J1.10 A PRELIMINARY BACK-TRAJECTORY AND AIR MASS CLIMATOLOGY FOR THE SHENANDOAH VALLEY

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1. ABSTRACT

Although trajectory analyses are commonly used in air quality studies, synoptic climatological techniques, which rely more on thermal/moisture properties of air masses than on wind fields, have also been successfully applied. We merge these two approaches in the development of a preliminary winter climatology for Roanoke, Virginia. The Spatial Synoptic Classification (SSC) is used to determine daily air mass type at Roanoke, and 72-hour back-trajectories from the HYSPLIT model are examined for consistency with the air mass on the terminal day. The dynamic variability of trajectories is largely consistent with the air mass characteristics. Future research will expand the spatial domain, include all seasons, and incorporate various air quality variables into the analysis.

2. INTRODUCTION

Trajectory analyses are commonly used in air quality studies to examine the source regions of air parcels moving into a given area, or the likely paths air parcels would take following a plume from a point source. In addition to tracking the movement of air parcels, it is also important to consider thermodynamic factors that could influence changes in air quality. In a climatological context, air mass characteristics have been successfully used over the past few decades to examine pollution concentrations, particularly with respect to daily air quality variability (e.g., Davis and Kalkstein, 1990; Davis and Gay, 1993; Greene et al., 1999; Power et al., 2006) and often in the context of air pollutant impacts on human mortality (e.g., Pope and Kalkstein, 1996; Smoyer et al., 2000; Sheridan and Kalkstein, 2004; Rainham et al., 2005).

Typically the trajectory- and air-mass based approaches are not both utilized in the same analyses. Here we examine linkages between independent characterizations of air mass types and trajectories within a climatological framework. In our analysis, we apply a commonly-used trajectory model (the HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model) and an increasingly popular air mass-based classification (the Spatial Synoptic Classification (SSC)) to characterize daily winter climate variability in Roanoke, Virginia. This preliminary analysis is part of a larger study that will involve examining the climatology of air quality variations in and around the Shenandoah Valley of Virginia and West Virginia. Ultimately, the full year will be examined for a suite of first-order weather stations.

3. DATA

The SSC requires multiple daily records of a variety of variables measured at the surface, including temperature, dew point temperature, wind, sea-level pressure, and cloud cover (total fraction). For Roanoke, these data are available hourly from 1949–2005.

To run the HYSPLIT model, we utilize wind/pressure initialization fields from the Eta Data Assimilation System (EDAS) at 80 km resolution. We run 72-hour back trajectories from Roanoke twice daily (at 0600 and 1800 GMT) for the period 1/1/97–4/30/04 with trajectories ending at six different elevations (10, 50, 100, 500, 1000, and 3000 m AGL). However, only the 500 m elevation is used in this analysis.

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4. METHODS

The SSC utilizes multivariate surface observations to classify air mass occurrence on a daily time scale. The procedure is designed so that air mass frequencies are spatially linked to neighboring stations, allowing for regional air mass comparisons over large areas. The result of the procedure is a discrete classification of each day's weather into one of seven predetermined air mass categories. Furthermore, because the SSC employs departures from time-varying within-year parameters, the classification is applicable year-round and is effectively a "relative" air mass classification. Thus, dry polar air can be observed in both winter and summer in Minneapolis, Minnesota and Houston, Texas. However, the seasonal and inter-annual frequencies of these air masses will change based upon shifts in the general circulation of the atmosphere and related air mass advection.

The SSC input variables are air temperature and dew point temperature at 0400, 1000, 1600, and 2200 local time, mean daily total cloud cover, mean daily sea-level pressure, and diurnal temperature, dew point temperature range, and horizontal wind. The input variables are standardized using a polynomial filter to facilitate classification in the shoulder seasons. A key component of this procedure is the development of "seed days," or characteristic values of the input variables linked to each air mass and location. The seed days are developed using a hybrid of objective and subjective procedures. As such, they are designed to be similar between adjacent sites. Upon establishment of seed days, each day's (standardized) input variables are used to classify that day into an air mass using discriminate function analysis. However, some days characterized by significant weather variability (such as a frontal passage) are not easily classified into a distinct air mass, and thus are classified into a "transition" category. Because the transition group includes a variety of weather situations, we do not include this category in our analysis. For complete details of the SSC procedure, refer to Kalkstein et al. (1996) and Sheridan (2002).

