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Atmospheric Environment 39 (2005) 7689–7701
ATMOSPHERIC ENVIRONMENT
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Using dispersion and mesoscale meteorological models to forecast pollen concentrations

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Received 9 November 2004; accepted 5 April 2005

Abstract

This work describes the results of research into a source-oriented pollen concentration forecasting technique. Tests were conducted using the National Center for Atmospheric Research/ Penn State Fifth Generation Mesoscale Model (MM5), the National Oceanographic and Atmospheric Administration (NOAA) Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT_4) Model combined with the locations of oak trees and their aerial coverage from biogenic emissions land cover database version 3.1 (BELD3). Daily forecasts of pollen concentrations via MM5 and HYSPLIT_4 were made with 30-min increments and tested against 30-min oak pollen data collected by the St. Louis County Department of Health in Clayton, Missouri, for the month of April 2000.

Results from these tests show that the combination of MM5 and HYSPLIT_4 with accurate source locations can provide short-term forecasts as indicated by the levels of forecast pollen and actual oak pollen levels, which follow similar profiles for the day. From the 30 individual pollen concentration forecasts, two example forecasts are presented. Additional studies need to be conducted to further validate these results, using an array of pollen collectors. A better understanding of the biology of pollen release is critical to improving these pollen concentration forecasts.

Keywords: Mesoscale; Meteorology; Pollen concentrations forecasting

1. Introduction

At least 35.9 million people in the United States have seasonal allergic rhinitis (Nathan et al., 1997). According to the American Academy of Allergy and Asthma and Immunology (AAAAI), seasonal allergic rhinitis, also known as "hay fever", is a disorder which causes sneezing, itching, a runny nose, and nasal congestion ([http://www.aaaai.org/public/fastfacts/glossary.stm]). In 1993, Stroms et al. (1997) estimated that the total cost associated with allergic rhinitis in the United States was $3.4 billion, of which $2.3 billion was for medications and $1.1 billion represented physician billings. It is clear that seasonal allergic rhinitis has not only a significant impact on the people who suffer from it but on the economy as well. The AAAAI recommends complete avoidance of the allergen as the best treatment option.

To meet the AAAAI guidelines, allergy sufferers and medical personnel need information on allergen concentrations to treat allergy symptoms effectively and/or take preventative action, such as avoiding

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doi:10.1016/j.atmosenv.2005.04.043

outdoor activity during times of high concentrations. In the United States, the only pollen concentration information available to the public is the daily pollen counts or statistical forecasts based on seasonal pollen cycles. Saint Louis, Missouri, is typical in this regard, in that the only pollen reports available is a 24-h summary of total pollen concentrations ending at 7 am at the pollen collection site in Clayton, Missouri. Forecasts of pollen concentrations can be made in one of two ways: a receptor-oriented method or a source-oriented method. Advancements in meteorological models and land cover databases now make it possible to create high spatial and temporal resolution forecasts of pollen concentrations using a source-oriented method.

Although the most common pollen causing seasonal allergic rhinitis is *Ambrosia,* (common name: ragweed) its impact varies widely from individual to individual. Pollens from various grasses and trees are also significant causes of seasonal allergic rhinitis. A single pollen was chosen, rather than all common pollens causing seasonal allergic rhinitis, for these experiments to simplify testing of the source-orientated forecasting technique. *Quercus* (common name: oak) was selected for several reasons. First, *Quercus* density is extremely high to the south and west of Saint Louis providing a large known source pollen source with directionality. Secondly, unlike *Ambrosia* whose location and density varies on a yearly and seasonal basis, *Quercus* locations and densities are well documented on a 1-km^2 scale (Pierce et al., 1998).

The source-orientated technique requires knowledge of source locations, emission rates, duration of emissions and the meteorological structure of the atmospheric boundary layer (ABL), including both spatial and temporal variations of wind, stability and moisture. This technique uses important features of the ABL that affect dispersion of atmospheric contaminants, in this case, pollen grains. The ability to forecast scales small enough to accurately forecast the parameters in the boundary layer have recently become available via mesoscale meteorological models. Highly accurate dispersion models, such as the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT_4; Draxler and Hess 1998), which make use of high-resolution mesoscale meteorological data, allow concentrations of a contaminant to be forecasted in both space and time.

Van de Water et al. (2002) described the use of the source-orientated technique to forecast *Juniperus Ashei* (mountain cedar) pollen for Tulsa and Oklahoma City, Oklahoma, and St. Louis, Missouri ([http://pollen.utulsa.edu/mcforecast.html]). This pollen is transported to great distances from the Edwards Plateau region of Texas during December and January. Levetin et al. (1998) determine if conditions will allow the release of *J. Ashei* and put it into one of three categories: unfavorable, favorable, and quite favorable. HYSPLIT_4 (Draxler and Hess, 1998) is used to calculate a forward trajectory to see where air parcels from the source region will move; if they move over a particular location, then that region is considered at risk for elevated levels of *J. Ashei* pollen. Precipitation along the trajectory is also considered, as it washes pollen out of the air. The forecast is in terms of risk; i.e., low, moderate, or high. This method has shown success in determining the timing of the influx of pollen, but predicting the concentration of pollen has been more problematic (Van de Water and Levetin, 2002).

A similar method to that of Levetin et al. (2002) is used by a group from the Department of Plant Pathology, North Carolina State University, Raleigh, North Carolina, to forecast transport of Tobacco Blue Mold and Cucurbit Downy Mildew (Main and Keever, 2000, and Main et al., 2001). The problem facing the agricultural community is the spread of plant disease by atmospheric transport. In the studies by Main et al. (1998), the transport of two different fungal pathogens is forecast. A network of County Extension agents from around the United States and other countries report infestations of these diseases to a central database. These reports are used by North Carolina State University as input to HYSPLIT_4 as the source strength for the dispersion part of the model. NCEP's Eta model is used for the meteorological fields as input for HYSPLIT_4.

2. Methodology

To use the source-orientated pollen forecasting method, it is necessary to know both the source strength and location of pollen emissions and a means to calculate the transport and dispersion of pollen along its trajectory. The BELD3 land use database is used to identify the aerial coverage of oak trees. The Pennsylvania State University and the University Center for Atmospheric Research, UCAR, Mesoscale Meteorological Model Version 5 (MM5), Dudhia et al. (2001), is used in this study.

