NH_3 inversion project and the primary results in the U.S. Corn Belt

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Motivations

- Atmospheric ammonia (NH_3) has increased dramatically in response to the production of synthetic nitrogen (N) fertilizer and proliferation of livestock, there are numerous unintended consequences in atmospheric, terrestrial and aquatic systems [*de Klein et al.*, 2006; *Shcherbak et al.*, 2014].

- Agricultural intensification during the 20th century has increased global soil nitrogen (N) surpluses from 20 to 138 Tg y^{-1}, with projected excesses of 170 Tg y^{-1} by 2050 [*Bouwman et al.*, 2013]. Growing synthetic fertilizer use has been accompanied by increases of 470% in ammonia (NH_3) [*Bouwman et al.*, 2013].

- Agricultural systems are having a profound influence on the global nitrogen (N) cycle and the flux of reactive nitrogen (N_r) into the atmosphere [*Erisman et al.*, 2008; *Zhang et al.*, 2015]. Knowledge regarding the NH_3 budget of the US Corn Belt is lagging far behind that for N_2O. Based on satellite observations, the US Corn Belt has been identified as a global hotspot for NH_3 emissions [*Van Damme et al.*, 2014, 2015].

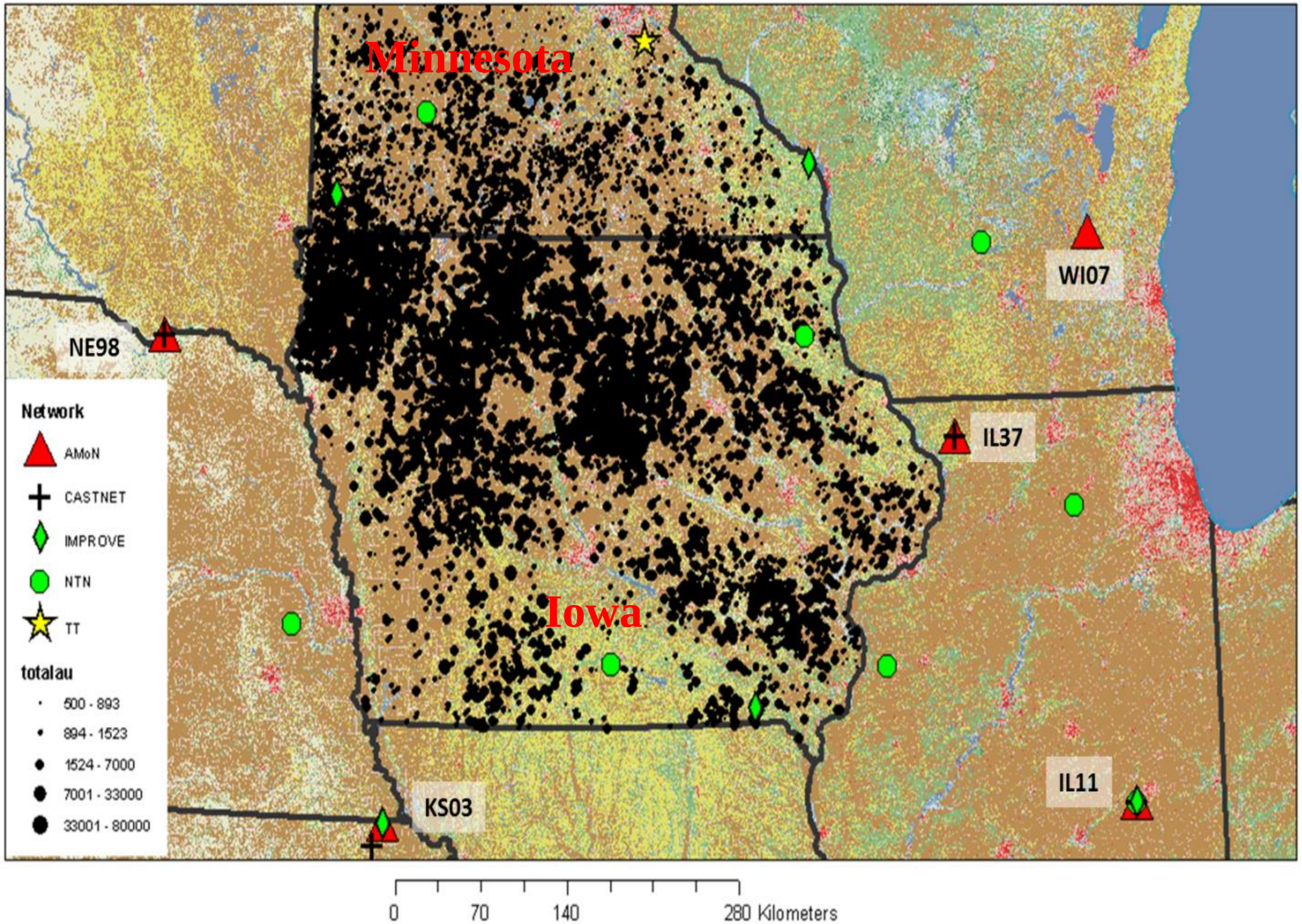
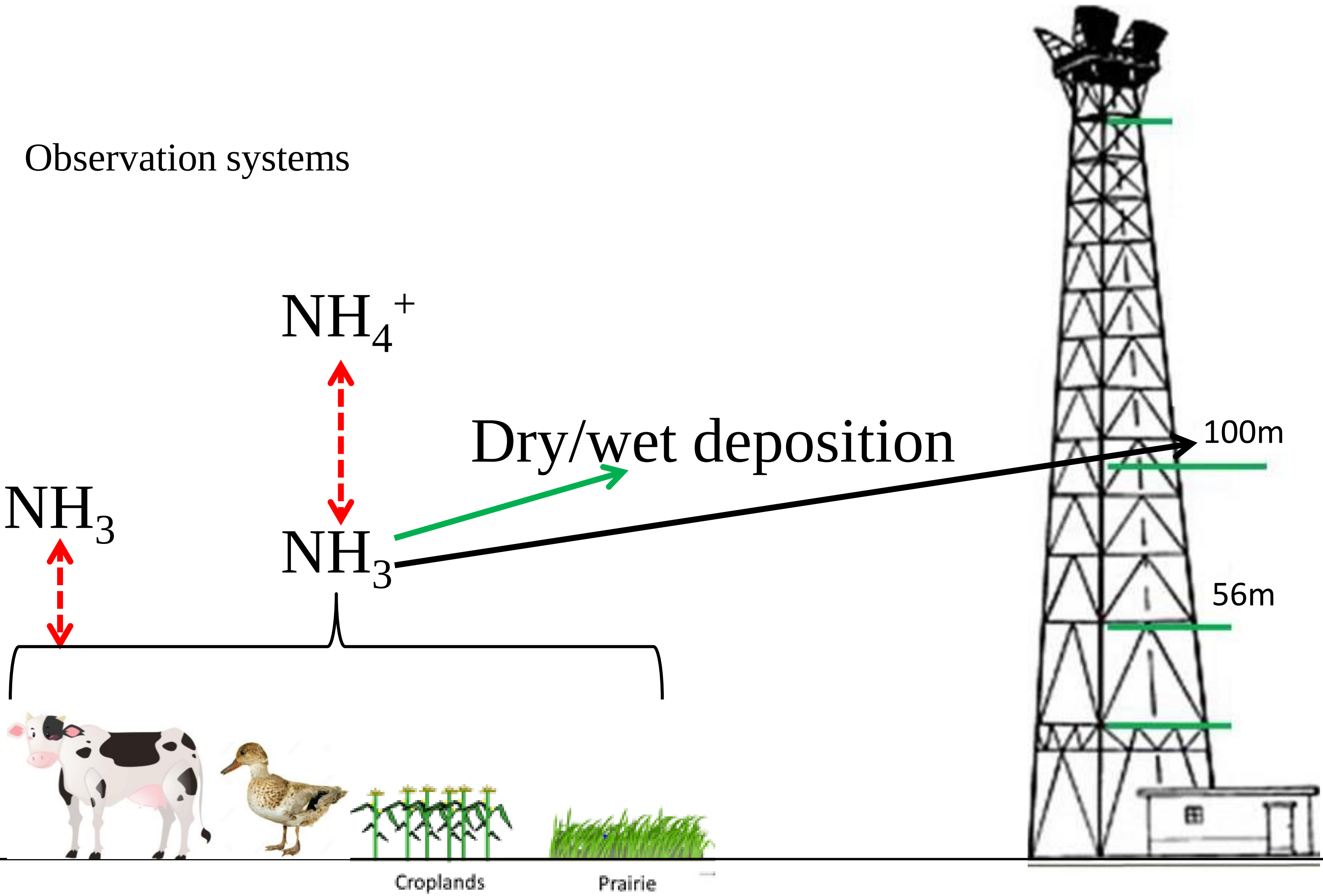


