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3.5A EFFECTS OF LINE-OF-SIGHT VELOCITY ON SPACED-ANTENNA MEASUREMENTS

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INTRODUCTION

Horizontal wind velocities in the upper atmosphere, particularly the mesosphere, have been measured using a multitude of different techniques. Most techniques are based on stated or unstated assumptions about the wind field that may or may not be true. In this brief paper we will point out some problems with the spaced antenna drifts (SAD) technique that usually appear to be overlooked. These problems are not unique to the SAD technique; very similar considerations apply to measurement of horizontal wind using multiple-beam Doppler radars as well.

Simply stated, the SAD technique relies on scattering from multiple scatterers within an antenna beam of fairly large beam width (BRIGGS, 1980). The combination of signals with random phase gives rise to an interference pattern on the ground. This pattern will drift across the ground with a velocity twice that of the ionospheric irregularities from which the radar signals are scattered. By using spaced receivers and measuring time delays of the signal fading in different antennas, it is possible to estimate the horizontal drift velocities. Although the technique is quite simple in principle, the numerical calculations are plagued by a high degree of statistical uncertainties because small variations from an assumed model can give large errors in the estimated velocity.

It is to be understood that the SAD technique ultimately relies on differential line-of-sight velocities to calculate the horizontal wind. The differences are due to changing line-of-sight components of the horizontal wind as a function of changing look angle within the finite beam width of the antenna. A radar with an infinitely narrow transmitting antenna beam width can never be used as a SAD radar. Although much can be said about the problems of implementing a SAD radar system, we shall limit ourselves to considering interpretation of the results under ideal conditions of no system noise. That is, we shall assume we can accurately measure the drift velocity of the interference pattern over the ground, and consider what motions in the scattering layer may give rise to this drift velocity.

DISCUSSION

As already mentioned, only the line-of-sight velocity of a scattering irregularity will give rise to a drifting interference pattern (Figure 1). Calculation of the horizontal drift velocity of the scattering irregularities therefore requires that two assumptions be made. These are (1) the horizontal wind component is everywhere the same within the radar volume, and (2) the vertical wind component is small and everywhere the same within the radar volume. Any violations of these assumptions will result in errors in the estimated horizontal wind velocity. A short mathematical derivation of the result of relative motion within the radar volume was given by ROYRVIK (1983). The contribution to this error from motions of different scales will be discussed.

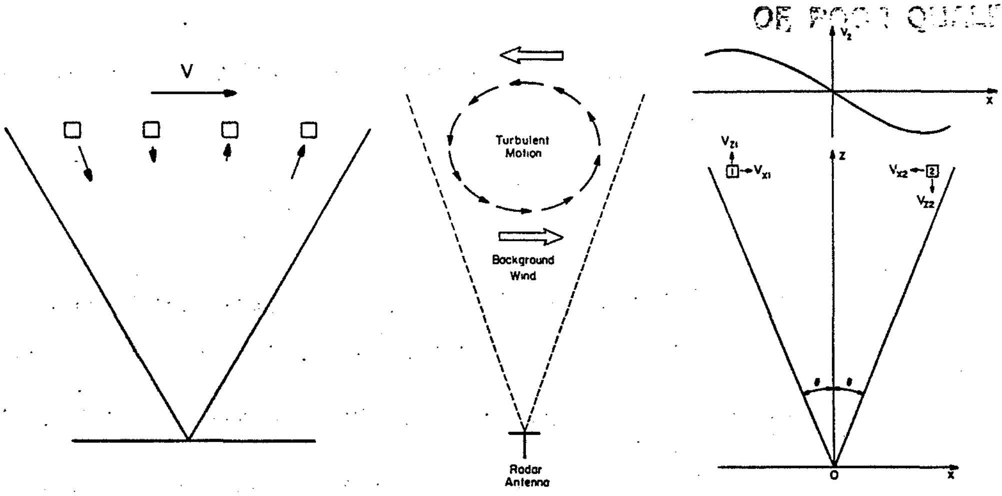

Figure 1. Schematics showing the differential wind velocities within a SAD radar scattering volume. Idealized vortex motion that may result from a wind shear (center); Radar situation with two scattering irregularities moving under the influence of a short-wavelength gravity wave (right).

