3.1B POTENTIAL ADVANTAGES OF THE SPACED ANTENNA METHOD FOR OPERATIONAL WIND PROFILING

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INTRODUCTION

The problem of very short-range forecasting is twofold. It is necessary to understand the processes that are being forecasted, and data appropriate to the scale of interest has to be generated. Coherent VHF and UHF radars are being used for operational wind profiling and are providing part of the solution to the data-acquisition problem (LARSEN, 1983). The Profiler system operated by the Wave Propagation Laboratory at NOAA has already shown great promise (STRAUCH, 1981; STRAUCH et al., 1982). As a result, plans are being considered for expanding the network of radars to cover a larger area of the country.

The Profiler uses what is commonly referred to as the Doppler method for measuring winds. Two beams are pointed off-vertical, and the Doppler shift of the echo determines the line-of-sight velocity. The velocity components along the beams are then translated to horizontal wind components. While there is no doubt that the Doppler method is adequate for wind profiling, we want to discuss a number of possible advantages of the spaced antenna (SA) method for operational wind profiling. There is virtually no difference in cost between the two types of systems. However, there may be some significant advantages of the SA method, particularly when smaller radars are being considered. Since any Profiler network is still only in the planning stage, now is the time to consider the various alternatives.

DESCRIPTION OF THE TWO TECHNIQUES

The Doppler method uses the same antenna array for transmitting and receiving. The array is phased in such a way that the beams point at some angle off vertical. The Doppler shift of the received signal is then proportional to the line-of-sight velocity, V' in the right-hand-side of Figure 1. Two beams pointing in different directions have to be used, together with the assumption that the vertical velocity is negligible, to determine the two horizontal wind components. The three-dimensional vector wind velocity can be determined uniquely only if three beam directions are used. The spaced antenna method (see ROTTGER, 1981 for a detailed description), shown in the left-hand-side of Figure 1, uses one transmitter array and three closely spaced receiving arrays with all beams pointing vertically. The three receiving antennas may be separated from the transmitting antenna, but more efficient is a configuration in which each third of the transmitting array is used as a separate receiving array. The horizontal velocities are calculated using the time lags at which the cross-correlations of the signals received in the various antennas maximize. The spaced antenna method essentially tracks the propagation of a perturbation in the refractive index across the distance separating the receiving antennas. The vertical velocity is calculated from the Doppler shift.

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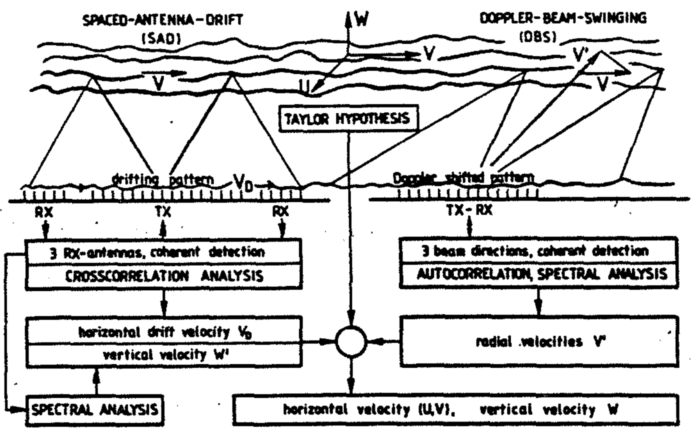

Figure 1. Schematic of the spaced antenna and the Doppler method for measuring the three-dimensional velocity in the troposphere, stratosphere, and mesosphere.

An objection to the spaced antenna method that is often heard is that the technique gives incorrect wind measurements when the medium is strongly affected by wave activity. In that case the scattering is primarily from the refractive index structure associated with the wave fronts, and the measured velocity is the phase of the waves rather than the true wind velocity. However, BRIGGS (1980) has shown rigorously that the Doppler method and spaced antenna method are, in fact, equivalent. Both techniques scatter from the same variations in the medium. Therefore, the effect of wave structures is equally a problem with the Doppler method and the SA method. There is no reason to expect that the latter will give poorer results on that account.

