Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research 55 (2015) 1366–1371
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

Influence of solar and geomagnetic activity on sporadic-E layer over low, mid and high latitude stations

Yabin Zhang [a,*], Jian Wu [a,b], Lixin Guo [a], Yanli Hu [b], Haisheng Zhao [b], Tong Xu [a]

[a] School of Physics and Optoelectronic Engineering, Xidian University, Xi'an, Shaanxi 710071, China
[b] National Key Laboratory of Electromagnetic Environment, China Research Institute of Radiowave Propagation, Qingdao, Shandong 266170, China

Received 29 July 2014; received in revised form 2 December 2014; accepted 7 December 2014
Available online 15 December 2014

Abstract

To study the influence of solar and geomagnetic activity on Es layers over low, mid and high latitude stations, hourly values of parameters of Es layer during four solar cycles (1970–2010) over different latitude stations are considered. It has been suggested that there is a relationship between solar and geomagnetic activity with Es layer, and the correlations are different over low, mid and high latitude stations. The reasons of different behavior of Es frequency parameters to solar and geomagnetic activity are also studied.

Keywords: Geomagnetic disturbances; Solar activity; Sporadic-E layer; Ion composition; Thermospheric circulation

1. Introduction

The sporadic E (Es) layers are thin dense layers of plasma forming mostly in the altitude range 90–130 km. The characteristics of Es have been studied extensively over many decades. It is now widely accepted that wind shear theory can take into account the formation of Es layer. Tidal waves, planetary waves and gravity waves, affecting through vertical wind shears, move the metallic and molecular ions into thin dense plasma layers in the mid-latitude (Whitehead, 1989; Haldoupis et al., 2006). Mathews (1998) concluded that magnetospheric electric fields could at times play a significant role in modifying the ion convergence produced by wind shear (Kirkwood and Nilsson, 2000; Batista et al., 1991).

Despite the success of the generalized wind-shear theory (including wind-shear plus minor modification by magnetospheric electric field), it is difficult to fully explain morphology of temperate Es such as the diurnal, seasonal and geographical variations (Whitehead, 1989). Another unexplained feature of mid-latitude Es is a close correlation with sporadic layers of neutral atoms of Na, Fe, and Ca (Batista et al., 1989; Beatty et al., 1989; Alpers et al., 1994, 1996).

Equatorial or low-latitude Es are believed to be two types, one which is the same as mid-latitude Es layers, and another which is caused by plasma-instabilities associated with the equatorial electrojet (Whitehead, 1970, 1989). Meteors, thunderstorms and ionospheric current systems etc. also play an important role in the formation of Es layer (Prasad et al., 2012; Farley, 1985).

High-latitude or auroral sporadic-E is mainly caused by the precipitation of charged particles. That is, the keV electrons which precipitate into the upper atmosphere and provide the excitation of oxygen and nitrogen which results in auroral emission and also ionize the atmosphere (Kirkwood and Nilsson, 2000; Prasad et al., 2012).

Many researchers studied the diurnal and seasonal variations of Es and tried to explain the sharp summer maximum and two minimums during the equinoctial (Whitehead, 1989; Baggaley, 1985, 1986). Haldoupis et al.

* Corresponding author.
E-mail address: ybzhang_2001@163.com (Y. Zhang).

http://dx.doi.org/10.1016/j.asr.2014.12.010
0273-1177/

(2007) shows that the marked seasonal dependence of sporadic E has a well correlation with the annual variation of sporadic meteor deposition in the upper atmosphere and gives a cause-and-effect explanation for the seasonal dependence of sporadic E layer.The influence of solar and geomagnetic activity on Es layer has also been investigated over the last few decades by many researchers. Baggaley (1984a) studied three solar cycles' *foEs* data in two southern hemisphere stations and gave results that there were no relationship between solar activity and Es layers. While next year Baggaley (1985) found the density of Es layers increased as sunspot increasing. Positive, negative and no correlations of Es layer with solar and geomagnetic activity were reported (Whitehead, 1970, 1989; Maksyutin and Sherstyukov, 2005; Pietrella and Bianchi, 2009; Closs, 1969; Tan et al., 1985; Rowe, 1973).

