Improved CMAQ Wet Deposition Fields Using a Precipitation Based Bias Correction

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ABSTRACT

Spatial interpolation of observed wet deposition values from the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) is used to estimate past and current loads of acidic (S+N) and nutrient (N) deposition on sensitive ecosystems for critical loads studies. Due to siting criteria, such approaches can miss important emission sources and geographic features that impact deposition, e.g. orographic effects on precipitation amounts. The Community Multiscale Air Quality (CMAQ) model provides spatial fields of wet and dry deposition that explicitly account for emission sources across the United States as well as geographic features of the domain. However, errors in modeled precipitation (from MM5 or WRF) and in emission inputs can lead to significant bias and error in the wet deposition predictions compared to observed values. We present an approach to post-process the CMAQ model output to adjust for errors in precipitation using observation-based gridded precipitation data. Accounting for errors in modeled precipitation reveals bias in wet deposition predictions that were previously hidden due to compensating errors. We further correct the model output by applying a bias adjustment based on observed wet deposition levels at the NADP/NTN sites. The final adjusted spatial fields of annual total wet deposition values (specifically SO_4^{2-}, NO_3^-, and NH_4^+) have less bias and are more highly correlated with observed wet deposition values compared to the base model output.

PRECIPITATION ADJUSTED WET DEPOSITION

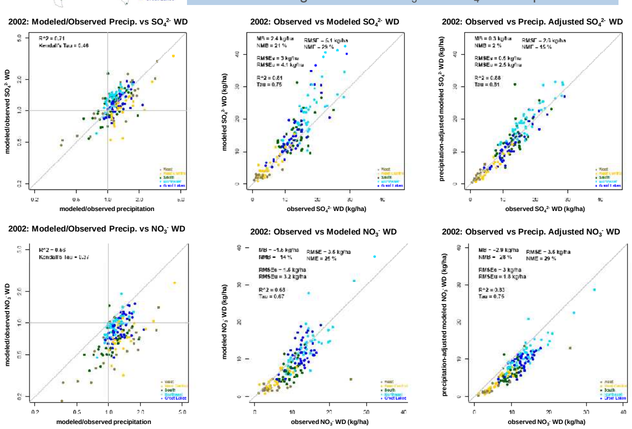
The relationship between precipitation and wet deposition depends on the species, the time scale of accumulation (e.g. hourly vs. annual), the time of year and the region. We found that on seasonal to annual time scales there is often a strong linear relationship between model *errors* in precipitation (defined as model/observed precipitation) and model *errors* in wet deposition (defined as model/observed wet deposition). We capitalize on this relationship by scaling the modeled wet deposition based on the errors in the model precipitation value:

$$\textbf{Precip Adjusted WD} = Precip_{obs}/Precip_{mod} \times WD_{mod}$$

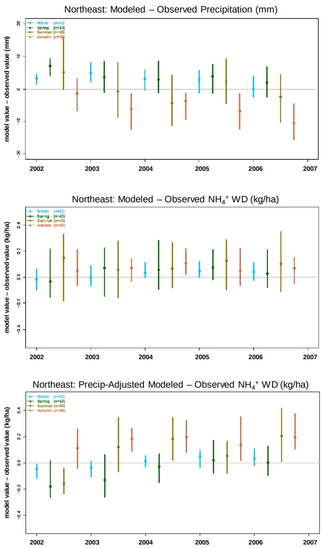
(Note: In the case that model precipitation is zero, the model wet deposition remains zero. This situation did not occur for the seasonal and annual totals considered in this study.)

NADP/NTN sites used in the study are split into 5 sub-regions based on observed biases in the modeled wet deposition and known issues with emissions inputs for these species.

Precipitation adjustment improves the agreement between modeled and observed SO_4^{2-} wet deposition and reveals a consistent negative bias in NO_3^- and NH_4^+ wet deposition.



SEASONAL PATTERNS IN WET DEPOSITION BIAS

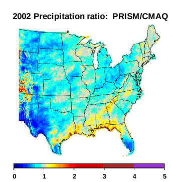


Plots show median bias (dot) and interquartile range of model – observed bias by season.

- Underestimation in modeled precipitation in the NE tends to increase across the five year period and is greatest in Autumn months.
- Modeled – Observed seasonal total NH_4^+ wet deposition in the NE shows mostly overestimation with no strong seasonal trend.
- Precipitation-adjustment of NH_4^+ shows overestimation tends to increase over time, suggesting the emissions inventory is not capturing an observed decrease in NH_3 emissions as dairy and poultry farms close across the NE.
- In a second example (not shown here) precipitation-adjusted NH_4^+ wet deposition in the Great Lakes region reveals a large underestimation in Spring and Summer months. This is likely due to errors in emissions associated with fertilizer applications and the bi-directional exchange of NH_3 flux from soil and vegetation. The bidirectional NH_3 flux model (available in the next CMAQ release) reduces this bias.

