LA-UR -87-1471

CONF-870864--8

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--87-1471

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TITLE: MEAN PHYSICAL PROPERTIES OF THE NOCTURNAL ALONG-VALLEY WIND IN BRUSH CREEK, COLORADO

AUTHOR(S): William E. Clements and John A. Archuleta
Atmospheric Sciences Group
Earth and Space Sciences Division
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

SUBMITTED TO: To be presented and published in the preceedings of
The American Meteorological Society's
Fourth Conference on Mountain Meteorology
August 25-28, 1987
Seattle, Washington

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Los Alamos National Laboratory
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MEAN PHYSICAL PROPERTIES OF THE NOCTURNAL ALONG-VALLEY WIND IN BRUSH CREEK, COLORADO

William E. Clements and John A. Archuleta

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

1. INTRODUCTION

During September and October of 1984, the U. S. Department of Energy's Atmospheric Studies in Complex Terrain (ASCOT) Program conducted a series of meteorological experiments in the Brush Creek Valley of western Colorado (Gudiksen et al., 1984). The purpose of the study, which employed a variety of instruments, was to investigate the nocturnal katabatic wind in the valley and its morning breakup. Tethered balloon systems measured vertical profiles of wind and temperature throughout the depth of the valley at several locations along its axis. We have used the data at one of these sites to investigate the mean properties of the nocturnal katabatic wind.

2. BRUSH CREEK VALLEY

Brush Creek Valley is located approximately 50 kilometers north of Grand Junction, Colorado. It is one of a series of parallel valleys draining the Roan Plateau area south of the Piceance Basin. The valley is 25 km long and runs from northwest to southeast as shown in Fig. 1. The width of the valley floor ranges from 300 m at mid-valley to 700 m at its mouth. In the area of the valley where studies were conducted it is 600 m deep with 30° to 40° sidewalls cut by numerous small tributaries. The valley floor slopes gently (1.5°) down to the southeast.

3. DATA

Figure 1 shows the location of the tethered balloon sounding systems operated in Brush Creek. Each measured wind speed, wind direction, temperature, wet-bulb temperature, and barometric pressure. Data were collected during balloon ascents from the surface up to a maximum of about 800 m above each site depending upon flying conditions. Each ascent lasted approximately forty-five minutes. There were eight flights, spaced an hour and a half apart, on each experimental night. The first flight started at 2300 MST and the final one at 1000 MST the following morning.

In the ensuing analysis we have used the data from the Los Alamos National Laboratory (LANL) site located approximately 8 km from the mouth of the valley (Fig. 1). Average profiles of wind and temperature were obtained from four flights between 0100 and 0600 MST on the mornings of September 18, 20, 26, and 30. The averaging period was selected to include the time when the katabatic wind was well established and in a relatively steady state. The four nights were selected because on each of them the wind at ridgetop above the katabatic flow had no down-valley component. Therefore, the cases under consideration are those for which the nocturnal katabatic wind established under conditions of some component of opposing winds above.

