Time series trend analysis of Temperature and Precipitation in North Carolina

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Introduction

- Temperature and Precipitation are two important components to assess climate variability.
- Historic monthly climate variability was analyzed for North Carolina, USA.
- North Carolina has one of the most complex climates in the United States. The average temperature varies more than 20°F from the lower coast to the highest elevations in all the season of the year. Average annual temperature on the southern part of the lower coast is nearly as high as that of interior northern Florida, while the average on the summit of Mount Mitchell is lower than that of Buffalo, NY (Robinson,2005). Southwestern North Carolina is the rainiest in the eastern United States, receiving 90 inches of rainfall annually due to southerly winds being forced upward in passing over the mountain barrier, whereas less than 50 miles from this region to the north, in the valley of the French Broad river, surrounded by mountain ranges on all sides, is the driest point south of Virginia and east of the Mississippi river (Robinson,2005).
- Maximum temperature (T_{max}), minimum temperature (T_{min}) and precipitation were evaluated for 249 ground-based stations in North Carolina for the period of 1950-2009. The significance and magnitude of the trends at all stations were determined using the non-parametric Mann-Kendall (MK) test and Theil-Sen Approach (TSA), respectively. The Sequential Mann-Kendall (SQMK) was also applied to find the initiation of abrupt trend changes. Lag-1 serial correlation and double mass curve were employed to address the data independency and homogeneity.

Study Area, Datasets and Tools

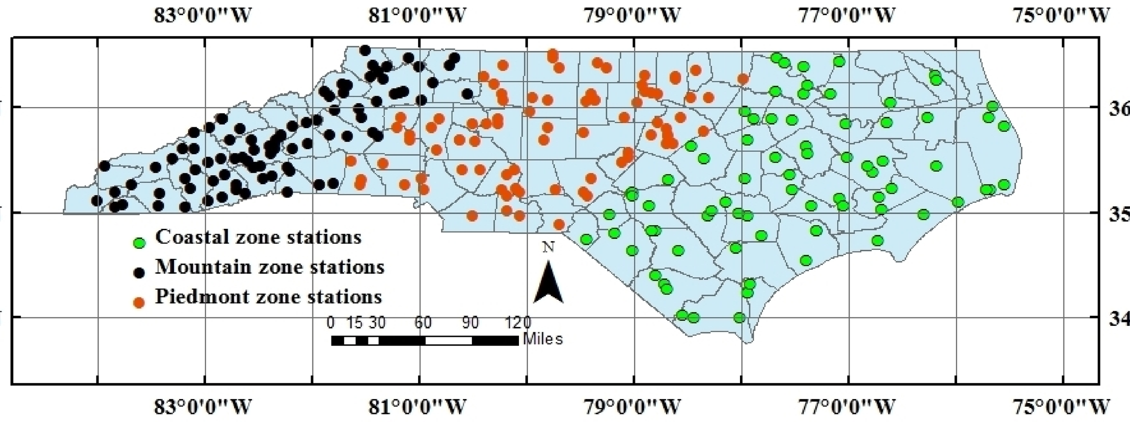


Fig. 1: Distribution of NOAA (COOP and WBAN) 249 ground based weather stations over North Carolina.

Data sets

- Data sets were collected from USDA-ARS (2012).
- These datasets were facilitated and quality controlled by National Oceanic and Atmospheric Administration (**NOAA**), which includes the meteorological stations of both Cooperative Observer network (**COOP**) and Weather-Bureau-Army-Navy (**WBAN**). These datasets are 99.99% complete.
- **Double mass curve** was used in addition with the agencies quality check to detect the **non-homogeneity/inconsistency.**

Tools:

- **Matlab R2012b**
- **ArcGIS 10.0**

Methodology

Trend test by Mann-Kendall (MK):

- The MK test is one of the most widely used non-parametric tests to detect trends in hydro-meteorological time series.
- Salient features:(i) low sensitive for non-homogeneous/inconsistent data sets (Modarres and Sarhadi, 2009), and (ii) it doesn't require the data sets to follow any particular distribution (Gocic and Trajkovic 2013).
- We've applied the MK test to detect if a trend in the temperature (maximum, minimum) and precipitation in monthly time series is statistically significant at 99% and 95% confidence levels over the period 1950~2009. At the 95% and 99% confidence levels, the null hypothesis of no trend is rejected if standard normal test statistics (Z_S) are: $|Z_S| > 1.96$ and $|Z_S| > 2.576$, respectively.

