EVALUATION AND FORECASTING OF THE ATMOSPHERIC CONCENTRATIONS OF ALLERGENIC POLLEN IN EUROPE

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1 INTRODUCTION

Diseases in the respiratory system due to aeroallergens, such as rhinitis and asthma, are major causes of a demand for increased healthcare, loss of productivity and an increased rate of morbidity. Pollenosis accounts for 12 - 45 % of overall allergy cases. The sensitisation to pollen allergens is increasing in most European regions. The adverse health effects of allergens can be reduced by pre-emptive medical measures. However, their planning requires reliable forecasts of high atmospheric pollen concentrations (Rantio-Lehtimäki, 1994), (Rantio-Lehtimäki & Matikainen 2002).

There is convincing evidence that the long-range transport of pollen from remote regions can significantly modify pollinating seasons in many European regions. This is particularly important for Northern Europe - and especially for Finland, where the flowering takes place later in spring. This transport causes unforeseen and sudden increases of concentrations of pollen that can occur up to a month before the start of the local pollen season (Siljamo *et al*, 2004). The long-range transport can substantially increase the concentrations of allergenic pollen also during the local pollen seasons.

However, the currently available pollen forecasts are based solely on local observations and do not consider the transport from other regions. At present, there is no modelling system in Europe that can simulate the pollen transport in the atmosphere. Further, there is no such model for evaluating the pollen emissions (including the pollinating season and the flowering characteristics of the relevant species) that would provide the input data for such atmospheric dispersion modelling.

The current paper presents an on-going project of the Finnish Academy aiming at development of a numerical dispersion model for operational forecasting the atmospheric transport of natural pollen in Europe. Overall objectives of the project are:

- to develop an integrated modelling system for simulating and forecasting the natural pollen emissions and transport at a European scale;
- to evaluate the spatial distributions of pollen emissions and concentrations in Europe.

2 MATERIALS AND METHODS

The birch pollen is the most important allergen with regard to atmospheric transport due to its ability to fly over large distances. There are two treelike birch species in Europe. Downy birch (*Betula pubescens*) is the most common in the northern part of Europe, while silver birch (*Betula pendula*) is dominating in more southern regions. Typical birch pollen grain has a size of 20-22 μm. It is fairly light (a full grain filled with protein material has a density of ~ 800 kg m^{-3}), and approximately spherical. It is therefore a comparatively typical coarse aerosol particle, which behaviour in the atmosphere is more or less known. However, already the birch pollen is bigger and heavier than a “typical” regionally-dispersed aerosol, which raises a set of questions regarding the existence of the whole phenomenon.

The three key questions to solve are: (i) whether the grain meets the assumptions behind all existing dispersion models, so that it can be treated as a “standard” (albeit coarse) atmospheric aerosol, (ii) what are the sources of pollen, their features and predictability by means of existing models; (iii) what are the features of such a pollutant, its physical and chemical transformations in the atmosphere and processes removing the grains from the air, which made it regionally- (or continentally-) dispersing?

There are two types of the European-wide observations that can be used for answering the above questions, as well as for the development, initialization and verification of the pollen transport model: phenological observations of the seasonal development of canopies, and measurements of the atmospheric pollen concentrations. The networks cover most of Europe in space, several decades in time, and numerous pollinating species, including the birch species. Some observations, such as those performed in Russia, are not reported to European databases and were added to the dataset.

The modelling systems of Finnish Meteorological Institute (FMI) are connected to operational meteorological data produced by the numerical weather prediction model HIRLAM, as well as to the databases of the European Centre of Medium-Range Weather Forecast (ECMWF). The HIRLAM model has been used operationally at the FMI since 1990 for the numerical weather predicting. Currently, the model produces 54-hour long forecasts four times a day covering Europe, Northern Atlantic and Western Russia. FMI participates also in the international HIRLAM development project.

There are several regional-scale birch forest inventories (e.g. Alexeyev& Birdsey, 1998, Köbler & Seufert, 2001), which will be used in combination with the satellite maps, in order to obtain a unified inventory of the birch forests in Europe and Western Russia. Information from satellites such as ERS and ENVISAT (MERIS) will provide the near-real-time vegetation growing index.

