6.4 THE INFLUENCE OF EXTREME AND NON-EXTREME DAILY TEMPERATURES ON DIURNAL TEMPERATURE RANGE TRENDS

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1. INTRODUCTION

Recent trends indicate increasing temperatures across the United States and the globe. Temperature changes over the past half-century are characterized by significant increases of minimum temperature with time, non-significant maximum temperature changes, and decreases in the Diurnal Temperature Range (DTR) (Karl et al. 1993; Gallo 1999). This is also consistent with increases in the number of extreme temperature threshold exceedences over time, which is found to be greatest for warm minimum temperatures (DeGaetano and Allen 2002a). Continued increases in the occurrence of extreme temperatures over subsequent decades are projected to cause a sizable increase in weather-related mortality, particularly in northern U.S. cities (Kalkstein and Greene 1997; Curriero et al. 2002).

The purpose of this study is to investigate DTR trends conditional on the occurrence of extreme daily minimum and maximum temperatures. DTR trends are determined based on both warm and cold extreme days (temperatures exceeding the 95th and 5th percentiles, respectively) as well as on non-extreme days. Comparisons of trend characteristics between the type of day (extreme, non-extreme), the type of temperature variable (minimum, maximum), the type of station (rural, suburban, urban), and the period of analysis (1930-96, 1950-96, 1970-96) are performed for summer (warm temperature extremes) and winter (cold temperature extremes).

2. DATA AND METHODOLOGY

Differences in daily maximum and minimum temperatures from a 361-station subset of the U.S. Historical Climatology Network (HCN) are used to calculate DTRs on each day that observations are available. Dates are classified as extreme or non-extreme, according to the recently developed Daily Historical Climatology Network for Extreme Temperature (HCN-XT) data set (DeGaetano and Allen 2002b). In this study, we utilize the 95th and 5th percentiles as temperature thresholds to classify days with extreme warm and cold temperatures, respectively.

The classification of each station's Land Use/Land Cover (LULC) type as rural, suburban or urban (Owen et al. 1998) is utilized to determine differences in DTR trends between each LULC type. These LULC classes utilize the Defense Meteorological Satellite Program Operational Linescan System (OLS), which was acquired during 1994 and 1995 (Elvidge et al. 1997). The LULC type classifications are therefore only valid for the most recent decade, however during our analysis we assume that a station's classification does not change throughout its period of analysis. While this is a valid assumption for rural stations, it is a poor assumption for suburban and urban stations. Conclusions about DTR trends at stations with various LULC types could be strengthened with an accurate knowledge of each station's LULC type throughout its entire period of record.

The computed DTRs are placed into extreme or non-extreme groups, depending on the type of day on which they occur. A median DTR for each group is calculated for each year at a station, and then standardized based on the period of analysis. Three sets of DTR time series (analyzed on extreme, non-extreme and all days) are produced at each station for four different types of extreme days: warm maximum temperature (WMAX); warm minimum temperature (WMIN); cold maximum temperature (CMAX); and cold minimum temperature (CMIN). As a result, 12 different DTR time series are analyzed at each station. The measurement of the trend in DTR is determined by the Student's t-test, based on the mean of the first difference series computed from equally weighted 10-year running means (Karl et al. 1987).

Statistical significance of the computed t-statistics is assessed through Monte Carlo techniques. The magnitude of each calculated statistic is assessed for significance (α=0.10 and α=0.05) through the use of 'moving blocks' bootstrap (Wilks 1997) using the percentile method. Due to high autocorrelations of the annual median DTRs, 'moving blocks' bootstrapping is necessary to maintain the correlation structure in the bootstrapped time series by resampling blocks of data, with replacement.

Field significance is assessed through similar randomization techniques. Due to a high degree of spatial correlation between DTR, the reordering of years at each station is kept the same when generating random samples, using a block length of 5 years. Different stations have different degrees of autocorrelations in their DTR time series, but most (~80%) require a block length less than 5 years to preserve the correlation structure in the bootstrapped time series. The selection of a block length of 5 years for each station thus provides a stringent significance test at most of the stations analyzed.

