A Statistical Model for Wind Prediction at a Mountain and Valley Station Near Anderson Creek, California

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ABSTRACT

Statistical models for surface-wind predictions at a mountain and a valley station near Anderson Creek, California, have been constructed. It is found that the surface wind speed depends primarily on the slope wind, cross-isobaric angle, surface thermal stability and geostrophic wind. The correlations between the calculated and observed surface wind speeds are found to be high for all time periods of the day and night.

Because the variability of wind direction, which is greatly affected by topography, geostrophic wind and turbulent motion, is generally larger than that of the surface wind speed, statistical models for wind direction are more complicated than those for the wind speed. It is found that wind direction depends primarily on the geostrophic wind direction, aspect angle of the topography, up-canyon direction and cross-isobaric angle in the boundary layer.

1. Introduction

Studies of relations between the geostrophic wind, heat transfer and surface wind are basic in the understanding of the mechanism for the maintenance of the kinetic and thermal energies associated with the mean and turbulent motions in the atmospheric boundary layer. For example, Lettau (1959), Kazanski and Monin (1960), Csanady (1967), Blackadar and Tennekes (1968) and Brown (1974) have analyzed the relations for the atmospheric and oceanic boundary layers under stationary, horizontally homogeneous and neutral stability conditions. Zilitinkevich *et al.* (1967), Zilitinkevich and Chalikov (1968), Clarke (1970, 1972), and Arya (1975) have extended the investigation to include the effect of vertical heat flux. However, all these studies have emphasized the geostrophic drag relations in the atmospheric boundary layer over flat surfaces.

The purpose of this paper was to seek statistical relations between the geostrophic wind, vertical heat flux and surface wind, under nonstationary conditions, in the atmospheric boundary layer near Anderson Creek, California (Fig. 1). The mountain and valley stations correspond to the locations of SRI-1 and SRI-5, shown in Fig. 1, respectively. The mountain station SRI-1 is located at a ridge crest of Cobb mountain and the valley station SRI-5 in a saddle at the center of Cobb valley. The data base for testing the model in this paper is small. However, the technique is promising.

2. Wind-speed model

Winds in complex terrain are greatly affected by the topography, pressure gradient force, thermal stability and cross-isobaric angle at the surface. To formulate a statistical equation for the surface wind speed in complex terrain, we assume that the ratio of the surface wind speed $V(t)$ to the geostrophic wind speed $G(t)$ takes the following form

$$\frac{V(t)}{G(t)} = a_1\left|\frac{V_s(t)}{G(t)}\right| + a_2\alpha_0(t) + a_3\mu(t) + a_4\,, \quad (1)$$

where $V_s(t)$ is the slope wind speed, $\alpha_0(t)$ is the cross-isobaric angle, $\mu(t)$ is a nondimensional thermal stability parameter. The term $V_s(t)/G(t)$ is taken by absolute value denoted by $|\ \ |$. The values of both α_0 and μ can be obtained from a nomogram determined empirically with the use of Wangara data (Arya, 1975) as a function of Rossby number,

$$\mathrm{Ro} = \frac{G(t)}{fz_0}\,, \quad (2)$$

and bulk stability number,

$$S = \frac{g[\theta_g(t) - \theta_0(t)]}{f\bar{\theta}(t)G(t)}\,, \quad (3)$$

where g is the gravity acceleration, $f = 2\Omega \sin\phi$ is the Coriolis parameter, $\theta_g(t)$ and $\theta_0(t)$ are respectively the potential temperature at the geo-

