Working Paper

Monitoring and Verification in the European Air Pollution Regime

Juan Carlos di Primio

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Preface

Hundreds or even thousands of international legal instruments on "the environment" are legally in force. What happens to international environmental agreements once they are signed, and how does the implementation of such agreements influence their effectiveness? These are the questions that motivate the IIASA project "Implementation and Effectiveness of International Environmental Commitments (IEC)." Research teams are examining these questions from many angles and with many methods.

In this paper, Juan Carlos di Primio examines the data reporting system of the Long Range Transboundary Air Pollution (LRTAP) Convention and a related system in the European Union. These systems are widely seen as among the most successful for gathering, exchanging and improving the accuracy of reported data. Di Primio explores the ways that the system has been implemented, its relationship to the substantive commitments of the LRTAP regime, and lessons that apply to making other data reporting systems more effective.

This is one of several IEC case studies that examine the operation and effectiveness of mechanisms for reviewing implementation of international agreements. The backbone of implementation review mechanisms (IRMs) is the accurate reporting of data, without which it would be difficult or impossible to identify and manage problems of non-compliance. Yet few agreements have active and effective data reporting systems. The present study contributes to IEC's efforts to understand what types of effective data systems are possible.

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Executive Summary

Most international environmental agreements have procedures to review domestic implementation, which we have collectively named **Implementation Review Mechanisms (IRMs)**. The main source of information for IRMs are the data provided by parties' self-reporting. These data are rarely, when at all, evaluated as of completeness, quality and reliability.

The main hypothesis that orientates the study is that IRMs are established to satisfy the desire of parties to know whether other have fulfilled -and continue to do so- the commitments incurred under the agreements. That is, IRMs respond to an implicit demand for verification of compliance. In general, no information additional to that delivered by the parties is collected by independent monitoring. Even when additional information exists, the questions arise whether all the data available are used in the review process, and whether that information would be sufficient to check upon compliance.

To examine the issue, data production, evaluation and use in the 1979 Convention on Long-range Transboundary Air Pollution (LRTAP) are analyzed in some detail.

LRTAP is a framework convention where commitments, targets and deadlines for air pollution abatement are spelled out in protocols. An important feature of this regime is that additional data to that reported by the parties is produced by the European Monitoring and Evaluation Programme (EMEP), which forms an integral part of LRTAP's structure.

EMEP consists of three centers that compile and evaluate the emission data reported by parties. Those centers also coordinate chemical analyses of pollutant concentrations in air and precipitation performed at national laboratories, carry out the modeling of long-range transport and assess results. In particular:

1. *Emission data.* The evaluation of time-series of emissions officially reported is at the basis of EMEP's efforts to improve data reliability through the development of a single methodology for emission inventorying, and the design of an approach to validate the inventories. Due to this approach, data transparency, completeness and reliability have steadily increased.

2. *Measurement program.* The quality assurance program of EMEP's Chemical Coordinating Center is in charge of critically assessing and enhancing raw national data on pollutant concentrations in air and precipitation.

3. *Modeling.* The models developed and run at two EMEP's Meteorological Centers address the long-range transport of air pollutants in Europe. Trajectories of air masses containing primary pollutants and their chemical transformation products, interacting with emission sources and dry and wet deposition, are followed from sources to receptor sites. Model inputs are emissions of sulphur and nitrogen compounds, and meteorological data. One model output is the geographical distribution of air concentrations and depositions on

the ground at points in the European EMEP grid, including sampling station sites. In addition, deposition matrices show the estimated exchange of acidifying pollution between countries.

4. *Correlations*. Comparison between measurements of depositions with emissions and with model calculations allow assessing the impact of abatement programs, at the same time provide information on the role of input factors and model design on model performance.

Verification of compliance involves performing an independent check of the veracity of a national declaration. Two main institutional conditions need to be met to guarantee the independence and effectiveness of a verification system: it should be embedded in the international domain of the treaty and empowered to install and operate its own monitoring and evaluation program.

Discussion and Conclusions. The main elements of the LRTAP IRMs are: i) reporting obligations: ii) national reports on emissions, abatement policies and strategies, including the data used to estimate inventories; iii) results of EMEP activities on data gathering (emissions, measurements), collation and quality assurance, and the modeling of long-range transport of air pollution; iv) the annual and 4-year major reviews on the state of air pollution in Europe prepared by the Secretariat; v) the implementation review by the Executive Body at its annual meetings.

The evolution of the LRTAP IRMs has been fostered by the parties' interest to know more about the fulfillment of obligations. National declarations and EMEP activities provide the data used by the LRTAP IRMs to follow and review domestic implementation.

Are that data enough to verify compliance? There are two aspects to this question: 1.- Are the available data sufficient for verification purposes? 2.- Is the extant institutional setup appropriate?

1.- The analysis of the technical components of the data collection and assessment system shows:

i) A large ongoing effort to improve the completeness, transparency and reliability of *emission* estimations has been the basis of the current development of a common methodology. From the existing databases it transpires that parties to the protocols have met their commitments on sulphur and nitrogen. However, although a single methodology would increase consistency of the data set and allow comparative analyses of emissions within and among countries, it doesn't necessarily improve the chance of verifying compliance. Since verification is always *ex post facto*, there is no way to be sure that the reported data are trustworthy, short of continuous measurement of all sources.

ii) The *measurement* program of chemical species in air and precipitation provides useful information for verification purposes. In spite of a number of reasons that led to discard part of the data for studies on deposition trends and comparison with model results, statistical analyses of seasonal and annual averages have shown clear qualitative trends (e.g., a slow, long-term decrease of acidity in precipitation) in line with those stemming from emission time-series evaluation.

iii) Annual averages of *model* results have increasingly shown a reasonable agreement with observations. Main origins for differences between calculated and observed seasonal and annual means are model formulation, and the authenticity of both emission and measurement data. The routine model is able to reproduce the general features of the phenomena. As a consequence, the deposition country-allocation matrices are accepted by the parties to consider abatement goals; in addition, sensitivity runs are appropriate to study the effect of changes in emission rates, an useful instrument for verification purposes.

2.- The institutional conditions are not completely satisfied by the LRTAP IRMs: although enjoying international standing, EMEP's centers are national laboratories. And no truly international monitoring system -i.e., one that may use national installations and capabilities but has also independent surveillance and evaluation means- has been installed.

The data supporting the LRTAP IRMs are *necessary but not sufficient* to handle verification of compliance, additional information as well as procedures will be required if the parties want to establish a verification system. This entails the need to take new steps, some technical (gathering more data to perform independent checks, development of methods and instrumentation) and some institutional (change of structure).

Some aspects of a verification system are envisaged in the 1994 Sulphur Protocol. Notably, an Implementation Committee and non-compliance procedures are being established to ensure that a forum exists where compliance problems can be handled. This Protocol is more stringent that its predecessors, compliance problems are more likely to erise.

Acknowledgments

At the early stage of this study a number of people facilitated access to primary sources of information and helped me become aware of the current state of EMEP activities, including those for estimating emission inventories. In particular, I am grateful to Harald Dovland (Norwegian Ministry of Environment), Gordon McInnes (European Environmental Agency), and Markus Amann and Zbigniew Klimont at IIASA. Various drafts of this paper were carefully reviewed by David Victor, whose detailed comments encouraged me to focus attention on issues at the center of interest of the IEC project. I have also greatly benefited from many other comments on various versions of this study, especially those of Harald Dovland and Jan Schaug (Norwegian Institute for Air Research), Jill Jäger (IIASA) and Kal Raustiala (IEC). I thank Peter Sand (IEC Advisory Committee) for the review of the final draft and his thorough remarks, which helped me correct some inconsistencies.

I. Introduction

A side-effect of the extraordinary expansion of human activities during the current century in the wake of accelerated industrialization and global population growth is the increasing deterioration of the environment, basically stemming from the combustion of fossil fuels for transportation and energy generation -the main sources of atmospheric pollution with gaseous and particulate emissions- and also from a number of industrial processes, agricultural practices, and the disposal and handling of various categories of waste from a myriad of sources. Many nations, in particular those that are highly industrialized, have taken steps to reduce or eliminate anthropogenic pollution and increasingly proceeded to protect natural resources and endangered species. National environmental policies have been formulated, strategies designed for implementing corrective measures, legislation passed and enforced. In the course of time, however, it became apparent that national responses are at times insufficient to reduce the stress on the environment, and that international cooperation and coordination are required to attain national goals. "It is by now a truism, but also true, that many forms of pollution do not stop at frontiers" [Brenton 1994].

A number of international environmental agreements have come into force during the last decades, addressing ways and means to collectively manage the utilization of natural resources and the implementation of policies to combat an environmental pollution of increasing complexity and dimensions, with deleterious effects on the quality of air, land and water.

Responses to local deterioration of environmental quality are in the hands of domestic authorities (at the national, state, county and municipal levels), which can be empowered by legislation to establish limits to pollution and enforce compliance. The implementation of measures resulting from policies and strategies agreed upon by states to deal with transboundary environmental problems -the subject of many international environmental agreements- cannot be dealt with equally. Clearly, once any such agreement is in force, its objectives, goals and targets constitute commitments that the parties have accepted to fulfill. However, with no supranational authority to enforce the parties' domestic implementation, the proof of compliance becomes a quite involved and sensitive issue.

Ideally, domestic implementation should start as soon as an international environmental agreement comes into force: in practice delays occur, often for long periods of time. In the majority of cases, treaty provisions require: i) that the parties keep each other informed about the progress of implementation, exchanging information by means of national reports issued at regular intervals; and ii) that these national reports be evaluated in an appropriate body where the parties review each other's performance using procedures which may be collectively referred to as **Implementation Review Mechanisms (IRMs)**[1] [see Victor et al. 1994]. The approach generally adopted by parties to international environmental agreements to review national implementation is simply to take notice of self-reported progress in the occasion of regular or special meetings. The assessment is generally done in a non-confrontational, cooperative fashion, where the question of credibility of information essentially stemming from self-reporting is carefully avoided. The apparent aim of the process is to increase the homogeneity and transparency of the reports, and eventually ensure that a reasonable completeness of information is achieved, especially when it has been compiled using a common methodology. As a result of such exercise, a better understanding of national capabilities for, and international trends of, implementation can be expected. But in general the IRMs of most international environmental agreements stop short of addressing questions of verification of compliance (Fischer 1991, USGAO 1992, Ausubel and Victor 1992)[2].

In the field of arms control, where national security is at stake and international agreements become dead letter when the capacity to closely follow implementation is lost or even weakened, IRMs can be basically equated to procedures for verifying compliance[3]. In the case of international environmental agreements it may appear, at first sight, that non-compliance is not a grave transgression but rather a misdemeanor, and so a rigorous surveillance of the parties' actions (and inactions) is not required. However, since

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[1] In this paper, only review mechanisms used in an international set-up to follow and assess the parties implementation are dealt with, i.e., **international IRMs**. However, a number of similar procedures are often employed at the national level by the institutions in charge of producing, compiling and assessing the national data that will be incorporated into the implementation reports. The corresponding activities constitute **national IRMs**, which may be more detailed and intrusive than their international counterparts. In general, the link between national and international IRMs is provided by the treaty's reporting system, unless specific provisions exist in the agreement to institutionalize the verification of compliance.

[2] This situation is changing. The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer requires the development of procedures and institutional mechanisms to address non-compliance, which were agreed upon at the parties 1992 fourth meeting [Széll 1995]. The 1991 LRTAP VOC Protocol (not yet in force) determines that "the parties shall establish a mechanism for monitoring compliance" (Art. 3.3). The 1994 Protocol to the LRTAP Convention on Further Reduction of Sulphur Emissions (not yet in force) creates an Implementation Committee (Art. 7) "to review the implementation of the present Protocol and compliance of the parties with their obligations".

[3] Verification of compliance is understood herein as an international, independent check of the parties's fulfillment of obligations incurred under international law.

environmental damage moves often at a slow pace, with unexpected and, in general, not well understood consequences in the long run, the above interpretation may not reflect the views of many parties.

At this point it seems pertinent to ask: why do most international environmental agreements incorporate IRMs? This recurrence suggests that the requirement reflects the parties' desire to know whether others have complied, and continue to comply, with the commitments incurred under the agreement[4]. It follows that the design, application and evolution of IRMs respond to an implicit demand for verifying compliance.

The demand for verification is related to the reasons that move a state to join an agreement. In the context of a nation's assessment of its international affairs, such demand may have low priority throughout, or the initial priority may decline in the course of time[5]. This will influence the design and implementation of the corresponding IRMs, which consequently may be under-developed and/or under-used.

In general, the data on implementation contained in national reports are often summaries condensing a wealth of information collected by each party. However, not much transpires from them about data completeness and reliability.

National reports may be compiled using formats that basically respond to the purpose of collecting the information in the first place, i.e., national interests and requirements. In this case, they will usually differ in coverage and degree of detail, and thus be hardly comparable with each other, so that an appropriate overview of a treaty's implementation may become impossible. Alternatively, the reports may be drafted in conformity with agreed guidelines, not only establishing a common format for reporting but also defining the minimum amount of information to be delivered, so that it would become viable to keep track of the formulation and evolution of national policies and action plans, as well as of the steps taken to implement them: this approach favors transparency and comparability. Some of the most recent international environmental agreements give special attention to the early development of common methodologies for the production of data, as well as guidelines for reporting.

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[4] As in the field of arms control, national interests are here also at play. This is to be expected since environmental deterioration and/or change may have serious -albeit internationally skewed- effects on the political economy of nations.

[5] There are many situations to consider. For example, states may have been "persuaded" to join a regime; or, the operation of the regime has shown unexpected drawbacks for most parties, or for a few powerful.

National activities for the protection and preservation of the environment are supported at home by different infrastructures for *monitoring*[6] the main parameters characterizing the problem in hand. Since this is costly in materials and manpower, rich nations are generally in a much better position than poor countries to identify the problems and assess effects, including those of mitigation and abatement measures. That is, a substantial difference exists among nations with regard to their capabilities for detecting issue-areas and following the effects of implementing policies. Irrespective of the adoption of common methodologies and guidelines, this situation affects the completeness and quality of some national reports, and hence the usefulness of the whole set.

While domestic as well as international activities to produce and evaluate data are not the only elements of IRMs, the efficacy of IRMs fundamentally depends on the completeness and reliability of the information at their disposal: the backbone of IRMs is data.

In this context, the question arises: to what degree are the data of extant IRMs of international environmental agreements sufficient to provide information on the fulfillment of obligations by the parties?

The answer will hopefully stem from a detailed consideration of selected cases. An appropriate start for such analysis would be provided by one case for which: i) the issue-area is such that many kinds of information must be gathered, collated, compiled, evaluated and stored -this will favor the analysis of the role played by data; ii) the agreement has been in force for a reasonably large number of parties during a reasonably long period of time -this will allow a look into evolutionary trends. Following these guidelines, the International Convention on Long-range Transboundary Air Pollution (LRTAP) was chosen as an appropriate candidate for study.

Widely regarded as a success, the approach of the LRTAP Convention to review implementation provides an end point, perhaps a model, for the design of data systems elsewhere. In practice, it has been closely interlinked with data systems development in the European Union, which will be considered here where relevant.

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[6] That is, following up changes by systematic periodic or continuous quantitative surveillance. "The idea of monitoring ... implies an active, continuing, and institutionalized collection and analysis of time-series data to assess the current condition and trends of key variables. In the case of environmental monitoring, these key variables would be ecological, biological, chemical, physical, or socioeconomic" [Rodenburg 1992]. [See also Ausubel and Victor 1992].

II. Case Study: The LRTAP Regime

1. Overview

1.1. Introduction

Many scholars, natural and social scientists as well as practitioners, have dealt with a variety of aspects of the LRTAP regime during the last two decades. On the one hand, an abundant scientific-technical literature has grown from initial efforts to understand the origin of acid rain, its environmental impacts, and the techno-economic requirements and opportunities for abatement and control. A number of these studies have been sponsored by, or conducted at, LRTAP-associated laboratories and institutes. Progress in knowledge contributed to the processes of policy formulation and implementation reviewing, which in turn provided the thrust to investigate key scientific and technological issues. This synergism sped up the extension of research and policy-making beyond acid rain, in line with the spirit and letter of the Convention.

On the other hand, political scientists and international lawyers have looked into aspects of international institutions and domestic implementation to assess the influence of the Convention on policy-making and the attainment of established goals [for recent appraisals see Wettestad and Andresen 1991, Wüster 1992, Levy 1993 and 1995, Wettestad 1996].

The main focus in what follows is on the interrelationship between the scientific-technical and the policy formulation and implementation activities; in particular, on the information provided by the former to follow domestic implementation.

The acidification of rain was known long before negotiations concluded with the adoption of the LRTAP Convention [for a historical overview see, for example, Wetstone 1987]. In Europe, the first measurements of chemical composition in precipitation were done in 1947 at a Swedish network of stations [Egnér et al. 1955]. That network was extended to other European countries during the 1950s, when nearly 100 stations were installed and coordinated by the Institute of Meteorology at the University of Stockholm. At the beginning of the 1960s, it was observed that precipitation at many of these stations became more acid. In a pioneering paper, Odén showed that acid precipitation in Scandinavia was expanding year after year [Odén 1968], a fact that he attributed to sulphur emissions transported from remote sources. The findings were reported to international fora: in 1969 to the Air Management Sector Group of the Organization for Economic Co-operation and Development (OECD), and in 1972 at the Stockholm Conference on the Environment, which identified long-range transboundary air pollution as a problem requiring urgent consideration in industrialized countries. By the early 1980s, the problem of forest damage and decline in central Europe was at first ascribed to air pollution and became an issue of public and governmental concern.

The first scientific in-depth study of causes and effects of regional acidification started in 1972 as the OECD Council launched the "Co-operative Technical Programme to Measure the Long Range Transport of Air Pollutants" with the participation of eleven OECD European Member Countries.

The OECD study is of special interest because it established the approach that was later to be followed and extended under the LRTAP Convention. Its objective was "to determine the relative importance of local and distant sources of sulphur compounds in terms of their contribution to the air pollution over a region, special attention being paid to the question of acidity in atmospheric precipitations" [OECD 1972]. If required, other substances could be included in the program at a later stage. Coordination responsibilities for measurements and analysis of data were assigned to the Norwegian Institute for Air Research (NILU), appointed as the Central Co-ordinating Unit (CCU).

The OECD program contributed to the creation of an European scientific-technical infrastructure "to determine the large scale regional pattern of transport of air pollutants: (to that end) information is required on the relation between emissions, meteorological data and concentration of air pollutants". It was then decided "to work out an emission survey based on information from the participating countries and to establish a number of representative ground level stations in each of them. Information on the vertical distribution of sulphur compounds should be obtained through aircraft sampling. The interpretation of the data was to be based on atmospheric dispersion models" [OECD 1979].

The first measurement phase of the OECD program began in July 1972. By the beginning of 1973, all ground stations were in operation. During this period, the CCU developed atmospheric dispersion models "which could describe the long range transport of the air pollutants with sufficient accuracy for a comparison with the observed data". Although measurements under phase I were not completed until January 1974, an evaluation of available results was done in September 1973. It showed that the "long-range transport of air pollutants was of considerable importance in the acidification of precipitation", a finding that prompted phase II in the period January 1974 - March 1975, thus allowing for the continuation of measurements throughout the winter season. This provided "the data needed for a first quantitative estimate of the long-range transport of sulphur oxides and their relation to the acidification of precipitation" [OECD 1979]. The OECD Programme showed that an extensive exchange of air pollution takes place between all the European countries, and that about 20 % leaves the area [Ottar 1978].

1.2. Institutional Structure

After extensive negotiations within the framework of the United Nations Economic Commission for Europe (UN/ECE) the **Convention on the Long-range Transboundary Air Pollution (LRTAP)** was adopted in Geneva on 13 November 1979 and entered into force on 16 March 1983; as of 31 May 1995 it had a membership of 39 parties, including the European Union[7].

