CHAPTER IV

TRANSPORT AND DIFFUSION OF AIRBORNE EFFLUENTS IN A VALLEY

4.1 OVERVIEW OF THE ASCOT-84 BRUSH CREEK EXPERIMENTS

The Atmospheric Studies in Complex Terrain (ASCOT) program was initiated in 1978 by the U. S. Department of Energy. The ASCOT program was designed to develop the technology needed to assess atmospheric properties and the impact of energy sources on air quality in areas of complex terrain. Major ASCOT field studies have been conducted during July 1979, September 1980, August 1981, July-August 1982 and September-October 1984.

The Brush Creek Valley (39°34' N, 108°26' W; Figure 4.1) is located approximately 50 km north of Grand Junction, Colorado. This valley drains into Roan Creek, which subsequently drains into the Colorado River Valley. Brush Creek is about 25 km long from its headwaters to its merger with Roan Creek. The valley floor has a gentle slope of 1.5 degrees in the ASCOT study area. The width of the valley floor gradually increases from about 300 m at mid-valley to about 700 m near its mouth. A large portion of the valley is about 600 m deep, and it has steep (35 to 40 degrees) sidewalls cut by numerous small tributaries. The valley-axis is oriented from northwest to southeast.

The 1984 ASCOT field study in Brush Creek was mainly intended to investigate the characteristics of the nocturnal and morning
Fig. 4.1 Simplified topography around the Brush Creek study area. Grand Junction is located in the lower left-hand corner.
transition wind, turbulence, and temperature fields in the valley, in its tributaries, and on its side-slopes, and how these are affected by the free stream conditions above the valley. Clements et al. (1989) give experimental design and objectives of the ASCOT-1984 Brush Creek valley study.

To enhance the understanding of pollutant transport and dispersion associated with valley flows, following technical objectives are designed.

i) Evaluation of mass, momentum, and energy fluxes along the valley axis, and of slope flows.

ii) Evaluation of transfer of mass, momentum, and energy between the valley and the free airstream above the valley.

iii) Evaluation of turbulence.

iv) Evaluation of the radiative energy exchange at the surface.

v) Evaluation of the wind and temperature structure over the region surrounding the Brush Creek Valley.

vi) Evaluation of dispersion processes through the release and sampling of tracers.

The objectives of the ASCOT program resulted in the selection and deployment of meteorological instruments and atmospheric tracers to investigate: wind, temperature, and turbulence on the sidewalls, in tributaries, and along the valley axis; winds on the mesa tops, and in a 200 km square region surrounding the study area; surface energy budget components at representative locations on the valley floor, on the sidewalls, and on a flat area of one of the bounding ridges (Skinner Ridge).
The experimental period extended from September 17 to October 7, 1984. Table 4.1 gives a list of the various types of instruments used for this study. The data were collected continuously for a few parameters throughout the entire period. Six nights (Table 4.2) were selected for intensive measurements when the conditions seemed right for good nocturnal drainage flows to occur. On these nights all instruments were operated from 2300 MST (Mountain Standard Time) to 1100 MST the next morning in order to study the drainage flow and daytime transition to upvalley flow. Atmospheric tracers were released from 2400 to 0900 MST on nights 1 through 5.

The tethered instrumented balloons measured wind speed, wind direction, temperature, wet-bulb temperature and pressure-altitude. The data were collected only during the slow ascent of the balloon up to a maximum of about 800 m above the site. Each ascent lasted for about 45 min. There were eight ascents, spaced 90 min. apart, on each experimental night, with the first ascent starting at 2330 MST and the final one at 1000 MST the following morning.

The Doppler acoustic sounders (sodars) were operated using 15 min. sequential averaging periods, and were programmed to average vertically over 30 m layers beginning 45 m and ending at 615 m above the surface at each site. All the sodars within the main valley measured the following quantities: horizontal wind speed and direction, standard deviation of the horizontal wind direction and standard deviation of the vertical wind speed.
### Table 4.1
Instruments used in ASCOT 84 Field Study.

<table>
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<tr>
<th>Instrument</th>
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<td>Vertical Turbulence Profiler</td>
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ASCOT 1984 Experimental Nights.