Figure 1. Livestock farms (all animal types) according to size (total animal units = totalau in legend) in Southern Minnesota and Iowa. The land cover is from the National Land Cover Database, brown represents cultivated crops, and yellow pasture/hay.

Table 1. Ammonia Emissions for Animal Husbandry in the United States
United States Environmental Protection Agency, National Emissions Inventory-Ammonia Emissions from Animal Husbandry Operations.

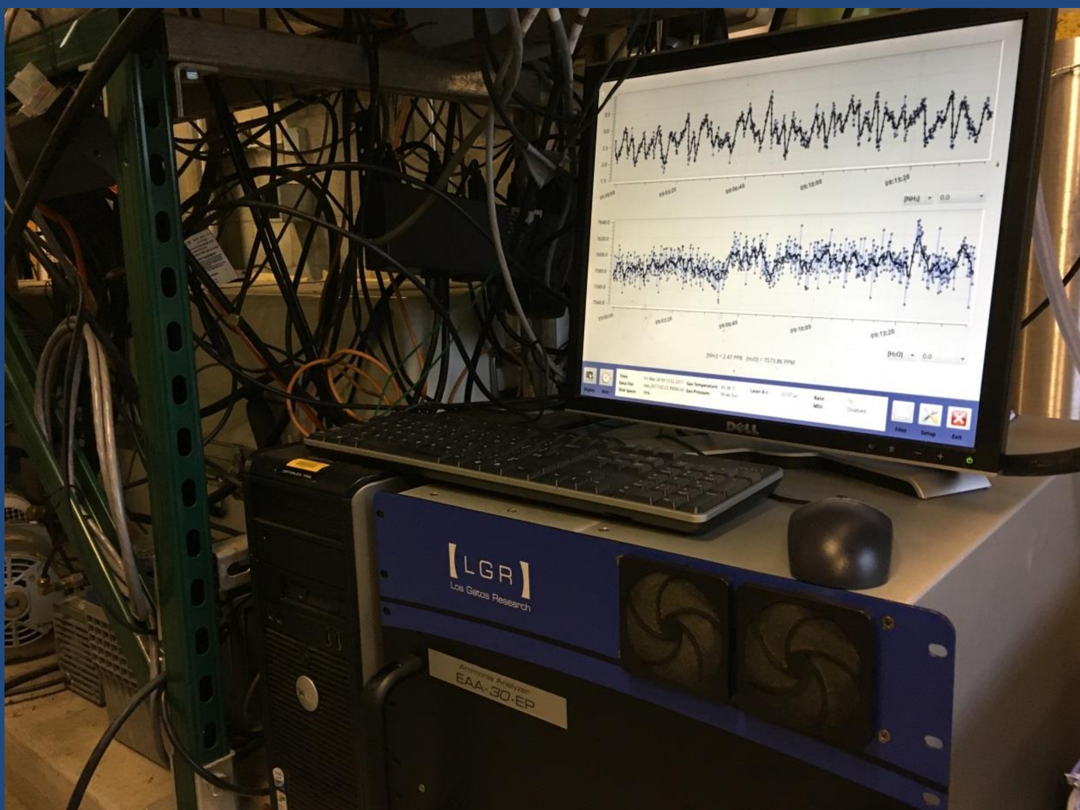
	Ammonia Emissions (tons per year)				
Animal Group	2002	2010	2015	2020	2030
Dairy	558,094	565,892	547,874	545,155	546,666
Beef	656,648	691,174	689,669	705,659	733,662
Poultry	664,238	648,200	720,449	770,068	869,348
Swine	429,468	485,223	512,458	529,288	518,082

