行政院國家科學委員會專題研究計畫　成果報告

中緯度地區散塊 E 層型態 1 不規則體三度空間結構的研究

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行政院國家科學委員會專題研究計畫成果報告

中緯度地區散塊 E 層形態 1 不規則體
三度空間結構的研究

The research of three-dimensional spatial structures
of mid-latitude type 1 Es irregularities

計畫編號：NSC 91 - 2111 - M - 034 - 003
執行期限：91 年 8 月 1 日 至 92 年 7 月 31 日

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一、中英文摘要

本計畫探討中壢特高頻雷達觀測散塊 E 層，形態 1 不規則體伴隨著形態 2 不規則體同時發生的情況，本事件的形態 1 不規則體持續約 8 分鐘其平均都卜勒速度在 250~302 m/s 之間，比赤道區與極光區一般的平均速度要小，將形態 1、形態 2 不規則體回波利用雷達干涉法分析後，投影到互相垂直的三組平面上都呈現為線條狀，表示不規則體為水平的薄層結構；此電漿薄層在高度 104~107 公里，厚度約 1.0~1.5 公里，檢視形態 1 不規則體的線條狀回波在東西方向延伸尺度為 12.7~6.8 公里而投影在水平面南北方向延伸則至少有 7.2~5.1 公里。總結觀測結果形態 1 不規則體的空間結構為東西方向尺度比較窄主要為南北方向延伸的平板狀薄層結構，本結果也支持 Haldoupis et al. (1996) 解釋激發中緯度形態 1 不規則體所提出的薄層板狀模型結構。

關鍵詞：中壢特高頻雷、散塊 E 層、形態 1、形態 2 不規則體

Abstract

Concurrent type 1 and type 2 radar returns from sporadic E (Es) irregularities detected by the Chung-Li VHF radar are analyzed and discussed in this proposal. For the present case the mean Doppler velocities of the type 1 echoes lasting about 8 minutes are between about 250m/s and 302 m/s, smaller than those observed in equatorial and auroral regions. Interferometry analysis indicates that the echo patterns of the type 1 and type 2 irregularities projected in mutually orthogonal planes are striation-like, strongly suggesting that the plasma structure associated with the irregularities is in a form of thin slab. The plasma slab with thickness of about 1-2.5 km locates in the height range from about 104 km to 107 km. The horizontal extents of the type 1 irregularities in the striation-like echoing region range from 12.7 km to 6.8 km in east-west direction and from at least 7.2 km to 5.1 km in north-south direction. The observational evidences that the slab structure has sharp edges in lateral edges and the type 1 irregularities drift in the meridional direction favor the slab model proposed by Haldoupis et al. (1996) to account for the excitation of the mid-latitude type 1 irregularities.

Keywords: Chung-Li VHF radar、sporadic E type 1、type 2 irregularities

二、前言與研究目的

In general, the occurrence of type 1 echoes in mid-latitude region is very rare compared to that in equatorial and auroral regions. The mid-latitude type 1 echoes occur sporadically during nighttime and last from several seconds to a few minutes. The average Doppler velocity of mid-latitude type 1 echoes with considerably narrow spectral width (in order of tens m/s) ranges from about 220 m/s to 350 m/s, smaller than nominal ion acoustic wave speed (about 360 m/s) in ionospheric E region. Moreover, the mid-latitude type 1 echoes usually appear simultaneously with type 2 echoes characterized by relatively broad spectral width and low average Doppler velocity. On the basis of dual frequencies experiment operated at 50 MHz and 144 MHz, Koehler et al. (1997) suggested that the mid-latitude type 1 waves are excited directly through two-stream instability, while type 2 irregularities are generated through secondary nonlinear cascade process from large scale (tens to a few hundreds meters) primary waves to meter scale irregularities in association with gradient drift instability.

Haldoupis et al. (1996) proposed a mechanism in relation to a plasma slab with sharp lateral boundaries, in which an intense Hall polarization electric field in the zonal direction is induced due to charge accumulation on the boundaries in response to a meridional background electric field. Unstable type 1 waves will be generated as the electron drift velocity of 3-m Es irregularities is greater than the threshold drift velocity required for the excitation of two-stream instability. Recently, Shalimov et al. (1998) improved the slab model proposed by Haldoupis et al. (1996) by including the effects of field-aligned current and anisotropic configuration of elongated plasma slab to explain the sustenance of intense polarization electric field in the elongated plasma slab with sharp boundaries. With employing simulation technique, Hysell and Burcham (2000) further pointed out that the dimension of minor axis in zonal direction for the elongated plasma slab structure should be less than 1 km such that the intense polarization electric field will not be shorted out by the current in F region through the process of electric potential mapping along the magnetic field line.