The final component is a model that can calculate transport and dispersion of pollen. HYSPLIT_4 was selected for this task.

2.1. Location of oak trees

The BELD3 (Pierce et al., 1998) land use database was selected to determine the location of oak trees. The US Forest Service provided data for each county or parish in the United States, which included the fraction of individual tree species to the total tree cover of all tree species. A fraction is given for coverage of all trees in a 1-km^2 area. The ratio of these two fractions should give a 1-km^2 resolution for tree species. In this study, the percentage in each 12-km^2 is the average of the 144 individual 1-km^2 from the BELD3 land use database. The fraction of oak tree coverage is shown in Fig. 1.

2.2. Mesoscale meteorological model

A mesoscale meteorological model is needed in order to produce a forecast of meteorological parameters, such as wind, temperatures, and moisture, in a sufficiently dense spatial and temporal distribution necessary to determine the transport of particulates, such as pollen. The MM5 mesoscale meteorological model, developed by Pennsylvania State University and the National Center for Atmospheric Research (NCAR), was selected for use in this study. The MM5 model has seven Planetary Boundary Layer (PBL) schemes to select, as well as many other physics options. This makes the MM5 model ideal for testing mesoscale features that may influence the transport and dispersion of pollen and other particulates. Noting the wide variation in local conditions, the National Weather Service has encouraged the use of MM5 by Forecast Offices. The local forecast offices can improve their forecasts by tuning the number of model levels in the boundary layer and the type of boundary layer and cumulus parameterization schemes used in MM5.

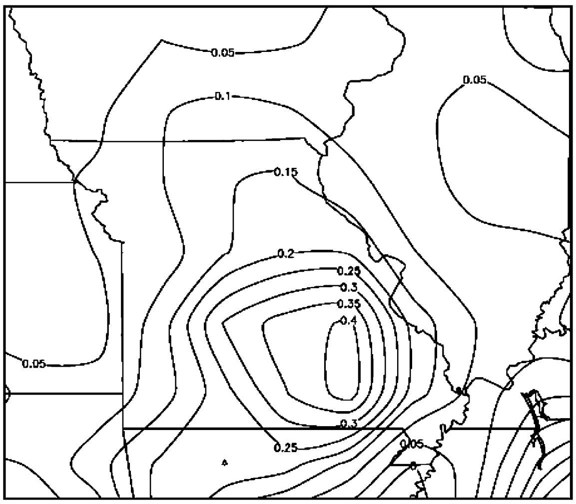


Fig. 1. Oak tree density from the BELD3 1-km^2 land cover database averaged over 12 km^2.

The MM5 model is configured to test three different PBL schemes: (1) Burke–Thompson, (2) Eta, and (3) Gayno–Seaman. The Burke–Thompson scheme uses only vertical mixing (Burke and Thompson, 1989), while the Eta PBL scheme includes local mixing and mixes adjacent layers (Janjic, 1990, 1994). The Gayno–Seaman (Gayno et al., 1994) scheme makes use of the liquid–water potential temperature as a conservative variable, allowing the simulation of the PBL in a more realistic manor in saturated conditions (Ballard et al., 1991; Shafran et al., 2000).

The MM5 is configured to use the National Center for Environmental Prediction (NCEP) 40-km Eta model (AWIPS-212 grids) forecasts to provide the lateral boundary conditions for MM5. Use of the larger 40-km Eta model forecasts as boundary conditions allows us to make use of two-way nesting. A simple "nudging" technique is used to push MM5's outermost domain toward the 6-h ETA forecasts. This simply "nudging" technique combined with MM5's two-way nesting minimizes the spin-up time required. Using the 00 UTC ETA initialization, a 36-h MM5 forecast was made. Using the last 24 h of the 36-h MM5 forecast, a 24-h HYSPLIT_4 forecast was made. Three nested domains are selected for the MM5 simulation. The outer domain, domain 1, has a grid spacing of 108 km, domain 2's spacing is 36 km while domain 3's spacing is 12 km. Domain 3, the region of interest for release of oak pollen, is the location of the St. Louis County Department of Health's pollen location site, which will be used to verify the pollen forecast. The MM5 model is configured with 42 vertical layers with 20 in the lowest 2 km for a detailed boundary layer description.

MM5 uses a land surface model that includes vegetation, soil, vegetation type, and deep soil temperatures. The vegetation data set selected is the 24-category database and physical parameter for North America. This database is divided into two seasons—summer and winter. Dudhia et al. (2001) define the winter season as 15 October–15

April and summer as 15 April–15 October. The input data resolutions used for the height and land-use database are: domain one, 30 min, ~56 km; domain two, 10 min, ~19 km; and domain three, 5 min, ~9 km.

2.3. HYSPLIT_4 model

The National Oceanic and Atmospheric Administration (NOAA) and Air Resources Laboratory (ARL) developed HYSPLIT_4, (Draxler and Hess (1998)), which is used in this project. The HYSPLIT_4 model is a system for modeling trajectories, dispersion and deposition of pollutants. According to Draxler and Hess (1998), this model uses gridded model output or a series of gridded analyses, such as Eta Data Analysis System (EDAS), or output of a forecast model such as MM5/PSU, Eta, AVN or other NCEP models, as input. The model uses a hybrid between the Eulerian and Lagrangian coordinates to calculate trajectories and dispersion of air parcels. Particle advection and diffusion calculations are made in a Lagrangian framework, while concentrations are calculated on a fixed grid. Air concentration calculations associate the mass of the airborne particulates with the release of puffs, particles, or a combination of both, which is user specified.

The dispersion rate is calculated from the vertical diffusivity profile, wind shear, and horizontal deformation of the wind field. Air concentrations are calculated at a specific grid point for puffs and as cell-average concentrations for particles (Draxler and Hess, 1998). One of the three assumptions can be used to compute air concentrations along the parcels trajectories: a puff model, a particle model or a combination of puff and particle models called PARTPUF. The combination method was used in this study. Other options in HYSPLIT-4 allow for gravitational settling, wet and dry deposition and re-suspension of pollutants (Draxler and Hess, 1998). These options give more flexibility to replicate realistic conditions and allow for various tests. This model has been under development since 1982.

