Wave disturbances in the earth's atmosphere during the passage of the leonids meteor stream on november 16-18, 2001

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ABSTRACT

An analysis is made of the disturbances in the atmosphere during the passage of the meteor flow on November 16-18, 2001, based on using simultaneous ground-based measurements (in the region of East Siberia) of the Earth's atmospheric airglow in the 558 nm (85-115 km altitudes of emission) and 630 nm (180-250 km) lines, and in the ultraviolet and blue spectral regions (360-410 nm), and ground-level microvariations of the pressure, visual observations, and satellite measurements of total electron content variations in the ionosphere. Result of spectral, cross-correlation and wavelet analyses of the measured quantities are presented. In the range of periods corresponding to acoustic-gravity waves, changes in amplitude-frequency characteristics of the variations of the measured quantities are observed in the maximum phase of the meteor flow. We discuss the possible relationship of the recorded dynamics of the variations and intensity disturbances of the upper atmospheric airglow, total electron content in the ionosphere, and ground-level pressure with the meteor flow.

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Keywords: atmospheric airglow, microvariations of the pressure, total electron content variations, meteor flow

1. INTRODUCTION

The study of disturbances in the Earth's atmosphere caused by the intrusion of meteor matter is of interest within the context of eventual changes in neutral composition and physical and chemical properties as well as in ionospheric ionization. Manifestations of traveling meteors and meteor streams in the Earth's middle and upper atmosphere include the generation of internal gravity waves (IGW) [1, 2], and changes of physical characteristics in the ionospheric D- and E_s-layers [3, 4]. Sources of IGW in the atmosphere can also be provided by other atmospheric phenomena: earthquakes and volcanic eruptions, hurricanes and thunderstorms, solar eclipses and the terminator, jet flows, auroral activity, explosions, and other phenomena. In this connection, the problem of discriminating the recorded IGW and identifying their sources is challenging importance.

This paper presents the data of ground-based measurements made in the region of East Siberia (52°N, 103°E), of the Earth's atmospheric airglow in the 558 nm (85-115 km altitudes of emission) and 630 nm (180-250 km) lines, and in the ultraviolet and blue spectral ranges (360-410 nm), ground-level pressure microvariations, visual observations and satellite measurements of total electron content (TEC) variations in the ionosphere during the passage of the Leonids meteor stream on November 16-18, 2001. Our analysis of the wave disturbances was based on using the spectral, cross-correlation and wavelet methods. The emphasis is on analyzing variations in airglow of the Earth's upper atmosphere which is a sensitive indicator of IGW [5].

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2. EQUEPMENT AND OBSERVING TECHNIQUE

The optical measurements were made with the zenith photometer “Phoenix” installed at the ISTP SB RAS geophysical observatory at the settlement of Tory (52°N, 103°E). The working wavelengths of 558 nm and 630 nm, and the 360-410 nm spectral band were used. Data with a time resolution of 27.5 s were used in this study. Whenever the recorded signal intensity showed an overshoot above a certain threshold of measurement, measurements were made with 8 ms resolution thus enabling optical flares from meteors to be recorded. The photometer’s angular field of view is ~5°. Ground-level pressure measurements with the microbarograph M75-2 and visual observations of the sky were carried out simultaneously. TEC was measured using signals from the navigation GPS system. GPS technology affords an opportunity to detect wave disturbances in the ionosphere on the basis of phase measurements of TEC by several spatially separated two-frequency GPS receivers [6]. This paper uses the GPS data with a time resolution of 30 s.

3. CHARACTERISTIC OF THE LEONIDS METEOR STREAM

Every year on November 17-18 the Earth crosses the Leonids meteor stream formed by remnants of the Tempel-Tuttle comet which continue in its orbit. The most dense part of this stream encounters the Earth every 33 years.

Meteor streams differ greatly in density. On the night from November 16 to 17, 1966, an exceptionally intense Leonids shower was observed, perhaps, the strongest for the whole history of scientific meteor observations. In the period of a maximum (about 20 min) the number of meteors reached 20 per sec, which corresponded to 150000 per hour (http://leonid.arc.nasa.gov/history.html).