Figure 1 shows LRTAP's current organization chart. The *Executive Body* (EB), constituted within the framework of the UN/ECE's Senior Advisers on Environmental Problems, yet formally independent of the UN/ECE, is the supreme decision-making assembly. Formed by representatives of all contracting parties, the Executive Body meets at least once a year to review the implementation of the Convention and to adopt the work-plan. Between sessions, the *EB Bureau*, consisting of the EB chairman and four vicechairmen, deals with matters requiring interim attention. The functions of *Secretariat* have been assigned to the UN/ECE Air Pollution Section, Environment and Human Settlements Division.

A number of expert groups have been created to help put the work-plan into practice: i) *Intergovernmental Working Groups* (WGs), established by the EB as standing subsidiary bodies open to all parties, including the *EMEP Steering Body* and at present three further WGs, namely on *Effects*, on *Strategies* and on *Technology*. Five *International Cooperative Programmes* (ICP) are currently active under the Working Group on Effects; ii) *Intergovernmental Task Forces* (TF), generally under the WGs, either formed *ad hoc* to furnish a specific report, or to supervise a continuing cooperative program. Responsibility for each ICP and TF rests with a designated lead country.

While the LRTAP Convention provided the framework to establish targets for air pollutant emission control in protocols, it required an appropriate agency to collect information on implementation. To that end the **"Co-operative Programme for Monitoring and Evaluation of Air Pollutants in Europe" (EMEP)** was incorporated as a principal institution

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[7] Economic Commission for Europe. 1995. Strategies and Policies for Air Pollution Abatement - 1994 Major Review. ECE/EB.AIR/44.

of the Convention.

EMEP was established in 1977 as a monitoring and research program of air pollutants in Europe under the auspices of UN/ECE in cooperation with the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) within the context of the inter-agency Global Environmental Monitoring System (GEMS) [Gosovic 1992, Dovland 1993, Sand 1996]. EMEP's funding was at first based on voluntary contributions. The main objective of EMEP is to provide governments with information on the deposition and concentration of air pollutants, as well as on the quantity and significance of their fluxes across national boundaries. EMEP is managed by the Steering Body, under which three Centers are established: the *Chemical Co-ordinating Centre (CCC)* at the Norwegian Institute for Air Research (NILU), responsible for the co-ordination of the chemical measurement program, data quality assurance, management and storage; the *Meteorological Synthesizing Centre-West (MSC-W)* at the Norwegian Meteorological Institute (DNMI) in Oslo and the *Meteorological Synthesizing Centre-East (MSC-E)* at the Institute for Applied Geophysics in Moscow, are in charge of modeling the transport and deposition of pollutants. In 1991, a *Task Force on Emission Inventories* was formed; it works directly under EMEP's Steering Body [Figure 2].

The first Protocol to LRTAP provided for funding of EMEP. The **1984 Protocol on Long-term Financing of the Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP)**[8] commits parties to mandatory annual contributions to the budget prepared by EMEP's Steering Body and approved by the Executive Body.

Subsequent Protocols have established targets and deadlines to implement abatement measures concerning the main pollutants, namely sulphur dioxide (SO_2), nitrogen oxides (NO_x) and volatile organic compounds (VOCs), as well as the parties' specific reporting obligations.

The **Protocol on the Reduction of Sulphur Emissions or Their Transboundary Fluxes by at least 30 percent**[9] committed parties to "reduce their national annual sulphur emissions or their transboundary fluxes by at least 30 per cent as soon as possible and at the latest by 1993, using 1980 levels as the basis for calculation of reductions" (Art.2). It has recently been

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[8] Adopted in Geneva on 28 September 1984, entered into force on 28 January 1988. As of 31 May 1995 it had 35 Parties, including the European Union.

[9] Adopted in Helsinki on 8 July 1985, entered into force on September 2, 1987. As of 31 May 1995 it had 21 parties.

succeeded by the **Protocol on Further Reduction of Sulphur Emissions** [ECE/EB.AIR/40], adopted in Oslo on 14 June 1994. It sets the parties' emission reduction obligations so that "depositions of oxidized sulphur compounds in the long term do not exceed *critical loads* for sulphur, given ... as critical sulphur depositions, in accordance with present scientific knowledge" (Art. 2). This reformulation of the parties' commitments with respect to the original Protocol introduces reductions that are guided by a scientific assessment of pollution effects, thus replacing the rather arbitrary selection of a flat-rate cut. As of 31 May 1995 the new SO_2 Protocol had been signed by 28 parties; it will enter into force when 16 parties have deposited with the UN Secretary-General their instruments of ratification, acceptance, approval or accession.

The **Protocol Concerning the Control of Emissions of Nitrogen Oxides or Their Transboundary Fluxes**[10] committed parties to a freeze of national annual emissions of nitrogen oxides or their transboundary fluxes at 1987 levels by the end of 1994. Consideration of a new version of the NO_x Protocol, to be based on the critical loads concept, is currently in progress.

The **Protocol Concerning the Control of Emissions of Volatile Organic Compounds or Their Transboundary Fluxes**, adopted in Geneva on 18 November 1991, is not yet in force. It proposes the reduction of VOC emissions in order to diminish the formation and fluxes of secondary photochemical oxidant products.

1.3. Commitments

The LRTAP Convention is a framework agreement establishing general principles, objectives and recommendations for behavior in order to achieve the general goal of air pollution abatement, while its Protocols establish definite commitments for action, including targets and deadlines. In addition, a number of clarifications regarding obligations have resulted from decisions taken by the Executive Body in relation to the annual work-plan, the most important concerning reporting duties.

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[10] Adopted in Sofia on 31 October 1988, entered into force on 14 February 1991. As of 31 May 1995 it counted with 25 parties.

1.3.1. Commitments Under the Framework Convention

Parties to the Convention shall:

==> endeavor to limit and, as far as possible, gradually reduce and prevent air pollution, including long-range transboundary pollution (Art. 2);

==> by means of exchanges of information, consultation, research and monitoring, develop the best policies and strategies -including air quality management systems- to combat the discharge of air pollutants (Art. 3 and 6);

==> exchange information on, and review national policies, scientific activities and technical measures aimed at combatting the discharge of air pollutants (Articles 4 and 8);

==> initiate and cooperate in research and development in the field of air pollution control technologies (Article 7);

==> promote implementation of the "Co-operative Programme for the Monitoring and Evaluation of the Long-range Transmission of Air Pollution in Europe" (EMEP).

Periodical information exchanges among Parties are required under Article 8 concerning: emissions of air pollutants from grid units of agreed size or on the fluxes of agreed air pollutants across national borders; major changes in national policies; control technologies and their potential impact; projected costs of emission control; meteorological, physico-chemical and biological data relating to the processes of transport and to the extent of damage.

The Convention does not include reduction targets of pollutant emissions nor provisions on reporting obligations by the parties.

1.3.2. Commitments Under the Protocols

The SO_2 Protocol established a reduction of national annual sulphur emissions or their transboundary fluxes by at least 30% below the 1980 national emission rate, as soon as possible and at the latest by 1993 (Art. 2); the parties shall study the need for further reductions (Art. 3) and report to the Executive Body on: i) their annual sulphur emissions and the basis upon which they have been calculated (Art. 4), and ii) their national programs, policies and strategies to reduce sulphur emissions or their transboundary fluxes (Art. 6).

The 1994 SO_2 Protocol currently in process of ratification calls for further, at times quite substantial, reductions, with ceilings (quantified in Annex II) by 2000-2010 determined on the basis of critical loads for sulphur; the parties shall apply specified emission limit values to all major new stationary combustion sources; a deadline is established to extend the application of such limits to existing similar sources with a thermal input above 500 MWth (Art. 2). The parties shall report to the Executive Body, in particular on: i) the implementation of national strategies and policies; ii) national annual sulphur emissions, including emission data for all relevant source categories (Art. 5). EMEP, in turn, shall "in good time before the annual session of the Executive Body" provide information on ambient concentrations and deposition of oxidized sulphur compounds, as well as calculations of sulphur budgets.

The NO_x Protocol calls for emission control and/or reduction of nitrogen oxides or their transboundary fluxes, at the latest by the end of 1994, so that these do not exceed their respective levels in 1987. In addition the parties shall take control measures of emissions by major stationary sources and apply emission standards to new mobile sources (Art. 2). Reporting on annual national emissions of nitrogen oxides, as well as on the progress in the application of emission standards and pollution control measures is required under Art. 8. This article also determines that the parties shall report "progress in establishing critical loads", an approach also adopted during current negotiations of a new NO_x Protocol.

The VOC Protocol establishes reductions of VOC emissions by at least 30% by the year 1999, using 1988 levels as reference.

1.3.3. Obligations Stemming from Decisions of the Executive Body

Important within the context of this study are obligations concerning data reporting. Under the auspices of EMEP, guidelines for reporting have been prepared and recommendations issued periodically concerning the extent and frequency of national reports containing emission data and the main indicators used for their calculation.

In its 1987 fifth session the Executive Body provided "guidelines for reporting by parties to the 1985 Helsinki Protocol". It reminded the parties about their reporting obligations under the Protocol's articles 4 and 6, so that EMEP could perform a "timely and accurate" calculation of sulphur budgets and transboundary fluxes on the basis of article 5. In particular, the Executive Body established that parties shall report not later than 1 May of each year on: i) their annual sulphur emissions for the year 1980 and for all years, starting with the year of entry into force of the Protocol for the party concerned; ii) national programs, policies and strategies for sulphur emission reductions. In addition, parties were requested to report on the basis upon which the 1980 emissions were calculated, "including emission factors by source category" [EC/EB.AIR/16]. At its 1990 eighth session [ECE/EB.AIR/24], the Executive Body approved the amended reporting schedule for the submission of emission data by December 31 rather than May 1 of each year, in agreement with EMEP's Steering Body recommendation that "...final emission data should be submitted before 31 December of the year following the year concerned, thus giving parties 12 months to produce the data" [Sandnes 1993].

In its 1991 ninth session [ECE/EB.AIR/29], the Executive Body endorsed the recommendation of EMEP's Steering Body concerning guidelines for estimation and reporting of emission inventories [ECE/EB.AIR/R.65] whose application by the parties to the LRTAP Convention would facilitate EMEP activities. The parties should submit annually information on emissions of sulphur oxides (SO_x), nitrogen oxides (NO_x), non-methane organic volatile organic compounds (NMVOCs), methane (CH_4), ammonia (NH_3) and carbon monoxide (CO). Emission data should be reported as totals and at least for the major source categories specified in the document; data to be used in modeling should be reported for 50x50 km grid cells.

At least in two occasions the Executive Body has given authoritative interpretations of the text of the Convention and its Protocols: in relation to the definition of "transboundary fluxes" in the Convention and three Protocols, and on the continuing commitment of parties to the Helsinki SO_2 Protocol not to increase their emissions after the 1993 target date [Sand 1996].

2. Data on Implementation: The Role of EMEP

The only body with authority to review the implementation of commitments under the LRTAP Convention is the parties' assembly, the Executive Body. The procedures used are: i) evaluation of the information on emissions, national programs, policies and strategies summarized in annual reviews in the light of major reviews that must be performed every four years; and ii) consideration and approval of the work-plan. According to the work-plan for the implementation of the Convention, as adopted by the Executive Body at its third session [ECE/EB.AIR/7, annex IV], major reviews of national strategies and policies for combatting air pollution shall be undertaken every fours years to ascertain the extent to which the objectives and fundamental principles have been met as laid down in the Convention and its Protocols. Reviews are based on national submissions and other official sources[11].

The Secretariat is entrusted with the tasks of drafting the work-plan and preparing both the annual and major reviews on the basis of information contained in national contributions enhanced with information from *other official sources*, such as EMEP, Working Groups, Task Forces and International Co-operative Programs. Although their work is only summarily reported in the above-mentioned reviews, the information they provide is fundamental for the elaboration of the annual work-plan. Therefore, some activities of these other official bodies should be seen as a support of the LRTAP Convention's IRMs (for example, the determination and mapping of ecosystems' critical loads).

Of special relevance in the context of this study are EMEP monitoring and evaluation programs which provide the data necessary to gain a detailed understanding of national implementation. In what follows, the focus will be on activities under EMEP supervision (emissions, depositions) or direct responsibility (data quality assurance programs, modeling of chemical change and transport of air pollutants). This will also serve the purpose to highlight the measures taken in the course of time to steadily increase both the quantity and the reliability of the data.

EMEP's basic work addresses: i) collation, evaluation and storage of the emission data reported by the parties; ii) development of a common methodology to calculate emissions; iii) design, coordination, quality assurance and control of the measurement program in air and

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[11] As yet three major reviews have been performed, respectively for the years 1986 [ECE/EB.AIR/14], 1990 [ECE/EB.AIR/27] and 1994 [ECE/EB.AIR/44].

precipitation; iv) modeling the atmospheric dispersion of the chemical species involved (including transformation and removal processes) on the basis of emission data and relevant meteorological parameters. These four activities are considered in order below.

2.1. Emissions

Emissions of acidifying pollutants stem from human activities as well as natural sources. The Convention focuses on anthropogenic emissions; however, it is important to have records of emissions from natural origin in order to understand the relative significance of those from anthropogenic sources and the limits of abatement measures. Besides, natural emissions are a necessary input for modeling the transport and deposition of air pollutants.

There are large uncertainties about the chemical speciation and the magnitude of the natural fluxes [Andreae 1985]. Emission estimates of important air pollutants are shown in Table 1: On the *global scale*, emissions from natural sources appear to be either of comparable magnitude with, or well in excess of, anthropogenic emissions. This does not seem to be the case for the *continental* emissions in North America and Europe, where estimates of both SO_2 and NO_x natural emissions amount to a few percent of those produced by human activities [Builtjes 1989]. Main sources of sulphur emissions are SO_2 from volcanic activity and biomass burning, dimethylsulphide (DMS) from oceanic plankton, hydrogen sulphide (H_2S) from soils and plants, and sulphate aerosols from sea spray. The most important sources of nitrogen oxides natural emissions are bacterial activity in soils, lightning, and combustion of biomass; while ammonia (NH_3) natural emissions stem primarily from soils, plants and manure.

2.1.1. Methodologies for Compiling Emission Inventories

In general, anthropogenic emissions are not directly measured[12] but are estimations supported by representative measurements made at main sources of all types. In general terms, estimations are arrived at by multiplying each source's *activity rate* (e.g., SO_2 emitted per ton of coal burned) by an appropriate *emission factor* (e.g., tons of coal consumed per year). Most of the chemical compounds whose emissions have to be reported under the LRTAP Convention are primarily formed during fossil fuel combustion.

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[12] Although in some countries continuous monitoring of a few pollutants is often implemented at a few large point sources like power plants and refineries.

Two main approaches for the compilation of emission data from the energy sector are in use: i) a "top-down" methodology based on aggregated energy statistics[13] that contain energy data and energy balances showing consumption (the activity rate) in the principal economic sectors, and a limited number of *average* emission factors; and ii) a "bottom-up" approach, in which the selection of a number of socio-economic activities[14] requires the identification of a great number of *specific* emission factors reflecting not only fuel characteristics but also engineering performance of equipments, machines and installations.

The estimation of anthropogenic emissions from sources other than fossil fuel combustion is generally based upon a few detailed analyses of national situations.

The huge amount and variety of statistical information that needs to be gathered, collated, compiled and stored, as well as the inherent difficulties in determining activity rates (e.g., details of energy consumption in the economic sectors, amount and type of fertilizers used in agriculture, volume and composition of waste) and emission factors introduce errors in the estimations, whose uncertainty range is generally poorly understood.

Up to now most emission data have been prepared using national methodologies. Various parties to the LRTAP Convention, in particular the most industrialized states, have developed detailed methods to determine emission rates of air pollutants. Although the procedures follow similar broad principles, there are a number of distinctive differences. For instance, variations in fuel specifications and the definition and composition of the economic sectors (e.g., the number of sub-sectors, the modal split of transportation) respectively affect the corresponding emission factors and the sectoral figures of activity rates. At the same time, a number of states have used a "top-down" approach based on gross activity aggregates and average emission factors. For these reasons, comparability of national emission inventories is low, and it is difficult to apply a national methodology directly to other country situations.

The above considerations suggest that the development of a common methodology for compiling emission inventories would improve the consistency of results and enable comparisons of past performance and inventories among countries. The preparation of guidelines for application of such methodology is an important feature of international

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[13] Such as those published by the United Nations Statistical Office, the OECD International Energy Agency (IEA) and the European Union Statistical Directorate (EUROSTAT).

[14] For example, distance travelled by various modes of transportation, tonnage of steel produced using a particular process, ambient temperature to be maintained in different kinds of housing.

cooperation to promote better and more reliable data.

2.1.1.1. The CORINAIR Methodology

Concerned by experts views that environmental data in Europe were of low quality, the European Council of Ministers established in 1985 an "experimental project for gathering, co-ordinating and ensuring the consistency of information on the state of the environment and natural resources in the Community"[15]. The work program was given the name CORINE [CO-oRdination d'INformation Environnementale]. It included a project labelled CORINAIR for collecting and organizing information on emissions relevant to acid deposition.

Within the framework of the CORINE program, a working group was established to develop a methodology for the compilation of national inventories of air pollutants. The task force was formed in 1986 with experts from national agencies to develop a common methodology and to compile the 1985 prototype emission inventory of atmospheric emissions of three pollutants, SO_2, NO_x, and VOCs (total volatile organic compounds) from eight main source sectors in the 12 member states of the Community. The inventory was completed in 1990 and recently published [Bouscaren et al. 1995]. Follow-up activities to prepare a 1990 inventory under the lead of a Task Force at the European Environmental Agency (EEA-TF) are also completed. At the time of writing, results for most countries are final and in process of publication. The 1990 CORINAIR nomenclature covers about 260 emission-generating activities grouped in 11 main source groups[16] , extending the 1985 list of pollutants to eight, namely: sulphur oxides (SO_x as SO_2), nitrogen oxides (NO_x as NO_2), non-methane volatile organic compounds (NMVOCs), ammonia (NH_3), carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). The approach has been made available to 30 European countries: 15 member states of the European Union, 2 from EFTA (Norway, Switzerland), 3 Baltic states (Estonia, Latvia, Lithuania), 9 Eastern and Central European countries (Albania, Bulgaria, Croatia, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia) and Russia. Thus, although pursuing the aims of the European Union, the CORINAIR project covers most requirements of the LRTAP Convention as well.

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[15] Council Decision 85/338/EEC.

[16] These are: 1 - Public power, cogeneration and district heating. 2 - Commercial, institutional and residential combustion. 3 - Industrial combustion. 4 - Production processes. 5 - Extraction and distribution of fossil fuels. 6 - Solvent use. 7 - Road transport. 8 - Other mobile sources and machinery. 9 - Waste treatment and disposal. 10 - Agriculture. 11 - Nature.

The CORINAIR methodology is bottom-up, it uses data on the types of plants or vehicles, types of emission controls, etc., as the fundamental basis for emission estimations. Plant-specific information is provided on a number of point sources (large power plants, sulphuric and nitric acid plants, integrated iron and steel plants, airports, etc.) while other smaller or more diffuse sources (road transport, domestic heating, solvent use, agriculture, etc.) are treated on an area basis to provide emission estimates from these sources. The selected spatial resolution for area sources corresponds to the department/county level. The emissions from both point and area sources can be determined by measurements or calculated with appropriate emission factors and activity statistics (energy consumption, industrial throughput, number of animals, etc.).

The CORINAIR project has worked out guidelines to estimate emissions -relevant activity statistics, emission factors, etc.- without making their use mandatory; countries may choose to use detailed country-specific data on emission-generating activities and emission factors which they consider best reflect national conditions for each of the emission generating activities included in the agreed CORINAIR activity list SNAP (Selected Nomenclature for Air Pollution). But it provides for *consistency* by specifying the activities to be quantified and the main source sectors and sub-sectors in which each activity is included, at the same time allowing for *flexibility* as to how each country estimates emissions for each activity[17] .Its implementation constitutes an important step towards increasing the transparency and comparability of national emission inventories, opening the way for a significant quality control process.

