COMPARISON OF SPATIAL RAINFALL DATA CALCULATED WITH A METEOROLOGICAL MODEL AND FROM MEAUREMENTS – IMPLICATIONS FOR ESTIMATION OF WET DEPOSITION WITH THE FRAME MODEL

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Abstract: The aim of this work is to quantify the differences between the two different sources of spatial information of precipitation on FRAME modelled wet deposition of oxidised sulphur, nitrogen and reduced nitrogen for the two selected years 2007 and 2008 for the area of Poland. For each year, atmospheric transport model FRAME was run twice, each time with different precipitation data. The first precipitation dataset was calculated with the WRF model (pWRF). The second was based on simple interpolation of measured precipitation with ordinary kriging (pOK). On average, the WRF model gives lower annual precipitation sums (country average 666 mm and 545 mm for years 2007 and 2008, respectively, vs 710 and 634 mm for pOK). The spatial allocation of precipitation is also different, with grid to grid correlation between the pWRF and pOK datasets at 0.71 and 0.69 for years 2007 and 2008. SO_x, NO_y and NH_x wet deposition calculated with pWRF precipitation gives lower minimum and country mean values if compared with pOK. The maximum values are higher for pWRF precipitation. Grid to grid correlation between pOK and pWRF modelled wet deposition is similar for both years, but differs between chemical species, with the lowest values for NH_x (0.46 for year 2007 and 0.48 for 2008) and the highest for SO_x (0.72 and 0.78 for years 2007 and 2008, respectively). The model-measurement agreement is generally better for the pOK FRAME run.

Key words: *wet deposition, sulphur, nitrogen, rainfall interpolation, modelling.*

INTRODUCTION

Spatial information on rainfall is of major importance for air quality modelling, as precipitation is responsible for the removal of chemical compounds from the atmosphere through wet deposition. Wet deposition is the pathway for the majority of the total mass of sulphur and nitrogen compounds deposited in Poland (Kryza et al. 2010) and in the United Kingdom (Matejko et al. 2009). For simple statistical atmospheric transport models like the Fine Resolution Atmospheric Multi-pollutant Exchange (FRAME), rainfall data is usually provided by spatial interpolation of the measurements gathered at meteorological stations. This approach is relatively simple, but highly dependant on the density of the measuring sites, especially over areas of complex terrain. On the other hand, mesoscale meteorological models, like Weather Research and Forecasting (WRF; Skamarock et al. 2008), can also be used to provide spatial information on rainfall for the FRAME model. The uncertainty here is related with other issues, e.g. parameterization of the cumulus processes, especially at high spatial resolution of several kilometres, which is a case of the FRAME model, used here for the area of Poland with 5km x 5km mesh.

The aim of this work is twofold. First, the WRF and interpolated rainfall fields are spatially compared. Second, the differences between the FRAME modelled wet deposition of sulphur and nitrogen compounds with interpolated and WRF-derived rainfall are assessed for the two selected years 2007 and 2008 and the area of Poland.

DATA AND METHODS

The FRAME model description and application

FRAME is a Lagrangian statistical trajectory model that has been used by the UK and Poland to support environmental management and protection. A detailed description of the model can be found in Singles et al. (1998), Fournier et al. (2004), and Dore et al. (2007). Details of the model configuration specific to Poland are provided by Kryza et al. (2010). The model describes the main atmospheric processes taking place in a column of air moving along straight-line trajectories. Here, version 9.3 of the model was applied for the area of Poland with 5km x 5km spatial resolution (160 x 160 grid squares). Vertically the domain consists of 33 layers of varying thickness, from 1 m at the surface to 100 m at the domain top (2500 m).

The annual country total emission inventory for years 2007 and 2008 was available after KOBIZE (2012) for SO_2, NO_x (as NO_2) and NH_3. The gridded information for the FRAME model was prepared according to the method presented by Kryza et al. (2010). The boundary conditions for the FRAME model were calculated with the FRAME-Europe model, which runs for the whole Europe with a 50km x 50km grid resolution.