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<td>17 - 18 Sept.</td>
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<tr>
<td>1</td>
<td>19 - 20 Sept.</td>
</tr>
<tr>
<td>2#</td>
<td>25 - 26 Sept.</td>
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<tr>
<td>3</td>
<td>27 - 28 Sept.</td>
</tr>
<tr>
<td>4#</td>
<td>29 - 30 Sept.</td>
</tr>
<tr>
<td>5</td>
<td>5 - 6 Oct.</td>
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</tbody>
</table>

* No tracer release

# Experiments used for the present analysis
A turbulence profiler package attached to a tethered balloon measured instantaneous values of the u,v,w wind components, temperature, humidity, pressure, and the vertical velocity and temperature gradients. Turbulence data were collected at selected heights above the valley floor to a height of 500 m on all the experimental nights. Turbulence data near ground were also collected with a sonic anemometer mounted on a short tripod.

The deployment of instrumented towers along several cross-valley lines and sidewall locations provided various meteorological data and turbulence measurements for evaluating slope flows, valley flows, and turbulence parameters in the Brush Creek.

The optical anemometer paths were set up within the valley and on the ridges to characterize the valley, tributary and mesoscale flows. The optical anemometers measure the wind speed component perpendicular to the path, averaged with an optical-weighting function over the total length of the path. Ten minute averaged data of the cross-path wind speeds were collected continuously during all experiments.

Oil fog and three gaseous perfluorocarbon tracers were used to study transport and diffusion processes. The oil fog was generated on the mesa top overlooking Pack Canyon to evaluate the pollutant transport and diffusion associated with nocturnal entrainment of air from the mesa top into a tributary, and subsequent merging of the tributary flows with the main valley.
evaluate the following:

a) transport and diffusion within the nocturnal valley flows and the transition layer above the nocturnal jet,
b) the extent of mixing between the transition layer and the underlying valley flows,
c) the merging of tributary slope flows with the nocturnal valley flows,
d) the spillover of tracers into adjacent valleys during nocturnal and morning transition periods, and
e) the rate of ventilation of the tracers out of the valley during the morning transition period.

The experiments involved simultaneous releases of three highly detectable perfluorocarbon tracers. The tracers were perfluoromethylcyclopentane (PMCP or PP1/2), perfluoromethylecyclohexane (PMCH or PP2) and perfluorodimethylcyclohexane (PDCH or PP3). These tracers have very low levels of ambient background concentrations.

Two locations were utilized for tracer releases. One site (723.14 km UTME, 4362.03 km UTMN; 2399 m MSL) was on top of Skinner Ridge along the northeast edge of Brush Creek Valley; oil fog and PP1/2 tracer were released from this site. The second release site (719.06 km UTME, 4383.92 km UTMN; 1926 m MSL) was at the bottom of Brush Creek Valley. PP2 and PP3 were released at this location; PP2 near ground level, and PP3 aloft, from a balloon-borne source tube. Due to difficulties with the balloons during the first three experiments, the actual release heights
varied from their intended heights. Table 4.3 gives the information on tracer releases.

A surface sampling network consisted of 60 BATS (Brookhaven Atmospheric Tracer Sampler) units and 30 ARL (Air Resources Laboratory) sampling units to provide the required spatial resolution. A good number of samplers were placed within Brush Creek Valley, primarily along the three major cross-valley arcs shown in Figure 4.2. The sample collection times varied from 15 to 60 min. Vertical concentration profiles were also measured at 11 sites. These detailed tracer measurements provide a valuable data set for developing and testing models for pollutant transport and dispersion in valleys. Tracer concentrations were given as the volume of tracer per volume of air, and were expressed relative to NTP (293°K and 1 atm.). The units of concentrations were either pico-liters (10^{-12} \text{ l}) of tracer per liter of air (\text{pIl/l}), or femto-liters (10^{-15} \text{ l}) per liter (\text{fl/l}).

In the following section of this chapter, valley meteorology will be discussed utilizing the observed meteorological data from ASCOT-84 experiments in Brush Creek Valley. Last section deals with atmospheric tracer dispersion in a deep valley which will be described from observed tracer distribution in the valley. The meteorological and observed tracer data from two experimental days has been used in the present analyses. This data in raw form was made available by the Atmospheric Turbulence and Diffusion Laboratory, Oak Ridge, U.S.A. from their data archive for the present study.
**Table 4.3**

Tracer Experiments in Brush Creek Valley (ASCOT 1984)

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<tr>
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<th>Total release (g)</th>
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<th>Release rate (g/s)</th>
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</table>

