FURTHER AFIELD TRANSPORT OF SPRAY DRIFT USING A COUPLING APPROACH

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Abstract: Air dispersion modelling of pesticide spray drift is critical to estimate possible population exposure or impact on vegetation not targeted by the spraying. Through a spraying application, droplets of different sizes are created. Because of their size and the altitude of release, most droplets tend to deposit locally within the targeted area. However, a small percentage of the droplets in the finest size of the distribution might stay longer in the atmosphere and has the potential to be transported offsite. Measurement studies (Stoughton et al., 1997, Miller and Stoughton, 2000) have demonstrated that under certain conditions small droplets can be dispersed through the atmospheric boundary layer and transported over longer distance. In an effort to explore the possible transport of pesticide spray drift further afield than the targeted area, the strong assets of two models, the USDA Forest Service AGDISP spray model and the CALMET/CALPUFF dispersion modelling system are combined. The capabilities of AGDISP model to define the drop size distribution of the material, to take into account the impact of the vortices created by the plane on the droplet distribution and to simulate the evaporation of the sprayed material provides a well defined source term for CALPUFF model. The capabilities of the non-steady-state CALMET/CALPUFF modelling system to simulate and take into account the temporal and spatial variability of meteorological parameters such as wind, temperature, atmospheric stability and mixing height along the path of the material allows the extension of the impact range of AGDISP model further afield. Meteorological outputs from CALMET model are transferred to AGDISP and outputs of AGDISP are used as source information for CALPUFF dispersion model. Sensitivity tests on the input data and how they are transferred from one model to the other are described. Recommendations on the choices to define the transitional parameters between the two models are drawn from that study.

Key words: *Air Dispersion, Spray Drift, AGDISP, CALPUFF, Exposure*

INTRODUCTION

Aerial spraying is used for various types of pesticides / insecticides applications with different goals. For pesticides spraying to protect crops against pests or invaded plants, the spray material is aimed at being deposited right in the area where it is sprayed, limiting how much spraying drifts off target. For mosquito control spraying, the goal is to keep a droplet suspended long enough above the area of mosquito proliferation to have a chance for mosquitoes to be reached by it while flying. The droplet sizes are then in the smaller side of the spectrum (25-40 μm) to make sure they stay aloft for a certain period of time. Such small droplets are subject to travel further afield if the atmospheric conditions change before the material deposits. For other insecticides spraying such as in forest areas, the droplet sizes are larger (80-125 μm) to be able to deposit in the targeted canopies.

The impact to off target vegetation and human exposure consequences of pesticides spraying are still under study. Research focuses on understanding the doses and concentrations of material that can be transported further afield and how far the transport occurs from the spraying area. There has been evidence of long-range transport of pesticides. For example, Muir et al. (2004) measured traces of pesticides in lakes in Canada and Eastern United States and the characteristics of the components measured show that they had not been sprayed locally, but from 50 km away or more. Hageman et al. (2006) measured current-use and historic-use pesticides in snow at National Parks in the Western United States. Since most of the pesticides measured were not used directly in the National Parks, one of their conclusions was that it demonstrates a potential transport of pesticides by the atmosphere and deposition by precipitation in the Parks. Stoughton et al. (1997) and Miller and Stoughton (2000) have demonstrated from measurements that in certain conditions small droplets can be transported through the atmospheric boundary layer. On the other hand, Tsai et al. (2005) show that aerial spraying applied in control conditions provides a very limited number of events when some of the material deposits off target. The conditions when it happened were linked to changing wind. Their model evaluation against observations shows good results in the vicinity of the spraying area. The large size droplets application they were evaluating shows a rapid settling of the material. They acknowledge that for finer size droplets and for longer range transport impact, a capability of the model to compute evaporation would be necessary.

The current study describes the coupling of two models, AGDISP spray drift model and the CALMET/CALPUFF modelling system. We are focusing on the input / output of each model and how to optimize the transfer of data from one model to the other and the sensitivity of the results on the choices made. Since no comparisons are made with measurements at this stage, we are evaluating which parameters can potentially change the impacts at determined distances from the source. The weather conditions are taken into account in the analysis. Selected meteorological parameters are transferred from CALMET to AGDISP for use in determining the fraction of the application leaving the target area. Outputs from AGDISP are then used to define the sources to be used as input for the CALPUFF simulations. One decision is to define the transport distance (called hereafter the "handoff distance") for extracting AGDISP outputs to be used to define the source for CALPUFF. We are also evaluating whether the resolution of information provided to CALPUFF can affect the dispersion of the material. Sensitivities to the proportion of evaporative material, the drop size distribution, and the weather conditions are examined.

