Investigating Sources of Ammonia Uncertainty in Modeling the Salt Lake City $PM_{2.5}$ Nonattainment Area

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- Contributing Ramboll colleagues:
  - Dr. Chris Lindhjem, Tejas Shah, Yesica Alvarez, Sai Sreedhar Varada, Dr. Greg Yarwood

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Overview

- Winter PCAP episodes can violate Federal 24-hour $PM_{2.5}$ air quality standard
  - Buildup of ammonium nitrate (from NOx) and carbon (from smoke)
- UDAQ applies a photochemical model to assess/project $PM_{2.5}$ levels
  - Model under predicts ammonium nitrate from lack of ammonia (NH_3)
  - Ad hoc blanket NH_3 emissions increase helps to alleviate under predictions
  - BUT: a major model uncertainty that may affect accuracy of projected $PM_{2.5}$
- We investigated causes for the modeled NH_3 shortfall
  - Benefitted from USU's 2019 WaFACO study
  - Reviewed emission inventories and measured concentration patterns
  - Investigated modeling uncertainties/deficiencies
  - Increased modeled NH_3 emissions from vehicles
  - Updated the model, re-evaluated modeling results and projected attainment-year $PM_{2.5}$

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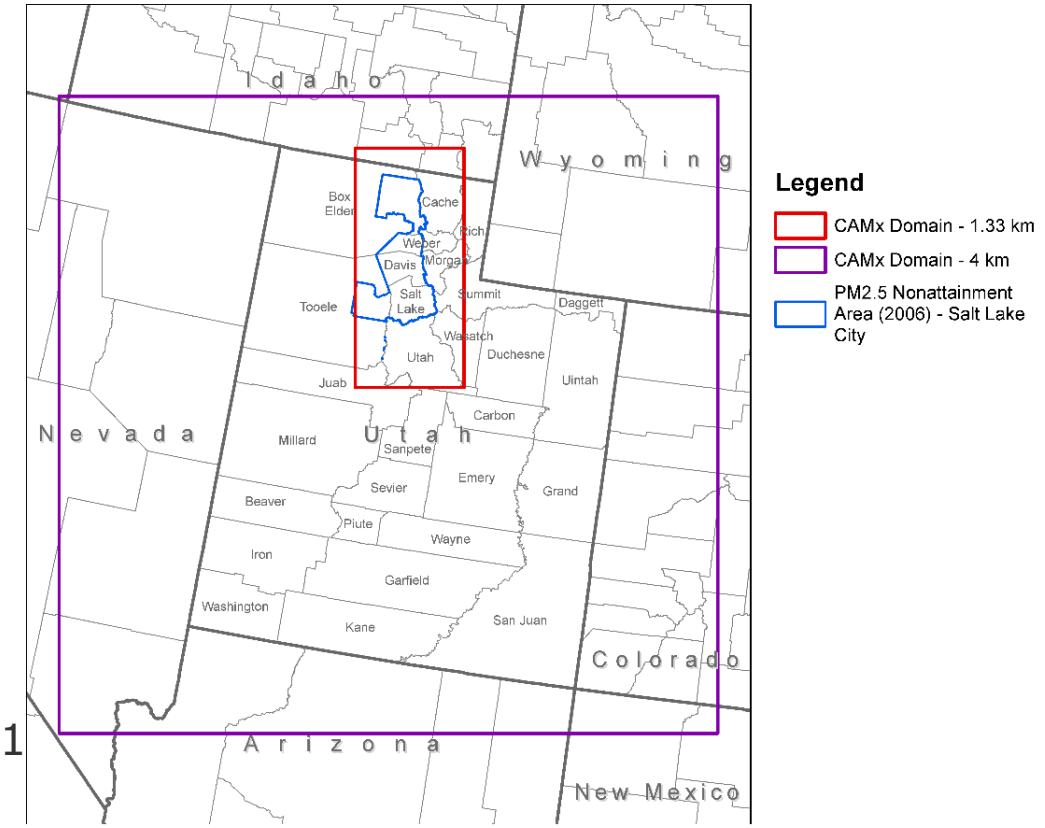
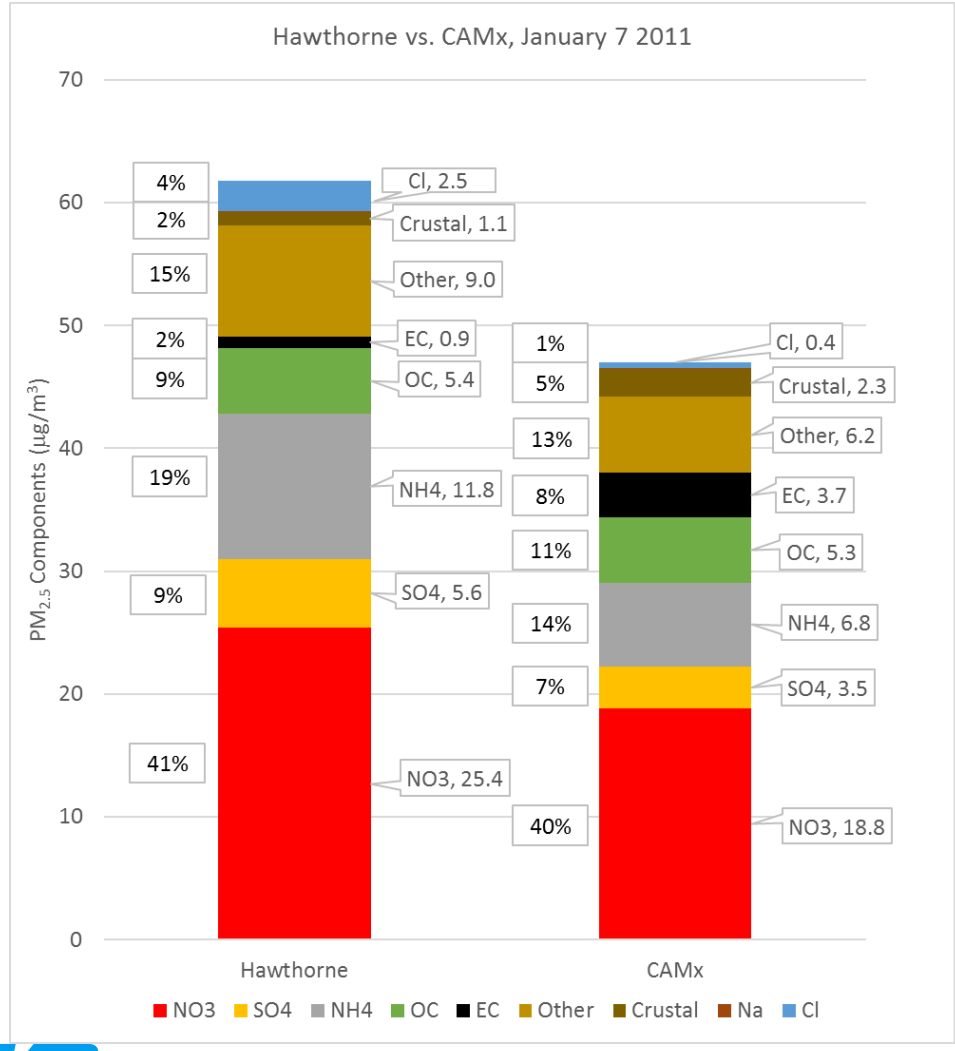
UDAQ Models and Datasets

