General comments:

A reasonable mechanism of Nas layer enhancement in MLT region by lower atmospheric electric field was proposed in this manuscript, based on the observation date of several kinds of detection tools. This paper also provided a detail process how lower atmospheric electric field influences the ionized and neutral components in the upper atmosphere. This research is so novel and the similar reports are quite little up towards now. Consequently this manuscript fitted the scope of ACP at the moment in my point of view, however the mechanism of Nas layer enhancement in this manuscript needs to be further analyzed in the proceeding steps.

We would like to thank the reviewer for the valuable comments and constructive suggestions. We have studied all comments carefully and revised the manuscript accordingly. We marked all the changes in red fonts in the revised manuscript. The point-by-point answers to the comments are given below in blue fonts.

Specific comments:

1. In Fig.1a, the peak density of Nas is more than 12000 cm^{-3} on 97.75 km at 14:40 UT (line 142). But it can be seen from Fig.1b, the peak density of Nas at the same time is only about 5000 cm^{-3}. Although the sodium density in Fig.1a and Fig.1b were given by two different kinds of lidars, the large difference of the density is difficult to be understood as these two lidars almost located at the same site. Is this large difference caused by the different resolutions or reversion methods? Authors should re-calculate the density in Fig.1a and Fig.1b, and give reasonable values.

Thanks for this valuable comment. We apologize on the confusions and imprecisions in the data analysis. We have now thoroughly checked the raw data files of the wideband fluorescence resonance lidar and the temperature/wind lidar. We have learnt more about the data reduction/inversion methods for both lidars. The key conflict could possibly come from the wideband lidar. Fig. 1*(a) shows the lidar system operated poorly after the midnight. But the first author made a reckless mistake in handling the bad data files (i.e., she accidentally deleted the bad file). Yet we can note that the signal to noise ratio (SNR) in the first half of the night is 10, still larger than the limitation of 2.

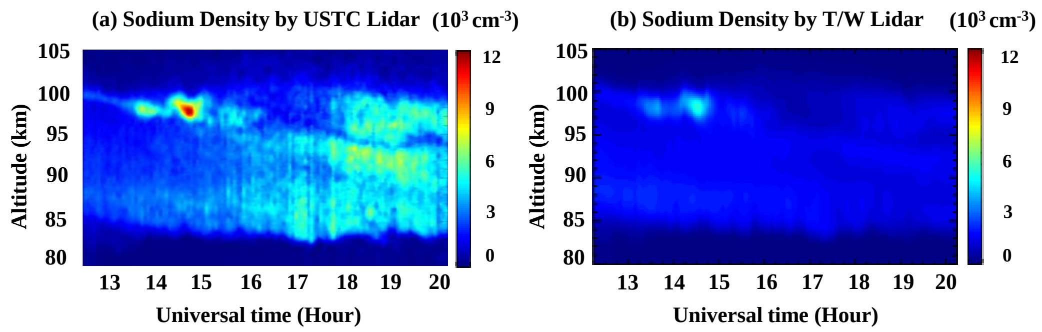

Fig. 1* (a) The entire sodium density profile observed by the wideband lidar on June 3rd, 2013. (b) The sodium density profile by T/W lidar.

For the wideband sodium fluorescence resonance lidar, the inversion formula for the sodium number density *N* at an altitude of *z* is given as follows:

$$N = \frac{\sigma_R n_a(z_0)}{\sigma_{N_a}} \cdot \frac{(P(z)-P_B)z^2}{(P(z_0)-P_B)z_0^2} , \qquad (1)^* \qquad \text{(Xue, 2007)}$$

where σ_R is the Rayleigh backscatter cross section,

$n_a(z_0)$ is the atmosphere density at a reference altitude, given by atmospheric model,

σ_{N_a} is the effective sodium backscatter cross section,

$P(z)$ is the number of photons detected in the range interval (z-Δz/2, z+Δz/2),

P_B is the expected photon count per range bin due to background signal and dark counts, calculated through the averaged background signal above 130 km, and,

$P(z_0)$ is the Rayleigh photocount at 30 km altitude, estimated by averaging the measured photon count over a 5-km range interval centered at 30 km (Gardner et al., 1986).

