

Long Distance Transport Of Man-Made Air Pollutants

By Donald Henderson, Mei-Kao Liu, and Douglas Stewart

Dangers of air pollution to human health and threats of air pollution damage to areas with sensitive resources have been investigated for over a hundred years. In recent years scientists have become more aware of ecological damage caused by man-made airborne pollutants in areas remotely located long distances from air pollution source regions. Since the advent of nuclear weapons at the close of World War II and subsequent testing of nuclear devices by various countries, the observed wide spread of radioactive materials has made scientists more keenly aware of long-distant transport of man-made air pollution.

World-wide industrialization during the past century has caused an increase in use of fossil fuels, which in turn has increased the amount of pollution in the atmosphere. Long-distant transport of pollutants is believed to make a significant contribution to acid deposition in Europe, United States and Canada. Naturally produced substances also are transported long distances and interact with man-made pollutants to further complicate our understanding of causes and effects of air pollution.

Global monitoring at selected locations throughout the world is being conducted to detect long-term changes which may be occurring in the total global pollution burden resulting from long-distant transport of air pollution. In recent years satellite photographs and global monitoring have detected pollutants long distances from their point of origin. Nuclear debris injected into the atmosphere over mainland China has been measured at high altitudes over the western United States. Recent volcanic eruptions of Mount St. Helens in Washington, and El Chichon in Mexico spewed pollutants into the upper atmosphere. The pollutants were transported long distances downwind from the source areas causing high enough concentrations to be detected by monitoring equipment at

various locations on the earth. Desert sands from the Sahara Desert occasionally are entrained into the atmosphere by strong winds and transported as far away as Europe and the Antilles Islands.

Regions of the earth near heavily industrialized areas, and even regions remotely located several hundred miles from heavily industrialized areas, are affected by air pollution emitted by man's activities. The main pollutants of concern are: sulfur dioxide, oxides of nitrogen, carbon monoxide, carbon dioxide, hydrocarbons, particulate matter, lead, and others.

During the past decade, monitoring studies have indicated a trend toward decreasing air pollution concentrations in urban areas. This trend is probably the result of air pollution control strategies that have been implemented as a result of tighter air pollution regulations. Additional controls may be necessary to reduce danger to human health and reduce threats of air pollution damage to sensitive resources. For example, there is evidence that increasing carbon dioxide from burning of fossil fuels will enhance the atmospheric "greenhouse effect" and cause a global warming trend that will result in undesirable climatological changes on a global scale.

In recent years, scientists have become increasingly concerned with the possibility of man's activities depleting the stratospheric ozone layer. Chlorofluorocarbons (CFCs, more commonly known by the trade name Freon) released into the atmosphere can become widely distributed in the global circulation patterns, and reduce ozone concentrations in the stratosphere. Depletion of the ozone layer would allow increased transmission of ultra-violet radiation to the surface of the skin, possibly increasing the incidence of skin cancer. Because of this concern, manufacturers in the U.S. have been regulated to discontinue use of Freon in spray cans. However, CFCs continue

