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ASCOT FY-1981 PROGRESS REPORT

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INTRODUCTION

Since the DOE Atmospheric Studies in Complex Terrain (ASCOT) Program was initiated in 1978, the major emphasis of the program has been on the study of nocturnal drainage winds using The Geysers Known Geothermal Resource Area of northern California as the study site. Summaries of program accomplishments during the past two years can be found in Dickerson and Gudiksen (1979, 1980). Studies during this year were related to reducing and analyzing the data taken during a major field study in September 1980, model development and testing, and conducting the last series of field experiments in this area to determine the interaction of cooling tower plumes from the geothermal power plants with nocturnal drainage and limited daytime mixing regimes. Funding for the cooling tower experiments were provided jointly by the DOE and the California Energy Commission.

The purpose of this report is to briefly summarize the ASCOT activities during FY-1981 and describe future activities.

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MODELING ACTIVITIES

The philosophy of the model development segment of the ASCOT program was to begin with models that existed among the various participating laboratories, determine their applicability to the study of drainage winds and, if appropriate, use these models as vehicles to develop a spectrum of modeling capabilities from one- to three-dimensional based on various physical parameterizations and mathematical techniques. Once the applicability of existing models was established then new developments were undertaken to supplement areas that appeared to be deficient in producing both research models that are used to understand the basic physics and application models used to address problems associated with air quality studies. Below are brief descriptions of the models presently under investigation and the name of the authors and their organizations. Readers interested in learning more about a particular model are encouraged to contact the author.

One-Dimensional Slope-Average Drainage Flow Model

Author — Alfred Garrett, Savannah River Laboratory (DOE), Aiken, South Carolina.

Description — The model solves the conservation equations for momentum and internal energy. Turbulent transport is modeled with an eddy viscosity approach, but the eddy viscosities (K 's) are computed from a turbulent kinetic energy budget equation. The model contains a 13-level soil layer plus solar and longwave radiation parameterizations (including effects of a cloud layer) to allow calculation of surface temperatures. A canopy layer with variable depth and coverage can be parameterized to investigate the effect on mean flow directly through drag terms and indirectly through turbulence and radiation fluxes. Model generated profiles of wind

speed, temperature and Richardson number were in good agreement with Manins and Sawford's data.

Hydraulic Model Proposed by Manins and Sawford

Modified K-Theory Model

Authors -- J. C. Doran and T. W. Horst, Pacific Northwest Laboratory (DOE), Richland, Washington.

Description -- The hydraulic model uses vertically integrated momentum, thermal energy and continuity equations, incorporating an entrainment coefficient. It has been successfully used to determine instrument placements for field measurements of drainage flows in The Geysers area and on a simple two-dimensional slope on Rattlesnake Mountain near Richland, Washington. The model appears to be a useful tool for determining experimental design in simple terrain.

The modified K-theory model (presently under development) incorporates equations of motion, thermal energy and turbulent kinetic energy, with exchange coefficients $K \sim E^{1/2}$. It will be used to simulate details of vertical wind and temperature structure.

Hydrodynamic Model

Author -- K. Shankar Rao, Atmospheric Turbulence and Diffusion Laboratory (NOAA), Oak Ridge, Tennessee.

Description -- Governing equations include equations of motion and thermal energy equation. Turbulent fluxes are computed from a turbulent kinetic energy (TKE) closure model. One-dimensional model predictions have been successfully tested against the results of a detailed second order closure model of the nocturnal boundary layer which simulated the Minnesota PBL data. Steady state results have

been compared with Prandtl's analytic theory of slope winds, and Defant's and Lettan's data. The model has been extended to include the prevailing synoptic wind speed and direction and the Coriolis force.

A two-dimensional drainage wind model has been formulated and developed (with Carmen J. Nappo) based on a semi-implicit finite-difference scheme.

Three-Dimensional Mass-Consistent Wind Field Model

Author -- Cecil G. Davis, Los Alamos National Laboratory (DOE), Los Alamos, New Mexico.

