Enhanced sporadic E occurrence rates during the Geminid meteor showers 2006-2010

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Summary

Sporadic E (Es) layer occurrence rates derived from GPS radio occultation measurements during the Geminid meteor showers 2006-2010 are compared with meteor rates obtained with the Collm VHF meteor radar. In most years, Es rates increase after the shower, with a short delay of few days. This indicates a possible link between meteor influx and the production of metallic ions that may form Es. However, the correlation between Es rates and meteor flux varies from year to year, indicating that more processes significantly influence Es occurrence also during meteor showers.

Zusammenfassung

Auftretensraten sporadischer E- (Es-) Schichten während der Geminiden 2006-2010 wurden mit Meteorraten aus Radarmessungen am Collm verglichen. Es zeigt sich, dass die Es-Raten kurz nach dem Meteorschauer ansteigen, was auf einen möglichen Zusammenhang zwischen Meteorfluss und der Produktion von Metallionen hinweist, welche Es bilden können. Die Korrelation ist jedoch in verschiedenen Jahren unterschiedlich, so dass auch andere Prozesse die Es-Bildung auch während eines Meteorschauers signifikant beeinflussen.

1. Introduction

Sporadic E (Es) layers are thin regions of enhanced electron density in the lower ionosphere. Their origin is generally accepted to be vertical ion drift convergence due to tidal wind shear (Whitehead, 1960), while the ions are generally accepted to be provided by meteors. There have been long discussions about how sporadic E layers are linked to meteor rates, and the similarity of the seasonal cycles of both meteor rates and Es occurrence rates or strength has given rise to speculations about a cause-and-effect explanation for the sporadic E layer seasonal dependence (Haldoupis et al., 2008).

However, not all features of the seasonal cycle of Es can be found in meteor rates, too. One reason may be that meteor radars, which are usually utilised to provide meteor rate seasonal cycles, only detect part of the incoming meteor flux. Another possible reason is that metallic ions are relatively long-lived and some details of short-term variability is thus not visible in Es. Nevertheless, it is of interest whether short-period meteor events, especially meteor showers, may influence Es rates.

The Geminids are a major meteor shower which forms every year between December 4-17 with its peak activity on December 13. Its parent body is the asteroid 3200 Phaeton. Geminid shower meteors are relatively slow ones with a geocentric velocity of 35 km/s (e.g., Stober et al., 2011a). Consequently, they burn at comparatively low altitudes and are thus well visible in the height range accessible to standard meteor radars (about 80-100 km). The Geminid meteor shower is the major shower visible in radio detections, while other showers are less well visible at least if the analysis is not focused on altitudes above about 100 km.

In this paper we present Es occurrence rates detected by the GPS radio occultation method using FORMOSAT-3/COSMIC data during the Geminid meteor showers 2006-2010, and compare them with meteor rates observed with the VHF meteor radar at Collm. In sections 2 and 3 the methods are briefly presented. In section 4, we present time series of Es and meteor count rates, which are discussed in section 5. Section 6 concludes the paper.

2. Sporadic E analysis using FORMOSAT-3/COSMIC radio occultations

The FORMOSAT-3/COSMIC (FORMOsa SATellite mission-3/Constellation Observing System for Meteorology, Ionosphere and Climate) constellation was launched on April 14, 2006. It consists of 6 satellites, and the main scientific instrument aboard each satellite is a GPS receiver, which applies the GPS radio occultation (RO) technique (e.g., Kursinski et al., 1997) for vertical atmosphere sounding on a global scale. Data and analysis results are made freely available to the international scientific community.

To obtain information on the sporadic E occurrence we use Signal-to-noise ratio (SNR) profiles of the 50 Hz GPS L1 signal according to Wu et al. (2005). Sudden changes in the vertical electron density gradients, as it is usual in presence of a sporadic E layer, appear as strong fluctuations in the SNR above 85 km altitude. The disturbances are caused by signal divergence/convergence which leads to a decrease/increase of the signal intensity at the receiving antenna. The fluctuations are extracted from the background by applying a band pass filter which only accepts disturbances stretching between 1.0 km and 12.5 km height range. If the standard deviation of the SNR in a 2.5 km interval exceeds the threshold of 0.2, the disturbance in the SNR profile is regarded as a significant one. Since Es are very thin layers, the standard deviation should rise abruptly. Consequently, a second criterion is introduced defining that the standard deviation has to rise suddenly by more than 0.14 between two adjacent intervals. In order to avoid using disturbances resulting from other effects than sporadic E, all profiles are excluded from further investigation if the standard deviation exceeds the threshold of 0.2 in more than five intervals. Are all the above mentioned conditions fulfilled, it is considered that the respective profile includes a sporadic E signature. The maximum deviation from the mean profile represents approximately the altitude of the sporadic E layer. For details, see, e.g., Arras et al. (2008, 2009). Note that this method does not provide information about the strength of the Es layer, but only on the occurrence rates in a given time and space interval.

