4. Tentatively exploring the likelihood of exceedances: Ensemble Assessment of Impacts (EAI)

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4.1 Introduction

Ensemble Assessment of Impacts (EAI) is presented in this chapter to tentatively explore the robustness of exceedances on a scale that could range from ‘exceptionally unlikely’ to ‘virtually certain’. This, in analogy to the manner in which uncertainties are proposed to be addressed in the IPCC Fourth Assessment Report (IPCC-AR4) as summarized in IPCC (2005; reprinted in Appendix C of this report).

The chapter is a follow-up of a CCE proposal to the 25th session of the Working Group on Effects (WGE; Geneva, 29-31 August 2007) and of a proposal presented at the 17th CCE workshop and 23rd Task Force on Modelling & Mapping (Sofia, 23-27 April 2007) to explore the applicability of the IPCC-AR4 approach under the effects-based programme. Uncertainty analysis is an important part of the medium-term work programme of the WGE and of the work plan of the European Consortium for Modelling Air Pollution and Climate Strategies (EC4MACS) under the LIFE+ programme of the European Commission. This work is proposed as a first step to a report on uncertainty that is planned by 2010 under EC4MACS.

Ensemble Assessment

The term ‘Ensemble Assessment’ is borrowed from ‘Ensemble Modelling’, the latter indicating the pooling of model results to improve the accuracy of predictions. Ensemble Modelling is well established in particular in the field of atmospheric sciences (e.g. Builtjes, 2004), climatology (e.g. see http://www.precis.org.uk or Lenderink et al., 2007) but also in hydrology (e.g. Viney et al., 2005) and other fields of environmental modelling involving uncertainty.

We note that – in the context of impacts of exceedances – the biology behind exceedances is developing, while the number of established models in this field is limited. For this reason we introduce the term ‘Ensemble Assessment of Impacts’ rather than ‘Ensemble Modelling of Impacts’.

Uncertainty of exceedances

The main aim of the critical load approach is the identification of the geographical location of an ecosystem of which the critical load is exceeded by atmospheric deposition. Ultimately it is the exceedance that matters, not the critical load as such. For the design of air pollution abatement policies it is important to know where (in Europe or in a country) adverse impacts can be expected to occur as a result of the dispersion of emissions and resulting excessive regionalized depositions. Moreover, policy analysts also wish to know the magnitude of the exceedance because it is assumed that an adverse effect may occur sooner when the exceedance is higher\(^2\). Therefore, when addressing

\(^2\) The future occurrence of an adverse effect caused by exceedance, is not solely dependent on the magnitude of exceedances, but also varies over European regions depending on soil, vegetation and meteorological characteristics. Using combinations of these conditions as inputs, dynamic models can be applied on a regional scale (see chapter 3) to analyze Damage Delay Times (DDT) when critical loads are exceeded and Recovery Delay Times (RDT) otherwise. However, a rule of thumb is that adverse effects occur sooner when exceedances increase.
ecosystem impacts, integrated assessment modellers and policy analysts are primarily interested in the likelihood of (the occurrence of) an exceedance, and its emission scenario-dependent trend.

Of course, we know that the uncertainty of exceedances depends on variables and data in the chain from emissions to depositions, and their spatial and temporal resolution. These include data and emission factors behind national emission reports, input data, meteorology and climate conditions behind atmospheric dispersion models and input data, soil-vegetation characteristics and modelling methods behind critical loads. Uncertainty analyses in this context have been conducted and reported under the LRTAP Convention in, e.g. Hettelingh and Posch (1997) and Suutari et al. (2001).

**Focus on critical loads of nitrogen**

This chapter is not reiterating all the aspects of the uncertainty of integrated assessment modelling. This does not mean that Ensemble Modelling is disqualified as a (promising) method to also analyze the chain from emissions to exceedances. Rather, to keep a preliminary application of the IPCC-AR4 approach simple, we assume that the propagation of uncertainties of emission and dispersion modelling is a non-quantified constraint. This allows us to take computed ecosystem-specific depositions in a 50×50 km$^2$ EMEP grid cell as our unchallenged starting point.

This has implications for the assumptions that lie at the basis of this chapter. The first is that we do not extend our analysis to include changes in the **model structures** behind emissions and depositions, emission and deposition results are given. We simply use the emission assessment structure of the RAINS/GAINS model, while the modelling of dispersion is covered by the EMEP model. We use the EMEP source receptor matrices that are based on a 5 year average meteorology, and which are also embedded in the RAINS/GAINS model.

