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Project Summary

Studies in Air Quality Meteorology at North Carolina State University

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This report summarizes eight studies in diverse areas of air quality meteorology resulting from a cooperative research program involving the graduate students and faculty of the atmospheric sciences program of North Carolina State University and the staff and facilities of the EPA Meteorology and Assessment Division.

Meteorological analysis of the St. Louis RAPS data has shown that: (1) The urban heat island strength during the day amounts to about 0.5°C and varies little with wind speed, cloud cover, or season. The nocturnal heat island, however, is highly responsive to all three factors as well as to anthropogenic heat sources. (2) Profiles of ozone above the urban nocturnal surface inversion are highly variable and apparently related to details of the wind structure. (3) Evaluation of the energy budget over concrete, blacktop, and soil surfaces suggests improvements in the parameterization of the surface heat flux in air quality models.

Studies of atmospheric visibility and suspended particulates reveal that: (1) Air transparency nation-wide has declined significantly between 1955 and 1972. The annual cycle in visibility is inversely related to that in relative humidity. (2) The relative contributions of haze, smoke, and dust to lowering visibilities in eastern Texas between 1949 and 1968 are determined. (3) Most sulfate concentration variability at fixed sites is due to the vagaries in long-range transport rather than to local conditions of temperature, humidity, or insolation.

Studies of the boundary layer mesoscale wind structure over the Appalachian Mountains indicate that: (1) A pronounced low-level jet with significant diurnal variability can form even during a period of air stagnation. (2) The standard 850 mb-level winds can be used to estimate surface winds in complex terrain given the valley-ridge orientation and time of day.

This project summary was developed by EPA's Environmental Sciences Research Laboratory, Research Triangle Park, NC, 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

The proximity of the atmospheric sciences program at North Carolina State University (NCSU) to the Meteorology and Assessment Division and other EPA facilities has engendered over the past several years professional and scientific cooperation among personnel of the two organizations. NCSU graduate students have benefitted through work at the EPA laboratory and helpful guidance in thesis research by EPA staff. It was proposed that this on-going cooperative research effort be enhanced through a formal program which focused the joint effort of NCSU students and faculty, and EPA staff, toward solving specific problems of the EPA in air quality meteorology.

This report contains results of this cooperative effort in the form of summaries of eight research theses on diverse topics. Three investigations are concerned broadly with the meteorological analysis of the St. Louis Regional Air Pollution Study (RAPS) data. The topics include the climatology of the St. Louis heat island, the problem of ozone variability in the urban boundary layer, and the analysis of the urban surface-energy budget in an effort to improve parameterization of the surface heat fluxes in air quality models.

Three more investigations examine the impact of suspended particulates as manifest in the generally deteriorating transparency of the air, both regionally and nationally.

The final two investigations discuss aspects of wind structure over the Appalachian Mountains The implications of this wind structure to pollutant transport and dispersal in complex terrain is also considered.

Research Investigations

Climatological Aspects of the St. Louis Urban Heat Island

Joseph E. Steigerwald, G. F. Watson, and J. K. S. Ching

The St. Louis urban heat island is studied using one year of temperature data (1976). Fluctuation in the strength of the urban heat island due to changes in cloud cover, wind speed, and season are explored.

The heat island strength varies diurnally and seasonally and is largest on fall evenings and weakest on summer mornings. It is also very strong under low wind speed and clear sky conditions, with the wind speed exerting more control on the nocturnal heat island strength than cloud cover. The daytime heat island, the nocturnal heat island, and the transition periods are examined in detail. The nocturnal heat island and the transition periods vary greatly with changes in cloud cover, wind speed, and season; the daytime heat island varies little with changes in these factors.

Summers' (1965) heat island model was used to evaluate the contribution of the anthropogenic heat output to the urban heat island. The results were compared with results derived from an analysis of the St. Louis Heat Emission Inventory. The emission data comparison was inconclusive.

A Study of the Vertical Distribution of Ozone and the Variability of the Wind Field Above a Nocturnal Radiation Inversion

Donald R. Hood and A. J. Riordan

The vertical distribution of ozone prior to the morning breakdown of the radiation inversion is related to the changes in the nocturnal wind field and the trajectory of the layer containing the ozone. Helicopter and hourly pilot-balloon data collected on five days during August 1976, in St. Louis, Missouri, were analyzed.

The ozone was assumed to be uniformly mixed throughout the boundary layer at sunset the previous evening. The study indicates that the similarities and differences between the vertical distribution of ozone assumed at sunset and observed the following morning are related to the variability of the nocturnal wind field.

Analysis of height-time cross sections of the nocturnal wind field indicated that the winds exhibited both vertical and temporal variability above an observation point. Most of the temporal variability in the nocturnal wind field occurs between scheduled radiosonde launch times and will not be completely detected. Therefore, the trajectory computations will not entirely represent the changes which occur. The study also indicates that due to the vertical variability of the wind field, more representative trajectories can be obtained by computing the trajectories for several thin layers versus computing a single trajectory for a thick layer.