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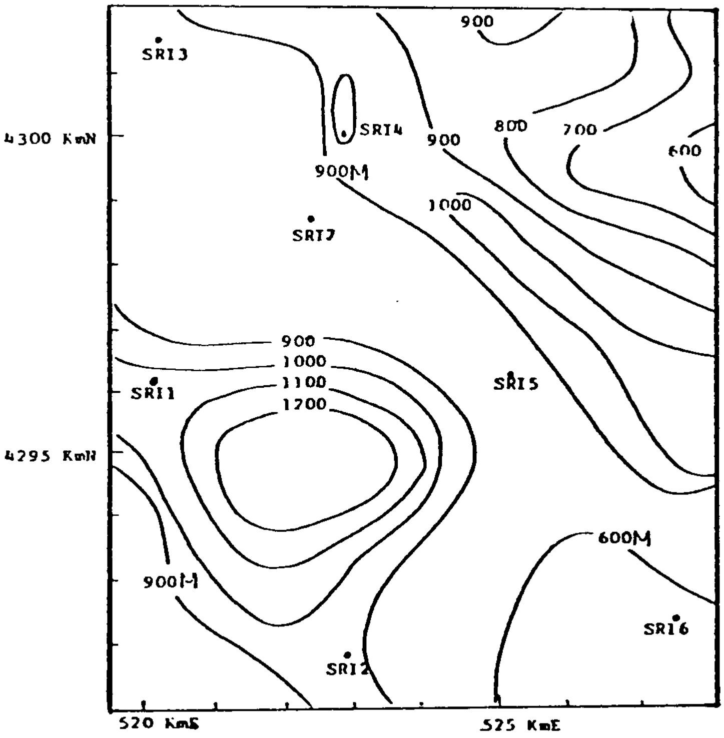

FIG. 1. Topographic configuration near Anderson Creek.

strophic wind level and at $z = z_0$, and $\bar{\theta}(t) = [\theta_g(t) + \theta_0(t)]/2$.

The slope wind is generally a function of the slope of the terrain, time of day, solar insolation and sky condition. The solution is based primarily on relationships developed by Petkovsek and Hocevar (1971) and Ryan (1974). Thus

$$V_s(t) = A\frac{(I - C_n)}{\tan S}[1 - \exp(-1.5\Delta t \tan^2 S)], \quad (4)$$

where $A = 0.895$ [unit: (m sec^{-1}) (cal min^{-1})$^{-1}$ cm^{-2}], I is the solar insolation [unit: (cal min^{-1}) cm^{-2}], C_n is a function of nighttime sky covering with $C_n = 0.67$ for cloud cover less than 0.5 and $C_n = 0.34$ for cloud cover greater than 0.5, Δt is the elapsed time in decimal hours since sunrise for upslope flow or from 2 h before sunset until 2 h after sunrise for downslope flow, and S is the slope of the terrain.

In order to calculate the coefficients a_i in Eq. (1), the meteorological data collected near Anderson Creek, California, from 1 to 20 August 1977, were used for this study. The coefficients a_i should be determined from a larger good observation data set which, unfortunately, is not available, particularly from a mountain-valley site. The technique for determining coefficient a_i is a method of stepwise multiple regression analysis which is a statistical technique for analyzing a relationship between a dependent variable and a set of independent variables and for selecting the independent variables in the order of their importance. The values of coefficients a_i for the mountain and valley stations in this study for the eight time periods (3 h for each time period) since midnight are listed in Tables 1 and 2.

Table 3 shows the correlation coefficients between the observed and calculated surface wind speed for

TABLE 1. Values of coefficients a_1, a_2, a_3 and a_4 for the mountain station at various time periods.

	Time period							
	1	2	3	4	5	6	7	8
a_1	0.719	0.485	−54.466	−3.257	5.652	8.166	12.996	0.719
a_2	0.022	0.029	0.006	0.026	−0.022	−0.060	−0.054	−0.049
a_3	0.005	−0.002	−0.002	0.004	0.005	0.011	0.006	0.005
a_4	0.629	−0.838	−5.554	−0.767	0.626	1.861	1.501	1.343

TABLE 2. Values of coefficients a_1, a_2, a_3 and a_4 for the valley station at various time periods.

