EGG--10617-4101

DE90 008956

THE VALUE OF ON-SITE SODARS VERSUS NEAREST RADIOSONDE SOUNDINGS IN REGIONAL EMERGENCY RESPONSE MODELING*

Ronald L. Baskett and John S. Nasstrom
EG&G Energy Measurements, Inc.
Pleasanton, CA

Rolf Lange
Lawrence Livermore National Laboratory
Livermore, CA

Submitted to

83rd Annual meeting of the
Air & Waste Management Association
June 24-29, 1990
Pittsburgh, Pennsylvania

Paper 90-85.3

* This work was supported by the U.S. Department of Energy under Contract No. DE-AC08-88NV10617 and No. W-7405-Eng-48.

INTRODUCTION

Lawrence Livermore National Laboratory's Atmospheric Release Advisory Capability (ARAC) provides real-time emergency response support for accidental radiological releases to the atmosphere at Department of Defense and Energy facilities throughout the country. ARAC uses diagnostic three-dimensional dispersion modeling as its primary emergency response tool.[1] The regional (20-200 km) modeling system is built around the MATHEW (Mass-Adusted THrEe-dimensional Wind field) and ADPIC (Atmospheric Dispersion Particle-In-Cell) models.[2,3] It is essential for ARAC to know the accuracy and transferability of the MATHEW/ADPIC models to a wide variety of settings and meteorological conditions. Consequently, the models have been evaluated against numerous tracer studies over the last decade.[4,5]

This paper provides some recent case studies of the model performance with a special focus on the wind input data. Real-time model initialization depends on readily available surface wind and upper air observations. Surface airways observations as well as rawinsonde soundings from civilian and military airports throughout the country provide the basic wind inputs for ARAC's models. ARAC receives and decodes these observations from the Air Force Global Weather Center using extensive automated software at the LLNL ARAC Center.[6] All ARAC-supported sites have at least hourly surface wind observations on-site. However, the standard twice-daily rawinsonde locations are frequently outside the modeling domain and may be up to 12 hours old, depending on the time of the calculation.

One remote sensing instrument which shows promise for providing the needed information about vertical wind variation is the Doppler acoustic sounder or sodar. Several Department of Energy (DOE) facilities are in the process of adding sodars to their array of on-site observations. If properly sited, one would expect that real-time soundings within the modeling domain would provide the best initialization of the boundary layer wind field. This paper compares the value on-site sodars versus the nearest rawinsonde for use as input to initialize the MATHEW/ADPIC model. Two case studies in two different settings are analyzed. One is the inland, gently rolling terrain of DOE's Savannah River, Georgia during the 1988 STAble Boundary Layer Experiment (STABLE) conducted by the Westinghouse Savannah River Co.[7] The second is the coastal, complex terrain of the Diablo Canyon Nuclear Power Plant, California during the 1986 tracer study conducted by the Pacific Gas and Electric Company (PG&E).[8] For each of the two tracer studies, the MATHEW/ADPIC models were initialized with real-time on-site vertical measurements as well as the nearest twice-daily rawinsonde soundings from outside the modeling domain.

INITIALIZING THE MATHEW/ADPIC MODELS

Initializing the MATHEW wind field model requires point measurements of wind speed and direction measured near the surface and in the vertical at various locations within or around a three-dimensional grid [9]. As a first step, the surface data are interpolated over the domain using an inverse-distance-squared weighting of the input data to the grid points. The three nearest stations usually dominate the surface wind speed direction at any grid point. Vertical interpolation between the surface measurement height up to the top of the surface layer is done using a standard wind speed power law formulation. Wind direction is kept constant within the surface layer. As a rule of thumb, the surface layer is specified as 10 percent of the boundary layer height. The top of the boundary layer is determined from rawinsonde or sodar soundings. It is specified as either the level where the wind speed and direction become constant with height or where an elevated temperature inversion occurs.

The initial vertical interpolation between the top of the surface layer and the top of the boundary layer is controlled by the model user and is the focus of this paper. It can be done using one of two methods: the "profile method" or the "parameterized method". The profile method is based on the observed profiles using an inverse-distance-squared weighting of the input data at each vertical level in the model. The profile method is used when representative vertical wind profiles are available within the modeling domain. The model user must determine whether or not the nearest available rawinsonde sounding is representative enough to be used to initialize the modeling domain.

If this is not the case, the modeler will use the parameterized method. Conditions when the upper air measurements may not represent the boundary layer to be modeled include the following:

- The rawinsonde stations are a great distance from the modeling domain,
- The rawinsonde data are many hours old , or
- The on-site profile is influenced by local terrain features.

