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Steering Body to the Cooperative Programme for Monitoring and Evaluation
of the Long-range Transmission for Air Pollutants in Europe (EMEP)
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Item 4 (a) of the provisional agenda

TASK FORCE ON MEASUREMENTS AND MODELLING
REVIEW OF THE UNIFIED EMEP MODEL

Summary report and conclusions of the workshop
prepared by the Chairman in collaboration with the secretariat

Introduction

1. The workshop to review and evaluate the unified EMEP model took place on 3-5 November 2003 in Oslo. It was organized by the Task Force on Measurements and Modelling and supported by the Meteorological Synthesizing Centre – West (MSC-W) and the European Environment Agency.

2. The workshop was attended by 72 experts from Austria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Italy, Latvia, Lithuania, Netherlands, Norway, Republic of Moldova, Russian Federation, Spain, Sweden, United Kingdom and the

European Community. Representatives of the World Health Organization (WHO), the World Meteorological Organization (WMO), the European Environment Agency (EEA), the Meteorological Synthesizing Centre - East (MSC-E), the Meteorological Synthesizing Centre - West (MSC-W), the Chemical Coordinated Centre (CCC), the Centre for Integrated Assessment Modelling (CIAM) and the Oil Companies' European Organization for Environment, Health and Safety (CONCAWE) also attended. A member of the UNECE secretariat was also present.

3. The presentations made at the workshop can be found on the Internet at: www.emep.int.

4. The objective of the workshop was to peer review the performance of the unified EMEP model. The review considered the ability of the EMEP model to provide concentration and deposition data to facilitate the evaluation of the effects of air quality on ecosystems, support the assessment of health effects by providing regional concentrations of health-relevant pollutants, determine trends in regional air concentration and deposition data over Europe, and establish the response of regional air quality to emission changes for use in the development of emission reduction strategies (source-receptor calculations).

5. The importance of the review and evaluation of the unified EMEP model not only for the work of the Convention but also for the EC Clean Air for Europe (CAFE) programme was reiterated. Attention was drawn to the time pressure as the programme was scheduled to be completed in July 2005.

6. The review and the evaluation of the model were based on three elements: examination of the processes and meteorological parameterizations, chemical mechanisms and the sources of model input data; evaluation of the model performance against daily observations of key model species and fluxes for the period 1980 – 2000; and a consideration of the source-receptor relationships for sulphur, nitrogen, ozone and particulate matter < 2.5 mm and < 10 mm ($PM_{2.5}$ and PM_{10}).

7. The review was preceded by an open process involving participation and cooperation with national experts. A significant amount of background information was made available on the Internet prior to the workshop. Several presentations were given on comparisons between results from the unified EMEP model and observations, as well as results from other models, despite the limited time which had been available for such studies. The conclusions regarding the performance and fitness of the model are presented in paragraphs 36-51 below.

I. SUMMARY OF WORKSHOP DISCUSSIONS

A. Model formulation

8. In addition to the unified EMEP model, a number of other models were presented in order to explain how model design was determined by its intended use and application.

9. In presenting the EMEP model, Mr. David Simpson (MSC-W) stressed that its design was focused on simplicity and robustness. The model as a whole, as well as its building blocks, had been carefully evaluated against observations. The testing of the building blocks was illustrated through the validation of the chemical mechanism. The dry deposition scheme, which now had an added level of complexity, had also been carefully compared with observations. For sulphur dioxide, a parameterization of co-deposition (for SO_2 and NH_3) had been added, which made modelled long-term SO_2 trends agree better with observations. Extensive comparisons with observations were documented in the EMEP Status Report, Part II. The key lessons learnt in the process of evaluation were that: (i) model evaluation required data for many years and many sites to prevent model “tuning”; (ii) evaluating the different components of the model was as relevant as evaluating the full model; (iii) only robust and quality assured meteorological data should be used; and (iv) the maximum possible number of observation sites should be used.

10. Mr. Peter Builtjes (Netherlands) introduced the LOTOS model, which focused on ozone, particles and acidification/eutrophication on the regional scale. It was designed as a state-of-the-art model with an intermediate level of complexity using consistent, coherent and transparent emissions data rather than official data. The approach had been to use data assimilation as both a general model validation tool and to evaluate emission algorithms.

11. Mr. Robert Vautard (France) introduced the CHIMERE model, which had been designed as a research tool for both long-term simulations and real-time forecasts. The CHIMERE model had a full range of parameterizations and was distributed for community development and use. The approach had been to use real-time forecasting as a means of learning about model performance.

