Model evaluation of aerosol wet scavenging in deep convective clouds based on observations collected during the DC3 campaign

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1. Introduction

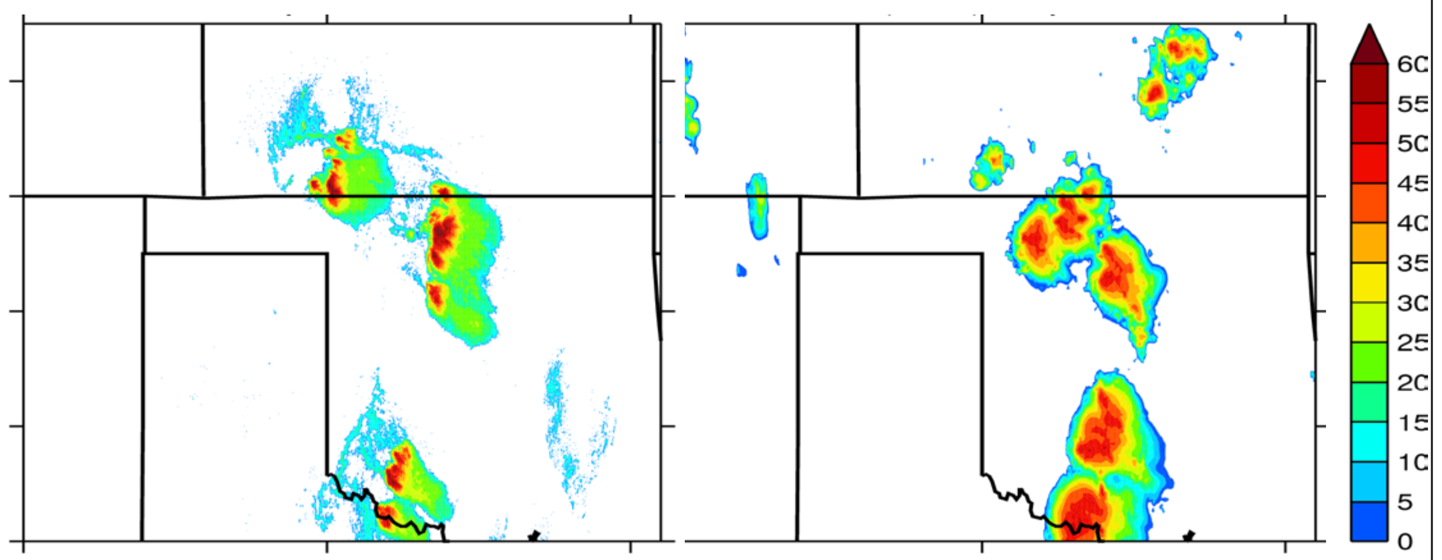
Deep convective storms greatly influence the vertical distribution of aerosols by transporting aerosols from the boundary layer and lower troposphere to upper troposphere and by removing aerosols through wet scavenging processes (i.e. in-cloud [or "rain-out"] and below-cloud [or "wash-out"] scavenging). Model representation of wet scavenging is a major uncertainty in simulating the vertical distribution of aerosols due partly to the lack of constraints by observations. The effect of wet scavenging on ambient aerosols in deep mid-latitude continental convective clouds is studied for a severe storm case in the vicinity of the ARM Southern Great Plains site on May 29, 2012 during the Deep Convective Clouds and Chemistry (DC3) field campaign.

2. WRF-Chem model

The chemistry version of Weather Research and Forecasting model (WRF-Chem) is used to simulate the convective event. The Model for Simulating Aerosol Interactions and Chemistry (MOSAIC) is implemented with a 8-bin sectional approach. An advanced volatility basis set (VBS) treatment of secondary organic aerosol formation has also been implemented. The VBS is coupled to SAPRC-99 gas-phase chemistry mechanism to model gas-particle partitioning and multiple generations of gas-phase oxidation of organic vapors. Meteorology is nudged with GFS data until six hours before the storm. The observed gas and aerosols before storm initiation were used as initial (six hours before initiation time) and boundary conditions.

