THE EFFECTS OF CLOUD ATTENUATION ON AIR QUALITY: A COMPARISON OF MODEL TREATMENTS

Pat Dolwick
Air Quality Modeling Group, Office of Air Quality Planning and Standards (OAQPS), USEPA, Research Triangle Park, North Carolina

Introduction / Outline

- Clouds are one of the hardest meteorological inputs to air quality modeling applications to accurately replicate. The widely varying horizontal and vertical scales of clouds are often ill-suited to Eulerian grid modeling applications.

- Errors and uncertainties in this modeling input can translate to large errors and uncertainties in the air quality modeling outputs.

- As part of a regional ozone and fine particulate air quality modeling applications over the eastern U.S. for the entire ozone season of 2001, this analysis attempts to answer three questions with regard to clouds and their attenuation effects on air quality.

  1) Can the effects of cloud attenuation on ozone modeling be isolated and quantified?

  2) How do various air quality models differ in their treatment of cloud attenuation?

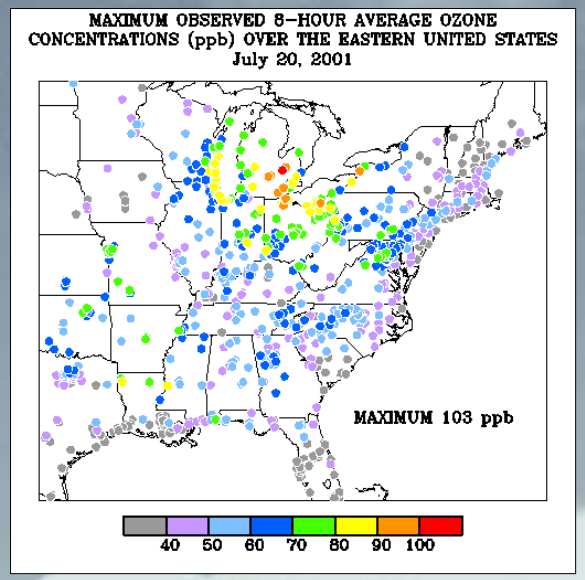
  3) Do differences in air quality model outputs result from varying cloud treatment?

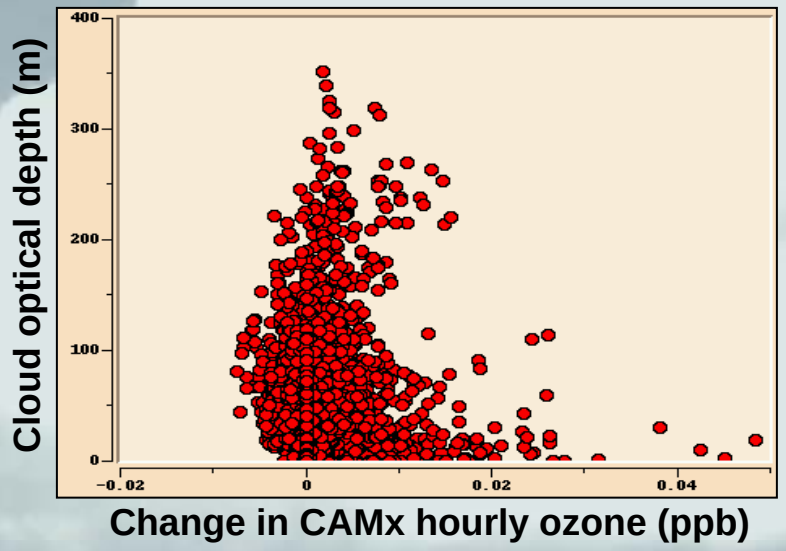
Introduction / Outline

- Both the Community Multi-scale Air Quality modeling system (CMAQ) and the Comprehensive Air Quality Model with Extensions (CAMx) have been applied to a large eastern U.S. domain.
- In both cases, the meteorological modeling input data were based on MM5.
- Several model simulations were conducted with the effects of cloud attenuation off or otherwise modified.
- These runs showed that even optically-thin clouds can have large suppressing effects on ozone (up to 40 ppb) and other photochemically activated pollutants.
- This analysis also showed that the two air quality models differ greatly in the way they simulate the attenuative effects of clouds.
  - CMAQ generates stronger-attenuating clouds than CAMx for most combinations of cloud liquid water path.

