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VR: leading the project, work with the SILAM system, and manuscript writing; OP: pollen count during the years 2009–2016; OT: data processing, maps of Ukraine, manuscript editing and suggestions on its improvements; OY: the idea of the manuscript, manuscript translation into English and suggestions on its improvements after the translation, data processing

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ORIGINAL RESEARCH PAPER

Modeling hay fever risk factors caused by pollen from *Ambrosia* spp. using pollen load mapping in Ukraine

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Abstract

The paper provides a simulation of the occurrence of *Ambrosia* pollen in Ukraine both in terms of a determination of the regions with high pollen concentrations and the time when the high pollen load occurs. Simulation was performed using the SILAM system and the following pollen mapping using the Grid Analysis and Display System. Simulation results were compared with the aerobiological data available from six monitoring stations in Ukraine. A decrease in the concentrations of *Ambrosia* pollen, the duration of the *Ambrosia* season, and patient exposure to the *Ambrosia* pollen were apparent from SE to NW of Ukraine. A close correlation between the modeled and actually registered pollen concentration values and ragweed pollen release periods was observed in all the cities for which the *Ambrosia* pollen monitoring data had been collected. Further investigations are required to provide accurate forecasts for other types of airborne allergens.

Keywords

ragweed pollen allergy; pollen load; pollen mapping; modeling

Introduction

Over the last 50 years, there has been a steady increase in the prevalence of allergic diseases in industrialized areas. Among adults of all ages, allergic diseases, including asthma, are the fifth most common chronic disease in the USA, whilst among children under 18 years old, they rank third [1]. Allergy affects 20%, or more than 150 million, of the European population, thus, being the most frequent chronic complaint [2]. According to some estimates [3], every second inhabitant of Europe regardless of their age, social position, or geographical location is expected to suffer from allergy symptoms by 2025 if the allergy epidemic is not checked. Presently, 40–50% of children of school age are estimated to be sensitized to one or more common allergens [4]. In 2012, respiratory allergies in the past 12 months were reported in 10.6% or 7.8 million children in the USA [5].

Agents of indoor and outdoor environments can cause respiratory allergy, in particular the seasonal type of allergy which is provoked by airborne pollen and spores and is popularly known as "hay fever". In addition, seasonal allergy is considered to be the main risk factor for asthma development in patients [6,7].

Plants of the genus *Ambrosia* (ragweed; Asteraceae) are a well-studied source of highly allergenic pollen [8], which is known to trigger development of allergy symptoms in the population in southern and eastern regions of Ukraine [9,10]. *Ambrosia* pollen grains have a prickly surface; they can easily penetrate and stick to the mucous membrane of the nasal cavity, swell and release the allergenic agents [11].

Ambrosia spp. have been introduced into Ukraine along several pathways and in different periods. A German pharmacist, Kricker, was known to grow ragweed in the Dnipropetrovsk region (SE of Central Ukraine) as a medicinal plant (a quinine substitute and an anthelmintic) in 1914 [12]. In the Kyiv region toward the north of the country, the first detection of ragweed was reported in 1925. Furthermore, the Volunteer Army brought *Ambrosia* spp. along with alfalfa seeds to the eastern regions of Ukraine during the Russian Civil War of 1918–1920. Afterwards, the weed spread to the Zaporizhia, Donetsk, and Lugansk regions. The next recorded introduction occurred when ragweed was unintentionally imported to the USSR from the United States in the first shipment of wheat in 1946. Once ragweed is introduced to a territory, it keeps spreading and contaminating ever-larger areas. Today, the presence of this allergenic weed (predominantly *A. artemisiifolia* L.) is noted in each of the 25 administrative regions of Ukraine [12]. Two other species, *A. aptera* DC. and *A. trifida* L., are also found in Ukraine [13].

In 2013 (the last year for which statistical data provided by the State Veterinary and Phytosanitary Service of Ukraine is available), the total area of land contaminated with ragweed was 31.5 times larger than in 1973 – 3,523,138.442 ha and 107,600 ha, respectively. The eastern parts of Ukraine are the most affected. According to the State Veterinary and Phytosanitary Service of Ukraine, the largest infested areas are recorded in Donetsk (1,016,796.04 ha), Zaporizhia (838,835.22 ha), Mykolaiv (813,406,318.3 ha), Kherson (288,763.88 ha), Kropyvnytskyi (former Kirovohrad) (276,334.67 ha), and Dnipropetrovsk (193,721.79 ha) regions (oblasts). As a rule, ragweed expands from the southern and eastern parts of Ukraine in a northwesterly direction. Seed dispersal occurs through transport along railways and roads by vehicles and agricultural equipment, as well as by contaminating crop seeds, for example, sunflower seeds which are shipped for planting from the steppe ecoregion to the forest-steppe of Ukraine [12].