In the parameterized method, only the wind speed and direction at the top of the boundary layer are used from the sounding to initialize the boundary layer wind field. Consequently, the entire boundary layer wind structure must be parameterized. There may be both shear in the wind speed as well as the wind direction with height, and this shear may differ throughout the model domain. The speed profile is parameterized by the well-known boundary layer power-law parameterization where the exponent is determined as a function of surface roughness and atmospheric stability.[10] However, there is no commonly-accepted universal prescription for the dependence of wind direction with height within the atmospheric boundary layer.

The parameterized method uses two inputs to control the initialization of the vertical wind direction profiles. The first input determines the direction of rotation and the second controls the shape of the profile. Winds usually rotate in a clockwise direction or veer with height in the northern hemisphere. On occasion, however, winds are known to rotate counterclockwise or back with height, such as when a front moves through an area. An input parameter specifying the maximum angle through which the winds are allowed to veer is used to control the direction of rotation with height. If the wind shear between the top of the surface and boundary layers is less than this maximum veering angle, then the model will be initialized with wind profiles that veer with height. Otherwise, they will be backed with height.

As with the wind speed profile, MATHEW uses a power law to initialize the wind direction profile in each vertical column throughout the model domain. It is difficult to specify the shape of the wind direction profile especially during light winds. Without any prior knowledge, we typically use a power-law exponent of one based on the assumption that the wind direction will change linearly from the top of the surface layer to the top of the boundary layer.

Either the profile or parameterized method is applied to the vertical wind profile in each of the model's grid cells. The resulting wind field on a grid of 50 x 50 x14 cells in the north-south, east-west and vertical directions, respectively, represents the initial wind field for the MATHEW model. MATHEW then adjusts the wind field by variational methods to be mass-conservative and to account for terrain effects. ADPIC then calculates the time and space varying transport (using the mean winds from MATHEW) and diffusion (using K-theory diffusion) of source material using thousands of Lagrangian "tracer" particles on a Eulerian grid which is 40 x 40 x 14 cells. The cell size in the MATHEW and ADPIC grids is variable and is specified for each problem. Both MATHEW and ADPIC cells are of the same size. The smaller, nested ADPIC domain is designed to avoid boundary effects of the wind fied.

STABLE TRACER STUDY

Description

The Savannah River Site (SRS) is a circular-shaped facility 30 km in diameter located on the southeast U.S. coastal plain. Several creeks result in an a few abrupt changes in elevation in the otherwise gently rolling, forested terrain. Eight 61-m meteorological towers measured the wind speed and direction on-site. In addition, a 300-m TV tower located 28 km northwest of the tracer release and instrumented at 7 levels gave wind and temperature measurements throughout the stable boundary layer. A sodar near the the tall TV tower during the experiment produced similar wind speed and direction profiles, but its data was not as readily available and was not used in this work. All meteorological data were averaged over 15-min periods for input to the MATHEW model. The ADPIC model domain was 20 km x 20 km x 280 m (each cell was 500 m by 500 m by 20 m).

Sulfur hexafluoride (SF_6) tracer gas was released continuously near the center of the SRS through a 61-m stack during stable conditions on during the early morning hours of April 14, 15, and 17, 1988. A continuous analyzer aboard a mobile van provided ground-level SF6 concentrations every 5 sec on roads 5-20 km downwind of the release stack. The data averaged over 30 sec were grouped in 15-min periods and compared with instantaneous model calculations at the midpoint of the 15 min. The tracer data from the first night was used as a case study to evaluate the value of the on-site wind profile data for an elevated release in the nocturnal boundary layer. It was the best night during the experiment when the plume was affected significantly by dispersion above the 61-m release height.

Stable Case Study Day

The winds from the eight 61-m towers were uniformly from 145 degrees at 4 m/sec at 0200 EDT, the beginning of the 4-hr release period on April 14, 1988.[7] Between 0315 and 0415 EDT the 61-m winds rotated 35-45 degrees counterclockwise and remained from 110 to 120 deg for the rest of the experiment. Vertical bivane measurements from the 300-m TV tower showed the top of the mixing layer was about 175 m during the experiment. Table I lists the 300-m winds from the TV tower with the same level from the previous 2000 EDT (0000 UTC) soundings at the three nearest rawinsonde stations. Note that these soundings from the previous afternoon were 6-9 hours old and more than 150 km from the release location. The 300-m wind direction interpolated to the site from the three rawinsonde soundings was from 313 degrees. During the experimental period the 300-m wind from the TV tower was always at least 70 degrees more southerly than the 313-deg interpolated rawinsonde direction.

Table I. Winds at 300 m above ground on April 14, 1988

Station	Distance from Release	Dir.	Time (EDT)	Wind Speed (m/sec)	Wind Dir.
TV tower	28 km	NW	0200	7.6	227
			0300	7.4	245
			0400	6.8	156
			0500	7.6	206
Rawinsondes:					
Athens, GA	170 km	WNW	0000	4.1	280
Waycross, GA	240 km	SW	0000	7.2	305
Charleston, SC	160 km	ESE	0000	7.2	355

STABLE Modeling Results

Three model runs were made for the STABLE first night 4-hr experiment period. The only difference in the runs was how the wind profile was initialized. Following are the initialization methods:

Run 1: On-site measured wind profile from the tall tower with the profile method of vertical wind interpolation.