Due to different conclusions in the above papers, the relationship between solar and geomagnetic activity with Es layers is still unclear and need to be further investigated. In this paper, in order to analyze influence of solar and geomagnetic activity on Es layer, the hourly values of parameters of Es layer during four solar cycles (1970–2010) over low, mid and high latitude stations are considered.

2. Data processing

Note that *foEs* is widely used in sporadic E studies to quantify the layer's intensity and variability. On the basis of the simplified form of the magnetoionic theory, *foEs* relates approximately to the maximum electron density in the layer, N_{em} which can be estimated from the equation: $foEs \approx 9.0(N_{em})^{1/2}$ (Haldoupis et al., 2007). This study analyzed the hourly ionosonde data during 41 years from 1970 to 2010 recorded at Hainan (20.00°N, 110.34°E), Lanzhou (36.06°N, 103.87°E) and Syowa (69.00°S, 39.60°E) stations. In order to analyze the relationship between solar and geomagnetic activity level with Es layer, the following parameters of Es are considered: the yearly averaged values of critical frequency of Es layer, *foEs*, the yearly averaged value of eliminating the contribution of the regular E layers in daytime: $\langle \Delta foEs \rangle = \sqrt{(foE_s)^2 - (foE)^2}$, the relative excess of sporadic ionization over monthly median values: $\langle \delta foEs \rangle = \frac{foEs - foEsm}{foEsm}$ and percentage of occurrence of Es layer for various intensity levels: $P(foEs > f_T)$ $(f_T =$ 3, 4, 5, 6 and 7 MHz). Daily values of sunspot number (W) and geomagnetic index (K_P) are used for solar and geomagnetic activity level description during the same period.- The selection of disturbed days is $K_P > 5$, and four days before and after the disturbed days are also considered. The parameters of Es layers are averaged over the whole day (00:00–23:00 L.T.), so over the daytime (09:00–15:00 L.T.) and nighttime (21:00–03:00 L.T.) over Hainan and Lanzhou stations. The daytime in Syowa station is from 04:00 to 20:00 L.T. in summer, and is from 11:00 to 13:00 L.T. in autumn and spring. While the nighttime in the station is from 16:00 to 08:00 L.T. in winter, and is from 23:00 to 01:00 L.T. in autumn and spring.

3. Results and discussion

The yearly averaged values of *foEs* in day and night time at the low, mid and high latitude stations during four solar cycles (1970–2010) are calculated. As shown in Fig. 1, the long-term series of averaged *foEs* values in daytime have a slowly descending tendency except at Lanzhou station. This trend is similar as revealed before (Maksyutin and Sherstyukov, 2005; Baggaley, 1984b, 1985). While in nighttime the values of *foEs* at the three stations have a slowly ascending tendency, which is different from early discovered Maksyutin and Sherstyukov (2005). These trends cannot be fully explained by known changes in the ionosphere conditions or observations (Maksyutin and Sherstyukov, 2005; Baggaley, 1984b).

The correlation of yearly averaged values of *foEs* and $\langle \Delta foEs \rangle$ with sunspot number W are also calculated, the results are presented in Table 1. The correlation coefficient of *foEs* with W is positive in daytime and negative in nighttime at low and mid latitude stations, but the correlation coefficients are all positive during day and night time over high latitude station. When eliminating the contribution of regular E layers, the correlation coefficient of $\langle \Delta foEs \rangle$ with W in daytime is negative at low latitude station and is positive at mid and high latitude station.