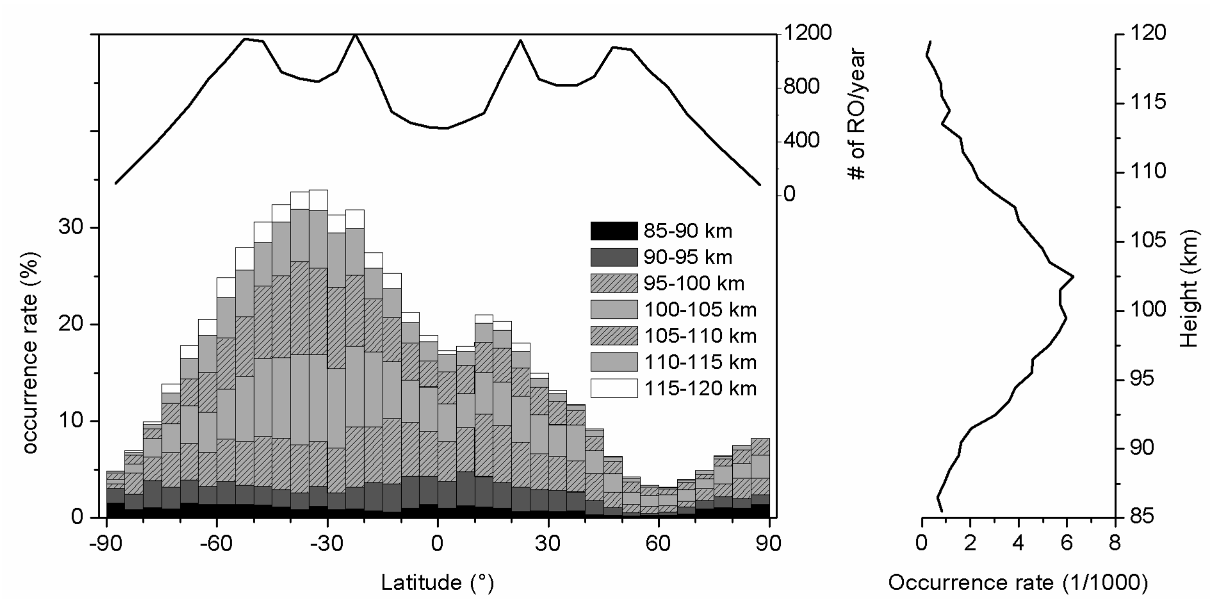

Fig. 1: Left panel: 2006-2010 mean sporadic E occurrence rates per 5km height interval for different 5° latitude bands for the time interval December 4-17 of each year. Right panel: Mean occurrence rates per 1 km height interval for all latitudes between 20°N and 60°N and for the same time interval.

GPS radio occultations are not uniformly distributed around the globe (see also Arras et al., 2009). In the left panel of Figure 1, the total number of occultations per 5 degree latitude interval between December 4 and 17, taken as the average of the years 2006 and 2010, are presented as black line. In the lower part of the panel, the occurrence rates, defined as the number of detected Es divided by the number of occultations in a 5 km height and 5 degrees latitude gate, are presented. One can see that the majority of Es are found in the Southern (summer) hemisphere, but there is also considerable Es activity at lower winter latitudes. The maximum number of Es is found at altitudes slightly above 100 km. Note that there is a tendency for lower altitudes in the winter hemisphere. In the right panel of Figure 1, the 20-60°N mean occurrence rates per 1 km height interval are presented. Most Es are found between 90 and 110 km. Note, however, that this result is partly due to the measurement method, which does not allow to detect Es above ~120 km.