Rainfall data

Two sets of precipitation data were prepared for the FRAME model. The first one was developed with a geostatistical approach and is based on the precipitation measurements gathered at 231 meteorological stations in Poland and neighbouring countries. The measurements were spatially interpolated with the ordinary kriging approach (Cressie 1991; Wałaszek et al. 2013). In the first step of the ordinary kriging interpolation, the relative differences between the measured rainfall and long term gridded precipitation were calculated for all sites. The long-term gridded precipitation data were taken after Kryza (2008), and regridded onto the 5km x 5km FRAME model mesh. The relative differences were spatially interpolated to 5km x 5km grid using ordinary kriging. The gridded long-term rainfall map was multiplied by the gridded relative differences for each year considered.

The second set of the rainfall data for years 2007 and 2008 was derived with the WRF model (Skamarock et al. 2008). The WRF model was configured using two one-way nested domains, as presented by Kryza et al. (2012). The outermost domain covers the entire Europe with 50km x 50km grid. The nested domain covers the area of Poland and neighbouring countries with a 10km x 10km grid. Vertically, the domains are composed of 35 terrain-following hydrostatic-pressure vertical coordinate, with the top fixed at 10 hPa. The model was run with the Yonsei University planetary boundary layer scheme and the MM5 similarity theory for surface layer, the Goddard scheme for microphysics and the Kain-Fritsch scheme for cumulus parameterization. The simulations for years 2007 ad 2008 were driven by the NCEP final analysis, available every 6h with 1^{o} x 1^{o} spatial resolution. The analysis nudging was applied for both d01 and d02, for all model runs (Otte, 2008). The WRF rainfall was calculated with a 10km x 10km spatial resolution and resampled to the 5km x 5km FRAME model grid using regularized spline with tension (Mitasova and Mitas, 1993).

The interpolated and WRF calculated precipitation fields were presented on maps. Country-wide statistics were used to compare two precipitation datasets, including country-average rainfall and the grid-to-grid Pearson correlation coefficient.

Evaluation of the FRAME modelled wet deposition

The FRAME model was run twice for each year, each time with different rainfall data: interpolated with ordinary kriging approach (pOK) and calculated with the WRF model (pWRF). FRAME derived wet deposition of sulphur and nitrogen compounds was compared with the wet deposition measurements gathered at 25 stations in Poland. The measurements of wet deposited SO_x, NO_y and and NH_x were gathered with wet-only collectors. The FRAME model error was calculated for each site as a difference between the modelled and observed wet deposition, and summarized using three statistics: mean bias (MB), mean absolute error (MAE) and Pearson correlation coefficient (Cor). For each chemical compound considered, year and rainfall field, the national wet deposition budget was calculated to quantify the impact of precipitation data on wet deposition at the country scale. The national wet deposition budgets calculated with the pOK and pWRF runs were also compared with the European scale EMEP-Unified model and the interpolation based wet deposition estimates provided by the Institute of Meteorology and Water Management (IMGW).

RESULTS

Spatial patterns of interpolated rainfall are presented in Fig. 1. Country average precipitation varies from 710 mm in year 2007 to 634 mm in year 2008. The largest amount of rainfall falls in the mountains in the south of the country. The second area of above the average precipitation is in the north. The large areas of central Poland have precipitation below the country average. The WRF calculated rainfall is in general agreement with the interpolated values, with the grid to grid correlation at 0.71 and 0.69 for years 2007 and 2008, respectively. The WRF derived precipitation is smaller if compared to interpolated values, with the country average values at 666 and 545 mm for years 2007 and 2008. There are some similarities between the spatial distributions of pWRF/pOK relative differences if both years are compared. The WRF-derived rainfall is higher than pOK for the mountain areas in the south and the regions close to the Baltic Sea in the north. The tendency is reversed for the central areas of the country, where WRF precipitation is significantly lower if compared to pOK.

Spatial patterns of FRAME modelled wet deposition are presented for the pOK simulations for years 2007 and 2008 and for reduced nitrogen only (Fig. 2). Wet deposition of NH_x is the highest in the central area of Poland, which is the source area for the NH_3 emissions, and in the mountains in the south due to high annual precipitation. Similar spatial patterns are also calculated for oxidised sulphur and nitrogen.

Spatial pattern of relative differences in wet deposition between the pOK and pWRF runs are similar for all chemical pollutants in a given year. The largest differences are found for the areas for which the largest differences in pOK and pWRF precipitation were calculated. There is strong grid to grid correlation between the relative differences in rainfall and wet deposition, with the Pearson correlation coefficient close to 1 for both years and all pollutants.

