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TITLE: A COMPARISON OF LATERAL AND VERTICAL DIFFUSION IN SEVERAL VALLEYS

AUTHOR(S): S. Barr

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Los Alamos National Laboratory
Los Alamos, New Mexico 87545

A COMPARISON OF LATERAL AND VERTICAL DIFFUSION IN SEVERAL VALLEYS

Sumner Barr
Atmospheric Sciences Group (MS D466)
Los Alamos National Laboratory
Los Alamos, NM 87545

1. INTRODUCTION

Nocturnal tracer experiments at four valley sites demonstrate a cross section of the complicating phenomena attending the transport and diffusion of airborne materials in complex terrain. This paper is a reanalysis of previously published data and it provides an intercomparison of dispersion at the four sites in terms of their topographic structure. Plume models are adopted as a focus of discussion and a point of departure to examine nonplumelike behavior in the tracer data.

Los Alamos Canyon is a small canyon on the laboratory site at Los Alamos, NM. It is oriented west-east with an unobstructed outflow at the east end. It is 60 m deep, 250 m wide, and 20 km long. The side walls are very steep and the floor is wooded with a pine canopy reaching about 25 m above ground. A series of seven nocturnal experiments were conducted in 1976 and 1977 (Archuleta et al., 1978) in which fluorescent particle tracer was released at 1 m above ground and sampled on three cross canyon lines out to 4 km as well as a 30-m tower at 1 km. In another series of tests described by Clements et al. (1980), two releases of SF_6 and one of heavy methane ($^{13}CD_4$) were sampled sequentially at a site on the canyon axis at 6 km from the release point.

Corral Gulch is another small feature located in the Piceance Basin of western Colorado on the oil shale lease tract, C-a. It originates near a 2600-m ridge and flows toward the northeast. A series of four SF_6 experiments were conducted during August 1980 and are described by Clements et al. (1981). Corral Gulch is about 60 m deep, 600 m wide and about 15 km long. It has a smoother cross section than Los Alamos Canyon and a quasi-uniform vegetative cover of 2- to 3-m-high sagebrush. The tracer experiments were supported by a network of six fixed wind and temperature stations and a tethersonde.

Parachute Creek is a 600-m-deep steep-walled valley that drains southward for 20 km from the Roan Plateau to the Colorado River in western Colorado. Wolf et al. describe a series of four nighttime tracer experiments using fluorescent particles. The valley is well-formed and moderately straight for much of its 20-km length. It has a width of 2-3 km. The dimensions and topographic relief are sufficient to generate a nighttime local wind that flows freely into the Colorado River valley. Tracer releases were made at 60 m above local ground level near the head of the valley and a sampling array along the valley axis allowed the estimate of dilution factors out to 20 km from the release point.

Anderson Creek Valley in California, the site of experiments by the U.S. Department of Energy's ASCOT[1] program in 1979 and 1980 has about an 800-m terrain variation from the ridge to the valley outflow. Rather than being a linear valley, Anderson Creek has the character of a bowl approximately 4 km in diameter sloping downward toward the east and north. It merges with Putah Creek Valley, a more linear feature that enters from the northwest. The outflow is not vigorous. The valley floor flattens out to form a broad basin. The cool air that drains from the upper slopes creates a stable cold pool of slowly moving air that grows in depth through the night to 200-300 m. There are at least four major drainage channels in the Anderson Creek experimental area and their interplay produces vertical layering and horizontal meandering in a tracer plume. These factors, as well as a nonuniform vegetative cover, give rise to decidedly inhomogeneous and nonstationary transport conditions during the night. The ASCOT experiments are discussed in detail in collected works of the program participants (Gudiksen, 1979; Dickerson, 1980).

During September 1980 a series of five experiments was conducted. In each experiment, five separate tracer gases were released at different locations to explore the effects of drainage channels, vegetation, and elevation on transport and diffusion. In this paper we will analyze the results of two deuterated methanes, $^{12}CD_4$ and $^{13}CD_4$, abbreviated Me-20 and Me-21, respectively. They were released concurrently at the same geographic location but the Me-20 was released at 60 to 90 m above ground while the Me-21 was a ground-level release. The supporting meteorological data included the NCAR PAM[2] surface network, a 60-m tower, six tethersondes, and radar-tracked tetroons.