	Time period							
	1	2	3	4	5	6	7	8
a_1	0.152	−0.284	11.011	5.479	2.299	0.769	1.672	0.799
a_2	−0.001	−0.011	−0.049	0.023	0.032	0.013	−0.001	−0.003
a_3	0.001	0.003	0.008	−0.004	−0.005	0.001	−0.001	−0.001
a_4	0.038	0.357	1.394	−0.752	−0.890	−0.380	0.022	0.089

TABLE 3. Correlation coefficients between the observed and predicted wind speeds.

	Time period							
	1	2	3	4	5	6	7	8
Mountain	0.751	0.701	0.849	0.967	0.954	0.936	0.906	0.854
Valley	0.733	0.911	0.989	0.992	0.882	0.927	0.711	0.772

the eight time periods in the computed range (from 1 to 20 August 1977). It is seen that the correlation between the calculated and observed surface wind speed is high for all time periods of the day and night.

Figs. 2 and 3 show the observed surface wind speed (solid lines) and the predicted surface wind speed (dashed curves) with the use of large-scale predicted geostrophic wind speed $G(t)$ shown in Eq. (1) at the mountain and valley stations for the periods in the predicted range from 23 to 27 August 1977. In the test here for comparing the model results with observations, the geostrophic wind speed and direction were extracted from Northern Hemisphere Data Tabulations (1977) which are available from the National Climatic Center. It is found that the predicted surface wind speeds agree well with the observed; their correlations for 5-day periods at the mountain and valley station are 0.94 and 0.91, respectively. It may be concluded that the surface wind speed at the mountain and valley stations depends primarily on the slope wind, cross-isobaric angle, surface thermal stability and geostrophic wind.

3. Wind-direction model

Because the variability of wind direction, which is greatly affected by topography, geostrophic wind and turbulence intensity, is generally larger than that of wind speed, statistical models for wind-direction prediction in complex terrain are more complicated than those for wind speed. Wind direction is found to depend primarily on the geostrophic wind direction (D_g), the aspect angle (A_{sp}) and the up-canyon direction, of which the values for the mountain and valley stations are observed and listed in Table 4.

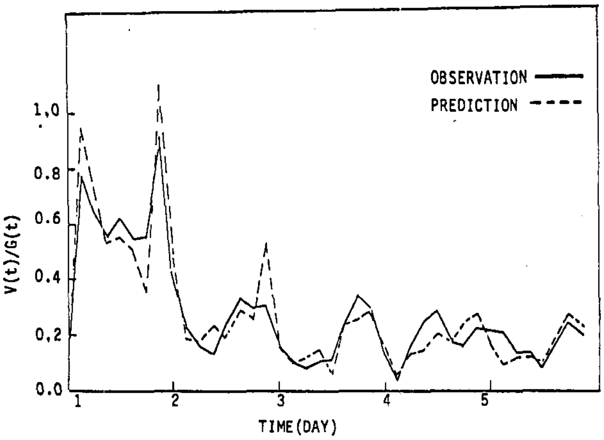

FIG. 2. Observed and predicted wind speeds at the mountain station.

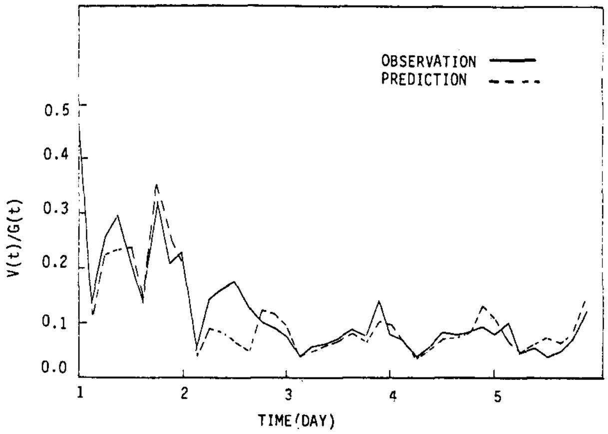

FIG. 3. Observed and predicted wind speeds at the valley station.

