An Analysis of Visual Range in the Eastern United States Under Different Meteorological Regimes

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Atmospheric visibility depends on the emissions of pollutants into the atmosphere and on the meteorological conditions in that atmosphere. Meteorology plays a critical role because a) certain meteorological conditions (such as rain and fog) naturally reduce visual range, irrespective of air quality, and b) under different meteorological scenarios, pollutant trajectories from the emission "source" areas impact different "receptor" regions, are dispersed to different degrees, and undergo different chemical transformation patterns. The meteorological conditions vary from day to day and place to place, and correspondingly influence the visibility.

To illuminate the relationship between visibility and meteorology, we present, in this technical note, a simple statistical analysis of visual range measurements in urban and rural areas of the eastern United States under different meteorological conditions.

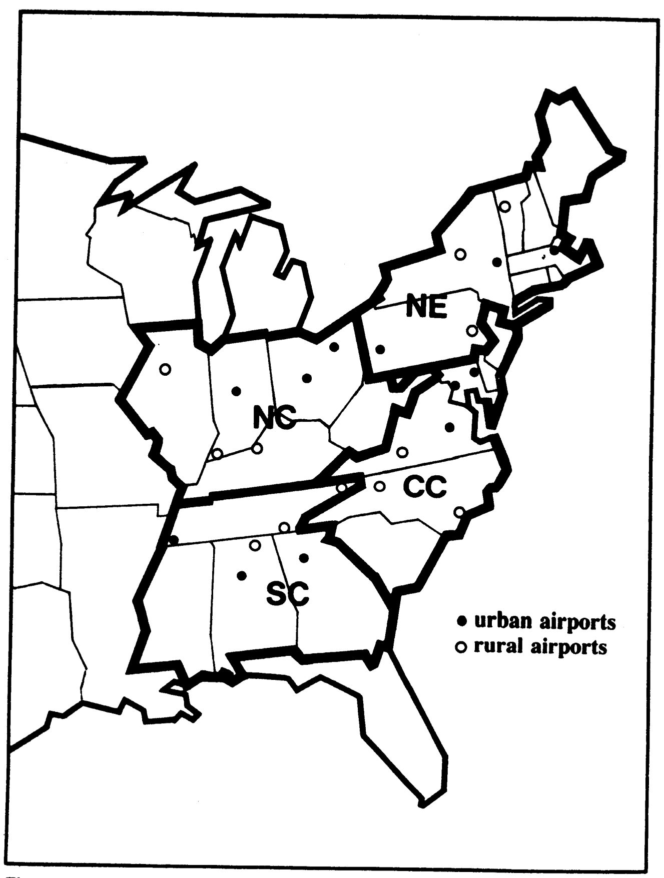

Figure 1. Regional classification of the Eastern United States: Northeast (NE), Coast Central (CC), North Central (NC), and South Central (SC).

Geography

The eastern United States was divided into four areas, as shown in Figure 1:

- *Northeast* (NE): Maine, Vermont, New Hampshire, Massachusetts, Connecticut, New York, Pennsylvania, Rhode Island
- *North Central* (NC): Illinois, Indiana, Ohio, Kentucky, West Virginia
- *Central Coast* (CC): New Jersey, Delaware, Maryland, Virginia, North Carolina, South Carolina, District of Columbia
- *South Central* (SC): Tennessee, Mississippi, Alabama, Georgia

This division is similar to the one proposed by Husar et al.[1] who, with their analysis of regional trends of haziness, confirmed the existence of geographic regions with coherent and consistent behavior.

Eight subregions were produced when the four areas above were subdivided into urban and rural sections. This urban/rural differentiation recognizes the fact that urban activities produce relatively greater amounts of fine and coarse particulate matter, both of which affect the local urban visibility. For example, studies in the St. Louis area have shown[2,3] that the average rural visual range can be 80 percent higher than the urban visual range. A more general evaluation of the Eastern United States, using the Sulfate Regional Experiment (SURE) and the Inhalable Particulate (IP) network data for fine and coarse particulate matter,[4] seems to indicate that the rural visual range is about 25 percent higher than the urban visual range. Consequently, it was important, in our analysis, to differentiate between urban and rural impact.

