18th Conference on Applied Climatology / 90th Annual Meeting of the American Meteorological Society 17 – 21 January, 2010, Atlanta, GA

P549 NEW HAMPSHIRE PRECIPITATION PATTERNS 2005-2009: A CLIMATOLOGICAL PRESPECTIVE

Mary D. Stampone

New Hampshire State Climate Office
Department of Geography
102 Huddleston Hall
University of New Hampshire
Durham, NH 03824

1. INTRODUCTION

The period of record from 2005 through 2009 has been characterized by five consecutive years of above average total annual precipitation for the state of New Hampshire. Although the type, intensity and intra-annual distribution of precipitation varied, some of the highest total monthly, seasonal, and annual precipitation amounts for the state were recorded during this period. The years 2008, 2005 and 2006 are the top three wettest years statewide since records began, while 2007 and 2009 rank within the top 20 wettest years (NCDC, 2010).

However extreme these events may seem, this recent wet period is not entirely unique within New Hampshire's climatological record. Statistical analysis of total annual precipitation for six New Hampshire stations, with records dating back to 1895 (NCDC, 2010) indicate that similar periods of consecutive years of significantly above average precipitation (1897-1902, 1936-1938, and 1951-1954) have occurred throughout the period of record. Other multi-year periods of above average precipitation, but not significantly so, also occur within the record and typically ranged in duration from three to five years. Periods characterized by consecutive years of above average precipitation tend to be separated by several years of average to below average total annual precipitation.

This pattern dominates the time series prior to 1970, when a pattern of high inter-annual variability emerges. For southern parts of the state, the period of high inter-annual variability that began around 1970 ends in 2004 with the onset of five consecutive years of above average precipitation. In addition to the change in the character of inter-annual variability across observed break points, each break point is followed by a period of higher average total annual precipitation than the preceding period.

*Corresponding author address: Mary Stampone, New Hampshire State Climate Office, Dept. of Geography, 102 Huddleston Hall, University of New Hampshire, Durham, NH 03824. E-mail: mary.stampone@unh.edu.

2. STATION SELECTION AND ANALYSIS

Time series of total annual precipitation, including rainfall and liquid water equivalent snowfall, for six New Hampshire COOP stations representing both climate zones were evaluated for the presence of break points (Figure 1). Station data were obtained from the National Climatic Data Center (NCDC) Climatological Data Publications for New England (1895-2009). Each station was established at or near its current location prior to 1900 and remains operational to the present (Table 1). Observations of total annual precipitation at Concord, Keene, and Nashua are over 90 % complete from 1895 to 2009 (inclusive) and the Durham time series is over 90 % complete for 1896 to 2009 (inclusive). Earlier records from Berlin and Nashua contain extended periods of no data and although these records are displayed graphically (Figure 2), they were not used in analysis.

Break points within each station record were determined using the student's t-test, which compares the significance of the differences between the means of two population samples (von Storch and Zwiers, 2003). The means of the two samples are assumed to be approximately the same (null hypothesis H_0: $\mu_1 = \mu_2$) unless the *t* value for the sample means falls within the critical region for the chosen significance level (α) and degree of freedom (ν). The *t* value for the means of two samples taken from the original dataset was determined by:

$$t_{n_1,n_2} = \left(\overline{X}_1 - \overline{X}_2\right)S^{-1} \quad (1)$$

where $\overline{X}_1$ and $\overline{X}_2$ are the means of two samples of size n_1 and n_2 respectively, $n_1 + n_2$ equals the total number of years (n), and S represents an estimate of the pooled sample standard deviation.

The null hypothesis was rejected in favor of an alternative hypothesis (H_a: $\mu_1 \neq \mu_2$) for samples in which t_{n_1,n_2} falls within the critical region for a 95 % confidence level. With respect to the two-tailed test, H_0

Table 1: Information on the location and period of record for the six COOP stations used in this study (NCDC).

