Technical Memorandum #3

Trajectory Analysis of Potential Source Regions Affecting Class I Areas in the MANE-VU Region

Prepared by Northeast States for
Coordinated Air Use Management
(NESCAUM)

For the MANE-VU Regional Planning
Organization

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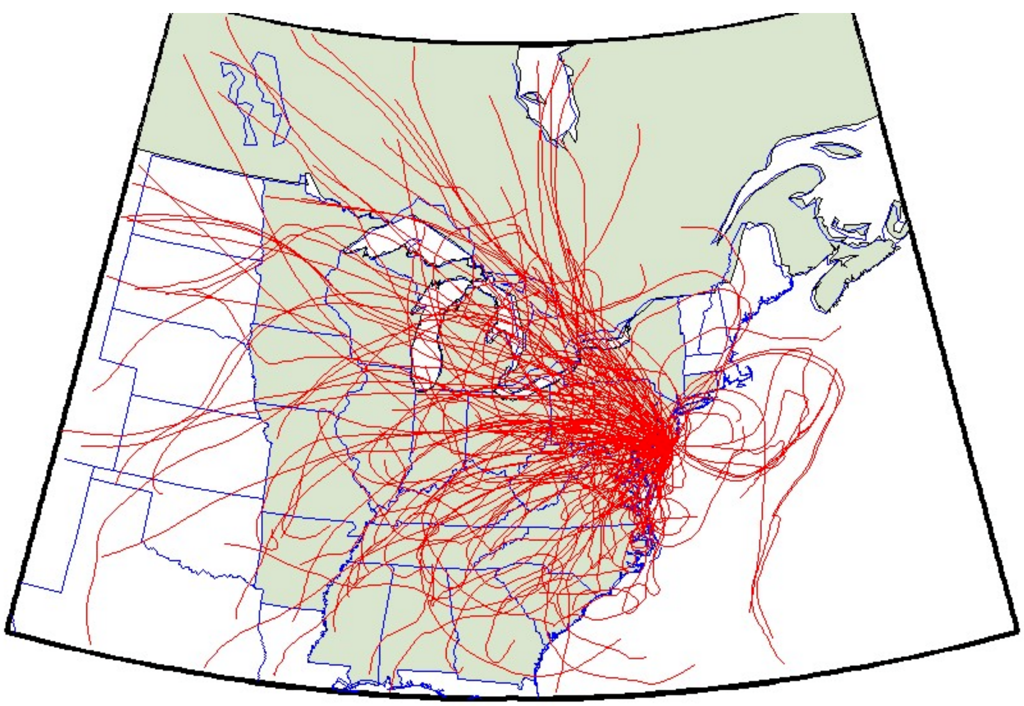

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February 15, 2002

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Executive Summary

Trajectory modeling techniques offer an empirical and visually powerful means of identifying geographic regions that are associated with the long-range transport of pollutants to specific locations. Previous attempts to define the source regions affecting Class I areas were conducted by the National Park Service prior to major emissions reductions that occurred as a result of the Acid Rain Program under Title IV of the Clean Air Act.

This technical memorandum discusses strengths and weaknesses in trajectory techniques and explains their appropriate role as one component in the regional haze planning process. This memorandum examines recent back trajectories from the 20 percent of days with the worst and best visibility at three Class I areas in the MANE-VU region and identifies a geographic region that lies upwind from these regions during these periods. Additionally, we present an analysis of the sensitivity of these results to trajectory starting height and use trajectory analyses for the Moosehorn Wilderness Area to explore the potential geographical limits of a modeling domain for Eulerian model platforms. Finally, alternative approaches for the use of trajectory modeling in understanding the causes and extent of regional haze in the MANE-VU region are presented.

I. Introduction

The USEPA guidelines for implementing Best Available Retrofit Technology (BART) indicate that eligible sources will be subject to BART if their emissions are released within a geographic region from which pollutants can be transported to a downwind Class I area. USEPA's 1999 regional haze rule further states in its preamble that such geographic source regions may extend for hundreds or thousands of kilometers. A first step in the MANE-VU RPO's regional haze planning efforts will necessarily require establishing the geographic source region for pollutants contributing to visibility impairment in Northeast and Mid-Atlantic Class I areas.

Trajectory modeling techniques offer an empirical and visually powerful means of identifying geographic regions that are associated with long-range transport of pollutants to specific locations. Previous attempts to define the source regions affecting Class I areas were conducted by the National Park Service prior to major emissions reductions that occurred as a result of the Acid Rain Program under Title IV of the Clean Air Act. A reexamination of the source regions that affect MANE-VU class I areas subsequent to these reductions is warranted.

A description of trajectory techniques and a discussion of their strengths and weaknesses are presented in Section II. In Section III, we review a trajectory analysis that was performed by the National Park Service prior to the emissions reductions of the mid-nineties and present its findings. NESCAUM has updated this analysis by examining back trajectories from the 20 percent of days with the worst and best visibility at three Class I areas that span the MANE-VU region and we examine the geographic region that lies upwind from these regions during these periods in Section IV. Finally, in Section V, we present the results of a sensitivity analysis of these source regions to choice of trajectory starting height and provide justification for our choice of starting height (500 meters).

With continued refinements, trajectory analysis will contribute to a weight-of-evidence approach for establishing potential source regions for future regional haze planning efforts.

II. Trajectory basics – the value and limitations of Lagrangian trajectory models

A. Background

Back trajectory analysis is a useful tool for analyzing source regions for haze and other transport-related pollution phenomena. This approach involves using meteorological data to track the prior "path" of parcels of air arriving at a particular monitoring site over a period of hours or days. Typically, trajectory models have very simple advection schemes that simply calculate the prior position of an air parcel using estimated wind speed and direction for the time period prior to the selected endpoint.

Some trajectory models have improved on these simplified techniques. For example, the HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT-4) model developed at the NOAA Air Resources Laboratory (ARL) (Draxler and Hess, 1997, 1998) calculates Lagrangian back trajectories from analyzed observed wind fields archived by the National Centers for Environmental Prediction (NCEP). In this latest version of the HYSPLIT model, a time interpolation feature is directly incorporated into the advection scheme. Thus a first guess, s', of a particle's position, s, at time $t + \Delta t$ is given by:

$$s'(t+\Delta t) = s(t) + v(s,t)\Delta t$$

and the final estimated position is given by:

$$s(t+\Delta t) = s(t) + 0.5\left\{v(s,t) + v(s',t+\Delta t)\right\}\Delta t \,.$$

In this way, information about the movement of an air parcel is calculated using information from before and after the calculated movement of that parcel.

Other trajectory models are available, such as the Atmospheric Transport and Diffusion Model (ATAD) (which is similar to HYSPLIT, but is run using observed wind fields, rather than analyzed data) and the CAPITA Monte Carlo Model which uses probabilistic determination of vertical mixing to generate more accurate predictions of the uncertainty associated with each trajectory (Kenski, 2001). This memorandum relies on the HYSPLIT model for calculating trajectories since both the model and input data required to run it are readily available on the web and the model has performed well in numerous validation exercises.

B. Limitations:

While many past pollution transport studies have focused on acid rain and ozone precursors, the basic transport mechanisms they identify also apply to the full range of visibility impairing pollutants. Table 1 shows the atmospheric residence time of key fine particle constituents. In this table, a combined, phase-specific residence time is derived from the literature for all precursor species of haze contributing pollutants. This suggests that once a sulfur dioxide molecule is emitted, the associated sulfur atom, will remain in the atmosphere in the gas phase for an average of 2-3 days. Once this sulfur atom has been incorporated into a particle, it can remain in the atmosphere as long as 3 weeks before deposition processes have removed it. The exact residence time of any individual sulfur atom is obviously a complicated function of meteorology and chemistry and varies with the weather. As is evident from the table, other regional haze pollutants – including secondary organic aerosols and primary fine particles – have residence times similar to or longer than those of sulfates and nitrates. Consequently, transport patterns and source regions for these haze pollutants are likely to be similar, given that they are emitted by many of the same urban and industrial sources and given that they are subject to the same (typically west to east) weather patterns.

Given the relative stability of fine particles and fine particle precursor species with respect to chemical transformation, the useful limits of trajectory modeling are determined by uncertainty in the trajectory calculations. Inadequacies of meteorological data and dynamic processes both contribute to this uncertainty.

The spatial and temporal resolution of analyzed gridded meteorological data is ultimately limited by the observing network that is used to produce them. The data used by HYSPLIT has a maximum spatial resolution over North America of 80 km in the horizontal, and a temporal resolution of 3 hours. Thus even after the observations have been manipulated and interpolated onto a uniform grid, significant spatial and temporal gaps exist in the data used to calculate the path of a trajectory. Any changes in wind speed or direction that occur more frequently or on a smaller spatial scale than the underlying data will be missed by the model.

Turbulent diffusion is the major dynamic process that contributes to the uncertainty in meteorological data. This process which take place on spatial scales too small to be resolved by the mean wind fields prevent the model from being able to calculate small deviations to the trajectory path with sufficient precision. The result is that this sub-grid scale process is not accounted for by the trajectory model. As additional trajectory endpoints are calculated, inadequacies in the meteorological data resolution and failure to account for sub-grid scale processes result in increasing model error. Thus error in a back trajectory is compounded and tends to increase linearly with increasing distance along the trajectory path.

Trajectory errors have been estimated using chemical tracer studies and balloon flights, whereby air parcels can be accurately tracked and their positions compared with trajectory calculations after the fact. Several studies have estimated the accuracy of individual HYSPLIT trajectories at 20-30 percent of travel distance (Draxler, 1991, 1996; Draxler and Hess,1998; Stunder, 1996). Despite the uncertainty inherent in an individual trajectory, a meaningful analysis can be performed through the use of a large number of trajectories. By examining the predominant meteorological pathways that are present during all of the twenty percent best and worst days over a three-year period, the effect of any particular back trajectory that could be in error is minimized. This approach has been applied in Section IV and V of this memorandum.

