Dynamic evaluation of CMAQ wet deposition estimates: Observed vs modeled trends from 2002-2012

Kristen M. Foley, Jesse O. Bash, Donna Schwede, Joseph Pinto
U.S. Environmental Protection Agency

www.epa.gov

Kristen Foley | foley.kristen@epa.gov | 919.541.5367

Abstract

❖ CMAQ is used to estimate past and current loads of acidic (S+N) and nutrient (N) deposition on sensitive ecosystems for critical loads studies.

❖ Dynamic evaluation of model predicted trends is an important step in establishing credibility in the model's ability to predict changes in deposition due to changes in emissions, land use and/or meteorology over time.

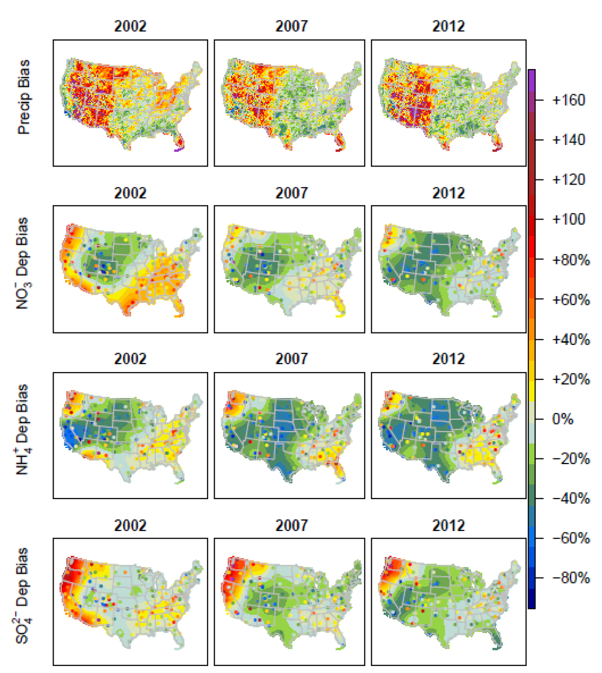
❖ Recent updates in the CMAQ system have led to improved seasonal and annual total wet deposition compared to previous model versions (Table 1).

❖ Errors in modeled precipitation and in emissions inputs continue to lead to errors in the simulation of wet deposition (Fig. 1).

❖ A bias correction method is applied to adjust modeled wet deposition of NO_3^-, NH_4^+ and SO_4^{2-}. Adjusted model values are shown to have lower bias and higher correlation with observations from the NADP network (Table 2) and provide better estimates of changes in wet deposition over time (Fig. 4).

Evaluation of CMAQv5.0.2 wet deposition

Figure 1: Model / observed bias fields for 2002, 2007 and 2012. WRF annual total precipitation is compared to PRISM data (http://www.prism.oregonstate.edu/). CMAQ wet deposition is compared to NADP observations (colored points). The interpolated bias field is provided to better distinguish the spatial patterns at clusters of NADP sites.



❖ Errors in precipitation explain much of the NO_3^- and SO_4^{2-} wet deposition bias in the eastern US (Fig. 2).

❖ Over prediction of SO_4^{2-} wet deposition along the west coast may be due to bias in boundary conditions.

❖ Under prediction of NH_4^+ in the central US may due to missing emissions from large CAFOs.

❖ Missing SO_4^{2-} and NO_3^- deposition in the West could be linked to errors in both biogenic (lightning, vegetation cover in BEIS) and anthropogenic sources (oil and gas production in US or Canada, errors in population growth driven factors).

