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Above-Canopy Dispersion Rates in Nighttime Downslope Flow

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1. INTRODUCTION

Estimates of dispersion over complex terrain differ from those over level ground both quantitatively and physically. These differences have been recorded in a number of studies. The adjustment of the stability class of the Pasquill-Gifford-Turner stability class (Turner, 1969) to a less stable class so that calculated values of dispersion would more closely agree with observations has been proposed (Hinds, 1970, Leahey and Halitsky, 1972, Start and others, 1975). That nonturbulent meander of wind in time and space would also lead to enhanced dispersal of materials, has been suggested (Fosberg and others, 1976, Fosberg and Fox, 1978). Turbulence was enhanced along the horizontal but not vertical plane along a lakeshore (Lanham, 1980). Highly organized small scale flows in valleys and enhanced turbulence and organized subgrid flow in complex terrain have been demonstrated (Wooldridge and Ellis, 1975, Wooldridge and Orgill, 1978).

Nocturnal drainage flows in complex terrain tend to follow watershed drainages under calm or light wind situations (Geiger, 1959). Large-scale flow influences drainage flows (Sterten and Knudson, 1961) through the radiational cooling rate, the momentum balance (Fosberg, 1967, 1969; Fosberg and Schroeder, 1966) and in particular, the transition layer (including the antimountain wind) is strongly influenced (Thyer and Buettner, 1962).

Lagrangian measurements of turbulence and trajectories with tetroons are fundamentally a measure of air parcel behavior. Horizontal movements of air parcel behavior are more accurately measured than the vertical movements because of the buoyancy restoring forces associated with constant density tetroons (Booker and Cooper, 1965, Cherry, 1971).

As part of the 1980 Atmospheric Studies in Complex Terrain (ASCOT) program, we obtained quantitative estimates of the turbulence and dispersion rates above the canopy. The study was designed to improve the fundamental knowledge of transport and dispersion processess in complex terrain, and to provide an improved method for performing air quality assessments.

2. METHODS

This paper reports the result of tetroon measurements of dispersion and turbulence in the Geysers Geothermal Area in the Coast Range of northern California. The specific area of study was in the Anderson and Putah Creek drainages, about 100 miles north of San Francisco (Fig. 1). Tetroons were released from the Thorne 7 wellpad in Anderson Creek, and from Larry's Cabin in Putah Creek on September 19-20, 1980. Tetroon flights were scheduled to provide direct support for the gas tracer experiments. One tetroon was released 1 hour before the gas tracer release, a cluster of at least three tetroons at the beginning of the tracer release, and 1 tetroon 1 hour later from each site. The purpose of the single tetroon flights was to provide a measure of the stationarity of the flow. All tetroons were balasted to fly 100 m above the release site.

Approximately 100 tetroons were flown during the 1980 ASCOT experiments. Transport, diffusion, and dispersion rates were calculated from both indiviudal tetroon flights and from tetroon clusters. Tetroon flights during these experiments were used to characterize the turbulence and dispersion rates in the transition layer above the drainage flows. The diffusion rates were measured both by direct calculation of the eddy diffusivity through time series analysis of individual tetroon flights and from spatial variance analysis of tetroon clusters.

Tetroons were tracked with an S band (3.05 GHz) radar in which the video (PPI) signal was processed by computer to track up to 20 identified targets simultaneously. A telemetry temperature and pressure package was used to resolve vertical position in order to compensate for the 3db (11 degree) angular antenna resolution in the vertical. The combined radar and telemetry systems provided 60-second fixes on each tetroon. Ground clutter problems were eliminated through use of transponders. These 100-milliwatt transponders returned a signal at 2.95 GHz.

When the local oscillator of the reserve was tuned to 2.95 GHz, all but the closest reflected signals were eliminated. Accuracy of radar position was to 0.65 degree horizontal and 18 m in range to 10 km and 150 m in range to 70 km. Tetroons used in these experiments were 1 m^3.