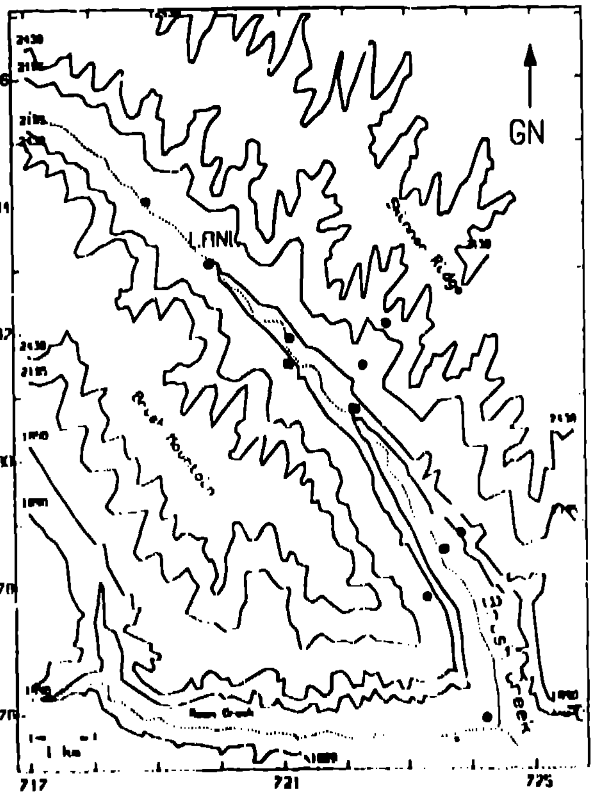


Fig. 1. Simplified topographic map of Brush Creek showing the locations of the tethered balloon sounding systems. Data from the LANL site are used in this paper. Contour lines are labeled in meters MSL and the top of the map is grid

4. ANALYSIS

Figure 2 shows the coordinate system used. At the LANL site the bearing of the valley axis looking downvalley is taken to be 140° true. We define u and v to be the along-valley and cross-valley wind speed components respectively. A positive u indicates a wind blowing downvalley and a positive v indicates a wind blowing <u>from</u> the southwesterly side of the valley.

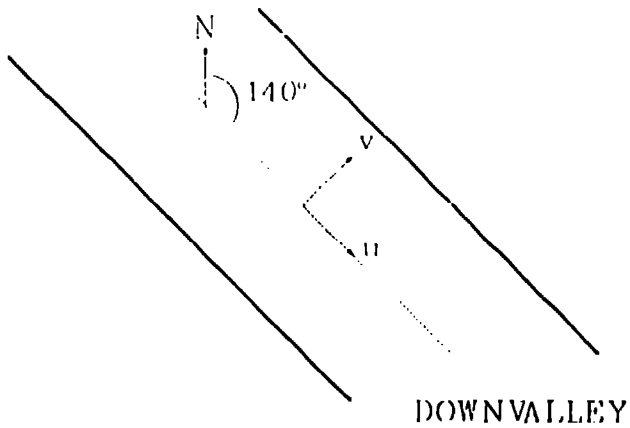


Fig. 2. Schematic of valley showing the coordinate system used.

The vertical profiles of temperature and along-valley wind speed for the four nights examined are presented in Fig. 3. The temperature profiles show a strong surface based inversion topped by a quasi-isothermal region reaching to ridgetop (600 m). We define the surface inversion strength, SIS, by

$$SIS = (T_i - T_s)/z_i \qquad (1)$$

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 surface air temperature in the lowest 10 m.

The along valley wind speed profiles show a low level down-valley jet which eventually gives way to the opposing flow above. We define:

- D, the depth of the katabatic wind; the height at which the along-valley wind speed goes to zero.
- u_m, the maximum wind speed in the jet of the katabatic wind.
- z_m, the height of u_m.

In addition, the total wind speed at ridge top is defined as

- S_{rt}, the average total wind speed, $(u^2 + v^2)^{1/2}$, between 600 and 700 m.

The profiles can be used to estimate the along-valley fluxes of quantities advected by the nocturnal katabatic wind. The along-valley flux F of a quantity Q is given by

$$F_Q = \int_0^D \int_{-h}^{+h} Qu(y,z)\,dy\,dz \qquad (2)$$

To compute the mass, momentum, kinetic energy, and internal energy fluxes we take

$$Q_m = \rho \qquad (3)$$

$$Q_p = \rho u \qquad (4)$$

$$Q_{KE} = (1/2)\rho u^2 \qquad (5)$$

$$Q_{IE} = \rho C_v T \qquad (6)$$

where ρ is the density of the air taken to be 1.0 kg/m^3 and C_v is the specific heat capacity at constant volume (718 $J\ kg^{-1}\ K^{-1}$).

