Arctic Atmospheric Research:

Pollution and Climate

Seminar & Workshop
Roskilde, Denmark
March 16-18, 1995

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Contents

Preface

A Seminar and Workshop on the interaction between Climate and Pollution in the Arctic Atmosphere was organised by the National Environmental Research Institute in cooperation with the Meteorological Department of the Geophysical Institute at the University of Copenhagen.

The general purpose was to bring Arctic atmospheric researchers in Eastern and Western Europe together for discussions on current and future work in a global change context, and to use the opportunity to consider ongoing projects in a wider perspective. The particular purpose was for the participants to explore the possibilities for international cooperation, information exchange and coordination in the field of Arctic air pollution and its climatic couplings under the heading:

Establishment of an ENRICH Network on Environment and Climatic Implications of Atmospheric Transport and Transformation of Airborne Pollutants from Euro-Asia to the Arctic.

The meeting was supported by the European Commisssion under the contract ENRICH 17/94 and the Danish Natural Science Research Council under grant no. 9500995.

Summary

A concerted Action

The outcome of the workshop and the plenary discussions was a joint decision among the participants to establish a network for cooperation based on a *Concerted Action on Climate and Pollution of the Arctic Atmosphere (CAPAC).* The rationale for this decision and the overall goals of CAPAC were summarized as follows:

Climate couplings

The Arctic is one of the last pristine regions on Earth. However this highly vulnerable area is recurrently burdened with significant air pollution originating mainly from anthropogenic activities in Western and Central Europe and Russia. Such perturbations of the naturally clean polar atmosphere may not only have widespread environmental consequences, the Arctic climate may also be affected. Since the region occupies an essential position in the atmospheric circulation system that dominates the Northern Hemisphere and in the chemical, radiative, and heat balance systems *there is a strong coupling between the Arctic and the global climate.*

Policy and Science

Therefore even small pollution induced changes in the Arctic may have global impacts. It is of importance to all nations in the Euro-Asian region that these problems be addressed and if possible redressed. These aspects are important to the formulation and implementation of a common European policy on curbing air pollution and its effects and should be included when setting goals for emission reductions for pollutants and greenhouse gases in both the western and eastern part of the continent.

Similarly it is of great interest to both the climatological and the environmental science communities to obtain a better understanding of the hemispheric-scale processes of northern contamination and to improve the ability to determine the horizontal transport of energy and aerosols and gases into the Arctic area.

The recent changes in the geopolitical scene are important in this context since they have opened new possibilities for including large and hitherto inaccessible parts of the Euro-Asian Arctic in cooperative scientific investigations and for cooperation with numerous and resourceful Russian experts. This unique opportu-nity should be seized now and its utilization given a high priority.

CAPAC

In recognition of these perspectives research institutions in Denmark, Finland, Germany, Norway, Belgium, France, Russia, Poland and Czech Republic propose to set up the concerted action CAPAC in order to improve cooperation and coordination in the fields of climate research and Arctic air pollution. It is important that this network includes both the Arctic receptor countries and the source countries of Western, Central, and Eastern Europe but it should also be open to other interested and relevant parties.

CAPAC objectives

The overall long-term objective of CAPAC is to strengthen the knowledge basis for a European policy on large scale impacts of air pollution.
Within the theme of Couplings between Climate and Pollution of the Arctic Atmosphere the objectives of the concerted action CAPAC are:

- *to establish an international forum for coordination of current and future work in the perspective of global change*
- *to set up a network as a vehicle for international cooperation, information and data exchange*
- *to optimize the use of existing logistics and resources*
- *to improve the understanding of the processes involved and the capabilities to model and predict Arctic atmospheric pollution and climate effects*
- *to assess the sensitivity of the Arctic climate to the Euro-Asian emissions and the long-range atmospheric transport.*

Cooperation

CAPAC will be based on further development of ongoing research activities. The common goal is to use the information obtained on modelling, prediction, and evaluation of climate impacts and Arctic air pollution for mutual benefit to the climatological and environmental science communities and to the European Union.

1 Seminar and Workshop

Time and Place

The Seminar and Workshop on "Arctic Atmospheric Research: Pollution and Climate"' was held in Jyllinge near Roskilde in Denmark 16. - 18. March 1995. It was attended by 27 participants from seven countries: Finland, Germany, Norway, Czechia, Russia, Poland, and the host country Denmark and a representative of the European Commission. The list of participants is given in Appendix 1.

Organisation

The meeting was organized in two parts with a three-fold set of objectives:

1. A one-day Seminar where a number of participants presented ongoing work at their home institution. The objective was to give everybody present an impression of *the knowledge and expertise represented at the meeting.*

2. A subsequent one-and-a half-day workshop with two objectives:

    a. To explore on the basis of the information given at the Seminar the possibilities for *setting up a network* among the participating institutions to further international cooperation on Arctic Atmospheric Research and the couplings between climate and pollution.

    b. To explore on this additional basis the possibilities for *defining and formulating a joint coordinated research project* that can obtain funding from national and international financial sources.

The reports and recommendations from the working groups established during the workshop were discussed at plenary sessions and formed the basis for the conclusions and actions summarized in this report.

Seminar

A total of 24 papers on current work at the participating institutions were presented at the Seminar. The programme of the seminar is given in Appendix 2.

The topics discussed ranged over the whole spectrum of large-scale air pollution problems and associated climate issues, ranging from emission measurements and mapping over ground based as well as airborne field measurements to studies and modelling of both climate, chemical and transport processes and parameters on hemispheric to global scales.

In addition a video with animated model results obtained by the danish hemispheric model was presented, showing circumpolar atmospheric sulphur concentrations in time steps of 3 hours from an 8 month period.

In the final overview of the seminar it was concluded that the presentations of ongoing national work given at the seminar of the meeting by the participating institutions had revealed that an extensive basis for future cooperation exists. It was further emphasized that a long range of problems need to be addressed, and that it would seem beneficial to all if that could be effected in an international context involving both the environmental and climatological science communities. If available the complete texts are contained in Appendix 3.

Workshop

The main topic for the subsequent workshop was therefore a closer exploration of the possibilities for future cooperation.
The workshop objectives were

- to consider the possibility for establishing a network of researchers and institutions interested in the global change aspects of the couplings between arctic air pollution and climate;
- to identify research priorities and areas suitable for future network cooperation
- to explore the possibilities for formulating a research project which can improve understanding, data analysis, and prediction capabilities in this area;
- to prepare a report summarizing the deliberations.

Specific working groups were set up to tackle one or more of the tasks described. In that context the working groups were asked to consider an appropriate selection of the following issues:

- transport dynamics in the atmosphere;
- chemical reactions in the atmosphere;
- pollution source inventories;
- pollution sinks and deposition;
- atmospheric modelling and prediction spanning short term through climate scales;
- existing data series, overview and suitability for joint exploitation and analyses (time series and trend);
- technological opportunities;

In addition the working groups were asked to take into account the information, discussions, and conclusions reached during the seminar.

The discussions in the working groups and at the plenary sessions confirmed the seminar conclusion that current projects and expertise cover such a broad range of relevant aspects that international cooperation and coordination based on ongoing national work should be initiated in some form.

Workshop decision

It was however also felt that it would be premature to launch a joint cooperative project and that the need rather was to continue common explorations on the theme of Couplings between Climate and Pollution of the Arctic Atmosphere in order to improve the understanding of the processes involved and to assess the sensitivity of the Arctic climate to the Euro-Asian emissions and the long-range atmospheric pollution transport.

It was therefore decided that future cooperation should be based on the concept of a '*Concerted Action on Climate and Pollution of the Arctic Atmosphere*' and that a proposal for this *CAPAC* should be submitted for funding by the Programme on Climate and Environment within EU's 4th framework programme 1995 - 1998.

If funded CAPAC will be coordinated by :

1. *The National Environmental Research Institute, Denmark* assisted by the four formal partners
2. *Finnish Meteorological Institute, Finland*
3. *Max Planck Institute for Meteorology, Germany*
4. *Environmental Protection Institute, Poland*
5. *Meteorological Synthesizing Centre - East, Russia.*

The description of CAPAC is contained as a separate chapter in this report. The themes, objectives and research activities, the budget, and the CAPAC Partners and Participants are annexed to this chapter.

Additional information

During (and shortly after) the meeting some additional information of interest to the participants was presented. This material, including reprints of papers on display (front pages only), is contained in Appendix 4. The full text of papers on display is available upon request.

2 CAPAC description

This chapter and its 3 annexes contains the full text of the project description forwarded with the application to EU´s 4th framework programme.

Concerted Action on Climate and Pollution of the Arctic Atmosphere (CAPAC)

Introduction
The Arctic, encompassing the central polar area of the high Arctic and the adjoining tundra plains and boreal forests, is one of the last pristine regions on Earth. It is however also very vulnerable to pollution and climate change since the harsh conditions exert a continuous stress on all ecological systems. Over the last 15 years investigations in the European, Russian, American, and Canadian Arctic have shown that even in this remote area the atmosphere is recurrently burdened with a significant pollution load of distant anthropogenic origin. In winter the major part of the pollution, known as Arctic haze, apparently originates from industrial and other anthropogenic activities in the Euro-Asian region, including in particular central Europe, northern Russia and the Ural region.

Such perturbations of the naturally clean polar atmosphere may not only have widespread environmental consequences, the Arctic climate may also be affected. Since the region occupies an essential position in the atmospheric circulation system that dominates the Northern Hemisphere and in the chemical, radiative, and heat balance systems *there is a strong coupling between the Arctic and the Global climate.* Therefore even small pollution induced changes in the Arctic, *e.g.* cloud patterns, methane emissions from the tundras or deep water formation, may have global impacts.

These perspectives are important to the formulation and implementation of a common European policy on combatting air pollution and its effects. It is necessary to quantify the European contribution to Arctic air pollution in order to include this aspect when setting up realistic goals and time schedules for emisson reductions for pollutants and greenhouse gases in both the western and eastern part of the continent.

Climate and Arctic air pollution
The climate of the Arctic is characterized by the prolonged light and dark periods where the extreme cold produces a very pronounced stratification of the lower atmosphere. Under these circumstances the break-down and turn-over processes of pollutants in the environment are much slower than in more temperate zones. Some pollutants such as persistent toxic organics even seem to accumulate in the Arctic environment. Conditions in the Arctic atmosphere are therefore unique and cannot be extrapolated from results from investigations at lower latitudes.

The Arctic climate is determined by a balance between the net loss of energy through radiation and the gain by convergence of the atmospheric and oceanic energy transport. The dynamics of the atmospheric flow is highly non-linear and show strong fluctuations on a broad spectrum of scales. It is thought to be responsible for a large portion of the variability within the Arctic area. It is not yet known what the driving forces are for these fluctuations.

The climate of the Arctic is to a large extent controlled by conditions in a very shallow boundary layer where *e. g.* temperature in the lower few hundred meters rises dramatically from very low surface values through tens of degrees. These conditions also govern the atmospheric transport along and to the surface. The position of this layer is critically close to the border of Arctic snow and ice and small changes may have large effects. The Arctic climate is therefore believed to be considerably more sensitive to disturbances than at lower latitudes.

It is observed that both climate and pollution parameters fluctuate on time scales spanning short term (days - weeks) through climate scales indicating that the pollution regularly afflicting the Arctic atmosphere can be responsible for changes in the climate of the region. Changes of the albedo or aerosol induced modifications of the radiation balance or of the precipitation patterns in the Arctic could as previously pointed out precipitate global changes.

Due to the severity of the climate conditions and the late realization of its economic, strategic and ecological importance the Arctic region is characterized by a scarcity of observing platforms or stations. Thus, the basic meteorological, oceanographical and air composition observational series of the region have large gaps and often only cover short periods. Consequently the knowledge of important climate or environmental processes in the Arctic is equally scarce.

It is therefore of great interest and importance to both the climatological and the environmental science communities to obtain a better understanding of the hemispheric-scale processes of northern contamination and to improve the ability to determine the horizontal transport of energy and aerosols and gases into the Arctic area.

International cooperation

It is of similar interest and importance to all nations in the Euro-Asian region that these problems be addressed and if possible redressed. This can only be achieved in an international cooperation where the basis is also an internationally coordinated effort to uncover the problems, their extent and implications. Such a common effort will therefore contribute to a strengthening of the European policy in the field of transboundary air pollution and its large scale detrimental effects.

Arctic activities have so far had a strong national weight and have with a few exceptions been carried out within limited areas. Only rarely has such work been based on bilateral or international cooperation. There is hence an urgent need to improve coordination among the local and regional efforts in order to achieve a better and more complete understanding of the environmental situation in the Arctic.

Some Arctic activities have however recently been launched within the International Global Atmospheric Chemistry (IGAC) core project of the International Geosphere and Biosphere Program (IGBP). A number of research projects on Polar Atmospheric and Snow Chemistry (PASC) have been started under the IGAC umbrella in a number of countries, mainly in the western hemisphere.

In additon the eight countries bordering on the Arctic have adopted an Arctic Environmental Protection Strategy. A cornerstone of this initiative is the implementation of AMAP, the Arctic Monitoring and Assessment Programme. The major aim of AMAP is to monitor the levels of anthropogenic contaminants in all major compartments of the Arctic environment and assess the environmental conditions in the area.

However for most of the national and international activities carried out in the Arctic the source-receptor aspects are not suffiently coordinated. Thus AMAP is an activity comprising all receptor countries in the Arctic but countries that contribute to the Arctic air pollution load from outside the Arctic area are not included. Similarly Arctic researchers and institutions do not in a systematic or comprehensive way represent both receptor and source countries.

Finally a large part of the Euro-Asian Arctic has for a long period been closed to cooperative scientific investigations due to the bipolarity of the political world. The recent changes in the geopolitical scene have opened the possibility for including wide Arctic regions in international investigations and for establishing renewed cooperation with numerous and ressourceful Russian experts. This unique opportunity should be seized now and its utilization given a high priority.

It is therefore proposed to set up a concerted action in order to improve cooperation and coordination between research institutions concerned with climate research and with Arctic air pollution. It is important that this network includes both the Arctic receptor countries and the source countries of Western, Central, and Eastern Europe but it should also be open to other interested and relevant parties.

General objective for the concerted action.

The possibilities for setting up an international network for cooperation and coordination of projects concerned with Arctic air pollution and its climatic couplings were explored at a recent meeting held in Denmark in March 1995 between representatives of Western and Eastern European institutions and sponsored by the ENRICH office of the European Commission.

The presentations of ongoing national work given at the seminar of the meeting by the participating institutions and the discussions at the subsequent workshop revealed that an extensive basis for future cooperation exists. Current projects and expertise cover such a broad range of relevant aspects that it was decided to initiate a cooperation based on ongoing national work and on the concept of a '*Concerted action*'.

The overall long-term objective of **CAPAC** *is to strengthen the knowledge basis for a European policy on large scale impacts of air pollution.*

Within the theme of Couplings between Climate and Pollution of the Arctic Atmosphere the objectives of the concerted action **CAPAC** *are*

- *to establish an international forum for coordination of current and future work in the perspective of global change*
- *to set up a network as a vehicle for international cooperation, information and data exchange*
- *to optimize the use of existing logistics and ressources*
- *to improve the understanding of the processes involved and the capabilities to model and predict Arctic atmospheric pollution and climate effects.*
- *to assess the sensitivity of the Arctic climate to the Euro-Asian emissions and the long-range atmospheric pollution transport*

With a focus on the relations between climate and Arctic air pollution the concerted action of **CAPAC** will address a field not covered specifically in other related international programs, notably AMAP, ACSYS, and the Arctic activities of IGAC. These programmes are dedicated to monitoring and assessment of the Arctic environment, studies of the role of oceanic currents and ice cover and of atmospheric chemistry. However the results and progress obtained in these programmes will be of great benefit to **CAPAC** - and *vice versa.*

CAPAC will focus on a number of themes each with its own set of objectives and research acitivities. The objectives are in the main to be seen as long term goals on which work can be started in a cooperative way by means of this concerted action. The common goal for the research activities is to use the information obtained on modelling, prediction, and evaluation of climate impacts and Arctic air pollution for mutual benefit to the climatologal and environmental science communities and to the European Union.

The concerted action **CAPAC**, agreed upon among research institutions in *Denmark, Finland, Germany, Norway, Belgium, France, Russia, Poland and Czech Republic* will be coordinated by the National Environmental Research Institute of Denmark assisted by partner institutions in Finland, Germany, Russia and Poland.

The international **CAPAC** coordination in these fields will take place through regular meetings among the parties, preferably twice a year.

The institutions participating in **CAPAC** all have proven records of excellence in their field of expertise, ranging from emission measurements and mapping over ground based as well as airborne field measurements to studies and modelling of both climate, chemical and transport processes and parameters on hemispheric to global scales.

A list of the participating institutions and contact persons is given in the enclosure.

Concluding remarks

The Concerted Action, CAPAC, will take place within the frame of the ENRICH initiative and, as mentioned above, the first meeting between the "core institutes" has been performed through funds made available by the ENRICH office. The continuation of this successful contact is intended as a contribution to the formulation and implementation of a common European policy on long range air pollution and its large scale effects and it will simultaneously add value to existing international programmes. The con-certed action **CAPAC** is foreseen as a joint effort by the Environment and Climate Programme under Activity I and the relevant programme part of Activity II under the 4'th Framework Programme.

CAPAC Annexes

Annex 1

The themes, objectives and research activities of CAPAC

Atmospheric Circulation and Climatic Implications

Objectives

- To study the climate and its basic dynamics on different time scales through analysis of time series obtained from ice cores.
- To study the chaotic regimes of climate change.
- To develop new statistical methods for validating climate models.
- To evaluate atmospheric models and their ability to simulate the transport of different tracers like dust, water isotopes and pollutants to the Arctic area in general and to the Greenland icecap in particular.
- To understand the observed variability of tracers in the ice cores representing the last decades.

Research Activities

- Climate data analysis, in particular ice core data.
- Modelling transport of tracers to the Arctic area and to the Greenland Ice sheet.

Emissions

Objectives

- Improved inventories of anthopogenic and natural emissions and validation by in situ measurements to allow establishment of better model simulations for the whole Arctic.
- Trend analysis of emissions necessary to put a perspective on the trends of ambient concentrations.

Research Activities

- Preparation and improvement of circumpolar emission inventories for dust, sulphur compounds, nitrogen compounds, heavy metals, and POPs in source regions (countries) contributing to the Arctic atmospheric load.
- Validation of emissions.
- Estimating emissions for the period 1965-1995, Emission projections towards 2005.
- Identification and influence of major point sources.
- Sources and sinks of greenhouse gases in the Arctic.

Assessment of Arctic Air Pollution

Objectives

- To obtain for the first time an overview of ambient concentrations in the Scandinavian and Russian Arctic and their seasonal variations.
- Identification of major source types and regions by using correlations among pollutants in receptor modelling.
- To determine the variability of the Arctic air pollution burden in a climatic context.
- To identify gaps in Arctic monitoring coverage and to recommend or establish supplementary measurements programmes.

- To use the total information contained in pooled sets of data for evaluation of trends over the last two-three decades on a statistically sound basis.

Research Activities

- Overview of seasonal and regional variations of Arctic air pollution from pooled monitoring data; receptor modelling.
- Trend analysis of pooled Arctic field data on sulphur, nitrogen compounds and heavy metals.

Arctic Air Chemistry

Objectives

- To identify and understand important physical and chemical processes under the particular Arctic circumstances of prolonged dark and light periods by field measurements and modelling.
- To improve the chemical process schemes for proper simulation by numerical models.

Research Activities

- Seasonality of important processes by field measurements.
- Refinement of chemical schemes in transport models.
- Combined ground based and airborne studies of ozone and chemically related species in the Arctic troposphere and their hemispheric interactions.
- Stratospheric ozone depletion in the Arctic and possible climate impacts.
- High altitude airborne studies over Scandinavia and Siberia of the chemistry of Polar Stratospheric Clouds with *e. g.* Russian turbofan aircraft.

Transport Modelling

Objectives

- To identify major source regions and pathways on a seasonal and regional basis.
- To quantify source contributions and validate emissions for various atmospheric pollutants.
- To obtain reliable deposition fields for the Arctic.
- To evaluate the budgets of air pollutants in the Arctic.

Research Activities

- Analysis of meteorological processes responsible for pollution import/export to and from the Arctic.
- Identification of major pathways for individual sectors of the Arctic.
- Refinement of deposition process descriptions in transport models.
- Improvement of spatial resolutions and nesting of models on various scales.

Annex 2

CAPAC Budget

Meetings	ECU Meeting	Annual	Total 1996-1998
Travels			
European flights at 700 ECU; 20 persons	14000	28000	84000
Accomodation			
Hotel & per diem at 150 EU; 20 p., 3 days	9000	18000	54000
Miscellaneous meeting costs			
Meeting facilities, local transport	2000	4000	12000
Total meetings	**25000**	**50000**	**150000**
Other costs			
Computer assistance, publications		15000	45000
Coordination			
NERI, DK: 0.15 man-years/year		7715	23150
NERI overhead 116 %		8950	26850
TOTAL		**81665**	**245000**

Annex 3

List of CAPAC participants

Network on Environment and Climatic Implications of Atmospheric Transport and Transformation of Airborne Components from Euro-Asia to Arctic

(Italics: Not participating in the ENRICH-meeting)

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Long range models, emissions

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Field: Mesoscale (& LRTAP) models

List of seminar participants

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Programme

A. SEMINAR **Thursday 16. March**

Welcome and Introduction

N.Z. Heidam:	Purpose and practicalities; Pollution Aspects.
A. Walløe Hansen:	Climate Aspects; ENRICH
F. Eybergen, EU:	ENRICH.

Presentations (20 min).

Finland

S. Joffre:	Presentation of FMI activities
E. Häsänen:	Elemental analysis of emissions and atmospheric aerosols
H. Ronde:	Emission measurements

Poland

A. Mazur:	Heavy metals in Poland - Emission inventory and regional model for atmospheric transport
M. Markiewicz:	Information on research work at the Meteorological and Air Pollution Department, Techn. University of Warsaw
M. Kachniarz:	Presentation of Activties at the Air Protection Div.

Germany

G. Hoffmann:	Isotototopic watertracers as indicators for atmospheric circulation in the arctic region.

Denmark

A. Rasmussen: DMI's research activities in the Arctic

A. Walløe Hansen: Global circulation models

K. Andersen: Desert dust in the Arctic atmosphere

P. Ditlevsen: Time series analysis of paleoclimatic data

Russia

S. Dutchak: Atmospheric modelling

A. Vinogradova: Element composition of atmospheric aerosols and long range transport of pollutants to the Russian Arctic

Denmark

N. Z. Heidam: Overview of danish activities in Greenland, gas and aerosol measurements

P. Wåhlin: Aerosol measurements in Greenland
J. Christensen: Transport of sulfur to the Arctic - & Video

G. Geernaert: Summary of Seminar: Overview of main issues

Appoint workshop organisation committee (OC) 3-6 persons

Evening Session (Organisation Committee):

OC: Organisation of Workshop.
Specify network working groups (WG) & tasks:
e.g.: Cooperation, Information exchange,
Coordination, Integration of pollution and climate aspects

Friday 17. March

Norway

F. Stordal:NILU's arctic atmospheric research -pollution and climate

B. WORKSHOP **Friday 17 & Saturday 18 March** (See this report)

Papers presented

F. Eybergen, EU:	Information on ENRICH and EU´s 4th framework programme
S. Joffre, Finland:	Arctic Research and Monitoring Activities at the Finnish Meteorological Institute
H. Ronde, Finland:	Emission Inventories and their Validation
E. Häsanen, Finland:	Elemental Analysis of Atmospheric Aerosols and Power Plant Emissions
A. Mazur, Poland:	Emission Inventory and Regional Model for the Atmospheric Transport of Heavy Metals over Poland
M. Markiewicz, Poland:	Mathematical Modelling of the Transport and Dispersion of Pollution in the Atmosphere
M. Kachniarz, Poland:	Atmosphere and Climate Protection in Poland
A. Walløe Hansen, Denmark:	Climate Research and Matematical Modelling at Copenhagen University
S. Dutchak, Russia:	Modelling Experience of the Arctic Pollution with Sulphur and Nitrogen Compounds, Heavy Metals from Sources of the Northern Hemisphere
A. Ryaboshapko, Russia:	Investigations carried out by Institutions of Russian Federal Service for Hydrometeorology and Environmental Monitoring (Hydromet)
Y. Tsaturov, Russia:	Characteristics of the Studies of Contamination levels in the Atmosphere of the Russian Arctic
N.Z. Heidam, Denmark:	Arctic Air Pollution Studies in Greenland
P. Wåhlin, Denmark:	One years continuous Aerosol Sampling at Summit in Central Greenland
J. Christensen, Denmark:	Danish Eulerian Hemispheric Model
F. Stordal, Denmark:	NILU´s Arctic Atmospheric research - Pollution and Climate

Seminar and Workshop on Arctic Atmospheric Research: Pollution and Climate

Presentation by Fred Eybergen
ENRICH Office, EC-DG-XII/JRC, Brussels
16 March 1995
Jyllinge, Denmark

Overview of the talk:

- *ENRICH:*

- rationale
- objectives
- structure and operation
- actions to stimulate networking
- networking principles

- *Workshop and Seminar:*

- relevant EC-instruments
- recommendations

ENRICH

EUROPEAN NETWORK FOR RESEARCH IN GLOBAL CHANGE

Fred Eybergen

Jyllinge, 16 March

ENRICH

Major Objectives

1. Promotion of a pan-European contribution to the international global change research programmes.

2. Fostering of collaboration between EU/EFTA, CEE/CIS, Africa and other developing countries .

3. Promotion of the establishment of networks (regional and thematic focus).

4. Improvement of access by the scientific community to EU mechanisms for global change research.

ENRICH

Structure and Operation

- **ENRICH Council (chair Dr. W. Menden (D/BMFT)):**

  - high level experts from EU/EFTA;
  - provides guidelines and advice;
  - information channel of national and european activities;

- **ENRICH Office:**

  located at EC-DG XII/JRC; (Head: Dr. A. Ghazi, Visiting Officer: Mr. F.Eybergen) daily functions, overall coordination

- **ENRICH Liaison Offices:**

  Liaison Officers appointed in:

  - Accra, Ghana (Dr. E. Odada)
  - Moscow, Russia (Prof. G. Golubev)
  - Prague, Czech Republic (Prof. I. Nemesova)

- **Interservices Group (ISG):**

  - information channel to and from policy makers
  - joint EC action on global change
  - representation: DGI, DGVIII, DGXI, DGXII, DGXXII).

ENRICH

Type of Actions to stimulate Networking

- **At scientific administrators level:**

  1) ENRICH Council meetings
  2) Regional Seminars (e.g. Budapest Sept.'94)
  3) Interservices Group meetings
  4) Specific Studies
  5) Specific activities

- **At level of scientific community:**

  1) Support to thematically and/or regionally focussed workshops
  2) Special meetings of programme managers
  3) Pilot Projects (ELOISE, TERI, HDP, EIPO)
  4) Support to IGBP/WCRP/HDP, START and assessments (ECSN)
  5) "ENRICH server" on Internet, Bulletin

ENRICH

NETWORKING PRINCIPLES

Meeting the EU policy objectives:

- Promotion of SD
- Improving quality of life
- Strengthening S&T base for competitive industries
- Promote cohesion

Key principles for ENRICH actions:

- National/regional importance and global significance
- Subsidiarity and complementarity
- Synergy and added value
- Optimalisation of existing resources
- "Natural niches" (is time ripe?)
- Response to real needs (temporary action)
- Mutual benefits
- Genuine equal partnerships

RELEVANT EC-INSTRUMENTS

Activity 1

Environment and Climate Programme (1994-98)

MAST-III (1994-98)

Activity 2

Cooperation with 3rd countries and international organisations (INCO, 1994-98):

- Area A1: EUREKA and COST
- Area A2: CEEC's and NIS (ecosystems in danger)

Activity 4

Training and Mobility of Researchers (TMR, 1994-98):

- Research networks
- Access to large scale facilities
- Training through research
- Accompanying measures

Joint Research Centre

EI

IRSA

Others

PHARE (1990->, DG-I)

TACIS (1991->, DG I)

INTAS (1992->, Foundation)

Workshop and Seminar on Pollution and Climate, Jyllinge, Denmark

Recommendations to participants:

- Build upon existing expertise and international programmes (IGBP-IGAC, WCRP-SPARC, GEWEX, EUROTRAC);
- Build upon relevant FP3 projects and networks like ARCTOC, EASOE, SESAME, ESMOS/ARCTIC;
- FP4 focus on ENV&CLI subareas:

  Theme 1 (environment and global change)

    - 1.1.1. : basic processes in climate system, (task 4);
    - 1.2.1.1: stratospheric chemistry, O3 depletion;
    - 1.2.1.2: tropospheric physics and chemistry (early warning signals)
- Consider possibilities of Theme 2 (environmental technologies) and Theme 3 (space techniques);
- Respond to EC strategy paper "Chemistry in the Atmosphere";
- Establish links with EIPO at Ispra;
- A stepwise approach:
    - identify existing relevant networks/initiatives;
    - identify priorities, niches;
    - subset of proposals in coordinated framework;
    - network (equal partners, mutual benefits);
- Consider to make use of the TMR (Activity IV) programme;
- Seek support through PHARE, INTAS and TACIS;
- Follow developments of Activity II (INCO);
- Inform national delegates in management committees.

Arctic Research and Monitoring Activities at the Finnish Meteorological Institute

Air Quality Research at the FMI

Long range transport of pollutants from the neighbouring countries and Central Europe has been the focus of the background air quality research in Finland during the last few years. The research has concentrated on the evaluation of the effect on the air composition and thus to the whole environment. Besides of the EGAP, ECE/EMEP, ECE/IM and national monitoring programmes the FMI has started new comprehensive monitoring and assessment activities to cover a wider range of the air chemistry and physics needed to understand the air compositon and its changes in Finland and in the whole arctic area. The measuring network of the FMI is presented in Fig. 1.

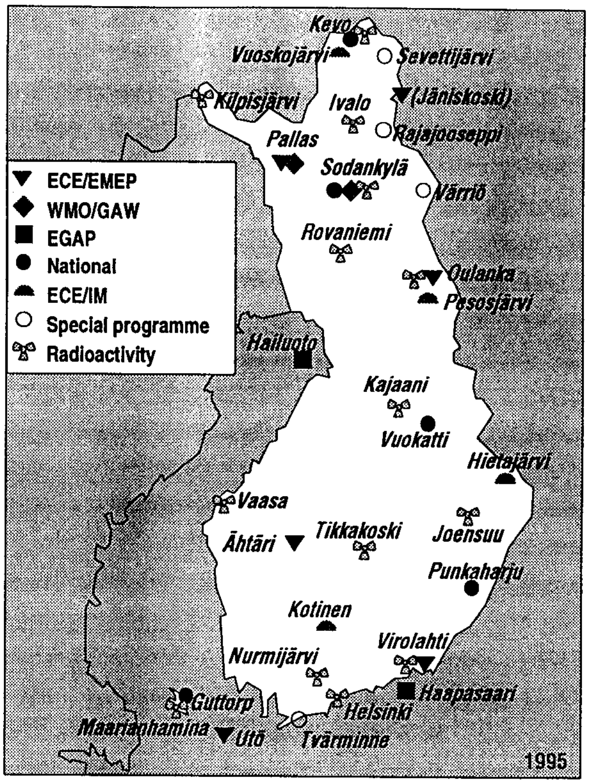
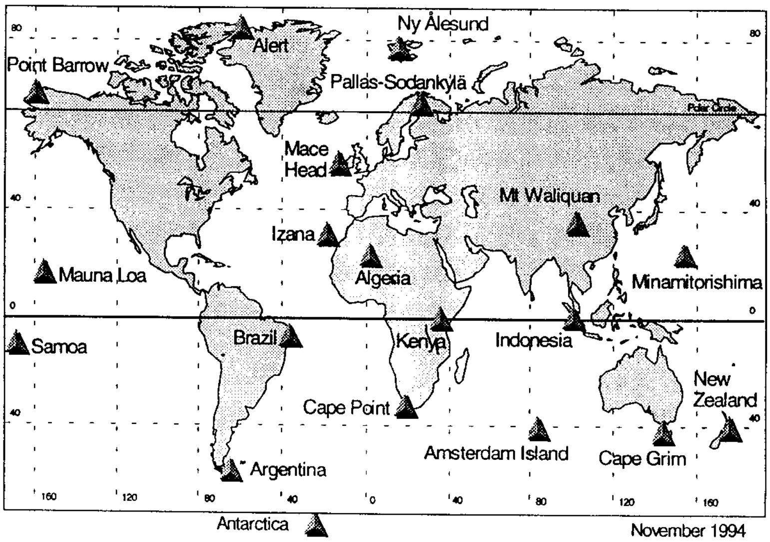


Fig. 1. Background air quality monitoring stations in Finland

WMO/GAW and AMAP

In recognition of its global responsibilities Finland has also established a new WMO/GAW station, Pallas-Sodankylä, officially recorded as a global station from the beginning of the year 1995. The station is important contribution to the monitoring and assessment of the global atmospheric baseline composition (Fig. 2). The measurements at Pallas-Sodankylä take place at two sites: upper-air soundings, synoptic measurements, total ozone observations and ozone soundings at the Sodankylä Meteorological Observatory (67°22 N, 26°39 E) and tropospheric air composition and related boundary layer meteorology measurements at Pallas (67°58 N, 24°07 E). The ongoing and planned measurements in Pallas-Sodankylä are presented in Table 1.

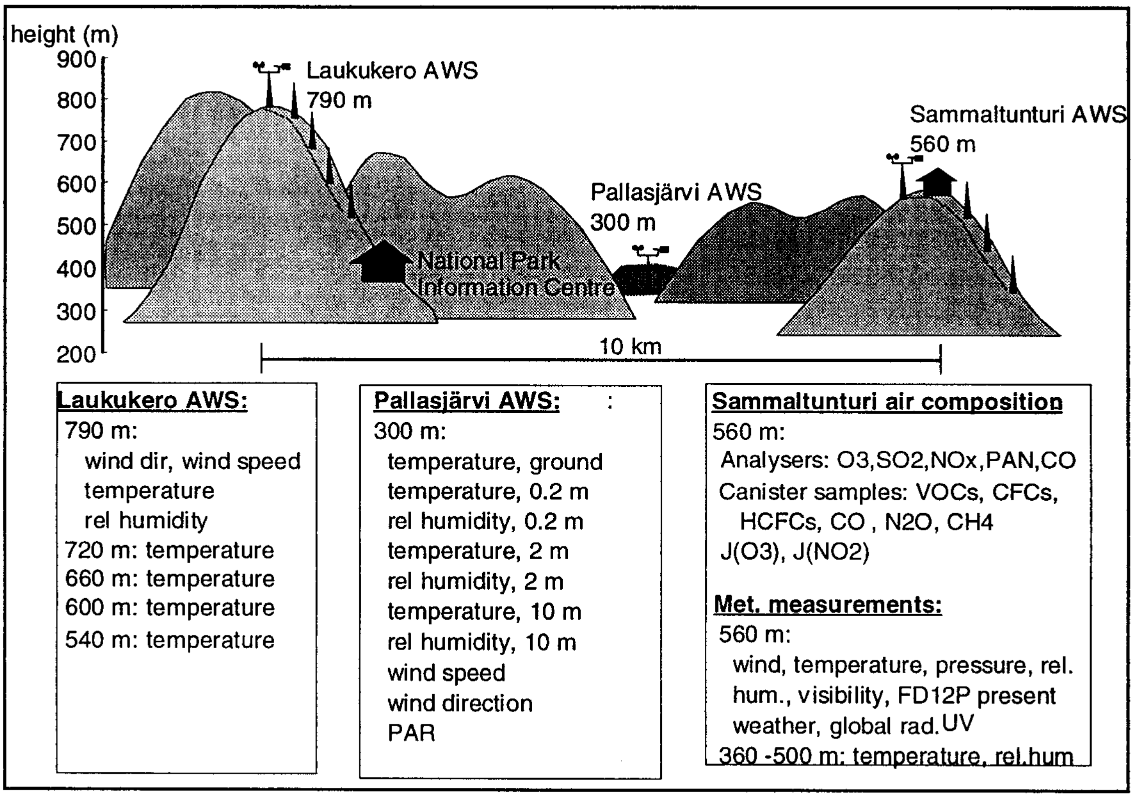


November 1994

Fig. 2. WMO/GAW global stations

In 1991, the Air Quality Department established an air quality measuring station in the Pallas-Ounastunturi National Park, on the top of an arctic mountain at the height of 560 m a.s.l. The station is over 150 m above the tree level, thus allowing the measurements of the air composition to be made above the surface inversion. At Pallas the height of the highest peaks is more than 500 m above the surrounding ground (Fig. 3.). This facilitates the measurements of temperature and wind profiles near the station to obtain information about the boundary layer. The meteorological measurements are made using three automatic weather stations and a weather camera.

The measurements of ozone, sulphur dioxide, nitrogen oxides and peroxyacetyl nitrate are made using automatic analysers. The measurements of volatile organic compounds (VOC), carbon dioxide, methane, and nitrous oxide are made from steel canister samples taken at the station twice a week. The air in the canisters is analysed by gas chromatography at the laboratory in Helsinki. The plans for the period 1996-1999 include also continuous *in situ* measurements of CO, CO_2, CH_4 and N_2O as well as the analysis of CFCs and HCFCs from the canister samples.



Laukukero AWS:
790 m:
wind dir, wind speed
temperature
rel humidity
720 m: temperature
660 m: temperature
600 m: temperature
540 m: temperature

Pallasjärvi AWS: :
300 m:
temperature, ground
temperature, 0.2 m
rel humidity, 0.2 m
temperature, 2 m
rel humidity, 2 m
temperature, 10 m
rel humidity, 10 m
wind speed
wind direction
PAR

Sammaltunturi air composition
560 m:
Analysers: O3,SO2,NOx,PAN,CO
Canister samples: VOCs, CFCs,
HCFCs, CO , N2O, CH4
J(O3), J(NO2)

Met. measurements:
560 m:
wind, temperature, pressure, rel. hum., visibility, FD12P present weather, global rad. UV
360 -500 m: temperature, rel.hum

sammalmv.pre/fw/pp/ 15.7.94

Fig. 3. Meteorological and air composition measurements at Pallas

The Sodankylä Meteorological Observatory has one of the longest radiosounding records (from 1949 on) and ozone sounding records (from 1988 on) in the European Arctic region. The observatory has also hosted several international Arctic ozone campaigns during recent years. For example a UV-visible SAOZ spectrophotometer has been used for the monitoring of column ozone and NO_2 from 1990 onwards, and Lidars and backscatter sondes have been used to measure stratospheric aerosol profiles in winters 1991/92 and 1994/95.

Pallas-Sodankylä is planned to become a master station in the Arctic Monitoring and Assessment Programme (AMAP). The planning of the measurements of persistent organic compounds and trace metals is going on at the FMI in cooperation with other Nordic institutes.

Table 1. Ongoing and planned measurements in Pallas-Sodankylä

	Situation in Jan 1995	Plans for 1996 - 1999
Greenhouse gases	- flask sampling (twice a week) for CO_2, CH_4 and N_2O	- continuous CO_2, CH_4 and N_2O-monitoring - analysis of CFCs and HCFCs from flask samples - *in situ* CFC measurements
Ozone, total column and vertical distribution	- Sodankylä: O_3-soundings and total column O_3 measurements	
Ozone, tropospheric	- two O_3-monitors in Pallas - O_3-monitor in Sodankylä	
Reactive gases	- Pallas: continuous SO_2, NO_x monitors. PAN analyzer. VOCs flask sampling - Sodankylä: SO_2 sampling using absorption solution method (twice a month)	- CO-monitor
Physical and chemical characteristics of atmospheric particles	- Pallas: Daily sampling of sulphate	- Sodankylä: campaign based vertical distribution of atmospheric aerosols using backscatter sondes and Lidar
Precipitation chemistry	- bulk precipitation sampling on daily basis in Pallas - monthly bulk precipitation sampling in Sodankylä	
Solar radiation	- Sodankylä: global, diffuse, reflected radiation, radiation balance and CIE-weighted UV-dose, and spectral UV-B - Pallas: global solar radiation	- Photosynthetically Active Radiation (PAR) and ultraviolet (UV-B) at Pallas
Meteorological parameters	- Pallas: three automatic MILOS500 weather stations at 300 m, 560 m and 790 m, FD12P present weather sensor and a weather camera at 560 m - Sodankylä: synoptic observations and upper-air soundings	
Radionuclides	- Sodankylä: daily ^{210}Pb	- Sodankylä: daily ^{7}Be

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Aerosol Research at the Finnish Arctic

Air Chemistry and Physics of the Aerosol System in the Lower Atmosphere
-Global Climate Change
-Arctic Research
Gases and Aerosols in the Finnish Arctic (Sevettijärvi, Lapland)
-The Station is Established in 1991
-Almost the Utmost Corner of Europe
-Most of Our Field Measurements

Projects

1. Aerosol Over the Greenland Ice Sheet
-Started 1989 (DYE 3)
-Field Measurements at Summit (Central Greenland) May-July 1995
-Part of the EU-Project (TAGGSI, Transport of Aerosol and Gases to Greenland Snow and Ice)

2. Concentrations and Chemistry of Nitric Acid, Nitrous Acid and Hydrochloric Acid in the Atmosphere
-Size Distribution Measurements for Major Inorganic Ions
-Gas Measurements by Denuder Systems
-NMR-Project

3. Natural sulfuric compounds (MSA) in the Finnish Arctic Atmosphere
-Ratio Between MSA and Non Seasalt Sulfate
-Size Distribution Measurements for MSA and Sulfates

4. Phase Transitions in the Atmosphere
-Development of a microphysical fog model, which includes detailed microphysics and uptake of various gaseous pollutants
-Chemical analysis of Fog in Finnish Arctic

5. Mathematical Modelling of Atmospheric Aerosol Phenomena

6. Development and Calibration of Aerosol Instruments for Arctic Research

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ARCTIC CLIMATE ACTIVITIES AT FMI

Climate studies are mainly focused on data analysis. There are also some activities aiming at the parametrization of specific processes. So far we have no activities involving the use of GCMs. Many activities are been done within the framework of the Finnish Climate Change programme (SILMU), that started in 1990 and is due to end at the end of this year. After that many of these activities will be shifted to the EC's 4th Framework Programme and/or IGBP. Grossly the climatological studies having by and large some involment into the Arctic or Boreal areas are the following:

- North Atlantic Climatological Dataset (NACD).
- Homogenisation of Finnish climatological data, trend studies.
- Global radiation (Spatial and temporal variation).
- Field experiments, parametrization and modelling of water exchange between surface and the atmosphere. Part of NOPEX (Northern Hemisphere Climate Processes Land-surface Experiment) and GEWEX.
- Determination of albedo from satellite observations (esp. case of snow/ice/melting)
- HIRLAM (Parametrization of snow and ice).
- Project on atmospheric circulation classification and extreme climatological events (EC)
- Project on the influence of atmospheric greenhouse gases and sulphate aerosols on climatology in Europe (EC).
- Availability of wind energy in Northern Lapland
- Stratospheric ozone and UV radiation research: Data and trend analysis, meteorological variability using measurements at Sodankylä and Jokioisten sounding stations, as well as modelling.

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- Climatology: Raino Heino
- Water exchange: Martti Heikinheimo
- Wind energy: Bengt Tammelin
- Ozone and UV- research: Esko Kyrö and Petteri Taalas

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Hidde Ronde
VTT, Finland

Emission Inventories and their Validation

Some thoughts on a possible cooperation between the VTT TACIS proposal and a proposal for the IV th EU Frameworkprogramme Environment and Climate: Emission inventories (H.Ronde,13.3.95): We are not interested in performing ambient air measurements, only in the measurement of main emission point sources; this means that our measurements can only be a partial validation for recorded/statistical data.

Origins of Arctic Tropospheric Aerosols/Surface Ozone Depletion
(Phase 1: The Kola Peninsula)

In the Arctic atmosphere the concentration of many pollutants is at least an order of magnitude greater during the late winter and early spring months than at other times of the year. The increased level of pollutants is believed to be due to the increased stability of the Arctic air mass at this time of the year, its extension to industrial sources in the south, and the scarcity of precipitation in the winter and early spring which increases the residence times of aerosols (1). During the last 15 years there has been increased interest in studying the sources of the Arctic aerosol as they pertain to its origin, composition, geochemical cycling, and effects(2).
These effects include a reduction in visibility and perturbation of the solar radiation budget as well as potential effects in the acidification and toxification of sensitive ecosystems(3).

Multicomponent analyses of air samples (or chemical signatures) for different sources have been related to corresponding signatures at receptor sites. A number of geographical locations in Asia and Europe are found to be of high potential to be the emission source areas(4,5,6,7,8,13,14).
Aircraft measurements supplemented with numerical modeling have shown that meteorological mechanisms favour near surface (up to 2.5 km)transport of air pollution from Europe and Northern Russia(17,18,19).During long-range transport, physical and chemical transformation processes distort systematically the chemical signatures of pollution sources (9).
In the case of Arctic haze we have the additional problem that the chemical composition of emissions in Russia and many other countries have not been established yet.

Recent initiatives in this respect have been the SO2,NOx and CO2 emission mapping with a resolution of 1x1 degree of East Asia(10) and the SO2,NOx,PM(particulate matter) and CO2 emission inventory for the Central European Initiative(11).
More research and international co-operation is needed, however, to obtain a complete,transparent and comparable emission inventory for major Russian source regions of Arctic pollution, particularly the Kola Peninsula (67N,35E), the Norilsk area (68N,85E) The Urals(50-60N,60-70E) and the Yakutsk region (65N,145E) (12).

Trace element compositions of aerosols in the Norwegian Arctic indicated the Kola Peninsula as a source region (7).
The enhanced levels of metals, notably Cu and Zn, and the high episodicity of the metallic factor in aerosols samples taken at sea-level in Greenland indicated the Ural region as a primary source area(13). Samples taken on the Greenland ice sheet are associated with trajectories from industrial regions of the

Western Russian Arctic (14). The latter authors indicate Ni to be a good tracer of regions of smelting in the Russian Arctic (Kola, Norilsk). Strong evidence was already presented in 1983 that the Norilsk plume could be detected in Alaskan aerosol (15). However new developments have shown the conclusion of the latter authors that Norilsk is only a minor contributor to Arctic sulphate to be incorrect: During the winter months sulphate, which is the major constituent of Arctic haze aerosols, is mostly in (and about equally divided over) two components, viz. an anthropogenic and a photochemical one, the latter of which involving gaseous precursors that can be of natural (e.g.dimethylsulphide) or of anthropogenic origin (9).
Finally the Yakutsk region -although not a major emitter (16) is interesting from a meteorological point of view due to its far eastern (and northern) location: On some occasions air pollution originating in Northern Russia may reach Alaska first and then travel further in a return flow over the Pole up to the Norwegian Arctic (12).

The main pollutant sources in Northern Russia are Copper-Nickel production facilities. Apart from being high SO2 and NOx emitters these facilities emit large quantities of trace pollutants.

The Finnish Meteorological Institute has recently -in cooperation with the Institute of Global Climatology and Ecology in Moscow- presented **an emission distribution of SO2** for the former USSR (20),using data compiled from a large number of single sources by the State Statistical Committee of the USSR (21). These estimates may be considered to be the most comprehensive existing set of former-USSR SO2 emission data, which have not been freely available before the present time. The data confirm the high SO2 emissions in the Kola Peninsula (0.6 million tonnes per year), The Urals (2 million tons per year) and the Norilsk area (2.2 million tons per year). The Yakutsk area is as mentioned above, a relatively small emitter (0.02 million tonnes per year). **Should these data be validated by actual emission measurements ?**

Furthermore an emission inventory as above could be compiled for NOx emissions, especially dark NOx emissions (i.e. emissions of the the most Northern facilities -Kola,Norilsk- during the Arctic night). The latter conditions favor the production of N2O5 (via the nitrate radical). Its reaction at that time with sea salt ,as proposed by Finlayson-Pitts et al.(22), could be an important route in the formation of particulate Bromine as well as (at the onset of arctic spring) a source of Bromine atoms (via NO2Br) that are believed to play a central role in the Arctic surface O3 depletion. **Should such NOx data be validated by actual emission measurements?**

The Norwegian Institute for Air Research has given an emission survey of a number of trace elements for the northern USSR (16), based on 1981 UN production and consumption statistics(23). **Also here an emission inventory of trace elements could be performed based on Russian data, followed by validation.**

It is also possible to differentiate between several type of sources with specific tracers or profiles of PAH's. Furthermore, it has been shown that the ratio's between some of the reactive PAH's and the total PAH concentration could be a valuable indicator of the transit time of the associated air mass between the source area and the sampling location (25).
Long-range transport of polycyclic hydrocarbons(PAH) has been

demonstrated during measurements in Norway and Sweden(24). High concentrations of PAH have been found to coincide with high concentrations of sulfate and soot. Preliminary measurements of the gaseous and particulate fraction of atmospheric PAH have been performed recently during the DGASP program on the Greenland Ice Sheet(26). The results indicate the absence of a gaseous fraction, low (heavy component) concentrations in the particulate phase, indicative of near-complete reaction allowed by long transport time.

Could an emission inventory of PAH's be performed followed by validation experiments?

VTT has ample experience with emission measurements of all mentioned pollutants of major emitters in various operational situations both in Finland as in The Baltic countries and Russian Karelia (27,28,29).

thus tentatively we could formulate:

The main objective is to assess the relative importance of anthropogenic emissions from Northern Russia on the formation of Arctic tropospheric aerosol.

Specific objectives could be as follows:

1. **To produce a Russian emission inventory of the above mentioned pollutants, based on available Russian data, with emphasis on the main emission areas in Northern Russia: Phase I:Kola Peninsula.**
2. **To validate this inventory by performing emission measurements on the main emitters in Northern Russia.**
3. **To provide insight in the various chemical signatures of these main emitters with a view on providing a more firm basis for past and future source-receptor modeling.**
4. **To provide data on dark NOx emissions in Northern Russia (Phase 1:Kola Peninsula)with a view to gain insight in primary processes that may eventually lead to springtime Arctic surface ozone depletion.**

Phase 1 could concentrate on emission areas in European Russia, viz. The Kola Peninsula. Phase 2 could subsequently deal with Norilsk and phase three with The Ural region and the Yakutsk Area.

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ELEMENTAL ANALYSIS OF ATMOSPHERIC AEROSOLS AND POWER PLANT EMISSIONS

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Direct methods for analyzing atmospheric aerosol samples or particulate phase in the stack gas emissions are instrumental neutron activation analyses (INAA), X-ray fluorescence (XRF) and proton induced X-ray emission (PIXE). In the two last mentioned ones, the matrix affects the analysis and there is a need for an aerosol filter reference material. For atomic absorption spectrophotometric methods (AAS), both flame and graphite furnace, and inductively coupled (ICP) techniques, the sample has to be brought into solution. The most commonly used method is wet ashing with different combination of acids, such as HNO_3+HCl, HNO_3+HCl+HF, HNO_3+$HClO_4$. The use of closed systems, especially with microwaves, for acid digestion has become a generally used method in the last few years. This has proven superior because of the high temperature during digestion and with no evaporative losses.

The only method, that has low enough detection limits to permit routine multielemental analysis (up to 65 elements) analysis of small (10-1000 μg) aerosol samples, is inductively coupled plasma massa spectrometry (ICP-MS). In this, most elements have detection limits of about 10 ng/l, which means in practice, when the air sample volume is 100 m^3 and the sample volume after dissolution 10 ml, atmospheric concentrations of 1 pg/m^3.

When analyzing emission samples, the sample size is the limitative factor only when using impactor samples for size distribution studies.

One of the most critical steps in the analysis process is the quantitative dissolution of the samples that are to be analyzed. When a fly ash sample has been collected from flue gases using filter sampling, a reliable analysis of the trace metal contents is possible, if the whole filter is digested. When cellulose or membrane filters are used, HNO_3-HCl mixture can be used, if the filter material is quarz, the acid mixture must contain also HF. Quarz fibre filters have been used, when the temperature in the sampling is too high for filters of other materials.

In VTT, in co-operation with the Technical University of Helsinki, the microwave digestion method has been developed for trace metal analyses of coal ash samples collected on a quarz fibre filter /1/.

The digestion (1 h) is performed in closed Teflon vessels in HNO_3(10 ml)-HF(1 ml) mixture at the digestion pressure 590 kPa (corresponds to about 170°C). The sample size in the recovery studies was 0.2-0.3 g (NIST Fly Ash 1633a). H_3BO_3 was added to the digested samples after cooling, they were diluted and analyzed for Be, Cd, Co, Cr, Cu, Mn, Ni, Pb, V and Zn by AAS (Zn by flame, the other elements by graphite furnace). The recovery percentages for the elements studied varied between 93 - 106. The method has been used when studying toxic mass flows in the coal fired power plants.

At the Finnish Meteorological Institute, in co-operation with VTT, a simple method for the dissolution of small aerosol samples has been developed /2/. The sample is dissolved at room temperature in a disposable test tube in HNO_3-HF mixture (1.5 ml + 0.5 ml). After two days the sample is diluted and the elemental concentrations are analyzed by ICP-MS. For NIST standard Coal Fly Ash 1633a the recoveries for As, B, Be, Ca, Cd, Co, Cr, Cu, Fe, Mg, Mn, Mo, Ni, Pb, Sb, Sr, Ti, Tl, U, V and Zn were over 90%. The recovery percentage for Al was 78%, for Ba 89%, for K 86%, and for Th 77%. The analysis results for real atmospheric samples were compared with results abtained by INAA for Al, Mn, Na, Ti and V. These agreed very well with each other, with correlation coefficients ranging between 0.970-0.988 for Al, Mn, Na, and V.

This test-tube method has been used in the analyses of aerosol samples collected on the backgroud areas in Finland /3,4/ and when studing emissions from oil-shale fueled power plants in Estonia in cooperation with the Technical University of Tallinn /5,6/. The results of these emission measurements have also been used in the model studies at the Finnish Meteorological Institute/7/.

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EMISSION INVENTORY AND REGIONAL MODEL FOR THE ATMOSPHERIC TRANSPORT OF HEAVY METALS OVER POLAND

Abstract

A regional model for atmospheric transport of for heavy metals: As, Cd, Pb and Zn over Polish territory is described in this paper. This model was developed in the frame of the result scientific cooperation between IMWM and IBM Bergen Environmental Sciences and Solutions Centre. It represents an Eulerian, two-dimensional approach to the transport problem. Heavy metal emissions from Polish sources were collected and compiled by authors to create an unique data base for emissions in Poland. This inventory was then used to distribute the emissions in the model grid squares. Calculated deposition maps for Poland for 1990 are presented in the paper. The model version presented here is compact and fast and can be easily implemented even on a PC. However, this version is only the first step in developing a fully three-dimensional, operational air pollution model for Poland.

Introduction.

Poland is one of the biggest emitters of various heavy metals, eg. arsenic, cadmium, lead and zinc, in Europe. This leads to enormous contamination of natural environment. Recently, many studies on this subject were launched. In 1992 a scientific cooperation between the Institute of Meteorology and Water Management in Warsaw and the IBM Bergen Environmental Sciences and Solutions Centre on the regional modelling of atmospheric transport of heavy metals was established. The research was focused on two main goals:

1. Developing two-dimensional, Eulerian model of atmospheric transport for four heavy metals.
2. Gathering and processing of available data on heavy metals emissions.

Preliminary inventory of arsenic, cadmium, lead and zinc emissions from Polish sources.

Strictly for the needs of the model the emissions inventory was created. It includes emission from: power plants (both commercial and industrial), heating power plants (both communal and industrial), steel mills and non-ferrous metals industry, cement production, chemical fertilizers production and mobile sources (traffic emissions). The basis for the data base were data prepared by governmental agencies, private enterprises (e.g. CIE 1991, 1992; OPOCZYŃSKI and ROSIŃSKA, 1992) and data measured at several power plants and factories (e.g. ZARĘBA, 1991; KONIECZYŃSKI, 1990). In several cases the emission factors prepared by Pacyna (PACYNA 1980, 1984, 1986, 1989, 1991). It should be emphasized here that so far this data base is almost unique for Poland.

Data base contents the following informations:

1. **Emission**
- annual amounts of emission of As,Cd,Pb and Zn from particular sources

2. **Emission parameters**
- height and diameter of a stack
- temperature and velocity of outflow gases

3. **Auxiliary data**
- energy production - commercial branch
  - annual amount of dust emission
  - type of furnace
- energy production - industrial branch
  - installed power
- mobile sources
  - total roads' mileage
  - traffic' intensity

Emission from the coal combustion processes was calculated for each source using one of the following formulas

$$E = CF_s \cdot (100-\eta) \qquad (1)$$

where C - metal concentration in coal (Table 1), F_s - source-dependent factor, η - effectiveness of dust collectors, or

$$E = C_p W_p \qquad (2)$$

where C_p - metal concentration in a stack dust (Table 2), W_p - dust emission factor

Table 1. Concentration of As,Cd,Pb and Zn in coal (ppm)

	Pit-coal		Brown coal	
Metal	European (averaged)	Polish (averaged)	European (averaged)	Polish (averaged)
As	-	5.9	-	32.5
Cd	0.47	1.9	0.61	0.65
Pb	4.9	27.0	4.7	6.0
Zn	35.0	125.0	28.0	46.3

Table 2. Concentration of As,Cd,Pb and Zn in stack dust (ppm)

Metal	estimated (averaged)	pit-coal (measured, averaged)	brown coal (measured, averaged)
As	75.0	55.4	21.5
Cd	24.3	6.6	11.3
Pb	300.1	213.0	175.0
Zn	435.0	537.0	355.0

Summarized emission from particular branches are shown in Table 3.

Table 3. Emissions of As, Cd, Pb and Zn in Poland in 1990.

	Number of sources		**Total emission Mg/y (included)**			
	total	**incl.**	**As**	**Cd**	**Pb**	**Zn**
Energy prod.						
- commercial power plants	69	69	54.7	17.3	188.3	271.4
- industrial .power plants	221	34	7.7 (5.2)	2.4 (1.7)	35.8 (24.2)	53.2 (36.0)
. heating power plants	5000	0	7.6 (0)	2.4 (0)	35.8 (0)	52.8 (0)
- communal heating p. plants	?	?	3.3 (0)	1.0 (0)	15.5 (0)	21.7 (0)
Non-ferrous metals production	18	18	10.5	3.7	182.5	236.5
Iron/steel production	23	14	? (0.12)	2.0 (2.4)	146.6 (115.2)	353.7 (277.6
Cement production	16	0	7.5	0.5	13.8	137.7
Fertilizers production	3	0	?	?	?	?
Others	?	0	?	?	?	?
Mobile sources					1160	
Total (included)			91.3 (70.52)	29.3 (25.1)	1778.3 (1670.2)	1127 (821.5)

Spatial distribution of emissions in model grids are presented in figures 10-13. It can be seen that distribution for three metals are similar, emissions occurs from big sources. In the case of lead - due to emissions from traffic - the spatial distribution is uniform.

Using data from the data base the effective emission height for every emission source was computed. Authors decided to use the Carson-Moses' formula

$$H_p = H + 5.32\frac{\sqrt{Q}}{u_h} \tag{3}$$

where Q - heat emission, H - stack height, u_p - wind velocity at H.

This data shall be applied to the 3-dimensional version of the model. The histograms of the effective emission height (summarized and for each metal separately) are shown in Figures 1-5.

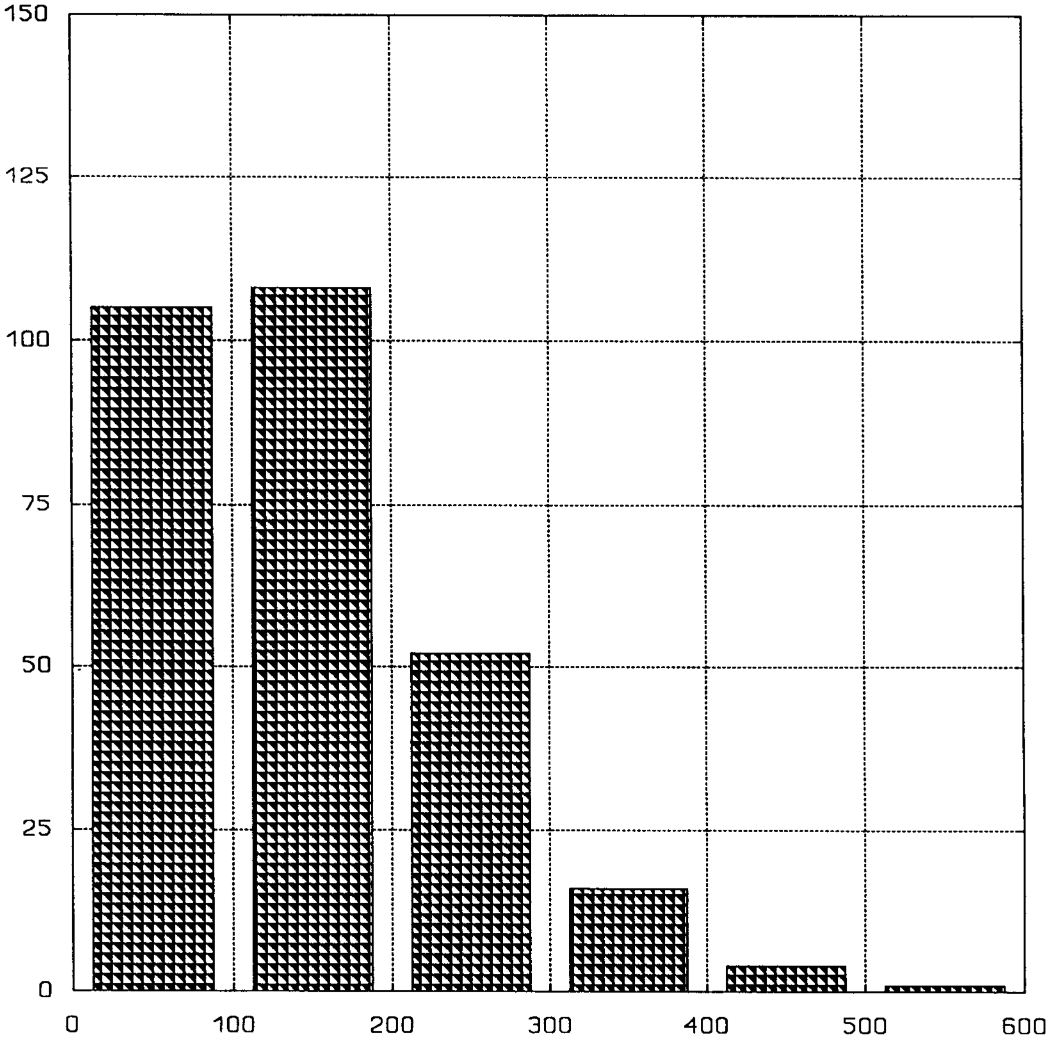

Figure 1 Histogram of effective emission heights (Polish sources, 1990)

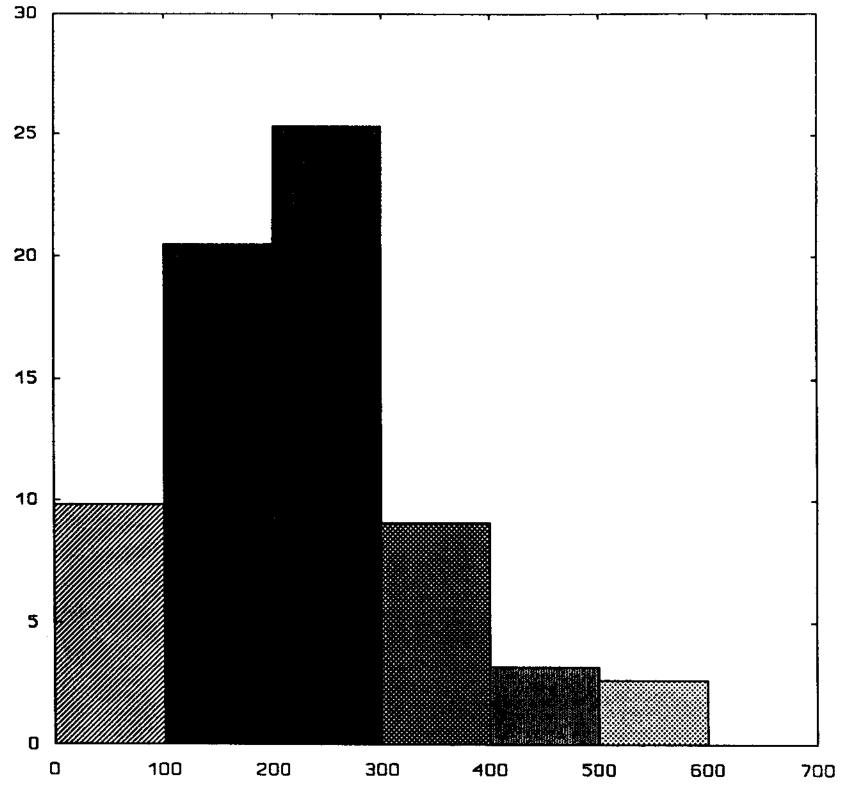

Figure 2 As - histogram of effective emission heights,Polish sources, 1990

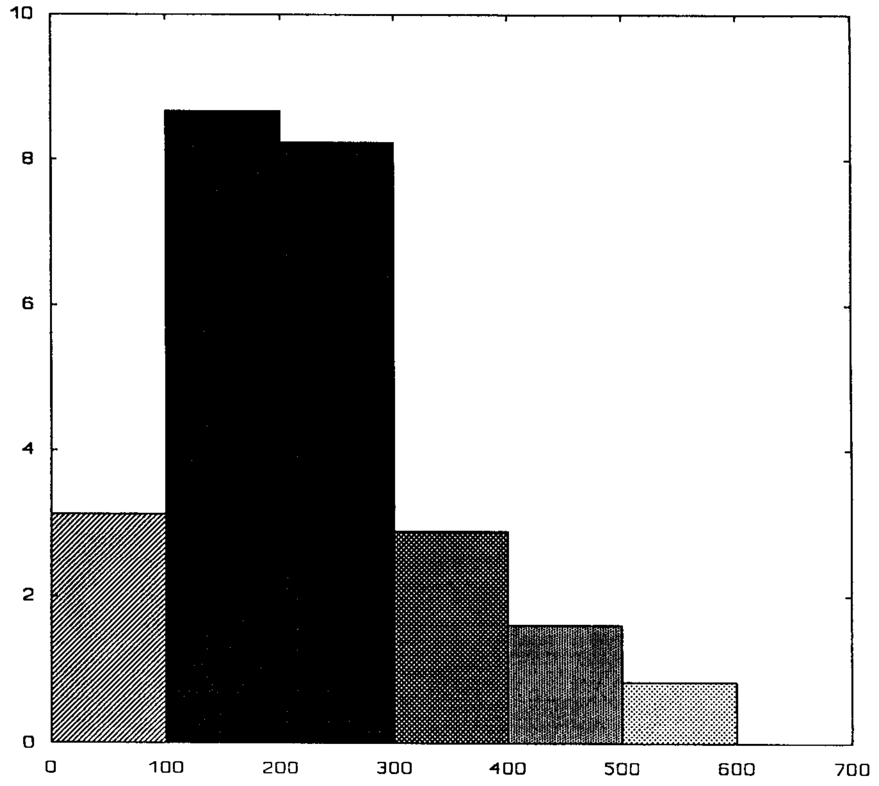

Figure 3 Cd - histogram of effective emission heights,Polish sources, 1990

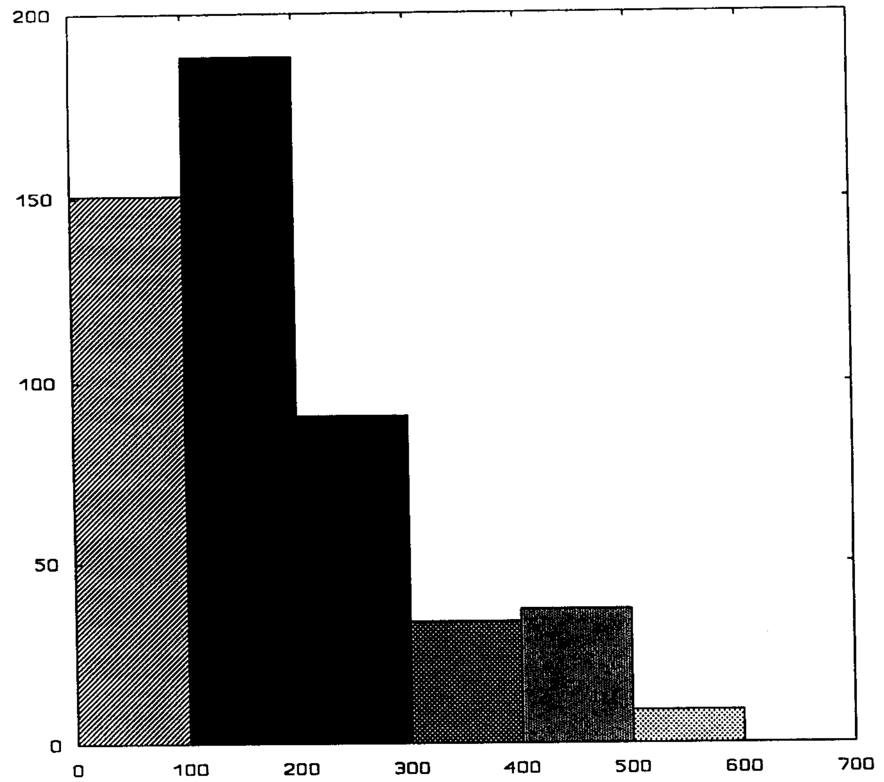

Figure 4 Pb - histogram of effective emission heights,Polish sources, 1990

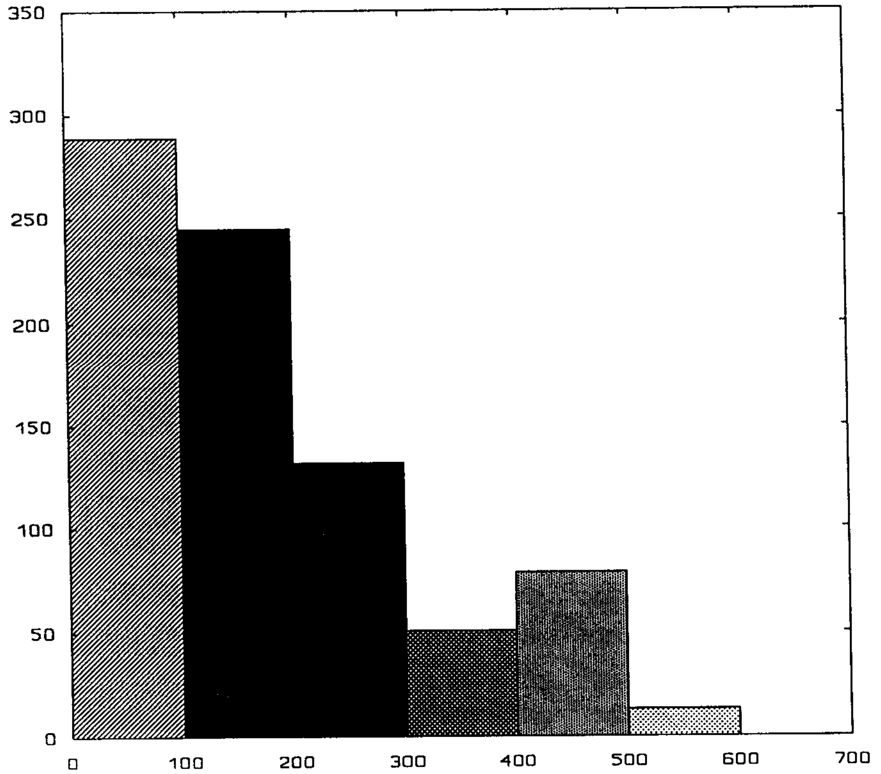

Figure 5 Zn - histogram of effective emission heights,Polish sources, 1990

The locations of main point sources of particular metal are shown in Fig. 6-9.

