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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

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SMR/760-45

"College on Atmospheric Boundary Layer and Air Pollution Modelling"
16 May - 3 June 1994

"Apollo: a Lagrangian Model for the Study of the Long-Range Transport of Atmospheric Pollutants"

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Testo pervenuto nel febbraio 1993

Edito a cura dell'ENEA, Direzione Relazioni Esterne.
Viale Regina Margherita, 125 - Roma
Finito di stampare nel mese di febbraio 1994
Fotoriproduzione e stampa
a cura della «Casa della Stampa»
Via Empolitana 120/C - Tivoli (Roma)

Questo fasciolo è stato stampato su carta riciclata

ENTE PER LE NUOVE TECNOLOGIE
L'ENERGIA E L'AMBIENTE
Direzione Centrale Sicurezza
Nucleare e Protezione Sanitaria

APOLLO
A LAGRANGIAN MODEL FOR THE STUDY OF THE LONG RANGE TRANSPORT OF ATMOSPHERIC POLLUTANTS

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RT/DISP/93/02

Sommario

Il presente rapporto descrive il modello di dispersione atmosferica APOLLO (Atmospheric POLlutant LOng range dispersion) e il relativo codice di calcolo . APOLLO e' stato sviluppato dall'ENEA-DISP per la valutazione in tempo reale delle conseguenze di rilasci accidentali in atmosfera a grandi distanze dalla sorgente, ed è stato applicato con successo nella esercitazione internazionale ATMES, basata sui dati radiologici raccolti durante l'incidente di Chernobyl.

Abstract

The present report describes the atmospheric dispersion model APOLLO (Atmospheric POLlutant LOng range dispersion) and its related computer code. APOLLO has been developed by ENEA-DISP for the real time assessment of long range air pollution episodes caused by accidental releases into the atmosphere, and has been successfully applied in the international benchmark ATMES based on radiological data collected during the Chernobyl accident.

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Introduction

The present report describes the atmospheric dispersion model APOLLO (Atmospheric POLlutant LOng range dispersion), developed by the Italian Agency for the New Technologies, the Energy and the Environment - Direction for Safety and Health Protection (ENEA-DISP) for the real time assessment of long range air pollution episodes caused by accidental releases into the atmosphere.

APOLLO has its origins in the modelling technologies ENEA-DISP has developed and applied over a period of several years as part of its activities in the field of environmental systems for both real-time and previsional assessment of the impact of pollutant releases into the atmosphere. It is presently operational into the ARIES-I (Atmospheric Release Impact Evaluation System - Improved) (Desiato and Maggi, 1991) emergency response system.

The Chernobyl accident outlined the need of operational models able to describe the long distance transport and diffusion of toxic materials accidentally released into the atmosphere.The need for such a real time estimate derives from the necessity and usefulness of both diagnostic and prognostic analysis concerning the space and time evolution of the pollutant dispersal as a fundamental technical support for public authorities who have the responsibility of making decisions for protecting the human health and the environment.

Dispersion models play an important role in this context, especially during the first stage of a pollution episode, when field measurement are missing ore insufficient and the need of a general description of the situation based on the available information and of its possible evolution is very important.

Many dispersion models have been developed which give a description of the atmospheric dispersion at long distances, but a real time estimate of the concentration and ground deposition patterns requires a model with special structure and characteristics. It must be able to calculate the dispersion in a physically consistent way based on meteorological data that could be reasonably available in real-time; it must be flexible with respect to the source and pollutant characteristics and to the domain size and position, all elements which cannot be known in advance; it must be fast enough to enable an effective real time response; the analysis and the results produced by the model must be clear for the easy and quick interpretation by the user.

Although puff models can provide a useful insight into the pattern of long range dispersion, they are generally limited in their three-dimensional treatment of the windfield; Eulerian grid models which integrate the equation for advection and diffusion of material across a three-dimensional grid can incorporate the three-dimensional wind field, but are not well suited for the treatment of a time dependent release from a point source due to the problem of numerical diffusion and the large computer time required.

It was therefore considered that a Lagrangian particle model, representing the release as a sequence of particles each advected across the domain according to the evolving three-dimensional windfield and with a suitable parameterization of turbulent motions, was the most appropriate type of model.

In spite of the different way of simulating the pollutant plume, APOLLO retains some basic concepts and features of puff models developed in the last years with similar purposes (ApSimon et al., 1985; van Rheineck Leyssius et al., 1988; Davis et al., 1988). Some expedient for limiting the computer time, which may in some case contrast with the level of the model sophistication, has also been adopted.

