Ammonia spatiotemporal amounts and trends over the Mid-Atlantic

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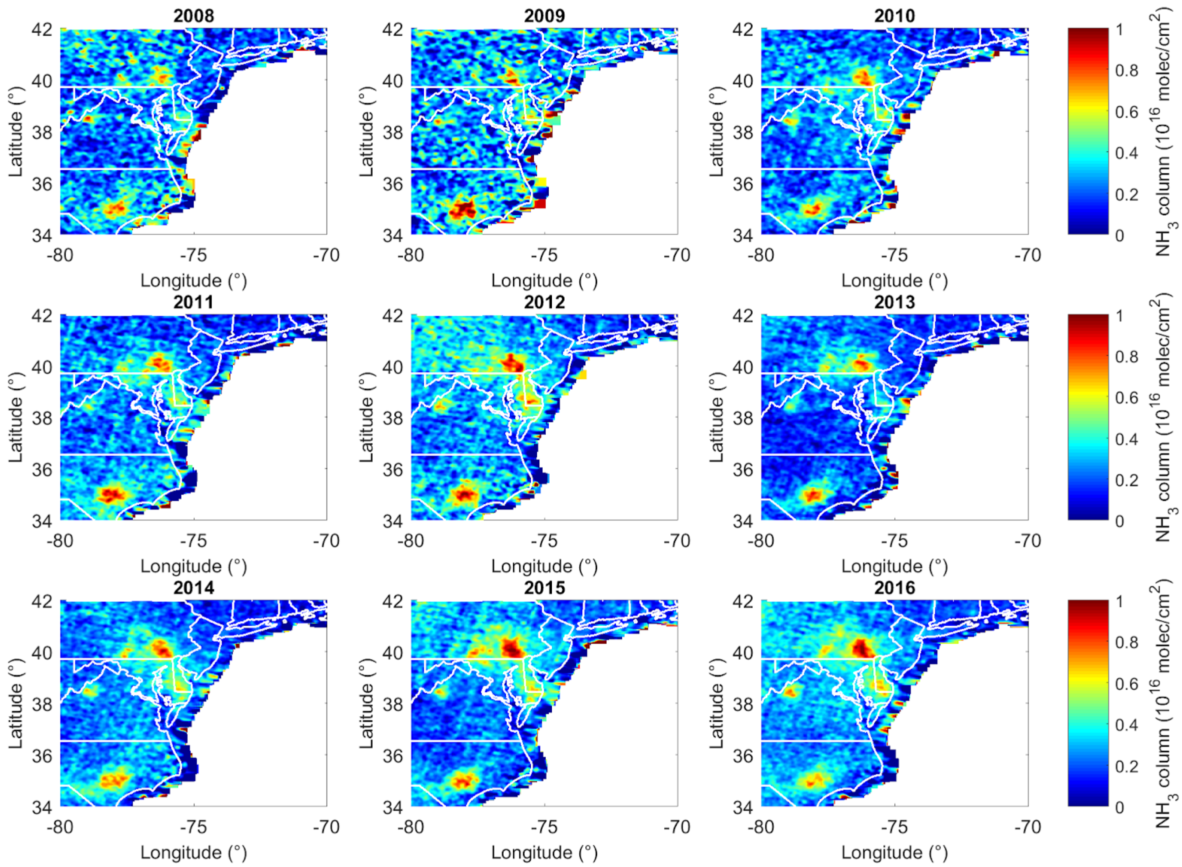
Satellite-based ammonia (NH_3) measurements are providing unprecedented observations of its spatiotemporal patterns, and these data can be used as constraints for emission inventories and air quality modeling. Ammonia is a critical precursor species for unhealthy fine particulate matter, and knowledge of the location of its sources and their associated temporal evolutions are necessary to reduce PM2.5 levels.[1] The purpose of this report is to document amounts of NH_3 in the mid-Atlantic, highlighting regional "hotpots" of this important precursor species and how these amounts and their distributions change monthly, seasonally, yearly, and the trends from 2008-2016 (cf. 2008 was the start of the satellite ammonia measurements).

These data were acquired from the Infrared Atmospheric Sounding Interferometer (IASI) instrument onboard the European Space Agency's MetOp/A and MetOp/B satellites (ANNI-NH3-v2.1R-I).[2] High-resolution spatial datasets product were derived through an oversampling algorithm applied to the Level 2 data to achieve 0.02º horizontal resolution measurements.[3] Similar approaches were used for deducing monthly NH_3 variations across the United States.[4]

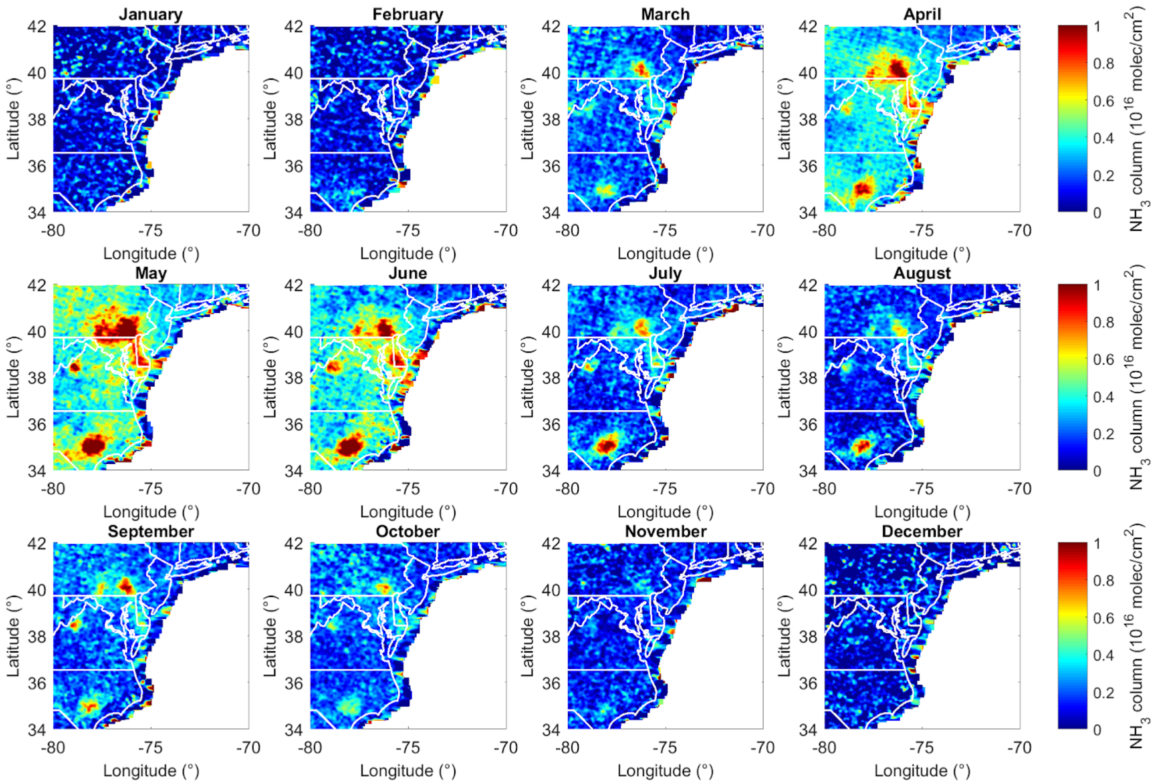
Figures on the following pages highlight various aspects of ammonia over the Mid-Atlantic region, a summary list is included below:

Figure 1. Annual NH_3 columns for each year, 2008-2016



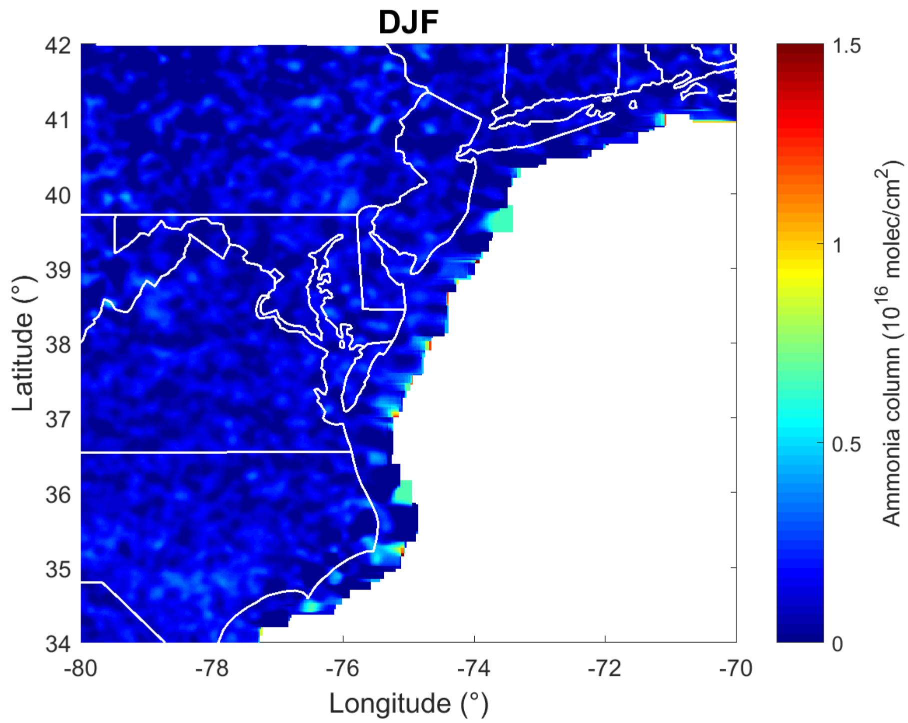
Hotspots can be found in Delaware, southeastern Pennsylvania, northwestern Virginia and southeastern North Carolina. The scale and magnitude of the hotspots show a growing trend over the years. Interannual differences are observed and may be related to meteorological and agricultural practice differences between years.

Figure 2. Monthly average NH_3 columns



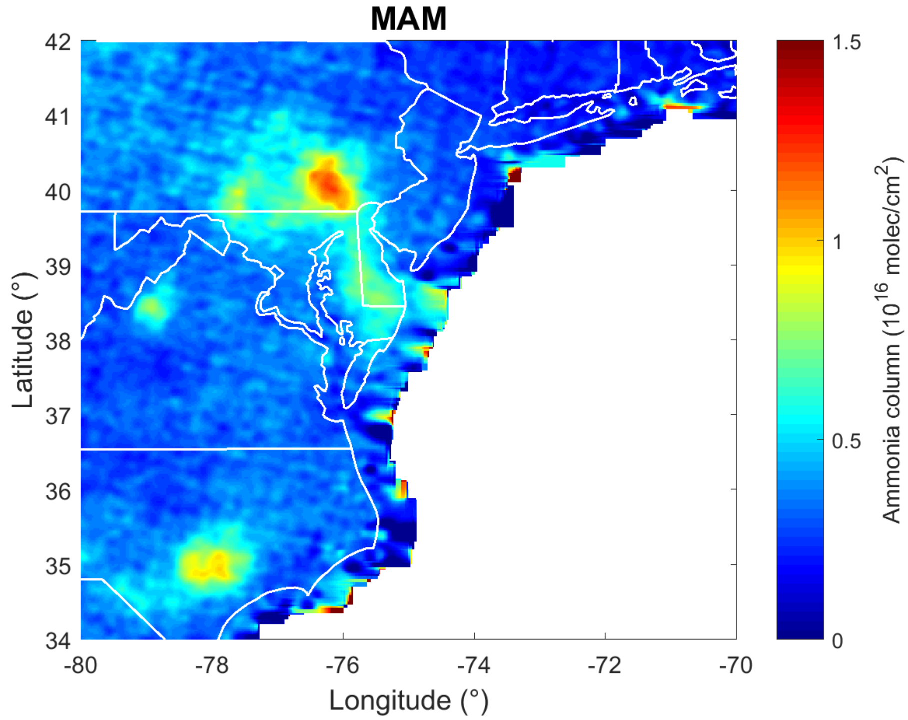
Monthly NH_3 in the Mid-Atlantic region from 2008-2016. NH_3 shows distinct season variabilities, peaking in spring and summer. NH_3 emissions are enhanced by elevated temperatures and agricultural activities (e.g. fertilizer application and re-emission) during these seasons.

Figure 3a. Seasonal map of NH_3 columns (winter)



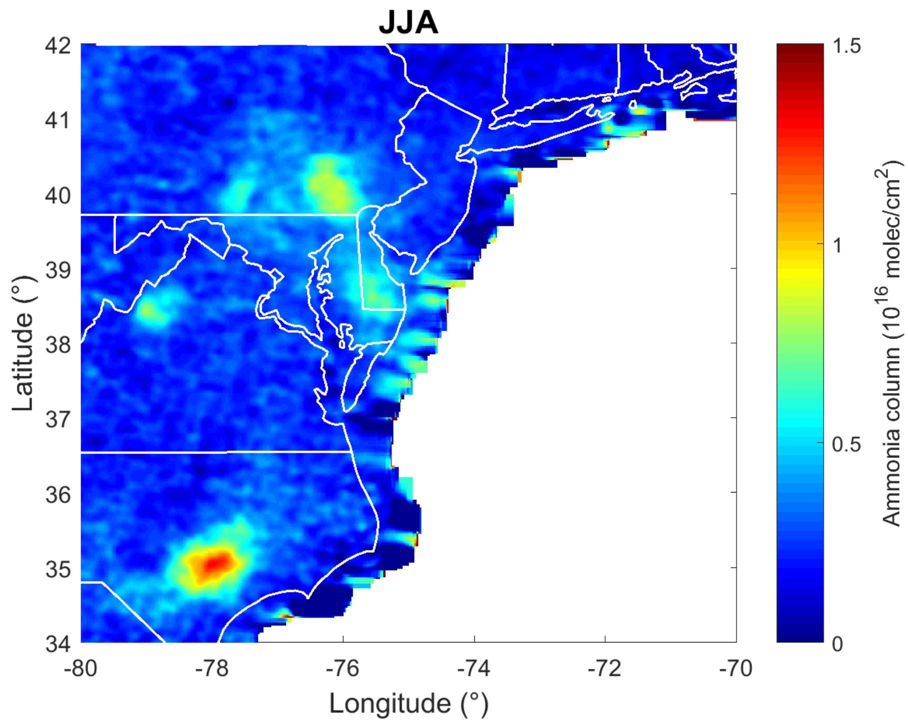
NH_3 in the winter (December, January, February) over the Mid-Atlantic region from 2008-2016. NH_3 is lower in this region in winter than other seasons. No obvious hotspots are observed.