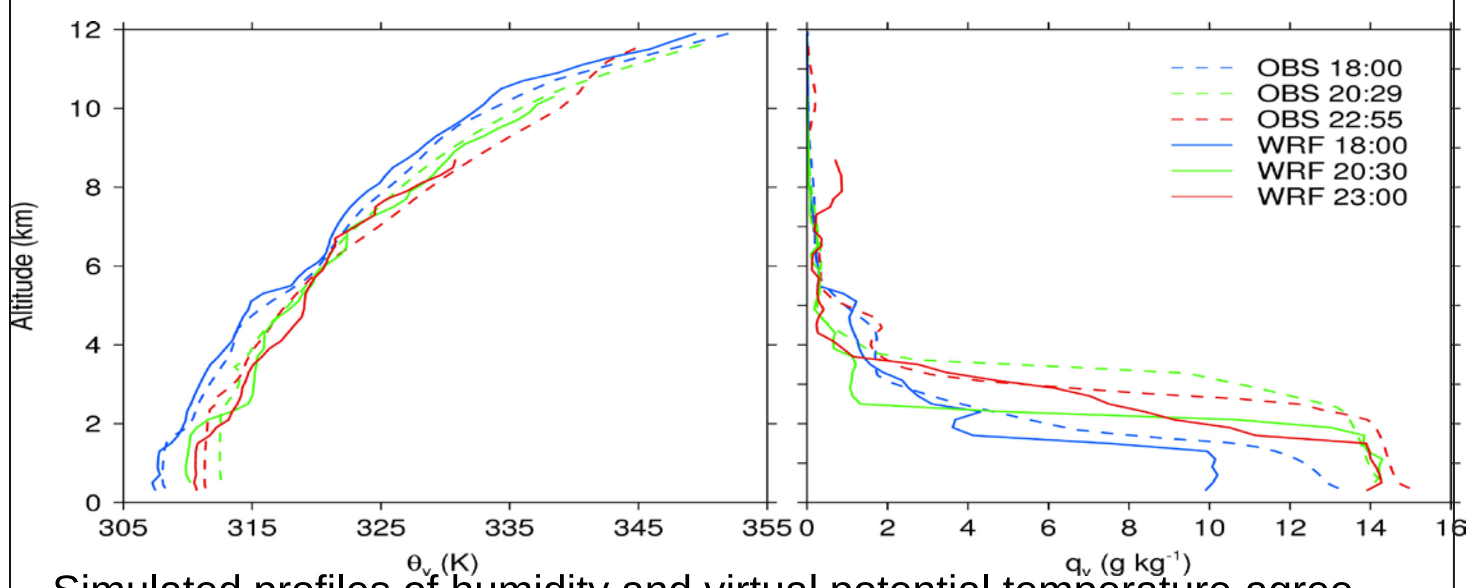
3. Meteorology and storm structure

Simulated and observed column max. reflectivity on May 29 23:00 UTC



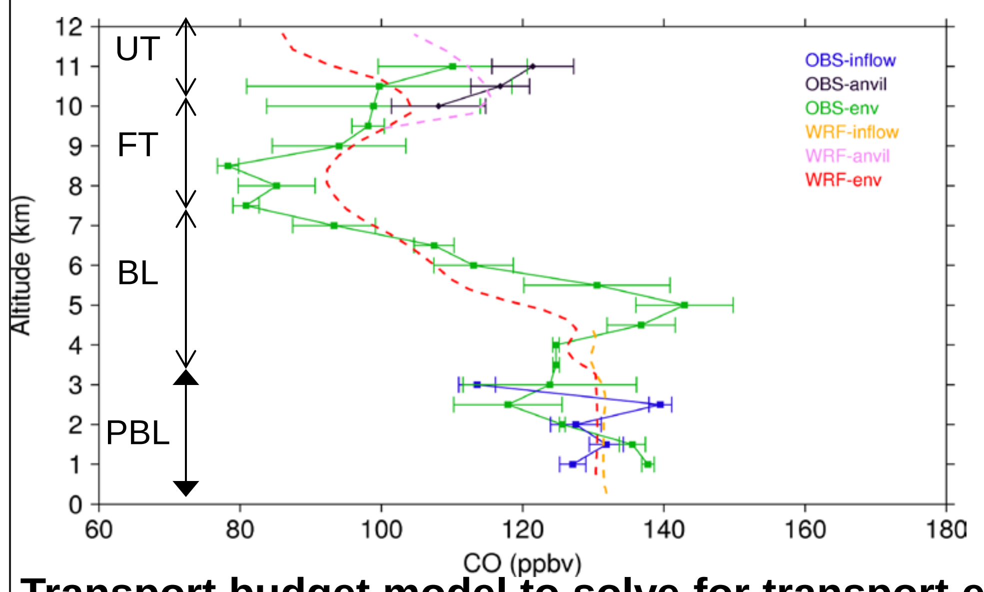
The model simulated the storm initiation timing and structure reasonably well when compared against radar reflectivity from the NSSL NMQ dataset.