Among all the parameters, the variables are σ_R, $P(z)$, P_B, $P(z_0)$, and *z* (means $N = f(\sigma_R, P(z), P_B, P(z_0), z)$. The error transfer formula of *N* equals to:

$$\frac{\Delta N}{N} = \left|\frac{\partial \ln f}{\partial \sigma_R}\right| \Delta \sigma_R + \left|\frac{\partial \ln f}{\partial P(z)}\right| \Delta P(z) + \left|\frac{\partial \ln f}{\partial P_B}\right| \Delta P_B + \left|\frac{\partial \ln f}{\partial P(z_0)}\right| \Delta P(z_0) + \left|\frac{\partial f}{\partial z}\right| \Delta z. \qquad (2)^*$$

The fourth term, $\left|\frac{\partial \ln f}{\partial P(z_0)}\right| \Delta P(z_0) = \left|\frac{1}{P(z_0)-P_B}\right| \Delta P(z_0)$, makes the final error inversely proportional to the absolute value of $P(z_0) - P_B$. The averaged photon count $P(z_0)$ at 30 km is given by:

$$P(z_0) = \eta T_A^2 \frac{\lambda J}{hc} \frac{A_R}{4\pi z_0^2} \sigma_R \Delta z n_a(z_0), \qquad (3)*$$

where η is the overall system efficiency and,

T_A one-way atmospheric transmittance of the lower atmosphere;

λ optical wavelength, 0.589 × 10 $^{-6}$ m;

J laser pulse energy, J;

h Planck's constant, 6.63 × 10^{-34} J s;

c velocity of light, 3 × 108 m/s;

A_R receiver aperture area, m^2;

$n_a(z_0)$ the atmosphere density at z_0 (Gardner et al., 1986).

To minimize shot noise, $P(z_0)$ at 30 km altitude is estimated by averaging the measured photon count over a 5-km range interval centered at 30 km (Gardner et al., 1986). Because the atmospheric density decreases approximately exponentially with altitude, the average photon count at 30 km is computed by first subtracting the estimated background count, multiplying the result by z^2, taking the natural logarithm and then averaging over the range 27.5 km to 32.5 km (Gardner et al., 1986). We can see that $P(z_0)$ is therefore sensitively influenced by the background atmosphere and lidar system conditions.

