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Cm-Hysplit: A Software Capability for Response in Nuclear Emergencies

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Abstract – *The computational system Cm-Hysplit (Customized Meteorology-Hybrid Single Lagrangian Particle Integrated Trajectory) is presented. Cm-Hysplit is an extended version of the well-known atmospheric model Hysplit, that uses for the prediction of trajectories, dispersion, and deposition from atmospheric releases, the forecast meteorological fields generated by EMY (the Hellenic National Meteorological Service). The applicability of the system is illustrated considering the nuclear emergency exercise INEX-2-HUN of November 1998. The system is shown to meet satisfactorily the operational requirements of EEAE (the Greek Atomic Energy Commission) in nuclear emergency situations.*

Keywords: *Radioactive release, nuclear emergency, dispersion, deposition, Hysplit.*

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1. INTRODUCTION

The Greek Atomic Energy Commission (EEAE) has specific statutory responsibility to respond to the authorities and the public in the occurrence of an international nuclear emergency which may affect the territory of Greece. The assistance offered to the authorities by EEAE is intended to provide the capacity for the authorities to anticipate appropriate response actions and to predict the consequences of actions as they are taken. An emergency response team, the so-called "nuclear technology team", is deployed in case of an event to provide the necessary assistance to EEAE. The team has been officially appointed, with members from the Institute of Nuclear Technology and Radiation Protection of "Demokritos" (ΙΠΤΑ) and the Hellenic National Meteorological Service (EMY). The role of the nuclear technology team is to provide expert judgment and services, as needed, to help predict the early effects. Hence, the provided assistance encompasses the estimation of the source term, the forecast of the transport, dispersion and deposition of the released material, and the assessment of the dose due to exposure. To maintain a high level of preparedness EEAE jointly with the nuclear technology team participate in the emergency exercises organized each year by the International Atomic Energy Agency (IAEA).

Recently, the Cm-Hysplit (Customized Meteorology-HYbrid Single Particle Lagrangian Integrated Trajectory) capability has been developed for the prediction of plume trajectories, dispersion and deposition, following a radioactive atmospheric release in Europe. As clearly attested by its name, Cm-Hysplit is an extension of the well known, state-of-the-science Hysplit model [1]. This extended version employs a customized input meteorological source, more specifically, the gridded forecast fields generated by EMY. The aim was to make available at the premises of EAEA a quick response independent software system to be used by the nuclear technology team.

The present report outlines briefly Cm-Hysplit and illustrates its capabilities. As it will become apparent Cm-Hysplit fulfills satisfactorily the operational requirements of EEAE, and as such it is recommended for standard use in a nuclear emergency, be it an exercise or a real event.

2. MODEL CHARACTERISTICS

The Hysplit model has been developed over many years of effort at the Air Resources Laboratory (ARL) of the U. S. National Oceanic and Atmospheric Administration (NOAA). The last version is Hysplit_4 and is available at the ARL/NOAA web site `http://www.arl.noaa.gov/ready.html`.

Hysplit is a complete computational system with capabilities ranging from simple trajectory calculations to complex dispersion and deposition simulations. It employs an hybrid approach in two respects. First, the overall method is a hybrid between Eulerian and Lagrangian approaches, in that advection and diffusion are calculated in a Lagrangian framework, whereas concentrations are calculated on a fixed grid. Second, advection and diffusion are modelled according to the hybrid approach of Hurley (1994), in which particle dispersion is employed in the vertical direction and puff dispersion in the horizontal. The model requires gridded meteorological data as input, which are mapped on an internally defined grid system. The latter is generated from a conformal map projection such as mercator, or polar stereographic. In the vertical, a terrain-following coordinate system is used.

A library is included containing gridded land use and roughness length data for the whole globe with a resolution of 1×1 degree.The model calculates vertical mixing and stability, and accommodates all the important removal mechanisms, such as gravitational settling, dry deposition, wet deposition and radioactive decay. Details on the Hysplit modelling system are given in Refs. [1] and [3] (also available in the network).