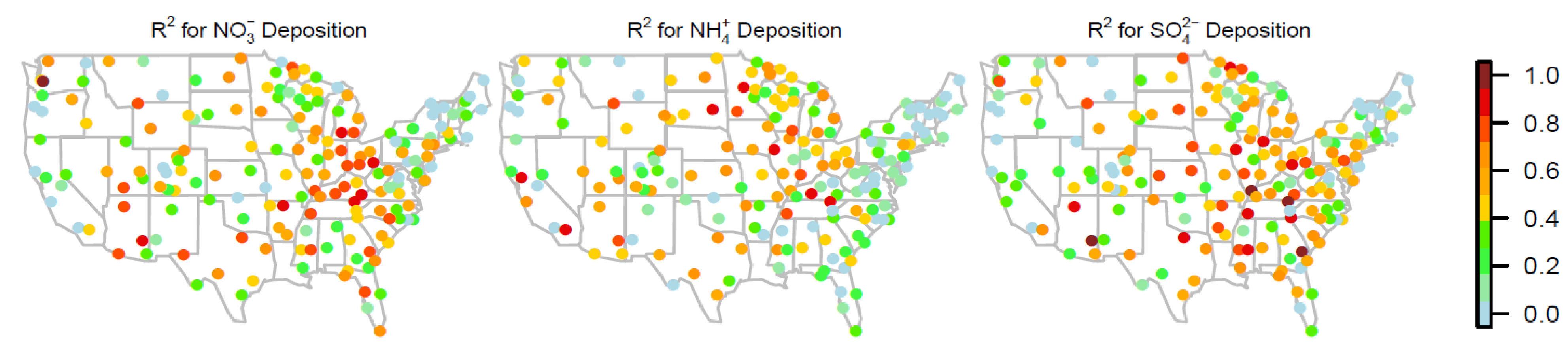
Table 1: Change in Normalized Mean Bias (%) from v4.7 (as reported by Appel et al. 2011) to v5.0.2 based on seasonal and annual total wet deposition at NADP sites.

NMB(%)	NO_3^-		NH_4^+		SO_4^{2-}	
2002-2006	CMAQv4.7	CMAQv5.0.2	CMAQv4.7	CMAQv5.0.2	CMAQv4.7	CMAQv5.0.2
Annual	**-15**	**2.9**	**-12.8**	**-6.9**	**7.9**	**-1.3**
Winter	13.7	15.3	-13.6	-20.8	17.2	-18.1
Spring	-14.5	-6.2	-19.9	-21.5	5.2	-1.1
Summer	-40.3	-3.9	-7.4	16.1	6.1	8.0
Fall	1.5	17.7	-9.5	-10.8	8.5	-3.4

Combining model and observed data

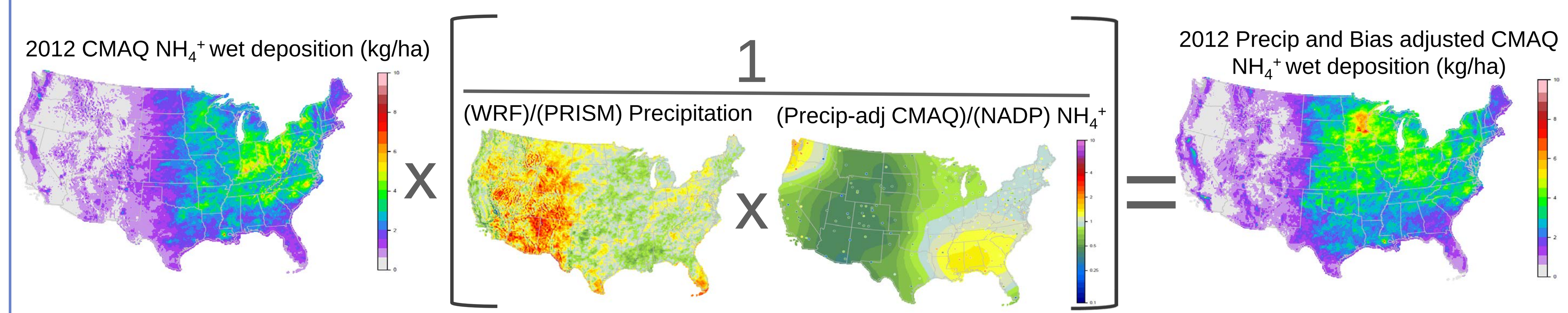
❖ **Precipitation adjustment:** On an annual time scale, there is a strong log-linear relationship between Mod/Obs precipitation and Mod/Obs wet deposition, particularly in the eastern half of the US (Fig. 2). Leveraging this high correlation, the modeled wet deposition for each year is scaled based on the ratio of PRISM to modeled precipitation (Fig. 3).