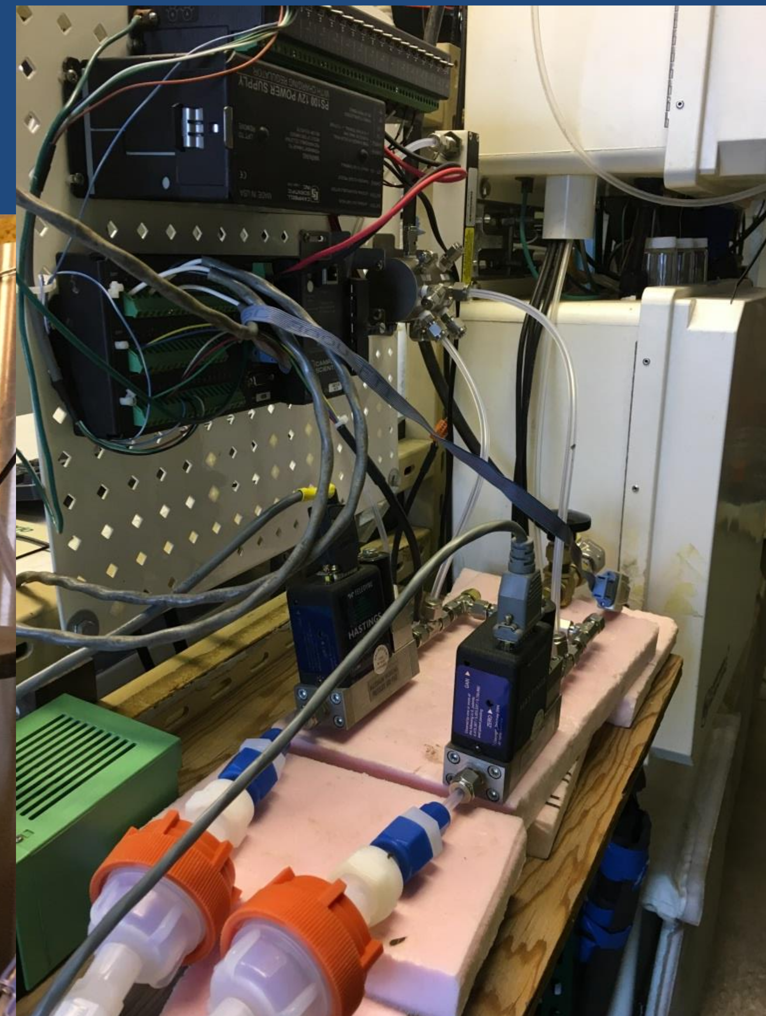
Observation systems



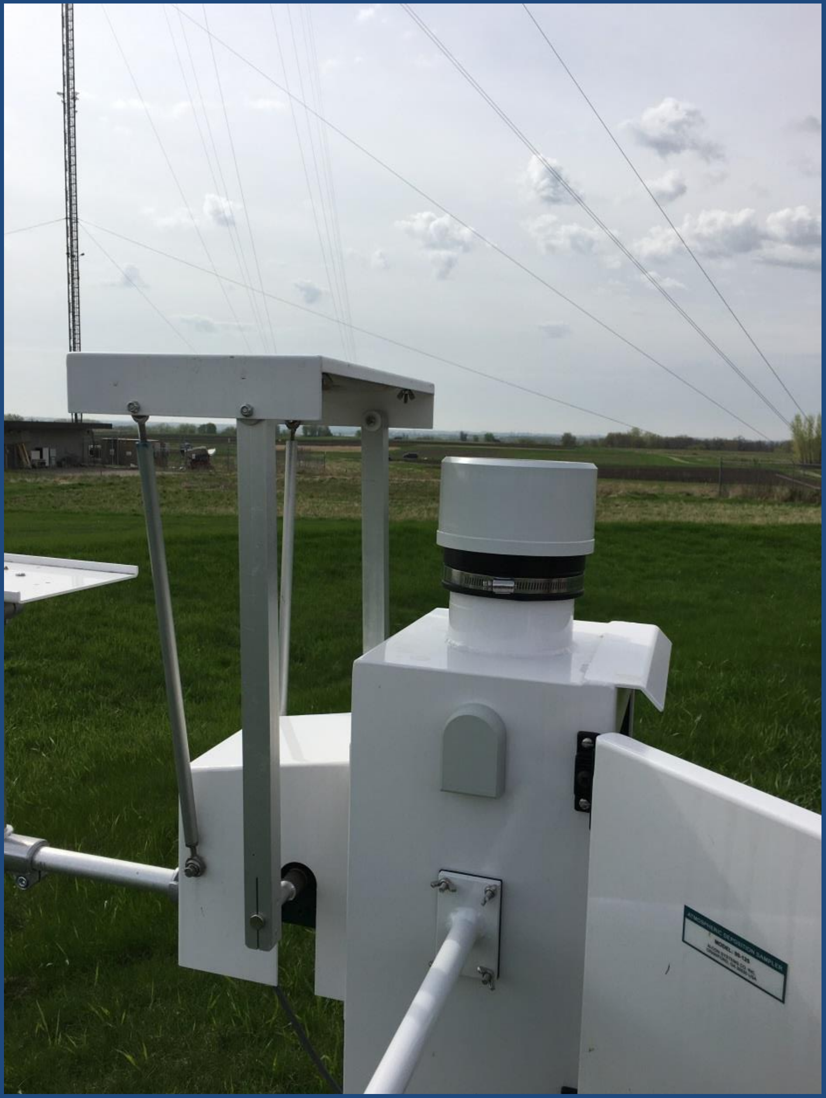
Installation of Teflon Lines for measuring NH3 mixing ratios at 56 m and 100 m

LGR Cavity Ring-down System for NH3 Measurement



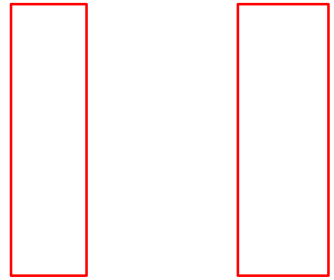


Wet Deposition Measured at Tall Tower



Preliminary Measurements

(a)



(b)

(c)

Figure 2. Time series of NH_3 and sonic temperature measured at the tall tower

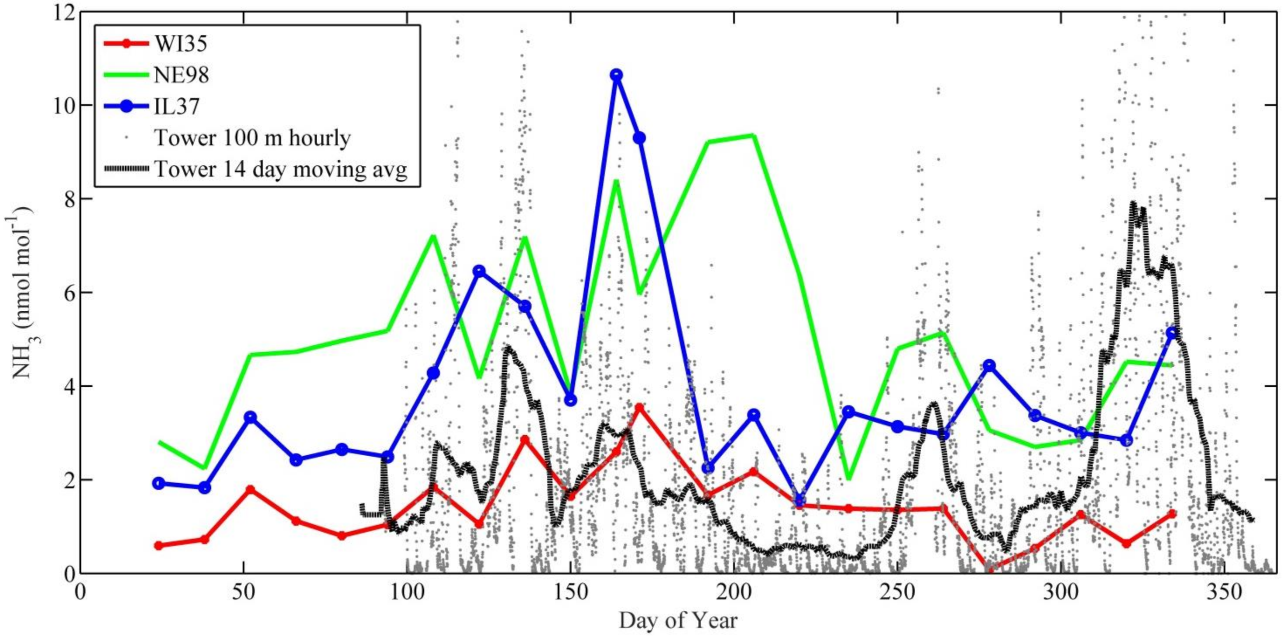
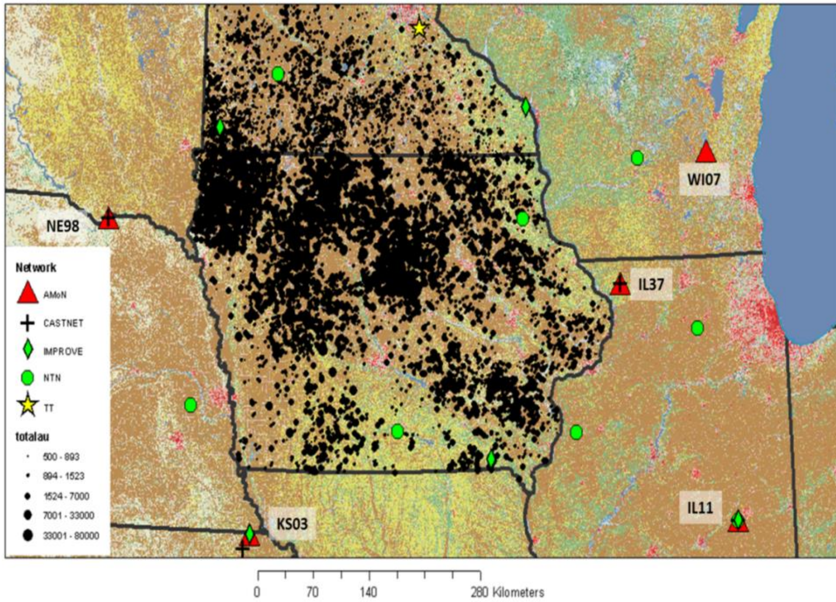


Figure 3. Comparison between our tall tower observations with AMoN NH_3 observation systems.



