Review of the paper entitled "Optimized below-cloud scavenging scheme and its prominent performance of nitrogen wet deposition in polluted region"

This manuscript presents an improved physically based below-cloud scavenging parameterization scheme implemented in the Nested Air Quality Prediction Model System (NAQPMS) to improve simulations of atmospheric nitrogen wet deposition over East Asia. The proposed Ge14-BWSC scheme incorporates three additional scavenging mechanisms—thermophoresis, diffusiophoresis, and electrostatic interaction—alongside conventional collision processes. The authors evaluate the updated scheme against observations and compare its performance with three existing wet deposition schemes. The study addresses an important source of uncertainty in regional chemical transport modeling, particularly in heavily polluted regions where conventional below-cloud scavenging parameterizations may substantially underestimate aerosol removal. The manuscript is generally well organized, the methodological development is scientifically meaningful, and the comparisons among four parameterization schemes provide useful evidence supporting the proposed improvements. A particular strength is the distinction between in-cloud and below-cloud scavenging and the evaluation of their respective contributions to oxidized and reduced nitrogen deposition. The improved agreement with observations in the Beijing–Tianjin–Hebei region, Northeast China, and the Yangtze River Delta highlights the potential value of the proposed scheme for regional nitrogen deposition assessments. Overall, I consider this manuscript a useful contribution to atmospheric chemistry and deposition modeling. The main conclusions are generally supported by the presented results, and I recommend publication after minor revision. The following comments are intended to improve the clarity, interpretation, and reproducibility of the study rather than require substantial additional modeling experiments.

Specific Comments

1. Clarification of the contributions of individual scavenging mechanisms (Section 2.2.2). The inclusion of thermophoresis, diffusiophoresis, and electrostatic interaction represents an important methodological improvement. However, their relative contributions to the enhanced scavenging efficiency are not clearly distinguished. The authors are encouraged to briefly discuss which mechanisms are expected to dominate within the Greenfield gap (0.1–2.5 μm) and how their relative importance may vary with aerosol size and environmental conditions. This clarification would strengthen the physical interpretation of the proposed parameterization without necessarily requiring additional simulations.

2. Uncertainties associated with the raindrop size distribution (Section 2.2.2). The authors derive a localized raindrop size distribution using observations collected in

Beijing and apply it to simulations covering East Asia. Although this approach is reasonable, precipitation microphysical characteristics may differ substantially across regions and precipitation types. A brief discussion of the representativeness of the Beijing-derived distribution and its potential influence on regional simulation performance would be valuable. In particular, the authors should clarify whether this assumption could contribute to the remaining biases in Korea, Japan, and southern China.

3. Influence of precipitation biases on model evaluation (Section 3.1). The WRF simulations exhibit a normalized mean precipitation bias of approximately 29%, which may influence the evaluation of nitrogen wet deposition. Although the authors acknowledge this uncertainty, its implications for interpreting the improvements achieved by Ge14-BWSC deserve further clarification. The authors should distinguish more explicitly between improvements attributable to the revised scavenging parameterization and uncertainties associated with simulated precipitation. A short discussion based on the existing results would be sufficient.

4. Interpretation of model performance in Table 2. The Ge14-BWSC scheme produces the smallest overall normalized mean bias in total inorganic nitrogen wet deposition (−7%), compared with −14% for Ge14-CAMx. However, its normalized mean error and RMSE are slightly larger than those of Ge14-CAMx. Therefore, the statement that Ge14-BWSC consistently outperforms the other schemes should be qualified. The authors should emphasize that its principal advantages concern reduced systematic bias, improved representation of high-concentration conditions, and better agreement in heavily polluted regions, rather than uniformly superior performance across all statistical metrics.

5. Remaining uncertainties in reduced nitrogen deposition (Sections 3.1–3.2). Despite the improvements introduced by Ge14-BWSC, reduced nitrogen wet deposition remains underestimated, with an NMB of −33% in Table 2. The authors attribute part of this discrepancy to underestimated NH_3 emissions. It would be helpful to discuss more explicitly the relative roles of emission inventory uncertainties, gas–particle partitioning, and wet scavenging parameterization in explaining the remaining negative bias. This would also clarify the extent to which the proposed scheme can address the broader uncertainties in nitrogen deposition modeling.

6. Interpretation of below-cloud contributions (Section 3.3; Figures 5 and 6). The improved agreement between simulated and observed below-cloud contributions of oxidized and reduced nitrogen is one of the strongest findings of this study. In particular, the Ge14-BWSC scheme reproduces the observed contributions in Beijing remarkably well. However, the authors should briefly acknowledge that these observational constraints are geographically limited. A short discussion of whether similarly high below-cloud contributions can be expected in other polluted regions with different aerosol composition and precipitation characteristics would improve the general applicability of the conclusions.

7. Implications for long-range nitrogen transport (Section 3.4; Figure 7). The authors suggest that enhanced below-cloud scavenging increases nitrogen deposition near emission sources while reducing transport and deposition in remote downwind regions. This interpretation is physically plausible and scientifically important. However, because the study does not perform quantitative source attribution, the conclusions regarding long-range transport should be expressed with appropriate caution. The authors should clarify that these findings represent modeled responses to the revised scavenging parameterization rather than direct quantitative estimates of source–receptor relationships.

8. Limitations and broader applicability of the proposed scheme (Section 4). The conclusions would benefit from a concise discussion of the limitations of the proposed parameterization. In particular, the simulations cover only 2014, employ a horizontal resolution of 45 km, and use a regionally derived raindrop size distribution. These factors may influence the transferability of the scheme to other years, regions, and chemical transport models. A brief acknowledgment of these limitations would provide a more balanced perspective on the broader applicability of the findings.

9. Figure presentation and clarity. The figures are generally informative and support the main findings. Nevertheless, several improvements would enhance readability. In Figure 1, the observational datasets and corresponding symbols should be more clearly distinguished. In Figure 3, the regional boundaries and site-level bias markers could be made easier to identify. In Figure 7, the seasonal differences between the two schemes should be more explicitly described in the caption, particularly regarding the interpretation of positive and negative deposition changes.

10. Technical and editorial corrections. Several minor grammatical and terminology issues should be corrected throughout the manuscript. For example, “adjustion” in Section 2.1 should be replaced with “adjustment,” and “employes” in Section 3.1 should be corrected to “employs.” The authors should also ensure consistent use of the terms below-cloud scavenging coefficient, below-cloud contribution, and wet deposition flux.

11. P9, Table 2: Regarding for model performance evaluation, the definitions of metrics can be found in the reference: Yu, et al., 2006 (New unbiased symmetric metrics for evaluation of air quality models. Atmospheric Science Letter, 7, 26-34).