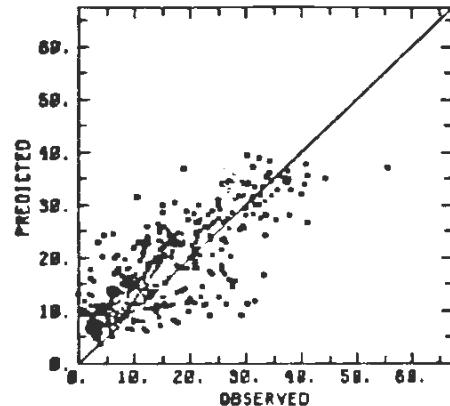


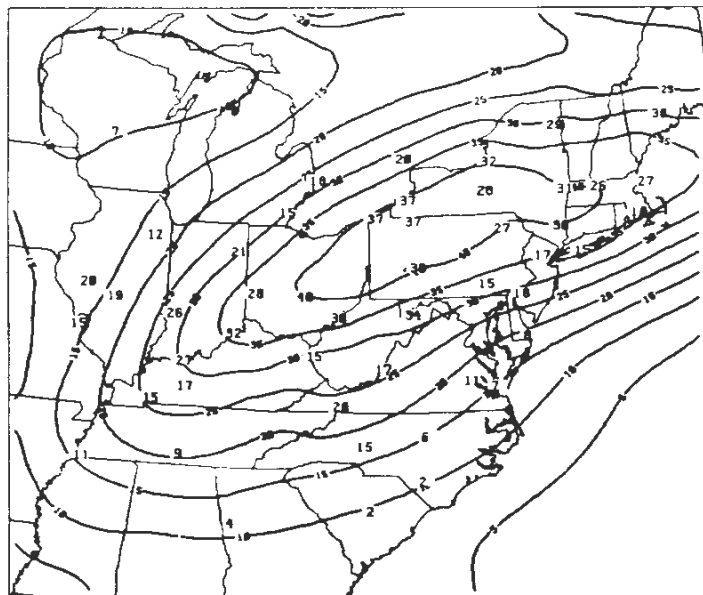
FIGURE 2 Scatter plot of predicted and observed 24-hour average concentrations. (Units are $\mu\text{g m}^{-3}$).

to be used in many parts of the world.

Photochemical oxidants, which are caused principally by incompletely burned fuel emitted by motor vehicles, have been measured at locations long distances downwind from metropolitan areas. Other man-made pollutants that are transported long distances and about which scientists are very concerned are sulfur oxides, nitrogen oxides and fine particulate matter. The long-range transport of these pollutants may impair atmospheric visibility, increase acidic deposition and cause significant adverse ecological effects at locations long distances from the source regions.

To a certain extent, the atmosphere is an efficient pollutant diluting system. Wet and dry deposition processes, and dispersion of pollution by fluctuating winds tend to dilute and cleanse the atmosphere of pollutants. There is evidence that the reduction of

(a) Daily (July 21, 1984)



(b) Annual (October 1977 - September 1978)

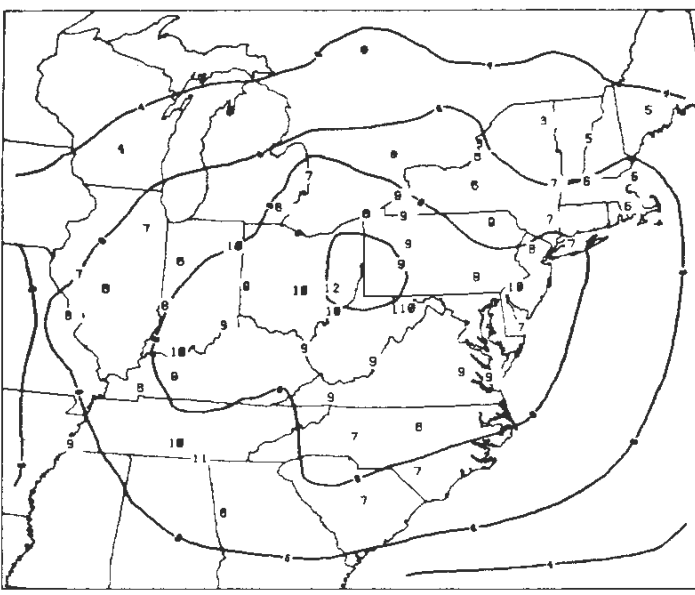


FIGURE 1 Daily (a) and Annual (b) sulfate concentrations predicted by RTM-II ($\mu\text{g m}^{-3}$).

sulfur emissions since the early 1970s in the U.S. has resulted in a proportional reduction in deposition of sulfur dioxide and sulfates to the earth's surface. If control strategies can be proven beneficial, then further action is needed to prevent undesirable and irreversible damage to ecological systems. A great deal of controversy surrounds control strategies because they affect not only the environmental element, but social and economic elements as well.

Why should the National Park Service be concerned with these issues? Lands managed by the Service are unique, with natural resources that are highly sensitive to man-made pollutants. To protect such resources, both the causes and effects must be studied to determine the source-receptor relationship. A task force appointed by the Environmental Protection Agency has found that some national parks such as Grand Canyon and Shenandoah are being damaged by pollution from distant source areas. The task force is finding that statutory or regulatory changes to existing laws may be necessary to protect national parks from air pollution.

