



Ragweed pollen observed in Turkey: Detection of sources using back trajectory models

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ABSTRACT

This paper discusses the pollen season and the source apportionment of ragweed (*Ambrosia*) grains detected in the atmosphere of Istanbul, Turkey. The dynamic migration of this invasive taxon is a serious environmental issue. Ragweed pollen is highly allergenic and causes sensitization in patients at low concentrations. At present, there is no floristic evidence of this taxon in the region. Aerobiological records presented here, though, indicate a local source. Moreover, we argue that ragweed pollen comes from distant sources through air mass movements. The analysis concerns the ragweed season 2007. Pollens were sampled with a Burkard trap and identified at a magnification of 400 $\times$. Grains were counted on 12 transverse traverses to estimate bi-hourly changes in concentrations. The peak day was on August 28 with 20 grains m⁻³. Ragweed was observed on 22 days during August and September 2007. On all days, except one, the daily average concentration was below 10 grains m⁻³. Diurnal bi-hourly ragweed concentrations reached a maximum at 11:00 EET. Relatively high concentrations were observed between 21:00 and 01:00 EET. This allowed for the assumption of a local and a remote ragweed pollen source. We used HYSPLIT backward trajectory ensembles to identify possible sources on peak day. A frequency analysis of back trajectories covering the entire ragweed season followed. Firstly, possible local sources were the Istanbul Province and Turkish Thrace; secondly, a likely over-regional source was Bulgaria; and lastly, remote sources of ragweed pollen were the Ukraine, the Russian coastal region of the Black Sea and Moldova. This study provides evidence that pollens detected on our receptor site stem from combined local and remote origins.

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1. Introduction

Ambrosia (ragweed) is one of the most feared pollen sources among hay fever sufferers (Mitman, 2007) due to its fierce allergy inducing properties. For the most part it is *Ambrosia artemisiifolia*, the common ragweed that has been spreading in the temperate climates of the Old World since its introduction from North America (Makra et al., 2005). The ongoing migration of ragweed has become a serious environmental issue, not only threatening human health, but also as a noxious weed (Brandes and Nitzsche, 2006).

Ragweed is a wind pollinating annual herb that produces large quantities of pollen grains in late summer and autumn (Fumanal et al., 2007). The amount of pollen produced could be related to allergenicity as the development of allergy (sensitization) is correlated to exposure (Roitt and Delves, 2001). Yet, the magnitude of pollen in the air does not always directly correlate with the development of symptoms, as several other factors play a role in the dose–response relationship. These factors include size, type of allergen, cross reactivity, air pollution

and the human factor itself: some patients are more sensitive than others, while some others react to several allergens at the same time (Subiza, 2001). The non-linear relationship of pollen concentrations with allergy incidence is also emphasized in Frenz (2001). Frenz argues that once a concentration triggers an allergic reaction, higher concentrations do not imply an increment in the severity of symptoms. Priming effects play a role in the symptomology, as well as late reactions of patients occurring in the aftermath of a pollen event.

In terms of *Ambrosia*, grains have an approximate size of 20 μ m (Beug, 2004), although even smaller average grain sizes of 13–15 μ m have been reported for French populations (Fumanal et al., 2007). *Ambrosia* pollen can, therefore, penetrate the upper airways. For those suffering from a severe allergy, a few grains of ragweed might be enough to provoke symptoms. Development of pollinosis is reported for daily pollen-concentrations of five to 20 grains m⁻³ (reviewed in Tamarcaz et al., 2005; Oswalt and Marshall Jr, 2008). When pollen is present in the air, the atmosphere is also known to contain pollen-fragments of a few microns in size (Solomon, 2002). These allergen carrying sub-pollen particles can cause inflammation of the lower airways (Bacsi et al., 2006). This implies further pressure upon the allergic population. In short, even small amounts of ragweed pollens in the atmosphere are cause for concern.

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Three species from the genus *Ambrosia* (Asteraceae) are reported for Turkey: *Ambrosia maritima*, native to the Mediterranean coast (Kupicha, 1975), *Ambrosia elatior* (= *A. artemisiifolia*) (Byfield and Baytop, 1998), and *Ambrosia tenuifolia* (Behcet, 2004). *A. artemisiifolia* was found in Trabzon, and *A. tenuifolia* in Malatya. Both reported stands are characterized by humid conditions, the former located on the north eastern shores of the Black Sea in an oceanic climate (Byfield and Baytop, 1998), the latter in moist agricultural land and rural areas with hundreds of individuals in the east of Turkey (Behcet, 2004). The actual status and distribution of both species are uncertain, as publications relating to this could not be found. As far as western Turkey is concerned, a visit to the herbarium ISTE (Istanbul University, Faculty of Pharmacy) in 2010 resulted in no other specimen than the ones relative to the above mentioned first record for Turkey by Byfield and Baytop (1998). Further, the herbarium EDTU (Trakya University, Faculty of Science) in Edirne, located on the border between Turkey, Greece and Bulgaria, about 200 km NW from the trap location, does not have *Ambrosia* specimen either (pers. comm. August 10, 2011, Mehmet Aybeke, head of the herbarium). Regarding the distribution of the native *A. maritima*, there are records for central and southern Mediterranean Turkey pertaining to Konya, Adana, Antalya and Hatay (TUBIVES). However, the database does not consider recent floristic data.

