Modelling emission, concentration and deposition of sodium for Poland

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1. INTRODUCTION

Sodium (Na^+), as well as chlorine and magnesium, is a major component of sea salt aerosol (SSA). Sodium, as a base cation, changes the surface pH when deposited, causing an increase in alkalinity and neutralizing the effects of acidity generated by sulphur and nitrogen deposition (Gong et al. 1997). Besides SSA, sodium also originates from land sources, both anthropogenic and natural. On average, the most significant anthropogenic contribution to sodium emission is from combustion in the manufacturing industry, sinter production in iron production as also domestic and power station coal burning (NAEI, www.naei.org.pl). Natural land emission mainly comes from soil surface erosion – wind blown dust (WBD).

Here we present the results of Na^+ emission estimations both anthropogenic and natural for Poland for the year 2007. The calculated maps of Na^+ emissions were used in the Fine Resolution Atmospheric Multi-pollutant Exchange model to obtain mean annual concentrations and wet deposition at the 5km x 5km spatial resolution for Poland. The modelled results were compared with measurements of wet deposition from the National Monitoring Network.

2. DATA AND METHODS

2.1. Emission estimations

Sea salt aerosol emission

For the smallest particles (r_{80}<0.8µm) parameterisation of Monahan et al. (1986), modified by Gong (2003), was used. For larger particles (0.8<r_{80}<4.0 µm) Monahan et al. (1986) was used, and for particles of r_{80}>4.0 µm, the formula of Smith and Harrison (1998). All functions describe the surface flux at 10m above the ocean of sea-spray aerosol, i.e. the number of droplets produced per unit surface area and per unit time.

Land emission

For Poland, there is no spatial information of Na+ emission for anthropogenic or natural sources. Na^+ anthropogenic emission was calculated using PM10 emission inventory and activity factors reported by the Polish Chief Inspectorate of Environmental Protection (CIEP). To calculate natural emission of Na^+ from soil erosion, the estimation of PM10 wind blown dust emission from NatAir project (Korcz et al. 2009) and concentration of Na^+ in topsoil were used (Geochemical Atlas of Europe, www.gsf.fi/publ/foregsatlas/).

2.2. FRAME model description

The atmospheric transport model, FRAME provides information on the annual mean deposition and concentrations of atmospheric pollutants. A detailed description of the FRAME model is provided by Singles et al. (1998), Werner et al. (2011).

The FRAME model was run with emission information prepared according to the methodology described above and meteorology data for the year 2007. Because there are no measurements of Na^+ air concentrations in Poland, FRAME modelled wet deposition was compared with measurements gathered at 25 stations of the Polish Chief Inspectorate of Environmental Protection (CIEP).

