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A New Technique for Radar Meteor Speed Determination: Inter-pulse Phase Changes from Head Echoes

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Abstract. We have implemented a 54 MHz radar located near Adelaide, South Australia, for novel forms of meteor observation. Here we describe a radically new form of meteor speed determination: we measure the rate of phase change for head echoes obtained from meteors propagating down the beam towards the radar. These not only provide speeds of unprecedented precision, but also deliver accurate deceleration measurements, these being of importance in understanding the meteoroid ablation process and exploring the physical parameters of such bodies.

1. Introduction

Conventionally, radar meteor experimenters have used equipments with wide beams directed towards large zenith angles (*e.g.*, McKinley 1961). Here we describe some near-zenith meteor observations using a pencil beam VHF (54.1 MHz) radar located 40 km north of Adelaide, South Australia. It has a peak power of about 20 kW, and a beam of width 3.2 degrees between half-power points. Our initial meteor investigations with this radar were of the height distribution (Steel and Elford 1991). More recently we have studied shower radiants, the narrow beam resulting in the radar being sensitive to a very restricted area of the sky at any time, so that shower activity may be identified even at low count rates (Cervera et al. 1993; Elford et al. 1994).

The subject of this paper is meteor speed determinations. The first technique used to measure meteor speeds with a radar was the range–time method of Hey and Stewart (1947; also Hey et al. 1947). These measurements made use of the head echo, the speed being obtainable because of the later occurrence of a body echo, indicative of a meteor trajectory at right angles to the radar beam. This method was soon superseded by the amplitude–time method which exploits the Fresnel diffraction characteristics of a specular reflection echo (Ellyett and Davies 1948; McKinley 1961). Evans (1966) made measurements of meteor speeds by directing a high-power UHF radar towards known shower radiants and measuring the doppler shifts of the echoes. Baggaley et al. (1994) have recently employed a time-of-flight method for finding meteor speeds, this being a derivative of the technique invented by T.R. Kaiser and introduced by Gill and Davies (1956) whereby times-of-flight for separated receiver sites were used to deduce the meteor radiant, and the speed from Fresnel profiles. Using the Adelaide VHF radar we have introduced a new, high-accuracy, method for determining meteor speeds: by measuring the rate of change of the phase of the complex returned signal as the meteor train is formed near the closest-approach point, Elford et al. (1995) have shown how the speed may be derived.