Figure 3b. Seasonal map of NH_3 columns (spring)



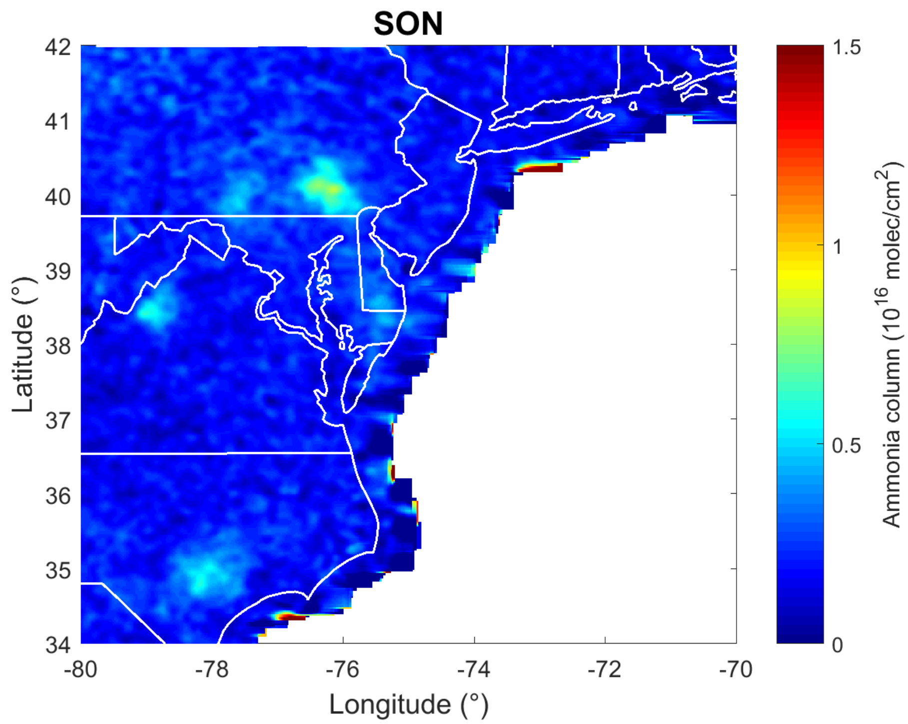
NH_3 in the spring (March, April, May) over the Mid-Atlantic region from 2008 – 2016. Ammonia starts to increase as fertilizer application begins and the temperatures increase, causing volatilization from feedlots and surface fertilizers. Hotspots can be found in Delaware, northwest Virginia, southeastern Pennsylvania and southeastern North Carolina.

Figure 3c. Seasonal map of NH_3 columns (summer)



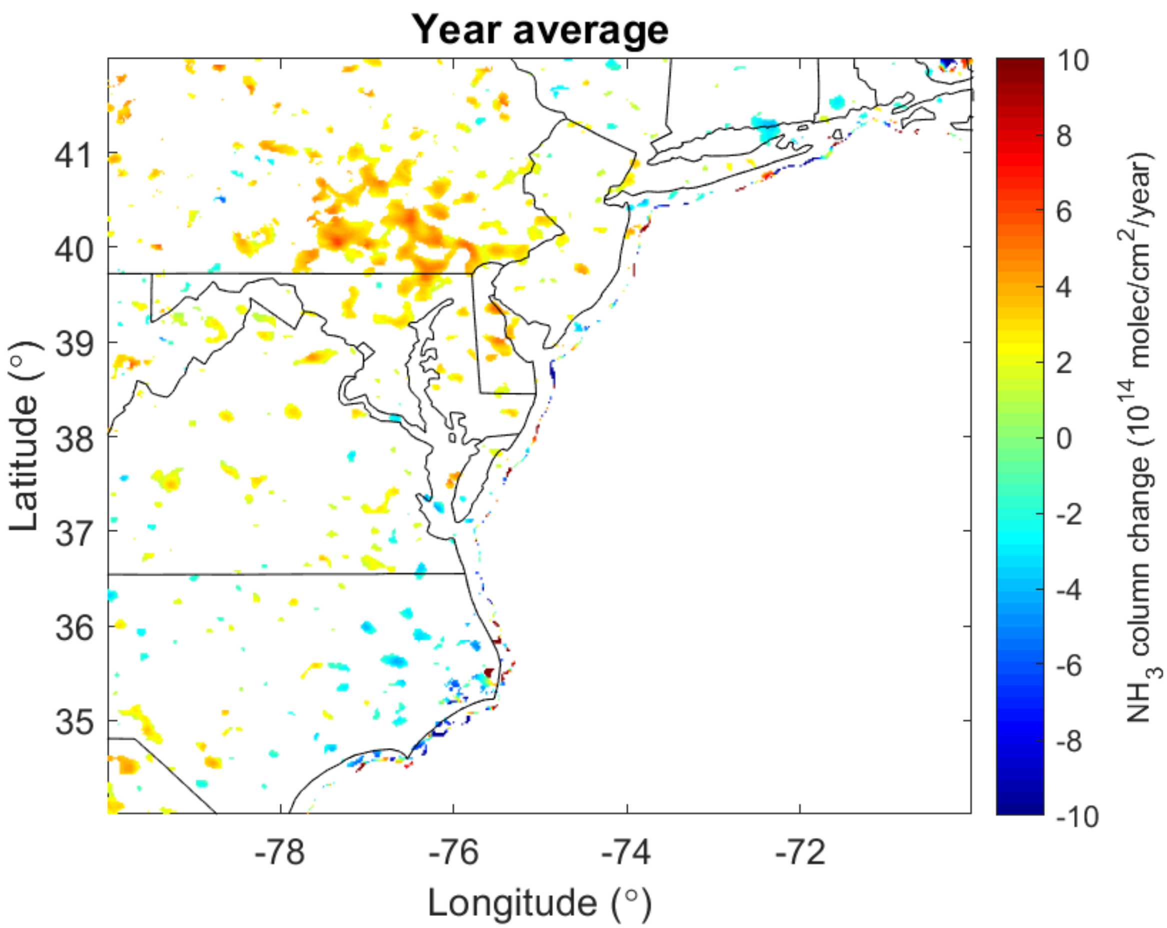
NH_3 in the summer (June, July, August) over the Mid-Atlantic region from 2008-2016. As the temperature further rises, more NH_3 is volatilized into the gas phase. Hotspots continue to stand out, and the highest NH_3 is found in North Carolina but with other hotspots in southern Delaware and near Lancaster County, Pennsylvania.

