Appendix E-4

Deposition Model Performance Evaluation
Southeastern VISTAS II Regional Haze Analysis Project

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Deposition Model Performance Evaluation

Southeastern VISTAS II Regional Haze Analysis Project

(Task 8.1)

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Abbreviations/Acronym List

AIRMon	Atmospheric Integrated Research Monitoring Network
Alpine	Alpine Geophysics, LLC
AMNet	Atmospheric Mercury Network
AMoN	Ammonia Monitoring Network
Ca^{2+}	Calcium
CAMx	Comprehensive Air Quality Model with Extensions
CASTNET	Clean Air Status and Trends Network
CIRA	Cooperative Institute for Research in the Atmosphere
Cl^{-}	Chloride
CMAQ	Community Multiscale Air Quality Modeling
DJF	December, January, and February (i.e., Winter)
EGU	Electricity Generating Unit
EPA	United States Environmental Protection Agency
EPIC	Environmental Policy Integrated Climate
ERG	Eastern Research Group, Inc.
g	Gram
ha	hectare
Hg	Mercury
HNO_3	Nitric acid
IMPROVE	Interagency Monitoring of Protected Visual Environments
JJA	June, July, and August (i.e., Summer)
K^{2+}	Potassium
kg	Kilogram
km	Kilometer
L	liter
m^2	Square meters
m^3	Cubic meters
MAM	March, April, and May (i.e., Spring)
MB	Mean Bias
MDN	Mercury Deposition Network
ME	Mean Error
MFB	Mean Fractional Bias
MFE	Mean Fractional Error
mg	Milligram
Mg^{2+}	Magnesium
MLM	Multi-Layer Model
MOVES	Motor Vehicle Emissions Simulator
MPE	Model Performance Evaluation
n	Number of samples
Na^{2+}	Sodium
NADP	National Atmospheric Deposition Program
NH_3	Ammonia
NH_4^+	Ammonium
NME	Normalized Mean Error

NMB	Normalized Mean Bias
NO_3^-	Nitrate
NTN	National Trends Network
O	Observed
P	Predicted
PM	Particulate matter
$PM_{2.5}$	Fine particle; primary particulate matter less than or equal to 2.5 microns in aerodynamic diameter
r	Pearson correlation coefficient
R	Programming software language called *R*
RHR	Regional Haze Rule
RMSE	Root Mean Squared Error
SESARM	Southeastern States Air Resource Managers, Inc.
SIP	State Implementation Plan
SO_2	Sulfur dioxide
SO_4^{2-}	Sulfate
SON	September, October, and November (i.e., Fall)
V_d	Deposition velocity
VISTAS	Visibility Improvement - State and Tribal Association of the Southeast

State Abbreviations (used in Appendices A and B)

AL	Alabama
AR	Arkansas
CO	Colorado
FL	Florida
GA	Georgia
IL	Illinois
IN	Indiana
KS	Kansas
KY	Kentucky
LA	Louisiana
MA	Massachusetts
MD	Maryland
ME	Maine
MI	Michigan
MN	Minnesota
MO	Missouri
MS	Mississippi
NC	North Carolina
ND	North Dakota
NE	Nebraska
NH	New Hampshire
NJ	New Jersey
NM	New Mexico
NY	New York
OH	Ohio

OK	Oklahoma
PA	Pennsylvania
SD	South Dakota
TN	Tennessee
TX	Texas
VA	Virginia
VT	Vermont
WI	Wisconsin
WV	West Virginia
WY	Wyoming

1. INTRODUCTION

Southeastern States Air Resource Managers, Inc. (SESARM) has been designated by the United States Environmental Protection Agency (EPA) as the entity responsible for coordinating regional haze evaluations for the ten Southeastern states of Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia. The Eastern Band of Cherokee Indians and the Knox County, Tennessee local air pollution control agency are also participating agencies. These parties are collaborating through the Regional Planning Organization known as Visibility Improvement - State and Tribal Association of the Southeast (VISTAS) in the technical analyses and planning activities associated with visibility and related regional air quality issues. VISTAS analyses will support the VISTAS states in their responsibility to develop, adopt, and implement their State Implementation Plans (SIPs) for regional haze.

The state and local air pollution control agencies in the Southeast are mandated to protect human health and the environment from the impacts of air pollutants. They are responsible for air quality planning and management efforts including the evaluation, development, adoption, and implementation of strategies controlling and managing all criteria air pollutants including fine particles and ozone as well as regional haze. This project will focus on regional haze and regional haze precursor emissions. Control of regional haze precursor emissions will have the additional benefit of reducing criteria pollutants as well.

The 1999 Regional Haze Rule (RHR) identified 18 Class I Federal areas (national parks greater than 6,000 acres and wilderness areas greater than 5,000 acres) in the VISTAS region. The 1999 RHR required states to define long-term strategies to improve visibility in Federal Class I national parks and wilderness areas. States were required to establish baseline visibility conditions for the period 2000-2004, natural visibility conditions in the absence of anthropogenic influences, and an expected rate of progress to reduce emissions and incrementally improve visibility to natural conditions by 2064. The original RHR required states to improve visibility on the 20% most impaired days and protect visibility on the 20% least impaired days.[1] The RHR

[1] RHR summary data is available at: http://vista.cira.colostate.edu/Improve/rhr-summary-data/

requires states to evaluate progress toward visibility improvement goals every five years and submit revised SIPs every ten years.

To demonstrate progress toward the improvement goals, the SESARM partners modeled visibility and air quality conditions for a base year of 2011 and future year of 2028. The SESARM VISTAS II Regional Haze modeling analysis was performed by the contractor team Eastern Research Group, Inc. (ERG) and Alpine Geophysics, LLC (Alpine). The preparation and modeling were conducted over several contract tasks, including emission inventory development, ambient data collection, Comprehensive Air quality Model with extensions (CAMx) modeling, and model performance evaluation of the base year. The VISTAS II modeling included particulate matter simulations and source apportionment studies using the 12-kilometer (km) grid based on EPA's 2011/2028el modeling platform and preliminary source contribution assessment,[2] updated to include a 12 km subdomain over the VISTAS region and augmented with revisions to electric generating unit (EGU) and non-EGU point source projections. The air quality modeling was conducted using CAMx. A detailed description of the modeling platform can be found in the Task 6 modeling report.

Under Task 8 of the Regional Haze Modeling for Southeastern VISTAS II Regional Haze Analysis Project, a thorough model performance evaluation (MPE) was conducted for particulate matter less than or equal to 2.5 microns in aerodynamic diameter ($PM_{2.5}$) species components, coarse particulate matter (PM) and light extinction to examine the ability of the CAMx v6.40 modeling system to simulate 2011 measured concentrations. As part of the study, the modeling team also performed a MPE for weekly wet deposition and weekly dry deposition species collected in under Subtask 4.1. This report documents the MPE for the wet and dry deposition values produced from the base year CAMx modeling of the VISTAS 12 km modeling domain.

2. APPROACH

This task uses the data collected under Subtask 4.1, *Collecting Additional Data (weekly wet deposition and weekly dry deposition)*, to conduct a MPE of the deposition rates modeled

[2] EPA. 2017. Documentation for the EPA's Preliminary 2028 Regional Haze Modeling. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. October. Available at: https://www3.epa.gov/ttn/scram/reports/2028_Regional_Haze_Modeling-TSD.pdf.

under Subtask 6.2, *2011 Base Year Air Quality Modeling*. The following sections provide an overview of the observed and modeled data used in the analysis. These sections detail the sources of the data and how the data were prepared for the analysis. This includes conversions and aggregation.

2.1 Observed Data

Under Subtask 4.1 weekly wet deposition and weekly dry deposition data were organized into a database for potential use by SESARM states or other parties (e.g., Federal Land Managers) to support other projects such as evaluation of acid deposition in watersheds. These data were used in the deposition MPE.

The primary source for deposition data is the National Atmospheric Deposition Program (NADP).[3] The NADP consists of the following monitoring networks:

- National Trends Network (NTN)
- Atmospheric Integrated Research Monitoring Network (AIRMon)
- Mercury Deposition Network (MDN)
- Atmospheric Mercury Network (AMNet)
- Ammonia Monitoring Network (AMoN)

MDN and AMNet collect mercury data only. As the CAMx run did not utilize chemistry mechanisms for mercury, these sites were not used in the analysis. Dry deposition information is also available from the Clean Air Status and Trends Network (CASTNET). These data were also collected and is available in the Subtask 4.1 deposition database and was utilized for the MPE.

The data from NTN and AIRMon were used in the wet deposition MPE and CASTNET and AMoN were used for dry deposition MPE. The MPE focused on the monitors from these networks within the VISTAS 12 km modeling domain, as it is of the most value to the VISTAS partners for using this modeling for any other activities in their jurisdiction. Figure 2-1 presents the spatial distribution of these deposition networks across the United States.

[3] National Atmospheric Deposition Program (NRSP-3). 2018. NADP Program Office, Wisconsin State Laboratory of Hygiene, 465 Henry Mall, Madison, WI 53706. http://nadp.slh.wisc.edu/

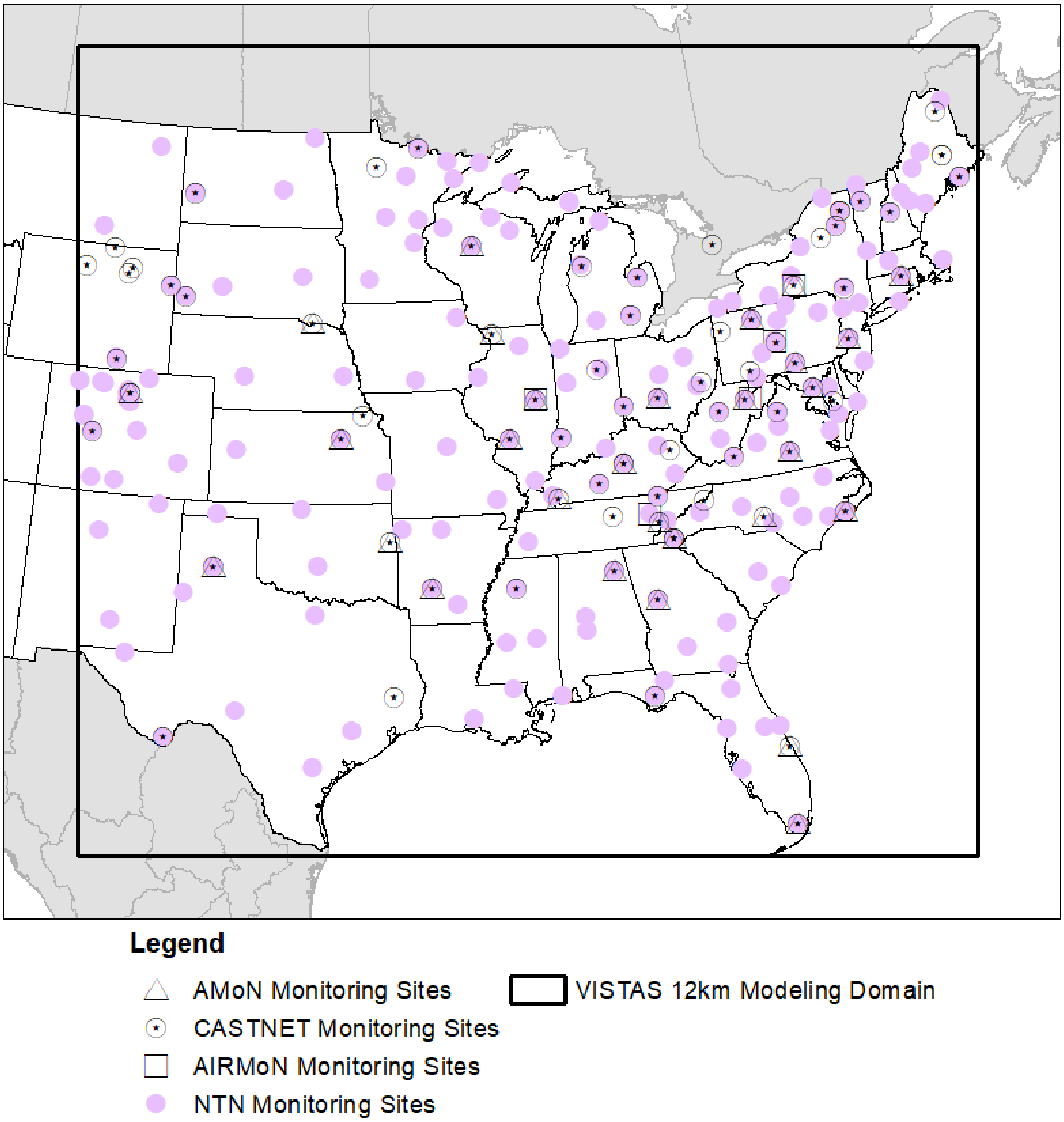

Figure 2-1. Deposition Monitors Included in the VISTAS II Database

Table 2-1 summarizes the measurements available from each deposition monitoring network. Each network is discussed separately in the following sections.

Table 2-1. Wet and Dry Deposition Monitoring Network Measurements

Measurement	Wet Deposition			Dry Deposition		
	NTN	MDN	AIRMon	AMNet	AMoN	CASTNET
Free acidity (H^+ as pH)	✓		✓			
Conductance	✓		✓			
Calcium (Ca^{2+})	✓		✓			✓
Magnesium (Mg^{2+})	✓		✓			✓
Sodium (Na^+)	✓		✓			✓
Potassium (K^+)	✓		✓			✓
Sulfate (SO_4^{2-})	✓		✓			✓
Nitrate (NO_3^-)	✓		✓			✓
Chloride (Cl^-)	✓		✓			✓
Ammonium (NH_4^+)	✓		✓			
Total mercury (Hg) total concentration		✓				✓
Total mercury (Hg) total deposition		✓				
Ammonia (NH_3)					✓	
Particulate Bound Mercury concentration				✓		
Average Gaseous Oxidized Mercury				✓		

Only observations that were flagged as valid in the NTN data file were used in the performance analysis. For the weekly measurements, NADP networks typically present measurements as concentration in milligram per liter (mg/L), which is equivalent to g/m^3. These concentrations are then multiplied by the precipitation in meters to yield wet deposition rates in units of g/m^2. These were further converted to kilograms per hectare (kg/ha), using the conversion of 1 ha = 10,000 m^2. The data were then filtered to remove any invalid measurements, per the data quality flags included in the database. The observations for the annual and seasonal analysis were based on the aggregate deposition data generated by NADP.

Dry deposition values from CASTNET were developed from the observed concentration multiplied by a deposition velocity (V_d) generated by the Multi-Layer Model (MLM)[4] for each site. The MLM generated deposition velocities are available for download with the CASTNET

[4] Meyers, T. P., Finkelstein, P., Clarke, J., Ellestad, T.G., and Sims, P.F. 1998. A Multilayer Model for Inferring Dry Deposition Using Standard Meteorological Measurements. J. Geophys. Res., 103(D17): 22,645-22,661, DOI: 10.1029/98jd01564.

observations. The observations for the annual and seasonal analysis were based on the aggregate deposition data generated and published by the EPA on the CASTNET website.[5]

Dry deposition data from the AMoN are measured as a concentration. Similar to CASTNET, the concentrations have to be multiplied by a deposition velocity to calculate the deposition per surface area. Deposition velocities for AMoN sites are not routinely calculated. However, the deposition velocities are calculated for CASTNET sites. These deposition velocities are calculated as an area-weighted V_d over vegetation types within 1.0 km.[6] Within the AMoN network, there are 29 sites within 1.0 km of a CASTNET site. Given the CASTNET deposition velocities are based on vegetation within 1km radius of the site, the CASTNET deposition velocities were applied to the AMoN sites within a 1 km radius to estimate the deposition at the AMoN sites. To calculate the deposition flux for the AMON sites, the hourly deposition velocities were averaged to match the collection periods for the AMoN sites. These average deposition velocities were then multiplied by the concentration to yield the deposition flux in Appendix B includes the list of AMoN sites and their paired CASTNET sites.

2.2 Modeled Data

Alpine extracted the daily wet and dry deposition values for the monitoring locations in the VISTAS 12 km domain. The available wet and dry deposition values were extracted for Cl^-, HNO_3, NH_3, NH_4^+, NO_3^-, SO_2 and SO_4^{2-} species. The CAMx deposition outputs are generated in grams per hectare (g/ha), which were converted to kg/ha, to have consistent units with the NADP monitoring networks and other studies. The data was then aggregated using the *R* software to match the monitoring network's concentration collection times.

Based on Appel et al. 2011, the CAMx wet deposition results were adjusted to account for chemical reactions that occur in the collected sample. For example, the SO_2 in rainwater is

5 U.S. Environmental Protection Agency Clean Air Markets Division Clean Air Status and Trends Network (CASTNET) Dry – Deposition Weekly, Dry deposition- Annual, Dry Deposition – Seasonal, and Dry Deposition Velocity - Hourly. Available at www.epa.gov/castnet Date accessed: July 2018. https://java.epa.gov/castnet/clearsession.do

6 U.S. Environmental Protection Agency. 2018. Clean Air Status and Trends Network (CASTNET) Quality Assurance Project Plan (QAPP) Revision 9.2, October 2018. Available at https://www3.epa.gov/castnet/docs/QAPP_v9-2_Main_body.pdf

oxidized to SO_4^{2-} by the time the samples are analyzed. To account for this, the CAMx estimates of SO_4^{2-} wet deposition include 150% (based on the ratio of the molecular weights of SO_2 and SO_4^{2-}) of the model estimated SO_2 wet deposition to account for the SO_2 captured in the observations. Similarly, for NH_4^+, the CAMx estimates of NH_4^+ wet deposition include 106% of the model estimated NH_3 wet deposition to account for reduced nitrogen (both NH_4^+ and NH_3) captured in the NTN observations. This is due to NH_4^+ being the favored phase at the pH of rainwater. Additionally, HNO_3 reacts with water and dissociates to NO_3^+. The CAMx estimates of NO_3^+ wet deposition were adjusted to include 98.4% of the model estimated nitric acid wet deposition to account for NO_3^+ captured as nitric acid, and thus converted to NO_3^+ in the measurements.

CAMx estimates of wet deposition were further adjusted to account for the error present in the model estimated precipitation using a ratio of the observed to estimated precipitation.[7] This is a linear adjustment using a ratio of the observed precipitation to the modeled precipitation. In instances where the observed precipitation is greater than the model estimated precipitation, the ratio is greater than one, and the model estimated wet deposition is increased. Similarly, if there is no measured precipitation at the site the modeled values are corrected to zero. In instances where the observed precipitation was indicated to be trace amounts (i.e., less than 0.01 mm), a value of 0.00001 was used for the adjustment.[8]

2.3 Metrics

Annual mean MPE statistics, like the statistics for the base year MPE, were developed for the wet deposition and dry deposition species available. Analysis included scatter plots of observations versus CAMx predictions, and their correlation (r), both annually and by season. Statistics and scatter plots can also be examined by VISTAS states to provide more refined MPE information to facilitate further use by the states.

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[7] Appel, K. W., et al. 2011. "A multi-resolution assessment of the Community Multiscale Air Quality (CMAQ) model v4. 7 wet deposition estimates for 2002–2006." Geoscientific Model Development 4.2 (2011): 357-371.

[8] Akyüz, A., et al. 2013. "Procedure for Assigning A Value for Trace Precipitation Data Without Changing the Climatic History". Journal of Service Climatology. (https://www.stateclimate.org/sites/default/files/upload/pdf/journal-articles/2013_Adnan_et_al_2013.pdf)

For this MPE, mean bias (MB) and normalized mean bias (NMB), mean error (ME) and normalized mean error (NME), and Pearson's correlation coefficient (r), mean fractional bias (MFB), mean fractional error (MFE), and root mean squared error (RMSE) are defined and calculated, per the equations below.

Mean bias (MB) is the average difference between modeled, or predicted (P), and observed (O) concentrations for a given number of samples (n):

$$MB(kg/ha) = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)$$

Normalized mean bias (NMB) is the sum of the difference between predicted and observed values divided by the sum of the observed values:

$$NMB(\%) = \frac{\sum_1^n(P - O)}{\sum_1^n(O)} * 100$$

Mean error (ME) is the average absolute value of the difference between predicted and observed concentrations for a given number of samples:

$$ME(kg/ha) = \frac{1}{n}\sum_{i=1}^{n}|P_i - O_i|$$

Normalized mean error (NME) is the sum of the absolute value of the difference between predicted and observed values divided by the sum of the observed values:

$$NME(\%) = \frac{\sum_1^n|P - O|}{\sum_1^n(O)} * 100$$

Pearson's correlation coefficient (r) is defined as:

$$r = \frac{\sum_{i=1}^{n}(P_i - \overline{P})(O_i - \overline{O})}{\sqrt{\sum_{i=1}^{n}(P_i - \overline{P})^2}\sqrt{\sum_{i=1}^{n}(O_i - \overline{O})^2}}$$

Mean Fractional Bias (MFB) is defined as:

$$MFB(\%) = \frac{2}{N}\sum_{1}^{N}\left(\frac{P - O}{P + O}\right) \times 100$$

Mean Fractional Error (MFE) is defined as:

$$MFE(\%) = \frac{2}{N}\sum_{1}^{N}\left(\frac{|P-O|}{P+O}\right) \times 100$$

Root Mean Squared Error (RMSE) is defined as:

$$RSME = \sqrt{\frac{\sum_{1}^{N}(P-O)^2}{N}}$$

Model predictions of deposition species are paired in space and time with observational data from the deposition monitoring networks. These results are presented based on the monitoring network's collection frequency and for annual and season (winter (DJF), spring (MAM), summer (JJA), and fall (SON)) accumulation. To prevent confounding the MPE results, the different deposition networks were examined separately. The MPE metrics were calculated based on the weekly collection periods, as well as the accumulated deposition for each season and year.

