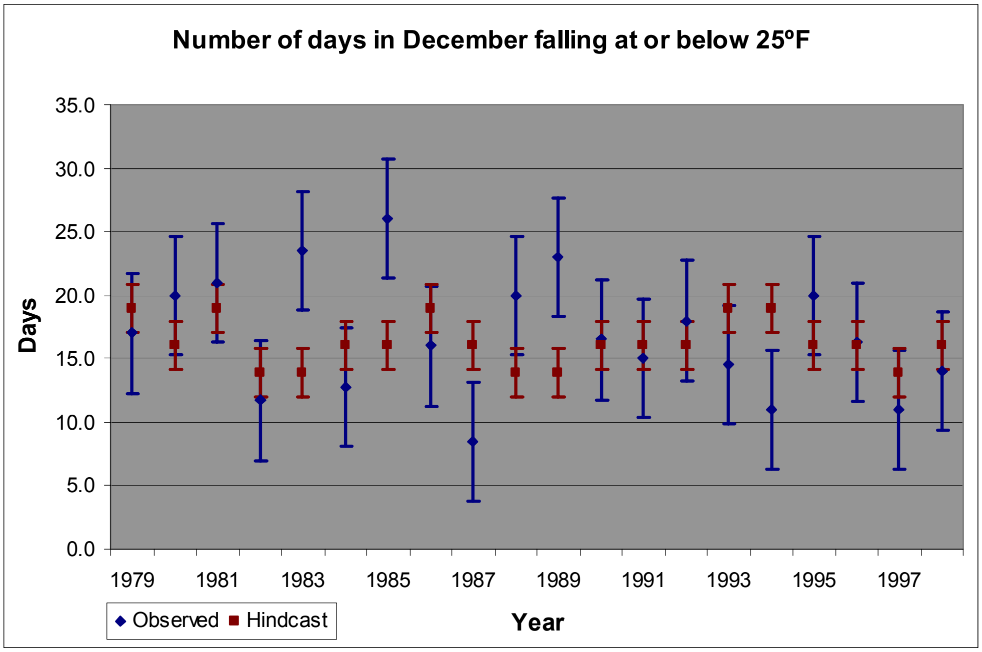


**Figure 4a. Number of days in December T(min) falls to 25ºF or below with error bars showing +/- one standard deviation.**

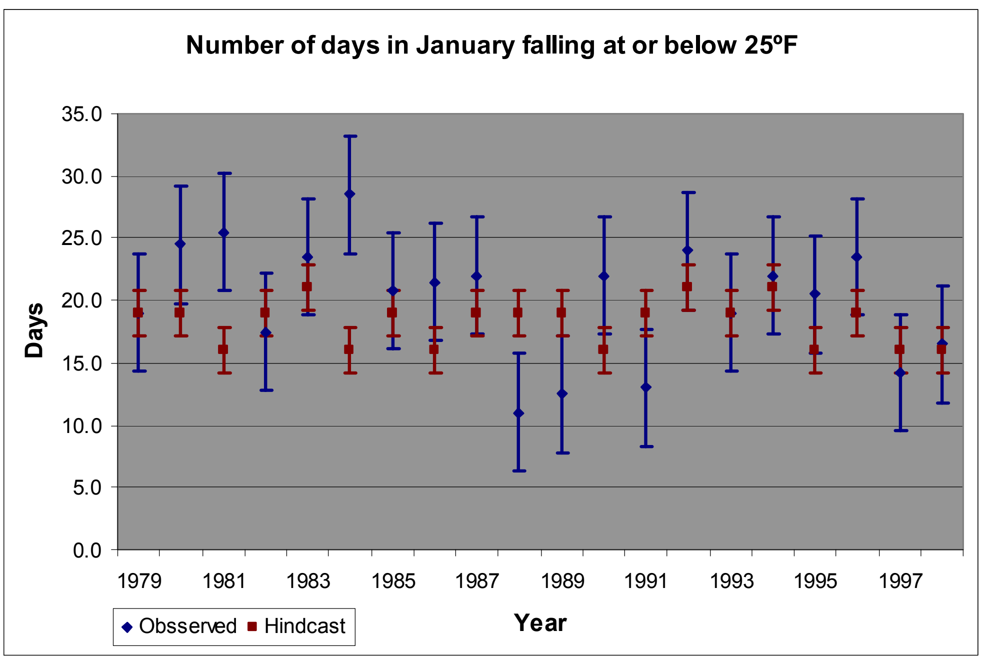


**Figure 4b. Number of days in January T(min) falls to 25ºF or below with error bars showing +/- one standard deviation.**

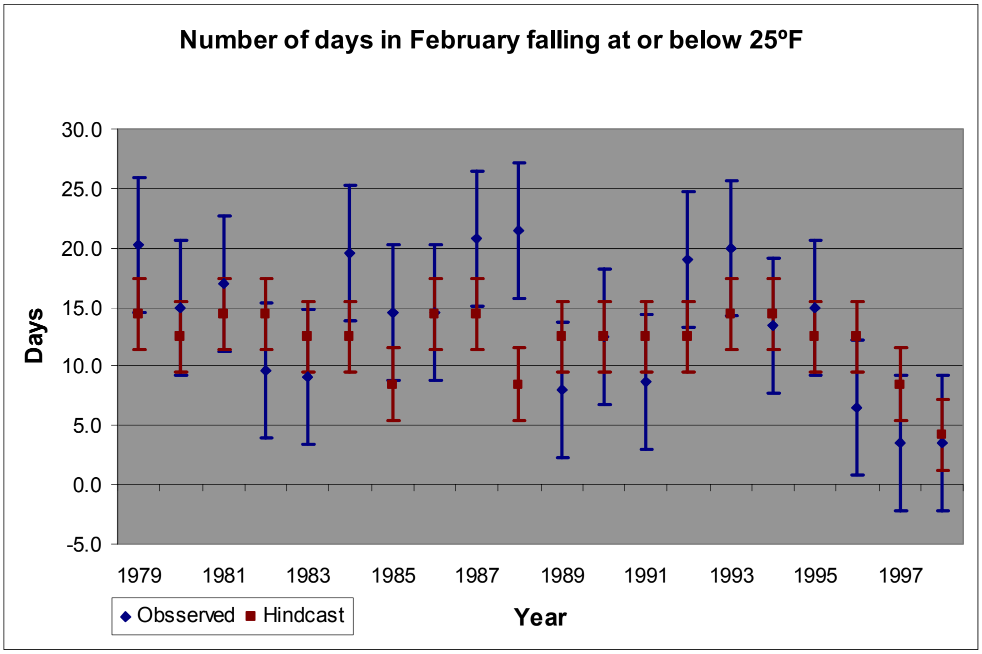


**Figure 4c. Number of days in February T(min) falls to 25ºF or below with error bars showing +/- one standard deviation.**