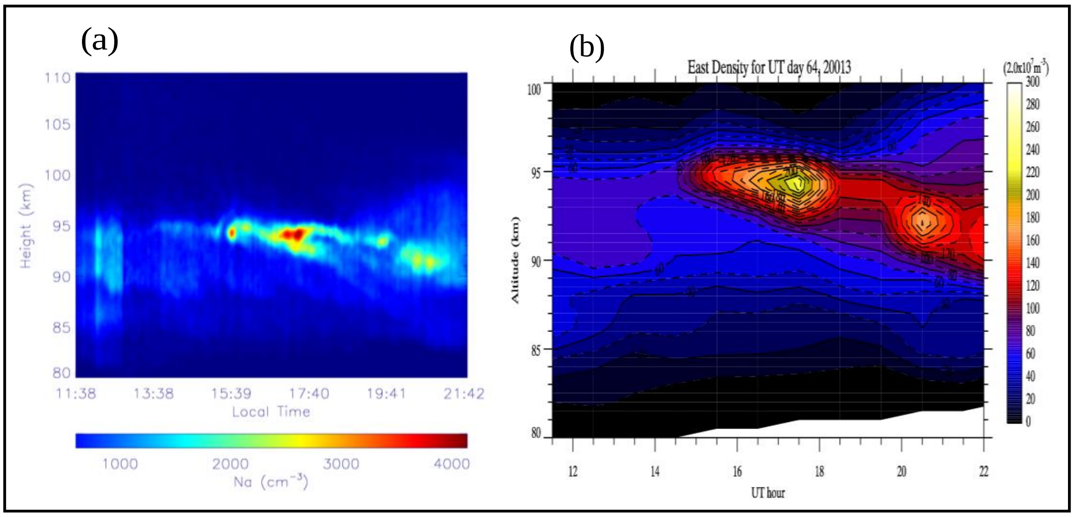

Fig. 2* (a) Sodium density profile detected by the wideband lidar on May 5th, 2013. (b) Sodium density profile detected by the T/W lidar on that day.

In comparison, we show that the sodium density profile detected on May 5th, 2013, by the wideband lidar is close to that by the T/W lidar (Fig. 2* (a) and (b)). Both profiles exhibit a peak density of about 4000 cm^{-3}.

Then we check the raw data files on June 3rd (the case we have chosen in the manuscript) and May 5th, 2013 (for comparison). Through $h = c \times t/2$, the reference height of $z_0 = 30km$ is equivalent to $t \approx 0.2ms$ (marked by the light line at .2000ms). On June 3rd, $P(z_0) = 106$ (highlighted by the red circle in Fig. 3* (a)), and the expected photocount at 130 km equals to 18 (not shown in Fig. 3*(a), but could be read from the data file). On May 5th, $P(z_0) = 501$, and $P_B = 7$ (Fig. 3*(b)). Since the error term is inversely proportional to the absolute value of $N(z_0) - N_B$, a much smaller $|P(z_0) - P_B|$ (about 5.6 times less) would cause the deduced sodium number density *N* to increase.

On the other hand, for the narrowband T/W lidar, the number of photons received by telescope from the range (z-Δz/2, z+Δz/2) is given by:

$$N(z, \nu_L, T, V) = \left(\frac{E_L}{hc/\lambda}\right) \times (\eta T_A^2) \times \left(\rho_{N_A}(z)\sigma_{SB}(\nu_L, T, V)\Delta z\right) \times \left(\frac{A_R}{z^2}\right) \times (T_\uparrow T_\downarrow) + N_B,$$

where (4)* (Li, 2005)

ν_L	Transmitter laser frequency;
T	Temperature (K);
V	Wind velocity (m/s);
E_L	Transmitted laser pulse energy (J);
η	System efficiency;
$\rho_{N_A}(z)$	Na number density (m^{-3});
$T_\uparrow$	Upward transmission in the Na layer;
$T_\downarrow$	Downward transmission in the Na layer.

Different from the wideband lidar, the deduced sodium number density $\rho_{N_A}(z)$ here is independent on the atmospheric conditions at a relative altitude z_0. Perhaps that is why they establish a necessary T/W lidar nearby.