Run 2: Parameterized wind profile based on a linear interpolation between the on-site 61-m tower data and the 300-m horizontally-interpolated rawinsonde data

Run 3: Parameterized wind profile based on a power law interpolation between the on-site 61-m tower data and the horizontally-interpolated rawinsonde data

Figure 1 shows a sample modeled vertical wind direction profile for two of the three runs at the center of the modeling grid. The wind direction from the nearest 61-m tower was from 110 deg. Using the TV tower observations, Run 1 indicates that the winds above 61 m veered steadily to 200 deg at 300 m. A linear interpolation between the 61-m tower data and the 300-m level in the rawinsonde observations was used for Run 2. The power law was used to extrapolate the tower wind speed and direction to the rawinsonde value in Run 3. An exponent of 3 in the power law causes the 61-m tower wind direction to be extended well up into the boundary layer before the wind direction veered to match the interpolated rawinsonde direction at the top of the boundary layer.

A 15-min SF_6 measurement period late in the experiment was chosen to illustrate the accuracy of the three model runs. The SF_6 tracer measurements centered on 0545 EDT are plotted with ground-level isopleths determined from Runs 1 and 2 in Figure 2. From 0937 to 0553 EDT, the SF_6 van drove from south to north along State Route 125 transecting the entire plume diagonally.

The MATHEW/ADPIC model reproduced the pattern of measured SF_6 concentrations quite well when the on-site tall tower data were used to initialize the upper air profile. The only portion of the plume missed by Run 1 was its southern edge because the wind field failed to rotate the plume with height. The comparison for Run 2 with the linear parameterized wind profile is much worse. Because the linear profile method produces southwest to west winds immediately above the 61-m release height, the top portion of the plume is sheared towards the west while the actual vertical wind shear was towards the east. Consequently the model sends the upper portion of the plume away from where it was measured at the ground along State Route 125. Figure 2b shows most of the plume never makes it to State Route 125 by 0545 EDT for Run 2. In Run 3, the 61-m wind is extended up through most of the plume's vertical cross-section via the power law parameterization. This results in a ground-level pattern nearly identical to that of Run 1. Figure 1 shows that the power law wind direction profile nearly matches the measured profile up to 200 m. The majority of the plume is contained below the 175-m deep mixed layer. The main difference in Runs 1 and 3 is that the wind speed from the interpolated rawinsonde soundings results in 5 m/sec winds at 200 m compared to 7 m/sec measured on the tall tower. As a result Run 3 produces slightly higher concentrations along the plume centerline.

A statistical analysis was performed on the ratios of measured to modeled SF_6 concentrations for April 14, 1988. Figure 3 shows the results from the three runs. The comparisons from the 0545 EDT period hold true for the other eight 15-min periods from 0315-0615 EDT. A total of 109 5-sec samples were compared in space and time for each run to produce Figure 3. Runs 1 and 3 produced results comparable to previous model evaluations against 30- to 60-min average tracer measurements taken in several complex terrain settings.[4]

DIABLO CANYON TRACER STUDY

Diablo Canyon Study Description

The Diablo Canyon tracer study took place from August 31 to September 17, 1986. It was conducted in the vicinity of the Diablo Canyon power plant near San Luis Obispo, California on the Central California coast. Tracer gas was release from several locations in the area during the study, including the power plant itself. Measurements of hour average SF_6 air concentration were made at 150 locations within a 40 km radius of the power plant.

PG&E's meteorological data was averaged over 15 min periods. These data included seven 10 to 60 m towers and 3 sodars measuring winds in twenty 30-m layers from 40 to 650 meters above ground. Hourly and 3-hourly data were also available from National Weather Service and Air Pollution Control District stations in the area. Vandenberg AFB (59 km south on the coast) rawinsonde observations were taken at 0500 and 1700 PDT (0000 and 1200 UTC).

Diablo Case Study Day

The first day of the study, August 31, 1986, was used to study the wind profile initialization. On this day, the SF_6 releases alternated between a 71-m high release from 0800-1000 PDT, to a 1.5 m release from 1100-1300 PDT, and back to a 71-m release from 1400-1600 PDT from the power plant site. Both releases were modeled using the MATHEW/ADPIC modeling system for the entire first day. The initial source geometry was a well-mixed volume approximating the reactor building size to account for building wake. Forty eight 15-min meteorological data sets were used in the calculation. The model domain was 50 km by 50 km in the horizontal and 560 m in the vertical (1 km horizontal by 40 m vertical grid cells).