The model has been validated through an extensive comparison campaign, including balloon trajectories from ACE (Aerosol Characterization Experiment), air concentrations from ANATEX (Across North America Tracer Experiment), radiological deposition from the Chernobyl accident, and satellite photographs of the Rabaul volcanic eruption. An overview of the various validation exercises can be found in Draxler and Hess (1998). The authors concluded that "in general the model's performance compared favourably to the observations in all areas, although there is still room for improvement, with particular regard to the vertical distribution of pollutants in different meteorological regimes; clearly this continues to be an active area of research and our computational methods will be modified accordingly".

The model has been designed for quick response to atmospheric emergencies ranging in character from accidental radiological releases to the hazards presented to aviation from volcanic ash eruptions. Owing to its capabilities and potential, it has attracted world-wide attention. It is accessible to anyone for interactive on-line use on the web server of ARL/NOAA, as part of the READY (Real-time Environmental Applications and DisplaY) system. Also, it can be downloaded for local use on a PC, and is provided with the necessary graphical display programs. However, both the interactive use on the network and the local use on the PC, share a common drawback, namely, the need to have access to NOAA's Hysplit-compatible archives containing the required input meteorological data. Hence, in addition to disposing the stand-alone Hysplit_4 version for PC, one needs to develop appropriate routines to convert the meteorological data he/she disposes to a model compatible format.

The Cm-Hysplit system, described in the next section, responds to the above need, for it accommodates a utility program which produces from the gridded forecast meteorological data generated by EMY an input file which can be read by the model.

3. DESCRIPTION OF CM-HYSPLIT

Cm-Hysplit is a modular DOS application, consisting of the utility program `emy2arl` which creates the model input file and the programs of the Hysplit package, namely, the trajectory prediction model `hymodelt`, the trajectory display program `trajplot`, the concentration prediction model `hymodelc`, and the concentration display program `concplot`. Normally these are run in sequence, however any program can be run separately if the appropriate input files were created in a previous simulation. Although these programs can be run as Windows applications, their Graphical User Interface (GUI) is not especially powerful. We found more convenient to run them from the command line (i.e. as a DOS application), which also offered more transparency during the run. Full details on the use of the programs are given in Hysplit user's guide [4], also available on-line at the READY web site. Note that the installation package contains two more graphical display programs, namely, `wintplot` for the trajectories and `wincplot` for the concentration. The latter produce much less refined graphical outputs in comparison to `trajplot` and `concplot` (which create very powerful graphics in Postscript format), and practically can be disregarded.

Besides `emy2arl` which has been developed in-house, the other programs are available only as executables. However, included as part of the model package are Fortran routines for helping the user to develop a customized input application. `Emy2arl` has been developed on that basis. The key is to modify appropriately the sample Fortran file `\data2arl\sample\dat2arl.f` (created during installation), which is provided to generate a test meteorological data set. The generated data are dummy meteorological fields, uniform in space and time, but offered a valuable guidance in developing `emy2arl`. The time and data subroutines harwired in `dat2arl` were modified in a way to commensurate with data input from the EMY meteorological files. The latter are expected to be in the same format, as that used in the recent nuclear emergency exercise INEX-2-HUN of November 1998; more specifically, as multiple ASCII files providing forecast values every 6 h for a total of 72 h, on a 121×56 grid, covering with a 1.5×1.5 degree resolution the domain ABCD where A=(82.5N latitude, 90W longitude), B=(82.5N latitude, 90E longitude), C=(0 latitude, 90E longitude), and D=(0 latitude, 90W longitude). Hence, a separate file is expected at each time step and level, for each meteorological parameter. The files are to be named as

```
dd-mm-yyyy.llllPP.ttt.-ssss
```

where

`dd-mm-yyyy`= initialization date (day-month-year)
`llll`=level identifier (see Table I below)
`PP`=parameter identifier (see Table I below)
`ttt`=time step identifier in hours elapsed (e.g. 006, 012, 018 etc.)
`ssss`=any 4-character additional identifier

To run the model there are certain minimum data requirements such as surface pressure, u-v wind components, and temperature. In addition, precipitation is required for wet removal calculations. Not required, but certainly necessary to improve vertical mixing calculations would be to provide some measure of low-level stability. This may take the form of a near-surface wind and temperature or the fluxes of heat and momentum. Similarly, there are several other parameters which can be provided optionally. If not provided, they are replaced with internal default values. It is also important to have sufficient vertical resolution. The set of parameters to be provided to Cm-Hysplit has been determined on a basis of a trade-off between the above considerations and what EMY can deliver on a routine basis. The set of parameters is listed in Table I. The amount of data to be transferred from EMY to EEAE is acceptable, corresponding to about 10 MB (in ZIP format).