Description -- The model produces three-dimensional mass-consistent wind fields that are used to provide mean winds for atmospheric transport and diffusion studies. Terrain following coordinates are used to increase the resolution in the lower boundary layer where drainage winds develop. In order to provide the model with additional data a one-dimensional boundary layer model was developed to provide "pseudo-winds" in critical areas where measurements were not available. This technique was favorably used to compare model calculations to tracer measurements made in The Geysers area during the July 1979 field studies.

MATHEW/ADPIC

Author -- Rolf Lange, Lawrence Livermore National Laboratory (DOE), Livermore, California.

Description -- The MATHEW model is a three-dimensional mass-consistent wind field model that is used to provide the transport and diffusion model (ADPIC) with mean transport winds. The MATHEW model uses non-terrain following coordinates and a staggered grid for computational purposes. ADPIC is a three-dimensional particle-in-cell code that automatically calculates diffusivity from wind

speed, surface roughness and stability data. These models have been favorably tested against tracer data collected during the July 1979 field experiment in The Geysers area. Also, tests were successfully conducted using wind fields from Ted Yamada's second-order closure model (see below) coupled with ADPIC to simulate transport and diffusion phenomena under drainage wind conditions in The Geysers area.

Hydrodynamic

Author -- Tetsuji Yamada, Los Alamos National Laboratory (formerly with Argonne National Laboratory) Los Alamos, New Mexico.

Description -- Governing equations are equations of motion, conservation equations for the mixing ratio of water vapor and internal energy. Turbulent fluxes are computed from a simplified second-moment turbulence closure model. Soil layers are used to determine surface temperature from the heat energy balance at the ground. Longwave radiation is used in the one- and two-dimensional models and topography is included in the two- and three-dimensional models. A simple parameterization has been included in the one- and two-dimensional versions to study flows influenced by canopy effects. The two-dimensional model has been favorably used to simulate the data collected by PNL on Rattlesnake Mountain and the Manins and Sawford data and the three-dimensional model has been run against data collected during the July 1979 ASCOT experiment in The Geysers area. As mentioned earlier, output from the three-dimensional model was used to drive the LLNL ADPIC model.

Finite Element Models

Author -- Robert L. Lee, Lawrence Livermore National Laboratory (DOE), Livermore, California.

Description -- This numerical modeling effort has focused on developing several finite element models for simulating atmospheric flows over complex terrain. Two two-dimensional Navier-Stokes models, one hydrostatic and one nonhydrostatic, are used to investigate several initial parameterizations and characterized potential numerical difficulties in simulating drainage wind phenomena. The two-dimensional nonhydrostatic model, being the most flexible and contains the more robust time-integration algorithms, is used as a standard for evaluating the simpler approaches required in a three-dimensional model now under development. Although the three-dimensional model initially assumes constant properties it is currently being modified to include K-theory turbulence parameterization and Coriolis effects.

Hydrodynamic Mesoscale Model

Authors -- Richard N. McNider and Roger A. Pielke, University of Virginia.

Description -- This model is presently being transferred to LLNL under the supervision of Charles Molenkamp and Robert Lee. This model is a basic primitive equation model utilizing the incompressible continuity equation and hydrostatic assumption. Longwave and shortwave radiation are incorporated along with a surface energy budget. Similarity relationships are utilized in the surface layer for turbulent flux. Above the surface layer, for the convective boundary layer, a cubic polynomial is utilized to specify turbulent exchange coefficients while in the stable boundary layer a local exchange coefficient dependent upon local gradient Richardson number is employed. This model has been applied to idealized three-dimensional valley configurations to simulate the mountain wind. We plan to test the model against field data taken in The Geysers area during the July 1979 and September 1980 field experiments.

Much of the ASCOT modeling effort in FY-1982 will be focused on testing the three-dimensional models against the September 1980 and August 1981 (discussed below) field data, parameterization and sensitivity studies with the one- and two-dimensional models and summarizing the results of our modeling effort for the past four years. In addition, we plan to make recommendations for future modeling studies that either the ASCOT participants or other investigators can pursue to improve understanding of the drainage wind phenomena, particularly as it interacts with the larger scale atmospheric flow systems.