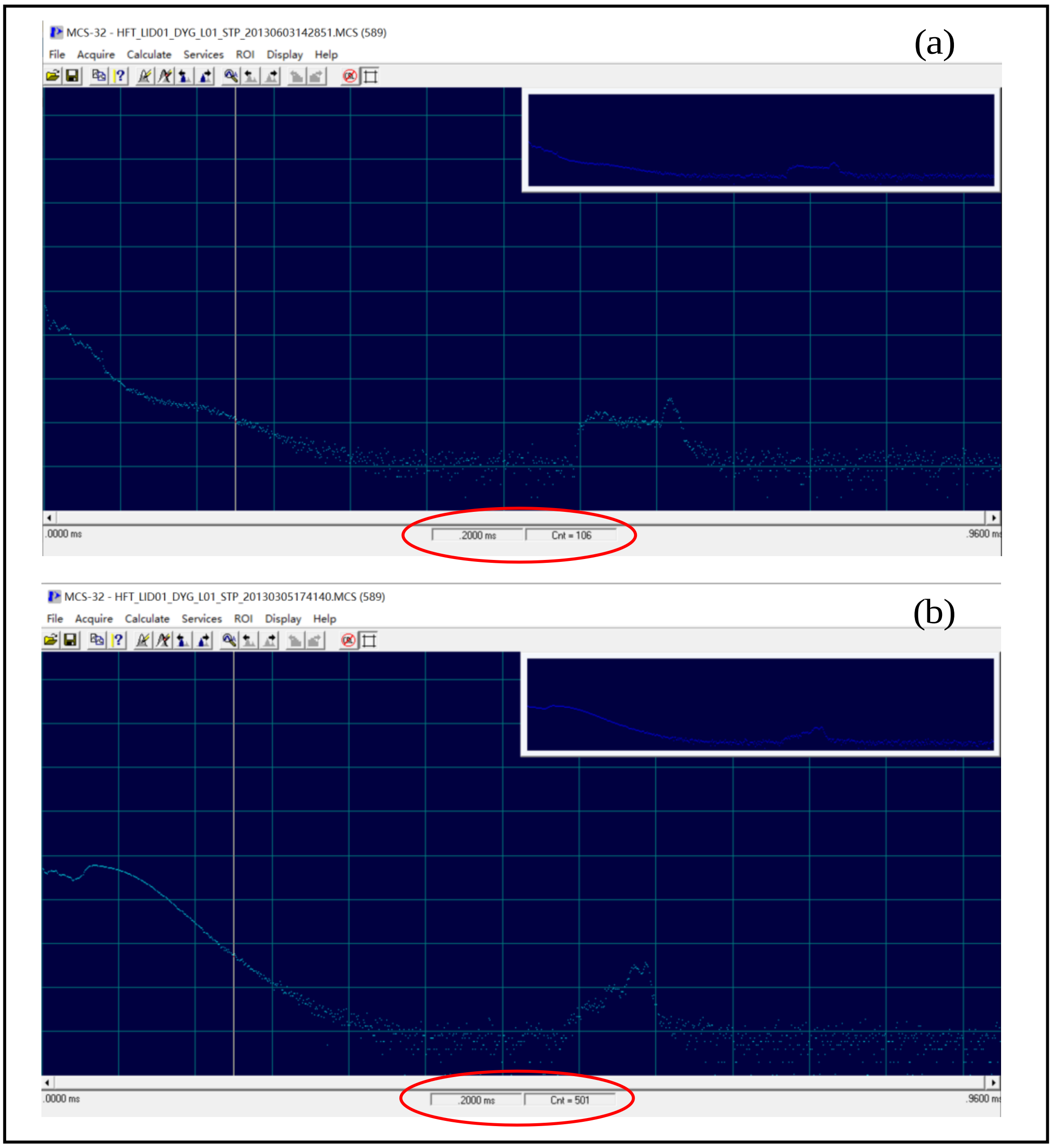

Fig. 3* (a) The raw data file at 14:28 UT on June 3rd. $P(z_0) = 106$ (pointed out by the red circle), and the expected photocount at 130 km equals to 18. (b) The raw data file at 17:41 UT on May 5th, 2013. $P(z_0) = 501$, and $P_B = 7$.

We have added more detailed explanation on the discrepancy of the peak densities, around lines 5 to 18 on page 4. We have redrawn Fig. 1(a) on page 20 of the revised manuscript.

2. In the Discussions, a clear causal chain is given by the authors: the lightning strokes induced the overturning of the electric field, and then induced the ionospheric disturbances, as well as Nas. However, it can be seen from Fig.2a: there is an

enhancement in the Es layer from 13:20 to 14:20, and the origin of this enhancement was not explained or discussed in the manuscript. Is it caused by lightning as proposed by Johnson and Davis (GRL, 2006) ? As the main contribution of this manuscript is to propose a new mechanism of Nas layer enhancement by lower atmospheric electric field, I suggest that Authors could explain or discuss the enhancement in the Es layer from 13:20 to 14:20.