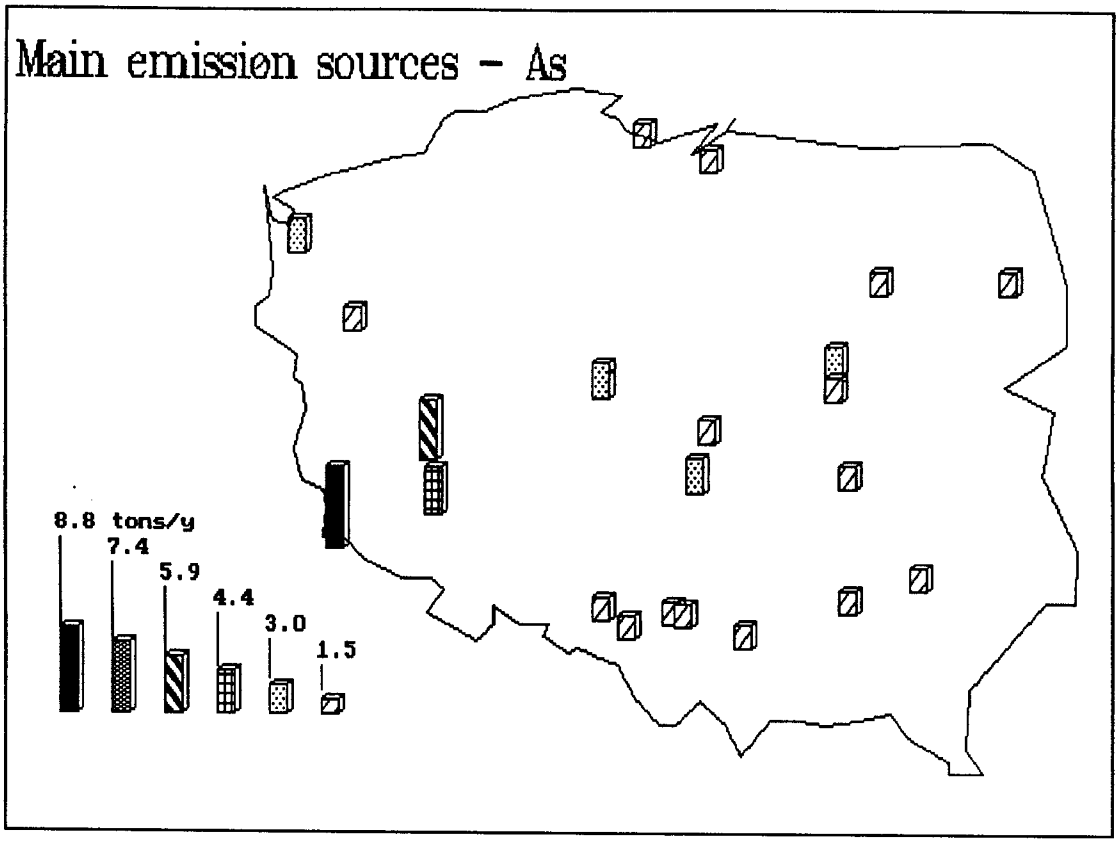

Figure 6 As - main Polish sources, 1990

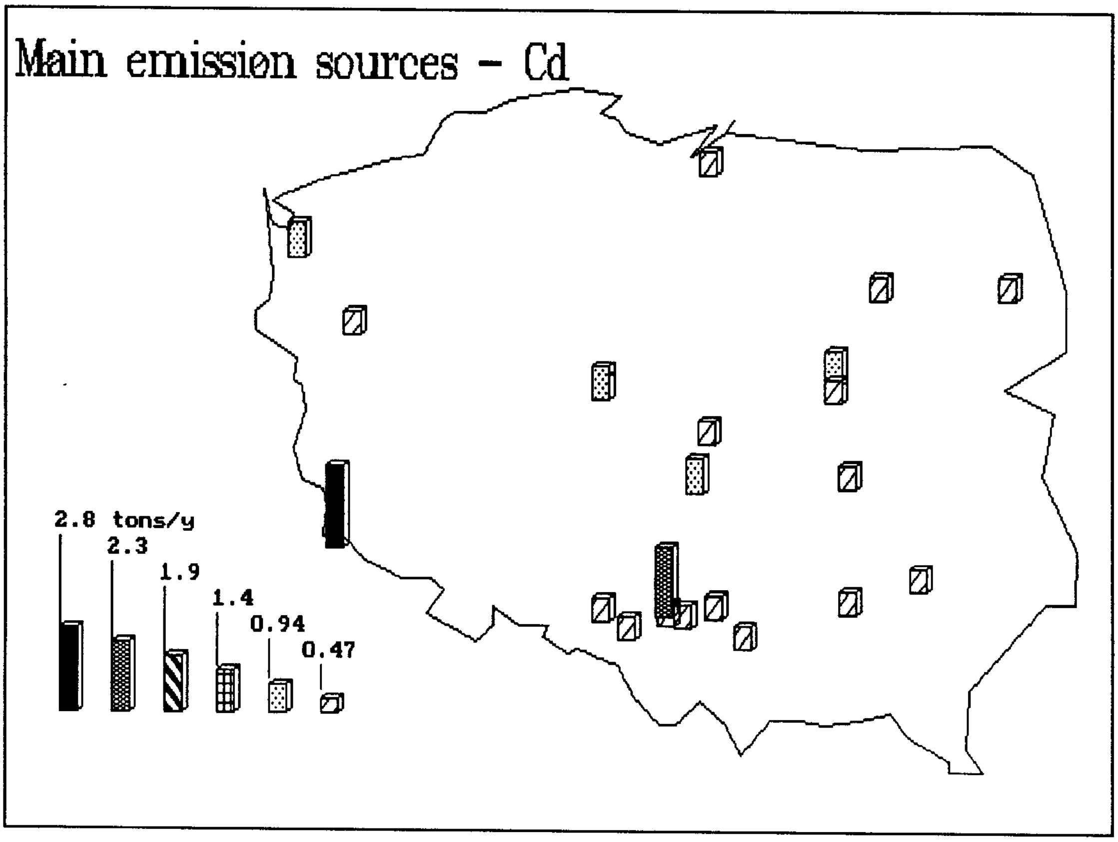

Figure 7 Cd - main Polish sources, 1990

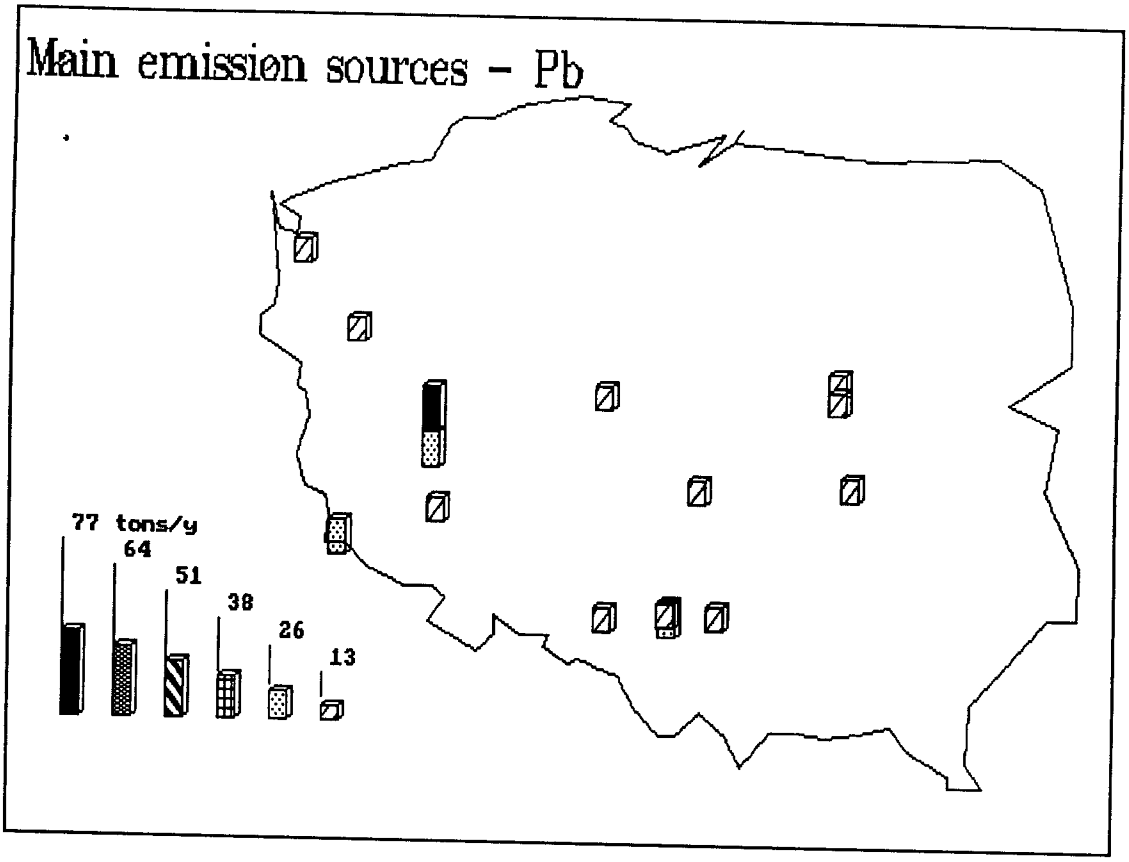

Figure 8 Pb - main Polish sources, 1990

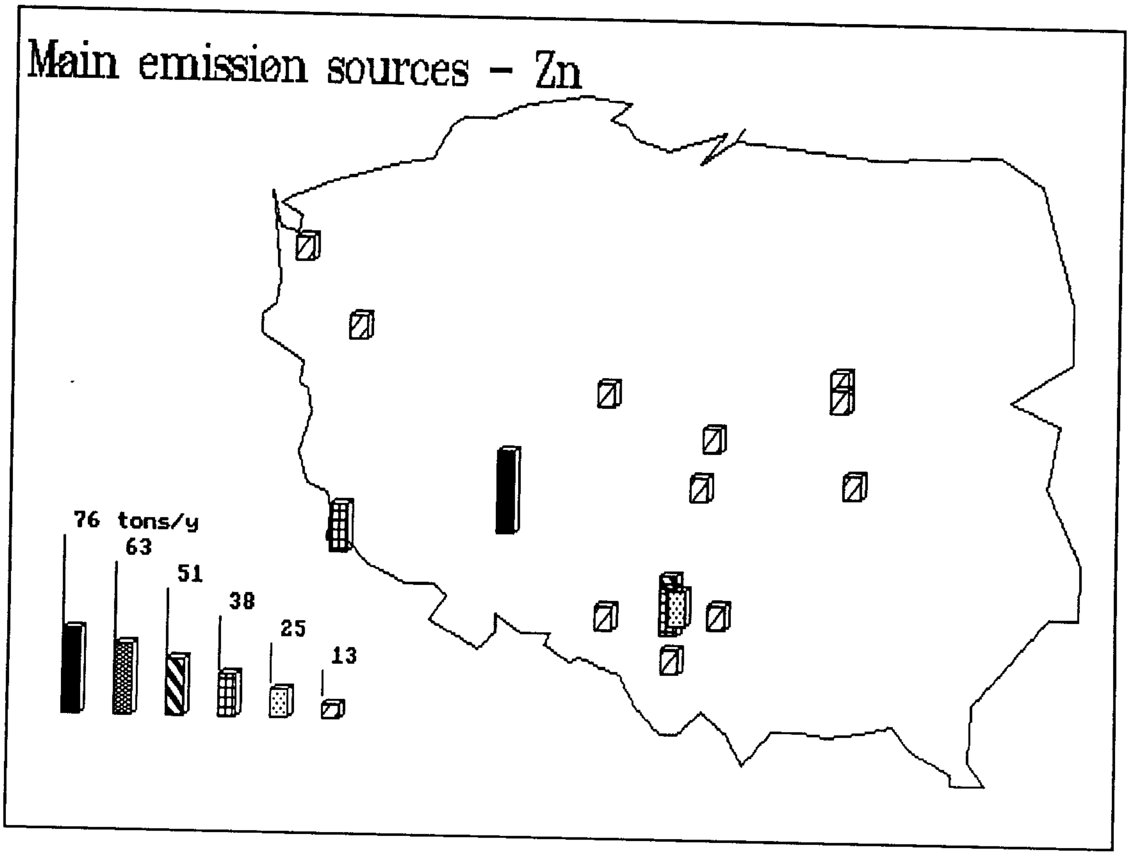

Figure 9 Zn - main Polish sources, 1990

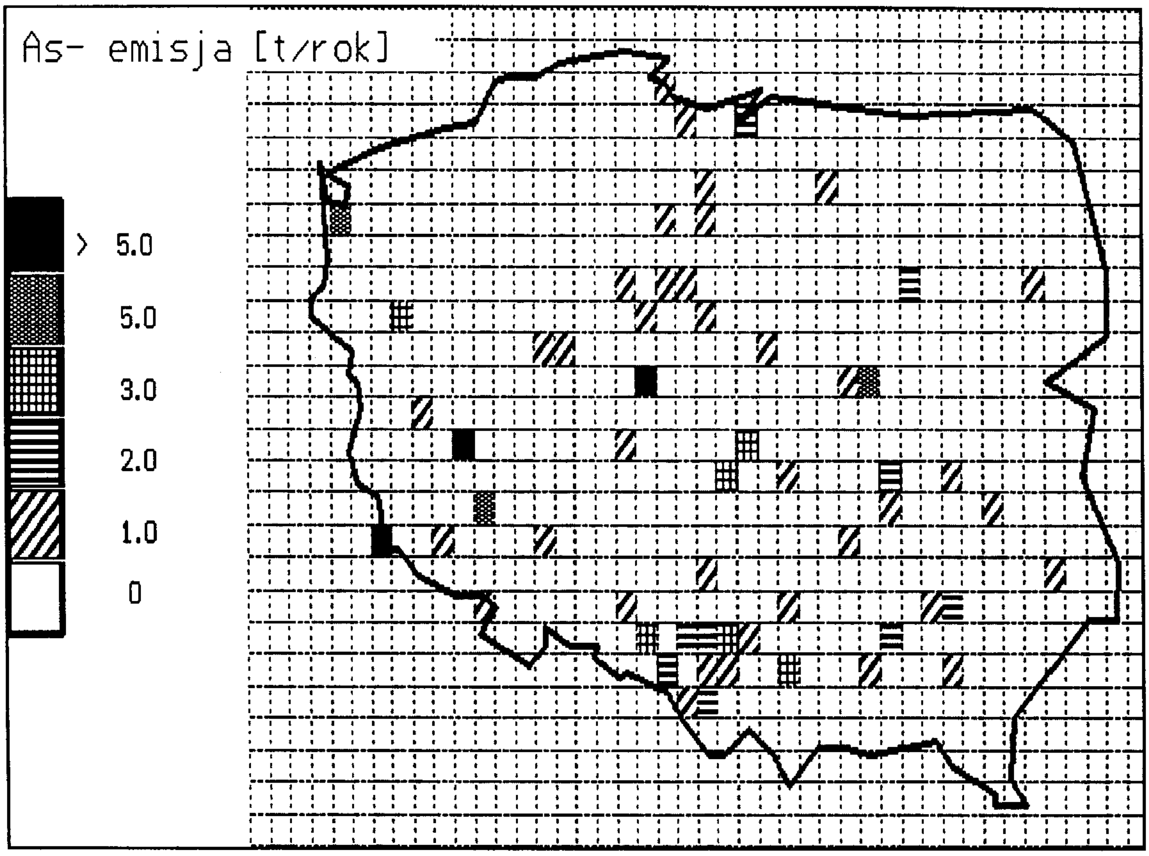

Figure 10 As emission, Polish sources, 1990.

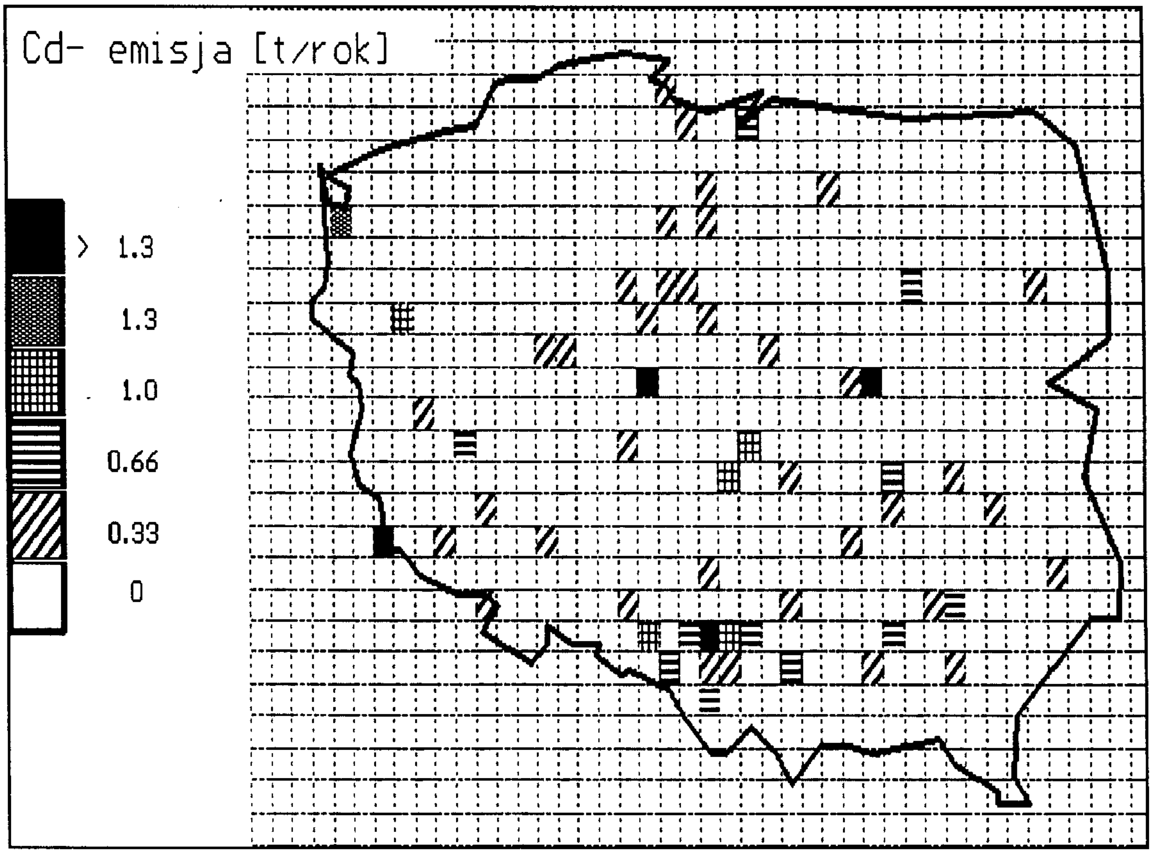

Figure 11 Cd emission, Polish sources, 1990.

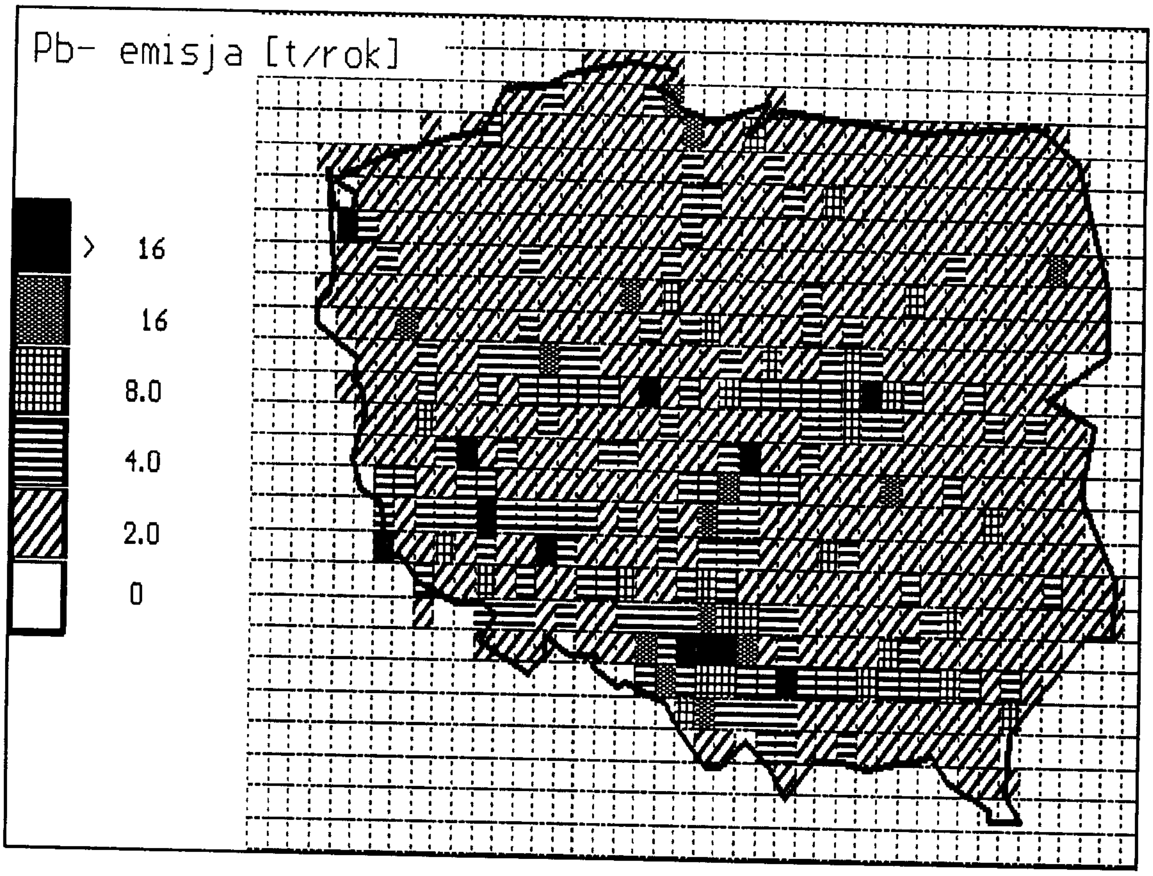

Figure 12 Pb emission, Polish sources, 1990.

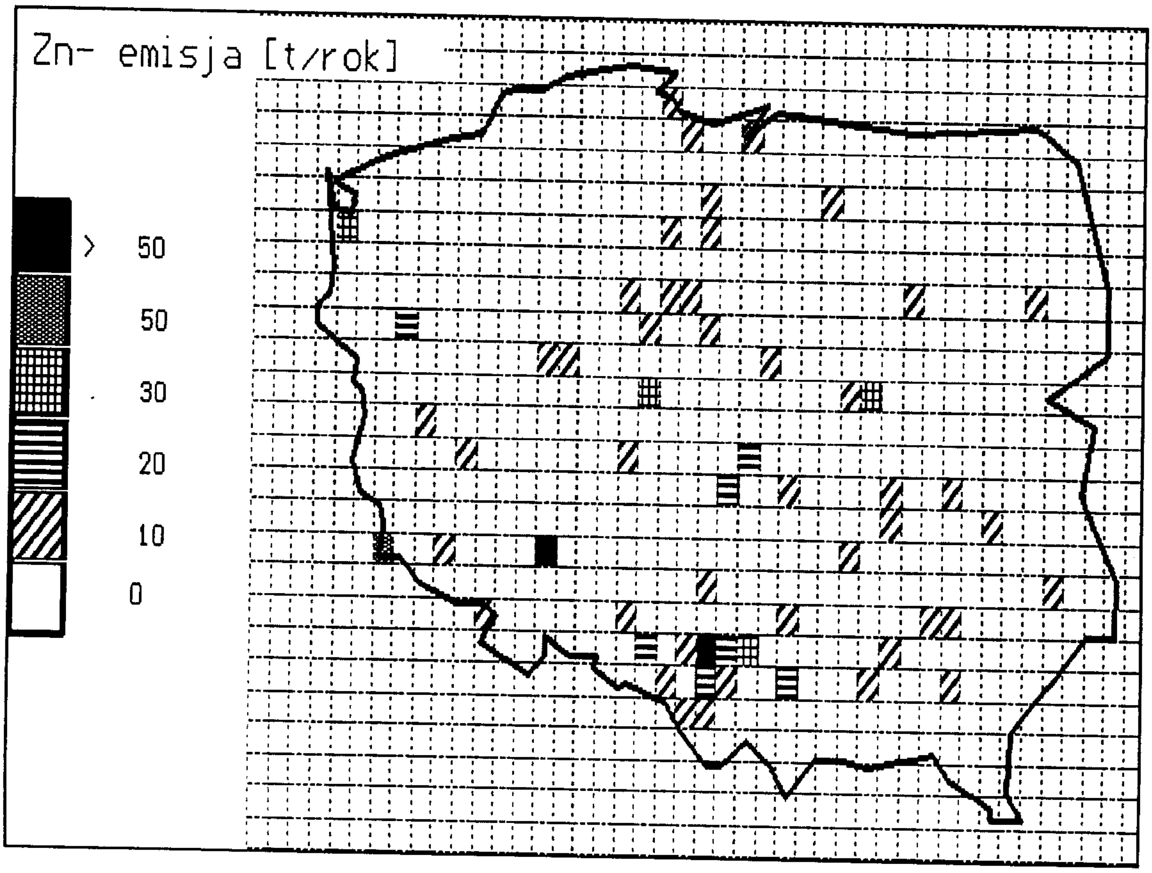

Figure 13 Zn emission, Polish sources, 1990.

Model description.

It is two-dimensional, Eulerian type model based on similar model for Europe (BARTNICKI, 1991 and 1992). The numerical grid system consist of 47x27 cells of the size 0.25x0.25° (in geographic co-ordinates).

The model consists of three main modules, the first sets parameters of the model (i.e. local deposition coefficient, washout ratio, dry deposition velocity), the second solves the advection equation and the last prepares output files for graphical presentation and statistical analysis.

The main equation of the model is two-dimensional advection equation of the following form:

$$\frac{\partial c_i}{\partial t}+\frac{\partial c_i u_j}{\partial x_j}=-\left(\frac{v_d}{h}+\frac{wP}{h}\right)c_i+(1-\alpha_i)e_i \tag{4}$$

where: c_i, i=1..4 - mass of As, Cd, Pb, Zn, respectively, u_j, j=1,2 - horizontal wind field components [m/s],h - mixing height [m], P - precipitation amount [mm/6h], w - washout ratio, v - dry deposition velocity [m/s], e_i, i=1..4 - emission of particular metal, α_i , i=1..4 - local deposition coefficient for each metal, t - time, x_j, j=1,2 - horizontal co-ordinates

The left side of equation is a substantial derivative of each metal mass. The first term on the right side describes the loss of mass due to dry and wet deposition, the second one - production of mass due to emission in the given grid. The equation is solved using the Area Flux Preserving method (BOTT, 1989).

In each time step total deposition D_{tot} (sum of dry and wet) is computed first, then dry D_d and wet D_w depositions are calculated as follows. Denoting k_{tot} as total deposition coefficient, k_d - and k_w - dry and wet deposition coefficient, respectively, one can get:

$$k_d=\frac{v_d}{h}, \qquad k_w=\frac{wP}{h} \tag{5}$$

$$k_{tot}=k_d+k_w \tag{6}$$

$$D_{tot}=c_i\cdot\left[1-\exp\left(-\frac{v_d}{h}\Delta t\right)\cdot\exp\left(-\frac{wP}{h}\Delta t\right)\right] \tag{7}$$

and, finally

$$D_d=D_{tot}\cdot\frac{k_d}{k_{tot}} \tag{8}$$

$$D_w=D_{tot}\cdot\frac{k_w}{k_{tot}} \tag{9}$$

where Δt is the time step.

The dry deposition velocity that is, as a matter of fact, a function of roughness height, friction velocity and particle diameter (SEHMEL, 1980), in above equations is treated as constant. This assumption does not produce big errors, because dominant part of Poland is flat and highest are located on the southern border only.

Table 1. Values of v_d for four metals.

metal	v_d
1. Arsenic	0.0030 m/s
2. Cadmium	0.0030 m/s
3. Lead	0.0015 m/s
4. Zinc	0.0030 m/s

Similarly, washout ratio is also assumed constant in this model.

Table 2. Values of w for four metals.

metal	w
1. Arsenic	500000
2. Cadmium	500000
3. Lead	500000
4. Zinc	500000

Since the model is two-dimensional, the decay of mass in the vicinity of each emitter is included in the equation in the form of constant coefficient denoted as the local deposition coefficient α equal 15% for lead and 10% for other metals.

Model results for 1990.

The first model run resulted in deposition patterns for every metal. These distribution are shown in figures 14 - 17. The results show that the southern part of Poland (Upper Silesia, Sudety Mts and Cracow region) is the most contaminated. Maxima are met near the biggest point sources in industrial regions. "The cleanest" part of Poland seems to be the north-eastern one (Białowieża Primeval Forest, Suwałki Voivodeship).

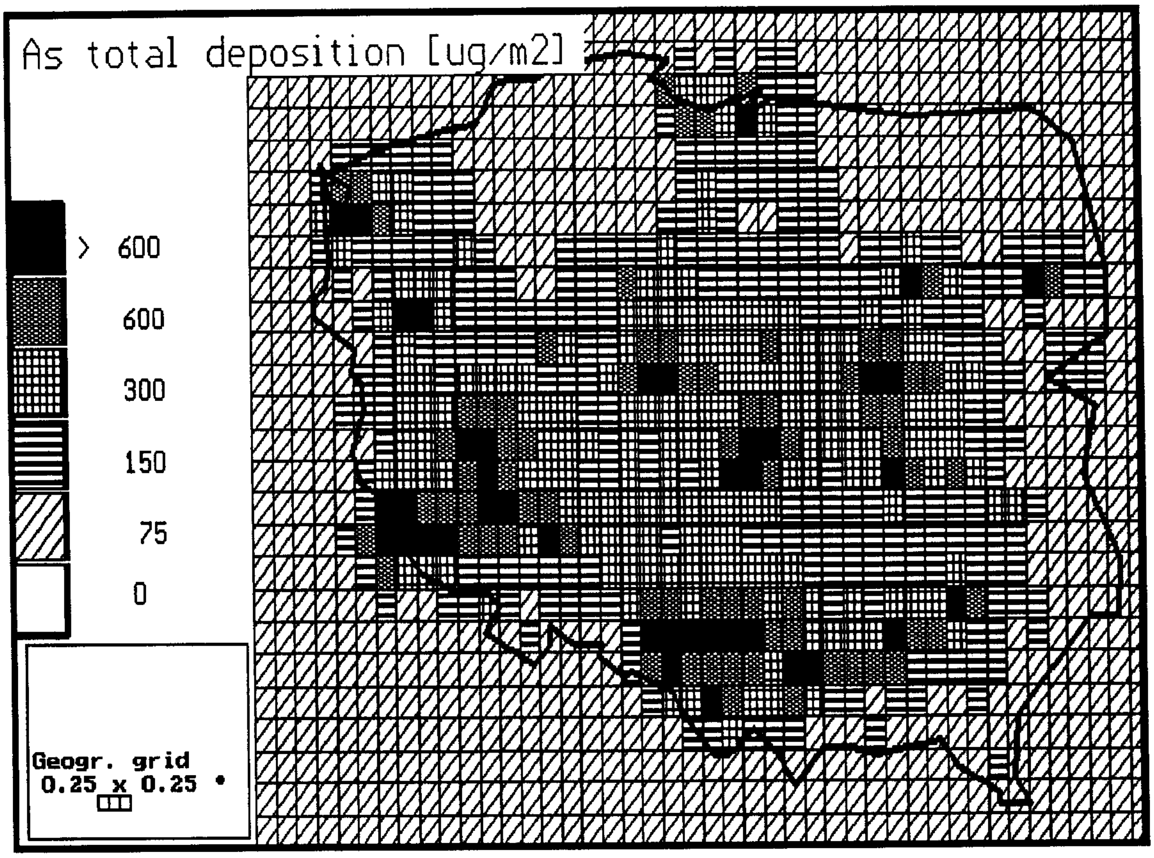

Figure 14 As total deposition in 1990 - model results.

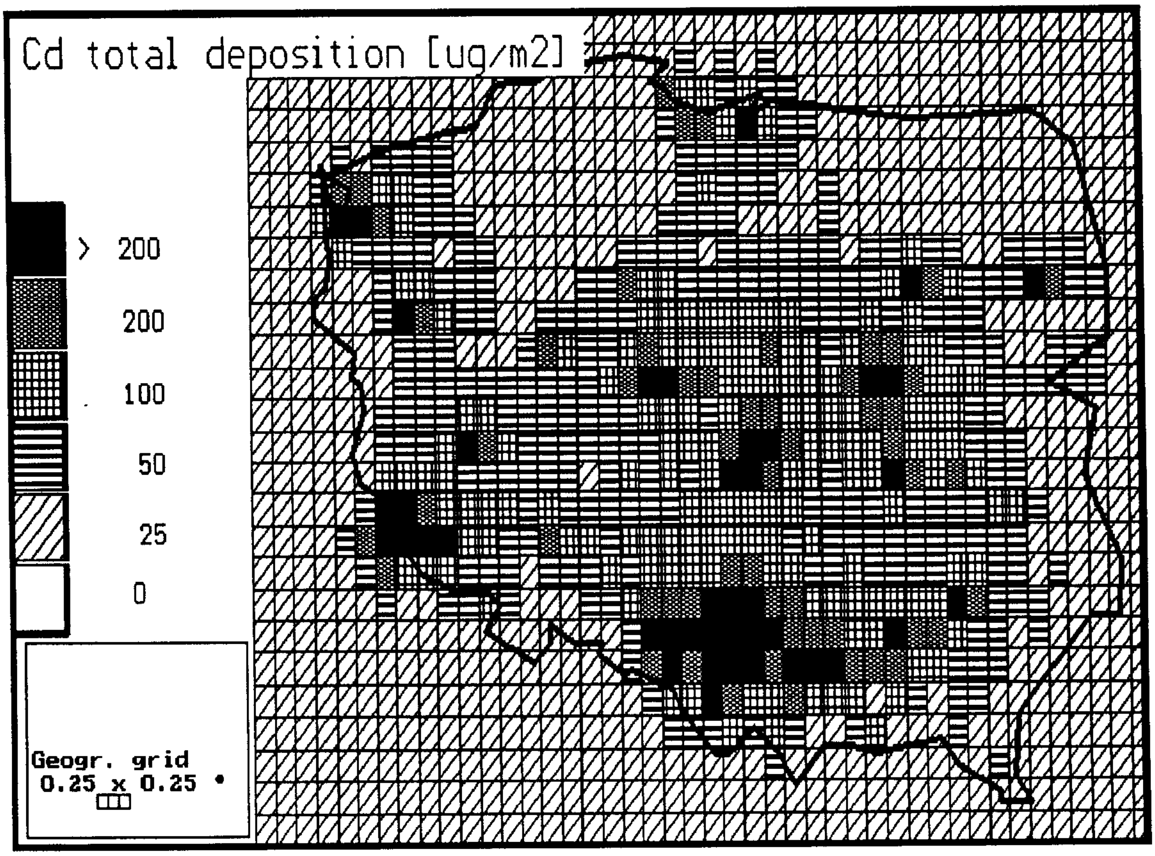

Figure 15 Cd total deposition in 1990 - model results.

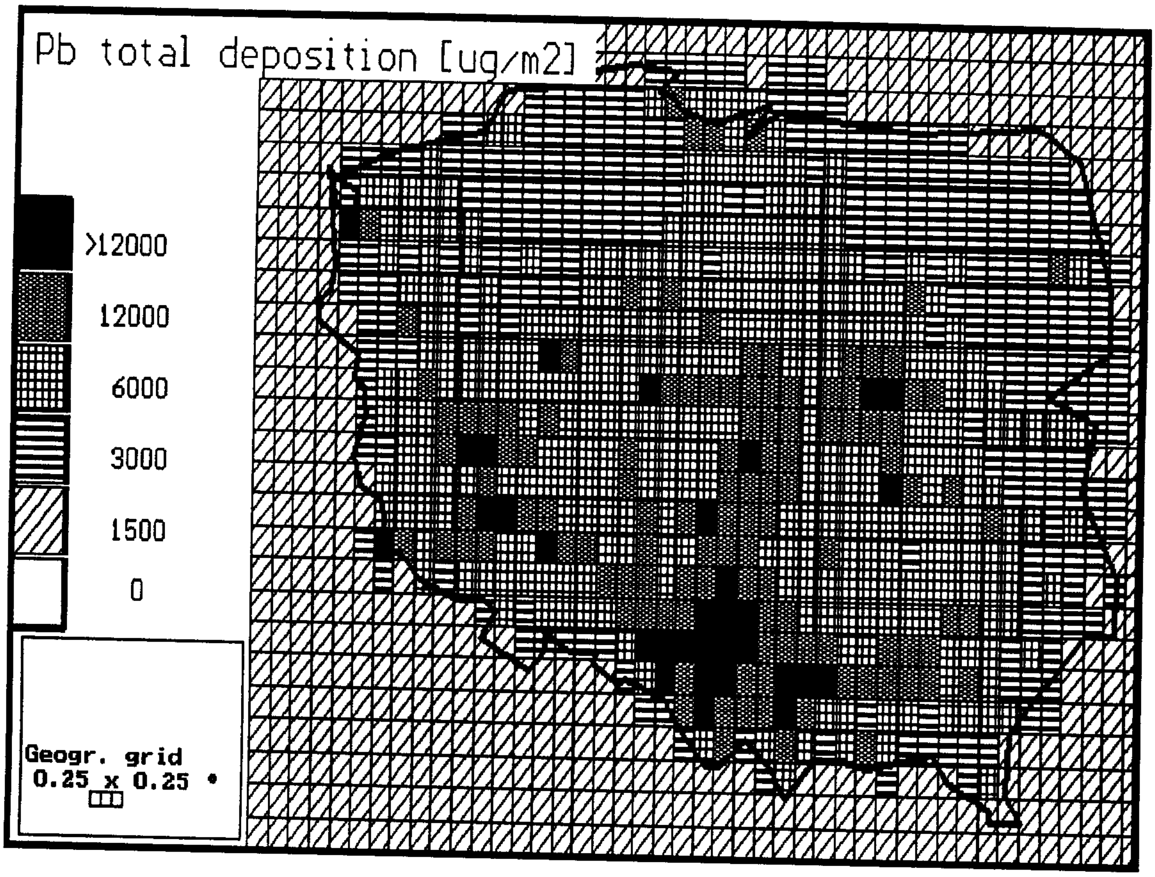

Figure 16 Pb total deposition in 1990 - model results.

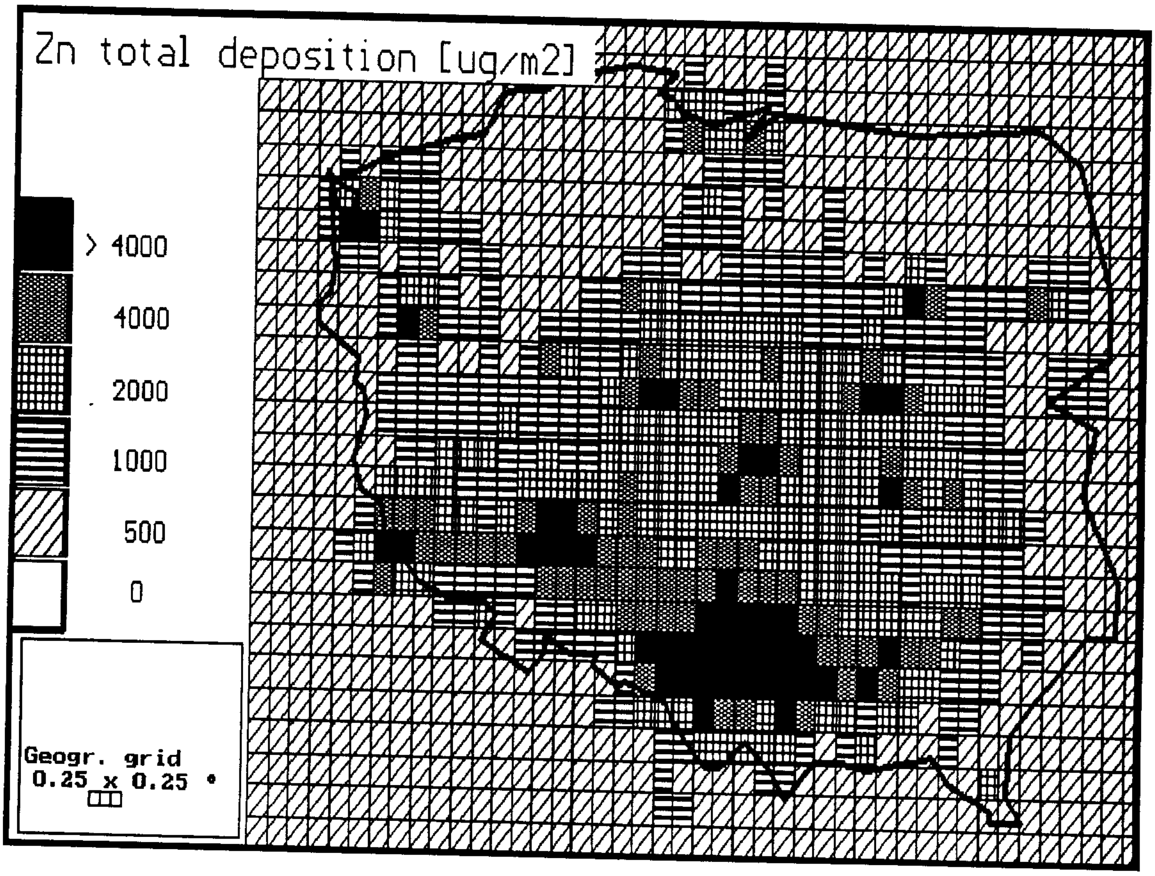

Figure 17 Zn total deposition in 1990 - model results.

Summary

The main results of two years research work are:

- Creation of unique heavy metals emission data base for Poland;
- Developing the operational version of model of atmospheric transport of heavy metal for Poland;

Results gained during research, additionally, point out that contamination level of natural environment of Poland is one of the biggest in Europe. It leads to the conclusion that such or similar research work is very important and should be continued in the future. Moreover, special attention should be paid to reduction of emissions of all harmful compounds to the atmosphere.

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MATHEMATICAL MODELLING OF THE TRANSPORT AND DISPERSION OF POLLUTION IN THE ATMOSPHERE - Information on the research work at the Division of Meteorology and Air Pollution, Institute of Environmental Engineering Systems, Warsaw University of Technology.

The main field of the research work carried out at the Division is the numerical mesometeorological modelling of the atmospheric boundary layer and the modelling of transport and dispersion of air pollution.

A group of mathematical models of air pollution transport and dispersion have been developed. The models are analytical as well as numerical ones.The models cover different time and space scales. They are used to determine air quality in the local and regional scale or in the whole country. Calculated distributions of air pollution concentrations refer to short-term or long-term averages.In some models a chemical submodel describing the gas-phase chemistry has been included.

The analytical models of air pollution transport and dispersion developed at the Department fall into the class of Gaussian plume models. They are based on the Gaussian steady-state equation. All the parameters, which influence the dispersion of pollution in the atmosphere are homogenous and constant in time. The input data to these models are easily available. As far as the meteorological data is concerned they are supplied by the routine meteorological stations. The Gaussian plume models are used in environmental impact assessment of different industrial plants on the atmosphere i.e. for regulatory purposes. (Chróściel St., Jagusiewicz A., Jaworski W., Juda J., Nowicki M., Warchałowski A., 1982;

Chróściel St., Jaworski W., Czaja L., Markiewicz M.,1985; Iwanek J., Abert K., Budziński K., Mihułka M., Warchałowski A.,1994)

In order to treat time-varying transport conditions a segmented Gaussian plume model SPM has been developed (Markiewicz M., 1990; Markiewicz M., 1994). In the SPM model the plume is broken up into independent elements whose initial features and time dynamics are a function of time varying emission and meteorological conditions encountered by the segments along their motion. The fact, that SPM model takes into account the change of emission parameters and the meteorological conditions in time and the variability of topographical conditions along the way of transport of pollution allows to extend the application of the Gaussian model to the few tens of km.The model verification carried out with the use of data from the tracer experiment has shown good agreement between the results of the model and measurements. Statistical evaluation of the results obtained has shown that SPM model is much better then the regulatory Gaussian plume model used in Poland.

The numerical models of air pollution transport and dispersion developed at the Division fall into the following classes: Lagrangian multibox models, Eulerian K-theory models and Lagrangian particle models.

The reactive plume multibox model RPMM has been design to study transport, dispersion and gas-phase chemistry of plumes out to few tens of km from the stack. This model allows to simulate the evolution of the plume emitted from the single stack taking into account the variability of emission and meteorological parameters. The RPMM model has been used to simulate the formation of the secondary pollution in the plume for the chosen scenario. The model preditions of key pollutants indicate that RPMM model is able to simulate the photochemical processes in the reactive plumes. The model has the potential to be embedded within a grid based regional air quality model as a submodel to provide the sub-grad scale resolution for the stack plumes. The RPMM model has been developed in cooperation with the Harwell Laboratory, U.K, which provided the Chemical submodel (Markiewicz M., 1994; Hov O. and Derwent D.,1982).

The SOXNOX model is an Eulerian, 2-dimensional K-theory model (Abert K., Budziński K., Juda-Rezler K., 1994). This model has been design for calculation of concentration and deposition fluxes of sulphur and nitrogen compounds for the area of Poland. The model operates with a time step of 0.5 hour and is used mainly to calculate the average seasonal or annual values. The submodel describing the chemical transformations introduced into the model is similar to the one in the EMEP model (Iversen T, Saltbones J, Sandnes H., Eliassen A., Hov O, 1989). The SOXNOX model is based on readily available input data, particularly only standard meteorological data supplied by the national meteorological network is used. The meteorological data are supplied to the model with a time step of 6 hours. The emission data, the terrain data and the meteorological parameters have been adjusted to the modelling domain of 960 * 960 km. The computational grid is based on the EMEP model grid, however with a smaller grid size of 30 * 30 km. The SOXNOX model sensitivity to the input parameters has been investigated. The influence of atmospheric stability and meteorological fields on the final distribution pattern of concentrations and depositions has been examined. The results showed that modelling results depend significantly on chosen values of dry deposition for respective pollutants as well as on the chosen values of the local deposition velocities (Abert K., Budziński .,Juda-Rezler K., 1992). Also significant dependance of modelling results on the value of mixing layer height has been found (Abert K., Budziński K ., Juda- Rezler K., 1993). Both dependencies are stronger then in case of year-to-year variations of meteorological fields (Abert K., Budziński K., Juda-Rezler K., 1994). All these analysis were performed as a Polish contribution in-kind to EMEP.

The Operational Short-term Air Pollution Dispersion System (OSAPDS) for the Izerskie Mountains region, which is under development at the Division is based on Mesoscale Dispersion Modelling System (MDMS). This system has been design to investigate the atmospheric flow and air pollution dispersion over complex terrain (Uliasz M., 1992;). The MDMS system includes a 3-dimensional mesoscale meteorological model (MESO), a Lagrangian particle dispersion (LPD) model and an Eulerian grid dispersion (EGD) model. These two dispersion models can be used separately or they can be linked together as a hybrid Lagrangian-Eulerian dispersion model. Two complementary approaches to air pollution dispersion modelling are available in the system: traditional source-oriented modelling and receptor modelling. The receptor oriented modelling is a more effective approach when air pollution at the receptor is of primary interest. In order to run the OSAPDS system the data base including meteorological, terrain and emission data has been prepared for the modelling area covering part of Poland Czech republic and Germany with the center in Izerskie Mountains. This region, called "Black Triangle", is one of the most polluted regions in Central Europe. The work on the OPAPDS system is carried out within the framework of the Polish Scientific Research Committee project (Madany A., 1995).

At the Division the mesoscale meteorological operational model Eta has been set working for the area of Central Europe. This model is working as a routine model at the National Meteorological Center, Washington U.S.A. (Madany A., 1995).

Mathematical models of air pollution transport and dispersion are used in the integrated assessment modelling. This modelling aims to choose the emission control strategy which brings the optimal (taking into account the given cost) improvement of the state of the environment in the considered region. The integrated assessment models include the following modules: emission control strategy module, mathematical air pollution dispersion model, model assessing the influence of the pollution on the environment and optimization module. The optymization system of the financial expenses on the environmental protection has been developed and implemented in the chosen regions of Poland (Juda J.,Budziński K., Krajewski K.,Abert K.,Warchałowski A., Dobija J., Rezler K. 1993).

At present the integrated assessment modelling is being carried out for the" Black Triangle" region located on the borders of Poland, Czech Republic and Germany. This project is an interdisciplinary study carried out within the COPERNICUS programme by the international team drawn from the research institutions in Great Britain (Imperial College in London), Poland (Warsaw University of Technology, Wrocław University of Technology) and Czech Republic (Institute of Landscape Ecology) (Juda-Rezler K.,1995).

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IEP's Activities Concerning Atmosphere and Climate Protection in Poland.

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Institute of Environmental Protection (IEP) is related to and supervised by the Ministry of Environment Protection, Natural Resources and Forestry. Research areas of the Institute cover:

- Atmosphere and climate protection;
- Integrated monitoring of the environment;
- Foundations of environmental protection policy and strategy;
- Water resources and Baltic Sea protection;
- Noise and vibration control;
- Soil protection and waste management;
- Landscape and nature conservation;
- Analysis of air, soil and water samples.

Air pollution and climate protection are main subjects of activities of the Atmosphere Protection Department and the Climate Protection Center, which are subdivisions of IEP. In particular we carry out environmental impact assessment based on local dispersion models, emission inventory of air pollutants for national statistics and international programmes.

Guidelines for monitoring of air pollution network have been designed and based on them national network for the general surveillance of the air quality in cities and in industrial agglomerations has been established. Now the network consists of 83 stations. A few research stations working for international programmes have been included to the network. Two of them: GEMS/EMEP station as well as US EPA/IEP automatic monitoring station in Warsaw are routinely operated by the IEP's staff.

Last year we participated in greenhouse gases emission inventory for Poland for the year 1992. This Country Case Study prepared for the Conference of Parties to the Convention has been sponsored by UNEP/GEF. Results of the inventory are presented in Table 1.

Chemical and physical properties of air pollutants emitted to the atmosphere cause that effects of their influence may have impact in places well beyond borders of the country where they originated. That applies as well to acids pollutants as to gases influencing changes in the Earth climate. Phenomena that have long been observed, like acid rains, acidification of lakes and soils, raising temperature, etc., prompted formulation of international conventions in that respect. Ratification of LRTAP Convention and Convention on Climate Change paves way for international cooperation concerning reduction of air pollutants emission, and monitoring of changes that occur in the environment.

Assessment of the relevant phenomena in individual countries, and carrying comparisons of the results needs a common language and demands that the same methods and tools are used. For this purpose the Corinair system and IPCC/OECD methodology have been elaborated to be used in assessment of air pollutants emissions. Similarly, for assessment of existing state, and changes taking place in the environment, guiding rules have been elaborated, concerning location of monitoring stations, procedures of measurements of ambient air pollution concentrations.

None of the mentioned above systems as of yet to work perfectly for the simple reason that databases of emission factors are not complete. As an example, estimation of emissions from natural sources may serve, which is practically still at its preliminary stage.

Table 1.

SHORT SUMMARY REPORT FOR NATIONAL GREENHOUSE GAS INVENTORY (1992)
(Gg)

GREENHOUSE GAS SOURCE AND SINK CATEGORIE	CO2	CH4	N2O	NOx	CO	NMVOC
Total (Net)National Emission and Sinks	359439.000	2473.920	50.200	1283.078	1609.474	644.864
1 All Energy (Fuel Combustion+Fugitive)	360988.057	821.323	5.794	1242.231	1494.971	415.878
A Fuel Combustion	360926.728	28.638	5.794	1242.231	1494.971	376.801
B Fugitive Fuel Emission	61.330	792.685	0	0	0	39.076
2 Industrial Processes	10602.723	8.107	12.918	39.508	75.013	61.786
3 Solvent Use	0	0	0	0	0	167.200
4 Agriculture	0	703.607	31.487	1.338	39.431	0
A Enteric Fermentation	0	646.894	0	0	0	0
B Animal Wastes	0	55.586	0	0	0	0
C Agricultural Soils	0	0	31.430	0	0	0
D Agricultural Waste Burning	0	1.127	0.057	1.338	39.431	0
5 Land Use & Forestry	-12151.780	0.004	0.000	0.001	0.059	0
6 Waste	0	940.878	0	0	0	0

Recent inventory prepared according Corinair/SNAP sector split prepared for EMEP is presented in Table 2.

Table 2.

National Emissions of SO_2, NO_2, NH_3, CO and CH_4

in Poland in 1993.

ACTIVITY	SO_2	NO_2	NH_3	CO	CH_4
	[Gg]	[Gg]	[Gg]	[Gg]	[Gg]
1. Public power, cogeneration and district heating	1290	380	1	20	1
2. Commercial,institutional & residential	750	130	<1	6130	19
3. Industrial combustion	535	160	<1	100	3
4. Industrial processes	100	30	20	25	14
5. Extraction & distribution of fossil fuels	0	0	0	0	1705
6. Solvent use	0	0	0	0	0
7. Road transport	50	420	<1	1590	9
8. Other mobile sources and machinery					
9. Waste treatment and disposal activities	NE	20	25	790	540
10. Agriculture activities	0	0	336	0	699
11. Nature	NE	NE	NE	NE	NE
TOTAL	2725	1140	382	8655	2990

NE - not estimated

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Contribution to the seminar on "Arctic atmospheric research: pollution and climate", Soefryd, Denmark 16-18/3 1995.

"The main research areas at the Geophysical Dept., University of Copenhagen, are **climate research** and **mathematical modelling.**

The key words describing the activities are:

climate research
- global perspective
- interdisciplinary approaches

mathematical modelling
- integration methods of dynamical models
- solution of inverse problems in geophysics
- analysis of various geophysical data fields, fex climate data

The interdisciplinary approach of the research activities is based on existing expertise in several geophysical disciplines: dynamical meteorology, oceanography, glaciology, solid earth physics and geodesy. One well known achievement worth mentioning in this context is the deep ice-core drilling project at the Greenland ice sheet.

During the seminar three abstracts will be presented. In the present one we will give a description of model simulations using a Hemispheric scale transport model.

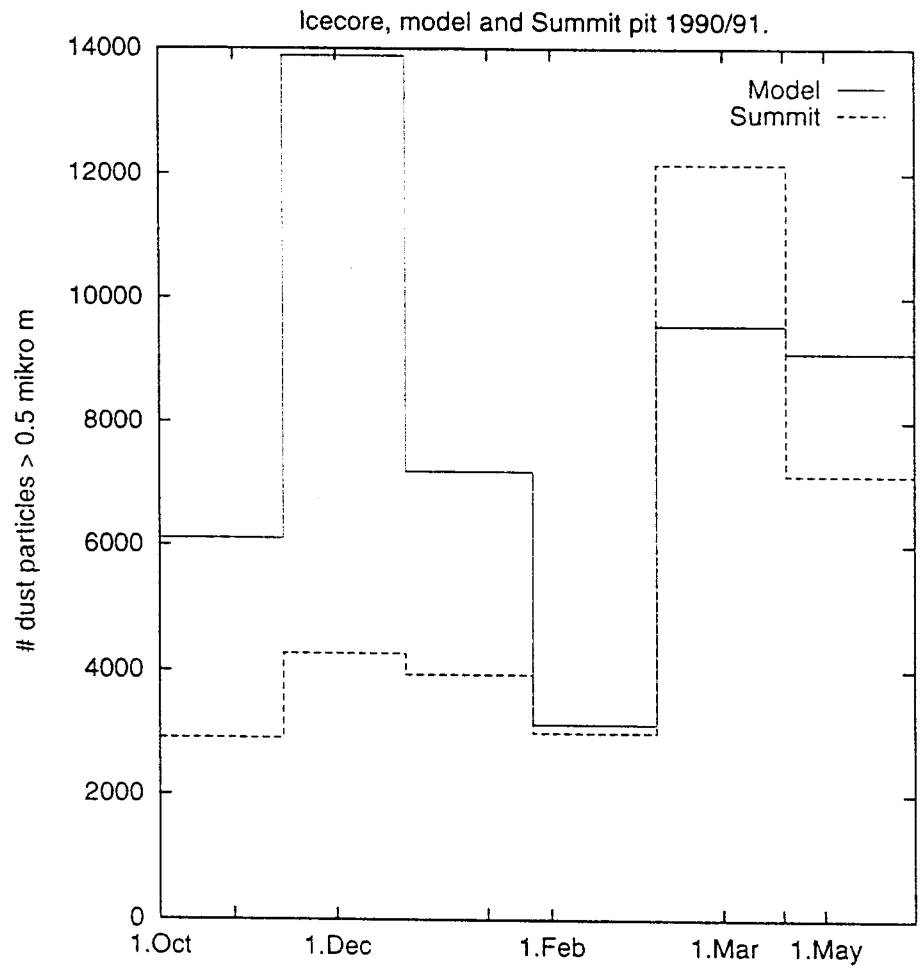
The research is focused on a better understanding of the atmospheric transport properties and its relation to the climate. Transport properties of the atmosphere are obviously essential to both the understanding of the pollution and the climate in the Arctic region as pollutants and energy have to be transported into the area. Correspondently, air pollutants can play an important role in studies of transport because they act as tracers for the air movement and they store information about the physical/chemical processes affecting them during the transport from source to sink.

The use of transport models in climate research is illustrated through the following example, where dust originating in the subtropics is transported in the atmosphere to the Arctic. A few details on the modelling experiments are given here: the simulation model has 10 layers and a horizontal resolution of 150 km. It is forced by prescribed, meteorological data for the period October 1990 to May 1991. A scheme for entrainment and deposition of dust is implemented and results for the deposition of dust at Greenland ice sheet is verified against values of the ice core concentrations obtained from the drilling projects at Summit (see figure).

It is proposed to use such a model approach also in more interdisciplinary studies of Arctic climate and air pollution. As the detailed flow pattern over complex terrain - say that of Greenland - is important for the simulation of the release of precipitation, further model experiments with a very high resolution model for the Greenland region are required. Such experiments can also be linked to the ongoing global scale climate modelling projects. "

Presently the work involves one scientist and one M.Sc. student.

Figure showing dust concentrations in model and ice



Sergei Dutchak

METEOROLOGICAL SYNTHESIZING CENTRE-EAST
(MSC-E)

MODELLING EXPERIENCE OF THE ARCTIC POLLUTION WITH SULPHUR AND NITROGEN COMPOUNDS, HEAVY METALS FROM SOURCES OF THE NORTHERN HEMISPHERE

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Content

I. MSC-E AREA of Expertise

II. Project proposals

III. Modelling experience
of the Arctic pollution

IIST OF REPORTS

1. Model for calculations of S, N	operational	October 93	Galperin M.V. et al	“MSC-E current model for the evaluation of SO_x, NO_x, NH_x and O_3 deposition and concentrations and its applications”
	local	11/93	Pekar M.I.	"Transboundary pollution transport in Northern Europe and perspective model for local pollution"
		12/93	Pekar M.I.	"A numerical model for the evaluation of local pollution within the framework of EMEP"
2. Model for calculations of HM	operational	3/94	Galperin M.V. et al	"Model evaluation of airborne Trace Metal transport and deposition. Short model description and preliminary results”
3. Theoretical studies of HM and	POP’s	5/93	Ryaboshapko A.J.	"Atmospheric heavy metals and high molecular organic substances"
	HM and POP’s	6/93	Galperin M.V.	"An approach to long-range transport and deposition modelling of heavy metals and persistent organic compounds"
	Mercury	7/94	Galperin M.V. Koropalov V.M.	"An approach to model evaluation of the airborne mercury transport"
	POP’s	14/94	Koropalov V.M.	"Long-range atmospheric transport of persistent organic pollutants (POP's)"
	HM		Tsybulsky V.V.	“Transformation and migration heavy metals in atmosphere”
4. Preparation of meteodata		6/94	Frolov A Rubinshtein K.	"System for Diagnosis of the lower Atmosphere state (SDA) for pollution transport model"
5. Statistical methods of comparison model-experiment		1995	Gusev A.V. Sofiev M.A.	“Model calibration environment for atmosphere pollution modelling”
S,N model calibration		4/94	Sofiev M.A. Gusev A.V.	"Results of MSC-East current model calibration with measurement of SO_X, NO_X, NH_X 1987-93”
6. Procedure of an evaluation of airborne pollution runoff from a watershed		7/93	Erdman L.K. et.al	"Airborne sulphur and nitrogen input to the Baltic Sea from its watershed. Provisional estimations"
7. Model results of Arctic and Atlantic pollution		3/92	Galperin M.V., Dedkova I.S., Sofiev M.A.	"Airborne Pollution of Arctic, Atlantic, Asia and Africa from European sources 1987-91”
Hemisphere S,N HM		1994	Galperin M.V., Erdman L.K. et al	“Modelling experience of the Arctic pollution with sulphur and nitrogen compounds, heavy metals from sources of the northern hemisphere”
Hemisphere S,N, 91		5/94	Galperin M.V. et al	"Evaluation of SO_X, NO_X and NH_X long-range atmospheric transport in the Northern Hemisphere for 1991"
Transboundary transport in CIS		·12/94	Erdman L.K.	"Transboundary transport of sulphur and nitrogen compounds over the territories of Russian Federation, the Ukraine, Belarus, Moldova, Baltic countries, Transcaucasian area and Central Asia”

I. MSC-E AREA OF EXPERTISE

1. We have and can now.

1.1. We have

1.1.1. Information

- Meteorological data (resolution 150×150 km^2, wind speeds at the levels of 1000 mb, 925 mb, 850 mb, precipitations, surface temperature).
  EMEP region 1987-94,
  Northern hemisphere 1991-94.
  Since 1995 in addition wind speeds at the level of 700 mb and temperature at each level will be available;
- Emission data
  Sulphur and nitrogen (as NO_x and NH_x) compounds - the whole Northern Hemisphere (1991) (partially own estimates are used) (resolution 150×150 km^2);
  Heavy metals (EMEP region):
  Cd, Pb, Hg, As, Zn (resolution 150×150 km^2) (1982);
  Pb, Cd - (resolution 50×50 km^2) (1990);
- Maps of concentrations and depositions
  of sulphur and nitrogen compounds for 1991 (sources and receptors are within the Northern Hemisphere);
  of heavy metals for 1989-91 (sources are within EMEP region, receptors are within the Northern Hemisphere);
- Maps of critical loads
  for sulphur (and nitrogen) compounds for whole Russia (including Asian part).

1.1.2. Models and methods

- Methods of meteorological data preparation for operational and local model calculations;
- Model for operational long-term calculations of S and N compounds;
- Model for operational long-term calculations of heavy metals (including Hg);
- Model for calculations of local pollution or episodes;
- Statistical methods of comparison of measure ments and modelling results;
- Methods of estimate of airborne pollution run-off from sea/lake/river watersheds.

1.2. We can

- Model sulphur and nitrogen compounds transport, transformation and deposition. Region - up to the whole Northern Hemisphere. Spatial resolution from 150×150 km^2 to 25×25 km^2; time periods: from several hours to several years;
- Model heavy metals transport. Region and spatial resolution are the same;
- Compare model with measurements and calibrate models;
- Model pollution transport at the local scale and episodes;
- Estimate airborne pollution run-off from watersheds to seas/lakes/rivers.

2. Problems under development.

- POP's modelling (benz(a)pyrene);
- Influence of S and N compounds on visibility in Arctic region;
- Dust emission and transport modelling (anthropogenic and non-anthropogenic sources);
- Influence of dust on visibility and albedo in the Arctic region.

3. What is possible to make additionally?

- Forward and backward trajectories calculations at various pressure levels (1000 mb, 925 mb, 850 mb, ...) and appropriate analysis;
- Extrapolation and interpolation of time series on S, N and some other compounds using model/measurement comparison;
- Extension of existing meteorological data base. (It is possible to have required meteorological data since 1965 up to now. Obtained meteorological data base for 30 years will give the opportunity of more detailed investigation of meteorological processes in the Arctic and of the determination of possible trends of meteorological parameters.);
- Extension and improving of existing emission data base for S and N compounds, heavy metals and some POP's (in any case for Russia and CIS members);
- Estimate of airborne pollution run-off from watersheds of northern rivers and coastal zone.

II. Project proposals

AN ASSESSMENT OF THE POLLUTION OF THE ARCTIC AND ITS REGIONS AND TREND ANALYSIS

Goal

Evaluation of deposition and concentration fields for S, N, (NO_x+NH_x), HM (Pb, Cd, Hg), POP's (benz(a)pyren), dust and analysis of Arctic pollution variations with years (1982-1993) and possibly for the period of 1965-95.

Institutes envolved in this project are listed in items 1-7.

1. Transport dynamics in the atmosphere

• • •

Goal

Analysis of meteorological processes which give rise to the pollution import to and export from the Arctic and circulation inside it (Analysis will be based on meteorological data for the period of 1965-1994(1995)). Calculation of forward and backward trajectories at various pressure levels and appropriate analysis.

A detailed analysis of typical synoptic situations for individual regions of the Arctic.

Results: 1) Main directions of the pollution transport in the Arctic at the levels of 1000, 850, 700, 500 mbar; 2) Characteristics of main meteoparameters: temperature and humidity at various levels, cloudiness, precipitations.

[Denmark, Walløe Hansen; Roshydromet (Hydrometcentre); MSC-E, Regional Centre of Arctic Monitoring, Scientific Research Institute of the Arctic and Antarctic (Radionov), Institute of Atmospheric Physics (Vinogradova); ...].

MSC-E contribution

There is meteorological database: (resolution 150×150 km^2, wind speeds at the 1000, 925, 850 mb levels, precipitations, surface temperature):

EMEP region, 1987-94;

The Northern Hemisphere, 1991-94.

From 1995 there are wind speeds at 700 mb level and temperature at each level. If it will be required it is possible to have corresponding meteorological data since 1965.

2. Chemical reactions in the atmosphere

• • •

Goal

Refinement of chemical blocks for the simulation of chemical transformation in the atmosphere (S, N, HM, POP's).

Results:

Determination of basic reactions and refinement of their constants in terms of the Arctic conditions.

[MSC-E, Institute of Global Climate and Ecology, Scientific Research Institute of Arctic and Antarctic, Institute of Atmospheric Physics; GKSS, Sweden (Munthe, ?), ...].

MSC-E contribution

Chemic blocks used for operational calculations (S, N, Hg).

3. Pollution source inventories

• • •

Goal

Preparation of the emission field (the Northern Hemisphere to the south of 30^{o}N) for the simulation of the atmospheric Arctic pollution by S, N, HM (Pb, Cd, Hg), POP's, dust.

Results:

Emission field (base year 1990) with spatial resolution 150×150 km^2, indication of powerful sources (official data from countries+estimates); assessment of Hg and POP's re-emission. Annual estimates of emission for the period of 1965-95. Assessment of the emission projected for 2000 and 2005.

[MSC-E, Institute of Atmospheric Physics, Institute of Global Climate and Ecology, Scientific Research Institute "Atmosphere", ...].

MSC-E contribution

Expert estimates of N (as NO_x and NH_x) and S compounds within the Northern Hemisphere (1990). There are two heavy metals emission data bases for the EMEP region: for 5 metals (Pb, Cd, Zn, Hg, As) (150×150 km^2 resolution, 1982) and 2 metals (Pb and Cd) (50×50 km^2 resolution, 1990). Expert estimates of emission of 3 metals (Pb, Cd, Hg) for Asian part of Russia (1990).

4. Pollution sinks and deposition

• • •

Goal

Refinement of coefficients of dry, wet and gravitational deposition under the conditions of the Arctic with allowance for characteristics of the underlying surface and its state.

Results:

1) description of coefficients; 2) description of underlying surfaces (possibly as maps); 3) deposition fields for various pollutants.

[MSC-E, Institute of Global Climate and Ecology, Scientific Research Institute of Arctic and Antarctic, Regional Centre of Arctic Monitoring, NERI, GKSS, Munthe, NILU].