We analyzed the data in two forms. First of these analysis were for Lagrangian turbulence characteristics from individual tetroon flights. Tetroon path coordinates were used to define the local coordinates. The x axis was always along the flight path, the y axis was horizontally normal to the flight path and the z axis was upwind. For a tetroon flying at a fixed mean altitude, we assumed that...

$$u\ (x,\ t) = \overline{u} + u'\ (x,\ t)$$
$$v\ (x,\ t) = v'\ (x,\ t)$$
$$w\ (x,\ t) = w'\ (x,\ t)$$

in which $\overline{v} = \overline{w} = 0$. Reynolds averaged turbulence terms from the momnentum equation yields the following pairs, u'^2, v'^2, w'^2.

Time series analysis of the autocorrelation normally produces an exponentially decaying function with time. The decay coefficient, with units of time, is the Lagrangian time constant. The product of the Lagrangian time constant and the mean of paired velocity coefficients gives the eddy diffusivity for momentum. In particular,

$$Ky = \overline{v'^2}\ \lambda y$$

A second estimate of dispersion was made through analysis of tetroon clusters. Tetroon were released in a cluster of three or more. The variance about the centroid of the cluster is equivalent to the dispersion coefficient of the Gaussian plume model.2.

The eddy diffusivity from single tetroon flights can be compared to the variances obtained from the clusters through

$$\sigma^2 = 2Kt$$

RESULTS

We present details of only one of the five experiments done in the study. This experiment, No. 4, was selected by ASCOT for intensive analysis and comparison. Tetroons flown from Larry's Cabin in Putah Creek, followed the drainage, along the east side of the Anderson Springs Basin, and into the Collayomi Valley (Fig. 2a). Tetroons flown from the Thorne 7 wellpad moved both upstream as well as downstream. Those tetroons which moved up Anderson Creek and up Gunning Creek were in the antimountain wind (Fig. 2b). Tranport characteristics were defined by transport time to downwind locations. The transport patterns (Fig. 3) show the rapid flow down the east side of Putah Creek and the slowing of flow at the upper end of the Collayomi Valley. The flow from Thorne 7 shows the slow speeds near Thorne 7 and across Ford Flats.

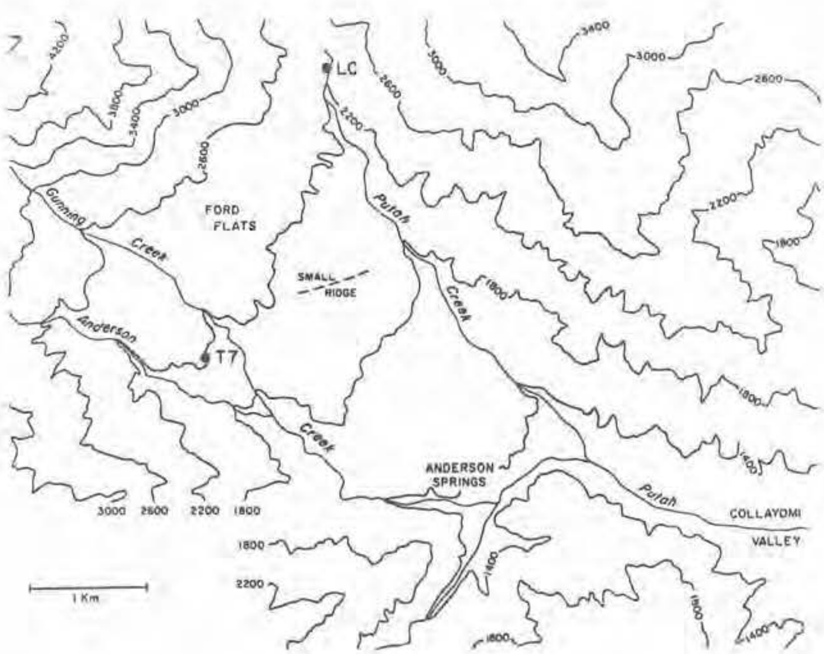

Fig. 1 The tetroon launch sites -- Thorne 7 (T7) from the Thorne 7 in Anderson Creek and Larry's Cabin (LC) in Putah Creek drainages are in the Coast Range, 100 miles north of San Francisco, California.

