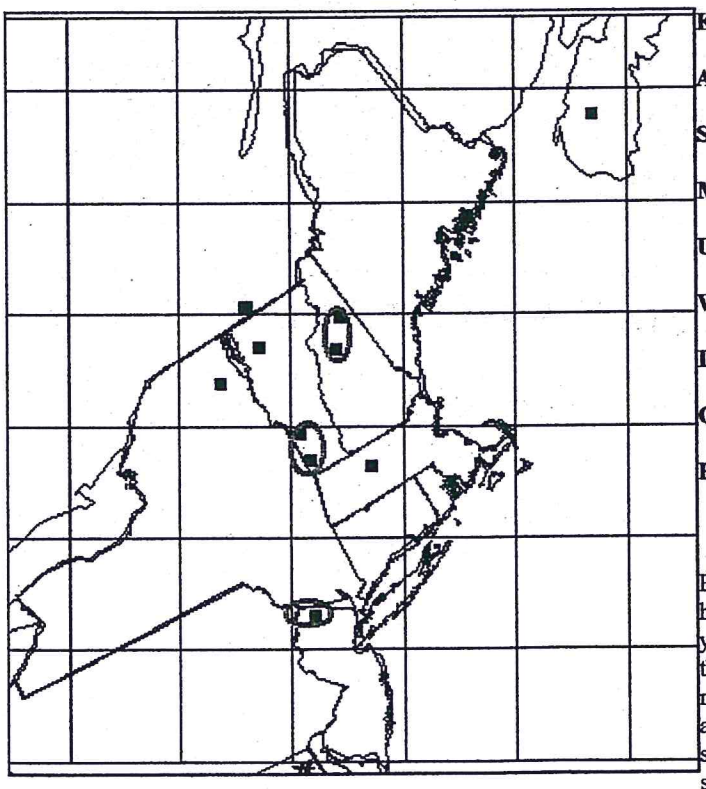
Air Mass History Pollution Climatology for Northeastern Forests and Parks

Status Report: January 17, 1998

This study is developing an "air mass history pollution climatology" for 9 rural, "forest" air monitoring sites in the Northeast (US and Eastern Canada). The work is being conducted cooperatively by the Vermont Dept. of Environmental Conservation (VTDEC), the Center for Air Pollution Impact and Trend Analysis (CAPITA), the Vermont Monitoring Cooperative (VMC), and the Northeast States for Coordinated Air Use Management (NESCAUM) - with funding support from the USDA Forest Service, Eastern Region (see proposal for a general project description).

The climatological analysis is enabled by the concurrent availability of long-term, multi-pollutant measurement data (Precipitation Chemistry, Aerosol Chemistry, and Ozone) at multiple sites, and gridded 3-dimensional meteorological data (NGM) suitable for driving synoptic-scale air trajectory models throughout the time period of 1989 through 1996. The basic approach is to develop two parallel databases for each monitoring site - one consisting of multiple pollutant concentrations, and one consisting of multi-day backward trajectory (or, more precisely "air mass history") calculations. These data bases will be merged and aggregated by techniques like "residence time analysis" to examine predominant pollutant transport pathways, "clean air corridors, and changes in these regional-scale influences over space and time. The selected monitoring site locations are displayed in Figure 1. Three of these sites are "composite sites" - utilizing ambient measurement data from 2 or 3 nearby monitoring stations.

Figure 1. Trajectory Climatology Monitoring Sites



Kejimkujik NP, NS

Acadia NP, ME

Sutton, Que.

