DEPENDENCE OF NEPHELOMETER SCATTERING COEFFICIENTS ON RELATIVE HUMIDITY
Evolution of Aerosol Bursts

by

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AFFILIATION

The author is on assignment with the U.S. Environmental Protection Agency from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

ABSTRACT

Observations on the temporal dependence of the nephelometer scattering coefficient on relative humidity are presented and discussed for four different cases. For each case, the weather at the Research Triangle Park, North Carolina was dominated by an anticyclonic weather system. By taking simultaneous nephelometer scattering coefficient observation at two different relative humidities, it was possible to conclude that with nocturnal stable atmospheric conditions:

- In general, the scattering coefficient increases from sundown to sunup due to aerosol growth and an increasing trend of the aerosol number density;

- In general, the relatively rapid increase and subsequent decrease of the scattering coefficient during a 2 to 3 hour period after sunup is due to a relatively rapid aerosol growth and shrinkage, and a relatively rapid increase and decrease of the aerosol number density.

The latter behavior of the scattering coefficient was called an aerosol burst. The relationship between an aerosol burst, fumigation, and early morning visibility deterioration is also discussed.

CONTENTS

FIGURES

TABLE

ACKNOWLEDGEMENTS

The author acknowledges the technical assistance of Mr. R. S. Soller with the instrumentation. Various discussions on the experimental data with Dr. F. Binkowski are gratefully acknowledged.

SECTION 1

INTRODUCTION

Various experimental and theoretical studies have been concerned with the dependence of aerosol size on the relative humidity.[1-10] Since the size of an aerosol will affect its light scattering properties, light scattering by aerosols can depend on the relative humidity. In our studies, an integrating nephelometer was used to measure the light scattering properties of atmospheric aerosols with respect to the relative humidity. The nephelometer readings will be referred to as the scattering coefficient. The scattering coefficient is a sum of contributions from atmospheric aerosols and gases.

At the Research Triangle Park, North Carolina (RTP), the smallest diurnal scattering coefficient usually occurs during the afternoon. A typical afternoon value for the scattering coefficient is 0.1 km^{-1}. Afternoon values of 0.03 km^{-1} and 0.3 km^{-1} would be characteristic values of a "clean" and "dirty" afternoon, respectively. During the night, there is usually a general increasing trend of the scattering coefficient which is typically 3 or 4 times larger at sunup than its afternoon value.

Beginning at sunup, the scattering coefficient is often observed to increase relatively rapidly and subsequently decrease relatively rapidly. The time span, from sunup until the scattering coefficient is changing relatively slowly, is between 2 to 3 hours. As a descriptive name for this phenomenon, the term aerosol burst will be used. Aerosol bursts are commonly associated with anticyclonic weather systems, and have been observed each month of the year. With passage of warm fronts, there have been a few occasions for which the scattering coefficient has been observed to vary somewhat like the variation observed during an aerosol burst. Only aerosol bursts associated with anticyclonic weather systems will be discussed in this paper.

A process involved in the aerosol burst phenomenon is the growth and shrinking of the aerosols due to the increase and decrease of the relative humidity, respectively. The increase of the relative humidity is due to the evaporation of moisture by solar radiation from grass or anything else on which dew is deposited during the night. Of course, after the moisture has evaporated,the relative humidity will decrease. It is also possible that the growth and shrinking of aerosols could be affected through the absorption of solar radiation by the aerosol which would result in moisture evaporation from the aerosol. In addition, it is conceivable that solar radiation absorption by an aerosol could induce aerosol spallation which would affect the growth and shrinking of aerosols. However, our observations do not indicate that such a mechanism occurs.

In general, variations of the aerosol number density are also occurring during an aerosol burst. After sunup, the aerosol number density increases to a maximum in a period of about 2 or 3 hours and subsequently decreases. A plausible explanation for the variations is that, as the mixing layer grows under the influence of solar radiation heating, aerosols from aloft can be diffused toward the ground. Assuming the aerosols aloft have a larger number density than the aerosols at ground level, an increase of the aerosol number density would be expected. As the nocturnal temperature inversion is dissipated, the aerosols will be mixed through greater depths and the aerosol number density will decrease.

In studies[11] on sulfate aerosol formation, "bursts" of the aerosol number density have been observed to occur by processes associated with solar radiation. The increase and decrease of the aerosol number density was attributed to aerosol formation and aerosol agglomeration, respectively. There is no evidence that these processes are of importance for the aerosol bursts discussed in this paper.

In Section 2, a discussion of the instrumentation for the observations is presented. The diurnal variation of the scattering coefficient is discussed for three different examples in Section 3.1. In Section 3.2., the relation between fumigation and visibility deterioration during the morning and an aerosol burst is discussed. A fourth example of the observed data is also presented. In Section 4, a summary of the conclusions are enumerated.

SECTION 2

INSTRUMENTATION

For these observations, two nephelometers were operated in an air conditioned room (inside nephelometers) and two nephelometers were operated outdoors at ambient atmospheric conditions (outside nephelometers). The intakes, for bringing outside air to the inlet orifices of the inside and outside nephelometers, were about 50 m apart and 6 m above ground level. All of the nephelometers were Model 1550 Meteorology Research Incorporated (MRI) integrating nephelometers. The redundant inside and outside nephelometers were used to perform various experiments as well as to monitor the reliability of the other corresponding inside or outside nephelometer.

Since the scattering coefficient is determined by the amount of light scattered from the air which is flowing through the nephelometer scattering chamber, the relative humidity of the air flowing through the scattering chamber must be known in order to determine the dependence of the scattering coefficient on the relative humidity. At any given instant, the relative humidity of the air in the scattering chamber can be determined provided the temperature and dew point of the air are determined in the scattering chamber.

Dew points were measured by placing humidity probes in the air flowing through the inlet and/or outlet orifices of the nephelometer scattering chamber. Initially, it was our intention to use a cooled mirror humidity sensor. However, our tests showed that this type sensor was not reliable because of sporadic contamination of the mirror. On the other hand, our tests showed that the saturated salt (lithium chloride) humidity sensor was very reliable and relatively unaffected by contamination. Measurements of the dew point were taken for the inside nephelometers and for the outside nephelometers with the saturated salt humidity sensor. Separate measurements were necessary because differences as large as 1 to 2°C in the dew point of air flowing through the inside nephelometers and of air flowing through the outside nephelometers were observed at various times. This difference in the dew points is due to differences in the moisture content of air entering the intakes, which are separated by 50 m, to the inside and outside nephelometers.

Temperatures were also measured by placing temperature probes in the air flowing through the inlet and/or outlet orifices of the scattering chamber. If the temperature, at any given instant, of the air flowing through the inlet and outlet orifices are the same, this temperature would be the same as the temperature of the air flowing through the scattering chamber.

For the outside nephelometers, the temperatures of the air flowing through the inlet and outlet orifices of the nephelometer scattering chamber were approximately the same (generally less than 0.5°C). In order to obtain this near equality of the temperatures, it was necessary to keep the temperature of the air in the enclosure housing the outside nephelometers equal to the ambient atmospheric temperature. This was done by drawing the ambient air into the enclosure and exhausting air in the enclosure to the outside with a fan.