Diablo Modeling Results

Three calculations were performed:

Run A: On-site sodar data was used with the parameterized method of vertical wind interpolation (except for the first hour when the plume was in the vicinity of the sodar at the power plant and the profile method was used)

Run B: Sodar data was used with the profile method of vertical wind interpolation.

Run C: Vandenberg upper air sounding was used with the parameterized method.

During first elevated release (08:00 to 10:00 PDT), the dispersion patterns within 10 km of the source are similar in all three runs. However, Figure 4 shows modeled and measured SF_6 air concentration (on a 25 km sub-area of the calculational grid) for a period when the three runs showed significantly different results. The first and third calculations were nearly identical; only Run A is shown. Also, they agree very well with the measurements for this period--11:00 and 12:00 PDT. Run B, however, does not model the split flow occuring in the area of San Luis Obispo Bay with transport of the material both northward inland with a sea breeze flow toward San Luis Obispo through the pass in the hills along U.S. Highway 101 and southeastward along the coast during this period.

The differences in the results are caused by a much stronger onshore flow in the area of San Luis Obispo Bay modeled by Run B. This is illustrated by the 200 m wind fields from Runs A and B in Figure 5. Figure 5 also shows the locations of the Diablo Visitors Center sodar and the sample modeled vertical profile discussed below.

Figure 5 shows the modeled vertical wind profiles at a location on the coast of San Luis Obispo Bay along with the nearest observed sodar and rawinsonde profiles.

Figure 6d shows the measure sodar wind profile from the Diablo Visitor Center sodar (see Figure 4 for it's location) at 11:00 PDT. This sodar is located in a valley and is 2.5 km inland from the coast. It shows a 200 m deep layer of onshore flow along the valley axis and winds veering above 200 m to a north-northwesterly flow aloft. Figure 5e is the measured wind profile from Vandenberg AFB at 05:00 PDT (12:00 UTC). showing northwesterly winds aloft. Figure 5a shows a sample modeled profile on the coast (see Figure 4 for its location) for Run A. The winds veer 70 degrees in the lowest 300 m. Figure 5b shows the modeled profile for Run B where the winds veer only 20 degrees in the lowest 300 m. Run A and C are similar because the Vandenberg sounding was representative of the boundary layer flow in the modeling domain on that day.

The comparison of modeled concentrations to measurements for the entire 11-hr measurement period is shown in Figure 6. As with the 11-1200 PDT period, the other samples show that Runs A and C compare well with the measurements while Run B does much poorer.

The inability of Run B to obtain a representative divergent flow pattern is a consequence of model incorrectly extending the influence of the inland Diablo Visitors Center sodar out beyond the coast. The strong influence of inland soundings resulted in winds in the 200 to 300 m layer being southerly along the valley axis when in reality the coastal flow should was probably more westerly at those levels. Tracer gas in that layer was not transported along the coast as in Runs A and C and as in the measured tracer gas plume.

SUMMARY AND CONCLUSIONS

In the STABLE case study, on-site verical profiling data was of great value in calculationg the dispersion of a near surface release since it was representative of the modeling domain. Use of rawinsonde data was of lesser value unless coupled with a power law interpolation of the vertical wind. However, it is unlikely that this type of parameterization may be applied *a priori*, especially in nightime stable cases when wind direction and speed can change significantly with height.

In the Diablo Canyon case study, the use of on-site vertical sounding proved more problematical. While the sodar data were undoubtedly a good measure of the vertical winds at their locations, in one case it may not have been representative for distances beyond 2 km. This indicates it may be desirable to place limits on the area of influence a measured vertical profile may have. Rawinsonde data was representative of the upper level winds in this case and was of significant value when coupled with good parameterization of the vertical wind.

These case studies were near-surface releases on horizontal scales which are a few tens of kilometers and do not provide conclusive results. However, they indicate that on-site vertical wind profiling can be very valuable when it's use is restricted to the areas for which it is representative. Furthermore, it is clear from these studies that modeling the vertical variation of the wind field can have an important impact ground-level air concentrations.

ACKNOWLEDGEMENTS

We would like to acknowledge the Westinghouse Savannah Co. for providing the STABLE data and PG&E for providing the Diablo Canyon data. Without these data sets, our study would not have been possible. We would also like to thank Tony Hoang for writing software to process PG&E data files, Robert Freis for his help in modifying model code,and Walter Schalk III for assistance in preparing figures.

REFERENCES

1. Dickerson, M.H. and R.C. Orphan, The Atmospheric Release Advisory Capability, Nuclear Safety17, 281-289 (1976).

2. Sherman, C.S., A mass-consistent model for wind fields over complex terrain", J. Appl. Meteor., 17, 312-319(1978).

3. Lange, R., A three-dimensional particle-in-cell model for the dispersal of atmospheric pollutants and its comparison to regional tracer studies. J. Appl. Meteor., 17, 320-329 (1978).

