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THE IGAC ACTIVITY FOR THE DEVELOPMENT OF GLOBAL EMISSIONS INVENTORIES: DESCRIPTION AND INITIAL RESULTS

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ABSTRACT

Modeling assessments of the atmospheric chemistry, air quality and climatic conditions of the past, present and future require as input inventories of emissions of the appropriate chemical species constructed on appropriate spatial and temporal scales. The task of the Global Emissions Inventories Activity (GEIA) of the International Global Atmospheric Chemistry Project (IGAC) is the production of global inventories suitable for a range of research applications. Current GEIA programmes are generally based on addressing emissions by species; these include CO_2, NH_3/N_2O, SO_2/NO_x, CFC, volatile organic compounds and radioisotopes. In addition a separate programme to inventory emissions from biomass burning is also being structured, plus an additional programme to address data management issues for all the developing inventories. Programme priorities are based on current knowledge and tasks needed to produce the desired inventories. This paper will discuss the different types of global inventories to be developed by the GEIA programmes, their key characteristics, and areas to be addressed in the compilation of such inventories. Results of the first GEIA task, a survey of existing inventories and auxiliary data, will be presented. The survey included status assessments for the available inventory information for nineteen different atmospheric species or groups of species on global and regional scales and over time. Of this entire body of information, the only inventory regarded as satisfactory was that for the global emissions of CFCs. An implication of the results of these assessments is that properly gridded emissions inventories are badly needed to support atmospheric modeling calculations on a variety of spatial and temporal scales. Initial studies in the development of global inventories of sulfur dioxide, currently the most advanced GEIA programme, will be presented and discussed.

INTRODUCTION

The International Global Atmospheric Chemistry Project (IGAC, Galbally [1]) is an international cooperative effort of atmospheric scientists designed to measure, understand, and attempt to predict changes in the chemistry of the global atmosphere over short and long time scales. Of particular interest are changes in the oxidizing capacity of the atmosphere, the impacts of these changes on climate, and the chemical interactions of the atmosphere and biota. These goals are broad and include several environmental issues of urgent concern, including greenhouse warming due to the accumulation of trace gases in the atmosphere, depletion of stratospheric ozone, increased acidity of rainfall, increased oxidant levels in the troposphere, and resulting biological damage. IGAC functions as a volunteer network linking scientists and projects in different countries and coordinating and stimulating research in areas of particular importance to the goals of the program.

One of the most important scientific tools used in the assessment of atmospheric chemistry, air quality, and climatic conditions of the past, present, and future is mathematical models of transport and transformations in the atmosphere. These models rely in part on inventories of emissions constructed on appropriate temporal and spatial scales and including the required chemical species. The production of such inventories, initially regarded as adjunct to modeling activities, is now a separate area of research whose importance to the accuracy of results of modeling and assessment activities has been fully recognized. The myriad of problems involved in the compilation of accurate inventories on a local or regional basis is multiplied manyfold when the geographic area of interest is extended to the multinational, hemispheric, and global domains. Recognizing that the most accurate information on emissions is usually developed by experts from individual countries, the IGAC Steering Committee has defined an activity whose main goal is the development of global emissions inventories by international teams of experts.

THE GLOBAL EMISSIONS INVENTORY ACTIVITY (GEIA).

The ultimate and very ambitious target of the Global Emissions Inventory Activity (GEIA, Graedel et al. [2]) of IGAC is to establish emissions inventories for a number of trace species, incorporating fluxes from both anthropogenic and natural sources, with recognized accuracy and enough spatial, temporal and species resolution to serve as standard inventories for the international community of atmospheric scientists. To accomplish this, GEIA has the following goals:

- To establish a framework for the development and evaluation of global emissions inventories.
- To conduct a critical survey of existing emissions inventories of compounds of major importance in global atmospheric chemistry.
- To publish inventories in the open literature and provide appropriate data files for use by scientists worldwide.

As with all other IGAC activities, GEIA tries to include all interested parties on a volunteer basis. Emissions inventory experts from individual countries, supported by local organizations, conduct their own research while maintaining contact through a network which includes FAX communication, electronic mail and participation in periodic face-to-face meetings, usually held in conjunction with other functions of mutual interest. The GEIA forum allows participants to discuss their work, draw on the combined expertise of their fellow members, and, most important, to coordinate their efforts so that results of their work are compatible and can be combined with a minimum of effort. GEIA activities include a project to provide basic data management support for the maintenance and distribution of the resulting inventories.