There are several semi-empirical models for predicting the start and duration of the flowering seasons. Descriptions of the flowering start time are based on three main principles: (i) climatological averaging of long-term observations (e.g., Rötzer & Chmielewski, 2001), (ii) heat sums (such as the so-called degree-days, and period units (Hänninen, 1990, Linkosalo, 2000 a,b, Luomajoki, 1999 and Sarvas, 1972) and (iii) dynamic models (e.g., promoter-inhibitor model of Schaber & Badeck, 2003). The climate-based values are available over the whole of Europe, while the methods (ii) and (iii) are usually based on local or, at best, country-wide observations, and are therefore not representative at a European scale.

The description of other parameters of flowering such as its intensity and the total amount of released pollen also require the use of semi-empirical models that predict the next-year flowering features, based on the conditions of the previous growing season (Masaka & Maguchi, 2001).

The development of the integrated model will be based on the emergency modelling system SILAM (Sofiev, 2002), (Sofiev & Siljamo, 2003), which is currently used for the operational forecasting of the consequences of potential emergency situations in the vicinity of Finland. The system is based on a so-called Lagrangian Monte-Carlo random walk dispersion model. The treatment of aerosol is based on a modal representation of the aerosol size spectrum and state-of-the-art parameterizations of the dry and wet deposition processes. The transport modules have been tested in the EU-funded ENSEMBLE project (http://ensemble.ei.jrc.it/), the ETEX project (http://rem.jrc.cec.eu.int/etex/) and the Nordic NKS MetNet (http://hirlam.fmi.fi/MetNet) project.

The block diagram of data, models and model evaluation of this study is presented in (Figure **1**).

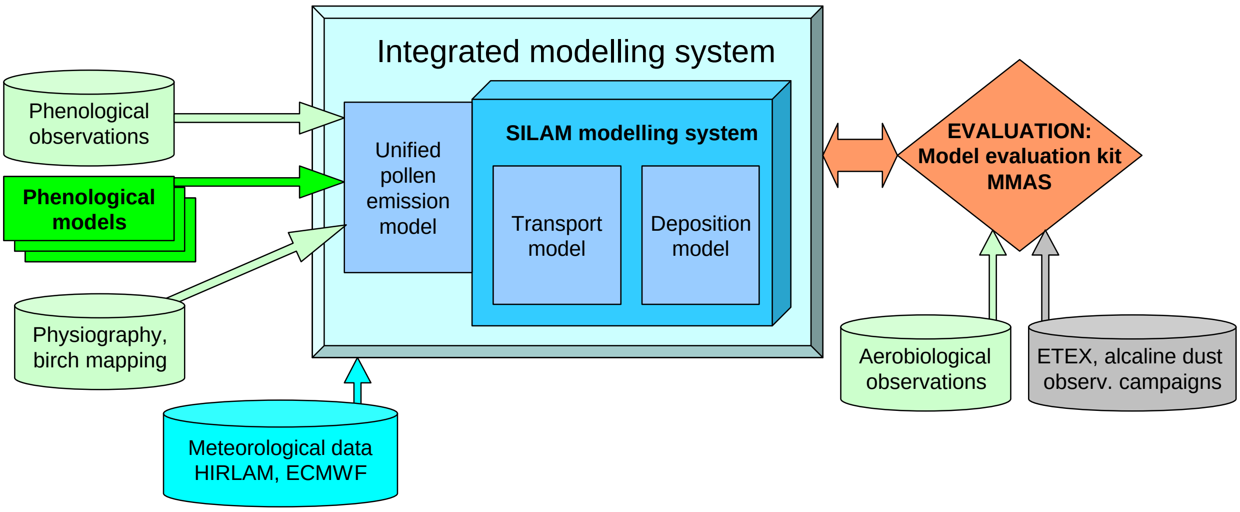

Figure 1. A schematic presentation of the utilization of the various input datasets, the integrated modelling system, and the evaluation of the system against experimental data.