Temporal Variation in the Surface Energy Budget Components for Three Land Use Patterns

Dennis C. Doll, G. F. Watson, and J. K. S. Ching

Special St. Louis RAPS data were used to examine the diurnal variation of the net radiation and heat flux components of the surface energy budget for a two-month spring time period for blacktop, concrete, and soil surfaces. Sensible and latent heat fluxes were analyzed from measured and calculated net radiation and ground heat fluxes for each surface.

Ground heat flux for concrete and blacktop was determined for different water contents of the underlying soil layer. A lower water content in the soil layer reduces the magnitude of the total ground flux throughout the blacktop and concrete layer and soil sublayer. An accurate determination of soil water content appears necessary in any ground heat flux evaluation.

The sum of sensible and latent fluxes for the soil surface was found to be nearly twice as large as that for the blacktop layer and approximately three times larger than for the concrete surface during the daytime period of the diurnal cycle. Latent heating appears to be an important component of the surface energy balance for the soil.

Hourly average net radiation and ground heat flux values resulted in an improvement of a parameterization technique based on the ground heat flux to net radiation ratio (G/Fn). Diurnal variation in G/Fn for each surface is distinctly different. For concrete and blacktop, G/Fn is constant at night but variable during the day. For soil, G/Fn changes throughout the diurnal period.

Trends in Atmospheric Visibility Across the United States from 1955 to 1972

Jerrold S. Foster, T. L. Tsui, and G. C. Holzworth

Regular daytime synoptic observations from 14 stations across the United States but excluding those with relative humidity greater than or equal to 90% and those with precipitation or fog present, were used to determine the trend in visibility from 1955 to 1972.

Comparison of statistics at the beginning and the end of the period, and linear regression of the monthly mean visibilities were used to discover relationships between visibility and other meteorological variables such as wind speed, wind direction, and relative humidity. Spectrum and cross-spectrum analysis of the time series of visibility and relative humidity were also performed.

The results of this study indicate: (1) a deterioration of the visibility at all 14 stations, (2) a bimodal (six and twelve month) oscillation in the annual cycle of visibility, and (3) an inverse correlation of relative humidity with the annual cycle of visibility.

A Visibility Study in the Eastern Half of Texas from 1949 to 1968

Alfonse J. Mazurowski, A. J. Riordan, and G. C. Holzworth

Hourly weather observations for times 0900-1500 CST were used to examine visibility trends, obstructions to vision, and the effects of different parameters on visibility for eight stations in the eastern half of Texas from 1949 to 1968.

Observations with any obstruction to vision, along with the individual obstructions by haze, smoke, and dust, were examined to determine their effect on visibility. Mean visibility categorized by wind direction was employed to investigate the influence of winds from industrial areas and cities on visibility at airports. Trend analyses of mean visibility data, both annual and seasonal, were performed using mean ridits and shifts in frequency from one visibility range to another. The effects on visibility of population growth and distance of stations from the Gulf of Mexico were also analyzed.

The main results of this study are: (1) a deteriorating trend in annual visibilities was apparent for seven of the eight stations, (2) smoke was a major factor in the reduction of visibility in Houston, (3) smoke appeared to be a result of local transport of air polution while haze and dust seem to be associated with long-range transport processes, (4) daily resultant winds from nearby industrial areas produced the lowest mean visibilities, (5) mean visibility increased significantly as the distance of stations from the Gulf of Mexico increased.

Synoptic-Scale Variability in Atmospheric Suspended Sulfate Concentrations

Brian W. Galusha, G. F. Watson, and G. C. Holzworth

The spatial variation in atmospheric suspended sulfate concentrations is studied for evidence of meteorologically linked sulfate transformation and transportation. Low frequency (every 12-14 days) data from 41 National Air Surveillance Network stations as well as higher frequency (every 2-3 days) data available from two special studies are examined. Variations in high frequency data with wind direction for St. Louis, Missouri, are compared to local and regional sources of precursor pollutants for two one-year periods; January-December 1969 and April 1975-March 1976. Spatial variations in low frequency sulfate concentrations during the spring season (March-May) for the six-year period 1969-1974 are compared with synoptic weather and wind circulation patterns. These comparisons indicate that regional and local sulfate transport can largely account for large-scale sulfate variations. Sulfate transformation due to humidity, temperature, and sunlight intensity do not adequately explain observed variations, but may be of secondary importance.

The existence of regionally high concentrations of sulfate in the northeastern United States and of a general summertime peak in sulfate values is confirmed.

Diurnal Variation of Wind Profiles Across Mountainous Terrain During an Air Stagnation Period

Julius A. Jackson, W. J. Saucier, and W. D. Bach

The diurnal variation of wind profiles across mountainous terrain during an air stagnation period was evaluated for seven days in the summer of 1957. The study was conducted across the north-central Appalachian Mountains, an area of heavy pollution concentration. The study was divided into easterly (16-18 July, 1957) and westerly (19-22 July, 1957) flow across the mountains.