2.1.1.2. The Task Force on Emission Inventories

The LRTAP Convention incorporates no explicit provision regarding the completeness and reliability of the emissions information in national reports. The data provided by the parties are stored in databases[18] and, in principle, taken at face value for various purposes, including modeling. However, complaints about data quality and delays in reporting have been voiced at various meetings. This has had the important effect of increasing the attention devoted to the preparation of emission data. A 1990 EMEP Workshop on International Emission Inventories contributed to the preparation of a draft of technical guidelines for estimation and reporting of national emissions of sulphur compounds, nitrogen oxides (NO_x), VOCs and

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[17] A complete harmonization of national systems would not have been possible.

[18] At the UN/ECE International Environmental Data Service (IEDS) and at EMEP's centers.

ammonia. The draft guidelines -proposing, *inter alia*, that total annual emission data should be reported for at least the 11 major source categories agreed upon with the CORINAIR project- were reviewed at the 1991 EMEP Workshop on Emission Inventory Techniques [Pacyna and Joerss 1991], which recommended: i) the approval of the final text by the appropriate official bodies, and ii) the establishment of a Task Force on Emission Inventories.

Thereafter, the Executive Body appointed the Task Force on Emission Inventories (TFEI) "to ensure an adequate flow of reliable information to support the work under the Convention..." [ECE/EB.AIR/29].

As a result of a comparison of emission inventory activities in various international bodies, in its first meeting the Task Force concluded that collaboration with other groups that had been engaged in similar activities would be the most sensible approach to establish an appropriate methodology, saving time and avoiding duplication of efforts. It decided to establish eight expert panels to work out methodological issues, one of which to deal with the verification of emission inventories (see Figure 2) [McInnes et al. 1992]. In the same year, the UN/ECE and the Commission of the European Communities (CEC) agreed to adopt a common source sector split for reporting emissions, and in 1993 they agreed to collaborate in drafting an Emission Inventory Guidebook. Proposals for the development of a Guidebook were elaborated by the TFEI Strategic Overview expert panel and endorsed at its second meeting, where it was stressed that "a detailed methodology such as CORINAIR would be required to allow verification of emission data" [McInnes et al. 1993]. The first edition of the Guidebook has recently been published [Mc Innes 1996]. The Verification Panel proposed a number of procedures to help developers of emission inventories make consistent and, as far as possible, error-free estimations, and to evaluate their reliability (section 3.2.).

2.1.2. Analysis of Emission Data

Time-series of SO_2 and NO_x emissions taken from the latest official report (see footnote 7) are reproduced in Tables 2 and 3 respectively, while Table 4 on NH_3 emissions is presented only to exemplify scanty reporting. The following four questions are of interest here: 1) How does the reporting performance look like?; 2) Is the reported information complete?; 3) Are the reported data reliable?; and 4) Have commitments been met? They will now considered in that order.

1) Tables 2 and 3 show that, in general, most *parties to the LRTAP Convention* have reported emissions for the reference year 1980 and since 1985, while there are many gaps between

1980 and 1985. However, only few *parties to the Protocols* have reported intermittently in that period. Comparison of similar records published in the LRTAP annual reviews show that parties delay by about two years the submission of the latest data. The official record of other air pollutants (NH_3, CH_4, NMVOCs and CO) is much less complete. Tables 5 and 6 illustrate, respectively, that out of the 20 European parties to the SO_2 Protocol after the unification of Germany only 10, that is 50 %, have a perfect reporting record in the period 1980-1993; in the case of the NOx Protocol, this is true for 10 out of 22 parties in the same period, that is 41 %. Most of the missing information corresponds to the period 1980-1985.

It may be asked: why the gaps and delays? Do they appear because of lack of explicit instructions? Or do they primarily reflect operational problems during implementation? The information available is not sufficient to answer those questions satisfactorily. Though it should be recalled that the Helsinki SO_2 Protocol asks the parties to provide information for the years *after* the instrument became in force for each (section 1.3.3.). A number of factors may also contribute to the situation, for example: want of urgency when a Protocol is not in force; absence of a common methodology, or the recommendation to use a too demanding one (in terms of infrastructure, personnel and cost); difficulties to implement data collection in the field, particularly in the case of small sources.

Incomplete emission reporting leads to a difficult, undesirable situation at EMEP's Meteorological Synthesizing Centers: since a complete time-series of emission data is a necessary input to the long-range dispersion models, the voids have to be filled up through interpolations and/or extrapolations. This procedure increases the uncertainty of results, in particular because emission data of nitrogen compounds other than NO_x (e.g. ammonia) are also required.

2) Now, is the reported information complete? The parties revise periodically the information on emissions that they have to report regularly to the Executive Body and EMEP as better knowledge on energy use and other sources becomes available, so that emission figures for previous years have been at times substantially modified. In the case of SO_2 emissions, it has been shown [Amann 1992] that the completeness (and the quality) of current information are not homogeneous. This may be grasped by looking into changes in emission figures for a given year that have been released at different reporting times.

With respect to SO_2 emission data for the reference year **1980** Table 7 shows that estimations made in 1985 are, in general, quite different from values reported at a later date (due account being taken of changes in national frontiers). In the majority of cases, 1980 emission figures have changed in the course of time and become stable in the two more recent reporting years, 1993 and 1995[19]. For some parties, the reported figures seem to reflect an incomplete inventory and/or the use of inappropriate estimation methods. Eastern European countries show the highest variability between emission values reported in 1985 and in later years. For **1985**, the data show a similar trend as discussed for 1980, i.e. the estimations done by the parties in 1985 are in all but one case at times well above data reported in later years; while for **1990**, SO_2 emission figures are rather similar, a fact that may reflect the experience accumulated by the parties during a decade of calculating and reporting.

The NO_x emission data shown in Table 8 present trends similar to those discussed above for SO_2 although the extraction of firm conclusions is impaired by the relatively short time the Protocol has been in force.

Information contained in Tables 7 and 8 suggests that a considerable effort has been made by the bodies and the contracting parties of the LRTAP Convention to improve methods for estimating emission inventories and extend their use to the whole UN/ECE region. It appears that emission inventories are at present more complete and homogeneous than at any previous time, covering the main sources and increasingly introducing common estimation methods. One way to explore whether this view is appropriate is to compare those figures with estimations performed independently.

3) Table 9 indicates that the CORINAIR detailed methodology lead to SO_2 emission figures that are consistent with, and at times lower than, the data most recently reported by the parties. In particular, most Southern European countries seem to have used results of CORINAIR 1985 to replace previous estimations since numbers coincide exactly. In addition, IIASA-TAP Project calculations, based upon international statistical data, show good agreement with the latest reported results for 1980 SO_2 emissions whereas for 1985 emissions figures are, in general, significantly higher than recently reported values: this is due to the fact that the IIASA-TAP figures correspond to "unabated emissions", i.e., estimations made without taking into account the parties' actual incorporation of pollution control technologies after 1980.

4) What about compliance with the emission abatement goals established in the Protocols? In the period 1980-1993, SO_2 emissions have been substantially cut by the parties to the Helsinki Protocol thus exceeding, both individually and as a group, the minimum reduction target of the Helsinki Protocol. Individual behavior has not been uniform throughout,

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[19] Croatia is an exception because the figures issued in 1993 correspond only to emissions from thermal power plants.

however. In the period until 1987 (the year when the Protocol entered into force) three East European countries did not perform quite as satisfactorily. The record of the Protocol's non-parties shows that only 2 countries out of 12 have reported emission data for each of the fourteen years under consideration, and emission increments as well as reductions took place in this time span. However, as a group these countries seem to have complied with the 30 % reduction target[20], so that the aggregate SO_2 emission reduction of Europe under the LRTAP Convention in the period 1980 - 1993 amounts to 46 %.

As the Protocol came into force in 1987, the large SO_2 emission reductions that took place before that date can be seen as not causally related with its adoption [Levy 1993]. Table 5 shows that most parties to the Protocol achieved substantial emission reductions in the period 1987-1993, suggesting the possible influence of the regime on domestic behavior. This interpretation seems more plausible in the case of the Eastern European countries, where the main part of emission reduction took place, precisely, after 1987.

With respect to the fulfillment of commitments by parties and non-parties to the NO_x Protocol, Table 6 shows that NO_x emissions of parties to the NO_x Protocol have in general diminished, remarkably at times, in the period 1987-1993 (1987 is the baseline year for all European parties): the intended stagnation has been achieved. No definite statement can be made for Europe under the LRTAP Convention because of inadequate reporting by non-parties.

In summary, due attention being paid to the relative "softness" of the data (the evaluation of errors in emission estimates indicate an uncertainty range of no less than +/- 10%) and the reporting gaps and delays, the above analysis suggests that the explicit statement of reporting obligations in the respective Protocols, complemented by decisions of the Executive Body, have induced parties to comply.

Non-parties performance is less clear. For example, the United States and the United Kingdom are not parties to the Helsinki SO_2 Protocol. These countries have practically perfect reporting records. In the reporting period 1980-1992 the United States reduction amounted only to 13 %, as might be expected. However, the United Kingdom shows a perfect reporting

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[20] Since 1993 emission figures are missing in most cases, the present assessment is at least provisory. Only the United Kingdom complied with the Protocol's minimum reduction target it did not formally adhere to.

record and a 37 % reduction of SO_2 emissions[21].

As stated above, there are parties to the LRTAP Convention that have (at least partially) implemented and reported abatement measures in spite of the fact that they are not parties to the SO_2 or NO_x Protocols; they are, in fact, overcomplying. On the contrary, some parties to the Protocols are not strictly in compliance with the reporting obligations established by the Executive Body (reports are not always timely issued, in particular there is lack or delay in the provision of gridded emission data) [see Styve in McInnes et al. 1993]. When all is taken into account, however, the most recent available emission record of the two pollutants can be seen as satisfactory.

2.2. Measurements of Air and Precipitation Quality

In their journeys from sources to sinks, emissions of sulphur and nitrogen compounds are partially transformed physically and chemically through reactions with other species present in the atmosphere and under the influence of radiation, so that new substances join the original, are taken together by the winds and discharged by dry and wet deposition[22].

EMEP's Chemical Co-ordinating Centre (CCC) supervises a continuous monitoring program of acidifying and other air pollutants at national laboratories distributed all over Europe. The deposition of a number of chemical species is measured daily in samples that have been collected at selected sites so that they are regionally representative and, as far as possible, unaffected by local pollutant sources. This is essential for the comparison between measurements and model results. Urban areas and locations exposed to major sources will have much higher average concentrations than the ones encountered at those sites.

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[21] Reasons to explain that behavior have been proposed in the literature [Levy 1993, Wettestad 1996].

[22] The effectiveness of individual removal processes of chemical species is reflected in their *residence times*, and determined by the physical and chemical characteristics of the particular substance (e.g., physical state, particle size, reactivity), meteorological factors (e.g. predominant wind regimes, occurrence of precipitation), and features of the underlying surface [NRC 1981]. For the substances of interest here *dry deposition* takes place relatively near the emission sources, while the distances travelled before *wet deposition* occurs are, in general, larger since precipitation has to be found and oxidant limitations reduce the amount of sulphur that can be wet deposited near source areas. For most sulphur and nitrogen compounds removal by precipitation is an efficient way of cleaning air from pollutants. In mid-latitudes, these removal processes are operative for distances in the range from hundred up to a few thousand kilometers [Irving 1991, Iversen 1993].

2.2.1. Measurement Program

EMEP's measurement program, originally designed to determine sulphur compounds, begun in October 1977. In the course of time, EMEP's measurement activity was gradually expanded. For example, during the program's third phase (1984-1986) two levels of activity were implemented: the minimum program on air concentrations of SO_2 and $SO_4^=$ as well as $SO_4^=$ and pH/H^+ in precipitation had to be carried out at all stations; in addition, an extended program which called for measuring further substances was carried out at few stations on a voluntary basis. In 1986 the Executive Body decided that the minimum and the extended measurement programs be combined to form a unified program for the fourth phase (1987-1989), thus covering the following chemical species [Hanssen et al. 1990]:

Gases	Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Ozone (O_3)
Particles	Sulphate ($SO_4^=$)
Gases + Particles	[Nitric Acid (HNO_3) + Nitrate (NO_3^-)]
	[Ammonia (NH_3) + Ammonium (NH_4^+)]
Precipitation	Amount
	Conductivity
	pH/H^+, $SO_4^=$, NO_3^-, Cl^-, Ca^{++}, Mg^{++}, K^+, Na^+, NH_4^+

All measurements had to be performed on a 24-hour basis except for ozone, which was to be reported as hourly averages. In this way the EMEP program included all important acidifying substances as well as ground level ozone.

More recently, the measurement program has again been extended to add the following further species in the 1995-1998 measurement program [Schaug 1995]:

Gases	Nitric Acid (HNO_3), Ammonia (NH_3), VOCs, Hg
Particles	Nitrate (NO_3^-), Ammonium (NH_4^+), Trace Metals
Gases + Particles	Persistent Organic Pollutants (POP)
Precipitation	Trace Metals, POP

In line with the steady increase of chemical species to be measured, the sampling network has also expanded: 46 stations in 14 countries were working during the first measurement phase of EMEP (1978-1980); by 1985 the number grew to 87 sites in 24 nations [Nodop 1990]. During EMEP's 4th measurement phase (1987-1989) the CCC received data from 102 sites: 79 stations reported both precipitation and air quality data, while 10 stations delivered data only from precipitation, and 13 stations only from air [Hanssen et al. 1990]. In 1990, the first year of EMEP's 5th measurement phase, the total number of measurement sites was 97 [Pedersen et al. 1992]. Currently, about 100 sites take part in the daily measurements; however, less than 30 had the full program implemented by the end of 1993, and there is still rather incomplete information about some substances in air, in particular nitrogen compounds [Berge et al. 1994]. Figure 3 shows the location of the EMEP sampling sites in 1993 [Dovland 1993].

Sampling sites and chemical laboratories in the participating countries started with, and often have continued to use, existing techniques and equipment. The consequence is that there are neither common air and precipitation sampling methods nor the same analytical techniques and equipment used in all the stations. A manual with recommended methods to harmonize those elements throughout Europe was issued by EMEP in 1977 and regularly updated thereafter. By 1990 most of the laboratories were using the methods described in the manual or other well established [Hanssen et al. 1990]. A completely revised version is currently in the process of adoption [Schaug 1995].

In spite of the large geographical coverage of the measurement program, the situation is not completely satisfactory: a few sampling sites may be influenced by emissions stemming from nearby sources; others are located at too high an elevation to give representative data at all times; the density of the station network is not uniform, as shown in Figure 3: while in Western and Central Europe the coverage is fairly wide, it is rather low in Eastern and Southern Europe.

2.2.2. Quality Assurance

Continuous efforts have been made by the CCC to attain and ensure an acceptable degree of data completeness, homogeneity and reliability. A number of quality assurance procedures are implemented both at NILU and at the national institutions.

There are several elements in the measurement program that can be the subject of such quality control. The CCC quality assurance plan addresses: i) selection of sampling sites; ii) field and laboratory operations; iii) training of personnel; iv) data handling [Schaug 1988].

The main precondition for a sampling site is that it should represent fairly well the "average" air quality and precipitation within the EMEP grid square in which it is located. This implies that sites placed in grid cells with high emissions may be influenced by large emission sources. The *representativeness* of a site is also determined by other factors, such as local climate, normal wind directions and the intended use of the information as well. An evaluation of various EMEP visits to sites and laboratories revealed that the majority of 25 inspected stations were properly located, with the exception of 4 stations, possibly influenced by emission sources or located at too high an elevation [Semb et al. 1992].

The CCC worked out *questionnaires* to collect detailed information about the *sampling and chemical analysis* methods and equipment, as well as the quality assurance procedures undertaken during the measurement steps. The questionnaires were distributed for the first time in 1988: information on present status and former major changes were asked for. The information gathered was included in the database, together with measurement data and remarks about measurement sites [Fähnrich et al. 1993].

An *expert consultation* program was established, initially intended as a *site inspection or audit program.* It may also be regarded as a way of providing more direct contact between the CCC and national laboratories, offering the opportunity for joint considerations of performance problems.

The participating stations use different sampling equipment with different sampling rates, air intakes, filter holders and materials. To check the effect on data, *field intercomparisons of samplers* have taken place. A pilot intercomparison for sulphur dioxide and aerosol sulphate in air was performed at the Langenbruegge station in the Federal Republic of Germany during 1985-1986; it showed systematic differences of up to 20% between results of different sampling systems. However, no clear conclusions on the origin of discrepancies were attained since the samples were analyzed by different laboratories [Nodop and Leyendecker 1988]. A further intercomparison done in 1990 at the Swedish Vavihill station detected many of the inherent sources of errors in air sampling for the determination of sulphur dioxide and sulphate concentrations [Semb et al. 1991].

The quality of the chemical analyses done at the national laboratories is routinely checked every year in *interlaboratory tests*. Synthetic and real samples are distributed to participants and analytical results compared. Results of the intercomparisons performed up to now showed that the mean of reported values was always close to the expectations. The relative standard deviations were mostly in the 5-10% range when one or two outlying results were excluded. In the last two intercomparisons, more than 70% of the outliers were reported by only six laboratories, three of which were the same in both cases [Hanssen and Skjelmoen 1992].

Under the quality assurance program much attention is paid to the management of data, including data control and reporting. EMEP works out and recommends procedures to be followed by the parties for data reporting. Data control has to be implemented both at the laboratory where measurements are carried out and at the Chemical Coordinating Centre. Any data suspect of inaccuracy has to be re-determined by a new analysis. Statistical tests are performed to identify possible outliers and results that appear erroneous when compared with previous measurements stored in the database. *Ion balance*[23] computations should be carried out as soon as possible to avoid effects from changes in the sample composition during storage and transportation. Together with the ionic balance test, the *electrical conductivity* of the precipitation samples is measured under standard conditions and compared with values calculated from measured concentrations. Several sets of *flags* are used by participants and the CCC to characterize the quality of data stored.

2.2.3. Measurement Data

All data that have passed the quality control program are stored in the database; if new evidence arises, corrections are incorporated, so that the database is continuously updated [Schaug 1995].

In order to show changes and trends in air and precipitation quality throughout Europe for any selected period of time, the huge amount of data is reduced to a representative and manageable set. In general, EMEP reports present results in terms of monthly, yearly or multi-annual arithmetic mean concentrations in air, and arithmetic precipitation-weighted mean concentrations in precipitation. These averages are used to transform the data stemming from the EMEP measurement station network into concentration and deposition fields, a procedure most recently done by the application of a statistical technique known as *kriging*[24]. Concentration and deposition fields are shown graphically through isopleths of pollutants in air and precipitation across the whole EMEP area. This information is routinely produced at

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[23] The measurement program begun in EMEP's 4th phase includes determination of all the main components in precipitation. A consistency check of results is the ionic balance: the sum of positive and negative ion concentrations expressed in microequivalents per liter, should be zero; alternatively, the ratio between anion and cation concentrations should be close to one [Schaug 1988].

[24] Kriging is an interpolation technique that uses observations, $Z(x_j)$, at location x_j to estimate "the true value Z_0 at the point x_0 where an observation is not available" [Venkatram 1988]. Kriging can thus be used to estimate unknown data from measurements in neighboring sectors, for example to evaluate deposition or concentration fields [Schaug, Iversen and Pedersen 1993].

the Chemical Coordinating Centre and published in annual reports as well as in summary periodic reports covering a whole measurement program[25]. "Comparisons of long-term averages of the period 1978-1982 with those of 1983-1987 for the sulphur components in air and precipitation show that the areas with the highest concentrations have been reduced. The differences between the nitrate concentrations in precipitation in the two long-term averages seem to be very small. The region with pH less than 4.1 which covered much of Central Europe in 1978-1982 has disappeared in the 1983-1987 average" [Hanssen et al. 1990].

