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Prepared for the U.S. Department of Energy
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PREFACE

This document reports the results of dose calculations from the Chernobyl reactor accident in April 1986. The calculations were completed in 1987. The results are now being published to disseminate the information to an audience of potential users.

SUMMARY

Radioactive material released on April 26 and 27, 1986, as a result of the Chernobyl nuclear reactor accident was detected throughout eastern and western Europe. This study's objective was to model the transport path of material released during April 26 and 27, the first 48 h of the accident. Since work in this report was completed during May 1986 immediately after the accident, preliminary information on release conditions and available meteorological data were used.

The transport path was determined from trajectories computed using the Multi-Layer Air Mass (MLAM) meteorological transport model, developed to model air mass movement on a meso-alpha to synoptic scale. The path traveled was indicated by displaying the surface footprint resulting from trajectories, located within 1000 m of surface, passing over an area. Additional information on transport path is given for material transported above 1000 m.

The trajectory surface footprints predict that the initial release on April 26, 1986, at 1:23 a.m. LST, moved north-northwest into Finland and Sweden. The surface footprints compare well with observations of radioactivity in Finland. A front was intercepted in southern Finland causing large-scale vertical motions and resulting in the plume being transported above 1000 m, including portions above 3000 m. This prediction was confirmed by aircraft measurements. Material released later on April 26 also moved northwest initially but on subsequent transport days remained within 1000 m of the surface and traveled west over Poland and central Europe. The transport path for material released on April 27 gradually switched from northwest to south and then southeast, affecting the southern portion of eastern Europe.

CONTENTS

FIGURES

1.0 INTRODUCTION

The objective of this study was to estimate the transport (how and where) of radioactive material released on April 26 and 27, 1986, during the Chernobyl nuclear reactor accident. The study was initiated because, although radioactivity was detected in eastern and western Europe, the data did not provide a clear understanding of the transport path between Chernobyl and available measurement sites. Therefore, shortly after the accident occurred this study was initiated to predict the transfer of material released during the accident's first 48 hours. The Multi-Layer Air Mass (MLAM) meteorological 3-D transport model was used to compute trajectory paths because MLAM incorporates redistribution of a plume caused by vertical mixing in a multi-layer framework. MLAM was chosen because the initial analysis of meteorological data indicated that atmospheric conditions over Europe involved vertical mixing as well as vertical movement.

A brief description of the MLAM model is given in the next section, followed by a description of the input data and model assumptions specific to the Chernobyl application. Then, the model results are presented along with a limited comparison to observations from Finland. The report concludes with a discussion of the study results and their limitations and context.

2.0 MLAM MODEL

MLAM is a multi-layer air mass model designed to transport and disperse a nondepositing tracer in three dimensions over meso-alpha and synoptic scales. The model is based in part on an earlier model developed by Davis (1983) for use in acid rain research (Davis and Glantz 1986).

A Lagrangian puff model, MLAM releases puffs at one or more sources and advects and disperses the puffs in hourly time steps. Transport in three dimensions is based on gridded fields of potential temperature, winds, and mixing ratios. Up to nine vertical layers, with depths selectable for each application, are used to incorporate vertical motion of a puff based on differences in potential temperature. For this study nine layers were used (100 to 500, 500 to 1000, 1000 to 1500, 1500 to 2000, 2000 to 2500, 2500 to 3000, 3000 to 4000, 4000 to 5000, and 5000 to 6000 m). During periods of atmospheric mixing, the model vertically redistributes, in a manner similar to that described by Draxler and Taylor (1982), the mass of a puff into multiple layers. The height over which the vertical redistribution occurs is computed from the maximum daily mixing height with an assumed daily sinusoidal curve. Redistribution for this study may occur twice per day, at 1:00 p.m. and 4:00 p.m. LST, during the first 4 days after a puff release. Although concentration calculations are not included in this study, the model uses standard horizontal and vertical Gaussian diffusion in conjunction with an air-mass screening procedure to predict surface concentrations. Air-mass screening uses the difference between hourly surface potential temperature and the potential temperature associated with the puff to limit the physical extent of diffusion to the surface.

3.0 METEOROLOGICAL DATA AND RADIONUCLIDE RELEASE ASSUMPTIONS

Meteorological surface and upper-air sounding data were obtained from the DATSAV (USAF ETAC 1977) data base maintained at Patrick Air Force Base. Data obtained from Lawrence Livermore National Laboratory and Weather Service International were used to supplement data missing for the western USSR and eastern Europe for the reporting time of 00Z on April 26. Wind, potential temperature, and mixing height fields were gridded at 00Z and 12Z from April 25 to May 5 for the region depicted in Figure 1. The meteorological data were the best available at the time the study was performed. Some of the upper-air sounding data above 1500 m are missing for 00Z on April 26.

Modeling the transport path of material released during the first 48 h after the accident required knowledge of the release height over time. Only limited information was available to aid in selecting an appropriate release height. Calculation of surface concentrations for each radionuclide released required, in addition, relative amounts of material with height and time.

The release of material was assumed to be from a vertical line source above the reactor. The line source release was assumed because of the thermodynamic structure of the atmosphere near the source at the time of release. To be compatible with the layers selected for the model, nine release points were used for the vertical line source: 300, 750, 1250, 1750, 2250, 2750, 3500, 4500, and 5500 m. For hourly released puffs on April 26, all nine release heights were applied, i.e., nine individual puffs were released each hour. On April 27, only the lower two release heights (300 and 750 m) were used. In the MLAM model results presented, information from individual release heights is collapsed into categories. For example, the 100- to 3000-m release category includes trajectories with initial release heights from 300 to 2750 m above the source.

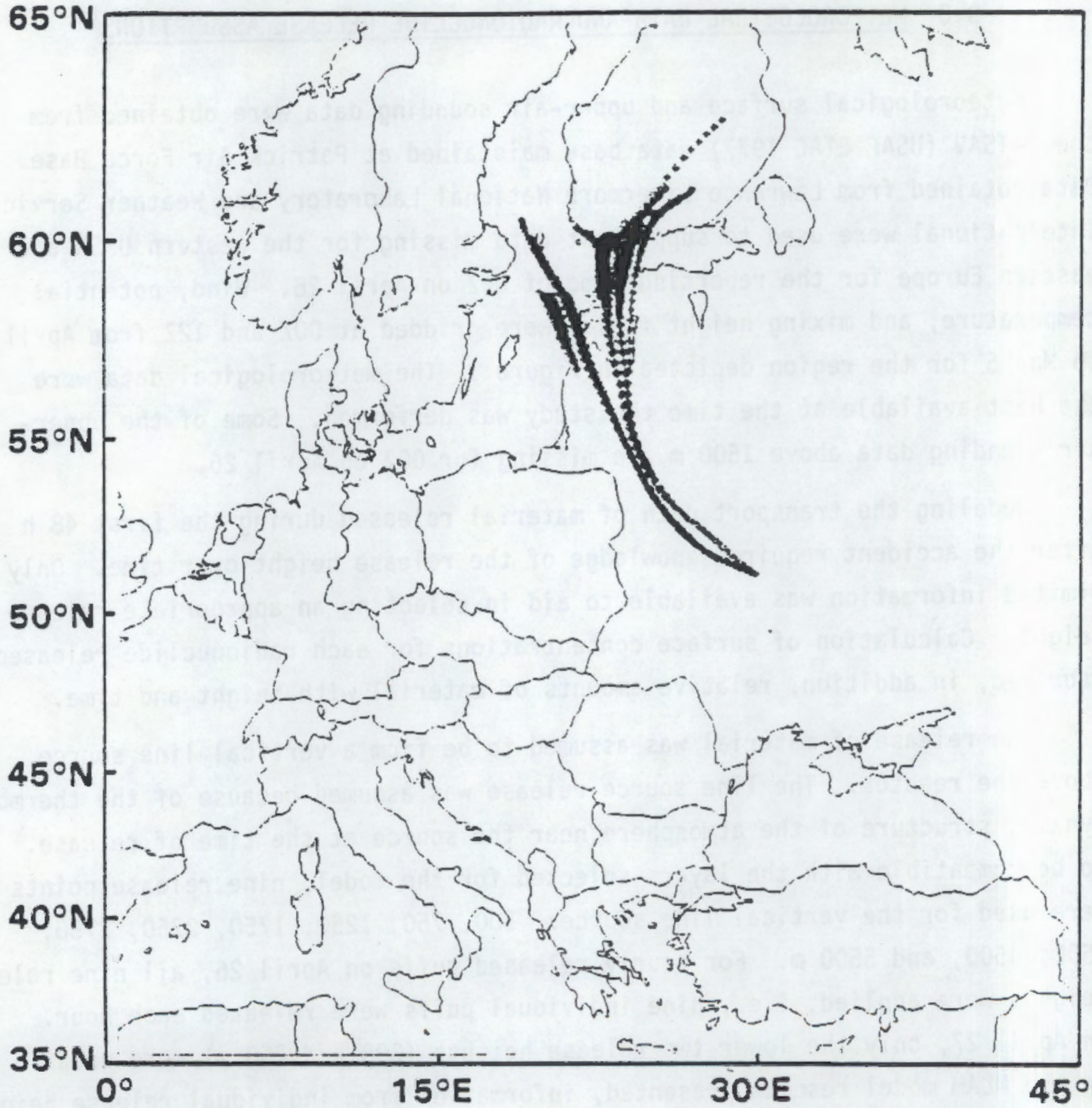

FIGURE 1. Surface Footprint for April 26 to May 5 Transport from 00Z April 26 Chernobyl Release (100 to 3000 m)

4.0 TRANSPORT PATH RESULTS

To illustrate how and where the material released was transported, individual trajectory paths for each puff released and transported by MLAM are examined. Since the location of each puff is known for each hour after release, the puff transport path can be determined by plotting these locations on a map of the geographic area. The projection of the puff locations onto a surface map is termed a surface footprint. The paths, and consequently the surface footprints, represent the predicted centerline of transport and do not give any information on the extent of diffusion, surface concentration, or deposition of material. No information is given on predicted surface or upper-air concentrations or surface depositions.