A significant influence of southerly flow (ag lands) on NH3 mixing ratio

(a)

(b)

(c)

(d)

Figure 4. Relationship between NH_3 concentration and wind directions.

Figure 5. Diurnal variation of NH_3 concentration at 2 heights.

(a)

(b)

Figure 6. Observed NH_3 net flux by gradient method.

Figure 7. Monthly averaged diurnal NH_3 flux from April 2017 to November 2017.

Figure 8. Observed wet deposition of NH_x around our tall tower.

Preliminary Modeling results

*NH_3, $NH4^+$ concentration
*dry/wet deposition of NH_3 and $NH4^+$

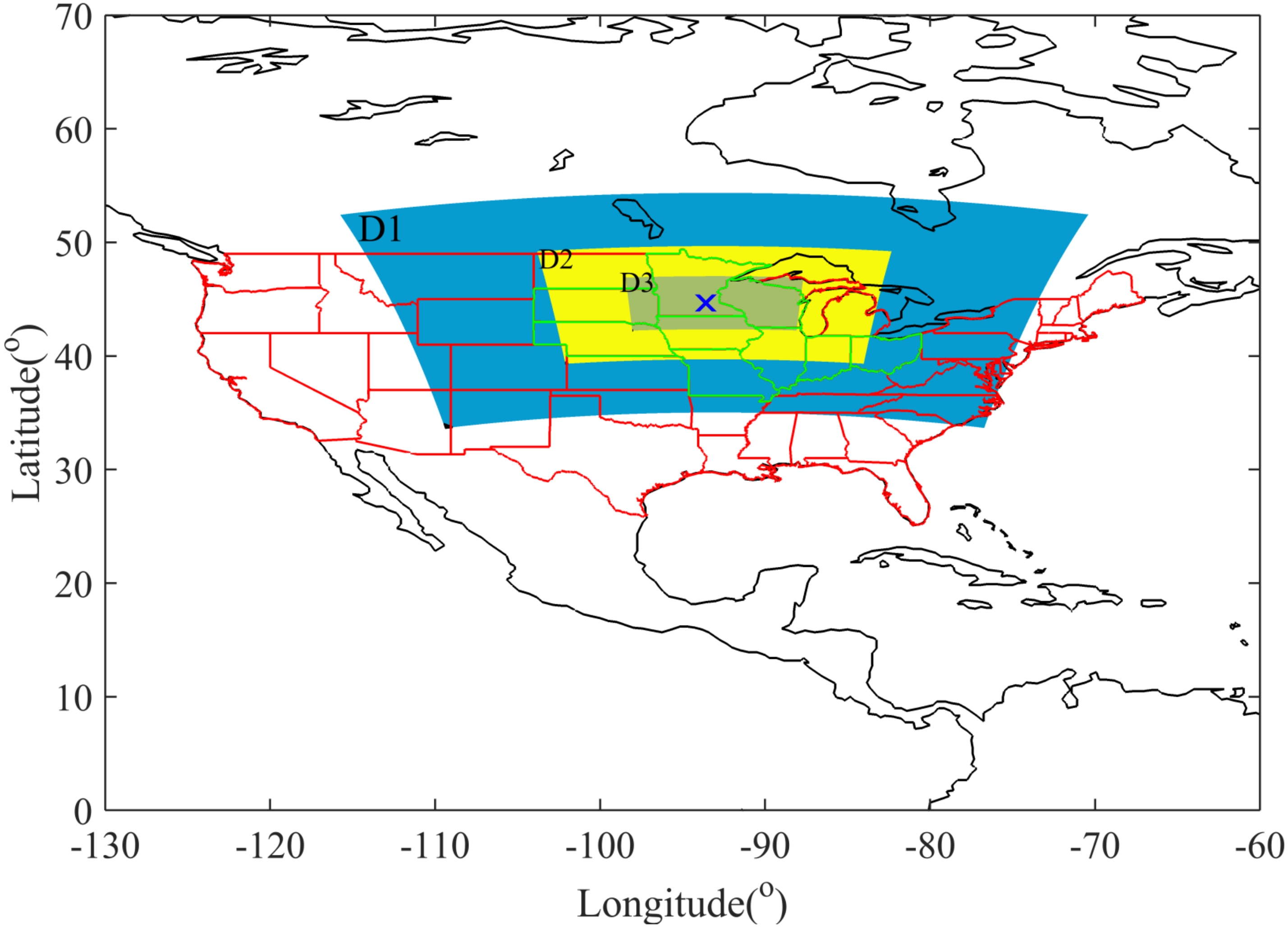
General idea of NH_3 inversion

Footprint × NH_x flux { NH_3 emission, NH_3 dry/wet deposition, NH_4 dry/wet deposition } = NH_3 concentration, NH_3 concentration loss, NH_4 concentration loss

- NH_3 emission → NH_3 concentration
- NH_3 dry/wet deposition → NH_3 concentration loss
- NH_4 dry/wet deposition → NH_4 concentration loss

