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Project Summary

Instrumentation, Recording, and Processing of Meteorological Data Near Portage, Wisconsin: Wisconsin Power Plant Impact Study

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As part of the Columbia Power Plant Impact Study, meteorological data were collected at a network of monitoring sites from 1972 through 1977. The data were the basis for a series of studies whose purpose was to elucidate the transport of airborne pollutants.

In a pilot diffusion climatology survey, local wind structure was interpreted in the context of synoptic weather patterns. A significant new low wind statistic was introduced: the number of crossings of the trace of a variable past its running mean during a given time interval.

A case study traced the movement of an elevated level of ozone from the Southern Plains across the Midwest to the East Coast. It showed that, although the relative contributions of transport vs. local or regional formation to an episode of elevated ozone (O_3) are not clear, some degree of large scale, long distance transport is necessary in order for elevated O_3 levels to occur in most parts of the United States. A related study showed that ambient O_3 levels are reduced sharply in the presence of the plume from a coal-fired power plant.

The horizontal variation of the wind field is an important factor in the transport of atmospheric pollutants in the range of 10 to 100 km. The wind field in the study area was shown to be organized as a function of both wind direction and wind speed around the Baraboo Hills. These hills therefore have an influence on the dispersion of pollutants from the Columbia power plant.

Finally, two models for estimating concentrations of SO_2 at ground level were compared. Both used the Gaussian plume equation, but one estimated the required dispersion coefficients from the Hino stability model, while the other was based on data for horizontal and vertical wind range. The wind range model was shown to have simpler data requirements and to give results which agreed more closely with observed SO_2 values.

This Project Summary was developed by EPA's Environmental Research Laboratory, Duluth, MN, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

In 1971, scientists at the University of Wisconsin-Madison began a long-term study of environmental changes related to the construction and operation of the Columbia Generating Station, a 1054-MW coal-fired power plant located in the floodplain of the Wisconsin River in south central Wisconsin. Meteorological data were required for interpreting the results of several subprojects, particularly those involving dispersion of air pollutants. In addition, the power plant could have a variety of direct effects on local climate. The purpose of this meteorology subproject was to provide baseline information on meteorological conditions at the site and to detect any changes in conditions during the course of the subproject. It was designed to:

1. Study meso-scale airflow in the vicinity of the generating station.
2. Measure atmospheric characteristics necessary for evaluating the mass budget of chemicals transported through the atmosphere from the generating station.
3. Determine the influence of the cooling pond on local climate, and detect any other local climatic effects of the power plant.

In addition to providing baseline meteorological data, this subproject produced a pilot diffusion climatology survey of the Columbia Generating Station, a study of depletion of ambient ozone by the plume from the generating station, a comparison of two models for estimating ground level concentrations of sulfur dioxide (SO_2) resulting from the operation of the generating station, and a study of the influence of the Baraboo Hills on the surface wind field at the site. Finally, national weather data were used to elucidate the observed long distance, large scale transport of ozone (O_3) across the Central and Eastern United States.

Monitoring

Data used for measurements of atmospheric dispersion must be valid for heights between the top of the stack and the highest rise of the plume. Because construction activity precluded erecting a tower on the site of the generating station, monitoring stations were established at four nearby sites where measurements could be made at the required heights (between 152 and 305 m) (Figure 1). Easterly winds are uncommon in the area. The Messer site was therefore essentially unaffected by the plume from the stack, and the most complete instrumentation was installed there. An additional advantage of the Messer site was that, with its 122 m elevation, it required only a 30 m tower for placing instruments at the same height as the top of the stack. The other three sites served primarily to corroborate observations of wind speed and direction made at Messer and to provide insight into variation caused by topographical differences and differences in direction relative to the generating station.

The investigators also used data collected by the Wisconsin Power and Light Company (WPL) at sites shown in Figure 1, and by the National Weather Service at Truax Field in Madison, Wisconsin.