4.1 SURFACE FOOTPRINTS

Although MLAM released puffs hourly for the first 48 h after the accident, surface footprint plots are presented for only eight time periods beginning at 00Z on April 26 and at 6-h intervals thereafter. It is assumed that the 00Z, April 26, release represents the transport path of material released during the first hour of the accident. To emphasize the transport paths that might be expected to impact the surface, the surface footprints display only those portions of the trajectory paths that are within 1000 m of the surface during transport. Because of MLAM's ability to incorporate vertical motion and redistribution of a puff, a surface footprint can include puffs whose initial release height is greater than 1000 m or exclude portions of a single puff trajectory if vertical motion causes the puff to be transported above 1000 m.

Surface footprints from puffs released at 00Z, 06Z, 12Z, and 18Z on April 26 are given in Figures 1 through 4. In each case the footprint includes the trajectory path from the time of initial release until 12Z on May 5, as long as the path remained in the geographic area covered by the plot. The multiple paths are caused by the line source release heights and redistribution of puffs through vertical mixing. At 00Z (Figure 1), the path initially starts west to northwest and then turns north toward the southern tip of Finland and southeastern part of Sweden. Arrival at Finland occurs about 48 h after

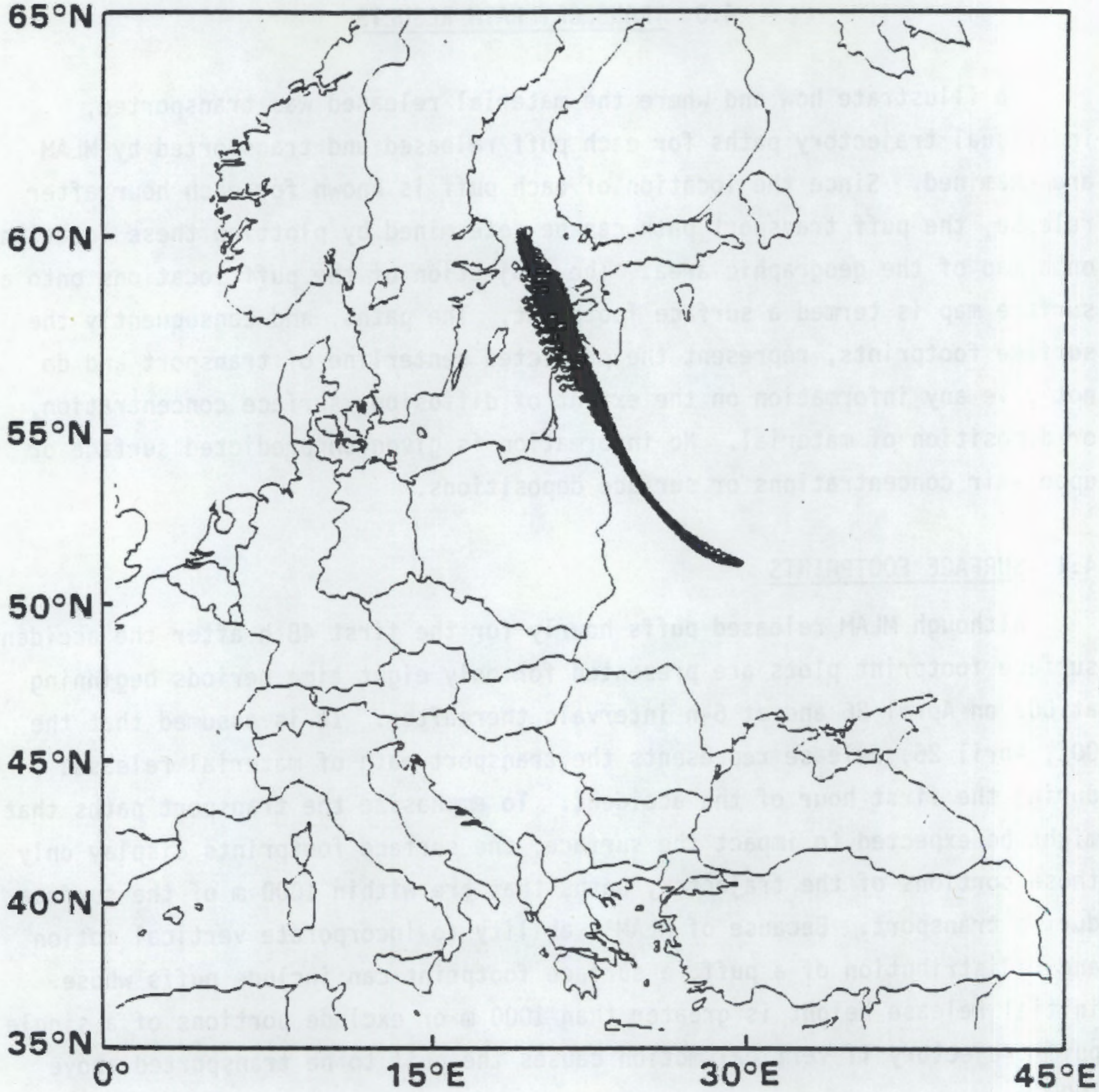

FIGURE 2. Surface Footprint for April 26 to May 5 Transport from 06Z April 26 Chernobyl Release (100 to 3000 m)

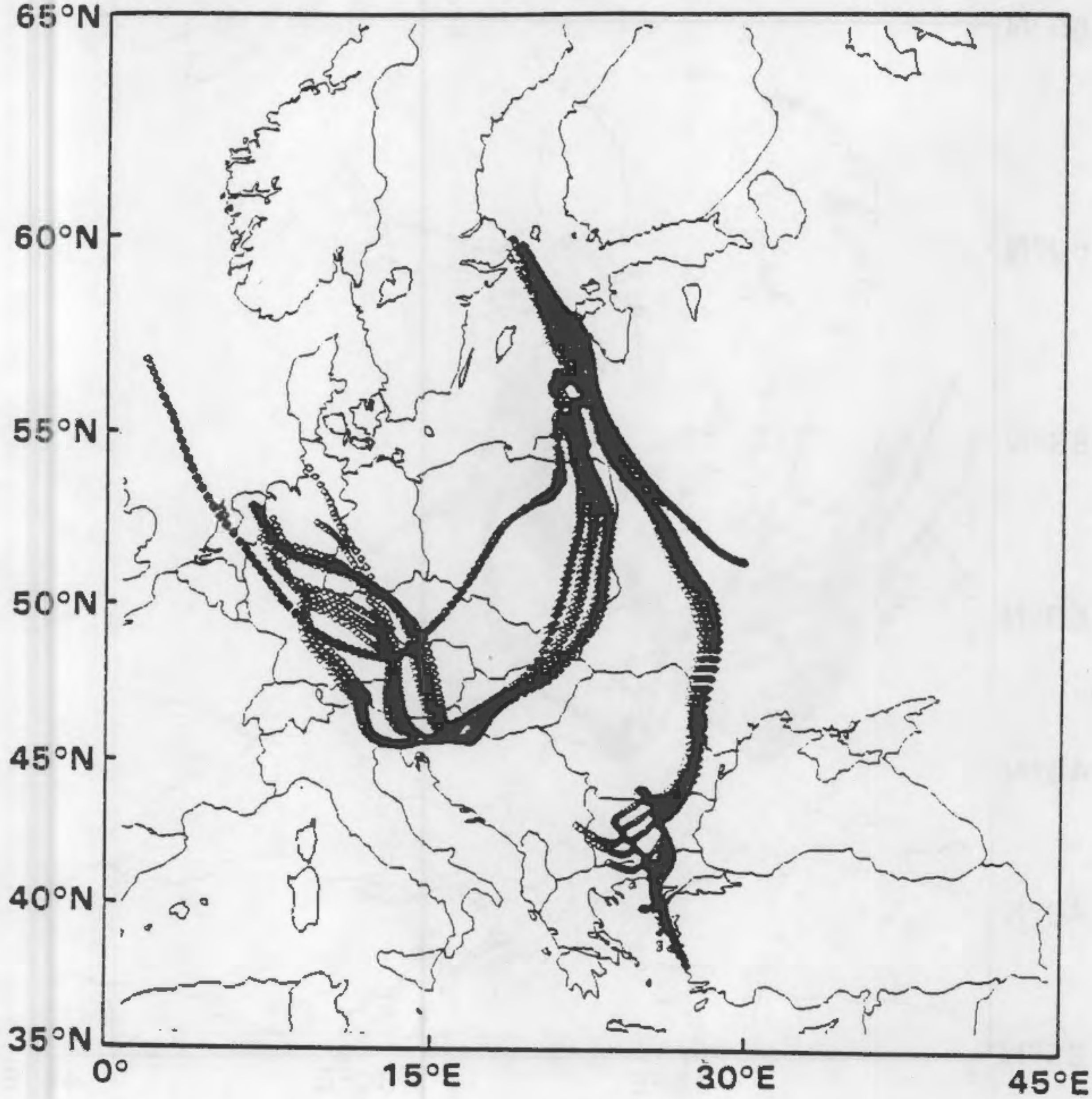

FIGURE 3. Surface Footprint for April 26 to May 5 Transport from 12Z April 26 Chernobyl Release (100 to 3000 m)

