Ozone Signatures and Frontal Passages at Shenandoah National Park and Richmond, Virginia

J. Calder, George H. Moody Middle School/Henrico High School; Henrico, Virginia

NASA Mentors: M. Pippin and S. Hyater-Adams; LaRC

Background

Shenandoah National Park is a rural site in Virginia which is relatively free of local pollution. The Big Meadows monitoring station is at an elevation of 1079 meters above mean sea level (amsl). Past studies have indicated air passing over the industrialized Midwest (Ohio River Valley and Great Lakes Region) as well as the highly populated northeastern seaboard to be sources of elevated ozone at the park's Big Meadows monitoring site (Moy et al., 1994).

Weather systems in this area are dominated in tracking by the upper-level Jet Stream, pushing air systems in a general west to east track. Moy et al. (1994) analyzed Big Meadows data through a cluster analysis, showing clean air arriving at the site from these same source areas. The study attributed pressure and air mass characteristics as another influence in the area. Davis et al. (2009) performed a study using HYSPLIT models to compare trajectories and air masses to explain ozone variability. The authors suggest air mass trajectories better explain ozone variability in the Shenandoah National Park and surrounding areas. For example, anticyclonic flow is more likely to produce higher ozone levels (Cooper et al., 1998; Cooper and Moody, 2000; Davis et al. 2009).

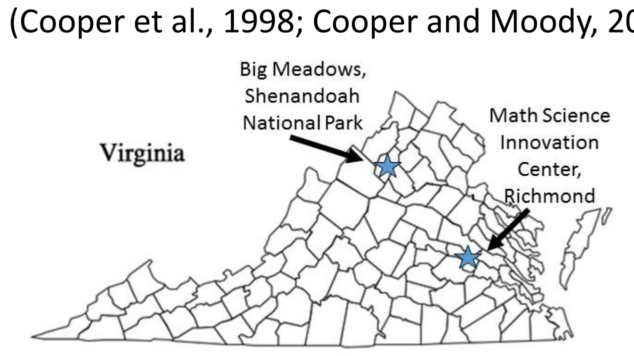

Figure 1: Location Map identifying the two study areas: Big Meadows, Shenandoah National Park, Virginia and Math Science Innovation Center, Richmond, Virginia.

Poulida et al. (1991) identified Big Meadows monitoring station as representative of regional air mass flow and conditions due to its elevation.

Boundary Layer Chemistry

The boundary layer in the atmosphere is typically located within one to two kilometers of the earth's surface. It represents an area where weather characteristics (such as humidity and temperature) are most influential on the dynamics of the layer. During the daytime (Figure 2), the air is turbulent due to the low heat capacity of the earth's surface. The land heats up from solar radiation therefore heating the air, causing the air to rise. Pollutants, such as ozone and NOx, are distributed vertically by convective forces, creating the mixed layer. At night, the land cools down, decreasing convection and therefore lowering the boundary layer. As a result, diurnal fluctuations can be seen in hourly ozone data with higher concentrations during the day, and lower concentrations at night. (Stull, 2006).

Typically, the Big Meadows monitoring station remains above the stable boundary layer. As a result, diurnal fluctuations are not evidenced in ozone data (Figure 3).

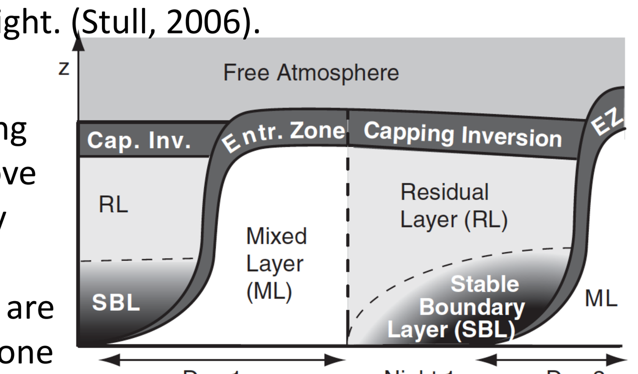

Figure 2: Diurnal changes in the stable boundary layer and mixed layer heights. Obtained from: http://www.geog.ubc.ca/g2field/subjects/climatology/lidar4.html

