EGU Meeting
2006. Apr. Wienna
ID-NR: EGU06-A-03830

Solitary neutral density waves of large amplitude in the thermosphere. Effect of meteor trails?

P. Bencze[1], E. Illés-Almár, [2]I. Almár[2]

[1]Geodetic and Geophysical Research Institute, Hungarian Academy of Sciences, H-9401 Sopron, P.O.Box 5, Hungary, E-mail: bencze@ggki.hu
[2]Konkoly Observatory, Hungarian Academy of Sciences, H-1525 Budapest, P.O.Box 67, Hungary

Abstract- Large amplitude solitary neutral density waves were revealed in the measurements of high temporal resolution carried out on board of the San Marco V satellite. The temporal distribution of these solitary waves in the thermosphere suggested that the solitary waves may be due to meteorites. The assumption was originally raised remembering the similar effect of meteorites in the ionosphere. As it is known, ionized trails produced by ionization of atoms evaporating from the surface of meteorites and moving with the neutral wind in the lower thermosphere enable determination of the direction and velocity of the wind. The assumption related to meteoritic origin of large amplitude solitary waves in the total neutral density has been verified comparing radius of the trail measured in vicinity of the end of the path to the radius traced back from width of the trail at its crossing by the satellite and also modelling of the effect in the neutral atmosphere using characteristics of the solitary waves and models of the neutral upper atmosphere.

1. Introduction

Large amplitude solitary neutral density waves were found in the high temporal resolution measurements carried out by the DBI accelerometer on board of the Italian San Marco V satellite (Arduini et al., 1993). Considering temporal distribution of impulse like ionospheric phenomena one by one and that of the density waves, the effect of meteorites has been selected for study them as a possible cause of large amplitude solitary waves in the neutral upper atmosphere. As it is known, an ionized trail is produced by impact of meteorites into the upper atmosphere. The ionized trail is formed, when atoms evaporating from the surface of metorites are ionized by the solar electromagnetic radiation. The ionized trails are drifting with the wind, thus they are suitable for determination of the neutral wind characteristics in the lower thermosphere. Meteor radars have been used for this purpose since the nineteen fifties (Greenhow, 1952; Greenhow and Neufeld, 1959; Pellinen-Wannberg and Wannberg, 1996; Grime et al., 2000). However, at higher altitudes, where the density of the atmosphere is low, first of all an „atom trail" is produced by the meteorite hitting the atmosphere. This is formed by neutral meteorite particles originating from track of the meteorite due to diffusion (Manning, 1958). The possibility of meteoritic origin of the large amplitude solitary neutral density waves arose considering that these solitary waves indicate succession of a density increase followed by a density decrease and then again by a density increase but deflections of opposite sign in this sucession, as well as transitional versions between them may also be observed. Similar succession of a maximum and a minimum, then again a maximum was observed in the surface brightness in cuts obtained by photometry indicating also density variations (Kruschwitz et al., 2001, Fig. 4). [Density depletions were also revealed in the total density measurements of the San Marco V satellite related to plasma bubbles (Illés-Almár et al (1998); Bencze et al. (2000); Illés-Almár et al., (2001)), furthermore, wavelike fluctuations of the total neutral density increasing abruptly at a certain height attributed to convective instability (Illés-Almár et al.,(2001))].

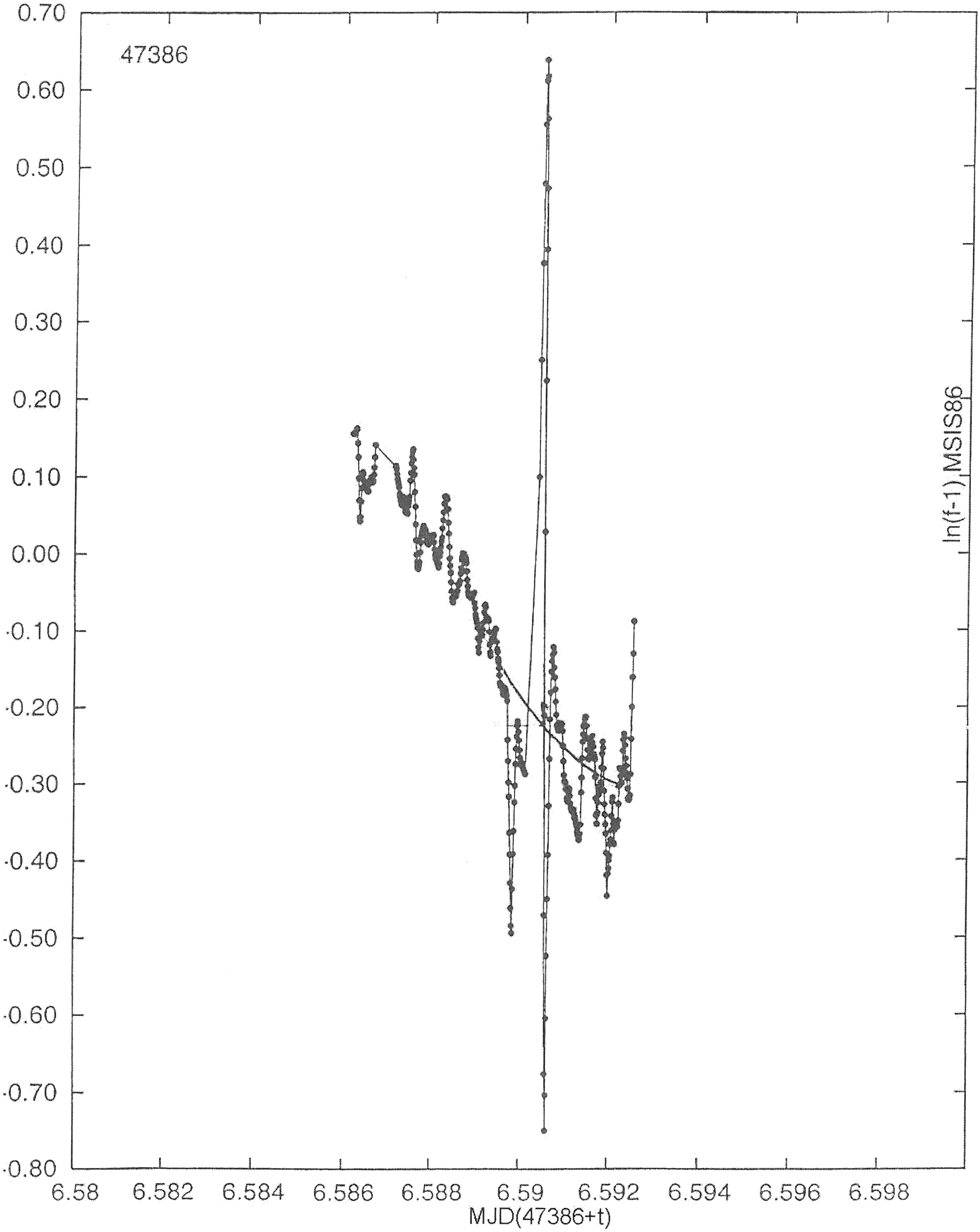
It can be advanced that the density in the upper thermosphere, where these solitary waves are observed is very low and thus, drag of the atmosphere is also small. However, it is to be noted that a smaller pressure change is also enough to produce density perturbation along the path of meteorites in this height region. Thus, large amplitude solitary neutral density waves would be observed, if the satellite crosses the trail produced by meteorites.

