4.4 TURBULENCE AND MIXING IN THE NOCTURNAL BOUNDARY LAYER OVER A SLOPE – VTMX FIELD PROGRAM RESULTS

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1. Introduction

The Vertical Transport and Mixing Experiment (VTMX) took place in Salt Lake City, Utah, in October 2000. This field campaign was carried out under the sponsorship of the Atmospheric Sciences Program of the Department of Energy to study the transport and mixing processes in complex terrain under stable conditions. Details of the filed campaign are given in J.C. Doran, J.D. Fast and J. Horel ('The VTMX 2000 Campaign', submitted to *Bull. Am. Meteorol. Soc.*) Measurements presented in this communication were conducted on an northeastern slope of the Salt Lake Basin with particular interest in nocturnal boundary layer (katabatic flows) in the absence of significant synoptic influence. Extensive measurements of mean flow, turbulence, temperature and solar radiation were made, from which circulation patterns on the slope and nature of stratified turbulence in katabatic winds were inferred.

2. Site and Instrumentation

The observation site was located in the northeastern side of the valley, in a grassy open area (aerodynamic roughness length ~0.1 m), adjoining the Mount Olivet Cemetery, having a gentle slope (~0.07, i.e. 4°). Because the measurements were made away from buildings and trees, the data can be considered as free from the immediate effects of obstacle wakes. Deployed instruments consisted of a 14 m mast equipped with two 3-cup anemometers, two thermistors, upward facing spectral pyranometer, and a downward facing pyrgeometer. A Data Logger provided computation and storage of 5 min-averaged air temperature, wind speed and radiation. Two ultrasonic fast-response anemometers-thermometers were used to measure three velocity components and air temperature with a sampling rate of 10 Hz. In order to analyze the vertical structure of the lower atmosphere, two tethered balloons were used to measure the air temperature, relative humidity, pressure, wind speed and wind direction. Simultaneous measurements of ground level aerosols and vertical aerosols profiles were also made.

3. Data Analysis

Sixty-second averages of ultrasonic data were used to evaluate eddy diffusivity of momentum

$$K_M = \frac{-\overline{u'w'}}{\left(\frac{\partial U}{\partial z}\right)} \qquad (1)$$

and heat

$$K_H = \frac{-\overline{w'\theta'}}{d\bar{\theta}/dz}, \qquad (2)$$

where z is the vertical coordinate, U mean slope velocity, θ mean potential temperature, $\overline{w'\theta'}$ vertical heat flux, and $\overline{u'w'}$ momentum flux.

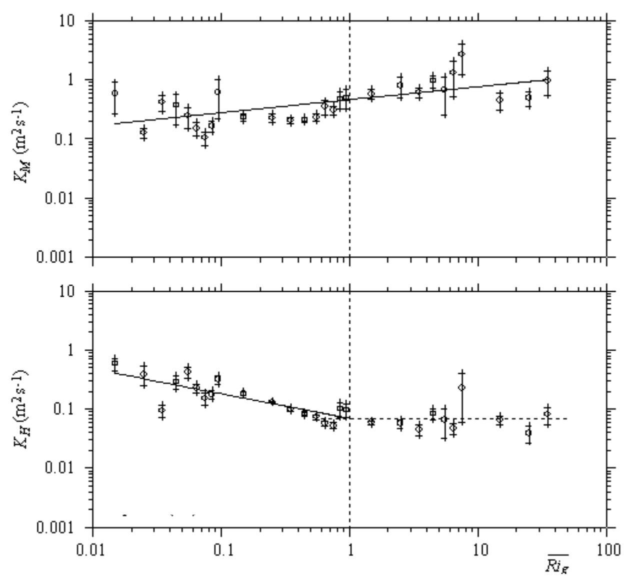

Figure 1 shows the dimensional form of K_M and K_H as a function of the Gradient Richardson number defined as

$$Ri_g = \frac{N^2}{\left|\frac{\partial \tilde{V}}{\partial z}\right|^2} = \frac{N^2}{\left(\frac{\partial U}{\partial z}\right)^2 + \left(\frac{\partial V}{\partial z}\right)^2}, \qquad (3)$$

where N is the buoyancy frequency and $\tilde{V}$ the mean velocity vector.

