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TRANSATLANTIC SULPHUR TRANSPORT.
PRELIMINARY ESTIMATES FROM A
THREE-DIMENSIONAL EULERIAN MODEL

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I INTRODUCTION

In recent years a number of studies on pollutant transport on the continental and intercontinental scale have emerged. Efforts have been made to evaluate the influence of anthropogenic emissions throughout the different continents. One problem of particular interest to the countries situated along the West coast of Europe is the deposition of sulphur of North American origin in these areas. The present investigation considers this question in the context of the three-dimensional global circulation of the atmosphere. The model employed resolves the troposphere into ten different height levels (vertical tropospheric analysis) and covers a major part of the Northern hemisphere. Some preliminary results are given in the following. It is expected that the investigation, when completed, may shed some light on the problem of unattributable or "background" sulphur deposition.

II THE "BACKGROUND" SULPHUR DEPOSITION

"Background" is the term traditionally used to designate the concentration or deposition of pollution of indeterminate or inattributable origin (EMEP, 1988). When one attempts to attribute sulphur deposition in Europe to contributions from different source areas, one discovers that in North and West Europe dispersion models will systematically underestimate sulphur concentrations, and in particular the concentration of sulphate in precipitation. In this sense, the "background" sulphur is introduced into model calculations in order to obviate a systematic underestimation.

A study of the background should make it possible to distinguish between: "anthropogenic intercontinental background" and "natural sources background". The anthropogenic intercontinental background needs to be connected to the atmospheric general circulation and the global distribution of anthropogenic source areas in order to be coherently explained. This can be done for example by using a global circulation model. Based upon the

anthropogenic emission values in different continents, this type of model can evaluate the influence of such emissions in any selected receptor area: for instance, the influence of North American emissions at the West coast of Europe.

The oceans, volcanoes and areas of dense vegetation are natural sources of sulphur. These emitting areas are also unevenly distributed over the globe and their emission intensities vary with time. A full description of the "background" concentrations would pass through the evaluation of these natural sources. Unfortunately, but understandable, no detailed reliable surveys of natural emitting areas are available for the moment.

In the present model, therefore, anthropogenic emissions are handled explicitly, and the very small constant "background" concentrations are assumed to originate only from natural sources. (see end of next section).

III THE MODEL

An Eulerian multilayer model of long-range transport is used for this global analysis. The model was developed at the Norwegian Institute for Air Research by Iversen (1987). Air concentrations of sulphur dioxide (SO_2) and sulphate (SO_4) are calculated throughout the whole northern hemisphere and at ten different heights. It uses an Eulerian grid of 300 x 300 km.

Entropy (measured as potential temperature, θ) is used as the vertical coordinate. The reason for this choice is that the change of entropy is generally a slow process in large scale atmospheric flows, so that the motion to a good approximation takes place in surfaces of constant θ . Errors associated with vertical and horizontal advection are therefore reduced.

Horizontal and vertical advection are calculated by an anti-diffusively corrected up-wind scheme (Smolarkiewicz, 1983).

The model calculates dry and wet deposition of sulphur and treats the sulphur chemistry as a linear oxidation process (Eliassen and Saltbones, 1983).

The northern hemispheric anthropogenic emissions are grouped in four main regions. Those are: (1) Europe and European part of the USSR, (2) USSR, (3) North America, (4) Far East. The values of the emissions are taken from the SO₂ emission survey of Semb (1985).

Natural source surveys are not available at the moment. The natural emission influence is taken into account through a constant "background" concentration, corresponding to the concentrations in air in absence of anthropogenic emissions. The assumed values are: 0.03 µg/m³ for sulphur dioxide and 0.05 µg/m³ for particulate sulphate.

IV PRELIMINARY RESULTS

The model has been tested on meteorological data for January 1983 to evaluate the influence of American emissions into the European west coast. The particular meteorological conditions of this month (strong westerly winds) favour the transatlantic transport of pollutants and make it a suitable period for qualitative testings. Results so far strongly suggest that the sulphur deposition in Europe due to North American sources is geographically unevenly distributed with a probable maximum in NW Europe.