The major difficulty in modifying `dat2arl` to create `emy2arl` was to customize the grid structure so that the domain of interest ABCD (defined above) be correctly mapped, and the gridded input data be correctly interpolated on the internal grid during the conformal transformation. The accomplishment of this delicate step required a considerable amount of effort, as well as the request of specific information from ARL [5]. Note also, that `emy2arl` invokes external routines for the conformal transformation, and for performing a final data compression in an especially required "direct-access" format. The data packing routines have been taken from the subdirectory `\data2arl\source` (created during installation). The

Level (identifier `llll`)	Parameters (identifier `PP`)
Surface (`0000`)	Pressure (`P0`), 6-h accumulated precipitation (`TP`), u-wind at 10 m agl (`U0`), v-wind at 10 m agl (`V0`), temperature at 2 m agl (`T0`)
1000 mb (`1000`)	Geopotential height (`HG`), u-wind (`UU`), v-wind (`VV`), temperature (`TT`), relative humidity (`RH`)
850 mb (`0850`)	Geopotential height (`HG`), u-wind (`UU`), v-wind (`VV`), temperature (`TT`), relative humidity (`RH`)
700 mb (`0700`)	Geopotential height (`HG`), u-wind (`UU`), v-wind (`VV`), temperature (`TT`), relative humidity (`RH`)

Table I: Meteorological input parameters.

conformal projection routines have been taken from the CMAPF (Conformal MAP Function) Fortran library (Taylor, 1997), available on the web site `http://www.arl.noaa.gov/ss/models/cmapf.html`.

Finally, we note that ARL kindly provided us with a complete map of Europe [5] which has been incorporated into Cm-Hysplit, because the map included in the default installation package does not support the eastern and south-eastern regions beyond the meridian of 20E longitude.

4. APPLICATION EXAMPLE

A good way to illustrate the applicability of Cm-Hysplit to emergency response situations is to consider the last European nuclear emergency exercise INEX-2-HUN held on 3 November 1998. The exercise postulated that at 0715 UTC an accidental release took place from the stack of the Hungarian reactor PAKS (latitude 46.5N, longitude 19E). In the first accident notification the 1-h released activity was communicated to be of $4.8 \cdot 10^{14}$ Bq, from which the activity of I-131 was $1.5 \cdot 10^{13}$ Bq, and that of Cs-137 was $3 \cdot 10^{12}$ Bq.

The meteorological data sets available from EMY include precipitation data on the surface, and the u-v wind components on the levels of 1000 and 850 mb (i.e. TP, UU and VV, see Table I). The data have been generated by EMY using the ECMWF (European Centre for Medium-Range Weather Forecast) prognostic data of 0000 UTC 02 November. Clearly, the available data sets are, not only premature by 24 h, but also less than the minimum required to run the model. To be able to perform a simulation for 3 d, we shifted arbitrarily the data initialization by 24 h, and we used for the missing parameters the standard atmosphere values. More specifically, a uniform surface pressure of 1013 mb is employed, a uniform temperature at the 1000-mb level of 287 K, and a temperature value of 279 K at the 850-mb level. Obviously, the used assumptions are strong. Still, however, this is acceptable for our purpose which is to demonstrate the operability of Cm-Hysplit, rather than to obtain accurate simulation predictions.