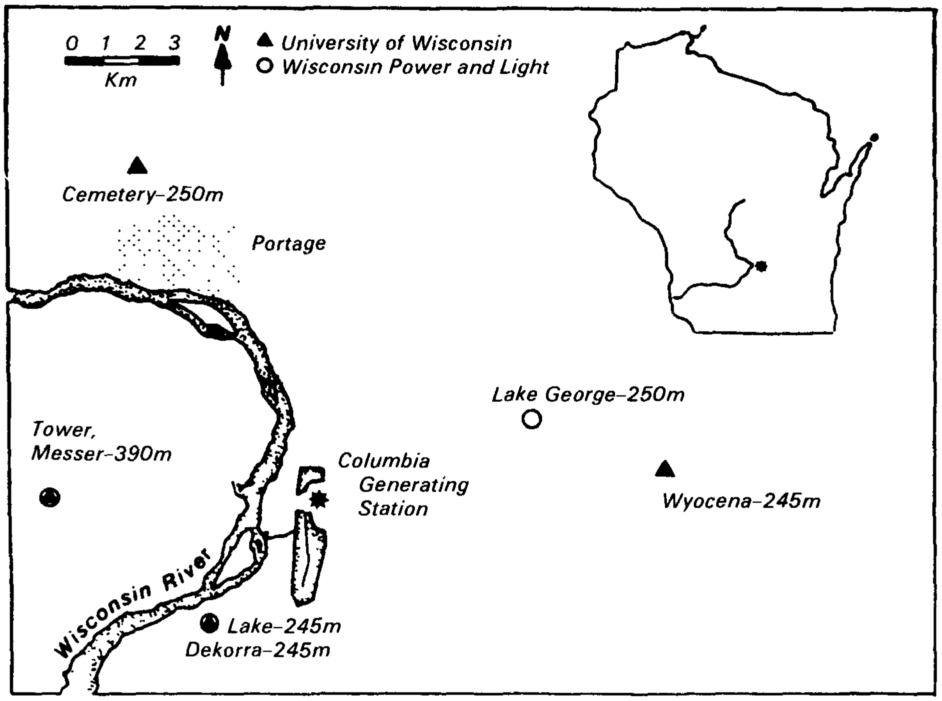

Figure 1. Monitoring sites for meteorological data.

Monitoring Procedures

Measurements necessary for determining the power plant's impact on climate differ in type and duration from those required for dispersion studies. Long-term measurements of rainfall and soil temperature are needed to document climatic change. Dispersion studies require seven types of continuous measurements at stack height: horizontal wind speed, horizontal wind direction, vertical wind speed, vertical wind direction, vertical air temperature gradient, total incoming solar radiation, and net radiation. Table 1 shows the instrumentation used to monitor these variables, the sites at which each variable was monitored, and the dates between which data were collected. Gaps exist in the data because of equipment failures and seasonal monitoring of certain variables. Data collection began at the Messer site in 1972 and at the other sites in 1973 or 1974.

Processing data recorded on charts involved the following general steps:

1. Timing the charts to mark hours and days.
2. Digitizing strip chart data.
3. Transferring chart data to 80-column IBM cards.
4. Checking data for errors.
5. Converting data to scientific units (e.g., m/sec) and averaging if necessary.

A Pilot Diffusion Climatology Survey for the Columbia Generating Station

The purpose of this study was to identify easily measured meteorological variables which indicate characteristics of atmospheric dispersion, and to relate them to synoptic weather patterns. Many climatological studies of the dispersion of air pollutants have relied on oversimplified models. This study, rather than smoothing the spectrum of hourly weather variations, sought to identify extremes during which adverse conditions for dispersion exist.

The study period was from August 15 to November 1, 1972. Twenty-one days were identified as potentially poor dispersion days on the basis of minimal wind speeds (generally < 4 m/sec) recorded during the early morning hours of 1100 Z to 1300 Z. For comparison of mesoscale analysis with macroscale patterns, daily 1200 Z synoptic weather charts were obtained from the National Oceanographic and Atmospheric Administration.

The statistics used in the wind structure analysis were the range of the wind speed and direction variables during each 10-min interval between 1100 Z and 1300 Z and the number of crossings made by the continuous trace of the variable past its running mean for the interval. In the final analysis, the ratio

Table 1. Meteorological Instrumentation

	Site	Sensor	Recorder	Dates
Horizontal wind speed	All sites	Stewart 4-cup anemometer	Esterline-Angus event marker	8/72-12/77
	Messer	Beckman-Whitley Type F 3-cup anemometer	Esterline-Angus pen	8/72-12/77
Horizontal wind direction	All sites	U.W. vane	Esterline-Angus pen	8/72-12/77
Wind angle, vector wind speeds	Messer	Gill 01002 bivane anemometer	Daystrom	8/72-11/77 Apr-Oct
Vertical wind speed	Messer	Gill 27100 vertical anemometer	Daystrom	12/73-12/77
Precipitation	All sites	Tipping bucket	Weather Measure P521 event recorder	8/72-10/77 Apr-Oct
Soil temperature	Messer	Bi-metal thermometer	Observed, recorded by investigator	8/72-12/77
Air temperature	Messer, Dekorra	Thermocouple	0-2.5 mv Brown	8/72-12/77
Air-soil temperature gradient	Messer, Dekorra	Thermocouple	0-2.5 mv Brown	8/72-12/77
Solar radiation	Messer	Eppley 10-junction pyranometer	Brown	8/72-12/77
Net radiation	Messer	Ventilated Suomi net radiometer	Brown	8/72-12/77
Inversion layer	Cemetery	Aerovironment 300 acoustic sounder system		1975-1977

of the total 10-min wind passage for each component direction to the number of crossing during the same period yielded a measure of the component eddy lengths.

