Development and testing of a module for estimating spatio-temporal dynamic pollen emission rates

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Abstract

Allergic diseases represent a complex health problem that is receiving increased attention. Europe has succeeded in unifying a network of 400 monitoring stations that share pollen counts through the European Aeroallergen Network (EAN) pollen database. Similarly, the emission and dispersion of particles of biogenic origin, such as aeroallergens, is getting an increasing interest. There is strong evidence supporting the hypothesis that in urban areas, the synergism of pollen and other air pollutants exacerbates respiratory diseases like asthma and allergic rhinitis. A prototype algorithm for simulating the emissions of allergenic particles originating from major tree families of the New York/New Jersey region was developed by extending the approach used for estimating biogenic gas emissions in the Biogenic Emission Inventory System (BEIS). A spatio-temporal vegetation map was derived from a number of different remote sensing sources. Ground level measurements of pollen levels were analyzed and correlated with environmental conditions in order to establish source strengths and the temporal extent of the pollen-shedding period. Photosynthetically Active Radiation (PAR), the absorbed fraction of radiation, which is a major indicator of the state and productivity of vegetation, was closely examined. A preliminary comparison of results derived from simulations utilizing the new pollen emission model is presented. Finally, a framework for aerobiological modeling applications is introduced and its advantages are discussed vis-à-vis the limitations posed by the lack of temporally resolved dynamic vegetation mapping and of a modern, automated pollen monitoring network for the US.

Introduction

The mechanism of dehiscence, the opening of the anthers or microstrobili and release of pollen varies in the different plant families. The released pollen grains are of irregular shape and diameter. They can hydrate and dehydrate and may even build up aggregates, due to a pollen kit present on their surface (entomophilous species). They have different densities, settling velocities, and their viabilities depend on the species, although they remain limited and mostly unknown (Treu and Emberlin, 2000). The concentration thresholds that cause allergic reactions for the patients also depend on the species. Pollen allergens are integral pollen constituents. They have to be released during a process of activation in order to become bioavailable (Behrend, 2001). The main pathway of exposure is through inhalation, while ingestion and dermal exposure are of lessen importance. The overall prevalence of seasonal allergic reactions in the upper respiratory system in Europe is estimated around 15%. Pollinosis accounts for at least 12 to 45% of all allergy cases.

Modeling of release, fate and transport of the pollen grains has gained interest due to the following reasons:

- The adverse health effects of the allergens can be reduced by pre-emptive medical measures. However, such planning efforts require reliable forecasts of the of both the duration and intensity of the pollen-shedding period. For this purpose, a number of monitoring networks have been deployed worldwide.
- Recent findings suggest that pollen grains found in urban aerosols may undergo chemical transformations, described by the mechanism of protein nitration, upon contact with pollutants such as nitrogen dioxide and ozone, and in this way acquire enhanced allergy-inducing properties (Franze, 2005).
- Furthermore, the increasing genetic manipulation of the plants leads to the problem of cross-pollination. To ensure purity of the plants, exact knowledge of the distances that can be travelled by pollen grains released by specific plant species is required.

Recent modeling approaches has be seen as separated in two tasks:

- Models that forecast the start and duration of pollen seasons. (examples: Latalowa et al., 2002;Groom-Adams et al., 2002).
- The numerical simulation of the spatial and temporal distributions of pollen grains. (example: Kawashima and Takahashi, 1999) .

Tree species	Significant allergen	Grain type	Size (μm)
Quercus (Oak)	Yes	3-colpate	22-36x19-39
Betula (Birch)	Yes	Prolate	18-34
Fraxinus (Ash)	Yes	Prolate	15-33
Acer (Maple)	yes	Spheroidal	22-26

Table 1. List of the tree species involved in this study based on their allergenic effect along with basic grain properties