Specific humidity and potential temperature compared with Sondes



Simulated profiles of humidity and virtual potential temperature agree reasonably well with Sonde measurements before and during the storm.

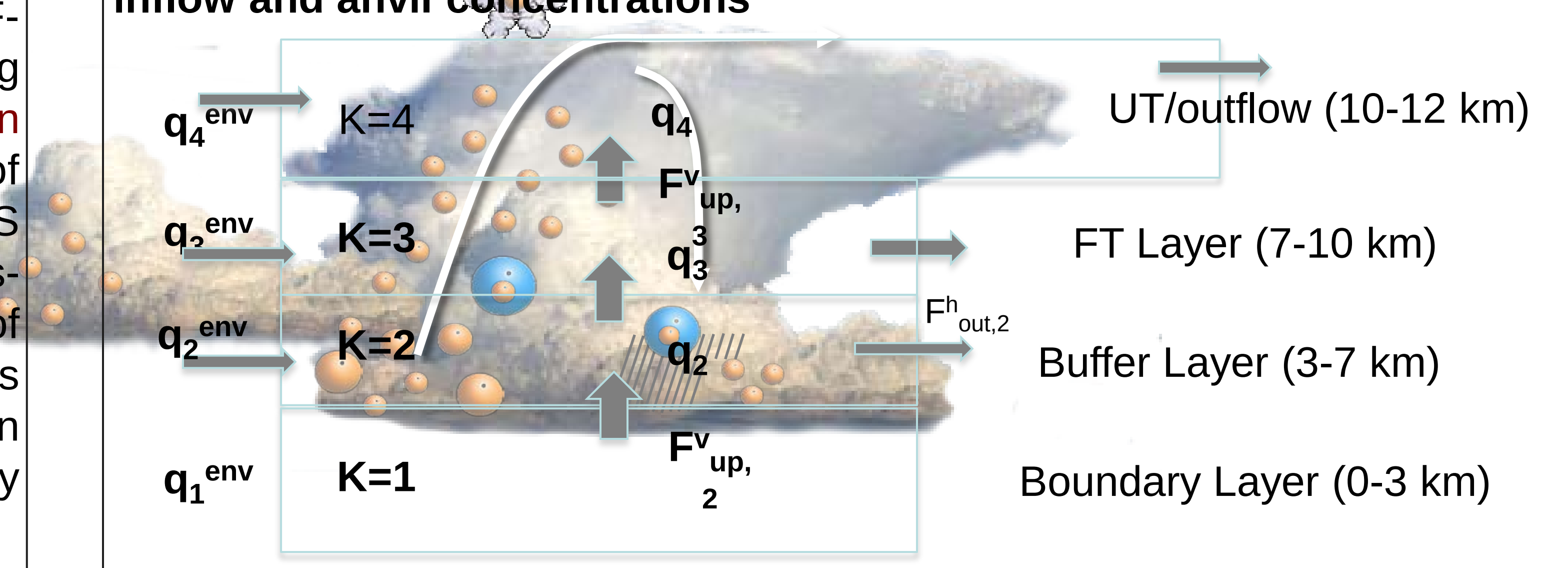
4. Trace gases and transport budget framework



Observed (GV flight) and simulated CO

Based on the vertical distribution of slowly reacting and nearly insoluble trace gases, the troposphere is divided into four layers for the purpose of mass budget analysis.

Transport budget model to solve for transport efficiency at the anvil based on measured CO, acetone, and benzene profiles including inflow and anvil concentrations



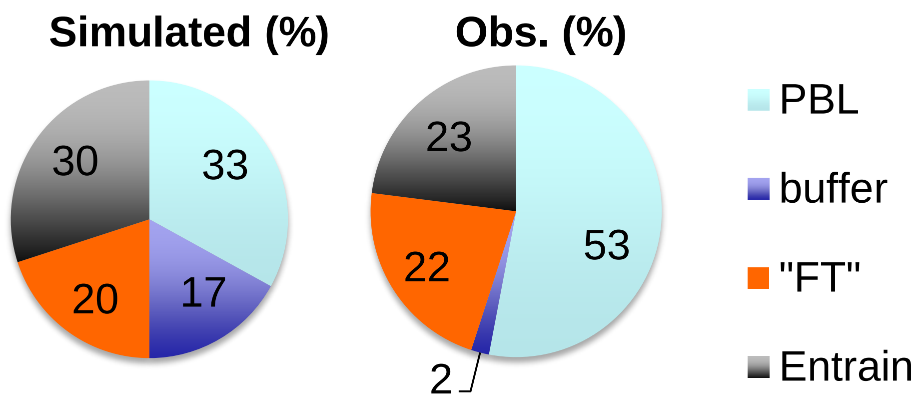
Assuming steady state: $F^h_{in,k} + F^v_{up,k} = F^h_{out,k} + F^v_{up,k+1}$