Quantifying Attenuation Effects on Ozone

- A three-day test period in 2001 was used for this analysis. (7/19 through 7/21)
- The plot to the lower left shows how the hourly ozone predictions for 2000 UTC, July 20th changed as a result of turning off the cloud attenuation effects in the CAMx simulation.
- While most of the values are near-zero, it is interesting to note that the largest changes in the sensitivity test occur where the cloud optical depth values are low.





Similarities and differences in cloud attenuation: CAMx vs. CMAQ

- The CMAQ and CAMx attenuation schemes are both derived from the RADM scheme.

  Both models use a scheme in which the clear-sky photolysis rates (J-values) are adjusted according to cloud fraction, zenith angle, and cloud transmissivity. Both models adjust the clear-sky J-values above, below, and within the cloud.

- The within-cloud adjustment of clear-sky photolysis differs between the two models for within-cloud calculations.

  In CMAQ the within-cloud adjustment is a height-based linear interpolation of cloud top photolysis and cloud bottom photolysis.

  CAMx treats within-cloud adjustments the same as below-cloud adjustments.

- The equation for cloud transmissivity is the same in both models.

  Transmissivity is a function of cloud optical depth and some constants. The same constants are used in cloud transmissivity calculations.

Similarities and differences in cloud attenuation: CAMx vs. CMAQ

- Cloud optical depth is calculated differently in CMAQ and CAMx.

  In CMAQ, cloud optical depth is calculated internally within the air quality model itself, that is not within the meteorological preprocessor and is a function only of the liquid water path (LWP), which is a function of a) cloud thickness and b) column-average cloud liquid water content. CMAQ uses an empirical formula to match these two variables to experimental data.

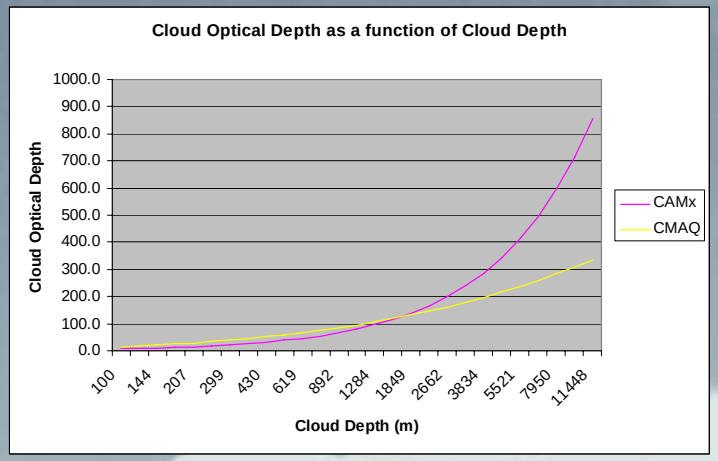
  In CAMx, cloud optical depth is calculated in the MM5CAMx preprocessor and is a function of: a) cloud thickness, b) column-average cloud liquid water content, c) the density of liquid water, and d) mean cloud drop radius. Constant values are employed for the density of liquid water and the mean cloud drop radius.

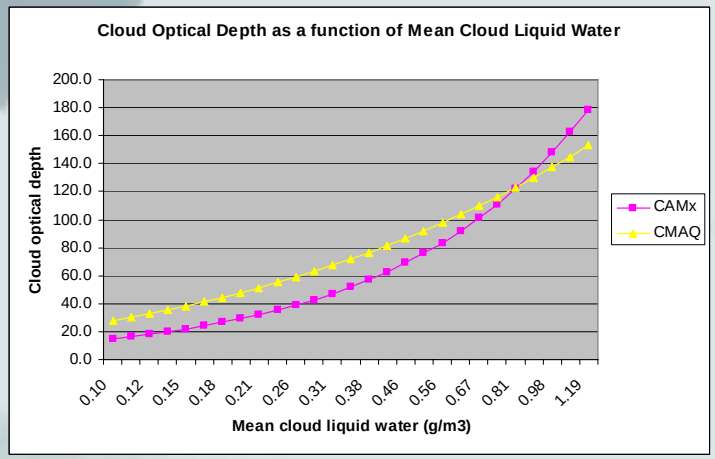
- Additionally, CAMx does not adjust clear-sky photolysis rates when the cloud optical depth is less than 5 m. The net effect is that for very optically-thin clouds, CMAQ will have some adjustment of clear-sky photolysis whereas CAMx will not.