APOLLO was applied in the ATMES (Atmospheric Transport Model Evaluation Study) benchmark, jointly organised by the World Meteorological Organization, The International Agency for Atomic Energy and the Commission of the European Communities, with very positive outcome. For a full description of the results the reader is referred to the ATMES final report (Klug et al., 1992). A detailed model evaluation ands a sensitivity study with respect to the mixing depth and horizontal diffusion parameterizations are in (Desiato, 1992).

The aim of the participation to ATMES was to test the model as it were used as a real-time tool in an actual emergency situation, and not, at least at the present stage, to implement the model to a higher level of sophistication that would require the use of data and/or hardware facilities currently not available at the ENEA-DISP emergency response system. For this reason, for example, only the meteorological gridded data at standard pressure levels which are generally avalaible in real time, have been used. With respect to the real-time version, for the application to ATMES the model has undergo only slight changes concerning the interface between the model and the particular input available for the Chernobyl simulation, and the output required.

1 - The model

1.1 - General description

APOLLO has been designed to estimate ground level concentration and deposition at distances up to some thousands of kilometers from one point source. Its application involves atmospheric pollutants either stable or first-order decaying, like radioactive pollutants. The pollutant is simulated by a large number of particles tracked by a three-dimensional wind field to which turbulent motions are superimposed.

APOLLO works in a latitude-longitude coordinate system, in which the following gridded data must be defined: topography (optional); roughness height (optional); horizontal wind component at standard pressure levels and at surface; vertical wind component at standard levels (optional); geopotential at standard levels; precipitation.

The time and space resolution of these data are flexible. Objective analysis and/or forecasted fields of wind and geopotential are tipically provided by the European Centre for Medium Range Weather Forecast. as for the simulation of the Chernobyl episode. A meteorological preprocessor for the estimate of the diurnal inversion height based on temperature vertical soundings is linked with APOLLO, but it has not been used for the Chernobyl simulation.

The advection component of the particle trajectories is determined by the space and time interpolation of the three-dimensional wind field. Turbulent motion is considered as follows. In the vertical, it is included in the calculation of particle trajectories by means of two distinct parameterizations for particles located in the mixing layer and in the reservoir layer; in this way both the vertical diffusion and the wind shear effect on horizontal diffusion are taken into account. In the horizontal, kernel density functions, dependent on travel time, are considered for each particle.

The effect of topography on ground level concentration is roughly taken into account into the model. It strongly depends on the resolution of both topographical and wind data. Actually, for the Chernobyl simulation a terrain data set with a good resolution was not available, and the topography was modeled at the same resolution of geopotential data (1.125° of spacing both in latitude and in longitude). Dry and wet deposition, as well as puff depletion due to both deposition mechanisms, are also included into the model.

Ground level instantaneous and integrated concentrations, total and wet deposition of a maximum of five pollutant species at a time are calculated on a latitude-longitude rectangular grid with flexible resolution and at a maximum of one hundred extra receptor points, at times that can be conveniently defined at the beginning of the simulation.

1.2 - Advection

The horizontal wind field and, optionally, the vertical wind component, must be specified on a regular latitude and longitude grid at a number of vertical levels (tipically the standard pressure levels) and at regular time intervals (tipically 6 hours).

When data of the vertical wind component are not available, vertical advection velocity of the particles is set to zero. When available, vertical wind data are supposed to model the effect of the topography on the windfield at the resolution of the available data.

The wind field is assumed to vary linearly in time and, with the exception of the vertical interpolation of the horizontal component within the mixing layer, in space. In the horizontal, time interpolation is performed on wind speed and direction separately, to avoid unrealistic reduction of wind speed during 180° rotation of wind direction in a time step.

The trajectory of a particle is calculated with the following procedure.

At each time step wind vectors V(i,j,k,t) at grid point (i,j,k) and time t between two successive sets of data separated by a time interval $\Delta t=t_2-t_1$ hours apart, , is computed by;

$$V(i,j,k,t)=V(i,j,k,t_1)(t_2-t)/\Delta t+V(i,j,k,t_2)(t-t_1)/\Delta t \qquad (1)$$

Then, the advection displacement of a particle m at $\mathbf{X}_1$ is computed by (Villone et al., 1992)

$$\mathbf{X}_m(t+\Delta t)=\mathbf{X}_1(t)+.5[\mathbf{V}_1(t)+\mathbf{V}_2(t+\Delta t)]\Delta t \qquad (2)$$

where $\mathbf{V}_1$ and $\mathbf{V}_2$ are the velocities at $\mathbf{X}_1$ and $\mathbf{X}_2=\mathbf{X}_1+\mathbf{V}_1(t)\Delta t$, respectively. Eq. (2) is iterated until the difference between $\mathbf{X}_2$ and $\mathbf{X}_m$ becomes less than a given value. Both $\mathbf{V}_1$ and $\mathbf{V}_2$ are linearly interpolated from the corner points of a wind cell. The conversion from pressure levels to the z vertical coordinate is performed by means of the geopotential height data.