WRF-STILT model : Footprint

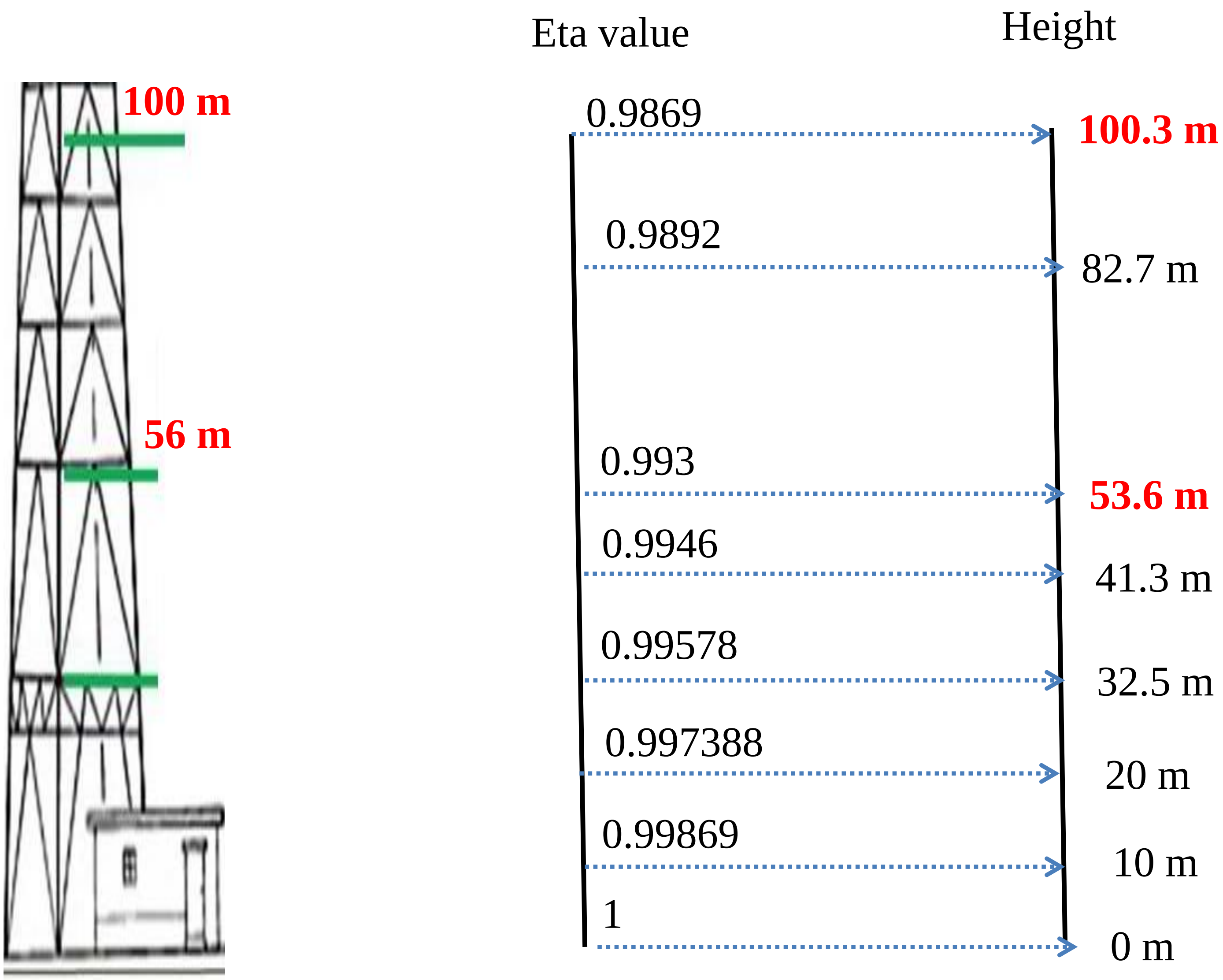
WRF-CHEM model: NH3 dry/wet deposition, NH^{4}+ dry/wet deposition



Chem_opt=202

Figure 9. WRF-CHEM domain setup.

WRF-CHEM model layers



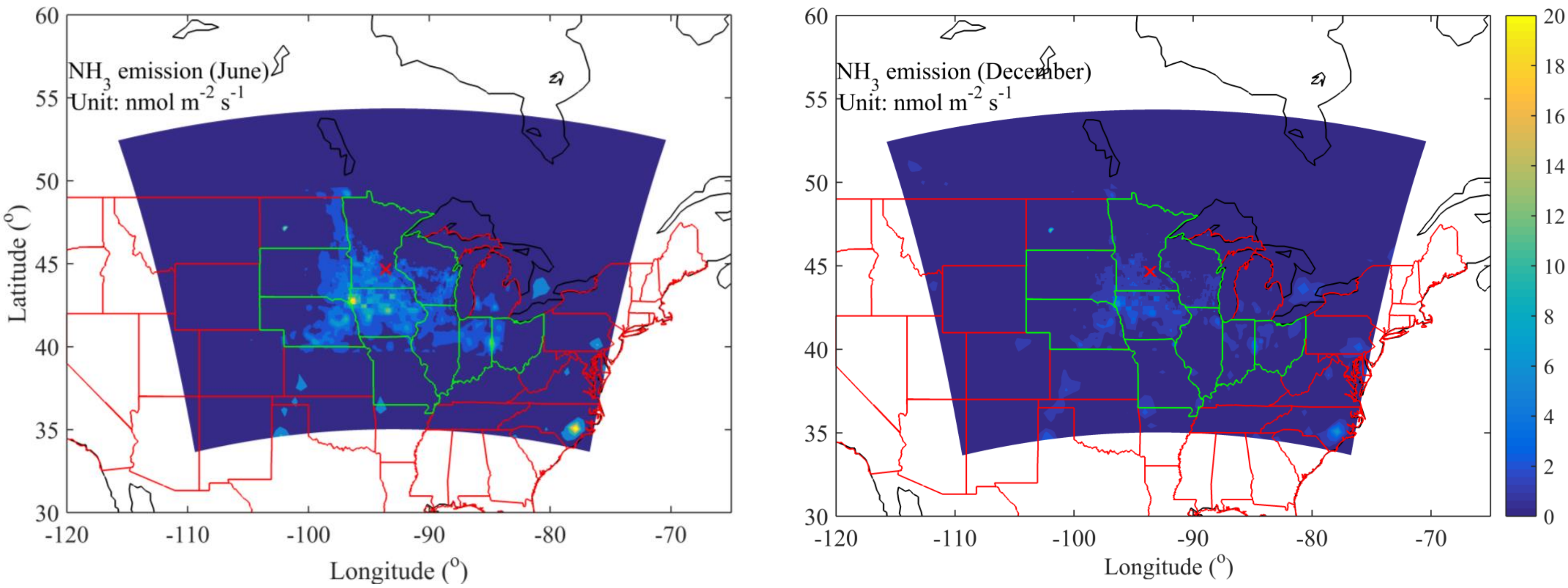


Figure 10. NH_3 emissions in June and December.