References

Cooper, O.R.; Moody, J.L.; Davenport, J.C.; Oltmans, S.J.; Johnson, B.J.; Chen, X.; Shepson, P.B; and Merrill, J.T. 1998. Influence of springtime weather systems on vertical ozone distribution over three North American sites. *Journal of Geophysical Research.* 103(D17). pp. 22,001-22,0013.

Cooper, O.R. and Moody, J.L. 2000. Meteorological controls on ozone at an elevated eastern United States regional background monitoring site. *Journal of Geophysical Research.* 105(D5). Pp. 6855-6869.

Davis, R.E.' Normile, C.P.; Sitka, L.; Hondula, D.M.; Knight, D.B.; Gawtry, S.P.; and Stenger, P.J. 2010. A comparison of trajectory and air mass approaches to examine ozone variability. *Atmospheric Environment.11* 44. pp. 64-74.

Moy, L.A.; Dickerson, R.R.; and Ryan, W.F. 1994. Relationship between back trajectories and tropospheric trace gas concentrations in rural Virginia. *Atmospheric Environment*. 28(17). Pp. 2789-2800.

Poulida, O.; Dickerson, R.R.; Doddridge, B.G.; and Holland, J.Z. 1991. Trace gas concentrations and meteorology in rural Virginia 1. Ozone and carbon monoxide. *Journal of Geophysical Research.* 96(D12). Pp. 22,461-22,475.

Stull, R. 2006. "Chapter 9: The Atmospheric Boundary Layer". From Wallace, J. and Hobbs, P. Atmosphere Science Second Edition: An Introductory Survey. Academic Press. P. 1-90

Ozone Data obtained from AirNow Tech.
Weather maps obtained from the National Weather Service.
Back Trajectories created using NOAA's HYSPLIT back trajectory analysis.
Satellite tropospheric ozone residual obtained from MY NASA DATA

Ozone Comparisons of Shenandoah National Park and Math Science Innovation Center

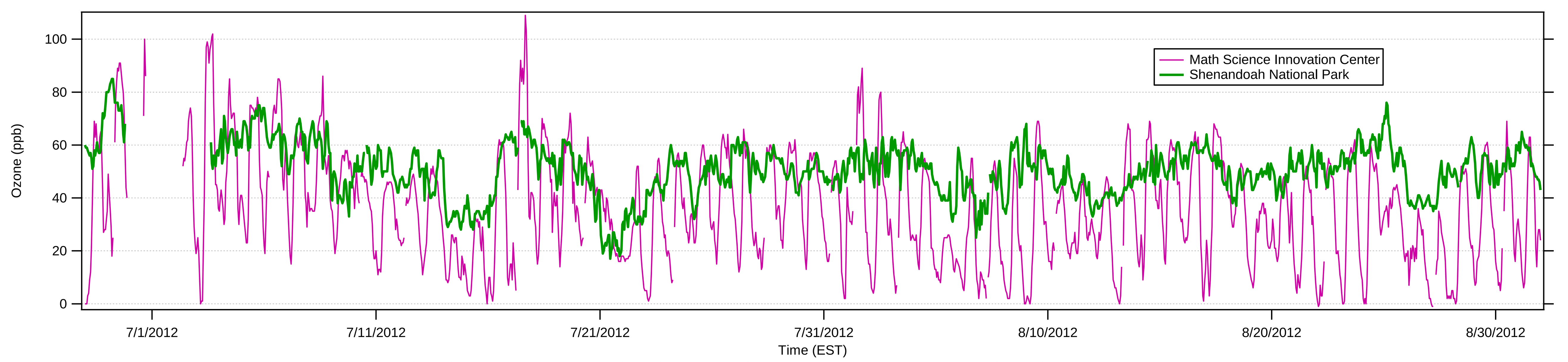

Figure 3: Ozone concentrations for Shenandoah National Park and Math Science Innovation Center for July 2013 to August 2013.

