Quantifying emissions of primary biological aerosol particle mass in Europe

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\textbf{A B S T R A C T}

Atmospheric concentration measurements of tracers for primary biological aerosol particles (PBAPs) have been used to obtain estimates of their release into the atmosphere. Emission flux data of surrogate compounds, for which concurrent concentration measurements were available, were used to quantify the release of PBAPs as PM\textsubscript{10} mass. Results indicate fungal spores to be the most important contributors. One other main source is plant debris. Area-based emission rates of 24 kg km\textsuperscript{-2} and year (range 6–90) have been assessed. Results scaled for Europe indicate a contribution of PBAPs to PM\textsubscript{10} concentrations in the low percentage range, with a maximum in summer when concentration levels are small. This is consistent with the range of measurements. Despite of the large uncertainties, results contribute to clarify the potential contribution of biological particles to global load of particle mass.

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\section{1. Introduction}

Primary biological aerosol particles (PBAPs) comprise material that originally derives from biological processes. This material has been transferred into the atmosphere without change in its chemical composition. A distinction is needed between particles which maintain their physical characteristics, specifically their cellular structure, and material which is the result of an abrasive process. The difference is significant as for the former particles much more distinct properties can be identified, concerning particle size, mass, and chemical composition. Individual structural units that are present in the atmosphere include pollen, spores, bacteria and viruses. In contrast, fractionated material may occur over a much larger size range.

Fractionated PBAPs can be identified by their composition. They may consist of plant debris as well as animal material. Like any atmospheric aerosol derived from a friction process, PBAP mass will be more abundant in the "coarse" aerosol mode particles (larger than 1 \mu m diameter).

The occurrence of PBAPs in the atmosphere has i.a. been described by Jaenicke (2005). They have been observed to act as cloud condensation nuclei (Sattler et al., 2001) and may play an important role for the long-range transport of trace elements into and away from specific biomes (Mahowald et al., 2005). Very little is known about their contribution to aerosol mass, specifically PM\textsubscript{10} mass.

Among structural units, the largest PBAP particles are pollen. In the atmosphere, pollen are typically of a size of 30 \mu m and above, with a few exceptions (birch pollen) as small as 10 \mu m. Thus intact pollen will hardly contribute to PM\textsubscript{10} mass (Riediker et al., 2000). Allergenic material derived from pollen is known to also occur at smaller particle sizes, but only as a consequence of a fractionation
Fungal spores, bacteria and viruses are clearly differentiated by their size. While the mass of spores is in the range of 13 pg C per entity (Bauer et al., 2002a; total mass: 33 pg, see Bauer et al., 2008b), bacteria are about three orders of magnitude smaller (17 fg C per entity; see Bauer et al., 2002b; Sattler et al., 2001). Still far smaller mass has been attributed to viruses.

Lacey and Venette (1995) provide information on number concentrations of PBAPs. At a count of 1000 pollen grains m\(^{-3}\), assuming 50 µm diameter and a density of 1, this results in 65 µg m\(^{-3}\). In extreme cases even 8000 pollen grains m\(^{-3}\) have been observed. Due to their large size, pollen tend to deposit earlier than fungal spores or bacteria, thus highest concentrations will be limited close to their emission sources. Still also transport over large distances has been reported (Sofiev et al., 2006).

Again Lacey and Venette (1995) report number concentrations on spores. While moss and fern spores are present at a few thousand per cubic meter, the number of fungal spores can be as high as 10\(^5\), under special circumstances up to 10\(^6\) m\(^{-3}\). With a spore mass of 33 pg per entity (see above; this is consistent with a sphere of about 4 µm diameter), concentrations of 0.3 µg m\(^{-3}\) can be derived—or up to 3 µg m\(^{-3}\), when referring to the highest counts. Spores can be assumed to remain suspended in air for an extended period of time. Lacey and Venette (1995) refer to plant surfaces, but also to wind-blown soil as important sources of fungal spores in the atmosphere.