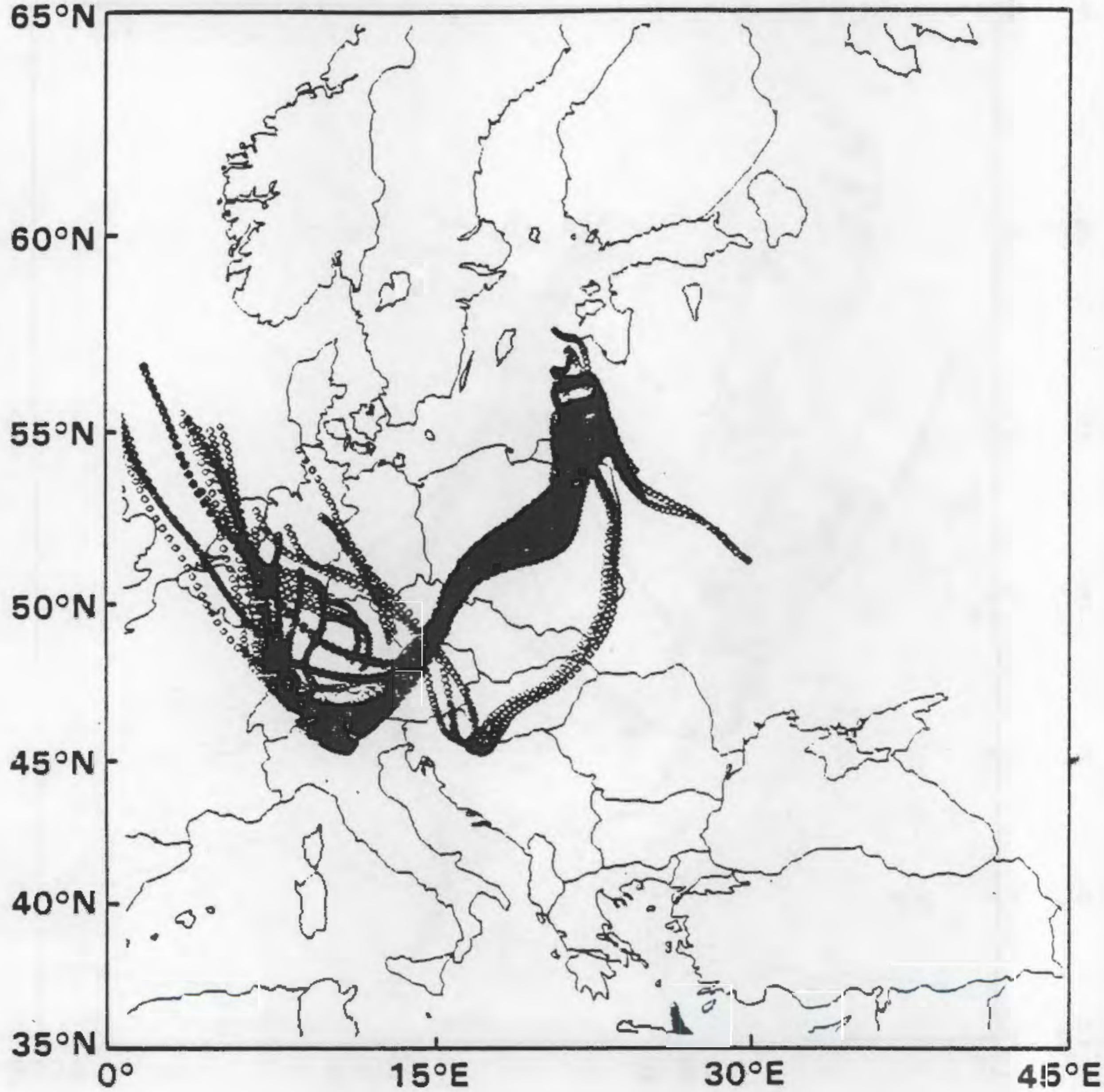

FIGURE 4. Surface Footprint for April 26 to May 5 Transport from 18Z April 26 Chernobyl Release (100 to 3000 m)

release. Absence of a surface footprint farther north than shown indicates large-scale vertical motion over a front, which lofted the puff above 1000 m. A similar, though less complicated pattern, occurs for puffs released at 06Z (Figure 2). At 12Z (Figure 3), the surface footprint shows the transport path initially to the northwest as before, but then a portion of the path turns to the south over Poland continuing over Austria to West Germany. The other portion turns southeast traveling over Romania and Bulgaria. In this case the material remains within 1000 m of the surface during most of the transport path. At 18Z (Figure 4), the transport path extends northwest for 24 h and then turns southwest over Poland continuing to Switzerland and then turns north toward Belgium.

In Figures 5 to 8, surface footprints for 00Z, 06Z, 12Z, and 18Z on April 27 show the transport path from the time of initial puff release until 12Z on April 30. The release heights on April 27 are only at 300 and 750 m, i.e., between 100 and 1000 m. The sequence of figures for April 27 illustrates the changing meteorological conditions influencing the transport path of the material. At 00Z (Figure 5), the path initial goes northwest to the border of Poland and then turns southwest and reaches Switzerland on April 30. The subsequent transport path is not illustrated because the MLAM model run ended on April 30. A similar pattern is observed for the 06Z release (Figure 6). In Figure 7, the 12Z surface footprint shows a complicated pattern. Immediately after release, sufficient vertical mixing occurred to redistribute the puff into several lower layers. In the presence of wind shear, portions of the material were transported west and southwest, while the remainder traveled south and southeast. By 18Z (Figure 8), the footprint traveled due east and then turned south toward the eastern end of the Black Sea. The 12Z and 18Z footprints indicate that vertical motion, with possible precipitation, may have lofted the plume above 1000 m due south of Chernobyl. Further analysis is required to verify this hypothesis.

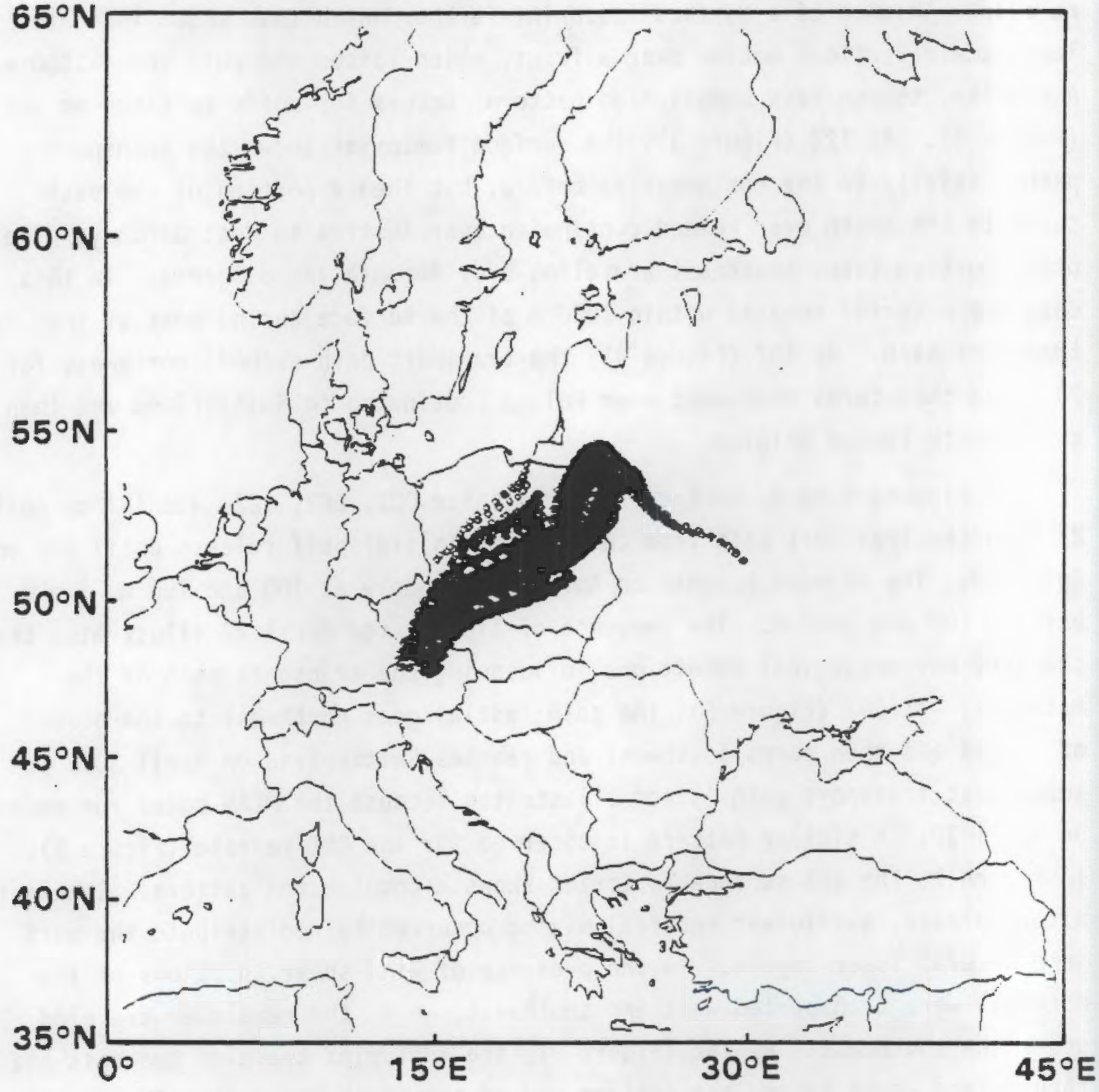

FIGURE 5. Surface Footprint for April 27 to April 30 Transport from 00Z April 27 Chernobyl Release (100 to 3000 m)

