BUOYANCY OF THE "Y2K" PERSISTENT TRAIN AND THE TRAJECTORY OF THE 04:00:29 UT LEONID FIREBALL

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Abstract. The atmospheric trajectory is calculated of a particularly well studied fireball and train during the 1999 Leonid Multi-Instrument Aircraft Campaign. Less than a minute after the meteor's first appearance, the train curves into a "2"-shape, which persisted until at least 13 minutes after the fireball. We conclude that the shape results because of horizontal winds from gravity waves with a scale height of 8.3 km at 79–91 km altitude, as well as a westerly wind gradient with altitude. In addition, there is downward drift that affects the formation of loops in the train early on.

Keywords: Fireball, leonids 1999, lower thermosphere, mesosphere, meteor, persistent train, winds

1. Introduction

A bright fireball of absolute magnitude about −13 appeared over the isle of Corsica at 04:00:29 UT in the night of November 18, 1999. The fireball registered on three slit-less spectrographs onboard the Leonid Multi-Instrument Aircraft Campaign, probing various wavelength ranges in the near-UV, visual and optical near-IR. The fireball provided the first spectrum of a meteor's afterglow, which made it possible to study the cooling rate of the emitting gas in the first seconds after the meteor (Borovicka and Jenniskens, 2000). Once the afterglow had subsided, a luminous glow persisted for more than 13 minutes. Such persistent trains have eluded a better understanding for over a century (Lockeyer, 1869).

Especially the latter aspect is of interest in understanding the physical conditions in the meteor path. We have examined the observations for evidence of such vertical motions

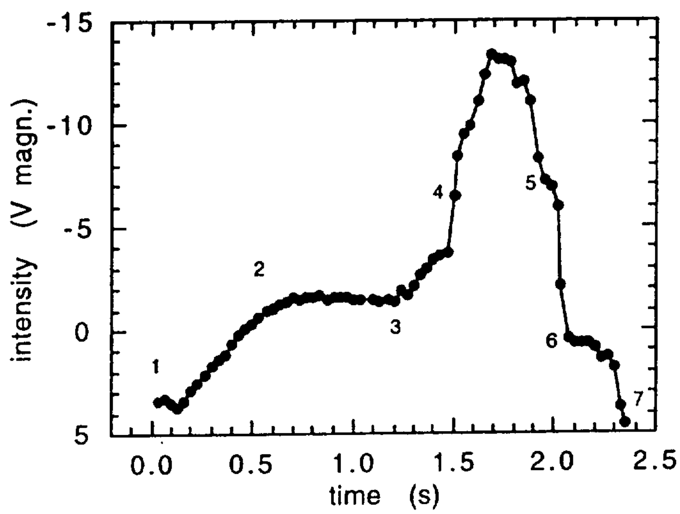

Figure 2 The visual light-curve magnitude of the meteor (normalized at 100 km distance) versus time. Markers as shown in Figure 1.

2. The observations

2.1. THE FIREBALL

The fireball was observed by a wide angle Mullard XX1332-intensified Hi-8 camera (Jenniskens, 1999) onboard ARIA (Figure 1). The video record was digitized with 640 x 480 resolution elements. Figure 1 is taken from a single frame shortly after the bright flare. The full frame is shown in Borovicka and Jenniskens (2000). Note that a small fragment of the meteor survives to the low altitude marker [7]. The field of view of the image is about 20 x 25 degrees. The meteor entered the frame at the top of the field as a faint point source (marker [1]). It soon spreads into the characteristic V-shaped structure first recognized by Spurny *et al.* (2000a). Shortly after, it turns into a droplet shape and at the same

Figure 3 The persistent train as seen from ARIA at different times following the meteor (in minutes and seconds).

After about 1.5 minutes from the time of the meteor (1:31 in Figure 3) the basic shape of a "2" is formed as a composite of the middle curl and the foot of the top curl. Because of its striking shape and occurrence, this particular nature's-own end-of-the-millennium fireworks was soon named the "Y2K train". The "2"-shaped feature, including its many 'billowing' features, does not significantly change over the next 12 minutes (Figure 5). Aircraft motion causes a gradual, but not substantial, drift in azimuth as seen by the projection of the train against the star background (Figure 3). The train was observed until 04:13:29 UT, when it drifted outside the field of view of the ARIA camera.

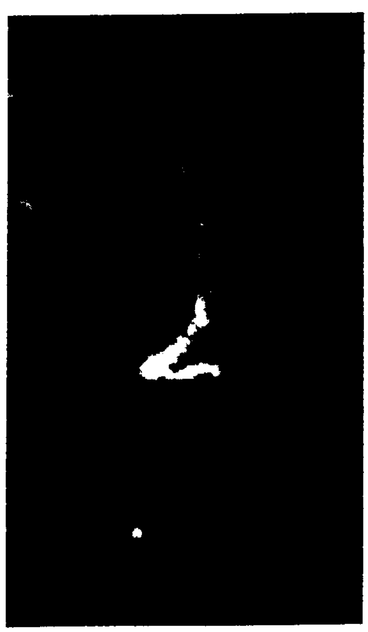

Figure 4. First view from FISTA 50 seconds after fireball (camera: FH50R). Notice the corkscrew pattern.

