NOTES AND CORRESPONDENCE

Shear Effects on Wind Interpolation Accuracy

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ABSTRACT

The dependence of wind interpolation accuracy on vertical shear was investigated using routine and supplemental rawinsonde data collected during the Cross Appalachian Tracer Experiment. Spatial interpolation error distributions for horizontal wind components were stratified by the "bulk" shear within the mixed layer. Results indicated that interpolation errors were approximately proportional to vertical wind shear.

1. Introduction

Recent papers by Kahl and Samson (1986) and Kuo et al. (1985) have shown that interpolation of rawinsonde data leads to errors in trajectory calculations. Kahl and Samson (1986) found that mean absolute errors in spatial and temporal interpolation of horizontal wind components ranged from 2 to 4 m s^{-1}. A weak relationship between spatial interpolation errors and wind speed was observed, suggesting that interpolation accuracy may be systematically dependent on vertical shear.

Vertical wind shear almost always exists due to the interaction of wind with the ground, but it is often intensified by mesoscale events such as frontal passages, nocturnal stratification, or complicated flow patterns around uneven terrain. Situations such as these are usually associated with *horizontal* as well as vertical shears. Horizontal shear decreases the autocorrelation of wind observations between adjacent rawinsonde stations, which in turn reduces the interpolative value of nearby measurements. Interpolation errors would therefore be expected to increase during conditions of elevated wind shear.

This note extends the earlier analysis of Kahl and Samson (1986) to examine the accuracy of spatial interpolation under varying degrees of vertical wind shear. Theoretical studies have demonstrated that wind shear is the dominant dispersing mechanism for transport times greater than one day (e.g., Saffman 1962; Tyldesley and Wallington 1965; Csanady 1972; Draxler and Taylor 1982). Quantification of interpolation errors under shear conditions is therefore of special interest to the air pollution modeling community.

2. Procedure

The database and analysis procedures used in this study are described briefly below. For more detail, refer to Kahl and Samson (1986).

a. Data

Rawinsonde data collected during the Cross Appalachian Tracer Experiment (CAPTEX), conducted in the northeastern United States and southeastern Canada during September and October 1983, were used to evaluate spatial interpolation accuracy. Existing National Weather Service and Canadian stations in the experimental area were augmented with twelve supplemental stations (Ferber et al. 1986). Measurements at the supplemental rawinsonde stations were used as independent verification of estimates formed by interpolating surrounding wind measurements.

For each rawinsonde profile, the wind speed and direction at all reported levels were first transformed into west–east and south–north vector components (u and v). Vertical cubic spline interpolation was used to estimate values at evenly spaced (about 100 m) levels throughout the depth of the profile (surface to 500 mb). Errors associated with the vertical interpolation procedure have been shown to be 2% at most (Kahl and Samson 1986).

The splined wind components were vertically averaged throughout the "mixed layer" of the atmosphere. This layer extends from the surface to the first critical potential temperature inversion based above 300 m above ground level, as defined by Heffter (1980).

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The mixed layer was utilized because pollutant transport models often assume that material is uniformly distributed throughout this layer and transported by the vertically averaged wind.

b. Spatial interpolation

Mixed-layer wind components at each supplemental station were estimated using a weighted average of mixed-layer winds measured at all stations within a 350 km radius. A minimum of two observations were required in the interpolation procedure. The weights were defined as $1/r^2$, where r is the distance from the interpolation point to the measurement site. Estimates were formed once using the normally available National Weather Service and Canadian rawinsonde data (referred to as low resolution), and again with the CAPTEX supplemental rawinsonde data included (high resolution). No attempt was made to correct for observational errors or position errors resulting from balloon drift.

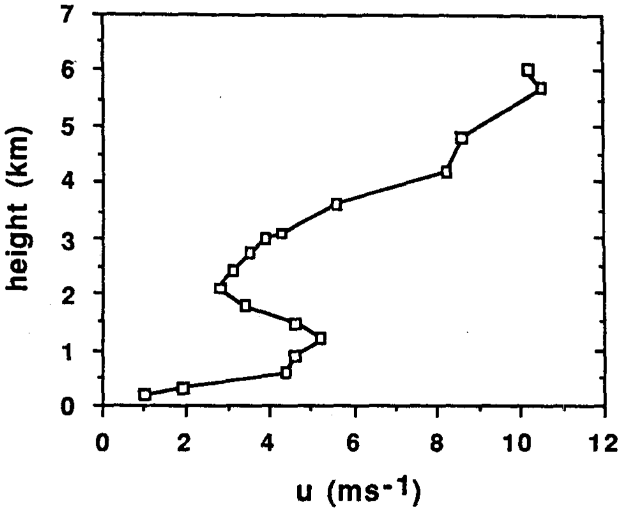

FIG. 1. Vertical profile of the u wind component measured at Maniwaki, Quebec, at 0000 UTC 1 September 1983.

c. Computation of vertical wind shear

The vertical wind shear vector **S** is usually defined as

$$\mathbf{S} = \frac{\partial \mathbf{V}}{\partial z}, \qquad (1)$$

where **V** is the horizontal wind velocity vector. Alternatively, the shear may be defined as a scalar

$$s = \frac{\partial V}{\partial z}, \qquad (2)$$

where V is the scalar wind *speed*. Heald and Mahrt (1981) noted that the shear can be computed as either

$$s \approx \frac{[(\Delta u)^2 + (\Delta v)^2]^{1/2}}{\Delta z} \qquad (3)$$

or

$$s \approx \frac{V_{\text{top}} - V_{\text{bot}}}{\Delta z} \qquad (4)$$

where Δ refers to finite differencing between the top (top) and bottom (bot) of the layer, and V is the magnitude of the wind vector $[V = (u^2 + v^2)^{1/2}]$. Application of either (3) or (4) on a wind profile such as that shown in Fig. 1 (only the u component is shown), however, would ignore the shear contained between 500 and 2000 m.