For the horizontal component within the mixing layer the vertical interpolation is not linear, and the equation

$$V_m=V_s+(V_h-V_s)(z-z_s)^p/(z_h-z_s)^p \qquad (3)$$

is used, where
V_s = surface wind velocity,
V_h = wind velocity at mixing layer top; V_h is calculated by linear interpolation between standard levels;

z_s = height of surface wind measurement;
z_h = mixing layer height;
p = .14

The value of p is representative of neutral atmospheric conditions. Above the upper level of the available data wind speed and direction are taken constant. Thus, the three components u_m, v_m, w_m of the advection velocity of a particle m are obtained at each time step.

1.3 - Turbulence

The turbulent motions affecting the particle diffusion are considered in two separate ways for the horizontal and vertical components.

The horizontal turbulent displacement of a particle is not expressly included in the calculation of the particles trajectories, so the new coordinates of a particle m at each time step Δt (usually one hour) are simply given by:

$$x_m(t+\Delta t)=x_m(t)+u_m\Delta t,\ \ y_m(t+\Delta t)=y_m(t)+v_m\Delta t \qquad (4)$$

The horizontal turbulent motions are considered, in the phase of air concentration calculation, by assigning to each particle a kernel density distribution dependent on the travel time (see ch. 1.6). Wind shear effect on horizontal diffusion is explicitly taken into account by computing the different trajectories of particles travelling at different heights. This method has the advantage of limiting the number of particles needed to simulate the pollutant plume and of being computationally simple. With respect to this, each particle is considered as a puff with a pre-defined time-dependent horizontal distribution.

On the contrary, the vertical component of turbulent motion is explicitly cosidered in the calculation of the particle trajectories. One drawback of long range puff models is that the center of mass of each puff is tracked at almost constant level during his history, therefore its trajectory is representative only of the wind field at the initial level of the release. Actually, it should be considered that each puff represents, after a relatively short time compared to long range travel times, an amount of pollutant dispersed over a thick layer, so that wind shear plays an important role in determining the direction of puff portions travelling at different levels.

This problem could be in principle addressed by considering the splitting of puffs every time a puff is sufficiently dispersed in the vertical. However, this process is computationally complicated and has the disadvantage of causing an indefinite growth of the number of puff and consequently of the computer time.

In APOLLO, a mixing layer depth h(x,y,t) is computed at each time step (see 1.5). Particles moving within the mixing layer diffuse differently from particles moving above it, in the reservoir layer.

In the mixing layer, it can be assumed that the time step is long compared with the characteristic time scale of the vertical diffusion; thus, the new vertical coordinate of a particle is given by;

$$z(t+\Delta t)=z_s+v\ h(x,y,t) \quad \text{if } z(t)<z_s+h(x,y,t) \tag{5}$$

where z_s is the surface height above sea level, h(x,y,t) is the depth of the mixing layer and v is a random number between 0 and 1.

In the reservoir layer the statistical approach of Monte-Carlo models is used (see for example Hanna, 1979):

$$z(t+\Delta t)=z(t)+w(x,y,z,t)\Delta t+w'(t)\Delta t \quad \text{if } z(t)>z_s+h(x,y,t) \tag{6}$$

where w' is a Lagrangian turbulent vertical velocity given by

$$w'(t+\Delta t)=w'(t)R+w''(t) \qquad R=\exp(-\Delta t/T_L) \tag{7}$$

T_L is the Lagrangian time scale, w''(t) is a purely random component related to w' by

$$\sigma^2_{w''}=\sigma^2_{w'}(1-R^2) \tag{8}$$

With (6) the vertical turbulent motion is a recursive sum of two terms: the first is a function of the previous w' and the second is a purely random generated. To apply (6), an estimate of $\sigma_{w'}$ and T_L is needed. According to Taylor's statistical theory of diffusion, for long travel times it can be assumed

$$K_z=\sigma^2_{w'}T_L \tag{9}$$

where K_z is a vertical diffusivity coefficient for the reservoir layer. For the Chernobyl study, the following values have been used:

K_z=1 m^2/s, $\sigma_{w'}$ = .01 m/s.

1.4 - Mixing layer

The daily cycle of space variable mixing height may have a strong effect on the concentrations and depositions that occur in long range dispersion episodes. The diurnal variation (due, for example, to the warming up of the surface), as well as the

along-trajectory variation of the mixing height, can cause a particle to be entrained in or extruded from the mixing layer, changing its possible contribution in affecting ground level air concentration and deposition.