Examination over the seven days showed a diurnal variation in boundary layer winds on the eastern side of the mountain range with a maximum amplitude of about 3 to 4 m sec^{-1} at 1000-1500 m MSL in both the easterly and westerly flows. On the western side of the mountain range, a diurnal variation with a maximum amplitude of about 4 m sec^{-1} at 600-1100 m MSL occurred in both flows.

This oscillation in the lower levels showed the presence of a low-level jet, which was unexpected in that this study was conducted during an air stagnation period. The low-level jet in the easterly flow across the mountains reaches a maximum wind speed at approximately 0600 GMT at about 300 m above ground level. In the westerly flow, the low-level jet occurs at approximately 1200 GMT at 600-800 m above the ground. This low-level jet is due to an inertial-type oscillation driven by the diurnal variation of the frictional forces aided by thermal forcing.

A Mesoscale Analysis of Air Flow in Complex Terrain

Christofer Maxwell, W. J. Saucier, T. L. Tsui, and G. C. Holzworth

Analyses of wind data are presented which examine the coupling of the surface and 850mb wind directions in a region of complex terrain. The data were grouped based on periods when the 850mb wind directions were parallel or perpendicular to the major valley axis. The diurnal and pressure gradient influences were also examined.

The analyses show that the surface and 850mb wind directions agree best when the 850mb winds are about parallel to the valley axis. The agreements are best during daytime periods when the 850mb wind speeds are strong. In addition, wind measurement sites in valleys agreed better with the 850mb winds than did sites located on ridges. When the 850mb winds were perpendicular to the valley axis, the wind measurement sites on ridges tended to agree better with the 850mb winds than did the valley sites.

Further analyses show that 30m tower wind sensors can be discriminately used to predict the direction of power plant plume travel in complex terrain regions. The tower sensors are unreliable during nighttime hours and are best during daytime hours when the 850mb winds are parallel to the valley axis.

Conclusions

Conclusions based on the eight research theses summarized in this report and worthy of special note are listed here by major topic.

Meteorological analysis of the St. Louis RAPS data:

1. The urban heat island strength during the day amounts to about 0.5°C and varies little with wind speed, cloud cover, or season. The nocturnal heat island, however, is highly responsive to all three factors, as well as to anthropogenic heat sources.
2. Variability in ozone profiles above the urban nocturnal surface inversion is significant and appears to be related to a similar variability in wind profiles. The relevant wind variability occurs on space and time scales unresolvable by the conventional radiosonde network.
3. Evaluation of the ratio of subsurface heat flux to net radiation over concrete, blacktop, and soil surfaces has

shown that this ratio can be better parameterized in air quality models by incorporating its dependence on surface type and on day versus night conditions

Atmospheric visibility and suspended particulates

4. Visibility at 14 sites throughout the United States has declined significantly between 1955 and 1972. The annual cycle in atmospheric transparency is inversely related to that in relative humidity.
5 The relative contribution of haze, smoke, and dust to decreasing visibilities at several sites in eastern Texas during the period 1949 to 1968 are identified. The haze contribution is part of a regional-scale problem, while the smoke contribution is associated with local sources and the wind direction.
6. Most sulfate concentration variability at particular sites appears explained by long-range transport as dependent on the wind pattern, rather than by local conditions of temperature, humidity, or insolation

Boundary layer wind structure in complex terrain:

7. The unexpected occurrence of a nocturnal low-level jet over the north-central Appalachian Mountains during a period of air stagnation has significant implications for regional pollutant transport.
8 Winds at the 850mb level can be useful in describing near-surface winds in mountainous terrain depending on valley-ridge orientation and time of day. This relationship provides a simple parameterization of winds in complex terrain for anticipating pollutant dispersal

Recommendations

Results of the work described in this report should, in many cases, be considered preliminary. Specific recommendations for further research work include:

1. Use of the full St. Louis RAPS data-set (1974-77) to strengthen the conclusions of the study of the urban heat island based on 1976 data. In particular, the role of rural soil moisture and of urban anthropogenic heat sources to the diurnal and seasonal heat island strength need further investigation.
2. Use of the full RAPS data-set to extend the two-month study period of energy budget evaluations for various types of surfaces. The ultimate goal of formulating an improved parameterization of the surface heat flux in air quality models which properly accounts for seasonal variability and the urban environment seems achievable with an extension of this study.
3. Further regional assessments of trends in atmospheric visibility, like that in eastern Texas, is one means of detecting the environmental impact of mass migrations of the U.S. populous as, for example, the apparent shift in population from the northeast to the "Sun Belt" states.
4. Further study of suspended sulfates and their relationship to source areas and meteorological variables. However, major revelations would only seem possible with increased sampling resolution over that provided by the present National Air Surveillance Network, as well as improved means of particulate collection and chemical analysis.
5. Additional studies of the mesoscale boundary layer wind structure in complex terrain with emphasis on consequent pollutant transport and dispersal over such regions.

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***Jason Ching** is the EPA Project Officer (see below).*
The complete report, entitled "Studies in Air Quality Meteorology at North Carolina State University," (Order No. PB 83-181 743; Cost: $13.00, subject to change) will be available only from:
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