* Tracer releases selected for simulation with VALPUFF model

@ Experiments selected for tracer data analysis

PDCH (PP3) Perfluorodimethylcyclohexane

PMCH (PP2) Perfluoromethylcyclohexane
4.2 VALLEY METEOROLOGY

The axial down-valley drainage wind (discussed in Chapter 2) is the result of an accumulation of slope flows created by cooling of the air in contact with cooling ground surface on the whole spectrum of slopes that make up the airshed of the valley. The intensity of the along-valley flow depends on the increase of temperature from the headwater to the outlet end of the valley. It was demonstrated, for example, by Kyle (1987), and McKee and O'Neal (1989), that the temperature gradient along the valley depends in part on radiative cooling of valley air, which in turn depends on the ratio of horizontal area at the top of the valley to the included volume. The along-valley variation of this area-to-volume ratio is a function of the valley topography, and in the case of Brush Creek favors a rigorous drainage.

A transition layer separates the valley drainage layer from freestream flow. The base height of the transition layer or, in other words, the drainage layer depth is identified as the height where the wind speed decreases to a minimum and, simultaneously, the wind direction changes by more than 50% of the difference between the down-valley direction and ridgetop wind direction. One of the main topographic features of a valley that relates to the variation of the transition height is the openness - the ratio of valley width to depth. A valley with a large openness ratio is more susceptible to external influences and has a shallower drainage than a valley with a small openness ratio (Petkovsek, 1978, 1980). For example, the openness ratio of Brush Creek Valley near the ridge top is 6.4 (4600 m / 719 m).
The general weather conditions favorable for valley drainage winds consist of clear skies, low humidities and light (\(<5 \text{ m/s})\) ambient winds. The effect of cloudiness and weather on the drainage transition layer has not been investigated extensively, but depends upon the cloud cover, cloud types, cloud height above the ground, and precipitation. These factors influence the transition layer through their accumulative effect on the outgoing (longwave) radiation, which is a function of surface and air (cloud) temperature; emissivity, and clouds also affect the transition layer (Miller, 1981).

The field experiments conducted on September 25-26 (Experiment 2) and September 29-30 (Experiment 4) are chosen for the present analyses. There were two simultaneous tracer releases on these experimental nights. The general weather conditions and flow characteristics on all the five experimental nights were discussed by Gudiksen and Shearer (1989). During Experiment 4 (Sept. 29-30), the winds above the valley were light and from the southeast, and the sky was clear. Experiment 2 (Sept. 25-26) was conducted under southeasterly to southwesterly winds aloft that varied in intensity from 2 to 10 m/s; clear skies prevailed initially, but high cirrus appeared during the morning transition period. These conditions overall could lead to development of drainage flows on both Experiment 2 and Experiment 4.

In Brush Creek area, the ambient wind field varies in response to a number of driving forces typical of mountainous terrain, such as synoptic pressure gradients (modulated by the
topographic setting), and thermally driven regional-scale circulations of western slope of the Rocky Mountains (Barr and Orgill, 1989).

In the following sections are presented discussion of the observed wind and temperature structure in the nocturnal drainage flows for the two experiments from two meteorological monitoring sites. One site, WPL (718.910 UTME, 4384.070 UTMN; 1930 m ASL) is located very close to the perfluorocarbon tracers release point in the valley, and the second site, PNL-Valley (723.552 UTME, 4378.609 UTMN; 1798 m ASL) is located near the mouth of the Brush Creek Valley. Dobosy et al (1989) and King (1987) examined the suitability of single-profile measurements for estimating the mass and momentum fluxes by comparing them with the corresponding results derived from Doppler lidar data. They concluded that the single-profilers like tethersondes would be adequate to characterize the drainage layer to a fairly good degree. Temperature and wind data from tethersonde profiles was used for this discussion. There were seven flights simultaneously from all tethersonde sites on each experimental night. The interest is restricted to the structure of the drainage layer (the base of the transition layer) because tethered balloon observations did not extend through the full extent of the transition layer.
4.2.1 OBSERVED STRUCTURE OF DRAINAGE FLOW

Temperature Profile:

The temperature profiles at WPL and PNL-Valley sites during Experiment 2 (25-26, Sept. 1984) and Experiment 4 (29-30, Sept. 1984) presented in Figure 4.3 and Figure 4.4 respectively. The temperature profiles, depicted for different periods, are characterized by strong surface-based inversion layers of 200 m AGL or more, topped by a near-isothermal region extending to above the ridgetop for nocturnal periods (0100, 0400, and 0700 MST). Whereas, transition periods (0830, and 1000 MST) are characterized by lapse conditions at lower levels indicating a gradual disruption of nocturnal valley flows. Since the temperature near the top of the drainage layer often approaches the ambient temperature rather slowly, it may be impossible to determine the exact depth of the inversion.