Figure 2: Coefficient of determination (R^2) between the log(Model/Observed) annual total precipitation and log(Model/Observed) annual total wet deposition for 2002-2012.



❖ **Bias adjustment:** While the precipitation adjustment increases the correlation between observed and modeled wet deposition, model bias remains due to: (1) cases where the wet deposition does not scale with changes in precipitation in a linear fashion and (2) bias in emission inputs (including missing emissions sources) and/or errors in other model processes effecting deposition. A second bias-adjustment is applied based on wet deposition observations from the National Atmospheric Deposition Program (NADP) (Fig. 3).

Figure 3: CMAQ NH_4^+ output for 2012 x (Precip Bias x Wet Dep Bias)$^{-1}$ = **Adjusted wet deposition**



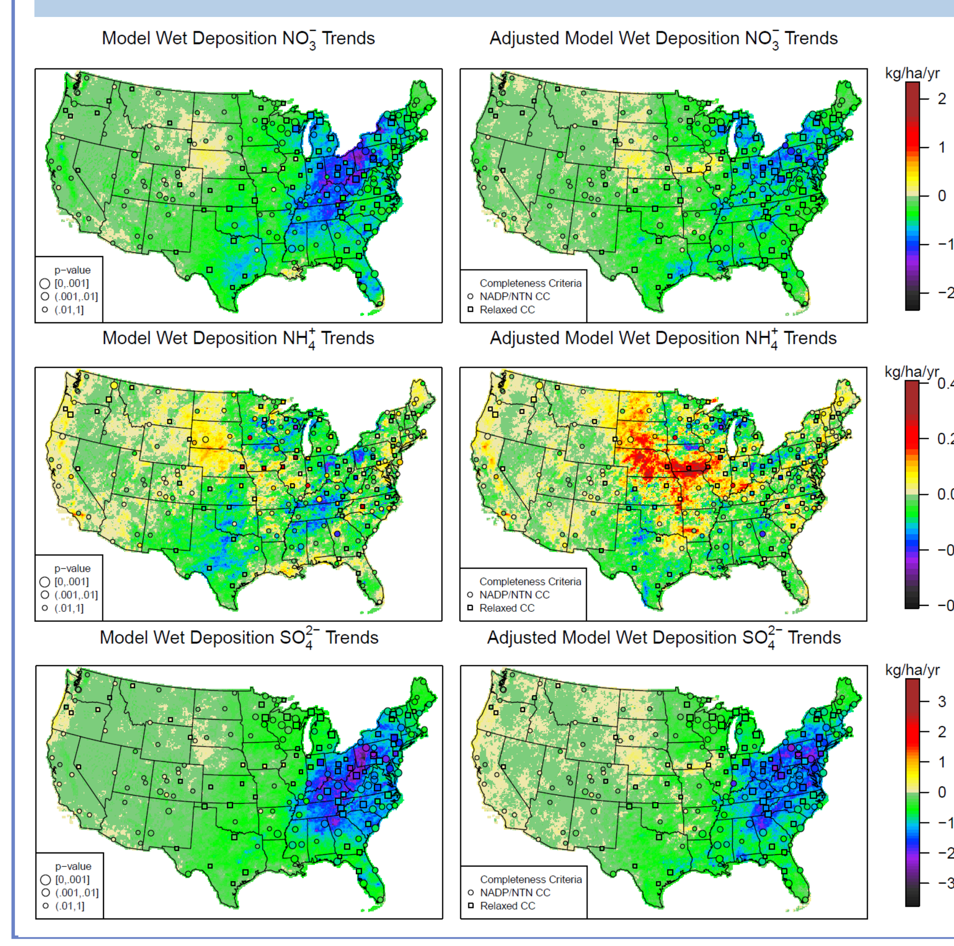
❖ Leave-one-out cross validation analysis of the adjusted model wet deposition outputs shows the adjusted wet deposition predictions evaluate well against observations (Table 2). In addition, using the adjusted wet deposition fields provides a robust method for estimating temporal trends across the US (Fig. 4).