The accuracy of trajectories using numerical models was tested by using data collected during Across North America Tracer Experiment (ANTEX), Draxler (1991). Overall results indicated that no discernible differences were seen with the three meteorological data sets, with the average error rate in the 20% to 30% range. The reported error statistics, in conjunction with the large emissions (Fig. 1) and relatively short distance between the emissions and pollen monitoring location, suggest that any dispersion model transport errors would not have any significant impact on our results.

3. Results

The oak pollen season is determined by 10 years of oak pollen data from the St. Louis County Department of Health, as summarized in Fig. 2. The St. Louis County Department of Health collects pollen and mold information using a Burkard air sampler following the AAAAI guidelines on a daily basis except for weekends and holidays. In cooperation with Saint Louis University, the Saint Louis County Department of Health used an alternate collection orifice and slower speed on the Burkard sampler to allow a 30-min sampling interval. Since the beginning of the oak pollen season occurs at the very end of March and extends to the beginning of

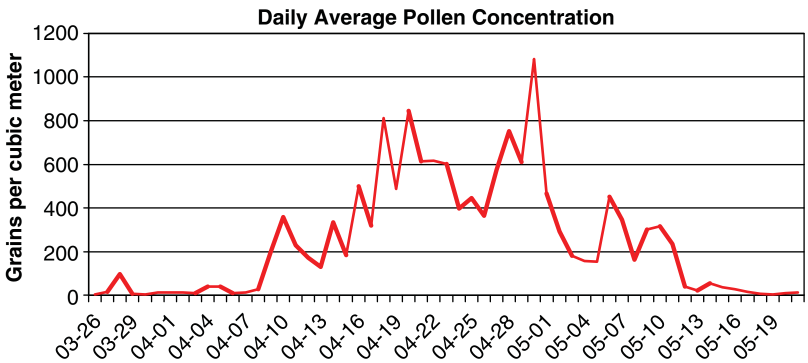


Fig. 2. 10-year daily average pollen concentration from the Saint Louis County Department of Health.

May, the Saint Louis County Department of Health specifically analyzed the collection slides from the Burkard sampler for *Quercus* at 30-min intervals from 1 April 2000 to 1 May 2000.

From the 30 days of pollen concentration forecasts, two dates, 15 and 16 April, were selected because they occur in the middle of the oak pollen season and they represent the best and worst forecasts for April 2000. Each of these dates has its own unique meteorological settings that are important to the quality of the pollen forecast.

Several important assumptions and configurations were used in HYSPLIT_4 to simulate pollen release and its motion: (1) pollen release started at 13 UTC and continued for 22 h, (2) pollen emission strength was proportional to area coverage of oak trees in each 12-km^2 grid cell, and (3) emission strength per unit area was uniform in space and time. We choose to convert the emission strength per unit area into a non-dimensional parameter related to the emission rate of a typical oak tree. The non-dimensional parameter was then used in HYSPLIT_4 to compute the pollen concentration at each 12-km^2-grid cell. The actual concentration pollen concentration at each 12-km^2-grid cell is then found by multiplying by the emission rate of typical oak tree. This allowed us to determine the shape and timing of the forecast pollen concentrations without knowing the actual value. Further, from a single forecast run we could test multiple emission rates to determine the actual concentrations. The results presented below are for an emission rate of 1.2×10^6 pollen grains per tree per hour. This emission rate is similar to that of Soybean rust which has been shown to be about 3.75×10^{15} spores per hectare per day (Isard et al., 2004). Latitudinal change of pollen emission rates was not taken into account.

HYSPLIT_4 has a number of configuration options that can be selected. Options include gravitational settling, resuspension, wet deposition, which includes rain out of particulates, washout by rain and absorption by cloud and cloud droplets. A gravitational settling velocity of $5\,\mathrm{cm\,s^{-1}}$ was chosen based on the terminal velocity of 23.5 μm particles with a density of nearly 1.0. In order to simulate normal usage, washout by rain and absorption by cloud and cloud droplets were set to default options. HYSPLIT_4 was configured in the vertical using its default coordinates. The surface layer is defined as the lowest 75 m of the atmosphere. Using this system, the center points of HYSPLIT_4 vertical layers in the boundary layer are: 5, 10, 38, 118, 247, 428, 658, and 937 meters. Oak pollen concentrations were calculated for these layers, as well as for pollen deposition.

3.1. 15 April 2000

The pollen forecast for 15–16 April 2000, indicates the need for an accurate meso-meteorological model forecast. Poor forecasts of wind, temperature and moisture from MM5 severely compromised HYSPLIT_4's ability to correctly forecast the dispersion and deposition of the oak pollen. The MM5 model over-forecasted the amount of low clouds over central Missouri and Illinois. The infrared satellite image for 1815 UTC presented in Fig. 3 shows a cloud free region from near Chicago, Illinois to northwest Arkansas. While the MM5 model, using the Eta PBL scheme, indicated the low cloud free area to be about 60 km to the northwest of the true cloud free region (Fig. 4). This led to a more stable model boundary layer over central Missouri and Illinois in the MM5 forecast, which resulted in little vertical mixing and horizontal transport during the day. The forecasted low cloud field also resulted in large temperature errors, greater than $-4\,^{\circ}\mathrm{C}$, to the southwest of St. Louis (see Fig. 3) where the dense oak forest of the Ozarks is located. Fig. 5 is the spatial correlation coefficients for pressure, temperature and winds over the 18-h forecast period for the Eta PBL scheme and the Grell (1993) CPS scheme. Although the spatial correlation coefficients are good early in the forecast, they decline with time falling as low as 0.2 for temperature by 06Z on 16 April 2000.