Meteorology

We analyzed the daily weather maps generated from the National Weather Service (NWS) data for the Eastern United States for the three-year period 1979–1981 and classified the air mass for each region and each day according to the standard meteorological classification described below. All days with midday relative humidity greater than or equal to 85 percent were placed in one class (k = 8) that reflected times in which meteorology was likely to play a major role in visibility impairment through precipitation or fog.* For relative humidity less than 85 percent, air mass transport class-

* Relative humidity was used, instead of direct measurements of precipitation and fog, to maintain a consistency between our approach and that used by other visibility studies (e.g., Latimer and Hogo).[5]

Reprinted from APCA JOURNAL, Vol. 39, No. 2, February 1989

TABLE I. Frequency f_{jk} and relative frequency p_{jk} of occurrence of each air mass transport class k for each region j.

		$k = 1$ cPk		$k = 2$ cPw		$k = 3$ mT		$k = 4$ Tr		$k = 5$ cT		$k = 6$ cP2		$k = 7$ mP		$k = 8$ all classes >85% RH	
j	Region	f	p	f	p	f	p	f	p	f	p	f	p	f	p	f	p
1	NE Urban	342	0.321	135	0.127	121	0.114	163	0.153	19	0.018	67	0.063	147	0.138	71	0.066
2	NE Rural	343	0.322	137	0.129	119	0.112	163	0.153	19	0.018	67	0.063	150	0.141	67	0.062
3	NC Urban	359	0.337	262	0.346	38	0.036	174	0.163	77	0.072	79	0.074	27	0.025	49	0.047
4	NC Rural	355	0.333	265	0.249	40	0.038	173	0.162	79	0.074	79	0.074	27	0.025	47	0.045
5	CC Urban	144	0.135	118	0.111	298	0.280	203	0.191	43	0.040	42	0.039	157	0.147	60	0.057
6	CC Rural	149	0.140	118	0.111	303	0.285	205	0.192	45	0.042	42	0.039	125	0.117	78	0.074
7	SC Urban	123	0.115	137	0.129	417	0.392	202	0.190	57	0.054	37	0.035	19	0.018	73	0.067
8	SC Rural	122	0.115	138	0.130	415	0.390	198	0.186	56	0.053	42	0.039	19	0.018	75	0.069

es (k = 1–7) were defined, as in the SURE study,[6] by the following:

k = 1: cPk. Continental polar colder air (cPk) is generally cool and dry. This class occurs most often during winter and in more Northerly areas. Northerly winds usually dominate, with moderate to strong wind speeds. Precipitation may occur in the form of light snow or showers.

k = 2: cPw. Following the high pressure zone cP2 (see below), in a normal progression comes the cPw, or continental polar warmed air. This air mass gives rise to slightly warmer temperatures and an increase in air stagnation as compared to the cPk condition. Winds become more moderate, with occasional precipitation.

k = 3: mT. When a continental high cell has moved off the Eastern coastline and amalgamated with the Bermuda high, it generates maritime tropical, or mT, conditions onshore. An increase in temperature and water content are strong characteristics of this air mass. Increased cloud cover with light to moderate onshore wind is also often associated with mT air.

k = 4: Tr. A fourth class of air mass, transitional or Tr, includes a variety of cyclonic systems and mixed air masses with little temperature and moisture homogeneity. Days when more than one air mass moved through an area were also included in this class.

k = 5: cT. As maritime tropical air intrudes into the continent, the air mass becomes a continental tropical, or cT, condition. These are usually hot and dry continental air masses that occur most frequently in the summer. Light to moderate cloud cover with possible slight precipitation usually occurs under cT conditions.

k = 6: cP2. Following the Western progression of the cPk air mass comes the standardized continental high pressure zone, cP2. This air mass, which occurs predominantly in the winter, is associated with light variable winds and colder than average temperatures. Precipitation is infrequent and ventilation is usually poor.

k = 7: mP. The maritime polar, mP, air mass originates over the North Atlantic. It is characteristically cool and moist with a tendency, in winter, to become unstable. Heavy precipitation, low cloud cover, and moderate winds generally occur under mP conditions.