MSC-E contribution

1. Coefficients applied to operational models;
2. Results of model calculations of S, N (sources of the Northern hemisphere) (1991-94) and heavy metals (sources of the EMEP region) deposition (1989-91) can be presented. As soon as emission database on heavy metals (Pb, Hg, Cd) is refined Russian Asia sources can be included in calculations.

5. Atmospheric Modelling

• • •

Goal

( ) Further development and improvement of pollution transport modelling for the Arctic region (S, N, HM, POP's dust) using various temporal and spatial scales.

Results:

1) Adaptation of global, regional and local models for the evaluation of the Arctic pollution. Model verifications using measurement data; 2) Assessments of the Arctic pollution using various spatial and temporal scales; 3) Gridded concentrations and deposition (, and) for the period of 1982-93, if necessary for 1965-95; 4) Identification of countries- and/or-their regions-emitters including major sources of the Northern Hemisphere to the Arctic Pollution; 5) Compiling of maps of critical load exceedances for the Arctic regions of Europe and Asia (S, N). [MSC-E, Denmark (Hansen), SRIAA, GKSS, NERI].

MSC-E contribution

1) S and N emission (150×150 km^2 resolution, Northern Hemisphere) (1991) (1982).

HM emission (the same resolution, EMEP region (Cd, Pb, Zn, As, Hg) and in addition Russian Asia (Cd, Pb)).

2) Meteorological data (list of parametres as described above)

1987-94 for EMEP region; 1991-94 for the Northern Hemisphere;

It is possible to have required data since 1965 up to now.

3) Models: for hemispheric and regional calculations as well as for local modelling and for episodes.

4) Calculation results (maps of deposition and air concentrations):

S and N compounds for 1991-94 (sources and receptors are within the Northern Hemisphere).

Heavy metals (Pb, Cd, Zn, As) for 1989-91 (sources are within EMEP region (1982), receptors are within the Northern Hemisphere). After obtaining emission data for Russian Asia it is possible to repeat calculations for the Northern Hemisphere including the USA and Canadian emission data available (the second part of 80-th).

5) Application of MSC-E statistical methods for time series analysis and model/measurement comparison.

6) Maps of critical loads for S and N compounds for Russian Federation.

6. Existing data series, overview and suitability for joint exploitation and analysis (time series and trend).

• • •

Goal

1. To refine available databases.

2. Replenishment and/or updating of these databases for specific problems of the evaluation of the Arctic pollution.

3. Required supplementary information and compilation of new databases using available ones.

[For example, database for characteristics of underlying surfaces or more detailed synoptic information for individual regions or major sources].

Result:

Series of databases updated for the evaluation of the Arctic pollution.

• • •

Measurement data of concentrations and deposition and/or their fields obtained on the basis of measurements of S, N, HM, POP's, dust (1982-95 and earlier).

Meteodata for global and regional modelling: wind speeds, humidity, temperature at levels 1000, 925, 850, 700, 500 mbar cloudiness and precipitations (resolution 150×150 km^2, 12-24 h). [AM, IGCE, MSC-E, Roshydromet].

MSC-E contribution

1. Meteorological data.

There is meteorological database: (resolution 150×150 km^2, wind speeds at the 1000, 925, 850 mb levels, precipitations, surface temperature):

EMEP region, 1987-94;

Northern Hemisphere, 1991-94.

From 1995 there are wind speeds at 700 mb level and temperature at each level.

If required it is possible to have corresponding meteorological data since 1965.

2. Modelling results on air concentrations and depositions for the whole Northern Hemisphere of S and N compounds (1991-94 emission for Northern hemisphere) and of Heavy metals (Pb, Cd, Zn, As, 1989-91, emission of EMEP region) can be presented.

3. MSC-E methods of model/measurements comparison.

4. Possible extrapolation and interpolation of time series for S and N compounds and some other pollutants using model/measurement comparison.

7. Supplementary investigations

7.1. The impact of S and N compounds and dust on visibility and albedo in the Arctic region [CAO, MSC-E, Germany ...].

7.2. Estimate of airborne pollution run-off from watersheds of northern rivers and coastal zone. [AM, MSC-E, NERI].

7.3. Exceedance of critical loads for S and N compounds for Arctic regions of Europe and Asia. [MSC-E].

Participants of the project

Denmark	NERI
Sweden	IVL
Germany	GKSS
Norvey	NILU

Russian Federation

MSC-E - Meteorological Synthesizing Centre	(Moscow)
Roshydromet	(Moscow)
IGCE - Institut of Global Climate and Ecology	(Moscow)

AM	Regional Centre of Arctic Monitoring (St.Peterburg)
CAO	Central Aerological Observatory (Dolgoprudnaya)
SRIAA	Scientific Research Institute of Arctic and Antarctic (St.Petersburg)
IPA	Institute of Atmospheric Physics (Moscow)
SRIA	Scientific Research Institute "Atmosphere" (St.Petersburg)

III. MODELLING EXPERIENCE OF THE ARCTIC POLLUTION WITH SULPHUR AND NITROGEN COMPOUNDS, HEAVY METALS FROM SOURCES OF THE NORTHERN HEMISPHERE.

1. The region of calculations.

To assess the atmospheric pollution of the Arctic, region of calculations including territories located to the north of 40^0N. is required. The region considered (fig.1) includes territories to the north of 31^0N. completely and territories to the north of 17^0N partially. Gridsize, similar to that of the EMEP grid is 150õ150 km^2.

2. Input and output data of the model.

Scheme of informational flows is presented in fig.2. Main input data are: geographical, meteorogical and emission data. Maps of depositions and concentrations for different countries or regions and budget "country by country" matrices are the output of the model. Besides, possibility of calculations of abatement strategy scenarios and comparison between calculated and measured values are provided as well.

3. Meteodata.

MSC-E has available the following meteoelements for the period of 1991-1993: windspeed components at levels 1000 hp and 850 hp, precipitation amount and surface temperature for every standard 6-hour period of observations in every grid square. These data were processed by methods developed in Hydrometeorological Centre of Russian Federation on the assignment of MSC-E. Information is being continuously accumulated on the operative basis.

4. Emission data.

The emission data for sulphur and nitrogen compounds within the calculation region [9-13] for 1991 were evaluated on the basis of official and literature data. In case of informational gap expert assessments of emission were made in MSC-E.

The emission values for the large-scale regions and countries are presented in tab.1, fig.3 shows their geographical location.

The emission data on heavy metals are incomplete and non-uniform at present.

It consists of the following information:

a. The data for Europe for 1982 taken from the work [14], supplemented with estimations of emission, made in MSC-E, for the countries of Middle East and North Africa for Pb, Cd, Zn, As.

b. The data for the USA (without Alaska) and Canada for 1986, based upon works [15,16] for Pb, Cd, As. Distribution of emission with the grid was made in MSC-E.

c. Incomplete data for the Asian part of Russian Federation for 1991, for Pb, Cd, As, and Zn.

Recently, MSC-E started estimations of Pb, Cd, As and Zn emission for the middle and the eastern Asia to fill the gap for the hemispherical grid.

5. The Model.

The scheme of the model calculations is presented in fig.4. Characteristics of consecutive model calculation stages are described below.

Advection and horizontal diffusion

The Lagrangian-Eulerian scheme of calculation is used, operating with complete masses of pollutants within each grid cell.

The results of the model testing for point sources without horizontal diffusion are shown in fig.5-7 for different windfield patterns. As it is clear from these figures, pseudodiffusion is absent.

Chemical transformation

The chemical transformation scheme for sulphur and nitrogen compounds is presented in fig.8. Heavy metals are considered chemically inert and bound with fine-dispersed aerosols at a stage of the atmospheric transport.

Dry deposition

Dry deposition velocity for each of sulphur and nitrogen compounds are calculated separately depending on air temperature and underlying surface type. For heavy metals this value is being recalculated at every time step as an average for spectrum of aerosol particles size.

Wet deposition

Non-linearity of sulphur and nitrogen oxides scavenging is taken into account in accordance with precipitation intensity and the pollutant concentration in the layer being washed out. For other compounds and heavy metals non-linearity of wash-out is considered for precipitation intensity only.

6. Verification of the model.

Comparison between the calculation results and measurement data is made for the sake of verification of the model. Special methods were developed in the MSC-E for more adequate consideration of noises properties [17,18]. Fig.9 shows the results of comparison of the calculated and measured values for sulphur compound concentrations for the majority of the EMEP stations in the period 1987-91. Each point on the plot corresponds to both calculated and measured mean annual value for each station.

Annual values of Pb concentrations, calculated for different points in 1991, compared to the measurement data, available for the same points, including data for other years, is presented in fig.10. The agreement of the measured and calculated values can be considered satisfactory.

7. Calculation results.

For sulphur and nitrogen compounds calculation was made on the basis of meteo and emission data of 1991 for the whole grid. Maps of depositions for sulphur compounds, oxidized and reduced nitrogen are presented in fig.11, 12 and 13 correspondingly. Characteristic transport pathways of pollutants from the major emission regions of the Northern Hemisphere to the Arctic and its further spread with the Circum-polar air parells are quite obvious. On the whole the pattern doesn't differ from the one shown in the work [19]. Totally, the Arctic region (within the north Polar circle) received 1288 kt sulphur as S, 420 kt of oxidized and 141 kt of reduced nitrogen as N, which made up 2.8%, 2.4% and 0.9% of its emission within the calculation region respectively.

Meteodata of 1991 were used for the calculation of heavy metals as well. In the first variant we used the emission of European sources only. Results of calculations are presented in fig.14-17 for Pb, Zn, Cd, As correspondingly.

Four groups powerful of sources were considered in the second variant.They were: Sadbury in Canada with the emission conventionally equal to that of Quebec and Ontario Provinces combined, Kola Peninsula, the north and central Ural and Norilsk. The results of calculations are shown in fig.18 for Cd and fig.19 for As. Used emission estimates are given in the tab.2.

Table 1.

The estimated emission of sulphur and nitrogen compounds from countries and regions included into computation region

Unit=1kt

	Countries or regions	Notation	Compounds		
			SO_2	NO_2	NH_3
1	USA	USA	20737	18758	1656
2	Canada	CND	3700	1923	295
3	Great Britain and Ireland	GBI	3964	2859	634
4	Northern Europe	NER	726	1295	266
5	Western Europe	WER	4554	3673	1533
6	Central Europe	CER	12335	6051	2323
7	Southern Europe	SER	8454	4076	1874
8	Eastern Europe	EER	3493	1414	1351
9	northern-European Russia	RUN	1225	254	121
10	central-European Russia	RUE	3123	2246	1416
11	Ural and western Siberia	UWS	1696	1310	319
12	Krasnoyarsk region	KSK	2588	110	51
13	Eastern Siberia and Far East	SFE	695	386	135
14	Africa and the Middle East	AME	1122	275	208
15	Middle Asia (Near East)	MAS	2314	990	666
16	South-Eastern Asia	SEA	21812	10192	6834
17	Atlantic	ATL	668	737	3
		TOTAL	93206	56549	19685

Table 2.

Estimated heavy metals emissions of source groups as used in calculations.

Unit = 1 ton/years

Source or group of sources	Variant	Pb	Zn	Cd	As
Europe, Africa* and the Middle East*	1	95780	41818	1172	5054
the Ural	2	-	-	111	1170
Kola Penincula	2	-	-	16	318
Norilsk	2	-	-	26**	850
Sadbury (Canada)	2	-	-	200	370

* within the computation area

** taken from "The state of the Arctic environment" reports, Arctic centre, University of Lapland 1991.

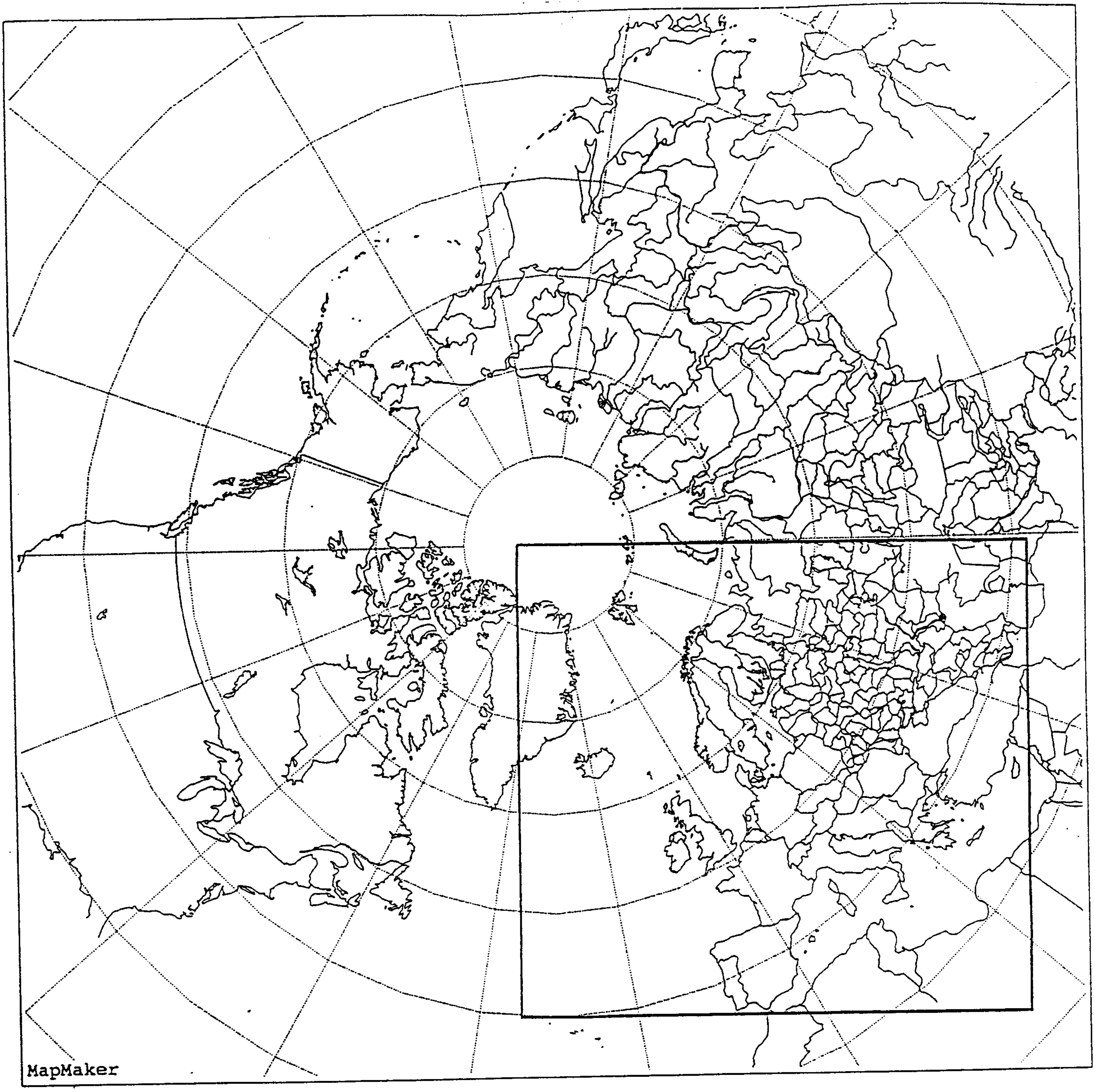


Fig. 1. Computation area.
Area of routine calculation of EMEP is limited by the solid line.

Рис.1. Область расчетов.
Область рутинных расчетов ЕМЕП выделена сплошной линией.

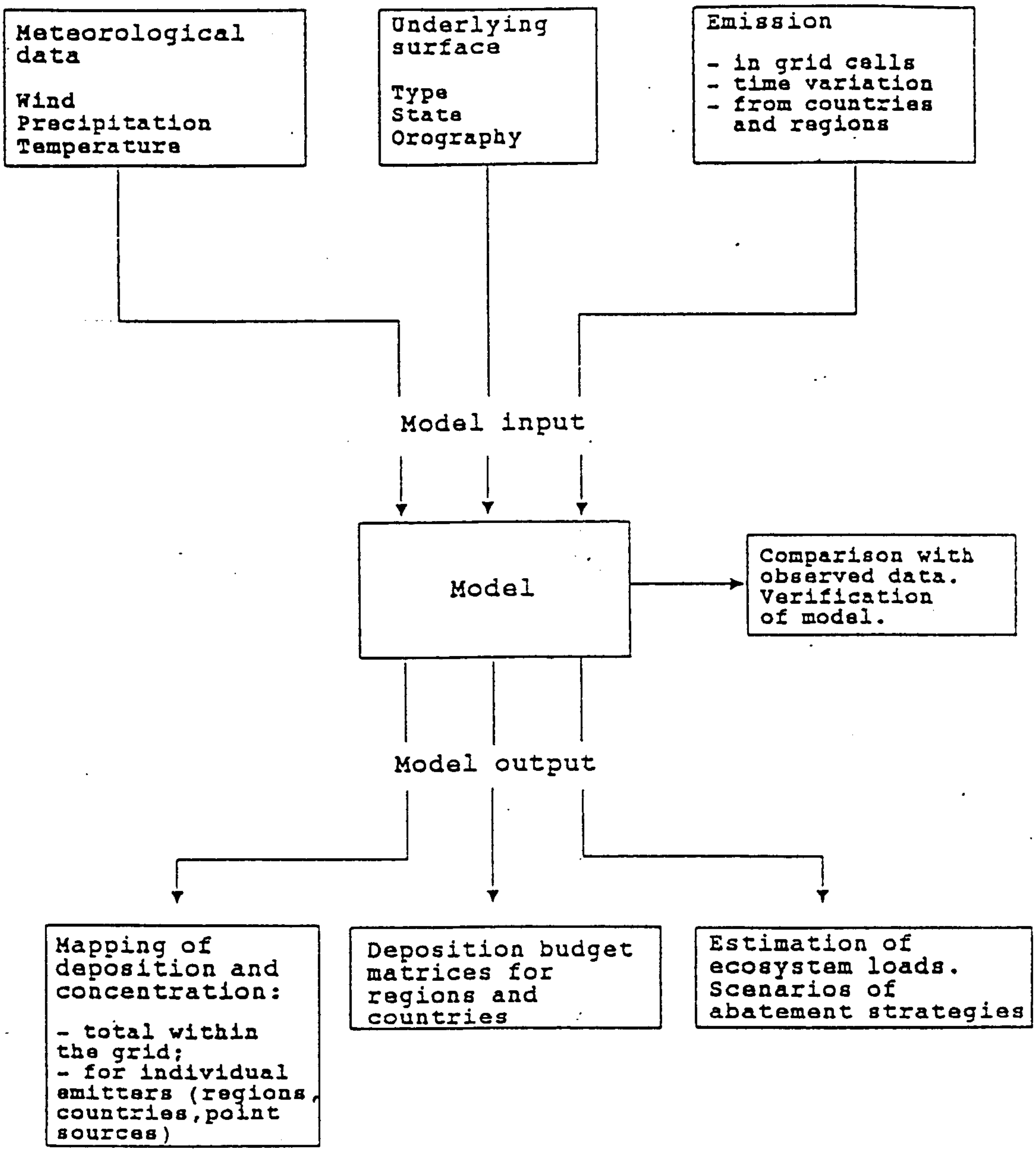


Fig. 2. Scheme of modelling.

Рис.2. Схема моделирования.

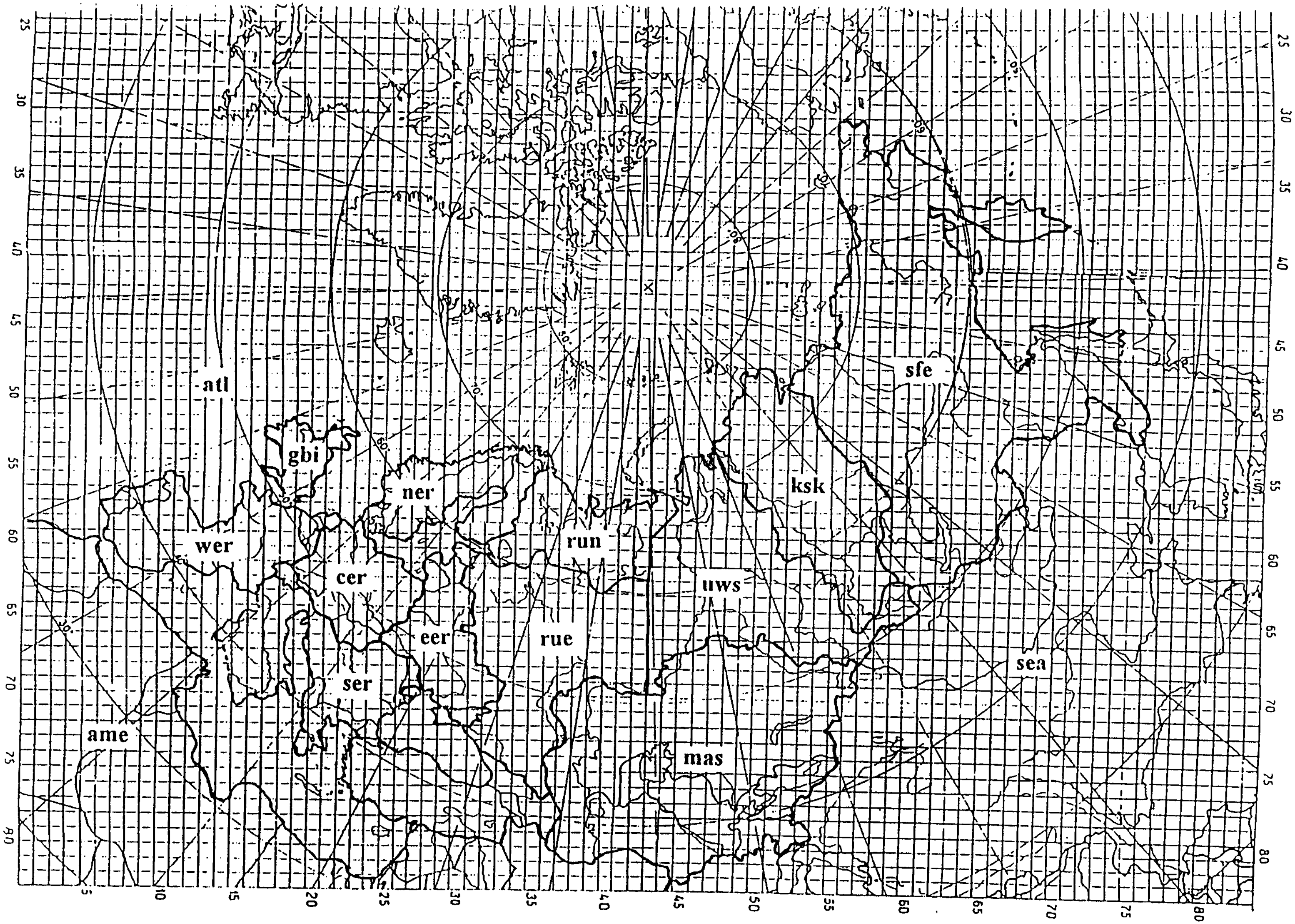


Fig. 3. Allocation of the chosen regions.
Рис.3. Расположение выделенных регионов.

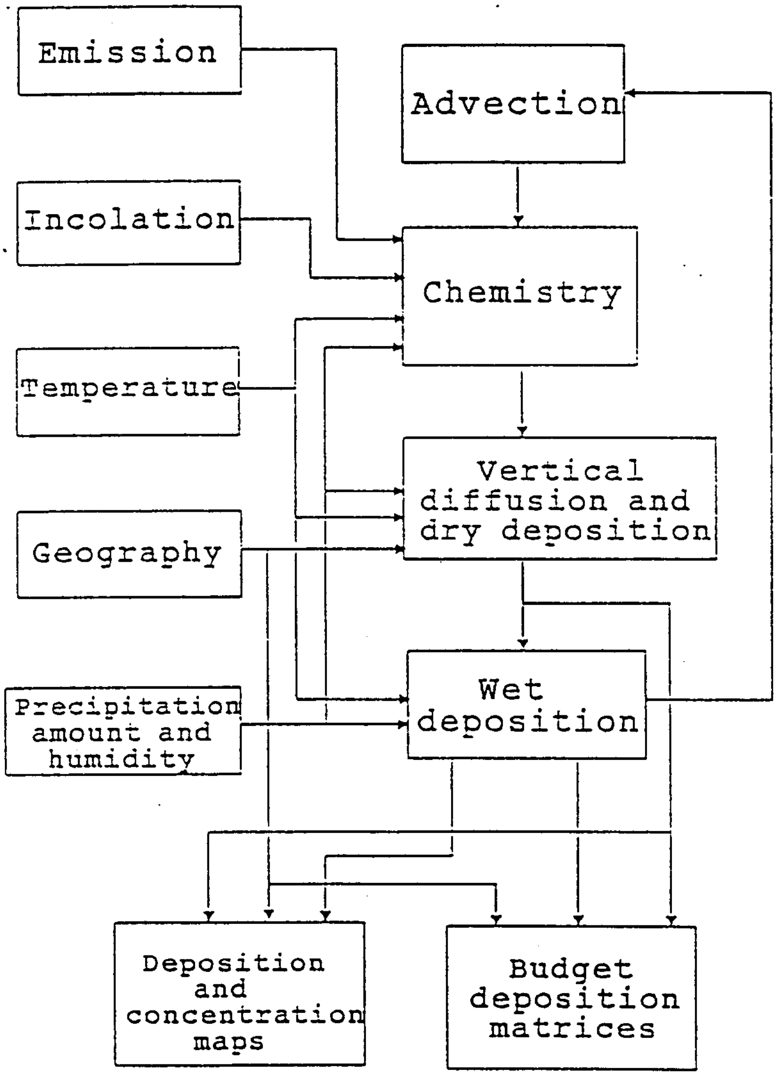


Fig.4. Calculation scheme.
Рис.4. Схема расчетов.

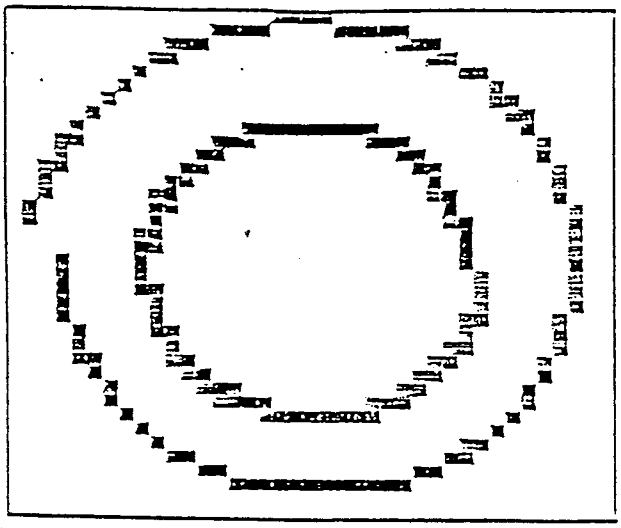


Fig.5.

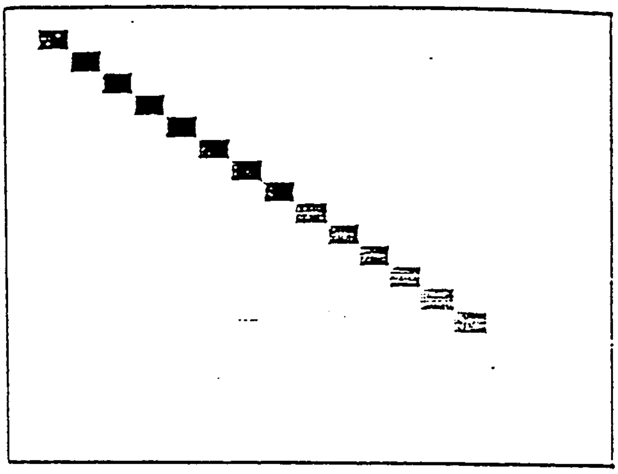


Fig.6.

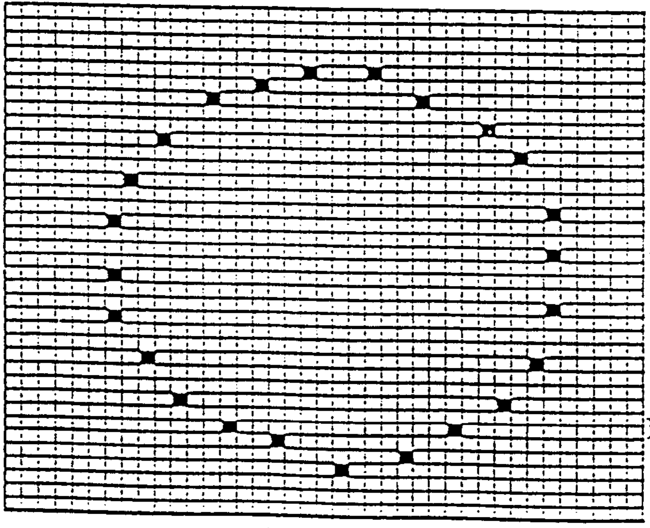


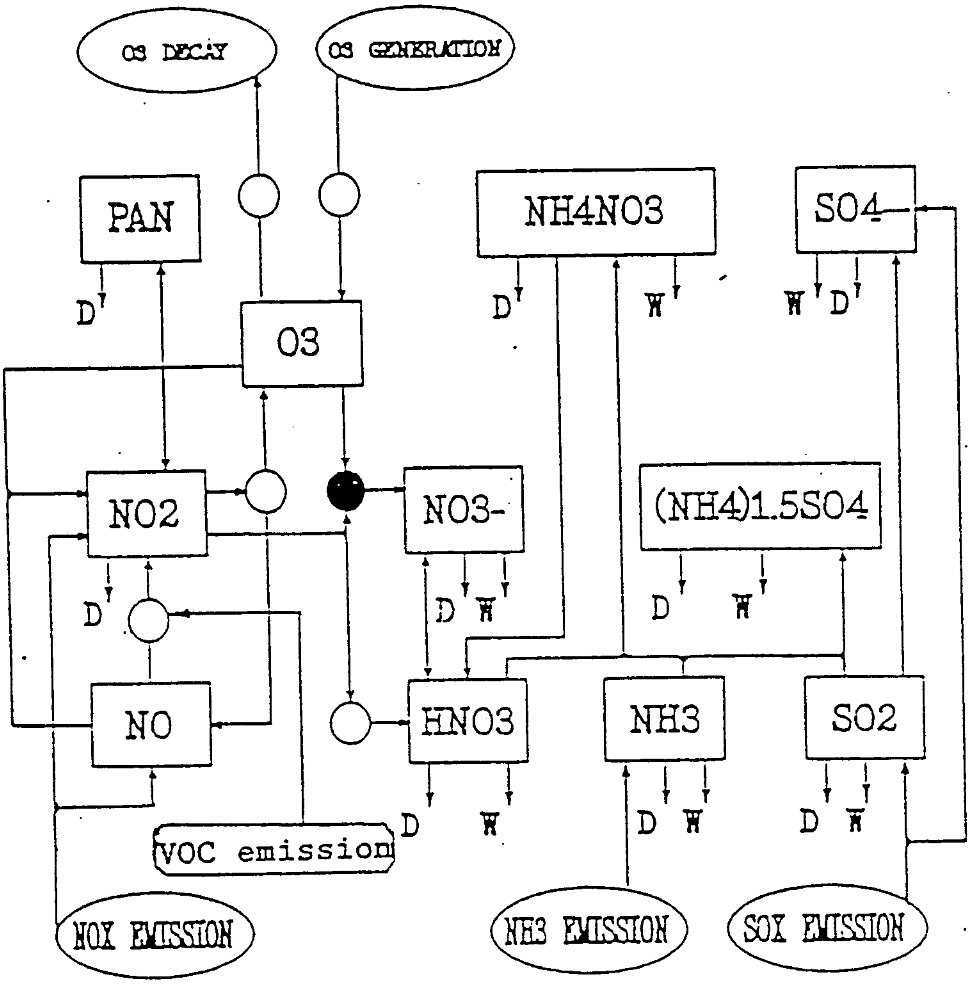
Fig.7.

Test model results:

Fig.5. The 6-days plumes from two point continuous sources in circular vortes (angular velocity 60° per day).

Fig.6. The 2-days plume from continuous source; both wind components are equal to 0.3 of grid size per hour.

Fig.7. Sequential location (in every 6 hours) of isolated puff in circular vortex (angular velocity 60° per day).



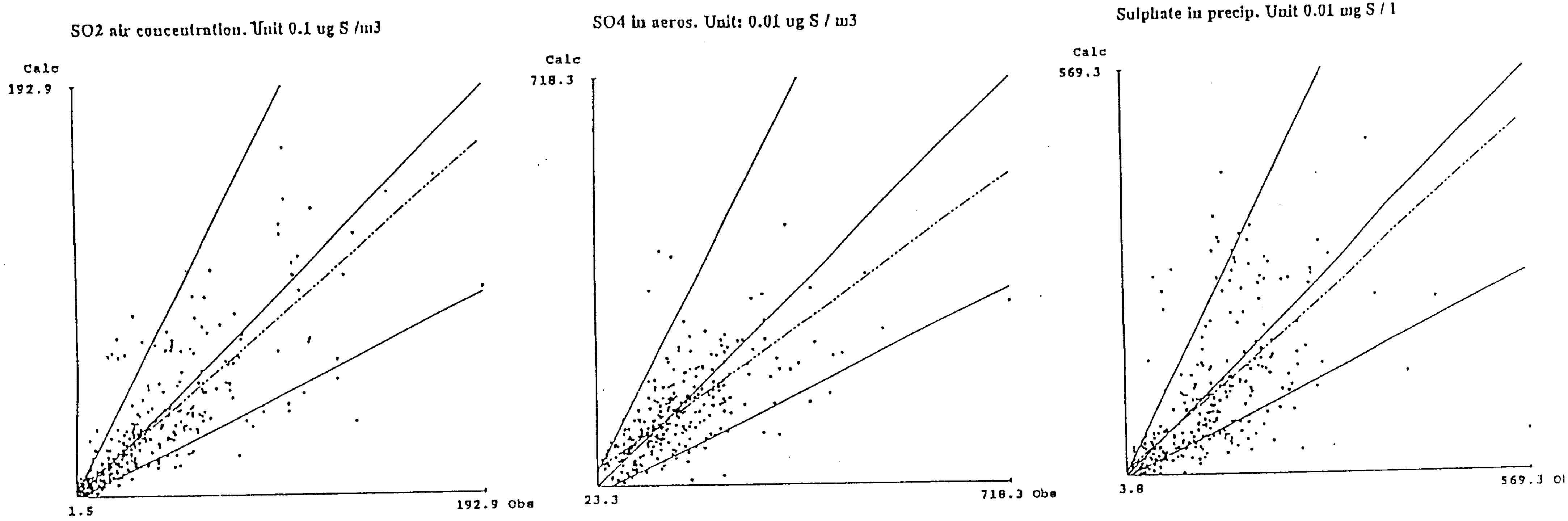
○ - Photochemical reaction

● - Dark reaction

D - Dry deposition

W - Wet deposition

Fig.8. Model chemical scheme.
Рис.8. Химическая схема модели.



SO2 air concentration. Unit 0.1 ug S /m3

SO4 in aeros. Unit: 0.01 ug S / m3

Sulphate in precip. Unit 0.01 mg S / l

Regression coefficients:

Methods	A	B
CPEH	0.846	3.228
Number of points	299	
Mean Calculated	33.232	
Mean Observed	35.941	
Correlation	0.762	

Regression coefficients:

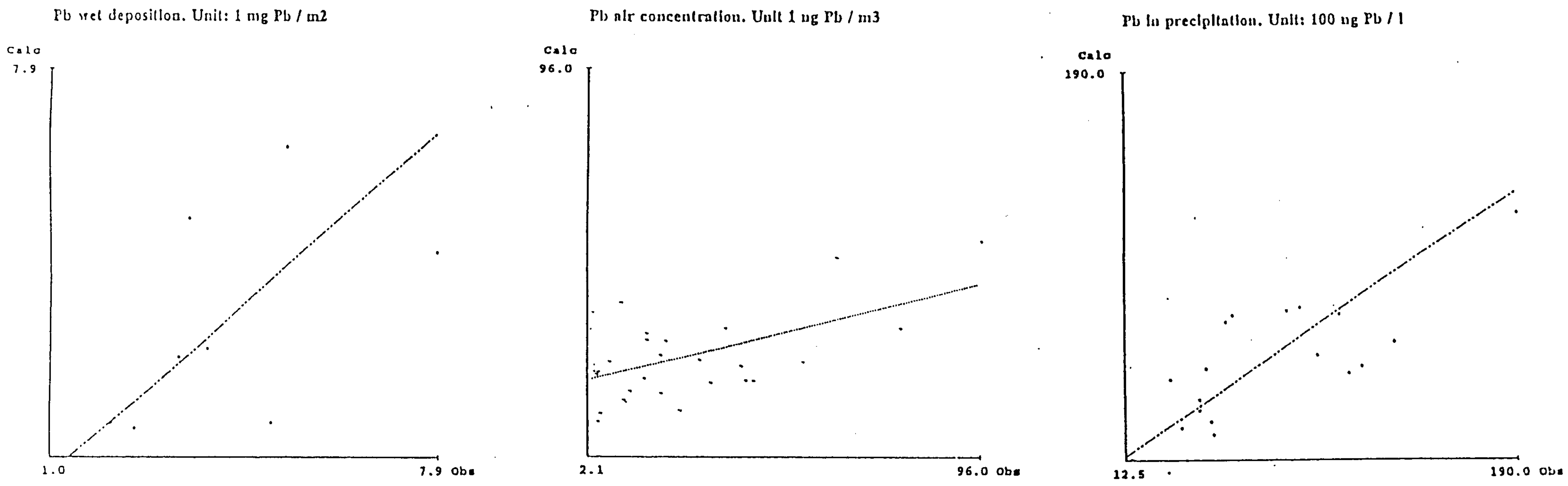
Methods	A	B
CPEH	0.717	37.028
Number of points	275	
Mean Calculated	148.820	
Mean Observed	159.279	
Correlation	0.647	

Regression coefficients:

Methods	A	B
CPEH	0.861	8.4
Number of points	257	
Mean Calculated	114.504	
Mean Observed	125.076	
Correlation	0.543	

Fig.9. Comparison of sulphur compound annual concentrations observed on EMEP stations and calculated by MSC-E model for 1987-1991

Рис.9. Сравнение расчетных среднегодовых значений соединений серы с наблюдениями на станциях ЕМЕП за 1987-1991 года.



Regression coefficients:

Methods	A	B
CPEM	0.874	-0.157
Number of points	10	
Mean Calculated	2.865	
Mean Observed	3.556	
Correlation	0.653	

Regression coefficients:

Methods	A	B
MLS-Stand	0.238	20.172
Number of points	30	
Mean Calculated	25.783	
Mean Observed	23.563	
Correlation	0.548	

Regression coefficients:

Methods	A	B
CPEM	0.679	5.619
Number of points	19	
Mean Calculated	54.500	
Mean Observed	75.605	
Correlation	0.772	

Fig.10. Comparison of Pb observed and calculated wet deposition and concentrations

Рис.10. Сравнение результатов расчетов и наблюдений концентраций и выпадений свинца.

Fig.11. Total deposition of sulphur compounds to the Arctic (Unit=10 mg(S)/m^2) in 1991.

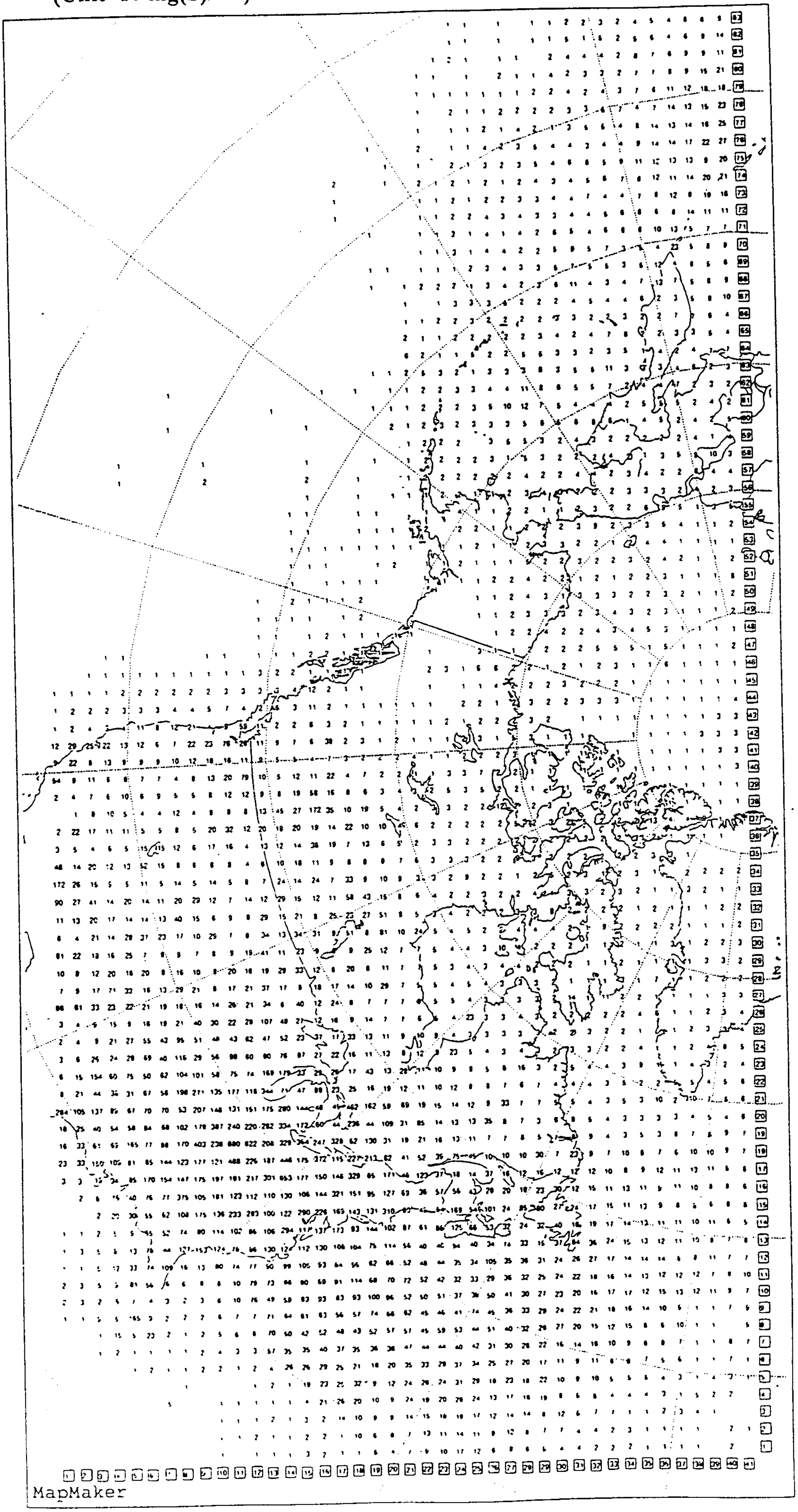


Рис.11. Суммарные выпадения соединений серы на Арктику (Ед.изм.=10 $mg(S)/m^2$) в 1991 г.

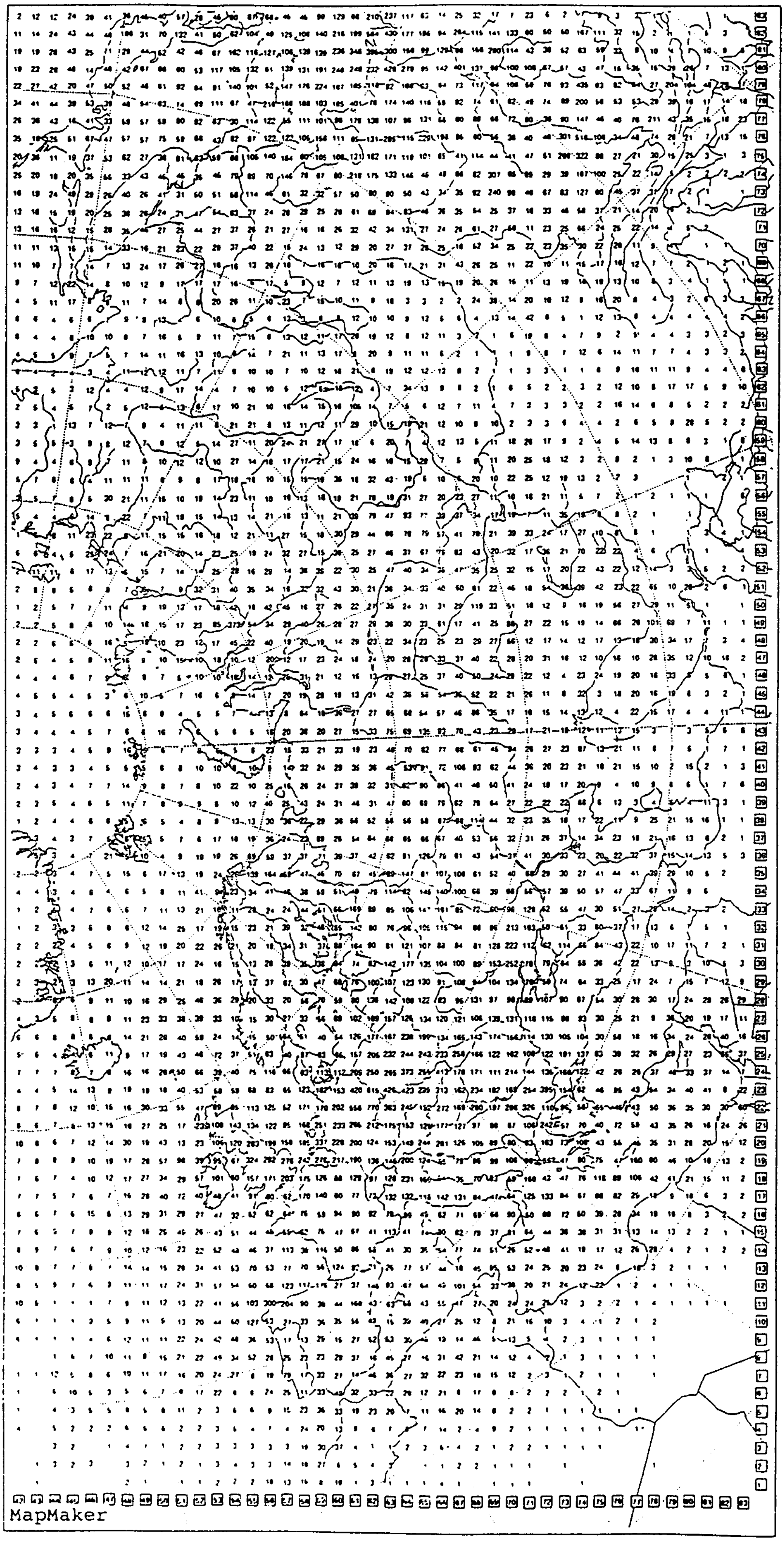
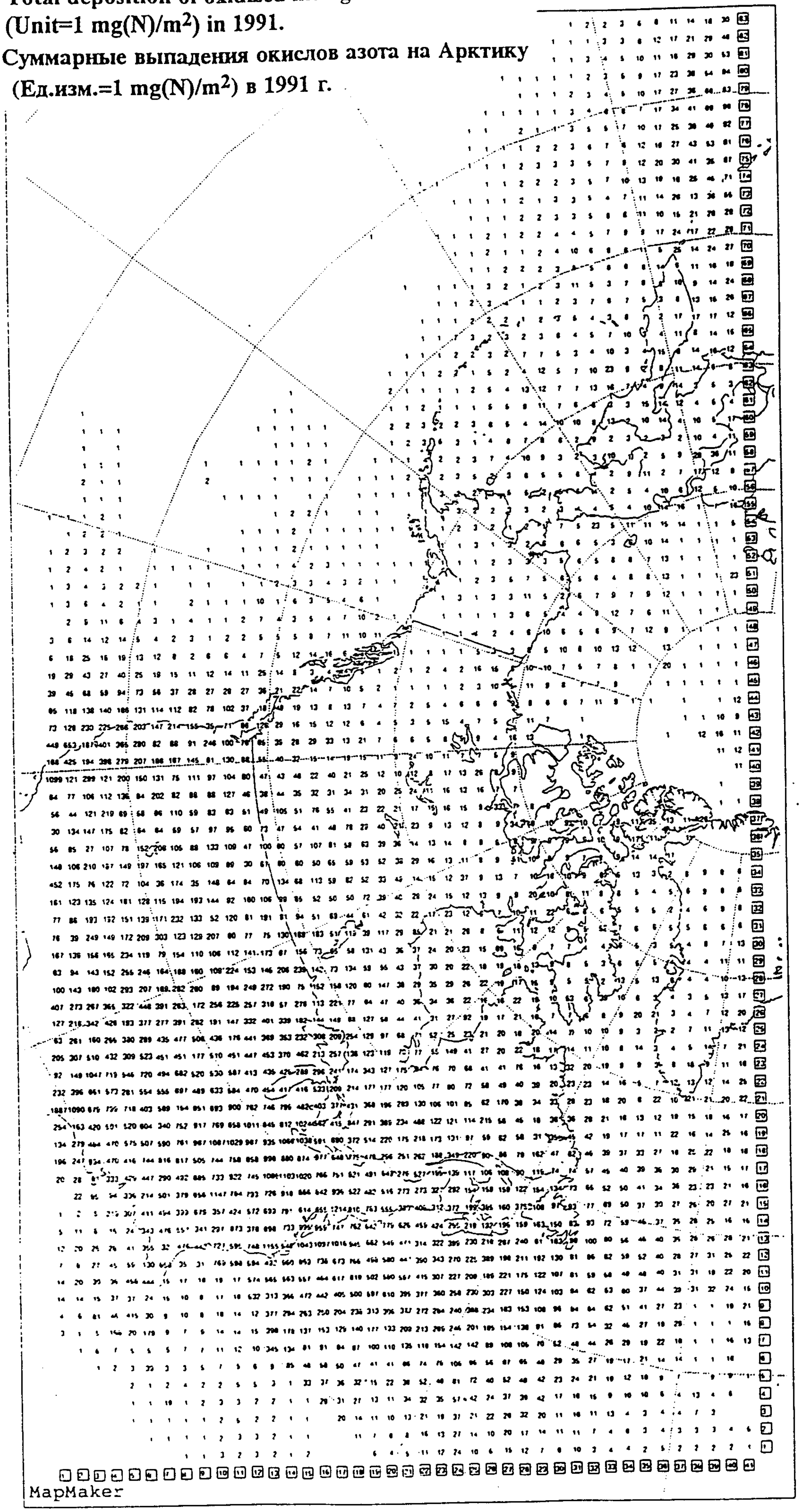


Fig.12. Total deposition of oxidized nitrogen to the Arctic (Unit=1 mg(N)/m^2) in 1991.

Рис.12. Суммарные выпадения окислов азота на Арктику (Ед.изм.=1 mg(N)/m^2) в 1991 г.



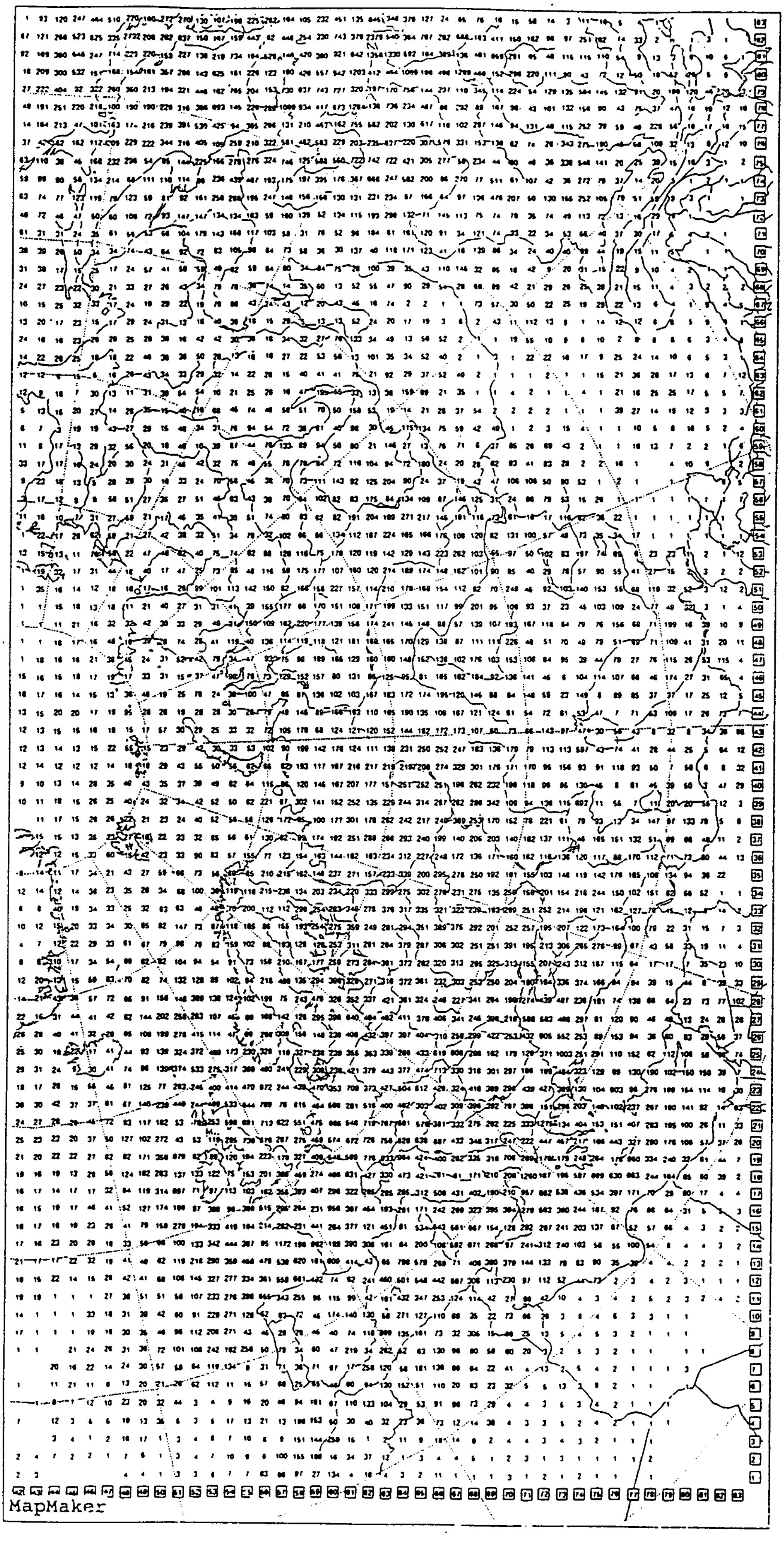

MapMaker

Fig.13. Total deposition of reduced nitrogen to the Arctic (Unit=1 mg(N)/m^2) in 1991.

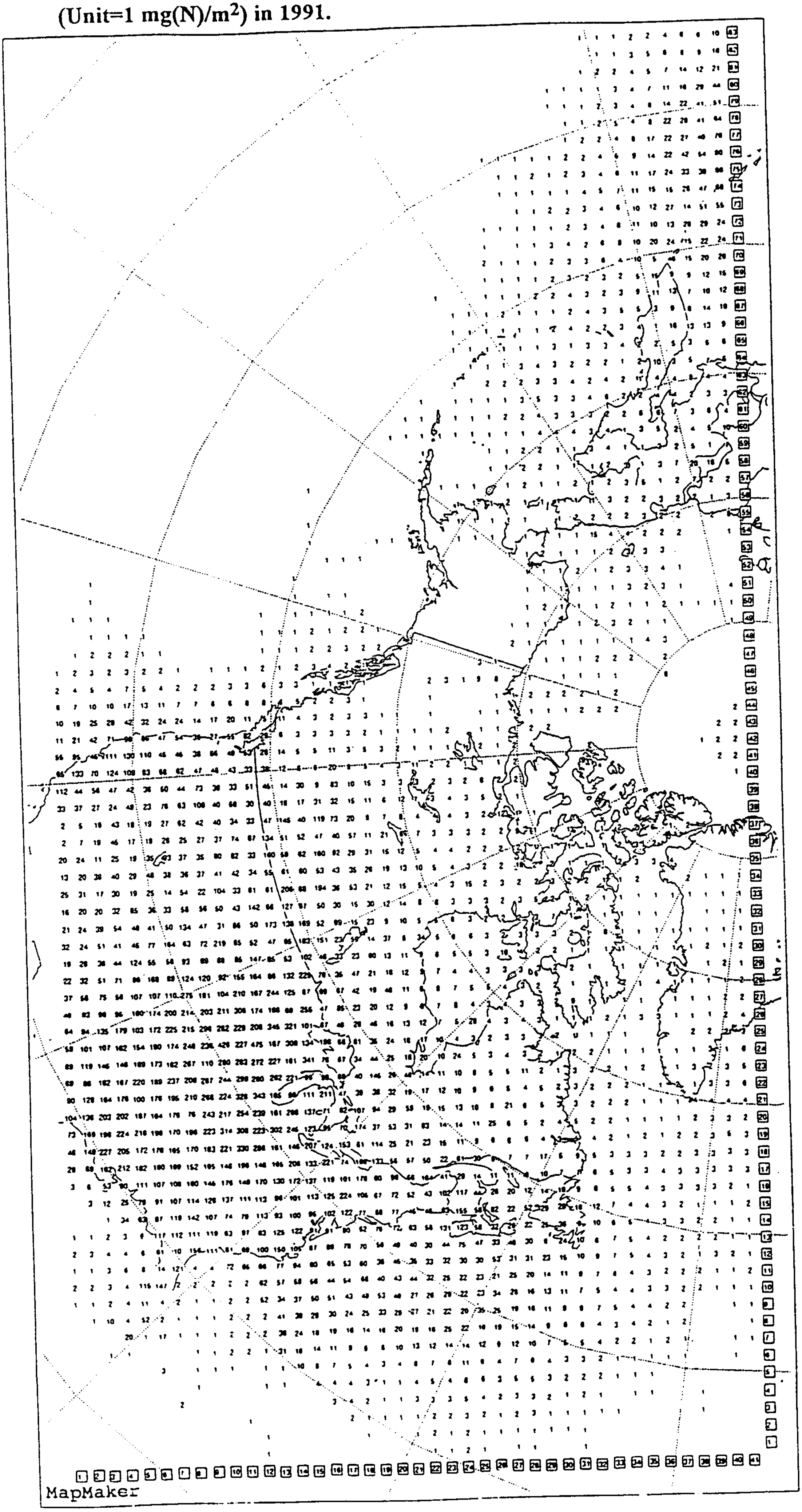


Рис.13. Суммарные выпадения восстановленного азота на Арктику (Ед.изм.=1 mg(N)/m^2) в 1991 г.

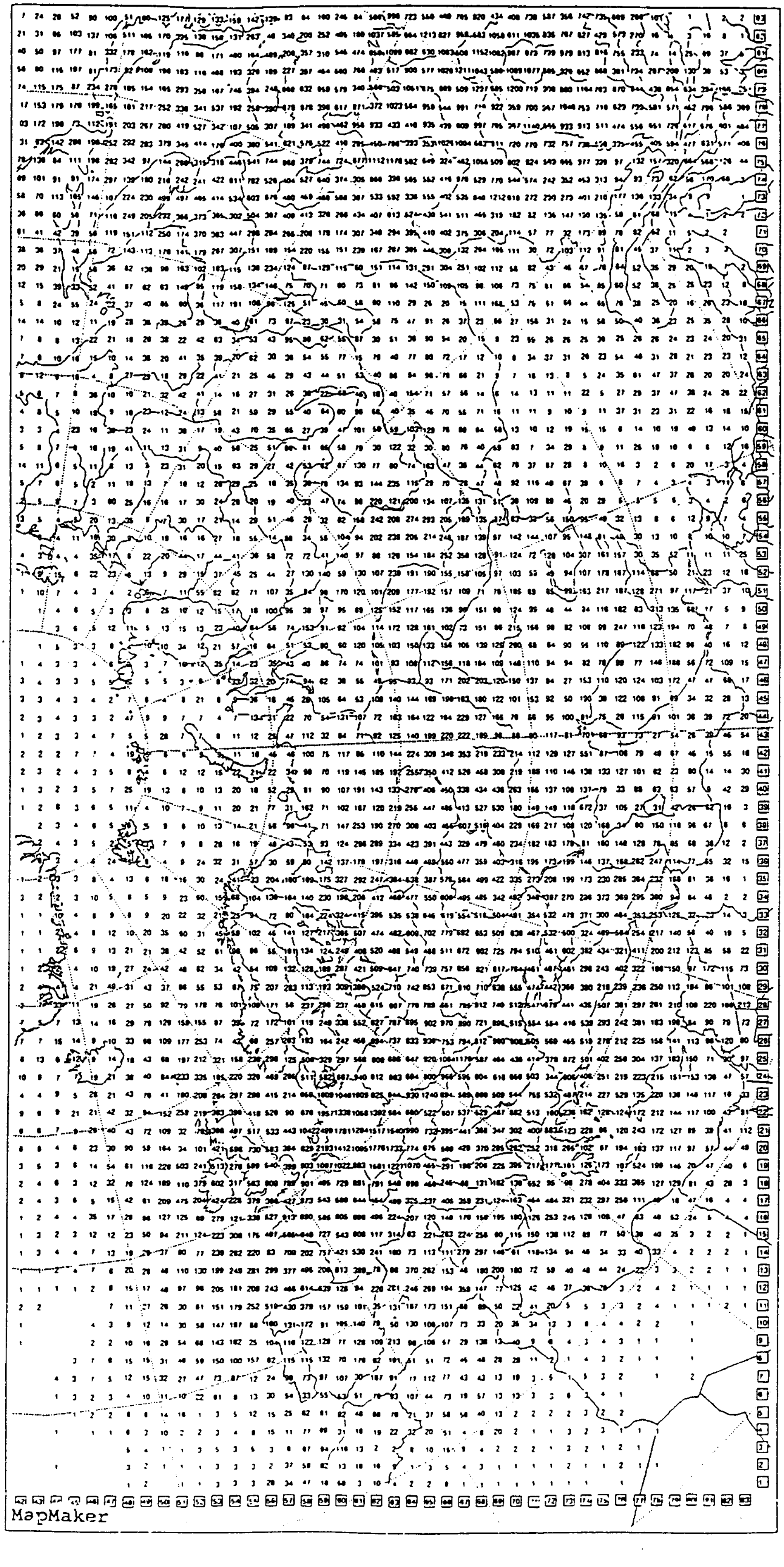
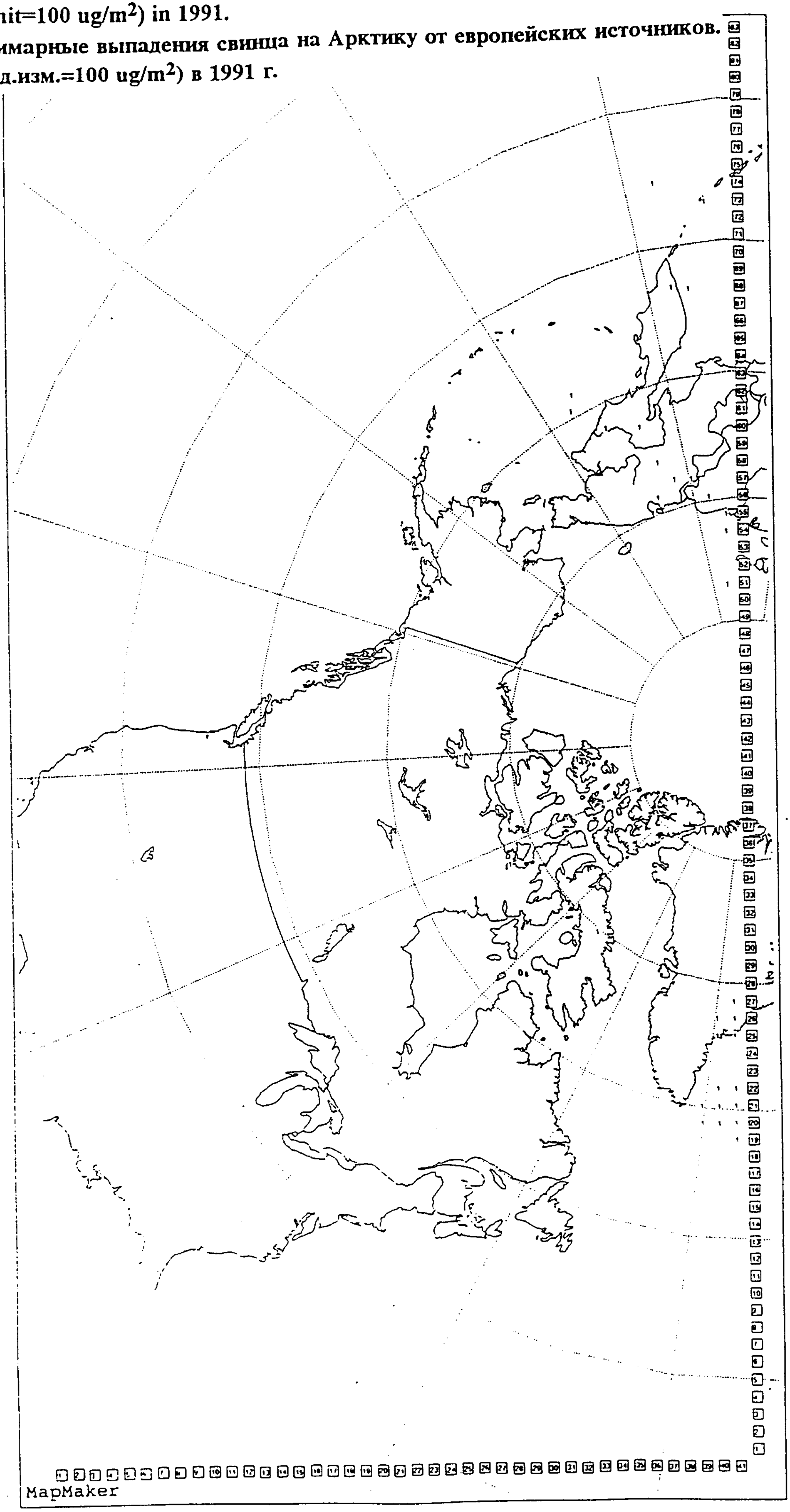


Fig.14. Total deposition of lead from the European sources to the Arctic (Unit=100 ug/m^2) in 1991.

Рис.14. Суммарные выпадения свинца на Арктику от европейских источников. (Ед.изм.=100 ug/m^2) в 1991 г.