Six air mass types are identified by the SSC. Because of the importance of thermal and moisture properties in delineating an air mass, the SSC categorization is comparable to the famous Bergeron scheme. The SSC air masses are:

Dry Polar (DP): Similar to continental polar (cP) air, DP represents the coldest and driest conditions in a region and is linked to cold-air advection from a polar anticyclone.

Dry Moderate (DM): Occasionally called Pacific or Superior air, DM air masses are mild and dry and are frequently associated with adiabatically warmed maritime air from Pacific sources regions and long westerly trajectories in zonal flow. DM also includes polar source region air that has been modified by advection over a warmer surface.

Dry Tropical (DT): Like continental tropical (cT) air, DT days are hot and dry and often are associated with source region air from deserts or strong local subsidence generating high temperatures and low humidities.

Moist Polar (MP): Cloudy and cool conditions associated with the advection of high latitude maritime source region air, MP air masses are often linked to frontal overrunning, particularly when the frontal boundary is some distance south of the station.

Moist Moderate (MM): A warmer and more humid version of MP, MM is also linked to overrunning but with the frontal boundary closer to the station. This air mass frequently is found south of MP air.

Moist Tropical (MT): Like classic maritime tropical air masses, this group includes most of the warm and humid days at a station and is associated with air originating from the Gulf of Mexico or the subtropical Atlantic on the western flank of an anticyclone. For some purposes, this group is further subdivided in MT+ and MT++ to identify the more extreme warm and humid days.

The HYSPLIT model was initially developed by NOAA's Air Resources Laboratory in 1982 (Draxler and Rolph, 2006). The current version of the model (version 4.8) is often applied to air quality assessment work (e.g., Jorba et al., 2004; Kleiman et al., 2006). The model computes single-particle trajectories via time integration of a spatial wind field interpolated in three-dimensional space (Draxler and Hess, 2004).

For each day in December, January, and February, 1949–2005, we identify the SSC air mass at Roanoke, Virginia. Back-trajectories are then examined based upon the air mass classification on the day when the trajectory terminates at Roanoke. The hourly end point along each trajectory is identified to develop horizontal density plots for examining within air-mass trajectory variability. In addition, we more carefully examine back-trajectories at 12-hour intervals to determine the frequency of the direction from which air approaches the terminal point based on a 16-point compass. Finally, the median trajectory end-point at 12-hour intervals is calculated in addition to the 25th and 75th-percentile vertical trajectories.

One source of error in this preliminary analysis lies in the grouping of the trajectories by the air mass present, as the air mass type might have changed over the 72-hour period for which we computed back trajectories. Consequently, our emphasis here is on the linkages between air mass types and trajectories over the 48 hours prior to the trajectory reaching Roanoke.

We also examine temporal changes in the frequency of each air mass. For this analysis, we use the change-point detection algorithm developed by Menne and Williams (2005) which utilizes a likelihood ratio test and multi-phase regression to identify both trends and change points in time series data. We apply this approach to the winter (December–February) SSC air mass frequencies.

5. RESULTS AND DISCUSSION

Winter DP air in Roanoke is characterized by subsidence and NW and WNW trajectories (Figure 1). The median 3-day trajectory originates in far northern Wisconsin and moves fairly little over the initial 24–36 hours. Then, the median trajectory accelerates and shifts slightly southward, such that the predominant direction in the 24 hours before arriving at Roanoke is west of northwest. DP is the coldest winter air mass in Roanoke with the lowest dew point temperatures, the lowest mean cloud cover and highest pressure.

DM air masses have a more westerly trajectory than DP, with the median 3-day trajectory originating in Iowa (Figure 2). The more southerly component arises from the inclusion of more trajectories originating from the southwest and more directional variability in general. Like DP, the air mass is also subsident, with trajectories arriving from a higher elevation than in DP. This trajectory pattern is consistent with Pacific air, as are the clear skies, low dew point temperatures, and moderate temperatures.