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3. RESULTS

3.1 *DTR Trends on Warm Extreme/Non-extreme Days*

The percentage of U.S. stations with significant (α=0.05) negative trends in DTR analyzed on WMAX extreme, non-extreme and all days is provided for each of the three periods of analysis in Figure 1a. The percentage of stations is significant (α=0.05) for each type of day analyzed during each period, and generally

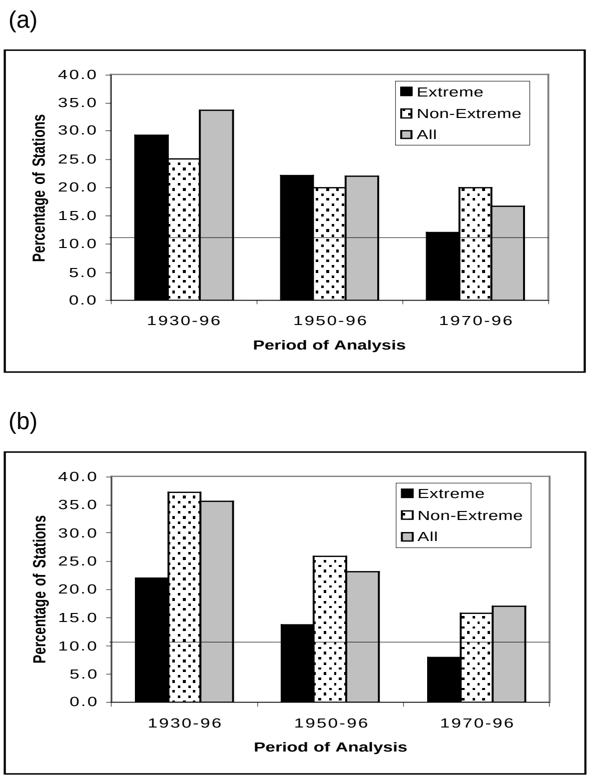

Figure 1. Percentage of stations with significant ($\propto$=0.05, above reference line) negative DTR trends when days are classified as (a) warm maximum temperature extreme and non-extreme, and (b) warm minimum temperature extreme and non-extreme.

decreases from the early to later period of analysis, particularly when extreme days and all days are used in the analysis. These percentages are also generally larger for extreme days compared to non-extreme days during the two early periods. Additionally, the percentage of stations with significant negative DTR trends is larger for urban stations than for rural stations during 1950-96 and 1970-96 (not shown). Spatially, the majority of stations with significant negative DTR trends occur in the Midwest U.S. and extreme Western U.S. regions. Very few stations have significant positive DTR trends and are thus not presented.

Figure 1b shows similar results for WMIN analysis, except the percentage of stations are greater for DTR trends analyzed on non-extreme days compared to extreme days during each of the three periods. Also, the percentage of stations decreases enough to become non-significant for the analysis on WMIN extreme days in the later period.

Decreases in the field significance do not necessarily mean that the magnitude of the DTR trend is becoming smaller with time at a station; significance is more difficult to obtain as the period of analysis becomes shorter. The relative consistency of the DTR trend magnitude between periods is seen in Figure 2, when all days are utilized in the analysis. The DTR trend magnitudes are significantly negative during each period of analysis, and the small changes in these DTR trends between periods are non-significant for all types of days. Despite the lack of change in DTR trends between periods of analysis, both maximum and minimum temperature trends do change significantly from one time period to another. It is apparent that significantly large negative trends in maximum temperature are an important influence on the negative DTR trends for the earliest period of analysis, while the significant positive minimum temperature trends are an

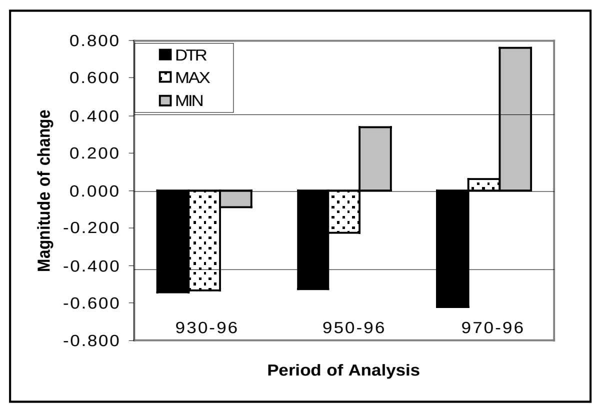

Figure 2. Magnitude of changes (t-statistic from first difference series) in DTR, maximum temperature and minimum temperature for three periods of analysis. Significant changes (trends) occur above and below the reference lines provided.

important influence for the most recent period. These recent trends are of particular importance since high minimum temperatures strongly influence heat-related mortality, particularly in urban centers where heat island effects have raised nocturnal temperatures by more than 2°C during Midwestern heat waves in 1995 (Kunkel et al. 1996) and 1999 (Palecki et al. 2001). These results for the most recent two periods of analysis are consistent with others who have studied these trend relationships (Karl et al. 1993; Gallo 1999).