The values of correlation coefficient listed in Table 1 can reveal difference of ions contribution of Es layers. Strong positive correlation of *foEs* with solar activity in daytime is mainly caused by the contribution of regular E layers which are deeply controlled by solar activity Zuo and Wan (2002). While other authors find less significant influence from the solar activity (Pietrella et al., 2014). So Es layer are mainly dominated of metallic ions in nighttime (Whitehead, 1970) and are both metallic and molecular ions contribution in daytime at low and mid latitude

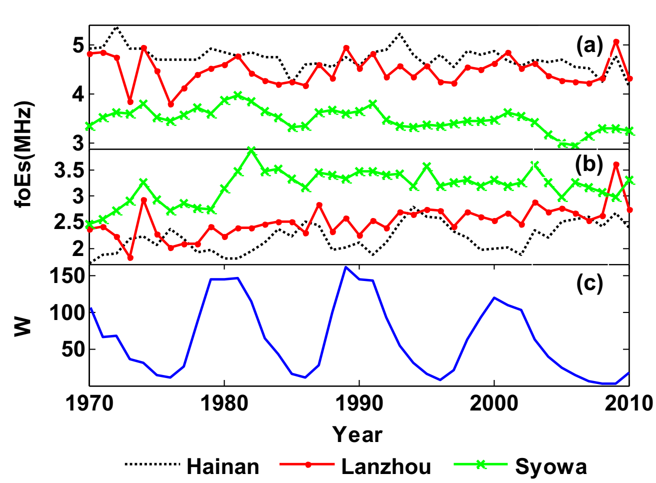

Fig. 1. Comparison of yearly averaged values of *foEs* in (a) daytime, (b) nighttime at the three stations with (c) sunspot number W.

Table 1
Correlation of yearly averaged values of $foEs$ and $\langle \Delta foEs \rangle$ with sunspot number W.

Station	$R(foEs, W)$			$\langle R(\Delta foEs, W) \rangle$
	All day	Day	Night	
Hainan	−0.47	0.33	−0.76	−0.05
Lanzhou	0.12	0.46	−0.25	0.33
Syowa	0.40	0.63	0.14	0.53

stations Maksyutin and Sherstyukov (2005). At high latitude station Es layers mainly formed from molecular ions during all day time.

The percentages of appearance of Es layer exceeding the frequency f_T, $P(foEs > f_T)$, are calculated from the value $f_T = 3$ MHz. The correlation of yearly averaged values of $P(foEs > f_T)$ with solar activity are given in Table 2. The correlation coefficients are positive for low intensity layers and negative for high intensity layers in daytime over Hainan and Lanzhou stations, and they are all negative in nighttime at low and mid latitude stations. In high latitude the coefficients are all positive during the whole days.

The values of the correlation coefficient listed in Table 2 can also reveal difference of ions composition of Es layers with different intensity. Thus, low intensive Es layers are mainly dominated of molecular ions, while high intensity layers are mainly due to metallic ions contribution in daytime (Whitehead, 1989; Carter and Forbes, 1999) at low and mid latitude stations. And in nighttime, Es layers all are mainly dominated by metallic ions at low and mid latitude stations, which is coincident with the former point of view. While no matter weak and high intensive Es layers at high latitude are formed from molecular ions over all day time.

Neutral molecules in the regular E layers transform into molecular ions due to photochemical effects, and the regular E layers are deeply controlled by solar activity Zuo and Wan (2002). Swider (1968) considered reactions such as $M^+ + O \rightarrow MO^+ + hv$ and $M^+ + O_2 \rightarrow MO_2^+ + hv$, where M is a metallic ion. While the ion–molecule chemistry and photochemical reactions could not explain why the correlation coefficients of metallic ions with W are negative during daytime. Carter and Forbes (1999) thought that in the absence of winds and electric fields, the metallic ion densities in Es layer altitude have slight diurnal variation through the effects of photoionization and chemistry reactions. According to Akchurin et al. (1995) the Es layers having high intensity are observed for neutral winds directed to the southeast within the upper mesosphere–lower thermosphere height range. During directed to the southeast prevailing winds, there is a vertical drift of ions directed upwards, which prevents "washing away" of metallic ions (Akchurin et al., 1995). The occurrence of southeast directed neutral winds will be decreased during maxima of solar activity, which will lead to a decrease of Es layer intensity (dominated of metallic ions) (Maksyutin et al., 2001; Akchurin et al., 1995). So the above analysis could give an explanation why metallic and molecular ion in Es layers correlate with W in an opposite way. And the same results were observed in mid-latitude by Maksyutin and Sherstyukov (2005).