On the other hand, the accurate estimate of a time and space variable mixing height for long range modelling requires meteorological and territorial data which are rarely available for real time applications at continental scale.

Mixing layers due to mechanical and to convective turbulence can be distinguished. The first requires the estimate of friction velocity and Monin-Obukhov length; the second requires integrated solar radiation or vertical temperature profiles.

In APOLLO, the following procedure for the estimate of the mixing layer height at each grid cell and each time step is adopted.

A mechanical mixing depth of a neutral stationary atmospheric boundary layer is derived from the asymptotic similarity theory (Blackadar and Tennekes, 1968):

$$h_m(x,y)=.25\ u_*/\ f \qquad (10)$$

f is the Coriolis parameter. The friction velocity u_* is derived using a neutral surface layer profile:

$$u_*(x,y)=kV_s\ /\ \ln(z_s/z_0) \qquad (11)$$

where k is the von Karman constant.

The roughness height z_0 must be deduced from territorial data base. For the Chernobyl study, three values of z_0 were derived from the topographic data at the resolution of 1.125 degrees:

z_0=.001 m over sea;
z_0=.2 m over terrain more than 1000 m above sea level;
z_0=.05 m elsewhere.

A convective mixing depth is also computed during local daytime. GMT daytime is defined as:

$$t_d+2<t<t_s-2 \qquad (12)$$

where t_d is GMT time of local dawn and t_s is GMT time of local sunset.

The convective mixing depth estimate h_c requires the estimate of an interpolated diurnal inversion height based on temperature vertical soundings. For this purpose, APOLLO is linked with a meteorological preprocessor that provides an estimate of h_c at 12 GMT based on the vertical temperature profiles contained in the TEMP

meteorological messages available in real time. For the Chernobyl study a fixed value $h_c(12)$ = 1000 m has been used as the inversion height at 12 GMT over the whole domain.

Given $h_c(12)$, the diurnal variation $h_c(t)$ is modeled (fig. 1) by a linear increase with time from the early morning mechanical mixing height to a convective mixing height extrapolated at four hours before sunset; for the two following hours the mixing height is taken constant at its maximum value:

$$h_c(t)=h_m(t_d+2)+[h_c(12)-h_m(t_d+2)]\,[t-(t_d+2)]/[12-(t_d+2)] \quad \text{if } td+2<t<ts-4 \qquad (13)$$
$$h_c(t)=h_c(t_s-4) \quad \text{if } ts-4<t<ts-2$$

Eq. (13) roughly reproduces the typical behaviour of diurnal mixing heights (see for example Verver and Scheele, 1988).

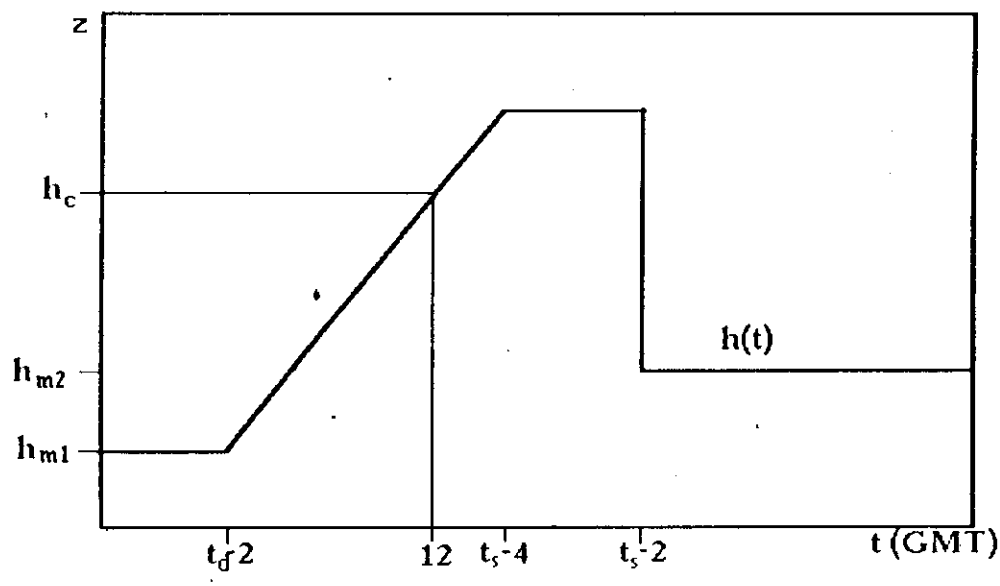

Fig.1 - The diurnal variation of mixing depth as modeled in APOLLO. t_d and t_s are dawn and sunset times respectively; h_{m1} and h_{m2} are the early morning and late afternoon mechanical mixing depths respectively; h_c is the convective mixing height derived from vertical temperature soundings at 12:00 GMT.