Mt. Washington/ Hubbard Brook, NH

Underhill, VT

Whiteface Mtn., NY

Lye Brook/Bennington, VT

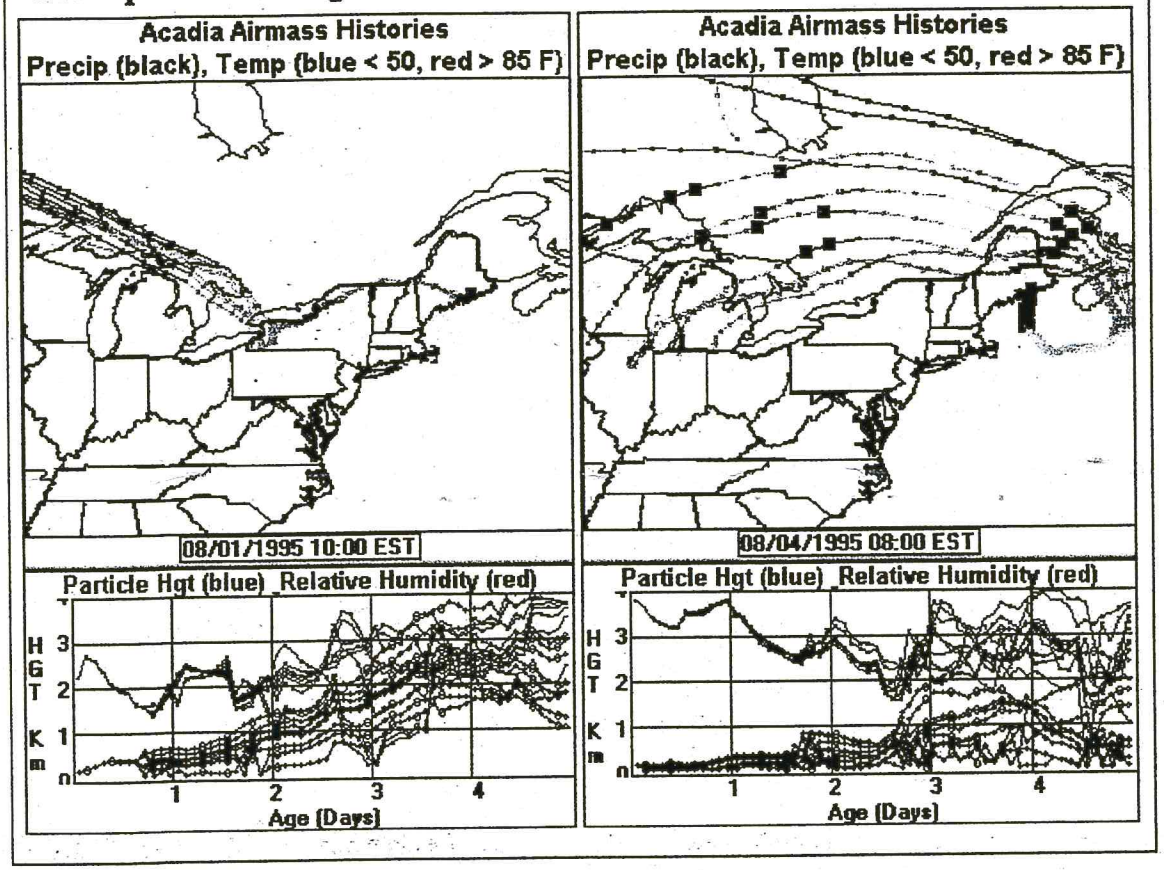
Quabbin Summit, MA

PANJNY (tri-state border area)

For each monitoring site, a series of 5-day backward air mass histories are being calculated every 2 hours every day for the years 1989-1996 using the CAPITA Monte Carlo model. For 3 of the 9 sites (Sutton, Lye Brook and Mt. Washington), ambient measurements are conducted at substantially different elevations, and 2 sets of air mass histories are being calculated for different starting elevations - for a total of 12 sets of air mass history starting locations. The CAPITA model incorporates an estimate of vertical mixing by releasing 10 particles and allowing the vertical position of each to move randomly within the mixed layer - such that for each release time, 10 separate air mass histories are calculated for each starting location. In addition to the traditional lat./long. (map) position of trajectory endpoints, various other aspects of the estimated air mass histories are also retained - including trajectory pressure height, precipitation, mixing height, relative humidity, specific humidity, temperature, velocity, and age. So for each air mass history for each particle, values of about 10 meteorological variables are calculated and retained every 2 hours for 5 days backward in time. For each of 12 starting locations, 120 air mass histories are calculated each day for 8 years, such that a total of about 2.5 billion meteorological data points are calculated and retained. Graphic illustrations of some of the air-mass history information retained for individual release times for the Acadia, NP site are displayed in Figure 2 (see also the movie animation displaying similar results for a 7-day period, 7/29 - 8/4/95). Note the influence of vertical mixing on the widely dispersed trajectories of particles arriving at the receptor on 8/4/95 at 8 AM, in contrast to the similar (horizontal and vertical) pathways traversed by all particles arriving on 8/1/95 at 10 AM. Note also the presence of precipitation along all trajectory paths just before arrival at Acadia on 8/4/95, and along several other locations further back along the particle pathways.