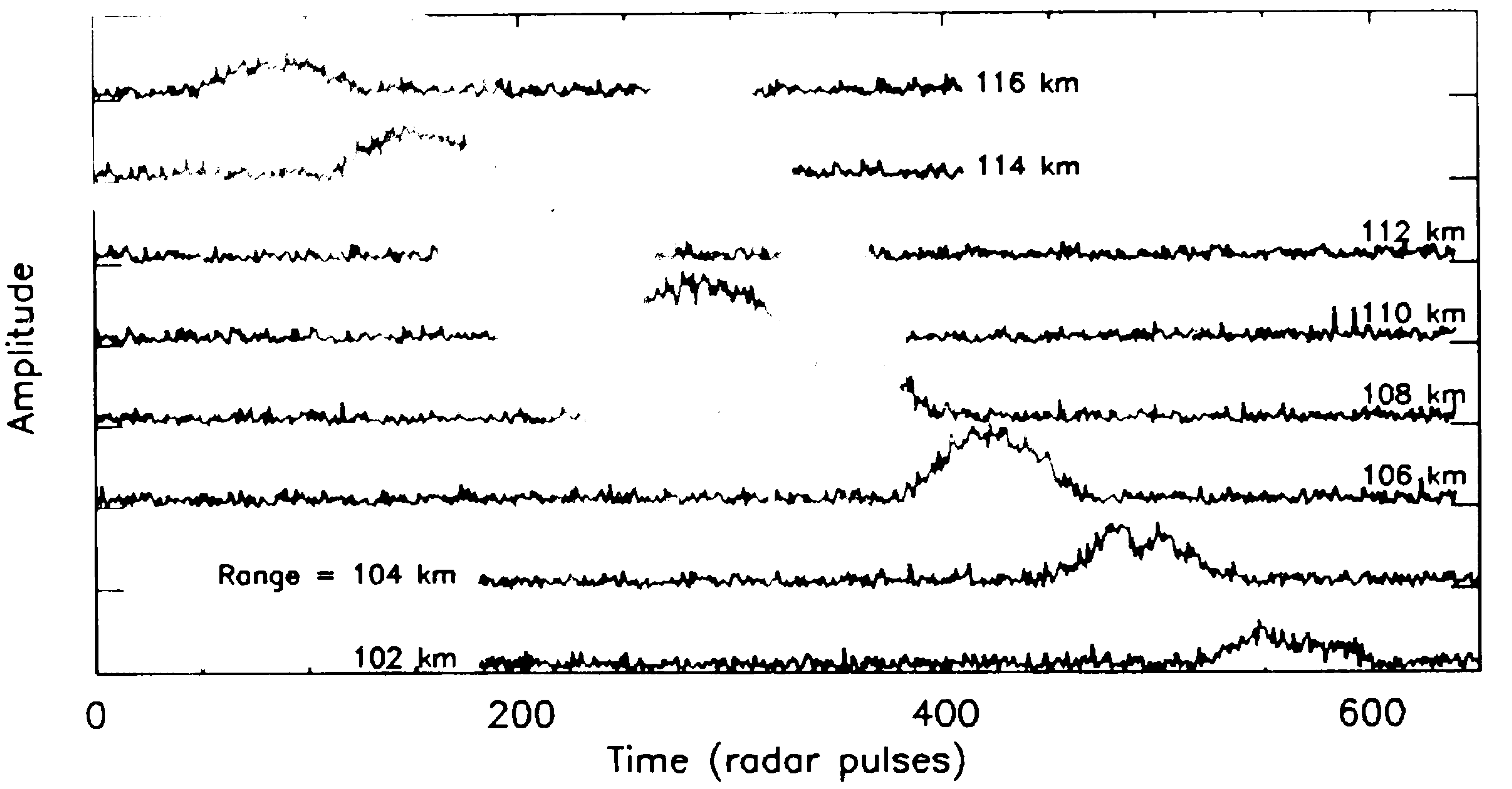

Figure 1. A head echo observed with the Adelaide VHF radar. An echo source is seen to propagate through eight adjacent range bins.

Many of the (specular reflection) echoes analysed using the technique of Elford et al. (1995) were quite different to the traditional body echoes of meteors, rather appearing to be produced through radio wave scattering from a very short length of the train. As such, these records are somewhat similar to the head echoes detected with other radars (see Jones et al. 1988, Jones and Webster 1991, and Thomas and Netherway 1989, for discussions). This sensitized us such that a previously-unrecognized type of meteor echo, pointed out to us by S. Avery, was soon interpreted as being produced by meteoroids moving down the beam towards the radar. It is the determination of speeds from such echoes that is the topic discussed here.

2. Observations and analysis

We give an example of the sort of echo in question in Fig. 1. The eight traces plotted show the signals received in eight adjacent range bins, as a function of time (the numbers represent time divisions of about a millisecond, because the radar was operated with a pulse repetition frequency of 1024 Hz). The range bins are each 2 km long. A transient echo source is clearly seen to move consistently in range, and we interpret this as a meteor which has passed obliquely — but not at right angles — through the pencil beam.

In principle one can derive a minimum value for the meteor speed from the rate of change of range, but the angle between the directions of meteor motion and the radar beam is required for a full evaluation. By performing cross-correlations between each pair of echo profiles in Fig. 1 we obtain a set of time delays for known distances, and hence speeds. The ranges are plotted against the mean time for each pair in Fig. 2(a), with the line-of-sight velocity being given by the slope.

A better speed determination may be derived from the phase change between pulses. Although the meteoroid moves a distance equivalent to many wavelengths between radar pulses, we can determine the number of phase cycles by comparison with the velocity calculated above. Figure 2(b) shows the

