AN EVALUATION OF POLLUTION CONCENTRATIONS IN PHILADELPHIA USING AN AUTOMATED SYNOPTIC APPROACH

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ABSTRACT: This paper develops a synoptic climatological categorization for summer in Philadelphia, PA. by means of principal components analysis and clustering analysis. We objectively provide distinctions of the ten major synoptic categories. In addition, this paper points out the relationships between synoptic categories and pollution concentrations. Usually, synoptic categories with high mean air temperature, stable situations, sunny skies, and light wind velocities provide particularly high pollution concentrations. Cluster 6 and 2 are identified as the severest polluted synoptic categories for summer in Philadelphia. Cluster 10 is cluster with lowest air pollution concentrations.

INTRODUCTION

Synoptic climatology has become popular to evaluate the impact of climate upon a wide variety of environmental problems. One of the reasons is ability of a synoptic climatological approach to categorize a complex set of meteorological variables within a coherent index(Kalkstein 1979; Perry 1983; Davis and Kalkstien 1990; Powley and Tan 1991; Cheng 1991). It is very useful to use a synoptic categorization that accentuates homogeneity in weather type or air mass to evaluate environmental factors such as pollution concentration, human health, and regional climate variation.

The objective of this study is to evaluate relationships between ozone and total suspended particulates(TSP) and synoptic climatological situations for summer in Philadelphia.

DATA

WEATHER DATA

Weather data were collected for the period of June to August for the years 1955 to 1991. The 1:00 AM, 7:00 AM, 1:00 PM, 7:00 PM values of air temperature(°F), dew point temperature(°F), pressure(mb), wind speed(knots), wind direction(azimuth). and total cloud cover(tenths of sky cover) were utilized for synoptic index development. Wind speed and direction were converted into southerly and westerly scaler velocities by sine-cosine transformation.

POLLUTION DATA

Among several pollution monitors in Philadelphia for each pollutant, the one that contained the longest and the most complete pollution data record was chosen. Hourly readings were recorded for ozone, and daily maximum values were identified for each day if there were observations during the period of 11:00 AM to 3:00 PM(normally the hours of highest ozone concentrations). The most complete ozone monitor in Philadelphia had 90% of observations in summer from 1975 to 1991. TSP was measured daily, and the best TSP monitor in Philadelphia had 84% of observations in summer from 1972 to 1991.

METHODOLOGY

The temporal synoptic index(TSI) assigns each day to a particular synoptic category based primarily on air mass differentiation(Kalkstein et al. 1987). This is accomplished by defining each day in terms of the 24 weather variables above.

TSI was developed by utilizing two statistical methods. Principal components analysis was performed to reduce a large number of intercorrelated weather variables to a small number of uncorrelated principal component variables which explain much of the variance within the original data set. Component loadings were calculated, which expressed the correlation between the original 24 variables and the newly formed components. The number of principal components(4 components in this study) to be retained was determined to calculate component scores, and days with similar meteorological situations would tend to exhibit proximate component scores. A clustering diagnostics procedure(average linkage clustering) was generated to provide an appropriate number of cluster, which classified those days with similar component scores into meteorologically homogeneous groups. If some clusters were very large, they were subdivided, or nested, to get an appropriate number of subcategories. Then average values and standard deviations were calculated for 24 meteorological variables for all days within each particular group. Weather map classification was also possible by reviewing maps for those days within a group and describing general similarities. Daily mean pollution concentrations for each synoptic category were calculated to ascertain particular weather categories were distinctively high or low.

SYNOPTIC CATEGORIZATION

The major synoptic categories in summer were uncovered for Philadelphia(Table 1). A major category is defined as consisting of 4% or more of total days. The categories were identified based on their mean meteorological characteristics. In addition, surface weather maps for a sample of days within each class were examined to enhance interpretability(Fig. 1). A brief discussion of the characteristics of each synoptic category for Philadelphia, PA. follows.