Figure 3 presents ozone concentrations for both Shenandoah National Park and the Math Science Innovation Center in Richmond, VA. Ozone concentrations at the Shenandoah National Park represent regional, background air quality as it is a rural site with no major metropolitan areas located nearby. The Math Science Innovation Center in Richmond, VA represents an urban location showing the diurnal variation of ozone. The National Park lacks a diurnal pattern due to its presence above the atmospheric boundary layer. However, the general increase and decrease of ozone concentrations throughout the summer are similar between the two sites despite the difference in land use.

Case Study *June 29th to 7th, 2013*

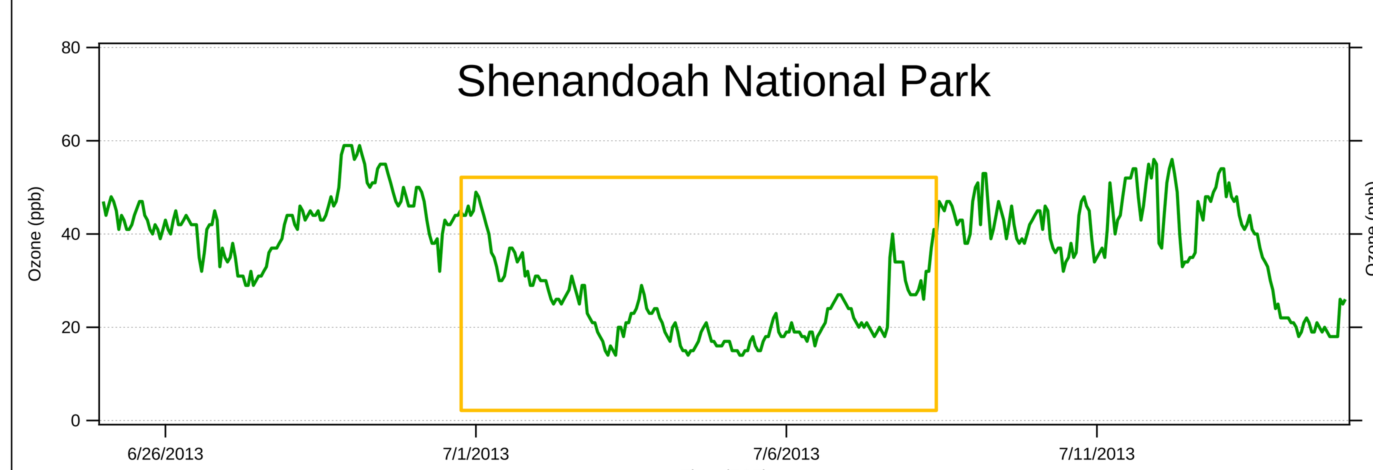

Figure 4: Ozone concentrations for Shenandoah National Park at Big Meadows from June 25, 2013 to July 15, 2013. The yellow box represents the period of the case study.