In this chapter, the variation of the distribution as well as of the magnitude of depositions is the sole result of emission reduction scenarios that are currently produced by the RAINS/GAINS modellers. Finally, in this chapter the focus is on the exceedance of critical loads of nitrogen by the deposition of oxidized and reduced nitrogen. The CCE background database is used to illustrate the Ensemble Assessment of Impacts.

4.2 **Addressing uncertainty of exceedances in the context of IPCC AR4**

The following is a preliminary attempt to interpret the IPCC Guidance note for lead authors of the IPCC AR4 on addressing uncertainties (IPCC, 2005; reprinted in Appendix C of this report) in the context of critical load exceedances.

- **Plan to treat issues of uncertainty and confidence:** We wish to explore the robustness of concluding that a grid-cell in Europe covers ecosystems at risk, under a particular emission scenario and related depositions. As stated above, in this chapter we do not address all kinds of uncertainties in the chain from emissions to depositions. On the basis of EMEP-depositions that are computed in a grid cell, aggregated to 3 ecosystem types, we wish to establish the likelihood that ecosystems in a grid cell have critical loads that are exceeded. More ecosystems in a grid cell are subject to risk of nitrogen effects as depositions are relatively high.

- **Review the information available:** The robustness of the occurrence of an exceedance could be increased by including more methods to compute critical loads (e.g. reverse dynamic modelling with geo-chemical and vegetation type models), or methods to assess exceedances (e.g. distinguish between special protection areas such as Natura 2000 from other sensitive areas). In addition one could extend the analysis to include deposition results of other emission scenarios. For the sake of experiment we restrict to the use of two, assumed independent, sets of critical loads, i.e. the empirical and modelled critical loads of nutrient nitrogen. If a deposition leads to exceedance using both sets of critical loads we feel that we can be more confident about the occurrence of an exceedance.
• **Make expert judgements:** We assume that an exceedance of an empirical critical load can be regarded as a measure for the risk to vegetation. Empirical critical loads are assigned to EUNIS and relevant geochemical classes of sensitive national ecosystems. Modelled critical loads are not qualitatively assigned, but computed using a mathematical model. An exceedance of a modelled critical load can be regarded as measure for the risk of eutrophication of soils. Of course, the risk of eutrophication can lead to vegetation effects. However, the critical limits used to compute modelled critical loads have not been derived from empirical critical loads, nor has one method be validated on the basis of the other. Therefore, we assume that both methods lead to critical loads of which the distributions (in on single grid cell) are independent, and that they reflect effects that are each others complement. Furthermore we assume that each of the two sets of critical loads in a single EMEP grid cell is representative for the (sensitive) ecosystems in that grid cell.

• **Use the appropriate level of precision to describe effects:** The guidance document proposes a hierarchy of 5 steps – with increasing specificity - by which statements for key findings can be substantiated (see Appendix C, paragraph 8). We can attempt to develop statements with respect to exceedances in the 4th and 5th category:
  - ‘A range can be given for the change in a variable as upper and lower bound, or as the 5th and 95th percentile based on objective analysis or expert opinion’; Think of the change of exceedances with respect to the 5th, the 95th or the highest percentile-critical load that is exceeded, when deposition changes. Depositions can change when alternative emission scenarios are compared.
  - ‘A likelihood or probability of occurrence can be determined for an event or for representative outcomes, e.g. based on multiple observations’; Think of the occurrence of an exceedance when using empirical or modelled critical loads. We propose the use of the scale provided in Table 4 of Appendix C as a basis for assessing the likelihood of exceedances in the next section.

• **Communicate carefully, using calibrated language:** In the past, when modelled critical loads were used in integrated assessment, the relative importance of exceedance was established through the comparison of emission scenarios. Areas where the critical load remained exceeded even after application of Maximum Feasible Reductions (MFR) could, tentatively, be judged as persistent. These could than be compared to areas which are exceeded under any base scenarios but become protected as further emission reductions are implemented in a sequence towards MFR. Communication generally revolved around the interpretation of scenario-dependent exceedances; are absolute magnitudes of exceedances as reliable as relative magnitudes in the context of a sweep of scenarios?

### 4.3 Deriving a scale to quantify the likelihood of exceedance

The IPCC guidance document defines likelihood (see Table 4 in Appendix C) ‘…as a probabilistic assessment of some well defined outcome having occurred or occurring in the future’ (IPCC, 2005, section 14, pp. 4). We address the likelihood of exceedance in an EMEP grid cell, meaning a grid cell of which AAE>0.