The run has been performed on a PC –a Pentium II at 300 MHz. It took less than 15 min, including the pre-processing phase (i.e. execution of `emy2arl`) and post-processing (i.e. execution of `trajplot` and `concplot`). The trajectory for a period of 3 d is shown in Fig. 1. Figs. 2 and 3 show respectively the results of Cs-137 deposition (Bq/ m^2) and Cs-137 near ground air concentration (Bq/ m^3) for the first 24 h following the emission. Obviously, the concentration and deposition results are rather crude, owing to the poor meteorological input data used, especially with regard to the vertical atmospheric structure. Notwithstanding this, the obtained patterns are in agreement with the predictions of other participants in the exercise. This can be seen from Figs. 4 and 5, which show the communications of the Canadian Meteorological Centre for the trajectory and air concentration.

5. CONCLUSION

The computational capability Cm-Hysplit –a customized version of the state-of-the-art atmospheric model Hysplit– has been developed to respond to the operational needs of EEAE in the event of a nuclear emergency. The program requires as meteorological input the gridded forecast fields generated by EMY for the parameters shown in Table I.

The operability of the system has been demonstrated. Its application complies satisfactorily with the operational requirements, and thus, it is recommended for standard use in emergency response situations.

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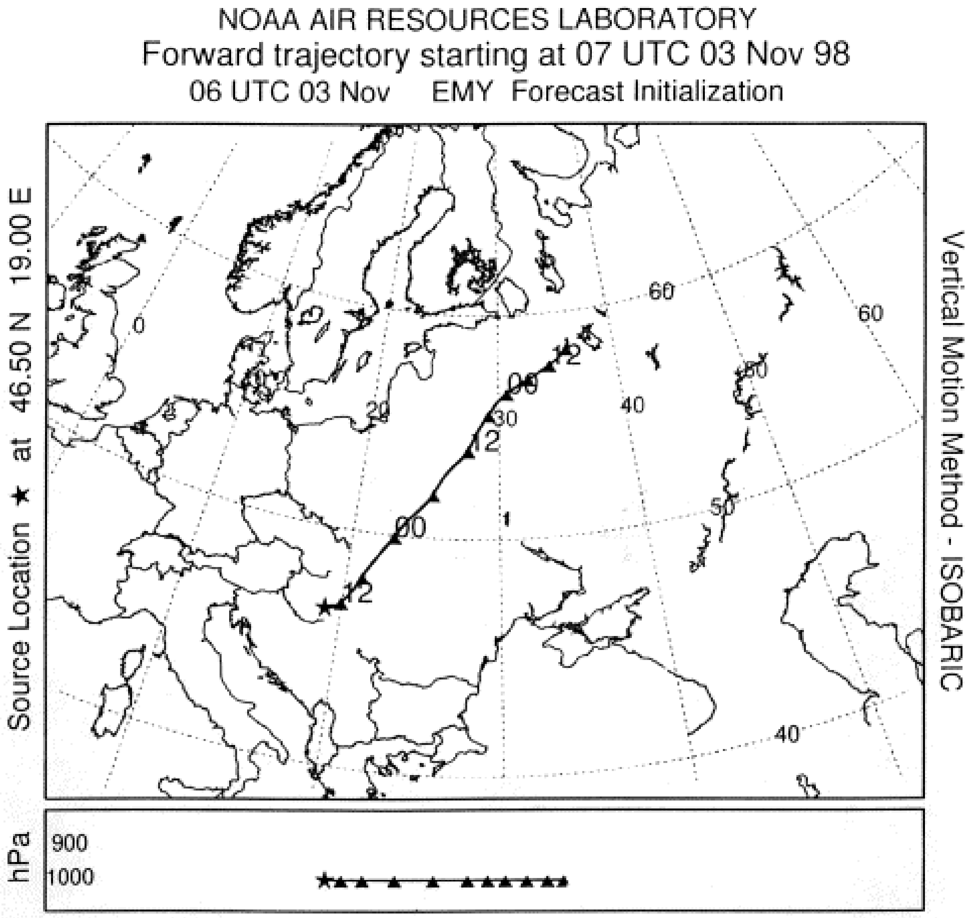
NOAA AIR RESOURCES LABORATORY
Forward trajectory starting at 07 UTC 03 Nov 98
06 UTC 03 Nov EMY Forecast Initialization
Source Location ★ at 46.50 N 19.00 E
Vertical Motion Method - ISOBARIC
hPa
900
1000