A classification of gustiness types for poor dispersion periods was developed from analysis of the range and appearance of horizontal wind direction traces. The five gustiness types were related to atmospheric stability, cloud cover, and eddy lengths derived from wind passage and trace crossing data. When eddy lengths are stratified according to gustiness types, recognizable patterns appear in the resulting histograms.

Attempts to correlate synoptic conditions with local wind structure analyses suggested that the resolution of isobaric analyses on daily surface weather maps is not good enough to provide an adequate picture of local pressure gradients and mesoscale flow. Regardless of the large scale distribution of cyclonic and anticyclonic pressure centers and macroscale pressure gradients, local dispersion remains to some extent a function of generally undetected local pressure variations. A researcher who is familiar with local circulation under a wide range of synoptic conditions might be able to predict local gradients from larger scale patterns.

In summary, this pilot study introduces the number of crossings of the trace of a variable past its running mean as a significant low wind statistic. It suggests that a similar study over a longer observation period, or perhaps another approach such as photography or tracer analysis, might provide a meteorological basis for a local diffusion climatology that would be of value in prediction and analysis of environmental impact.

Study of the Large Scale Transport of Low Level Ozone Across the Central and Eastern United States

Recent evidence shows that ozone (O_3) can be transported over long distances, and elevated levels of O_3 are often found in areas remote from sources of pollution. This section of the report presents the findings of a case study of the distribution and transport of low level O_3 east of the Rocky Mountains from September 4 to September 10, 1976. The production, chemistry, and photochemistry of O_3 were reviewed. Possible relationships between high O_3 levels and weather conditions such as visibility were investigated. Backward trajectories were constructed to trace air movements in the boundary layer.

All available data for all states east of the Rocky Mountains were used to construct daily maximum O_3 maps. Daily maxima exceeding 70 and 100 ppb were analyzed for the Central and Eastern United States. Meteorological data from the National Weather Service included daily surface maps showing sea level pressure and surface winds, visibility, and dew point, an 850 mb contour map, and a maximum surface temperature map.

At the beginning of the case study, a large area with O_3 levels >70 ppb formed under an 850 mb ridge in the Southern Plains. This area spread northward into the Northern Plains and then eastward across the northern Midwest, as the 850 mb ridge moved toward the East Coast. A smaller area with O_3 levels >100 ppb developed within the larger area over the northern Midwest. Another area with levels >70 ppb formed over the Ohio Valley. These two areas subsequently merged over the Great Lakes, and then spread to the East Coast. Ozone levels subsided sharply as a cold front swept eastward across the United States.

Trajectories averaged through the 300-2000 m layer agreed well with the movement of elevated ozone areas. Surface winds, however, were not necessarily in the same direction as the direction of O_3 transport.

The relative contributions of O_3 transport and local or regional formation of O_3 to an episode of elevated O_3 levels are not clear. On the basis of this study, however, large scale transport seems necessary in order for elevated O_3 levels to occur in most parts of the United States. More extensive and strategic monitoring of O_3 is needed for better understanding of this phenomenon.

Depletion of Ambient Ozone by the Plume from the Columbia Generating Station

Coal-fired power plants contribute sulfur dioxide (SO_2), nitrogen oxides (NO and NO_2, or NO_x), and many other chemicals to the atmosphere. The plume from such a plant can deplete O_3 to a distance of 15 km or more downwind, primarily through the reaction: $O_3 + NO \rightarrow NO_2 + O_2$. This effect was studied at the Columbia Generating Station during the summer of 1976.

The meteorological monitoring network supplied data on wind speed and direction at stack height and on solar radiation. SO_2, O_3, and NO_x were monitored 10 km north of the power plant. High hourly averages of these gases indicated times when the plant plume was drifting over the site. The simultaneous, instantaneous extremes of the levels of SO_2, O_3, and NO_x were then analyzed. Ambient levels were subtracted from the total, to focus the study on the effects of the plume.