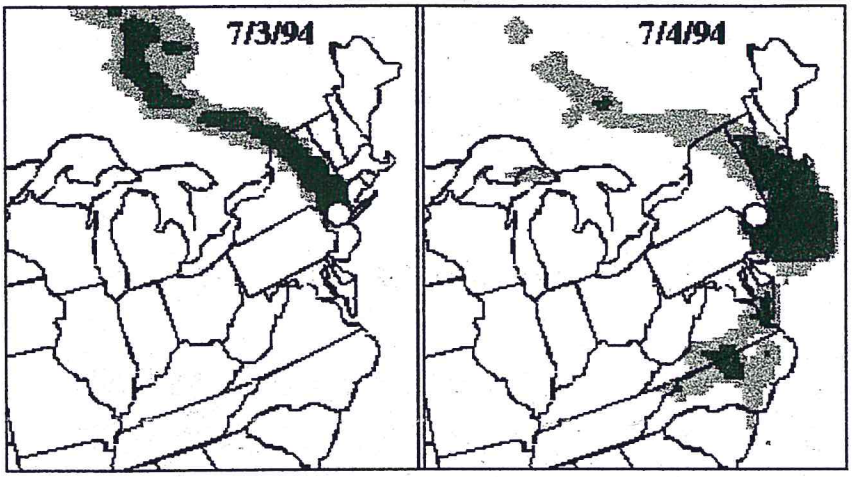
Figure 2. Example CAPITA Monte Carlo Air Mass Histories

For 10 particles arriving at Acadia NP on 8/1/95, 10 AM (left) and 8/4/95, 8 AM (right)



The individual air mass history information is tracked on a grid of 1,440 80x80 km squares). To reduce data volume, and to facilitate direct comparison with ambient pollutant data (much of which is only available on a 24 hour basis), the air mass history data for each receptor site are converted to a 24 hour basis by aggregating all (120) air mass history results for each calendar day for each grid square. This aggregation assumes that the air mass history information for each of 10 particles released at each of 12 arrival times during a 24-hour period is equally representative of the upwind meteorological characteristics associated with pollutant concentrations measured during that 24-hour period. Rather than a single trajectory line, this approach identifies an upwind area (and its associated met. parameters) as an upwind region of potential influence for each 24-hour measurement period. Several examples of daily aggregate air mass history results (for the PANJNY site on 7/3/94 and 7/4/94) are displayed in Figure 3 (see also example movie animation of daily aggregates for 7/1/94 through 7/18/94). In these examples, the spatial characteristics of all 120 airmass histories for each day are displayed as " residence-time probabilities", with 25% of the day's upwind residence-time hours included in each separately shaded area. Note that on 7/3/94 (left side of Figure 3), the upwind residence-time probability is relatively tightly constrained along a narrow upwind path - suggesting relatively strong, persistent flow from the northwest of the receptor. On the following day (7/4/94 at right side of Figure 3), the upwind probabilities are more broadly distributed over nearby areas to the east and northeast of the receptor.