Clements et al (1989) define the surface inversion strength as

\[ SIS = \frac{(T_i - T_S)}{z_i} \]

where \( z_i \) is the height above ground where the temperature gradient becomes less than 0.01 °K/m, \( T_i \) is the temperature at \( z_i \), and \( T_S \) is the air temperature in the lowest 10 m. The calculated SIS ranged from 0.022 to 0.028 °K/m and 0.020 to 0.026 °K/m at WPL site for Experiment 2 and Experiment 4 respectively. The inversion layer at the WPL site extended on the average upto 62% of the ridge height (≈510 m AGL) during the Experiment 2 and about 81% of the ridge height during the Experiment 4. Similarly,
Fig. 4.3 Temperature profiles at different periods in the Brush Creek Valley, ASCOT-1984.
(a) WPL site, 09/26/84; (b) PNL-Valley site, 09/26/84;

Fig. 4.4 Temperature profiles at different periods in the Brush Creek Valley, ASCOT-1984.
(a) WPL site, 09/30/84; (b) PNL-Valley site, 09/30/84
at the PNL-Valley site, the SIS ranges are 0.019 to 0.033 K/m and 0.021 to 0.026 K/m respectively for Experiment 2 and Experiment 4. The mean thickness of the inversion layers are respectively 65% and 80% of the ridge crest height (~ 640 m AGL) at this PNL-Valley site during the Experiment 2 and Experiment 4. The increase in inversion height at the PNL site, located close to the valley mouth where Brush Creek merges with Roan Creek, is likely the effect of the Roan Creek drainage on Brush Creek - a partial pooling or blocking effect (Barr and Orgill, 1989).

Increasing potential temperatures are observed on both the nights throughout the depth of the valley; hence, although the strong inversions occur only in the lower levels of the Brush Creek valley, the entire depth of the valley atmosphere is stable.

*Wind Profile:*

The wind profiles at WPL and PNL-Valley sites for Experiment 2 and Experiment 4 are shown in Figures 4.5 and 4.6 respectively. The nocturnal down-valley flow that is evident from wind profiles is driven by local cooling apparent in the temperature profiles. The wind within the cooled inversion layer is essentially downslope during nocturnal periods in the Brush Creek Valley. Above this inversion layer the buoyancy force, proportional to the potential temperature difference between the valley air and the freestream air, decreases rapidly and so does the drainage wind speed. Near the top of the drainage layer, the wind direction begins to rotate to the direction of the higher-level ambient winds.
Fig. 4.5 Wind profiles at different periods in the Brush Creek Valley, ASCOT-1984.
(a) WPL site, 09/26/84; (b) PNL-Valley site, 09/26/84

Fig. 4.6 Wind profiles at different periods in the Brush Creek Valley, ASCOT-1984.
(a) WPL site, 09/30/84; (b) PNL-Valley site, 09/30/84
ASCOT–84, WPL, 09/30/84

WIND SPEED (m/s)

--- Fig 4---

--- Fig 4---
A low-level jet was observed on both the experimental nights with its core located few tens of meters AGL. The wind direction within the nocturnal drainage layer was essentially down-valley. The low-level wind maxima recorded at WPL station varied between 5 m/s and 6.5 m/s with a mean value of 6 m/s for Experiment 2, while the ranges were 4 - 6 m/s and the mean was 5 m/s at PNL-Valley site for the same day. The speed of the low-level jet at WPL site varied from 5.5 m/s to 7.5 m/s and the mean value being 6.7 m/s, whereas the PNL-Valley tethersonde recorded the jet speeds ranging between 4 m/s and 5.5 m/s with a mean wind speed of about 4.7 m/s for Experiment 4. The mean ratio of the low-level jet height to the temperature inversion height is 0.26 at WPL site and 0.17 at the PNL-valley site during Experiment 2. The ratios are 0.17 and 0.21 respectively at WPL and PNL-valley sites during Experiment 4. Though the drainage layer is extended to higher levels at PNL site lesser wind speeds in the low-level jet might be attributed to interference of Roan Creek valley flows with the Brush Creek drainage at the lower reaches.