The typical meteorological conditions in the North-Atlantic, with strong westerlies and the confluence of air associated with the quasi-permanent Icelandic lows, channels the polluted air towards Britain, Scandinavia and the Arctic regions. These same areas exhibit the highest percentage of background sulphur conditions (EMEP, 1983). The mechanism described above can only be taken into account by a full three-dimensional dispersion model.

As expected, the North American sulphur reaching the West coast of Europe is present mainly as particulate sulphate. At 40 m height, the sulphate concentration in air due to North American sources averaged over January 1983 is $0.1-0.02 \mu\text{g}/\text{m}^3 = 0.08 \mu/\text{m}^3$ in Norway. (To arrive at this value, note that Figures 4 and 5 show the sum of concentrations due to North American sources and a constant "background" of $0.05 \mu\text{g}/\text{m}^3$, see end of Section III). The corresponding SO_2 -concentrations are about $0.01 \mu\text{g}/\text{m}^3$. (Figures 2 and 3 show the sum of concentrations due to North American sources and a constant ambient "background" of $0.03 \mu/\text{m}^3$, see end of Section III).

The accumulated January 1983 total (wet + dry) deposition of sulphur from North American sources varies significantly along the West coast of Europe (see Figure 1), with high values turning up in Scotland and Western Norway. The total deposition in Norway due to these sources is about 1500 tonnes S. This can be compared to the deposition in Norway due to all European sources, estimated at about 10000 tonnes S.

For the same period, the EMEP sulphur model gives a deposition in Norway due to European sources of only 4400 tonnes S. This discrepancy probably arises because the EMEP model only follows the sulphur for 96 hours, sulphur travelling longer being "lost" by the model. In January 1983, the meteorological situation was characterized by a predominating westerly airflow towards Norway from the Atlantic ocean, with few cases of direct transport from the central European emission areas. This situation will maximize the errors caused by ignoring transport of more than four days duration.

Another difficulty is that the Eulerian multi-layer model generates its own precipitation amounts from its relative humidity and vertical velocity fields, whereas the EMEP model works with observed precipitation data over land, where such data are available. In this particular case, the rainfall of Eulerian model was considerably smaller than the observed data of the EMEP

model. At the present stage it is not possible to correct the Eulerian model results for the underestimate of precipitation amounts in any consistent way. Nevertheless it seems highly probable that the 1500 tonnes of deposition to Norway from North American sources is a considerable underestimate, implying the possibility that a significant part of the background or unattributable sulphur deposition predicted by the EMEP model in Norway (in this case as large as 15100 tonnes S) and other countries along the West coast of Europe, can be explained by these sources. More accurate estimates cannot be made before the Eulerian model has been improved with respect to precipitation and wet deposition, however. This work is now under way.

V CONCLUSIONS

Although these results should only be considered qualitatively, they demonstrate that a significant part of the hitherto unattributed sulphur deposition in Europe might well be of North American origin. The deposition of North American sulphur will vary over Europe in a way governed by the general circulation of the atmosphere. There is an obvious possibility that this deposition will be concentrated more in Northwest Europe than elsewhere, because of the confluence of trajectories often associated with the westerly airflow across the North Atlantic. It is further demonstrated how necessary three-dimensional dispersion models are in the study of intercontinental air pollution transport.

VI REFERENCES

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- Semb, A. (1985). Circumpolar SO₂ emission survey. NILU-OR 69/85. 14 pp.
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- Figure 1: Accumulated total deposition due to North American sources. Averaged over January 1983.
- Figure 2: Averaged sulphur dioxide (SO_2) concentrations in air ($\mu\text{g}/\text{m}^3$) at 40 m height, due to North American sources. Concentrations are averaged over January 1983. Note that an ambient "background" concentration of $0.03 \mu\text{g}/\text{m}^3$ has been added (see end of Section III).
- Figure 3: Averaged sulphur dioxide (SO_2) concentrations in air ($\mu\text{g}/\text{m}^3$) at 5000 m height, due to North American sources. Concentrations are averaged over January 1983. Note that an ambient "background" concentration of $0.03 \mu\text{g}/\text{m}^3$ has been added (see end of Section III).
- Figure 4: Averaged sulphate (SO_4) concentrations in air at 40 m height due to North American sources. Concentrations are averaged over January 1983. Note that an ambient "background" concentration of $0.05 \mu\text{g}/\text{m}^3$ has been added (see end of Section III).
- Figure 5: Averaged sulphate (SO_4) concentrations in air at 5000 m height due to North American sources. Concentrations are averaged over January 1983. Note that an ambient "background" concentration of $0.05 \mu\text{g}/\text{m}^2$ has been added (see end of Section III).