Figure 3d. Seasonal maps of NH_3 columns (fall)



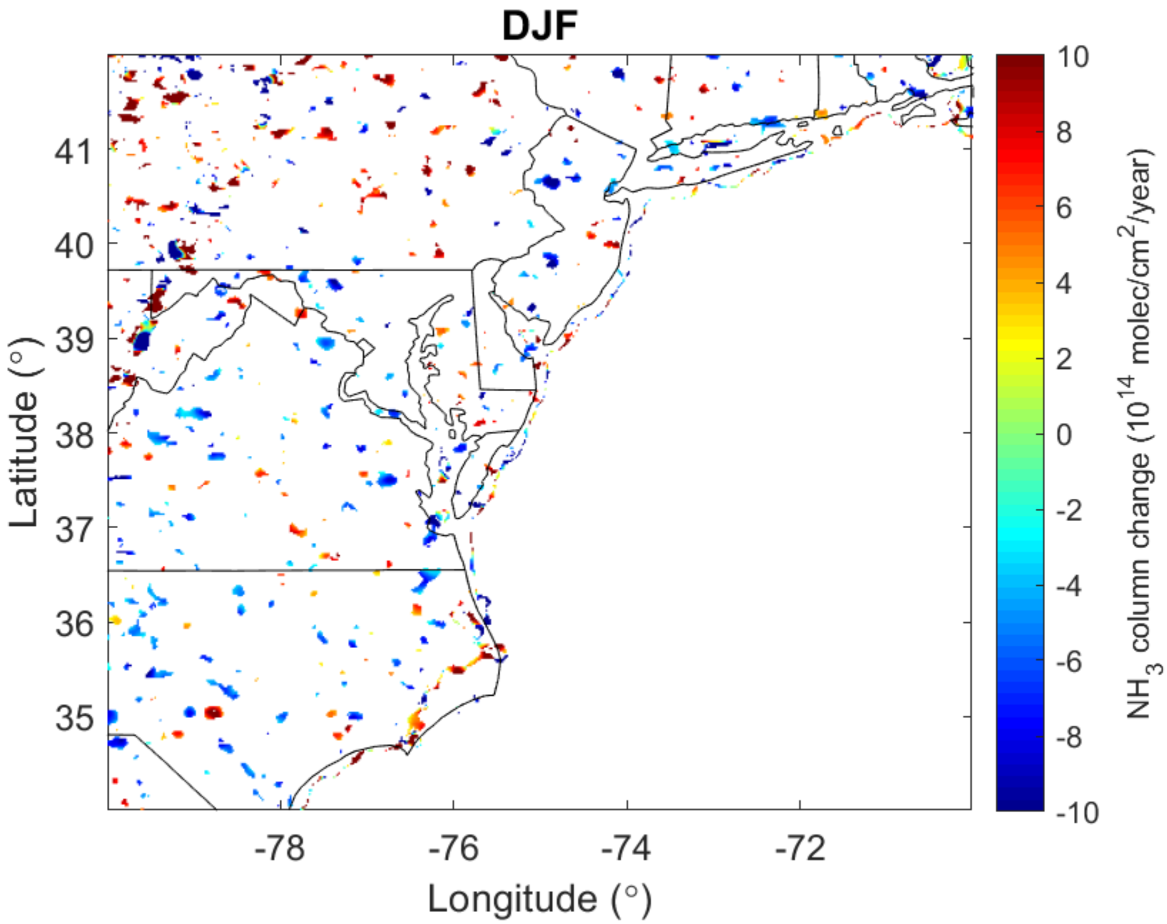
NH_3 in the fall (September, October, November) over the Mid-Atlantic region from 2008-2016. Ammonia starts to reduce as the temperature cools and agricultural activities decrease.

Figure 4. Absolute annual trend of NH_3, averaged over 2008-2016



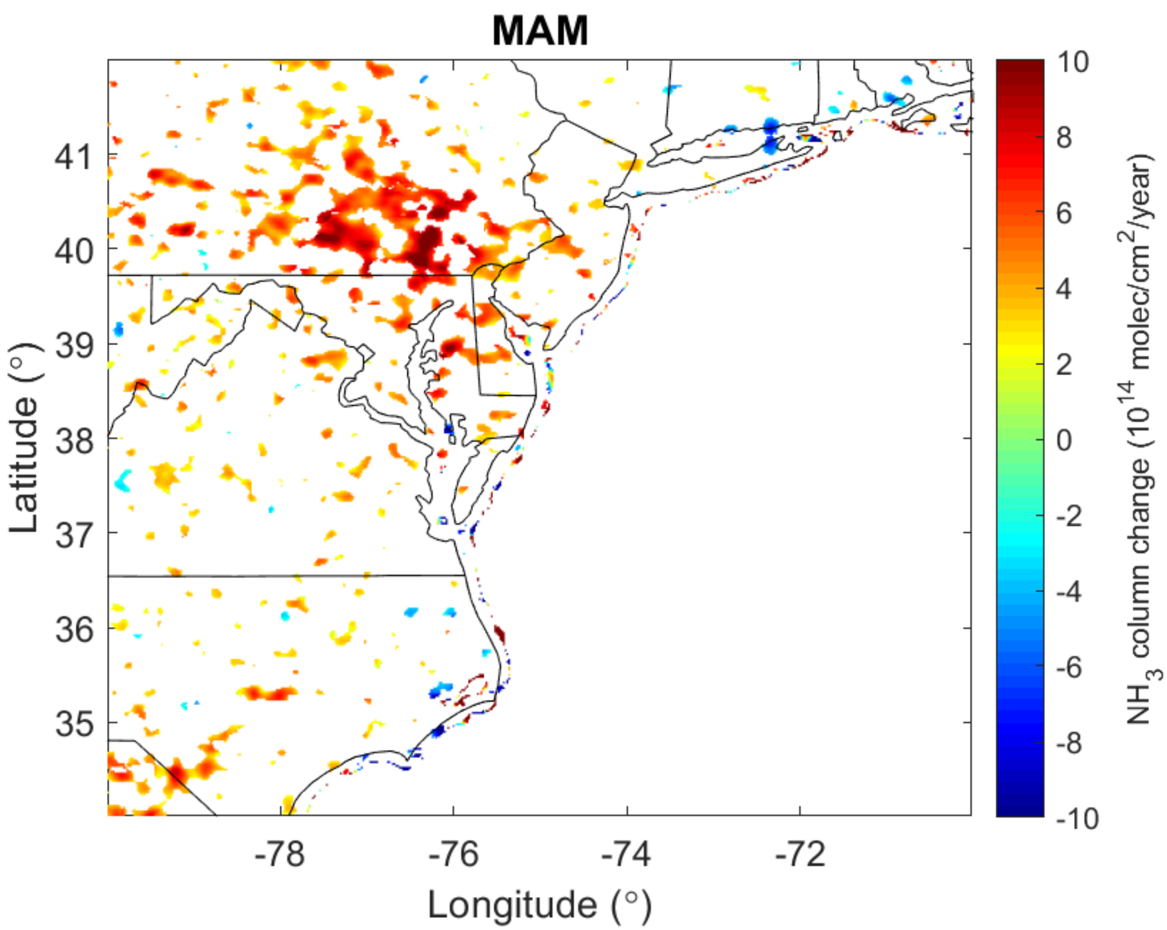
This map was calculated using the annual average NH_3 in the Mid-Atlantic region from 2008-2016 to perform a trend analysis during this period. For each year, each grid point must have at least one "observation" (the sum of normalized spatial response function) in each season to calculate the 9-year trend, otherwise the year was excluded. The white regions indicate either (1) insufficient data to perform the trend analysis, or (2) no significant trend (p>=0.05). Significant positive trends can be observed are mainly observed in eastern Pennsylvania.