Assessment of existing conditions is essential. Two approaches generally are used. One is to conduct extensive, expensive measurement in areas where effects are known, or suspected to exist. Such measurements, often limited in scope by inadequate funding and too few personnel, are being conducted in certain areas. Another approach is to use mathematical models to make such assessments. Transport, dispersion, chemical transformation, and wet and dry deposition of pollutants are analyzed by the models. However, if models are used, they must be tested and

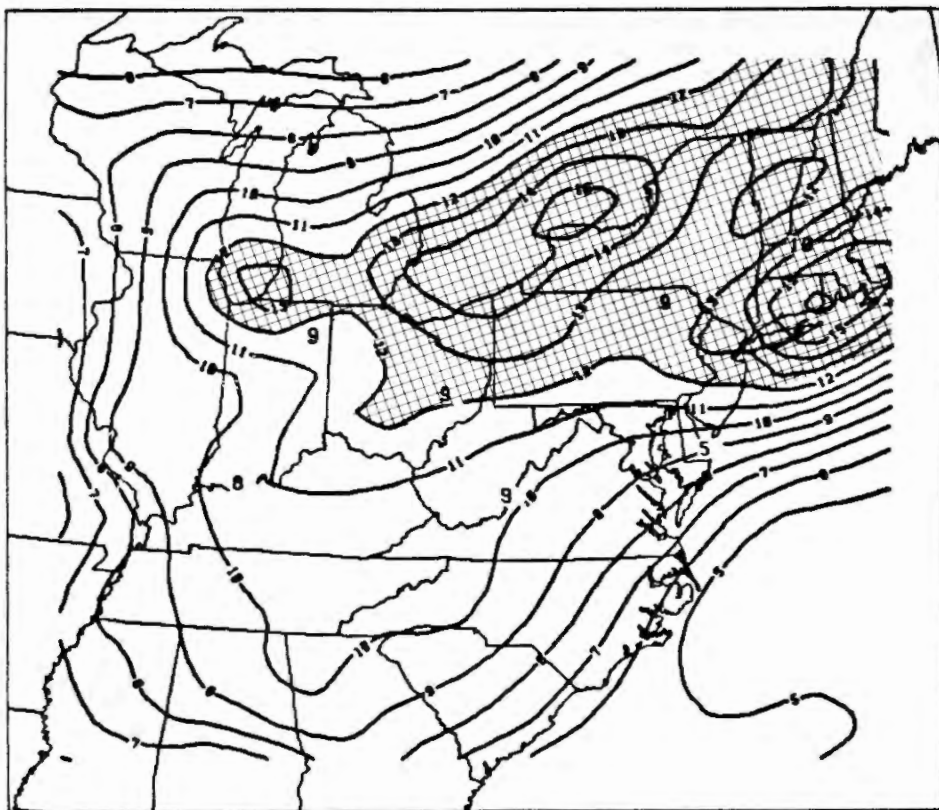


FIGURE 3 Predicted ozone concentrations in the mixed layer (pphm) on 20 July 1978 from 1400 to 1500 EST.