FIELD MEASUREMENTS

During the past two years the ASCOT field experiments were focused on a generic study of the transport and dispersion of pollutants entrained in nocturnal drainage flows within the Anderson Creek valley of The Geysers geothermal area. In contrast, the experiments, conducted during August 1981 were concerned with (1) the application of the measurements and modeling methodologies to pressing air quality issues facing the geothermal development, and (2) to perform nocturnal drainage flow studies in a new environmental setting, the Big Sulfur Creek valley, to test the general applicability of the methodologies developed from the past studies in the Anderson Creek valley. The purpose of these experiments was to acquire the data needed to evaluate existing cooling tower plume models and atmospheric transport and dispersion models for improving our capabilities for predicting the impact of the H_2S emissions from future power plant cooling towers during nocturnal drainage flows and daytime limited vertical mixing periods; two meteorological scenarios that have been identified as situations that may lead to potential air quality impacts. Utilizing the cooling tower plumes generated by power plants

situated within the Big Sulfur Creek valley where most of the geothermal development has occurred, the specific technical objectives of these experiments were:

- Evaluate the transport and dispersion of gaseous pollutants injected in or near nocturnal drainage flows by cooling tower plumes and surface sources.
- Define the temporal and spatial characteristics of the drainage flows within the Big Sulfur Creek Valley as well as the regional scale flows over the ridges.
- Evaluate the transport and dispersion of gaseous pollutants emitted by a cooling tower plume during daytime limited vertical mixing periods and the potential entrainment of these pollutants into the drainage flows formed within the Cobb, Anderson Creek, and Big Sulfur Creek Valleys during the following night.
- Evaluate the temporal and spatial characteristics of the surface and upper air wind fields and temperature structure during the daytime limited mixing periods as well as the transition periods leading into the nocturnal drainage flows over the region of interest.
- Obtain a comprehensive data base on the stabilization heights of power plant plumes during nocturnal drainage flows and daytime limited mixing periods.

Since the plumes generated by geothermal power plants rise several hundred meters above the cooling tower, the H_2S emitted in the cooling towers situated well up on the slopes near the ridges was expected to enter the regional scale flows, even during the nocturnal drainage flow situation. However, this is probably not the case for plumes emitted from power plants located near the bottom of a valley where the ridge tops exceed the plume stabilization heights. Under such conditions,

a considerable fraction of the materials in the plume may be entrained in the drainage flows and the transition layer overlying the drainage flows. Thus, Unit 14 was selected for the nocturnal drainage study since it is situated at the bottom of the Big Sulfur Creek Valley where the ridge tops rise to a height of roughly 500 meters above the unit.

For the daytime limited mixing experiments, Units 9 and 10 cooling towers were selected. They are located on the west side of Cobb Mountain, just below the Anderson Ridge but still within the Big Sulfur Creek Valley. They were selected on the basis of topographical setting, the likelihood of future power plants in this area and the potential air quality impact of these units in Anderson Springs, Whispering Pines and Cobb during this particular meteorological situation.

EXPERIMENTAL PLAN

A series of three nocturnal drainage experiments and two daytime limited mixing experiments were carried out during August 1981. The resources available for these experiments were:

- Two perfluorocarbon tracers and associated surface and vertical profile sampling systems
- Sulfur hexafluoride tracer and associated surface and airborne sampling systems
- Airborne Lidar system
- Time-lapse photographic equipment
- Two laser anemometers
- Five tethersondes
- Rawinsonde

