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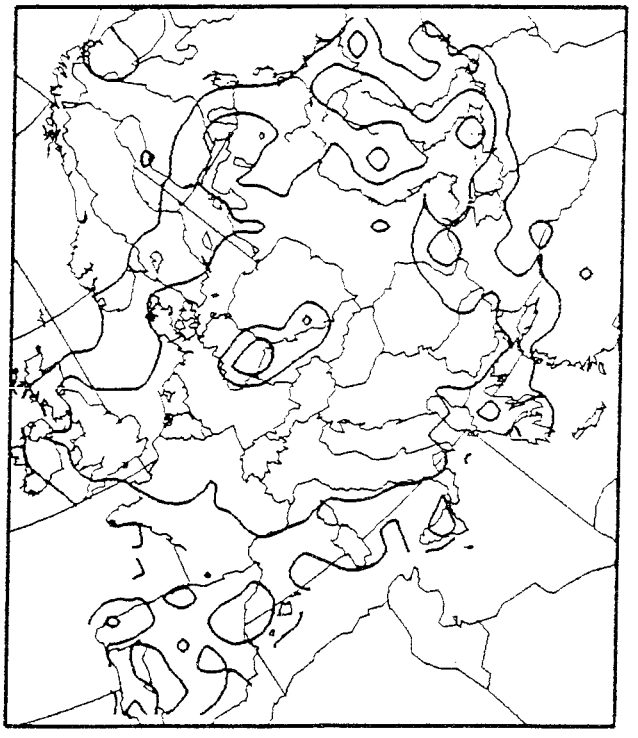
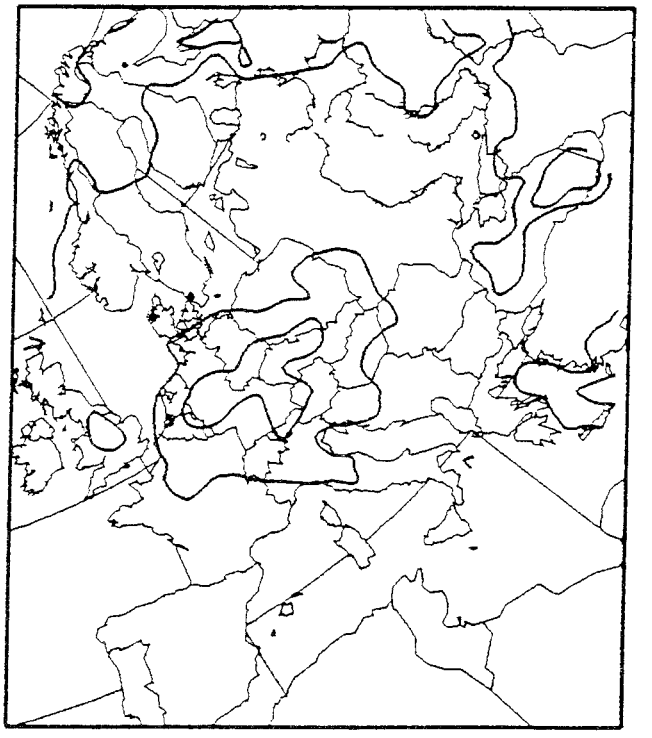
CALCULATED BUDGETS FOR AIRBORNE SULPHUR AND NITROGEN IN EUROPE.

Trond Iversen, Nina E. Halvorsen,
Jørgen Saltbones, Hilde Sandnes.

DET NORSKE METEOROLOGISKE INSTITUTT Technical Report no. 86





MSC-W

METEOROLOGICAL SYNTHESIZING CENTRE - WEST
THE NORWEGIAN METEOROLOGICAL INSTITUTE
P.O.BOX 43-BLINDERN, N-0313 OSLO 3, NORWAY

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PREFACE AND ACKNOWLEDGEMENTS.

This report presents the latest budgets for deposition of sulphur and nitrogen in Europe as calculated with the ten-component model at The Meteorological Synthesizing Centre - West of EMEP. The budgets are updated according to the latest available official emissions by 31. August 1990, and provisional estimates of 1989-budgets are also included. Several changes have been introduced in the modelling compared with the version presented in the 1989-report to the thirteenth session of the Steering Body of EMEP (Iversen *et al.*,1989; EMEP MSC-W Report 2/89). The budgets are now believed to be significantly improved, in particular with respect to the treatment of background concentrations leading to depositions of indeterminate origin. With the new model version we are presently only able to present calculations for 1988 and 1989. Estimated budgets for earlier years made by old model versions, can be found in the 1989-report, or in Iversen (1990) (EMEP MSC-W Report 1/90).

This report also contains an appendix (Appendix B) with country-to-grid square budgets for sulphur, and for oxidised and reduced nitrogen in 1988.

This report is the replacement of the draft report that was presented to the fourteenth session of the Steering Body of EMEP which approved the procedure to submit the final version afterwards, and the main final results to be presented to the eighth session of the Executive Body to the Convention of the Long-Range Transboundary Air Pollution. This delay provided the fortunate circumstance that the calculations now includes new emission data up to 31. August 1990, some even in gridded form, from several countries in Europe. Furthermore, a few adjustments of model parameters have been made since the draft report.

The authors are grateful for valuable suggestions from Professor Anton Eliassen, Professor Øystein Hov, and Mr. David Simpson. Mr.Per Egil Haga has estimated the subgrid scale distribution of precipitation.

The routine activities at MSC-W strongly depend on access to high quality meteorological data. These data are provided by the routine Numerical Weather Prediction model at The Norwegian Meteorological Institute. The data on emissions from ships in international trade have been compiled by MARINTEK, Trondheim, Norway under a contract by The Norwegian State Pollution Control Authority.

The calculation of nitrogen budgets is made possible through access to a supercomputer (CRAY X-MP/28) at the Technical University of Norway, SIMa/RUNIT, Trondheim, Norway.

1. INPUT DATA.

Calculations of air quality and deposition of air pollutants require basic input information of two categories. Data on emissions of pollutants of anthropogenic and natural origin as well as meteorological parameters are necessary in order to calculate concentration levels and deposited amounts. The model calculates approximate solutions to a set of partial differential equations, and includes parameterizations of chemical reactions and physical processes through coefficients which depend on the meteorological and physico-chemical state of the air.

1.1 Emissions.

As far as possible, the emission data employed in the calculations are official data submitted by the countries participating in EMEP. In this context, the attention is drawn to a decision of the fourth session of th Executive Body for the Convention of Long-Range Transboundary Air Pollution (ECE/EB.AIR/10, para. 27(c)), in which the Steering Body of EMEP is invited to calculate estimates of sulphur budgets "*on the basis of preliminary emission data to be provided, if possible, by each Party not later than 1 May of the year following the year for which the calculations are to be made (reference year), and to update these calculations using more accurate data according to article 4 of the 1985 Protocol*[1] *not later than 1 May of the second year following the reference year*". For emissions of other components than sulphur, there has been no agreement on fixed timelimits for submission of official data. However, in Article 8 of the "NOx-protocol"[2] it is stated that "*The Parties shall exchange information by notifying the Executive Body ... , and in particular on: (a) The levels of national annual emissions of nitrogen oxides and the basis upon which they have been calculated;*". Furthermore in Article 9: "*EMEP shall, utilizing appropriate models and in good time before the annual meetings of the Executive Body, provide to the Executive Body calculations of nitrogen budgets and also of transboundary fluxes and deposition of nitrogen oxides within the geographical scope of EMEP*". This implies in practice the same routine for reporting of NOx-emissions as for sulphur-emissions, though it is not explicitely stated. If emission data for some reason are missing, information is sought from available open sources, or estimated as far as possible by MSC-W and CCC (The Norwegian Institute for Air Research) in co-operation.

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[1]The 1985 Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on the Reduction of Sulphur Emissions or their Transboundary Fluxes by at least 30 per cent. (ECE/EB.AIR/12)

[2]The 1988 Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution Concerning the Control of Emissions of Nitrogen Oxides or their Transboundary Fluxes. (ECE/EB.AIR/21)

1.1.1 Sulphur

Table 1 gives the national total emissions for sulphur as they are updated according to official information up to 31. August 1990. For countries that have given data only for a selection of years, linear interpolation has been applied. Linear extrapolation in time has likewise been made when predictions for future years have been provided. This practice is, however, not very satisfactory since some emission projections may be quite uncertain. In the future we will probably avoid using these projections.

In this report we present budget calculations for 1988 and 1989. Up to 31. August 1990, 19 out of 28 countries have given official estimates for 1988, 6 of them in gridded form. Provisional data for 1989 have been provided by 11 countries, 4 in gridded form. However, only one country has never submitted any emission data, and 21 countries have given gridded sulphur emissions for at least one year. In addition to the national land-based emissions, the calculations includes emissions from international trade (shipping), and natural biogenic emissions from the sea. The international ship emissions have been estimated by MARINTEK, Trondheim, Norway on a contract with The Norwegian State Pollution Control Authority, and includes traffic in the Atlantic Ocean (ATL), The North Sea (NOS), and The Baltic Sea (BAS). The data have been transformed into gridded form by MSC-W. The natural sea-emissions (NAT) is a first attempt at including biogenic emissions of dimethyl sulphide (DMS) by the very crude assumption that these produce 2000 tons (SO_2) per gridsquare over sea. It is known that the DMS-emissions have a pronounced variation both geographically and temporally. The scientific knowledge in this field is increasing (e.g. Watts *et al.*, 1990), and we hope to have better estimates in the near future. In Table 4 total emission figures used for biogenic sea-emissions and emissions from international trade are given. Figure 1 shows the gridded emission map for sulphur used for the 1988-calculations of sulphur. The sulphur emissions are multiplied by a factor varying as a sine-function from its maximum 1.33 in January to its minimum 0.67 in July, to adjust for the changing need of heating.

TABLE 1: Emissions of Sulphur Dioxide. Unit: 10^3 tonnes (S) per annum.

			1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990-1995
1	Albania	AL	[25]	[25]	[25]	[25]	[25]	[25]	[25]	[25]	[25]	[25]	
2	Austria	AT	185	160	134	109	91	89	79	68	57	52	47(90)
3	Belgium	BE	414	356	347	280	250	226	237	207	208	209	210(90)
4	Bulgaria	BG	517	535	552	570	558	547	535	535	515	515	
5	Czechoslovakia	CS	1550	1555	1560	1565	1570	1575	1510	1480	1400	1387	1375(90)
6	Denmark	DK	224	182	184	156	148	170	139	125	121	127	133(90)
7	Finland	FI	292	268	244	187	184	191	166	164	151	139	126(90)
8	France	FR	1669	1294	1245	1047	933	735	671	644	608	636	
9	German Dem. Rep.	DD	2132	2158	2775	2318	2519	2670	2679	2803	2629	2621	
10	Germany Fed. Rep. of	DE	1600	1500	1450	1350	1300	1200	1150	1000	650	530	
11	Greece	GR	200	193	187	180	215	250	250	250	250	250	
12	Hungary	HU	816	795	773	752	730	702	685	646	609	542	582(90)
13	Iceland	IS	3	3	3	3	3	3	3	3	3	3	
14	Ireland	IE	110	100	90	80	70	69	75	80	74	91	107(90)
15	Italy	IT	1900	1792	1683	1575	1328	1252	1185	1205	1205	1205	
16	Luxembourg	LU	12	10	8	7	7	8	7	7	6	6	5(90)
17	Netherlands	NL	233	211	189	167	153	138	138	141	139	127	125(90)
18	Norway	NO	71	64	56	52	48	49	45	38	33	33	35(93)
19	Poland	PL	2050	2070	2090	2110	2130	2150	2100	2100	2090	1955	2250(90)
20	Portugal	PT	133	140	146	153	126	99	117	109	102	104	106(90)
21	Romania	RO	100	100	100	100	100	100	100	100	100	100	
22	Spain	ES	1625	1625	1625	1625	1614	1603	1592	1581	1570	1559	1527(92)
23	Sweden	SE	257	226	195	163	132	135	125	110	107	105	102(90)
24	Switzerland	CH	63	59	56	52	48	48	32	35	37	34	31(90)
25	Turkey	TR	138	138	138	138	138	161	177	199	199	199	
26	Soviet-Union *)	SU	6400	6309	6237	5700	5926	5555	5925	5452	5062	4659	4790(90)
27	United Kingdom	GB	2424	2194	2082	1909	1837	1838	1929	1932	1832	1776	1900(90)
28	Yugoslavia	YU	650	650	650	700	725	750	750	775	800	825	
	Sum		25793	24712	24824	23073	22908	22338	22426	21814	20582	19814	

Data that have been officially submitted are underlined. Data estimated by MSC-W/CCC are given in square brackets. The table includes corrections received at the ECE Secretariat up to August 31, 1990. Submitted emission predictions for 1990-1995 are also shown.

*) European part of USSR, within EMEP area of calculation.

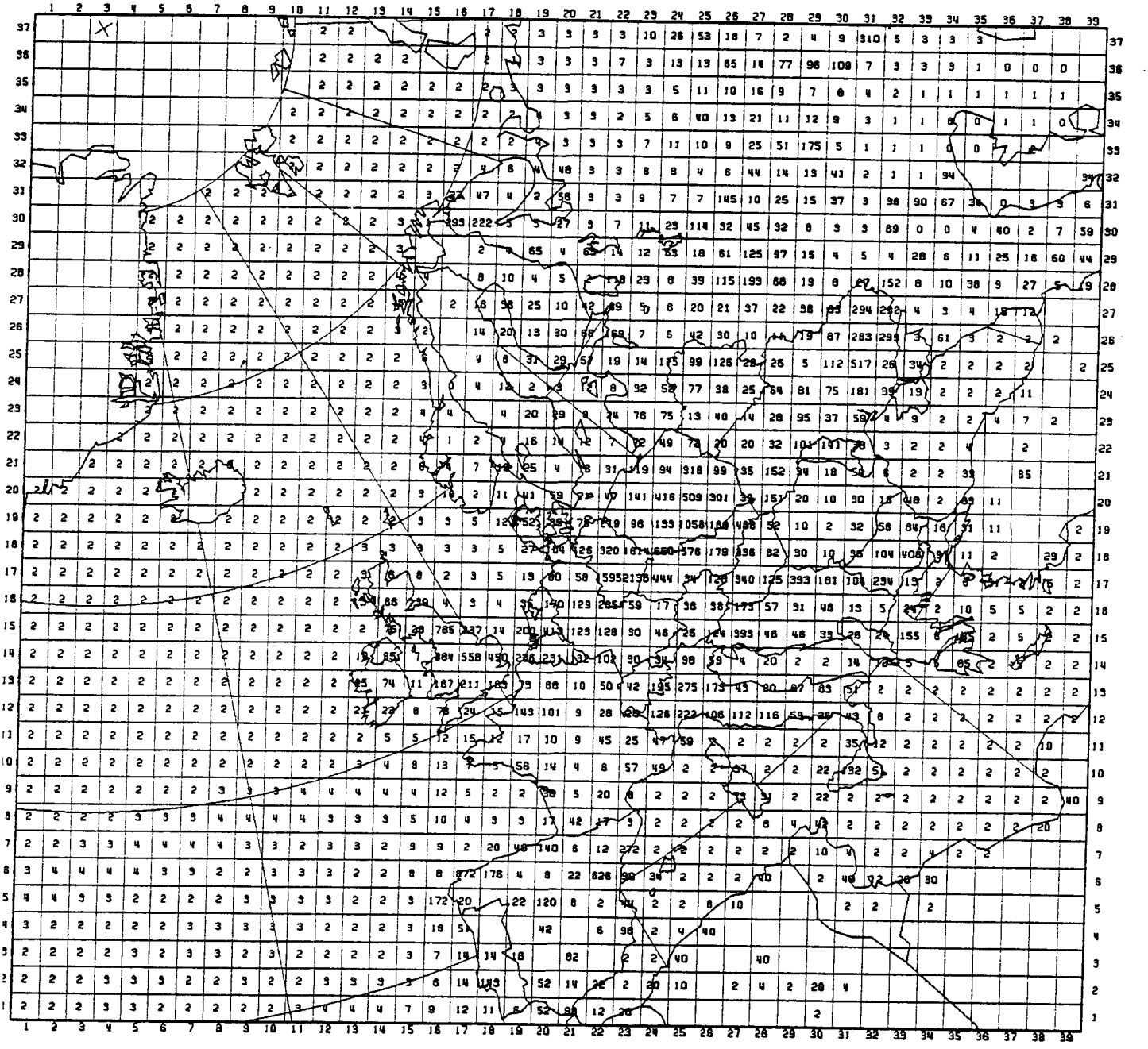

Figure 1. 1988 - emissions of Sulphur Dioxide in each grid square of the EMEP/MSC-W grid for calculations. Unit: 1000 tonnes per annum as SO_2.

1.1.1 Nitrogen

The emissions of nitrogen oxides (NOx = NO + NO_2) are as the sulphur emissions taken from officially submitted data from the countries if such are available. Otherwise, the estimates of Semb and Amble (1981) are used. The budget calculations of nitrogen also require data on emissions of ammonia (NH_3), for which the major source is agricultural activity. Only one country has provided an official estimate such emissions, and that has been given in gridded form. In all other cases the estimates of Buijsman *et al.* (1985) are used (see also Buijsman *et al.*, 1987), but multiplied with a factor 1.2 due to advice from the authors of that report. We hope that more countries will work out national surveys of ammonia emissions in the near future. The emissions of ammonia is assumed to be at its maximum in early summer when the open land is fertilized and at its minimum in winter.

Table 2 shows the status of the emissions of NOx as reported by 31. August 1990. As for sulphur interpolations and extrapolations are made whenever possible. For the years for which calculations are made, the status is that 19 out of 28 countries have given official emissions in 1988 and only 8 countries have given provisional estimates in 1989. 16 countries have given estimates of NOx-emissions in gridded form at least once since 1980. 3 countries have never given any official information on NOx-emissions. Table 3 shows the emissions employed for ammonia in both 1988 and 1989. These emission numbers probably have a large potential for improvement. Figures 2 and 3 shows the gridded emissions used for the 1988 calculations. The part of the NO_x-emissions reported as high emissions are assumed to include stationary sources only, and is supposed to have the same seasonal variation as the sulphur emissions. The lower emissions, being mainly from mobile sources, is not supposed to have seasonal variations.

A substantial part of the NOx-emissions originates from mobile sources. For some countries emissions from domestic ferries, boat traffic and offshore installations are relatively large. As far as known at MSC-W, only one country has included these emissions in its survey. Furthermore, emissions from international shipping is probably more important for NOx than for sulphur, because oxidised nitrogen in its primary phase is almost not water soluble. Therefore the dry and wet deposition over sea is negligible until the NOx is further oxidized to nitrate in any form. It is a hope that more countries will include NOx emissions from domestic boat traffic and other offshore activities, and that further work will be carried out to estimate emissions from international shipping. Table 4 shows the presently used emissions from ships in international trade.

TABLE 2: Emissions of Nitrogen Oxides.
Unit: 10^3 tonnes (NO_2) per annum.

		1985	1986	1987	1988	1989	1990-1995
1	AL	[9]	[9]	[9]	[9]	[9]	
2	AT	230	224	218	212	207	201 (90)
3	BE	281	292	297	298	299	300 (90)
4	BG	150	150	150	150	150	
5	CS	1127	1060	965	950	950	
6	DK	258	266	262	249	252	254 (90)
7	FI	251	256	270	276	282	321 (95)
8	FR	1615	1618	1605	1655	1761	
9	DD	955	955	1001	1008	1005	
10	DE	2950	3000	2900	2850	2729	2000 (95)
11	GR	746	746	746	746	746	
12	HU	262	268	276	259	249	264 (90)
13	IS	12	12	12	12	12	
14	IE	68	74	77	77	93	109 (90)
15	IT	1595	1607	1700	1700	1700	
16	LU	19	19	18	17	16	15 (90)
17	NL	544	551	559	552	552	503 (90)
18	NO	203	222	232	227	226	
19	PL	1500	1530	1520	1550	1480	
20	PT	96	110	116	122	132	142 (90)
21	RO	[390]	[390]	[390]	[390]	[390]	
22	ES	950	950	950	950	950	
23	SE	394	305	301	390	382	373 (90)
24	CH	214	187	191	194	189	184 (90)
25	TR	[175]	[175]	[175]	[175]	[175]	
26	SU	3369	3330	4214	4190	4190	
27	GB	2278	2350	2429	2480	2513	
28	YU	400	420	440	480	480	
	Sum	21041	21076	22023	22168	22119	

Data that have been officially submitted are underlined. Data estimated by MSC-W/CCC are given in square brackets. The table includes corrections received at the ECE Secretariat up to August 31, 1990. Submitted emission predictions for 1990-1995 are also shown.

*)European part of USSR, within EMEP area of calculation.

TABLE 3: Emissions of Ammonia employed for 1988 and 1989. Unit: 10^3 tonnes (NH_3) per annum.

		1988	1989
1	AL	[24]	[24]
2	AT	[85]	[85]
3	BE	[94]	[94]
4	BG	[147]	[147]
5	CS	[200]	[200]
6	DK	129	125
7	FI	43	43
8	FR	[841]	[841]
9	DD	[242]	[242]
10	DE	380	380
11	GR	[112]	[112]
12	HU	[151]	[151]
13	IS	[3]	[3]
14	IE	[139]	[139]
15	IT	[426]	[426]
16	LU	[6]	[6]
17	NL	218	199
18	NO	[41]	[41]
19	PL	[478]	[478]
20	PT	[55]	[55]
21	RO	[350]	[350]
22	ES	[273]	[273]
23	SE	[62]	[62]
24	CH	61	61
25	TR	[699]	[699]
26	SU	[3180]	[3180]
27	GB	[478]	[478]
28	YU	[235]	[235]
	Sum	9152	9129

TABLE 4: Emissions of SO_2 and NOx from ships in international trade, and biogenic emissions from sea. (Unit: 10^3 tonnes per annum SO_2 or NO_2 as appropriate).

Emission Origin		SO_2	NO_2
BAS	Baltic Sea	[73]	[80]
NOS	North Sea	[173]	[192]
ATL	Rem. Atl. Ocean inside calc.-area	[317]	[349]
MED	The Mediteranian	[12]*	[13]*
BLS	Black Sea	no data	no data
NAT	Biogenic sea emission	[1510]	[0]

* Data only close to Gibraltar, otherwise no data.

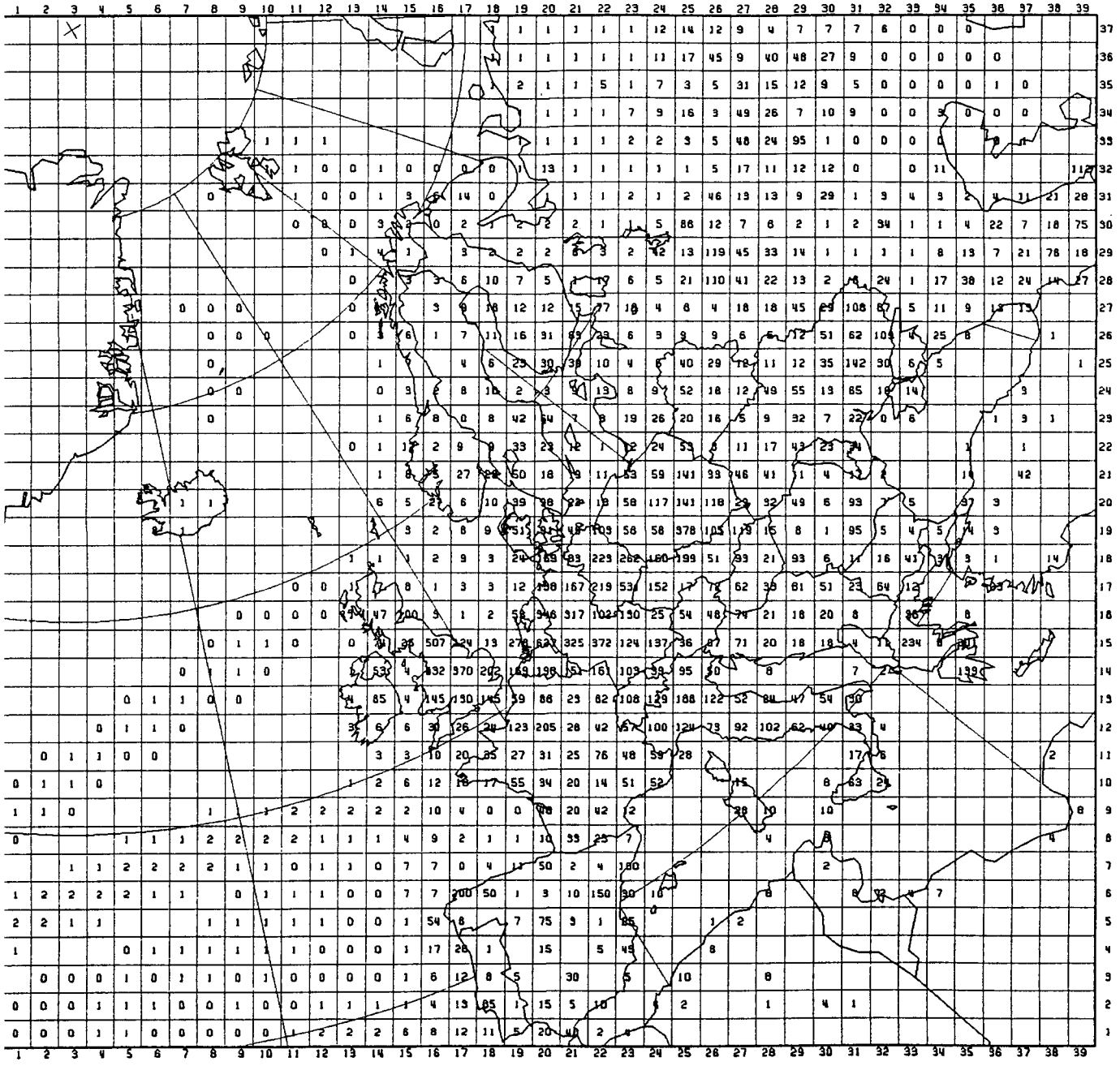

Figure 2. 1988 - emissions of Nitrogen Oxides in each grid square of the EMEP/MSC-W grid for calculations. Unit: 1000 tonnes per annum as NO_2.

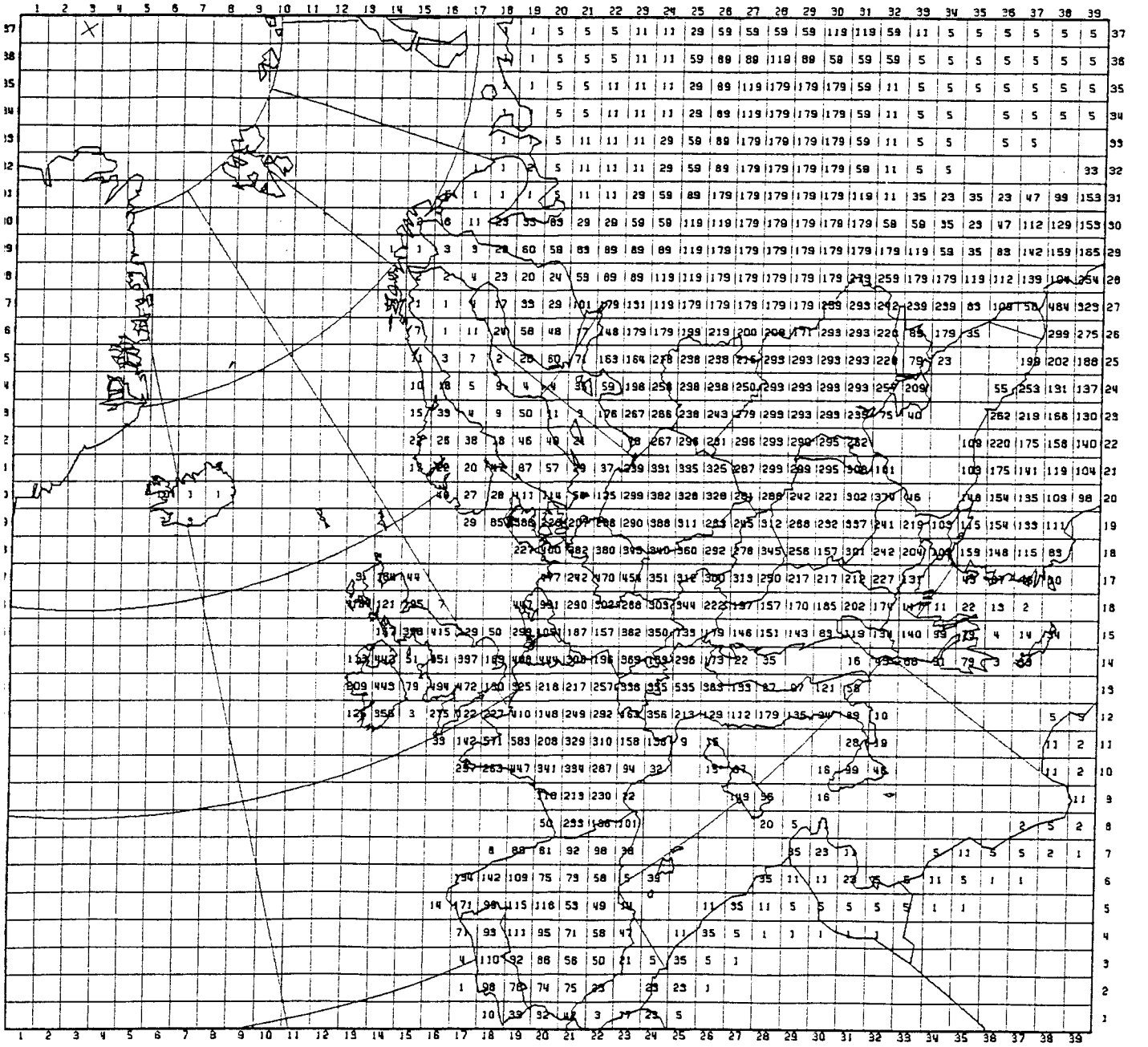

Figure 3. Emissions of Ammonia in each grid-square of the EMEP/MSC-W grid for calculations. Unit: 100 tonnes per annum as NH_3.

1.2 Meteorological Data.

Despite being only a one layer model, the dispersion model requires input of a considerable amount of meteorological data. The main reason for this is the ambition of using actual meteorological data rather than long term climatological information that necessarily must encompass large variabilities in the parameters, and concequently in the coefficients of the equations. Long term, statistical modelling gives with relatively modest resources, semi-quantitative information which may support the development of conceptual ideas on causal questions. In the problem area of "acid rain" such calculations were helpful in the early stage in order to check the possibilities for atmospheric long range transmission of air pollutants (Rodhe, 1972; Bolin and Persson, 1975). Later such models have been used to give a first estimate of long-term behaviour (Venkatram *et al.*, 1982), or as research tools to test complex chemical schemes (e.g. "The Harwell Model", Derwent and Nodop, 1986) or possibilities for transport pathways not considered earlier (e.g. Whelpdale *et al.*, 1988). In order to calculate budgets of deposition allocated to known emission areas, one must design models which have a fair chance to reproduce day to day variations. This is particularly important for components that are water soluble and can be wet deposited by precipitation. Long term, climatic models involving averaged meteorological parameters often oversimplifies this process so that it becomes purely diffusive, while it in reality leads to systematic accumulations. The investigation by Mylona (1989) revealed that interannual variations in meteorological data cause changes in the concentration levels of the same size as reported emission reductions. This interannual variability is not taken into account when climatological data are used. Other sources of systematic errors in climatological models are connected with the process of making long term averages. For example taking the time-averaged wind in each point in space (Eulerian mean) does not produce winds that are representative for the mass transport of atmospheric tracers.

There is a balance between the degree of detail that is necessary to include in the model and the quality of input data. The present routine dispersion models at MSC-W is aimed at describing the transport after the emitted pollutants have had time to mix evenly in the atmospheric boundary layer, but before significant mixing into the free troposphere above has taken place. This is supposed to be more or less valid for transport distances from a few hundred to a few thousand kilometers, and concentrations averaged over 1-2 days are representative measures. Presently the models take meteorological information every 6 hours with a spatial resolution of 150 km. This is in fair accordance with the required accuracy as described above.

The meteorological data needed are summarized in Table 5. Most of the data are taken from the Numerical Weather Prediction model in routine at The Norwegian Meteorological Institute. Through four-dimensional data assimilation such a routine combines, in an optimal way, meteorological observations with short term model predictions (Hollingsworth, 1987). Thus, observations are included in a way that does not counteract the physical laws of nature. The NWP model is formulated in terrain-following "σ-coordinates". It carries prognostic equations for surface pressure, wind, temperature, water

TABLE 5: Meteorological data presently used for routine dispersion modelling at MSC-W of EMEP.

Physical Parameter	Level	Period between Input	Purpose	Source
v Advection wind	σ=0.925 z≈750m	6 hours	Horizontal transport, trajectories.	NWP-model
H_M Height of mixed layer	above ground	24 hours (12 GMT)	Initial dilution of emissions.	Analysed observations
P Grid element average precipitation	ground	6 hourly accumulated	Wet deposition.	Ocean: NWP-m. Land: An. Obs.
w Vertical velocity	σ=0.85 z≈1500m	6 hours	Free troposphere exchange.	NWP-model
p_s Ground surface pressure	σ=1 (ground)	6 hours	Air density at ground surface	NWP-model
T_2 Temperature in ground air	z = 2m	6 hours	Aerodynamic resistance to dry dep.	NWP-model
τ Turbulent stress	Surface layer	6 hours	Aerodynamic resistance to dry dep.	NWP-model
H_d Turbulent heat flux-density	Surface layer	6 hours	Aerodynamic resistance to dry dep.	NWP-model
C Cloud cover	Free troposphere	6 hours	Photolysis rate of NO_2.	NWP-model
T Temperature in mixed layer	σ=0.925	6 hours	Chemical reaction rates	NWP-model
U Relative humidity	σ=0.925	6 hours	Ammonium nitrate equilibrium	NWP-model

vapor and liquid water, and a diagnostic equation (the hydrostatic equation) for the height of the coordinate surfaces. In the version employed in the EMEP work, it is run with 150 km grid resolution with the EMEP grid as a subgrid. The model has 10 layers in the vertical, and includes a physical package with turbulent diffusion in the atmospheric boundary layer, stratiform and convective precipitation, and short- and long-wave radiation. The data assimilation cycle is 6 hours, and geopotential height, horizontal wind, and relative humidity is analysed from observations. More information about the NWP model is given by Grønås and Hellevik (1982), Grønås and Midtbø (1986) and Nordeng (1986). In addition to the fields from the NWP model, the dispersion model employes fields for the height of the daytime well mixed layer analysed from vertical soundings every 1200 GMT. In Europe this approximates the afternoon maximum mixing height. Furthermore, since quantitative precipitation still is connected with considerable uncertainties, six-hourly precipitation amounts are analysed from observations over continental regions. Over oceans, however, model estimates are fully used.

2. MODEL FORMULATION AND EVALUATION.

The model calculates concentrations averaged over the well mixed layer. Thus it is a one-layer model, and it calculates the horizontal transport by the Lagrangian approach. The mass balance for pollutants is calculated for air parcels following the motion along air pathway trajectories. The model is receptor oriented, trajectories that are four days long and end up in a selected set of receptor points every six hours are used. Points along the trajectories are determined with two-hourly intervals, hence each trajectory is defined by 49 points in space. The algorithm used for trajectory calculation given the horizontal wind is taken from Petterssen (1956), and is also summarized in the report of the OECD-project (OECD, 1979). Presently there are 1170 arrival points, 147 are measurement sites in Europe while 1023 are points in a rectangular grid of size 33 times 31 with resolution 150 km. There are 10 chemical components in the model (NO, NO_2, PAN, HNO_3, NO_3^-, NH_4NO_3, NH_3, SO_2, $SO_4^=$, ($(NH_4)_2SO_4$ + NH_4HSO_4)/2 $\equiv$ $(NH_4)_{1.5}SO_4$), and concentrations and depositions are allocated to 38 emission areas. In Figure 4 the chemical scheme is outlined. The present version of the model uses about 36 CPU hours on the CRAY X-MP/28 to produce a budget for a total year.

Several changes have been introduced as compared with the version described as the Nitrogen Model in Iversen *et al.* (1989). Of particular importance is the inclusion of sub-grid scale effects of the precipitation scavenging which permits somewhat longer transport distances for pollutants that are scavenged. Furthermore, the treatment of background concentrations is changed and as far as possible taken from measurements. The ozone concentration which is an input parameter has been adjusted to fit better with known measurements. Emissions from ships in international trade has been included as mentioned in Chapter 1. Finally, several minor changes of technical nature have been made in the programme code.

2.1 Equations.

All concentations are assumed to be given as number densities with unit molecules/cm^3. The number density of a calculated chemical component is denoted by its chemical symbol within a square bracket. The rate of change of a variable q with respect to time experienced in an air parcel, is denoted by the material derivative Dq/dt:

$$\frac{Dq}{dt} = \frac{\partial q}{\partial t} + \mathbf{v} \cdot \nabla q \, , \qquad (1)$$

where t is time, $\partial q/\partial t$ is the partial derivative, $\mathbf{v}$ is the horizontal advection wind ($\mathbf{v}=u\mathbf{i}+v\mathbf{j}$), and ∇ is the horizontal gradient ($\nabla q=\mathbf{i}\partial q/\partial x + \mathbf{j}\partial q/\partial y$). In the following, the height of the air parcel is denoted by h, emissions by Q, dry deposition speed by v_d, wet scavenging ratios by Λ, chemical reaction coefficients by k, and photolysis rates by J. Subscripts are added to this notation to signify components and processes. Concentrations of components that are not calculated but given as external parameters are underlined and not put in square brackets.

All continuity equations for components which are not wet scavenged, are in the following standard form:

$$\frac{Dq}{dt} = - \kappa_d \, q + A \, , \qquad (2)$$

where the decay coefficient in general can be written as $\kappa_d = v_d/h + k_i$, and the inhomogeneous term as $A = Q/h + k_j p$, where p is the number density of any of the 10 components except q. Assuming a time-step Δt short enough to approximate κ and A as constants over the interval $[t,t+\Delta t]$, the solution is

$$q(t+\Delta t) = \frac{A}{\kappa_d} + \left[q(t) - \frac{A}{\kappa_d} \right] \exp(-\kappa_d \, \Delta t) \qquad (3)$$

where q is the number density of the component in question. The model employes a time step of Δt=15 min.

For components that are washed out by precipitation, the sub-grid scale distribution of the precipitation is taken into account. Depending on the total grid square averaged precipitation amount P, the probability of being hit by precipitation when P>0 is ϕ. Thus, even if P>0, a part $(1-\phi)$ of the grid square is not hit by precipitation, and pollutants in that part will not be depleted due to wet scavenging. This therefore will extends the possible transport length of pollutants being washed out by precipitation. In section 2.4 this is outlined in further detail.

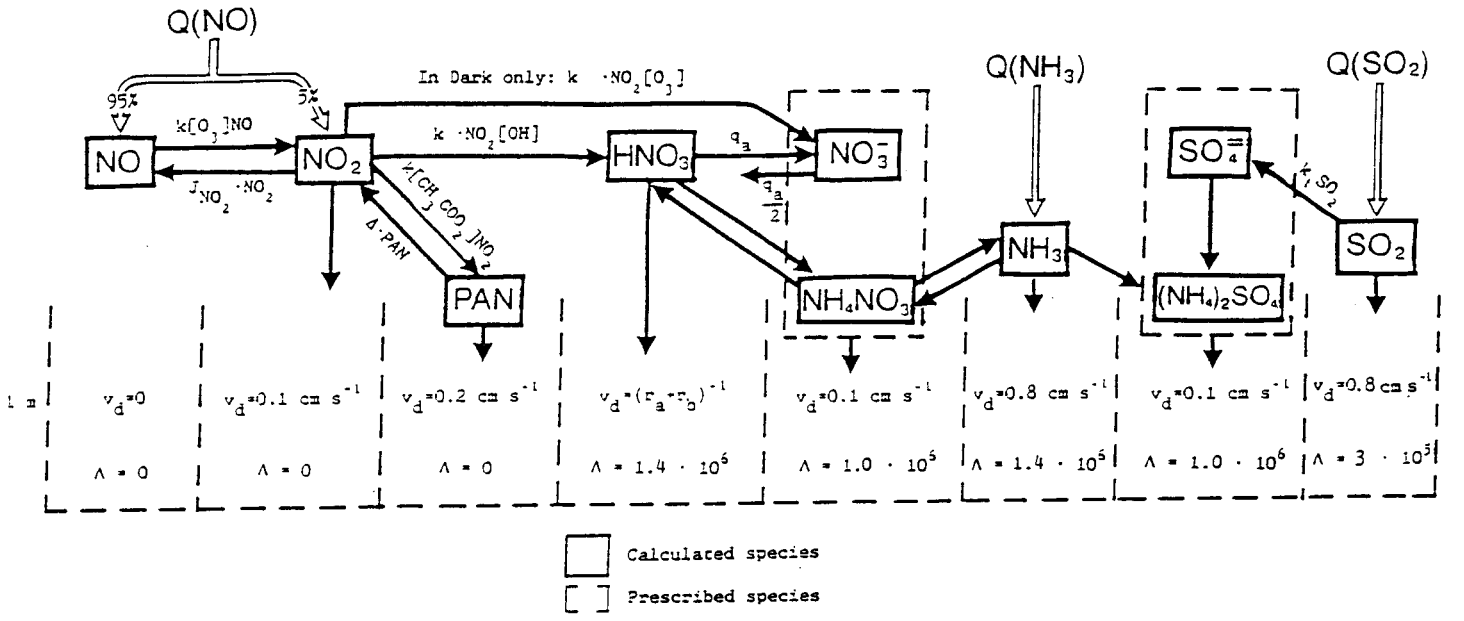

Figure 4. Overview of the chemical scheme. The 10 components inside solid boxes are calculated by the model. Species denoted in brackets are prescribed. The two dashed boxes denote nitrate and sulphate particles, which both occur in two different forms in the model.

The continuity equations for components that are scavenged by precipitation can be summarized in a standard form:

$$\frac{D^2q}{dt^2} + (\kappa_d+\kappa_w)\frac{Dq}{dt} = - \kappa_d\kappa_w\, q + [\phi\, \kappa_d + (1-\phi)\, \kappa_w]\, A \qquad (4)$$

where D^2q/dt^2 is the second order individual derivative, κ_d and A are as above, and $\kappa_w = \kappa_d+\Lambda P/(\phi h)$. If, as above all coefficients are assumed constant over $[t,t+\Delta t]$, the solution is

$$q(t+\Delta t) = \phi \left[\frac{A}{\kappa_w} + \left(q(t) - \frac{A}{\kappa_w} \right) \exp(-\kappa_w\, \Delta t) \right]$$

$$+ (1-\phi) \left[\frac{A}{\kappa_d} + \left(q(t) - \frac{A}{\kappa_d} \right) \exp(-\kappa_d\, \Delta t) \right] . \qquad (5)$$

In the following, values for the coefficients are given for each component. Table 6 defines all the important parameters that enter into the model equations.

2.1.1 Nitrogen Monoxide, NO

NO is neither wet nor dry deposited. The time-integration follows Eq. (3), with $q = [NO]$.

$$A(NO) = (1-\varepsilon)Q_{NOx}/h + J_{NO2}[NO_2]$$
$$\kappa_d(NO) = k_{11}\underline{O_3} \tag{6}$$

2.1.2 Nitrogen Dioxide, NO_2

Nitrogen dioxide is not wet scavenged, and the time-evolution is described by Eq. (3), with $q = [NO_2]$.

$$A(NO_2) = \varepsilon(1-\gamma)Q_{NOx}/h + k_{11}\underline{O_3}[NO] + \Delta[PAN]$$
$$\kappa_d(NO_2) = J_{NO2} + k_{21}\underline{OH} + k_{77}\underline{CH_3COO_2} + 2k_{12}\underline{O_3} + v_{dNO2}/h \tag{7}$$

2.1.3 Nitric Acid, HNO_3

Nitric acid in the gas phase is efficiently dry and wet scavenged, and the time-evolution is described by Eq. (5), with $q = [HNO_3]$.

$$A(HNO_3) = k_{21}\underline{OH}[NO_2] + (q_a/2)[NO_3^-]$$
$$\kappa_d(HNO_3) = q_a + v_{dH}/h \tag{8}$$
$$\kappa_w(HNO_3) = \kappa_d(HNO_3) + \frac{\Lambda_H P}{\phi\, h}$$

The solution of (5) with these parameters does not contain all processes involving HNO_3. The obtained concentration can be further modified by an equilibrium reaction between HNO_3, NH_3 to form or dissolve NH_4NO_3. This process is described in section 2.2.

2.1.4 Peroxyacetyl Nitrate, PAN

PAN is not wet scavenged, and the time-evolution is described by Eq. (3), with $q = [PAN]$.

$$A(PAN) = k_{77}\underline{CH_3COO_2}[NO_2]$$
$$\kappa_d(PAN) = \Delta + v_{dP}/h \tag{9}$$

TABLE 6: Definition of parameters in the equations.

Symbol	Definitions, references, values
A: EMISSIONS	
Q_{SOx}	Emission of sulphur oxides (SO_x) per unit area and time; section 1.1.1; Seasonal sine-variation imposed by a factor: max=1.33 (Jan.), min=0.67 (July)
α	fraction of SO_x-emission deposited locally in emission grid square; α=0.15;
β	fraction of SO_x emitted directly as particulate sulphate; β=0.05;
Q_{NOx}	Emission of nitrogen oxides (NO_x) per unit area and time; section 1.1.2; Seasonal sine-variation, stationary part only: max=1.33 (Jan.), min=0.67 (July)
γ	fraction of NO_x-emission deposited locally in emission grid square; γ=0.04;
ε	fraction of NO_x emitted as NO_2; ε = 0.05;
Q_{NH3}	Emission of ammonia per unit area and time; section 1.1.2; Seasonal sine-variation imposed by a factor: max=1.30 (June), min=0.70 (Jan.)
ϖ	fraction of NH_3-emission deposited locally in emission grid square; $\varpi=\varpi_w+\varpi_d$; ϖ_d=0.19, $\varpi_w=\varpi_d \cdot P/[P+(v_{dNH}/\Lambda_{NH})]$; $\varpi_{max}=2\varpi_d$;
B: PRESCRIBED FIELDS	
O_3	prescribed ozone concentration (Isaksen and Hov, 1987; Logan, 1985); section 2.3;
OH	prescribed hydroxyl concentration (Isaksen and Hov, 1987); section 2.3;
CH_3COO_2	prescribed peroxyacetyl radical concentration (Isaksen and Hov, 1987); section 2.3;
C: CHEMISTRY	
J_{NO2}	dissociation rate for the reaction $NO_2 + h\nu \rightarrow NO + O$, calculated as a function of latitude, time of year, local time, and cloud cover (a complete cloud cover will reduce J_{NO2} by 50%); $J_{NO2} = a(1-C/2)\exp(-b \sec\theta)$; a=0.01$s^{-1}$, b=0.39, C is fractional cloud-cover, and θ is the sun's zenit angle;

continued next page

TABLE 6: (continued).

Symbol	Definitions, references, values
C: CHEMISTRY (continued)	
k_{11}	speed of reaction $NO + O_3 \rightarrow NO_2 + O_2$; $k_{11} = a_{11} \exp(-b_{11}/T)$; $a_{11}=2.1\cdot10^{-12}$ $cm^3s^{-1}molecule^{-1}$, $b_{11}=1450$ K.
k_{12}	speed of net model reaction $2\ NO_2 + O_3 + H_2O \rightarrow 2\ NO_3^- + 2\ H^+ + O_2$ which only takes place in darkness according to the following steps: $NO_2+O_3\rightarrow NO_3+O_2$; $NO_3+NO_2\leftrightarrow N_2O_5$; $N_2O_5+H_2O\rightarrow 2NO_3^-+2H^+$. The first step is assumed rate determining for the net reaction. $k_{12}=a_{12} \exp(-b_{12}/T)$; $a_{12}=1.2\cdot10^{-13}$ $cm^3s^{-1}molecule^{-1}$, $b_{12}=2450$ K.
k_{21}	speed of model reaction $NO_2 + OH \rightarrow HNO_3$; $k_{21}=1.1\cdot10^{-11}$ $cm^3s^{-1}molecule^{-1}$.
k_{77}	speed of model reaction $NO_2 + CH_3COO_2 \rightarrow PAN$; $k_{77}=3.2\cdot10^{-12}$ $cm^3s^{-1}molecule^{-1}$.
k_t	oxidation rate of SO_2 + (oxidant) $\rightarrow SO_4^=$, where (oxidant) is OH in the gas phase or H_2O_2 and O_3 in the liquid phase; this model reaction parameterizes all possible oxidation pathways of SO_2, and takes indirectly into account the photo-chemical activity creating oxidants as well as occurrence of cloud droplets in which liquid phase oxidation takes place efficiently; $k_t = a_t + b_t\sin[2\pi(\tau-\tau_0)/\tau_a]$, $a_t=3\cdot10^{-6}s^{-1}$, $b_t=2\cdot10^{-6}s^{-1}$, τ=time of year, τ_0=80days, τ_a=1year;
Δ	speed of thermal decomposition of PAN; $\Delta=a_\Delta \exp(-b_\Delta/T)$; $a_\Delta=7.94\cdot10^{14}s^{-1}$, $b_\Delta=12530$ K;
q_a	speed of gas-to-particle reaction $HNO_3 \rightarrow NO_3^-$; $q_a=10^{-5}s^{-1}$; the backward reaction (particle-to-gas) is supposed to half of that speed;
D: DEPOSITION AND SCAVENGING	
(i) gases:	
v_{dNO2}	dry deposition speed of NO_2; over water $v_{dNO2}=0$, over land it varies with season and latitude with max value $v_{dNO2}(max)=0.1$ cm/s at height 1 m; the model uses the value at 50 m, see section 2.2.4;
v_{dP}	dry deposition speed of PAN; over water $v_{dP}=0$, over land it varies with season and latitude with max value $v_{dP}(max)=0.2$ cm/s at height 1 m; the model uses the value at 50 m, see section 2.2.4;
v_{dH}	dry deposition speed of HNO_3; over the whole area $v_{dH}=4.$ cm/s at the surface ($z=z_0$=roughness length); the model uses the value at 50 m, see section 2.2.4;

continued next page

TABLE 6: (continued).

Symbol	Definitions, references, values
D: DEPOSITION AND SCAVENGING (continued)	
Λ_H	wet scavenging ratio for HNO_3; $\Lambda_H=1.4\cdot10^6$;
v_{dNH}	dry deposition speed of NH_3; over water $v_{dNH}=0.8$ cm/s at height 1 m; over land it varies with season and latitude with max value 0.8 cm/s at height 1m; the model uses the value at 50 m, see section 2.3.4;
Λ_{NH}	wet scavenging ratio for NH_3; $\Lambda_{NH}=1.4\cdot10^6$;
v_{dq}	dry deposition speed of SO_2; over water $v_{dq}=0.8$ cm/s at height 1 m; over land it varies with season and latitude with max value 0.8 cm/s at height 1m; the model uses the value at 50 m, see section 2.2.4;
Λ_q	wet scavenging ratio for SO_2; the value is supposed to vary with season to account for variations in H_2O_2; $\Lambda_q=3\cdot10^5 + 1\cdot10^5 \sin[2\pi(\tau-\tau_0)/\tau_a]$ see note on k_t in this table;
(ii) particles	
v_{dN}	dry deposition speed of NO_3^- and NH_4NO_3; over the whole area $v_{dN}=0.1$ cm/s;
Λ_N	wet scavenging ratio for NO_3^- and NH_4NO_3; $\Lambda_N=1.0\cdot10^6$;
v_{ds}	dry deposition speed of $SO_4^=$ and $(NH_4)_{1.5}SO_4$; over the whole area $v_{ds}=0.1$ cm/s;
Λ_s	wet scavenging ratio for $SO_4^=$ and $(NH_4)_{1.5}SO_4$; $\Lambda_s=1.0\cdot10^6$;

2.1.5 Particulate Nitrate, NO_3^- (not including ammonium nitrate)

Nitrate in the particulate phase is efficiently wet scavenged, and the time-evolution is described by Eq. (5), with $q = [NO_3^-]$.

$$
\begin{aligned}
A(NO_3^-) &= 2k_{12}O_3[NO_2] + q_a[HNO_3] \\
\kappa_d(NO_3^-) &= q_a/2 + v_{dN}/h \\
\kappa_w(NO_3^-) &= \kappa_d(NO_3^-) + \frac{\Lambda_N P}{\phi\, h}
\end{aligned}
\qquad (10)
$$

2.1.6 Sulphur Dioxide, SO_2

Sulphur dioxide is wet scavenged, and the time-evolution is described by Eq. (5), with $q = [SO_2]$.

$$A(SO_2) = (1-\alpha-\beta)Q_{SOx}/h$$

$$\kappa_d(SO_2) = k_t + v_{dq}/h \qquad (11)$$

$$\kappa_w(SO_2) = \kappa_d(SO_2) + \frac{\Lambda_q P}{\phi\ h}$$

2.1.7 Particulate Sulphate, $SO_4^=$ (not including ammonium sulphate)

Nitrate in the particulate phase is efficiently wet scavenged, and the time-evolution is described by Eq. (5), with $q = [SO_4^=]$.

$$A(SO_4^=) = \beta Q_{SOx}/h + k_t[SO_2]$$

$$\kappa_d(SO_4^=) = v_{ds}/h \qquad (12)$$

$$\kappa_w(SO_4^=) = \kappa_d(SO_4^=) + \frac{\Lambda_s P}{\phi\ h}$$

2.1.8 Ammonia, NH_3

Ammonia is efficiently dry and wet scavenged, and the time-evolution is described by Eq. (5), with $q = [NH_3]$.

$$A(NH_3) = (1-\varpi)Q_{NH3}/h$$

$$\kappa_d(NH_3) = v_{dNH}/h \qquad (13)$$

$$\kappa_w(NH_3) = \kappa_d(NH_3) + \frac{\Lambda_{NH} P}{\phi\ h}$$

The local deposition of NH_3 in the emission grid square includes a wet part (see Table 6), and $\varpi = \varpi_d + \varpi_w$. Since ammonia predominantly is a ground-level area source, it is necessary to correct for the vertical concentration gradient in emission areas before comparing with measurements. Calculated air concentrations are therefore added the amount $\Delta[NH_3]_A = \varpi_d Q_{NH3}/v_{dNH}$, and calculated concentrations in precipitation the amount $\Delta[NH_3]_L = \varpi_w Q_{NH3}/P$.

Equations (5) and (13) do not include the full chemical pathway for NH_3. If available, it will combine with $SO_4^=$ to form ammonium sulphate immediately. If there still is some ammonia left after this reaction, it enters into equilibrium with HNO_3 to form or dissolve ammonium nitrate. This is described in section 2.2.

2.1.9 Ammonium Nitrate, NH_4NO_3

Ammonium nitrate is deposited as other nitrate particles, and the time-evolution is described by Eq. (5), with q = $[NH_4NO_3]$.

$$\begin{aligned} A(NH_4NO_3) &= 0 \\ \kappa_d(NH_4NO_3) &= v_{dN}/h \\ \kappa_w(NH_4NO_3) &= \kappa_d(NH_4NO_3) + \frac{\Lambda_N P}{\phi\, h} \end{aligned} \tag{14}$$

Other sources and sinks for ammonium nitrate is the equilibrium reaction between NH_3 and HNO_3 to form or dissolve NH_4NO_3, section 2.2.

2.1.10 Ammonium Sulphate, $(NH_4)_{1.5}SO_4$

Amonium sulphate may occur in two forms, $(NH_4)_2SO_4$ and NH_4HSO_4. An assumption in the model is that the concentrations of these two forms are equal, and the sum of the two components is the modelled ammonium sulphate with the chemical notation as above. Ammonium sulphate is deposited as other sulphate particles, and the time-evolution is described by Eq. (5), with q = $[(NH_4)_{1.5}SO_4]$.

$$\begin{aligned} A((NH_4)_{1.5}SO_4) &= 0 \\ \kappa_d((NH_4)_{1.5}SO_4) &= v_{ds}/h \\ \kappa_w((NH_4)_{1.5}SO_4) &= \kappa_d((NH_4)_{1.5}SO_4) + \frac{\Lambda_s P}{\phi\, h} \end{aligned} \tag{15}$$

The source for ammonium sulphate is the instantaneous reaction between NH_3 and $SO_4^=$, as described in section 2.2.

2.2 Other Processes

The chemical processes described in section 2.1 are not complete. Two nonlinear reactions that can not be described as terms in the differential equations, are also included.

2.2.1 Production of Ammonium Sulphate

The formation of $(NH_4)_{1.5}SO_4$, which is not included in eq. (15), is assumed to take place instantaneously and irreversibly after each timestep of 15 min. Starting with the concentrations of NH_3 and $SO_4^=$ obtained from the stepping of eq. (5) with proper coefficients, ammonium sulphate is formed by assuming 3 molecules of NH_3 combine

with two molecules of $SO_4^=$ to form two molecules of $(NH_4)_{1.5}SO_4$. This process goes on until there is either no ammonia left or no $SO_4^=$ left.

2.2.2 Production and Loss of Ammonium Nitrate

If any ammonia is left in the air after the instantaneous ammonium sulphate production, it enters into equilibrium with HNO_3 to form or dissolve ammonium nitrate. The equilibrium coefficient, K, is dependent on temperature ,T, and relative humidity, U. If the gases are in equilibrium with the ammonium nitrate particles, we have

$$[NH_3]_e \cdot [HNO_3]_e = K \tag{16}$$

where e denotes equilibrium concentrations. If the actual, non-equilibrium concentrations (denoted by ne) gives a product larger than K, then ammonium nitrate particles are created until equilibrium is reached. Otherwise, if the product between the gas concentrations is smaller than K, then amonium nitrate particles are dissolved until equilibrium is reached if there are enough particles available. Given the non-equilibrium concentrations, the equilibrium is calculated by assuming

$$[NH_3]_e + [NH_4NO_3]_e = [NH_3]_{ne} + [NH_4NO_3]_{ne}$$

and (17)

$$[HNO_3]_e + [NH_4NO_3]_e = [HNO_3]_{ne} + [NH_4NO_3]_{ne}$$

in addition to eq. (16). Thus the sum of reduced nitrogen as well as of oxidised nitrogen are conserved in the process. These three equations with three unknowns are combined to give a quadratic equation for $[NH_3]_e$ with the following physical solution

$$[NH_3]_e = ([NH_3]_{ne}+[HNO_3]_{ne})/2 + [\ ([NH_3]_{ne}+[HNO_3]_{ne})^2/4 + K\ ]^{1/2} \tag{18}$$

The remaining two equilibrium concentrations are taken from (16) and one of the equations in (17). If the thus obtained ammonium nitrate concentration is negative, then there was not enough available to reach equilibrium, and the final concentrations then are zero for ammonium nitrate and the sum of the non-equilibrium gas and the particle concentrations for ammonia and nitric acid.

The equilibrium coefficient depends on temperature and relative humidity in the following manner. The point of delisquiscence for a given temperature is given by

$$\ln U_d = a_d/T + b_d \tag{19}$$

where a_d=856.23 K, and b_d=1.2306 if U_d is given in % (b_d=-3.3746 if U_d is given with unit 1). The equilibrium coefficient at the point of delisquiscence is given by

$$\ln K_d = a_K - b_K/T - c_K \ln(T/d_K) \tag{20}$$

where it is assumed thet K_d is given in units of molecules per cm^3, and a_K=70.78,

b_K=24220K, c_K=6.1, and d_K=298K. If K also is assumed given in units of molecules per cm^3, the formula for its calculation is

$$\ln K = \begin{cases} \ln K_d & \text{for } U < U_d \\ \ln K_d - \dfrac{20.75 + \ln K_d}{U_0 - U} \cdot \dfrac{U - U_d}{U_0 - U_d} & \text{for } U \geq U_d \end{cases} \qquad (21)$$

d
where U_0=101 and U and U_d are in units of %.

2.2.3 Free Troposphere Exchange

Even though the model is designed for calculating transport as long as the major part of the pollutants exist inside the well mixed layer, exchange with the free troposphere above must be included since it may be important for transport to the more remote parts of Europe. The mechanism is described in Eliassen and Saltbones (1983). In the present model version, the height of an air parcel starts out as the height, $H_M(t_1)$, of the well mixed layer at time t_1=1200 GMT in the point where it is situated. As the air parcel moves along its trajectory $\mathbf{r}(t)$ with time t, the height may change as a consequence of vertical motion in accordance with horizontal divergence and convergence, so that the volume is concerved. After 24 hours at time t_2, its height is

$$h(\mathbf{r}(t_2),t_2) = H_M(\mathbf{r}(t_1),t_1) + \int_{t_1}^{t_2} w_r(\mathbf{r}(t),t)\, dt \qquad (22)$$

where w_r is the vertical velocity on top of the mixed layer estimated from the value from the NWP-model given in Table 5 through

$$w_r(\mathbf{r},t) = \begin{cases} w(\mathbf{r},t) & \text{for } h \geq H_{1000} \\ w(\mathbf{r},t)\, h(\mathbf{r},t)/H_{1000} & \text{for } h < H_{1000} \end{cases} \qquad (23)$$

so that the vertical velocity is reduced linearly for heights below H_{1000} = 1000 m. At the time t_2 the air parcel height is redefined to equal the local mixing height, $H_M(\mathbf{r}(t_2),t_2)$, at its new position $\mathbf{r}(t_2)$. Through this redefinition, the free tropospheric exchange is modelled as follows. If $q(t_2)$ is the concentration of a species in the boundary layer after integration of the above equations and the prescribed free troposphere concentration is q_a, then the new concentration after exchange is

$$q_2 = \begin{cases} q(\mathbf{r}(t_2),t_2) & \text{for } H_M \leq h \\ q_a + (q(\mathbf{r}(t_2),t_2)-q_a)\, h(\mathbf{r}(t_2),t_2)/H_M & \text{for } H_M > h \end{cases} \qquad (24)$$

In both cases, the redefined height of the air parcel is $H_M(\mathbf{r}(t_2),t_2)$.

2.2.4 Dry deposition

The dry deposition of gases that stick to the ground surface is controled by the chemical / biochemical affinity between the gas and the surface, the molecular diffusion through the laminar sublayer very close to the ground. The dry deposition speeds for gases frequently given in the scientific literature includes these two effects, and thus is valid on top of the laminar sublayer which typically has a thickness of several decimeters. We assume this height to be 1 m over the ground. As indicated in Table 6, the 1 m dry deposition speed for some of the gases varies considerably according to their water solubility. Thus, NO_2 and PAN is not dry deposited over water, while SO_2, HNO_3 and NH_3 is most efficiently over water. Dry deposition over non-melting snow is known to be slow for some gases (Whelpdale and Shaw, 1974; Dovland and Eliassen, 1976), and this effect also coincides with the annual variation of biochemical uptake of vegetation which also has a diurnal cycle. Over land these two effects have been roughly taken into account through the formula:

$$v_d(B,\tau,t) = a_1(\tau)\,\Delta(t)\,v_{dmax} + a_2(\tau)\,v_{dw}(B) \equiv f_d(B,\tau,t)\,v_{d1} \qquad (25)$$

where $v_d(B,\tau,t)$ is the dry deposition speed at height 1 m, latitude B, time of year τ, and time of day t. The parameter v_{dmax} is the maximum summertime dry deposition speed, while v_{dw}, which varies with latitude, is a dry deposition speed typical for mid-winter conditions. At the equator, $v_{dw}=v_{dmax}$, whilst at the north pole $v_{dw}=0$. The factor Δ is a factor to account for the diurnal variation of biochemical uptake, and equals to 1 during daytime (04-22 Loc. T.) whereas at night it is 0.25. The factors a_1 and a_2 are squared trigonometric functions:

$$a_1(\tau) = \sin^2[\pi(\tau-\tau_0)/\tau_a] \; ; \qquad a_2(\tau) = \cos^2[\pi(\tau-\tau_0)/\tau_a] \qquad (26)$$

where τ_0 is 1. February and τ_a is one year. The function f_d is shown in Figure 5 for daytime conditions. Note that according to eq. (25), the wintertime dry deposition speed does not vary with the time of day. Eq. (25) is applied to NO_2 (v_{dmax}=0.1 cm/s), PAN (v_{dmax}=0.2 cm/s), NH_3 (v_{dmax}=0.8 cm/s), and SO_2 (v_{dmax}=0.8 cm/s). The value 0.1 cm/s for NO_2 is in accordance with estimates presented by Johansson (1987) where the deposition velocity is shown to be dependent on the concentration level. The concentrations occuring in connection with long range transport in Europe suggest values close to the one chosen here.

The model calculated concentrations are supposed to represent the well mixed layer, and therefore cannot be combined with the 1 m dry deposition speed without reducing its value according to the aerodynamic resistance determined by the turbulence in the surface boundary layer. This is done by applying the similarity theory for the constant flux layer which is about 50 m thick. According to this theory, the dry deposition speed in two different levels z_1 and z_2 relate to each other through the formula:

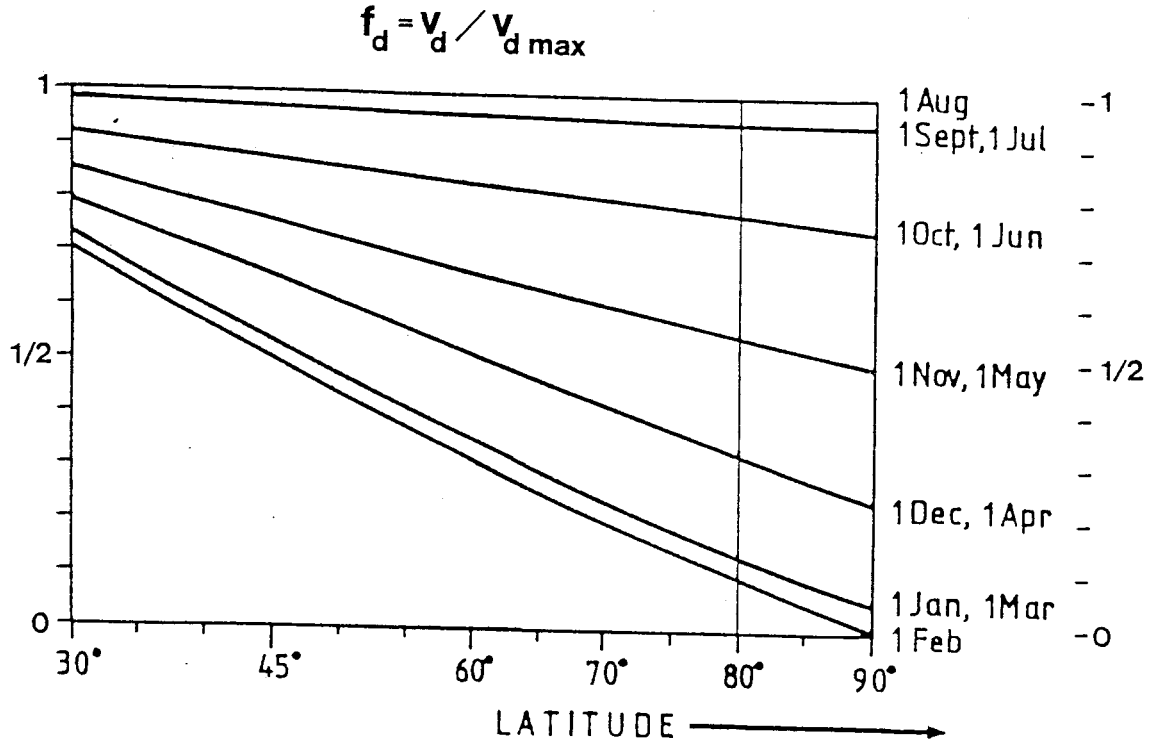

Figure 5. The function f_d representing the ratio between the actual daytime dry deposition speed at height 1 m and the maximum, as a function of latitude and season.

$$v_d(z_2) = v_d(z_1) \,/\, \left[1 + \frac{v_d(z_1)}{\kappa\, u_*} \left(\psi(z_2/L) - \psi(z_1/L) \right)\right] \qquad (27)$$

In this case z_1 = 1 m and z_2 = 50 m. The function ψ represents the dimensionless vertical concentration profile, and we have chosen

$$\psi(x) = \begin{cases} -2 \ln\left[(1 + (1-15x)^{1/2})/2\right] & \text{for } x < 0 \text{ (unstable)} \\ \ln x + 5\, x & \text{for } x \geq 0 \text{ (neutral and stable)} \end{cases} \qquad (28)$$

The vertical profile of concentration is

$$\frac{q(z_2)-q(z_1)}{q_*} = \psi(z_2/L) - \psi(z_1/L) \qquad (29)$$

and u_*, L and q_* represent friction velocity, the Monin-Obukhov stability length, and characteristic concentration, respectively. From the input meteorological data the turbulent stress, τ, and the upward heat flux density, H_d, are given. Thus the Monin-Obukhov length can be calculated

$$L = \frac{(\tau/\rho)^{3/2}\ T_2}{\kappa g\ (-H_d/c_p\rho)} \tag{30}$$

where $\tau = \rho\ u_*^2$, $\rho = p_s/RT_2$ is air density, T_2 is the absolute temperature at height 2 m, p_s is the ground level pressure, R=287 J K^{-1} kg^{-1}, g = 9.8 m/s^2, c_p = 1004 J K^{-1} kg^{-2}, and κ is the von Karman constant.

The dry deposition speed of particles (sulphate and nitrate) is assumed to be representative for an old aerosol dominated by particles of size a few tenths of a micrometer (accumulation mode). Its value is assumed to be constant equal to 0.1 cm/s.

In reality the dispersion of pollution inside the atmospheric boundary layer is not instantaneous as assumed in the model. During the first phase of dispersion, the ground level concentrations are therefore systematically underestimated, and the dry deposition close to emission sources would accordingly be too small if it was not corrected. The correction is made by assuming that a fraction of the emission is deposited locally inside the same grid square as emitted. The rest of the emission takes part in the long range transport. The value of this fraction depends of the dry deposition speed and the elevation of the emissions above the ground. For SO_2 the value is 0.15, for NO zero, NO_2 0.04, and NH_3 0.19. Note that the dry deposition from a country to itself will depend quite significantly on the value of this fraction deposited locally.

2.3 Background Concentrations

Models like the present which calculates budgets for air transport within a limited part of the atmosphere (the boundary layer over Europe) over a limited time-span (four days long trajectories), phase the problem of deciding initial and boundary conditions. In the present case concentrations of 10 components must be given in the start point of each trajectory, and in the free troposphere adjacent to the atmospheric boundary layer. The origins of these concentration cannot be traced by the model, and thus contributes to concentrations and depositions of indeterminate origins in the final budgets.

Inside the boundary layer the model calculates concentrations inside a rectangular domain consisting of 1023 points (see Fig. 6). Back trajectories starting inside the same domain can use earlier calculated concentrations as initial condition. This procedure called assimilation is now in full use. Thus, prescribed background concentrations inside the boundary layer are only necessary for the whole domain if one starts out without calculations for the preceding period, and otherwise outside the central domain of concentration calculations.

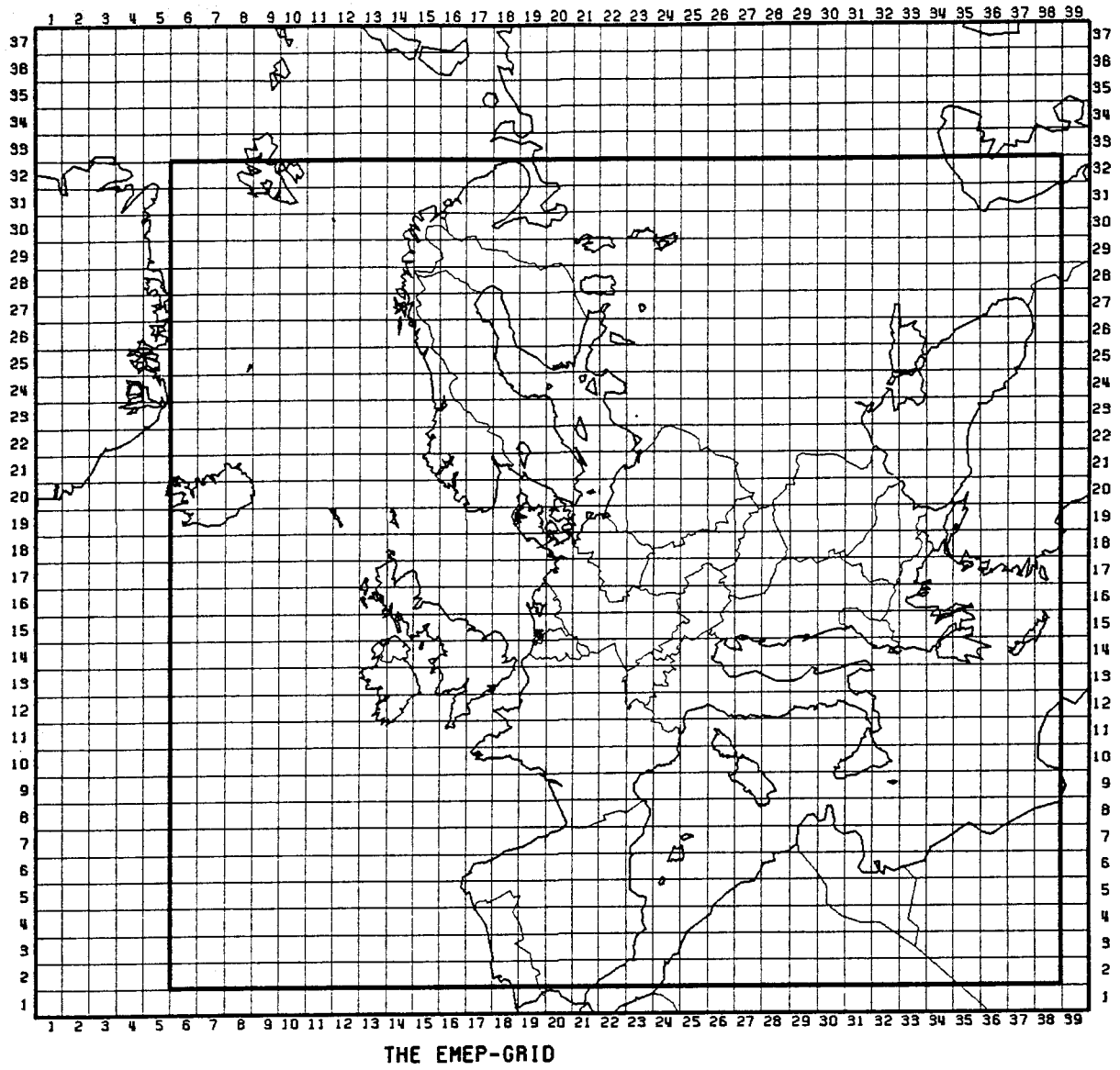

Figure 6. The applied grid system.
Emissions and meteorological data are given in the entire grid. Concentrations and depositions are calculated in the rectangular subgrid of size 33 by 31. Boundary-layer concentrations are used in the assimilation procedure inside this subgrid.

There are two main sources for data on background concentrations, output from other models and measurement results. For sulphur the concentrations calculated by the eulerian, multilayer, hemispheric-scale model have been used as guidelines (Iversen and Tarrason, 1990). For boundary-layer NO_x and PAN we have made use of the rather extensive measurements reviewed by Fehsenfeld *et al.* (1988). In the free troposphere measurements are scattered and few, and these concentations have simply been assumed to be a given fraction of their mixed-layer values. For the sum of the three possible forms of nitrate, the number density has been assumed the same as for total sulphate in

the boundary layer, and half the total sulphate value in the free troposphere. This rather crude estimate is motivated by the fact that both species are secondary pollutants with emission sources having similar patterns. Nitrate is, however, faster deposited than sulphate so that older pollution, as found above the well mixed layer, should contain relatively less nitrate than sulphate. Ammonia is very fast depleted in the atmosphere, so the concentration pattern very much follows the emission pattern which is different from that of sulphur and NO_x because of the rural influence. For ammonia the concentration pattern earlier estimated by the model is used as guideline, together with what is assumed about the emissions. Above the boundary layer the concentrations of ammonia is assumed to be 10% of the boundary layer values.

Background concentrations are estimated on a monthly basis and in areas of different typical state of pollution. For NO_x such areas are central inland Europe, remote inland Europe and Northern Africa, and North Atlantic Ocean. For sulphur which is based on model results, the remote inland is separated into four subregions including the Nordic countries, Northern Africa, and the part of USSR outside the inner domain of calculation.

It leads too far to describe all the possibilities for the background concentrations. Some examples are, however, included in Tables 7 and 8. The speciation of nitrate and sulphate is determined by the immediate turnover and equilibrium described in sections 2.2.1 and 2.2.2.

TABLE 7: Background concentrations in the boundary layer used as initial concentrations for trajectories when assimilation is not possible. Values are shown in a point inside the most polluted subregion, and averaged over the area where assimilation of previous calculations is impossible. Four different months are selected. Units are $\mu g\ m^{-3}$ as N or S as indicated.

		Central Europe (10°E, 51°N)				Average (420 points)			
		Jan.	Apr.	Jul.	Oct.	Jan.	Apr.	Jul.	Oct.
NO	N	0.889	0.593	0.296	0.652	0.065	0.065	0.065	0.065
NO_2	N	2.666	1.778	0.889	1.955	0.194	0.194	0.194	0.194
PAN	N	0.711	0.474	0.237	0.521	0.052	0.052	0.052	0.052
SO_2	S	8.584	5.722	5.722	5.722	0.320	0.320	0.228	0.320
NH_3	N	0.424	0.760	0.760	0.561	0.016	0.028	0.035	0.022
HNO_3	N	0.739	0.412	0.412	0.501	0.068	0.066	0.048	0.053
NO_3^-	N	1.751	1.168	1.168	1.168	0.158	0.154	0.113	0.125
NH_4NO_3	N	0.012	0.089	0.089	0.000	0.000	0.000	0.000	0.000
$SO_4^=$	S	0.000	0.000	0.000	0.000	0.009	0.008	0.007	0.008
$(NH_4)_{1.5}SO_4$	S	5.722	3.814	3.814	3.814	0.495	0.484	0.354	0.388

TABLE 8: Background concentrations in the free troposphere above the boundary layer used as ambient concentrations in the interaction between the well mixed layer and the free troposphere. Values are shown in a point inside the most polluted subregion, and averaged over the whole grid. Four different months are selected as examples. Units are $\mu g\ m^{-3}$ as N or S as indicated.

