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A comparison of trajectory and air mass approaches to examine ozone variability

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ABSTRACT

Back trajectory analysis is a commonly-used tool for understanding how short-term variability in surface ozone depends on transport into a given location. Lesser-used but equally effective methods are air-mass based approaches that are primarily driven by changes in temperature and humidity conditions. We compare and combine these two fundamentally different approaches by evaluating daily near-surface afternoon warm-season ozone concentrations from 2001 to 2006 in and around the Shenandoah Valley of Virginia. Analysis of variance is used to compare summer afternoon ozone levels between air masses as identified by the Spatial Synoptic Classification to clusters of 72-h back trajectories estimated by the HYSPLIT model.

Ozone concentrations vary significantly across both air masses and trajectory clusters at all ozone monitors. Concentrations are highest for air masses characterized by dry, warm conditions and for air originating from the north and west of the study area or circulating over the mid-Atlantic region. In many cases, the interaction between synoptic types and back trajectory clusters produce results not evident from the examination of simple trajectories or air masses alone. For example, ozone concentrations on Moist Moderate days are 30 ppb higher when air parcels travel moderate distances into the Shenandoah Valley from the west than when they travel longer distances from the north or northeast. Combining air mass and trajectory approaches provides a more useful characterization of air quality conditions than either method alone.

1. Introduction

Day-to-day surface ozone variations at a given location are influenced by a variety of meteorological factors, including advection of ozone from upstream sources and *in situ* production. Ozone transport is often examined by tracing the trajectory of a hypothetical air parcel into the location of interest (e.g., Jiang et al., 2003; Taubman et al., 2006; Suthawaree et al., 2007; Delcloo and De Backer, 2008). These back trajectories are primarily calculated from the observed wind/pressure field and often have been used as the basis for ozone climatologies (Moody and Galloway, 1988; Dorling et al., 1992a,b; Moy et al., 1994; Dorling and Davies, 1995; Moody et al., 1995, 1998; Harris and Oltmans, 1997; Brankov et al., 1998; Eneroth et al., 2003).

Although air flow impacts ozone levels, ozone production depends on a variety of other meteorological factors, such as actinic radiation levels, temperature, and humidity (e.g., Comrie, 1990; Comrie and Yarnal, 1992; Liu et al., 1994; Poissant et al., 1996; Xu et al., 1997; Seinfeld and Pandis, 1998), factors that are not explicitly considered with back trajectory approaches. Air mass classifications use a suite of meteorological variables as inputs, including both wind and thermal-moisture variables. Air mass-based approaches have been successfully applied to examine ozone variability in the United States (Comrie and Yarnal, 1992; Greene et al., 1999; Lennartson and Schwartz, 1999; Rohli et al., 2004), Canada (Heidorn and Yap, 1986; McKendry, 1994; Cheng et al., 2007), the United Kingdom (McGregor and Bamzelis, 1995), New Zealand (Khan et al., 2007), Hong Kong (Tanner and Law, 2002), and Taiwan (Cheng et al., 2001). However, air mass approaches are not used as often as trajectory-based methods in air quality research. Despite the geographic diversity of these studies, some climatological consistency is evident. High ozone events tend to be associated with the approach of a slow-moving anticyclone from the west (Comrie, 1990; Cheng et al., 2007) and linked to high temperature, low humidity conditions and clear skies (Greene et al., 1999; Ellis et al., 2000). Some cases even report locally high ozone linked to specific orographic effects that create a subsidence inversion (Cheng et al., 2001; Tanner and Law, 2002). The impact of wind direction tends to vary by location because of the presence of high ozone regions nearby, advection of air masses associated with

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high ozone levels, and unique local topographic factors (e.g., Lennartson and Schwartz, 1999; Greene et al., 1999; Ellis et al., 2000; Rohli et al., 2004).

Our goal is to examine, both separately and in combination, the efficacy of air mass and back trajectory approaches in accounting for afternoon near-surface ozone concentrations in Virginia. Our study is focused on the Shenandoah Valley of Virginia and surrounding areas as a component of the larger Shenair Initiative, a multi-institutional effort to explore air quality variability in the region. Using data from ozone monitors in the Shenandoah Valley and from stations throughout Virginia, we examine the variability of ozone based upon the resident air mass, the general characteristics of the 72-h back trajectory terminating on that day, and the combined effects of both air masses and trajectories.

2. Data

The Shenandoah Valley of Virginia is a 320-km long northeast-to-southwest oriented valley extending from the eastern West Virginia panhandle southwestward to north of Roanoke, Virginia (Fig. 1). The Valley is predominantly rural with an overall population of approximately one million. The hourly ozone data used in this study were obtained from the Environmental Protection Agency's Air Quality System database, an on-line archive of ambient air quality monitor observations (http://www.epa.gov/ttn/airs/airsaqs/detaildata/downloadaqsdata.htm). Because ozone production depends in part on photochemical reactions, ozone has strong diurnal and seasonal components. In an effort to limit these influences, we sampled ozone at 1800 UTC (1400 local time) from April 1 through October 31, 2001–2006. This period of record was selected for consistency with a different component of the larger Shenair project that involves relating air quality to respiratory health in the region.