2. DISCUSSION OF INDIVIDUAL VALLEYS

2.1 Anderson Creek Valley

The tracer dispersion in Anderson Creek Valley responds to the basin character of the site. There is a systematic drainage wind on the hillsides that accumulates into a pool of cool air in the basin. Outflow from the basin is weak as the pool deepens during the night. Within the cool air there is a tendency toward recirculation and meandering. In such an environment, time integrated concentration would show a wider

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[1] Atmospheric Studies in Complex Terrain

[2] National Center for Atmospheric Research's Portable Automated Meteorological stations

pattern than would be expected for a systematically moving plume. The heavy methane tracers were released at a point on the upper slopes of Anderson Creek Valley more than 600 m above the valley floor. The first kilometer of plume travel was unaffected by stagnation effects and the lateral growth rate is well described by the plume parameterization of Cramer et al. (1964) using meteorological inputs from a tower on the hillside. However, beyond 1 or 2 km, the σ_y values increase rapidly with travel distance as shown in Fig. 1.

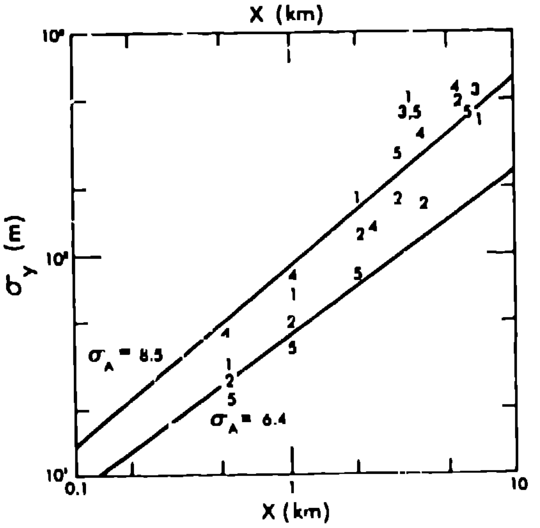

Fig. 1. The lateral standard deviation of the dosage profile for Anderson Creek Valley. The numerals represent the experiment number. The lines are the approximate bounds given by meteorological indicators.

Two additional considerations support the hypothesis of a slowly drifting and meandering tracer cloud in Anderson Creek Valley. One is the cloud passage time at a sequential sampler near the confluence of Anderson and Putah Creeks. The cloud that was released over a 1-h period takes as much as 6 h to clear the sequential sampler. The Me-21 released at ground level has a shorter residence at the sequential sampling site than the Me-20 released above the drainage wind. The Me-21 took 3-4 h to pass while the Me-20 was present for 5-6 h. The other observation is shown in Fig. 2, which depicts the agreement between the tracer plume boundary (for the first experiment (September 16, 1980) and the topographic contour equivalent to the top of the cool air pool as estimated from tethersonde profiles.

Axial dilution factors in Fig. 3 are generally consistent with near neutral dispersion conditions out to about 10 km. This agrees with the general range of turbulent fluctuation data from the tower. The tower's location well above the top of the stagnant cool air would not be expected to represent the meandering within the pool.

Vertical concentration profiles were measured up to 90 m near the confluence of Anderson and Putah creeks, generally near the center of the tracer plumes. Plume depths

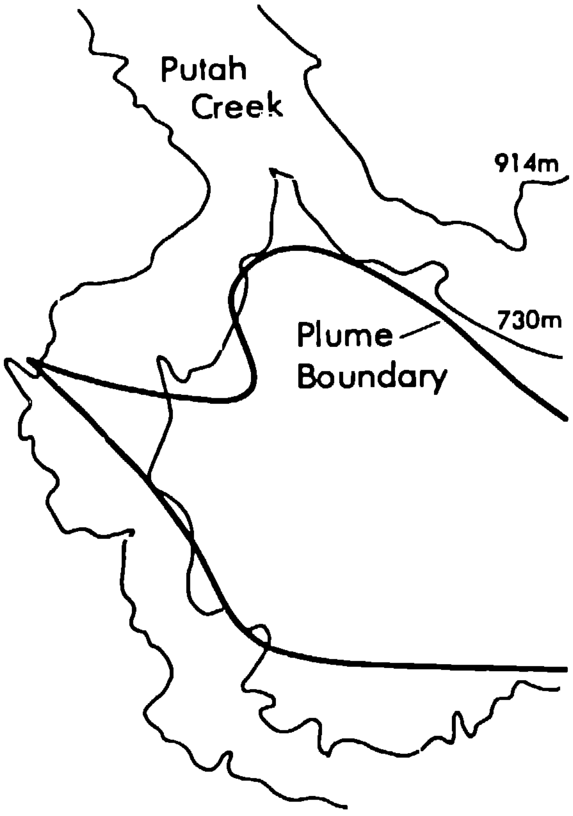

Fig. 2. The plume boundary and selected topographic contours for September 12, 1980. The 730 m contour is the approximate height of the cold pool.

expressed as σ_z values are in the range of near neutral to slightly stable dispersion. A series of estimates of σ_z based on mass conservation using the observed crosswind integrated dosage agrees very well with the measured values (Table 1) except for the second experiment where mass conservation leads to σ_z of 528 m while the observed σ_z is only 81 m. It is possible that the profile missed the center of the plume.