These large forecast errors result in a poor pollen concentration forecast. The low cloud field that developed in all three simulations caused the boundary layer to be cooler in the main source region of oak pollen. The best forecast appeared to be the Gayno–Seaman PBL because it reduced the low clouds the fastest, had the smallest temperature errors for the central part of domain-3, and the best fit for sea level pressure for St. Louis. In spite of the poor pollen forecast results, a welcome outcome was found from these correlations. A positive relationship between the quality of the meteorological model forecast and the accuracy of the pollen forecast was demonstrated. The GS MM5/PSU performed the best among the three models used in regard to low clouds. As the modeled low cloud fraction became closer to the observations, the quality of the pollen forecast increased, as seen by

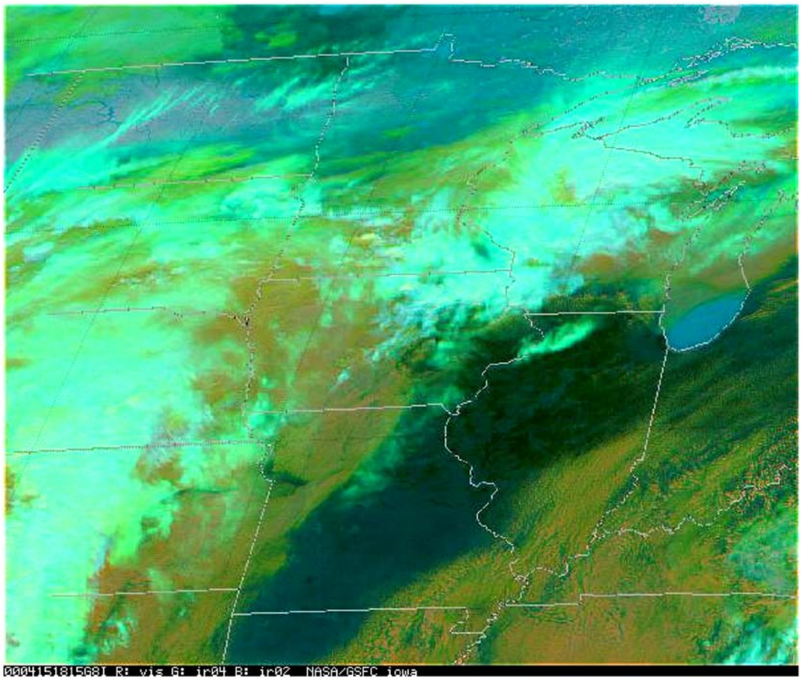


Fig. 3. The infrared satellite image for 1815 UTC 15 April 2000.

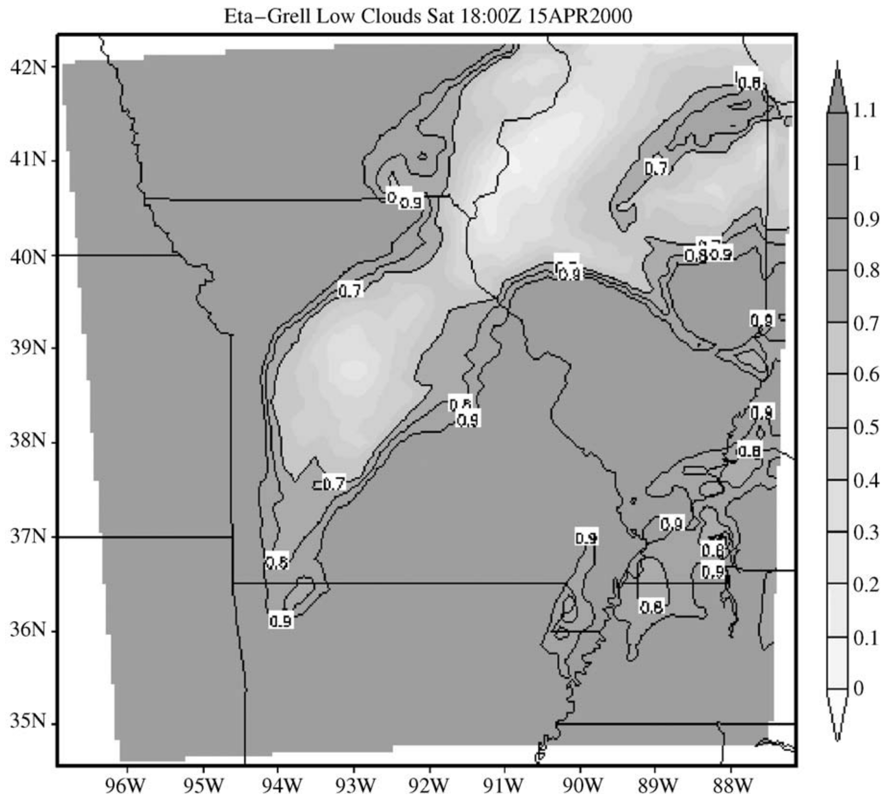


Fig. 4. Eta-Grell MM5 forecast of low-cloud concentration for 18Z 15 April 2000.

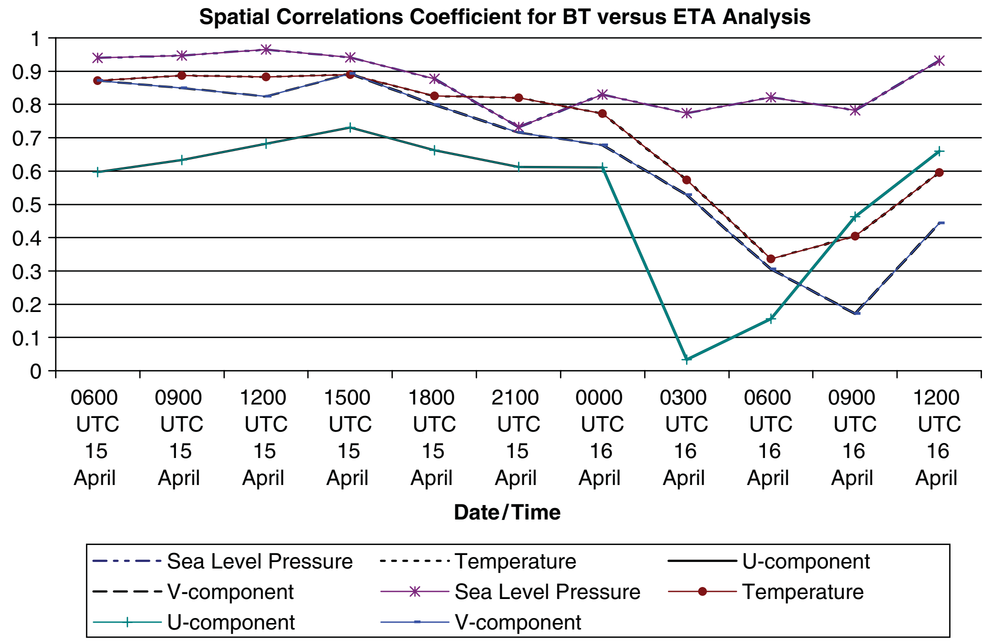


Fig. 5. Spatial correlations between NCEP Eta analysis and MM5/PSU with Burke–Thompson PBL and Grell CPS forecast for sea level pressure, temperature, U-component, and V-component of the wind at sigma level 0.995.