EMISSIONS INVENTORIES

Existing emissions inventories have been compiled for a variety of uses. Their spatial, temporal and species resolution are dependent not only on their final use but also on the resources available for and the methodologies used in their development. Historically, emissions inventory development started with what may be termed "effects inventories"; these inventories were directed toward specific impacts, such as environmental acidification or atmospheric visibility, or towards species that contribute to those effects. These inventories were generally regional or national in scope and included only anthropogenic sources. With the advent of environmental regulations, inventories were also needed to develop and administer these regulations; additional details on emission sources were included in the inventories to help in these endeavors.

Since individual measurement of every emissions source in large geographic areas is beyond the scope of any inventory project, emissions inventory methodologies must rely on combining "ancillary" data with extrapolation of detailed studies of representative samples of emission sources. In the compilation and use of the ancillary data, two main methodologies have been used; we choose to distinguish them as top-down and bottom-up; methodology selection depended on the level of detail needed in the inventory and the resources available. Top-down methods collect ancillary data at a high level of aggregation (e.g., fuel use in a geographic region), estimate emissions, and apportion these to lower levels via the use of surrogate information. Bottom-up methods collect ancillary data on a disaggregated level (e.g, fuel use by individual installation), estimate emissions, and aggregate values to obtain results at higher levels of aggregation. In general, inventories which must also support regulatory activities require details on individual sources and so use the later method to estimate emissions.

As scientific studies of environmental problems advanced, it became recognized that the interaction between natural and anthropogenic emissions could not be separated. Thus emissions from natural sources must be known with the same attributes as for anthropogenic sources. Because of this belated recognition, however, work on detailed emissions inventories from natural sources has lagged behind that for anthropogenic sources. In addition, the atmosphere is ignorant of regional and national boundaries and provides a mixing and reaction chamber for all emissions. It was also recognized that chemical interactions between disparate species must be considered, especially if the effects of changes in emissions patterns are to be evaluated. Thus the need developed for inventories of both anthropogenic and natural sources, incorporating multiple species and covering large geographic areas. Resources and expertise needed to compile detailed inventories covering these large areas (multinational, hemispheric, and global) were generally not available to individual scientific projects. To date, the development of large inventories has been accomplished using top-down methods, and has encountered large difficulties obtaining appropriate data.

The GEIA activity will encompass all the phases of the compilation of the desired emissions inventories. To help direct the work, inventories have been initially classified into five types: supporting inventories, effects inventories, process inventories, specific events inventories, and past/future inventories.

- Supporting inventories do not themselves include atmospheric data nor emissions values; these are the inventories (or data files) needed for the derivation or apportionment of the actual emissions values, i.e., the ancillary data. These data may reflect natural conditions or human activities; examples include populations (human, animal, etc), vegetation cover, topography, land use, soil type, etc.

- Effects inventories have been described above; these inventories are directed to the study of a specific impact such as acidification, or towards a species that contributes to that effect. As previously mentioned, these were the first types of inventories to be developed and are the most common to date.

- Process inventories are those connected with a specific process or activity; biomass burning is a good example. Biomass burning is a significant contributor to many global atmospheric budgets and is a periodic event in many parts of the world.

- Specific events inventories comprise those emissions arising from specific events. These inventories are usually produced as the need arises rather than on a regular basis; examples include emissions from large volcanic events, emissions related to war, etc. Development of inventories for some events, previously considered of short duration, are being extended to a more regular basis; an example is inventories of emissions from degassing volcanoes.

- Past/future inventories refer to specific periods in the past, used in studies related to historical atmospheric chemistry, or present scenarios of emissions for some future period of time, used in connection with predictive studies of atmospheric chemistry and air quality. In connection with field data from sediments and ice cores, they provide the potential to link emissions with effects over very long time periods.

Key atributes of emissions inventories include geographic area covered, spatial scale, temporal resolution, species included, etc. These attributes mainly depend on the purpose for which the inventory is assembled and on compromises between data availability and the resources available for inventory compilation. Two of the most important attributes of any inventory are the geographic area covered and the spatial scale. For some urban areas and regional locales emissions inventories are available on quite detailed spatial and temporal scales; however, in general, current availability of detailed emissions information for large areas is limited and is expected to be no easier to assemble in the future. This presents problems for atmospheric modelers. Regional and urban area models in use today have the potential to use inventories with spatial scales of only a few kilometers. While today's best climate models typically have spatial resolutions of about 4° latitude by 5° longitude, as computing power increases over the next decade or so these models are expected to improve their spatial resolution to 1° by 1° and to add increasingly sophisticated chemistry. These detailed and refined models will be of limited benefit unless reliable emissions inventories on the same spatial scale are available.

