AN EVALUATION OF THE VARIABILITY OF AIR MASS CHARACTER BETWEEN URBAN AND RURAL AREAS

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ABSTRACT

While numerous studies have examined the magnitude of the urban heat island, no large-scale study has yet analyzed its variability using an air-mass based methodology. The air-mass approach can provide unique insight by discerning how large-scale weather patterns may impact the magnitude of the heat island effect. This study utilizes the Spatial Synoptic Classification (SSC) scheme, a recently-revised air mass classification system which is available for over 300 North American stations for 50 years.

For several urban areas across the eastern United States, daily maximum and minimum temperatures were compared between urban and rural sites. Data are segregated by air mass and by season. Overall, the three "dry" air masses show considerably larger urban heat island disparities than the three "moist" air masses. These effects are much more pronounced with minimum temperature than maximum temperature. Summertime minima are slightly more affected than wintertime minima, with the exception of one air mass which shows the opposite trend. The air masses traditionally associated with elevated mortality in urban areas have some of the most intense urban/rural differentiations, with overnight temperatures typically 3° C or more above outlying areas. Temporal trends (over the second half of the century) are also examined. For most urban locations, the summer urban heat island appears to be strengthening, whereas in winter little to no change is observed. This may be related to increased air conditioning use during the summer, although further research is needed to ascertain the effects of air conditioning upon the urban heat island.

INTRODUCTION

While the urban heat island has been studied using a variety of techniques, there is a lack of comprehensive studies which attempt to determine whether certain synoptic situations possess more significant urban-to-rural temperature differences than other situations. We hypothesize that the synoptic situation is an important determinant of the urban heat island's magnitude. To test this hypothesis, we are presently evaluating the urban regions of the United States Northeast using the Spatial Synoptic Classification (SSC) system. The goals of this study are not only to discern differences in the urban warming among air mass categories, but also to assess whether these have changed over time. As it is also believed that some of the most significant urban warming occurs during synoptic situations associated with elevated urban mortality, the biometeorological implications of this research are also important.

THE SPATIAL SYNOPTIC CLASSIFICATION (SSC)

The SSC is a recently developed method for classifying days at a particular location into distinct air mass categories, and integrating these classifications over a larger domain into spatially cohesive air mass regions (1). It is a *hybrid* categorization system, employing both manual and automated segments. The initial stage requires manual identification of air masses; once this is completed, an automated classification of days follows. The system was originally developed using discriminant function analysis for classification purposes, and was only available for the three winter months (December, January, February) and the three summer months (June, July, August) (1). The system has been subsequently redeveloped (2) for year-round use, and is presently available for 328 stations in the United States and Canada. Both pure climatological studies, including assessments of air mass frequency and character trends (3,4), and applied studies, including the impact of weather on heat-related mortality (5), have utilized SSC calendars.

As the original developers of the SSC believed the "traditional" air mass system (cP, cT, mP, mT) was too limited for practical use, **six** air masses affecting the North American continent are identified:

- **DP (Dry Polar),** synonymous with the traditional cP classification.
- **DT (Dry Tropical)**, synonymous with cT.
- **DM (Dry Temperate)** has no analogue in the historical classification system. It has been defined for the continental U.S. as 'transformed Pacific air', or orographically dried Pacific air. This air mass is usually more humid than DP or DT air, and features temperatures somewhere between the two.
- **MP (Moist Polar)** and **MM (Moist Temperate)** together comprise the traditional mP air mass. MM air, associated with overrunning conditions, typically contains somewhat higher dew points and temperatures than MP air.
- **MT (Moist Tropical)** is the same as mT.

A **transition (TR)** day is also defined to account for days in which a change in air mass occurs.

The foundation of the SSC rests upon the proper identification of **seed days** for each locale, which represent days with the typical meteorological characteristics of a given air mass at that location. With the aid of synoptic weather maps, manual identification of typical air mass characteristics is performed for four two-week "windows" throughout the year; programs then select days which meet all of these criteria for each air mass during each window. Routines are then performed to produce polynomials that utilize the mean conditions from the selected seed days to produce "typical" values for the twelve different meteorological parameters in Table 1 for each day of the year.

Each day in a station's period of record is evaluated, comparing the character of that day with expected values obtained from the polynomials for each air mass for the particular day of the year. For each variable, for each air mass, squared *z*-scores (the square of the difference between the actual value and expected value, divided by the standard deviation) are calculated. After being summed across all variables for each air mass, the day receives the designation of the air mass whose total score is lowest, an indication that its expected values are most similar to that day's actual values. A similar procedure is subsequently used for determine if a day is transitional, with three variables (dew point range, wind shift, and pressure change) used for this assessment.

Table 1. The twelve variables used to discriminate among air masses.