One goal of this note is to define the magnitude of the total shear throughout the mixed layer. Thus, a shear parameter was required that characterized both speed and directional shear in a layer containing multiple measurement levels. Equations (3) and (4) may be revised to form a "bulk" shear parameter $\langle s \rangle$ that considers variations in speed and direction throughout the entire layer rather than at the top and bottom only. This is

$$\langle s \rangle \approx \frac{[(\sum_{i=1}^{n-1} \Delta u_i)^2 + (\sum_{i=1}^{n-1} \Delta v_i)^2]^{1/2}}{h}, \qquad (5)$$

where

$$\Delta u_i = |u_{i+1} - u_i|, \qquad (6)$$

$$\Delta v_i = |v_{i+1} - v_i|, \qquad (7)$$

h is the depth of the mixed layer and n is the number of measurement levels.

One useful property of (5) is its independence of n. Although increasing n adds more terms to the numerator of (5), it also decreases the finite differences in (6) and (7). This technique may therefore be applied to raw wind profiles without applying a vertical smoother. However, increasing n through vertical interpolation by cubic splines offers the advantage of identifying maxima and minima that may contribute to the total shear.

Bulk wind shear parameters according to (5) were calculated throughout the depth of the mixed layer for all CAPTEX-area[1] rawinsonde profiles in all of 1983. Mean mixed-layer depths and their standard deviations were 1658 m and 770 m for 0000 UTC profiles, and 1167 m and 772 m for 1200 UTC profiles. The shear distributions were divided into quartiles separately for daytime (1800 and 0000 UTC) and nighttime (0600 and 1200 UTC) soundings. Daytime and nighttime cases were treated separately because of the differences

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[1] The area bounded by 38°N and 47°N latitude, and 70°W and 85°W longitude.

TABLE 1. Mean absolute spatial interpolation errors (m s^{-1}) for mixed layer wind components measured at supplemental CAPTEX rawinsonde stations. Errors are stratified by the observed vertical wind shear $\langle s \rangle$. Interpolation of low- and high-resolution data is indicated by Low and High, and sample size is indicated by N.

		Interpolation errors				
		Low		High		
1983 shear quartile	Observed shear (m s^{-1} km^{-1})	u	v	u	v	N
	Daytime:					
1	$\langle s \rangle \leq 5.9$	1.9	2.9	1.5	2.1	31
2	$5.9 < \langle s \rangle \leq 8.5$	2.0	2.2	1.9	2.1	95
3	$8.5 < \langle s \rangle \leq 12.6$	2.6	2.9	2.1	2.3	140
4	$\langle s \rangle > 12.6$	3.2	3.6	2.9	2.7	107
	Nighttime:					
1	$\langle s \rangle \leq 7.8$	2.8	3.4	2.3	2.7	77
2	$7.8 < \langle s \rangle \leq 11.7$	3.4	3.0	2.7	2.4	117
3	$11.7 < \langle s \rangle \leq 18.0$	3.6	4.0	2.7	3.2	97
4	$\langle s \rangle > 18.0$	5.0	5.2	3.6	3.6	63

in meteorological processes that produce shear during these periods. The wind interpolation errors were stratified according to the observed shear $\langle s \rangle$ and assigned to the appropriate 1983 shear quartile.

3. Results

Table 1 contains mean absolute errors in spatial interpolation of mixed-layer wind components stratified by the observed level of wind shear. Results are presented for interpolation using both low-resolution and high-resolution data. The table shows that spatial interpolation errors were approximately proportional to vertical wind shear. Daytime interpolation of (u, v) wind components ranged from (1.9, 2.9) m s^{-1} in the lowest shear quartile to (3.2, 3.6) m s^{-1} in the highest quartile. Interpolation was less accurate during the night, presumably due to elevated wind shear associated with nocturnal stratification. The nighttime mean absolute errors ranged from (2.8, 3.4) to (5.0, 5.2) m s^{-1} from the lowest to the highest quartile. Errors were reduced by an average of 20%, when high resolution data were used.

Nonparametric statistical tests were conducted to determine whether the absolute interpolation error distributions differed significantly among the four shear quartiles.[2] The Kruskal–Wallis test indicated that for daytime interpolation, differences in (u, v) error distributions were significant only when low-resolution data were used. For nighttime interpolation, differences were significant for both low- and high-resolution data.

4. Conclusion

Interpolation of mixed-layer wind components measured during CAPTEX became less accurate as the vertical wind shear increased. Errors in mixed-layer trajectory calculations are therefore likely to increase when the trajectory encounters an area of elevated wind shear.

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[2] Analysis of variance techniques could not be used because the error distributions were non-normal. Significance tests were performed at the 0.05 level.