3. Collm meteor radar measurements

At Collm (51.3°N, 13.0°E), a meteor radar is operated at 36.2 MHz since summer 2004. The radar is a commercial SKiYMET all sky system. The radar antenna system consists of one 3-element Yagi transmitting antenna and five 2-element Yagi receiving antennas, forming an interferometer. Peak power is 6 kW. Pulse repetition frequency is 2144 Hz, but effectively only 536 Hz, due to 4-point coherent integration. The sampling resolution is 1.87 ms. The angular and range resolutions are ~ 2° and 2 km, respectively. The pulse width is 13 μs, the receiver bandwidth is 50 kHz (see also Stober et al., 2011b).

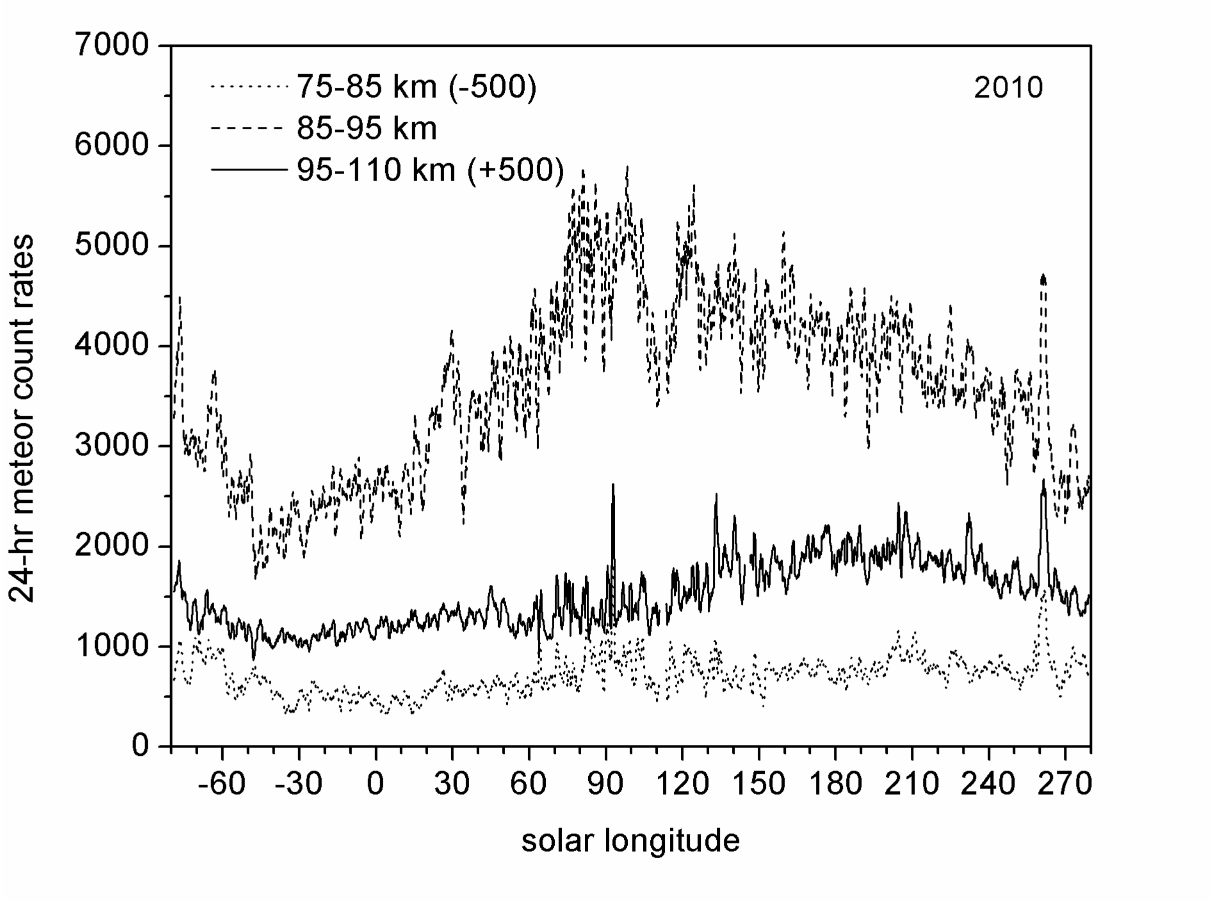

Fig. 2: 24-hr count rates (at 2 hrs step) as measured at Collm during 2010 for 3 different height gates. The curves for the upper and lower height gates have been shifted by +500 and -500 meteors/24 h, respectively.

The radar system was originally designed for wind measurements, but has been used for meteor studies as well. Here we consider zenith angles between 0° and 70°, and distances of up to 400 km from the transmitter. Count rates are taken every 2 hours, and running 24-hr means are calculated.