三、研究方法

The data used for analysis were taken on 24 January 1997 from 22:28 LT to 22:47 LT. In order to reconstruct 3-dimensional structure of Es irregularities in echoing region by using interferometry technique, three radar modules were operated simultaneously. The 40 kW peak power for each module was transmitted, and the 28 μs pulse length with 7-bit Barker code was employed to improve the signal-to-noise ratio of the radar returns from Es irregularities. The inter-pulse period was 2 ms and the coherent integration time was 4 ms. The radar probing range was set from 114.6 km to 150 km, in which 60 range gates were sampled. The 128-point fast Fourier transform (FFT) algorithm was utilized to compute the Doppler spectra of the Es echoes. The complex normalized cross spectrum was then computed, in which 20 raw spectra were taken to obtain the ensemble average. The averaged phase of each frequency bin (containing 7 frequency components) for type 2 radar spectrum was employed to calculate the elevation and azimuth angles of the type 2 irregularities in accordance with interferometry equations for the Chung-Li VHF radar (Wang and Chu, 2001).

四、 結果與討論

Figure 1 presents range-time-intensity (RTI) contour plot of Es echoes observed by the Chung-Li VHF radar on 24 January 1997 from 22:27:58 LT to 22:46:30 LT. As indicated, the Es echoes lasting about 20 minutes appear in the range extent from 125 to 143 km. The echoes that the relatively strong backscatter with signal-to-noise ratio (SNR) higher than surrounding echoes by more than 6 dB in the range extending from 136 km to 140 km during the period 22:32 – 22:39 LT are categorized into type 1 echoes. Figure 2 shows spectrogram of the Es echoes at range 136.8 km, in which striking type 1 echoes accompanied with relatively weak type 2 echoes appear in the period from 22:32LT to 22:39LT. As indicated, noticeable changes in the Doppler velocity of type 1 echoes is seen, especially after 22:38 LT when type 1 echoes are gradually weakened. We argue that the governing factor that leads to the change in the Doppler velocity of type 1 echoes is likely to be electric field, rather than neutral wind. In order to investigate in more detail the properties of type 1 and type 2 radar spectra, the range variations of Doppler spectra of the Es echoes in the period from 22:31:17 LT to 22:39:54 LT are plotted and depicted in Figure 3. Obviously, the type 1 echoes with very narrow spectral width primarily occur in the range from 136 km to 141 km and type 2 echoes with relatively broad spectral width appear in a very wide range from 125 km to 142 km. As shown in Fig.3, type 1 irregularities are first excited at around 22:31:17 LT in the range extent from 137 km to 141 km. Subsequently, the ranges that type 1 echoes occupy decrease gradually. Fig.4 shows selected spatial distributions of Es echoes projected on three mutually orthogonal planes, in which type 1 (marked with open circle) and type 2 echoes (marked with cross) are shown separately. The panels in the left column of Fig.4 display the Es echoes projected in vertical planes with the axes along vertical and north-south directions, where two solid lines, declined from upper right to lower left, correspond to the elevation angles of 51.5° and 49°, respectively. The panels in the middle column of Fig.4 display the projections of the echoes in azimuth planes with axes along vertical and east-west directions, while the panels in the right column represent the projections of the Es echoes on horizontal planes. The most striking feature revealed in Fig.4 is the appearance of striation-like echo patterns after 22:31:17 LT, when the type 1 echoes are observed and coexist with type 2 echoes. Basically, the striations in vertical and azimuth planes are horizontal and centered at the constant height of about 106 km. However, the striations in horizontal planes incline from northwest to southeast with angles of around 60° toward west with respect to the boresight of antenna beam. As shown, the Es echoes during the period of 22:27:58 – 22:31:01 LT consist of only type 2 echoes and they are unstructured and distribute unsystematically in the echoing region. During the period from 22:31:17 to 22:42:06 LT, type 1 echoes appear and coexist with type 2 echoes, and the corresponding patterns of the type 1 echoes in different projection planes are also in a form of striation. After 22:42:21 LT, type 2 echoes dominate the radar returns and their echo patterns are less structured, but still striation-like. In light of the fact that field-aligned property of Es irregularities plays a crucial role in the precise reconstruction of 3-dimensional spatial structure of the Es irregularities in the echoing region, it is necessary to examine whether the backscatter observed here are highly aspect sensitive. As shown in Fig.4, the observed Es echoes projected in vertical planes do not distribute along the line normal to geomagnetic field line. In order to verify the radar returns from Es irregularities presented in this article are highly aspect sensitive, the observed (dotted points) and expected (crosses) echoing regions are compared as shown in Fig.5, in which the expected echoing region is computed from IGRF95 model and the magnetic aspect angle of ±0.25° and the height range of 104.5 - 107 km are employed in the computation. Fig.5 shows that the angular extent of the expected echoing region in elevation is a function of azimuth angle, ranging from 52° at azimuth angle of 0° to 49° at azimuth angle of –15°. In light of this, it is concluded that the observed angular positions of the Es irregularities in the echoing region are correct and Es irregularities are indeed field-aligned with aspect angle less than 0.25°.