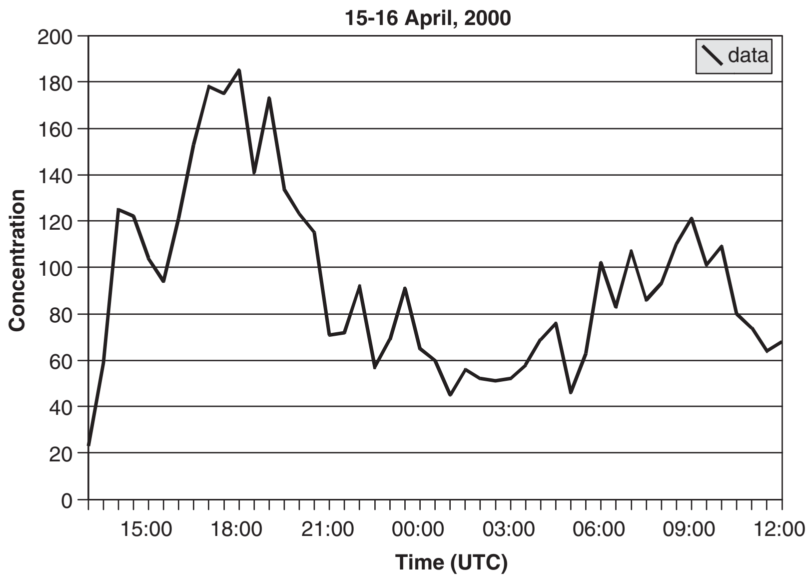


Fig. 6. Measured pollen concentration (grains m^{-3}) from the St. Louis County Department of Health pollen collection site, in Clayton, Missouri.

the increase of the correlation coefficients of the pollen forecast. This indicates that the overall quality of the meteorological forecast is a substantial factor to the quality of the pollen forecast.

Fig. 6 is the observed pollen concentrations at the Clayton Missouri sampling site and the forecasted pollen concentrations for the Gayno–Seamon, ETA and Burke–Thompson. Note that the concentrations drop off rapidly while the forecasted pollen concentrations continue to increase with time. The forecast stable boundary layer limited the amount of vertical and horizontal dispersion of the oak pollen concentrated in this layer. In reality, clear skies encouraged mixing of the boundary layer, increasing the amount of vertical and horizontal dispersion and thereby reducing the actual pollen concentration. Fig. 7 is the 38-m oak pollen concentration forecast for the Saint Louis County Department of Health collection site in Clayton, Missouri, for all three PBL schemes. The forecast underestimates the pollen concentrations early in the forecast period and overestimates the pollen concentrations in the last half of the forecast period.

While investigating the causes of the poor pollen concentration forecast, experiments with the wash-out options were conducted. It was noted that the pollen concentration forecast could be improved by removing all washout. Removal of all washouts raised the early morning concentrations to near actual concentrations. This implies that the low clouds forecasted by MM5 had several negative effects on the pollen forecast. First, the low clouds suppressed the forecasted temperature, reducing mixing in the boundary layer. Second, the low clouds increase the washout of pollen grains, reducing the amount of pollen grains suspended in the air. The reduced pollen payload is reflected in the lower forecasted pollen concentrations at the Clayton, Missouri, sampling site. In reality, the low clouds were not present, the boundary layer became deeper and there was very little washout.

3.2. 16 April 2000

The MM5 model produced an accurate representation of the meteorological conditions on 16–17 April 2000. The temporal correlations for sea-level pressure at St. Louis Lambert International Airport for all planetary boundary layer schemes are presented in Table 1. Using the time of the frontal passage as a marker and altering the MM5 forecasts improves the Eta temporal correlation coefficient by 10%. The spatial correlation coefficients for sea-level pressure in the inner domain are shown in Fig. 8. The spatial correlations for all boundary layer parameterization schemes were greater than 0.8 except for a short period near 15Z where the correlations dropped to 0.75. The wind and

Table 1
Temporal correlation coefficients for St. Louis Lambert International Airport of observed sea-level pressure versus MM5 sea-level pressures for 16–17 April 2000

Planetary boundary layer scheme	Correlation coefficient	Frontal passage error
Burke–Thompson	0.78	1 h late
Gayno–Seamon	0.66	1 h early
Eta	0.70	1 h early

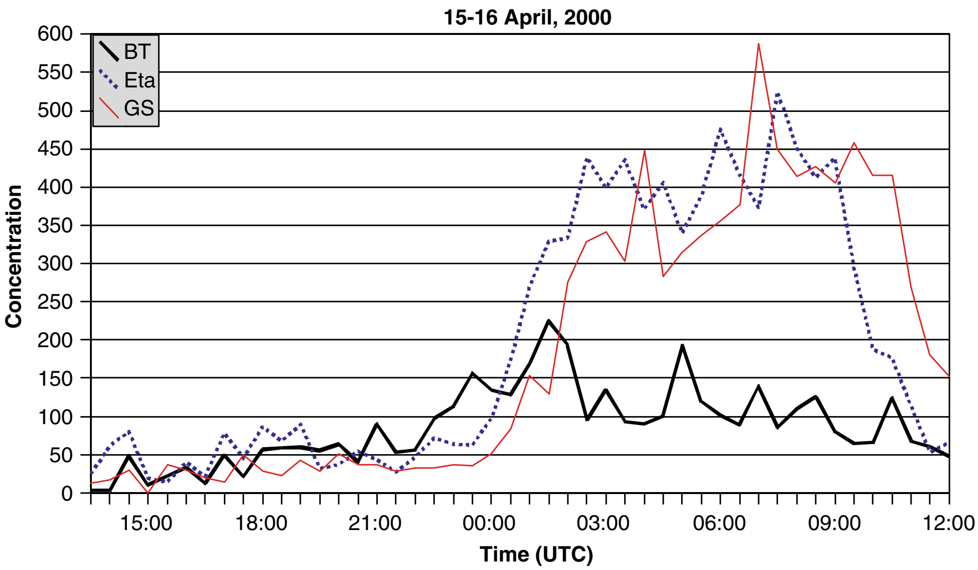


Fig. 7. Thirty-eight-meter pollen forecast for 15–16 April 2000 for the pollen collection site in Clayton, Missouri, from the BT, Eta and GS PBL schemes from the MM5/PSU models using HYSPLIT_4.