		Central Europe (10°E, 51°N)				Average (1443 points)			
		Jan.	Apr.	Jul.	Oct.	Jan.	Apr.	Jul.	Oct.
NO	N	0.355	0.237	0.118	0.260	0.033	0.027	0.021	0.028
NO_2	N	0.829	0.552	0.276	0.608	0.109	0.095	0.082	0.098
PAN	N	0.237	0.158	0.079	0.174	0.116	0.112	0.108	0.113
SO_2	S	0.953	0.953	0.953	0.953	0.491	0.496	0.511	0.511
NH_3	N	0.019	0.047	0.047	0.019	0.003	0.005	0.005	0.002
HNO_3	N	0.063	0.063	0.063	0.063	0.035	0.037	0.037	0.036
NO_3^-	N	0.146	0.146	0.146	0.146	0.083	0.086	0.085	0.084
NH_4NO_3	N	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$SO_4^=$	S	0.000	0.000	0.000	0.000	0.030	0.028	0.027	0.030
$(NH_4)_{1.5}SO_4$	S	0.953	0.953	0.953	0.953	0.453	0.475	0.472	0.459

Specific for the present model is that boundary-layer concentrations of another 3 components must be prescribed to estimate chemical reaction speeds. The model itself does not calculate these concentrations, so they cannot be included in the assimilation procedure. The components are ozone O_3, the hydroxyl radical OH, and the peroxy-acetyl radical CH_3COO_2. Presently their concentrations are varying with season and latitude, and the values are taken from the two-dimensional, global model of Isaksen and Hov (1987). Comparisons with measurements (Logan, 1985) show that the values for ozone are too large, especially during winter and spring and when compared with mountain sites representative of the background atmosphere. The seasonal variation of ozone is consequently reduced with a factor which is constant with latitude, in order to arrive at values that coincide better with observations. Furthermore it is assumed that the minimum ozone mixing ratio never is smaller than 25 ppb. The two radicals are also given a diurnal cycle according two the received sunlight. Table 9 shows employed values for these components.

TABLE 9: Mixing ratioes for ozone and number densities of the hydroxyl and peroxy-acetyl radicals. The data shown are valid for January and July for five different latitudes, and the radicals are shown for 0000 and 1200 local time. The variation due to changing solar radiation assumes no cloud cover in this table.

	January					July				
	O_3	OH		CH_3COO_2		O_3	OH		CH_3COO_2	
	ppb	10^4molec./cm^3		10^4molec./cm^3		ppb	10^4molec./cm^3		10^4molec./cm^3	
		0000	1200	0000	1200		0000	1200	0000	1200
80°N	25	0.01	0.01	120.	120.	38	5.38	18.3	14.0	39.8
70°N	25	0.05	0.05	31.0	31.0	35	0.29	28.8	5.34	58.7
60°N	25	0.68	68.2	29.0	320.	41	0.82	82.6	9.01	99.2
50°N	25	1.21	122.	32.2	354.	46	1.41	142.	19.3	212.
40°N	26	1.38	139.	36.5	402.	46	1.58	160.	26.2	288.

2.4 Subgrid Precipitation

The six-hourly accumulated precipitation amounts used in the model for estimating wet scavenging of water soluble compounds, are estimates of grid-area averages. Thus the precipitation P has earlier been assumed to be uniformly distributed over the six-hour period and over the grid square. In reality the precipitation does not behave in such a manner, but shows a patchy distribution with pronounced fluctuations, even over areas of 150 by 150 km and over six hours. This is demonstrated by the scatter plot in Figure 7. Along the ordinate is the modelled (i. e. the objectively analysed) number of days in 1988 with precipitation on the EMEP monitoring stations, and along the abscissa the number of days in 1988 with observed precipitation. It is clearly seen that the modelled, grid-area average over-estimate the frequency of pricipitation in the different points inside the grid square.

The meteorological data available for pollution calculations at MSC-W do not include information on the distribution of precipitation on a finer scale than the grid squares over six hours. This subgrid distribution is therefore taken into account statistically. If P is the grid square averaged, six-hourly accumulated precipitation amount, then the probability of precipitation in an arbitrary point in the grid square at a time wihin the six hour interval is a function of P. It is also a function of the geographical position of the grid square and the season, but this is not taken into account at present. We now assume that this probability equals the fraction, ϕ, of the grid square being hit by precipitation during the period. Furthermore, it is assumed that the precipitation is uniformly distributed within the "wet fraction" of the area. This is a crude approximation, but is far better than assuming uniformity over the whole grid square. Moreover, it is difficult to do anything better without really increasing the space and time resolution of the precipitation fields.

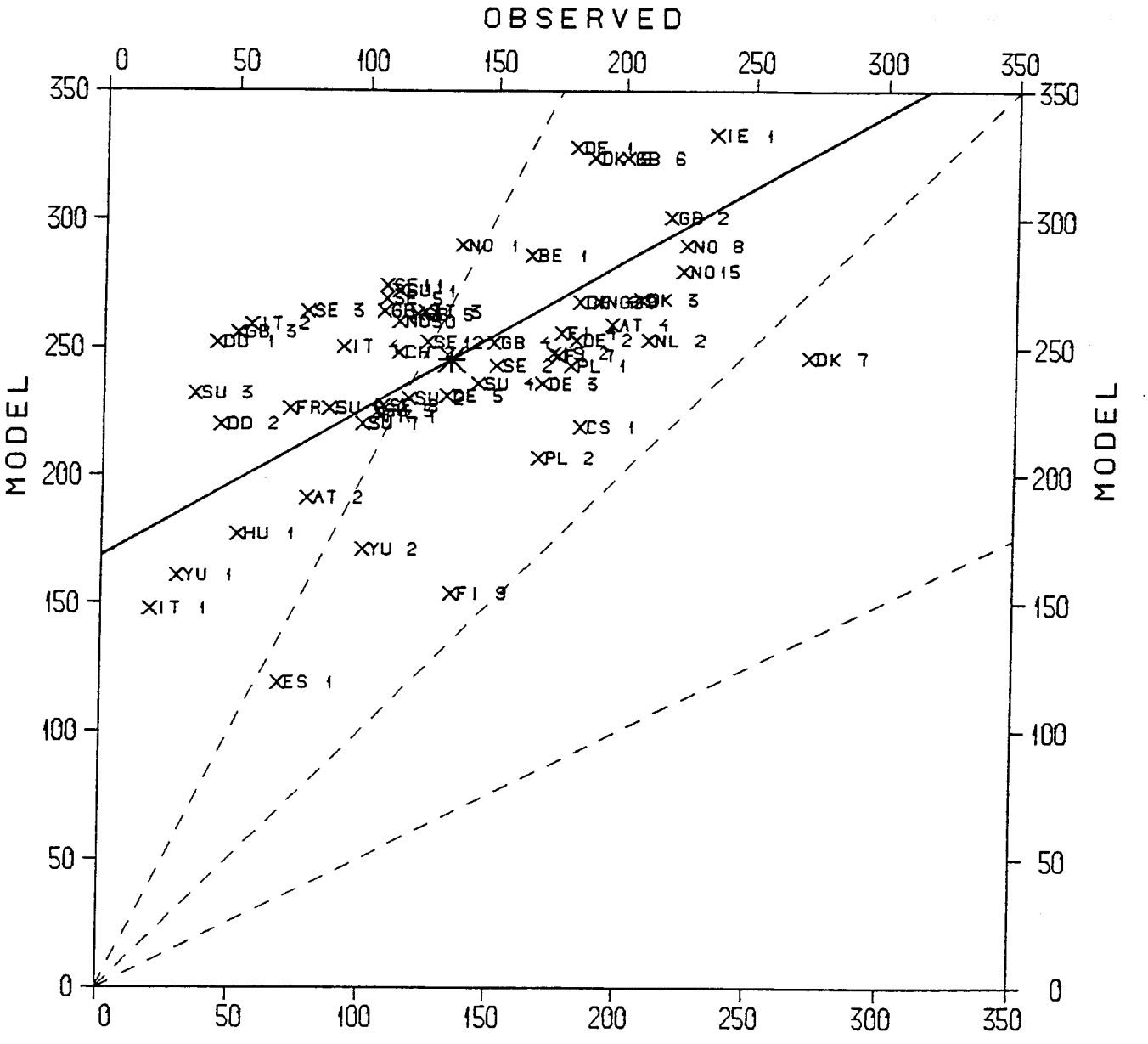

Figure 7. Scatter plot showing the number of days with modelled precipitation against the number of days with observed precipitation on the EMEP measurement sites in 1988. See Figure for definition of station codes.

With the above assumptions, the precipitation intensity in the wet fraction is

$$P_w = P/\phi, \tag{31}$$

and the pollutant concentration, q, can be expressed as a linear combination between the concentration in the wet and dry fractions:

$$q = \phi\, q_w + (1-\phi)\, q_d. \tag{32}$$

This subgrid separation of pollution mass is defined by the area where wet scavenging

is acting, and there is no physical obstruction for mixing of air between the wet and the dry fraction of the grid square. Hence, it is unphysical to keep the separation between the fractions for a longer time than it normally takes to mix the two subgrid air masses. Depending on the precipitation amount P, one should think of the area fractions in such a way that there are patches of one of the area fractions within the other (like cheese holes). The mixing therefore should be rather fast. Presently we assume separate budget equations for the two fractions over the model time-step of Δt=15 min, and that they then are intermixed. Now the concentration q_d is only affected by effects not involving wet scavenging, whilst q_w is fully involved in all processes. Using the same notation as in section 2.1, the budget equations for the to subareas over Δt, are

$$\frac{Dq_d}{dt} = - \kappa_d q_d + A$$

and (33)

$$\frac{Dq_w}{dt} = - \kappa_w q_w + A \, .$$

The budget for the average concentration in the whole grid square over Δt is obtained by differentiation of (32) and introducing from (33):

$$\frac{Dq}{dt} = \phi \frac{Dq_w}{dt} + (1-\phi)\frac{Dq_d}{dt} = A - \kappa_d q - \phi(\kappa_w-\kappa_d) q_w \qquad (34)$$

Differentiating (34) and utilizing the expression for q_w that can be solved for by (34), gives

$$\frac{D^2q}{dt^2} + (\kappa_d+\kappa_w)\frac{Dq}{dt} = - \kappa_d\kappa_w q + [\phi \kappa_d + (1-\phi) \kappa_w] A \qquad (35)$$

where it is assumed that DA/dt = 0. Components that are scavenged by precipitation is assumed to follow eq. (35) with constant coefficients over the time step length Δt. The initial conditions is in accordance with the assumption that there is full intermixing every Δt. The general solution to (35) is

$$q(t+\Delta t) = \frac{\phi\kappa_d+(1-\phi)\kappa_w}{\kappa_d\kappa_w} A + C_d e^{-\kappa_d\Delta t} + C_w e^{-\kappa_w\Delta t} \qquad (36)$$

The integration constants, C_d and C_w, are determined by the initial conditions that $[q(t+\Delta t)]_{\Delta t=0} = q(t)$ and $[Dq/dt]_{\Delta t=0}$ is given by eq. (34), thus we arrive at the solution in eq. (5).

The function $\phi(P)$ has been estimated by continuous registrations of precipitation amounts (pluviograph data), and compare momentary data with six-hourly averages. This work has been performed by a student at the University of Oslo, Mr. Per Egil Haga. In Table 10, ϕ is given for some values of P.

TABLE 10. The fraction, ϕ, of a grid square area which is hit by precipitation as a function of the six-hourly accumulated, grid square averaged precipitation amount P.

P (mm/6h):	0	3	6	9	12	20	50	90	150
ϕ (%) :	0	31	48	60	66	72	80	85	91

2.5 Quality Assessment

Only very few of the components calculated are measured regularly with a reasonable coverage. At present we are only able to compare with observations of SO_2, total particulate sulphate, and NO_2 in air. For species in precipitation we are able to compare sulphate-, nitrate-, and ammonium-ions. For ammonium, however, the comparison is very uncertain since the measurements are taken in rural areas where emission of ammonia in many places is strong, so that they hardly are representative for long-range transport. In the future it is expected that measurements of more nitrogen compounds in air will be available for verification in the EMEP network. The present model verifications are made towards measurements in 1988. Measurements for 1989 are not yet available. Figures referred to in this section are found in Appendix A.

Figure A1 shows a scatter plot of calculated and measured yearly averaged NO_2. There are only 16 stations with observations on 75% of the days or more. The model underestimate the observations in general, and at two stations the underestimation is slightly more than a factor two. In Figure A2 is shown a time series plot of daily observed and calculated concentrations at two of the stations (NO 1, Birkenes and DE 2, Langenbrugge). The differences at NO 1 occur throughout the year, but seem to be at the largest when concentrations are low. Moreover, the correlation is very good (0.74), actually the best of all the stations. At DE 2, which is situated close to the major emission areas, the concentrations are generally larger and the agreement is better even if the correlation is somewhat lower (0.59). Nevertheless, the model underestimates the observations when the concentrations are at the lowest also on this station. Figure A3 shows relative model errors and correlations as a function of the emission in the grid-square in which the station is situated. There is considerable spread in both these parameters, but there is little systematic trend in model quality as a function of nearby emissions.

The verification of NO_2 in air is not of full value because of the small number of measurement stations with regular observations. This is an even worse problem for other airborne nitrogen compounds.

The scatter plot for calculated and observed SO_2 in Figure A4 includes 38 stations for which the data coverage is larger than 75% of the year. The model has a slight tendency to overestimate the measurements, and for three stations the disagreement is a factor of two or more. Figure A5, showing concentrations as a function of time at NO 1 and DE 2, show very good agreement, and the agreement is generally satisfactory over

Europe. The same impression is also reflected in the diagrams for performance as a function of grid square emissions (Figure A6). As for NO_2 there is very little trend in these diagrams.

The agreement between calculations and measurements for particulate sulphate (Figure A7) is very similar to SO_2, though this is not correct for each particular station. For example at PL 2 (Jarczew) SO_2 is overestimated while particulate sulphate is underestimated. At SU 5 (Svityaz), which is quite close to PL 2, both components are overestimated, however, very much less for particulate sulphate than for SO_2. At the station DE 3 (Schauinsland) both components are clearly overestimated, and the reason for this probably is that the station is situated at a mountain peak 1200 m above sea level which for long periods of the time is above the representative mixed layer. The time series plots for daily concentrations at NO 1 and DE 2 (Figure A8) give confidence in the model's ability to reproduce realistic long term behavior of sulphate in air. Figure A9 shows that there is not a clear trend in performance from highly polluted areas to remote areas. However, there are many more stations in remote areas than close to the large emissions.

When evaluating the concentrations in precipitation, one must bear in mind that measurements of such faces a double problem; measuring precipitation amounts and measuring chemical contents in precipitation. As seen in section 2.4, the precipitation measured in a single point may differ considerably from the grid-averaged quantity that is carried in the model.

The scatter plot in Figure A10 shows that the model slightly underestimates the sulphate in precipitation. At some stations the underestimation is very large. At DK 7 (The Faeroe Islands) and FR 5 (La Hague) also the correlation is approximately zero (Figure A11), whilst at IE 1 (Valentia), which is a station with similar surroundings, the correlation is 0.6. Nevertheless, the general impression is that there are reasonable agreements for a majority of the stations.

Also for nitrate the concentration in precipitation is somewhat underestimated, especially in remote areas (Figures A12 and A13). This underestimation is smaller than for sulphate. For a majority of the stations, the agreement is reasonably good.

The scatter plot for ammonium (Figure A14) reveals large underestimations. This may partly be due to the fact that the measurements are taken in rural areas where local emissions of ammonia can be very large. In Figure A15 one can see that some of the stations situated in areas with small grid emissions has larger underestimations than stations in areas with larger emissions. For example at SE 8 the observed concentrations are among the largest in the whole EMEP area, while the local grid emission is very small. The ammonium problem is therefore highly probable connected with the emission distribution which is still in a relatively bad condition as compared with sulphur and oxidized nitrogen.

Table 11 gives a summary of the verification results as depicted in the figures in

Appendix A. We advocate that the total model properties are close to the real world when it comes to long term behaviour. The table also includes a quality factor, M, that encompass both the relative deviation between calculations and observations, and the correlation of daily averages. The chosen formula is

$$M = \frac{2\,R}{3\,\Delta q_r + 2} \tag{37}$$

where $\Delta q_r = 2|q_{cal}-q_{obs}|/(q_{cal}+q_{obs})$, q_{cal} and q_{obs} are calculated and observed concentrations and R is the correlation between observed and calculated daily concentrations. The relative deviation Δq_r equals to 2/3 for deviations of a factor 2, and to 2/5 for deviations of a factor 1.5. The quality parameter M varies between 1 and -1, and it has the same sign as R. If R=1 and Δq_r=0, then M=1. If R=1 and q_{cal} deviates from q_{obs} with a factor 2, then M=1/2. If R=0.4 and the deviation is a factor 1.5, then M=0.25.

The table reveals that air concentrations compare better with measurements than concentrations in precipitation. Less than half of the stations have more than 25% data coverage for precipitation as compared with the model precipitation, which is grid area averages. This stresses the problem of representativity of measurements of species in precipitation. The general underestimation of concentration in precipitation, however, is probably linked to the deep tropospheric character of the precipitation process. Precipitation is released when air converges in the low layers and rises into the free troposphere. This process will cause the model air parcels to lose some of their pollutants since the model does not follow the budget for the free tropospheric air any further. This is, however, a theory that is not fully verified quantitatively.

TABLE 11. Summary of comparison between measurements and calculations for 1988. By $\nu(r)$ is meant the relative number of stations for which the statement r is valid (unit %). The signs <M> and σ_M signify average and standard deviation of the variable M over the measurement network. For components in air, the statistics are only including stations with at least n_l=75% data coverage. For precipitation and components in it, the statistics requires n_l=25% data coverage.

	n_l	ν $n>n_l$	ν $\Delta q_r<2/5$	ν R>0.4	ν $\Delta q_r<2/5$ & R>0.4	<M>	σ_M	M MIN	M MAX	ν M>0.25
	(%)	(%)	(%)	(%)	(%)					(%)
NO_2 in air	75	50.0	56.3	56.3	31.3	0.32	0.13	0.10	0.54	62.5
SO_2 in air	75	61.3	65.8	78.9	55.3	0.37	0.14	0.14	0.76	81.6
$SO_4^=$ in air	75	75.4	58.7	67.4	41.3	0.29	0.13	0.04	0.51	60.9
$SO_4^=$ in prec.	25	84.2	60.4	27.1	12.5	0.21	0.12	0.00	0.55	33.3
NO_3^- in prec.	25	80.0	75.0	38.6	34.1	0.26	0.16	-0.05	0.59	47.7
NH_4^+ in prec.	25	83.3	57.8	22.2	15.6	0.18	0.12	-0.02	0.42	28.9
Precipiation	25	47.6	80.0	94.0	76.0	0.49	0.18	0.07	0.89	86.0

3 RESULTS

The new model version has been run for two full years, 1988 and 1989. Results presented for 1988 are supposed to be final, whilst those for 1989 are preliminary in accordance with the reporting routine of annual emissions from countries (see section 1.1). Experience has shown, however, that calculations that should be final may be changed due to late changes in emissions and changes in the model formulation according to new knowledge from research.

3.1 Acid Pollution in Europe

The Figures 8, 9, 10 and 11 shows calculated isolines for deposition of oxidised sulphur, oxidised nitrogen, reduced nitrogen, and total nitrogen respectively, calculated for 1988. The pattern for oxidised sulphur reflects to much higher degree than oxidised nitrogen the emission distribution. This is because oxidised nitrogen in its primary phase (NO_x) is slowly deposited, whilst SO_2 on the contrary is efficiently dry deposited. Thus, oxidised nitrogen has time to be transported longer than oxidised sulphur before it is deposited. The highest depositions of sulphur of more than 7 g(S)/m^2 are found in central parts of Europe, in the border area between The German Democratic Republic, Czechoslovakia and Poland. Oxidised nitrogen has a more flat distribution, with an area of more than 1 g(N)/m^2 extending from southern Denmark to Northern Italy and from The Netherlands and Belgium to south-east Poland. Reduced nitrogen reflects even more the emissions than oxidised sulphur. Nevertheless, the distribution in large parts of Europe is rather flat because of the emissions that are distrubuted very evenly over agricultural land areas. There are, however, sharp gradients along the coastlines. The total nitrogen deposition exceeds 1.5 g(N)/m^2 in large parts of mainland Europe, and 2.5 g(N)/m^2 in western and central regions.

On the next few pages are shown calculations of annually averaged concentrations in air for some components. The Figures 12, 13, 14 and 15 show sulphur compounds, the Figures 16, 17, 18, 19, 20, 21, 22, 23 compounds of oxidised nitrogen, and the Figures 24 and 25 compounds of reduced nitrogen. Most of the sulphate (80% - 90%)is in the form of ammonium sulphate. The very fast oxidation of NO to NO_2 causes about 90% of the NO_x to occur as NO_2, even in areas of high emissions. The distribution of PAN is very flat except in coastal areas, and it constute a very small part of the available oxidised nitrogen in primary phase. Most of the nitrate (60% - 70%) is in the form of particulate nitrate (not including ammonium nitrate). Nitric acid gas and ammonium nitrate particles is about equally important, but somewhat different distributed.

3.2 Country-to-Country Budgets

For each of the 10 calculated species the model keeps track of subconcentrations arising from emissions in 35 different emission areas. Area 1 to 28 are European countries, area no. 29 (REM) is the part of North Africa that is included in the domain of calculation, area 30 to 35 are different subdivisions of sea areas, see Table 12 and

Figure 26. This implies that the model keeps track of 350 concentration fields, and addition to 700 deposition fields.

TABLE 12: Definition of codes for the sub-areas used in the emission-deposition matrices

1	AL	Albania	19	PL	Poland
2	AT	Austria	20	PT	Portugal
3	BE	Belgium	21	RO	Romania
4	BG	Bulgaria	22	ES	Spain
5	CS	Czechoslovakia	23	SE	Sweden
6	DK	Denmark	24	CH	Switzerland
7	FI	Finland	25	TR	Turkey*
8	FR	France	26	SU	Soviet-Union*
9	DD	German Dem. Rep.	27	GB	United Kingdom
10	DE	Germany, Fed. Rep.	28	YU	Yugoslavia
11	GR	Greece	29	REM	Remaining areas*
12	HU	Hungary	30	BAS	The Baltic Sea
13	IS	Iceland	31	NOS	The North Sea
14	IE	Ireland	32	ATL	Rem. Atlantic Waters
15	IT	Italy	33	MED	The Mediteranian*
16	LU	Luxembourg	34	BLS	The Black Sea
17	NL	The Netherlands	35	NAT	Biogenic sea emissions
18	NO	Norway	36	IND	Dep. of indeterminate origins

*The part inside the EMEP domain of calculation.

The governing differential equations in section 2.1 are all linear in the concentrations. Any two sets of solutions to this system of equations can be added to give a sum that also will be a set of solution of the equations. This means that one can calculate the concentrations due to emissions in each sub-domain, and then sum over the individual contributions to get the total concentrations.

The model is, however, not completely linear due to the processes producing amonium sulphate and ammonium nitrate. Both these processes depend on the concentrations of the components involved in a non-linear way. The contributions from the emission sub-domains to the concentration of these two ammonium components, are calculated in two different ways. The first allocation points to emissions of ammonia, and the second to emissions of NO_x (ammonium nitrate) or SO_2 (ammonium sulphate). Their production is only calculated on the basis of total emissions from all countries. An increment in the concentration of one of these species is allocated to emissions of ammonia when a reduced nitrogen budget is made, and to emissions of NO_x (SO_2) when an oxidised nitrogen (sulphur) budget is made.

Calculated country-to-country budgets for oxidised sulphur, and oxidised and reduced nitrogen for 1988 and 1989 (preliminary) are given on the next pages (Tables 13 and 14 for oxidised sulphur; Tables 15 and 16 for oxidised nitrogen; Tables 17 and 18 for reduced nitrogen). Both SO_2 and NH_3 are efficiently dry deposited, while NO_x is not. This is reflected in the budgets on the main diagonal (contributions from a country to itself).

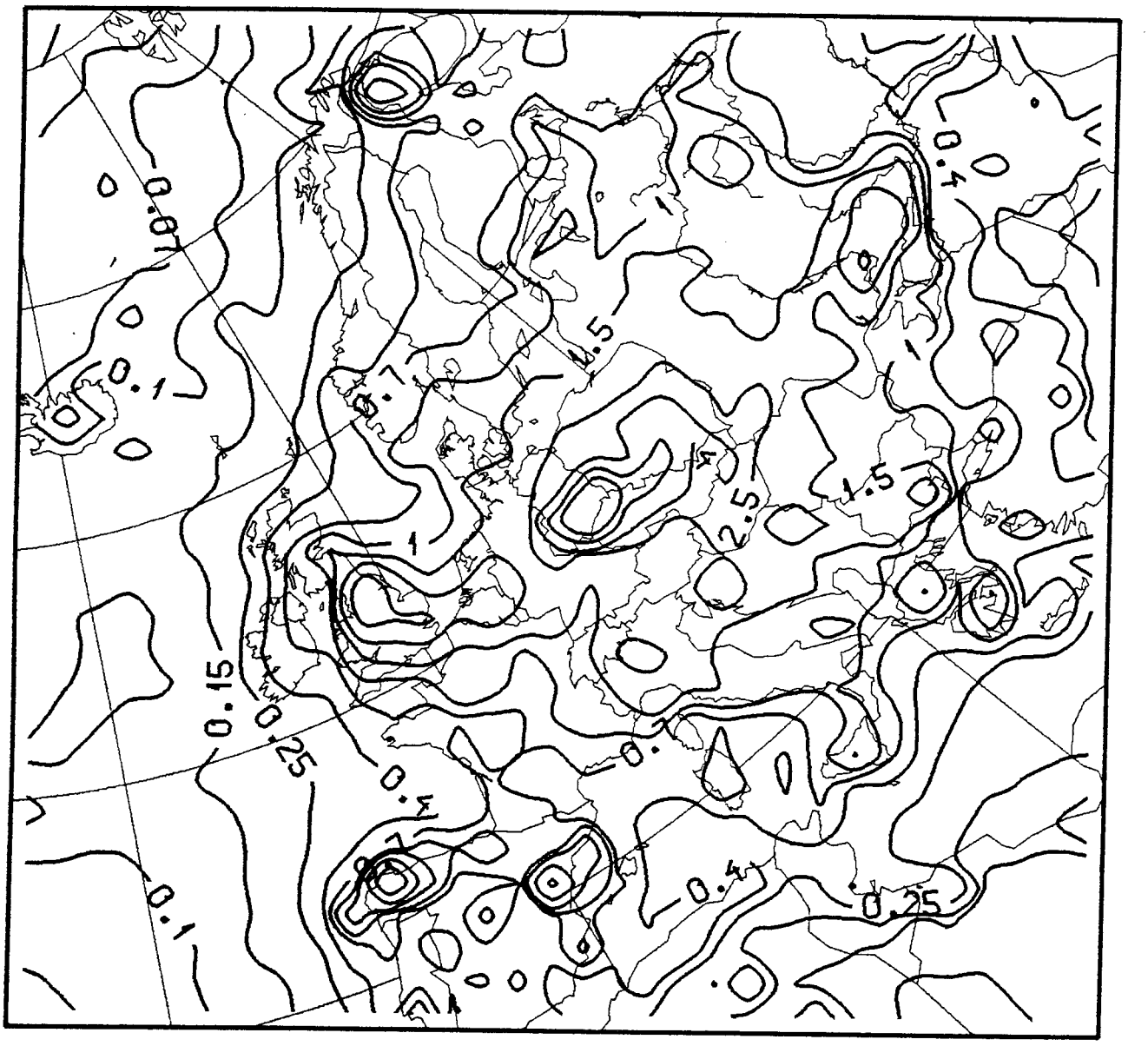

Figure 8. Model estimated annual deposition of Oxidised Sulphur for 1988.
Isolines for 0.01, 0.02, 0.04, 0.07, 0.1, 0.15, 0.25,
0.4, 0.7, 1.0, 1.5, 2.5, 4.0, 7.0, 10.0 g(S) m^{-2}.

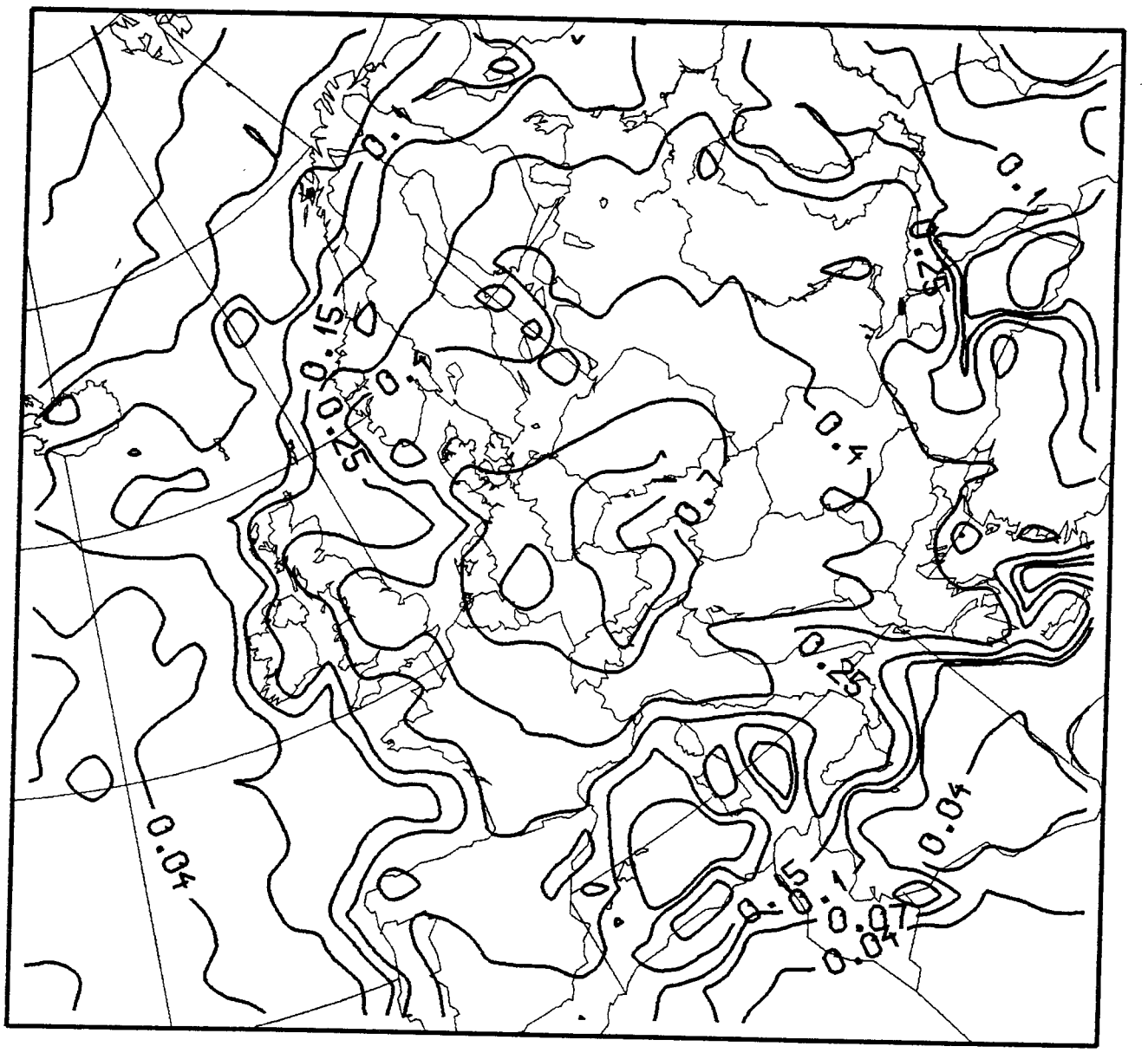

Figure 9. Model estimated annual deposition of Oxidised Nitrogen for 1988.
Isolines for 0.01, 0.02, 0.04, 0.07, 0.1, 0.15, 0.25,
0.4, 0.7, 1.0, 1.5, 2.5, 4.0, 7.0, 10.0 g(N) m^{-2}.

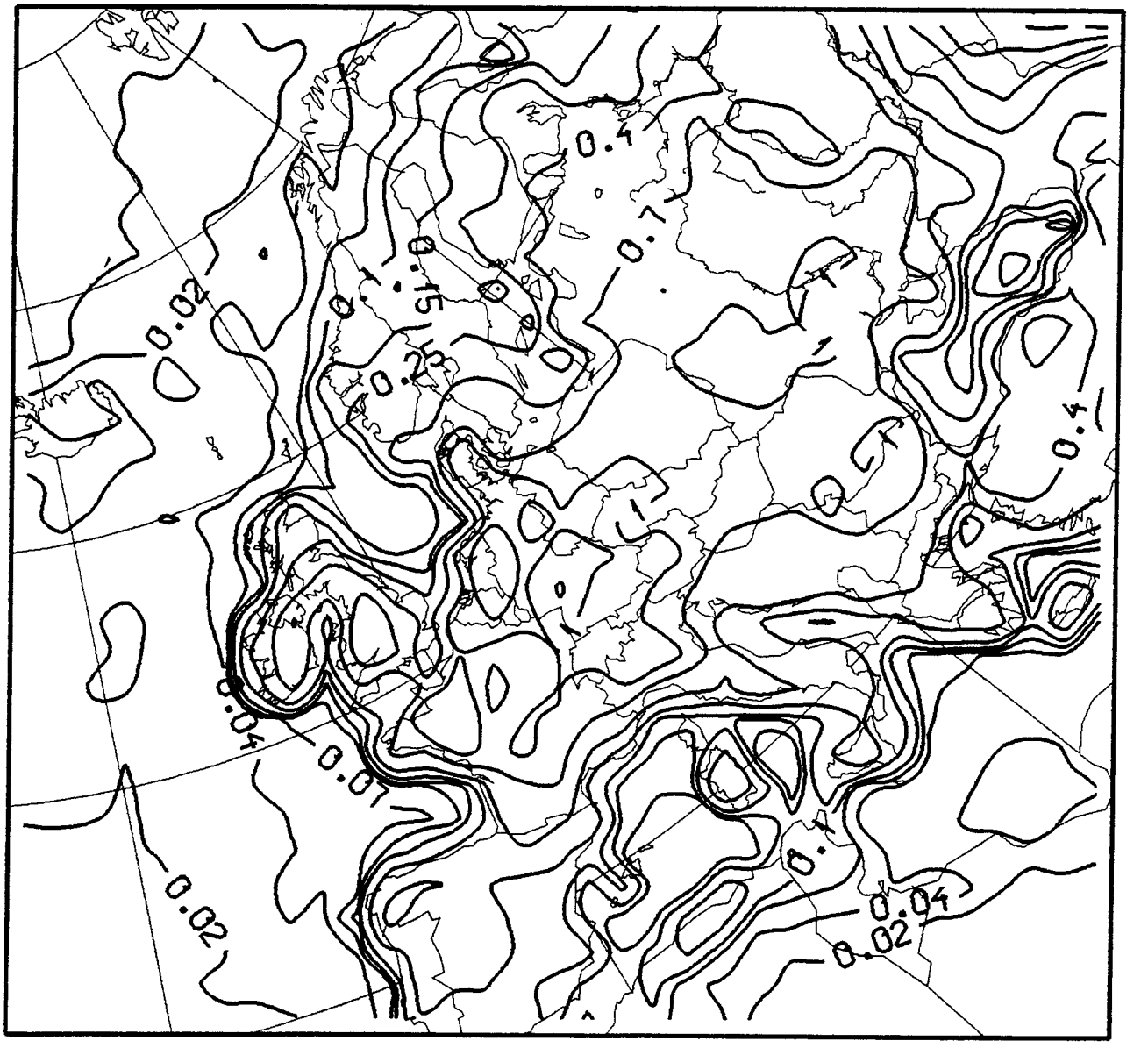

Figure 10. Model estimated annual deposition of Reduced Nitrogen for 1988.
Isolines for 0.01, 0.02, 0.04, 0.07, 0.1, 0.15, 0.25,
0.4, 0.7, 1.0, 1.5, 2.5, 4.0, 7.0, 10.0 g(N) m^{-2}.

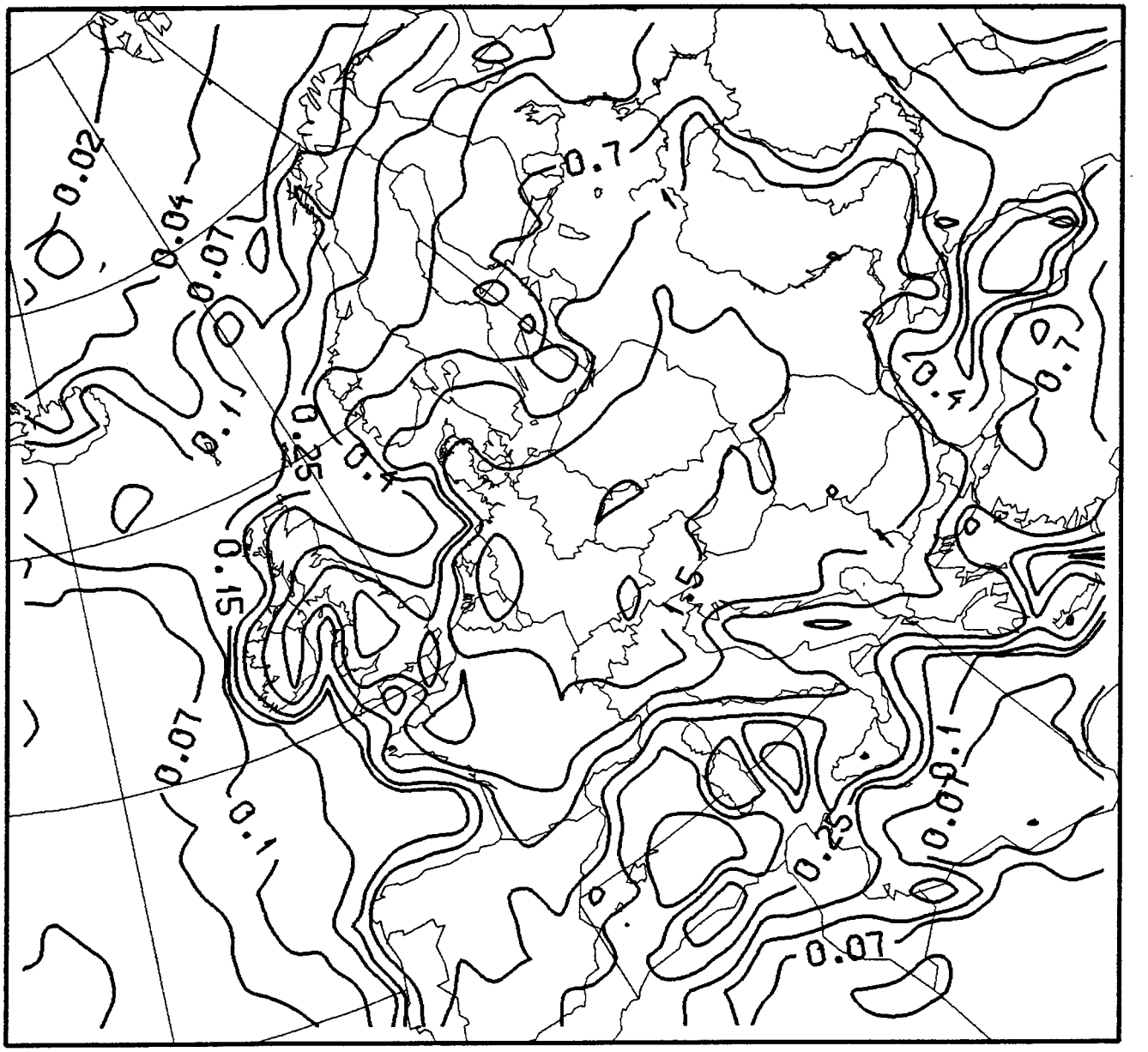

Figure 11. Model estimated annual deposition of Total Nitrogen for 1988.
Isolines for 0.01, 0.02, 0.04, 0.07, 0.1, 0.15, 0.25,
0.4, 0.7, 1.0, 1.5, 2.5, 4.0, 7.0, 10.0 g(N) m^{-2}.

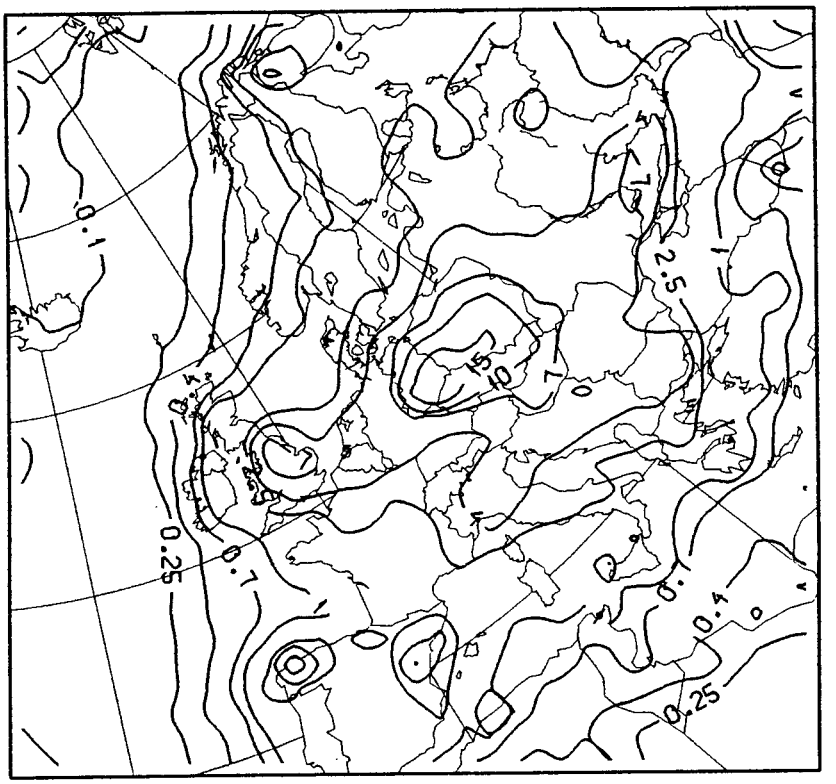

Figure 12. Model estimated annual concentration of Sulphur Dioxide for 1988.
Isolines for 0.01, 0.04, 0.07, 0.1, 0.25, 0.4, 0.7,
1.0, 2.5, 4.0, 7.0, 10., 15., 25., 40.0 μg(S) m^{-3}.

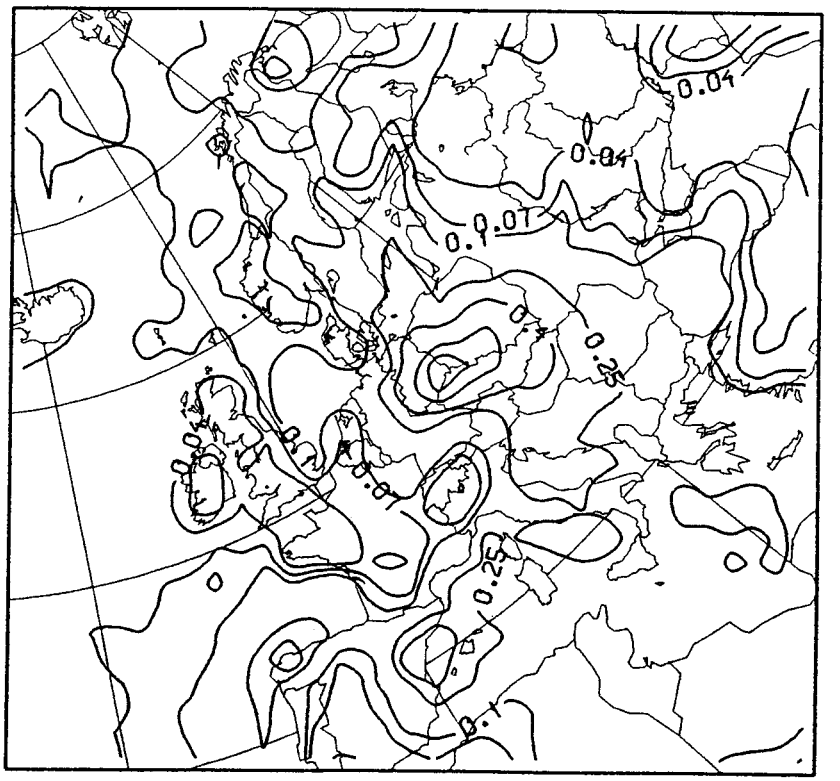

Figure 13. Model estimated annual concentration of Particulate Sulphate
(not including Ammonium Sulphate) for 1988.
Isolines for 0.01, 0.04, 0.07, 0.1, 0.25, 0.4, 0.7,
1.0, 2.5, 4.0, 7.0, 10., 15., 25., 40.0 μg(S) m^{-3}.

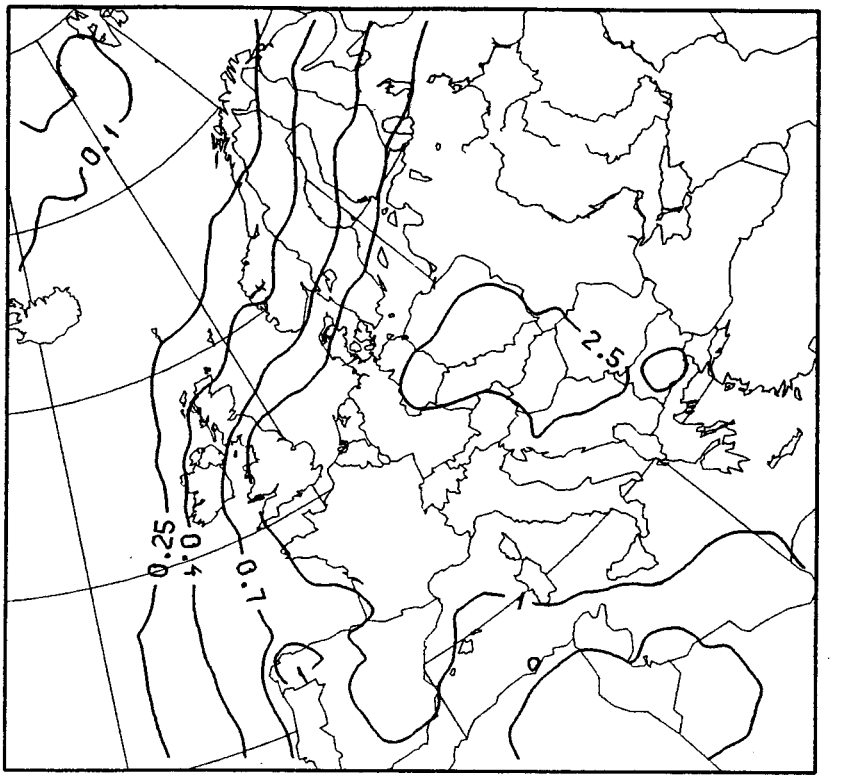

Figure 14. Model estimated annual concentration of Ammonium Sulphate for 1988.
Isolines for 0.01, 0.04, 0.07, 0.1, 0.25, 0.4, 0.7, 1.0, 2.5, 4.0, 7.0, 10., 15., 25., 40.0 μg(S) m^{-3}.

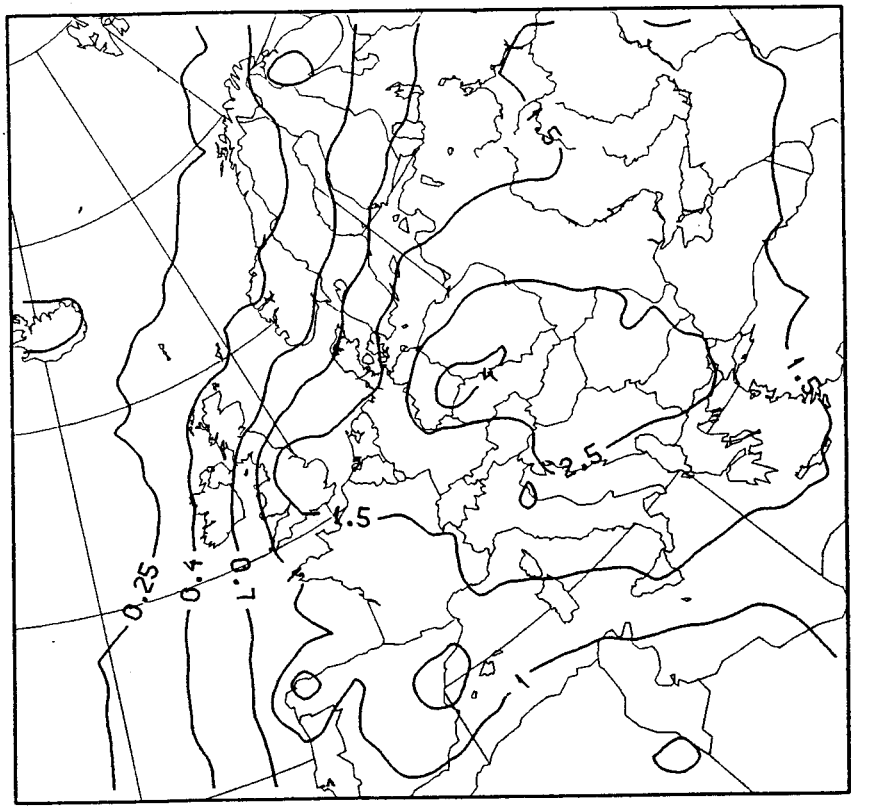

Figure 15. Model estimated annual concentration of Total Particulate Sulphate for 1988.
Isolines for 0.01, 0.04, 0.07, 0.1, 0.25, 0.4, 0.7, 1.0, 2.5, 4.0, 7.0, 10., 15., 25., 40.0 μg(S) m^{-3}.

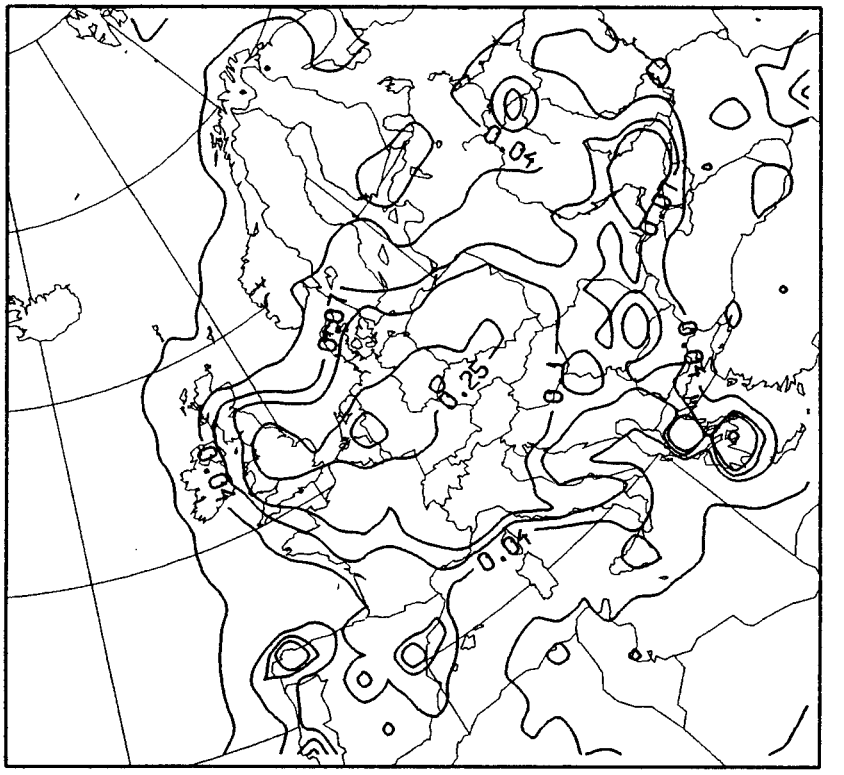

Figure 16. Model estimated annual concentration of Nitrogen Monoxide for 1988.
Isolines for 0.01, 0.04, 0.07, 0.1, 0.25, 0.4, 0.7,
1.0, 2.5, 4.0, 7.0, 10., 15., 25., 40.0 μg(N) m^{-3}.

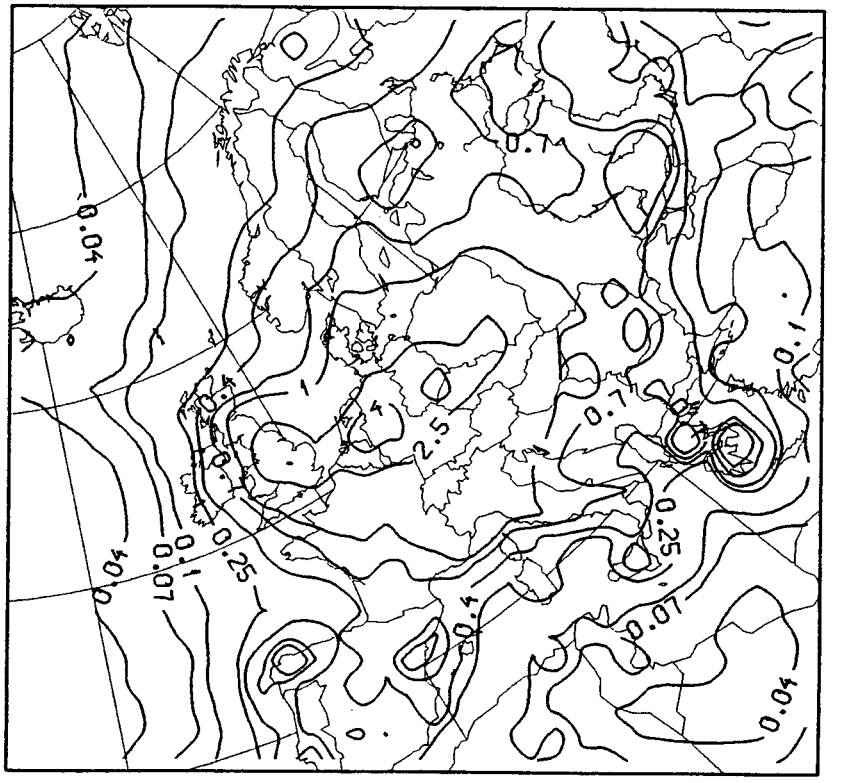

Figure 17. Model estimated annual concentration of Nitrogen Dioxide for 1988.
Isolines for 0.01, 0.04, 0.07, 0.1, 0.25, 0.4, 0.7,
1.0, 2.5, 4.0, 7.0, 10., 15., 25., 40.0 μg(N) m^{-3}.

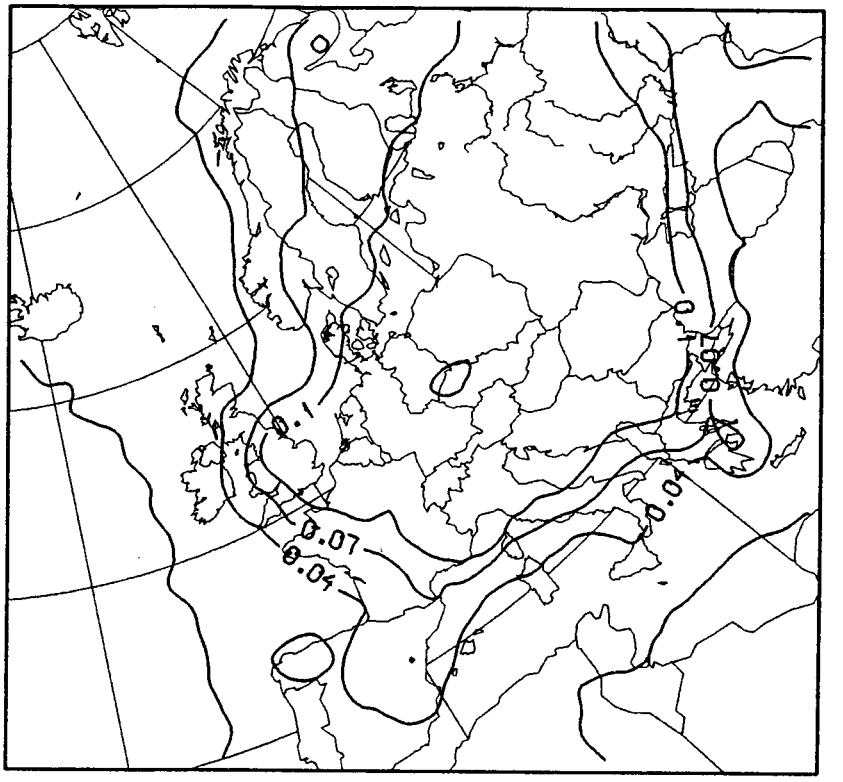

Figure 18. Model estimated annual concentration of PAN for 1988.
Isolines for 0.01, 0.04, 0.07, 0.1, 0.25, 0.4, 0.7,
1.0, 2.5, 4.0, 7.0, 10., 15., 25., 40.0 μg(N) m^{-3}.

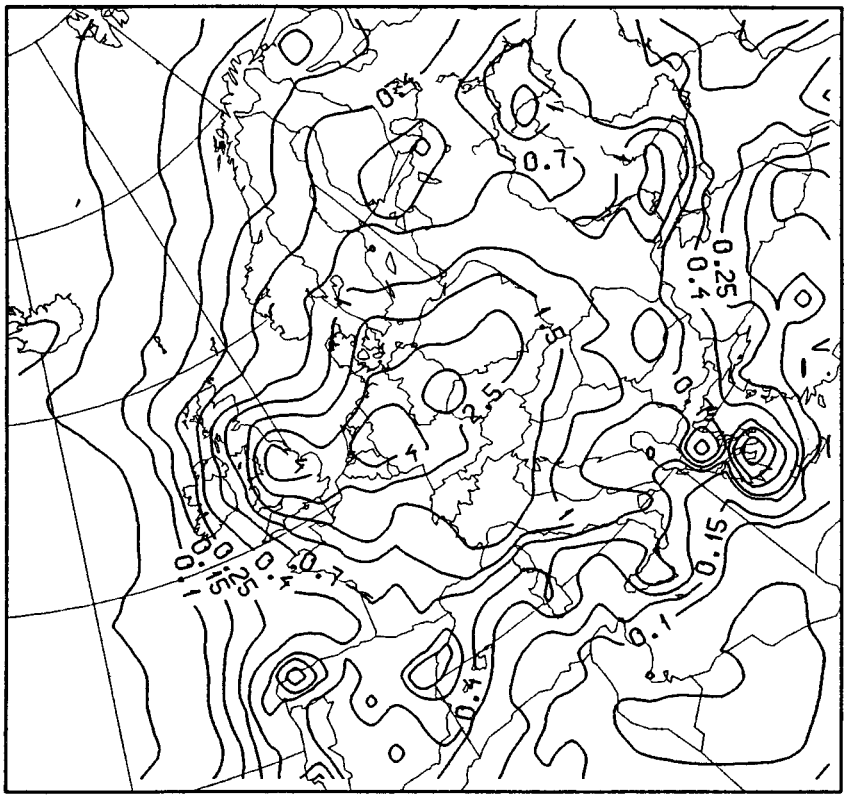

Figure 19. Model estimated annual concentration of Primary Oxidised Nitrogen ($NO + NO_2$ + PAN) for 1988.
Isolines for 0.01, 0.04, 0.07, 0.1, 0.25, 0.4, 0.7,
1.0, 2.5, 4.0, 7.0, 10., 15., 25., 40.0 μg(N) m^{-3}.

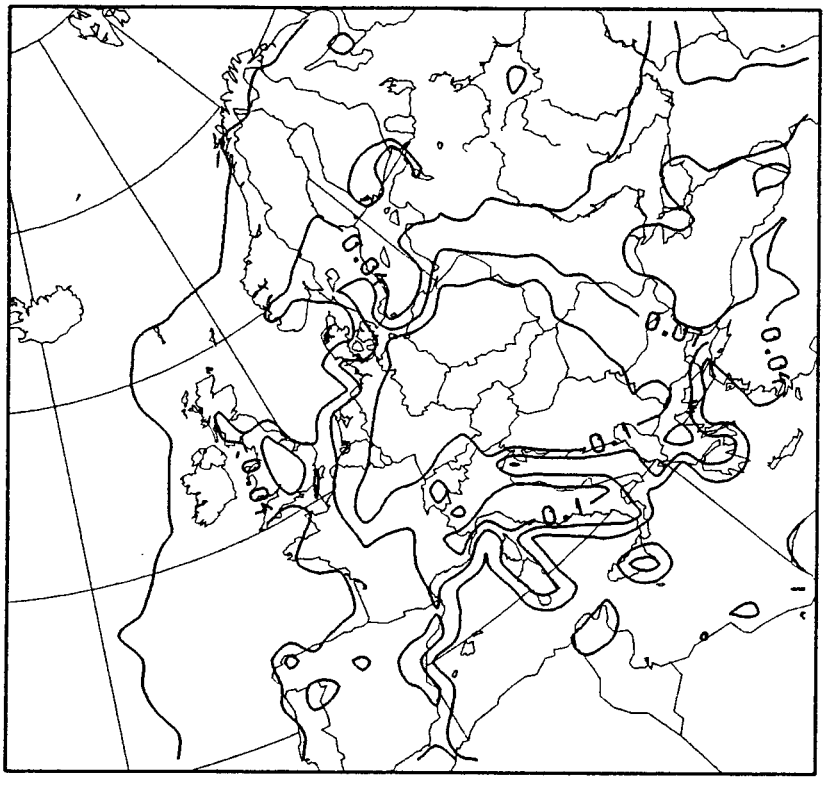

Figure 20. Model estimated annual concentration of gaseous Nitric Acid for 1988.
Isolines for 0.01, 0.04, 0.07, 0.1, 0.25, 0.4, 0.7,
1.0, 2.5, 4.0, 7.0, 10., 15., 25., 40.0 μg(N) m^{-3}.

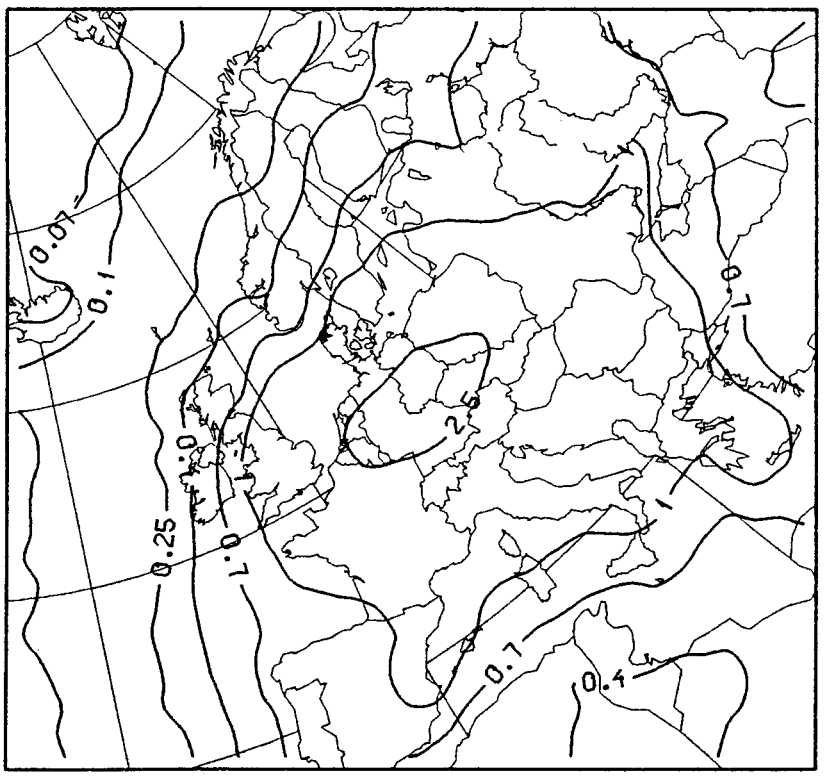

Figure 21. Model estimated annual concentration of Particulate Nitrate (not including Ammonium Nitrate) for 1988.
Isolines for 0.01, 0.04, 0.07, 0.1, 0.25, 0.4, 0.7,
1.0, 2.5, 4.0, 7.0, 10., 15., 25., 40.0 μg(N) m^{-3}.

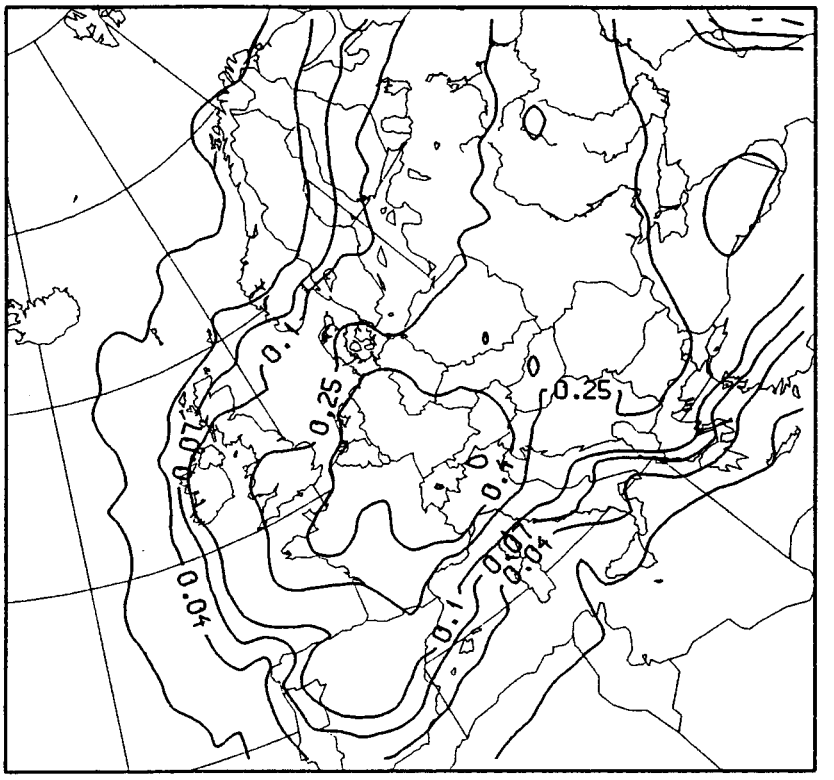

Figure 22. Model estimated annual concentration of Ammonium Nitrate for 1988.
Isolines for 0.01, 0.04, 0.07, 0.1, 0.25, 0.4, 0.7,
1.0, 2.5, 4.0, 7.0, 10., 15., 25., 40.0 μg(N) m^{-3}.

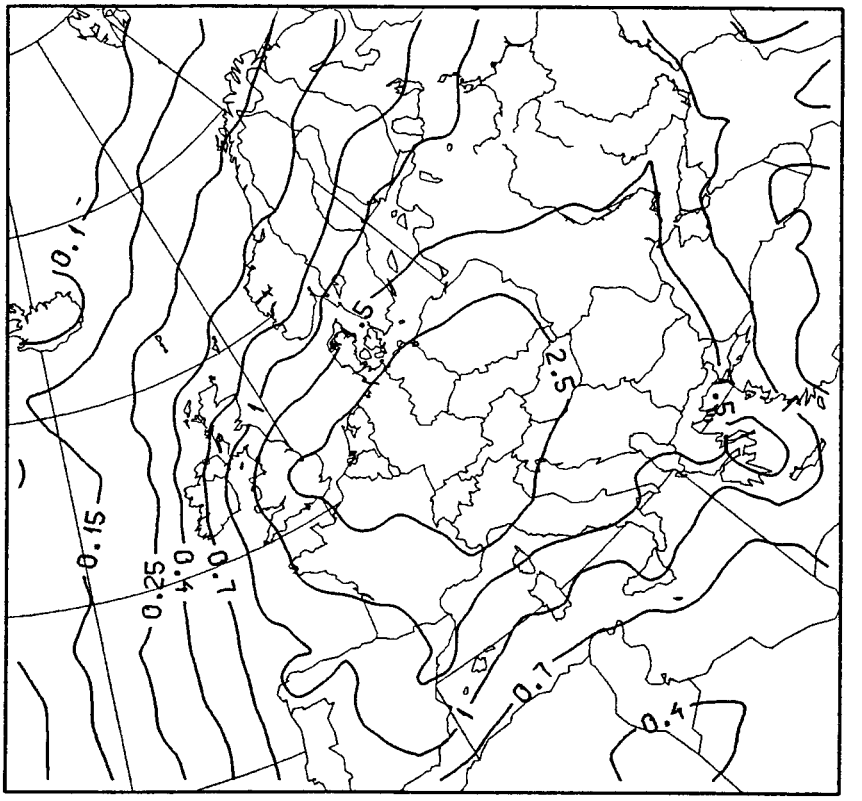

Figure 23. Model estimated annual concentration of Total Nitrate for 1988.
Isolines for 0.01, 0.04, 0.07, 0.1, 0.25, 0.4, 0.7,
1.0, 2.5, 4.0, 7.0, 10., 15., 25., 40.0 μg(N) m^{-3}.

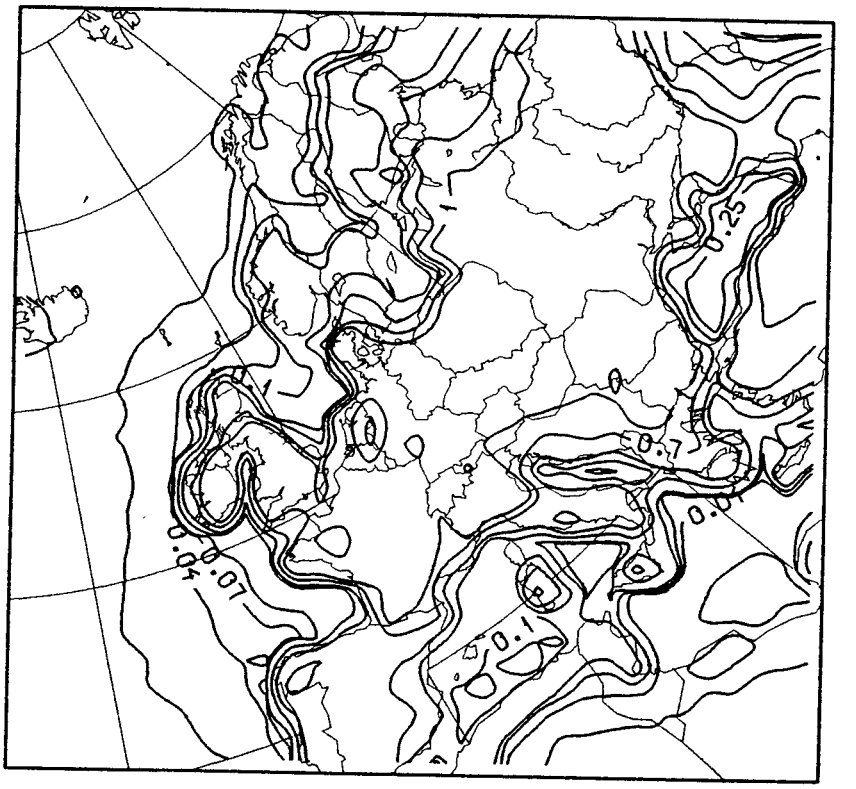

Figure 24. Model estimated annual concentration of Ammonia for 1988.
Isolines for 0.01, 0.04, 0.07, 0.1, 0.25, 0.4, 0.7,
1.0, 2.5, 4.0, 7.0, 10., 15., 25., 40.0 μg(N) m^{-3}.

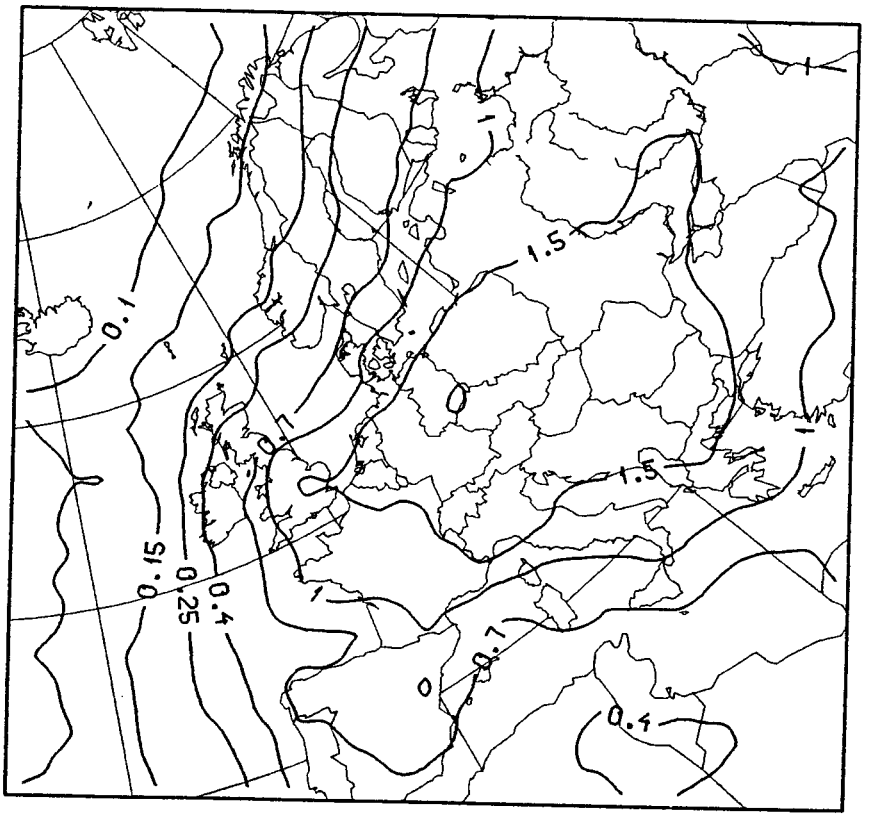

Figure 25. Model estimated annual concentration of Total Ammonium for 1988.
Isolines for 0.01, 0.04, 0.07, 0.1, 0.25, 0.4, 0.7,
1.0, 2.5, 4.0, 7.0, 10., 15., 25., 40.0 μg(N) m^{-3}.

3.2.1 How to read the Matrices

The matrices are splitted into to parts. The upper part gives deposition to areas 1 through 34 (vertical) from emission in areas 1 through 20 (horizontal), while the lower part gives deposition to areas 1 through 34 (vertical) from emissions in areas 21 through 36 in addition to the total depositions denoted by SUM (horizontal).

To find the contributions from other countries to a certain country, follow the horizontal row starting from the relevant country code on the far left. To find the contributions to other countries from a certain country, follow the vertical collumn starting from the relevant country code at the top.

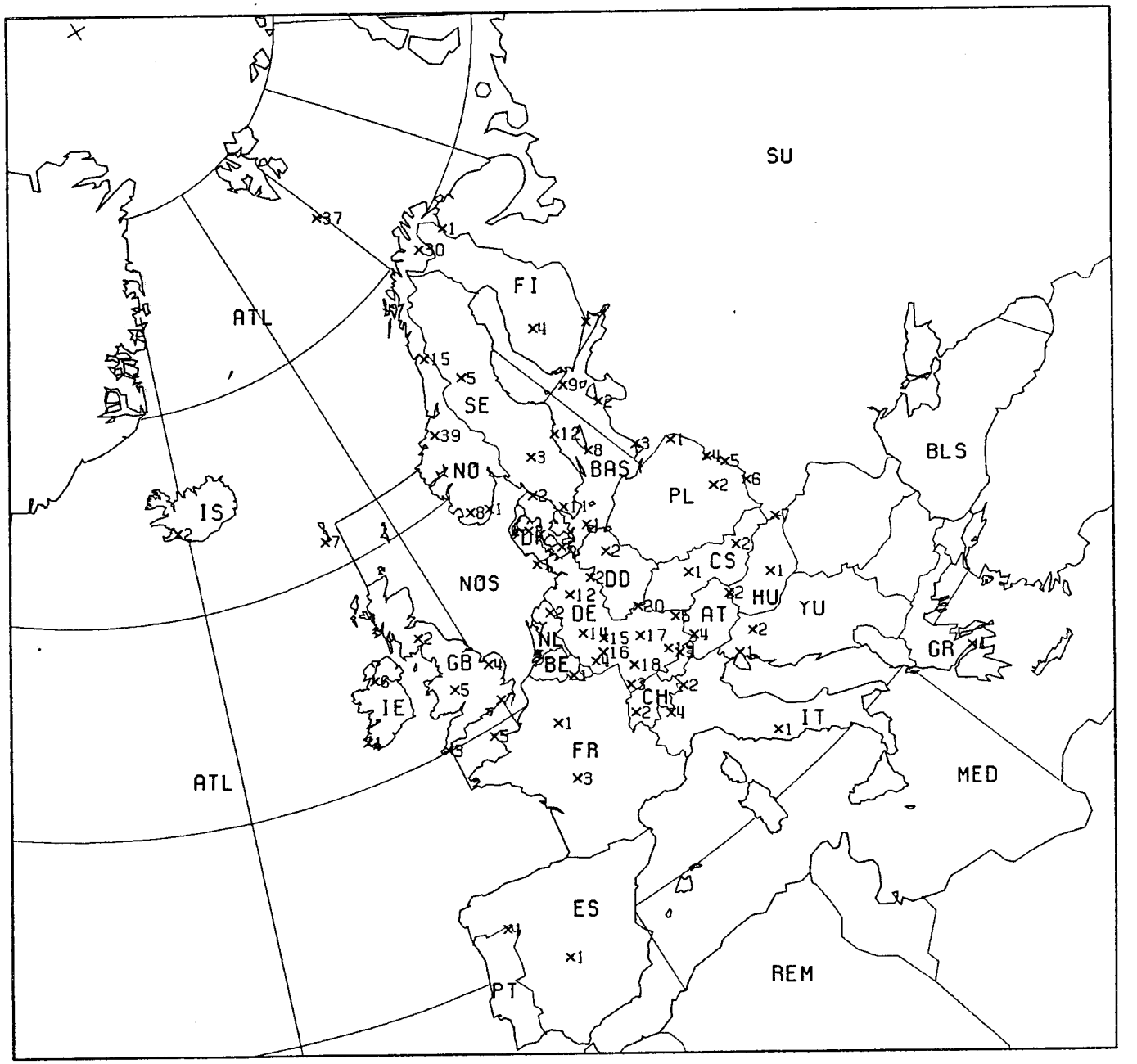

Figure 26. Map showing the different emission sub-domains.
EMEP monitoring stations for 1988 are also marked.

