SEASONAL TEMPERATURE AND PRECIPITATION FORECASTS USING A CLIMATE PROBABILITY APPROACH: BUFFALO, NEW YORK

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ABSTRACT: *Spatially-derived seasonal temperature and precipitation forecasts are available from the Climate Prediction Center (CPC) based on complex algorithms. This study explores a simpler placed-based approach to predicting the conditions of future seasons, one simply based on the average weather of past seasons. The data used for this research includes average monthly temperatures and monthly precipitation totals, from December 1942 through to November 2008. The data were obtained from the Buffalo New York Office of the National Weather Service. The monthly data were first organized into four climatological seasons. By looking over the past 65 years of data, a seasonal forecast was developed based on the statistical probability of a 'forecast' season experiencing 'above' or 'below' average conditions, based on whether the 'predictor' season experienced 'above' or 'below' average condition. While most seasonal pairings (predictor season to forecast season) showed no statistical relationships, significant relationships were found for some seasonal pairings. The strongest of these pairing is a forecast relationship between winter and summer seasons. Thus, when winter temperatures are substantially above or below the seasonal average, 'like' conditions are forecast; and when winter precipitation is substantially above or below the seasonal average, 'unlike' conditions are forecasted, in each case 7.4 times out of 10. In other words, there is a 74% chance that a cold , wet winter forecasts a cold, dry summer. A handful of seasonal pairings appear to provide statistically significant seasonal forecasts. Local seasonal connections may be related to atmospheric teleconnections such as the El Niño Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) among others. These teleconnections offer a mechanism to account for season-to-season continuity or discontinuity.*

Keywords: *Climate, Forecasts, Probability, Temperature, Precipitation, Buffalo, New York*

INTRODUCTION

One of the most common questions faced by a meteorologist/climatologist after a review of the 'current season', is *"What will the next season be like?"* Responses may vary dependent on whether one believes our weather is random, in this case the answer will be "I don't know", or that our weather maintains an equilibrium, thus a warm summer will likely lead to a cold winter, or our weather is dictated by trends, thus a warm summer leads to a warmer winter—at least until conditions trigger a change. The question is not a trivial one, as agriculture, industry, transportation, commerce, tourism, and insurance are becoming more dependent on long range weather forecasts (Adams et al., 1995).

The "Old Farmer's Almanac" is arguably the most famous source of non-scientific seasonal forecasts in the United States. The Almanac contains seasonal forecasts for both the winter and summer for the entire continental US and for 16 regions within the United States. These forecasts include predictions on whether it is going to be warmer or cooler than normal and wetter or drier than normal. A 'normal' is defined as the most recent 30-year period, updated every decade. The founder of the Almanac, Robert B. Thomas, believed that sunspot activity influences our weather, thus sun spot activity and historical weather conditions remain at the heart of the Almanac's secret formula (Stillman, 2009). Secret formulas abound as a tool in forecasting seasonal weather, as used by companies such as WeatherWiz.com and DryDay.com.

The Climate Prediction Center (CPC) issues seasonal outlooks for the United States up to 13 months in advance. These seasonal outlooks provide the probability of temperatures or precipitation occurring at simple 'above' or 'below' normal conditions. However, the algorithm to determine these outlooks is complex, including analyses of various climatic oscillations—El Niño Southern Oscillation (ENSO), North Atlantic Oscillation (NOA), the Pacific Decadal Oscillation (PDO), and the Madden Julian Oscillation (MJO)—temperature and precipitation trends, persistence of wet and dry soils in the summer, snow and ice cover anomalies in the winter, as well as various dynamical and statistical forecast tools (Goddard et al., 2001). Unlike the "Old Farmer's Almanac" and other companies which issue weekly details in their long-range forecasts, the CPC lacks such detail in their forecasts, recognizing that chaos in the system limits detailed forecasts to about a two week outlook (Epstein, 1988; Williams, 2009).