Trend magnitude by Theil-Sen Approach (TSA):

- The MK test does not provide an estimate of the magnitude of the trend. For this purpose, a nonparametric method referred to as the Theil-Sen approach (TSA) is used.
- This approach provides a more robust slope estimate than the least-squares method because it is insensitive to outliers or extreme values and competes well against simple least squares even for normally distributed data in the time series

Trend shift prediction by Sequential Mann-Kendall (SQMK) test:

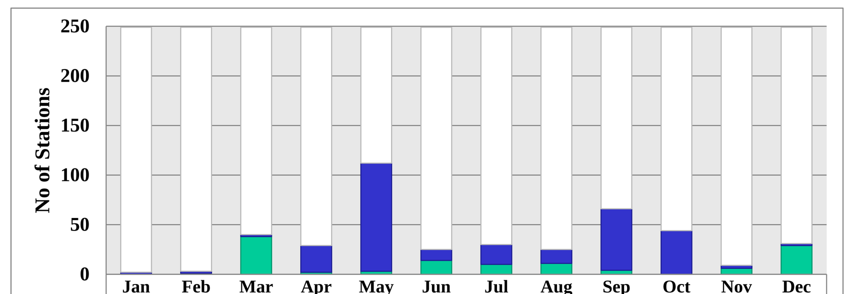
- SQMK test is an extension of the MK method that is widely used to detect the time when trend has a shift.
- SQMK is a sequential forward (u(t)) and backward (u'(t)) analyses of the MK test. If the two series are crossing each other, the year of crossing exhibits the year of trend change.
- If the two series cross and diverge from each other for a longer period of time, the beginning diverge year exhibits an abrupt trend change.

Independency of data by Pre-whitening:

- MK test and TSA approach require time series to be serially independent.
- Existence of serial correlation will affect the test's ability to assess the significance of a trend.
- Thus, pre-whitening technique was used to eliminate the serial correlation prior to the application of MK test and TSA approaches (von Storch, 1995).

Results and Discussion

T_{max} trend



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No sig	247	246	209	220	137	224	219	224	183	205	240	218
(-)	2	2	2	27	109	11	20	14	62	44	3	2
(+)	0	1	38	2	3	14	10	11	4	0	6	29

Fig.2a.T_{max} trends considering monthly scale data series over the periods 1950~2009 in North Carolina. No of stations (out of 249) in MK test find significant positive-negative trends in 95% confidence levels.