In response to the unusual sighting, the FISTA aircraft quickly changed its direction in order to bring this train into view of its onboard cameras and spectrometers. The earliest record is taken with the upward looking camera FH50R, only 48 seconds after the meteor appeared (Figure 4). The corkscrew pattern is clearly visible with most of the light intensity now being in the middle and upper parts of the train.

The lowest visible part of the train (at time 04:06) is at about 79 km altitude.

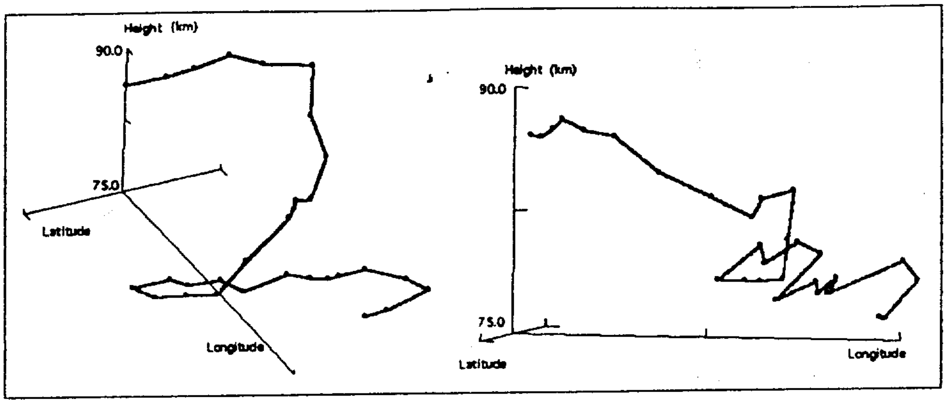

Figure 6. The 3-dimensional structure of the train at 04:04:35 UT, at time 04:06 after the meteor from two perspectives. The positions of train features are indicated.

TABLE I

#	H (km)	R (ARIA) (km)	R (FISTA) (km)	#	H (km)	R (ARIA) (km)	R (FISTA) (km)
1	91.6 ± 3	308 ± 6	191 ± 4	16	82.6	320	203
2	90.9	304	189	17	84.2	320	205
3	91.0	303	188	18	83.2	319	204
4	91.0	300	187	19	83.8	318	205
5	90.2	302	191	20	83.2	318	205
6	89.7	296	186	21	80.3	309	197
7	88.4	300	189	22	81.3	310	199
8	86.7	302	191	23	80.5	309	198
9	85.5	312	195	24	81.4	309	199
10	86.3	309	197	25	80.5	306	196
11	86.6	312	201	26	81.7	308	200
12	85.9	316	202	27	80.5	307	200
13	82.1	318	203	28	79.2	308	199
14	82.1	318	203	29	79.3	310	200
15	82.4	331	216				

the train gradually decline in elevation, which is mostly an effect of the aircraft moving away from the train. The expected effect is an increase in zenith distance by about 0.012 deg/s. The upper part, above marker point 14 (above the foot of the "2") stays at nearly constant elevation. This implies that the train drifts either towards FISTA (in west/southwestward direction) at a rate of about 70 m/s, or this part of the train moves upward at a rate of about 25 m/s, relative to the train below marker 14. A relative 75 m/s west/northwestward drift is implied by the shape of the train in Figure 6, suggesting that most of the effect is in fact due to a horizontal wind gradient with altitude.

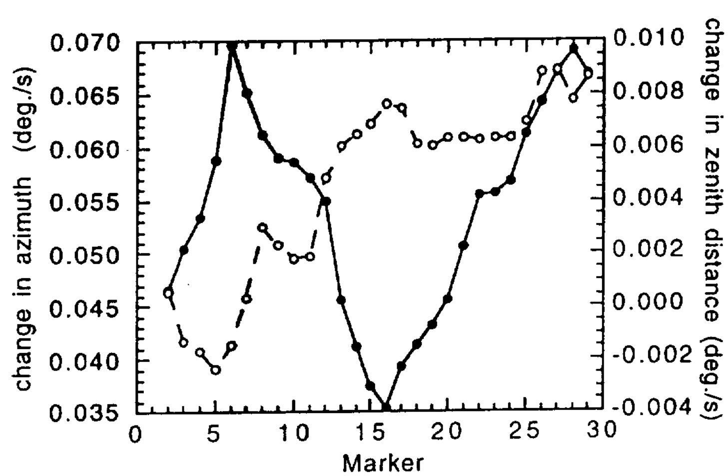

Figure 8. Mean rate of change in azimuth and zenith distance between times 03:38 and 08:20.