Ozone data were available from 16 monitoring stations in and around the Shenandoah Valley (Fig. 1). One topic of interest to the Shenair Initiative is the extent of regional ozone transport into the Valley as compared to local ozone production. Two potential external sources for transport include the Washington, D.C. and Richmond metropolitan areas. Although both cities are east of the Valley and prevailing winds are westerly, easterly transport will occur given the appropriate synoptic conditions. To simplify portions of our analysis, we averaged the ozone readings from Alexandria, Arlington, Franconia, McLean, and Mount Vernon into the "Washington" group and the observations from Caroline, Charles City, Chesterfield, Hanover, and Henrico into the "Richmond" group. These stations were grouped because of their proximity and statistically significant inter-station Pearson correlations (greater than 0.89 for the Washington group and from 0.77 to 0.89 for Richmond). The six remaining monitors were analyzed individually with Chantilly, Fauquier, and Prince William linked to a first-order weather station in the northern Shenandoah Valley and Roanoke, Rockbridge, and Wythe associated with a southern valley station.

On a station-by-station basis, average 2 p.m. warm-season ozone concentrations vary from about 47 to 54 ppb (Table 1). Over the period of record, all of the stations recorded values over 100 ppb except for the two rural, southern monitors. We selected monitoring sites based upon data completeness (all stations were at least 95% complete). Station-days with missing observations were excluded from the analysis.

Average monthly ozone levels are comparable from April through August, with a slight increase in mid-summer (Fig. 2a).

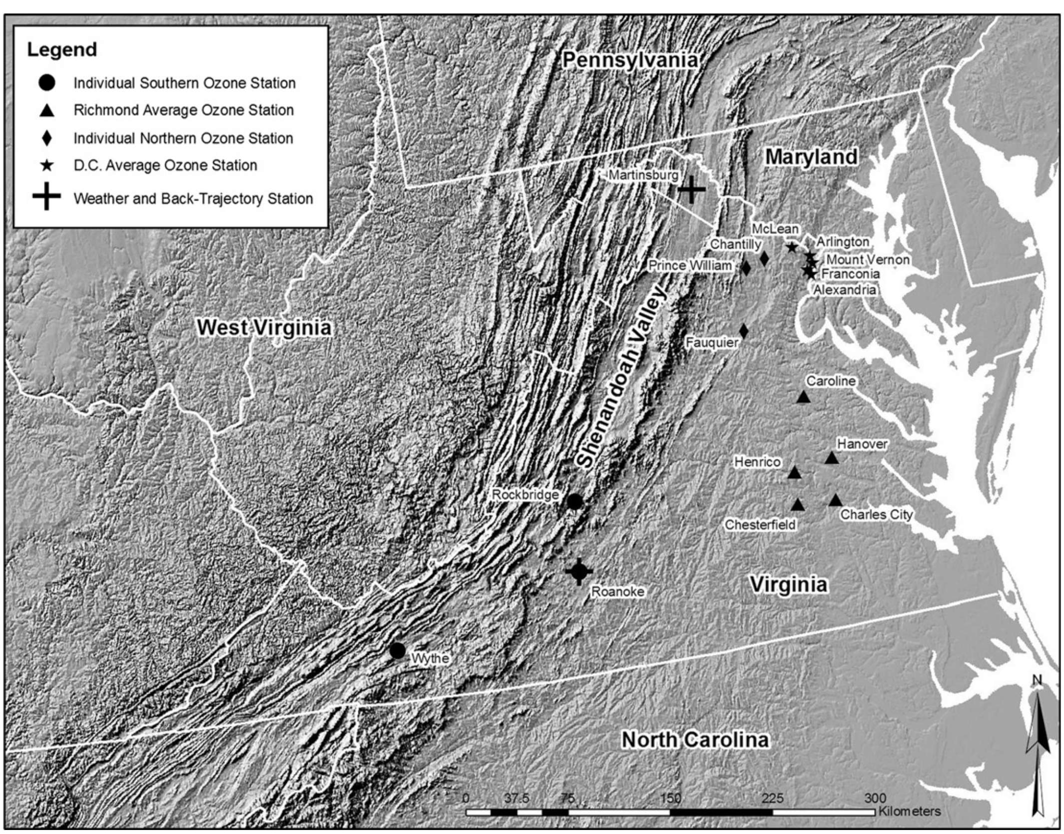

Fig. 1. Map of meteorological stations and ozone monitors used in this study. The ozone monitors indicated by stars are combined into an average value for Washington, D.C. and the monitors indicated by triangles are averaged for Richmond, Virginia. The remaining ozone monitors are examined individually.