Analysis

ESTIMATING SURFACE WIND VELOCITIES ON AN ISOLATED MOUNTAIN BY EXTRAPOLATION AND INTERPOLATION

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ABSTRACT

Accurate estimates of windspeed and direction are often needed in remote mountainous areas where no observations are available. Such estimates are useful in natural resources management activities including wildfire suppression, prescribed fires, application of pesticides, and monitoring speed and movement of smoke and air pollution. In a study at San Antonio Mountain in north-central New Mexico near Antonito, Colorado, extrapolation and interpolation of surface wind velocities were compared. The methods compared were estimating surface winds at remote locations by extrapolating from nearby surface locations, extrapolating from 700-mb winds, and interpolating between two surface locations. Interpolation between two stations provided more accurate estimates of wind velocity than did extrapolation from a nearby surface observation station or from 700-mb winds. The error of the estimated surface winds extrapolated from 700-mb winds was relavitely small. Error was often as low as, and in some cases less than, error from estimates made by extrapolation from surface observations. Proximity of observation stations to remote stations was positively correlated to the accuracy of estimates.

1. INTRODUCTION

Accurate estimates of wind speed and direction are often required in remote mountainous areas where no observations are available. Such estimates are needed for natural resources management activities, including wildfire suppression, prescribed fires, application of pesticides, and assessment of the speed and direction of movement of smoke and air pollution. Often no surface observations are available in remote areas, and only upper-level observations and forecasts are available. Often, extrapolation—estimating outside the observation field, or interpolation—estimating between two or more observations is difficult because of spatial and diurnal variation in wind velocity caused by slopes, canyons or valleys, and of the sheltering and diverting effects of the terrain (2). Establishing and maintaining surface stations is expensive. And so, it is important to know what, if any, increase in extrapolation or interpolation estimation accuracy can be gained from additional surface observations. To perform objective extrapolation and interpolation, a mathematical model was used (3). The efficacy of using techniques of the model in this area of simple topographic features was tested previously in a case study for 1 day at two observation locations (4).

This paper compares the extrapolation and interpolation of hourly surface wind velocities during September, 1981, on an isolated mountain in north-central New Mexico.

2. DATA

Data for this study were collected from the nine-station experimental network (Figure 1) on San Antonio Mountain (5) an isolated conically-shaped mountain rising about 800 meters above the nearly flat and level San Luis Valley in north-central New Mexico, 125 km north of Los Alamos (Figure 2). The terrain includes no significant canyons or gulleys, and winds are not influenced by any bodies of water. Typical of mountainous areas is the difficulty of establishing similar exposures for anemometers and vanes at all locations. For example, some station sites were on higher ridges, one was near the peak, some were near trees, while others were in grass or brush covered areas. Five stations—1, 2, 3, 6 and 7 — measured winds at 10 m above the tower base and the other four measured winds at 2.5 m. Directions and speeds were averaged over 2-minute periods. The instrumentation at Station 1 was from Electronics Techniques, Inc. (6), those at Stations 2, 3, 6 and 7 were from Handar (6), and the other four from Climatronics (6). Several stations did not record data for the first 12 or 13 days of the month. Station 4 began recording at 1700 GMT on 12 September 1981, followed on 13 September by Station 5 at 0000 GMT, Station 8 at 2000 GMT and Station 9 at 2100 GMT.

Hourly geostrophic winds at 700 mb were interpolated from 12-hourly National Weather Service RAWINSONDE observations, between locations separated by more than 160 km, to the area above the mountain (Figure 3). Interpolation between RAWINSONDE stations was done with considerable subjectivity from analyses and observations. Interpolation of these estimated wind velocities to the area over the mountain for each hour was done by straight-line interpolation from the 0000 GMT and 1200 GMT east-west and north-south vectors.

3. GENERAL WEATHER SITUATION

Frontal passages, with little rain, occurred every 3 to 4 days during September, 1981. Twenty-seven of the 60 wind directions interpolated from RAWINSONDE observations to 700 mb over the study area during the month were between 270° and 360°. Three-fourths of the interpolated directions had a component from the west. Windspeeds during the month interpolated to 700 mb over the study site were between 3 and 20 knots. Only eleven of these were greater than 10 knots; four were 20 knots, and seven were 15 knots.

4. METHOD

Wind speed and direction at surface observation locations were estimated each hour of the month by three methods: (a) extrapolation from upper-level winds, (b) extrapolation from a nearby surface observation, and (c) interpolation between two surface stations. Winds estimated by each of the three methods were compared with observed winds and the error of estimation determined for each hour.

Four stations, 1, 3, 6, and 7, were chosen as key stations from which to extrapolate to other stations. Stations 1, 3, 5, 6, and 7 were used for interpolation. Station 1 was chose to investigate if, as a peak station, it had any special advantage as a station from which to extrapolate or interpolate. The other stations were chosen because they were in a straight line across San Antonio Mountain, and all had instrumentation at the same height above the ground. More stations were not used because of the large amount of computation needed for each station.