Figure 5a. Absolute annual trend by season (winter)



Annual averaged NH_3 in the Mid-Atlantic region from 2008-2016 were used to perform trend analyses. For each year, the grid must have at least one "observation" (the sum of normalized spatial response function) to calculate the 9-year trend, otherwise the year was excluded. The white regions indicate either (1) insufficient data to perform trend analysis, or (2) no significant trend (p>=0.05). Significant positive trends can be observed in spring, especially in southern Pennsylvania.

Figure 5b. Absolute annual trend by season (spring)



Large trends of NH_3 columns are observed over southern Pennsylvania in springtime, consistent with the timing of fertilization. In fact, the annual trend of NH_3 is largely dominated by the trend in springtime.

Figure 5c. Absolute annual trend by season (summer)

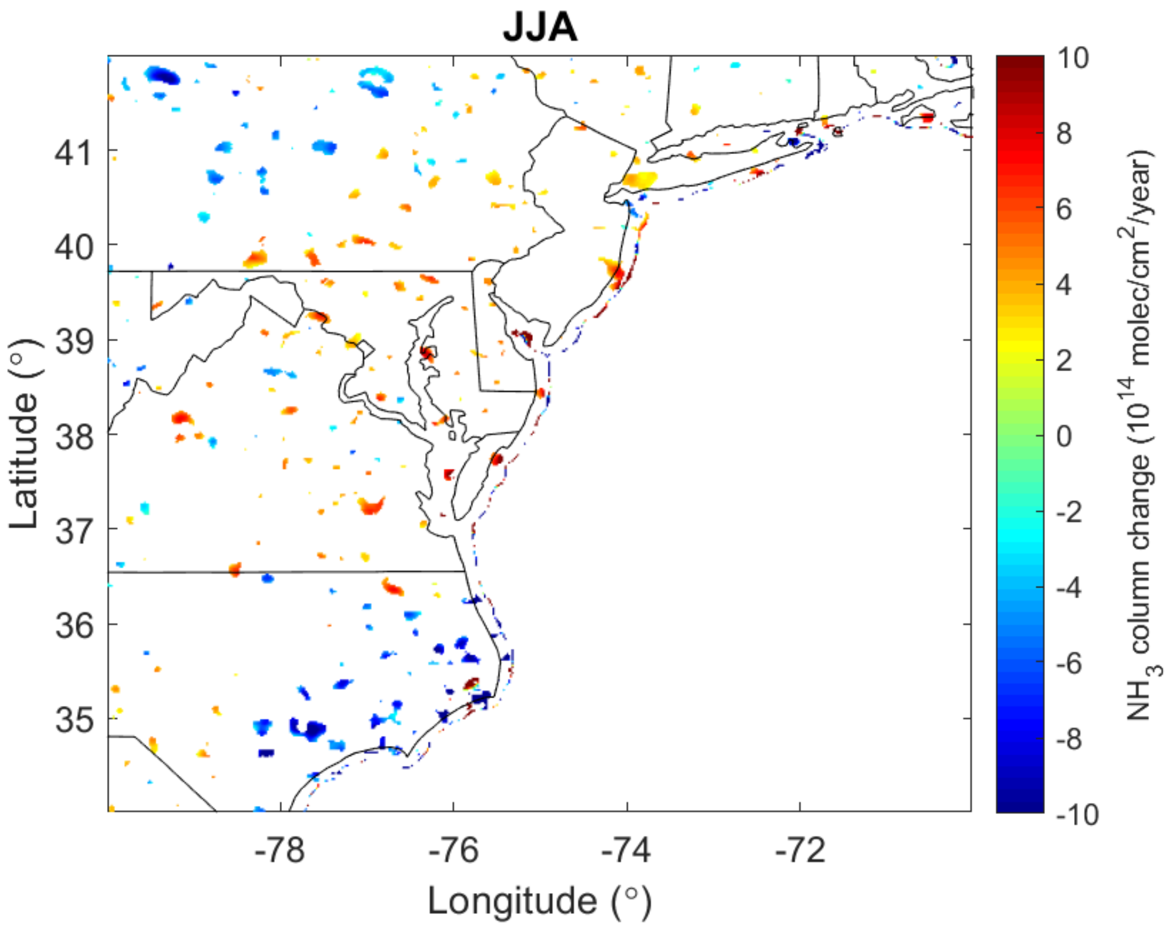


Figure 5d. Absolute annual trend by season (fall)