Numbers found for airborne bacteria are typically smaller than for spores. Due to their vastly smaller mass, their contribution to total aerosol mass becomes negligible. The same is the case for viruses, which are not considered to occur as individual particles but instead to form clusters or droplets.

Assessment of bioaerosols is important for animal breeding. Indoor concentrations and emissions from animal houses have been quantified as a function of the breeding cycle and the distance from the potential release site. While clear differences can be observed for the number of colony forming units (CFU) of bacteria downwind of animal houses, background concentrations of fungal spores do not permit an identification of a plume (Hartung et al., 2005). It may be concluded that fungal spores are ubiquitous.

Quantification of fractionated material is more difficult, as neither structure nor size are well defined. Guidance to which particles are to be considered PBAPs is given by their composition. A comprehensive approach to cover PBAPs which particles are to be considered PBAPs is given by their cellulose content.

The same is the case for viruses, which are not considered to be PBAPs. Even airborne due to air motion.

2. Plant debris

Plant material contains cellulose as structural element. Measurements of atmospheric concentrations of cellulose are available from a handful of sites in Europe (Sánchez-Ochoa et al., 2007). The analytical procedure has been described in detail by Kunit and Puxbaum (1996) and by Puxbaum and Tenze-Kunit (2003). No information on emission fluxes is available, as also the emitting process is not readily defined. One may assume that different fractions of plant material are broken up by mechanical and/or decay processes, and the resulting particles become airborne due to air motion.

As emission is likely distributed over a very large area, assessment of minute concentration gradients in order to derive emission fluxes is expected to be very difficult. Instead of a direct assessment, here we will attempt an indirect approach, comparing atmospheric concentration of plant debris (plant debris is considered to contain 50% cellulose (see Puxbaum and Tenze-Kunit, 2003)) with those of other compounds, for which the emission fluxes are known. If emissions occur concurrently, the ratio of concentration should reflect the ratio of emissions, allowing to derive an emission flux:

\[ E_{PD} = \frac{c_{PD}}{c_{tracer}} E_{tracer}, \]  

where \( E_{PD} \) is the emission flux of plant debris, \( E_{tracer} \) reflects the emission flux of a tracer compounds, and \( c_{PD} \) and \( c_{tracer} \) refer to the respective atmospheric concentrations.

Unfortunately, no single compound is expected to reproduce the temporal and spatial emission pattern of plant debris. Moreover, emission data are available only for very specific compounds. So any attempt to apply this indirect approach will have to rely on compounds for which both concentration data and emissions are available concurrently to cellulose (plant debris) measurements. Repeating the approach for several sites and several tracer compounds will allow to understand the reliability of the resulting plant debris emission flux.

The above-mentioned cellulose measurements (Sánchez-Ochoa et al., 2007) have been collected as part of the CARBOSOL project from six sites along a west-east transect of Europe. Simultaneous measurements have been reported by Pio et al. (2007) which include the compounds black carbon (BC), organic carbon (OC) and PM\(_{2.5}\) mass (one site only). Furthermore, measurements of
levoglucosan have been performed (Puxbaum et al., 2007). Levoglucosan is a tracer for wood fire. We can derive atmospheric woodsmoke concentration from levoglucosan measurements, based on measured conversion rates of wood lignin during combustion (Fine et al., 2002). Measurements have been performed over 2 years, on a weekly basis.

Emission inventory data have been taken from IIASA’s GAINS model (wood smoke as PM$_{10}$ emissions from wood combustion in domestic sources, PM$_{10}$–OS1–DOM, as well as total PM$_{2.5}$ according to IIASA (2005); BC and OC according to Kupiainen and Klimont (2004). The resolution of this data (annual totals per European country) strongly limits its applicability. Instead of taking advantage of the distinctive annual cycle of concentrations, only annual mean values (here: taking the average of the summer and winter means as presented by Pio et al., 2007) can be compared to emissions. Moreover, a signal detectable at a measurement site will not necessarily reflect representative emissions of a certain country. Two of the six CAR-BOSOL sites were excluded from further evaluations, as they have been selected as remote sites, and certainly will not reflect the emissions of the country they are situated in (Azores and Portugal, or Sonnblick Observatory and Austria).

