MODELLING THE LONG-RANGE TRANSPORT, CONCENTRATIONS AND DEPOSITION OF ATMOSPHERIC POLLUTANTS IN POLAND - APPLICATIONS OF THE FRAME MODEL

MODELOWANIE TRANSPORTU, KONCENTRACJI I DEPOZYCJI ZANIECZYSZCZEŃ ATMOSFERYCZNYCH W POLSCE - ZASTOSOWANIA MODELU FRAME

Summary: FRAME (Fine Resolution Atmospheric Multi-pollutant Exchange) is a statistical Lagrangian atmospheric transport model. It has high spatial (5 km x 5 km) and vertical resolution (33 layers). The model was developed in the Centre for Ecology and Hydrology (Edinburgh, UK) and has successfully been used for modelling long-range transport and deposition of atmospheric pollutants. The model is used as a tool to support government policy in assessing the effect of abatement of pollutant gas emissions. The FRAME model has been recently adopted to work for the area of Poland. This study presents the spatial patterns of dry and wet deposition of SO\(_x\), NO\(_x\), and NH\(_x\) as well as the yearly average air concentrations of SO\(_2\), NO\(_x\), and NH\(_3\) for Poland for the year 2002. The model results are compared with the measurements. The modelled concentrations are found to be in a good agreement with observations, with a determination coefficient around 0.7 for SO\(_2\) and NO\(_x\). The NH\(_3\) concentrations are not routinely measured in Poland, therefore only the spatial pattern of air concentration is presented. FRAME dry and wet deposition of SO\(_x\), NO\(_x\), and NH\(_x\) was compared with the EMEP data and the measurement-based estimates provided by the IMWM (wet only). The calculated deposition budgets were found to be in close agreement. Spatial patterns of dry and wet deposition are generally similar to those reported by EMEP and CIEP/IMWM. Because of the higher spatial resolution of the FRAME model, the calculated depositions are locally higher, especially in the mountainous areas where the seeder-feeder effect is incorporated.

Keywords: atmospheric pollution, pollutant concentration, deposition, numerical modelling, FRAME, Poland

As the result of pollutant abatement policy on a national scale in Poland, since the beginning of the nineties, substantial reduction of gaseous emissions has been observed, with SO\(_2\) being reduced most [1]. Emissions of SO\(_2\) and NO\(_x\) have fallen by 69 and 29%, respectively, during the period 1980-2004, with further decrease of 44 and 51% over the next 15 years [2]. However, pollutant deposition is still high and often exceeds critical load limit values.

Atmospheric long-range transport models are important instruments to estimate the fate of pollutants and to understand the effects of changes in emissions. Until recently, the EMEP model [3] was the main source of information on long-range transport, air concentration and deposition of atmospheric pollutants. The main drawback of the EMEP model is coarse spatial resolution (50 km x 50 km).

This paper contains a general description and presents preliminary results of the modelling of SO\(_2\), NO\(_x\) and NH\(_3\) concentrations and SO\(_x\), NO\(_x\) and NH\(_x\) deposition for Poland with the fine resolution FRAME model. The results are compared with the EMEP and CIEP/IMWM (Chief Inspectorate of Environmental Protection, Institute of
Meteorology and Water Management) estimates as well as with the available measurements.

**Model outlook & input data**

A detailed description of the FRAME model can be found in papers [4-7]. Because of certain limitations, only the most important features are presented here.

FRAME is a national scale Lagrangian model with 5 km x 5 km horizontal resolution. The grid dimension is 160 by 160 grid squares and covers the whole area of Poland. Input gas and aerosol concentrations at the edge of the model domain are calculated with the FRAME-Europe model, using the EMEP expert emission inventory for Europe and run on the EMEP 50 km scale grid. An air column is divided into 33 layers moving along straight-line trajectories with a 1° angular resolution. The air column advection speed and frequency for a given wind direction is statistically derived from radio-sonde measurements [8]. Layer thickness varies from 1 m at the surface to 100 m at the top of the mixing layer. Vertical diffusion in the air column is calculated using K-theory eddy diffusivity and solved with the Finite Volume Method.

The model chemistry includes gas phase and aqueous phase reactions of oxidised sulphur and oxidised nitrogen, and conversion of NH$_3$ to ammonium sulphate and ammonium nitrate aerosol. The modelled chemical species treated include: NH$_3$, NH$_4^+$ aerosol, NO, NO$_2$, HNO$_3$, PAN, NO$_3^-$ aerosol, SO$_2$, H$_2$SO$_4$ and SO$_4^{2-}$ aerosol.

The point sources emissions of SO$_2$, NO$_2$ and NH$_3$ were taken from the EPER database [9]. The national totals of low level emissions of SO$_2$, NO$_2$, and NH$_3$, presented by the National Inventory Report 2002 [10], were spatially disaggregated based on census and traffic data provided by the National Statistical Office [11], the General Directorate for National Roads and Motorways, and the landcover map. The low-level emission of NH$_3$ was calculated separately for cattle, pigs, poultry and sheep and mixed into the lowest surface layers with a source-dependent emissions height. The low level emissions in the surrounding countries, which are partially in the model domain, were taken from the EMEP expert emission inventory.