2.2 Parachute Creek

The meteorological data presented by Wolf et al. were sufficient to deduce that the four experiments were conducted under moderately

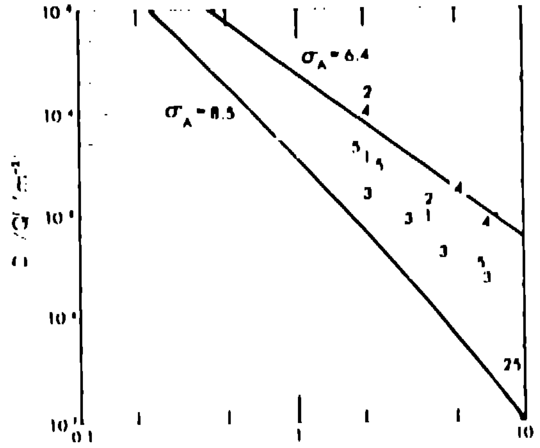

Fig. 3. Dilution Factors for Anderson Creek Valley

TABLE I
PLUME DEPTH PARAMETERS FOR ANDERSON CREEK
$x = 4.8$ km

Experiment	σ_z (CWID)	σ_z (obs)	σ_z (Cramer)	σ_z (P-G)
1	130	107	1100	34
2	528	81	200	34
3	1850	93	-	34
4	63	51	1600	34
5	144	141	110	34

stable conditions. Simply applying the curves from Turner's (1967) Workbook for the E stability class yields a good agreement between 3 and 20 km as shown in Fig. 4. We might ask why such a simple method would be that successful in such a complex topographic setting. The reason could be that the valley is reasonably straight and the local winds brisk and steady. Also the valley is wide enough so that the plume doesn't interact much with the walls until the exit point. Perhaps of more interest is the departure of the close-in samples at 0.3 km from modeled plume behavior. Referring again to the conventional curves we find that turbulence levels equivalent to Pasquill-Gifford category C would explain the higher close-in dosages. Wolf et al. describe a factor of 3 difference in turbulence intensity at the source and at mid-valley with the source values higher. It is quite reasonable to expect the early plume behavior to be described by parameters at the source while later behavior to be better represented by meteorological data from the middle of the valley. The main complication in Parachute Creek indicated by these data would seem to be inhomogeneity, at least between the valley head and the remaining portion of the valley.

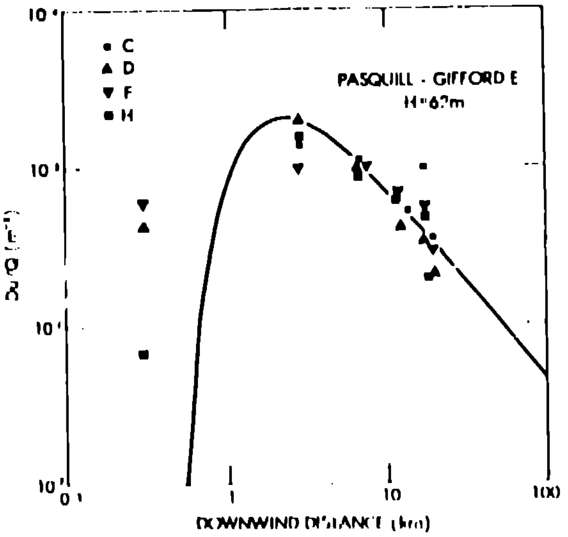

Fig. 4. Dilution Factors for Parachute Creek

2.3 Los Alamos Canyon

Downwind axial dilution factors between 1 and 6 km are reasonably well represented by the 2 m gross turbulence parameter, σ_A measured upwind of the release point. Figure 5 shows predictions using Cramer et al. (1964) compared with the observed dilution factors. The observed values decrease more slowly with travel distance than the model suggests. This doesn't change