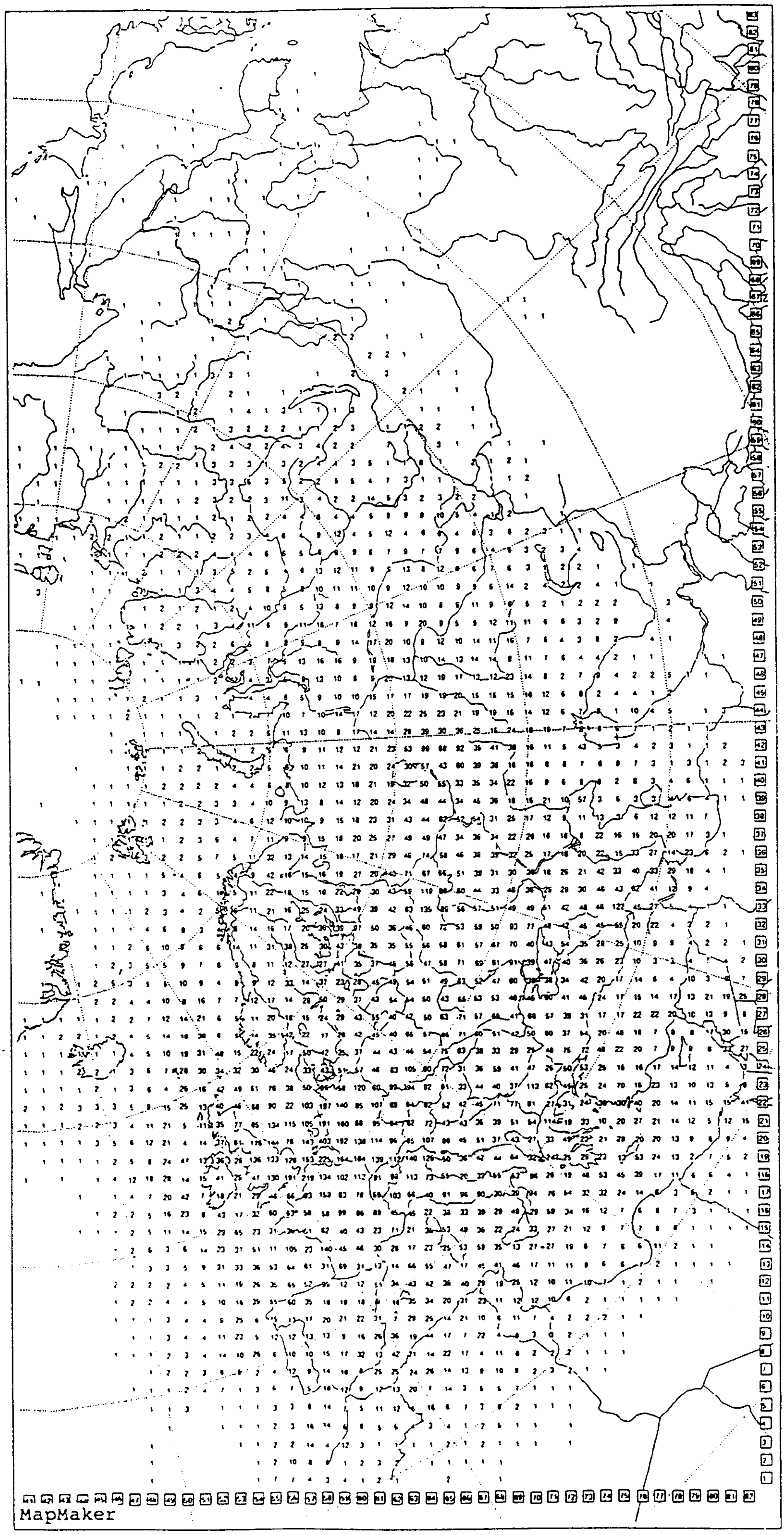

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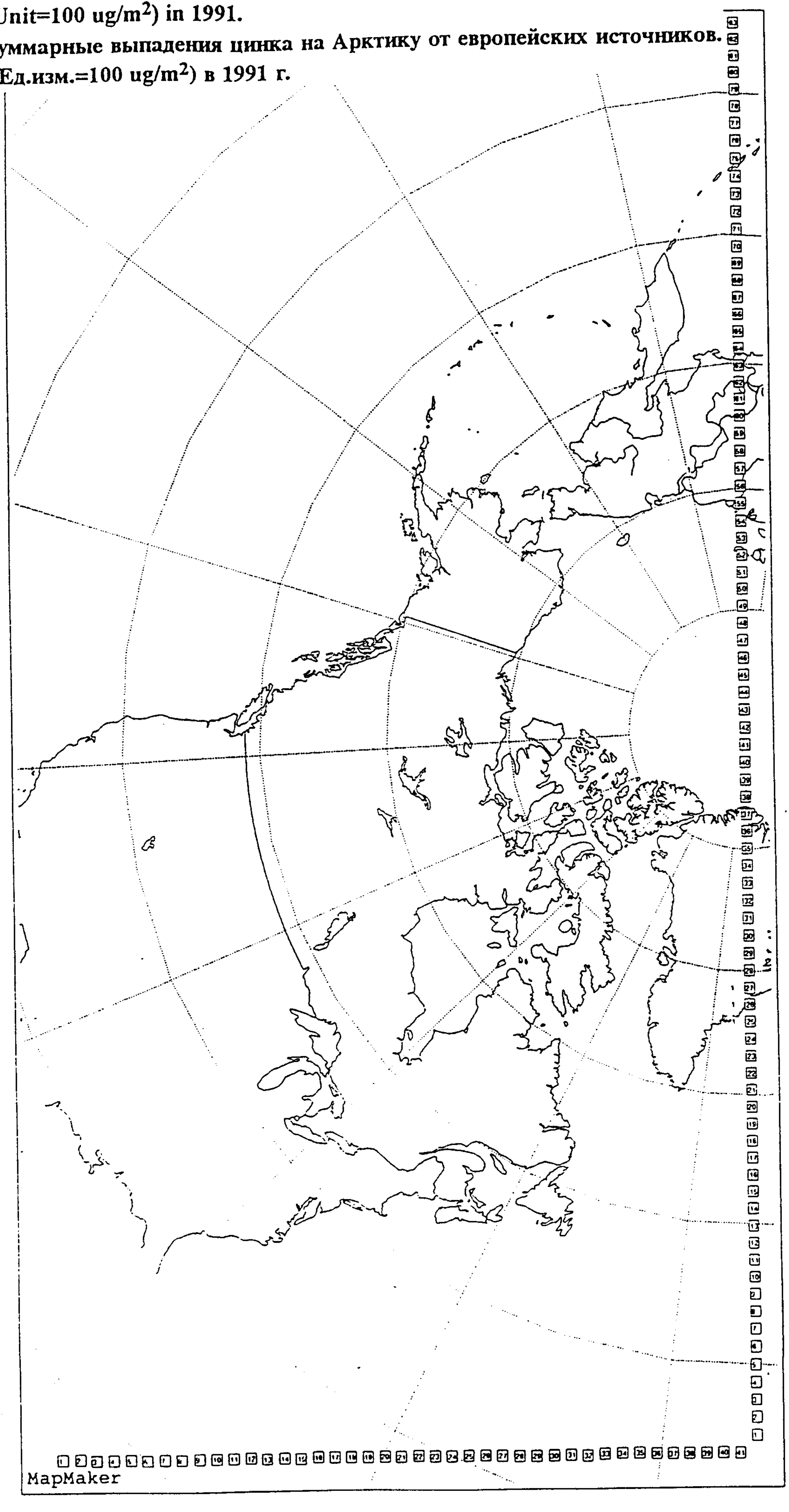
Fig.15. Total deposition of zink from the European sources to the Arctic (Unit=100 ug/m²) in 1991.

Рис.15. Суммарные выпадения цинка на Арктику от европейских источников. (Ед.изм.=100 ug/m²) в 1991 г.



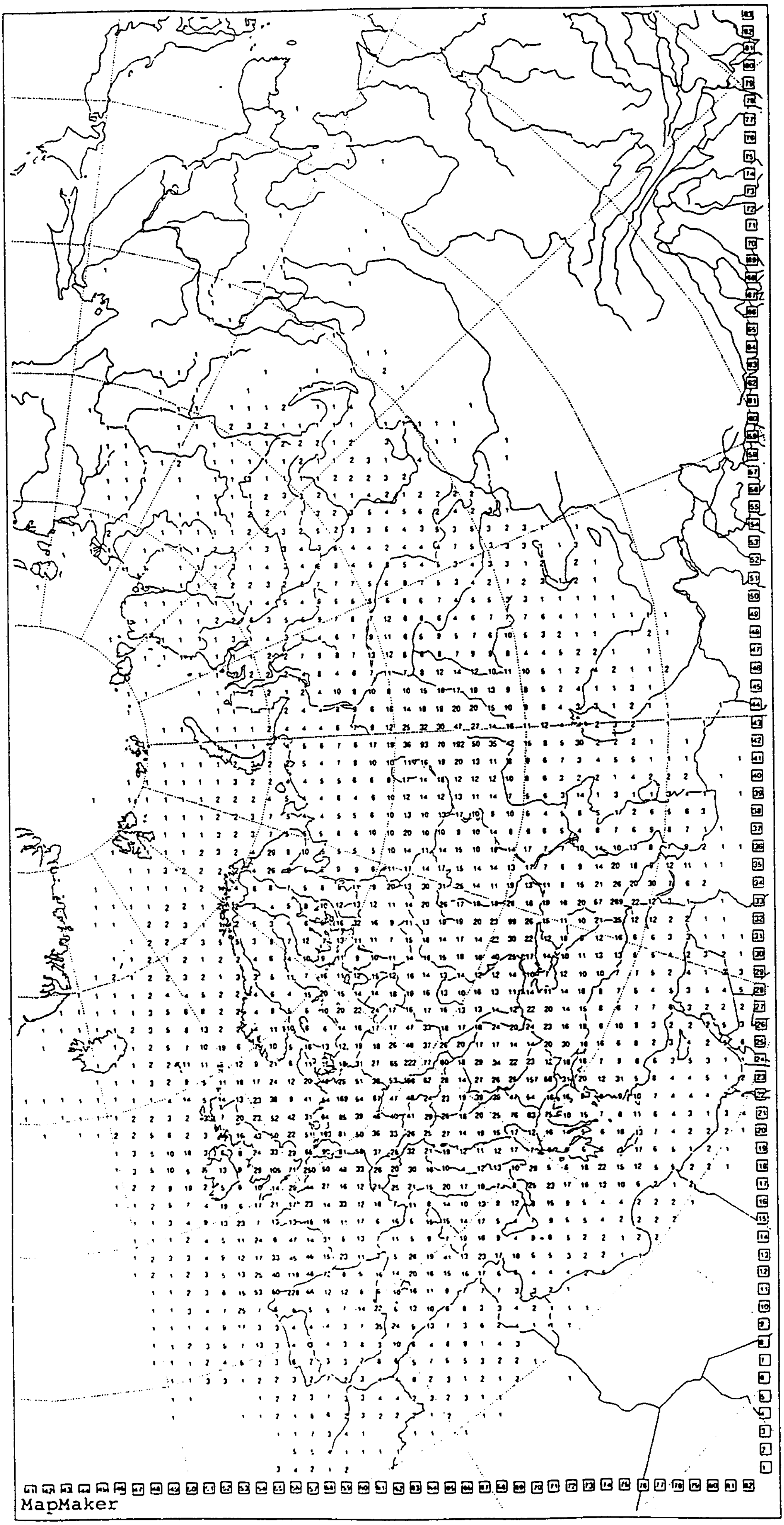
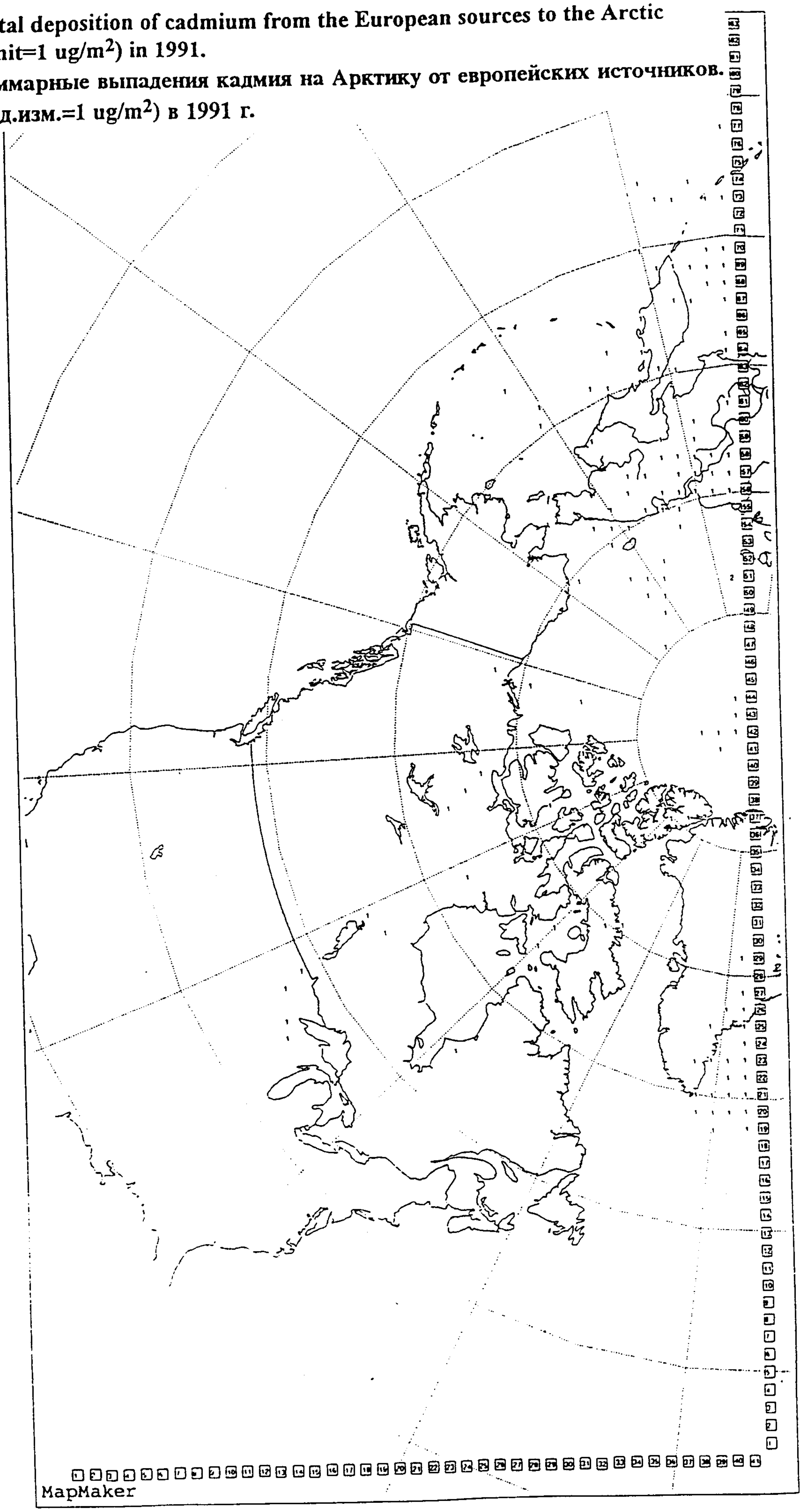
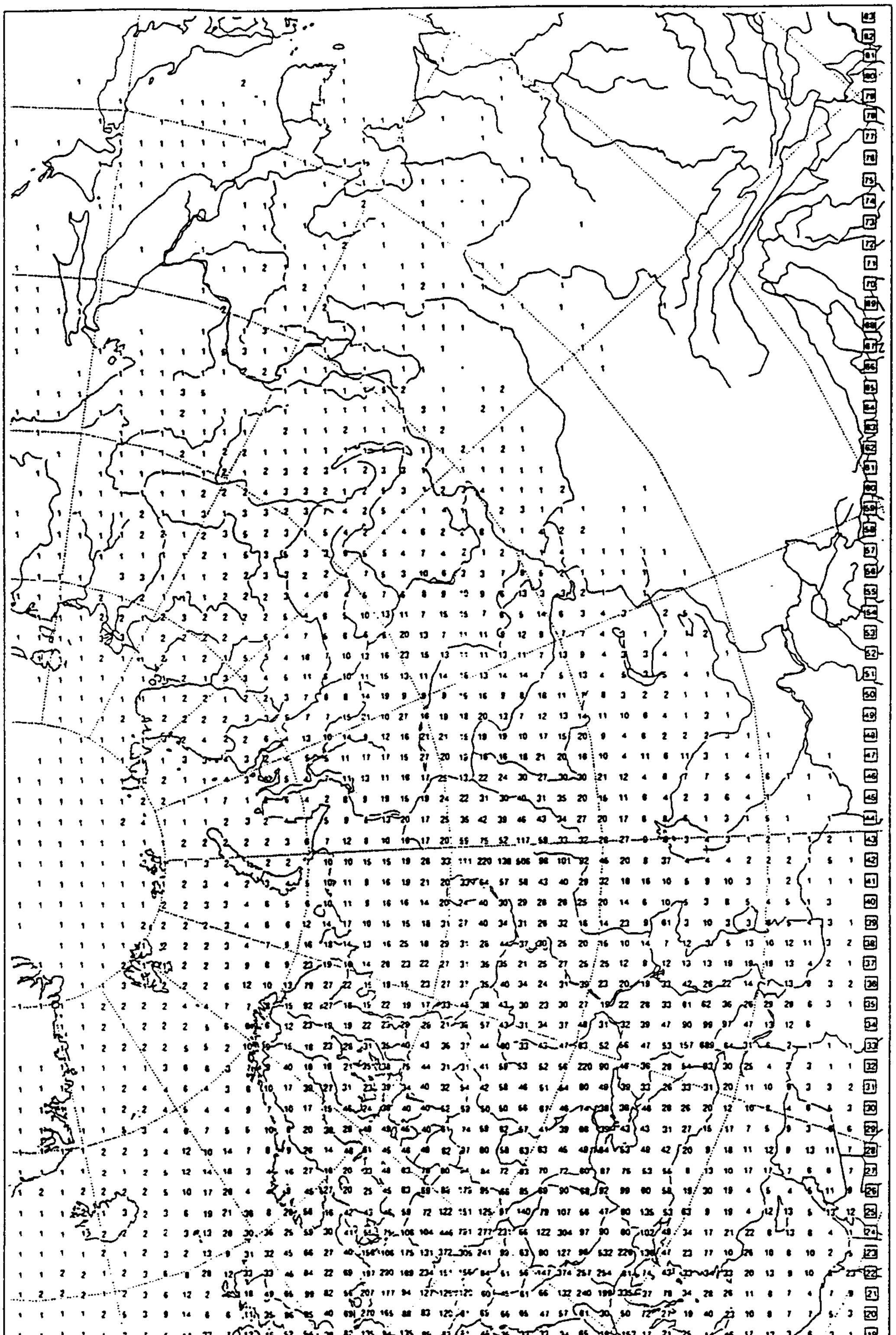

MapMaker

Fig.16. Total deposition of cadmium from the European sources to the Arctic (Unit=1 ug/m^2) in 1991.

Рис.16. Суммарные выпадения кадмия на Арктику от европейских источников. (Ед.изм.=1 ug/m^2) в 1991 г.





MapMaker

Fig.17. Total deposition of arsenic from the European sources to the Arctic (Unit=10 ug/m^2) in 1991.

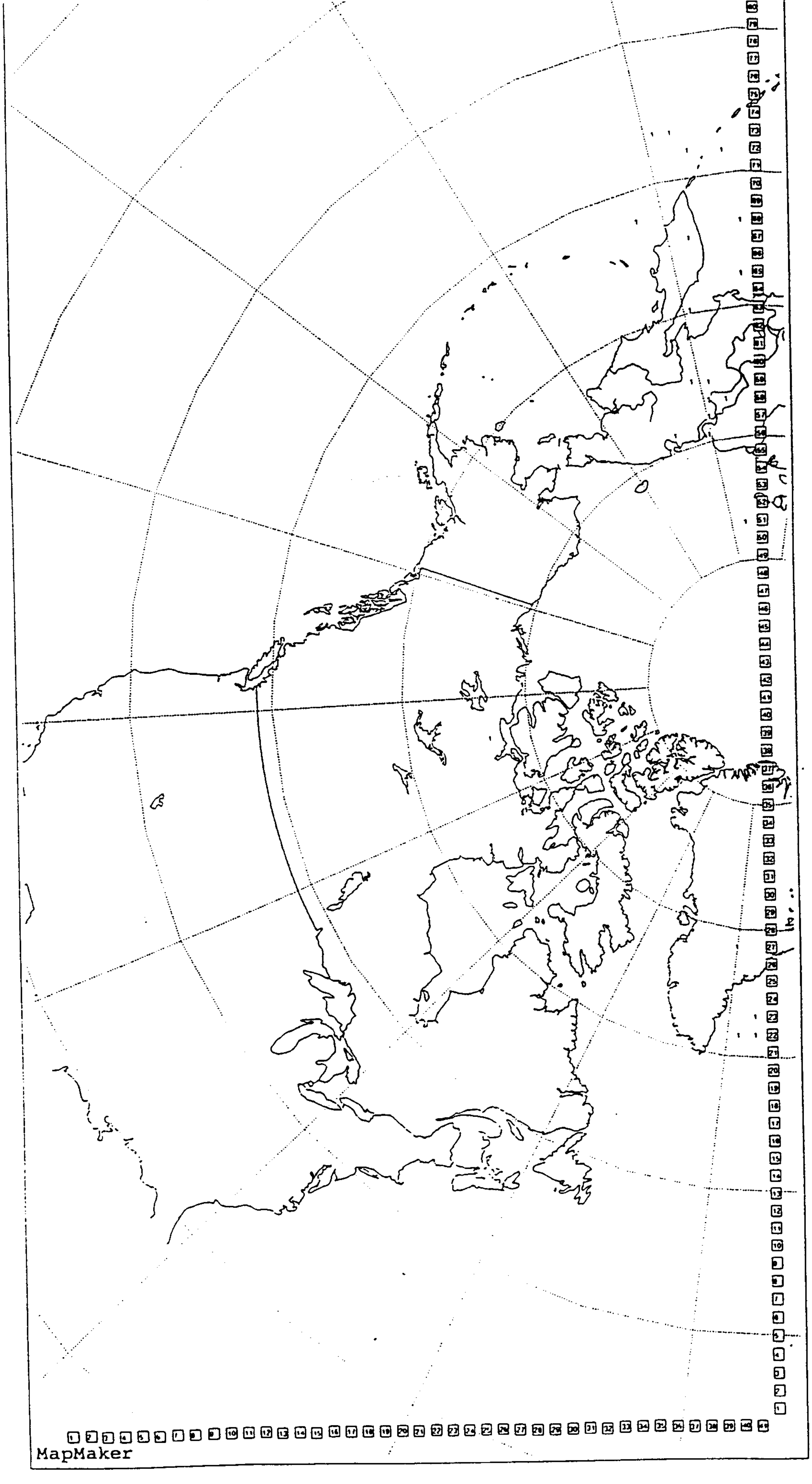


Рис.17. Суммарные выпадения мышьяка на Арктику от европейских источников. (Ед.изм.=10 ug/m^2) в 1991 г.

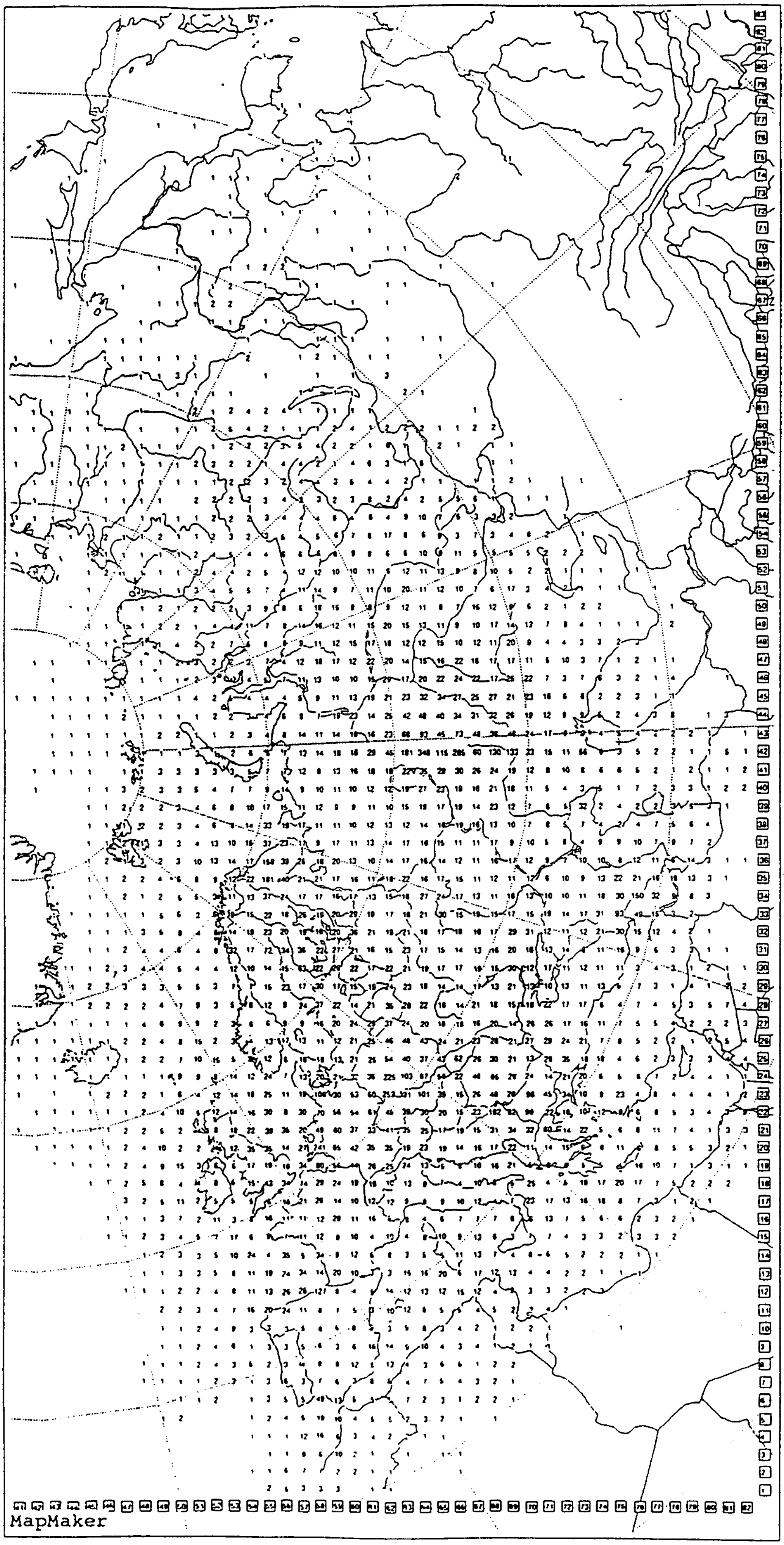
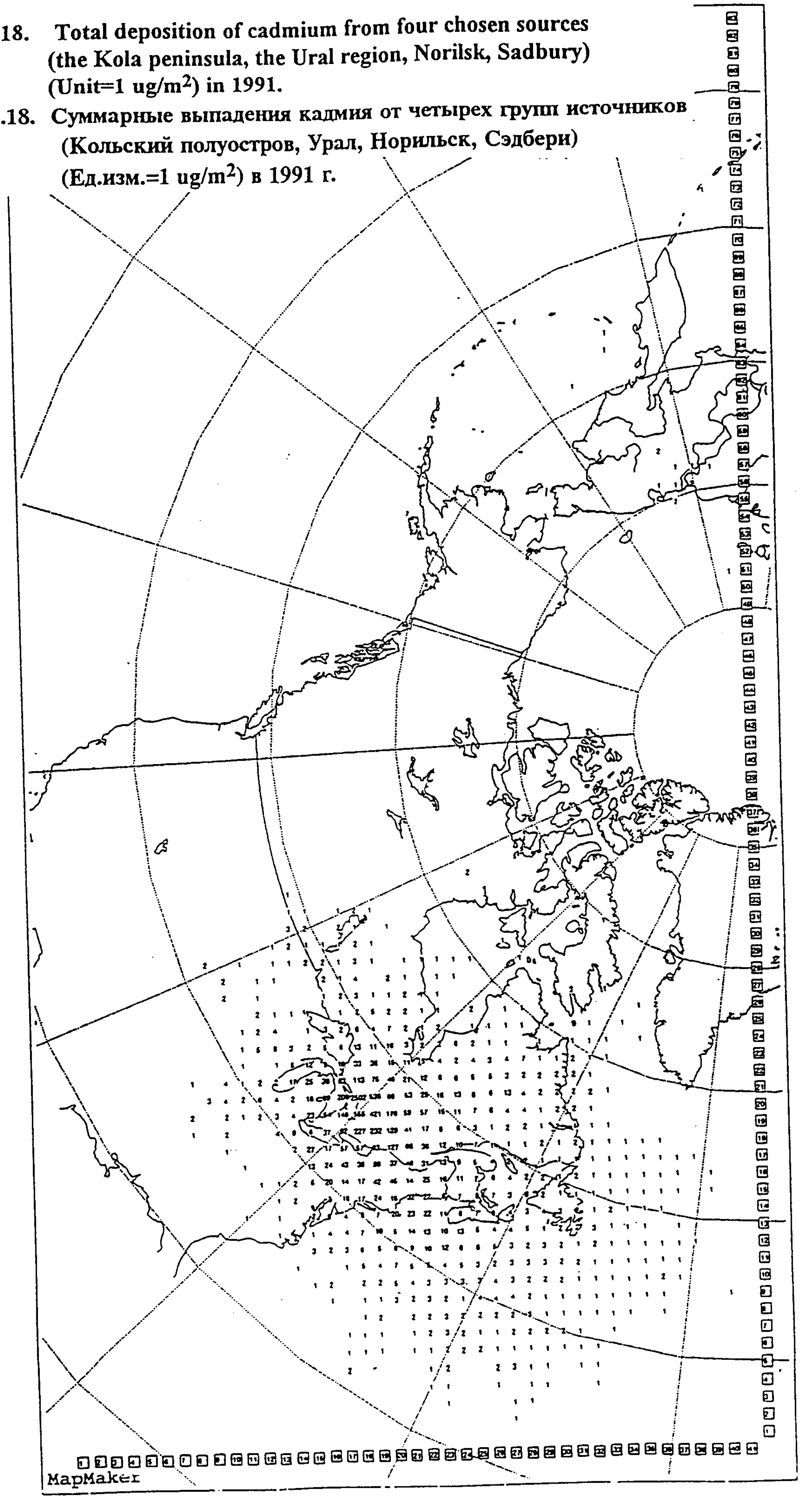
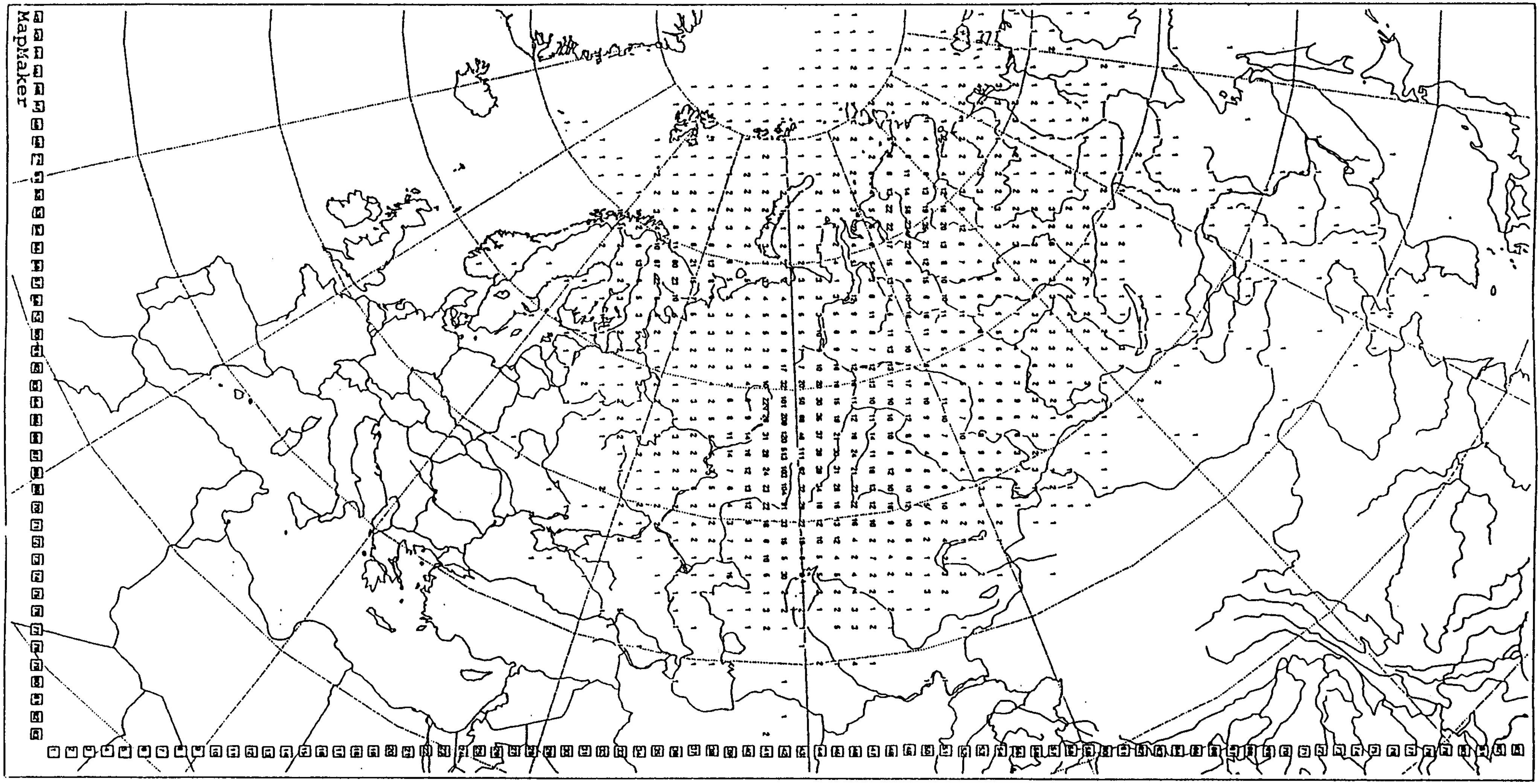


Fig.18. Total deposition of cadmium from four chosen sources
(the Kola peninsula, the Ural region, Norilsk, Sadbury)
(Unit=1 ug/m²) in 1991.

Рис.18. Суммарные выпадения кадмия от четырех групп источников
(Кольский полуостров, Урал, Норильск, Сэдбери)
(Ед.изм.=1 ug/m²) в 1991 г.

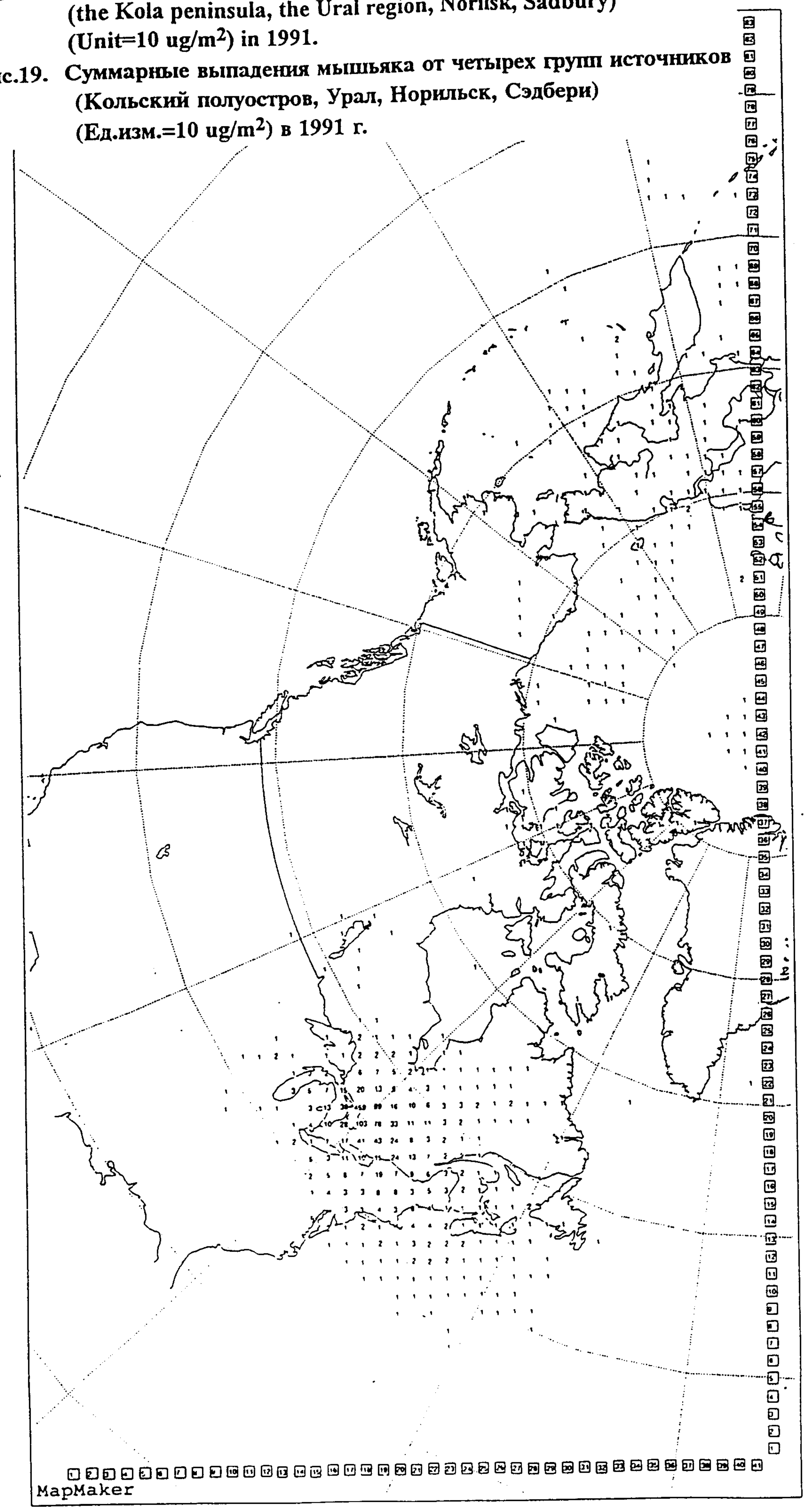


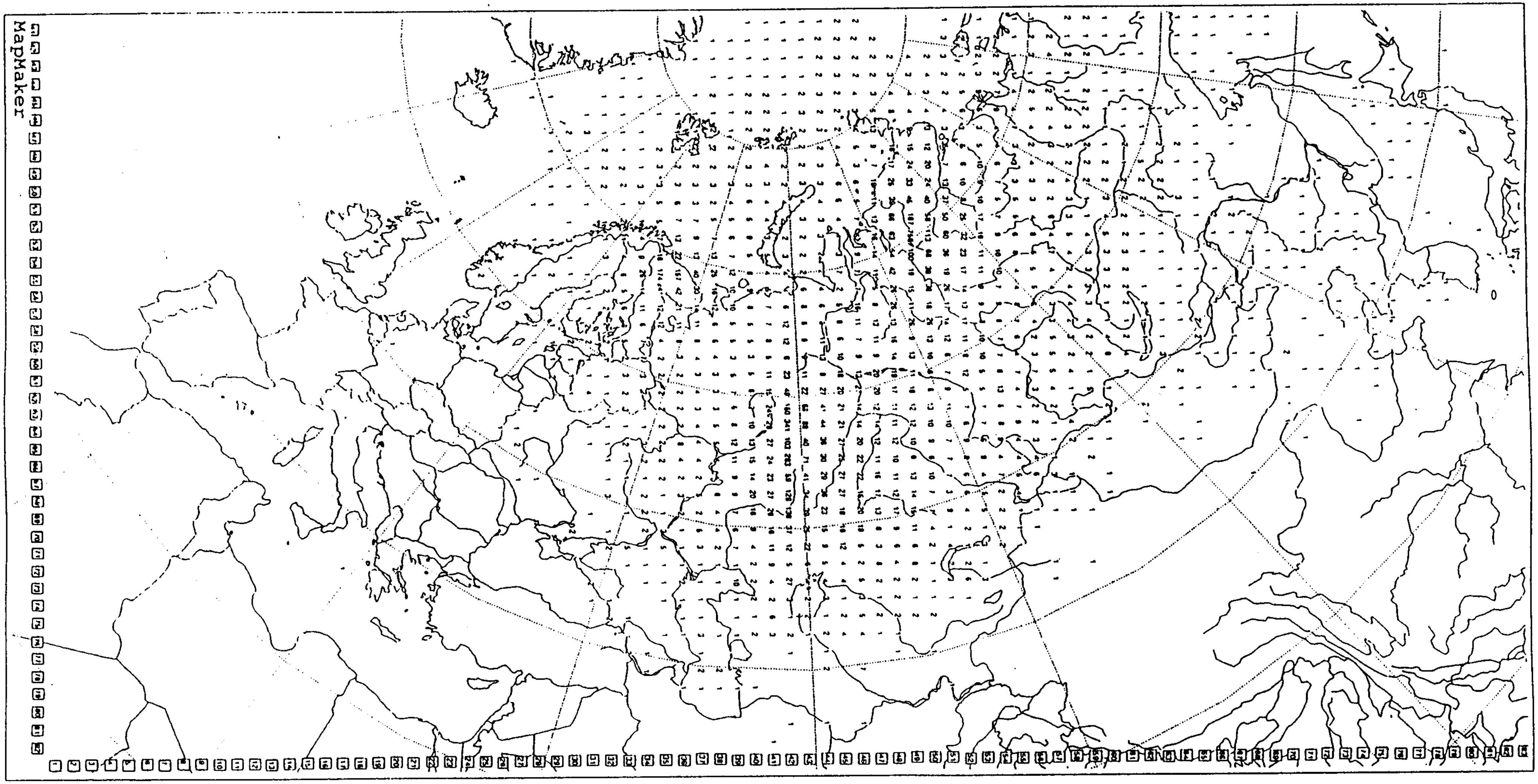


MapMaker

Fig.19 Total deposition of arsenic from four chosen sources (the Kola peninsula, the Ural region, Norilsk, Sadbury) (Unit=10 ug/m^2) in 1991.

Рис.19. Суммарные выпадения мышьяка от четырех групп источников (Кольский полуостров, Урал, Норильск, Сэдбери) (Ед.изм.=10 ug/m^2) в 1991 г.




MapMaker

Alexey Ryaboshapko

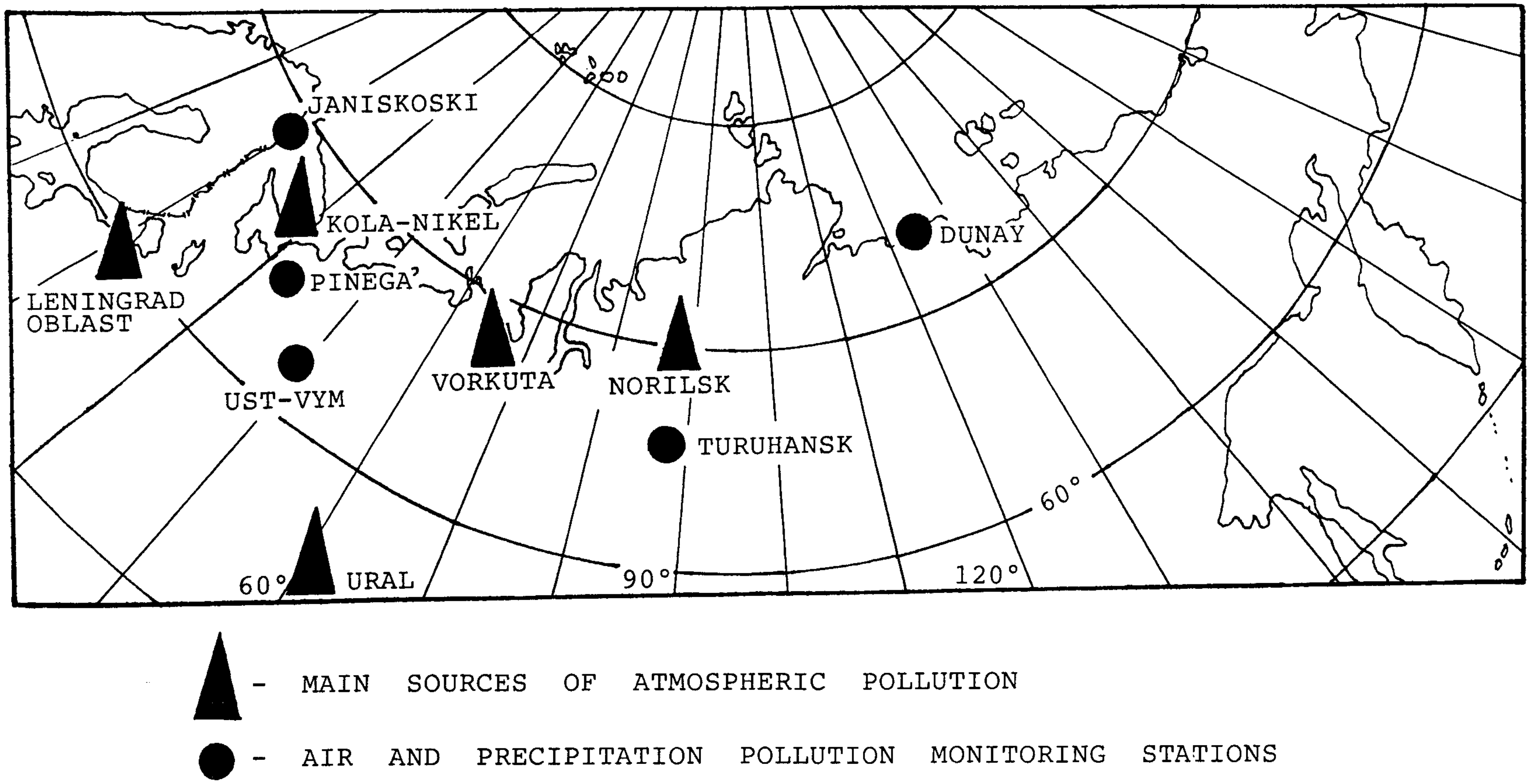
INVESTIGATIONS CARRIED OUT BY INSTITUTIONS OF RUSSIAN FEDERAL SERVICE FOR HYDROMETEOROLOGY AND ENVIRONMENTAL MONITORING (HYDROMET)

Russian sector of the Arctic ranges from 30 degree East to 170 degree West engaging about 45% of the Arctic area. More than 2.5 million people in Russia are living northward of the Polar Circle. Some areas of Russian Arctic are very industrialized. The main industrial branches here are extracting and processing metal ores and fossil fuels. Industrial enterprises in the Arctic and sub-Arctic zones are strong sources of atmospheric pollution. Taking into account economical importance of the Arctic, its potential capacity for the subsequent development of the country, and already existing ecological problems in the Arctic the Russian Federation are objectively interested in environment protection in the Arctic and in assessment of consequences of global changes in its environment and climate.

Monitoring of atmospheric precipitation composition in the USSR territory including Arctic and sub-Arctic areas was begun at the end of the 50th. During the 70th international programs of integrated background monitoring and monitoring of long-range transport of air pollutants commenced their developing in the country. At present all observations have being integrated into the Global Atmospheric Watch under the auspices of the WMO. As a result of such development some permanent stations for monitoring of atmospheric pollution and precipitation chemistry were established in the Arctic and sub-Arctic areas of Russia (see figure). Besides that investigations of atmospheric pollution levels over some territories of special interest, in particular at drifting and island Arctic stations were carried out. Such monitoring activities and atmospheric pollution assessment in the Arctic have being carried out mainly by the Institute of Global Climate and Ecology (IGCE), the Main Geophysical Observatory (MGO), the Institute of Arctic and Antarctic (IAA), the Meteorological Synthesizing Center - East (MSC-E), the Regional Center "Arctic Monitoring", and by Hydrometeorological Departments in the Northern provinces of Russia.

In addition to monitoring and assessment activity some projects on pollutant emission inventories, model calculations of atmospheric transport of pollutants and their deposition on underlying surface were implemented by the above mentioned institutions. In 1992-1993 radiative properties of sulfate aerosols were investigated.

Observations of chemical composition of the atmosphere and atmospheric precipitation at permanent monitoring stations are carried out according to the following programs:


JANISKOSKI
KOLA-NIKEL
PINEGA'
LENINGRAD OBLAST
UST-VYM
VORKUTA
NORILSK
TURUHANSK
DUNAY
URAL
60°
90°
120°
60°
▲ - MAIN SOURCES OF ATMOSPHERIC POLLUTION
● - AIR AND PRECIPITATION POLLUTION MONITORING STATIONS

Station	Coordinates	Species and parameters	Sampling frequency	Program	Year of start
Janiskosky	69N,29E	Precipit.: SO_4,Cl,NO_3, NH_4,Na,K,Ca,Mg,pH,EC Aerosols: SO_4,NO_3,NH_4 Gases: SO_2,NO_x,O_3	1 d (*)	EMEP	1980
Pinega	65N,43E	Precipit.: SO_4,Cl,NO_3, NH_4,Na,K,Ca,Mg,pH,EC Aerosols: SO_4,NO_3,NH_4 Gases: SO_2,NO_2,O_3	1 d	EMEP	1989
Ust-Vym	62N,51E	Precipit.: SO_4,Cl,NO_3 HCO_3,NH_4,Na,K,Ca, Mg,pH,EC	30 ds	BAPMoN	1958
Turukhansk	66N,88E	Precipit.: SO_4,Cl,NO_3 HCO_3,NH_4,Na,K,Ca, Mg,pH,EC	30 ds	BAPMoN	1962
Dunay	74N,124E	Aerosols: POP, HM	7 ds	(**)	1993

Notes: (*) Ozone at Janiskosky station is measured at hourly base
(**) Russian - Canadian project of 1993-1995

In the vicinity of enterprises of nonferrous metallurgy in Kola peninsula annual observations on heavy metal contents in snow cover have been performed. Such observations gave possibility to estimate in the first approximation parameters of atmospheric transport and deposition of some metals onto underlying surface.

The IGCE in cooperation with the Finnish Meteorological Institute developed a model to estimate atmospheric transport and deposition of sulphur compounds over the Northern Fennoscandia. The model allowed to evaluate the sulphur transboundary fluxes and to determine with high spatial resolution the fields of deposition of acid sulphur compounds which emitted by the nonferrous metallurgy enterprises in Kola peninsula. Comparison of calculated values of SO2 and sulfate concentrations with the data observed at Russian, Finnish, Norwegian and Swedish monitoring stations allowed to estimate the rate of SO2 oxidation in conditions of the Arctic atmosphere. A similar model was used for estimation of atmospheric transport of heavy metals in the Kola peninsula region.

At the end of the 80th the IGCE in cooperation with the IAA fulfilled experiment to determine chemical composition of ice cores obtained at Arctic island glacier "Vavilov Dome" (79.3N, 95.3E). The depth of ice shield allowed to trace back the chemical composition of atmospheric precipitation in the course of the last 90 years.

During the last years some attempts on estimations of acidic compounds emissions into the atmosphere were done. Emissions of sulphur and nitrogen compounds for the whole country and spatial emission distributions with 1x1 degree resolution were estimated. The inventory was based on so called balance method, which in contrast to official statistical inventory gives a possibility to take into account all sources of emissions. Such a work was started for some heavy metals.

In the framework of planned project under the auspices of ENRICH/EU the institutions of Russian Hydromet can give their contributions within the following directions of investigations:

1. Estimation of spatial distribution of emissions of sulphur and nitrogen compounds, heavy metals, persistent organic compounds over the Russian territory with resolution 1x1 degree. Obtained emission fields can be used for model calculations of atmospheric transport on hemispheric level.
2. Estimation of temporal anthropogenic emission dynamics in the course of the last 100 years. Such series can be used for model estimation of long-term environmental and climatic changes.
3. Estimation of climatic effects caused by transport of sulfate aerosols into the Arctic atmosphere.
4. Estimations of roles of the strongest anthropogenic sulphur sources in the Russian territory (Norilsk, Kola peninsula) in Arctic atmosphere pollution by sulfate, and in acidification of Arctic ecosystems.
5. Monitoring of atmospheric pollution at Russian stations located in Arctic and sub-Arctic regions. Analysis of longterm series of observations in order to reveal long-term global change signals.

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FEDERAL SERVICE OF RUSSIA FOR HYDROMETEOROLOGY
AND ENVIRONMENTAL MONITORING

CHARACTERISTICS OF THE STUDIES OF CONTAMINATION LEVELS IN THE ATMOSPHERE OF THE RUSSIAN ARCTIC

Yu. S. Tsaturov, S.A. Mel'nikov, S.V. Vlasov, A.N. Gorshkov

St. Petersburg
1995

SUMMARY

CHARACTERISTICS OF THE STUDIES OF CONTAMINATION LEVELS IN THE ATMOSPHERE OF THE RUSSIAN ARCTIC

Yu. S. Tsaturov, S.A. Mel'nikov, S.V. Vlasov, A.N. Gorshkov

This report presents information on the programs and organization of monitoring of atmospheric contamination in the Russian Arctic for the period from 1984 to 1994. Brief characteristics of specialized data bases and banks that exist at present at the research institutes of Rosgidromet and that are available for investigating the processes of long-range transfer of contaminants and related levels of anthropogenic impact on the underlying surface are given.

Some typical examples of spatial distribution and temporal variability of the levels of main groups of contaminants in atmospheric precipitation, aerosol and snow cover of the seas of the Russian Arctic and the Central Arctic Basin are presented.

1. Observation program and organization of monitoring

Already in the early 70s an increase in total discharges to the environment outside the Arctic zone and increased industrial activities in the region have required creating of an observation system in the Russian Arctic. This system was to provide collection of a sufficient amount of information on concentrations of contaminants in environmental compartments for assessing levels of anthropogenic impact on the Arctic ecosystems and predicting their change on the basis of analysing the climatic factors.

There were several stages in the formation of the observation system.

At the first stage in 1975-1977 the subsystems for radioactive contamination control, state of continental water bodies and marine environment in the vicinity of the Arctic ports were included into the system. Further they were supplemented by control of atmospheric air contamination in human settlements, systematic examination of the area of the six Arctic Seas (White, Barents, Kara, Laptev, East-Siberian, Chukchi Seas), measurements of chemical and hydrometeorological parameters in the regions of large industrial facilities, as well as by studies of the damage of forests and tundra vegetation on the Kola and Taimyr peninsulas.

In 1984 a multiprofile system for a comprehensive environmental monitoring has been formed in the Russian Arctic. It has been fully operational for 10 years (from 1984 to 1994).

Vast dimensions of the region, its special physical-geographical conditions, a dominating role in the inflow of contaminants, their transport with air and water flows govern specific requirements to the organization and functioning of the environmental monitoring system in the Arctic zone. Also, an extremely high cost of polar studies should be taken into account.

That is why for the last 10-15 years the strategy for developing national monitoring network in the Russian sector of the Arctic was based on a combination of observations at stationary stations, systematic and task expedition studies over the main part of the controlled territory, as well as control at impact level within human settlements and in the areas of industrial plants.

The main volume of information on spatial distribution and temporal variability of concentrations of contaminants in the environmental media, including atmosphere both at background and impact levels was obtained in the framework of the General State Observation System for Environmental Contamination (GSOS) of Rosgidromet.

A systematic control for atmospheric contamination at impact level was carried out in 16 towns of Russia.

A systematic character and the list of the analysed indicators in the surface atmospheric layer depend on the location of the observation site. The compulsory program includes measurements of NO2, CO, SO2 and dust emissions. In accordance with the character of the emission sources in different points, in addition to these indicators the following contaminants are also determined: benz(a)pyrene, heavy and non-ferrous metals (iron, cadmium, cobalt, magnesium. manganese, copper, sodium, nickel, lead, cromium, zinc), solid fluorides,fluorine hydride, formaldehyde (Table 1.1).

Table 1.1

List of indicators, determined in the atmoshere of the cities of the Russian Arctic

City	Substances measured
Amderma	sulphur dioxide, nitrogen dioxide
Apatity	dust, sulphur dioxide, carbon oxide, nitrogen dioxide, benz(a)pyrene, heavy metals
Dikson	sulphur dioxide, nitrogen dioxide
Zapolyarny	dust, sulphur dioxide, carbon oxide, nitrogen dioxide, formaldehyde, heavy metals
Kandalaksha	dust, sulphur dioxide, carbon oxide, nitrogen dioxide, solid fluorides,HF,benz(a)pyrene, heavy metals
Kirovsk	dust, sulphur dioxide, carbon oxide, nitrogen dioxide
Kovdor	dust, sulphur dioxide, carbon oxide, nitrogen dioxide, benz(a)pyrene, heavy metals
Kola	dust, sulphur dioxide, carbon oxide, nitrogen dioxide, formaldehyde
Monchegorsk	dust, sulphur dioxide, carbon oxide, nitrogen dioxide, formaldehyde, benz(a)pyren, heavy metals
Murmansk	dust, sulphur dioxide, carbon oxide, nitrogen dioxide, nitrogen oxide, formaldehyde, mercury, benz(a)pyren, heavy metal

(to be continued)

Table 1.1 (continued)

City	Substances measured
Nickel	dust, sulphur dioxide, carbon oxide, nitrogen dioxide, formaldehyde, benz(a)pyren, heavy metals
Noril'sk	dust, sulphur dioxide, carbon oxide, nitrogen dioxide, nitrogen oxide, formaldehyde, hydrogen sulphide, phenol, chlor, benz(a)pyren, heavy metals
Olenegorsk	dust, sulphur dioxide, carbon oxide, nitrogen dioxide, heavy metals
Pevek	sulphur dioxide, nitrogen dioxide
Severomorsk	sulphur dioxide, carbon oxide, nitrogen dioxide, heavy metals
Tiksi	dust, sulphur dioxide, carbon oxide, nitrogen dioxide, benz(a)pyrene

The data bank of impact monitoring of atmospheric contamination is at the Main Geophysical Observatory of Rosgidromet (GGO, St. Petersburg).

Stationary observations of the parameters of background atmospheric contamination were carried out at the EMEP system station (from 1991) located in Yaniskosky settlement on the Kola peninsula, the work program of which is oriented to the control of transboundary transfer of anhydrides of acids and heavy metals, and at the station for control of atmospheric contamination at the Dunai island (from 1992) in the Lena river delta. The work program of this station includes studies of levels of stable organic compounds (chlorinated hydrocarbons, polycyclic aromatic hydrocarbons, etc.).

The work under these programs is supervised by the Institute for Global Climate and Ecology of Rosgidromet (IGCE, Moscow).

Since 1961, before the GSOS functioning, 40 stationary sites for radiation situation control have been operating in the Arctic. Geographically, the network of sites covers the entire coast and islands of the Russian Arctic seas from the White to the Barents Seas (Arkhangelsk and Murmansk) to the Bering Sea (Anadyr' town). The studies on radiation situation are supervised by the scientific-operational association "Taifun" of Rosgidromet (NPO "Taifun", Obninsk).

By the early 80s much of the area of the Russian Arctic Seas, including estuaries of the largest Siberian rivers presented a white gap in terms of availability of reliable information on the levels of contaminants, assessment of the role of different natural factors on the formation of a spatial distribution and temporal variability of their concentrations.

In connection with this in 1981-1982 as requested by Rosgidromet the Regional Center "Monitoring of the Arctic" has developed and implemented a program for a comprehensive monitoring of the environmental state of the Russian Arctic Seas in the framework of GSOS.

Geographically the project covers the areas of the White, Barents, Kara, Laptev, East-Siberian and partly Bering Seas including their gulfs and bays. A spatial resolution of the network is 100-200 km with a smaller spacing in the estuaries and coastal regions up to 10 - 50 km. A temporal interval of the studies in the regions of the seas with comparable hydrometeorological conditions is within a synoptic cycle (3-8 days). This allows resolving the goals of monitoring the contamination levels of both background and impact regions, including study of transfer of contaminants by air and water flows from the sources outside the Arctic region.

At the first stage from 1982 to 1988 the studies were made in the least investigated four seas of the Siberian shelf and from 1989 the studies under this project were extended to the area of the shelf zone of the Barents Sea.

A total number of the stations over the area of the six seas is 177 (Fig. 1.1).

Before 1994 the studies were performed twice a year during the characteristic winter-spring and summer-autumn periods. With solution of technological problems and accumulating of initial data the study program has undergone significant changes. By 1986 content of observations became stable and envisaged control of the levels of main groups of contaminants in surface sea water, bottom sediments, marine suspended matter, sea ice, snow cover, atmospheric precipitation and surface air layer. The list of the compounds to be analysed includes: heavy metals, organochlorines, oil hydrocarbons, polycyclic polyaromatic hydrocarbons, phenols, including compounds that have cancerogenic activity, radionuclides, nutrients, components of mineral water chemistry, parameters of snow cover acidification. other hydrochemical indicators.

The compulsory program also includes measurements of hydrophysical and meteorological parameters necessary for interpreting the results of the studies of the levels of toxicants and estimates of bioproductivity of the areas: salinity, temperature, ice thickness, wind speed and other characteristics.

The content of works at a specific point depends on its location and the season of the year. In summer the monitoring program also envisages examination of the extent of spreading of organic slicks of weak intensity over the ice-free areas.

It should be added that from 1982 through 1990 regular observations of the levels of contaminants in atmospheric precipitation and aerosols, snow cover were carried out at the drifting stations "North Pole" in the central Arctic basin in the framework of the GSOS (heavy metals - 10 components, organochlorines, petroleum and polycylic aromatic hydrocarbons, parameters of precipitation acidification).

When studying the processes forming the variability of the concentration fields of contaminants and related ecological effects the Central Arctic.

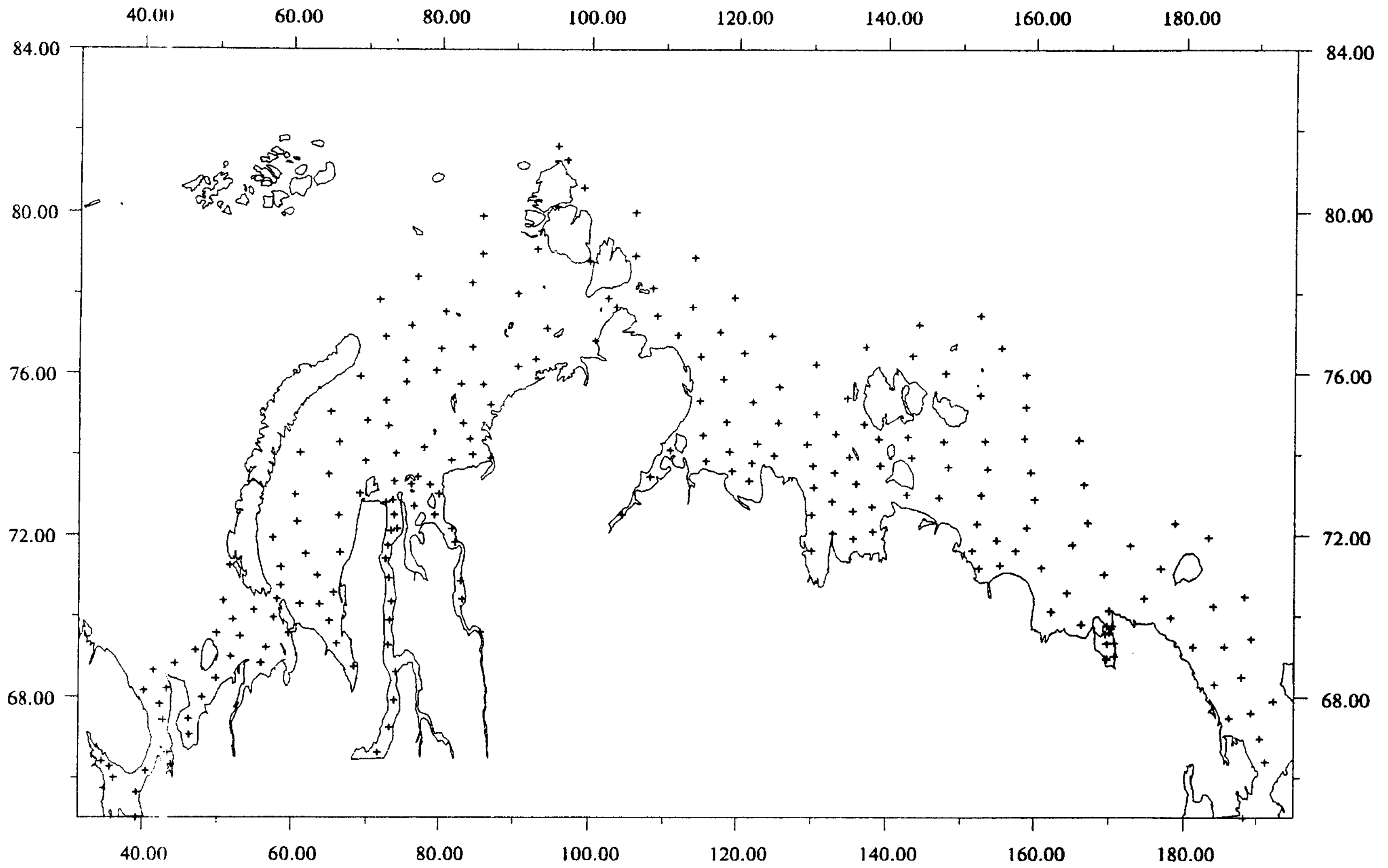


Fig.1.1. Scheme of points of a complex monitoring of the environmental state in the Russian Arctic seas and mouth areas of the Arctic zone rivers.

Basin (CAB) is a baseline region with regard to the seas of the Siberian shelf with close hydrometeorological ice hydrological and climatic conditions.

In addition to systematic observations over the GSOS network and in the framework of related programs in recent years the measurements of concentrations of main groups of contaminants (HM, OCCs, PCBs, OH, total aerosol concentration) in the surface air layer, middle and upper troposphere were carried out episodically by the expeditions of the research institutes of Rosgidromet: AARI, IGCE, IAG.

More often such observations were performed from aircraft over the area of the Kara and Laptev Seas, CAB, as well as at the polygons "Vavilov Dome", at the Severnaya Zemlya archipelago and Vrangel island.

On the whole data sets on the levels of contaminants in the atmosphere of the Russian Arctic accumulated for the last 10-12 years taking into account available series of hydrometeorological information and available climatic models allow estimating the variability of anthropogenic impact levels on water bodies and terrestrial ecosystems including scales of a long range atmospheric transfer of contaminants.

2. Brief characteristics of the databases of Rosgidromet available for investigating processes of long-range transfer of contaminants to the Russian Arctic.

The information collected from the GSOS in the Russian Arctic, as well as the results of specialized expeditions according to the information exchange scheme of Rosgidromet have been accumulatedg for a number of years in respective research institutions. The observation series formed served as a basis for currently functioning specialized databases and banks on technical media and formed Geoinformation systems in these institutes.

Brief characteristics of the main available databases and banks of this type are given below.

2.1. Data Bank "Contamination of the Arctic Ocean (AO) Basin" of the Regional Center (RC) "Monitoring of the Arctic"

A specialized Data Bank "Contamination of the AO Basin has been established on the basis of the information archive of the RC "Monitoring of the Arctic", accumulated as a result of multiyear expedition activities in the seas of the Russian Arctic from 1982 to 1994 inclusively.

The Data Bank contains information on the levels of main groups of contaminants (organochlorines, heavy and non-ferrous metals, petroleum hydrocarbons, polycyclic aromatic hydrocarbons, phenols, detergents, acidity, gamma-, beta- and alpha-emitting radionuclides) in the environmental compartments of the AO Basin, data on the values of major hydrochemical and hydrophysical indicators of natural waters, data of associated meteorological, hydrological, ice observations, as well as descriptions of the granulometric composition of bottom sediments and soils.

The list of the media under study includes:

- waters of marine and continental reservoirs;
- sea and river suspensions;
- snow cover;
- bottom sediments;
- soils;
- atmospheric air;
- atmospheric aerosol;
- atmospheric precipitation;
- marine and freshwater microbionts (benthos organisms, fishes);
- terrestrial organisms (birds, mammals);
- biomedia and tissues of the indigenous and non-indigenous population of the Arctic coast.

A quantitative characteristics of the Data Bank by information types is given in Table 2.1.

In terms of geography the Data Bank covers the Central Arctic Basin of the Arctic Ocean (the Barents, White, Kara, Laptev, East-Siberian, Chukchi Seas), estuaries and mouth areas of rivers, as well as some lake systems of the Russian Arctic.

The information of the Data Bank "Contamination of the AO Basin" has been systematized and transferred to technical media and an assessment of its reliability is given.

The structure of the Data Bank is implemented in the PARADOX shell for WINDOWS. The User's Interface is developed in PAL (Paradox Application language) for WINDOWS and provides for the presentation of the User's documents in plain language, in the form of diagrams, tables and maps in automated mode by a prescribed sampling.

Structurally, the Data Bank "Contamination of the AO Basin" (Fig. 2.1) consists of six information blocks (specialized databases).

The information blocks (specialized databases have structure of the same type, consisting of a number od electronic tables with a small number of fields and a "non-restricted" number of records. All tables are connected into one whole by a set of key fields. The data of different information blocks are compatible by the medium under study and geographical coordinates of the sampling place.

The Data Bank under description appears to be most complete of the existing similar Data Banks on this region.

Table 2.1

A quantitative characteristics of the Data Bank "Contamination of the Arctic Ocean Basin"

Type of information	Compaunds (indicators)	N of records
Organochlorins	HCH groups, DDT groups, chlordanes, nonachlors, polychlorobenzenes, mirex, PCBs	26.600
Heavy and non-ferrous metals	Zn, Fe, Mn, Ni, Cu, Cd, Pb, Co, Cr, Al, Hg, As, Tl	60.910
Petroleum hydrocarbons	Total content, benzene-toluene-xylene fraction	3.108
Polycyclic aromatic hydrocarbons	Total content, specific PAH, naphthalene, acenaphthylene, acenaphthene, fluorene, benz-(a)pyrene, dibenz(a,h)anthracene, benz(g,h,i)perylene, etc. in total 16 compaunds	4.100
Phenols	Total content, individual phenols, compaunds of chloro- and nitro-phenols,in total 9 compaunds	5.355
Detergents	Anionic- and cationic synthetic surface active substances	3.420
Radionuclides	Alpha-, beta-, gamma-emitting radionuclides	2.115
Nutrients	NO2, NO3, NH4, PO4, SiO2	107.900
Main hydrochemical parameters	pH, Alk, O2, chemical oxigen consumption, salinity	101.300
Salt elements	Na, K, Ca, Mg, Cl, SO4	26.180
Main ions in atmospheric precipitation and snow cover	Na, K, Ca, Mg, Cl, SO4, NO3, NO2, HCO3, CO3	11.780

STRUCTURE OF THE REGIONAL DATA BANK "CONTAMINATION OF THE ARCTIC OCEAN BASIN" OF THE REGIONAL CENTER "MONITORING OF THE ARCTIC"

THE DATA BANK
"CONTAMINATION OF THE ARCTIC OCEAN BASIN"

Database "Water of continental reservoirs"

Contains information on concentrations of main groups of contaminants and other hydrochemical indicators in natural media of continental reservoirs, as well as data on associated meteorological, hydrological and ice observations.

Database "Sea areas"

Contains information on concentrations of main groups of contaminants in natural media of the Central Arctic Basin, seas, estuaries and river mouths of the Russian Arctic, as well as data on associated meteorological, hydrological and ice observations.

Database "Soils"

Contains information on concentrations of main groups of contaminants and soil acidification in different water catchment regions of the Arctic Ocean Basin.

Database "Atmosphere"

Contains information on concentrations of main groups of contaminants and main ions in atmospheric air and precipitation over the area of the seas of the Arctic Ocean, continental reservoirs and baseline coastal regions.

Database "Flora and fauna"

Contains information on the state of hydrobionts and terrestrial organisms of the Arctic, including data on the levels of toxic compounds in the tissues of enzyme organs.

Database "Health levels"

Contains a data set of observations of the health level of indigenous and non-indigenous population of the Russian Arctic and data on levels of toxic compounds in biomedia and tissues of the human organism.

Fig. 2.1

2.2. Database of hydrometeorological information from the network of Arctic stations (including drifting stations)

The database of hydrometeorological parameters at the Arctic stations is to address the basic and applied goals of climatology, atmospheric pollution, studies of hydrometeorological regime of the Northern Polar Region.

It includes different information data sets (archives) as the main blocks:

2.2.1. Surface meteorology.

Archived data with a monthly interval at 70 permanent stations for the period of 1961-1992 (air temperature, pressure at sea level, monthly precipitation, partial pressure of water vapour).

Mean monthly values of temperature, pressure, humidity, wind, cloud, monthly precipitation and dangerous meteorological phenomena at 120 Russian and 99 foreign stations from the beginning of observations up to 1992.

2.2.2. Actinometric observations.

Monthly sums of direct, diffused, total radiation and balance at 15 actinometric stations.

Daily sums of direct, diffused, back-scattered total radiation and balance, albedo at drifting NP-3 - NP-31 (North Pole stations).

Mean monthly coefficients of integral atmosphere transparency at 14 Russian Arctic stations.

2.2.3. Upper-air observations

Daily data at standard isobaric surfaces for two fixed hours 00 and 12 GMT from 70 stations of the Northern Polar Region for 1955-1972.

Data at standard isobaric surfaces and special points for two hours 00 and 12 GMT, arranged by months at 144 stations for 1978-1992.