3. 2011 Model Performance Evaluation Results

Visualization of observations and model estimates, and computation of model performance statistics were calculated using the *R* software, which utilized the *openair* package.

3.1 Wet Deposition

Wet deposition model performance was evaluated at the site's weekly collection frequency as well as for seasonal and annual accumulation. Overall, the MPE metrics show weak performance for replicating deposition at the monitoring site collection frequency. However, modeling performance improved for the accumulated seasonal and annual wet deposition. This suggests that season and total annual wet deposition are adequately captured while weekly trends are not captured well by the model. Metrics and plots by state are available in Appendix A.

3.1.1 Weekly Wet Deposition

Table 3-1 summarizes the aggregated weekly MPE metrics for wet deposition in the VISTAS 12-km domain. The model demonstrates a negative mean bias for NH_4^+ and SO_4^{2-} and a positive mean bias for NO_3^+ compared to the weekly NTN observations. The AIRMon sites have a larger positive mean bias for all pollutants.

Table 3-1. Weekly Wet Deposition MPE Metrics for NADP Sites in the VISTAS 12 km Domain

Network	Pollutant	n	MB (kg/ha)	ME (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFB (%)	MFE (%)	RMSE (unitless)
NTN	NH_4^+	3,404	-0.025	0.045	-32%	58%	0.629	-19%	34%	0.092
	NO_3^+	3,404	0.024	0.123	12%	62%	0.642	6%	29%	0.242
	SO_4^{2-}	3,404	-0.001	0.118	0%	57%	0.681	0%	29%	0.245
AIRMon	NH_4^+	158	-0.003	0.020	-13%	76%	0.534	-7%	41%	0.041
	NO_3^+	158	0.051	0.097	67%	127%	0.398	25%	47%	0.192
	SO_4^{2-}	158	0.018	0.091	20%	100%	0.352	9%	46%	0.197

The normalized and mean fraction bias suggest there is larger over/under prediction issue with the data, which is better visualized in the scatter plots in Figure 3-1 and Figure 3-2.

The Figure 3-1 and Figure 3-2 scatter plots present observed versus modeled deposition fluxes for the NTN and AIRMon sites respectively. The scatter plots include the 1:1 line (solid line), the line all the points would fall on for a perfect replication of observed conditions. The plot also includes the “2-to-1” (2:1) and “1-to-2” (1:2) lines as the two dashed lines on the plot. These lines help show how close the points are to a “1-to-1” (1:1) relationship. Points that fall within these two lines are within a “factor of 2” of the observed value. The plots show substantial spread differences in the observed and predicted, especially for lower flux values.

The number of points outside the dashed lines show many predictions are more than a “factor of 2” off from the observations. These plots suggest there is a mix of instances where the wet deposition in both over and under prediction, which have moderated the ME and MB metrics. The NMB and MFB metrics do hint at this larger spread in the data.

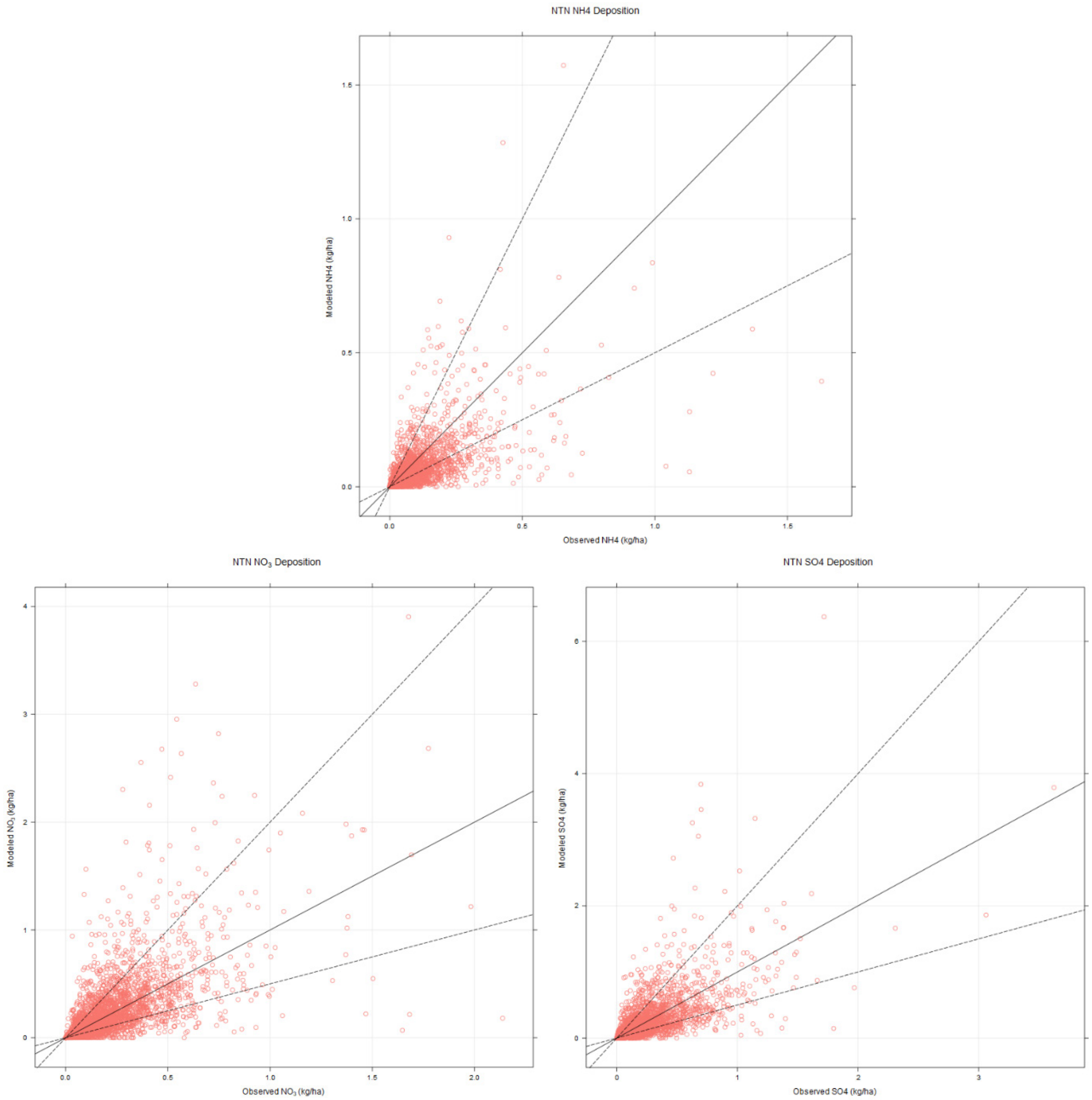

Figure 3-1. Scatter Plots of Weekly Wet Deposition for NTN Sites in the VISTAS 12 km Domain for NH_4^+ (top), NO_3^+ (bottom left), and SO_4^{2-} (bottom right)

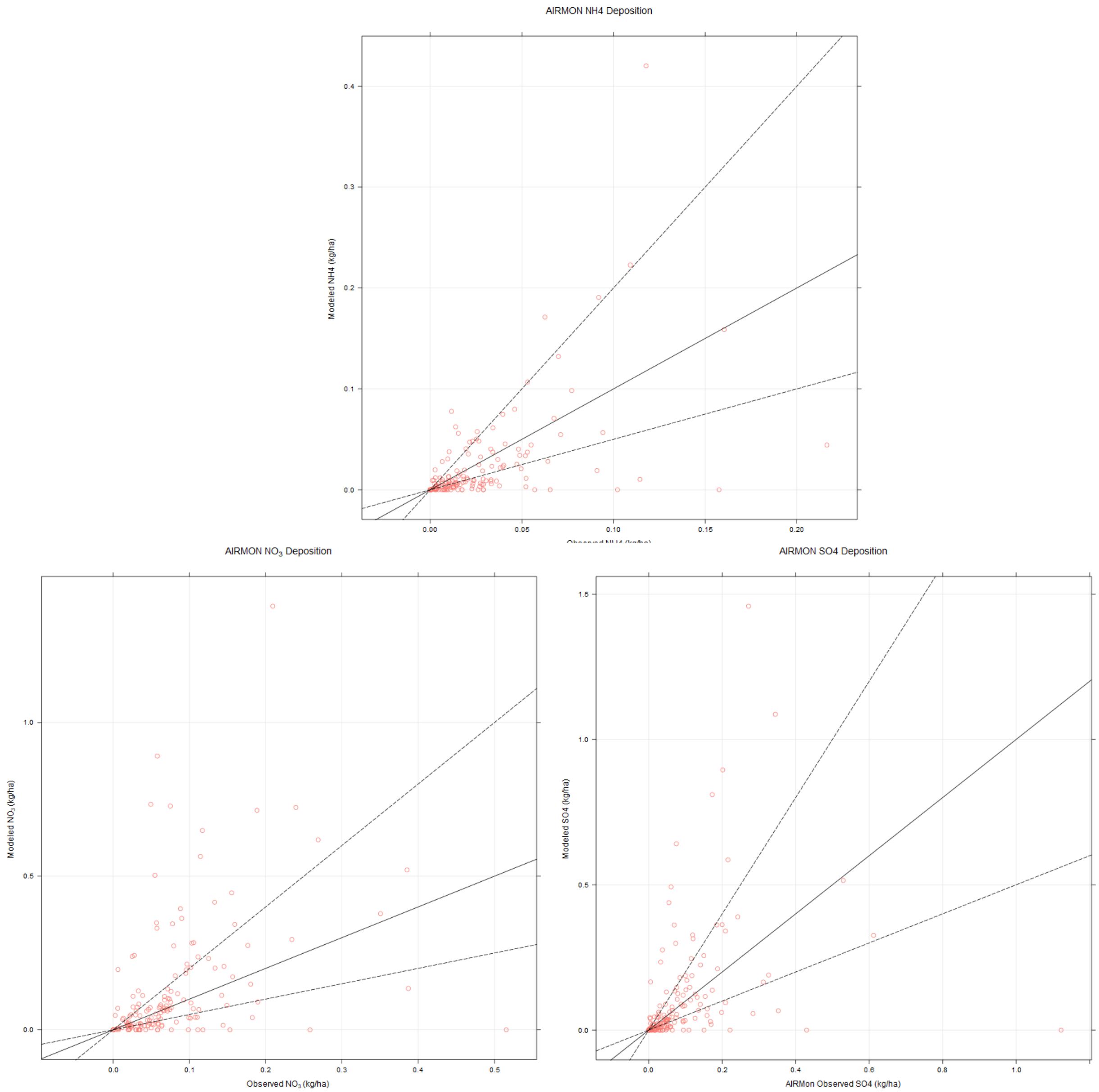

Figure 3-2. Scatter Plots of Weekly Wet Deposition for AIRMon Sites in the VISTAS 12 km Domain for NH_4^+ (top), NO_3^+ (bottom left), and SO_4^{2-} (bottom right)

3.1.2 Accumulated Seasonal Wet Deposition

When deposition values are aggregated to total accumulated wet deposition for a season there is still a negative bias for most pollutants as presented in Table 3-2. The exceptions are NO_3^+ for the summer and fall and SO_4^{2-} for the summer months. There is improvement from the weekly performance, as the NMEs are all below 50% and there is a substantial increase in the correlation coefficients. There is also more precision and accuracy seen in the scatter plots for each pollutant, as presented in Figure 3-3, as more of the sites fall within a factor of 2 of the 1:1 line than the weekly performance.

Table 3-2. Accumulated Seasonal Wet Deposition MPE Metrics for NADP Sites in the VISTAS 12 km Domain

Season	Pollutant	n	MB (kg/ha)	ME (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFB (%)	MFE (%)	RMSE (unitless)
Winter	NH_4^+	98	-0.150	0.163	-43%	47%	0.718	-28%	30%	0.215
Spring	NH_4^+	96	-0.542	0.545	-43%	44%	0.830	-28%	28%	0.717
Summer	NH_4^+	99	-0.363	0.407	-32%	36%	0.769	-19%	22%	0.571
Fall	NH_4^+	98	-0.193	0.232	-33%	40%	0.740	-20%	24%	0.302
Winter	NO_3^+	98	-0.176	0.501	-12%	34%	0.656	-6%	18%	0.823
Spring	NO_3^+	96	-0.237	0.569	-9%	21%	0.850	-5%	11%	0.810
Summer	NO_3^+	99	0.207	0.746	7%	27%	0.838	4%	13%	0.972
Fall	NO_3^+	98	0.325	0.543	21%	34%	0.838	9%	16%	0.785
Winter	SO_4^{2-}	98	-0.313	0.494	-25%	39%	0.720	-14%	22%	0.725
Spring	SO_4^{2-}	96	-0.441	0.690	-15%	23%	0.878	-8%	13%	0.961
Summer	SO_4^{2-}	99	0.235	0.726	8%	26%	0.887	4%	12%	1.066
Fall	SO_4^{2-}	98	-0.127	0.529	-7%	30%	0.781	-4%	15%	0.811

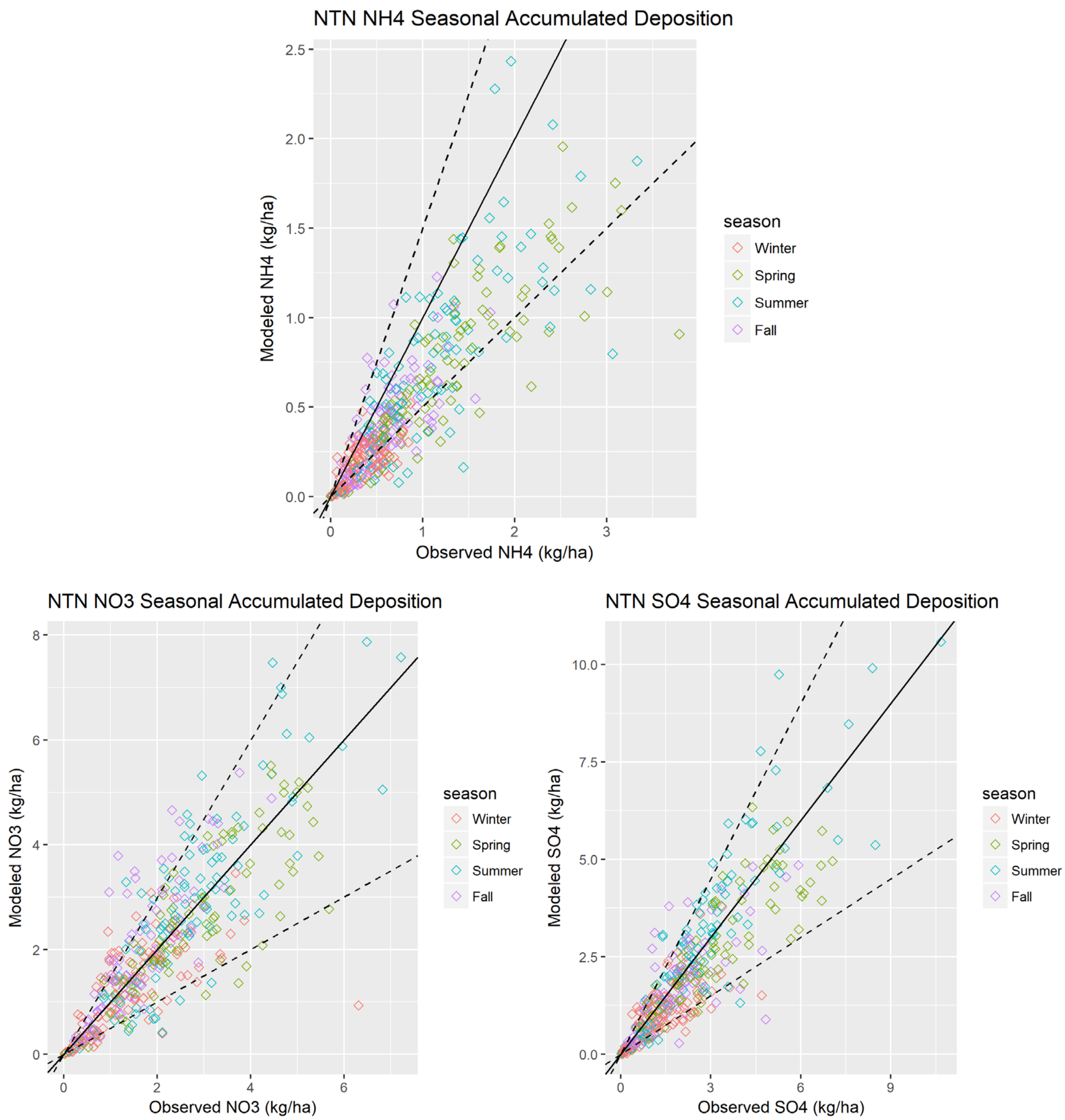

Figure 3-3. Scatter Plots of Seasonal Accumulated Wet Deposition for NADP Sites in the VISTAS 12 km Domain for NH_4^+ (top), NO_3^+ (bottom left), and SO_4^{2-} (bottom right)

3.1.3 Accumulated Annual Wet Deposition

When considering the total accumulated wet deposition for the calendar year, there is still under prediction of NH_4^+ and SO_4^{2-}, and a slight over prediction of NO_3^+. However, we see continued improvement from the seasonal accumulated performance with respect to the NME and r values, as presented in Table 3-3. More of the data fall within a factor of 2 of the 1:1 line, as presented in Figure 3-4, which suggests an overall decent prediction of the total annual wet deposition at the NADP sites.

Table 3-3. Accumulated Annual Wet Deposition MPE Metrics for NADP Sites in the VISTAS 12 km Domain

Pollutant	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFB (%)	MFE (%)	RMSE (unitless)
NH_4^+	99	-1.245	1.246	-38%	38%	0.861	-23%	23%	1.536
NO_3^+	99	0.134	1.453	2%	17%	0.901	1%	8%	1.933
SO_4^{2-}	99	-0.585	1.604	-7%	18%	0.916	-3%	9%	2.142

3.2 Dry Deposition

Similar to the wet deposition performance, comparing weekly modeled deposition to the weekly observations does not show good agreement. The comparisons of the accumulated seasonal dry deposition improve, but most species have at least one season with poor model performance. The seasons with poor performance usually affect the model performance with respect to the annual accumulated deposition rates. Metrics and plots by state are available in Appendix B.

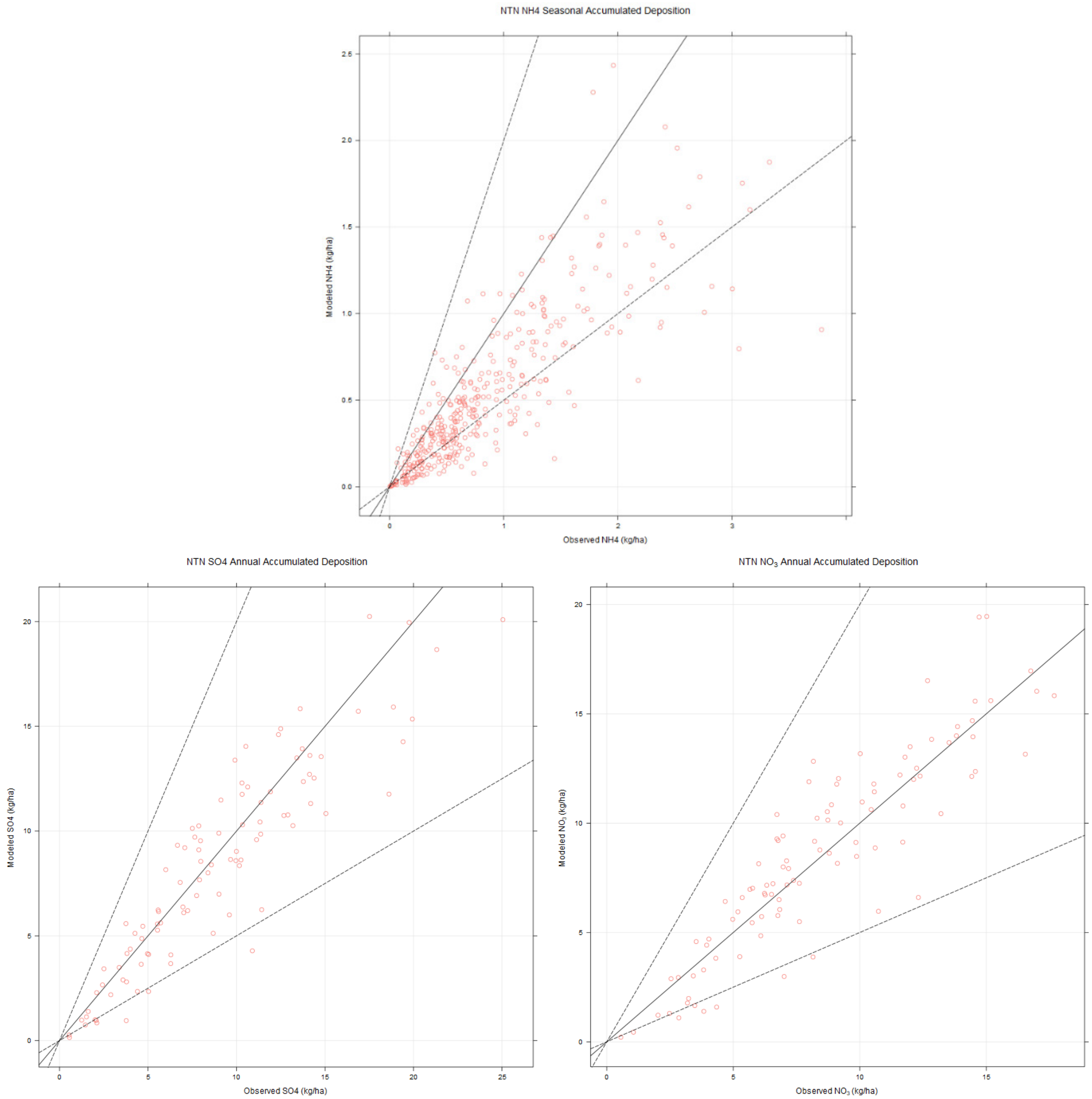

Figure 3-4. Scatter Plots of Annual Accumulated Wet Deposition for NTN Sites in the VISTAS 12 km Domain for NH_4^+ (top), NO_3^+ (bottom left), and SO_4^{2-} (bottom right)

3.2.1 Weekly Dry Deposition

The weekly dry deposition MB and ME presented in Table 3-4 would seem to suggest relatively good model performance for the CASTNET sites. However, these metric results are not consistent with other calculated metrics. The normalized mean and mean fraction bias and error values show that the weekly model performance is not particularly good, especially for Cl^-, SO_2, and HNO_3. The weekly dry deposition observations are quite small, so the small values presented in Table 3-4 are deceptive. In actuality, Cl^-, SO_2, and HNO_3 are grossly under predicted, which is presented clearly in Figure 3-5. The other pollutants fair better, but the performance is not optimal. Similar for NH_4^+ at AMoN sites, there is a large under prediction as shown in Figure 3-6.

