The Effect of Nitrogen Oxide Emissions from Automobiles on the Concentration of Tropospheric Ozone in the Great Smoky Mountains National Park

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ABSTRACT

The Great Smoky Mountains National Park (GSMNP) is the most visited national park in the United States, drawing over 9 million visitors per year. Emissions of nitrogen oxides (NO_x) from the exhaust of automobiles transporting those visitors into and through the park combine with biogenic emissions of volatile organic compounds (VOCs) from the extensive park forests to form tropospheric (i.e., ground level) ozone, (O_3) which is harmful to plants, animals and humans. In this project, the National Oceanic and Atmospheric Administration's Atmospheric Chemistry and Canopy Exchange Simulation System (ACCESS) model is being used to estimate the impact of automobile NO_x emissions on O_3 within and downwind of GSMNP. The one-dimensional column model ACCESS utilizes a current state-of-the-science, near explicit atmospheric chemistry mechanism to simulate tropospheric O_3 from ground level to the top of the planetary boundary layer (PBL) (~2 km) and accounts for turbulent vertical atmospheric transport of trace species from within the forest canopy and up throughout the full depth of the PBL. NO_x emissions from varying levels of automobile traffic in the park will be simulated with ACCESS and the impact of the traffic on O_3 concentrations will be evaluated. Data from air quality monitoring sites within and around GSMNP will be used to assess ACCESS results.

OBJECTIVES

1. Assess how ACCESS Runs on an HPC platform.
2. Generate raw data from a reduced version of ACCESS on both an HPC platform and a personal computer. Compare the results to ensure that ACCESS outputs are being produced properly.
3. Take actual data of ozone concentrations recorded within the GSMNP and compare that to concentrations predicted with ACCESS.

AN ILLUSTRATION OF OUR PURPOSE: Ozone Levels in the Great Smoky Mountains as of July 15th, 2013

The National Park Service (NPS) has sensors all over the park to track the amounts of several air pollutants, including ozone. You can see a gradual climb, with the maximum peaks, as of now, being just around noon on Friday, July 12, 2013, and at around the same time on Saturday, July 13, 2013. Right now, ozone levels are in what the NPS calls the "Good" zone. However, we are not that far off from the moderate zone. We hope to keep these levels "in the green", if you'll forgive an obvious pun. We will use ACCESS to predict these levels in a steady state simulation, and hopefully be able to make useful predictions of the levels of ozone within the park based upon traffic level within the park.

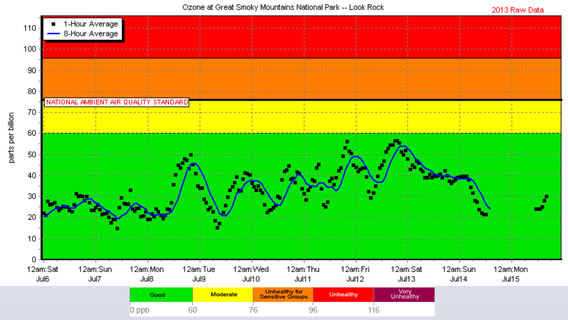


Image Source: National Park Service, "Great Smoky Mountains National Park: Air Quality 10-day Charts"

URL:http://www.nature.nps.gov/air/webcams/parks/grsmcam/grsm_datatimelines.cfm

RESULTS FROM "TOY" VERSION OF ACCESS

The results from the "toy" version of ACCESS are very simplified representations of the actual chemistry within the canopy. This is because the toy version only contains around 77 reactions which it can account for. The full version of ACCESS, however, contains almost a hundred times that, topping out at well over 7,000 chemical reactions within its database.. That being said, this makes it easier to compare ACCESS performance on different computing platforms in a reasonable amount of time. We do this comparison in the next two columns.

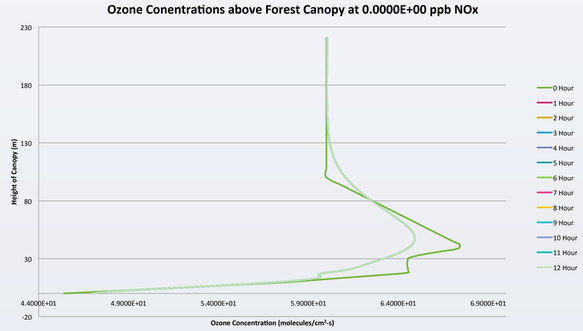
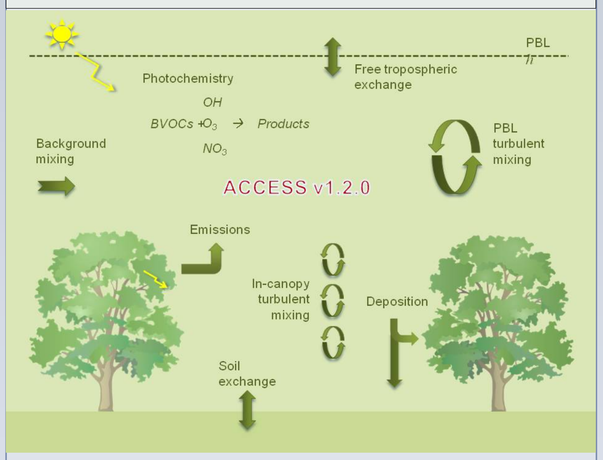
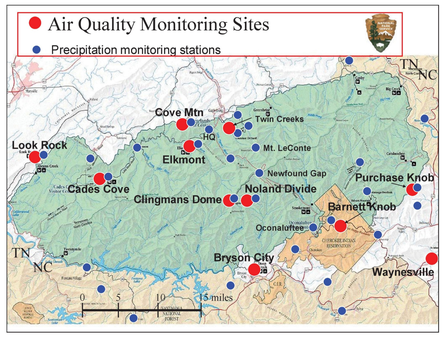


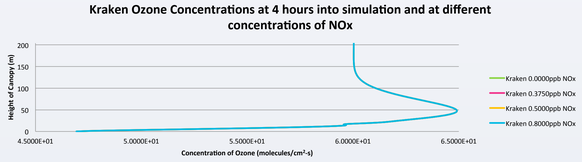
Image Source: Dr. Rick D. Saylor, Diagram of ACCESS.