The passage by the earth of the main part of the dense cluster of the Leonids swarm was expected to occur in 1999. And, indeed, the stream was rather intense (about 4000 meteors per hour), and the rain duration totaled 4 hours [7]. In 2000, the stream somewhat decreased in activity and was about 2000 meteors per hour in 2001 according to observations in Australia (http://www-space.arc.nasa.gov/~leonid/live/viewflux/live_Chabot.html). According to our visual observations (Tory), the activity of the November 17-18, 2001 meteor stream was estimated at ~4000 meteors per hour.

4. OBSERVATION RESULTS

During the passage of meteor streams, of the greatest interest is the 558 nm emission behavior, as the altitudes of this emission (85-115 km) coincide with those where meteor bodies of small mass (<1 g) start to interact with the atmosphere (80-115 k). Intrusion of large meteor bodies and bolides can be accompanied by the generation of shock waves at lower heights (60-90 km) [8]. Fig. 1 presents the spectra of 558 nm emission S(T) variations for three nights of November 16, 17 and 18, 2001 (a, b, and c, respectively). The spectra were obtained suing a standard spectral analysis procedure upon removing low-frequency trends (periods > 120 min). The spectra of 558 nm emission variations for November 18, 2001 clearly show change of the form of the spectral distribution of the oscillations when compared with the two preceding days. There is a relative increase of the signal amplitudes in the range of ~5-50-min periods (quasi-continuous spectrum), with an attendant increase of the number and amplitudes of discrete harmonics with periods of ~1-13, ~23-25 and ~30-50 min. The fluctuation amplitudes of 558 nm emission intensities at periods of 23-25 and 30-50 min were as high as 15-20% of the current values of the 558 nm emission intensity. In the spectra of 630 nm emission variations for November 18, 2001, the tendency of the form of the spectral distribution of the fluctuations to increase, similar to the 558 nm emission, when compared with the preceding days, is pronounced to a lesser extent and is clearly seen only in harmonics with periods of ~50-60 and 100 min. Variations with periods of ~23-25 and ~30-50 min are also present in oscillation spectra of this emission. The distinctive feature of the 630 nm emission variations, when compared with the 558 nm emission variations, is the lack of any pronounced variations with periods of ~11-13 min.

The presence of pronounced 558 and 630 nm emission variations with the same periods corresponding to different height levels is suggestive of an association of these variations with a single source of excitation. In this connection, cross-correlation functions $\rho(\tau)$ were calculated for time samples of a length of 2 hours, enclosing the largest of the above-mentioned variations with periods of 30-50 min. Values of $\rho(\tau)$ for the time series of 558 and 630 nm emissions in some of the time intervals of November 18, 2001 were as high as ~0.7-0.8 with time shifts of 0-50 min. Fig. 2 shows the form of $\rho(\tau)$ for the time series of 558 and 630 nm emissions for the time interval of 19-21 UT of November 18, 2001. The change of sign of $\rho(\tau)$ from the value -0.81 with a time shift of ~50 min to the value +0.82 with an increase of the shift to 100 might suggest a quasi-harmonic character of the disturbance. The quasi-harmonic character of the disturbance can also account for the appearance of large values of $\rho(\tau)$ in the case of negative shifts and, in particular, in other time samples (as high as 0.74, 15-17 UT).

In visual and instrumental observations there appeared bright meteors which can be interpreted as large meteors, bolides. It is therefore of interest to discriminate disturbances in recorded signals from isolated meteors. In this connection, noteworthy is the behavior of the ground-level pressure microvariations after 22 UT of November 18, 2001. Fig. 3 presents the data on ground air pressure variations for three days used in the analysis: November 16-18, 2001. After 22 UT on November 18, 2001, signals of ground air pressure variations show an unusual (for preceding hours and days) ground-level pressure fluctuations with periods of 7-16, 20-28, ~47 and ~140 min (spectral analysis data) with an amplitude exceeding 1.5 gPa. Fig. 4 shows the $\rho(\tau)$ for the time series of TEC and 558 and 630 nm emission variations for the time interval of 20-23 UT when there were disturbances in ground air pressure variations. Maximum $\rho(\tau)$ between time series of ground air pressure and 558 nm emission for the time interval 22-23.1 UT were ~0.75 with a time shift of ~33 min. The $\rho(\tau)$ has an oscillating character with a period of ~22 min, which is also suggestive of the quasi-harmonic character of the disturbance.