In Figure 2, meteor count rates for 3 different height gates are presented for the year 2010. The main bulk of meteors is detected at heights between 85 and 95 km. The seasonal cycle is due to the orientation of the radar with respect to the ecliptic plane in the morning hours, when the majority of meteors are detected. This leads to a clear seasonal cycle of fast (and thus high) meteors with minimum in spring and maximum in autumn. This is clearly different from the seasonal cycle of Es. At lower altitudes, where slower meteors are detected, the seasonal cycle is different. It can also be seen that fast meteor showers, like the Leonids (at solar longitude λ = 234°) is only visible at upper altitudes. Showers of slow meteors, like the Quadrantids in early January or the Geminids in December (λ = 262°), are visible at each height gate.

In the following, we consider the Geminid meteor shower as one that is visible in each height gate, and which considerably influences meteor count rates. We analyse count rates at altitudes between 75 and 105 km.

4. Results

As an example, in Figure 3 the 24-hr mean meteor count rates and Es occurrence rates are shown for the year 2010. The minimum in spring is visible in every year, followed by an increase and maximum Es and meteor rates in summer. This behaviour led to the conclusion that the annual cycle of meteor rates is responsible for the seasonal cycle of Es (Haldoupis et al., 2008). However, from then on meteor rates remain at an approximately constant level until November, while Es rates decrease. There is an increase of Es rates during December which is, however, not visible in each year.

From Figure 3 one may conclude that the seasonal cycle of meteor rates only partly explains the seasonal cycle of Es. On shorter time scales, however, some peculiarities are found when Es and meteor rates behave in a similar manner. One of them is the enhancement of Es rates in autumn (maximum around day #285) which is accompanied by increased meteor rates. Another one is the maximum of Es rates during the Geminid meteor shower in December. This may lead to the conclusion that strong meteor showers could lead to enhanced Es rates owing the increasing mass flux and thus ion production rate. Thus, in the following Es rates during the Geminid meteor showers will be analysed in more detail.

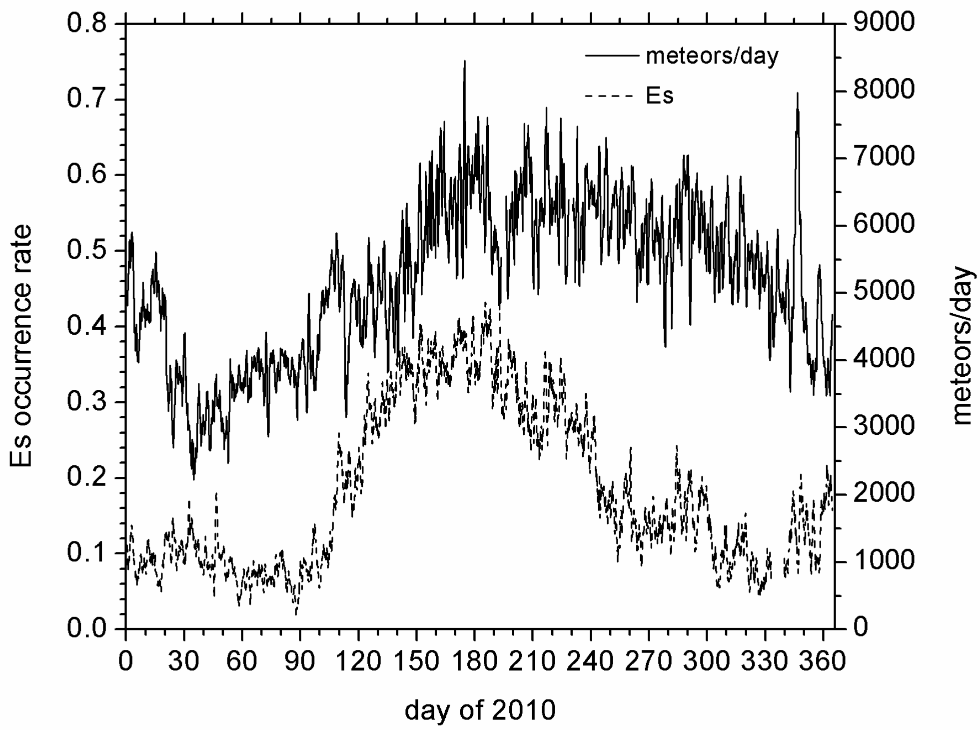

Fig. 3: 24-hr mean Collm meteor count rates and 20-60°N mean sporadic E occurrence rates in 2010.