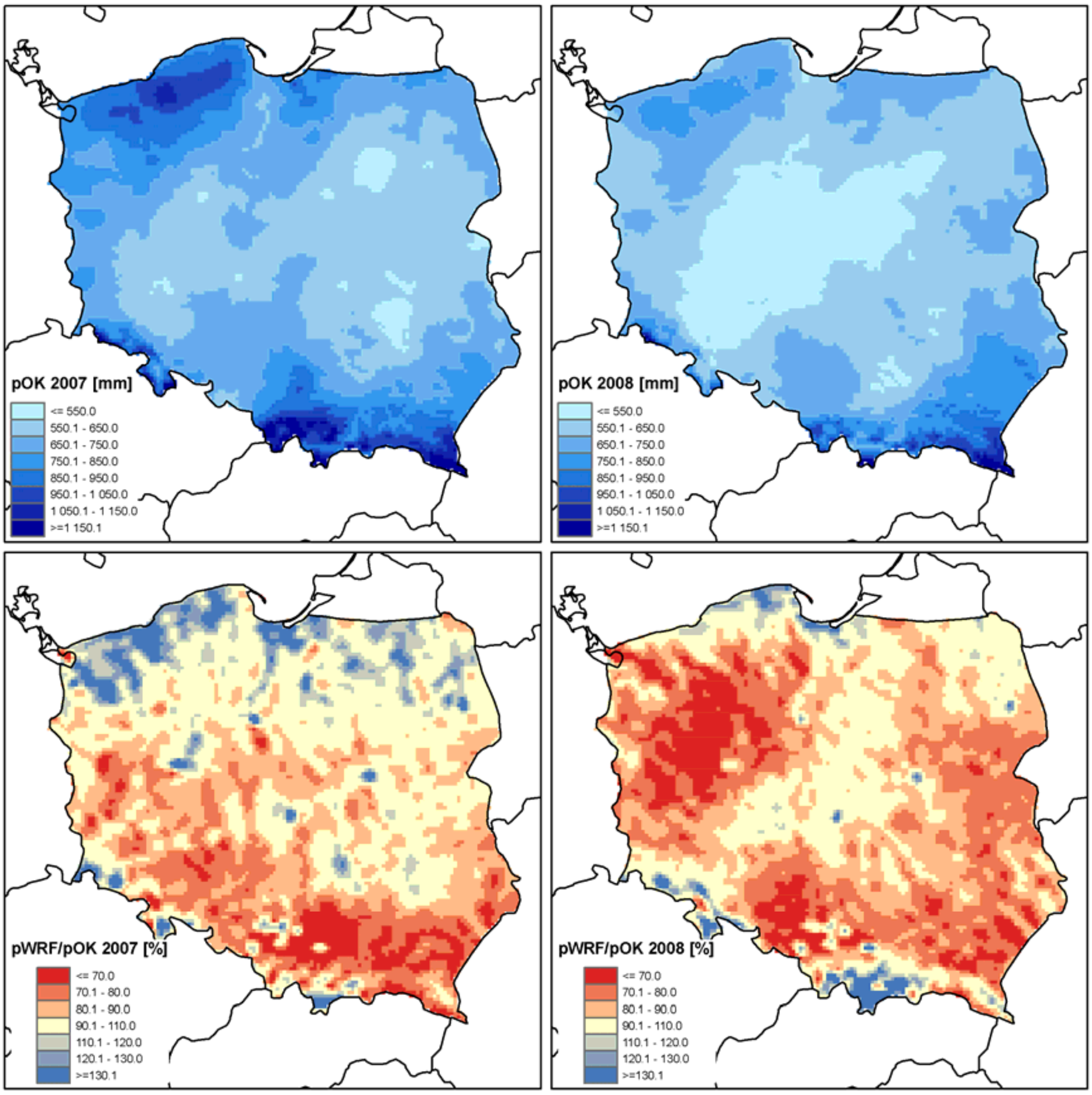

Fig. 1 Interpolated precipitation (top row) and relative differences between the WRF and interpolated rainfall (bottom) for years 2007-2008