(a) Differential Horizontal Motion

The average horizontal wind within a radar scattering volume which is limited by the antenna beam width in the horizontal direction and the range gate in the vertical direction, is due to oscillations with long horizontal wavelengths. The oscillations are caused mainly by long-period gravity waves and tides. Horizontal winds of the order of tens of meters per second are expected to result from these oscillations. In comparison, horizontal winds resulting from short-wavelength, short-period oscillations have amplitudes of only a few meters per second. Thus, even if these oscillations have horizontal wavelengths comparable to the horizontal dimension of the scattering volume, the error in the calculated horizontal velocity would not be more than 10% which in most cases is less than could be expected from statistical errors. Therefore we will not consider differential horizontal wind further.

(b) Differential Vertical Motion

The assumption that the vertical wind velocity is uniform throughout the radar volume does not hold true in most circumstances. There are three different length scales that can contribute to these vertical velocity differences. On the smallest scale are the turbulent velocity oscillations, which are considered to be randomly distributed throughout the scattering volume. They do not contribute to the measurement of the horizontal velocity in a systematic way; however, they contribute indirectly to the random error because increase in turbulent velocity will decrease the signal correlation time, which again makes the horizontal velocity more difficult to calculate (ROYRVIK, 1983). As the correlation time decreases, the irregularity pattern changes faster while drifting across the ground from one receiving antenna to another. Thus making the time sequences observed by the antennas become more dissimilar, and the time lag between them become more difficult to measure.

Vertical velocities that change systematically in the horizontal direction within the radar volume will contribute a large systematic error to the calculated horizontal velocity (ROYRVIK, 1983). The reason is that the SAD technique relies on changing line-of-sight velocity within the antenna beam; but, since it has no way to determine if the contribution is from horizontal or vertical wind, it assumes that there is a horizontal wind component only. If there is a differential wind component, however, it contributes much more efficiently to the line-of-sight velocity than does the horizontal wind and can contribute large errors. An antenna beam with angular half width of 10° is a factor of 5 more sensitive to vertical velocity differences than horizontal wind.

There are two different mechanisms that can generate differential vertical velocities with the required horizontal wavelength of one to twenty kilometers in the mesosphere. At the shorter end of this scale there are the organized motions resulting from overturning Kelvin-Helmholtz vortices with estimated horizontal wavelengths from a few hundred meters to a few kilometers. Differential vertical velocities of as much as 5 m/s may be generated. For a large antenna having very narrow beam width with cross section of 1 to 3 km in the mesosphere matching the dimensions of the vortices, this mechanism may account for calculated horizontal velocities of hundreds of meters per second. At the other end of the spectrum (10 km or more) short wavelength gravity waves will contribute to the calculated horizontal velocity. Doppler radars have shown that short-period waves in the mesosphere typically have amplitudes of 1-5 m/s, and the estimated horizontal wavelengths of these waves are from 20 km and upwards. Such waves combined with an antenna beam width of approximately 10° will give rise to oscillations in the estimated horizontal wind of 10-50 m/s. This error is of the same order of magnitude as the actual horizontal wind resulting from the tidal oscillations.

SUMMARY

From this discussion it should be evident that short-period oscillations observed by the SAD technique do not necessarily reflect oscillations in the horizontal velocity in the mesosphere. For oscillations with periods of one hour or more, the vertical velocity is very small compared to the horizontal velocity. The horizontal wavelength will also be large compared to the horizontal dimension of the radar volume. In this case the assumption of uniform wind within the scattering volume is valid, and the horizontal wind velocity can be measured accurately to within the statistical limitations of the SAD technique.

We conclude that the effect of vertical line-of-sight velocities is to preclude measurements of short-period horizontal wind oscillations.

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