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Air Quality Studies in the Western United States

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INTRODUCTION

There are several on-going air quality studies in the western United States: SCENES¹, DMAT², GLADIS³, and SCAQS⁴. These projects have their own objectives and focused on specific areas of interest. There are, however, some objectives common to all the projects

1. To quantify the source/receptor relationship, i.e., to estimate how much each source contributes to the pollutants distribution and
2. To develop a data base for testing, evaluating, and improving air quality simulation models

Los Alamos investigators participated in SCENES, WHITEX, Winter Intensive Tracer Experiments conducted from January 7 through February 18, 1987, in the area 400 km (east-west) x 250 km (north-south) centered around Page, Arizona. The purpose of the experiment was to quantify the attribution of a local source (Navajo Generating Station) and remote sources (copper smelters in southern Arizona, Mojave generating station, power plants and large urban areas) to the haze occurrences in the Grand Canyon and Canyonlands National Parks, and Glen Canyon National Recreation area.

In order to "tag" plumes emitted from the Navajo Generating Station (NGS), a trace gas was released from the NGS stack during the entire experimental period. Some of the highlights from the measurement program are

- ¹ Subregional Cooperative Electric Utility, Department of Defense, National Park Service and Environmental Protection Agency Study
- ² Desert and Intermountain Air Transport
- ³ Greater Los Angeles Distant Impact Study
- ⁴ Southern California Air Quality Study

1. Consistently higher sulfate concentrations at Canyonlands National Park (northeast of NGS) than at Grand Canyon (southwest of NGS) National Park,
2. On the other hand, consistently lower trace gas concentration at the Canyonlands than at the Grand Canyon National Parks.
3. Consistently higher concentrations of sulfate and trace gas at Page than at Hopi Point (Grand Canyon).
4. Little systematic diurnal variation in the observed trace gas concentration, particularly in the Grand Canyon area.
5. Little correlation between the upper air wind direction and the surface concentrations of trace gas and sulfate, and
6. Large variation in the wind direction with height.

Items 1 and 2 apparently contradict each other unless there were additional SO_2 sources in the vicinity of the Canyonlands National Park while tracer was released only from NGS. On the other hand, both trace gas and sulfate behaved similarly as evidenced in Item 3. Item 5 is very unlikely for plumes transported over flat terrain, but is quite possible over complex terrain since wind direction varies considerably with height due to wind circulations generated by differential heating and cooling of the sloped surfaces.

The purpose of this paper is to illustrate, by using Los Alamos three dimensional atmospheric flow models, large diurnal and spatial variations of wind, turbulence and plume characteristics over complex topographic areas.

MODEL DESCRIPTION

The basic equations for mean wind, temperature, mixing ratio of water vapor and turbulence are similar to those used by Yamada, et al. elsewhere in this proceedings. Transport and diffusion is modeled by using a Lagrangian statistical random particle method, and the concentration of trace gas is computed by assuming a Gaussian concentration distribution centered at a particle location. Standard deviations of the Gaussian distribution were computed from Taylor's (1921) theorem and the modeled standard deviations of velocity components. Both meteorological and diffusion models used in this study are fully described by Yamada and Bunker (1988), and are not repeated here with the exception of

a brief description of initial and boundary conditions.

Surface boundary conditions are constructed from empirical formulas by Dyer and Hicks (1970) for nondimensional wind and temperature profiles. The temperatures in the soil layer are obtained by solving the heat conduction equation. Appropriate boundary conditions are the heat energy balance at the soil surface and specification of the soil temperature at a certain depth.

The turbulent fluxes (momentum, heat, and water substance) are obtained from simplified turbulence-closure equations (Yamada, 1983). The long-wave radiation flux is computed according to Sasamori (1968). The lateral boundary values are obtained by integrating the corresponding governing equations except that variations in the horizontal directions are all neglected.

The computational domain is approximately 120 km (east-west direction) x 150 km (north-south direction) centered at around Page, Arizona. The top of computational domain is placed 3500 m above the highest ground elevation (3080 m above mean sea level) in the study area. An initial wind profile at the southwestern corner of the computational domain is first constructed by assuming a logarithmic variation (initially $u_0 = 0.2$ m/s and $z_0 = 0.1$ m) from the ground up to the level where the wind speed reaches an ambient value (3 m/s). Initial wind profiles at other grid locations are obtained by scaling the southwestern corner winds to satisfy mass continuity. Wind directions in the upper layers are assumed to be southeasterly everywhere. The vertical gradients of the synoptic potential temperature are assumed to be 0.0005 K/m for the height equal or lower than 1900 m msl, and 0.008 K/m for the levels higher than 1900 m msl.

Initial potential temperatures are assumed to be uniform in the horizontal directions. The turbulence kinetic energy and length scale are initialized by using the initial wind and temperature profiles, and the relationships obtained from the level 2 model. These expressions are given by Yamada (1975).

The governing equations are integrated by using the Alternating Direction Implicit method (Richtmyer and Morton, 1967) and a time increment is chosen to satisfy the Courant-Friedrich-Lewy criteria. In order to increase the accuracy of finite difference approximations, mean and turbulence variables are defined at grids which are staggered both

in horizontal and vertical directions. Mean winds, temperature, and water vapor vary greatly with height near the surface. In order to resolve these variations, nonuniform grid spacings are used in the vertical direction.