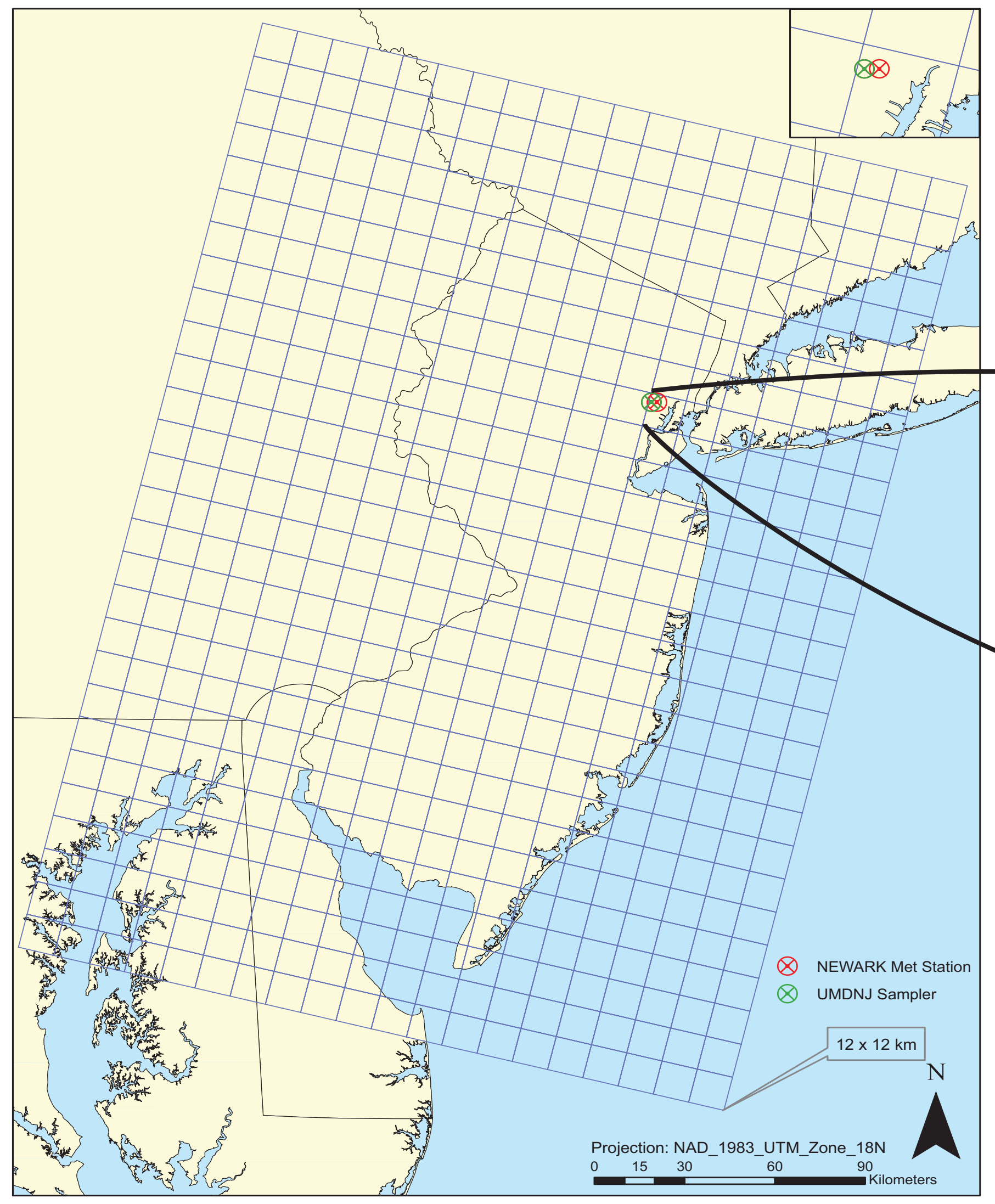
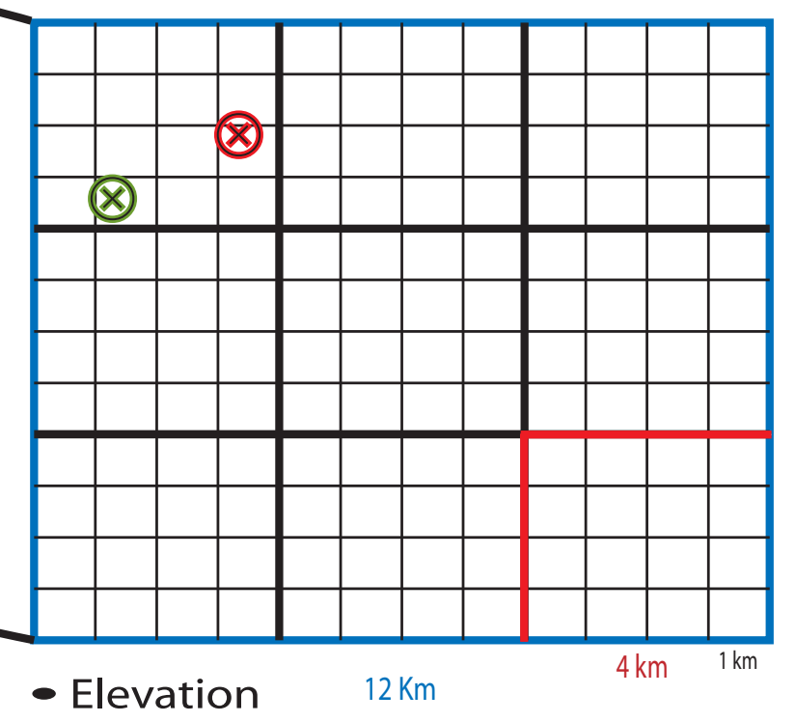


Figure 1. Georeferenced depiction of the extent and grid of the modeling domain used in this study