In the first method, the geostrophic wind over the area at 700 mb was extrapolated to anemometer height at each station. The first estimate using this method was made by assuming that the wind at the remote site was the same as the 700-mb wind. The second estimate included model technique estimates of the effects of the terrain on the change of wind velocity from 700 mb to near the surface. The error in the estimated velocities, as compared with the surface observations at the remote location, were then computed for each hour of the month and the mean errors for the month were calculated.

In the second method, observed winds at each of Stations 1, 3, 6, and 7 were extrapolated to the other eight locations. The first estimate using the second method was made by assuming the winds at the remove site were the same as the observed winds. The second estimate included model simulation techniques to estimate effects of topography. These estimated velocities are subtracted from observed wind velocities to estimate what the wind velocity would have been if the terrain were featureless and not near a body of water. This normalized component is referred to as the General Wind. The effects of the topography at the nearby remote site were estimated and added to the General Winds, under the assumption that the General Winds at the observation site were the same as at the remote location. Errors in these estimates were calculated for extrapolations from each one of the four key-stations to the other eight stations in the network. In the third method, observed winds on opposite sides of a remote site were interpolated to the remote site. The first estimate was made by interpolating these observed winds directly to the remote location using the relationship in equation (1)

$$C_i = \sum_{K=1}^{M} C_k r_k^{-2} \Big/ \sum_{K=1}^{M} r_k^{-2} \qquad (1)$$

in which C_i is the interpolated value of u_e, u_o, v_e, or v_o; C_k is the estimated or observed wind component at the k^{th} easuring station; and r_k is the distance from the remote station to an observation station. The r^{-2} istance-weighting factor was based on results reported by Goodin and others (7). The second estimate was made by using the model techniques to find the General Wind at each of the two observation stations, interpolating them to the remote site using relationship 1, and then using the model techniques again to estimate and add in the effects of the topography at the remote site on the wind.

Interpolation from several pairs of stations was used to estimate winds at Station 2, 4, and 6. Five cases were studied. At Station 2 winds were estimated by interpolation between Stations 1 and 3, and between 6 and 3; at Station 4 by interpolation between Stations 1 and 5; and at Station 6 by interpolation between 3 and 7 and 1 and 7.

Comparisons were quantified by computing the magnitude of the mean absolute (MMA) vector error of estimation for the month:

$$e = \sum [(u_e - u_o)^2 + (v_e - v_o)^2]^{1/2}/N \qquad (2)$$

and the magnitude of the mean (MM) vector error:

$$E = \{[\sum (u_e - u_o)]^2 + [\sum (v_e - v_o)]^2\}^{1/2}/N \qquad (3)$$

where u_e is the east-west component of the estimated wind, u_o is the east-west component of the observed wind, v_e is the north-south component of the estimated wind, v_o is the north-south component of the observed wind, and N is the number of observations for the month. Ratios of both of these error statistics to the mean wind speed at the remote station for the month were also computed. The mean speed and direction errors, the mean absolute speed and direction errors, and the standard deviation of the errors for each method for September, 1981 were computed.

5. RESULTS

A comparison of the error statistics calculated for all of the stations using interpolation between two surface stations yielded better results than did extrapolation from any surface station or from 700-mb winds (Figures 4 and 5). The five interpolations gave an average MMA vector error/mean wind speed ratio of 0.6 and an average MM vector error ration of 0.16. The average MMA vector error ratio for extrapolation to the same locations varied from 0.77 to 1.2, and the MM vector error ratio varied from 0.17 to 0.51. For interpolation, the average absolute direction error calculated was 30^o, and the average absolute speed error 1.32 m/s. But for extrapolation, the direction error was 50^o and the speed error 1.86 m/s. Estimates by interpolation resulted in less error than any of the estimates obtained by extrapolation. Mean winds for the month varied from 3.3 m/s at Station 2 to 5.2 m/s for Station 8.

Extrapolation from the 700-mb level modified by estimates of the effects of surface friction and sheltering and diverting of the wind by the terrain gave relatively good results. The average MMA vector error ratio for extrapolation to all surface stations was 0.83. This ratio was better (smaller) than six of the nine other average error ratios. The average error ratio for extrapolation from surface stations was over 0.9.

Proximity was an important factor (Figure 6). Errors tended to increase as the distance of the observation station from the remote station increased. This relationship is reasonable because the error under the assumption that the General Wind was the same at the remote location as at the observation station would tend to increase as the distance increased.