Clements and Hoard (1987) have shown that the cross-valley structure of the along-valley wind is of the parabolic form

$$u(z) = u^*(z)\{A + B[y/h(z)]^2\} \qquad (7)$$

where $u^*(z)$ is the maximum wind speed at z above the ground, y is the cross-valley coordinate, and h(z) is the valley half-width at z. A and B are constants of value 1.0 and -0.8 respectively.

Using Eq. (7) in Eq. (2) it can be shown that the along-valley flux F^* for a quantity Q obtained by assuming horizontal homogeneity in u is proportional to the flux F obtained using the parabolic distribution of u by

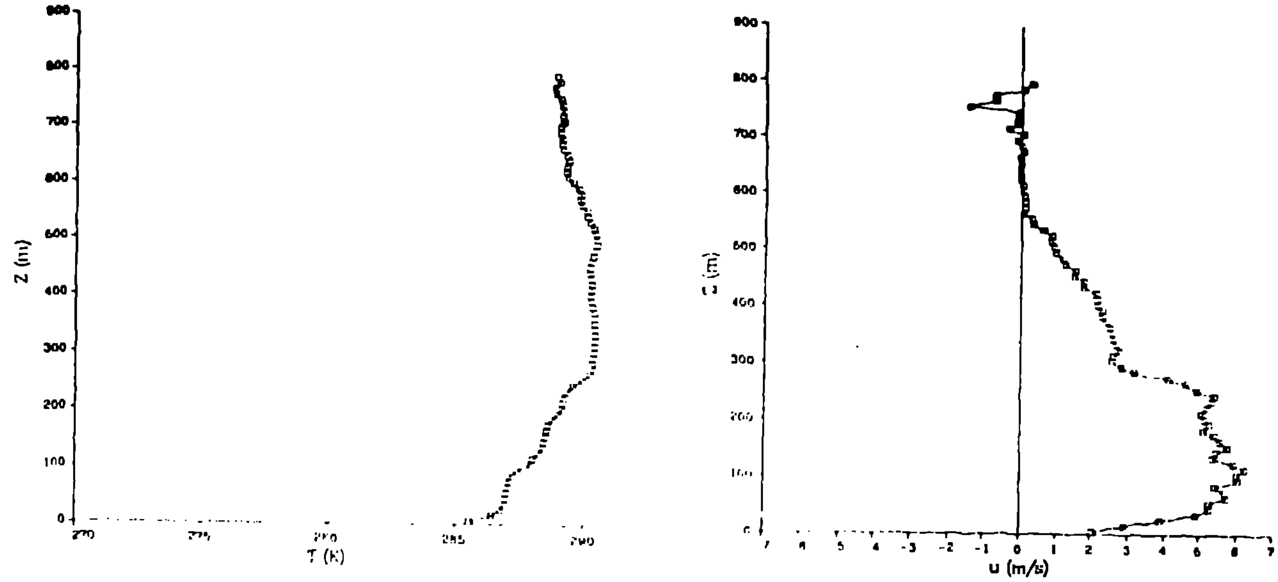
$$F_Q = K_Q(A,B)F^* \qquad (8)$$

where K_Q is a constant for Q which is a function of A and B. For A = 1.0 and B = -0.8 it can be shown that