The results of an evaluation according to Eq. (1) have been normalized to the “relevant emission area” in order to move from a country-specific number to an emission factor that is generally applicable. The emission factors derived and the respective “relevant emission area” are listed in Table 1. We consider the “relevant emission area” to consist of all area where we deem emissions possible—taken from a land use database compiled from CORINE and global land cover information by JRC (Koeble, personal information). This excludes water and barren land, but keeps most of the total area of a country. As Matthias-Maser et al. (2000) observe highest PBAP concentrations in urban surroundings, also built-up area is included.

In an ideal case, the emission factors for emissions of plant debris presented in Table 1 would be identical. The quite considerable variations that are actually shown reflect, on one hand, the above-mentioned reservations in methodology. On the other hand, they provide an indication on the robustness of this data. For any evaluation, one needs to consider that no previous emission factors are available, even if global emissions totals have been presented (see the Discussion and Conclusions sections in this paper).

The emission factors derived exhibit a considerable range, with a low at 3 kg km$^{-2}$ and year, and high values close to 200 kg km$^{-2}$. A close inspection reveals that the highest values all derive from mountain sites (Puy de Dome, Schauinsland) and from compounds that are more relevant for winter pollution (BC and wood smoke). This may indicate that the high values refer to situations considerably influenced by wintertime inversion situations, typically for those sites (Pio et al., 2007). Excluding these extreme values leaves the range between 3 and roughly 20 kg km$^{-2}$ and year, with several points close to 6 kg km$^{-2}$. These figures therefore constitute the “best value” and the uncertainty range that we will apply to the emission factor of plant debris.

Still also the lower values need further consideration. OC and PM in general not only derives from emission but is also formed in the atmosphere. Considering that the measurements are influenced by a secondary fraction will at the same time increase the emission factors for plant debris. In Table 1, we estimate a third of PM$_{2.5}$ as the secondary fraction, but due to lack of data will not attempt quantification for OC.

It is interesting to note that a modeling approach based on basically the same data (Simpson et al., 2007) indicates considerable inconsistencies between measured and modeled concentrations of levoglucosan and total carbon (OC+BC), while reflecting agreement for elemental carbon (equivalent to BC) for the two sites in flat terrain (Aveiro, K-Puszta). The authors discuss these differences in quite some detail, which is beyond the scope of the current study. Here it is just important to note that the BC-derived emission factors are on the higher end of the scale, such as also consideration of secondary OC formation (see above) would lead to increasing factors. We may assume that the chosen factor of 6 kg km$^{-2}$ and year represents rather a conservative lower estimate.

### 3. Fungal spores

Again, only a handful of measurements are available globally on the atmospheric concentrations of fungal spores. Fungal material consists of chitin, not of cellulose as structural material. Measured concentrations therefore add to the “plant debris” discussed above.

We take advantage of fungal spore counts in the Vienna area, which have in part been taken concurrently with cellulose measurements (Bauer et al., 2006, 2008b). In contrast to cellulose, spore counts display a distinctive seasonal pattern, with a clear minimum in wintertime and a maximum in summer (Fig. 1). PM$_{10}$ mass (also depicted) shows a seasonal pattern with a maximum in winter, such that spores contribute little during the time of high PM pollution.