- Elevation
- Land Cover (BELD)
- DVI (MODIS)
- fPAR (MODIS)
- fPAR (MM5)
- LAI (MODIS)
- LAI (BEIS)
- Ground Level Temp. (MODIS)
- Ground Layer Temp. (MM5)
- Humidity
- Precipitation
- Wind Speed
- Wind Direction

Figure 4 List of the measured/modeled variables along with their higher (inner grids) and lower spatial resolution

Materials and Methods

The area of interest for our investigations is covering a portion of the Northeastern states with the focus being the metropolitan areas of New York, New Jersey and Philadelphia,as depicted in Figure 1. Pollen levels were monitored on a daily basis with the help of a Rotorod impaction sampler located at the roof of the UMDNJ clinique, in Newark, NJ for the years 1997-1999. The aerobiological significance of the area of interest was evaluated through the pollen counts, and the corresponding meteorology obtained from the Newark station for the same period. From the resulting figures,we can verify the effect of the increasing temperature on the start of the pollen period, as well as the removal process that is initiated by precipitation. Since there is no information on the tree species or grain size distributions, the compilation of a region-representative pollen cocktail was the initial step for identifying the potential sources within the domain. The resulting Table 1, shows the most significant allergenic tree species for the Northeast , a compilation of particle specificparameters, and the corresponding allergy test availability. The common pollen-shedding period for trees in the domain starts in March and ends usually in May (Figure 2).

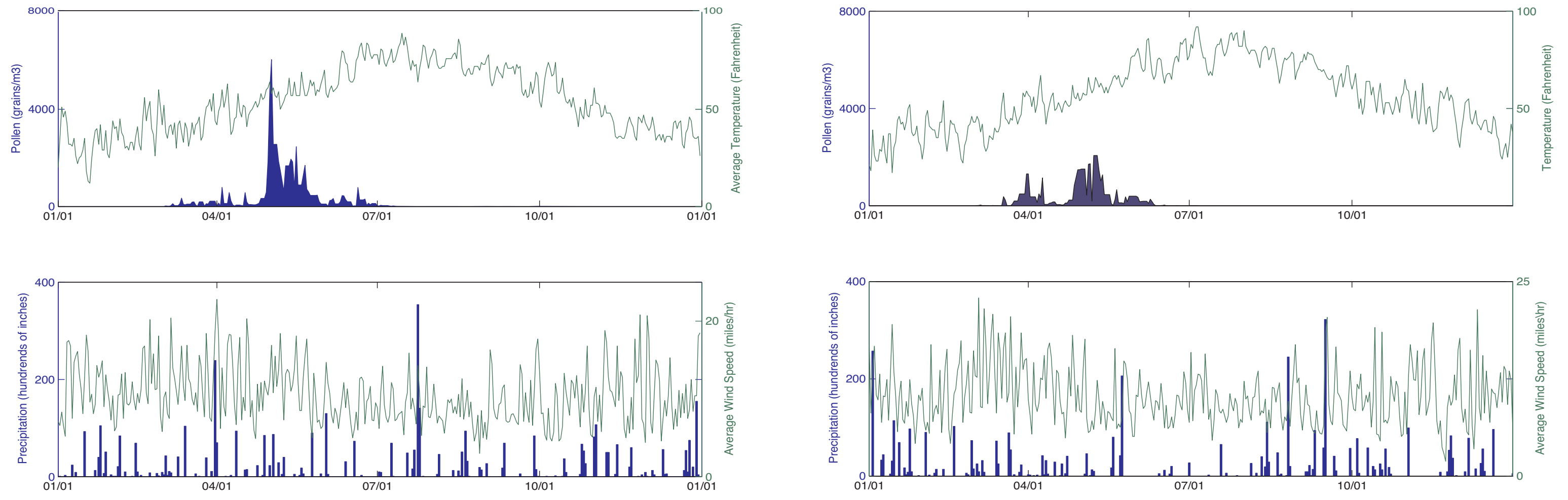


Figure 2. Pollen counts for the years 1997 (LEFT) and 1999 (RIGHT),plotted against average temperature, average windspeed, and mean daily precipitation

$$F_p = \frac{c_p \times K_m \times P_{tot} \times u \cdot}{LAI \times h_c}$$

where:

F_p is the pollen flux in grains /m^2 / sec

c_p a plant-specific factor that describes the likelihood to bloom

K_m is a meteorological adjustment factor

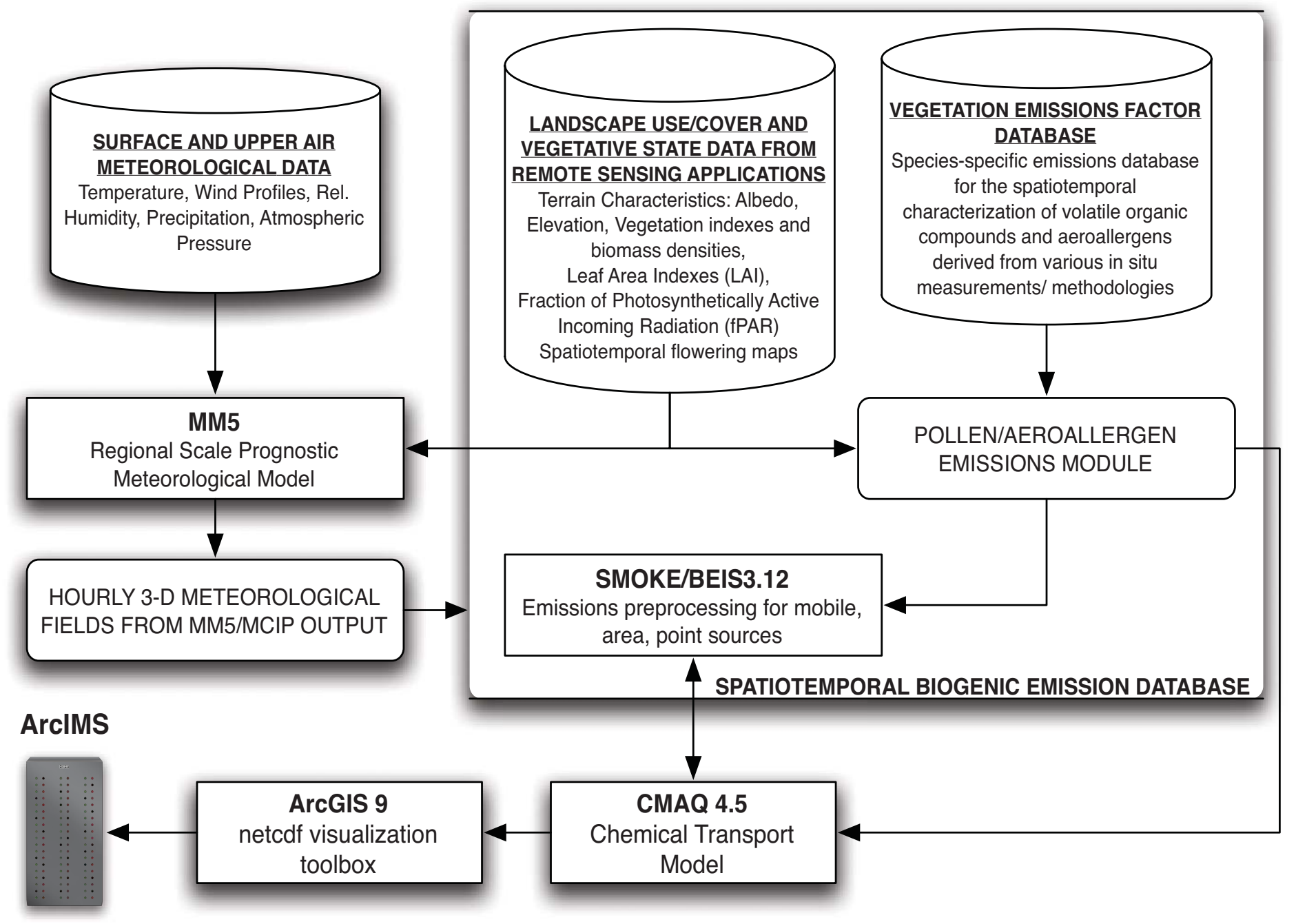
P_{tot} is the species-specific total annual maximum pollen grains released

u is a characteristic velocity in m/s

LAI is the Leaf Area Index

h_c is the height of the canopy (m)

Equation 1 A basic equation for estimating tree pollen.fluxes (species specific, modified from Helbig et al., 2004).



SURFACE AND UPPER AIR METEOROLOGICAL DATA
Temperature, Wind Profiles, Rel. Humidity, Precipitation, Atmospheric Pressure

LANDSCAPE USE/COVER AND VEGETATIVE STATE DATA FROM REMOTE SENSING APPLICATIONS
Terrain Characteristics: Albedo, Elevation, Vegetation indexes and biomass densities, Leaf Area Indexes (LAI), Fraction of Photosynthetically Active Incoming Radiation (fPAR) Spatiotemporal flowering maps

VEGETATION EMISSIONS FACTOR DATABASE
Species-specific emissions database for the spatiotemporal characterization of volatile organic compounds and aeroallergens derived from various in situ measurements/ methodologies

MM5
Regional Scale Prognostic Meteorological Model

POLLEN/AEROALLERGEN EMISSIONS MODULE

HOURLY 3-D METEOROLOGICAL FIELDS FROM MM5/MCIP OUTPUT

SMOKE/BEIS3.12
Emissions preprocessing for mobile, area, point sources

SPATIOTEMPORAL BIOGENIC EMISSION DATABASE

ArcIMS

ArcGIS 9
netcdf visualization toolbox

CMAQ 4.5
Chemical Transport Model

Figure 3 Overview of a simplified modeling network for emission and transport of pollen grains within the MM5/BEIS/CMAQ environment.