Finally, the mixing layer depth is selected with the following criteria:

over sea: $h(x,y,t)=h_m(x,y,t)$ always

over land: $h(x,y,t)=h_m(x,y,t)$ if $t<t_d+2$ or $t>t_s-2$;

$h(x,y,t)=\max[h_m(x,y,t),h_c(x,y,t)]$ if $td+2<t<ts-2$.

1.5 - Air concentration

Ground level air concentration are calculated each time step on a rectangular grid in geographic coordinates with a resolution, specified as input, which can be different from the meteorological grid resolution.

Only particles located within the mixing layer contribute to ground level air concentration, i.e.

$$z_m(x,y)<z_s(x,y)+h(x,y) \qquad (14)$$

must be satisfied for a particle with vertical coordinate $z_m(x,y)$.

A particle initially in the reservoir layer may be entrained into the mixing layer, and therefore contribute to ground level air concentration, due to the presence of a topographic relief along its trajectory. Vice versa, a particle initially in the mixing layer may be extruded from it due to the combined effect of topography on mixing layer and on particle trajectory.

As stated in ch. 4, each particle is spread out with a kernel density distribution which depends on its travel time. In the horizontal, a Gaussian density function has been adopted, with standard deviation σ given by

$$\sigma = at^b \qquad (15)$$

where the coefficients a and b may be defined as model input parameters. For example, $\sigma = .5t$ (Heffter, 1965), or $\sigma=(2K_y t)^{.5}$ (Fay and Rosenzweig, 1980), where K_y is a horizontal eddy diffusion coefficient.

In the vertical, particles located within the mixing layer are assumed to be uniformly distributed between the surface and the mixing layer height when computing concentrations.

Thus, for each grid point (i,j);

$$C_n(i,j)= \Sigma_m q_{n,m}[2\pi h(i,j)\sigma_m^2]^{-1}\exp[-(x_m-x_i)^2/2\sigma_m^2]\exp[-(y_m-y_i)^2/2\sigma_m^2] \qquad (16)$$

where $C_n(i,j)$ is the ground level air concentration of pollutant n and $q_{n,m}$ is the nth pollutant amount of the particle m.

Eq (16) is also used for calculating time integrated concentration CT_n:

$$CTn(i,j,n\Delta t) = n\Delta t \, \Sigma_k \, C_n(i,j,t_k), \quad k=1,n \qquad (17)$$

1.6 - Source and pollutant characteristics

Up to five pollutant species or nuclides can be considered at a time. Each particle represents a pollutant amount or activity determined at the time of the release. The amounts or activities are then progressively reduced due to plume depletion during the transport according to the probabilities of deposition and decay.

The source is described by the following parameters:
- coordinates;
- release height $z_e = z_s+h_e$, where z_s is surface height above sea level and h_e is the effective height including plume rise;
- release intensity for each species (g/s or Bq/s);

If r_n is the release rate of the nth species, the initial amount of a particle m is given by

$$q_{m,n} = r_n \Delta t / n_g \qquad (18)$$

where n_g is the number of particles generated in a time step.

During the simulation, particles that exit from the model domain are deleted, to limit the total number of particles for very long releases. For the Chernobyl study, ng = 25 has been used, which gave rise to a maximum of about 4000 particles during the simulation of dispersion for 14 days.

The effective height and the release rates can change with time, with a resolution of one time step (usually one hour) at minimum. Initially, the particles are uniformly displaced in a vertical layer Δz_e centered at z_e. For the Chernobyl study, a large value $\Delta z_e = h_e/2$ was used to take into account material thrown at different heights and the uncertainty of the effective plume height estimate. Thus, depending on the mixing layer height at the location and the time of the release, some particle may start to travel and diffuse in the mixing layer and some others in the reservoir layer.

1.7 - Specific effects

Dry deposition

Ground depositions are calculated over the same grid of air concentrations, and accumulated over each time step as time integrated air concentrations.

A deposition velocity v_d is required for each pollutant or nuclide. In principle, it depends on the turbulence and surface resitance, however at present APOLLO only considers an average value which should be representative of the average terrain and turbulence conditions during the long range transport of the pollutant.

For the Chernobyl study the following values were used:

v_d = .003 m/s for Iodine 131;
v_d = .001 m/s for Cesium 137.

As for the air concentrations, only particles located inside the mixing layer contribute to ground deposition. At each time step, the increment in deposited amount or activity of species n at grid point (i,j) is given by;

$$D_n(i,j) = C_n(i,j)\, v_{dn}\, \Delta t \qquad (19)$$

Wet deposition

Wet deposition is one of the most critical aspects of long range dispersion models, due to the difficulty of modelling washout and rainout processes in frontal and convective precipitation systems.