Two examples of Es rates and meteor rates during different years are presented in Figure 4. We added the 2-hourly mean meteor rates multiplied by 12, to give an impression how the 24-hr means are obtained. Meteor rates have a distinct diurnal cycle with maximum rates in the early morning. This may influence the trends of the 24-hr means presented and definitely makes it difficult to detect the exact time of a meteor shower peak. The Es rates are taken over all longitudes and thus do not show the diurnal cycle. In 2006, the Es rates increase with some delay after the time of increasing meteor rates. Meteor rates after solar longitude λ = 256° show a double-peak structure, which is also represented in Es rates. In 2010, however, the picture is not that clear. Es rates undergo an oscillation not very clearly linked to the Geminid shower. However, in most cases an Es increase is preceded by an increase in meteor rates with a time delay of 2 to 3 days, although there is no quantitative connection between the respective maxima.

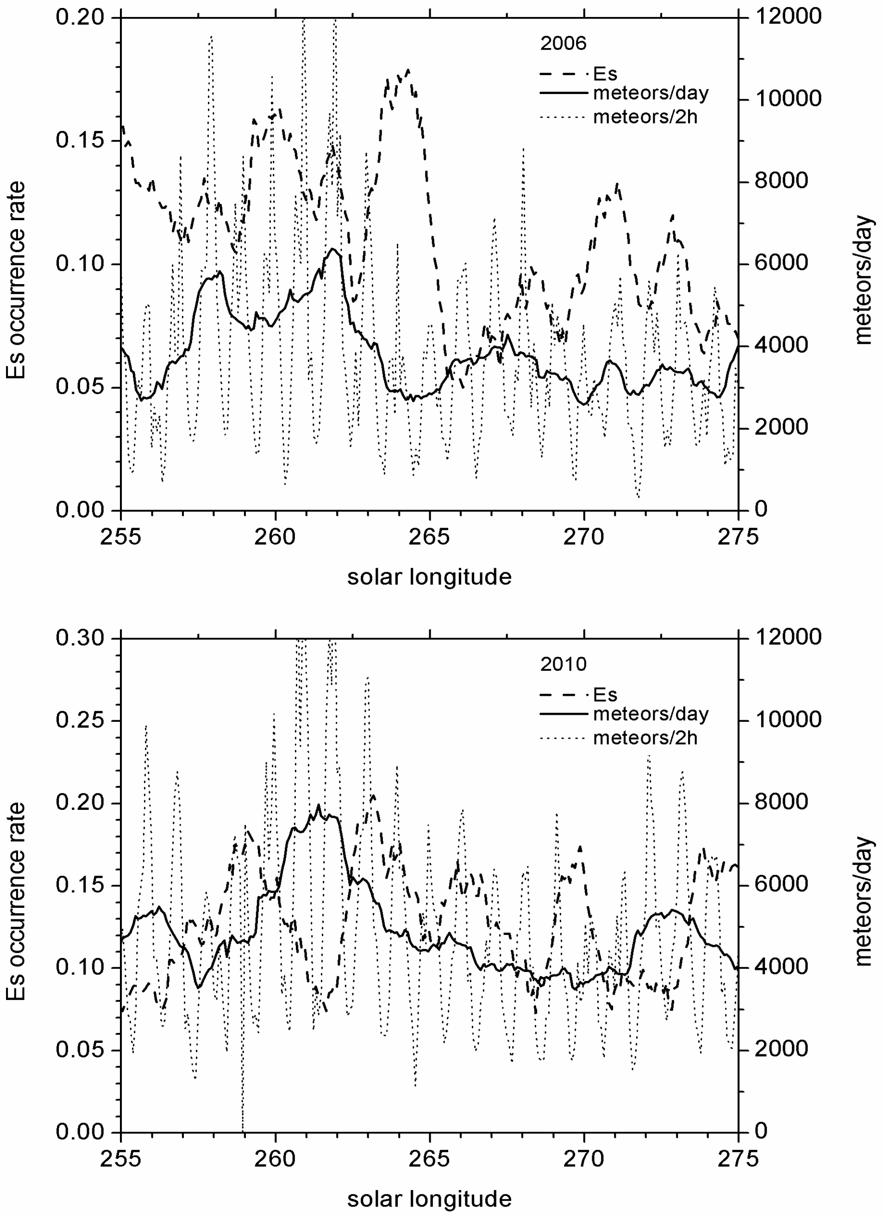

Fig. 4: Daily sporadic E layer occurrence rates in 2006 (top) and 2010 (bottom). Daily mean meteor rates are added, as well as 2-hourly meteor rates multiplied by 12.