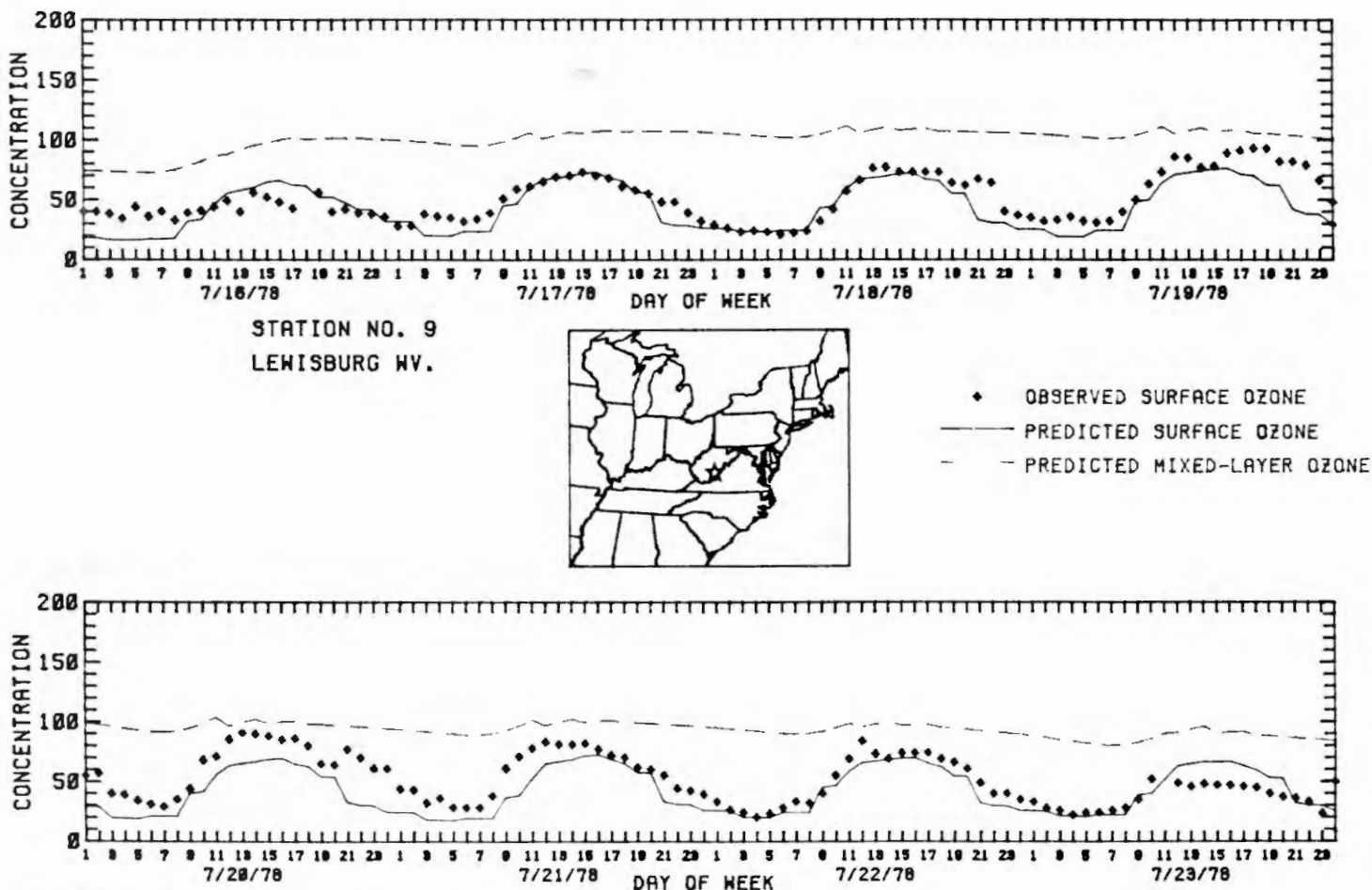


FIGURE 4 Time History of Hourly Ozone Concentrations (ppb).

evaluated to determine their performance characteristics so the results may be used with confidence.

An assessment of existing conditions is necessary, but not sufficient. The National Park Service must have the capability of assessing current conditions, as well as assessing the influence of future activities of mankind on national park resources. Measurements can be made of existing conditions, but future conditions can be determined only by some type of estimation technique. Mathematical models based on well-founded theoretical physical principles and evaluated to determine their performance capability, are valuable tools in making assessments of future conditions.

The National Park Service, Air Quality Office, has contracted a four-phase research effort over the past five years to develop and test mathematical models to be used for assessing long distant transport of man-made pollutants. A mathematical model (RTM-II) has been developed, evaluated, and is currently being applied to simulate sulfur dioxide and sulfate concentrations in four national parks (Acadia, Great Smoky Mountains, Mammoth Cave, and Shenandoah) where existing air pollutants are suspected of damaging park resources. The model will be applied in other areas as needed. Another version of the model has been developed to calculate photochemical oxidant concentrations. This version, named RTM-III, also will be applied to these four national parks.

Prior to the models being applied in national parks, model calculations were compared to measurements to evaluate model performance. Figures 1a and 1b show examples of the model calculations for daily and annual average sulfate concentrations. The isopleths for Figure 1a are plotted for $5 \mu\text{g m}^{-3}$ increments. The measured concentrations also are plotted for easy comparison with calculations. Figure 1b illustrates annual average sulfate calculated concentration isopleths as well as measured values. The isopleths for annual average sulfates are plotted in $2 \mu\text{g m}^{-3}$ increments.

Figure 2 shows a scatter plot of observed versus predicted, 24-hour, sulfate concentrations. The scatter plot indicates that the model simulates sulfate concentrations quite accurately. The model also was used to simulate sulfur dioxide concentrations, however, the estimates were less accurate. The greater ability to predict sulfate concentrations can be explained by the nature of the two pollutants. Sulfate is formed as a secondary pollutant downwind of sources that emit the precursor sulfur dioxide. At these downwind distances, turbulent dispersion and chemical transformation have resulted in more uniform concentration gradients. The sensitivity of concentration predictions to slight error in transport or removal rates is therefore reduced.