Parameterization of the emission flux

The starting point for the most of the pollen modeling approaches is the maximum pollen grains in one season produced from one plant species. Molina (1996) determined the number of pollen grains from 10 different plant species. However, pollen grain numbers were given per branches, trees, or crown diameters. Pollen production is supposed to depend on different factors, such as the climate of the preceding year, vernalisation, or simply on biological rhythms (Stanley and Liskens, 1974). Several authors have documented that the emission depends strongly on meteorological conditions, the resulting product of which is has a diurnal cycle. A common term that has been used in other studies, is the escape fraction of pollen from the canopy. The vertical flux of the pollen grains is proportional to a characteristic concentration of pollen (Equation1). Here, the Leaf Area Index (LAI) and the canopy of the height should be the limiting factors of the area source term. A metorological adjustment factor was applied with parameterizations resulting from recent methods developed for dust transport (Lu and Shao, 2001). For activating the saltation process, a modified threshold friction velocity was used. A meteorological coefficient takes into account threshold meteorological values that control the release.

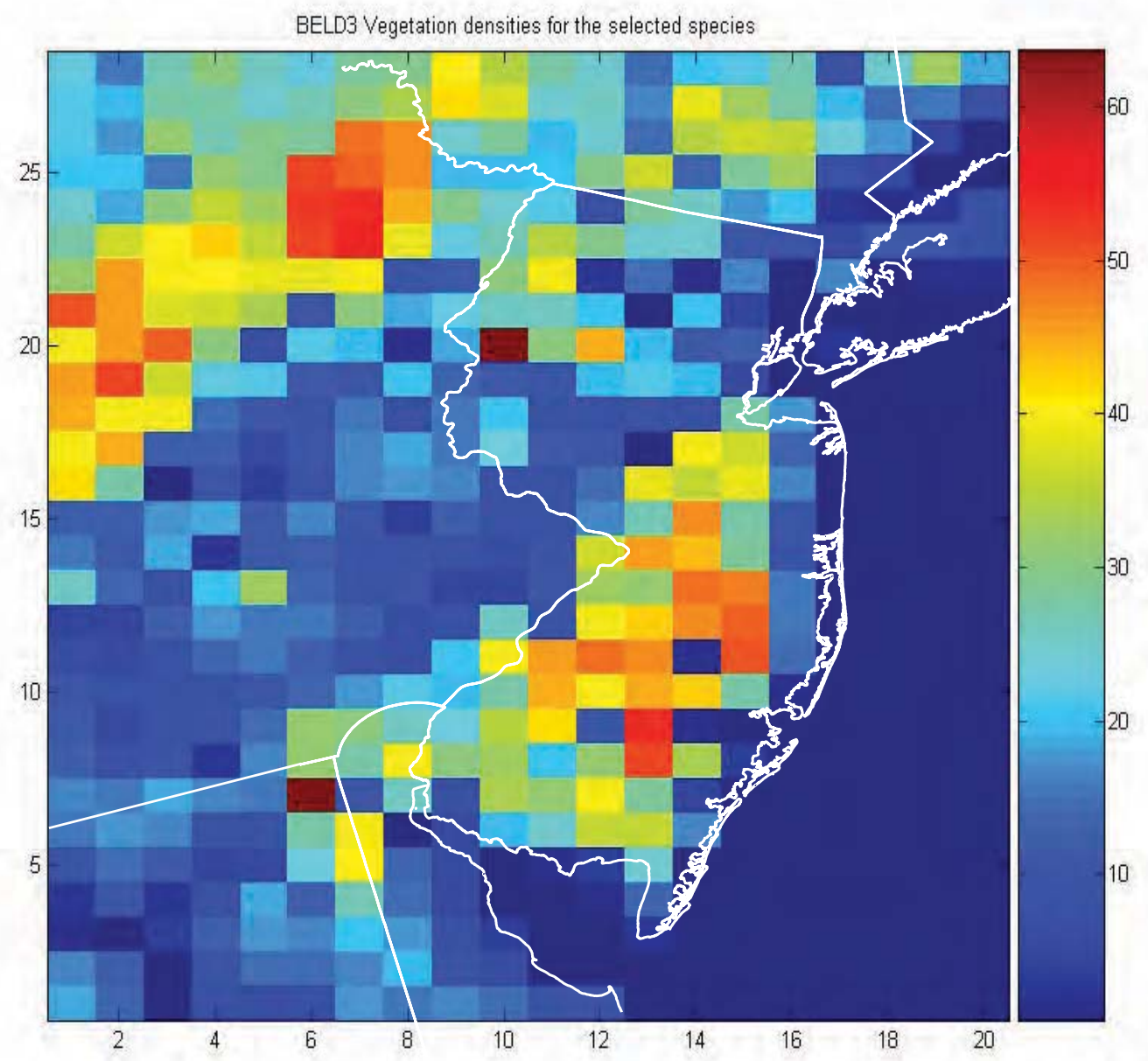


Figure 4a Aggregated densities of the allergenic tree species of interest for this study (source:BELD)