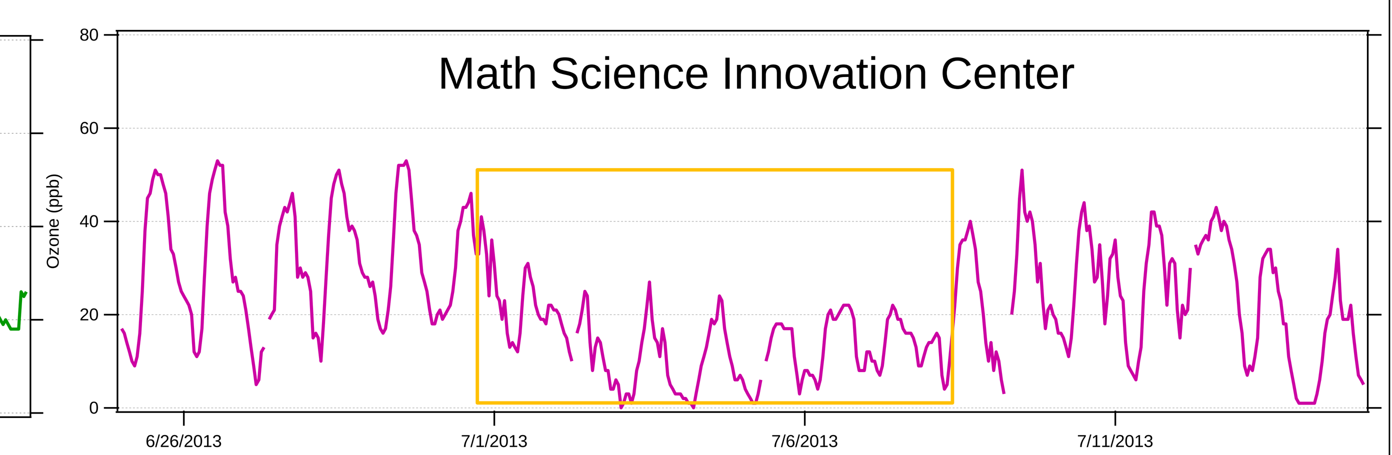

Figure 5: Ozone concentrations for Math Science Innovation Center in Richmond, VA from June 25, 2013 to July 15, 2013. The yellow box represents the period of the case study.

In early July of 2013, Shenandoah National Park (Figure 4) and Richmond, Virginia (Figure 5) experienced a low ozone event lasting for a few days. Ozone levels in the Park remained below 30 parts per billion (ppb) throughout the event. An investigation into the weather history shows the presence of a stationary front directly west of Virginia (Figure 6) immediately prior to the low ozone event. Once the front passed over the state, high pressure moved in from the south, providing clean air to the region. The low ozone event was also present at the Math Science Innovation Center in Richmond, VA as well as other monitoring stations across the state.