Examining Fig.4 in more detail shows that the type 1 and type 2 echoes do not mix together thoroughly over the plasma layer. Instead, the type 1 echoes occur primarily at the west and north end of the echoing region, while the type 2 echoes appear mostly in the east and south part of the region. A question arises as to whether or not the polarized electric field responsible for the excitation of the type 1 irregularities in the plasma layer may also affect simultaneously the drift of concurrent type 2 irregularities that separate from type 1 irregularities by a few kilometers. Namely, we would like to know if the polarized electric field in the plasma layer is a localized or general phenomenon. Fig.6

compares the Doppler velocities of type 1 echoes at range 137.4 km with those of type 2 echoes at range 132 km. Notice that, because the spatial structure of the Es irregularities is in a form of horizontal thin layer, slant ranges 137.4 km and 132 km correspond roughly to north-west and south-east ends of the structure, respectively. As indicated, the variations of Doppler velocities for type 1 and type 2 echoes are almost in phase and the magnitude of the Doppler velocity variation for the type 1 echoes ranges between 20 and 50 m/s. However, analysis shows that for the Chung-Li VHF radar the contribution of horizontal neutral wind to the Doppler velocity of type 1 echoes is generally less than 10 m/s. Therefore, it is very likely that the change in Doppler velocity of type 1 echoes is attributed to temporal variation in the zonal polarization electric field. In light of the coherent variation of the Doppler velocities between type 1 and type 2 echoes, it is reasonable to speculate that the variation in the Doppler velocity of type 2 echoes is also resulted from the electric field, rather than neutral wind. Therefore, it follows that the zonal polarization electric field developed in accordance with the process suggested by Haldoupis et al. (1996) drive the electron density irregularities over the whole plasma layer.

五、計畫成果自評

By using the Chung-Li VHF radar, intense type 1 echoes with relatively low Doppler velocity (between about 250 and 302 m/s) were observed and investigated in this report. Interferometry results show that type 1 irregularities coexisting with type 2 irregularities are confined in a very thin layer with sharp boundaries not only on top and bottom sides, but also on lateral sides. In this report, we also show that the range variation of type 1 echoes in RTI plot may result from the variation of horizontal extent of the type 1 irregularities in the echoing region, rather than height variation of the irregularities. Basically, interferometry measurements presented in this proposal favor the slab model proposed by Haldoupis et al. (1996) to explain the formation of mid-latitude type 1 irregularities. However, the slab model cannot explain satisfactorily observed phenomena, including large zonal extent of type 1 irregularities and sustenance of intense zonal polarization electric field over wide region. A refinement of the existing slab model such that it can satisfactorily account for the observations is required.

The result of this report comes up to the expection of proposal and has been published in J.G.R. [Chu and Wang, 2002].

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七、圖表

Figure 1. Range-time-intensity contour plot of type 1 Es echoes, where Type 1 echoes start at 22:32LT and end at 22:39LT.