TABLE 13: Budget of Oxidised Sulphur in 1988. (Unit: 100 tonnes as S)

Emitters

Receivers	AL	AT	BE	BG	CS	DK	FI	FR	DD	DE	GR	HU	IS	IE	IT	LU	NL	NO	PL	PT	
AL	38	1	1	14	14	0	0	3	19	3	12	14	0	0	38	0	1	0	12	0	AL
AT	0	131	24	3	278	4	1	77	369	145	0	66	0	1	195	1	13	0	112	0	AT
BE	0	0	405	0	9	1	0	112	29	69	0	1	0	2	2	2	36	0	8	0	BE
BG	4	3	2	1207	63	1	1	5	66	11	33	87	0	0	38	0	2	0	60	0	BG
CS	0	25	28	6	3485	8	1	56	1403	166	1	332	0	1	58	1	17	1	573	0	CS
DK	0	0	13	0	23	135	1	15	109	52	0	3	0	2	1	0	12	2	45	0	DK
FI	0	1	8	1	43	17	470	11	125	34	0	12	0	1	2	0	7	4	140	0	FI
FR	0	3	201	1	74	7	1	1981	223	224	1	18	0	13	178	7	68	0	39	16	FR
DD	0	3	46	0	522	21	1	65	6331	297	0	12	0	2	13	2	35	1	178	1	DD
DE	0	12	226	1	268	29	1	384	1071	1956	0	27	0	9	83	10	149	2	140	2	DE
GR	9	1	2	158	35	1	0	6	40	8	453	36	0	0	46	0	1	0	33	0	GR
HU	0	17	7	10	283	2	1	17	202	34	2	1520	0	0	82	0	5	0	173	0	HU
IS	0	0	0	0	0	1	0	1	1	1	0	0	5	1	0	0	0	0	2	0	IS
IE	0	0	2	0	0	0	0	5	2	2	0	0	0	153	0	0	1	0	1	1	IE
IT	1	15	22	9	146	4	0	147	217	85	7	85	0	2	2859	1	11	0	95	2	IT
LU	0	0	3	0	1	0	0	9	2	5	0	0	0	0	0	10	1	0	0	0	LU
NL	0	0	97	0	15	2	0	64	50	148	0	0	0	2	1	1	204	0	16	0	NL
NO	0	1	24	0	50	41	14	28	200	68	0	8	0	6	1	0	23	78	114	0	NO
PL	0	15	53	10	1139	49	9	79	2730	273	1	229	0	3	52	2	43	2	6672	1	PL
PT	0	0	1	0	0	0	0	5	1	1	0	0	0	0	0	0	1	0	0	206	PT
RO	2	10	8	160	305	4	3	19	312	45	17	458	0	0	102	0	7	0	346	0	RO
ES	0	0	19	0	5	1	0	107	17	17	0	6	0	3	14	0	10	0	4	112	ES
SE	0	2	26	0	125	103	77	34	457	107	0	24	0	4	4	1	23	25	298	1	SE
CH	0	2	15	1	22	1	0	97	68	54	0	5	0	1	147	1	7	0	10	1	CH
TR	2	2	3	144	52	1	1	9	60	11	76	54	0	0	38	0	2	0	75	0	TR
SU	2	20	55	122	981	85	254	97	1632	263	22	651	0	4	118	2	43	9	3167	1	SU
GB	0	0	33	0	11	4	0	64	57	36	0	0	0	56	1	0	20	1	18	1	GB
YU	14	26	17	131	320	3	2	51	336	70	30	415	0	1	444	1	10	0	225	1	YU
REM	1	2	10	6	26	2	0	52	41	17	9	11	0	1	85	0	5	0	13	8	REM
BAS	0	49	109	2	257	247	201	60	963	228	0	49	0	5	11	1	39	10	926	1	BAS
NOS	0	1	213	0	98	122	4	355	457	306	0	6	0	48	6	2	285	34	183	4	NOS
ATL	17	0	71	0	39	38	62	302	175	96	0	5	10	199	5	1	45	38	102	204	ATL
MED	40	23	56	253	369	14	2	362	501	149	445	285	0	6	2194	2	30	1	309	23	MED
BLS	1	2	3	180	126	3	13	6	107	16	27	77	0	0	25	0	2	0	187	0	BLS
SUM	115	324	1739	2419	9144	950	1087	468	418	372	4997	1139	4496	15	530	6842	48	1158	21114	276	586	SUM
	AL	AT	BE	BG	CS	DK	FI	FR	DD	DE	GR	HU	IS	IE	IT	LU	NL	NO	PL	PT	

Emitters

Receivers	RO	ES	SE	CH	TR	SU	GB	YU	REM	BAS	NOS	ATL	MED	BLS	NAT	IND	SUM	
AL	1	3	0	0	1	6	4	36	2	0	0	0	0	0	7	55	285	AL
AT	2	18	1	12	0	9	65	80	0	1	6	2	0	0	8	138	1764	AT
BE	0	8	0	0	0	2	119	0	0	0	12	2	0	0	6	42	867	BE
BG	36	3	1	0	5	144	7	157	2	0	1	0	0	0	12	181	2130	BG
CS	6	12	3	3	0	39	72	82	0	2	7	2	0	0	9	182	6580	CS
DK	0	1	6	0	0	8	96	1	0	5	10	1	0	0	10	55	609	DK
FI	1	1	49	0	0	649	48	6	0	16	4	1	0	0	36	336	2022	FI
FR	0	574	2	14	0	7	536	24	8	1	49	49	0	0	96	725	5141	FR
DD	1	12	3	2	0	13	131	6	0	4	13	2	0	0	12	134	7864	DD
DE	1	57	4	22	0	20	450	21	1	4	45	10	0	0	34	342	5385	DE
GR	7	6	0	0	12	50	7	64	7	0	1	0	0	0	25	215	1225	GR
HU	13	6	1	1	0	37	22	231	1	1	2	1	0	0	5	125	2803	HU
IS	0	0	0	0	0	3	12	0	0	0	1	1	0	0	21	48	98	IS
IE	0	4	0	0	0	0	101	0	0	0	2	9	0	0	19	52	355	IE
IT	2	96	2	21	0	12	97	207	19	1	6	4	0	0	58	503	4737	IT
LU	0	1	0	0	0	0	4	0	0	0	0	0	0	0	0	3	39	LU
NL	0	5	1	0	0	2	177	0	0	0	19	2	0	0	8	48	863	NL
NO	0	3	37	0	0	134	262	1	0	7	19	6	0	0	63	324	1512	NO
PL	10	16	16	3	1	219	199	84	0	14	17	3	0	0	28	445	12417	PL
PT	0	131	0	0	0	0	8	0	2	0	0	21	0	0	13	59	450	PT
RO	317	7	2	1	7	509	27	421	2	1	3	1	0	0	16	404	3519	RO
ES	0	3857	0	1	0	1	106	4	18	0	6	48	2	0	61	364	4785	ES
SE	1	5	306	1	0	243	213	7	0	28	17	4	0	0	59	404	2597	SE
CH	0	28	0	90	0	1	47	9	1	0	3	2	0	0	6	84	704	CH
TR	14	6	1	0	557	248	9	63	6	0	1	0	0	0	49	722	2207	TR
SU	93	20	84	3	64	2028	239	279	2	49	22	5	0	0	165	5128	35708	SU
GB	0	23	1	0	0	2	4775	0	0	1	43	25	0	0	55	183	5412	GB
YU	19	26	2	3	2	70	59	2469	6	1	4	2	0	0	35	454	5250	YU
REM	0	191	1	1	1	3	56	24	605	0	3	5	1	0	55	598	1834	REM
BAS	2	9	177	1	0	649	273	22	0	120	25	4	0	0	131	505	5076	BAS
NOS	0	49	24	1	0	32	3467	1	0	10	292	39	0	0	255	652	6946	NOS
ATL	0	2052	36	1	0	580	1754	2	4	7	62	668	1	0	2137	3238	11951	ATL
MED	23	1210	5	11	87	163	258	626	322	3	16	18	2	0	572	2013	10393	MED
BLS	34	2	2	0	151	1052	12	64	2	1	1	0	0	0	116	634	2848	BLS
SUM	585	8443	770	195	886	2693	3137	12	4991	1010	280	712	939	7	0	4182	19395	156168	SUM
	RO	ES	SE	CH	TR	SU	GB	YU	REM	BAS	NOS	ATL	MED	BLS	NAT	IND	SUM	

TABLE 14: Budget of Oxidised Sulphur in 1989. (Unit: 100 tonnes as S)
PROVISIONAL ESTIMATE ONLY

Emitters

Receivers	AL	AT	BE	BG	CS	DK	FI	FR	DD	DE	GR	HU	IS	IE	IT	LU	NL	NO	PL	PT	
AL	40	1	0	22	11	0	0	1	11	1	18	12	0	0	26	0	0	0	9	0	AL
AT	0	135	18	4	365	4	1	58	412	110	1	93	0	1	240	1	12	0	166	0	AT
BE	0	0	417	0	15	1	0	132	39	66	0	1	0	2	3	2	34	0	8	0	BE
BG	3	2	2	1249	68	2	1	4	66	8	36	83	0	0	22	0	1	0	103	0	BG
CS	0	27	23	5	3642	9	2	54	1437	136	2	314	0	1	46	1	14	0	721	0	CS
DK	0	0	13	0	22	140	1	16	97	36	0	2	0	2	2	0	12	1	26	0	DK
FI	0	0	10	1	43	20	405	12	138	24	0	7	0	2	1	0	8	6	119	0	FI
FR	0	5	212	1	97	6	1	2224	262	212	0	24	0	13	320	8	60	0	53	15	FR
DD	0	3	47	1	638	25	1	76	6794	280	0	16	0	2	13	2	31	1	168	0	DD
DE	0	18	229	2	388	28	2	418	1393	1705	0	24	0	7	118	11	138	1	128	2	DE
GR	9	1	1	199	28	1	0	3	32	4	471	29	0	0	32	0	1	0	40	0	GR
HU	0	19	5	11	341	2	1	13	196	25	3	1468	0	0	72	0	3	0	254	0	HU
IS	0	0	0	0	0	0	0	1	1	1	0	0	5	1	0	0	1	0	0	0	IS
IE	0	0	5	0	4	1	0	9	9	5	0	0	0	194	0	0	3	0	3	0	IE
IT	2	19	19	23	153	3	1	132	199	60	15	88	0	1	3213	1	9	0	95	3	IT
LU	0	0	3	0	1	0	0	11	2	5	0	0	0	0	1	10	1	0	0	0	LU
NL	0	0	109	0	13	2	0	75	47	142	0	1	0	3	2	1	195	0	11	0	NL
NO	0	0	17	1	31	36	11	25	126	43	0	5	0	12	3	0	14	74	64	0	NO
PL	0	14	51	9	1233	56	10	90	3067	243	2	183	0	5	42	2	36	2	6516	1	PL
PT	0	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	0	0	255	PT
RO	3	9	7	165	330	4	3	14	296	31	24	468	0	0	66	0	5	0	454	0	RO
ES	0	0	10	1	5	1	0	96	17	14	1	4	0	3	41	0	4	0	4	113	ES
SE	0	1	27	2	101	114	52	36	351	77	1	16	0	7	9	0	22	28	239	1	SE
CH	0	4	15	0	30	1	0	91	81	45	0	5	0	0	200	1	6	0	7	1	CH
TR	1	1	1	107	31	1	1	2	51	6	59	29	0	0	13	0	1	0	78	0	TR
SU	1	19	67	124	1037	115	248	103	1949	245	25	544	0	11	97	2	50	13	3183	1	SU
GB	0	0	48	0	17	7	1	91	64	40	0	1	0	72	3	0	29	0	32	2	GB
YU	14	29	7	160	361	5	2	31	310	43	40	478	0	0	385	0	4	0	255	0	YU
REM	0	1	6	6	7	0	0	31	8	7	11	5	0	1	73	0	2	0	4	5	REM
BAS	0	44	114	3	214	283	156	72	895	189	1	32	0	8	14	1	41	11	737	1	BAS
NOS	0	2	222	1	112	105	3	399	416	248	0	7	0	62	11	2	268	30	115	3	NOS
ATL	21	1	96	1	36	34	57	400	162	109	0	3	10	252	17	2	54	34	62	232	ATL
MED	45	18	33	323	284	5	1	270	326	74	525	242	0	4	2340	1	15	0	241	18	MED
BLS	1	2	3	155	109	4	11	4	128	14	21	57	0	0	11	0	2	0	231	0	BLS
SUM	120	333	1776	2575	9734	1016	941	4998	19379	4247	1256	4241	16	667	7437	50	1074	206	14125	657	SUM
	AL	AT	BE	BG	CS	DK	FI	FR	DD	DE	GR	HU	IS	IE	IT	LU	NL	NO	PL	PT	

Emitters

Receivers	RO	ES	SE	CH	TR	SU	GB	YU	REM	BAS	NOS	ATL	MED	BLS	NAT	IND	SUM	
AL	2	3	0	0	0	5	1	40	2	0	0	0	0	0	6	52	265	AL
AT	3	13	2	12	0	21	41	96	1	1	3	1	0	0	7	176	1999	AT
BE	0	8	0	0	0	1	106	1	0	0	12	2	0	0	5	39	894	BE
BG	41	1	1	0	12	139	4	168	2	0	1	0	0	0	12	213	2244	BG
CS	5	9	3	3	0	56	47	77	0	2	5	1	0	0	8	214	6867	CS
DK	0	3	5	0	0	4	98	1	0	5	10	1	0	0	10	49	558	DK
FI	1	1	55	0	0	450	71	3	0	15	5	1	0	0	36	343	1780	FI
FR	0	534	1	18	0	4	510	55	7	1	51	39	0	0	88	729	5553	FR
DD	0	11	3	1	0	14	109	8	0	5	13	2	0	0	11	143	8421	DD
DE	1	60	4	26	0	18	362	19	0	5	41	7	0	0	28	345	5529	DE
GR	10	3	0	0	16	54	2	53	5	0	0	0	0	0	24	209	1227	GR
HU	15	5	1	1	0	52	11	261	1	1	1	0	0	0	5	165	2933	HU
IS	0	1	0	0	0	0	15	0	0	0	0	1	0	0	22	48	98	IS
IE	0	5	0	0	0	1	109	0	0	0	3	9	0	0	23	70	452	IE
IT	4	83	1	21	1	13	51	277	22	1	4	3	0	0	61	554	5132	IT
LU	0	1	0	0	0	0	3	0	0	0	0	0	0	0	0	3	41	LU
NL	0	8	0	0	0	1	162	0	0	0	20	2	0	0	8	45	847	NL
NO	0	6	24	0	0	102	333	5	0	5	19	8	0	0	78	398	1444	NO
PL	7	15	18	3	1	210	164	77	1	17	17	3	0	0	29	483	12603	PL
PT	0	172	0	0	0	0	5	0	3	0	0	23	0	0	15	75	555	PT
RO	320	6	2	1	13	489	19	443	2	1	2	0	0	0	15	441	3633	RO
ES	0	4290	0	0	0	1	74	12	28	0	5	44	3	0	68	478	5319	ES
SE	1	5	277	0	0	123	225	9	0	24	19	5	0	0	62	408	2244	SE
CH	0	27	0	91	0	1	37	9	1	0	3	2	0	0	5	80	744	CH
TR	12	3	1	0	551	262	5	32	4	0	0	0	0	0	45	697	1996	TR
SU	84	21	103	2	48	184	31	347	243	2	58	29	5	0	170	4833	32210	SU
GB	0	29	2	0	0	12	4784	1	0	1	50	28	0	0	63	224	5602	GB
YU	27	20	1	2	2	80	18	2889	7	1	2	1	0	0	31	519	5725	YU
REM	0	97	0	1	1	3	12	13	604	0	1	3	1	0	53	624	1577	REM
BAS	2	13	179	1	0	415	295	16	1	119	29	4	0	0	131	487	4508	BAS
NOS	0	63	19	1	0	25	3335	4	0	8	295	42	0	0	254	616	6669	NOS
ATL	0	2197	31	1	0	512	1808	6	4	6	68	685	1	0	2127	3203	12232	ATL
MED	29	1050	1	7	119	171	100	688	344	1	9	12	2	0	603	2044	9944	MED
BLS	32	2	2	0	134	902	13	54	1	1	1	0	0	0	108	597	2602	BLS
SUM	598	8765	737	194	898	2257	3132	76	5559	1041	281	720	936	8	0	4210	19603	154248	SUM
	RO	ES	SE	CH	TR	SU	GB	YU	REM	BAS	NOS	ATL	MED	BLS	NAT	IND	SUM	

TABLE 15: Budget of Oxidised Nitrogen in 1988. (Unit: 100 tonnes as N)

Emitters

Receivers	AL	AT	BE	BG	CS	DK	FI	FR	DD	DE	GR	HU	IS	IE	IT	LU	NL	NO	PL	PT	
AL	1	1	1	1	5	0	0	4	3	7	10	2	0	0	22	0	1	0	4	0	AL
AT	0	34	15	0	62	4	1	83	50	238	1	9	0	1	88	1	23	1	30	0	AT
BE	0	0	26	0	2	1	0	58	4	50	0	0	0	1	1	1	25	0	2	0	BE
BG	0	4	1	24	17	1	1	5	10	20	36	14	0	0	23	0	3	0	18	0	BG
CS	0	24	19	1	207	8	1	63	143	281	1	37	0	1	38	1	33	2	115	0	CS
DK	0	0	8	0	6	17	0	17	18	71	0	1	0	1	1	0	20	3	14	0	DK
FI	0	1	7	0	16	21	119	16	30	83	0	2	0	1	1	0	18	13	54	0	FI
FR	0	4	74	0	21	5	1	777	35	295	2	3	0	7	81	5	81	2	12	10	FR
DD	0	4	28	0	76	14	1	72	170	356	0	2	0	1	9	2	56	3	44	0	DD
DE	0	11	103	0	67	18	1	329	122	993	0	5	0	5	40	8	175	7	43	1	DE
GR	1	2	1	9	10	1	0	8	6	16	129	6	0	0	28	0	2	0	10	0	GR
HU	0	18	5	1	59	2	1	21	30	67	3	59	0	0	55	0	9	0	50	0	HU
IS	0	0	0	0	0	1	1	1	0	3	0	0	2	0	0	0	1	1	1	0	IS
IE	0	0	1	0	0	0	0	8	0	5	0	0	0	9	0	0	2	0	0	1	IE
IT	0	16	13	1	40	4	0	162	33	138	10	15	0	1	480	1	18	1	29	2	IT
LU	0	0	1	0	0	0	0	5	0	5	0	0	0	0	0	0	1	0	0	0	LU
NL	0	0	23	0	4	1	0	42	6	73	0	0	0	1	0	0	51	1	5	0	NL
NO	0	1	18	0	17	34	11	38	42	146	0	1	0	4	1	0	47	60	42	0	NO
PL	0	19	37	1	237	39	9	97	330	481	1	31	0	2	34	2	81	7	579	0	PL
PT	0	0	1	0	0	0	0	5	0	3	0	0	0	0	0	0	1	0	0	28	PT
RO	0	14	6	15	81	4	3	22	49	87	21	65	0	0	62	0	13	1	104	0	RO
ES	0	0	11	0	2	1	0	103	3	31	0	1	0	2	9	0	17	0	2	48	ES
SE	0	3	20	0	43	68	51	43	92	210	0	5	0	3	3	1	48	43	111	0	SE
CH	0	2	8	0	6	1	0	88	9	76	0	1	0	1	47	1	11	0	3	0	CH
TR	0	3	2	12	16	1	1	11	11	24	89	10	0	0	24	0	4	0	27	0	TR
SU	0	34	41	15	299	89	176	129	323	561	29	104	0	3	80	2	90	31	984	0	SU
GB	0	0	13	0	3	3	1	55	11	54	0	0	0	19	1	0	22	2	7	1	GB
YU	1	29	11	10	89	3	2	64	52	130	32	59	0	0	252	1	19	1	73	0	YU
REM	0	4	8	1	10	2	0	73	9	40	12	2	0	1	53	0	11	1	5	4	REM
BAS	0	5	29	0	66	75	58	71	143	331	0	8	0	3	7	1	68	18	188	0	BAS
NOS	0	2	73	0	26	47	3	226	71	352	0	1	0	20	4	2	168	31	50	3	NOS
ATL	0	1	42	0	12	40	25	246	38	189	0	1	7	48	3	1	79	81	38	33	ATL
MED	2	24	29	15	77	11	2	313	60	222	220	34	0	2	546	2	43	2	70	10	MED
BLS	0	2	2	7	19	2	2	5	14	24	22	10	0	0	11	0	3	0	45	0	BLS
SUM	7	262	677	114	1594	516	470	3259	1916	5659	618	489	11	135	2003	36	1243	315	2758	144	SUM
	AL	AT	BE	BG	CS	DK	FI	FR	DD	DE	GR	HU	IS	IE	IT	LU	NL	NO	PL	PT	

Emitters

Receivers	RO	ES	SE	CH	TR	SU	GB	YU	REM	BAS	NOS	ATL	MED	BLS	NAT	IND	SUM	
AL	2	1	0	0	0	2	2	8	0	0	0	0	0	0	0	18	96	AL
AT	3	5	3	19	0	3	42	15	0	1	5	2	0	0	0	57	796	AT
BE	0	3	1	0	0	1	55	0	0	0	6	3	0	0	0	17	258	BE
BG	37	1	1	0	2	43	4	26	0	0	1	0	0	0	0	54	345	BG
CS	8	3	6	6	0	12	51	18	0	2	7	2	0	0	0	72	1163	CS
DK	0	0	5	0	0	3	63	0	0	2	7	1	0	0	0	22	283	DK
FI	1	0	68	1	0	133	39	2	0	13	6	1	0	0	0	107	753	FI
FR	1	152	4	19	0	3	268	6	2	1	32	51	0	0	0	250	2203	FR
DD	1	3	6	4	0	6	84	2	0	3	12	3	0	0	0	58	1019	DD
DE	2	16	9	32	0	8	261	5	0	3	34	11	0	0	0	142	2450	DE
GR	11	2	1	0	3	17	4	15	1	0	0	0	0	0	0	72	360	GR
HU	15	1	2	3	0	10	14	40	0	1	2	1	0	0	0	42	510	HU
IS	0	0	1	0	0	3	12	0	0	0	1	1	0	0	0	27	58	IS
IE	0	2	0	0	0	0	48	0	0	0	2	7	0	0	0	22	108	IE
IT	4	32	3	26	0	5	59	42	3	1	5	4	0	0	0	173	1320	IT
LU	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	18	LU
NL	0	1	1	0	0	1	78	0	0	0	9	2	0	0	0	19	320	NL
NO	0	1	50	1	0	23	193	0	0	7	20	6	0	0	0	121	885	NO
PL	14	4	27	7	0	59	138	19	0	11	18	4	0	0	0	164	2452	PL
PT	0	24	0	0	0	0	5	0	0	0	1	16	0	0	0	38	123	PT
RO	136	2	4	3	3	128	18	65	0	1	3	1	0	0	0	118	1029	RO
ES	1	366	0	1	0	0	69	1	4	0	7	44	2	0	0	173	898	ES
SE	3	2	155	2	0	92	151	2	0	19	19	4	0	0	0	141	1331	SE
CH	0	8	1	28	0	0	30	2	0	0	3	2	0	0	0	31	360	CH
TR	24	2	2	1	72	109	5	16	1	0	1	0	0	0	0	264	731	TR
SU	125	6	154	10	25	3368	177	72	0	46	26	6	0	0	0	1463	8466	SU
GB	0	8	3	0	0	1	573	0	0	1	20	23	0	0	0	71	891	GB
YU	28	8	4	7	1	22	33	161	1	1	4	2	0	0	0	146	1247	YU
REM	1	56	1	4	0	2	41	8	37	0	4	5	1	0	0	333	726	REM
BAS	4	2	104	3	0	128	171	5	0	27	22	5	0	0	0	152	1692	BAS
NOS	0	13	23	2	0	10	978	0	0	7	73	34	0	0	0	221	2441	NOS
ATL	1	181	46	2	0	66	883	1	0	8	56	257	0	0	0	1379	3761	ATL
MED	28	170	9	17	12	44	127	92	24	2	12	13	1	0	0	579	2816	MED
BLS	30	0	3	1	20	226	6	10	0	1	1	0	0	0	0	133	598	BLS
SUM	477	1076	698	200	139	4526	4684	632	76	158	416	513	5	0	0	6678	42503	SUM
	RO	ES	SE	CH	TR	SU	GB	YU	REM	BAS	NOS	ATL	MED	BLS	NAT	IND	SUM	

TABLE 16: Budget of Oxidised Nitrogen in 1989. (Unit: 100 tonnes as N)
PROVISIONAL ESTIMATE ONLY

Emitters

Receivers	AL	AT	BE	BG	CS	DK	FI	FR	DD	DE	GR	HU	IS	IE	IT	LU	NL	NO	PL	PT	
AL	1	1	0	2	3	0	0	1	2	3	16	2	0	0	15	0	0	0	3	0	AL
AT	0	48	12	0	79	5	1	65	58	221	1	14	0	0	106	1	25	1	50	0	AT
BE	0	1	31	0	4	1	0	70	5	59	0	0	0	1	2	1	29	0	3	0	BE
BG	0	3	1	28	18	1	1	3	10	15	41	13	0	0	13	0	2	0	30	0	BG
CS	0	27	16	1	245	9	2	63	149	270	3	38	0	1	31	1	31	2	161	0	CS
DK	0	1	7	0	6	18	1	17	15	54	0	0	0	1	1	0	19	3	7	0	DK
FI	0	1	9	0	15	23	108	18	33	68	0	1	0	2	1	0	19	18	45	0	FI
FR	0	8	87	0	30	6	1	941	43	340	0	5	0	7	147	5	89	2	18	10	FR
DD	0	4	28	0	96	16	2	80	216	409	0	3	0	1	9	2	57	3	41	0	DD
DE	0	17	111	0	95	18	2	357	170	1174	0	5	0	4	53	8	200	5	41	2	DE
GR	1	2	1	12	9	1	0	4	6	10	146	5	0	0	20	0	1	0	13	0	GR
HU	0	20	3	1	71	2	1	16	29	57	5	76	0	0	51	0	6	0	77	0	HU
IS	0	0	1	0	0	0	0	2	0	3	0	0	2	1	0	0	2	1	0	0	IS
IE	0	0	4	0	1	1	0	15	2	14	0	0	0	13	0	0	8	0	1	0	IE
IT	0	23	13	3	43	3	1	157	32	128	20	15	0	1	599	1	19	1	33	2	IT
LU	0	0	2	0	0	0	0	7	0	5	0	0	0	0	0	0	1	0	0	0	LU
NL	0	1	27	0	3	2	0	46	6	89	0	0	0	1	1	0	62	1	3	0	NL
NO	0	1	14	0	10	29	10	39	31	109	0	1	0	7	2	0	32	59	22	0	NO
PL	0	19	33	1	259	43	12	107	358	482	2	30	0	3	31	2	72	8	617	1	PL
PT	0	0	0	0	0	0	0	4	0	1	0	0	0	0	1	0	0	0	0	44	PT
RO	0	12	4	16	82	4	3	15	45	67	31	71	0	0	44	0	10	1	125	0	RO
ES	0	0	7	0	2	1	0	117	4	32	2	1	0	2	34	0	9	0	2	60	ES
SE	0	2	18	0	31	72	39	45	70	162	1	3	0	5	7	1	43	52	83	0	SE
CH	0	4	10	0	9	1	0	90	13	94	0	1	0	0	59	1	12	0	2	1	CH
TR	0	2	1	8	11	1	1	3	11	15	68	6	0	0	10	0	2	0	29	0	TR
SU	0	32	49	14	312	116	192	141	379	601	34	92	0	7	76	2	116	39	956	1	SU
GB	0	1	20	0	6	6	1	73	12	73	0	0	0	23	2	0	39	2	12	1	GB
YU	2	36	5	16	95	5	2	38	49	96	48	74	0	0	226	0	10	1	86	0	YU
REM	0	1	5	1	2	0	0	50	2	18	17	1	0	0	46	0	6	0	1	3	REM
BAS	0	4	29	0	59	86	49	74	138	292	1	5	0	4	10	1	67	22	156	0	BAS
NOS	0	3	63	0	25	34	2	209	54	291	0	1	1	23	5	2	147	25	30	2	NOS
ATL	0	1	60	0	12	32	25	376	34	250	0	1	7	57	11	2	104	70	21	42	ATL
MED	2	21	19	20	60	4	1	246	40	140	264	30	0	2	574	1	26	1	61	8	MED
BLS	0	2	1	6	15	3	2	3	16	22	20	7	0	0	5	0	3	0	47	0	BLS
SUM	8	297	688	131	1710	542	457	3493	2032	5663	721	504	12	168	2191	35	1271	318	2774	181	SUM
	AL	AT	BE	BG	CS	DK	FI	FR	DD	DE	GR	HU	IS	IE	IT	LU	NL	NO	PL	PT	

Emitters

Receivers	RO	ES	SE	CH	TR	SU	GB	YU	REM	BAS	NOS	ATL	MED	BLS	NAT	IND	SUM	
AL	2	1	0	0	0	2	0	8	0	0	0	0	0	0	0	15	80	AL
AT	5	3	5	20	0	7	29	18	0	2	4	1	0	0	0	68	850	AT
BE	0	2	0	0	0	0	58	0	0	0	7	2	0	0	0	17	296	BE
BG	42	0	1	0	4	43	3	26	0	0	0	0	0	0	0	57	358	BG
CS	7	3	7	7	0	18	36	18	0	3	6	1	0	0	0	80	1237	CS
DK	0	1	4	0	0	1	69	0	0	2	7	2	0	0	0	19	257	DK
FI	1	1	76	0	0	88	56	1	0	13	7	2	0	0	0	105	710	FI
FR	1	139	3	24	0	2	328	15	1	1	42	42	0	0	0	273	2611	FR
DD	1	3	6	3	0	6	73	2	0	4	12	2	0	0	0	62	1140	DD
DE	2	16	7	37	0	7	233	5	0	4	33	8	0	0	0	149	2763	DE
GR	14	1	1	0	4	19	1	11	1	0	0	0	0	0	0	64	346	GR
HU	18	1	2	2	0	16	8	46	0	1	1	0	0	0	0	51	565	HU
IS	0	1	0	0	0	0	16	0	0	0	1	1	0	0	0	28	58	IS
IE	0	3	0	0	0	0	50	0	0	0	3	8	0	0	0	29	153	IE
IT	7	30	2	28	0	5	34	55	4	1	4	4	0	0	0	182	1448	IT
LU	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	20	LU
NL	0	2	1	0	0	0	85	0	0	0	11	2	0	0	0	20	365	NL
NO	1	2	33	1	0	10	254	1	0	5	18	9	0	0	0	150	851	NO
PL	9	4	32	8	0	65	118	20	0	13	17	3	0	0	0	171	2542	PL
PT	0	38	0	0	0	0	4	0	1	0	0	19	0	0	0	44	157	PT
RO	156	1	4	1	5	127	12	68	0	1	2	0	0	0	0	113	1022	RO
ES	1	458	1	1	0	0	56	5	6	0	6	43	3	0	0	215	1068	ES
SE	2	2	139	1	0	40	171	2	0	17	20	5	0	0	0	140	1171	SE
CH	0	9	1	37	0	0	25	2	0	0	3	2	0	0	0	32	409	CH
TR	20	1	2	0	73	117	4	9	1	0	0	0	0	0	0	239	633	TR
SU	109	7	180	8	18	2966	270	60	0	52	33	6	0	0	0	1356	8222	SU
GB	0	9	3	1	0	4	664	0	0	1	23	23	0	0	0	89	1089	GB
YU	40	7	3	5	1	25	12	216	1	1	2	1	0	0	0	151	1254	YU
REM	1	34	0	2	1	1	9	5	37	0	2	3	1	0	0	338	587	REM
BAS	3	4	112	2	0	67	176	4	0	27	23	4	0	0	0	143	1561	BAS
NOS	0	16	16	3	0	7	967	1	0	5	68	34	0	0	0	215	2250	NOS
ATL	1	201	40	3	0	39	888	2	0	6	59	256	0	0	0	1371	3972	ATL
MED	34	146	2	12	18	45	57	96	25	1	8	10	1	0	0	562	2537	MED
BLS	26	0	3	0	18	180	6	8	0	1	1	0	0	0	0	116	514	BLS
SUM	500	1149	686	207	142	3906	4775	702	81	163	425	494	6	0	0	6666	43093	SUM
	RO	ES	SE	CH	TR	SU	GB	YU	REM	BAS	NOS	ATL	MED	BLS	NAT	IND	SUM	

TABLE 17: Budget of Reduced Nitrogen in 1988. (Unit: 100 tonnes as N)
VERY FEW COUNTRIES HAVE GIVEN OFFICIAL EMISSION DATA

Emitters

Receivers	AL	AT	BE	BG	CS	DK	FI	FR	DD	DE	GR	HU	IS	IE	IT	LU	NL	NO	PL	PT	
AL	77	0	0	2	1	0	0	2	1	1	6	2	0	0	8	0	0	0	1	0	AL
AT	0	326	7	1	46	3	0	55	23	102	0	17	0	1	66	1	14	0	14	0	AT
BE	0	0	321	0	1	1	0	79	2	13	0	0	0	2	0	2	40	0	1	0	BE
BG	2	1	0	510	5	0	0	2	2	2	17	12	0	0	7	0	1	0	6	0	BG
CS	0	28	7	1	721	5	0	31	73	71	0	49	0	1	15	1	17	0	71	0	CS
DK	0	0	4	0	2	447	0	9	15	30	0	1	0	2	0	0	17	1	11	0	DK
FI	0	1	2	0	5	11	197	6	13	15	0	2	0	1	1	0	9	3	29	0	FI
FR	0	3	75	0	6	4	0	4033	17	59	0	3	0	17	36	6	54	0	6	6	FR
DD	0	3	13	0	16	18	0	38	847	114	0	2	0	2	3	1	42	1	29	0	DD
DE	0	13	82	0	28	27	0	270	91	1621	0	5	0	10	20	8	256	2	23	1	DE
GR	6	1	0	22	3	0	0	4	1	2	333	5	0	0	8	0	1	0	3	0	GR
HU	0	13	1	2	39	1	0	9	8	11	1	534	0	0	21	0	3	0	19	0	HU
IS	0	0	0	0	0	0	0	2	0	1	0	0	10	1	0	0	1	0	0	0	IS
IE	0	0	0	0	0	0	0	7	0	1	0	0	0	540	0	0	1	0	0	0	IE
IT	1	12	6	1	12	2	0	126	9	33	2	14	0	1	1580	1	8	0	8	1	IT
LU	0	0	2	0	0	0	0	6	0	1	0	0	0	0	0	16	1	0	0	0	LU
NL	0	0	40	0	1	2	0	40	3	34	0	0	0	3	0	0	754	0	3	0	NL
NO	0	1	8	0	5	37	3	19	21	30	0	1	0	7	0	0	26	175	26	0	NO
PL	0	12	14	3	99	35	2	44	166	87	0	27	0	2	12	1	43	2	1964	0	PL
PT	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	179	PT
RO	1	6	2	66	30	2	1	10	13	13	8	88	0	0	22	0	4	0	43	0	RO
ES	0	0	5	0	0	1	0	104	1	4	0	1	0	4	4	0	8	0	0	55	ES
SE	0	2	8	0	11	73	15	21	43	42	0	5	0	4	1	0	27	21	66	0	SE
CH	0	2	5	0	2	1	0	107	5	32	0	1	0	1	47	1	7	0	2	0	CH
TR	1	1	1	26	5	0	0	4	2	3	23	8	0	0	7	0	1	0	9	0	TR
SU	1	17	14	38	104	50	44	59	111	96	9	99	0	4	30	1	45	7	589	0	SU
GB	0	0	8	0	1	3	0	64	6	10	0	0	0	95	0	0	14	0	4	1	GB
YU	12	22	3	25	34	1	0	35	12	18	16	79	0	1	108	0	6	0	24	0	YU
REM	0	1	2	1	2	1	0	49	2	4	2	2	0	1	17	0	3	0	1	2	REM
BAS	0	4	11	1	19	131	27	33	96	95	0	8	0	5	3	1	44	6	155	0	BAS
NOS	0	1	61	0	8	116	1	303	41	111	0	1	0	49	1	1	181	20	35	1	NOS
ATL	0	1	21	0	3	26	5	378	17	29	0	1	5	261	1	1	38	27	18	29	ATL
MED	19	12	11	30	22	5	0	276	13	28	81	28	0	4	324	1	17	0	19	6	MED
BLS	0	1	0	27	7	1	0	2	3	3	6	8	0	0	3	0	1	0	21	0	BLS
SUM	122	486	737	757	1239	1005	296	6229	1656	2715	504	1003	15	1023	2345	42	1686	267	3200	283	SUM
	AL	AT	BE	BG	CS	DK	FI	FR	DD	DE	GR	HU	IS	IE	IT	LU	NL	NO	PL	PT	

Emitters

Receivers	RO	ES	SE	CH	TR	SU	GB	YU	REM	BAS	NOS	ATL	MED	BLS	NAT	IND	SUM	
AL	2	0	0	0	1	2	0	11	0	0	0	0	0	0	0	16	134	AL
AT	4	2	1	16	1	4	10	12	0	0	0	0	0	0	0	43	769	AT
BE	0	1	0	0	0	1	20	0	0	0	0	0	0	0	0	15	501	BE
BG	88	0	0	0	10	56	0	30	0	0	0	0	0	0	0	52	806	BG
CS	13	1	1	3	1	20	10	10	0	0	0	0	0	0	0	54	1206	CS
DK	0	0	5	0	0	5	17	0	0	0	0	0	0	0	0	18	585	DK
FI	2	0	15	0	0	196	6	1	0	0	0	0	0	0	0	103	618	FI
FR	1	67	1	15	0	4	91	3	2	0	0	0	0	0	0	231	4740	FR
DD	1	1	2	2	0	7	18	1	0	0	0	0	0	0	0	41	1201	DD
DE	3	5	2	38	0	11	74	3	0	0	0	0	0	0	0	112	2706	DE
GR	13	1	0	0	12	17	1	14	1	0	0	0	0	0	0	62	509	GR
HU	31	0	0	1	0	12	2	33	0	0	0	0	0	0	0	35	777	HU
IS	0	0	0	0	0	2	5	0	0	0	0	0	0	0	0	19	42	IS
IE	0	0	0	0	0	0	31	0	0	0	0	0	0	0	0	16	599	IE
IT	4	12	1	22	0	4	11	26	4	0	0	0	0	0	0	148	2049	IT
LU	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	29	LU
NL	0	1	0	0	0	1	29	0	0	0	0	0	0	0	0	17	929	NL
NO	0	0	18	0	0	24	53	0	0	0	0	0	0	0	0	100	556	NO
PL	20	1	9	3	1	136	26	9	0	0	0	0	0	0	0	134	2855	PL
PT	0	27	0	0	0	0	1	0	0	0	0	0	0	0	0	17	230	PT
RO	1421	1	1	1	12	217	2	53	0	0	0	0	0	0	0	121	2137	RO
ES	1	1045	0	0	0	0	15	1	4	0	0	0	0	0	0	93	1346	ES
SE	4	1	266	1	0	110	30	1	0	0	0	0	0	0	0	121	873	SE
CH	0	4	0	237	0	1	7	1	0	0	0	0	0	0	0	27	491	CH
TR	29	1	0	0	1821	116	1	9	1	0	0	0	0	0	0	218	2290	TR
SU	256	2	36	4	18	214	626	33	42	0	0	0	0	0	0	1525	18021	SU
GB	0	2	1	0	0	1	1951	0	0	0	0	0	0	0	0	54	2216	GB
YU	37	3	1	2	2	25	5	923	1	0	0	0	0	0	0	131	1527	YU
REM	1	16	0	1	1	1	7	3	166	0	0	0	0	0	0	162	449	REM
BAS	6	1	59	1	0	255	38	3	0	0	0	0	0	0	0	148	1148	BAS
NOS	0	4	12	1	0	16	475	0	0	0	0	0	0	0	0	187	1625	NOS
ATL	1	79	9	1	0	68	422	0	0	0	0	0	0	0	0	976	2419	ATL
MED	32	76	1	7	52	42	24	68	34	0	0	0	0	0	0	478	1712	MED
BLS	64	0	0	0	144	416	1	6	0	0	0	0	0	0	0	156	872	BLS
SUM	2034	1353	443	359	224	116	394	3416	1262	217	0	0	0	0	0	5635	58959	SUM
	RO	ES	SE	CH	TR	SU	GB	YU	REM	BAS	NOS	ATL	MED	BLS	NAT	IND	SUM	

TABLE 18: Budget of Reduced Nitrogen in 1989. (Unit: 100 tonnes as N)
PROVISIONAL ESTIMATE

Emitters

Receivers	AL	AT	BE	BG	CS	DK	FI	FR	DD	DE	GR	HU	IS	IE	IT	LU	NL	NO	PL	PT	
AL	82	0	0	3	1	0	0	0	0	0	8	2	0	0	5	0	0	0	1	0	AL
AT	0	352	5	2	63	3	0	37	25	99	0	26	0	1	72	1	15	0	31	0	AT
BE	0	0	322	0	1	1	0	74	2	15	0	0	0	2	1	2	37	0	1	0	BE
BG	2	1	0	530	5	1	0	1	2	2	21	12	0	0	4	0	1	0	12	0	BG
CS	0	31	5	2	751	5	1	25	70	74	1	52	0	1	11	0	17	0	105	0	CS
DK	0	0	4	0	2	426	0	9	12	24	0	0	0	2	1	0	13	1	5	0	DK
FI	0	0	3	0	4	12	190	7	14	12	0	1	0	2	0	0	9	4	29	0	FI
FR	0	4	80	0	8	4	0	4004	14	61	0	5	0	15	57	6	46	0	8	4	FR
DD	0	3	11	0	19	19	0	33	876	123	0	2	0	2	2	1	41	1	32	0	DD
DE	0	19	79	1	36	24	0	242	113	1667	0	6	0	6	24	8	230	1	22	1	DE
GR	5	1	0	26	2	0	0	2	1	1	346	4	0	0	5	0	0	0	3	0	GR
HU	0	15	1	4	51	1	0	6	7	11	1	566	0	0	19	0	3	0	32	0	HU
IS	0	0	0	0	0	0	0	1	0	0	0	0	11	1	0	0	1	0	0	0	IS
IE	0	0	2	0	1	0	0	11	1	2	0	0	0	546	0	0	3	0	1	0	IE
IT	1	16	6	3	12	1	0	108	8	33	4	13	0	1	1656	1	8	0	11	1	IT
LU	0	0	2	0	0	0	0	7	0	1	0	0	0	0	0	17	1	0	0	0	LU
NL	0	0	39	0	1	2	0	35	3	38	0	0	0	2	0	0	697	0	1	0	NL
NO	0	1	6	1	4	30	2	20	15	23	0	1	0	11	1	0	16	177	15	0	NO
PL	0	11	10	2	103	35	2	36	167	90	1	27	0	3	9	1	35	2	2045	0	PL
PT	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	195	PT
RO	2	5	1	71	30	2	1	5	11	10	11	98	0	0	13	0	3	0	50	0	RO
ES	0	0	3	0	0	1	0	118	2	5	0	1	0	3	14	0	4	0	1	57	ES
SE	0	2	7	1	10	78	12	20	37	37	0	3	0	6	3	0	22	26	59	0	SE
CH	0	3	6	0	2	1	0	90	5	38	0	1	0	1	51	1	7	0	1	0	CH
TR	1	1	0	20	3	0	0	1	2	2	17	5	0	0	3	0	1	0	9	0	TR
SU	1	15	16	37	97	59	46	47	123	102	9	85	0	7	24	1	53	7	565	0	SU
GB	0	0	13	0	2	5	0	75	7	15	0	0	0	98	1	0	22	0	9	1	GB
YU	11	27	1	35	42	2	0	20	11	17	22	103	0	0	97	0	4	0	32	0	YU
REM	0	0	2	1	1	0	0	30	0	2	2	1	0	0	13	0	4	0	0	1	REM
BAS	0	3	12	1	17	141	22	32	92	86	0	5	0	5	3	0	37	7	138	0	BAS
NOS	0	2	54	0	6	83	1	288	28	92	0	1	0	48	2	1	145	18	21	1	NOS
ATL	0	1	28	0	3	22	6	477	15	39	0	1	5	260	3	1	45	25	13	33	ATL
MED	21	9	8	35	17	2	0	215	8	21	91	25	0	3	323	1	11	0	17	4	MED
BLS	0	1	0	26	5	1	0	1	4	4	5	6	0	0	1	0	1	0	18	0	BLS
SUM	128	525	728	800	1297	963	286	6080	1677	2746	542	1051	16	1024	2419	42	1532	272	3286	299	SUM
	AL	AT	BE	BG	CS	DK	FI	FR	DD	DE	GR	HU	IS	IE	IT	LU	NL	NO	PL	PT	

Emitters

Receivers	RO	ES	SE	CH	TR	SU	GB	YU	REM	BAS	NOS	ATL	MED	BLS	NAT	IND	SUM	
AL	2	0	0	0	0	2	0	11	0	0	0	0	0	0	0	15	134	AL
AT	8	1	2	14	0	16	6	15	0	0	0	0	0	0	0	61	856	AT
BE	0	1	0	0	0	0	18	0	0	0	0	0	0	0	0	13	490	BE
BG	93	0	0	0	16	67	0	27	0	0	0	0	0	0	0	64	862	BG
CS	13	1	2	3	0	38	7	10	0	0	0	0	0	0	0	68	1291	CS
DK	0	0	4	0	0	2	18	0	0	0	0	0	0	0	0	16	539	DK
FI	2	0	17	0	1	144	11	1	0	0	0	0	0	0	0	104	568	FI
FR	1	57	1	16	0	3	98	6	2	0	0	0	0	0	0	228	4728	FR
DD	1	1	2	1	0	7	14	1	0	0	0	0	0	0	0	46	1239	DD
DE	3	5	3	43	0	12	56	2	0	0	0	0	0	0	0	116	2719	DE
GR	15	0	0	0	15	21	0	10	1	0	0	0	0	0	0	57	519	GR
HU	42	0	0	1	0	30	1	39	0	0	0	0	0	0	0	52	886	HU
IS	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	20	38	IS
IE	0	1	0	0	0	0	30	0	0	0	0	0	0	0	0	25	624	IE
IT	6	10	0	22	1	6	8	29	4	0	0	0	0	0	0	163	2132	IT
LU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	30	LU
NL	0	0	0	0	0	1	26	0	0	0	0	0	0	0	0	15	864	NL
NO	1	1	11	0	0	11	74	1	0	0	0	0	0	0	0	134	556	NO
PL	16	1	11	3	1	166	20	10	0	0	0	0	0	0	0	151	2960	PL
PT	0	38	0	0	0	0	1	0	0	0	0	0	0	0	0	23	261	PT
RO	1439	0	1	0	16	242	1	51	0	0	0	0	0	0	0	137	2202	RO
ES	1	1123	0	0	0	1	15	3	6	0	0	0	0	0	0	128	1487	ES
SE	2	1	258	1	1	58	35	1	0	0	0	0	0	0	0	127	806	SE
CH	0	3	0	241	0	1	6	1	0	0	0	0	0	0	0	26	485	CH
TR	22	0	0	0	1831	135	0	5	1	0	0	0	0	0	0	205	2266	TR
SU	239	1	40	2	13613715		45	32	0	0	0	0	0	0	0	1400	16906	SU
GB	0	3	1	0	0	9	1989	0	0	0	0	0	0	0	0	72	2322	GB
YU	50	2	1	2	2	39	1	988	1	0	0	0	0	0	0	159	1670	YU
REM	1	11	0	0	1	1	2	2	164	0	0	0	0	0	0	172	413	REM
BAS	4	1	63	1	0	168	37	3	0	0	0	0	0	0	0	144	1022	BAS
NOS	0	5	8	1	0	11	462	0	0	0	0	0	0	0	0	177	1455	NOS
ATL	1	87	9	1	0	51	413	1	0	0	0	0	0	0	0	971	2511	ATL
MED	36	63	0	5	71	51	14	67	34	0	0	0	0	0	0	455	1608	MED
BLS	57	0	0	0	127	360	1	5	0	0	0	0	0	0	0	140	763	BLS
SUM	2056	1418	436	361	222015369		3412	1321	216	0	0	0	0	0	0	5686	58202	SUM
	RO	ES	SE	CH	TR	SU	GB	YU	REM	BAS	NOS	ATL	MED	BLS	NAT	IND	SUM	

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APPENDIX A.

COMPARISON BETWEEN MODEL CALCULATIONS AND MEASUREMENTS 1988

Figure A1: Scatter plot of modelled and observed concentrations of NO_2 for a selection of stations with a data coverage of more than 75 %, unit $\mu g(N)\ m^{-3}$. The dashed lines shows perfect agreement and disagreement with a factor of two. The full line represents optimal linear regression, i. e. the sum of squares of distances measured from the points normal to the line is minimised. Station codes are given in Figure 26.

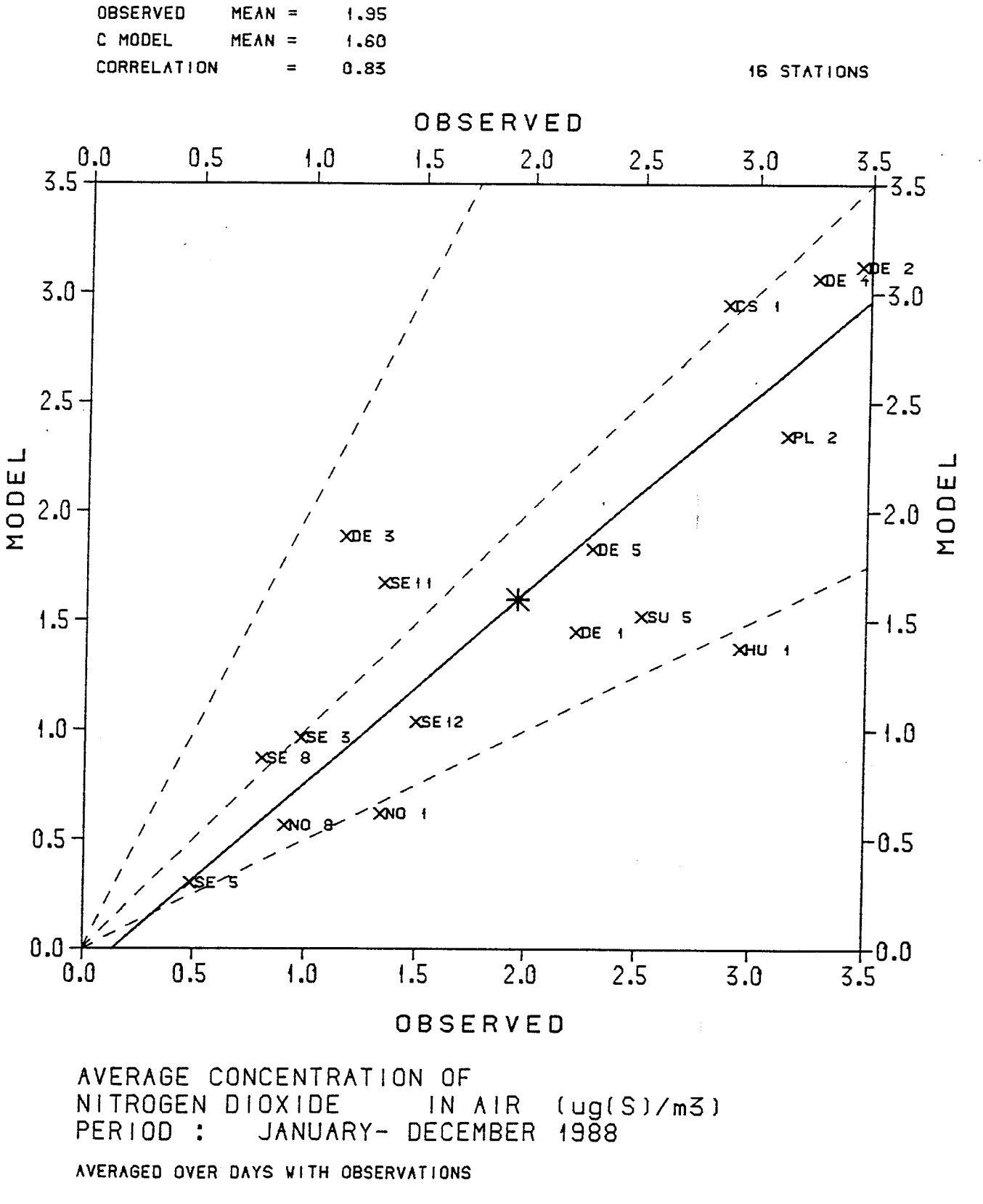
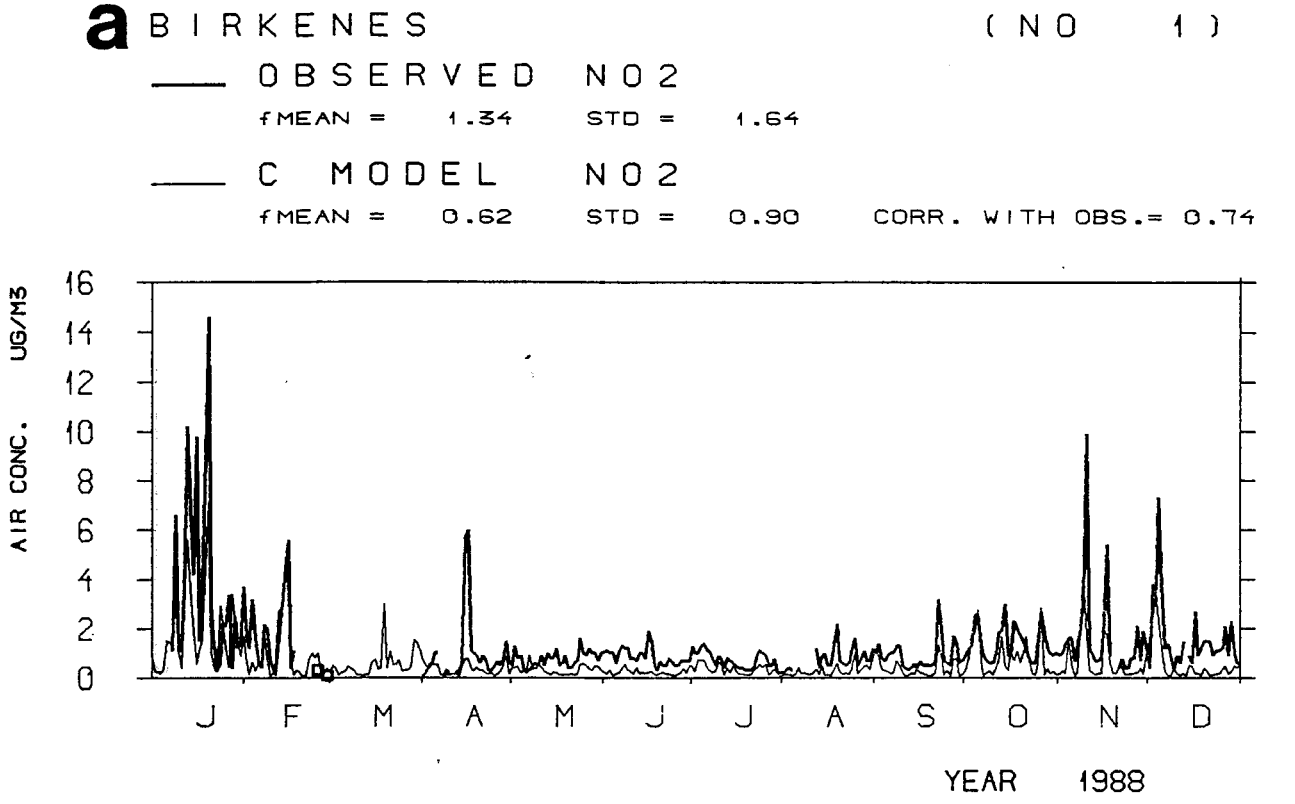


Figure A2: Calculated (thin line) and observed (thick line) daily concentrations of NO_2 in 1988, unit $\mu g(N)\ m^{-3}$. a) NO 1, Birkenes ; b) DE 2, Langenbrugge.



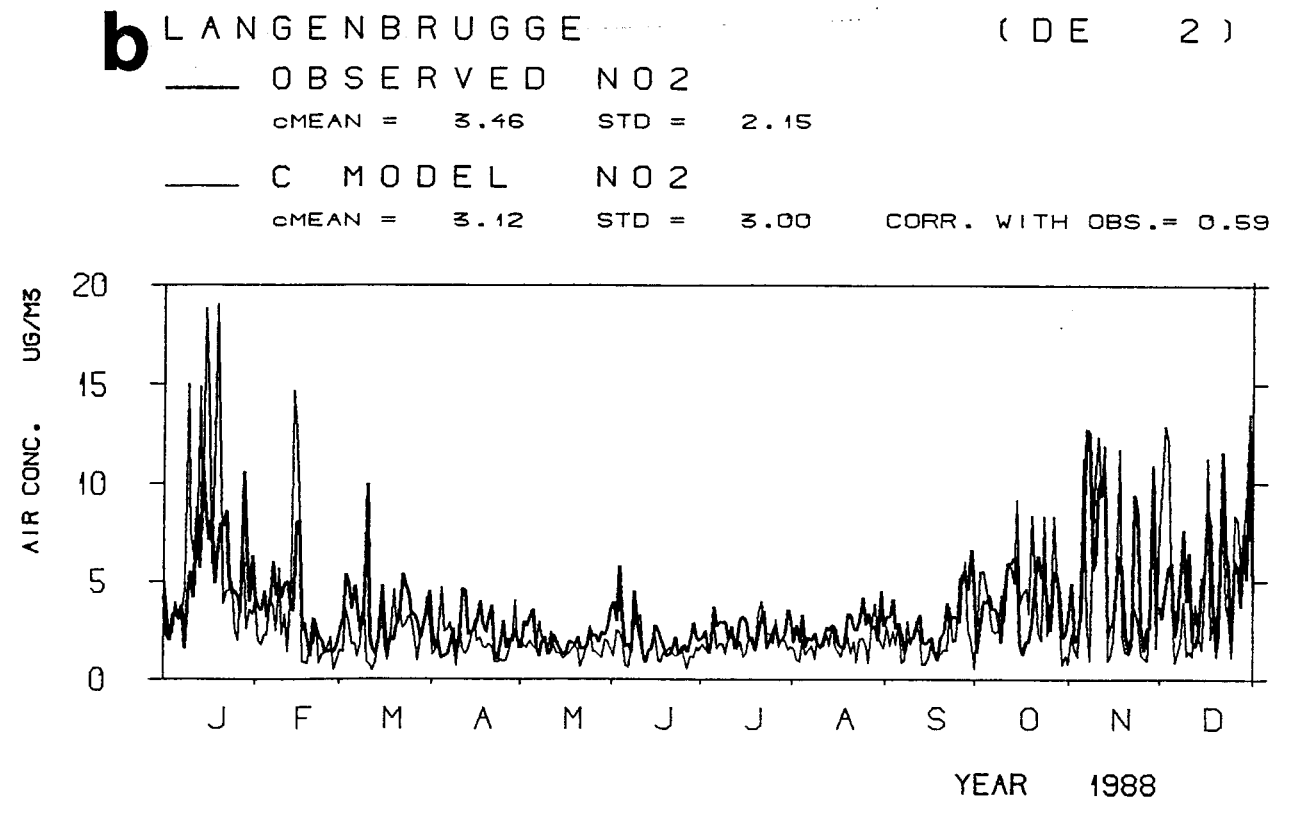
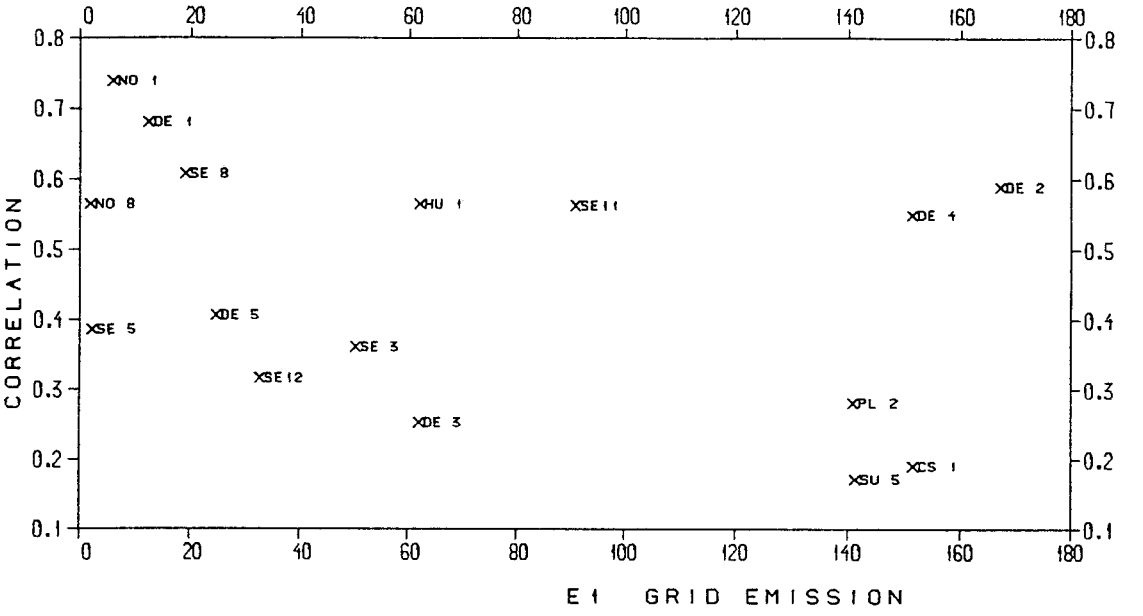


Figure A3: Statistical parameters relating calculations and measurements of NO_2 at EMEP-stations with more than 75 % data coverage, represented as a function of the emission of NOx ($kt(NO_2)/a$) in the grid-squares in which the stations are situated. Station codes are given in Figure 26.
a) Correlation between modelled and observed daily concentrations.
b) Difference between modelled and observed concentrations relative to the observed.

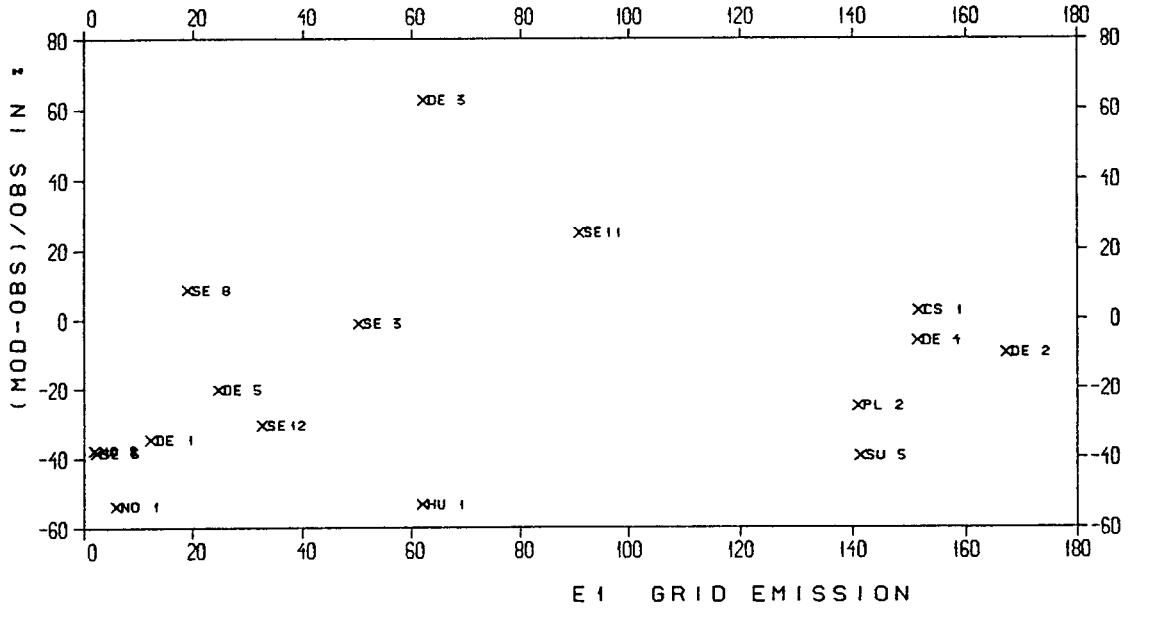
a



NITROGEN DIOXIDE IN AIR

NOX EMISSION AS 1000 TONNES(NO2)/YEAR
PERIODE : JANUAR -DESEMBER 1988
DATA FROM MODEL VERSION C
NO. OF STATIONS : 16
REQUIERMENT : AT LEAST 75. % COMMON DAYS WITH DATA

b



NITROGEN DIOXIDE IN AIR

NOX EMISSION AS 1000 TONNES(NO2)/YEAR
PERIODE : JANUAR -DESEMBER 1988
DATA FROM MODEL VERSION C
NO. OF STATIONS : 16
REQUIERMENT : AT LEAST 75. % COMMON DAYS WITH DATA

Figure A4: Scatter plot of modelled and observed concentrations of SO_2 for a selection of stations with a data coverage of more than 75 %, unit μg(S) m^{-3}. The dashed lines shows perfect agreement and disagreement with a factor of two. The full line represents optimal linear regression, i. e. the sum of squares of distances measured from the points normal to the line is minimised. Station codes are given in Figure 26.

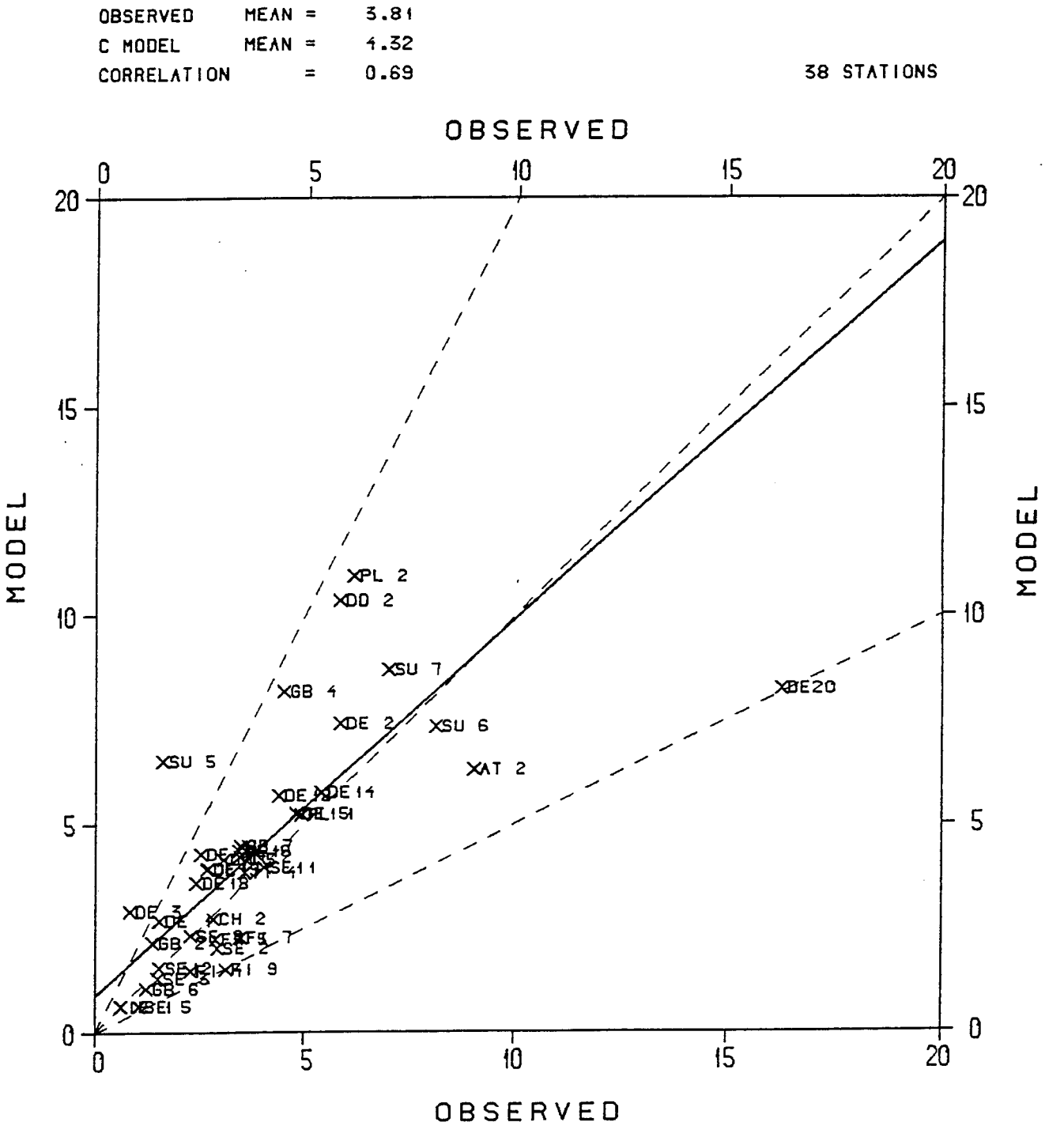
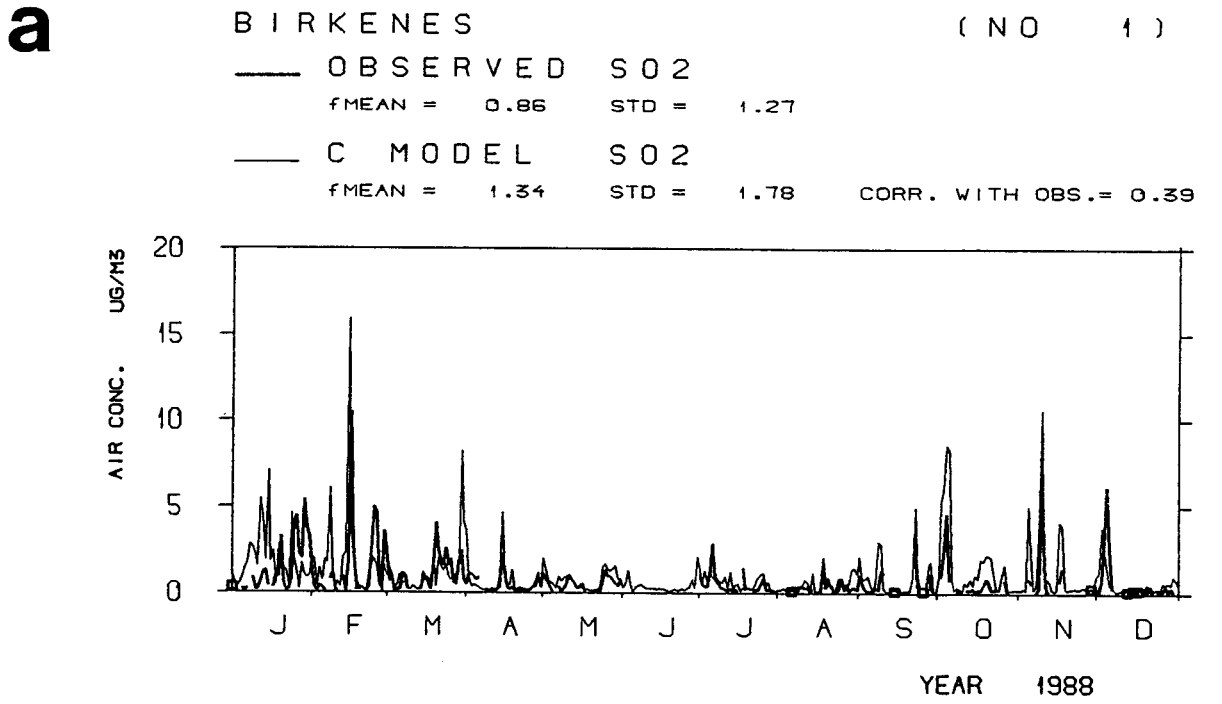


Figure A5: Calculated (thin line) and observed (thick line) daily concentrations of SO_2 in 1988, unit $\mu g(S)\ m^{-3}$. a) NO 1, Birkenes ; b) DE 2, Langenbrugge.



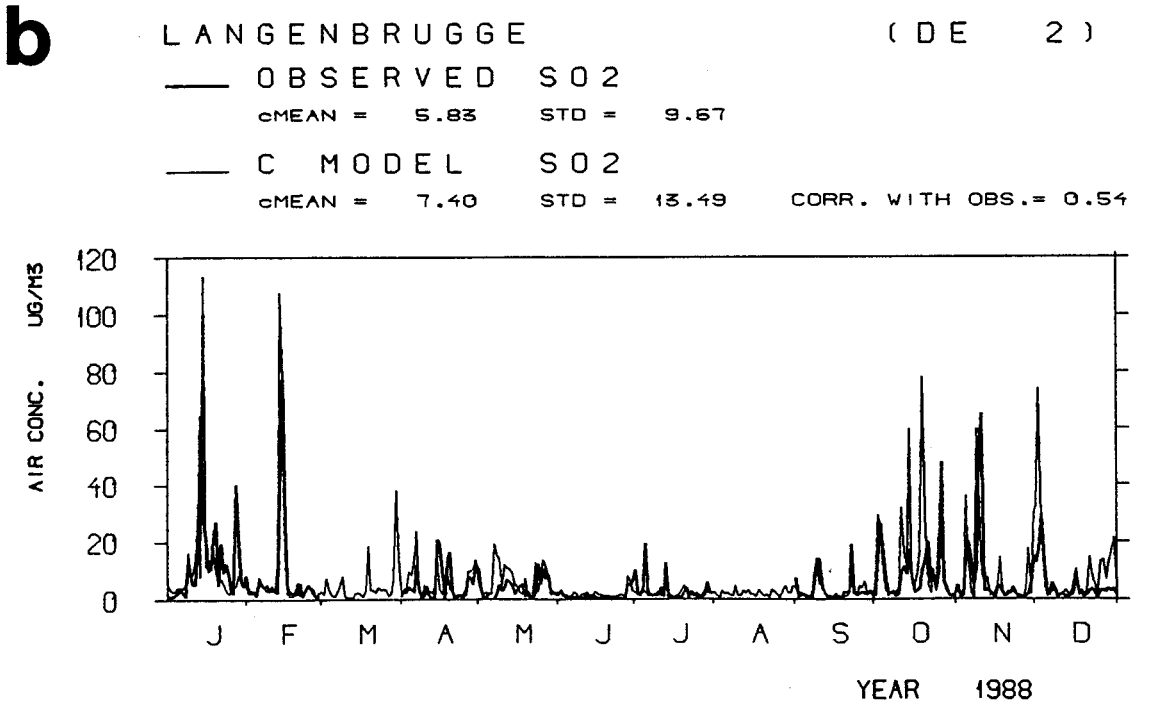
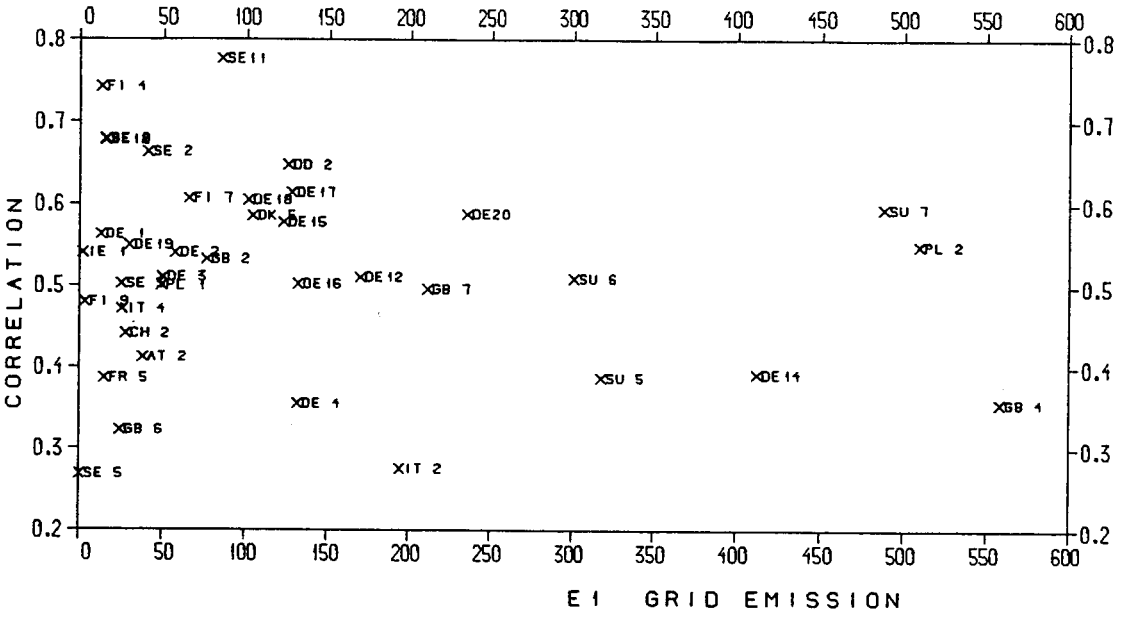


Figure A6: Statistical parameters relating calculations and measurements of SO_2 at EMEP-stations with more than 75 % data coverage, represented as a function of the emission of SO_2 ($kt(SO_2)/a$) in the grid-squares in which the stations are situated. Station codes are given in Figure 26.
a) Correlation between modelled and observed daily concentrations.
b) Difference between modelled and observed concentrations relative to the observed.

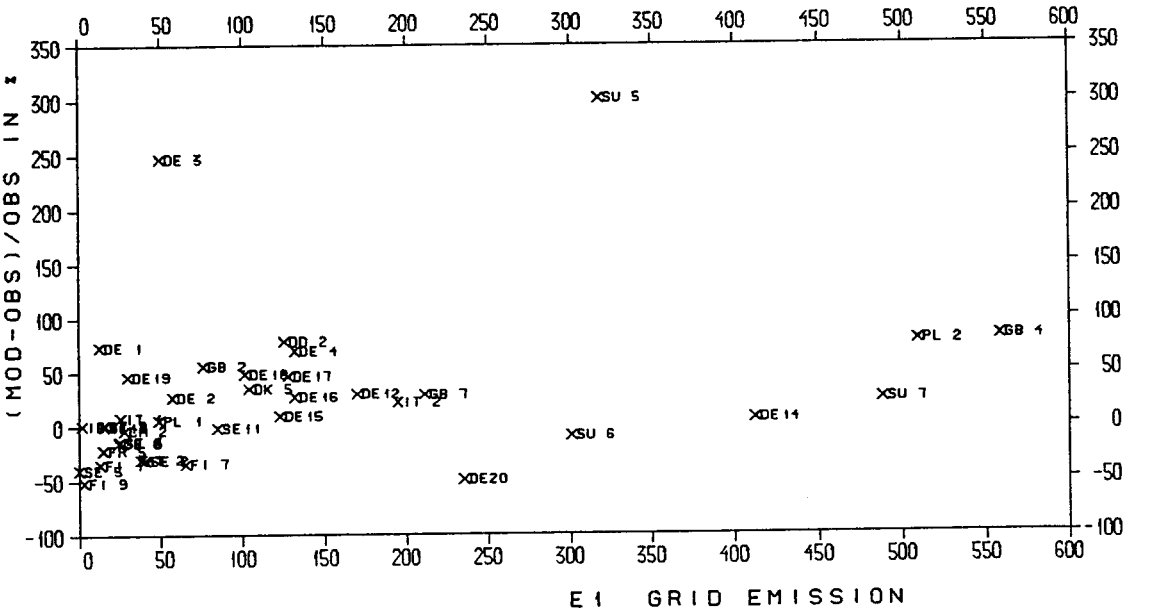
a



SULPHUR DIOXIDE IN AIR

SOX EMISSION AS 1000 TONNES(SO2)/YEAR
PERIODE : JANUAR -DESEMBER 1988
DATA FROM MODEL VERSION C
NO. OF STATIONS : 38
REQUIERMENT : AT LEAST 75. % COMMON DAYS WITH DATA

b



SULPHUR DIOXIDE IN AIR

SOX EMISSION AS 1000 TONNES(SO2)/YEAR
PERIODE : JANUAR -DESEMBER 1988
DATA FROM MODEL VERSION C
NO. OF STATIONS : 38
REQUIERMENT : AT LEAST 75. % COMMON DAYS WITH DATA

Figure A7: Scatter plot of modelled and observed concentrations of total particulate $SO_4^=$ for a selection of stations with a data coverage of more than 75 %, unit μg(S) m^{-3}. The dashed lines shows perfect agreement and disagreement with a factor of two. The full line represents optimal linear regression, i. e. the sum of squares of distances measured from the points normal to the line is minimised. Station codes are given in Figure 26.