Cluster 1 clearly represents an easterly flow, ocean influenced air mass. Air temperatures and dew point temperatures also reflect the oceanic influence by the prevailing east wind. The large-scale synoptic condition responsible for intrusion of this air mass into the Philadelphia area usually features a surface cyclone to the south or southeast with a well-developed surface high over Eastern Canada.

Cluster 2 is defined as a maritime tropical air mass. The characteristics are the highest temperatures within all the synoptic categories, very high dew point temperatures, moderate southwesterly wind velocities, and mostly clear skies.

Cluster 3 represents a maritime tropical air mass, with the highest cloud cover of all the synoptic categories and a strong southwesterly wind. The front is usually very close to Philadelphia. Therefore, pressures and temperatures are lower than those in Cluster 2.

Cluster 4 identifies a modified maritime tropical cluster with overcast conditions. The major difference between Cluster 4 and Clusters 2 and 3 is that there is no frontal system adjacent. Therefore, air pressures within Cluster 4 are the highest of these three clusters.

Cluster 5 is defined as a frontal passage from maritime tropical to continental. The typical synoptic feature for this cluster is a front passing by Philadelphia from west to east as indicated by steadily decreasing dew points. Thus, air pressures within the cluster are the lowest for all the synoptic categories.

Table 1. Mean values of meteorological variables for summer synoptic categories in Philadelphia

Synoptic cluster	Days (frequency)	Time (hrs)	T_a(°F)[c]	T_d(°F)[d]	Pressure (mb)	Cloud cover (10ths)	Wind[e]
1 Easterly flow, ocean influence	691 (20.3%)	00:00	67.1	60.6	1018.1	6.6	
		06:00	65.4	59.9	1018.4	8.1	E
		12:00	75.2	60.8	1018.6	8.2	moderate
		18:00	74.0[b]	61.1	1017.3	7.8	
2 Maritime tropical(sunny)	396 (11.6%)	00:00	75.2[a]	69.5[a]	1016.8	3.7	
		06:00	73.5[a]	69.5[a]	1016.8	5.1	SW
		12:00	89.0[a]	69.9	1016.3	3.7	moderate
		18:00	86.5[a]	69.4	1014.4	4.7	
3 Maritime tropical(cloudy)	382 (11.2%)	00:00	73.1	67.9	1013.9	7.8[a]	
		06:00	72.3	68.9	1013.0	9.1[a]	SW
		12:00	82.4	69.9	1012.5	8.4[a]	moderate
		18:00	79.7	69.0	1011.0	8.2[a]	
4 Modified maritime tropical	299 (8.8%)	00:00	73.4	69.0	1017.4	7.3	
		06:00	72.4	69.1	1017.5	8.8	S
		12:00	82.6	70.2[a]	1017.5	8.0	light
		18:00	80.0	70.0[a]	1016.0	7.9	
5 Frontal passage (maritime to continental)	241 (7.1%)	00:00	74.0	68.8	1010.5[b]	6.7	
		06:00	72.6	68.0	1010.2[b]	6.8	W
		12:00	85.0	66.5	1010.6[b]	5.7	strong
		18:00	82.7	64.1	1010.0[b]	5.3	
6 Continental (non-polar origin)	216 (6.3%)	00:00	69.3	62.3	1019.0	1.9	
		06:00	67.5	62.7	1020.0	3.1	SW
		12:00	85.5	63.5	1019.5	3.3	moderate
		18:00	83.9	64.8	1017.5	3.4	
7 Modified continental polar	162 (4.8%)	00:00	72.5	65.4	1014.0	3.7	
		06:00	69.4	61.8	1015.5	2.8	NNW
		12:00	83.6	59.8	1016.4	2.5[b]	moderate
		18:00	83.2	58.9	1015.7	2.4[b]	
8 Modified continental polar(adjacent wave)	223 (6.6%)	00:00	68.3	61.9	1014.0	5.1	
		06:00	66.6	61.5	1014.3	6.6	W
		12:00	80.6	61.7	1014.4	6.9	moderate
		18:00	79.2	61.6	1013.2	6.3	
9 Continental polar	445 (13.1%)	00:00	62.9[b]	51.7[b]	1019.9[a]	1.5[b]	
		06:00	59.9[b]	51.0[b]	1021.2[a]	2.1[b]	NW
		12:00	77.0	50.7[b]	1021.5[a]	3.2	light
		18:00	76.6	51.8	1020.0[a]	3.5	
10 Continental polar(recent frontal passage)	215 (6.3%)	00:00	65.0	55.7	1010.7	4.4	
		06:00	62.0	53.4	1011.9	4.3	NW
		12:00	74.7[b]	52.0	1012.6	5.0	moderate
		18:00	74.9	51.2[b]	1012.4	4.3	