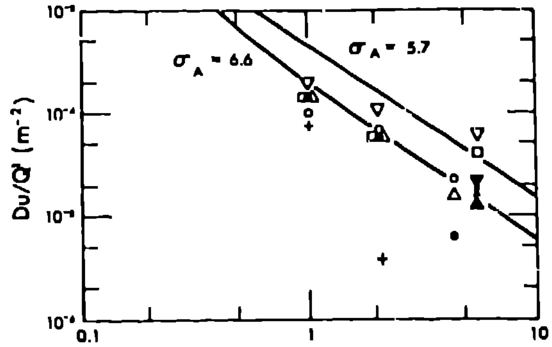

Fig. 5. Dilution Factors for Los Alamos Canyon

when we use Pasquill-Gifford curves. The clue to the relatively slow downwind dilution shows up in Fig. 6, the lateral standard deviation of the plume dosage profile, σ_y. The lateral plume dimension exhibits scatter over a factor of 2 but is essentially independent of travel distance between 1 and 6 km. The limiting σ_y value corresponds to a plume whose full width is the width of the canyon itself. Cross canyon dosage profiles show a mid-canyon peak even at the last line rather than a trend to a uniform profile.

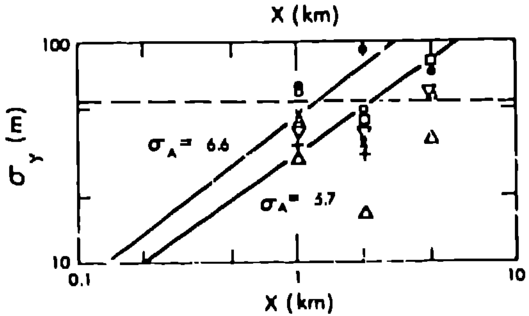

Fig. 6. Downwind σ_y profile for Los Alamos Canyon

Plume depths were estimated at the 1-km-sampling line only since a tower there provided a comparison. The parameter σ_z was estimated from the tower profiles by selecting the height at which one-tenth the maximum dosage occurred and dividing that height by 2.15. The vertical growth required to maintain mass conservancy between the source, Q', and the crosswind integrated dosage (CWID) is given by:

$$\sigma_z = \frac{2}{\pi} \; \frac{Q'}{u\ (\mathrm{CWID})} \qquad (1)$$

Table II shows values for σ_z from the tower, from the CWID and from Cramer et al. using the 2-m meteorological input. Agreement between the mass conservation and meteorological estimation methods is good except for experiment 77-2 for which the meteorological data are likely to be nonrepresentative. The estimates from the tower are systematically lower. It's possible that the 30-m tower was not tall enough to see all the tracer or that the other methods overestimated σ_z. Loss of tracer by deposition or a low mean wind speed could increase the estimated σ_z. The tower position on the canyon axis is seldom far from the ground-level dosage maximum but if the plume tilts with height towards one side of the canyon, the tower could see an abnormally shallow plume. There is not enough data to resolve the difference at this point.

TABLE II
PLUME DEPTH PARAMETERS FOR LOS ALAMOS CANYON
x = 1

Experiment	σ_z(m) (CWID)	[illegible]) T[illegible]	σ_z(m) Model
77-1	29	13	30
2	42	15	120
3	32	18	25
10	37	15	25
11	20	15	25

2.4 Corral Gulch

The tracer results from this series of experiments are discussed in detail by Barr et al. (1982) and will only be summarized here. Plume parameters σ_y and σ_z exhibit slightly greater diffusion than would be indicated by simple stability-based prediction methods or the gross turbulence indicators. The lateral coefficient, σ_y (Fig. 7) appears to diminish slightly between 3 and 6 km. Two terrain-related mechanisms contribute to the development of the plume. A meandering component immediately downwind of the confluence of two branches of the gulch gives the appearance of an abnormally wide-time integrated plume. Further downstream the mean wind direction stabilizes and the plume dimension reflects diffusive spread due to small-scale turbulence. A weak but persistent inflow of cool air down the sides of the gulch provides a convergence mechanism resisting lateral spread and promoting vertical expansion. Vertical plume parameters were estimated from mass balance considerations and the crosswind integrated dosage and are given in Table III.