RESULTS

The purpose of the present study is to understand the mechanisms which resulted in large variations in space and time of wind and turbulence distributions in the WHITEX study area. This is essential in resolving the seemingly contradicting behavior of the sulfate and trace gas concentration distributions discussed earlier.

Figure 1 shows a three-dimensional representation of the ground elevation of the simulation area. The horizontal grid spacing of 4 km is used for both in the x (east-west) and y (north-south) directions. The vertical grid spacing is small (4 m) near the surface to resolve the large diurnal variations of wind and temperature profiles, and gradually increases with height. A total of 30 x 38 x 24 (vertical) grid points are used to cover the area of 116 km x 148 km x 6.6 km (vertical). The computation initiated at 5 p.m. on Julian day 32 and continued for 57 hours to obtain wind and turbulence distributions for trace gas concentration simulations.

Figure 2 illustrates typical nighttime (Fig. 2a) and daytime (Fig. 2b) modeled wind distributions near the surface (14 m above the ground). During the nocturnal period (Fig. 2a), the surface wind directions are downslope since the air near the surface cools faster and becomes heavier due to the longwave radiation cooling than the air at the same level but away from the sloped surface. Exactly the opposite happens during the convective daytime and the surface wind direction becomes upslope (Fig. 2b). The sloped surface faced east and south receive the sun's heating earlier than the surfaces facing west and north. The differential heating and large scale pressure gradient imposed in the simulations resulted in homogeneous and asymmetric distributions of wind vectors (Fig. 2b).

In addition to winds, turbulence also exhibits large diurnal variations. The long wave cooling at the ground surface produces stable air density stratification and suppresses turbulence motion. Figure 3a shows the standard deviation of the vertical wind component. On the other hand, turbulence motion is greatly enhanced during the daytime due to strong

heating from the sun at the ground. The corresponding standard deviation of the vertical wind component at 2 p.m. (Fig. 3b) is much larger in magnitude and deeper in the vertical extent than the counterpart at 1 a.m. (Fig. 3a).

The modeled wind and turbulence distributions are used to compute transport and diffusion of a trace gas from NGS. The trace gas plume is represented by many puffs released continuously at NGS. The effective height of the plume at NGS was estimated to be 500 m above the ground. Projections of the modeled puff centers at 2 p.m. and 7 p.m. are shown in Fig. 4a and Fig. 4b, respectively. The modeled turbulence apparently reached the plume height (500 m above the ground) around 2 p.m. (Fig. 4a) evidenced by the disturbed distribution of the puff centers. The modeled puff centers continued to spread horizontally as well as vertically due to the combination of the intensified turbulence and wind shears in the vertical direction (Fig. 4b). The modeled concentration of trace gas (Figs. 5a and 5b) at the ground level also shows considerable variations in space and time. The concentration contours represent the values after \log_{10} is applied. For example, -5 contour represents the concentration of 10^{-5} g/m³. The daytime concentration distribution (Fig. 5a) retains a plume like feature but the nighttime counterpart (Fig. 5b) shows very complex and nonhomogeneous characteristics which cannot be simulated by a simple Gaussian model.

Finally, the modeled surface concentrations at Page averaged over 6 hours are plotted as a function of the local time in Fig. 6. The dotted line indicates the averaged concentration over the entire simulation period. The modeled daytime peak concentration and averaged concentration over the entire simulation period are in good agreement with the observations but the nighttime values are slightly underestimated.

ACKNOWLEDGEMENT

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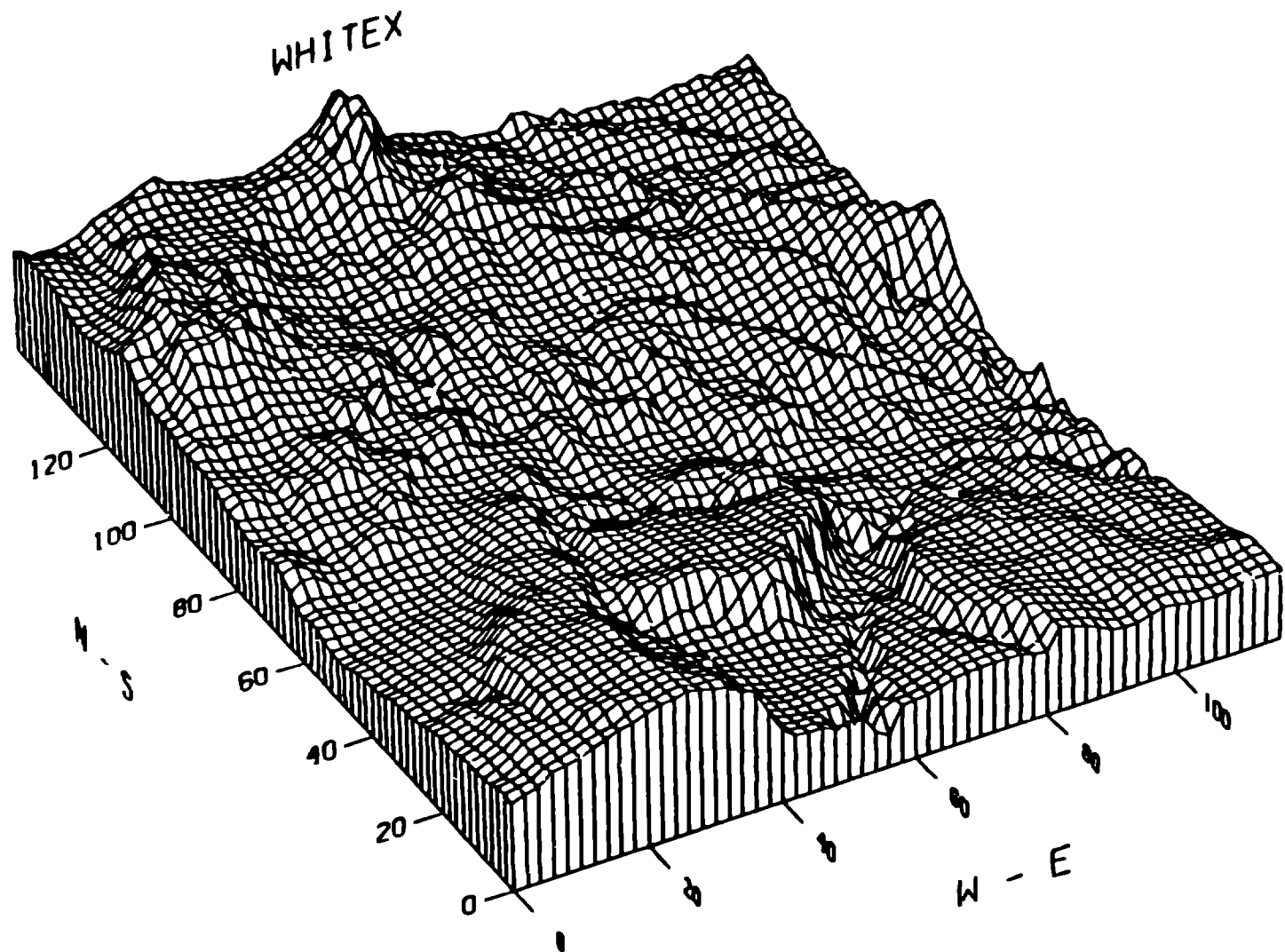