For the inside nephelometers, particular attention must be given to the temperature measurements. For one inside nephelometer, ambient outside air enters the nephelometer scattering volume after a relatively short journey of about 2 m through tubing in the room. In general, the temperature of air entering the scattering chamber will be different than the ambient outside temperature. In addition, the temperature of air leaving the scattering chamber will be different than the temperature of air entering the scattering chamber. Under certain conditions, the temperature difference of air flowing through the inlet and outlet orifices of the nephelometer scattering chamber was measured to be as large as 5°C. Thus, in general, there would be a relative humidity of, say, less than 45 percent, the relative humidity gradient is probably not important since the scattering coefficient is not much affected by the relative humidity. Consequently, for sufficiently small relative humidities, the dependence of the scattering coefficient on relative humidity is relatively small.

Before air enters the other inside nephelometer, the system has been designed so that the temperature and/or dew point can be increased or decreased before the air enters the nephelometer scattering chamber. Since the particular details of this system is not pertinent to the discussions of this paper, the system will not be described. For air entering the scattering chamber of this nephelometer, the journey of the air through tubing in the room has been sufficient for the air to be in equilibrium with the room temperature. Consequently, the relative humidity gradient of the scattering chamber is small. Usually, the relative humidity is small enough for the inside nephelometers so that the scattering coefficients of the two inside nephelometers do not vary significantly because of differences of the relative humidity.

Scattering coefficient data taken with the inside and outside nephelometers will be referred to as the inside and outside scattering coefficients respectively. Likewise, the relative humidity of the air flowing through the inside and outside nephelometers will be referred to as the inside and outside relative humidity.

A Bascom-Turner electronic recorder was used for data collecting, processing and storing. The rate of data acquisition was 500 readings in 24 hours for each observed parameter. The 24-hour period was arbitrarily chosen to begin at 1400 EST. Except for periods of equipment maintenance and repairs, data have been recorded continuously since December 1978.

SECTION 3

SCATTERING COEFFICIENT VARIATIONS

3.1 DIURNAL

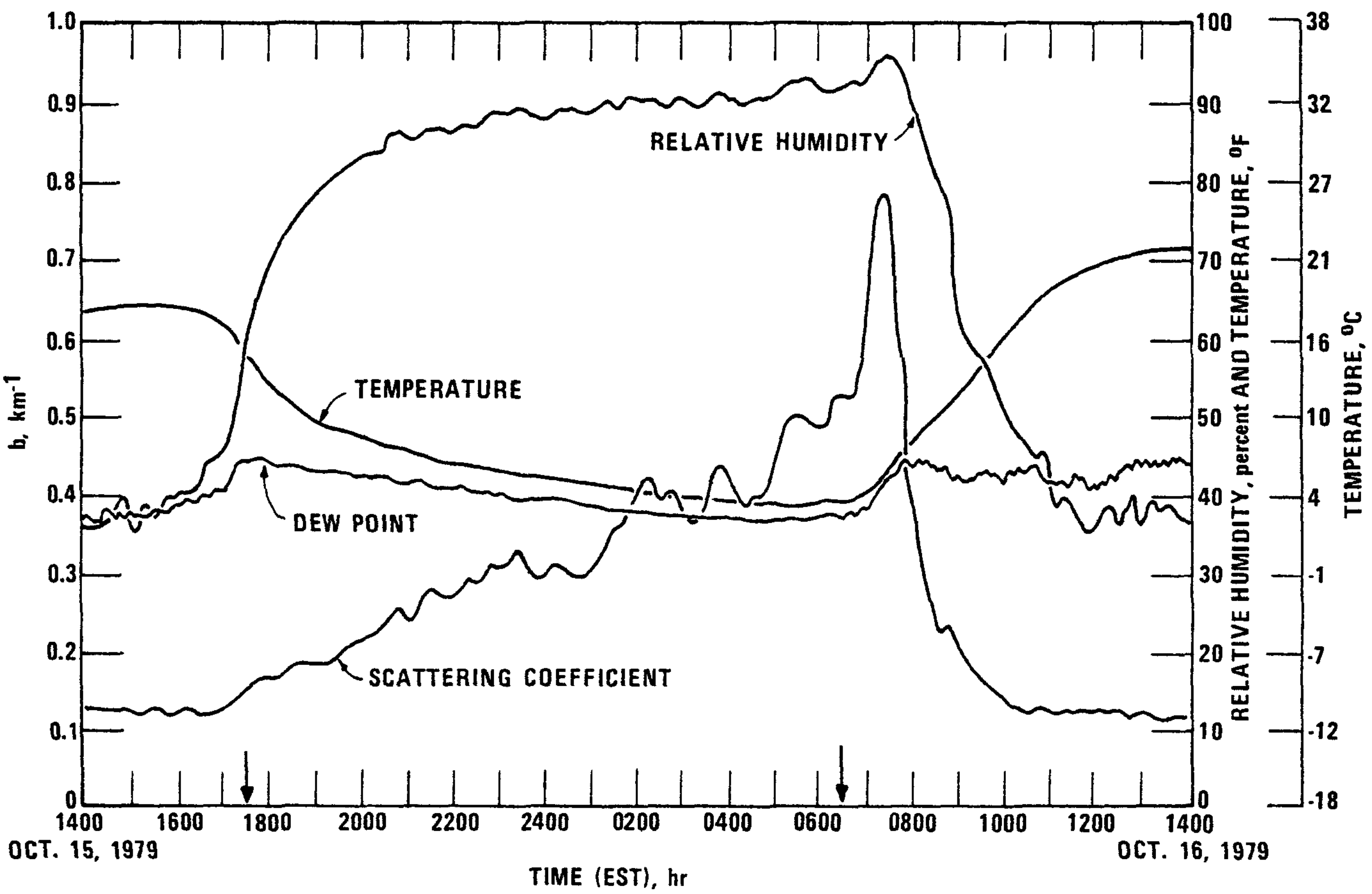
The RTP is located in a non-urban area. On rare occasions, the scattering coefficient data have obviously been affected by local sources such as the emissions from burning tree piles located 3 or 4 km away. However, in general, the presence of possible emissions from nearby sources can not be identified. For each of the four examples to be discussed, the RTP was dominated by anticyclonic pressure systems.

(a) October 15-16, 1979

In addition to the outside scattering coefficient, the 24-hour variation of the atmospheric temperature, dew point, and outside relative humidity are shown in Figure 1. The arrows indicate the time of sunup and sundowns given in tables prepared by the U.S. Naval Observatory. For discussion of the temporal behavior of the scattering coefficient, it is convenient to consider two time periods. The first time period is from 1400 EST until sunup while the second time period is for a period of approximately 3 hours after sunup.

Between 1400 EST and sunup, the relative humidity and scattering profiles began increasing at sundown and continued throughout the night. Impressed on the increasing trend of both profiles is an undulating structure which became most prominent after about 2000 EST. At this same time, the wind speed was calm (<2 ms^{-1}) and remained calm until about 0800 EST the next day. In addition, the weather observations at the Raleigh-Durham Airport (RDU) indicated that there were no clouds.