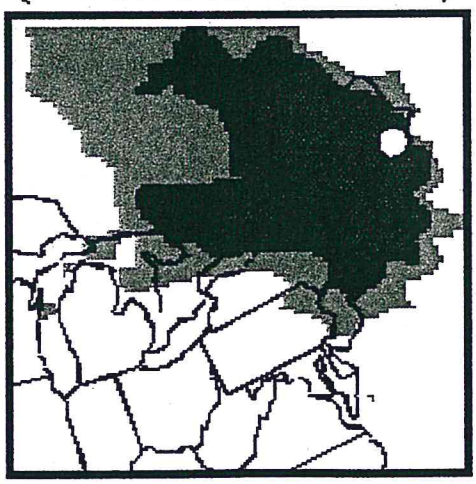
Figure 3. Example 24-hour Aggregation of Trajectory Results Based on 10 particles released every 2 hours from PANJNY site on:



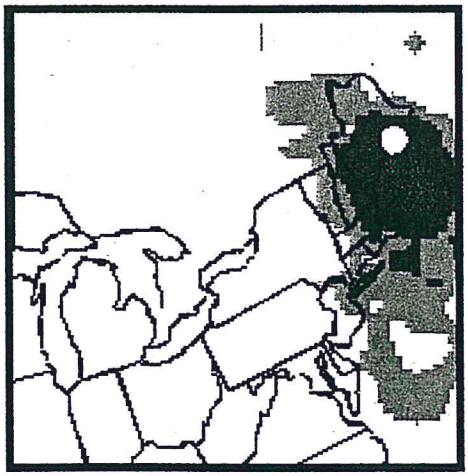
The examples in Figure 3 show the most probable upwind locations of mixed air parcels arriving at the PANJNY receptor site throughout the indicated 24-hour periods, and are based on only the backward "trajectory" (horizontal location) information of the 120 particles released each day at the receptor. Additional aspects of the air mass histories are also retained as 24-hour aggregates. For example, Figure 4 shows residence-time probabilities for Acadia National Park which are aggregated for the 3rd quarter (July-Sept.) of 1989, and which are sorted into high and low pressure subsets. On the left, the probability plot is based only on upwind particle locations for which the pressure was less than 950 MB (corresponding approximately to heights of 500 meters or more above sea level). The plot on the right is based only on particles at pressures of > 950 MB (approximately less than 500 meters elevation). The lower elevation flows (right) are much more tightly distributed close to the receptor and exhibit a much stronger southerly or southeasterly orientation than the upper elevation flows (left) which tend to have previously resided over a larger area to the west and northwest of the receptor.

Figure 4. Residence-Time Probabilities, Q3, 1989, Acadia NP

Pressure < 950 MB (> 500 meters above msl)



Pressure > 950 MB (< 500 meters above msl)

