FINE SCALE APPLICATION OF THE EMEP UNIFIED AIR POLLUTION MODEL TO THE UNITED KINGDOM

Massimo Vieno[1,3], Peter Wind[2], Keith J. Weston[1],
Anthony J. Dore[3] , Leonor Tarrasón[2] and Mark A. Sutton[3]
[1]Institute for Atmospheric and Environmental Science, School of Geosciences, University of Edinburgh, Edinburgh, United Kingdom
[2] Norwegian Meteorological Institute, Blindern, Oslo, Norway
[3] Centre for Ecology and Hydrology Edinburgh, Bush Estate, Penicuik, United Kingdom

INTRODUCTION

The EMEP Unified Model (Simpson *et al.,* 2003 and Tarrasón (ed.), 2003) is an Eulerian atmospheric transport model used to evaluate concentrations and deposition of various pollutants across Europe. The model predictions include all the major chemical species that cause acidification, eutrophication, photochemical oxidants and atmospheric particulate matter.

In a joint effort between the University of Edinburgh, CEH Edinburgh and the Norwegian Meteorological Institute, the Unified EMEP model is presently been applied with increased spatial resolution over the United Kingdom. The new application is intended to allow mesoscale atmospheric transport model calculations over the British Isles. However for the present study, only the emissions and land surface associated with the United Kingdom have been included.

The new model application is called EMEP4UK and is effectively the same model as the Unified EMEP model implemented at the much finer horizontal resolution of 5 x 5 km^2. Initial and boundary conditions are directly interpolated from the 50 x 50 km^2 Unified EMEP model output. At these preliminary stages of development, the same vertical structure of the troposphere as in the Unified EMEP Model is used. The model is defined vertically with 20 layers of increasing thickness, from the surface up to ~16 km of height using the so-called σ coordinates. The relationship to convert pressure coordinates to sigma coordinates is:

$$\sigma = \frac{p - p_t}{p_*} \qquad (1)$$

where $p_* = p_s - p$ and p, p_t and p_s are pressure at level σ, pressure at the top of the vertical boundary (100 hPa) and pressure at the surface, respectively.

The main equation describing transport, chemical transformation, emissions and deposition in EMEP4UK, is the continuity equation shown in equation (2):

$$\frac{\partial Cp_*}{\partial t} = -m^2 \nabla_H \cdot \left(\frac{V_H Cp_*}{m} \right) - \frac{\partial \sigma Cp_*}{\partial \sigma} + \frac{\partial}{\partial \sigma} \left(K_\sigma \frac{\partial Cp_*}{\partial \sigma} \right) + \frac{p_* S}{\rho} \qquad (2)$$

where C is the mixing ratio in air, m is a scaling factor related to the polar stereographic projection, V_H is the horizontal speed, σ is the first derivative of σ with respect to time, K_σ is the vertical eddy diffusivity coefficient, S is the source/sink term, and finally ρ is the air density.

The mesoscale model application requires new sets of meteorological and emission input data. The availability and reliability of these refined input data will influence the quality of the atmospheric transport simulations of the EMEP4UK. For this study, only some preliminary input datasets have been used. The model input datasets used for this study are: a) the ERA40 data reanalysis originally in ~125 x 125 km^2 has been interpolated down to at 5 x 5 km^2 for the meteorological fields and parameters; b) the national atmospheric emissions inventory (NAEI, www.naei.org.uk) from NETCEN for the nitrogen dioxide and sulphur dioxide emissions; c) the ammonia emissions are from CEH Edinburgh, and d) all the remaining emissions have been interpolated from the 50 x 50 km^2 EMEP emissions inventories. For this preliminary test, land-use and other input data have also simply been interpolated from a 50 x 50 km^2 grid.

MODEL RESULTS

The EMEP4UK model is applied to the UK for the year 2001. The model is run for January 2001 only since at present a single month simulation takes up to 3 days to be completed on a 100 processor 32 bit INTEL Xeon cluster computer. Results have been compared with FRAME model predictions in order to test the validity of this preliminary implementation. In Figure 1 the EMEP4UK predicted ammonia surface concentration is compared with the FRAME model prediction (Fournier et al. 2004). Both models share the same horizontal resolution of 5 x 5 km^2.