The highest levels of airborne *Ambrosia* pollen in Europe are known to be recorded in France, Northern Italy, the Pannonian Plain, and Ukraine [14,15]. Mean values of atmospheric *Ambrosia* pollen tend to decrease away from these centers. High levels of atmospheric *Ambrosia* pollen have also been recorded in the Black Sea region of Turkey and Georgia [16,17]. Significant increases in the amount of airborne *Ambrosia* pollen tend to be in the areas considered to be at the forefront of *Ambrosia* expansion, such as Nevers in France and Salgótarján in Hungary [18–20]. Significant increases of ragweed pollen have also been noted in Lithuania in recent years [21,22].

It has been predicted that the future distribution of invasive weeds and the abundance in the area is affected by climatic conditions [22]. It is also accepted that allergic symptoms in people intensify due to climate change [23,24], and are due to the increases in pollen concentration and allergenicity (consequently its impact on the human body) related to higher average temperatures that extend the pollen release period for particular allergenic plants [24,25]. Processes associated with global warming cause changes in the boundaries of areas populated by plants that release potentially allergenic pollen, which in turn leads to the appearance of previously unseen aeroallergens over new territories. Pollen of the invasive species that are not common in the pollen spectrum of a certain area is an additional major factor for the increase in pollen allergy cases [26]. Another significant challenge of modern aerobiology is monitoring of areas invaded by nonindigenous plant species as well as tracking the trajectory of atmospheric transport of pollen grains and spores to a certain area from neighboring territories [27]. Thus, it is of vital importance not only to determine the species composition and concentration levels of pollen allergens, but also to predict the spread of potentially hazardous invading species into a given area.

According to data from the International Study of Asthma and Allergies in Childhood (ISAAC), Ukraine and Great Britain are ranked at the top among the European countries by prevalence of allergic symptoms [28]. The statistical data show that >25% or 10 million of Ukrainians suffer from allergic diseases. Annual healthcare costs for allergy treatment in Ukraine exceed 10 billion UAH [29]. The Vinnitsa region is amongst the areas in Ukraine with the highest level of allergic rhinitis. Asthma morbidity also appears to be on the increase in this country [6].

There are no cures for allergies. They can only be managed with proper prevention and treatment [30]; that is why the problem of allergy prevention by avoidance of contact with known allergens is one of the most important for developing allergy treatment strategies and healthcare provision [31]. In view of this, both the spectra of airborne allergens in a region and possible routes of pollen transport with air masses during the pollen release period should be taken into consideration [32,33]. Modeling of pollen release seasons is a further powerful tool available to make allergy symptoms prevention more effective. Various models used in aerobiology allow predicting the distribution of species and their pollen for a few years ahead [27,34].

Since ragweed pollen is an important seasonal allergen in Ukraine [35], it is necessary to monitor the dates of onset and duration of ragweed pollen release season in this country. Pollen monitoring is important for providing an early warning of the expansion of this invasive and noxious plant [22]. On the other hand, the season for *Ambrosia* spp. pollen release can be modified by processes associated with climate change [36]. Whilst new climatic conditions and anthropogenic activity affect both human health and plant pollen release time, it is a major task to prevent the hay fever symptoms in the current environment. Thus, the aim of this study was to examine the change in ragweed pollen release pattern in Ukraine over the last decades and simulate the possible temporal and spatial variations in seasonal ragweed pollen load in Ukraine to help in the control of hay fever.

Material and methods

Sampling sites

Air sampling was performed by the volumetric method over the period of 2009–2016 in the city of Vinnytsia, which is situated in the forest-steppe ecoregion in Central Ukraine. In 2010, air monitoring data were also gathered for the metropolitan areas of Odesa, Simferopol, Donetsk, Dnipropetrovsk, and Poltava.

Data collection and pollen analysis

Air samples were collected with a Burkard spore and pollen trap (Hirst type) in all cities. Sampling of airborne pollen was conducted daily from the 1st of March until the 31st of October in all the sampling sites and throughout all the years under observation. The samples collected were delivered to Vinnytsia for microscopic analysis and were analyzed at 400× magnification with an optical microscope (LM) by the method of three horizontal transects (years 2009–2011) or 12 vertical transects (years 2012–2016).

