# *VERTICAL TRANSPORT AND MIXING IN COMPLEX-TERRAIN AIRSHEDS*

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## ABSTRACT

A comprehensive research program will be carried out to study phenomena of consequence with regard to transports and mixing in areas of rugged (complex) terrain. Particular attention will be given to thermally induced circulation, for example, slope and valley wind systems, pooling of cold air in basins and breakup of cold pools during which the trapped air is dispersed vertically. Several approaches, laboratory experiments, theoretical modeling, numerical simulations and field observations will be used for the investigations, but major emphases will be on laboratory experiments and field observations.

A series of specially designed laboratory experiments will mimic the nocturnal cooling of escarpments by subjecting a uniform rough incline to time-dependent cooling. In simulating atmospheric motions in the laboratory, the equations for conservation of momentum, mass and buoyancy in the physical experiments can be shown to be similar to those in the atmosphere under certain conditions. In particular, the counterparts of the potential temperature and Exner function in the atmosphere correspond to the specific volume and pressure, respectively, for the experimental fluid. The displacement, velocity and temperature fields play similar roles in the atmosphere and in the model. In light of these dynamic similarities, the extrapolation of laboratory results taken under turbulent flow conditions to the atmosphere appears to be justified. State-of-the-art flow diagnostic techniques will be used to evaluate the flow fields, using which the balance of forces, scaling and similarity issues and the spatial variability of the ensuing katabatic flows will be evaluated. Some of the questions to be addressed are: What is the time scale of flow development, especially the time required to achieve a quasi-steady state over the slope upon imposition of a constant surface temperature? Does the flow achieve surface similarity? What are the major factors that retard the flow? Can a simple momentum balance be established for the flow? Can the previously proposed internal hydraulic theories be substituted by the laboratory data? How does the stream-wise loss of buoyancy (or the dilution) of the flow depend on governing variables (i.e., temperature difference between the surface and the flow, background stratification, geometric parameters and the slope)?

Also investigated using another laboratory setup will be the flow evolution in a basin in response to a cooling/heating cycle, with emphasis on the development of stably stratified layer corresponding to cooling. The "nocturnal" down-slope flows are expected to pool within the basin, thus generating stably stratified skewed shear layers sustaining (weak) turbulence. The up-slope flow and convective turbulence associated with the heating cycle can cause the breakup of the cold pool. The experiments will focus on the mapping of flow patterns, the measurement of mean and turbulent flow parameters, the effects of an overlying (synoptic) flow and the establishment of scaling for flow processes occurring during cooling and transition periods. Some questions to be addressed are: How do the boundary-layer thickness and the characteristic velocity of the drainage flow along the basin boundaries compare with those of the idealized flat-plate drainage flow studies? How does the velocity profile change upon entering the cold pool at the bottom of the basin? Is the cold-pool evolution scenario of Whiteman (1990, *Meteor. Monogr.*, **23**) supported by laboratory observations? What determines the stratification within the cold pool? How do temperature and velocity profiles obtained in the model valley compare with previous numerical results? Can the criteria for basin-flow evolution recently proposed by Whiteman et al. (1999, *J. Appl. Meteor.*, In Press) be supported?

What is the nature of turbulence in the basin during different phases of evolution? and, What are the effects of an overlying synoptic flow?

The findings of laboratory studies described above will be compared with those obtained by Dr. Whiteman's group at PNNL during the VTMX field program. In addition, numerical simulations will be carried out to investigate some of the above cases to supplement the laboratory experiments, and inter-comparison of results obtained by the two approaches will be used to assess the efficacy of parameterizations used for numerical models to be used.

It is also planned to carry out limited field observations during the VTMX field program, wherein the vertical structure of the mean and turbulent fluctuations of velocity and density and the aerosol concentration in the basin flow will be investigated by deploying an instrumented tethered meteorological tower. Single and two-point turbulence measurements together with sampling and chemical analyses of aerosols will be collectively used to study how the mean flow and turbulence of different vertical layers of the basin lead to basin-scale transports and vertical dispersion of contaminants. The inferences of this field study will also be compared with those of two previous field experiments (PAFEX) conducted in the complex-terrain airshed of Phoenix. PAFEX data remain underutilized and will be analyzed as part of the proposed work. Several weeks of data covering the entire diurnal cycle and a week of data on transition periods alone are available for analysis. PAFEX data will also play a supporting role in the planning of VTMX field experiments. The issues to be addressed are: How does the micrometeorology relate to the local energy balance and to the magnitude of differential heating across the valley? What are the typical air flow patterns in the valley and their vertical variation during the day, night and transition period and how are they related to transport properties? How does the lower atmospheric structure change in the presence of synoptic winds? How do the components of turbulent velocity respond to the diurnal cycle? What should be the spectra of stably-stratified turbulence in cold pools? How can the eddy diffusivities of momentum and temperature in basins be parameterized? The overall research program is expected to contribute significantly to the knowledge of complex-terrain flow processes and will lead to better prediction and management tools for urban air quality.

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