AN EXPERIMENT TO COMPARE THE TWO TECHNIQUES

The SOUSY-VHF-Radar is one of the few radars at present where a comparison between the Doppler technique and the spaced antenna technique can be carried out directly. The configuration of the antenna system is shown in Figure 2. The large antenna can be used for both transmitting and receiving in the Doppler mode. The three smaller antennas can also be used as spaced receivers in combination with the large transmitting array. In October 1979, an experiment was carried out with this radar to compare the two measurement techniques.

The spaced antenna wind measurements can be made either by cross correlating the received power at the three receiving antennas or by cross correlating the complex amplitudes. The latter approach retains the phasing information and gives better results because it is consistent with the process of coherently integrating the signals. Figure 3 showns the resulting comparison. It is clear that the complex amplitude cross correlation provides data over a greater height range than the simple power cross correlation. Especially, the region between 8.2-km and 9.7-km altitude and the lower stratospheric heights should be compared.

It is well known that signals at VHF have a strong angular dependence near the zenith. Specular reflections or Fresnel scattering associated with the stable temperature stratification in the atmosphere produce enhanced echoes at vertical incidence. The echo strength decreases rapidly, by as much as 10 dB (GREEN and GAGE, 1980), at even a few degrees off vertical. The spaced antenna

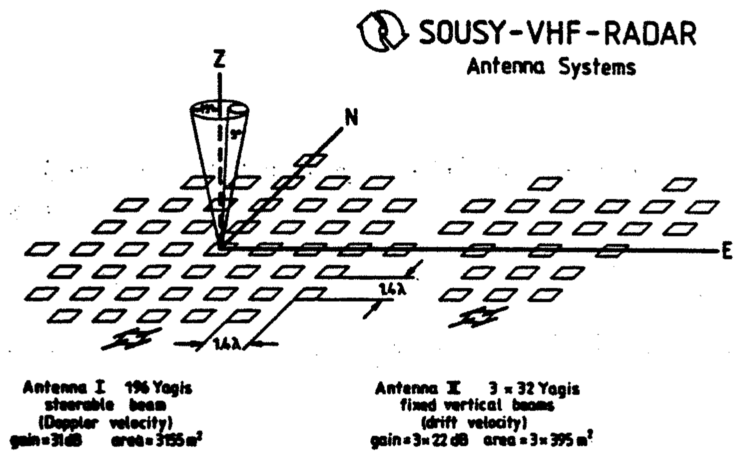

Figure 2. Antenna systems of the SOUSY-VHF Radar (from ROTTGER 1981). Antenna I is the smaller system of 3 x 32 four-element Yagi antennas which are used in the spaced antenna mode for reception when the large array of 196 Yagis is used for transmission.

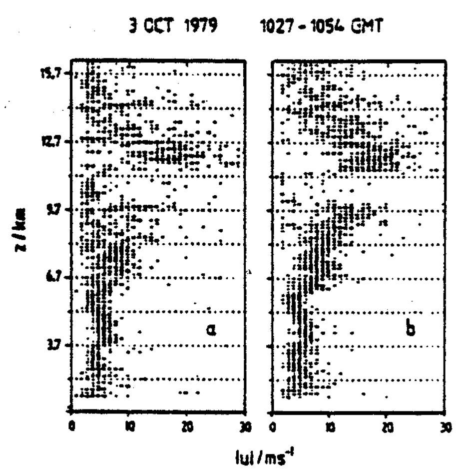

Figure 3. Height profiles of drift speed deduced from (a) power cross correlation and (b) complex amplitude cross correlation.

technique makes maximum use of this effect since all the beams are pointed vertically, producing a higher signal-to-noise ratio at those heights where the winds are measured. The Doppler method does not take advantage of the effect since the beams have to be pointed off vertical to make the wind measurements.

