Review of the manuscript “Reevaluation of EISCAT plasma parameters during the May 2024 geomagnetic storm using O+ ratios from AMIE-driven SD-WACCM-X”

In this manuscript, the authors compare plasma parameters derived from measurements by the EISCAT incoherent scatter radar in Svalbard (ESR), using ion compositions as a prior from the original IRI model and the AMIE-driven WACCM-X model. The results differ with different ion compositions. Based on their analysis, the authors also suggest developing a correlation model to quickly correct the original EISCAT GUISDAP analysis. The authors argue that their method is advanced because it is based on first-principles simulations, and this physics-based approach reduces biases in EISCAT plasma parameter fits compared with standard analyses. However, this argument may not be sufficient based on the current analysis. Additional analysis and discussions are needed. Please see my comments as follows:

Authors:

We thank the reviewer for their evaluation and helpful suggestions.

Major comments:

1. The authors emphasize that their method is advanced because the first-principles model WACCM-X, with AMIE as the driver, is used to provide a more accurate ion composition. However, the question is whether the model itself can reproduce the ionospheric parameters during this May 2024 superstorm, particularly locally at ESR. If significant deviations are observed between the simulation results and ESR measurements, it may not be appropriate to claim that using the simulated ion composition can debias the fitting results. I suggest comparing Ne, Te, and Ti between the simulation outputs and GUISDAP results, with and without the new ion composition.

2. Comment 1 is also associated with a question on the temporal and spatial resolution of simulations. The simulation may provide large-scale distributions; however, it performs poorly under highly dynamic conditions, especially during geomagnetic storms. A discussion of the temporal and spatial scales of ion composition in the model should be conducted.

Authors (combined answer for major comments 1&2):

The advancement of our method is only with reference to applying IRI O+ ratios. Visual comparison to Cai et al., 2026 (see response to comment 4) suggests that the physics-based ion composition matches the BAFIM results better than IRI (though a distinct overestimation of O+ appears to be the case, likely connected to the overall overestimation of O/N2 in WACCM-X). Our method should therefore reduce the bias of EISCAT parameters, even if the plasma temperatures and density are moderately reproduced by the physics-based model. A comparison of model and measurement plasma parameters can be given in the supplementary material, but would, in our opinion, not benefit the study.

A discussion of the temporal and spatial scales is indeed relevant and will be added to the manuscript.

3. The linear correlation model and Equation 2 are based on the assumption that the actual or more accurate O+ ratio is known. Although the authors suggest a “quick correlation” can be applied for a user who is not familiar with EISCAT analysis. However, in practise, the user needs to know the O+ ratio in advance. If a simulation model like WACCM is needed, it will require computational resources and may not be “quick”. Please clarify this if possible.

Authors:

For the existing database of EISCAT measurements, available WACCM-X long-runs can be applied as O+ ratio source (e.g., [WACCM-X Simulation of the Atmosphere From 1950 Through 2024 at an Hourly Resolution - Brown - 2026 - Journal of Geophysical Research: Space Physics - Wiley Online Library]). For new measurements, additional simulations need to be conducted, which, as the reviewer states correctly, requires computational resources. The applicability of TIE-GCM rather than WACCM-X should be investigated, as it requires fewer computational resources, and the boundary conditions are easier to set to recent conditions.

4. In this study, the ion composition from the model is used to fit the ionospheric parameters of the ISR. On the other hand, the fitted parameters, especially the ion temperature, can affect ion-neutral reactions and hence modify the ion composition. As mentioned in Section 4.2, the BAFIM module with the Ion Density Calculator (IDC) was developed to fit the EISCAT parameters, including the ion composition. One of the advantages of that technique is that it iteratively fits the parameters to ensure that the ion and electron temperatures input to IDC are based on measurements, and that the fitted combination of plasma parameters is reasonable from a chemistry point of view. Hence, that technique is also suitable for rapid changes in ion temperature and composition, which typically occur during active geomagnetic conditions, such as substorms and storms. In addition, a recent study by Cai et al. (2026) used the BAFIM analysis to show the ionospheric responses to the May 2024 superstorm, including changes in ion composition. A discussion on the similarities and differences between the two studies can be made.