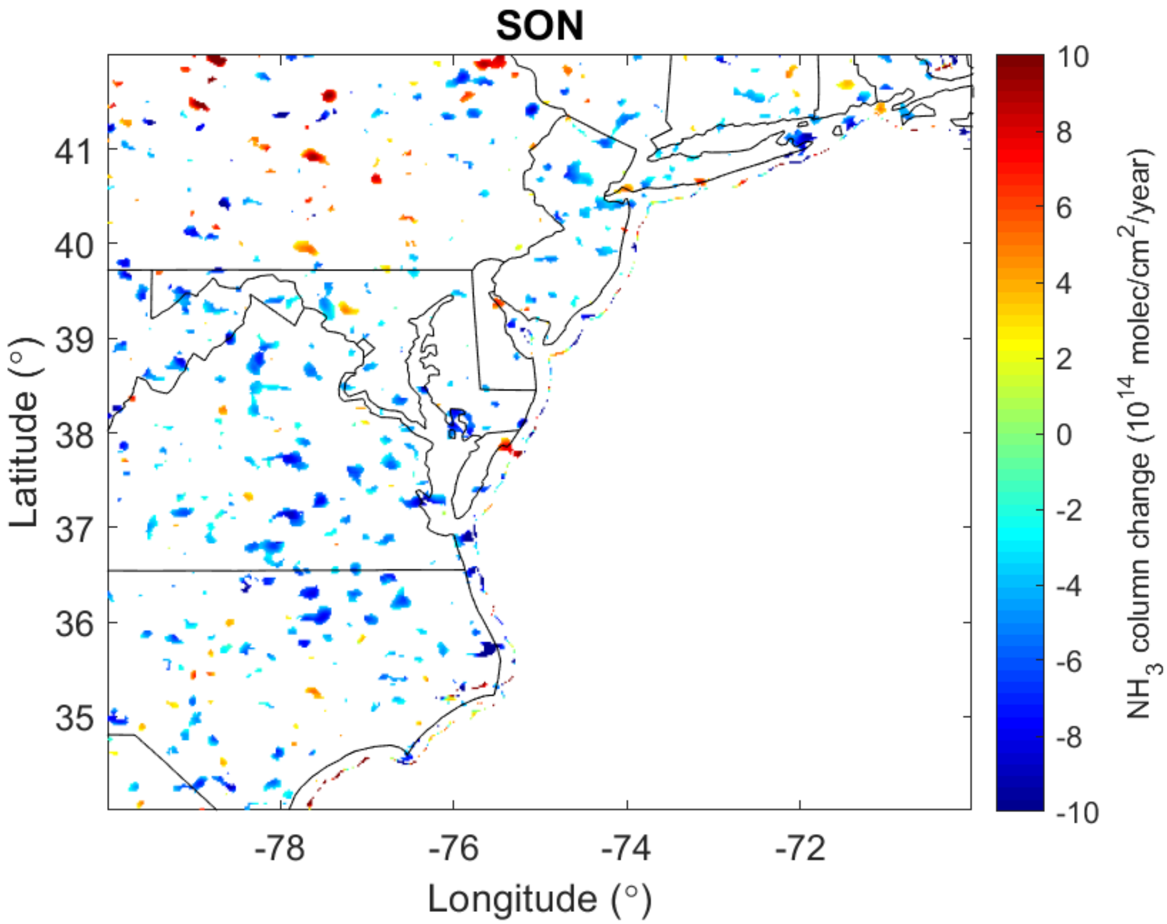
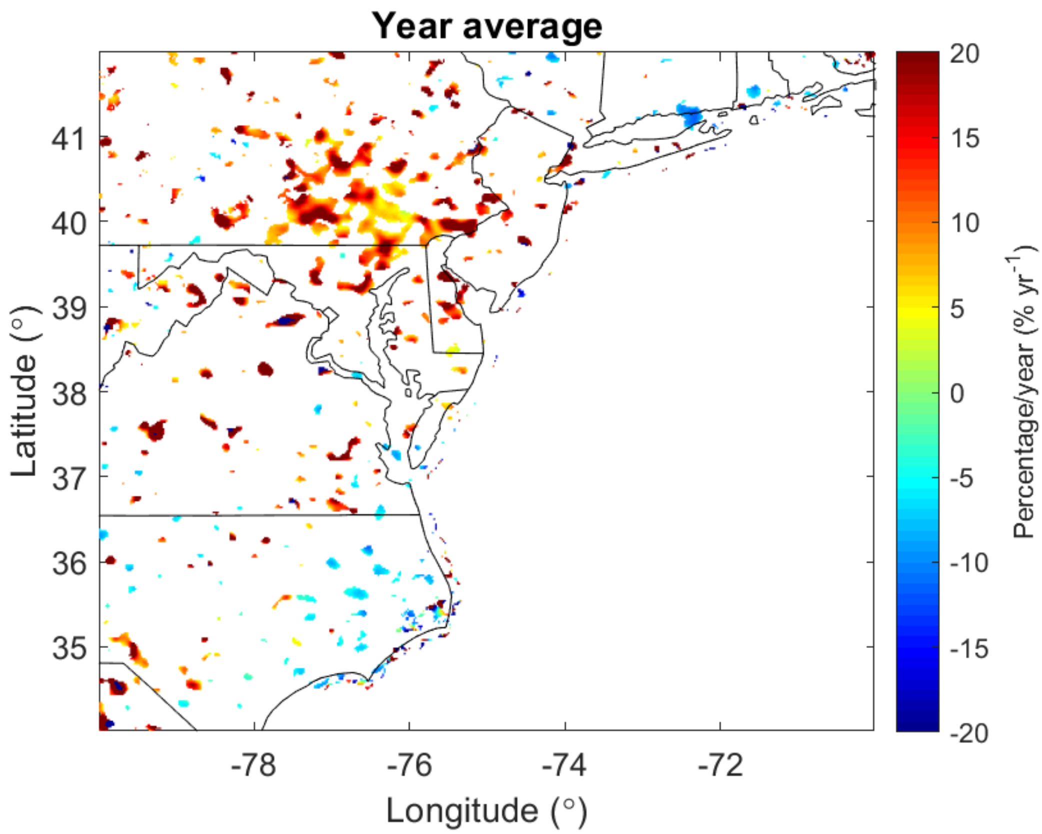
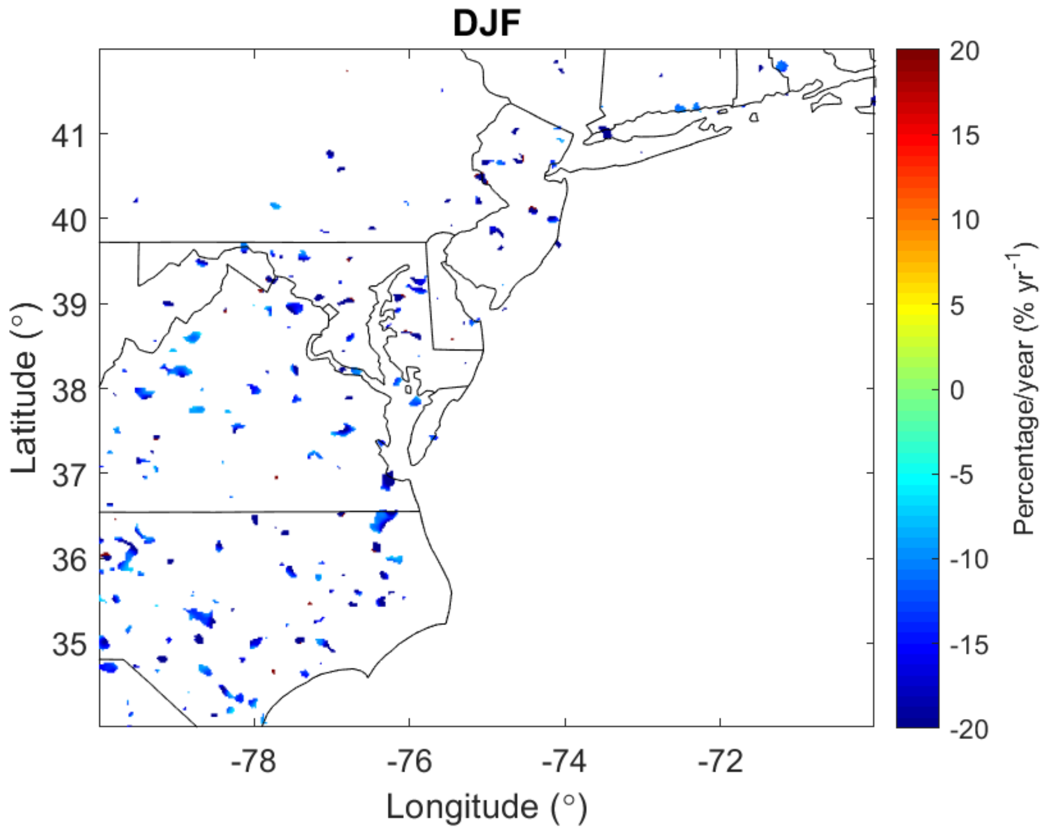


