THE DEVELOPMENT OF A PUFF DISPERSION MODEL FOR USE IN MODELLING SHORT TERM ACCIDENTAL RELEASES, BASED ON THE ADMS 4 MODEL: ADMS-STAR2

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Abstract: To help enable the United Kingdom Food Standards Agency to protect the food chain in the event of an accidental atmospheric release, it has funded the development of a puff dispersion model, called ADMS-STAR2, based on the existing ADMS 4. The ADMS-STAR2 model can be run using a range of input parameters or defaults within the model, dependant on the information available following a release. Meteorological inputs include basic surface derived observational data or full 3-D spatially and temporally varying NWP data. Thermal and explosive releases penetrating the boundary layer can be modelled. The use of FLOWSTAR within ADMS-STAR2 allows consideration of complex terrain effects, with deposition responsive to spatially varying surface roughness. Output options include isopleth display on *ArcGIS* of total ground deposition.

Key words: ADMS-STAR2, ADMS, puff model, dispersion, accidental release.

1. DESIGN PHILOSOPHY

The Food Standards Agency in the United Kingdom has a requirement to model the deposition to the food chain following the atmospheric release of pollutants, especially radionuclides. The human food chain can often be the critical exposure pathway. The Food Standards Agency uses dispersion models to provide an initial indication of the potential impact on the food chain, forming a basis for the issuing of precautionary advice and as a guide to monitoring or possible food based restrictions.

For many years, the Food Standards Agency has utilised short range Gaussian based models, based of the R91 (Clarke, 1979) and ADMS (CERC, 1999 and CERC, 2007) models. These have been developed by the Food Standards Agency to optimise their ability to respond to Short Term Accidental Releases (STAR), including an ability to estimate source terms, by performing back calculations from monitoring results. R91STAR (CERC, 2004a) and ADMS-STAR (CERC, 2006) are examples of these models. As with all simple Gaussian based models, these rely on single source static meteorological conditions with dispersion limited to below the boundary layer.

Although basic models, such as R91STAR and ADMS-STAR provide a very quick and initial indication of possible deposition, their application is very limited with respect to the nature of the release and the effects of the terrain. The Food Standards Agency, therefore, had a requirement for a dispersion model that would be able to predict the deposition from large thermal releases or explosions and in regions of complex terrain, as well as an ability to utilise spatially and temporally varying meteorological data. However, given that data can often be very limited in the early stages of an accidental release, it was considered essential that the model be very flexible in its input data requirements. Conversely, for significant fixed sites, such as nuclear power stations, it was recognised that pre-planning enables the creation of site specific geographical data files, such as topography and surface roughness, which can be exploited by advanced features of a model.

2. REQUIREMENTS OF THE MODEL

Features of the model considered essential were:
- the capability to model instantaneous and extended releases;
- the modelling of dispersion below and above the boundary layer;
- the use of spatially and temporally varying meteorological parameters;
- modelling of both gaseous and particulate releases;
- spatially varying surface features, including topography;
- the determination of air flows in regions of complex terrain;
- both forward and back calculations, using monitoring data, for source estimation;
- inclusion of radionuclide decay terms;
- output of deposition isopleths to GIS software, optimised to food chain intervention levels.

However, it was also considered important that the model:
- can be used in a basic smooth plane mode with constant surface parameters;
- can run with meteorological data, ranging from single point source to three dimensional numerical weather prediction (NWP) data;
- can run with default values of parameters where user specified ones are unavailable;
- has a familiar (*MS Windows* style) user interface to minimise training requirements;
- has output options accessible without the requirement for GIS software.

It was also decided that the model would not contain explicit source terms, but would rely on empirical estimates of source temperature (in the case of a fire), TNT equivalent (for an explosion) or observed height of plume rise, using information available from the emergency services or other qualified agencies.

After consideration of a range of existing models, it was decided that development of the existing ADMS-STAR model would provide the best solution to the above requirements, especially as members of the Agency's emergency response teams were familiar with the existing ADMS and ADMS-STAR models. Development was undertaken in collaboration with Cambridge Environmental Research Consultants (CERC) Ltd., with the new model being named ADMS-STAR2.

3. TECHNICAL DESIGN

Many technical aspects of the ADMS-STAR2 model design exist within the ADMS 3 and ADMS 4 models, although some are utilised in different ways. This paper concentrates on those aspects of ADMS-STAR2 which are different to existing ADMS based models, whilst giving an overall description of the model.

Meteorological Data

The user may enter a range of meteorological data. In its simplest mode, this will be surface based observational data for a single location, similar to the format required by the standard ADMS model (CERC, 1999 and CERC, 2007), entered by the user in the model interface. A total of 72 lines of meteorological data can be entered, with a minimum resolution time of 30 minutes. ADMS-STAR2 can also be run using meteorological data files derived from NWP generated data. A total of 27 parameters are used in this format. The user may select data of different resolutions, appropriate for the size of the modelling domain, with no limit on the number of data points. Typically, with NWP data supplied by the UK Met Office a resolution of either 4 km or 12 km would be used, with data points in a grid format.