Isolated geomagnetic disturbances influence on Es layers is also analyzed, as shown in Figs. 2–5, the maximum of geomagnetic disturbances are the fifth day. Draw symmetric error bars that are one standard deviation unit in length during Figs. 2–5. As drawn in Fig. 2, an increase of Es layers intensity over the next day after the geomagnetic disturbance is observed during winter, spring and autumn seasons, while the increase happens not only in the disturbed days but also in one day before and after the events in summer season at Hainan station are also observed. The influence of geomagnetic activity on Es layer is larger during winter than in other seasons, while more weakly during autumn days.

As shown in Fig. 3, the density of Es layers also increases after the geomagnetic disturbance in Lanzhou station, the increasing of Es layers intensity insists on about two days during winter and spring days, while during autumn about one day. The regeneration of Es layer intensity is more prolonged in winter days, which agrees with the results at Moscow station by Maksyutin and Sherstyukov (2005).

Among the three stations the variation of Es layer influenced by the geomagnetic disturbances is largest in Syowa. As shown in Fig. 4, the maximum of the increase of Es layer intensity is over disturbed day. And recovery of Es layer intensity is also more prolonged in winter days and spring days.

It is noticed that the difference between "night" and "all day" in Fig. 4 in winter is substantially larger than in spring in spite of much longer spring daytime period. These may be influenced by the planetary wave. Planetary waves can influence on the formation of Es layers in a direct or indirect way (Pancheva et al., 2003; Shalimov

Table 2
Correlation of Es layer for various intensity levels with sunspot number W.

Frequency	Hainan			Lanzhou			Syowa		
	All day	Day	Night	All day	Day	Night	All day	Day	Night
$R(P(foEs > 3\text{ MHz}), W)$	−0.26	0.33	−0.83	0.46	0.57	−0.07	0.37	0.44	0.17
$R(P(foEs > 4\text{ MHz}), W)$	0.23	0.67	−0.79	0.53	0.70	−0.14	0.26	0.34	0.15
$R(P(foEs > 5\text{ MHz}), W)$	−0.28	0.12	−0.76	0.04	0.32	−0.24	0.27	0.29	0.25
$R(P(foEs > 6\text{ MHz}), W)$	−0.38	−0.15	−0.55	−0.14	0.04	−0.26	0.29	0.27	0.33
$R(P(foEs > 7\text{ MHz}), W)$	−0.26	−0.16	−0.31	−0.21	−0.13	−0.25	0.28	0.27	0.36

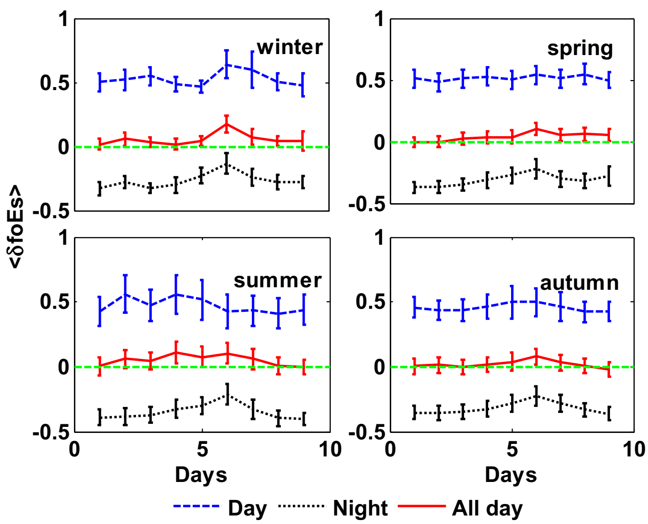

Fig. 2. Influence of geomagnetic disturbances on seasonal averaged value of $\delta foEs$ at Hainan station. The error bars are one standard deviation unit.