	June	November	December
NH_3 emissions ($nmol\ m^{-2}\ s^{-1}$)	2.736	1.751	0.820

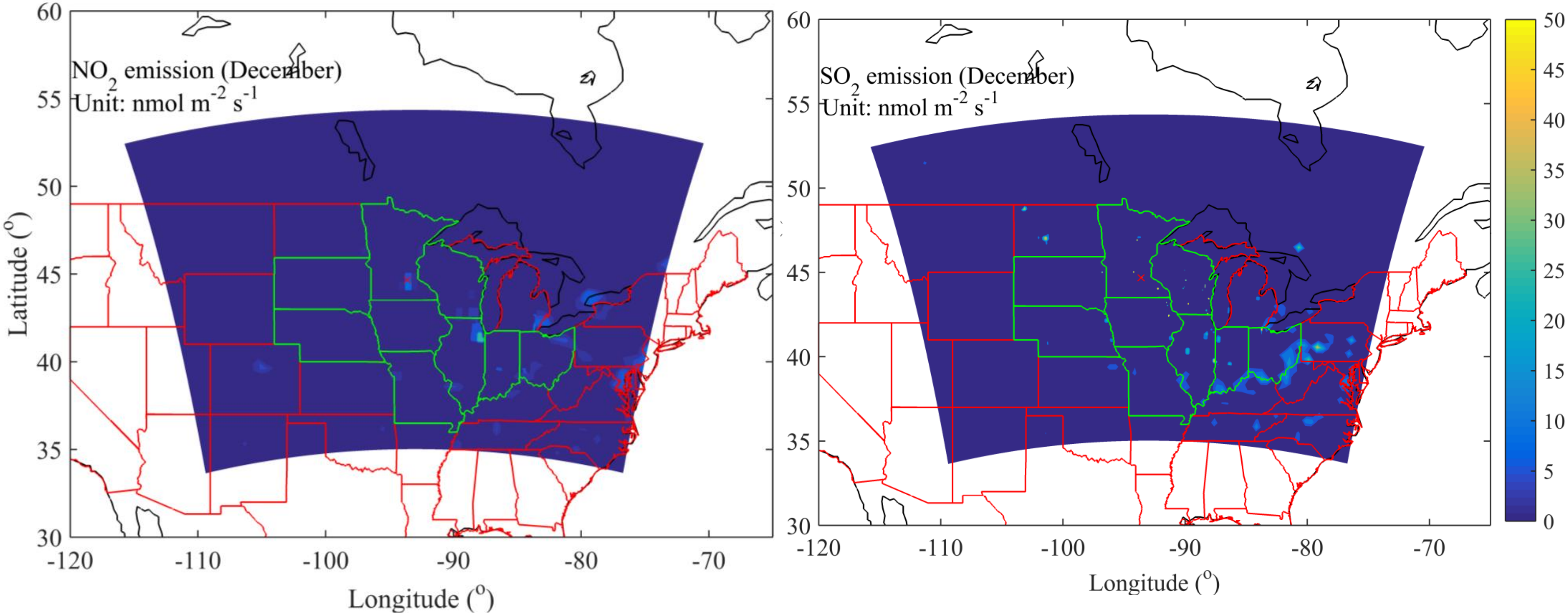
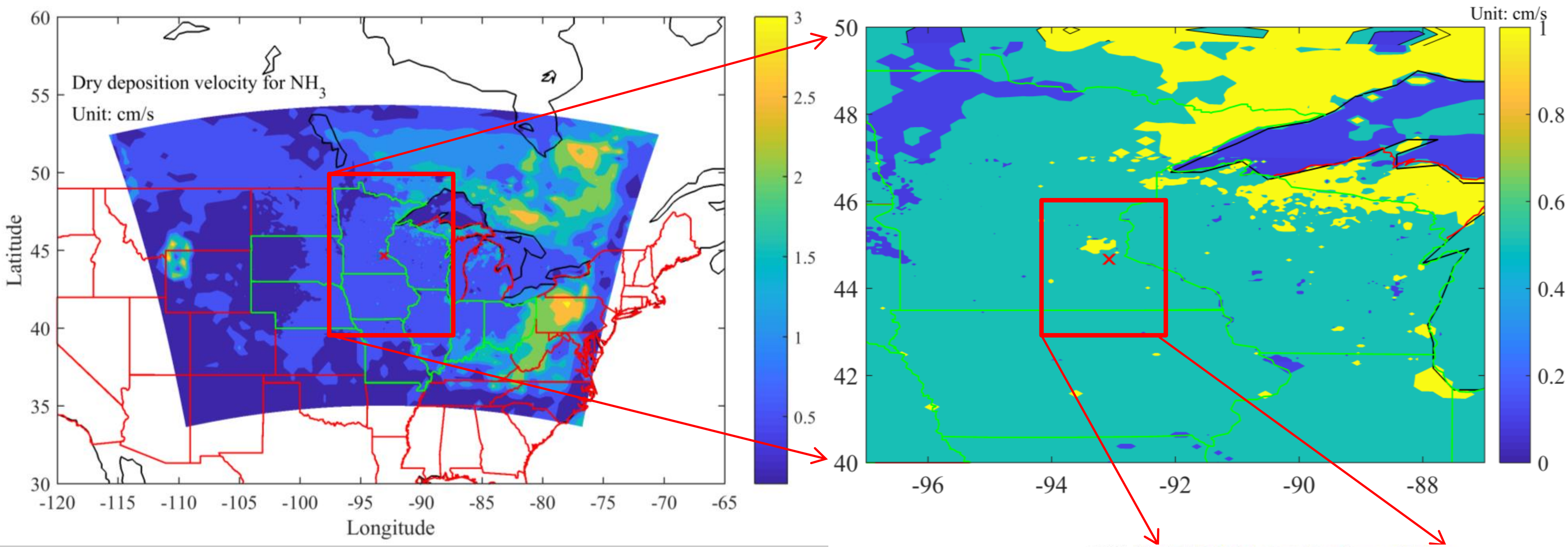


Figure 11. Emission map for NO_2(left) and SO_2 (right).



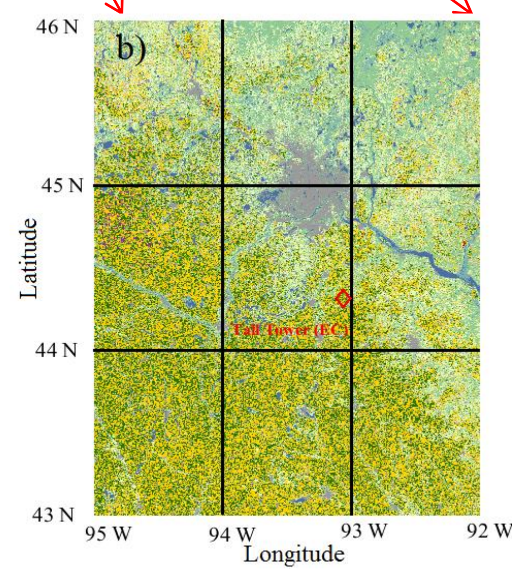


Figure 12. Dry deposition velocity of NH_3 in our model domain.