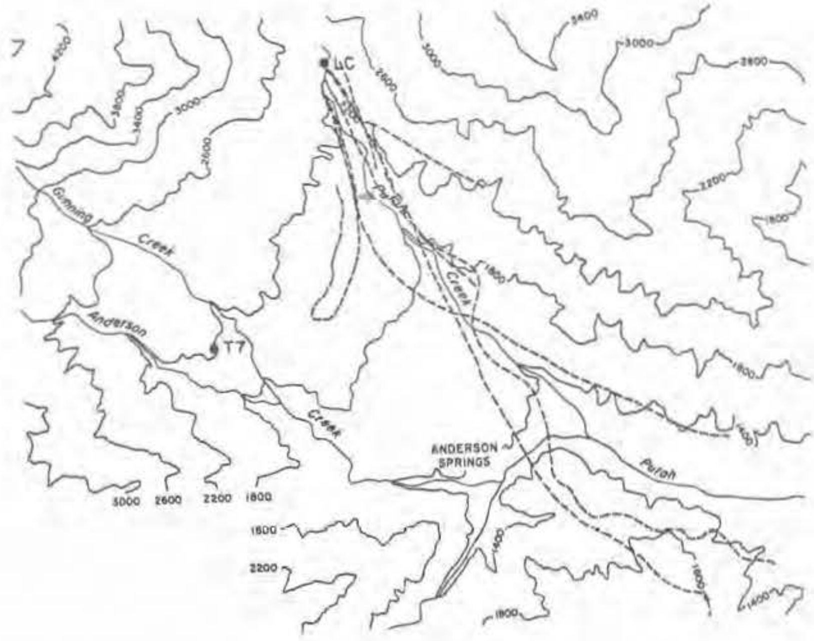

Fig. 2a Trajectories of tetroons: flow in the Putah Creek drainage

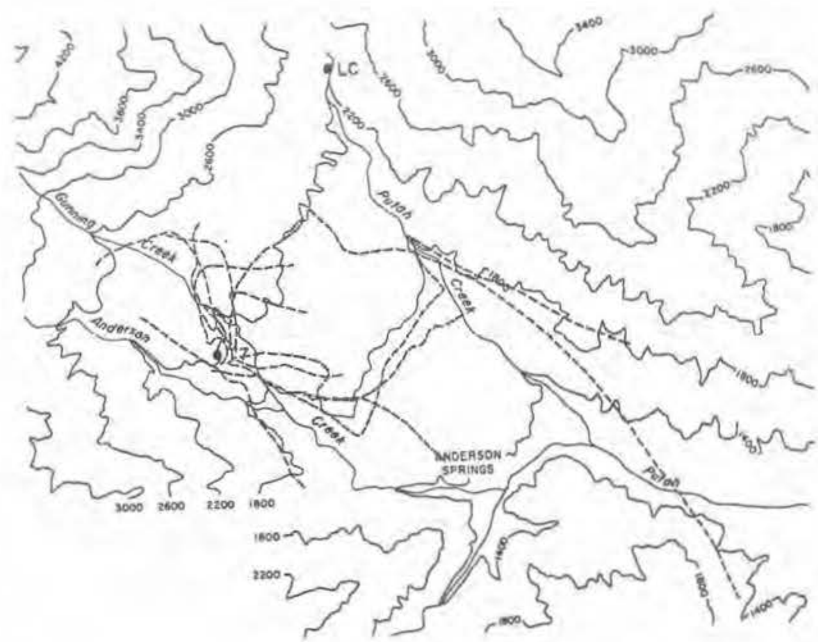

Fig. 2b Trajectories of tetroons: movement from the Thorne 7 site

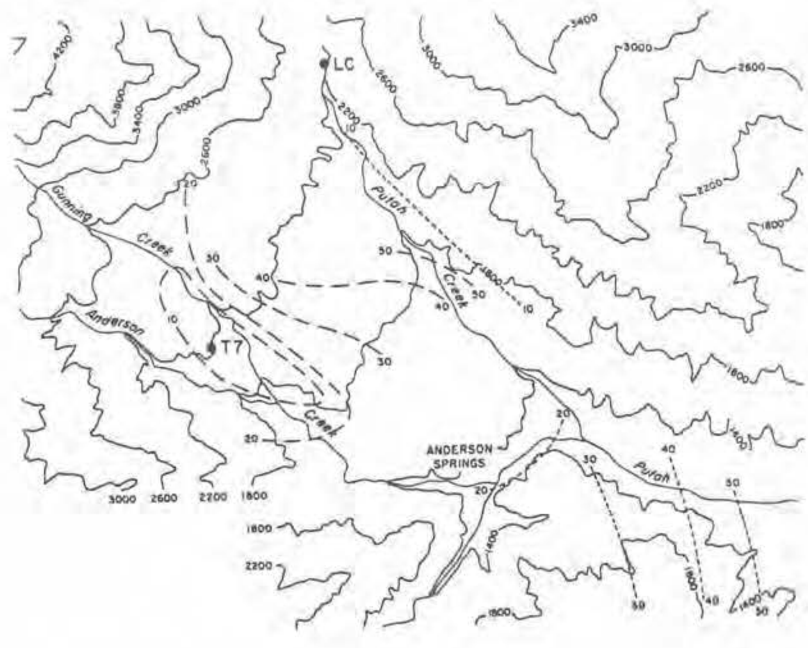

Fig. 3 Transport times from the launch sites Thorne 7 (T7) and Larry's Cabin (LC).

Turbulence estimates of Ky and σy from individual tetroon flights varied widely, by launch site (Table 1). The eddy diffusivities ranged from 34 to 245 m^2 s^{-1}. The range for eddy diffusivities in which a corresponding σy was computed were 37 to 216 m^2 s^{-1}. We calculated the dispersion coefficient σy from the tetroon clusters

Table 1--Eddy diffusivity and estimated dispersion from individual tetroon flights.

Experiment and launch site1/	v^2 m^2 s^{-2}	λy s	Ky m^2 s^{-1}	Distance (km)	σ m^2
No. 1:					
LC	0.1889	198	37.4	1.6	211
			2.0	423	
T7	0.2233	49	145.1	1.2	417
	0.1924	526	101.2	1.2	348
	0.7149	220	157.2	1.2 439	
No. 4:					
LC	0.4681	205	96.4	3.9 480	
T7	0.7765	278	216.4	2.0 1139	
No. 3:					
T7	0.4650	527	245	-	-
	0.4121	177	73.3	-	-
	0.1979	173	34.4	- -	

1/LC = Larry's Cabin; T7 = Thorne 7

(Table 2). In both analyses, the measured dispersion was near the Pasquill-Gifford-Turner stability class of A. Large uncertainty existed for all estimates of the dispersion rates. The standard deviation about the cluster means was a factor of 2 (Fig. 4). Because of the few estimates of σy available from individual flights, these values were not included. Except for one flight, the estimates were a factor of 2 greater than those obtained from the cluster estimates.

4. CONCLUSIONS

Dispersion in Putah Creek was consistently less than in Anderson Creek. Dispersion calculations showed high variability. The slope of the mean dispersion coefficients (σy) paralleled the Pasquill-Gifford-Turner curves. In particular, the dispersion rate was near that of Class A stability. The two estimates of dispersion did not give similar values. Conversion of the eddy diffusivities to σy gave values approximately twice those obtained by the cluster analysis. Because of the limited number of eddy diffusivity measurements, we are unable to account for these differences. All estimates of dispersion showed that the dispersion rates were significantly over those expected from stability considerations alone.

Table 2.--Composite dispersion coefficient and standard deviation, by launch site.