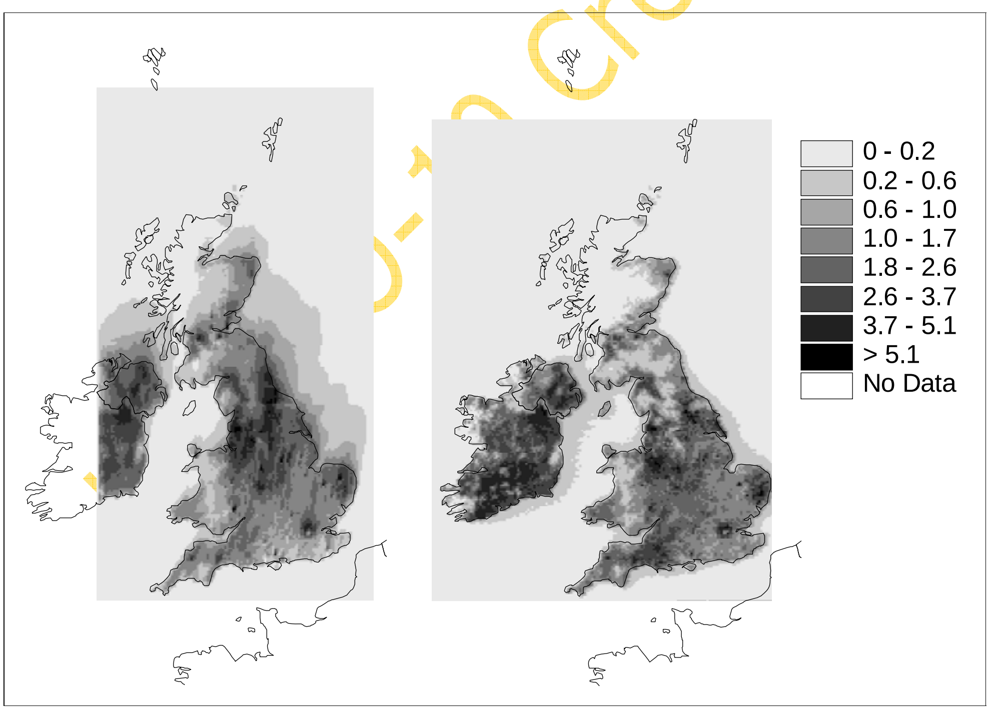

Figure 1: NH_3 surface concentration ($\mu g\ m^{-3}$) at 5 x 5 km^2 resolution as estimated by a) EMEP4UK model (for January 2001) and b) FRAME model (average for 2001).

The two models predict similar concentrations and spatial distribution for ammonia; however there is a clear difference between the model results in UK ammonia export foot-print.

EMEP4UK predicts export from the UK in the northerly direction where FRAME predicts the export in the easterly direction. This is because January 2001 had a predominant southerly wind direction where the FRAME model uses a long term average wind frequency rose with greatest frequency in the south-westerly wind direction. In addition, the results from the EMEP4UK simulation are affected by a larger transport over sea areas, probably a consequence of the coarse interpolation of the meteorological fields from ERA40 down to 5 x 5 km^2.

The main advantage of the present simulation is the introduction of high resolution emission data as compared to 50 x 50 Km^2 simulations from the EMEP Unified model simulations. The EMEP4UK model results are compared to the Unified EMEP model and shown in Figure 2. The EMEP4UK model uses the GB National Grid whereas the Unified EMEP model uses a polar stereographic projection. Therefore to be comparable, the EMEP4UK model results are aggregated to a 50 x 50 km^2 and re-projected to the EMEP grid. ArcView, a GIS tool, is used to perform the required re-projection using the 8th order nearest neighbours algorithm. The two models share similar spatial distribution of ammonia concentrations, but the magnitude of concentrations predicted by the EMEP4UK model are somewhat higher than the ones predicted by the EMEP model. Regionally both models agreed in showing high ammonia concentrations in East Anglia, central England and north of Ireland (Fournier et. al. 2004) with low concentrations predicted in the Scottish Highlands (Sutton et. al. 2004).