2. Method and data

As a first proof of our assumption, statistical analysis of the temporal and spatial occurrence of the solitary waves were carried out. Concerning temporal occurrence, diurnal and annual variations of the occurrences have been analysed. In case of the spatial occurrence distribution of the solitary wave occurrences with height has been studied. Thus, comparing temporal and spatial occurrences with temporal and spatial occurrences of meteorites the possible origin of solitary neutral density waves could be cleared.
Concerning the data, high temporal resolution measurements of the total neutral density carried out on board of the Italian San Marco V satellite were used. The San Marco satellite had an orbital inclinatin of $\pm 3°$ and perigee of 130 km, as well as apogee of 600 km. However, most of the measurements refer to heights above 250 km. The satellite was in operation from April to December 1988 and time resolution of the measurements was 1 s. The number of measurements was limited on the one hand by the time, during which the DBI accelerometer was switched on in course of a revolution. On the other hand, the accelerometer was not switched on during every revolution. These conditions limited the number of solitary wave observations. Thus, 54 events in the total neutral density could be identified. In Fig. 1 examples of the large amplitude changes in the total neutral density are presented. It is to be noted that structure of the meteoritic trail may change moving away along the path formed by the meteorite. There are not only single (isolated) solitary waves (Fig. 1a), but several, succesively occurring solitary waves are also observed (Fig. 1b). These succession of solitary waves occurred in time of the meteor showers (May, June, December, see Fig. 2). The amplitude of solitary waves changed between $0.8 \cdot 10^{-15}$ and $1.3 \cdot 10^{-12}$ gcm^{-3}.

3. Results and discussion

Diurnal and annual variations of occurrence frequency of the large amplitude solitary neutral density waves were studied. Diurnal variation of the occurrence frequency indicates a minimum by day and a maximum in the afternoon and at night. Similar diurnal variation has been found in case of diurnal variation of the hourly meteor rate (Janchez et al., 2002, Fig. 6). Concerning annual variation of the occurrence frequency demonstrated by large amplitude solitary waves, it was found that annual variation of their occurrence is similar – also in details – to annual variation of the monthly average meteor rates (Greenhow and Lovell, 1960; Goldsbrough and Ellyett, 1976); that is occurrence of the large amplitude solitary waves indicates maximum occurrence in the months June and August, as well as in December (Fig. 2).
Study of the spatial variation of these waves included height distribution of the occurrence frequency. The occurrence frequency of solitary waves indicates a maximum in that height range (250-450 km), where these waves are produced by meteorites capable of production of neutral density disturbances in the upper thermosphere as observed. It may be assumed that above this height range density of the atmosphere is not enough to cause an appreciable disturbance. Decrease of the occurrence number below this height range is due to decreasing number of measurements. Nevertheless, it is also necessary to confirm our assumption by theoretical computations determining in the total neutral density effect of the meteorites



47386
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
-0.70
-0.80
6.58
6.582
6.584
6.586
6.588
6.59
6.592
6.594
6.596
6.598
MJD(47386+t)
ln(f-1) MSIS86