temperature fields at 18Z on 16 April 2000, for MM5 at sigma level 0.995 (about 35 m above ground level) and the near surface are presented in Fig. 9. The location of the surface low at 18Z in the MM5 forecast is slightly to the southeast from the analyzed position, but the frontal position as determined by wind and temperature fields is well placed in the MM5 forecast. The forecasted wind, temperature, humidity and pressure forecasts from MM5 accurately describe the conditions on 16–17 April 2000.

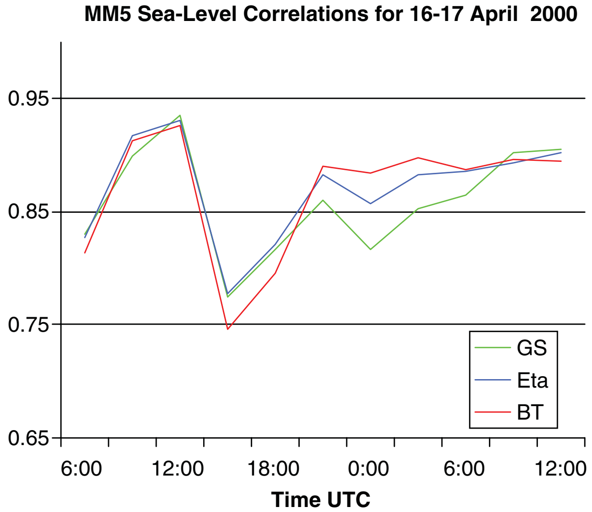


Fig. 8. Spatial correlation coefficients for Saint Louis Lambert International Airport sea-level pressure using the Burke–Thompson, Gayno–Seamon and Eta boundary layer parameterization schemes.

The pollen data collected by the St. Louis County Department of Health is presented in Fig. 10. The pattern shows two peaks, one in the morning at 15:00 UTC, and another peak at night at 06:00 UTC. HYSPLIT_4 pollen concentrations forecast for the three PBL simulations indicate the sensitivity of the pollen forecast to the planetary boundary layer parameterization scheme. Fig. 11 is the HYSPLIT_4 pollen forecasts for 38, 118, and 247 m above ground level (AGL) for all 3 PBL schemes at the Saint Louis County Department of Health collection site. These forecasts have several features that are common to all levels and PBL schemes. As expected, the forecasted pollen concentrations decrease with height above ground. Pollen concentration values at 38, 118, and 247 m AGL all rose and fell at nearly the same time. Further, the time of the peak concentrations in

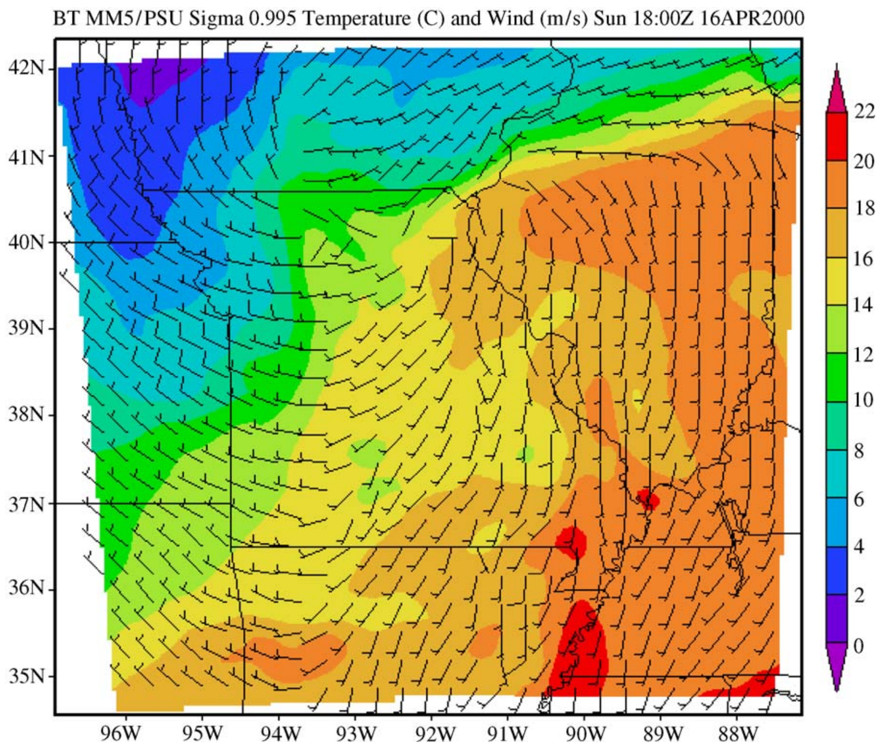


Fig. 9. 1800UTC 16 April 2000 Burke–Thompson PBL Scheme MM5/PSU results for temperature, °C and winds, ms^{-1}.

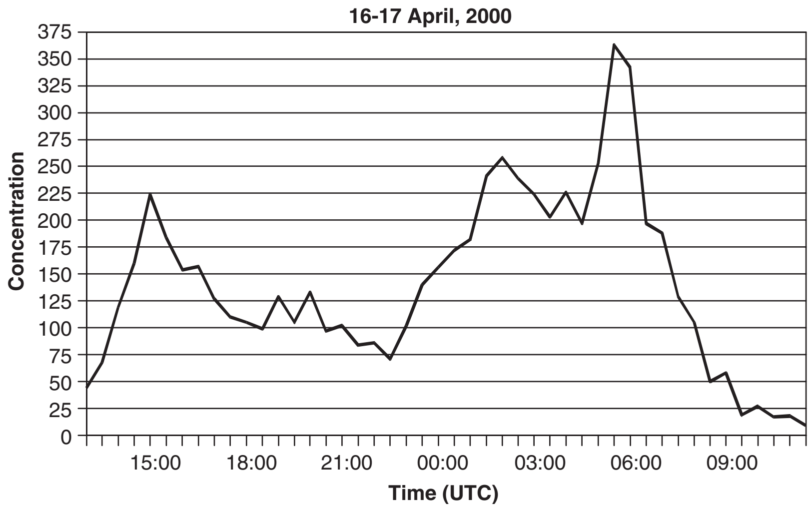


Fig. 10. Observed oak concentrations from the Saint Louis County Department of Health collection site at Clayton, Missouri.

forecasts corresponded to the actual time of peak pollen concentrations at Clayton, Missouri. The forecasted pollen concentrations are also sensitive to the choice of PBL scheme, with the Gayno-Seaman PBL scheme producing the largest concentrations. Correlations between the actual and forecast values for the three levels are presented in Fig. 12.

