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THREE ATMOSPHERIC DISPERSION EXPERIMENTS INVOLVING OIL FOG PLUMES MEASURED BY LIDAR

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Introduction

The Wave Propagation Laboratory (WPL) participated with the U.S. Environmental Protection Agency (EPA) in a series of experiments with the goal of developing and validating dispersion models that perform substantially better than models currently available. We briefly describe the lidar system deployed and the data processing procedures used in these experiments. Highlights are presented of conclusions drawn thus far from the lidar data.

Equipment and Processing

The lidar was a substantially upgraded version of the one operated at the Cinder Cone Butte experiment (Eberhard and McNice, 1982; Eberhard, 1983). The laser for the experiments described here was a frequency-doubled Nd:YAG laser with a pulse rate of 10 s^{-1}. The data acquisition system was modernized to handle the higher pulse rate and to monitor system operation more fully. Automatic scan control by computer was implemented; operators can modify the scan instructions without interrupting data acquisition.

Computer processing programs to refine the plume data were also substantially improved over those used for the Cinder Cone Butte experiment. It was necessary to compensate the data for the attenuation by the plume and surrounding ambient air, to subtract out the backscatter from the ambient air, and to edit spurious signals such as those from the ground or vegetation. Earlier we performed these tasks through interactive graphics on a pulse-by-pulse basis; for these three experiments the interaction was with an entire scan, which was much more efficient. Other software interpolated the tracer distributions from lidar coordinates to rectangular grids that are more conducive to dispersion analysis. Concentration profiles and other plume parameters were calculated for both individual and averaged scans. The processing computer archived the results on digital magnetic tape, printed tables, and hardcopy graphs to make analysis as convenient as possible.

The tracer plume consisted of a polydispersion of oil drops with a mode diameter of several micrometers. The lidar performed a repeating sequence of vertical scans to obtain cross sections of the plume at typically five distances

The detailed derivations will be presented and discussed.

References

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downwind of release. Tracer concentrations were inferred from the elastic backscatter. We found that the backscatter coefficient of the oil fog was not fully conserved with distance downwind. We attribute the decline mainly to partial evaporation of the drops.

Hogback Ridge Experiment

The 1982 plume diffusion experiment at The Hogback, a ridge near Farmington, New Mexico, was the second field study in the Complex Terrain Model Development (CTMD) project of the EPA. The main objective was to study impaction of elevated plumes on a ridge during stable conditions. This experiment was similar to the one at Cinder Cone Butte (Eberhard and McNice, 1982), where the topographical "target" was a hill. Oil fog at The Hogback was released from a 150-m meteorological tower or a crane upwind of the ridge. The lidar scanned in vertical planes almost parallel with the crest of the ridge.

Important information from the lidar includes the small but significant amount of plume rise that was caused by the heat from the oil fogger. The lidar data reveal whether the released plume passed over the ridge, impacted its side, or was embedded in the blocked region. The vertical deflection of the plume relative to the surface is an important factor in modeling surface concentrations. Strimaitis et al. (1985) were able to substantiate the importance of the plume's position with respect to the height of the dividing streamline. Flow above the dividing streamline has sufficient kinetic energy to overcome the density gradient and pass above the crest of the hill or ridge. Flow below the dividing streamline must pass around the side of a hill or suffer blocking in front of long ridge. Strimaitis et al. found that the degree of stratification above the dividing streamline had a secondary but significant effect on the plume's standoff distance above the crest of the ridge, but accounting for the amount of wind shear in the same zone did not improve the prediction.

Processed data from this experiment are archived with EPA, and a technical report on the lidar data is under preparation. This data set includes 3079 individual and 304 averaged cross sections that span 84 hour-long analysis periods.

Tracy Power Plant Experiment

A 1984 experiment at Tracy Power Plant was the culminating field study in the CTMD project. The plant, which is located beside the Truckee River east of Reno, Nevada, is surrounded by hills and mountains. Drainage winds were expected frequently to carry a plume from the stack toward higher terrain near a bend in the river. The stack exhaust was seeded with oil fog because the plume from the gas-fired plant is essentially free of particulates. Lidar scans were designed to monitor plume rise, to measure the plume's behavior and growth as it approached terrain, and to observe the initial encounter of the plume with the terrain.

The algorithm for vertical plume growth that was developed from the Cinder Cone Butte data substantially overpredicted the observed growth of the plant's plume. Since the plume at Cinder Cone Butte was within or near the top of the surface-based mixed layer, whereas the plant's plume was usually embedded in flow that was completely decoupled from the surface, the algorithm may not be valid in the latter setting. Work will continue on this and other problems that the lidar data are expected to help solve.

The lidar data from this experiment that is archived at EPA contains 4507 individual and 433 averaged cross sections that span 84 experimental hours. A technical report on the lidar data is in preparation.

CONDORS

The CONDORS (CONvective Dispersion Observed with Remote Sensors) experiment took place during 1982 and 1983 at the Boulder Atmospheric Observatory (BAO). Eberhard et al. (1985) described the experiment and presented some preliminary results. The goal was to determine the validity of the tank model predictions of Willis and Deardorff (e.g., 1981). Under highly convective conditions, when bouyancy dominates shear as a source of turbulence, they found that the vertical profile of a tracer deviated markedly from the form predicted by a Gaussian model. For instance, their locus of maximum concentrations from a nonbouyant, elevated release descended to the surface instead of remaining level at source height.

The 300-m meteorological tower at the BAO was the platform for elevated releases of oil fog, but several surface releases were also performed. The lidar monitored the height of the haze to infer the depth of the mixed layer, which is a critical scaling parameter in convective conditions. The shape of the vertical profiles of oil fog resembled the tank results in a general way, but some of the differences observed may prove to be significant. On the basis of an empirical calibration of the lidar-oil tracer system, the measured oil fog concentrations near the surface were in good agreement with surface samples of a gaseous tracer that was released from the same point as the oil fog. "Chaff" (aluminized filaments), which was tracked by a 3-cm-wavelength Doppler radar, was another important tracer used during CONDORS.

The tracer and meteorological data from CONDORS are comprehensive and of high quality. A data report is near completion, and analysis of results are in progress. They will include 911 individual lidar scans that have been combined into 81 averaged cross sections; these data span a total of 10 experimental hours.

Summary

The WPL lidar was a key component of the Hogback, Tracy, and CONDORS plume dispersion experiments. The results are important for air pollution modeling because they address situations in which high concentrations of a pollutant can occur at the surface. We were pleased with the dependability of the lidar, which performed satisfactorily for about 95% of the scheduled operating time. The lidar acquired a voluminous amount of data, from which about 2/3 was selected for reduction. Processed lidar data have been archived and will be made available on request. Some of the scientific results are already available; additional interpretation of the lidar data is in progress.

Acknowledgement

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