Table 1: Atmospheric residence times of various regional haze constituents

Visibility impairing constituents and their precursors	Molecular formulas	Combined residence time[a] of PM precursors and constituent components (days)
Sulfate (gas phase)	SO_2 + H2SO4 (combined lifetime in the gas phase)	2.1[b,c], 3[d]
Sulfate (aqueous, solid)	SO_4^{2-} + $(NH_4)_2SO_4$ + NH_4HSO_4 + $(NH_4)_3H(SO_4)_2$ (combined lifetime in the particle phase)	3-20[b]
Nitrate (gas phase)	NO_2 + NO + HNO_3	1-4 days[b]
Nitrate (aqueous, solid)	NH_4NO_3 + NO_3^-	3-20[b]
Organics (gas phase)	VOCs, non-volatile organics	hours-days[e]
Secondary Organic Aerosol	partially oxidized VOCs, organics	1-20[e]
Primary $PM_{2.5}$	EC, dust, soil, minerals	3-20[b]

Notes:
[a]Atmospheric residence time refers to the time for roughly 2/3 of initial concentrations of a pollutant to be removed. We note that roughly 1/3 of the pollutant will still be present in the atmosphere after this time has elapsed.
[b]Seinfeld and Pandis, 1998.
[C]Assumes that sulfur is present as 50% SO_2 and 50% sulfate.
[d]Schlesinger, 1997.
[e]Finlayson-Pitts and Pitts, 2000.

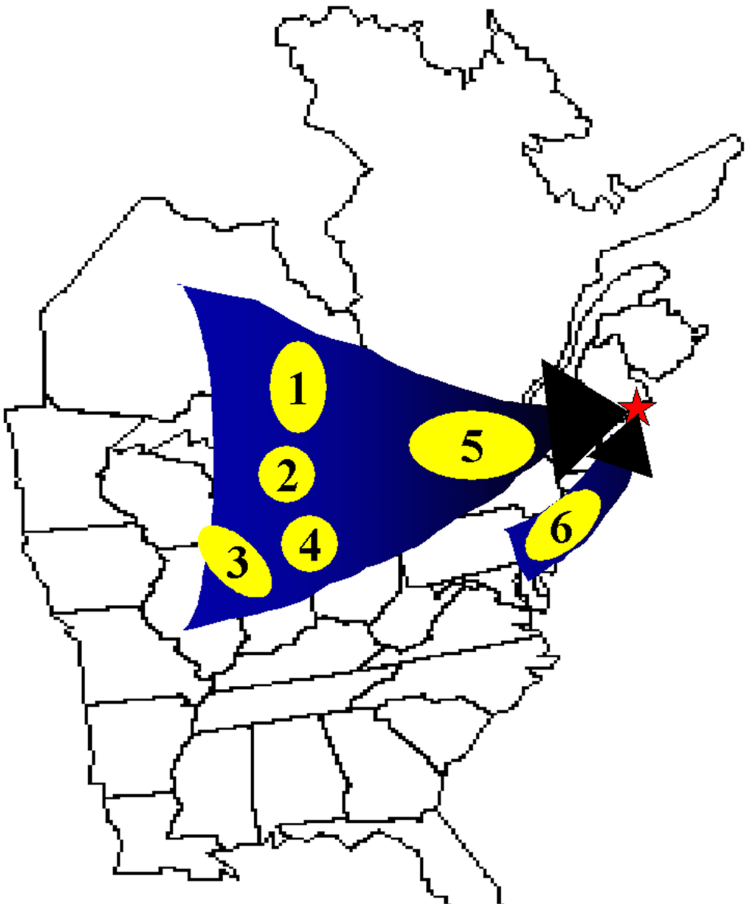
III. Previous analysis of airsheds affecting Acadia National Park

Studies conducted by the National Park Service in the early 1990s indicated that ambient sulfate concentrations at Acadia National Park in Maine were influenced by emissions from as far away as Illinois to the west, North Carolina to the south and Ontario, Canada to the north. Figure 1 shows the result of this early analysis, specifying the contribution of pre-1990 SO_2 emissions from different upwind areas on days when sulfate concentrations at Acadia were extremely high (Gebhart and Malm, 1990; Malm, 1992).[1] Though emissions patterns have changed since these studies were conducted, the general finding that distant SO_2 sources have an impact on sulfate levels far downwind remains valid. With an atmospheric lifetime of several days, the ability of SO_2 and sulfate to travel hundreds of miles before deposition has been well documented since acid rain issues were raised in the mid to late-1980s.

Similarly, past studies have pointed to the role of long-range transport in creating high levels of ground-level ozone across large portions of the eastern U.S. during the summer months (e.g. NESCAUM, 1997; CEC, 1997). These studies have demonstrated that severe ozone conditions in the Northeast and Mid-Atlantic states are strongly correlated with meteorological conditions that favor the transport of tropospheric ozone and its precursor pollutants, especially NO_X, from major sources in the industrial Midwest. These and other findings from the extensive air quality modeling conducted by the multi-state Ozone Transport Assessment Group (OTAG) in the late 1990s form the basis of recent federal efforts to require substantial NO_X reductions from power plants and other major industrial sources throughout a broad eastern states region. They are supported by field studies indicating the presence of low-level jets (200-800 meters above sea level) that are capable of transporting pollutant-laden, aged airmasses hundreds of miles up the Northeast corridor. Additionally, these studies found boundary layer synoptic transport (800-2000 meters above sea level) across the Appalachians from the Western OTR and Midwest (Blumenthal et al., 1997).

[1] "Extreme" was defined as one standard deviation above the geometric mean sulfate concentration. The results shown in Figure 1 were generated using back trajectory analysis. It should be cautioned that the specific results of this early analysis are based on pre-1990 emissions, which do not reflect control programs – such as the Acid Rain Program – introduced later in the 1990s. For example, the large contribution from Sudbury, Ontario identified at that time was due to nickel smelter operations that have since implemented SO_2 reductions of over 80 percent (personal communication, Guy Fenech, Environment Canada). Additionally, this study focused on episodic visibility impairment, while the haze rule addresses the twenty percent worst and best visibility conditions.

Figure 1: Pre-1990 source region sulfate contribution to Acadia National Park, ME.
(adapted from Malm, 2000)



1. Sudbury, Ontario 29%
2. Central MI 9%
3. Chicago 5%
4. Toledo 5%
5. Northern NY 24%
6. New York City & Philadelphia 15%
7. Other Sources 13%

IV. Source regions affecting MANE-VU Class I areas

By examining dominant air trajectories during the hours and days preceding the measurement of best and worst visibility conditions at Class I sites, source regions influencing those conditions can be identified. Figures 2 through 4 show the results of back trajectory analyses conducted for Acadia National Park, Lye Brook Wilderness Area, and the Brigantine Wilderness Area.[2] Back trajectories were calculated from a point 500 meters[3] above each Class I area for 72-hour periods ending at 6:00 AM, 12:00 PM and 6:00 PM on each of the 20 percent worst and best visibility days between 1997 and 1999.[4,5] Note that much of the SO_2 emitted into the path of these trajectories during the 72-hour period preceding best and worst visibility conditions would be likely to contribute to subsequent impairment at the downwind monitoring site, given that the atmospheric residence time of a sulfur atom – from its emission as SO_2 to deposition as its chief product, sulfate – is typically a week or more.

Figures 2a and b show that air masses contributing to worst-case visibility conditions in Acadia National Park tend to originate far to the south and west of the Park's boundaries. By comparison, air masses present over the park during the 20 percent of days with the best visibility conditions tended to originate from the north over Canada. For the Lye Brook Wilderness, Figure 3a shows back trajectories for the 20 percent worst visibility days clustered over New York State, northwest Pennsylvania, and Ohio as well as along a more southerly route over New York City and New Jersey. By comparison, the best visibility days at Lye Brook (Figure 3b) are strongly associated with back trajectories over northern New York State and the Quebec/Ontario border. Unlike

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[2] In all cases back trajectories were calculated using the HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT-4) model developed at the National Oceanic and Atmospheric Administration Air Resources Laboratory (NOAA ARL) (Draxler and Hess, 1997, 1998). Model details are available at http://www.arl.noaa.gov/ready/hysplit4.html. Note that the accuracy of the trajectories is affected by the temporal and spatial resolution of the input meteorological data. NOAA ARL archives analyzed meteorological products for use with the HYSPLIT model including the Eta Data Assimilation System (EDAS) wind fields, which cover North America with an 80 km spatial resolution and are based on 3-hourly variational analyses. Using these spatial and temporal resolutions, the HYSPLIT model has been shown to have a trajectory accuracy of 20-30 percent of the total transport distance (Draxler, 1991, 1996; Draxler and Hess, 1998; Stunder, 1996). When EDAS data was unavailable or incomplete, trajectories were calculated using the FNL meteorological data (approximately 190 km spatial resolution). If neither EDAS or FNL data were available, NCEP/NCAR Reanalysis data were used (a description of all NOAA archived meteorological data products can be found at http://www.arl.noaa.gov/ss/transport/archives.html). Case studies (Draxler and Hess, 1998) have also shown that due to large variations of wind speed and direction near the ground relative to higher altitudes, it is essential that the atmosphere's vertical structure be well represented by the input data. It is estimated that the HYSPLIT forecast trajectories have one-third of the relative trajectory error during low shear conditions than during high shear conditions (Stunder, 1996). It is reasonable to assume that these meteorological conditions would have a similar effect on our back trajectories.