The spore counts have been converted to mass assuming an average C-content of 13 pg C (Bauer et al., 2002a, b), 50% C per dry mass, and a water content of 20% of the spore (Sedlbauer and Krus, 2001), yielding 33 pg mass per spore. Assuming a density of 1, this mass is consistent with the mass of a sphere of 4 μm diameter. The size conforms to microscopic evidence (Wittmaack et al., 2005). At spore counts averaging 25,000 m$^{-3}$, almost 1 μg m$^{-3}$ of

### Table 1

Assessing an emission factor for plant debris emissions

<table>
<thead>
<tr>
<th>Site</th>
<th>Country</th>
<th>Emission area (km$^2$)</th>
<th>Emission factor (kg km$^{-2}$) based on measured concentrations of Wood smoke BC OC PM$_{2.5}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aveiro</td>
<td>Portugal</td>
<td>86,157</td>
<td>5.02  12.13  3.42  3.60</td>
</tr>
<tr>
<td>Puy de Dome</td>
<td>France</td>
<td>538,369</td>
<td>167.41  75.13  13.42  n.a.</td>
</tr>
<tr>
<td>Schauinsland</td>
<td>Germany</td>
<td>355,796</td>
<td>37.12  82.50  10.91  n.a.</td>
</tr>
<tr>
<td>K-Puszta</td>
<td>Hungary</td>
<td>91,497</td>
<td>5.86  18.01  5.67  n.a.</td>
</tr>
</tbody>
</table>

n.a.: not available.
observed PM$_{10}$ concentrations may be attributed to spores. Depending on the specific circumstances, spores can make up between roughly 0.5% and 5% of PM$_{10}$. Highest contributions are in summer outside the urban centers, the lowest contributions in those periods that are relevant for PM$_{10}$ thresholds: urban winter situations.

Comparing plant debris data (from cellulose measurements) and fungal spores allows deriving an emission rate. Fungal spores occur at the same mass concentrations up to about five times the concentrations of plant debris. The difference may mostly be attributed to the seasonal cycle of fungal spore counts. We use an average factor of 3 resembling the annual mean. Applying the plant debris emission factor of annually 6 kg km$^{-2}$ leads to an estimated 18 kg km$^{-2}$ emissions of fungal spores per year. The same area (total area less barren land and water) seems relevant as for plant debris. Uncertainty may be taken from the differences of seasonal ratios between plant debris and spores, roughly between 1 and 4. Applying this to the respective upper and lower boundaries of the plant debris emission factor will yield a range between 3 and 80 kg km$^{-2}$. This range could be considerably narrowed if the annual trend is ascertained as a seasonal effect rather than an uncertainty, and if the spatial sample of possible situations is extended.

While applying data from just one city to all of Europe seems far from representative, we can only use a few sets of measured concentrations to validate our assessment. Graham et al. (2003, data from the Amazon forest) report spore counts resulting in concentrations of 0.3–3 µg m$^{-3}$ (with the higher concentrations observed during nighttime). Matthias-Maser et al. (2000) and Jaenicke (2005) apply a totally different method—dying particles with a protein-sensitive dye, and subsequent microscopy analysis. They arrive at concentrations of total PBAPs between 0.3 (remote areas) and even 6.5 µg m$^{-3}$. They find the highest concentrations in suburban Mainz, giving another reason not to exclude built-up area as a potential source area.

4. Discussion

4.1. Health relevance of PBAPs

Studies on the health assessment of PM$_{10}$ (e.g. Dockery et al., 1993; Pope et al., 1995, and similar) are based on relating health-relevant parameters to observed particle concentrations. The observed concentrations include particles of different species and different origins. One may argue that the same effect as in the health study would be achieved when the same mix of particles could be recreated. In the absence of any detailed information on the particles, the contribution of different classes to the health effect has to be assumed identical. Thus no differentiation is needed.

There is, however, some differences to be stated. Numbers presented in health studies do not consider large particles (>10 µm), which therefore may be treated as ineffective in terms of health. This is the case for pollen. Moreover, health effects are typically assumed to be stronger for very small particles (PM$_{2.5}$: WHO, 2004), which will exclude spores and most of the PBAPs. Currently aerosol in the size range between 2.5 and 10 µm is still considered health relevant, even if not to the same extent as these small particles.

On the other hand, the health effects observed in the PM studies do not include typical problems of bioaerosols: allergies, or diseases prone to bacteria or viruses. Instead they focus on inflammation-guided long-term health effects. This is just to be stated here to explain the relevance and the type of data (by bacterium species, etc.), available, but not given any further notice as here we focus on PM$_{10}$.