In the analysis of the possible disturbances in the upper atmosphere we also sued satellite data on total electron content (TEC) variations in the ionosphere measured using signals from the navigation GPS system. For the time interval 21-24 UT of November 18, 2001, spectral analysis of the TEC variations gives maxima at characteristic periods of 20-30, ~43 and ~130 min. maximum values of $\rho(\tau)$ for this period of time between time series of TEC variations and 630 nm emission were ~0.74.

5. DISCUSSION

A spectral analysis of the 558 and 630 nm emission variations revealed an increase in oscillation amplitudes with periods of 5-100 min on November 18, 2001 during a maximum of the Leonids meteor stream when compared with preceding days. Oscillations with these periods correspond to IGW in the Earth's atmosphere [9]. Variations of upper atmospheric emission characteristics and their connection with IGW were addressed in a large number of theoretical and experimental publications (see, for example, in Ref. 10,11). unfortunately, only a few publications deserve mention, which are concerned with the study of separate aspects of the influence of meteors and meteor streams on characteristics of upper-atmospheric emissions. Thus, the authors of Ref. 12 investigate the influence of meteor activity on the mean intensities of atomic oxygen emissions at 558 nm, Na589.0-589.6 nm, OH bands, and the NO_2 continuum. They found an increase in intensities of emissions at Na589.0-589.6 nm and NO_2 continuum 3-4 days after a maximum of the Perseids meteor stream. No pronounced effect was observed in the intensity variations of 558 nm and OH. The authors of Ref. 13 describe the fact of a visual observation (from space complex "Mir") of an unusual region of ionospheric emission in the form of an anomalous spot at the place of fall of a meteorite or space body. Rays went upward to an altitude as high as 250 km from the spot lying at the height of the first emission layer (557.7 nm), and the spot itself was expanding in a horizontal direction with a concurrent bending of the emission layer. The bending of the emission layer is associated by the authors of Ref. 13 with the effect exerted on the atmospheric boundary by the shock wave generated wen meteors enter the atmosphere with a supersonic speed. The author of Ref. 14 considers some issues related to the formation of anomalously large regions of airglow (~1 km or larger) near space bodies, and other accompanying phenomena (generation of a leading echo, sporadic E_s-layers, mechanisms of 557.7 nm excitation, and other questions). The author of Ref. 14 arrives at the conclusion that in some cases the ionosphere can develop conditions where small disturbances can lead to a heating of electrons, to the excitation of the airglow, and to the ionization of the environment. Disturbing factors can include electromagnetic waves or disturbances associated with the movement of the body, and with an increase of the traveling velocity, there is an increase of the excitation level of the environment.

We were unable to find out publications concerned with the manifestation of IGW in emissions of the upper atmosphere during the passage of meteor streams. Disturbances from meteors and meteor streams were investigated mainly through radar of meteor tracks [15] or by recording acoustic or infrasound signals [2, 8].

Meanwhile there are a relatively large number of publications reporting the registration of variations and disturbances of upper-atmospheric 558 and 630 nm emissions in the range of periods of 5-100 min or longer, from other sources of disturbances, and discrete periods were identified in some cases. Fluctuations of 558 nm emission with periods of 5-10 min and an amplitude of several percent of the mean intensity were obtained in Ref. 16; they were associated with the small-scale structure of a turbulent field in the turbopause region. Oscillations of 558 nm emission with periods of 25, 28 and 38 min and of 630 nm emission with a period of 50 min were detected in Ref. 17 for the period of two total lunar eclipses. With the purpose of identifying IGW, the authors of Ref. 18 recorded simultaneously the 558 nm emission intensity variations and the atomic oxygen temperature that was determined from the Doppler broadening of the 558 nm line. By applying Fourier-analysis, for two days they identified the periods of 60 and 69 min, respectively, for the intensity and temperature. The 558 nm emission intensity and temperature variations made up, respectively, ~4-5% and ~8-9%, and the source of disturbances was not indicated. In Ref. 19, an enhancement of the 558 nm emission variations with periods of 7-8, ~12-15 and ~30 min was detected at the time of build-up and development of an earthquake.

Thus it should be noted that different sources of disturbances can cause upper-atmospheric emission variations in the range of IGW periods with discrete periods of oscillations. Furthermore, according to Ref. 18, not all emission variations with these periods can be referred to IGW. Many variations can be caused by turbulence accompanied by upward and downward flows and by the general atmospheric circulation. Besides, the possibility of formation of sporadic E_s-layers during the passage of meteor streams [20] and their influence on atmospheric emission variation [21] should not be ruled out. For that reason, only those variations and disturbances of measured parameters, for which it is possible to establish the fact of their spatial propagation by indicating the velocity and direction, can be ascribed to IGW [18].