A. artemisiifolia and *A. tenuifolia* are introduced species originally from North and South America, respectively. Nonnative *Ambrosia* was introduced to the Old World as byproducts of seeds (Makra et al., 2005). These annual herbs preferably grow in moist warm conditions on open grounds including agricultural land, roadsides or ruderal sites (e.g. Makra et al., 2005; Brandes and Nitzsche, 2006; Oswalt and Marshall Jr, 2008). Neophytic ragweed species invade prevalently countries with temperate continental climates. Yet, invasive ragweeds have started spreading on the Mediterranean coasts as in Israel (Waisel et al., 2008), for example, where irrigated fields, moist riverbeds and lake margins provide suitable conditions for the growth of ragweed.

Annual ragweeds complete their life cycle in one year and need disturbed land to germinate (Brandes and Nitzsche, 2006; Oswalt and Marshall Jr, 2008). Due to succession, plants move from the site over time (Brandes and Nitzsche, 2006) or may disappear altogether after inopportune growth seasons.

Pollen dispersal of *A. artemisiifolia* follows a diurnal cycling with mid-morning loads largely outweighing night time concentrations (Martin et al., 2010). Pollen loads trapped around midday may indicate a close source. Local pollen is then dispersed in the atmosphere with convective currents. However, pollen trapped at night is usually carried to the receptor site by air masses from distant sources. Aerobiological counts performed to investigate fluctuations in diurnal pollen concentrations can, hence, be indicative of the growth of near or remote source populations (Jaeger, 2000; Laiidi et al., 2003; Martin et al., 2010).

Aerobiological studies may also indicate the presence of a species in a region before the plant is actually found. I experienced this personally as a research assistant in a herbarium in northern Italy. Only after the local pollen warning service had indicated the presence of ragweed in the local air, was I directed to find the species.

If a local source for pollen trapped is uncertain, naturally one must also look at remote origins. Long distance transport of pollen has been the interest of research for a long time (cf. Hirst et al., 1967). Meteorological factors, but mostly wind vectors like wind direction, persistence and speed, cause biological particles to be carried over long distances. For the interest of public health, ragweed pollen has been closely monitored in this regard for many years. Many studies have debated that ragweed pollen incursions from remote sources can be associated with air mass movements (e.g. Mandrioli et al., 1998; Saar et al., 2000; Stepalska et al., 2002; Sofiev et al., 2006). Trajectory analyses are a scientific tool which is used to examine the transport patterns and dynamic processes of air masses (Stohl, 1998). Back trajectories allow visualization of air movements and they can be used to

define possible dislocations of airborne particles, including pollens (Cabezudo et al., 1997; Rousseau et al., 2006). With regard to tracing the origin of allergenic pollen associated to specific ragweed events, back trajectories were applied, for instance by Cecchi et al. (2006, 2007) in Italy associating sensitization of patients through pollen from distant sources, by Stach et al. (2007) and Smith et al. (2008) in Poland, as well as Sikoparija et al. (2009) in the Balkans. However, models based on backward trajectories used in frequency analysis (FA) and potential source contribution analysis (PSCF) (Polissar et al., 2001; Karaca et al., 2009; Karaca and Camci, 2010) can visualize the effect of prevailing wind systems and air mass movements to a receptor site over a time span – in our case – a pollen season.

The aim of this study was to report and analyze the ragweed pollen season of 2007 in Istanbul and, to explore the hypothesis of potential distant sources of ragweed pollen with a back trajectory modeling system following a bi-hourly count to discriminate local from distant sources. This study intends to fill the gap of information on this pressing environmental and public health issue related to this region of Turkey.

2. Materials and methods

The study area Istanbul, a metropolis with a population of 14 million, is located in northwestern Turkey on the Bosphorus at the borderline between Europe and Asia (Fig. 1). Air parcels commonly trespass this route carrying airborne particles from Europe to Asia and the Mediterranean. Air masses originating from the Carpathians move toward the Black Sea and further over Istanbul (Kindap et al., 2006). The average annual temperature lies between 12 and 16 °C and mean annual precipitation ranges between 600 and 800 mm. While the Marmara coast of Istanbul has a Mediterranean climate with dry summers and mild, rainy winters, the climate of the forested areas in the northeastern part of Thrace is humid to sub-humid. During June, July and August the relative humidity in Istanbul lies between 60 and 70%, apart from a small strip of land along the Black Sea coast, which experiences 70 and 80% humidity during the same time of year (Atalay, 1994).