4. Lange, R., Transferability of a three-dimensional air quality model between two different sites in complex terrain. J. Climate Appl. Meteor., 28, 665-679 (1989).

5. Dickerson, M.H. and D.L. Ermak, The evaluation of emergency response trace gas and dense gas dispersion models. Advanced Studies Institute Short Course on Meteorological Aspects of Emergency Response. Amer. Meteor Soc., Boston, 1988.

6. Baskett, R.L, Structured analysis techniques applied to the design of a national emergency response system. 77th Annual Meeting of the Air Poll. Control Assoc. 1984, Paper 84-14.8.

7. Weber, A.H. and R.J. Kurzeja, Overview and first results from Project STABLE. Amer. Meteor. Soc. Sixth Joint Conf. on Appl. of Air Poll. Meteor., Anaheim, Calif., Amer. Meteor. Soc., Boston, 1989, pp.142-145.

8. Thuillier, R.H., Tracer experiments and model evaluation at Diablo Canyon Nuclear Power Plant, Proc. of the ANS Topical Meeting on Emergency Response-Planning, Technologies, & Implementation, CONF-880913, Amer. Nuc. Soc., LaGrange, Ill., 1988.

9. Rodriguez, D.J., et al., User's guide to the MATHEW/ADPIC models, UASG82-16, Lawrence Livermore Nat. Lab., Livermore, Calif., 1982.