Table 3-4. Weekly Deposition MPE Metrics for CASTNET Sites in the VISTAS 12 km Domain

Network	Pollutant	n	MB (kg/ha)	ME (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFB (%)	MFE (%)	RMSE (unitless)
CASTNET	Cl^-	965	-0.001	0.001	-87%	89%	0.796	-77%	79%	0.004
	NH_4^+	965	0.001	0.003	13%	51%	0.603	6%	24%	0.004
	SO_4^{2-}	965	0.0004	0.007	3%	43%	0.650	1%	21%	0.009
	SO_2	965	-0.031	0.031	-96%	96%	0.656	-93%	93%	0.052
	NO_3^+	965	0.001	0.004	12%	80%	0.601	6%	37%	0.006
	HNO_3	965	-0.062	0.062	-95%	95%	0.612	-90%	90%	0.077
AMoN	NH_3	355	-0.007	0.007	-95%	95%	0.463	-90%	91%	0.013

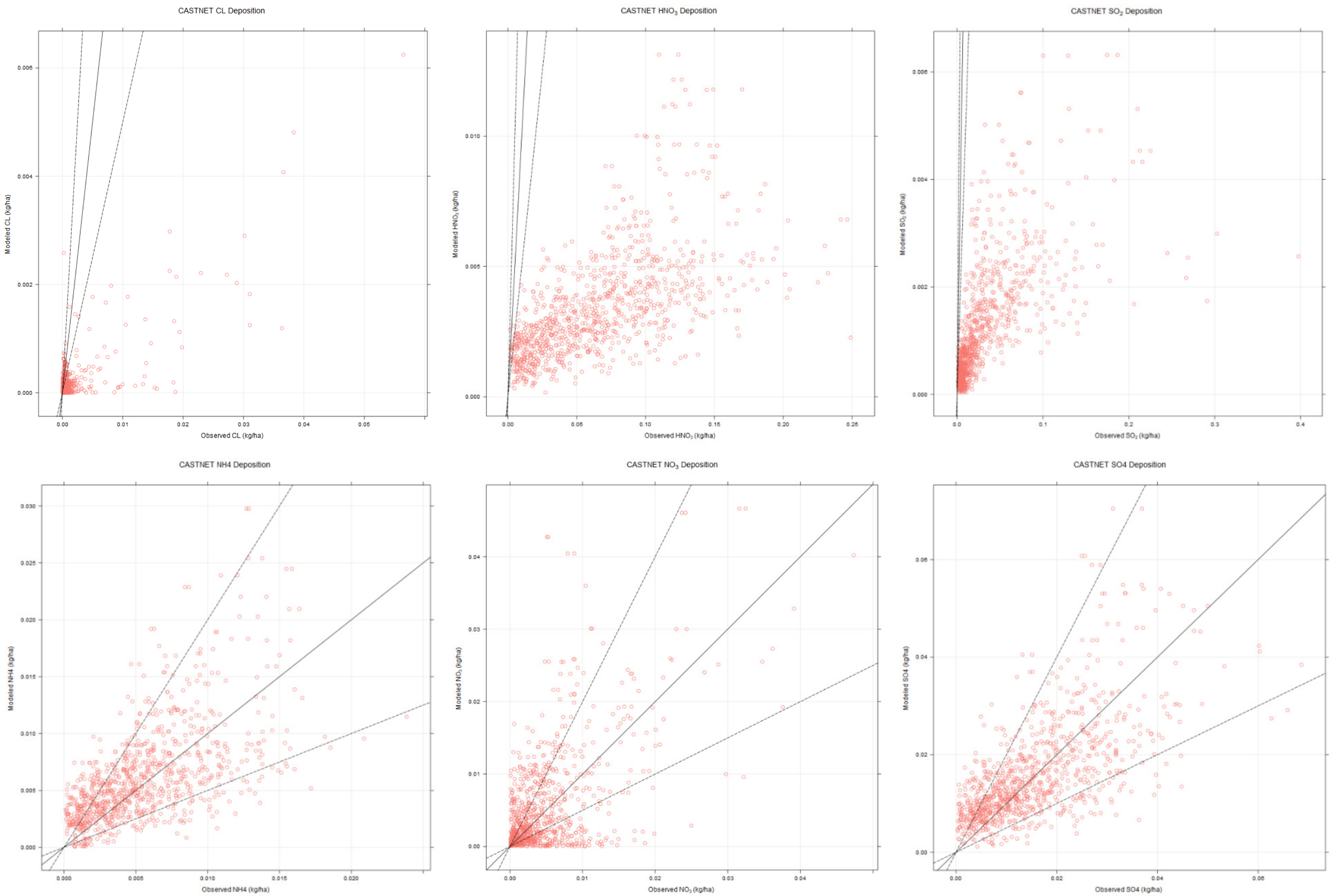

Figure 3-5. Scatter Plots of Weekly Dry Deposition for CASTNET Sites in the VISTAS 12 km Domain for Cl^- (top, left), HNO_3 (top middle), SO_2 (top right), NH_4^+ (bottom, left), NO_3^+ (bottom, middle), SO_4^{2-} (bottom right)

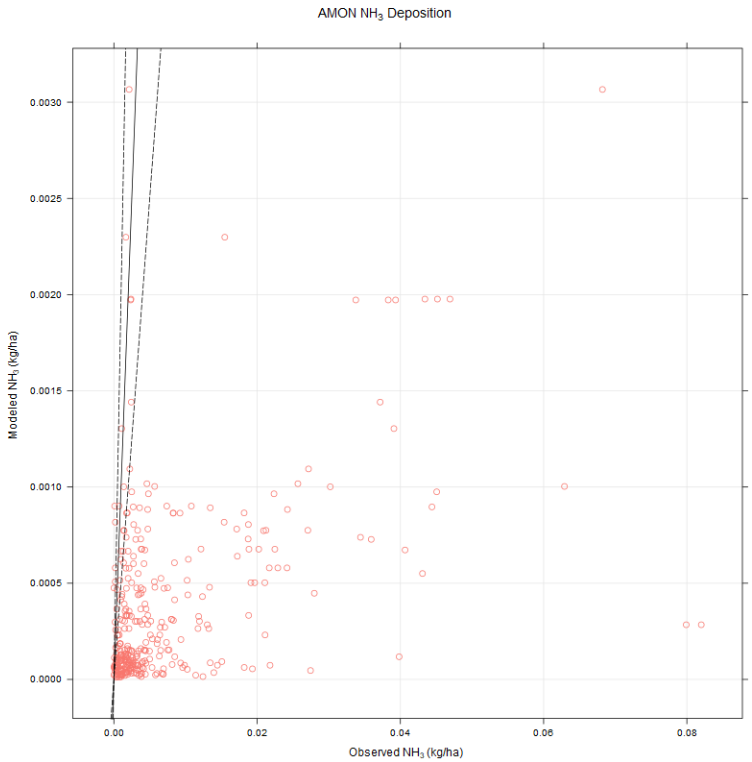

Figure 3-6. Scatter Plots of Weekly Dry Deposition for AMoN Sites in the VISTAS 12 km Domain for NH_3

3.2.2 Accumulated Seasonal Dry Deposition

As presented in Table 3-5, continued poor model performance is observed when comparing accumulated modeling results by season to accumulated seasonal observations, especially for Cl^-, SO_2, and HNO_3. The SO_4^{2-} and NO_3^+ pollutants exhibit seasonality in their predictions: that is, three of the four seasons are under predicted, with one season over predicted. Conversely, NH_4^+ is opposite in that three seasons are over predicted, and one is not (summer). The correlation for the accumulated seasonal predictions is mixed, with varying degrees of correlation across the seasons.

Figure 3-7 presents the various metrics, including color coding to help distinguish how each pollutant has at least one season that under performs.

Table 3-5. Accumulated Seasonal Dry Deposition MPE Metrics for CASTNET Sites in the VISTAS 12 km Domain

Season	Pollutant	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFB (%)	MFE (%)	RMSE (unitless)
Winter	Cl^-	18	-0.010	0.010	-80%	80%	0.981	-66%	66%	0.029
Spring	Cl^-	18	-0.017	0.017	-86%	87%	0.900	-76%	77%	0.048
Summer	Cl^-	19	-0.009	0.009	-92%	92%	0.960	-86%	86%	0.026
Fall	Cl^-	18	-0.016	0.016	-89%	90%	0.994	-81%	81%	0.045
Winter	NH_4^+	18	0.008	0.022	14%	35%	0.680	6%	17%	0.025
Spring	NH_4^+	18	0.005	0.023	6%	29%	0.599	3%	14%	0.030
Summer	NH_4^+	19	-0.027	0.034	-27%	35%	0.783	-16%	20%	0.042
Fall	NH_4^+	18	0.007	0.016	14%	34%	0.552	7%	16%	0.020
Winter	SO_4^{2-}	18	-0.008	0.036	-6%	27%	0.709	-3%	14%	0.043
Spring	SO_4^{2-}	18	-0.021	0.077	-9%	33%	0.261	-5%	17%	0.096
Summer	SO_4^{2-}	19	-0.063	0.096	-21%	32%	0.770	-12%	18%	0.110
Fall	SO_4^{2-}	18	0.016	0.050	12%	36%	0.258	5%	17%	0.057
Winter	SO_2	18	-0.825	0.825	-98%	98%	0.803	-96%	96%	1.201
Spring	SO_2	18	-0.318	0.318	-96%	96%	0.839	-93%	93%	0.431
Summer	SO_2	19	-0.336	0.336	-96%	96%	0.907	-93%	93%	0.465
Fall	SO_2	18	-0.295	0.295	-96%	96%	0.785	-92%	92%	0.405
Winter	NO_3^+	18	0.021	0.051	22%	54%	0.682	10%	24%	0.059
Spring	NO_3^+	18	-0.002	0.042	-2%	54%	0.539	-1%	27%	0.058
Summer	NO_3^+	19	-0.023	0.024	-68%	71%	0.223	-52%	54%	0.040
Fall	NO_3^+	18	-0.001	0.019	-1%	44%	0.543	-1%	22%	0.025
Winter	HNO_3	18	-0.647	0.647	-95%	95%	0.509	-91%	91%	0.751
Spring	HNO_3	18	-0.916	0.916	-96%	96%	0.507	-92%	92%	1.039
Summer	HNO_3	19	-1.068	1.068	-96%	96%	0.732	-92%	92%	1.212
Fall	HNO_3	18	-0.619	0.619	-94%	94%	0.631	-89%	89%	0.716

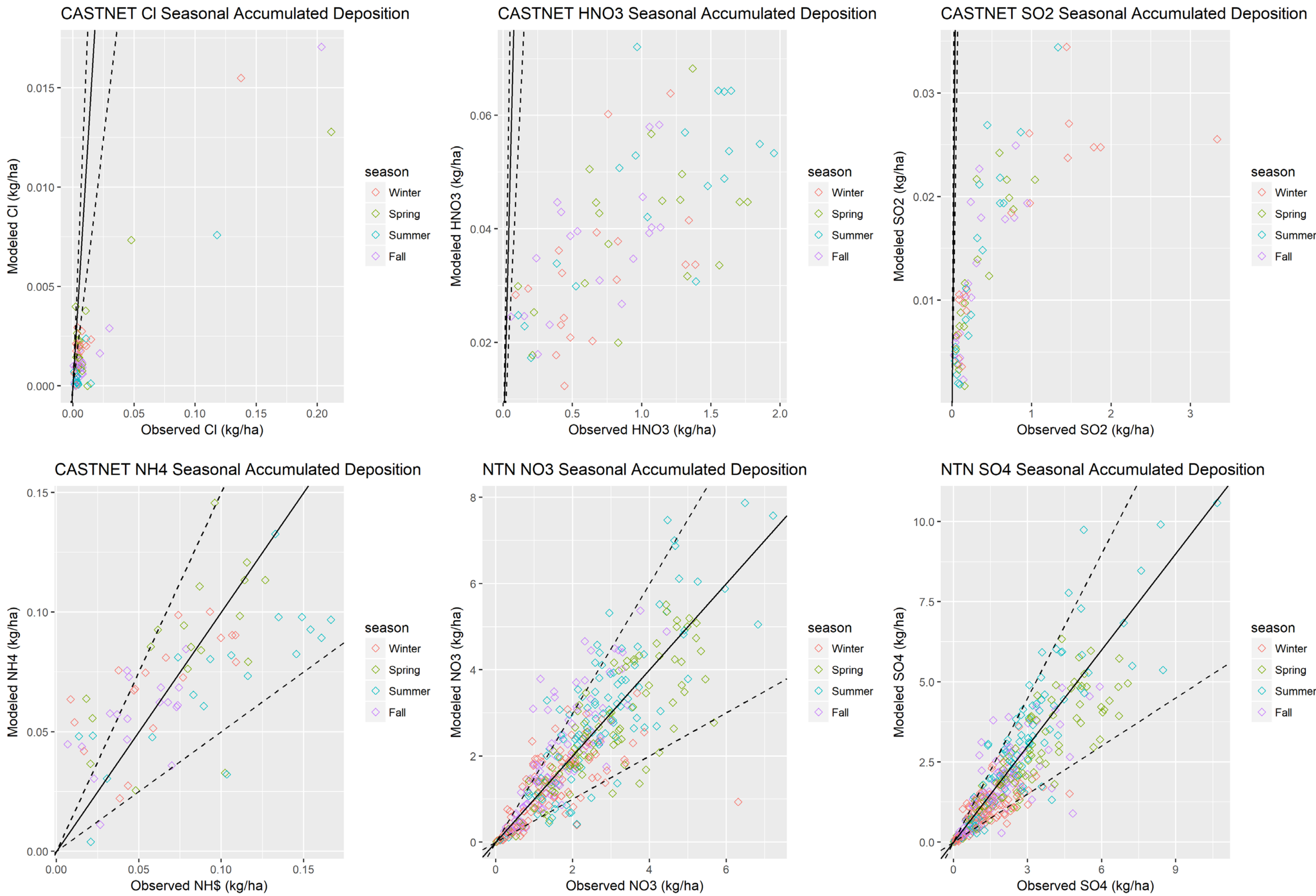

Figure 3-7. Scatter Plots of Seasonal Dry Deposition for CASTNET Sites in the VISTAS 12 km Domain for Cl (top, left), HNO_3 (top middle), SO_2 (top right), NH_4^+ (bottom, left), NO_3^+ (bottom, middle), SO_4^{2-} (bottom right)

3.2.3 Accumulated Annual Dry Deposition

As presented in Table 3-6, most pollutants, except for NO_3, are under predicted, based on the total accumulated dry deposition. SO_2 and HNO_3 have the worst under prediction of all the pollutants, followed by Cl^-.

Table 3-6. Accumulated Annual Dry Deposition MPE Metrics for CASTNET Sites in the VISTAS 12 km Domain

Pollutant	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFB (%)	MFE (%)	RMSE (unitless)
Cl^-	19	-0.054	0.054	-88%	88%	0.981	-78%	78%	0.156
NH_4^+	19	-0.002	0.077	-1%	27%	0.688	0%	14%	0.090
SO_4^{2-}	19	-0.067	0.219	-8%	27%	0.537	-4%	14%	0.268
SO_2	19	-1.616	1.616	-97%	97%	0.869	-94%	94%	2.221
NO_3^+	19	0.001	0.113	1%	46%	0.572	0%	23%	0.154
HNO_3	19	-3.272	3.272	-95%	95%	0.607	-91%	91%	3.688

Of particular note for Cl^- is that one site (EVE419, Everglades National Park) appears to be an outlier, thereby skewing model performance, which can easily be seen in Figure 3-8. This point seems to be a large driver for the error and bias performance metrics, as the correlation value suggests the annual accumulated dry deposition is captured fairly well by the model.

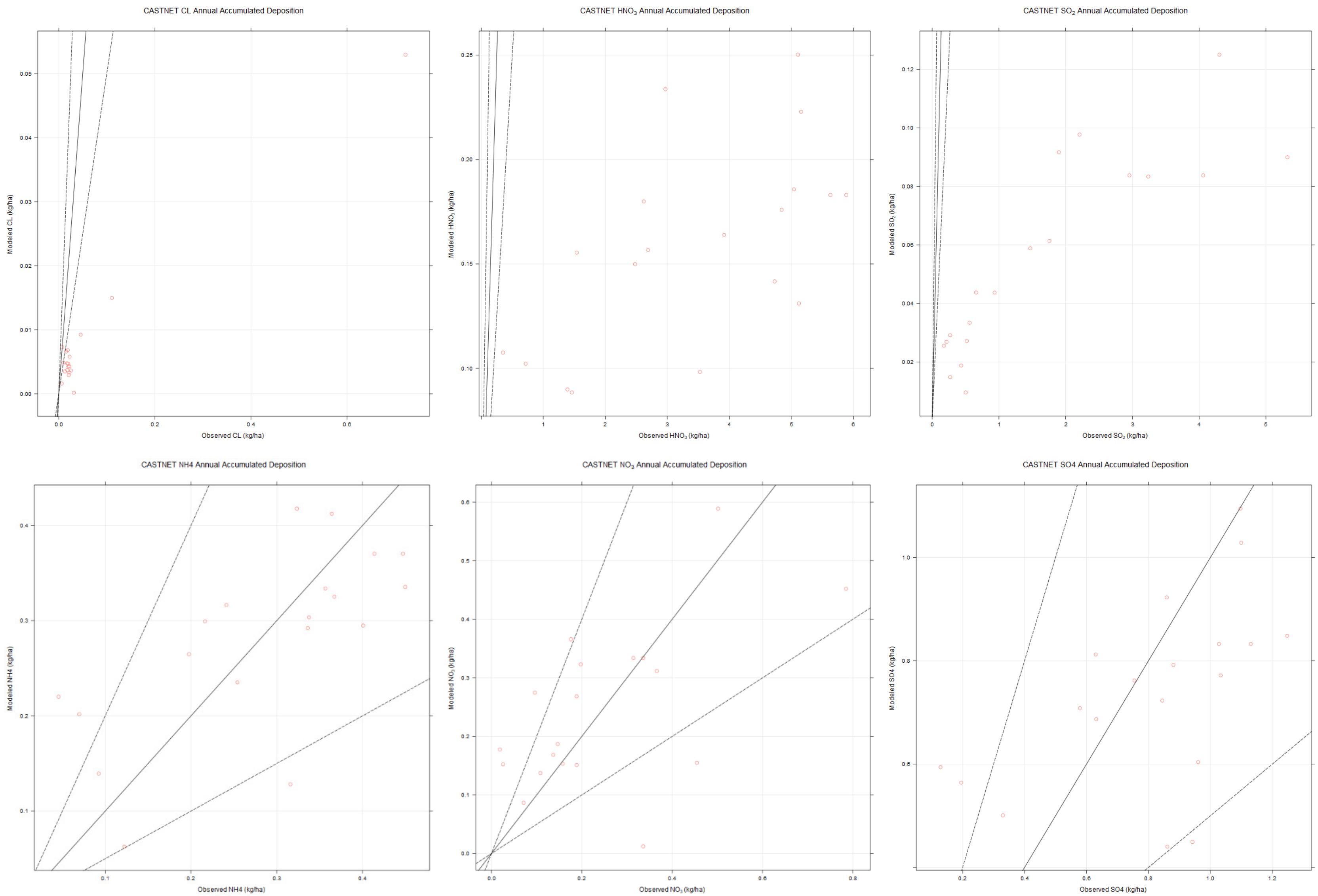

Figure 3-8. Scatter Plots of Annual Accumulated Dry Deposition for CASTNET Sites in the VISTAS 12 km Domain for Cl^- (top, left), HNO_3 (top middle), SO_2 (top right), NH_4^+ (bottom, left), NO_3^+ (bottom, middle), SO_4^{2-} (bottom right)

4. Comparison to NADP Annual Maps

A final MPE step was to compare the annual deposition totals from the VISTAS II base year modeling to the annual Total Deposition Maps[9] developed by the NADP and EPA. These total deposition maps are produced via a hybrid approach that combines the monitored data with modeled data to produce a gridded map of total sulfate and nitrate depositions[10]. While not entirely observed truth, these hybrid estimates provide the ability to evaluate the model performance for the entire domain in areas where data availability is limited due to incomplete records from the monitoring sites.