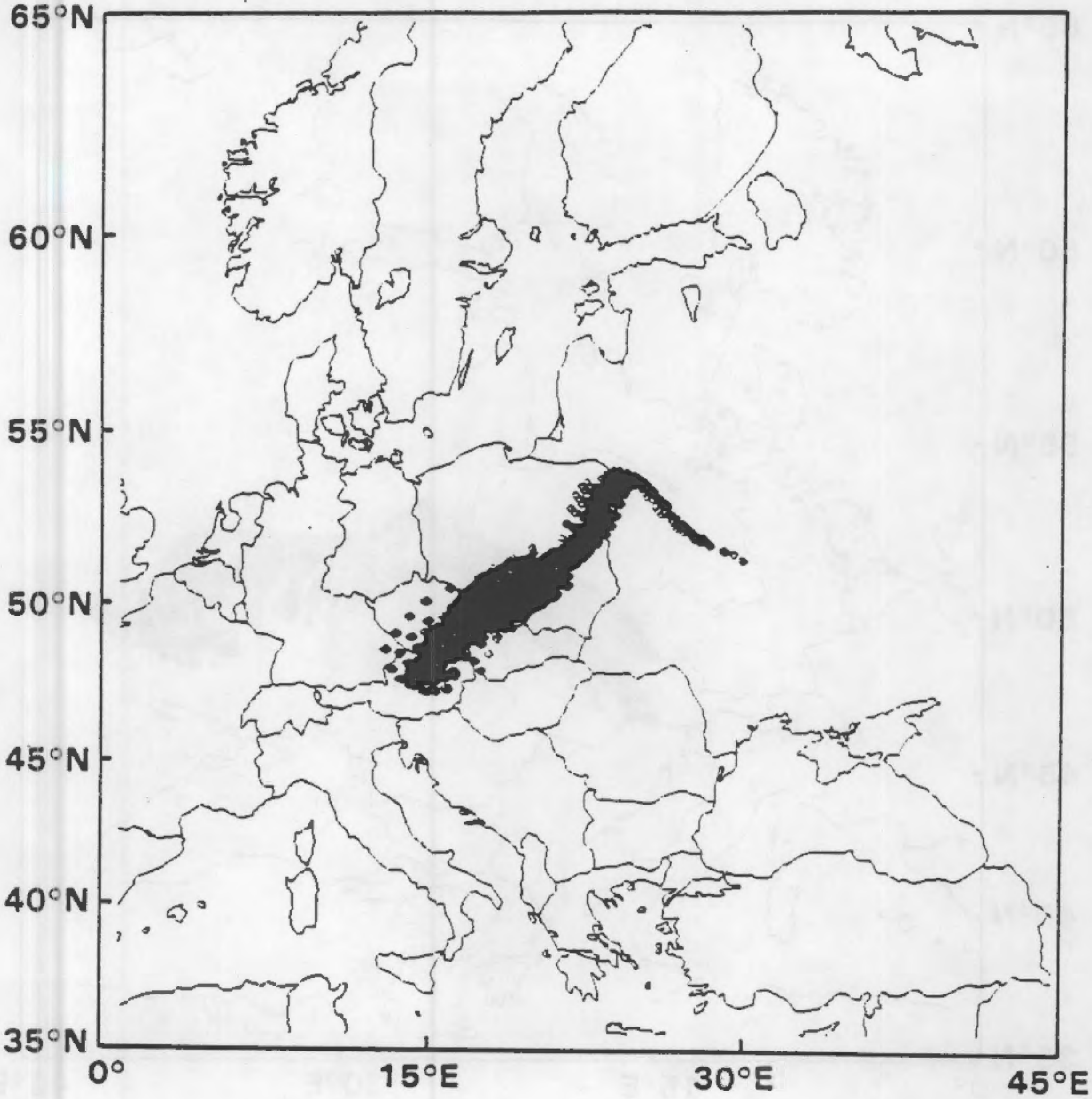

FIGURE 6. Surface Footprint for April 27 to April 30 Transport from 06Z April 27 Chernobyl Release (100 to 3000 m)

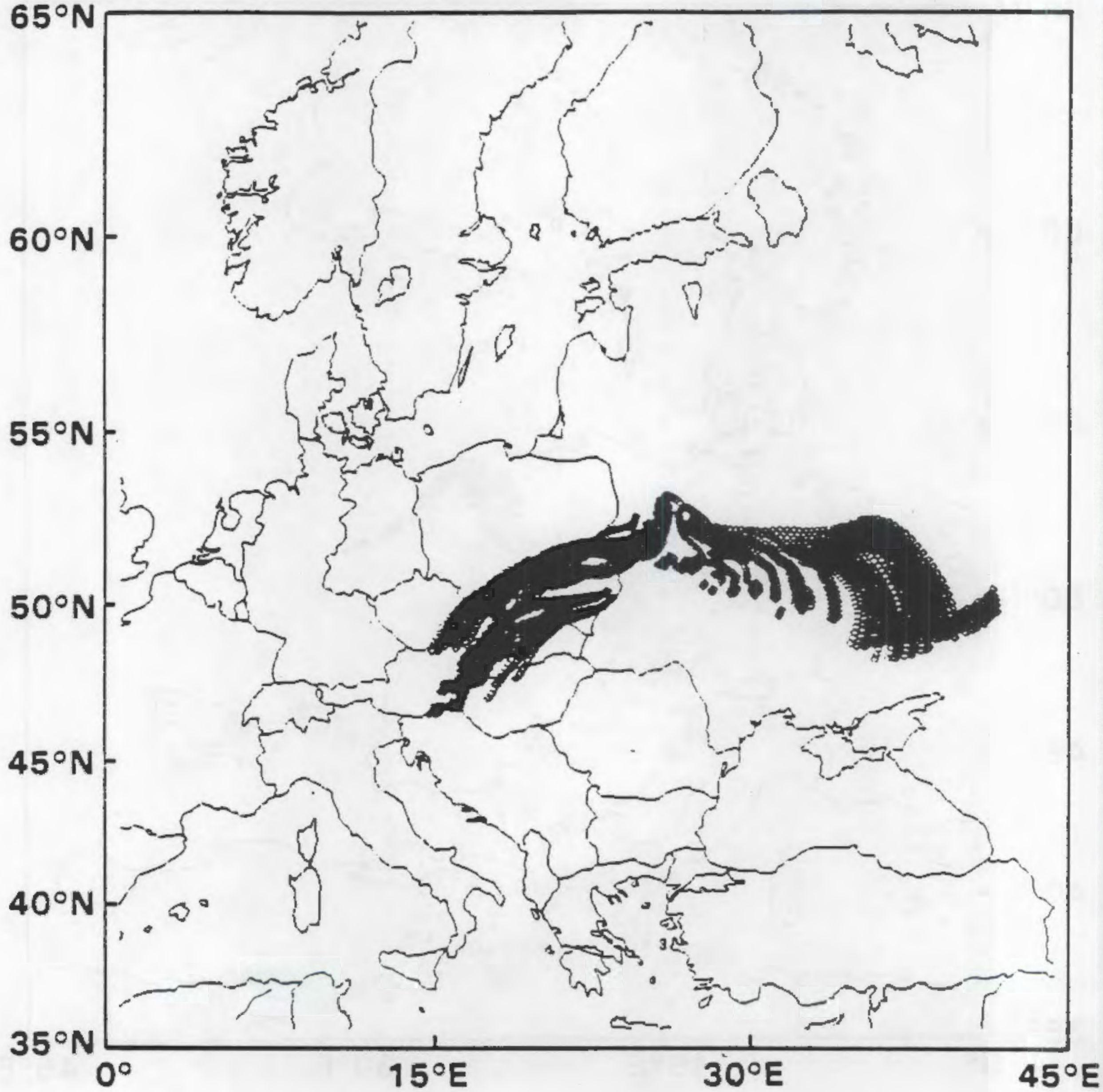

FIGURE 7. Surface Footprint for April 27 to April 30 Transport from 12Z April 27 Chernobyl Release (100 to 3000 m)