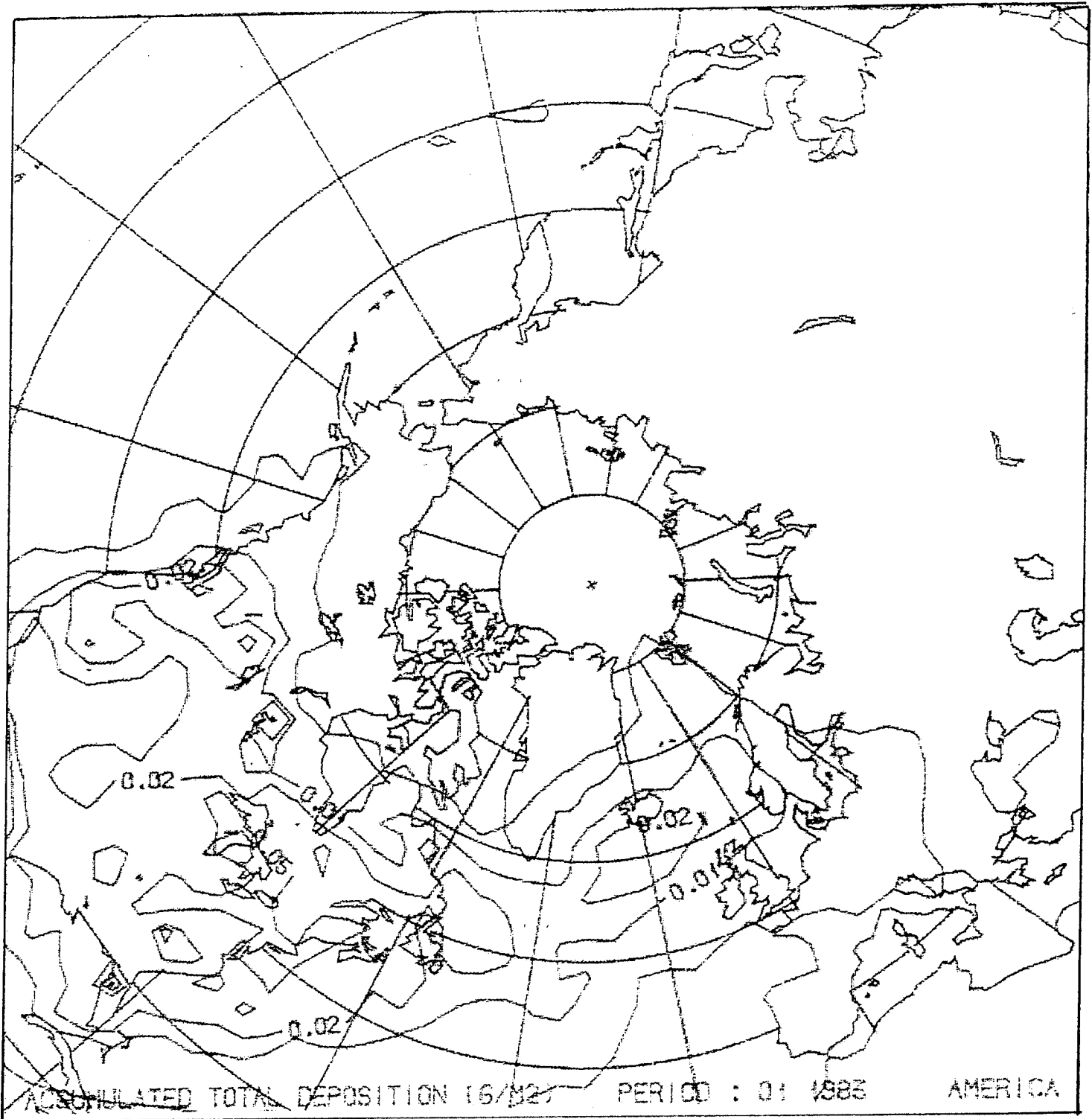


Figure 1.