The ability of the model to simulate the distribution of high, as well as low sulfate concentrations is quite good despite the tendency to overpredict low concentrations and to slightly underpredict high concentrations. The overall correlation coefficient of 0.8 indicates that 64 percent of the variance in all observations can be explained by the model.

RTM-III was used in a pilot study to estimate the distribution of photochemical oxidants at eight locations in the eastern United States. Figure 3 illustrates an example model result for July 20, 1978 at 1400 hours. The cross-hatched area indicates the region where ozone concentrations are estimated to exceed the 1-hour standard (.12 parts per million). Figure 4 shows a time series plot of predicted and measured ozone concentrations at a particular station from July 16 to 23, 1978. The diurnal variation of predictions

and measurements is clearly evident. The model estimates the variation of measured values quite accurately. The scatter plot, Figure 5, shows an overall trend for the model to over-predict small values and under-predict high values.

In summary, the long-range transport models can be useful tools for application in estimating air pollution concentrations. They also can be useful for assessing regional atmospheric visibility degradation, and simulating wet and dry deposition of acidic substances to the surface. Control strategies and management decisions may be made using the model results. For example, the estimates made with RTM-II indicate annual average sulfate wet deposition in the general area of Shenandoah NP to be 25 kilograms per hectare per year for the year 1978. The U.S.: Canada Transboundary Committee has indicated that chemical and biological effects are not observed when sulfate loading is less than 20 kilograms per hectare per year. Therefore, the model indicates that emissions reduction is necessary in source regions which affect deposition in Shenandoah NP.

The long-range transport models are valuable tools for estimating long-range transport of pollutants, and determining necessary pollutant emission reductions within pollutant source regions.

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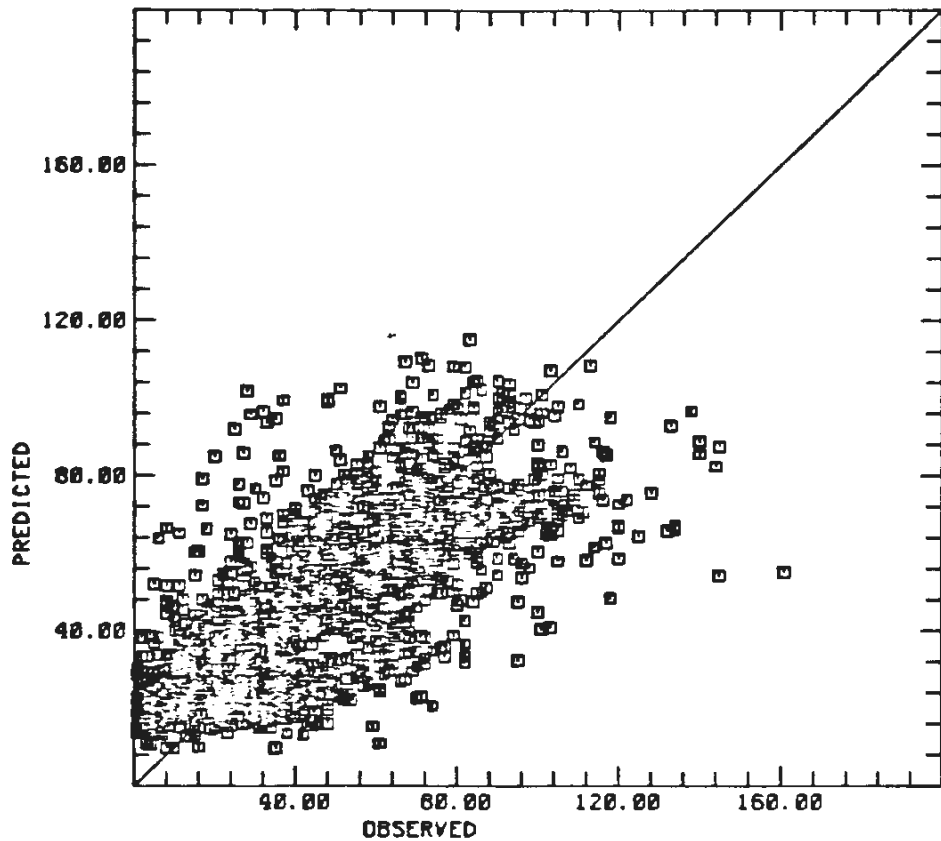


FIGURE 5 Scatter diagram of the predicted and observed O_3 concentrations (ppb).