Figure 1. Twenty four hour variation of the outside scattering coefficient, temperature, dew point and outside relative humidity. The scale for the scattering coefficient is given on the left hand side. Scales for the remaining parameters are given on the right hand side. For temperature and dew point, degrees fahrenheit is to be substituted for percent. A scale is also given for the temperature and dew point in degrees Celsius. The arrows indicate time of sundown and sunup.



Nephelometer observations taken in New York and Ohio[12] indicated a similar increasing trend of the scattering coefficient between sundown and sunup. Evidently a corresponding undulating structure of the scattering coefficient was not observed. The most plausible explanation of the undulating structure is that, as calm conditions set in at about 2000 EST, there is little turbulence to produce a homogeneous mixture of atmospheric moisture. Thus, if there are undulations of the relative humidity, undulations of the scattering coefficient are to be expected.

During the subsequent time period, which begins at sunup, an aerosol burst occurs. Initially, the scattering coefficient increases relatively rapidly. This increase is most likely to be due to aerosol growth resulting from the increase of the relative humidity. This assertion will be examined more critically in the discussion of the data shown in Figure 2.

Atmospheric processes similar to the formation of evaporation fog[13,14] may be responsible for the increase of relative humidity. In any case, there must be an adequate source of moisture to account for an increase of the relative humidity. The moisture source or, perhaps more correctly, interim moisture source is formed during the night by the deposit of moisture on the grass or other surfaces. After sunup, the ground is heated by solar radiation. Part of the solar energy is used in moisture evaporation which increased the dew point of the overlying air. Since the dew point increased more rapidly than the air temperature during the initial period after sunup, the relative humidity increases.

Solar radiation sensors were located near and at the same level as the nephelometer inlet orifice. Solar radiation data are useful to examine the energetics of increases of the temperature and dew point in addition to information on the cloud cover.

In the first 30 minutes after the diffuse solar radiation was first detected, the increases of the various parameters were: (1) air temperature from 4.6 to 5.2 C; (2) dew point from 3.2 to 4.4 C; relative humidity from 91.2 to 95.2 percent; (4) scattering coefficient from 0.54 km^{-1} to 0.75

km^{-1}; and (5) total solar radiation from 0.0 to 0.5 cal cm^{-2}.

Assuming the temperature and dew point increases, in the first 30 minutes after the diffuse solar radiation was detected, are due to solar energy, it is possible to answer the question of whether sufficient solar energy was received to account for the increases. Our calcuations showed that 0.1 cal cm^{-2} and 0.2 cal cm^{-2} were required to produce the temperature and dew point increases respectively. Since 0.5 cal cm^{-2} of solar energy was received, it was concluded that the solar energy received was sufficient to account for the temperature and dew point increases.

As will be noted in Figure 1, the maximum of the aerosol burst is nearly coincident with the maximum of the relative humidity. There have been observations for which the aerosol burst maximum occurs before the maximum of the relative humidity. If the relative humidity maximum occurs before the aerosol burst maximum, it must be rare at the RTP since it has not been observed since the observations began in December 1978. Transition between calm (<2 ms^{-1}) and the customary daytime fluctuating winds occurred at about 0800 EST. This transition is always observed to occur after the maximum of the aerosol burst. This transition can also be noted by an examinatiuon of the dew point profile since, as the winds start fluctuating, the dew point will be observed to fluctuate.

During the discussion of the data presented in Figure 1, the growth of the aerosols as a consequence of an increase of the outside relative humidity, was asserted to be mainly responsible for the increase of the outside scattering coefficient during an aerosol burst. Obviously, an increase of the aerosol number density could also be responsible for part of the increase of the outside scattering coefficient during an aerosol burst. By analyzing the data presented in Figure 2 or the inside and outside nephelometers, the relative importance of aerosol growth and aerosol number density increase can be assessed.

From sundown until sunup, the inside scattering coefficient increased, roughly, from 0.1 to 0.2 km^{-1}. During this period, the inside relative humidity was less than 30 percent. In addition, there was a relatively small decreasing trend of the inside relative humidity. Consequently, the inside relative humidity can not be assumed to be responsible for the increasing trend of the inside scattering coefficient. The most plausible explanation is that there is an increasing trend of the aerosol number density. During this period, the outside scattering coefficient increased, roughly, from 0.1 to 0.5 km^{-1}. Thus, from sundown until sunup, the growth of aerosols and the increase of the aerosol number density, contributed about 0.3 and 0.1 km^{-1} respectively to the increasing trend of the outside scattering coefficient.

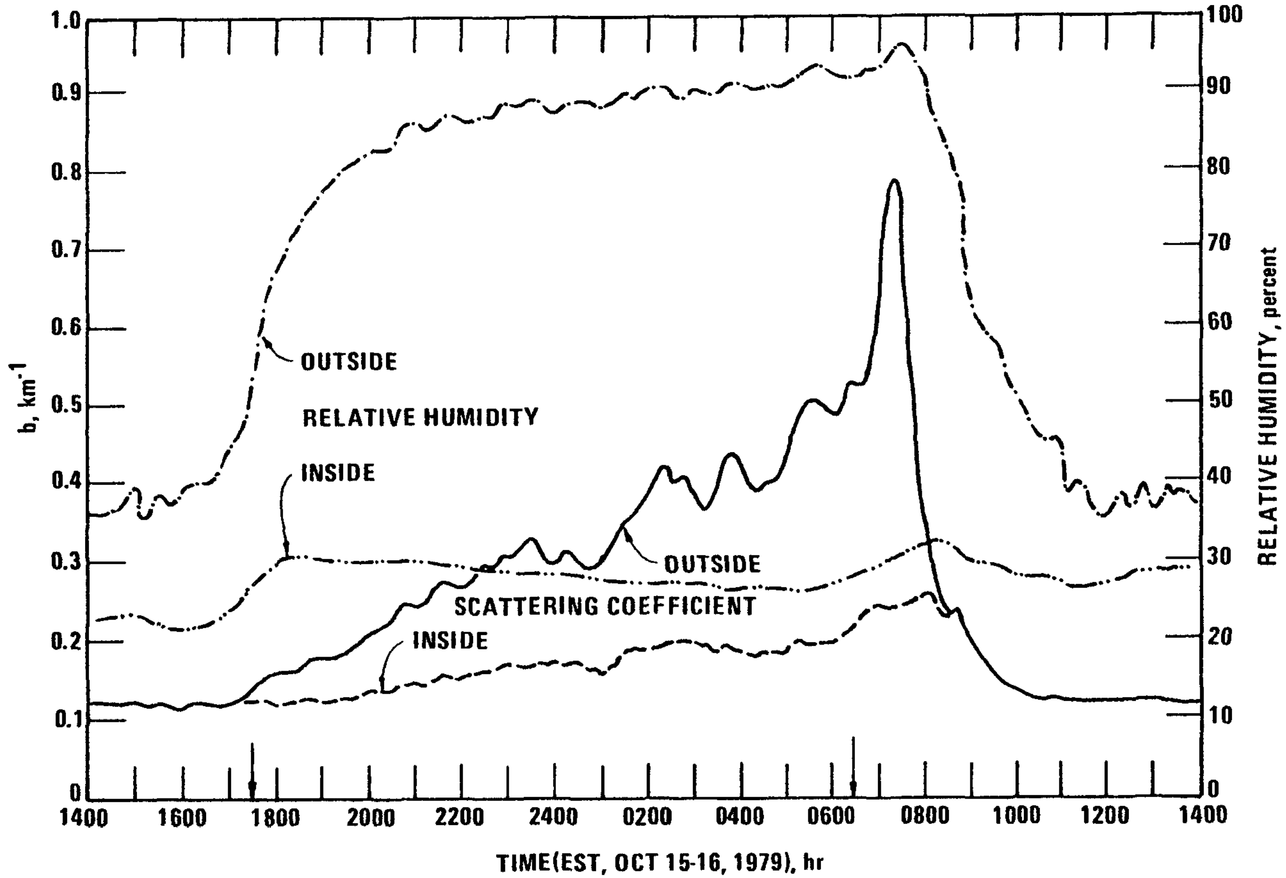
By a similar analysis for the increase of the outside scattering coefficient during the aerosol burst, the contribution by aerosol growth was roughly 0.3 km^{-1} and roughly 0.05 km^{-1} by an increase of the aerosol number density. Thus, as asserted previously, the growth of the aerosols, as a consequence of an increase of the outside relative humidity, appears to be the dominate mechanism for the relatively rapid increase of the outside scattering coefficient during the aerosol burst.