Fig. 1. Three-dimensional representation of the topography for the area simulated.

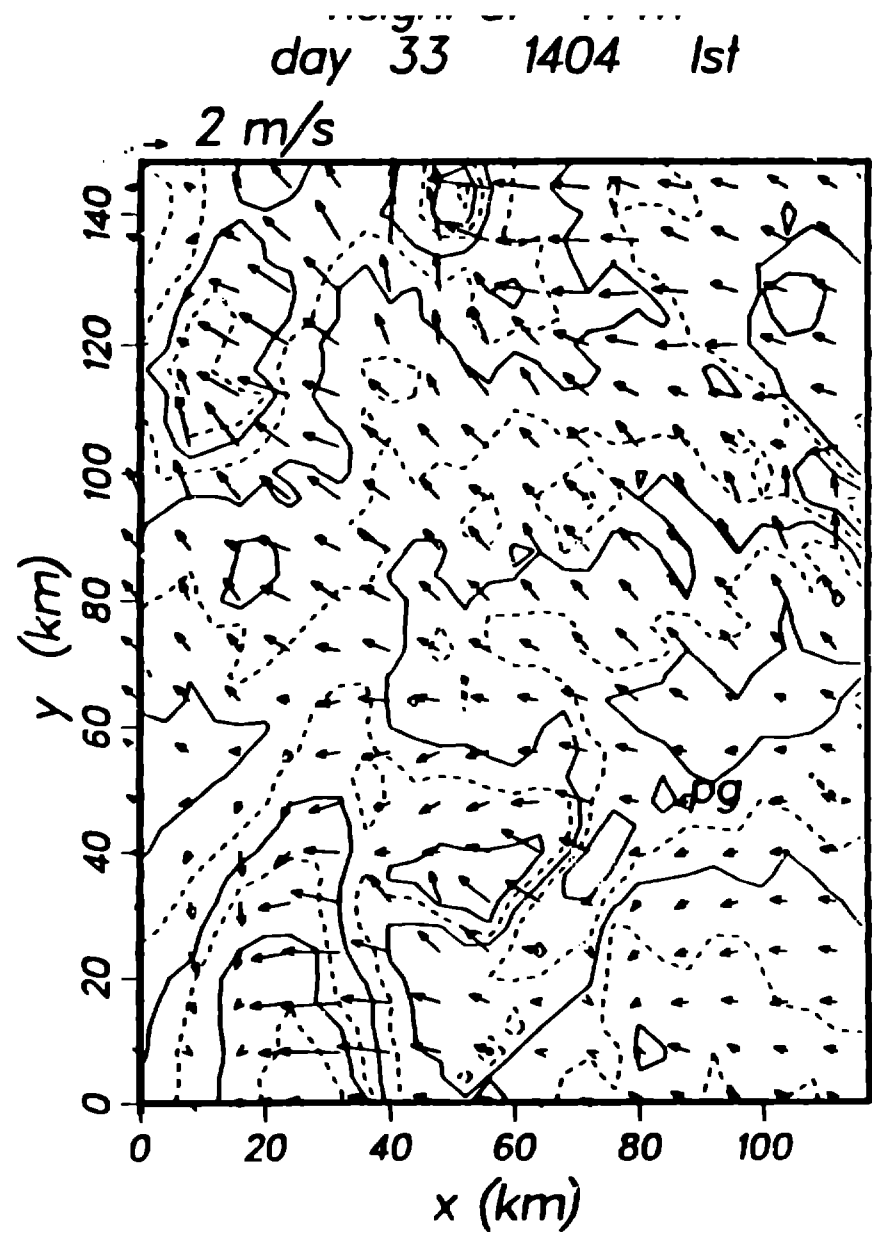
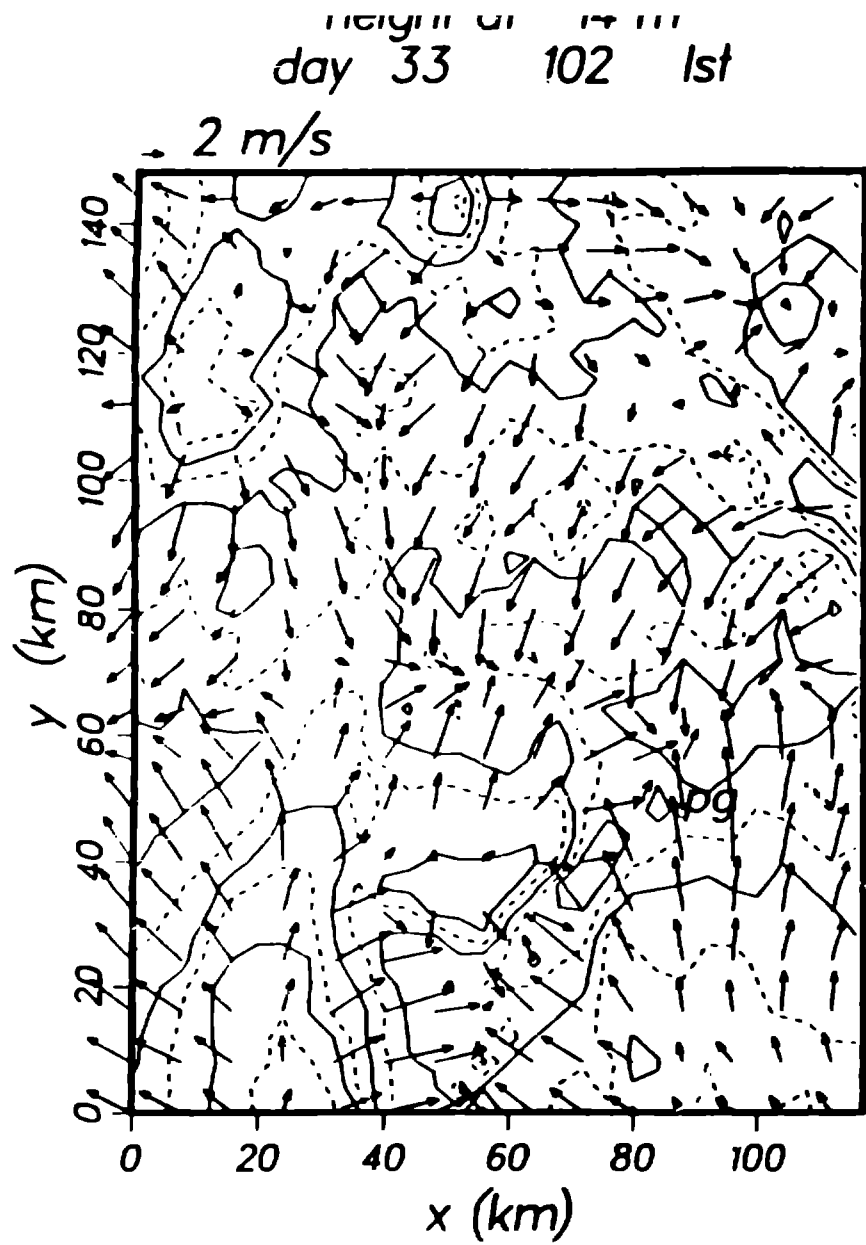


Fig. 2. Modeled wind vectors at 14 m above the ground. Terrain is contoured by solid lines with an increment of 400 m with dashed lines at intermediate levels. a) at 1:00 a.m. and b) at 2:00 p.m.