12. Mr. Julian Wilson (European Commission’s Joint Research Centre (JRC)) introduced the M7 model, a global aerosol model addressing both primary and secondary particle emissions, formation and transport. The model used a modal approach addressing the nucleation, Aitken, accumulation and coarse modes. Model intercomparisons were presented against vertical profiles and size distributions from field campaigns.

13. Mr. Ian Rodgers (United Kingdom) presented the MODELS-3 approach and its application within Europe on a nested set of grids down to the 4 km scale. The model was designed to provide

the modelling community with a flexible framework and a choice of science treatments which facilitated sensitivity analysis. The approach was more detailed than the EMEP model and was also subject to continual improvement through scientific review.

14. Mr. Rainer Stern (Germany) described the REM-3 model and its application on the regional, urban and local scales across Germany. The model used a flux-based transport scheme to maintain accuracy. The chemical mechanism included both secondary inorganic and organic aerosol formation. Attention had been given to natural particle sources from sea salt and wind-blown dust. The model was based on observed meteorological data and was used to assess present and future air quality.

15. Participants in the workshop expressed a high level of confidence in the representation and parameterization of meteorological processes in the EMEP model. There was a growing level of confidence with regard to the model input data and parameterizations covering emissions and the representation of chemistry and deposition processes.

B. Deposition of acidifying and eutrophying agents

16. Mr. Joakim Langner (Sweden) described comparisons between the MATCH model and the EMEP model after outlining differences in their parameterizations. The models gave similar results for sulphur deposition over Sweden, but the NO_y deposition in the EMEP model was higher than in MATCH. The reduced nitrogen deposition may have been underestimated by the models compared with the mapped measurements over Sweden.

17. Mr. Jesper Christensen (Denmark) described the Danish Eulerian hemispherical model (DEHM) and compared its parameterizations with those in the EMEP model. A 10-year comparison of the time series from DEHM with the EMEP model and with EMEP measurements was presented.

18. Mr. Ron Smith (United Kingdom) presented results from the FRAME model for the United Kingdom, which had a 5km x 5km resolution. Comparisons were shown with the EMEP model, which revealed a less detailed spatial structure, as expected. There appeared to be significant differences in the NO_y dry deposition budget estimates. Measured reduced nitrogen fluxes and EMEP model predictions showed discrepancies of a factor of 2.

19. Ms. Hilde Fagerli (MSC-W) described the performance of the EMEP model against EMEP measurements on a seasonal and regional basis. Detailed results were available in the documentation provided for the workshop. The performance for the years 1980, 1990 and 2000 was broadly similar. Several factors would have produced changes over this period, such as trends

in the oxidizing capacity of the atmosphere, and the co-deposition of ammonia and sulphur dioxide. Changes in the N_2O_5 parameterizations had led to improvements in the prediction of particle NO_3. There were still some problems with ammonia and precipitation components in the EMEP model.

20. Mr. Guus Velders (Netherlands) presented an evaluation of the EMEP model compared with the OPS model for the Netherlands, which had a 5km x 5km resolution. For NO_y, the Netherlands-to-Netherlands source-receptor term was much lower in the EMEP model than in the OPS model. Reasonable agreement was found for sulphur and reduced nitrogen when the two models were compared with measurements from the Netherlands national monitoring network. The EMEP predictions of nitrogen oxides appeared low.

21. Mr. Olle Westling (Sweden) compared monitored forest deposition based on throughfall measurements with predictions from the EMEP model for 160 sites of the International Cooperative Programme (ICP) on Forests. Some open field measurements were also included. The general picture showed good agreement, with the EMEP model estimates of total sulphur deposition slightly higher than the ICP data.

22. Mr. Maarten van Loon (Netherlands) described a preliminary model intercomparison between the EMEP model and six other models (CHIMERE, DEHM, LOTOS, MATCH, MODELS3 and REM) for around 160 locations in Europe. The performance of the models, based on correlation coefficients and bias (compared with measurements), was generally similar, with the EMEP model performing well. NO_x appeared to be underestimated by all the models. The EMEP model performed well and towards the high end of the range of the other models for ozone, NO_x and total oxidants. PM_{10} was generally underestimated in regional air quality models. The EMEP model performance for particles was in line with other models.