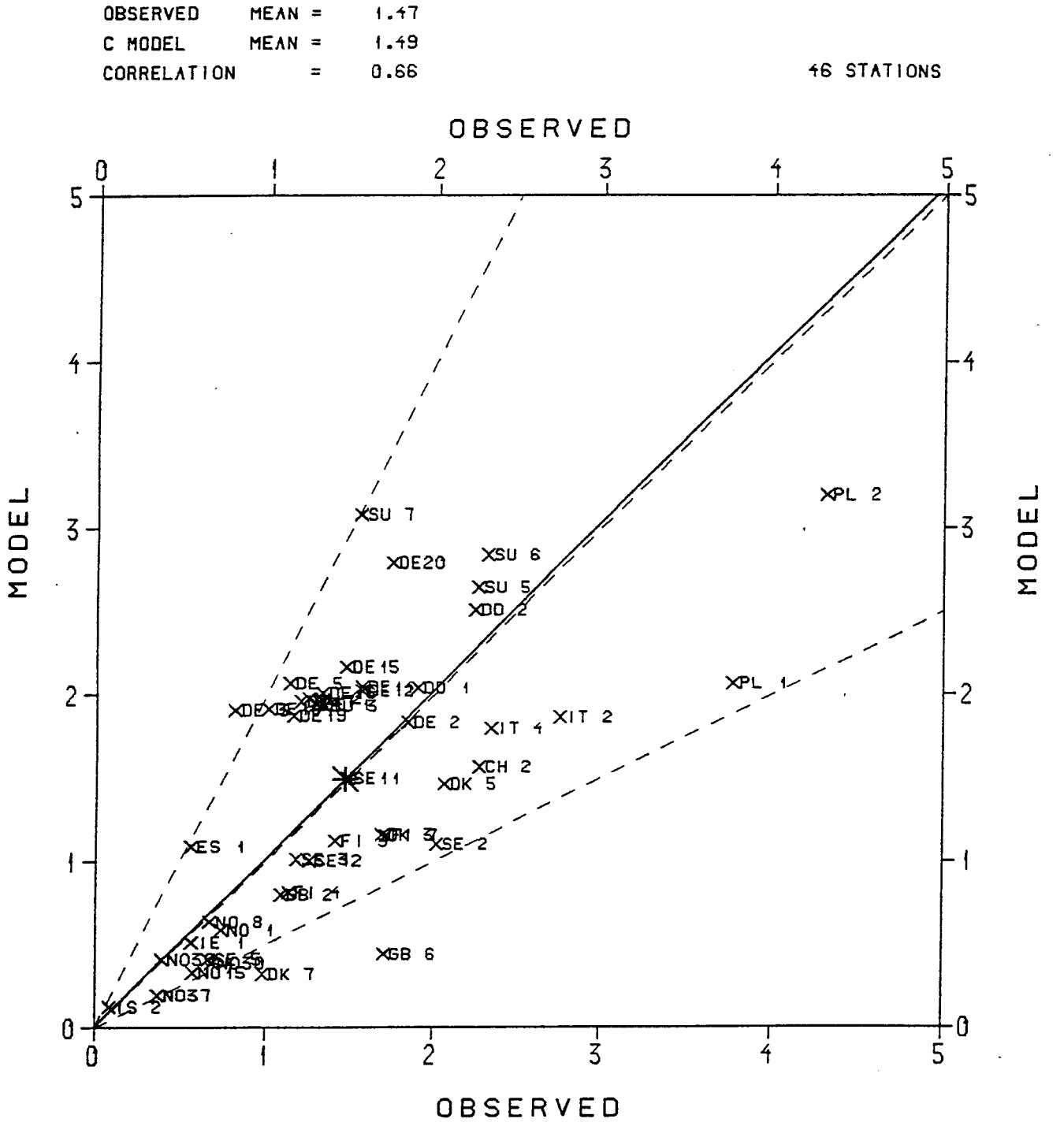
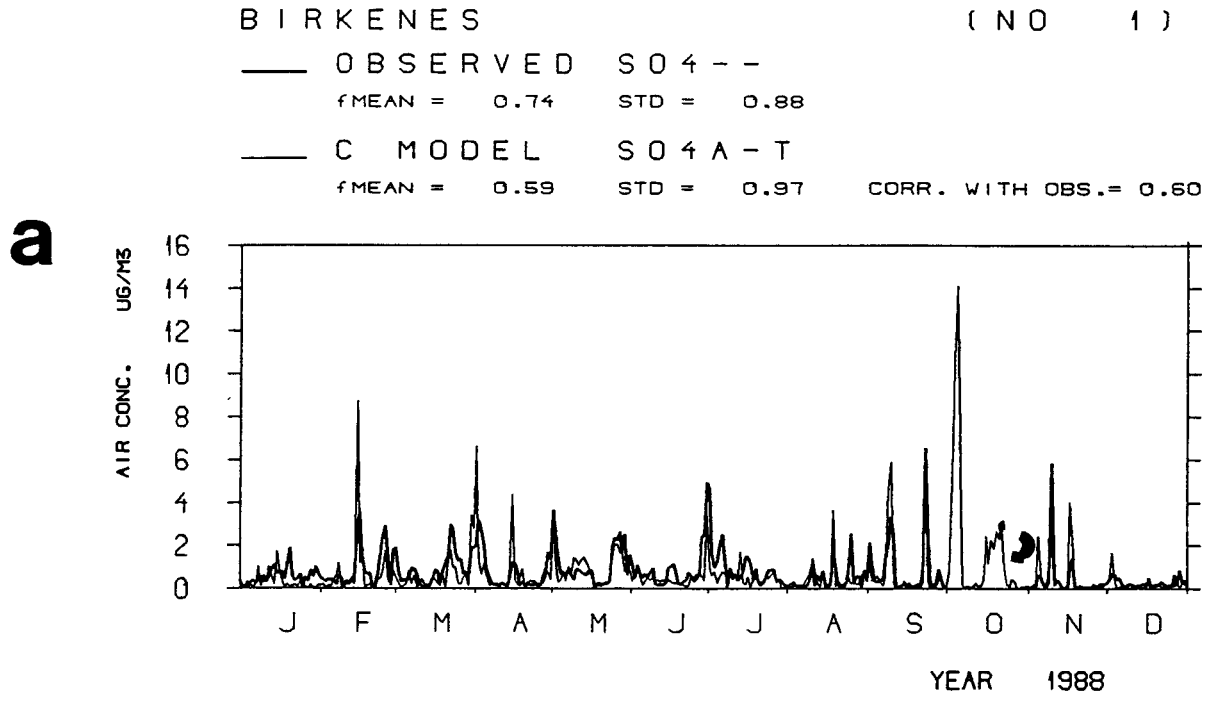


Figure A8: Calculated (thin line) and observed (thick line) daily concentrations of total particulate sulphate in 1988, unit μg(S) m^{-3}. a) NO 1, Birkenes ; b) DE 2, Langenbrugge.



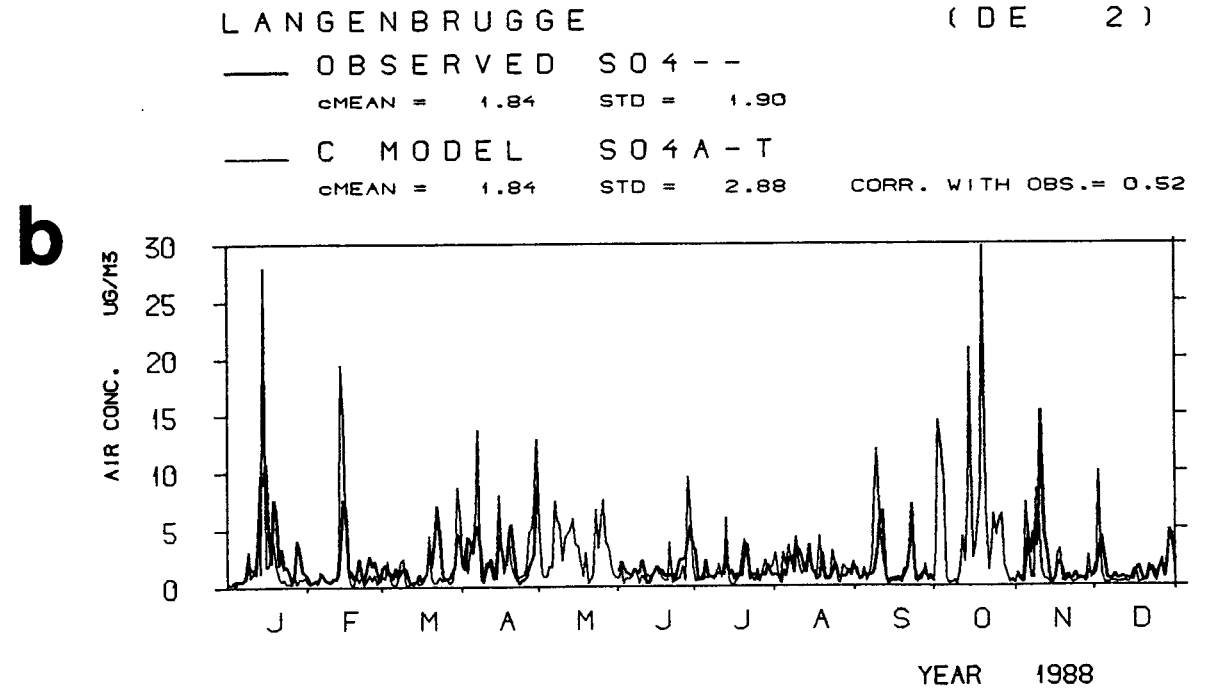
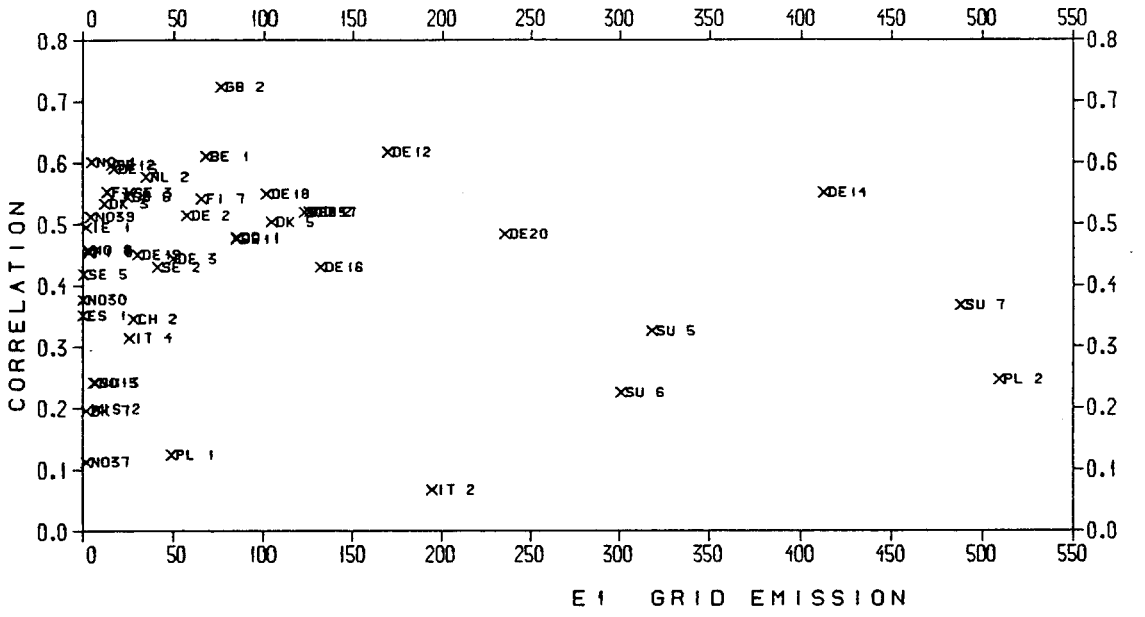


Figure A9: Statistical parameters relating calculations and measurement of particulate sulphate at EMEP-stations with more than 75 % data coverage, represented as a function of the emission of SO_2 ($kt(SO_2)/a$) in the grid-squares in which the stations are situated. Station codes are given in Figure 26.
a) Correlation between modelled and observed daily concentrations.
b) Difference between modelled and observed concentrations relative to the observed.

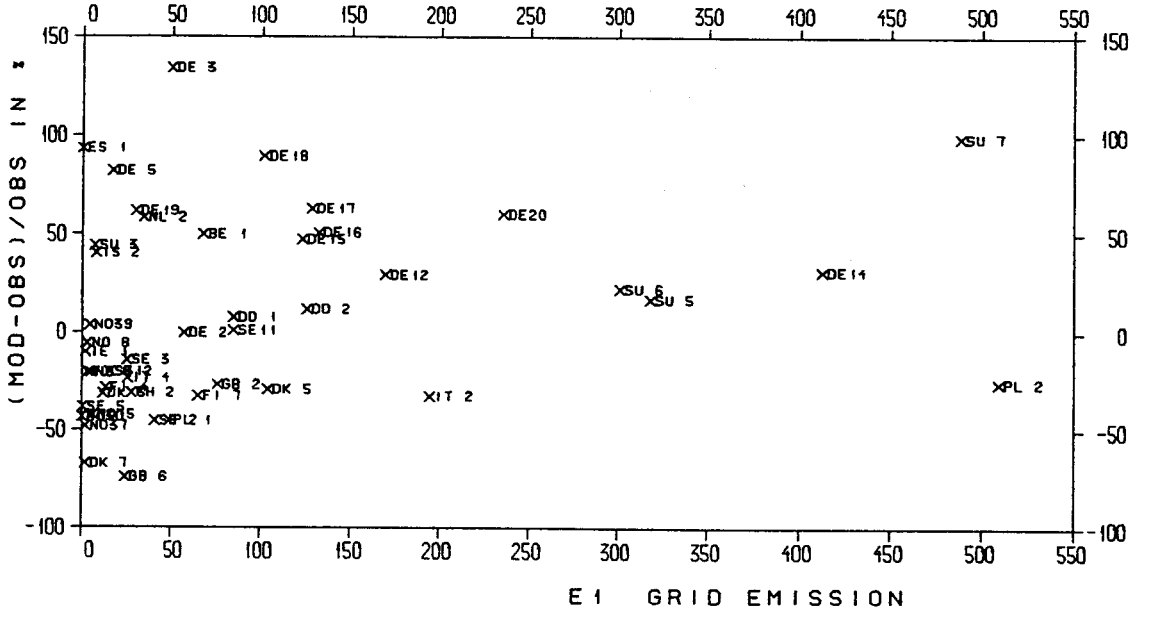
a



PARTICULATE SULPHATE IN AIR

SOX EMISSION AS 1000 TONNES(SO2)/YEAR
PERIODE : JANUAR -DESEMBER 1988
DATA FROM MODEL VERSION C
NO. OF STATIONS : 46
REQUIERMENT : AT LEAST 75. % COMMON DAYS WITH DATA

b



PARTICULATE SULPHATE IN AIR

SOX EMISSION AS 1000 TONNES(SO2)/YEAR
PERIODE : JANUAR -DESEMBER 1988
DATA FROM MODEL VERSION C
NO. OF STATIONS : 46
REQUIERMENT : AT LEAST 75. % COMMON DAYS WITH DATA

Figure A10: Scatter plot of modelled and observed concentrations of sulphate in precipitation for a selection of stations with a data coverage of more than 25 %, unit mg(S) l^{-1}. The dashed lines shows perfect agreement and disagreement with a factor of two. The full line represents optimal linear regression, i. e. the sum of squares of distances measured from the points normal to the line is minimised. Station codes are given in Figure 26.

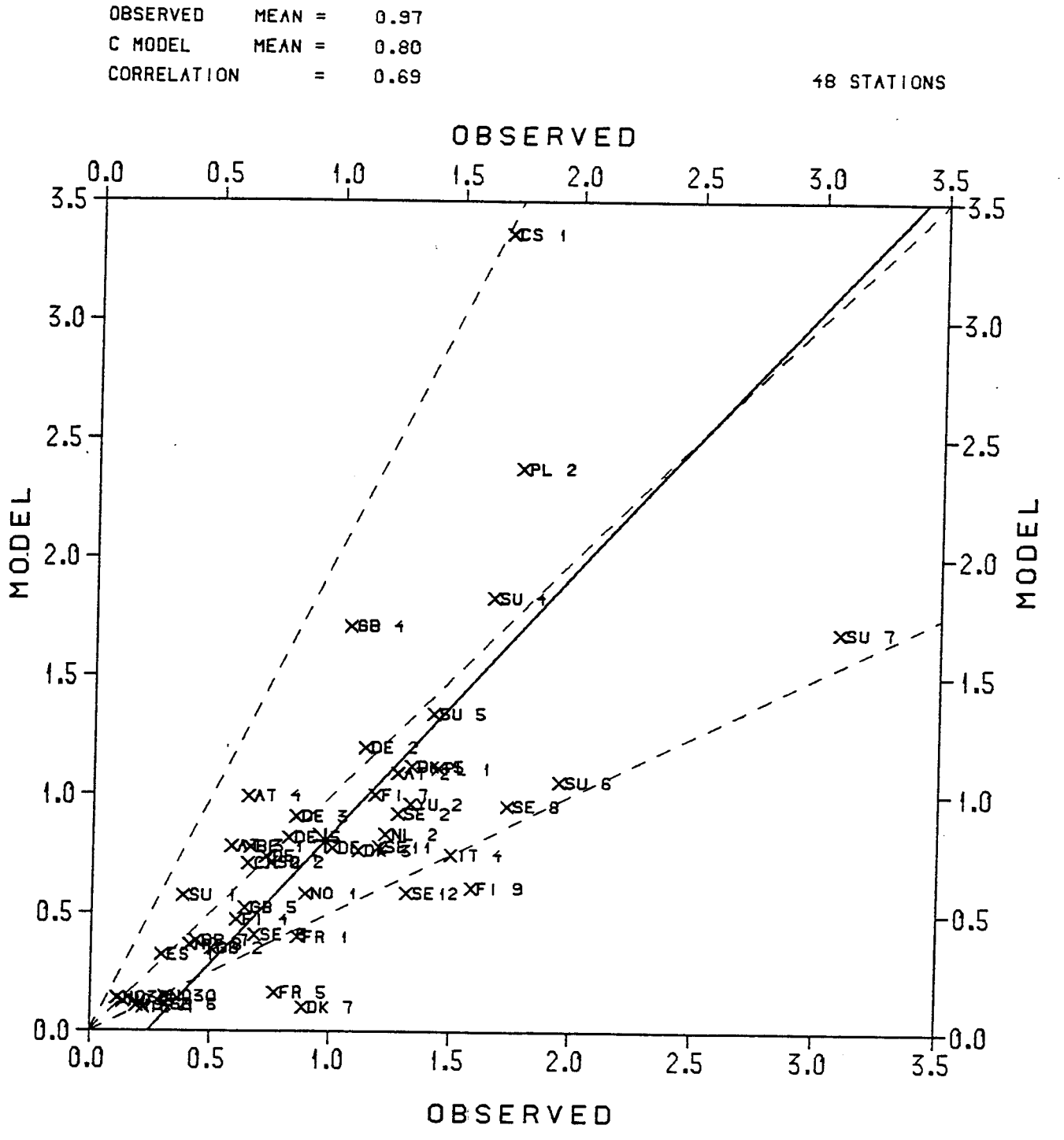
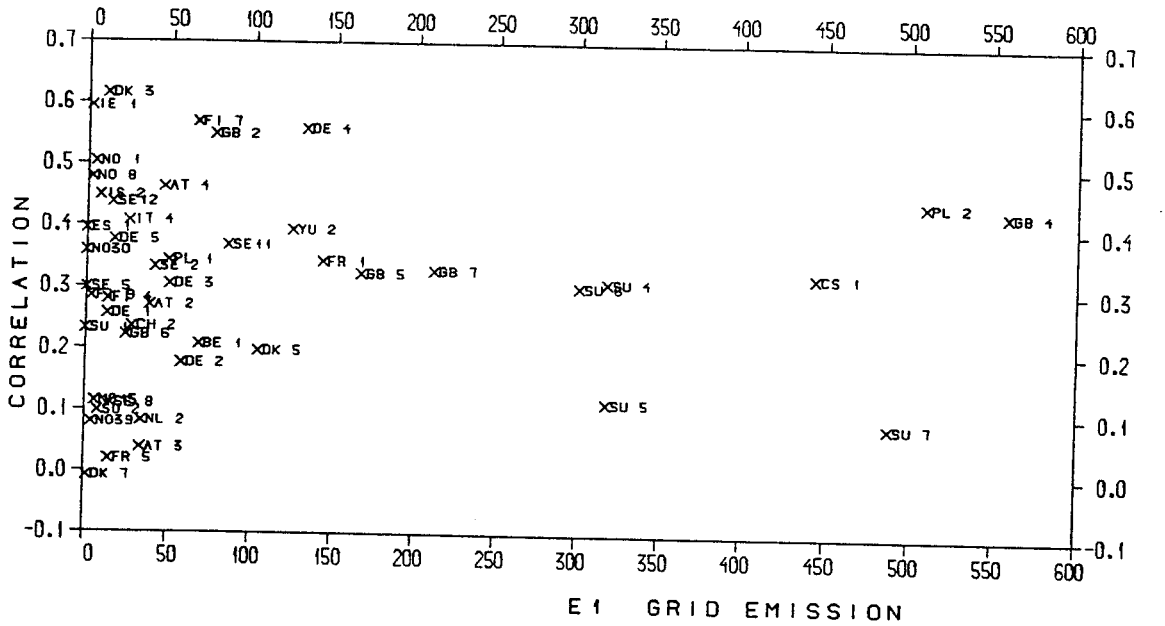


Figure A11: Statistical parameters relating calculations and measurement of sulphate in precipitation at EMEP-stations with more than 25 % data coverage, represented as a function of the emission of SO_2 ($kt(SO_2)/a$) in the grid-squares in which the stations are situated. Station codes are given in Figure 26.
a) Correlation between modelled and observed daily concentrations.
b) Difference between modelled and observed concentrations relative to the observed.

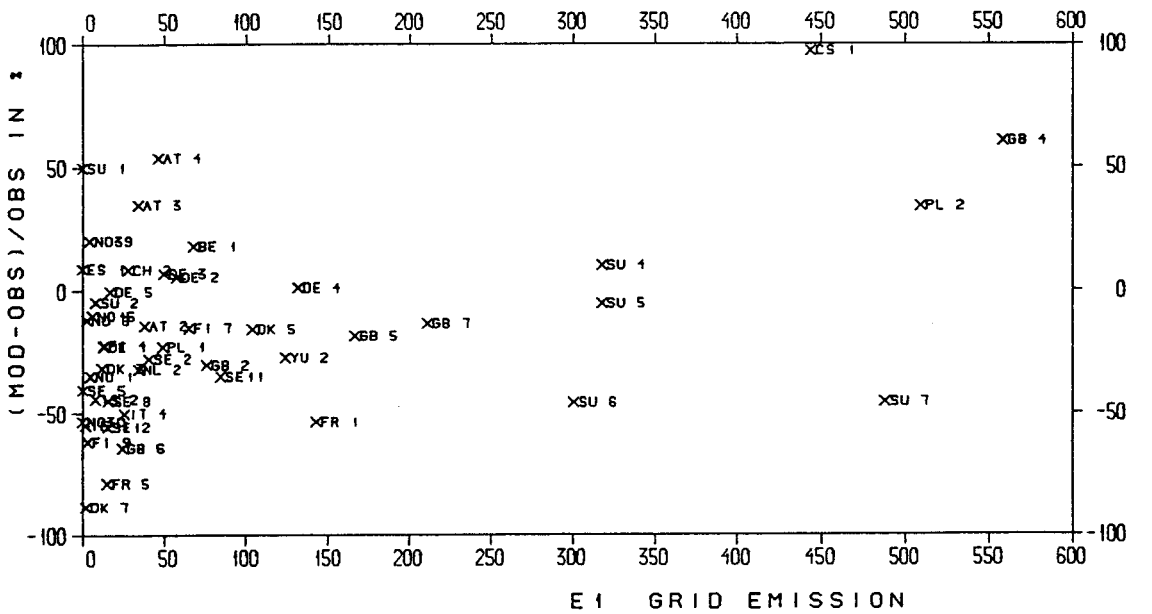
a



SULPHATE IN PRECIPITATION (WET ONLY)

SOX EMISSION AS 1000 TONNES(SO2)/YEAR
PERIODE : JANUAR -DESEMBER 1988
DATA FROM MODEL VERSION C
NO. OF STATIONS : 48
REQUIERMENT : AT LEAST 25. % COMMON DAYS WITH DATA

b



SULPHATE IN PRECIPITATION (WET ONLY)

SOX EMISSION AS 1000 TONNES(SO2)/YEAR
PERIODE : JANUAR -DESEMBER 1988
DATA FROM MODEL VERSION C
NO. OF STATIONS : 48
REQUIERMENT : AT LEAST 25. % COMMON DAYS WITH DATA

Figure A12: Scatter plot of modelled and observed concentrations of nitrate in precipitation for a selection of stations with a data coverage of more than 25 %, unit mg(N) l^{-1}. The dashed lines shows perfect agreement and disagreement with a factor of two. The full line represents optimal linear regression, i. e. the sum of squares of distances measured from the points normal to the line is minimised. Station codes are given in Figure 26.

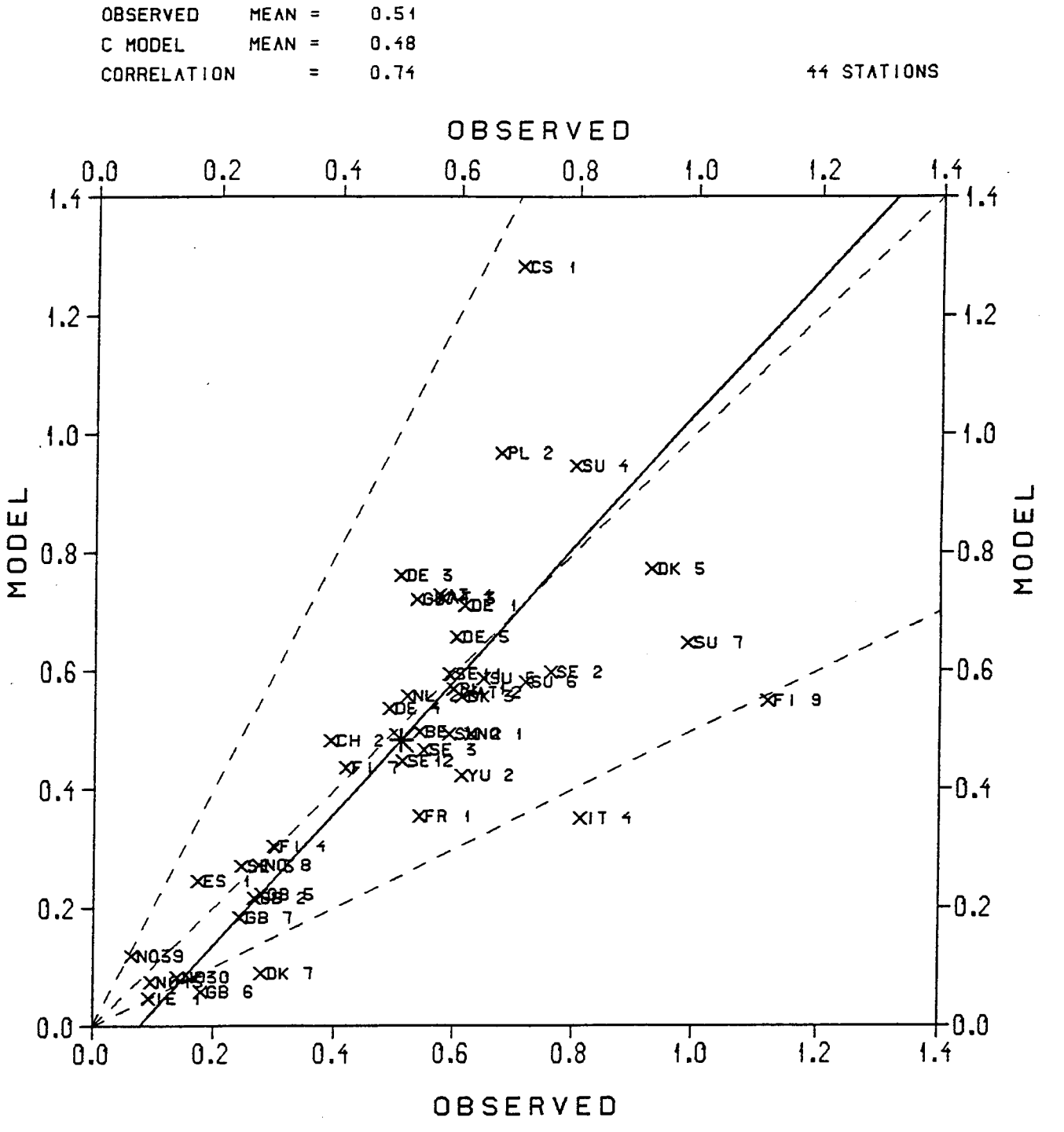
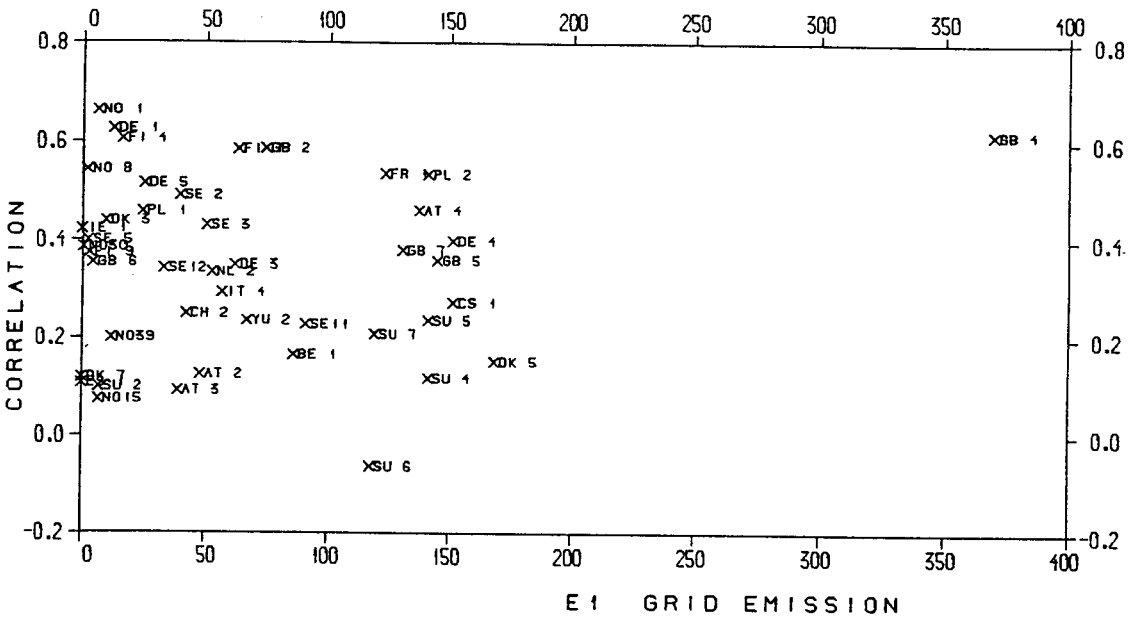


Figure A13: Statistical parameters relating calculations and measurement of nitrate in precipitation at EMEP-stations with more than 25 % data coverage, represented as a function of the emission of NO_2 ($kt(NO_2)/a$) in the grid-squares in which the stations are situated. Station codes are given in Figure 26.
a) Correlation between modelled and observed daily concentrations.
b) Difference between modelled and observed concentrations relative to the observed.

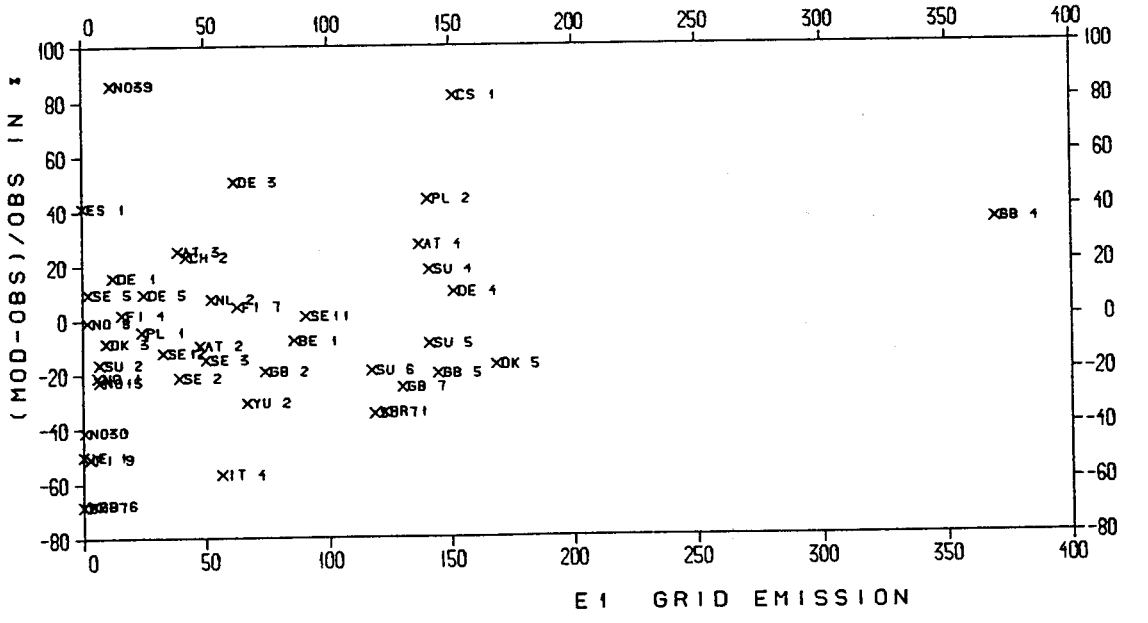
a



NITRATE IN PRECIPITATION (WET + DRY)

NOX EMISSION AS 1000 TONNES(NO2)/YEAR
PERIODE : JANUAR -DESEMBER 1988
DATA FROM MODEL VERSION C
NO. OF STATIONS : 44
REQUIERMENT : AT LEAST 25. % COMMON DAYS WITH DATA

b



NITRATE IN PRECIPITATION (WET + DRY)

NOX EMISSION AS 1000 TONNES(NO2)/YEAR
PERIODE : JANUAR -DESEMBER 1988
DATA FROM MODEL VERSION C
NO. OF STATIONS : 44
REQUIERMENT : AT LEAST 25. % COMMON DAYS WITH DATA

Figure A14: Scatter plot of modelled and observed concentrations of ammonium in precipitation for a selection of stations with a data coverage of more than 25 %, unit mg(N) l^{-1}. The dashed lines shows perfect agreement and disagreement with a factor of two. The full line represents optimal linear regression, i. e. the sum of squares of distances measured from the points normal to the line is minimised. Station codes are given in Figure 26.

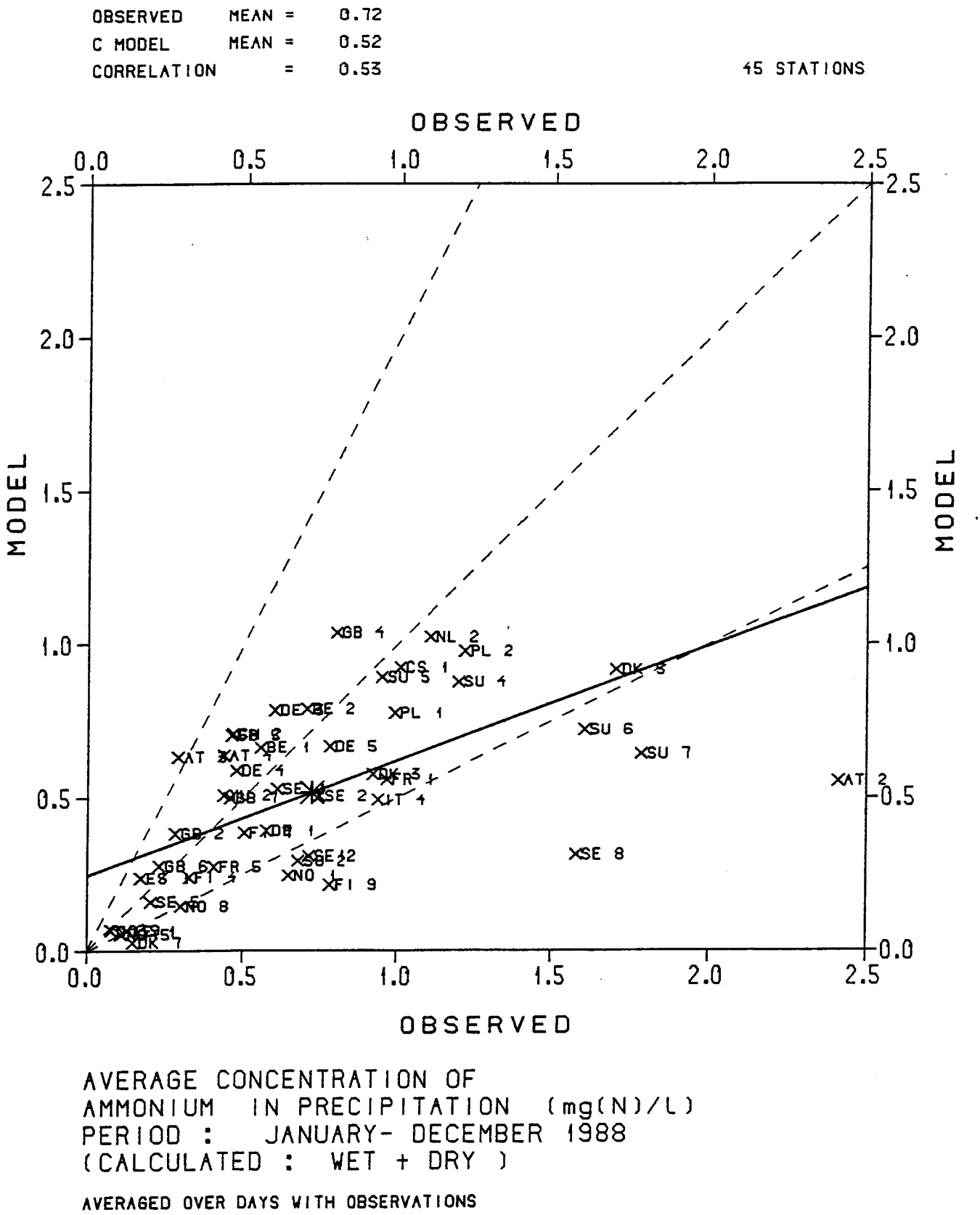
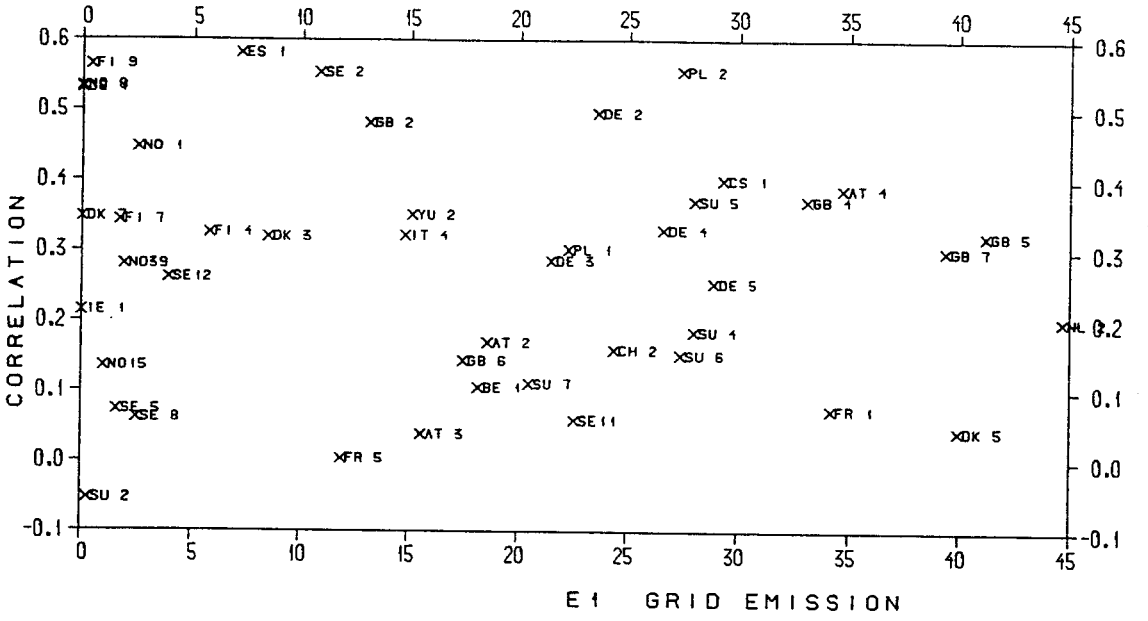


Figure A15: Statistical parameters relating calculations and measurement of ammonium in precipitation at EMEP-stations with more than 25 % data coverage, represented as a function of the emission of NH_3 ($kt(NH_3)/a$) in the grid-squares in which the stations are situated. Station codes are given in Figure 26.
a) Correlation between modelled and observed daily concentrations.
b) Difference between modelled and observed concentrations relative to the observed.

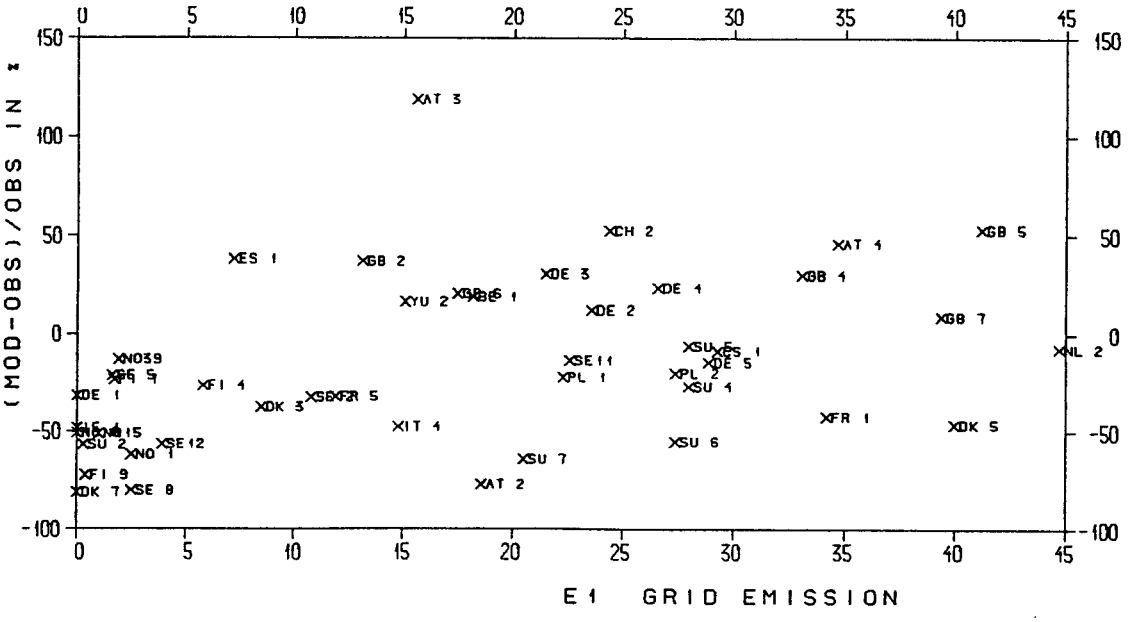
a



AMMONIUM IN PRECIPITATION (WET + DRY)

NH3 EMISSION AS 1000 TONNES(NH3)/YEAR
PERIODE : JANUAR -DESEMBER 1988
DATA FROM MODEL VERSION C
NO. OF STATIONS : 45
REQUIERMENT : AT LEAST 25. % COMMON DAYS WITH DATA

b



AMMONIUM IN PRECIPITATION (WET + DRY)

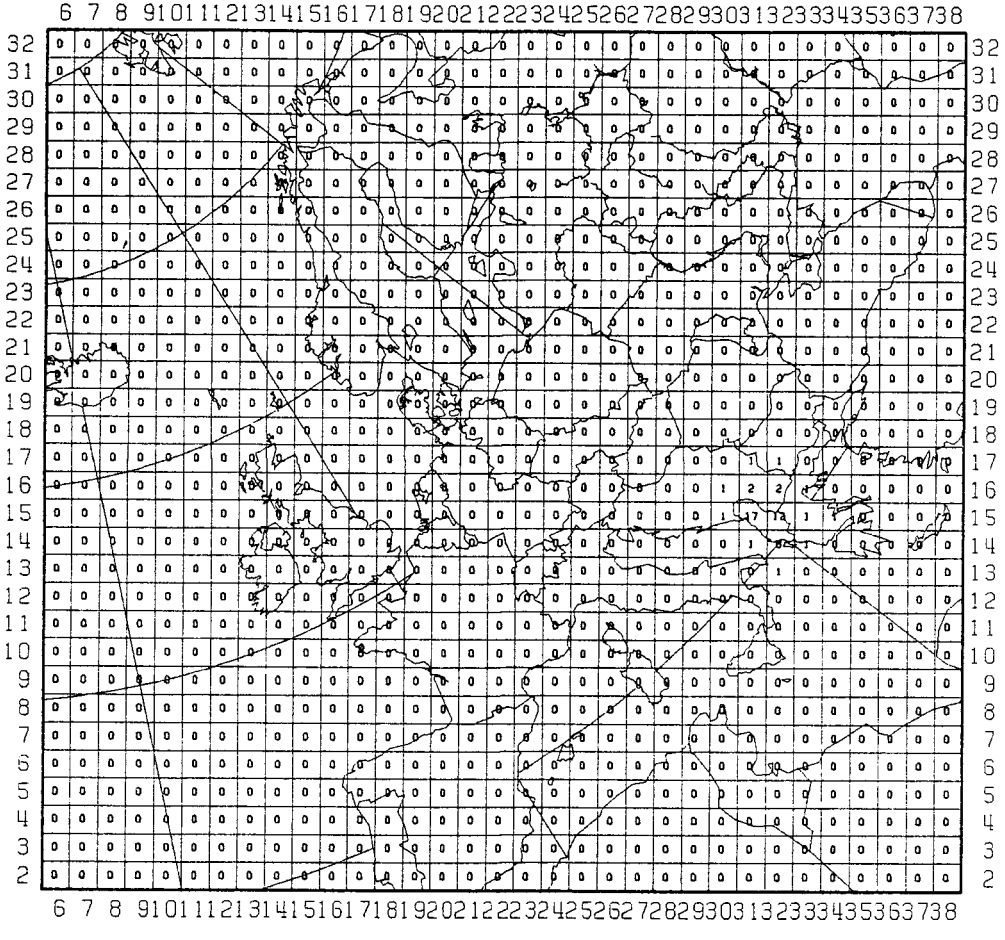
NH3 EMISSION AS 1000 TONNES(NH3)/YEAR
PERIODE : JANUAR -DESEMBER 1988
DATA FROM MODEL VERSION C
NO. OF STATIONS : 45
REQUIERMENT : AT LEAST 25. % COMMON DAYS WITH DATA

APPENDIX B.

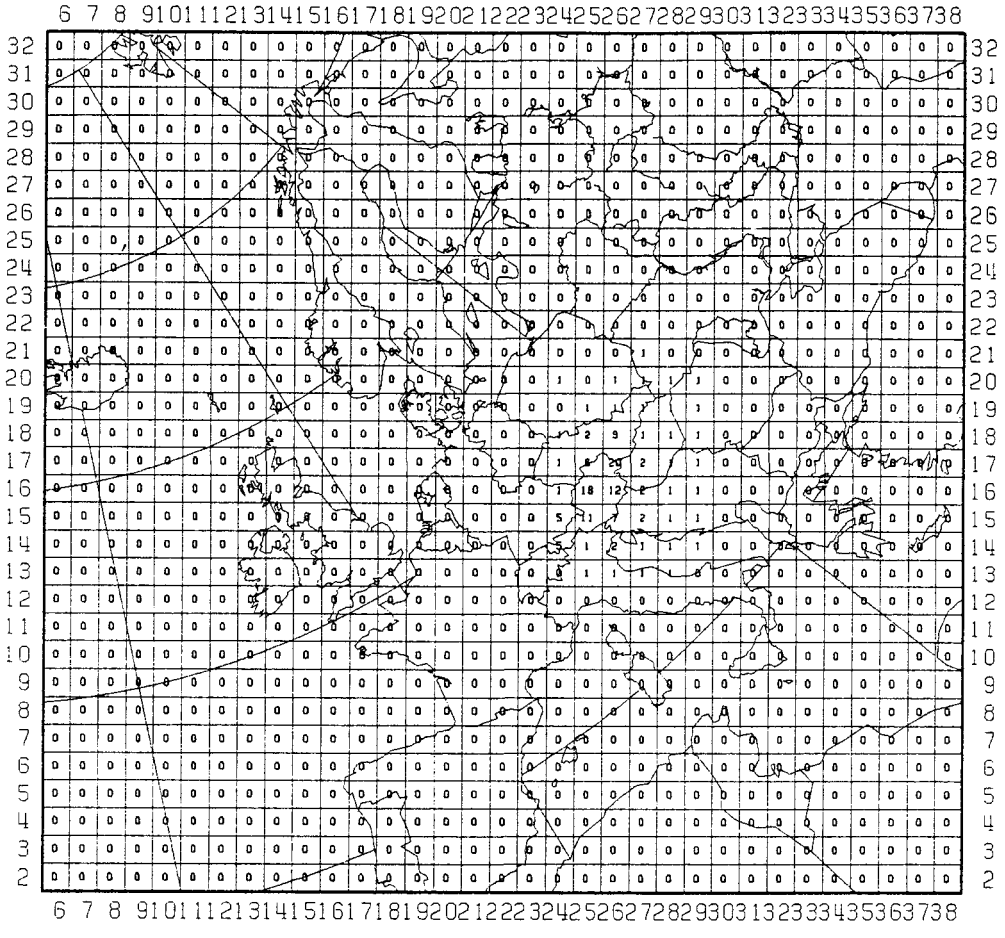
COUNTRY ALLOCATED DEPOSITIONS FOR 1988

The appendix shows maps with numbers in EMEP grid squares for depositions allocated to emissions in the sub-domains defined in Table 12.

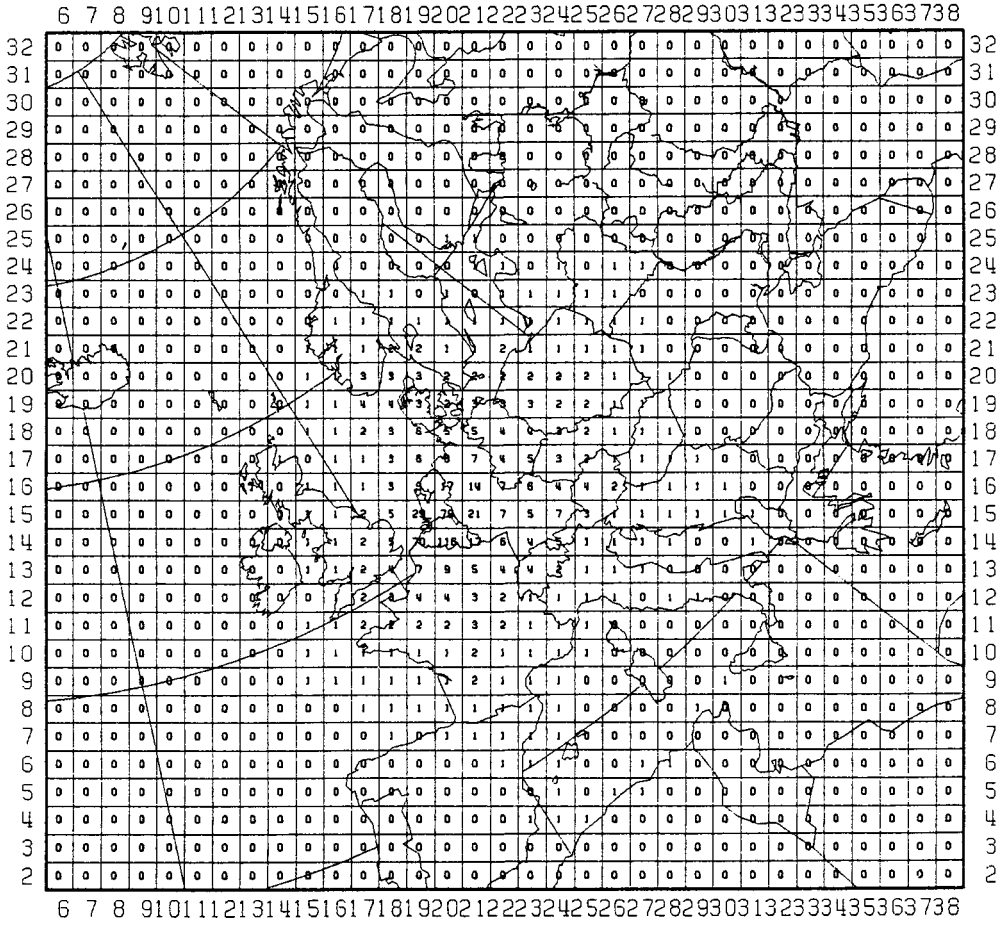
Units are: cg/m^2 as S for oxidised sulphur,
and mg/m^2 as N for oxidised and reduced nitrogen.



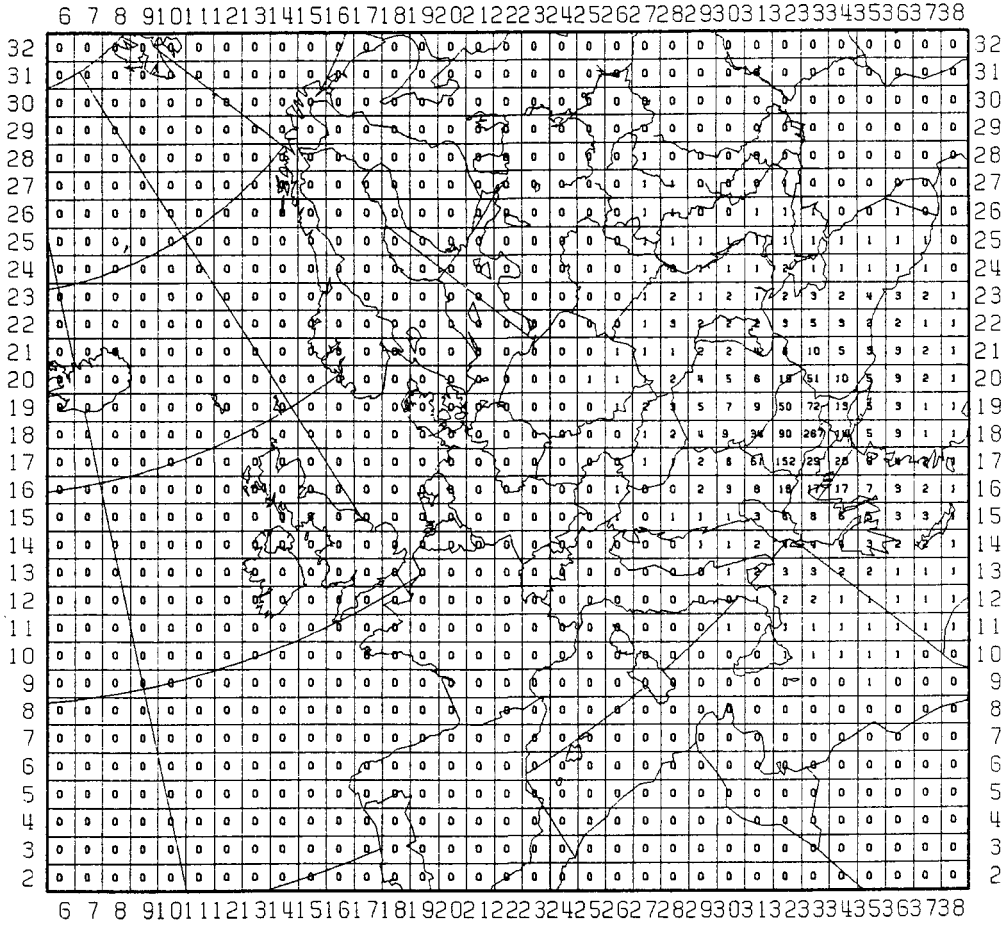
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - ALBANIA - AL
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



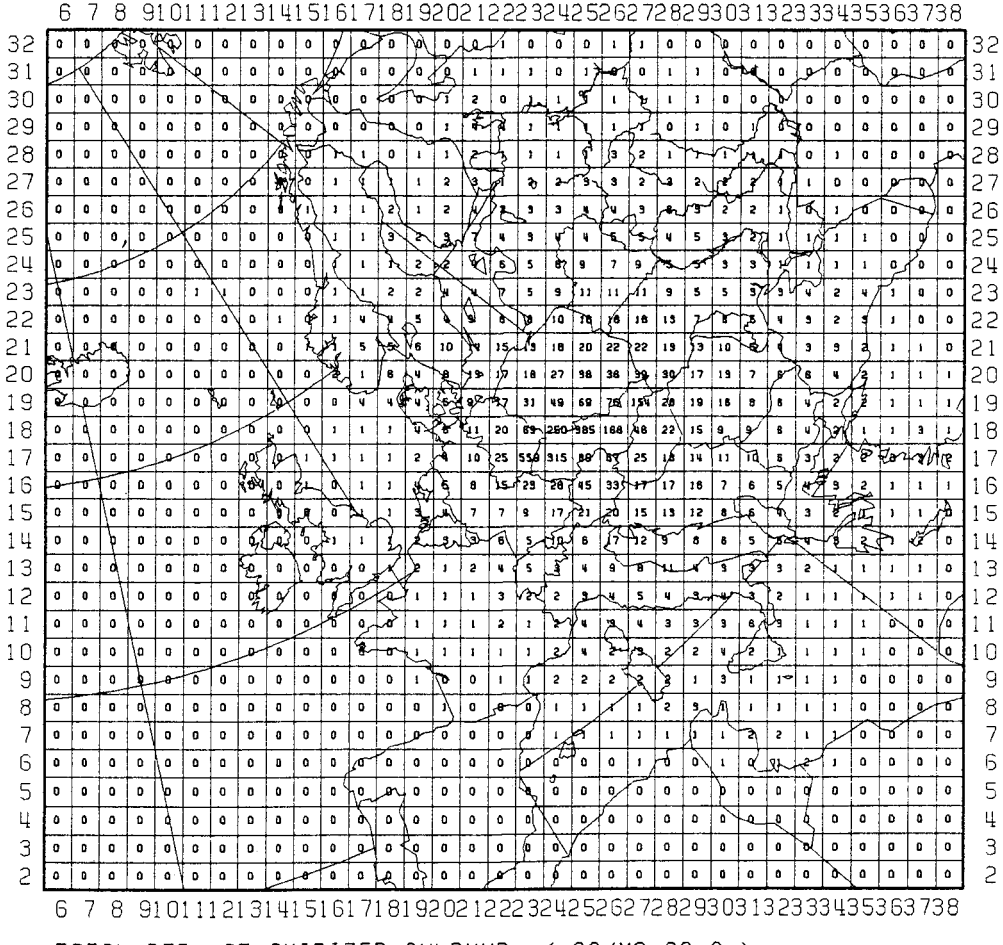
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - AUSTRIA - AT
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



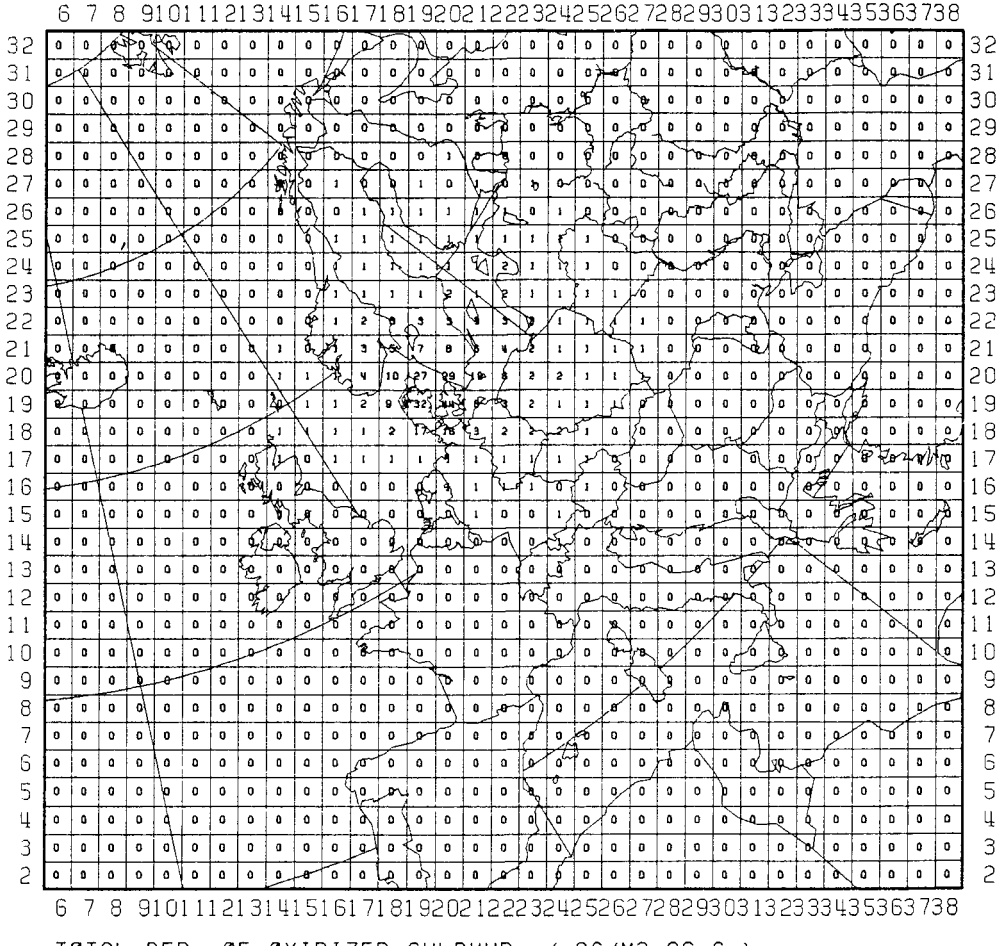
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - BELGIUM - BE
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



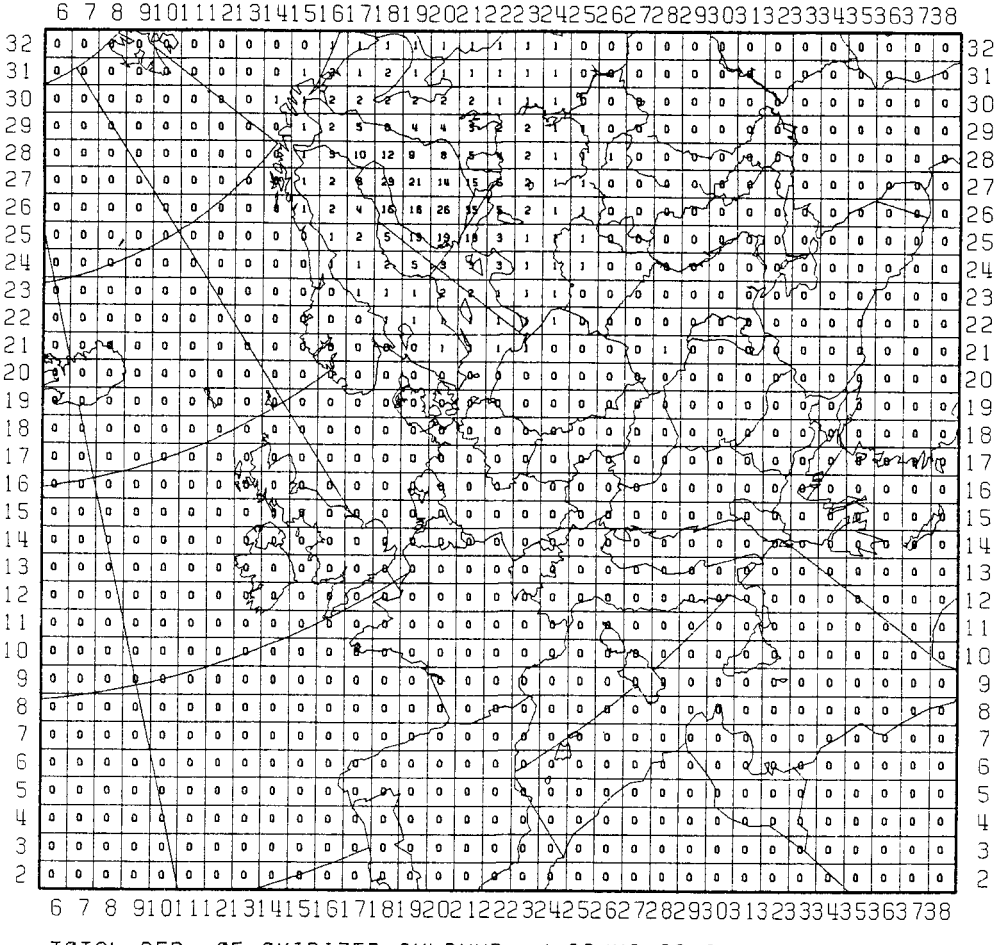
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - BULGARIA - BG
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL



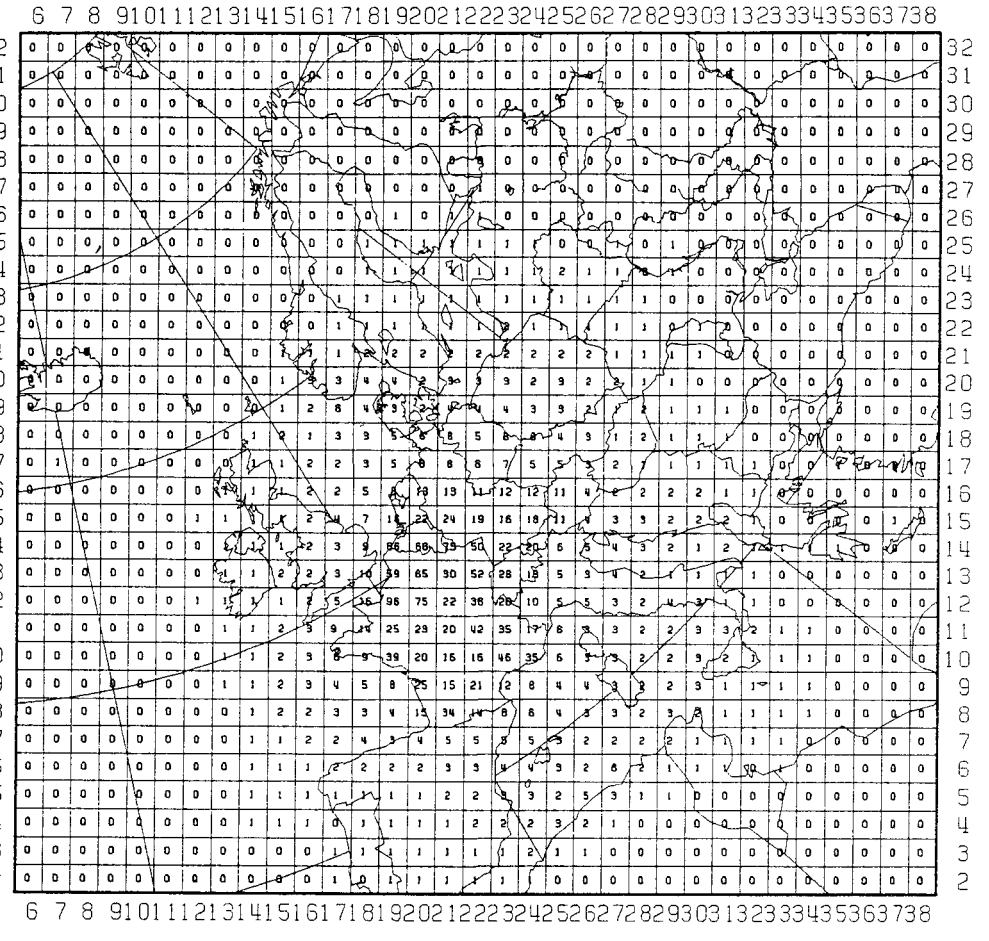
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - CZECHOSLOVAKIA - CS
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



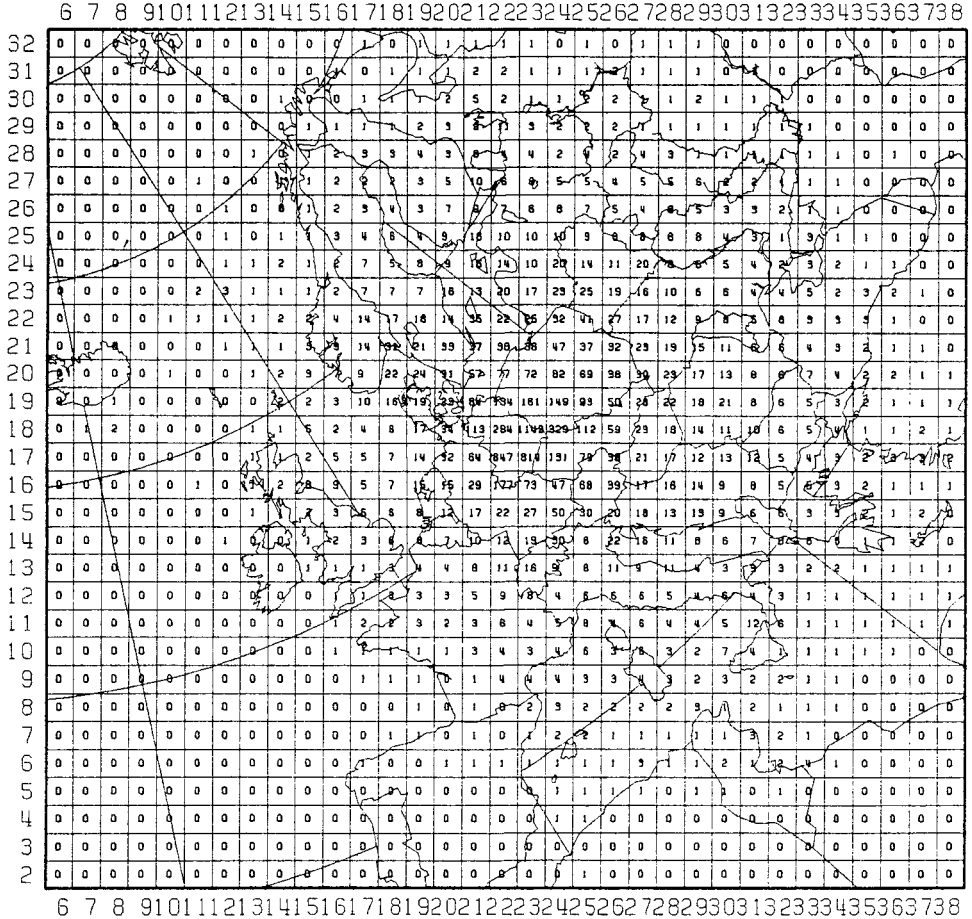
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - DENMARK - DK
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



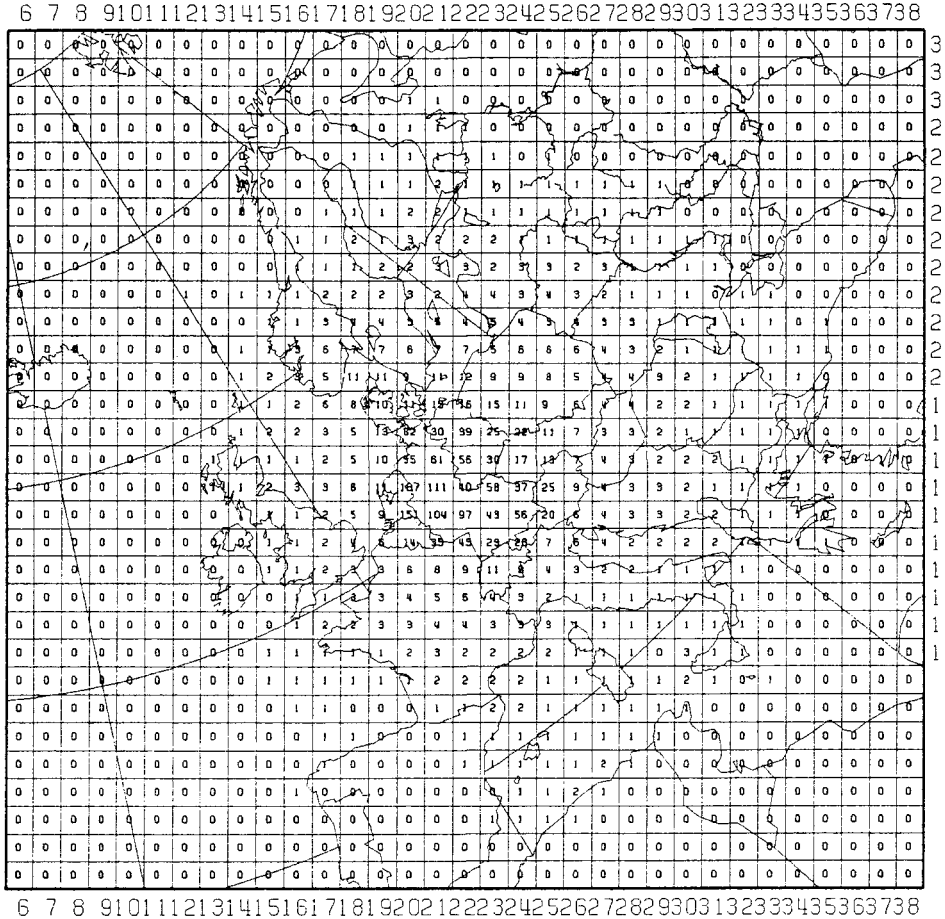
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - FINLAND - FI
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



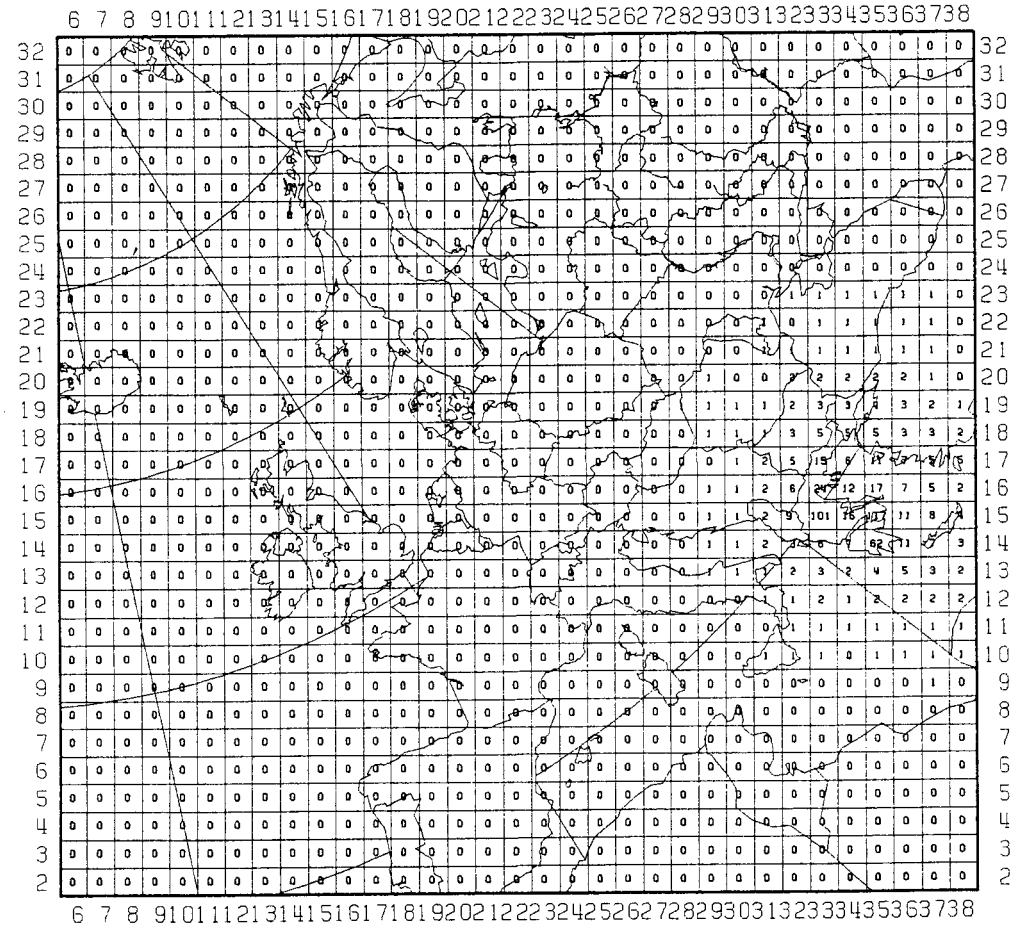
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - FRANCE - FR
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



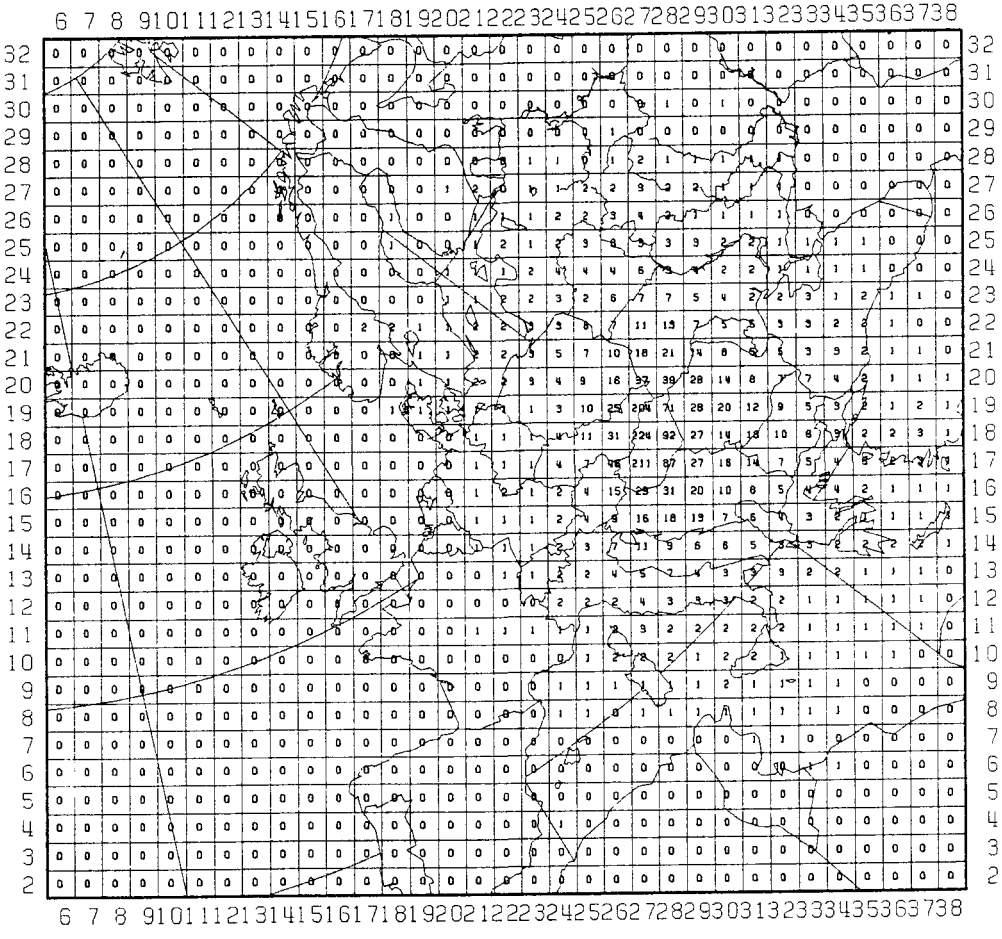
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - GERMAN DEMOCRATIC REP- DD
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