The mechanism, which is responsible for the increasing trend of the aerosol number density during the night, is not known. There are several possibilities. Among these possibilities are thermophoresis and or sedimentation processes. To elucidate the nature of the processes responsible for the increasing trend of the aerosol number density during the night, additional observations would be needed.

In Figure 2, it will be noted that the maxima of the inside and outside scattering coefficient do not occur at the same time. Also, the peak of the inside scattering coefficient appears to be closely associated with the relatively small protuberance on the aerosol burst profile. The significance of the protuberance will be discussed in Section 3.3.

Another feature to be noted in Figure 2 is that the outside scattering coefficient at 1400 EST on October 15, 1979 is nearly equal to the outside scattering coefficient 24 hours later. Thus, there was apparently no net

Figure 2. Twenty four hour variation of the outside and inside scattering coefficient and the outside and inside relative humidity. The arrows indicate the time of sundown and sunup.



change of the aerosol number density during the 24 hour period of the observations even though there were changes of the aerosol number density at certain times during the period.

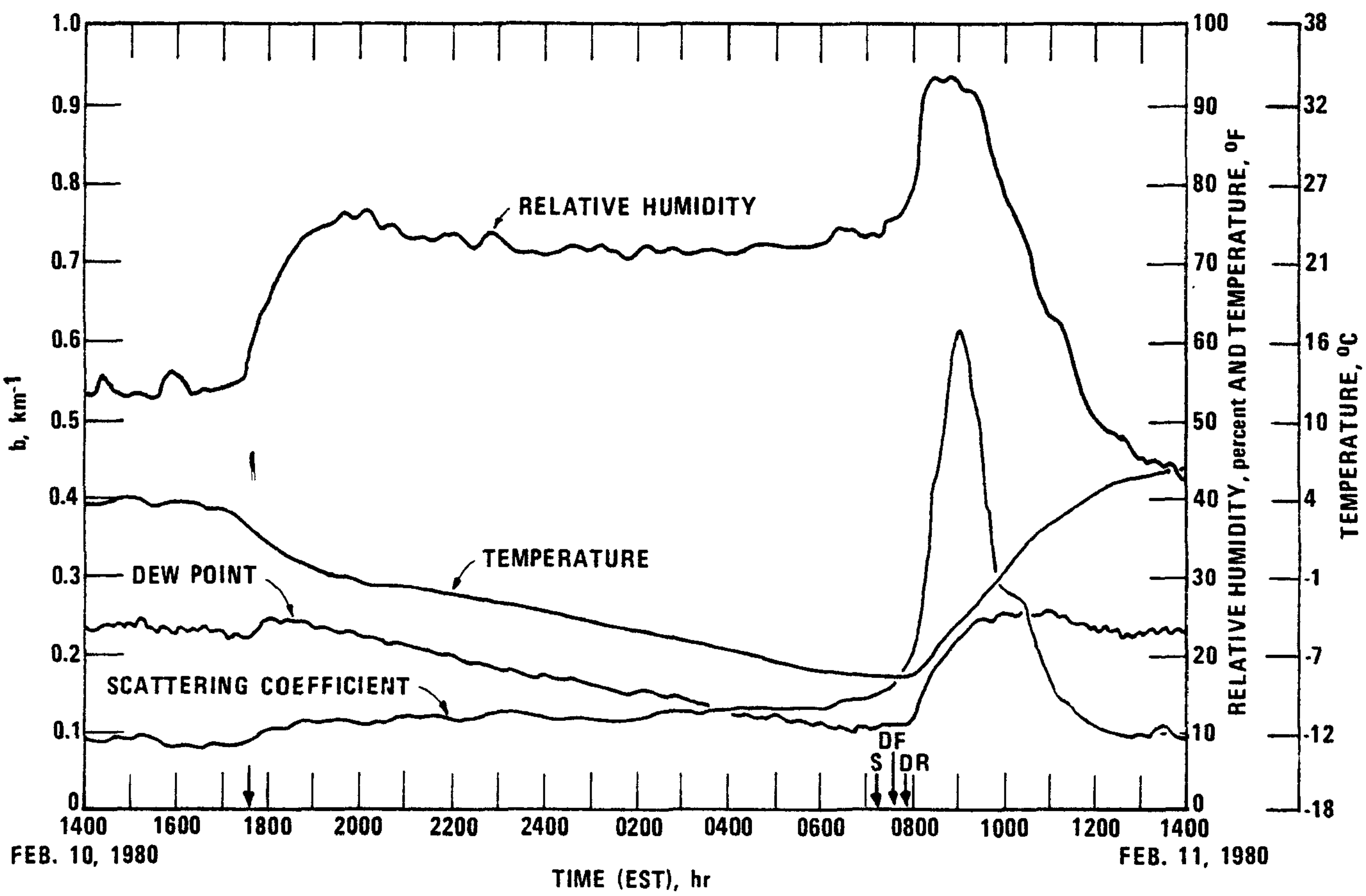
(b) February 10-11, 1980

During the observing period of February 10-11, 1980, the ground was snow-covered at the RTP. These conditions are rare at the RTP. The observational data are shown in Figure 3. It is also of interest to note that throughout the period the dew point was below freezing and the temperature was below freezing most of the period. Thus, particularly for the temperature and dew point, meteorological conditions were quite different from those for Figure 1.

In comparison to the variations of the outside scattering coefficient during the night shown in Figure 1, the outside scattering coefficient is relatively smooth during the night in Figure 3. This feature of the profiles suggests that the scattering coefficient shown in Figure 3 was influenced relatively little by variations of the relative humidity. Generally, our observations show that there is a minimum relative humidity for which the scattering coefficient is relatively more sensitive to variations of the relative humidity as the relative humidity increases to larger relative humidities. This sensitivity of the scattering coefficient to variations of the relative humidity appears to be in harmony with the data shown in Figures 1 and 3. Presumably, in Figure 3, the relative humidity would have had to be greater than the relative humidity in Figure 1. The gradual increase of the scattering coefficient from sunset to sunup is primarily due to an increase of the aerosol number density rather than the growth of the aerosols. This assertion will be discussed in relation to the data presented in Figure 4.