Station	Latitude	Longitude	Elevation (ft)	Climate Zone	Total Record Length	Period of Record Analyzed
Berlin	44.4486	-71.1841	930	01 - Northern	115	1918 - 2009
Concord	43.1952	-71.5011	346	02 - Southern	155	1895 - 2009
Durham	43.1500	-70.9500	80	02 - Southern	115	1896 - 2009
Hanover	43.7032	-72.2848	603	02 - Southern	167	1895 - 2009
Keene	42.9390	-72.3247	511	02 - Southern	117	1895 - 2009
Nashua	42.7911	-71.4733	140	02 - Southern	125	1925 - 2009

was rejected for $\left|t_{n_1,n_2}\right| \geq t_{\alpha/2,\nu}$ where $\alpha = 0.05$ and to period two ($\overline{X}_2$, n_2) was identified as a point $\nu = n_1 + n_2 - 2$. In cases where H_0 was rejected, the year representing the transition from period one ($\overline{X}_1$, n_1) in time in which the average total annual precipitation for period two was significantly higher ($+t_{n_1,n_2}$) or lower ($-t_{n_1,n_2}$) than that of period one.

3. RESULTS

The amount of total annual precipitation received at six stations in New Hampshire throughout the 20th century vary both temporally and spatially; however, several consistent patterns are present. Evaluation of temporal patterns in total annual precipitation indicates that most station records contain multiple break points in the temporal distribution of total annual precipitation (Table 2). Observed break points may be indicative of discontinuities within the time series in response to changes in station location or as a function of the series length and/or starting point. Break points that cannot be attributed to station modifications or limitations within the observation record may be indicative of real changes in the amount and temporal distribution of total annual precipitation.

Table 2: Occurrence of statistically significant break points in total annual precipitation time series (1895 – 2009) for six stations in New Hampshire.

Station	Break Points
Berlin	*1971*, 1994
Concord	1932, 1967, 2004
Durham	1932, 1982, 2004
Hanover	1930, 1967, 2004
Keene	1932, 1971, *2001*
Nashua	1951, 1971, 2004

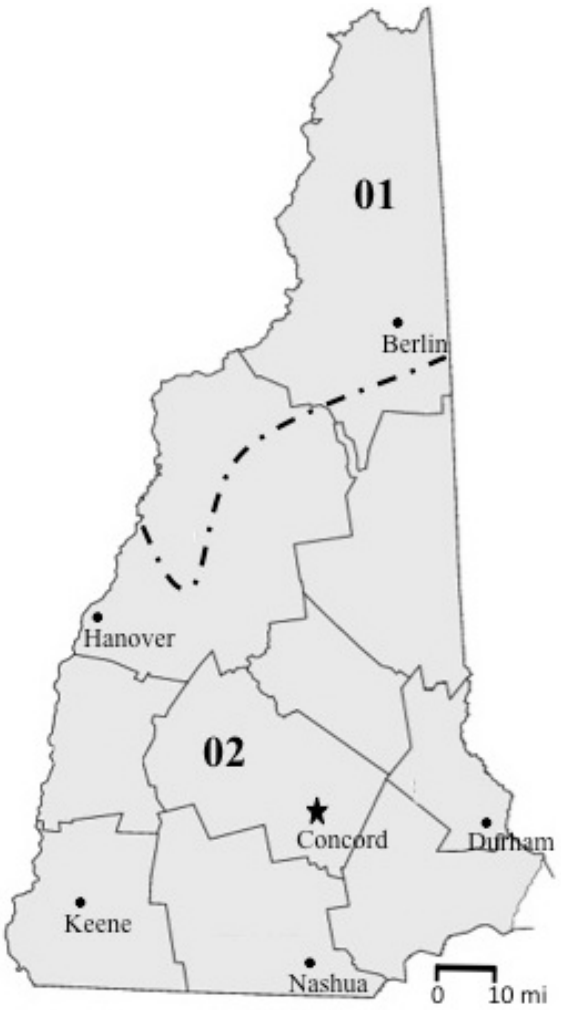

Figure 1: Location of New Hampshire stations with climate records for the period 1895 to 2009 inclusive.

Review of station metadata indicates several discontinuities resulting from station modifications. These years are indicated in italics in Table 2. Break points at 1971 within the Berlin record and 2001 at Keene coincide with notable station relocations resulting in a change in station elevation. Break points occur earlier in the record at Concord, Durham and Keene (1930) and at Hanover (1932) however there is a lack of metadata for these stations prior to 1933. It is therefore unclear whether or not this is due to station changes, a product of the period of record, or a climatologically significant change in the character and distribution of total annual precipitation. Due to the lack of station metadata for the earliest decades of each record, the earliest break points must be also viewed with caution.