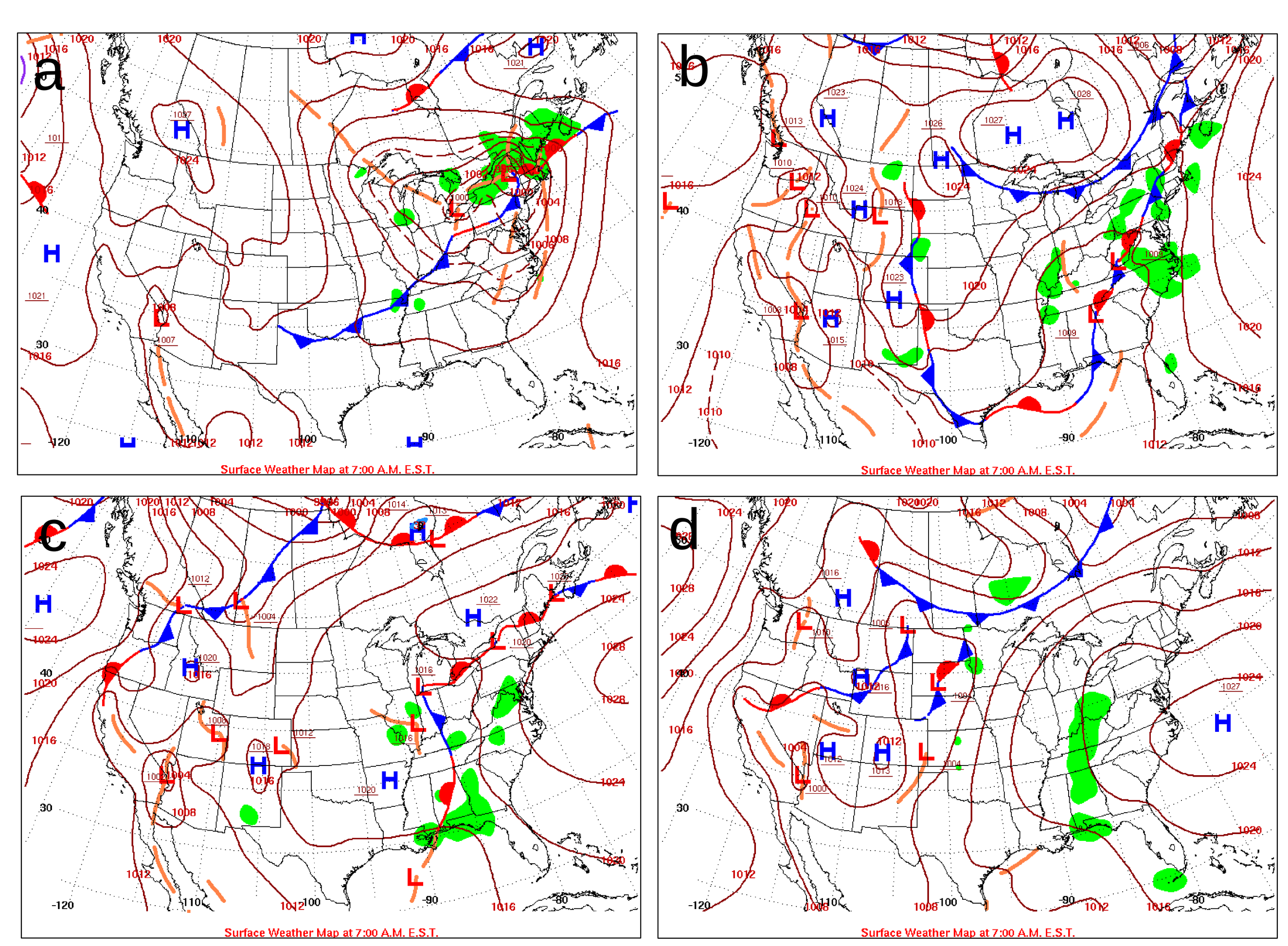

Figure 6: Weather maps for the United States identifying locations of fronts, pressures, isobars, and precipitation from throughout the case study interval: (a) June 28, 2013, (b) July 1, 2013, (c) July 3, 2013, and (d) July 6, 2013

Using NOAA's HYSPLIT model, back trajectories of air masses at both Shenandoah National Park and the Math Science Innovation Center (Figure 7) were conducted for the study period. The analysis was performed for 500, 1000 and 1500 meters amsl using EDAS 40 km (US, 2004 to present). During the case study, air masses originated from the south and travelled over a long distance prior to reaching the sites.