Gallo (1996) has shown that as a station transitions from rural to suburban, or suburban to urban, the range of diurnal temperature decreases. Tables 1a and b show differences in the magnitudes of DTR decreases between the urban and rural station classifications (Urban – Rural) for WMAX and WMIN classified days, respectively. Here, negative differences represent a larger negative trend in DTR at urban stations when compared to rural stations. This result is consistent for each type of day and each period analyzed. During each time period in Table 1a, DTR trends are significantly different between station types, with the exception of WMAX non-extreme days during 1930-96. For WMIN extreme and non-extreme days (Table 1b), only the intermediate period of 1950-96 shows significant station type differences. Gallo et al. (1999), however, find no significant differences in annual DTR trends between station classes for their period of analysis (1950-96).

Table 1. Differences in the magnitudes of DTR trends (t-statistic) between urban and rural stations (Urban – Rural) for (a) WMAX extreme and non-extreme days, and (b) WMIN extreme and non-extreme days.

(a)

WMAX	1930-96	1950-96	1970-96
Extreme	-0.294**	-0.409**	-0.455**
Non-extreme	-0.158	-0.369**	-0.390**

(b)

WMIN	1930-96	1950-96	1970-96
Extreme	-0.113	-0.282**	-0.186
Non-extreme	-0.108	-0.319**	-0.013

** Urban DTR trends are significantly different from Rural DTR trends at ∝=0.05.

Various differences in the magnitudes of DTR decreases analyzed on different types of days are presented in Table 2. Differences between WMIN extreme and non-extreme days, and between WMAX extreme and WMIN extreme days, show relative consistency through the three time periods. Large differences between periods occur when comparing WMAX extreme with non-extreme days, and WMAXnon-extreme with WMIN non-extreme days. Differences that occur for various types of station classifications are not shown, but are discussed below.

Table 2. Differences in the magnitude of DTR trends (t-statistic) between different types of extreme (X) and non-extreme (nonX) days

	1930-96	1950-96	1970-96
(MAX X) – (MAX nonX)	-0.186	-0.052	0.446**
(MIN X) – (MIN nonX)	0.286**	0.417**	0.427*
(MAX X) – (MIN X)	-0.242	-0.398**	-0.246
(MAX nonX) – (MIN nonX)	0.230**	0.071	-0.286**

* Trend differences are significantly different at ∝=0.10.
** Trend differences are significantly different at ∝=0.05.

WMAX non-extreme days have significantly (α=0.05) greater negative DTR trends than WMAX extreme days during 1970-96, while earlier periods show small and insignificant differences. These results are consistent between different station classes. WMIN non-extreme days have significantly (α=0.05) greater negative DTR trends than WMIN extreme days during 1930-96 and 1950-96. These differences are similar for 1970-96, but only reach moderate significance (α=0.10).

Comparison of the two types of extreme days (WMAX, WMIN) reveals that DTR trends are more negative for WMAX extreme days, but reaching high significance only for the intermediate time period (1950-96). These results are consistent for different station classes, however suburban and urban stations reach moderate significance (α=0.10) during 1970-96 while rural stations do not.

Comparison of the two types of non-extreme days shows significantly greater negative DTR trends for WMIN non-extreme days during 1930-96, and significantly greater negative DTR trends for WMAX non-extreme days during 1970-96. Once again, these results are consistent for each of the three station classes.

3.2 *DTR trends on Cold Extreme/Non-extreme Days*

Compared to DTR trends analyzed on warm extreme days, those analyzed on cold extreme and non-extreme days show little significance. The percentage of stations with significant negative DTR trends only reaches high significance (α=0.05) for CMAX and CMIN extreme days during 1930-96 and 1950-96. A greater percentage of stations have significant positive DTR trends during the winter than during the summer, but none of these percentages are significant.

Significantly greater negative DTR trends at urban stations do occur for CMAX non-extreme days during 1950-96 and 1970-96, but significance is not reached for CMAX extreme days. Urban/Rural differences are only moderately significant (α=0.10) for CMIN non-extreme days during 1950-96 and 1970-96, and during 1950-96 for CMIN extreme days. Interestingly during 1930-96, rural stations have greater negative DTR trends, but these results are not highly significant.

The only significant difference between DTR trends analyzed on different day types occurs between CMIN extreme and CMIN non-extreme days (Table 3). CMIN extreme days have greater negative DTR trends than non-extreme days, and these differences are highly significant during 1930-96 and 1950-96. Station class results are also presented in Table 3, showing that urban stations have greater differences during 1930-96, but rural stations have greater differences during 1950-96 and 1970-96.

