Back Trajectory Analysis: Air Parcel Histories and Forest Pollutant Exposure

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Abstract

Population, land cover, and regional pollutant emissions were analyzed for each of the five flow regimes indentified at UMBS in order to assess the pollutant levels for arriving air masses. The results show that the south/southwest and east/southeast flow regimes display the highest levels of NOx, CO, and anthropogenic VOC exposure (in terms of kilograms/square kilometer/ozone season day(OSD)) while the north/northwest and northeast flow regimes display the lowest. NOx, CO, and anthropogenic VOC exposure levels were estimated to be 18.0, 82.0, and 14.0 $kg/km^2/OSD$, respectively, for the south/southwest flow regime; 10.2, 57.4, and 9.3 kg/ km^2/OSD, respectively, for the east/southeast flow regime; 6.9, 29.5, and 5.0 kg/ km^2/OSD, respectively, for the west flow regime; 0.8, 3.8, and 0.5 $kg/km^2/OSD$, respectively, for the northeast flow regime; and 0.4, 1.8, and 0.3 kg/ km^2/OSD, respectively, for the north/northwest flow regime. Pollution exposure levels were estimated for back trajectories according to the anthropogenic emissions (known point and area sources) for each flow regime as a whole. This method of assessing pollutant exposure was then compared with a finer-scale treatment that follows an individual trajectory. The comparison showed the coarse-scale treatment can result in both underestimates and overestimates of pollutant exposure depending on the trajectory's path.

Introduction

The Need for Understanding an Air Mass's History

Back trajectories trace an air parcel's path back in time and indicate where the air parcel has been before it reaches the sites where it is analyzed. The applications for such a capability are extensive and many studies have used back trajectories as a tool their research. Jaffe et. al. (1999) used back trajectories to verify that anthropogenic emissions from Asia can have a significant impact on the concentrations of species arriving in North America. Merrill et. al. (1989) found that the temporal variations in mineral aerosol concentrations in the North Pacific were caused by the seasonality of dust storms in Asia. Furthermore, Moody et al. (1998) used back trajectories to determine regional-scale patterns in transport history (referred to as PATH). Moody was then able to show that varying seasonal signals in trace gas concentrations could be connected with different flow regimes. From these studies it can be seen that back trajectories help observers understand the variability in their data.

Air Flow Regimes at UMBS

For over a decade the 31m PROPHET tower at the University of Michigan Biological Station (UMBS) in Northern Michigan has been measuring pollutant levels over the surrounding mixed hardwood forest. During this period both pollutants and biogenic emissions have been measured by scientists from all over the country (e.g., Cooper et.al., 2001; Carroll et. al., 2001; Karl et. al., 2003; Westberg et. al., 2001; Pressley et. al., 2005; Apel et. al., 2002). The site has few local sources of pollution, and its nearest metropolitan centers (Chicago ~400 km to the southwest, Detroit ~350 km to the southeast, and Toronto ~400 km to the east-southeast) are hundreds of miles away (Carroll et. al., 2001).

Back trajectories have been used in past studies at the biological station. Cooper et. al. (2001) calculated back trajectories for the summer of 1998 and used the results in a meteorological overview and an air-mass classification. The summer study revealed that the air arriving at the station was dominated by southerly transport (24% of the time), northerly transport (44%), and transitional periods (32%). In 2002, Joshua Abrams (an AOSS REU student) conducted an analysis of back trajectories for air parcels reaching the PROPHET site. In the process, he was able to create a method of classifying air parcels reaching the site according to the source region over which each trajectory passed on its way to UMBS. Five air flow regimes were derived from his work and they are the same regimes that are referenced throughout this study (figure 1). Abrams concluded that the last 36 hours of an air parcel's trajectory was the most significant in terms of pollutant sources, so 36-hour trajectories were calculated and then categorized

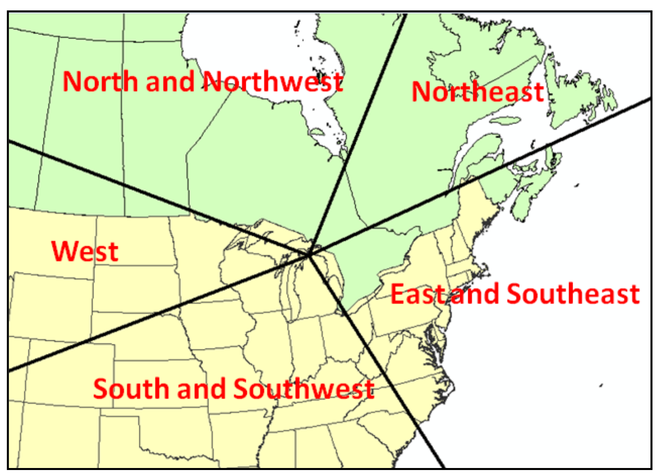


Figure 1: *Classification scheme for air masses arriving at UMBS*

according to air flow regime. Trajectories that cross the lines in figure 1 (and therefore cross more than one source region) during the last 31 hours of the 36-hour trajectory were evaluated as not fitting the criteria for assigning a flow regime. Although it is recognized that a more thorough knowledge of the air parcel's entire history is desirable, this treatment was found to be more useful than the Cooper et. al. 2001 treatment for purposes of examining relationships among pollutants in air parcels reaching the PROPHET site. For example, the expected relationship between ozone and carbon monoxide was immediately evident in data obtained during south & southwesterly air flow. Illissa Ocko, a REU student in 2006, calculated back trajectories for each day for the period 1999-2005 and characterized the climatology of flow regimes (Ocko, 2006). This study found that, for the years 1999-2005, 28-35% of the time the flow was north and northwesterly, 22-25% was south and southwesterly, 9-14% was westerly, 4-6% was east and southeasterly, and 25-30% of the trajectories were categorized a indeterminate. Pollutant levels in air masses reaching the site from these flow regimes vary significantly. For example, a northerly or northwesterly air mass is characterized by clean air (O_3 levels generally between 20-30 ppbv) while a southerly or southwesterly air mass would be characterized by moderate to high pollutant levels (40-100 ppbv O_3).