Similarities and differences in cloud attenuation: CAMx vs. CMAQ

- Within a spreadsheet it was a simple process to determine how each model's cloud optical depth estimates would vary given differing values of cloud depth and mean cloud liquid water. These plots are shown to the right.

- It was determined that CMAQ has a tendency to generate greater-attenuating conditions when the clouds are relatively thin (i.e., less than 1000m) and have relatively low amounts of liquid water content (i.e., less than 0.8 g/m3).

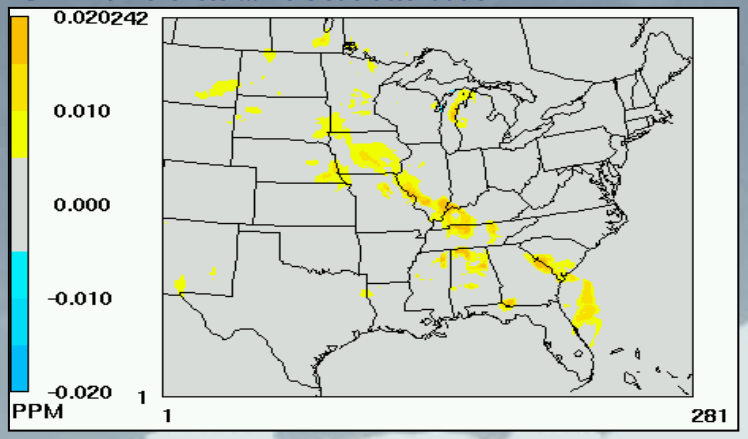




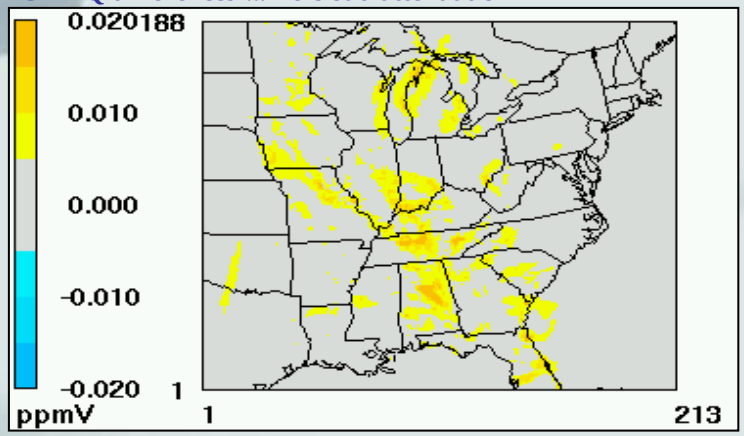
Do differences in air quality model outputs result from varying cloud treatment

- Both air quality models were run with and without cloud attenuation in an attempt to determine the maximum effect of clouds on ozone modeling results.
- As seen in the difference plots, the simulated ozone on this day was increased by 5 to 15 ppb over a large swath of the modeling domain. Peak impacts on afternoon ozone levels could be as high as 40 ppb.
- While both models predicted similar impacts of clouds, the locations of the changes differed somewhat between the two models and the CMAQ response tended to be larger despite using an identical set of input meteorology.

CAMx differences w/ no cloud attenuation



CMAQ differences w/ no cloud attenuation



Conclusions

- The results of this study are not definitive as they only represent a very few modeling days and may not represent all possible scenarios. However, these sensitivity tests have confirmed what has been long known, that ozone formation can be strongly limited by the existence of clouds. A potentially new wrinkle in this conclusion is that ozone formation (within the models) can be strongly limited by even those clouds that are optically thin.

- Further, it is apparent that the CMAQ and CAMx approaches for simulating the effects of cloud attenuation on photolysis rates are different. For thinner clouds that are typically not associated with rainfall (i.e., lower liquid water content), it appears that the CMAQ model will simulate more attenuation (slower photochemistry, less ozone) than CAMx.

- These model differences are shown to result in differences in the simulated ozone patterns. While the results are consistent with our concerns of CMAQ underestimations and CAMx overestimations, it is not clear how big a role cloud treatments play in this regard.