

This paper evaluates the Surface Tiled Aerosol and Gaseous Exchange (STAGE) dry deposition and bidirectional exchange model against field-scale micrometeorological flux measurements and satellite observations. The work addresses an important gap evaluating regional model parametrization against site measurement data and satellite data. The paper is generally well written and presents interesting inputs as well as practical value and operational contribution to the CMAQ modeling community. It is well in the scope of GMD.

We thank anonymous referee 2 for their thoughtful feedback and constructive comments. We have revised the discussion around the regional scale application of limited field scale observations and the evaluation against satellite observations.

General comments:

- The site scale box model is evaluated against two sites Duke Forest (2012) and Lillington (2007) and one season of measurement each. Ammonia flux measurements are not easily available for model comparison however, stating that these measurements are “representative” of continental forests and grassland is too much of an extrapolation. Perhaps authors can replace this statement and discuss the limitation of such an approach.

Response: This is a good point and we agree, rather than generally representative we have revised section 3.2 to soften this statement. Specifically, the statement “The annual regional scale CMAQ model NH₃ biases evaluated against CrIS observations are consistent with the box model simulations, assuming that the results at Lillington, NC and the results from Duke Forest, NC may be generally representative of an agricultural cropping system and grasslands, respectively.” has been revised as follows “The annual regional scale CMAQ model NH₃ values evaluated against CrIS observations show biases that are directionally consistent with the box model simulations over both grasslands and agricultural areas indicating that the default tabular values are contributing to the observed model biases. ”

- The paper does not compare STAGE against previous CMAQ schemes or other regional models or simpler approaches thus making it difficult to quantify whether STAGE represents an improvement and whether the added complexity is justified.

Response: We believe this is outside the scope of this manuscript. The evaluation of CMAQ with the STAGE and M3Dry deposition options against network observations has been extensively reported in the CMAQ v5.3 evaluation manuscript (Appel et al., 2021). Additional evaluation of the CMAQ deposition options and other regional scale models against observational network and O₃ flux field studies can be found in the AQMEII4 special issue (https://acp.copernicus.org/articles/special_issue1130.html). The motivation of the development of this scheme is that it treats the transport processes of bidirectional and dry deposition schemes consistently and can be used for field scale evaluation of multiple pollutants.

- Parametrization of ammonia emission potential or Gamma is proposed as an explanation for the difference between modeled and observed ammonia fluxes. While it is completely

coherent that parametrization with measured values would give better results than with more generalized values, no mechanistic explanation is given for that, tuning another parameter in the model would probably also have improved the performance. Furthermore, no sensitivity analysis is conducted or referred to, to justify this.

Response: This is a good point and highlights the strengths of the observations used here. Sensitivity simulations were conducted for both the Lillington and Duke Forest sites by perturbing the minimum stomatal resistance, cuticular resistance, and soil resistance by $\pm 50\%$. This really highlights the benefit of having flux observations at sites with different land use and observations of multiple species as well as a model that uses a common representation of dynamics across species.

The following was added to the second paragraph of section 2.3.

To investigate the parameter uncertainty of the STAGE model, a sensitivity simulation was conducted for both field scale sites. These simulations consisted of perturbing the CMAQ v5.3.2 default minimum stomatal resistance, cuticular resistance, and ground resistance by $\pm 50\%$

The following was added to section 3.1

At the Duke Forest site, the sensitivity simulations perturbing the minimum stomatal resistance, cuticular resistance, and ground resistance were unable to capture the direction of the mean observed NH₃ flux and generally increased the biases of the modeled SO₂ flux, Table S1. The modeled HNO₃ flux generally insensitive to the canopy resistance parameters as it is primarily governed by the aerodynamic resistance, Table S1. At the Lillington site, the modeled NH₃ flux was sensitive to both the emission potential and the ground resistance indicating the importance of accurately characterizing soils in fertilized agricultural sites for estimating NH₃ fluxes, Table S1.

