行政院國家科學委員會專題研究計畫成果報告

利用中壢 VHF 雷達對電離層散塊 E 層不規則體水平漂移速度的估算

The estimation of horizontal drift velocities of the Es irregularities using the Chung-Li VHF radar

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一、中文摘要

本計畫利用中壢 VHF 雷達的 3 米尺度電漿不規則體回波來研究散塊 E 層(Es)電子不規則體的漂移速度。雷達干涉法顯示來自高度 109 - 122 公里具有極高方向靈敏度（與正交角度偏差在±0.25°內）的一段 Es 回波，重建其三度空間結構了解到，此回波是由一團具有橢圓截面的滴狀不規則體所產生；比較此滴狀不規則體在水平面上投影的移動速度（稱為追蹤速度）與最小平方法所估算的速度（稱為真實速度），發現真實速度要比追蹤速度約略有大 2 倍的關係。

關鍵詞：散塊 E 層、追蹤速度、真實速度

Abstract

The drift velocity of echoes from 3-meter plasma irregularities of ionospheric sporadic E (E_s) layer are analyzed in this proposal by using the Chung-Li VHF radar. The interferometry result indicates that the Es echoes extending from about 109 to 122 km altitude are extremely aspect sensitive with enormously narrow aspect angle of ±0.25°. After reconstructing the 3-dimensional structure of the echoes, we find that the object responsible for the radar returns is an isolated and solid blob-like plasma structure with elliptical cross section. A comparison between the so-called trace velocity V_a deduced from the bulk displacement of the plasma structure projected on three mutually orthogonal planes and the true velocity V_t estimated from the least squares fit is also made. We find that for the present case in average V_t is systematically larger than V_a by a factor of 2.

Keywords: sporadic E、 trace velocity、 true velocity

二、緣由與目的

Basically, patterns in range-time-intensity (RTI) plots and the Doppler velocity of the radar echoes are strongly related to the movement and the spatial distribution of the Es irregularities in the echoing region. Therefore, one might speculate that the dynamic behavior and the spatial structure of the irregularities can be inferred from the information contained in RTI plots and Doppler spectra in cooperation with the pointing direction of the radar beam. For example, the Es irregularities are thought to drift in vertical or northward direction if corresponding echoes with negative Doppler shift (away from the radar) show a positive range rate (defined as the slope dr/dt of echo intensity contour, where r is range and t is time) in RTI plot. However, in this report we will show that the Es type-2 irregularities moving westward can also produce the echoes with positive range rate in RTI plot and negative Doppler shift, provided the effective radar beam width is broad enough and the irregularities locate in the west side of the effective radar beam for a north-pointing radar beam.

An attempt is made in this article to investigate the three-dimensional spatial structure and the velocity of a discrete and blob-like plasma structure appearing in the nighttime E region. Once the 3-dimensional spatial structures of the Es irregularities are obtained by using the interferometry technique, the bulk velocity, termed as trace velocity thereafter, of the large scale plasma structure can be inferred from the consecutive displacement of the echo patterns projected on the mutually orthogonal planes. In order to estimate the trace velocity, the mean position of each echo pattern is calculated first, the displacements of the mean position of the echo pattern in north-south and east-west directions are measured from the projections on the horizontal planes. Alternatively, the velocity of the plasma structure can also be estimated by using least-squares method, which we call true velocity.

三、結果與討論

The data employed in this investigation were taken by the Chung-Li VHF radar on August 11,1997, 22:00 ~ 23:00 LT. The radar parameters were set as follows: peak transmitter power (for each module) of 40 kW, interpulse period of 2.0 ms, pulse width of 28 μs with 7 bits Barker code, coherent integration of samples of two interpulse periods, and 66 range gates were recorded. The radar probing range was set from 123.6 to 159 km with range resolution of 0.6 km. Pronounced Es echoes were observed in the period from 22:1 to 22:33 LT. The 512-point fast Fourier transform (FFT) algorithm was utilized to compute the Doppler spectra of the echoes for each range gate and receiving channel. Fig.1 presents the RTI contour plot of the radar echoes. As indicated in Fig.1, an intense and well-organized contour lasting about 15 minutes extends from 136 to 159 km with positive range rate of about 16 m/s. The average thickness of the contour is about 15 km in range. Fig.2 shows the consecutive variations of the spatial distributions of the Es echoes projected on three mutually orthogonal planes. The panels in the top row of Fig.2 display the Es echoes projected in vertical plane with the axes along vertical and north-south directions, where four solid lines, declined from upper right to lower left, correspond to the elevation angles of 52°, 51°, 50° and 49°, respectively. The panels in the middle row of Fig.2 display the projections of the echoes in azimuth planes with axes along vertical and east-west directions, while the panels in the bottom row represent the projections of the Es echoes on horizontal planes. The vertical straight line in each panel in the middle and bottom rows of Fig.2 represents the projection of the apex direction of effective radar beam.