Fig.1a.jpg

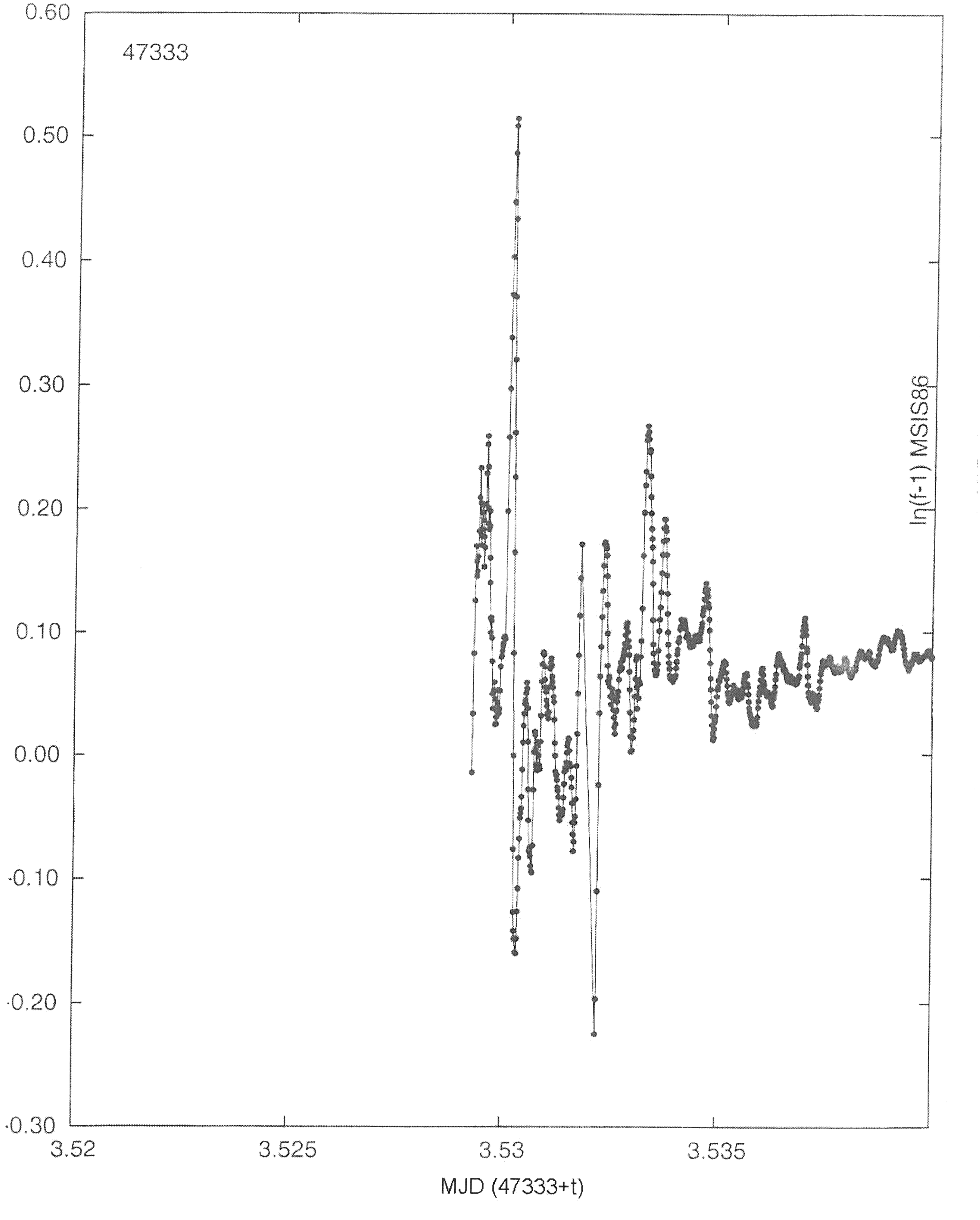
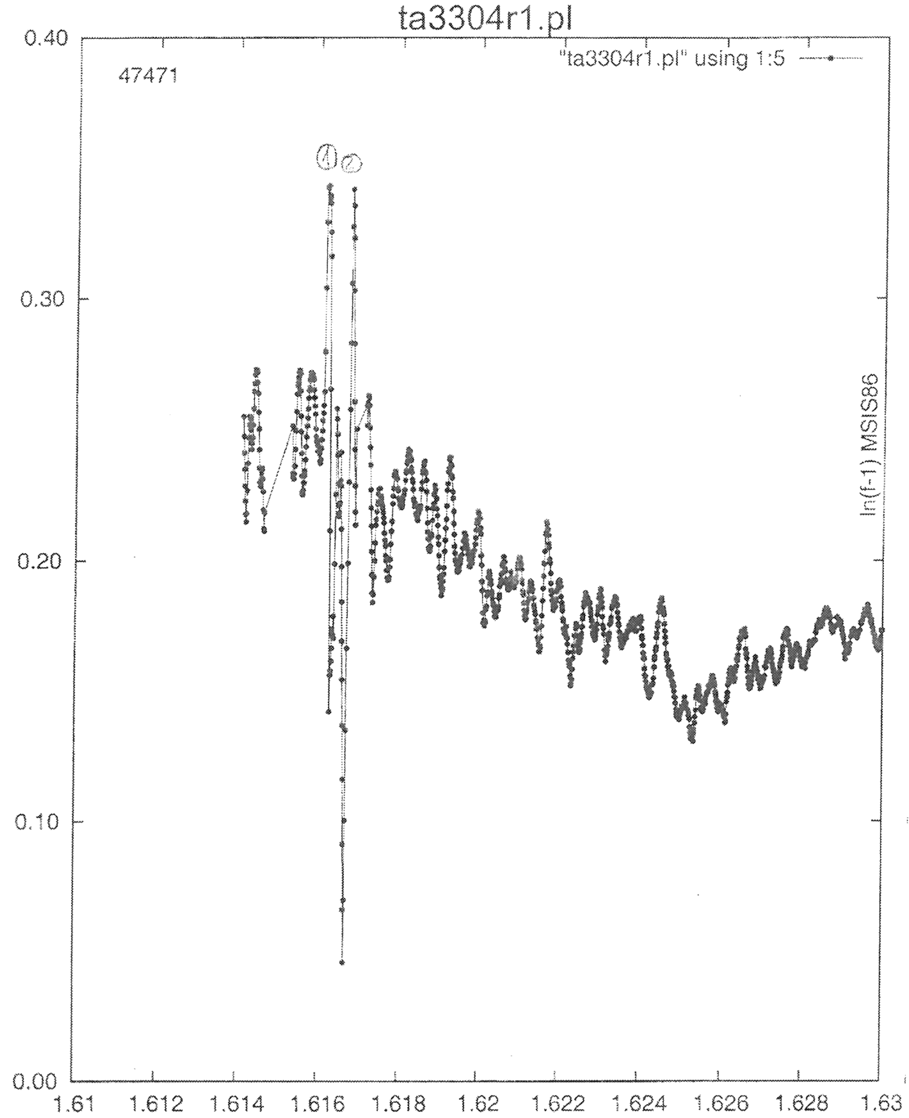
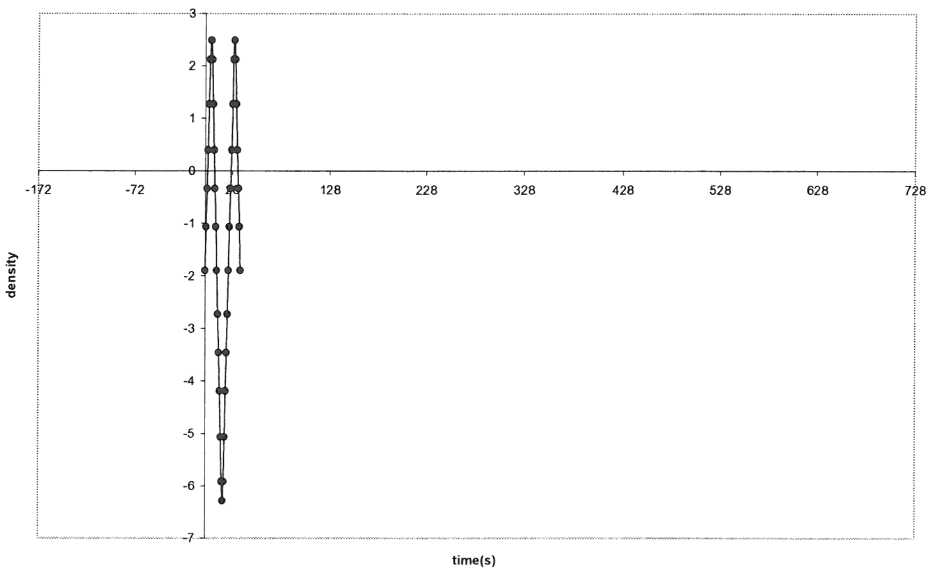