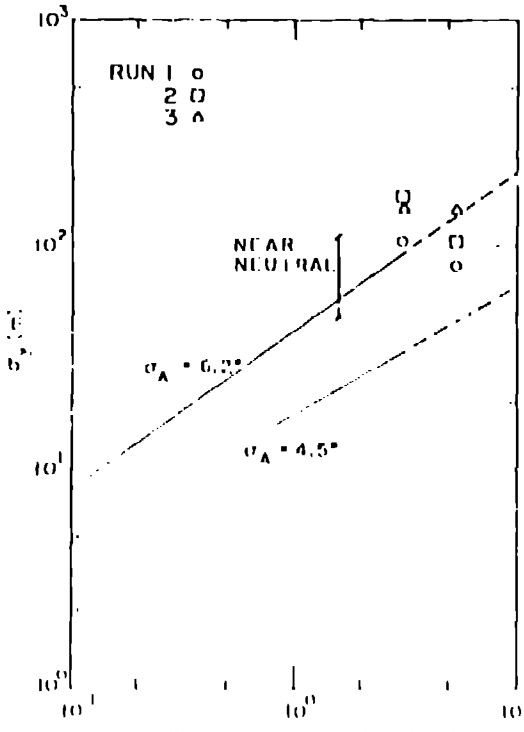

Fig. 7. Downwind σ_y profile for Corral Gulch

TABLE III
PLUME DEPTH PARAMETERS FOR CORRAL GULCH

Experiment	3 km σ_z (CWID)	6 km σ_z (CWID)
1	90	180
2	100	175
3	100	130

3. SUMMARY AND CONCLUSIONS

We have examined the turbulent dispersion of tracers in four valleys. Two are reasonably large with greater than 600-m terrain relief and two are well-formed but are shallow and narrow. Both Anderson Creek, California and Parachute Creek, Colorado are large and deep enough to produce a systematic cool air drainage wind regime although the difference in valley shapes makes the structure of that wind field quite different. Parachute Creek is a deep linear valley in which a vigorous down-valley flow develops and exits at the mouth without significant obstruction. Throughout most of the valley the dispersion in Parachute follows the conventional prescription using either radiation-windspeed or σ_A predictors, although the head of the valley has higher turbulence levels. Anderson Creek is a three-dimensional bowl with a very flat outflow region from which the cool air backs up to form a quasi-stagnant pool 200-300 m deep. Inhomogeneous turbulence is a major factor in the transport history of tracers in Anderson Creek. In the slope-wind portion of the basin the plume growth is systematic and about 1.5 to 2 Pasquill-Gifford categories more vigorous than estimated by radiation and windspeed. However σ_A is a good predictor, at least in the ensemble as long as it is observed in the same downslope regime. The slower mean wind and greater meandering that the plume encounters in the cool air pool makes a distinct change in the tracer cloud behavior. Residence times are long and the apparent width of a time integrated plume is much greater than predicted by plume model considerations.

The two small-scale terrain features, Corral Gulch and Los Alamos Canyon, tend to channel the wind generated locally on the next larger scale but produce only weak, shallow slope-wind characteristics themselves. The gross diffusion is more vigorous by about one Pasquill-Gifford category than indicated by the radiation-windspeed system and is consistent with measured σ_A values. Both valleys tend to constrain the lateral spread of tracer. Vertical growth estimates suggest that plumes can grow above the height of the valley walls. It is reasonable to expect that material thus exhaled by a valley is distributed in the surrounding area including adjacent valleys.

On any scale, a confluence zone of adjoining branches creates horizontal meandering and vertical stratifications of tracer and clear air.

4. RECOMMENDATIONS

Tracer experiments or plume monitoring in valley environments encounter a number of complications not expected in flat topography. Shallow slope wind domains, horizontal inhomogeneities and temporal development all contribute to the need to select very carefully the input meteorological data to any transport and diffusion estimation method. Valleys often simplify sampling networks by defining an axis of mean transport but it is advisable to design several crosswind sampling lines and a vertical sampling capability into the network. Also, each line should have a time resolving sampler (continuous or sequential) in order to discern variations in transport speed. If constrained area access makes crosswind arcs impossible, a uniform distribution of samplers is quite interpretable. This was done in Anderson Creek valley. Meteorological support should include an adequate network of surface based sensors to distinguish the important inhomogeneities and should include vertical information through a layer at least as deep as the plume. Gross turbulence parameters such as σ_A seem to characterize some of the important processes that complicate valley environments.

In view of the ease of measuring gross turbulence with modern instrumentation, these parameters should be a routine requirement in a sampling program. Since σ_A is a function of the sampling duration, that time (e.g. 10 min, 60 min) should always be reported along with the σ_A values.

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