[3] Sensitivity to trajectory starting height is explored in section V.

[4] Meteorological input (EDAS) data were unavailable prior to 1997 and data on monitored visibility conditions were available only through September 1999 at the time of analysis.

[5] Some trajectories could not be calculated for the full 72 hours due to errors in the meteorological input data or in cases where a trajectory went outside the domain for which meteorological data were available. If an error in the meteorological data led to the truncation of a trajectory prior to 48 hours, a complete trajectory was calculated using alternate meteorological input data as described in footnote 2.

the more northern Class I sites, back trajectories for Brigantine (see Figure 4) indicate that the worst 20 percent visibility days at that site are associated with air masses coming from further south as well as from the west. Conversely, air masses on the best visibility days at Brigantine seem to originate from all directions *except* the west or southwest. These results provide strong evidence that SO_2 emissions from sources distributed over a large portion of the eastern U.S. and parts of Canada can contribute to poor visibility in Northeast and Mid-Atlantic Class I areas.

Figure 2a: Back trajectories on 20% worst visibility days at Acadia National Park during 1997-99.

Figure 2b: Back trajectories on 20% best visibility days at Acadia National Park during 1997-99.

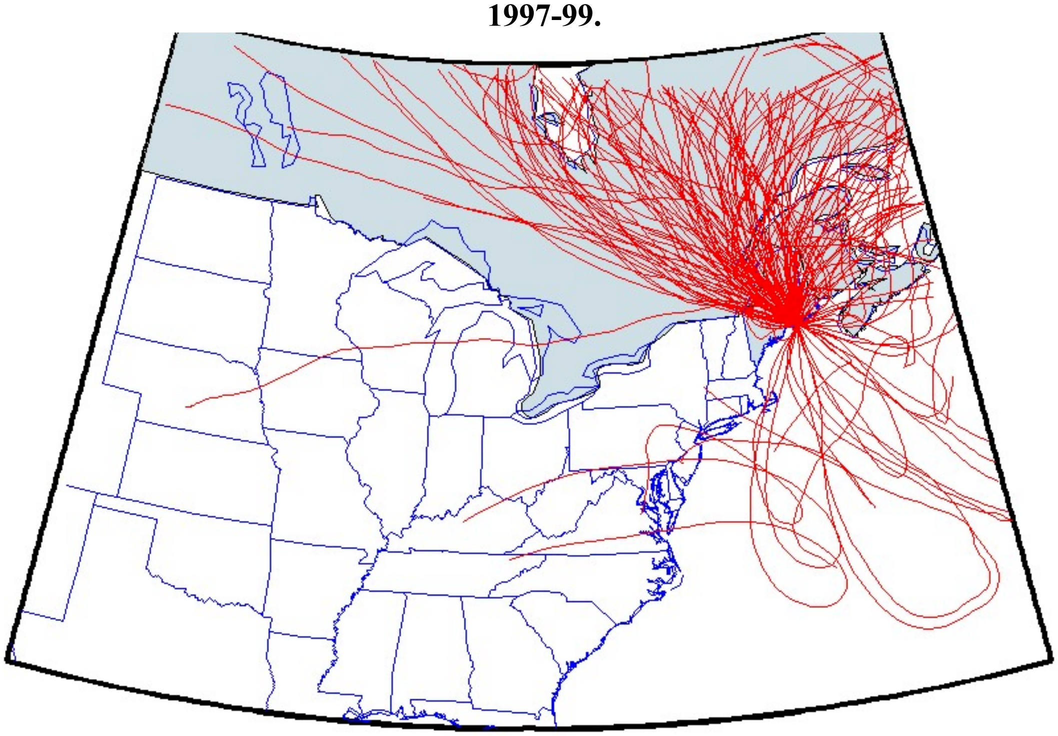


Figure 3a: Back trajectories on 20% worst visibility days at Lye Brook Wilderness Area during 1997-99.

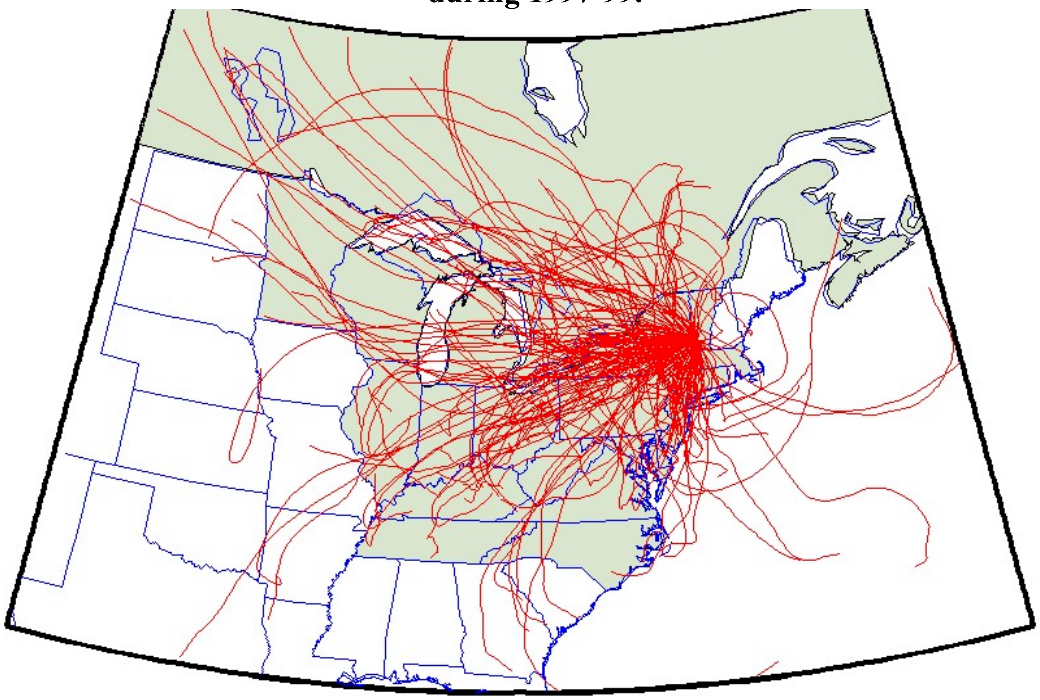


Figure 3b: Back trajectories on 20% best visibility days at Lye Brook Wilderness Area during 1997-99.

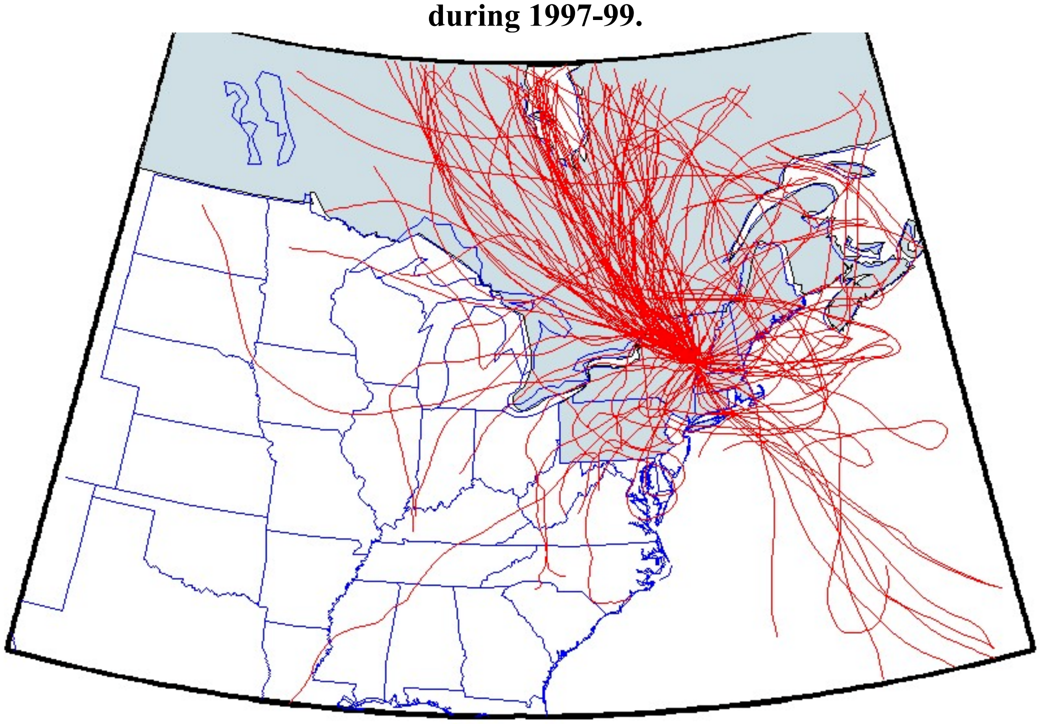


Figure 4a: Back trajectories on 20% worst visibility days at Brigantine Wilderness Area during 1997-99.