The strong angular dependence of the reflectivities does pose a potential problem for the Doppler technique when small antenna arrays are used. There are generally practical limitations on how far off vertical the beams can be pointed, and, of course, the beam width increases as the dimension of the antenna array decreases. When the beam width is wide, the received signal is really a convolution of the antenna pattern and the angular dependence of the echo strength, as shown in Figure 4. The result is that the apparent look angle is different than the real look angle, and the horizontal winds tend to be underestimated. The effect is critical when the vertical pointing direction is within the main lobe of the radiation pattern.

The effect is shown in the experimental results presented in Figure 5. Figure 5a shows the velocity profile derived from the complex cross correlation of the spaced antenna signals. Simultaneous aircraft wind measurements, shown by the open circles, indicate good agreement between the two independent wind measurements. Panel b shows the vertical velocity profile which could only be measured with the VHF radar. Figure 5c gives the velocity profile derived from the Doppler method using a beam pointed 7° off vertical and shows very good agreement with the spaced antenna method. However, the beam width of the large array is 5°, and when the beam is pointed at only 3.5° off vertical, there is a significant contribution from the vertical direction. The resulting wind profile is much poorer since it has broader scatter and underestimates the velocities.

DISCUSSION

The data from the October 1979 experiment are not conclusive, but they do indicate that there may be certain advantages in using the spaced antenna method, particularly for systems with small dimensions of the type likely to be used in operational wind profiling. Problems associated with the aspect sensitivity only arise when the beam width is large. It is, in fact, likely that when larger systems are used, there is little difference between the two techniques since the beam widths are small then. Therefore, the SOUSY comparison may not fully show the advantages of the spaced antenna method for small tropospheric sounding systems, and further comparison should be carried out in the future.

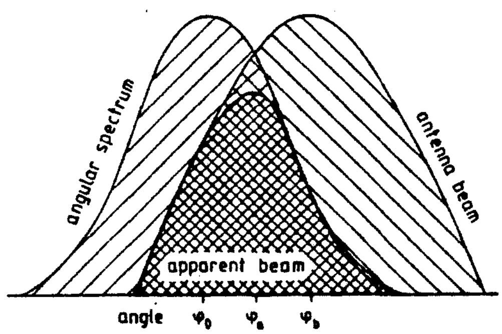

Figure 4. Formation of an apparent beam direction.

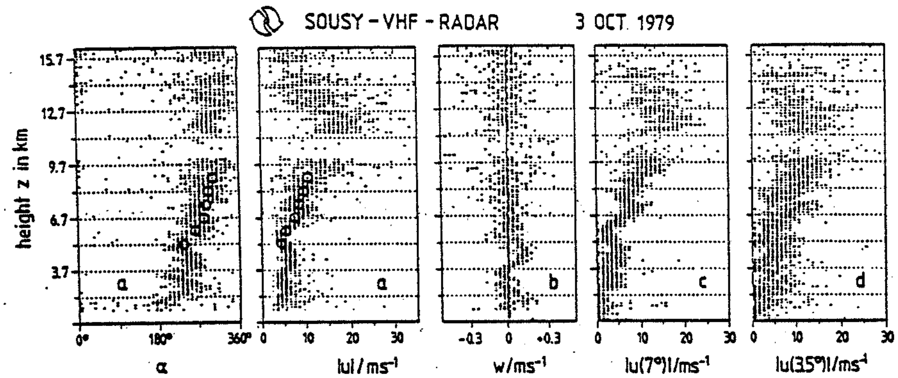

Figure 5. Height profiles of (a) wind direction and wind speed measured with the spaced antenna method and comparison with aircraft winds shown by the open circles. (b) vertical velocity. and (c) wind speed measured with the Doppler method using a beam pointing at 7° and (d) 3.5° off vertical.

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