Chapter 17
Calculation of Source-Receptor Matrices for Use in an Integrated Assessment Model and Assessment of Impacts on Natural Ecosystems

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Abstract A computationally efficient atmospheric chemical transport model (FRAME) was used to generate source-receptor concentration and deposition data from a variety of spatially distributed and point sources of nitrogen and sulphur emissions. The model was evaluated by comparison with measurements of nitrogen compounds in the gaseous, particulate and aqueous phase and found to be fit for purpose as a policy tool for assessing the effects of future emissions controls. A scenario for the year 2030 predicted that 64 % of the area of natural ecosystems in the UK would be subject to deposition of nitrogen exceeding critical loads.

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17.1 Introduction and Model Description

Deposition of nitrogen occurs both as oxidized nitrogen (emitted primarily as NO_x from combustion processes) and reduced nitrogen (emitted mostly as NH_3 from agricultural sources). This leads to the eutrophication of terrestrial and fresh water ecosystems promoting excessive plant growth and causing a reduction in water quality. Field experiments have correlated nitrogen deposition to a loss of bioviersity in a wide range of ecosystems. Nitrogen deposition has been identified as a global environmental concern.

Atmospheric chemical transport models can be used to assess changes in nitrogen deposition based on future predictions of atmospheric emissions and thus provide the basis for the quantification of changes in impacts. Source-receptor matrices link the emissions of pollutants from specific sources to air concentrations and deposition of pollutants. They are indispensable input data for integrated assessment models (IAMs, Oxley et al. 2013) to evaluate measures to abate pollutant emissions. IAMs are widely used to generate scenarios and to identify optimised strategies for improved air quality and reduced pollutant deposition.

FRAME (Fine Resolution Multi-pollutant Atmospheric Exchange) is a Lagrangian model using straight line trajectories (Dore et al. 2012) with a 1° angular resolution which runs at either a 1 km or a 5 km horizontal resolution over the British Isles and 50 km resolution over Europe with a fine vertical grid spacing (1 m at the surface). Area emissions are injected into sector dependent levels and point source emissions are treated with a plume rise routine. Vertical diffusion in the air column is calculated using K-theory eddy diffusivity. Wet deposition is calculated using a 'constant drizzle' approximation driven by an annual rainfall map. Five land classes are considered and a vegetation specific canopy resistance parameterisation is employed to calculate dry deposition of SO_2, NO_2 and NH_3. The model chemistry includes gas phase and aqueous phase reactions of oxidised sulphur and oxidised nitrogen as well as aerosol formation. To generate source-receptor data for the integrated assessment model, 619 simulations were undertaken. These involved 25 % reductions in emissions from individual targeted spatially distributed and point sources from five regions of the United Kingdom (England, Scotland, Wales, Northern Ireland and London). Data from the EMEP Eulerian model (Simpson et al. 2012) was used to calculate the contribution to concentration and deposition from non-UK European sources.

17.2 Results

The FRAME model was found to give a good representation of aerosol and gas concentrations of nitrogen compounds as well as wet deposition when compared with measurements from the UK national monitoring networks. Table 17.1 illustrates the correlation with annually averaged measurements of gas, aerosol and

Table 17.1 Statistics for the FRAME model correlation with annual average measurements of precipitation concentration (μM l^{-1}) and air concentrations (μg m^{-3}) for the year 2012 (N: number of samples; R: Pearson correlation coefficient, NMB: Normalised Mean Bias; FAC2: 'Factor Of 2' percentage of modelled points less than twice and greater than half the measured value)

	N	R	NMB	FAC2
NH_4^+ in precipitation	38	0.94	−0.07	92
NO_3^- in precipitation	38	0.92	−0.01	92
NH_3 gas	88	0.72	0.17	80
NO_2 gas	26	0.98	−0.30	96
NH_4^+ particulate	30	0.94	−0.19	82
NO_3^- particulate	30	0.95	−0.09	86

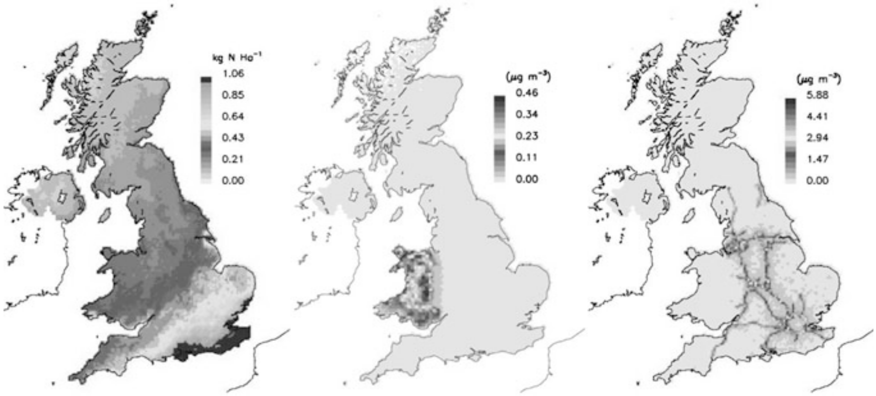

Fig. 17.1 Examples of source-receptor data for the year 2025: Dry deposition of NO_y from international shipping (*left*); NH_3 concentrations from poultry in Wales (*centre*); NO_x concentrations from heavy goods vehicles in England (*right*)

precipitation concentration for the year 2012. The model generally satisfied the criteria for 'fitness for purpose' of: $-0.2 < \text{NMB} < 0.2$ and $\text{FAC2} > 50$.