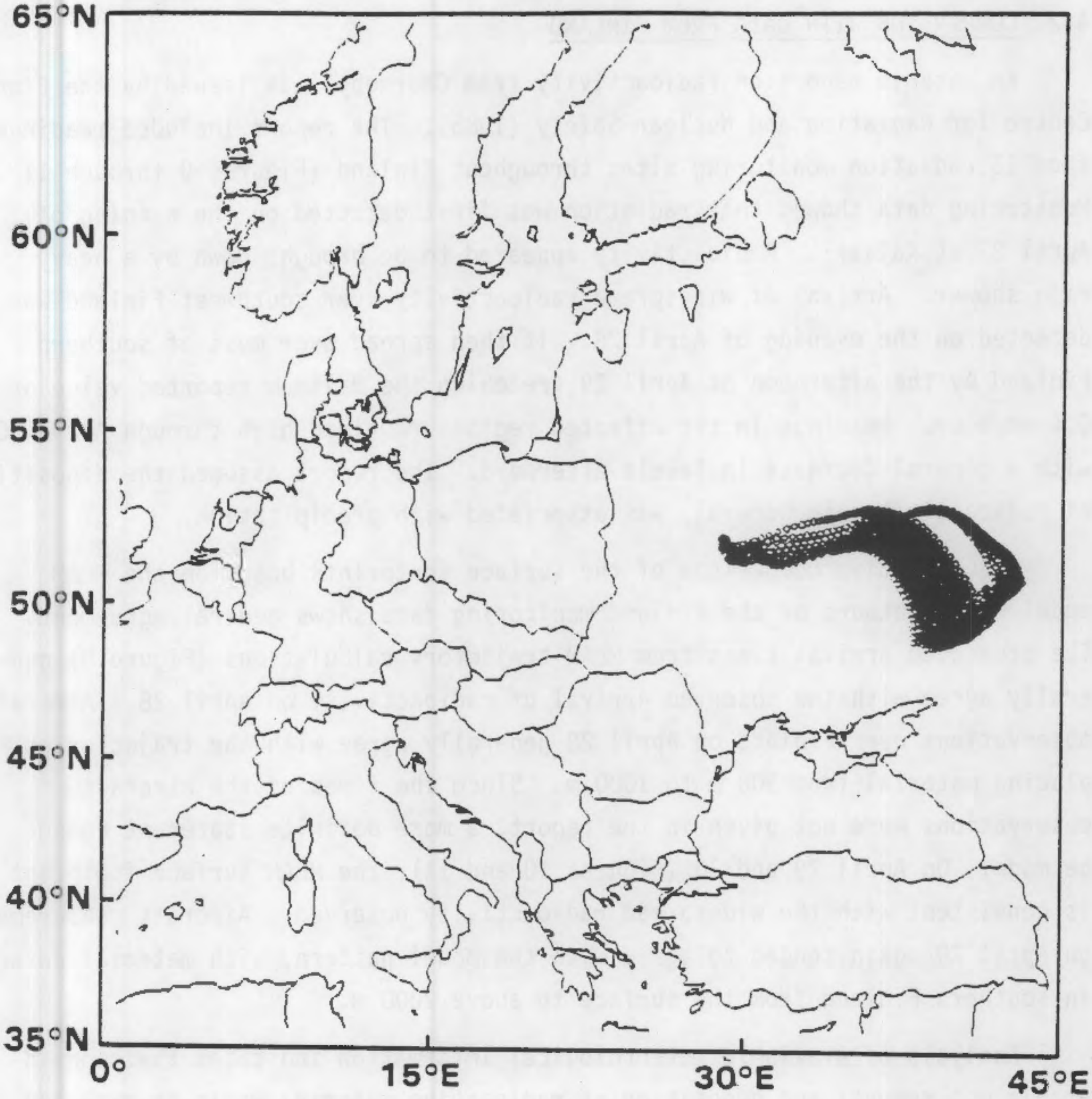

FIGURE 8. Surface Footprint for April 27 to April 30 Transport from 18Z April 27 Chernobyl Release (100 to 3000 m)

4.2 COMPARISON WITH DATA FROM FINLAND

An interim report on radioactivity from Chernobyl was issued by the Finnish Centre for Radiation and Nuclear Safety (1986). The report included readings from 13 radiation monitoring sites throughout Finland (Figures 9 through 11). Monitoring data showed that radiation was first detected on the evening of April 27 at Kajaari. Radioactivity appeared to be brought down by a heavy rain shower. Arrival of widespread radioactivity over southwest Finland was detected on the evening of April 28. It then spread over most of southern Finland by the afternoon of April 29, reaching the maximum reported value of 0.4 mR/hour. Readings in the affected regions remained high through April 30, with a general decrease in levels afterward. The report assumed the deposition of radioactivity, in general, was associated with precipitation.

A qualitative comparison of the surface footprints based on the MLAM model with contours of the Finland monitoring data shows general agreement. The predicted arrival times from MLAM trajectory calculations (Figure 9) generally agree with the observed arrival of radioactivity on April 28. Aircraft observations over Finland on April 28 generally agree with the trajectories placing material from 500 m to 1000 m. Since the times of the aircraft observations were not given in the report, a more definite statement cannot be made. On April 29 and 30 (Figures 10 and 11), the MLAM surface footprint is consistent with the widespread radioactivity observed. Aircraft measurements on April 29 again tended to agree with the model pattern, with material detected in southern Finland from the surface to above 2000 m.

Analysis of available meteorological information indicates that considerable wet removal and deposition of radioactive material would be expected. The Finnish Centre report notes appreciable precipitation occurred from April 26 to May 2. From April 26 to 28, the rain appeared to be showers in the south, with continuous rain near central Finland. From April 29 to May 1, widespread rain occurred. The coincidence of plume passage and shower activity would result in substantial wet deposition of radioactive material. The Finnish Centre report states that maximum radiation levels were observed where rain occurred.

Since only trajectory paths were predicted by MLAM model, it is not possible to make a direct comparison on wet deposition. However, vertical

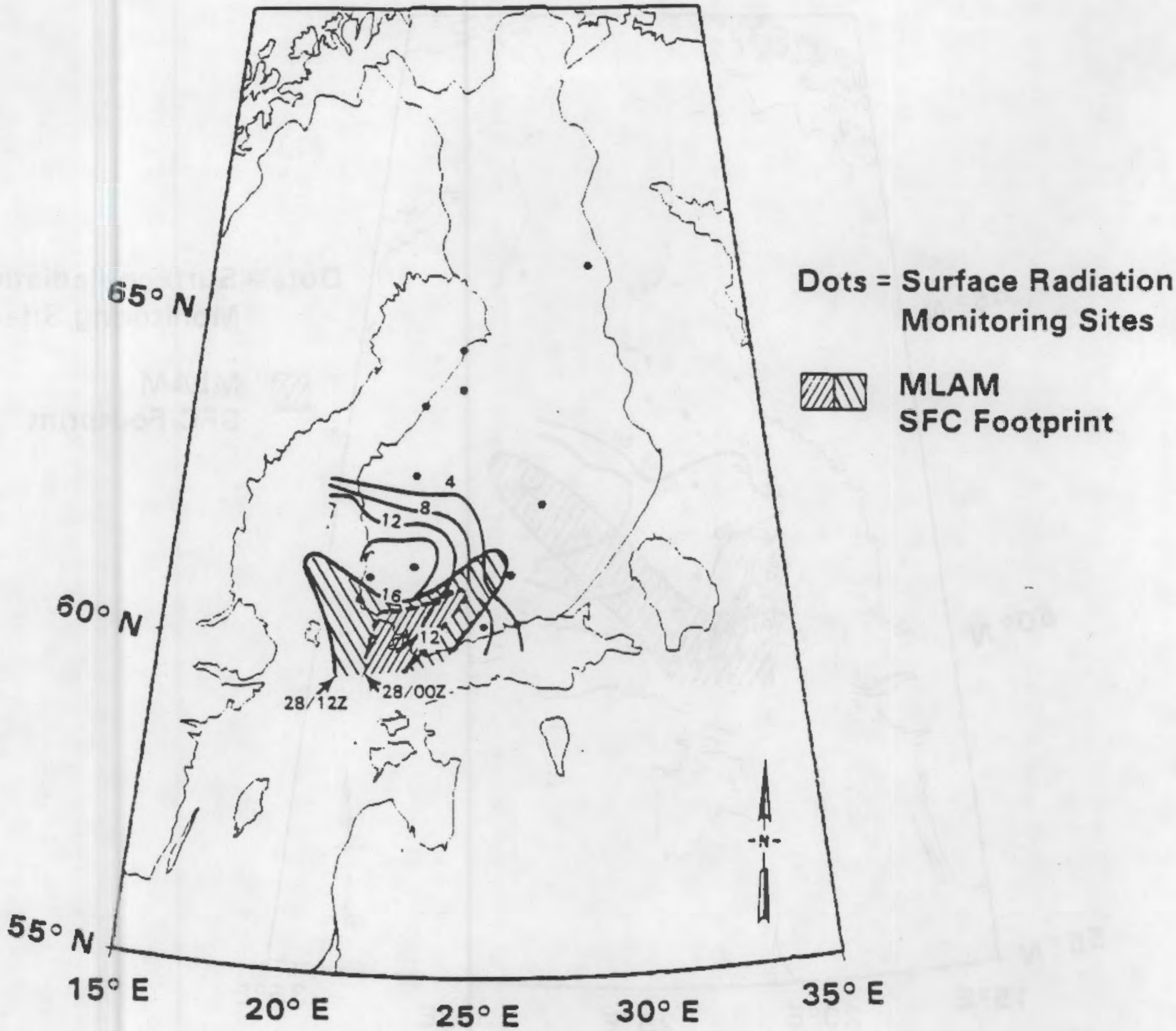

FIGURE 9. Contours of Observed Radioactivity (mR/h) in Finland on April 28, 1986, with Overlay of Predicted MLAM Surface Footprint