DT air is very uncommon in Roanoke during winter (Figure 3). Although subsidence also predominates, most of the subsident motion occurs in the first 48 hours, with little vertical variation in the latter half of the time period. Most of the DT air approaches Roanoke from the SW or WSW over the latter 48 hours. It is noteworthy that the median 72-hour trajectory is only half the length of that for DM air. More than either of the other dry air masses, DT includes a higher density of easterly trajectories around Roanoke. These results are suggestive of slowly moving air being locally recycled around a stagnating anticyclone. The southward shift of DT trajectories over time is also consistent with the slow eastward migration of an anticyclone over the station. As expected, DT air is unusually mild and dry with low cloud cover and mean southwesterly winds.

At first glance, MP trajectories appear to be somewhat similar to DM; there are, however, some important differences (Figure 4). First, MP air is descending from a median elevation below 1000 m and the median elevation is ascending in the last 12 hours before reaching Roanoke. Second, although the trajectories originate from similar locations in the first 24 hours, MP air actually contains a greater number of trajectories with an easterly component, especially in the last 24 hours approaching Roanoke. On the trajectory plot, there appears to be a NE mode that is verified by the 12- and 24-hour trajectory roses. Thus, winter MP in Roanoke includes both westerly and easterly winds. Weather conditions during MP are typically cloudy and cool with moderately low pressure.

MM air is probably the most difficult air mass to characterize. The median MM trajectory exhibits the strongest ascent in the 24 hours prior to terminating at Roanoke, no doubt related to the inherent instability of this air mass (Figure 5). Although most trajectories are predominantly westerly with a southerly bias, MM trajectories emanate from almost all compass directions. This lack of strong directional preference is reflected in the short median trajectory. Nevertheless, over the last 12 hours there is a very distinct westerly preference, which may be indicative of MT source region air that has modified (becoming cooler and drier) with a long residence time over the

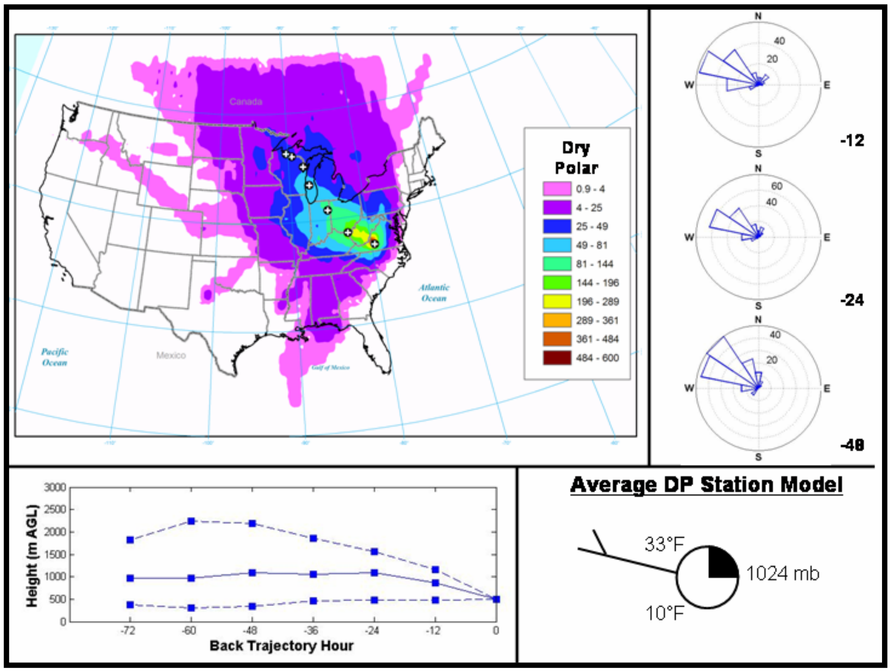

Figure 1. Characteristics of the Dry Polar (DP) air mass in winter (Dec.–Feb.) at Roanoke, Virginia. The median 72-hour back-trajectory is indicated at 12-hour intervals by black circles with crosses (top left). The background color field represents trajectory counts at hourly intervals on a 1°x1° latitude/longitude grid. Median trajectory elevations at 12-hour intervals are shown on the bottom, along with the 25th and 75th-percentile elevations. The roses on the right show trajectory frequencies on a 16-point compass at 12, 24, and 48 hours prior to the trajectory ending at Roanoke, calculated by comparing the endpoint of the trajectory at –12, –24, and –48 hours to the location of Roanoke. The station model on the bottom right shows mean afternoon (1854 UTC) temperature, dew point temperature, sea-level pressure, cloud cover, and wind in the standard format. All of these data are calculated for all DP days in winter from 1997–2004.