4.2. Anthropogenic source of PM$_{10}$

At this point, little is known about the generation process of PBAPs. Without information on the generation process, it is also difficult to assign the responsibility of an emitter. While PBAPs are definitely the result of biological processes, it is not at all clear whether such processes should be considered natural. Plant debris may be triggered by agriculture, the release into the atmosphere enhanced by wind blowing along harvested stubble fields, agricultural machinery of even road traffic. Fungal spores can be the result of composting agricultural waste, of specific soil treatment methods, or similar. At least some of the material included here has classically been reported under PM emissions from agriculture (e.g. animal housing).

From atmospheric concentrations alone, without a proper source term, it is almost impossible to correctly attribute the origin of PBAPs in the atmosphere. Consequently, an exemption from a requirement to reduce the concentrations, being a natural source, cannot be substantiated. From the perspective of the citizen's health, there is no reason for a differentiation between this source being natural or anthropogenic: as stated above, no information is available that this source, if at all natural, is less hazardous—or to the contrary, atmospheric concentrations observed from natural sources should rather lead to enhanced abatement of man-made PM emissions in order to arrive at a balanced situation of acceptable air quality.
4.3. Emissions in Europe

Using the emission factors derived for plant debris \((6 \text{ kg km}^{-2} \text{ yr}^{-1})\) and fungal spores \((18 \text{ kg km}^{-2} \text{ yr}^{-1})\), total PBAP emissions can be derived using an overall emission factor of \(24 \text{ kg km}^{-2} \text{ yr}^{-1}\) (uncertainty range: \(6-90 \text{ kg km}^{-2} \text{ yr}^{-1}\)). As discussed earlier, this may be seen as a conservative estimate based on low concentrations—yet the representativity of the factors derived cannot be assured.

In Table 2, the relevant area (from CORINE data, where applicable, otherwise derived from JRC, in both cases excluding water area and barren land) and annual emissions are presented per country. The assessment includes the full NATAIR domain (see Fig. 2), not only Europe, but not necessarily the whole country (specifically, this is a problem for Russia). Note that some emissions are assigned to sea area—this is due to wrong classification (some islands were not attributed to their respective countries) and indicates the error involved in country attribution.

The total emissions for the NATAIR domain are about 283 Gg yr\(^{-1}\), 233 of which occur in geographical Europe. We can compare this number to the total anthropogenic PM\(_{10}\) emissions in Europe, which have been assessed in the CEPMEIP study (Pulles, 2001) at 6 Tg (or Mton). PBAP would constitute roughly 4% of the anthropogenic PM emissions.

When using RAINS data on European PM\(_{10}\) (without Russia: IIASA, 2005), we have to compare their 3.5 Tg towards 135 Gg PBAPs from Europe except Russia—again resulting in 4%. As we can assume one-third to half of atmospheric particles to be formed in the atmosphere, the expected contribution to aerosol concentrations in Europe is between 2% and 3%. This number agrees very well with the atmospheric concentrations observed in the Vienna area, where typical PBAP concentrations make up between 1% and 5% of PM\(_{10}\).

**Fig. 2.** NATAIR domain and countries covered (two-letter ISO code, see Table 2).

**Table 2**

Annual emissions of PBAPs from the NATAIR domain (Europe plus some areas in Northern Africa and the Middle East