The latest version (2018.02) of the NADP deposition modeling uses CMAQ version 5.0.2 at a 12 km resolution. Emission data is based on the 2011 Nation Emissions Inventory (NEI) version 1, with mobile sources information derived from Motor Vehicle Emissions Simulator (MOVES) 2010b (2011 emission factor and 2012 activity data) modeling runs, and Satellite Mapping Automated Reanalysis Tool for Fire v2 for fire data. The runs also utilized the bidirectional NH_3 module, fertilizer emissions from the Environmental Policy Integrated Climate (EPIC) model (http://epicapex.tamu.edu/), and inline biogenic emissions. Results are available as ESRI ArcGRID exported gridded deposition fields (.e00 format) and static maps via the EPA ftp site[11].

The SESARM modeling was completed with CAMx based on EPA's "el" platform, which is based on 2011 NEI version 2. This inventory includes several updates from the NADP modeling platform, including updates the underlying NEI (including updates to point sources, nonpoint sources, and fires), the switch to MOVES2014a and updates to international emissions[12]. Given these differences in modeling platforms, it is not surprising that there are differences in between the two models. However, there are some similarities.

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9 http://nadp.slh.wisc.edu/committees/tdep/tdepmaps/

10 Schwede, Donna B. and Lear, Gary G., "A novel hybrid approach for estimating total deposition in the United States" (2014). U.S. Environmental Protection Agency Papers. 219. Available at: http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1219&context=usepapapers

11 ftp://ftp.epa.gov/castnet/tdep/grids/; ftp://ftp.epa.gov/castnet/tdep/images/

12 Eyth, Alison. And Vukovich, Jeff, "Technical Support Document (TSD) Updates to Emissions Inventories for the Version 6.3, 2011 Emissions Modeling Platform for the Year 2028". Available at: https://www.epa.gov/sites/production/files/2017-11/documents/2011v6.3_2028_update_emismod_tsd_oct2017.pdf

Wet deposition of particulate NH_4^+ has comparable spatial pattern between the two models. As Figure 4-1 shows higher values stretching from the Great Lake regions south and west into the central plains and Texas. The VISTAS12 modeling also contains the peaks in eastern North Carolina and in northern Georgia/Alabama that appear in the NADP modeling. The extent of the higher values into Texas and Oklahoma is greater in the VISTAS12 modeling and values are more varied in than the NADP modeling. The smoothed appearance of the NADP modeling is likely due to the inverse distance weighting used to nudge the model toward the monitored values. However, the VISTAS12 wet deposition pattern for particulate NO_3^+ (Figure 4-2) has some high deposition values in the Midwest but isn't as extensive as the area in the NADP modeling. NADP did not have a separate wet deposition layer for particulate SO_4^{2-}.

The dry deposition patterns for NH_4^+ (Figure 4-3) is not as well matched as the wet deposition pattern. The VISTAS12 modeling tends to highlight the urban areas, as areas like Chicago, Detroit, Cleveland, and other Midwestern population centers show up as hot spots on the map. This pattern holds for NO_3^+ (Figure 4-4) and SO_4^{2-} (Figure 4-5). Overall the differences seen in the patterns of deposition are to be expected, as the two sets of modeling did use different emissions inventories.

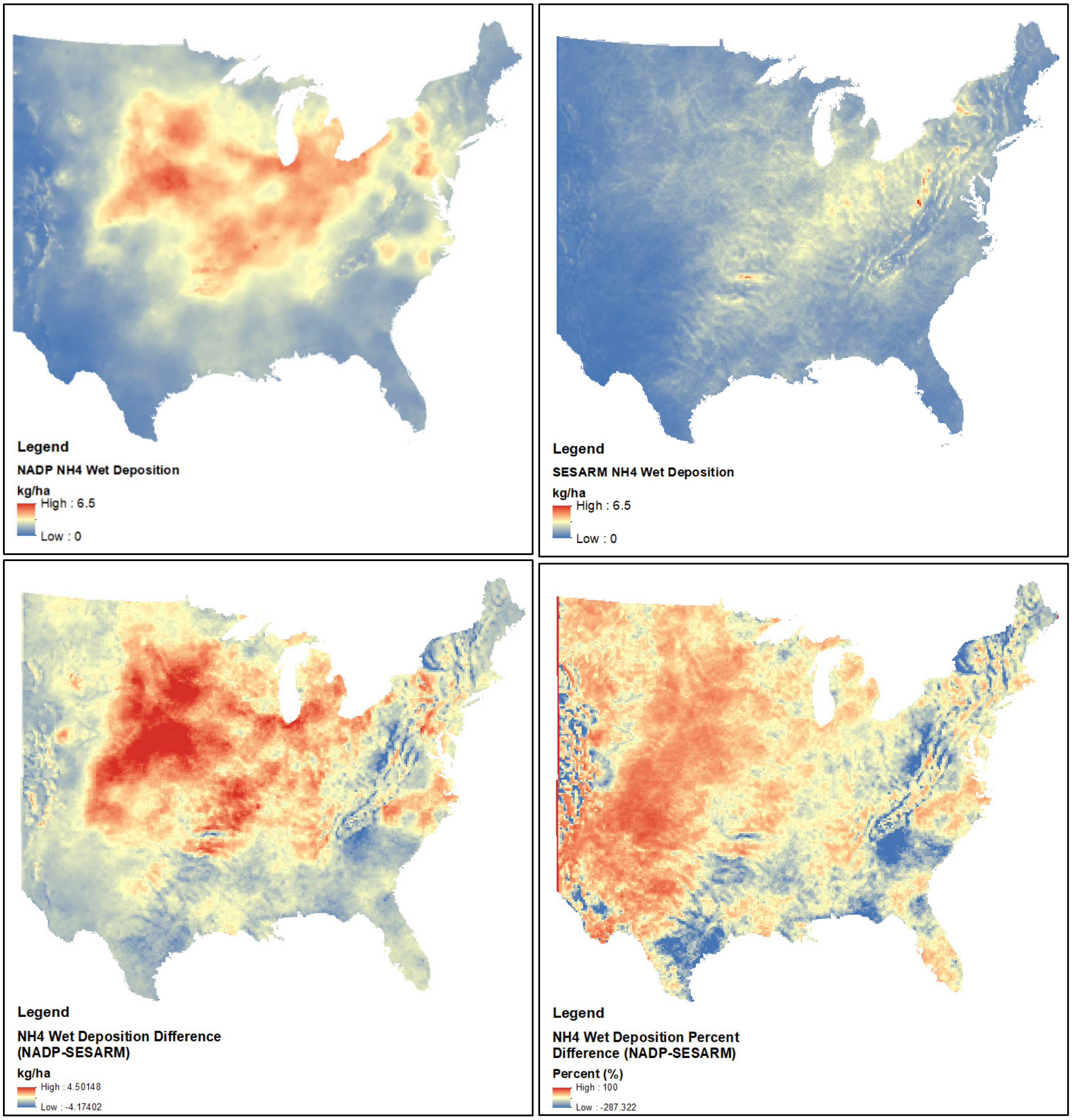

Figure 4-1. Plots of Total Annual Particulate NH_4^+ Wet Deposition. NADP Wet Deposition (top left), SESARM Wet Deposition (top right), Difference (bottom left), Percent Difference[13] (bottom right).

[13] Percent Difference = 100*[(NADP Deposition) – (SESARM Deposition)]/(NADP Deposition)

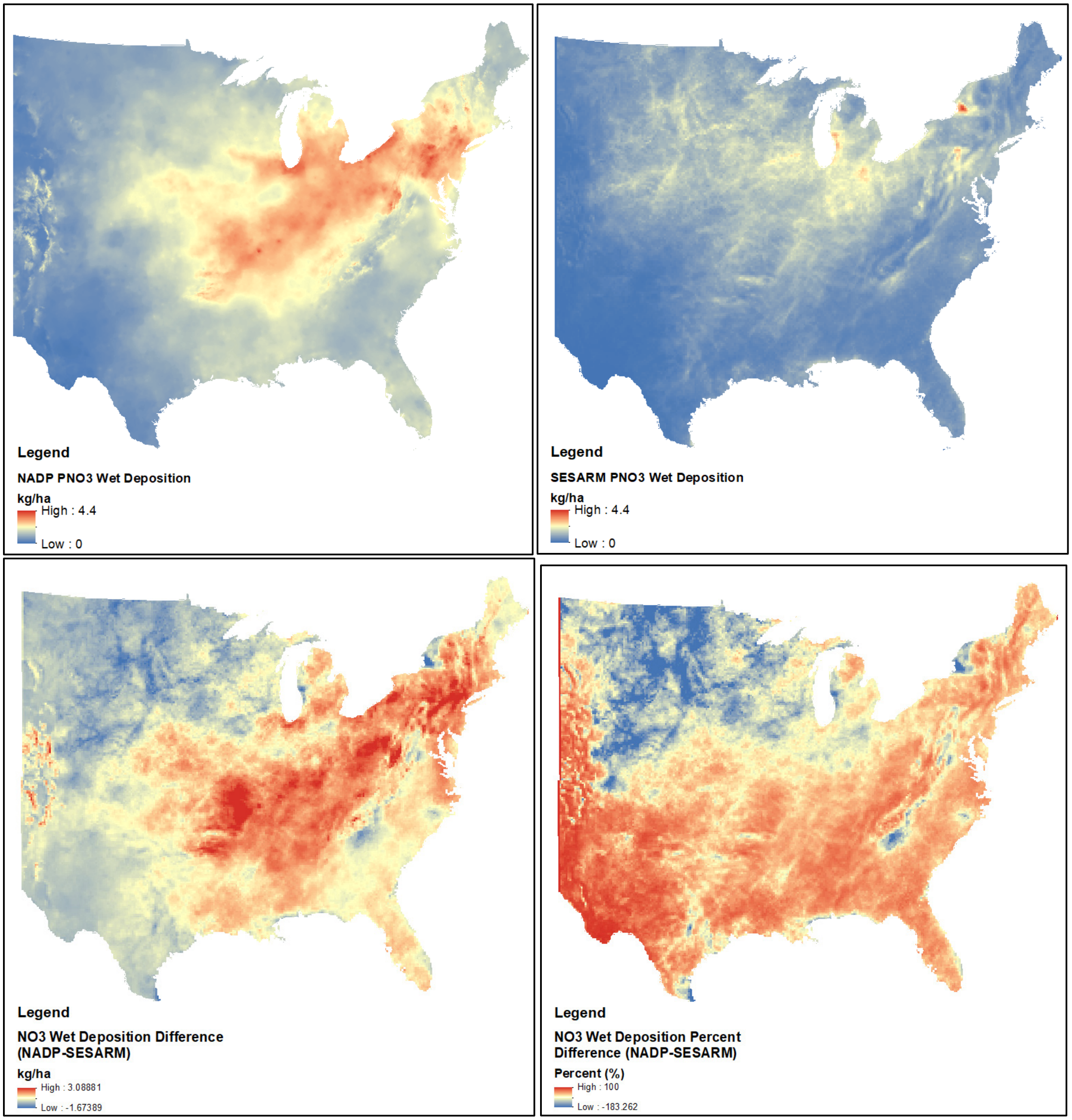

Figure 4-2. Plots of Total Annual Particulate NO_3^+ Wet Deposition. NADP Wet Deposition (top left), SESARM Wet Deposition (top right), Difference (bottom left), Percent Difference[14] (bottom right).

[14] Percent Difference = 100*[(NADP Deposition) – (SESARM Deposition)]/(NADP Deposition)

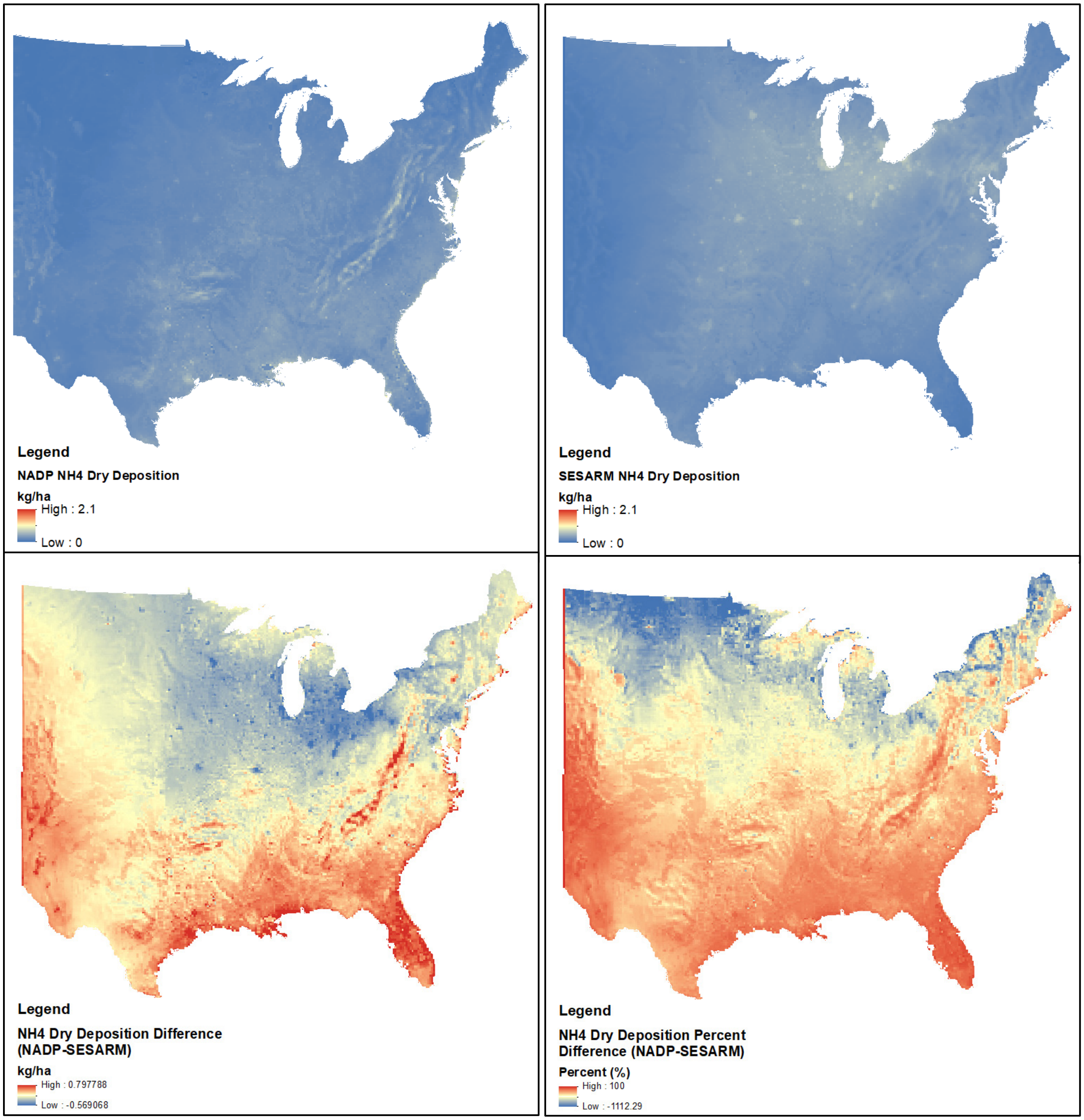

Figure 4-3. Plots of Total Annual Particulate NH_4^+ Dry Deposition. NADP Dry Deposition (top left), SESARM Dry Deposition (top right), Difference (bottom left), Percent Difference[15] (bottom right).

[15] Percent Difference = 100*[(NADP Deposition) – (SESARM Deposition)]/(NADP Deposition)

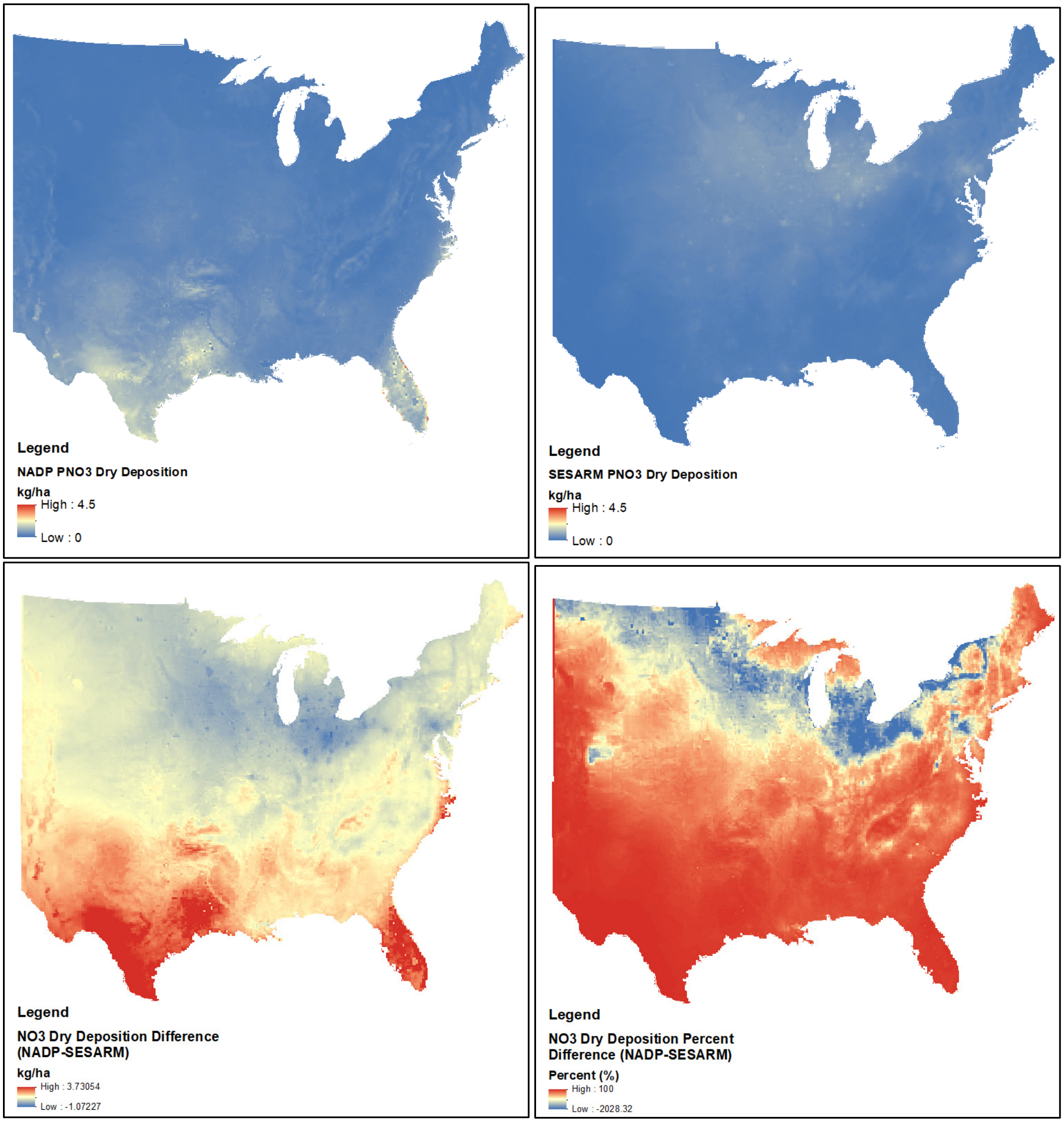

Figure 4-4. Plots of Total Annual Particulate NO_3^+ Dry Deposition. NADP Dry Deposition (top left), SESARM Dry Deposition (top right), Difference (bottom left), Percent Difference[16] (bottom right).