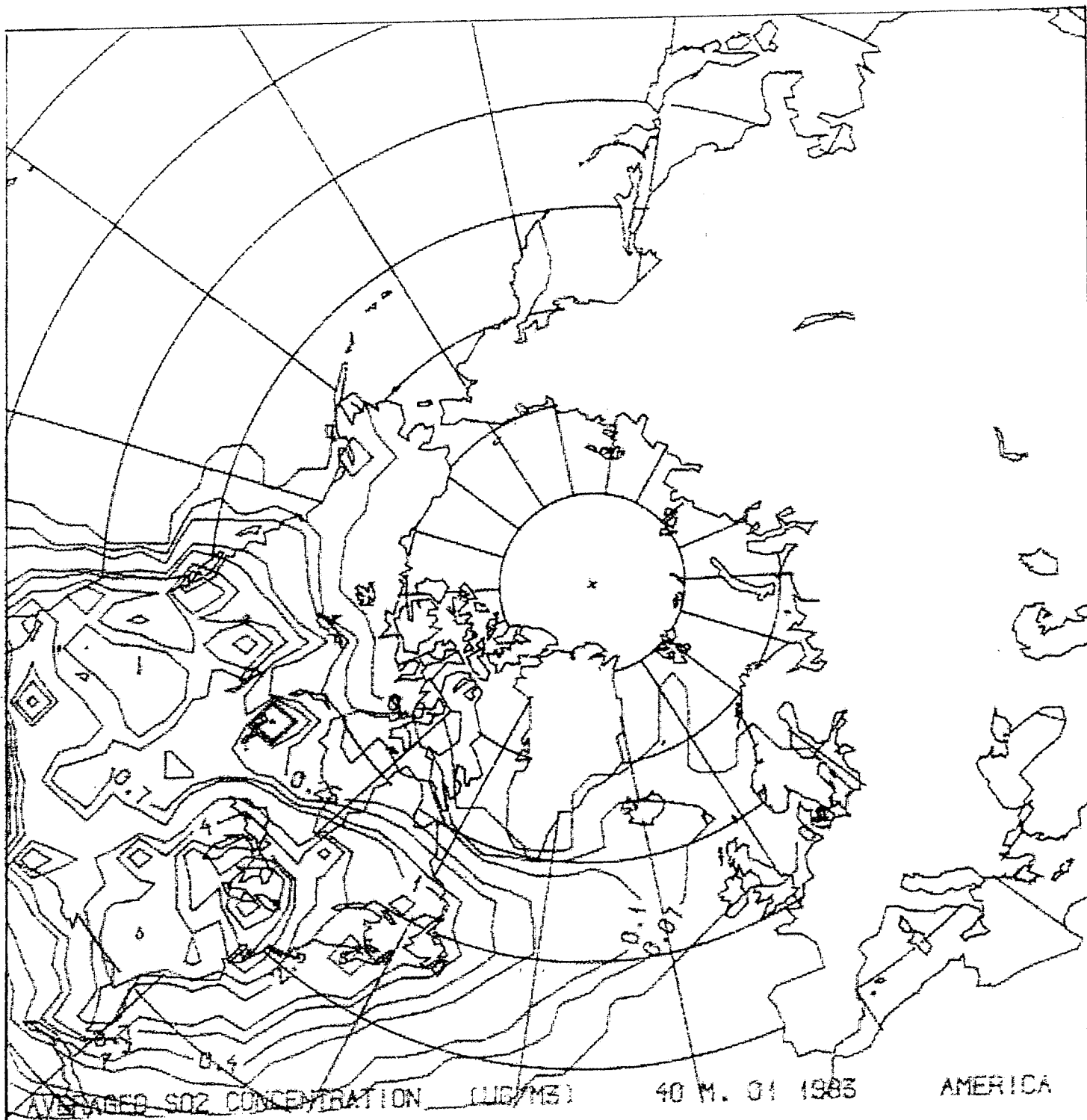


Figure 2.