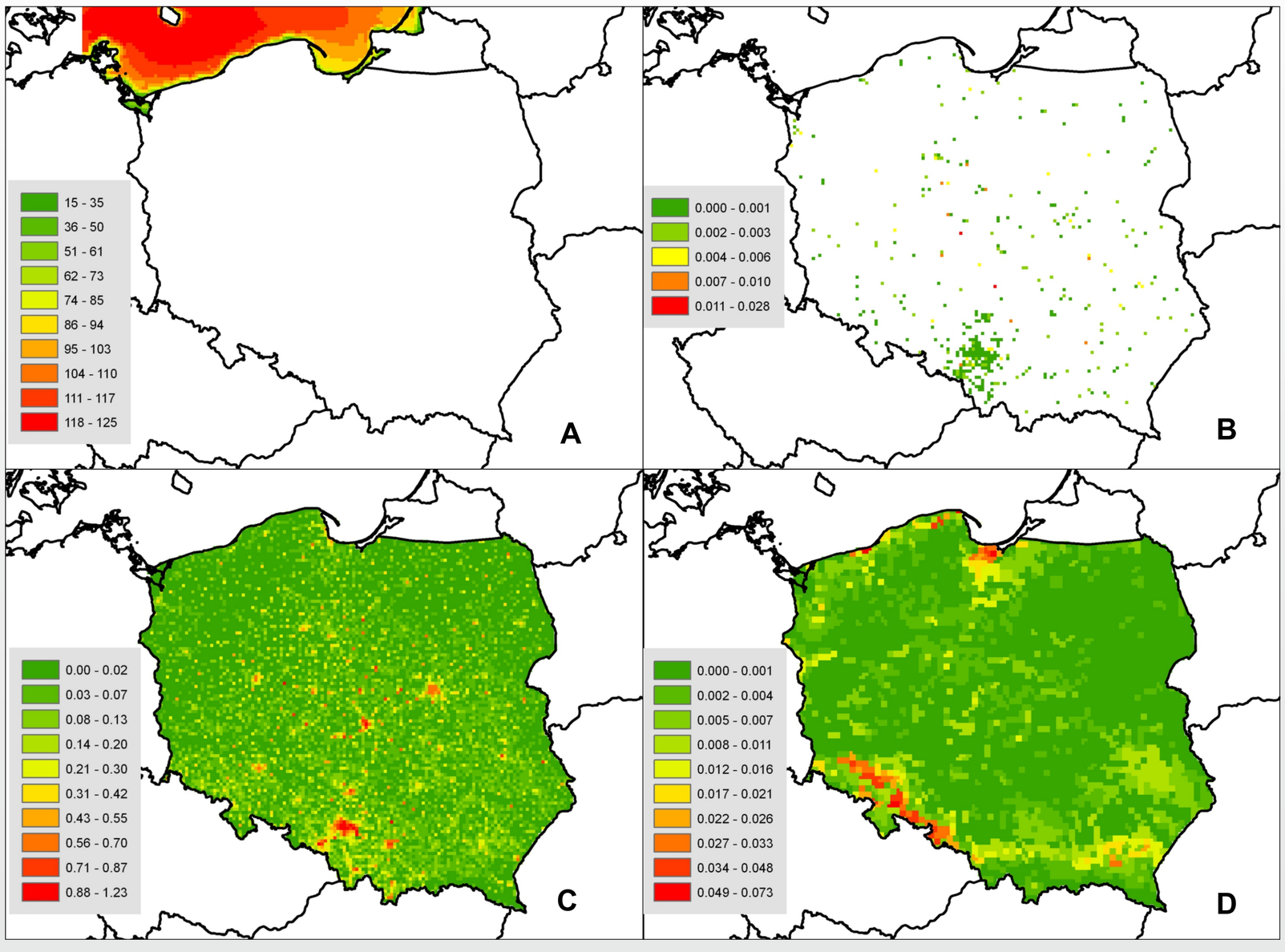

Fig 1. Sodium emission for Poland : (A) SSA (B) anthropogenic point sources (C) anthropogenic area sources (D) WBD [area: kg ha^{-1} year^{-1}, point sources: Gg]

3. RESULTS

The highest values of marine Na^+ emissions are noted for regions with the highest wind speed (Fig. 1). For the central areas of the Baltic Sea, Na^+ emission exceeds 100 kg ha^{-1} year^{-1}. Lower values are evident in bays and in general near the coastline. In case of Na^+ wind blown dust emisison over the land, increased values correspond to the high emission of PM10 (Delta of Wisla, Lower Silesia, Lubelska Upland, Fig. 1). The land anthropogenic emission, WBD emission and import from the Baltic Sea and North Atlantic Ocean contribute to 3.5 Gg, 0.19 Gg and 720 Gg of the annual total emission in he model domain, respectively.

Spatial information on Na^+ deposition and concentration, calculated with FRAME, is presented in Fig. 2. The concentrations are particularly high over the source Baltic Sea region. A gradient in concentration is observed from the coastal region towards S and SE over land. An average yearly concentration of sodium amounts to 1.9 µg m^{-3} for the entire domain, with the maximum exceeding 20 µg m^{-3} over the the north – west region. Similarly, the highest value of wet deposition is on the north – west Poland, where amounts of 20 kg ha^{-1} year^{-1} and locally 30 kg ha^{-1} year^{-1} are reached. Additionally, higher concentrations on the west could be also related to the predominant westerly wind directions bringing air masses formed over the North Atlantic.