[16] Percent Difference = 100*[(NADP Deposition) – (SESARM Deposition)]/(NADP Deposition)

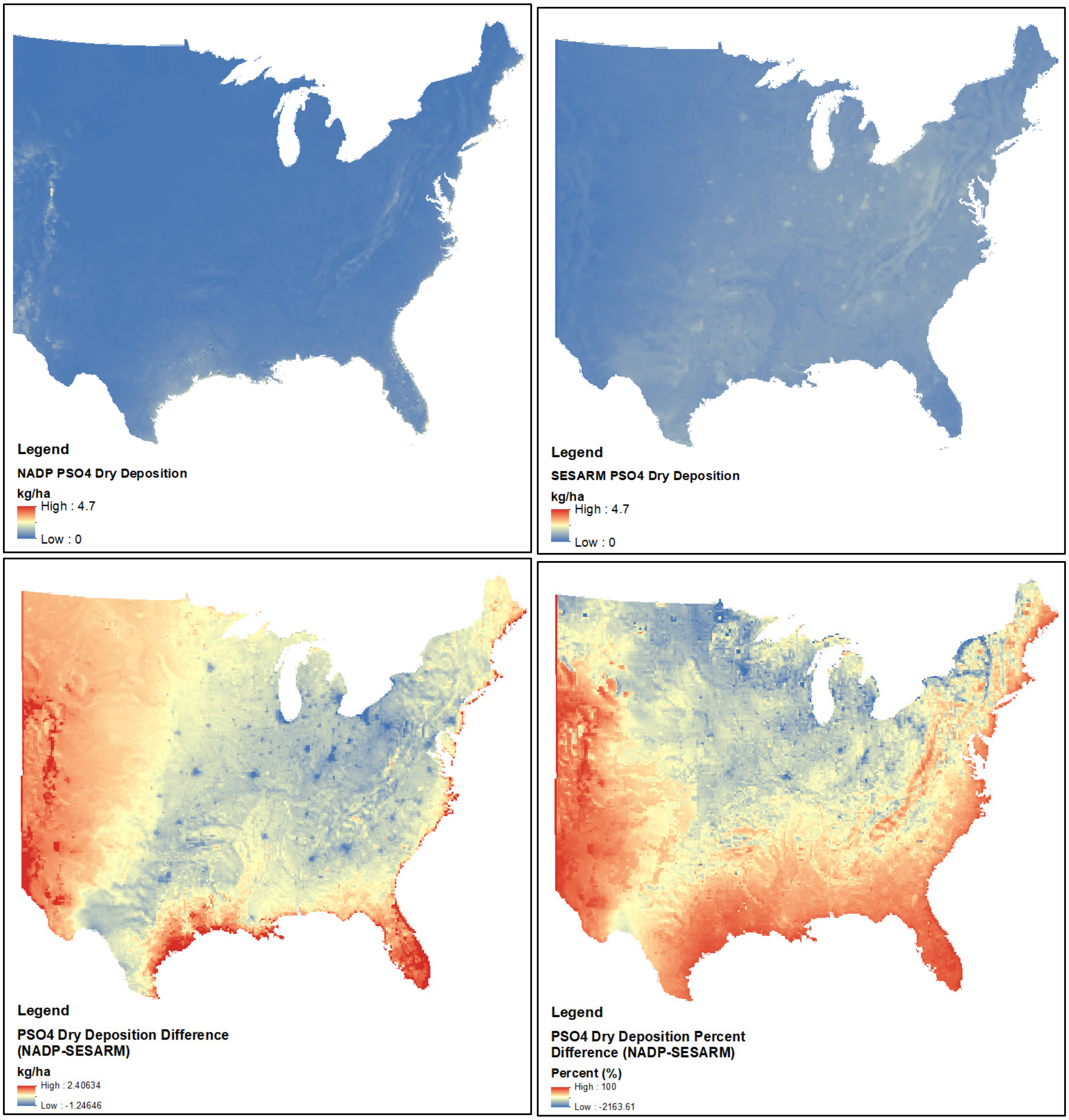

Figure 4-5. Plots of Total Annual Particulate SO_4^{2-} Deposition. NADP Dry Deposition (top left), SESARM Dry Deposition (top right), Difference (bottom left), Percent Difference[17] (bottom right).

[17] Percent Difference = 100*[(NADP Deposition) – (SESARM Deposition)]/(NADP Deposition)

Appendix A
Wet Deposition MPE Results by State

Table A-1. Model Performance Metrics for NTN NH_4^+ Wet Deposition

Network	Pollutant	State	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFB (%)	MFE (%)	RMSE (unitless)
NTN	NH_4^+	AL	38	-0.003	0.020	-8%	57%	0.585	-4%	30%	0.039
		AR	118	-0.022	0.054	-24%	60%	0.624	-14%	34%	0.123
		CO	290	-0.023	0.024	-64%	68%	0.696	-47%	50%	0.044
		FL	156	-0.018	0.034	-41%	75%	0.346	-26%	48%	0.077
		GA	42	-0.014	0.023	-29%	50%	0.669	-17%	29%	0.041
		IL	124	-0.046	0.067	-38%	55%	0.717	-24%	34%	0.126
		IN	130	-0.052	0.060	-41%	47%	0.863	-26%	30%	0.099
		KS	99	-0.050	0.080	-39%	63%	0.625	-24%	39%	0.148
		KY	109	-0.018	0.049	-21%	57%	0.574	-12%	32%	0.083
		LA	28	-0.031	0.055	-39%	70%	0.329	-24%	43%	0.135
		MA	80	-0.015	0.024	-37%	58%	0.613	-23%	36%	0.040
		MD	35	-0.017	0.040	-22%	53%	0.601	-13%	30%	0.052
		ME	157	-0.005	0.019	-14%	55%	0.742	-8%	29%	0.034
		MI	169	-0.018	0.055	-20%	62%	0.609	-11%	34%	0.108
		MN	140	-0.033	0.058	-37%	64%	0.558	-23%	39%	0.122
		MO	64	-0.038	0.058	-32%	49%	0.514	-19%	29%	0.141
		MS	35	-0.007	0.037	-13%	69%	0.548	-7%	37%	0.061
		NC	243	-0.010	0.051	-12%	62%	0.611	-6%	33%	0.096
		ND	42	-0.046	0.047	-65%	66%	0.804	-48%	49%	0.093
		NE	35	-0.123	0.132	-53%	57%	0.733	-36%	39%	0.257
		NH	40	-0.008	0.027	-18%	61%	0.554	-10%	34%	0.042
		NJ	31	-0.023	0.039	-29%	50%	0.633	-17%	29%	0.058
		NM	39	-0.015	0.015	-82%	83%	0.652	-70%	70%	0.032
		NY	239	-0.030	0.048	-38%	59%	0.552	-23%	37%	0.079
		OH	127	-0.029	0.054	-24%	45%	0.705	-14%	25%	0.093
		OK	50	-0.030	0.043	-37%	53%	0.715	-23%	32%	0.069
		PA	165	-0.028	0.042	-33%	49%	0.666	-19%	29%	0.065
		SD	59	-0.041	0.066	-37%	60%	0.678	-23%	37%	0.108
		TN	63	-0.011	0.033	-16%	48%	0.684	-8%	26%	0.058
		TX	124	-0.027	0.034	-49%	63%	0.714	-32%	42%	0.064
		VA	82	-0.007	0.036	-11%	55%	0.673	-6%	29%	0.062
		VT	69	-0.013	0.032	-26%	62%	0.603	-15%	36%	0.056
		WI	88	-0.006	0.034	-10%	57%	0.840	-5%	30%	0.064
		WV	64	-0.016	0.050	-20%	64%	0.425	-11%	36%	0.083
		WY	30	-0.056	0.058	-61%	62%	0.471	-43%	45%	0.200

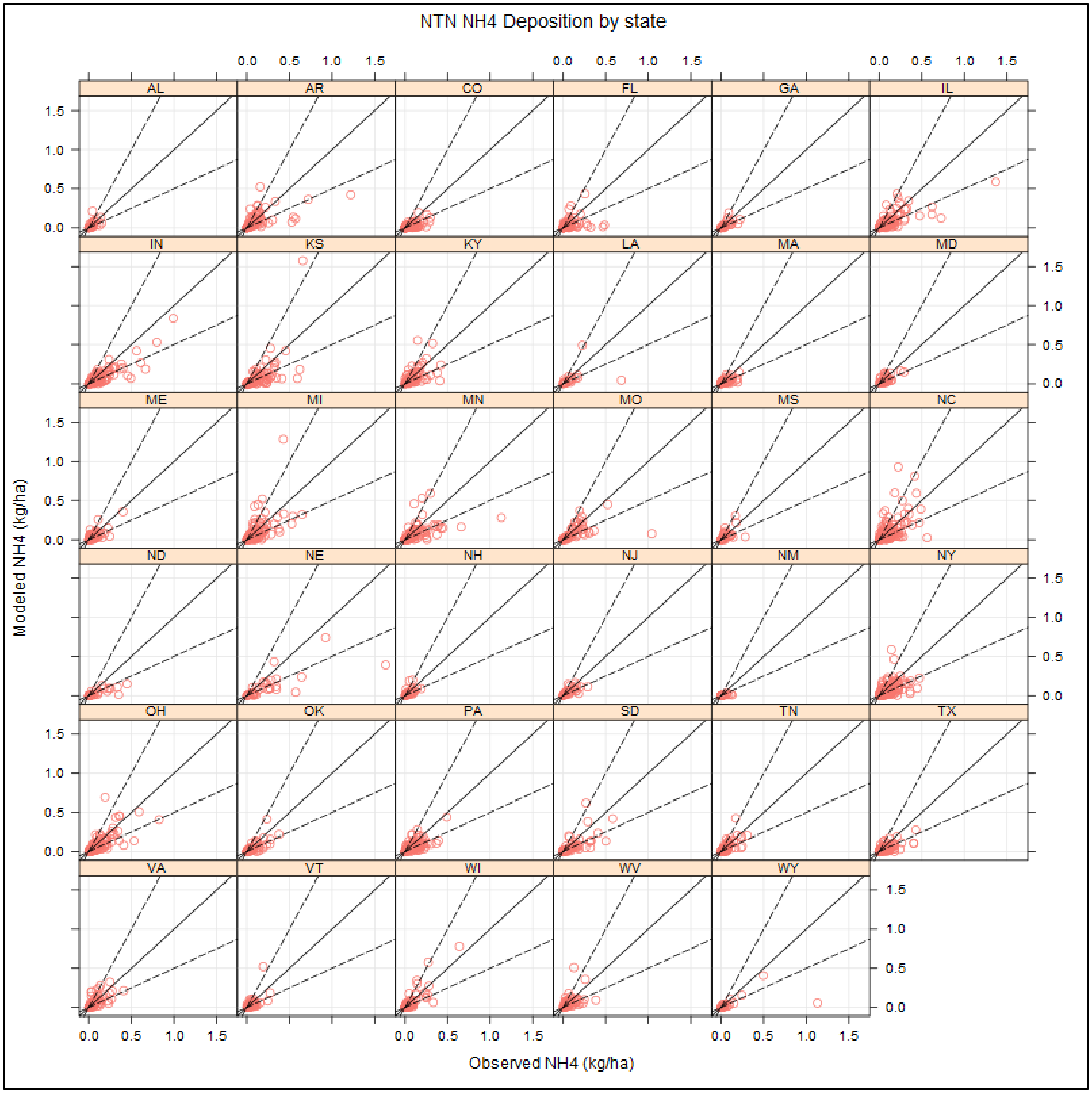

Figure A-1. Modeled NH_4^+ versus NTN Observed NH_4^+ Wet Deposition, by State

Table A-2. Model Performance Metrics for NTN NO_3^+ Wet Deposition

Network	Pollutant	State	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFB (%)	MFE (%)	RMSE (unitless)
NTN	NO_3^+	AL	38	0.050	0.096	37%	70%	0.746	15%	30%	0.160
		AR	118	0.069	0.162	33%	76%	0.587	14%	33%	0.322
		CO	290	-0.068	0.076	-54%	60%	0.566	-37%	41%	0.155
		FL	156	0.039	0.123	25%	80%	0.618	11%	35%	0.289
		GA	42	0.037	0.077	30%	63%	0.643	13%	27%	0.143
		IL	124	0.015	0.141	5%	50%	0.748	3%	24%	0.248
		IN	130	0.008	0.139	3%	49%	0.796	1%	24%	0.269
		KS	99	-0.004	0.143	-2%	60%	0.652	-1%	30%	0.266
		KY	109	0.071	0.175	28%	70%	0.561	12%	31%	0.307
		LA	28	0.106	0.162	50%	76%	0.813	20%	30%	0.297
		MA	80	0.015	0.097	9%	54%	0.622	4%	26%	0.141
		MD	35	0.087	0.151	40%	69%	0.500	17%	29%	0.264
		ME	157	0.029	0.081	22%	62%	0.604	10%	28%	0.128
		MI	169	0.066	0.149	31%	70%	0.658	13%	30%	0.326
		MN	140	0.006	0.088	4%	62%	0.622	2%	30%	0.170
		MO	64	-0.006	0.150	-2%	51%	0.554	-1%	26%	0.309
		MS	35	0.055	0.151	34%	94%	0.442	15%	40%	0.234
		NC	243	0.046	0.106	29%	68%	0.626	13%	30%	0.220
		ND	42	-0.024	0.048	-25%	52%	0.772	-14%	29%	0.090
		NE	35	-0.005	0.193	-1%	59%	0.692	-1%	30%	0.317
		NH	40	0.037	0.133	19%	70%	0.478	9%	32%	0.228
		NJ	31	0.029	0.107	11%	40%	0.766	5%	19%	0.148
		NM	39	-0.029	0.031	-56%	59%	0.818	-39%	41%	0.074
		NY	239	0.018	0.154	7%	59%	0.592	3%	28%	0.263
		OH	127	0.076	0.172	24%	55%	0.688	11%	25%	0.314
		OK	50	0.059	0.117	34%	67%	0.644	15%	29%	0.334
		PA	165	0.019	0.155	6%	51%	0.565	3%	25%	0.231
		SD	59	0.012	0.092	8%	61%	0.691	4%	29%	0.171
		TN	63	0.041	0.141	19%	63%	0.520	8%	29%	0.249
		TX	124	0.018	0.092	14%	74%	0.571	7%	34%	0.186
		VA	82	0.046	0.109	27%	64%	0.534	12%	28%	0.238
		VT	69	0.020	0.105	10%	55%	0.573	5%	26%	0.202
		WI	88	0.049	0.096	40%	78%	0.828	17%	33%	0.217
		WV	64	0.044	0.189	16%	68%	0.408	7%	32%	0.341
		WY	30	0.006	0.067	5%	56%	0.904	2%	27%	0.121

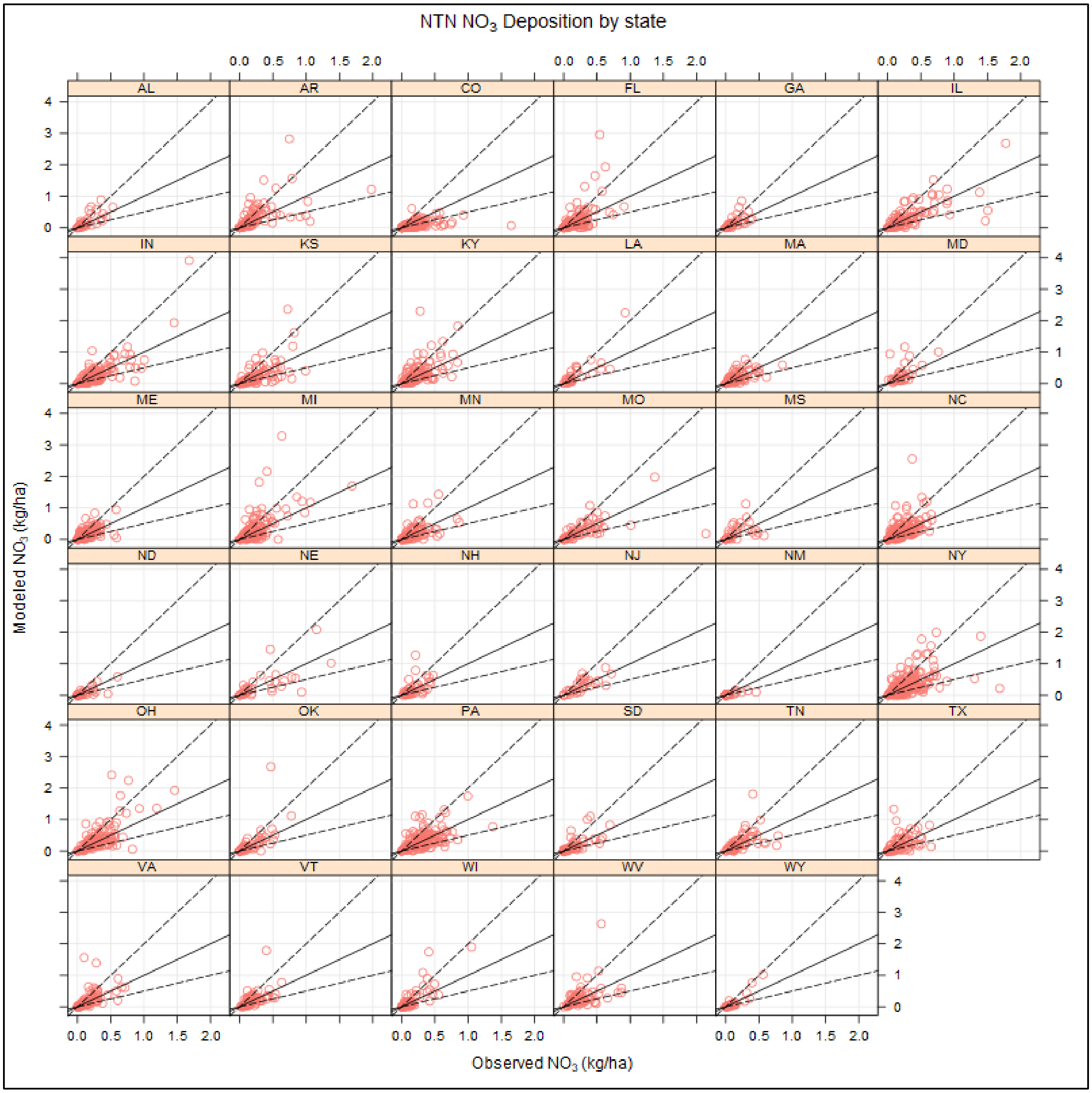

Figure A-2. Modeled NO_3^+ versus NTN Observed NO_3^+ Wet Deposition, by State

Table A-3. Model Performance Metrics for NTN SO_4^{2-} Wet Deposition

Network	Pollutant	State	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFB (%)	MFE (%)	RMSE (unitless)
NTN	SO_4^{2-}	AL	38	0.021	0.105	11%	58%	0.747	5%	27%	0.180
		AR	118	0.035	0.166	14%	66%	0.633	7%	31%	0.364
		CO	290	-0.033	0.039	-48%	58%	0.721	-32%	38%	0.069
		FL	156	-0.037	0.121	-22%	71%	0.485	-12%	40%	0.216
		GA	42	0.017	0.094	10%	54%	0.681	5%	26%	0.176
		IL	124	-0.018	0.162	-6%	52%	0.721	-3%	27%	0.288
		IN	130	-0.075	0.142	-23%	44%	0.832	-13%	25%	0.197
		KS	99	-0.005	0.118	-3%	59%	0.592	-1%	30%	0.311
		KY	109	0.041	0.187	14%	65%	0.623	7%	30%	0.299
		LA	28	-0.017	0.144	-7%	55%	0.688	-3%	29%	0.300
		MA	80	-0.052	0.111	-27%	57%	0.456	-15%	33%	0.203
		MD	35	0.013	0.128	5%	53%	0.618	3%	26%	0.184
		ME	157	0.019	0.080	14%	60%	0.634	7%	28%	0.135
		MI	169	0.032	0.117	16%	61%	0.672	8%	28%	0.258
		MN	140	0.005	0.065	5%	67%	0.585	2%	33%	0.121
		MO	64	-0.036	0.145	-12%	48%	0.649	-6%	25%	0.286
		MS	35	0.026	0.125	15%	70%	0.494	7%	33%	0.235
		NC	243	0.023	0.116	13%	62%	0.631	6%	29%	0.238
		ND	42	-0.014	0.032	-23%	54%	0.758	-13%	30%	0.062
		NE	35	-0.034	0.146	-14%	58%	0.714	-7%	31%	0.229
		NH	40	0.031	0.105	19%	65%	0.602	9%	30%	0.187
		NJ	31	0.005	0.127	2%	50%	0.681	1%	25%	0.191
		NM	39	-0.017	0.021	-53%	66%	0.652	-36%	45%	0.048
		NY	239	0.013	0.150	5%	60%	0.617	3%	29%	0.310
		OH	127	-0.015	0.209	-3%	48%	0.764	-2%	24%	0.358
		OK	50	-0.014	0.097	-8%	54%	0.714	-4%	28%	0.162
		PA	165	-0.027	0.164	-8%	47%	0.679	-4%	25%	0.252
		SD	59	0.012	0.058	13%	61%	0.718	6%	29%	0.104
		TN	63	0.010	0.154	4%	58%	0.552	2%	28%	0.268
		TX	124	-0.012	0.092	-8%	62%	0.713	-4%	32%	0.156
		VA	82	0.005	0.106	2%	48%	0.739	1%	24%	0.185
		VT	69	0.000	0.101	0%	59%	0.603	0%	30%	0.200
		WI	88	0.032	0.064	36%	72%	0.811	15%	30%	0.128
		WV	64	0.114	0.269	32%	75%	0.687	14%	32%	0.652
		WY	30	-0.003	0.056	-3%	60%	0.761	-2%	31%	0.118