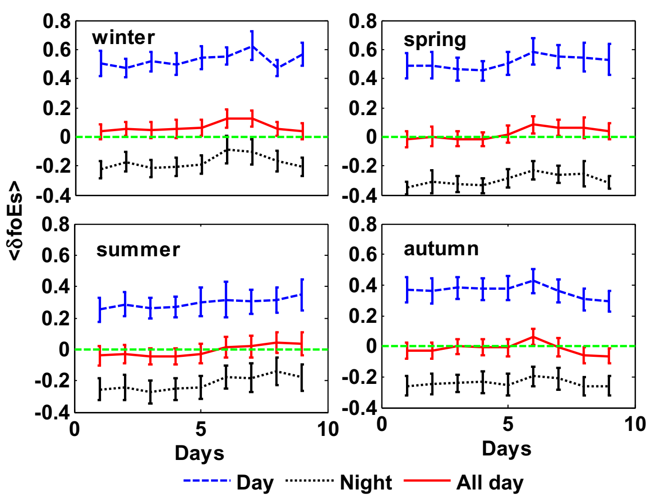

Fig. 3. Influence of geomagnetic disturbances on seasonal averaged value of $\delta foEs$ at Lanzhou station. The error bars are one standard deviation unit.

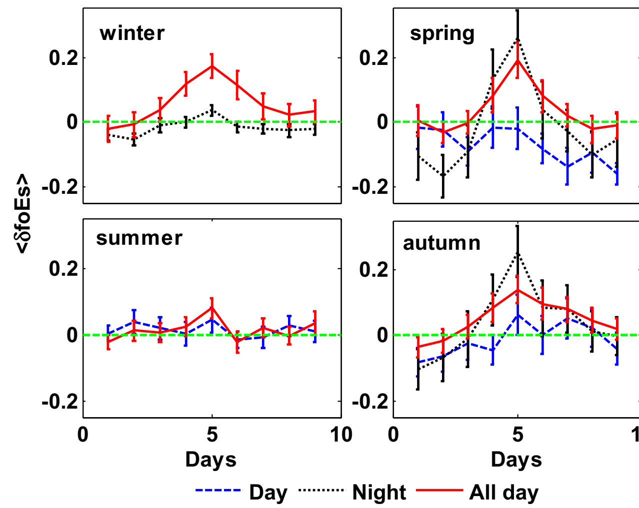

Fig. 4. Influence of geomagnetic disturbances on seasonal averaged value of $\delta foEs$ at Syowa station. The error bars are one standard deviation unit.

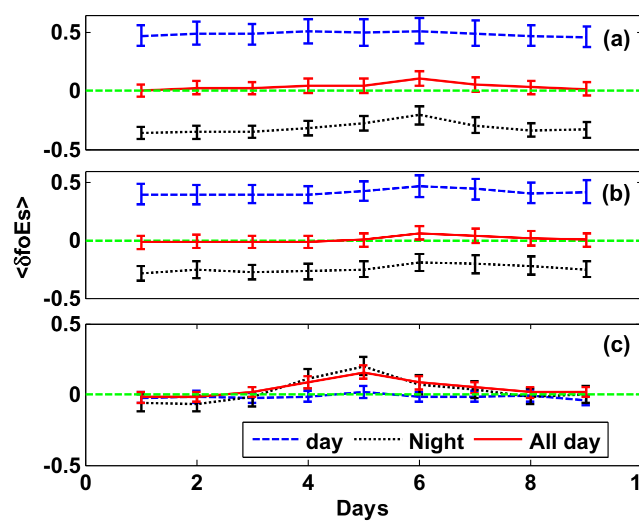

Fig. 5. Influence of geomagnetic disturbances on yearly averaged value of $\delta foEs$ at (a) Hainan station, (b) Lanzhou station and (c) Syowa station. The error bars are one standard deviation unit.

et al., 1999; Shalimov and Haldoupis, 2002; Haldoupis and Pancheva, 2002). Moreover, the stationary planetary wave amplitudes are strong during the wintertime and almost vanish during the summertime in the high latitude (Xu et al., 2014). So the influence of the planetary wave on Es layers could give a possible explanation about the phenomenon in Fig. 4.

Meanwhile, the influence of geomagnetic disturbances on yearly averaged value of Es layers intensity is also estimated. As presented in Fig. 5, the influence of geomagnetic activity on the Es layer is very little during daytime respect to nighttime. Furthermore, the influence on Es layers is largest in Syowa station among the three stations.