Mean monthly values of temperature and geopotential at isobaric surfaces 500, 100, 50, 10 hPa for the period from 1961 to 1992, supplemented by data from the charts in the areas of the seas and oceans.

2.2.4. Trace gases.

Total level of carbon oxide and methane at three stations (Zhokhov island, Severnaya Zemlya Archipelago, Wrangel island) in spring from 1982 to 1988.

2.2.5. Atmospheric aerosol.

Archive of concentration of aerosol particles with more than 0.4 um dimensions at Severnaya Zemlya Archipelago from 1984 to 1986 and in spring at Wrangel island in 1985, over the areas of the Arctic Seas in 1992, 1993 and Tsigler island in 1994.

Archive of spectral aerosol optical thickness of the atmosphere over the Arctic Ocean in 1979, Severnaya Zemlya Archipelago from 1979 to 1986, Kotel'ny island from 1985 to 1989, Wrangel island in 1984 and 1985.

To create these information sets the archives of the AARI, databases of VNIIGMI-WDC, results of expedition studies have been used.

There are corresponding softwares for the work with the archives.

2.3 Database of Main Geophysical Observatory "Atmosphere".

It contains information on concentrations of mixtures in the atmosphere of the Arctic cities, on levels of mixtures in atmospheric precipitation at the coast of the Arctic Ocean.

The observation data and mean annual characteristics are contained in tables, on magnetic tapes, and the database - in computer and in the form of annual reports on air quality in the cities and at baseline level.

2.4. Data Bank "Radioactive contamination of environmental compartments of the Russian Arctic" of the NPO "Typhoon"

A specialized Data Bank “Radioactive contamination of environemnntal compartments of the Russian Arctic” has been established on the basis of the information archive, accumulated as a result of multiyear observations over the network of the State System of Radiation Monitoring of Rosgidromet from 1965 to 1994.

The information on the strength of the gamma-emission dose, density of radioactive fall-out and radionuclide concentration in the surface atmospheric air in the vicinity of 40 permanent observation sites serves as a basis of the Data Bank. Geographically the network of sites covers the entire coast adn islands of the seas of the Russian Arctic from the White (Arkhangelsk) to the Chukchi Sea (Anadyr’) and the mouth areas of the most important rivers from the Severnaya Dvina river to the Amguema river.

In addition, the Data Bank includes the results of systematic permanent observations and expedition studies of the levels of radionuclides in river and sea waters, bottom sediments, soils, benthos organisms and samples of terrestrial biota, also in the regions of radioactive waste dumping and nuclear explosions, as well as data on the accumulation of 137-Cs in soils, including the regions affected by the accident at Chernobyl’ nuclear power plant.

The information has been transferred to technical media, which are stored in the form of electronic tables. Total number of records of the data bank exceeds 200 000, the DBMS has been developed on the basis of software package DBase 3+.

Characteristics of media and indicators, presented in the Data Bank of radiation monitoring of NPO "Taifun"

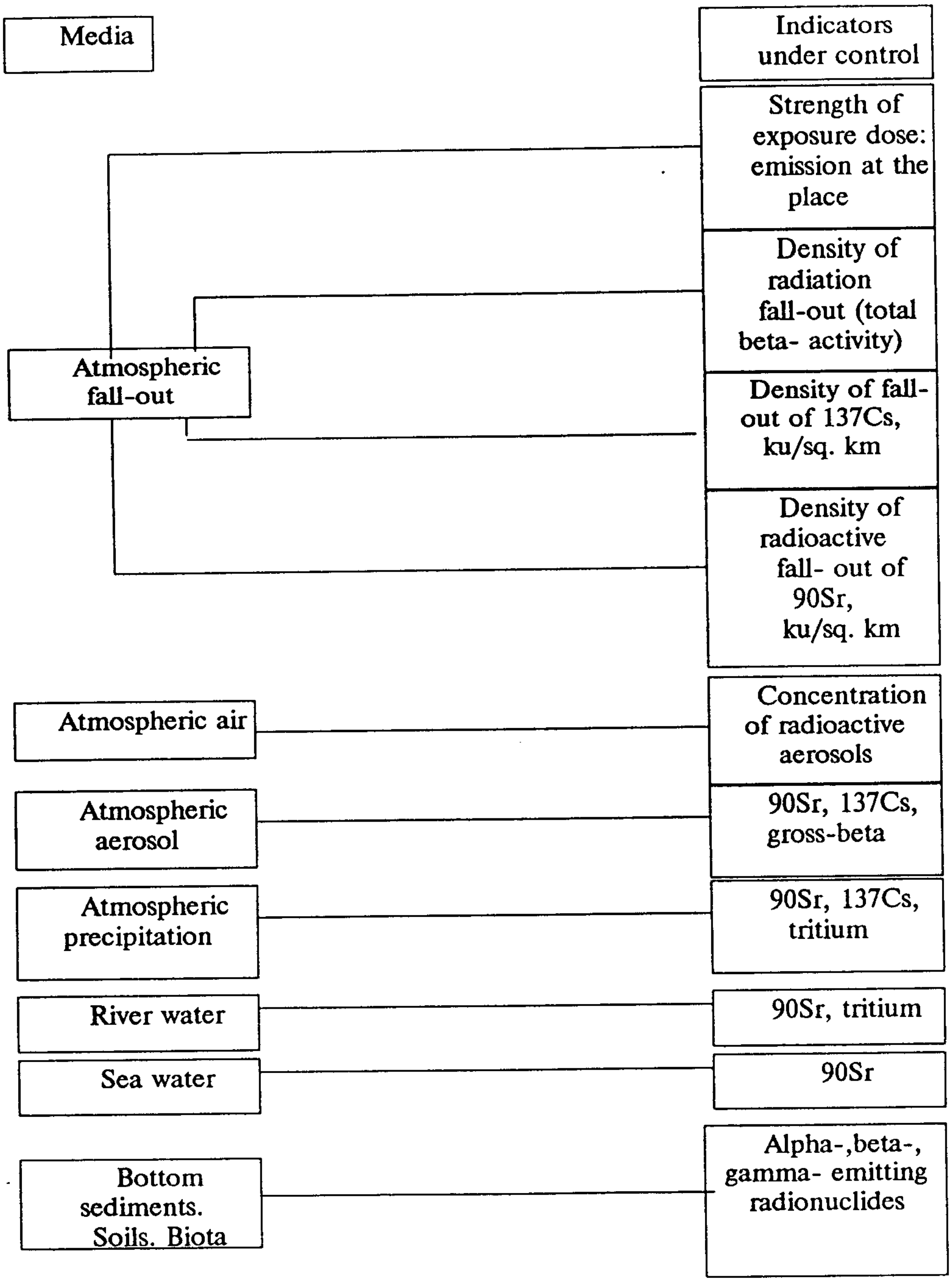


Fig. 2.4.

2.5 Database of a complex background atmosphere polution monitoring of the Institute of Global Climate and Ecology.

The database of a complex background atmospheric monitoring contains information on the concentration of contaminants in atmospheric air and precipitation at the stations Barentsburg, Pinega (Arkhangelsk area) Yaniskoski (Kola peninsula), Dunai peninsula (Lena delta), as well as additional meteoinformation.

The database information has been transferred to technical media and is stored in the form of files in the QBase3+ format. IGCE provides services to users by means of query procession from the viewpoint of topical and technical requirements.

Table 2.5

Characteristics of the contents of the database of a complex atmospheric monitoring of the IGCE.

Work area	Length of observation	Compounds (indicators) to be determined
Spitsbergen Barentsburg station	1992 - 1994	Concentrations of heavy metals (Pb, Cd, Cu, Ni) in atmospheric air
Kola peninsula: Yaniskoski station; Arkhangelsk district: Pinega station.	1988 - 1994	Concentrations of sulphur and nitrogen in atmospheric air and atmospheric precipitation acidity of atmospheric precipitation
Lena river delta: Dunai station	1993 - 1994	Concentrations of persisten organic compounds and heavy metals in atmospheric air

3. Characteristics of spatial and temporal variability of the main groups of contaminants in atmospheric precipitation, aerosol and snow cover of the seas of the Siberian shelf.

More than a decadal observation series of the contamination level of the Russian Arctic Seas obviously indicates that at present the input of contaminants as a result of atmospheric transfer and transport by water flows, including inflow of water transformed by the river runoff of the Ob', Yenisey, Pyasina, Khatanga, Lena, Indigirka, Kolyma to the study territory is predominant.

A direct discharge of industrial and communal wastes, solid and gaseous waste is of a restricted character. It induces only local consequences directly in the discharge zone and is actually restricted by activities of industrial, transport and communal enterprises of few coastal settlements and ports.

The input of contaminants as a result of using ships along the NSR is not comparable to the scales of the effect of the river runoff and atmospheric fall-out, too.

An analysis of background circulation characteristics observed in the seas of the Siberian shelf has been performed on the basis of anomalies of high-latitudinal indices (I3) and the determination of prevailing air flows from 1985 to 1993. It has shown that in February-May the flows of north-western and western directions prevail (80% of cases) over the area of the Barents and Kara Seas), thus governing comparatively low cumulation coefficients of organic contaminants in surface snow cover and high level of its acidification.

The effect of meridional transports of southern and south-western directions is mainly related to transfer of pollutants from relatively close (up to 1000 km) sources.

The Laptev Sea is characterized by prevailing south-western, southern and south-eastern flows (65% of cases). This governs transfer of contaminants from the industrial regions of the Urals and West Siberia.

The flows of south-western and southern directions (77% of cases) prevail over the East-Siberian and Chukchi Seas, i.e. the main transfer of contaminants to the area of these seas is from the regions of the Far East, including Japan and China.

On the whole the intensity of meridional and latitudinal transfer of contaminants and seasonal variations of their concentrations for all directions are governed by the position of the polar front (a reservoir model). And the polar front is assumed to be a zone of intensive mixing of air masses of northern and temperate latitudes.

According to this model the upper troposphere of the Arctic in winter can be considered to be a reservoir of mixed aerosol to which aerosol from temperate latitudes contaminated by heavy metals, inflows during winter, as the polar front boundary is located south of industrial and densely populated regions of the Eurasian and North-American continents.

In spring the intensity of aerosol removal with precipitation sharply increases and the boundary of the front shifts northward isolating the central Arctic from the inflow of contaminated air masses.

In the fall the polar front shifts again southward opening a possibility for a meridional transfer of contaminants.

The information available at the RC "Monitoring of the Arctic" allows a conclusion that instant and mean seasonal concentrations of heavy metals, organochlorines and oil polycyclic aromatic hydrocarbons in marine environment compartments including snow cover and surface atmospheric layer are in most cases within the regional or global geochemical background.

This makes considerably difficult to obtain correct estimates of anthropogenic impact levels on the ecosystems of the regions.

From our viewpoint, for monitoring contamination levels of most natural water bodies subjected to a chronic impact of a large number of different contamination sources that do not create permanent zones of extremely high concentrations of controlled parameters over some considerable territory in the absence of accident discharges and at available significant data sets it is most preferable to use a factor-statistical and correlation analysis of the set of obtained data for estimating and analysing the situation.

At this approach the concentrations of contaminants and other hydrochemical parameters at a specific point are compared with mean values of these parameters in the regions of the water reservoir with comparable hydrological, hydrometeorological and ecological conditions or with mean values for the water body on the whole.

Ranging of concentrations at specific points by the number multiple to a standard deviation from the mean (arithmetic or geometric) in combination with a multifactor correlation analysis allows a stable delineation of the zones with relatively enhanced levles of contaminants (enhanced relative to mean regional value) both in the regions which are characterized by low (much lower than permissible limit concentrations) values of mean and instant concentrations of contaminants and in local zones of the area with high levels of contaminants in the presence of a direct discharge of wastes to the waters of the body under control.

The use of this method allowed a reliable identification of steadily recorded from year-to-year regions and zones with elevated levels of main groups of contaminants in the snow cover of all seas under control relative to the adjacent areas and territories.

3.1. Oil hydrocarbons and organochlorines.

An analysis of a spatial distribution of the total level of oil hydrocarbons (OH) and organochlorines (OCC) in the winter-spring period in surface snow cover confirms the absence of large sources of their direct input into the marine environment, as well as absence of pronounced latitudinal and meridional tendencies for the change in concentrations of the compounds of these groups over the entire area under description. At the same time in spite of an obviously probabilistic character of instant concentrations of OH and OCCs at specific points it is possible on the basis of describing the concentration field using a factor-statistical analysis to identify a number of zones with enhanced detection frequency of significant amounts of OH and OCCs with higher mean concentrations, as compared with adjacent regions (Fig. 3.1 and 3.2).

And the dispersion of mean zonal concentrations for a specific year relative to the mean for all observation years is, as a rule, within the double standard deviation. This indicates a stability of the flows of these compounds.

At the same time the East-Siberian and Chukchi Seas are characterized by a higher detection frequency of the OCCs of the group of DDTs and PCBs in snow cover (up to 60% of all samples analyzed), as well as by enhanced levels (as compared with the Kara and Laptev Seas) of a toxic isomer in the Gamma-HCH (up to 30%). This is directly related to the differences in the prevailing directions of the flows over the area of the seas of the western and eastern sectors of the Russian Arctic.

3.2. Heavy metals.

A spatial distribution of heavy metals (HM) in snow cover is characterized by the same tendencies as that of organic contaminants.

And maximum levels of toxic metals are typical of the coastal regions of the Kara and Laptev Seas. This is governed by the effect of meridional transfers from the emission sources that are at a medium distance (1000-1500 km) relative to the areas under consideration (Fig. 3.3).

3.3. Snow cover acidity.

Mean values of pH values of snow cover over the area of the Arctic Seas for the observation period of 1986-1993 are given in Table 3.1 (Determination of mean pH was made by recalculation of mean concentration of hydrogen ions). A spatial distribution of pH values in 1993 is given in Fig. 3.4.

Table 3.1.

Average values of hydrogen index (pH) of the snow cover on the arctic seas area, 1987-1993.

Sea Basin	Years						
	1987	1988	1989	1990	1991	1992	1993
Kara	5.02	4.72	4.85	4.82	5.10	4.79	4.62
Laptev	5.22	5.40	5.42	5.08	5.71	5.29	5.32
East-Siberian	5.30	4.87	5.32	5.21	5.31	5.51	5.56
Chukchi	5.40	5.10	5.22	5.55	5.71	5.66	5.68

In 1993 an enhanced acidity background, as in previous years was observed over the area of the Kara Sea (mean pH=4.62). This is in a good agreement with known understandings about a long-range atmospheric transfer of anhydrides of acids from industrial regions to the western sector of the Russian Arctic.

The variability interval of pH values of snow cover of the Kara Sea is 4.53 - 6.66. Over its area the acidity maximum has been observed during the observation period of 1993. Mean pH value in the Yenisey Bay is 4.78 units. This is close to the values observed in the preceding 3 years. The largest values of snow cover acidity were observed, as in previous years in the Ob' Gulf up to 4.43 units.

The pH values of the snow cover over much of the area of the other seas are considerably larger (5.4 - 7.2).

Local zones with a noticeable acidification are consistent with local emission sources.

3.4. Levels of contaminants in atmospheric precipitation of the Central Arctic Basin.

As indicated above, the CAB is a baseline region relative to the marginal seas. Therefore, studies of the chemistry of atmospheric precipitation at the drifting stations "North Pole" allow estimating the significance of different transfer directions for the formation of the fields of concentrations of contaminants accumulated by snow cover of these seas.

Fig. 3.5 and 3.6 present levels of HM and OCCs in fresh snow and corresponding transfer trajectories.

An analysis of synoptic situations preceding sampling allows a conclusion that in most cases a sharp increase in concentrations of HM in snow cover of the central basin of the Arctic Ocean is related to precipitation fall-out contacting air masses from the industrial air masses of Russia, USA and Canada.

Minimum concentrations of HM in fresh snow correspond to the cases of close circulation of air masses in the central Arctic (trajectory I) or to their shift from the North Atlantic regions.

A significant increase of lead, manganese, nickel, cadmium, copper and zinc in the precipitation coincides with the shift of air masses from the regions of the territory of Russia (trajectory 2) and through the territory of the USA and Canada (trajectory 3).

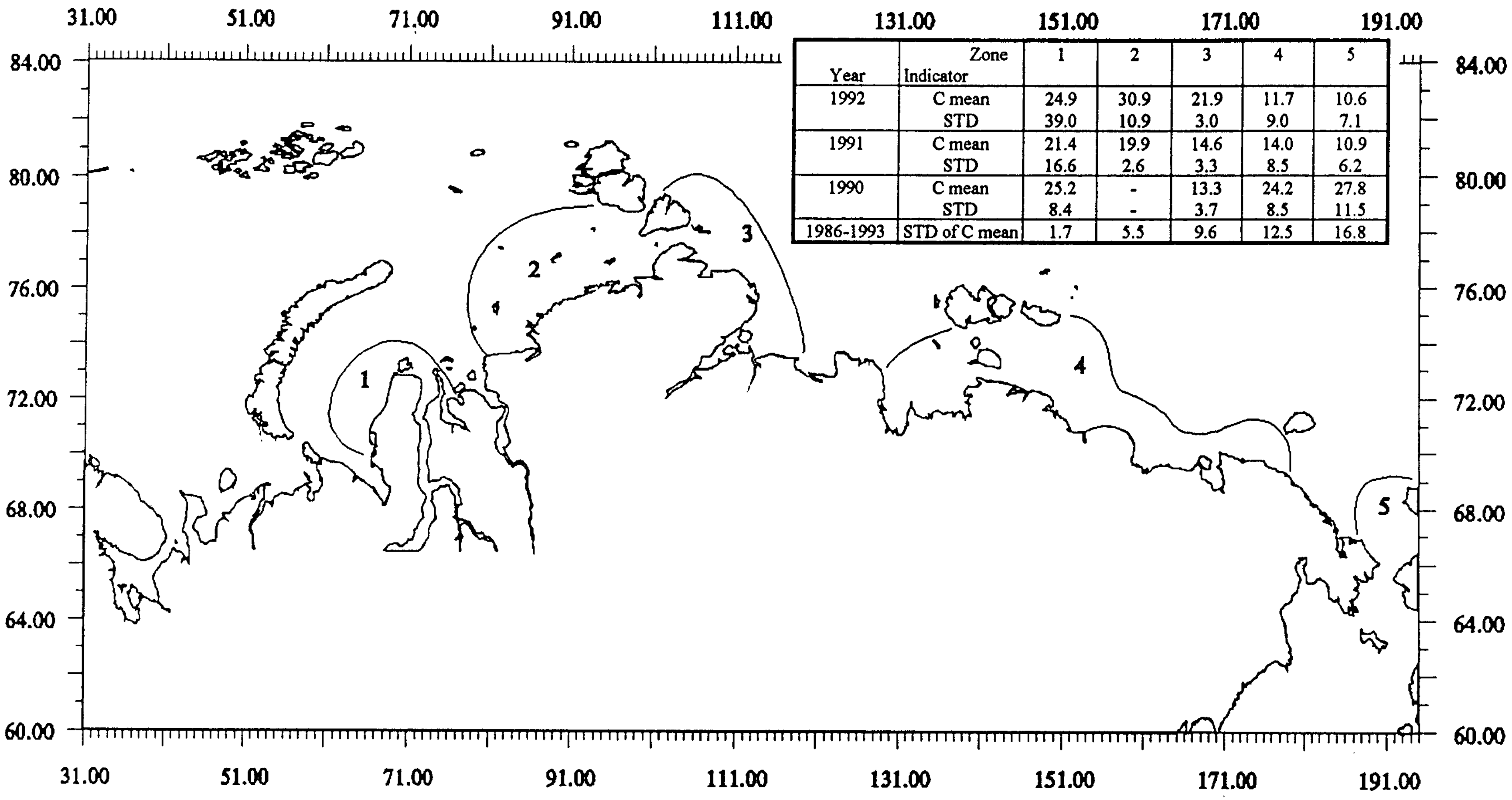
Maximum concentrations of the OCCs and a spectrum of the compounds of this group detected in samples are typical of the trajectories of type 4 (South-Eastern Asia and Far East).

3.5. Contaminants in atmospheric aerosol.

Tables 3.2 and 3.3. present the results of studies of the levels of HM and OCCs in atmospheric aerosol samples collected in 1994 over the Kara Sea area (Fig. 3.7).

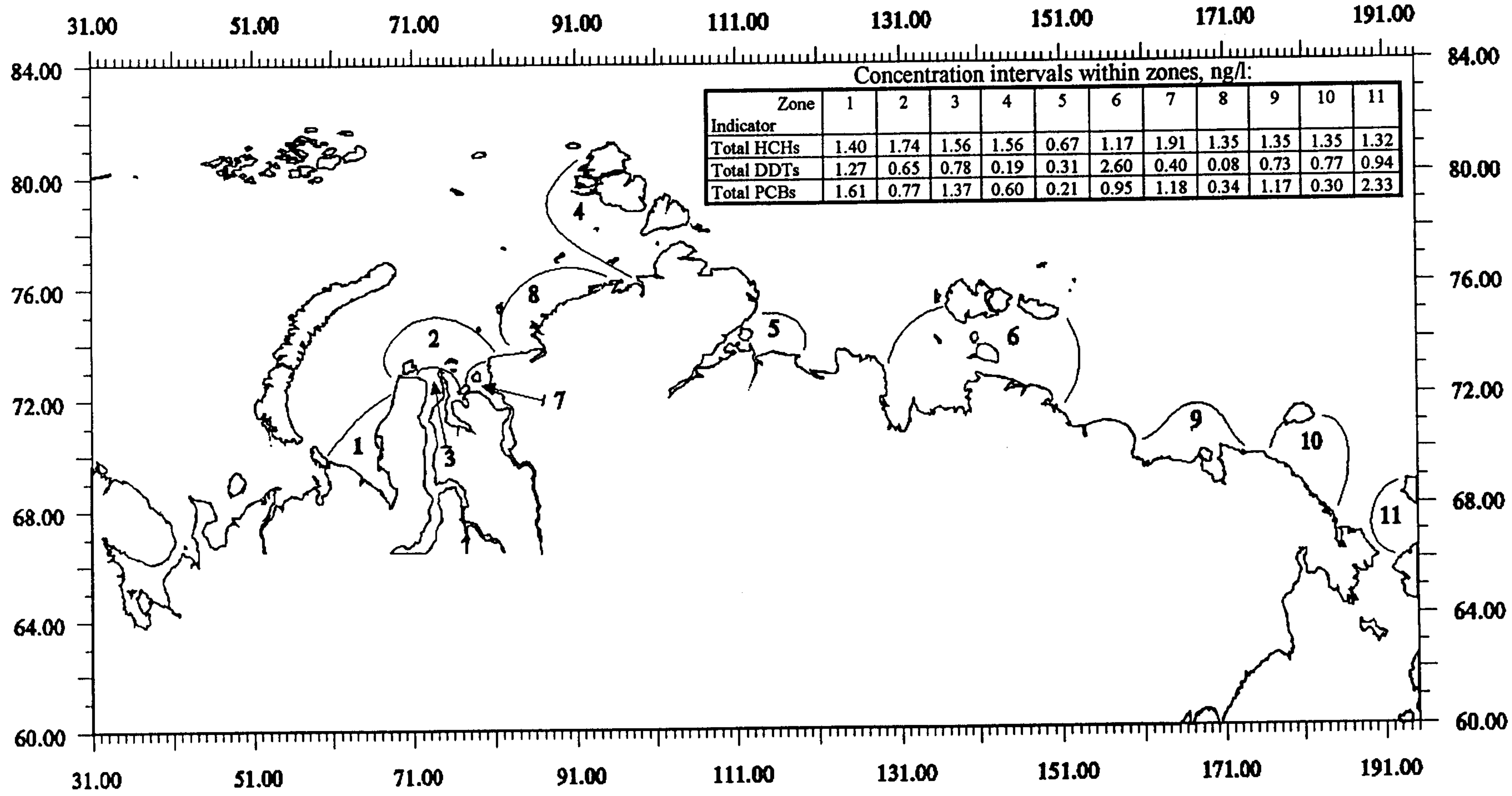
An analysis of these results in this report is not possible due to a restricted work scope.

In conclusion it should be noted that section 3 on the whole is of illustrative character and does not fully reflect the volume of infoprmation contained in the data bank "Arktika".



Year	Indicator / Zone	1	2	3	4	5
1992	C mean	24.9	30.9	21.9	11.7	10.6
	STD	39.0	10.9	3.0	9.0	7.1
1991	C mean	21.4	19.9	14.6	14.0	10.9
	STD	16.6	2.6	3.3	8.5	6.2
1990	C mean	25.2	-	13.3	24.2	27.8
	STD	8.4	-	3.7	8.5	11.5
1986-1993	STD of C mean	1.7	5.5	9.6	12.5	16.8

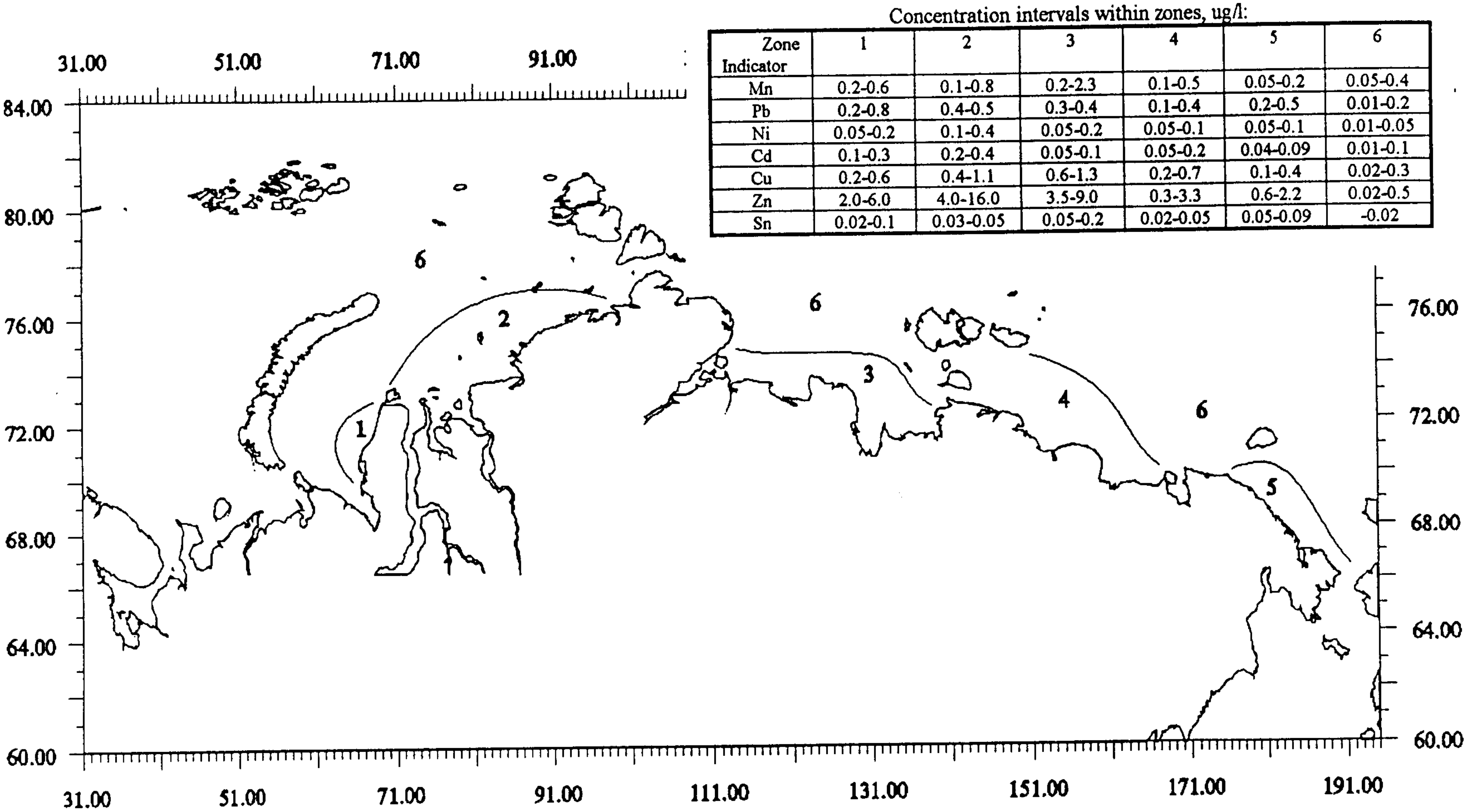
Fig.3.1 Zones with relatively enhanced contant of petroleum hydrocarbons in the snow cover at the area of the Arctic seas.



Concentration intervals within zones, ng/l:

Zone Indicator	1	2	3	4	5	6	7	8	9	10	11
Total HCHs	1.40	1.74	1.56	1.56	0.67	1.17	1.91	1.35	1.35	1.35	1.32
Total DDTs	1.27	0.65	0.78	0.19	0.31	2.60	0.40	0.08	0.73	0.77	0.94
Total PCBs	1.61	0.77	1.37	0.60	0.21	0.95	1.18	0.34	1.17	0.30	2.33

Fig.3.2 Zones with relatively enhanced content of organochlorines in snow cover at the area of the Arctic seas, 1984-1993.



Concentration intervals within zones, ug/l:

Zone Indicator	1	2	3	4	5	6
Mn	0.2-0.6	0.1-0.8	0.2-2.3	0.1-0.5	0.05-0.2	0.05-0.4
Pb	0.2-0.8	0.4-0.5	0.3-0.4	0.1-0.4	0.2-0.5	0.01-0.2
Ni	0.05-0.2	0.1-0.4	0.05-0.2	0.05-0.1	0.05-0.1	0.01-0.05
Cd	0.1-0.3	0.2-0.4	0.05-0.1	0.05-0.2	0.04-0.09	0.01-0.1
Cu	0.2-0.6	0.4-1.1	0.6-1.3	0.2-0.7	0.1-0.4	0.02-0.3
Zn	2.0-6.0	4.0-16.0	3.5-9.0	0.3-3.3	0.6-2.2	0.02-0.5
Sn	0.02-0.1	0.03-0.05	0.05-0.2	0.02-0.05	0.05-0.09	-0.02

Fig.3.3. Zones with relatively enhanced levels of heavy metals in snow cover of the seas of the Siberian shelf, 1993.

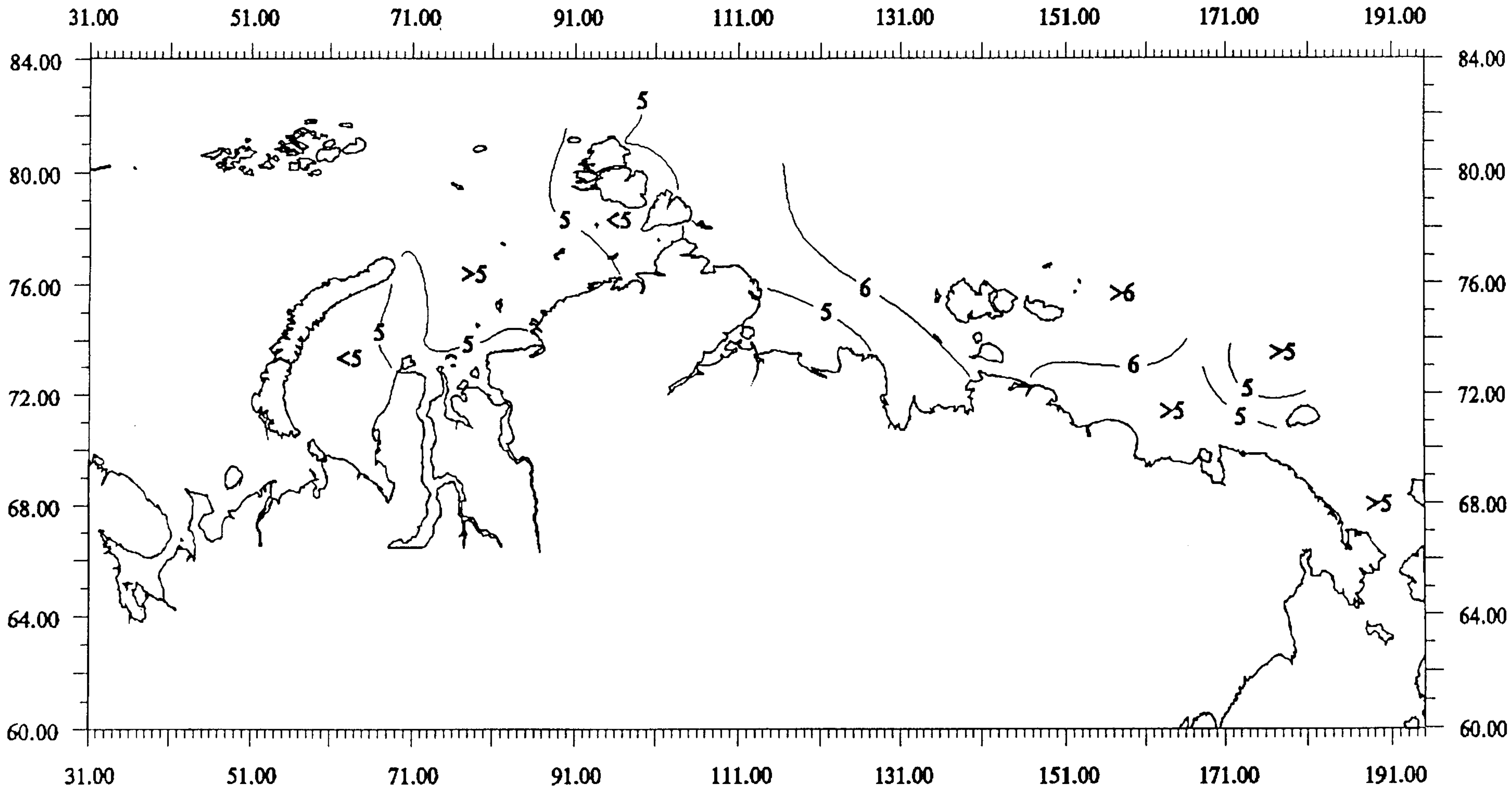


Fig.3.4. The distribution of hydrogen index value in snow cover of Siberian shelf seas, winter-spring 1993.

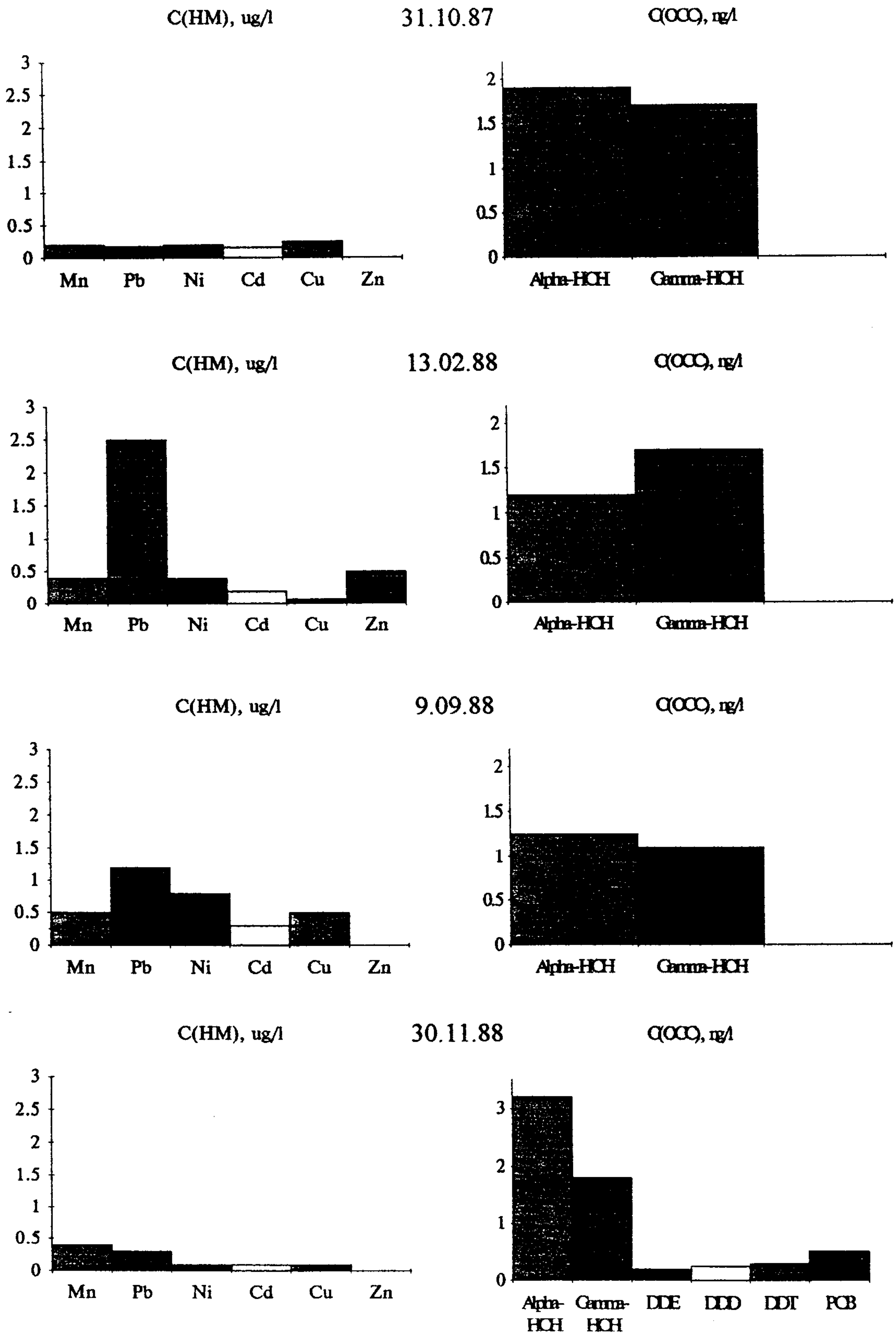


Fig.3.5. Heavy metals and Organochlorines levels in atmospheric precipitation, North Pole-27.

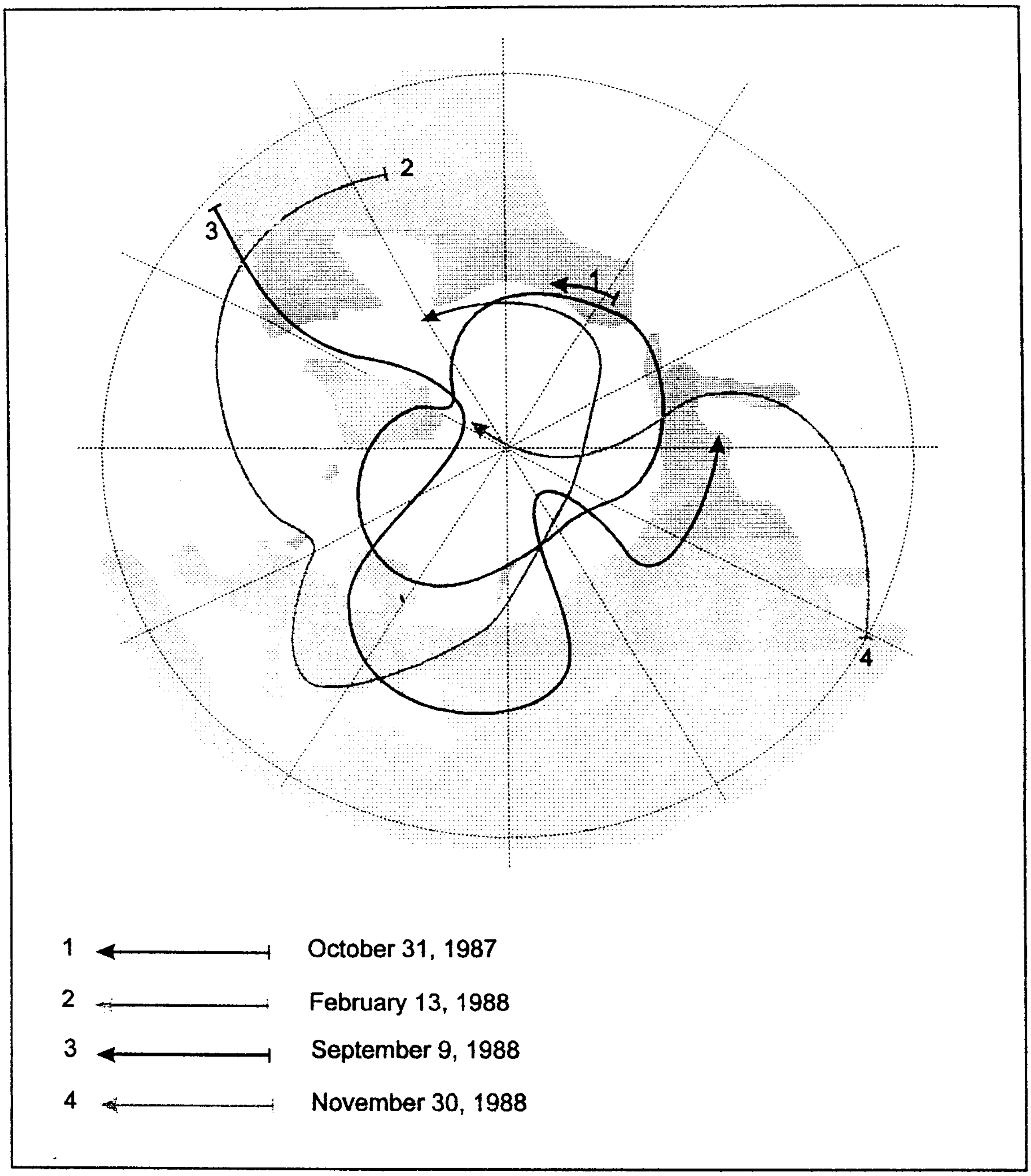


Fig.3.6. Main airflow (at H=500 mB) with the polluted atmospheric precipitation.

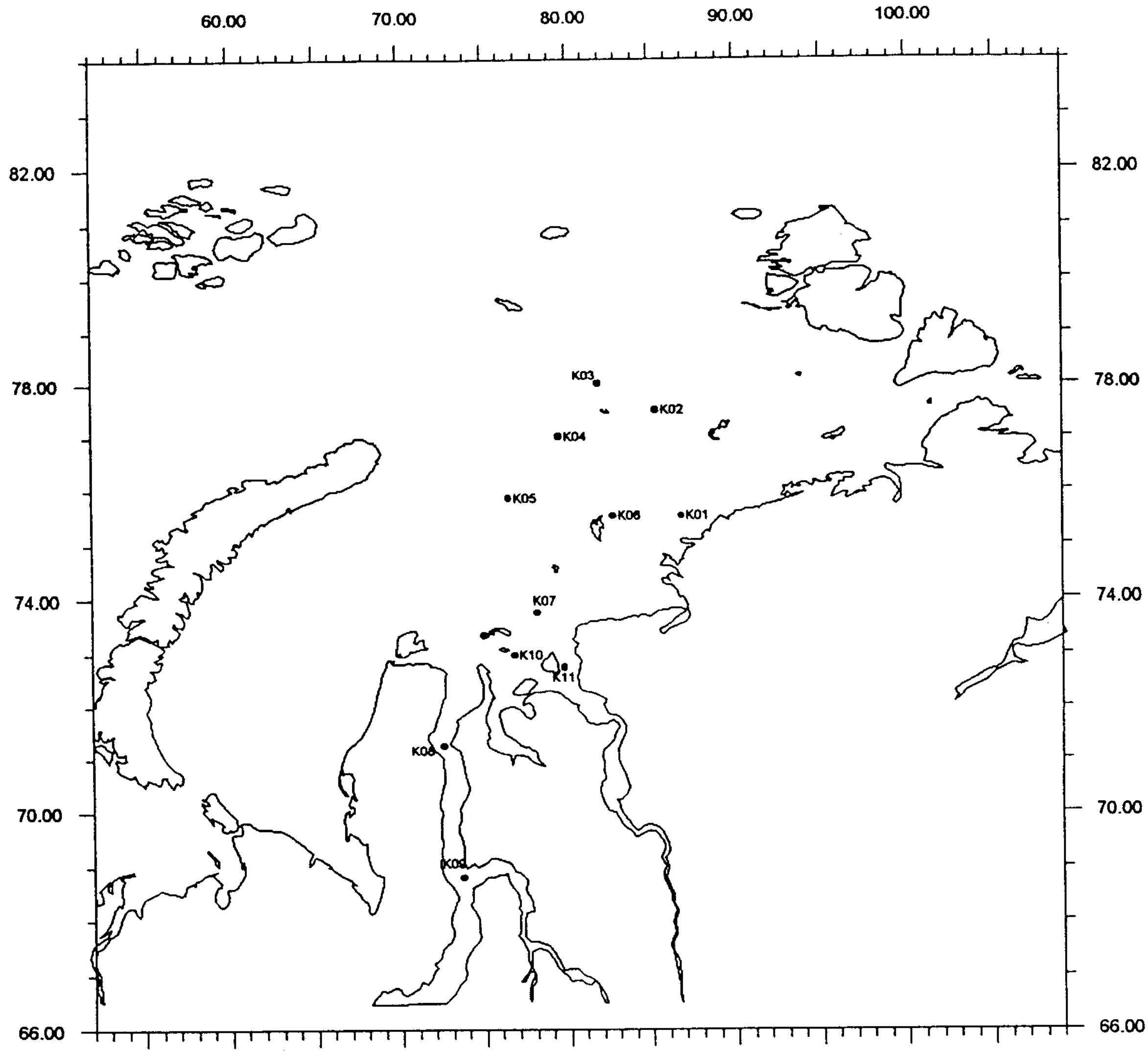


Fig.3.7..Stations of atmospheric aerosol integral sampling (24 h exposition) : K01-K11.

Table 3.2

Heavy metal concentrations in atmospheric aerosol in the Kara Sea area, pg/m3 of air

Sampling	Contaminant	Value
N station.......K01	Zinc	16.20
Sampling date...25-Aug-94	Iron	27.30
Latitude........ 75 deg 30.0 min	Tin	0.23
Longitude....... 86 deg 50.0 min	Manganese	6.57
	Nickel	0.23
	Copper	3.47
	Cadmium	2.77
	Lead	4.16
	Cobalt	0.31
	Arsenic	0.20
	Mercury	0.00
N station.......K10	Zinc	0.34
Sampling date...10-Sep-94	Iron	12.73
Latitude........ 72 deg 59.0 min	Tin	0.46
Longitude....... 76 deg 49.0 min	Manganese	1.73
	Nickel	0.46
	Copper	0.34
	Cadmium	0.46
	Lead	0.23
	Cobalt	0.23
	Arsenic	0.23
	Mercury	0.00
N station.......K11	Zinc	0.23
Sampling date...12-Sep-94	Iron	10.20
Latitude........ 72 deg 45.0 min	Tin	0.54
Longitude....... 79 deg 45.0 min	Manganese	2.30
	Nickel	0.90
	Copper	0.55
	Cadmium	0.41
	Lead	0.94
	Cobalt	0.38
	Arsenic	0.21
	Mercury	0.00
N station.......K02	Zinc	10.10
Sampling date...27-Aug-94	Iron	6.24
Latitude........ 77 deg 30.0 min	Tin	0.38
Longitude....... 85 deg 20.0 min	Manganese	1.73
	Nickel	0.52
	Copper	2.76
	Cadmium	0.92
	Lead	0.30
	Cobalt	0.34
	Arsenic	0.26
	Mercury	0.00

(to be continued)

Table 3.2 (continued)

Sampling	Contaminant	Value
N station.......K03 Sampling date...28-Aug-94 Latitude........ 78 deg 0.0 min Longitude....... 81 deg 50.0 min	Zinc	12.73
	Iron	5.78
	Tin	0.23
	Manganese	2.31
	Nickel	0.23
	Copper	2.31
	Cadmium	1.15
	Lead	0.23
	Cobalt	0.33
	Arsenic	0.00
	Mercury	0.01
N station.......K04 Sampling date...30-Aug-94 Latitude........ 77 deg 0.0 min Longitude....... 79 deg 30.0 min	Zinc	6.17
	Iron	10.74
	Tin	0.20
	Manganese	1.08
	Nickel	0.21
	Copper	1.46
	Cadmium	2.01
	Lead	0.56
	Cobalt	0.27
	Arsenic	0.28
	Mercury	0.00
N station.......K05 Sampling date... 1-Sep-94 Latitude........ 75 deg 50.0 min Longitude....... 76 deg 30.0 min	Zinc	11.57
	Iron	5.78
	Tin	0.23
	Manganese	0.69
	Nickel	0.23
	Copper	0.46
	Cadmium	3.00
	Lead	0.46
	Cobalt	0.23
	Arsenic	0.19
	Mercury	0.00
N station.......K06 Sampling date... 2-Sep-94 Latitude........ 75 deg 30.0 min Longitude....... 82 deg 45.0 min	Zinc	2.31
	Iron	4.62
	Tin	0.23
	Manganese	3.47
	Nickel	0.46
	Copper	1.15
	Cadmium	0.69
	Lead	0.23
	Cobalt	0.23
	Arsenic	0.24
	Mercury	0.00

(to be continued)

Table 3.2 (continued)

Sampling	Contaminant	Value
N station.......K07 Sampling date... 4-Sep-94 Latitude........ 73 deg 45.0 min Longitude....... 78 deg 10.0 min	Zinc	1.15
	Iron	9.25
	Tin	0.23
	Manganese	1.15
	Nickel	0.23
	Copper	1.16
	Cadmium	0.92
	Lead	0.23
	Cobalt	0.23
	Arsenic	0.32
	Mercury	0.00
N station.......K08 Sampling date... 5-Sep-94 Latitude........ 71 deg 25.0 min Longitude....... 73 deg 24.0 min	Zinc	0.69
	Iron	9.25
	Tin	0.69
	Manganese	1.15
	Nickel	1.04
	Copper	0.46
	Cadmium	0.34
	Lead	0.23
	Cobalt	0.23
	Arsenic	0.36
	Mercury	0.02
N station.......K09 Sampling date... 6-Sep-94 Latitude........ 69 deg 5.0 min Longitude....... 73 deg 35.0 min	Zinc	11.57
	Iron	32.40
	Tin	0.69
	Manganese	1.15
	Nickel	1.04
	Copper	1.38
	Cadmium	0.34
	Lead	0.57
	Cobalt	0.34
	Arsenic	0.24
	Mercury	0.00

Table 3.3

The organochlorines and chlorobiphenil concentrations in atmospheric aerosol in the Kara Sea area, pg/m3 of air

Sampling	Contaminant	Value
N station....... K01 Latitude........ 75 deg 30.0 min Longitude....... 50 deg 50.0 min Sampling date... 25-Aug-94	Sum of DDT	5.2
	Sum of TDE	25.3
	Sum of DDE	26.8
	alpha-HCH	12.1
	gamma-HCH	14.3
	Dieldrin	1.1
	Hexachlorobenzene	1.8
	Heptachlor	0.0
	Cis-chlordan	0.0
	Trans-chlordane	
	Cis-nonachlor	
	Trans-nonachlor	0.0
	Mirex	0.0
	Pentachlorobenzene	10.2
	Heptachlorepoxide	14.0
	PCBs	0.0
N station....... K10 Latitude........ 72 deg 59.0 min Longitude....... 49 deg 49.0 min Sampling date... 10-Sep-94	Sum of DDT	0.0
	Sum of TDE	20.8
	Sum of DDE	27.8
	alpha-HCH	9.3
	gamma-HCH	12.7
	Dieldrin	1.2
	Hexachlorobenzene	2.3
	Heptachlor	0.0
	Cis-chlordan	0.0
	Trans-chlordane	
	Cis-nonachlor	
	Trans-nonachlor	0.0
	Mirex	2.3
	Pentachlorobenzene	6.9
	Heptachlorepoxide	20.8
	PCBs	0.0
N station....... K11 Latitude........ 72 deg 45.0 min Longitude....... 45 deg 45.0 min Sampling date... 12-Sep-94	Sum of DDT	6.9
	Sum of TDE	4.7
	Sum of DDE	1.2
	alpha-HCH	2.3
	gamma-HCH	3.5
	Dieldrin	0.0
	Hexachlorobenzene	1.2
	Heptachlor	1.2
	Cis-chlordan	0.0
	Trans-chlordane	
	Cis-nonachlor	
	Trans-nonachlor	3.5
	Mirex	0.0
	Pentachlorobenzene	1.2
	Heptachlorepoxide	1.2
	PCBs	49.8

(to be continued)

Table 3.3 (continued)

Sampling	Contaminant	Value
N station....... K02 Latitude........ 77 deg 30.0 min Longitude....... 20 deg 20.0 min Sampling date... 27-Aug-94	Sum of DDT	9.3
	Sum of TDE	8.1
	Sum of DDE	4.6
	alpha-HCH	3.5
	gamma-HCH	5.8
	Dieldrin	0.0
	Hexachlorobenzene	1.2
	Heptachlor	2.3
	Cis-chlordan	0.0
	Trans-chlordane	
	Cis-nonachlor	
	Trans-nonachlor	0.0
	Mirex	0.0
	Pentachlorobenzene	1.2
	Heptachlorepoxide	1.2
	PCBs	32.4
N station....... K03 Latitude........ 78 deg 0.0 min Longitude....... 50 deg 50.0 min Sampling date... 28-Aug-94	Sum of DDT	0.0
	Sum of TDE	9.9
	Sum of DDE	12.6
	alpha-HCH	4.8
	gamma-HCH	7.2
	Dieldrin	0.0
	Hexachlorobenzene	2.2
	Heptachlor	2.1
	Cis-chlordan	0.0
	Trans-chlordane	
	Cis-nonachlor	
	Trans-nonachlor	0.0
	Mirex	0.0
	Pentachlorobenzene	0.0
	Heptachlorepoxide	0.0
	PCBs	10.1
N station....... K04 Latitude........ 77 deg 0.0 min Longitude....... 30 deg 30.0 min Sampling date... 30-Aug-94	Sum of DDT	2.3
	Sum of TDE	6.9
	Sum of DDE	6.9
	alpha-HCH	2.3
	gamma-HCH	4.6
	Dieldrin	0.0
	Hexachlorobenzene	1.2
	Heptachlor	1.2
	Cis-chlordan	0.0
	Trans-chlordane	
	Cis-nonachlor	
	Trans-nonachlor	0.0
	Mirex	0.0
	Pentachlorobenzene	0.0
	Heptachlorepoxide	2.3
	PCBs	47.4

(to be continued)

Table 3.3 (continued)

Sampling	Contaminant	Value
N station....... K05 Latitude........ 75 deg 50.0 min Longitude....... 30 deg 30.0 min Sampling date... 1-Sep-94	Sum of DDT	1.1
	Sum of TDE	5.7
	Sum of DDE	6.1
	alpha-HCH	4.2
	gamma-HCH	4.7
	Dieldrin	0.0
	Hexachlorobenzene	1.9
	Heptachlor	2.2
	Cis-chlordan	0.0
	Trans-chlordane	
	Cis-nonachlor	
	Trans-nonachlor	0.0
	Mirex	0.0
	Pentachlorobenzene	0.0
	Heptachlorepoxide	0.0
	PCBs	15.4
N station....... K06 Latitude........ 75 deg 30.0 min Longitude....... 45 deg 45.0 min Sampling date... 2-Sep-94	Sum of DDT	0.0
	Sum of TDE	4.8
	Sum of DDE	5.2
	alpha-HCH	2.1
	gamma-HCH	4.1
	Dieldrin	0.0
	Hexachlorobenzene	0.0
	Heptachlor	1.0
	Cis-chlordan	0.0
	Trans-chlordane	
	Cis-nonachlor	
	Trans-nonachlor	0.0
	Mirex	0.0
	Pentachlorobenzene	0.0
	Heptachlorepoxide	0.0
	PCBs	37.1
N station....... K07 Latitude........ 73 deg 45.0 min Longitude....... 10 deg 10.0 min Sampling date... 4-Sep-94	Sum of DDT	0.0
	Sum of TDE	16.4
	Sum of DDE	18.2
	alpha-HCH	0.1
	gamma-HCH	11.4
	Dieldrin	1.0
	Hexachlorobenzene	2.6
	Heptachlor	0.0
	Cis-chlordan	0.0
	Trans-chlordane	
	Cis-nonachlor	
	Trans-nonachlor	0.0
	Mirex	1.3
	Pentachlorobenzene	5.0
	Heptachlorepoxide	9.4
	PCBs	0.0

(to be continued)

Table 3.3 (continued)

Sampling	Contaminant	Value
N station....... K08 Latitude........ 71 deg 25.0 min Longitude....... 24 deg 24.0 min Sampling date... 5-Sep-94	Sum of DDT	24.3
	Sum of TDE	5.8
	Sum of DDE	23.1
	alpha-HCH	23.1
	gamma-HCH	28.9
	Dieldrin	0.0
	Hexachlorobenzene	2.3
	Heptachlor	0.0
	Cis-chlordan	0.0
	Trans-chlordane	
	Cis-nonachlor	
	Trans-nonachlor	0.0
	Mirex	0.0
	Pentachlorobenzene	10.4
	Heptachlorepoxide	10.4
	PCBs	0.0
N station....... K09 Latitude........ 69 deg 5.0 min Longitude....... 35 deg 35.0 min Sampling date... 6-Sep-94	Sum of DDT	37.0
	Sum of TDE	22.0
	Sum of DDE	20.8
	alpha-HCH	6.9
	gamma-HCH	2.3
	Dieldrin	0.0
	Hexachlorobenzene	0.0
	Heptachlor	4.6
	Cis-chlordan	0.0
	Trans-chlordane	
	Cis-nonachlor	
	Trans-nonachlor	0.0
	Mirex	2.3
	Pentachlorobenzene	1.2
	Heptachlorepoxide	33.6
	PCBs	0.0

Arctic Atmospheric Research
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ARCTIC AIR POLLUTION STUDIES IN GREENLAND.

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INTRODUCTION

Arctic Atmospheric Research has a long tradition at NERI/DEAP. Because of the close association between Denmark and Greenland this work has over the years naturally been concentrated on investigations in the Greenland Arctic. In this paper past and current research and monitoring activities are reviewed and illustrated by a selection of results from the Danish programme SAGA, Studies of Aerosols in the Greenland Atmosphere and AMAP, Arctic Monitoring and Assessment Programme.

The main outcome of this work has been the realisation and demonstration that even in the remote Polar area the atmosphere is burdened with a significant pollution load of distant anthropogenic origin. (Arctic Air Chemistry, 1977, 1981, 1985, 1989; AGASP, 1984; Arctic Air Pollution, 1986; Heidam, 1984, 1985; Ottar et al. 1986). Such perturbations of the naturally pristine Polar atmosphere may have widespread environmental and climatic consequences since the Arctic region occupies an essential position in the atmospheric circulation systems that dominate the Northern Hemisphere.

The present day activities comprise both field investigations and model development. The experimental measurements in Greenland are directed towards determination of the composition of the atmospheric pollution and the seasonal variations. To that end ambient concentrations of both gases and aerosols are measured over several years and in widely separated locations.
The model being developed is an eulerian model covering the whole Hemisphere and at present incorporating simple sulfur chemistry. It is intended as a tool for studying the origins of the pollution and the atmospheric transport and transformation mechanisms responsible for Arctic air pollution.

ARCTIC HAZE AEROSOLS

SAGA 1979-1983.

In the period August 1979 to May 1983 aerosol filter samples were collected on a semi_weekly basis at the four coastal stations THUL, NORD, GOVN, and KATO/MEST located as shown in Fig. 1 (the station MEST replaced station KATO in the fall of 1980). The purpose was to determine the levels, composition and seasonal variations of arctic aerosols in Greenland, based on the elemental contents determined by PIXE analyses.

Monthly geometric mean values at the two northern stations THUL and NORD for the four elements Sulphur, Lead, Zinc and Titanium are shown in Fig. 2. The first two elements, S and Pb, show the typical behaviour of the anthropogenic combustion component of the aerosol, Zn is representative of the metallic component, and Ti represents the crustal part of the aerosol.

The anthropogenic components are characterized by a systematic and recurrent behaviour with large winter maxima that occur almost synchronously at these two stations separated by more than 1000 km. In view of the absence of any large sources of this nature in the region this behaviour must be interpreted as evidence of an Arctic-wide phenomenon of long range atmospheric transport from distant sources. The maximum concentrations of particulate sulphur, the main component of Arctic Haze observed all over the Polar region in winter, are in fact comparable to levels found in rural regions of Europe. The secondary summer-maxima of Pb and Zn are on the other hand thought to be of a more local origin (Heidam, Arctic Air Pollution 1986). The temporal variation of the crustal component as exemplified by Ti is more erratic and consistent with that of wind-blown dust particles of indigeneous origin since large coastal tracts of Greenland are snow free in summer.

Individual results are shown on a logarithmic scale for Sulphur at all stations in Fig. 3. for the whole experimental period of the SAGA project. The plots are arranged spatially to reflect the geographic positions of the stations. To facilitate comparisons smoothed spline-curves, representing low-pass filters, are shown. The curves correspond approximately to moving averages over 15 observations, i.e. 1.8 months.

The temporal variations are particular to the site, reflecting a geographical variation of source impacts. But the models are essentially the same at all stations, signifying the strong influence of long range atmospheric transport from remote sources on the Greenland aerosol. This influence is weakest at the southern stations but closer inspection reveals that both the marine and combustion components do possess regular seasonal variations, particularly at GOVN on the west coast. The systematic recurrency of annual maxima and minima are much more pronounced at the northern sites, in particular at NORD where they range over more than two decades. Thus Northeast Greenland seem to be the region most systematically exposed to long range transport.

SAGA (AMAP) 1990 -

Quite similar results have been found to persist at Station NORD 10 years later. These measurements have been resurrected in the 1990's as a preparation to the implementation of AMAP. In this new programme the measurements comprise both gaseous and particulate compounds that are measured on a weekly basis.

Results on both sulfur and nitrogen compounds from 1991 and 1992 are shown in Figs. 4 and 5. It is clear that the annual patterns are similar to the ones described above. It is surprising, though, that the gaseous compounds sulfurdioxide and ammonia occur with such abundance so far from the source areas and that they have not to a much larger extent been converted to the particulate phase during transport.

SOURCE RELATED AEROSOL COMPONENTS

In order to elucidate the origins and transport routes of arctic air pollution the results were subjected to Factor Analysis (Harman, 1976; Heidam, 1982, 1984). In the ensuing factor models the structure of the variations and covariations of the 15 - 20 elements detected is represented by a small set of factors which can be interpreted physically in terms of a few virtually independent aerosol components. Examples of these models are shown in Tables 1 and 2 and it is seen that 3 - 4 factors suffice to account for 85 - 90 % of the total variance associated with the concentration variations. The variance is distributed over the factors as shown and the column of communalities, which are the fractions of variance explained by the model, shows the distribution over individual elements. The modelling of the individual elements is also quite good since the communality is generally greater than 75 %. The interpretation of the factors as representations of physical aerosol components is based on the composition of elements most strongly coupled to the factor.

The models obtained at the various stations for both coincident (Heidam, 1984, 1985) and separate time periods (Tables 1 and 2) turn out to be mutually quite similar in that they contain the same set of source related components: Anthropogenic components originating from combustion processes in power generation and transportation or industrial processes such as metal smelting and natural components of a crustal or marine character. Although the strengths of these source influences might vary from station to station it can be concluded that this simple source-related composition is a general characteristic of the Arctic aerosols, not only in Greenland but in the Arctic in general. This conclusion allows the most important characteristics of the aerosol variations to be illustrated by a few elements selected as tracers for the various aerosol components.

TRANSPORT MECHANISMS

The mechanisms responsible for the strong periodicity of air pollution concentrations in the high Arctic have been explored in many investigations (Arctic Air Chemistry 1981, 1985, 1989). The explanation is to be found in the large scale atmospheric circulation patterns that dominate the higher latitudes in winter. There are three main meteorological features involved.

The first one is the northeastern movements of the Atlantic low pressure systems from west of the American continent towards Europe as depicted in Fig. 6. During the passage of the northern parts of western and central Europe the northeastbound air samples the pollution released from the widespread sources in this industrialized region. The second meteorological feature responsible is the large high pressure system which as seen in Fig. 6 resides over Asia at this time of the year. This anticyclonic system combines with the cyclone now residing somewhere over the Barents Sea north of Russia to form a 'geostrophic pump' that forces the air northwards. The anticyclone lends atmospheric stability with little vertical movement to the air while the cyclone governs the air in a large circle towards Spitzbergen and Northeast Greenland, cf. Fig. 6. This northern region is therefore the one most exposed to Arctic Haze.

The third feature which is responsible for the high concentrations reached in the Arctic is the scarcity of precipitation in winter. That entails long residence times with subsequent concentration build-up for any air pollutants, gaseous or particulate, that have entered the region. The injection of pollutants is greatly facilitated by the position of the Polar front which in winter is frequently south of major industrial source areas. The Polar front constitutes a fuzzy barrier between the cold polar air and the more humid air at temperate latitudes where precipitation is frequent. Therefore, at this time of year air pollution is often released north of this barrier and the pathway to the Polar region is open.

The effect of these mechanisms is to favour near-surface transport of air pollution from Europe and northern Russia which are therefore considered to be the major source regions for the pollution of the lower Arctic troposphere. Given slightly different positions of the weather systems more direct routes from these regions and northwards may also occur (Heidam, 1984). Additional aircraft measurements supplemented with numerical modelling have shown that the Arctic Haze pollution reaches altitudes up to 3.5 km with the major part of Euroasian origin below 2.5 km and that contributions from more distant source areas, such as the southern parts of Russia and the eastern part of USA, are significantly smaller and tend to occur at higher altitudes the more distant the source (AGASP, 1984; Ottar et al., 1986; Barrie et al., Arctic Air Chemistry 1989).

All the controlling meteorological features break down, however, in late spring: The Atlantic cyclones follow different routes, the Asian High disappears, the Polar front moves north to isolate the Arctic from midlatitude injections and local precipitation increases. The result is a rapid decrease to the extremely low concentrations observed in summer.

In order to describe these processes in more detail an eulerian model covering the northern hemisphere has been developed. In addition it is necessary to incorporate chemical transformation schemes. At present the models only contains a simple sulfur chemistry but the plans are also to include nitrogen chemistry and atmospheric photochemistry.
In the existing version the model is nevertheless capable of reproducing the main features of the transport processes and the seasonal variations of atmospheric sulfur in the Arctic region. This is seen in Fig. 7 where the distribution of airborne sulfurdioxide and surface pressures are shown. The figure clearly reproduces the transport patterns shown in Fig. 6.
The model is described in more detail elsewhere (Christensen, 1995, this report).

THE ICECAP EXPERIMENT

SAGA 1989 -

The systematic occurrence of anthropogenic Arctic Haze aerosols all along the North Greenland coastline and the fact that it extends to altitudes up to 3000 m opens the question of penetration of Arctic Haze into the vast Greenland Icecap and the impacts on atmospheric conditions here with possible consequences for climate and environment.

Present studies are therefore focused on Arctic aerosols at Summit in central Greenland, see Fig.1. Little is known of the level and composition of the aerosol in this remote and elevated region. A few results have been obtained during summer campaigns as a supplementary to snow deposition studies (Davidson et al. Arctic Air Chemistry, 1985) but long continuous timeseries of the kind collected in the SAGA project 1979-1983 are needed to cover all seasonal variations and to determine the origin of this aerosol.

The Greenland Icecap is the second largest permanent ice-mass on Earth, it covers an area of 1.8 million km^2 and and reaches heights of more than 3000 m. Large scale penetration of pollution derived aerosols into this pristine area may severely perturb the precipitation and cloud distribution patterns or the tropospheric radiation balance with possible climatic impacts on an hemispheric scale.

That some penetration does occur is evident from reports that the contents of heavy metals, sulfate, and nitrate in deposits recovered form ice-cores have risen dramatically over the last decades (Murozumi et al. 1969; Weiss et al. 1971; Busenberg and Langway 1979; Barrie and Hoff, Arctic Air Chemistry 1985; Finkel et al. 1986; Mayewski et al. 1986). To obtain factual evidence on-site measurements are needed since the topography of the Icecap makes it unlikely that extrapolation of results obtained from the low-lying coastal sites can yield reliable results.

The central icecap of Greenland is virtually inaccessible without special and costly equipment. In addition the region is unfit for prolonged stays and the SAGA Icecap Experiment is therefore carried out with automated equipment (Kemp and Wåhlin, 1992). It was started in association with the joint European Greenland Icecore Programme, GRIP, one of two large international icecoring projects carried out in the period 1989 - 1993 at SUMMIT at an altitude of 3200 m a.s.l. The purposes of GRIP and the American project GISP 2, to retrieve 3000 m icecores down to bedrock, were achieved in 1992 and 1993, respectively.

Aerosol sampling was started in the summer 1989 about 6 km north of the GRIP-site and has continued since then athough drilling has now stopped. Particulate samples in two size ranges are collected consecutively on a weekly basis and analyzed for elemental contents by PIXE. Retrieval of the samples occurs only once a year during a summer visit to the site. In order to estimate the degree of penetration of Artic Haze aerosols into the central Greenland region concurrent measurements are carried out with identical equipment deployed in Northeastern Greenland at Station Nord (Wåhlin, 1992).
The experiment is desribed in more detail elsewhere (Wåhlin, 1995 and this report).

Ackowledgements
The valuable contribution to the Icecap Experiment from Jens Tscherning Møller at the instrumental workshop is gratefully ackowledged.
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Table 1. Varimax rotated 3-factor model for the Arctic aerosol. NORD June 1981 - May 1982.

	FACTOR1 EROSION	FACTOR2 METALS	FACTOR3 COMBUSTION	COMMU-NALITY
AL_13	0.977	0.012	-0.004	0.954
FE_26	0.968	0.153	0.062	0.965
TI_22	0.941	0.067	0.013	0.891
SI_14	0.871	-0.014	-0.262	0.826
CA_20	0.870	0.206	0.227	0.850
K_19	0.834	0.417	0.206	0.912
MN_25	0.811	0.514	0.206	0.964
SR_38	0.566	0.472	0.410	0.710
ZN_30	0.202	0.831	0.345	0.850
CU_29	0.002	0.763	0.449	0.785
CR_24	0.503	0.634	0.274	0.730
BR_35	0.016	0.228	0.973	0.999
S_16	-0.151	0.456	0.754	0.799
PB_82	0.191	0.259	0.640	0.513
Variances explained	6.317	2.732	2.698	11.747 83.9 %

Table 2. Varimax rotated 4-factor model for the Arctic aerosol.
THUL May 1982 - May 1983.