In general, a comparison of results shows a temporal trend towards lower deposition rates and higher pH values (i.e. less acidity) in parts of Central Europe and Southern Scandinavia, indicating that the level of rain acidity has either been steadily reduced or that areas that showed high rain acidity have become smaller in later years. These qualitative, "visual" trends have been highlighted by applying appropriate statistical data-evaluation methods.

Taking into account the difficulty of establishing unique cause-effect relationships in this complex issue with so many variables at play, it is important to review EMEP's efforts to analyze the magnitude of the changes, and their relationships to the reported air pollutant emission reduction and stabilization measures.

2.2.3.1. Trend Analysis

A good example of EMEP's data evaluation approach is a study of trends in the measurements record of selected stations within the period 1979-1988 [Hanssen et al. 1990]: data for at least six years were used, and included only those years with data for more than 70% of the time. A particularly useful statistical method, the Mann-Kendall non-parametric test, was applied for the analysis[26].

Figure 4 reproduces the results for sulphur dioxide at 0.05 significance level (the probability of being wrong if the hypothesis "no trend" is rejected, therefore accepting the alternative hypothesis "upward trend" or "downward trend"). It shows that there is no trend or a trend

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[25] See, for instance, the summary reports for the third and fourth EMEP measurement phases, respectively published as EMEP/CCC-Report 3/87 and EMEP-CCC-Report 2/90. The 1990 annual data were published in the EMEP/CCC-Report 2/92.

[26] The method is applicable even when the information is not complete (e.g., data from a few scattered stations are missing); in addition, the data available need not to conform to any particular statistical distribution [Gilbert 1987].

downwards at all sites that could be included in the computation. Significant downward trends appear for France, the United Kingdom, southern Scandinavia and some sites in Germany; while in the other parts of Europe included in the analysis there are no significant trends. A similar picture was obtained for sulphate in particles. A subsequent analysis of the whole data set (annual average concentrations of sulphur dioxide and sulphate in aerosols), based on Sen's non-parametric slope estimator method indicated that in those regions where the Mann-Kendall test showed significant sulphur dioxide reduction there is at least a 20 to 40% decrease in the United Kingdom and France, and between 10 and 40% in southern Scandinavia (Figure 5 shows the results for SO_2).

The question arises as to whether or not these trends are at least partially due to changing meteorological conditions in space and time. A comparison of measured data with dispersion model sensitivity runs revealed that reductions of both sulphur dioxide and sulphate in particles occur in areas where the effect of reduced emissions would be expected to appear [Mylona 1989].

2.2.3.2. Sector Analysis

The spatial distribution of pollutant concentrations in air and precipitation can, in a first approximation, be associated to differences in wind direction during the period of measurement. The origin of air masses and the way they move are estimated by trajectory models based on meteorological information. By assigning measured data at each station to wind direction classes, or transport sectors, it is possible to reach conclusions on the sources of pollutants [Nodop 1990].

The Meteorological Synthesizing Centre-West has developed a trajectory allocation program that permits the assignment of measurements to direction sectors of arriving trajectories. Eight 45° sectors are defined, reflecting air transport from 8 cardinal points. Data is allocated to one of these sectors when more than half of the arriving trajectory positions fall within it during the measurement period; if this criterium is not met the measurement data is allocated to an "undetermined" sector. Only trajectory positions between 150 km and 1500 km from the station are taken into consideration [Hanssen et al. 1990]. Figure 6 displays the link between transport directions and concentrations in air samples at selected stations: in general, sectors with high concentrations and depositions coincide with the direction from where the most important emission sources are located. However, the interpretation of the data is not quite straightforward, since interaction between air currents and the paucity of measurements can reduce the value of the information provided to a mere indication of possible trends. "The interpretation of the trends in monitoring data simply by variations in emissions is confused by the evidence of inaccuracies in both the sampling and the analytical methods for sulphur oxides" [Hidy et al. 1978].

2.3. Modeling the Transport of Air Pollutants

The establishment of the link between national emissions and *in situ* measurements of acidifying pollutants is undertaken by modeling the physical and chemical processes that determine their long-range transport and deposition. "A major goal of (the) study of the atmospheric aspects of air pollution is to be able to describe mathematically the spatial and temporal distribution of contaminants released into the atmosphere" [Seinfeld 1986].

To study the source-receptor relationships, standard techniques include the description of the movement of an air parcel, i.e., its trajectory, with the help of mathematical transport models. This applies to both the receptor-oriented problem (i.e., the identification of the source of a pollutant that has been found in remote areas), as well as to the source-oriented problem (i.e. the description of the dispersion of a pollutant from a known source) [Rodhe 1985]. To go beyond a simple trajectory analysis, a quantitative model needs to deal with emission, dispersion, transformation, transport and removal processes. Such a model may be formulated on the basis of trajectories (Lagrangian model) in which parcels of air are followed as they travel with the wind and concentration changes are described relative to the moving fluid in interaction with the environment; or based upon data specified at fix grid points (Eulerian model) in which the integration of the mass-balance equation is performed in a geographically fixed grid. Lagrangian long-range transport models are, in principle, simpler to handle than Eulerian models, i.e., cheaper to run on the computer and less susceptible to numerical difficulties. Eulerian models are more flexible in incorporating various physical and chemical processes, in particular when these need to be represented by non-linear equations [Eliassen 1984]. The selection of the type of model depends on a number of factors, including the availability of spatial and temporal emission and meteorological data.

2.3.1. Model Description

The modeling activity entrusted to EMEP's Meteorological Synthesizing Centres began about two decades ago, at the time when the OECD-LRTAP Programme was established. The present routine model at the Meteorological Synthesizing Center-West (MSC-W) is a direct descendant from that first successful attempt to demonstrate the existence of long-range transport and deposition of air pollutants and their transformation products using a receptor-oriented model [OECD 1979]. The model developed at the Meteorological Synthesizing Center-East (MSC-E) is based on the same basic principles, but the specific approach is slightly different: it is a source-oriented model keeping track of pollutant plumes from emission grid elements. "The differences in model structure yield slightly different estimates of the European sulphur budget. The budgets from both models must be regarded as reasonable estimates of the actual sulphur budgets" [ECE/EB.AIR/GE.1/18, Annex 1]. Based on the abundant material available from the MSC-W a description of the features, necessary input and the information the model delivers will be briefly considered in the following.

At the MSC-W, calculations of the transport and deposition of acidifying sulphur and nitrogen compounds are performed using a receptor-oriented, one-layer Lagrangian long-range transport model. The model calculates concentrations averaged over the well-mixed layer: budget equations for the chemistry of air parcels[27] following the motion of air along trajectories are integrated by including emissions from the underlying grid, chemical processes in the atmosphere, and dry and wet deposition to the ground. The budget equations are ordinary, first order differential equations in the time coordinate. Trajectories are followed 96 hours backward in time from their arrival sites, the mid-points of all grid's unit cells and EMEP's sampling stations as well; four trajectories arrive at each site every day every 6 hours [Iversen 1993]. In the current model version emissions are distributed over the year, using a sine function to reflect the seasonal pattern.

Last reported model runs were performed for the whole 9-year period 1985-1993 [Tuovinen et al. 1994]: trajectories reached 1155 arrival points in a grid composed by 33 x 35 cells with resolution 150 kilometers (Figure 7) and 119 points coinciding with the selected measurement sites of the EMEP program as well. The model was used to calculate *daily average* concentrations of the following chemical species:

Concentrations in air and dry deposition: Nitrogen oxide (NO), nitrogen dioxide (NO_2), peroxyacetyl nitrate (PAN), nitric acid (HNO_3), ammonium nitrate (NH_4NO_3), other particulate

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[27] The air parcel under consideration here is defined by the area of the grid's unit cell (in this case 150 x 150 km) and the height of the *atmospheric boundary layer (ABL)*. The ABL is the lowest part of the atmosphere, and forms as a consequence of interactions with the underlying surface (land or sea) over time scales of one day or less. In this layer the effects of surface roughness, temperature and other properties are transmitted through turbulent mixing. In the volume so defined pollutant concentrations are assumed to be homogeneous. The ABL height was initially kept constant at 1000 meters; this constraint has been relaxed to roughly account for day-to-day and seasonal variations.

nitrates (NO_3^-), ammonia (NH_3), sulphur dioxide (SO_2), ammonium sulphates [$(NH_4)_2SO_4$ + NH_4HSO_4]/2 = $(NH_4)_{1.5}SO_4$], other particulate sulphates ($SO_4^=$);

Concentrations in precipitation and wet deposition: Sulphate ($SO_4^=$), nitrate (NO_3^-), ammonium (NH_4^+).

In addition, *monthly averages* are allocated to 48 subregions, of which 43 are land areas (mainly countries) and 5 are sea areas.

2.3.1.1. Model Inputs

1) Emissions of SO_2, NO_x and NH_3 in gridded form: current requirements are for the parties to provide information in a grid of unit cell 50 x 50 kilometers.

The gaps in, and the delays of, reporting national emission estimations do not fit the rather stringent modeling requirements. In particular, calculations involving long time periods compel modelers to fill the gaps with their own estimates or simple interpolations and extrapolations. The uncertainty of the emission figures is very likely to increase during the next step of allocating annual national data to the EMEP grid: the parties are asked to make this conversion, since they are conversant with the specific national features that need to be taken into account (e.g., population density and distribution, location of main emission sources). In practice, since the reporting record of gridded data is rather poor, the procedure has been often carried out by the CORINAIR project or by the modelers. Table 10 [Tuovinen et al. 1994] summarizes the situation. The final uncertainty increases even more because the model requires the input of sulphur emission data from international maritime trade and from natural sea sources which, in general, are crude estimations based on a limited number of measurements.

2) Meteorological information.

EMEP modeling activities respond to the goals of the LRTAP Convention. Basic questions that must be addressed (e.g., what is the amount of deposition in one country that stems from emissions elsewhere?) have been attended to in model design. This is why actual meteorological data is used rather than long-term climatological information. This decision is further supported by research results showing that annual variations of meteorological data cause changes in the observed concentration levels of at least the same magnitude as the reported emission reductions [Mylona 1989].

The meteorological data are taken from the Numerical Weather Prediction model at the Norwegian Meteorological Institute.

2.3.1.2. Model Outputs

1) Concentrations of pollutants in air and precipitation at the selected sites.

2) Country-to-country allocated depositions.

In addition to the total concentrations the model keeps track of subconcentrations arising from emissions in different emission areas for each of the chemical species. Since the model's governing differential equations are all linear in the concentrations, any two sets of solutions to this system of equations can be added to give a sum that also will be a set of solutions. Therefore, it is feasible to calculate pollutant concentrations due to emissions in each subdomain, and then add the individual contributions to get the total concentrations. This characteristic of a Lagrangian model makes it possible to prepare matrices showing one country's emission contributions to depositions in another. Quite early in the program [see, for example, Eliassen and Saltbones 1983] it was shown that in most European countries the deposit of sulphur due to foreign sources represented an important contribution to total depositions. Figure 8 shows a cut of such a transport matrix. More recently, the exercise has been extended and country-to-country allocated depositions of sulphur, and oxidized and reduced nitrogen matrices have been issued, as well as tables showing the net import/export budgets of those pollutants [e.g. see Tuovinen et al. 1994].

2.3.2. Comparison of Model Results with Measurements

It is relevant to recall the differences features and the amount of data provided by the three main activities coordinated and/or conducted by EMEP.

First, *annual total emission* estimates are reported by the current 39 parties to the LRTAP Convention. Although reporting should include information on emissions of the agreed 11 source categories as well as of Large Point Sources (LPS), this is not often the case. Assuming that all parties report at least total annual emissions, data on the three pollutants used as input in the modeling will be available for 39 countries at the end of each year. As already mentioned, primary data on annual emission rates have to be transformed into gridded data, thus increasing the size of the database.

Second, EMEP's measurement program should deliver *daily concentrations* in air and precipitation of at least 10 substances at roughly 100 sampling sites; i.e., ideally, the database on observations is increased every year by about 365 000 values. Actually, this is not the case: "an extensive set of measurement data is available for atmospheric concentrations of SO_2 and total particulate sulphate; and for sulphate, nitrate and ammonium concentrations in precipitation. A more limited number of stations have measured NO_2, and for other atmospheric nitrogen species only a few stations take measurements" [Tuovinen et al. 1994]. Under these circumstances, the annual raw data production by the measurement program would be reduced to about half of the indicated amount. In order to make comparisons with model calculations, point data is transformed into gridded information using a procedure developed at NILU.

Third, model runs produce much more direct gridded data, since each arrival point in the Lagrangian model represents the average value of each pollutant in the corresponding grid cell, as well as at the sampling sites. Therefore, concentrations in air and precipitation of 13 chemical species are available four times a day for approximately 1255 points in a grid of 33 x 35 unit cells, each with a side length of 150 km (this number will substantially increase with the adoption of a unit cell of 50 x 50 km thus giving rise to a grid of 151 x 133 cells).

The differences in scope, quantity and quality of the three data sets suggest that validating the model through comparison of its results with observations is a complex and difficult endeavor. The information on chemical species provided by the measurement program is too limited -and when available it is often restricted by deficiencies that may exclude a significant part of the data- to be used for validating the modeling of transformation processes, which in turn is paramount to assess the model capability to accurately describe the treatment of chemical processes. For such reasons most comparisons between calculations and observations pertaining to the whole EMEP area are done using mean values of concentrations for long periods of time (about a year and longer) with the aim of detecting general trends, as well as disclosing major reasons for differences, pointing out the shortcomings of model design, measurements and input data (emissions, meteorology).

In one of the first comparisons [Eliassen and Saltbones 1983] the authors carefully attended to the representativeness of the observed data: they used the results of the third EMEP intercalibration test of national laboratories to detect systematic errors in the chemical analyses of SO_2 and particulate sulphate in air and sulphate in precipitation. Variations in reported data were significant for particulate $SO_4^=$, so that before making the comparison, measurements were corrected by multiplying the reported data by a scaling factor for each laboratory. In addition, data from those sampling stations in which results of chemical analysis were not available for at least 230 days on air quality and for at least 50 days on precipitation during the whole two-year period under consideration (October 1978 to September 1980) were excluded. Also, results of two stations located at high altitude were discarded.

A scatter plot of two-year averages of observed versus calculated SO_2 air concentrations at 40 stations showed a reasonable agreement between observed and calculated data (the correlation coefficient **r** was 0.82, and the observed and calculated means were 4.77 and 4.73 micrograms sulphur per cubic meter, respectively). A similar comparison for the two-year averages of particulate sulphate concentrations at 48 stations also showed a reasonable agreement between observed and calculated data (**r** = 0.85), but on the average particulate sulphate seemed to be underpredicted by the model. The opposite case occurred for sulphate in precipitation, for which the agreement was not as good (**r** = 0.70). Some of the differences were attributed to model simplifications, inaccurate emission data and sampling errors (these are not checked in the interlaboratory tests).

Ten years later, a study addressed issues of verification and trends in a comparison of observed and calculated annual (1989) means of 6 substances, namely: NO_2, SO_2 and particulate sulphate in air; and NO_3^-, $SO_4^=$, NH_4^+ in precipitation [Iversen 1993]. As in the earlier study observations were discarded if daily measurements in air were available for less than 75% (in precipitation for less than 25%) of the days covered in model calculations. Scatter plots of measured and calculated values showed that the model underestimated measured NO_2 concentrations by a factor of 1.7. Reasons for such behavior were sought through complementary analyses: i) measured and calculated mean 1989 concentrations of NO_2 were plotted versus the NO_x emissions in the grid square where the measurement site was located (a close-to-linear relationship between concentrations and emissions is expected in this case): here model results showed a better correlation with emissions than with measured values; ii) the year-to-year variation of observed and calculated concentrations was used to distinguish between emission and measurement problems.

As already indicated, meteorological variability masks the effect of changes of emission rates. In line with a previous analysis [Mylona 1989], this study confirmed that keeping meteorology constant from year to year during computer runs reveals that calculated air concentrations and depositions correspond with reported emissions. In addition, trends in measurements and calculations generally corresponded although 1989 values of sulphur in air were an exception, very likely due to the warm 1989 winter, so that higher-than-actual emission values were projected to complete missing country reported data.

The approach and results of these studies have been summarily presented to exemplify EMEP's activities in the performance, evaluation and application of model calculations. In fact, the modeling activity is quite large, including e.g. the spatial and temporal (seasonal, daily) model performance, development and test of Eulerian models, modeling of long-range transport of other air pollutants (ozone) or is in progress (heavy metals, persistent organics). Their consideration is, however, beyond the scope of this paper.

3. Verification of Compliance

There are at least two relevants aspects concerning the behavior of parties to international agreements, namely whether they fulfill their obligations and, in any case, what are the reasons for their conduct. Consideration of the latter issue is outside the scope of this study [to this point see, for example, Young 1979, Chayes and Chayes 1993].

One main thesis in the present study is that the design, application and evolution of IRMs in international environmental agreements respond to an implicit demand for verifying compliance. In this section the focus is on the relationship between the procedures used to trail domestic implementation, i.e. the IRMs, and those necessary for establishing the parties' compliance. As already stated, verification of compliance is understood herein as the independent check of the fulfillment of obligations incurred by the contractual parties to an international agreement.

3.1. Definitions and Requirements

The requirements that a compliance verification system has to satisfy and the activities to be performed go beyond those which are typical of current IRMs. This will be discussed now in some detail.

Once the political decision to verify compliance has been taken, the immediate question is how much verification would be enough. The degree of detail and intrusiveness of international surveillance, what has been called the verification *density*, will be essentially dictated by the political perception of the problem[28]. In the real world, however, the political goal becomes qualified by the feasibility of implementing verification under various constraints, including costs. What could be done in practice is a function of two main factors: the verification *suitability*[29] of the objects/sectors/systems to be properly scrutinized, and the

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[28] The intensity of verification arises from the political relevance of the issue-area, the degree of mistrust on the willigness of actors to observe contractual obligations, and the available information level [Fischer et al. 1990].

[29] The verification suitability is basically determined by the physical and chemical features of the system. For example, emissions of greenhouse gases arise from well defined big, stationary, isolated sources, such as power stations and refineries, where continuous measurements and control can be implemented; many mobile sources (e.g. vehicles, cattle) where follow up of emissions is impaired by sheer numbers and the cost of implementing

technical verification *capability*[30] to measure representative indicators with appropriate accuracy and precision. Consider, for example, the disparate systemic and measurement-related features of international agreements on fisheries in international waters, pollutants dumped into the oceans, gaseous emissions delivered into the atmosphere [Fischer et al. 1990, di Primio 1992, Greene 1994].

Compliance control must be concerned with every item contained in the reports on national implementation. The corresponding verification activities may be divided into two categories: i) those required to check whether the information reported by the parties is complete and free of errors, inconsistencies and omissions -labelled here as an exercise on *validation*; in addition, ii) those purporting to detect the extent to which parties have complied. To be credible, the results of verification should stem from activities performed impartially and independently. Therefore, a verification endeavor needs to be protected from political pressures as much as possible and empowered to conduct own research and monitoring, including audits and *in situ* inspections.

Thus, ideally, two conditions should be met to attain an effective assessment of the parties' performance in keeping with their commitments, namely: the creation of a dedicated international institution within the international environmental agreement[31] with the right to

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measurements; diffuse fields, at times the sum of many tiny, individual emitters, where emission measurements are difficult or impractible [Efinger 1991, di Primio et al. 1992, Mitchell and Chayes 1995]. However, technological development of monitoring methods and equipment can solve some current problems. For example, remote sensing applied to quantify deforestation areas and rates, also to detect oil spills at sea; new optical sensors used for long-path monitoring of atmospheric pollution [Partridge 1990/1991].

[30] In terms of the availability of appropriate methods, equipment, trained personnel, laboratories.