Break points that are independent of station modifications are found in all stations and tend to occur at or near the same time period. Coincident break point occurs at 1967 at Concord and Hanover and a few years later in 1971 at the southernmost stations of Keene and Nashua. The most spatially consistent break point occurred during 2004 at all stations located within climate zone 02 with the exception of Keene, which had a station relocation in 2001. Although the timing of break points is fairly consistent across stations located within climate zone 02, the time series at Berlin (climate zone 01) does not align with the others. The lack of long-term records within climate zone 01 limits interpretation of the differences between the occurrence of break points between the two climate zones.

In addition to the timing of break points, the average total annual precipitation for the period following each point is significantly higher than the preceding period at the 99 % significance level for all stations. Within climate zone 02, the earliest decades of the 20th century represent the “driest” period on record while the past five years represent the “wettest” period. Although precipitation totals for Berlin (climate zone 01) follow the statewide trend of being above average from 2005 to 2009, this period is not significant with respect to the entire record.

The interannual distribution of total annual precipitation also changes across the 1967/71 and 2004 break points. Prior to 1967/71, interannual precipitation patterns tend to be cyclical between “wet” and “dry” years with periodicities of 5 to 7 years. The change from multiyear precipitation cycles to high interannual variability also changes around 1970 at Durham, but this does not coincide with the break point in total annual precipitation, which occurs later in the record. Between 1967/71 and 2004, the pattern becomes highly variable from year to year with no discernible multiyear pattern. The most recent period beginning at the 2004 break point is characterized by five consecutive years of above average precipitation, peaking at the Seacoast stations of Concord, Durham and Nashua in 2008.

4. CONCLUSIONS

Although periods characterized by several consecutive years of above average total annual precipitation are present in long-term precipitation records statewide, few, if any, of these periods has resulted in cumulative total precipitation amounts as high as that of 2005 to 2009. The years 2005, 2006 and 2008 rank as the top three years in terms of total annual precipitation over the period of record at Concord, Keene and Nashua and rank within the top five at Durham and Hanover. Although the years 2005 to 2009 were above average for the period of record at Berlin, only 2005 ranked within the top five wettest years.

Statewide, total annual precipitation amounts and variability can be defined by three or four periods bound by break points that are statistically significant at the 99 % significance level. Total annual precipitation increases across each break point and for many stations, later break points coincide with a change in the pattern of interannual precipitation as well.

The geographic distribution of break points indicates that there may be a spatial pattern in the occurrence of transitional years. Of the two most spatially consistent break points observed at 1967/71 and 2004, the former follows a period of below average precipitation present at all six stations during the 1960’s. This transition to the wetter, more variable interannual pattern observed during the 1971 to 2000 climate normal period began a few years earlier within central and western parts of the state than it did in the south and east.

The most striking pattern is the mid-2000’s transition to the most recent wet period, which was observed only at stations located within climate zone 02. This transition marks the beginning of the recent period of consecutive years of above average total annual precipitation. Moreover, the total annual precipitation amount received from 2005 through 2009, as well as the difference from the mean, decreases north and west throughout the state.

Examination of total annual precipitation within the context of long-term climate records results in the following general conclusions.

- The period of record from 2004 through 2009 has a higher average total annual precipitation at the 99 % significance level than the preceding period record for the stations analyzed within climate zone 02.

- Periods of three to five consecutive years of above average precipitation are common at stations within climate zone 02 during the period of record beginning in the early 1930’s to approximately 1970. These periods were usually followed by longer periods of average to below average total annual precipitation.