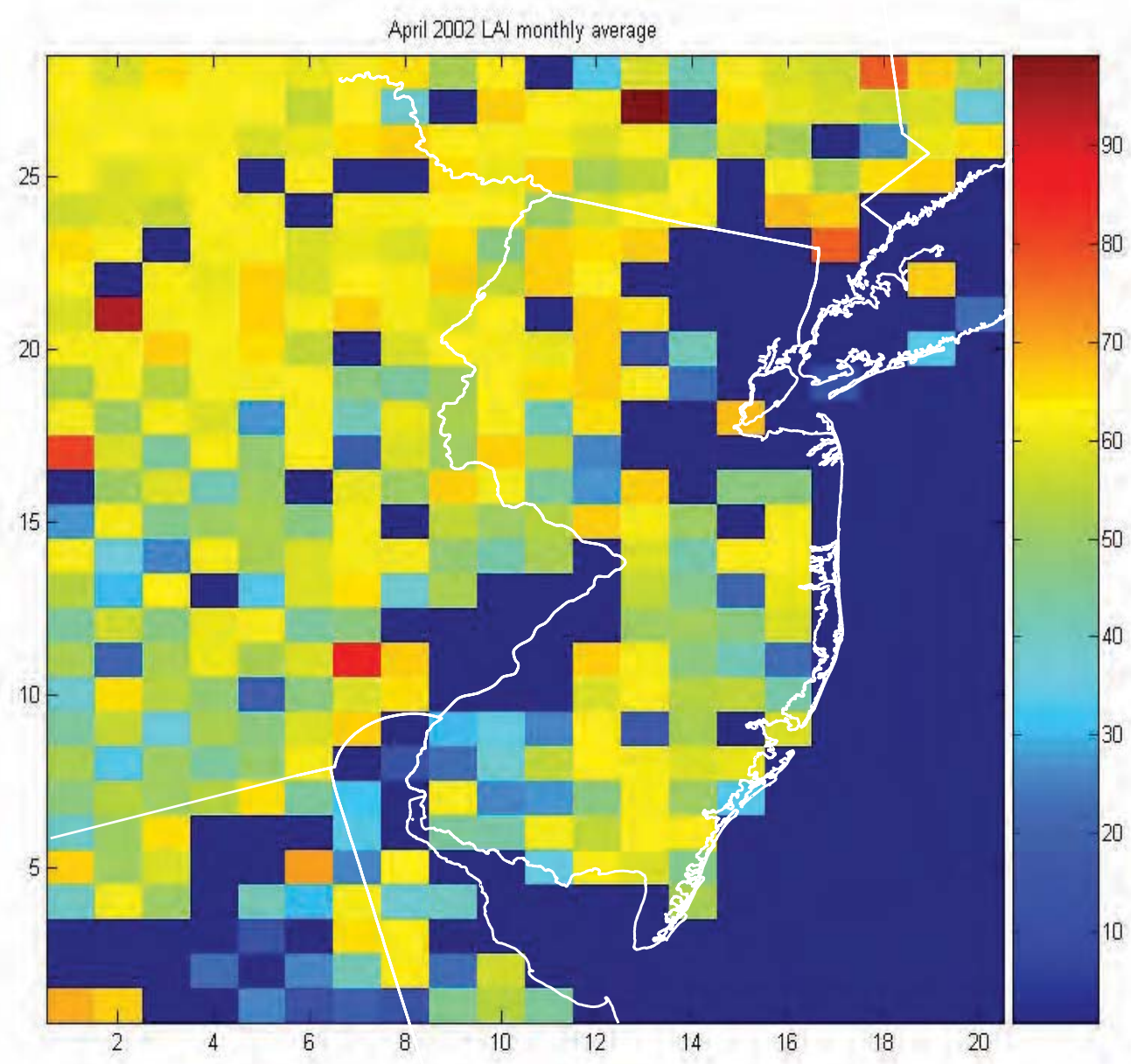


Figure 4b MODIS/Terra instrument product showing the Leaf Area Index (LAI) averaged for the month of April 2002

Results

Coupling with MM5 and high resolution remote sensing products

A major portion of this preliminary work has been spent in order to make the best of the possible use of the proposed framework depicted in Figure 5. Meteorology obtained from the MM5 model was used for the month of April of 2002. A same month Leaf Area Index 2-granule dataset from the MODIS instrument was also processed and used in conjunction (Figure 4b). This product provides satellite information on the fraction of Photosynthetically Active Radiation (fPAR) that can be easily used as an adjustment of the incoming radiation fraction coming from the processed MM5, used in BEIS3.12 with a correction factor of 0.45. The variables passed through the module are also listed with respect to the spatial resolution as shown in the grid cell (Figure 4).Spatial limitations of the 12Km grid were not taken into account, since such small domains are more efficient for such initial experimentations with the parameterization of the module. A dynamic pollen emission map relating from one timestep ofthe calculations performed on hourly basis, is given in Figure 6a. In this figure, we still are at the beginning of the pollen period and the strength of the source is at its maximum. As we can see from the graph 6b, the source is gradually emitting less pollen in the atmosphere above the canopy. Such daily profiles are typical for tree pollen but not for particles produced by weeds and grasses (Helbig et al., 2004).