The analysis of seasonal patterns of ragweed pollen distribution – in particular, the onset and end dates of the pollen release season as well as peak concentrations – was conducted using the statistical tools of European Aeroallergen Network (based in Vienna, Austria). The Vinnytsia air monitoring station has been an EAN registered user and supplier since 2009.

The complex model of ragweed pollen dispersal was designed on the basis of the System for Integrated modeLling of Atmospheric coMposition (SILAM) in collaboration with the Finnish Meteorological Institute (Helsinki) where this system was developed [37].

The development of the model for *Ambrosia* is based on a double-threshold temperature sum model that describes the dynamics of the flowering season and is analogous to the thermal time models employed to predict the onset and duration of flowering. Another parameter considered whilst modeling the *Ambrosia* pollen release season is the duration of daylight; ragweed is a short-day plant, thus, it begins flowering when the day length shortens and the photoperiod is about 14.5 hours.

The model was used to simulate the invasion of *A. artemisiifolia* in Europe. The simulation takes into account the climate suitability (temperature during the vegetative season, annual variations in dormancy-breaking temperature, available moisture, etc.), transport and dispersal of seeds from infested areas, suitability of land use for ragweed propagation as well as quarantine measures aimed at controlling the spread of the plant. The accuracy was calibrated against the actual pollen concentration data obtained in Ukraine [38]. Further processes covered in SILAM include the full life cycle of pollen in the atmosphere after it is released into the air by transport with air masses, turbulent mixing and removal by the processes of dry and wet deposition.

Results of modeling were visualized using the pollen mapping tools of the Grid Analysis and Display System. Simulation results were compared against data of aerobiological investigations available for six monitoring stations in Ukraine. To develop the maps of Ukraine, a scale of 1:10,000,000 was adopted as being optimal for general mapping of the country territory.

Results

The analysis of the ragweed pollen release season in Ukraine revealed that *Ambrosia* releases the pollen from the mid-July (start date varied from July 12 to August 8) to the end of October, with peak intensity from mid-August to mid-September (the earliest peak date was recorded on the August 13, 2010 and the latest on September 18, 2012 in Vinnytsia) (Fig. 1). In general, the affected areas indicated on the map created for the year 2010 (Fig. 2) correlate well with the ragweed infested regions of Ukraine. This year was used for mapping and further model calibration, and it represents the most complete database for Ukraine. Based on the SILAM simulation, a ragweed season map was created showing the total seasonal pollen load to which the population of Ukraine is exposed. (Fig. 3). This is the first map that shows the aero-palynological parameters of the *Ambrosia* pollen release season and the potential impact on human health in Ukraine.

The highest pollen load of 10,000–30,000 pollen grains/m^3 per season was characteristic of the central and southwestern parts of Odessa and the northern parts of Mykolaiv and Kherson. The majority of the population in SE Ukraine is subjected to the total pollen load of 3,000–10,000 grains/m^3 per season. The edge of this area approximately corresponds to the boundary of the steppe ecoregion of Ukraine. In the forest steppe, the total *Ambrosia* pollen load was 1,000–3,000 grains/m^3 per season and in the forest ecoregion, 300–1,000 grains/m^3. The population of Eastern Ukraine is exposed to higher concentrations of ragweed pollen grains in the northern part of Ukraine (Fig. 3).

The data presented in the map can help in prevention and treatment of seasonal allergy symptoms among sufferers in this country, and it has been regularly utilized to create allergy forecasts for inhabitants. In addition, the SILAM simulation to estimate the total seasonal load was also employed to calculate the 10-day mean pollen grain