47333
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
3.52
3.525
3.53
3.535
MJD (47333+t)
ln(f-1) MSIS86

Fig. 1b.jpg

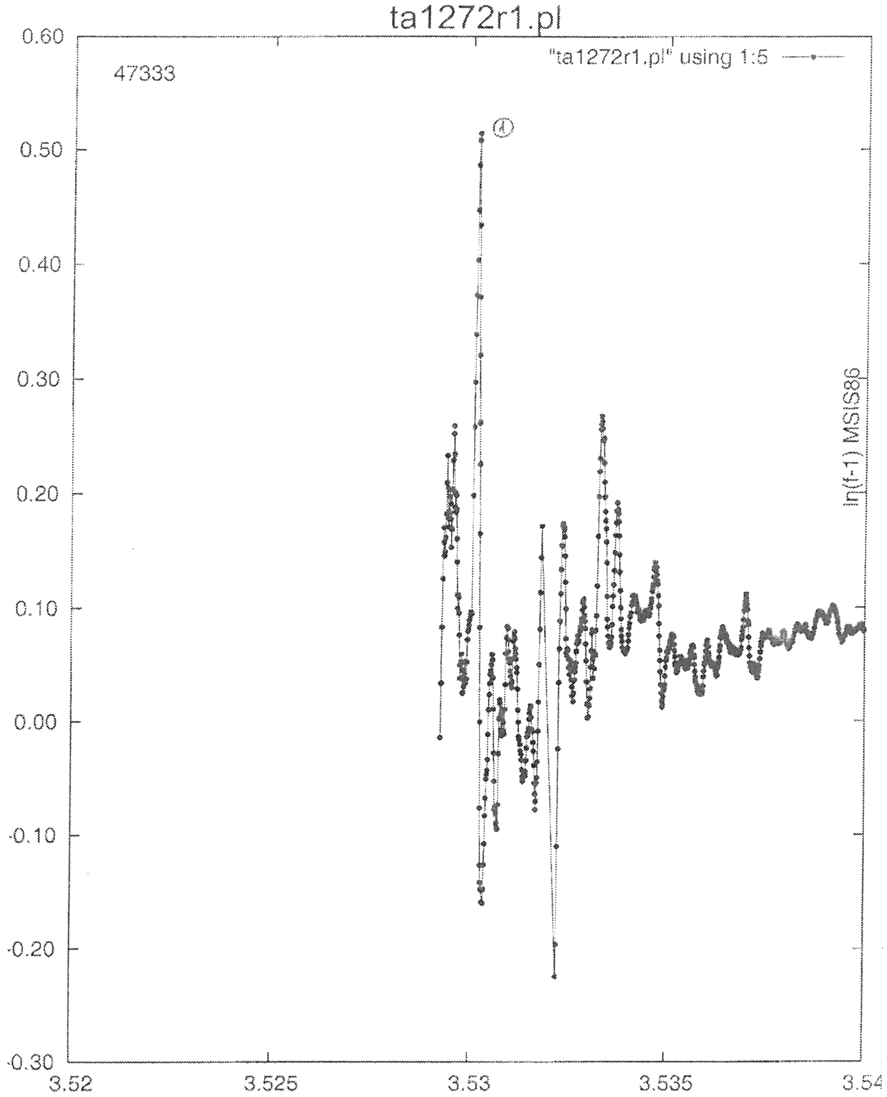


ta3304r1.pl
"ta3304r1.pl" using 1:5
47471
ln(f-1) MSIS86
0.40
0.30
0.20
0.10
0.00
1.61
1.612
1.614
1.616
1.618
1.62
1.622
1.624
1.626
1.628
1.63



density
time(s)
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-172
-72
128
228
328
428
528
628
728