Table I presents both the frequency of occurrence (f_{jk}) and the relative frequency of occurrence (p_{jk}) of each air mass transport class (k) in each region (j) during the three-year period 1979–1981. The calculated frequencies show small differences between the urban and the rural values in the same region. This variation is due to differences in relative humidity measured at the urban and rural stations, which directly affects the frequency values of the class k = 8 and indirectly affects the frequencies of the other seven classes.

Each meteorological regime has different significance for visibility. Among the several meteorological parameters affecting visibility (e.g., temperature, humidity, solar radiation), the wind plays the major role. Visual range will be relatively high under good ventilation conditions, but relatively low when stagnant conditions permit accumulation of pollution. Similarly, wind coming from relatively clean regions, such as the Atlantic Ocean, is generally associated with good visibility.

Visual Range

We used a visibility data set provided by Dr. Rudolf Husar at Washington University in St. Louis (an updating of the data described in Reference 7). These data were collected at airports and represent point estimates of midday conditions. We calculated regional averages of visual range by selecting, in each of the eight subregions, three airports (for visual range and relative humidity observations). Regional averages were then computed by averaging the available data during each day in each subregion, eliminating those few days with large, unrepresentative spatial variations. We filtered out those days in which the range of variation of the measurements to be averaged was larger than the average itself.†

The airports whose data we used were selected using the results of previous evaluation studies. A survey of airport visibility data[9] was analyzed. It provided a data summary (availability and quality) and specifics of data quality for each airport. Other data and results of previous analyses[9] provided trends of percentiles of airport visual range data that allowed us to select airports with good data patterns and without suspicious trends. (This issue is particularly important for large visual range values, which are sometimes not recorded properly at airports.) These airports were (see Figure 1):

- *NE urban:* Pittsburgh, Pennsylvania; Albany, New York; Boston, Massachusetts
- *NE rural:* Burlington, Vermont; Syracuse, New York; Allentown, Pennsylvania
- *NC urban:* Indianapolis, Indiana; Columbus, Ohio; Akron, Ohio
- *NC rural:* Peoria, Illinois; Evansville, Indiana; Louisville, Kentucky
- *CC urban:* Baltimore, Maryland; Washington, D.C.; Richmond, Virginia
- *CC rural:* Roanoke, Virginia; Wilmington, North Carolina; Greenville, South Carolina

† The percentage of these days varied from 4 to 12 percent of the total number of days, depending on region.