Methods

Back Trajectories and the HYSPLIT4 Software

Back trajectories were also used throughout this project to analyze an air mass's history. Back trajectories were calculated using the HYSPLIT4 (Hybrid Single-Particle Lagrangian-Integrated Trajectory) modeling software. This software was freely accessed through the Air Resource Laboratory (ARL) of the National Oceanic and Atmospheric Administration (NOAA). The HYSPLIT4 model referenced archived meteorological data in order to compute back trajectories.

For the purposes of this project, the EDAS40 (Eta Data Assimilation System) meteorological archive was used in conjunction with HYSPLIT for 2006-2008. This archive begins in 2004 and is continually updated with current data. It is provided by the National Weather Service's National Centers for Environmental Prediction (NCEP). The EDAS40 archive uses 40 km Lambert Conformal Grids for its datasets. For the years of 1997 and 1998 the FNL archive was used due to the EDAS archive missing a considerable amount of data during this time. Trajectories derived from the FNL archive were compared to EDAS derived trajectories (figure 2). The differences in back trajectory paths were not considered to be an issue for the purposes of this project because they did not vary enough spatially to alter air flow regime classifications. The FNL archive contains

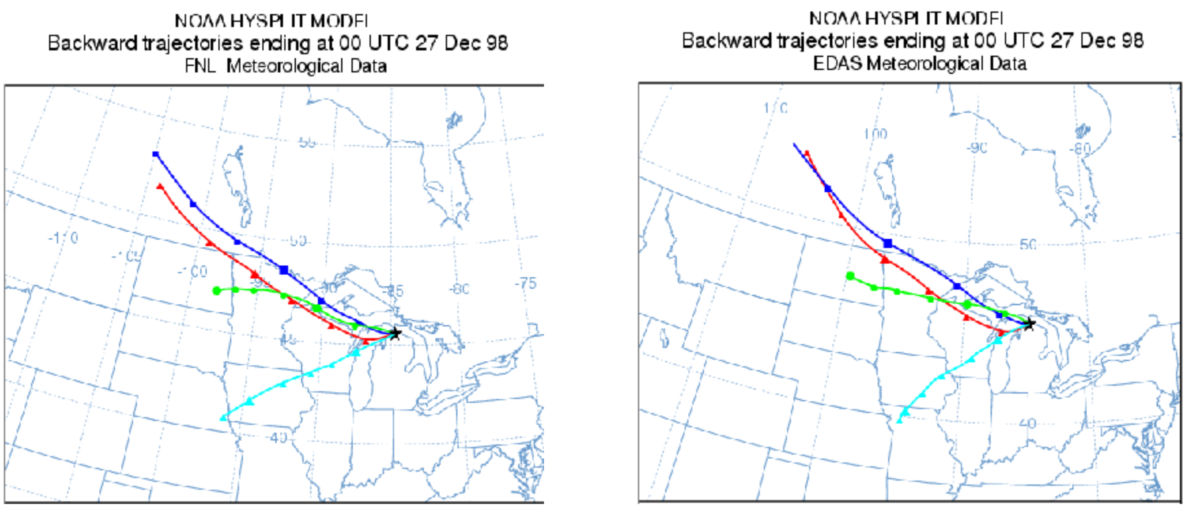


Figure 2: *Back trajectory using FNL archive (left) and EDAS archive (right). The differences between the two archives are minor.*

six-hourly data provided by NCEP's Global Data Assimilation System (GDAS). The FNL archive uses 129 by 129 polar stereographic grids for data interpretation. There were a few dates throughout 1997 and 1998 in which the FNL archive was incomplete and the EDAS80 archive was used. These dates were February 22 – March 1, 1998; September 15-17 and 25-27, 2007; and July 25-28, 2007. The EDAS80 archive contains meteorological data fields that are on 80 km grids (instead of 40) for its datasets. Additional information on all of the archives used can be found at (http://www.arl.noaa.gov/ss/transport/archives.html).

Each trajectory that was created started at UMBS (45.56N, 84.70W) at 500 meters above ground level and was calculated back thirty-six hours. Four trajectories were calculated for each day: 0000 UT, 0600 UT, 1200 UT, and 1800 UT. Once the trajectories were created they were exported as a GIS shapefile in order to be analyzed with ArcMap software.

ArcMap

ArcMap (version 9.2), a component of ESRI's ArcGIS Geographical Information System (GIS), was used for mapping purposes. A shapefile was created for each day from the corresponding back trajectory dataset and projected in ArcMap as an individual layer (Figure 2). Each data point in a back trajectory shapefile represents both a position (latitude and longitude) and a time (in hours before reaching the biological station). One shapefiles was created for each day for the periods of June-December 1997, 1998, 2006, 2007, and January-July 2008 (the periods for which back trajectories had not been previously calculated).

Once the daily shapefiles were entered into Arcmap they were grouped by month and merged into a single shapefile (figure 3). These monthly shapefiles were then used to reate kernel density plots for each month (figure 4). The kernel density plots represent the density of the trajectory points for the monthly shapefiles.

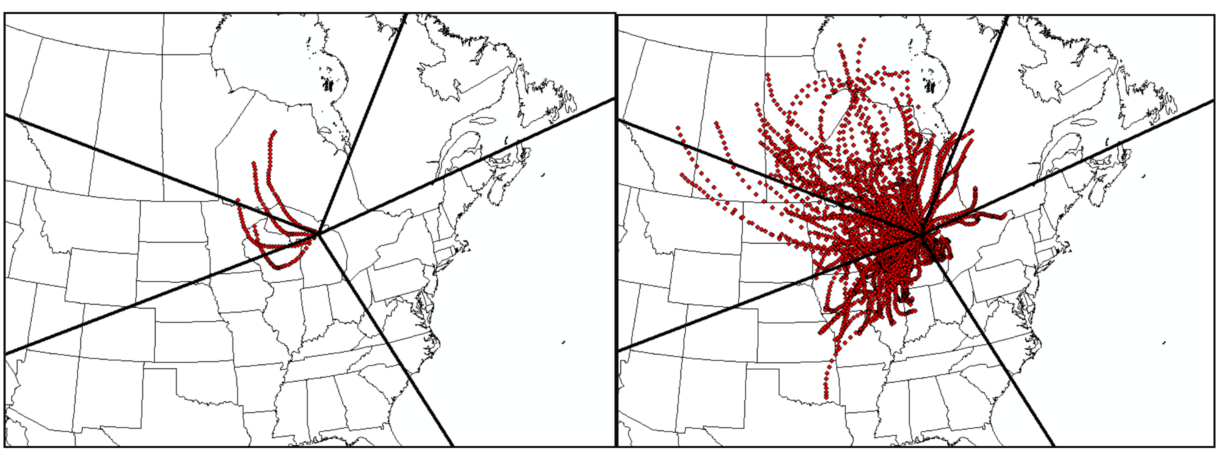


Figure 3: *Back trajectory shapefile for one day (left) and for one month (right) in Arcmap.*

