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Subseasonal climate variability for North Carolina, United States

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ABSTRACT

Subseasonal trends in climate variability for maximum temperature (T_{max}), minimum temperature (T_{min}) and precipitation were evaluated for 249 ground-based stations in North Carolina for 1950–2009. The magnitude and significance of the trends at all stations were determined using the non-parametric Theil–Sen Approach (TSA) and the Mann–Kendall (MK) test, respectively. The Sequential Mann–Kendall (SQMK) test was also applied to find the initiation of abrupt trend changes. The lag-1 serial correlation and double mass curve were employed to address the data independency and homogeneity. Using the MK trend test, statistically significant (confidence level ≥ 95% in two-tailed test) decreasing (increasing) trends by 44% (45%) of stations were found in May (June). In general, trends were decreased in T_{max} and increased in T_{min} data series in subseasonal scale. Using the TSA method, the magnitude of lowest (highest) decreasing (increasing) trend in T_{max} is −0.050 °C/year (+0.052 °C/year) in the monthly series for May (March) and for T_{min} is −0.055 °C/year (+0.075 °C/year) in February (December). For the precipitation time series using the TSA method, it was found that the highest (lowest) magnitude of 1.00 mm/year (−1.20 mm/year) is in September (February). The overall trends in precipitation data series were not significant at the 95% confidence level except that 17% of stations were found to have significant (confidence level ≥ 95% in two-tailed test) decreasing trends in February. The statistically significant trend test results were used to develop a spatial distribution of trends: May for T_{max}, June for T_{min}, and February for precipitation. A correlative analysis of significant temperature and precipitation trend results was examined with respect to large scale circulation modes (North Atlantic Oscillation (NAO) and Southern Oscillation Index (SOI)). A negative NAO index (positive-El Niño Southern Oscillation (ENSO) index) was found to be associated with the decreasing precipitation in February during 1960–1980 (2000–2009). The incremental trend in T_{min} in the inter-seasonal (April–October) time scale can be associated with the positive NAO index during 1970–2000.

1. Introduction

Temperature and precipitation are two most important climate parameters that are most studied in climate studies because of their immediate impact in various socio-economic sectors (e.g., agriculture and hydrology) including human comfort. A number of studies have been performed to investigate trends in temperature and precipitation records in the U.S. and across the globe. For example, Wang et al. (2009) have found positive precipitation trends in the U.S. with the largest positive trend over the central and southern U.S. in the fall season. Similarly, Karl and Knight (1998)

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showed that between 1910 and 1996, annual precipitation increased 10% across the U.S. during the period 1910–1996. Total precipitation has also increased during the last several decades in the eastern U.S. (Small et al., 2006).

Positive temperature trends of surface air temperature during the winter (December–February; DJF), spring (March–May; MAM), and early summer (June–August; JJA) along with a modest country wide negative trend in late summer and fall (September–November; SON) have been found over the U.S. during 1950–2000 (Wang et al., 2009). Trenberth et al. (2007) concluded that the southeastern U.S. is one of the few regions of the Earth showing a cooling trend during the twentieth century. Portmann et al. (2009) added that this cooling trend is strongest in the late spring–early summer period.

Several researches noted that global-scale historic climate observations are less useful for local/regional scale planning (Barsugli et al., 2009; Brekke et al., 2009). Portmann et al. (2009) suggested that changes in climate during the twentieth century are varying from region to region across the U.S. Thus, it is important to analyze climate variability on a local scale, especially in regions that exhibit complex weather patterns, e.g. North Carolina (NC).

The altitude variation from the eastern Atlantic coast to the western mountains provides NC with one of the most complex climates in the U.S. (Boyles and Raman, 2003; Robinson, 2005). The average temperature of NC varies more than 20 °F from the lower coast to the highest elevations in all seasons of the year. Southwestern NC is the rainiest region in the eastern U.S., receiving 90 in. of rainfall annually in association with additional orographic lifting of the mountain chains. Less than 50 miles from this region to the north in the valley of the French Broad River is the driest point south of Virginia and east of the Mississippi River (State climate office of North Carolina, 2013).