The NWP derived data files may be spatially and temporally varying within a maximum modelling domain of 3,000 x 3,000 km (although much smaller domains would normally be selected). Below the boundary layer, the meteorological parameters used are the same as those generated by the meteorological processor of the ADMS-STAR2 model using single lines of meteorological data. This enables local observational data to be entered at the release point, thus enabling local meteorological conditions (such as winds) to be represented if the user considers these significant. The model 'relaxes' from the observed data to the NWP data using a linear interpolation method.

Dispersion

A release is modelled using a finite puff (CERC, 2003). For a prolonged release, a series of puffs are released. The puff duration may be defined by the user, along with the time steps between puff releases (the default values of which are 60 seconds in both cases). This helps the user control the run-time of the model (the model provides the user with an option to determine an indicative run-time based on these parameters prior to running). The boundaries of a puff are Gaussian in behaviour, and determined by the local turbulence parameter values. Where spatially varying meteorological data is used, puffs respond to the mean wind flow and turbulence parameter values at the centre of the puff. If a plume rises partially above the boundary layer, it splits and becomes two discreet puffs.

Mean air flow in regions of complex terrain may be modelled using the FLOWSTAR model (CERC, 2004b). FLOWSTAR calculates profiles of the mean air flows and turbulence parameters using linearised analytical solutions of momentum and the continuity equations. Digitised contour maps can be created for different sized domains. For small domains, individual hills may be modelled, but for larger domains, resolution may be down to hill ranges. Within the FLOWSTAR domain, dispersion is governed by the parameter values derived by the model. Outside of the FLOWSTAR domain, dispersion is governed by the input parameter values. Between these two regions, there is a transition zone, where the parameter values are calculated by linear interpolation between the values at the edge of the FLOWSTAR domain and those in the simple terrain.

The ADMS-STAR2 model also includes the Marine Dispersion Model developed for the ADMS 4 model (CERC, 2007). This enables dispersion across a marine area (i.e., within a marine boundary layer) to be modelled. This makes use of the Charnock parameter, along with air and sea surface temperatures, to determine the marine boundary layer characteristics. Wind speed and surface roughness are interdependent. However, at present the model cannot combine complex terrain and marine dispersion in a single run.

Some surface parameters may also be spatially variable, should the user so select. These include surface roughness, which can be entered through a surface parameter file. For a fixed site, this enables the production of pre-prepared surface parameter files with seasonal variable values. The variable surface roughness is important, since it allows the model to determine variable stability parameters and because deposition within the model can be responsive to surface roughness.

Deposition

The user may select whether the dry deposition velocity is 'standard', user specified or 'calculated'. The standard dry deposition velocity uses the default values within the model over the whole modelling domain. If the user has more specific knowledge about the possible deposition velocity, the user may specify a value; again for use over the whole domain. If a 'calculated' deposition velocity is selected, the deposition velocity is dependant on both pollutant and surface parameters. For a particulate, this includes particle density and size (with the user able to enter up to 10 particle sizes for a given pollutant) and is responsive to surface roughness and turbulence. Gravitational settling and resistance components are determined, with the latter responsive to friction velocity. Gaseous deposition is determined by resistance only, with the model assigning different values of surface resistance for reactive, non-reactive and inert (noble) gases, of 30, 1000 and infinite sm[-1], respectively (CERC, 2005). For wet deposition, a wash-out coefficient approach is adopted (CERC, 2000a).

Radionuclides

The model contains a large database of radionuclides, with details of the half-life, daughter products and standard (default) deposition velocities. For each radionuclide, the relevant surface deposition which would lead to Maximum Permissible Levels (MPLs) of the radionuclide being reached, in a range of food types, are also included. The decay of radionuclide and daughter production are modelled (CERC, 2000b). The user may also enter a User Defined pollutant, specifying a 'half-life' (or residence time) and a specified deposition velocity, as well as specifying whether it is a particulate or gas. The user may also specify a contour level for a total deposition, equivalent to an MPL or other trigger level.

Thermal and Explosive Releases

It was decided at an early stage in the design of ADMS-STAR2 that explosive and fire source terms would not be included within the model. This was due to the lack of reliable data in open sources for the potentially very wide range of complex scenarios and the potential for a false sense of certainty that could be generated. However, the flexibility of the model input options allow the model to be run with either observed (or estimated) data, or pre-prepared data options. The model user's knowledge is important in this respect.

For an explosive release, the model requires the user to enter the mass (or total activity for a radionuclide) of dispersed material and either a TNT equivalent of explosive, or a cloud top height. More than one dispersed material can be entered and may be particulate or gaseous. For a particulate material, up to ten particle and mass fractions can be entered. If an explosive release penetrates the boundary layer, it is modelled using a stem and cap approach (Deave, D. M. and C. R. Hebden, 2004), with the user either selecting default mass particle fractions within the cloud, or ones defined by the user. The stem and cap segments are then modelled as discrete puffs. For releases contained within the boundary layer, a uniform vertical distribution is assumed.