Due to different results obtained by Maksyutin and Sherstyukov (2005) and Pietrella and Bianchi (2009) about the influence of geomagnetic activity on Es layers, hourly averaged values of critical frequency of Es layers during the period 1970–2010 are calculated. To clarify what presented in Fig. 6, one day before and after the disturbed days, quiet and disturbed days are selected. From Fig. 6 and combined with the above analysis, the conclusion could be obtained that there is a relationship between geomagnetic activity and Es layers. An increase of Es layers intensity happens over the next day after the geomagnetic disturbance in low and mid latitude stations, and in high latitude station the density of Es layers increases at the disturbed day. Thus, these results suggest a positive correlation between geomagnetic activity and unusually intense Es layers, which coincides with the results observed at low magnetic latitudes (Closs, 1969).

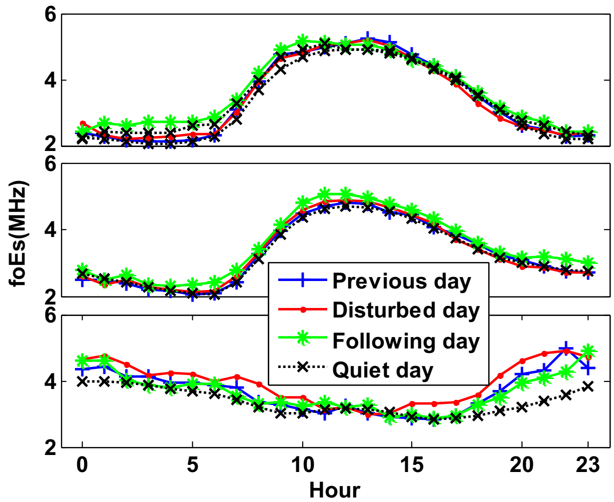

Fig. 6. Influence of geomagnetic disturbances on hourly averaged value of *foEs* at (a) Hainan station, (b) Lanzhou station and (c) Syowa station.

The Earth's ionosphere, the ionized component of the Earth's upper atmosphere, responds markedly to geomagnetic storms. During geomagnetic disturbances, the heating at high latitude causes rapid expansion of the neutral atmosphere. The rapid expansion can cause upwelling of air through constant pressure surfaces, which leads to diffusive imbalance and increases the mean molecular mass. The expansion also gives rise to pressure gradients which change the global thermospheric circulation (Buonsanto, 1999; Prölss, 1987). The disturbed thermospheric circulation could affect tidal winds, planetary waves, gravity waves, etc. which control the occurrence and strength of Es layer. The process of the disturbed thermospheric circulation from high to low latitudes needs several hours and this explains how the Es layer intensity increases during disturbed days at high latitude station and the same phenomenon occurs in the next day after the geomagnetic disturbance in the two lower latitude stations. In addition, during global thermospheric circulation, the affections of the enhanced equatorward winds on the Es layers become weaker as latitude decreasing, which could explain that the influence of geomagnetic disturbances on Es layers intensity is strong in Syowa station and very weak in Lanzhou and Hainan stations.

As the results obtained from Tables 1 and 2, Es layers mainly formed from molecular ions during all day time over high latitude station. It is noticed that the density of Es layers mainly formed by molecular ions is stronger in nighttime in Syowa station shown in Fig. 6. During geomagnetic disturbances, the enhanced equatorward winds accompanied by the changed composition transport to lower latitudes are usually stronger at night (Buonsanto, 1999; Prölss, 1987). Thus the composition of lower thermospheric is changed and molecules become richer (Rishbeth, 1998) at night which improve possible chance to generate molecular ions in Es layer. These could give a possible interpretation that the influence of geomagnetic disturbances on the Es layer during day period is more weakly than during night period.

4. Conclusions

We analyzed the hourly values of parameters of Es layer during four solar cycles (1970–2010) over three low, mid and high latitude stations to investigate a relationship between solar and geomagnetic activity with Es layer. The results show that there is a relationship between them, and the correlations are different over different latitude stations.

At low and mid latitude stations, the correlation coefficients of Es layer with solar activity are positive in daytime and negative in nighttime. The coefficients are positive for low intensive layers and negative for high intensive layers in daytime, and they are all negative in nighttime. According to different values of coefficients, Es layers are mainly dominated by metallic ions in nighttime and are both metallic and molecular ions contribution in daytime.