As this is a large area of research, the current work focuses on studying the simulation of pesticides drift emitted during aerial spraying applications. Other possible sources of pesticides for long-range transport can be pesticides deposited on plants re-evaporated in the atmosphere or pesticides deposited on sand/dust re-entering the boundary layer in certain wind conditions and transported further but this is not in the scope of the current study.

MODELS DESCRIPTION

AGDISP spray drift model

The AGricultural DISPersion (AGDISP) model developed by Bilanin et al. (1989) is a near-wake model based on a Lagrangian approach to the solution of the spray material equations of motion, and includes simplified models for the effects of the aircraft wake and aircraft-generated and ambient turbulence. It is developed mostly by the USDA Forest Service and is used for estimating spray deposition and drift in agricultural spray dispersion in the vicinity of the spraying area. AGDISP is a model that can predict the motion of spray material released from aircraft and from ground sprayer booms. AGDISP is a droplet evaporation model, which uses a single evaporation constant for active, additive and carrier components of the aerial spray. In AGDISP, the active fraction of an individual droplet (whose movement is predicted by a set of Lagrangian trajectory equations) changes as the droplet evaporates. Evaporation effects are included from both the active and additive ingredients, as well as the carrier. Only a single rate of evaporation, applicable for all three components of the spray mix (active, additive, and carrier), is currently programmed into the model. AGDISP model has been evaluated against field observations for aerial spraying (Bird et al. 2002). It is applicable to the region in which the aircraft wake is expected to have influence over the behaviour of the released spray material. Previous studies (Bird et al., 2002 and Teske and Thistle, 2003) stated that within 300m, assumptions such as elliptical wing loading, vortex decay, and simple water-like evaporation are valid. Beyond such distance, other physical effects are present and not modelled by AGDISP due to the fact that it is driven by single point steady state meteorology.

CALMET / CALPUFF modelling system

CALMET is a diagnostic meteorological model (Scire et al., 2000a) that produces three-dimensional wind fields based on parameterized treatments of terrain effects such as slope flows, terrain blocking effects, kinematic effects and vertical wind shear effects. It uses available sources of meteorological and geophysical information to produce a spatially varying wind field that is consistent with the local terrain and land use features and atmospheric stability conditions. Either meteorological observations data from measurements and/or outputs from prognostic models can be used as input to CALMET.

CALPUFF is a non-steady-state Gaussian puff dispersion model (Scire et al., 2000b) developed to be suitable for use in the near-field at distances of tens of metres out to distances of several hundred kilometres. It includes near-field effects, such as transitional plume rise, momentum and buoyant plume rise, as well as far-field effects. CALPUFF accounts for spatial changes in the meteorological fields provided as input, variability in surface conditions (elevation, surface roughness, vegetation type, etc.), chemical transformation, wet removal due to rain and snow and dry deposition, and terrain influences on plume interaction with the surface. CALPUFF has also the ability to treat non-steady-state features such as calm wind conditions, stagnation, recirculation, plume fumigation, spatial in-homogeneities, causality effects, multiple hour emissions accumulations and sub-hourly capabilities. CALPUFF has been evaluated against a number of field studies with very good results. The following technical considerations made the capabilities of a model such as CALPUFF the model of choice to couple with AGDISP for simulating the effects of pesticides spraying off targets in the vicinity of the spraying and further afield:

- CALPUFF contains puff sampling routines. For near-field applications during rapidly-varying meteorological conditions, an elongated puff (slug) sampling function may be used. An integrated puff approach is used during less demanding conditions. Both techniques reproduce continuous plume results under the appropriate steady state conditions.

- CALPUFF contains an optional puff splitting algorithm that allows vertical wind shear effects across individual puffs to be simulated. Differential rates of dispersion and transport among the “new” puffs generated from the original, well-mixed puff can substantially increase the effective rate of horizontal spread of the material.