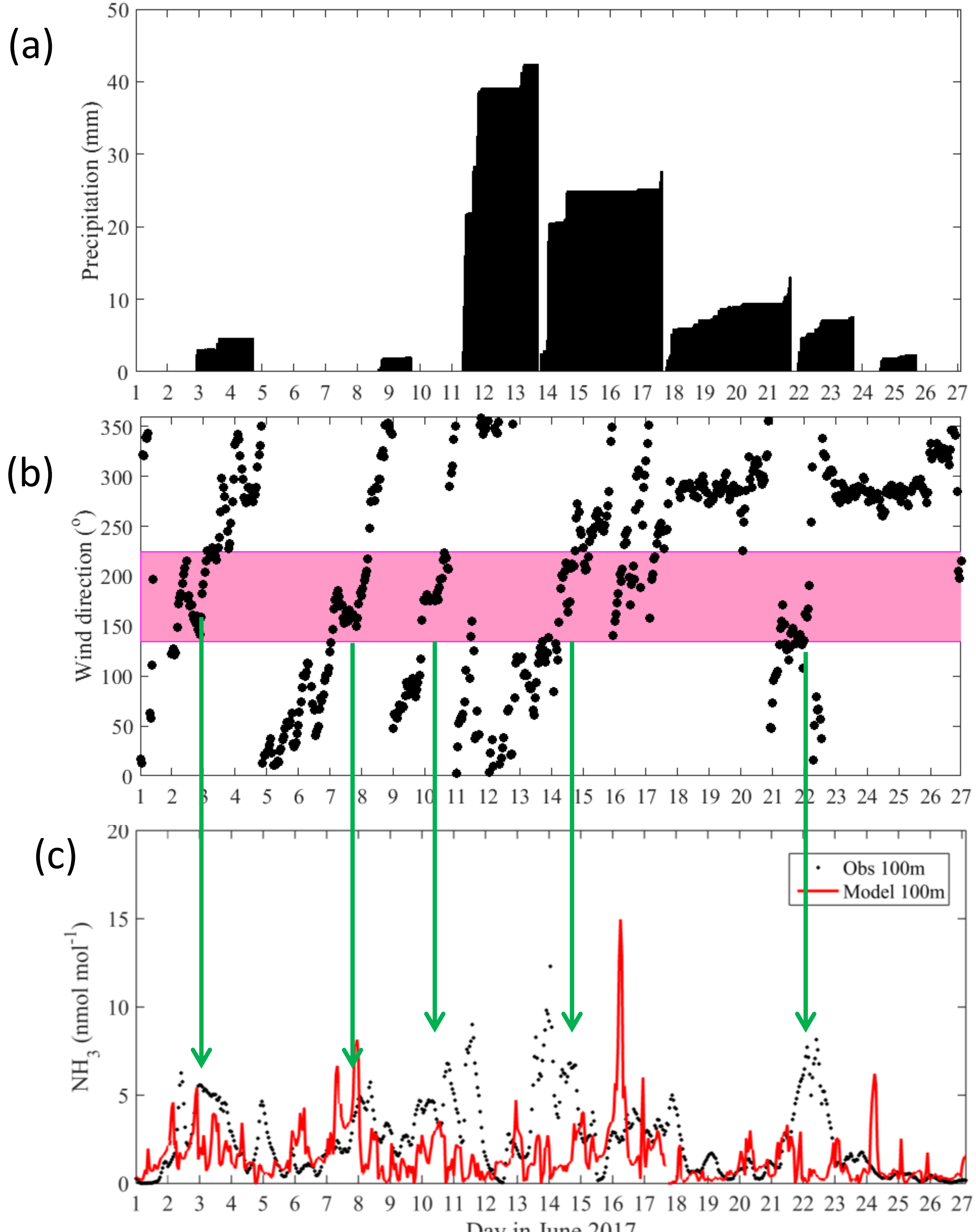


Figure 13. Comparison between modeled and observed NH_3 concentration in June 2017.

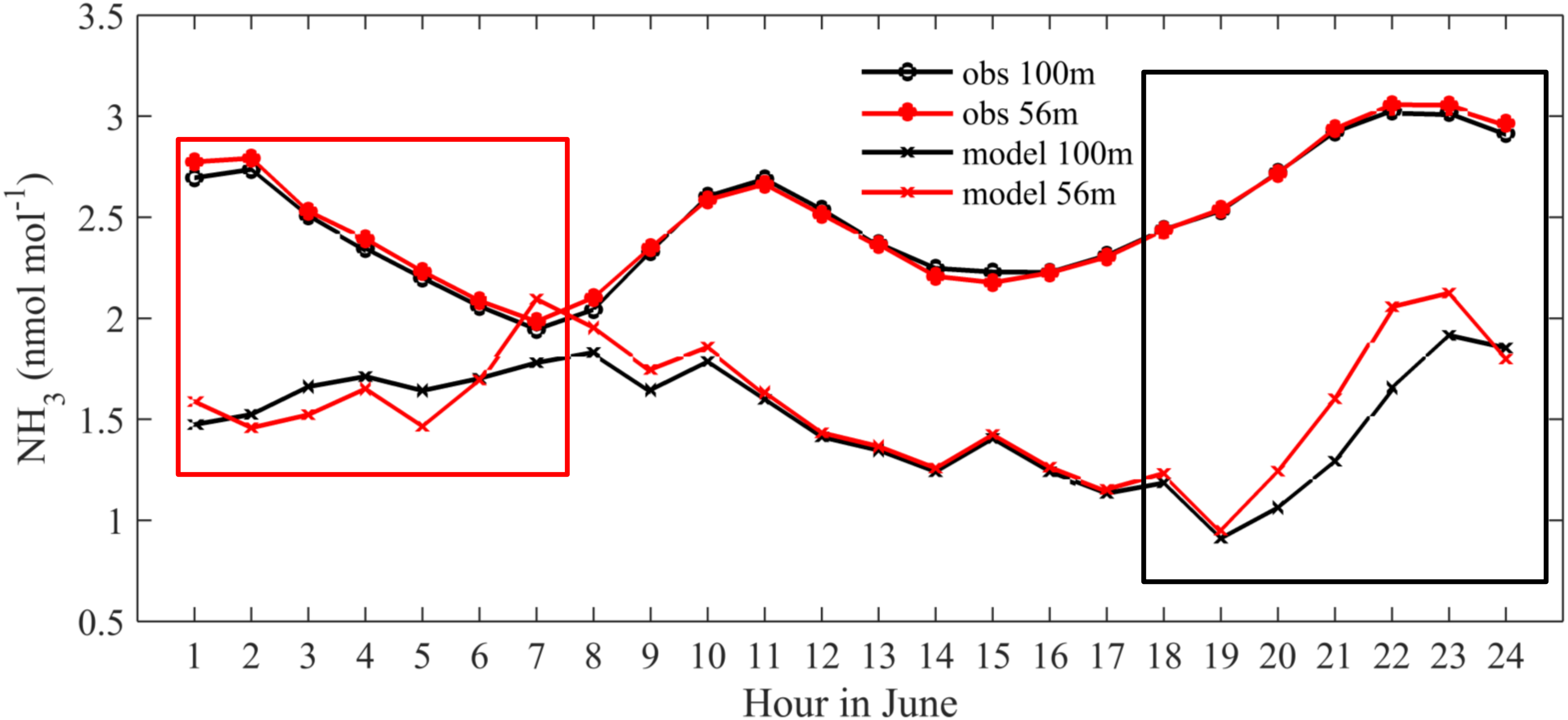


Figure 14. Monthly averaged diurnal variation of NH_3 concentrations in June.