0400 EST Temperature	0400 EST Dew Point
1000 EST Temperature	1000 EST Dew Point
1600 EST Temperature	1600 EST Dew Point
2200 EST Temperature	2200 EST Dew Point
Daily Dew Point Range	Daily Temperature Range
Daily Mean Cloud Cover	Daily Mean Sea Level Pressure

As the spatial cohesiveness of the SSC is paramount, an important objective is to assure that neighboring stations have similar criteria for the same air mass. To accomplish this, a complex set of procedures transfers actual seed days from one station to an adjacent station. Local climatic factors are accounted for, which ensures a relatively smooth pattern of air mass identification on a regional scale, with a good station-to-station correlation.

METHODS

SSC calendars are available for most US first-order weather stations since 1948, coinciding with the availability of hourly meteorological data. For each of several metropolitan areas (Baltimore, New York, Philadelphia, and Washington), station "pairs" (consisting of one urban location and one suburban/rural location) are selected. Stations must have at least 30 years of coinciding weather data to be selected. When both stations have available hourly data, morning and afternoon temperatures are compared. When this is not the case, maximum and minimum daily temperatures are compared. In order to test the hypotheses mentioned above, data are stratified by air mass, and then further subdivided by season and segments of the period of record.

RESULTS AND DISCUSSION

Typical of the results for the region analyzed are those discovered for Washington. Means for the period of record (1962 to 1998) comparing National Airport (DCA), in the center of the heat island, and Dulles Airport (IAD), 50 km away in a recently-suburbanized locale, are listed in Table 1. As expected, the heat island is much more significant overnight than during the day. Also, among-air mass variability is also much more significant overnight; on summer afternoons virtually no difference among the air masses is noted.

Overnight temperatures between urban and rural areas for most air masses show a greater disparity during summer than winter. The three dry air masses (DM, DP, DT) all have temperature differences which are at their lowest in winter (1° to 3°C across the regions), increasing to 2° to 5° in the summer, and maintaining this level through the autumn. With the moist air masses (MM, MP, MT), a more complex pattern emerges. Moist Tropical (MT) follows a similar pattern to the dry air masses, although with a much larger amplitude. The summer urban/rural disparity is nearly as strong as that of the dry air masses, with virtually no difference in winter (Figure 1). This discrepancy probably reflects the different geneses of MT throughout the year. During winter in the region of interest, MT usually only arises with cloudy and windy conditions, which would minimize temperature differences. In the summer, however, MT is less cloudy, and calmer nighttime winds would allow for a greater urban-to-rural temperature difference. In contrast, the Moist Moderate (MM) air mass has a nearly flat trend at most locations, with the difference between the summer and winter heat island less than 1°C. Moist Polar (MP) is the only air mass whose heat island is greater in winter than summer (Figure 1). This difference appears in each metropolitan area examined. We hypothesize the cause involves the necessity of a strong northeasterly flow for an MP classification in the warm season, but not the cold season.

As mentioned above, afternoon temperature disparities in most locations contain much less variability among the air masses. It is worth noting that the magnitude of the heat island during the day is actually greater during the winter than the summer, opposite of the overnight pattern. While the exact magnitudes differ across metropolitan areas, due to local station differences, the pattern and the muted differentiation among air masses occurs throughout.

Urban-rural temperature differences have also shown trends and disparities over time. Unlike the above results, those uncovered here are not consistent among the metropolitan areas studied. This disparity can be attributed to either different trends over time in the pace of urbanization near a particular site, or a relocation of instrumentation, although

Table 2. Mean frequency of occurrence of air masses at Washington DC National Airport (DCA), along with the temperature differences between DCA and Dulles International Airport (IAD), averaged for the period 1963-1998. Note that transitional situations are excluded.

	DM	DP	DT	MM	MP	MT
JANUARY						
Frequency of occurrence (%)	24.1	35.2	1.0	12.7	17.3	2.2
Difference, 0400 Temperature (°C)	2.6	2.8	2.7	1.7	2.6	0.1
Difference, 1600 Temperature (°C)	0.7	1.1	1.6	1.2	1.0	-0.5
JULY						
Frequency of occurrence (%)	22.5	4.8	5.5	18.3	0.9	41.7
Difference, 0400 Temperature (°C)	4.4	3.6	4.0	2.4	1.8	3.0
Difference, 1600 Temperature (°C)	0.9	0.6	0.9	0.7	0.8	0.9

