3.2B SPACED ANTENNA DRIFT

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INTRODUCTION

The spaced antenna drift (SAD) technique has been used extensively for measuring horizontal wind by MF/HF radars (BRIGGS et al., 1950). Recently it has been suggested that this technique could also be successfully used by VHF radars (VINCENT and ROTTGER, 1980) and that it would be superior to a Doppler-beam-swinging (DBS) technique because it would take advantage of the aspect sensitivity of the scattered signal, and also might benefit from returns from single meteors. It appears, however, that the technique suffers from several limitations. On the basis of one SAD experiment performed at the very large Jicamarca radar it is concluded that the SAD technique can be compared in accuracy to the DBS technique only if small antenna dimensions are used.

A SAD experiment was run on the Jicamarca radar on October 17, 1981. The full antenna was used to transmit a 20 μsec pulse vertically, and the west, north, and east quarter sections were used for separate reception of the scattered signal. The 3 dB beam width of the transmitting antenna was only one degree, and the separation of the receiving antennas were 150, 150 and 211 m for the different pairs of antennas in the triangle. Horizontal velocities were calculated using the method of similar fades (BRIGGS and PHILLIPS, 1950 and FOOKS, 1965).

Minute-by-minute horizontal velocities were attempted calculated for five altitudes from 67 km to 79 km in the region of strong scattered power. Only about 50% of the minutes yielded a successfully calculated velocity, and a large fraction of these velocities were unreasonably large (>100 m/s). This compared to the vertical velocity that was successfully calculated in more than 90% of the minutes. Only by rejecting such large velocity points, and averaging the remaining velocities for one hour was it possible to get somewhat reasonable results. The reasons for this limited success are multiple, and since they all affect different size radars to a different degree we shall consider them separately and not try to give any detailed blame for the problems.

DEPENDENCE ON ANTENNA SIZE

It is possible to use separate transmitting and receiving antennas and thus the spacing between the receiving antennas can be chosen randomly. However, since it is more convenient to use sections of the transmitting antenna for reception we will consider only this possibility. BRIGGS and VINCENT (1973) have shown that such an arrangement results in a reasonably large cross correlation between the signals in any two antenna sections regardless of the actual antenna size, if it is assumed that the scattering is isotropic.

We shall first assume semi-isotropic and homogeneous scattering and show that the accuracy of the calculated horizontal velocity depends on the antenna size. We will also assume that the signal-to-noise ratio is large.

The true drift velocity of the irregularity pattern over a one-dimensional surface is given by (FOOKS, 1965)

$$V_t = \frac{(V_c')^2}{V'} .$$

Here $V' = \frac{d}{\tau'}$ and $V_c' = \frac{d}{\tau_s}$ where τ_s is the time delay at which the auto-correlation function has a value equal to that of the cross-correlation function at zero time delay. It can be shown that τ_s is a function of both the true drift velocity V_t and the true fading velocity V_c and can be expressed as (BRIGGS, 1980).

$$\tau_s = kT_{0.5}(1 + V_t^2/V_c^2)^{-1/2}$$

$T_{0.5}$ is the half-correlation time after the effect of the mean drift has been removed and k is a constant. Then combining these equations we get

$$V_t = \frac{d\tau'}{k^2 T_{0.5}^2} (1 + \frac{V_t^2}{V_c^2}) \qquad (1)$$

At this point we make an assumption that can be shown to be valid for the Jicamarca radar and other radars with antenna dimensions of more than one hundred meters. The inequality

$$V_t^2 << V_c^2$$

reduces the equation (1) to

$$V_t = \frac{d\tau}{k^2 T_{0.5}^2} \qquad (2)$$

As long as the correlation time is mainly a function of internal changes in the irregularity pattern and not dependent on the drift velocity the width of the peak in the cross-correlation function will be constant regardless of the amplitude of the drift velocity. The accuracy with which the location of the peak in the cross-correlation function can be determined is proportional to the width of the peak. This means it is easier to find the location of the maximum in a narrow peak, than in a broad peak. Thus it seems reasonable to introduce a fixed error $\Delta\tau'$ in the measurement of τ' since the half-width of the correlation function is virtually constant as a function of V_t as long as $V_t << V_c$. Thus equation (2) yields

$$V_t + \Delta V_t = \frac{d\tau}{k^2 T_{0.5}^2} + \frac{d}{k^2 T_{0.5}^2} \Delta\tau' \qquad (3)$$

Equation (3) expresses two related results. First, since the true velocity V_t is not dependent on the antenna dimensions it is clear that an increase in d will decrease the time delay to maximum cross-correlation τ'. Also since $\Delta\tau'$ is assumed to be constant we see that an increase in antenna dimensions will increase the error in the calculated horizontal velocity ΔV_t.

In discussing these results it is appropriate to emphasize the findings of BRIGGS (1980) that the DBS and SAD techniques both rely on scattered signals from several off-vertical directions to measure horizontal velocities in the ionosphere. Larger off-vertical look angle will give better horizontal velocity estimates if the DBS technique is used. Thus the most natural conclusion is that also the SAD technique would give better measured horizontal velocity with increasing beam width, or smaller antenna dimensions. This is of course in accordance with the results of equation (3).