Fig. 4a


ta1272r1.pl
47333
"ta1272r1.pl" using 1:5
ln(f-1) MSIS86
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
3.52
3.525
3.53
3.535
3.54

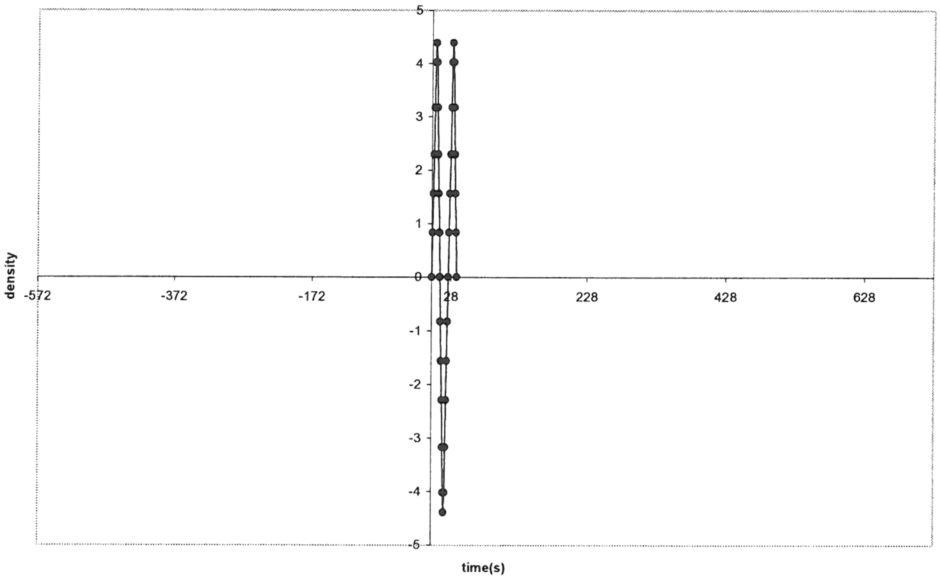
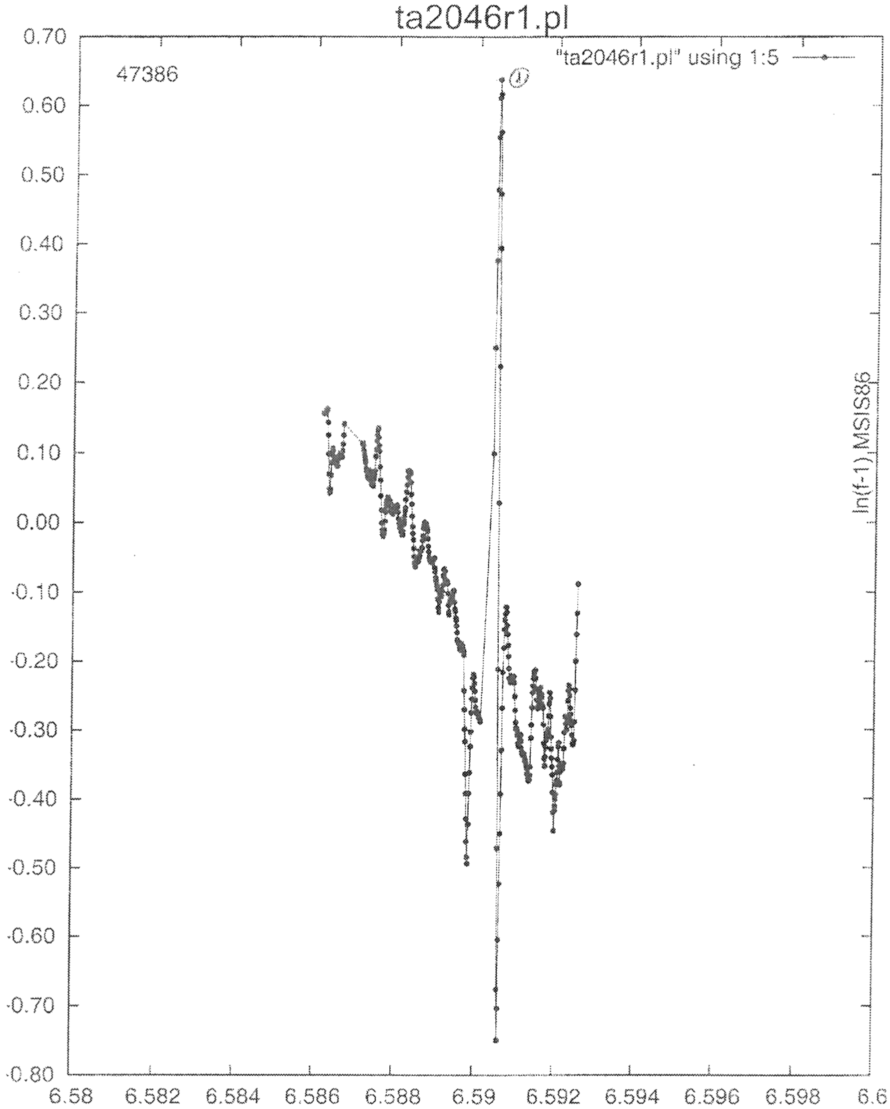

density
time(s)
-572
-372
-172
28
228
428
628

Fig. 4b


ta2046r1.pl
47386
"ta2046r1.pl" using 1:5
ln(f-1),MSIS86
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
-0.70
-0.80
6.58
6.582
6.584
6.586
6.588
6.59
6.592
6.594
6.596
6.598
6.6