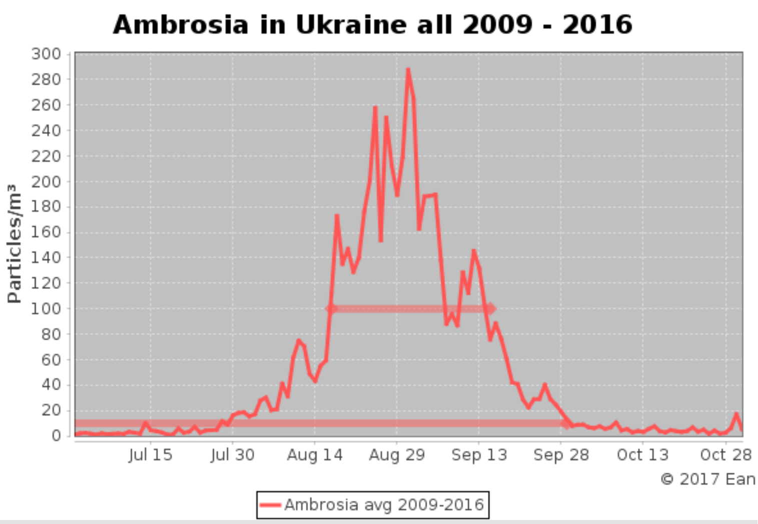

Fig. 1 The average ragweed pollen season in Ukraine based on the data from all the monitoring sites, 2009–2016.

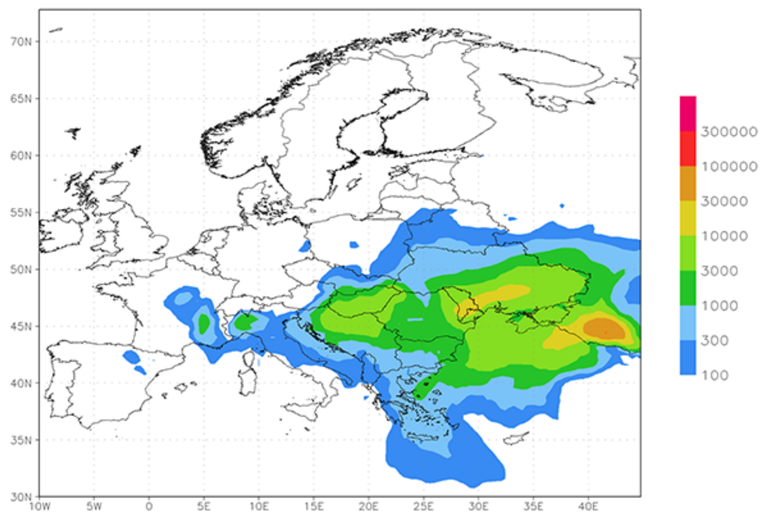

Fig. 2 The total seasonal *Ambrosia* pollen load in Europe (grains/m³).

Fig. 3 The total seasonal *Ambrosia* pollen load in Ukraine (grains/m³). Red triangles denote pollen traps locations.

concentration for each of the months of ragweed pollen release season in Europe. It predicted that the highest 10-day mean ragweed pollen count for the period from August 21 to 31, which closely correlates with the actual pollen concentration registered for Ukraine.

The highest *Ambrosia* pollen concentrations during study period were characteristic for the Odessa, the central part of the steppe ecoregion. This high concentration belt closely corresponds to the territory for which the highest seasonal ragweed pollen load was recorded in Ukraine (Fig. 2).

On the basis of the SILAM maps for Europe (Fig. 4), the map of the mean *Ambrosia* pollen load during the peak pollen release intensity was created for Ukraine (Fig. 5), which also enabled the development of more informed and effective preventive measures and treatment of ragweed pollen allergy. Simulation demonstrated, that ragweed pollen levels remained significant during the following 10 days – from August 31 to September 10 in the air over Europe (Fig. 6), as it is characteristic for Ukraine (Fig. 1). The mean pollen load in the south of Ukraine was lower than in the previous 10 days and comprised 300–1,000 grains/m³ (Fig. 6). However, the overall area with ragweed pollen load of 300–1,000 grains/m³ increased encompassing the southern, eastern, and central regions of Ukraine (Fig. 7).

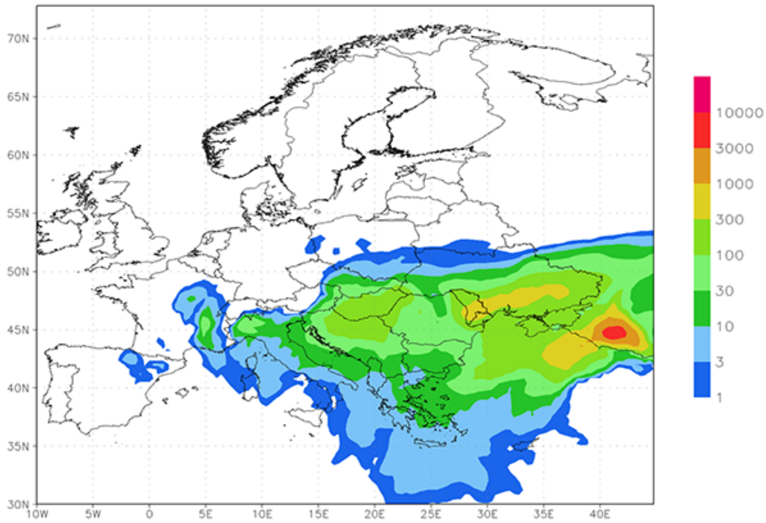

Fig. 4 The mean ragweed pollen load during the peak intensity period from August 21 to 31, 2010 in Europe (grains/m^3).