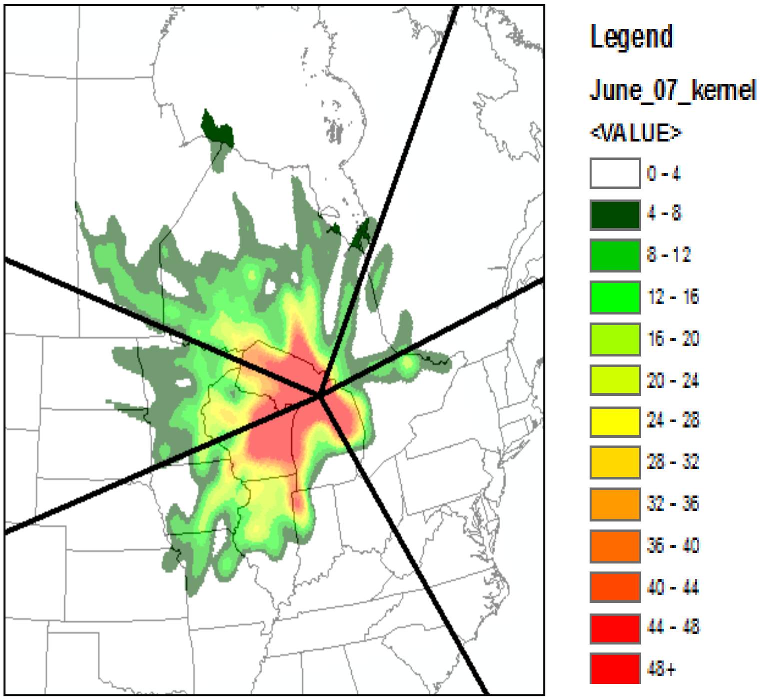


Figure 4: *Kernel density plot and scale for June 2007. The scale's units are trajectory points per grid cell.*

Emission Inventory Mapviewer

The Emissions Inventory Mapviewer, which is a product of collaborative work between the National Oceanic and Atmospheric Administration's (NOAA) Aeronomy Lab and the National Geophysical Data Center, was used in order to obtain pollutant emission levels for each of the five air flow regimes. The Emission Inventory Mapviewer can calculate the total emissions of nitrogen oxides (NOx = nitric oxide (NO) + nitrogen dioxide (NO_2)), sulfur dioxide (SO_2), carbon monoxide (CO), anthropogenic volatile organic compounds (VOCs), ammonia (NH_3), and particulate matter (PM 10 and PM 2.5) for any rectangular grid in its coverage area.

In order to determine appropriate rectangular grids to use to represent the air flow regimes at UMBS, a 804.5 kilometer (500 mile) radius circle was first drawn around the biological station in Arcmap. This area was chosen to ensure that the grids from each air flow regime would be approximately the same distance from the station by not exceeding the boundary and because the 804.5 km radial distance encompasses the area over which the back trajectories most frequently passed. With the 804.5 kilometer radial perimeter in place around the station, each air flow regime now formed an individual "slice" within the circle. Three rectangular boxes were then

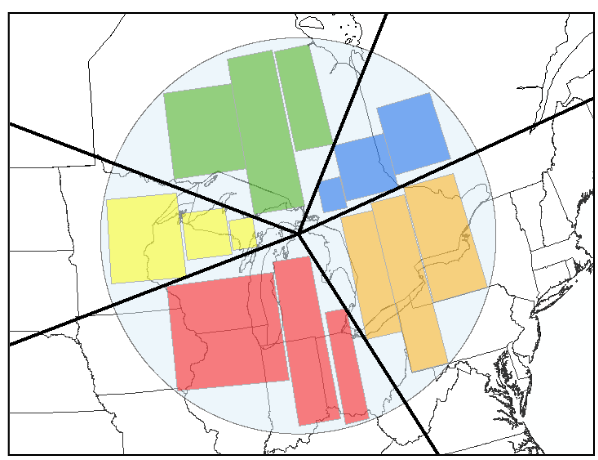
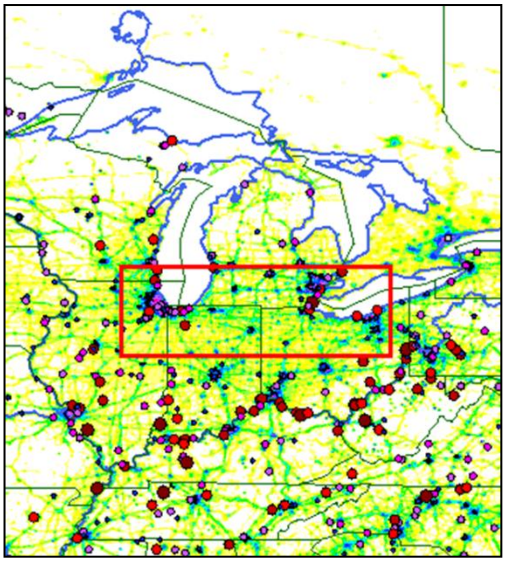


Figure 5: *Grids used to represent each air flow regime. These grids were reproduced in the Emissions Inventory Mapviewer to obtain emission levels.*