23. As a result of the discussion that followed the presentations, the participants at the workshop agreed that:

(a) There was high confidence in the EMEP model's ability to represent the broad spatial patterns in the deposition of sulphur and oxidized nitrogen compounds across Europe;

(b) While a spatial resolution of 50 km x 50 km represented a major improvement on the EMEP Lagrangian model, considerable sub-grid scale variations could still be expected and so some additional statistical treatment would be required to account for in-square variations;

(c) There was every confidence in the model's ability to reproduce the observed trends in sulphur and oxidized nitrogen deposition;

(d) There was limited confidence in the model's ability to represent the spatial pattern and trends in reduced nitrogen deposition because of the lack of understanding of the fate and behaviour of ammonia and the difficulties associated with the model representation of ammonia emissions and deposition.

C. Ozone and particulate matter

24. Mr. Jan-Eiof Jonson (MSC-W) presented details of the performance of the unified EMEP model for ozone and selected indicators. Ozone episodes and seasonal cycles were effectively modelled over much of Europe during 2001 though peak levels were underestimated. The model performed well for nitrogen dioxide for 2001 with an overall bias of only 2%; though it performed less well for 1980-1995. The sensitivity of the model ozone concentrations to nitrogen oxides control varied across Europe and paralleled the [O_3]/[NO_y] indicator ratios. The model policy responses to NO_x and volatile organic compound (VOC) controls were therefore likely to be firmly based and robust.

25. Mr. Vautard presented details of the ozone and particle parameterizations in the CHIMERE model, which showed an excellent level of model performance against observations for ozone and particulate sulphate and an acceptable level for PM_{10}.

26. Mr. Kjetil Torseth (CCC) discussed the validation of the EMEP model using Norwegian observations. Model performance against observations for particulate sulphate and wet sulphur deposition was good, clearly reproducing spatial gradients across Norway. The model overestimated sulphur dioxide and particulate nitrate concentrations, particularly during wintertime. It underestimated wet NO_y and reduced nitrogen deposition.

27. Mr. Sverre Solberg (CCC) presented a comparison of the EMEP model performance for VOCs with observations from the EMEP VOC monitoring network. Model performance for formaldehyde, ethane and isoprene against observations was reasonably good across much of Europe. The VOC monitoring data had been shown to be invaluable for model validation.

28. Ms. Svetlana Tsyro (MSC-W) described the performance and verification of the EMEP model for suspended particulate matter. The model underestimated observed PM_{10} and $PM_{2.5}$ levels by 30-60% and 25-50% respectively, and was unable to reproduce the full spatial gradients observed across Europe. Discrepancies in the model may be accounted for by the omission of secondary organic aerosols, mineral dusts and particle-bound water, and by the underestimation of primary elemental and organic carbon. More PM_{10} and $PM_{2.5}$ measurements were required in a number of additional areas supplemented with analyses of the chemical composition by particle size range.

29. Mr. Wilson presented the results of a study of the “ageing” process in which black carbon became more readily wet scavenged the longer it remained in the atmosphere.

30. Mr. Simpson described progress with modelling primary and secondary organic aerosols. He concluded that without an adequate observational basis in Europe, it was premature for this work to be included in the EMEP PM_{10} and $PM_{2.5}$ model.

31. As a result of the discussion that followed concerning the modelling of ground-level ozone, the participants agreed that:

(a) There was a high level of confidence in the EMEP model’s representation of the broad spatial pattern of ozone exposure levels across Europe and of the major areas of VOC and NO_x limitation. This level of confidence extended to the assessment of the exposure levels required to estimate ozone crop and vegetation impacts on the regional scale and to the regional background levels, which were an essential input to the estimation of health impacts on the urban scale;

(b) There was limited confidence in the model’s ability to evaluate more advanced strategies, for example, for individual emission source categories, because of the limited VOC speciation provided in European emission inventory data and the necessarily simplified chemical mechanism employed.