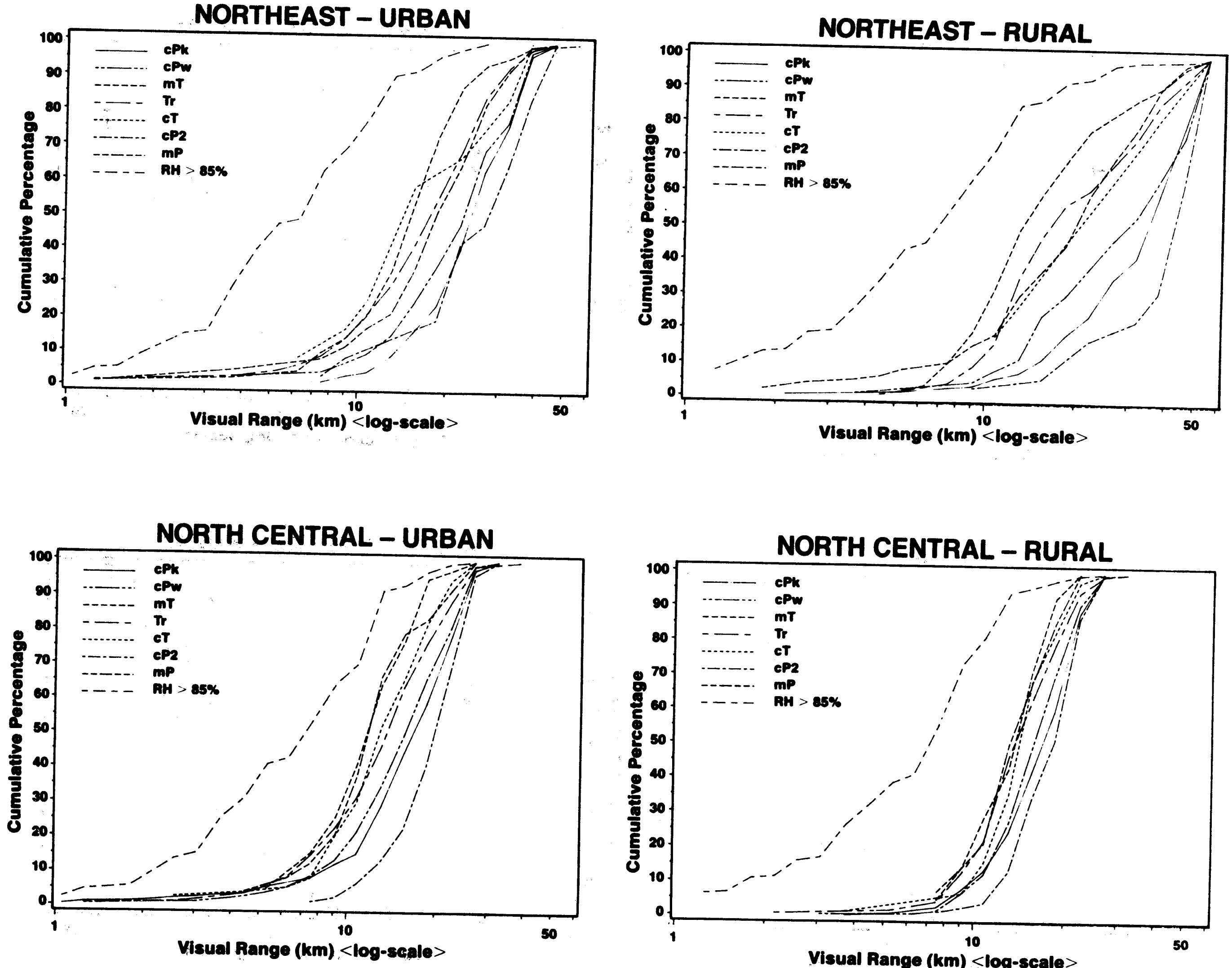

Figure 2. Cumulative distributions of visual range in the Eastern United States.

- *SC urban:* Atlanta, Georgia; Birmingham, Alabama; Memphis, Tennessee
- *SC rural:* Chattanooga, Tennessee; Huntsville, Alabama; Bristol, Tennessee

The choice of airport locations was affected by a variety of factors such as data availability, data quality and proximity to sulfate monitoring stations.‡ Given these limitations, some of the designations of airports as urban or rural were more relative than absolute.

Figure 2 shows the cumulative frequency distributions of the visual range in the eight regions for the eight different meteorological regimes during the three-year period 1979–81. The curves in Figure 2 indicate that:

- Days with high relative humidity are characterized by the lowest visual range, with median (i.e., 50th percentile) values that range between 5 and 10 km. The deviation of this curve from the others justifies its special treatment as an independent meteorological class.
- The "continental" meteorological regimes (cPk, cPw, and cP2) are associated with higher visual ranges, while "maritime" conditions (mT and mP) have lower visual range.
- The better visual ranges in rural regions are generally greater than those in urban regions and the variability with meteorological class is larger in rural regions than in urban regions. These differences are more evident in the coastal areas (NE and CC).
- Coastal regions (NE and CC) generally have higher visual ranges than central regions (NC and SC).
- Coastal regions (NE and CC) show a larger variation in visual range under different meteorological scenarios, while visual range in the central regions (NC and SC) seems less affected by the meteorology (except, naturally, for high relative humidity conditions).

Day to day meteorological variations can thus be seen to significantly influence visibility impairment in the Eastern United States. We should note that the results presented above provide an empirical quantification of *regional* visibility variations as a function of meteorology. Caution should be used in applying these results to subregional or local evaluations (e.g., in a particular state or city), since local visibility may differ substantially from regional averages.

‡ This proximity is important for other analyses that are not discussed in this technical note.