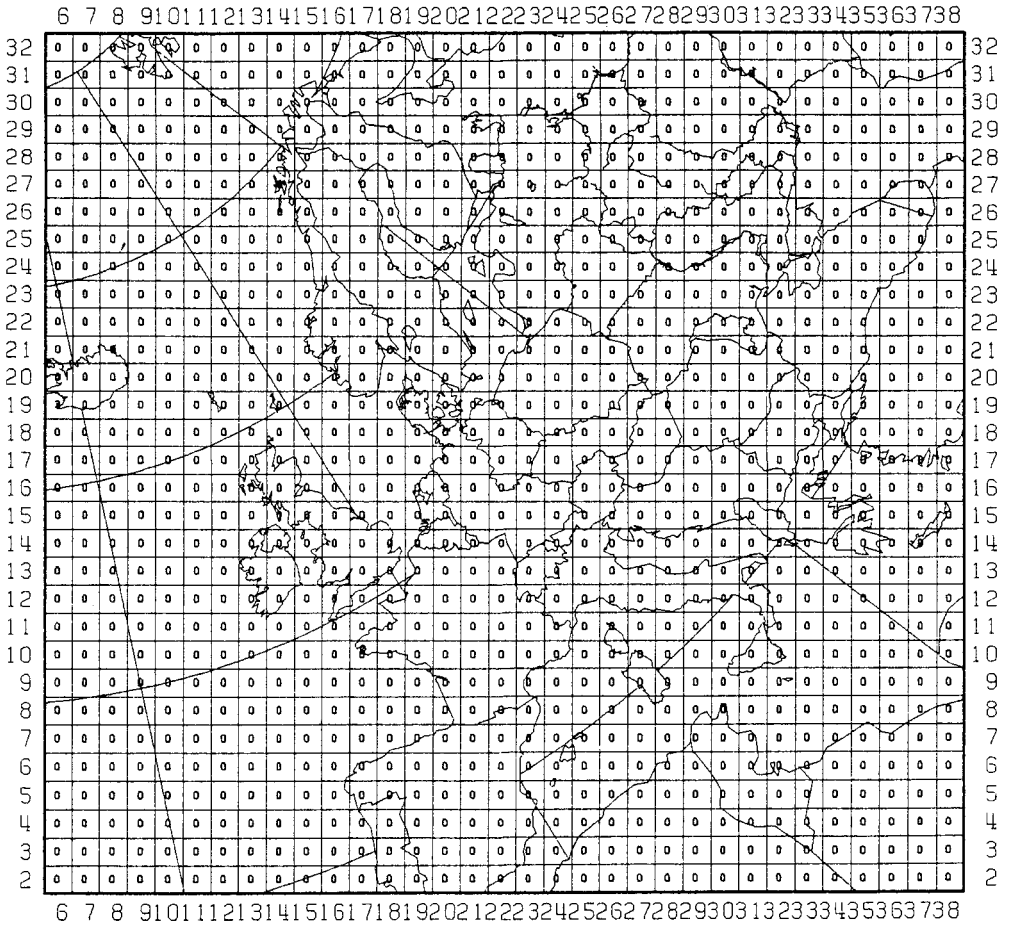
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - GERMANY, FEDERAL REP.- DE
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



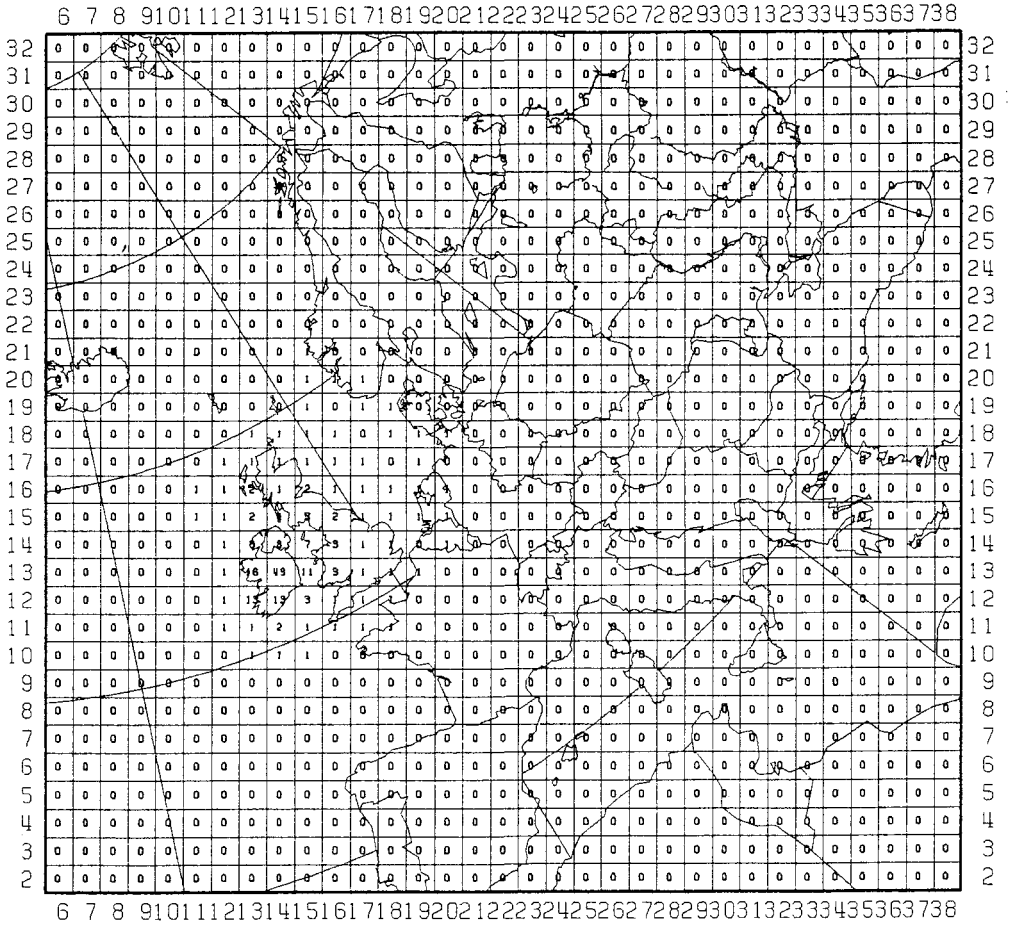
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - GREECE - GR
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



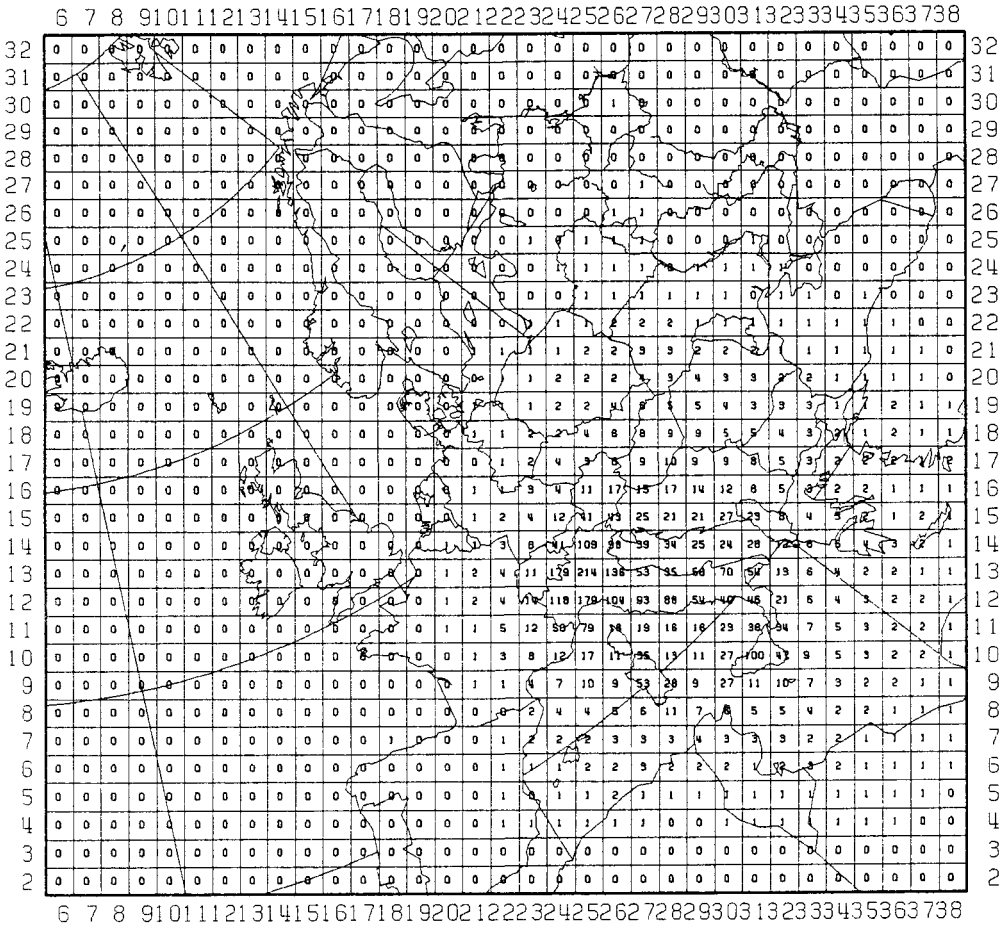
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - HUNGARY - HU
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



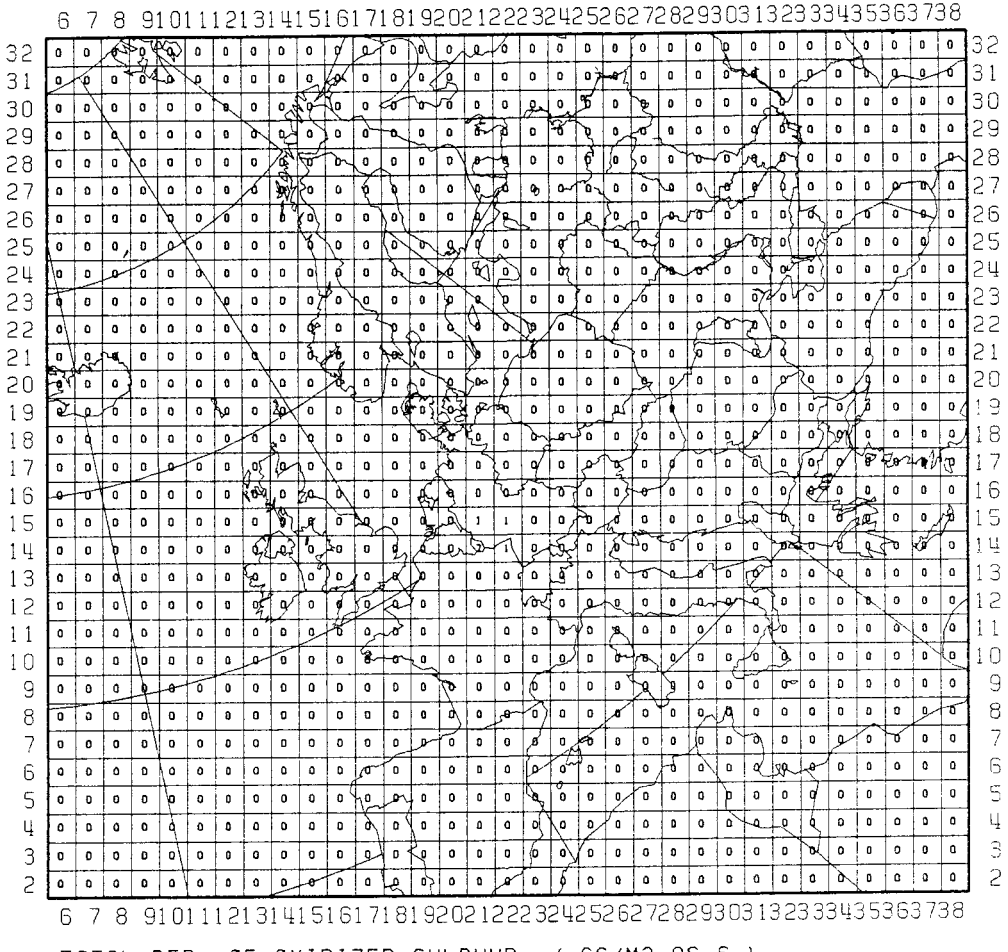
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - ICELAND - IS
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL



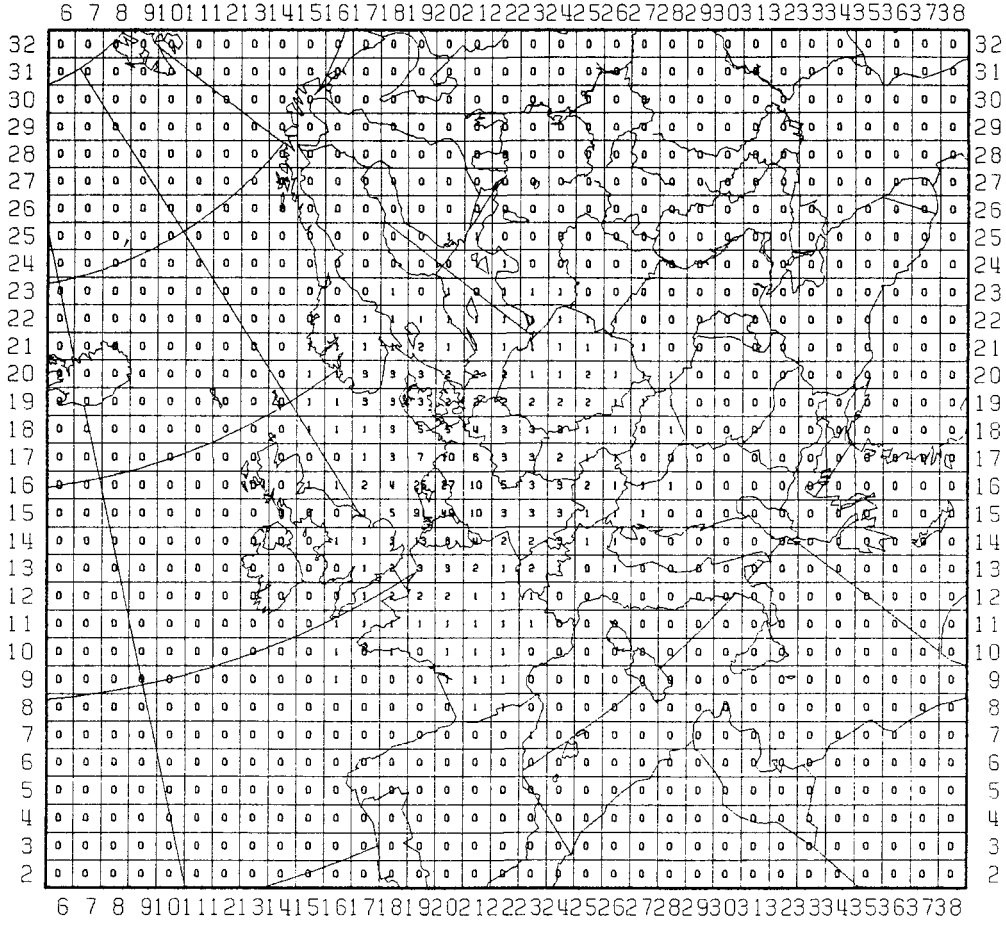
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - IRELAND - IE
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL



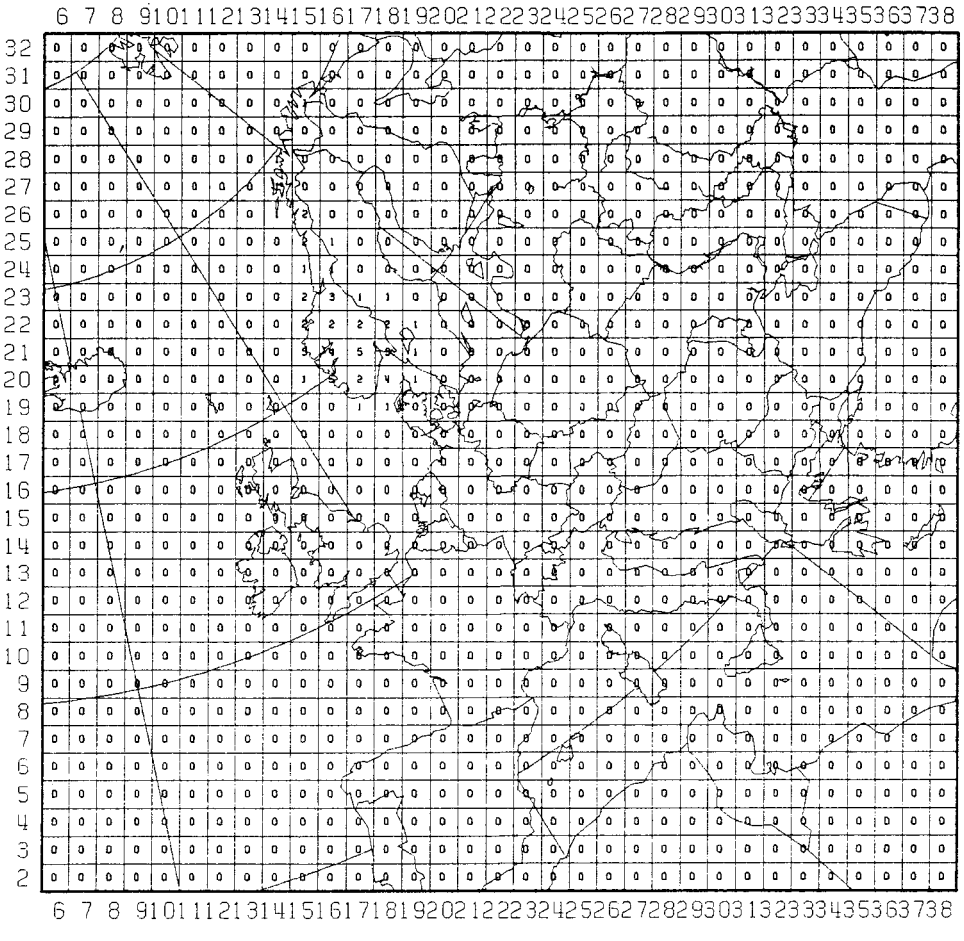
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - ITALY - IT
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



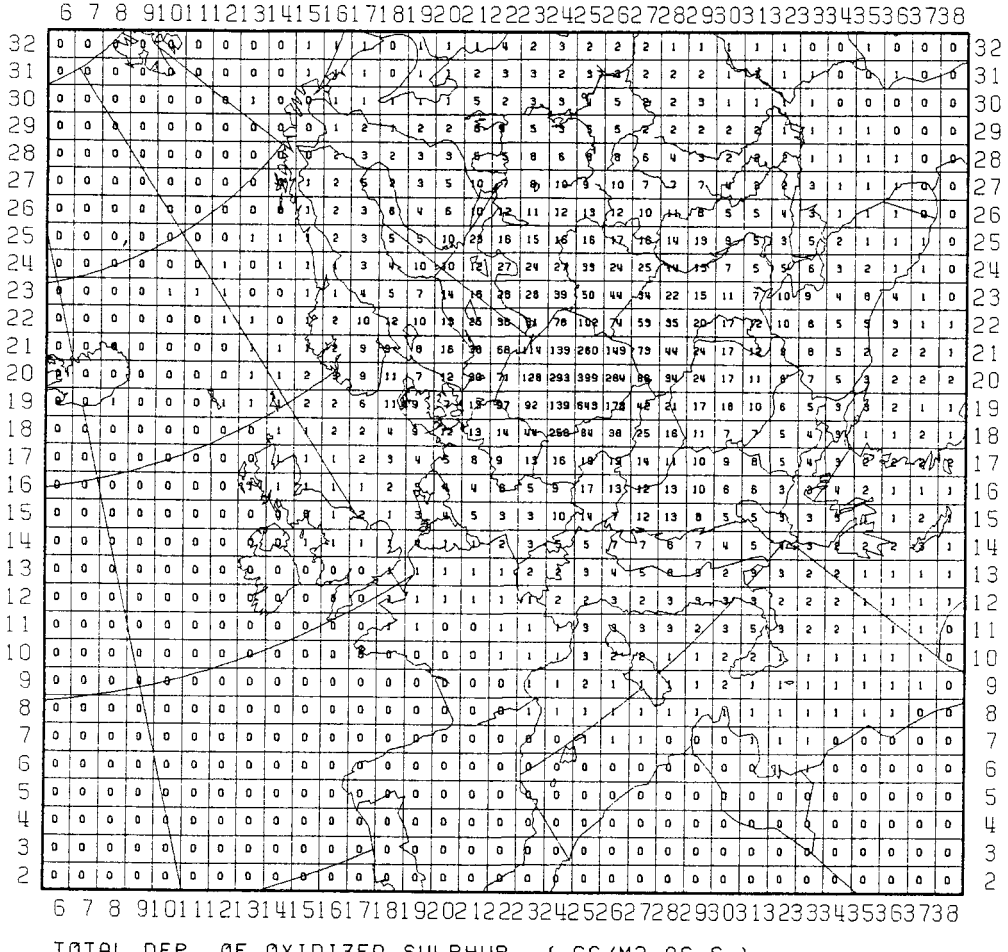
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - LUXEMBOURG - LU
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



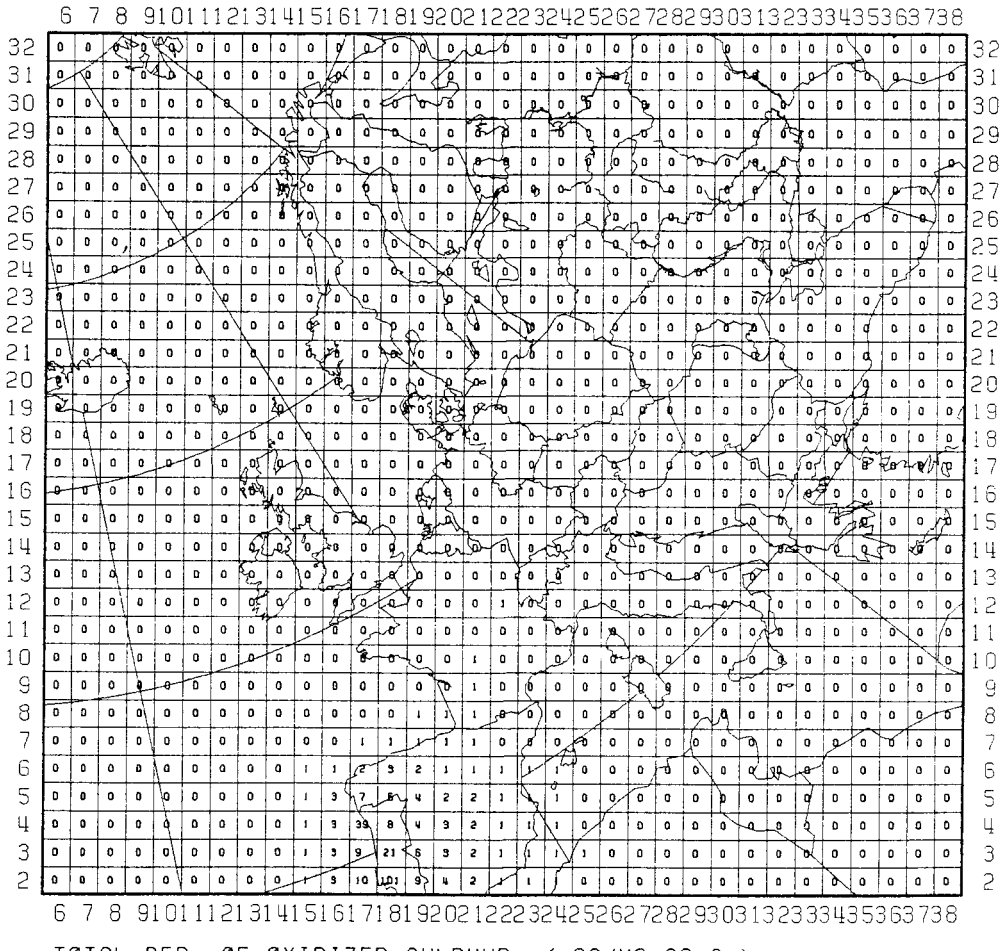
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - NETHERLANDS - NL
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



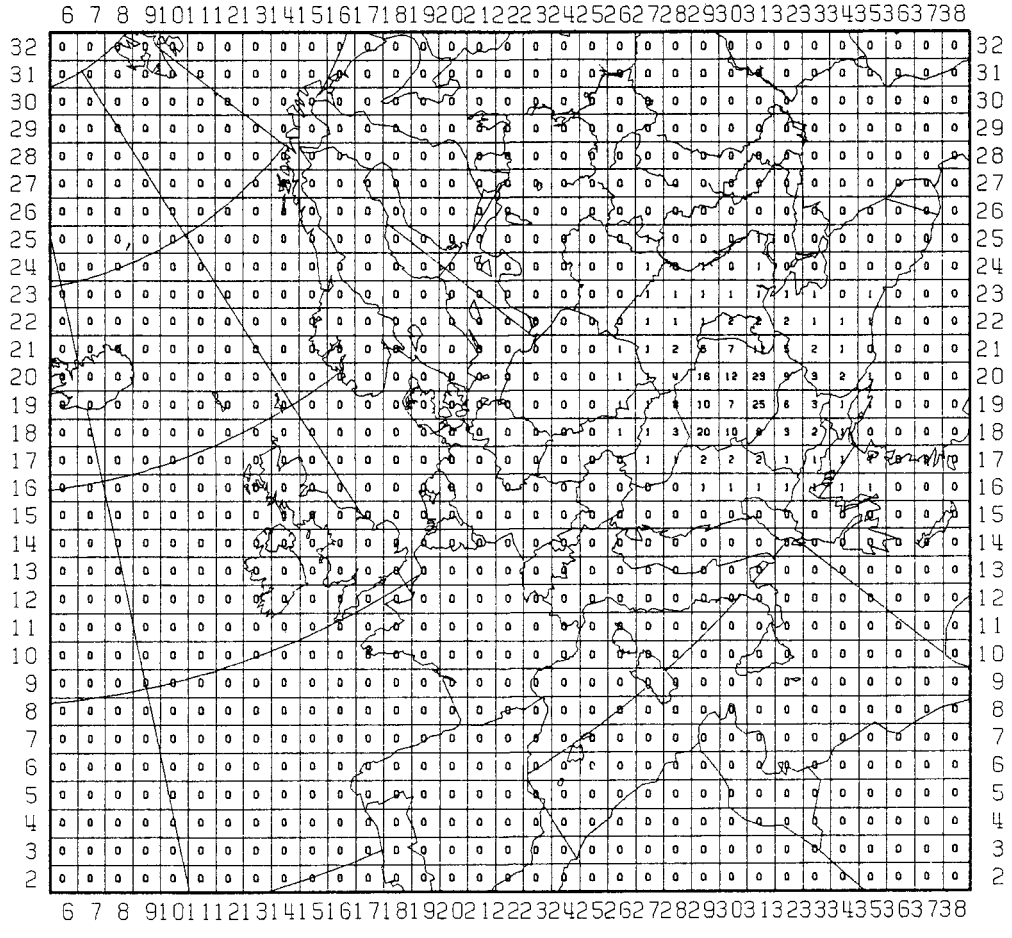
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - NORWAY - NO
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



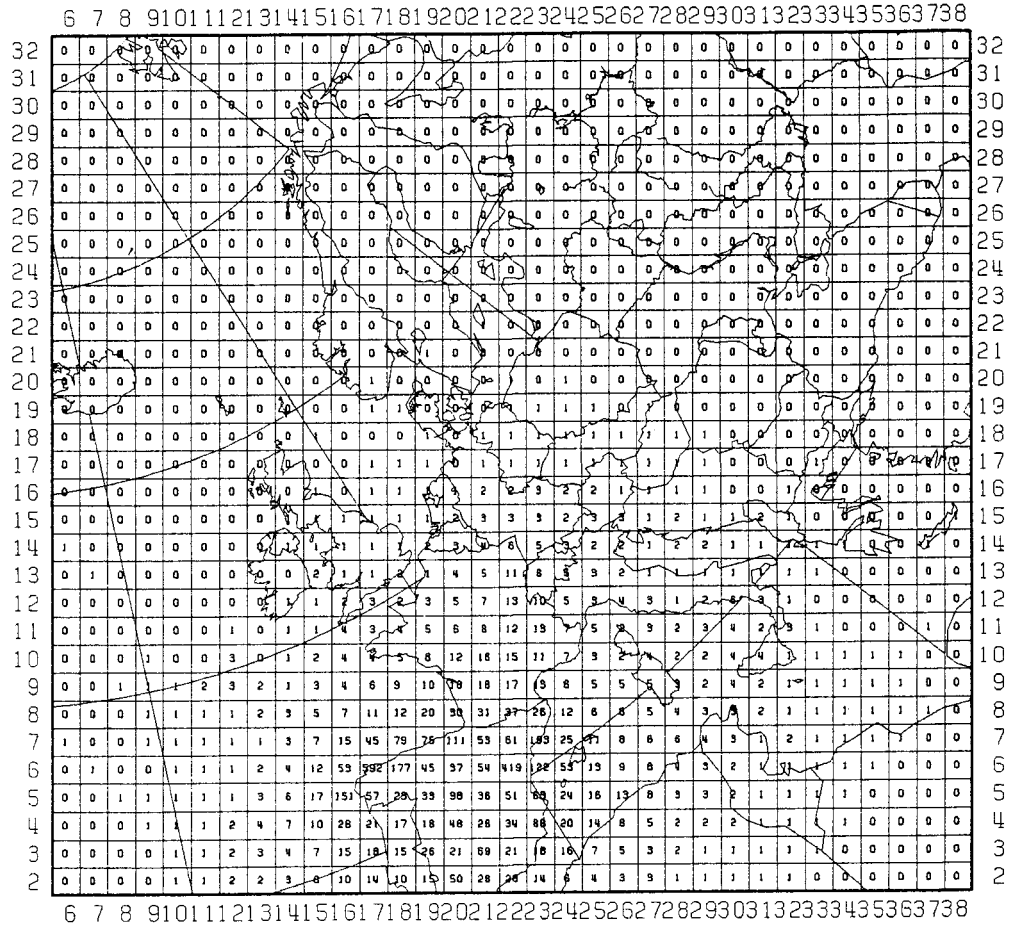
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - POLAND - PL
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



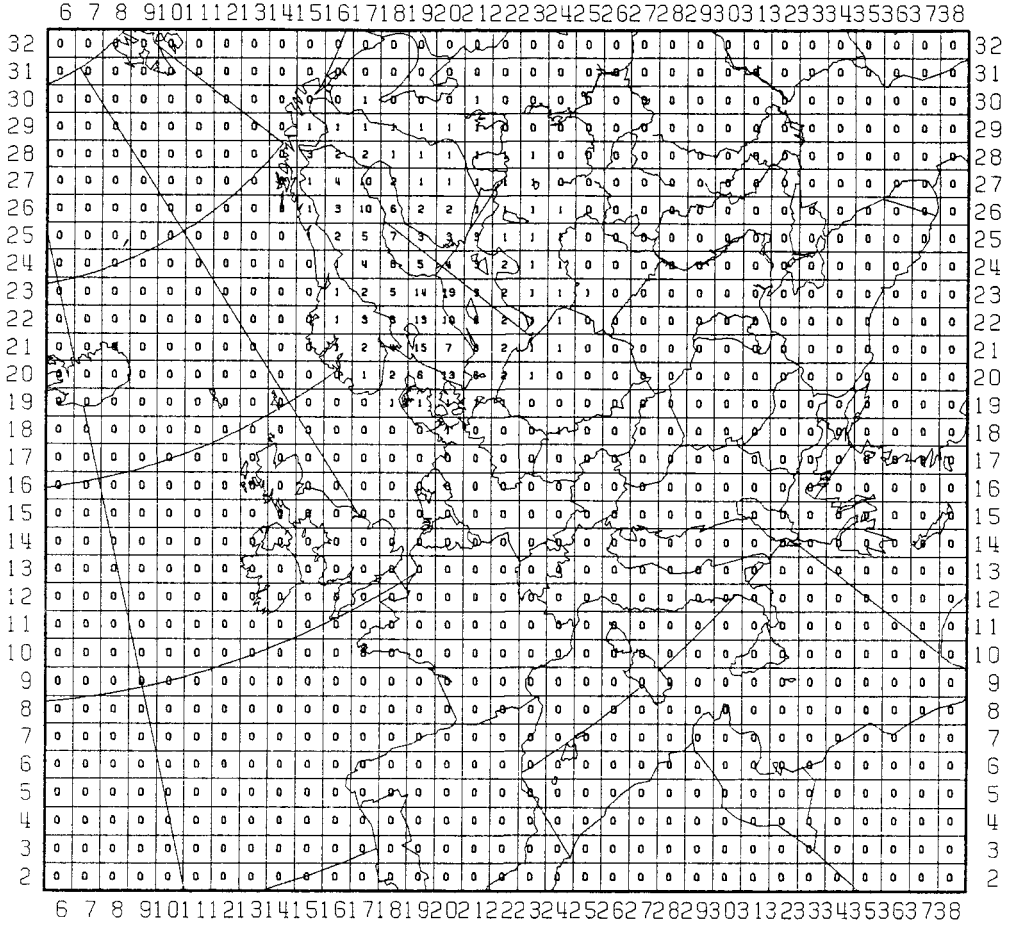
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - PORTUGAL - PT
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



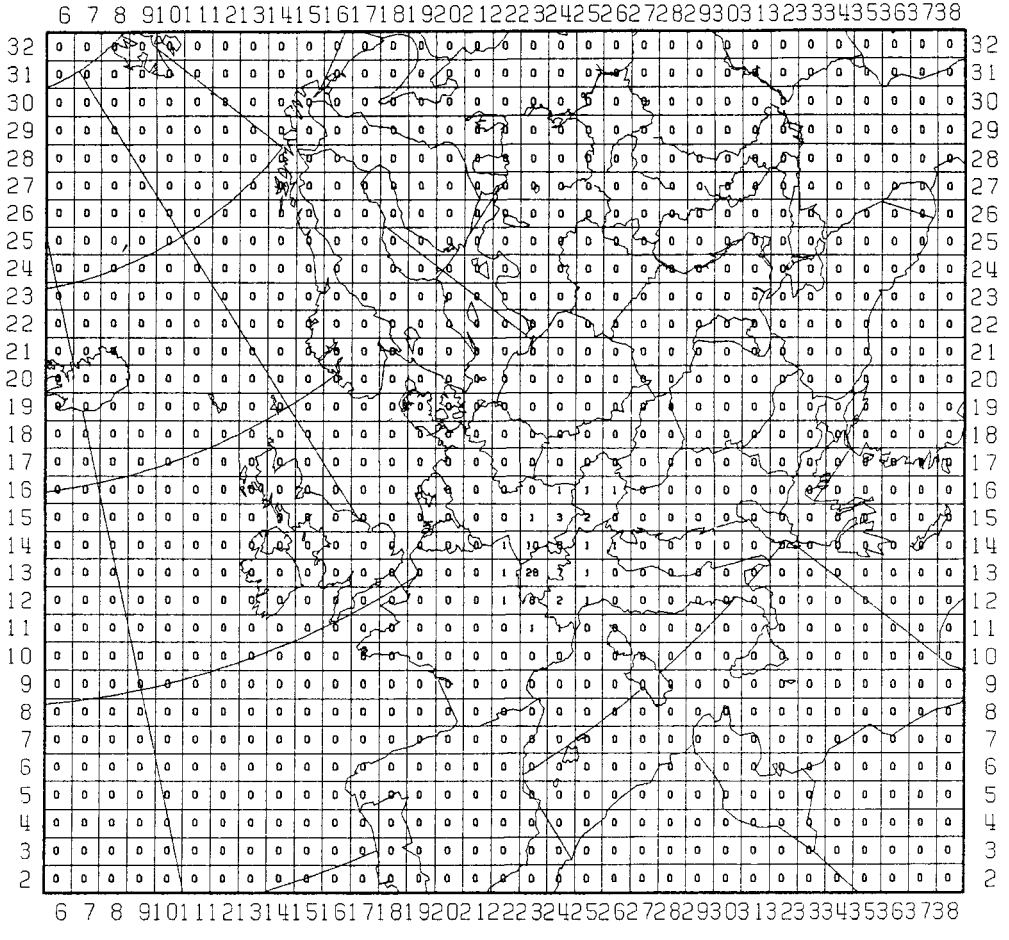
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - ROMANIA - RO
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL



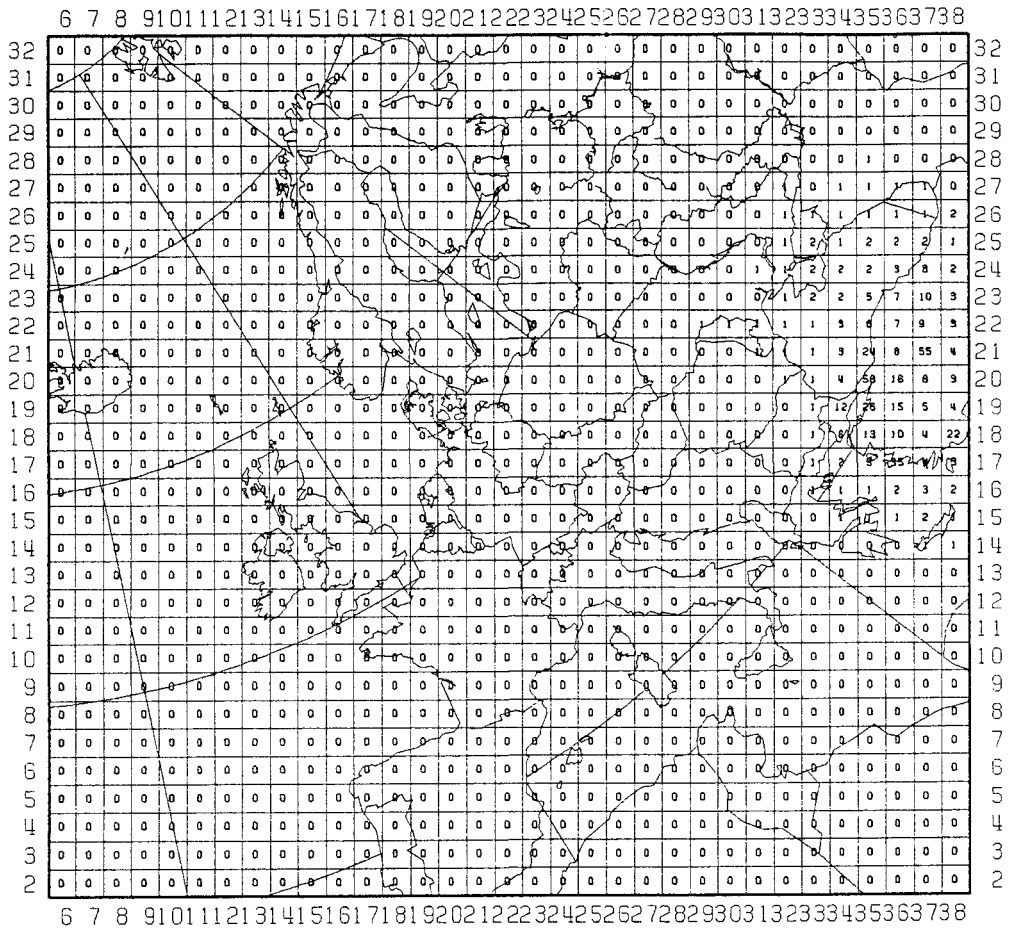
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - SPAIN - ES
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL



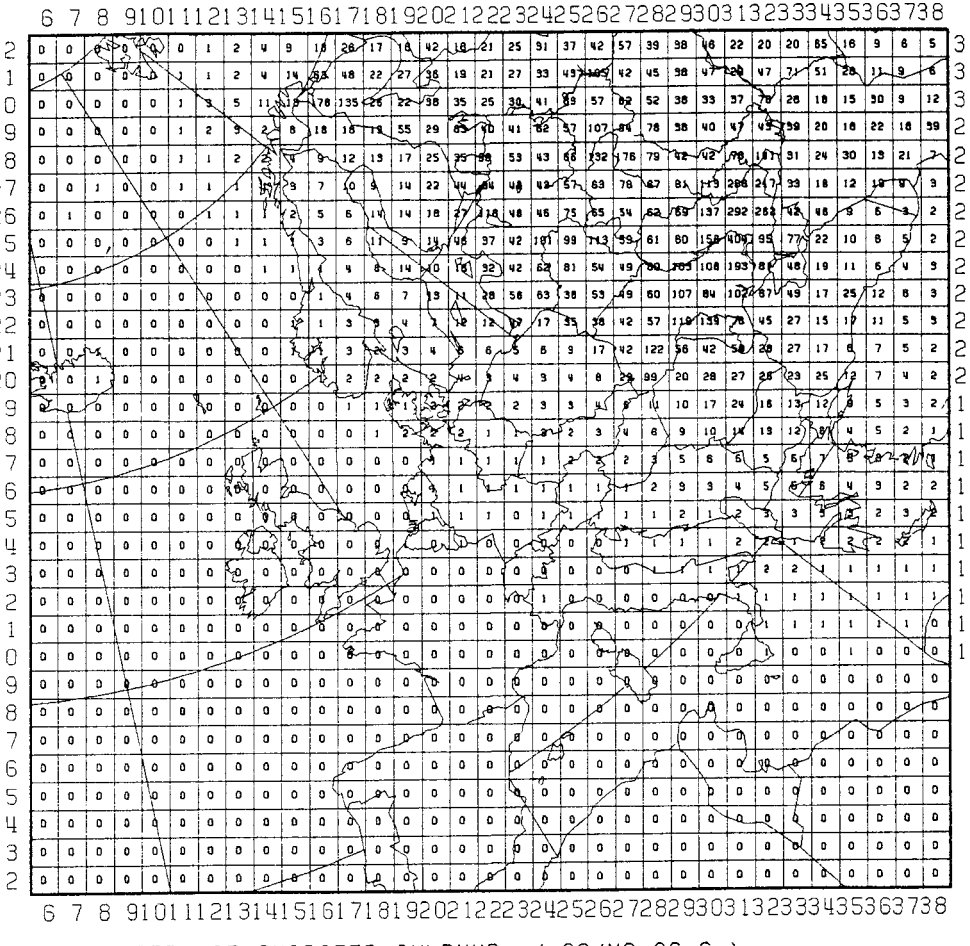
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - SWEDEN - SE
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



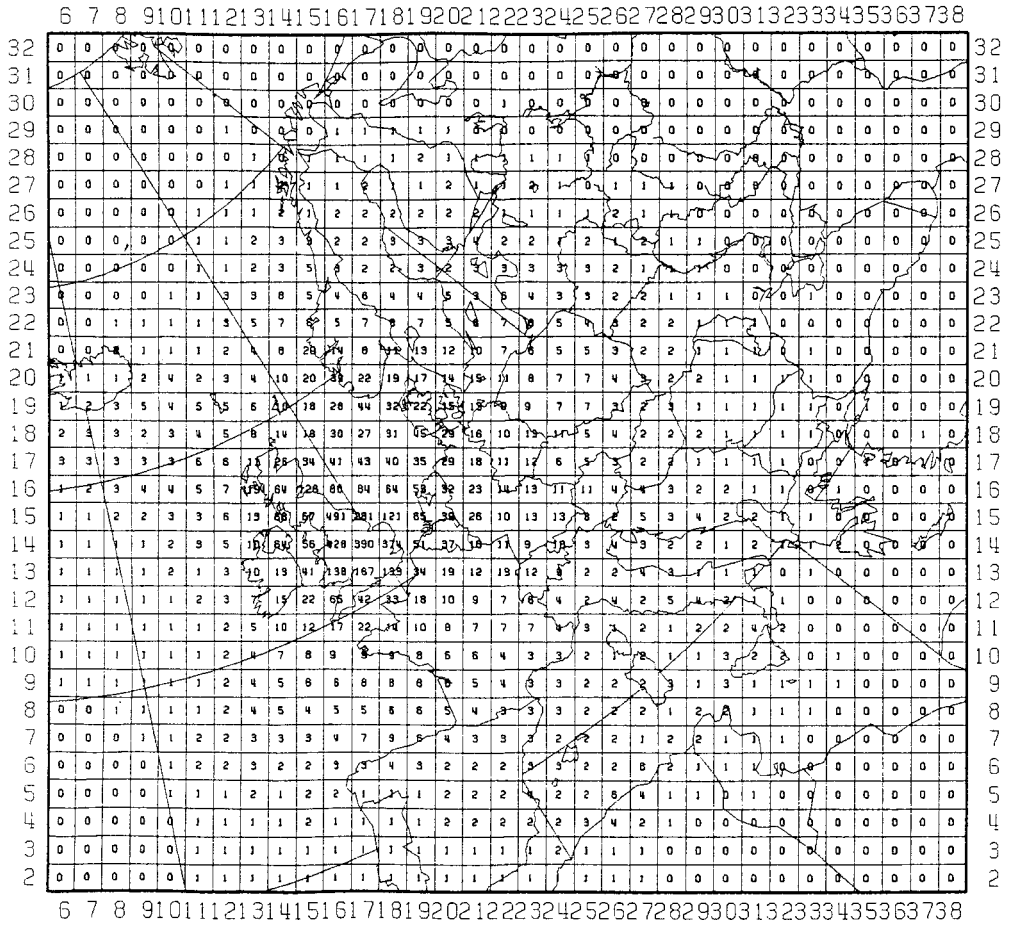
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - SWITZERLAND - CH
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



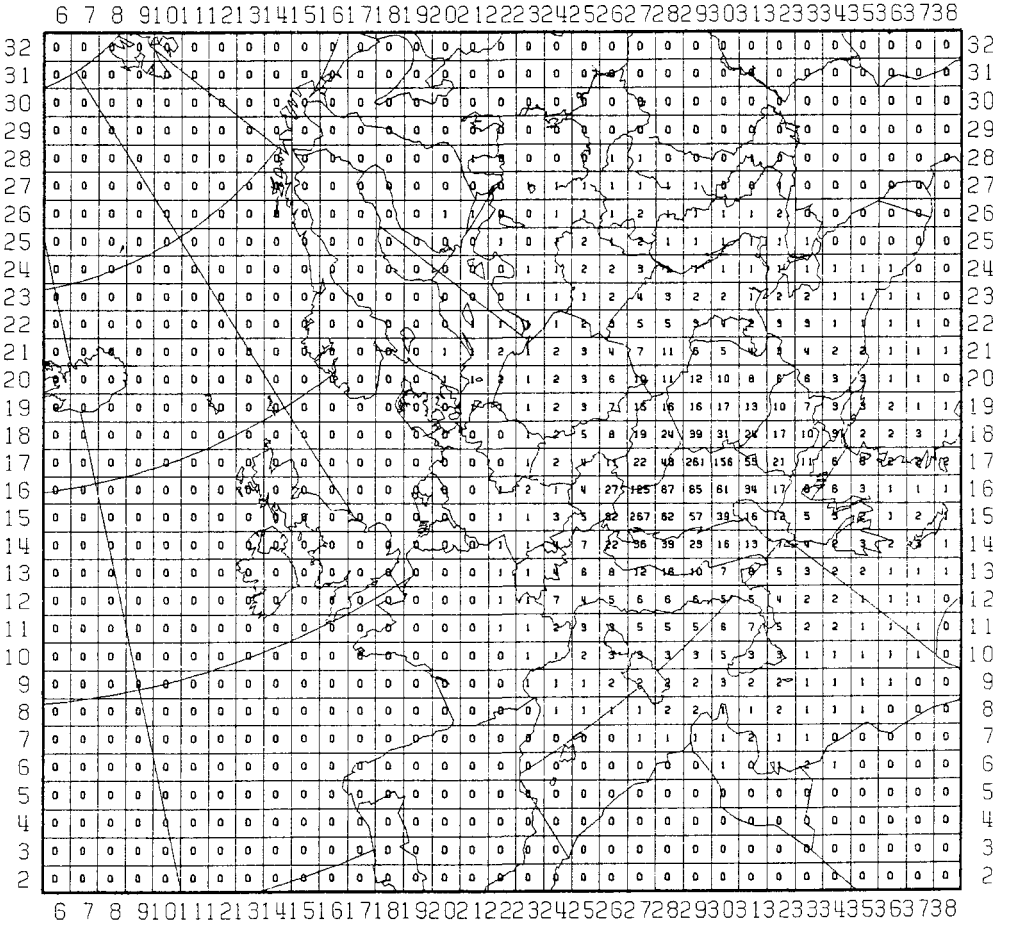
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - TURKEY - TR
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



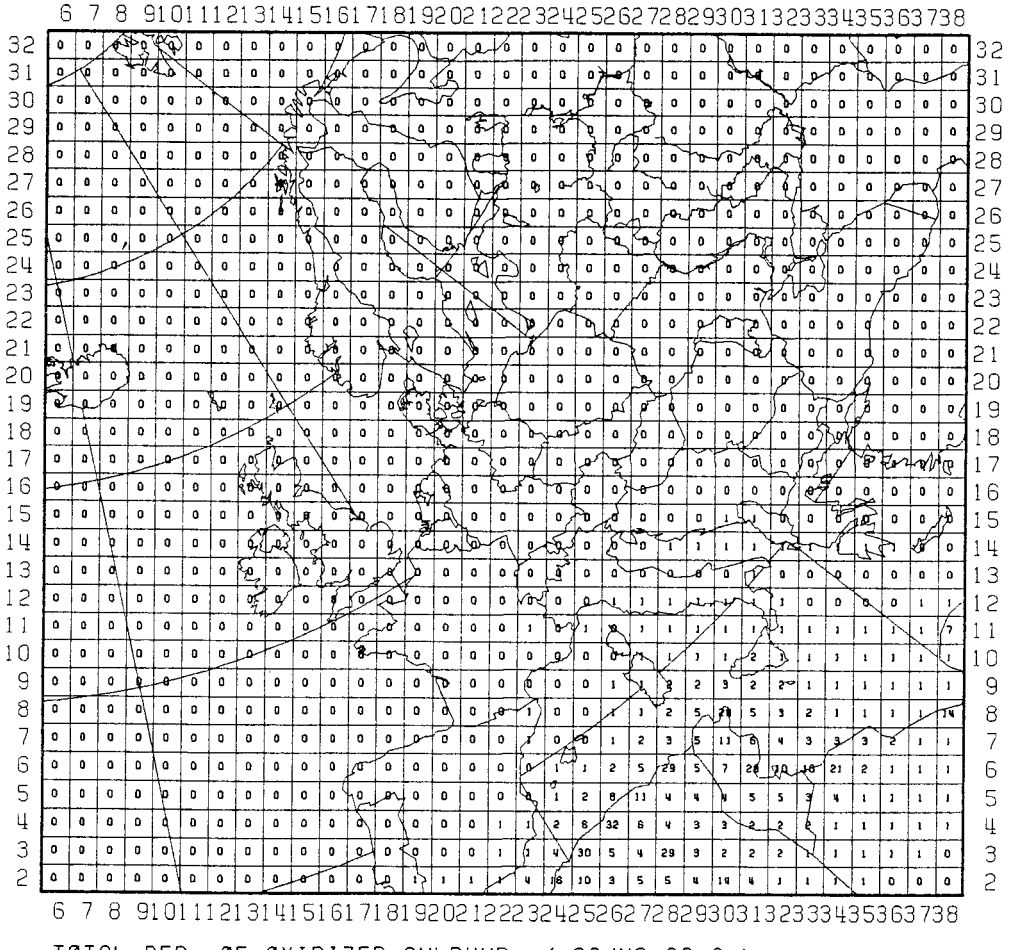
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - USSR (EUROPEAN) - SU
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



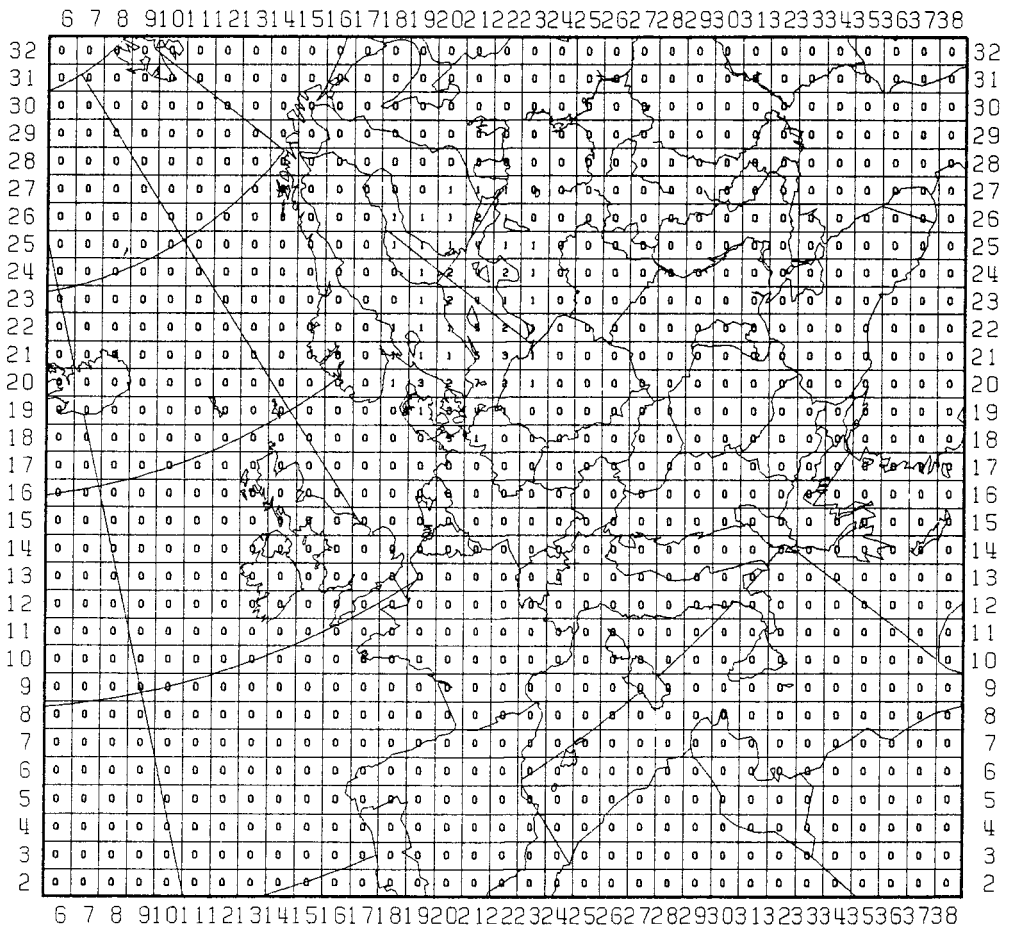
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - UNITED KINGDOM - GB
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



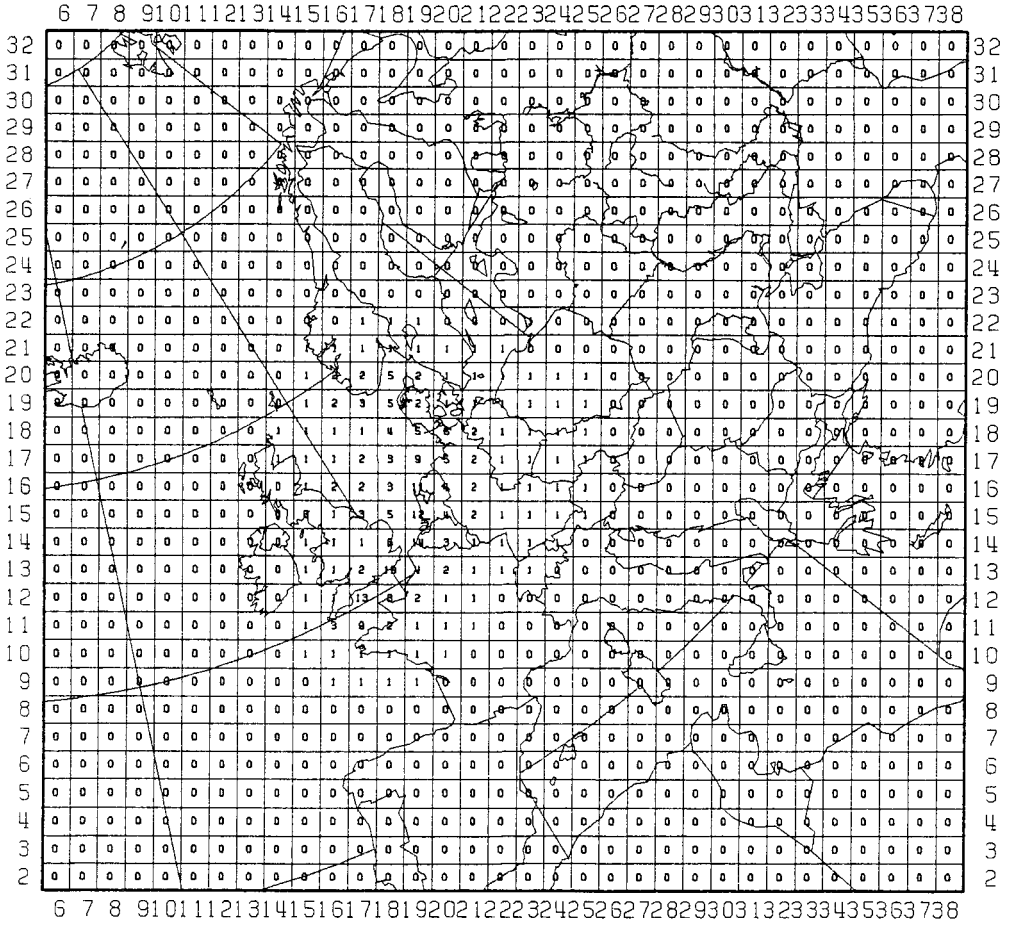
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - YUGOSLAVIA - YU
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



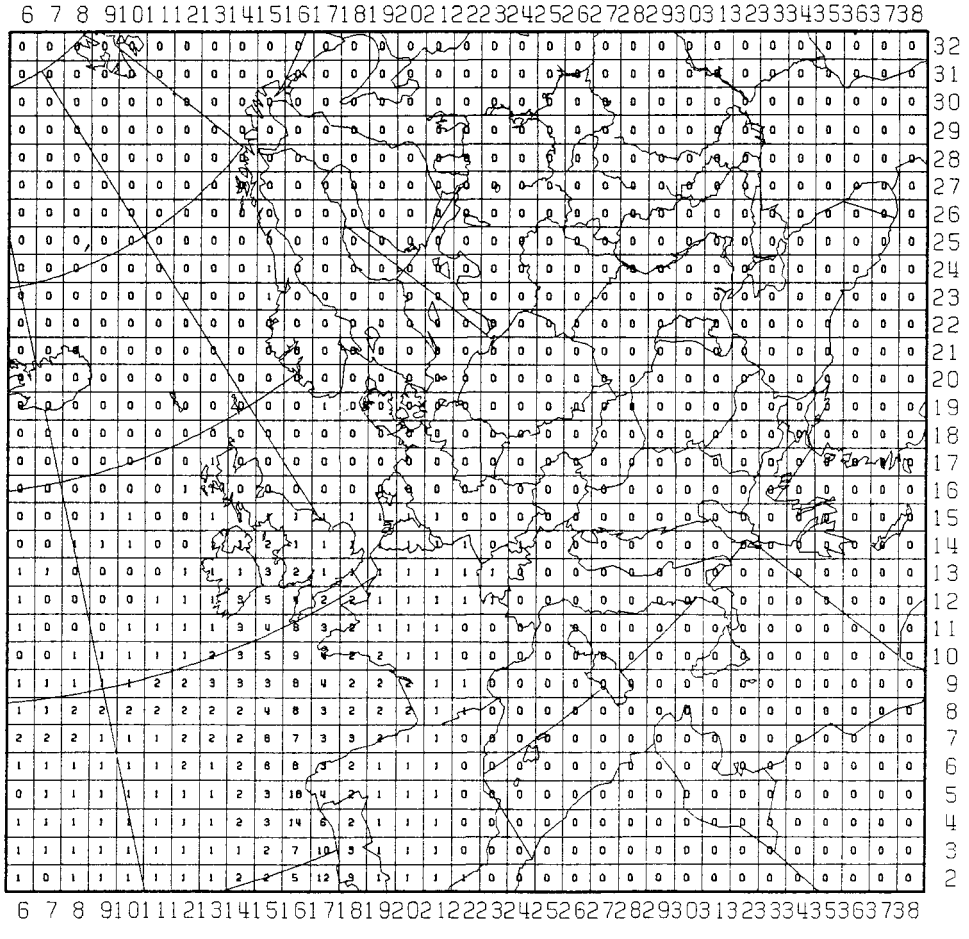
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - REMAINING AREAS -REM
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



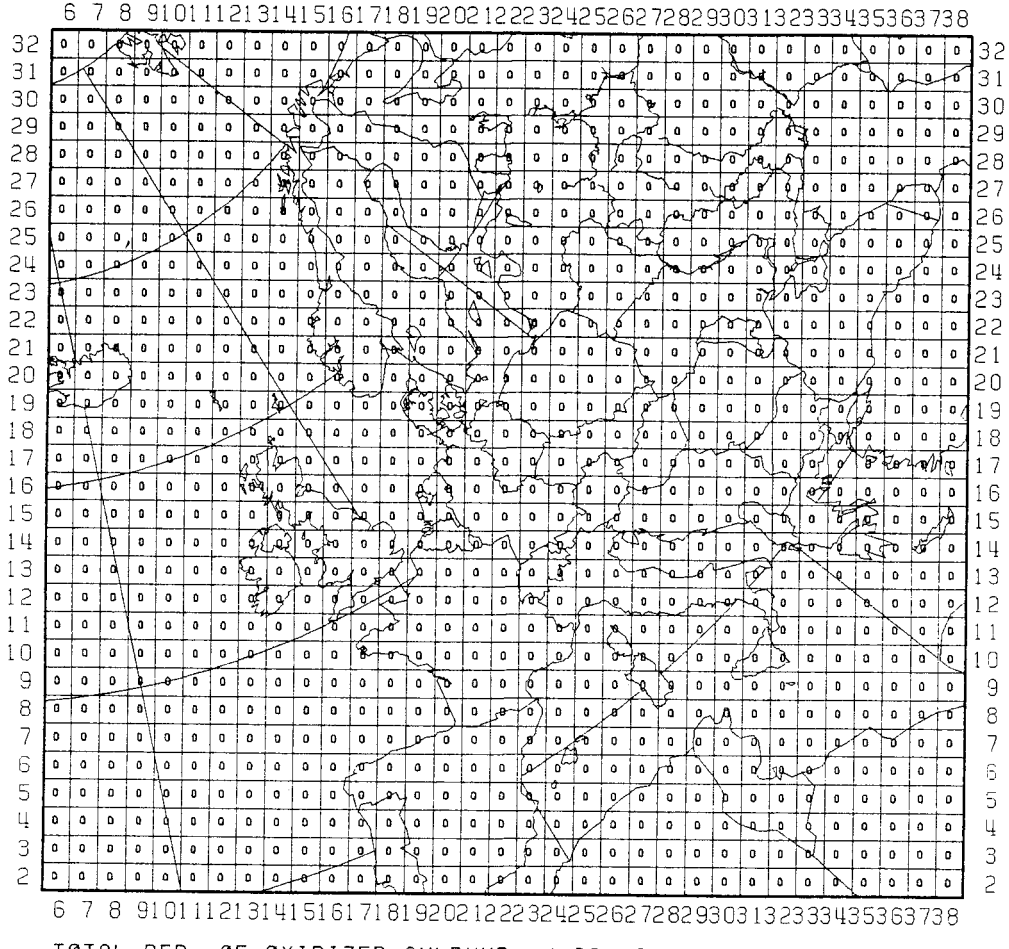
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - INT. TRADE, BALTIC SEA -BAS
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



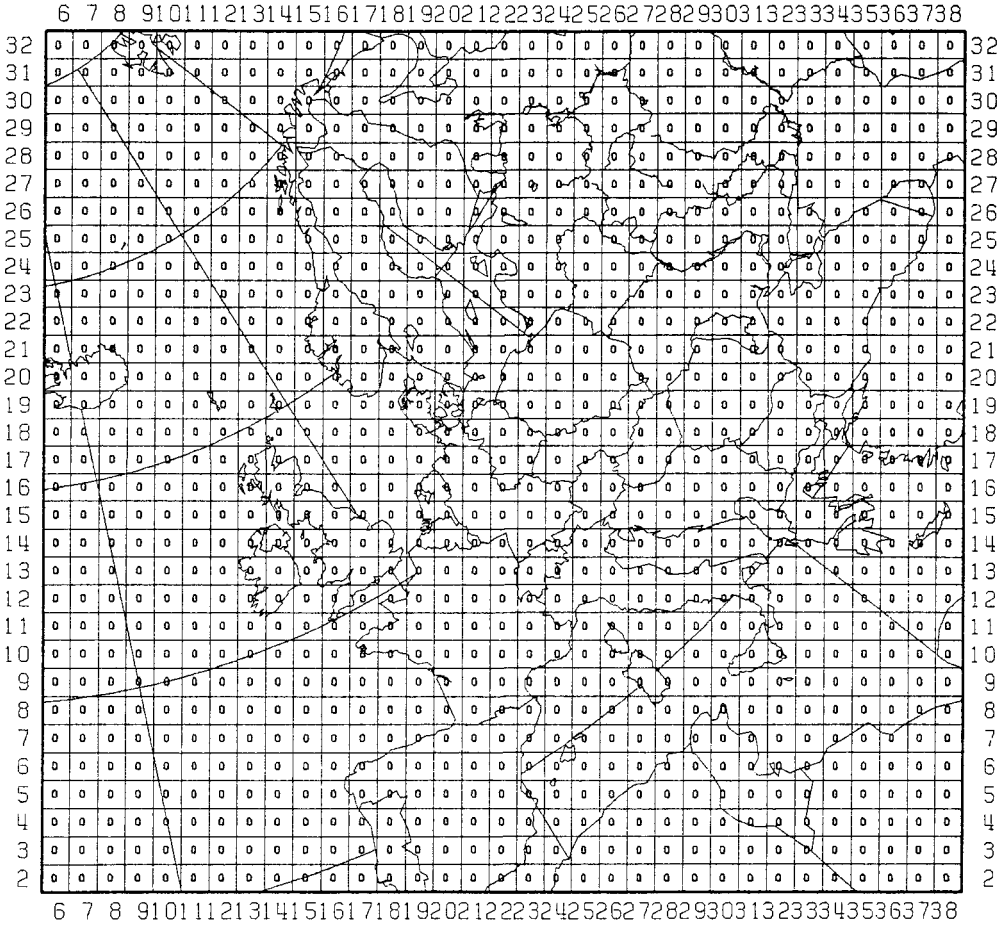
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - INT. TRADE, NORTH SEA -NOS
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



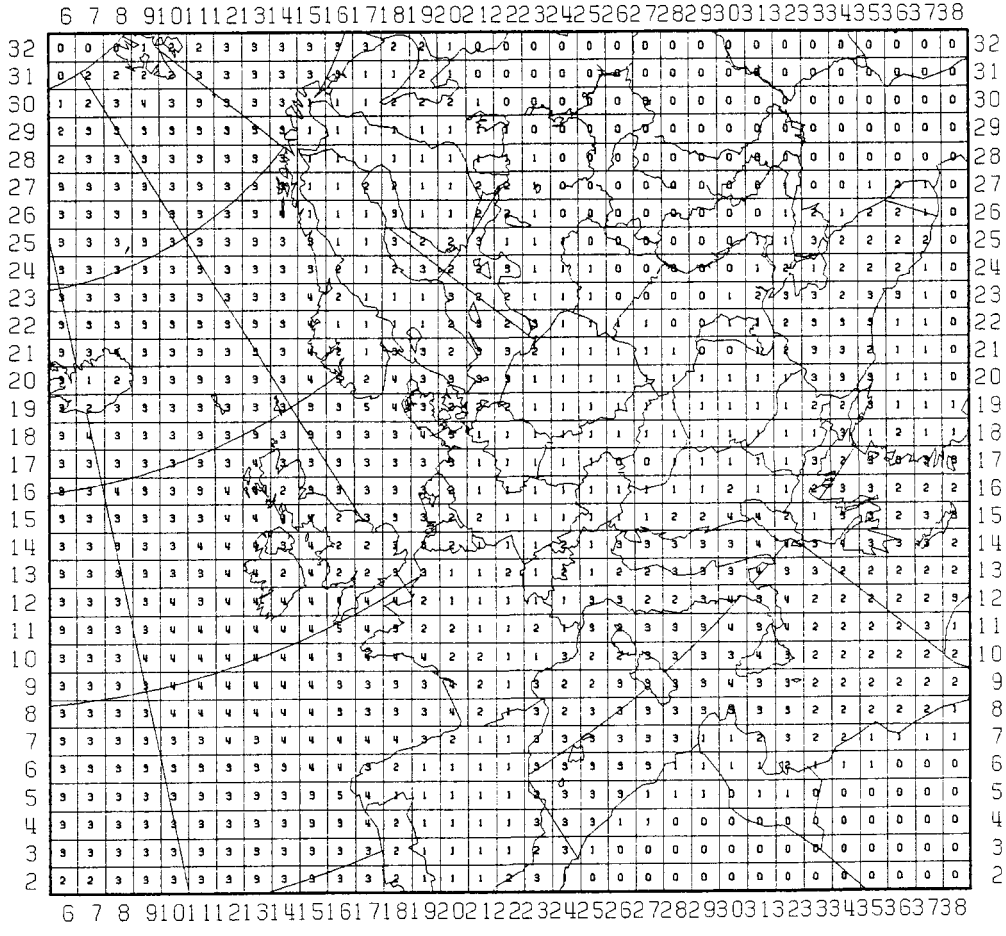
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - INT. TRADE, REM. ATL. -ATL
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



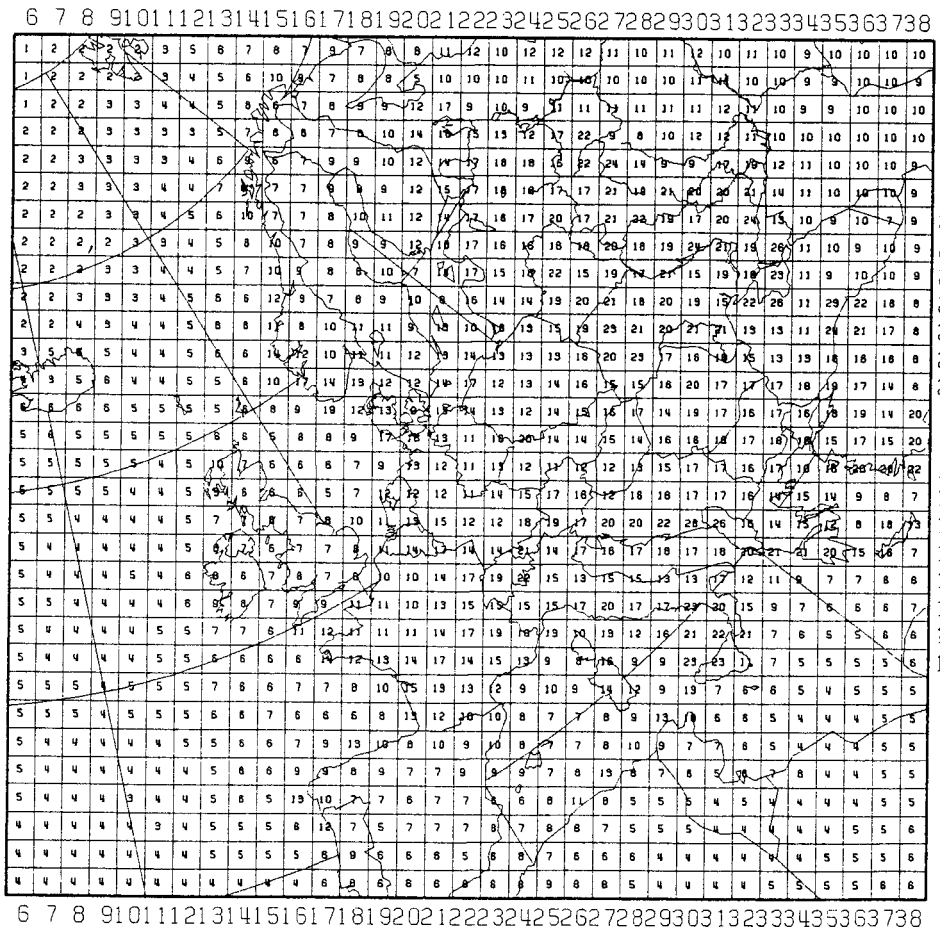
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - INT. TRADE, BLACK SEA -BLS
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



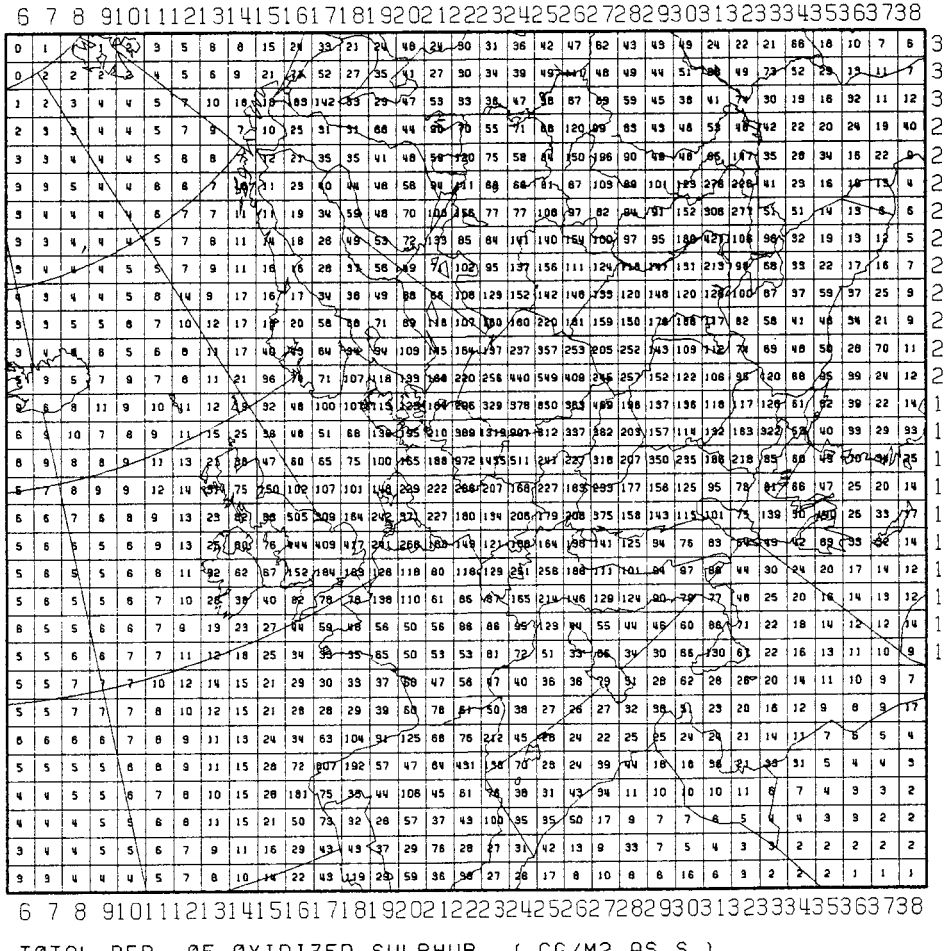
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - INT. TRADE, MEDITER. -MED
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



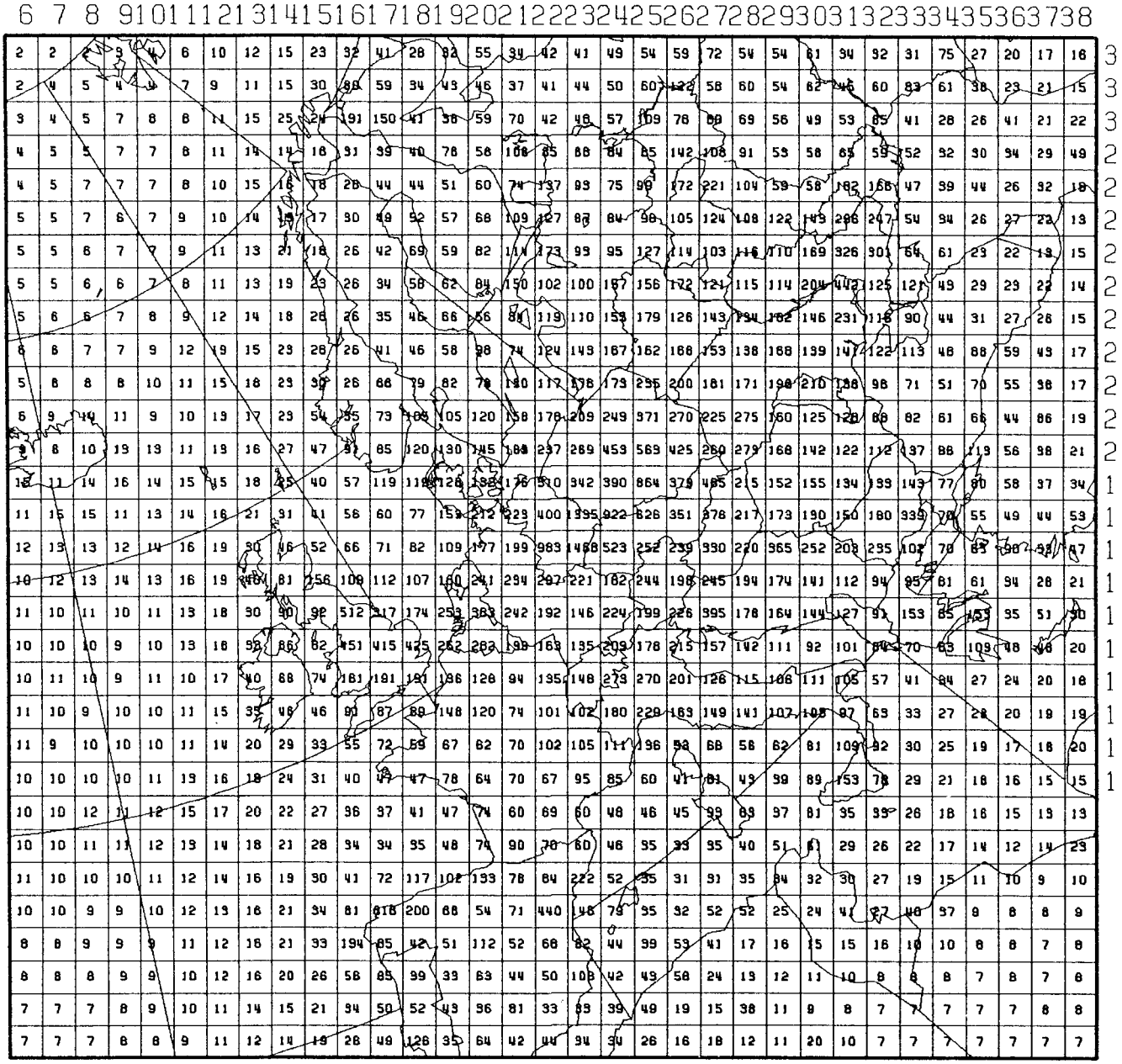
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
CONTRIBUTION FROM - NATURAL EMISSIONS -NAT
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