<table>
<thead>
<tr>
<th>Country (ISO code)</th>
<th>Area relevant for PBAP emissions (km(^2))</th>
<th>Emissions of PBAPs (ton yr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albania (AL)</td>
<td>26,507</td>
<td>636</td>
</tr>
<tr>
<td>Algeria (DZ)</td>
<td>256,117</td>
<td>6147</td>
</tr>
<tr>
<td>Andorra (AD)</td>
<td>127</td>
<td>7</td>
</tr>
<tr>
<td>Armenia (AM)</td>
<td>28,365</td>
<td>681</td>
</tr>
<tr>
<td>Austria (AT)</td>
<td>77,515</td>
<td>1860</td>
</tr>
<tr>
<td>Azerbaijan (AZ)</td>
<td>48,343</td>
<td>1160</td>
</tr>
<tr>
<td>Belgium (BY)</td>
<td>207,017</td>
<td>4968</td>
</tr>
<tr>
<td>Belgium (BE)</td>
<td>31,107</td>
<td>747</td>
</tr>
<tr>
<td>Bosnia-Herzegovina (BA)</td>
<td>50,818</td>
<td>1220</td>
</tr>
<tr>
<td>Bulgaria (BG)</td>
<td>110,330</td>
<td>2648</td>
</tr>
<tr>
<td>Croatia (HR)</td>
<td>55,345</td>
<td>1328</td>
</tr>
<tr>
<td>Cyprus (CY)</td>
<td>9076</td>
<td>218</td>
</tr>
<tr>
<td>Czech Republic (CZ)</td>
<td>78,053</td>
<td>1873</td>
</tr>
<tr>
<td>Denmark (DK)</td>
<td>43,388</td>
<td>1041</td>
</tr>
<tr>
<td>Egypt (EG)</td>
<td>44,589</td>
<td>1070</td>
</tr>
<tr>
<td>Estonia (EE)</td>
<td>43,740</td>
<td>1020</td>
</tr>
<tr>
<td>Faroe Islands (FO)</td>
<td>1,183</td>
<td>28</td>
</tr>
<tr>
<td>Finland (FI)</td>
<td>306,112</td>
<td>7347</td>
</tr>
<tr>
<td>France (FR)</td>
<td>538,369</td>
<td>12,921</td>
</tr>
<tr>
<td>Georgia (GE)</td>
<td>68,571</td>
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<td>Germany (DE)</td>
<td>355,796</td>
<td>8539</td>
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<td>Greece (GR)</td>
<td>127,601</td>
<td>3062</td>
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<tr>
<td>Hungary (HU)</td>
<td>91,497</td>
<td>2196</td>
</tr>
<tr>
<td>Iceland (IS)</td>
<td>79,655</td>
<td>1912</td>
</tr>
<tr>
<td>Iran (IR)</td>
<td>38,157</td>
<td>916</td>
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<td>Iraq (IQ)</td>
<td>99,891</td>
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<td>Israel (IL)</td>
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<td>Italy (IT)</td>
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<td>Jordan (JO)</td>
<td>19,485</td>
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<td>Kazakhstan (KZ)</td>
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<td>5135</td>
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<tr>
<td>Latvia (LV)</td>
<td>63,039</td>
<td>1513</td>
</tr>
<tr>
<td>Lebanon (LB)</td>
<td>10,393</td>
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<td>Libya (LY)</td>
<td>74,235</td>
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<td>Liechtenstein (LI)</td>
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<td>Lithuania (LT)</td>
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<td>Macedonia (MK)</td>
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<td>592</td>
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<tr>
<td>Malta (MT)</td>
<td>347</td>
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<td>Moldova (MD)</td>
<td>33,675</td>
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<td>Morocco (MA)</td>
<td>198,281</td>
<td>4759</td>
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<tr>
<td>Netherlands (NL)</td>
<td>35,206</td>
<td>845</td>
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<tr>
<td>Norway (NO)</td>
<td>272,557</td>
<td>6541</td>
</tr>
<tr>
<td>Poland (PL)</td>
<td>309,546</td>
<td>7429</td>
</tr>
<tr>
<td>Portugal (PT)</td>
<td>86,157</td>
<td>2068</td>
</tr>
<tr>
<td>Romania (RO)</td>
<td>234,037</td>
<td>5617</td>
</tr>
<tr>
<td>Russian Federation (RU)</td>
<td>4,051,842</td>
<td>97,244</td>
</tr>
<tr>
<td>Saudi Arabia (SA)</td>
<td>23,033</td>
<td>553</td>
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<tr>
<td>Slovak Republic (SK)</td>
<td>49,099</td>
<td>1178</td>
</tr>
<tr>
<td>Slovenia (SI)</td>
<td>20,273</td>
<td>487</td>
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<tr>
<td>Spain (ES)</td>
<td>485,060</td>
<td>11,641</td>
</tr>
<tr>
<td>Svalbard and Jan Mayen Islands (SJ)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sweden (SE)</td>
<td>403,411</td>
<td>9682</td>
</tr>
<tr>
<td>Switzerland (CH)</td>
<td>38,093</td>
<td>914</td>
</tr>
<tr>
<td>Syria (SY)</td>
<td>95,077</td>
<td>2282</td>
</tr>
<tr>
<td>Tunisia (TN)</td>
<td>90,769</td>
<td>2178</td>
</tr>
<tr>
<td>Turkey (TR)</td>
<td>766,953</td>
<td>18,407</td>
</tr>
<tr>
<td>Ukraine (UA)</td>
<td>585,194</td>
<td>14,045</td>
</tr>
<tr>
<td>United Kingdom (UK)</td>
<td>244,827</td>
<td>5876</td>
</tr>
<tr>
<td>Yugoslavia (Serbia-Montenegro, YU)</td>
<td>101,318</td>
<td>2432</td>
</tr>
</tbody>
</table>