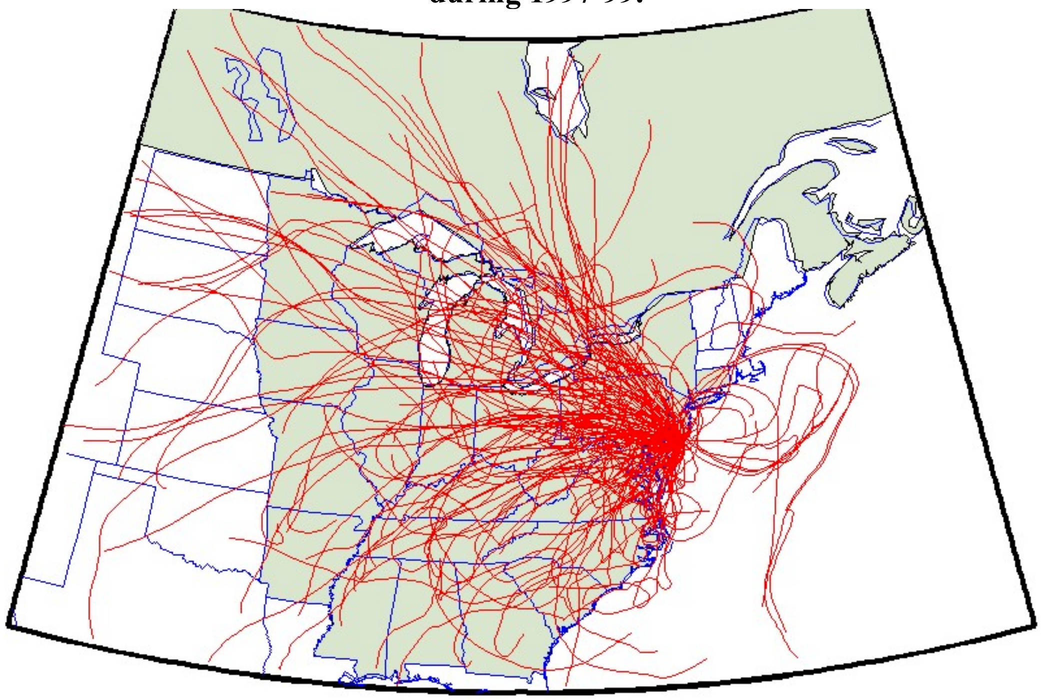


Figure 4b: Back trajectories on 20% best visibility days at Brigantine Wilderness Area during 1997-99.

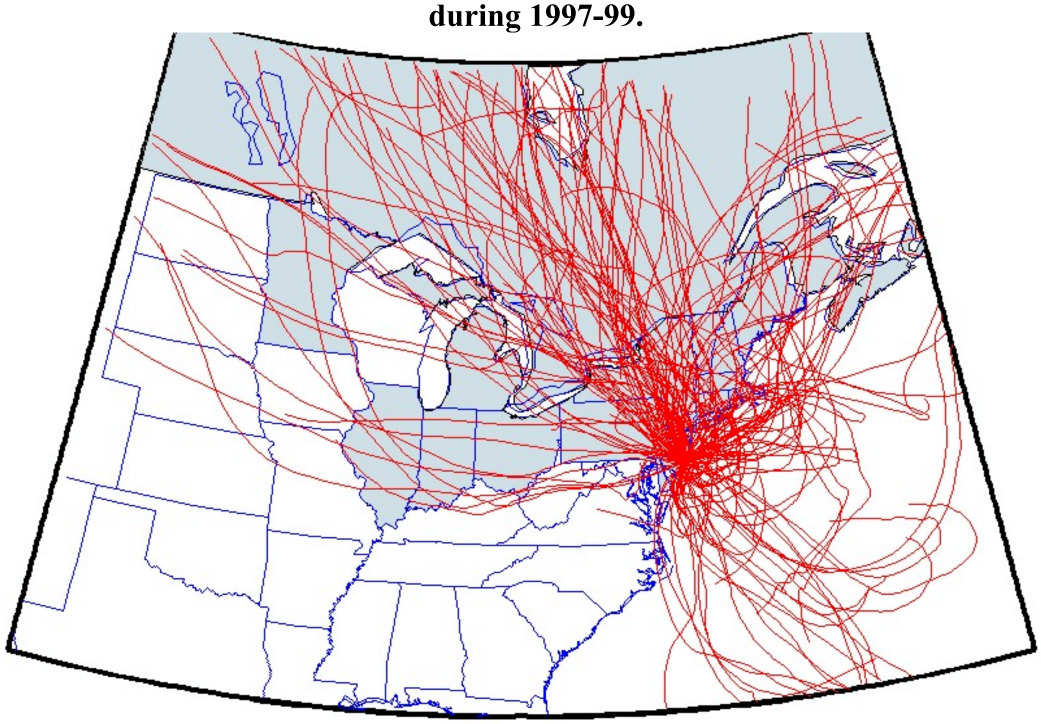
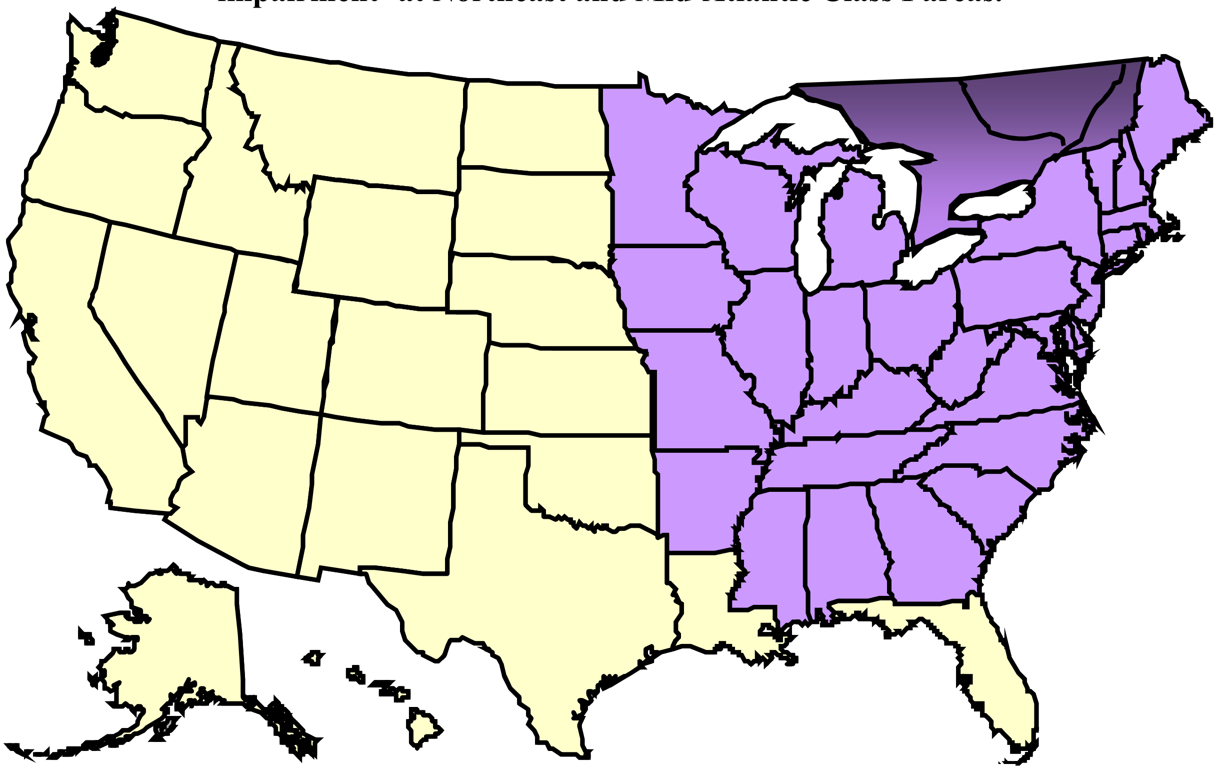


Figure 5 shows the probable source region for pollutants contributing to visibility impairment[6] in Northeast and Mid-Atlantic Class I areas based on the back trajectories associated with poor visibility conditions at Brigantine, Lye Brook and Acadia. Each of the 29 states shown in the figure is traversed by at least eight of the back trajectories constructed for the 20 percent haziest days at these sites.[7] Note that the identified region provides a preliminary but probably fairly accurate estimate of the likely source region to be included in future visibility-related emissions reductions efforts.

Figure 5: Source region reasonably anticipated to cause or contribute to visibility impairment[6] at Northeast and Mid-Atlantic Class I areas.