3.2. TRIANGULATION OF THE METEOR

By extrapolating the train motion backward in time, we can reconstruct the position of the meteor as seen from FISTA and calculate the trajectory by comparison with the meteor record from ARIA (Figure 1). We use the fact that the FISTA aircraft motion was almost linear during the period of interest (03:38–08:20), as shown in Figure 9. Figure 10 shows the resulting position of each marker point, in azimuth and zenith distance as seen from FISTA. We show the results for both linear and a parabolic extrapolations of the observed trend of position versus time for each feature in the train.

additional constraint, because it defines the length of the observed trajectory and thus the position of the meteor's path in distance from the aircraft. No reasonable solution is obtained for a fit differing more than ±0.4 degree in zenith distance from that shown as a dashed line in Figure 10. If the zenith distance is as low as implied by the data in Figure 10 the computed solution for the speed of the meteor will be too high and hence the trajectory too far from both aircraft.

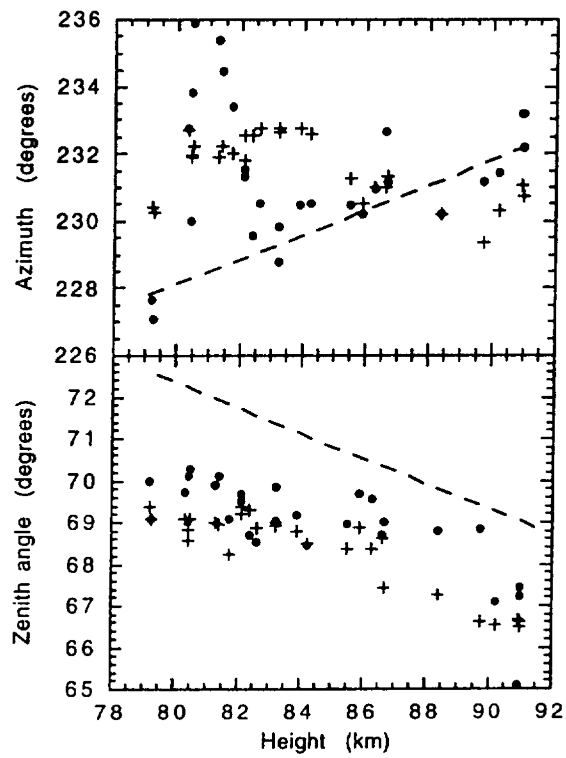

Figure 10. Azimuth and zenith distance angle of the meteor itself as seen from FISTA. The position of the meteor is derived from assumed linear (+) or parabolic (•) extrapolation of train drift. Dashed lines show the trajectory that provides the best triangulation results with ARIA.

The reason for this discrepancy remains unknown. However, the best fitted meteor trajectory (dashed line) is in good agreement with other Leonid fireball trajectories, with key features at similar altitudes. The meteor discussed here was first detected at about 195 km altitude and ended the so-called 'diffuse phase' (Spurny *et al.*, 2000a) at about 136

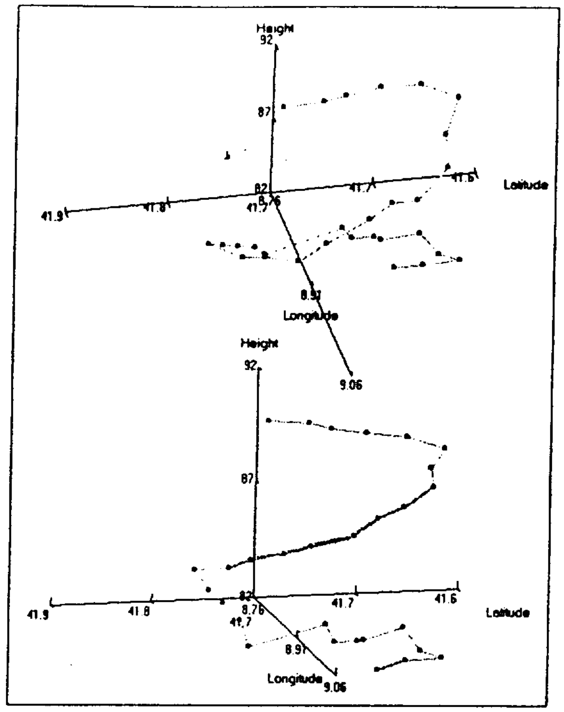

Figure 11. Model of the Y2K train at 04:04:35 UT by imposing a periodic wind variation with altitude but without a wind gradient.

Radar wind measurements in middle-Europe (Singer *et al.*, 2000) showed tidal wind oscillations with an amplitude of about 40 m/s and a scale height of about 8.5 km between 85 and 105 km altitude. At 04 UT, the zonal winds were changing in direction from east to west, more quickly at higher altitude. These observations are consistent with the observed east-west gradient in Figure 6.

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