Figure 1

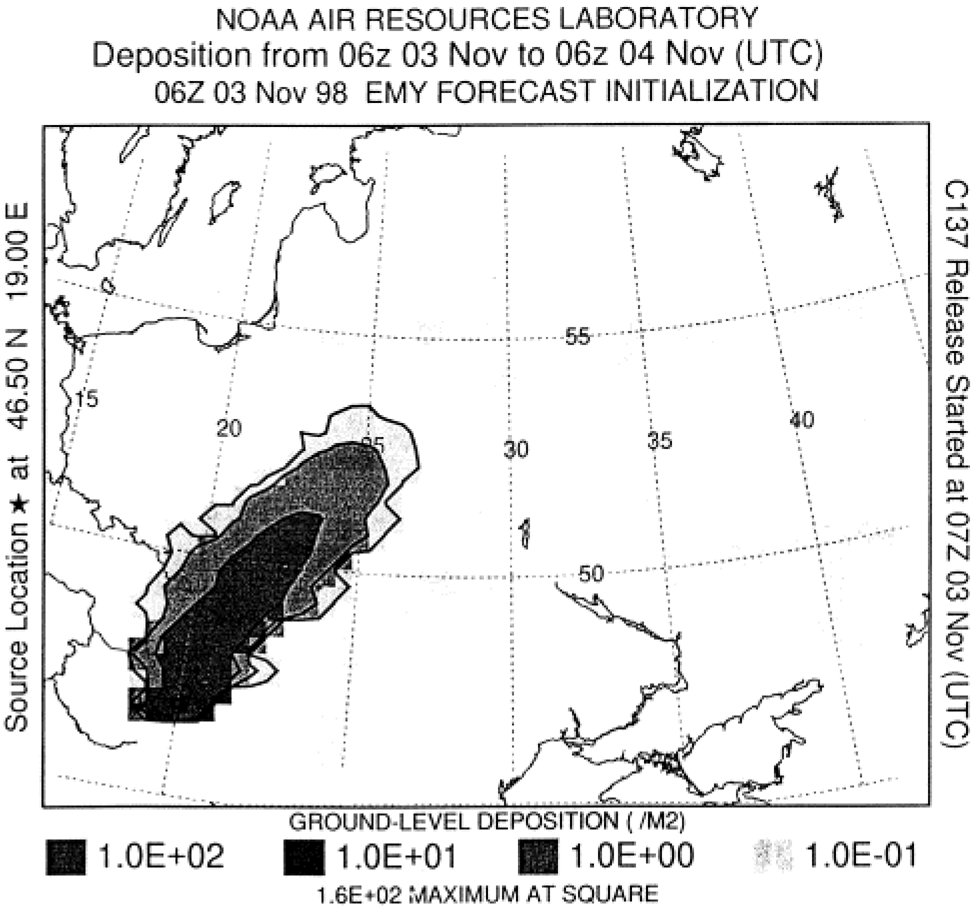
NOAA AIR RESOURCES LABORATORY
Deposition from 06z 03 Nov to 06z 04 Nov (UTC)
06Z 03 Nov 98 EMY FORECAST INITIALIZATION
Source Location ★ at 46.50 N 19.00 E
C137 Release Started at 07Z 03 Nov (UTC)
55
50
15
20
25
30
35
40
GROUND-LEVEL DEPOSITION (/M2)
1.0E+02
1.0E+01
1.0E+00
1.0E-01
1.6E+02 MAXIMUM AT SQUARE