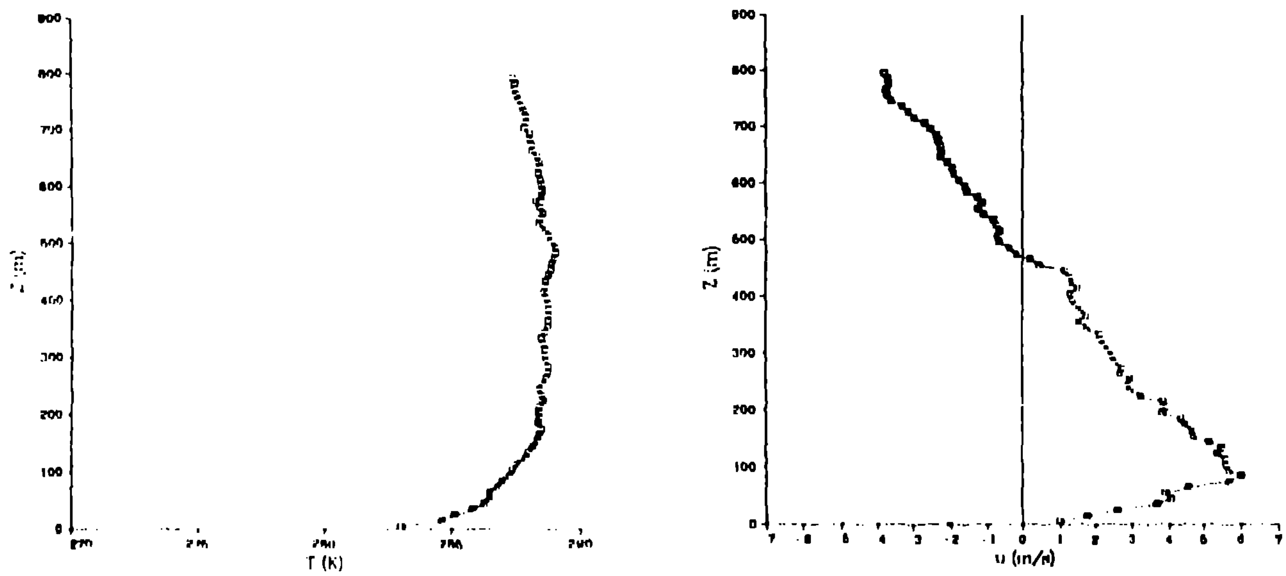
$$K_m = K_{IE} = 0.7$$

$$K_p = 0.6$$

$$K_{KE} = 0.5$$

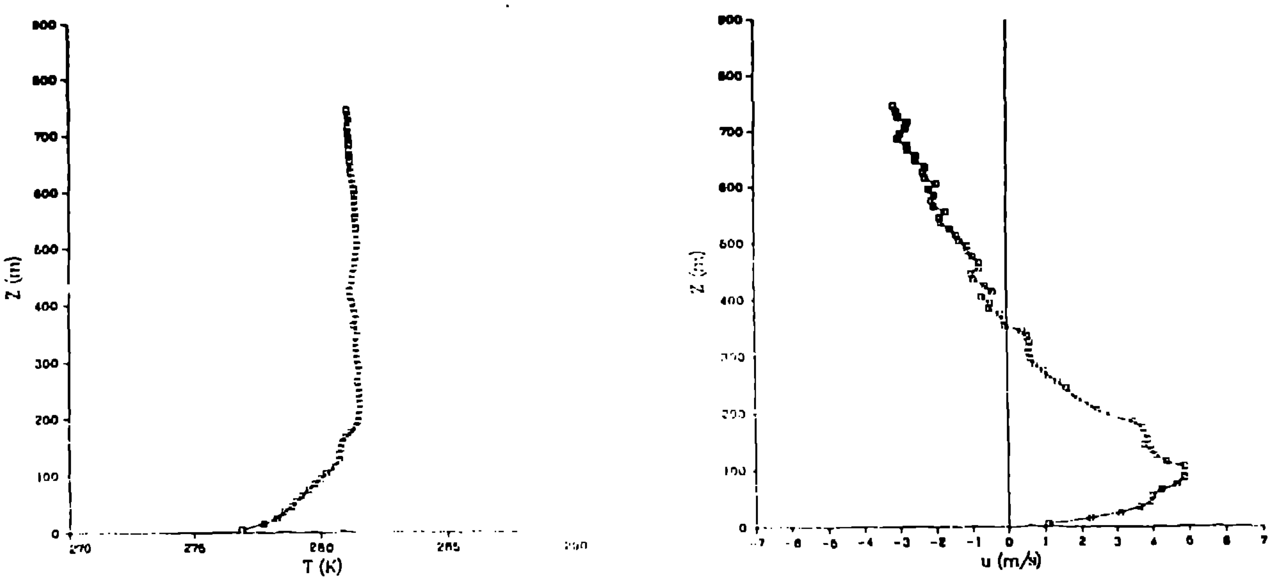


September 18, 0100 - 0600 MST

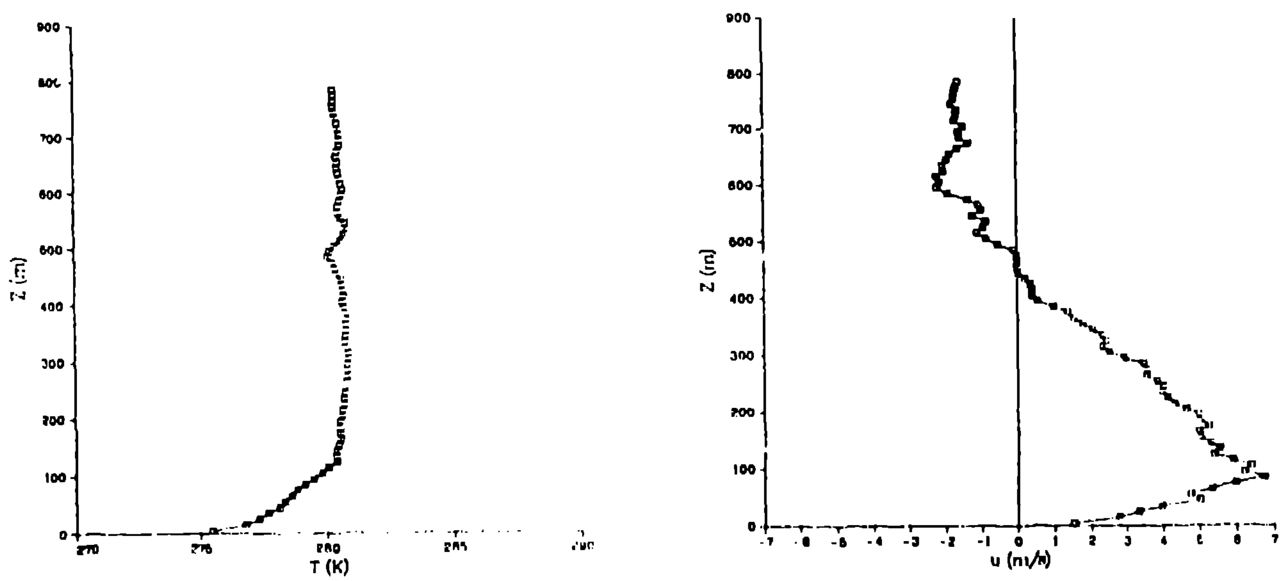


September 20, 0100 - 0600 MST

Fig. 1. Mean (0100 to 0600 MST) vertical profiles of the temperature T and along-valley wind speed u measured at the LANL site in Brush Creek.



September 26, 0100 - 0600 MST



September 30, 0100 - 0600 MST

Fig. 3. (Continued) Mean (0100 to 0600 MST) vertical profiles of the temperature T and along-valley wind speed u measured at the LANL site in Brush Creek.

If we assume that the along-valley wind speed obtained from the tethered balloon profiles is the maximum wind speed $u^*(z)$ in Eq. (7) and, for lack of other data, that the temperature field is horizontally homogeneous, we can estimate the along-valley fluxes of Eqs. (3-6) by

$$F_Q = K_Q \int_0^D Q u^*(z) W(z) dz \qquad (9)$$

where $W(z)$ is the valley width at z.