Buyukcekmece, where the trap is located (41.09°N, 28.62°E), is a town on the western fringes of greater Istanbul within the watershed of Buyukcekmece Lake in Turkish Thrace (Fig. 1). To the south, the area is delineated by the Marmara Sea, to the immediate west and north mostly by farmland, calcareous dry grasslands and some urban development, while the land to the east is densely urbanized and industrialized with few green spaces. Farmland prevails on the shores of the lake along with some afforested patches of land. Most of the coastal area on the Marmara is residential with gardens and uncultivated land. Further from the north-west to the north-east up to the shores of the Black Sea there is a wooded belt mainly consisting of thermophilous coppice oak woods, with patches of maquis, pseudomaquis, heather and afforested pine (*Pinus nigra*).

Crops farmed are mainly grains, sunflower and canola; to a lesser extent, onion, watermelon, pumpkin, tomato, peppers, eggplant, cucumber and cabbage.

In Istanbul, urban and industrial development causes constant alterations in land use (Geymen and Baz, 2008; Yilmaz, 2010). As an immediate result, plant communities of wastelands and barren lands are frequent. These anthropogenic ruderal and segetal (weed communities in arable land) communities include weeds and grasses. The floristic aspect of autumn associations on disturbed grounds is often dominated by *Xanthium strumarium*, *Chenopodium* spp., *Atriplex* spp., *Amaranthus* spp., *Artemisia* spp., *Conyza* spp. *Rumex* spp. *Xanthium spinosum*, etc. Most of the natural environs consist of grasslands, which look dry and brown in summer and autumn. In contrast to anthropogenic communities, there are also natural vegetation types in greater Istanbul. Such formations, including dry grasslands, forests and wetlands, are ideally characterized by low human impact while persisting in their near natural floristic composition.

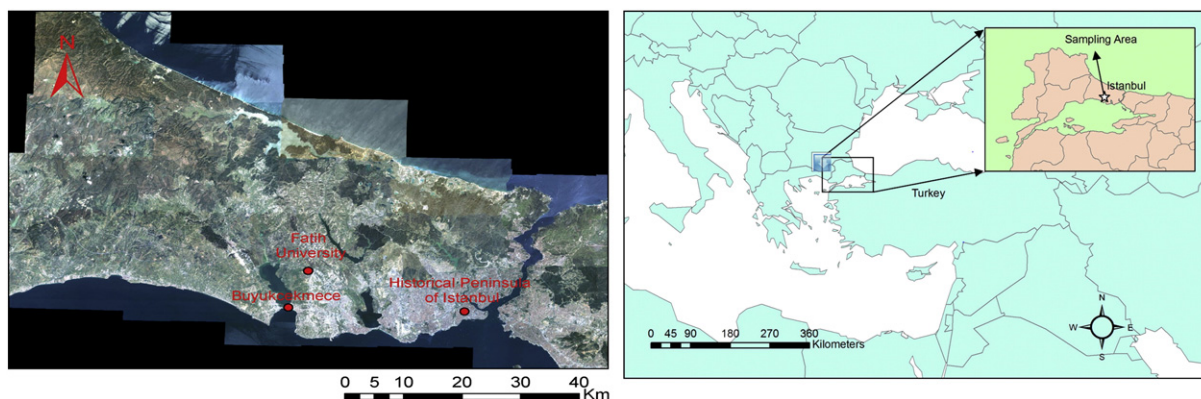


Fig. 1. Map of the study area. Left: Province of Istanbul. White and gray color patches on the satellite image indicate urban development. Nuances of green-brown are arable land or forests. Right: Larger geographical context of the study area. The box delineates the Marmara Region with its provinces. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

2.1. Pollen sampling and identification

Data on airborne pollen and spores have been recorded at Fatih University (Buyukcekmece, Istanbul) since May 15, 2007. Pollens were sampled with a Burkard trap located on the roof of a building at 15 m in 2007. The Burkard trap samples air particles through an orifice by means of a vacuum pump at a flow rate of 10 L/min. In this way, a total of 14.4 m³ of air is sampled in 24 h. Grains are trapped on a trapping tape with adhesive tape mounted on a rotating drum while the device is turning at a speed of 2 mm/h. The cylinder with the trapping tape was collected once a week. Glycerin jelly stained with safranin was used as permanent mount for microscopic slides and these slides were sealed with nail polish to allow storage (British Aerobiology Federation, 1995; Lacey and West, 2006).

The identification of *Ambrosia* pollen was based on McAndrews et al. (1973), Smith (1990), Moore et al. (1991), Beug (2004), polleninfo.org (2004), Kagen et al. (1998–2005), and Punt and Hoen (2009). Sample images were sent to Branko Sikoparija, Laboratory for Palynology, Faculty of Sciences, University of Novi Sad, Serbia, and to Victoria Rodinkova, Laboratory of Aeroallergen Methods, Vinnitsa National Pirogov Memorial Medical University, Ukraine for confirmation. Beug (2004) includes *A. artemisiifolia* (common ragweed) pollen into the *X. spinosum*-type (spiny cocklebur). Although *X. strumarium* (common cocklebur) pollen is similar in shape, it lacks pronounced echinae (spikes) and is bigger in size. In the present study, *Ambrosia* pollen was identified mainly on the basis of distinct broad based echinae, as suggested in Punt and Hoen (2009), which were discernible under the light microscope, and of grain size.

