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A Brief Overview of Atmospheric Transport and Dispersion Models in the Environmental Emergency Response Section

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Trajectory

The trajectory model is a simple tool designed to calculate the trajectory of a few air parcels moving in the 3-D wind field of the atmosphere. The model is described in D'Amours & Pagé, 2001. Only transport by the winds is considered without taking into account any other physical or atmospheric processes, such as diffusion (turbulence), dry and wet deposition or gravitational settling. The advection of an air parcel is computed according to a time discretization scheme based on the Runge-Kutta method of order four.

The model estimates the trajectories of the parcels, originating from or arriving at the same geographic location, but for different levels in the vertical. The location and levels are defined by the user. The model can be run to obtain a quick estimate of the expected trajectory of an air parcel, whose point of origin or point of arrival (back trajectory) is specified as the input parameter.

MLDP0

MLDP0 (*Modèle Lagrangien de Dispersion de Particules d'ordre 0*) is a Lagrangian particle dispersion model of zeroth order designed for long-range dispersion problems occurring at regional and global scales and is described in details in D'Amours & Malo, 2004. Dispersion is estimated by calculating the trajectories of a very large number of air parcels (or particles). Large scale transport is handled by calculating the displacement due to the synoptic component of the wind field and diffusion through discretized stochastic differential equations to account for the unresolved turbulent motions. Vertical mixing caused by turbulence is handled through a random displacement equation (RDE) based on a diffusion coefficient. This coefficient is calculated in terms of a mixing length, stability function, and vertical wind shear. Lateral mixing (horizontal diffusion) is modeled according to a first order Langevin Stochastic Equation (LSE) for the unresolved components of the horizontal wind (mesoscale fluctuations).

MLDP0 is an off-line model and uses the full 3-D meteorological fields provided by a Numerical Weather Prediction (NWP) system. Therefore fields of wind, moisture, temperature and geopotential heights must be provided to the model, which are obtained either from the GEM model forecasts and objective analysis systems in Global, Regional or high resolution configurations.

Dry deposition is modeled in term of a deposition velocity. The deposition rate is calculated by assuming that a particle contributes to the total surface deposition flux in proportion to the tracer material it carries when it is found in a layer adjacent to the ground surface. Wet deposition will occur when a particle is presumed to be in a cloud. The tracer removal rate is proportional to the local cloud fraction.

The source term is controlled through a sophisticated emission scenario module which takes into account the different release rates of several radionuclides over time. For volcanic eruptions, a particle size distribution can be used to model the gravitational settling effects in the trajectory calculations according to Stokes' law. The total released mass can be estimated from an empirical formulas derived by Sparks *et al.*, 1997, and Mastin *et al.*, 2009, which is a function of particle density, plume height and effective emission duration (Malo, 2011).

In MLDP0, tracer concentrations at a given time and location are obtained by assuming that particles carry a certain amount of tracer material. The concentrations are then obtained by calculating the average residence time of the particles, during a given time period, within a given sampling volume, and weighting it according to the material amount carried by the particle. Concentrations are expected to be estimated more accurately near the source with a Lagrangian model than with an Eulerian model.

MLDP0 can be executed in few different configurations. The model operates on a polar stereographic grid and can run on both hemispheres. The grid size and resolution define the geographical domain. Five horizontal grid resolutions are available: 50 km (687×687), 33 km (229×229), 15 km (503×503), 10 km (229×229) and 5 km (457×457). A global configuration also exists at horizontal resolution of 1° (360×181). MLDP0 can be executed in inverse (adjoint) mode. The model has been used extensively in this configuration in the context of the WMO-CTBTO cooperation. The vertical discretization is made for 25 levels in the SIGMA, ETA or HYBRID terrain following coordinates depending on the version of the GEM NWP model used.

The model can be used for several types of applications:

- Medium range problems (from 10 to 100 km)
- Long range problems (>100 km, up to ~10^4 km)
- Simulations up to 10 days in forecast mode (up to 30 days in hindcast mode)
- Complex meteorological conditions & topography
- Volcanic eruptions
- Nuclear accident (multiple radionuclides)
- Foot-and-Mouth Disease (FMD) virus
- Toxic material fire, chemical release
- Forest fire, sand dust storm

MLDP1

MLDP1 (*Modèle Lagrangien de Dispersion de Particules d'ordre 1*) is a full 3-D first order Lagrangian particle dispersion model presently applied to problems on horizontal domains of 100-200 km, with a time horizon of about 12 h. This short range stochastic dispersion model is well described in Flesch *et al.*, 2004. In this off-line model, the fluctuating components of the turbulent wind are obtained by partitioning the Turbulent Kinetic Energy (TKE) calculated in the driving NWP models. Concentrations are expected to be estimated more accurately near the source with a first order model. MLDP1 is parallelized and runs on several nodes on the IBM supercomputer at CMC. It uses both distributed and shared-memory standards. Distributed-memory parallelism is implemented with MPI (Message Passing Interface) library while shared-memory parallelism relies on OMP (Open Multi-Processing) directives.

The model can be used for several types of applications:

- Short, medium and long range problems
- Simulations up to 10 days in forecast mode (up to 30 days in hindcast mode)
- Complex meteorological conditions & topography
- Nuclear accident (multiple radionuclides)
- Foot-and-Mouth Disease (FMD) virus
- Toxic material fire, chemical release
- Forest fire, sand dust storm

MLCD

MLCD (*Modèle Lagrangien à Courte Distance*) is a Lagrangian Particle Model described in details in Flesch *et al.*, 2002, and was developed by the Department of Earth and Atmospheric Sciences of University of Alberta and with the collaboration of the Environmental Emergency Response Section. It is designed to estimate air concentrations and surface depositions of pollutants for very short range (less than ~10 km from the source) emergency problems at Canadian Meteorological Centre. As in MLDP0 and MLDP1, this 3-D Lagrangian dispersion model calculates the trajectories of a very large number of air particles. MLCD is a first order Lagrangian Particle Dispersion Model because the trajectories of the particles are calculated from the velocities increments, while MLDP0 is a zeroth order Lagrangian Particle Dispersion Model since the trajectories of the parcels are updated from the displacements increments.

The Langevin Stochastic Equation is based on the turbulent components of the wind associated to the turbulent kinetic energy (TKE). These fluctuating vertical and horizontal components are generated from a "user provided" set of wind observations (velocity + direction) time dependant through a “two-layer” model (Wilson & Flesch, 2004). For example, these wind observations can be obtained from a meteorological tower or from detailed real-time forecasts from NWP Global and Regional operational models. Wind profiles can change over time and vary in the vertical, but are horizontally uniform, which represents an important difference with MLDP0 and MLDP1 that use full 3-D meteorological fields.

MLCD can take into account the horizontal diffusion for unresolved scales operating at time scales longer than those associated to the TKE (meanders). The removal processes of radioactive decay, wet scavenging and dry deposition can also be simulated by the model. MLCD can be run in forward or inverse mode. Air concentrations and surface depositions can be calculated over five different types of grids (time-fixed or time-variable, constant or variable horizontal resolution, polar stereographic or cylindrical equidistant) and for specific layers in the atmosphere through a user specified list of vertical levels. Concentrations and surface depositions are more accurate near the source than for MLDP0.

The model can be used for several types of applications:

- Short-range problems (< 10 km)
- Simulations up to 12 hours (forecast or hindcast mode)
- Uniform meteorological conditions
- Flat and uniform topography
- Nuclear accident (single radionuclide)
- Toxic material fire, chemical release

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