	FACTOR1 EROSION	FACTOR2 COMBUSTION	FACTOR3 METALS	FACTOR4 MARINE	COMMU-NALITY
TI_22	0.971	0.029	0.154	0.135	0.986
SI_14	0.966	-0.065	0.163	0.094	0.973
AL_13	0.961	0.095	0.166	0.106	0.972
FE_26	0.957	0.138	0.214	0.114	0.995
MN_25	0.853	0.310	0.354	0.104	0.959
K_19	0.609	0.386	0.348	0.506	0.897
S_16	-0.085	0.919	0.207	-0.171	0.923
BR_35	0.055	0.847	0.385	0.149	0.890
NI_28	0.138	0.823	0.289	0.019	0.781
CA_20	0.410	0.623	0.369	0.438	0.885
PB_82	0.230	0.397	0.804	0.060	0.860
CU_29	0.317	0.257	0.778	0.149	0.794
ZN_30	0.230	0.485	0.765	0.089	0.881
CR_24	0.363	0.527	0.546	0.090	0.715
CL_17	0.080	-0.117	0.032	0.844	0.734
SR_38	0.491	0.503	0.310	0.633	0.990
Variances explained	5.599	3.908	3.012	1.717	14.234 89.0 %

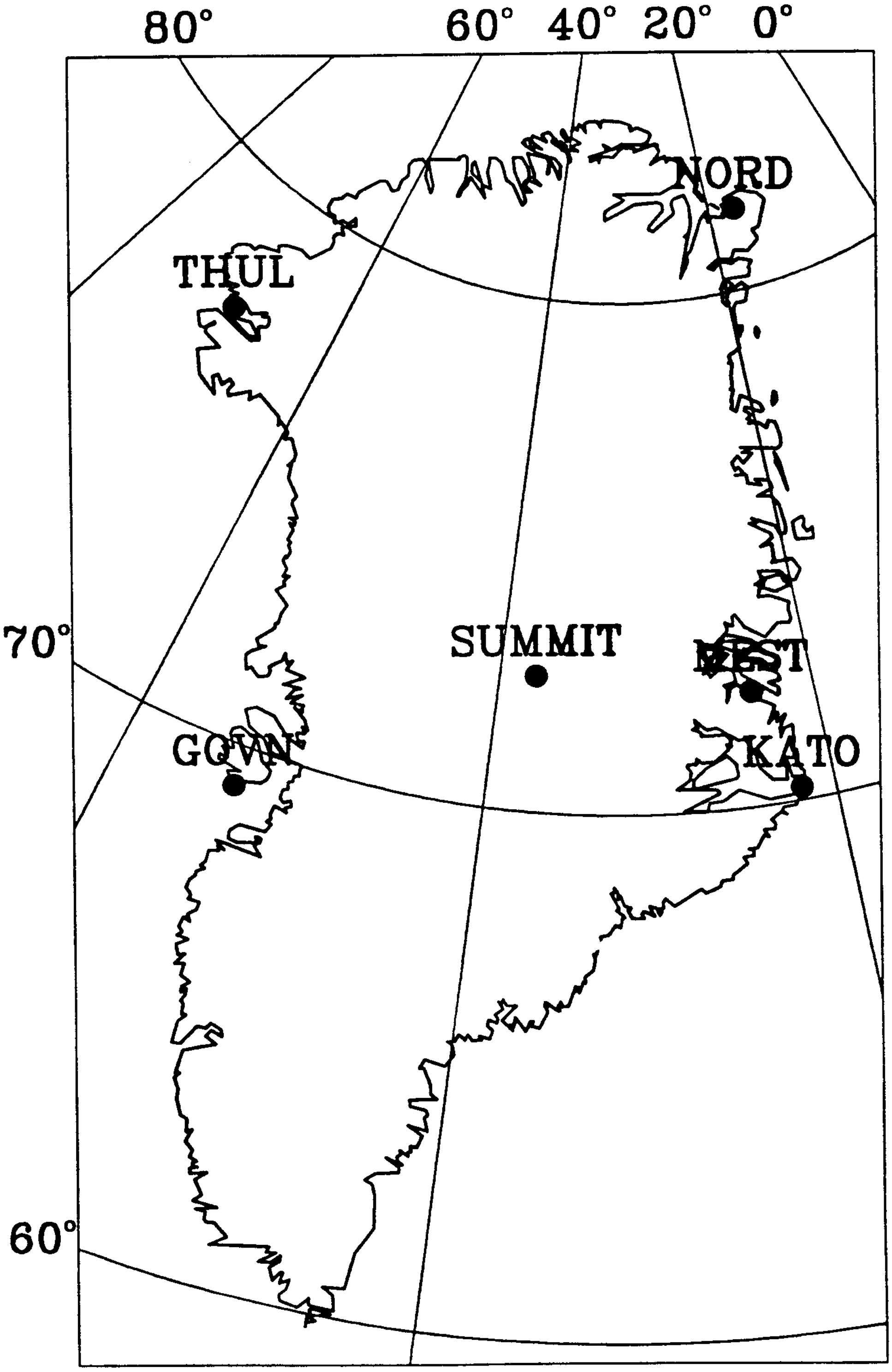


Fig.1. Location of the coastal SAGA-stations and the SUMMIT site on the Ice Cap.

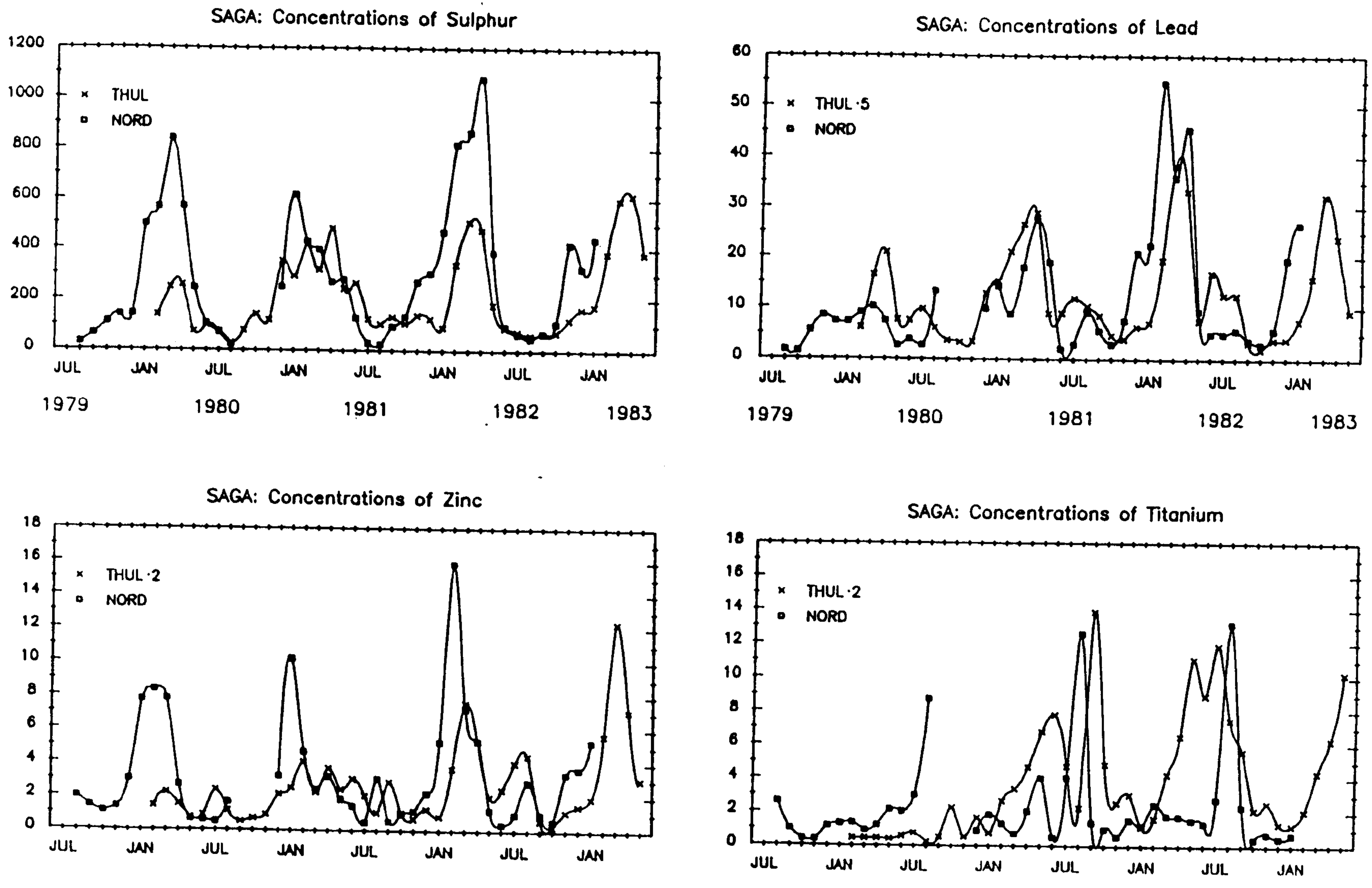


Fig. 2. Monthly geometric mean values of concentrations at THUL and NORD. Units: ng·m^{-3}.

fig 2

SAGA 1979–1983

Sulphur Concentrations

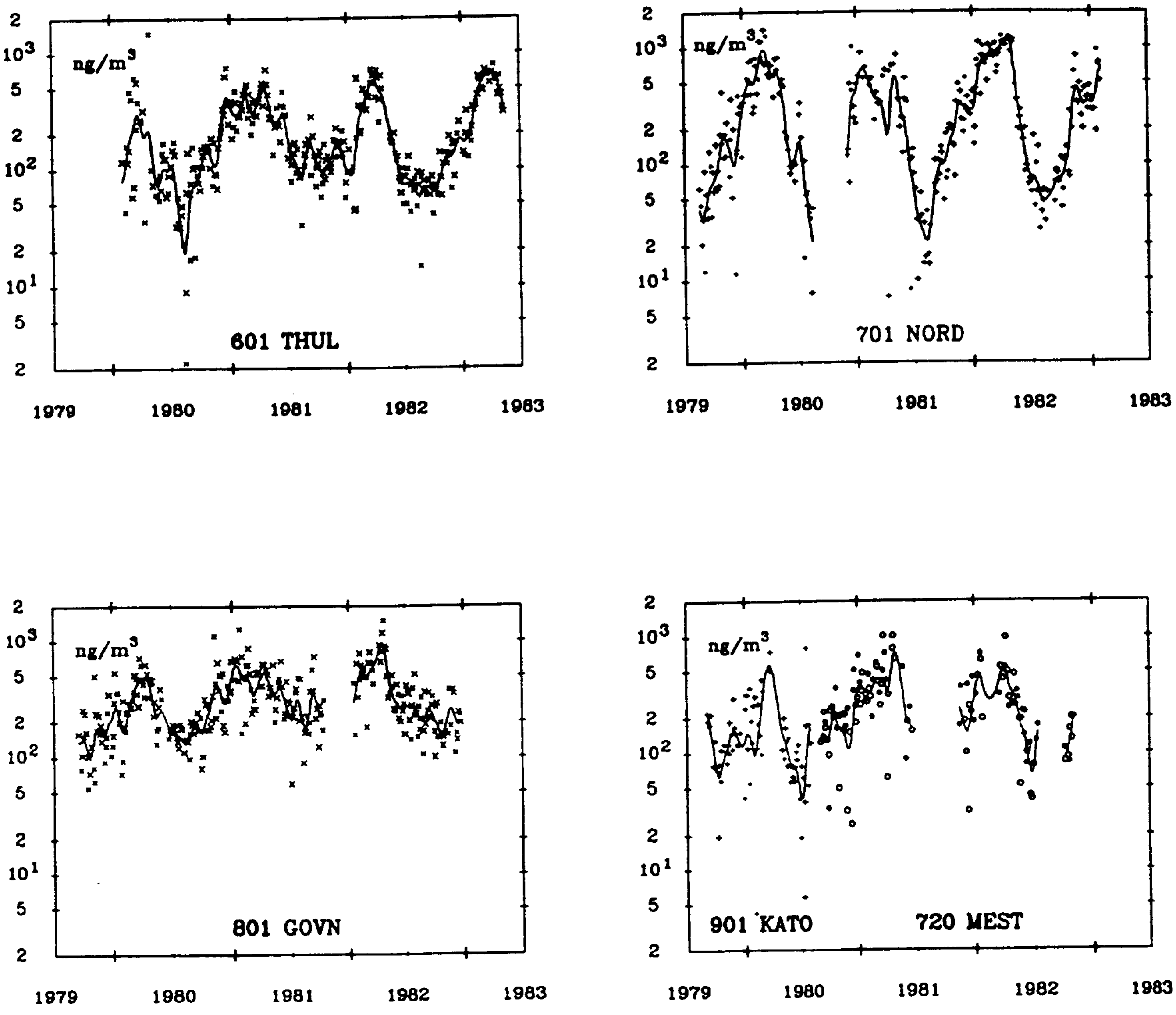


Fig. 3. Observed concentrations of Sulphur at the four SAGA stations.
Individual values and smoothing curves. Units: ng m^{-3}.
(The station MEST replaced station KATO in the fall of 1980).

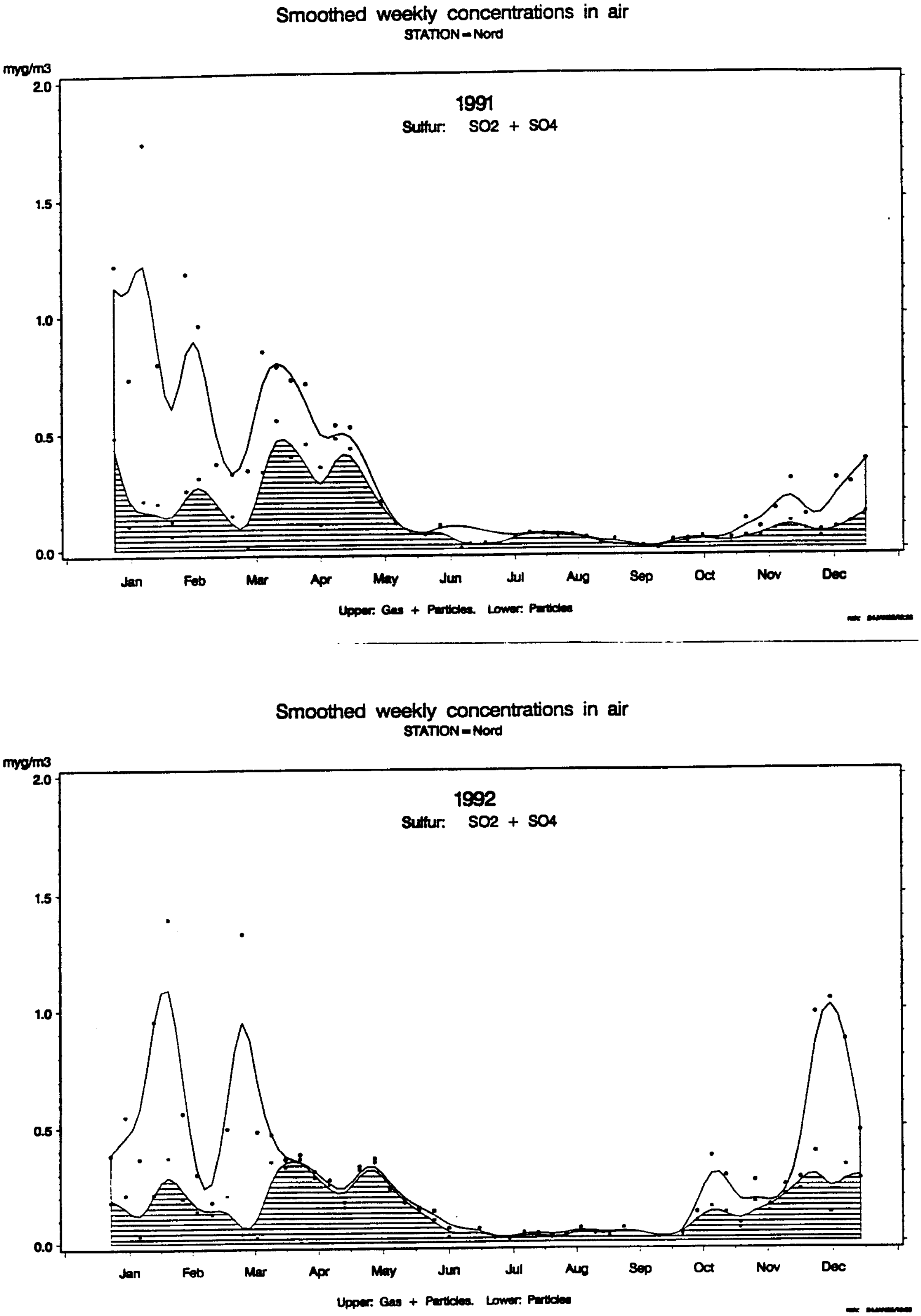


Fig. 4. Observed concentrations of gaseous and particulate sulfur at NORD, 1991 and 1992.

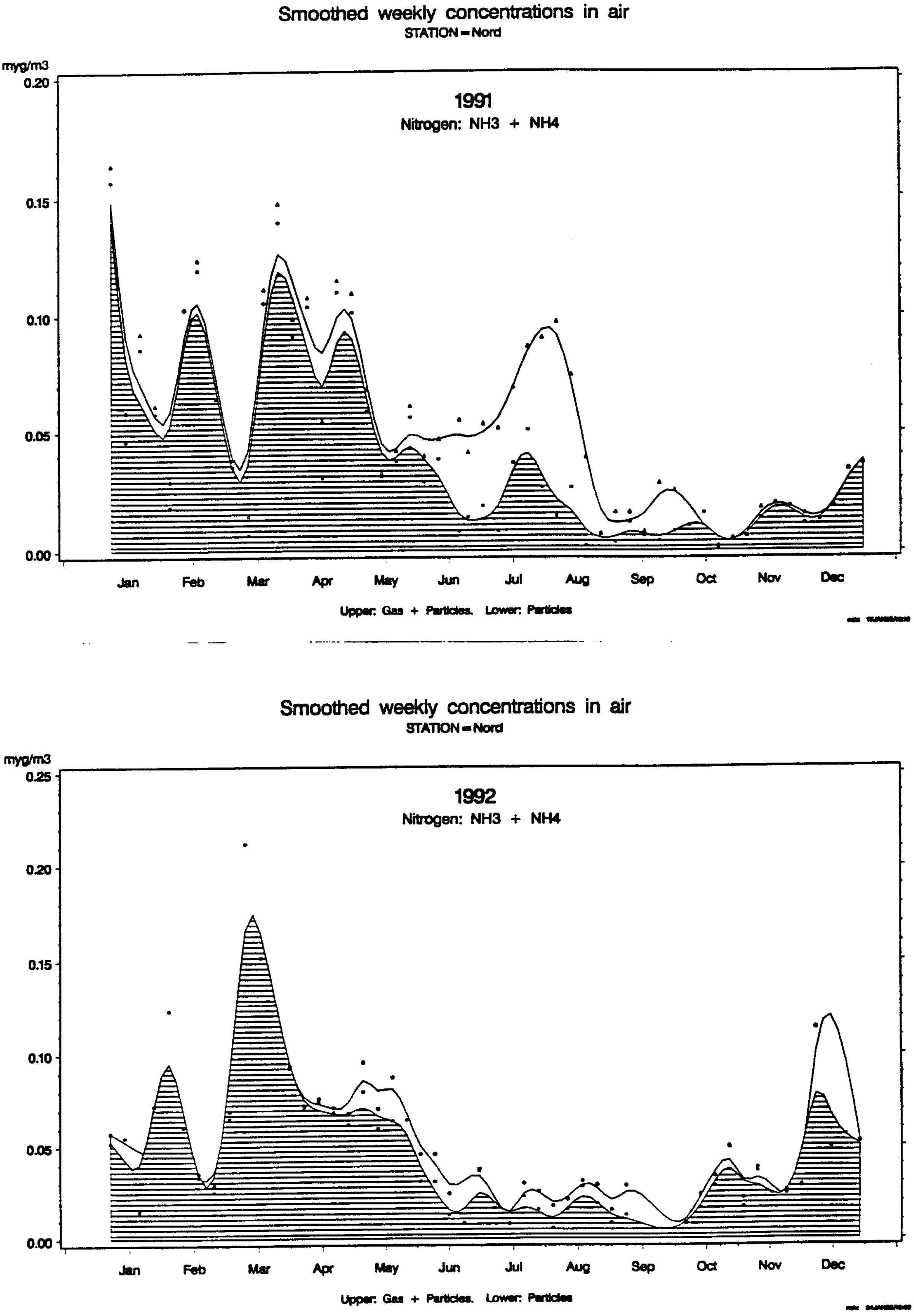


Fig. 5. Observed concentrations of gaseous and particulate reduced nitrogen at NORD, 1991 and 1992.

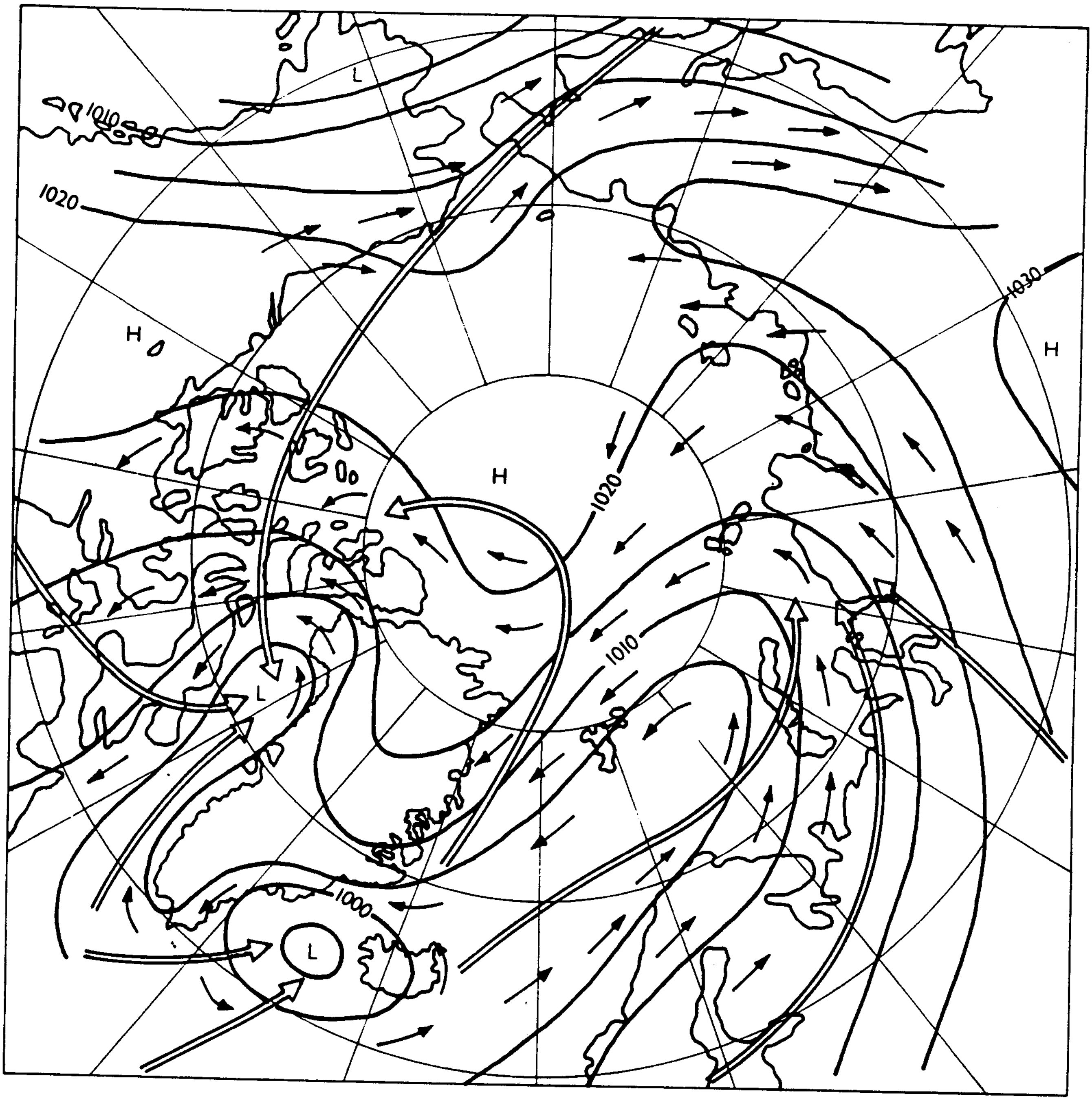
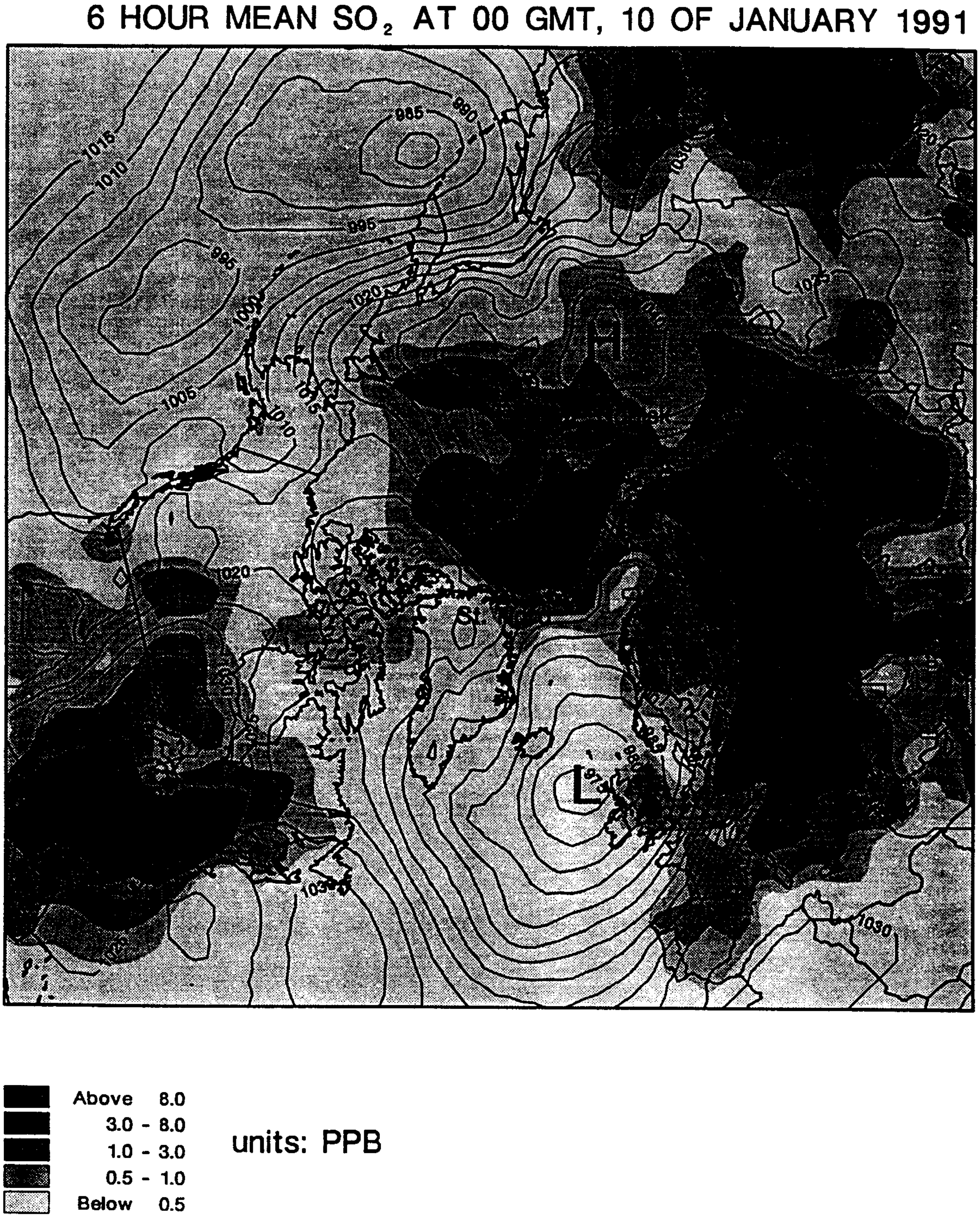


Fig. 6. Average distributions of surface pressures (in mb), winds (single arrows) and cyclone trajectories (double arrows) in January.



6 HOUR MEAN SO_2 AT 00 GMT, 10 OF JANUARY 1991

Fig. 7. Modelled distributions of sulfurdioxide in *ppb* and surface pressures in *mb* for a particular situation in January 1991.

Seminar and workshop on Arctic Atmospheric Research, Roskilde, Denmark 16.-18. March 1996. Also presented at NATO ARW: Processes of Chemical Exchange between the Atmosphere and Polar Snow, Il Ciocco, Italy 19.-23. March 1995.

ONE YEAR'S CONTINUOUS AEROSOL SAMPLING AT SUMMIT IN CENTRAL GREENLAND

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Abstract—Aerosol samples were collected continuously in two size fractions from June 1993 to June 1994 at a site 6 km north of the GRIP camp at Summit in central Greenland. The battery-driven sampling equipment was designed for automatic operation and low energy consumption. The samples were analyzed for elements using Particle Induced X-ray Emission (PIXE). The elements Al, Si, S, Cl, K, Ca, Ti, Mn, Fe, Zn, Br, Sr and Pb were measured well above the detection limits in many samples. The contents of most of these elements can be attributed to three sources, a crustal, a sea salt and an anthropogenic source. Additional contributions from other sources seem to be of importance for S and especially for Br. The crustal source had a peak incidence in the spring, while the anthropogenic source was present all year, strongest in winter and spring. The sea salt signal was very weak and difficult to resolve from the data, but was strongest in the winter. The results from Summit are compared with published data from Dye 3 on the southern part of the Greenland Ice Sheet, and with measurements from Station Nord, a sea level site in northeastern Greenland.

INTRODUCTION

Snow deposition studies are very important for the interpretation of icecore data. Measurements of chemical species in air compared with measurements of the same species deposited simultaneously in snow are of obvious importance for studies of how icecore data can be used as a record of atmospheric conditions in the past. A great effort is made in these years to retrieve such data in the Summit region in central Greenland, where the GISP 2 and GRIP deep core drillings have been carried out. Determination of sources and studies of deposition mechanisms depend on long continuous time series to cover all seasonal variation. While doing measurements on winter snow is hardly more difficult than doing measurements on summer snow, this is not the case for the corresponding atmospheric measurements because of the harsh climatic conditions and the resulting short summer field seasons. The data presented here are results from work done in association with GRIP in an attempt to do all-year aerosol sampling near the GRIP camp using an unattended, automatic sampler. The sampling began in the summer 1989 but has until now not been very successful and, although an all-year air concentration record can now be presented for a series of elements in two size fractions, some reservations must be made for possible errors that are due to imperfect sampling.

EXPERIMENTAL

The samples are collected with a battery-driven two-stage discrete streaker in miniature designed to provide small samples suitable for Particle Induced X-ray Emission (PIXE) analysis (Kemp and Wåhlin, 1992). The sampler, shown schematically in Fig. 1, is encased in a cylinder 35 cm in length and with a diameter of 15 cm. Particles separated at about 2 μm diameter are collected sequentially in small spots on a sampling wheel with two coaxial discs. Coarse particles are deposited by means of a rectangular impaction nozzle on a Apiezon coated mylar foil, while fine particles are collected on a 0.4 μm Nuclepore filter. The size of the sample spots matches the cross-section of the proton beam in the PIXE apparatus and is small enough to allow 64 samples to be collected on the same foil/filter. A comprehensive set of blank samples are obtained by skipping every eight sample position. The air flow is ~15 cm^3/s corresponding to ~ 6 m^3/week (STP) at Summit conditions. The power consumption is less than 4 W which makes it possible to use batteries (600 kg zinc/air cells) as the power source for a whole year. The main power consumer is a small pump. The sampling wheel is controlled by a small computer and is automatically turned a 5° angle once a week (Monday at 0 GMT) which allows the collection of weekly samples in more than one year. The computer also logs time, wheel position, air flow and temperature.

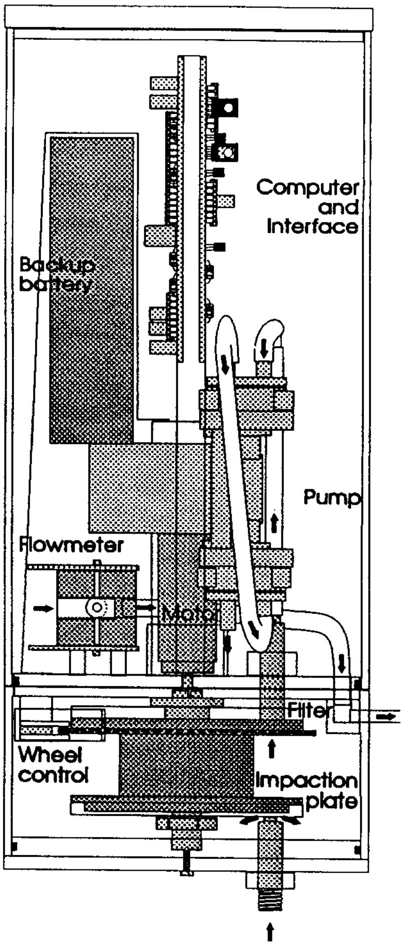

Fig. 1. Schematic drawing of the streaker.

The sampling site is situated 6 km north of the GRIP camp at Summit (72°35' N, 37°38' W, 3220 m a.s.l.) The deployment of the streaker on the icecap is shown in Fig. 2. As the ambient temperature may range below -60 °C the instrument is placed inside a large aluminum box insulated with polystyrene foam. With this geometry the energy dissipated internally in the compact instrument can maintain a temperature of about 30 °C above that of the surroundings. The box is placed in a 2 m pit and covered with snow, which ensures that ambient temperature is constantly close to the annual average of -30 °C at Summit. A 2 W heating element is automatically turned on if the temperature inside the streaker falls below 0 °C. The air intake is constructed to avoid blocking by blowing snow. It is equipped with an ordinary Frisbee disc to minimize turbulence around the sampling point (Hall and Upton, 1988).

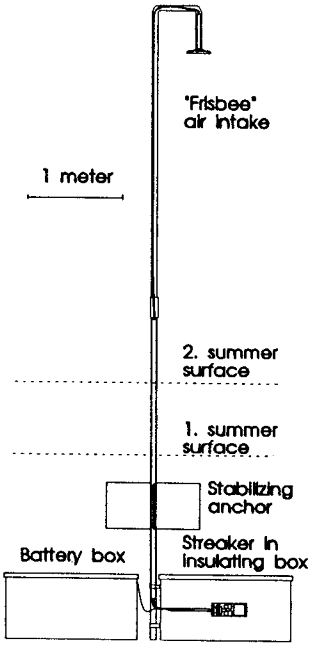

Fig. 2. The experimental set-up at the sampling site.

The first years of the sampling, which began in 1989, can retrospectively be considered as prototype testing. Different incidents of error were encountered such as computer malfunctions and too high pump voltage. The most serious problem, however, has been condensation of rime and blocking with ice in the air inlet, although this was not realized in the

Table 1. Detection limits in ng/m^3 for a series of elements.

	Fraction	
	Fine	Coarse
Al	4	3
Si	3	2
S	1.5	1.5
Cl	0.8	2
K	0.4	0.4
Ca	0.2	2
Ti	0.05	0.06
V	0.03	0.04
Cr	0.05	0.04
Mn	0.02	0.02
Fe	0.1	0.07
Ni	0.015	0.02
Cu	0.015	0.02
Zn	0.01	0.3
Ga	0.007	0.008
As	0.015	0.015
Se	0.01	0.007
Br	0.07	0.015
Rb	0.03	0.015
Sr	0.02	0.015
Zr	0.04	0.02
Pb	0.05	0.04

beginning. The condensation takes place in the subsurface part of the inlet, and it seems to be a summer phenomenon caused by the relatively high vapor content, when the temperature of air is higher than that of the equipment below in the snow. Steps have been taken to prevent blocking of the inlet by progressively widening the subsurface part of the inlet, and the sampling season from June 1993 to June 1994 was the first successful in the sense that the inlet was never blocked and the streaker had operated satisfactorily. Nevertheless, as discussed later, there are still indications for some occurrence of condensation processes leading to losses of particles.

The air flow, recorded as float positions in the variable area flowmeter, was calculated and rescaled from Summit conditions (average air pressure 0.68 atm) to STP (1 atm, 0 °C) using the laboratory calibration values, the Bernoulli equation and the law of ideal gases. The flowmeter is read with an uncertainty of about 10% by means of an array with 11 sets of LED/phototransistors.

The samples were analyzed by means of PIXE using a Van de Graaff accelerator in Copenhagen. With the filter/foil used the PIXE provides detection limits down to 10^{-10} - 10^{-11} g for medium atomic weights. Concentrations down to 0.01 ng/m^3 could be measured for several elements (Table 1). Detection limits for some elements were rather high due to impurities in the foil/filter materials.

OBSERVATIONS

The continuous series of 51 coarse fraction samples and 51 fine fraction samples ranged over almost one year in the period from 21-6-93 to 8-6-94 with one week's sampling of each (except the last one in each series) beginning on Mondays at 0 GMT. The elements Al, Si, S, Cl, K, Ca, Ti, Mn, Fe, Zn, Br, Sr and Pb were measured well above the detection limits in many samples. The air volume ranged from 4.5 to 6 m^3 (STP).

The annual variation of Al, Si, K, Ca, Ti, Mn, Fe, Zn, Sr and Pb

The concentration data for all elements except S, Cl and Br could be expressed in reduced form using a constrained multivariate receptor model.

The model

$$x_{ij} \cong \sum_k a_{ik} f_{kj} \quad (\mathbf{X} \cong \mathbf{AF})$$

Table 2. Summit mean values June 1993 - June 1994. Unit: ng/m^3 (STP). The source contributions are determined only for the fine fraction data.

	Fine fraction	Soil	Sea	Combustion	Coarse fraction
Al	1.4±0.3	100%			1.3±0.3
Si	6.2±0.6	65%		35%	2.8±0.3
S	46±4	-	-	-	7.7±0.7
Cl	2.8±0.3	-	-	-	1.2±0.2
K	1.26±0.12	35%	5%	60%	0.47±0.05
Ca	1.21±0.11	70%	5%	25%	0.7±0.2
Ti	0.090±0.009	85%		15%	0.064±0.008
Mn	0.034±0.004	60%		40%	0.022±0.003
Fe	1.24±0.11	70%		30%	0.90±0.08
Zn	0.092±0.008	~0%		100%	0.03±0.02
Br	0.061±0.008	-	-	-	0.0019±0.0013
Sr	0.013±0.002	70%	15%	15%	0.0084±0.0015
Pb	0.075±0.008	~0%		100%	0.005±0.003

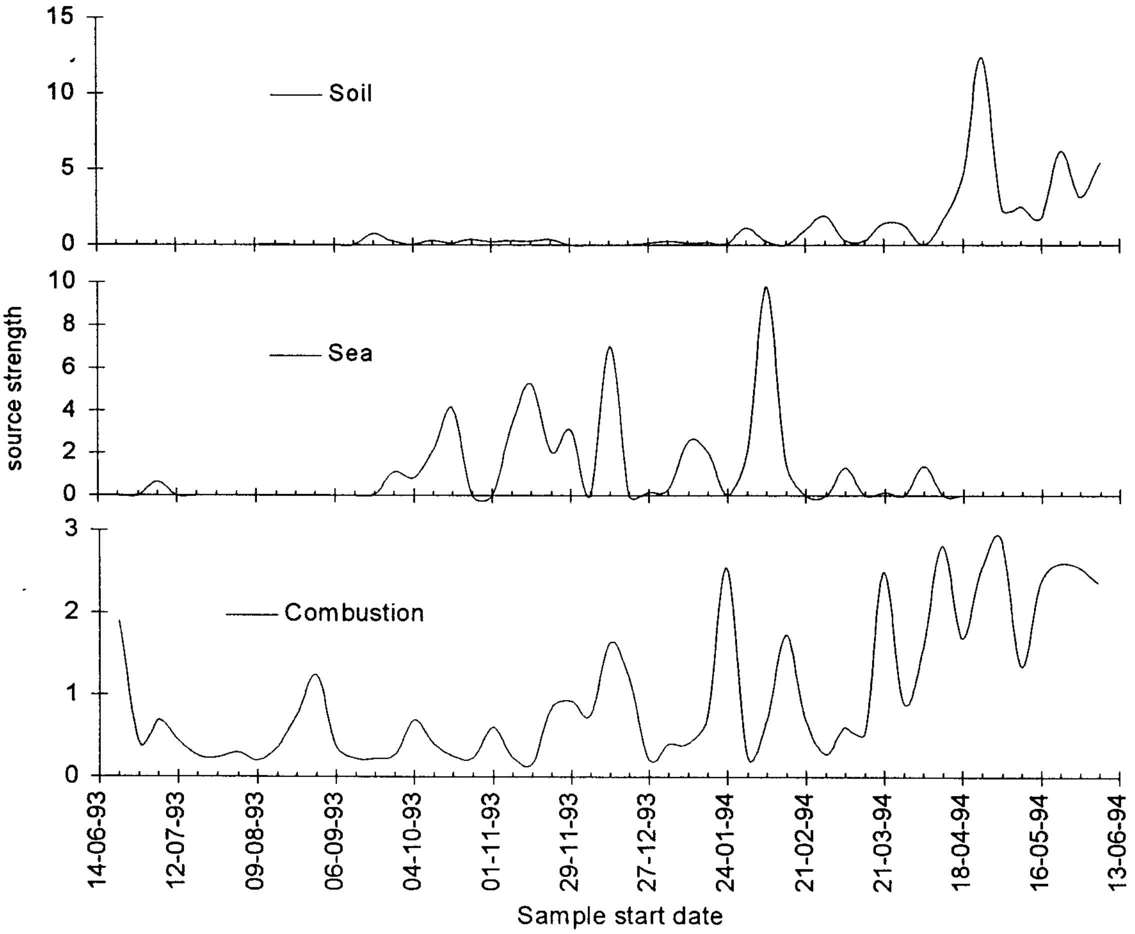

Fig. 3. Normalized strengths (mean value = 1) of the soil, sea and combustion sources.

expresses the measured concentrations x_{ij} as linear combinations of constant source profiles a_{ik}. The coefficients f_{kj} represent the source strengths found in the individual samples. Index i refers to the chemical elements, index j to the samples and index k to the sources. An iterative method is used in which the elements of the **F** matrix and selected elements of an initial **A** matrix are fitted by turns, and the model is confined to permit only non-negative elements of **A** and **F** (Wåhlin, 1992). Those elements of **A** which are not allowed to change are marked with zeros in a form matrix with the same number of rows and columns as **A**. The model has a hybrid character. It can be characterized as a chemical mass balance model with a built-in ability to fine tune source profiles. On the other hand, if all elements of **A** are allowed to adjust freely (permitting a confusion of more or less mixed up sources), the method has resemblance to factor analysis. The uncertainties of the measurements, σ_{ij}, are handled in an appropriate manner in the fitting process, in which the chi-square,

$$\chi^2 = \sum_j \sum_i \frac{(x_{ij} - \sum_k a_{ik} f_{kj})^2}{\sigma_{ij}^2},$$

is minimized within the limits imposed by the constraints. This also allows data below the detection limit to be put on a par with other data.

Three sources were recognized: A prominent crustal (soil) source, a prominent anthropogenic (combustion) source, and a third, rather indistinct, marine salt (sea) source. Only the fine fraction data was used in the model, because the coarse fraction data was considerably closer to detection limits. The reference values of Sverdrup et al. (1942) were used in the sea profile, while the composition of the soil source and the combustion source were allowed to change freely except for Zn and Pb, which in the soil profile were fixed to Fe in the very small ratios found in igneous rock (Kaye and Laby, 1959). A fairly good total fit ($\chi^2 = 611$, $\nu = 387$) was achieved, in which only the analytical uncertainties (without air volume uncertainties) were used as weights. The mean values are shown in Table 2 along with the fractions assigned by the model to each source. The annual variation of the source strengths are shown

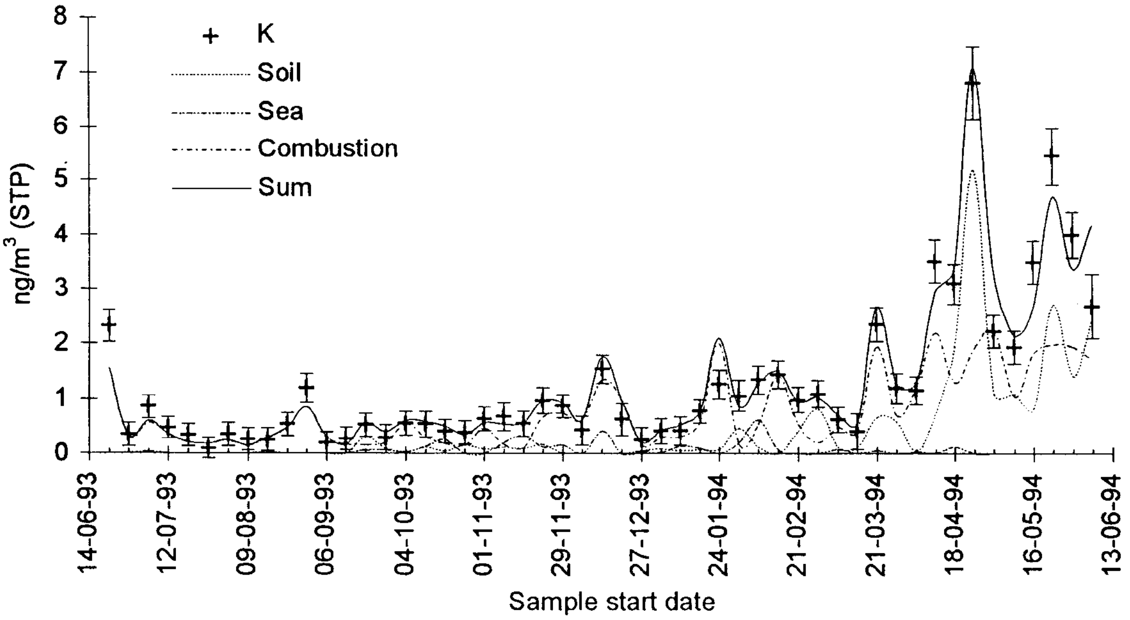

Fig. 4. Concentrations of K in the fine fraction samples fitted with contributions from three sources.

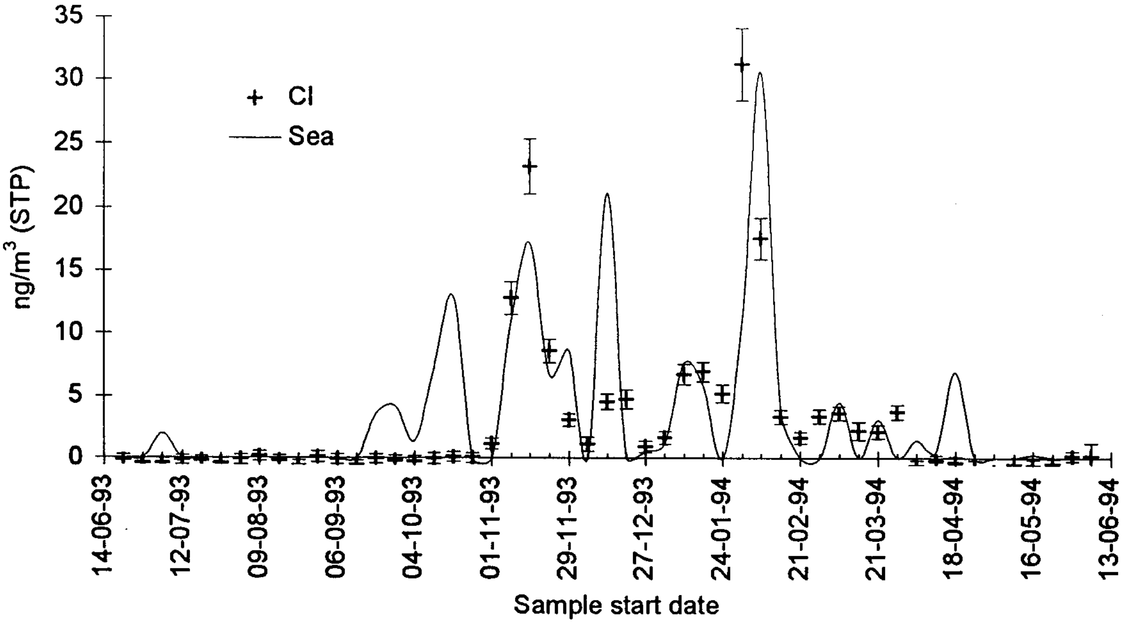

Fig. 5. Fine fraction concentrations of Cl compared with the estimate of the contribution from sea salt.

in Fig. 3. The source contributions to the individual fine fraction samples can be constructed by multiplying the normalized source strengths (in Fig. 3) by the mean values and the source fractions (in Table 2). The determination of the sea source strengths is uncertain because it relies on small contributions from only three elements K, Ca and Sr. (Only 5%, 5% and 15%, respectively, of the annual mean concentrations are assigned to the sea source). In Fig. 4 the fit is shown for K to which all three sources contribute.

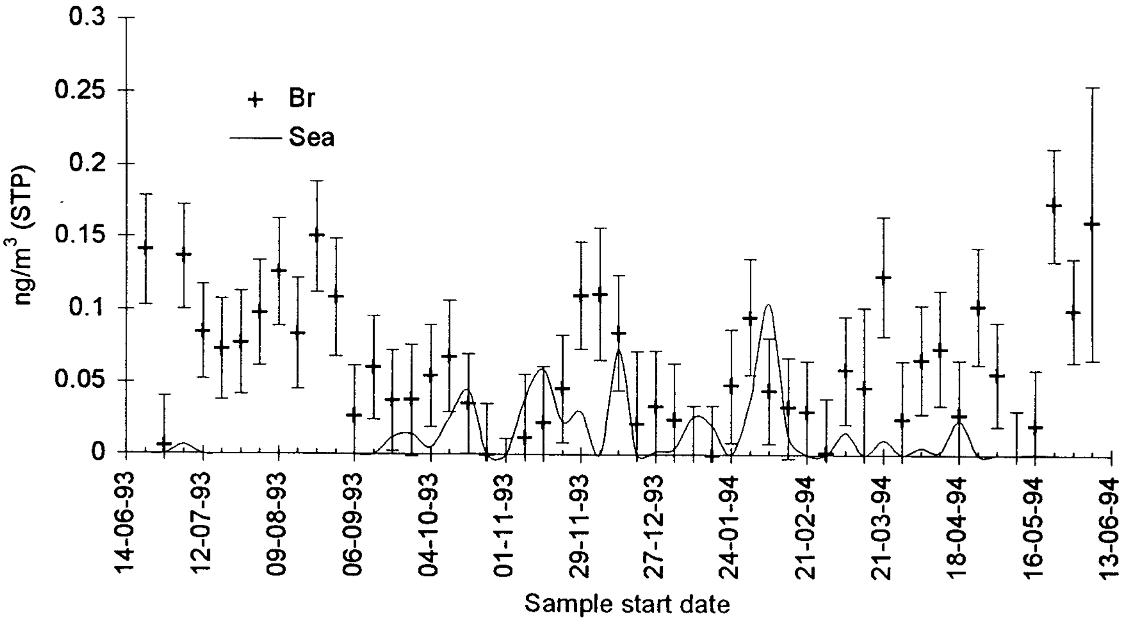

Fig. 6. Fine fraction concentrations of Br compared with the estimate of the contribution from sea salt.

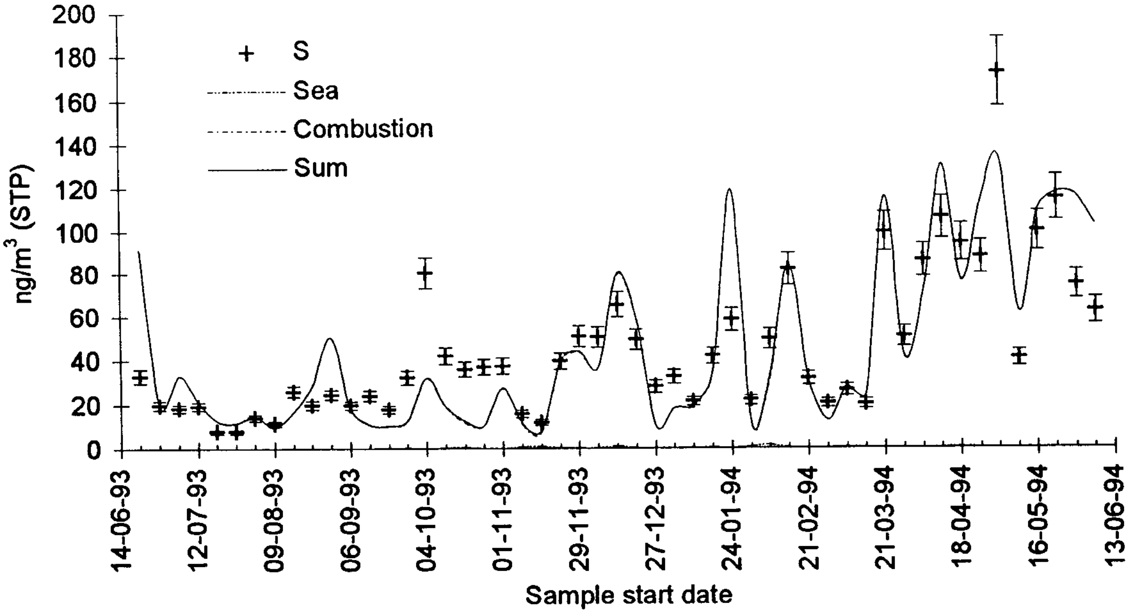

Fig. 7. Fine fraction concentrations of S compared with model. The sea salt contribution is negligible.

The sea salt components Cl and Br

In Fig. 5 the fine fraction concentrations of Cl are compared with the expected contribution from sea salt using the fitted source strength values mentioned in the preceding section. Halogen depression associated with volatilization by the effect of H_2SO_4 in filters from sea level sampling sites in the Arctic has been reported by several authors (cf. Shaw, 1991), but it is not observed with certainty in these samples. The agreement between the experimental values and the corresponding model values is not good in all samples, but, since the mean values agree well, this is probably due to the high uncertainty in the sea source strength values. This indicates that the sulfate aerosol at Summit is well aged and neutralized.

The fine fraction concentrations of Br are in the same manner compared with expected sea salt contributions in Fig. 6. Although both the Br data and the details in the estimate are uncertain, it is possible to recognize a rise in Br concentration in the spring and in the summer which is not related to sea salt. High spring Br has previously been observed in the Arctic (cf. Br measurements at Station Nord presented later in this paper) and comes possibly from other marine sources (Barrie and Barrie, 1990).

Sulfur

The fine fraction concentrations of S are shown in Fig. 7. The measurements are compared with the sum of the (negligible) sea salt contribution and a contribution from the combustion source that is normalized to 100% of the measured fine fraction mean value 46 ng/m^3 (STP). The agreement is reasonably good, except in the fall when the model predictions are systematically too low for a period of about two months. An explanation for the lack of agreement could be the delayed oxidation of sulfurdioxide and special scavenging mechanisms in the atmosphere or impact from a source region with different elemental profile composition, but it might also be influence from other sulfur sources, e.g. marine dimethylsulfide production or volcanic activity. Measurements of methanesulfonic acid (MSA) in the summer aerosol and snowpit samples at Summit (Jaffrezo et al., 1994) show that the marine MSA contribution to the sulfur budget is not negligible, but, on the other hand, MSA seems to peak in the summer rather than in the fall.

Particle losses

Comparison with other aerosol measurements at Summit indicates that particles are lost in the streaker inlet. Some preliminary results are available of sulfate and Ca measurements in the summer 1993 and the summer 1994 with daily high volume sampling on filters at the ATM camp, which were situated on two slightly different positions 30-45 km SW of the streaker site (Jaffrezo, 1994). It is possible, on the basis of these data, to calculate weekly mean values of sulfate-S concentrations, which overlap the streaker measurements. The values are compared in Fig. 8 with the sum of the fine fraction and the coarse fraction streaker measurement of S. As can be seen, the ATM values are between 25% and 200% higher than the streaker values. The ATM values are biased towards higher daytime concentrations because the sampling is suspended during fog episodes, which often occur during the nights. Even so, it is most likely that the streaker values are too low. Actually, the comparison between available ATM concentrations of Ca and the corresponding streaker values shows even more serious discrepancies. In the first sample (21-06-94) the ATM value is 26 times higher than the fine fraction streaker value and in the 5 last samples the ratios are between 3 and 9. (The streaker coarse fraction values are below detection limit because of high Ca content in the impaction foil.) This strongly supports the hypothesis that particles are lost in the inlet by filtering in rime, which will preferably sort out the larger particles. Cascade impactor sampling at Dye 3 (Hillamo et al., 1993) has shown that particles of anthropogenic origin and of crustal origin exhibit almost unimodal size distributions, but with very different geometric mean aerodynamic diameters (respectively 0.6 μm and 2 μm). A speculative explanation of the particular large deviations in the first samples could be that condensation occurs in the summer and, since only a little amount of rime was observed when the sampler was retrieved in early June 1994, that the rime evaporates again during the winter.

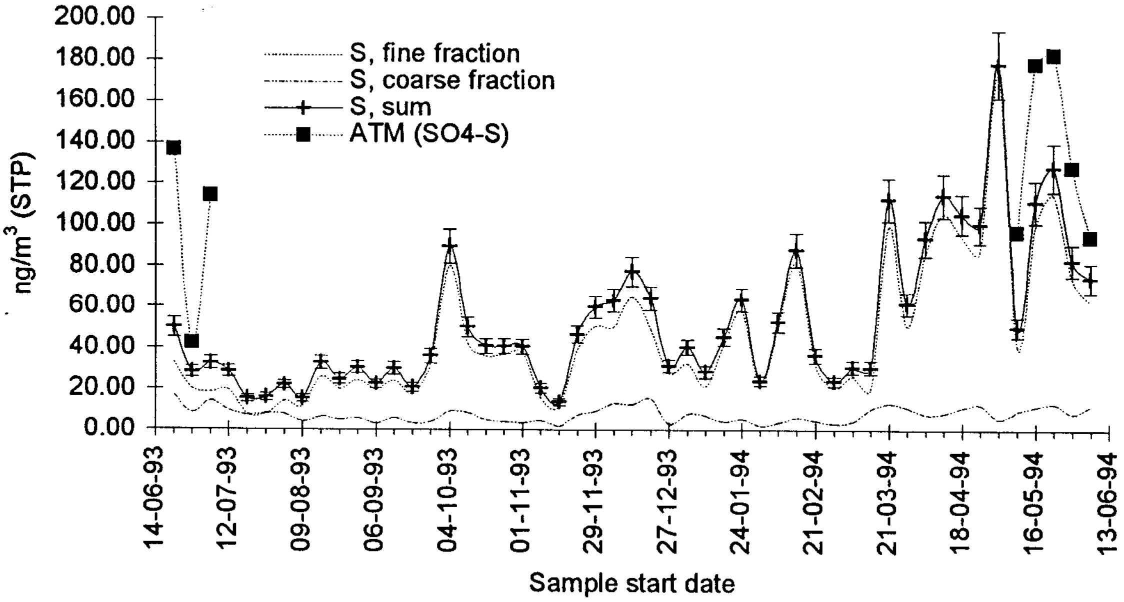

Fig. 8. Total concentrations of S compared with high volume sampler measurements of sulfate.

COMPARISON WITH OTHER ALL-YEAR DATA FROM GREENLAND

Dye 3 on the southern dome of the Greenland Ice Sheet.

The Dye 3 Gas and Aerosol sampling Program (DGASP) was conducted during August 1988 – July 1989 at the Dye 3 radar base on the Greenland Ice Sheet. The location relative to Summit is approx. 850 km SSW at an altitude of 2480 m. Airborne concentrations of SO_4^{2-}, gases, radionuclides and several trace elements were measured during a whole year. Both SO_4^{2-} and the crustal elements had strong springtime peaks, while the sea salt elements had maxima in the winter (Davidson et al., 1993a). This is in agreement with the Summit measurements. The Summit measurements of elemental sulfur are compared with sulfate-S values from Dye 3 in Table 3. The numbers are not directly comparable, due to different sampling times and averaging methods (arithmetic versus geometric means), but estimates of arithmetic means at Dye 3, assuming a log-normal number distribution (last column in Table 3), seem to show that the levels of sulfur are relatively higher at Dye 3 in spring and fall.

Table 4. Three year's arithmetic mean values at Station Nord in northeastern Greenland. Unit: ng/m^3.

	Soil	Sea	Combustion	Other sources
Al	19		3	
Si	57		7	
S		13	345*	
Cl		270†		
K	6	5	4	
Ca	14	6	4	
Ti	1.48		0.17	
V	0.04		0.18	
Cr	0.05		0.10	
Mn	0.23		0.21	
Fe	15		4	
Ni	0.02		0.09	0.03‡
Cu	0.02		0.09	0.17‡
Zn	0.02		1.09	
As			0.14	
Se			0.019	
Br		0.93		1.11§
Sr	0.04	0.19	0.06	
Zr	0.05			
Pb			0.79	

*Sum of S in sulfurdioxide (189 ng/m^3) and sulfate (156 ng/m^3).

†Due to Cl depletion the measured value was only 42 ng/m^3

‡Metal source

§Non sea salt spring Br

Table 3. Summit arithmetic mean concentration of S compared to Dye 3 geometric mean concentrations of sulfate-S with geometric standard deviations in parentheses (Davidson, 1993a). The numbers in parentheses in the last column are estimated arithmetic means assuming a log-normal number distribution. Unit: ng/m^3 (STP).

	Summit arith. means	Dye 3 geom. means	Dye 3 arith. means
spring	88	83(3.4)	(176)
summer	35	18(1.7)	(21)
fall	37	32(3.6)	(72)
winter	52	11(5.8)	(52)

Comparison between annual arithmetic mean values of trace element concentrations measured at both places shows that the Dye 3 values (Mosher et al.) are about 5-10 times higher than the Summit streaker values. This does not necessarily reflect any real difference between the levels at Summit and at Dye 3. It is more probably a consequence of the loss of particles which was observed for Ca and consequently is expected for other elements in the coarse particle mode.

Sea level sampling in Greenland.

The first aerosol measurements in Greenland of trace elements were performed in the years 1979-83 at five different locations round the Greenland coast line. A distinct anthropogenic component was found at all locations with a pronounced winter maximum and a summer minimum (Arctic haze). The highest levels of

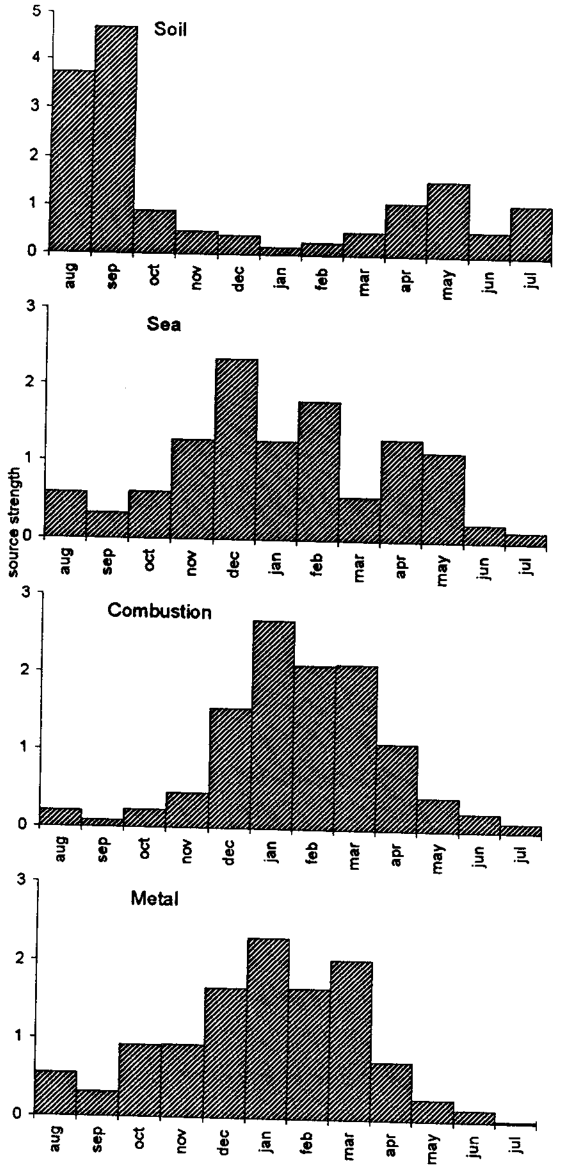

Fig. 9. Seasonal variation of normalized source strengths expressed as monthly means. The values summarize results from three year's continuous aerosol sampling at Station Nord in northeastern Greenland (Aug. 90 - July 93).

the anthropogenic metals Cr, Cu, Zn and Pb were found at the northernmost site Station Nord (Heidam, 1984).

A continuous monitoring at Station Nord of gases and particles was initiated in the summer 1990. Weekly samples of particulate matter were collected on membrane filters together with gases on impregnated filters in filterpacks. Unpublished results from the first 3 years (Aug. 90 - July 93) are summarized in Fig. 9 and Table 4. The source types found at Summit are also recognized at Station Nord (soil, sea, combustion, non sea salt bromine), but in addition to these is also found a metal component with extra contributions of Cu and Ni. The combustion signal and the metal signal have nearly the same characteristic seasonal variation with a winter maximum in January/February, only the metal signal appears a little earlier in the fall/winter which spots the polluters to be situated in the northern part of the main source region. The winter appearance of anthropogenic pollution (Arctic Haze) is a well known phenomenon at sea level monitoring sites around the Arctic Sea, so it is noticeable that the situation in the winter is very different at Summit and at Dye 3, where the anthropogenic signal is much weaker and first peaks in April/May. Two factors, especially, are believed to be responsible for the difference. First, the Greenland Ice Sheet is at an elevation well above the Arctic Haze which, due to subsidence and surface radiational cooling in the winter, presumably is confined to the lower part of the Arctic air (cf. Barrie and Hoff, 1984). Second, the southern part of Greenland is much more influenced by midlatitude Atlantic pathways than sites within the Arctic Basin, where transport over the Pole from Eurasia is most important (Davidson et al., 1993b).

The soil source has a peak in April/May both at Station Nord and at Summit, and the sea salt source has maximum in the winter at both places. The very high soil signal in August/September at Station Nord is probably of regional/local origin and connected with the lack of snow cover in the summer.

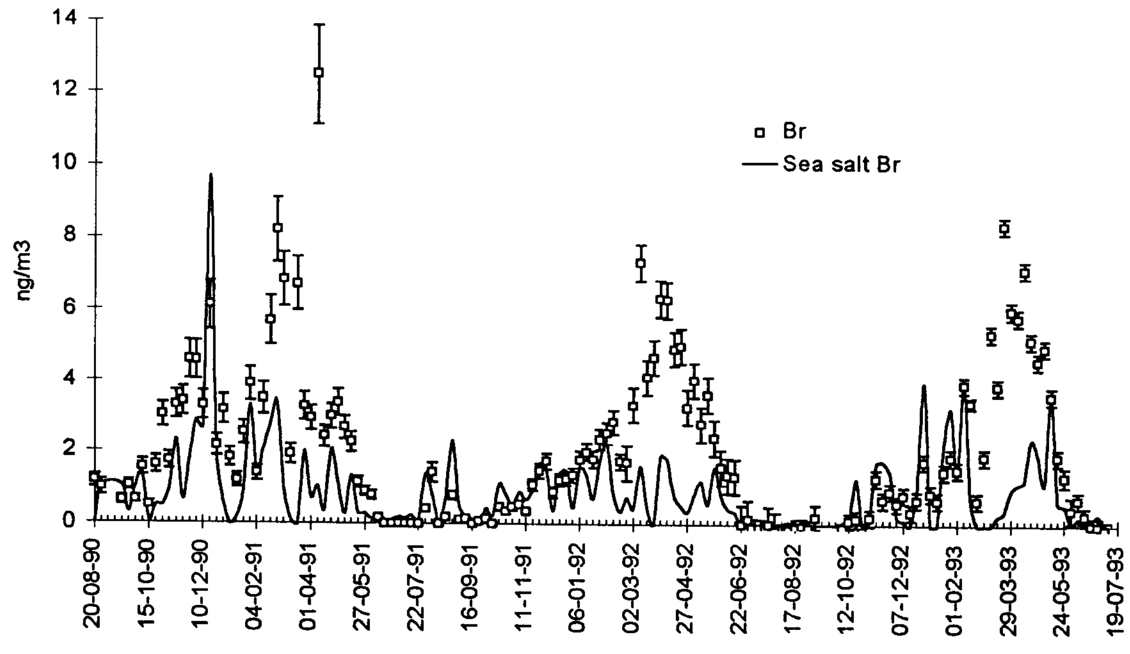

Fig. 10. Measurements of particulate Br at Station Nord compared with model calculation of sea salt Br. High values not related to sea salt are measured in the spring.

The appearance in the spring of filterable non sea salt bromine (Fig. 10) has been observed at many different places in the Arctic and has been connected with the destruction of tropospheric ozone at Polar Sunrise (Bottenheim et al., 1990).

Because particulate sulfur did fit badly, it was not included in the mathematical analysis which led to the results summarized in Fig. 9 and Table 4, but it is demonstrated in Fig. 11 that the sum of particulate sulfur and sulfurdioxide fits fairly well with the combustion source. The concentrations found at Station Nord of sulfurdioxide and sulfate, as well as the high fractions of sulfurdioxide in the Arctic night, are similar to the levels found at other places around the Arctic Sea (cf. Barrie and Hoff, 1984).