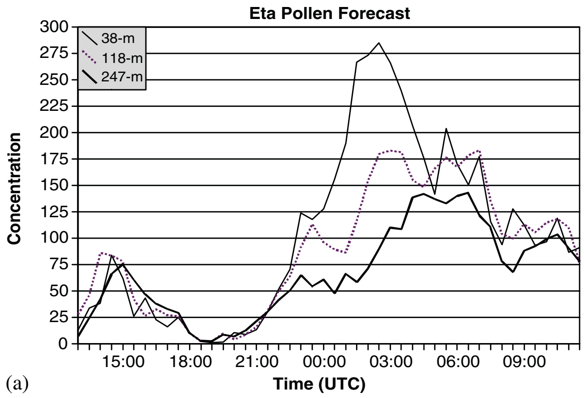
The forecasted pollen concentration correlation coefficients decrease with time. One reason for the drop in the quality of the pollen forecast could be that the air temperature at upwind locations fell to near 5 °C at Kansas City and Kirksville, Missouri, and 7 °C at Columbia, Missouri by 0300 UTC 17 April. These colder temperatures may have reduced pollen production, which is not accounted for in the model. A question remains about the production of pollen and air temperature. Antepara et al. (1995) showed that colder days produce less pollen. This would have resulted in a forecast that produced too much pollen after 0300 UTC 17 April throughout the inner domain. Without the pollen release, the actual pollen concentrations showed a dramatic drop in forecasted pollen concentrations. Fig. 13 is the observed pollen concentrations at the St. Louis County Department of Health sampling site at Clayton Missouri, and the forecasted pollen concentrations for the Gayno–Seamon, Eta and Burke–Thompson boundary layer parameterization schemes. The forecasted pollen concentrations for each boundary layer match the observed values to a remarkable degree.

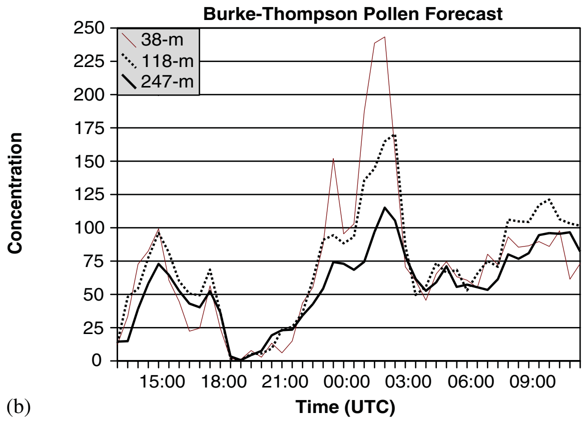
Another important aspect of this research is to understand the relationship of the meteorology to the transport and concentration of pollen. In order to appreciate this, the MM5 wind field and pollen forecast at about 40 m above ground level is displayed in Fig. 14. This is taken from the Gayno–Seamon PBL MM5 simulation. Darker regions indicate higher concentrations of oak pollen. It is interesting to note that pollen accumulates in confluence zones in the streamlines. The dark circle in the center of Fig. 14 is the location of the Saint Louis County Department of Health pollen collection site in Clayton, Missouri. The shaded regions correspond well to convergent zones, frontal boundaries and other meteorological features and are consistent with those shown in Fig. 9. Although not shown here, these regions of high oak pollen concentrations show consistency both in time and with the meteorological features. Again, these are model results and need to be verified by a network of pollen collectors.

Although there are differences in pollen concentrations, these differences would not be significant for an allergy sufferer. The many assumptions made to reduce the forecasting problem to a more tractable form for these experiments have a significant effect on the forecasted concentrations. Improvements in our understanding of the mechanisms controlling pollen releases would improve the accuracy of the pollen concentration.

4. Conclusions

The motivation for these series of experiments in this study is to determine if the source orientated





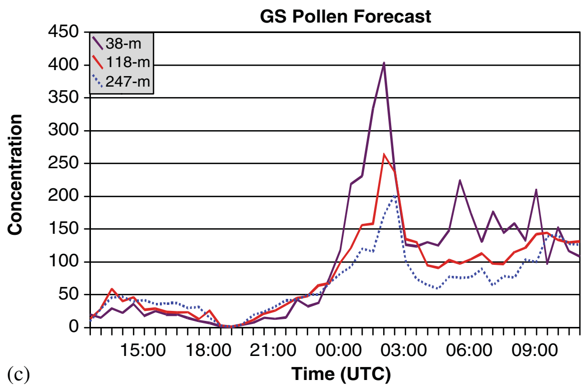


Fig. 11. HYSPLIT_4 pollen concentration forecasts for 38, 118 and 247 m AGL f or (a) Eta, (b) Burke–Thompson and (c) Gayno–Seaman PBL schemes.

