9.5A MENTOR -- ADDING AN OUTLYING RECEIVER TO AN ST RADAR FOR METEOR-WIND MEASUREMENTS

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INTRODUCTION

Radar scattering from ionized meteor trails has been used for many years as a way to determine mesopause-level winds. Scattering occurs perpendicular to the trails, and since the ionizing efficiency of the incoming meteoroids depends on the cosine of the zenith angle of the radiant, echoes directly overhead are rare. ST radars normally sample within 15° of the vertical, and thus receive few meteor echoes. Even the higher powered MST radars are not good meteor radars, although Avery and coworkers have successfully retrieved meteor winds from the Poker Flat, Alaska MST radar by averaging long data intervals.

It has been suggested that a receiving station some distance from an ST radar could receive pulses being scattered from meteor trails, determine the particular ST beam in which the scattering occurred, measure the radial Doppler velocity, and thus determine the wind field. This concept has been named MENTOR (Meteor Echoes; No Transmitter, Only Receivers). This paper is a preliminary look at system requirements and possibilities.

There are a number of immediate questions to be answered, such as; If we receive a pulse scattered from an ST beam, how can we tell which beam it's from? How can we measure the Doppler velocity without access to the ST's oscillator? Can we also measure the altitude of scattering? Can we use this information to determine the wind field? In this paper we sketch one possible approach to these questions.

SITE LOCATION

Consider a typical ST radar with 3 beams; one vertical, one steered 15 degrees due North, and the third pointed 15 degrees East, as shown in Figure 1.

Many STs forego the vertical beam, and with it the ability to measure vertical winds. The MENTOR approach probably can't measure vertical winds anyhow, but viewing the third beam of an ST radar will increase the MENTOR rate by 50%. If all three ST beams use a common frequency, no additional hardware is required.

For the geometry shown in Figure 1, the best location for a MENTOR site is probably along a NE-SW line, so that the three ST beams can be seen from the MENTOR site as three separate beams with maximal separation. We will consider two MENTOR sites; one 100 km from the ST site and one 300 km from the ST site.

ST BEAM DETERMINATION

Consider a pair of MENTOR antennas defining a line normal to the MENTOR - ST axis. Let D be the spacing between the two antennas. Then the horizontal projection of the geometry is as shown in Figure 2. (This figure actually shows the horizontal projection for a MENTOR site located to the SW, rather than NE, of the ST site.) We want to choose D so that the spacing of the ST beams maps into, say, 90 degrees phase difference between this pair of MENTOR antennas.

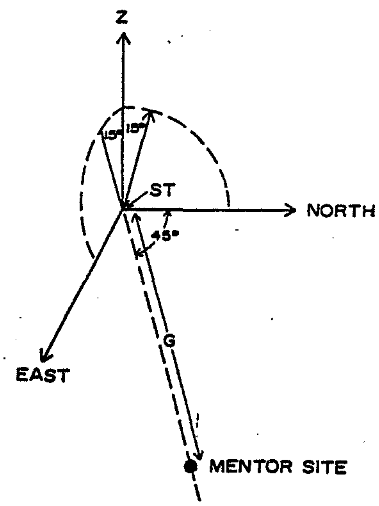

Figure 1. ST configuration and Mentor siting.

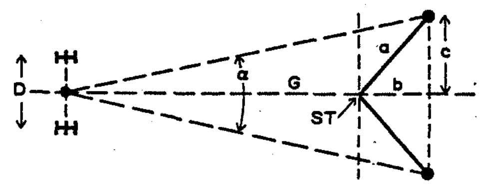

Figure 2. Beam-determination geometry.