Wet deposition can affect noticeably total ground deposition levels and plume depletion; on the other hand, precipitation data at sufficient space and time resolution, especially for real-time applications, are usually not available.

In APOLLO, it is assumed that fields of accumulated precipitation over a certain time interval (tipically 6 hours), and with some grid resolution, are available. In addition, no distinction is made between in-cloud processes of rainout and scavenging below the cloud of washout.

For the purpose of wet deposition estimate, the rainfall amounts are distributed uniformly among the time steps comprised into the interval of the accumulated precipitation, giving a rain intensity R(i,j,t) in mm/h. This is justified by the quasi-linear dependence of the washout on the rain intensity (see eq. 21).

(i,j) represent here a point of the output wet deposition grid; For going from the precipitation grid to the output grid the interpolation method of the 'area of influence' (or Thiessen polygons) is used. Then, according to its kernel density distribution, the contribution of the particle m to wet deposition of species n at point (i,j) in the time step Δt is given by:

$$w_n(i,j)=\Lambda q_{m,n}(2\pi\sigma_m^2)^{-1}\exp[-(x_m-x_i)^2/2\sigma_m^2]\exp[-(y_m-y_i)2/2\sigma_m^2]\Delta t \qquad (20)$$

where (ApSimon et al., 1985):

$$\Lambda = W\, R^{.8}(i,j) \qquad (21)$$

W is the washout coefficient. The value $W=5\ 10^{-5}\ s^{-1}$ has been adopted for the Chernobyl study. Independently on their vertical coordinate, all particles contribute to wet deposition, which is supposed to be caused by clouds with vertical extension sufficient to include the upper particles.

Depletion and decay

Depletion of the particles is described by exponential reductions of their pollutant amount at each time step, due to the first order chemical reaction or to radioactive decay and to the scavenging by dry and wet deposition:

$$q_{m,n}(t+\Delta t) = q_{m,n}(t)\, \exp(-\lambda_n\, \Lambda t), \qquad (22)$$

where $\lambda_n = \ln 2 / T_n$ and T_n is the half life of the nth pollutant;

$$q_{m,n}(t+\Delta t) = q_{m,n}(t)\, \exp(-v_{dn} \Delta t / h), \qquad (23)$$

where h is the mixing layer height at the particle location;

$$q_{m,n}(t+\Delta t) = q_{m,n}(t) \exp(-\Lambda \Delta t), \qquad (24)$$

where Λ has the same meaning as in the washout equation (21).

Only particles located in the mixing layer are depleted due to dry deposition.

2 - The code

2.1 General features

APOLLO is written in FORTRAN 77 language and consists of a program main and nineteen subroutines. The computing time is nearly proportional to the number of particles, which, in its turn, grows linearly with the time of simulation, at least until the first particles reach the boundary of the model domain. As an example, a two days simulation requires less than 5 minutes, while a 14 days simulation requires more than 6 hours on a VAX 6300 computer.

2.2 - Input

The input to APOLLO consists of the files containing the two-dimensional matrixes of meteorological and geographical data, and three files in the form of FORTRAN namelist: GEO, REL, SAMP.

The meteorological files are the following:
USURFddhh, VSURFddhh, where dd is the day and hh the hour, containg the u-and v-components of the wind field at the surface, in m/s.
Uppp(p)ddhh, Vppp(p)ddhh, Wppp(p)ddhh, where dd is the day and hh the hour, containing the u-, v-, w- components of the wind field at pressure level ppp(p), in m/s.
Zppp(p)ddhh, where dd is the day and hh the hour, containing the geopotential height at pressure level ppp(p), in m.
RAINddhh, where dd is the day and hh the hour, containing accumulated precipitation in the time interval preceding ddhh, in mm.
HINVdd, where dd is the day, containing the estimated inversion height at 12 GMT, in m.

The geographical files are the following:
OROG, containing topographical data, in m.
Z0, containg roughness height data, in m.

All values are intended at the knots of the grid, with the convenction that the element (1,1) is the low left corner.

GEO contains the coordinates and spacing of meteorological and geographical matrixes, the pollutants characteristics and code parameters. REL contains release data. SAMP contains the coordinates of extra receptor points whee concentration and deposition are calculated in addition to the standard grid. In the following a list of the input variables for each file is given.

GEO

LAT0MET, LAT1MET, LON0MET, LON1MET
Minimum and maximum latitude and longitude of the meteorological grids (decimal degrees).

DELXMET, DELYMET
X-Y spacing of the meterological grids (decimal degrees).

LAT0TOP, LAT1TOP, LON0TOP, LON1TOP
Minimum and maximum latitude and longitude of the topography grid (decimal degrees).