Another important attribute of emissions inventories is the temporal scale. The majority of existing inventories are constructed on an annual basis, a time scale appropriate for very long-lived species such as chlorofluorocarbons, or for models interested in assessing long-term variability of atmospheric chemistry. In many cases, models are designed to assess atmospheric chemical variability on shorter time scales: seasonal, monthly, diurnal, etc. As with spatial scale, the temporal scale of emissions inventories must be suited to the problem that will use the information, or results will be of limited usefulness. Today's best global climate models have temporal scales of annual or at most seasonal; this resolution is expected to be maintained for some time.

Yet another important attribute of emissions inventories is the chemical species that are included, since atmospheric chemistry models may involve complex reactions. The study of photochemical smog is an example of a problem requiring complex chemistry. The necessary emissions inventories include information on oxides of nitrogen, hydrocarbons and perhaps other species. Hydrocarbon emissions require further chemical speciation; categories to be included depend on the chemical mechanisms being used and vary between different models. The compilation of inventories for this problem needs to draw on inventories designed for compatibility, and in which the same techniques are used to derive emissions estimates for all chemical species of interest.

Emissions inventories produced under GEIA auspices are not expected to begin to be available before 1993, and many will require a much longer time period. In advance of providing GEIA's internationally recognized emissions inventories, a GEIA subcommittee has compiled a summary and description of existing inventories, together with their spatial and temporal attributes and a few interpretive comments (Graedel et al. [2]). The only global ensemble emissions inventory that is regarded as good at the present is that for CFCs. Those for CO_2, CH_4, NO_x, SO_2, reduced sulfur, and radon are regarded as fair. "Good" implies an estimated accuracy of 20% or better, "fair" of 50% or better. In selected regions, the spatial resolution of emissions is well-determined for CO_2, CO, NO_x and SO_2. The temporal resolution of existing inventories is almost uniformly poor. This compilation provides the detailed justification for the GEIA inventory activities, while, in addition, serving to some degree the needs of the modeling community on the immediate time scale.

CURRENT GEIA ACTIVITIES

Work under the GEIA umbrella is directed by a Steering Committee and carried out by study groups. The Steering Committee is drawn from members of the individual study groups; it sets the overall direction for and coordinates all GEIA activities. The Steering Committee has adopted several principles of operation to govern emissions inventory tasks:

- The ultimate goal of GEIA is to produce emissions inventories for all species of interest on a 1° by 1° global grid.
- All inventories shall be accompanied by point by point assessments of their degree of uncertainty.
- The study groups formed for each GEIA activity shall be international and intercontinental in makeup.

Given the many possibilities for inventory development, the Steering Committee has decided to begin the GEIA tasks by concentrating on evaluating and producing effects inventories targeted to individual species or groups of closely related species. Individual study groups will be established as the interest of participants develops. Table 1 presents a summary of the GEIA study groups active as of January 1992, the director or directors for each group, and the target temporal resolution for each inventory. Supporting inventories, especially those used for the development of the effects inventories to be evaluated and used, will be recognized and encouraged but will not be a formal part of GEIA. Part of the mandate of the Data Management group is to develop and implement the GEIA policy towards this type of inventory. Event inventories, historical inventories and future scenario inventories are also within the GEIA purview; these will be accomplished as time, personnel and resources allow. In fact, one of the current GEIA study groups is addressing what was previously defined as a "regular specific event", biomass burning.

ANTHROPOGENIC SO_2/NO_x INVENTORY: INITIAL WORK

Currently the most advanced work of the GEIA study groups is the compilation of an anthropogenic emissions inventory of SO_2 and NO_x. The study group, headed by Jozef Pacyna of the Norwegian Institute for Air Research (NILU), has set a deadline of June 1992 for an initial version of annual inventories and December 1992 for an initial version of seasonal inventories. Inventories are being assembled in an incremental mode; a basic global inventory is selected and emissions for a particular geographic area are substituted as more accurate, complete data become available. Work on inventories covering two timeframes, annual and seasonal, is proceeding in parallel.