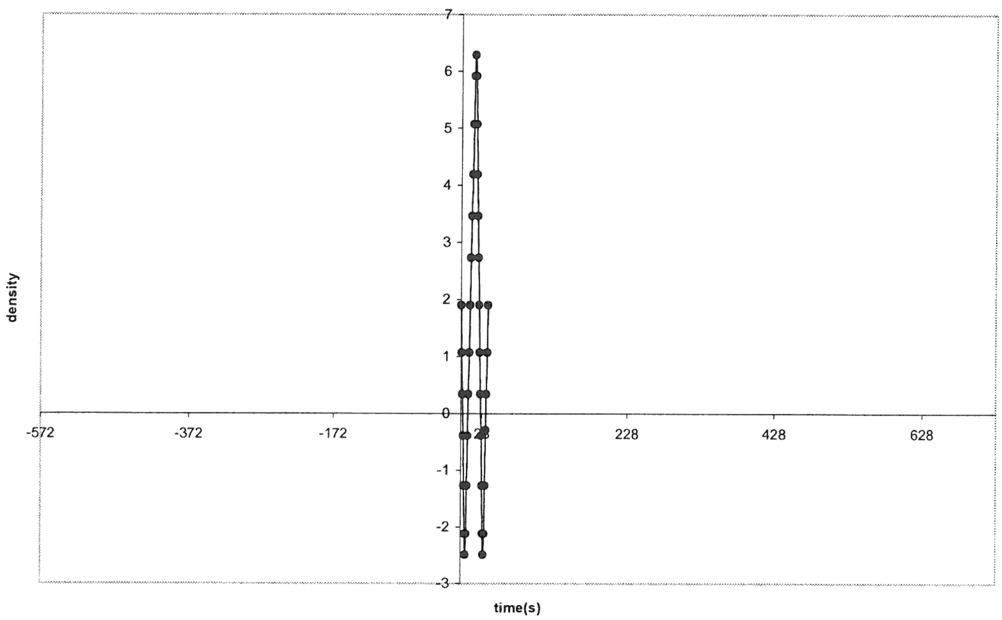
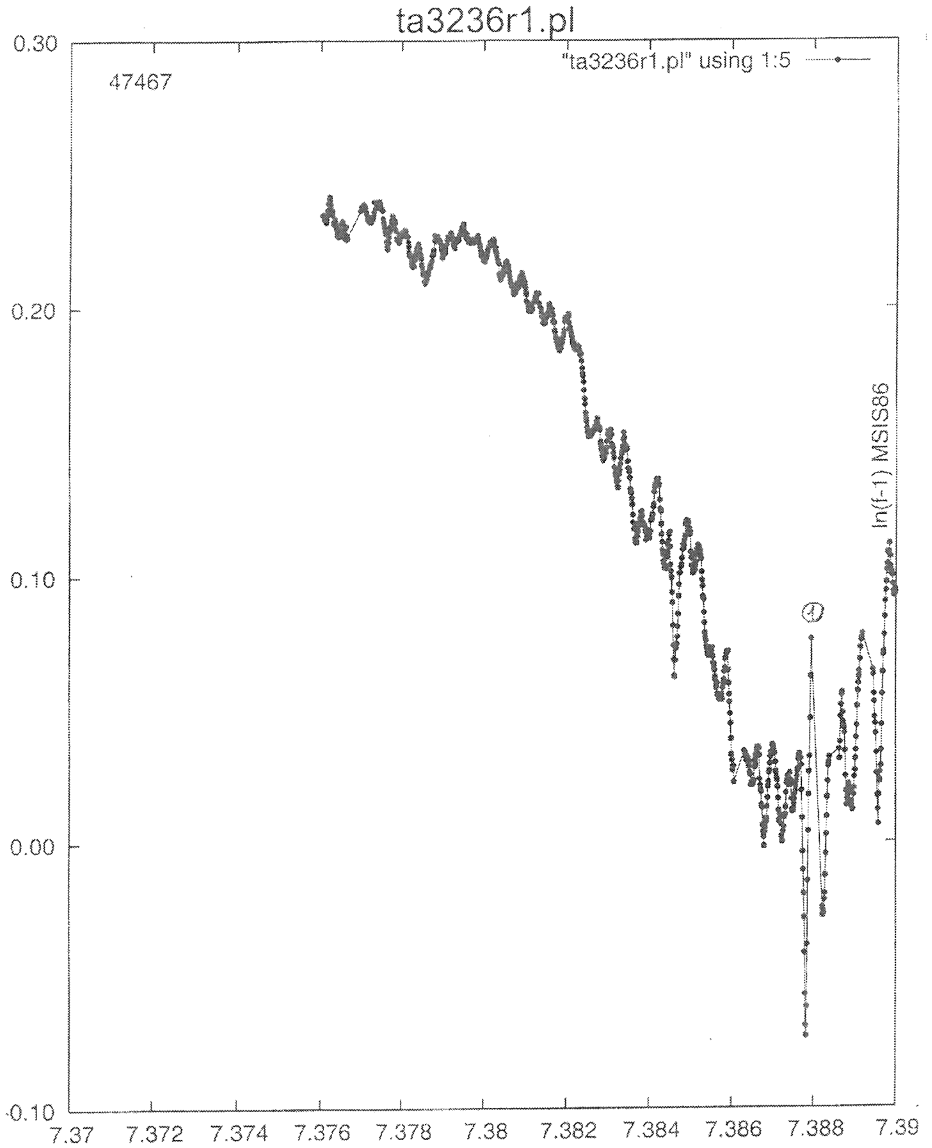