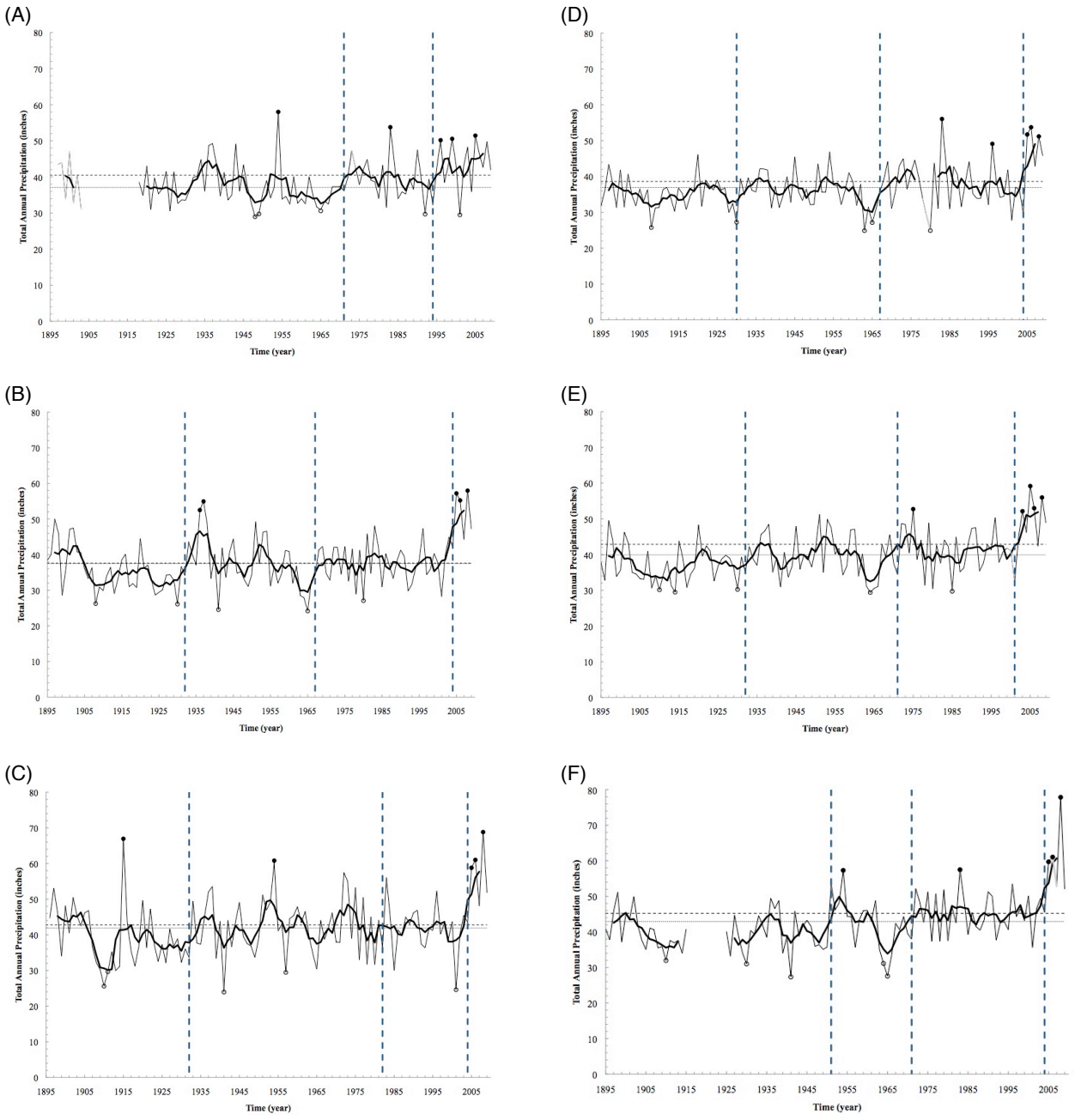

Figure 2: Total annual precipitation (thin) for (A) Berlin, (B) Concord, (C) Durham, (D) Hanover, (E) Keene and (F) Nashua, New Hampshire from 1895 to 2009 along with the five-year average (thick), average annual precipitation for the period of record (dotted), average total annual precipitation for the climate normal period 1971-2000 (dashed) and statistically significant break points (vertical dashed). Filled/open circles indicate the top five wettest/driest years for the period of record.

- Amount and interannual variability in total annual precipitation decreases north and west within the state.

- The climate record for Berlin, located within climate zone 01, does not follow the patterns identified within the records for stations located in climate zone 02.

5. ACKNOWLEDGEMENTS

The author would like to thank the National Weather Service Forecast Offices at Gray, ME and Taunton, MA for preliminary New Hampshire data for 2009 and Sandra Coit and Kaitlin Cole of the Department of Geography at the University of New Hampshire for assistance with digitizing and organizing the climate records used in this study.

6. REFERENCES

National Climatic Data Center (NCDC)/National Environmental Satellite, Data, and Information Service (NESDIS), 2010: NOAA Satellite and Information Service. National Climatic Data Center, Asheville, NC.

von Storch, H. and F.W. Zwiers, 2003: *Statistical Analysis in Climate Research*. Cambridge University Press, 484 pp.