The behavior of the aerosol burst depicted in Figure 3 is quite similar to that shown in Figure 1. In the first 30 minutes after the detection of the diffuse solar radiation, the increase of the various parameters were: (1) temperature from -8.0 to -6.2 C: (2) dewpoint from -11.7 to -7.0 C: (3)

Figure 3. Twenty four hour variation of the outside scattering coefficient, temperature, dew point and relative humidity. The scale for the scattering coefficient is given on the left hand side. Scales for the remaining parameters are given on the right hand side. For temperature and dew point, degrees fahrenheit is to be substituted for percent. A scale is also given for the temperature and dew point in degrees Celsius. Arrows are shown for sundown (unmarked), sunup (S), diffuse solar radiation (DF), and direct solar radiation (DR).



relative humidity from 75.3 to 93.9 percent; (4) scattering coefficient from 0.16 to 0.41 km^{-1}; and (5) total solar radiation from 0.0 to 4 cal cm^{-2}.

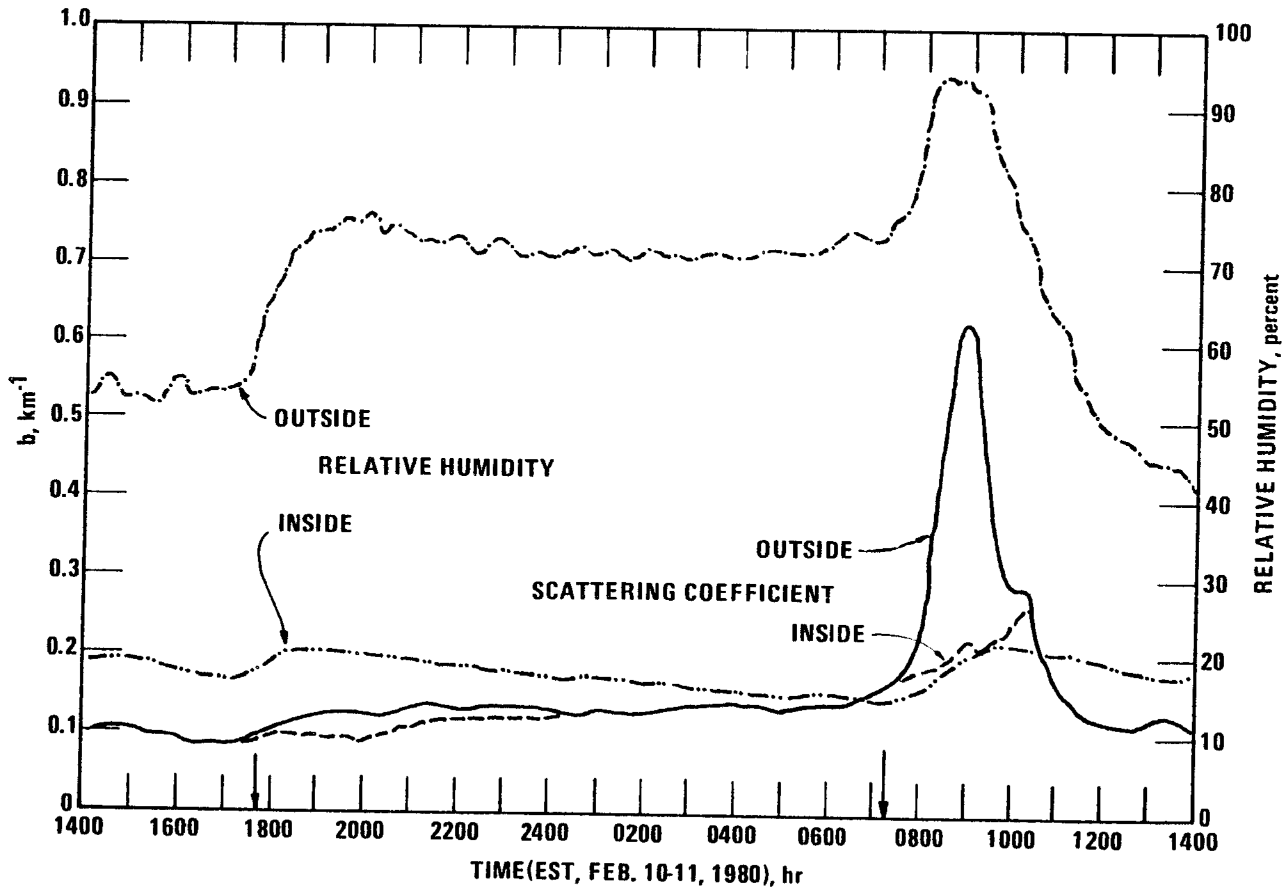
Comparing the total solar radiation received with the solar energy received October 16, 1979, it will be noted that it was much larger on February 1, 1980. This would be expected since the scattering coefficient was much smaller on February 11, 1980. Our calculations showed that 0.3 cal cm^{-2} was necessary to account for the temperature rise and 0.2 cal cm^{-2} for the increase of the dew point. Thus, solar radiation could provide the necessary energy to account for the increases of the temperature and the dew point.

At about 1000 EST, there is a protuberance on the scattering coefficient profile which, as remarked previously, appears to be related to fumigation. It will be noted that the scattering coefficient at 1400 EST on February 10, 1980 is nearly equal to the scattering coefficient 24 hours later and suggests that there had been no net change of the aerosol number density.

In analyzing the data presented in Figure 3, it was asserted that the increasing trend of the outside scattering coefficient during the night was primarily due to an increasing trend of the aerosol number density. Similar to the previous analysis, the relative importance of aerosol growth and of an increase of aerosol number density to the increasing trend of the outside scattering coefficient during the night can be assessed by an analysis of the data on the inside and outside nephelometers shown in Figure 4.

Referring to Figure 4, it will be noted that, except for the period from about 1800 EST until midnight, there are no essential differences between the inside and outside scattering coefficient profiles from sundown until sunup. During this period, the inside relative humidity was less than 20 percent. Consequently, in contrast to the previous example, the increasing trend of the outside scattering coefficient must have been almost entirely due to an increase of the aerosol number density. On the other hand, the increase of the scattering coefficient during the aerosol burst

Figure 4. Twenty four hour variation of the outside and inside scattering coefficient and the outside and inside relative humidity. The arrows indicate the time of sundown and sunup.



was almost entirely due to a growth of the aerosols which resulted from the increase of the outside relative humidity.

Perhaps, it is worth mentioning again that the outside scattering coefficient was observed to be larger than the inside scattering coefficient from 1800 EST until midnight. This difference in the magnitudes of the scattering coefficients suggests that aerosol growth, resulting from an increase of the outside relative humidity, was responsible. As a consequence of this difference in the magnitude of the scattering coefficients, it appears that the growth of an aerosol depends not only on the relative humidity but also on the time rate of change of the relative humidity. It is likely that this dependence is also responsible, at least in part, for an aerosol burst.