Figure 6. Relative annual trend of NH_3, averaged over 2008-2016



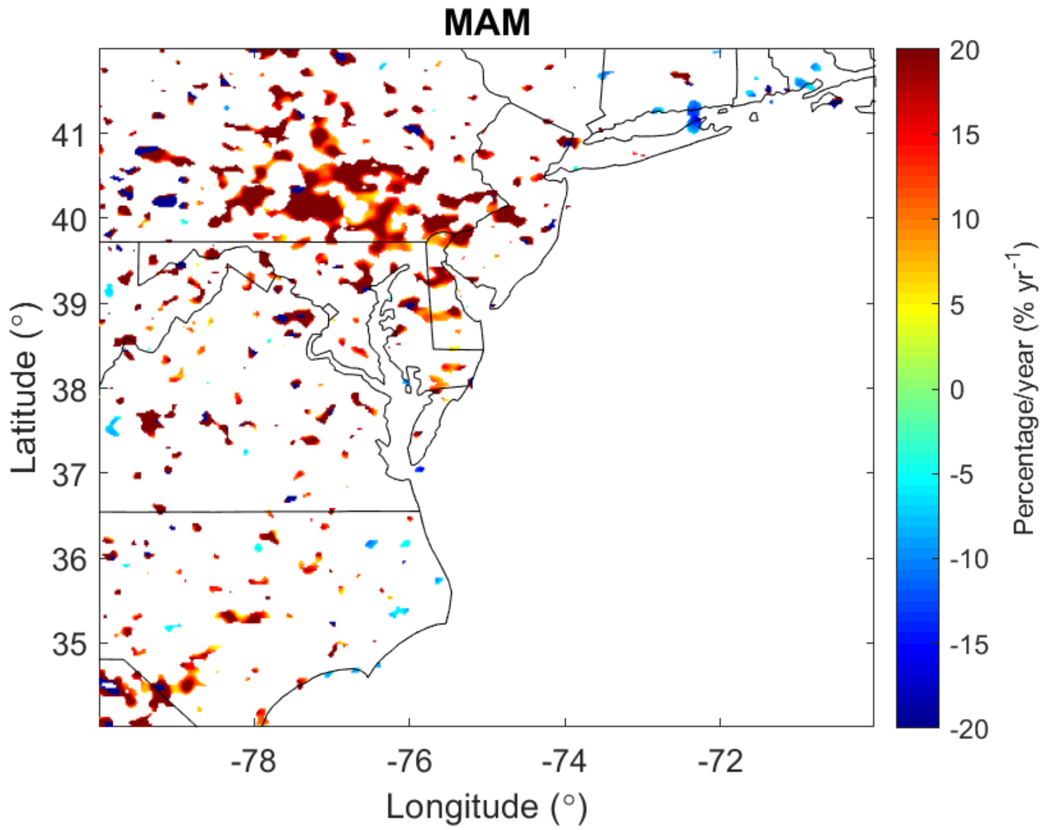
Average annual relative trends are shown for the 2008-2016 period, relative to the 2008 annual average column. Trends of ~ 10% per year are observed in parts of southeastern Pennsylvania, with some negative trends in eastern North Carolina. Caution is advised in interpreting this map, as some trends near the background may be spurious. Trends in hotspot regions should be valid, but over background regions some trends may be spurious in nature and not significant.

Figure 7a. Relative annual NH_3 trends by season (winter)



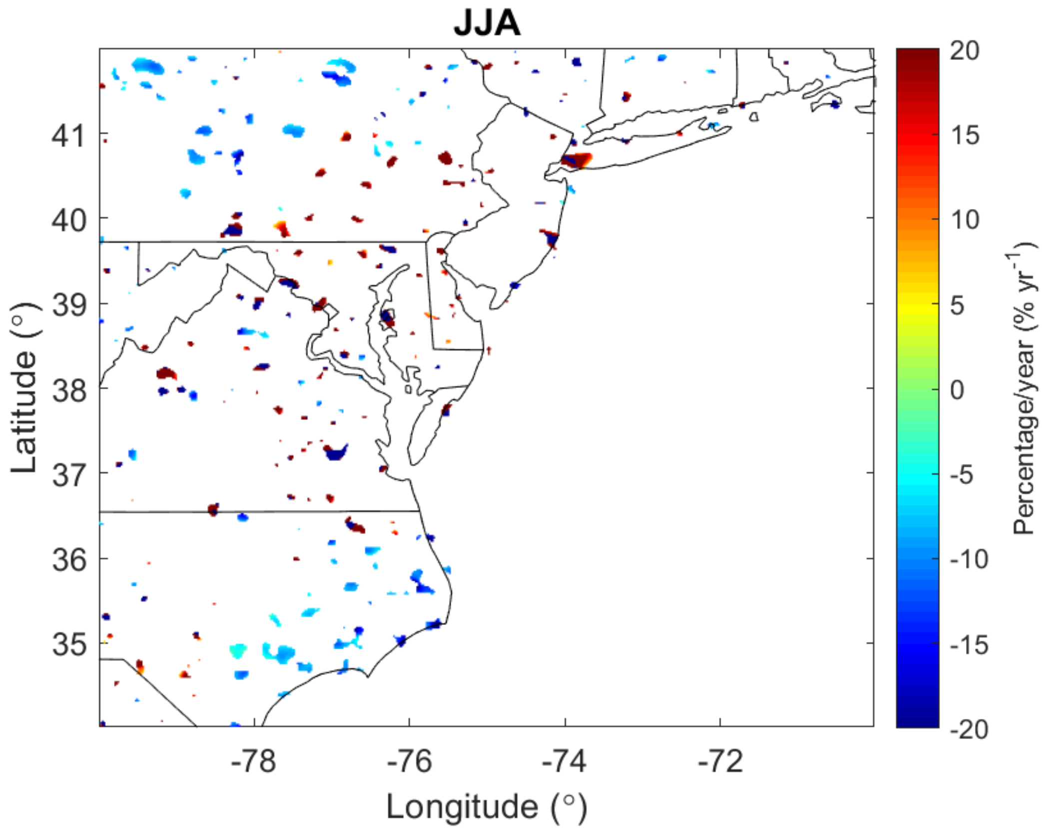
Caution is advised in interpreting this map, as some trends near the noise limit may be spurious. Trends in hotspot regions should be valid, but over background regions some trends may be spurious in nature and not significant.

Figure 7b. Relative annual NH_3 trends by season (spring)