DELXTOP, DELYTOP
X-Y spacing of the topography grid (decimal degrees).

LAT0Z0, LAT1Z0, LON0Z0, LON1Z0
Minimum and maximum latitude and longitude of the roughness grid (decimal degrees).

DELXZ0, DELYZ0
X-Y spacing of the roughness grid (decimal degrees).

LAT0RAIN, LAT1RAIN, LON0RAIN, LON1RAIN
Minimum and maximum latitude and longitude of the precipitation grid (decimal degrees).

DELXRAIN, DELYRAIN
X-Y spacing of the precipitation grid (decimal degrees).

LAT0CON, LAT1CON, LON0CON, LON1CON
Minimum and maximum latitude and longitude of the output concentration grid (decimal degrees).

DELXCON, DELYCON
X-Y spacing of the output concentration grid (decimal degrees).

ISLATGR, ISLATPR, ISLONGR, ISLONPR
Release point coordinates (degrees and primes).

ISTMON, ISTDAY, ISTHOU
Month, day, hour of the beginning of the release.

KALTT(I), I=1,100
Elapsed times from the beginning of required output (hours).

IDELT
Time step of a cycle for particles motion (hours)

ELEM(I), I=1,5
Strings identifying the pollutant species.

VDEP(I), I=1,5
Deposition velocities (m/s).

THALF(I), I=1,5
Half lifes (s)

NGEN
Number of particles to be generated each time step.

LEVW(I), I=1,7
Pressure levels of meterological data (hPa).

IFLAGW(I), I=1,7
Flag indicating the presence or absence of the vertical wind component w for a pressure level. If IFLAGW(I)=1, w is present for pressure level i.

IDELTMET
Time interval between successive meteorological data (hours).

KZ
Vertical eddy diffusion coefficient in the reservoir layer (m^2s^{-1})

REL

RATE(N,I),N=1,5,I=1,20
Release rate of species N at time interval I (g/s or Ci/s).

IRDAY(I),I=1,20, IRHOU(I),I=1,20
Day and hour of the beginning of release time interval I.

SHEIGHT(I),I=1,20
Effective height for time interval I.

2.3 - Output

The output of APOLLO consists, for each considered pollutant species, of four series of files containing the following analysis on the standard grid, at the required output times, for successive contour lines plotting:
Ieeeek, where eeee is the species and k is an index identifying the output time. I stands for Instantaneous air concentration (g/m^3 or Ci/m^3).
Teeeek, where eeee is the species and k is an index identifying the output time. T stands for Time-integrated air concentration (g s/m^3 or Ci s/m^3).
Deeeek, where eeee is the species and k is an index identifying the output time. D stands for total Deposition (dry+wet deposition) (g /m^2 or Ci /m^2).
Weeeek, where eeee is the species and k is an index identifying the output time. W stands for Wet deposition (g /m^2 or Ci /m^2).
The same analysis are provided at the extra receptor points specified in the input file SAMP.

In figs. 2 and 3 examples of particle display and countour lines patterns obtained with APOLLO simulating the Chernobyl episode, are shown.

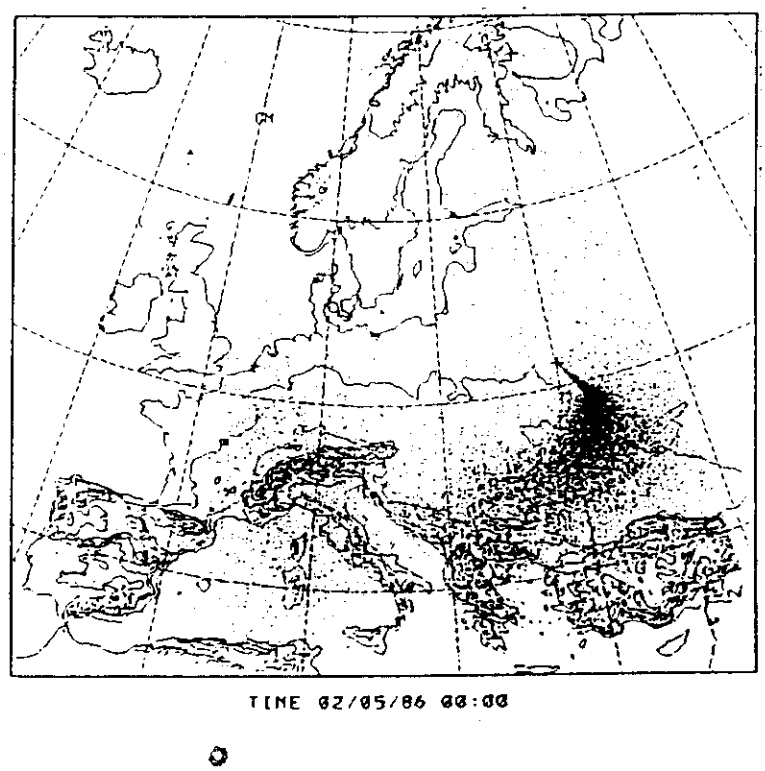

Fig. 2. - Particle display on the x-y plane for the Chernobyl simulation, 6 days after the beginning of the release.