[31] In the case of framework conventions, the establishment of a single verification body should be preferred to creating a verification agency for each protocol or amendment: the supporting argument is that a unique body commands an overview of the issue and thus fosters a more balanced assessment of policy priorities and implications. Similar considerations should apply to the institutionalization of IRMs. There are examples of both approaches, however: the current implementation review process of the LRTAP Protocols is the responsibility of just one institution, the Executive Body, to which the Implementation Committee created by the 1994 SO_2 Protocol will directly report. At difference, the Ozone regime has formally created two COPs, one for the Vienna Convention and other for the Montreal Protocol, to which its Implementation Committee reports.

implement independent surveillance through monitoring and assessment[32].

The main **functions** of a verification agency can be summarized as follows:

==> Be the recipient and depository of national implementation reports, as well as of the complete information used by the parties to prepare them.

==> Be able to establish and operate its own monitoring and assessment system.

==> Issue a periodic assessment of the parties' compliance with their commitments and report the findings to the supreme decision-making body.

How would the **specific tasks** of such a verification agency look like in the present case? Since the verification system has to be tuned to the systemic features (verification suitability) of the issue-area, it is not possible to describe its activities in a general way. Unlike the pollution of land and water, atmospheric pollution stems from gaseous emissions of primary chemicals that are released and may be partially transformed into secondary compounds, all these substances becoming diluted in the atmosphere and dispersed by the winds. The final fate of these emissions depends basically on the atmospheric lifetime (residence time) of each species. On the one hand, sulphur and nitrogen compounds are quite reactive in the troposphere, their products of transformation and the primary pollutants as well have rather short residence times (up to a few days) and are efficiently returned to the ground by the processes of dry and wet deposition known as acid rain. Therefore, where monitoring is concerned, it is possible to measure concentrations of the chemical species not only in air, but also in precipitation and on the ground. On the other hand, the atmospheric lifetimes of the typical greenhouse gases are much longer and there is no washing out of by-products through precipitation; also, the chemicals first identified as causing stratospheric ozone depletion are rather inert substances *vis-a-vis* tropospheric oxidants and are only dissociated through photochemical reactions in the stratosphere. Atmospheric concentrations of the two last groups of substances and their secondary products are all that can be directly measured.

Since air pollution starts with gaseous emissions from a variety of sources, the immediate response to combat it is to reduce or eliminate emissions of primary pollutants, eventually of secondary products of their transformation. Emission inventories play a key role in the

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[32] This implies that the parties have to accept some limitations of their sovereignty in favor of the international system, so that an international agency can perform a set of well-defined activities in their territories (which is the case in the nuclear field within the Non Proliferation Treaty).

implementation of abatement measures[33]. From the point of view of verification, emission inventories are the central element of a national declaration.

In order to verify whether commitments have been fulfilled in international agreements addressing atmospheric pollution, procedures to check on the reported emission rates must be designed and applied. Some of these procedures form part of current IRMs, but complementary activities would be required (for example, establishment of international measurement networks and databases, *in situ* inspections) to get the information necessary to independently assess compliance. In addition, the implementation of national policies and strategies to control air pollution should be checked. This may be a cumbersome undertaking because of: i) the sheer number and diversity of alternative policies and technologies open to selection by the parties involved; and ii) the rather intrusive nature of the activities required to corroborate the reported information[34].

In the case of the LRTAP regime, systemic features are more favorable for verification purposes than in the Framework Convention on Climate Change and the Montreal Protocol. A broad list of tasks to be performed by an international verification agency on long-range transboundary air pollution might look as follows:

a. Get the methodology(ies) used by the parties to calculate national emission inventories.

b. Get all data used by the parties to perform the calculations. Validate such data by independent means, e.g., using other measurements of emission factors, collecting additional activity data, applying (or developing) sectoral models.

c. Check the reported emission inventories for completeness and reliability: this would require recalculation using information in items a. and b. above, eventually the procurement of complementary information (via e.g., use of porxys, agency retrieval or measurement of emissions at point sources, audits, *in situ* inspections).

d. Look into differences and explain where they come from.

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[33] This is certainly the reason for the large effort devoted to reach a reasonable international consensus on the design and application of methodologies for emission inventories.

[34] Unless extraordinary circumstances require an in-depth view, it appears that verification of national policies and strategies may be first confined to data gathering and evaluation, which will provide knowledge for performing a further check of emission inventories.

e. Make comparative analyses of reported emission inventories with the results of recalculations as well as independent information on national, regional and global inventories.

f. Get all the information on air quality determined at the EMEP stations and the results of its modeling exercises on long-range transport of air pollutants. Use statistical and other techniques to evaluate and compare results, in particular their link to reported emission rates.

g. Get the national policies and strategies as well as abatement plans.

h. Gather all data on implementation of strategies and policies for pollution abatement. Compare with results of above activities to verify inventories.

i. Draft a quantitative assessment. To this end clarify previously any doubts with party(ies) involved.

3.2. TFEI's Proposals on Verification of Emission Inventories

As indicated in section 2.1.1.2., the first edition of the EMEP/CORINAIR Atmospheric Emission Inventory Guidebook has been published [McInnes 1996]. The chapter on "Procedures for Verification of Emission Inventories" is an extensive, valuable and well-documented discussion on verification, defined as "the collection of activities and procedures that can be followed during the planning and development, or after completion of an inventory that can help to establish (its) reliability for the intended applications". Further, it is stated that "the concepts of verification discussed are not intended to support the idea of compliance to norms or international protocol", the procedures proposed were conceived "to help inventory developers prepare high quality data for analytical purposes". However, the authors are clearly aware of the possible application of those activities to assess compliance, as it transpires from their discussion on the use of some elements to a political evaluation.

The procedures proposed by the Expert Panel can be broadly arranged in two categories, namely: i) checks and comparisons to help improve the quality and transparency of emission inventories, and ii) methods best suited to establish their reliability. The first set may be summarily described as follows: once the methodology selected for the intended application has been documented and used, comparisons of the emission inventory with alternative estimates should be undertaken, if possible incorporating an assessment of the respective levels of uncertainty.

The second category, "Ground Truth Verification", involves techniques to prove the reliability of the inventory via comparisons with known indicators, directly or indirectly related to the reported emissions. In this context, the verification procedures discussed are based essentially on the results of monitoring activities. The document gives details on techniques currently available, and contains most of the elements proposed to verify compliance in section 3.1. Attention is focussed on the uncertainty of emission inventories. The use of classical uncertainty analysis would be more the exception than the rule, since estimates stem mostly from calculations based on data from a reduced number of measurements; alternatively, expert judgments expressed in the form of data quality ratings may be better suited to provide assessment of bounds.

The difference between TFEI's approach and the one discussed in the previous section seems to be in some way semantic, but it goes deeper than that. It lies in that in this study activities purporting to confirm or ratify estimations have been labelled an exercise in validation, while verification has been identified with actions undertaken to establish trustworthiness: one thing is to compile a complete and reliable emission inventory, another quite different is to determine whether it represents the true situation. Validation can be done both by compilers and users of emission inventories, while verification is an endeavor of parties or bodies other than the party whose performance is beign assessed, in order to determine whether contractual obligations have been complied with.

The above difference also bears on the respective assignment of responsibilities for the performance of monitoring and verification activities in the case in hand: according to the TFEI they should be done by the developers of emission inventories, the position sustained herein is that an international agency should definitely be in charge of checking all the information contained in the national reports, i.e., emission inventories as well as the implementation of national policies and strategies for emission abatement.

4. Discussion and Conclusions

The principal *elements* of the LRTAP IRMs are: i) the reporting obligations; ii) the national reports on emissions, policies and strategies, including the data used for calculating inventories; iii) EMEP's monitoring and modeling activities; iv) certain functions of the Secretariat, in particular, the preparation of annual reviews and four-year major reviews; v) the yearly implementation review at the meetings of the Executive Body[35].

A survey of the specific actions undertaken by EMEP on data collection, collation, assessment and use has been presented. It is important to realize that the huge amount of data produced throughout Europe does not necessarily constitute a complete and reliable set. EMEP's endeavor to gather and process such an information flood and, in so doing learning how the initial approaches need to be changed and/or extended in order to cover the whole field and reach high quality standards is the core of a monitoring system which has no precedents in the environmental field [Sand 199C].

The study involvement with details of EMEP's activities proved to be essential to elaborate on the data actually available, their reliability and the uses they are and might be put to work. In addition, it irresistibly led to judgements on some related matters.

4.1. Are the Current IRMs Useful Tools to Verify Compliance?

The central question that set off this study was whether the data accumulated through the workings of IRMs in environmental agreements could be used for verification of compliance. This question has two main aspects, namely: 1) whether the institutional activities and the data available are sufficient, and 2) whether the institutional arrangements are appropriate.

1) A large effort on **emission** estimations has been a principal ongoing task under the LRTAP Convention. This activity has been continually accompanied by questions about the reliability of emission inventories and the uncertainty of estimations. The relevance of those issues is

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[35] The implementation review at the EB ordinary meetings appears to consist in a perusal of the reports drafted by the Secretariat, basically to give parties the opportunity for modifying/enlarging their contributions. No analysis of compliance seems to be undertaken at the meetings. The dispute-settlement mechanism of the Convention and its Protocols currently in force has never been used.

clearly revealed when different methodologies are applied to compile an emission inventory[36]. To help correct the situation, an important decision to unify the methodology through collaboration was made by the UN/ECE and the EU, and instrumented by EMEP and the CORINAIR Project.

Students of international environmental regimes coincide in the assessment that the LRTAP Convention and its Protocols constitute a high compliance regime [e.g. Sand 1990, Levy 1993, Wettestad 1996]. This assessment is essentially based on the evaluation of official emission data. However, there is no clear indication that all the data is equally reliable, and that parties have consistently delivered all the information used in the calculations together with the corresponding emission inventories. Even if they have done it, there is no direct evidence that such information has been used to validate emission inventories. Up to this day, a proposal for data emission validation made by the TFEI (see section 3.2.) has yet to be implemented.

A careful analysis of emission time-series published at different times shows:

i) On the one hand, there are parties who seem to continuously upgrade their emission figures, the data show slight variations in the course of time; in general, emission reductions are not steady, there are ups and downs that appear to correlate with known social and economic variations. Most of these parties have been largely involved in developing their own methods to estimate emission inventories. The sum of these features suggests that the reported data has a high confidence level.

ii) On the other hand, some data can be questioned because time-series are overtly incomplete, and/or show constant rounded figures for long periods, and/or consider as provisory emissions for previous years, perhaps indicating the adoption of a new methodology in current calculations but no revision of previous reported data.

The situation briefly described does not mean, however, that there are serious reasons to suspect an intention to deceive; EMEP's assessments at meetings and workshops indicate that, in general, the uneven quality of the data is mostly due to lack of infrastructure at some quarters, in some cases to domestic political and economic hindrances. But the uncertainty thus introduced unfortunately affects the entire endeavor and is sufficient to cast a doubt on the reliability of the database.

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[36] This has been analyzed in the case of CO_2 emissions from fossil fuels combustion [von Hippel et al. 1993, di Primio 1993].

A cautionary statement is appropriate at this point: even under conditions of perfect (i.e., complete, high-quality and timely) reporting, the consistent application of the same methodology by all parties does not much improve the chances for verification of compliance. Here is an example of verification suitability: since verification is always *ex post facto*, there is no way to be sure that the reported values are correct, short of continuous measurement of all sources in the period under consideration. However, a common methodology is a big step forward, fostering consistency and making comparative analyses meaningful.

The *measurement* program of chemical species in air and precipitation delivers useful information for verification purposes. EMEP's permanent attention to the need of increasing sampling sites and improving data reliability via the quality assurance program notwithstanding, still some problems remain: i) the sampling station network is not dense enough to cover the whole EMEP area, nor is the siting of the sampling stations always appropriate; ii) methods for sampling and chemical analyses are not homogeneous from country to country so that the data delivered are sometimes open to question; iii) not all chemical species included in the measurement program are analyzed in all laboratories, and data on those which are analyzed sometimes do not cover a significant part of the period of interest. All these factors have resulted in discarding a more or less significant part of the data in studies on deposition trends and comparisons with model results; in both cases, seasonal and yearly mean values are generally used to minimize the effect of local climate variability.

Of course, EMEP is well aware of the necessity to remedy a situation which basically depends on the willingness of the parties to increase investments. In spite of the existing conditions, EMEP's statistical analyses are instrumental in showing clear qualitative trends (e.g., a slow, long-term decrease of acidity in precipitation) in line with those resulting from the evaluation of emission time-series.

The *modelling* exercise is a complex and challenging undertaking. In principle, neither the mathematical formulation of the problem is completely satisfactory, nor are all the inputs known or trustworthy, so that no model is able to fully reproduce a past situation. What has been strived for with considerable dedication, however, is to attain an average representation of the long-range transport problem for rather large periods of time, from seasons to years.

The real validation of the model would be a satisfactory agreement with the measured concentrations in air and precipitation: this has been explored by looking at the differences between the respective seasonal or annual mean values. The approach gives an indication of the possible origin of discrepancies. Model results have increasingly shown a fairly good agreement with observations for annual averages, which is in some way surprising in view of the compounded uncertainty from input and model shortcomings. This suggests that, on the average, the model is robust and able to reproduce the general features of the phenomena. The main consequence is that the parties accept model results, in particular the country-allocation matrices as a measure of one state contribution to depositions elsewhere and as a guide for the design of abatement policies and strategies.

A detailed description of the modeling approach does not help much to understand the contribution it makes to the review process. Model runs exploring the effect of inputs changes have shown how far results are sensitive to the completeness and quality of emission data. Comparison of calculated and measured concentrations have pointed into shortcomings of the extant sampling station network. Thus, the modellers critical assessment of the sources of basic information is an important contribution to the strengthening of EMEP's monitoring activities.

2) In what concerns *institutions*, the LRTAP regime has taken advantage of existing national institutes with long tradition and high scientific standards to prepare the information required for the implementation review. While those centers are no international institutions, they indeed enjoy international standing. This situation does not meet, however, one of the conditions postulated in section 3.1 to guarantee the verification agency's neutrality and independence. In practice, the establishment of an international verification agency has only been accomplished in multilateral arms control agreements (e.g., the nuclear Non Proliferation Treaty).

The second condition, namely ownership of monitoring and assessment capabilities, has also not been implemented. Monitoring is coordinated by EMEP but it takes places at national sites and laboratories. This has forced EMEP to establish the quality assurance program to follow the performance of the sampling stations and the analytical laboratories. At present, it is difficult to visualize whether from EMEP's measurement network a truly international monitoring system would ever evolve, i.e., one that uses national installations and capabilities, but also has independent surveillance and analytical means.

In conclusion, as part of the LRTAP regime EMEP developed key elements of the IRMs to follow the parties' implementation. They constitute a ripe monitoring and evaluation system, which can provide a sound basis for a practical start towards verifying compliance with commitments under the LRTAP regime. However, it has never been used to that end.

After about 15 years of reviewing implementation a number of key people (mostly senior members of the "epistemic community" [Haas 1992]) are undoubtedly aware of the parties' level of compliance. Although this constitutes a valuable asset in the decision-making process, it does not reach full potential because it constitutes a knowledge *in petto* of a select minority. But knowledge limited to an elite strongly reduces its deterrence value. It may be concluded that well established IRMs (and verification systems) will gain on effectiveness if their findings are made accessible to the public.

Current IRMs of the LRTAP regime provide a *necessary but not sufficient* part of the information required to implement an independent monitoring and evaluation capability. This qualification refers both to the amount and reliability of data that would be needed to say something definitive about compliance and to the institutional structure necessary to perform the tasks.

The 1994 SO_2 Protocol explicitly addresses compliance[37], an Implementation Committee will be appointed as soon as the agreement comes into force. One can expect that the shift from IRMs typical activities to verification of compliance will require additional steps, both of quantitative (more data, new tasks) and qualitative (political decisions on regime and institutional structure) nature. Such evolution may pave the way towards a greater internationalization of institutions [see Széll 1995].

4.2. Evolutionary Trends of the LRTAP Regime and Its IRMs

The evolution of the *LRTAP regime* has been extensively treated in the literature [see, for example, Nordberg 1992, Wettestad 1996, Levy 1993 and 1995, Gehring 1994]. The development has mainly been guided by the continuous search for scientific evidence in the issue-area. Scientific activities cover an ample spectrum of basic and applied research, e.g., consideration of further pollutants, development of the critical loads approach, selection and recommendation of abatement technologies.

The increase in knowledge has been used to extend the regime's scope and shape commitments, thus influencing the establishment of abatement goals and of research priorities. In the course of time protocols covered more terrain and gained "more teeth": initially focussing on the substances firstly identified in acid rain, later addressing chemical precursors

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[37] To the question why the issue of compliance -that apparently has been brewing for a long time- was brought into the open after many years of quiet build up of an adequate monitoring and assessment system, a LRTAP experienced high official answered that a favorable political situation was required to start a frank discussion. That situation appeared in the early 1990s with the end of the Cold War.

of photoxidants, more recently considering heavy metals and persistent organic compounds as the next candidates for regulation. The scope of a regime created to determine the extent and to understand the reasons and effects of acid rain has been expanding to include interactions and effects of other air pollutants that are detected far away from their sources.

The regime settled the basic requirements to examine the parties behavior. The evolution of the *LRTAP IRMs* has been fostered by the parties' desire to know more about compliance, and shaped by the growth in depth and extension of work on emissions, measurements of air pollutant concentrations, and the application of atmospheric transport models. Their formation and growth led to a better grasp of national implementation performance and contributed to expand the scope of the LRTAP regime[38].

Still, it would be debatable whether the entire process of tightening up the regime resulted from the incorporation of new legal instruments as time went by or, conversely, the provisions on targets, timetables, reporting duties, etc., were introduced because of the increasing knowledge provided by the activities of the Convention's bodies. The appropriate view may be that both interpretations are pertinent since there has been considerable interaction and feedback during a long learning process. One may conclude that "monitoring and reporting (have) served the dual objectives of tracking compliance and of furnishing information for adjusting the standards set by the international legal instrument" [Sachariew 1991].

4.3. Lessons Learned and Their Applicability to Other Cases

Why can LRTAP IRMs be regarded as a success?

First, because the regime's systemic features are quite favorable: acid rain can be measured, it can be sensibly reproduced in models, some of its effects can be seen and evaluated. Second, because of the way IRMs have been institutionalized. Responsibilities are clearly defined: the chain of authority starts at the Convention level with the Executive Body assuming the overall decision-making power, the IRMs are centrally coordinated so there is no room for overlapping competences. That has increased the effectiveness of the IRMs operation, avoiding confusion and speeding up the decision-making process.

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[38] In this context, the North-American situation is exceptional. Both the United States and Canada are parties to the Convention, Canada is party to the two Protocols currently in force while the USA is only a party to the NO_x Protocol. In spite of regular and thorough exchanges between North American and European parties on technical and general policy matters, the application of IRMs has been limited to the European area under EMEP.

The IRMs structure that has been achieved is consequence of a combination of those features, but also from specific circumstances such as: the limited number of parties with a common tradition; the comparatively high economic, scientific and institutional levels of the more industrialized parties; the willigness to collaborate extensively among themselves and with others.

However, the acquired knowledge is not applicable *in toto* to other cases of atmospheric pollution. For instance, the implementation of effective IRMs in the Framework Convention on Climate Change (FCCC) would be, in principle, more difficult, because pollutant measurements would be essentially confined to atmospheric concentrations which, in turn, cannot be linked to reported national emission rates[39].

Certain features of the institutional approaches that have evolved in the LRTAP regime may be helpful in the process of establishing the FCCC IRMs; in particular, the way institutions have been incorporated within the international domain of the convention. At this early stage of the FCCC, still with no Protocols determining abatement standards, targets and timetables, its Subsidiary Bodies and the Secretariat have begun the orderly processing and evaluation of national reports on greenhouse emission inventories. In light of the LRTAP experience it seems appropriate to suggest the convenience of rapidly creating an international agency for coordinating, and eventually perform some activities to monitor implementation, in a way and position similar to the one EMEP enjoys in the LRTAP regime: this shall start a process conducive to the creation and installation of FCCC IRMs.