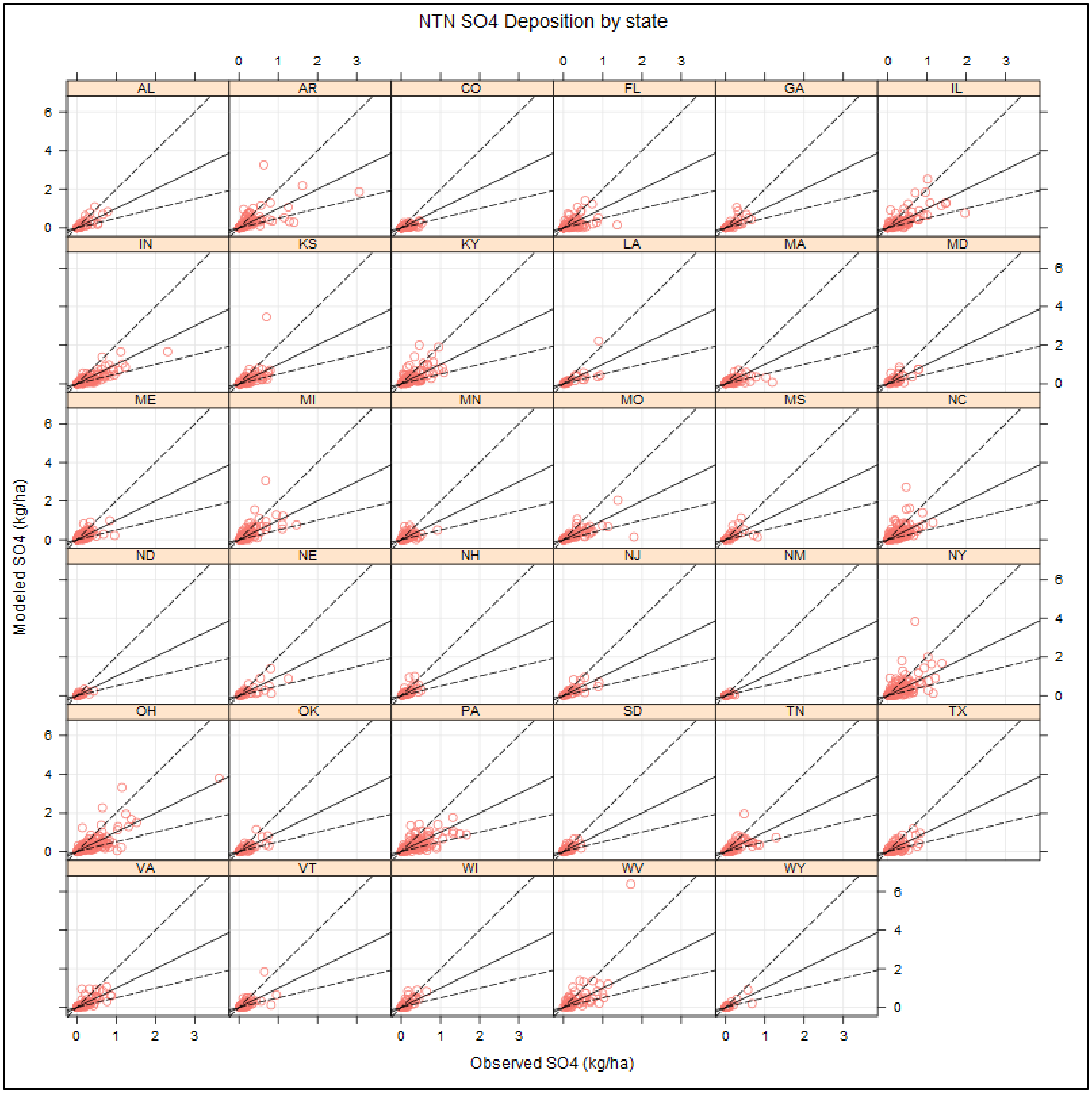

Figure A-3. Modeled SO_4^{2-} versus NTN Observed SO_4^{2-} Wet Deposition, by State

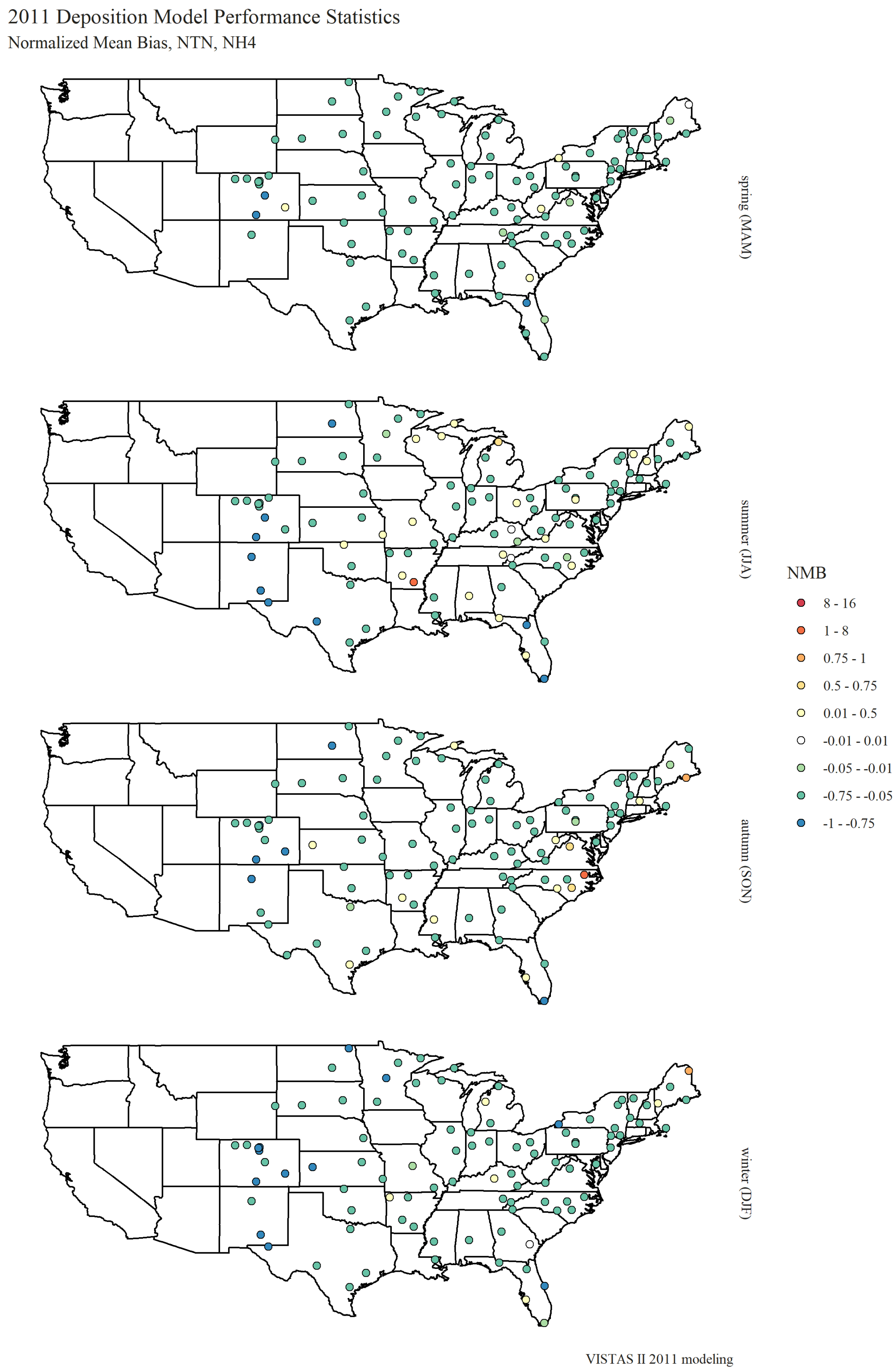

Figure A-4. Normalized Mean Bias for NTN NH_4^+ Wet Deposition, by Season

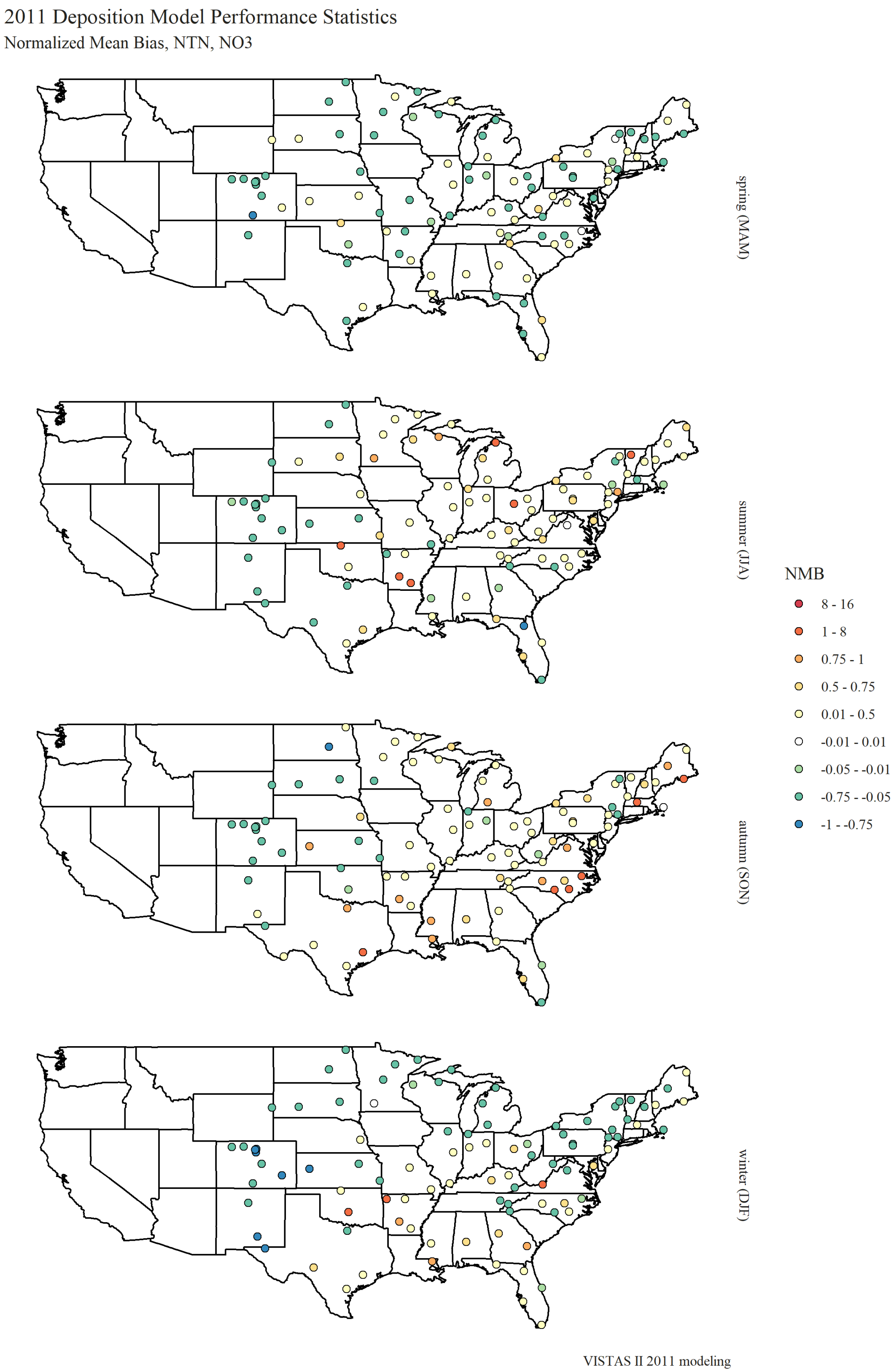

Figure A-5. Normalized Mean Bias for NTN NO_3^+ Wet Deposition, by Season

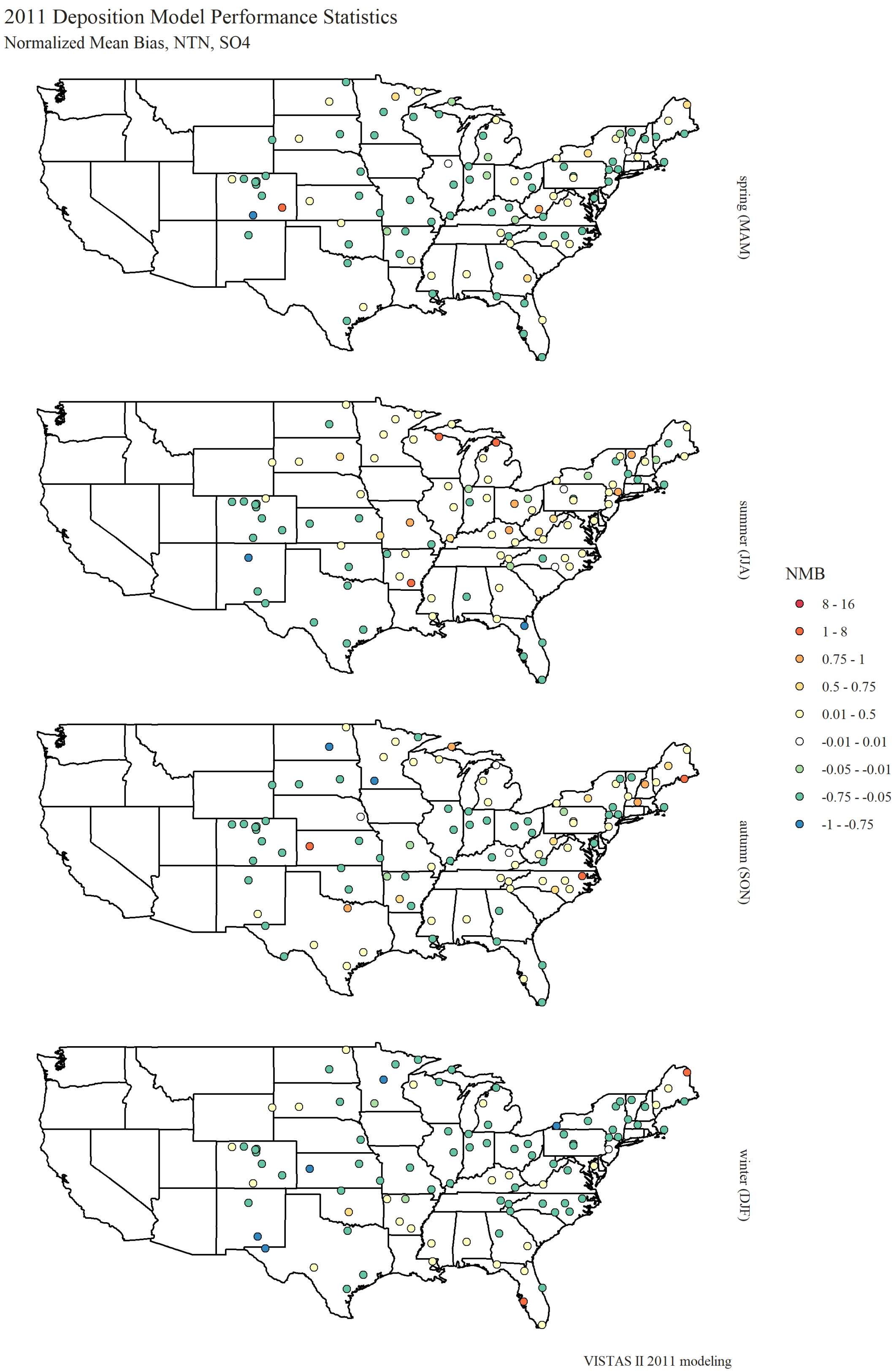

Figure A-6. Normalized Mean Bias for NTN SO_4^{2-} Wet Deposition, by Season

Table A-4. Model Performance Metrics for AIRMon NH_4^+ Wet Deposition

Network	Pollutant	State	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFB (%)	MFE (%)	RMSE (unitless)
AIRMon	NH_4^+	IL	39	-0.007	0.019	-21%	57%	0.715	-12%	32%	0.033
		PA	40	-0.005	0.020	-20%	85%	0.281	-11%	47%	0.035
		TN	41	-0.002	0.021	-6%	75%	0.493	-3%	39%	0.039
		VT	38	0.000	0.021	-1%	100%	0.633	0%	50%	0.054

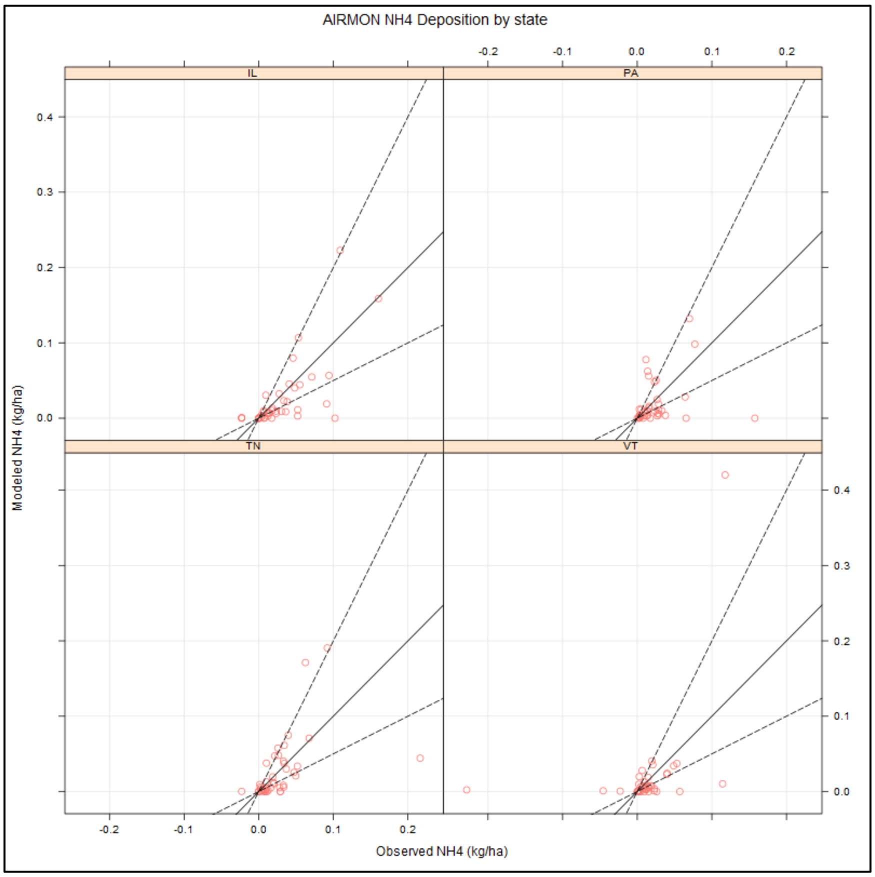

Figure A-7. Modeled NH_4^+ versus AIRMon Observed NH_4^+ Wet Deposition, by State

Table A-5. Model Performance Metrics for AIRMon NO_3^+ Wet Deposition

Network	Pollutant	State	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFB (%)	MFE (%)	RMSE (unitless)
AIRMon	NO_3^+	IL	39	0.033	0.070	42%	89%	0.691	17%	37%	0.126
		PA	40	0.039	0.111	44%	125%	0.192	18%	51%	0.201
		TN	41	0.084	0.122	111%	162%	0.320	36%	52%	0.219
		VT	38	0.047	0.084	75%	132%	0.507	27%	48%	0.208

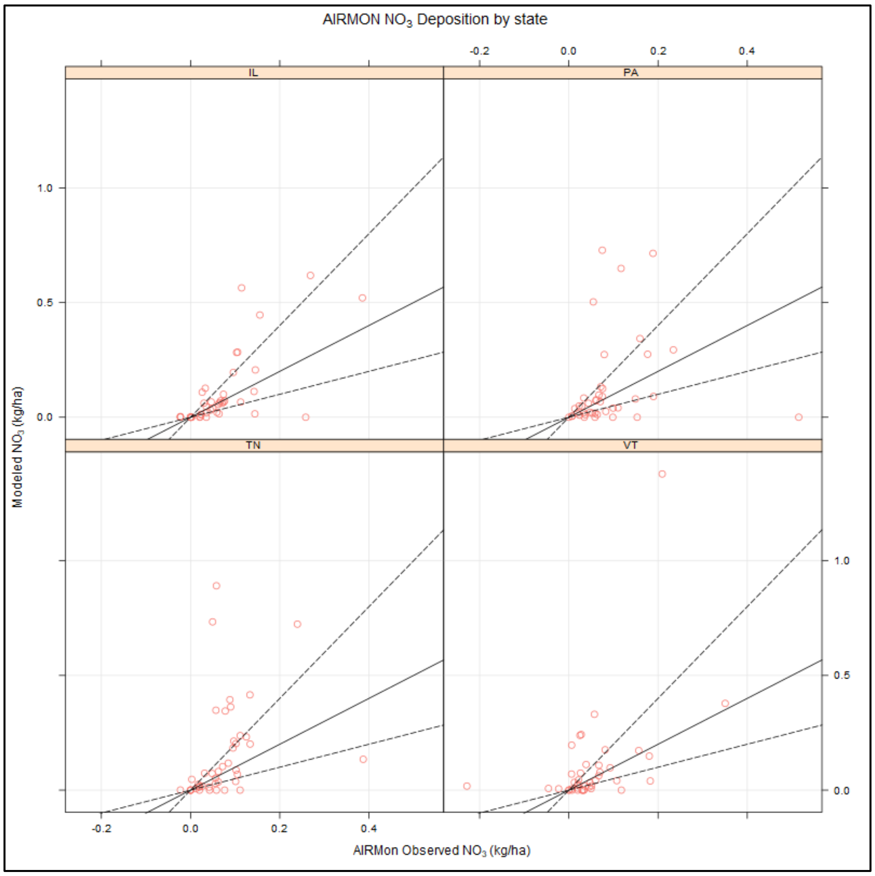

Figure A-8. Modeled NO_3^+ versus AIRMon Observed NO_3^+ Wet Deposition, by State