Cai, L., Aikio, A., Geethakumari, G. P., Vanhamäki, H., Virtanen, I. I., Oyama, S.-i., et al. (2026). Ionosphere-thermosphere coupling in the Northern polar region during the May 2024 geomagnetic superstorm. Journal of Geophysical Research: Space Physics, 131, e2025JA034495. https://doi.org/10.1029/2025JA034495

Authors:

The mentioned paper was published shortly before the original submission of our manuscript and, hence, is not part of the original discussion. We are thankful for the chance to include it in the now extended discussion and the reviewers' helpful elaborations on the BAFIM technique. We would like to specifically state that the method proposed in our paper is not intended to achieve an accuracy comparable to the BAFIM method, but as an alternative approach applicable in certain cases where a fast debiasing of multiple EISCAT measurement campaigns is required (See comment 3).

Additionally, our proposed method is an initial step towards the application of EISCAT measurements for data assimilation in physics-based models. As the reviewer correctly states, the ion composition affects the ion temperature, in turn affecting the ion composition. Assimilation of EISCAT measurements can therefore only be done meaningfully if the entire scatter spectra, rather than single parameters, are assimilated. We see this paper as a demonstration of this issue.

As suggested, we added a discussion on the similarities and differences between Cai et al., 2026 and the presented study.

Minor comments:

L30: Could you clarify why to select the May 2024 storm? There are also many publications focusing on this storm. A brief literature review can be conducted of studies of high-latitude electrodynamics during this storm, particularly those associated with incoherent scatter radar analysis.

The missing parameterization of IRI ion compositions with geomagnetic activity is most pronounced during storm conditions. With the availability of multi-day EISCAT measurements and AMIE data assimilation, we chose this event as a favorable example for the proposed method as well as an interesting case study on ISR analysis techniques. We extended the literature review of this event.

L75: Kp exceeded 9

Kp is, by definition, limited to a maximum value of 9, whereas more recently developed indices are allowed to exceed this limit. For historical categorization, Kp still has considerable merits, but we clarified the statement in L75.

L78: In addition to Themens et al., 2024, Cai et al. (2026) studied the polar ionosphere-thermosphere coupling using multiple observations. They showed that both Ti increases and neutral composition changes are important for F-region recombination and hence result in electron density depletion and ion composition changes in the polar region.

We thank the reviewer for the suggestion and have added the proposed statement.

L105: It's unclear during which time period and at which height ranges the data are used for the correlation analysis.

The correlation analysis involves all altitudes and time periods shown in Figure 1. As this study only provides a proof-of-concept, no outlier removal or data filtering has been performed. For the development of an actual debiasing function that uses a larger EISCAT database across diverse geomagnetic conditions, some data cleaning will be required.

L108: ".. except for dNe below the transition altitude." In Figure 4a, there are several linear dependencies between drO+ and dNe when nO+ < 0.5 Ne. Could you discuss why there are several dependencies? Also, similar dependencies are visible in Figure 4c for Te.

Figure 4c shows Ti, which the reviewer presumably means. The different linear dependencies come from different altitude levels. This could indicate that the linear correlation of the O+ difference and the parameter change depends on background conditions, which, of course, vary with altitude. The fact that this is mainly (or rather most dominantly) observed below the transition altitude of the O+ ratio (rO+=0.5) could also indicate that this is related to assumptions about the molecular ion mass. However, at the present stage, we can only speculate, and further investigations will be necessary. We added a brief discussion to the manuscript.

L124: Could you expand the discussion on Figure 5 and Table 1. For example, what is the physics meaning of such relations?

The relations in Table 1 are empirical observations based on Figure 5. We assume they are rather a mathematical consequence of the GUISDAP fitting process and do not carry a physical meaning. However, this is a mere assumption for which we do not feel able to give a reasonable explanation. We expanded the discussion on Figure 5 and Table 1 to adequately state our assumption and the lack of evidence for it.

Figures: Figures 2-7: The font size of the labels is too small to see. Please increase the size. Figures 1,2,5: time ticks are not visible. In addition, it's better to turn on minor ticks to identify times of day.

Done.