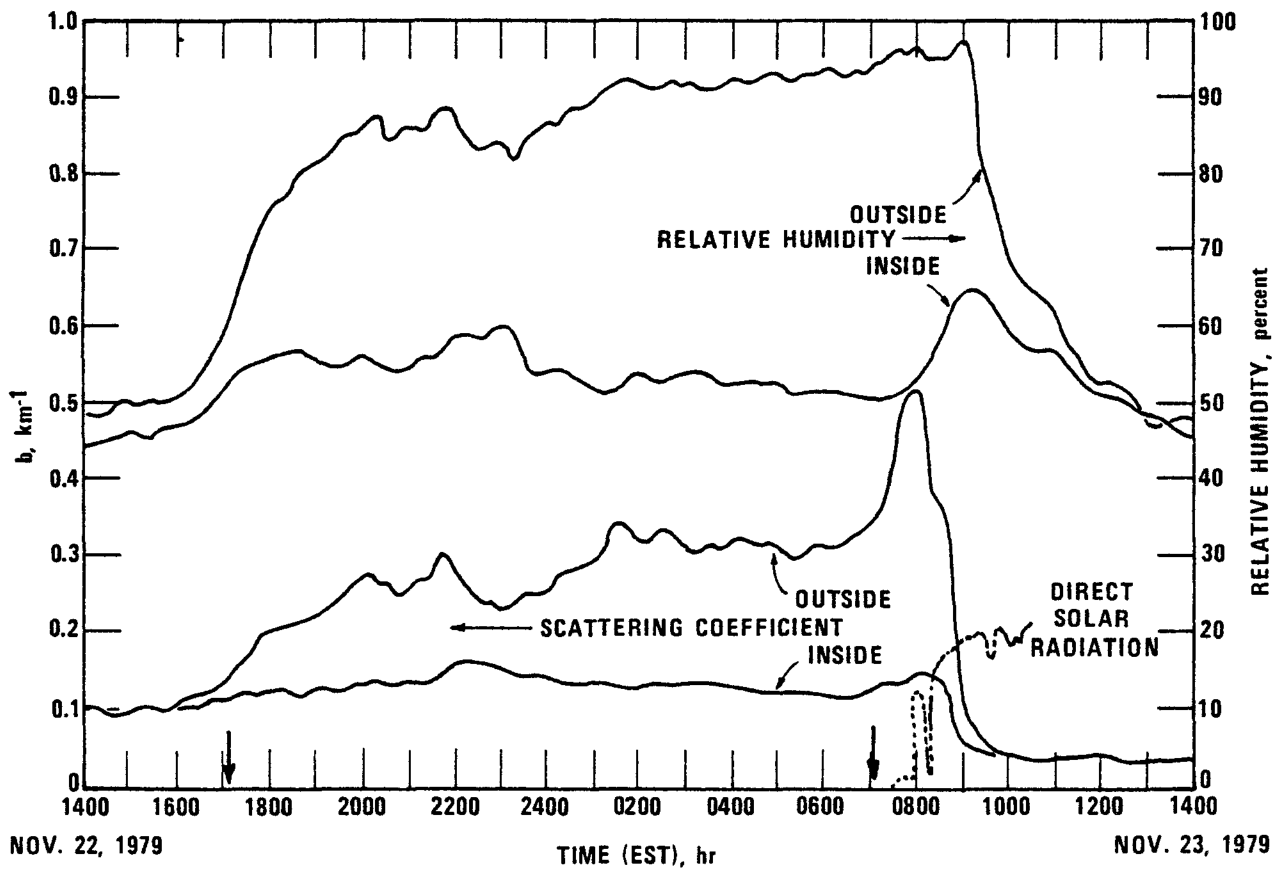
Similar to the features shown in Figure 2, the maximum of the inside scattering coefficient occurs after the maximum of the outside scattering coefficient in Figure 4. The protuberance on the aerosol burst is clearly associated with the maximum of the inside scattering coefficient. As mentioned previously, the significance of the relatively small protuberance will be discussed in Section 3.3.

As for the previous example, there were little net change of the outside scattering coefficient from 1400 EST on February 10, 1980 to 1400 EST on February 11, 1980. Consequently, there was little net change of the aerosol number density during this period.

(c) November 22-23, 1979

For the previous two examples, it was concluded that there was no net change in the aerosol number density from the beginning of the observatinal period at 1400 EST until the end of the observational period at 1400 EST the next day. In contrast, the data presented in Figure 5 suggests that there was a decrease of the aerosol number density during the observational period. This conclusion is based on the observation that the inside and outside scattering coefficients decreased from about 0.1 km^{-1} at 1400 EST

Figure 5. Twenty four hour variation of the inside and outside scattering coefficient and the corresponding inside and outside relative humidity. The scale for the scattering coefficient is on the left hand side. The scale for the relative humidities is on the right hand side. The scale for the portion of the direct solar flux is arbitrary. The arrows indicate time of sundown and sunup.



on November 22, 1979 to about 0.03 km^{-1} at 1400 EST on November 23, 1979. Examining the profile of the inside scattering coefficient in Figure 5, it will be observed that the inside scattering coefficient was roughly constant until the aerosol burst occurred. Subsequently, there was an abrupt decrease of the inside scattering coefficient. This definitely indicates that the RTP was not gradually engulfed by air with a smaller aerosol number density. Rather, there was a relatively abrupt decrease of the aerosol number density which occurred during the aerosol burst. It is also important to note in Figure 5 that the inside relative humidity was about 45 percent at the beginning and the end of the observational period. Consequently, it is not likely that the decrease of the scattering coefficient can be attributed to a shrinking of the aerosols.

From sundown to sunup, there was an increasing trend of the outside scattering coefficient. Since the inside scattering coefficient was roughly constant during this period, the increasing trend of the outside scattering coefficient was most likely predominately due to a growth of the aerosols resulting from the increasing relative humidity. In contrast to the previous two examples, the evidence for an increase of the aerosol number density between sundown and sunup is debatable.

From sunup until the maximum of the outside scattering coefficient at about 0800 EST, the outside relative humidity increased from about 92 to 95 percent. From 0800 until 0900 EST, the outside relative humidity decreased from 95 to 94 percent during the first 15 minutes, remained relatively constant for the next 30 minutes, and subsequently increased to a maximum of about 96 percent by 0900 EST. From 0900 EST until the end of the period at 1400 EST, there was a decline of the relative humidity to about 48 percent. With this information on the relative humidity, a better understanding of the aerosol burst is possible.

From sunup until the maximum of the aerosol burst, there was a relatively small increase of the inside scattering coefficient. Consequently, the increase of the outside scattering coefficient is primarily due to the growth of the aerosols which results from the 3 percent increase of the outside relative humidity.

From 0800 until 0815 EST, there was a relatively rapid decrease of the outside scattering coefficient. Evidently, this decrease was in response to the 1 percent decrease of the relative humidity. During this time there is no evidence of a decrease of the aerosol number density since the inside scattering coefficient was relatively constant even though the inside relative humidity was constant.