Ozone levels were reduced sharply when the plume was present. The amount of O_3 depletion depended on ambient O_3 levels and on levels of SO_2 and NO_x associated with the plume. The amount of NO_2 from the plume was proportional to the amount of O_3 removed from the ambient air. This relationship can be summarized: $[NO_2] + [O_3] =$ constant.

Influence of the Baraboo Hills on Surface Winds Near the Columbia Generating Station

The horizontal variation of the wind field is an important factor in the transport of atmospheric pollutants in the range of 10 to 100 km. Wind data collected from the monitoring network (Figure 1) provides strong evidence that the Baraboo Hills have a significant influence on surface winds in the area. This influence is reflected in the linear wind field and in the first order properties of divergence and vorticity as calculated by the Bellamy Triangle Technique. For wind directions resulting in convergence, continuity arguments imply a compensating upward vertical motion, while divergence requires a downward motion. Such motions would be important in the transport and diffusion of atmospheric pollutants.

The wind field appears to be organized as a function of both wind direction and wind speed around the Baraboo Bluffs. This organization is most apparent when the wind direction is perpendicular to the bluffs. Although the data from the Wyocena site give an adequate estimate of the mean wind field for the region, deviations at the other sites must be considered in an accurate determination of pollutant transport. The wind direction at Dekorra deviated about 15° from that at Wyocena. Data from Messer, strongly influenced by the direction of the wind relative to the bluffs, provided a poor representation of the mean wind field in the valley. The symmetric variation of the divergence and vorticity fields about the azimuthal direction of the southern bluffs support the conclusion that the bluffs are important in the kinematics of the regional wind field.

A Comparison of the Hino Stability Method and the Wind Range Method for Estimating Concentrations of SO_2 at Ground Level

Gaussian diffusion models are widely used in pollution studies. This study emphasizes the advantages of calculating horizontal and vertical dispersion coefficients from actual wind statistics, rather than basing them on a classification of stability.

Two methods for estimating the dispersion coefficients used in the Gaussian plume equation were compared. All other parameters in the equation are identical for the two methods. The Hino stability method estimates the dispersing characteristics of the lower atmosphere from a net radiation budget for the lower atmosphere. It is an indirect method based on variables such as cloud cover and lapse rate. The vertical and horizontal wind range method uses wind data to describe the turbulent structure of the atmosphere and estimate the dispersion coefficients. The results predicted by the two methods were compared with concentrations of SO_2 measured at six monitoring sites.

Overall, results from the wind range model were closer to observed values than results from the stability model, particularly at low wind speeds. For the 343 hours included in this study, 64% of the values from the range method lie within a factor of two of the observed values, while only 53% of the results from the stability method fall within these limits. The discrepancies are still large, but the range method clearly represents an improvement.

Table 2 shows the standard deviations from observed data for both methods, according to monitoring site. The accuracy of both models improves as the distance from the power plant increases. A partial explanation for this may be that the Gaussian plume equation assumes a normal vertical distribution of pollutant — a condition which is poorly fulfilled in proximity to the power plant. This explanation is supported by occasional erratic fluctuations in SO_2 data. These fluctuations are not readily explained and are not reflected by the model; but they are most frequent and most pronounced as the Dekorra site which is closest to the power plant.

Discrepancies in the range model may be due in part to the source of wind data. Calculations were based on measurements made at the Messer site, the only place where a vertical anemometer was installed. The topographical study showed, however, that the Messer site was not typical of the area because of the influence of the Baraboo Bluffs.

In summary, the vertical and horizontal wind range method offers two significant improvements over the traditional stability classification method. First, it is far superior during light wind conditions. Second, it employs fewer atmospheric variables while offering a more direct approach to estimating the dispersing conditions of the atmosphere.

Table 2. Standard Deviations of Predicted SO_2[a] Values from Observed Values, for Range and Stability Models, at Six Sites

Site	Standard deviation		Distance from power plant, km
	Range method	Stability method	
Dekorra	61	66	4.4
Lake George	49	57	5.9
Messer	37	32	7.3
Genrich	43	43	8.3
Bernander	17	18	14.6
Russell	27	21	15.5

[a] Units are $\mu g/m^3$.

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The complete report, entitled "Instrumentation, Recording, and Processing of Meteorological Data Near Portage, Wisconsin: Wisconsin Power Plant Impact Study," (Order No. PB 84-172 469; Cost: $16.00, subject to change) will be available only from:
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