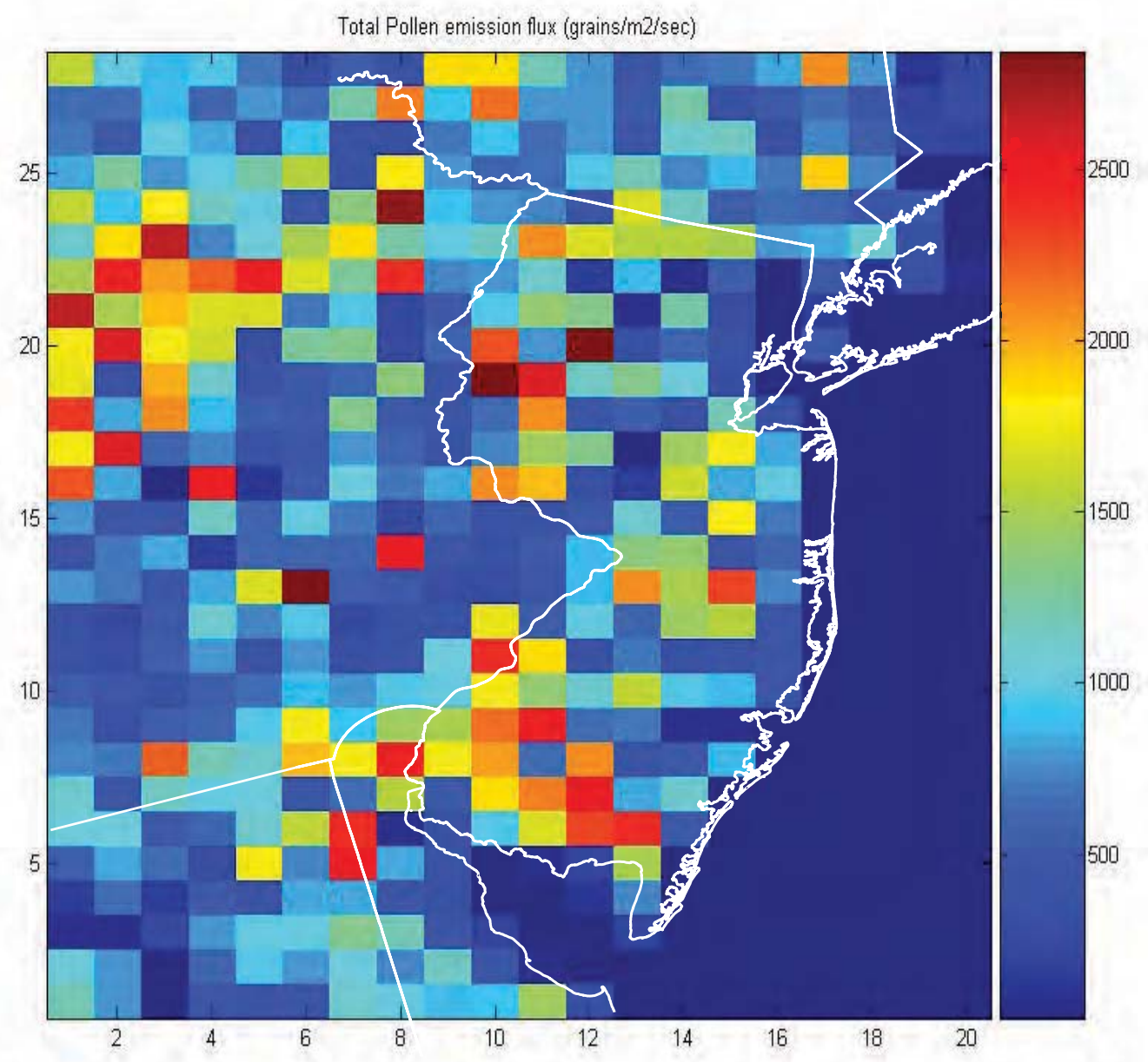


Figure 6a. Emission flux distribution for the total pollen released by the 4 species of interest