Depth of Drainage Flow:

The depth of drainage flow is needed in estimating the fluxes of mass, momentum, energy or pollutant carried by the flow. From the preceding discussion of the wind and temperature profiles it is apparent that there are several ways to define the depth of the katabatic flow, depending on what feature of the flow is to be described. Simple models of drainage winds (Ellison and Turner, 1959; Manins and Sawford, 1979a; Fitzjarrald, 1984) treat the flow
as a single layer with homogeneous properties of wind and temperature.

The depth of the surface inversion, or the height at which the temperature equals the ambient temperature, defines the height at which the buoyancy force equals zero. This may be difficult to determine precisely if the temperature near the top of the inversion approaches the ambient temperature asymptotically as in the case of Brush Creek drainage flow. The height of a shift in wind direction from the downslope direction and height of a minimum in the wind speed above the low-level jet are also useful indicators of the extent of katabatic influence. A fourth depth for the slope flow is the vertical extent of turbulence mixing. This is commonly recorded from sodar backscatter records, but the depth of slope flows may be comparable to or below the minimum sodar detection height (for example, Horst and Doran, 1986).

The above mentioned depth scales depend on selecting the height of a characteristic feature of the wind or temperature profile. In contrast, models that treat the katabatic flow as a single layer define integral scales by predicting vertically-averaged properties such as

\[
U_H = \frac{h}{\int u \, dn} \quad \text{and} \quad U^2 H = \frac{h}{\int u^2 \, dn}
\]

(Ellison and Turner, 1959; Manins and Sawford, 1978a) based on mass and momentum conservation principles. Here \(U\) and \(H\) are
integral wind speed and height scales, respectively, and h is a height above the influence of the katabatic flow, where the ambient wind is assumed to be zero. Although the momentum depth H has the advantage of not depending on the selection of a single characteristic point of the wind or temperature profile, its interpretation is often uncertain because the ambient wind is seldom light enough to neglect its contribution to the integrals.

Here, the validity of the above simple model is tested by estimating the integral height at WPL and PNL-valley sites on both the nights. The mean integral drainage depth is about 70% of the temperature inversion height at WPL site on both the experimental nights. Whereas, the estimated depth is about 75% of the temperature inversion height at PNL-valley site.

Ridge top wind speed has been playing considerable role in restricting the extent of the drainage layer. Higher intensity ridgetop winds led to shallow drainage layer depths and vice versa. Drainage layer could fill only about 65% of the valley depth (valley bottom to ridgetop height) at both the tethersonde sites on the Sept. 26 when the ridgetop winds are moderately high (4 m/s and above). On the other hand, 80% of the valley was filled with drainage flow on the Sept. 30 when the ridgetop winds were of low intensity (< 3 m/s).

Turbulence:

It has been established that the fluctuations of horizontal and vertical wind direction would give a measure of the turbulence
intensity. Rao and Schaub (1989) studied the variations of horizontal and vertical wind fluctuations ($\sigma_\theta$ and $\sigma_\phi$) in the Brush Creek drainage flow (including morning transition periods). Mean wind and turbulence measurements from Doppler acoustic sodars and instrumented towers in the study region were used in the analysis.

Figures 4.7 and 4.8 show the temporal variation of $\sigma_\theta$ and $\sigma_\phi$ from tower and sodar data respectively. The temporal variation of hourly-averaged sigmas derived from sodar data and the tower data show good agreement, though the sodar data would probably be more characteristic of tracer dispersion from an elevated source, while the tower data would better represent dispersion from a surface release (Rao et al., 1989). The observed hourly average sigma theta and sigma phi in the nocturnal drainage flow are about $20^\circ$ to $25^\circ$ and $5^\circ$, respectively; these values are much larger than those generally observed over flat terrain during nighttime stable conditions. After sunrise, as the valley warms and the flow direction changes to up-valley, these parameters increase sharply to their peak values at about 0800 MST and then decrease to their normal daytime values after about two hours.

Rao and Schaub also found that in the drainage flow, the hourly average $r_\theta$ varies inversely with wind speed according to the relation $\sigma_\theta u \sim 0.7$ m/s. The vertical standard deviation ($\sigma_\phi$) is much less enhanced by complex terrain than the horizontal standard deviation ($\sigma_\theta$).
Sodar Data Sept. 25–26, 1984

Time (hours MST)

\( \sigma_\theta \) (deg)

- LANL
- ANL
- PNL
Tower Data Sept. 25-26, 1984

\[ \sigma_\theta \text{ (deg)} \]

- LANL
- WPL-V
- WPL-M
- LLNL

Time (hours MST)

23 00 01 02 03 04 05 06 07 08 09 10
Sodar Data Sept. 25-26, 1984

Time (hours MST)

\[ \sigma_\phi \text{ (deg)} \]

- LANL
- ANL
- PNL
4.3 TRANSPORT AND DIFFUSION

Field experiments conducted in September 1984 included a series of tracer releases. The principal objectives of these studies are envisaged in section 1 of this chapter.