The change in rainfall field used for wet deposition modelling with the FRAME also has a large impact on the national deposition budget for all chemical components considered. Because the WRF calculated rainfall is smaller than pOK, the national wet deposition budget is also smaller for pWRF FRAME model runs (Fig. 3). The differences in wet deposition budget for the year 2008 are larger than for year 2007. Noticeably, there are also large differences between the pOK and pWRF FRAME model runs and the deposition budget of sulphur and ammonia calculated by EMEP and IMGW approaches. The EMEP wet deposition budget is close to pWRF runs, with the exception of NO_y for the year 2007. The IMGW estimates, which are based on spatial interpolation of wet deposition measurements, show the highest values with the exception of NO_y wet deposition budget. The differences between the various estimates of national wet deposition budget are the largest for reduced nitrogen.

The pOK FRAME model runs show better agreement with the measurements if compared to pWRF in terms of all chemical species and years considered (Table 1). The only exception is MB for reduced nitrogen, for which pWRF runs are closer to zero than pOK. This can be linked with generally lower rainfall produced by the WRF model, and overestimation of wet deposition by the pOK runs.

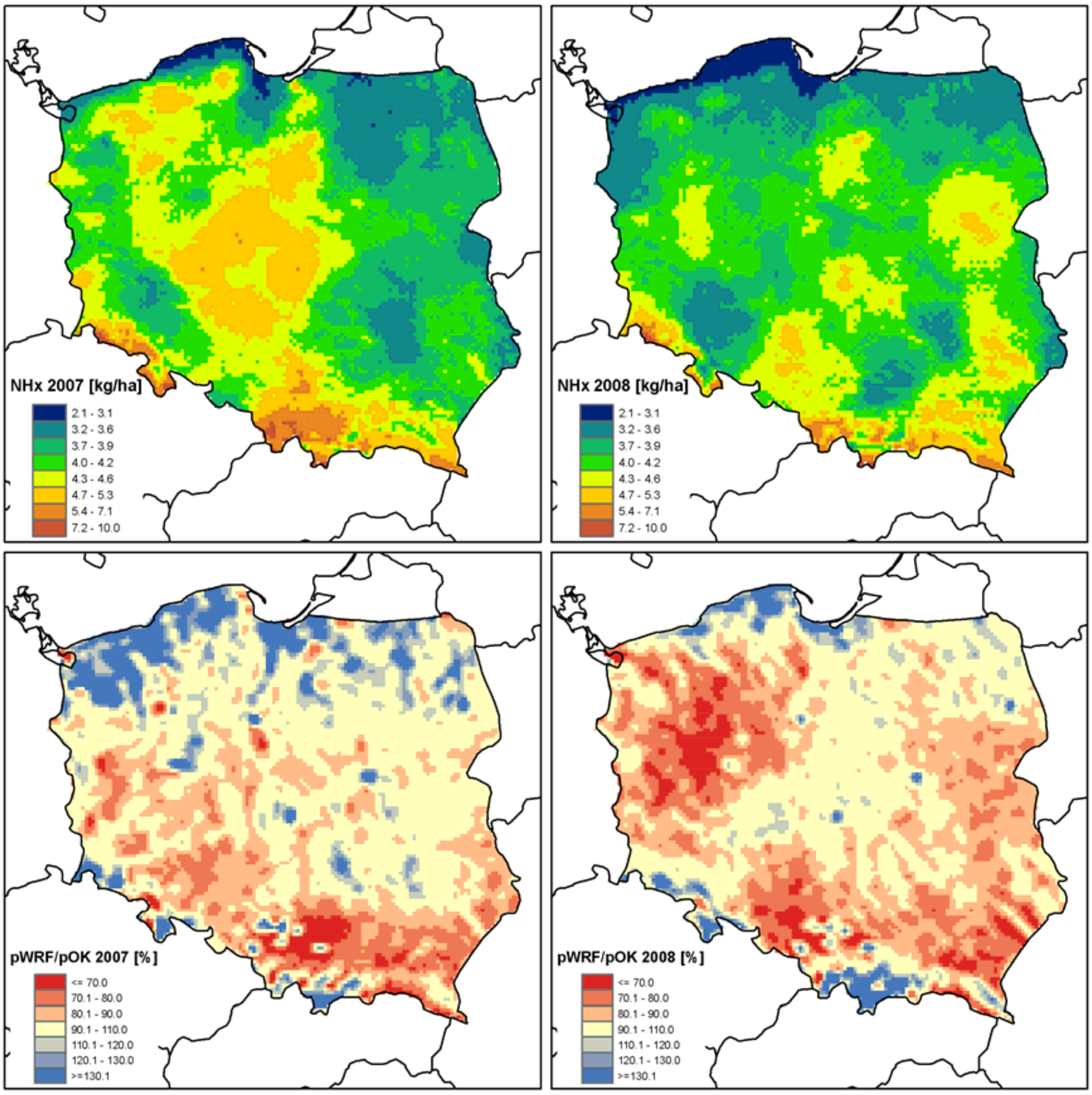

Fig. 2 Modelled wet deposition of NH_x (with pOK, top row) and relative differences between the pOK and pWRF modelled wet deposition of NH_x (bottom row)

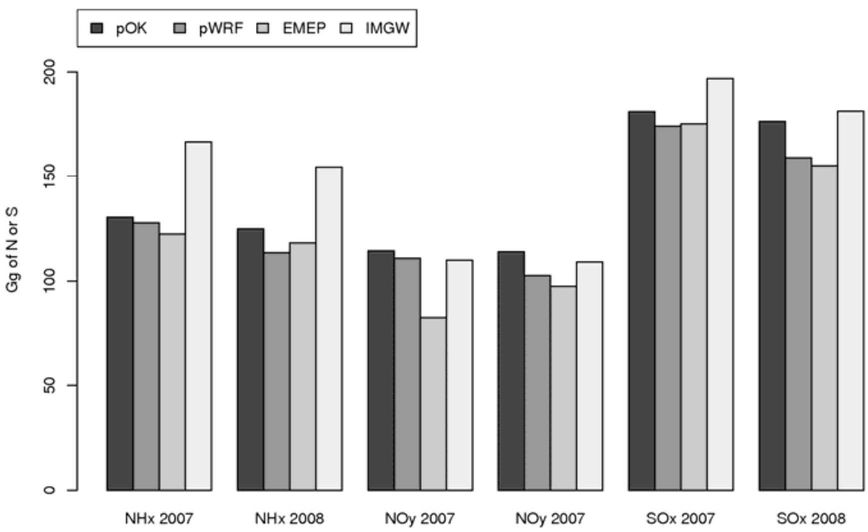

Fig. 3 National deposition budget for NH_x, NO_y and SO_x modelled with FRAME, EMEP and provided by spatial interpolation approach used by IMGW.