2.2. Counting

Data presented in this study cover the ragweed season of 2007. All pollen types were recorded under a light microscope at a magnification of 400× along twelve transverse traverses of the microscopic slide (48 mm × 14 mm). In this method, all particles visible in the microscopic field under a magnification of 400× on the traverse (0.45 mm × 14 mm) were counted, if more than half of the pollen grain was within the field. The distance between each transverse traverse was 4 mm on the Vernier scale. Daily average concentrations and bi-hourly pollen concentrations were assessed as grains per cubic meter (grains m⁻³) of air using the conversion factor 0.62 calculated according to the British Aerobiology Federation (1995). The bi-hourly count was performed to investigate the diurnal rhythm of the counts: morning counts would indicate a local source, night time counts, on the other hand would imply distant sources. The assumption was based on the work of Laiidi et al. (2003), Sikoparija et al. (2009) and Martin et al. (2010).

2.3. Backward trajectory model (HYSPLIT)

The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) modeling system (Air Resources Laboratory, 2011) was used to calculate backward trajectories from gridded meteorological data at regular time intervals. For the ending time of the trajectories the corresponding mixing depth value was computed. The HYSPLIT is a complete system for computing trajectories for particles of complex dispersion and for simulating their deposition. In this study, the PC version of HYSPLIT model (Version 4.9) was used with the meteorological data obtained from the operational system of the National Weather Service's National Centers for Environmental Prediction (NCEP), Global Data Assimilation System (GDAS). Refer to the NCEP website (<http://www.emc.ncep.noaa.gov/modelinfo/index.html>) for information on this model. Five-day backward trajectories for every hour belonging to the pollen events of 2007 for Buyukcekmece, Istanbul (41.09°N, 28.62°E) were computed. The trajectory ensemble option added to the HYSPLIT model makes it possible to create 27 potential trajectories by offsetting the meteorological data on a single pollen event – in this case a daily average concentration. This way, an ensemble of trajectories can define potential sources (Uygur et al., 2010).

Like other source apportionment methods, FA, which uses several trajectories in one function to define possible sources with higher statistical accuracy, was applied in the present work. The data used for the FA comprises one ragweed season. Karaca et al. (2009), for instance, used seasonal time spans for the source apportionment of episodic mass concentrations of atmospheric particulate matter.

To do so, multiple trajectory files are firstly displayed in some user-selected grids over the computational domain. Then, the numbers of trajectory intersections over each grid point are counted. Finally, the frequency values of each grid cell are calculated by dividing those counts to the total number of trajectories. Each of the hourly trajectories of the selected events may only intersect a grid point once. Each trajectory is defined by one output file that is only permitted to contain one trajectory. The grid resolution was selected as 1° according to the scale of the desired result.

3. Results

3.1. Ragweed pollen records

Discontinuous counts were made from August 1, 2007 onward, but only starting with 18.08.2007 counts were non-zero on five consecutive days. This date marked the start of the main ragweed season 2007 (Fig. 2). The peak day was on 28.08.2007 and the season ended with three consecutive days of non-zero ragweed counts on 13.09.2007.

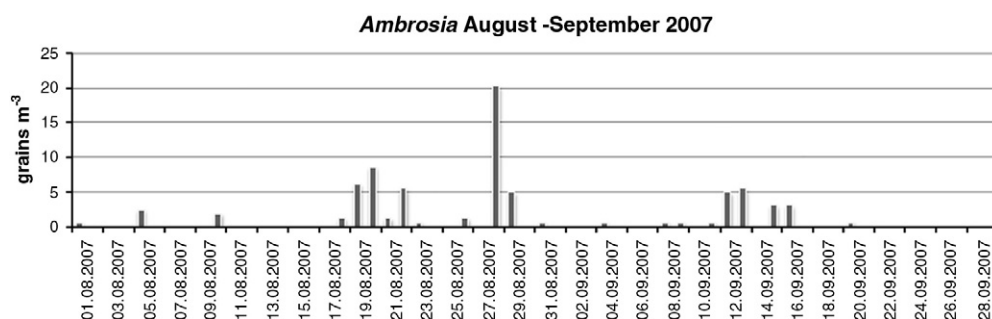


Fig. 2. Daily average *Ambrosia* concentrations during August and September 2007.

The daily average concentration during August and September was 2 grains m^{-3} , while the total monthly sum was 76 grains m^{-3} .