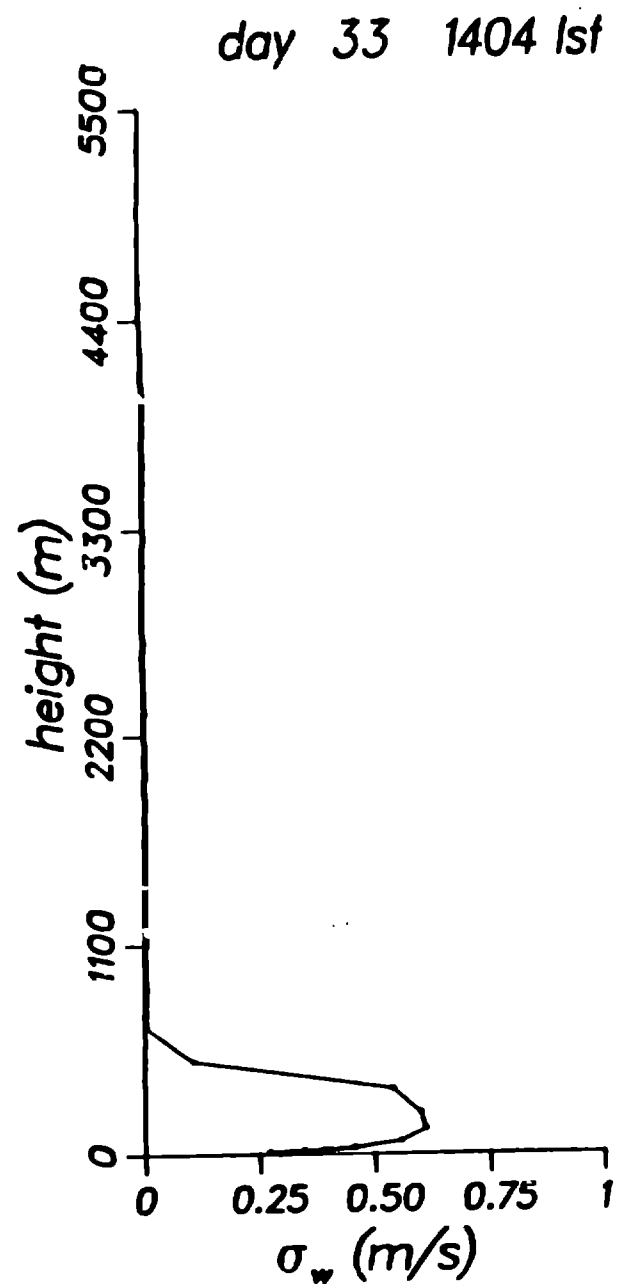
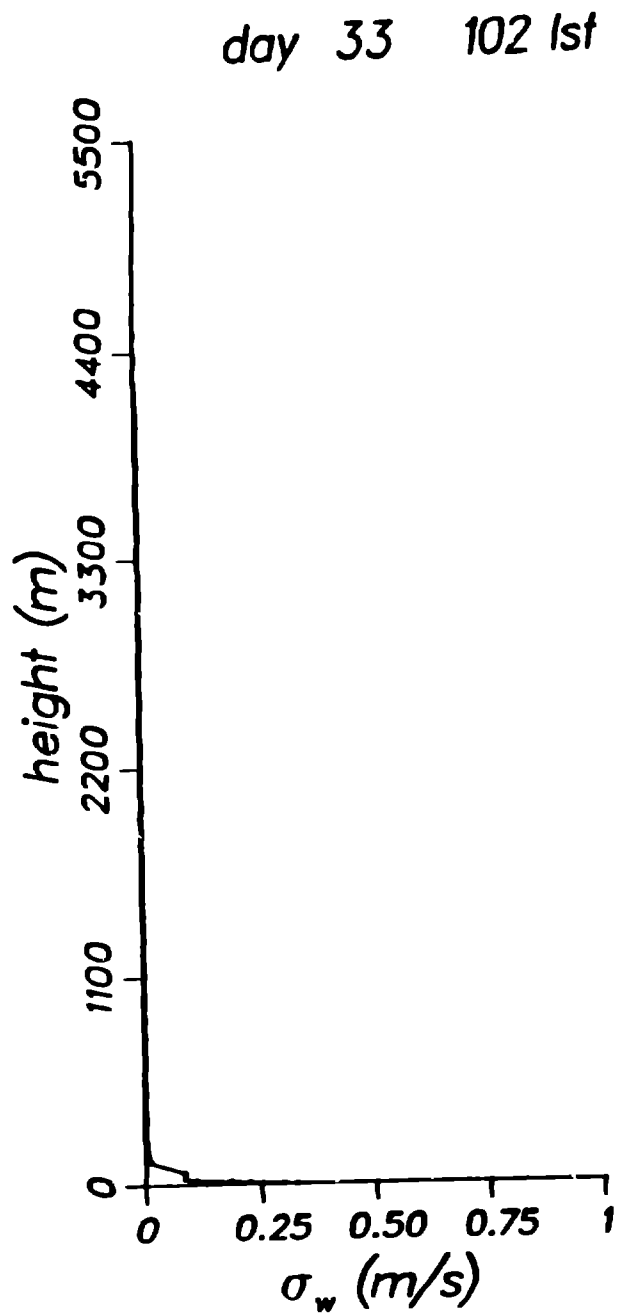