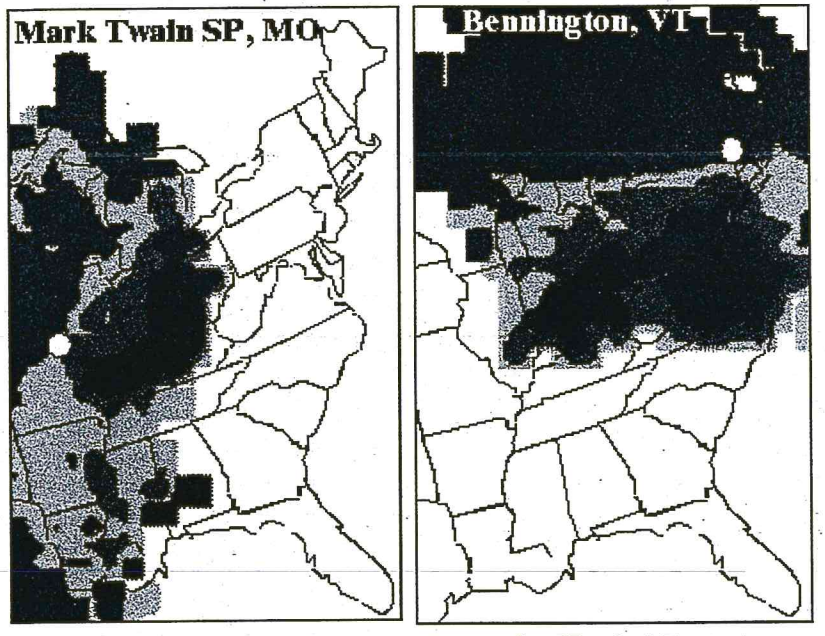


A variety of similar types of meteorological sorting or screening applications might be employed to explore upwind residence-time probabilities for a variety of conditions. For example to compare upwind probabilities for air parcels: previosly residing above or below the mixing height, moving at high or low speeds, passing areas with or without precipitation, characterized by high or low temperatures, etc. Such screening might also be employed with selective aggregation of the daily results to investigate differences among seasons, to compare early years with more recent ones, or to evaluate the meteorological "representativeness" of short-term field intensives or episodic modeling

studies.

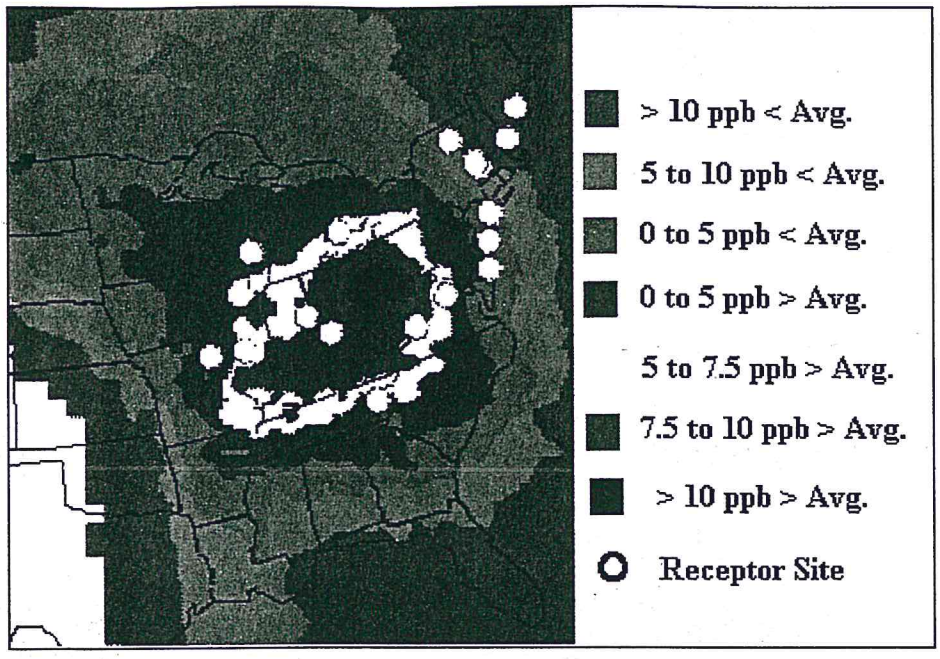
When the daily airmass history results are completed for the 9 sites (Figure 1) and 8 years (1989-96), the ultimate objective is to combine the with the ambient pollutant measurement data, to explore long-term associations between pollutant levels at the receptors and upwind airmass history. Several examples of this kind of analysis are displayed in Figures 5-8. These examples are based on previous applications using the NOAA HY-SPLIT trajectory model, and are based only on the locational (trajectory) aspects of the HY-SPLIT results. Figure 5 shows changes in average Summer ozone as a function of prior trajectory location for Benington, VT and for Mark Twain State Park, MO - about 1000 miles to the WSW. Bennington typically experiences below-average ozone if the air has previously resided to the North, and highest ozone if the air has previously resided to the South or Southwest. A much different pattern is evident for the distant MO site, but note some areas common to both sites - low ozone from Canada and higher ozone if the air has previously resided over the central Midwest.