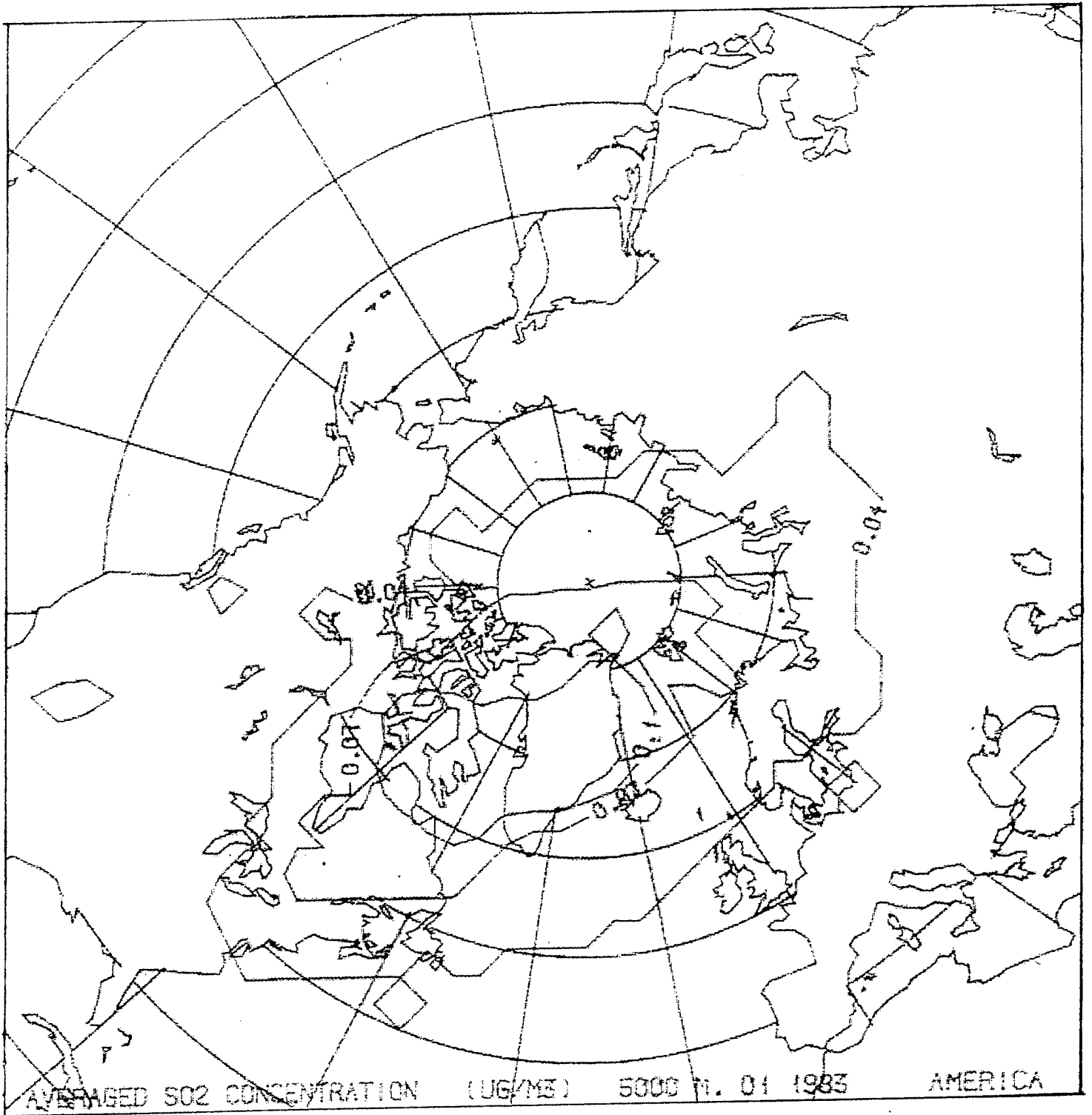


Figure 3.