On the upper panel of Figure 5, the 5-year averages of Es occurrence and meteor rates are presented together with the standard error. Owing to the small number of years included, the error is partly large due to interannual variability. One can see that on an average, Es rates maximise about 2.5 days later than meteor rates. Note that there is an Es maximum also shortly before the meteor rate maximum, however, this is preceded by a weak enhancement of meteor rates, too. In the lower panel of Figure 5, the cross-correlation functions, taken from data of the days #335-355 of each year, are presented. One can see that the Es-meteor rate correlation in respective years behave in different manners, but there is a tendency for the cross-correlation to maximise at a lag of few days, except for 2007, when the correlation is low at a lag of few days.

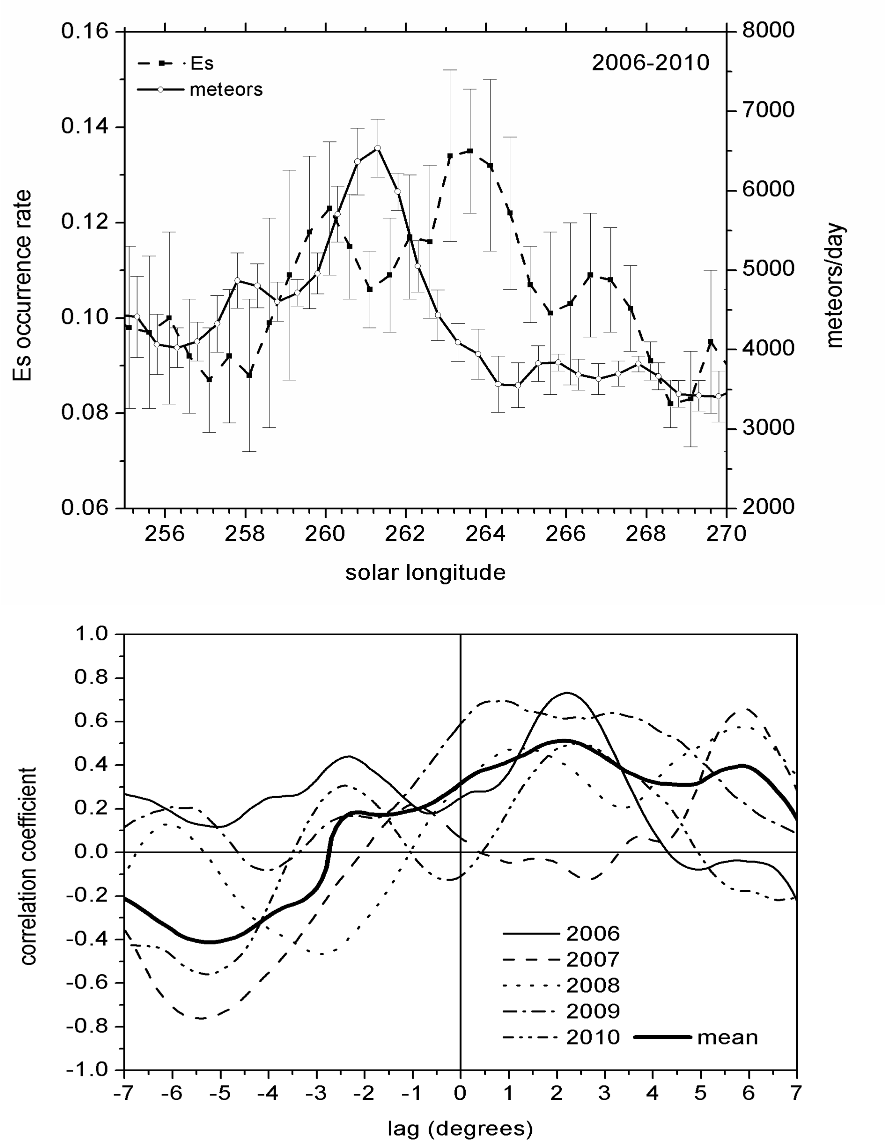

Fig. 5: Upper panel: 2006-2010 mean sporadic E occurrence rates (dashed) and 24-hr mean meteor count rates (solid). Standard errors are added. Lower panel: cross-correlation functions between sporadic E occurrence rates and meteor count rates. Positive lag denotes meteor rate changes heading Es ones.