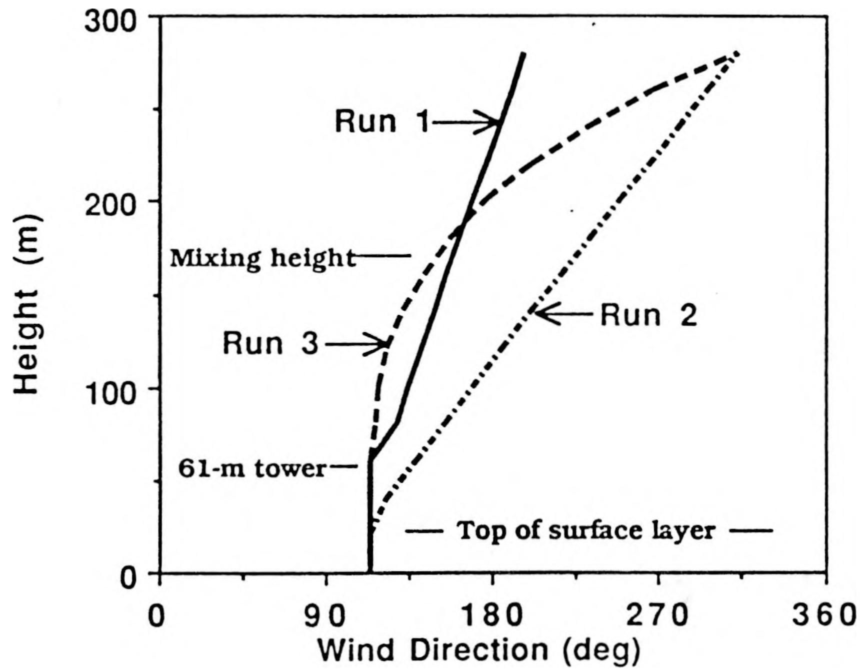

Figure 1. Modeled vertical wind direction profiles at 0500 EDT, April 14, 1988

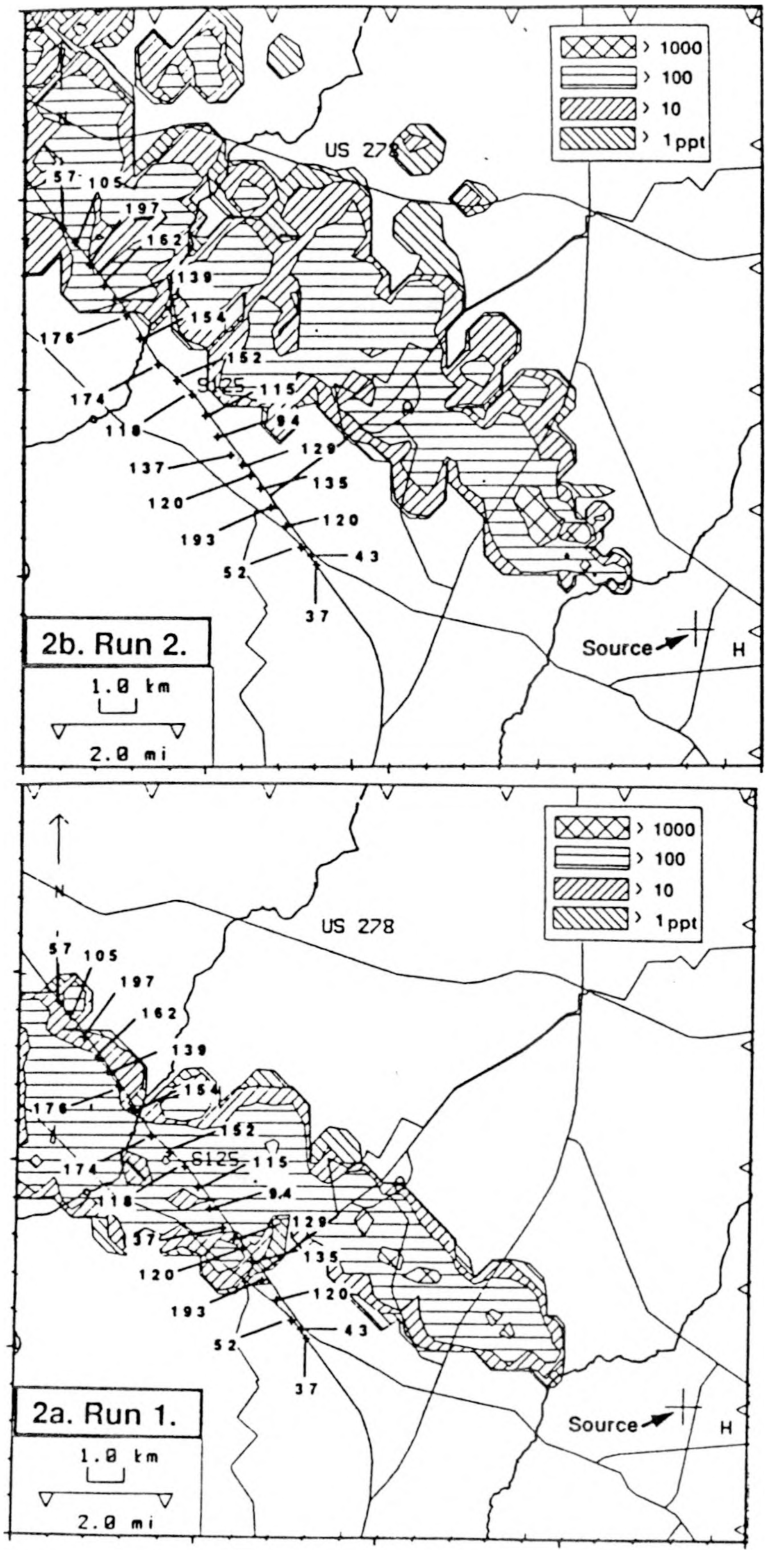

Figure 2. Comparison of model with measurements for Stable 14 Apr 1988 at 0545 EDT.

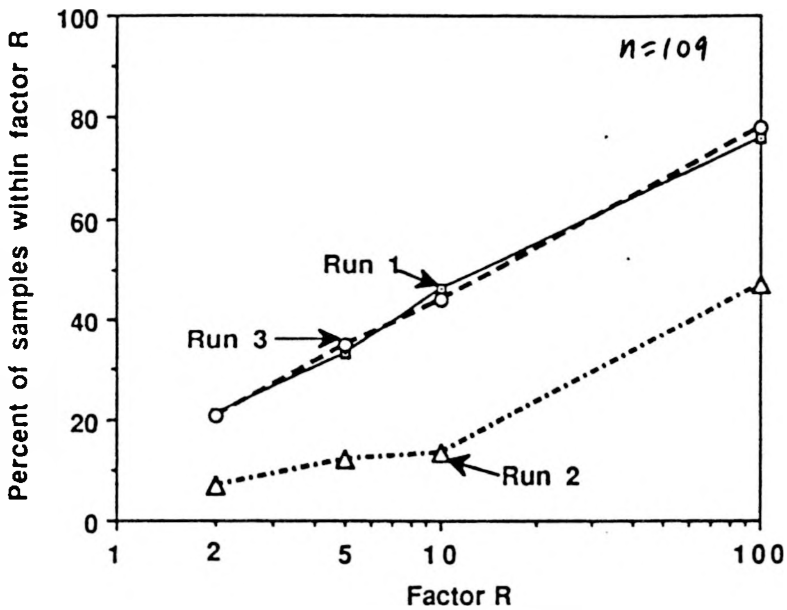

Figure 3. Percent of computed air concentrations within a factor R of measured values for STABLE April 14, 1988.