SIMULATION SPEED COMPARISON FOR OPTIMIZATION FOR HPC PLATFORM

The following is a comparison of the outputs from ACCESS under the same conditions but on different platforms. The first graph comes from my own personal laptop, the second graph comes from the Kraken-XT5, an HPC platform at Oak Ridge National Laboratories, in Oak Ridge, TN. Both simulations show the exact same prediction, which is a good sign that the program will work on Kraken. Whether we can get the full version to run in a timely manner is another question altogether.



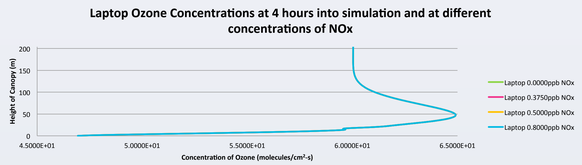


Image Source: ClimateScience.gov – "Schematic of chemical and transport processes related to atmospheric composition. These processes link the atmosphere with other components of the Earth system, including the oceans, land, and terrestrial and marine plants and animals.

URL: www.climatescience.gov/Library/stratplan2003/final/ccspstratplan2003-chap3.htm

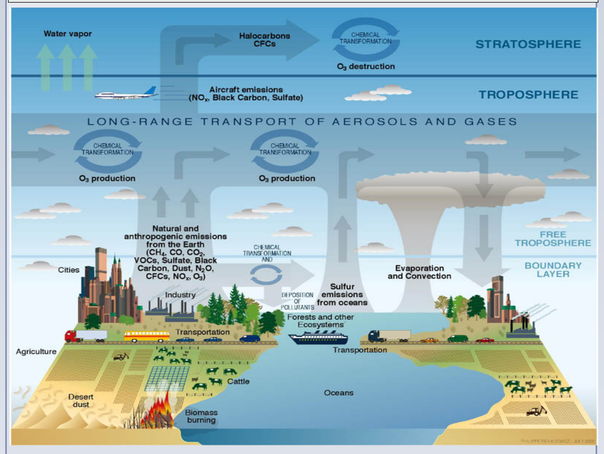
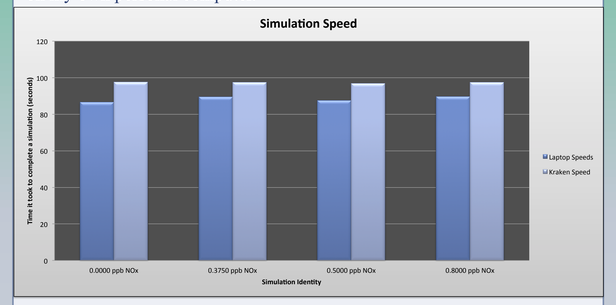


Image Source: Nancy Finley. Air Quality in the Great Smokey Mountains (PowerPoint Presentation). National Conference of State Legislatures Advisory Council on Energy. Oak Ridge, TN.

SIMULATION TIME COMPARISON

The graph that follows is a comparison of the time it takes for a simulation to complete on Kraken versus the time it takes for a simulation to complete on my own personal computer.



Average Simulation Speed (Laptop) = 88.381 ± 1.472 seconds
Average Simulation Speed (Kraken) = 97.352 ± 0.384 seconds

WHAT REACTIONS ACCESS ACCOUNTS FOR

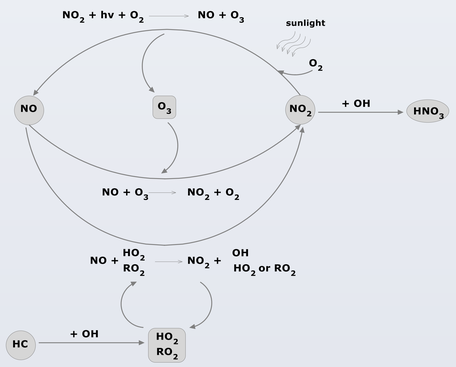


Image Source: Rick D. Saylor – NOAA. *Simplified diagram of reactions that take place in our atmosphere to create smog.*

FUTURE EXPERIMENTS

The next steps in our project will be to create appropriate input files for ACCESS simulations to simulate exhaust emissions of NO_x from automobile traffic in the GSMNP. Meteorological and forest canopy morphological inputs to ACCESS will be selected for typical mid-summer conditions in East Tennessee and background concentrations for the simulations will be determined from air quality monitoring sites located throughout the park. ACCESS simulations will then be performed to assess the effect of varying levels of automobile NO_x emissions on ozone concentrations within and downwind of GSMNP. Results from the simulations will be used to evaluate and interpret a long-term analysis of ozone data from monitoring sites in East Tennessee and Western North Carolina.

REFERENCES

Saylor, R. D. (2012). The Atmospheric Chemistry and Canopy Exchange Simulation System (ACCESS): model description and application to a temperate deciduous forest canopy. *Journal of Atmospheric Chemistry and Physics*, *12*(9). Retrieved from http://www.atmos-chem-phys.net/13/693/2013/acp-13-693-2013.pdf.

IMAGE ACKNOWLEDGEMENTS

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•National Parks Service

•US Climate Change Science Program

•Rick D. Saylor – NOAA Air Resources Lab, Atmospheric Turbulence and Diffusion Division