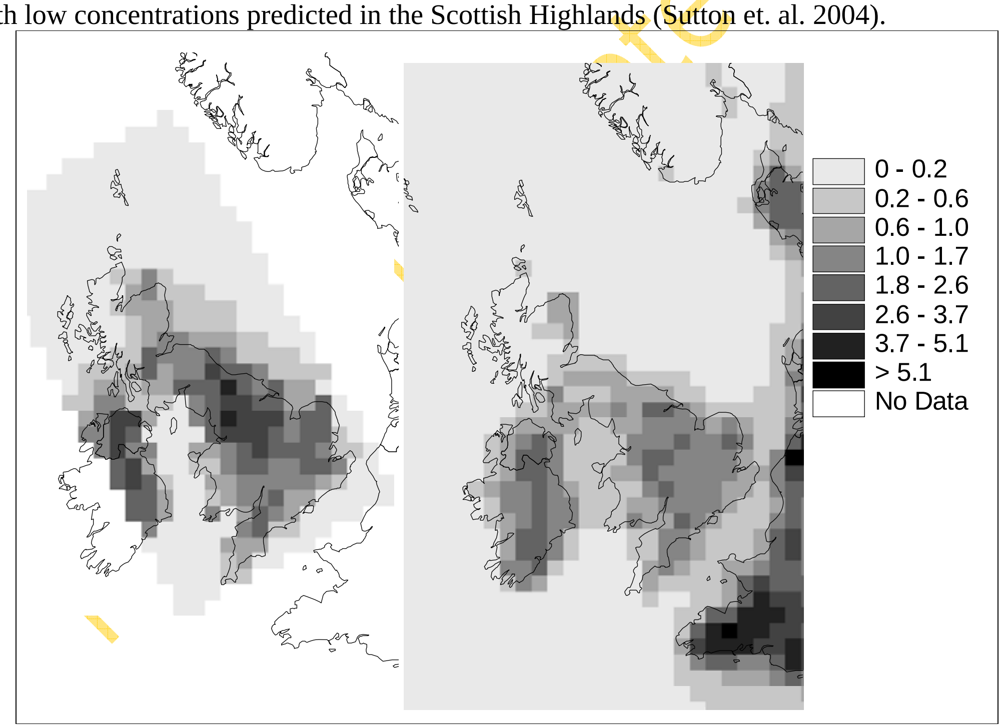

Figure 2: a) January 2001 EMEP4UK model and b) 1999 EMEP model NH_3 surface concentration. The EMEP4UK model output is aggregated at a 50 x 50 km^2 resolution and re-projected to the official EMEP grid (polar stereographic). Units are $\mu g\ m^{-3}$.

Ammonia has a very strong spatial variability and is emitted very close to the ground; therefore the emissions inventory is critical to a good model performance. The EMEP4UK model and FRAME used the AENEID spatial NH_3 inventory (Dragosits et al. 1998), which contains a different spatial distribution of NH_3 emissions to that used in the EMEP model.

A potential application of the EMEP4UK model is to conduct specific pollution investifations at high resolution of specific events which may occur. In Figure 3, the surface concentration for nitrogen dioxide is shown for five consecutive days of January 2001 from 12:30 of 1 January (Figure 3 part a) to12:30 of 5 January (Figure 3 part h) with intervals of 12 hours.

An interesting event is shown in Figure 3 part f) where a region of relatively high concentration of nitrogen dioxide is advected outside the UK mainland boundary and transported towards the Shetland Islands as shown in Figure 3 part g). However, to predict specific events the interpolated ERA40 meteorology driver is probably not accurate enough. To improve the model prediction further a higher resolution for the meteorological driver is required. It is intended to proceed with the EMEP4UK application using a higher resolution meteorological driver, either from MM5 mesoscale model and/or using the 4 x 4 km^2 resolution UK Met office unified model (when available).