Thanks for the comment. We would like to explain the E_S enhancement through electron acceleration by the reverse electric field. Usually, the mid-latitude E_S layers would be brought down gradually by tidal fluctuations (Mathews, 1998). Professor Plane's E_S theory predicts that when a series of E_S layers descend below 100 km, they will be depleted through recombination of ions and electrons (Cox and Plane, 1998). Since the recombination of $Na^+ + e^- \rightarrow Na + hv$ is inefficient in generating Na_S, Na^+ is believed to first form a ligand $Na^+ \cdot N_2$ through the recombination reaction:

$$Na^+ + N_2 + M \rightarrow Na^+ \cdot N_2 + M, \quad (5)^*$$

with a rate coefficient of $k_1 = 4.8 \times 10^{-30}(T/200)^{-2.2}$ cm^6 $molecule^{-2}$ s^{-1} (Cox and Plane, 1998). $Na^+ \cdot N_2$ can either switch with CO_2 (which will undergo dissociative electron recombination to form Na), or O (which reforms Na^+)(Cox and Plane, 1998). So the key factor of E_S mechanism depends on the ratio of [O]/ [CO_2]. Recombination of $Na^+ \cdot CO_2$ and e^- will increase rapidly as [O]/ [CO_2] decreases below the value of 100 (Cox and Plane, 1998). Then the sodium atoms could be formed directly from the following chemical reaction:

$$Na^+ \cdot CO_2 + e^- \rightarrow Na + CO_2. \quad (6)^* \text{ (Cox and Plane, 1998)}$$

The chemical reaction rate (v) for this second-order reaction could be calculated using the following equation:

$$v = k[Na^+ \cdot CO_2]N_e, \quad (7)^*$$

The reaction rate coefficient k_2 for the chemical reaction is experimentally measured to be:

$$k_2 = 1 \times 10^{-6}\sqrt{\frac{200}{T}} \quad (cm^6\ molecule^{-2}\ s^{-1}) \quad (8)^*$$

(Collins et al., 2002; Cox and Plane, 1998; Daire et al., 2002), and the electron density

N_e can be calculated using the following equation:

$$N_e = 1.24 \times 10^4 foE_S^2 (cm^{-3}) \quad (9)^*$$ (Bittencourt, 2004).

Overall, this Es mechanism is most widely accepted, if we neglect k_1 as being too small with an order of 10^{-30}. A possible adaptation is to assume a plenty quantity of pre-existing $Na^+ \cdot N_2$ / $Na^+ \cdot CO_2$ in the sodium layer, and the Es just needs to provide enough additional electrons. Figure 4* (d) shows Es descending near 100 km at about 13:20 (marked by the blue dashed line). Then the Es depletes, and a moderate enhancement of Na occurs from 13:30 UT to 14:00 UT (pointed out by the green arrow in Figure 4*(a)). This sodium increase exhibits no obvious peak, which could probably be in accord with a normally descending Es governed by tides. In comparison, the peak profile of the Nas shows intense enhancement and sharp peak, indicating a distinct mechanism.