A simple place-based approach to predicting the conditions of future seasons, one simply based on the average weather of past seasons, is attempted. For example, does the occurrence of a hot, dry summer foreshadow a cold, wet winter ahead? This research applies a statistical approach to the climatological seasons of Buffalo, NY, over the past 65 years, to determine if there is a statistical relationship between predictor and forecast seasons. The obvious advantage to this approach is that it is easy to calculate and specific to a particular place. While the focus of this research is on the climate of Buffalo, NY, the methodology described here can be applied to any city.

METHODOLOGY

The data used for this research includes average monthly temperatures and precipitation totals, from December 1942 through to November 2008. The data were obtained from the Buffalo New York Office of the National Weather Service. The period of study covers the time period when weather data were collected at the Greater Buffalo International Airport site—having moved in 1942 from downtown Buffalo, New York.

The monthly data were organized into four climatological seasons: Winter (December, January, and February); Spring (March, April, and May); Summer (June, July, and August); and Autumn (September, October, and November). Seasonal temperature averages and precipitation totals were calculated for each of the individual years. Subsequently, the yearly seasonal temperature averages and yearly precipitation totals were calculated to obtain averages for the entire data record.

Each year's seasonal average (total in the case of precipitation) were compared to the corresponding data record to determine if the yearly seasonal average was above (+) or below (-) the average for the entire data record. A climate-probability approach was then used to forecast future seasons based on the record of past seasons—predictor seasons (e.g. a past winter temperature used to forecast a summer temperature). The percentage of years that both seasons ('predictor' and 'forecast') were similar (both '+' or both '-') in the data record were labeled as 'like', whereas the percentage of years that the seasonal signs were different were labeled as 'unlike'. By looking over the past 65 years of data, a seasonal forecast can be developed based on the statistical probability of a 'forecast' season experiencing 'above' or 'below' average conditions, based on whether the 'predictor' season experienced 'above' or 'below' average conditions.

Seasonal means and standard deviations (STD) are shown for temperature and precipitation in Table 1. A chi-square test was used to determine the level at which a significant relationship exists between a 'predictor' and 'forecast' season. The chi-square test compares observed percentages with the expected percentage for each category. In this case, the expected percentage for both the 'like' and 'unlike' categories, or null hypothesis, is 50% (a coin toss). The chi-square test determines what observed percentages are significantly different from that of the null hypothesis at P=0.05.

Table1. Seasonal Mean and Standard Deviation Values for Temperature and Precipitation

Season	**Temperature (^{o}F)**		**Precipitation (inches)**	
	Mean	**STD**	**Mean**	**STD**
Winter	26.7	2.93	9.07	2.30
Spring	45.2	2.17	9.19	2.25
Summer	69.0	1.63	9.70	2.50
Fall	51.7	1.59	10.58	2.79

RESULTS AND DISCUSSION

Temperature

All 12 seasonal predictions and the percentage of times that seasonal temperatures were 'like' or 'unlike' are shown in Table 2. In most cases, the predictor/forecast seasons have a predictability hovering around 50% (a coin toss). It is interesting to note that 10 out of the 12 predictor/forecast season exhibit a 'like' comparison. This suggests that temperatures (warmer or cooler than average) persist beyond a single season.

Results of the chi-square test show that seasonal differences of ≥ 60% or ≤ 40% is considered significantly different (*p=0.05*) from the expected percentage of 50%. Thus at 61%, only the winter season provides a significant forecast for the summer season. In other words, below or above average winter temperatures forecast below or above average summer temperatures, 6.1 times out of 10.

Table 2. Seasonal Forecasts (Temperatures)

Seasons	Like	Unlike
Winter-Spring	53%	47%
Winter-Summer	**61%**	**39%**
Winter-Fall	45%	55%
Spring-Summer	56%	44%
Spring-Fall	52%	48%
Spring-Winter	54%	46%
Summer-Fall	55%	45%
Summer-Winter	54%	46%
Summer-Spring	45%	55%
Fall-Winter	51%	49%
Fall-Spring	49%	51%
Fall-Summer	51%	49%

Values in bold represent a significant difference.