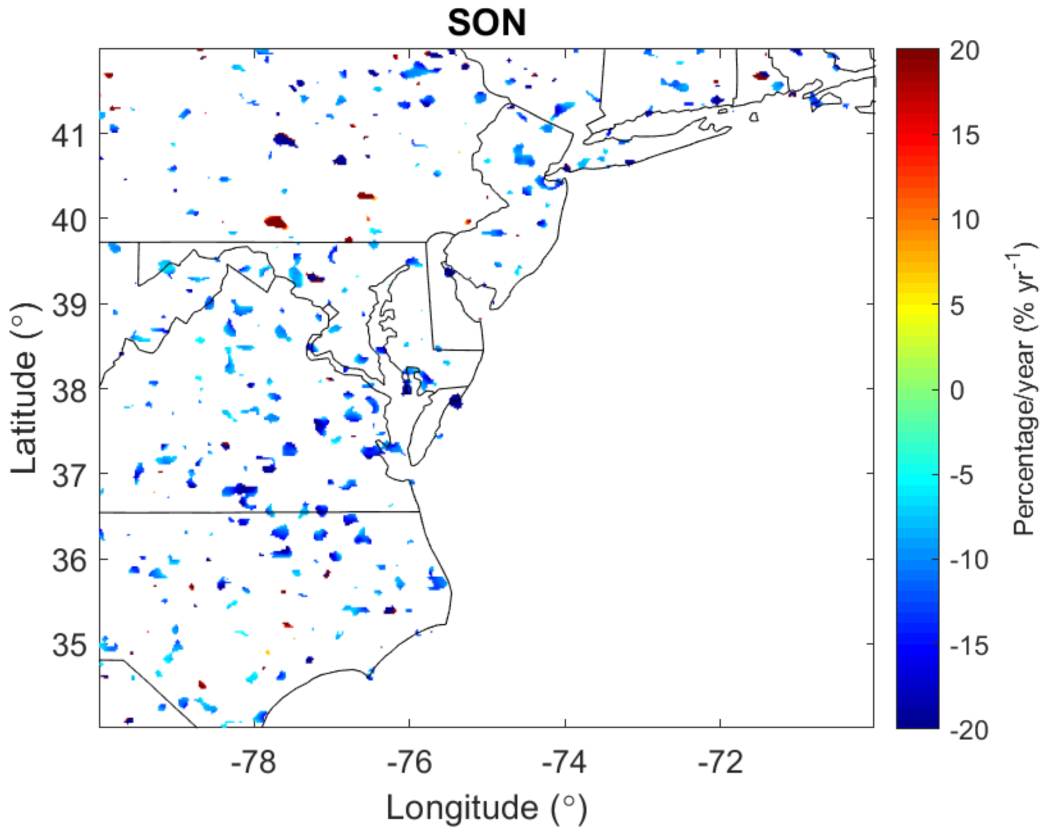
Large relative trends of NH_3 columns are observed over southern Pennsylvania in springtime, consistent with the timing of fertilization. In fact, the annual trend of NH_3 is largely dominated by this trend in springtime. Caution is advised in interpreting this map, as some trends near the noise limit may be spurious. Trends in hotspot regions should be valid, but over background regions some trends may be spurious in nature and not significant.

Figure 7c. Relative annual NH_3 trends by season (summer)



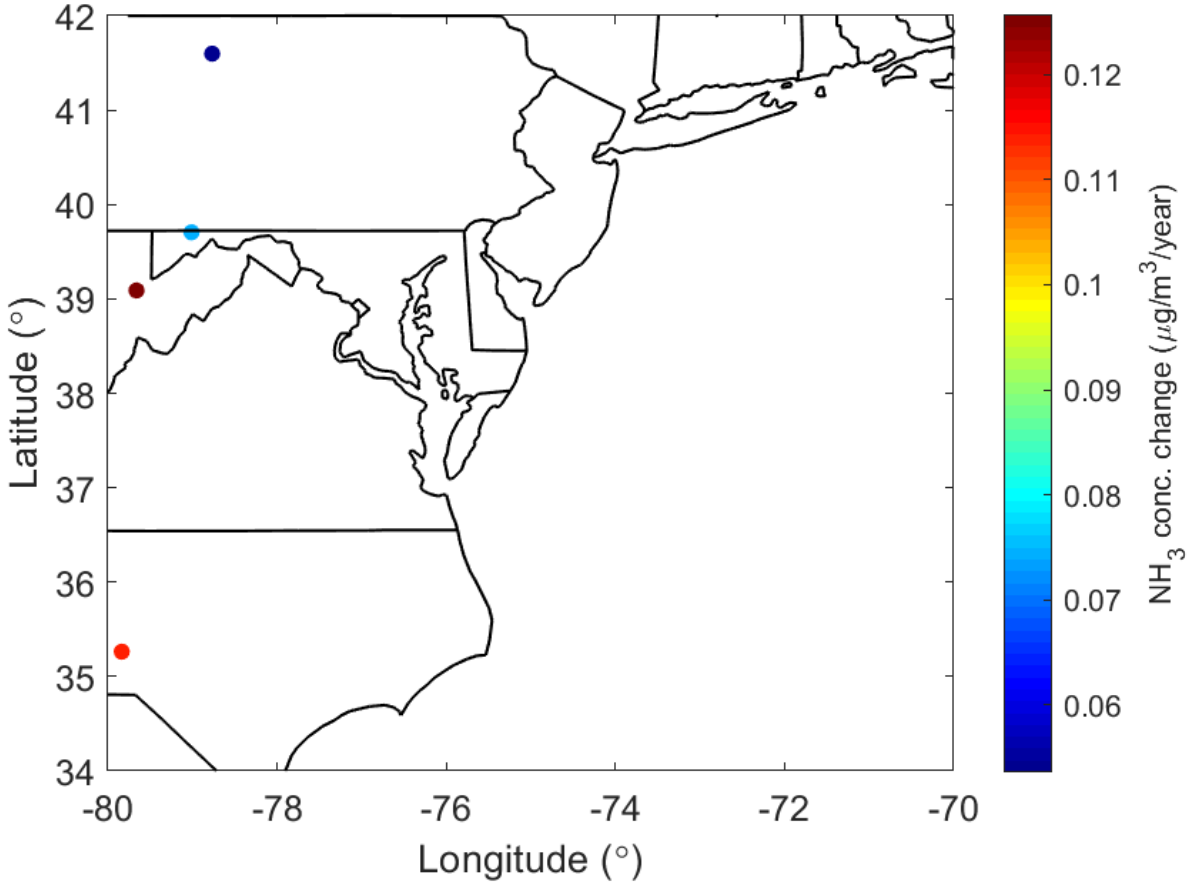
Caution is advised in interpreting this map, as some trends near the noise limit may be spurious. Trends in hotspot regions should be valid, but over background regions some trends may be spurious in nature and not significant.

Figure 7d. Relative annual NH_3 trends by season (fall)



Caution is advised in interpreting this map, as some trends near the noise limit may be spurious. Trends in hotspot regions should be valid, but over background regions some trends may be spurious in nature and not significant.

Figure 8. Ammonia Monitoring Network trends in the Mid-Atlantic



This map shows Ammonia Monitoring Network sites in the Mid-Atlantic with a period of record from 2008-2016. The annual average AMoN NH_3 for each site was used to perform the trend analyses. To calculate annual mean concentration, full year coverage was required in the datasets. Only sites that have a statistically significant trend ($p<0.05$) are shown. Positive trends are observed where the criteria are met, consistent with the overall positive relative trends from satellite. The wider spatial coverage is a key advantage for satellite data when compared to ground-based networks.

References

1. For example, J. Plautz, *Science*, *361*, 6407, 1060-1063, doi: 10.1126/science.361.6407.1060.

2. van Damme *et al.*, *Atmos. Meas. Tech.*, *10*, 4905–4914, 2017, https://doi.org/10.5194/amt-10-4905-2017.

3. Sun *et al.*, *Atmos. Meas. Tech.*, *11*, 6679–6701, 2018, https://doi.org/10.5194/amt-11-6679-2018.

4. https://earthobservatory.nasa.gov/images/144351/the-seasonal-rhythms-of-ammonia