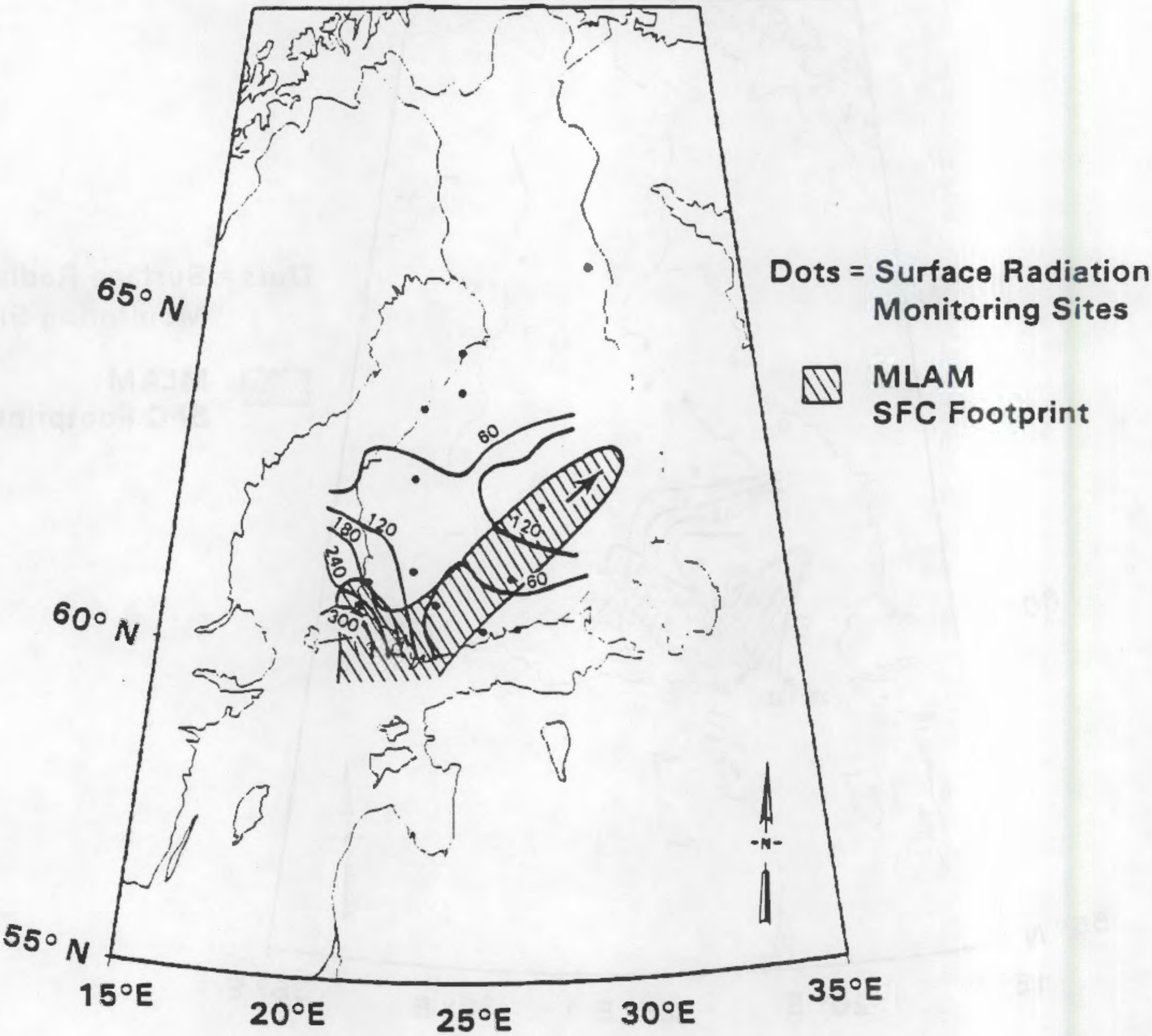

FIGURE 10. Contours of Observed Radioactivity (mR/h) in Finland on April 29, 1986, with Overlay of Predicted MLAM Surface Footprint

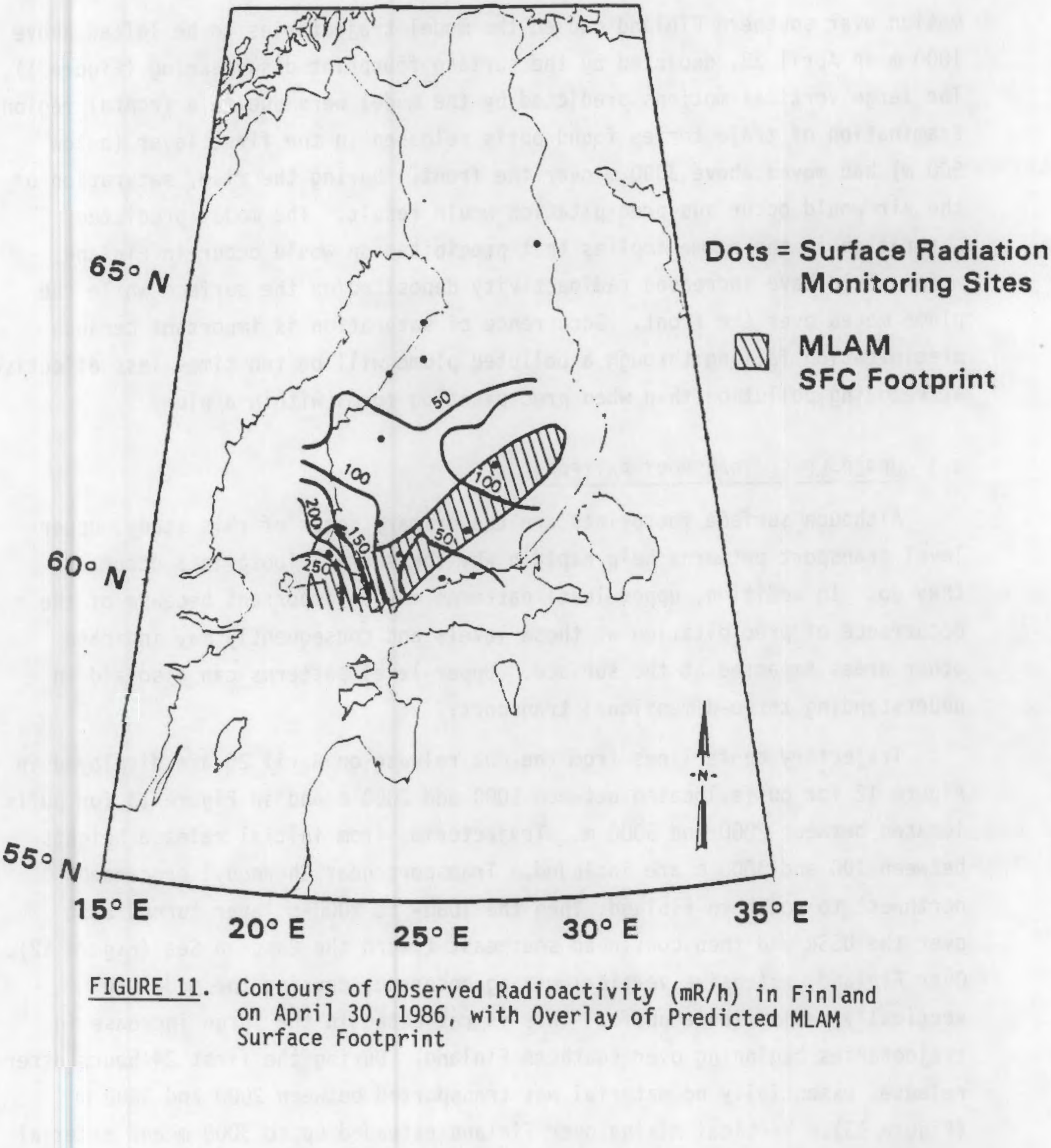

FIGURE 11. Contours of Observed Radioactivity (mR/h) in Finland on April 30, 1986, with Overlay of Predicted MLAM Surface Footprint

motion over southern Finland caused the model trajectories to be lofted above 1000 m on April 28, depicted by the surface footprint disappearing (Figure 1). The large vertical motions predicted by the model were due to a frontal region. Examination of trajectories found puffs released in the first layer (below 500 m) had moved above 3000 m over the front. During the rise, saturation of the air would occur and precipitation would result. The model-predicted saturation in the plume implies that precipitation would occur in Finland, which would have increased radioactivity deposited on the surface while the plume moved over the front. Occurrence of saturation is important because precipitation falling through a polluted plume will be ten times less effective at removing pollution than when precipitation forms within a plume.

4.3 UPPER-LEVEL TRANSPORT PATTERNS

Although surface footprints are the primary focus of this study, upper-level transport patterns help explain why the surface footprints occur as they do. In addition, upper-level patterns may be important because of the occurrence of precipitation at those levels and consequently may indicate other areas impacted at the surface. Upper-level patterns can also aid in understanding three-dimensional transport.