Table 3. Differences in the magnitude of DTR trends (t-statistic) between CMIN extreme days and CMIN non-extreme days

	1930-96	1950-96	1970-96
Rural	-0.367**	-0.559**	-0.569*
Suburban	-0.471**	-0.383**	-0.205
Urban	-0.578**	-0.508**	-0.274
All Stations	-0.497**	-0.476**	-0.329

* Trend differences are significantly different at ∝=0.10.
** Trend differences are significantly different at ∝=0.05.

4. SUMMARY AND CONCLUSIONS

Trends in diurnal temperature range on days with extreme and non-extreme temperatures are analyzed for a 361-station subset of the U.S. Historical Climatology Network. Differences in trend characteristics are assessed between the type of day (extreme, non-extreme), temperature variable (minimum, maximum), station (rural, suburban, urban) and the period of analysis (1930-96, 1950-96, 1970-96) utilized. The following lists important conclusions that result:

- Significant (α=0.05) negative DTR trends occur on days with warm extreme and non-extreme temperatures;
- Greater negative DTR trends occur on non-extreme days, in general;
- Greater negative DTR trends occur at urban stations compared to rural stations, particularly on days with warm maximum temperature extremes;
- No significant differences in DTR trends between time periods of analysis are found, however significant differences between periods for maximum and minimum trends are present;
- Significant negative maximum temperature trends are the main influence on DTR trends in 1930-96, while significant positive minimum temperature trends are the main influence on DTR trends in 1970-96;
- Very little significance occurs for DTR trends on cold extreme and non-extreme days, however trends are significantly more negative for cold minimum temperature extreme days than for cold minimum temperature non-extreme days.

REFERENCES:

Curriero F.C., K.S. Heiner, J.M Samet, S.L. Zeger, L. Strug and J.A. Patz, 2002: Temperature and mortality in 11 cities of the eastern United States, *Amer. J. Epidem.*, **155**, 80-87.

DeGaetano, A.T. and R.J. Allen, 2002a: Trends in 20th century temperature extremes across the United States, *J. Climate* [Submitted].

DeGaetano, A.T. and R.J. Allen, 2002b: A homogenized historical temperature extreme dataset for the United States, *J. Climate* [Submitted].

Elvidge, C.D., K.E. Baugh, E.A. Kihn, H.W. Kroehl and E.R. Davis, 1997: Mapping city lights with nighttime data from the DMSP operational linescan system. *Photogramm. Eng. Remote Sens*., **63**, 727-734.

Gallo, K.P., D.R. Easterling and T.C. Peterson, 1996: The influence of land use/land cover on climatological values of the diurnal temperature range. *J. Climate*, **9**, 2941-2944.

Gallo, K.P., T.W. Owen, D.R. Easterling and P.F. Jamason, 1999: Temperature trends of the U.S. Historical Climatology Network based on satellite-designated land use/land cover. *J. Climate*, **12**, 1344-1348.

Kalkstein L.S., and J.S. Greene, 1997: An evaluation of climate/mortality relationships in large US cities and the possible impacts of a climate change. *Env. Health Pers.*, **105**, 84-93.

Karl, T.R. and C.N. Williams Jr., 1987: An approach to adjusting climatological time series for discontinuous inhomogeneities. *J. Climate Appl. Meteor.*, **26**, 1744-1763.

Karl, T.R. and Coauthors, 1993: A new perspective on recent global warming: Asymmetric trends of daily maximum and minimum temperature. *Bull. Amer. Meteor. Soc*., **74**, 1007-1023.

Kunkel, K.E., S.A. Changnon, B.C. Reinke and R.W. Arritt, 1996: The 1995 heat wave in the Midwest: A climatic perspective and critical weather factors. *Bull. Amer. Meteor. Soc.*, **77**, 1507-1518.

Owen, R.W., K.P. Gallo, C.D. Elvidge and K.E. Baugh, 1998: using DMSP-OLS light frequency data to categorize urban environments associated with U.S. climate observing stations. *Int. J. Remote Sens*., **19**, 3451-3456.

Palecki M.A., S.A. Changnon and K.E. Kunkel, 2001: The nature nad impacts of the July 1999 heat wave in the Midwestern United States: Learning from the lessons of 1995. *Bull. Amer. Meteor. Soc.*, **82**, 1353-1367.

Wilks, D.S., 1997: Resampling hypothesis tests for autocorrelated fields. *J. Climate*, **10**, 65-82.