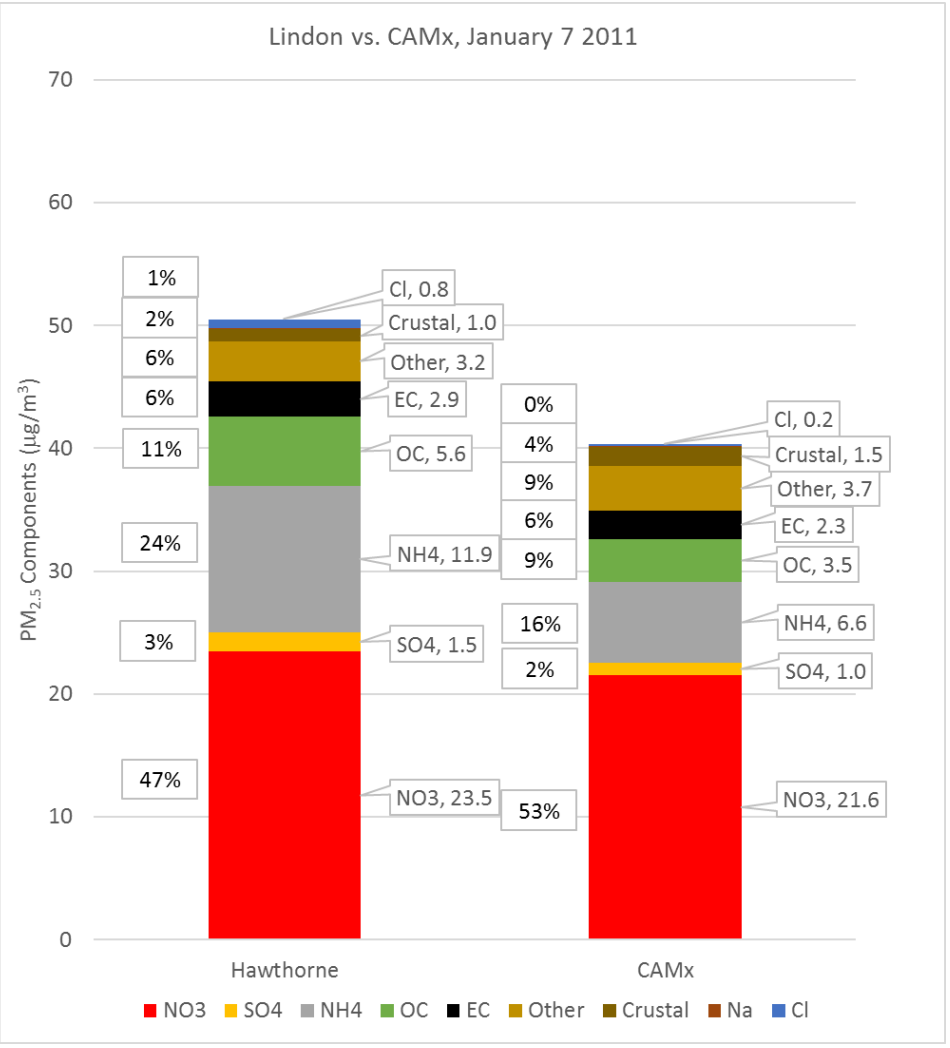
- Photochemical Model – CAMx v6.3
  - PCAP event during January 1-10, 2011
  - Models dispersion, chemistry, surface sink for:
    - Gas precursors and oxidants: NOx, VOC, SO_2, CO, NH_3, ozone
    - $PM_{2.5}$ components: sulfate, nitrate, carbon, salts, dust, other
  - Project $PM_{2.5}$ levels to 2019 attainment year
- Meteorology – WRF v3 (Crossman and Foster, 2016)
  - Hourly/gridded winds, temperature, humidity, clouds, etc.
- Emissions – SMOKE v3.6.5
  - Hourly/gridded/chemically speciated based on Triennial 2011 and 2014 annual county-level inventories
  - Projected to future years: activity growth, vehicle fleet turnover, stationary source controls