Note: [a] Maximum value of variable for all ten clusters.

[b] Minimum value of variable for all ten clusters.

[c] Air temperature. [d] Dew point temperature. [e] Wind direction and speed.

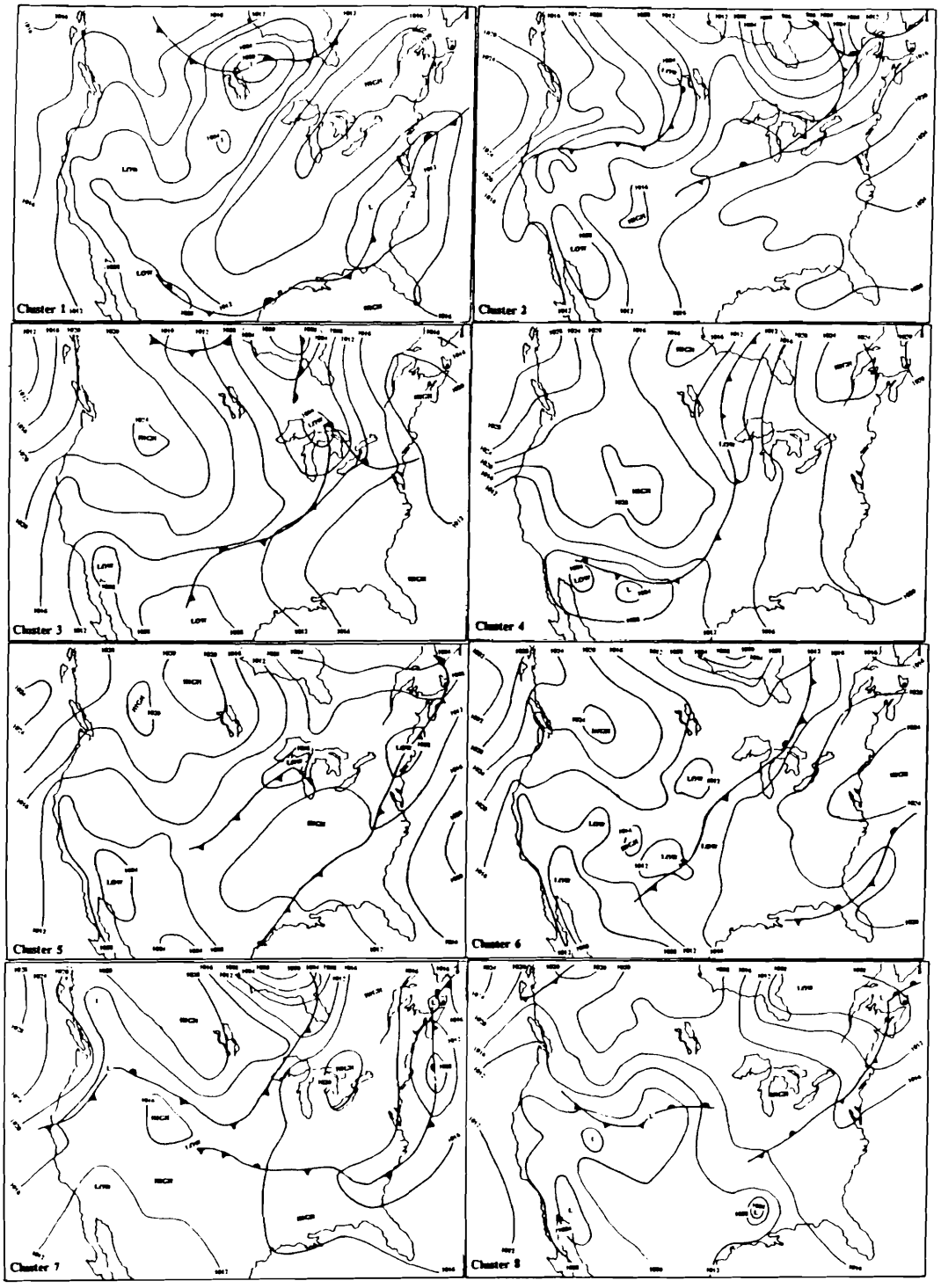

Figure 1. Typical surface synoptic situations for each major cluster.

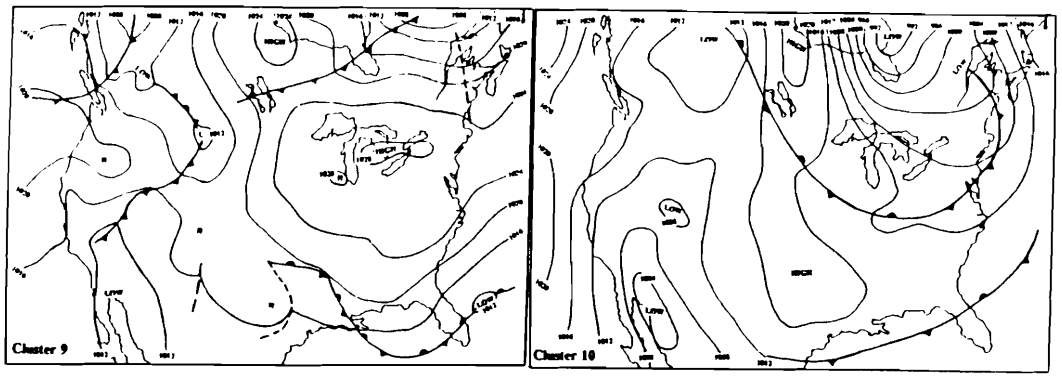

Figure 1. Continued.

Cluster 6 represents a continental air mass(non-polar origin). This cluster has the second highest air temperatures for all ten synoptic categories, very high air pressure, a large dew point depression, moderate southwesterly wind, and little cloud cover.

Cluster 7 is a modified continental polar air mass, with a moderate northwesterly flow and little cloud cover. The dew point temperatures are steadily decreasing indicating a recent frontal passage. The large-scale synoptic conditions in this cluster usually feature a surface cyclone and frontal system over the Atlantic Ocean near to the East Coast, and a surface anticyclone moving toward the area.

Cluster 8 is defined as modified continental polar(adjacent wave). Air pressure and temperature in Cluster 8 is lower than Cluster 7, and cloud cover is greater. In addition, the locations of anticyclones are different for both clusters. A anticyclone in Cluster 8 usually is in west to Philadelphia, while it is often to the north or northwest in Cluster 7. So, wind directions are west and north in Cluster 8 and Cluster 7 respectively.

Cluster 9 represents a continental polar air mass with an anticyclone. This cluster has the lowest dew point temperatures and the highest dew point depression for all synoptic categories. The cloud cover is least for all clusters, and wind speed are very light.

Cluster 10 is influenced by continental polar air after a recent front passage, with lower air pressure than Cluster 7. One of several marked differences between Cluster 10 and Cluster 7 is that there is not an adjacent anticyclone in Cluster 10.