Compilation of global emissions inventories for SO_2 and NO_x started in the early 1980s. The following articles describe information that can be utilized.

Cullis and Hirschler [3] developed a global inventory of sulfur emissions from all sources; the methodolo-

Table 1. GEIA Study Groups, January 1992

Species	Source Type	Temporal Res.	Director
SO_2	Anthropogenic	S	J.M. Pacyna, NOR
NO_x	Anthropogenic	S	J.M. Pacyna, NOR
CO_2	Anthropogenic	A	G. Marland, USA
NH_3, N_2O	Natural	S	A.F. Bouwman, NL
VOC	Anthropogenic	S	C. Veldt, NL
Radioisotopes	Natural	A	M. Kritz, USA
Biomass Burning		S	B.J. Stocks, CAN J.S. Levine, USA
VOC	Natural	S	N. Hewitt, UK A. Guenther, USA
Data Management	NA	NA	P. Middleton, USA

A=Annual S=Seasonal NA=Not applicable

gy used is based on estimates of activity rates, fuel sulfur content, and appropriate emission factors. Their global estimate for 1976 is 103.6 Tg S, of which 91.1 Tg S are from fuel use.

Möller [4] developed a global inventory of anthropogenic sulfur emissions from all sources. His methodology is based on estimates of activity rates, fuel sulfur content, and appropriate emission factors. The total global estimate for 1985 is 90 Tg S; for fuel combustion sources only, the figure is 82.5 Tg S. Linear interpolation to 1980 results in 80.0 Tg S total emissions and 74.0 Tg S for emissions from fuel combustion. Langner and Rodhe [5] have allocated the Möller 1980 figures to geographic grids based on the emission pattern for CO_2 presented by Marland et al. [6] and Rotty [7].

Várhelyi [8] developed a global inventory of anthropogenic sulfur emissions from all sources for 1970 and 1979. The methodology used is based on a data survey of the consumption of fossil fuels containing sulfur, their sulfur contents, production statistics of SO_2 emitting industrial processes and the appropriate emission factors. Total emissions for 1979 is 79.2 Tg S yr^{-1}, and from fuel combustion 64.1 Tg S yr^{1}. This inventory is not available in gridded form.

Hameed and Dignon [9] developed global inventories of anthropogenic sulfur and nitrogen emissions of SO_2 and NO_x which includes fuel combustion only and extend to 1980. The methodology used was detailed in Dignon and Hameed [10] and consists of statistical regression models based on available emissions data from the U.S. and some other member countries of the Organization of Economic Co-operation and Development (OECD), which includes Australia, Canada, Japan and western European countries. Control regulations are incorporated via the use of different statistical parameters. The data were allocated to a 5° x 5° latitude/longitude grid based on population. Global estimates are 57 Tg S yr^{1} and 20 Tg N yr^{1}. Dignon [10] upgraded this inventory to a 1^0 by 1° grid, with global emissions of 62 Tg S yr^{-1} and 22 Tg N yr^{-1}.

Levy and Moxim [12] developed an inventory of NO_x emissions on a 2.4° x 2.4° grid with three levels in the vertical. Data for this inventory were derived from values in the National Acid Precipitation Assessment Program's 1980 inventory for North America, from values in Eliassen et al. [13] for Europe and from Hameed and Dignon [9] for the rest of the world.

Spiro et al. [14] developed a global inventory of anthropogenic and biogenic sulfur emissions for 1980. Methodology used was also based on activity rates, sulfur contents of fuels and appropriate emission factors. Revised estimate of anthropogenic emissions is 88.4 Tg S yr^{-1}; emissions from fuel combustion are given as 81.7 Tg S yr^{-1}.

Two gridded inventories of anthropogenic SO_2 emissions are based on a 1° x 1° grid: Dignon [11] and Spiro et al. [14]. The Dignon inventory includes only emissions from fossil fuel combustion, while the Spiro et al. inventory includes emissions from industrial activities. Only one inventory of anthropogenic NO_x emissions is based on a 1° x 1° grid: Dignon [11]. However, at the start of our project to compile the annual inventory for GEIA the only data files available were from the Dignon work, so these were selected as the basic GEIA inventories for SO_2 and NO_x. The grid definition from these inventories was also adopted for the GEIA grid: origin at 180°W, 90°S, 1° x 1° resolution (i.e., 360 cells in the longitude direction, 180 cells in the latitude direction).