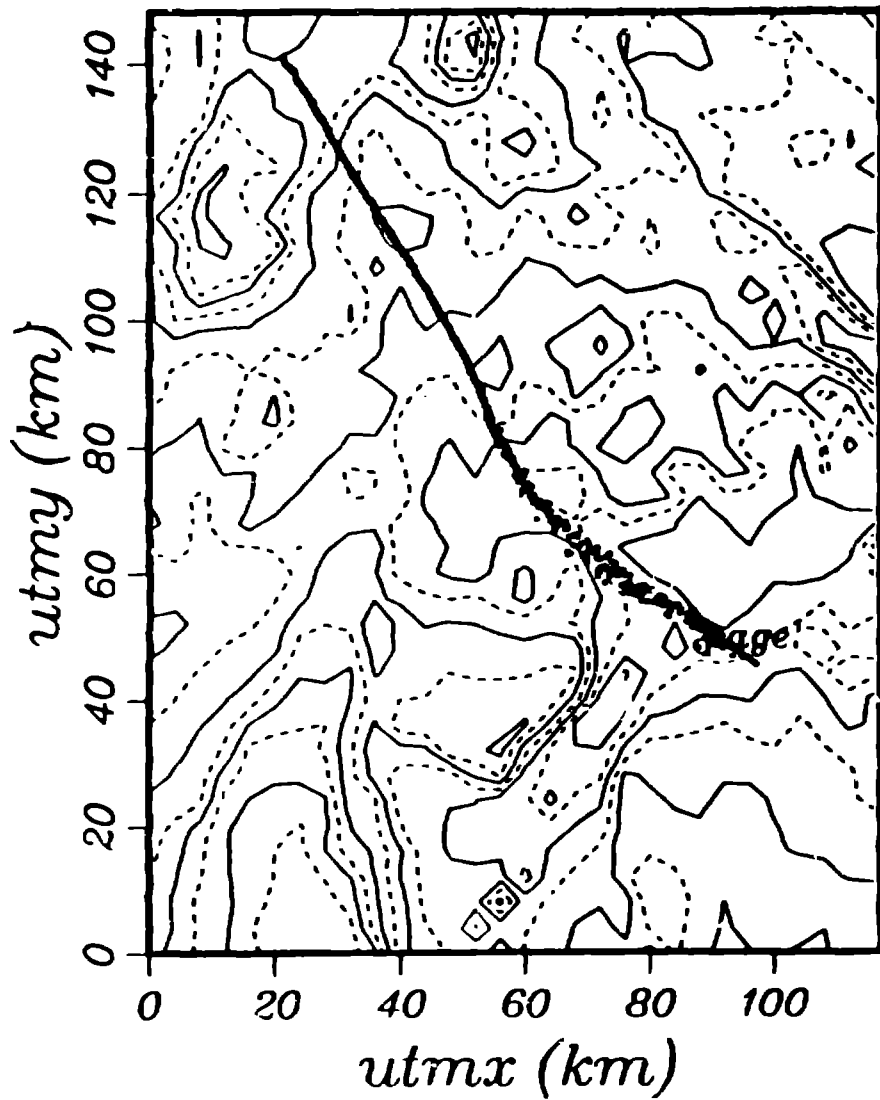


