MST radar observations of meteor showers and trail induced irregularities in the ionospheric E–region

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The Doppler spectra of amplitude variations for meteor trails and sporadic–E layers have simultaneously been recorded with MST radar at Gadanki during the active periods of Perseid, Leonid and Geminid meteor showers in 2007. The variations of the activities of the radar meteors during the shower periods and the occurrences of E–region irregularities as observed with MST radar are presented in this paper. It has been noticed that the discrete strata of sporadic–E occurring in the altitude range 95–110 km during these shower periods with maximum percentage of occurrence on the nights of peak activities of these meteor showers. The close inspection of radar meteor data reveal the generation of faint Type-1 echo during the peak active period of the Geminid shower with reduced Doppler velocities by 20% at the altitude of 91 km and are found to be imbedded in the strong Type–2. The radar data of meteors are also used to retrieve the temperatures of MLT region.

Keywords: Meteor shower, Perseid meteor shower, Leonid meteor shower, Geminid meteor shower, E-region irregularities

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1 Introduction

The E–region irregularities have been studied over past five decades globally using VHF and UHF radars which were observed to vary from latitude to latitude, with time of the day. The spectral studies of E–region irregularities revealed two distinctive classes of irregularities which are broadly classified into: Type–1 irregularities known as two stream or Farley – Buneman, when relative electron – ion drift speed near the altitude of 105 km exceed the plasma ion – acoustic speed $C_s$ characterized by narrow spectral peak having a Doppler velocity that equals approximately $C_s$; and Type–2 irregularities termed as gradient drift instability characterized by low mean Doppler velocity and broader spectral width$^1$. Type–1 irregularities occur at equatorial and auroral latitudes where strong horizontal electrojets exist because ambient electric fields there attain relatively large values$^2$, at mid and low latitudes as they are away from the equatorial electrojet region, their threshold electrical fields are only a few mV m$^{-1}$, well below the threshold required for excitation of the two stream instability, thus exhibit gradient drift instability.

Several studies over E-region irregularities have been done and interesting facts were revealed from the low latitude station like Gadanki (13.5$^\circ$N, 79.2$^\circ$E, dip latitude 6.5$^\circ$N), India and its generation mechanisms were discussed without considering the meteor activity [refs (3-5) and the references cited therein]. In this regard, it is very important to study the role played by major periodic meteor showers on the E–region irregularities from this low latitude site, as the effect of meteooric activity on background E–region irregularities can’t be ruled out.

2 Observations

MST radar is a powerful tool for undertaking the detailed observations of meteor echoes because of its high pulse repetition frequency (PRF) and high power narrow near vertical beams. The MST radar system description, technical details and experimental specifications are given by Rao$^6$. In view of the high backscatter from the ionospheric E–region irregularities occurring at the meteor heights an observational program on major night time meteor showers namely, the Geminid, Perseid, Leonid and the associated Sporadic–E (E$_s$) occurrences has been carried out with the MST radar at Gadanki during 2007. The Leonid – 1999 meteor storm has been observed with MST radar and also the ionospheric
irregularities caused by this meteor storm during the period of Leonid activity. The results of the Rocket experiment conducted during the Leonid storm activity in 1999 are also presented in the paper.

The Doppler spectra of the amplitude variations of meteor trails and E\textsubscript{S} layers have been continuously recorded throughout the active nights of Perseid, Leonid and Geminid meteor showers with the beams E\textsubscript{20}, W\textsubscript{20}, Z\textsubscript{x} and N\textsubscript{13} for E\textsubscript{S}, respectively. The observations were taken from 2000 hrs LT to 0600 hrs LT each night continuously during 10–14 August for Perseids, 15–20 November for Leonids, 11–15 December for Geminids during 2007 with the Radar operated in meteor mode. The hourly rates of occurrence of meteors for each shower were estimated from the counts of the offline display of the Doppler spectra of the meteors (meteor echoes can be differentiated as they have a sharp rise followed by an exponential decay with SNR less than 10dB). The Leonid meteor flux rates (averaged over peak shower days only) observed with the MST radar at Gadanki (13.5°N, 79.2°E) during 1996 – 2007 are presented in Fig. 1. Figures 2(a-c) show the variation of meteor activity on peak days of Perseid, Leonid and Geminid meteor showers, respectively for the year 2007.

3 Results and discussion

Figures 3(a-c) give a clear picture of the formation of thick, dense metallic ion layers(blanketing sporadic–E during the Geminid meteor shower days and is observed to be concentrating in altitude regime of 100–105 km thus extending to two – three range bins with SNR of 6 dB. The blanketing E\textsubscript{S} layer is formed when there is an adequate wind shear along the ionization columns and metallic ion traces released during the ablation of impinging meteoroids.