Trajectory centerlines from the 00Z release on April 26 are displayed in Figure 12 for puffs located between 1000 and 2000 m and in Figure 13 for puffs located between 2000 and 3000 m. Trajectories from initial release heights between 100 and 3000 m are included. Transport near Chernobyl proceeded northwest to southern Finland, then the 1000- to 2000-m layer turned east over the USSR and then continued southeast toward the Caspian Sea (Figure 12). Over Finland, extensive vertical mixing occurred, causing the model to vertically redistribute puffs. This is reflected in the large increase in trajectories beginning over southern Finland. During the first 24 hours after release, essentially no material was transported between 2000 and 3000 m (Figure 13). Vertical mixing over Finland extended up to 3000 m and material remained between 2000 to 3000 m to be transported along a path similar to the layers immediately below. However, material lofted earlier tended to move northeast and then continue east from Finland. Even the limited information

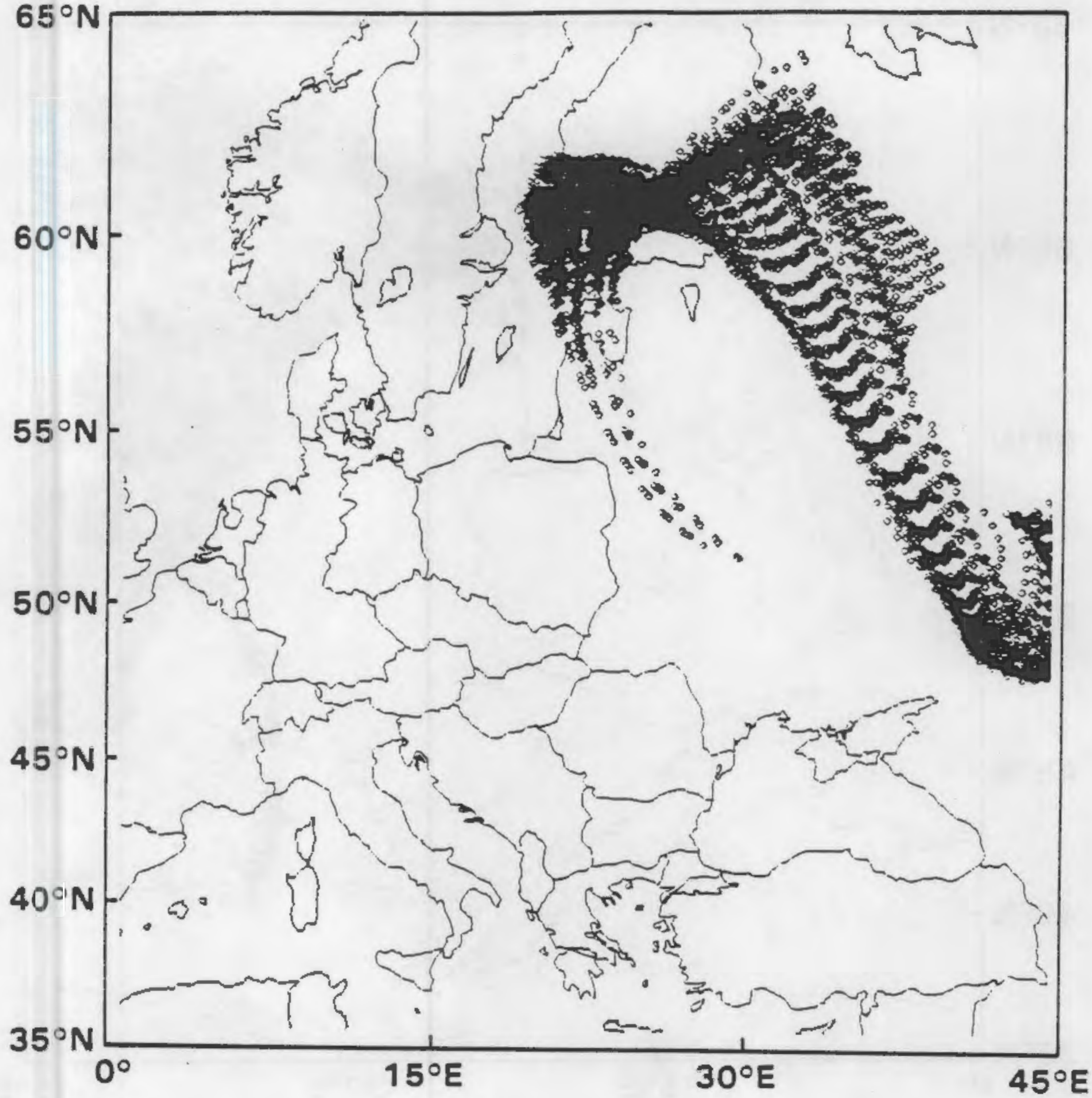

FIGURE 12. 1000-m to 2000-m Upper-Level Transport Pattern for April 26 to May 5 from 00Z April 26 Chernobyl Release (100 to 3000 m)

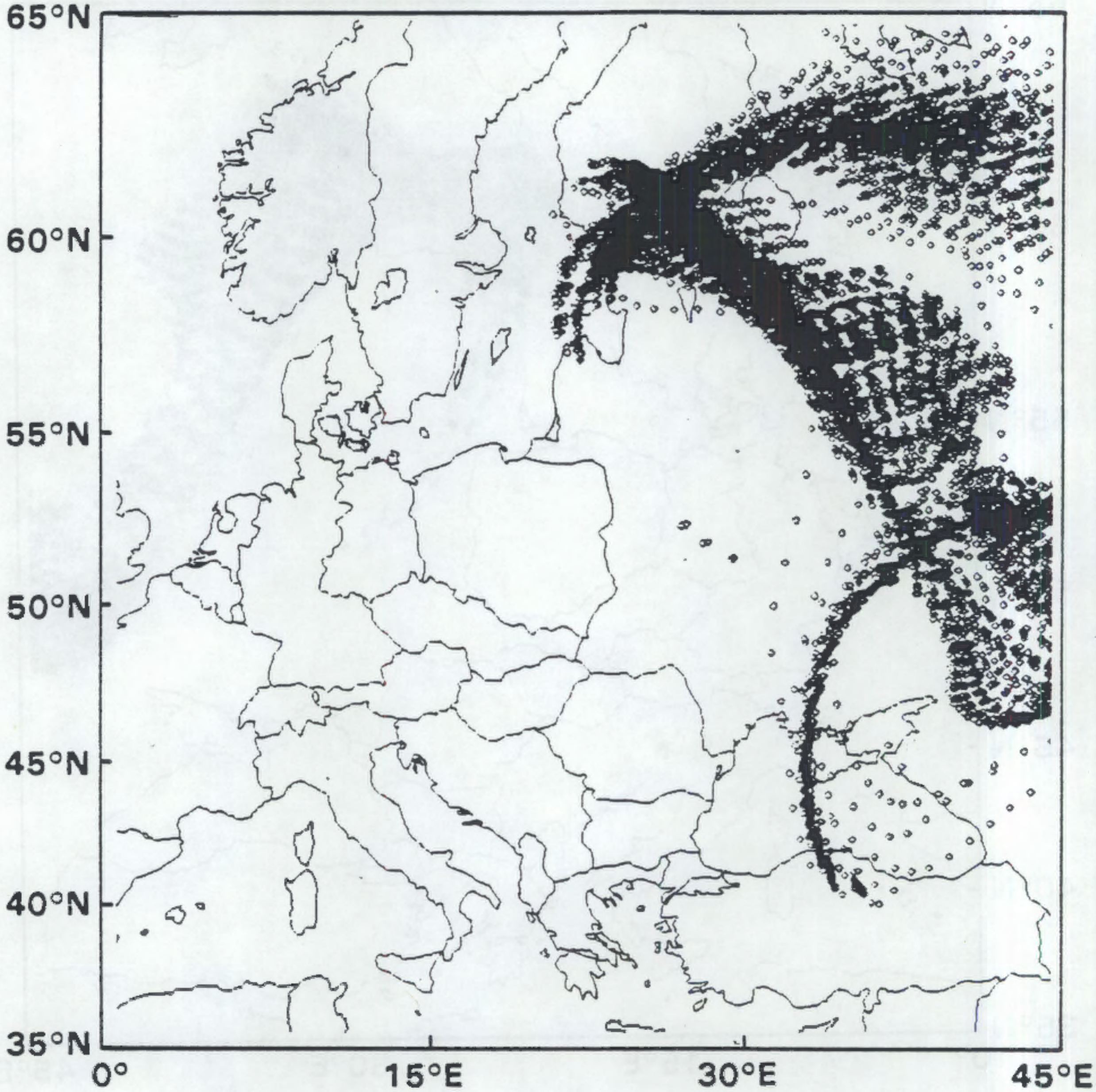

FIGURE 13. 2000-m to 3000-m Upper-Level Transport Pattern for April 26 to May 5 from 00Z April 26 Chernobyl Release (100 to 3000 m)

provided by Figures 1, 12, and 13 illustrates the complicated meteorological conditions encountered by the material released during the first hour of the accident.

Twelve hours later, the transport pattern for material between 1000 and 2000 m (Figure 14) and between 2000 and 3000 m (Figure 15) differed significantly from the first hour. The former layer proceeded northwest to the southwestern tip of Finland, turned south to northeastern Poland, and then diverged in all directions between southeast and southwest. The latter layer also proceeded northwest, but then predominantly moved southeast over the USSR. Over northeastern Poland, material in lower layers was vertically mixed above 2000 m and then was transported to the southeast as indicated by the model.