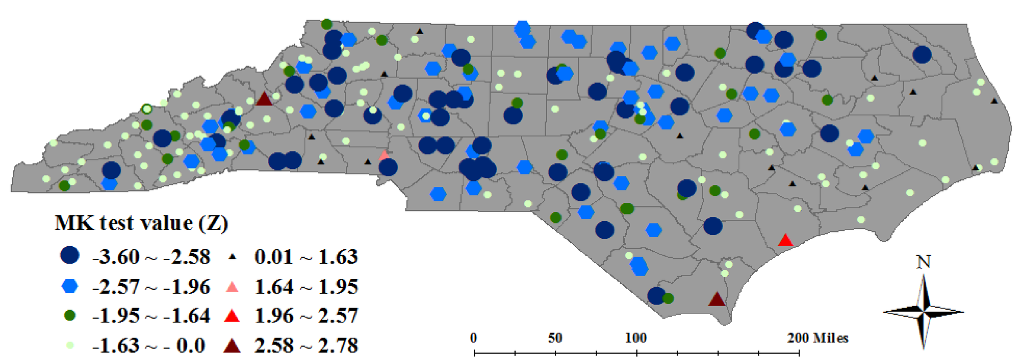


Fig.2b. Spatial distribution of T_{max} trends in the month of May

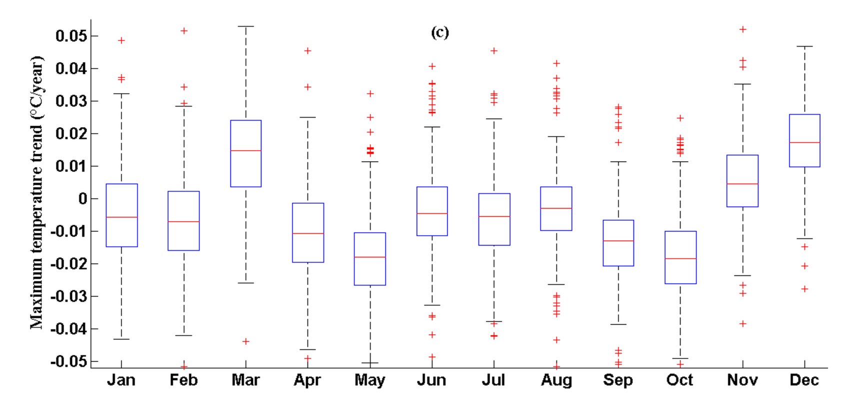


Fig.2c. T_{max} trend magnitude (°C/year) estimated by TSA method considering monthly scale data series over the periods 1950~2009 in North Carolina, inner box denotes the interquartile range and median, whiskers extend to points within a distance of 1.5 times the interquartile range.

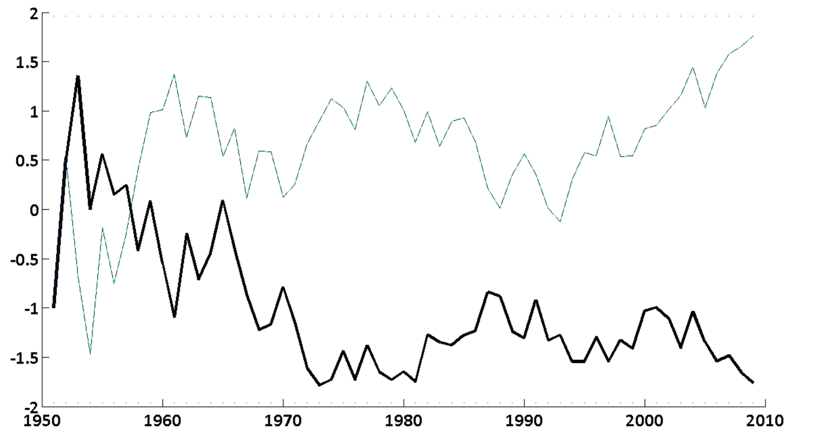
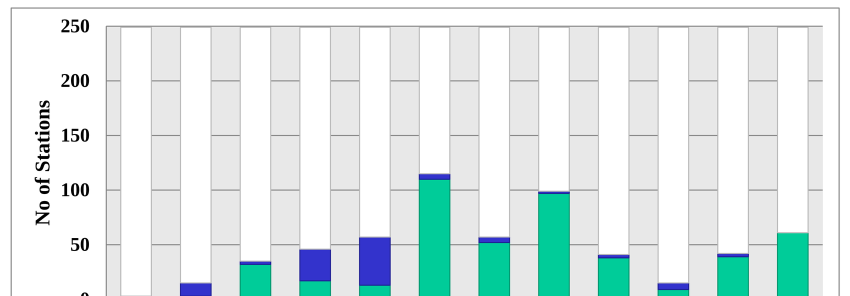


Fig.2d. Forward-backward series of SQMK method was applied in the T_{max} data series for the month of May averaging of all the stations over the periods of 1950-2009 in North Carolina.