Inert gas with mr q: $q^{env}_{in,k} * F^h_{in,k} + q_{k-1} * F^v_{up,k} = q_k (F^h_{out,k} + F^v_{up,k+1})$

Let dilution factor $\beta_k = \frac{F^h_{in,k}}{F^h_{out,k} + F^v_{up,k+1}}$, thus the anvil concentration,

$$q_4 = \beta_4 * q^{env}_{in,4} + (1-\beta_4) * \beta_3 * q^{env}_{in,3} + (1-\beta_4)*(1-\beta_3)*\beta_2*q^{env}_{in,2} + \underline{(1-\beta_4)*(1-\beta_3)*(1-\beta_2)}*q^{env}_{in,1}$$

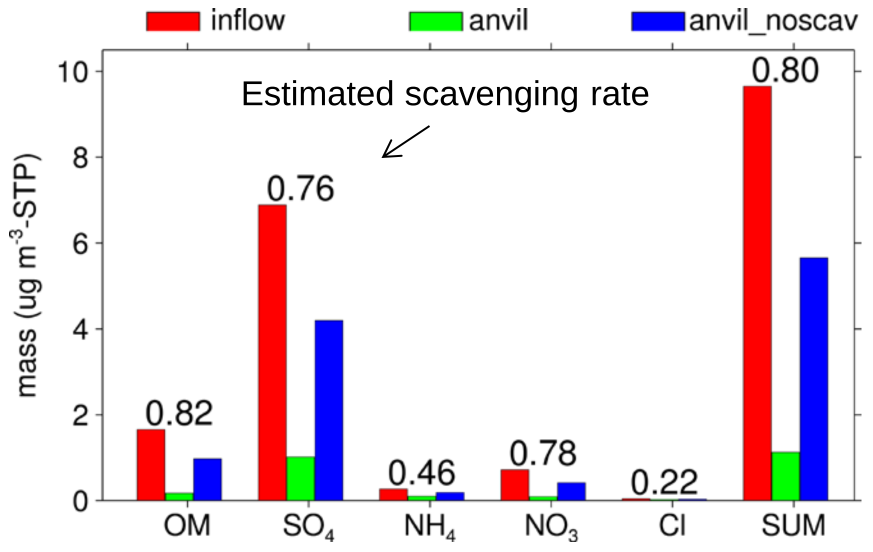
PBL contribution



Estimated contributions (%) to the anvil concentrations.

5. Aerosol wet scavenging efficiencies

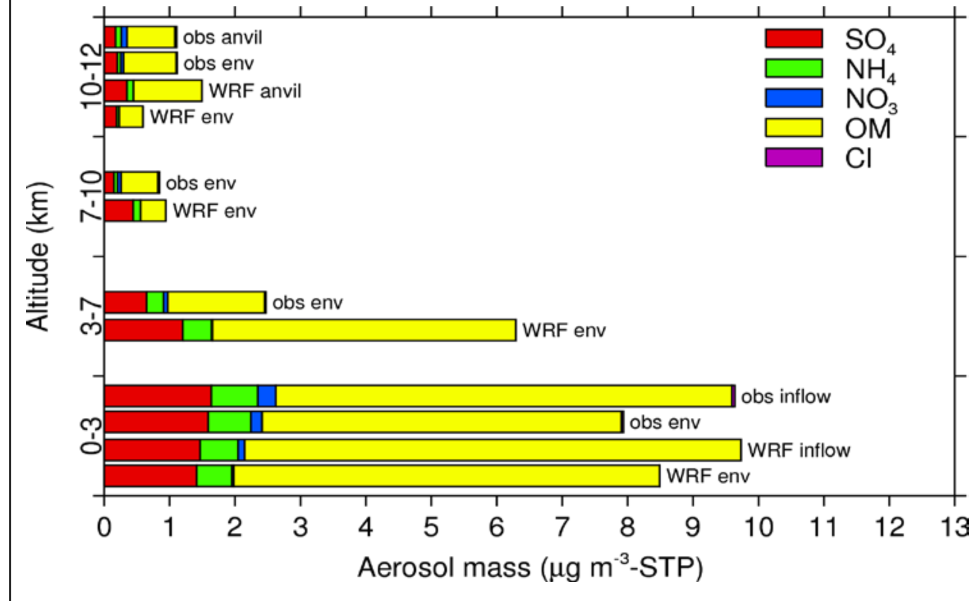
Observed aerosol concentrations at the inflow and anvil