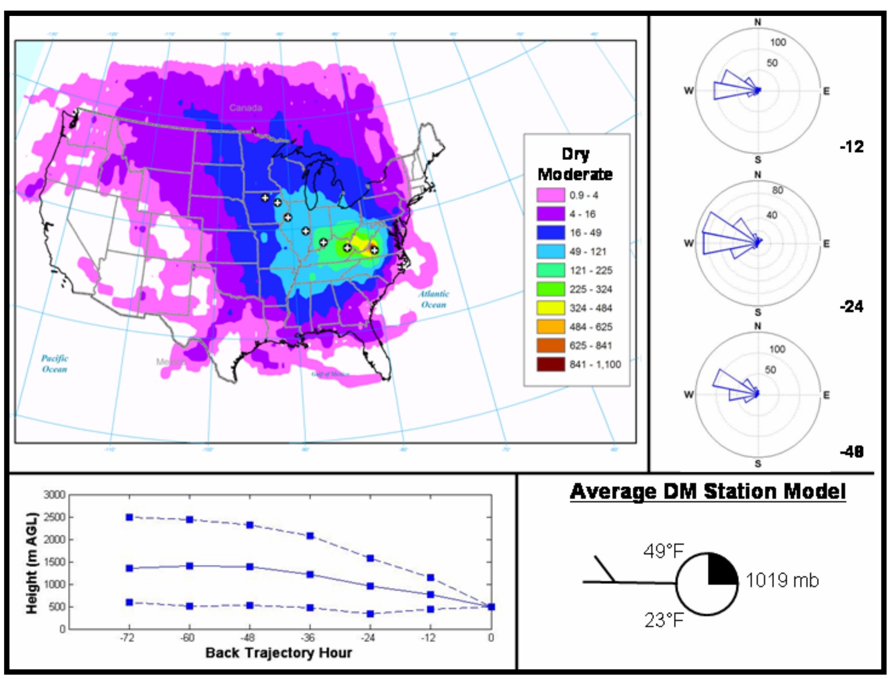

Figure 2. Same as in Figure 1 for Dry Moderate (DM) days.

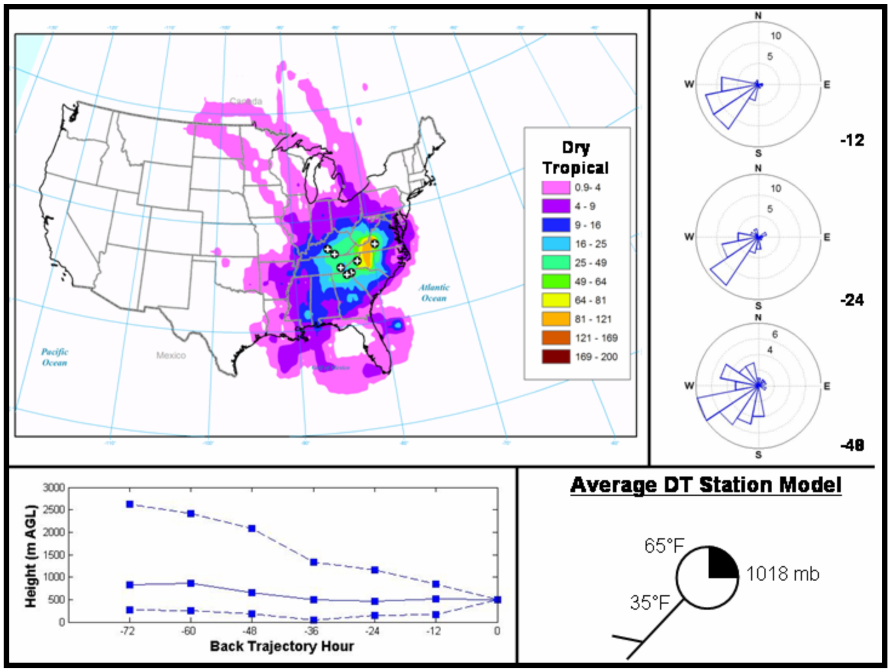

Figure 3. Same as in Figure 1 for Dry Tropical (DT) days.