In view of the comparatively strong turbulent motion during the daytime, surface wind is more affected by the geostrophic wind than the topography of the terrain, whereas in the evening and early morning it is more affected by the terrain topography than the geostrophic wind. For this reason, statistical models for wind direction are classified according to time periods 3, 4, 5, 6 (daytime) and 7, 8, 1, 2 (evening and early morning). The wind direction models for the mountain and valley stations are as follows:

Mountain station SRI-1

If $D_g > A_{sp}$,

$$D = D_g - 0.32(D_g + \alpha_0 - A_{sp}), \quad \text{for periods 3, 4, 5, 6}$$

$$D = D_{uc} - 0.50(D_g - A_{sp}), \quad \text{for periods 7, 8, 1, 2}$$

If $180° < D_g \leqslant A_{sp}$,

$$D = D_g + 0.32(D_g + \alpha_0 - A_{sp}), \quad \text{for all periods}$$

If $D_g \leqslant 180°$,

$$D = D_g + \alpha_0 \quad \text{for all periods.}$$

TABLE 4. Terrain constants for the mountain and valley stations.

	D_{uc} (Upcanyon direction)	A_{sp} (Aspect angle)	S (Slope of terrain)
Mountain	45°	200°	4.5°
Valley	−15°	230°	5.4°

Valley station SRI-5

If $D_g > A_{sp} - \alpha_0$,

$$D = D_g - 0.50(D_g + \alpha_0 - A_{sp}), \quad \text{for periods 3, 4, 5, 6}$$

$$D = D_{uc} \quad \text{for periods 7, 8, 1, 2}$$

If $180° - \alpha_0 < D_g \leqslant A_{sp} - \alpha_0$

$$D = D_g + 0.50(D_g + \alpha_0 - A_{sp}), \quad \text{for periods 3, 4, 5, 6}$$

$$D = D_{uc} - 0.80(D_g + \alpha_0 - A_{sp}), \quad \text{for periods 7, 8, 1, 2}$$

If $D_g \leqslant 180° - \alpha_0$,

$$D = D_{uc} \quad \text{for all periods.}$$

Comparing the observed and calculated wind directions, we have found that the differences (Δ) between the calculated and observed wind directions having the following percentages for the mountain and valley stations are

Mountain station SRI-1

$\Delta < 20°$	47.8%
$20° \leqslant \Delta < 40°$	14.0%
$40° \leqslant \Delta < 60°$	5.8%
$60° \leqslant \Delta < 80°$	3.0%
$\Delta < 80°$	29.0%

(Observed mean wind direction: 152°; standard deviation: 86°)

Valley station SRI-5

$\Delta < 20°$	52.2%
$20° \leqslant \Delta < 40°$	16.9%
$40° \leqslant \Delta < 60°$	6.6%
$60° \leqslant \Delta < 80°$	4.3%
$\Delta < 80°$	20.0%

(Observed mean wind direction: 30°; standard deviation: 65°).

4. Conclusions and discussion

Statistical models for surface wind predictions at a mountain and a valley station near Anderson Creek, California, have been constructed. It is found that the surface wind speed depends primarily on the slope wind, cross-isobaric angle, surface thermal stability and geostrophic wind. The correlations between the calculated and observed surface wind speeds is found high for all time periods of the day and night.

Because the variability of wind direction, which is greatly affected by topography, geostrophic wind and turbulent motion, is generally larger than that of the surface wind speed, statistical models for wind direction are more complicated than those for the wind speed. It is found that wind direction depends primarily on the geostrophic wind direction, aspect angle of the topography, up-canyon direction and cross isobaric angle in the boundary layer.

We agree with a reviewer's comments that as the geostrophic wind speed increases, the surface direction over the topography would depend more on dynamic channeling effects. Perhaps an additional stratification of the data by geostrophic wind speed would improve the predictability.

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