Table A-6. Model Performance Metrics for AIRMon SO_4^{2-} Wet Deposition

Network	Pollutant	State	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFB (%)	MFE (%)	RMSE (unitless)
AIRMon	SO_4^{2-}	IL	39	0.008	0.079	9%	83%	0.558	4%	40%	0.175
		PA	40	-0.003	0.114	-2%	104%	0.054	-1%	53%	0.233
		TN	41	0.043	0.095	45%	100%	0.509	18%	41%	0.167
		VT	38	0.024	0.073	40%	122%	0.507	17%	51%	0.206

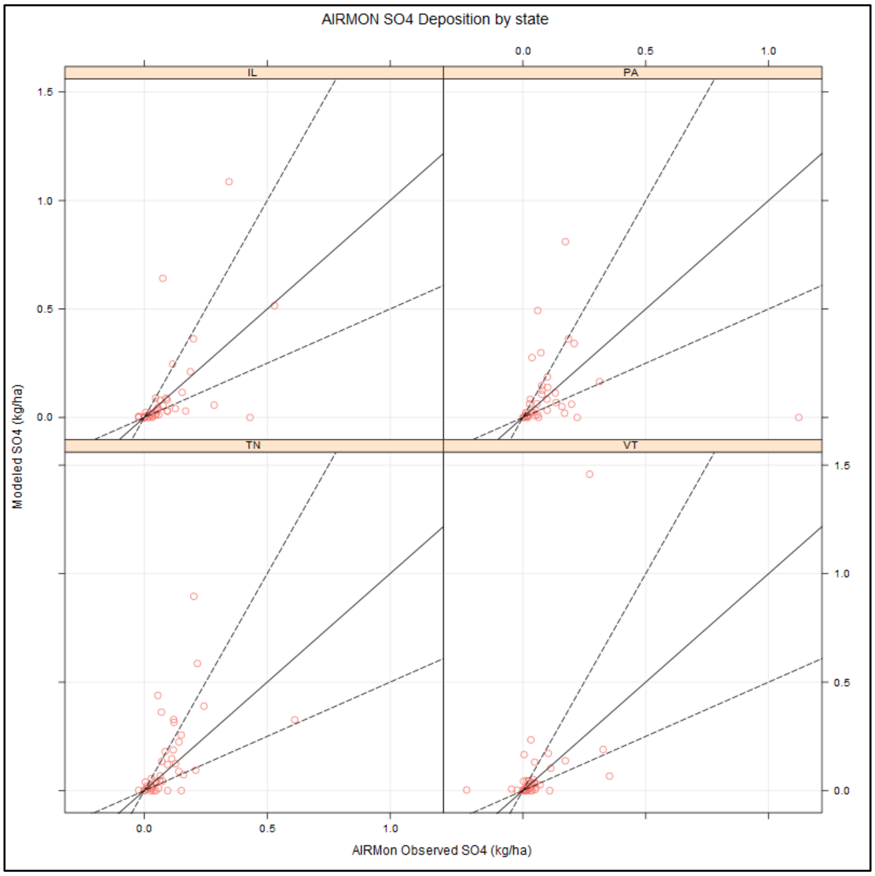

Figure A-9. Modeled SO_4^{2-} versus AIRMon Observed SO_4^{2-} Wet Deposition, by State

Figure A-10. Normalized Mean Bias for AIRMon NH_4^+ Wet Deposition, by Season

Figure A-11. Normalized Mean Bias for AIRMon NO_3^+ Wet Deposition, by Season

Figure A-12. Normalized Mean Bias for AIRMon SO_4^{2-} Wet Deposition, by Season

Appendix B
Dry Deposition MPE Results by State

Table B-1. Model Performance Metrics for CASTNET Cl^- Dry Deposition

Pollutant	State	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFE (%)	MFB (%)	RMSE (unitless)
Cl^-	AR	52	-0.0003	0.0004	-86%	88%	0.043	77%	-75%	0.001
	FL	52	-0.013	0.013	-93%	93%	0.797	86%	-86%	0.017
	GA	52	-0.001	0.001	-80%	84%	0.254	70%	-67%	0.001
	IL	52	-0.0002	0.0002	-64%	69%	0.365	51%	-47%	0.0003
	KS	45	-0.0004	0.0004	-85%	85%	0.510	74%	-74%	0.001
	KY	104	-0.0002	0.0003	-60%	74%	0.227	53%	-43%	0.0004
	ME	52	-0.002	0.002	-87%	87%	0.724	77%	-76%	0.004
	MI	52	-0.0002	0.0002	-74%	77%	0.031	62%	-59%	0.0002
	NC	52	-0.0004	0.0004	-85%	85%	0.672	75%	-75%	0.001
	NH	52	0.0000	0.0002	-2%	115%	0.087	58%	-1%	0.0005
	NY	93	-0.0002	0.0002	-85%	86%	0.464	75%	-74%	0.0002
	PA	104	-0.0002	0.0002	-68%	77%	0.253	58%	-51%	0.0003
	TX	52	-0.001	0.001	-99%	99%	0.644	99%	-99%	0.001
	VA	100	-0.0002	0.0003	-70%	77%	0.468	59%	-54%	0.0004
	WV	51	-0.0002	0.0003	-73%	75%	0.308	59%	-57%	0.0004

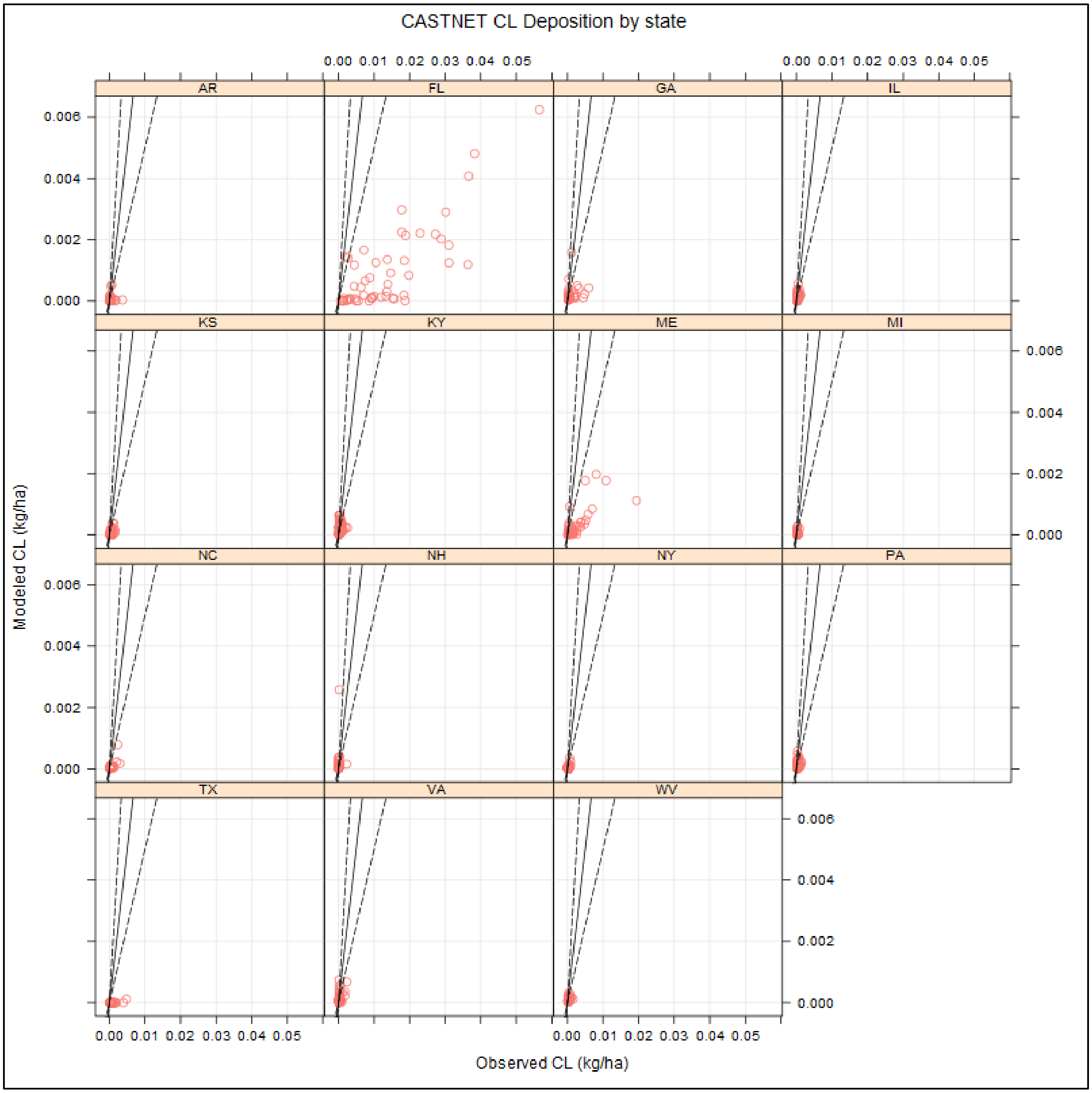

Figure B-1. Modeled Cl⁻ versus CASTNET Observed Cl⁻ Dry Deposition, by State

Table B-2. Model Performance Metrics for CASTNET NH_4^+ Dry Deposition

Pollutant	State	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFE (%)	MFB (%)	RMSE (unitless)
NH_4^+	AR	52	0.001	0.002	33%	50%	0.475	21%	14%	0.002
	FL	52	-0.001	0.001	-49%	54%	0.685	36%	-33%	0.001
	GA	52	-0.002	0.003	-27%	34%	0.617	20%	-16%	0.004
	IL	52	0.001	0.002	12%	35%	0.439	17%	6%	0.003
	KS	45	-0.0003	0.002	-5%	34%	0.635	17%	-2%	0.003
	KY	104	0.006	0.006	71%	72%	0.730	26%	26%	0.007
	ME	52	0.001	0.001	47%	66%	0.373	27%	19%	0.001
	MI	52	0.001	0.002	29%	37%	0.727	16%	13%	0.002
	NC	52	-0.0004	0.001	-8%	31%	0.649	16%	-4%	0.002
	NH	52	0.003	0.003	373%	373%	0.654	65%	65%	0.004
	NY	93	0.001	0.002	25%	66%	0.549	29%	11%	0.003
	PA	104	0.000	0.003	-6%	43%	0.561	22%	-3%	0.003
	TX	52	-0.004	0.004	-60%	61%	0.420	43%	-42%	0.005
	VA	100	0.0005	0.003	7%	39%	0.534	19%	4%	0.003
	WV	51	-0.001	0.003	-10%	42%	0.639	22%	-5%	0.004

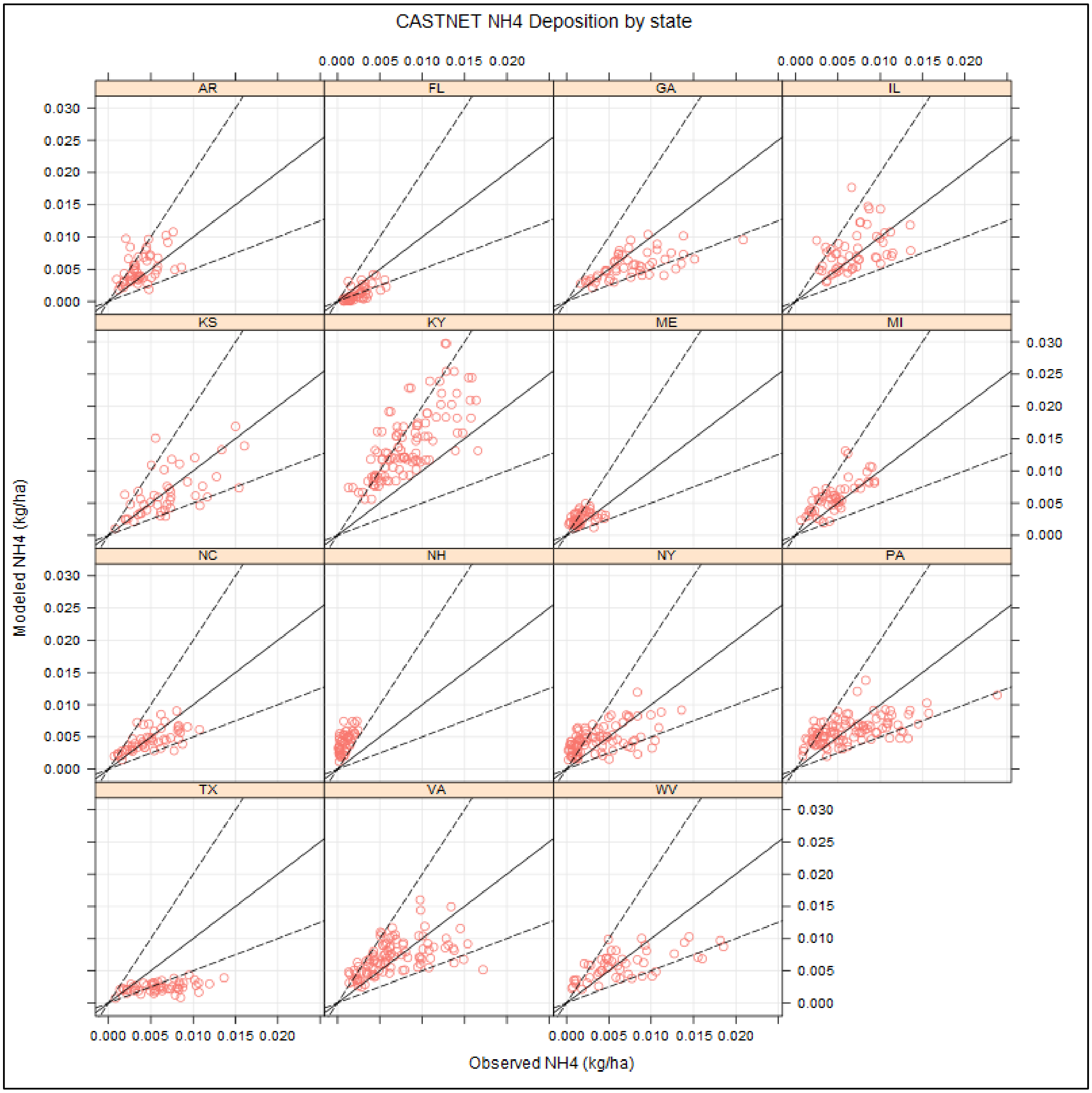

Figure B-2. Modeled NH_4^+ versus CASTNET Observed NH_4^+ Dry Deposition, by State

Table B-3. Model Performance Metrics for CASTNET NO_3^+ Dry Deposition

Pollutant	State	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFE (%)	MFB (%)	RMSE (unitless)
NO_3^+	AR	52	0.001	0.002	22%	87%	0.587	39%	10%	0.003
	FL	52	-0.006	0.006	-66%	66%	0.223	49%	-49%	0.008
	GA	52	-0.001	0.002	-22%	60%	0.486	34%	-12%	0.003
	IL	52	0.001	0.005	15%	47%	0.740	22%	7%	0.006
	KS	45	-0.006	0.007	-41%	48%	0.830	30%	-26%	0.009
	KY	104	0.006	0.007	101%	113%	0.753	37%	34%	0.011
	ME	52	0.0004	0.001	17%	66%	0.651	31%	8%	0.002
	MI	52	0.002	0.003	59%	81%	0.711	31%	23%	0.005
	NC	52	0.0003	0.001	19%	73%	0.557	33%	9%	0.002
	NH	52	0.003	0.003	800%	803%	0.409	80%	80%	0.005
	NY	93	0.001	0.002	64%	120%	0.435	46%	24%	0.003
	PA	104	0.001	0.003	24%	74%	0.541	33%	11%	0.005
	TX	52	-0.006	0.006	-96%	96%	0.197	93%	-93%	0.007
	VA	100	0.002	0.003	53%	97%	0.622	38%	21%	0.004
	WV	51	0.001	0.002	27%	60%	0.711	27%	12%	0.003

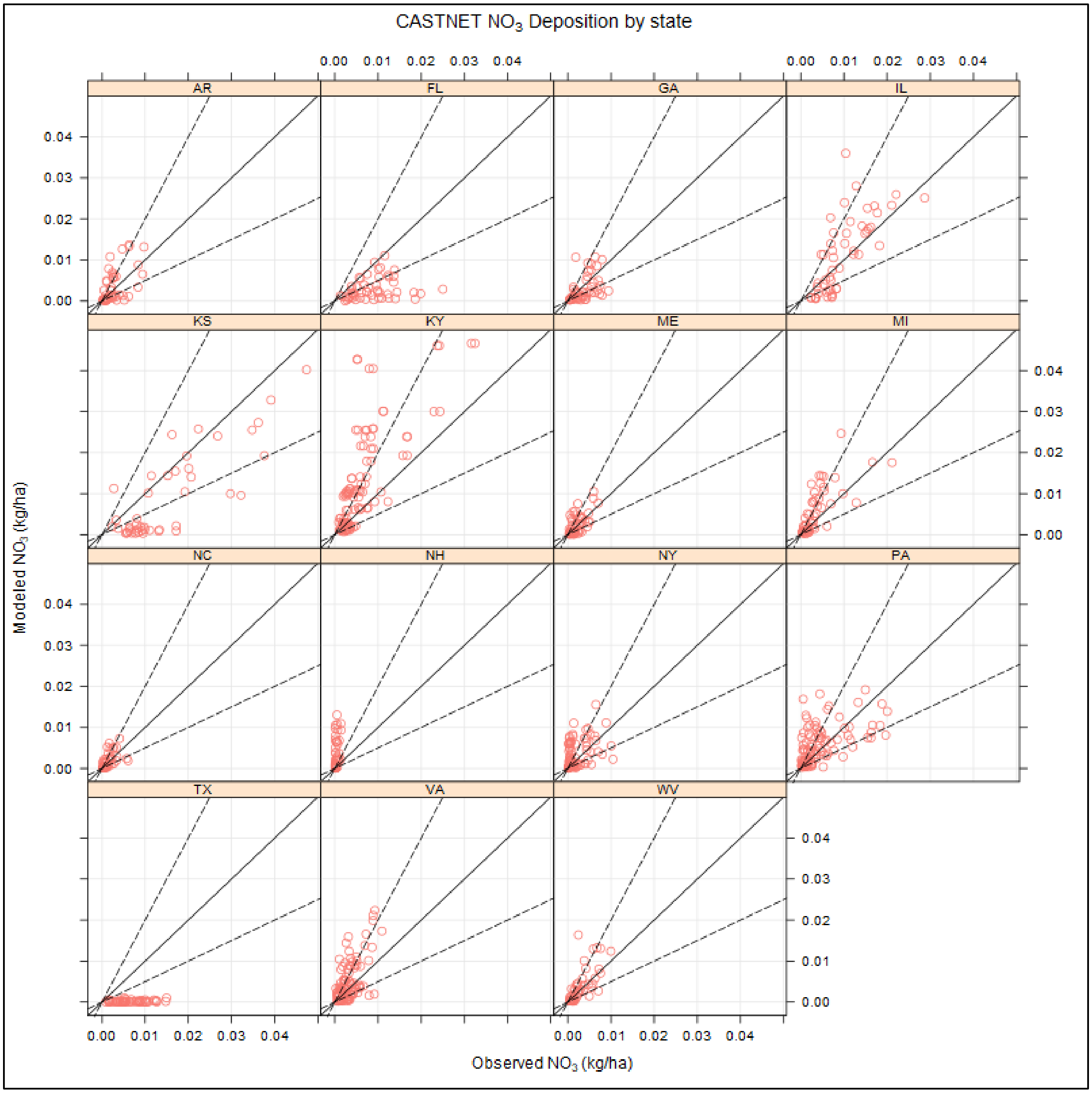

Figure B-3. Modeled NO_3^+ versus CASTNET Observed NO_3^+ Dry Deposition, by State