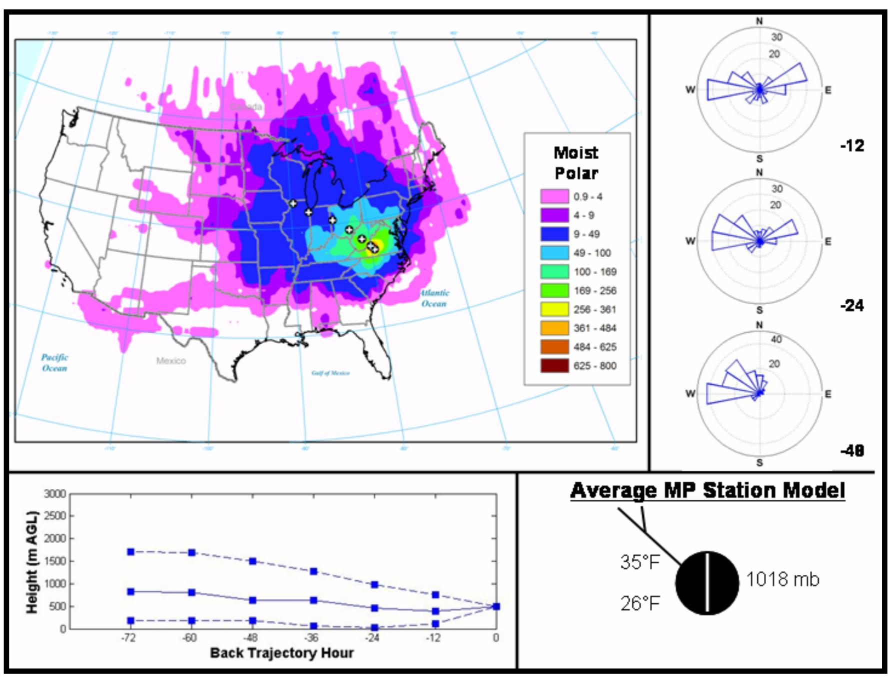

Figure 4. Same as in Figure 1 for Moist Polar (MP) days.

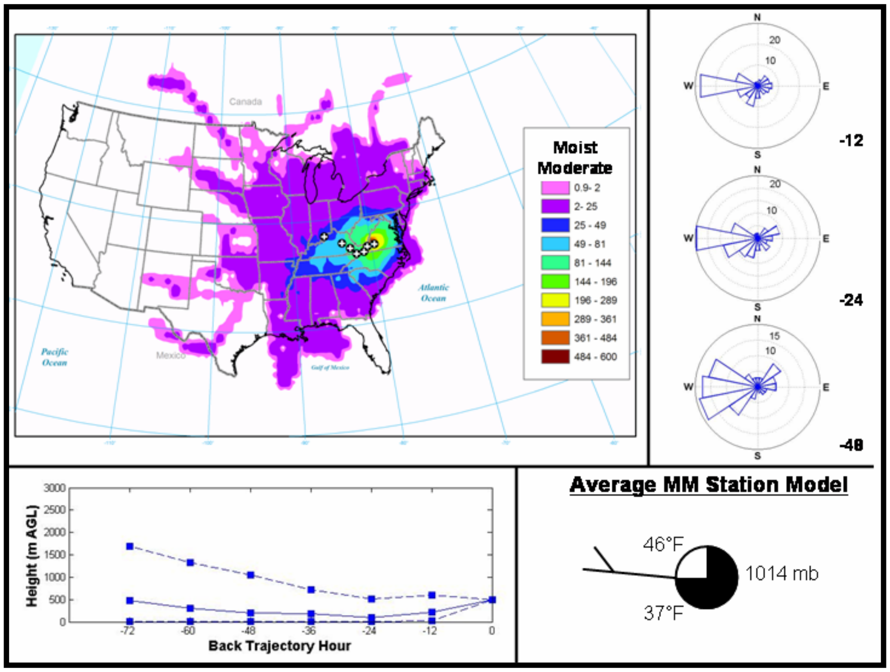

Figure 5. Same as in Figure 1 for Moist Moderate (MM) days.