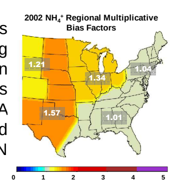
PRISM PRECIPITATION ADJUSTMENT

NADP/NTN observed precipitation does not provide the spatial coverage needed to adjust the entire CMAQ wet deposition field. The PRISM climate group at Oregon State University provides monthly and annual precipitation totals (4km x 4km grid) using point measurements and the Parameter-elevation Regressions on Independent Slopes Model (PRISM). The PRISM model was designed to handle orographic precipitation in complex terrain. In 2002, the MM5 modeled precipitation tends to be too high across most of the domain compared to the PRISM data.



NTN–BASED BIAS ADJUSTMENT

Adjusting the wet deposition values to account for errors in the model precipitation inputs revealed compensating errors for nitrate and ammonium. The negative bias seen in these species after the precipitation adjustment is believed to be due to missing emissions sources. A second bias adjustment was performed for nitrate and ammonium based on observed levels at the NADP/NTN sites.

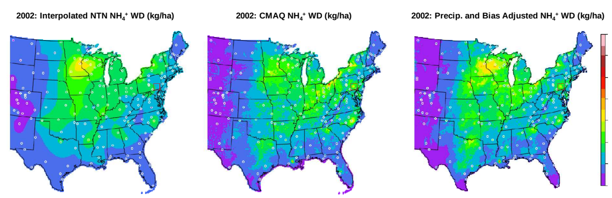


IMPROVED WET DEPOSITION FIELDS

The PRISM precipitation fields and the NTN-based multiplicative bias factors are used to adjust the CMAQ annual total wet deposition fields for 2002-2006. The final fields retain the emission sources and geographic features included in the CMAQ output and are consistent with the precipitation events characterized by the PRISM dataset, including orographic effects across the Appalachian and Rocky Mountains. These features cannot be captured by simple spatial interpolation of the observed wet deposition data due to the sparseness of the National Trends Network. The post-processing of the modeled wet deposition fields reduces the model error and increases the correlation between model predicted values and observed wet deposition for all three species.

The panel plots below show interpolated observed NTN NH_4^+ wet deposition observations (left) CMAQ NH_4^+ wet deposition values (center) and precipitation and bias adjusted CMAQ values (right). All plots are annual totals for 2002. The precipitation adjustment tends to decrease the modeled wet deposition across the Eastern half of the US except for along the Gulf Coast and some regions in GA, NC, CO and NM. The NTN-based bias factors increase the deposition levels in the Great Lakes and western regions. Future model improvements in the CMAQ model may eliminate the need for this second bias adjustment.

Spatial interpolation smooths the gradients in the wet deposition field and misses emissions sources due to the siting of the network monitors. For example in Lancaster County, PA the model shows elevated levels of NH_4^+ due to high levels of NH_3 emissions from poultry and chicken farms (red box). Since there was no monitor near these sites in 2002, this hot spot is missing in the interpolated field. A monitor was added in this region in 2003, confirming the model predictions for this county.



Average model performance results across 2002-2006 for CMAQ modeled wet deposition and the precipitation and bias adjusted values. Model performance is consistently improved for all three species by the post-processing procedure.

	SO_4^{2-}		NO_3^-		NH_4^+	
	CMAQ	Precip. Adjusted	CMAQ	Precip. and Bias Adjusted	CMAQ	Precip. and Bias Adjusted
R^2	.80	.84	.72	.74	.59	.71
RMSE (kg/ha)	4.5	3.5	2.6	2.2	.84	.70
NME (%)	25	21	21	17	24	19

IMPLICATIONS AND FUTURE WORK

In the past, the ecological community has been reluctant to use CMAQ wet deposition predictions to assess critical loads because of large model biases. The post-processing approach described here has been well received as a method to address model performance concerns and to take advantage of the PRISM precipitation data, which are already widely used for critical loads analyses. On-going model development should address the existing model biases and errors in precipitation and wet deposition.

Future work includes using a seasonal precipitation adjustment, evaluating error in dry deposition predictions and reevaluating the NO_3^- and NH_4^+ bias adjustments using new model simulations that include emissions of nitrogen oxide produced by lighting and bi-directional flux of ammonia.

REFERENCES

Appel *et al.* (2010) A multi-resolution assessment of the Community Multiscale Air Quality (CMAQ) model v4.7 wet deposition estimates for 2002 – 2006, *submitted to Geoscientific Model Development*.

PRISM Climate Group, Oregon State University, http://www.prismclimate.org