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Empirical best fits to the data show following relations:

$$K_M = 0.45 \cdot \overline{Ri_g}^{\,0.22} \qquad (\mathrm{m}^2\mathrm{s}^{-1}), \qquad (4)$$

for the entire $\overline{Ri_g}$ range,

$$K_H = 0.07 \cdot \overline{Ri_g}^{\,-0.45} \qquad (\mathrm{m}^2\mathrm{s}^{-1}), \qquad (5)$$

for $\overline{Ri_g} < 1$ (solid line), and

$$K_H = 0.07 \qquad (\mathrm{m}^2\mathrm{s}^{-1}), \qquad (6)$$

for $\overline{Ri_g} > 1$ (dashed line). Note that in the $\overline{Ri_g}$ range investigated both K_H and K_M are much larger than their molecular diffusive counterparts ($k_H = 2 \cdot 10^{-5}$ and $k_M = 1.5 \cdot 10^{-5}$ $\mathrm{m}^2\mathrm{s}^{-1}$, respectively) indicating the dominance of turbulent transport.

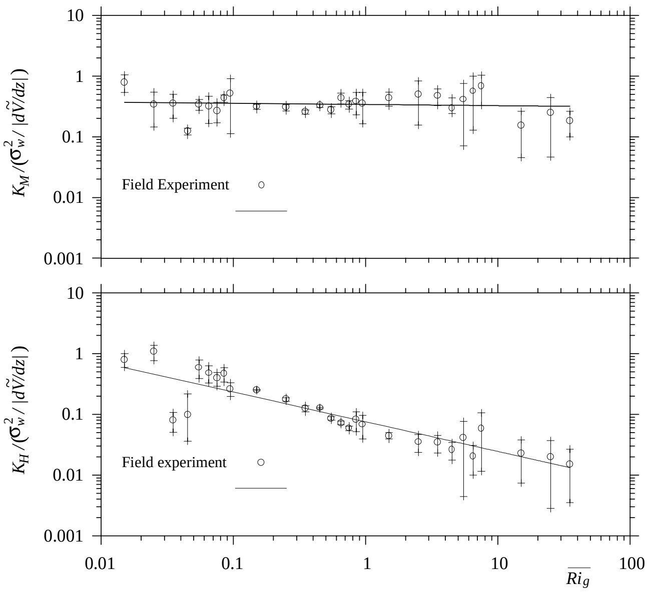
Attempts were made to express eddy diffusivities in non-dimensional form by employing suitable length and velocity scales of nocturnal boundary layer. Several scaling possibilities were considered. It was concluded that the shear length scale $L_s = \sigma_w \big/ \left| d\tilde{V}/dz \right|$ and *rms* of vertical velocity σ_w could be taken as a proper length and local velocity scales, respectively. A plausible scaling for both eddy coefficients is $\sigma_w L_S$, or equivalently $\sigma_w^2 \big/ \left| d\tilde{V}/dz \right|$. K_M and K_H so normalized are shown as a function of $\overline{Ri_g}$ in Figure 2. The normalization has arranged the data of Figure 1 to a more regular variation, with normalized K_M being approximately a constant and normalized K_H is a decreasing function of $\overline{Ri_g}$. The best fit lines to the data show:

$$\frac{K_M}{\sigma_w^2 \big/ \left| d\tilde{V}/dz \right|} = 0.34 \cdot \overline{Ri_g}^{\,-0.02} \approx 0.34, \qquad (7)$$

and

$$\frac{K_H}{\sigma_w^2 \big/ \left| d\tilde{V}/dz \right|} = 0.08 \cdot \overline{Ri_g}^{\,-0.49} \approx 0.08 \cdot \overline{Ri_g}^{\,-0.5} \qquad (8)$$

It is interesting that (7) and (8) reduces to the expressions $K_M \approx 0.34 \cdot \sigma_w^2 \big/ \left| d\tilde{V}/dz \right|$ and $K_H \approx 0.08 \cdot \sigma_w^2 \big/ N$.



4. Summary

Nocturnal atmospheric boundary layer data taken during the Vertical Transport and Mixing eXperiment (VTMX), conducted in the Salt Lake City air basin during October 2000, were used to study the downslope (katabatic) flow. The eddy diffusivities of momentum and heat inside katabatic layer were evaluated as a function of $\overline{Ri_g}$, and were found to be well above their molecular counter parts. A striking behavior was noted when the diffusivities are scaled with the shear length-scale and the *rms* of vertical velocity fluctuations.

5. References

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