At high latitude station, the correlation coefficients are all positive and Es layers is mainly formed from molecular ions during day and night periods.

Moreover it is a positive correlation between geomagnetic activity and unusually density Es layers. During the geomagnetic disturbances, the density of Es layers has an increase at the disturbed day over high latitude station, while the increasing happens at the next day after the geomagnetic disturbance in low and mid latitude stations, which could be possible attributed to disturbed thermospheric circulation effect.

During geomagnetic disturbances, the composition of lower thermospheric is changed and molecules become richer at night which improve possible chance to generate molecular ions in Es layer. These could give a possible interpretation that the influence of geomagnetic disturbances on the Es layer is very weak during daytime respect to nighttime

Acknowledgments

The authors thank the NICT for providing ionosonde data of Syowa station, and thank SPIDR for sunspot data and global geomagnetic activity data. This work is supported by National Natural Science Foundation of China (Grant Nos. 41104108, 41004065, 41104102).

References

Akchurin, A.D., Zykov, E.Yu., Makarov, N.A., et al., 1995. Influence of lower of thermosphere dynamics on the appearance of E sporadic layer. Geomag. Aeron. 35, 130.

Alpers, M., Höffner, J., von Zahn, U., 1994. Sporadic Fe and E layers at polar, middle and low latitudes. J. Geophys. Res. 99, 14971–14985.

Alpers, M., Höffner, J., von Zahn, U., 1996. Upper-atmosphere Ca and Ca^{+} at midlatitudes – first simultaneous and common-volume lidar observations. Geophys. Res. Lett. 23, 567–570.

Baggaley, W.J., 1984a. Three solar cycles of day-time southern hemisphere Es activity. J. Atmos. Terr. Phys. 46 (3), 207–210.

Baggaley, W.J., 1984b. Ionospheric sporadic-E parameters: longterm trends. Science 225, 830.

Baggaley, W.J., 1985. Changes in the frequency distribution of *foEs* and *fbEs* over two solar cycles. Planet. Space Sci. 33, 457–459.

Baggaley, W.J., 1986. Structure in the seasonal variations of Es at southern latitudes. J. Atmos. Terr. Phys. 48 (4), 385–391.

Batista, I.S., Clemesha, B.R., Batista, I.S., Simonich, D.M., 1989. Characteristics of the sporadic sodium layers observed at 23 degrees S. J. Geophys. Res. 94, 15349–15358.

Batista, I.S., De Paula, E.R., Abdu, M.A., Trivedi, N.B., 1991. Ionospheric effects of the March 13 1989 magnetic storm at low and equatorial latitudes. J. Geophys. Res. 96, 3943–3952.

Beatty, T., Collins, R., Gardner, C.S., Hostetler, C.A., Sechrist, C.F., Tepley, C.A., 1989. Simultaneous radar and lidar observations of sporadic E and Na layers at Arecibo. Geophys. Res. Lett. 16, 1019–1022.

Buonsanto, M.J., 1999. Ionospheric storms: a review. Space Sci. Rev. 88, 563–601.

Carter, L.N., Forbes, J.M., 1999. Global transport and localized layering of metallic ions in the upper atmosphere. Ann. Geophys. 17, 190.

Closs, R.L., 1969. Low latitude sporadic E associated with geomagnetic activity. J. Atmos. Terr. Phys. 31, 873–875.

Farley, D.T., 1985. Theory of equatorial electrojet plasma waves: new developments and current system. J. Atmos. Terr. Phys. 47, 729–744.

Haldoupis, C., Pancheva, D., 2002. Planetary waves and midlatitude sporadic E layers: strong experimental evidence for a close relationship. J. Geophys. Res. 107. http://dx.doi.org/10.1029/2001JA000212.

Haldoupis, C., Meek, C., Christakis, N., Pancheva, D., Bourdillon, A., 2006. Ionogram height–time–intensity observations of descending sporadic E layers at mid-latitude. J. Atmos. Sol. Terr. Phys. 68, 539.