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[39] The key issue here is the respective residence times of the species under consideration. CO_2 emission source allocation is limited to North-South hemispheric imbalances. In the case of acid rain, modeling allows to relate emissions with atmospheric concentrations, and a view of countries' contributions to depositions elsewhere.

REFERENCES

AMANN, M. 1992. Emissions of Acidifying Components, pp. 65-76 in T. SCHNEIDER (Ed.) Acidification Research. Evaluation and Policy Applications. Elsevier Science Publ.

ANDREAE, M.O. 1985. The Emission of Sulfur to the Remote Atmosphere. Background Paper, pp. 5-25 in J.N. GALLOWAY et al. (Eds.) The Biogeochemical Cycling of Sulfur and Nitrogen in the Remote Atmosphere. NATO ASI Series: Series C: Mathematical and Physical Sciences Vol. 159. Reidel Publishing Company. Dordrecht.

AUSUBEL, J. and D.G. VICTOR. 1992. Verification of International Environmental Agreements. *Annual Review of Energy and Environment* **17**, 1-43.

BERGE, E., J. SCHAUG, H. SANDNES and I. KVALVAGNES. 1994. A Comparison of Results from the EMEP/MSC-W Acid Deposition Model and the EMEP Monitoring Sites During the Four Seasons of 1989. EMEP/MSC-W/CCC Note 1/94.

BOUSCAREN, R. et al. 1995. CORINAIR Inventaire des emissions de dioxyde de soufre, d'oxydes d'azote et des composes organiques volatiles dans la Communaute europeenne en 1985. Report EUR 13232. Luxembourg.

BRENTON, T. 1994. The Greening of Machiavelli. Earthscan Publ. Ltd., London.

BUILTJES, P.J.H. 1989. The Use of Emission Data Bases in Air Pollution Dispersion Modeling. Pp. 3-18 in H. van DOP, (Ed.) Air Pollution Modeling and its Applications VII. Plenum Press.

CHAYES, A. and A. H. CHAYES. 1993. On Compliance. *International Organization* **47** (2) 175-205.

DOVLAND, H. 1993. EMEP - The European Monitoring and Evaluation Programme. Paper presented at the Expert Meeting on Acid Precipitation Monitoring Network in East Asia, Toyama, Japan, 26-28 October 1993. NILU F 30/93.

DOVLAND, H. 1995. Implementation Issues in the Acid Rain Convention, pp. 61-80 in Implementing Environmental Conventions. Second High-level Nordic Policy Seminar, October 27-28, 1994, Copenhagen. Scandinavian Seminar College.

EFINGER, M. 1991. Vertrauen ist gut, Kontrolle ist besser. Nomos Verlagsgesellschaft. Baden-Baden.

EGNER, H., G. BRODIN and O. JOHANSSON. 1955. Sampling Technique and Chemical Examination of Air and Precipitation. *Kungl. Lantbrukshögskolans Annaler* **22**, 369-410.

ELIASSEN, A. 1984. Aspects of Lagrangian Air Pollution Modelling. In C. de WISPELAERE (Ed.) Air Pollution Modelling and Its Applications, III. Plenum Publishing, New York.

ELIASSEN, A. and J. SALTBONES. 1983. Modelling of Long-range Transport of Sulphur Over Europe: A Two-year Model Run and Some Model Experiments. *Atmospheric Environment* **17**, 1457-1473.

FAEHNRICH, B., J.E. HANSSEN and K. NODOP. 1993. Comparison of Measuring Methods for Nitrogen Dioxide in Ambient Air. EMEP/CCC Report-3/93.

FISCHER, W. 1991. The Verification of International Conventions on Protection of the Environment and Common Resources. KFA Report Jül-2495. Research Center Jülich. Germany.

FISCHER, W., J.C. di PRIMIO and G. STEIN. 1990. A Convention on Greenhouse Gases: Towards the Design of a Verification System. KFA Report Jül-2390. Research Center Jülich. Germany.

GEHRING, T. 1994. Dynamic International Regimes - Institutions for International Environmental Governance. Peter Lang GmbH. Frankfurt am Main.

GILBERT. R.O. 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold Co., New York.

GOSOVIC, B. 1992. The Quest for World Environmental Cooperation. The Case of the UN Global Environmental Monitoring System. Routledge. London and New York.

GREENE, O. 1994. On Verifiability, and How it Could Matter for International Environmental Agreements. IIASA Working Paper WP-94-116.

HAAS, P.M. 1992. Epistemic Communities and International Policy Coordination. *International Organization* **46**(1), 1-35.

HANSSEN, J.E., U. PEDERSEN, J. SCHAUG, H. DOVLAND, J.M. PACYNA, A. SEMB and J.E. SKJELMOEN. 1990. Summary Report from the Chemical Co-ordinating Centre for the Fourth Phase of EMEP. EMEP/CCC-Report 2/90.

HANSSEN, J.E. and J.E. SKJELMOEN. 1992. The Twelfth Intercomparison of Analytical Methods Within EMEP. EMEP/CCC-Report 7/92.

HIDY, G.M.; P.K. MUELLER and E.Y. TONG. 1978. Spatial and Temporal Distribution of Airborne Sulfate in Parts of the United States. *Atmospheric Environment* **12**, 735-754.

von HIPPEL, D., P. RASKIN, S. SUBAK and D. STAVISKY. 1993. Estimating Greenhouse Gas Emissions from Fossil Fuel Consumption. *Energy Policy* **21** (6), 691-702.

IRVING, P.M. (Ed.). 1991. Acid Deposition: State of Science and Technology. Summary Report of the U.S. National Acid Precipitation Assessment Program (N.A.P.A.P.).

IVERSEN, T. 1993. Modelled and Measured Transboundary Acidifying Pollution in Europe Verification and Trends. *Atmospheric Environment* **27A** (6), 889-920.

LEVY, M.A. 1993. European Acid Rain: The Power of Tote-Board Diplomacy. Chapter 3 in P.M. HAAS, R.O. KEOHANE and M.A. LEVY (Eds.). Institutions for the Earth - Sources of Effective International Environmental Protection. The MIT Press. Cambridge, Massachusetts.

LEVY, M.A. 1995. International Co-operation to Combat Acid Rain in H.O. BERGESEN AND G. PARMANN (Eds.) Green Globe Yearbook 1995. The Fridtjof Nansen Institute. Oxford University Press.

McINNES, G. (Ed.). 1996. Atmospheric Emission Inventory Guidebook. First Edition. A joint EMEP/CORINAIR Production. Prepared by the EMEP Task Force on Emission Inventories.

McINNES, G., J.M. PACYNA and H. DOVLAND. 1992. Proceedings of the First Meeting of the Task Force on Emission Inventories, London, United Kingdom, 5-7 May 1992. EMEP/CCC-Report 4/92.

McINNES, G., J.M. PACYNA and H. DOVLAND. 1993. Proceedings of the Second Meeting of the Task Force on Emission Inventories, Delft, the Netherlands, 7-9 June 1993. EMEP/CCC-Report 8/93.

MITCHELL, R. B. and A. CHAYES. 1995. Improving Compliance with the Climate Change Treaty, pp. 115-145 in H. LEE (Ed.) Shaping National Responses to Climate Change. Island Press. Washington D.C.

MYLONA, S.N. 1989. Detection of Sulphur Emission Reductions in Europe During the Period 1979-1986. EMEP/MSC-W Report 1/89.

NODOP, K. 1990. Weitraümige Verteilung und zeitliche Entwicklung saürebildender Spurenstoffe in Europa, 1978 bis 1985. Berichte des Instituts für Meteorologie und Geophysik der Universität Frankfurt/Main, Nr. 81.

NODOP, K. and W. LEYENDECKER (Eds.). 1988. Expert Meeting on Sampling, Chemical Analysis and Quality Assurance, Arona, October 1988. EMEP/CCC Report 4/88.

NORDBERG. 1992. Introduction, pp. 109-113 in G. McINNES, J.M. PACYNA and H. DOVLAND (Eds.) Proceedings of the First Meeting of the Task Force on Emission Inventories, London, United Kingdom, 5-7 May 1992. EMEP/CCC Report 4/92.

NRC. 1981. National Research Council. Atmosphere-Biosphere Interactions: Toward a Better Understanding of the Ecological Consequences of Fossil Fuel Combustion. A Report Prepared by the Committee on the Atmosphere and the Biosphere.

ODEN, S. 1968. The Acidification of Air and Precipitation and its Consequences in the Natural Environment (in swedish). In Ecology Committee Bulletin No. 1, Swedish National Research Council, Stockholm.

OECD. 1972. Decision of the OECD-Council of 18 April 1972, C(72) 13 (Final).

OECD. 1979. The OECD Programme on Long Range Transport of Air Pollutants - Measurements and Findings. Second Edition. OECD. Paris.

OTTAR, B. 1978. An Assessment of the OECD Study on Long Range Transport of Air Pollutants (LRTAP). *Atmospheric Environment* **12**, 445-454.

PACYNA, J.M. and K.E. JOERSS. 1991. Proceedings of the EMEP Workshop on Emission Inventory Techniques, Regensburg, Germany, 2-5 July, 1991. EMEP/CCC-Report 1/91.

PARTRIDGE, R.H. 1990/1991. Long-path Monitoring of Atmospheric Pollution. *Measurement + Control* **23**, 293-298.

PEDERSEN, U., J. SCHAUG and J.E. SKJELMOEN. 1992. Data Report 1990. Part 1: Annual Summaries. EMEP/CCC Report 2/92. Norwegian Institute for Air Research.

di PRIMIO, J.C. 1992. Establishing Energy-Related GHG Emission Inventories for Verification Purposes: Problems and Needs, in J.C. DI PRIMIO and G. STEIN (Eds.) 1992, A Regime to Control Greenhouse Gases, Proceedings of a Workshop, Bad Neuenahr, June 12-14, 1991. Konferenzen des Forschungszentrum Jülich, Band 10. Jülich Research Center.

di PRIMIO, J.C. 1993. On the Variability of Carbon Dioxide Emission Calculations. Final Report under EUROSTAT Contract Nr. 2881008, Project 1.7.

di PRIMIO, J.C.; G. STEIN and H.F. WAGNER. 1992. Verifying Compliance with an International Convention on Greenhouse Gases. *Environment* **34** (2) 4-5, 45.

RODENBURG, E. 1992. Eyeless in GAIA. World Resources Institute.

RODHE, H. 1985. The Transport of Sulphur and Nitrogen Through the Remote Atmosphere. Chapter 6, pp. 105-124 in J.N. GALLOWAY et al. (Eds.). 1985. The Biogeochemical Cycling of Sulphur and Nitrogen in the Remote Atmosphere. NATO ASI Series C Vol. 159. D. Reidel Publishing Company. Dordrecht.

SACHARIEW, K. 1991. Promoting Compliance with International Environmental Legal Standards: Reflections on Monitoring and Reporting Mechanisms. *Yearbook of International Environmental Law* **2**, 31-52.

SAND, P. 1990. Regional Approaches to Transboundary Air Pollution. pp. 246-264 in J.L. HELM (Ed.). Energy - Production, Consumption and Consequences.

SAND, P. 1996. Private communication.

SANDNES, H. 1993. Calculated Budgets for Airborne Acidifying Components in Europe, 1985, 1987, 1988, 1989, 1990, 1991 and 1992. EMEP/MSC-W Report 1/93. Norwegian Meteorological Institute, Oslo.

SCHAUG, J. 1988. Quality Assurance Plan for EMEP. EMEP/CCC Report 1/88. Norwegian Institute for Air Research.

SCHAUG, J. 1995. Private communication.

SCHAUG, J., T. IVERSEN and U. PEDERSEN. 1993. Comparison of Measurements and Model Results for Airborne Sulphur and Nitrogen Components with Kriging. *Atmospheric Environment* **27 A** (6) 831-844.

SEINFELD, J.H. 1986. Atmospheric Chemistry and Physics of Air Pollution. J. Wiley and Sons. New York.

SEMB, A.; K. ANDREASSON, J.E. HANSSEN, G. LOVBLAD and A. TYKESSON. 1991. Vavihill. Field Intercomparison of Samplers fur Sulphur Dioxide and Sulphate in Air. EMEP/CCC Report 4/91.

SEMB, A., J.E. HANSSEN and J. SCHAUG. 1992. Site and Laboratory Visits Under the Expert Consultation Programme, Summary of Findings. EMEP/CCC Report 5/92. Norwegian Institute for Air Research.

SZELL. P. 1995. The Development of Multilateral Mechanisms for Monitoring Compliance. Pp. 97-109 in W. LANG (Ed.) Sustainable Development and International Law. Graham & Trotman/Martinus Nijhoff. London.

TUOVINEN, J.-P., K. BARRETT and H. STYVE. 1994. Transboundary Acidifying Pollution in Europe: Calculated Fields and Budgets 1985-93. EMEP/MSC-W Report 1/94.

UN/ECE. 1992. UN Statistical Commission and ECE. The Environment in Europe and North-America: Annotated Statistics 1992. New York.

USGAO. 1992. United States General Accounting Office. International Agreements Are Not Well Monitored. GAO/RCED-92-43.

VENKATRAM, A. 1988. On the Use of Kriging in the Spatial Analysis of Acid Precipitation Data. *Atmospheric Environment* **22** (9) 1963-1975.

VICTOR, D.G., O. GREENE, J. LANCHBERY, J.C. di PRIMIO and A. KORULA. 1994. Review Mechanisms in the Effective Implementation of International Environmental Agreements. IIASA Working Paper WP-94-114.

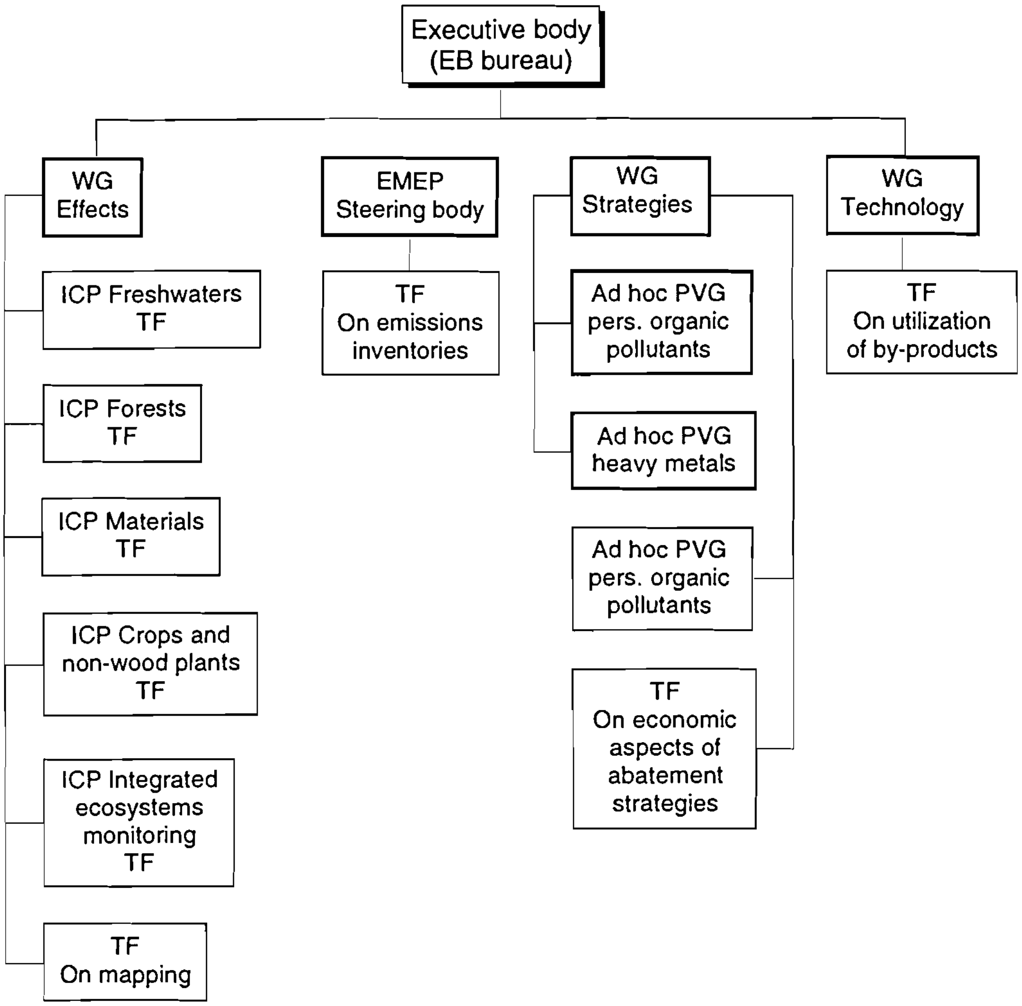
WETSTONE, G.S. 1987. A History of the Acid Rain Issue. Chapter 12, pp. 163-195 in H. BROOKS and C.L. COOPER (Eds.). Science for Public Policy, Pergamon Press.

WETTESTAD, J. 1996. Acid Lessons? Assessing and Explaining LRTAP Implementation and Effectiveness. IIASA Working Paper WP-96-18.

WETTESTAD, J. and S. ANDRESEN. 1991. The Effectiveness of International Resource Cooperation: Some Preliminary Findings. Fridtjof Nansens Institute R:007-1991.

WÜSTER, H. 1992. The Convention on Long-range Transboundary Air Pollution: its Achievements and its Potential. Pp. 221-239 in T. SCHNEIDER (Ed.). Acidification Research, Evaluation and Policy Applications. Elsevier Science Publishers.

YOUNG, O.R. 1979. Compliance and Public Authority - A Theory with International Applications. The John Hopkins University Press. Baltimore.



EMEP = *Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe*
WG = *Working Group*
PWG = *Preparatory Working Group*
TF = *Task Force*
ICP = *International Cooperative Programme*

Figure 1. LRTAP organizational structure. Source: UN/ECE Secretariat, 1995.

EMEP

Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe

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- **Chemical Coordinating Centre [CCC]** – Norwegian Air Research Institute (NILU), Kjeller

- **Meteorological Synthesizing Centre–West [MSC–W]** – Norwegian Meteorological Institute, Oslo

- **Meteorological Synthesizing Centre–East [MSC–E]** – Institute for Applied Geophysics, Moscow

- Task Force on Emission Inventories

Created in 1991 to develop a methodology to prepare emission inventories for European countries and to establish procedures to ensure compatibility and transparency among the inventories. The Task Force first established 8 Expert Panels, namely:

Strategic Overview
Volatile Organic Compounds
Ammonia
Heavy Metals and Persistent Organic Compounds
Power Plant and Industry
Mobile Source
Marine
Verification

The Expert Panel *Emission Projections* was incorporated at a later date

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Figure 2.

Figure 3. EMEP sampling network in 1993. Source: DOVLAND 1993.