Whether a predictor season which is substantially above or below its seasonal average is a better forecaster of future seasons was examined by considering only those predictor seasons with an average temperature of either 1°F or one standard deviation above or below the seasonal average (see Table 1). In other words, is a 'very' cold or warm winter a better predictor of summer conditions? In Table 3, the first two columns represent years where the predictor season was at least 1°F above or below the average. The second two columns represent years where the predictor season was at least 1 STD above or below the average. As shown in Table 3, the number of significant predictor/forecast seasons has jumped from one to four: winter to summer; summer to winter; summer to spring, and winter to fall. The winter to summer forecast percentage increases to 67% when temperatures vary by at least 1^{o}F from the winter average, and to 74% when the variation is at least one standard deviation. Thus, when winter temperatures are substantially above or below the seasonal average, 'like' conditions are forecast for the summer 7.4 times out of 10. Summer shows a barely significant predictability when temperatures are at least +/- 1^{o}F, but not +/- 1 STD. It is interesting to note that the 'like' pattern breaks down when the forecast period exceeds 9 months (62% 'unlike' for winter-fall, and 73% 'unlike' for summer-spring), suggesting a controlling mechanism that resets weather patterns on a yearly cycle, possibly dictated by changes in the winter season.

Table 3. Seasonal Forecasts when Temperature of Predictor Season is +/- 1°F or +/- STD from the Seasonal Average

Seasons	Like +/-1°F	Unlike +/-1°F	Like +/-STD	Unlike +/-STD
Winter-Spring	50%	50%	52%	48%
Winter-Summer	**67%**	**33%**	**74%**	**26%**
Winter-Fall	**38%**	**62%**	43%	57%
Spring-Summer	59%	41%	59%	41%
Spring-Fall	54%	46%	55%	45%
Spring-Winter	52%	48%	44%	55%
Summer-Fall	51%	49%	44%	56%
Summer-Winter	**61%**	**39%**	55%	44%
Summer-Spring	**27%**	**73%**	44%	56%
Fall-Winter	51%	49%	44%	48%
Fall-Spring	52%	48%	44%	56%
Fall-Summer	51%	49%	52%	48%

Values in bold represent a significant difference.

Precipitation

All 12 seasonal predictions and the percentage of times that seasonal precipitation was 'like' or 'unlike' are shown in Table 4. As with temperature, most of the comparisons favor the 'like' category, suggesting that precipitation patterns may persist beyond seasonal time scales. As shown in Table 4, only two of the 12 seasonal predictions are significant: winter to summer; and fall to summer. Unlike temperatures, there is a significant probability of 'unlike' conditions for winter to summer forecasts. In other words, a total precipitation below or above winter averages will forecast above or below average precipitation totals for the summer 6.5 times out of 10, respectively.

Table 4. Seasonal Forecasts (Precipitation)

Seasons	Like	Unlike
Winter-Spring	56%	44%
Winter-Summer	**35%**	**65%**
Winter-Fall	55%	45%
Spring-Summer	52%	48%
Spring-Fall	41%	59%
Spring-Winter	57%	43%
Summer-Fall	53%	47%
Summer-Winter	53%	47%
Summer-Spring	48%	52%
Fall-Winter	47%	53%
Fall-Spring	41%	59%
Fall-Summer	**63%**	**37%**

Values in bold represent a significant difference.

As with temperature, this study also looked at how the forecasting percentages may change if the predictor season was substantially above or below the average precipitation for that season, either +/- 1 inch or +/- 1 STD of precipitation (see Table 1). As shown in Table 5, five of the predicting seasons are significant: winter to summer; spring to summer; fall to summer; spring to winter; and winter to fall. As in Table 4, the winter to summer forecast strengthens support for 'unlike' conditions. Thus, when winter precipitation is substantially above or below the seasonal average (> STD), 'unlike' conditions are forecast 7.4 times out of 10. Similarly, a substantially wet or dry winter forecasts 'unlike' conditions for the fall (7.0 times out of 10). This 'unlike' pattern suggests a controlling mechanism that varies on a yearly cycle, but in the case of precipitation, is reset by changes in the winter season.