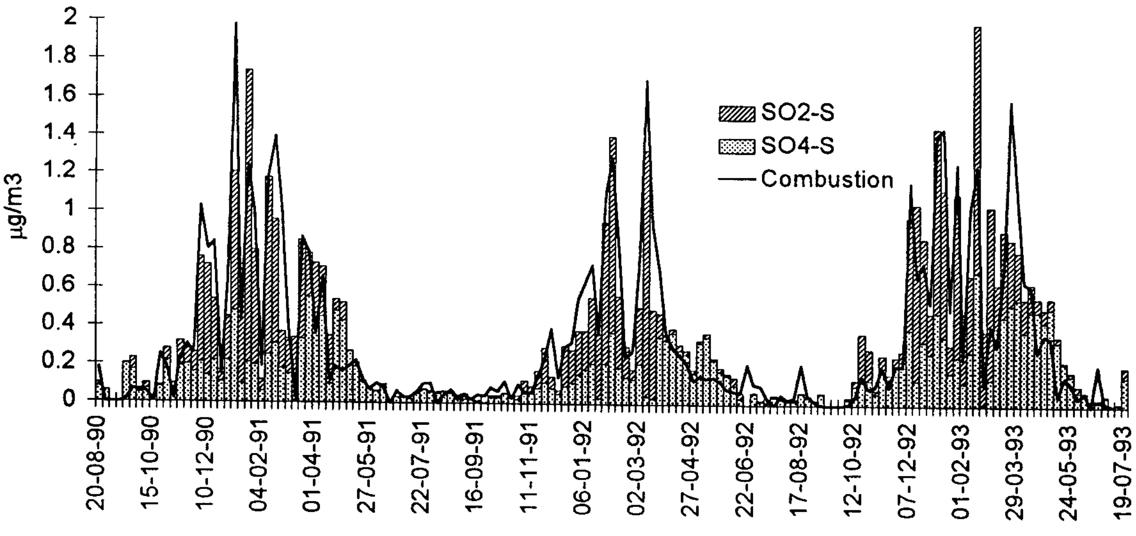

Fig. 11. Measurements of sulfurdioxide-S and sulfate-S at Station Nord compared with the combustion signal. The combustion source strengths are normalized to the sum of the sulfurdioxide and sulfate mean values.

CONCLUSION

The elemental content in the samples from Summit, which cover almost a whole year, can be apportioned to three source types, a crustal source, a sea salt source and a combustion source. In addition to this, a rise is observed in the Br concentration in the spring and summer which is probably connected to photochemical reactions and the ozone depletion at Polar Sunrise. The comparison with independent summer measurements of sulfate indicates that particles are lost in the inlet of the streaker sampler in the summer, and maybe also in the rest of the year. This imposes some uncertainty on the absolute levels, which may be underestimated, and also on the annual variation, which shows a crustal peak in the spring, a weak winter appearance of sea salt, and a combustion source that is present all year, strongest in winter and spring. The annual pattern of the anthropogenic component is very unlike the pattern found at sea level sites in the Arctic, where a pronounced peak of anthropogenic compounds (Arctic Haze) appears every winter.

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Danish Eulerian Hemispheric Model

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The background for this model project is that there has been a long tradition at NERI/DEAP to develop models in connections with observations and use the models to analyze the observations. Therefore this project was started in 1991.

DEHM is a three-dimensional model that includes a full three-dimensional advection-diffusion equation. The horizontal space of the model is define on a regular 96x96 grid with a griddistance of 150 km at 60° N (see fig. 1) . The vertical coordinates is defined by using the terrain following σ coordinates (=(pressure at the level)/(surface pressure) and the grid is an irregular with 12 gridpoints, which cover most of the troposphere with a fine resolution of the planetary boundary layer.

Input to the model are three-dimensional meteorological data and surface data from the European Centre for Medium-range Weather Forecasts (ECMWF) (TOGA data sets).

The model has a simple parameterization of the vertical diffusion, which is based on Monin-Obukhov similarity theory, where the K_z profile for the surface layer is extended to the whole mixing layer by using a simple parameterization. The height of the mixing layer is parameterize in a new way by using the three dimensional wind at the top of the mixing layer, sensible heatflux and friction velocity.

There are four species in the present version of the model: SO_2, SO_4^{2-}, humidity and cloud water. The last two species are for a new feature, a the condensation scheme, which is a simplified version of the scheme by Sundquist et al. (1989), and it is used to calculate the rate of the release of precipitation. The precipitation is very important for the deposition of SO_2 and SO_4^{2-}, and therefore also for the life time of the sulphur species in the troposphere. The reason for using the condensation scheme to calculate the precipitation is that the meteorological data does not have any information about precipitation.

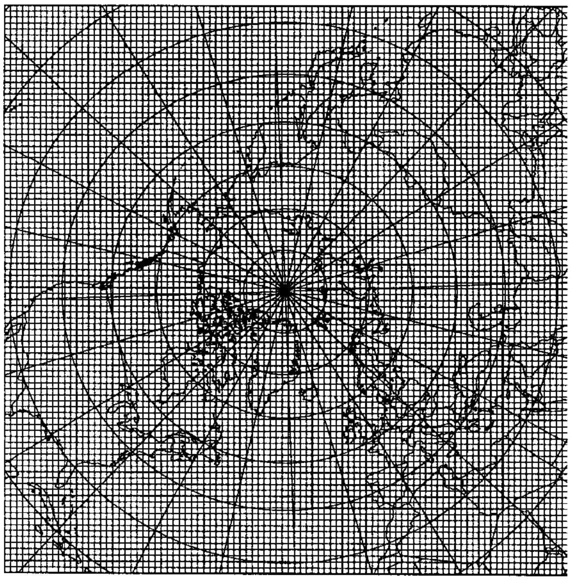

Figure 1.The model area and the horizontal grid.

Emissions are both anthropogenic emissions of SO_2, natural emissions of Di-Methyl Sulphide (DMS) from oceans (emitted as 44% SO_2, 4% SO_4^{2-} and the rest as Methane Sulphonic Acid (MSA), which are not used in the present version of the model) and latent heatflux for the humidity.

The sulphur chemistry is a simple linear SO_2-SO_4^{2-} chemistry, where the oxidant rate depends on the season and the latitude.

The dry depositions of the sulphur species are parameterized by the resistance method, and the wet depositions by scavenging ratios for the in-cloud and below-cloud scavenging.

The model has been run for 8 months: from October 1990 to May 1991. In defiance of the many uncertainties the model seems to give reasonable results:

The model results of the mixing heights and precipitation have been compared intensively with meteorological data given by EMEP Meteorological Synthesizing Centre - West, Norwegian Meteorological Institute.

The model results for sulphur concentrations and depositions have been compared with measurements from different EMEP monitoring stations in Europe. The model reproduces reasonably well the measured concentrations both on monthly basis and for many stations also on daily basis.

There has been performed similar comparisons with measurements from two monitoring stations in the Arctic areas, Station Nord by National Environmental Research Institute and Spitzbergen by NILU in Norway. Again the model reproduces reasonably well the measured concentrations, especially the large seasonal variation in the sulphur concentrations in the Arctic area (see fig. 2), and also most

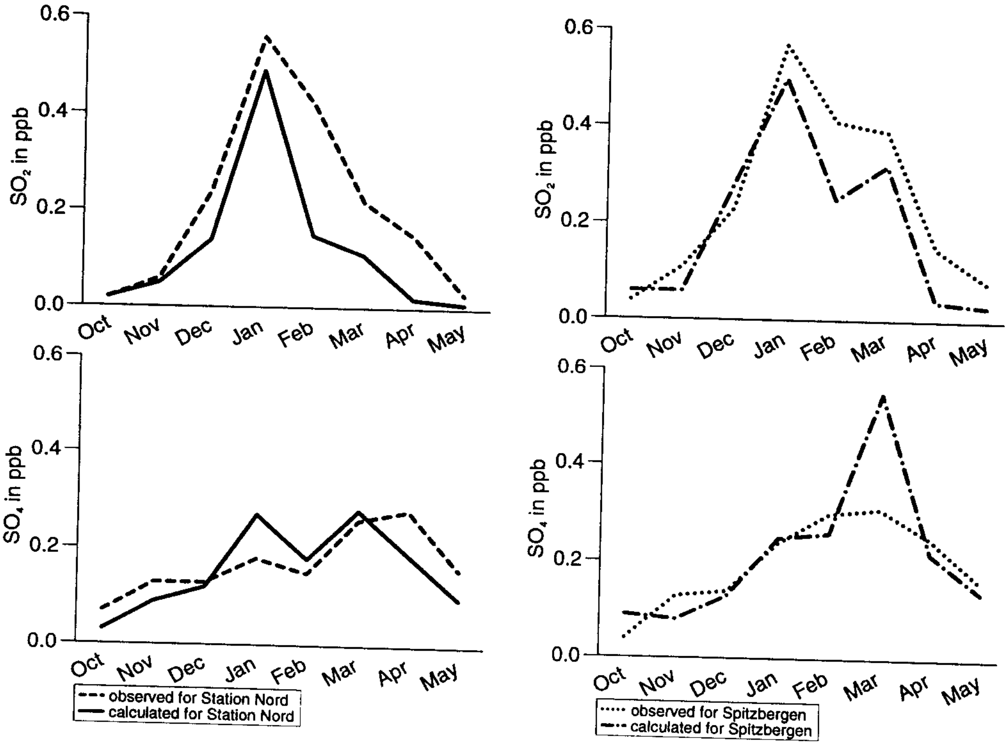

Figure 2. Calculated and observed monthly mean concentrations of SO_2 and SO_4 for Station Nord and Spitzbergen.

of the Arctic episodes observed at the two Arctic stations are well reproduced (see fig. 3 and 4). Figure 5 shows 6 hour mean concentration of SO_2 in ppbv together with the mean-sea-level pressure in hPa at 10 of January 1991. The figure shows an episode, where there is an eastward transport of SO_2 from Europe to Russia caused by the low-pressure system (L) over North Atlantic. The air moves over northern Russia and passes Noril'sk. The high-pressure system over Siberia blocks further transport to the east and pushes the air northwards.

The model has been used to study the contribution to the sulphur concentrations and depositions in the Arctic from different sources in the Northern Hemisphere. The results show that especially Noril'sk and the other Russian sources are the most important sources for the Arctic air pollution.

The future work with the model will focus on the following issues:

- Model calculations for a longer period for a more extensive evaluation of the current version of the model.
- Extension of the chemical scheme to include nitrogen oxides, ammonia, and hydrocarbons which are all important for the tropospheric chemistry. Possibly also Heavy Metals (HM), Persistent Organic Pollutants (POP) and dust will be included.
- Further development of the model to improve the description of the physical and chemical processes.

The further development of the model is an important part of the danish part of the international Arctic Monitoring and Assessment Programme (AMAP).

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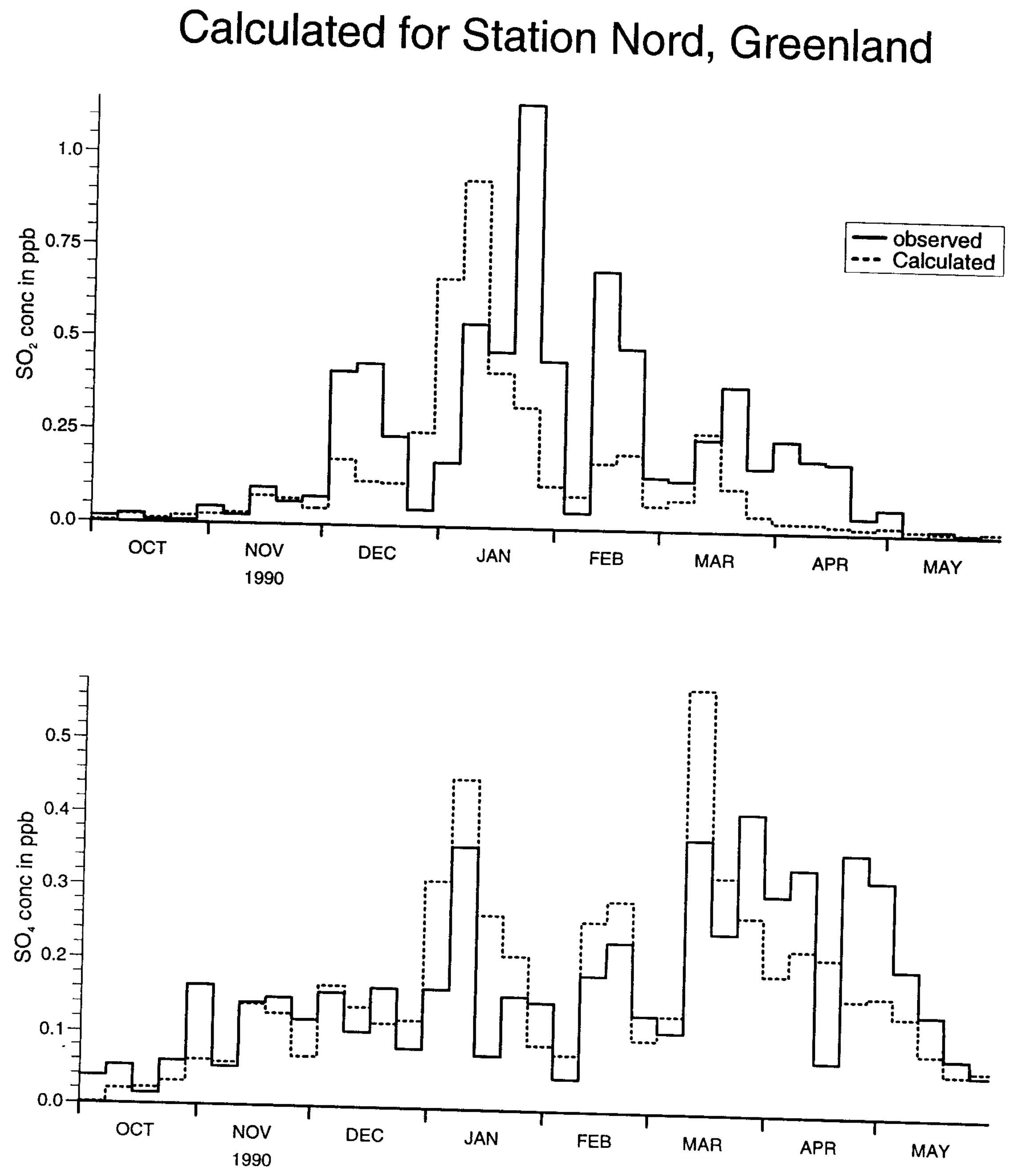
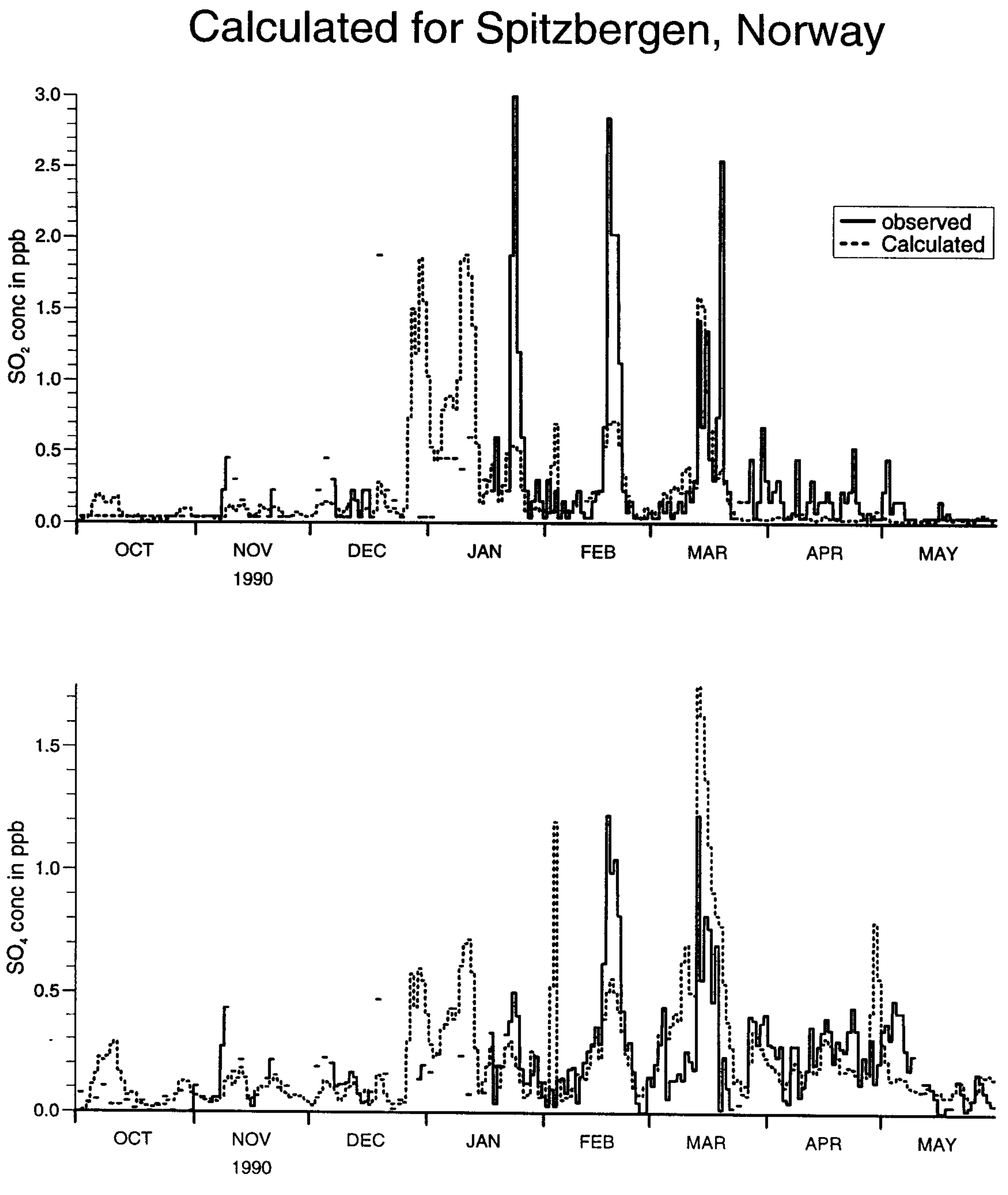


	October 1990		November 1990		December 1990		January 1991		February 1991		March 1991		April 1991		May 1991		Total	
	SO_2	SO_4	SO_2	SO_4	SO_2	SO_4	SO_2	SO_4	SO_2	SO_4	SO_2	SO_4	SO_2	SO_4	SO_2	SO_4	SO_2	SO_4
Calculated	0.02	0.03	0.05	0.09	0.14	0.12	0.49	0.27	0.15	0.18	0.11	0.28	0.02	0.19	0.01	0.10	0.13	0.16
Observed	0.02	0.07	0.06	0.13	0.24	0.13	0.56	0.18	0.42	0.15	0.22	0.26	0.15	0.28	0.03	0.16	0.22	0.17
Correlation																	0.49	0.67

Figure 3. Observed and calculated weekly mean values of SO_2 and SO_4^{2-} for Station Nord in North Eastern part of Greenland



	October 1990		November 1990		December 1990		January 1991		February 1991		March 1991		April 1991		May 1991		Total	
	SO_2	SO_4	SO_2	SO_4	SO_2	SO_4	SO_2	SO_4	SO_2	SO_4	SO_2	SO_4	SO_2	SO_4	SO_2	SO_4	SO_2	SO_4
Calculated	0.06	0.09	0.06	0.08	0.28	0.13	0.50	0.25	0.25	0.26	0.32	0.55	0.04	0.22	0.03	0.14	0.19	0.24
Observed	0.04	0.04	0.11	0.13	0.23	0.14	0.57	0.24	0.41	0.30	0.39	0.31	0.15	0.25	0.08	0.16	0.26	0.21
Correlation	0.00	0.26	0.57	0.58	-0.07	0.23	0.13	0.15	0.79	0.41	0.51	0.79	-0.14	0.08	0.08	0.38	0.42	0.56

Figure 4. Observed and calculated daily mean values of SO_2 and SO_4^{2-} for Spitzbergen on Svalbard

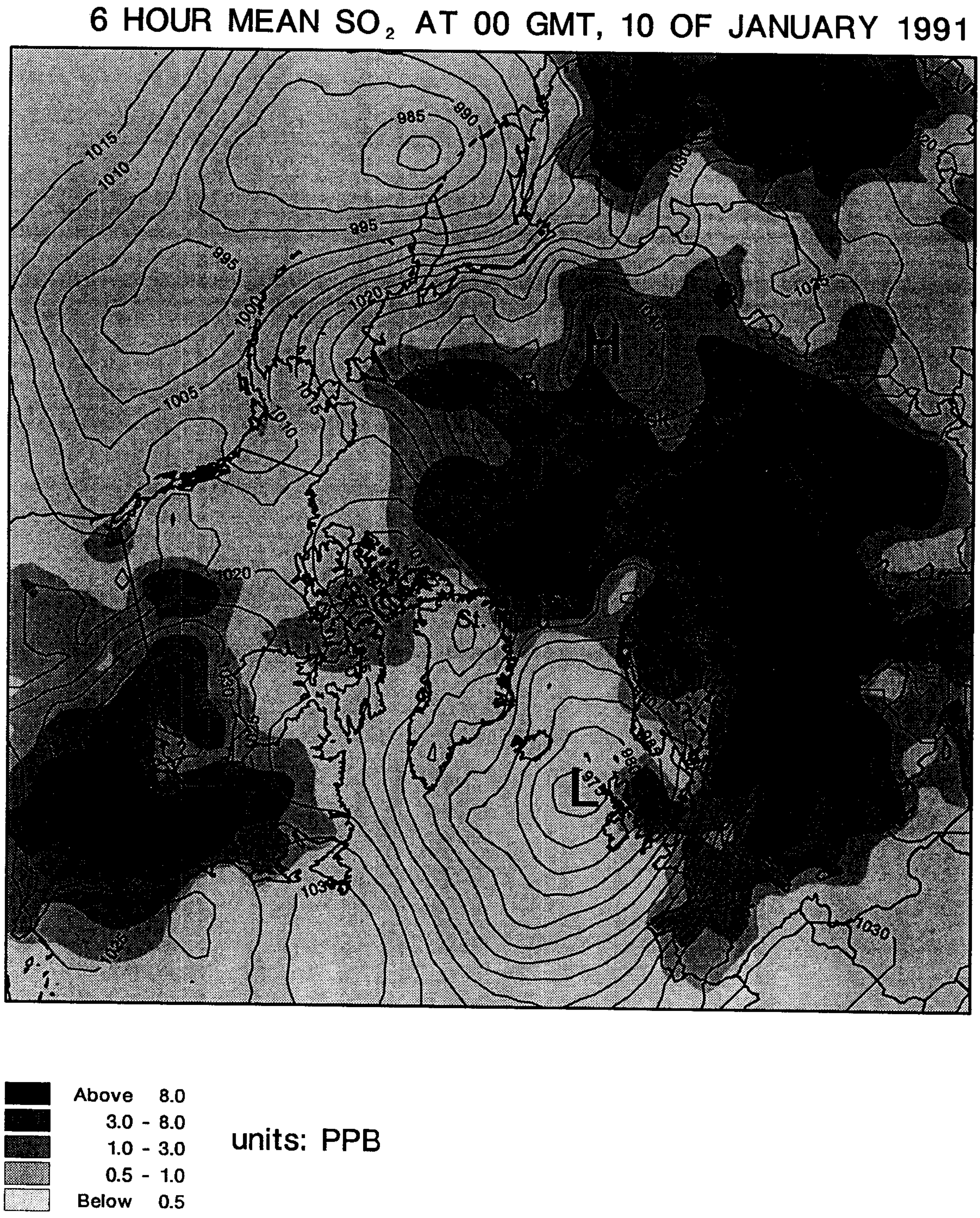


Figure 5. 6 hour mean SO_2 in ppbv for the surface level and the isobar lines in hPa for the Mean-Sea-Level pressure at 10 of January 1991

NILU's Arctic atmospheric research – Pollution and climate

by

Frode Stordal, Arne Semb, John-Erik Haugen and Sverre Solberg
Norwegian Institute for Air Research, P.O. Box 100, N-2007 Kjeller, Norway

1. Introduction

NILU's first involvement in Arctic air chemistry studies coincide with the discovery of the Arctic Haze effect by Rahn and several co-authors in the late 70's. In a follow-up study in 1982-1985 (Ottar et al., 1986), transport patterns for polluted air masses were investigated and supported by model calculations (Iversen, 1986a,b; 1989). Aircraft measurements were also used to describe the vertical and horizontal distribution of pollutants and aerosol particles in the Arctic. In addition, two new research topics were introduced. One of these were the occurrence of persistent chlorinated organic compounds such as PCB's (Oehme and Ottar, 1984), another was the occurrence of light hydrocarbons in the Arctic and their possible relevance for the large scale photochemical formation of tropospheric ozone in the northern hemisphere (Hov et al., 1984; Isaksen et al., 1985). These findings led to the establishment of a permanent monitoring station at Ny Ålesund, located on the top of a small mountain.

2. Arctic haze

One of the reasons for the establishment of the monitoring station at Ny-Ålesund is the strategic position of this site in relation to the transport of polluted air masses from the Eurasian continent towards the Arctic, and also the shifts between these continental Arctic air masses and air masses from the North Atlantic. Relatively clean Arctic air may also occur during winter. Although aircraft measurement campaigns are capable of giving much more detailed information on the spatial variability of the occurrence of air pollutants, such a permanent monitoring station is more valuable in the study of long-time trends, which may be due to changes in the emissions, or to changes in the transport patterns. The long and continuous time series of sulphur dioxide and aerosol sulphate concentrations does show a decrease, which appear to be consistent with the emission reductions in Europe, but the source-receptor relationship has not been fully investigated. Very little has been done on the subject of nitrogen compounds in the Arctic, mainly because of the low concentrations in ambient Arctic air. The main oxidized nitrogen compound in the Arctic is peroxy-acetyl nitrate, the concentrations of nitrogen dioxide and nitric oxides are very low, and few measurements of nitric acid and nitrate in the particle phase are available.

3. Persistent organic pollutants (POP)

The Norwegian Institiute for Air Research (NILU) has experience with measurement of persistent organic pollutants in Arctic ambient air for the last 15 years. Our first measuring campaign on persistent organic compounds was carried out during 1981-1984 on Spitsbergen and the Norwegian mainland (Oehme and Manø, 1984; Oehme and Ottar, 1984; Pacyna and Oehme, 1988, Oehme, 1991; Oehme et al., 1994). More recent measurement campaigns were carried out in 1992 (Oehme et al., 1995).

3.1 Recent and ongoing POP measuring campaigns in polar regions

Since spring 1993 weekly measurements in ambient air at Ny-Ålesund, Spitsbergen, have been carried out as a part of the AMAP programme. In Octobober/November 1993 we carried out our first POP measuring campaign in the Antarctic (Terra Nova Bay) in coorporation with the Italian National Agency for Energy and Environment (ENEA) (Oehme et al., 1994). Since december 1994 we are carrying out weekly measurements of POP in ambient air at Signy Island, Antarctica, in coorporation with the British Antarctic Survey (BAS).

The following POP compounds are being measured: pesticides (HCHs, Chlordanes, DDT-group, HCB, Toxaphenes), polychlorinated biphenyls (PCB-28, 31, 52, 101, 105, 118, 138, 153, 156, 180), and polyaromatic hydrocarbons (38 compounds). It will also be carried out analysis of toxaphenes (pesticide) and dioxins in selected air samples from the Ny-Ålesund station as a part of the 1995 measurements.

3.2 Quality assurance

The laboratories at NILU are accredited according to EN 45001 which ensures high quality analytical results. NILU is regularly participating in worldwide intercalibrations on persistent organic compounds in different sample material.

3.3 Research/results

Our studies can be summarized in the following conclusions:

3.3.1 The Arctic

- Long range atmospheric transport seems to be the most important source of pollution to the Arctic
- Concentrations of more volatile organochlorines in Arctic air are about the same as in air much closer to source areas
- The physical behaviour of POP favours their enrichment in the Arctic
- Differences in wet and dry deposition rates and photochemical processess change concentration ratios of POP compared to source areas.
- Transport time of HCHs from source areas to the Arctic can be within 48 to 72 hours based on isobaric back trajectories

  Comparison of 1981-1984 data with 1992-1994 data shows increased levels of lindane in Arctic air, and indicates use of pure γ-HCH (lindane)
- Increased α-HCH and decreased γ-HCH levels from south to north

3.3.2 The Antarctic

- Levels of chlordanes are about the same in Arctic and Antarctic air
- Similar PCB congener distribution and ambient air levels
- Higher α-HCH level in Arctic air compared to Antarctic

3.4 Modelling

NILU is part of the Polar Environmental Centre recently established in Tromsø, Norway. One of our main activities at the centre will be modelling of POP transport to the Arctic. In order to evaluate and quantify the pathways of POP into polar regions, a multicompartment model of POP on a global scale (zonally averaged model) is applied to emission and measuring data. One of the research activities will focuse on exchange processes of POP between atmosphere, snow and ice.

4. Tropospheric ozone and precursors

Continuous monitoring of surface ozone on Spitsbergen started in October 1988 at Ny-Ålesund, near the sea surface. In September 1989 the measurement instruments were moved to the new research station on the nearby Zeppelin Mountain, 474 masl. The measurements are done by an automatic UV absorption instrument, and the data are reported as hourly values.

Automatic monitoring of NO_2 and sum nitrate (HNO_3 (g)+NO_3-(s)) have been done in the same period, and at the same locations as for ozone, by daily filter samples. A large part of the filter samples are, however, below the detection limits (0.2-0.5 µg (N)m^{-3} for NO_2 and 0.01-0.03 µg (N)m^{-3} for nitrate). A CRANOX instrument, continuously measuring NO_x ($NO+NO_2$) and NO_y (sum of all oxidised nitrogen species) at low concentrations has been in operation on the Zeppelin Mountain for limited periods the last years. From 1994 PAN and PPN have been measured continuosly on the Zeppelin Mountain.

Measurements of light hydrocarbons started on the Zeppelin Mounain in September 1989 as a part of the EUROTRAC project TOR (Tropospheric Ozone Research). The hydrocarbon samples are collected manually in canisters with a sampling time of 10-15 min. The subsequent analyses are made in the laboratory at NILU. From 1989-1991 nine C_2-C_5 hydrocarbons were analysed, and from 1992 the number was extended to 26., including aromats and C_6-C_7 alkanes. The samples are normally taken 2-3 times/week, but in spring 1993 and spring 1994 the sampling was done on a daily basis. Grab sampling of carbonyl compounds have been performed on the Zeppelin Mountain since 1994, normally on the same days as the hydrocarbons, using HPLC.

The average seasonal cycle of ozone is quite different at Ny-Ålesund than at lower latitudes, indicating that the concentration of surface ozone in the Arctic is controlled by other mechanisms than further south.

The measurements of light hydrocarbons on the Zeppelin Mountain indicate that there is an accumulation of these components throughout the northern troposphere in winter, due to efficient mixing of polluted air masses from further south and a slow chemical decay this time of year. In winter the average concentrations were similar at the two locations, while the seasonal cycle on the Zeppelin Mountain was more pronounced than at Birkenes.

Hourly measurements of PAN and NO_y were made on the Zeppelin Mountain for the first half year of 1994. These first results of the simultaneous measurements of PAN and NO_y indicate a peak in the average NO_y and PAN concentration in spring. A major fraction of NO_y is in the form of PAN.

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ENRICH INFO FICHE

Seminar and Workshop on Artic Atmosphere Research:
Pollution and Climate
16-18 March 1995, Roskilde, Denmark

If you wish to receive a personal copy of the displayed publications or additional information, please address your requests directly to the services mentioned.

Displayed publications:

1) The fourth framework-programme for research and technological development, European Commission, DG-XII, 44 p.,1994

2) The environment - at the heart of European R&D, European Commission, DG-XII, Report EUR 15882 EN, 48 p.,1994

3) Environment and Climate - Workprogramme and Information Package, European Commission, DG-XII, Edition 1994

4) Marine Science and Technology (MAST-III) - Workprogramme and Information Package, European Commission, DG-XII, Edition 1994

5) Training and Mobility of Researchers (TMR) - Workprogramme and Information Package, European Commission, DG-XII, Edition 1994-1995

6) Scientific and technological cooperation with Eastern Europe, European Union initiatives to support the countries of Central and Eastern Europe and the New Independant States, European Commission, DG-XII, Report EUR 15716 EN, 36 p.,1994

7) European Network for Research in Global Change (ENRICH) - Implementation Plan, ENRICH Office at the European Commission, DG-XII/JRC, 30 p.,1995

8) Summary Report of the Regional Seminar for Central and eastern Europe and countries of the former Soviet Union, Budapest, 15-17 September 1994, ENRICH Office at the European Commission, DG-XII/JRC, 17 p.,1995

9) European Land-Ocean Interaction Studies (ELOISE) Science Plan, European Commission, DG-XII, Ecosystems Research Report 11, EUR 15608 EN, 52.p,1994

10) Terrestrial Ecosystems Research Initiative (TERI) Science Plan, European Commission, DG-XII, Ecosystems Research Report 17, EUR 15608 EN, 25.p,1994

11) Options for EC-level research activities on the Human Dimensions of Global Change, European Commission,
DG-XII/D, 69p.,1994

12) Project summaries, Research on economic and societal aspects of environmental issues, European Commission,
DG-XII/D, 162p.,1994

13) Chemistry in the Atmosphere, A strategy for European research into global environmental issues, European Commission, DG-XII, Report EUR 15351 EN,33 p., 1993

14) Second European Stratospheric Arctic and Mid-latitude Experiment (SESAME) 1994-1995, A European contribution to the stratospheric ozone issue, A brochure of the European Commission, DG-XII/D, 12p.,1994

15) European Arctic Stratospheric Ozone Experiment (EASOE), A brochure of the European Commission, DG-XII/D, 7p.

16) Promotion of East-West cooperation in research and development, INTAS-brochure, INTAS Secretariat Brussels, 6p.

17) Participation in the Fourth Framework Programme, A CORDIS focus Supplement 5, CORDIS, European Commission,
DG-XIII/D2, 64p., issue 15 december 1994.

HOW TO OBTAIN THESE DOCUMENTS ?
In order to obtain these documents and further information you may contact the following addresses:

- **for publication numbers 1 to 4 and 9 to 14 please contact DG-XII/D:**

  FAX: + 32-2-2963024

- **publication number 4 can be obtained from DG-XII/G3:**

  FAX: + 32-2-2962136/2962133/2956995/2963270

- **for publication 15 please contact the INTAS secretariat in Brussels:**

  FAX: + 32-2-5490156

- **for publication 16 please contact the CORDIS focus RTD- Help Desk:**

  FAX: + 352-430132084

For other publications and general information on global change research initiatives of the European Commission you may contact the ENRICH Office in Brussels:

ENRICH Office, DG-XII/JRC, SDME 1/21,
European Commission
Rue de la Loi 200, B-1040 Brussels.
FAX: + 32-2-2950146
E-mail: FE@dgccr.ccr.jrc.it

Information about ENRICH will soon be available from the ENRICH Web Server presently under construction on Internet. The ENRICH Home Page was installed in January 1995.
The Universal Resource Locator (URL) is:
http://www.enrich.hi.is/
(please note: the server is still under construction!)

European Commission

Directorate General for Science, Research and Development

Joint Research Centre

European **N**etwork for **R**esearch **I**n Global **CH**ange

(ENRICH)

IMPLEMENTATION PLAN

February 1995

CONTENTS

Commission of the European Communities
Directorate-General XII
Science, Research and Development

JOINT
RESEARCH
CENTRE

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ENRICH
European Network for Research In Global CHange

Brussels, 2/3/95
FE/ja N°419

NOTE FOR THE ATTENTION OF THE ENRICH COUNCIL MEMBERS
and
ENRICH LIAISON OFFICERS

Subject: *Participation of 3rd countries in the Environment and Climate and MAST-III programmes*

1. Following an earlier note from the ENRICH Office (20.12.94) please find enclosed herewith updated information on the situation with regard to the possibilities and problems concerning the participation of scientists from non-EU countries in specific programmes relevant to ENRICH.

2. For your information: the next Meeting of the Management Committee of the Activity II programme is on 24 March 1995/

3. I hope that this information will assist you in understanding the current situation and at the same time could prove useful in guiding researchers in the preparation of proposals.

Best wishes,

Eybergen

F. Eybergen
ENRICH Office

Participation of Third Countries
in the
Environment & Climate and MAST-III programmes

With this informative note the ENRICH Office attempts to provide some extra information and guidance for potential proposers that consider to either submit proposals to the Environment and Climate and MAST-III programmes or to the Activity II programme on Cooperation with third countries and international organisations (INCO). Information is given concerning the possibilities for support to third countries through the Activity II programme. In addition information is provided with regard to the modalities of participation. The formal situation with the possibilities to utilise PHARE funds for this purpose is explained.
In annex 1 you will find a note prepared by the Commission on the "Participation modalities of participants from non-EU countries" in the specific programmes of the 4th Frameworkprogramme other than the INCO programme.

1. Participation of third countries

Participation of third countries including CEEC's, NIS and Developing Countries in projects in the Activity I programmes Environment and Climate and MAST-III a project must:
- be in the interest of the EU policies;
- contribute effectively to the programme implementation;
- follow the principle of mutual benefit

(see the special fiche attached to annex 1)

The participation of third countries in specific programmes other than that covered by activity 2 should normally be funded by the resources of the country concerned.

2. Financial support to third counties

Financial support can be provided on a limited scale only:
- if the proposal is considered eligible (complete, timely submitted, in conformity with programme objectives (of 2 programmes!) and of a transnational nature;
- if a proposal is submitted correctly (see section 3 of annex 1);
- if the proposal has been evaluated and selected for the short-list according to criteria of the FP4 and the relevant specific programmes.
- if the proposal fits with the priorities and the earmarked budgets set by the INCO management;
- after the INCO Management Committee has delivered its opinion.

As concerns activity 2 support for third countries to participate in specific programmes like Environment and Climate, there is no fixed budget yet. Yearly budgets will have to be defined for that purpose. The amounts available most probably will be limited. Before the INCO mamagement committee can deliver its opinion on financial support from INCO for participants from third countries in certain projects a tentative amount for support for participation will have to be earmarked and priorities identified. To that end the management of the Environment programme will make proposals to the INCO management for discussion in the INCO Committee. With regard to CEEC/NIS the available budget will in addition depend on the Council decision (10.3.95) on the budget for INTAS.

It should be mentioned clearly that each proposal to the FP4 involving third country participation will have to meet the requirements of two programmes. It will have to be evaluated by two seperate evaluation committees and be approved by two Management Committees. This will require good coordination between INCO and the specific programme in question. In order to do so the INCO Committee will need to be consulted on all short-listed proposals which involve third country participants. This consultation will be done parallel to the consultation of the specific programme committee concerned. A problematic factor however is that the implementation schemes of the Environment and Climate programme and the INCO programme especially with respect to CEEC/NIS are out of phase (see annex 2).

The conclusion is that even if a particular proposal has gone through the phase of selection and is put on the short list of the Environment programme with a positive opinion of the INCO management, there still exists the limitations of the available budget and the different time schedules. Chances to obtain this support therefore depend strongly on the level of priority that global change relevant research projects will get by INCO. projects therefore should clearly meet with the Activity II programme areas relevant to ENRICH:
For CEEC/NIS (Area A2): Environmental protection and preservation of natural balances (especially ecosystems in danger);
For DC's (Area C): Sustainable management of renewable resources and Improvement of agricultural and agro-industrial production (more in particular: research on ecosystems and basic natural resources).
In the given situation it is recommendable to proposers to inform their national delegates in the respective programme committees about the situation with respect to third country participation in their projects.

What can ENRICH do in this context?
On the basis of the principles, objectives and overall strategy of its Implementation Plan, the ENRICH structure will play a facilitating and stimulating role mainly through timely provision of targetted information.
The ENRICH Office in this regard will:
- distribute relevant information (a.o. through information notes, (thematic issues of) newsletter and the ENRICH Internet server) to Council members, regional liaisons and the global change community;
- facilitate and promote internal collaboration and coordination between the relevant programme managers of the Commission;

The ENRICH Council members should take care of further exchange of information to the relevant national bodies and inform their national delegates in the relevant programme committees.
The ENRICH liaison officers will take care of dissimination of relevant information of ENRICH throughout their respective regions.

4. Utilisation of PHARE funds for participation in FP4.

In view of the "Conclusions of Copenhagen" (Summit meeting June 1993) all Community programmes and activities have been opened to the Associated countries, including financial support for their participation through a genuine budgetary line and through the possibility to use up to 10% of each country's PHARE share to cover the costs of such participation. But unfortunately in contrast to this that for legal and financial reasons such financing is excluded. This is due to Article 130i of the EC Treaty which stipulates that any financial support from other Community instruments for projects within the FP4 may not overshoot the maximum fixed amount of S&T Community funds.
The conclusion is that financial support from PHARE and the new specific budget line for participation from associated countries of CEEC's can be

PARTICIPATION MODALITIES OF PARTICIPANTS FROM NON-EU COUNTRIES

in the specific programmes (other than the specific programme in the field of cooperation with third countries and international organizations) of the Framework Programmes
(1994 - 1998)

1. WHO CAN PARTICIPATE ?

1.1. According to the "130 J rules"[1] the participation in RTD activities is open to any legal entity
- established in the EU, or
- in a third country associated with and contributing financially to the implementation of the relevant specific programme through an agreement concluded with the Community in accordance with Article 130m of the Treaty.

International organizations and legal entities from third countries (other than States associated with the programme) may participate on a project by project basis if the legal entity is established
- in a European third country, or
- a third non-European country which has concluded a scientific and technical cooperation agreement with the Community covering activities of the relevant programme.

1.2. Certain specific programmes provide participation possibilities also for third non-European countries who have not concluded a scientific and technical cooperation agreement with the Community.

1.3. An overview of the present participation possibilities for participants from non-EU countries is annexed.

1.4. A participant from a third country (or an international organization) can also be scientific-technical coordinator of a project if all parties to the contract have agreed.

---

[1] Council decision of 21 November 1994 concerning the rules for the participation of undertakings, research centres and universities in research, technological development and demonstration activities of the European Community, Official Journal no L306 of 30.11.1994

granted to all EU programmes except the RTD Framework Programme. The only way for CEEC's to make use of PHARE funds for R&D is to include in its priorities relevant to S&T infrastructural improvement and modernisation. So moderisation and upgrading of technical equipment, laboratories and institutes is possible. This will increase the qualifications of researchers to participate in the FP4 specific programmes.

5. The Work Programme of Activity II has been approved recently. Copies will become available with the issue of the Information Packages before the opening of the first call on 15 March. Information about INCO can be obtained from DGXII/B-3 (fax: + 32-2-2953990).
The information packages for Environment and Climate and for MAST-III are already available and distributed widely. Information about Environment and Climate and on MAST-III can be obtained from DGXII/D (fax: + 32-2-2963024).

2. FINANCIAL CONTRIBUTION FROM THE COMMUNITY ?

2.1. As a rule, only participants from EU Member States and from associated States may receive a financial contribution from the Community for a project.

2.2. The participation of participants from countries other than those above 2.1. will normally be financed by resources of the country concerned. No financing is available from the specific programme to which the proposal refers.

2.3. However, in order to facilitate the participation of organizations from Central and Eastern European States, from the Newly Independent States of the former Soviet Union, and from Developing Countries, limited Community financial support might be made available according to priorities established by the Commission assisted by the relevant programme committee in the framework of the specific programme dedicated to cooperation with Third Countries and International Organizations (activity 2).

2.4. Other Community instruments (e.g. PHARE) may not finance participation in specific programmes of the Framework Programmes. These instruments may, however, be used in order to develop a country's scientific and technological potential or to improve the infrastructures on which its RTD activities depend.

3. HOW TO SUBMIT A PROPOSAL ?

3.1. Proposals from non-EU participants must be submitted together with proposals of EU participants in the project, i.e. in the same package, not separately.

3.2. A project proposal must comprise at least two legal entities which must be established in different EU Member States or in at least one EU Member State and one associated State (or by at least one legal entity and the Joint Research Center). Proposals from third States and of International organizations may be only in addition to the minimum number of legal entities from the Community and any associated states. Participation of only third country participants in a project is therefore not allowed. This means that participants from third countries must have found partners from EU Countries.

3.3. The proposal must be sent to the address indicated on the relevant documents (in particular the information packages), i.e. normally the Commission services responsible for the management of the specific thematic programme to which the proposal refers. It is not to be sent to the services responsible for International Cooperation.

3.4. If no financial support has been obtained from the country concerned (cf 2.2. above), and limited financial support is requested from the Community (cf 2.3. above), it must be clear from the proposal what amount is asked for.

4. HOW IS THE PROPOSAL EVALUATED AND SELECTED ?

4.1. Project proposals are evaluated by external experts ad personam chosen by the Commission for the specific programme to which the proposal refers. Some experts may come from third countries.

4.2. Proposals are evaluated and selected according to criteria specified in the Framework programmes and in the information packages of the specific programmes. Other criteria are set out in the "130 J rules", e.g. participation from a third country in a project must be in the interest of Community policies.
It should be clear from the proposal that these objectives and criteria are met.

4.3. On the basis of the evaluation, the Commission, assisted by the specific programme committee, decides the list of selected proposals and their financial support for participants from EU Member States and associated States.

4.4. Concerning participation of partners from countries other than EU Member States and associated States, the Commission will also be assisted by the International Cooperation programme committee, in particular as regards financial support from activity 2 (see above 2.3.).
In granting such support, priority will be given to projects best meeting the selection criteria and objectives (cf 4.2. above).

4.5. Proposers will be informed on the selection of projects and on the financial support as soon as the decision by the Commission is taken.

5. HOW ARE CONTRACTUAL QUESTIONS HANDLED ?

5.1. After approval of a project, a "Contract Negotiation Form" (CNF) must be filled in by each proposer, taking into account the level of funding accepted by the Commission. The CNF must be sent to the address indicated in the relevant documentation.

5.2. Participation from third countries are covered by the same contract as participants from EU countries.
The contract will also specify whether the Community will make a financial contribution or not, and what type.

5.3. The contracts will be negotiated and managed, both from the scientific-technical and from the administrative point of view , by the Commission services responsible for the management of the programme to which the proposal refers, not by the services responsible for International Cooperation.

<table>
<tr><td colspan="3">PARTICIPATION POSSIBILITIES AND FINANCIAL SUPPORT POSSIBILITIES FOR LEGAL ENTITIES FROM NON EU COUNTRIES IN SPECIFIC PROGRAMMES OF THE FRAMEWORK PROGRAMMES (1994-1998)
(Situation as per 16/01/1995)</td><td>-Industrial and materials techn.
-Agriculture and fisheries
-Telematics
- Dissemination and optimisation of results
- Training and mobility
- Non-nuclear energy (except R&D part)
-Nuclear fission safety (except radiol. impact, mastering events)
-Biotechnology (except prenormative research, biodiversity, social acceptance)
-Socio-econ. research (except evaluation of S/T policy options)
-Biomedicin (pharmaceutical research and research on biomedical technology and engineering)</td><td>-Marine sciences and technologies
-Standards, measurements & testing
-Information technologies
-Communication technologies
-Transport
-Environment and climate
-Non-nuclear energy (R&D part)
-Nuclear fission safety (radiol. impact, mastering events
-Biotechnology (prenormative research, biodiversity, social acceptance)
-Socio-econ. research (evaluation of S/T policy options)
-Biomedicin (except pharmaceutical research and excep research on biomedical technology and engineering)</td></tr>
<tr><td rowspan="6">SOCIATED COUNTRIES</td><td>EEA</td><td>ICELAND</td><td colspan="2" rowspan="6">TYPE I AND II PROGRAMMES
Organisations from countries associated with the programme :
1. can participate
2. can receive financial contribution from the Community.
Agreements with SWITZERLAND and ISRAEL are under negociation.
LIECHTENSTEIN is expected to be associated early 1995.</td></tr>
<tr><td></td><td>NORWAY</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>OTHERS</td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="23">EUROPEAN THIRD COUNTRIES</td><td>CEEC</td><td>ALBANIA</td><td colspan="2" rowspan="23">TYPE I AND II PROGRAMMES
Organisations from European Third Countries :
1. may participate if the participation in the project is in the interest of Community policies.
2. The participation should normally be financed by resources of the third country concerned. No financing is available from the specific programme in question.
However, in order to facilitate participation of organizations from CEEC, NIS, and Developing Countries, limited Community financial support might be made available, in areas and under conditions to be determined, in the framework of the specific programme in the field of Cooperation with Third Countries and International Organizations.</td></tr>
<tr><td></td><td>BULGARIA</td></tr>
<tr><td></td><td>CZECH REP.</td></tr>
<tr><td></td><td>ESTONIA</td></tr>
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<tr><td></td><td>ROMANIA</td></tr>
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<tr><td></td><td>SLOVENIA</td></tr>
<tr><td>NIS</td><td>ARMENIA</td></tr>
<tr><td></td><td>AZERBAIJAN</td></tr>
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<tr><td></td><td>GEORGIA</td></tr>
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<tr><td></td><td>UKRAINE</td></tr>
<tr><td>OTHERS</td><td>CYPRUS</td></tr>
<tr><td></td><td>MALTA</td></tr>
<tr><td></td><td>SWITZERLAND</td></tr>
<tr><td></td><td>TURKEY</td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="8">NON EUROPEAN COUNTRIES</td><td rowspan="7">WITH S/T AGREEMENT</td><td></td><td colspan="2" rowspan="7">TYPE I AND II PROGRAMMES
Organisations from non European Countries with S/T Cooperation Agreement :
1. may participate if the participation is in the interest of Community policies, and if the activity of the relevant programme is covered by the Agreement (see back page).
2. Shall not receive a financial contribution from the Community
NB. : The Agreement with AUSTRALIA is in force. The Agreement with CANADA awaits ratification. Contacts with SOUTH AFRICA are at an early stage.</td></tr>
<tr><td></td></tr>
<tr><td>AUSTRALIA</td></tr>
<tr><td>CANADA</td></tr>
<tr><td>SOUTH AFRICA</td></tr>
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<tr><td>WITHOUT S/T AGREEMENT</td><td></td><td>TYPE I PROGRAMMES
cannot participate</td><td>TYPE II PROGRAMMES
1. may participate if the participation is in the interest of Communit policies and provided that it contributes effectively to the implementation of the programme, taking into acc the principle of mutual benefit
2.limited financial support might be available for developing countri areas and under conditions to be determined in the framework of th specific programme on cooperation with Third Countries.</td></tr>
<tr><td colspan="3">INTERNATIONAL ORGANISATIONS</td><td colspan="2">International organisations may participate under the conditions set for European Third Cou In duly specified cases, the participation of international research organisations situated in may receive financial support from the Community.</td></tr>
<tr><td colspan="3">CONSORTIUM COMPOSITION</td><td colspan="2">A project is to be carried out by at least two legal entities (in some areas with industrial participation), wich must be established in different Member States or in at least one Men State and one associated State (or by at least one legal entity and the Joint Research Cen Participation from third States and of International organisations must take place together the minimum number of legal entities from the Community and any associated states.</td></tr>
</table>

Non-European countries with S/T Agreement :

The Agreement with Australia covers the following areas :

Biotechnology; Medical and health research; Marine Sciences and Technologies; Environment; Information Technologies; Communication Technologies.

The Agreement with Canada will cover the following areas :

Agriculture and fisheries; Medical and health research; Non-nuclear energy; Environment including earth observation; Forestry research; Information Technologies; Communication Technologies; Telematics for economic and social development; Mineral processing.

The Joint Research Centre can be a partner in a network of legal entities for the submission of proposals in all mentioned specific programmes.

CALLS FOR PROPOSALS (FP4)

Implemention Schedule (1st Call)

Programme	Opening	Deadline	Evaluation/Selection	First Contracts (Anticipated Dates)
Environment and Climate	17.01.95	27.04.95 [1]	May-October 1995	November 1995-June 1996
MAST	15.12.94	15.03.95 [1] 15.06.95 [1]	April-June 1995 July-September 1995	November 1995-June 1996 February 1996-June 1996
Activity II - A2 (CEE/NIS)	September 1995	December 1995	January 1996-February 1996	October 1996
Activity II - C (DCs)	15.03.95	15.06.95 06.09.95	July-September 1995 October 1996-February 1996	January 1996 September 1996
Activity IV (TMR)	17.01.95	18.04.95 15.05.95 15.06.95 [2]	-	-

(1) Coordinated evaluation process (start June 1995) for ELOISE and parts of Area A3 (Regional Seas Research) and Area B (Strategic Marine Research: Coastal and Shelf Research and Coastal Engineering and Natural Defences)

(2) Deadlines respectively for: conferences courses, schools and access to large facilities (18.04.95); training through research (15.05.95) and research networks (15.06.95).

Cooperation with Eastern Europe in the field of science and technology

European Union initiatives to support the countries of Central and Eastern Europe and the New Independent States

Contents

page

Atmospheric circulation and aerosol pollution in the western Arctic

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Among the factors influencing the climate and the state of the ecosystems the aerosols from anthropogenic sources are of increasing significance. They affect directly or indirectly the optical characteristics and the radiation regime of the atmosphere not only in the region of the pollution source, but also at a significant distance from it. Therefore, an estimate of the present state and monitoring of the levels of aerosol air pollution, as well as determination of the contribution of anthropogenic source-s appear to be important. Purposeful studies of the aerosol component in polar regions have been active only for the last 10-15 years. That is why, the obtained fragmentary results cannot yet be fully used for finding out long-term tendencies in the change of aerosol pollution. This possibility is provided by the results of measuring optical atmospheric parameters that also indirectly characterize the aerosol component. In particular, actinometric observations of direct solar radiation that are carried out at some arctic stations from the 30s allow tracking multiyear changes in atmospheric transparency.

Fig. 1 presents multiyear variations of the parameter T2 (Radionov, 1994, Radionov et al., 1994) characterizing the attenuation of direct solar radiation at the station Bukhta Tikhaya (80N19, 50E48) from 1933 to 1939, Dikson Island (73N30, 80E14) from 1938 and in Mirny Observatory (66S03, 93E01) in Antarctica from 1956. Mean T2 values for spring (March-May in the Arctic and September-November in Antarctica) and for summer (July-August in the Arctic and December-January in Antarctica) are presented. The parameter T2 may be formally referred to as an optical depth of the atmosphere for broadband radiation in a wide range of wavelengths from 0.4 mkm to 4 mkm. Major factors influencing T2 variations are changes in atmospheric water vapour and aerosol content (Radionov 1994, Radionov and Marshunova 1992).

The dramatic increases of T2, especially well-pronounced in Antarctica, are caused by the stratospheric turbidity following the eruption of Mt. Agung (1964), El-Chichon (1982) and Pinatubo and Hudson (1991) volcanoes.In both the Arctic and the Antarctic, the increase of turbidity after the volcanic eruptions persisted for 1.5-2 years.

Two features of the parameter T2 obtained in the Arctic should be stressed:

- there is an upward trend of turbidity in spring in the Arctic. This trend has been shown to be significant at the 99% confidence level. The parameters of the trend $y=a+bx$ are $a= -0.021\pm0.004$; $b= (1.1\pm0.2)*10^{**-3}$. The summer trend is negligible at the 95% confidence level;

- from the second half of the 50s the values of the parameter T2 in spring exceed those in summer. This effect is nowhere observed except for the Arctic.

An analysis of obtained data (Radionov and Marshunova 1992) has shown these two features to be connected only with an increase in aerosol turbidity of the atmpshere. The arctic sources proper could not induce the indicated features in multiyear variations of the parameter T2. This could be only caused by the input of additional aerosol quantities from the sources in temperate latitudes. One of the first explanations for a possible aerosol transport to the Arctic was suggested in (Heidam 1984). The differences in the polar front position in winter and summer account for the observed differences in the turbidity values of the Arctic atmosphere in the winter and summer periods. But the suggested scheme does not explain a stable increase in T2 and does not describe in detail the transport processes.

In principle, two causes for the trend of the T2 increase are possible:

- increase in the number of emissions from the sources;
- intensification of meridional transports of polluted air masses.

Fig. 2 presents data of L. Barrie (Barrie 1986) about SO2 emissions from Europe, acidity of ice from the Agassiz glacier, Ellesmere Island and our record of the turbidity parameter T2.

As is evident, there is a very good agreement between the three presented parameters. Thus, a preliminary conclusion can be drawn that an increase in aerosol turbidity of the atmposphere in the Arctic since the second half of the 50s was related to an increase in anthropogenic emissions from industrial sources located, in particular, in Russia.

What were the circulation conditions during this period? One of the most composite characteristics of the general atmospheric circulation are considered to be long thermal-pressure waves. Their classification was developed at the AARI by G.Ya. Vangengeim and A.A. Girs (Dmitriyev 1994). They identified three main atmospheric circulation forms characterizing the prevailing tropospheric transports in the Atlantic-Eurasian sector of the Northern Hemisphere: western W, eastern E and meridonal C. The processes of the form W mainly correspond to a zonal atmospheric state, while the processes of the forms E and C - to a meridional state but with a different spatial localization of ridges and troughs (Fig. 4). From the point of view of air mass transport there is a prevailing zonal transport at the form W and the interlatitudnal (meridional) air exchange is enhanced at the forms E and C. As a result a scheme for air mass transport at different types of the three main circulation forms W, E and C has been formed. It is given in Fig. 4 (Karimova and Chukanin 1988).

The Department of Long-Range Weather Forecasts of the AARI has prepared a detailed catalogue of multiyear variability of the circulation processes from 1990 up to the present time. In accordance with it the period of 1949-1971 was characterized by a simultaneous or alternating development of the processes of the forms E and C and by the attenuation of the form W processes. Since 1972 the processes of the form E prevailed (Dmitriyev 1994).

Thus, it can be concluded that an increase in emissions of pollutants in temperate latitudes of the European mainland that occurred at the background of prevailing meridional circulation forms has resulted in a stable growth of aerosol pollution of the atmosphere in the western Arctic from the 50s to the mid-80s. In the second half of the 80s there was a tendency for a change of the circulation epochs. The number of days with zonal transports of the form W blocking the meridional transport commenced to increase and, respectively, the number of days with meridional forms decreased. But at the same years there was a sharp reduction in industrial production at the territory of the former USSR. As a result, in 1991 for the first time after 1957 the spring values of the parameter T2 became equal to the summer values (see Fig. 1). In this case it is difficult to differentiate explicitly between the influence of the change in the circulation types and the reduction in industrial emissions as a result of "perestroyka" on the occurrence of this phenomenon. It is likely that an increase in transparency or a decrease in atmospheric turbidity are related to a decrease of anthropogenic emissions after the reduction in industry in the USSR republics.

As a result of these features of the aerosol input to the Arctic, one can observe there a unique character of the behavior of aerosol-optical atmospheric parameters. Direct measurements of the aerosol optical thickness of the atmosphere have shown the attenuation of solar radiation due to aerosol particles in the Arctic to be maximum in March-April and comparable by value with the continental conditions (Radionov and Marshunova 1992, Radionov et al. 1994).

Such intraannual variations of aerosol extinction with a maximum in spring are observed only in the Arctic.

The results of direct measurements by photoelectric counters of the concentration of aerosol particles more than 0.4 mkm and 1mkm in size are given in Fig. 5. The concentration maxima are observed from January to April. And the concentration of particles in the surface layer is well correlated with the strength of surface inversions (Barteneva et al. 1991). In summer as a result of a decreasing intensity of meridional transports, destruction of the inversion stratification and increased cloudiness and precipitation washing out aerosol particles from the atmosphere, their concentration in the surface layer is 20-30-fold decreased. And the aerosol optical thickness of the atmosphere at a wavelength of 0.5 mkm decreases from 0.25 in April to 0.05 in July.

In principle, one could expect the microphysical aerosol parameters in the Arctic to differ from those measured over the mainland. But according to the data of measurements in March-April of 1994 at the Franz-Josef Land, the character of the distribution function of the volumes (i.e. mass) of particles by size turned out to be similar to that in Obninsk in May of 1994 (Fig. 6). The measurements were made by means of photoelectric counters A3-5 and Royko in the range of sizes from 0.4 mkm to 10 mkm and by an electrostatic counter DAES-2M in the range of 0.005-0.5 mkm.

Moreover, the mass of particles with the sizes from 0.5 to 2 mkm turned out unexpectedly to be by 1.5-2 times more in the Arctic than over the mainland. The character of the dependency of the variability function on size (a ratio of the standard deviation to mean concentration of particles) in the Arctic is on the whole the same as in most of the points of the Earth, as also in the case of model experiments (Smirnov, 1992).. The variability function minimum is in a submicron range of sizes (Fig. 7).

This result indicates that the mechanisms for the formation and evolution of the aerosol in the Arctic are close or identical to the continental ones. At the same time the observed effects contradict the existing understanding that microphysical parameters of aerosol particles in the Arctic differ significantly from the continental ones.

The obtained new information should be considered as a basis for the hypotheses in further studies.

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FIGURE CAPTIONS

Fig. 1. Long-term variations of T2 in the Arctic and the Antarctic.

Fig. 2. A comparison of the historical record of SO2 emission from Europe (a), acidity observations in ice of the Agassiz glacier, Ellesmere Island (b) and turbidity of the atmospehre at Tikhaya Bukhta and Dikson Island (c).

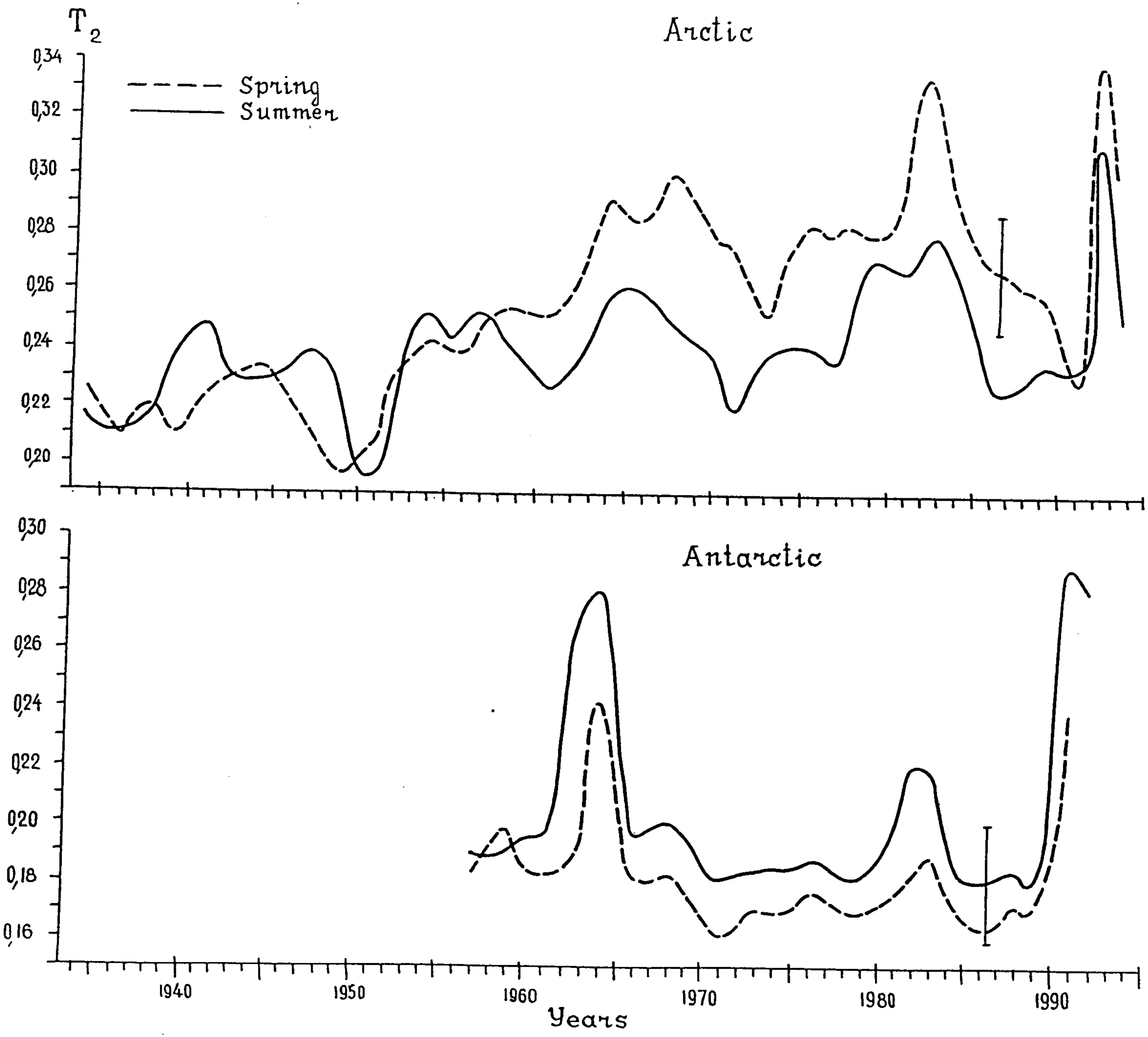
Fig. 3. A scheme of location of altitudinal (500 hPa) ridges and troughs at three kinds of the atmospheric circulation forms:
1 - form W;
2- form C;
3- form E.

Fig. 4. A scheme of air mass transport.

Fig. 5. Interannual variations in the concentration of aerosol particles,
1 - diameter is more than 0.4 mkm,
2 - more than 1 mkm.

Fig. 6. Size distribution of the volume of aerosol particles:
1 - Tsigler Island, Franz-Josef Land, March-April, 1994;
2 - Obninsk, May 1994.