Fig. 5 The mean *Ambrosia* pollen load affecting the population of Ukraine during the peak intensity of pollen release from August 21 to 31, 2010 (grains/m^3). Red triangles denote pollen traps locations.

In order to generalize and visualize the timing of periods with pollen counts that exceed the clinically determined threshold concentrations for triggering allergy symptoms, the ragweed season maps of different seasonal indicators were created. They represent the number of hours during which the *Ambrosia* pollen release intensity was higher than a certain threshold level. The concentration of 10 pollen grains/m^3 was used as the threshold value of ragweed pollen sensitization. That corresponds to the recorded threshold concentration level known to trigger hay fever symptoms among the affected population in Ukraine [23].

The map clearly shows the SE–NW gradient of the total pollen release period of 900 hours (38 days) or more in the most heavily contaminated regions in SE Ukraine. In Odessa, this period lasts more than 1,100 hours (46 days) per season. In Ukraine in general, the map reveals a succession of 11 belts (from SE–NW) with periods of pollen concentrations above the threshold level ranging from >50 to >1,100 hours (Fig. 9).

A close correlation between the modeled and actually registered pollen concentration values and ragweed pollen release periods was observed in all the cities for which the air monitoring data had been collected. For Vinnytsia, for example, the simulation

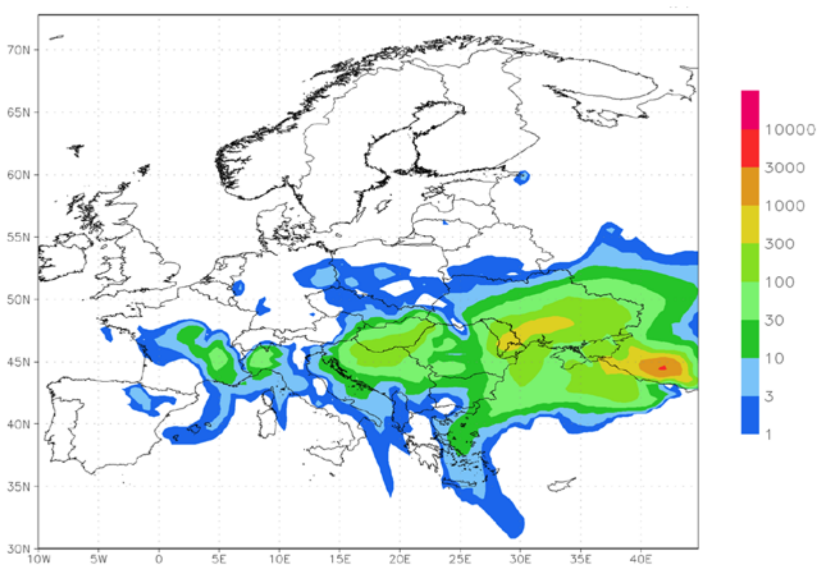

Fig. 6 The mean ragweed pollen load during the peak intensity period from August 31 to September 10, 2010 in Europe (grains/m³).

Fig. 7 The mean *Ambrosia* pollen load affecting the population of Ukraine during the peak intensity of pollen release from August 31 to September 10 (grains/m³).

predicted 700–800 hours of pollen concentrations above the threshold level. The recorded value comprised 744 hours per season (Tab. S1).

Discussion

Ambrosia pollen is considered to be an important allergen in many European countries [22,39,40]. Ragweed pollen mapping is essential for the prediction of allergy risk symptoms in any particular territory [41,42]. Symptoms of patients are often predicted using self-reporting data, which are based on self-assessment and so do not involve data on possible pollen sources and pollen transport [10,43,44].