Results reported in short tons per ozone season day per selected area

Total area selected: 146816 km²

	POINT	AREA	NONROAD	ONROAD	Total
NOX	1,008.35	77.51	688.14	1,004.05	2,778.05
SO2	1,611.14	108.85	71.88	40.99	1,832.86
CO	1,247.29	261.34	5,542.59	6,914.36	13,965.58
VOC	274.04	943.51	467.58	701.66	2,386.78
NH3	13.74	352.79	0.61	35.90	403.03
PM10	198.03	1,532.98	65.65	29.26	1,825.92
PM25	155.52	331.73	59.98	22.01	569.23

Selection box coordinates:
-89.558, 40.540
-86.283, 40.540
-86.283, 45.407
-89.558, 45.407
-89.558, 40.540

Figure 6: *When the rectangular grids are drawn in the Emission Inventory Mapviewer, the program outputs the total emissions of various pollutants along with the total area.*

drawn within each "slice" that would cover the maximum area without exceeding the circular perimeter (figure 5). The fifteen total grids that were formed (5 air flow regimes x 3 grid per regime) were then redrawn in the Emissions Inventory Mapviewer and total emissions for each grid were calculated (figure 6). Each total emission value was provided in short tons per selected grid area per ozone season day (OSD). An ozone season day is considered to be an average 24-hour day between June 1 and August 31.

The data from the five sets of three rectangles that represent each flow regime were then compiled separately. For the purposes of this project, only the total area and total NOx, CO, and anthropogenic VOC emissions were considered. The total emissions for NOx, CO, and anthropogenic VOCs for each flow regime's grid set were then divided by the grid set's total area to obtain the average emission levels for each pollutant in each flow regime in terms of short tons per square kilometer per ozone season day. These values were then converted to obtain emission values in kilograms (NOx, CO, or anthropogenic VOCs) per square kilometer per ozone season day.

Plotting Emission Exposure: Course and Fine-Scale Methods

Little is known about the quantitative pollution exposure levels of indeterminate trajectories at UMBS. If an assessment of the total pollutant exposure experienced by the

PROPHET site is to be made, then indeterminate trajectories' exposure levels must first be understood. Indeterminate trajectories encompass 25-30% (Ocko, 2006) of the total air flow that arrives at thePROPHET site.

The back trajectory of 0600 UT from March 1, 2008 was chosen as an example for plotting emission exposure because its path traversed three different air flow regimes (which made it indeterminate). Starting back in time 36 hours before reaching the station, this trajectory began its journey at the outskirts of Chicago, Illinois in the south/southwest flow regime (figure 7). The trajectory then headed north through eastern Michigan and through the western flow regime. The trajectory then entered the northern peninsula of Michigan and then traveled southeast through the north/northwest flow regime for the remainder of the path until reaching the biological station. Along this path, each of the trajectory's 36 data points was assigned a NOx (CO and anthropogenic VOC values could also be used) exposure level according to the air flow regime they were positioned. This method for assessing pollutant exposure by air flow regime will be referred to as the coarse-scale method.

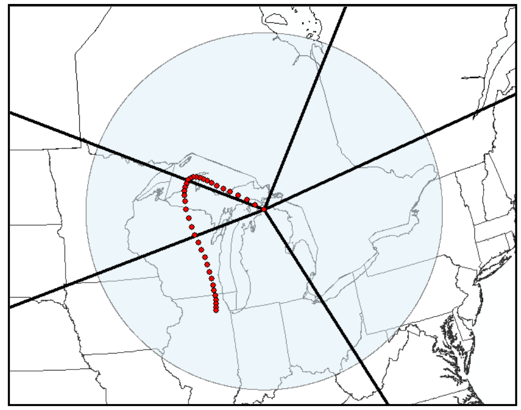


Figure 7: *March 1, 2008 back trajectory. The trajectory crosses three flow regimes and ends near Chicago, Illinois.*

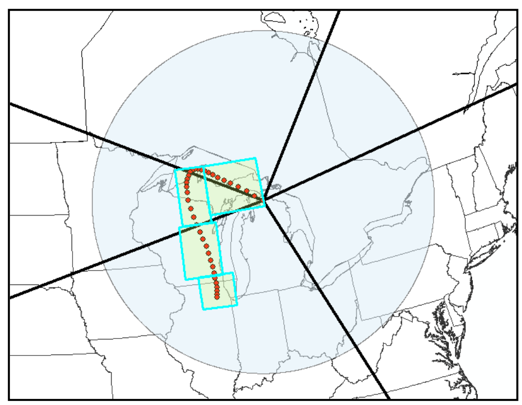


Figure 8: *March 1, 2008 back trajectory with the 4 grids that would that would be used to obtain emission levels in the Mapviewer*

To test if calculated average pollution levels for the air flow regimes accurately indicate pollution exposure, the same back trajectory for March 1 was examined with a different protocol. With this test, which is referred to as the fine-scale method, a new grid set (4 grids) was chosen that would more accurately incorporate only the land area over which the trajectory actually traveled (figure 8). These grids were again created in the Emission Inventory Mapviewer and total emission levels for NOx, CO, and anthropogenic VOCs were created. As with the previous grids, emission levels were transformed into units of kilograms/ km^2/OSD. Each of the trajectory's 36 data points were then given a new NOx level according to the four grids in which they were positioned. The results of this fine-scale technique were then compared to the results of the coarse-scale technique. This comparison would reveal both the total variation the techniques had from one another and also indicate in what areas the greatest variation occurred. In other words, it would indicate whether the greatest variation occurred around the metropolitan areas such as Chicago in the south / southwest flow regime, or in the rural areas of the north / northwest regime.