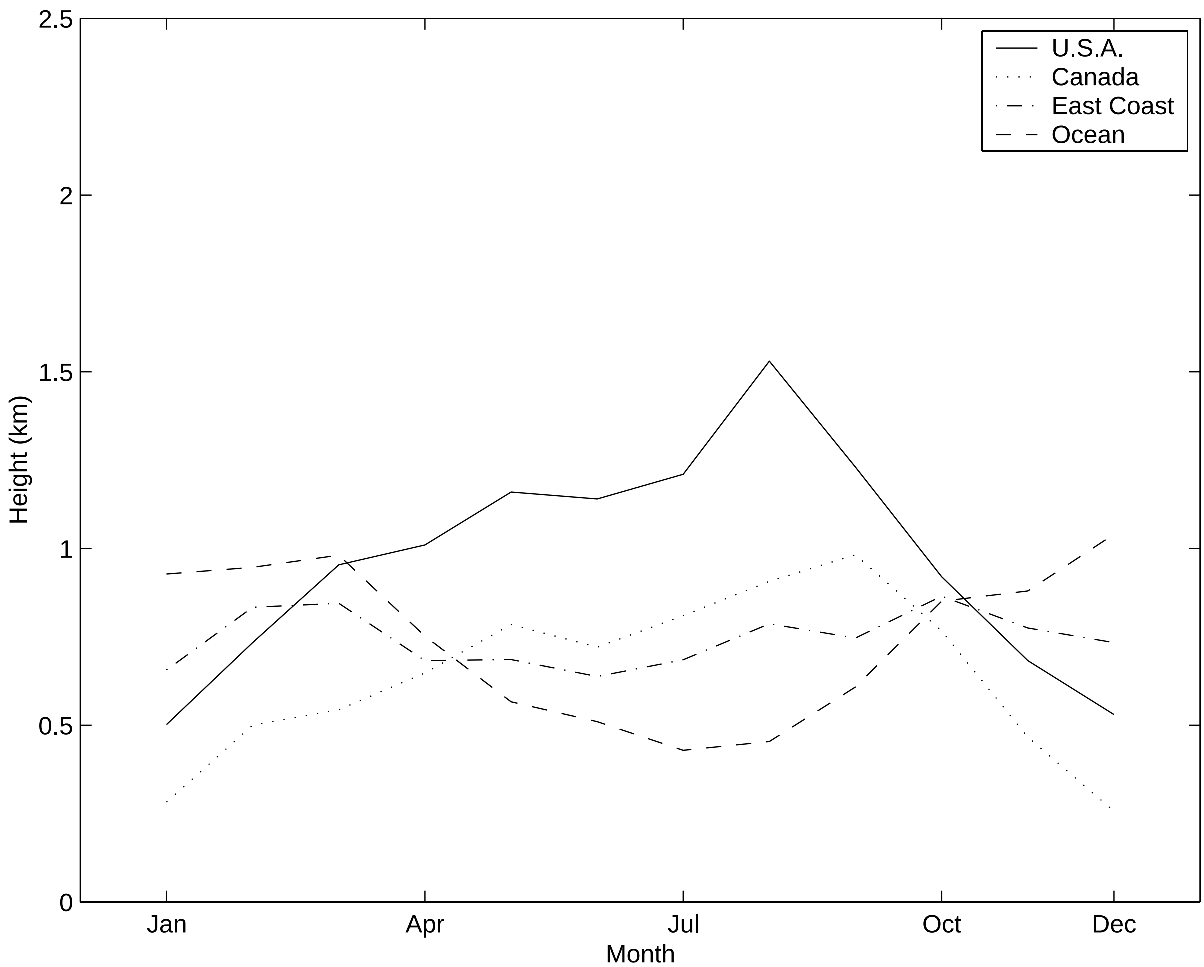
[6] This region addresses visibility impairment on the 20 percent worst days only. A different source region must be considered to address visibility impairment on the 20 percent best days. This region will likely include different regions (e.g. Atlantic provinces of Canada) and may be important in preventing deterioration of current visibility on the 20 percent best days, as called for by the regional haze rule.

[7] Eight trajectories (seven for Lye Brook) represent greater than 5 percent of the available trajectories which were calculated for the 20 percent worst visibility days between 1997 and the end of 1999 (130-150 trajectories per site).

V. Sensitivity of trajectory analysis to starting height

Based on analysis of climatological mean boundary layer heights in the eastern United States a trajectory starting height of 500 meters was selected as the most reasonable starting height for eastern coastal locations (Kleiman and Prinn, 2000). To verify that 500 meters is an appropriate starting height for back trajectories in the MANE-VU region, climatological mean boundary layer heights between 1985 and 1993 were obtained from remote sensing data as analyzed by NASA (NASA, 2001). Data from four separate geographically distinct areas were binned including marine, coastal, interior U.S. and interior Canada. Figure 6 shows the monthly mean mixed layer height averaged over each one of these areas. One can see from the figure that for trajectories started along coastal regions of the Eastern U.S., a 500 meter starting height will usually be in the upper third of the boundary layer. This positioning is ideal as trajectories calculated at lower altitudes are subject to interference from surface features (terrain and buildings), whereas higher altitude trajectories may be above the mixed layer at times and not representative of the air mass in the mixed layer.

Figure 6: Boundary layer seasonality for four areas of the Eastern U.S. and Southeastern Canada



In order to better understand the influence that a trajectory starting height has on resulting source regions, NESCAUM performed a sensitivity study by comparing the geographic source regions identified using three different starting heights: 200, 500 and 1000 meters above ground level. Figures 7, 8 and 9 show back trajectories on the twenty percent worst visibility days started at a 200 meter starting height and Figure 10 show the geographic source region identified using these trajectories and the same selection criteria as for the 500 meter analysis presented in Section IV.

The back trajectories that were started at 200 meters are very likely to remain in the boundary layer throughout the year, as demonstrated in Figure 6. Thus 200-meter back trajectories will usually represent well mixed air masses that contribute to visibility conditions experienced at ground level in MANE-VU Class I areas. However, these trajectories are more strongly influenced by orographic effects and other surface features, as demonstrated most markedly by many of the back trajectories for Brigantine shown in Figures 9 relative to those depicted in Figure 4a. The 200-meter trajectories tend to cluster along specific paths and many trajectories wander randomly as they are influenced by localized surface flows. The 500-meter trajectories are spread more uniformly across the south and west, with fewer trajectories exhibiting the chaotic behavior characteristic to shallow surface flows. The potential source regions identified by these two sets of back trajectories are very similar with the only differences occurring among the southern tier of states which have a lower trajectory density in the 200-meter analysis.

Figures 11-13 show back trajectories calculated for the three sites on the twenty percent worst days but using a 1000 meter starting height. Figure 14 shows the potential source region identified for this case. In this instance, the source region has significant differences from that identified using 500-meter trajectories. As highlighted in Figure 6, many trajectories that were started at 1000 meters were likely above the boundary layer when the back trajectory calculation was started and the general pattern of these trajectories is consistent with a strong influence of upper level winds in the free troposphere. While trajectories that migrate out of the boundary layer and into the free troposphere may accurately reflect the path of an air parcel that subsides and ultimately resides in the mixed layer, those trajectories that reside in the mixed layer throughout are likely to better represent the source region whose emissions contribute to the ambient concentrations observed at the trajectories' ends.

This sensitivity analysis demonstrates that, although trajectory starting height has a strong influence on resulting trajectories, most states identified in the preliminary MANE-VU source region have a robust association with the visibility on the twenty percent of days with the worst conditions. A more detailed analysis (perhaps using Eulerian grid models or receptor techniques) is required to better understand the role on visibility conditions in MANE-VU Class I areas played by states west of Missouri and south of Tennessee where currently available trajectory densities are too low to make definitive associations.

Figure 7: Back trajectories started at 200 meters on 20% worst visibility days at Acadia National Park during 1997-99.

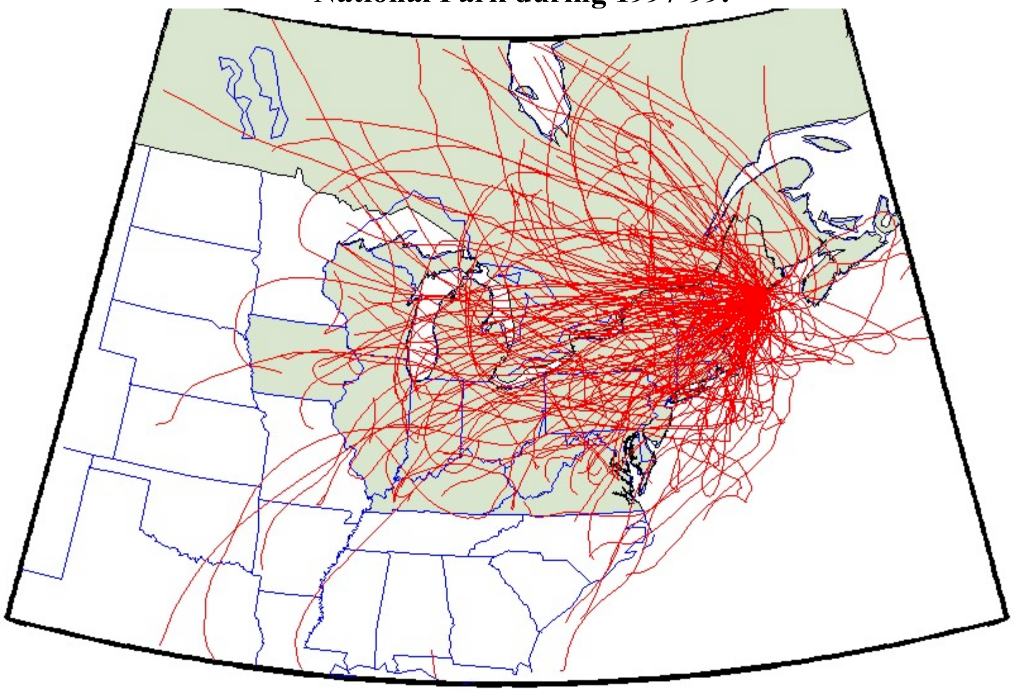


Figure 8: Back trajectories started at 200 meters on 20% worst visibility days at Brigantine Wilderness Area during 1997-99.