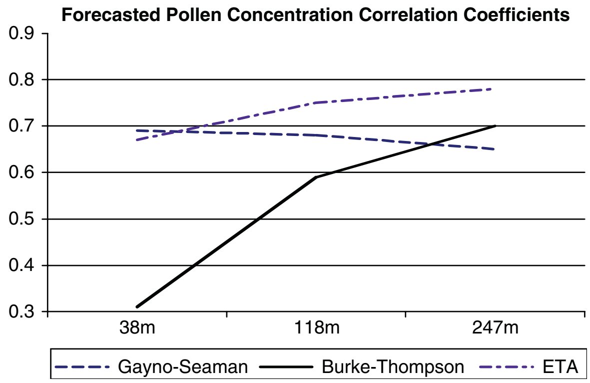


Fig. 12. Forecasted pollen concentration temporal correlation coefficients at 38, 118 and 247 m AGL for Gayno–Seaman, Burke–Thompson and Eta PBL schemes.

method of forecasting pollen is a viable technique. Simplifying assumptions were made as to the rate of pollen emission, proportional to area coverage, and its duration, for 22 h starting at 13 UTC. The results indicate that 16–17 April 2000 pollen forecasts performed very well, but the 15–16 April 2000, pollen forecasts were poor.

The results, especially for 16–17 April 2000, indicate that the source-oriented method has promise as a viable method to forecast oak pollen. The need for a quality mesoscale meteorological forecast has also been demonstrated in the experiments for 15–16 April 2000. With this in mind, methods should be developed to increase the quality of the MM5/PSU real-time forecasts. Is the use of only NCEP's Eta forecast series alone the best way to produce quality mesoscale forecasts? Is the use of NCEP's Eta forecast series the best one to use as initial fields for the MM5/PSU model or should other models be selected? Once the quality of the forecast is improved, how does it change the pollen forecast?

Another area that needs further research is the biological cycle relating to how and when pollen is released. Relative humidity greater than 90% at flower level is known to nearly stop pollen release. How do parameters such as temperature, sunshine, moisture, and wind speed impact pollen release into the atmosphere? Further experiments should be conducted on how to use these parameters to alter HYSPLIT_4 source strength for each cell. This will allow biological sensitivity studies to be conducted.

In this preliminary study, only one site was available to verify the results of the pollen forecast. Several pollen collection sites, stationary and mobile, should be used to properly verify this methodology. Measurements of vertical distribution of pollen should be made to better understand the dynamics of the transport of particulate matter in the boundary layer.

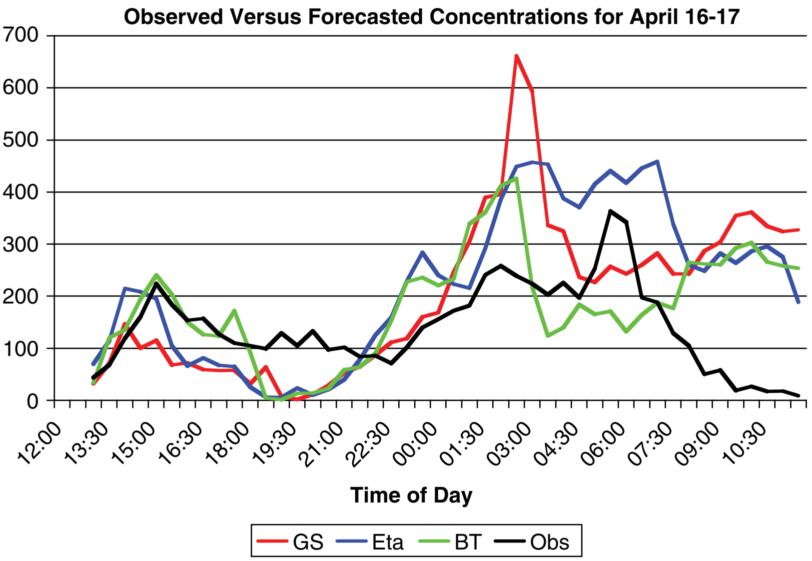


Fig. 13. Observed pollen concentrations at the St. Louis County Department of Health sampling site at Clayton, Missouri, and the forecasted pollen concentrations for the Gayno–Seamon, Eta and Burke–Thompson boundary layer parameterization schemes.

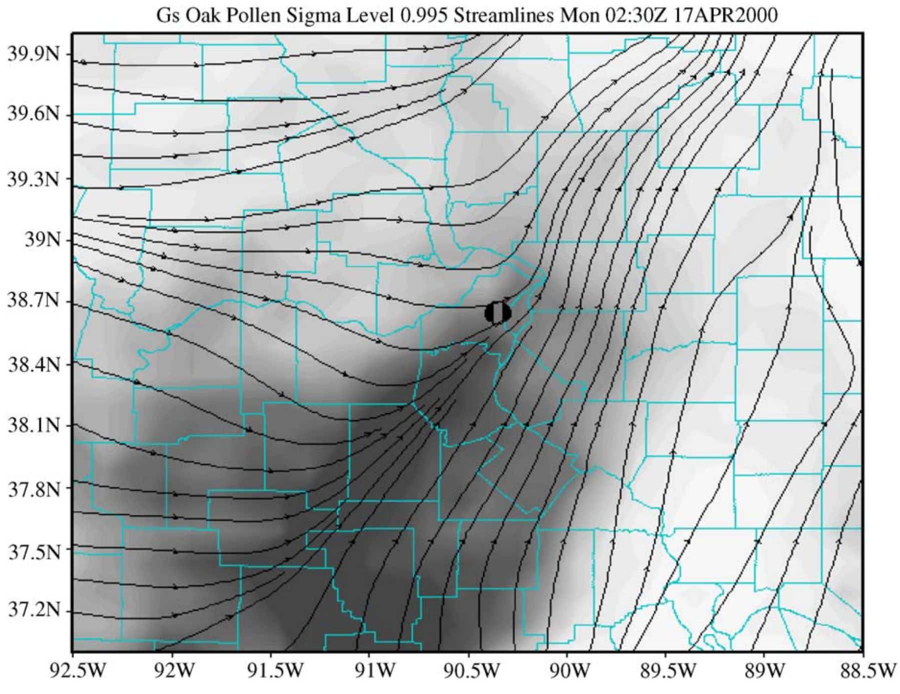


Fig. 14. 0230 UTC 17 April 2000 sigma level 0.995 streamlines from the Gayno–Seamon MM5/PSU model and HYSPLIT_4 pollen concentration at 38 m.

Acknowledgments

The authors and the Department of Earth and Atmospheric Sciences of Saint Louis University would like to thank the Saint Louis County Department of Health and specifically Dr. Robert Nicolleti and Wayne Wilhelm for their help and participation in this research. We would like to especially thank Wayne Wilhelm for arranging for the special collection period and for counting *Quercus* pollen on the resulting slides.

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