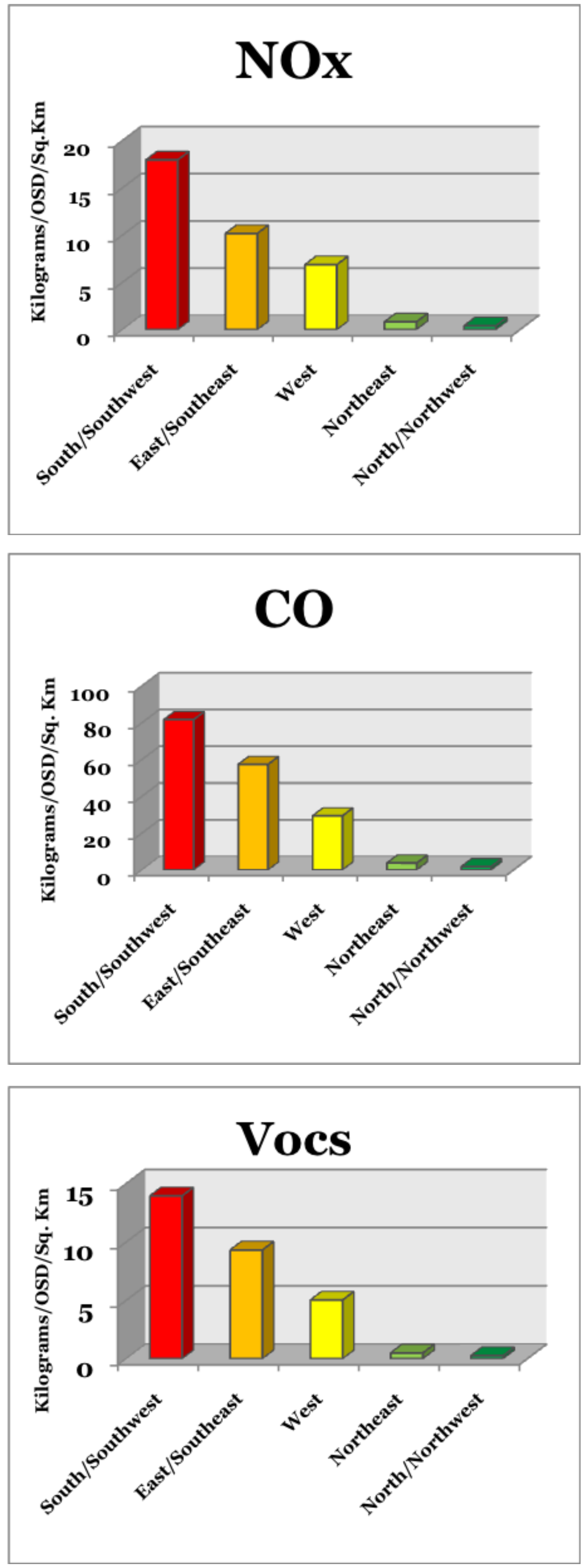


Figure 9: *Emission levels for NOx, CO, and VOCs by air flow regime.*

Results

Emission Levels By Flow Regime

When emissions levels for NOx, CO, and anthropogenic VOCs were calculated for each flow regime (figure 9), a distinct pattern arose. The south/ southwest flow regime consistently recorded the highest emission levels with NOx at 18.0, CO at 81.8, and anthropogenic VOCs at 14.0 kg/km²/OSD. At the other extreme, the north/northwest flow regime registered the lowest levels of emissions with NOx, CO, and anthropogenic VOCs at 0.42, 1.84, and 0.27 kg/km² /OSD respectively. Between these two flow regimes was the east/southeast flow regime that had the second highest levels of all three pollutants, the west with the third highest level of all three pollutants, and the northeast with the fourth highest level.

The set of four grids that were created to enclose the March 1 trajectory yielded levels of emissions that varied from those of the air flow regimes. The grid that enclosed the urban regions of the Chicago area registered emission levels of 47.9 kg/km²/ OSD for NOx, 276.1 kg/km²/OSD for CO, and 46.2 kg/km²/OSD for anthropogenic VOCs. The lowest emission levels for NOx of the four grids was from the North Wisconsin grid with 1.42 kg/km²/OSD. The lowest emissions for CO and anthropogenic VOCs occurred in the Upper Peninsula where levels were 6.78 and 1.24 kg/km²/OSD respectively. With average emission levels in place for both the air flow regimes and the four grid set, the emission exposure for the March 1 back trajectory could now be examined under the two scenarios. Each of the 36 data points of the March 1 back trajectory were given a NOx exposure value equal to the NOx emission value (in kg/km²/OSD) of the corresponding air flow regime. These 36 position points were also given NOx exposure values according to the box (of the four box set) in which the point was located. The 36 data points for the back trajectory were plotted as line graphs according to the two different exposure scenarios to show variations between the scenarios for each data point (figure 10). The fine-scale method had over double

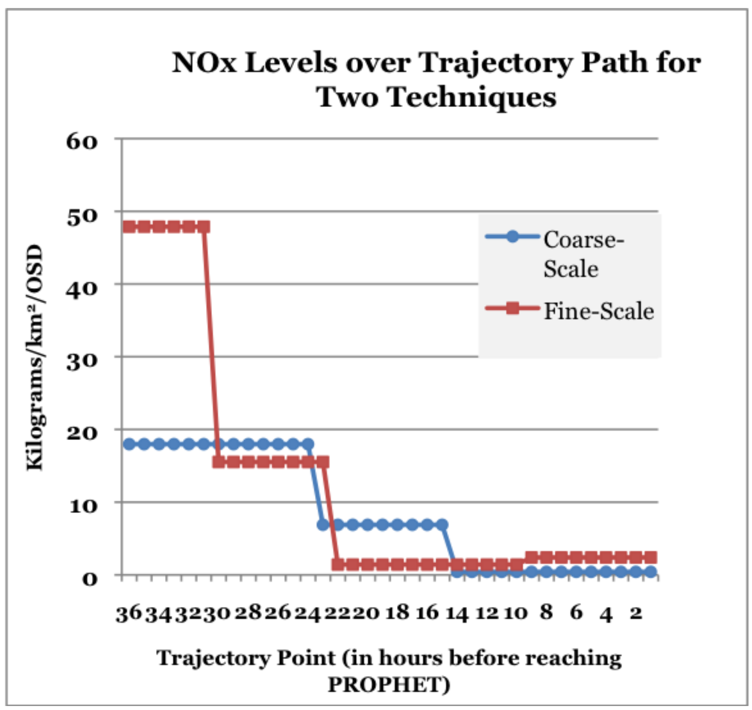


Figure 10: *NOx exposure levels along the March 1, 2008 trajectory for the two different measurement techniques.*