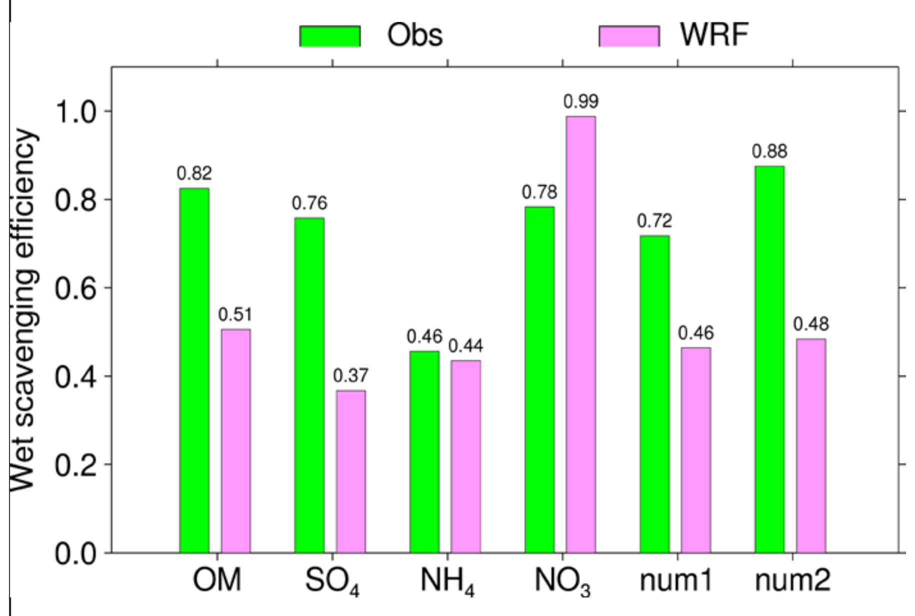
Using the know β_k values, the aerosol **concentrations at the anvil (q_4) can be calculated using the equation above, which assumes "inert behavior" of aerosols.**
scavenging efficiency =

$$1 - \frac{q_{anvil}(derived)}{q_{anvil}(observed)}$$

Comparisons of AMS observed and simulated Dp <1μm aerosol mass



Organic is the main aerosol component followed by sulfate during the May 29th convective event and it also dominates in the anvil concentrations.



Estimated scavenging efficiencies are large for both mass and number concentrations, and their variations with speciation is small (except NH_4 which might be influenced by small amount of ice contaminated data). Model underestimates the scavenging efficiency by ~40%.

Masses: Dp <1μm. Num1 and num2: Dp = .03-.15 and .15-2.5 μm

6. Summary and next steps

- The convective storm shows significant enhancements of trace gas concentrations at the anvil. A new budget analysis approach estimates that 50%, 2%, and 23% of the "inert" gas in the anvil came from PBL, buffer layer, and entrained in the UT, respectively. Model simulates similar inert gas enhancement in the anvil as observed but with a larger contribution from buffer layer (17%) and a smaller contribution from PBL (30%).
- High scavenging efficiencies (~80%) for aerosol number (Dp<2.5μm) and mass (Dp<1μm) are obtained from the observations. Except for observed NH_4, there is little chemical selectivity to wet scavenging, and slightly higher scavenging efficiency is found for larger particle sizes (0.15-2.5μm versus 0.03-0.15 μm). The scavenging efficiency is comparable between aerosol mass and number.
- The model underestimates the wet scavenging efficiency in general. (An exception is nitrate which can also evaporate to HNO_3.) . This general underestimation in the model is quite likely due to neglect of secondary activation above cloud base, which will be implemented.
- It is challenging to estimate transport and wet removal for a convective storm due partly to the uncertainties and limitations in the measurement data (e.g., no wet deposition) and the analysis approach.
- On-going and future work also includes adding new treatment of ice-borne aerosol to improve the representation of aerosol wet scavenging, and evaluate the sensitivity of aerosol wet scavenging to different microphysical schemes.

7. Acknowledgement

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