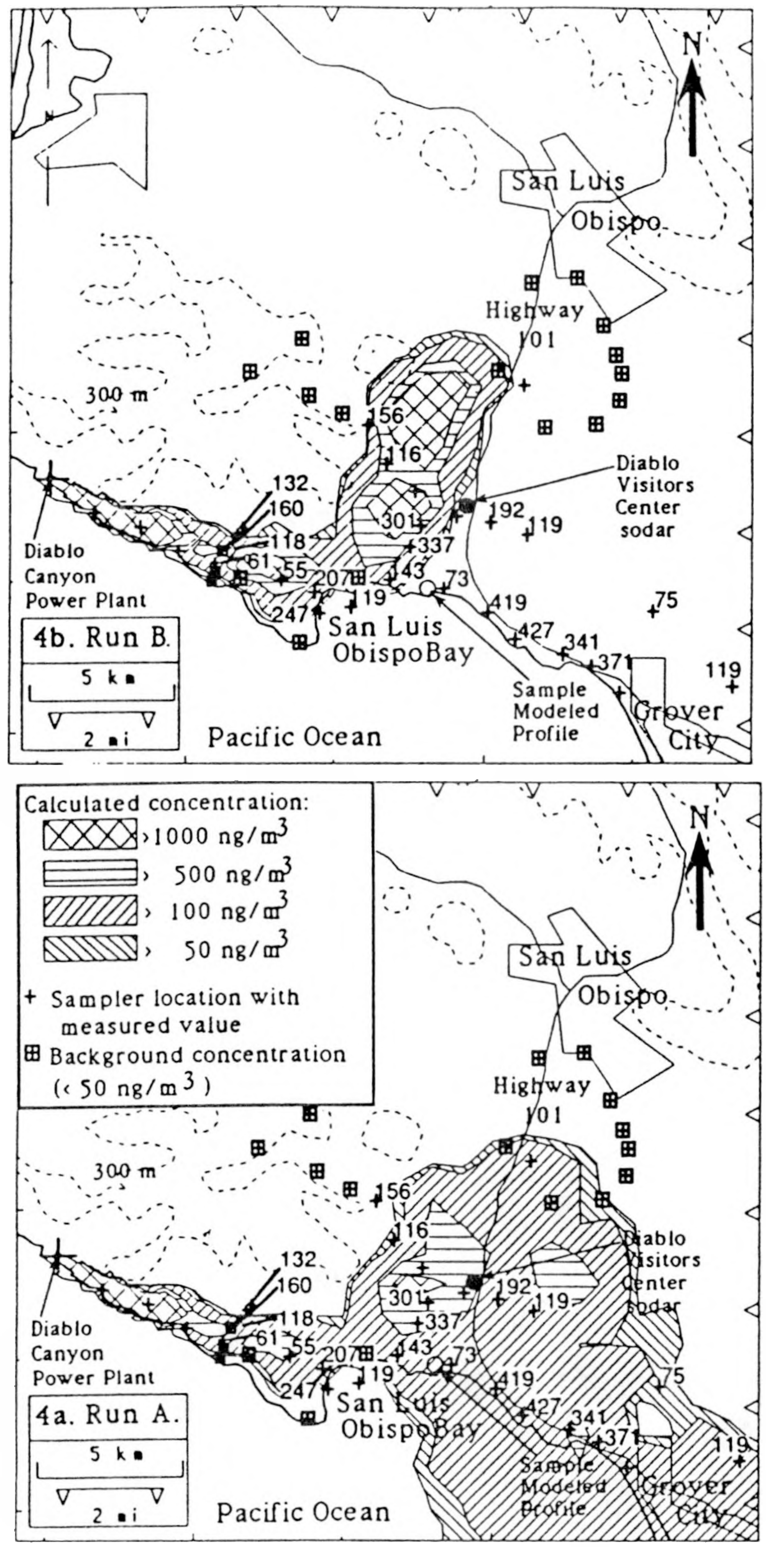

Figure 4. Comparison of measurements with model concentrations for Diablo Study, Aug 31, 1986 at 11-1200 PDT.