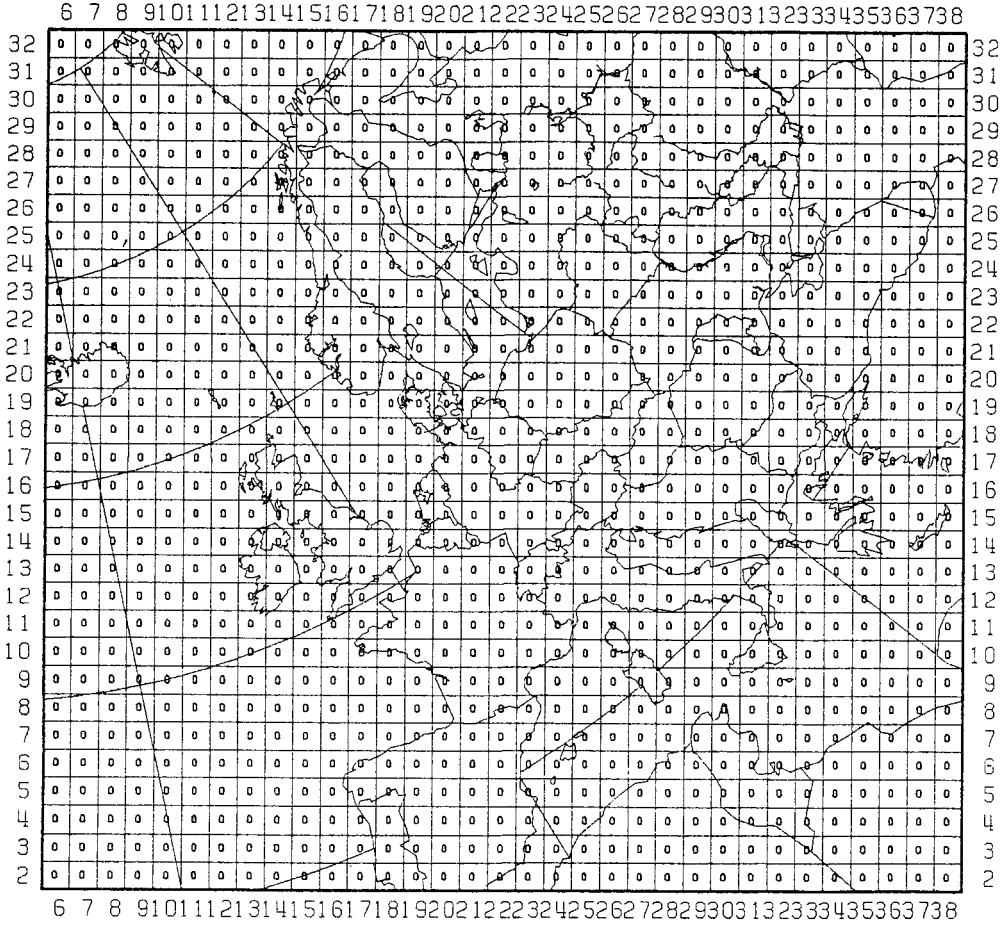
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
INATTRIBUTABLE CONTRIBUTIONS - IND
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



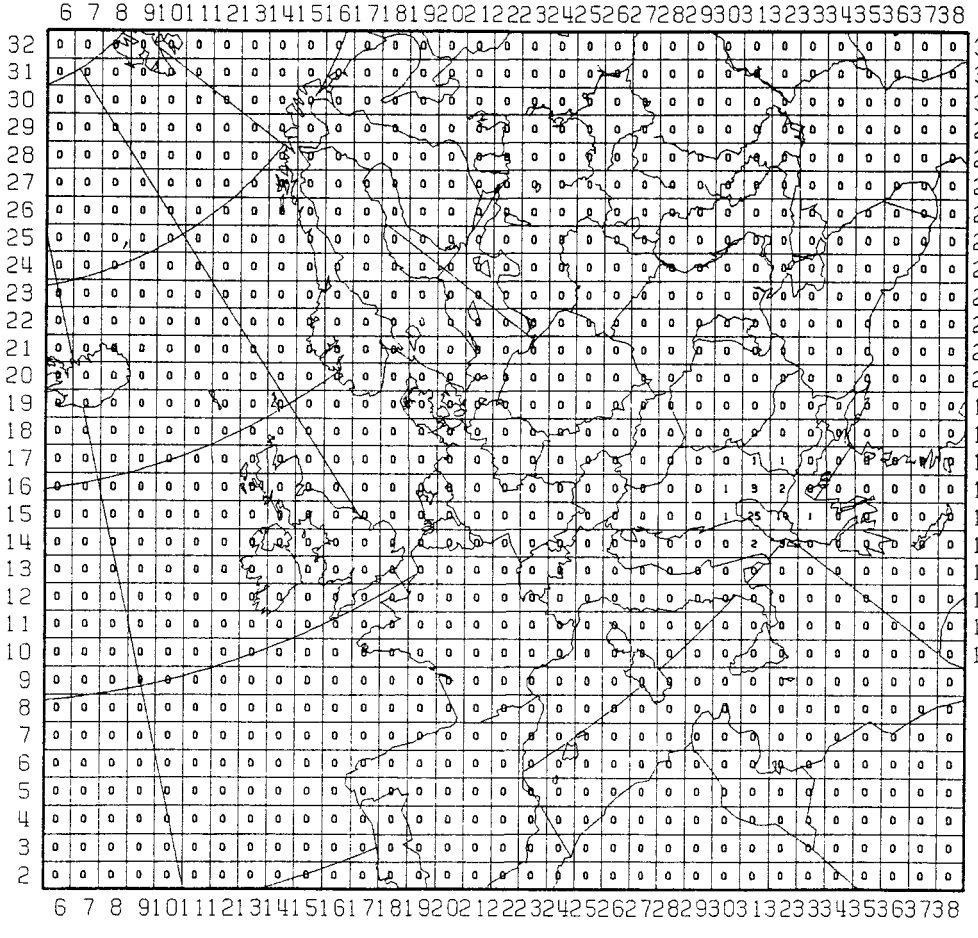
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
SUM OF ATTRIBUTABLE CONTRIBUTIONS -SUM
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



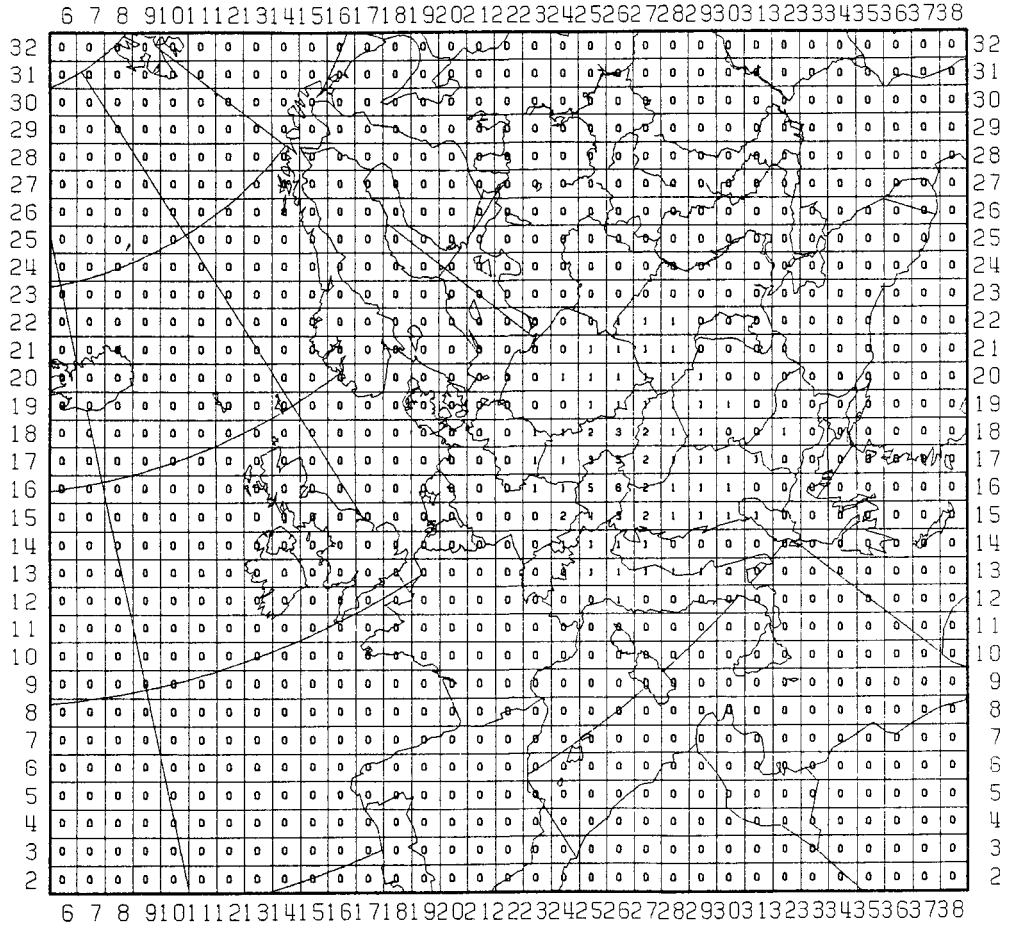
TOTAL DEP. OF OXIDIZED SULPHUR (CG/M2 AS S)
GRAND TOTAL (ALL CONTRIBUTIONS) - TOT
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



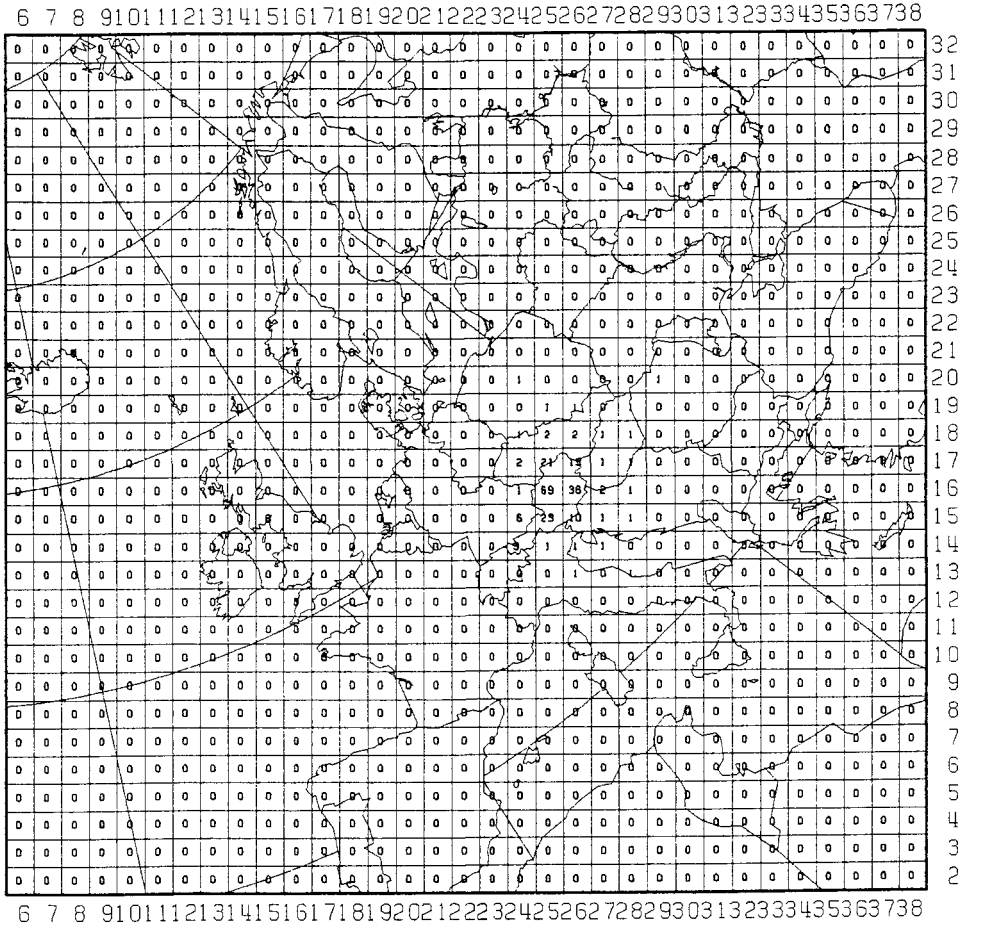
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - ALBANIA - AL
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



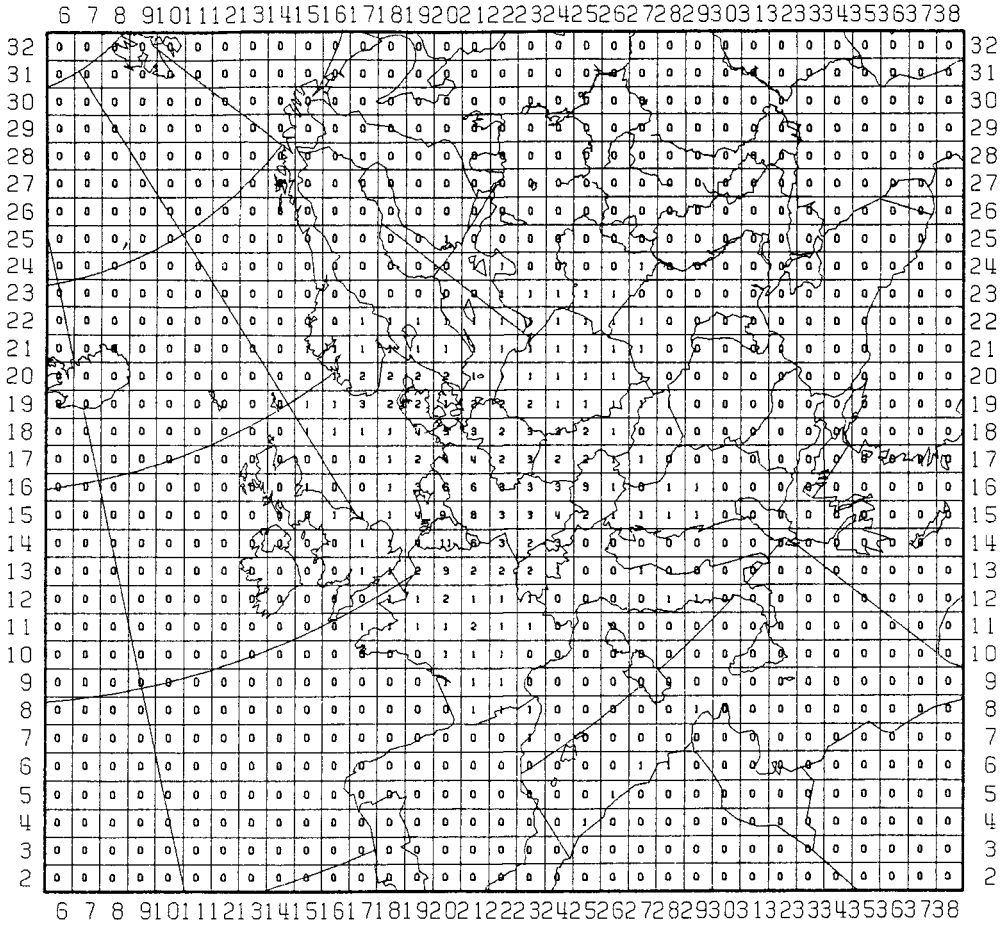
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - ALBANIA - AL
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



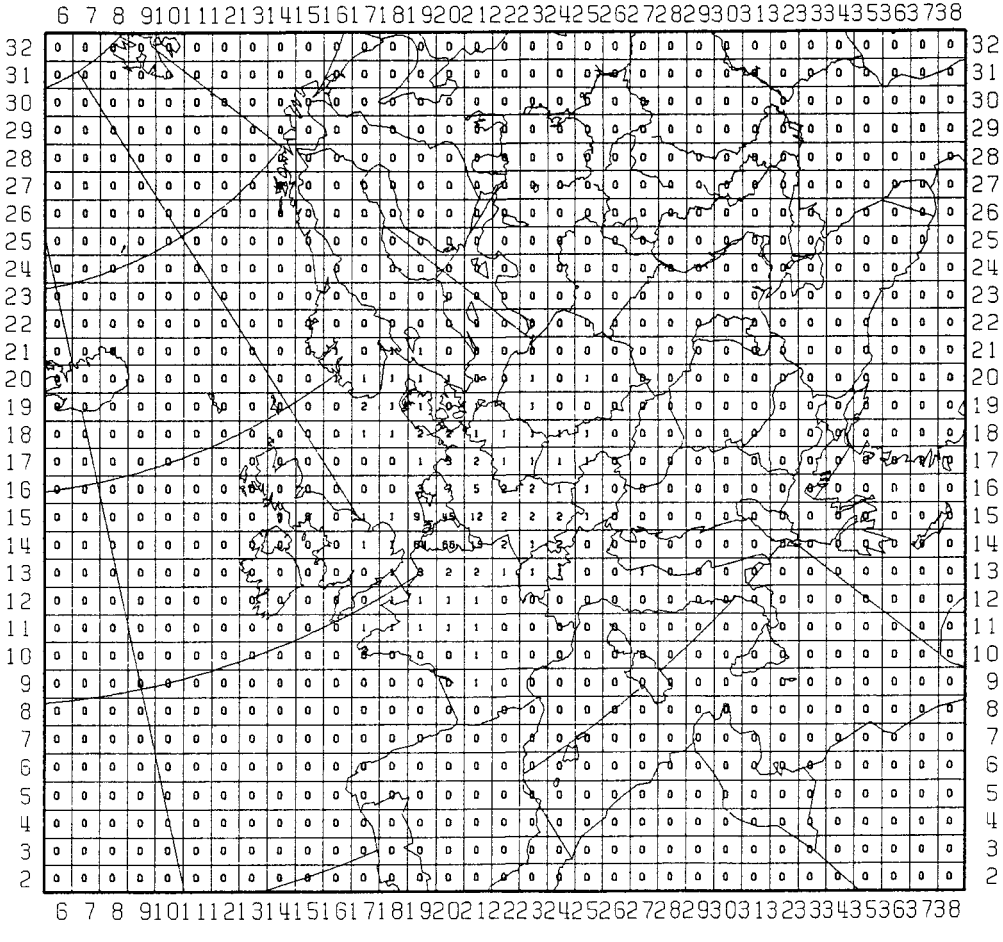
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - AUSTRIA - AT
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



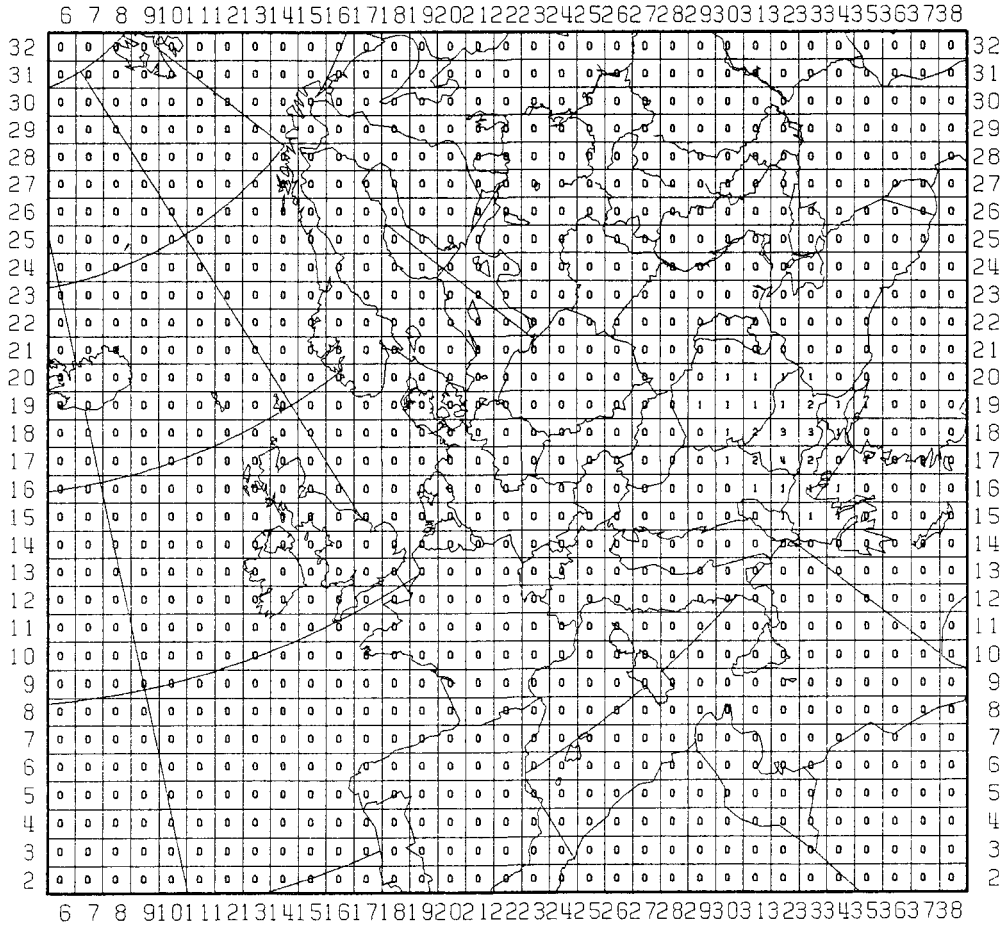
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - AUSTRIA - AT
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



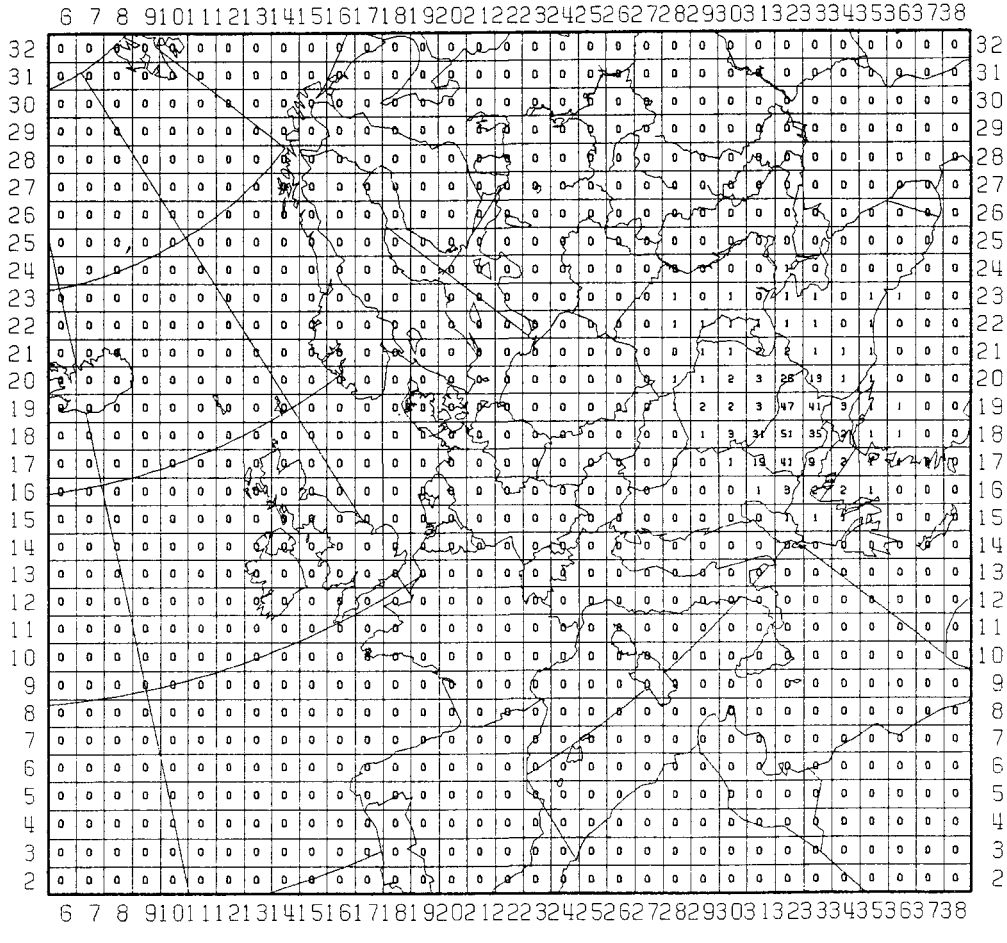
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - BELGIUM - BE
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



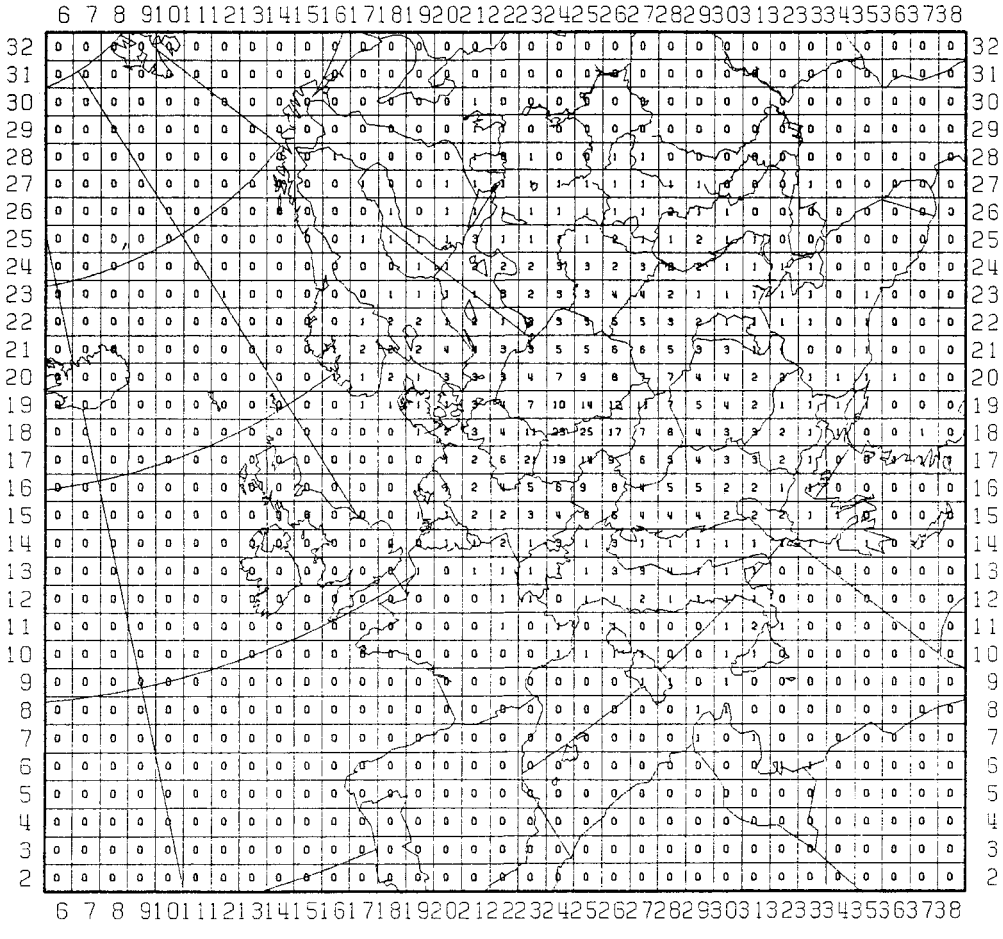
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - BELGIUM - BE
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



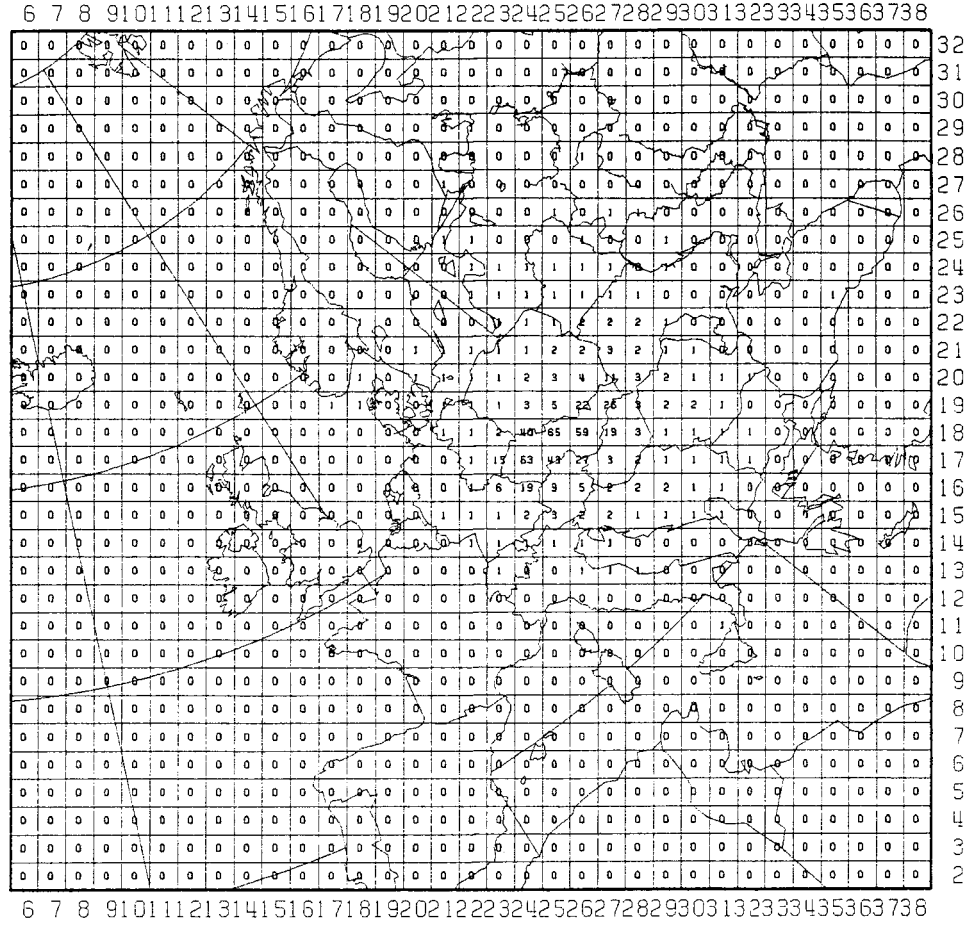
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - BULGARIA - BG
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



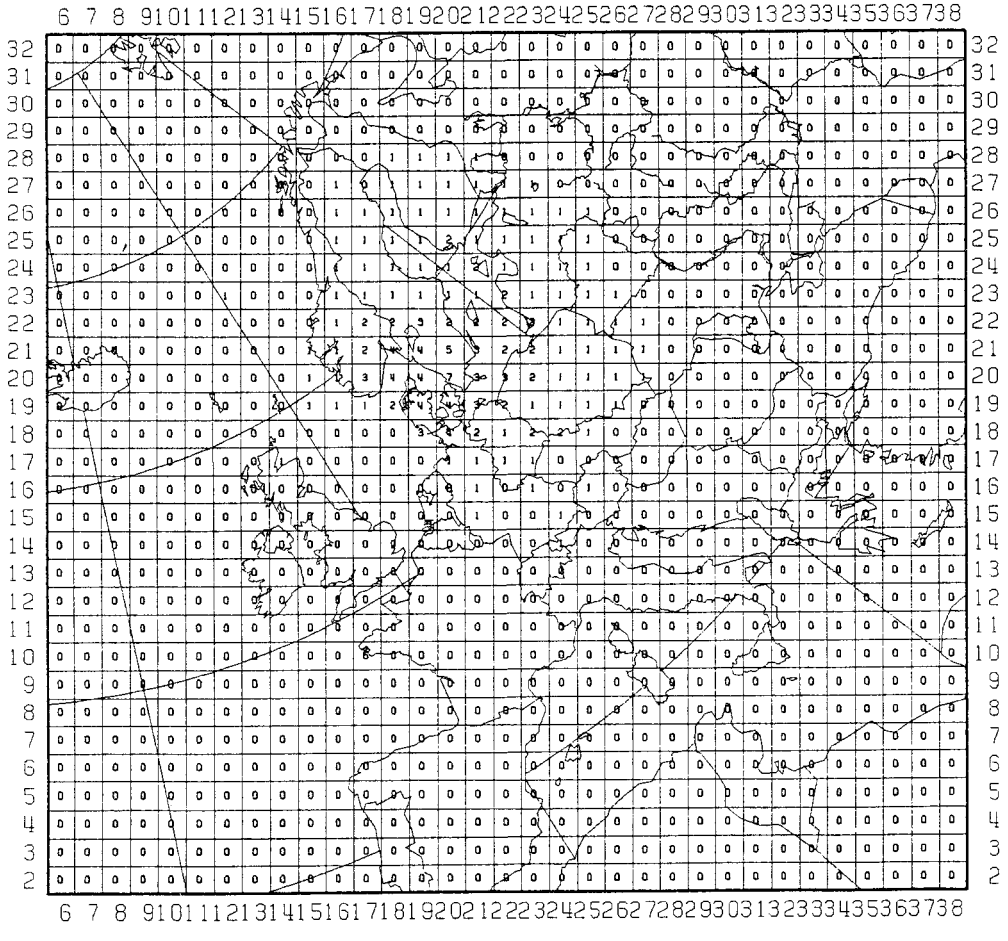
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - BULGARIA - BG
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



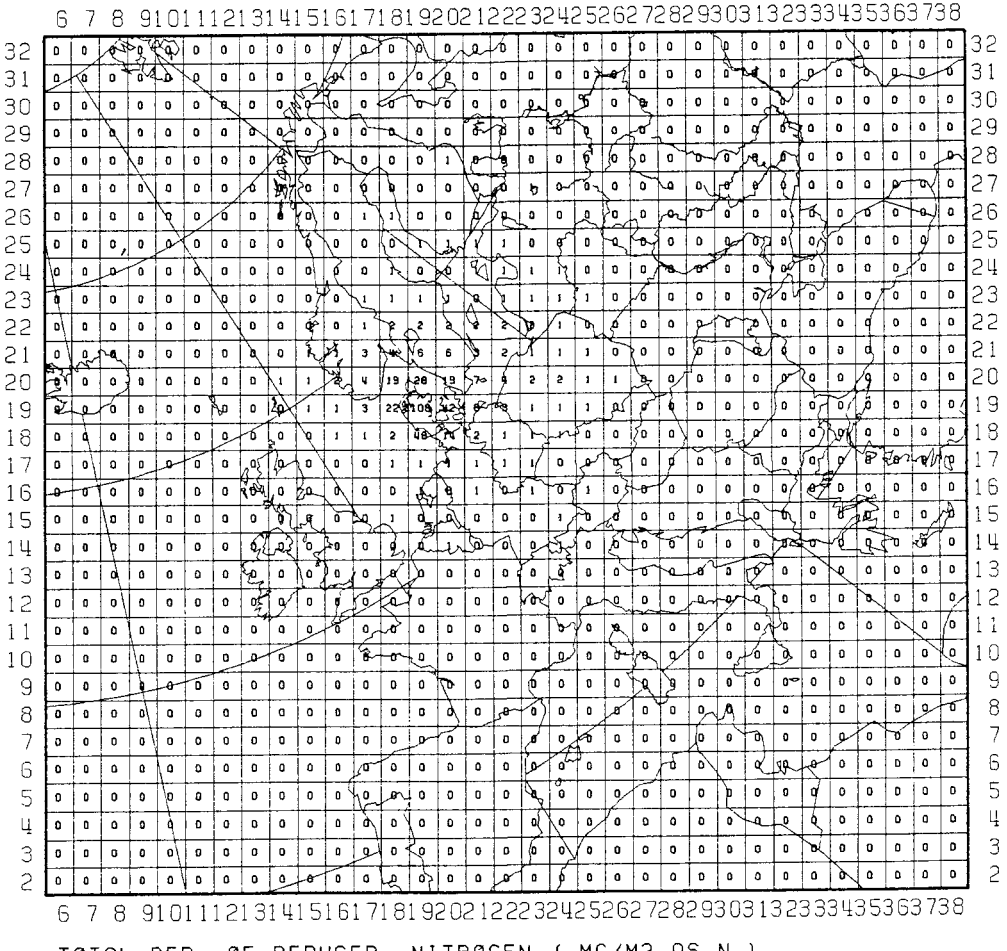
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - CZECHOSLOVAKIA - CS
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



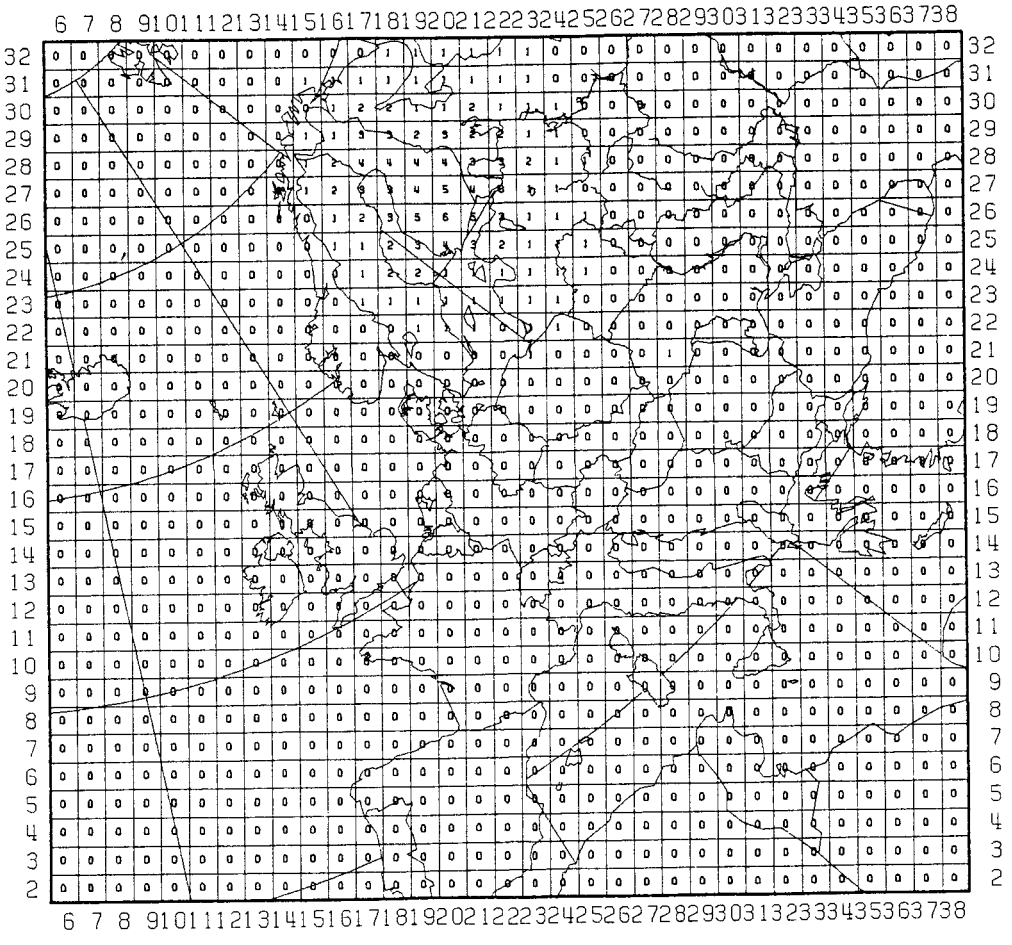
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - CZECHOSLOVAKIA - CS
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



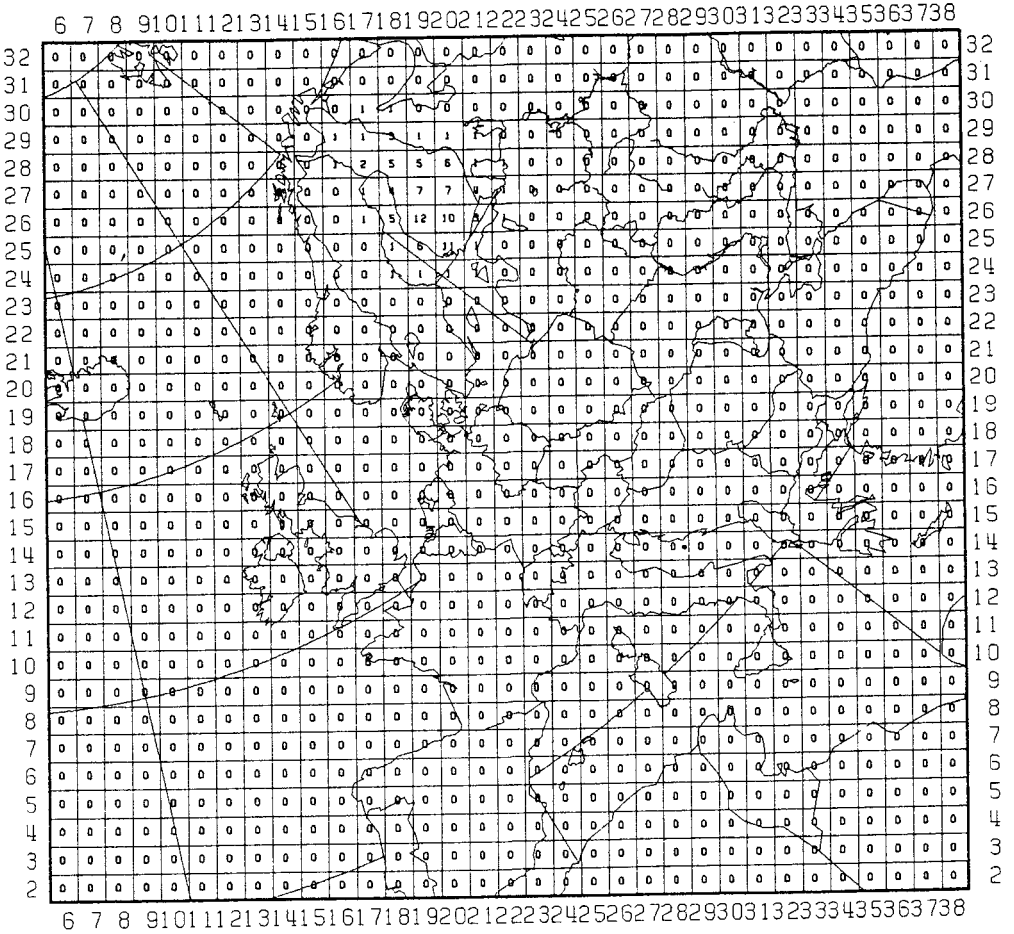
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - DENMARK - DK
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL



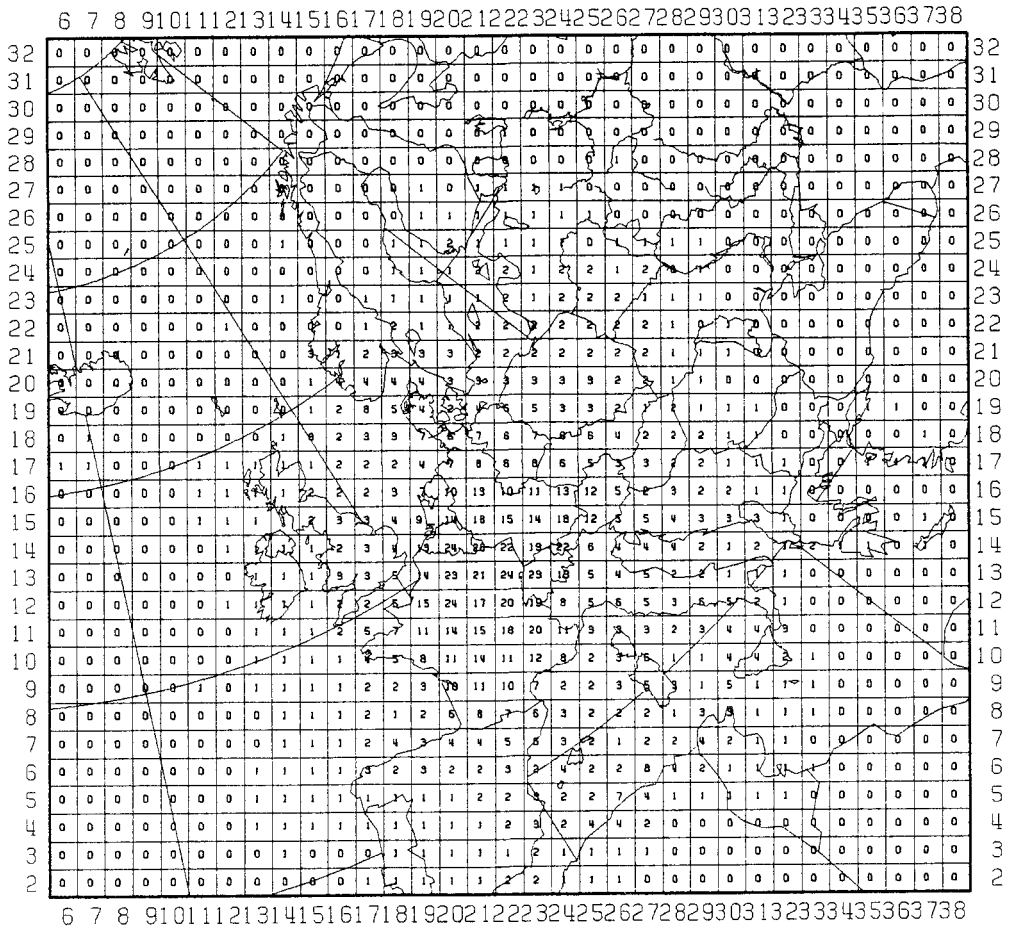
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - DENMARK - DK
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL



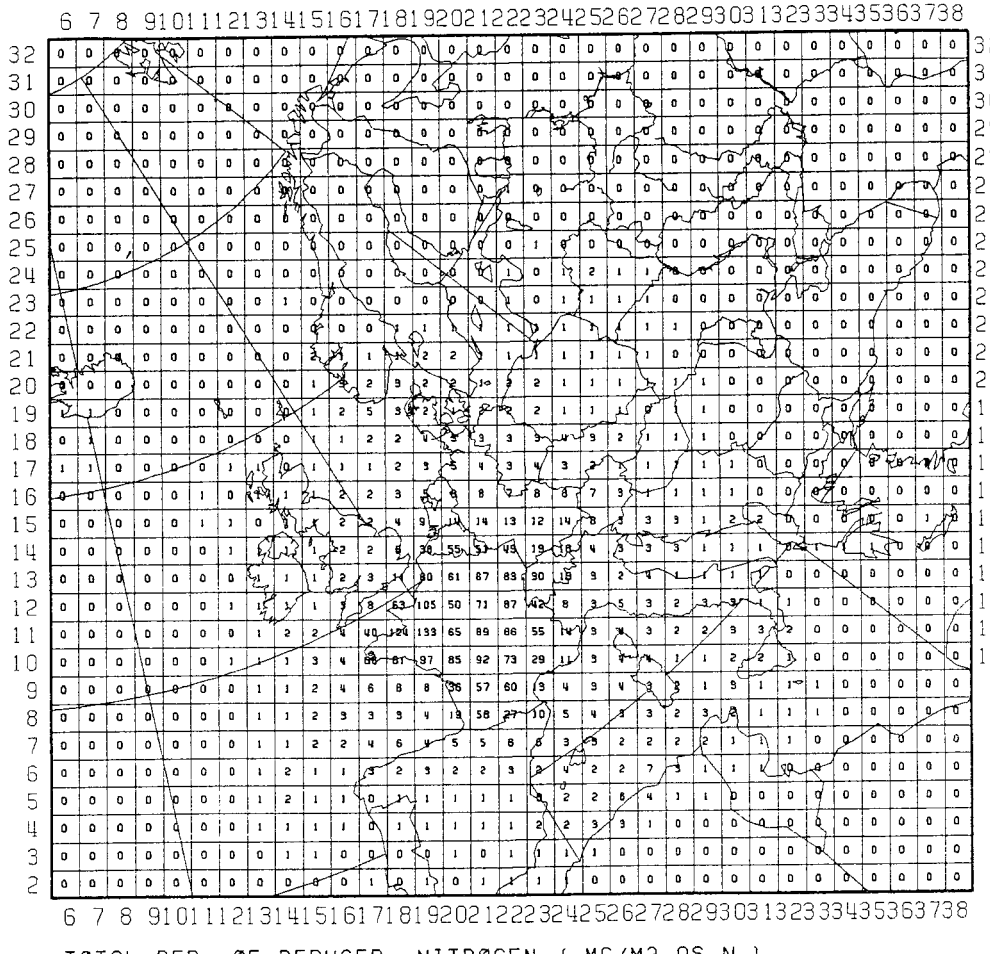
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - FINLAND - FI
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL



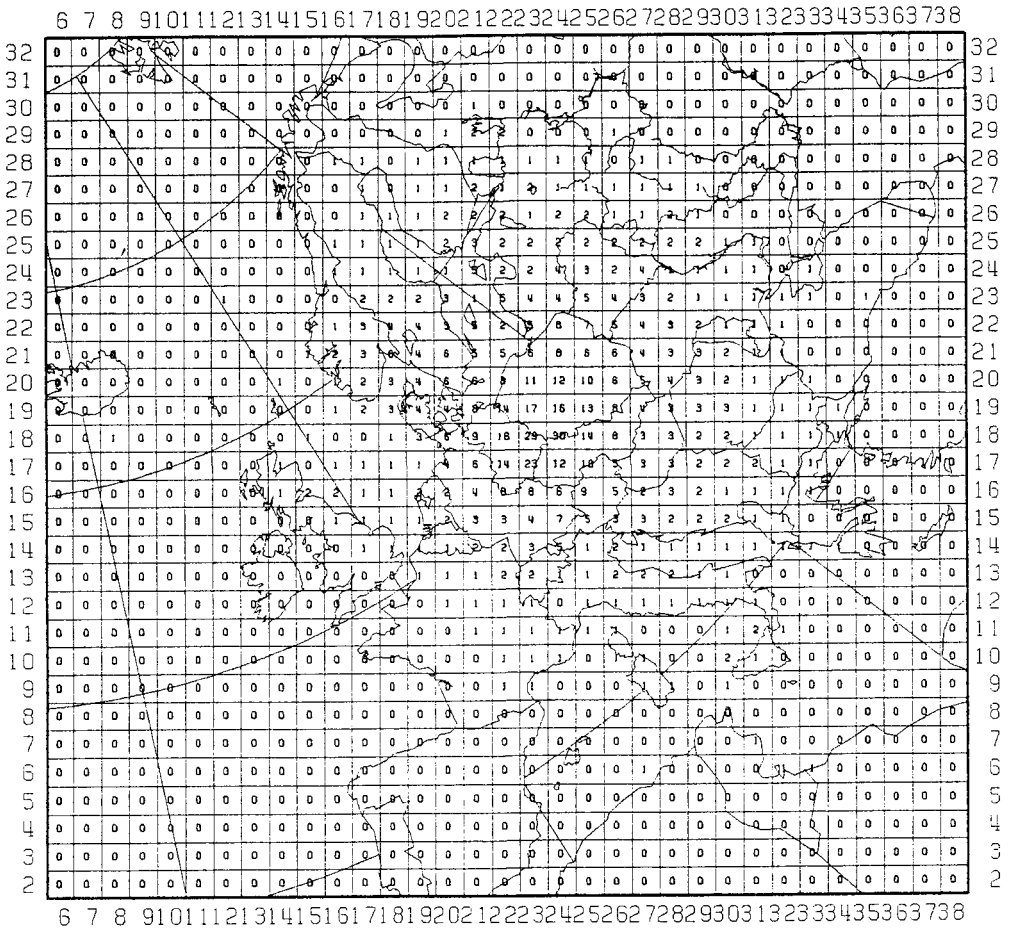
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - FINLAND - FI
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL



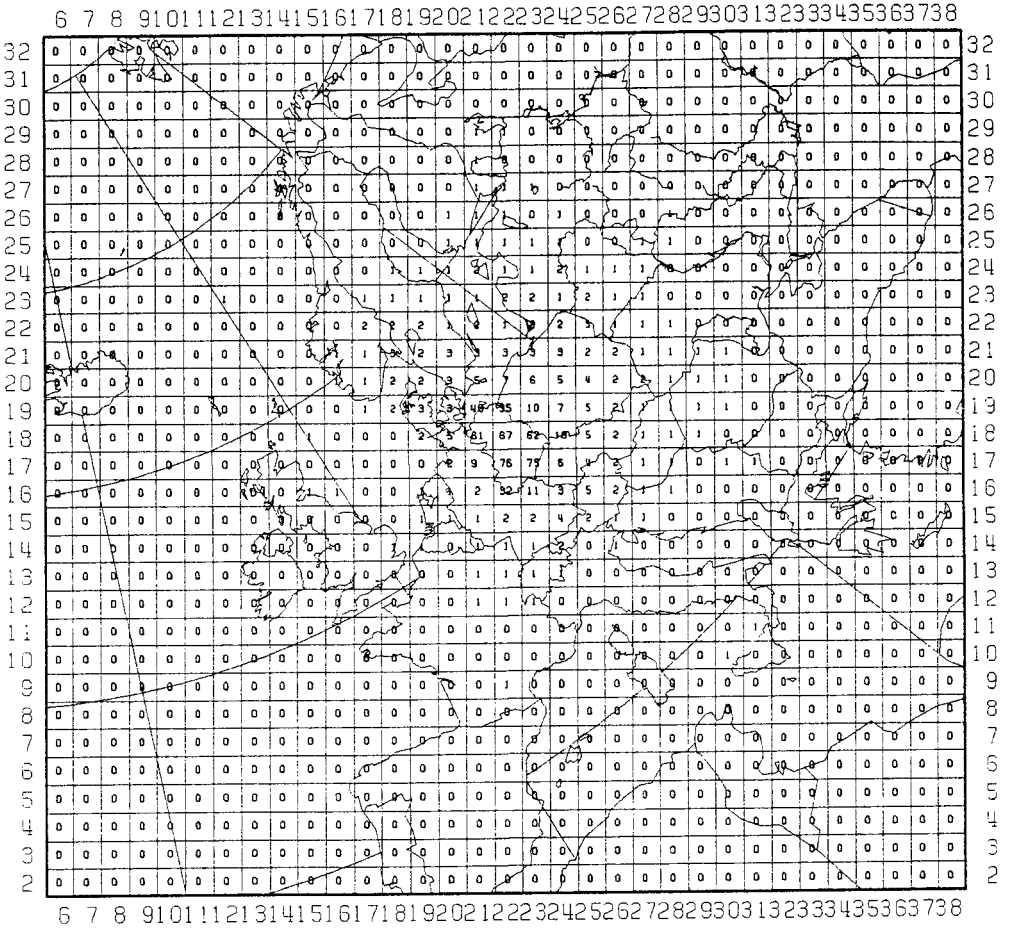
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - FRANCE - FR
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



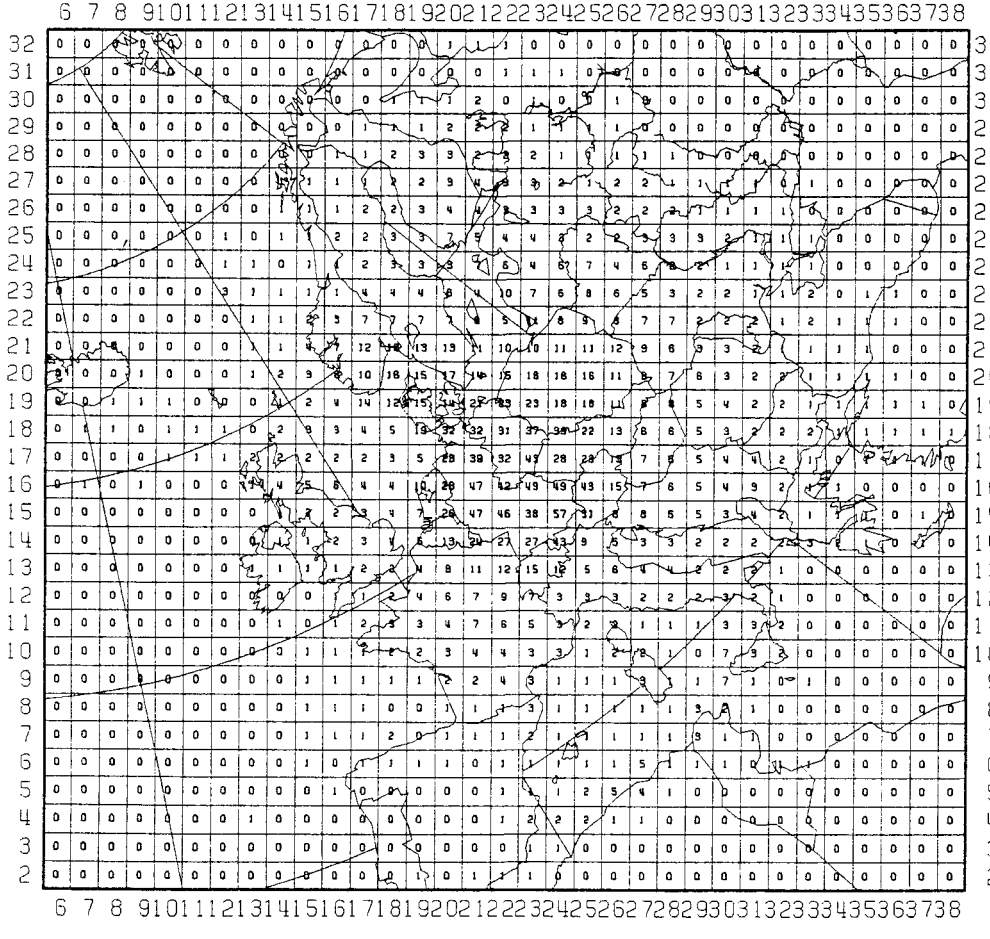
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - FRANCE - FR
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



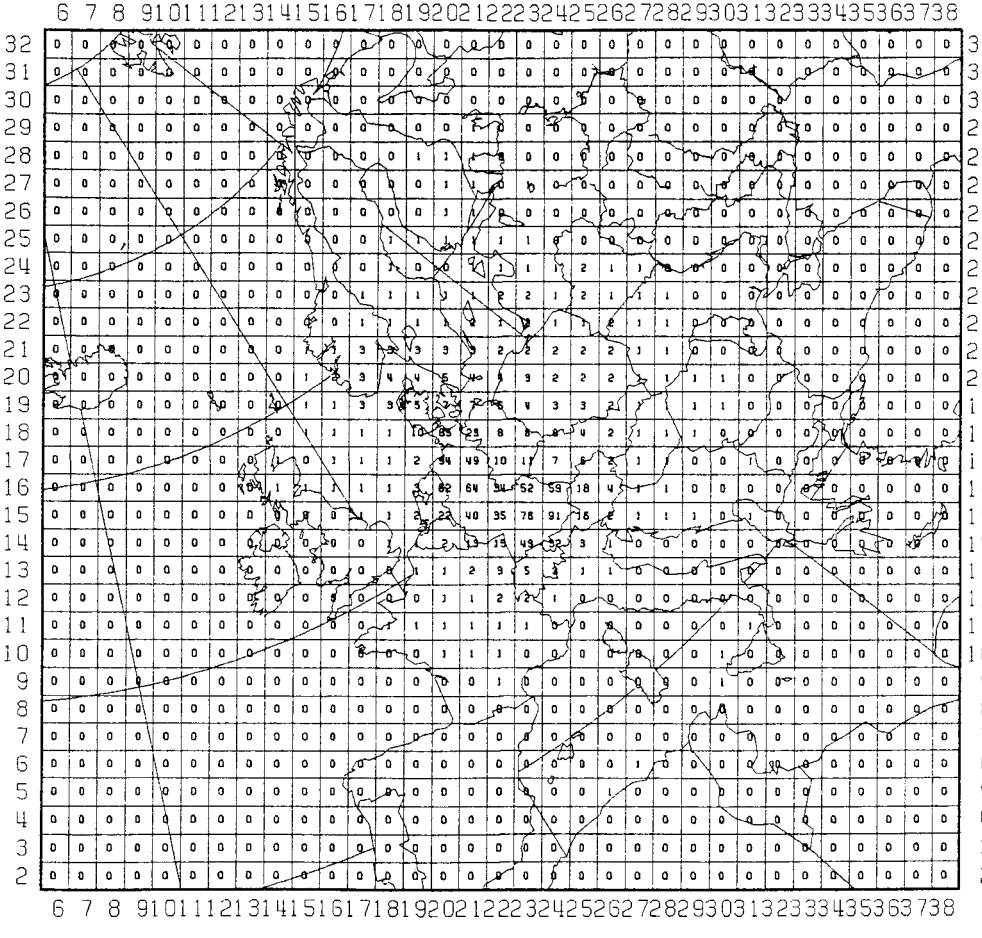
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - GERMAN DEMOCRATIC REP- DD
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



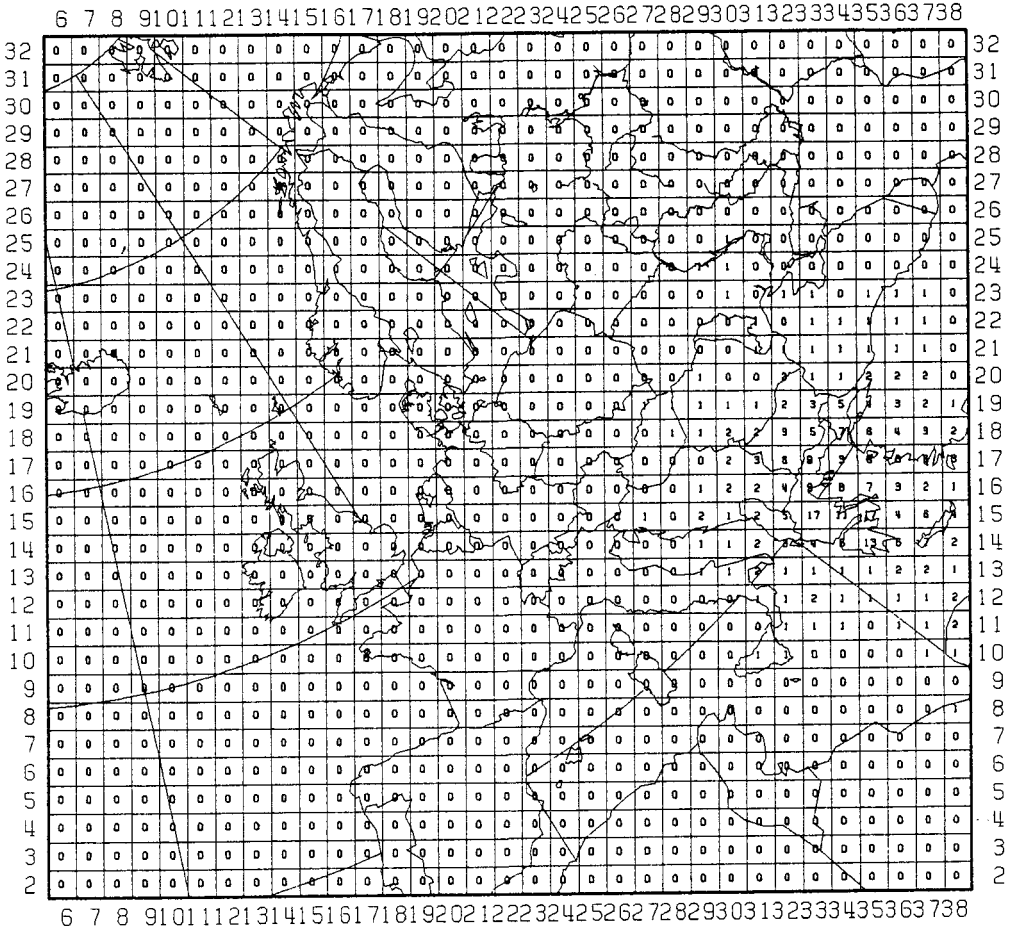
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - GERMAN DEMOCRATIC REP- DD
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



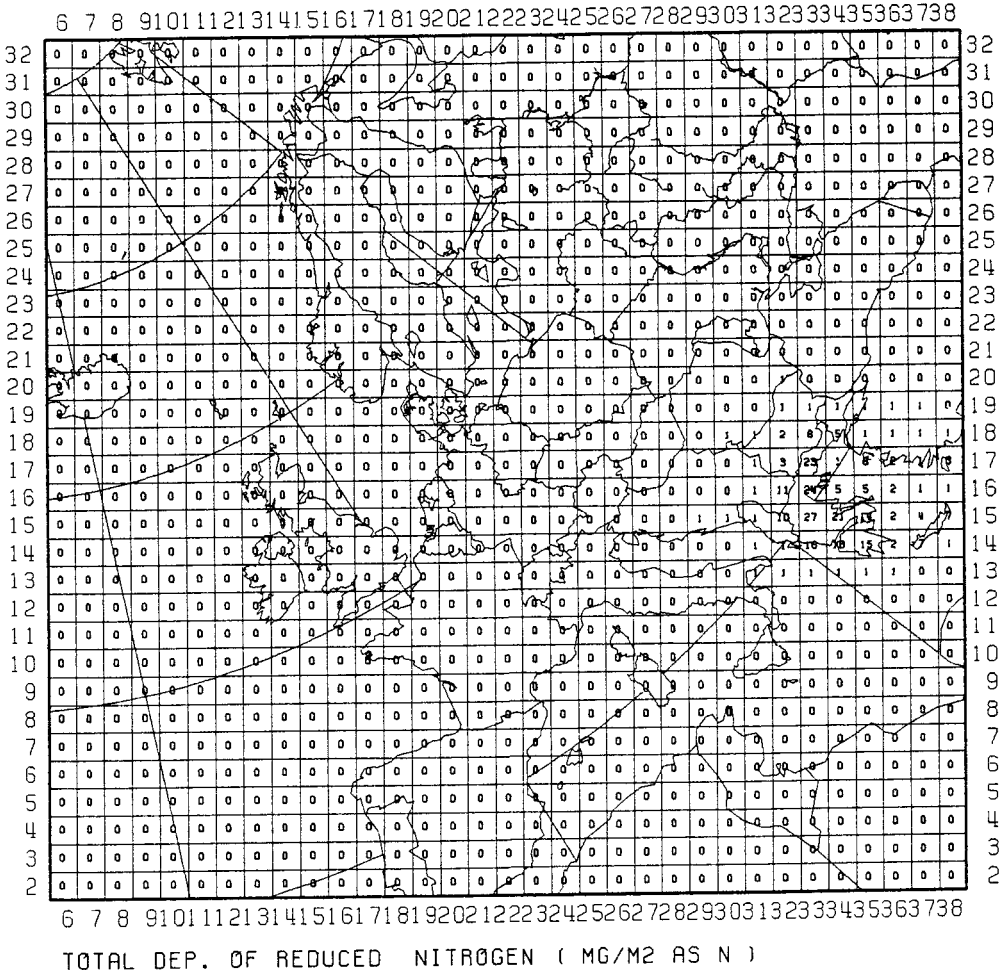
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - GERMANY, FEDERAL REP.- DE
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



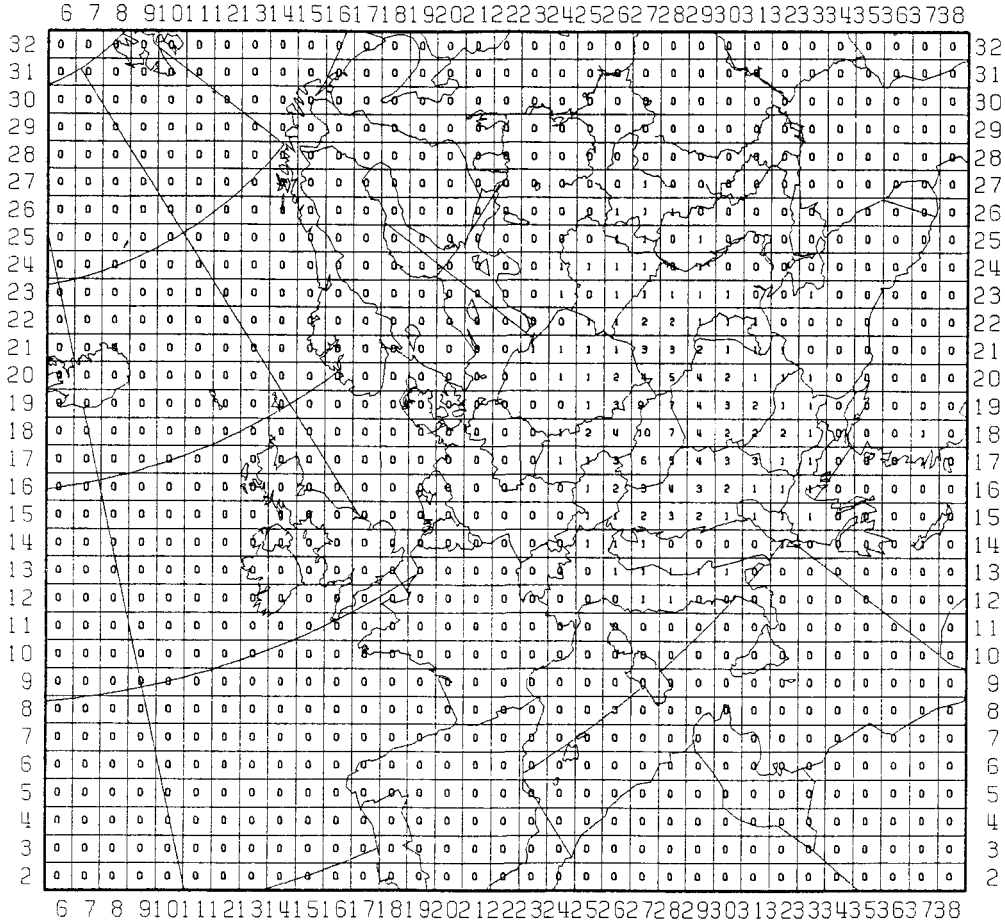
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - GERMANY, FEDERAL REP.- DE
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



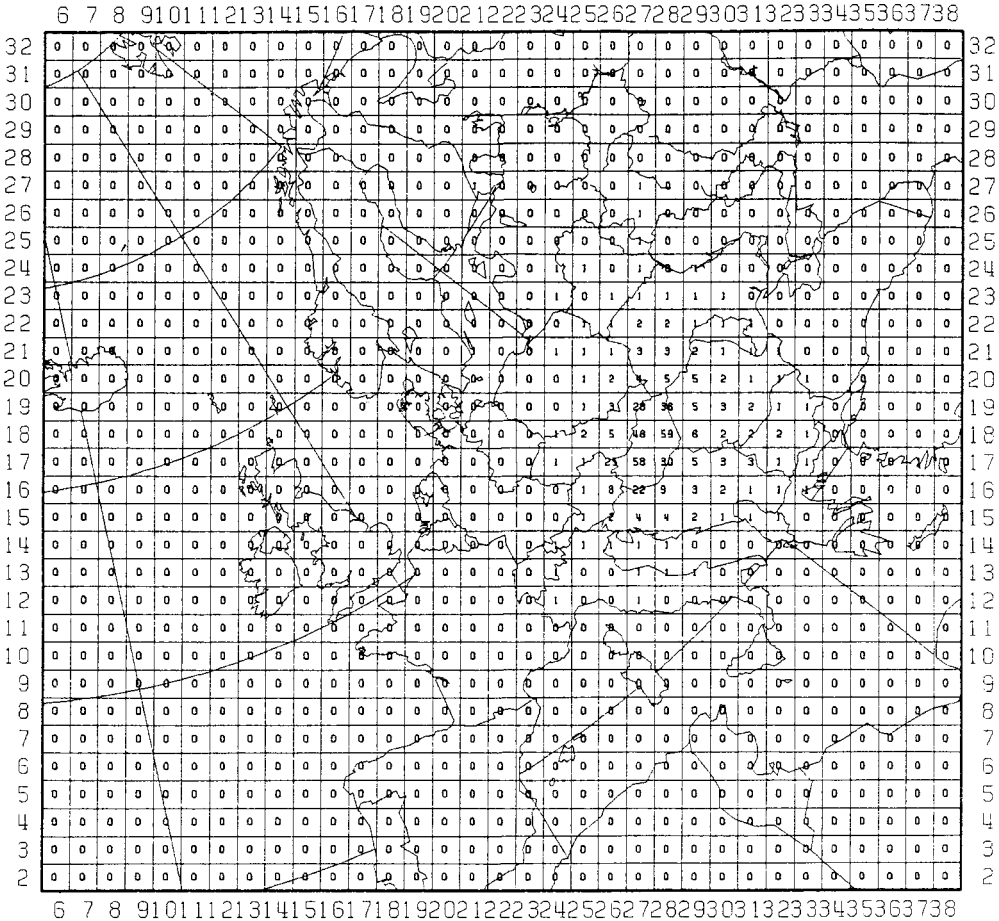
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - GREECE - GR
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL



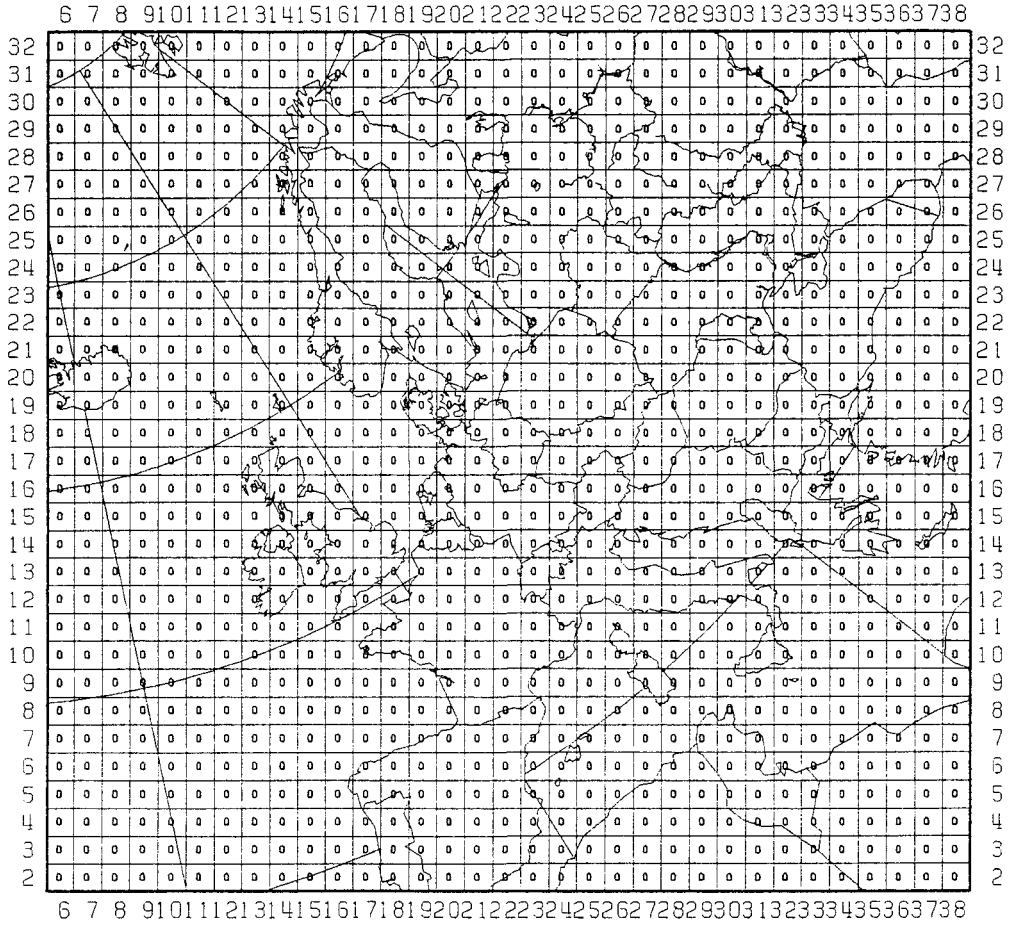
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - GREECE - GR
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL



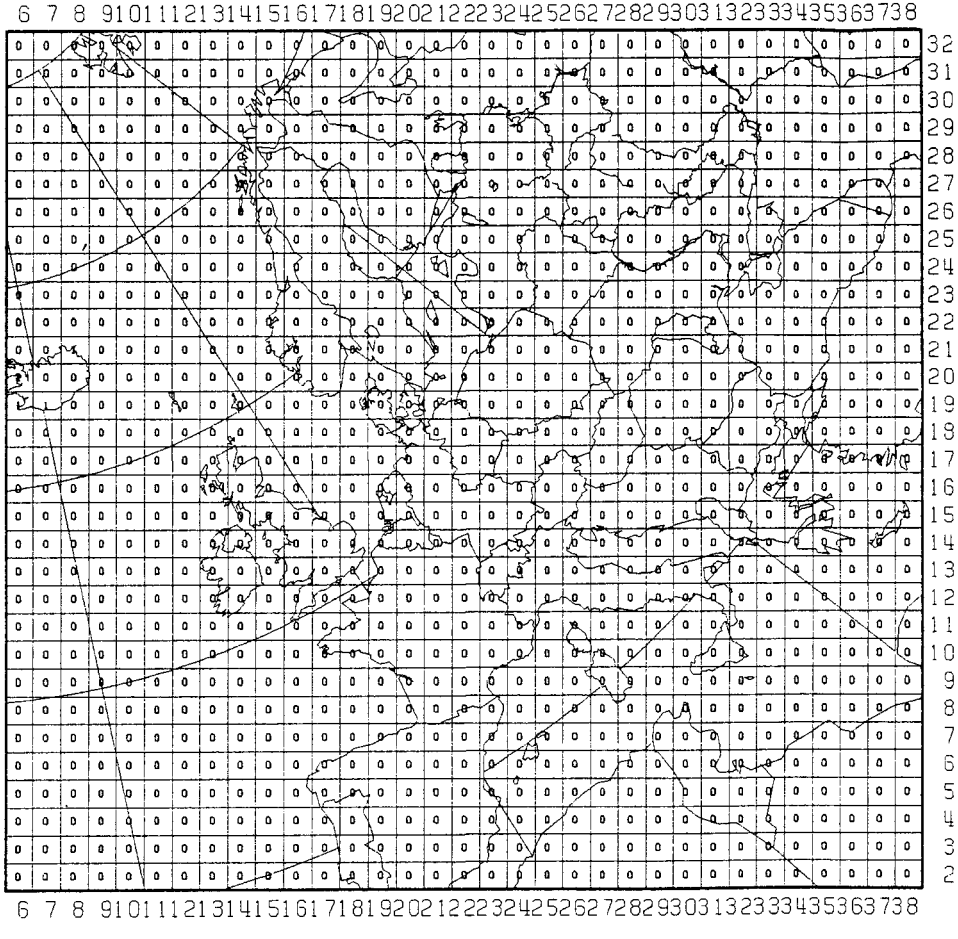
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - HUNGARY - HU
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