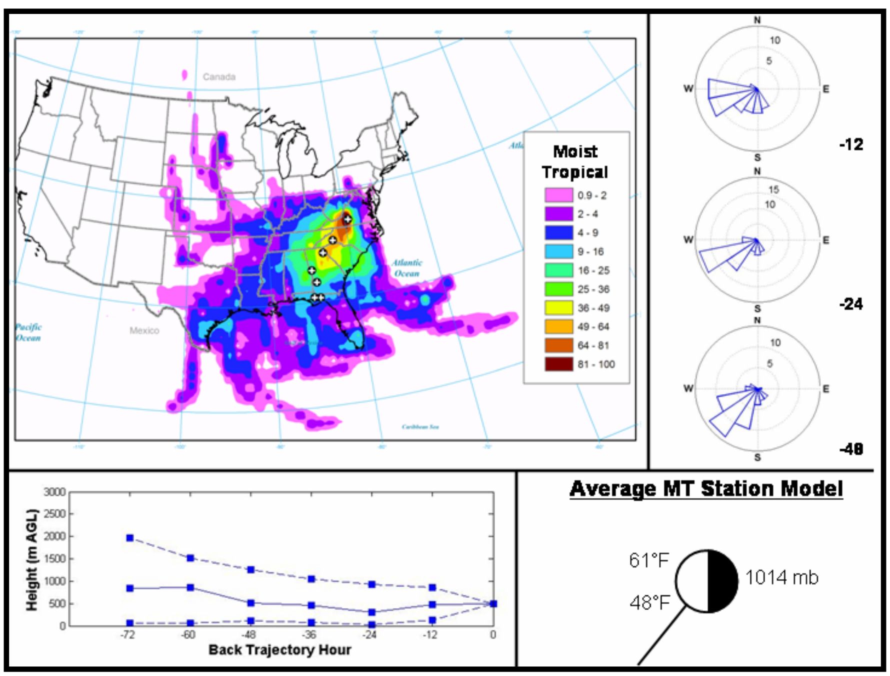

Figure 6. Same as in Figure 1 for Moist Tropical (MT) days.