To date, the most comprehensive inventories of SO_2 and NO_x emissions for the United States and Canada has been compiled by the National Acid Precipitation Assessment Program (NAPAP, Saeger et al. [15]). Version 2 of the NAPAP base year 1985 emissions inventories were selected to replace values in the basic GEIA inventories for the U.S. and Canada. Annual values for point sources were directly allocated to the GEIA 1° x 1° grid; the NAPAP spatial allocation file, which allocated area sources to the NAPAP 20 km grid was used as the basis for the allocation of area sources to the GEIA grid. Table 2 presents an overall summary of results.

Table 2. Summary of North American Emissions in GEIA Inventory

	SO_2	NO_x
Units: 10^6 metric tons as	S	N
Basic GEIA fuel combustion emissions	62.8	21.9
NAPAP 1985 total emissions for NA	12.3	6.2
Current GEIA global emissions	62.1	21.4
Basic GEIA emissions for NA	13.0	6.7
Basic GEIA emissions for non-NA cells	49.8	15.2
NAPAP 1985 combustion emissions	9.8	5.9
NAPAP 1980 combustion emissions	11.3	6.3

The NAPAP 1985/1980 combustion emissions were obtained from the corresponding NAPAP reports (Saeger et al. [15]; Wagner et al. [16]) by adding the categories: electric utilities, industrial combustion, commercial/residential/ other combustion and transportation.

The most comprehensive inventories of European SO_2 and NO_x emissions compiled under a unified methodology have been assembled by the Co-Operative Program for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe (EMEP, Iversen et al. [17]). Values from this inventory have been selected to replace values in the basic GEIA inventories for Europe. The EMEP inventory values are available in a 150 km x 150 km polar stereographic grid; these values will be transferred to the 1° x 1° GEIA grid and will replace the corresponding values in the basic GEIA inventories.

Contact has been established with researchers in Japan, who are working to compile inventories of SO_2 and NO_x emissions for Asia. This work is expected to be based on geopolitical entities (provinces, etc.) for the larger countries, and on the country basis for smaller countries. Emissions will be apportioned to the GEIA grid based on population, using the methodologies and data files developed for the Dignon [11] work. Contact has also been established with researchers in Australia; an inventory for this area is expected in June 1992. Additional contacts have been established with researchers in Brazil; it is hoped that these and future contacts will be able to provide more accurate emissions data for their geographic areas.

DISCUSSION

One of the most important scientific tools used in the assessment of atmospheric chemistry, air quality and climatic conditions of the past, present and future is the mathematical model of transport and transformations in the atmosphere. Such models rely in part on inventories of emissions constructed on appropriate temporal and spatial scales and including the required chemical species. The production of such inventories is an area of research whose importance to the accuracy of results of modeling and assessment activities has come to be fully recognized.

The ultimate goal of the Global Emissions Inventory Activity (GEIA) of IGAC is to establish emissions inventories for all trace species of interest to the modeling community, incorporating fluxes from both anthropogenic and natural sources, with enough spatial, temporal and species resolution and of recognized accuracy to serve as standard inventories for the international community of atmospheric scientists. The current GEIA study groups (Table 1) represent a vigorous start toward that goal, but many other topics also require attention. In Table 3 we list a number of inventories that have been proposed by atmospheric modelers. We invite anyone who would like to take the lead or participate in developing any of these inventories to contact either of the authors.

Table 3. Proposed GEIA Study Groups, January 1992.

Species	Source Type	Temporal Resolution
Effects Inventories		
Ammonia	Anthropogenic	S
Carbon Monoxide	Anthropogenic	S
Methane	Anthro + Natural	S
Organochlorines	Anthropogenic	A
Reactive Chlorine	Anthro + Natural	S
Reduced Sulfur	Anthro + Natural	S

Species	Source Type	Temporal Resolution
Soot	Anthro + Natural	S
Particulate Matter	Anthro + Natural	S
Trace Metals	Anthropogenic	A
Process Inventories		
Aircraft	Anthropogenic	S
Specific Event Inventories		
Volcanoes	Natural	A
Past/Future Inventories		
Historic Carbon	Anthro + Natural	D
Historic Nitrogen	Anthropogenic	D
Historic Sulfur	Anthropogenic	D
Future Scenarios	Anthropogenic	A

S = seasonal A=annual D=decadal.