7. CONCLUSIONS

This study demonstrated the relative effectiveness of three methods of estimating surface winds in remote areas. In the relatively smooth terrain of San Antonio Mountain, interpolation gave significantly more accurate results than did the other methods. But the extrapolated 700-mb winds, modified by the estimated effects of surface friction and sheltering and diverting of the terrain, gave comparatively good results. Any forecasts of surface winds depend on the upper-level forecasts, such as the National Weather Service's LFM forecasts. No comparable surface forecasts are available on which to base interpolation or xtrapolation. Proximity of the observation site to the remote location improved the accuracy of extrapolation. In more complex terrain, especially where a deep canyon or sea breeze may influence the flow, interpolation may lose some of its advantage over extrapolation. And proximity may also lose much of its importance until the locations are close enough to be on the same terrain feature. The greater spatial and diurnal variation of winds in more complex terrain is an important factor. More study in other types of terrain has to be completed before broader generalizations can be made.

FOOTNOTES AND REFERENCES

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7. Goodin, W. R., G. J. McRae, and J. H. Seinfeld, 1979: A comparison of interpolation methods for sparse data: Application to wind and concentration fields, J. Appl. Meteorol., 18, 10 pp.

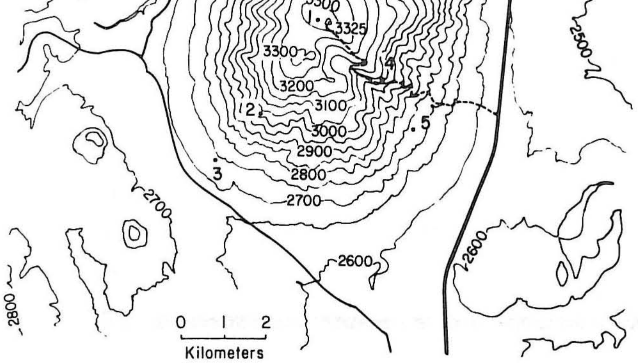


Figure 1. Nine observation stations were set up on San Antonio Mountain to estimate wind speed and direction. Contours are expressed in meters.

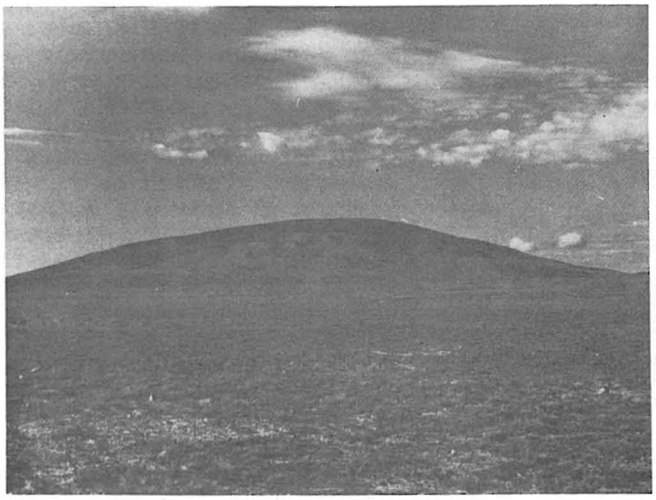
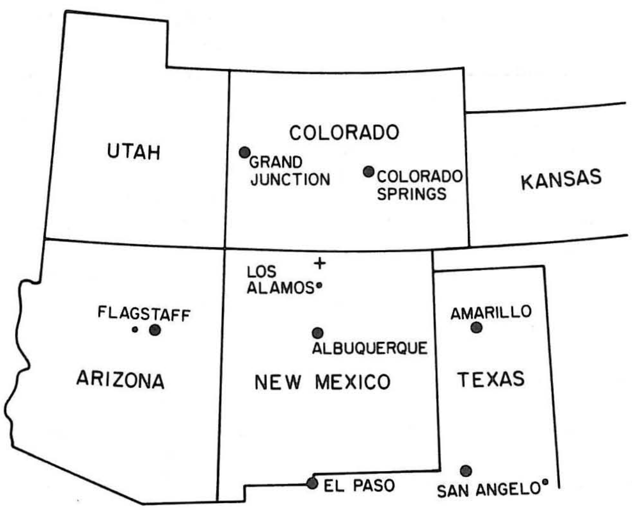


Figure 2. San Antonio Mountain, looking south-southwest, lies a few miles south of Antonito, Colorado.

Figure 3. San Antonio Mountain (+) lies north of Los Alamos, New Mexico. Upper-level winds over San Antonio Mountain must be interpolated from RAWINSONDE observations (•). Small dots indicate locations of some nearby cities.