In Fig. 2a, significant decreasing T_{max} trend was found 55 (54) number of stations at 99% (95%) confidence level in the month of May which counted as 44% of stations. Spatial distribution of T_{max} trends in the month of May is presented in Fig.2b. Highest increasing (decreasing) trend magnitude of +0.052 (-0.051) °C/year in the month of March (May) was found in Fig. 2c. Fig. 2d shows the initiation of T_{max} decreasing trend beginning in 1958.

T_{min} trend



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No sig	246	234	214	203	192	134	192	150	208	234	207	188
(-)	1	12	3	29	44	5	5	2	3	6	3	0
(+)	2	3	32	17	13	110	52	97	38	9	39	61

Fig.3a.T_{min} trends considering monthly scale data series over the periods 1950~2009 in North Carolina. No of stations (out of 249) in MK test find significant positive-negative trends in 95% confidence levels.

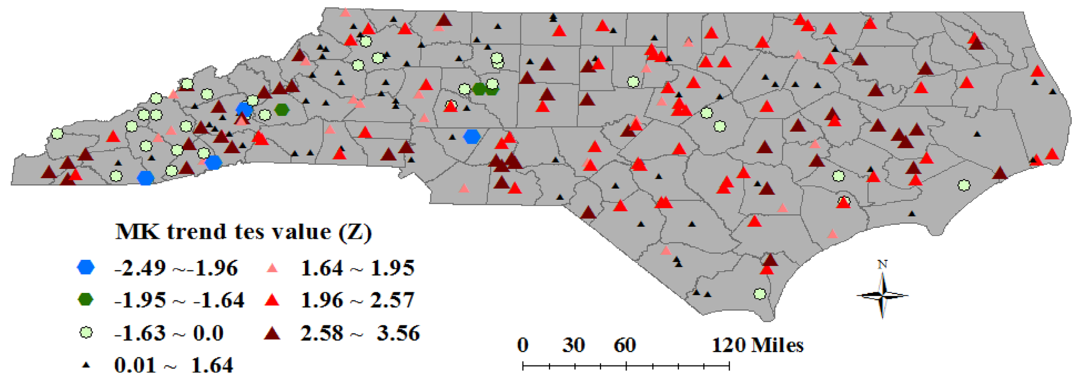


Fig.3b. Spatial distribution of T_{min} trends in the month of June.

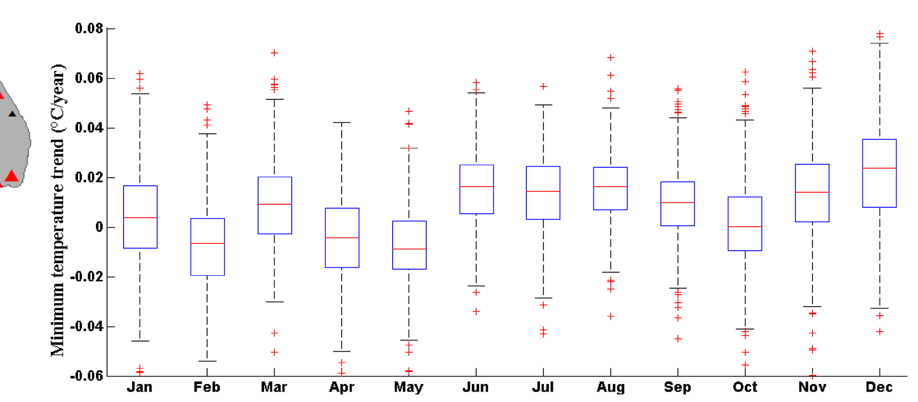


Fig.3c. T_{min} trend magnitude (°C/year) estimated by TSA method considering monthly scale data series over the periods 1950~2009 in North Carolina, inner box denotes the interquartile range and median, whiskers extend to points within a distance of 1.5 times the interquartile range.