the emission exposure for the trajectory points 36-31. In other words, for the period between 36 and 31 hours before the back trajectory reached the station, the fine-scale indicates that the air associated with the back trajectory would have experienced over twice as much NOx emission (47.9 kg/km^2/OSD compared to 18.0 kg/km^2/OSD) than the levels indicated by the coarse-scale method. For the next six hours along the trajectory's path the coarse-scale method, with emission levels still at 17.98 kilograms, indicated marginally higher levels of NOx than the fine-scale method which indicated only 15.5 kg/km^2/OSD over the same period. The 23rd hour again had the fine- scale method (15.5 kg/km^2/OSD) doubling the exposure level of the coarse-scale method (6.9 kg/km^2/OSD) which had just switched to western flow levels. The 22nd to 15th hour displayed a completely new scenario where the coarse-scale recorded levels five times higher (6.9 vs. 1.4 kg/km^2/OSD) than the fine-scale method. However, from the 14th hour until the back trajectory reached the station the fine-scale method had consistently higher emission levels. From the 14th hour until the 10th hour these higher emissions (1.4 kg/km^2/OSD) were over three times the emission of the coarse-scale value of 0.42. The final period from the 9th hour until the back trajectory reached the station recorded the fine-scale method's level at five times the coarse-scale's level (2.4 vs. 0.4 kg/km^2/OSD). The weighted average for the exposure level in the fine-scale method was 12.5 kg/km^2/OSD while the average in the coarse-scale method was 8.4 kg/km^2/OSD.

Since the results for the first back trajectory run with the coarse-scale and fine-scale methods resulted in the coarse-scale method being an apparent underestimate of pollutant exposure, another back trajectory was tested using both methods to investigate whether the large scale method could instead be an overestimate of pollutant exposure under a different scenario. Since the contributions from the Chicago area were the main reason for the initial underestimate by the coarse-scale method, the second back trajectory that was chosen for investigation (the July 19, 2008 trajectory that started at 0000 UT) did not pass in close proximity to any metropolitan areas (figure 11). The NOx exposure levels of this July 19 trajectory were calculated for both the coarse-scale and fine-scale methods in the same manner as the March 1 trajectory. Four grids were again drawn around this trajectory in order to represent the fine-scale method (figure 12).

The coarse-scale method for the July 19 trajectory recorded higher levels of NOx for all 36 data points (figure 13). Since the trajectory's path was contained entirely inside the westerly flow regime, the coarse-scale method estimates a constant emission exposure level of 6.9 kg/ km²/hr. In contrast, the fine-scale method estimates a weighted average NOx exposure of 2.7 kg/km²/OSD: NOx exposure levels of 4.7, 1.1, 3.0, 3.1 kg/km²/hr for the 36th-30th,29th-17th,16th-9th, and 8th-1st hours before reaching the station, respectively. This value is over two and a half times lower than the estimate produced via the coarse-scale's method. Thus, for the July 19 back trajectory, the estimate generated by the coarse-scale's method appears to be a significant overestimate of pollutant exposure.

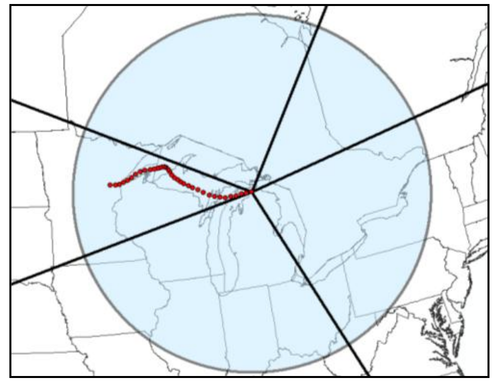


Figure 11: *Back trajectory for July 19, 2008. This trajectory was chosen because it does not travel near any major urban areas.*

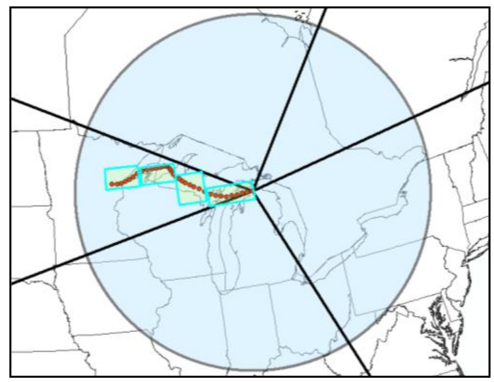


Figure 12: *Grids drawn around July 19, 2008 back trajectory for use in small scale method.*

Discussion

Emission Level Variation

When considering the emission levels of NOx, CO, and anthropogenic VOCs by flow regime, some reoccurring trends appear. As expected, the south/southwest flow regime leads all other flow regimes in all three pollutant categories. Similarly, on the other extreme the north/northwest flow regime has the

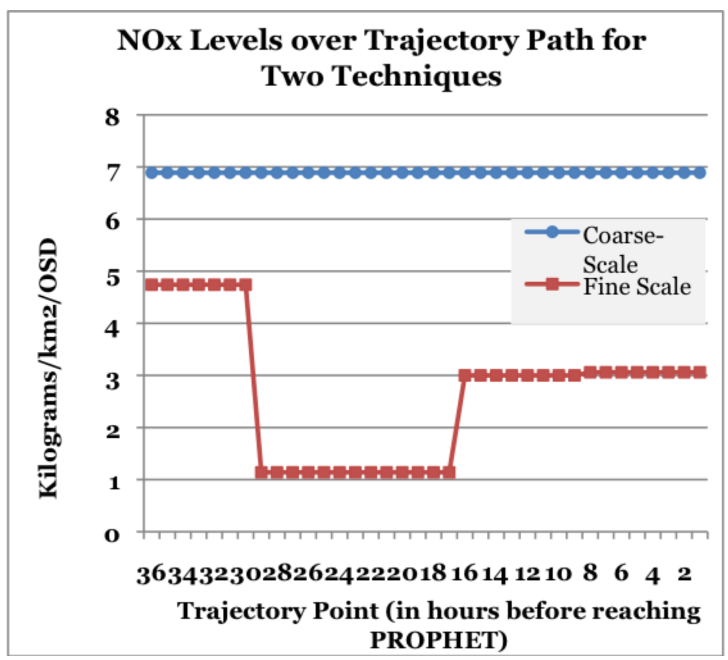


Figure 13: *NOx levels for large scale method and small scale method for July 19, 2008 trajectory.*

lowest emissions values for all three pollutants. The east/southeast, west, and northeast flow regimes also followed similar trends by registering the second, third, and fourth highest levels for all pollutants respectively.