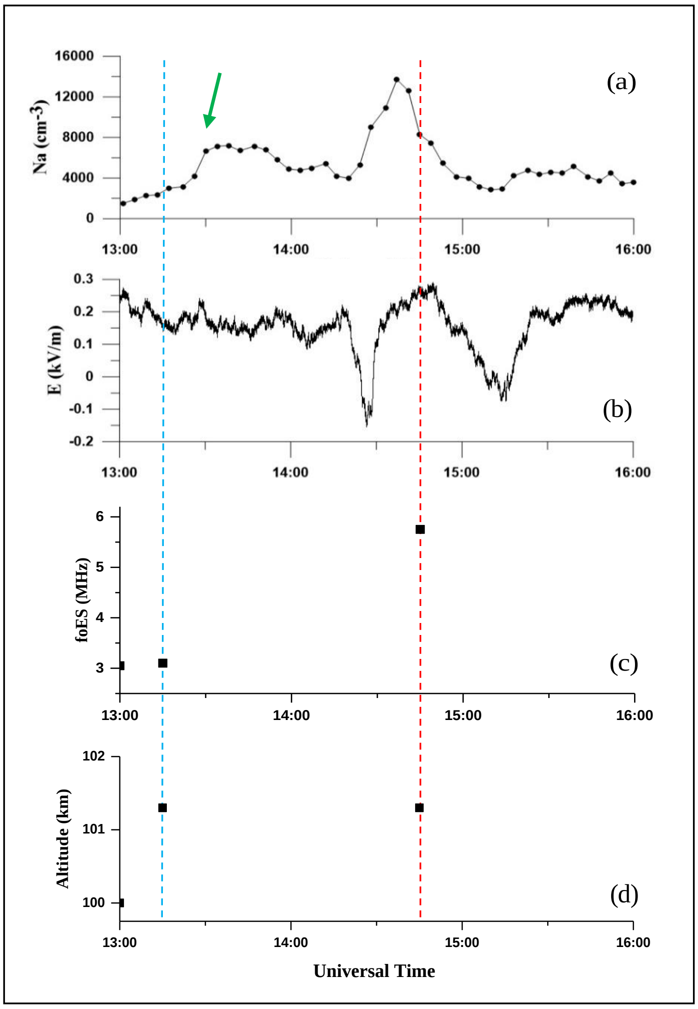

Figure 4* (a) Time series of sodium density variations. (b) Atmospheric electric field

variations. (c) foE$_S$ variations from 13:00UT to 16:00 UT. (d) Altitudes of E$_S$. (Blue and red dashed lines and green arrow are discussed in this reply, see the text).

Furthermore, a link between the electric field reverse and E$_S$ enhancement at 14: 40 UT (marked by the red dashed line) could be established through the acceleration of electrons. Normally, positive particles will move along the direction of electric field, and negative particles do the opposite (Griffiths, 1999). Since metal ions are much heavier than electrons, the ions would drag electrons in order to move/drift together, this process is called the bipolar diffusion (Griffiths, 1999). In the initial stage, ions and electrons descend gradually under the southward electric field. In a partially ionized plasma, the characteristic frequencies for ions and electrons are associated with the collisions of the plasma particles with stationary neutrals (e.g., the electron–neutral collision frequency ν_{en} and the ion–neutral collision frequency ν_{in}). The collision frequency ν_{sn} for scattering of the plasma species *s* by the neutrals is

$$\nu_{sn} = n_n \sigma_s^n V_{Ts} ,$$ (10)* (Shukla and Mamun, 2002)

where n_n is the neutral number density,

σ_s^n is the scattering cross section (which is typically of the order of 5×10^{-15} cm^2 and depends weakly on the temperature Ts),

and $V_{Ts} = (k_B T_s / m_s)^{1/2}$ is the thermal speed of the species *s*.

So the relaxation times $\tau = \frac{1}{\nu}$ for ions and electrons are different in a partially ionized plasma, and electrons would respond much faster than the heavier sodium ions do (since $m_i \gg m_e$). At the moment when the electric field reverses, electrons will be rapidly accelerated by the northward electric field, and ions would be regarded as essentially remaining northward or unchanged. So no matter how many Na^+ ions are in E$_S$, the electrons in the E$_S$ are always sufficient to produce Na$_S$. Perhaps that is why we often observed that even a very weak E$_S$ is always accompanied by Na$_S$ (Dou et. al., 2010).

We have added a new section 3.2 to discuss the E$_S$ and Na$_S$ described in this reply in details for our revised manuscript.