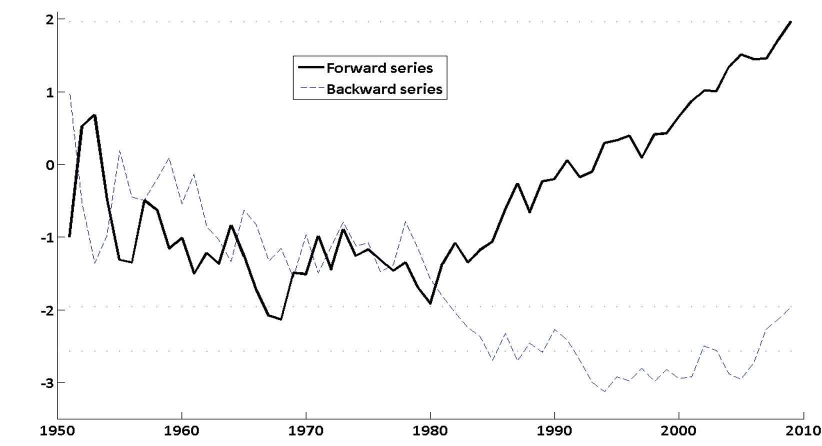
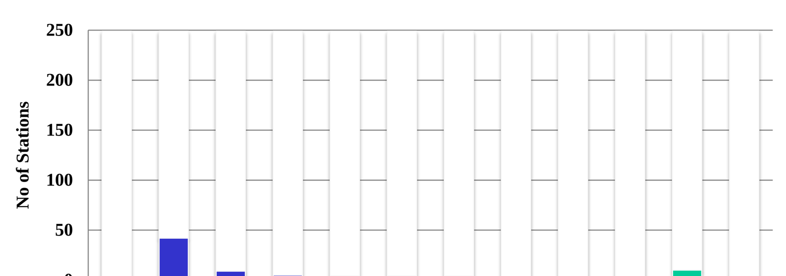


Fig.3d. Forward-backward series of SQMK method was applied in the T_{min} data series for the month of June averaging of all the stations over the periods of 1950-2009 in North Carolina

In Fig. 3a, significant decreasing T_{min} trend was found 50 (60) number of stations at 99% (95%) confidence level in the month of June which counted as 45% of stations. Spatial distribution of T_{min} trends in the month of June is presented in Fig.3b. After analyzing TSA method for T_{min} monthly data series, highest-increasing (lowest-decreasing) trend magnitude was found in the month of December (February) about + 0.075 (- 0.055) °C/year. In Fig.3d, increasing trend of T_{min} begins in 1980 and becomes significant around the year 2010.

Precipitation trend analysis



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No sig	249	207	240	244	245	245	245	246	248	247	239	248
(-)	0	42	9	3	2	0	1	2	0	1	0	1
(+)	0	0	0	2	2	4	3	1	1	1	10	0

Fig.4a. Precipitation trends considering monthly scale data series over the periods 1950~2009 in North Carolina. No of stations (out of 249) in MK test find significant positive-negative trends in 95% confidence levels.

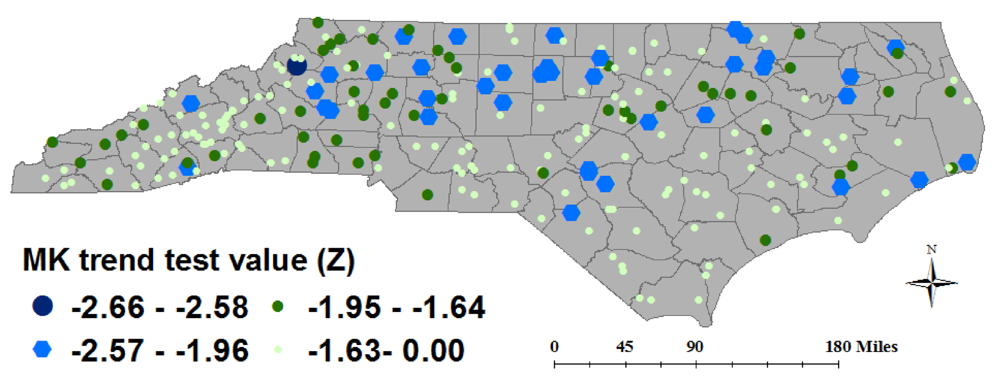


Fig.4b. Spatial distribution of precipitation trends in the month of February.