- A full resistance model is provided in CALPUFF for the computation of dry deposition rates of gases and particulate matter as a function of geophysical parameters, meteorological conditions, and pollutant species. And an empirical scavenging coefficient approach is used to compute the depletion and wet deposition fluxes due to precipitation scavenging. The scavenging coefficients are specified as a function of the pollutant and precipitation type (i.e., frozen vs. liquid precipitation).

Coupling approach

Previous studies have involved the combination of AGDISP and CALPUFF for simulating aerial spraying of pesticides / insecticides. Thistle et al. (2005) discussed how AGDISP outputs can be used as a source for an air dispersion model such as CALPUFF. Bond et al. (2011) discussed how AGDISP and CALPUFF can be combined to be used for Public Health operations with regards to controlling adult mosquito population insecticide spraying in Florida. In the current study, we are looking at the sensitivity of the results concentrations to the data inputs and data transfer from one model to the other. AGDISP requires meteorological information and provides data to calculate a source term for CALPUFF dispersion model.

Meteorological data necessary for AGDISP modelling are extracted from the CALMET simulation and passed to AGDISP. Wind speed, temperature, relative humidity and stability criteria are the parameters needed. AGDISP produces a discrete distribution of the droplet sizes still airborne at a selected distance from the spraying area, the volume of material in each droplet categories and the percentage of material still airborne at that distance. This information is passed to CALPUFF and is used to define the source terms available for air transport.

The coupling of the two models allows a detailed simulation of the near wake (with AGDISP) in combination with the transport at greater distance incorporating real time meteorological data and/or prognostic fields (with CALPUFF). In the current study, prognostic data only from MM5 model are used as input to CALMET model.

A number of decisions need to be made on the transfer of data from AGDISP to CALPUFF. One is to determine at which ”handoff distance” the Droplet Size Distribution (DSD) and the fraction of material aloft are extracted from AGDISP. The sensitivities of the concentrations simulated to different extraction “handoff distance”, to the detail of the DSD, to the percentage of volatile material and to the weather conditions (relative humidity, stability conditions, and wind speed) are tested.

RESULTS

A CALMET/CALPUFF modelling domain of 40 x 40km is set up in a relatively flat terrain environment, centred on the source location, a field of 350m by 700m. The resolution of the domain grid size is 500m. Gridded receptors are placed on the entire domain and discrete receptors are placed in circles at distances of 500m, 1 km, 1.5 km, 2 km, 5 km and 10 km from the centre of the field. A pool of 47 events, with different meteorological conditions in terms of wind speed, relative humidity, temperature and stability classes are selected. Hourly meteorological prognostic outputs from MM5 model as a 12 km resolution are used as input to CALMET and process to provide 3-dimensional field at a 500m resolution. For uniformity, one aircraft type, a AT-802, with its default characteristics described in AGDISP and one Droplet Size Distribution (DSD), the reference ASAE Fine to Medium (VMD=254.74 μm, relative span=1.3), a spectrum covering droplets sizes from 10.77 μm to 1201.66 μm are selected. The no canopy option has been chosen. The parameters to be varied are the “handoff distance” for AGDISP data extraction, the material evaporative property, the meteorological conditions, the release height and the detail of the DSD to be passed to CALPUFF.

The “handoff distance” extraction distance

Previous studies (Bird et al., 2002 and Teske and Thistle, 2003) evaluated that after 300m, the solution process should be controlled by the background meteorology as discussed earlier. We are testing this evaluation by comparing extraction of output data to be transferred to CALPUFF at an AGDISP “handoff distance” of 200m, 300m and 400m. The concentrations transported by CALPUFF to 500m are the largest for the AGDISP extractions at 200m, a bit less for the extraction at 300m and even lesser for extraction at 400m. However, the difference of concentrations tends to attenuate for a larger distance from the source, for example 10 km-sampled CALPUFF concentrations using AGDISP extractions at 200mn 300m or 400m are not as different as it was at 500m, especially for larger relative humidity values. Both when using evaporative material (75% volatile) or less evaporative (25% volatile), the emissions for CALPUFF are larger using a Handoff distance of 200m than 400m. More material had the time and space to deposit for a handoff distance of 400m.