5. RESULTS

The profiles of temperature and along-valley wind speed averaged from 0100 to 0600 MST for the four nights are shown in Fig. 3. As mentioned above the temperature profiles are characterized by a strong surface based inversion overlayed by a quasi-isothermal region. The potential temperature calculated from the temperature profiles increases throughout the depth of the valley on all nights. Hence, although the strong inversion occurs in the lowest 200 m, the entire depth of the valley atmosphere is stable.

The along-valley wind speed profiles show a strong low-level jet in the katabatic wind. This gradually gives way to the opposing flow at higher elevations. Profiles of the cross-valley wind speed (not presented here) show only small components in the katabatic layer indicating that the flow is reasonably aligned along the chosen valley axis.

Table 1 summarizes some of the mean physical properties of the nocturnal katabatic wind determined from the profiles in Fig. 3. The depth of the katabatic wind filled the valley on 9/18 when the the ridgetop wind was very weak. Since in the four cases examined the along-valley component of the ridgetop wind was upvalley, one would expect that its strength would affect the katabatic wind. Figure 4 shows the linear relationship that exists between the depth D of the katabatic wind and the ridgetop wind speed S_{rt}. The data also indicate that the maximum wind speed u_m in the katabatic jet varies linearly with the surface inversion strength SIS as shown in Fig. 5. The height z_m of the jet is, to within experimental uncertainties, related to D by

$$z_m/D = 0.20 \qquad (10)$$

Table 1

Properties of the Katabatic Wind.

Property	Date 18	20	26	30
S_{rt} (m/s)	0.3	2.7	5.6	2.7
D (m)	605	455	375	435
SIS (K/100 m)	2.9	3.2	2.5	4.3
u_m (m/s)	5.3	5.9	4.9	6.3
z_m (m)	100	85	95	85

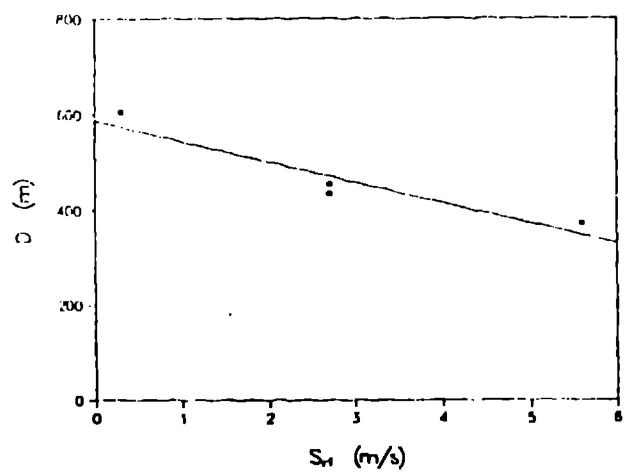


Fig. 4. Depth of katabatic wind as a function of ridgetop wind speed. The solid line is a least squares fit to the data.

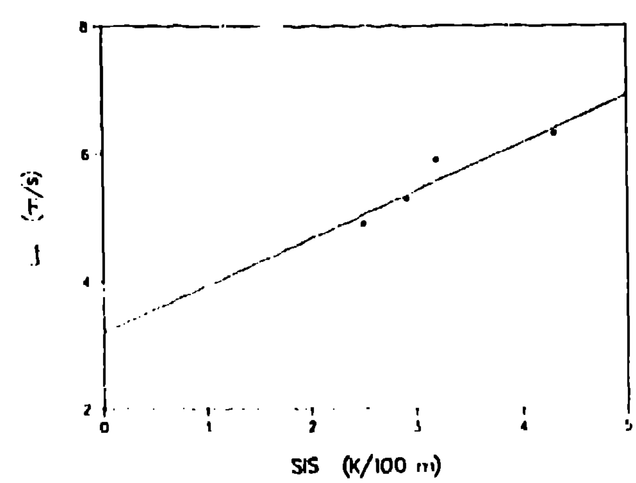


Fig. 5. Maximum wind speed in the katabatic jet as a function of the surface inversion strength. The solid line is a least squares fit to the data.