	Larry's Cabin		Thorne 7	
Distance downwind (Km)	Mean dispersion coefficient	Standard deviation	Mean dispersion coefficient	Standard deviation
		Meters		
0.5	90	35.3	174	6.9
1.0	182	50.5	156	37.3
1.6	290	36.6	223	84.8
2.0	354	126.0	603	-
2.6	311	-	-	-
3.0	298	-	-	-
3.6	443	-	-	-

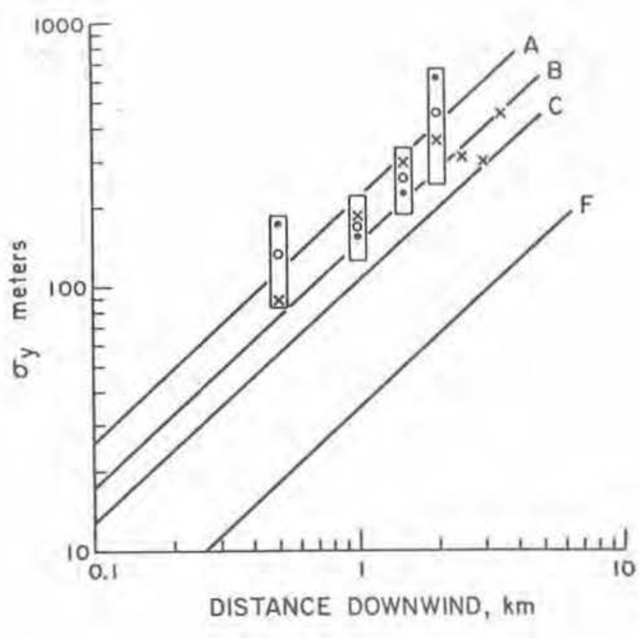

Fig. 4 Measured dispersion rates from all experiments compared to Pasquill-Gifford-Turner dispersion curves. X's = σy in Putah Creek; dots, for Anderson Creek, open circles, means for both drainages. Vertical bars = one standard deviation about the composite mean.

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REFERENCES

Booker, D. R., and L. W. Cooper, 1965: Superpressure balloons for weather research. J. Appl. Meteor. 4, 122-129.

Cherry, N. J., 1971: Characteristics and performance of three low cost superpressure ballon (tetroon) systems. J. Appl. Meteor. 20, 982-990.

Fosberg, Michael A., Douglas G. Fox, E. A. Howard and Jack D. Cohen, 1976: Nonturbulent dispersion processes in complex terrain. Atmos. Environ. 10, 1053-1055.

Fosberg, Michael A., and Douglas G. Fox, 1978: Reply nonturbulent dispersion processes in complex terrain. Atmos. Environ. 12, 966.

Geiger, R., 1952: The Climate Near the Ground. Harvard Univ. Press, Cambridge, MS. 494 pp.

Hinds, W. T., 1970: Diffusion over coastal mountains of southern California. Atmos. Environ. 4, 107-124.

Lanham, L., 1980: Wintertime dispersion processes in the Lake Tahoe Basin, Second Joint Conference on Application of Air Pollution Meteorology and Second Conference on Industrial Meteorology. American Meteor. Soc., Boston, MS. 520-525.

Leahey, D. H., and J. Halitsky, 1972: Low wind turbulence statistics and related diffusion estimates from a site located in the Hudson River Valley, Atmos. Environ. 7, 49-61.

Start, G. E., C. R. Dickson and L. L. Wendell, 1975: Diffusion in a canyon within rough mountainous terrain. J. Appl. Meteor. 14, 333-346.

Sterten, A. K., and J. Knudson, 1961: Local and Synoptic Investigations of the Mountain and Valley Wind System. Forsvarets Forskning singstitutt, Kjeller-Lillestrom, Norge, 1391.

Thyer, N. H. and K. Buettner, 1962: Part A on valley and mountain winds, Dept. of Atmos. Sci., Univ. of Washington, Seattle.

Turner, D. B., 1969: Workbook of atmospheric dispersion estimates. U.S. Dept. of Health Education and Welfare, Public Health Service Pub. 999-AP-26. 84 pp.

Wooldridge Gene L. and R. T. Ellis, 1975: Stationarity of mesoscale airflow in mountainous terrain. J. Appl. Meteor. 14, 124-128.

Wooldridge, Gene L. and M. M. Orgill, 1978: Airflow, diffusion and momentum flux patterns in a high mountain valley. Atmos. Environ. 13, 803-808.