Although these trends can be expected from past pollutant measurements and back trajectory studies, the purpose of this study was also to examine some underlying potential causes of these patterns. The first potential cause to these patterns that was examined was the population density differences between flow regimes. A population density map from 2000 was split into the UMBS air flow regimes in order to examine population levels (figure 14). From this map it becomes apparent that the greatest densities in population are in the south/southwest and east/southeast flow regimes. The north/northwest and northeast flow regimes, on the contrary, have very low population values. The west regime is in the middle of these two extremes and has a mixture of both heavily and sparsely populated regions. These density levels show the same patterns between flow regimes as the emission levels. The south/southwest and east/southeast flow regimes which have the highest densities in population also have the highest levels of pollutant emission. Similarly, the northeast and north/northwest regimes, which have the lowest population density levels, also have the lowest emission levels. To complete this pattern, the west flow regime, with a population density level in the middle of the other flow regimes, has emission levels that are also in the middle range among the flow regimes.

A land cover map (figure 15) was also split into the UMBS flow regimes and examined for trends that would help explain the pollutant emission levels among the flow regimes. For the regions around the biological station urban areas, cropland, and forests were the three major land cover types. From this map it again becomes apparent that the largest concentrations of population are in the south/southwest and east/southeast flow regimes. The lowest concentrations are again in the north/northwest and northeast while the west is still in the middle of the two extremes. Cropland has its highest abundance (about two-thirds of total area) in the south/southwest regime flowed by the east/southeast and west regimes which have approximately one-third of the total land area dominated by cropland. The north/northwest and northeast regimes have very little of their land area (>5%) dominated by cropland. For forests, the highest percentages

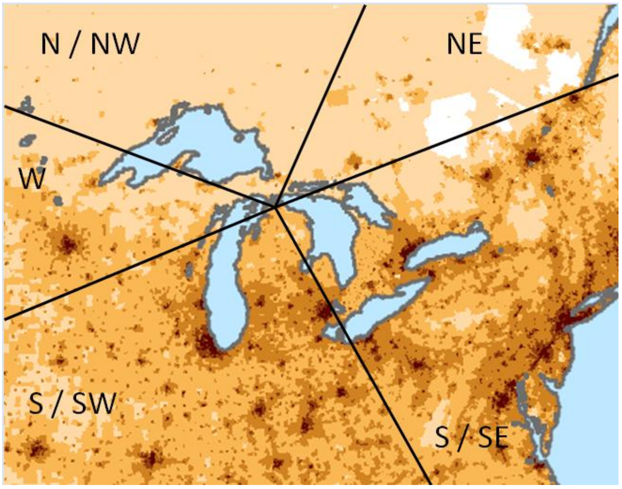
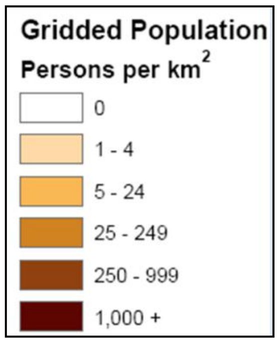


Figure 14*: Population density map of 2000 sectioned by air flow regimes*



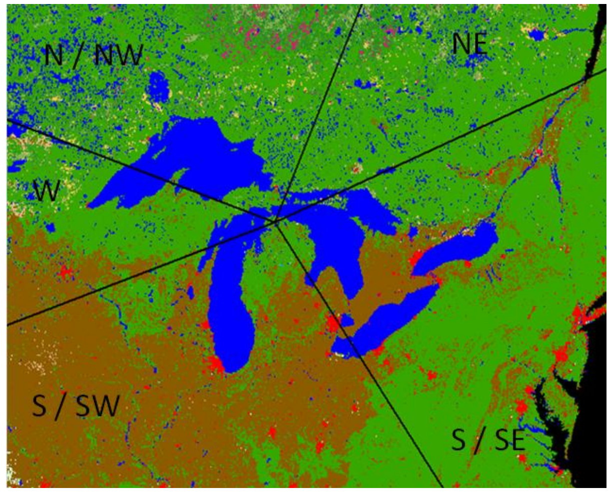
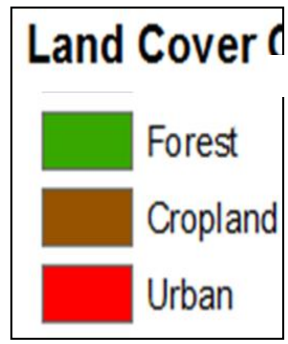


Figure 15: *Land cover map of 2000 sections by air flow regimes*



of land covered are in the two northern regimes where they are over 90% of the total area. The west and east/southeast regimes have approximately two-thirds of their area cover by forests while the south/southwest has only about one-third total forest cover.

From the population density and land cover map it appears that the higher levels of pollution in the south/southwest and east/southeast flow regimes are correlated with higher levels of population density and higher percentages of cropland land cover. In contrast, it appears that the north/northwest and northeast flow regimes derive their low pollution levels from low levels of population and high levels of forest cover. The west flow regime has a moderate amount of densely populated regions, cropland, and forest cover so it is not surprising that its pollutant levels are also in the middle with respect to flow regimes.