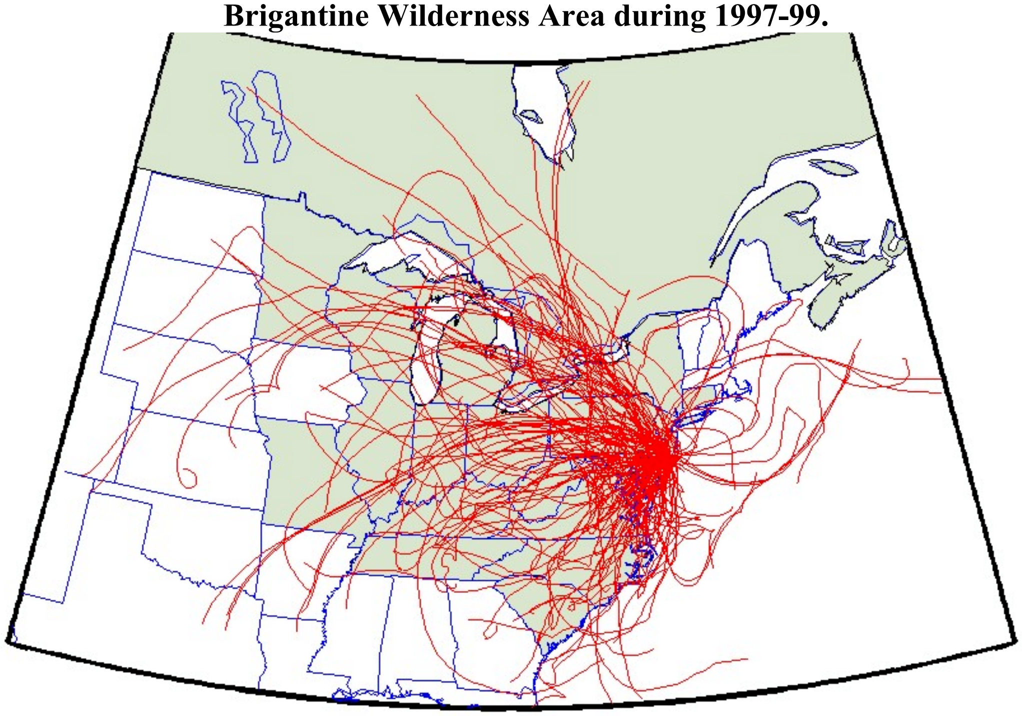


Figure 9: Back trajectories started at 200 meters on 20% worst visibility days at Lye Brook Wilderness Area during 1997-99.

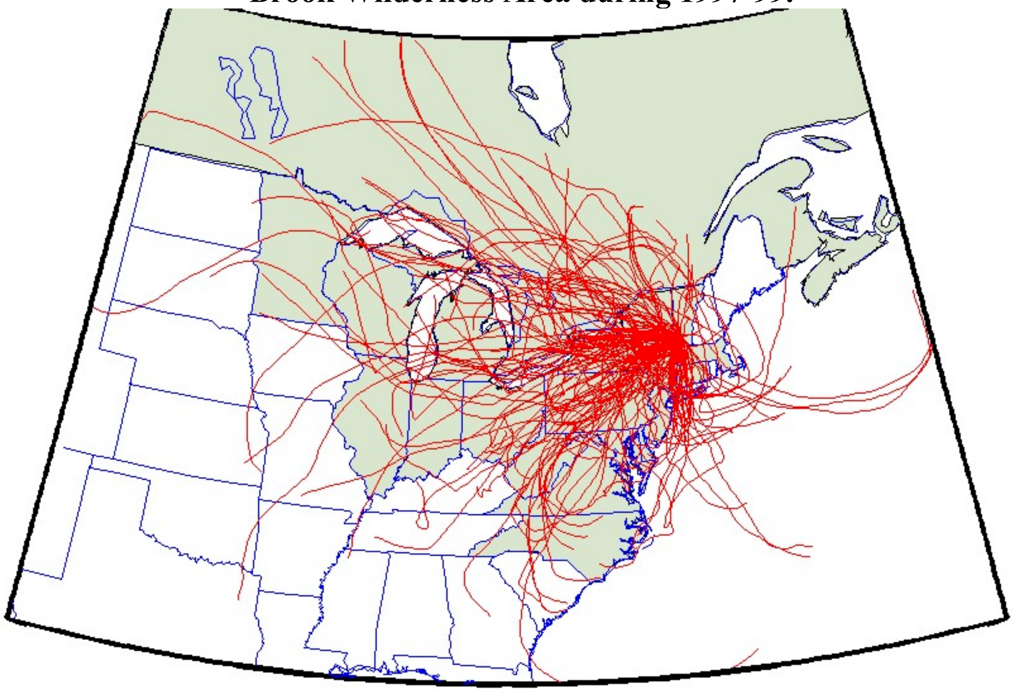


Figure 10: Source region of influence on twenty percent worst visibility days based on back trajectories started at 200 meters above ground level.

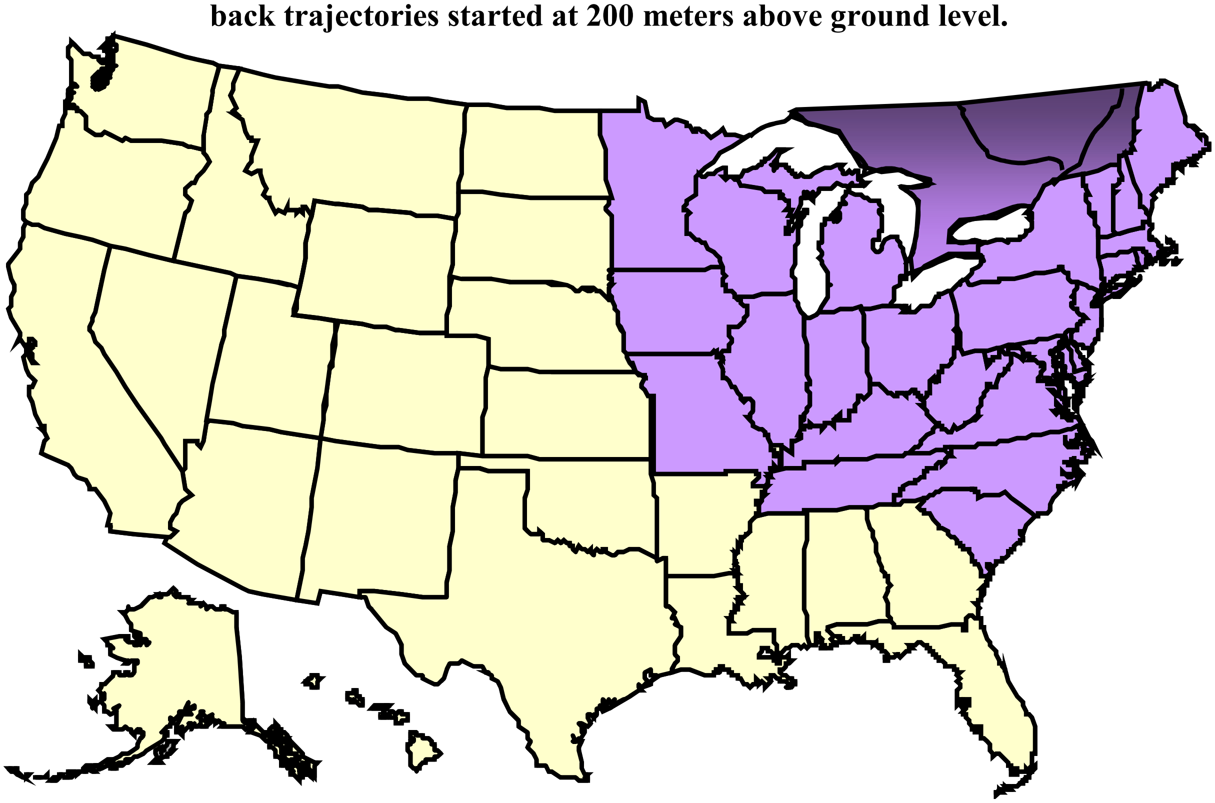


Figure 11: Back trajectories started at 1000 meters on 20% worst visibility days at Acadia National Park during 1997-99.

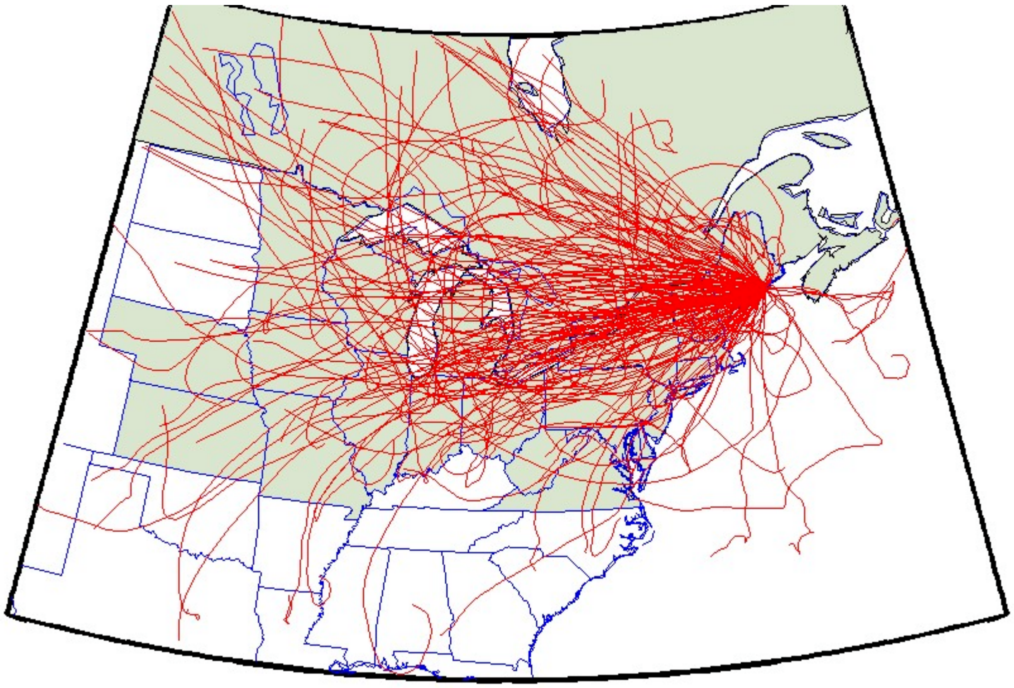


Figure 12: Back trajectories started at 1000 meters on 20% worst visibility days at Brigantine Wilderness Area during 1997-99.