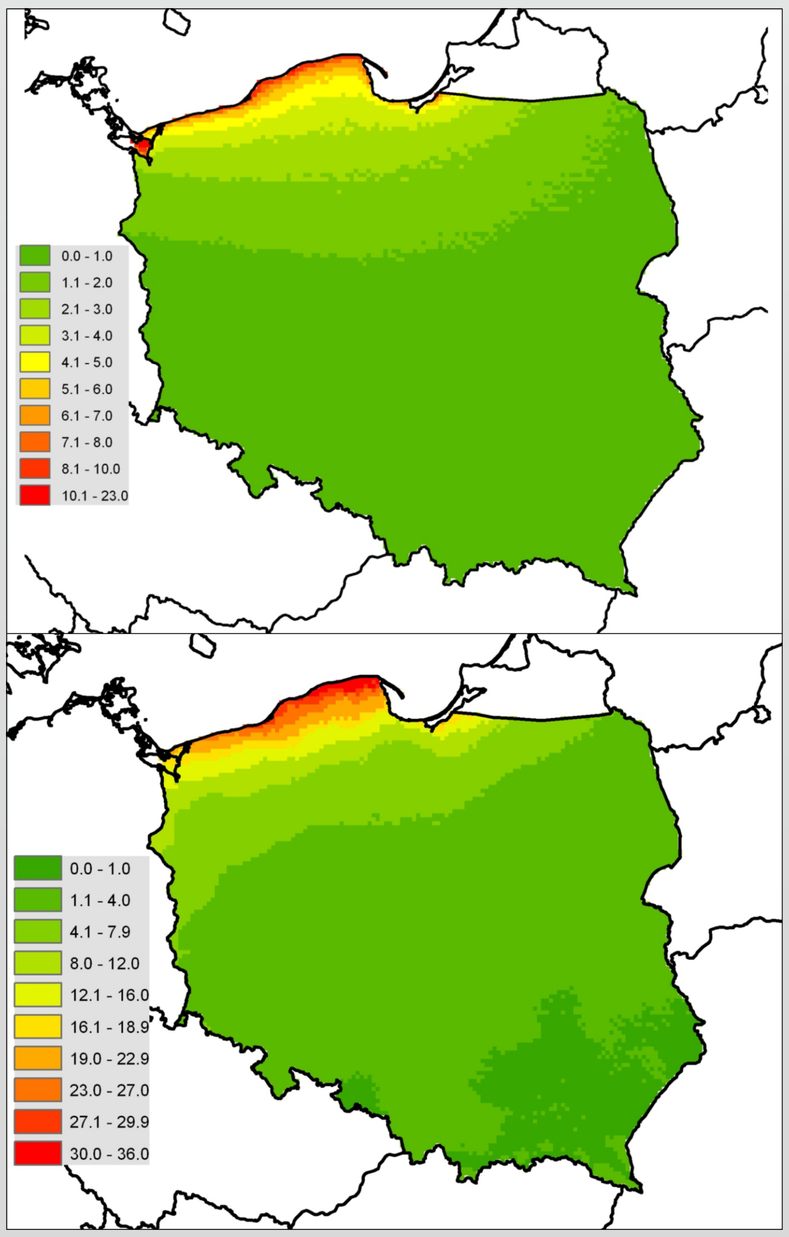

Fig 2. Sodium concentration [top, ug m^{-3}] and wet deposition [bottom, kg ha^{-1} year^{-1}] for year 2007.