3 RESULTS

The results presented in this section are largely based on a feasibility study conducted by the FMI and TU in 2003-2004. More examples of the model applications can be found in (Siljamo *et al.,* this issue). The primary goal of the feasibility study was to evaluate the problem and check the applicability of the existing technologies to simulating and forecasting the pollen long-range transport, in particular, by answering the three key questions listed in the introduction.

The first answer (applicability of existing dispersion models to pollen transport simulations) follows from a simple theoretical consideration. The dispersion models assume that the pollutant follows both the macro- and micro- air flows (i.e., both the mean wind and turbulent eddies). It is therefore enough to compare the inertia of the pollen grain with forces pushing it with the air streams. Using a spherical assumption on the grain shape, one can get that a typical relaxation time t and distance l depend on grain diameter *d* and density r_{part}, as well as on the air viscosity h:

$$t = \frac{d^2 r_{part}}{18h} \sim 10^{-3}\,\mathrm{sec}\,,\; l \sim 1\ mm$$

Evidently, the above values are small enough to satisfy the main assumption of the dispersion models: the (birch) grains are capable of following even small turbulent eddies. This consideration also allows computing an equilibrium settling velocity (using the Stoke's equation) that determines the dry deposition:

$$u = \frac{g r_{part} d^2}{18h}$$

Here *g* is the acceleration of gravity. For birch pollen, this velocity is: u » $1.2\ cm\ sec^{-1}$.

Wet deposition is less known. There is a classical work of Chamberlian (1953) that determined the sub-cloud scavenging due to impaction, while the in-cloud microphysics is uncertain. It is known that the grains tend to dry-up during the atmospheric transport in clear-sky conditions and refill with water inside clouds but quantitative studies of such processes are lacking. Therefore, at the current stage we accept the "standard" description of scavenging used in SILAM for broad-range particles, which was mainly parameterised using the Chernobyl data.

4 DISCUSSION

Considerably more difficult to tackle is the problem of pollen emission parameterization, i.e., the flowering description. As shown in the trial forecasts for 2004, long-term averages may not be representative for a specific year. Approaches relying on information on the real-time situation can be grouped into two classes:

- the "dynamical phenological emission" approach, that is based on empirical phenological models that compute the timing and intensity of flowering using historical and real-time meteorological parameters and previous-year flowering characteristics. There are several empirical models for the evaluation of flowering start-time: various heat sums (Hänninen,1990; Linkosalo, 2000a,b; Luomajoki, 1999, Sarvas 1972) and more sophisticated models, such as the promoter-inhibitor approach of Schaber and Badeck (2003).

- the "emission data assimilation" approach relies on real-time observations (satellite-born or in-situ) of the phenological processes. An example of satellite products that might be used is shown by Høgda *et al*., (2002). Another option is assimilating the real-time observed pollen concentrations directly into a dispersion model or using them to find out information about the grain sources – as in Sofiev & Atlaskin (2004)

So far, it is difficult to say in what form these methods will be most effective. Each of them has both strong and weak points, and none is ready for an immediate Europe-wide application – mainly due to the strongly regional and empirical character of all the above models. Their generalization for the whole of Europe is not straightforward. The computation of the emission source term thus remains the most challenging part of the pollen forecasting problem.

5 CONCLUSIONS

The long-range transport of allergenic pollen can significantly affect the local pollinating seasons well before or after the local flowering period. Such episodes are strong enough to cause harmful medical consequences and therefore require proper predictive methodologies, which have to be based on atmospheric dispersion models.

From general point of view, the pollen grain is quite close to a typical coarse aerosol but somewhat lighter and has lower threshold level of the significant concentrations, in relation to the near-source values. This makes it susceptible for regional scale of dispersion.

The key challenge in forecasting the pollen transport is in development of an adequate emission module. Available methodologies are of primarily local character or based on climatologic values and thus cannot be used for short-term Europe-wide simulations. A combination of such models and near-real-time satellite and in-situ observations might improve the accuracy of the forecasting.

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