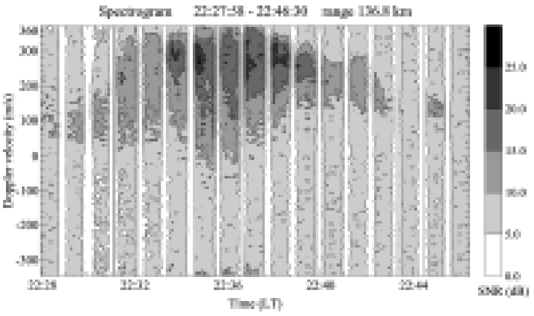

Figure 2. Spectrogram of type 1 Es echoes at range of 136.8 km.

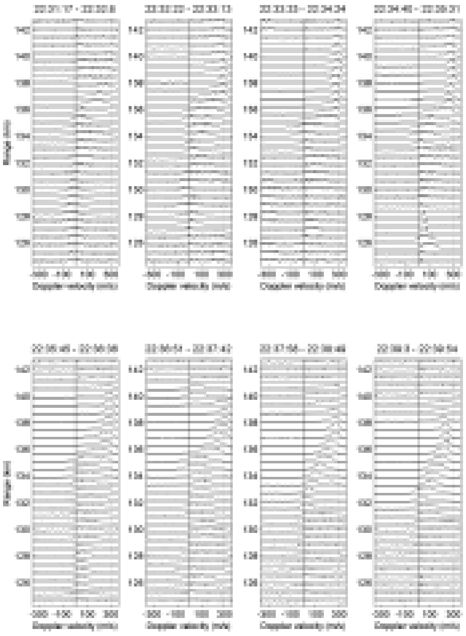

Figure 3. Range variations of selected Doppler spectra.

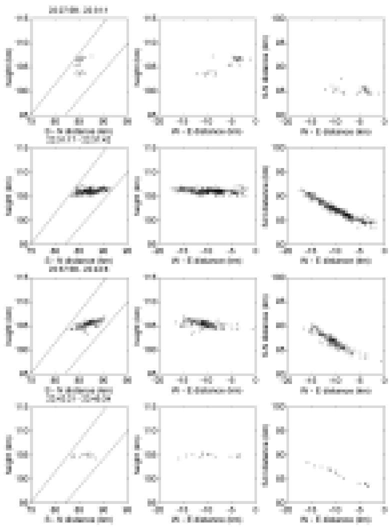

Figure 4. Selected echo patterns comprised of type 1 (open circle) and/or type 2 echoes (cross) projected in mutual orthogonal planes, where two tilted lines from upper right to lower left in the left column correspond to elevation angles of 51.5° and 49°, respectively.

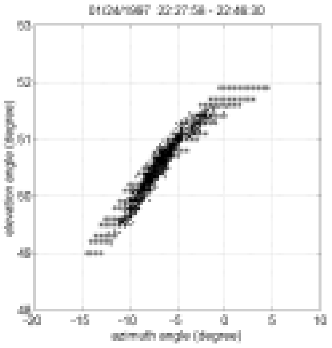

Figure 5. A comparison of observed (dot) and modeled (asterisk) echoing regions in elevation-azimuth plot, where the modeled echoing region is calculated from IGRF95 in the height range of 105-107 km with magnetic aspect angle of ±0.25°.

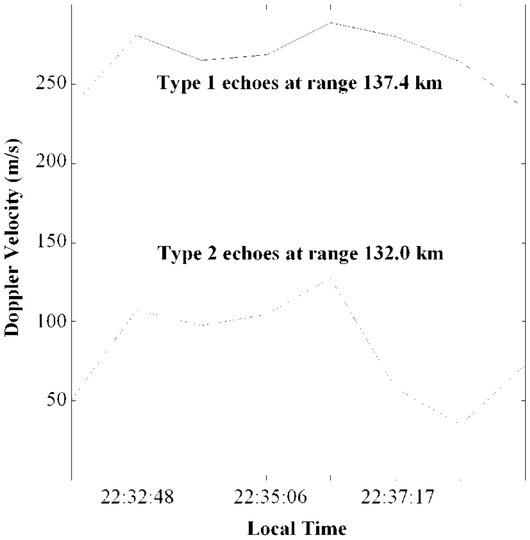

Figure 6. A comparison of Doppler velocities between type 1 echoes (solid curve) and type 2 echoes (dashed curve).