From about 0845 to 0900 EST, the outside relative humidity increased from 94 to 96 percent. There is no expected increase of the outside scattering coefficient. Rather, there is a continued decrease. To explain this anomaly, the only plausible explanation appears to be that the aerosol number density was decreasing. The inside scattering coefficient supports this conjecture since it decreases rapidly during this period.

As a matter of interest, a portion of the direct solar radiation profile is shown in Figure 5. Dips in the profile indicates that there were a few clouds. The weather station at RDU reported scattered clouds at 8 km. For this case, it is not apparent that the scattered clouds had any influence on the relative humidity. However, at times, the influence of clouds on the relative humidity can be easily noted since the clouds retard the evaporation of moisture. Consequently, it is possible for clouds to influence the aerosol burst.

According to the above analysis, "clean" air began arriving at the RTP at about 0845 EST. At 0840 EST, the records indicate that there was a transition from calm winds ($<2\ ms^{-1}$) to the customary daytime fluctuating winds. At that time, air above the nocturnal inversion can be mixed downward. If this air has a relatively small aerosol number denisty, the air near the surface would be diluted by mixing and the decrease of the aerosol number density could be understood.

After 1400 EST until sunset on November 23, 1980, the inside and outside scattering coefficients were essentially the same and about 0.03

km^{-1}. Thus, the RTP was bathed with relatively "clean" air for at least 7 hours. At times after a thunderstorm, the scattering coefficient will be as small as 0.03 km^{-1}. However, these periods seldom last over an hour. Consequently, it would appear that there must be a large source region for the "clean" air. Information concerning a possible source region was obtained by consulting the weather maps.

On November 23, 1979 at 0700 EST, there was a low pressure system centered over Lake Superior. A relatively slow moving cold front, which was roughly oriented in a north-south direction from Lake Superior to Western Louisiana, was associated with the low pressure system. Precipitation, associated with the front, was quite extensive and back of the front. On November 23, 1979, the front was about 400 km to the west of the RTP. Maps of the upper winds indicated that the winds had been from the west and southwest for at least 3 days. Thus, the weather maps indicated that a possible source region of "clean" air did exist since rainfall would be expected to purge the atmosphere of aerosols.

Presumably, the "clean" air was transported to the RTP above the nocturnal temperature inversion and brought to the surface during the aerosol burst by turbulent mixing processes. In any case, the "clean" air could not be associated with the passage of a front or a change of the wind direction. This example most likely represents a case of which there has been a long distance. transport ($\sim$500 km) of "clean" air to the RTP.

3.2 AEROSOL BURST, FUMIGATION, AND VISIBILITY DETERIORATION

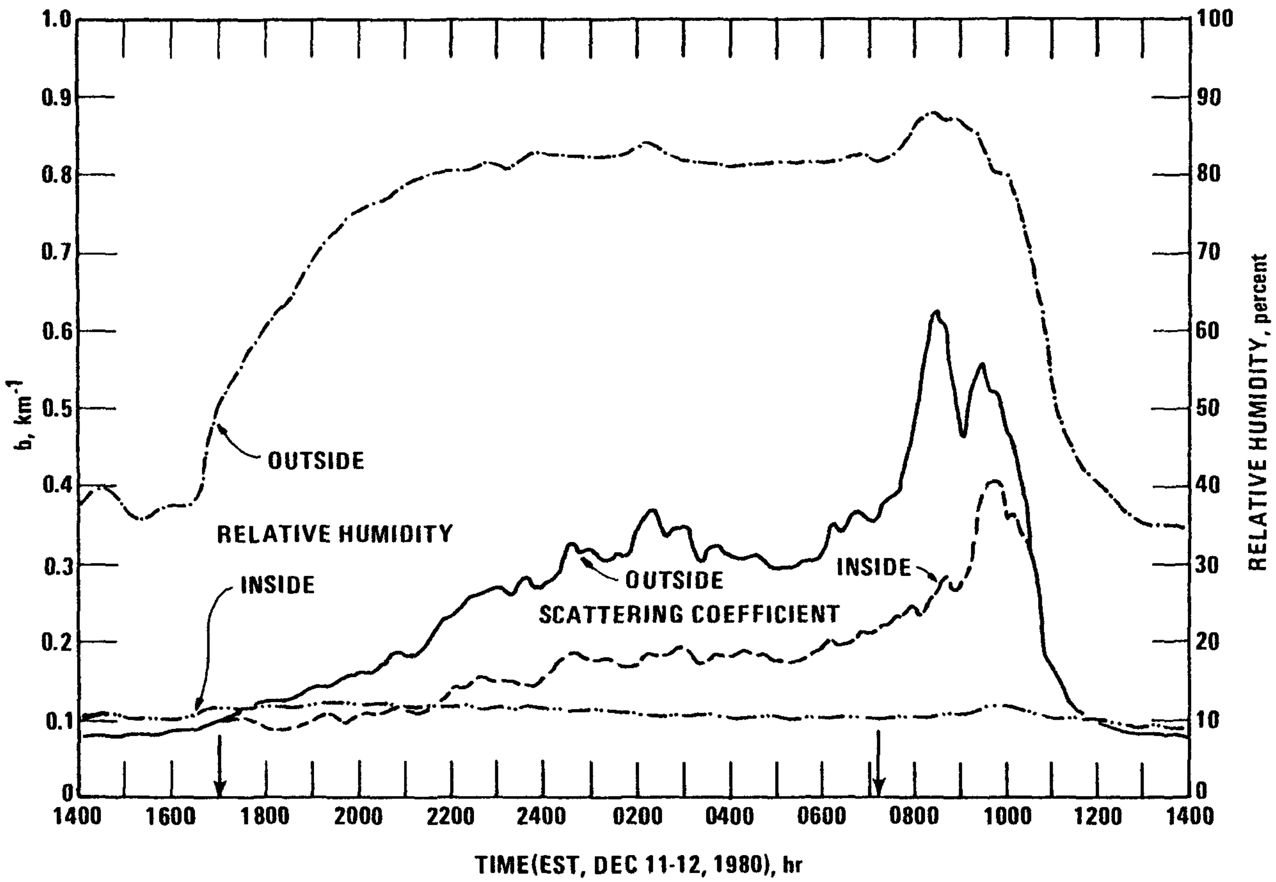
For each of the examples previously presented, a relatively small protuberance was observed on the profile of the outside scattering coefficient. It was located after the maximum of the profile which resulted from the growth and shrinking of the aerosols due to the influence of the relative humidity. The protuberance was observed to be due to an increase and subsequent decrease of the inside scattering coefficient which resulted from an increase and subsequent decrease of the aerosol number density. Processes associated with solar heating are the most plausible explanation for the variations of the aerosol number density which will now be discussed.

When solar heating commences after sunup, atmospheric mixing begins and will increase as solar heating increases with time. As a result of mixing, aerosols aloft will be diffused and transported toward the ground. To account for an increase of the inside scattering coefficint after sunup, the aerosols aloft must have a larger aerosol number density, at least initially, than aerosols closer to the ground. As the mixing layer increases in depth, the aerosol number density must eventually decrease by dilution.