density
time(s)
7
6
5
4
3
2
1
0
-1
-2
-3
-572
-372
-172
228
428
628

Fig. 4c


ta3236r1.pl
0.30
0.20
0.10
0.00
-0.10
47467
"ta3236r1.pl" using 1:5
ln(f-1) MSIS86
7.37
7.372
7.374
7.376
7.378
7.38
7.382
7.384
7.386
7.388
7.39

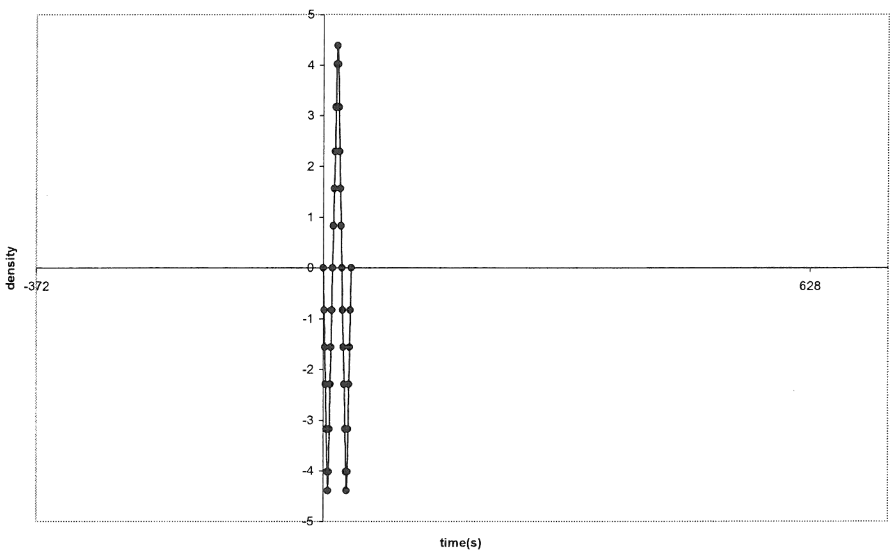

density
time(s)
-372
628
5
4
3
2
1
0
-1
-2
-3
-4
-5

Fig. 4d

Large amplitude neutral density waves in the thermosphere, effect of meteor trails?

Bencze, P.[1], E. Illés-Almár [2], I. Almár [2]

[1]Geodetic and Geophysical Research Institute, Hungarian Academy of Sciences, 9401 Sopron, P.O.B. 5, Hungary, E-mail: bencze@ggki.hu
[2]Konkoly Astronomical Research Institute, Hungarian Academy of Sciences, 1525 Budapest, P.O.B. 67, Hungary E-mail: illes@konkoly.hu

1. Introduction

Large amplitude solitary waves were found in measurements of the total neutral density having high temporal resolution carried out on board of the Italian San Marco V satellite by the DBI accelerometer. Looking for simultaneous occurrence of bay-like like ionospheric phenomena and these solitary waves no temporal coincidence could be shown. However, annual variation of the occurrence of the solitary waves indicated a variation similar to that of the occurrence of meteorites (Fig. 1). These conditions prompted us to assume meteoritic origin of the solitary waves. At higher altitudes, in the thermosphere, where the density of the atmosphere is small, first of all an „atom trail" is produced by the meteorite hitting the atmosphere (Manning, 1958). The possibility of the meteoritic origin of the large amplitude neutral density waves was assumed considering that these waves indicate mostly a succession of density maxima and minima.

2. Formation of the meteoritic trail in the thermosphere

If the meteoritic origin of the large amplitude neutral density waves is accepted, generally two different situations can be distinguished. The first situation would correspond to the succession of large amplitude density waves forming the meteoritic trail not far from the meteorite as the satellite crosses the trail. It consists of a density minimum flanked by two maxima, the minimum corresponding to centre line of the trail, from where the meteorite pushed out the air. The maxima are produced by air piled up at the flanks of the minima. The other situation would occur far from the meteorite along its path observed by the satellite crossing the trail. In this situation, the minimum is removed by diffusion due to the density gradient formed by the maximum and minimum, moreover as a result of the dynamics of this process a maximum develops in the centre line with two minima at its sides.

3. Results

In Fig. 2, the radius of the trail r is shown as a function of altitude for two different times (0s, 13s) in the height of the satellite 400 km computed by the classical form of the diffusion rule of a lingering trail with the molecular diffusion coefficient $D = \mu / \rho$

$$r^2 = 2Dt + r_0^2$$

where r is radius of the trail, t is time and r_0 is initial radius of the assumed trail, μ, ρ being the dynamic viscosity and density, respectively (Drummond et al., 2002). Calculations indicate that radius of the trail increases with altitude due to the increasing diffusion coefficient. Curves in Fig. 2 indicate that calculations support the meteoric hypothesis resulting in initial radii observed by radar measurements (Close et al., 2002; Janches et al., 2002), if the radius found by the satellite crossing the trail, is taken as starting point. The increase of radius can be explained by the diffusion coefficient increasing with height because of the decreasing atmospheric density.