In the case under consideration the presence of time shifts in $\rho(\tau)$ for the 558 and 630 nm emission variations (Fig. 2) is suggestive of the fact of presence of IGW. An estimate of the vertical phase velocity of wave disturbances obtained from the delay between 558 and 630 nm variations for the Fig. 2 conditions, gives the value ~50-80 m/s. An estimate of the phase velocity of wave disturbances obtained from the delay of variations of 558 nm emission and ground air pressure for the time interval 22-23.1 UT gives the value ~50 m/s. The resulting values of the vertical phase velocities of wave disturbances correspond to typical values of this quantity for IGW [22].

The large time delays in $\rho(\tau)$ for TEC and 630 nm emission (Fig. 4) indicate that the regions of TEC disturbances and 630 nm emission can be very much separated in altitude. The 630 nm emission is distinguished within a sufficiently wide layer at ~180-300 km altitudes, with a maximum at ~250 km altitude (ionospheric F2-region). Electron content in the F2-region makes the main contribution to TEC under geomagnetically quiet conditions. However, TEC disturbances can, in principle, be observed outside of this height range at, for example, E-layer heights in the case of formation of E_s- or lower layers. There exists a time delay of ~17 min between disturbances of 558 nm emission and TEC (Fig. 4), and the sign of the delay indicates that the disturbance was first observed in TEC variations and then in 558 nm variations. The small value of the delay is due to the fact that the TEC disturbance region lay near the 558 nm emission layer (85-115 km). Considering that the time delay between disturbances of TEC and 630 nm emission has a substantially larger value it can be suggested that the TEC disturbance region lay below the 558 nm emission altitudes and was possibly associated with an additional ionization of the atmosphere at these altitudes whic, in turn, could be modulated by propagating disturbances.

It has been pointed out above that one of the difficulties in investigating the IGW is the determination of their source. Fig. 5 for November 18, 2001 presents the spectral composition of 558 nm emission variations obtained by the wavelet method, the hourly values of the Leonids stream from observations in Australia [23] (in the near-lying longitude zone), and the histogram of the number of optical flares from bright meteors according to the data from the zenith photometer "Phoenix". One can see a fairly good time correlation over the time interval 16-20 UT between a maximum of the Leonids stream and 558 nm emission disturbances, which might serve as an indirect indication of the association of these phenomena.

Ground air pressure variations during transits of large meteors and bolides as recorded in the form of acoustic and infrasound signals, were reported repeatedly [8, 23, 24].

6. CONCLUSIONS

During the maximum phase of passage of the November 18, 2001 Leonids meteor stream, airglow variation spectra (559 and 630 nm emissions) showed a change of the form of the spectral distribution of the oscillations against preceding days, implying a relative increase in signal amplitudes over the range of ~5-100-min periods. Values of the cross-correlation function $\rho(\tau)$ for time series of 558 and 630 nm emission during separate time intervals of November 18, 2001 were as high as ~0.7-0.8, with time shifts of 30-50 min. These oscillation periods were also observed in variations of total electron content and ground air pressure, for which some of the time intervals showed high correlation coefficients with 558 and 663 nm emission variations. These oscillation periods and the vertical phase velocities of wave disturbances estimated from our data correspond to IGW characteristics in the upper atmosphere. Time intervals which are characterized by the above-mentioned typical changes of variation spectra coincide with the time of enhancement of the Leonids meteor stream according to data of visual and instrumental observations, which is an indirect indication of this stream being the possible source of the recorded wave disturbances in the Earth's atmosphere on November 18, 2001.