Table 1 Evaluation of the pOK and pWRF FRAME model runs for years 2007 and 2008

	year 2007						year 2008					
	MB		MAE		Cor		MB		MAE		Cor	
	pOK	pWRF	pOK	pWRF	pOK	pWRF	pOK	pWRF	pOK	pWRF	pOK	pWRF
NH_x	0.78	0.62	1.14	1.43	0.63	0.47	0.57	0.54	0.91	1.20	0.67	0.49
NO_y	-0.49	-0.55	0.71	0.84	0.79	0.68	-0.55	-0.55	0.64	0.90	0.70	0.59
SO_x	-0.29	-0.37	1.60	1.88	0.74	0.66	-0.75	-0.77	1.69	2.04	0.63	0.55

SUMMARY AND CONCLUSIONS

The FRAME model was run with two different rainfall datasets to calculate spatial patterns of wet deposition of sulphur and nitrogen in Poland for year 2007 and 2008. The following conclusions can be drawn from the study:

- There is general agreement between the interpolated and WRF-calculated annual rainfall field. The WRF modelled precipitation is lower that interpolated for the majority of the country area. This might be related to the WRF model configuration applied, especially the cumulus scheme used (Kuell et al. 2007).
- There are large differences in the national wet deposition budget calculated with pOK and pWRF FRAME model runs, especially for reduced nitrogen. There are also large discrepancies if pOK and pWRF deposition budgets are compared with the EMEP and IMGW estimates. This shows relatively large uncertainties in wet deposition estimates due to different meteorological input used and methods applied.
- The FRAME model – measurements agreement is better if interpolated rainfall is used for wet deposition calculation. Application of WRF calculated precipitation leads to larger model-measurements errors.

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