32. As a result of the discussion that followed with regard to particulate matter, the participants agreed that:

(a) An excellent start had been made within EMEP to begin the challenging task of modelling the fate and behaviour of particulate matter across Europe by initially focusing on the mass fraction of particular components within PM_{10} and $PM_{2.5}$;

(b) There was high confidence in the model’s ability to represent the broad spatial pattern of particulate sulphate across Europe, its trend and the role played by its long-range transport in providing the regional background levels required as an input to urban health impact studies;

(c) There were insufficient particulate nitrate and ammonium measurements available to provide an adequate test of the performance of the EMEP model;

(d) Confidence in the understanding of the mechanism of the formation of secondary organic aerosols and of the quantification of some natural aerosol sources was so low that they had not been included in the EMEP model, leading to underestimates for PM_{10} and $PM_{2.5}$;

(e) Understanding was growing steadily in the quantification of primary particle emissions and this would lead eventually to increased confidence in the estimation of regional levels of primary particles emitted, thereby improving the assessment of PM_{10};

(f) Whilst there remained a significant fraction, by mass, unaccounted for between the model and observed PM_{10} and $PM_{2.5}$ levels, there was limited confidence in the model's ability to assess levels of PM_{10} and $PM_{2.5}$.

D. <u>Non-linearities and source-receptor relationships</u>

33. Ms. Leonor Tarrasón (MSC-W) presented the unified EMEP Eulerian model responses to emission changes. A number of model limitations were noted at the outset: underestimation of episodic ozone peak concentrations; model spatial resolution; particle speciation; and undesirable initial and boundary terms for NO_y. The evaluation would be limited to 3 meteorological years. Primary particles showed an entirely linear behaviour with respect to emission changes. Non-linearities were found between sulphur and reduced nitrogen in their source-receptor relationships, due to co-deposition, and between the components of secondary inorganic aerosols.

34. Mr. Kees Cuvelier (JRC) and Mr. Markus Amann (CIAM) presented the preliminary results from the EURODELTA model intercomparison, which evaluated 8 emission reduction scenarios in up to 6 models over a full range of species concentrations and deposition fluxes. The performance of the EMEP model for the accumulated concentration over a threshold of 30 parts per million (AOT_{30}) looked excellent, but for PM_{10} the model performance evaluation was hampered by the lack of observations and missing model components.

35. Mr. Fabio Monforti (Italy) presented preliminary results from the MINNI model addressing source-receptor relationships for Italy.

II. CONCLUSIONS AND RECOMMENDATIONS

36. The participants concluded that the unified EMEP Eulerian model represented a substantial development and enhancement compared to the earlier Lagrangian model used for the development of the Gothenburg Protocol and the European Union's National Emissions Ceilings Directive. The main improvements included:

(a) A higher resolution in source-receptor relationships (50 km grid size instead of 150 km);

(b) An improved description of the long-range transboundary transport and dispersion of pollutants, giving a more complete source allocation of the deposited material;

(c) A more integrated description of the physical and chemical processes, allowing the evaluation of long-term trends and emission changes;

(d) A realistic quantification of the deposition of sulphur and nitrogen to specific ecosystem types;

(e) The inclusion of suspended particulate matter.

37. The EMEP model was developed in order to support policy development for regional and transboundary air pollution in Europe, at a spatial scale of 100-1000 km. For smaller scales, the EMEP model should be complemented with local-scale models. Since the purpose of the model was to assist in the development of long-term strategies, it should rely on long-term statistics. The model should also be able to produce data for several years to account for inter-annual variability, without necessarily describing extreme events.

38. Based on an evaluation of the model formulation and an examination of intercomparisons between monitored data as well as with other models, the participants drew the following conclusions regarding the performance of the unified EMEP model and its use for policy applications.

A. Sulphur and nitrogen deposition

39. The model was suitable for the calculations of source-receptor relationships for sulphur and nitrogen deposition to support European air quality strategies. It was able to calculate the atmospheric deposition of sulphur and nitrogen compounds for estimating ecosystem impacts. It could reproduce changes in their concentrations and deposition to an extent that it could be used to evaluate the consequences of further emission reductions.

40. Intercomparisons with monitored data gave, in general, good agreement for sulphur and nitrogen but uncertainties remained to be quantified. Further evaluation of oxidized and reduced nitrogen data and process parameterizations was necessary to understand the current level of model performance.

41. It was recommended that, in the short term, model performance with respect to oxidized and reduced nitrogen should be quantified and emissions data be re-examined with respect to changes in emission patterns (geographical distribution and emission heights). In the longer term, consideration should be given to the sub-grid scale modelling of ecosystems.

B. Ozone

42. The model was suitable for the assessment of vegetation exposure to ozone and for the assessment of human health effects on the regional scale to support European air quality strategies. It was suitable for the establishment of source-receptor data on the regional scale for human health exposure and vegetation exposure/uptake of ozone and could predict changes in ozone concentrations caused by changes in precursor emissions on a European level.