We assume the distribution of empirical critical loads to be independent of the modelled critical loads. Therefore, the distribution of linear transformations, i.e. exceedances of both types of critical loads, can also be assumed independent. Since we also assume each set of critical loads to be representative for the population of all ecosystems in an EMEP grid cell, we can state that the probability of the occurrence of an exceedance can be reflected by the percentage of the ecosystem area in an EMEP grid cell that is at risk. This implies that the joint probability of an exceedance of empirical and modelled critical loads is the product of both percentages of ecosystem areas at risk. This product can then be used to characterize likelihood of the occurrence of an exceedance and introduce a typology of scales as proposed by the IPCC as follows.
The likelihood of $\text{AAE}>0$ in an EMEP grid is said to be ‘likely’, ‘very likely’ or ‘virtually certain’ if the square root of the product (i.e. the geometric mean) of the exceedance percentages based on empirical and modelled critical loads are in the ranges 0-33%, 33-67% and >67% respectively (Figure 4-1). The likelihood is ‘unlikely’ when exceedance percentages based on both critical loads turn out to be zero. If only one of the two percentages is equal to 0 then the likelihood of an exceedance is said to be ‘as likely as not’. As in the guidance document we consider the categories that are thus defined to have ‘fuzzy’ boundaries, i.e. allowing some undefined extent of small overlap.

![Figure 4-1. The likelihood scale indicating the simultaneous probability of an exceedance of the empirical critical load and the modelled critical load of nutrient nitrogen.](image)

### 4.4 Tentative results

The use of the assessment methodology to scale the likelihood of exceedances in Europe yields Figure 4-2. The legend corresponds to probabilities depicted in Figure 4-1.

![Figure 4-2. The likelihood that the Average Accumulated Exceedance of an EMEP grid cell exceeds zero, i.e. that it contains at least one ecosystem of which the critical load of nutrient N is exceeded with current legislation.](image)

Figure 4-2 illustrates that ecosystem areas of which critical loads are ‘virtually certain’ to be exceeded (red shaded) cover broad parts of Austria, Belgium, Bulgaria, Denmark, France, Germany, Ireland, The Netherlands, Poland, The Czech Republic and Switzerland. Countries and regions that have
ecosystem areas that are ‘very likely’ (orange shaded) to be at risk include Belarus, Lithuania, the southern part of Russia and the south-eastern and south-western part of Europe. Areas where exceedances are ‘as likely as not’ (blue shaded) cover important parts of northern and southern Europe as well as Russia. Finally, areas where exceedances are unlikely are computed to be mostly in northern Europe.

4.5 Conclusions and recommendations

This chapter tentatively summarizes the Ensemble Assessment of Impacts (EIA) methodology. The objective of EIA is to improve the accuracy of exceedance assessments by pooling different kinds of constituents of exceedance calculation and scale the likelihood of exceedances in analogy to the treatment of uncertainties under the IPCC (see appendix C). In this chapter two different kinds of critical loads, i.e. empirical critical loads and computed critical loads were used. Using EIA in this way, exceedances are assessed to be ‘virtually certain’ or ‘very likely’ in central and western Europe.

This chapter provides a first indication that EIA may contribute to the assessment of the uncertainty of the location of exceedances. Whether EIA needs to – or can – be further developed to include the uncertainty of the magnitude of exceedances depends on a number of issues that are relevant for the description of the variability of modelled phenomena in general, and exceedances in particular.

Uncertainty analysis is particularly important for the assessment of phenomena that are difficult to validate. This is the case for forecasted changes to the biology caused by modelled critical load exceedance as much as it holds for forecasted changes to our climate system caused by modelled changes of carbon dioxide concentrations. Standard methods of uncertainty analysis include statistical variation of model drivers and parameters since about five decades. Since the nineties, also qualitative methods were introduced which aim to take into account expert judgements and alternative ways and pedigrees to parameterize uncertainty. These methods have an understanding in common, i.e. that the system that underlies the model is not subject to structural change. The methods and models that are designed to represent a particular part of a (natural) system cannot deal with fundamental system changes. The introduction of ensemble methodologies, based on the pooling of methods and models, has further improved the treatment of uncertain assertions by including different models of the same system. Recently, Beck (2004) addressed the challenge to construct and apply models ‘to generate environmental foresight in the presence of structural change’.

Further work is needed to further assess the likelihood of exceedances and the risk of impacts. This could include the elaboration of EIA by incorporating the pooling of other drivers that are relevant to assess the likelihood of exceedances of ecosystems in EMEP grid cells, subject to:

- Different land cover classes,
- Natura 2000 areas and its biological characteristics (habitat/birds directive),
- Different methods to establish the relationship between (national) emissions and depositions on ecosystems in EMEP grid cells,
- The (statistical) variation of ‘modelled’ critical loads,
- The distinction of ‘importance’ of EMEP grid cells using knowledge on the sensitivity of its ecosystems, i.e. its Damage Delay Times or Recovery Delay Time urgencies.

References