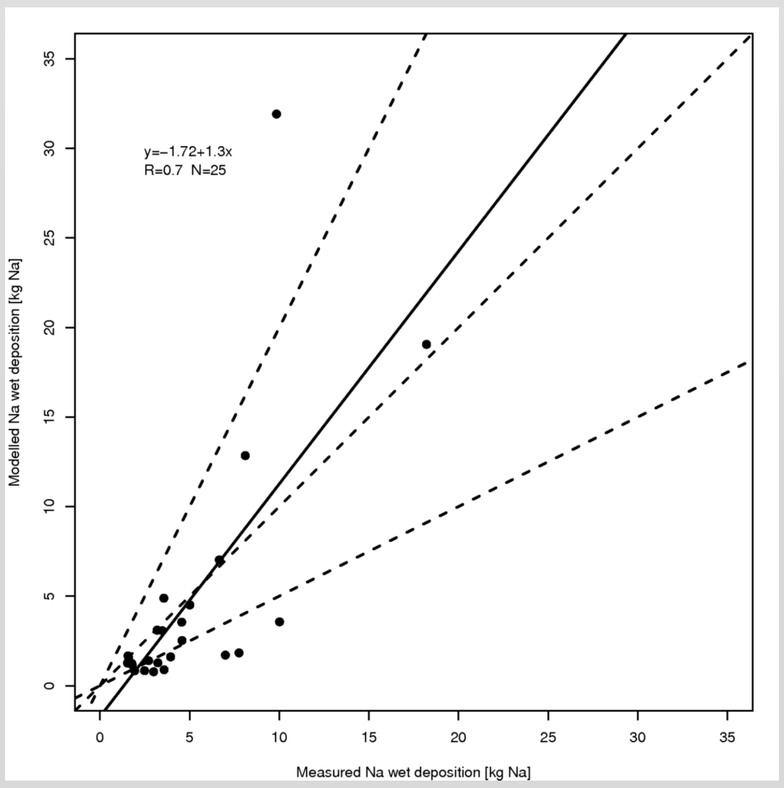

Fig 3. Comparison of FRAME and measured data for Na wet deposition.

The comparison of the FRAME modelled and measured values of wet deposition is presented in Fig. 3. There is no general tendency for underestimation or overestimation by the model. In general the agreement between modelled and measured values is reasonable, with correlation coefficient equal 0.7 and mean absolute error equal 2.6 kg ha year^{-1}. The highest overestimation appears for one out of three coastal stations – Łeba, whereas the highest underestimation is for mountainous stations –Kasprowy Wierch and Śnieżka.

4. SUMMARY

Although Poland is not a typical coastal country, the main source of sodium is the aerosol produced from the sea surface both from the Baltic Sea and Atlantic Ocean. There is a very low contribution of natural land emission. This estimation was based on PM10 WBD emission calculated by the NatAir project which is characterised by large uncertainty. Further work is needed to improve estimations of natural land emission. Spatial patterns of Na^+ air concentrations, modelled with FRAME and presented here, show the gradient from the coastal region towards low concentrations over land. The wet deposition gradient from the north west to the east is related with the dominant westerly wind directions bringing oceanic masses of air. Locally, an increase in wet deposition also appears in the Sudety Mountains. As this is an area of special environmental protection, increased deposition is of special importance for ecosystems conservation.

The comparison of FRAME results with measurements showed that the model was capable of predicting the spatial distribution of sodium. The model result of Na+ wet deposition was found to be in reasonable agreement with measured wet deposition. The highest overestimation was noticed in Łeba, but for the others coastal stations overestimation did not appear. Further work will concern modelling remaining elements of base cations (Mg^{2+}, Ca^{2+}, K^+), for which greater contributions are from anthropogenic and natural land emission.

REFERENCES

Gong, S. L, L.A. Bartie, J.P. Blanchet, 1997: Modeling sea-salt aerosols in the atmosphere. Model development. J. Geophys. Res., 102, 3805–3818.

Gong, S. L, 2003: A paramterization of sea-salt aerosol source function for sub- and super-micron particles. J. Geophys. Res, 17, 1097.

Korcz, M, J. Fudala, C. Klis, 2009: Estimation of wind blown dust emissions in Europe and its vicinity. Atmos Environ., 43, 1410-1420.

Monahan, E.C, D.E. Spiel, K.L. Davidson In: Monahan, E.C., Mac Niocaill, G. (Eds.), 1986: Oceanic Whitecaps., Riedel, Norwell, MA, 167–174 pp.

Singles, R. J, M. A. Sutton, K. J. Weston, 1998: A multi-layer model to describe the atmospheric transport and deposition of ammonia in Great Britain. Atmos Environ, 32, 393–399.

Smith, M. H, N. M. Harrison, 1998: The sea spray generation function. J. Aerosol Science, 29 (Suppl. 1), 189–190.

Werner, M, M. Kryza, A. J. Dore, M. Błaś, S. Hallsworth, M. Vieno, Y. S. Tang, R. I. Smith, 2011: Modelling of marine base cation emissions, concentrations and deposition in the UK. Atmos. Chem. Phys., 11, 1023–1037.