Finally, we emphasize that no amount of development of atmospheric modeling capability can produce improved assessments of atmospheric chemistry and its associated impacts unless suitable, rigorous emissions inventories are available. The development of these inventories, in close cooperation with the scientific community, is the goal of the GEIA project. We invite contributions of all interested parties throughout the world.

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REFERENCES

1. I.E. Galbally (ed), The International Global Atmospheric Chemistry Programme, ISBN 0 643 05062 0, Commission on Atmospheric Chemistry and Global Pollution of the International Association of Meteorology and Atmospheric Physics.

2. T.E. Graedel, T.S. Bates, A.F. Bouwman, D. Cunnold, J. Dignon, I. Fung, D.J. Jacob, B.K. Lamb, J.A. Logan, G. Marland, P. Middleton, J.M. Pacyna, M. Placet and C. Veldt, "A Compilation of Inventories of Emissions to the Atmosphere", (submitted for publication) (1992).

3. C.F. Cullis and M.M. Hirschler, "Atmospheric Sulfur: Natural and Man-Made Sources", Atmos. Environ. 14:1263-1278 (1980).

4. D. Möller, "Estimation of the Global Man-Made Sulphur Emission", Atmos. Environ., 18 (1):19-27 (1984).

5. J. Langner and H. Rodhe, "Anthropogenic Impact on the Global Distribution of Atmospheric Sulfate", in Proceedings of the Conference on Regional and Global Atmos. Chemistry, Beijing, China, May (1989).

6. G. Marland, R.M. Rotty and N.L. Treat, "CO_2 From Fossil Fuel Burning: Global Distribution of Emissions", Tellus 37B:243-258 (1985).

7. R.M. Rotty, "A Look at 1983 CO_2 Emissions from Fossil Fuels (with Preliminary Data for 1984)", Tellus 39B:203-208 (1987).

8. G. Várhelyi, "Continental and Global Sulfur Budgets - I. Anthropogenic SO_2 Emissions", Atmos. Environ., 19:1029-1040 (1985).

9. S. Hameed and J. Dignon, "Changes in the Geographical Distribution of Global Emissions of NO_x and SO_x from Fossil-Fuel Combustion Between 1966 and 1980", Atmos. Environ., 22:441-449 (1988).

10. J. Dignon and S. Hameed, "Global Emissions of Nitrogen and Sulfur Oxides from 1860 to 1980", J. Air Pollut. Control Assoc., 39:180-186 (1985).

11. J. Dignon, "NO_x and SO_x Emissions from Fossil Fuels: A Global Distribution, Atmos. Environ. 26A:1157-1163 (1992).

12. H. Levy II and W.J. Moxim, "Simulated Global Distribution and Deposition of Reactive Nitrogen Emitted by Fossil Fuel Combustion", Tellus, 41B:256-271 (1989).

13. A. Eliassen, O. Hov, T. Iversen, J. Saltbones and D. Simpson, Estimates of Airborne Transboundary Transport of Sulfur and Nitrogen over Europe, The Norwegian Meteorological Institute Meteorological Systhesizing Centre West of EMEP, Oslo, Norway (1988).

14. P.A. Spiro, D.J. Jacob and J.A. Logan, "Global Inventory of Sulfur Emissions with a 1°x1° Resolution", J. Geophys. Res. (in press) (1992).

15. M. Saeger, J. Langstaff, R. Walters, L. Modica, D. Zimmerman, D. Fratt, D. Dulleba, R. Ryan, J. Demmy, W. Tax, D. Sprague, D. Mudgett and A.S. Werner, The 1985 NAPAP Emissions Inventory (Version 2): Development of the Annual Data and Modelers' Tapes, EPA-600/7-89-012a, U.S. Environmental Protection Agency, Washington, D.C (1989).

16. J.K. Wagner, R.A. Walters, L.J. Maiocco, and D.R. Neal, Development of the 1980 NAPAP Emissions Inventory, EPA-600/7-86-057a. U.S. Environmental Protection Agency, Washington, D.C.

17. T. Iversen, N.E. Halvorsen, S. Mylona and H. Sandnes, Calculated Budgets for Airborne Acidifying Components in Europe, 1985, 1987, 1988, 1989 and 1990, EMEP/MSC-W Report 1/91, Meteorological Synthesizing Centre - West, The Norwegian Meteorological Institute, Oslo, Norway.

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