Fig. 3. Vertical profiles of the modeled standard deviation of vertical velocity at a) 1:00 a.m. and b) 2:00 p.m.

day = 33 lst 1400
total



day = 33 lst 1900
total

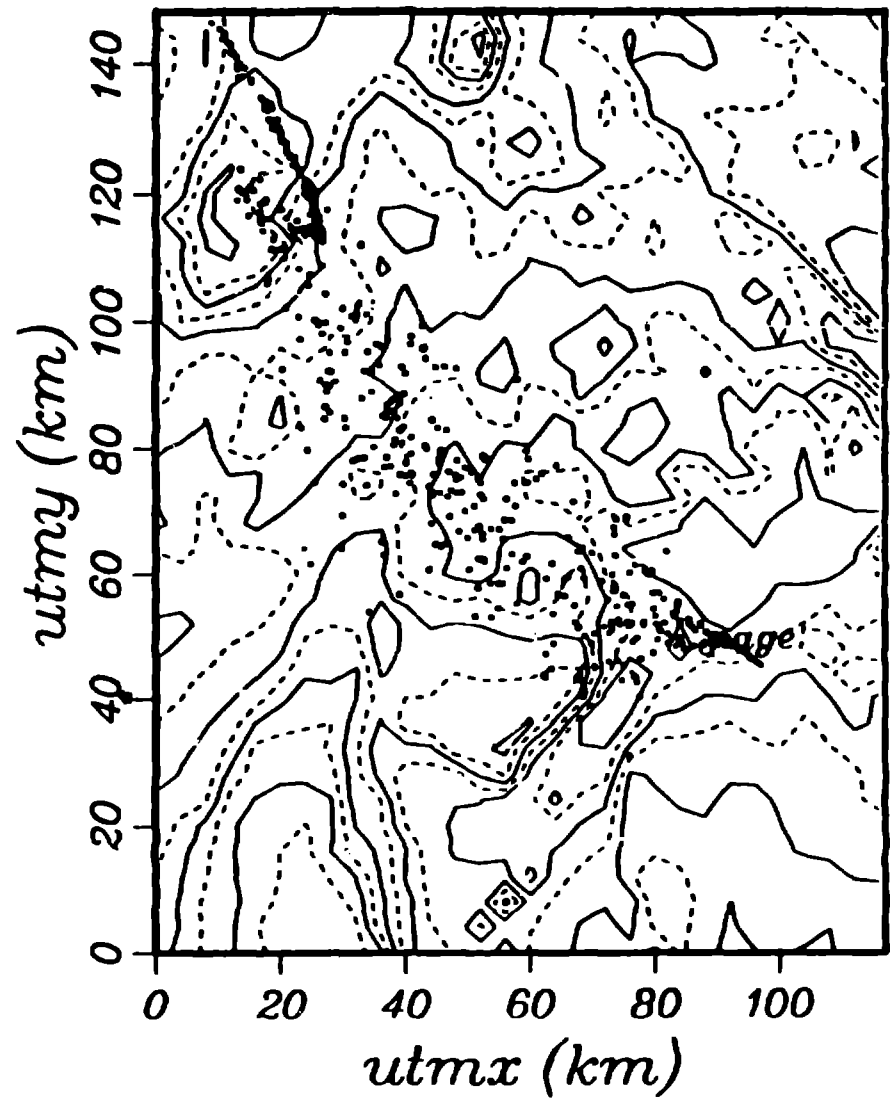
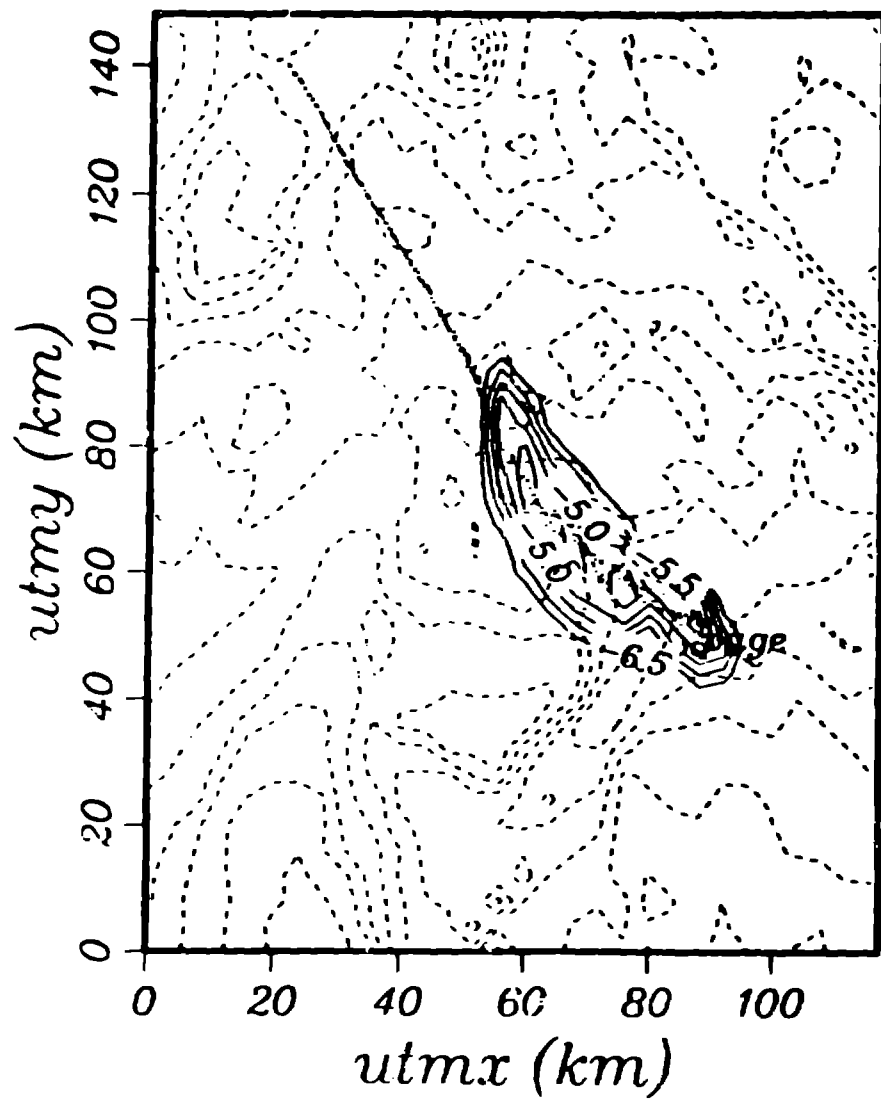