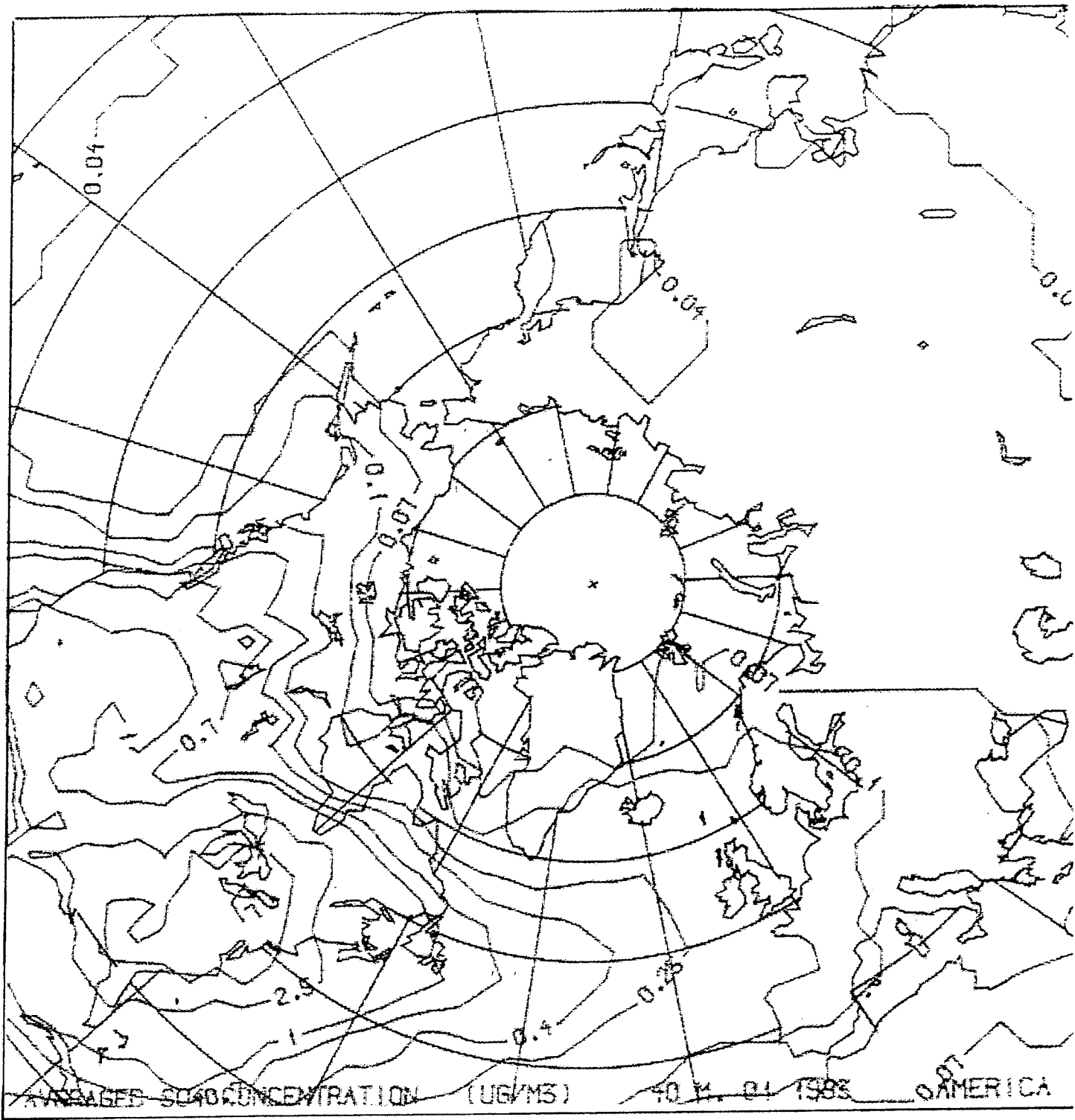


Figure 4.