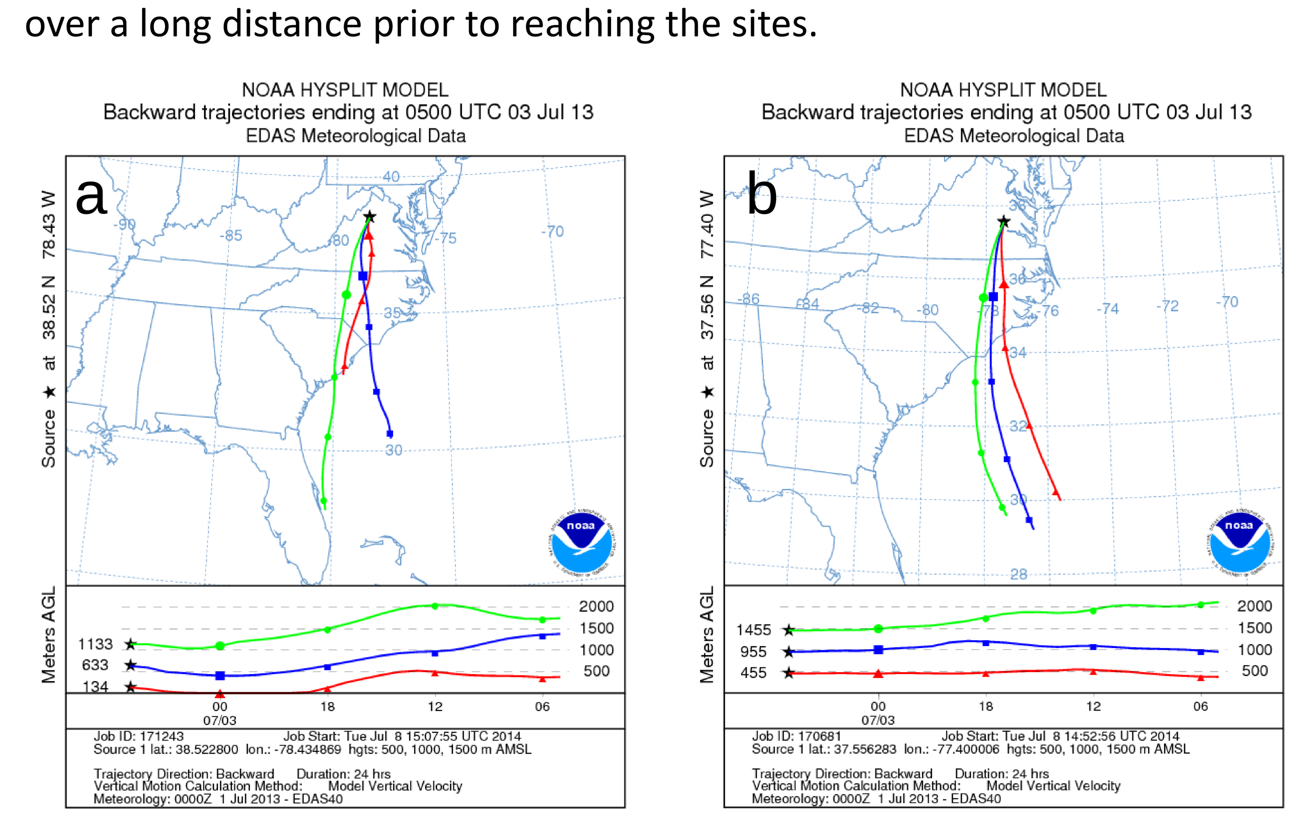

Figure 7: Back trajectories using NOAA's HySplit Model for (a) Shenandoah National Park and (b) Math Science Innovation Center for July 3, 2013.