These layers are found to exist for a very short duration and are thin extending up to two to three range bins. The improper ionization and inadequate wind shear weakens the layer and finally disappears (not shown here). The atmospheric gravity waves (AGW) generated at lower heights grow in amplitude and propagate upwards to attain saturation and wave breaking leading to turbulent diffusion at lower thermospheric levels leading to the gradients in the E–region.

In Fig. 4(a) during the peak activity period of the Geminid shower, the Doppler velocities were observed to be varying from +130.9 to –329.35 ms\textsuperscript{-1}. During 0230-0330 hrs LT, there were glimpses of the Doppler velocities ranging in -252 and -329 ms\textsuperscript{-1} (away from the radar) at the altitude of 90.75 km, can be noticed in zoomed figure Fig. 4(b) and it is also observed from Fig. 2(c) that it was the period of intense meteor shower activity. The wave velocities

![Fig. 1 — Variation of Leonid activity during 1996–2007](Image)

![Fig. 2 — Semidiurnal variation of meteor activity: (a) Perseid on 12-13 August 2007; (b) Leonid on 17-18 November 2007; and (c) Geminid on 12-13 December 2007](Image)
Fig. 3 — Signal to noise ratio (SNR) plots of Geminid meteor shower on: (a) 11-12 December 2007; (b) 12-13 December 2007; and (c) 13-14 December 2007
were observed to be at least lower than that required for Type-1 irregularities by 20% indicating the generation of weak Type-1 irregularity during the meteoroid ablation at that height where generally bright meteors (heavy) do appear. The average velocity thus observed is lower than nominal E-region ion acoustic speeds, probably because of the presence of heavy metallic ions in the sporadic-E layers that appear to be associated with meteor activity and forming the blanketing $E_S$ layer.

The observed Doppler velocities do basically belong to Type-2 echoes with velocities fluctuating between $\pm 100$ ms$^{-1}$, however, it is also observed from the spectrogram that some velocities exceed $\pm 250$ ms$^{-1}$. Inspection of sequential spectra during the peak activity period shows that weak Type-1 echoes do

![Range time velocity plot during meteor showers: (a) Perseid on 12-13 August 2007; (b) Leonid on 17-18 November 2007](image)
appear for short time during the much stronger Type–2 spectrum. Thus, Type-1 echoes were observed to be fairly weak and are imbedded in a much stronger Type–2 with negative Doppler shifts (northward motion) and existed for not more than few seconds. These types of echoes that has appeared at times of strong meteor shower activity might be because of dense plasma meteor trail which has a much higher conductivity than the ambient E–region ionosphere, especially at night time. The component of a strong external DC electric field along the trail axis induces a strong current within the trail that cannot be closed in the ionosphere and must stop at trail edges. As a result, the trail edges acquire net electric charges that partially cancel the external electric field. And also, it should have the magnitude of electron drift velocity ($4 \text{ km s}^{-1}$) perpendicular to the magnetic field which exists within the meteor trail in order to observe Type–1 echoes.

On peak activity day of Leonids and Perseids and during the peak hours of activity as shown in

Fig. 4(c&d)—Range time velocity plot during meteor showers: (c) Geminid on 12-13 December 2007; and (d) Zoomed plot of 12-13 December 2007
Figs 4(c-d), Doppler velocities was hardly observed to be around $\pm 150 \text{ ms}^{-1}$ (towards / away from the radar). But for Geminids, it exceeded $280 \text{ ms}^{-1}$ (away from the radar) during peak hours and during remaining days, the Doppler velocity was as usual. This indicates that the observed Doppler velocities during peak hours of Geminid activity differ from the others. The observed velocities, thus, belong to Type-2 where the velocities are very low, but during the peak hour of activity of Geminids, the observed velocities were found to be reduced Type-1 and estimated to be reduced by around 20%. The reduction in Type–1 velocities can be attributed to the generation of heavy metallic ion layers which were found to exist at 102 km as shown in Fig. 3(c).

The case may be because of Geminids was found to be relatively stronger than Leonids and Perseids as the parent comets of both i.e. 55P/ Tempel–Tuttle (Leonids) and 109P/ Swift-Tuttle (Perseids), respectively were now receding back into the outer Solar system as their comet’s orbital period is about 33 and 130 years, respectively and theory predicts that such outburst rates should dwindle as the comet to Earth distance increases and their recent perihelion passages occurred in the years 1998 (for Leonids) and 1992 (for Perseids), respectively. But for Geminid, its parent body, Phaethon has an extremely short orbital period of 2.6 years, hence, it regularly releases fresh cometary’s dust and hence, it is quite denser than its counterparts Leonids and Perseids.

4 Conclusion

The analysis of the data during the major periodic shower of Geminid gives a substantial evidence for the occurrence of weak Type-1 irregularities over low latitude station like Gadanki where in general Type–2 irregularities are prominent. Type-1 phenomenon was only observable when the shower was strong, dense with bright meteors and at peak hours of activity. Further observations are required to establish its occurrence during the meteoric showers.

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