Fig. 3 shows both the concentration on the peak day and the average diurnal bi-hourly count of ragweed pollen for the months of August and September. Concentrations below 1 grain m^{-3} reflect the average taken from the total sum of grains recorded every 2 h over the two-month period, which ranged between 12 and 2 grains m^{-3} per day. The respective curve suggests a twofold climax: one before noon and the other at early night. The concentrations on the peak day (28.08.2007) reached a high around 9:00, while the evening peak was in alignment with the two month average around 21:00. Fig. 3 also contains the mixing depth value in meters [m] AGL corresponding to the sampling hour on August 28, which was the day with the highest *Ambrosia* pollen concentrations.

3.2. HYSPLIT

In this analysis, we used *Ambrosia* pollen concentrations obtained during August and September 2007. The HYSPLIT model is able to calculate any mixing depth value, the atmospheric layer above the ground where turbulences occur and particulate atmospheric matter is mixed, along with the trajectories. To confirm our assumption of distant sources, we ran backward trajectories consistently coinciding with the highest morning and evening counts made on August 28 at 7:00 UTC + 2 and 19:00 UTC + 2 respectively (Figs. 4 and 5). The elevation at arrival time was set to 100 m AGL as geographical barriers affecting northerly air masses coming from the Black Sea are minor. The region is flat or hilly and pronounced mountain ridges lie only in the Anatolian Marmara Region, southeast of Istanbul and away from the main wind direction.

The main differences between the figures lie in their vertical profiles. Please note that all the times and figures in the table are based on UTC, hence their corresponding times to our receptor site is UTC + 2. Figs. 4 and 5 are ensemble backward trajectories with respective arrival times at 7:00 UTC and 19:00 UTC. During the last 24 h before arrival, air masses that arrived at 9:00 local time (Fig. 4) crossed the Ukraine, as well as the coastal regions of Bulgaria and Romania during daytime, and the Black Sea during night. In contrast, air masses arriving at 21:00 local time were over the Crimean Peninsula and the coastal region of the Ukraine at night about 20 h before arrival continuing most of their daytime journey over the Black Sea.

Fig. 6 is an interpolated map of frequencies of hourly trajectories for ragweed pollen events belonging to August and September 2007. In this figure, sections of the darkest color are potential sources with 10% of frequencies. Frequency values were calculated for each $1^\circ \times 1^\circ$ grid, and the total of all grids amounts to 100%. In short, the 10% frequency region indicates a high level of probability of occurrence. The second region of brighter nuance with 1% frequency covers a wider area with substantial potential of pollen origin. Any delineated area over a marine environment does not imply a possible pollen source but a route.

4. Discussion

4.1. Ragweed pollen records

We marked the beginning of the season with the first day in August after which five days with non-zero *Ambrosia* counts followed. The main season was assessed this way because the count started in May and, hence, data for a full year was not available. The data showing highest

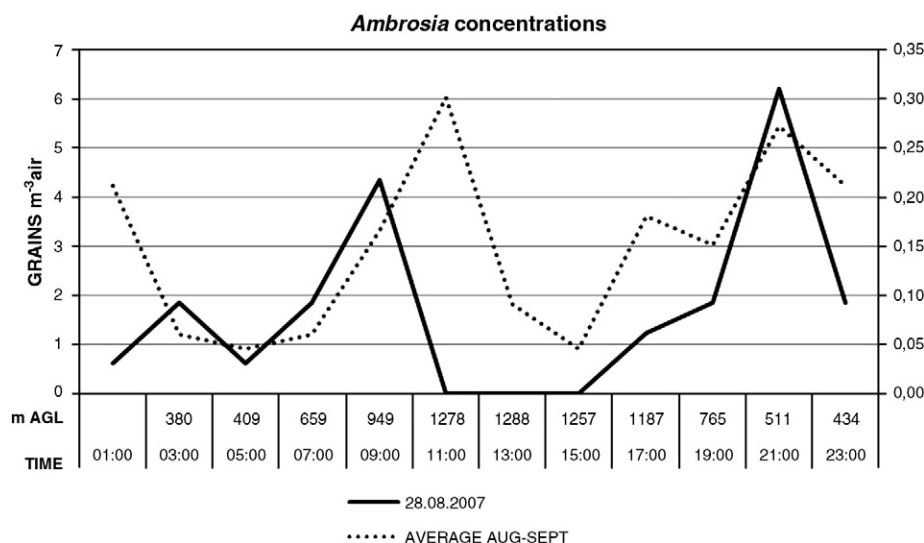


Fig. 3. Diurnal bi-hourly pollen concentrations of *Ambrosia* on 28.08.2007 (solid line) with corresponding trajectory arrival heights at local time and respective bi-monthly average concentration (dotted line).