Summarizing, it is concluded that for large antenna dimensions, comparable to the Jicamarca radar, individual irregularities in the ground pattern last only a fraction of the time it takes to cover the distance separating receiving antennas, and thus it is natural that the horizontal drift velocity should be difficult to measure.

MEEK et al. (1979) have suggested using the normalized time discrepancy (NTD) as one measure of the accuracy of individual velocity measurements. A value of NTD of less than 0.2 has been advocated as a reasonable criteria for accepting the calculated horizontal velocity. It is clear however that NTD depends not only on the accuracy with which the time delay of the peak in the cross correlation can be measured, but also on the velocity of the pattern over the ground. In the extreme case of almost zero velocity and a finite pattern correlation time the equation

$$\mathrm{NTD} = \frac{|\Sigma\tau_{ij}' + \Delta\tau_{ij}'|}{\Sigma|\tau_{ij}' + \Delta_{ij}'|}$$

reduces to

$$\mathrm{NTD} = \frac{|\Sigma\Delta\tau_{ij}'|}{\Sigma|\Delta\tau_{ij}'|}$$

where $\Delta\tau_{ij}'$ is the error in measuring τ_{ij}'. Since individual $\Delta\tau_{ij}'$ are expected to be statistically independent NTD ($V \to 0$) is expected to be randomly distributed between zero and one. If $\Delta\tau_{ij}'$ is kept constant and τ_{ij} is increased as a function of increasing velocity it can also be seen that NTD will decrease. Thus using NTD as a measure of reliability of the horizontal wind will tend to select measurements with high wind values. In Figure 1 the relationship between NTD and measured wind velocity have been plotted, and as can be seen the average wind velocity measured decreases as the NTD increases. It is concluded that NTD is not very useful as a test of the accuracy of the wind measurement, and using it can systematically change an averaged wind value. However, in practical situations use of NTD is more serious for a large radar antenna like the Jicamarca than it is for the substantially smaller SOUSY-VHF radar (ROTTGER, 1981).

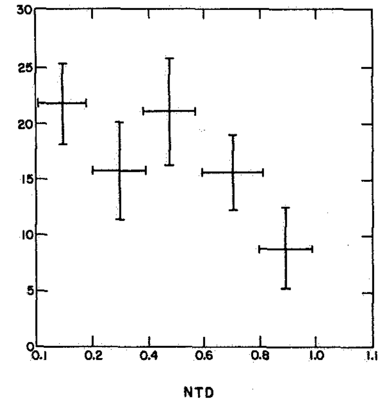

Figure 1. Normalized time discrepancy as a function of ionospheric velocity averaged for the time 9:40 to 12:30 LST and for all altitudes.

REFLECTION FROM STRATIFIED LAYERS AND METEORS

It has been suggested that the SAD technique is superior to the DBS technique because it takes advantage of the additional power received from the vertical direction from partially reflecting stratified layers where such layers exist (VINCENT and ROTTGER, 1980). However, it can be easily shown that only that part of the signal that comes from the off-vertical direction gives any information about the horizontal velocity, and the larger off-vertical angle the better (ROYRVIK, 1983). It then becomes a matter of superposition of useless vertical signal, and useful off-vertical signal. It should be obvious that the more aspect sensitive the scattered/reflected signal is, the more of it can be attributed to the useless vertical signal. Thus increased aspect sensitivity decreases the signal-to-noise ratio where the noise is in the form of useless vertical signal. So no advantage is had from an increase in aspect sensitivity, and thus the SAD technique cannot benefit from measuring it. On the other hand, it can be argued that the DBS technique has an advantage because it can more easily distinguish between the enhanced signal in the vertical antenna, and the really useful signal in the off-vertical antenna however small this signal may be.

It has also been suggested that the SAD technique could calculate the full velocity field from one single meteor (ROTTGER, 1981). This is clearly not the case since the irregularity pattern on the ground resulting from a long train of irregularities would be a series of semi-parallel lines. Drift of the meteor trail perpendicular to the trail direction would only shift the lines in the parallel direction and thus produce no observable fading in the returned signal. It is also questionable whether the velocity parallel to the meteor trail could be measured since the SAD technique assumes an eliptical irregularity pattern, whereas the actual pattern is a series of parallel lines. In any case, great care should be taken in using meteor echoes since contamination can result from both saturation of the receiving system and reflection from the traveling meteor head. This applies to both the SAD and the DBS techniques.

It is concluded that the most useful size of a SAD antenna is such that the irregularities on the ground on the average, drifts from one receiving antenna section to another in one half-correlation time (ROYRVIK, 1983). Assuming correlation time of a VHF signal of 1 s and horizontal velocities of typically 15 m/s in the mesosphere, a transmitting/receiving antenna 60 meters on a side would be ideal. Larger antennas, although they may increase the signal-to-noise ratio, only degrades the performance of the SAD radar.

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