Variation between Large Scale and Small Scale Methods

Assuming that the fine-scale method is a more accurate representation of pollutant exposure, comparison estimates produced using the coarse-scale method were found to either significantly overestimate or significantly underestimate NOx exposure levels. The fine-scale method was considered to be a more accurate representation because it incorporates only the land area (and resulting emission data) that is in close proximity to the trajectory's path. The fine-scale method for the July 19 study incorporated only 67,000 square kilometers in its four grids while the coarse-scale method included emission data from the three large grids of west flow regime (out to the 804.5 km radial perimeter) that combined to over 153,000 square kilometers. For the March 1 trajectory, the fine-scale method included only 172,000 square kilometers while the coarse-scale method incorporated over 827,000 square miles across three flow regimes.

From the two trajectories that were studied, it appears that the coarse-scale method will produce an underestimate when the trajectories travel close to large metropolitan areas. This occurs when the large emissions associated with relatively small areas (such as cities) are diluted in the coarse-scale method by large areas with much lower emission levels. In contrast, the coarse-scale method appears to produce an overestimate when trajectories do not pass close to metropolitan areas. This trend arises because cities emit enough pollution in their relatively small vicinities to raise the entire flow regime's average pollution levels. Therefore, even if a back trajectory traverses exclusively rural areas on its path to UMBS, the coarse-scale method would produce fairly high estimates of pollutant emissions due to its communal distribution properties.

Trajectory Data beyond 36-Hours

It is important to remember that the back trajectories have pollution influences beyond the 36-hour scope of this treatment. The back trajectories pollutant exposure is not zero at the 37th hour and back trajectories can enter the last 36-hour period with high or low levels of pollutants depending on their travel path. These levels can be important to total exposure levels for the PROPHET site, especially when considering pollutant with longer lifetimes. The 36-hour time span for the trajectories and the 804.5 km radial circle around the PROPHET site are both arbitrary values that were chosen in an attempt to include the most important areas for air masses reaching the PROPHET site.

Conclusion

The coarse-scale method for deriving pollutant exposure for back trajectories has immediate potential uses at UMBS. This coarse-scale method could be readily integrated with the current back trajectory classification archive that now spans over a decade, and it can be used to estimate pollution exposure for all back trajectories that meet the criteria for being assigned to one of the five air flow regimes. This method could also be used for back trajectories that are listed as indeterminate. In this case, such trajectories can be broken down into different air flow segments for which exposure levels are estimated, and then combined to arrive at an estimate of total exposure.

Future Work

The small scale method is a potentially useful way to assess pollutant exposure (via back trajectories) on the UMBS forest. However, the raster datasets from the Emissions Inventory Mapviewer must first be transferred into a more efficient processing program, such as Arcmap, before this method will become practical. Also, it would be interesting to process new data such as population density maps, land cover maps, and raster sets from the Emissions Mapviewer as they becomes available. Changes in population or land cover could then be compared to changes in emission levels for the same period in order to see to what extent population and land cover drive the level of pollutants observed at the PROPHET site.

It would also be beneficial to weight pollutant emissions according to their proximity to UMBS. This is a key step because pollutants have different lifetimes in the atmosphere. When deriving the pollutant exposure to UMBS, a pollutant that has a shorter lifetime may need lower weights as its distance from the station increases. On the other hand, the methods used herein may produced a reasonable estimate of local exposure for pollutants that are longer lived.

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References

Apel, E. C., D. D. Riemer, A. Hills, W. Baugh, J. Orlando, I. Faloona, D. Tan, W. Brune, B. Lamb, H. Westberg, M. A. Carroll, T. Thornberry, and C. D. Geron. "Measurement and Interpretation of Isoprene Fluxes and Isoprene Methacrolein, and Methyl Vinyl Ketone Mixing Ratios at the PROPHET Site during the 1998 Intensive." Journal of Geophysical Research 107 (2002): ACH 7-1-15.

Carroll, M. A., S. B. Bertman, and P. B. Shepson. "Overview of the Program for Research on Oxidants: Photochemistry, Emissions, and Transport (PROPHET) Summer 1998 Measurements Intensive." Journal of Geophysical Research 106 (2001): 24275-24288.

Cooper O.R, J. L Moody, T. D. Thornberry, M. S. Town, and M. A. Carroll. "PROPHET 1998 Meteorological Overview and Air-Mass Classification." Journal of Geophysical Research 106 (2001): 24289-24299.

Croskrey, Jennifer. "Investigation of Ozone Stomatal Flux in a Northern Mixed Hardwood Forest during the 1999 to 2004 Growing Seasons."

Jaffe, Dan, T. Anderson, D. Covert, R. Kotchenruther, B. Barbara, J. Danielson W. Simpson, T. Bernsten, S. Karlsdottir, D. Blake, J. Harris, G. Carmichael, and I. Uno. "Transport of Asian Air Pollution to North America." Geophysical Research Letters 26 (1999): 711-714.

Karl, T., A. Guenther, C. Spirig, A. Hansel, and R. Fall. "Seasonal Variation of Biogenic VOC Emissions above a Mixed Hardwood Forest in Northern Michigan." Geophysical Research Letters 30 (2003): SDE 2-1 -4.

Merrill, J., M. Uematsu, and R. Bleck. "Meteorological Analysis of Long Range Transport of Mineral Aerosols Over the North Pacific. Journal of Geophysical Research 94 (1989): 8584-8598.

Moody, J. L., J. W. Munger, A. H. Goldstein, D. J. Jacob, and S. C. Wofsy. "Harvard Forest Regional-Scale Air Mass Composition by Patterns in Atmospheric Transport History (PATH)." Journal of Geophysical Research 103 (1998): 13,181-13,194.

Ocko, Ilissa. "Air Flow Regime from 1999 to 2005 at The University of Michigan Biological Station and its Relation to Variability in Net Carbon Dioxide Flux and Tropospheric Ambient Ozone; Summer 2006 Analysis."

Pressley, S., B. Lamb, H.Westberg, J.Flaherty, and J. Chen. "Long-Term Isoprene Flux Measurements above a Northern Hardwood Forest." Journal of Geophysical Research 110 (2005): D07301 (1-12).

Westberg, H., B. Lamb, R. Hafer, A. Hillis, P. Shepson, and C. Vogel. "Measurements of Isoprene Fluxes at the PROPHET Site." Journal of Geophysical Research 106 (2001): 24,347-24,358.