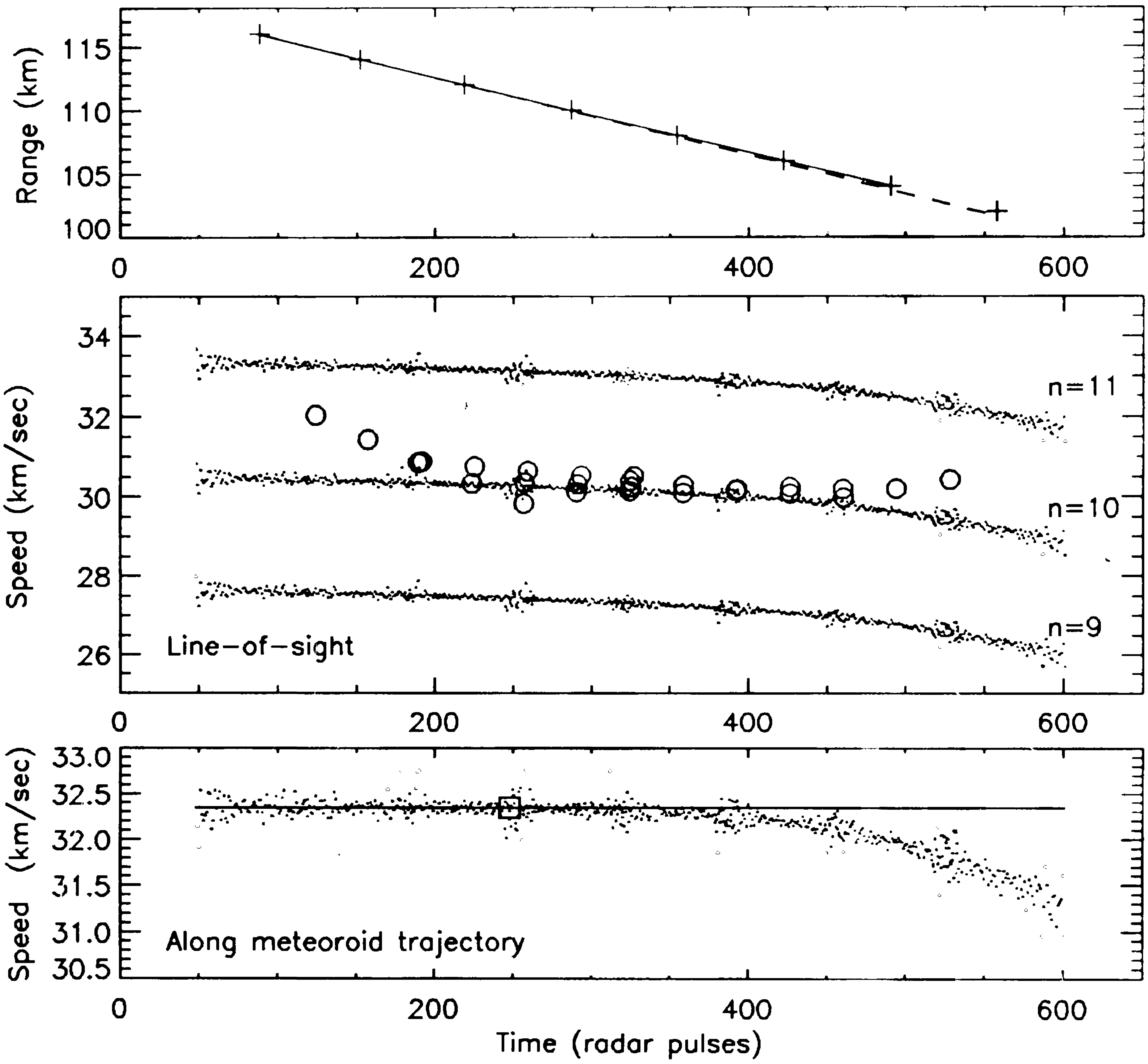

Figure 2. (a) The mid-time over which the meteor was detected for each range in Fig. 1 plotted against that range; the slope of the resultant curve provides the line-of-sight speed. The dashed line (a straight line extended from the slope between the first two points) deviates from the solid line (a fit to the data), indicating the deceleration, but this cannot be measured accurately using only these amplitude data. The uncertainties in these values are smaller than the symbols plotted, and except in the cases of a few anomalous echo profiles we always find a deceleration to be indicated by this analysis.
(b) Cross-correlations were calculated for all range pairs in Fig. 1 thus producing the values, shown here as circles, for the meteor speed as a function of time. The three curves represent the expected pulse-to-pulse phase changes, 9, 10 and 11 cycles, for different meteor speeds; the concentration near the middle curve (n=10) leads to that value being adopted. There is no meaning to the trend of these circles — the values at the beginning and end are affected by the signal characteristics (cf. Fig. 1) — and they are used solely to indicate which integer value of n to use.
(c) Assuming zero deceleration in the initial part of the ablation, until the square box, the meteor speed along its trajectory is calculated. That the speeds continue to follow the zero deceleration after the box supports this assumption. The slope in the early part of (b) indicates a trajectory at an angle of 20.4 degrees to the radar beam. This allows the pre-atmospheric meteoroid speed to be derived, along with a curve of speed against time showing the deceleration as the meteoroid ablated.

three curves resulting from 9, 10 or 11 complete cycles, although a large number of integer values are *a priori* possible. The grouping of cross-correlation speeds (circles) clearly favors n=10 as the answer. Assuming zero deceleration in the initial part of the train, as the ablation is starting, then one can infer the angle at which the meteor crossed the beam from the slope of the appropriate curve in Fig. 2(b). We plan to test this assumption using a new antenna permitting observations of known shower radiants. Using this angle the line-of-sight speed can be converted to a speed along the meteor trajectory as in Fig. 2(c); this renders the pre-atmospheric speed of 32.4 km/sec. [Making the less likely assumption that the meteor trajectory was directly down the beam, with significant deceleration along all of the trail, the derived line-of-sight speed would be identical with the along-track speed.] Note that we have no knowledge of the aspect of the meteor trajectory across the beam, so that the radiant is only restricted to being on a specified circle on the sky (in this case, of radius 20.4 degrees centered on the beam direction). The speed curve shown in Fig. 2(c) is clearly of high quality, especially compared to the value that might be derived from the range–time plot in Fig. 2(a), essentially because the ruler we are now using is only about 5.5 m long (the wavelength), rather than 2 km (the range bin length). Here the deceleration is obvious and measurable with considerable precision as a function of time, which will allow new high-quality information to be derived pertaining to the ablation coefficients, compositions and densities of meteoroids.

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