2002-2012	NO_3^- CMAQv5.0.2	NO_3^- Precip. and Bias Adjusted	NH_4^+ CMAQv5.0.2	NH_4^+ Precip. and Bias Adjusted	SO_4^{2-} CMAQv5.0.2	SO_4^{2-} Precip. and Bias Adjusted
NMB (%)	-1.2	0.8	-11.0	-2.5	-4.5	0.4
NME (%)	21.2	14.6	27.7	19.9	21.7	15.5
RMSE (kg/ha)	2.2	1.5	0.9	0.7	2.7	2.0
R^2	0.76	0.86	0.60	0.77	0.81	0.90

Table 2: Leave-one-out cross validation statistics for predicted annual total wet deposition based on N=1,964 NADP obs. from 2002-2012.

Trends in Wet Deposition

Figure 4: Theil-Sen trends (i.e. slopes) for 2002-2012 time series of annual total deposition at each NADP location and each grid cell based on raw CMAQ output (left column) and adjusted CMAQ output (right column) for wet deposition of NO_3^- (top row), NH_4^+ (middle row) and SO_4^{2-} (bottom row). A larger symbol indicates a statistically significant linear trend in the observed time series (based on a Kendall rank test).



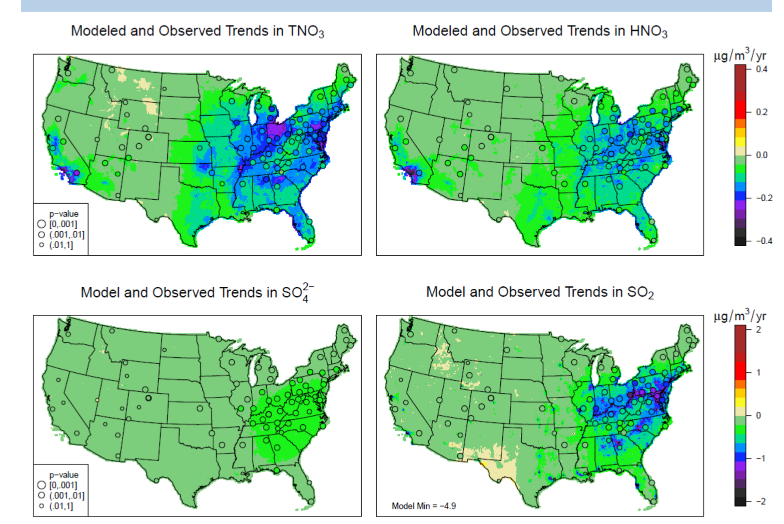
❖ Trends based on adjusted model output show better agreement with observed trends for all three species.

❖ Adjusted model predicted trends show a steady decrease in NO_3^- and SO_4^{2-} in the eastern US.

❖ Trends in NH_4^+ are more spatially heterogeneous with some increasing trends in the Great Plains and flat or slightly decreasing trends in the South.

Trends in Annual Total Deposition

Figure 5: Modeled and observed trends in annual average concentration.



❖ Quantifying trends in total N and S deposition requires credible estimates of dry deposition which makes up 40-50% of the total deposition budget (Fig. 6).

❖ Due to the limited availability of dry deposition observations in both time and space, ambient concentrations from the CASTNet network are used to establish the model's ability to predict trends in dry deposition (Fig. 5).

Figure 6: Time series of modeled total N (right) and S (left) deposition over the CONUS.