Percentage of evaporative material

Three percentages of volatile material are tested in the current study: A 75 percent volatile, 50 percent volatile and 25 percent volatile. In all three tested material the active material represents 25 percent.

For the DSD used in this study, ASAE Fine to Medium (VMD=254.74µm, relative span=1.3), the percentage of evaporative material does not significantly impact the maximum droplet size or the median of the DSD to be passed to CALPUFF. The minimum droplet size is slightly smaller for 75 percent volatile than for 50 percent and 25 percent volatile material. The percentage of volatile material affects more largely the percentage of drift left aloft and hence the emission value to be calculated and passed to CALPUFF. More volatile material generates a larger fraction left aloft than a less volatile material.

Level of detail of the DSD to be passed to CALPUFF

Tests are performed on the level of detail of the AGDISP outputs passed to CALPUFF with regards to the size of the droplets. In one case, the median size diameter of the DSD is passed as a single species in CALPUFF (called single particle size method hereafter). On the other hand, the number of species corresponding to the number of bins of 10 microns range from 0-10 microns, 10-20 microns, etc... up to the largest bin range needed, defining the entire DSD (called detailed particle sizes method hereafter). In CALPUFF, dry and wet deposition modules can be activated, which handle differently each species based on their size characteristics. The results show little impact if one method or the other is used for CALPUFF concentrations sampled at 500m distance from the source. While for the CALPUFF concentrations sampled at a 10 km distance from the source, the detailed particle sizes method displays significantly larger concentrations than the single particle sizes method, more noticeably for larger relative humidity and stable conditions.

Release height

Tests on release heights of 22 ft and 8 ft were performed. The concentrations simulated at 500m from the source and 10 km from the source are significantly impacted by the release height of the aircraft as expected, much lower concentrations are simulated off target and further afield for the 8 ft release height.

CONCLUSION

This study was testing the sensitivity of the simulated concentrations at a number of distances from the spraying area to the input data and the data transfer carried out from one model to the other in the coupling of AGDISP model and CALMET/CALPUFF modelling system. It shows how the concentration simulations at longer range are sensitive to the characteristics of the material sprayed itself but also to the meteorological conditions. It also shows how quickly the concentrations decrease as the distances from the source increase. Only, a maximum of 6% of the concentrations at 500m is simulated at 10km within the meteorological conditions selected.

The results of the study showed the importance of using a model such as AGDISP to define the source for CALPUFF to treat the droplet evaporation process and take into account the aircraft wake and provides a detail drop size distribution and airborne drift, which are affected by both process. The importance of CALPUFF has also been shown as it can take into account the variability in the meteorological conditions as the material is transported further afield.

For the coupling of the two models, AGDISP and CALPUFF to simulate long-rang transport of pesticides aerially applied, it is recommended to use meteorological parameters representative of the local conditions during the spraying period for input into AGDISP and a detail DSD represented as a discrete number of size particles for species in CALPUFF rather than as a single size particle species., The latter has been shown to have a significant impact on the concentrations simulated at longer distance from the spraying area. The "handoff distance" contributes to discrepancies in the concentrations simulated both at 500m and 10km. Outside the validity distance of AGDISP, volatile material might still be subject to evaporation. We are suggesting the introduction of a droplet evaporation scheme in CALPUFF as a future work to palliate to the potential evaporation process outside the validity of AGDISP model. For non-volatile material, it is not as important.

The strengths of the two models combined in this approach create a tool that could be used to evaluate potential exposure and risk assessment in the vicinity of the spraying area and further afield. In addition, by using this tool in forecast mode, the spraying user might be able to select the weather conditions that is adapted to the type of spraying needed and limit to a minimum the off target impact or provide a buffer zone around the spraying area during the period of spraying.

This study is a work in progress. Further analyses are to be performed. For instance, an evaluation of the tool against observations should be performed as a first step. This study focused on aerial spraying, it could be evaluated how AGDISP / CALPUFF coupling can be used for ground spraying applications. And also, for very light wind speeds, it is important to consider sub-hourly time steps and the possible accumulation of material at some receptors, the capabilities of both AGDISP and CALPUFF allow such investigation.

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