Fig. 4. Trajectory of the modeled puff centers projected on the surface at a) 2:00 p.m. and b) 7:00 p.m.

day 33 1400 lst
ground level concentration



day 34 100 lst
ground level concentration

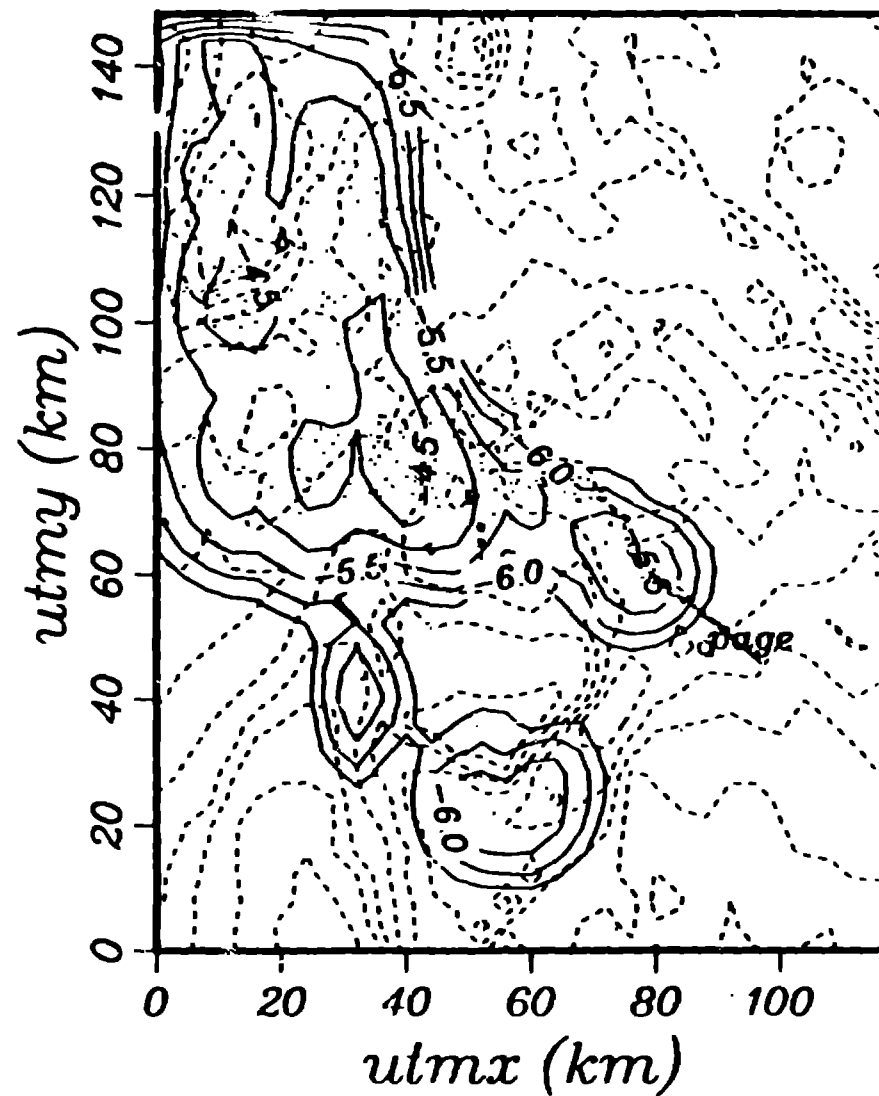


Fig. 5. Modeled concentration of α trace gas at the surface. Concentration (gm^{-3}) is given in terms of \log_{10} .