The study involved two simultaneous tracer releases from the same location, one at ground level and the other at higher levels, on each experimental nights. In the present analyses, tracer releases conducted on Sept. 26 (Experiment # 2) and Sept. 30, 1984 (Experiment # 4) are considered. The tracer release point (719.06 UTME, 4383.92 UTMN, 1926 m ASL) was located approximately 11 km up Brush Creek Valley from its confluence with Roan Creek Valley. Analyses from ground release (PP2 tracer) of Experiment 2 and elevated release (PP3 tracer) of Experiment 4 are discussed and described here.

To illustrate the general characteristics of the tracer distribution in the valley, it was convenient to select one cross-valley cross-section and one along-valley cross-section. So, the tracer analysis is mainly made from the samplers along the valley axis, and also from the samplers located on an arc approximately 8 km down-valley of the tracer release point. This arc is referred to as the first arc (refer to Figure 4.2). Of the eleven vertical samplers three were near the first arc; these three samplers provided tracer concentrations averaged over very short periods in different layers above the ground. Surface level samplers provided tracer concentrations averaged over periods of 15 min. or more. The concentrations are expressed in picoliter/liter units.
Observed tracer concentration patterns are found by drawing concentration isopleths across the first arc and along the valley-axis utilizing the vertical soundings of concentrations and the time-averaged surface values. Isopleths are drawn for the periods for which vertical samplers were also active (0100 MST, 0230 MST, 0400 MST, 0530 MST, 0700 MST, 0830 MST, and 1000 MST).

Tracer concentration isopleths for the first arc are presented with UTME (km) along the X-axis, and elevation (km ASL) along the Y-axis. The Y-axis scale is exaggerated by a factor of 1.6. UTMN (km) is along the X-axis for the valley-axis plots with the origin at 4385 km and decreasing to the right, and the Y-axis scale is exaggerated by a factor of 7.5. Observed tracer concentrations at different sampling points are shown on the diagrams. Iso-concentration lines are plotted in thick solid lines and the boundaries of the valley sides and valley bottom are represented by a thin line.

4.3.1 Results and Discussion

(a) GROUND RELEASE (PP2 tracer, Experiment 2, September 26):

The PP2 (PMCH) tracer was released at ground (5 m) level during the Experiment 2. The average release rate was 0.22 g/s for this tracer and release period was from 0000 MST to 0800 MST. Tracer concentration distribution at different sampling periods are presented in Figures 4.9(i)-(vii) for this ground release. Concentration patterns at the first arc cross section (upper frame) and along valley axis (lower frame) are depicted for each sampling period separately.
Fig. 4.9 Tracer concentration patterns for Ground release (PP2 tracer), Experiment 2, September 26, 1984 at (a) first arc cross-section, and (b) along valley axis.

(i) 0100 MST, (ii) 0230 MST, (iii) 0400 MST, (iv) 0530 MST, (v) 0700 MST, (vi) 0830 MST, and (vii) 1000 MST
Test 2, 09/26/84, 0100 MST, PP2

(a) UTME (km) vs. Elevation (km)

(b) UTMN (km) vs. Elevation (km)
Test 2, 09/26/84, 0530 MST, PP2

(a) UTME (km) vs Elevation (km)

(b) UTMN (km) vs Elevation (km)
Test 2, 09/26/84, 0830 MST, PP2

(a) Elevation (km) vs. UTME (km)

(b) Elevation (km) vs. UTMN (km)
First Arc:

First arc which is situated approximately 8 km from the release point registered reasonably high concentrations in the first hour of the sampling period ending at 0100 MST revealing good transport conditions. Peak tracer concentrations were recorded along the lower parts of the east sidewall during most of the nocturnal periods. Concentrations decreased rapidly on all sides away from the peak value location. The tracer plume was confined to lower layers of the valley to about 300 m deep for the nocturnal periods. The release was continued with a fairly uniform rate until 0900 MST in the morning. Inspite of this, concentrations levels were drastically reduced after local sunrise (e.g., 0830 MST) with a simultaneous increase on the west sidewall. This could be attributed to excess dilution in the valley after sunrise which initiated convective action by heating-up the west sidewall.