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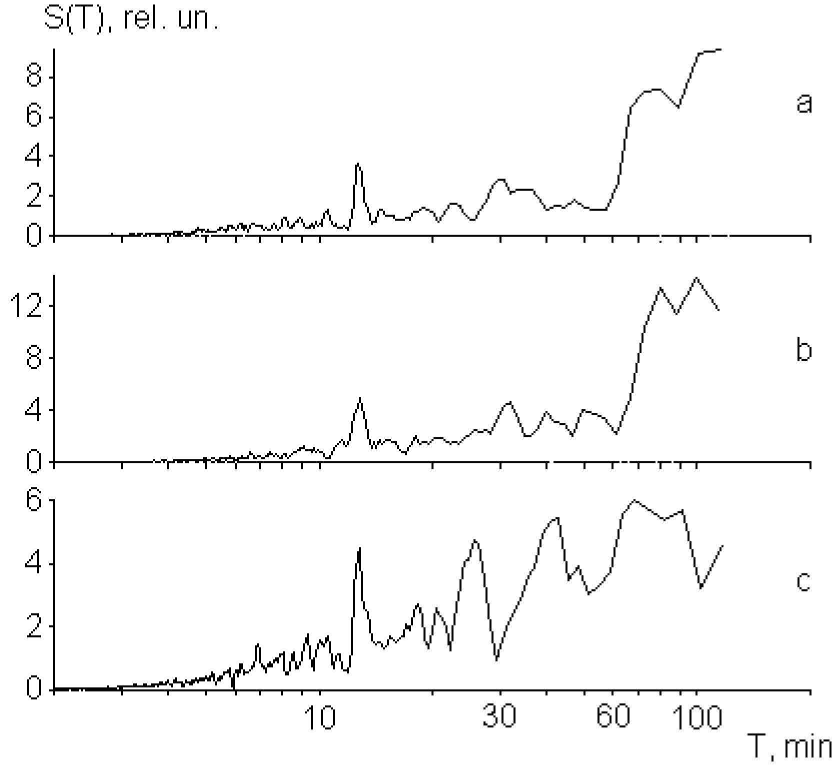

Figure 1: Spectra of 558 nm emission variations S(T) for three nights of November 16, 17 and 18, 2001 (a, b, and c, respectively).

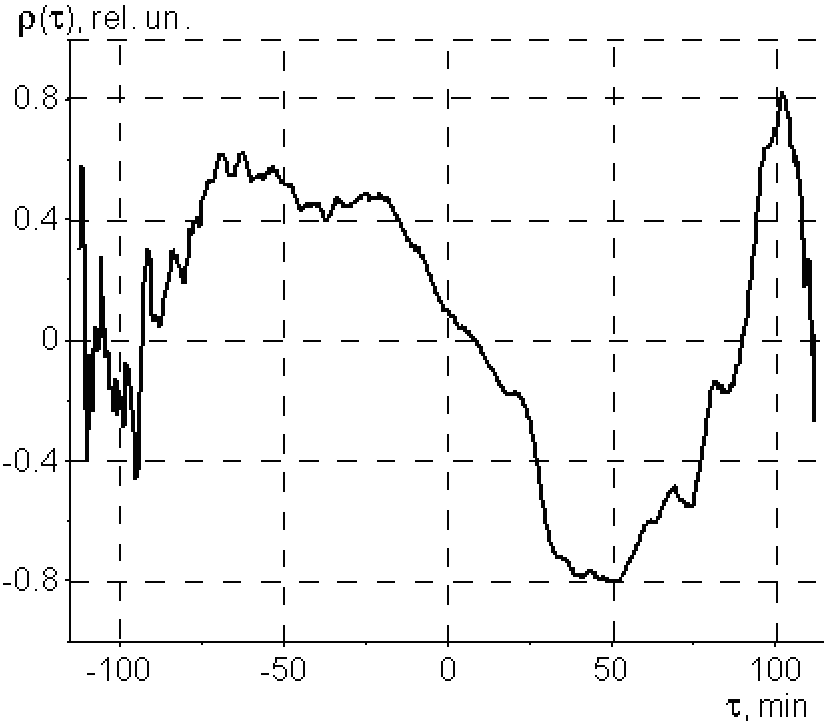

Figure 2: Cross-correlation function ρ(τ) for time series of 558 and 630 nm emissions for the time interval 19-21 UT of November 18, 2001.

Figure 3: Ground air pressure variations for November 16 (line 1, axis $P_2(t)$), November 17 (line 2, axis $P_1(t)$), and for November 18, 2001 (line 2, axis $P_1(t)$).