The following was added to the SI

| | Lillington, NC NH ₃ | Duke Forest, NC NH ₃ | Duke Forest, NC SO ₂ | Duke Forest, NC HNO ₃ |
|--------------|-----------------------------------|------------------------------------|------------------------------------|-------------------------------------|
| CMAQ v5.3.2 | 40.5% (0.616) | -117.6% (-0.007) | -4.8% (0.411) | 19.3% (0.705) |
| 50% Rst_min | 49.1% (0.625) | -112.5% (0.116) | 7.2% (0.416) | 19.4% (0.705) |
| 150% Rst_min | 37.0% (0.611) | -118.7% (-0.135) | -8.1% (0.406) | 19.3% (0.705) |
| 50% Rcut | 36.1% (0.616) | -119.5% (-0.064) | 19.4% (0.401) | 21.5% (0.705) |
| 150% Rcut | 43.3% (0.615) | -116.1% (-0.072) | -14.7% (0.415) | 17.3% (0.704) |
| 50% Rgnd | 157.0% (0.593) | -127.4% (-0.276) | 23.5% (0.401) | 24.6% (0.704) |
| 150% Rgnd | 0.6% (0.632) | -113.5% (0.040) | -15.0% (0.413) | 17.4% (0.705) |
| LO, DFOS | -12.6% (0.515) | 2.0% (0.437) | -4.8% (0.411) | 19.3% (0.705) |

- One of the results highlights that H₂O fluxes are overestimated for both sites Duke and Lillington which is argued can be explained by errors in stomatal conductance. This error

can propagate to the estimation of NH₃ fluxes. This is not mentioned or discussed. Again a sensitivity analysis could help answer this issue.

Response: This was addressed in the comment above.

- The comparison to CrIS data is not sufficiently discussed. CrIS data specially for areas with low concentrations are accompanied by high uncertainty and should be discussed.

Response: This is a good point and why we primarily focused our discussion around NH₃ in agricultural regions and the Great Plains where CrIS observations where the observations are above the reported instrument detection limit of approximately 0.5 ppb reported in Shephard et al., 2025.

Shephard, M.W., Kharol, S.K., Damers, E., Sioris, C.E., Bell, A., Jansen, R., Caron, J., Snel, R., Palombo, E., Cady-Pereira, K.E., McLinden, C.A., Lutsch, E., Knuteson, R.O.: Infrared Satellite Detection Limits for Monitoring Atmospheric Ammonia. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 18, 10272–10291. <https://doi.org/10.1109/JSTARS.2025.3557240>, 2025

- Table 2 presents median values of measured gammas at different sites. Perhaps adding seasonal values or at least uncertainty values to give an idea of the variability of the measurements.

Response: The standard deviation of the observations was added to Table 2.

Specific comments:

- Axis for figures show grid indices rather than geographic coordinates. Perhaps replacing with lon/lat is more explanatory.

Response: I can provide the projection information, but unfortunately no longer have access to the raw CMAQ output files and cannot perform the coordinate transformation.

- Add an a small paragraph the logic for having a non zero values for Gamma cuticle.

Response: Section 3.1 was revised to further discuss the non-zero cuticular gamma values in context of the NH₃ evasion from the evaporation of dew.

Typos and language:

- "and indicates" → "indicate" (ligne 25) ;

Response: "and indicates" was replaced with indicated

- "evaluate" → "evaluated" (ligne 82) ;

Response: The referee's suggestion was taken

- "Figure 1" → "Figure 2" (ligne 291) ;

Response: This was corrected

- "Sierra Nevada's" → "Sierra Nevadas" (ligne 340) ;

Response: This was corrected

- "ares" → "areas" (ligne 341) ;

Response: This was corrected

- "factor a of 5" → "a factor of 5" (ligne 364) ;

Response: This section was revised

- "sight" → "site" (ligne 364).

Response: This was corrected