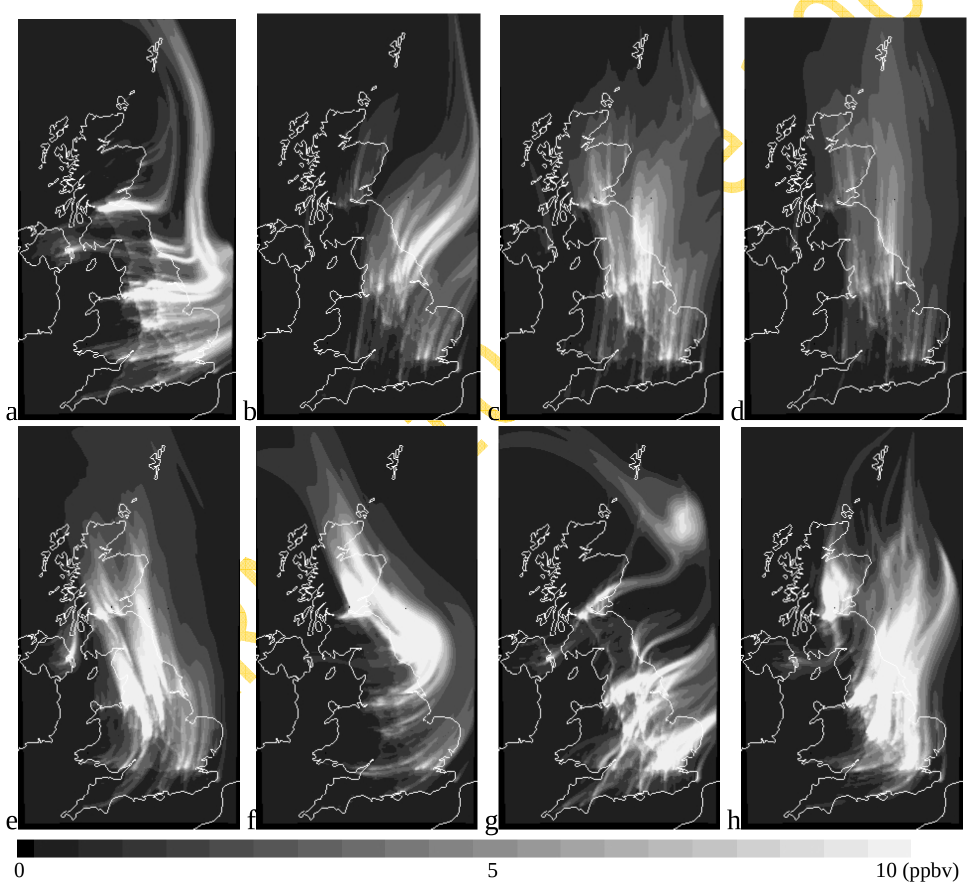

Figure 3: Surface NO_2 concentration predicted by the EMEP4UK model for five consecutive days (01/01/2001 - 05/01/2001): a) 12:30, 01/01; b) 00:30, 02/01; c) 12:30, 02/01; d) 00:30, 03/01; e) 12:30, 03/01; f) 00:30, 04/01; g) 12:30, 04/01; h) 00:30, 05/01.

Acknowledgements

We are grateful for funding of this work from Defra (Air and Environment Quality program), the Centre for Ecology and Hydrology and the Norwegian Meteorological Institute.

REFERENCE LIST

Dragosits U., Sutton M.A., Place C.J. and Bayley A., (1998). Modelling the spatial distribution of ammonia emissions in the UK. Env. Poll. **102**, S1, 195-203.

Fournier N., Dore A. J., Vieno M., Weston K. J., Dragosits U., and Sutton M. A., (2004). Modelling the deposition of atmospheric oxidised nitrogen and sulphur using a multi-layer long-range transport model. Atm. Env. **38**, 683-694

Simpson, D., Fagerli, H., Jonson, J.E., Tsyro, S., Wind, P. and Tuovinen, j.-P., (2003). The EMEP Unified Eulerian Model. Model Description. EMEP MSC-W Report 1/2003, Part I, Norwegian Meteorological Institute, Oslo, Norway.

Sutton M.A., U. Dragosits, S. Hellsten, C.J. Place, A.J. Dore, Y.S.Tang, N. van Dijk, L. Love, N. Fournier, M. Vieno, K.J. Weston, R.I. Smith, D. Roy, J. Hall and D. Fowler, (2004) Ammonia emissions, deposition and potential environmental impacts in Scotland, The ScientificWorld, **4**, 795 – 810.

Tarrasón, L. (ed.) 2003, EMEP Report 1/2003, Transboundary Acidification, Eutrophication and Ground Level Ozone in Europe. Part II, Unified EMEP Model Performance, EMEP Status Report 2003, Norwegian Meteorological Institute, Oslo, Norway. www.emep.int.