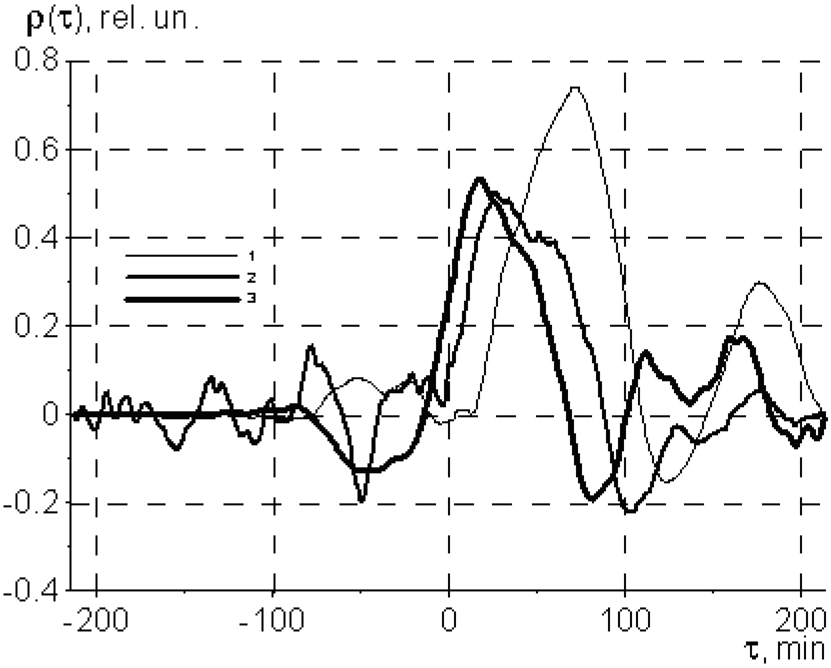

Figure 4: Cross-correlation functions ρ(τ) for variations of TEC and 630 nm emission (1), 558 and 630 nm emissions (2), and variations of TEC and 558 nm emission (3) for the time interval 20-23 UT.

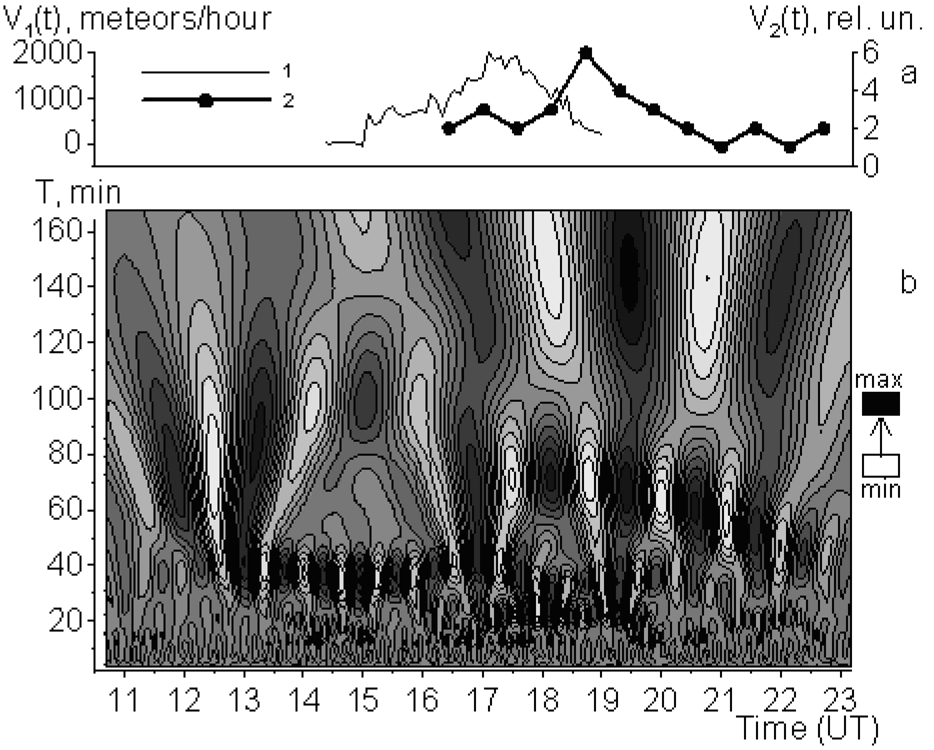

Figure 5: Hourly zenith values of the Leonids stream as observed in Australia, and histogram of the number of optical flares from meteors according to the data from the zenith photometer "Phoenix" (line 1, axis $V_1(t)$, and line 2, axis $V_2(t)$, respectively) - Fig. 5(a), and spectral composition of 558 nm emission obtained by the wavelet method, for November 18, 2001 - Fig. 5(b).