UDAQ $PM_{2.5}$ Base Year Modeling

Peak $PM_{2.5}$ Day on January 7, 2011





Ramboll Investigative Modeling

- Physical Processes
  - Vertical Mixing - Reduce to improve simulated $PM_{2.5}$ and gas concentrations, decrease apparent NH_3 shortfall
  - Bi-directional NH_3 Surface Exchange – A source of NH_3 shortfall?
    - Snow cover squelches NH_3 deposition and re-emission, and daytime snow melt enhances deposition
- Emission Processes
  - On-Road Gasoline Vehicle NH_3 Emissions - Scale-up ~2x as supported by scientific literature
  - On-Road Gasoline Vehicle NH_3 Emissions in Cold Weather - Scale-up ~40% as supported by scientific literature
  - NOx Emissions – Does remaining NOx under prediction bias affect $PM_{2.5}$?
    - Scale up of non-point NOx by 20% results in lower ammonium nitrate – highly non-linear system!
- Chemical Processes
  - Inorganic PM Chemistry – Does alternative chemistry affect $PM_{2.5}$? No significant impacts
  - Halogen Chemistry – Do more chlorides impact $PM_{2.5}$? Negligible effects on total $PM_{2.5}$ but higher particulate chloride
  - Snow Albedo – Increase to observed levels have small effects on $PM_{2.5}$
  - Cloud Chemistry – How does cloud over prediction impact $PM_{2.5}$?
    - Little photolysis sensitivity and an unwanted reduction in aqueous sulfate production