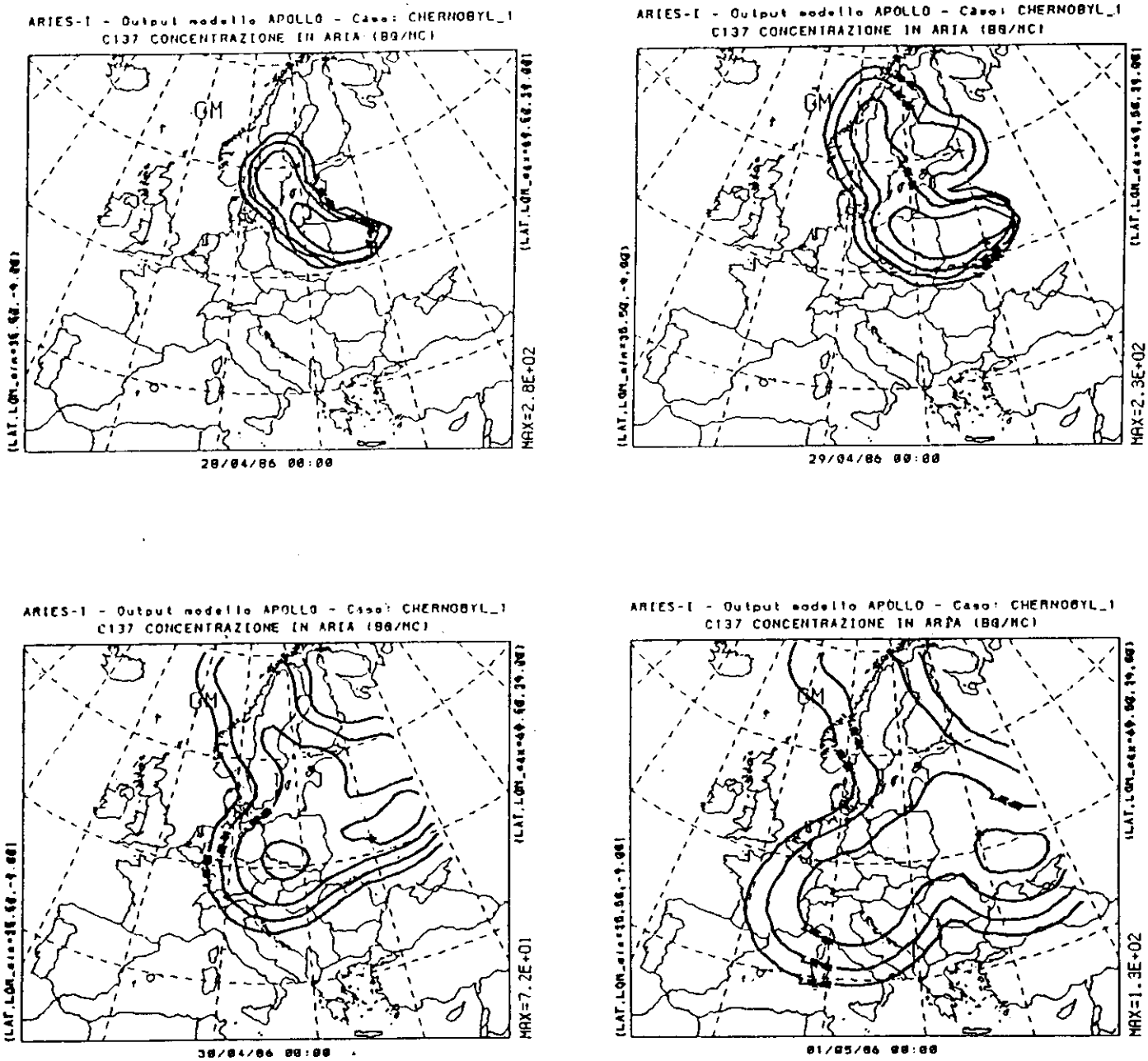

Fig. 3. - Sequence of Cs-137 isopleth patterns calculated by APOLLO 2,3,4 and 5 days after the beginning of the Chernobyl release. The levels of 10, 1, .1 and .01 Bq m^{-3} are plotted.

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