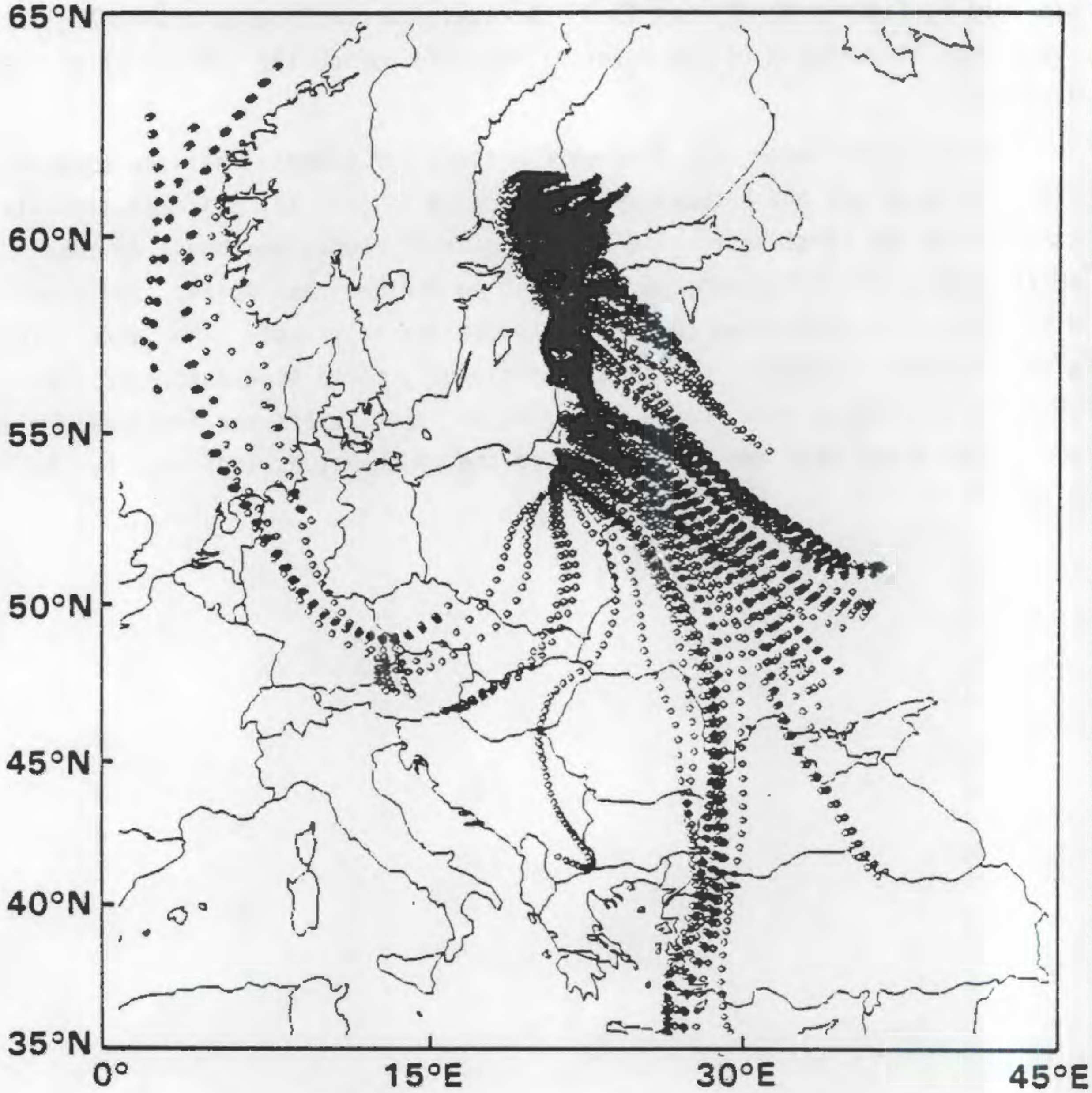

FIGURE 14. 1000-m to 2000-m Upper-Level Transport Pattern for April 26 to May 5 from 12Z April 26 Chernobyl Release (100 to 3000 m)

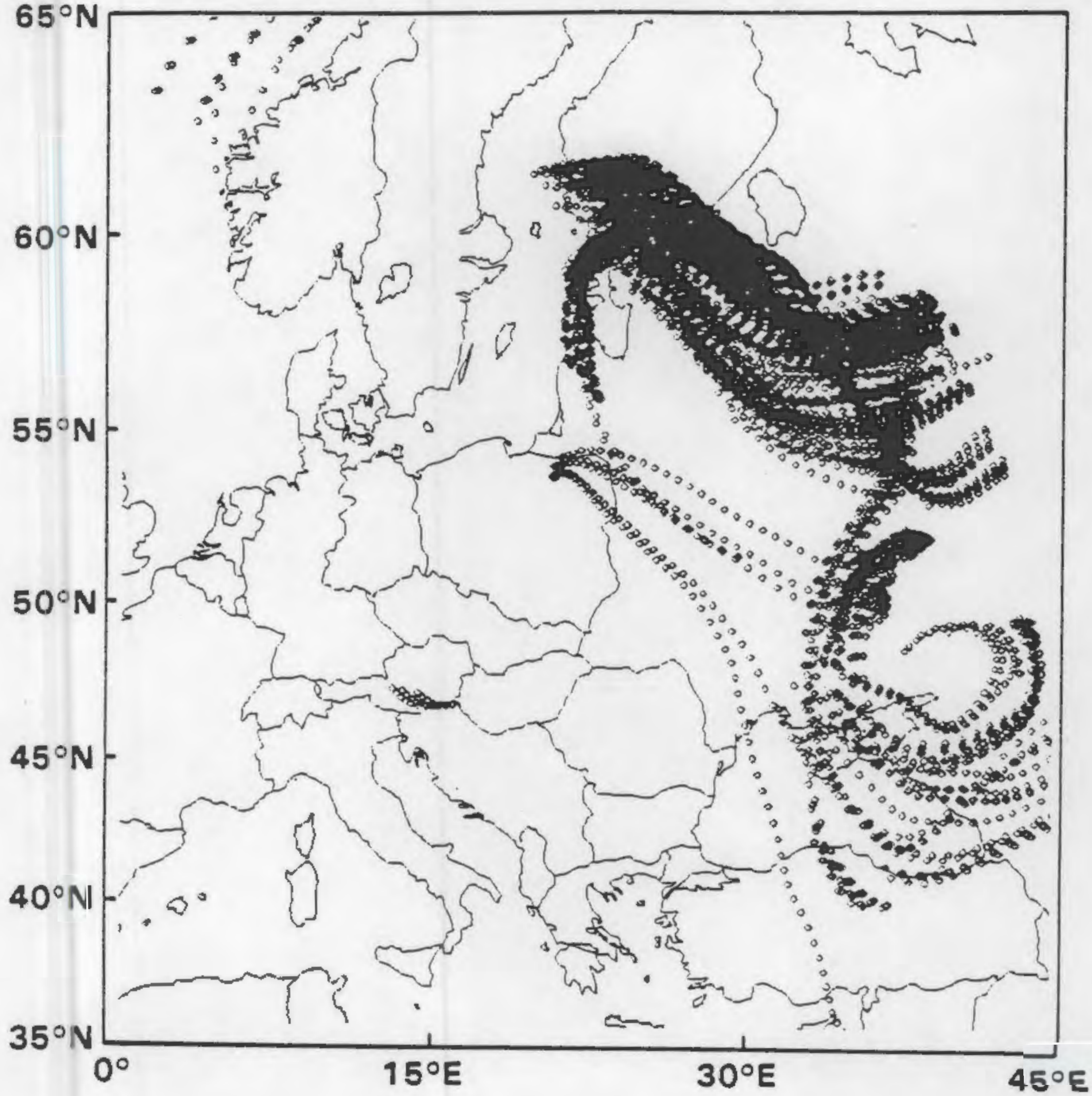

FIGURE 15. 2000-m to 3000-m Upper-Level Transport Pattern for April 26 to May 5 from 12Z April 26 Chernobyl Release (100 to 3000 m)

5.0 DISCUSSION

This study was undertaken immediately after the Chernobyl nuclear reactor accident with the objective to provide information on and understanding of the probable transport path of radioactive material released during the first 48 h after the accident. The approach taken, as a result of time and information constraints, was to calculate three-dimensional trajectory paths and their surface footprint. The study was limited by the lack of information on the release height over time of the material. Since the meteorological conditions within the first few days after the accident were complicated, the correct specification of the injection heights of the material was critical. No onsite meteorological data were available (Kiev and Gomel being nearest data), so knowledge of the initial transport was limited.

The meteorological conditions encountered along the transport path illustrate the necessity for a model to be able to handle complicated three-dimensional transport. Material appeared to be transported in multiple layers and encountered fronts causing material to be lofted vertically as well as vertically mixed (redistributed). After encountering these conditions, material was transported in diverse directions (as a result of wind shear) depending on the height of the material. Limited information on the occurrence and arrival of radioactivity in Europe, Japan, and the United States was consistent with the patterns derived from the MLAM trajectory model.

6.0 REFERENCES

Davis, W. E. 1983. "Preliminary Results of an Eight-Layer Regional Assessment Model Applied to the Problem of Acid Rain." In Energy and Environmental Chemistry, Vol. 2, Acid Rain, L. H. Keith, ed., Ann Arbor Science, Ann Arbor, Michigan.

Davis, W. E., and C. S. Glantz. 1986. "A Comparison of a Multi-Layer Regional-Scale Acid Rain Assessment Model (MLRAPT) with a Single-Layer Assessment Model (RAPT)." Water, Air and Soil Pollution 30:857-866.

Draxler, R. R., and A. D. Taylor. 1982. "Horizontal Dispersion Parameters for Long-Range Transport Modeling." J. of Applied Met. 21:367-372.

Finnish Centre for Radiation and Nuclear Safety. 1986. Interim Report on Fallout Situation in Finland from April 26 to May 4. FCRNS, Surveillance Department. STUK-B-VALO 44, ISSN 0781-2868, Library of Congress, Washington, D.C.

USAF Environmental Technical Applications Center. 1977. USAFETAC DATSAV Data Base Handbook, USAFETAC-TN-77-2, Scott Air Force Base, Illinois.

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