- Five acoustic sounders
- Ten surface meteorological stations

Nocturnal Drainage Flow Experiments

The two perfluorocarbon tracers were utilized during the nocturnal drainage flow experiments. One of these tracers was injected into the cooling tower plume of Unit 14 while the second tracer was released simultaneously on the surface (directly into the drainage flows) near the power plant. The releases occurred over a one hour period after the drainage flows had been established. The surface sampling network consisted of roughly 50 BATS samplers which were capable of collecting up to 22 samples sequentially. Four of these operated with 10-15 minute sample averaging times to provide plume passage time information as a function of distance along the valley floor from the source; while the remainder operated with one hour averaging times for a period of six hours during each experiment. Figure 1 shows the layout of this surface sampling array which extends out to a distance of roughly 10 km from Unit 14 where the Big Squaw Creek joins the Big Sulfur Creek. In addition, two balloon-borne vertical profiling systems were situated downstream of Unit 14 to define the vertical distribution of the perfluorocarbon tracers as a function of time up to about ridge height; approximately 500 m above the valley floor. Their locations are also shown in Fig. 1.

The cooling tower plume rise was defined by the airborne lidar system and the visible portion of the plume was catalogued by surface-based time lapse photography. The lidar system was dedicated to defining the Unit 14 plume during the one hour tracer release period and was then diverted to cover the Units 1 and 2, 3 and 4, and 5 and 6 plumes which may also interact with the drainage flows within the Big Sulfur Creek. The time-lapse photography of the Unit 14 plume provided a

FIGURE 1. Perfluorocarbon sampling sites. ● BATS sampling sites, ▲ BATS sequential sampling sites, and ■ Vertical profiling sites.

continuous visual image of the visible parts of the plume throughout each experimental night.

These tracer experiments were coordinated with a series of meteorological measurements. Five tether sondes and acoustic sounders were used to define the spatial and temporal characteristics of the drainage flows as well as the regional scale flows over the ridges of the Big Sulfur Creek Valley that may interact with the drainage flows. A layout of these systems is shown in Fig. 2. In addition, 10 surface meteorological measurement stations were situated near the power plant and along the valley slopes to define the surface wind and temperature structure at specific sites of interest within the valley. Their locations are shown in Fig. 3 along with that of the laser anemometers which was used to define the spatially averaged drainage winds down the valley.

Daytime Limited Mixing Experiments

The two daytime limited mixing experiments were designed to evaluate the air quality impacts of cooling tower emissions into a westerly seabreeze situation with potential entrainment into the drainage flows that may develop within the Anderson Creek, Cobb, and Big Sulfur Creek Valleys during the following night. These experiments involved the release of sulfur hexafluoride into the Units 9 and 10 cooling tower plume over a six-hour period; from about 2:00 to 8:00 p.m. This ensured the release of the tracer into the westerly flow regime and into the transition period but short of the initiation of the drainage flows.

A network of 50 surface samplers, situated within the three valleys and on adjoining ridges collected hourly averaged samples from one hour prior to the release until approximately two hours after midnight -- well into the nocturnal drainage period. This array of surface sampling sites is shown in Fig. 4. Two

FIGURE 2. The locations of acoustic sounders (○), tethersondes (●), and rawinsondes (▲) during nocturnal drainage experiments.

FIGURE 3. Surface meteorological measurements sites and laser anemometer paths.

FIGURE 4. Sulfur hexafluoride sampling sites.

airborne sampling systems provided information on the tracer concentrations within the initial power plant plume as a function of height above the cooling tower as well as vertical profiles of tracer concentrations over most of the region.

The airborne lidar system was totally dedicated to defining the plume rise of the Unit 9 and 10 plume during these experiments. The array of meteorological measurements systems was changed somewhat from the drainage experiments, as shown in Fig. 5, to provide the additional coverage in the Anderson Springs, Cobb and Whispering Pines areas. The surface meteorological measurements stations remained as shown in Fig. 3.

Participating Organizations

These experiments utilized the talents of many individual investigators from a variety of organizations in a manner similar to the 1979 and 1980 ASCOT experiments. The participating organizations and their contributions were:

Air Resources Laboratory (NOAA) -- Perfluorocarbon tracers and sampling systems

Argonne National Laboratory -- Cooling tower measurements and modeling

Atmospheric Turbulence and Diffusion Laboratory (NOAA) -- Tethersonde

Battelle-Pacific Northwest Laboratory -- Tethersonde, acoustic sounder, rawinsonde, and an airborne tracer sampling system.