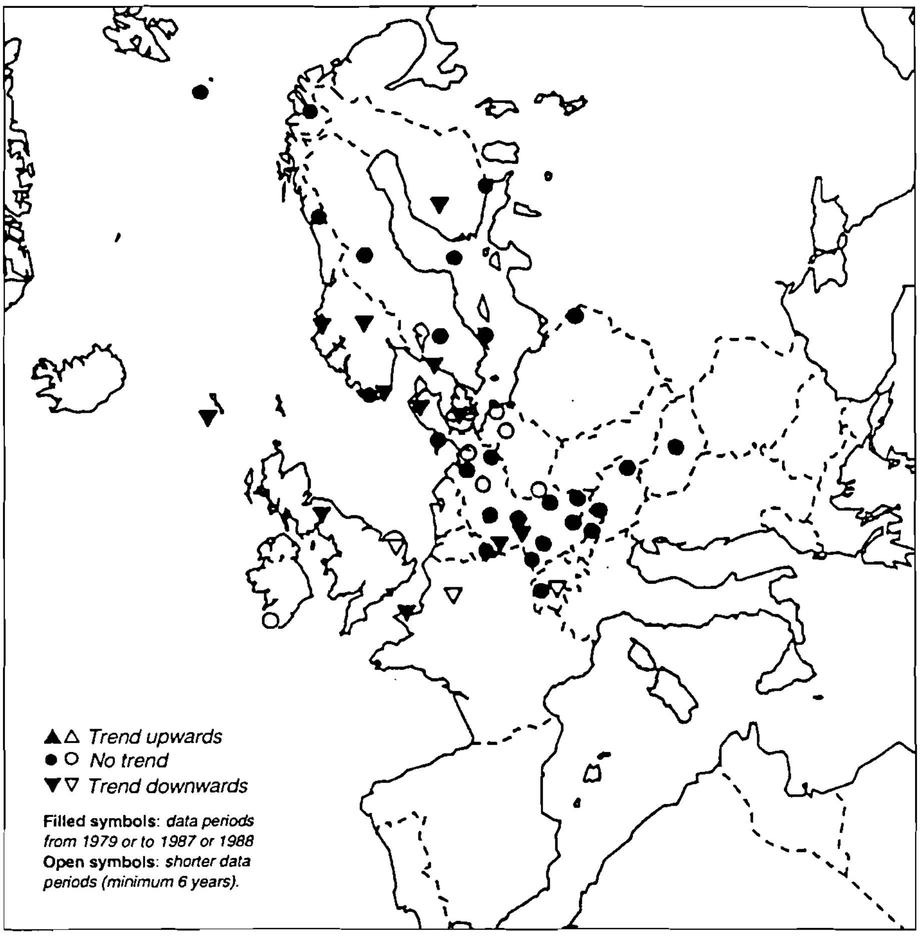

Figure 4. Trends in sulphur dioxide concentrations. Source: Hanssen *et al.*,1990.

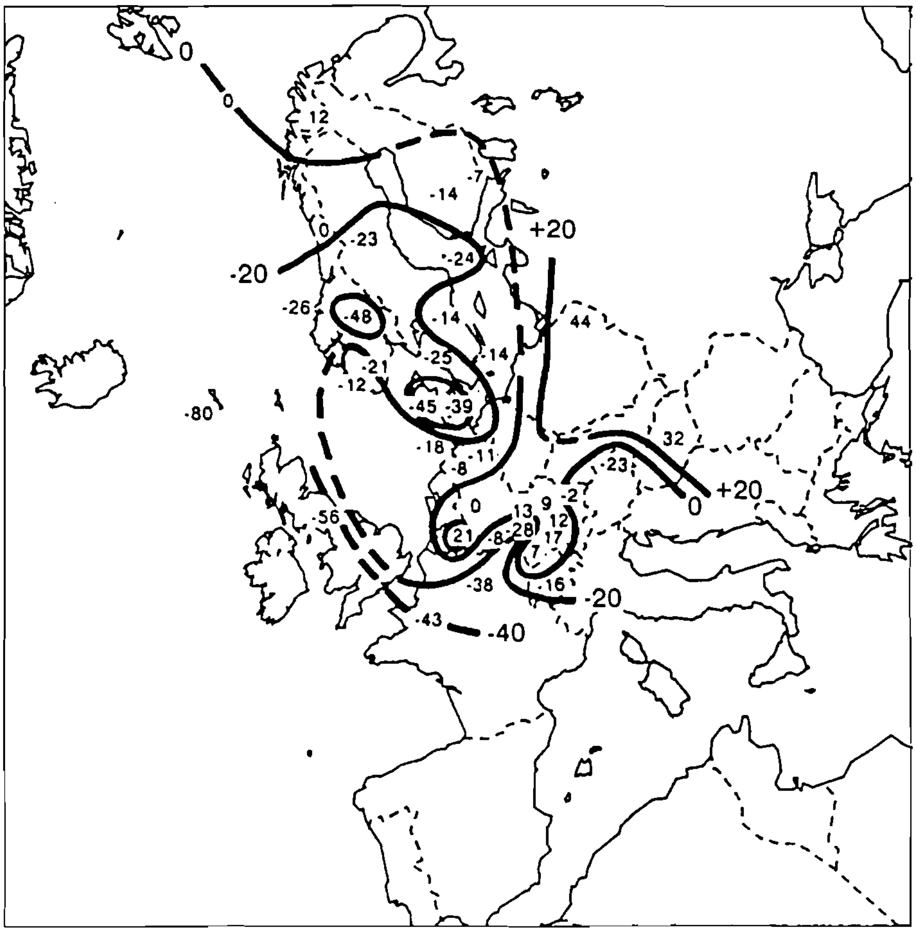

Figure 5. Changes in the yearly average concentrations of sulphur dioxide 1980-1987. Computed from Sen's slope estimator. Source: Hanssen *et al.*, 1990.

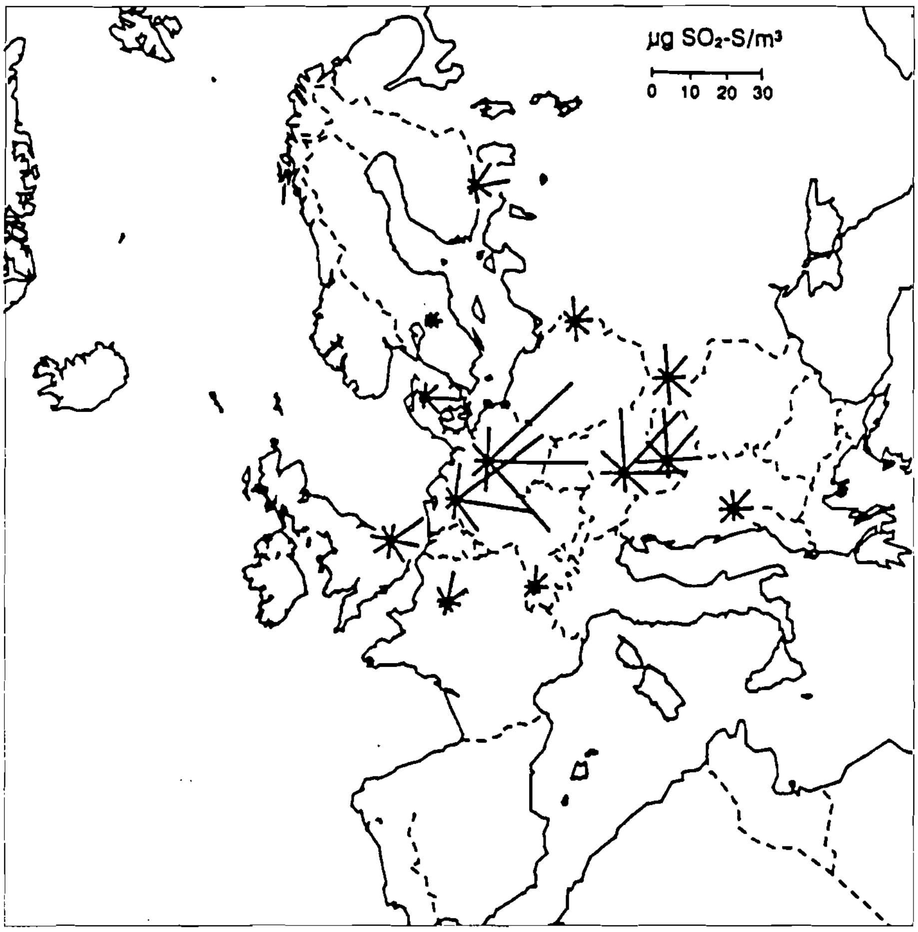

Figure 6. Mean concentrations of sulphur dioxide in air for different directions of arriving trajectories, 1983-1987. Source: Hanssen *et al.*, 1990.

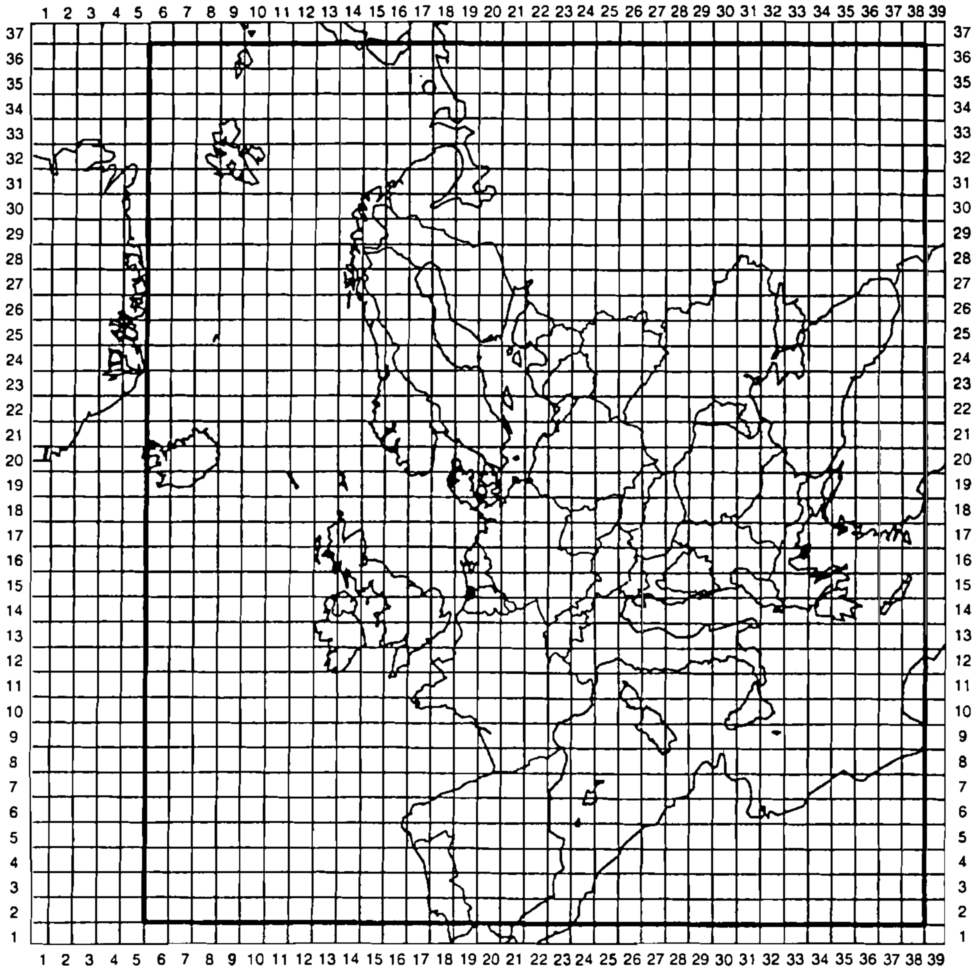

Figure 7. The EMEP grid. The polar stereographic projection is applied. The side length of a square is 150 km at 60°N. Pollutants are followed in the whole domain. Resulting concentrations and depositions are obtained at the 33 ´ 35 receptor squres of the rectangular subgrid.
Source: TUOVINEN *et.al.*, 1994

TABLE 1

Estimated Atmospheric Emissions, Anthropogenic and [Natural], in 1985 (million tonnes/year)

	GLOBAL	N. AMERICA	EUROPE
Sulphur Dioxide (in SO2)	160 [130]	25	50
Nitrogen Oxides (in NO2)	80 [89]	22	20
Total Susp. Particulates	200 [3700]	9,2	.....
Carbon Monoxide (in CO)	1600 [1200]	74	.....
Ammonia (in NH3)	6 [260]	.....	9
Non-methane VOCs	80 [180]	22 [35]	22 [18]
Methane (in CH4)	180 [350]	.....	.....

Source: UN/ECE 1992

TABLE 2

TOTAL SO2 EMISSIONS 1980-1993 IN THE UN/ECE REGION (in thousands of tonnes SO2 per year)

SOURCE: Document ECE/EB.AIR/44

	1980	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**
AUSTRIA	397			242		195		152	122	93	90	84	76	71
BELARUS	740	730	710	710	690	690	690	811	780	720	710	724	509	433
BELGIUM	828	712	694	560	500	400	377	367	354	325	317	324	304	
BULGARIA	2050							2420	2228	2180	2020	1667	1120	1422
CANADA	4614	4241	3612	3625	3955	3692	3627	3762	3835	3695	3267	3151	3030	3042
Croatia	150*										180			
Cyprus						36	37	41	46	47	51	41	45	43
CZECH REPUBLIC	2257	2341	2387	2338	2305	2277	2177	2164	2066	1998	1876	1776	1538	1419
DENMARK	451	362	369	314	296	339	284	251	242	193	180	242	189	157
FINLAND	584	534	484	372	366	383	332	328	302	244	260	194	139	121
FRANCE	3338	2588	2490	2094	1866	1470	1342	1290	1226	1334	1298	1378	1238	1136
GERMANY a/	3166	3010	2843	2666	2578	2369	2230	1907	1218	939	5633	4430	3896**	
GERMANY, former GDR	4320	4374	4611	4678	5084	5385	5406	5434	5255	5250				
Greece	400					500					510			
HUNGARY	1633					1404	1362	1285	1218	1102	1010	913	827	
Iceland	6				6	6								
Ireland	222	192	158	142	142	140	162	174	152	162	178	179	160	
ITALY	3800**			3150**	2656**	2244**	2257**	2274**	2216**	2001**	2251			
LIECHTENSTEIN	0,4				0,1						0,1			
LUXEMBOURG	24			14		16								
NETHERLANDS	489	463	403	323	299	261	263	262	247	205	201	177	167**	168**
NORWAY	142	127	110	103	95	98	91	74	67	59	54	45	37	37
Poland	4100					4300	4200	4200	4180	3910	3210	2996	2830	2725
Portugal	266			306		198	234	218	204		282	290**	346**	290**
Romania								1762	2397	1647	1504	1167	559	
RUSSIAN FEDERATION b/	7161	6949	7090	6934	6503	6191	5707	5622	5145	4677	4460	4392	3839	3456
SLOVAKIA	780					613	604	614	589	573	543	446	380	325
Slovenia	235	254	256	270	249	240	244	218	210	211	195	180	188	182
Spain	3319			2543		2190	1961	1903	1587	1950	2316			
SWEDEN	507	431	371	304	296	267	272	226	224	160	130	113	102	103**
SWITZERLAND	126				95			80	73	68	62	62	59	58
Turkey	860				276	322	354							
UKRAINE	3850	3492	3427	3498	3470	3463	3393	3264	3211	3073	2782	2538	2376	2194
United Kingdom	4898	4438	4213	3682	3721	3726	3897	3900	3813	3721	3780	3574	3500	3069**
United States	23779	22512	21211	20618	21467	21218	20391	20520	20948	21042	20701	20659	20621	
European Union (12) c/	25513					13626								

NOTE: Parties to the SO2 Protocol are identified with CAPITAL letters

*Estimate

**Preliminary data

a/ Figures apply to the FRG as prior to 1989

b/ Figures apply to the European part within EMEP

c/ CORINAIR total of 12 EU member States

TABLE 3

TOTAL NOx EMISSIONS 1980-1993 IN THE UN/ECE REGION (in thousands of tonnes NO2 per year)

SOURCE: Document ECE/EB.AIR/44

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
AUSTRIA	246			241		245		234	226	221	222	216	201	182
BELARUS	234	235	235	237	240	238	258	263	262	263	285	281	224	206
Belgium	442					315	307	321	335	347	343	350		
BULGARIA								416	415	411	376	273	260	238
CANADA	1959	1907	1897	1884	1871	1984	1959	2037	2117	2120	1999	1976	1939	1952
Croatia	60*										83			
Cyprus						9	9	10	10	11	11	13	13	14
CZECH REPUBLIC	937	819	818	830	844	831	826	816	858	920	742	725	698	574
DENMARK	274	240	260	254	266	294	312	302	292	272	269	319	274	264
FINLAND	264	248	245	236	233	252	256	270	276	284	284	286	257	253
FRANCE	1823	1701	1688	1645	1632	1615	1618	1630	1615	1772	1584	1619	1599	1519
GERMANY a/	2926	2842	2817	2862	2923	2908	2939	2861	2777	2617	3033	2934	2904**	
GERMANY, former GDR	514	510	513	514	550	568	572	590	596	604				
Greece						306								
HUNGARY	273					262	264	265	258	246	238	203	183	
Iceland	13				12	12								
IRELAND	73	86	86	85	84	91	100	115	122	127	115	119	125	
ITALY	1480**				1568**	1741**	1804**	1904**	1982**	2035**	2053			
LIECHTENSTEIN	1					1					1			
LUXEMBOURG	23			21		19								
NETHERLANDS	582	575	561	554	571	573	586	597	599	583	570**	561	550**	568**
NORWAY	186	178	183	190	205	216	230	237	229	233	231	220	220	225
Poland	1500					1500	1590	1530	1550	1480	1280	1205	1130	1140
Portugal	166			192		96	110	116	122		211	232**	248**	245**
Romania								369	253	1753	883	805	443	
RUSSIAN FEDERATION b/	1734	1915	2002	1976	1879	1903	1871	2653	2358	2553	2675	2571	2298	2269
SLOVAKIA								197		227	227	212	192	184
Slovenia	48	49	49	48	49	50	54	53	55	54	53	50	51	57
SPAIN	950			937		839	854	892	892	992	1257			
SWEDEN	424	417	412	401	411	426	432	434	412	404	398	397	391	391**
SWITZERLAND	196				214			200	194	189	184	175	161	150
Turkey														
UKRAINE	1145	1145	1153	1153	1102	1059	1112	1094	1090	1065	1097	989	830	700
UNITED KINGDOM	2392	2328	2312	2332	2321	2438	2533	2644	2749	2842	2860	2835	2750	2752**
UNITED STATES	18672	18609	18048	17488	17952	17785	17614	18028	18677	18512	18599	18535	18217	
EUROPEAN UNION (12) c/						10428								

NOTE: Parties to the NOx Protocol are identified with CAPITAL letters

* Preliminary data

** Provisional data

a/ Figures apply to the FRG as prior to 1989

b/ Figures apply to the European part within EMEP

c/ CORINAIR total of 12 EU member States

TABLE 4

TOTAL AMMONIA EMISSIONS 1980-1993 IN THE UN/ECE REGION (in thousands of tonnes per year)

SOURCE: Document ECE/EB.AIR/44

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Austria a/											99	99	100	101
Belarus											4			
Belgium						74					79	78	77	
Bulgaria											323	280	130	220
Canada														
Croatia														
Cyprus														
Czech Republic											105	88	77	74••
Denmark						152		152		146	140	134		126
Finland						43		45			41		41	
France											645	635	623	625
Germany b/	571	558	565	576	586	589	581	572	561	557	759	666	648••	
Germany, former GDR	263	264	253	266	268	268	266	266	270	262				
Greece														
Hungary	170					170	170	150		170	176	150	140	
Iceland														
Ireland											126			
Italy						508••	505••	506••	501••	497••	384			
Liechtenstein														
Luxembourg														
Netherlands	251						258			234	215	221	170••	162••
Norway									38	39	39	39	40	40
Poland	550					550	550	550	550	550	550	470	447	382
Portugal											93	93••	93••	93••
Romania														
Russian Federation c/	1189	1192	1214	1245	1247	1239	1286	1277	1269	1258	1191	1161	1084	903
Slovakia											62		61	
Slovenia														
Spain											324			
Sweden											74	73	72	71••
Switzerland	62				60						61	61	62	63
Turkey														
Ukraine											23			
United Kingdom											382			382••
United States						1685								
European Union														