POLLUTION ASSOCIATIONS

As each of the ten clusters exhibits a distinctive air mass and synoptic signature, a characteristic regime of pollutant concentrations should be associated with each because of the critical impact of weather conditions on the dispersion or accumulation of air pollutants(Kalkstein and Corrigan, 1986). This approach should provide valuable information about the synoptic factors responsible for various pollution regimes. Mean pollution concentrations vary considerably for each of the ten synoptic categories(Table 2). The figures of ozone and TSP range from 6.7 parts per hundred million(ppm) and 56.82 mg/m^3 for Cluster 10 to 10.6 ppm and 92.38 mg/m^3 for Cluster 6 respectively. The most polluted synoptic category, Cluster 6, possesses characteristics that are conductive to extreme pollution episodes. The cluster has the least cloud cover for all ten clusters, very high air pressures , and very high mean air temperatures. The surface synoptic pattern with this cluster encourages very stable situations. Cluster 2, which is also associated with high pollution concentrations, has characteristically the highest mean air temperature of all ten synoptic categories and sunny skies. Cluster 10 possesses the lowest mean to air pollution because it possesses characteristics that encourage dispersal. Cluster 10 is usually influenced by cyclonic and frontal system. The synoptic characteristics usually are low air pressures, dew point temperatures, and unstable situations.

Table 2. Daily mean pollution concentrations for summer synoptic categories in Philadelphia

Number of cluster	Pollutant	
	Ozone(ppm)[a]	TSP(mg/m^3)[b]
1	0.069	62.58
2	0.099	92.08
3	0.081	79.91
4	0.076	76.21
5	0.079	76.39
6	0.106	92.38
7	0.078	65.78
8	0.090	75.27
9	0.081	59.65
10	0.067	56.82

Note: [a] ppm, a part per million.
[b] TSP, total suspended particulates; its units micrograms/cubic meter.

We calculated the percentage of total days in each cluster within the top 50 polluted days during the entire period. Table 3 indicates that Cluster 6 is much more highly represented within the top 50 pollution days than would be expected based on its frequency of occurrence. Cluster 6 occurs within the top 50 ozone days 3.59 time more frequently than expected. Cluster 2 is disproportionately frequent among the highest TSP days. Forty percent of the top 50 TSP days are within Cluster 2 even through this cluster has a frequency occurrence of slightly more than 12 percent. Conversely, Cluster 10 is obviously very clean based on its low representation among the top 50 days.

Table 3. The percentage of total days vs. the percentage of the top polluted 50 days within each summer cluster in Philadelphia

Number of cluster	Ozone			TSP		
	Percent of total days (1)	Percent of top 50 days (2)	(2)/(1)	Percent of total days (1)	percent of top 50 days (2)	(2)/(1)
1	19.26	6.00	0.31	18.80	2.00	0.11
2	12.10	16.00	1.32	12.47	40.00	3.21
3	9.77	10.00	1.02	9.95	8.00	0.80
4	9.63	4.00	0.42	9.69	12.00	1.24
5	8.09	8.00	0.99	7.36	10.00	1.36
6	6.68	24.00	3.59	7.11	18.00	2.53
7	5.84	6.00	1.03	5.49	2.00	0.36
8	5.91	8.00	1.35	5.94	2.00	0.34
9	14.06	12.00	0.85	13.44	6.00	0.45
10	5.70	4.00	0.70	6.07	0.00	0.00

CONCLUSIONS

It is apparent that the synoptic index provides very useful information about the synoptic relationships between weather and pollution concentrations. This paper provided several results. (1) The procedure objectively identified distinctions of 10 major synoptic categories in summer for Philadelphia. (2) We identified that Cluster 6 and Cluster 2 were the two most polluted synoptic categories. The characteristics of these clusters are very high air pressure, air temperature, dew point temperature, sunny skies, and stable situations. (3) Cluster 10 was the cleanest cluster, and possessed very low air pressure, air temperature, dew point temperature, cloudy, and unstable situations. It is possible that a watch/warning system predicted presence of offensive synoptic situations.

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