Fig.3 shows the scatter diagram of L_V (vertical extent of the Es echoes) versus L_{NS}, where L_V and L_{NS} are scaled from the echo patterns in the vertical plane. It is clear from Fig.3 that the correlation between the north-south size and the vertical size is significantly high (with correlation coefficient of about 0.94) and the slope of the linear regression line fitted to the data is 1.26. Note that the mean elevation angle of the effective radar beam in the echoing region for the Chung-Li VHF radar is about 51.6°. As a consequence, the expected value for the slope of the fan-like effective radar beam should be 1.262 (equal to tan(51.6°)), in an excellent agreement with the observed value of 1.264. Therefore, evidences shown in Fig.2, and 3 suggest that the Es echoes displayed in Fig.1 were originated from a solid and discrete blob-like plasma structure with an asymmetric gross cross section.

Fig.4 presents the time series of the trace velocities in north-south and east-west direction. A wave modulation on the east-west and north-south components of the trace velocity at the period of about 3-4 minutes is seen. The average westward and northward trace velocities are, respectively, 41.5 m/s and 0.4 m/s, corresponding to the horizontal trace speed of 41.9 m/s at the azimuth angle of -90.2° (toward west) with respect to the geographical due north. Therefore, the direction of the trace velocity is almost exactly westward.

Fig 5 shows the profiles of the zonal (solid curve with asterisks) and meridional (dashed curve with dots) components of the true velocity, where positive (negative) values in the abscissa indicate the direction toward east/north (west/south). As shown, the true velocity is primarily dominated by the zonal (westward) components and the magnitude of the true velocity ranges from about 68 to 165 m/s. In addition, the change in the true velocity with height is not significant, except at the initial stage of the plasma structure.

The 3-meter Es irregularities responsible for the radar returns investigated in this article are categorized into type 2 irregularities. It is believed that the type 2 irregularities are resulted from primary kilometer wavelength plasma waves through non-linear cascade process, which have grown sufficiently due to gradient drift instability (Sudan, 1983). Therefore, 3-meter Es irregularities can be treated as tracers to study the dynamic behavior of plasma waves and background ionosphere. Note that the true velocity is estimated from information of angular positions and velocities of electron density 3-meter irregularities deduced from Doppler spectra. Therefore, the true velocity can be regarded as the electron drift velocity. However, the trace velocity, obtained from the displacement of the echo patterns projected on the mutual orthogonal planes, can be thought to be the phase velocity of the large scale plasma wave, in which type 2 irregularities are embedded. Because of the close connection between large scale plasma wave and type 2 irregularities as mentioned above, one can speculate that the large scale plasma structure results from the primary plasma wave. If this is the case, the trace velocity will be the phase velocity of the plasma wave. According to Kudeki et al. (1982), the phase velocity of a kilometer plasma wave will be

$$V_p = \frac{V_d}{1+\cdot}\frac{1}{(1+k_0^2/k^2)} \qquad (1)$$

where V_d is electron drift velocity, k_p is the wavenumber of the plasma wave, $k_0=\nu_i/(\Omega_i L(1+\psi))$ is a characteristic wavenumber which corresponds to a wavelength of λ_0, L is the scale length of ambient electron density gradient, $\psi=\nu_\iota\nu_e/\Omega_i\Omega_e$, ν_i and ν_e are, respectively, collision frequencies of ion and electron, Ω_i and Ω_e are, respectively, gyrofrequencies of ion and electron. In mid-latitudes at altitude of 110 km, $\psi \sim 0.02$ and $\lambda_0 \sim 1.35$L. Therefore, from (1) V_p will be approximately $V_d/2$ if $\lambda \sim \lambda_0$. Figs.6a, 6b, 6c, and 6d display, respectively, the time series of zonal component, meridional component, velocity magnitude, and velocity direction for true (asterisk) and trace (opened circle) velocities, where the true velocities are the height-averaged values calculated from the data presented in Fig.5. It is clear from Fig.6 that a substantial difference in true and trace velocities is seen, not only in the magnitude, but also in the direction. Further computation shows that the magnitude of the true velocity is greater than that of trace velocity by about a factor of 2, consistent with the theory as mentioned above.