5. Discussion

Considering the standard error bars of the 5-year mean Es rates, one finds that the enhancement of Es after the Geminid meteor shower is hardly significant. Part of this may be due to the small number of years considered, but definitely there is considerable interannual variability of the Es behaviour, which, as is the case in 2007, during some years does not seem to be strongly influenced by the meteor shower, while in other years a rather strong correlation is found. Clearly, other factors must play a role.

The wind shear theory predicts that at midlatitudes Es are formed at the convergence nodes of vertical ion drift owing mainly to vertical shear of the zonal wind. The main contribution to wind shear is by the semidiurnal tide (SDT), such that the SDT signature is clearly visible in Es (e.g. Arras, 2009). Figure 6 presents SDT zonal wind amplitudes as measured at Collm during December 2006-2010. One can see that the amplitudes are smaller in 2007, 2008, and 2010 compared to 2006 and 2009. Comparing this with Figure 5 reveals that these are the years when the cross-correlation function at lag up to some 5 days does not exceed values of 0.5, while in 2006 and 2009 larger values are found. Although the number of years considered is too small to draw substantial conclusions, and the amplitudes are only a sort of proxy for the wind shear, this nevertheless indicates that SDT wind shear variability may modulate the Es reaction on meteor showers.

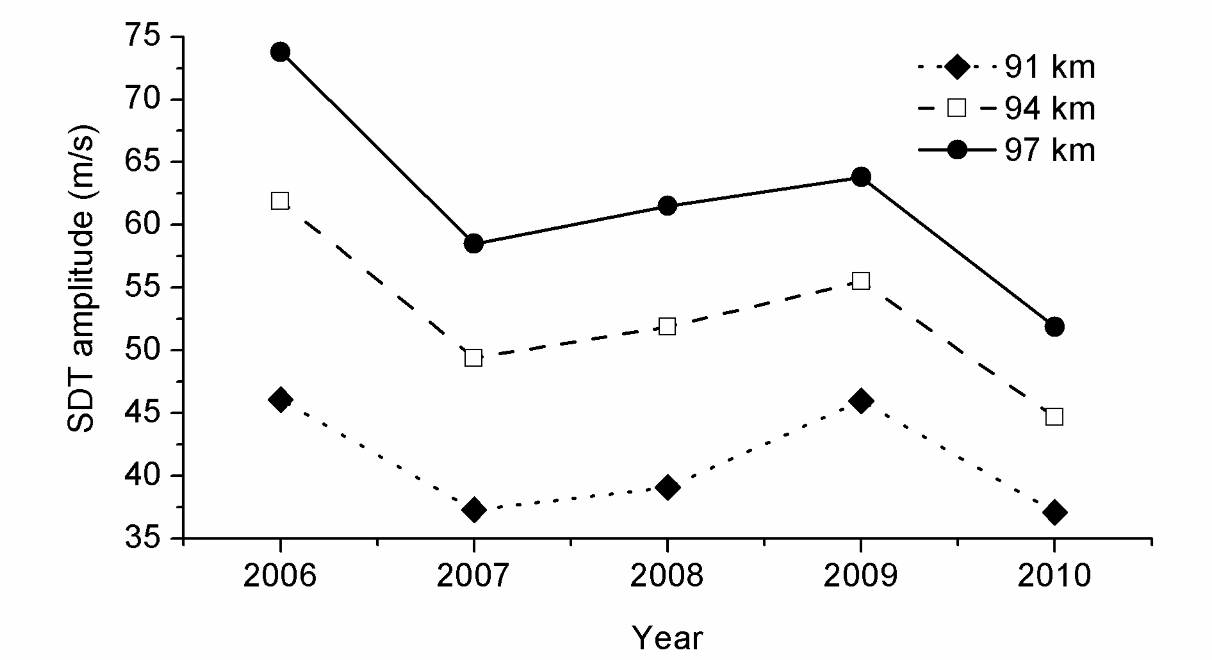

Fig. 6: December mean SDT zonal wind amplitudes as observed at Collm.