In Figs. 3-6 those large amplitude solitary neutral density waves can be seen, which represent different phases of the development of these waves as effect of the meteor trail. The first phase is the development of density minimum not far behind the meteorite plotted together with its simulation. In Fig. 3 the fully developed phase of the situation characterized by a density minimum is presented together with its modelled version. In the second phase the maxima and the minimum indicate a transition situation (Fig. 4). The third phase may be observed far from the meteorite showing a not fully developed state consisting of minima and a maximum (Fig. 5). Fig. 6 demonstrating that stage, when these extremes reached their final values.

4. Conclusions

Radii of meteor trails determined on the basis of its effect in the neutral density compared with values found by incoherent scatter radars seem to support the meteoritic origin of these density perturbations (Fig. 2). This agreement has been further studied by simulation of the density perturbations observed by a satellite and good correspondence have been found in all phases of the development of the density perturbations (Figs. 3-6).

References

Close, S., Oppenheim, M., Hunt, S., Dyrud, L.: Scattering characteristics of high resolution meteor head echoes detected at multiple frequencies. J. Geophys. Res., 107, A10, SIA9, 2002.

Drummond, J. D., Grime, B. W., Gardner, Ch. S., Liu, A. Z., Chu, X., Kelley, M. C., Kruschwitz, E., Kane, T. J.: Observations of persistent Leonid meteor trails 3. The „Glowworm". J. Geophys. Res., 107, A8, SIA 5, 2002.

Janches, D., Pellinen-Wannberg, A., Wannberg, G., Westman, A., Häggström, I., Meisel, D. D.: Tristatic observations of meteors using the 930 MHz European Incoherent Scatter radar system. J. Geophys. Res., 107, A11, SIA 14, 2002.

Manning, L. A.: The initial radius of meteoric ionization trails. J. Geophys. Res., 63, 181-196, 1958.

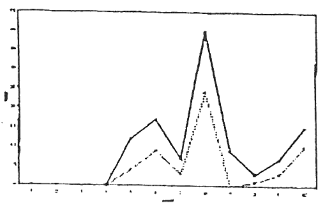


Fig. 1.
Annual variation of the mean hourly meteorite rate.

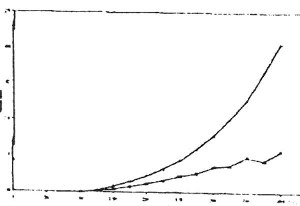


Fig. 2.
Variation of the meteor trail radius with height assuming that the satellite crossed the trail at 0s and 13s, respectively, passed since the observation of the large amplitude solitary density wave.

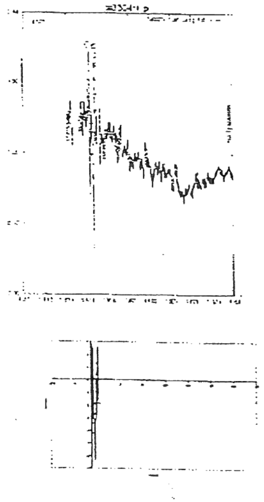


Fig. 3.
Above, variation of the parameter ln([illegible]) indices SM and MSIS indicating measured and model values and referring to that case, when the satellite crossed the path of the meteorite behind the meteorite. The density perturbation consists of a minimum flanked by maxima of smaller magnitude, fully developed case.
Below, the corresponding modeled density perturbation.

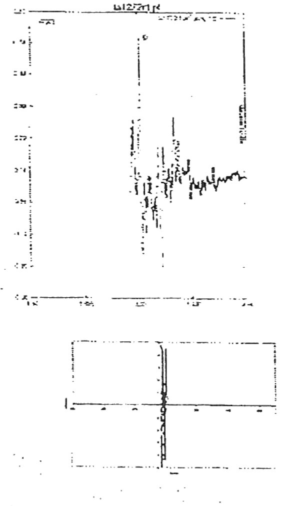


Fig. 4.
Above, variation of the parameter ln([illegible]) indices SM and MSIS indicating measured and model values and referring to that case, when the satellite crossed the path of the meteorite not far behind the meteorite. The density perturbation consists of a minimum flanked by maxima of the same magnitude.
Below, the corresponding modeled density perturbation.

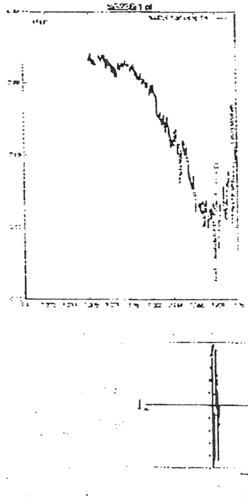


Fig. 5.
Above, variation of the parameter ln([illegible]) indices SM and MSIS indicating measured and model values and referring to that case, when the satellite crossed the path of the meteorite far behind the meteorite. The density perturbation consists of a maximum flanked by minima of the same magnitude.
Below, the corresponding modeled density perturbation.

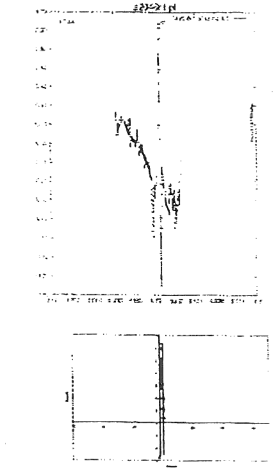


Fig. 6.
Above, variation of the parameter ln([illegible]) indices SM and MSIS indicating measured and model values and referring to that case, when the satellite crossed the path of the meteorite far behind the meteorite. The density perturbation consists of a maximum flanked by minima of smaller magnitude, fully developed case.
Below, the corresponding modeled density perturbation.

HAS GGRI

EGU ID-NR: EGU06-A-03830 Wienna 2006. Apr.