CLEAR-AIR DOPPLER RADARS: BISTATIC VS MONOSTATIC

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1. Introduction.

Clear-air Doppler radars have achieved considerable success in the past decade in the measurement of wind, turbulence, layers and associated phenomena (such as gravity waves and fronts) in the lower 20 Km of the atmosphere. For the most part these measurements have been accomplished with monostatic configurations, usually because of their relative simplicity or previous existence. Bistatic arrangements have been used on occasion, but more for the purpose of getting around a particular difficulty than for exploring their inherent value. The bistatic concept has been used in the past in the form of transhorizon propagation (troposcatter) where the application was often as a communication link; even in atmospheric probing its use was usually confined to low-angle forward-scatter geometries. With the present rapid development of clear-air radars and the push to develop networks of them, it is appropriate to take a more careful look at the potentialities of bistatic configurations, and at the possible incorporation of bistatic operation within a monostatic network. This paper examines briefly a few of these points.

2. Sensitivity and resolution.

In the monostatic case the scattering volume is delineated by antenna beam width and pulse length. In the bistatic case the scattering volume may also be so delineated, but, since the geometry is different, so also are several other quantities: the shape and size of the scatter volume, the operative scale size in the atmospheric spectrum, and the Doppler relations. For purposes of comparison here we will assume the scattering volume to be relatively restricted by narrow beams and a short pulse, and to be uniformly filled with the scattering medium, which we will take to be clear air having a Kolmogorov turbulence spectrum.

First we will compare a single monostatic radar with a single bistatic pair. It will be convenient to place the former at the midpoint of the latter's path and to let the zenith angle of its beam-pointing be the tilt-angle of the bistatic scattering plane with respect to the great-circle plane. Antenna apertures are all horizontal, either arrays or filled, and we take them to be of equal size in the two cases. Frequency, however, may differ, and we consider pulse width to be inversely proportional to frequency. With these simplifying assumptions, we find that the ratio of received power, bistatic to monostatic, is inversely proportional to the two thirds power of the frequency ratio, and directly proportional to the four thirds power of the quantity, $Q = 1 + (d/2h)^2$, which is the square of the cosecant of half the bistatic scatter angle. Here d is the bistatic baseline and h is the monostatic slant height. Similarly, the ratio of the scattering volumes is inversely proportional to the third power of the frequency ratio and directly proportional to the five halves power of Q. For equal transmitter powers and equal frequencies, the bistatic case has more received power to work with since Q is greater than unity. However, the size of the scatter volume is larger, so that resolution suffers.

For many purposes it would be desirable to trade sensitivity for resolution. This can be accomplished by increasing the bistatic frequency over the monostatic. For example, in the case of the assumptions used above, if the bistatic frequency is 4 times the monostatic, there is a base-line range from 40 to 150 Km within which the received power is greater in the bistatic case while the slant-height resolution is better; for a frequency 2 times greater, the base-line range for these conditions to prevail is 30 to 70 Km; and for a frequency 8 times greater, it is 60 to more than 200 Km. One can argue about the details of the assumptions used here, but the essential point is that by going to a higher frequency than used in a monostatic system one can achieve a comparable performance from a bistatic system, insofar as sensitivity and spatial resolution are concerned.

3. Doppler shift and wind speed.

A monostatic radar measures the radial component of the wind, and, with measurements at two (or more) zenith angles in a given azimuth, can separate vertical and horizontal components. A bistatic radar measures the component of wind normal to the elliptical constant-delay shells, and measurements at two (or more) tilt angles permit separation of vertical and horizontal components in a plane perpendicular to the path. For the conditions assumed above (for comparative purposes), the expression for the Doppler frequency shift in the latter case is the same as that in the former except that it is multiplied by the sine of half the scatter angle. Since both are proportional to radar frequency, their ratio is the radar-frequency ratio times the sine of half the scatter angle. Thus, for equal frequencies, the Doppler shift would be lower in the bistatic case, but by using a higher frequency this situation can be reversed. For the specific numerical examples mentioned above, the Doppler frequency ratio (bistatic to monostatic) ranges from unity to more than four, assuming the actual wind is the same for both. In the bistatic system, then, less Doppler resolution is needed to achieve a given velocity resolution, and therefore a shorter measurement time is permissable.

To obtain the vector wind, a third measurement is needed. The monostatic system uses an additional beam, usually at an orthogonal azimuth. For a bistatic system to use an orthogonal across-path wind, an additional receiving location and antenna would be needed. In order to use the same receiving site and antenna, different beam positions are required so that the scatter volume is no longer in the mid-path transverse plane, but as near one end as is feasible, and in the great-circle plane. Then the Doppler measurement arises from wind components in the vertical and in the horizontal parallel with the baseline. In this configuration of beams the bistatic is less competetive with the monostatic, but sample numerical calculations show the method to be feasible.

4. Networks of wind radars.

If one is considering, not a single isolated radar, but a network, then the comparison can be made differently. If the purpose of the network is to obtain a large-scale picture of the wind field, spatial resolution is of less concern than representative coverage. Some of the constraints imposed on the bistatic system are relaxed, such as the emphasis on higher frequencies, shorter pulse-lengths and narrower beams at steeper angles, and there is no need for the parallel-with-the-baseline measurement. In a purely bistatic network it is possible for half the stations to be transmitting stations and half to be receiving. Transverse and vertical wind components are measured in the regions between stations.

Another attractive possibility is a combination of mono- and bi-static. For example, two separated bistatic receivers beamed at the volume illuminated by the slant beam of a monostatic radar permit three wind components to be measured on the same region of air. Thus one can visualize a network in which each monostatic transmitting station also has receiving beams that look back at adjacent transmitting stations.

5. Remarks.

A monostatic radar will always have many advantages over a bistatic: simplicity, self-contained stations, repeatedly demonstrated capability, numerous existing systems, to mention a few. The point here is not to advocate a bistatic system as a competitor to the monostatic, but rather to point out that it has some merits which have not been explored, and that in some situations it could well serve as an effective supplement. In circumstances where ground clutter is a problem, a bistatic system can be configured so that the ground backscatter will have a delay that does not conflict with the desired atmospheric scatter delays. Our discussion has centered on Doppler techniques for wind measurement. However, there are also other possibilities, such as the combination of a bistatic configuration with the spaced-antenna-drift method of wind measurement.