Haldoupis, C., Pancheva, D., Singer, W., Meek, C., MacDougall, J., 2007. An explanation for the seasonal dependence of midlatitude sporadic E layers. J. Geophys. Res. 112, A06315. http://dx.doi.org/10.1029/2007JA012322.

Kirkwood, K., Nilsson, H., 2000. High-latitude sporadic-E and other thin layers – the role of magnetospheric electric fields. Space Sci. Rev. 91, 579–613.

Maksyutin, S.V., Sherstyukov, O.N., Fahrutdinova, A.N., 2001. Dependence of sporadic – E layer and lower thermosphere dynamics on solar activity. Adv. Space Res. 27, 1265–1470.

Maksyutin, S.V., Sherstyukov, O.N., 2005. Dependence of E-sporadic layer response on solar and geomagnetic activity variations from its ion composition. Adv. Space Res. 35, 1496–1499.

Mathews, J.D., 1998. Sporadic E: current views and recent progress. J. Atmos. Sol. Terr. Phys. 60, 413.

Pancheva, D., Haldoupis, C., Meek, C.E., Manson, A.H., Mitchell, N.J., 2003. Evidence of a role for modulated atmospheric tides in the dependence of sporadic E layers on planetary waves. J. Geophys. Res. 108. http://dx.doi.org/10.1029/2002JA009788.

Prasad, S.N.V.S., Prasad, D.S.V.V.D., Venkatesh, K., Niranjan, K., Rama Rao, P.V.S., 2012. Diurnal and seasonal variations in sporadic E – layer (Es layer) occurrences over equatorial, low and mid latitude stations – a comparative study. Indian J. Radio Space Phys. 41, 26–38.

Pietrella, M., Pezzopane, M., Bianchi, C., 2014. A comparative sporadic-E layer study between two mid-latitude ionospheric stations. Adv. Space Res. 54, 150–160.

Pietrella, M., Bianchi, C., 2009. Occurrence of sporadic-E layer over the ionospheric station of Rome: analysis of data for thirty-two years. Adv. Space Res.. http://dx.doi.org/10.1016/j.asr.2009.03.006.

Prölss, G.W., 1987. Storm-induced changes in the thermospheric composition at middle latitudes. Planet. Space Sci. 35, 807–811.

Rishbeth, H., 1998. How the thermospheric circulation affects the ionospheric F2-layer. J. Atmos. Terr. Phys. 60, 1385–1402.

Rowe Jr., J.F., 1973. A statistical summary of Arecibo night-time E region observations. J. Geophys. Res. 78, 6811–6817.

Shalimov, S., Haldoupis, C., Voiculescu, M., Schlegel, K., Midlatitude, E., 1999. Region plasma accumulation driven by planetary wave horizontal wind shears. J. Geophys. Res. 104, 28207–28213.

Shalimov, S., Haldoupis, C., 2002. A model of mid-latitude E-region plasma convergence inside a planetary wave cyclonic vortex. Ann. Geophys. 20, 1193–1201.

Swider Jr., W., 1968. Radiative association: possible important loss process for metallic ions in the ionosphere. Nature 217, 438.

Tan, Z., Huang, X., Wang, S., 1985. A preliminary investigation of ionospheric Es-s over Wuchang, China. J. Atmos. Terr. Phys. 47, 959–963.

Whitehead, J.D., 1970. Production and prediction of sporadic E. Rev. Geophys. Space Phys. 8, 65–144.

Whitehead, J.D., 1989. Resent work on mid-latitude and equatorial sporadic E. J. Atmos. Terr. Phys. 51, 401–424.

Xu, J., Smith, A.K., Liu, M., Liu, X., Gao, H., Jiang, G., Yuan, W., 2014. Evidence for nonmigrating tides produced by the interaction between tides and stationary planetary waves in the stratosphere and lower mesosphere. J. Geophys. Res. Atmos. 119, 471–489. http://dx.doi.org/10.1002/2013JD020150.

Zuo, X.M., Wan, W.X., 2002. The correlation between sporadic E – layers and solar activity. Chin. J. Geophys. 45 (6), 759–765, in Chinese.