• Preliminary data

•• Provisional data

a/ Including nature

b/ Figures apply to the FRG as prior to 1989

c/ Figures apply to the European part within EMEP

TABLE 5

SO2 EMISSIONS - REPORTING AND REDUCTION PERFORMANCES							
Source: ECE/EB.AIR/44 (1995)							
		Sulfur Dioxide					
		(10e3 tons SO2/yr)				Change %	
	Nr. Years						
	Reported in	1980	1987	1993	1980-87	1980-93	*1987-93*
	1980-1993				Ref.: 1980		Ref.: 1987
EUROPEAN PARTIES TO SO2 PROTOCOL							
AUSTRIA	10	397	152	71	-62	-82	*-53*
BELARUS	14	740	811	433	10	-41	*-47*
BELGIUM	12	828	367	[304]	-56	[-63]	*[-17]*
BULGARIA	8	2050	2420	1422	18	-31	*-41*
CZECH REPUBLIC	14	2257	2164	1419	-4	-37	*-34*
DENMARK	14	451	251	157	-44	-65	*-37*
FINLAND	14	584	328	121	-44	-79	*-63*
FRANCE	14	3338	1290	1136	-61	-66	*-12*
GERMANY a/	13	3166	1907	3896*	-40	-48	*-47*
GERMANY DR	10	4320	5434		26		
HUNGARY	9	1633	1285	[827]	-21	[-49]	*[-36]*
ITALY	9	3800	2274	[2251]	-40	[-41]	*[-1]*
LIECHTENSTEIN	3	0,4	[0,1]	[0,1]			
LUXEMBOURG	3	24	[16]	[16]			
NETHERLANDS	14	489	262	168	-46	-66	*-36*
NORWAY	14	142	74	37	-48	-74	*-50*
RUSSIAN FEDER.	14	7161	5622	3456	-21	-52	*-38*
SLOVAKIA	10	780	614	325	-21	-58	*-47*
SWEDEN	14	507	226	103	-55	-80	*-54*
SWITZERLAND	9	126	80	58	-36	-54	*-27*
UKRAINE	14	3850	3264	2194	-16	-43	*-33*
SUB-TOTAL		36643	28841	18394	-21	-50	*-36*
EUROPEAN PARTIES TO LRTAP BUT NOT TO SO2 PROTOCOL							
Croatia	2	150	[180]	[180]	[20]	[20]	*0*
Cyprus	9	[36]	41	43	[14]	[19]	*5*
Greece	3	400	[500]	[510]	[25]	[27]	*[2]*
Iceland	3	6	[6]	[6]	0	0	*0*
Ireland	13	222	174	[160]	-22	[-28]	*[-8]*
Poland	10	4100	4200	2725	2	-33	*-35*
Portugal	10	266	218	290	-18	9	*33*
Romania	6	[1762]	1762	[559]	0	[-68]	*[-68]*
Slovenia	14	235	218	182	-7	-22	*-16*
Spain	8	3319	1903	[2316]	-43	[-30]	*[22]*
Turkey	4	860	[354]	[354]	[-59]	[-59]	*0*
United Kingdom	14	4898	3900	3069	-20	-37	*-21*
SUB-TOTAL		16254	13456	10394	17	-36	*-23*
EUROPE UNDER LRTAP		52897	42297	28788	-20	-46	*-32*
Notes							
a/ Figures apply to the FRG as prior to 1989 --- 1993 figure is for unified Germany							
1/ Figures between brackets are inter- or extrapolations from nearest reported year							

TABLE 6

NOx EMISSIONS - REPORTING PERFORMANCE AND STATUS						
Source: ECE/EB.AIR/44 (1995)						
		Nitrogen Oxides (10e3 tons NO2/yr)				
	Nr. Years Reported in 1980-1993	1980	1985	1987	1993	Change % 1987-93
EUROPEAN PARTIES TO NOx PROTOCOL						
AUSTRIA	10	246	245	234	182	-22
BELARUS	14	234	238	263	206	-22
BULGARIA	7	[416]	[416]	416	238	-43
CZECH REPUBLIC	14	937	831	816	574	-30
DENMARK	14	274	294	302	264	-13
FINLAND	14	264	252	270	253	-6
FRANCE	14	1823	1615	1630	1519	-7
GERMANY a/	13	2926	2908	2861	[2904]*	[-16]
GERMANY DR	10	514	568	590		
HUNGARY	9	273	262	265	[183]	[-31]
IRELAND	13	73	91	115	[125]	[9]
ITALY	8	1480	1741	1904	[2053]	[8]
LIECHTENSTEIN	3	1	1	[1]	[1]	0
LUXEMBOURG	3	23	19	[19]	[19]	0
NETHERLANDS	14	582	573	597	568	-5
NORWAY	14	186	216	237	225	-5
RUSSIAN FEDER.	14	1734	1903	2653	2269	-14
SLOVAKIA	6	[197]	[197]	197	184	-7
SPAIN	8	950	839	892	[1217]	[36]
SWEDEN	13	424	426	434	391	-10
SWITZERLAND	8	196	[214]	200	150	-25
UKRAINE	14	1145	1059	1094	700	-36
UNITED KINGDOM	14	2392	2438	2644	2752	4
SUB-TOTAL		17290	17346	18634	16988	-9
EUROPEAN PARTIES TO LRTAP BUT NOT TO NOx PROTOCOL						
Belgium	8	442	315	321	[350]	[9]
Croatia	2	60	[60]	[83]	[83]	0
Cyprus	9	[9]	9	10	14	40
Greece	1	[306]	306	[306]	[306]	0
Iceland	3	13	12	[12]	[12]	0
Poland	10	1500	1500	1530	1140	-25
Portugal	10	166	96	116	245	111
Romania	6	[369]	[369]	369	[443]	[20]
Slovenia	14	48	50	53	57	7
Turkey	0					
SUB-TOTAL		2913	2717	2800	2650	-5
EUROPE UNDER LRTAP		20193	20063	21434	19638	-8
Notes						
a/ Figures apply to the FRG as prior to 1989 --- 1993 figure is for unified Germany						
1/ Figures between brackets correspond to nearest reported year						

TABLE 7

SULPHUR DIOXIDE EMISSIONS (in thousands of tonnes SO2 per year)

IN YEAR	1973	1980				1985				1990	
Information	*I*	*II*	*III*	*IV*	*V*	*II*	*III*	*IV*	*V*	*IV*	*V*
Issued in	*1977*	*1985*	*1991*	*1993*	*1995*	*1985*)*	*1991*	*1993*	*1995*	*1993*	*1995*
Austria	442	440	370	397	397	386	178	195	195	90	90
Belarus a/		Under USSR	740	740	740	Under USSR	690	690	690		710
Belgium	998	809	828	828	828	650	452	452	400	443	317
Bulgaria		(1000)	1034	2050	2050					2020	2020
Canada		4516	4644	4614	4614		3686	3692	3692	3700	3267
Croatia b/				59	150			59		69	180
Cyprus								18	36	27	54
Czech Republic c/		3100	3100	2257	2257	3350	3150	2277	2277	1876	1876
Denmark	622	437	448	451	451	399	340	343	339	180	180
Finland	548	595	584	584	584	535	382	382	383	260	260
France	3232	3270	3338	3338	3338	3270	1470	1470	1470	1202	1298
Germany d/	3928	3200	3210	3194	3166		2450	2396	2369	1029	5633
Germany, former DR			4264	4300	4320		5340	5400	5385	4774	
Greece		(700)	400	400	400		500	500	500		510
Hungary		1633	1632	1632	1633	1675	1404	1404	1404	1010	1010
Iceland		(10)	6	6	6		6	6	6		
Ireland			222	222	222		140	140	140	168	178
Italy		3800	3800	3800	3800*		2504	2504	2244*		2251
Liechttenstein		Under Switz.		0,8	0,4	Under Switz.				0,2	0,1
Luxembourg			24	24	24		16	16	16		
Netherlands	782	480	466	466	489		276	276	261	207	201
Norway	182	137	142	142	142	90	98	98	98	54	54
Poland		2755	4100	4100	4100		4300	4300	4300	3210	3210
Portugal		(170)	266	266	266		198	198	198		282
Romania		200	1800	1800							1504
Russian Federation a/		25000	12800	7161	7161	23000	11110		6191	4460	4460
Slovakia				700	780			622	613	539	543
Slovenia				235	235			240	240	195	195
Spain			3250	3319	3319	2730	2190	2190	2190	2316	2316
Sweden	830	496	514	503	507	309 (1983)		292	267	130	130
Switzerland	150	119	126	126	126	102		96		62	62
Turkey		(1000)			860		322	322	322		
Ukraine a/		Under USSR	3850	3850	3850	Under USSR	3464	3464	3463	2782	2782
United Kingdom	5606	4680	4848	4898	4898	4000	3676	3724	3726	3780	3780
United States		24100	23900	23780	23779		21600	21670	21218	21060	20701
European Union (12)					25513				13626		

References

*) Preliminary data

I: OECD Programme on LRTAP - Measurements and Findings, Paris (2nd. Edition, 1979)

II: ECE/EB.AIR/R.1/Rev. 1 (1985)

III: ECE/EB.AIR/27. 1990 Major Review (1991)

IV: ECE/EB.AIR/R.76 (1993)

V: ECE/EB.AIR/44. 1994 Major Review (1995)

Notes

a/ Data reported before 1993 were included under USSR

b/ Data reported before 1994 included only emissions from thermal power plants

c/ Data reported before 1993 contain Slovakia

d/ Figures apply to the FRG as prior to 1989

TABLE 8

EMISSIONS OF NITROGEN OXIDES (in thousands of tonnes NO2 per year)												
IN YEAR	1980				1985				1990			
Information	*III*	*IV*	*V*	*VI*	*III*	*COR'85*	*IV*	*V*	*III*	*IV*	*V*	*COR'90*
Issued in	*1991*	*1993*	*1995*	*1994*	*1991*	*1991*	*1993*	*1995*	*1991 *)*	*1993*	*1995*	*1995*
Austria	233	246	246	243	230		245	245	201	222	222	227
Belarus a/	244	244	234	334	220		220	238	271		285	
Belgium	442	442	442	442	281	317	281	315	300	334	343	343
Bulgaria				352					271	376	376	361
Canada	1959	1959	1959		1887		1887	1984	1923	1923	1999	
Croatia b/		6	60				7			9	83	83
Cyprus							9	9		11	11	
Czech Republic c/	1204	937	937	791	1127		831	831		742	742	773
Denmark	241	273	274	254	258	271	298	294	254	283	269	273
Finland	264	264	264	242	251		262	252		290	284	269
France	1823	1823	1823	2019	1615	1605	1615	1615		1750	1584	1590
Germany d/	2970	2980	2926	2917	2930	2715	2959	2908		2584	3033	2424
Germany, former DR		590	514	845			640	568		606		556
Greece				246	746	308	746	306				544
Hungary	273	273	273	302	262		262	262	264	238	238	191
Iceland	13	13	13		12		12	12				
Ireland	73	73	73	96	91	85	91	91	135	135	115	116
Italy	1480	1480	1480	1501	1595	1574	1595	1741			2053	2053
Liechtenstein		0,7	1				0,8	1		0,6	1	
Luxembourg	23	23	23	32	19	22	19	19	15			23
Netherlands	548	548	582	579	544	471	544	573		552	570	576
Norway	184	186	186	168	203		216	216		230	231	232
Poland			1500	1385	1500		1500	1500		1280	1280	1446
Portugal	166	166	166	158	96	96	96	96	142		211	221
Romania				646							883	546
Russian Federation a/	3167	1734	1734	2712	3369			1903		2675	2675	
Slovakia											227	227
Slovenia		43	48				44	50		48	53	57
Spain	950	950	950	983	950	839	839	839		249	1257	1257
Sweden	398	424	424	340	394		426	426	373	396	398	345
Switzerland	196	196	196	188					184	184	184	164
Turkey				375								
Ukraine a/			1145	1614	1059		1059	1059	1099	1097	1097	
United Kingdom	2418	2365	2392	2361	2278	2125	2392	2438	2573	2779	2860	2773
United States	20300	23560	18672		19700		19390	17785		19380	18599	
European Union (12)						10428		10428				12194

References

III: ECE/EB.AIR/27. 1990 Major Review (1991) --- 1991 *) = Projections

COR'85: CORINAIR'85 - CEC Document SEC(91) 958 (1991)

IV: ECE/EB.AIR/R.76 (1993)

V: ECE/EB.AIR/44. 1994 Major Review (1995)

COR'90: CORINAIR 90 Summary --- EEA/053/95 (1995)

VI: IIASA-TAP Project . Private communication (1994)

Notes

a/ Data reported before 1993 were included under USSR

b/ Data reported before 1994 included only emissions from thermal power plants

c/ Data reported before 1993 include Slovakia

d/ Figures apply to the FRG as prior to 1989

TABLE 9

SULPHUR DIOXIDE EMISSIONS (in thousands of tonnes SO2 per year)

IN YEAR	1980			1985				1990		
Information	*IV*	*V*	*VI*	*COR'85*	*IV*	*V*	*VI*	*IV*	*V*	*COR'90*
Issued in	*1993*	*1995*	*1994*	*1991*	*1993*	*1995*	*1994*	*1993*	*1995*	*1995*
Austria	397	397	329		195	195	325	90	90	93
Belarus a/	740	740	842		690	690	798		710	
Belgium	828	828	821	392	452	400	509	443	317	317
Bulgaria	2050	2050	1014				1063	2020	2020	2008
Canada	4614	4614			3692	3692		3700	3267	
Croatia b/	59	150			59			69	180	180
Cyprus					18	36		27	54	
Czech Reoublic c/	2257	2257	3099		2277	2277	3010	1876	1876	1863
Denmark	451	451	444	333	343	339	389	180	180	198
Finland	584	584	596		382	383	435	260	260	227
France	3338	3338	3330	1482	1470	1470	1772	1202	1298	1300
Germany d/	3194	3166	3147	2316	2396	2369	2676	1029	(5633)	912
Germany, former DR	4300	4320	4411		5400	5385	4931	4774		4343
Greece	400	400	517	500	500	500	601		510	641
Hungary	1632	1633	1617		1404	1404	1574	1010	1010	905
Iceland	6	6			6	6				
Ireland	222	222	209	141	140	140	141	168	178	178
Italy	3800	3800	3840	2090	2504	2244	2958		2251	2253
Liechtenstein	0,8	0,4						0,2	0,1	
Kuxembourg	24	24	18	17	16	16	19			14
Netherlands	466	489	462	200	276	261	295	207	201	201
Norway	142	142	136		98	98	109	54	54	54
Poland	4100	4100	3687		4300	4300	3743	3210	3210	3273
Portugal	266	266	263	198	198	198	263		282	283
Romania	1800		1711				1769		1504	1311
Russian Federation a/	7161	7161	7654			6191	8827	4460	4460	
Slovakia c/	700	780			622	13		539	543	542
Slovenia	235	235			240	240		195	195	196
Spain	3319	3319	2617	2190	2190	2190	2417	2316	2316	2206
Sweden	503	507	494		292	267	372	130	130	105
Switzerland	126	126	126		96		90	62	62	44
Turkey		860	860		322	322	1212			
Ukraine a/	3850	3850	5107		3464	3463	5168	2782	2782	
United Kingdom	4898	4898	4831	3767	3724	3726	4071	3780	3780	3787
United States	23780	23779			21670	21218		21060	20701	

References

COR'85: CORINAIR Programme. CEC Document SEC(91) 958 (1991)
IV: ECE/EB.AIR/R.76 (1993)
V: ECE/EB.AIR/44. 1994 Major Review (1995)
VI: IIASA-TAP Project. Private communication (1994)
COR'90: CORINAIR 90 Summary — EEA/053/95 (1995)

Notes

a/ to d/ same as in Table 5. In addition:
e/ VI: unabated emissions from RAINS module

Table 10. Summary of the EMEP/MSC-W emission data for SO_x, NO_x and NH_3. "Low" and "High" refers to the height separation of emissions (LPS = Large Point Sources). "Valid" denotes the year of the most recent grid data received and "Rep." when these data were reported to EMEP.

	Number of totals 1985-1992			Grid information				
	SO_2	NO_x	NH_3	Component	Low & High	50 × 50 km^2	Valid	Rep.
Albania	-	-	-	-	-	-	-	-
Austria	7	7	3	SO_2 NO_x NH_3	Yes, LPS	Yes	1990	1994
Belarus	4	4	-	SO_2 (NO_x NH_3)	-	-	1992	1994
Belgium	8	8	1	SO_2 NO_x	Yes	-	1983	1984
Bosnia & Herzegovina	-	-	-	-	-	-	-	-
Bulgaria	4	4	-	SO_2 NO_x	Yes, LPS	-	1990	1994
Croatia	1	2	-	-	-	-	-	-
Czech Republic	8	8	1	SO_2 NO_x NH_3	-	Yes	1990	1994
Denmark	7	7	4	SO_2 NO_x	Yes	-	1980	1984
Estonia	-	-	-	-	-	-	-	-
Finland	7	7	2	SO_2/NO_x	NO_x only	-	1987/80	1988/86
France	8	6	3	SO_2 NO_x	-	-	1989	1990
Former GDR	7	7	7	SO_2 NO_x	-	-	1988	1990
Former FRG	7	7	7	SO_2 NO_x	Yes	-	1983	1986
Greece	2	1	-	-	-	-	-	-
Hungary	7	7	1	SO_2 NO_x	Yes	-	1987	1989
Iceland	1	1	-	-	-	-	-	-
Ireland	8	8	1	SO_2 NO_x NH_3	LPS	Yes	1990	1994
Italy	4	4	-	SO_2 NO_x	-	-	1980	1987
Latvia	-	-	-	-	-	-	-	-
Lithuania	-	-	-	-		-	-	-
Luxembourg	1	1	-	-	-	-	-	-
Macedonia, FYR[1]	-	-	-	-	-	-	-	-
Moldova	-	-	-	-	-	-	-	-
Netherlands	7	7	4	SO_2 NO_x	Yes	-	1983	1984
Norway	7	7	4	SO_2 NO_x NH_3	Yes	-	1992	1994
Poland	8	8	3	SO_2 NO_x NH_3	Yes	Yes	1990	1994
Portugal	5	5	1	SO_2 NO_x	Yes	-	1980	1984
Romania	1	-	-	-	-	-	-	-
Russia	8	8	-	SO_2 NO_x	NO_x only	-	1992	1994
Slovakia	8	4	-	-	-	-	-	-
Slovenia	8	8	-	SO_2 NO_x	-	Yes	1993	1994
Spain	1	1	-	SO_2 NO_x	Yes	-	1983	1984
Sweden	8	8	2	SO_2 NO_x	Yes	-	1986	1990
Switzerland	8	6	3	SO_2 NO_x NH_3	Yes	Yes	1990	1992
Turkey	2	-	-	-	-	-	-	-
Ukraine	8	8	1	SO_2 NO_x NH_3	Yes	-	1990	1994
United Kingdom	7	7	1	SO_2 NO_x	Yes	Yes	1992	1994
Yugoslavia[2]	8	8	-	-	-	-	-	-

[1] *The former Yugoslav Republic of Macedonia.*

[2] *The former Yugoslavia excluding Bosnia and Herzegovina, Croatia, Slovenia, and FYR Macedonia.*

Table 11. Deposition of Oxidised Sulphur 1990 [100 tonnes as 5]. Source: Tuovinen *et al.*, 1994.

		EMITTERS									
		AL	AT	BE	BG	CS	DK	FI	FR	···	SUM
R	AL	103	0	0	30	7	0	0	2	···	315
E	AT	0	115	17	4	223	1	0	61	···	1454
C	BE	0	0	425	0	11	1	0	117		885
E	BG	10	2	2	2395	55	0	0	4		3406
I	CS	0	24	28	13	3096	4	1	60		5843
V	DK	0	0	15	0	18	100	1	19		547
E	FI	0	1	8	2	39	14	382	12		1659
R	FR	0	3	185	2	98	4	0	1959		4753
S	⋮	⋮									⋮
	SUM	311	302	1879	5543	8826	703	943	4763	···	157181