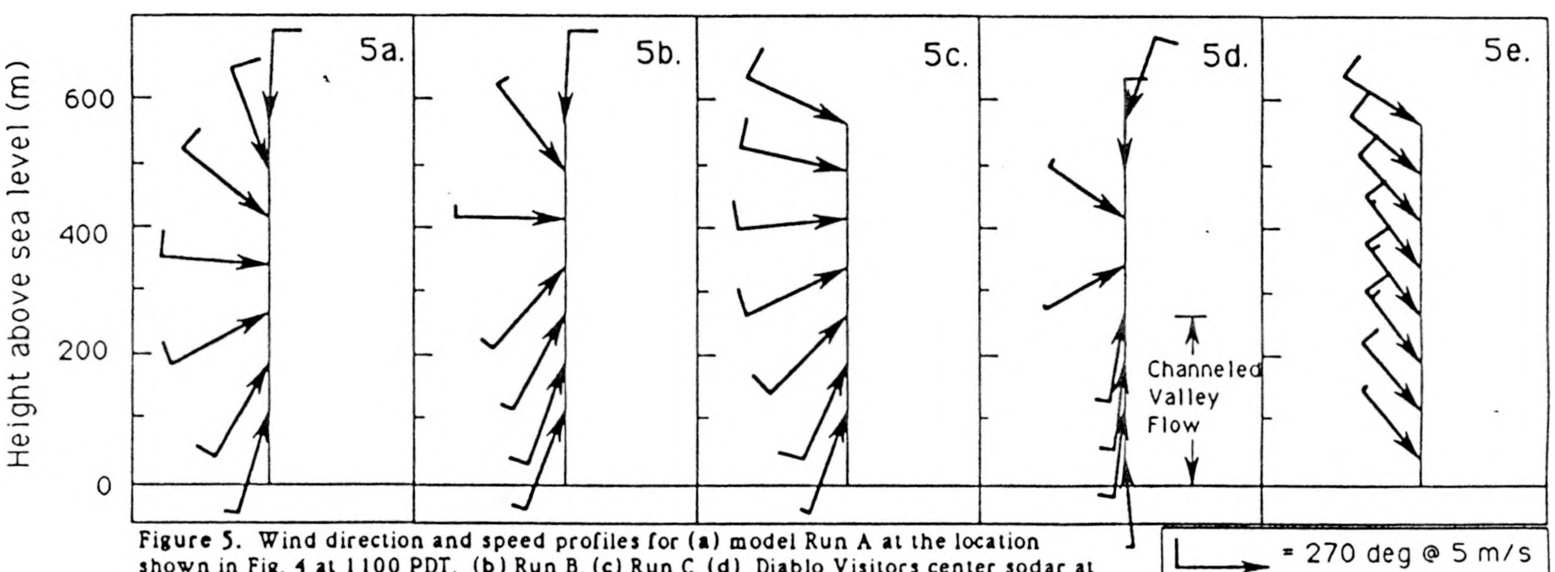

Figure 5. Wind direction and speed profiles for (a) model Run A at the location shown in Fig. 4 at 1100 PDT, (b) Run B, (c) Run C, (d) Diablo Visitors center sodar at 1100 PDT, and (e) measured profile at Vandenberg AFB at 0500 PDT.

~~Data from " Factors/%"~~

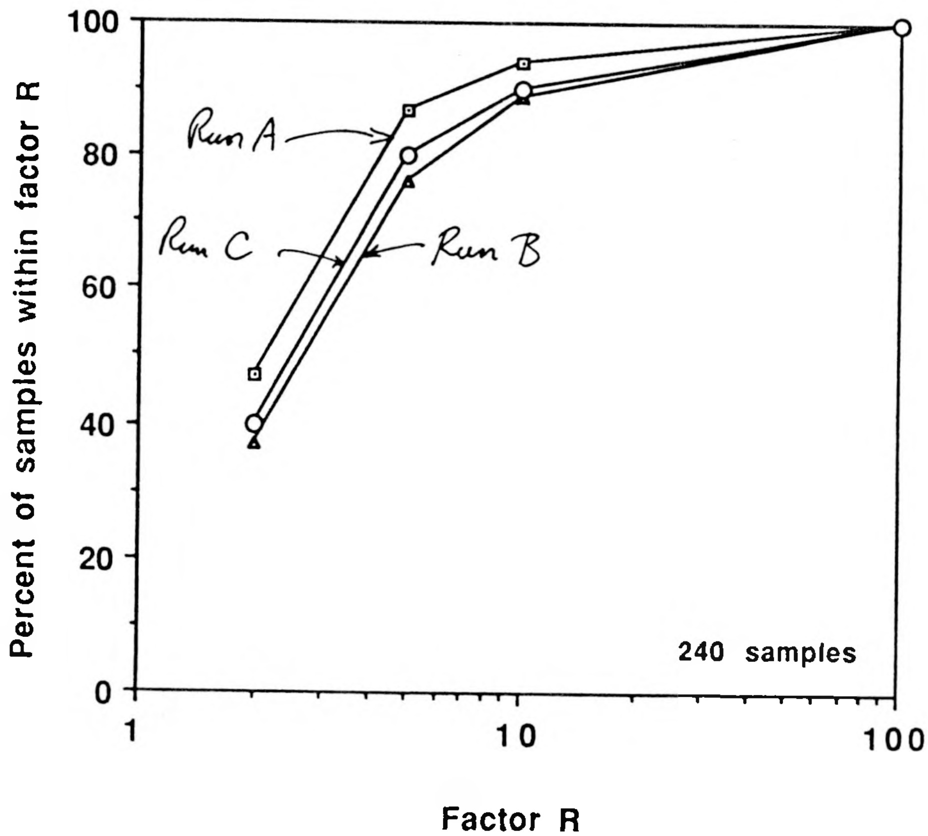

Fig. 6 Percent of computed air concentrations within a factor R of measured values for Diablo Study, Aug 31, 1986