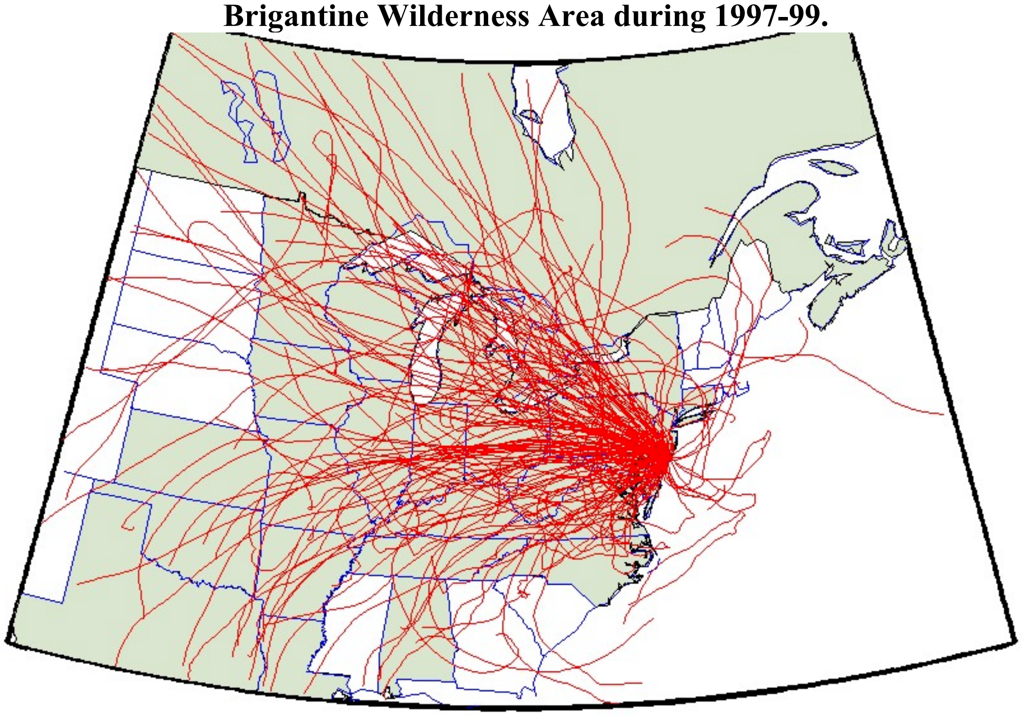


Figure 13: Back trajectories started at 1000 meters on 20% worst visibility days at Lye Brook Wilderness Area during 1997-99.

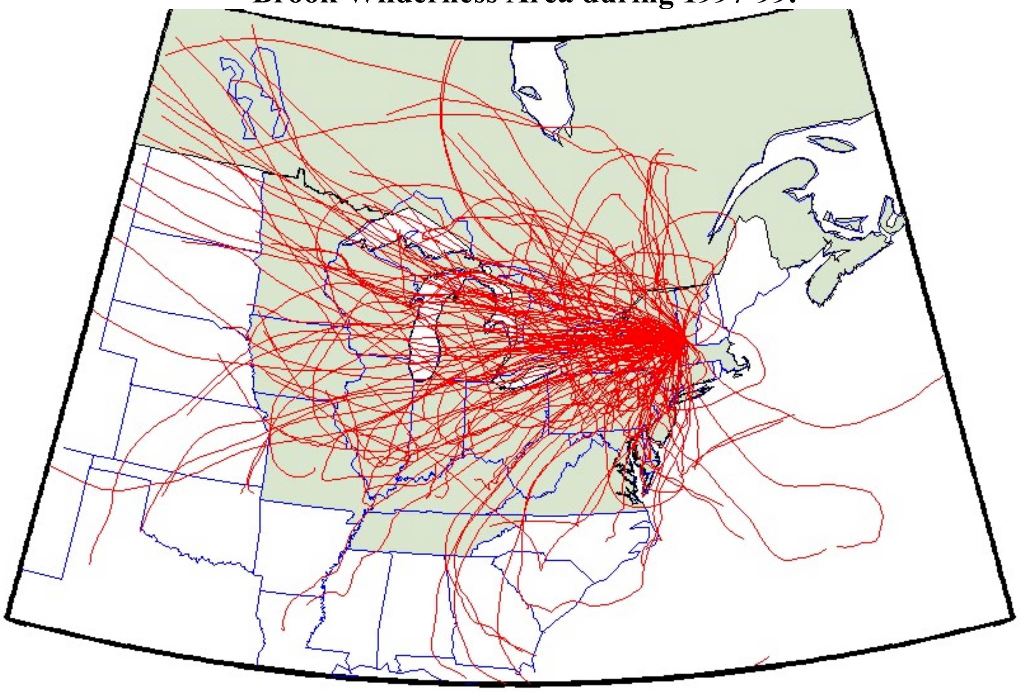
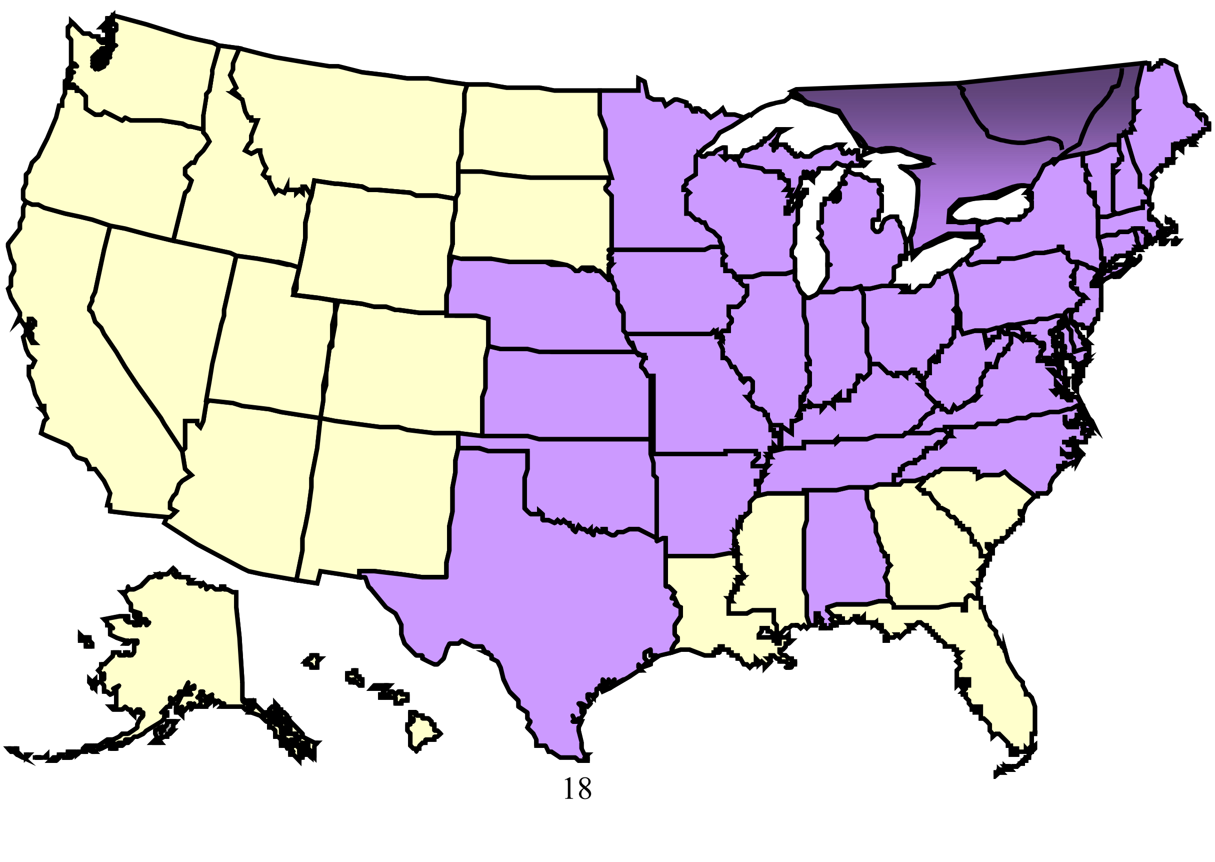


Figure 14: Source region of influence on twenty percent worst visibility days based on back trajectories started at 1000 meters above ground level.