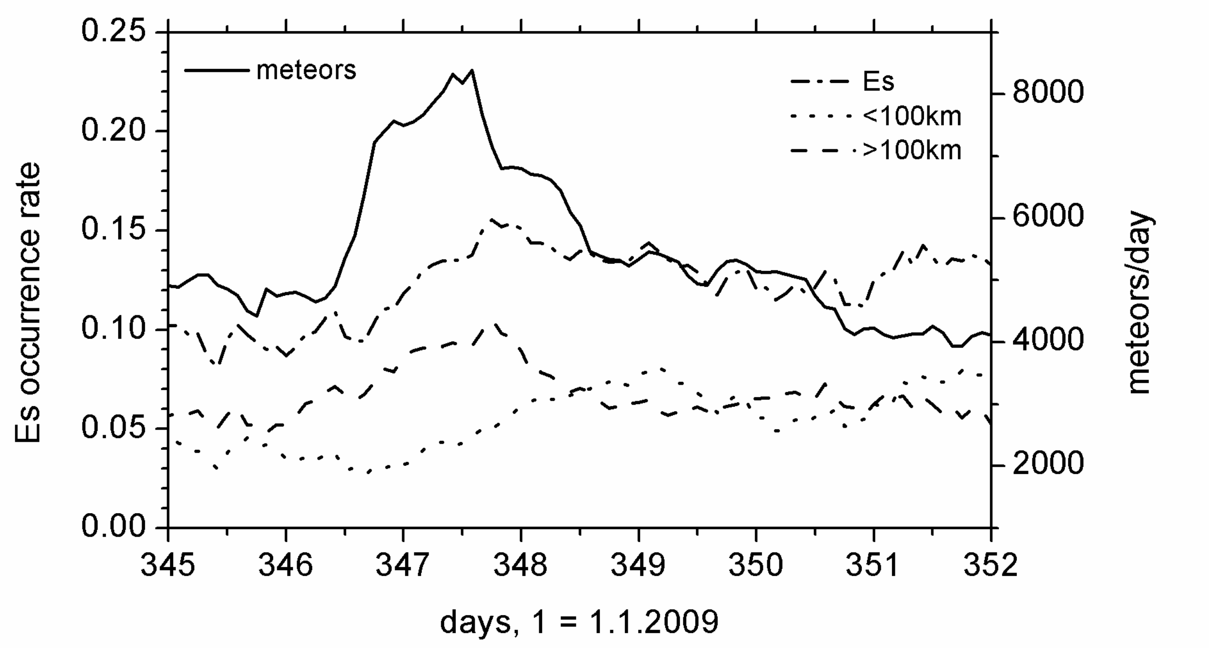

Fig. 7: Time series of meteor rates (solid line), total Es occurrence rates (dash-dotted line) and occurrence rates for heights higher and lower than 100 km (dashed and dotted lines, respectively) in 2009.

One has to note also that possible enhancement of Es after meteor showers should be a rather indirect process. To date there is no proof that after the Geminid shower the concentration of metallic ions is really enhanced, and measurements showed inconclusive and partly contradicting results (Stober, pers. comm.). One reason may be that the mass influx of the Geminids is not very large compared with the sporadic background. Moreover, other slow meteor showers like the Quadrantids do not seem to have considerable influence on the Es rates (see Figure 3).

Another open question refers to the time delay between meteor shower and Es increase. To clarify, in Figure 7 we present the Es occurrence rates above and below 100 km altitude. One can clearly see that above 100 km there is no delay of the Es rates with respect to the meteor rates, while below 100 km the Es rates increase later. This means that, although the Geminid meteors are found in every height accessible to the Collm radar, ions probably first form at greater altitude and are then transported downwards. In total, this leads to a time delay of the overall Es occurrence rate. However, descent speeds of Es layers in winter are usually of the order of 2 km/h (Arras et al., 2009), so that there is another source for delay of the layer formation. Generally, the Es layer descent follows the phase speed of the SDT convergent node at altitudes well above about 100 km, but slows down owing to enhanced ion-neutral collisions (Haldoupis et al., 2006; Christakis et al., 2009).

6. Conclusions

Comparison shows that there is a tendency for sporadic E layer occurrence rates to increase after the Geminid meteor shower. This increase happens with a time delay of 2.5 days on an average. The effect is expressed with variable strength in different years, in particular during 2007 it appeared to be quite weak. Comparison with SDT amplitudes indicates a possible relationship with changing wind shear magnitudes.

Taking into account the small number of years considered so far and the comparatively large error bars of the mean effect, conclusions should be drawn with care. This is also the case, since supporting evidence of increasing metal concentration after meteor showers is not available. Further studies, both experimental and modelling ones, are required to substantiate the results.

Acknowledgements

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