Average Concentrations at PAGE, Day 33

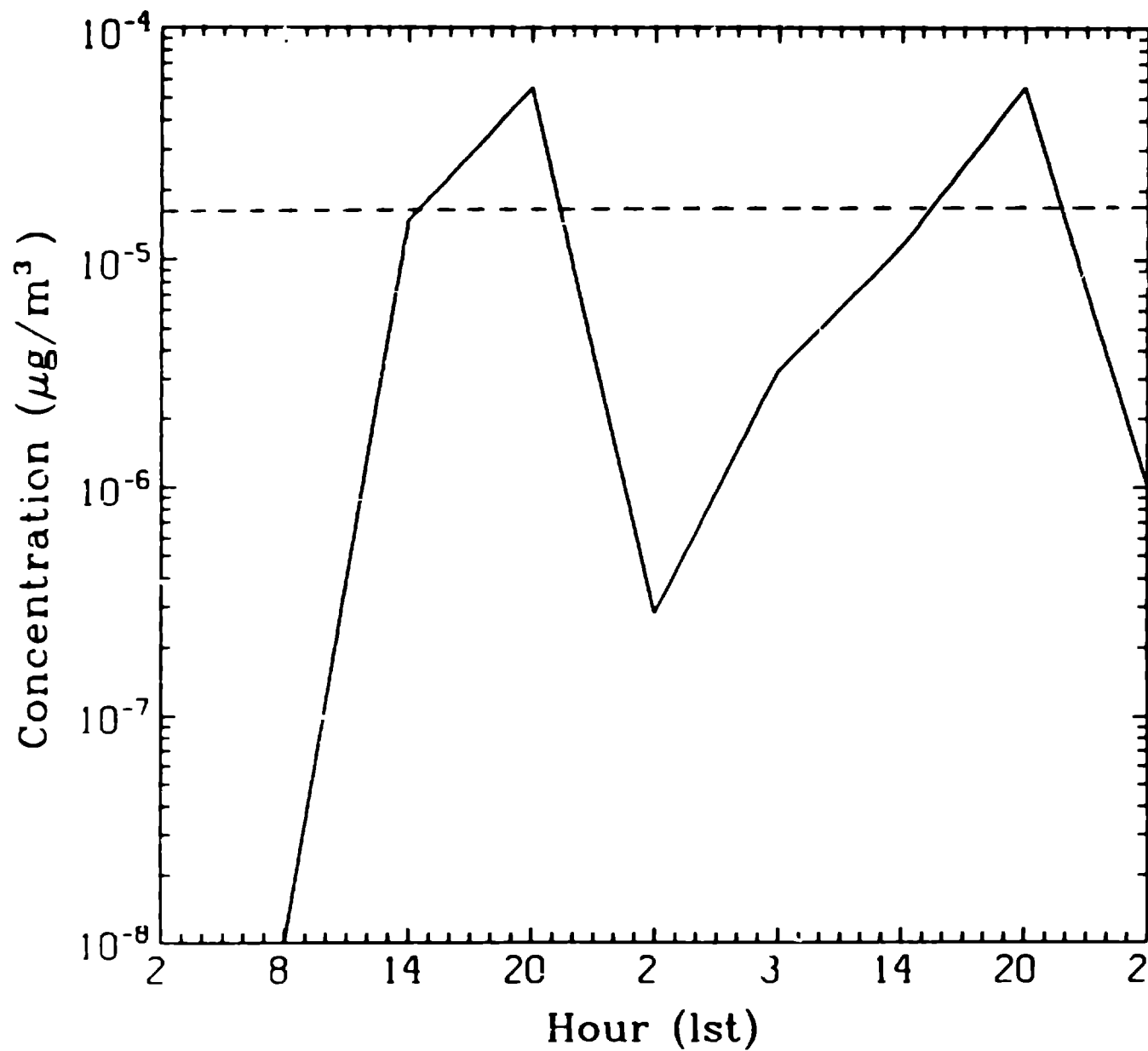


Fig. 6. Time variations of the modeled trace gas concentration averaged over 6 hours at Page, Arizona. The dashed lines indicates an average value over the entire simulation period.