VI. Trajectory defined domains for Eulerian grid modeling

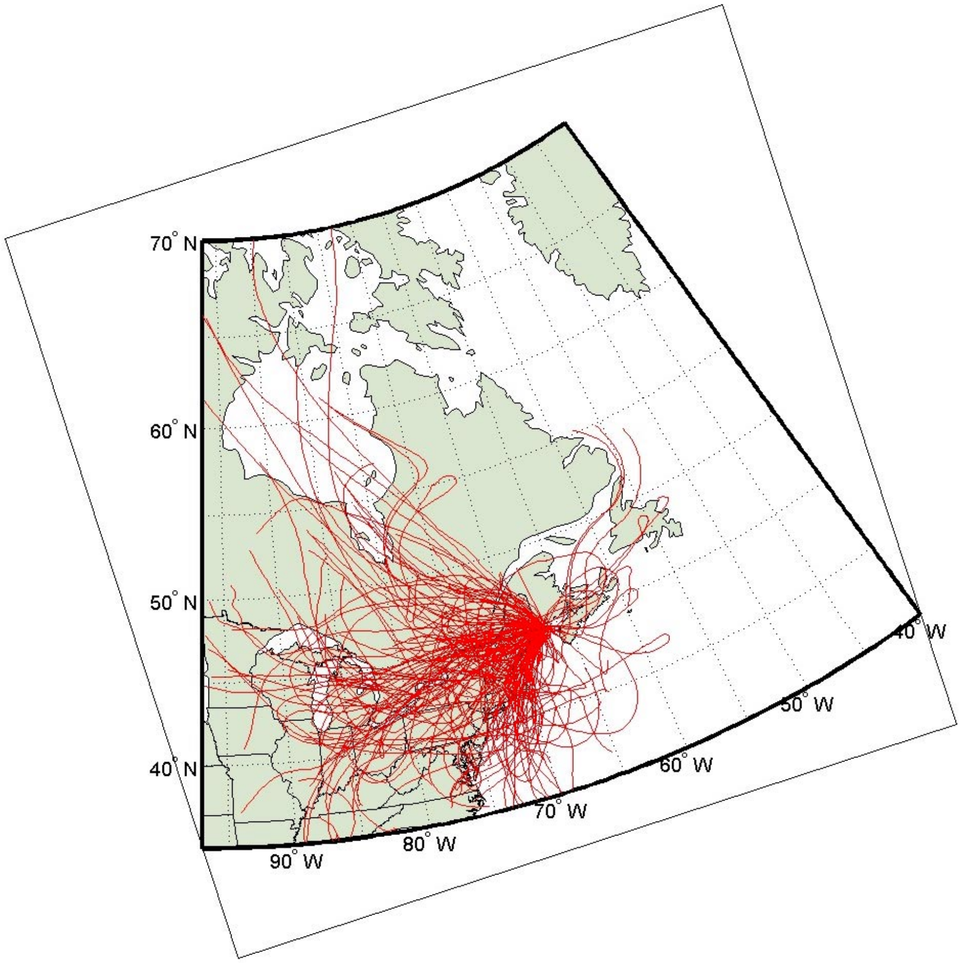
One recommended use of trajectory models is to assist in identifying appropriate geographic domains for other modeling exercises. For example, a 3-dimensional Eulerian photochemical grid model will certainly provide additional information on the nature and extent of visibility impairment across the region; however, in order for these modeling exercises to be successful, an appropriate domain must be identified. This domain must include all major source regions for precursor pollutants which contribute to regional haze. Additionally, those regions which export clean air masses that are subsequently found in and around Class I areas during the best visibility conditions must be included.

The work presented in section IV of this memorandum serves to identify a broad part of the continental United States that must be included in a modeling domain which attempts to simulate regional haze at the western-most Class I areas. In order to adequately address the northeast corner of such a modeling domain, a separate analysis has been conducted for the northeastern Class I areas. Moosehorn Wilderness Area hosts the IMPROVE monitor located furthest north and east in the MANE-VU region. This monitor provides coverage for both Moosehorn and the Roosevelt-Campobello International Park. An analysis of regions affecting these two Class I areas on the best and worst visibility days is needed in order to adequately determine the appropriate extent of modeling domains for the MANE-VU region.

Figures 15 and 16 show back trajectories started 500 meters above the Moosehorn IMPROVE monitor on the twenty percent of days with the worst and best visibility conditions respectively. While the analysis is qualitatively similar to that performed for Acadia National Park (see Figures 3a and b), the current analysis used meteorological input data based on the final run of the Eta model analysis routine (the FNL data set). This data set has a much larger domain extending over the entire Northern Hemisphere, though with a coarser spatial resolution. The result is that this analysis is able to track trajectories back beyond the edge of the meteorological data grid used in the previous analysis that was focused on continental source regions. Here we are able to see both the continental regions that contribute to poor visibility on the worst days as well as those pristine continental and marine areas that generate clear air masses on the best days.

Figure 15 demonstrates that for Moosehorn, much as for Acadia, the region most associated with visibility on the twenty percent of days with the worst visibility stretches across New England and Southern Ontario, well into the Upper Midwest with additional contributions from the East Coast. Figure 16 is perhaps more interesting from the perspective of defining a modeling domain. It reveals that airmasses present at Moosehorn on the best visibility days originate across a broad expanse of Northern Ontario, Quebec, and New Brunswick. While some trajectories pass over Nova Scotia and Labrador, these tend to be associated with maritime airmasses that quickly pass over the regions, rather than airmasses that lingered and were significantly affected by them.

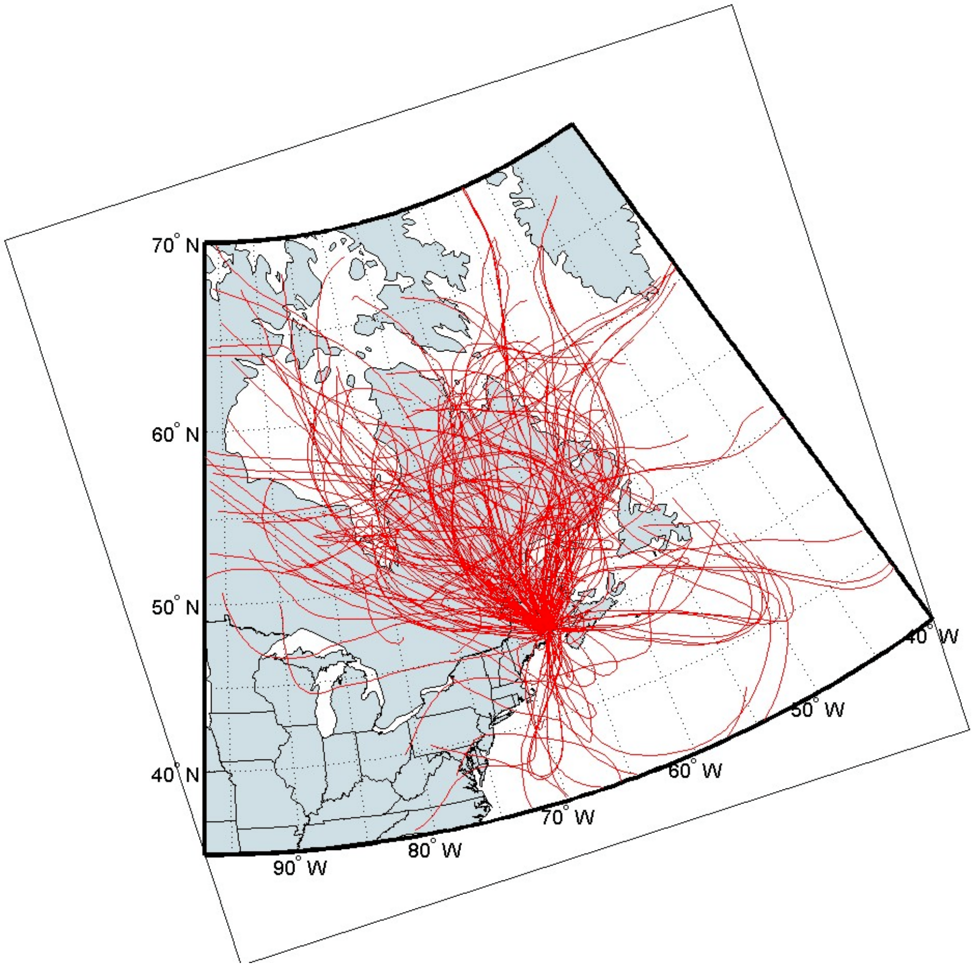
Figure 15: Back trajectories started 500 meters above Moosehorn Wilderness Area on the 20% worst visibility days during 1997-99.



Both Figure 15 and Figure 16 are mapped using a Lambert Conformal projection with true parallels at 33º north and 45º north latitude. This projection has been selected by the five regional planning organizations as the projection for presenting future haze analyses. The figures have been rotated to keep the left edge of the frame, which is located at 97º west longitude, vertical. The point at 97º west longitude and 45º north latitude has been designated as the center of the national modeling domain for regional haze planning. MANE-VU is likely to select a subset of the national domain to focus its more detailed analysis of the Northeast and Mid-Atlantic region.

Figure 16 suggests that both a national domain and a Northeast specific domain should extend as far north as 50º north latitude and as far east as 60º west longitude.

Figure 16: Back trajectories started 500 meters above Moosehorn Wilderness Area on the 20% best visibility days during 1997-99.



VII. Future work

While the analyses presented here provide insight as to the likely meteorological pathways that influence visibility at MANE-VU Class I areas on the best and worst visibility days, there remains significant room for refinement of these techniques and application of novel approaches. As additional monitoring data continue to be collected and as the archive of meteorological drivers for the HYSPLIT model is extended, additional trajectory calculations can be performed. With sufficient trajectory density, performing an ensemble trajectory analysis becomes a possibility. These techniques allow the trajectory density to be mapped onto a fixed grid such that one can calculate quantitative probabilities that each grid cell was upwind of a given receptor under specific conditions (i.e. best or worst visibility days) (Kenski, 2001).

In addition, these ensemble techniques can be used in combination with source apportionment results (e.g. MARAMA, 2001) to identify regions that have the greatest probability of contributing to specific components of measured fine particle mass at receptor sites.[8] This type of analysis will be an essential part of MANE-VU's contribution assessment required in the regional haze committal SIP.

The New Hampshire Department of Environmental Services (NHDES) is investigating trajectory analysis using distance weighted techniques that will attribute more influence to nearby sources which are likely to have a greater impact on a specific receptor than sources which are far from the site.

Researchers at the University of Virginia have used cluster techniques to identify meteorological pathways that define a "center of mass" for the most frequent trajectory patterns at specific sites (Moody, 1998). This type of analysis would be very useful if applied to Class I areas within the MANE-VU region and across the country.

All of these future options for further analysis of back trajectories suggest that trajectory analysis will continue to play a significant role in the data analysis efforts of the MANE-VU RPO. As the time to submit haze SIPS nears, their specific role in the overall planning process should become better defined.

[8] Examples of this sort of analysis can be found in Poirot and Wishinski (2001a) and Poirot et al. (2001b) found at: http://capita.wustl.edu/NEARDAT/Reports/Brigantine/index.htm.

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