

Reviewer Comments to Author(s):

The manuscript "Metal Layer Depletion during the Super Substorm on 4 November 2021" presents intriguing observations of metal layer depletion during a super substorm, combining lidar data, GUVI satellite observations, and numerical simulation. The integration of multi-instrument data and modelling to link metal layer changes with geomagnetic storm-induced oxygen density variations is a strong point. However, several issues related to clarity, grammar, scientific argumentation, and figure presentation need attention to enhance the paper's impact and precision.

Line 17-18:

"Due to the viscous force of air, the wind and electric field disturbances of a magnetic storm is hard to penetrate deep into the Earth's dense atmospheric region."

The statement is oversimplified and lacks precise backing. While viscous forces and neutral atmosphere density limit electric field penetration, wave and particle interactions can cause storm effects in the MLT region. Clarify referencing and nuances.

Line 20-26:

The core hypothesis that metal atom depletion is caused by increased atomic oxygen forming metal compounds during storm is compelling. However, more direct chemical kinetic evidence or references supporting the rates and abundances of such reactions at MLT altitudes during storms would strengthen this argument.

Suggest discussing or referencing existing atmospheric metal chemistry models more explicitly.

Line 42-43:

"It is widely accepted that chemical reactions below 85 km altitude have an important impact on the density variation of Na atoms, but the chemical reaction above 85 km has little influence."

This conflicts with later claims about chemical reactions influencing metal layers during storms at ~90-100 km. The authors should clarify how their findings contrast with or extend prior understanding.

Line 55-58:

Claiming that the storm cannot penetrate to metal layers is common but somewhat oversimplified. Some studies have shown ion-neutral coupling effects in MLT during storms — this could be acknowledged.

Line 58-59:

"Whether a storm can affect the atmospheric layers as low as the Mesosphere and Low Thermosphere (MLT) region is a very interesting topic."

This is true, but not a novel question. The authors should better situate their work in the context of previous MLT storm effects research.

Line 64:

Statement that this is the first time a storm effect on metal layer has been introduced is somewhat strong. The work is likely first strong evidence of depletion caused by changed chemistry, but literature on sporadic E-layer and metal ion responses exists. This should be framed carefully.

Line 69-76:

Description of lidar systems needs clarity on detection limits, uncertainty, and calibration methods. Are all metal densities quantitative and directly comparable?

Line 94-113 (Geomagnetic Indices):

The storm description is adequate. However, consider adding direct linkage of timing of substorm peaks with metal layer depletion timing for clarity.

Line 167-176:

The statistical argument that simultaneous depletion at 4 stations with low chance of random occurrence ($p=1.334\times 10^{-7}$) supports storm causality is good.

However, the low correlation coefficients between metal layers (e.g. 3.578×10^{-4} for Pingquan-Na and Yanqing-Ca) invite discussion — why do metal species respond differently? Is variability noise or physical reason? This warrants explanation.

Line 209-250:

The TIEGCM model description and simulated O/N₂ enhancements support the scenario. It is a limitation that TIEGCM bottom boundary is ~97 km, slightly above some metal layers' lower height ~80 km. Authors should discuss how simulation resolution affects conclusions and chemical coupling.

Line 252-291:

The detailed chemical pathway for Ca compounds affecting Ca atom abundance is well presented (Equations 1-6).

For a stronger theoretical argument, extend these to Na, Ni chemistry or provide reasoning why Ca is emphasized.

Line 293-312:

Recommend highlighting limitations explicitly (measurement spatial coverage limited to mid-latitudes China, need for more latitude coverage).

Suggest stating potential implications on atmospheric chemistry and space weather forecasting more explicitly.

3. Grammatical, Syntax, and Stylistic Issues

Line 17: "wind and electric field disturbances of a magnetic storm is hard" → "are hard" (plural subject-verb agreement)

Line 20: "metal layers were observed to deplete by three lidars" → "were observed to deplete by three lidars" is unclear. Better: "were observed to decrease by observations from three lidars"

Line 21: "The Na , Ca and Ni densities on the storm day" → remove extra space after Na

Line 22: "The O/N2 column density ratio ... was much higher than that on the quiet days," → "was much higher than on quiet days,"

Line 35: "turn into compounds, deposit on the Earth's" → "turn into compounds, depositing..." / or "turn into compounds that deposit..."

Line 40: "density of Na peaks in winter and reaches its lowest level in summer at all latitudes" → Add comma after "winter"

Line 56: "variations in ionosphere," → "variations in the ionosphere,"

Line 64: "and it is the first time to introduce the influence of storm" → "and this is the first time the influence of a storm on the metal layer is introduced"

Line 70: "dual-wavelength simultaneous detection system is used for Na and Ni observation and the all-solid-state narrowband lidar is used to observe the Ca layer" → awkward; better split into two sentences

Line 102: "20:00 UT indicating beginning of the storm" → "indicating the beginning of the storm"

Line 124: "metal atoms dataset can be accessed in" → "metal atoms dataset is accessible at"

Line 138-140: Multiple phrasing issues with awkward expressions like "is lower than those on the reference days as well as those of month average" → "is lower than on reference days and monthly averages"

Line 169: "but the lowest column abundances in all the four plots of Fig. 3 occurred on 4 Nov. 2021 as shown by the red bars." → "in all four plots of Fig. 3" (remove "the")

Line 200: "vertical advection during the upwelling will reduce O and enhance N₂, thus lead to the depletion of the O/N₂." → "thus leads to the depletion"

Line 221: "The simulated ΣO/N₂ over Yanqing and Pingquan is 1.0109 and the GUVI measurement is 1.0181..." → The values are very close; it would be better to say "is 1.0109, close to the GUVI measurement of 1.0181"

Line 246: "The largest increase was $1.9 \times 10^{10}/\text{cm}^3$ at 100 km altitude..." → write as " $1.9 \times 10^{10} \text{ cm}^{-3}$ " with correct spacing and units

Line 262: "As a result, the increased O density converts more Ca atoms to compounds, and thus the Ca density in the metal layer decreases significantly." → merge last two clauses: "...to compounds, thus decreasing Ca density significantly."