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Variations in meteor heights at 22.7°S during solar cycle 23

L.M. Lima [a,*], L.R. Araújo [a], E.O. Alves [a], P.P. Batista [b], B.R. Clemesha [b]

[a] Dep. Física, PPGCTA, Universidade Estadual da Paraíba, UEPB, 58.109-790, Campina Grande, PB, Brazil
[b] Instituto Nacional de Pesquisas Espaciais, INPE, Brazil

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ABSTRACT

The meteor radar measurements obtained at Cachoeira Paulista (22.7°S), Brazil, have been used to study a possible relationship between meteor echo height variations and solar flux during solar cycle 23. A good concordance between the normalized values of the annual mean of the meteor peak heights and $F_{10.7}$ solar radio flux and Mg_II solar indexes have been observed during declining phase of the solar cycle 23. After eliminating the solar activity influence, the annual mean of the meteor echo peak heights showed a linear decrease of 30 m/year when Mg_II solar index is used and 38 m/year when $F_{10.7}$ solar radio flux is used. When the trend is eliminated the relationship between meteor peak heights and $F_{10.7}$ solar flux indicate a trend of 672 m/100 sfu (sfu-solar flux unit). The meteor amplitude signals and the decay time drops after mid-2004, which may be attributed to the decreasing of the electron density in the meteor trails. The meteor echo peak height decrease has been interpreted as being caused by a reduction in air density in the upper atmosphere.

1. Introduction

Meteors are the visible streak of light that are created along of the meteoroid's path when they enter into the atmosphere and rapidly vaporize. Furthermore, these heated and ionized meteoric trails reflect radio waves and constitute an outstanding tracer to study the dynamics of the upper mesosphere and lower thermosphere (MLT) region. Measurements undertaken by modern meteor radar system enables us to measure a number of atmospheric and astronomical parameters, such as neutral winds, ambipolar diffusion coefficient, temperature and density of the upper atmosphere, location of the meteor in the sky, meteor entry speed into the atmosphere, meteor fluxes, as well as the source positions of meteor shower radiants (Hocking et al., 2001).

The existence of the metallic species in the MLT region has been attributed to meteoroid's ablation occurrence and it is regarded that some phenomena are closely related with their presence (Plane, 2003). The presence of noctilucent clouds in the polar mesopause region during their summer months, are probably caused by water vapor freezing and clutching the meteor smoke particles to form tiny crystals (Bardeen et al., 2008). The formation and strength of sporadic E layers are commonly explained by ionization of the ablated meteoric metals as well as by wind shear theory (Haldoupis et al., 2007; Yeh et al., 2014).

The meteor phenomenon occurrence depends on the meteoroid properties (mass, density, entry speed). Moreover, the variations in the neutral and ionized atmospheric density can contribute to meteor height occurrences. Variations in the upper atmosphere density due to the influence of solar activities in their physical state induce fluctuations on neutral and ionized upper atmosphere. Bumba (1949) has been the first to suggest a connection between meteor count variability and the maxima and minima solar activities. Lindblad (1976) has analyzed a long-term variation in meteor count and found that the rate of radar meteor echoes observed during the years of solar minimum activity is larger than the one observed in years of solar maximum. These findings have been confirmed and a possible cause has been pointed out to be due to changes in the atmospheric density on meteoroid's ablation region (Ellyett and Kennewell, 1980).

Clemesha and Batista (2006) have shown the presence of planetary waves, seasonal and long-term variations in the meteor ablation trail height from 5 years of data obtained by meteor radar at 23°S, and they concluded that long-term fluctuations in the meteor peak height should be a consequence of long-term variations in air density. Pellinen-Wannberg et al. (2009) have reported that the atmospheric density has an impact on beginning ablation heights of the meteor trails, in which the meteors can ablate up earlier during solar maximum than minimum conditions. Using meteor head-echo data obtained at 18.3°N and 65.1°N, Sparks and Janches (2009) have observed a weak diurnal and strong seasonal variability for meteor altitude distribution at high latitudes, however, in the tropical latitudes an opposite behavior has been observed, which has been attributed to astronomical properties of

* Corresponding author.
E-mail addresses: lourivaldo_mota@yahoo.com.br (L.M. Lima), lucianarodriggues@uol.com.br (L.R. Araújo), eoalves@uepb.edu.br (E.O. Alves), ppbatista@laser.inpe.br (P.P. Batista), brclemesha@gmail.com (B.R. Clemesha).