Table 5. Seasonal Forecasts when Precipitation Predictor Season is +/- 1" or +/- STD of Seasonal Precipitation Amount

Seasons	Like +/- 1"	Unlike +/-1"	Like +/- STD	Unlike +/-STD
Winter-Spring	52%	48%	45%	55%
Winter-Summer	**38%**	**62%**	**26%**	**74%**
Winter-Fall	55%	45%	**30%**	**70%**
Spring-Summer	55%	45%	**63%**	**37%**
Spring-Fall	45%	55%	42%	58%
Spring-Winter	**61%**	**39%**	**68%**	**32%**
Summer-Fall	53%	47%	50%	50%
Summer-Winter	52%	48%	57%	43%
Summer-Spring	41%	59%	**35%**	**65%**
Fall-Winter	49%	51%	55%	45%
Fall-Spring	44%	46%	**36%**	**64%**
Fall-Summer	**69%**	**31%**	50%	50%

Values in bold represent a significant difference.

Teleconnections

While most predictor/forecast seasonal pairings appear random, there are a handful of seasonal pairings that appear to provide a statistically significant seasonal forecast. It is unreasonable to expect that the rhythm of the seasons, with regard to above or below normal seasonal conditions, would change or remain unchanged with any predictability given a change of calendar date and the apparent randomness of weather. However, there are possible mechanisms that can explain connections between seasons. It can be stated that local weather is determined by global climate. This statement refers to atmospheric 'teleconnections'. Such connections may be found in a number of atmospheric oscillations or teleconnections, such as the El Niño Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), the North Atlantic Oscillation (NAO), and the Arctic Oscillation (AO) to name a few with implications to North America's climate (Aguado and Burt, 2007; Hurrell et al., 2003; Glantz, 2002). A quick review of the Oceanic Niño Index (ONI)—the standard used by NOAA to identify El Niño and La Niña events—reveals that these events and neutral conditions typically extend beyond six months. Specific to Buffalo, NY, both ENSO and NAO events have been shown to have an impact on winter temperatures (Hamilton, 2005). Interestingly, this impact may be enhanced or hindered by combining teleconnections. For example, an ENSO event occurring at the same time as a positive NAO results in an additional warming, while an ENSO event occurring at the same time as a negative NAO results in a cooling. While the cause and effect of these teleconnections are beyond the scope of this paper, there is ample evidence to support long term trends and global controls on local climate.

CONCLUSIONS

While most predictor/forecast seasonal pairings show an insignificant 'randomness' to predicting future seasonal temperatures and precipitation, there are a handful of seasonal pairings that provide a statistically significant seasonal forecast. The strongest of these pairings is winter-summer, where 'winter' conditions serve as a predictor of 'summer' temperature and precipitation. In the case of temperature, 'like' conditions are forecasted between winter and summer (i.e. a warmer than average winter forecasts a warmer than average summer), while for precipitation 'unlike' conditions are forecasted. (i.e. a wetter than average winter forecasts a drier than average summer). The probability of these forecasts strengthened the greater the winter anomaly—winter temperature and precipitation anomalies greater than 1 STD provide a 74% probability for summer conditions. For temperature, other significant seasonal pairings include: summer-winter ('like'), summer-spring ('unlike'), and winter-fall ('unlike'). For precipitation, other significant seasonal pairings include: spring-summer ('like'), fall-summer ('like'), spring-winter ('like'), and winter-fall ('unlike'). Teleconnections such as ENSO and NAO are likely contributors to local season-to-season climate continuity or discontinuity.

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