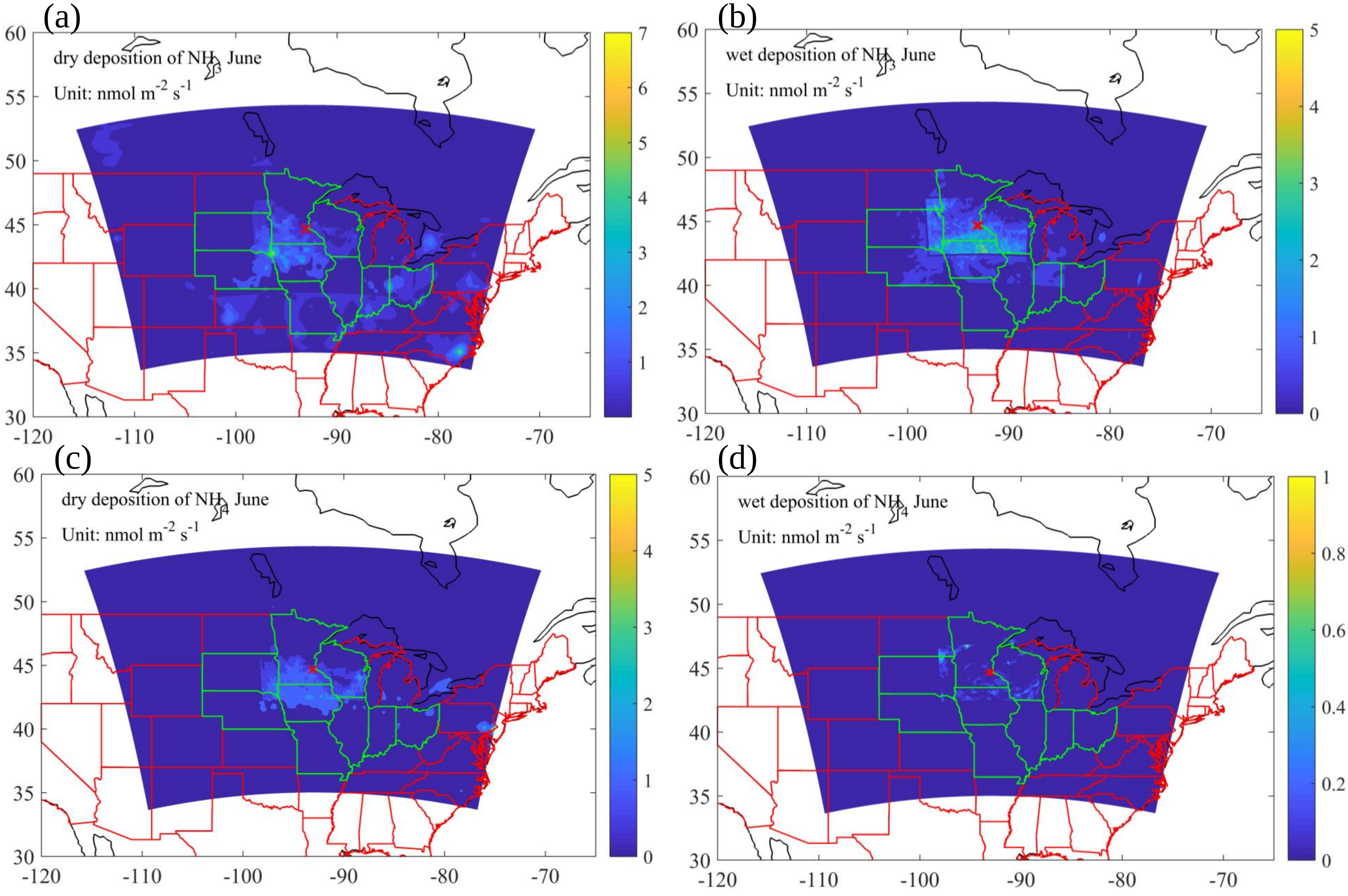


Figure 15. NH_x maps for a) dry deposition of NH_3, b) wet deposition of NH_3, c) dry deposition of NH_4^+, and d) wet deposition of NH_4^+, respectively.

Table 2. NH_x flux balance for dry and wet deposition.

June	NH_3 emissions	NH_3 dry deposition	NH_3 wet deposition	NH_4^+ dry deposition	NH_4^+ dry deposition
Domain3 (nmol m^{-2} s^{-1})	2.736	0.749	1.079	0.654	0.064

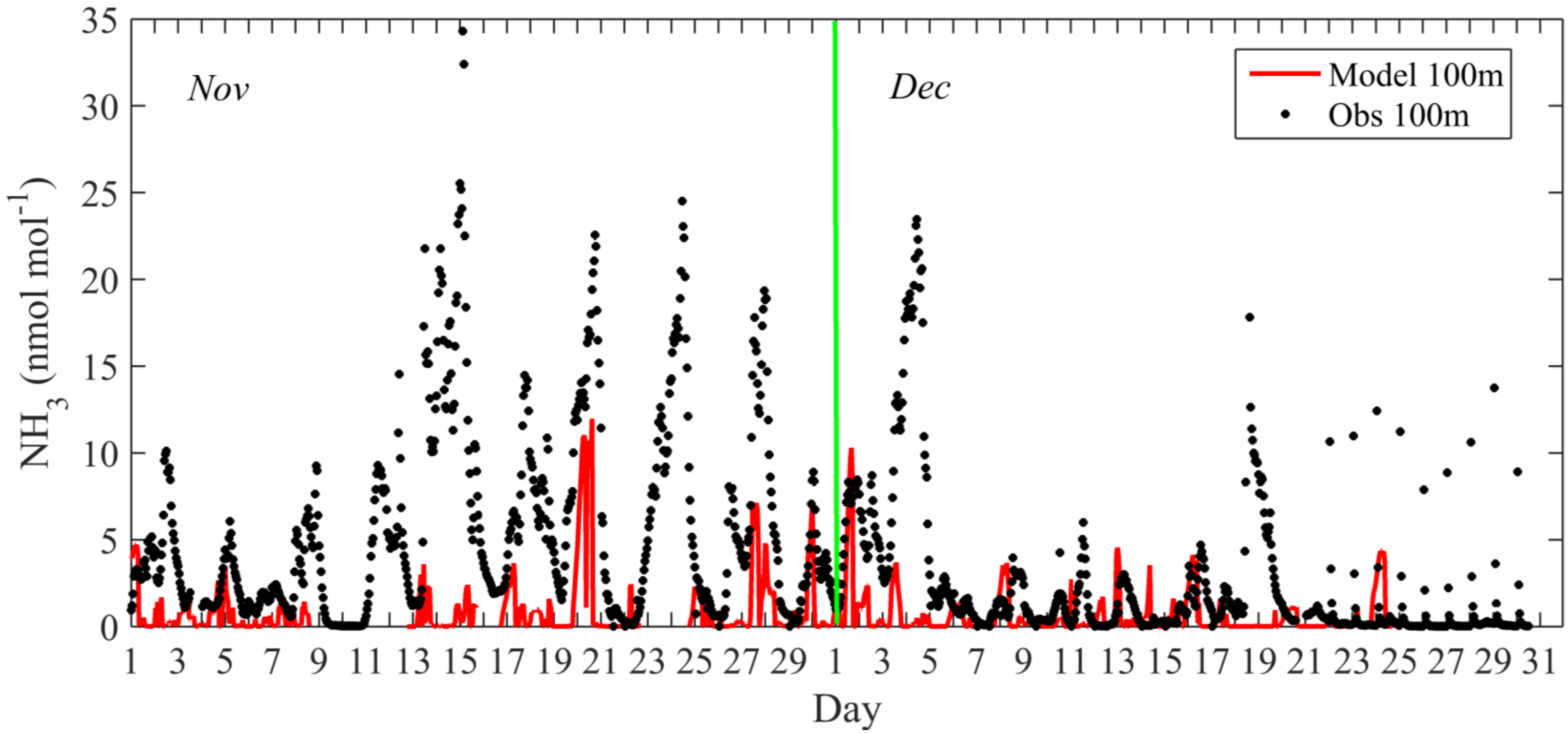


Figure 16. Comparison between modeled and observed NH_3 concentration at 100 m height in November and December, 2017.

Conclusions

❖ Observed NH_3 concentration shown large seasonal variations, with the maximum occurred in November and early December for the fertilizer application, while the EDGAR NH_3 products did not well capture the seasonal variations of NH_3 emissions.

❖ Observed NH_3 net flux in different months displayed distinct diurnal variation. Land surface can act as NH_3 sinks before sunrise, and act as sources in the daytime.

❖ Modeled NH_3 budget of NH_3 emissions, NH_3 dry deposition, NH_3 wet deposition, NH_4 dry deposition, and NH_4 wet deposition are 2.736, 0.749, 1.079, 0.654, and 0.064 nmol m^{-2} s^{-1} in June for our Domain3.

❖ WRF-CHEM model results in November indicate the potential low NH_3 emissions in EDGAR, which does not fully considered the application of fertilizer.

Next steps

- Simulate the NH_3 flux for the whole year.

- Combine the footprint (WRF-STILT) model with Bayesian inversion method to constrain NH_3 flux at the U.S. Corn Belt.