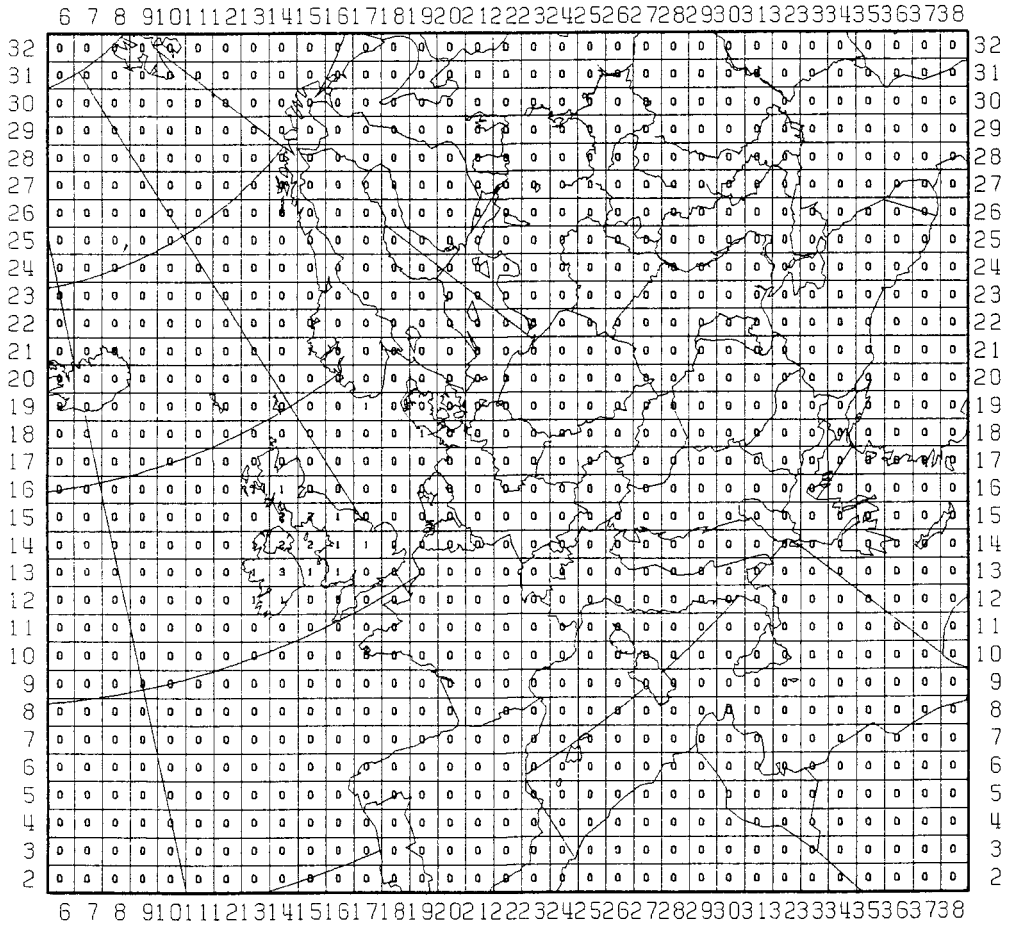
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - HUNGARY - HU
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



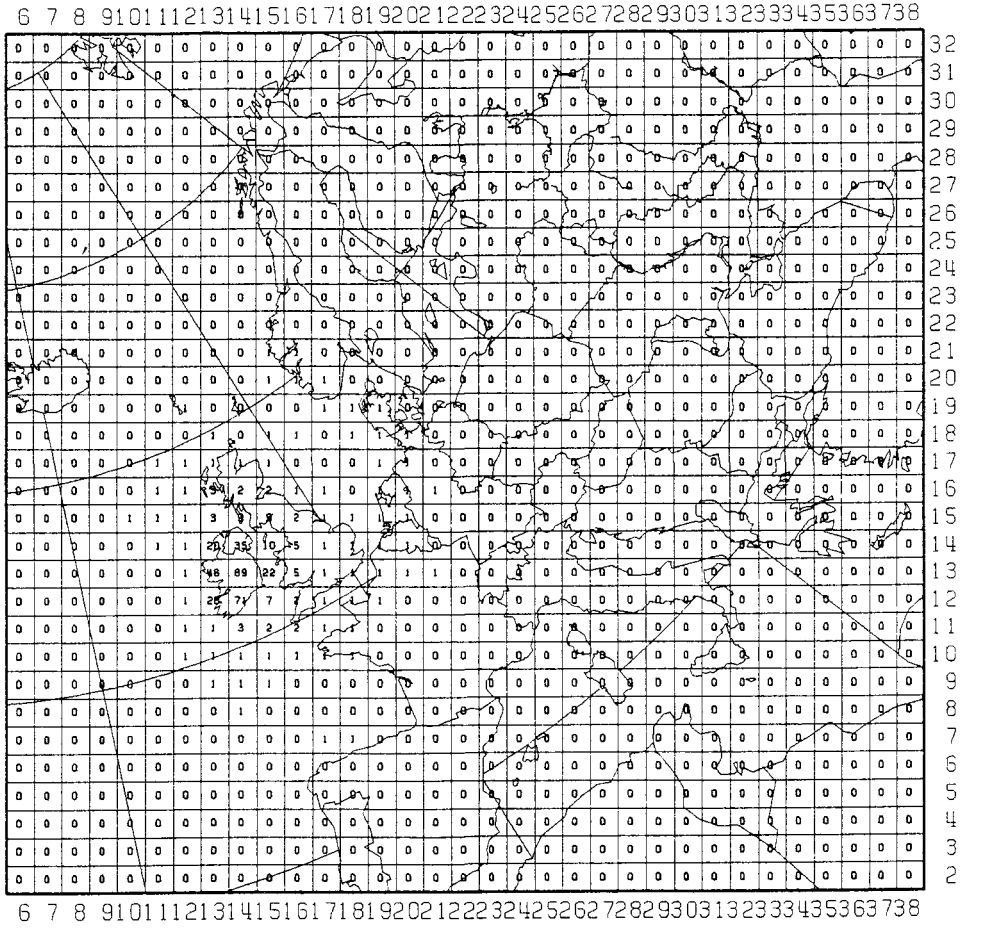
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - ICELAND - IS
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



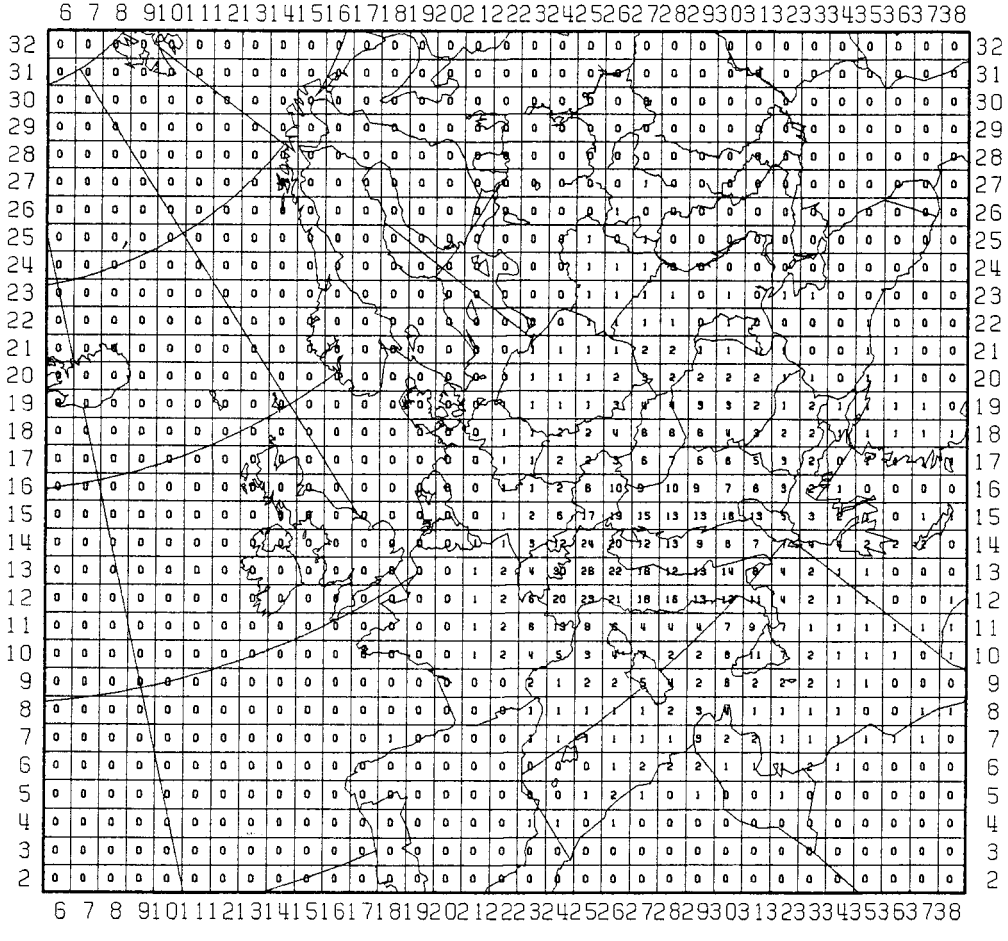
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - ICELAND - IS
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



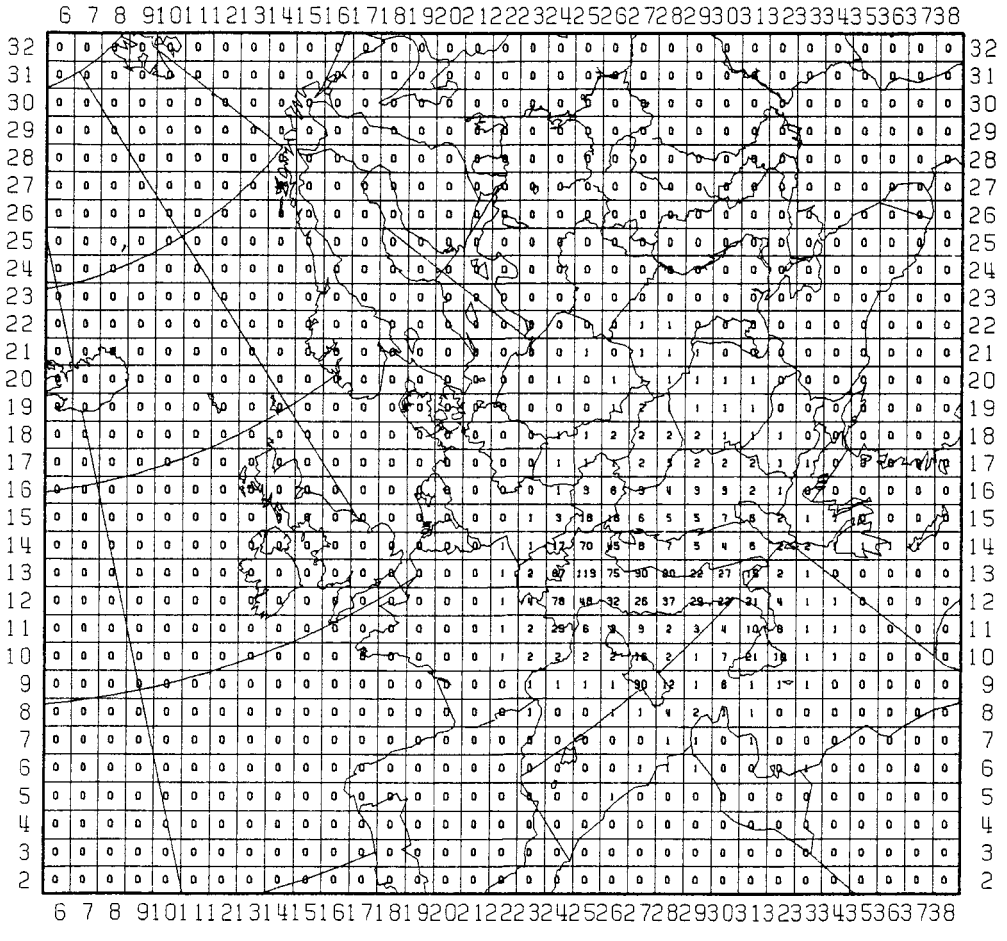
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - IRELAND - IE
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



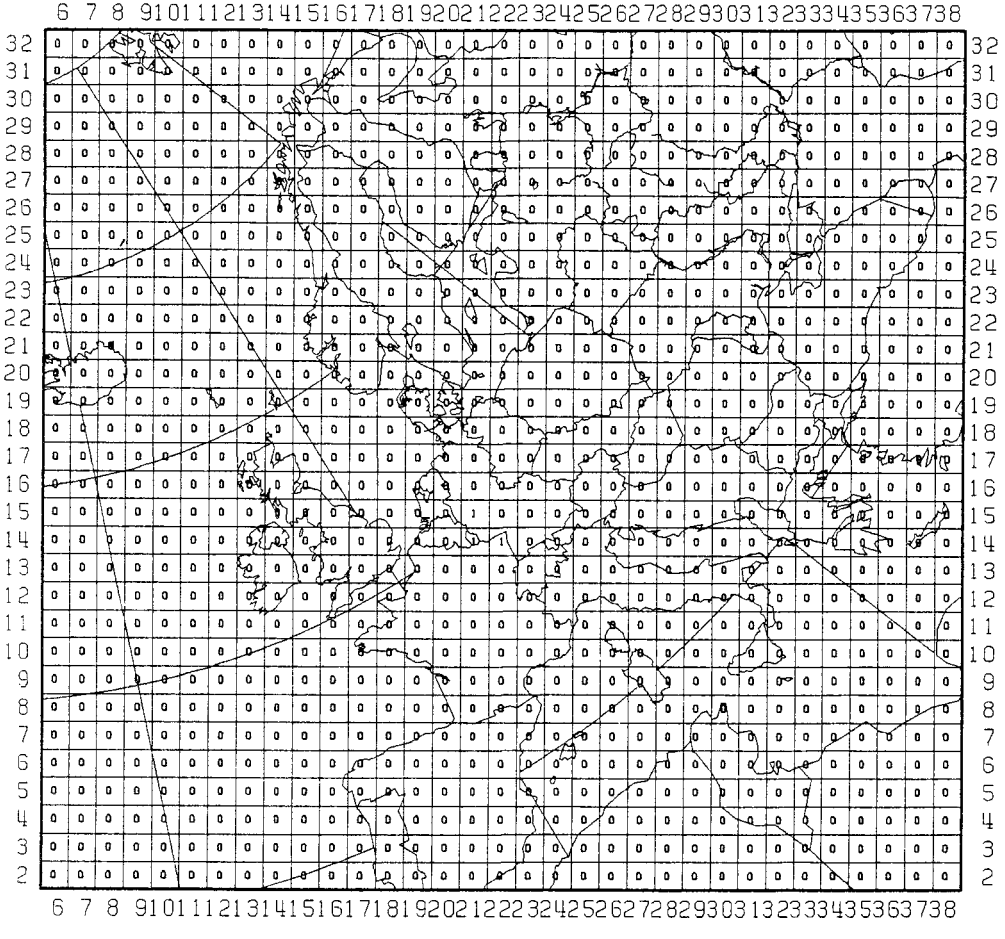
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - IRELAND - IE
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



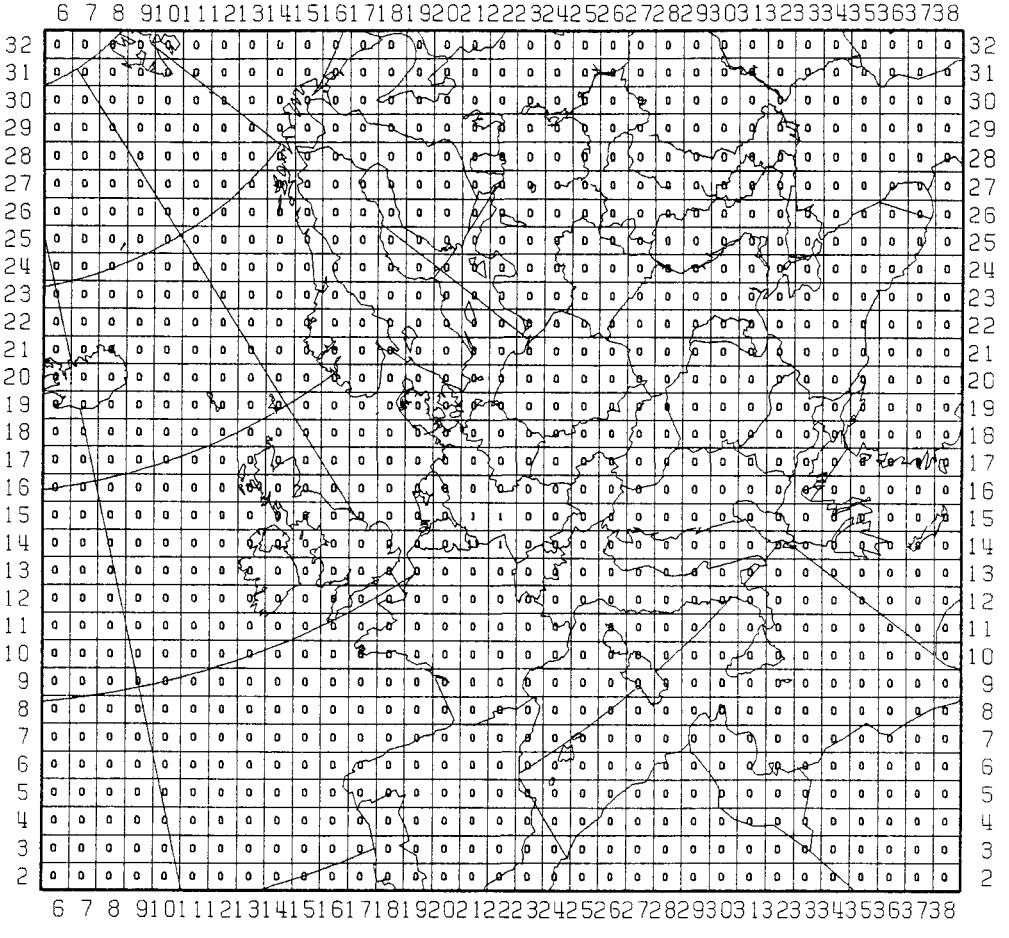
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - ITALY - IT
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



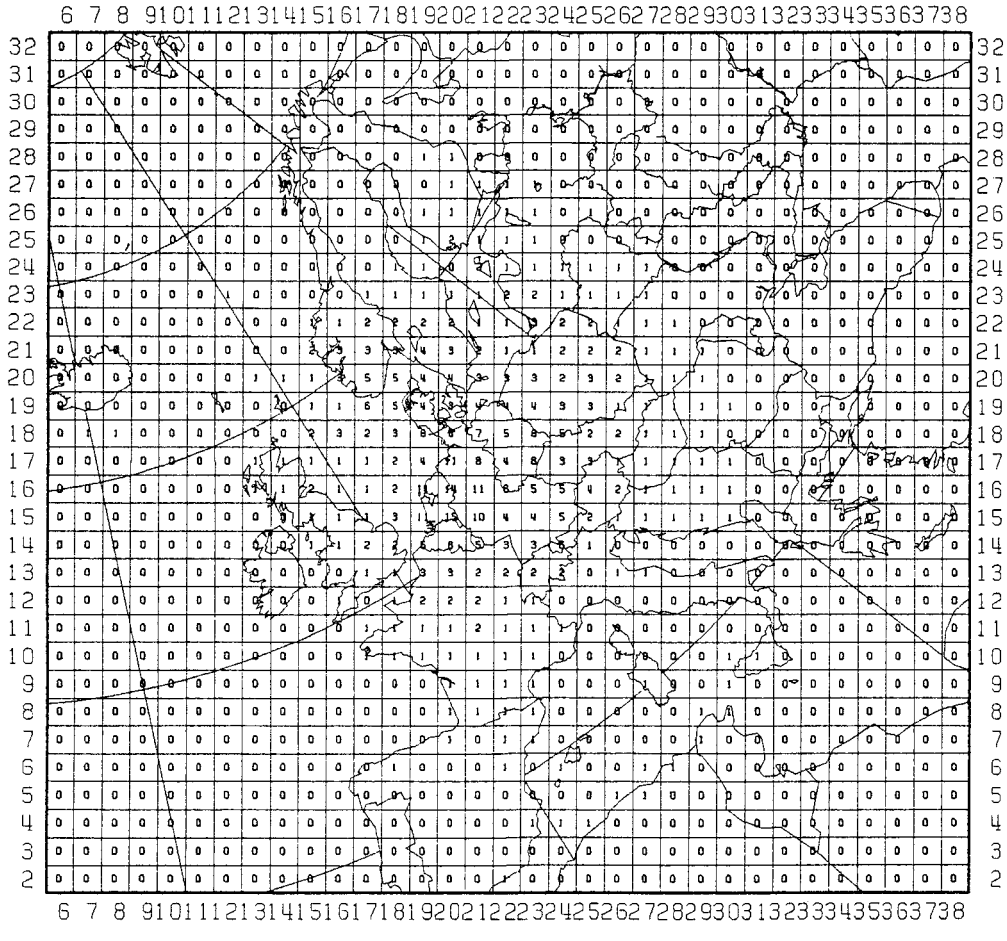
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - ITALY - IT
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



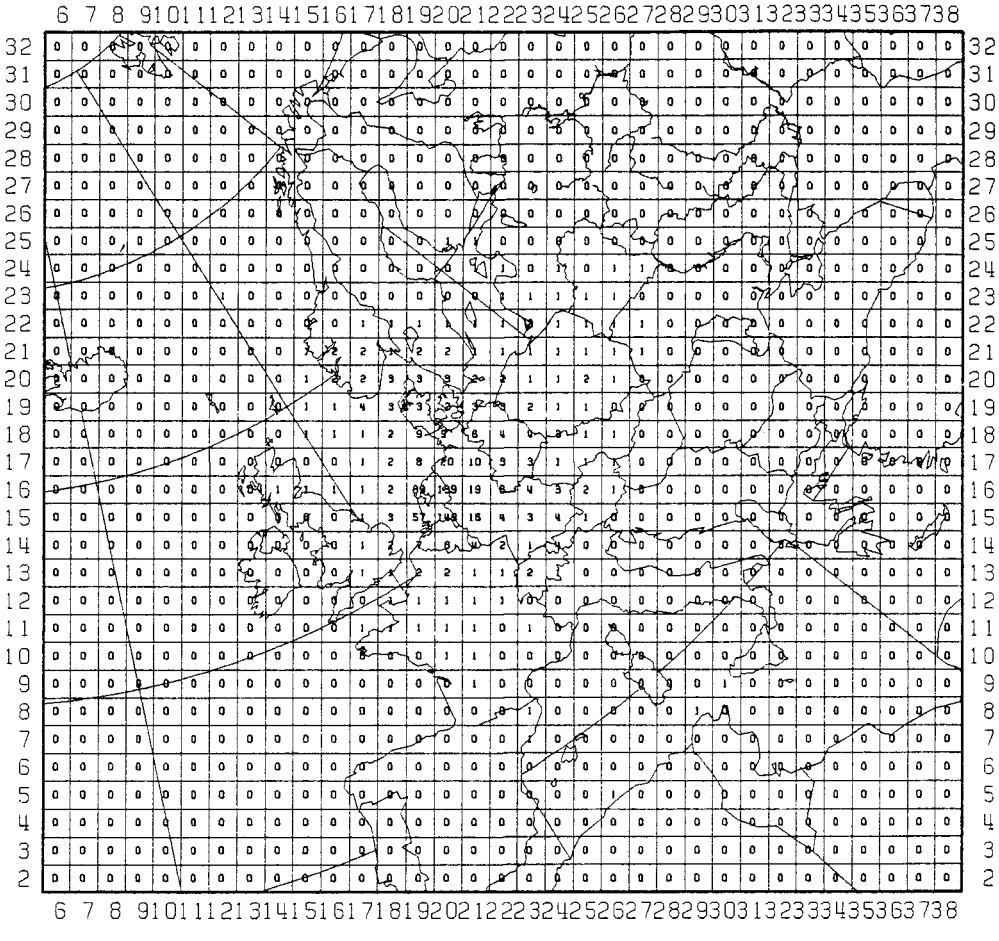
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - LUXEMBOURG - LU
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



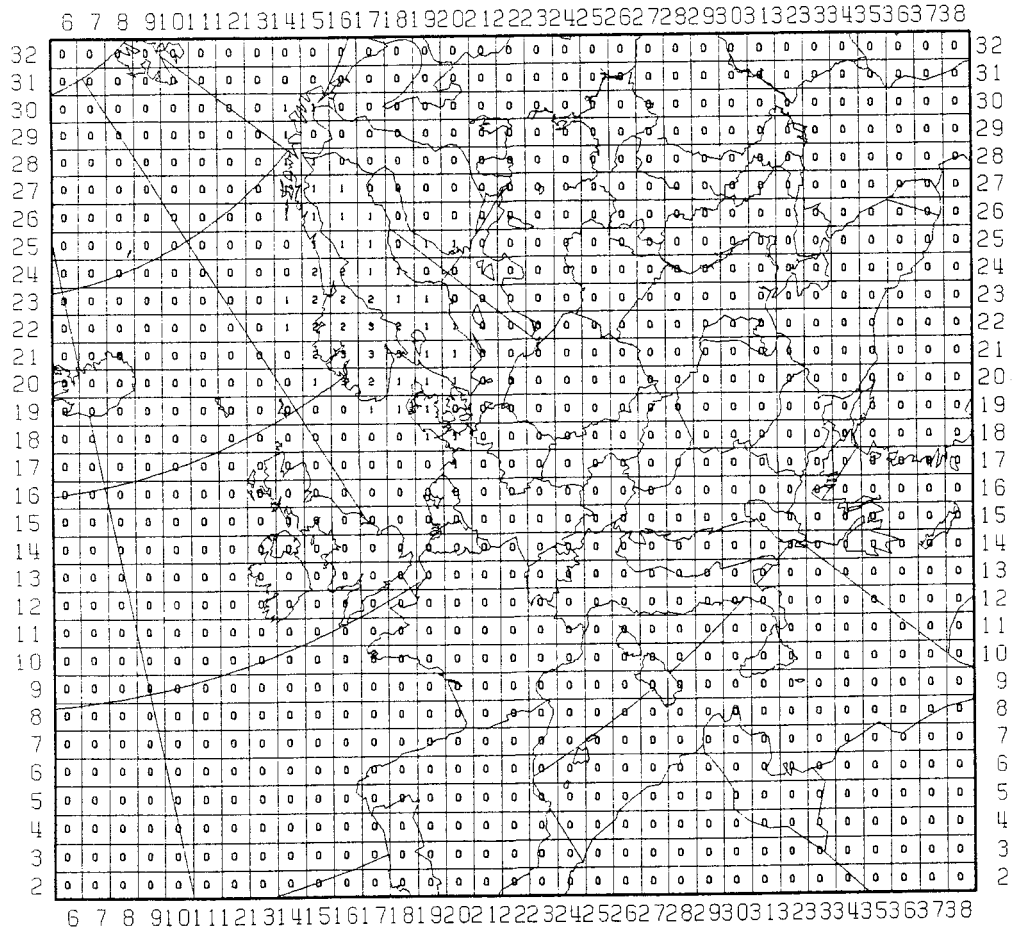
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - LUXEMBOURG - LU
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



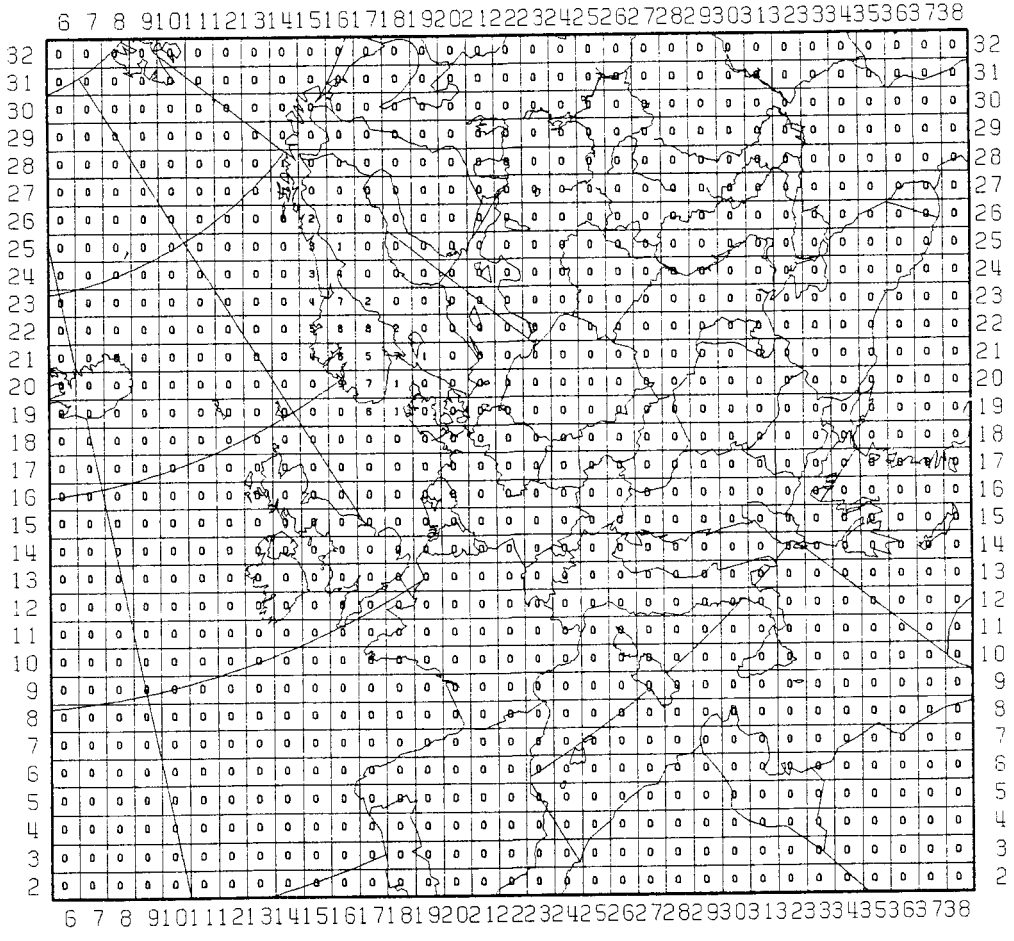
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - NETHERLANDS - NL
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



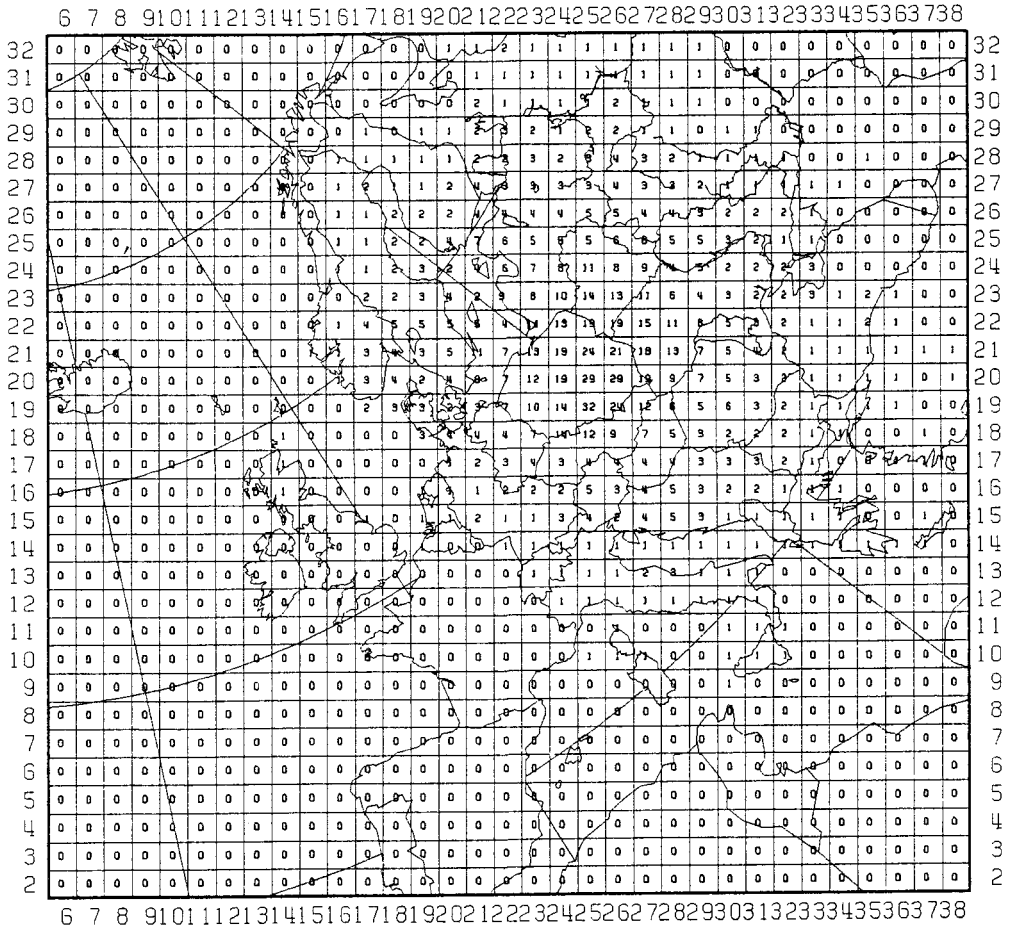
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - NETHERLANDS - NL
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



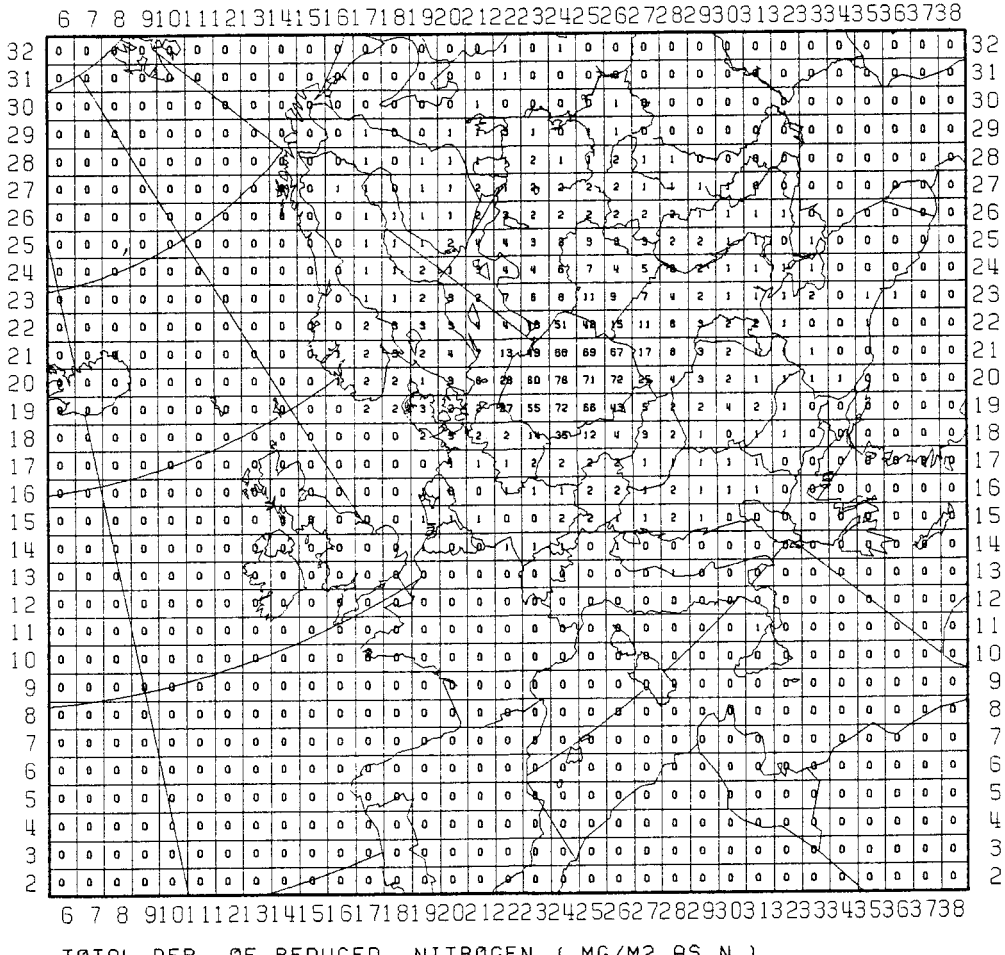
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - NORWAY - NO
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



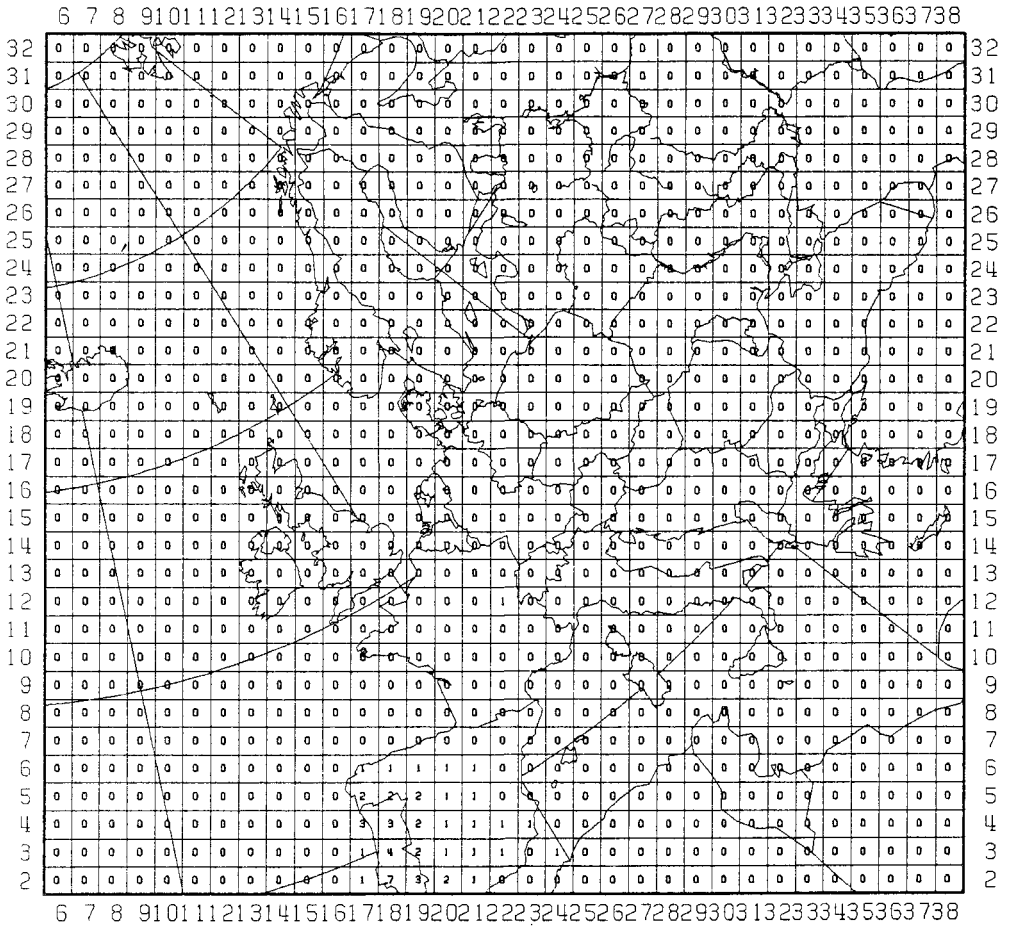
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - NORWAY - NO
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



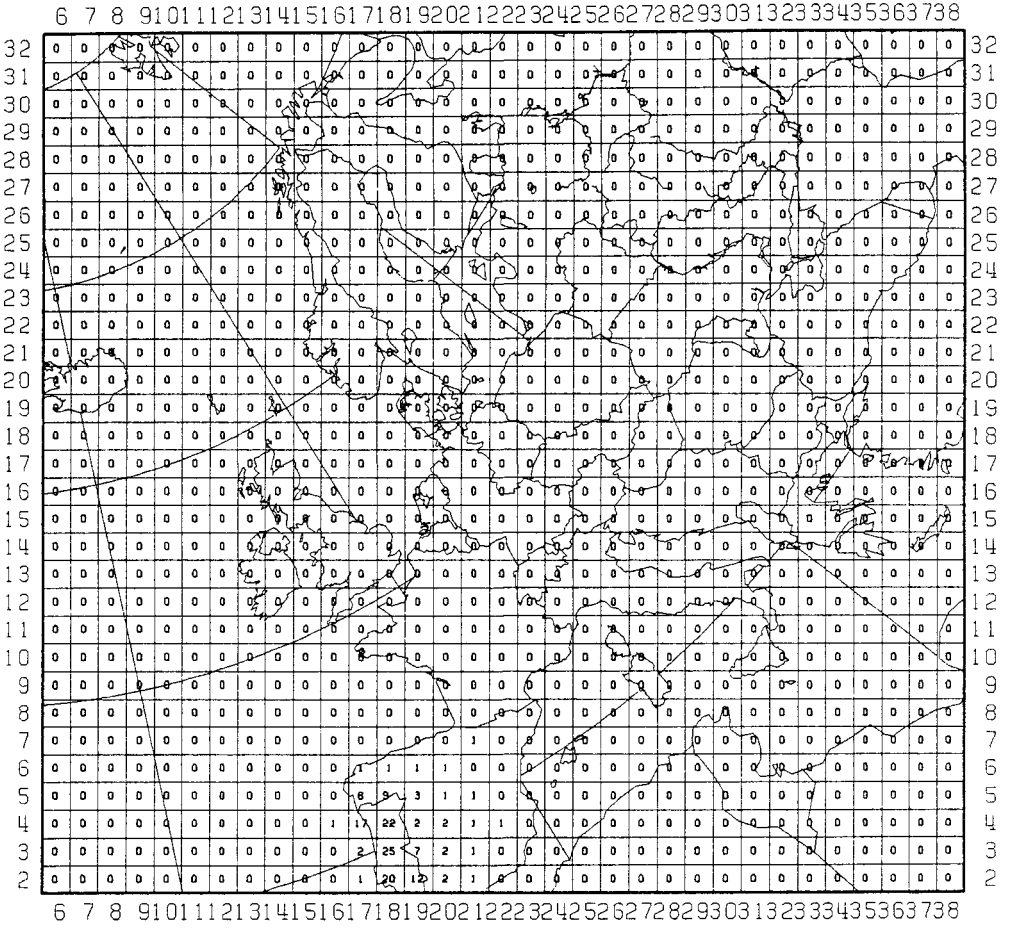
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - POLAND - PL
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL



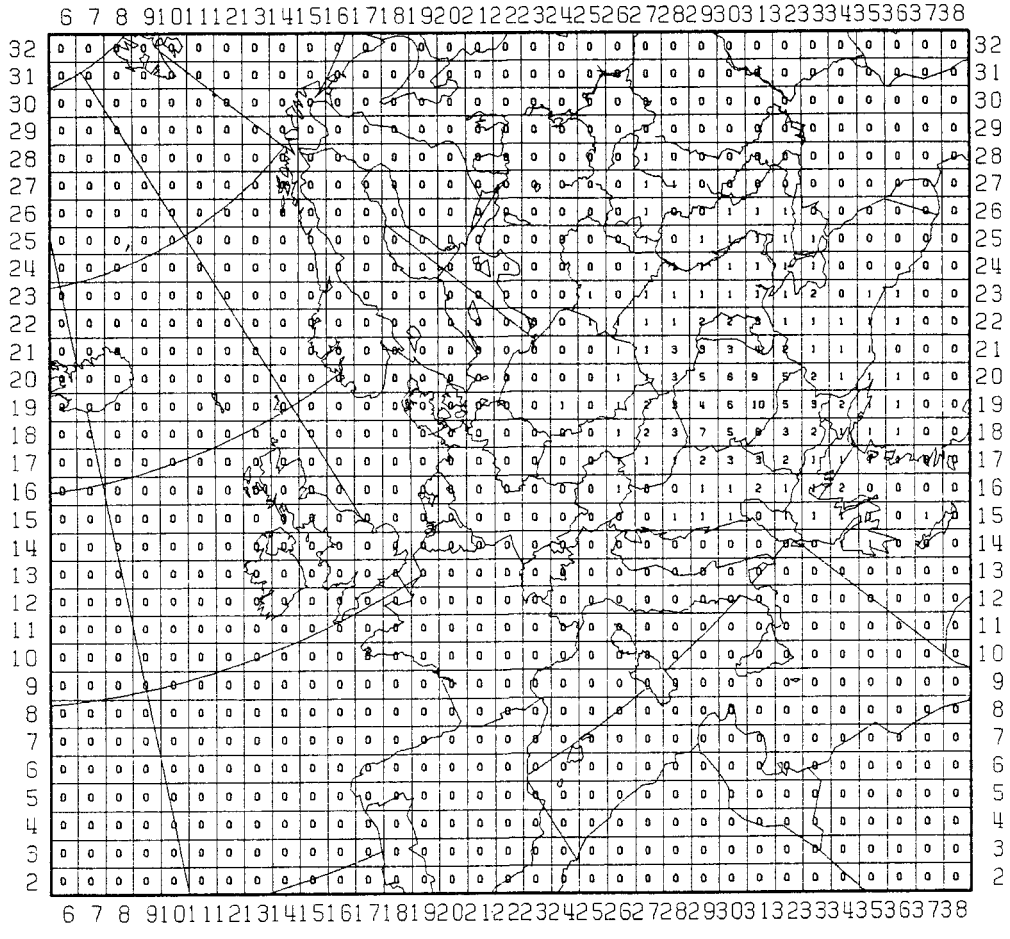
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - POLAND - PL
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL



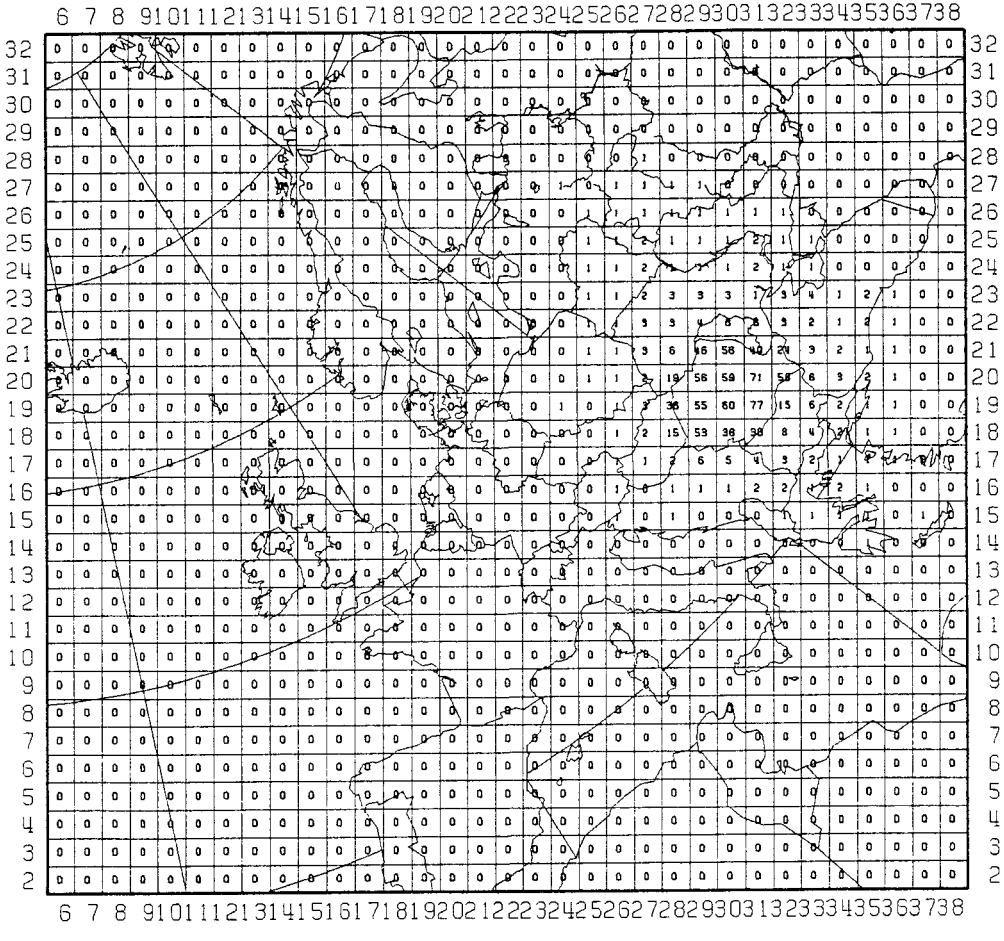
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - PORTUGAL - PT
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



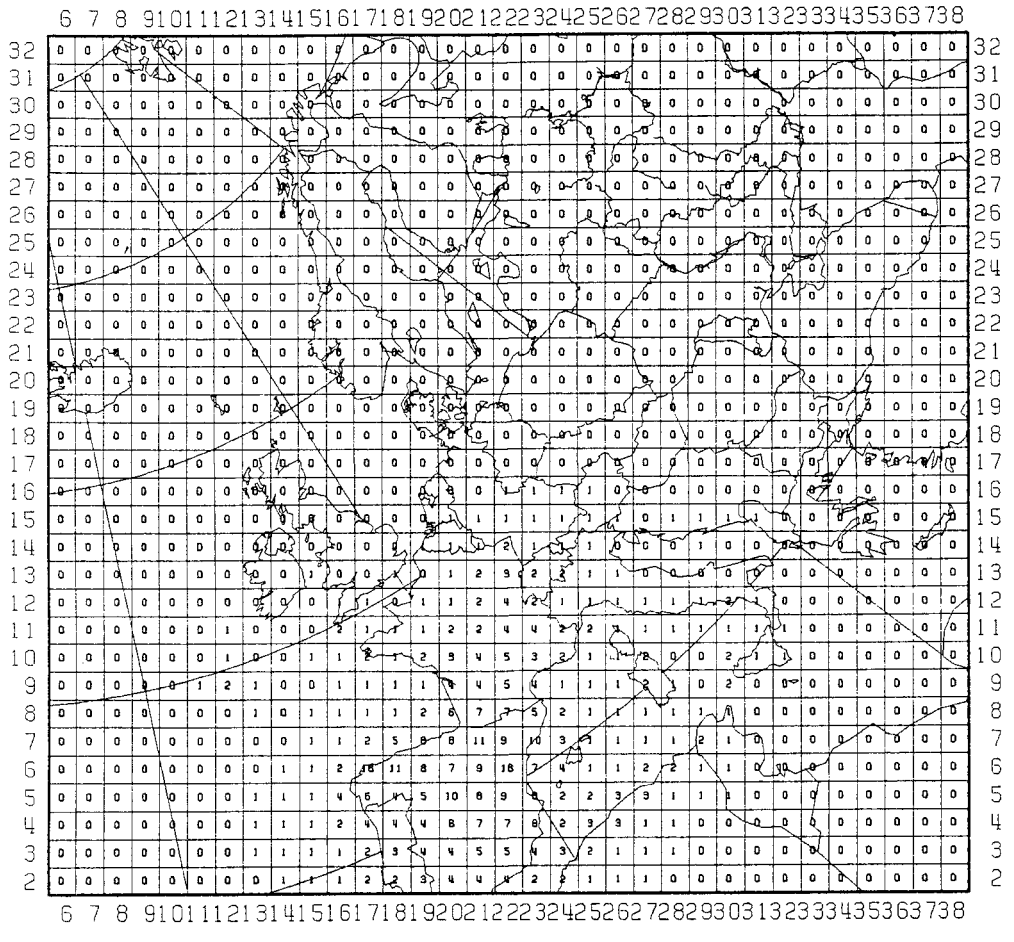
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - PORTUGAL - PT
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



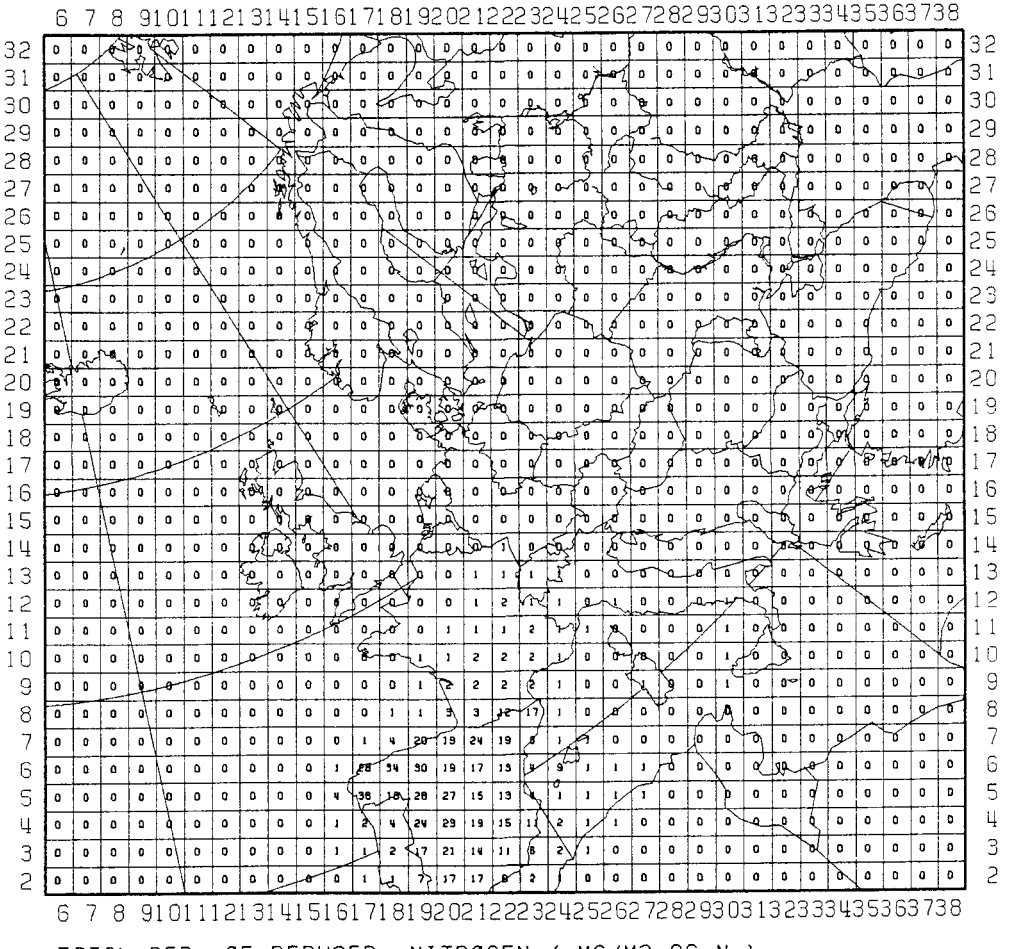
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - ROMANIA - RO
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



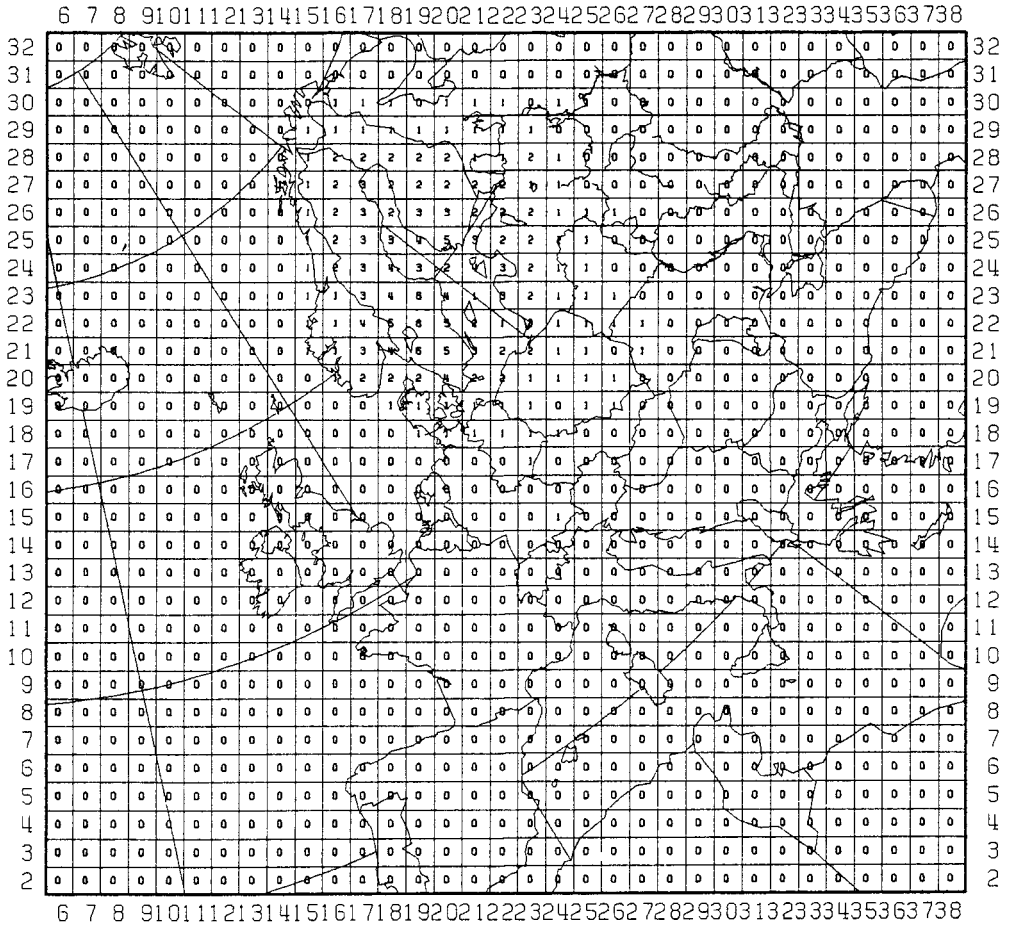
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - ROMANIA - RO
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



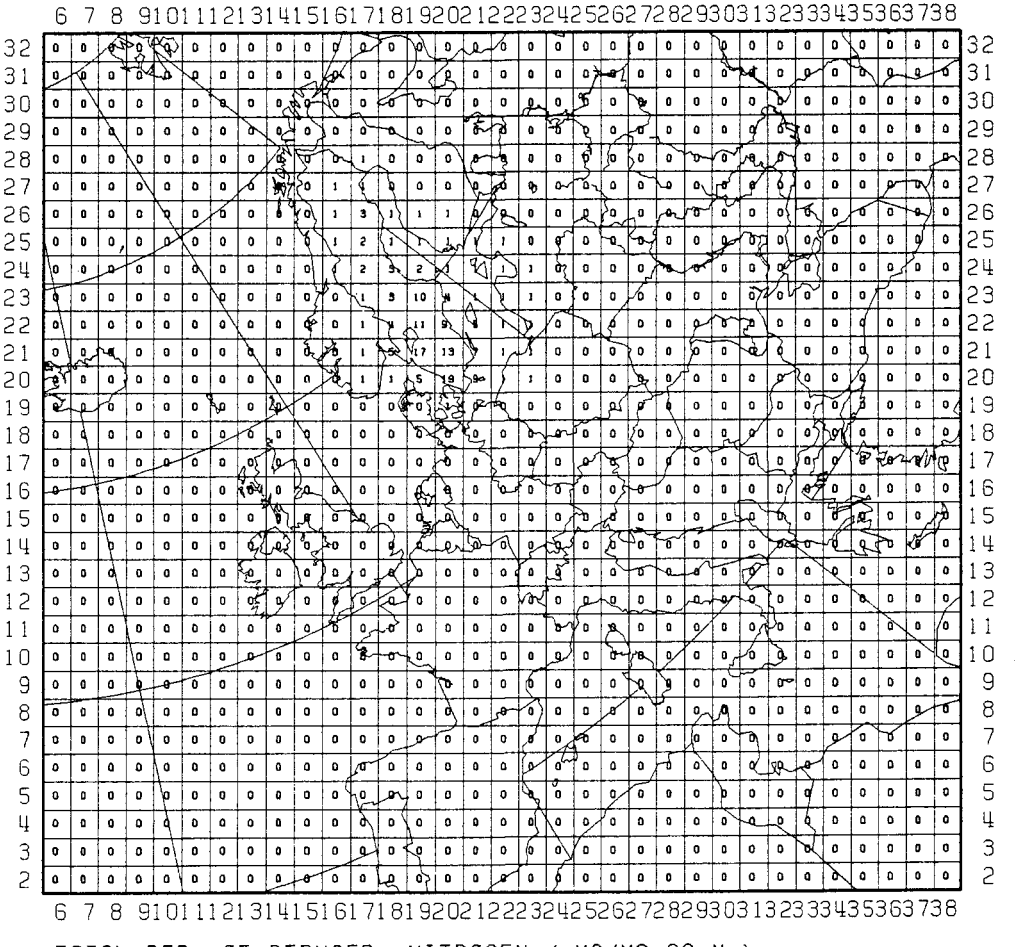
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - SPAIN - ES
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



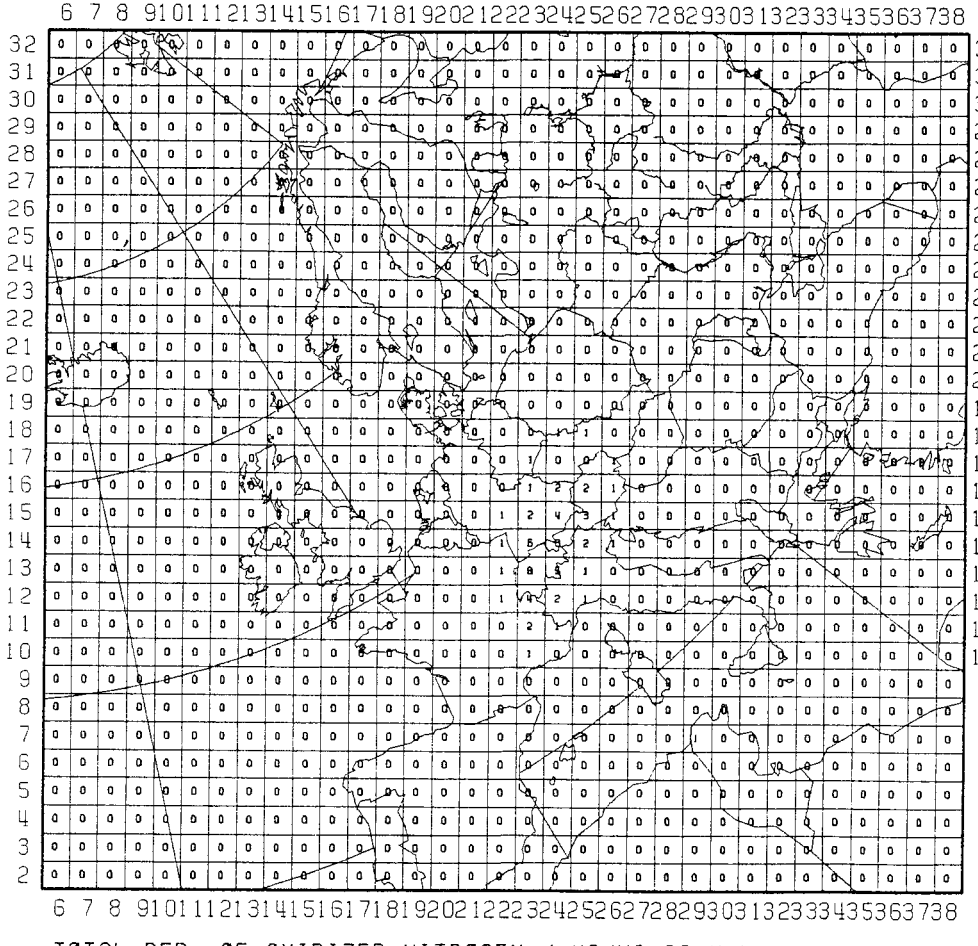
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - SPAIN - ES
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



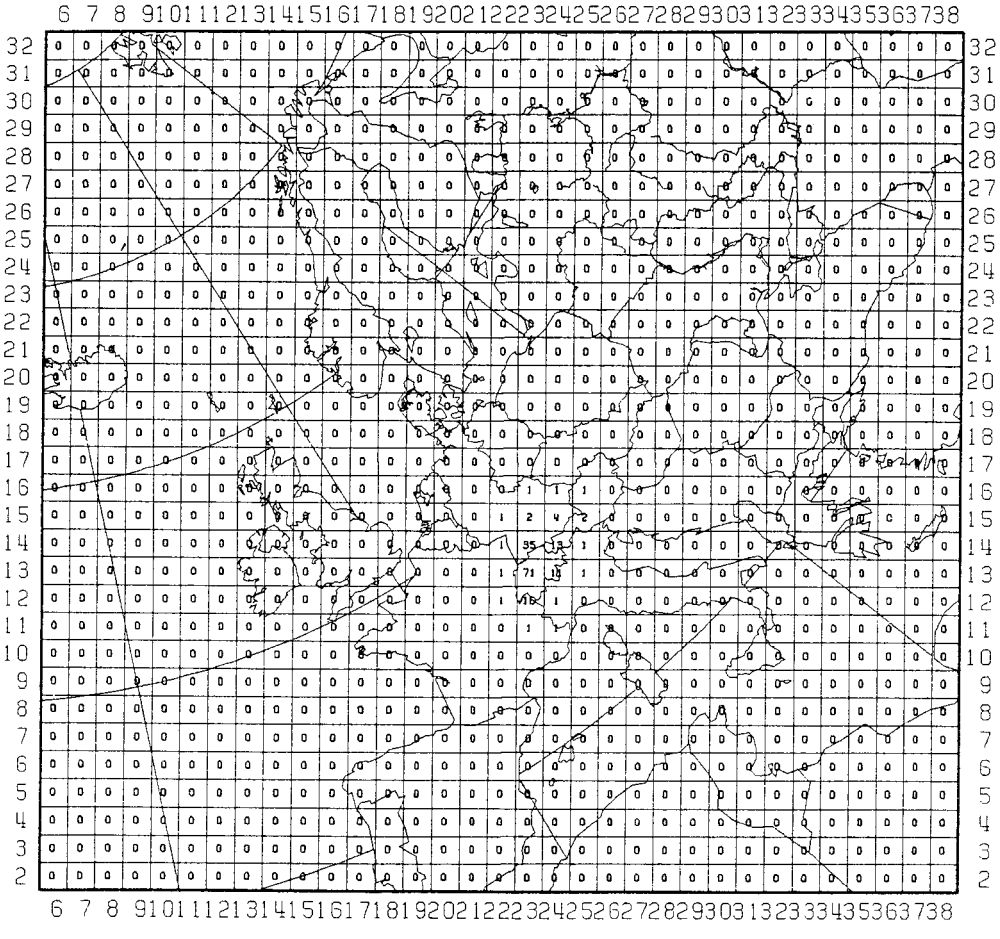
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - SWEDEN - SE
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



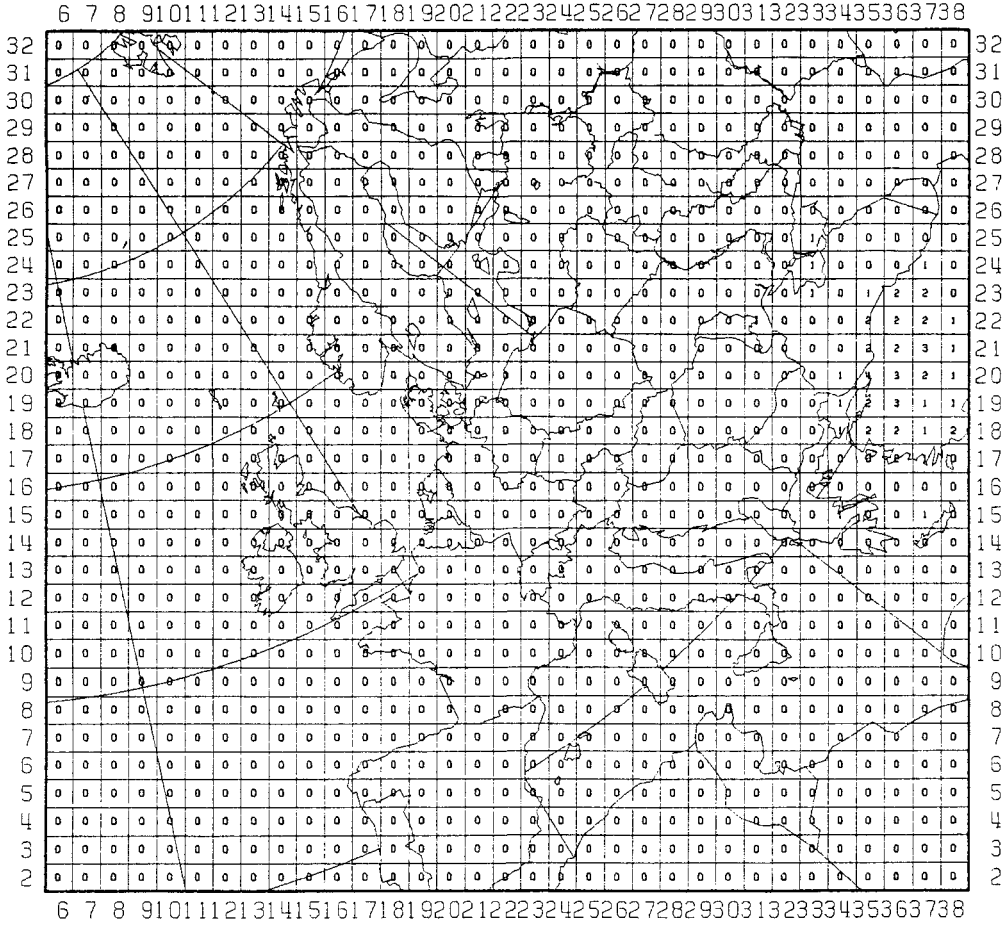
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - SWEDEN - SE
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



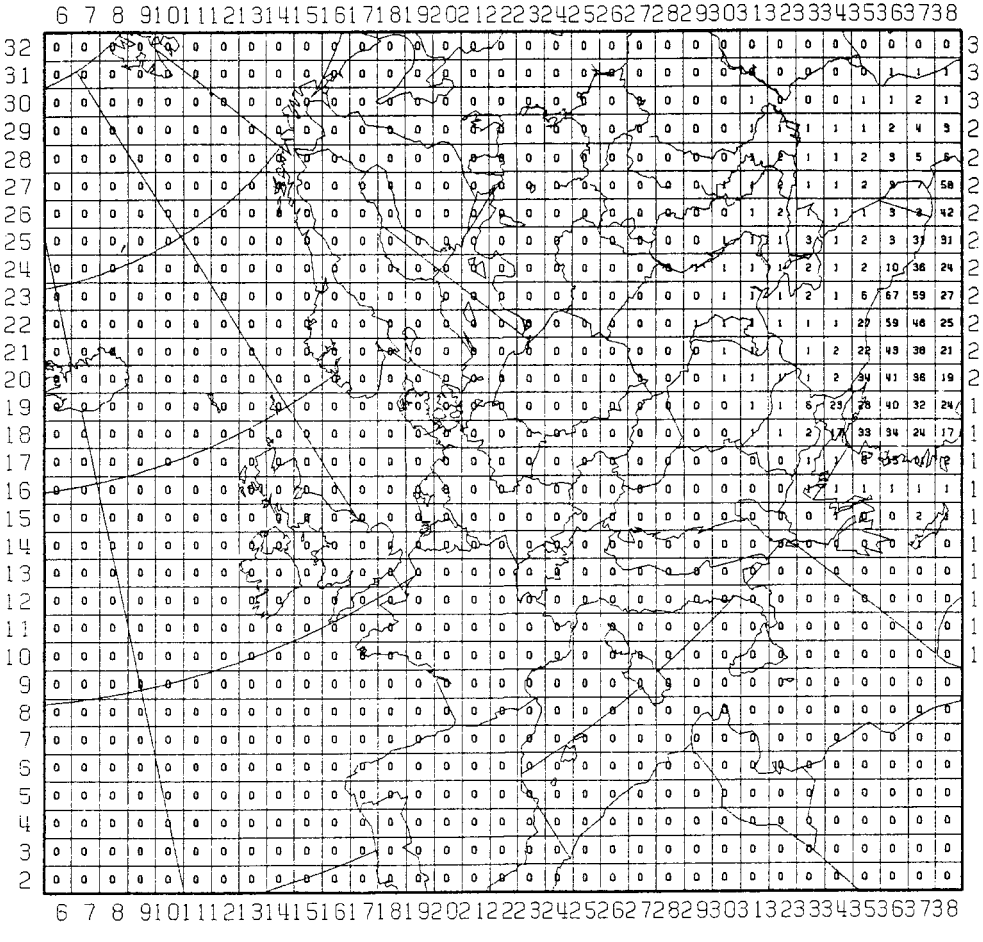
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - SWITZERLAND - CH
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



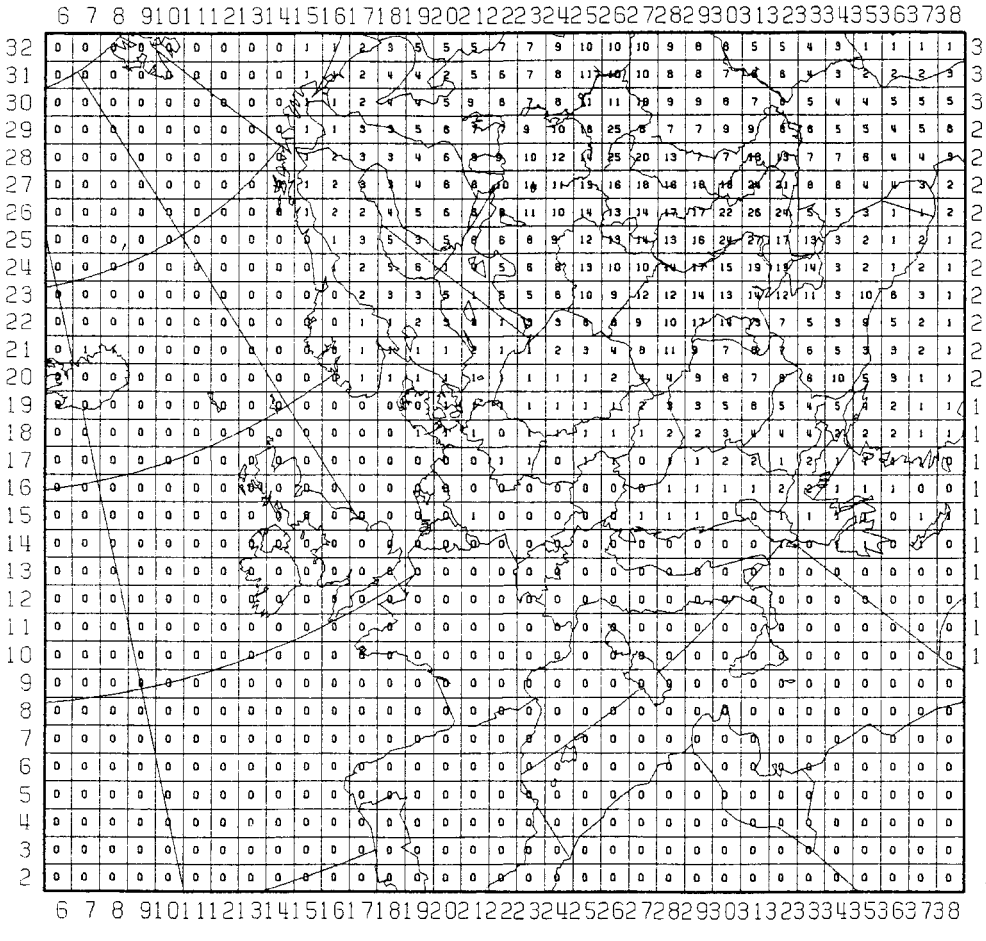
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - SWITZERLAND - CH
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



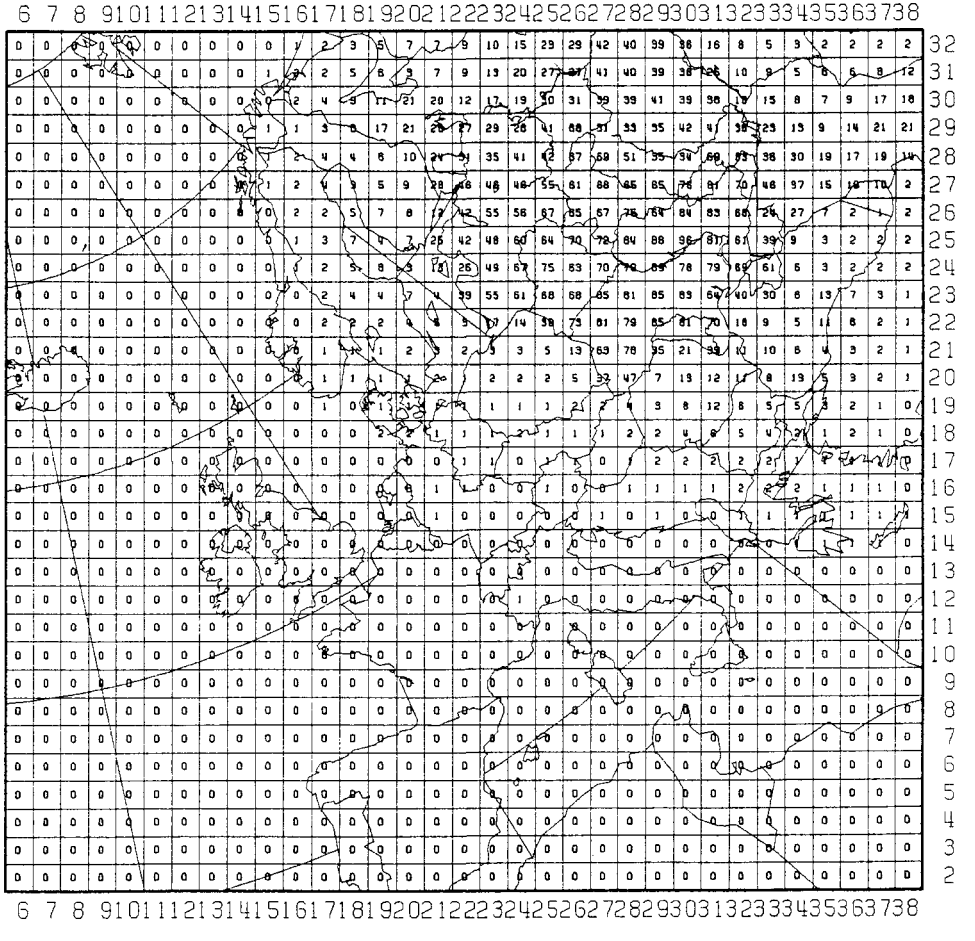
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - TURKEY - TR
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



