NH$_3$ inversion project and the primary results in the U.S. Corn Belt

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Motivations

• Atmospheric ammonia (NH₃) 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 (NH₃) [Bouwman et al., 2013].

• Agricultural systems are having a profound influence on the global nitrogen (N) cycle and the flux of reactive nitrogen (Nᵣ) into the atmosphere [Erisman et al., 2008; Zhang et al., 2015]. Knowledge regarding the NH₃ budget of the US Corn Belt is lagging far behind that for N₂O. Based on satellite observations, the US Corn Belt has been identified as a global hotspot for NH₃ 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

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<tbody>
<tr>
<td>Dairy</td>
<td>558,094</td>
<td>565,892</td>
<td>547,874</td>
<td>545,155</td>
<td>546,666</td>
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<tr>
<td>Beef</td>
<td>656,648</td>
<td>691,174</td>
<td>689,669</td>
<td>705,659</td>
<td>733,662</td>
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<tr>
<td>Poultry</td>
<td>664,238</td>
<td>648,200</td>
<td>720,449</td>
<td>770,068</td>
<td>869,348</td>
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<tr>
<td>Swine</td>
<td>429,468</td>
<td>485,223</td>
<td>512,458</td>
<td>529,288</td>
<td>518,082</td>
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</table>
Observation systems

$\text{NH}_3$

$\text{NH}_4^+$

Dry/wet deposition

$\text{NH}_3$

Croplands

Prairie
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
Figure 2. Time series of NH3 and sonic temperature measured at the tall tower
Figure 3. Comparison between our tall tower observations with AMoN NH₃ observation systems.
A significant influence of southerly flow (ag lands) on NH3 mixing ratio

Figure 4. Relationship between NH$_3$ concentration and wind directions.
Figure 5. Diurnal variation of NH$_3$ concentration at 2 heights.
Figure 6. Observed NH₃ 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

*NH₃, NH₄⁺ concentration
*dry/wet deposition of NH₃ and NH₄⁺
General idea of NH$_3$ inversion

WRF-STILT model: Footprint

WRF-CHEM model: NH$_3$ dry/wet deposition, NH$_4^+$ dry/wet deposition
Figure 9. WRF-CHEM domain setup.

Chem_opt=202
WRF-CHEM model layers

<table>
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<tr>
<th>Eta value</th>
<th>Height</th>
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<tbody>
<tr>
<td>0.9869</td>
<td>100.3 m</td>
</tr>
<tr>
<td>0.9892</td>
<td>82.7 m</td>
</tr>
<tr>
<td>0.993</td>
<td>53.6 m</td>
</tr>
<tr>
<td>0.9946</td>
<td>41.3 m</td>
</tr>
<tr>
<td>0.99578</td>
<td>32.5 m</td>
</tr>
<tr>
<td>0.997388</td>
<td>20 m</td>
</tr>
<tr>
<td>0.99869</td>
<td>10 m</td>
</tr>
<tr>
<td>1</td>
<td>0 m</td>
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</table>
Figure 10. NH$_3$ emissions in June and December.

<table>
<thead>
<tr>
<th>NH$_3$ emissions (nmol m$^{-2}$ s$^{-1}$)</th>
<th>June</th>
<th>November</th>
<th>December</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>2.736</td>
<td>1.751</td>
<td>0.820</td>
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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\textsubscript{x} flux balance for dry and wet deposition.

<table>
<thead>
<tr>
<th>June emissions (nmol m\textsuperscript{2} s\textsuperscript{-1})</th>
<th>NH\textsubscript{3} dry deposition</th>
<th>NH\textsubscript{3} wet deposition</th>
<th>NH\textsubscript{4}\textsuperscript{+} dry deposition</th>
<th>NH\textsubscript{4}\textsuperscript{+} dry deposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain3</td>
<td>2.736</td>
<td>0.749</td>
<td>1.079</td>
<td>0.654</td>
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</table>
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.