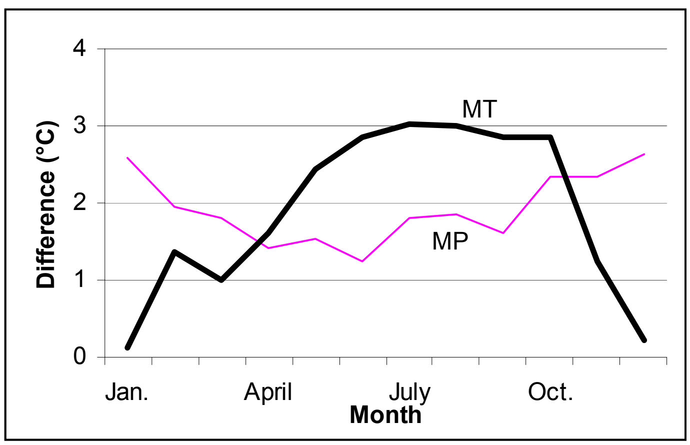

Figure 1. Mean magnitude of the difference in 0400 EDT temperature between DCA and IAD by month, averaged for the period 1963-1998, for the MP and MT air masses.

no relocation has been confirmed for any of our studies. In general, however, most stations show an increased heat island effect in summertime, and a relatively flat, to slightly decreasing, effect in wintertime. The same trends appear both with afternoon/maximum temperatures and morning/minimum temperatures. In our example for Washington, however, a slight decrease in temperature difference is noticed in both summer and winter. In this case, this difference likely does not reflect a decreased urban heat island in downtown Washington. Rather, we believe that the Washington heat island has increased over time, with the downward trend since around 1980 related to the commencement of rapid suburbanization near Dulles Airport. Within these overall trends, differentiation among air masses still occurs. Figure 2 depicts the summertime temperature differences over time for the DT and MT air masses. While the heat island on DT days (which is typical of all dry air masses) has diminished significantly since 1980 (around 2°), the temperature difference between DCA and IAD on MT days has not decreased as significantly (only around 1°). Further research

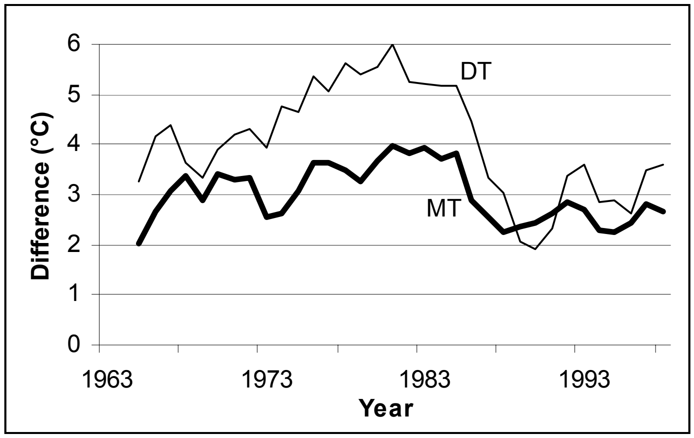

Figure 2. Three-year running means of the summertime (June through August) difference in 0400 EDT temperature between DCA and IAD by year, for the DT and MT air masses.

needs to be performed on truly rural stations in the Washington metropolitan area to clarify the significance of these trends.

CONCLUSIONS

Initial results show that a segregation of days by air mass provides interesting insight into the urban heat island effect. For our work within the US Northeast Megalopolis, with overnight or minimum temperatures, dry air masses show a greater temperature difference between urban and rural stations than moist air masses; summertime greater than wintertime. Maximum temperatures do not show as large of a differentiation. Also, the urban heat island has varied over time, increasing in some locales and decreasing in others, apparently a reflection of the differential rates of urbanization in these areas.

We have begun to analyze additional stations in each metropolitan area, and incorporating the history of urbanization into the assessment. With our previous work showing a strong relationship between elevated mortality and certain air masses, and the additional importance of minimum temperatures within a given oppressive air mass, understanding the effects of urbanization is of great importance to the biometeorological field as well.

REFERENCES

1. Kalkstein, L.S., Nichols, M.N., Barthel, C.D., and Greene, J.S., 1996. A New Spatial Synoptic Classification: Application to Air-Mass Analysis. Int. J. Climatol. 16: 983-1004.
2. Kalkstein, L.S., Sheridan, S.C., and Greybeal, D.Y., 1998. A determination of character and frequency changes in air masses using a spatial synoptic classification. Int. J. Climatol. 18: 1223-1236.
3. Sheridan, S.C., and Kalkstein, L.S., 1999. Redevelopment of a spatial synoptic classification for year-round application. Preprints, 11th Conference on Applied Climatology, Dallas, Texas, Amer. Meteor. Soc., 381-382.
4. Sheridan, S.C., 1997. Using a synoptic classification system to assess climate trends and variability in Texas. Preprints, 10th Conference on Applied Climatology, Reno, Nevada, Amer. Meteor. Soc., 287-289.
5. Kalkstein, L.S., and J.S. Greene, 1997. An evaluation of climate/mortality relationships in large U.S. cities and the possible impacts of a climate change. Env. Health. Perspectives. 105(1): 84-93.