For most of the non-European countries, their area is not fully within the domain and thus estimated emissions refer to a part of their area only.)
Despite of the very limited amount of measurement data available, and the lack of providing an adequate coverage of different situations in Europe, we thus have some evidence to support the emission factor provided. According to all data considered, PBAPs constitute an interesting, but by far not dominating contribution to atmospheric PM mass over Europe.

5. Conclusions

Previous figures on emissions of PBAPs are available on the global scale. They range from 56 Tg annually (Penner et al., 2001), to a value as high as 1000 Tg (Jaenicke, 2005). This discrepancy justifies a rather unsophisticated approach to be taken for clarification.

In the current study, the most important fractions of atmospheric PBAPs have been identified as plant debris and fungal spores. Annual emissions of 233 Gg have been derived based on comparing atmospheric concentrations of PBAPs to other atmospheric compounds. Scaling European emissions by land area allows an indication of a global figure. Europe covers about 7% of global land mass, expected emissions thus are in the range of a few Tg. Even considering the considerable uncertainty involved and the potential higher activity of the tropical biosphere, this assessment tends to support the lower of the literature values available, if at all, and rather suggests even considerably lower estimates.

Extrapolation performed here is based on area, excluding barren land and water area. Scaling based on more complex parameters (Mahowald et al., 2005, use above ground biomass) implies additional knowledge exists on the release process, but would not affect our results by more than a factor of 2–3. On the global scale, our limitation to vegetated land area neglects potential mechanisms that include an oceanic source (see e.g. Blanchard and Syzdek, 1970). As long as the source terms of such mechanisms remain in the same order of magnitude as the ones we imply for Europe, an extrapolation would still yield results in the low 10 Tg PBAP emissions per year.

Understanding the release mechanisms and developing “source terms” of emissions is thus needed to refine emission estimates. Emissions of fungal spores are considered active processes (as reviewed by Elbert et al., 2007). For such active processes, the development of source terms seems feasible on the basis of the respective mechanism, even if considerably more research will be required. In particular the use of selective tracers would allow to quantify the emission of PBAPs. In this respect have been proposed: phospholipids (Womiloju et al., 2003), β-1,3 α-glucan (Foto et al., 2004), ergosterol (Lau et al., 2006), manninitol (Elbert et al., 2007) and arabitol or manninitol (Bauer et al., 2008a). Measurements of atmospheric concentrations of tracers that are considered specific for fungal material, may allow discrimination of source emissions above a background and in this way support the development of source terms. Also this approach will certainly require more measurements to better quantify the contribution of fungal spores to atmospheric PBAPs and to particulate matter altogether.

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References