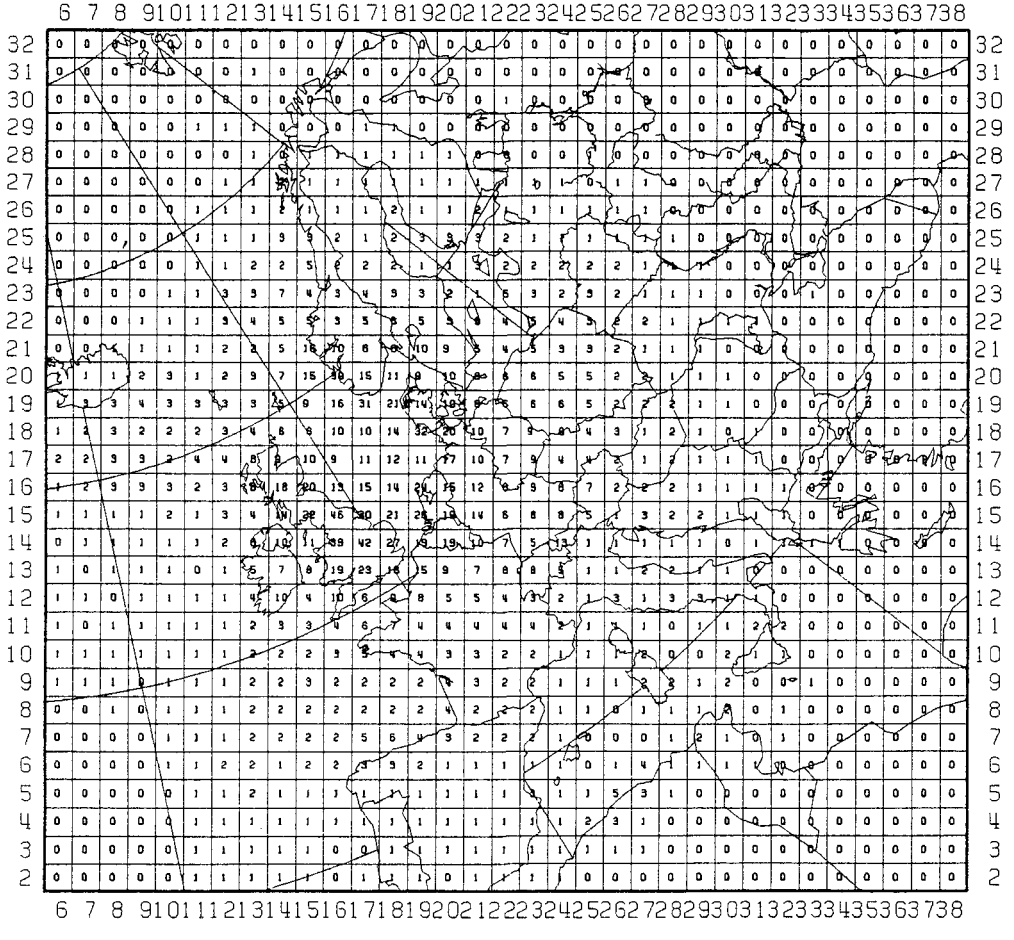
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - TURKEY - TR
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



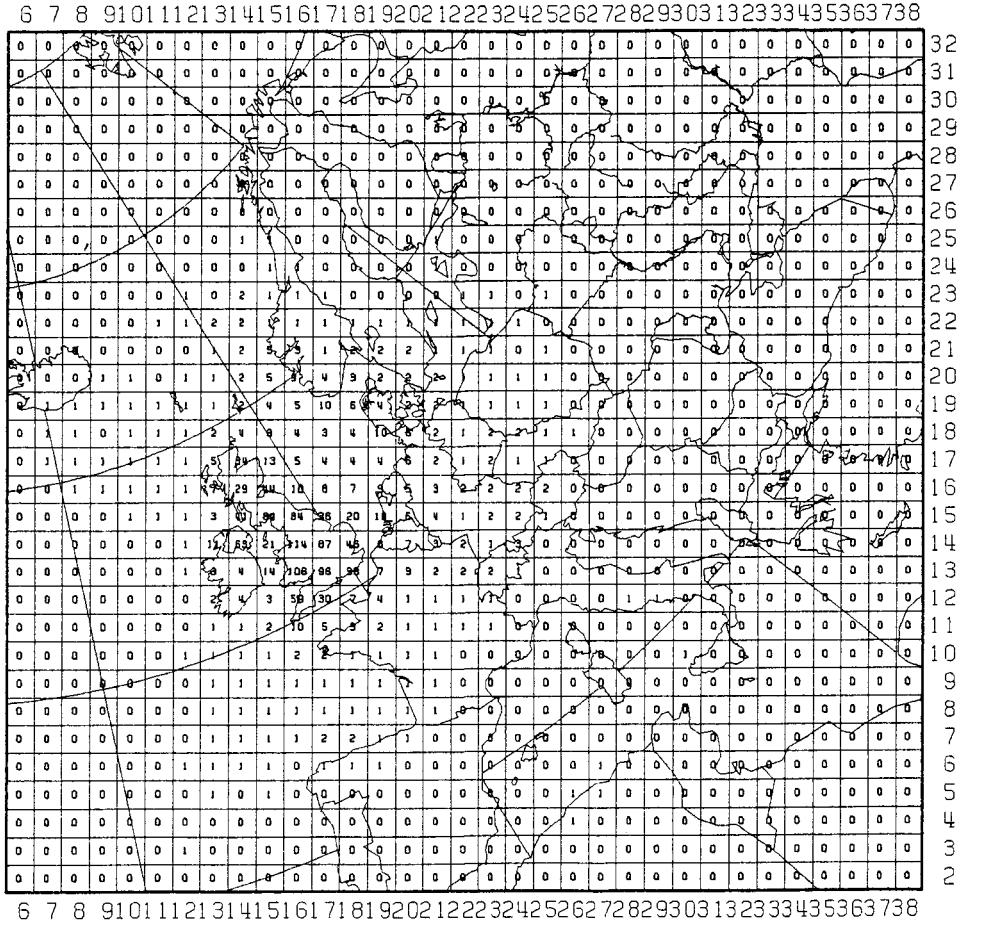
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - USSR (EUROPEAN) - SU
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



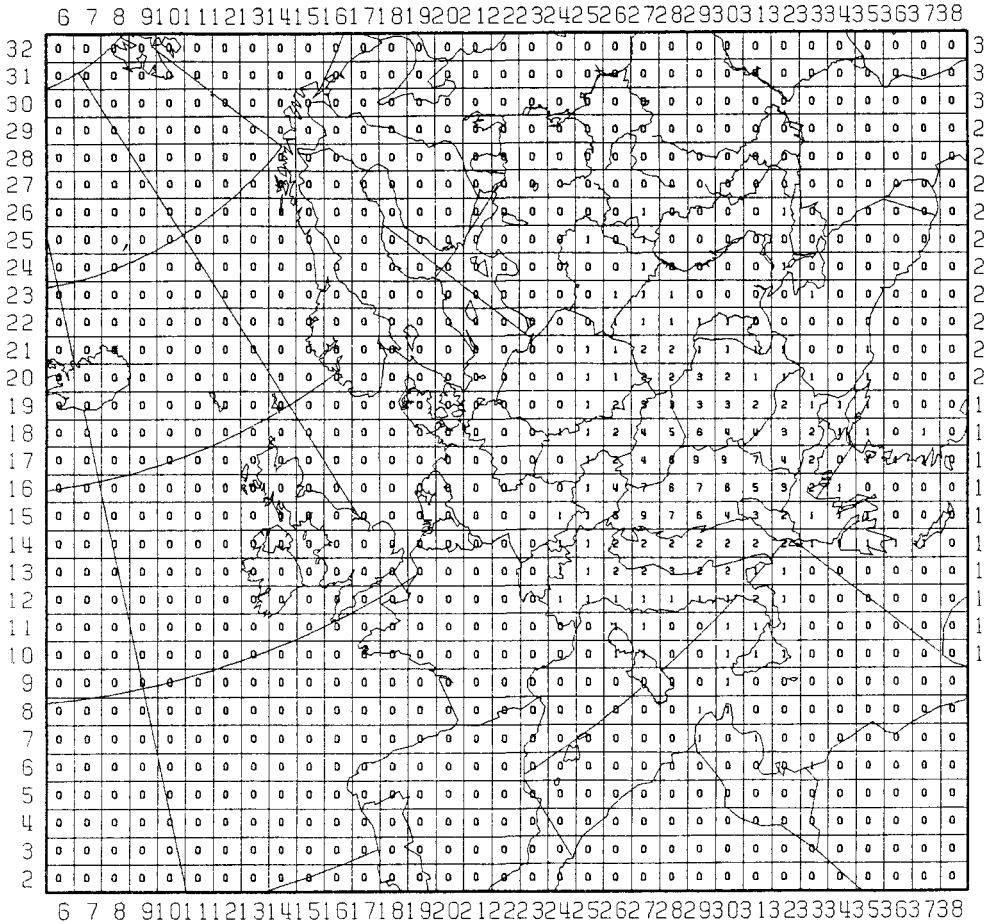
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - USSR (EUROPEAN) - SU
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



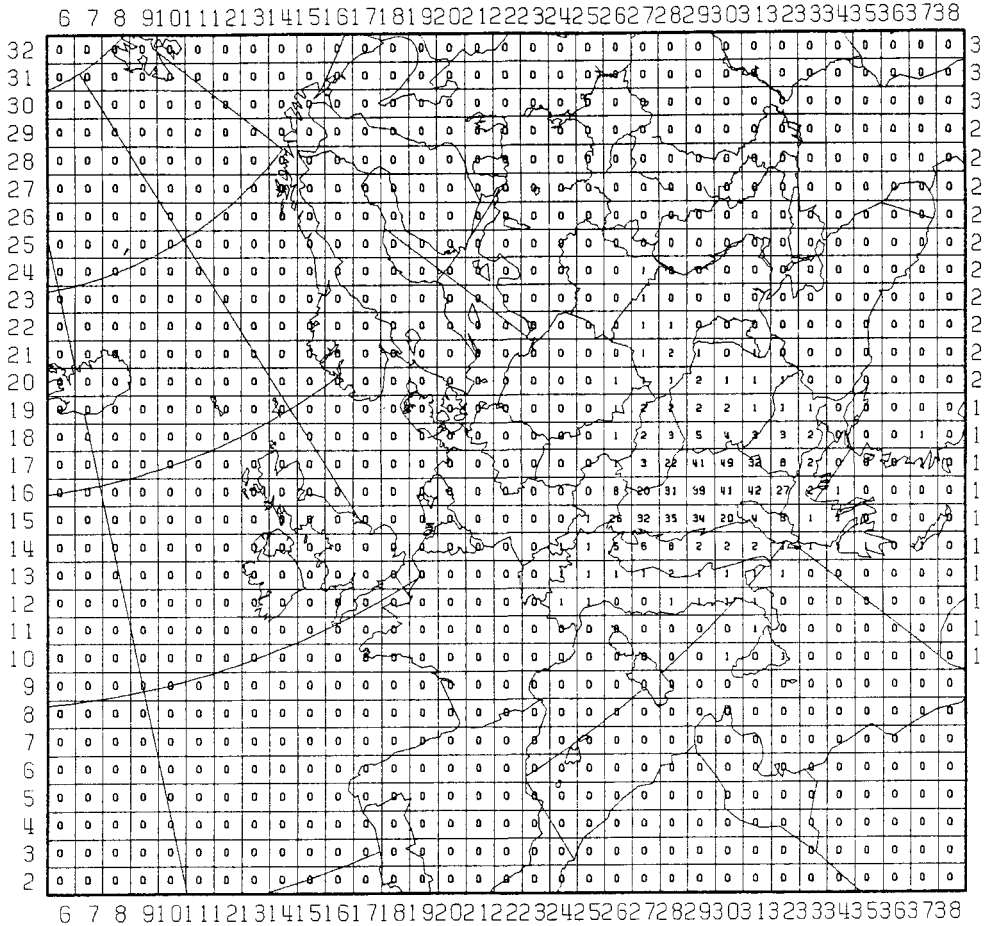
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - UNITED KINGDOM - GB
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



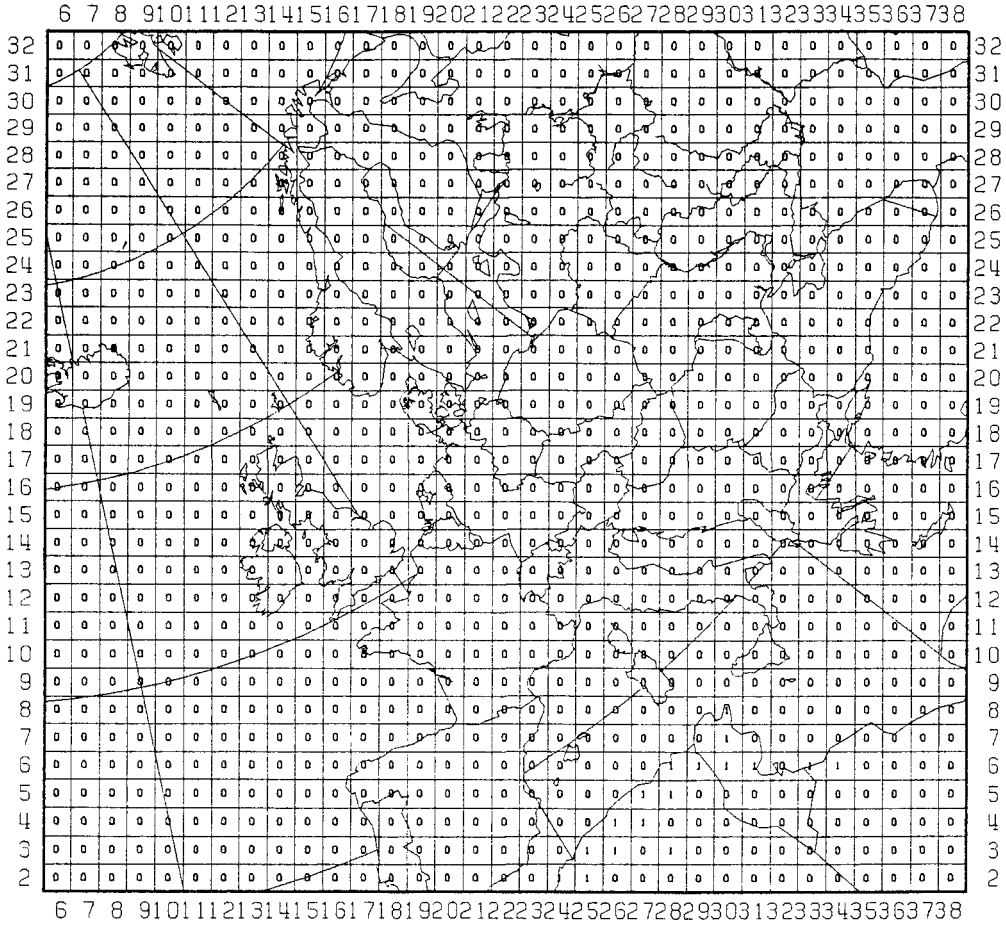
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - UNITED KINGDOM - GB
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



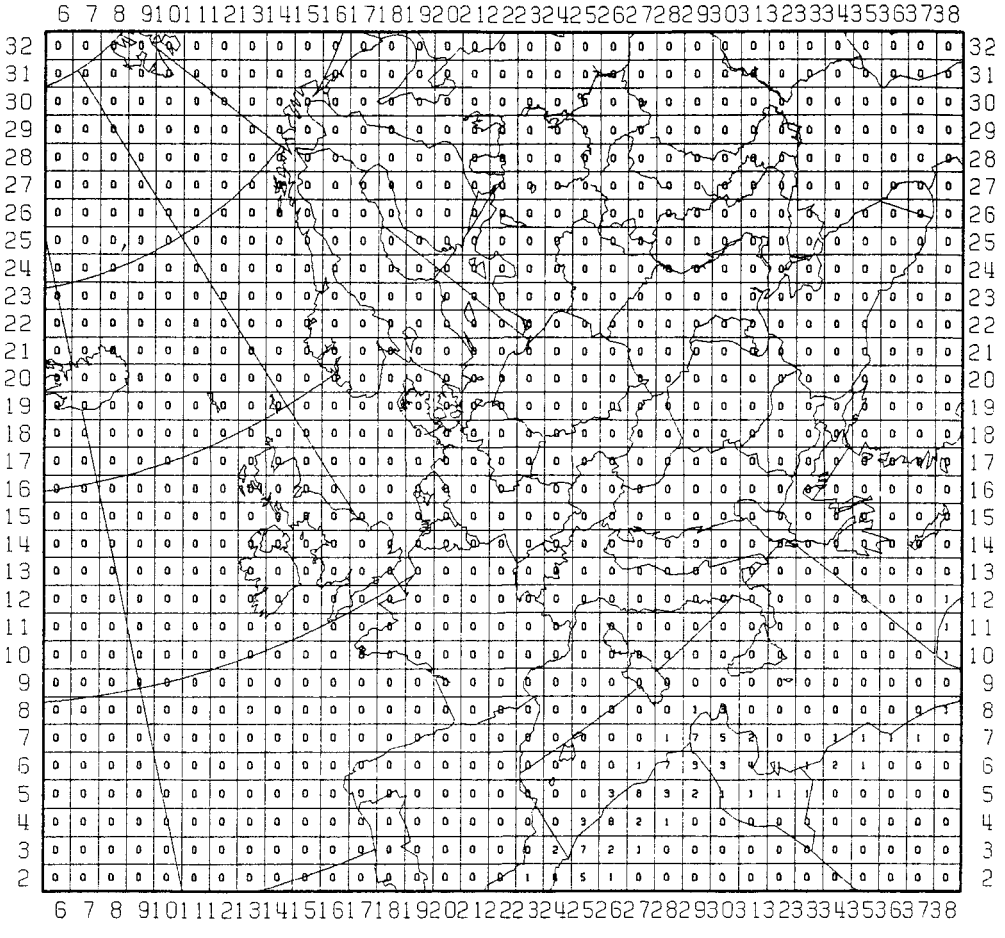
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - YUGOSLAVIA - YU
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



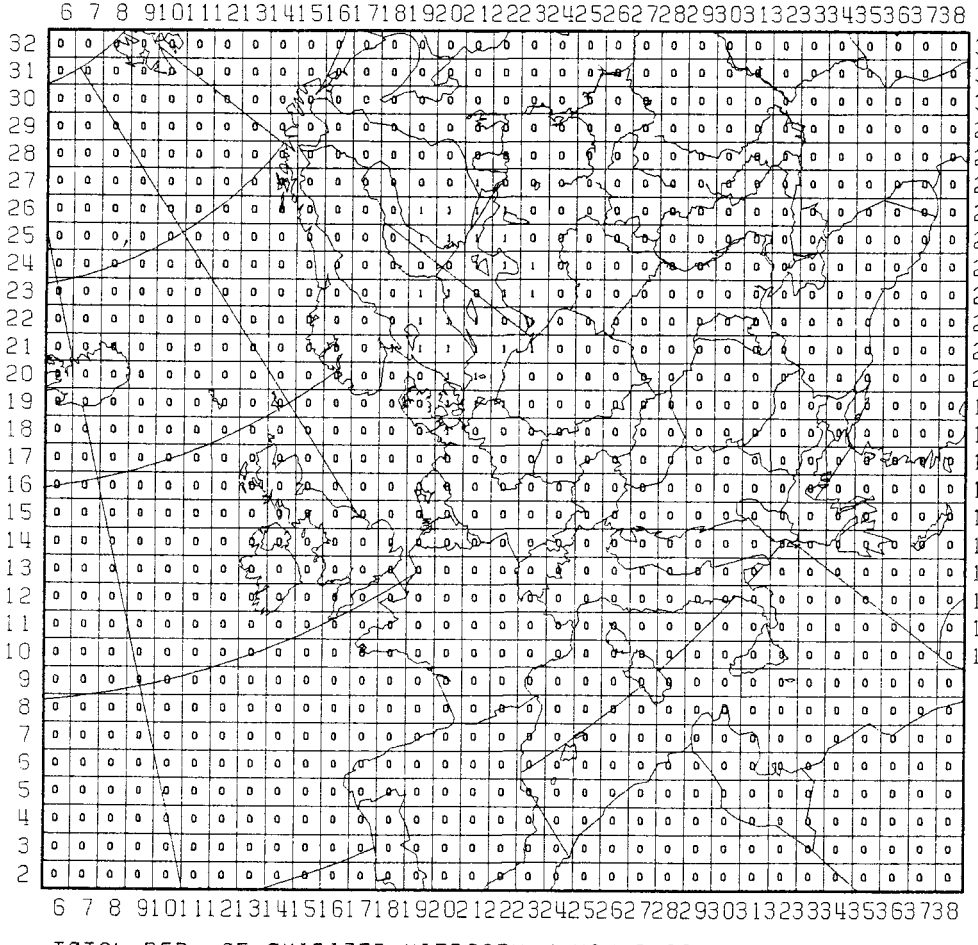
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - YUGOSLAVIA - YU
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



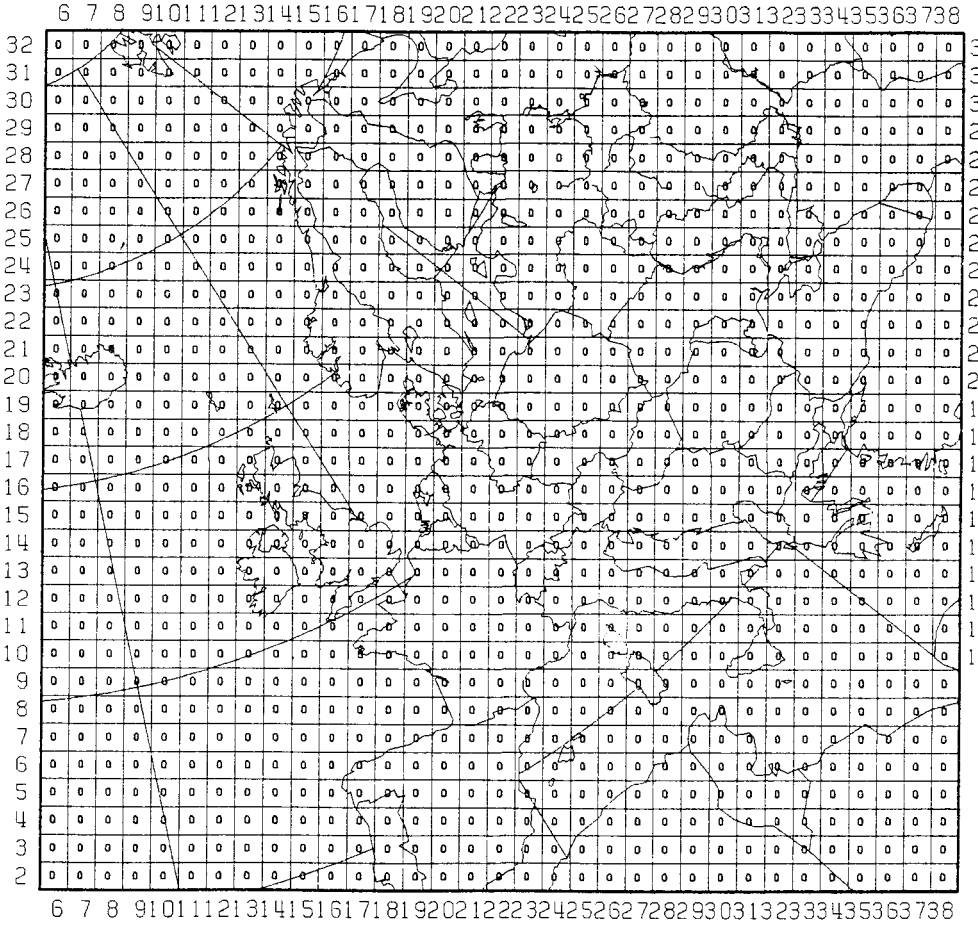
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - REMAINING AREAS -REM
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



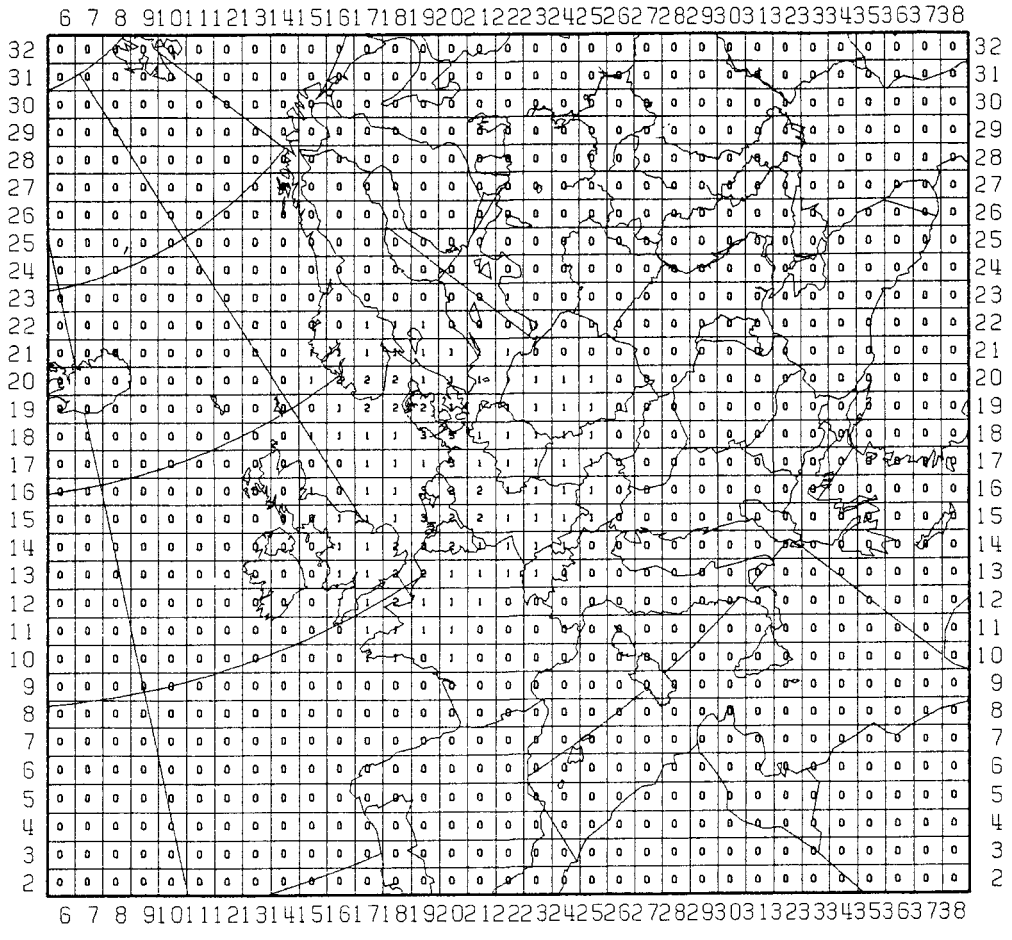
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - REMAINING AREAS -REM
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



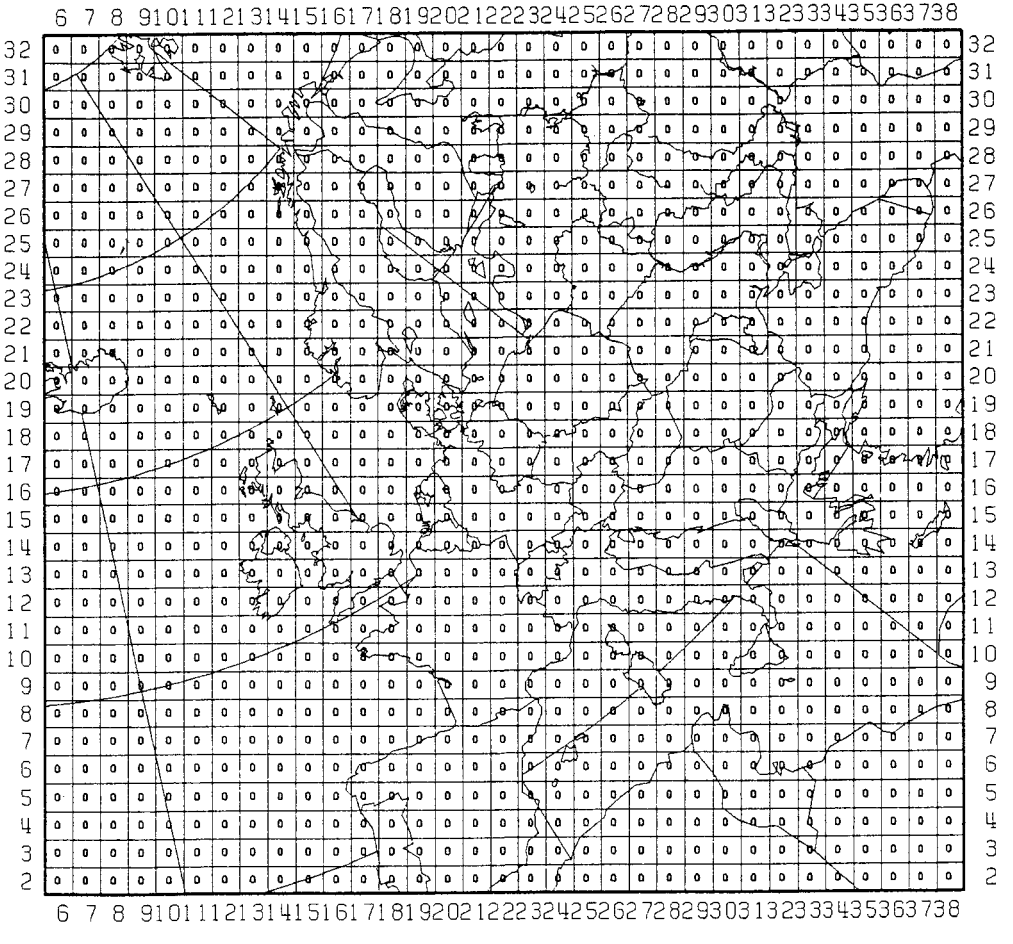
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - INT. TRADE, BALTIC SEA -BAS
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



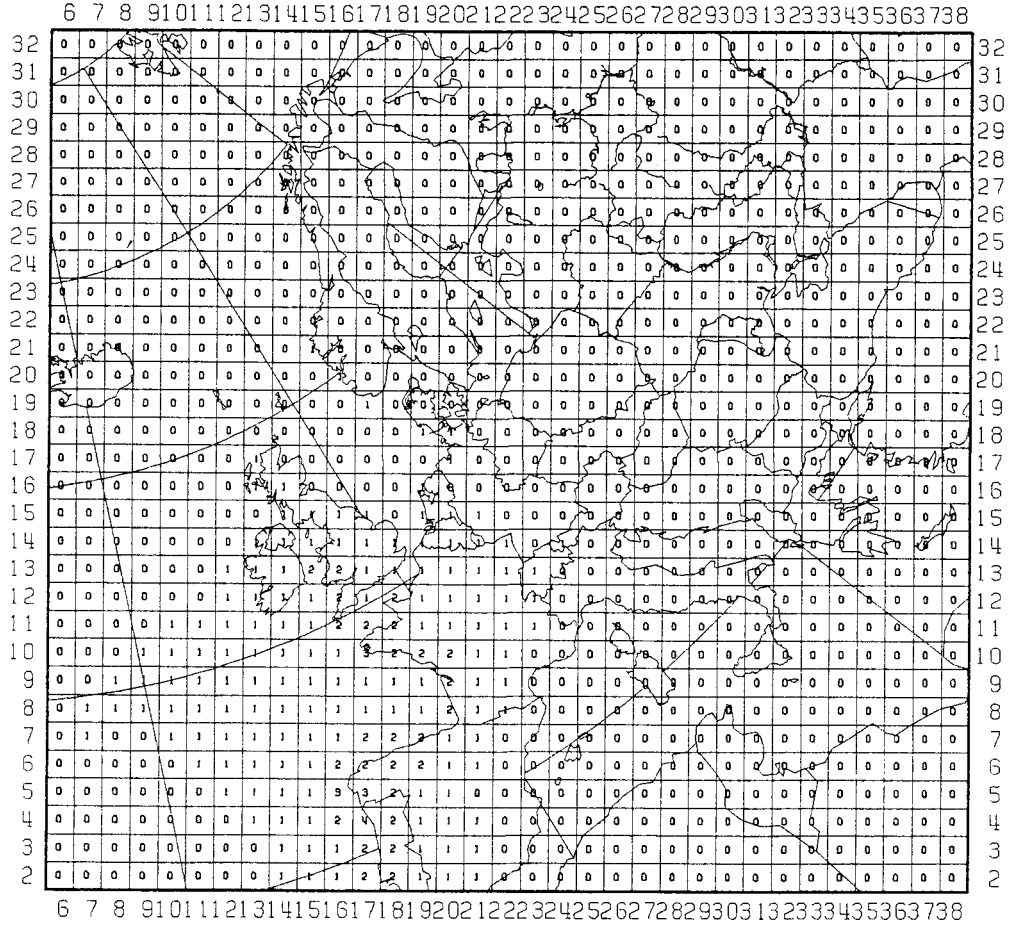
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - INT. TRADE, BALTIC SEA -BAS
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



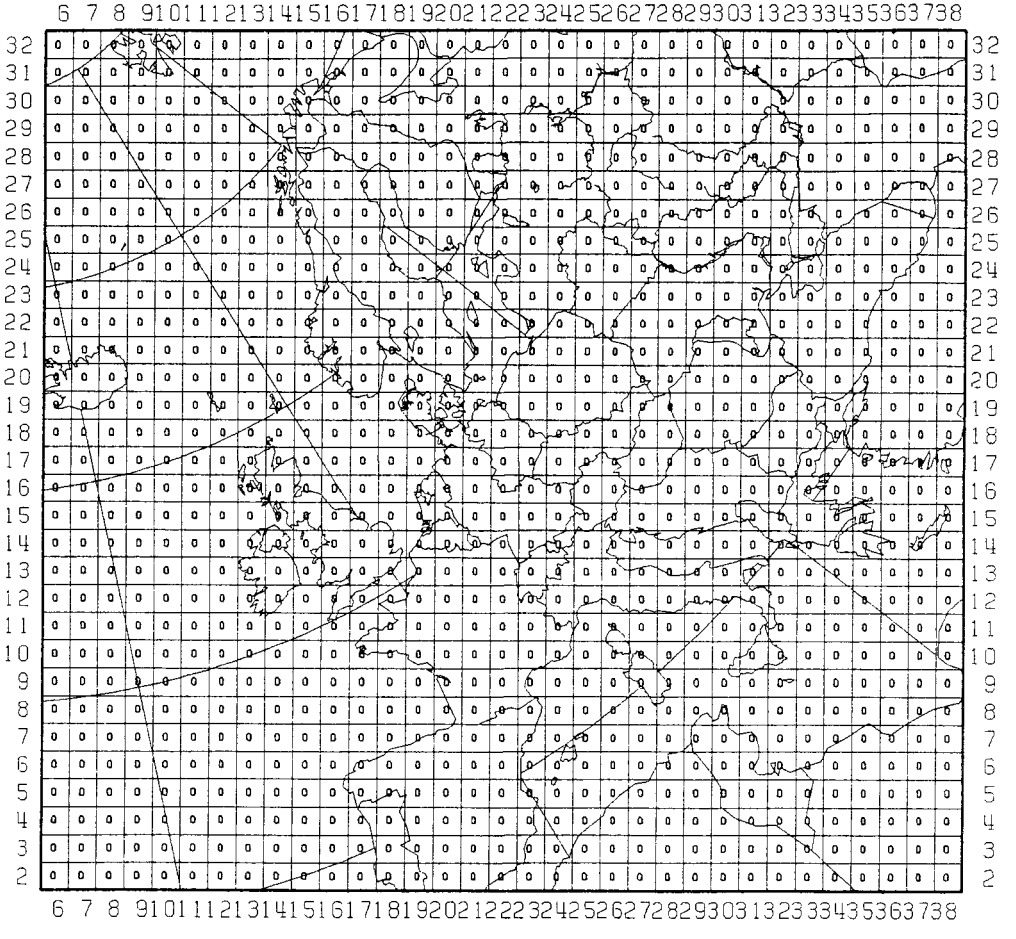
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - INT. TRADE, NORTH SEA -NOS
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



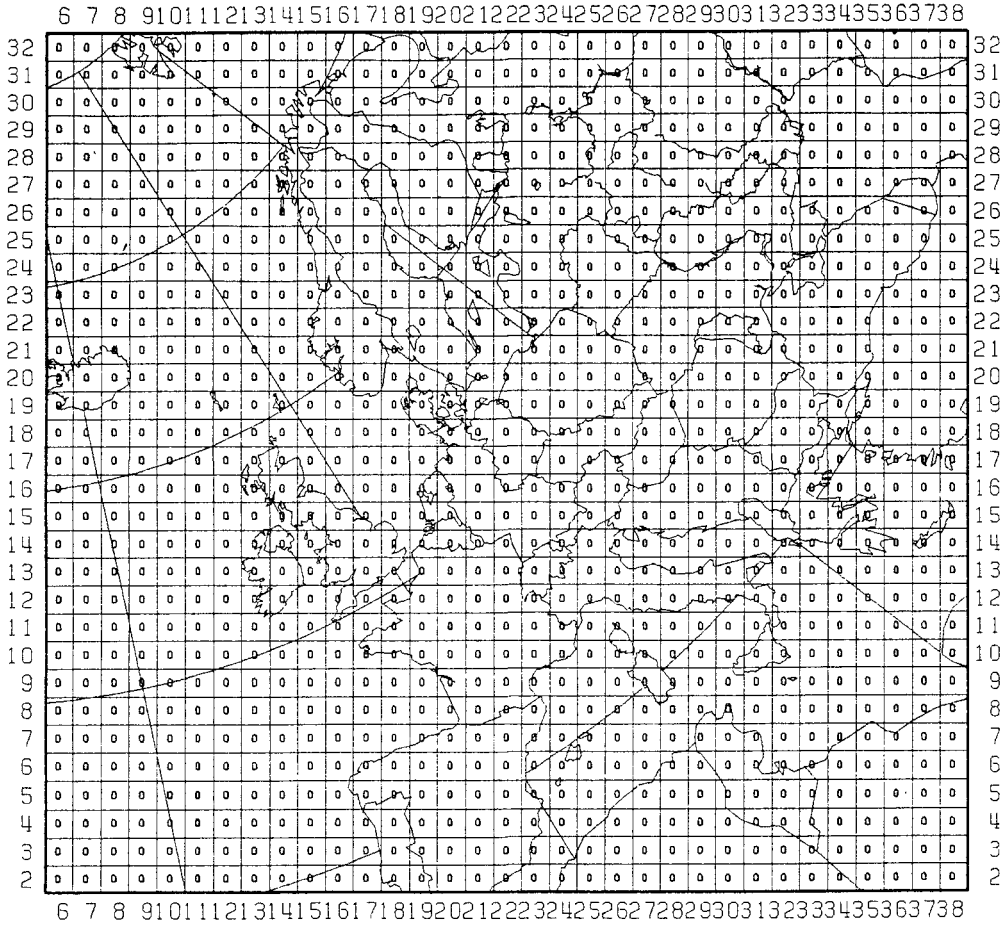
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - INT. TRADE, NORTH SEA -NOS
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



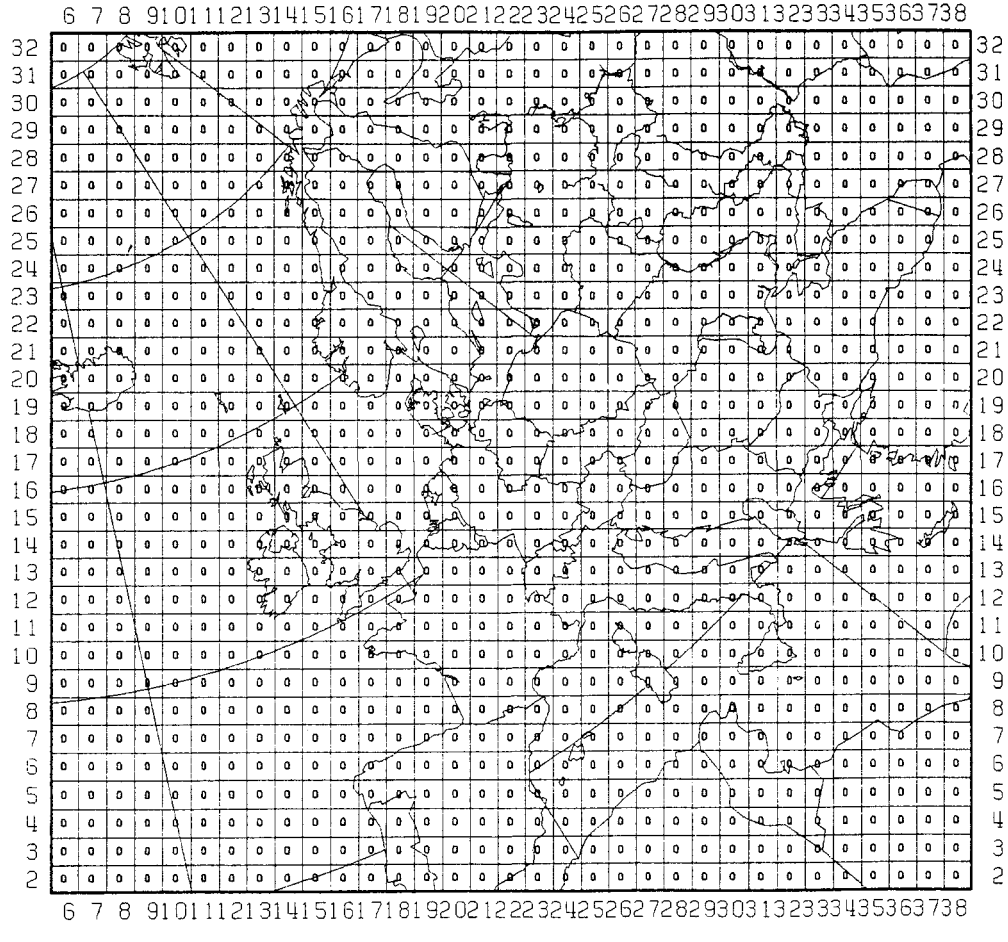
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - INT. TRADE, REM. ATL. -ATL
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



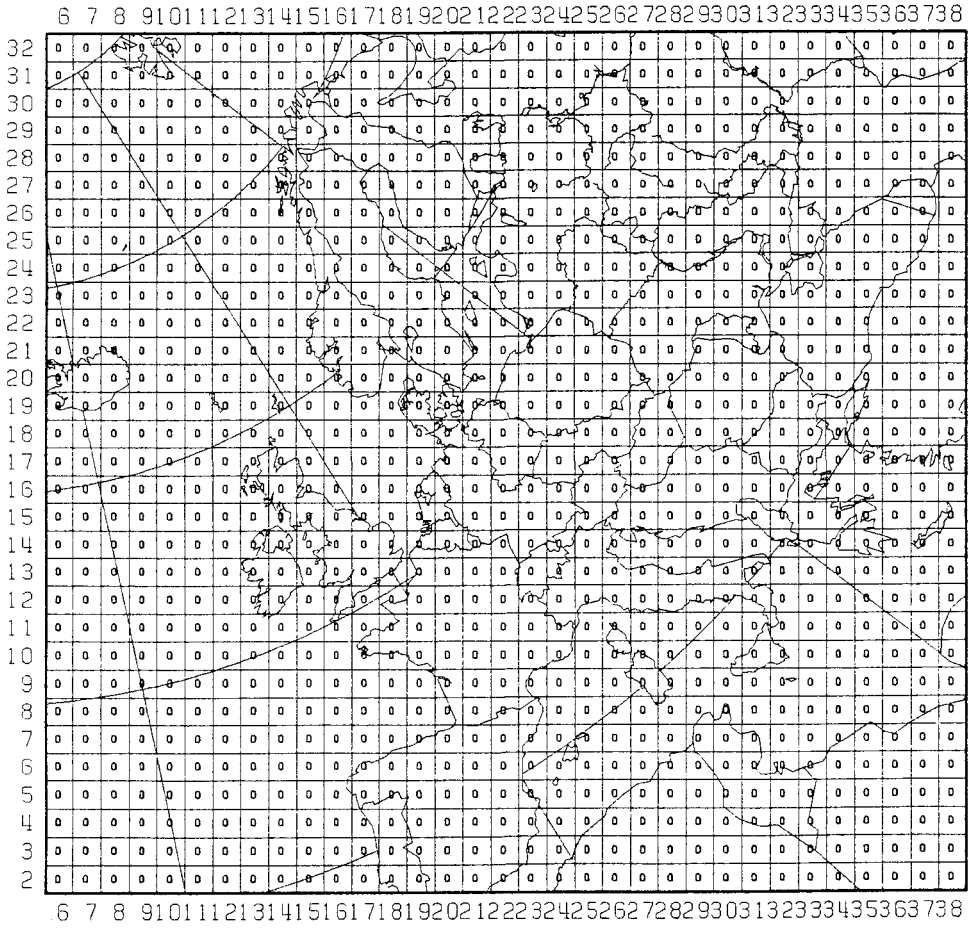
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - INT. TRADE, REM. ATL. -ATL
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



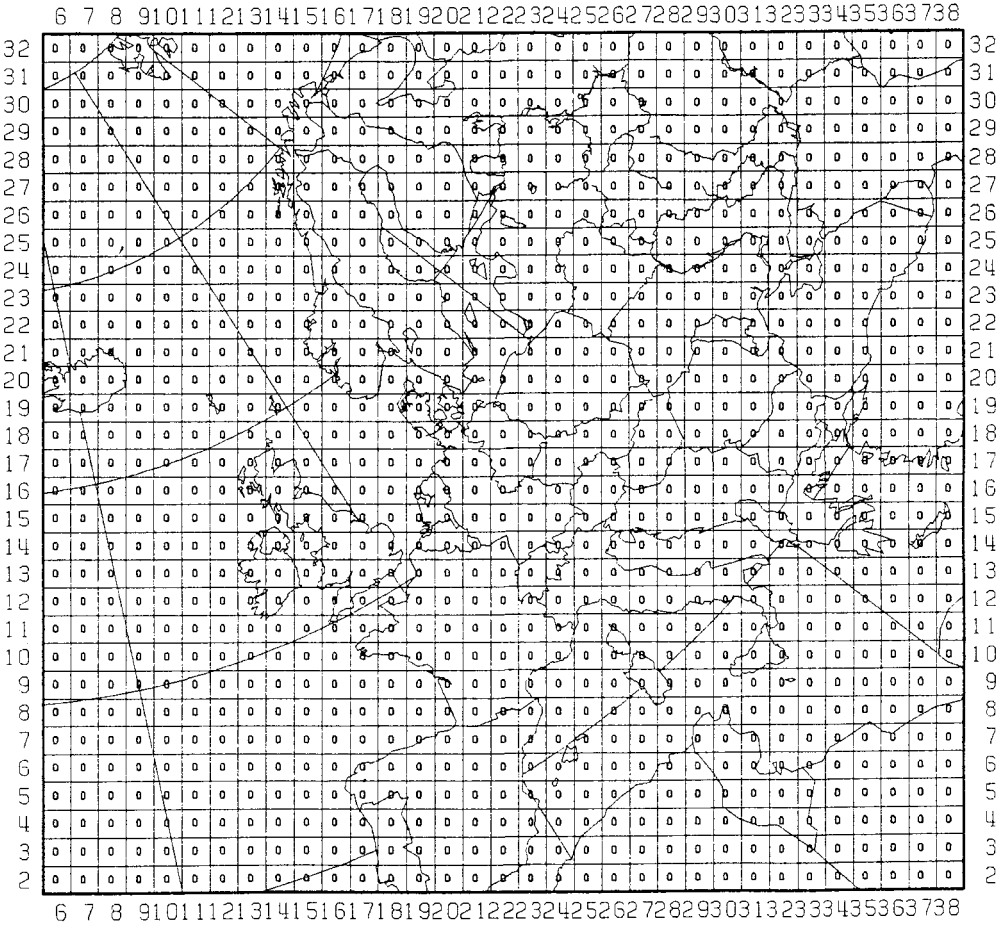
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - INT. TRADE, MEDITER. -MED
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



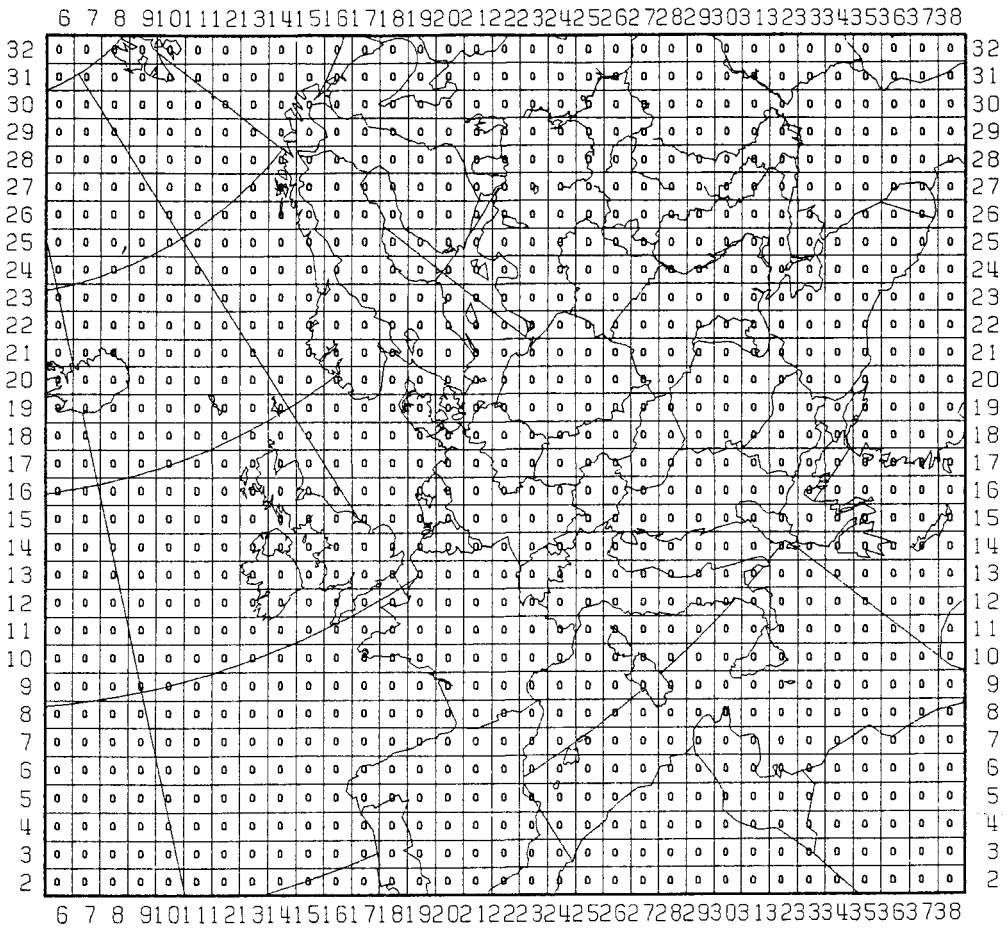
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - INT. TRADE, MEDITER. -MED
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



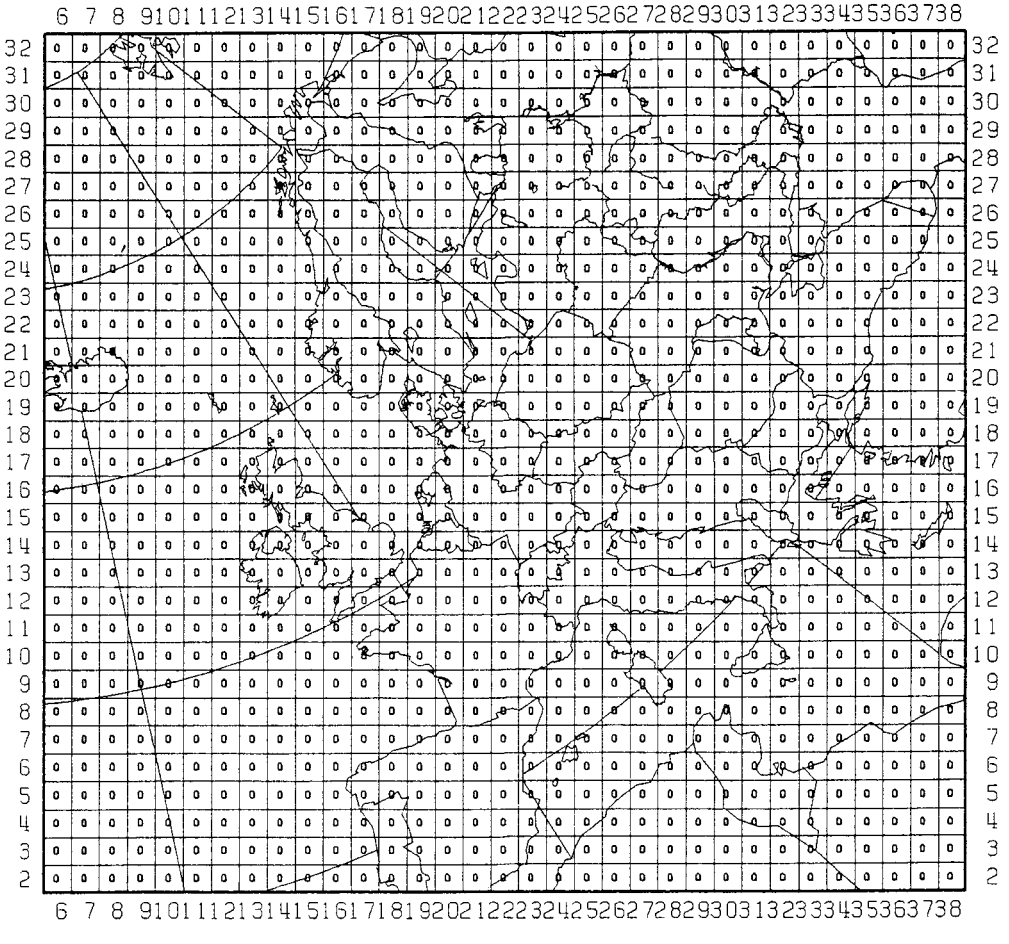
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - INT. TRADE, BLACK SEA -BLS
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



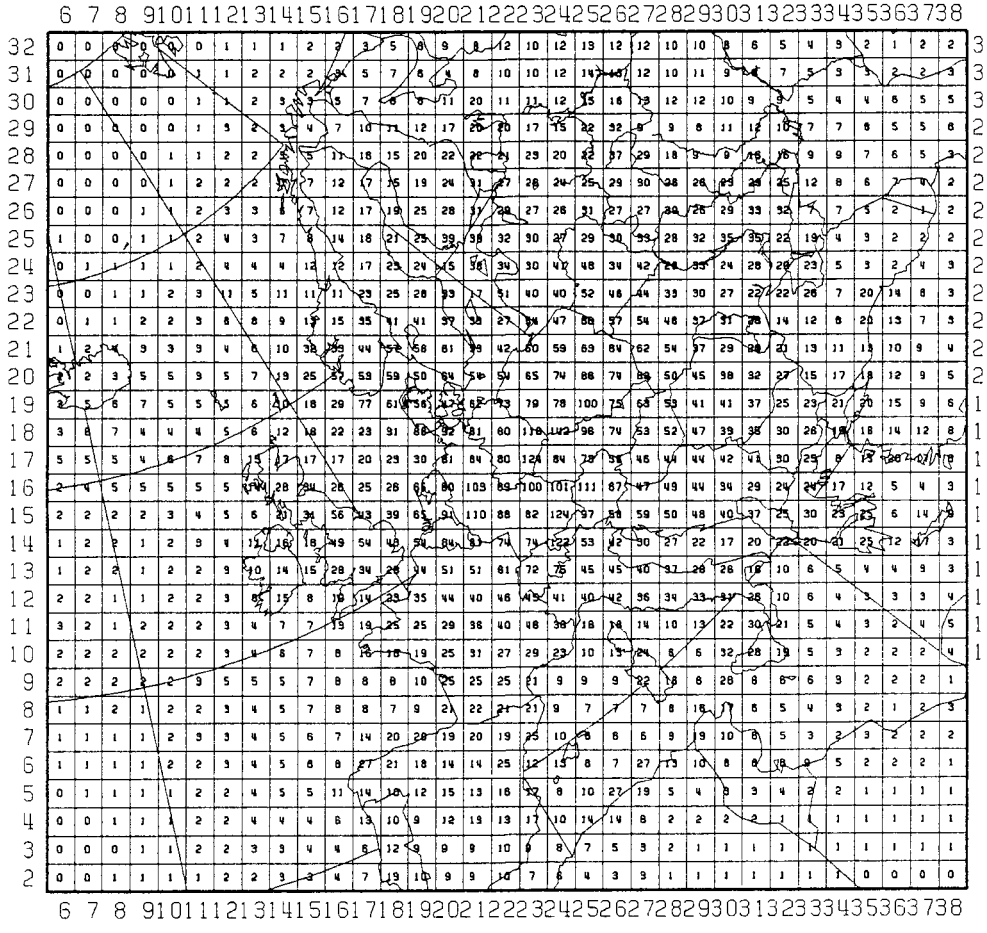
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - INT. TRADE, BLACK SEA -BLS
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



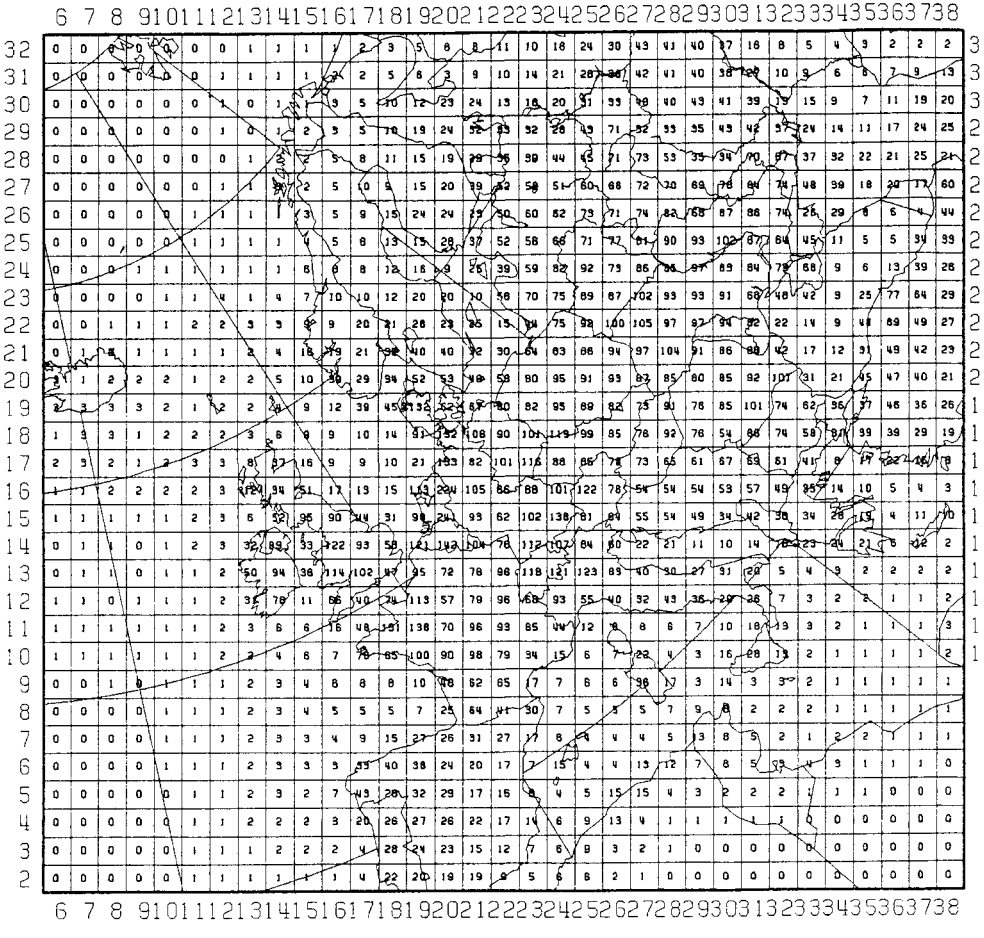
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - NATURAL EMISSIONS -NAT
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL



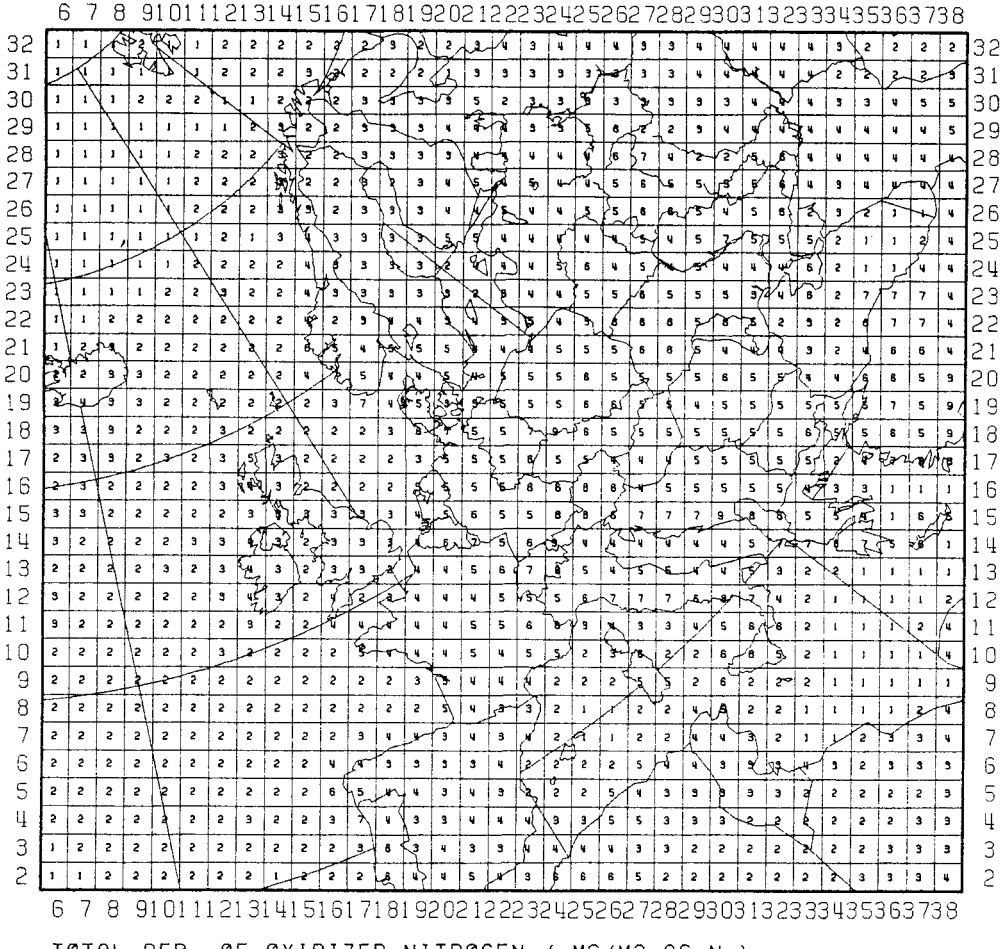
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
CONTRIBUTION FROM - NATURAL EMISSIONS -NAT
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL



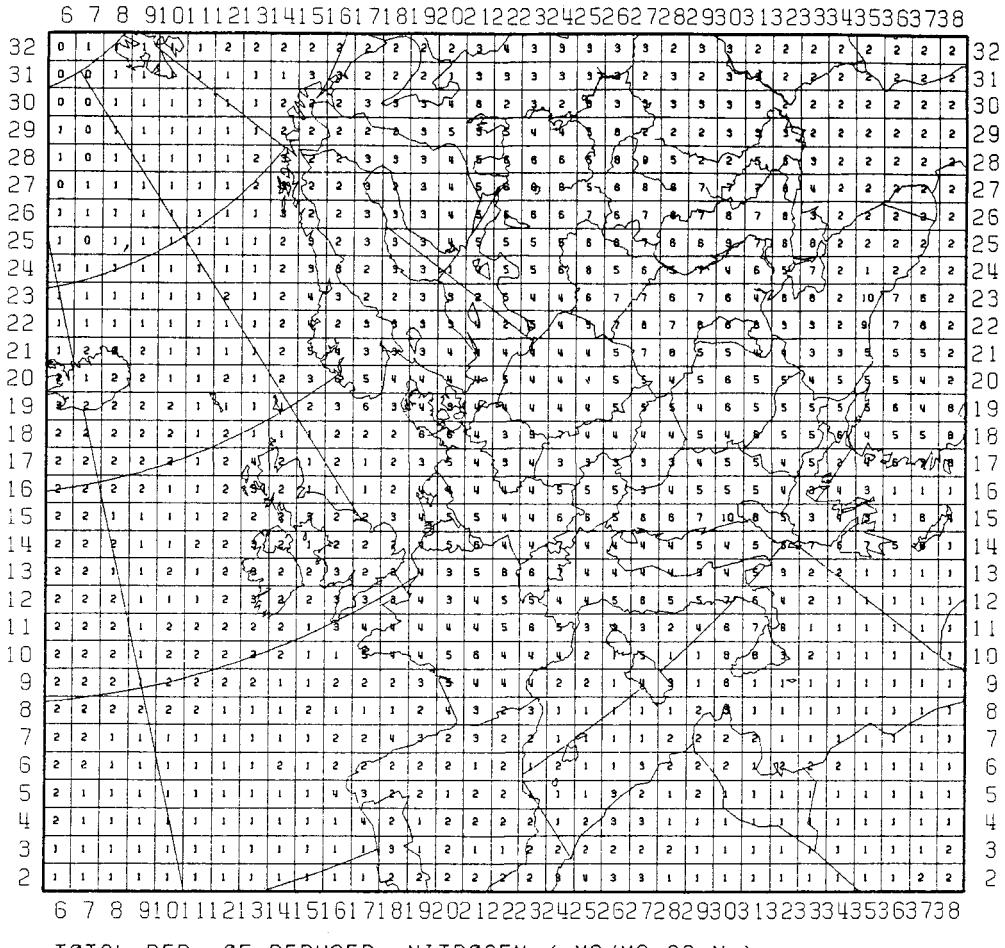
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
SUM OF ATTRIBUTABLE CONTRIBUTIONS -SUM
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



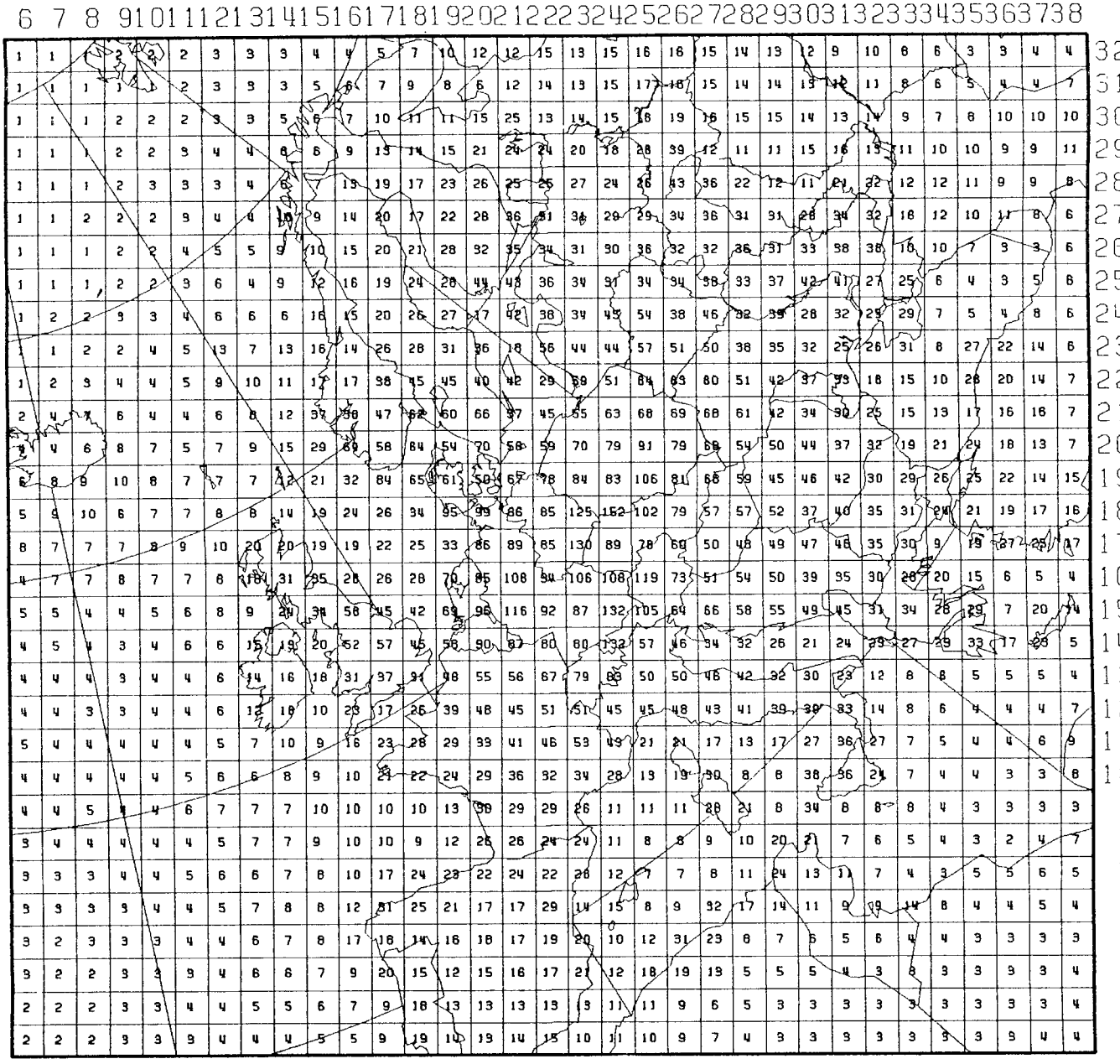
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
SUM OF ATTRIBUTABLE CONTRIBUTIONS -SUM
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



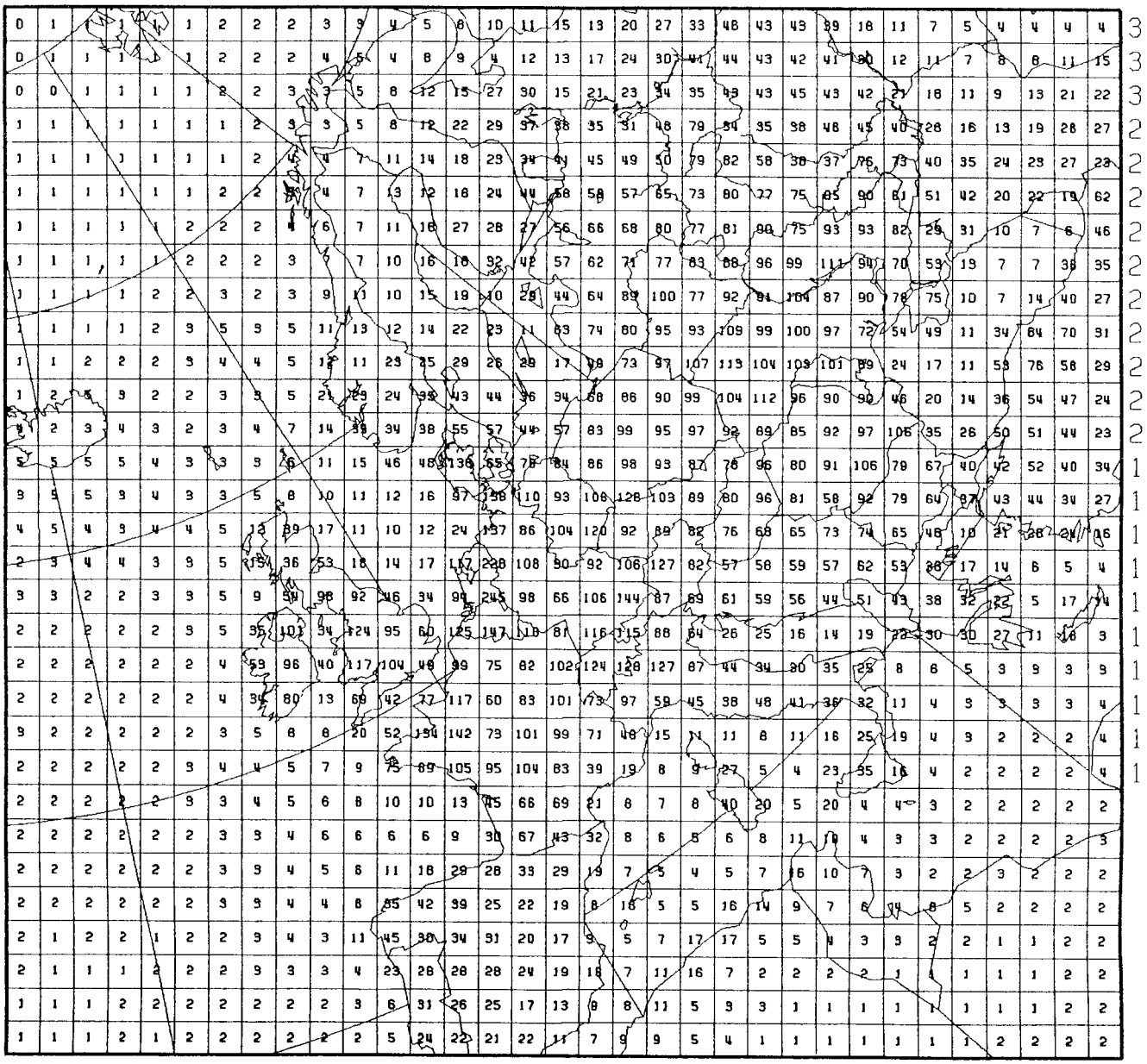
TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
INATTRIBUTABLE CONTRIBUTIONS - IND
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



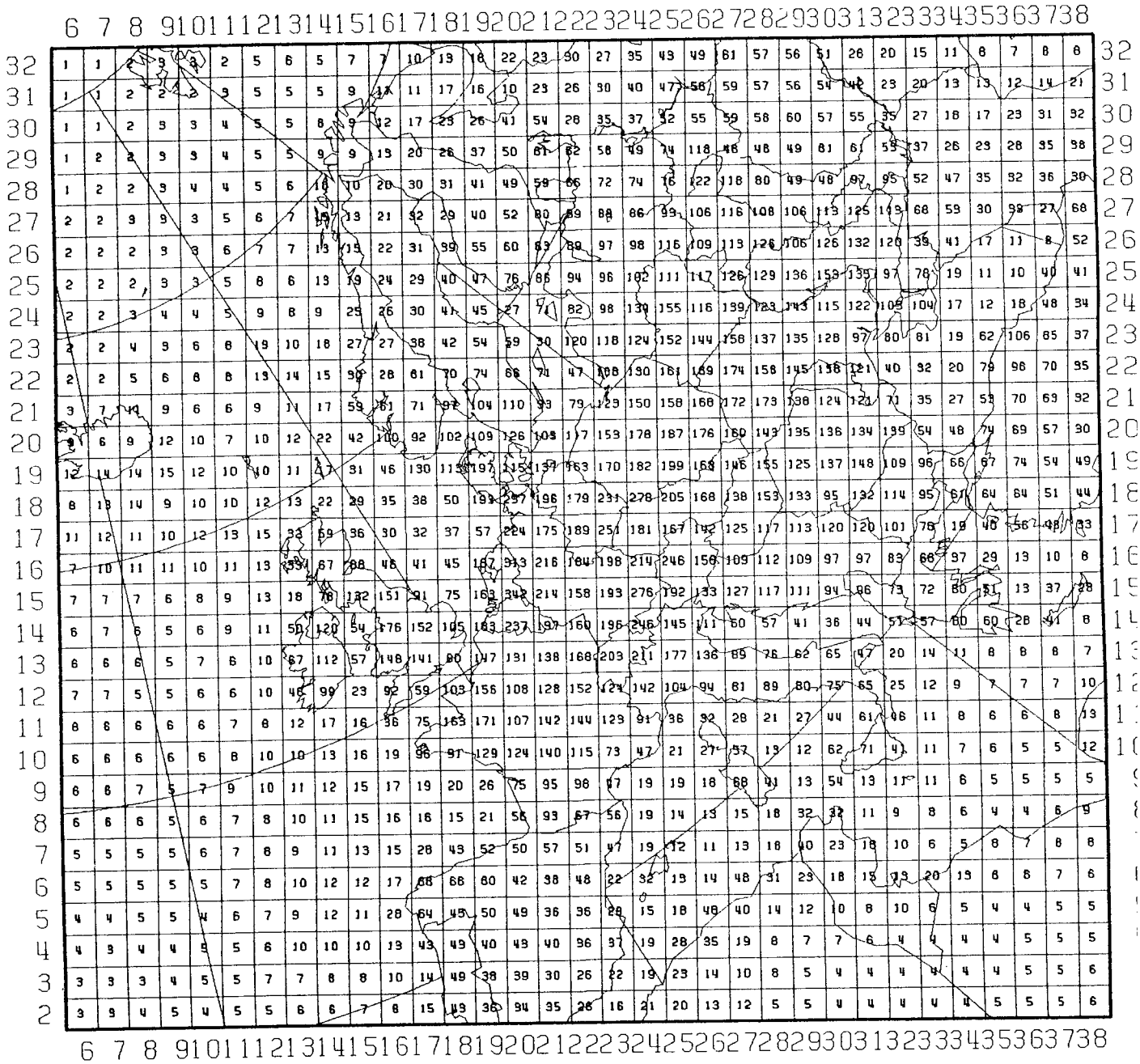
TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
INATTRIBUTABLE CONTRIBUTIONS - IND
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



TOTAL DEP. OF OXIDIZED NITROGEN (MG/M2 AS N)
GRAND TOTAL (ALL CONTRIBUTIONS) - TOT
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



TOTAL DEP. OF REDUCED NITROGEN (MG/M2 AS N)
GRAND TOTAL (ALL CONTRIBUTIONS) - TOT
THE WHOLE YEAR - 1988, EMEP/MSC-W NOX-MODEL



TOTAL DEPOSITION OF NITROGEN (MG/M2 AS N)
GRAND TOTAL (ALL CONTRIBUTIONS) - TOT
THE WHOLE YEAR - 1988. EMEP/MSC-W NOX-MODEL