Figure 2

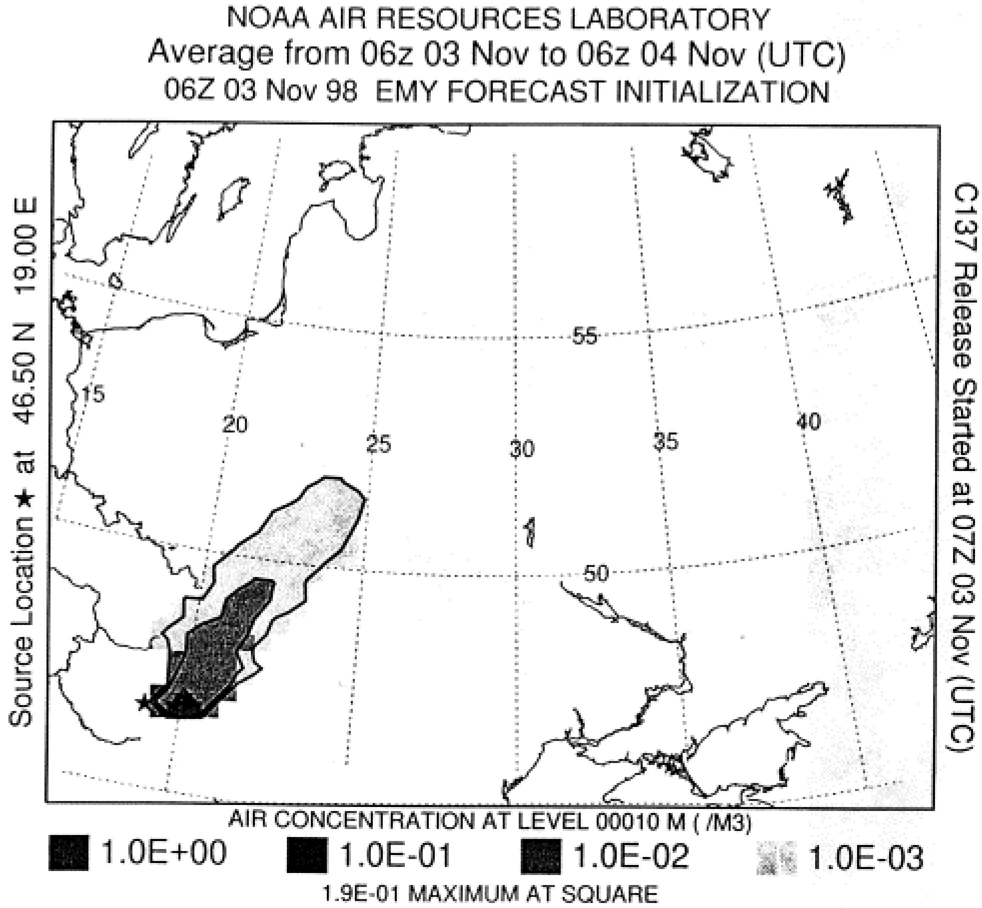
NOAA AIR RESOURCES LABORATORY
Average from 06z 03 Nov to 06z 04 Nov (UTC)
06Z 03 Nov 98 EMY FORECAST INITIALIZATION
Source Location ★ at 46.50 N 19.00 E
C137 Release Started at 07Z 03 Nov (UTC)
55
50
15
20
25
30
35
40
AIR CONCENTRATION AT LEVEL 00010 M (/M3)
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.9E-01 MAXIMUM AT SQUARE