Figure 5. Average Ozone at Mark Twain SP, MO and Bennington, VT As Function of Upwind Trajectory Location: Summers 1989-1995



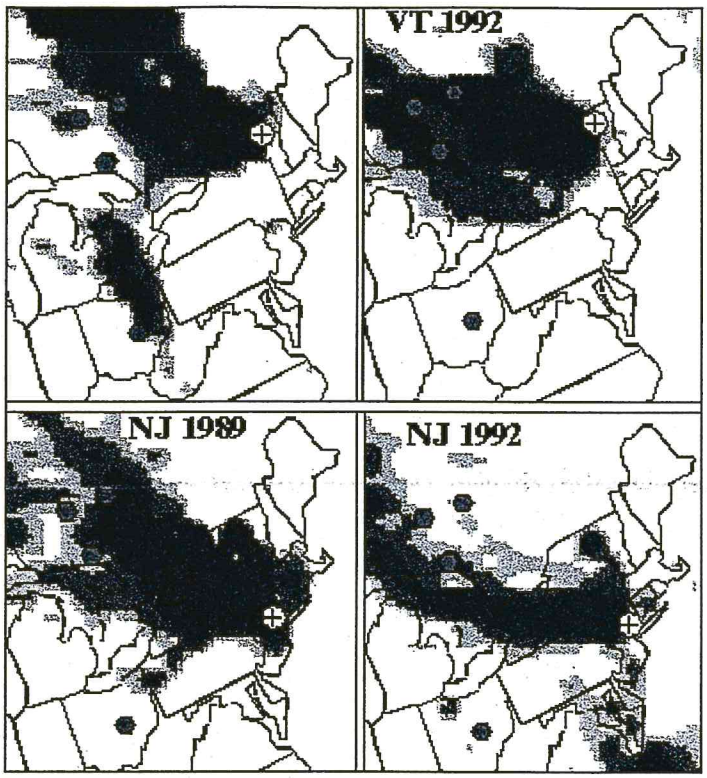
In Figure 6, these results from VT and MO sites are combined with similar results from 15 other monitoring sites in the Eastern US. The shaded areas represent upwind areas associated with deviations from the mean summer ozone concentrations averaged across all 17 receptor sites. The central (red and black) areas aren't necessarily associated with peak ozone levels at any one receptor site, but rather are chronically associated with above average ozone levels at many sites.

Figure 6. Average 1989-95 Ozone at Multiple Sites by Upwind Location (changing ozone levels represent averages across 17 monitoring sites)



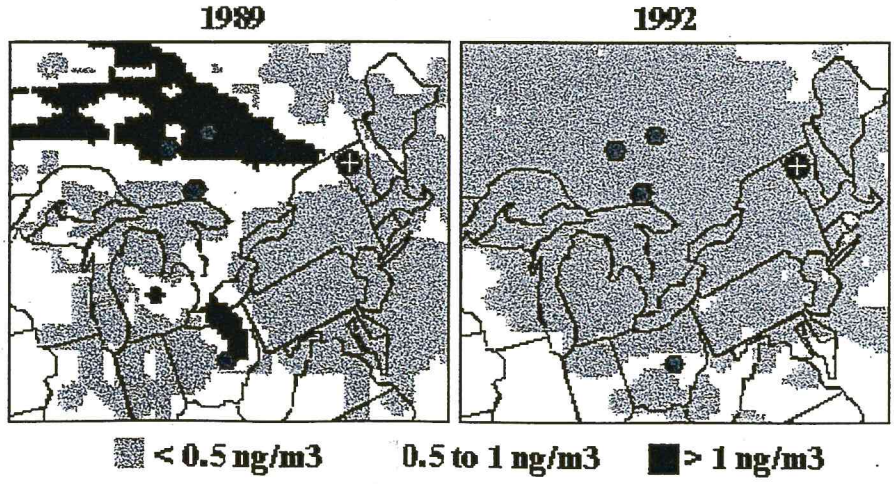
A different method of combining pollutant and trajectory information is displayed in Figure 7 - which is based on 1889 and 1992 measured concentrations of fine particle arsenic at Underhill, VT and Ringwood State Park, NJ. In this case, only trajectories on days with above-average arsenic levels are considered. The plots show "incremental probability fields" depicting areas most likely to be upwind of these sites if the arsenic was above average (for those specific years and sites). The blue dots represent selected smelter locations, which are often characterized by high arsenic emissions. Note that both VT and NJ sites experienced elevated arsenic levels in both years with flows from the direction of several Canadian smelters. Note also a slight southerly shift in the high probability areas between 1989 and 1992.