Fig. 7. The variability function of the particle concentration:
1 - the High Plains, the USA;
2 - a district near Moscow;
3 - Obninsk;
4 - haze and fog;
5 - the Atlantic Ocean;
6 - after destruction in "aerosol box" experiment;
7 - typical "aerosol box" experiment;
8 - Wrangel Island, the Arctic;
9 - Tsigler Island, Franz-Josef Land.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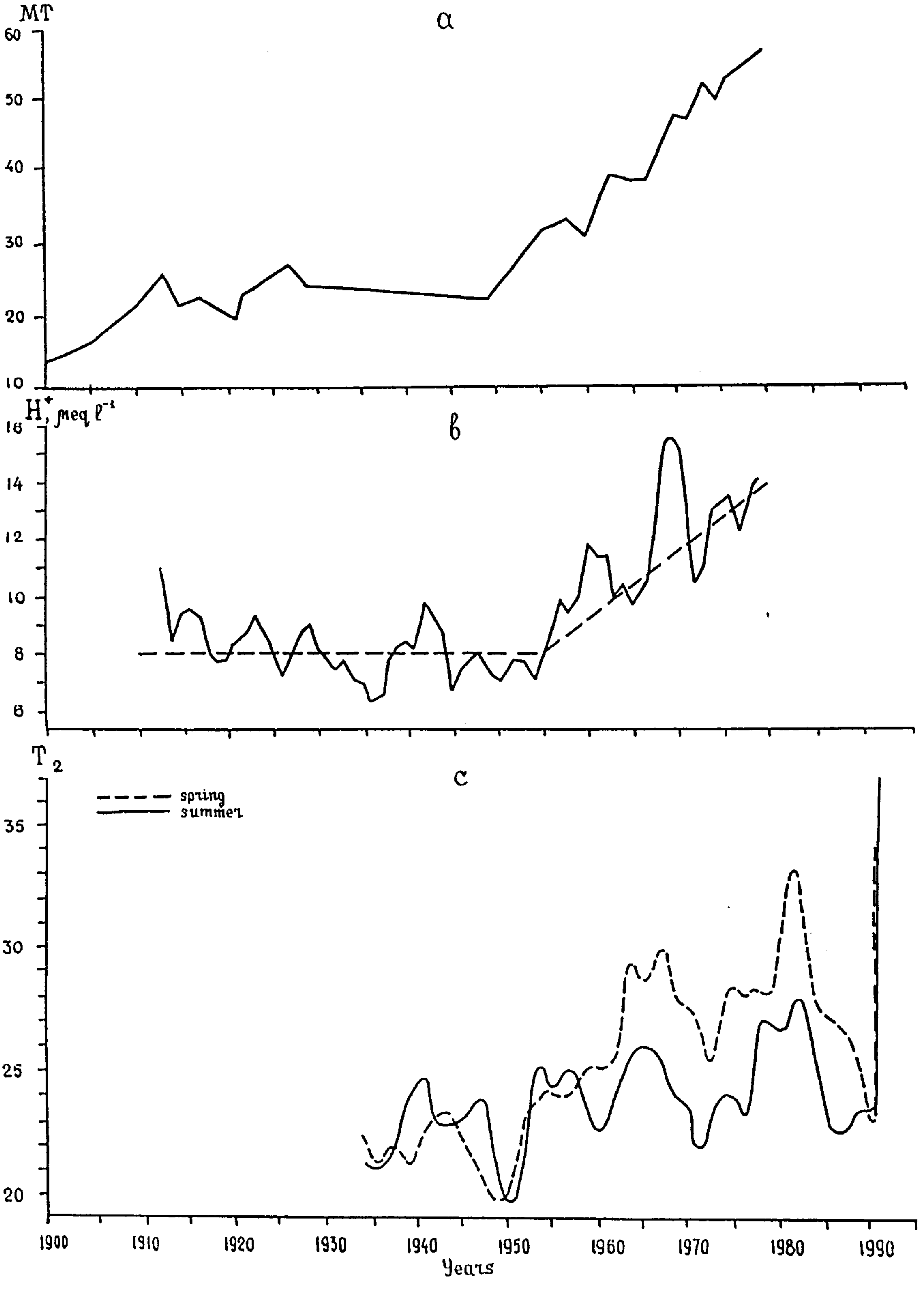
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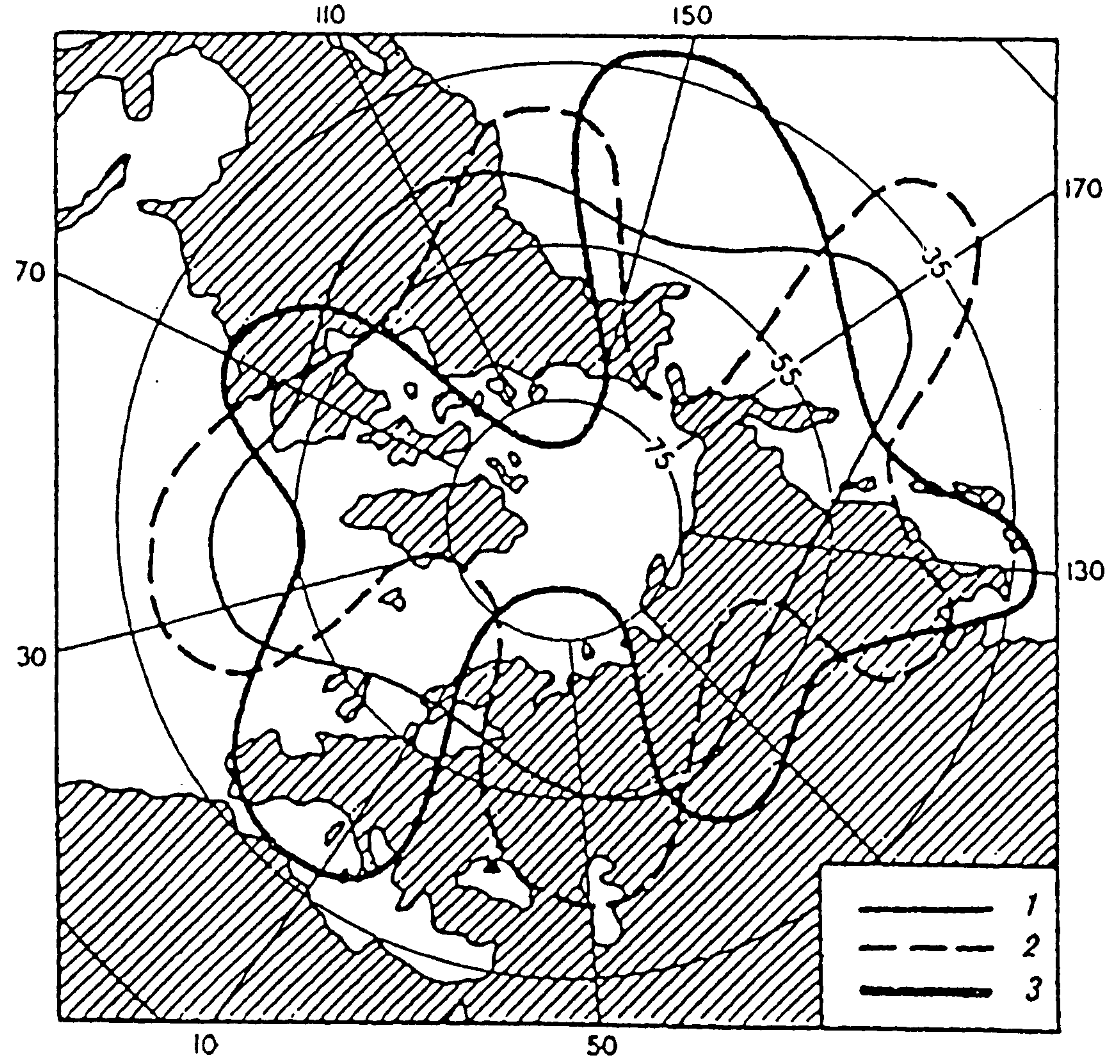
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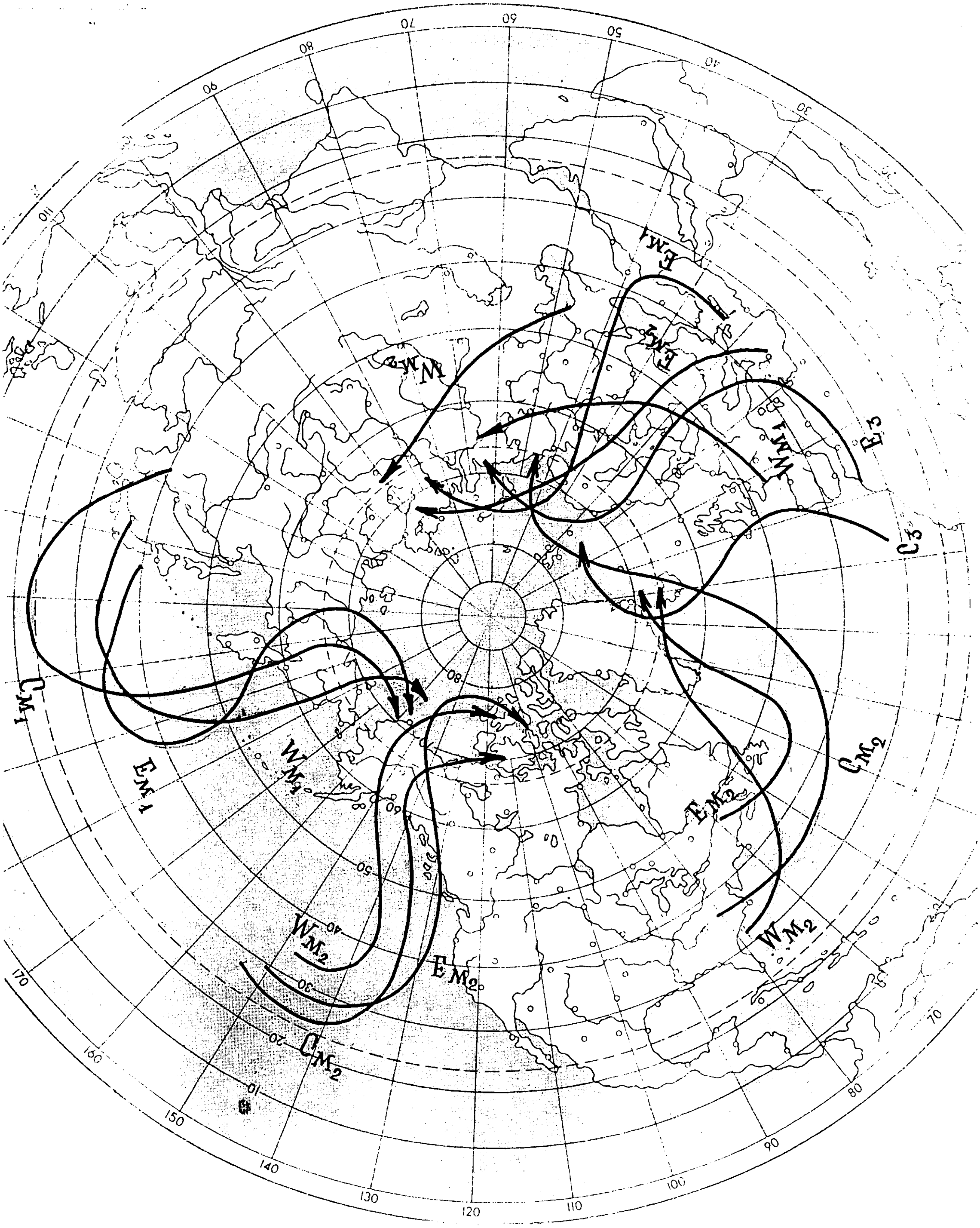
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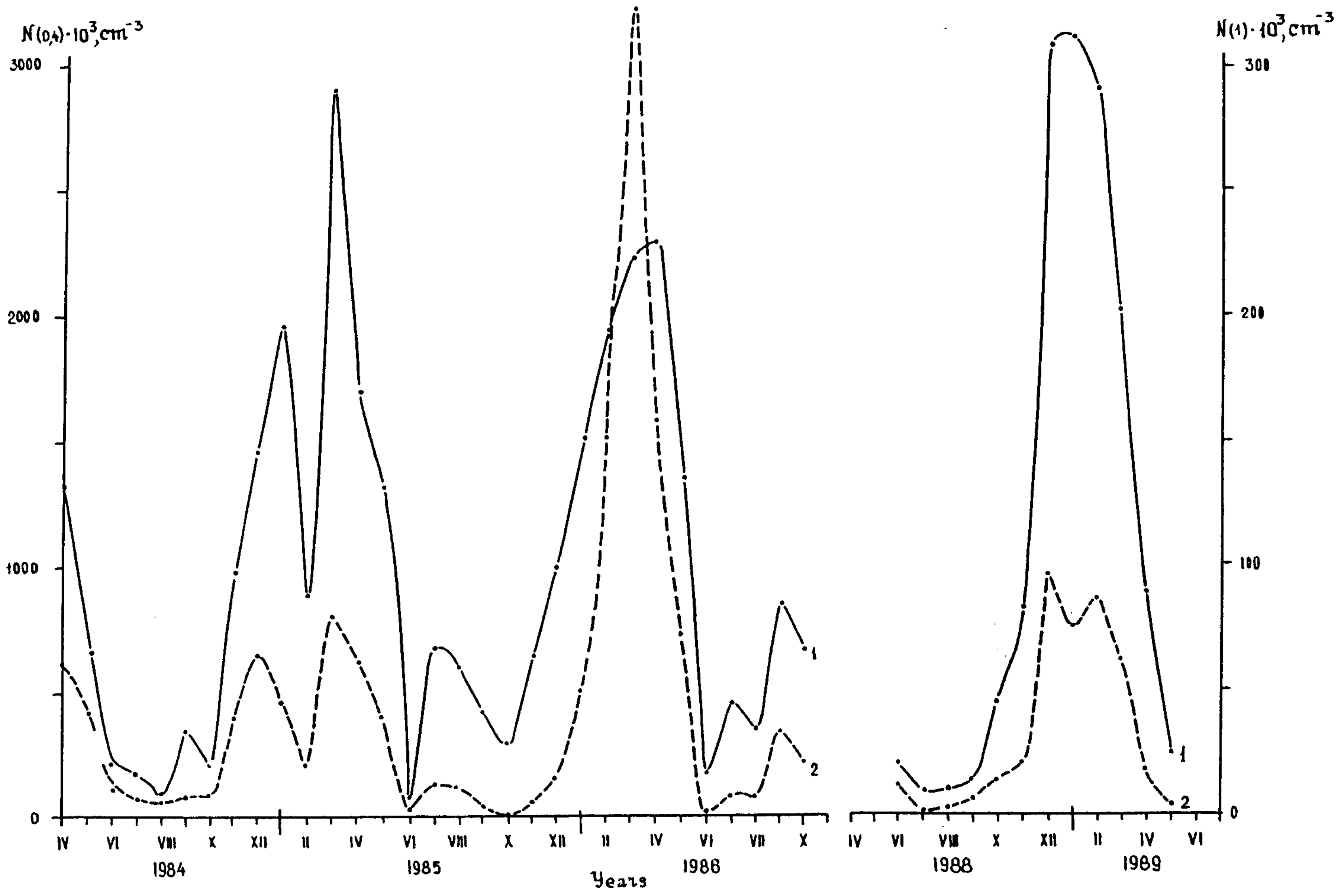
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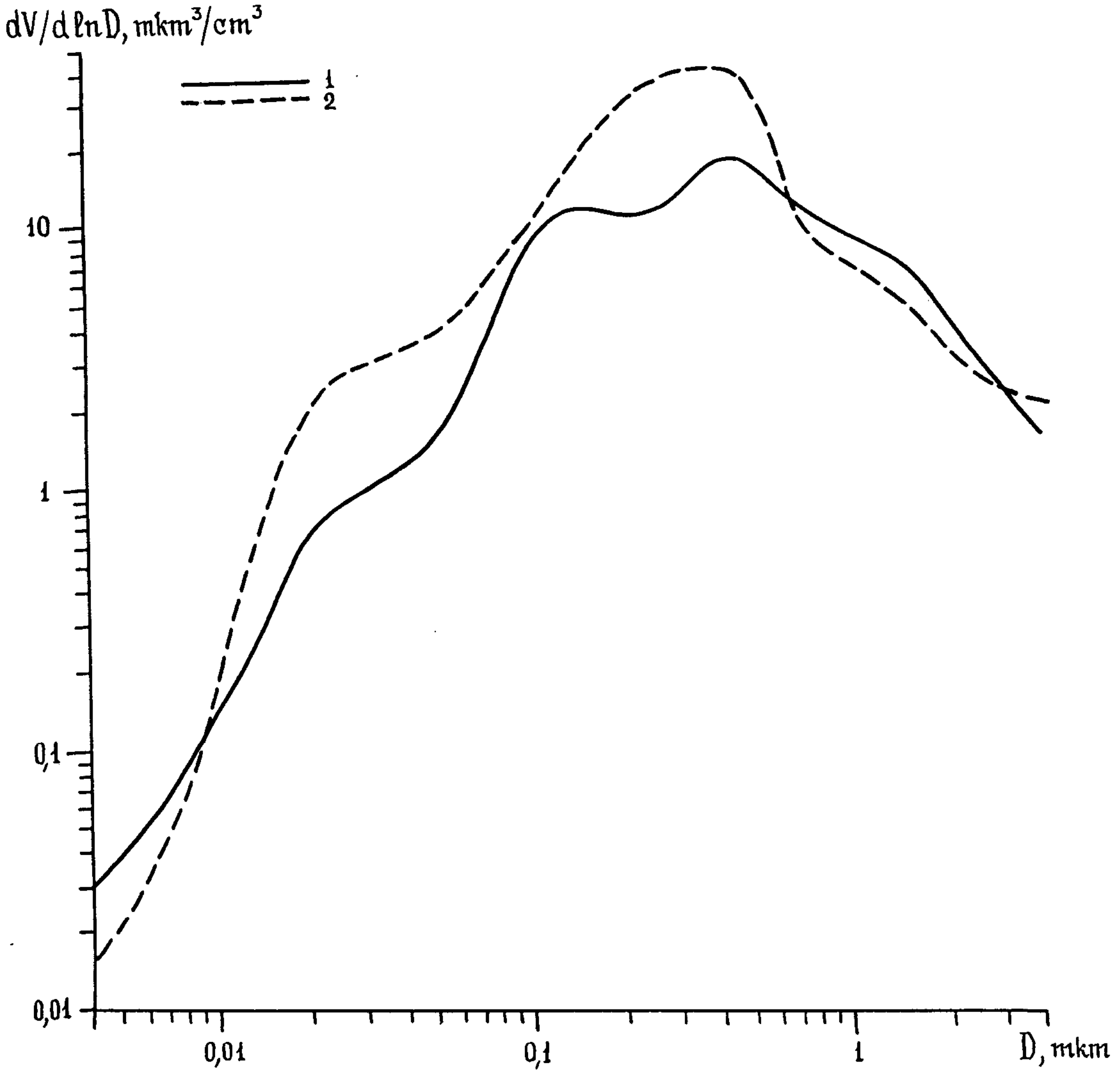
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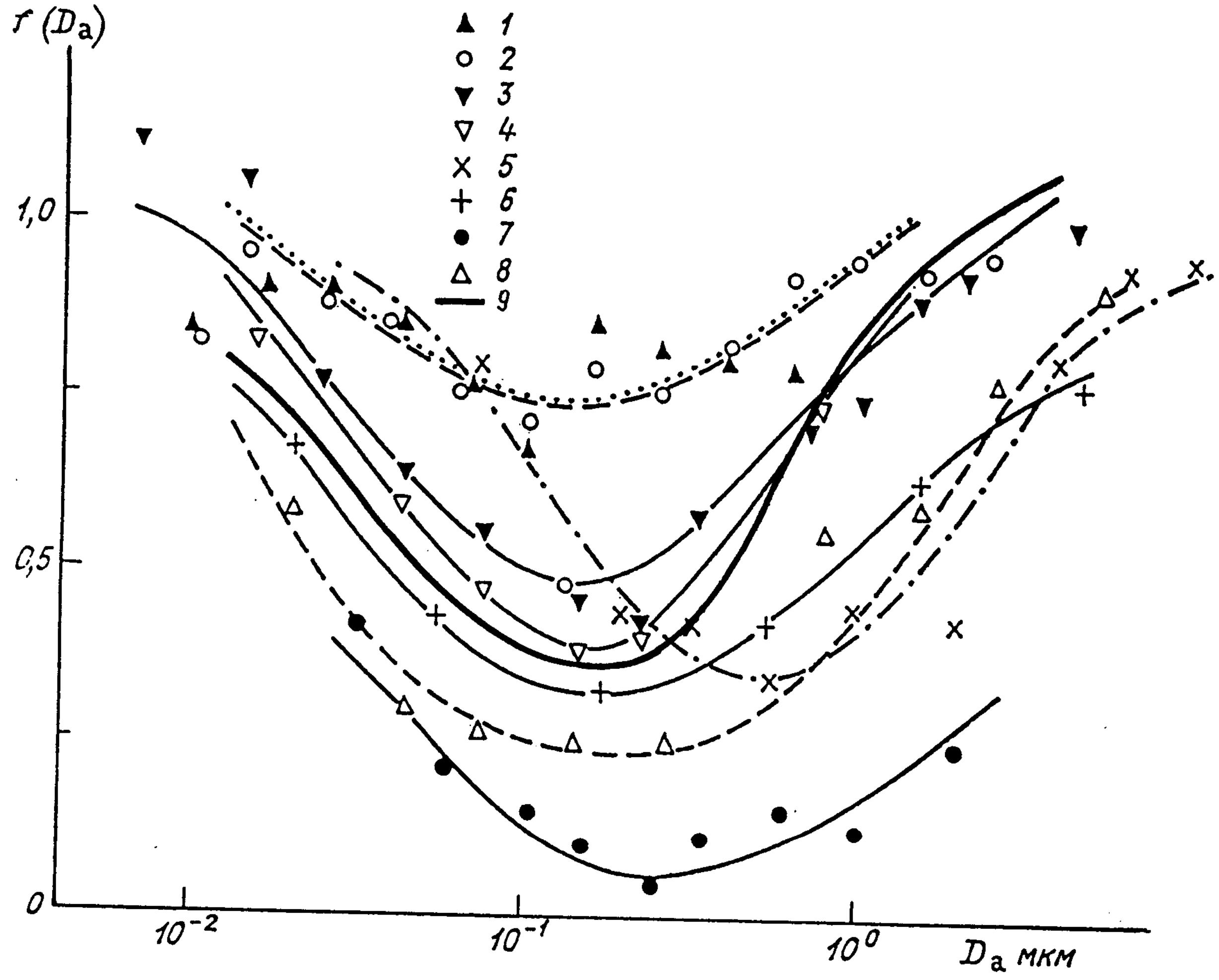
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Antarctic Science 6 (3): 419–424 (1994)

Variability of aerosol extinction of solar radiation in Antarctica

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Abstract: Temporal variations of the aerosol optical depth and transmission coefficient of the atmosphere are considered using data from Mirny Observatory, Antarctica. Year-to-year variability of these parameters is determined mainly by stratospheric aerosol pollution due to volcanic activity. A considerable increase of atmospheric turbidity has been observed since the end of September 1991. This phenomenon seems to be associated with the Mount Pinatubo volcanic eruption.

Received 4 January 1993, accepted 3 April 1994

Key words: Antarctic, transmission coefficient, aerosol optical depth

Introduction

Studies of atmospheric aerosol are of interest because of its considerable influence on radiative processes. Since the late 1970s a great number of observations of the aerosol extinction of solar radiation in various regions of the Earth have been made (Bodhaine 1983, Kondratyev 1978, Kondratyev & Binenko 1981, Bodhaine 1989, Sakunov *et al.* 1986). Such measurements in Antarctica, which is not directly affected by man-made aerosol, have revealed the main features of the variability of the background aerosol and atmospheric optical characteristics on a range of time scales (ranging from time scales of less than one day to interannual ones). They have, in particular, corroborated the episodic data obtained earlier (Liljequist 1957, Kuhn 1972, Sakunov 1975) showing an annual cycle of aerosol extinction with a summer (December–January) maximum in Antarctica. Information on the variation of the optical state of the atmosphere, covering a few decades, may be obtained from actinometric measurements. A detailed analysis of observed time series of direct solar radiation at the Antarctic stations Novolazarevskaya (70°46'S, 11°50'E), Molodezhnaya (67°40'S, 45°50'E), Mirny (66°33'S, 93°01'E) and Vostok (78°28'S, 106°48'E) from the beginning of observations to 1975 is given in the monograph of M.S. Marsunova (1980). Direct measurements of aerosol optical depth in the atmosphere, started in 1979 at Mirny Observatory, have provided an opportunity to compare them with the results of actinometric measurements.

Methods

Transmission coefficient

The following characteristic of the optical state of the atmosphere is used to interpret actinometric observations from the Russian network of stations:

$$P_2 = \sqrt{S_{M,2}/S_0} \qquad (1)$$

P_2 is the coefficient of the total transparency (transmission coefficient), $S_{M,2}$ is the intensity of the direct solar radiation at the mean distance between the Sun and the Earth, incident on a surface normal to the solar ray direction and attenuated by two optical air masses ($m = 2$), and S_0 is the solar constant. The correction of the measured radiative intensity $S(h)$ (h is the Sun elevation) to allow for the variation in the distance to the Sun is made by standard methods.

The direct solar radiation $S(h)$ was measured by the thermoelectric actinometer M-3 which is an analogue of the Eppley actinometer. All the instruments were calibrated in St. Petersburg before and after the study. Additionally, the actinometers were verified at least once a month at the stations using a standard actinometer, which was annually calibrated against the Ångström pyrheliometer.

The accuracy of the measurement of the flux of direct solar radiation is ± 10 $\mathrm{Wm^{-2}}$. The values of $S(h)$ are reduced to a Sun elevation $h = 30°$ (i.e. $m = 2$) by Sivkov's method (Sivkov 1968) using empirical tables. This method eliminates the Forbes effect (i.e. an apparent increase of transmittance at large air masses) over a broad range of atmospheric turbidity changes. The empirical relation between $S(h)$ and $S(30°)$ used in this method is

$$S(30°) = 1367 \left[\frac{S(h)}{1367}\right]^{1.42\sin h + 0.29} \qquad (2)$$

(Evnevich & Savikovsky 1989) where $S(h)$ is in $\mathrm{Wm^{-2}}$. The error in computing $S(30°)$ using (2) averages at 16 $\mathrm{Wm^{-2}}$. P_2 is calculated using

$$P_2 = \left[\frac{S(h)}{1367}\right]^{(\sin h + 0.204)/1.41} \qquad (3)$$

To compute P_2 the measured data $S(h)$ for $h > 10°$ and with no clouds closer than 20° to the solar disc are used. The variability of the daily average of P_2, usually estimated from five to seven separate measurements, does not exceed 2%. The determination of the transmission coefficient P_2 is similar to a procedure for estimation of a so-called 'apparent transmission' (Bodhaine *et al.* 1989). The value of P_2 is determined from values of direct solar radiation in a wide range of wavelengths from 0.4 μm to 4 μm and it therefore depends on extinction due to Rayleigh scattering, Mie scattering and selective absorptions by various

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 98, NO. D10, PAGES 18,441–18,447, OCTOBER 20, 1993

Comparison of Trends in the Tropospheric and Stratospheric Aerosol Optical Depths in the Antarctic

A. HERBER,[1] L. W. THOMASON,[2] V. F. RADIONOV,[3] AND U. LEITERER[4]

Temporal variations of the aerosol optical depth of the Antarctic troposphere and stratosphere are considered on the basis of long-term Sun photometer and actinometer measurements which have been made at Mirny and Georg Forster stations since 1956 and 1988, respectively. This data is supplemented by measurements of the stratospheric aerosol optical depth by the satellite-borne stratospheric aerosol measurement II instrument. These observations indicate that under undisturbed conditions, the stratospheric aerosol optical depth represents approximately 25% of the total atmospheric aerosol optical depth. The aerosol optical depth in the Antarctic is most notably affected by volcanic eruptions, such as El Chichon in 1982 and Mount Pinatubo and Cerro Hudson in 1991, and by the occurrence of polar stratospheric clouds during Antarctic winter and spring. Apart from these episodic events, no long-term trend in the aerosol optical depth can be discerned from the nearly 40-year record.

INTRODUCTION

Aerosols are important, among other reasons, because of their effect on the transfer of visible and infrared radiation in the atmosphere. For instance, in the aftermath of major volcanic injections of aerosols into the stratosphere, significant increases in stratospheric temperatures have been reported [*Labitzke et al.*, 1983; *Labitzke and McCormick*, 1992]. It has also recently been suggested that the predicted increase in global temperature in response to increasing levels of greenhouse gases may be mitigated in part by increasing levels of anthropogenic tropospheric aerosols [*Charlson et al.*, 1991]. On a global scale, increasing tropospheric aerosol levels have a negative impact on surface temperatures [*Ackerman*, 1988; *Kerr*, 1992]. This is not necessarily the case in polar regions, where the combination of high surface albedos and increased tropospheric aerosols could lead to a warming of the surface of the Earth. Since most global warming scenarios also suggest that polar regions will experience the greatest temperature increases, the importance of understanding temporal variations and trends in both the Antarctic tropospheric and stratospheric optical depths is obvious.

Since the 1950s, measurements of aerosol optical depth at Antarctic coastal and inland stations have been carried out by a number of workers [*Liljequist*, 1957; *Kuhn*, 1972; *Shaw*, 1982; *Herber*, 1992; V. F. Radionov, manuscript in preparation, 1993 (hereinafter referred to as Radionov, 1993)]. Since Antarctica is an ice-covered continent surrounded by ocean and practically free of local anthropogenic aerosol contamination, the Antarctic aerosol optical depth has normally been found to be very low. The primary components of Antarctic aerosol are H_2SO_4-H_2O droplets of volcanic and biogenic origin, sea-salt particles from the surrounding ocean [*Wagenbach et al.*, 1988; *d'Almeida et al.*, 1991], and mineral particles from the desert regions of southern Africa and Australia [*Meanhaut and Zoller*, 1979]. In this paper the temporal variation of aerosol turbidity or optical depth, and the influence of volcanic aerosol and polar stratospheric clouds will be discussed on the basis of optical measurements which have been carried out at Mirny Observatory (67°S, 93°E) since 1956, at Georg Forster Station (71°S, 12°E) since 1988, and on satellite observations made by the stratospheric aerosol measurement (SAM) II instrument since 1978 [*McCormick et al.*, 1993].

INSTRUMENTATION

Sun Photometers

Measurements with Sun photometers have been performed continuously at Georg Forster Station during polar day since March 1988 and during annual summer campaigns at Mirny from 1982 to 1992. The Sun photometers, the Achtkanal Boden-Atmosphären Sonnenphotometer and the Boden-Atmosphären Sonnenphotometer as developed by *Leiterer and Weller* [1988], measure direct solar transmittance and thus the atmospheric optical depth at 8 and 37 narrow wavelength intervals between 0.38 and 1.10 μm, respectively. The half widths of the intervals range from 0.008 to 0.015 μm. The Sun photometers can be used to measure not only the direct solar radiation but also reflectance from different surfaces and from skylight in the almucantar. The aerosol optical depth $\delta_i(\lambda)$ is obtained from the atmospheric optical depth by accounting for the effects of Rayleigh scattering and absorption by trace gases including NO_2, O_3, and H_2O. The Rayleigh-scattering correction is derived from the technique described by *Fröhlich and Shaw* [1980]. The NO_2 absorption optical depth is very small in the Antarctic region [*Murcray et al.*, 1988] and can be neglected, while measurements of the column ozone concentration using an M124 ozonometer [*Feister*, 1991] are used to correct for the ozone absorption at measurement wavelengths within the Chappius band (0.45–0.75 μm). Since column water vapor measurements are not routinely available, the aerosol optical depth is determined only at wavelengths without significant water vapor absorption, such as

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Assessment of wet sulphur deposition over the former USSR

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(Manuscript received 22 February 1993; in final form 14 December 1993)

ABSTRACT

The data obtained by different national and international networks of precipitation chemistry monitoring the territory of the former Soviet Union (FSU) have been generalized. Analyses of long-term trends of sulphur concentrations in precipitation for a 30-year period showed that the changes did not correlate with the dynamics of anthropogenic sulphur emissions into the atmosphere both over the FSU territory and Europe as a whole. Sulphur concentrations in precipitation reveal an obvious seasonal dependence with the spring maximum while deposition intensity has its maximum during summer time. All the FSU territory has been divided into 20 regions, and the mean values of sulphur concentration in precipitation and wet deposition have been estimated for each of them. The highest values were characteristic of the south-western part of the country and lowest ones of the remote areas of NorthEast. In the 80s, about 6.0 Tg of sulphur were annually wet deposited over the European territory of the FSU, about 3.0 Tg over the territory of Kazahstan and Central Asia, about 5.7 Tg in Siberia and the Russian Far East. The total wet sulphur deposition made up 60–90% of the anthropogenic sulphur emissions into the FSU atmosphere.

1. Introduction

Assessments of sulphur deposition with precipitation from the atmosphere form the basis of our knowledge of the atmospheric sulphur cycles both at the global and regional levels. The bulk of anthropogenic sulphur does not leave the continental atmosphere and settles down to the surface within hundreds of kilometers from its sources (Rayboshapko, 1983). Thus, Galloway and Whelpdale (1987) indicated that only 25–30% of anthropogenic sulphur is transported beyond the North American continent into the Atlantic Ocean. It is quite natural that a still greater portion of anthropogenic sulphur should settle down on the Eurasian continent since the bulk of sulphur is released into the atmosphere over the western periphery of the continent and transported inland by the prevailing easterly air flows.

Available estimates indicate that by the late 1980s, the continental man-made sulphur emission was 15 Mt/yr in Western and Central Europe (Iversen et al., 1990), from 8 (GOSCOMSTAT, 1990) to 13 Mt/yr (Ryaboshapko, 1990) in the USSR, 10 in China, 0.6 in Japan, 0.8 Mt/yr in the Korean Peninsula (Kato and Akimoto, 1992). The spatial emission distribution over the European part of the former Soviet Union (FSU) was studied within the framework of the international EMEP programme (Iversen et al., 1990). Fig. 1 shows the distribution over the Asian part of FSU with a resolution of 5 × 5° (based on the data of GOSCOMSTAT, 1990). As it follows from EMEP data and Fig. 1, the bulk of atmospheric sulphur emissions over FSU was associated with the western and central regions. Taking into account the pattern of the global atmospheric circulation, it can be stated a priori that the largest part of sulphur emitted deposited directly over FSU whose area exceeded $22 \cdot 10^6$ km^2.

The first episodic observations of precipitation chemistry in Russia data back to the end of the last century. Regular observations were initiated in

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Zur Variabilität der optischen Eigenschaften der Atmosphäre im Nordatlantik

Von W. M. Wolgin, W. F. Radionov, U. Leiterer

With 4 Figures

Zusammenfassung: Es werden Ergebnisse von Messungen zur spektralen optischen Aerosoldicke der Atmosphäre und des gerichteten Aerosolstreukoeffizienten in der Sonnenaureole von 2° bis 20° Streuwinkel vorgestellt, die im Rahmen von Schiffsexpeditionen in der Grönlandsee und im Europäischen Nordmeer 1988 gewonnen wurden.

Summary: Results of aerosol optical thickness measurements and of the directed aerosol scattering coefficients in the solar-aureole for a 2°-to-20° scattering angle are presented. The results were obtained during a ship expedition on the Greenland Sea and the Norwegian Sea in 1988.

Einführung

Die Erforschung der optischen Eigenschaften der Atmosphäre, insbesondere ihrer spektralen Durchlässigkeit und der spezifischen Helligkeit der Sonnenaureole haben praktische Bedeutung für die Anwendung von Fernerkundungsmethoden über Ozeanen, für die Sichtforschung und auch für klimatologische Fragestellungen.

Die Zahl der Veröffentlichungen zu dieser Thematik über offenen Seegebieten ist sehr gering. So sind zum Beispiel für den Nordatlantik im Bereich der Grönlandsee und des Nordmeeres nur optische Dicken von *Karimowa* u. a. (1976) und *Lukjanchikova* u. a. (1981) veröffentlicht.

Es werden nicht nur die Ergebnisse der optischen Dicke und der Aureolenmessungen sowie ihre Genauigkeit vorgestellt, sondern auch die Zusammenhänge zur vertikalen Verteilung der meteorologischen Elemente und zur synoptischen Situation diskutiert. Außerdem erlauben die Meßergebnisse (direkte Sonnenmessung und Messung der Streustrahlung in der Sonnenaureole) die Berechnung der Streueigenschaften und der Größenverteilungen des Aerosols, welches eine aktive Rolle bei Kondensationsprozessen spielt. Die Kondensationsprozesse haben eine besondere Bedeutung im Bereich des Nordmeeres und des Grönländischen Beckens, wo ständig hohe Luftfeuchtigkeiten im Bereich von 80–90 % relativer Feuchte herrschen.

Meßergebnisse

Die Messungen wurden während der 45. Expedition des Forschungsschiffes „Professor Zubov“ im Zeitraum Mai bis Juli 1988 durchgeführt. 16 Spektren der optischen Aerosoldicke und 7 Aureolenmessungen im Winkelbereich 2 bis 20° bilden die Datenbasis.

Die direkte Sonnenstrahlung wurde mit 2 Sonnenfotometern, welche mit 9 Kanälen im Spektralbereich 0,46 bis 1,64 µm arbeiten, gemessen. In beiden Sonnenfotometern waren Interferenzfilter entsprechend Tabelle 1 eingesetzt (λ_0: zentrale Wellenlänge, $\Delta\lambda$: Halbwertsbreite der Filter, S: Durchlässigkeit des Filters außerhalb der 3fachen Halbwertsbreite in Bezug auf seine maximale Durchlässigkeit). Als Strahlungsempfänger dienen Fotodioden vom Typ FD-7K (Silizium) und FD-7G (Germanium).

Die Fotodioden werden auf eine Temperatur, die höher als die Umgebungstemperatur ist, geheizt und thermisch bei 45 °C stabilisiert. Der ebene Feldwinkel beträgt ca. 3°. Der Meßfehler für den benutzten Sonnenfotometertyp wurde in einer Arbeit von *Villevalde* u. a. (1988) bereits untersucht und beträgt $\Delta\tau_A = 0{,}005$ bis 0,01. Die sonnennahen Indikatrixwerte wurden mit einem Aureolenfotometer bei Streuwinkeln γ von 2°, 4°, 6°, 8°, 10°, 15° und 20° für die Wellenlänge $\lambda = 0{,}557$ µm gemessen. Das Aureolenfotometer ist mit einer speziellen Schattenscheibe ausgerüstet, damit die Einflüsse der direkten Sonnenstrahlung auf die Meßergebnisse korrigiert werden können. Der Anteil der Rayleigh-Streuung wurde durch Messungen bei Bedingungen mit sehr geringer optischer Dicke ermittelt.

In Tabelle 2 sind die Meßergebnisse zusammengestellt:

- die optische Aerosoldicke τ_A,
- der gerichtete Aerosolstreukoeffizient μ_A, siehe auch Gleichung (3)
- der Angström'sche Wellenlängenexponent α, Definition: $\tau_A(\lambda) = \tau_A(1{,}0\ \mu\mathrm{m}) \cdot \lambda^{-\alpha}$
- der van de Hulst'sche Koeffizient q. Definition: $\mu_A(\gamma) = \mu_A\ (1^\circ)\ \gamma^{-q}$

Tabelle 1
Angaben zu den Spektralkanälen der Sonnenfotometer; λ: Wellenlänge; $\Delta\lambda$: spektrale Halbwertsbreite; S: Transmission des Filters außerhalb der dreifachen Halbwertsbreite in Bezug auf seine maximale Durchlässigkeit.

Table 1
Details to the spectral channels of the sunphotometers; λ: wavelength; $\Delta\lambda$: spectral half bandwidth; S: Transmission of the filters outside of the threefold half bandwidth relating to the maximal transmission

	Spektralkanäle der Sonnenfotometer								
	1	2	3	4	5	6	7	8	9
λ µm	0.461	0.513	0.551	0.573	0.653	0.743	0.853	1.016	1.640
$\Delta\lambda$ µm	0.010	0.005	0.005	0.004	0.003	0.007	0.006	0.004	0.016
S	10^{-4}	10^{-4}	10^{-4}	$5 \cdot 10^{-5}$	10^{-5}	10^{-4}	10^{-4}	$5 \cdot 10^{-4}$	10^{-3}

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Determination of Paths by Which Anthropogenic Aerosol is Transported into the Arctic

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The most probable routes by which anthropogenic aerosol is transported into the northern USSR (on specific days in the spring of 1985) are determined by comparing the elementary composition of individual aerosol samples with published data on the elementary composition of the aerosol in various large source regions. The results of a synoptic analysis of the paths of transport of air masses to the locations at which the aerosol was sampled are also used.

Studying human impact on the composition and roperties of the atmosphere is now a high-pririty ecological problem. The study of aerosol ollution of the Arctic atmosphere is an imporant aspect of the problem.

The Arctic region accumulates large amounts f anthropogenic aerosol in winter as a result of arge-scale transport from industrial areas in iddle latitudes [1] and the extremely low effiiency of aerosol elimination from the Arctic tmosphere during that period [2]. The winter ncrease in the aerosol content of the Arctic tmosphere has considerable climatic and ecologial consequences. It is of considerable interest n connection with various related problems to etermine the possible sources of the winter Arcic aerosol; it has been shown [3-5] that the haracteristics of its elementary composition can e used for this purpose.

In the present paper we describe an attempt o determine the paths by which anthropogenic erosol is transported into the northern USSR in erms of the elementary composition of individual erosol samples and a synoptic analysis of the ovement of air masses.

Sampling and Processing of Experimental aterial. The aerosol samples were collected on he Severnaya Zemlya archipelago and on Wrangel sland in the spring of 1985 by pumping air from he surface layer through AF-KhA-20 or Whatman ilters (100-2000 m^3) for 1 to 2 days. The conentrations of various elements on the filter ere determined by neutron activation analysis nd were converted to the concentrations of the orresponding elements in the atmospheric surface ayer at the sampling locations. The mean conentrations of 21 elements and several prelimiary conclusions based on an analysis of the exerimental data were presented earlier [6].

In the present paper we focus on aerosols of arious elementary compositions collected on diferent days and a comparison of the characterisics of the individual samples with the characeristics of the source areas described in [5, 7], in order to identify the origins of the aerosols in the samples.

In a discussion of the problem of identifying possible sources of the aerosols in the Arctic region, Rahn and Lowenthal [3-5] developed a system of characteristics of the elementary composition of aerosol that express distinctive features of the composition of anthropogenic emissions from a given source and that meet the important criterion of small variability during transport.

The system consists of the following set of concentration ratios: As/Sb, Se/SB, V/Sb, Zn/Sb, and In/Sb. These elements are predominantly of anthropogenic origin* [8] and are typical of the emissions of specific production processes. For this reason, as Rahn and Lowenthal show [5], the set of values of these ratios expresses rather well the individuality of the source and can be used as its signature. It is also significant that all of the elements in question tend to concentrate in particles less than 2 μm in diameter [9], so that the rates of their separation from the air flow are low [9] and as a result the concentration ratios vary little along the path of the air masses.

The values of these characteristics for several large source regions, taken from [5], are presented in Table 1.** They were obtained from special observations at specific geographic locations. An important methodological factor was the choice of data representing synoptic situations under which the origin of the aerosol could be unambiguously related to the air mass arriving from the source area in question. Note that the identification of sources is tentative and is more closely related to the geographic zonation of the territory than to the distribution of the production processes and plants that govern the anthropogenic contribution to the atmospheric aerosol above these regions.

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*The terrigenous contribution to the concentration of Mn and V in the air above snow-covered areas of the northern hemisphere is very low.

**The errors in determining the concentration of In in aerosol samples are very large, and the In/Sb ratio is therefore not considered large.

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Some Results of the Investigation of the Composition of the Aerosol Near the Ground in Arctic Regions

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Quantitative data on the concentrations of 21 elements in air near the ground in the northern regions of the USSR during the spring of 1985 are presented. The content of anthropogenic components in Arctic air does not exceed their content in continental air in the background regions. The changes in the composition of the aerosol near the ground are compared with data from synoptic analysis of the mixing paths of air masses.

The aerosol in Arctic regions has been actively studied over the last decade [1]. This is a result primarily of the observed intensive contamination of Arctic air by the products of man's activity [2], whose sources are located in the middle-latitude industrial regions of Europe, Asia, and North America. Such studies are important because of the possibility of climatic consequences in connection with the accumulation of a large quantity of absorbing particles in the air in northern regions during the winter-spring period, which can alter the radiative properties of both the atmosphere itself and of the underlying surface. On the other hand, statistical analysis of the elemental composition of the Arctic aerosol can be employed to determine the locations of the most probable natural and anthropogenic sources of this aerosol [3].

The purpose of this work was to collect quantitative data on the content of a number of elements (including those which, as demonstrated in [3], can be effectively used as tracers in determining the sources of pollutants) in the air near the ground in the northern regions of the USSR, as well as to compare the changes in the chemical composition of the aerosol near the ground with the changes in the synoptic situation at the sample collection points.

PROCEDURE FOR COLLECTING AND ANALYZING SAMPLES

In this work we used two methods for studying the aerosol composition: 1) study of the quantitative content of separate elements in all of the aerosol matter (without separation by size) and 2) qualitative method for studying the chemical composition of the transmission spectra of aerosol samples deposited on a substrate with the help of an impactor, separating the submicron fraction.

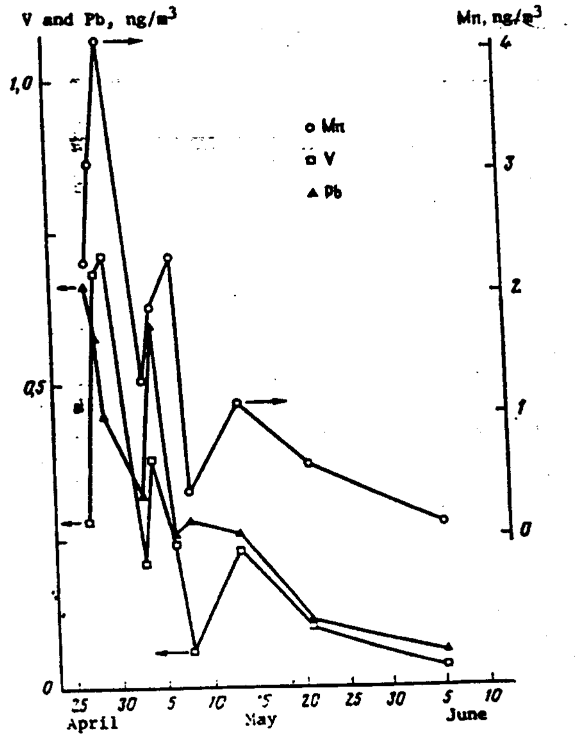

Fig. 1. Time dependences of the concentrations of Mn, V, and Pb in the air layer near the ground on Wrangel Island during the spring of 1984.

The aerosol samples used for elemental analysis were collected at the polar stations of the Arctic and Antarctic Scientific-Research Institute on Wrangel Island in April-June of 1984 and April-May of 1985 as well as on the archipelago

Investigation of the Arctic aerosol pollution

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Abstract

Lately the investigations of the Arctic atmospheric aerosol are actively carried out. It is connected, in the first place, with the long-range transport of anthropogenic pollutants to the Arctic from the Middle latitudes and their accumulation in the Arctic atmosphere during winter-spring season. The importance of such investigations is caused by possible ecological and, in particular, climatic effects of pollution accumulation in the Arctic atmosphere.

In the present work the results of the investigations carried out by the Institute of Atmospheric Physics in some regions of the Arctic (Severnaya Zemlya, the Wrangel Island, North Atlantic) in 1984–91 [1-3] are summarized. We had studied the element composition of the Arctic aerosol (including element carbon) and possible pathways of the aerosol transport to the observation points.

1. The element composition of the Arctic aerosol

The ground level aerosol samples for the element composition analysis were collected in spring seasons at the Wrangel Island (in 1984, 1985, 1988, and 1989) and at Severnaya Zemlya (in 1985 and 1988). The air was drawn through the AFA–HA–20 (or Wathman) filters during 1–5 days.The obtained samples were analyzed by the methods of neutron activation analysis and of atomic absorption spectrophotometry. In Table 1, the mean concentrations of 25 elements for the Wrangel Island and Severnaya Zemlya are given. In the same table are also given the ranges of concentration values of these elements in the ground layer of the air as they are supplied by the available literature data for the foreign Arctic. It should be pointed out that the crustal (terrogenous) element concentrations are ten time more at the Wrangel Island than at Severnaya Zemlya. For the marine elements this difference is not so considerable but is also appreciable. This fact can be connected with the spring reconstruction of the Arctic atmospheric circulation processes which reveals itself first of all in the Eastern Arctic [4]. As a result, in spring seasons the air masses from North Pacific are frequently transported to the Wrangel Island. In these air masses the marine (from the open water) and crustal (from the land surface without snow) element concentrations can be significant.

The comparison of our data with the data for the foreign Arctic allows to make a conclusion that the natural element concentration fields are more or less uniform in the Arctic atmosphere.

Based upon the data of Table 1, the anthropogenic elements can be divided into three groups in which the element concentrations in the Russian Arctic: (1) approximate the analogous values in the foreign Arctic (Zn, Cr, Mn, V, Cu, I); (2) differ from them less than one order of magnitude (Se, Sb, Co, As, Ni); (3) are one order or more over the corresponding upper levels

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Elemental Composition of the Surface Atmospheric Aerosol in the Arctic Regions of Russia

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We studied the elemental composition of the surface aerosol in the Archipelago Severnaya Zemlya and on Ostrov Vrangel' during the spring of 1985, 1986, 1988, and 1989. The average concentrations of most elements and their enrichment ratios (compared with the composition of the earth's crust) agree with the published data. The high values of these parameters for gold and silver in the aerosol from Archipelago Severnaya Zemlya as well as the back-traced trajectories of long-range transport of air masses indicate that the atmosphere in the central Arctic is polluted by industrial emissions from the territory of Northeastern Europe. Correlation analysis of the data revealed two groups of strongly correlated elements, whose sources could be of the same nature or they are simply located in the same territory. The characteristics of the aerosol investigated (ratios of the concentrations of the elements) are compared to the composition of the emissions of a number of industrial regions. Factor analysis of the data revealed three groups of elements: terrogenic (Fe, Al, Mn), oceanic (Na, Cl, Br), and anthropogenic, whose sources could be thermal and electric power plants (Co, Sb) or smelters (Sb, Zn).

It can now be considered as proven that a large amount of chemicals produced by anthropogenic activity at middle latitudes of the northern hemisphere accumulate in the Arctic atmosphere during the winter-spring period [1, 2]. In addition, for a number of reasons, the contributions of Asia, Europe, and North America to the total content of anthropogenic elements in the Arctic atmosphere are approximately in the ratio 60:30:10, respectively. In spite of the fact that the Arctic coast of Russia comprises half of the entire coast of the northern Arctic Ocean, there is virtually no data on the level of aerosol pollution of the atmosphere in these regions. This limits the possibility of interpreting the results obtained by non-Russian authors and makes it difficult to solve different types of problems (climatic, ecological, etc.) associated with the pollution of the atmosphere in the entire Arctic region.

This work is a continuation of the studies indicated on Ostrov Vrangel' and the Archipelago Severnaya Zemlya in 1984 [3, 4]. We present here the results of systemization of data on the elemental composition of the surface aerosol, samples of which were collected at these points during the spring of 1988 and 1989. We focus our attention mainly on the absolute concentrations of different elements, their variability in time, the observation of some correlations between the elements, and a discussion on their possible origin on the basis of trajectory analysis. The possibilities of identifying the sources and paths of long-range transport of pollutants in the Arctic by the method of factor analysis of the elemental composition of aerosol samples are also discussed.

AEROSOL SAMPLING

Samples of atmospheric aerosol were obtained at an elevation of 1.5 m from the earth's surface by pumping air (up to 2000 m^3) through AFA-KHA-20 filters or Whatman drawing paper. The specific sampling periods and the number of samples for different points are indicated in Table 1. The collection period for one sample ranged from 1 to 10 days, depending on the purity of the air and the meteorological conditions. The content of different elements was determined by the method of neutron-activation analysis* in the filters, after which the absolute concentrations of these elements in the air were calculated. It should be noted that a complete set of concentrations of all elements studied was not obtained for any sample. This is because information is lost because of the small surface area of the filter (the content of a number of elements did not exceed the limit of sensitivity of the apparatus) or because of large measurement errors owing to strong contamination of the Russian AFA-KHA filter material.

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*The analysis was performed at the Affiliate of the L. Ya. Karpov Scientific-Research Institute of Physical Chemistry.

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IMPACT OF THE SULPHUR DIOXIDE SOURCES IN THE KOLA PENINSULA ON AIR QUALITY IN NORTHERNMOST EUROPE

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Abstract—An account is presented of sulphur pollution in northernmost continental Europe, based on analysis of recent observations and on dispersion model calculations. To complement the routine daily observations made at background stations, SO_2 has also been measured using an hourly registering monitor at Jäniskoski in the Russian Kola Peninsula. Sulphur dioxide emissions from the Kola Peninsula, totalling 600 Gg (10^3 tonnes) yr^{-1}, have a dominant impact on SO_2 concentrations and S deposition over large areas, producing an environmental load exceeding the thresholds for potential detrimental effects. The major part of these emissions is produced by two non-ferrous smelters. Due to these sources, SO_2 concentrations vary considerably within the study area, from the low "remote background" values to pollution episodes with $\sim 100\ \mu g(SO_2)\ m^{-3}$ as an hourly average, depending on wind direction. High concentrations also occur in summer, providing a great potential for dry deposition and suggesting that exposure is a highly episodic process. On an annual basis, dry deposition predominates over wet deposition. Precipitation acidity is related mainly to sulphate, and neutralization by alkaline cations is exceptionally low in the north. According to model calculations, a potentially critical deposition of 0.3 $g(S)\ m^{-2}\ yr^{-1}$ is exceeded over an area of 150,000 km^2, 32,000 km^2 of which are in Finland and 19,000 km^2 in Norway. Within this area the contribution of smelter emissions to sulphur deposition ranges from 40% to almost 100%.

Key word index: Arctic pollution, Russian pollution, sulphur emissions, sulphur dioxide, sulphate, acid precipitation, sulphur deposition, dispersion modelling.

1. INTRODUCTION

The opening-up of the former Soviet Union has revealed major environmental problems, which also exist in the vicinity of its western borders. Until 1988 environmental data and related information were defined as classified (Gasilina *et al.*, 1991), and freely published data on atmospheric emissions were of a highly aggregated nature, and those on air quality very limited. Typically, only the total emissions from the whole European U.S.S.R. and measurements from a few background stations were provided for international projects. Active international co-operation is now needed in order to update our knowledge, and also to support the solving of consequent problems, many of which have both local and regional, and even global significance.

One example of local disaster-scale problems is the air pollution caused by the metallurgical complexes situated in the Kola Peninsula in Arctic Russia in the neighbourhood of northern parts of the Scandinavian countries. The total sulphur dioxide emissions in the Kola Peninsula alone exceed the total sum of those in Finland, Sweden and Norway, and the discharge of heavy metals is also huge. Expressively, the state of the environment around the main sources has been termed a "technogenic wasteland" by local scientists (e.g. Kryuchkov, 1990). A great concern for nature, and even for public health, has arisen in Finland and Norway in areas closest to these sources (Tikkanen and Varmola, 1991; Sivertsen *et al.*, 1992).

Arctic Russia also plays an important role in questions concerning the large-scale air pollution in the Arctic, e.g. in an understanding of the origin of arctic haze. Since the advent of the arctic haze concept, arctic air pollution studies have focused mainly on the long-range transport of pollutants and the behaviour of particulate matter, as reviewed by Barrie (1986) and Heintzenberg (1989). In the present study we shall characterize the regional sulphur pollution on the fringes of the Arctic and estimate the influence of large localized SO_2 sources, emphasizing the importance of gaseous pollution. We report on the latest data on the sulphur emissions in the Kola Peninsula and other parts of Russia, and on measured concentrations and the deposition of sulphur species in northernmost

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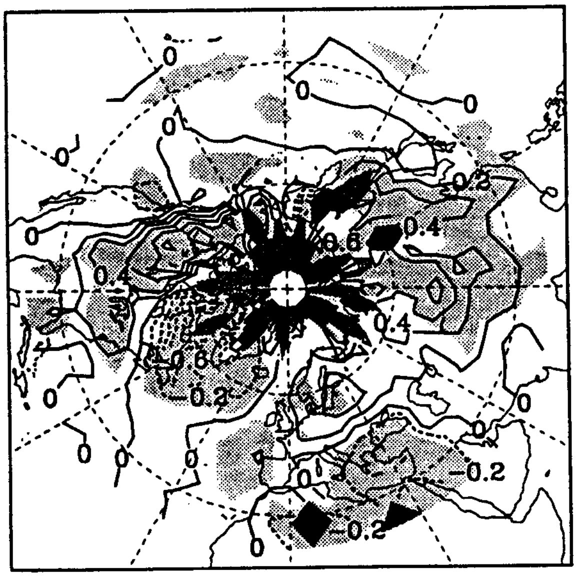

Observed Surface Air Temperature Trends
$\overline{\text{DJF}}$ 1957/58-1991/92 [K/dec]

RECENT NORTHERN WINTER CLIMATE TRENDS DUE TO OZONE CHANGES AND INCREASED GREENHOUSE GAS FORCING ?

by

HANS-F. GRAF • JUDITH PERLWITZ • INGO KIRCHNER • INGRID SCHULT

HAMBURG, February 1995

Recent Northern Winter Climate Trends due to Ozone Changes and Increased Greenhouse Gas Forcing?

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Abstract

Recently considerable trends in ozone concentration with positive values mainly in the upper troposphere, and decreasing concentrations in the lower stratosphere of the Northern Hemisphere middle and high latitudes were shown (WMO, 1992). The data basis consists approximately of 15 to 20 years of observations at various locations.

These changes are discussed on the background of observed variations of temperature and circulation during the last decades. The observed increased lower stratospheric high latitude westerlies are part of a natural coupled mode of lower stratospheric and tropospheric circulation. This coupled mode has its strongest tropospheric effects over the North Atlantic with increased westerlies, and positive air temperature anomalies over Scandinavia and Siberia. The intensity of the part of this natural coupled mode which is associated with enhanced polar stratospheric westerlies has increased during the last decades. A primary contribution to this intensification due to the low latitude greenhouse-gas effects is suggested. The observed ozone trends when introduced into a General Circulation Model do not produce substantial changes in circulation supporting the initial greenhouse gas effects.

Concluding, a comprehensive climate model including atmospheric chemistry in combination with a good representation of the whole stratosphere is needed to study future climate scenarios. Most possibly greenhouse-gas effects and ozone concentration are not independent.

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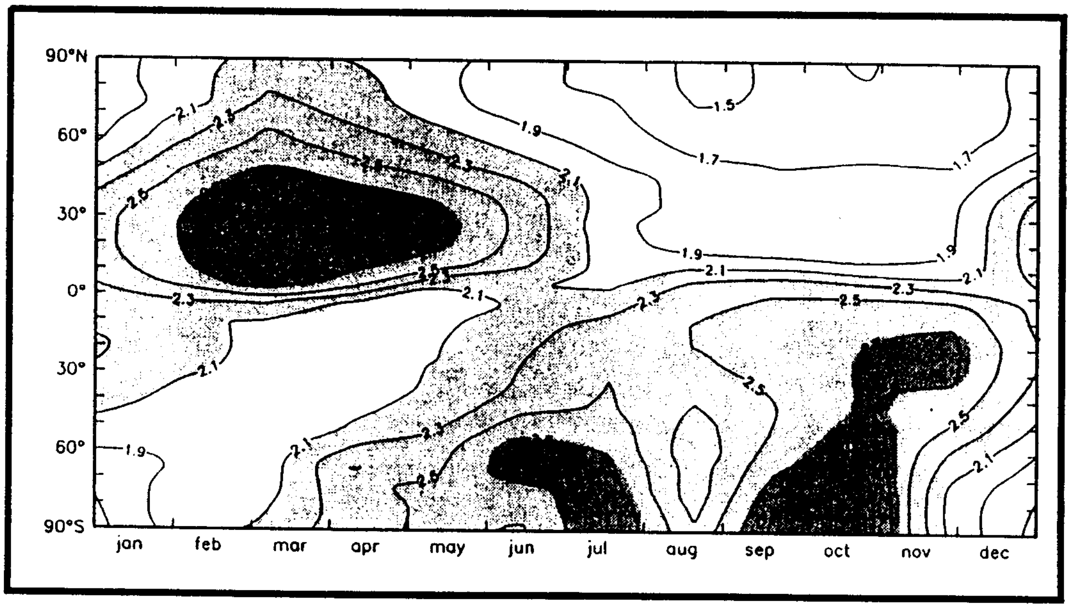

THREE-DIMENSIONAL ATMOSPHERIC TRANSPORT SIMULATION OF THE RADIOACTIVE TRACERS ^{210}Pb, ^{7}Be, ^{10}Be and ^{90}Sr

by

STEFAN REHFELD • MARTIN HEIMANN

HAMBURG, September 1994

Three-dimensional atmospheric transport simulation of the radioactive tracers ^{210}Pb, ^{7}Be, ^{10}Be and ^{90}Sr

by

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b 144

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Abstract.

A global three-dimensional transport model of the atmosphere, having a grid resolution of 7.83° (latitude) x 10° (longitude) x 19 layers in the vertical and driven by ECMWF (European Centre for Medium Range Weather Forecasts) wind field analyses of 1990, is used to simulate the distribution of natural (^{210}Pb, ^{7}Be, ^{10}Be) and artifical (^{90}Sr), radioactive, water-soluble, aerosol-borne tracers. Due to their well known source-sink distribution these tracers build an ideal tool to depict transport processes in the whole atmosphere and to test the models ability of reproducing these. In particular, this paper focuses on mass exchange between stratosphere and troposphere, using the concentration ratio ^{10}Be/^{7}Be as an indicator.

In general, the agreement between observations and model results is quite good, except in polar regions. Modelled arctic ^{210}Pb and ^{7}Be concentrations are overestimated and the annual cycle is underestimated. The modelled antarctic annual cycle of ^{10}Be/^{7}Be shows maxima in winter and spring whereas the observations exhibit a summer maximum. These discrepancies are attributed to deficiencies in ECMWF wind fields, to differences between observed and model used precipitation, and to the employed parameterization schemes of dry and wet deposition which may be inadequate in the cold polar regions.

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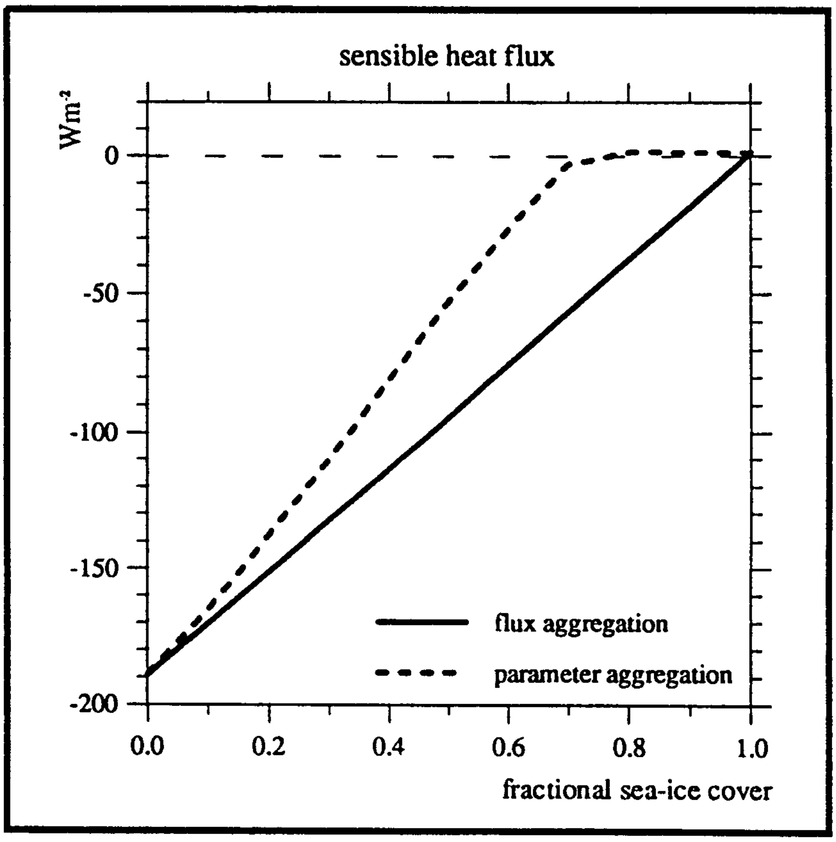

THE IMPACT OF SUB-GRID SCALE SEA-ICE INHOMOGENEITIES ON THE PERFORMANCE OF THE ATMOSPHERIC GENERAL CIRCULATION MODEL ECHAM

by

ANSELM GRÖTZNER • ROBERT SAUSEN • MARTIN CLAUSSEN

HAMBURG, September 1994

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WATER TRACERS
IN THE ECHAM
GENERAL CIRCULATION MODEL

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Abstract

WATER TRACERS IN THE ECHAM GENERAL CIRCULATION MODEL.

A water tracer model has been installed into the ECHAM General Circulation Model (GCM) parametrizing all fractionation processes of the stable water isotopes ($^1H_2{}^{18}O$ and $^1H^2H^{16}O$). A five year simulation was performed under present day conditions. Emphasis is placed on the applicability of such a water tracer model to obtaining information on the quality of the hydrological cycle of the GCM. An analysis of the simulated $^1H^{18}O$ precipitation composition indicates too weakly fractionated precipitation over the Antartic and Greenland ice sheets and too strongly fractionated precipitation over large areas of the tropical and subtropical land masses. It can be shown that these deficiencies are connected with problems of model quantities such as the precipitation and the resolution of the orography. The linear relationship between temperature and $\delta^{18}O$ value, i.e. the Dansgaard slope, is reproduced quite well in the model. The slope is slightly too flat, and the strong correlation between temperature and $\delta^{18}O$ vanishes at very low temperatures compared to the observations.

1. INTRODUCTION

The water isotopes $^1H_2{}^{18}O$ and $^1H^2H^{16}O$ are among the most interesting tracers in climate research. The isotopic water molecules pervade the whole hydrological cycle and undergo fractionation during any evaporation and condensation process. The enrichment in the liquid (or solid) phase relative to the vapour phase depends on temperature, amount of precipitation, relative humidity and many other physical parameters. The relationship between water tracers and climate parameters has been investigated by empirical and theoretical studies [1, 2]. Such studies are usually based on simple Rayleigh precipitation models, and the calculated $\delta^{18}O$ mainly reflects the temperature difference between the sites of evaporation and precipitation.

Recently, isotopically different water tracers have been used to test the hydrological cycle of General Circulation Models (GCMs) [3, 4]. Fractionation processes take place whenever evaporation and condensation occur. Therefore, modelling of water tracers is a good independent test of the hydrological cycle of a GCM, which is probably the most critical process of a climate model. For example, water tracer concentrations transport information on the location and on how precipitation is

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THE COMPONENTS OF THE ARCTIC AEROSOL

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(*First received* 19 *May* 1983 *and received for publication* 8 *September* 1983)

Abstract—Atmospheric aerosol samples have been collected through a year at five locations in Greenland. The samples have been analyzed by PIXE to determine the elemental composition of the Arctic aerosol. The results for one of the stations are described in detail and related to those obtained at the other sites.

Annual and monthly geometric means of the concentrations in the aerosol of the elements Al, Si, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, Br, Sr and Pb are reported. The results have been subjected to factor analyses, which show that the Arctic aerosol can be considered to be composed of at most five different components, the characteristics of which are described. The components consist of three different anthropogenic and a crustal component and, in addition, a sea salt component at sites exposed to open seas within mesoscale distances.

Possible origins of the various components are discussed in view of the seasonal variations of the factor estimates, their statistical independence, and their relation to a selection of synoptic situations. It is concluded that the high Arctic troposphere in winter constitutes a well mixed aerosol reservoir which in most cases masks the origins in distant source areas.

1. INTRODUCTION

In recent years, several investigations of the chemical and elemental composition of the Arctic aerosol have revealed that it contains a sizeable pollution component, particularly during the winter. This pollution is ascribed primarily to very long-range atmospheric transport from midlatitude source regions, the locations of which are still a matter of debate (Rahn and McCaffrey, 1980; Rahn, 1981b; Carlson, 1981) and secondarily to the sparsity of precipitation in the Arctic which increases normal residence times by almost an order of magnitude (Rahn and McCaffrey, 1980).

This paper gives results obtained within the SAGA project, i.e. the Danish programme of Studies of the Aerosol in the Greenland Atmosphere, which is part of the Arctic air-sampling programme, initiated in 1977 (Rahn, 1981a). After a pilot phase in 1978 (Heidam, 1981) the project proper started in August 1979 and has been running until the beginning of 1983.

The results described cover the first year of measurements (1979–1980) at the five stations, THUL, NORD, GOVN, KATO and PCS located as shown in Fig. 1. (THUL should not be confused with Thule Air Base at Dundas about 100 km to the south. MEST was not in operation in 1979–1980.) At these stations membrane filter samples representing about 200 m^3 of air were taken twice a week and shipped to our laboratory for elemental analysis by the PIXE-method. Every tenth filter was not exposed, but used as a blank. Considering the topography of the area, the local winds, exposure to local air pollution, and errors in the procedures of sampling and analysis, NORD was selected as a 'Reference' station as it appeared to entail the smallest errors. Detailed results are given only for this station. For the other stations summaries are given and compared with the data from NORD.

A full report on the SAGA-project, including site descriptions, wind statistics, sampling and analytical techniques and detailed results from all the SAGA-stations obtained during the first year of operation is available on request (Heidam, 1983).

2. GEOMETRIC MEAN CONCENTRATIONS

The determination by PIXE of elements in a filter sample can in most cases be performed with an accuracy of 10–15% and as many as 25 elements may be detected in some samples. In other samples some elements may be below detection limits. The data have been screened as as to retain only those elements present in more than 70–75% of the samples (Heidam 1982, 1983).

The concentrations of these constituents are to a good approximation log-normally distributed (op. cit.) and, therefore, geometric means and standard deviations are reported.

Table 1 lists the annual geometric means and standard deviations for all these elements, identified by their atomic number and chemical symbol, from all stations. It should be noted that for THUL and PCS data cover limited periods only.

In general, the levels on the western coast fall off towards the north, GOVN displaying the highest and THUL the lowest annual levels. On the eastern coast the levels at NORD and KATO are rather similar, lying between THUL and GOVN. Notable exceptions are the metals Cr, Cu, Zn and Pb, which are most abundant at NORD. It is noteworthy that the southern

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CRUSTAL ENRICHMENTS IN THE ARCTIC AEROSOL

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(*First received* 5 *November* 1984, *in final form* 11 *March* 1985 *and received for publication* 31 *May* 1985)

Abstract—Aerosol samples collected at various sites in Greenland for over a year have been analyzed by PIXE to determine the elemental composition. The data have been converted to crustal enrichment factors E using Ti as reference. After a short description of the results of a previous analysis of the total elemental concentrations, annual and monthly means of enrichment factors for the elements Al, Si, S, Cl, K, Ca, Cr, Mn, Fe, Ni, Cu, Zn, Br, Sr and Pb are presented. It is argued that the logarithm of the enrichment factor is a useful statistical measure of excess or non-crustal aerosol and these data are then studied by means of principal factor analyses. It is found that the non-crustal aerosol can be considered to be composed of 2–3 different source-related components that contribute equally to the total variance. One of these is a General Industry component of highly enriched elements that appears to originate in midlatitude regions. It has a pronounced winter maximum and is quite similar to a combustion component of the total aerosol. In the remaining components non-enriched elements are dominant. One of these components appears to be of distant marine origin, whereas the other derives from ferro-metal processes in industrial source areas and has a sharp peak in midwinter.

Key word index: Arctic aerosol, Greenland, enrichment factors, sources, transport, factor analysis.

1. INTRODUCTION

The origins of the Arctic aerosol are now known to extend from distant midlatitude sources to indigeneous sources within mesoscale range. The sources are of both natural and anthropogenic character and their influences in the Arctic vary strongly with the season.

These conclusions have been reached in a number of studies (e.g. AGASP, 1984) and also in the Danish Study of the Arctic Greenland Aerosol (SAGA) (Heidam, 1983, 1984). In the SAGA project, atmospheric aerosol samples were collected twice a week at various sites in Greenland (see Fig. 1) for more than a year and analyzed by PIXE to determine the elemental concentrations in the aerosol.

The above study was concerned with these total concentrations, but it appears that additional information on the composition and origins of the Arctic aerosol can be extracted from the data through a study of the crustal enrichment factors of the elements.

To facilitate a comparison with the new results presented here, a brief summary of the earlier findings will be given. At the Thule site the time series has, however, been extended from 6 to 16 months.

2. CONCENTRATIONS

The samples under consideration were collected in the period August/September 1979–August/September 1980 at the sites NORD, GOVN and KATO and at THUL from February 1980 to May 1981. About 15 different elements were detected regularly above the detection limits.

The elemental composition of the aerosol was studied by means of factor analysis of the logarithmic concentrations (Harman, 1976; Heidam, 1982). The result of the analysis was remarkable. It was found that the atmospheric aerosol in Greenland, sampled at these sites separated by up to 1600 km, can be described by the same 4–5 different source related and statistically independent components. This can be seen in the summary of the factor models shown in Table 1. For each station and each factor or aerosol component the more important elements loaded on that factor are listed. Elements with factor loadings $a^2 > 0.5$ are labelled prominent and those with $a^2 > 0.1$ are labelled weak members of the factors. For weakly coupled elements the dominant membership is listed separately. The remaining elements with statistically significant loadings $a^2 < 0.1$ are called minor members. They are not listed, but if they dominate the loadings of a factor, that factor is labelled minor member collector (MMC).

The temporal behaviour of the components at NORD and THUL is illustrated in Figs 2 and 3 by monthly geometric means of selected prominent member elements. Two of the aerosol components have a natural origin as they consist of a crustal component that derives from erosion processes and a marine component produced by sea spray. They account for 40–60 % of the total logarithmic variance. In winter and early spring the crustal component, represented by monthly geometric means of Ti at NORD and Fe at THUL, appears to have very distant

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