Take the altitude region of interest to be 95 ± 15 km, and ignore effects due to the Earth's curvature. Assume an ST frequency of 50 MHz, so that $\lambda = 6$ meters. Let the ST-to-MENTOR distance be G (= either 100 or 300 km for the two strawman locations we have chosen.) Then we get

$$a = 95 \tan(15°) = 25.5 \text{ km}$$

$$b = c = a/\sqrt{2} = 18 \text{ km}$$

$$\alpha = 2 \tan^{-1}\left(\frac{c}{G+b}\right) = 17.3° \quad (G = 100 \text{ km})$$

$$= 6.5° \quad (G = 300 \text{ km})$$

$$\Delta\phi = \frac{2\pi D}{\lambda} \sin \alpha$$

Thus we find the desired spacing of the transverse pair of antennas to be 10.1 meters for the near site and 26.5 meters for the far site. With this spacing, the phase difference across the antennas will be 0 degrees if the received pulse originated in the STs vertical beam, +90 degrees if it came from the ST's North beam, and -90 degrees if it came from the ST's East beam. The range of altitudes (+/- 15 km) maps to a spread in the phase-difference values of +/- 25 degrees.

Some STs operate using different frequencies on different beams to improve beam separation. This makes beam identification easy, but means that two MENTOR channels are needed at each ST frequency for altitude determinations.

ALTITUDE DETERMINATION

For altitude determinations, we need an antenna (and receiver channel) to form a longitudinal pair with one of the first two antennas. Now consider the phase difference across this pair of antennas for an echo from thr vertical beam at an altitude z, as shown in Figure 3.

$$\Delta\phi = \frac{2\pi D}{\lambda} \sin\left(\tan^{-1}\left(\frac{z}{G}\right)\right)$$

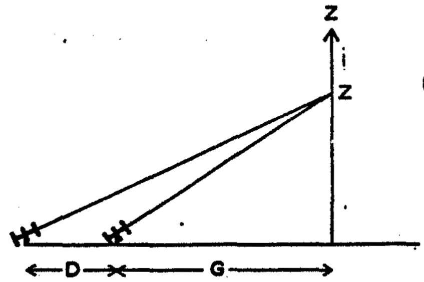

Figure 3. Altitude-determination geometry.

Thus we can choose the separation of the altitude-determining pair of antennas so that the expected range of altitudes (80-110 km) is mapped into phase differences from, say, 0 to 90 degrees. This will give an altitude resolution of 0.5 km with the anticipated MENTOR phase resolution of 1.5 degrees (slightly better or worse for the tipped beams, depending on which way they're tipped). Notice that no time-of-flight information about the pulse is needed for the altitude determination.

If it is necessary to operate the MENTOR receiver from a site such that two of the ST's beams are too closely coplanar (a projected separation of less than, say, 3 degrees), then the transverse pair of MENTOR antennas cannot discriminate between the overlapped pair of ST beams. However, if the MENTOR site is close enough to the ST site so that the regions lying between 80 and 110 km don't overlap in projection, then the longitudinal pair of MENTOR antennas can resolve the overlapped pair of ST beams. This is sketched in Figure 4. From the geometry shown,

$$x = 110 \tan (15°) = 29.5 \text{ km}$$

$$\theta_L = \tan^{-1}\left(\frac{110-80}{x}\right) = 45.5°$$

$$G_L = \frac{80}{\tan\theta_L} = 78.6 \text{ km}$$

The limiting ground distance is 78.6 km; beyond that, it would be necessary to add logic to MENTOR to determine the time-of-flight of the pulse from the ST, and use that information to determine which beam the pulse came from. We will not consider this case further.

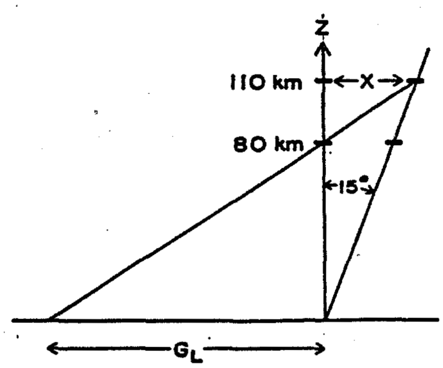

Figure 4. Limiting geometry for overlapped beams.