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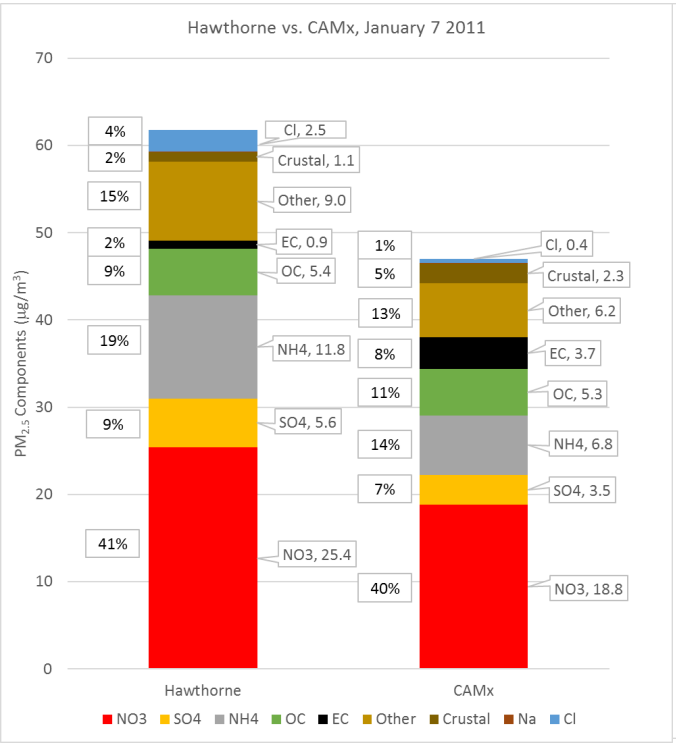
Blue text = incorporated into the revised model

Revised Base Year Modeling

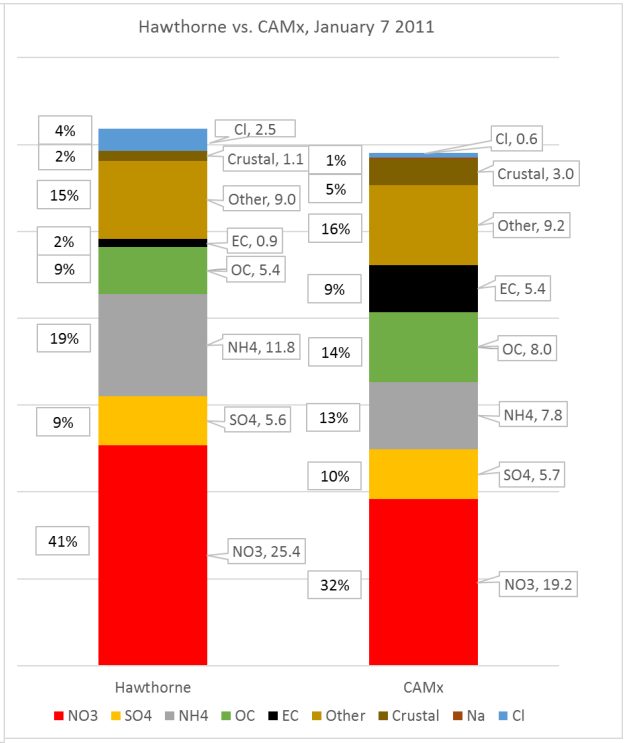
- Improved agreement for total $PM_{2.5}$ mass over all site-days; especially inorganic compounds
- Largest relative errors remain for species that have small to negligible $PM_{2.5}$ contributions