The wind rose employed in FRAME uses 6-hourly operational radiosonde data from the stations of Wrocław, Legionowo, Łeba, Greifswald, Lindenberg, Prague, Poprad and Kiev, spanning the whole 2002 year period. High resolution maps of yearly precipitation, developed with the multidimensional interpolation method [12], were converted to the 5 km FRAME grid and used in simulations.

Wet deposition is calculated using a diurnally varying scavenging coefficient depending on mixing layer depth and a ‘constant drizzle’ approximation driven by a map of annual precipitation. Dry deposition is ecosystem specific and includes five land classes: forest, moorland, grassland, arable, urban and water.

**Results**

The SO$_2$, NO$_x$ (Fig. 1) and NH$_3$ (not shown here) concentrations, calculated with the FRAME model, are highest close to the low level emission sources. The spatial patterns presented here are generally similar to those calculated with the EMEP model, though
FRAME modelled concentrations are locally higher. This is because of the high spatial and vertical resolution of the FRAME model.

FRAME modelled concentrations of SO$_2$ and NO$_x$ are in close agreement with measurements [13], with the determination coefficient close to 0.7 for both species. For certain monitoring stations, the model underestimates the concentrations. FRAME was not able to reflect the measured high concentrations on the four urban stations located close to the main roads. NH$_3$ concentrations are not routinely measured at monitoring stations in Poland, therefore it is not possible to validate the model estimates in a similar way.

The general pattern of the FRAME modelled dry and wet deposition is similar to that calculated by the EMEP model. The largest discrepancies are found for the dry deposition of NH$_x$ (Fig. 2), as the FRAME model shows high spatial variation. For the mountainous areas, FRAME shows significantly higher wet deposition of SO$_x$, NO$_y$ and NH$_x$ than the EMEP model. The main peaks are in the Western Sudety Mts. and Beskid Żywiecki (SW and S Poland). This occurs due to the seeder-feeder mechanism [14] incorporated in the high-resolution FRAME model, contrary to the coarser-resolution EMEP model which may not capture fine scale orographic precipitation effects. The detailed measurement-based annual precipitation map used for the FRAME simulation can also positively influence the results. FRAME modelled wet deposition of SO$_x$, NO$_y$ and NH$_x$ was checked against the available measurements showing good agreement, with an $R^2$ of 0.76, 0.72 and 0.46 for NH$_x$, NO$_y$, and SO$_x$, respectively.

![Fig. 1. FRAME modelled yearly average air concentrations of SO$_2$ (a) and NO$_x$ (b)](image)

<table>
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<tr>
<th>Table 1</th>
<th>Dry, wet and total deposition of SO$_x$, NO$_x$, and NH$_x$ for Poland (Gg of S or N per year; 2002)</th>
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The FRAME modelled wet, dry and total deposition budgets for SO$_2$, NO$_x$ and NH$_x$ were checked against the results obtained with the EMEP model and interpolation-based estimates of wet deposition calculated by CIEP/IMWM [13] for the year 2002 (Tab. 1). FRAME dry deposition budget is generally slightly lower than that reported by EMEP whereas wet deposition budget is in close agreement with the CIEP/IMWM estimates.

Fig. 2. FRAME (left column) and EMEP (right) dry (upper row) and wet (bottom) deposition of NH$_x$

**Conclusions**

The Fine Resolution Atmospheric Multi-pollutant Exchange model, originally developed for the United Kingdom, was used to assess the spatial patterns of yearly averaged air concentrations and wet and dry deposition for the area of Poland with 5 km by 5 km resolution. The modelled concentrations and wet deposition are in close agreement
with measurements and deposition budget estimates provided by the EMEP and CIEP/IMWM. The FRAME model, despite its relatively simple meteorological parameterisations, is well suited to calculate average annual concentration and deposition of pollutants for Poland.

References

powietrza GIOŚ. Stwierdzono duży zgodność modelu FRAME z pomiarami, wyrażoną współczynnikiem determinacji na poziomie ok. 0,7 (dla obu związków). Ze względu na to, że rutynowe pomiary koncentracji zanieczyszczeń, prowadzone w sieci IOŚ, nie obejmują stężenia NH₃, wykonanie podobnej analizy dla amoniaku nie jest możliwe. Bilanse suchej i mokrej depozycji SOₓ, NOₓ i NH₃, obliczone na podstawie map depozycji uzyskanych za pomocą modelu FRAME, są zbliżone do danych raportowanych przez EMEP i GIOŚ/IMGW (tylko mokra depozycja). Mapy depozycji obliczone modelem FRAME są podobne w ogólnym zarysie do prezentowanych przez dwa pozostałe źródła. Różnią się głównie ze względu na dużą rozdzielczość przestrzenną FRAME, która pozwala uwzględnić procesy działające w małej skali (np. efekt seeder-feeder).

Słowa kluczowe: zanieczyszczenie powietrza, koncentracja zanieczyszczeń, depozycja, modelowanie numeryczne, FRAME, Polska