Figure 7. Upwind Locations preceding Highest Aerosol Arsenic at Underhill, VT (top), Ringwood, NJ (bottom), '89 (left), '92 (right)



There was a substantial decline in the peak and average arsenic concentrations at both monitoring sites between 1989 and 1992. Figure 8 shows the average 1989 and 1992 arsenic at Underhill as a function of upwind airmass location. So while some Canadian smelter influence (Figure 7) is still discernable in 1992 (especially from the more southerly ones, or from other unknown nearby sources), the magnitude of that influence has been reduced substantially since 1989.

Figure 8. 1989-92 Changes in Average Aerosol Arsenic at Underhill, VT as a Function of Upwind Trajectory Location



Analyses similar to the above examples can be developed in much greater detail with the more comprehensive air mass histories and multi-pollutant data sets being generated in the current study.

Status

The status (as of 1/17/98) of the work is as follows:

- The final sites have been selected (Figure 1), the airmass history variables have been determined, and the initial CAPITA Monte Carlo airmass histories have been calculated for these 12 sites (9 locations with 2 elevations at 3 sites). These data have been transferred to VT DEC for gridding and aggregation, which is currently underway.
- A majority of the raw ambient pollutant measurement data for ozone, wet deposition chemistry and aerosol chemistry have been obtained by VT DEC for the US sites from the respective data repositories (AIRS, NADP and IMPROVE-NEPART). These data have been transferred to VMC for additional processing (daily aggregation/disaggregation and conversion to multi-pollutant relational database), which is currently underway. Similar data are also available for the Canadian (Sutton and Keji) sites and have been requested from Environment Canada. A majority of these Canadian data are anticipated within 30 days.
- The VMC database structure will accommodate future additions of other "unique" measurement data from any of these individual sites (for example SO_2, NO_x, Hg, hydrocarbons, aerosol acidity, etc.). A parallel database structure is also being developed by VMC to house the daily aggregate airmass history data, and to facilitate the merging and sorting of the pollutant and meteorological data sets.
- The scope of the study has expanded to include several additional sites (12 vs. 6), accommodate retention of additional meteorological variables, and to produce a more robust intermediate database structure which will facilitate "easy" exploration of the rich information content in the short and longer-term future. These additions are based on suggestions from external reviewers and on the consensus of the co-investigators. We find them desirable (to improve the quality of the results) and necessary (to justify the unexpectedly large time requirements expended to date).
- The time schedule is delayed substantially beyond the originally anticipated 12/1/97 completion date. This was due initially to the unanticipated required involvement of key personnel in the OTAG process (Ozone Transport Assessment Group) for about 6 months beyond the originally scheduled OTAG termination period. More recently, we have encountered difficulties in the gridding and aggregation of the initial CAPITA Monte Carlo airmass history data - stemming from the different computer formats employed at CAPITA and VTDEC, and from the shear volume of raw data. These difficulties have been (mostly) resolved, and it is anticipated that the meterological data processing will be completed within the next 30 to 60 days. It is anticipated that the VMC database structure will also be completed in a similar timeframe, and that initial results will be forthcoming by about 3/1/98.
- The co-investigators plan to present selected results at a May 26-28, 1998 conference on "Lake Champlain and its Basin". Additional intermediate results (this status report for example), data products (to allow exploration by other investigators) and a final summary report will be distributed via the NEARDAT Internet website (http://capita.wustl.edu/neardat). Comments, questions and suggestions on these Internet reports can be posted publically using the interactive features of the NEARDAT website, or can be submitted directly to Rich Poirot by phone (802) 241-3840 or E-mail (richp@qtm.anr.state.vt.us).