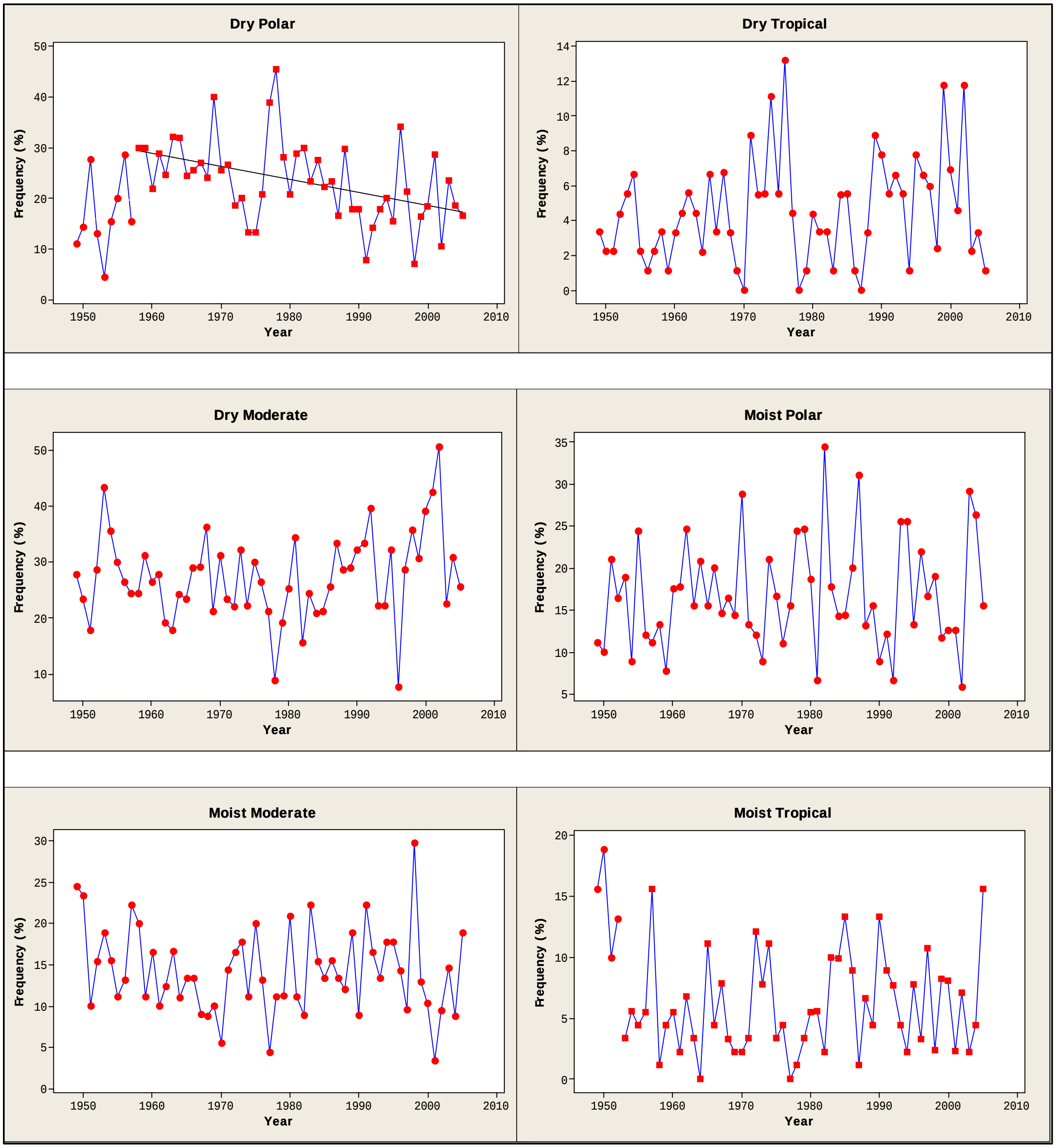

Figure 7. Time series of the winter relative frequencies of each SSC air mass in Roanoke, 1949–2004. A regression line indicates evidence of a statistically trend (alpha=0.05) based upon the Menne and Williams (2005) change-point detection method.

continent. MM air is warmer than MP air with lower pressure arising from closer proximity of a surface cyclone or front.

Finally, MT air has a very strong southerly component with air originating in the Gulf or Mexico and the Atlantic Ocean (Figure 6). Trajectories are from the SW quadrant almost exclusively, particularly from 24–48 hours. Although the predominant mode of transport is from the Gulf of Mexico, there is also a clear, secondary set of trajectories that originated or passed over the Atlantic Ocean off of the South Carolina coast. MT conditions are warm with high dew point temperatures, partly cloudy skies, and a strong southerly wind component.

With respect to temporal changes, we examined winter within-season air mass frequencies over time. We detected only one statistically significant trend—a decline in DP air from 1958–2005 (Figure 7). Although there are no other significant trends, the seasonal DP frequencies are negatively correlated with DM. Thus this decline may represent a warming of DP air masses such that the SSC is more frequently classifying warm DP air masses into DM.

6. CONCLUSIONS

Preliminary analyses linking HYSPLIT back-trajectories to SSC air masses for winter in Roanoke are very encouraging. Although the SSC air mass classification uses multivariate surface weather observations, the classification is fundamentally based upon variations in temperature and humidity; and although back-trajectories are calculated solely from wind fields, air mass variability can be inferred from trajectory information. These results indicate very strong consistency between the trajectory and air mass-based approaches, even without considering the impacts of day-to-day evolution of air masses at the terminal station.

In the future, we will run similar analyses for other stations in and around the Shenandoah Valley for all four seasons. Ultimately, we hope to use these coupled trajectory/air mass methods to examine the climatology of air quality variations in the Shenandoah Valley. As air quality depends both on the path of emissions into the target regions and the thermal, moisture, and stability changes along the way, we hope this multi-faceted approach will provide improved insights into all factors that influence air quality variability.

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