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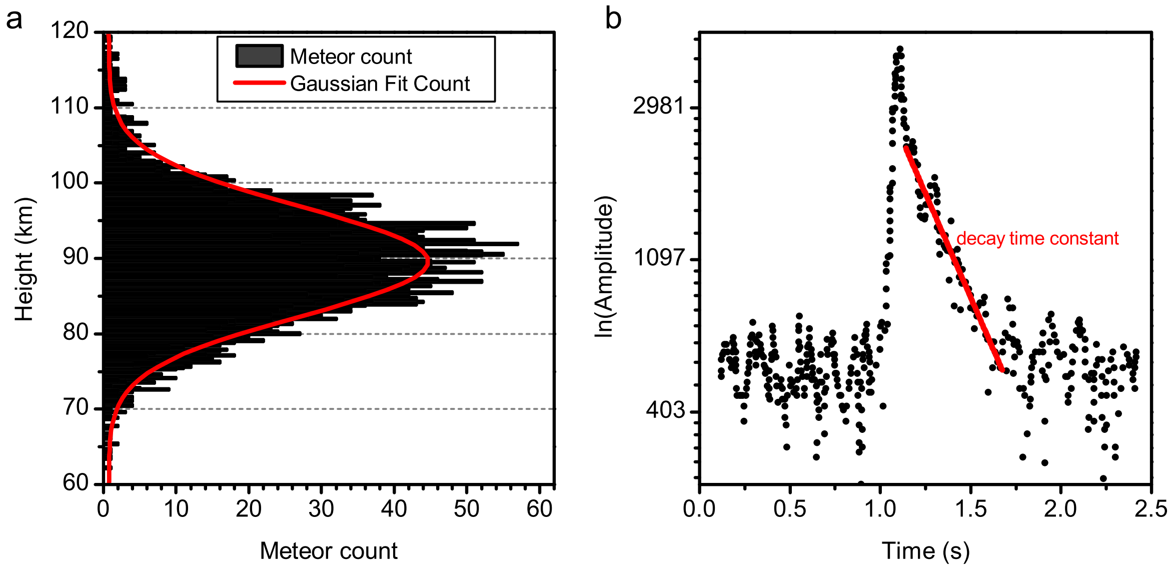

Fig. 1. (a) Meteor count height distribution and a Gaussian fit for data obtained in 1st January 2008 at Cachoeira Paulista. (b) Typical amplitude plot of a meteor echo received by SKiYMET on logarithmic scale. The red straight line represents the decay time constant. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the meteoric flux. Jacobi et al. (2011) also found that mean meteor heights measured with VHF meteor radar showed a decrease during solar minimum. Using meteor data obtained during winter season 2009/2010, Stober et al. (2012) have investigated air density variations due a 16-day wave from sporadic meteor peak altitude fluctuations and have demonstrated their potential to provide information about of oscillations with planetary wave periods on mesopause region.

In this paper, the peak altitude of the sporadic meteor echoes observed from meteor radar at a low latitude station in the southern hemisphere has been used to investigate a possible relationship between meteor trail height variations and solar flux, during the solar cycle 23.

2. Observations

Meteoroids impinging on Earth's upper atmosphere ablate and form meteor ionized trails at 70–140 km height range, which are able to reflect and scatter incident radio waves in the high frequency (HF), very high frequency (VHF) and ultra high frequency (UHF) bands (e.g., Mathews et al., 2010; Pifko et al., 2013). The meteor heights used here were obtained by SKiYMET meteor radar at Cachoeira Paulista (22.7°S, 45°W), Brazil. The system is an all-sky VHF radar that uses a single three-element Yagi antenna transmitting at a frequency of 35.24 MHz with a pulse width of 13.3 µs and with a peak power of 6 kW until Nov/2001 when was changed to 12 kW. The meteor specular echo reflections are detected by five two-element receiving antennae oriented along two orthogonal baselines, by forming an interferometric array that provide a meteor position determination with a good accuracy. The data used include the time interval from March 1999 to July 2006 and from September 2007 to October 2008.

The meteor trail location in the sky has been determined by solving for the angle of arrival of the reflected radio wave, which is computed from phase differences of the meteor trail signal between the different receivers (Jones et al., 1998). It should be noted that VHF SKiYMET radar is limited to detect only the observable meteor trails in the 70–110 km altitude range. Because of the height ceiling effect (Ceplecha et al., 1998), which depends on radar wavelength, the VHF radars are unable to detect the meteor trails formed above of the height cutoff.

The height of the meteor trail is determined from range of the echo and zenith angle (Hocking et al., 2001). However, a spread in heights is obtained from a large population of meteor echo measurements, due the instrumental errors and an adjustment is necessary. As a solution, Hocking et al. (1997) assumes that the vertical distribution of underdense meteor trail echoes observed with VHF radar systems can be approximated by a Gaussian function. The same procedure has been used in the present study.

To estimate the daily meteor height peak, after the adjustment, a Gaussian function has been fitted to meteor echoes count as function of the altitudes. The height distribution of the underdense meteor echoes observed during 1st January 2008 at Cachoeira Paulista is presented in the Fig. 1a, in which the Gaussian fit is also shown. As shown in this figure, it is possible to perceive that the meteor echoes count spread mainly between 70 and 110 km (altitude limits of the SKiYMET radar), and from the Gaussian fit has been found a peak at around 89.70 ± 0.18 km for this day. A typical amplitude plot of a meteor echo received by SKiYMET system on logarithmic scale is presented in the Fig. 1b. The red straight line is obtained by linear fit and represents the decay time constant which is used to determine the ambipolar diffusion coefficients of meteor trails.

3. Results and discussion

The daily meteor echo peak heights, obtained during time interval from March 1999 to July 2006 and from September 2007 to October 2008 at Cachoeira Paulista, are represented in the Fig. 2 together with the 30-day running averaged (red line). The meteor echo peak heights exhibit a clear annual variation with maximum values occurring in December–January and the minimum in May–June. The observations include almost the full 11-year solar cycle 23, which is represented by daily F10.7 cm solar radio flux ($F_{10.7}$) and Bremen composite Mg II (B_MgII) index as shown in the Fig. 3, that also includes their 30-day running averaged (red line). The $F_{10.7}$ solar radio flux is given in solar flux units (sfu) (1 sfu = 10^{-22} W/m^{2}Hz) and is an important indicator of solar activity which is widely used. The B_MgII index has been produced from of the magnesium irradiance ratio on lines 279.56 and 280.27 nm (core-to-wing ratio) using European Space Agency (ESA) satellite measurements, which is a good proxy for solar