It is of interest to note that the transition from relatively calm winds (<2 ms^{-1}) to the usual daytime fluctuating winds occurs roughly at the time of the maximum of the inside scattering coefficient. In addition, by acoustic soundings, it has been observed that the time of the maximum of the inside scattering coefficient is roughly the time that thermal plumes begin penetrating the base of the nocturnal temperature inversion. At that time, aerosols are more easily diffused upward with a corresponding decrease of the aerosol number density. After the nocturnal temperature inversion dissipates, it would be anticipated that aerosols are distributed nearly uniform in the vertical from the ground to the top of the planetary boundary layer.

The processes discussed in the literature to explain the fumigation of smoke after sunup[15] are the same as the processes which were presented as a explanation of the increase and subsequent decrease of the inside scattering coefficient after sunup. During fumigation, there is an initial increase and subsequent decrease of the aerosol number density which also is responsible for the variations of the inside scattering coefficient. Thus, the protuberance, which was observed on the outside scattering coefficient profiles of the examples presented, appears to be due to the phenomenon of fumigation. In part, the prominence of the protuberance will depend on the magnitude and vertical distribution of the aerosol number density. An example of a more prominent protuberance is shown in Figure 6.

Figure 6. Twenty four hour variation of the outside and inside scattering coefficients and the outside and inside relative humidity. The arrows indicate the time of sundown and sunup.



In Figure 6, there is an increasing trend of the inside and outside scattering coefficients from sunset to sunup. For the inside scattering coefficient, the increasing trend must be attributed to an increasing trend of the aerosol number density. For the outside scattering coefficient, the increasing trend must be attributed to the growth of the aerosols resulting from the increasing trend of the relative humidity and to the increasing trend of the aerosol number density. At sunup, the contributions due to an increase of the aerosol number density and the growth of aerosols to the outside scattering coefficient were approximately 0.12 and 0.14 km^{-1}, respectively.

The first prominent peak on the outside scattering coefficient is due to the growth and shrinking of the aerosols under the influence of the relative humidity. The second prominent peak corresponds to the protuberance on the outside scattering coefficient profiles discussed earlier. Its prominence in Figure 6 is apparently due to the existence of a relatively large aerosol number density aloft. The transition from relatively calm winds (<2 ms^{-1}) to the usual daytime fluctuating winds occurred at about 0930 EST. The expected decrease of the scattering coefficient was also observed to start occurring for reasons previously discussed. The source of the aerosols could not be determined. It should be noted that the scattering coefficient at 1400 on December 11, 1980 was approximately equal to the scattering coefficient 24 hours later which indicates that there was not net change of the aerosol number density.

It has been shown that there is a linear relation between the visibility observations at RDU and the inverse of the scattering coefficient observation at RTP.[16] There was also an excellent correlation between these parameters. Thus, the visibility observed at RDU is usually representative of the visibility at the RTP. Consequently, it is of interest to examine the visibility observed at RDU during an aerosol burst. Table 1 presents the hourly visibility observations during the aerosol burst for the four examples which have been presented.

TABLE 1. HOURLY VISIBILITY DURING AN AEROSOL BURST

DATE	TIME (EST)	VISIBILITY (miles)
October 16, 1979	0453	10
	0551	7
	0653	7
	0754	7
	0853	8
	0953	10
February 11, 1980	0751	12
	0850	6
	0951	6
	1051	10
November 23, 1979	0554	15
	0656	7
	0755	10
	0852	10
	0950	20
December 12, 1980	0651	12
	0748	5
	0853	7
	1003	7
	1050	10

In Table 1, it will be noted that, during each aerosol burst, the visibility was smaller than it was before and after the aerosol burst. Thus, as would be expected, the visibility decreases during an aerosol burst. This decrease of the visibility is due to an increase of the scattering coefficient during an aerosol burst. In part, the meteorological conditions for an aerosol burst to occur after sunup is that the preceeding night should be calm (<2 ms^{-1}) and the sky should be essentially free of clouds. It is of interest to note that these meteorological conditions have been enunciated as being necessary for the phenomenon of visibility deterioration during a winter morning.[17] There can be little doubt that an aerosol burst is responsible for the phenomenon of visibility deterioration during the morning.

SECTION 4

SUMMARY OF CONCLUSIONS

It will be instructive to summarize the significant conclusions concerning the growth and shrinking of aerosols and the variations of the aerosol number density deduced from nephelometer observations at the RTP. The conclusions are intended to be only appropriate for anticyclonic pressure systems. Four examples of the observations have been presented. In particular, the conclusions pertain to meteorological conditions such that the atmosphere is stable during the night. In addition, the sky has few clouds and the wind is relatively calm.

The conclusions are:

- The outside scattering coefficient increases nearly monotinically from sundown until sunup. In general, aerosol growth and an increase of the aerosol number density are responsible for the increasing trend of the outside scattering coefficient.

  Occasionally, an increasing trend of the aerosol number density is the only process responsible for the increasing trend of the outside scattering coefficient during the night. While aerosol growth is most likely due to an increasing trend of the relative humidity, the processes responsible for an increasing trend of the aerosol number density are vague.

- For an aerosol burst, which occurs within a 2 to 3 hour period after sunup, the outside scattering coefficient is a composite of contributions by the growth and shrinking of aerosols and the increase and decrease of the aerosol number density.

Contributions to the outside scattering coefficient by the growth and shrinking of the aerosols occur due to the increase and decrease of the relative humidities. Variations of the relative humidity are primarily due to the evaporation of moisture by solar radiation heating. The moisture was deposited at ground level during the night.

The processes responsible for the increase and decrease of the aerosol number density are the same as the processes responsible for the phenomenon of fumigation. These processes result from turbulent mixing of the atmosphere due to solar radiation heating.

The maximum contribution to the outside scattering coefficient, by the growth and shrinking of aerosols, occurs before the maximum contribution by the increase and decrease of the aerosol number density.

- The phenomenon of visibility deterioration during the morning is due to the phenomenon of an aerosol burst.

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TECHNICAL REPORT DATA
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1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE DEPENDENCE OF NEPHELOMETER SCATTERING COEFFICIENTS ON RELATIVE HUMIDITY Evolution of Aerosol Bursts		5. REPORT DATE 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) George W. Griffing		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS (same as block 12)		10. PROGRAM ELEMENT NO. CDTA1D/03-1327 (FY-81) 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Sciences Research Laboratory - RTP, NC Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED In-house 14. SPONSORING AGENCY CODE EPA/600/09
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Observations on the temporal dependence of the nephelometer scattering coefficient on relative humidity are presented and discussed for four different cases. For each case, the weather at the Research Triangle Park, North Carolina was dominated by an anticyclonic weather system. By taking simultaneous nephelometer scattering coefficient observation at two different relative humidities, it was possible to conclude that with nocturnal stable atmospheric conditions:

- o In general, the scattering coefficient increases from sundown to sunup due to aerosol growth and an increasing trend of the aerosol number density:
- o In general, the relatively rapid increase and subsequent decrease of the scattering coefficient during a 2 to 3 hour period after sunup is due to a relatively rapid aerosol growth and shrinkage, and a relatively rapid increase and decrease of the aerosol number density.

The latter behavior of the scattering coefficient was called an aerosol burst. The relationship between an aerosol burst, fumigation, and early morning visibility deterioration is also discussed.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES 38
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)