Brookhaven National Laboratory -- Perfluorocarbon sampling systems

California Energy Commission -- Manpower support

Environmental Measurements Laboratory -- Perfluorocarbon sampling systems

Environmental Systems and Service -- Sulfur hexafluoride tracer and sampling systems, surface meteorological stations, acoustic sounder, and logistical support

Lawrence Livermore National Laboratory -- Laser anemometer, acoustic sounder, surface meteorological stations, tethersonde, and vertical tracer profiling system

FIGURE 5. The locations of acoustic sounders (○), tethersondes (●), and rawinsondes (▲) during daytime limited mixing experiments.

Sandia National Laboratories -- Vertical tracer profiling system

SRI International -- Airborne Lidar system

Savannah River Laboratory -- Tethersonde

Wave Propagation Laboratory (NOAA) -- Acoustic sounders and a tethersonde

The principal emphasis of the experimental program during FY-1982 is the analysis of the data acquired during the September 1980 and August 1981 experiments. To facilitate this task individual investigators are summarizing specific elements of the data to enable the group as a whole to describe the physics of drainage flows. This will include a qualitative analysis of the development and continuation of the drainage flows using both tracer and meteorological data and a description of the physical processes involved in drainage winds. In addition, we will be making recommendations on the deployment of various types of instrumentation for measuring the most important parameters pertinent to drainage flows. Finally, we will also be stating how the state-of-the-art has been advanced through this work as well as making recommendations for future work.

FUTURE PLANS

Present planning indicates that the ASCOT program will be focusing on studies in the oil shale area of western Colorado beginning in FY-1983. Several program participants are beginning to investigate and define the role that ASCOT can play in this area. Since we will be expanding our scale of interest from approximately 10 km to several 10's of kilometers and other agencies have interests in the air quality aspects of the various energy resource developments in this region, we will be working closely with federal, state, and local groups to develop research plans that are coordinated to ensure that costs and benefits can be shared. Although it will not

be until FY-1983 that the majority of the ASCOT program will be moved to this area, it is possible that several preliminary studies could be initiated in FY-1982.

ASCOT PUBLICATIONS

During the past two years, many ASCOT participants have published their work in the open literature and for presentation at professional conferences. In addition to these publications, the following reports have been published as ASCOT reports.

Dickerson, M. H. and P. H. Gudiksen, "ASCOT FY-1979 Progress Report," ASCOT 80-1, 1980.

Porch, W. M. and J. J. Walton, "Statistical Analysis of Summer Winds in Geysers Area Prior to ASCOT 1979 Experiment," ASCOT 80-2, 1980.

Dickerson, M. H., editor, "Atmospheric Studies in Complex Terrain (ASCOT) Information Survey," ASCOT 80-3, 1980.

Orgill, M., "Atmospheric Studies in Complex Terrain (ASCOT): A Planning Guide for Future Studies," ASCOT 80-4, 1980.

Rao, S. and H. F. Snodgrass, "Modeling the Nocturnal Drainage Flows, Part I," ASCOT 80-5, 1979.

Barbieri, J. R., R. Nyholm, C. Castro, and K. Hill, "The ASCOT Data Base Management System," ASCOT 80-6, 1980.

Dickerson, M. H., editor, "A Collection of Papers Based on Drainage Wind Studies in The Geysers Area of Northern California; Part I," ASCOT 80-7, 1980.

Porch, W. M., "Comparison of Wind Spectra from Spatially Averaged and Point Measurements in Complex Terrain, ASCOT 80-8, 1980.

Gudiksen, P. H., editor, "ASCOT Data from the 1979 Field Measurement Program in Anderson Creek, California," ASCOT 80-9, 1980.

Dickerson, M. H. and P. H. Gudiksen, "ASCOT FY-1979 Progress Report," ASCOT 80-10, 1980.

Davis, C. and B. E. Freeman, "Modeling Drainage Flow with SIGMET," ASCOT 81-1, 1981.