RADIAL DOPPLER FREQUENCY DETERMINATION

MENTOR will use, as do the ST radars, coherent detectors, so that both quadrature components of the signal (and thus amplitude and phase) are measured. This gives both the magnitude and the sign of the Doppler velocity. The problem of determining the radial Doppler velocity becomes the problem of determining $d\phi/dt$, with ϕ measured every pulse over a typical meteor-trail lifetime of 1/3 second. At the ST's pulse rate of 217 pulses/second, this will yield 72 measurements of the phase over the lifetime of the signal. If we take 150 m/sec to be a likely upper limit to the radial component of the mesospheric wind speed, then the maximum $d\phi/dt$ will be 83 degrees/pulse, which is extreme, but measureable.

REFERENCE OSCILLATOR STABILITY

The remote measurement of meteor echoes as envisaged here requires good oscillator stability for both the ST transmitter and the MENTOR receivers. Even good commercial oscillators have enough aging drift that frequent recalibration would be needed. However, commercial WWVB phase-lock receivers are available at moderate cost. Retrofitting existing STs appears to be no problem. The velocity error due to frequency instability will thus be < 1 m/sec.

WIND VELOCITY DETERMINATION

Operation of the MENTOR system will be similar to other meteor-wind radars; meteor echoes and their characterizations will be accumulated until all three beams are well sampled in as many altitude bins as possible, commensurate with the wave periods of interest. A three-dimensional wind vector can then be fitted to the data. An ST radar uses one beam that is carefully vertical, since a typical vertical velocity is overwhelmed by even a small component of the (usually) much-larger horizontal velocity. The geometry of the MENTOR system appears to preclude vertical velocity measurements, or at least to render them difficult. It is also clear that the error of the horizontal wind determination will increase as the MENTOR - ST spacing increases. The error goes as

$$\frac{\sqrt{G^2 + Z^2}}{Z}$$

so that the error will be 40% larger than the "ST equivalent" at the near site ($G = 100$ km) and x 3.2 larger at the far site ($G = 300$ km).

NETWORK POSSIBILITIES

There are two areas, Colorado and Pennsylvania, where networks of ST radars are operating (or soon will be). It is feasible to operate a single MENTOR receiving site to monitor meteor winds above a number of ST radars, provided they're all within, say, 500 km of a common site. (Received signal strength is the limiting parameter.) The Colorado network is shown in Figure 5. The ST radar sites now operating are shown as large solid circles; a likely MENTOR site is indicated. This site would give a maximum ground distance of 310 km to the furthest ST site. The differential cost for monitoring an additional ST radar, once the initial MENTOR system is installed, is expected to be small.

SUMMARY AND CONCLUSIONS

Meteor-wind measurements can be made by siting a three-channel receiver

COLORADO ST NETWORK

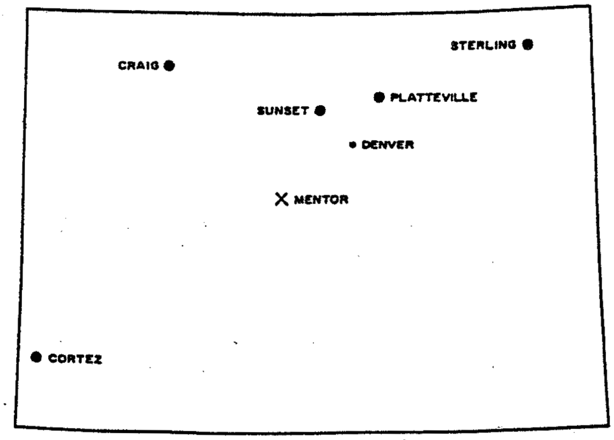

Figure 5.

some distance from an ST radar, then measuring Doppler velocities from meteor-trail scattering of the ST's pulses. Much of the gravity-wave activity in the mesosphere is thought to occur with horizontal wavelengths of 10 to 1000 km. A single MENTOR site in Colorado or Pennsylvania could add useful information over much of this range. We are working on data-rate calculations and system design.