Examples of a selection of source-receptor data generated with the FRAME model using projected emissions estimates for the year 2025 are illustrated in Fig. 17.1. These comprise: dry deposition of NO_y from international shipping, NH_3 concentrations from poultry in Wales and NO_x concentrations from heavy goods vehicles in England. Such sets of deposition and concentration data are correlated to emissions for specified sources and can be re-combined in an integrated modelling framework using projected emissions reductions based on targeted technical measures. This leads to estimates of different future nitrogen deposition scenarios depending on the adoption of control measures based on their implementation costs.

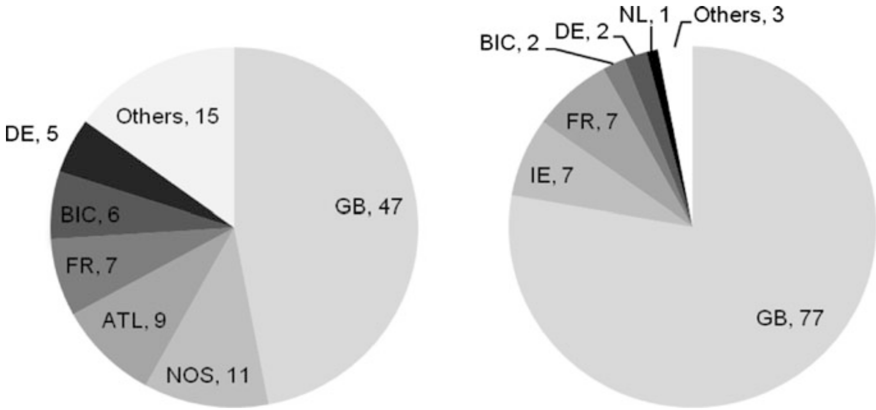

Fig. 17.2 Contribution to NO_x deposition (*left*) and NH_x deposition (*right*) in the UK from different European countries (including international shipping: NOS North Sea, ATL Atlantic) calculated with the EMEP model for 2012

The computationally efficient FRAME model (with a run time of 15 min on a single 16 core node) is effective at performing multiple simulations. However the EMEP Eulerian model (Simpson et al. 2012) is better suited for estimating the trans-boundary component of nitrogen deposition originating from emissions sources in other European countries. The contribution to oxidised and reduced nitrogen deposition in the UK from European countries as well as international shipping calculated with EMEP is illustrated in Fig. 17.2. It is evident that NH_x deposition is predominantly from domestic sources (due to efficient dry deposition of locally emitted ammonia). The picture for NO_x deposition is however more complex with long range transport of nitrate aerosol originating from international shipping and other European countries contributing more than half of the deposition.

Using existing legislation for the introduction of technical measures to reduce emissions of NO_x and NH_3, a scenario for the year 2030 was defined. The exceedance of critical loads for nutrient nitrogen deposition was calculated for the future scenario and compared to the baseline year 2010 (Table 17.2). These results show that nitrogen deposition will continue to pose a risk to natural ecosystems over the next two decades. Further control of emissions of both ammonia (primarily from the UK) and of oxides of nitrogen from European sources and international shipping will be necessary in order to reduce the threat to biodiversity from eutrophication.

Table 17.2 Exceedance of critical loads for the years 2010 and 2030 for different ecosystems in the UK based on emissions projections using existing policy

Broad habitat	Habitat area (km^2)	Percentage area exceeded	
		2010	2030
Acid grassland	15,235	64.4	58.9
Calcareous grassland	3,578	94.4	95.8
Dwarf shrub heath	24,826	47.6	43.1
Bog	5,526	47.2	44.7
Montane	3,129	86.0	79.0
Coniferous woodland (managed)	8,383	91.5	90.0
Broadleaved woodland (managed)	7,482	97.6	97.3
Fagus woodland (unmanaged)	719	100.0	100.0
Acidophilous oak (unmanaged)	1,434	96.4	93.8
Scots Pine (unmanaged)	204	48.5	39.8
Other unmanaged woodland	1,761	95.5	95.3
Dune grassland	323	46.2	46.3
Saltmarsh	427	0.9	2.1
All habitats	73,027	67.5	64.2

17.3 Conclusion

The use of source-receptor relationships from an atmospheric chemical transport model allows the rapid re-construction of future scenarios for concentration and deposition of pollutants based on implementation of technical measures to reduce atmospheric emissions. The focus of this work is on the deposition of nitrogen. Large areas of natural ecosystems in the UK were calculated to be subject to nitrogen deposition in exceedance of critical loads for the year 2030. This indicates that future UK and European policy will need to be applied to control nitrogen emissions in order to protect natural ecosystems.

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Questions

Wouter Lefebvre: Do you take into account compensation points and $v_d = f(C_{NH3})$ relationships?

Answer: As the model runs in a fast 'annual average' mode, it is not suitable for inclusion of canopy compensation point calculations. The deposition velocity of ammonia is calculated separately to six different surface types (forest, moorland, improved grassland, arable, urban and water) using a canopy resistance formulation with the canopy resistance based on annual average values.

Questioner: Have you tested your assumption of linearity?

Answer: The change in nitrogen deposition has been tested for different percentage reductions in emissions from a single point source. These revealed a close to linear relationship for smaller emissions changes with some divergence for large percentage emissions reductions (close to 100 %). Source receptor relationships were calculated with a 25 % reductions in emissions for each source to avoid the non-linear chemical perturbation associated with higher percentage emissions changes.

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