Table B-4. Model Performance Metrics for CASTNET HNO_3 Dry Deposition

Pollutant	State	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFE (%)	MFB (%)	RMSE (unitless)
HNO_3	AR	52	-0.049	0.049	-94%	94%	0.471	89%	-89%	0.054
	FL	52	-0.025	0.025	-94%	94%	0.661	88%	-88%	0.033
	GA	52	-0.093	0.093	-96%	96%	0.581	93%	-93%	0.101
	IL	52	-0.088	0.088	-97%	97%	0.831	94%	-94%	0.103
	KS	45	-0.096	0.096	-97%	97%	0.740	95%	-95%	0.114
	KY	104	-0.104	0.104	-94%	94%	0.367	88%	-88%	0.109
	ME	52	-0.026	0.026	-94%	94%	0.721	89%	-89%	0.031
	MI	52	-0.045	0.045	-94%	94%	0.715	89%	-89%	0.052
	NC	52	-0.027	0.027	-90%	90%	0.629	82%	-82%	0.031
	NH	52	-0.005	0.005	-70%	70%	0.466	54%	-54%	0.006
	NY	93	-0.048	0.048	-94%	94%	0.802	89%	-89%	0.069
	PA	104	-0.068	0.068	-95%	95%	0.404	91%	-91%	0.079
	TX	52	-0.066	0.066	-97%	97%	0.507	95%	-95%	0.076
	VA	100	-0.082	0.082	-95%	95%	0.652	91%	-91%	0.088
	WV	51	-0.053	0.053	-92%	92%	0.581	85%	-85%	0.060

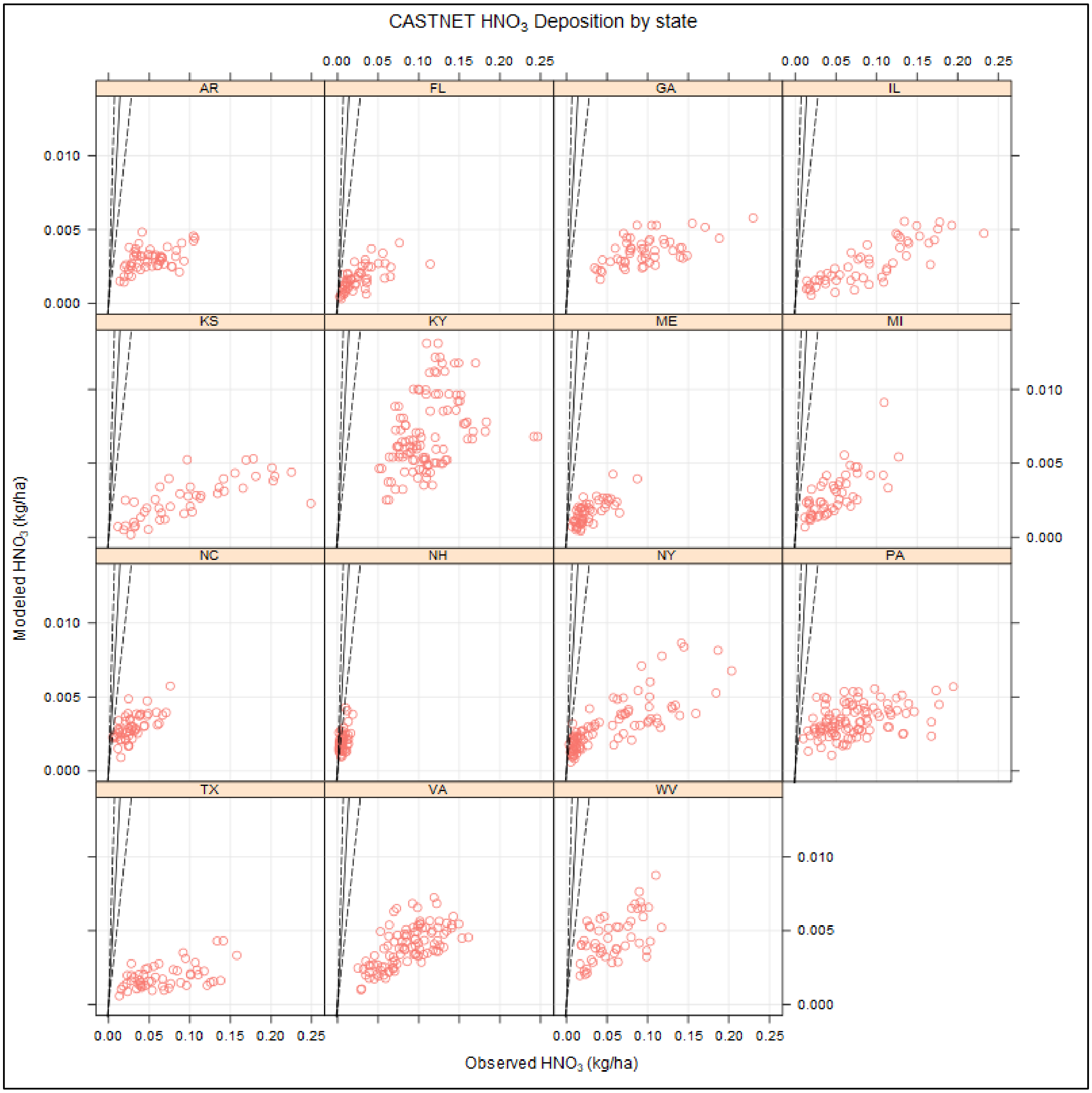

Figure B-4. Modeled HNO3 versus CASTNET Observed HNO3 Dry Deposition, by State

Table B-5. Model Performance Metrics for CASTNET SO_4^{2-} Dry Deposition

Pollutant	State	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFE (%)	MFB (%)	RMSE (unitless)
SO_4^{2-}	AR	52	0.001	0.004	9%	36%	0.528	17%	4%	0.006
	FL	52	-0.008	0.008	-49%	49%	0.779	33%	-33%	0.010
	GA	52	-0.008	0.008	-32%	34%	0.710	20%	-19%	0.012
	IL	52	-0.002	0.005	-15%	30%	0.757	16%	-8%	0.007
	KS	45	-0.007	0.007	-36%	38%	0.817	23%	-22%	0.009
	KY	104	0.011	0.011	54%	54%	0.816	21%	21%	0.014
	ME	52	0.003	0.004	50%	60%	0.369	24%	20%	0.005
	MI	52	0.002	0.003	22%	28%	0.877	13%	10%	0.004
	NC	52	0.00005	0.004	0%	30%	0.704	15%	0%	0.006
	NH	52	0.009	0.009	357%	357%	0.756	64%	64%	0.010
	NY	93	0.004	0.006	37%	63%	0.706	27%	16%	0.007
	PA	104	-0.001	0.006	-5%	35%	0.765	18%	-3%	0.007
	TX	52	-0.010	0.010	-53%	56%	0.408	38%	-36%	0.013
	VA	100	0.0004	0.005	2%	28%	0.782	14%	1%	0.008
	WV	51	-0.001	0.005	-7%	25%	0.894	13%	-3%	0.007

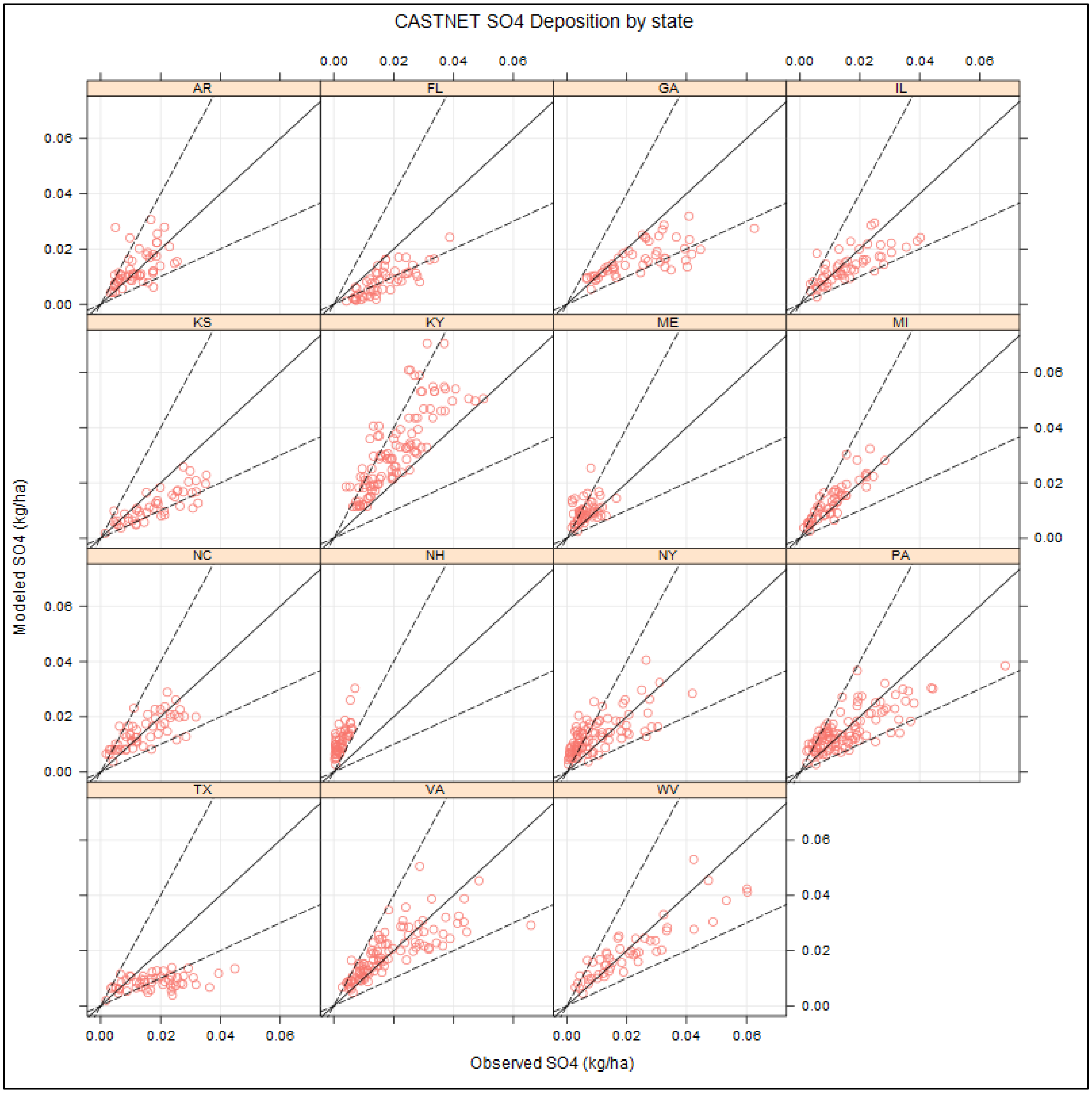

Figure B-5. Modeled SO_4^{2-} versus CASTNET Observed SO_4^{2-} Dry Deposition, by State

Table B-6. Model Performance Metrics for CASTNET SO_2 Dry Deposition

Pollutant	State	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFE (%)	MFB (%)	RMSE (unitless)
SO_2	AR	52	-0.010	0.010	-94%	94%	0.484	89%	-89%	0.011
	FL	52	-0.005	0.005	-95%	95%	0.447	90%	-90%	0.005
	GA	52	-0.033	0.033	-97%	97%	0.678	93%	-93%	0.039
	IL	52	-0.061	0.061	-97%	97%	0.423	95%	-95%	0.070
	KS	45	-0.009	0.009	-95%	95%	0.194	90%	-90%	0.011
	KY	104	-0.064	0.064	-95%	95%	0.545	91%	-91%	0.081
	ME	52	-0.008	0.008	-96%	96%	0.801	92%	-92%	0.010
	MI	52	-0.012	0.012	-93%	93%	0.503	88%	-88%	0.014
	NC	52	-0.005	0.005	-89%	89%	0.555	81%	-81%	0.005
	NH	52	-0.003	0.003	-86%	86%	0.595	75%	-75%	0.004
	NY	93	-0.010	0.010	-94%	94%	0.562	89%	-89%	0.013
	PA	104	-0.068	0.068	-98%	98%	0.302	95%	-95%	0.096
	TX	52	-0.009	0.009	-98%	98%	0.262	96%	-96%	0.011
	VA	100	-0.053	0.053	-97%	97%	0.725	94%	-94%	0.066
	WV	51	-0.041	0.041	-96%	96%	0.421	92%	-92%	0.050

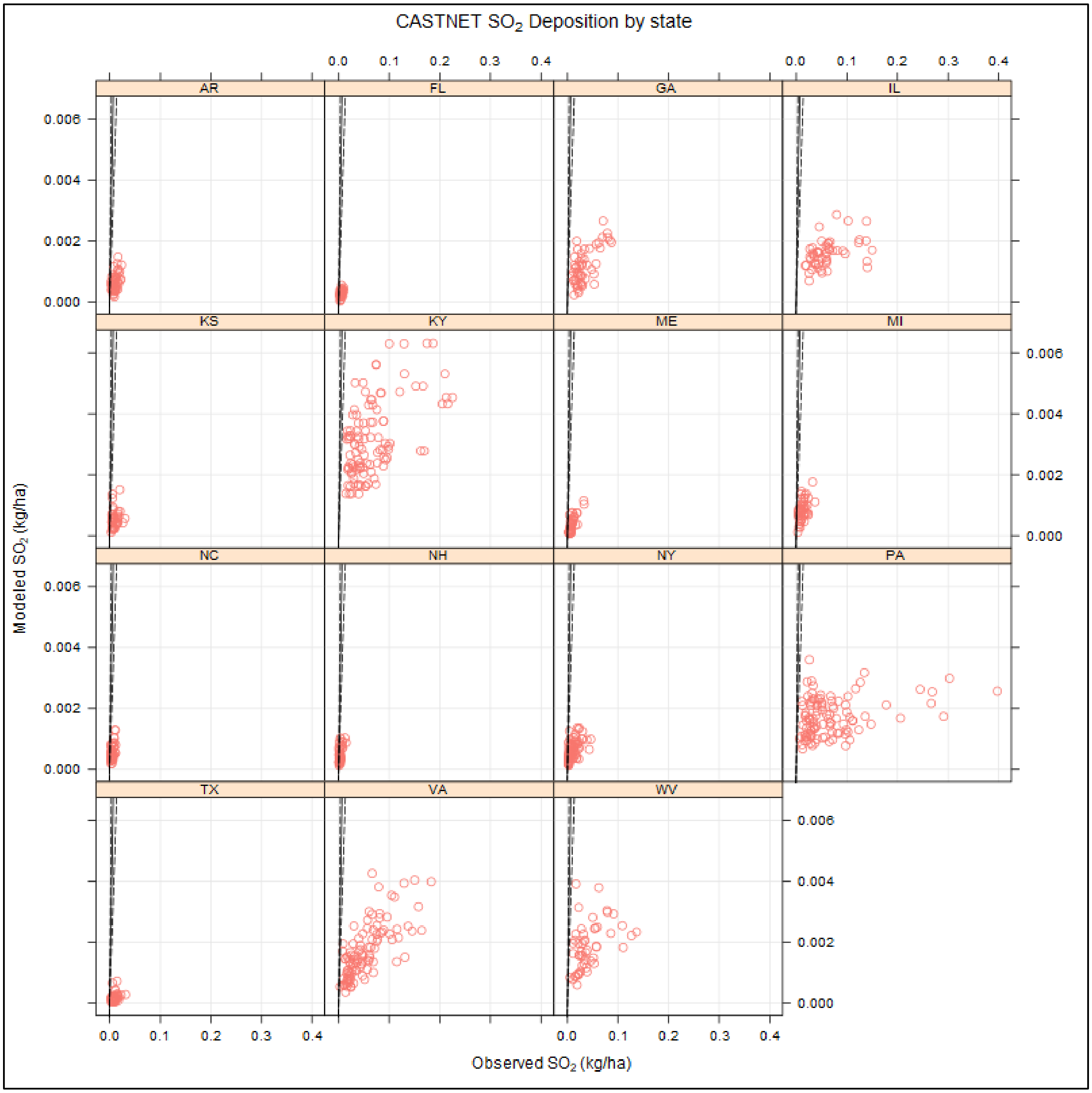

Figure B-6. Modeled SO_2 versus CASTNET Observed SO_2 Dry Deposition, by State

Figure B-7. Normalized Mean Bias for CASTNET Cl⁻ Dry Deposition, by Season

Figure B-8. Normalized Mean Bias for CASTNET NH_4^+ Dry Deposition, by Season

Figure B-9. Normalized Mean Bias for CASTNET NO_3^+ Dry Deposition, by Season

Figure B-10. Normalized Mean Bias for CASTNET HNO_3 Dry Deposition, by Season

Figure B-11. Normalized Mean Bias for CASTNET SO_4^{2-} Dry Deposition, by Season

Figure B-12. Normalized Mean Bias for CASTNET SO_2 Dry Deposition, by Season

Table B-7. Model Performance Metrics for AMoN NH_3 Dry Deposition

Pollutant	State	n	MB (kg/ha)	MGE (kg/ha)	NMB (%)	NME (%)	r (unitless)	MFB (%)	MFE (%)	RMSE (unitless)
NH_3	AR	30	-0.003	0.003	-89%	90%	0.448	-80%	81%	0.004
	FL	40	-0.007	0.007	-99%	99%	0.329	-98%	98%	0.011
	GA	30	-0.004	0.004	-92%	92%	0.209	-85%	86%	0.006
	IL	77	-0.010	0.010	-95%	95%	0.440	-91%	91%	0.019
	KS	28	-0.019	0.019	-94%	95%	0.103	-89%	90%	0.028
	KY	44	-0.008	0.008	-93%	93%	0.408	-87%	87%	0.012
	NC	29	-0.002	0.002	-94%	94%	0.277	-89%	89%	0.002
	PA	45	-0.002	0.002	-96%	96%	0.737	-93%	93%	0.003
	WV	32	-0.003	0.003	-98%	98%	-0.097	-97%	97%	0.005

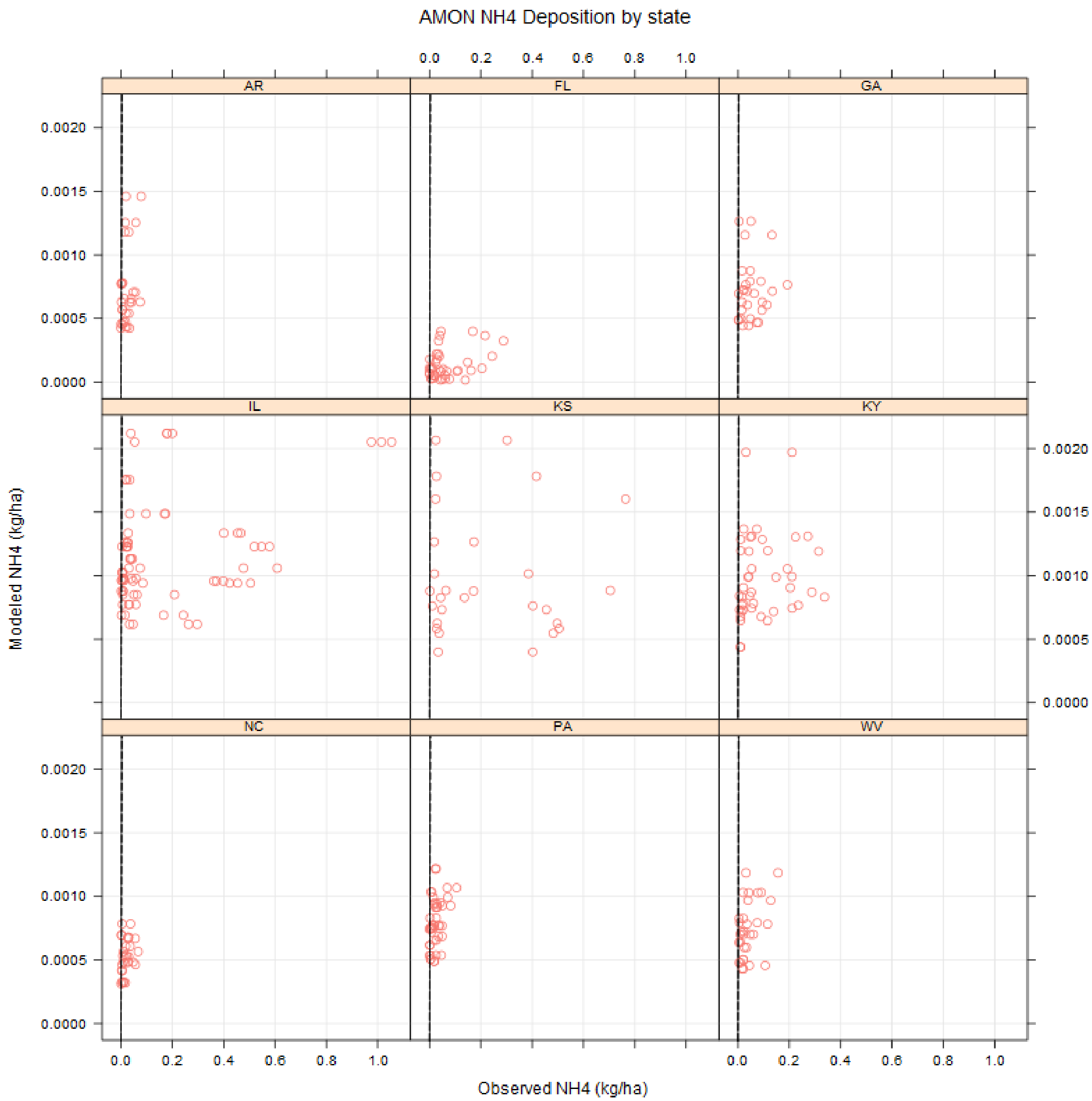

Figure B-13. Modeled NH_3 versus AMoN Observed NH_3 Dry Deposition, by State

Figure B-14. Normalized Mean Bias for AMoN NH_3 Dry Deposition, by Season