Figure 3

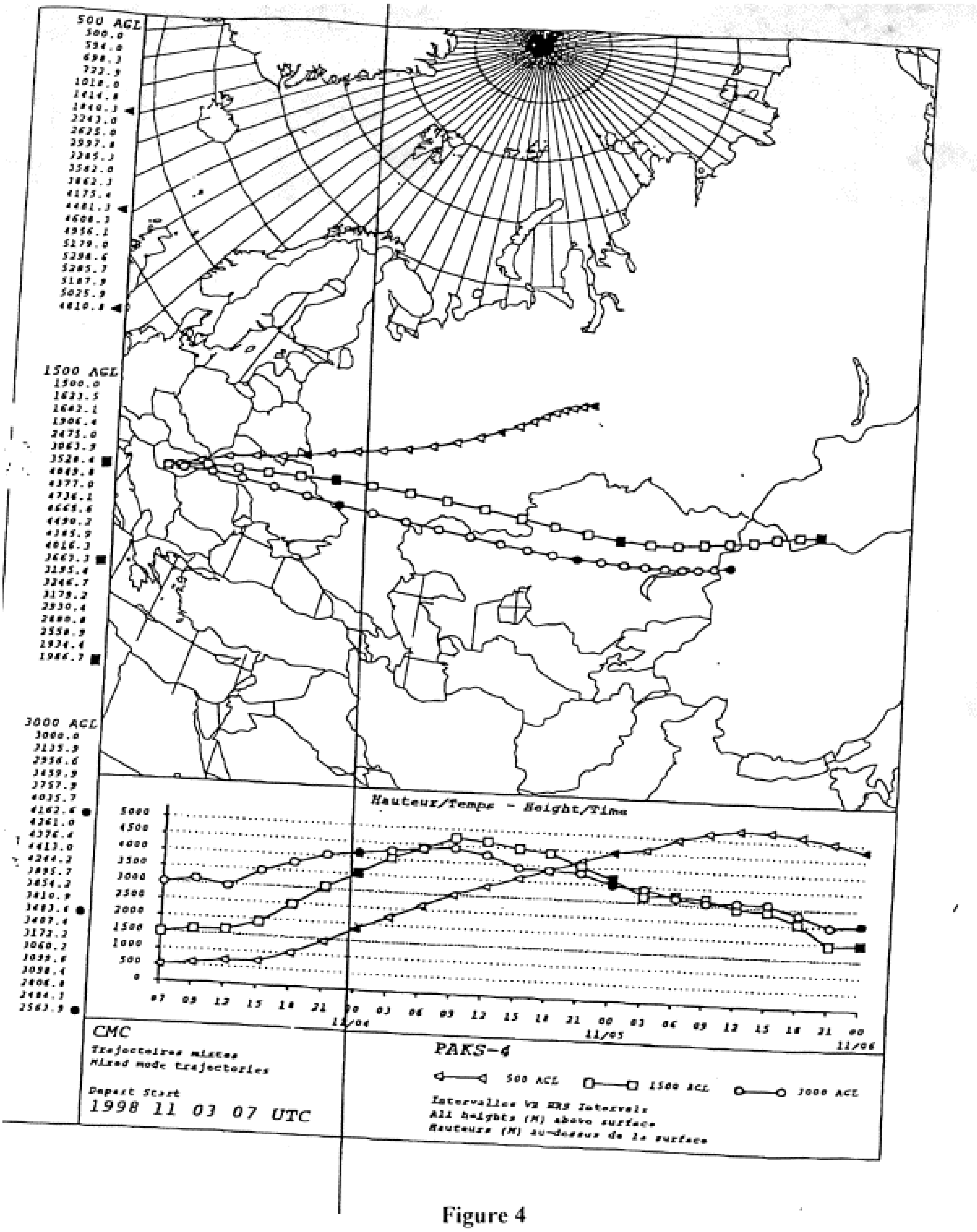
500 AGL
1500 AGL
3000 AGL
Hauteur/Temps - Height/Time
CMC
Trajectoires mixtes
Mixed mode trajectories
Depart Start
1998 11 03 07 UTC
PAKS-4
500 AGL
1500 AGL
3000 AGL
All heights (M) above surface