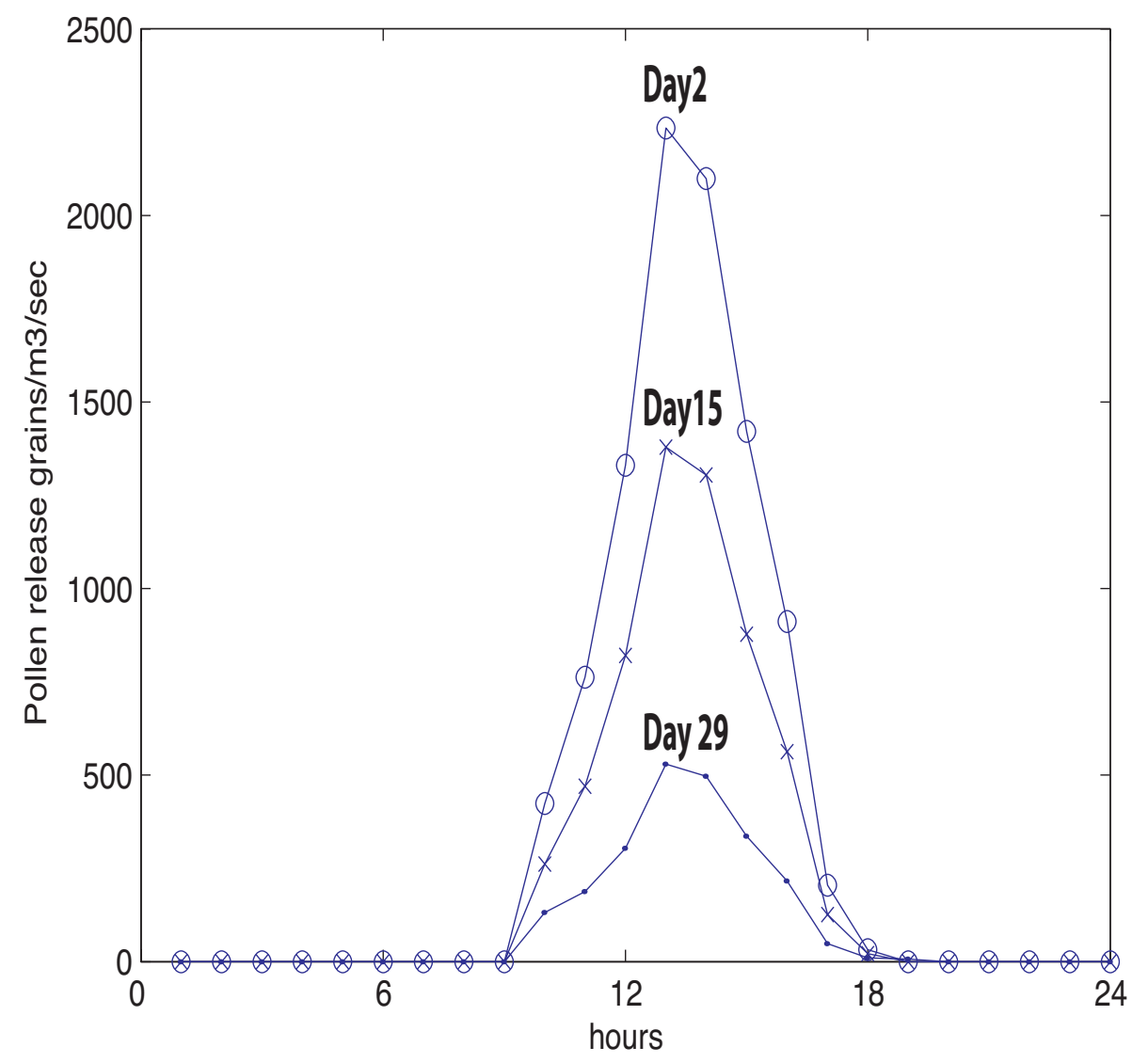


Figure 6b. Daily temporal profile of the emission flux for the single cell that includes the meteorological station and pollen sampler

Future Work

A set of parameterizations was developed or adopted for this work, in order to be proposed for future usage in three dimensional dispersion models. The area that was carefully investigated is the emission algorithns, and an inital attempt was made to include the resuspension mechanism of pollen.The improvements of this module involve the incorporation of a more detailed spatio-temporal flowering map and the better usage of vegetation remote sensing products to evaluate and improve the performance of the algoritm. Coupling the model with satellite observations, showed potential appication in evaluating the MM5/BEIS output, while at the same time it revealed certain areas of uncertainty. Experience showed that there is a need for several kinds of input data to forecast the pollen grain number density in the sense of daily numerical weather forecast. The most important data are pollen production, pollen grain properties (e.g. settling velocities, viabilities, densities, diameters) and plant specific threshold meteorological values.

The future tasks of this study involve:

- Incorporate pollen hourly emissions in the CMAQ model and evaluate the ISORROPIA scheme for the processes involved in the treatment of particulate matter
- Perform simulations with higher spatial resolution to better encapture both the emission and dispersion of pollen
- Study the improvement of a such a module for estimating critical parameters used also in the BEIS code for BVOC calculations (fPAR,LAI).

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