Valley Axis:

Tracer concentration patterns for the ground release at different sampling periods are shown in the bottom frames of figures 4.9 (i)-(vii). For obvious reasons, peak concentrations are recorded by the surface samplers very close to the release point. Drainage flow velocity increased sharply to reach a maximum value at about 60 m AGL, which transported part of the tracer plume over a longer distance near the height of the jet. Nocturnal drainage periods (0100 MST, 0230 MST, 0400 MST, 0530
MST, and 0700 MST) are characterized by the tracer plume confined within the drainage layer but for some unusual concentrations beyond the drainage layer during 0700 MST. This unusual tracer levels could be related to sporadic turbulence (Nappo, 1989) in the valley environments. The confluence of Brush Creek Valley into Roan Creek Valley is at the right end of the diagrams. The vertical sampler and a surface sampler located in this merging zone consistently recorded higher concentrations indicating the blocking of Brush Creek drainage flow and interference of Roan Creek drainage flow with the Brush Creek drainage. This is also evident in Brush Creek drainage speed at the confluence.

Post-sunrise periods are characterized by rigorous mixing due to convection and reduced concentration levels. Flow reversal in the up-valley direction could be seen from the 1000 MST (one hour after the termination of release) distribution showing tracer levels near the source.

(b) ELEVATED RELEASE (PP3 tracer. Experiment 4, Sept. 30):

The PP3 (PDCH) tracer was released during 0000-0800 MST on the September 30, 1984 in the Brush Creek Valley with the release heights varying between 120 and 200 m AGL. The tracer release rate was 0.22 g/s. The concentration patterns at the first arc and along the valley-axis are given in Figures 4.10 (i)-(vii).

First Arc:

An examination of the tracer dispersion for the nocturnal periods at the first arc cross-section indicates that the patterns
Fig. 4.10 Tracer concentration patterns for Elevated release (PP3 tracer), Experiment 4, September 30, 1984 at (a) first arc cross-section, and (b) along valley axis. (i) 0100 MST, (ii) 0230 MST, (iii) 0400 MST, (iv) 0530 MST, (v) 0700 MST, (vi) 0830 MST, and (vii) 1000 MST.
Test 4, 09/30/84, 0100 MST, PP3

(a)

(b)
Test 4, 09/30/84, 0400 MST, PP3

(a) UTME (km) vs. Elevation (km)

(b) UTMN (km) vs. Elevation (km)
Test 4, 09/30/84, 0700 MST, PP3

UTME (km) vs. Elevation (km) plot

UTMN (km) vs. Elevation (km) plot
are similar to those of ground release but for some variations. Reduced concentrations were observed at the valley-base, suggesting that the plume centerline was away from the valley axis, and probably injected into the drainage jet. Peak tracer concentration values were observed near the lower half of the canyon toward the east sidewall in the nighttime drainage period. Secondary concentration maxima were observed occasionally at higher elevations (source level) but within the drainage layer.

It is evident from Doppler lidar data (Post and Neff, 1986) that the nocturnal drainage jet core was not located exactly along the Brush Creek valley axis, but towards the eastern sidewall. The valley geometry, which has slight curvature, and the contribution from the tributaries on the east sidewall to the Brush Creek drainage flow (Porch et al., 1989) must have led to the shifting of the low level jet towards east sidewall. The drainage jet location could explain the occurrence of peak concentrations on the east sidewall.

Peak concentrations are observed on the east sidewall even after the local sun-rise (0700 MST). However, a secondary maximum was registered on the west sidewall, indicating the effect of the warming of the west sidewall by the sun. The west sidewall was warmed enough by 0830 MST to cause the tracer to be carried up the sidewall by the convective upslope flows; this was clearly describable in the concentration pattern of the post-sunrise period.

Porch et al. (1984) proposed a three layer structure in the
tributary flows and suggested that the upper and possibly the middle layers of the tributary flow are relatively warmer than the main valley flow, and tend to ride above the valley drainage. They felt that this provides a mechanism for turbulent exchange that allows tracer material to mix either out of the tributary flow, or out of the main valley flow to greater heights than would be predicted from the drainage layer measurements made away from the tributaries. Unusual concentration levels observed above the drainage layer in the nighttime periods may be examples of this mechanism.