43. The model showed an excellent level of performance for daily maximum ozone concentrations. For nitrogen dioxide, the performance was less good, in common with all other models, possibly due to sub-grid variations. The model showed a tendency to underestimate the peak ozone concentrations. Uncertainties would be higher for source-receptor compared with extreme value statistics.

44. It was recommended that, in the longer term, further consideration should be given to the outcome of the CITY-DELTA exercise, the continued increase in background ozone concentrations for the assessment of trends, the further investigation of the model and measured trends in VOCs and their oxidation products and developing improved partitioning of stomatal and non-stomatal fluxes of ozone to vegetation, validated against field observations.

C. Particulate matter

45. The model, in the form presented, underestimated observed PM_{10} and $PM_{2.5}$ due to an incomplete description of relevant processes and emissions. It was, however, able to calculate the regional component of the main anthropogenic PM fractions (sulphate, nitrate, ammonium, some primary components) with enough accuracy to assess the outcome of different control measures. Urgent attention was required to develop the model further for the full assessment of the anthropogenic fraction of $PM_{2.5}$.

46. The unaccounted-for particle mass was the most important issue for the development and evaluation of pollution control strategies. Due to the urgency of the policy development process, it was, however, important to make the best use of present knowledge and modelling results.

47. In the short term, attention should be given to:

(a) The exploration of empirical approaches to the development of a model for secondary organic aerosol formation based on available data and knowledge;

(b) The evaluation of present emission inventories in the light of atmospheric concentration measurements and analysis;

(c) The analysis of measurements and anthropogenic emissions of specific species of PM and the contribution to particle mass from particle-bound water.
Achieving full mass closure in the longer term required evaluations against speciated monitoring data, the inclusion of improved emission inventories, the inclusion of biogenic primary emissions and the formation of secondary biogenic aerosols.

D. Further model development and validation

48. Because of the complexity of the policy strategies being assessed, it was important that model development continued in parallel with policy application. The modelling development and applications undertaken in several European countries were crucial for the validation and further improvement of the EMEP model. The participants strongly supported the continuation of the model intercomparisons such as those undertaken within the EURODELTA programme and by the Netherlands research and technology organization TNO.

49. The final validation of the EMEP model was through comparison with observations. Observational data of high and known quality was fundamental for model validation and development. Model validation required all relevant processes to be adequately described with sufficient temporal resolution and at a proper density of sites. This should be achieved by combining a low number of sites with a comprehensive measurement programme, an intermediate number of sites providing a full description of parameters of general interest, and data from related networks for more specific parameters. Current model validation was limited by a lack of sites over large parts of the region, and by the fact that many of the required parameters, such as gas-particle distribution, VOCs and aerosol parameters, were not monitored at all sites. Further model development and validation were limited by the lack of observational data, so the monitoring network should be strengthened. There was a significant amount of monitoring activity going on in Europe both within EMEP, the EU AIRBASE and for other purposes. It was important to make the best use of these data to validate further the EMEP model and to give indications and directions for further research and development.

50. In the revision of the EMEP monitoring strategy, account should be taken of the experiences gained during the review of the EMEP model.

III. FUTURE WORK

51. The workshop's participants recommended that MSC-W should give consideration within its future work programme to:

(a) The primary and secondary organic carbon components of particulate matter;

(b) Developing empirical methods to complete the mass closure for PM_{10} and $PM_{2.5}$ and hence allow the source apportionment and evaluation of policy options;

(c) Further developing the treatment of natural PM emissions to include sea salt, wind-blown dust, Saharan dust and forest fires, including treatment of sources beyond the geographical scope of EMEP;

(d) The potential benefits of a closer cooperation with the European Centre for Medium-range Weather Forecasting (ECMWF) and of an involvement with real-time air-quality forecasting;

(e) Country-specific VOC speciation data;

(f) Performing sensitivity studies on the model vertical resolution to aid comparison with vertically resolved observations and estimation of deposition fluxes;

(g) Down-scaling approaches, for example, with the CITY DELTA project to assist with the assessment of urban-scale ozone and suspended particulate matter, as well as to address effects in general;

(h) Land-use databases, their harmonization and improvement;

(i) Cooperation with other activities concerned with the monitoring of deposition fluxes such as the ICP programmes and national programmes;

(j) Biogenic nitrogen oxide emissions from soil; and

(k) Model uncertainty and the approach of ensemble modelling.