Figure 4

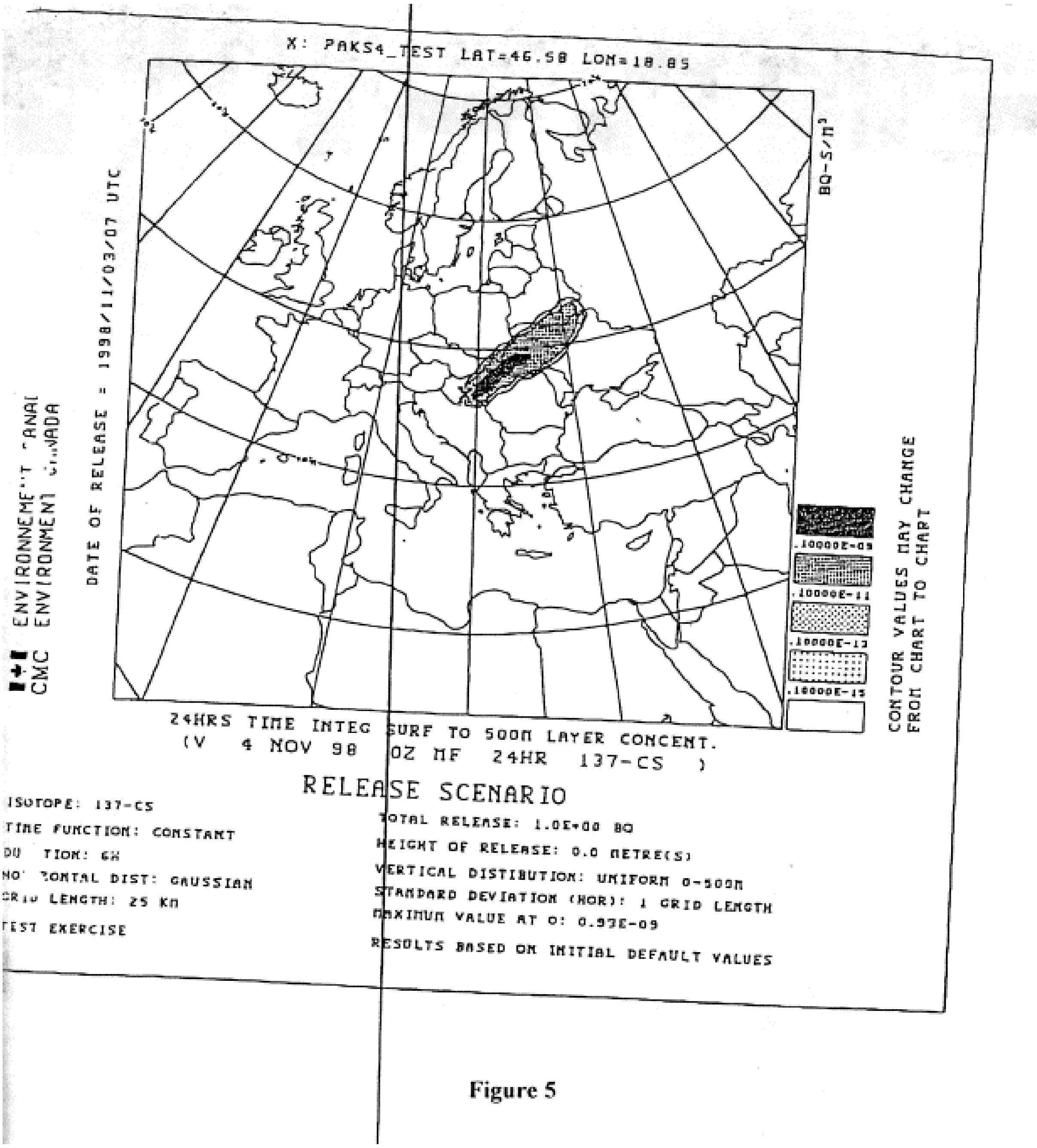
X: PAKS4_TEST LAT=46.58 LON=18.85
BQ-S/M³
ENVIRONNEMENT CANADA
ENVIRONMENT CANADA
CMC
DATE OF RELEASE = 1998/11/03/07 UTC
.10000E-09
.10000E-11
.10000E-13
.10000E-15
CONTOUR VALUES MAY CHANGE
FROM CHART TO CHART
24HRS TIME INTEG SURF TO 500M LAYER CONCENT.
(V 4 NOV 98 0Z MF 24HR 137-CS)
RELEASE SCENARIO
ISOTOPE: 137-CS
TIME FUNCTION: CONSTANT
GRID LENGTH: 25 KM
TEST EXERCISE
TOTAL RELEASE: 1.0E+00 BQ
HEIGHT OF RELEASE: 0.0 METRE(S)
VERTICAL DISTIBUTION: UNIFORM 0-500M
STANDARD DEVIATION (HOR): 1 GRID LENGTH
MAXIMUM VALUE AT O: 0.93E-09
RESULTS BASED ON INITIAL DEFAULT VALUES

Figure 5