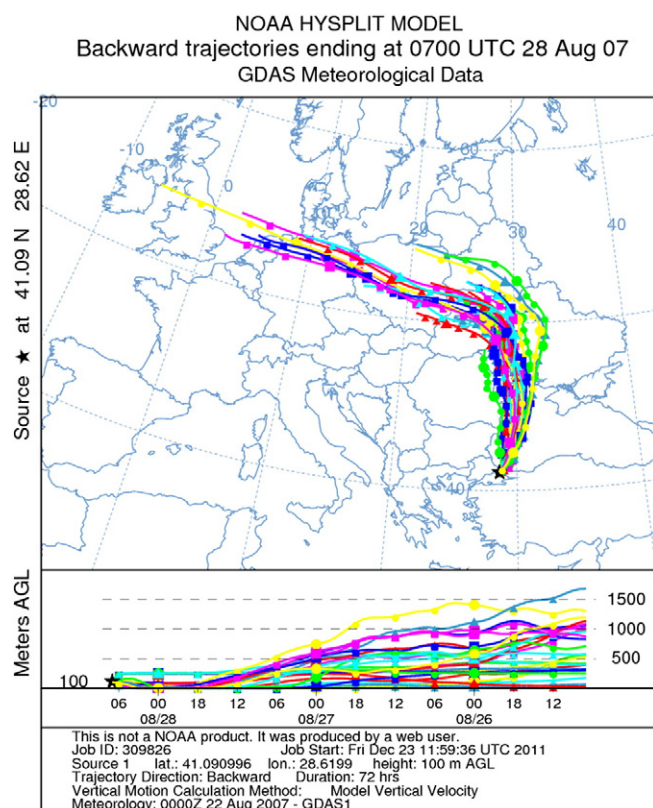


Fig. 4. Backward trajectory ensemble belonging to the *Ambrosia* pollen episode recorded at 07:00 UTC (9:00 local time) on 28.08.2007.

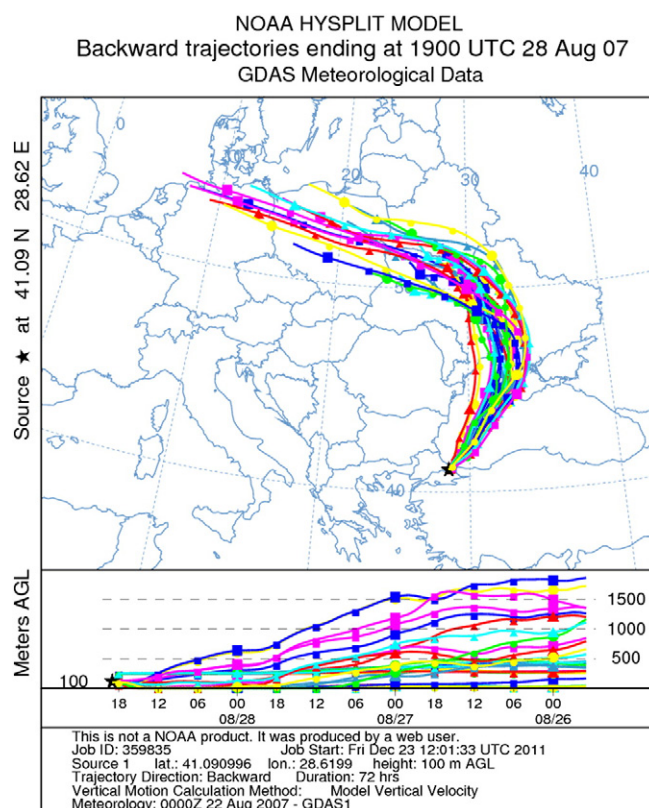


Fig. 5. Backward trajectory ensemble belonging to the *Ambrosia* pollen episode recorded at 19:00 UTC (21:00 local time) on 28.08.2007.

concentrations toward the end of August reflect typical ragweed flowering behavior. *Ambrosia* is a short day-plant that enters the germinative phenophase when day lengths are below a critical length of 12 h (Bianchi et al., 1959; Brandes and Nitzsche, 2006). The development of the flowers and subsequent anthesis takes some weeks, which usually leads to pollen release after mid-August. Peak days the same year in Novi Sad, Serbia were observed between August 24–26 (Branko Sikoparija, personal comm.), and in Skopje, F.Y.R.O.M. on August 26–27 (Sikoparija et al., 2009). The authors reported 10 and 14 grains m^{-3} on above mentioned peak days for Skopje (42°01'16"N 21°27'09"E), which are similar to the records made in Istanbul (41.09°N, 28.62°E). Interestingly, both in our site and Skopje, local populations were unknown and night time counts indicated long range transport.

The course of ragweed pollen concentrations, as shown by our circadian pollen count with peaks between mid-morning and noon, leads to the assumption that there is a small source of *Ambrosia* pollen somewhere rather close. Our pollen release curve reflects *A. artemisiifolia* pollen dispersal behavior as elucidated by Martin et al. (2010). Similar to our results, maximal daytime pollen loads in Lyon, France occurred between 9:00 and 11:00 (Laiidi et al., 2003). Ragweed has been a problem weed in the region where Lyon is located. Likewise, Sikoparija et al. (2009), linked peak counts around midday in Novi Sad and Ruma, both situated in the Pannonian Plain, to local sources of ragweed.