Hawthorne

Base

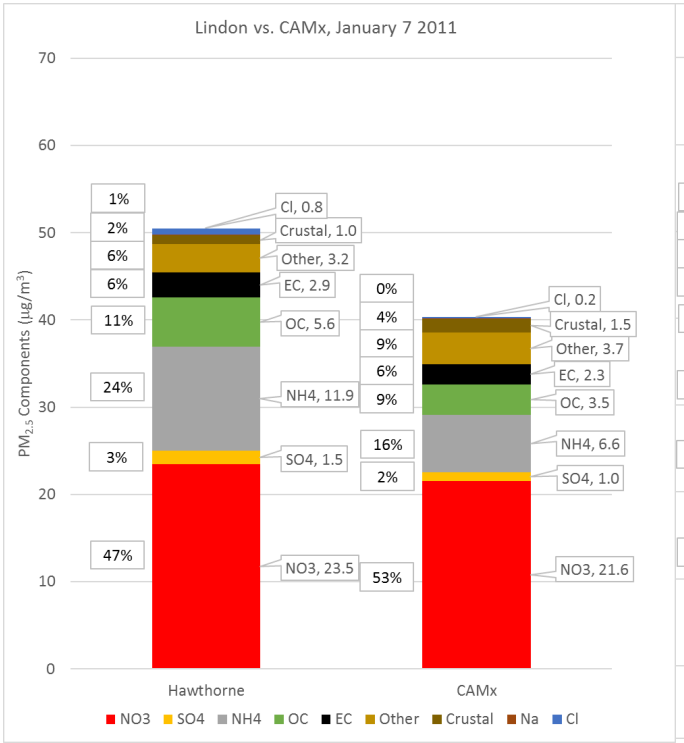


Revised



Lindon

Base



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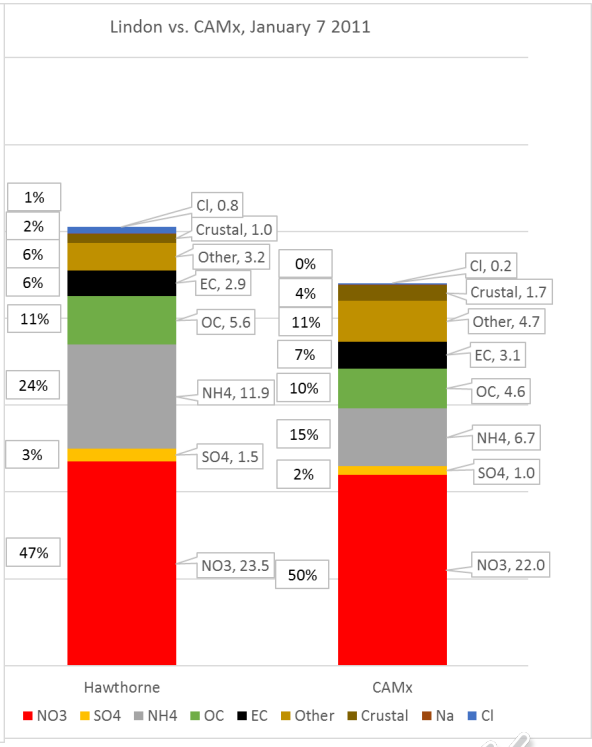

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$PM_{2.5}$ Projections to 2019

- 2017 and 2019 (attainment year) emission inventory from UDAQ
- We applied the same model updates as described previously
- EPA's Software for Modeled Attainment Test (SMAT) projects observed 2016-2018 design values (DV) to 2019 based on modeled projections
- Our 2019 $PM_{2.5}$ DV projections are similar to UDAQ's; all sites attain 35 $\mu g/m^3$ standard

AIRS ID	Site Name, County	2016-2018 DVb	UDAQ 2019 DVf	Ramboll 2019 DVf
490030003	Brigham City, Box Elder	32.4	33.5	33.4
490110004	Bountiful, Davis	28.5	28.3	28.6
490353006	Hawthorne, Salt Lake	33.4	34.0	33.2
490353010	Rose Park, Salt Lake	34.9	35.4	35.0
490494001	Lindon, Utah	31.1	29.8	30.6
490495010	Spanish Fork, Utah	28.4	28.9	28.5
490570002	Ogden, Weber	30.2	30.7	30.2

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Conclusions

- Simulated urban $PM_{2.5}$ responded well to increased on-road gasoline vehicle NH_3 emissions
  - Scale-up by a factor of ~2 is supported by scientific literature
  - UDAQ NH_3 injection added ~65% to Salt Lake County emissions, while the NH_3 scale-up added ~40%

- Final model resulted in improved agreement with $PM_{2.5}$ measurements in urban areas
  - NH_3 (based on 2019 WaFACO) and sulfate are simulated well
  - Nitrate remains under predicted by ~30% (but consistent with other western US $PM_{2.5}$ modeling)
  - Carbon (mostly from smoke) is over predicted and smoke speciation may need adjustment
  - Continued $PM_{2.5}$ under predictions at rural sites where agricultural NH_3 sources are important

- Projected $PM_{2.5}$ DVs using the updated model were similar to UDAQ's projections
  - No sites projected to exceed the standard

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Conclusions

- Modeling indicates basin is in "NOx-disbenefit" condition during PCAP events, in agreement with recent field studies
  - NOx-saturated and oxidant-lean
  - NOx emission reductions can raise oxidant levels and secondary PM formation rates
  - Has implications for accurately projecting $PM_{2.5}$ based on anticipated emission inventory changes

- Modeling indicates basin is near balance between NH_3-limited and nitrate-limited conditions, in agreement with recent field studies
  - BUT: $PM_{2.5}$ response is affected by remaining model uncertainties and biases

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Recommendations

- Model a more recent $PM_{2.5}$ episode to analyze contemporary air quality and update projections
- Carry key updates identified in this project into any new $PM_{2.5}$ modeling
- Investigate improvements for meteorological simulations of PCAP episodes
- Improve NH_3 emission inventory and spatial allocation for livestock and landfills
- Investigate causes for under estimates of NOx and chloride
- Improve speciation for wood smoke among organic/elemental carbon and other components
- Investigate the role of snow in modulating surface-atmosphere NH_3 exchange
- Investigate impacts of all updates on $PM_{2.5}$ response to future projected and/or alternative emissions scenarios

End