四、計畫成果自評

As illustrated in this report, interferometry analysis shows that a blob-like plasma irregularity drifting westward is responsible for the echoes. The comparison between true velocity calculated by using a least squares fit method and the trace velocity deduced from the displacement of the echo patterns in the horizontal planes is also presented in this article. The result shows that the former is greater than the latter by a factor of about 2. Presumably, this discrepancy is attributed to the effect of the propagation of a large scale plasma wave and the evolution of the plasma structure. The result comes up to the expectation of this proposal and has been published in J. Atmos. Solar-Terr. Phys.

五、參考文獻

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3. Wang C. Y., and Chu Y. H., Interferometry investigations of blob-like sporadic E plasma irregularity using the Chung-Li VHF radar, J. Atmos. Terr. Phys., 63, 123-133, 2001.

六、圖表

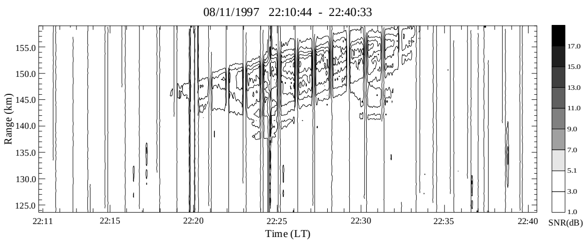

Fig.1. Range-time-intensity contour plot of the Es echoes.

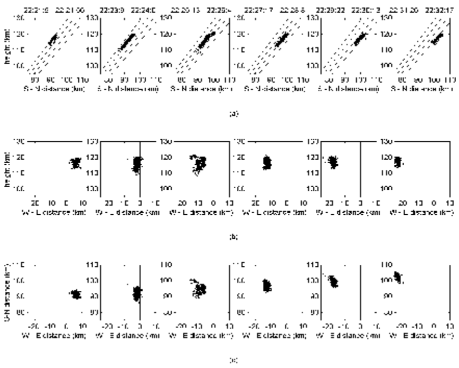

Fig.2. Six examples of the 3-dimensional spatial structures of the Es echoes resolved by interferometry technique.

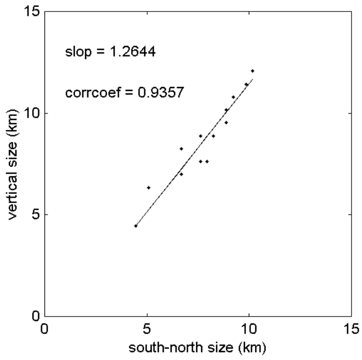

Fig.3. Scatter plot of north-south size and vertical size of the irregularity.

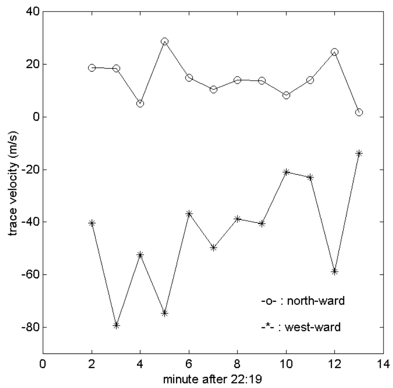

Fig.4. Time series of trace velocities in north-south and east-west directions.

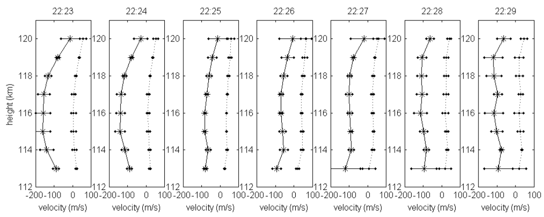

Fig.5. Consecutive variation of the profiles of the zonal (solid curve with asterisk) and meridional (dashed curve with dot) components of the true velocity.

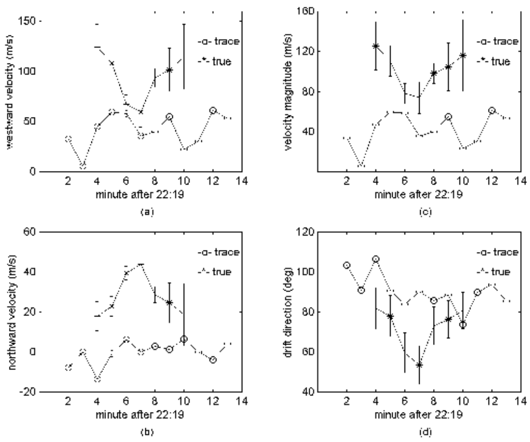

Fig.6. Time series of (a) zonal component, (b) meridional component, (c) velocity magnitude, and (d) velocity direction for true (asterisk) and trace(opened circle) velocities.

附件：封面格式

行政院國家科學委員會補助專題研究計畫成果報告

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執行單位：中國文化大學物理系

中　華　民　國　　91 年　10 月　15 日