This is the first study that reports a ragweed season in Istanbul (Aytug, 1973; Aytug et al., 1990; Celenk et al., 2010). Although a synopsis on the pollen grains of Turkey by Bicakci et al. (2009) reports *Ambrosia* for the autumn air spora of the Marmara Region, which Istanbul is part of, ragweed has not been published in Istanbul's latest pollen calendars (Celenk et al., 2010). Also pollen studies related to towns in the range of 200 km from the trap location including Sakarya (Bicakci, 2006), Tekirdag (Erkan et al., 2010), Kırklareli (Erkan et al., 2011) do not report *Ambrosia*.

Celenk et al. (2010) reported *Xanthium* sp. (cocklebur) pollen among the eight dominant taxa found in the Asian part of Istanbul. *Xanthium* strongly resembles *Ambrosia* but lacks distinct spikes. *Iva axillaris* (poverty weed) pollen, however, is indistinguishable from *Ambrosia* (McAndrews et al., 1973) in aerobiological routine counts. Besides, *Iva* does not appear in any of the references taken into consideration for this paper, identification manuals and agricultural reports excluded. Although cocklebur is common in arable and wastelands in and around Istanbul, we only had a few grains in our August and September samples. *Ambrosia* (and *Iva*), on the other hand, is not (yet) listed as part of the regional flora.

The species *A. artemisiifolia* is known to occur in Bulgaria and Greece (Vladimirov et al., 2006, 2007; Greuter and Raus, 2008). Ragweed was also part of the air spora in Thessaloniki (Damialis et al., 2007), which is approximately the same latitude as Istanbul and has somewhat similar climatic conditions. Cocklebur, though, was not reported in the above mentioned paper. *Xanthium* (*strumarium*) is self-compatible and mainly self-pollinating (Weaver and Lechowicz, 1982), which generally leads to less pollen trapped compared to *Ambrosia*. This is in alignment with our own (unpublished) observations.

Whether or not *I. axillaris* is a pollen contributor or not, remains obscure but is considered unlikely as literature in regard to this is hardly available. It should be stated that poverty weed is a potentially invasive plant from North America, known to be introduced in Russia. It mainly pollinates in July and seems to be better adapted to spread in Mediterranean countries than common ragweed due to its draught resistance, but it is still of limited distribution or missing (European and Mediterranean Plant Protection Organisation, 2012).

4.2. HYSPLIT model source apportionment

Although most pollen stay close to the source, a fraction of them becomes airborne and is affected by convection, gusts or air mass-

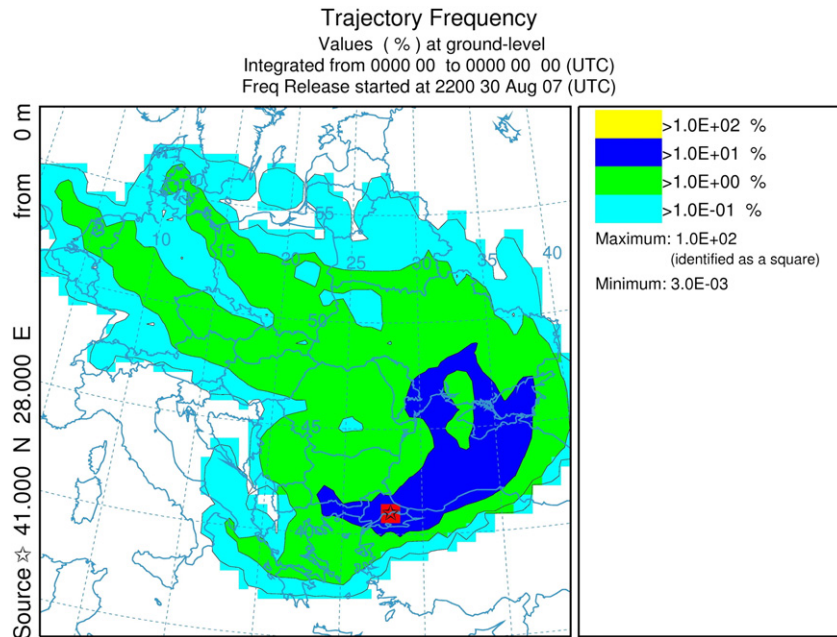


Fig. 6. Frequency distribution map of trajectories indicating potential ragweed pollen sources in Istanbul during summer and autumn 2007.

movements (Lacey and West, 2006) that keeps them in the atmosphere for some time. Birch pollen, for example can travel about 10^3 km in three days (Sofiev et al., 2006). Apart from the amount of pollen produced, the allergenicity of a species is further connected to its fall speed or terminal velocity (the rate of fall under gravity per unit of time) (Frenz, 2001). Grains with a small fall speed, which results from the surface structuring, the size and the density of a grain, move further from its source than other allergenic pollen types (Frenz, 2001; Lacey and West, 2006). To illustrate, ragweed has a fall speed of 0.8 cm/s compared to birch, whose fall speed is reported to be 1.7 cm/s (reviewed in Frenz, 2001). Another estimate on the fall speed of birch is about 1 cm/s according to Sofiev et al. (2006). In short, ragweed, like birch, is a species prone to long-distance transport.