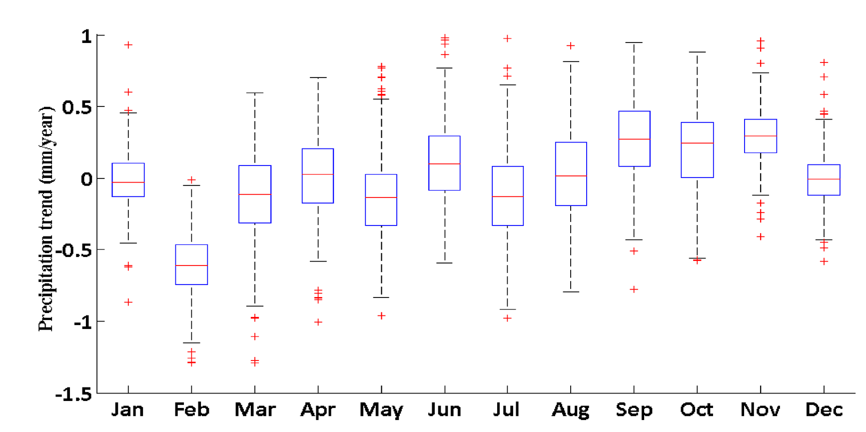


Fig.4c. Precipitation trend magnitude (°C/year) estimated by TSA method considering monthly scale data series over the periods 1950~2009 in North Carolina, inner box denotes the interquartile range and median, whiskers extend to points within a distance of 1.5 times the interquartile range.

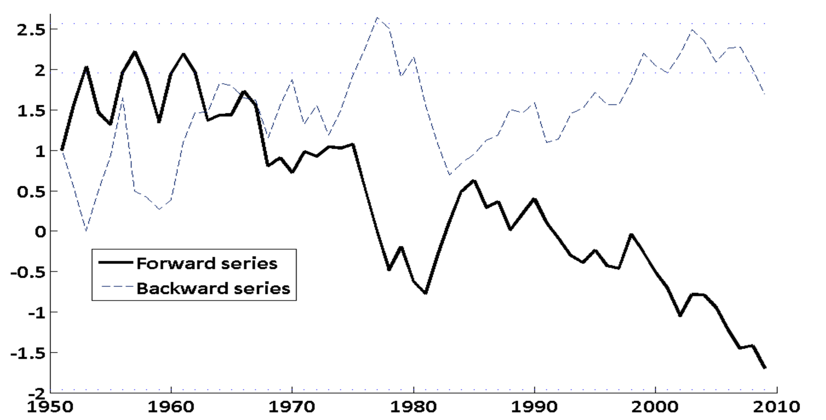


Fig.4d. Forward-backward series of SQMK method was applied in the Precipitation data series for the month of February averaging of all the stations over the periods of 1950-2009 in North Carolina

It is obvious from Fig.4a that the precipitation trends were not significant in North Carolina. February was chosen to show the spatial distribution of precipitation trends in Fig.4b. Only one station possessed lower critical Z (negative -2.57) value in MK trend test found in the northwestern part of North Carolina.. In Fig.4c, TSA method demonstrated the highest-increasing (lowest-decreasing) precipitation trend magnitude in the month of September (February) about + 1.0 (- 1.20) mm/year. In Fig. 4d, the precipitation trend starts decreasing around 1965 and 1985 and became significant in recent years.

Conclusion

- In this monthly scale historic trend analysis, T_{max} showed more pronounced decreasing trends than increasing and vice versa for T_{min}.
- The statistically significant trend tests results were used to develop spatial distribution of trends. Month of May for maximum temperature, June for minimum temperature, and February for precipitation was chosen and represented spatially.
- Overall increasing/decreasing trends for precipitation are not significant in North Carolina.
- Driving forces/mechanism associations (e.g. the moisture components, such as total cloud cover, soil moisture and/or large scale circulation such as North Atlantic Oscillation , Southern Oscillation) with these trends are the ongoing research investigation .

References

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