Back Trajectories of Elevated Ozone

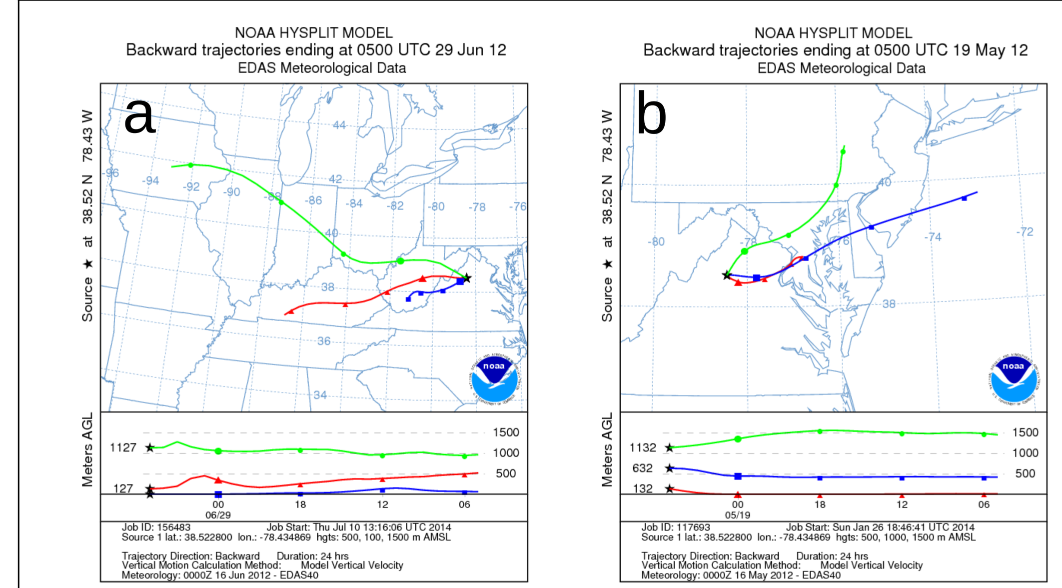

Figure 8: HYSPLIT back trajectories for (a) June 29, 2012 and (b) May 19, 2012 for elevated levels of ozone at Shenandoah National Park. On June 29, 2012, ozone levels reached 85 ppb and on May 19, 2012, ozone levels reached a maximum of 76 ppb.

Elevated ozone at the Shenandoah National Park are sourced from two main locations: the Ohio River Valley and the Northeastern seaboard (Figure 8).

Tropospheric Ozone Residual (TOR)

Tropospheric ozone residual data averaged monthly was obtained using satellite data for January 1979 to December 2005. Figure 9 compares averaged monthly ozone data from January 2000 to December 2005 for both Shenandoah National Park and Math Science Innovation Center. Both areas possess nearly identical signatures for the five year span.

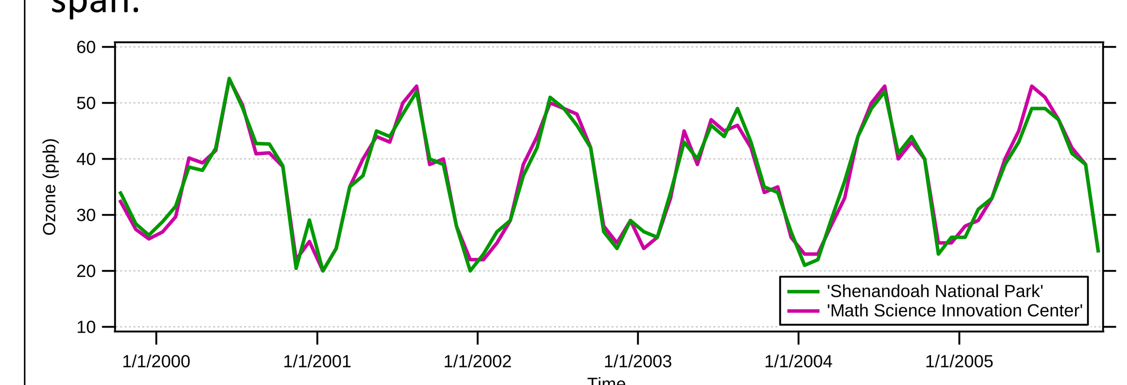

Figure 9: Total ozone residual from January 2000 to December 2005 for Shenandoah National Park.

Student Engagement

Students at Henrico High School were provided the opportunity to investigate differences between tropospheric and stratospheric ozone using real data and active research. Initially students were asked to brainstorm previous knowledge about ozone. Student responses focused on stratospheric ozone. The teacher provided students with links to various websites, including the Environmental Protection Agency, to learn about tropospheric ozone. Lastly, students analyzed graphs comparing seasonal ozone levels averaged hourly for a whole month. Two sites were selected for the analysis: Shenandoah National Park and the Math Science Center Innovation Center, located in Richmond, VA. The latter was chosen for its proximity to Henrico High School. Brainstorming, research and analysis was recorded on large sheets of paper for easy visibility. Lastly, students participated in activity modeling the formation and destruction of stratospheric ozone under natural conditions and with the addition of chlorofluorocarbons (bottom right image).

Students became more cognizant of the health and environmental concerns associated with tropospheric ozone. Most students were unaware of how ozone forms at breathing level and ozone's easily identifiable sweet odor. Many questioned the levels presented to them, why the two areas had such varying ozone signatures, as well as potential health concerns around the school such as in the copy rooms.