When modelling a thermal release (a fire), the user can enter either a vertical velocity or plume height, along with a source temperature. However, the model assumes an open fire and makes no allowance for the effects of containing buildings or entrainment. Whereas an explosive release is modelled as an instantaneous release, a thermal release is treated as an extended one, consisting of a series of puffs. To represent the possible fluctuation of the pollutant release with changing fire conditions (or pressure, as may be the case with a power station de-pressurisation, for example), variable release rates can be modelled. As with ADMS 4, this is based on a relative release rate (CERC, 2007).

Back calculations

An important aspect of the ADMS-STAR2 model, is its ability to back calculate and estimate a source term, based on monitoring data. This approach was originally developed with the R91STAR and ADMS-STAR models (CERC, 2004a and CERC, 2006). Both ground level air concentration and deposition monitoring results can be entered by the user. In both cases, the model back calculates the dispersion and estimates the source term; the model then uses this to forward calculate dispersion and deposition. If several monitoring results are entered, a mean value of the source term is calculated and used for the forward dispersion. If the pollutants are radionuclides, the effects of radioactive decay are allowed for within the back calculation.

Monitoring data can be entered either directly into the model or into an *ArcGIS* database. In the latter case, monitoring results from our associated laboratories can be bulk entered directly, in the form of an *MS Excel* spreadsheet. The user can then select data for use by the ADMS-STAR2 model, with data being validated by the interface software prior to import. In addition to the sampling location and time, multiple analytical results can be entered. This is particularly important with a radiological release from a nuclear site, where a significant range of radionuclides may constitute the release.

Output

The ADMS-STAR2 model predicts the total ground deposition of those pollutants entered into the source term. If radionuclides are being modelled, then daughter products may also be included in the output. There are several forms of output from the model the user can access. The user can select a meteorological output file at a user selected location. This has the value of helping the user to interpret what may appear as unusual results at the selected

location. Output file options also include the instantaneous ground level air concentrations at specified receptor points, for the end of each meteorological run step, along with the total deposition up to that time step. Also, total deposition predictions can be displayed graphically at ten degree intervals, as a function of distance. However, due to the use of spatially and temporally varying meteorological data, the prime form of output is to *ArcGIS*. As the Food Standards Agency is concerned with deposition to the food chain, the model produces isopleths which correspond to those levels of deposition which may result in the MPLs being exceeded. When running the model, the user can select to determine isopleths appropriate for a single nuclide (or group of nuclides, such as the iodine group) and selected primary food types (milk, cereals, fruit, leafy vegetables, etc.) or a range of nuclides for a chosen food type. However, the user can also define a range of values for the isopleths. This is particularly relevant if modelling the release of a user defined non-radioactive pollutant. An example of the model output in the *ArcGIS* format is given in Figure 1.
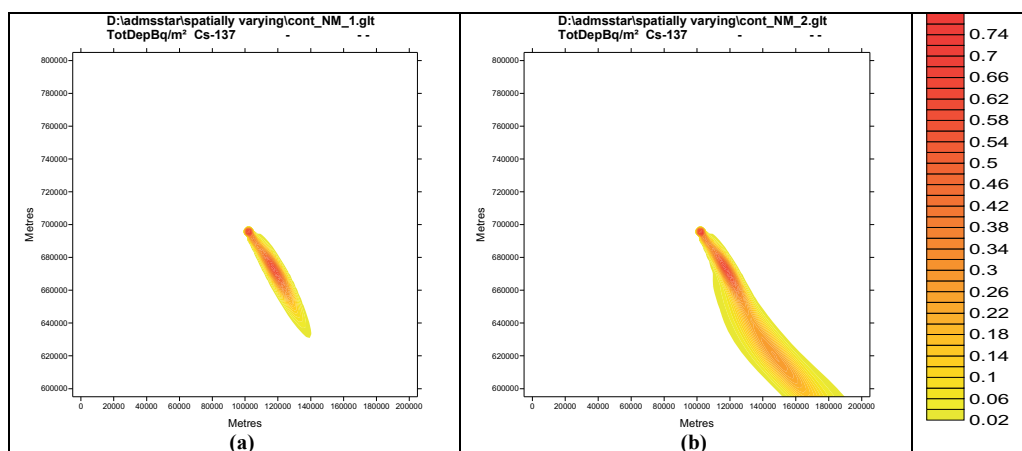

Figure 1. An example of ADMS-STAR2 output in *ArcGIS*, showing total deposition after (a) one hour and (b) two hours, using NWP meteorological input data.

Future Development

At the time of writing, the ADMS-STAR2 model is still in its final stage of completion as a beta version. After completion of acceptance testing, it is envisaged that a significant programme of validation studies will be undertaken, along with sensitivity studies and model comparisons. As many aspects of the dispersion algorithms have been validated through ADMS 3 and ADMS 4 studies (CERC, 2008), primary emphasis is likely to focus on thermal and explosive releases penetrating the boundary layer, as well as the impact of the use of NWP meteorological data on predictions. However, the Food Standards Agency considers that the ADMS-STAR2 model will remain a live model subject to future up-grades and development.

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