Boyles and Raman (2003) studied temperature and precipitation trends on seasonal and annual time scales for 1949–1998 utilizing 75 precipitation measuring stations in NC. Linear time series slopes were analyzed to investigate the spatial and temporal trends of precipitation. They found a warmer temperature trend during the 1990s and the warmest being 1950. They also found the wettest precipitation trend during the 1990s.

Though mean surface temperature has been used by researchers for climate variability analysis, mean temperature trends may not truly represent the variations and physical processes that can be explained by maximum temperature (T_{max}) and minimum temperature (T_{min}; Christy, 2002; Christy et al., 2009). In this study, we examine climate variability (trends of T_{max}, $T_{min,}$ and precipitation) on a subseasonal scale for the period 1950–2009 by analyzing 249 ground-based weather station records across NC.

2. Data sets and methodology

In this study, Matlab R2012b was used to implement analysis algorithms. Arc-GIS 10.0 was used for data mapping.

2.1. Climatic regions and data sets

In this study, 249 meteorological observation stations with long term (January 1, 1950–December 31, 2009) daily T_{max}, T_{min} and precipitation records across NC were used. The datasets were collected from USDA-ARS (2012), which have been facilitated and quality controlled by the National Oceanic and Atmospheric Administration (NOAA), Cooperative Observer network (COOP) and Weather Bureau–Army–Navy (WBAN) ground based stations. We consider the data sets of the stations based on record length, record completeness, spatial coverage, and historical stability over the study period (1950–2009). These datasets are 99.99% complete (USDA-ARS, 2012) and found to be of high quality.

As discussed above, this study utilizes a dense network of observational data (249 stations in 136,000 km^2) than a previous study of Boyles and Raman (2003) for the same region. The spatial distribution of the meteorological observation stations across NC is shown in Fig. 1. NC topography ranges from sea level in the Atlantic coast to 6684 ft at the summit of Mount Mitchell, the highest peak in the eastern U.S. (Robinson, 2005). Thus, NC represents one of the most complex climates in the U.S. Fig. 2 shows the climatological T_{max}, $T_{min,}$ and precipitation monthly scale distribution in NC for 1950–2009.

2.2. Homogeneity of data

Instrumentation and alteration of surrounding land cover might create non-homogeneity and/or inconsistencies in hydro-meteorological data recordings (Gocic and Trajkovic, 2013; Tabari et al., 2011; Tabari and Hosseinzadeh Talaee, 2011). In our study, a double mass curve (Gocic and Trajkovic, 2013; Tabari et al., 2011; Tabari and Hosseinzadeh Talaee, 2011) was used in addition to the agencies' quality check to detect the non-homogeneity and/or inconsistencies of the data sets. If relocation affects the observation data sets, a significant jump around the relocated year should be noticed. No jumps were noticed with direct visualization when we employed double mass curve analysis of T_{max}, T_{min} and precipitation data series within the study period.

2.3. Trend test

Various statistical methods have been utilized over the years to study climatological variables (Gocic and Trajkovic, 2013; Martinez et al., 2012; Modarres and Sarhadi, 2009; Sonali and Nagesh, 2013; Tabari et al., 2011; Tabari and Hosseinzadeh Talaee, 2011). Non-parametric methods have been favored over parametric methods due to their robustness and flexibility (Sonali and Nagesh, 2013). In this study, the statistical significance of a trend in time series is assessed using the MK test, which is a rank based non-parametric test (Mann, 1945; Kendall, 1975). The MK test has been widely used to detect trends in hydro-meteorological time series (Gocic and Trajkovic, 2013; Martinez et al., 2012; Modarres and Sarhadi, 2009; Sonali and Nagesh, 2013; Tabari et al., 2011; Tabari and Hosseinzadeh Talaee, 2011). We have applied the MK test to detect if a trend in $T_{max,}$ $T_{min,}$ and precipitation in monthly time series is statistically significant at the 99% and 95% confidence levels for 1950–2009.

2.4. Trend magnitude

To complement the climate variability analysis, trend magnitude is required in addition to the trend significance.