The tracer distribution was rather uniform for the post-sunrise period (0830 MST and 1000 MST).

Valley Axis:

The concentration isopleths for elevated release along the valley-axis are presented in Fig. 4.10 (bottom frames). The concentration pattern for this elevated release is not as simple and uniform as that of the ground release. Inspite of the presence of a low-level drainage jet of very good intensity (~ 6 m/s), surface samplers placed close to the release site consistently recorded peak values. This consistency provides evidence for a suspected subsidence in the Brush Creek drainage flow. Part of the plume was injected into the drainage jet leading to a good dispersion of the material along the jet in the valley.

Despite the fact that the release rate remained the same, ground level tracer concentrations at 0830 MST are only about half
of the 0700 MST concentration levels. This was due to convective activity and dispersion of tracer material into a greater volume of air in the post-sunrise periods; concentration distributions at the first arc also support this point. Part of the tracer plume has spread to levels above the release height, which might be due to the tributary flows.

**TEMPORAL VARIATION OF TRACER DISTRIBUTION:**

An analysis of variation of tracer concentrations with time at a few locations was conducted to understand ventilation in the Brush Creek Valley. Sampling points that have registered peak values on each of the three arcs were utilized for this analysis. It is interesting to note that the peak concentration values were consistently observed at the same receptor point on each arc for all four tracer releases on the two experimental nights, with only minor variations. Gudiksen and Shearer (1989) studied the valley ventilation during the morning transition period by averaging the tracer concentrations from all 12 individual tracer releases performed during 1984 ASCOT study.

Mean normalized concentrations for each arc are shown in Figures 4.11(a) and 4.11(b) for ground releases and for the elevated releases respectively. Generally, the concentration levels were higher at all three arcs for ground releases. For elevated releases there was a common systematic trend in the tracer concentrations at all three arcs. Tracer concentration maxima were recorded at about 0400 MST. Interestingly, the receptor on the third arc which was closer to the release site.
Fig. 4.11 Temporal variation of observed peak tracer concentrations at each sampling arc. (a) ground releases, and (b) elevated releases.
Temporal variation – Ground release

![Graph showing temporal variation of C/Q](image)

- **First arc**
- **Second arc**
- **Third arc**

**TIME (hours MST)**

01 03 05 07 09 11

**C/Q**

0 1 2 3 4 5 6 7 8 9 10
Temporal variation – Elevated release

[Graph showing temporal variation with C/Q on the y-axis and time (hours MST) on the x-axis. Different lines represent first, second, and third arcs.]
consistently registered high concentration levels for elevated as well as ground releases. This suggests a strong subsidence in the valley. Rapid dilution of tracer material and reduced concentrations were noticeable after the occurrence of local sunrise for all releases.

Comparison:

The tracer concentration patterns at the first arc from both the elevated release and ground release suggest the following:

* the tracer plume is generally confined to the drainage layer;
* maximum concentrations occurred on the lower parts of east sidewall;
* a layer (~150 m deep) of uniform concentration is observed a few tens of meters above the valley floor for the elevated release. No such layer of uniform tracer distribution is noticed for the ground release, but the observed concentrations are relatively low at the base of the valley cross-section;
* the influence of a relatively warmer upper layer of the tributary flows is evident in the form of unusual concentration levels at higher elevations; and
* warming of the west sidewall and subsequent ventilation of the tracer by upslope flows after local sunrise is clearly observed on both days.

The tracer concentration distribution along the valley-axis
from the two (elevated and ground) releases suggests the following important points.

* the nocturnal jet location undoubtedly played a major role in tracer concentration distribution;
* despite the presence of the nocturnal jet, high concentrations are observed very close to the release location, providing evidence for strong subsidence in the valleys;
* the tracer plume is generally confined within the drainage layer;
* the influence of tributary flows as indicated by Porch et al. (1984) is noticeable on both the experimental nights.

**SUMMARY**

Observed meteorological data and atmospheric tracer data from two ASCOT-1984 conducted in Brush Creek Valley, U.S.A., are analyzed to get an insight into the flow phenomena and, transport and diffusion of airborne effluents in valley environments.

In the following chapter an air pollution dispersion model based on the Gaussian puff algorithm developed for valley setups is described. Several of the phenomena observed in the Brush Creek valley are incorporated in the model. The model simulations are then compared with the actual observed tracer data from the above discussed tracer experiments.