Maps for the countries, showing the pollen load at different times of the season are scarce. The inventory maps are available at present for Europe mostly at continental scale [15,18–20,38,45]. Available ragweed inventory mapping data for the USA is obsolete

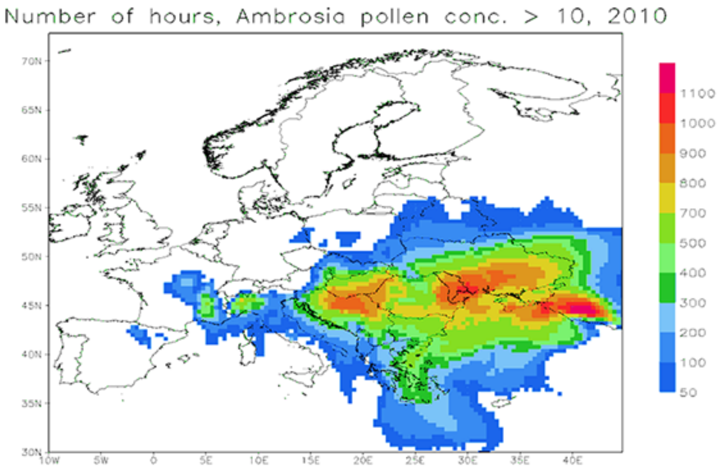

Fig. 8 The ragweed pollen release period (hours/season) with concentrations above the clinically relevant threshold level of 10 pollen grains/m³ in Europe.

Fig. 9 The ragweed pollen release period (hours/season) with concentrations above the clinically relevant threshold level of 10 pollen grains/m³ in Ukraine.

[46] and current forecasting is based on the comprehensive analysis of the ragweed pollen season there [47]. The modeled maps that we obtained in the current study became the basis for the creation of accurate allergy forecasts regarding potentially hazardous airborne ragweed pollen counts over the territory of Ukraine. The result of a SILAM simulation performed in order to determine the parameters of *Ambrosia* maps demonstrates that the model closely reproduces the main pollen release season of *Ambrosia* in the regions of Ukraine where ragweed colonies are well established (Tab. S1). As well as for ragweed, similar maps were modeled for birch and grasses, which together make up the group of three most dangerous airborne pollen allergens affecting the population of Ukraine.

Allergy forecasts, which are provided for their users for free, are published annually by the Vinnytsia Aerobiology Scientific Research Group on the EAN website http://polleninfo.org from March to October with weekly updates. Now, the content is available on the Ukrainian page of the EAN database [48].

Updates of pollen maps are constantly available on the EAN website, but with climate change, both pollen load and inventories may vary over the time [49]. *Ambrosia* pollen data, obtained in Ukraine, is constantly used by SILAM modeling system to calibrate and improve simulation accuracy [50].

Conclusions

- Modeling can be a powerful tool for assessing a potential allergen load over a given area and its results proved to correspond closely to actual data available from field observations.
- Simulation based on real data of air monitoring is indispensable for modeling the pollen load for a territory with an insufficient spatial coverage of pollen monitoring sites and it is accurate enough to predict the hay fever risk for any area at a given time period.
- Further investigations are required to provide accurate forecasts for more types of airborne allergens.

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Supplementary material

The following supplementary material for this article is available at http://pbsociety.org.pl/journals/index.php/aa/rt/suppFiles/aa.1742/0:

Tab. S1 Modeled and observed data of ragweed pollen release in Ukraine, used for mapping.

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Modelowanie czynników powodujących ryzyko wystąpienia alergii wywołanej przez pyłek *Ambrosia* spp. za pomocą metody mapowania.

Streszczenie

W pracy przeprowadzono symulację występowania pyłku *Ambrosia* spp. na terytorium Ukrainy wykorzystując dane dotyczące wysokiego stężenia pyłku *Ambrosia* spp. oraz okresu trwania sezonu pyłkowego. Prognozowanie przeprowadzono wykorzystując system SYLAM oraz mapowania za pomocą systemu GrADS. Wyniki symulacji porównano z danymi aerobiologicznymi uzyskanymi z 6 miast zlokalizowanych na terenie Ukrainy. Obniżenie stężenia pyłku *Ambrosia* spp., oraz skrócenie okresu narażenia pacjentów na alergeny pyłku notowano w kierunku od północnego wschodu do południowego zachodu. W przypadku wszystkich miast wystąpiła ścisła zależność pomiędzy wartościami modelowymi a rzeczywistą koncentracją pyłku *Ambrosia* spp. oraz czasem trwania okresu pyłkowego. Konieczne są dalsze badania w celu precyzyjniejszego przewidywania występowania alergenów w powietrzu.