Acknowledgments

This technical note was prepared as part of a larger study[10] by AeroVironment Inc. prepared for the Utility Air Regulatory Group (UARG). The authors thank UARG for this support and express their appreciation to Dr. Prem

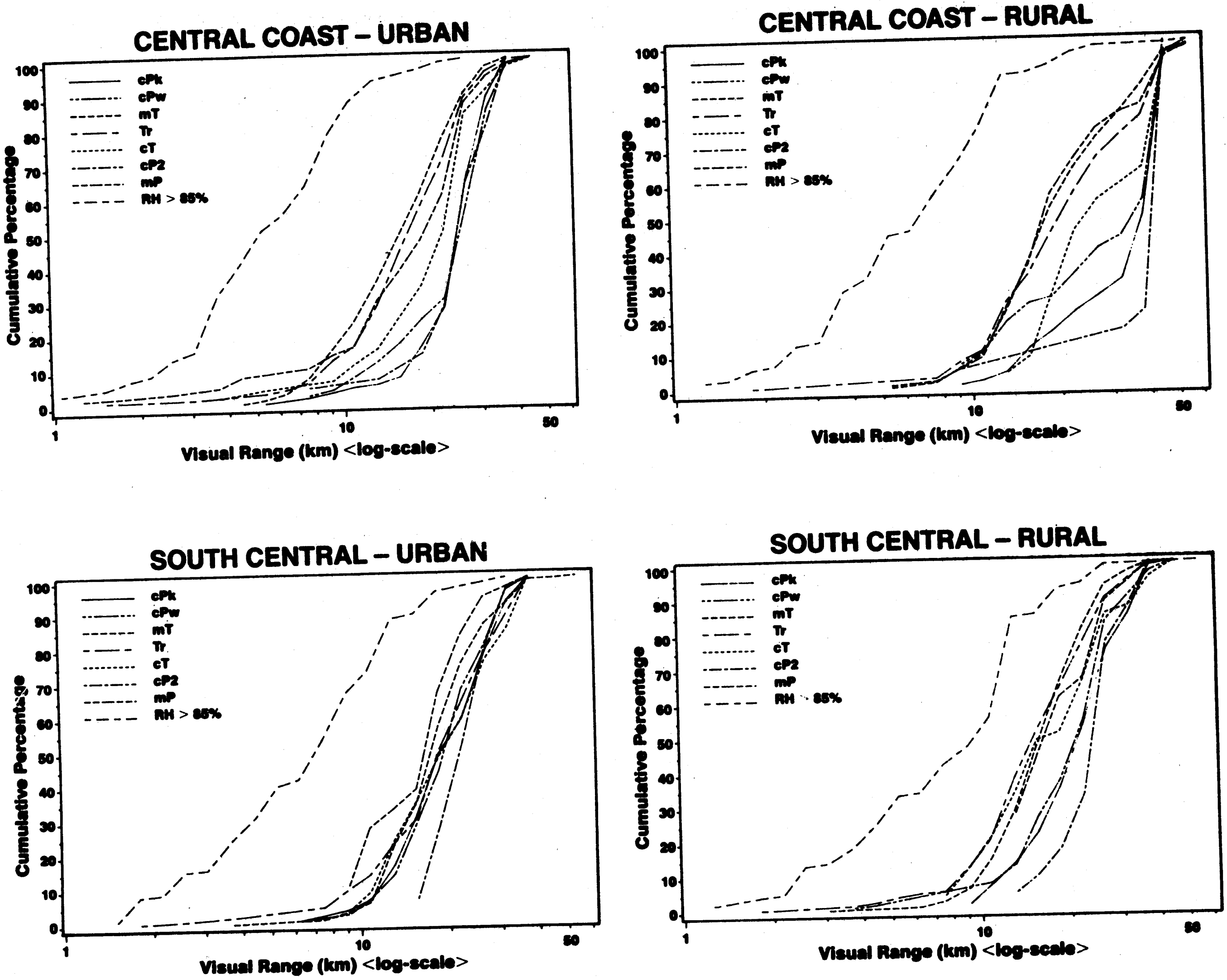

Figure 2. Cumulative distributions of visual range in the Eastern United States (Continued).

Bhardwaja (Salt River Project) for his critical review. We also thank Dr. William Balson of Decision Focus, Inc., for useful discussions, and Ms. Lydia Chu of AeroVironment for computer graphics support.

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