3. From the progress of Nas in Fig.1a：The density of Nas increases with height drops after the Nas height lower than 100 km. A maximum of Nas is present at 97km around 13:30, and later the density of Nas decreases. But another maximum of Nas is present again around 14:20 (almost the same height), and the authors think that this Nas is produced by the overturn of low-altitude electric field. According to Plane's theory, when the Es drops below 100 km, Na ions in the Es are rapidly neutralized to form Nas. As the height decreases, the rate of Na ion neutralization increases. And so there's Nas maximum at about 13:20 UT around 97 km. Later, the Nas gradually weakened due to excessive consumption of Na ions. But for the bigger Nas around 14:20, there needs to be an implicit condition if the ions in the Es contribute. That is, Na ions in the Es increased at 13:30. This may be due to the addition of surrounding sodium ions resulting in Es increase. So there may be a possible mechanism: A reversal of the electric field adds sodium ions nearby, and these ions enhance Es. And then the sodium ions in the Es are neutralized to form Na atoms, with Es weakened.

Thanks for the comment. We agree with this enhancement mechanism described by the referee, except that we would like to replace the enhanced ions with electrons. We have added the possible mechanism in detail under the new section 3.2.

Technical corrections:

1. From line 22 to line 26 in the abstract: rewrite this long sentence.

Thanks for the comment. We have rewritten the sentence around lines 24 to 26 on page 1.

2. From line 47 to line 49, "the metal layers (especially the sodium layer), which located between about 80~110 km, could possibly act as a window to detect the MLT parameters by means of fluorescence resonance lidars." please add the corresponding reference.

Thanks for the comment. We have added the references around line 6 on page 2.

3. And from line 49 to line 51 please also add the reference.

Thanks for the comment. We have added the references around line 8 on page 2.

4. At the end of Line 64, please consider the word “candidate” whether is proper or not.

Thanks for the comment. We have changed it to “proposed mechanisms”.

5. The author should pay much attention to the tense of the manuscript， the past tense shall be used when giving background information in the Abstract and Introduction, when describing methods used, and when presenting and discussing results. There are indeed quite a lot of such serious problems throughout all the manuscript. If possible, please ask a native speaker for help.

Thanks for the comment. We have tried our best to use appropriate tenses depending on the actual time of occurrences.

6. Line 137, please consider about the abbreviation “T/W lidar” as it appeared there for the first time.

Thanks for the comment. We have added the full name and a reference for the T/W lidar around line 4 on page 4.

7. Please change the line 162 as “in accord with our previous reports WHICH shown that an Nas higher than 96 km tended to be…

Thanks for the comment. We have modified this sentence around lines 28 to 29 on page 4.

8. Line 182, Based on the ABOVE observations

Thanks for the comment. We have modified it around line 5 on page 9.

9. Line 215 also POINTED out by the vertical red dashed line.

Thanks for the comment. We have rewritten the figure caption around line 4 on page 22.

10.Line 234 could be changed to “It is worth mentioned that…”

Thanks for the comment. We have changed it to “It is worth mentioning that” around line 32 on page 5.

11. Line 254 could be changed to “The electric field could change through within two distinct ways as below:”

Thanks for the comment. We have change it to “as below” around line 13 on page 6.

12.Line 291-292: “mainly concentrating in two ranges about (35.8ºN, 118.1ºE) and (25.1ºN, 113.8ºE).” please rewrite this sentence.

Thanks for the comment. We have modified this sentence in the figure caption 4 on page 23.

13.Line 302 could be changed to “Afterwards, no strong stroke WAS detected again in the discussed area.”

Thanks for the comment. We have modified this sentence around line 13 on page 7.

14.Line 311-313 the caption of Figure 5 (a)~(l): please unify the tense of verbs and pay attention to the English writing again as I remind.

Thanks for the comment. We have rewritten the caption of Fig. (5).

15.Lines 335-336, “similar to how moving cars will crash in a traffic accident in the car in front suddenly turns back or brakes” Please rewrite this sentence within much more scientific aspect.

Thanks for the comment. We have deleted this scenario in the manuscript.

16.Line 338, are you sure by three steps? Please check it.

Thanks for the comment. We have modified the legend to be four steps in total, around lines 4 to 9 on page 9.

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