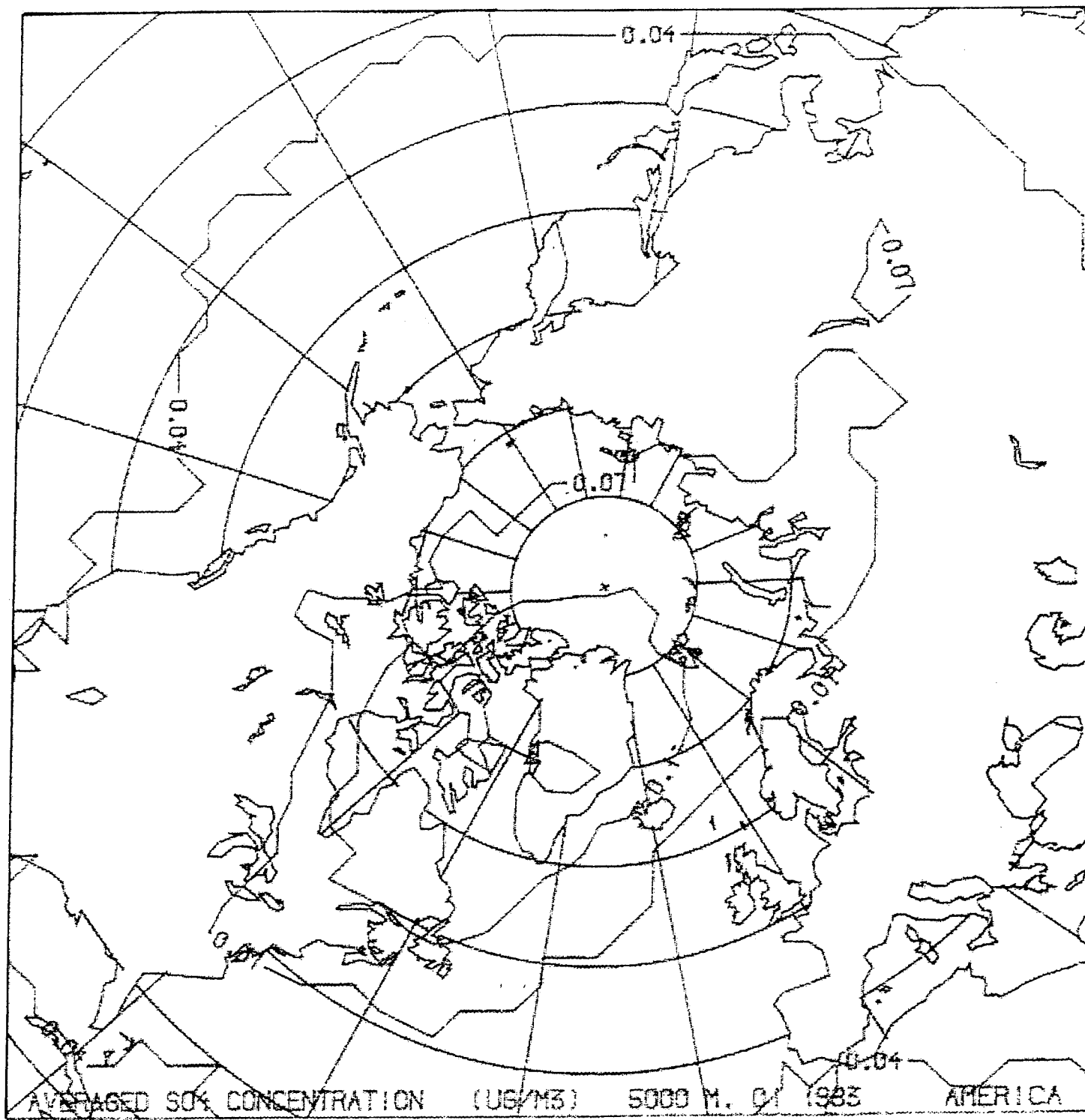


Figure 5.