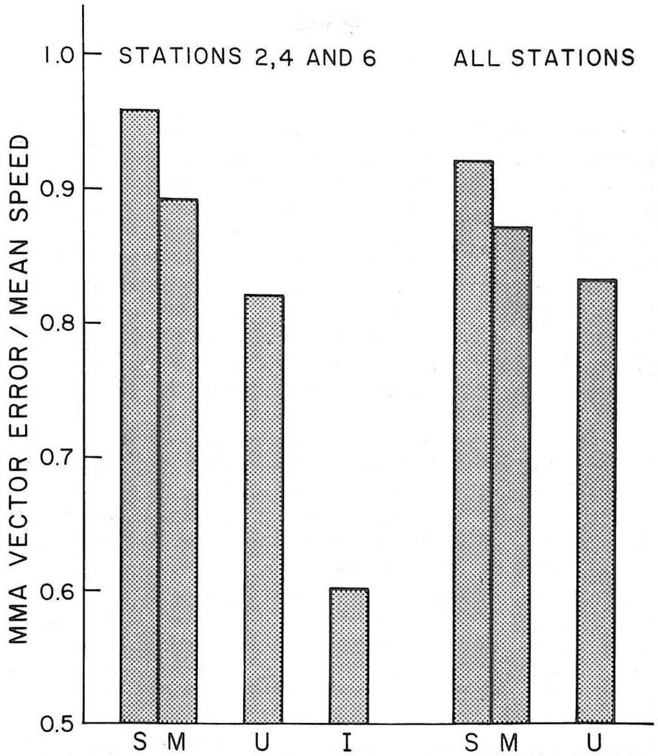


Figure 4. Average ratios of the magnitudes of the mean absolute vector errors to the mean wind speeds at each of the stations for September 1981.
s: surface observations used for extrapolation
m: surface observations with modification to estimate terrain and topographic effects used for extrapolation.
u: upper level observations with modification to estimate terrain and topographic effects used for extrapolation.
I: surface observations used for interpolation.

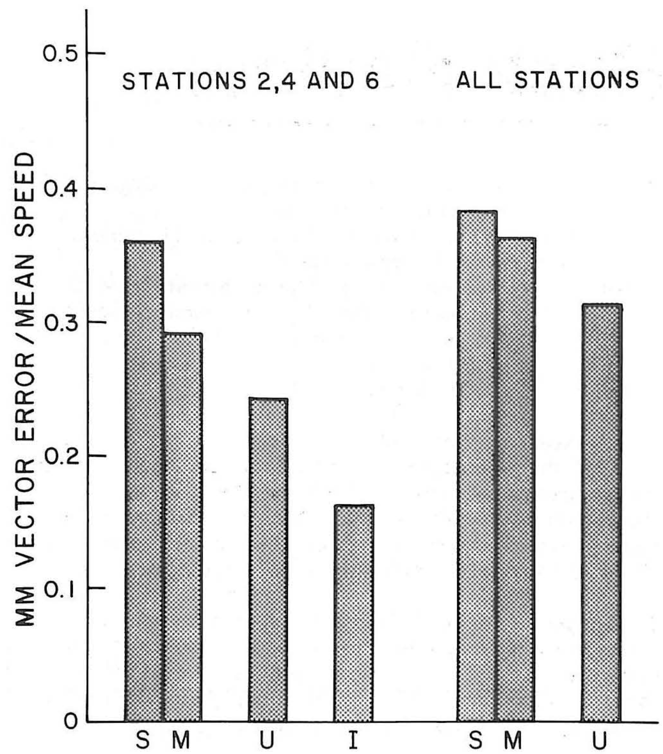


Figure 5. Average ratios of the magnitudes of the mean vector errors to the mean wind speeds at each of the stations for September 1981.
s: surface observations used for extrapolation.
m: surface observations with modification to estimate terrain and topographic effects used for extrapolation.
u: upper level observations with modification to estimate terrain and topographic effects used for extrapolation.
I: surface observations used for interpolation.

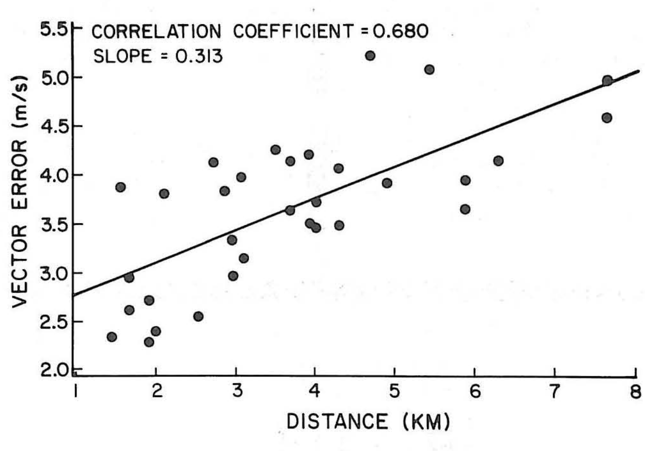


Figure 6. The magnitude of the mean absolute vector errors and distance between the observation site and remote surface location.