Backward trajectory analysis is a simple but effective tool to visualize routes of pollen (and pollutants) in the atmosphere. Backward trajectories of multiple events over an extended period of time allow for statistical analysis of data and subsequent enhancement of accuracy (Owega et al., 2006). As in our case, they can confirm results relative to a sole event.

We created a source apportionment model on the base of seasonal ragweed observations made during the night and the assumption that pollen are not shed at night. By following the trajectories that coincide with the evening peak (Fig. 5), we can see that air masses carrying the pollen plume must have been enriched when crossing the Ukraine during the daily emission. Shortly after midnight we observed a drop in *Ambrosia* pollen concentrations. This can be explained with the ending of the daily emissions in the Ukraine and the arrival of ragweed-free air masses in Istanbul.

Regarding the mid-morning peak – although the circadian data support the presence of a local source – and following the same logic, we cannot exclude that air masses arriving in the morning (Fig. 4) contributed to our count with ragweed pollen from the morning shed collected over the coastal zones of the north western Black Sea. Our frequency distribution map of all ragweed events recorded during the 2007 season supports our findings: the Ukraine including the Crimean Peninsula appeared to be an example for a high probability (10%) source for ragweed pollen in the summer and autumn of 2007 (Fig. 6).

In the Ukraine, an area of 10,000 km² is infested and spreads are still continuing (Ustinova and Sizovenko, 2006 in Reznik, 2009). This also reflects on ragweed loads in the air spora of Kiev, where peak concentrations in August and September 2007 amounted to 3487 grains m⁻³ and 6432 grains m⁻³ air, respectively (Turos et al., 2009). According to the same model, other distant core pollen contributing locations to the atmosphere in Istanbul are concentrated in the Russian Black Sea coast and Moldova.

By means of the frequency analysis (Fig. 6) we further identified over-regional (a), regional (b) and local sources (c). Estimated over-regional sources (a) are located in Greek Thrace, Macedonia (Greece), Bulgaria as well as the north-western coastlines of the Turkish Black Sea Region. Among these locations, Bulgaria is the most probable source country (cf. Vladimirov et al., 2007). Although the frequency model shows otherwise, we cannot surely say how much regional sources including the Anatolian Marmara Region (b), contributed to the count. The pollen observed in the morning at the receptor site is most probably connected to small local emissions in the Province of Istanbul or its hinterland in Turkish Trace (c).

Ragweed is known to occur, in some cases massively, in most of the countries of the 10% region of our frequency model (Greuter and Raus, 2008; Sikoparija et al., 2009; Vladimirov et al., 2006; 2007; Hodisan and Morar, 2008).

Our work provides results from the seasonal collectivity of ragweed pollen events, thus allowing for a comprehensive synopsis of possible ragweed allergen incursions correlated to air mass movements to a receptor site throughout a pollen season.

5. Conclusions

We can conclude that local and remote sources contribute to *Ambrosia*-type pollen trapped in Istanbul. Pollen records made in the morning indicate most probably origins in the Istanbul Province itself or its immediate hinterland in Turkish Thrace. We speculate, though, that ragweed pollen collected the previous day during the early morning shed from coastal areas of countries bordering the Black Sea in the northwest could have contributed to the count. We connected records made at early night with air mass movements from middle over Eastern Europe collecting pollen mainly over the

Ukraine and crossing the western Black Sea before arrival at the receptor site. Are there regional populations around the Marmara? The source apportionment model on the base of seasonal data does indicate the Marmara Region and western Black Sea Region of Turkey as regional sources, but we cannot definitely confirm these locations with our research. Greek Thrace, Macedonia (Greece) and Bulgaria are rather close over-regional sources, whereby Bulgaria is known for having established ragweed populations. According to our analysis, it is most likely pollen from the Ukraine accounting for the bulk of ragweed observed in Istanbul along with a local source. Other probable further distant origins of pollens are Moldova and south-western European Russia bordering the Black Sea.

Invasive ragweeds occur in countries neighboring Turkey in the west and north, and we venture to say that there are local (regional) populations which still need to be found. The concentrations in 2007 were not yet too high but might pose a future threat to the allergic population of Istanbul, if ragweed pollen events become regular or if local ragweed populations increase. Further and continuous pollen monitoring will supply answers in this regard.

We presented evidence that pollens on the receptor site stem from combined origins. Data on air masses holding a combination of pollen from a variety of known sources can provide more sophisticated information for allergy treatment than local pollen counts can (Solomon, 2002).

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