Table 2 gives the along-valley fluxes of mass, momentum, kinetic energy, and internal energy generated by the katabatic wind on each of the four nights. The momentum, kinetic energy, and internal energy fluxes are included for reference, but discussions of them are beyond the scope of this paper.

Table 2

Along-Valley Fluxes.

Flux	Date 18	20	26	30
Mass[1]	0.91	0.71	0.43	0.68
Momentum[2]	2.4	2.2	1.1	2.2
K. E.[3]	7.9	8.0	3.8	8.6
I. E.[4]	0.19	0.15	0.09	0.14

[1] 10^6 kg/s
[2] 10^6 (kg m)/s^2
[3] 10^6 J/s
[4] 10^{12} J/s

The mass transported by the katabatic flow ranges from 0.4 to 0.9 million cubic meters per second. A strong correlation exists between the mass flux and the ridgetop wind speed as shown in Fig. 6. This again is expected since in all cases the along-valley component of the ridgetop wind opposes the katabatic wind. Extrapolation of the data of Figs. 4 and 6 would indicate that a ridgetop windspeed of 10-15 m/s might prevent the establishment of the nocturnal katabatic wind in the valley.

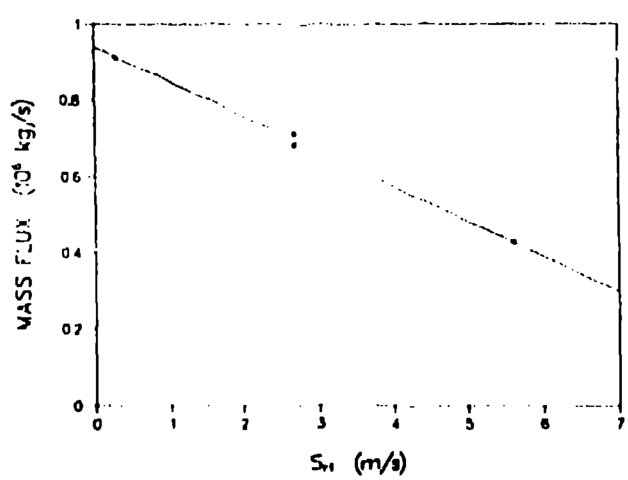


Fig. 6. Mass flux in katabatic wind as a function of the ridgetop wind speed. The solid line is a least squares fit to the data.

6. SUMMARY

Some physical properties of the nocturnal katabatic wind in Brush Creek, Colorado have been examined for four nights when the ridgetop wind had an upvalley component. If these four cases can be considered representative of this situation in Brush Creek, then the following mean characteristics of the katabatic wind can be expected

$$SIS = 3.2 \pm 0.8 \quad K/100\ m$$

$$D = 470 \pm 100 \quad m$$

$$u_m = 5.6 \pm 0.6 \quad m/s$$

$$z_m/D = 0.2 \pm 0.03$$

$$\text{mass flux} = (0.7 \pm 0.2) \times 10^6 \ kg/s$$

The maximum wind speed u_m in the katabatic jet increases linearly with the surface inversion strength SIS. Furthermore, the depth and the mass flux decreases linearly with increasing ridgetop wind speed. These relationships suggests that a ridgetop wind speed of 10-15 m/s may completely cut off the katabatic wind.

7. ACKNOWLEDGEMENTS

This research was performed under the auspices of the U. S. Department of Energy. Los Alamos National Laboratory is operated by the University of California.

8. REFERENCES

Clements, W. E. and D. E. Hoard, The Cross-Valley Structure of the Nocturnal Along-Valley Wind in Brush Creek, Colorado, Proceedings of the Fourth Conference on Mountain Meteorology, August 25-28, 1987, Seattle, WA, American Meteorological Society, Boston, MA, 1987.

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