8.3 FOOTPRINT DETERMINATION IN STABLE TO CONVECTIVE STRATIFICATION USING AN INVERSE 3D LAGRANGIAN PARTICLE MODEL

Natascha Kljun[1]*, Peter de Haan[2], Mathias W. Rotach[1], and Hans Peter Schmid[3]
[1]Institute for Climate Research, ETH, Zurich, Switzerland
[2]Infras AG, Bern, Switzerland
[3]Indiana University, Bloomington, Indiana

1. INTRODUCTION

Common micrometeorological techniques for determing a trace gas flux or concentration yield little information about the source location, since any source near the ground could potentially contribute to the measurement at a given receptor. In recent years, several models have been proposed to estimate the size of this upwind surface area of influence (footprint) for a measured flux or concentration; the footprint's dependence on the height of the measurement, the surface roughness, heterogeneous underlying surfaces, atmospheric stability and the turbulent velocity fluctuations has been discussed. However, most of the analytical models for footprint prediction (e.g. Schmid, 1997) are limited to the surface layer, whereas all the footprint models based on a Lagrangian particle model (e.g. Horst and Weil, 1992) fulfill the well-mixed condition only for one given stability regime.

2. MODEL DESCRIPTION

The present footprint model is based on the 3-dimensional Lagrangian Stochastic Particle Dispersion Model after Rotach et al. (1996) and de Haan and Rotach (1998). Using a so-called 'transition function', it satisfies the well-mixed condition continuously for stable to convective stratification, as well as for receptors above the surface layer (e.g., for use in connection with aircraft measurements).

The model employs a recently established approach using backward trajectories of particles (Flesch et al., 1995), i.e. the particles are tracked backwards in time, from the receptor location to the surface source. For each particle, initial velocity, as well as touchdown locations and velocities are collected. Using this model output, the flux footprint for a given receptor is determined according to Flesch (1996) (see Figure 1 as an example for unstable stratification). In the following, this model will be denoted as LPDM-B.

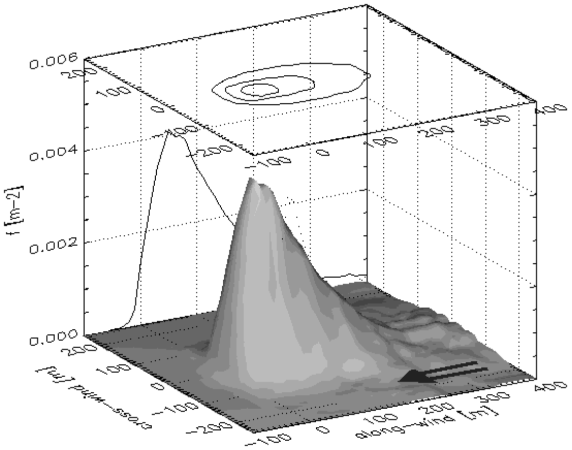

Figure 1: Footprint as predicted by LPDM-B for a measurement location at (0,0) at 20m height under unstable conditions. The wind direction is indicated by an arrow.

For the first time in a footprint model, a density kernel method is introduced following the suggestions of de Haan (1999). Locally optimized bandwidths are applied for appropriate smoothing depending on the particle density.

3. EVALUATION

It is difficult to validate a footprint model on observational data due to the very limited available data sets. Therefore, the approach is evaluated indirectly by comparing the model results with corresponding estimates of the well-established analytical footprint model FSAM (Schmid, 1997). Although FSAM is theoretically restricted to moderate stratification within the surface layer, it is often used under convective conditions, as no other simple model for unstable conditions exists so far.

4. DISCUSSION AND CONCLUSIONS

Usually, for interpretation of a particle model's output, the 'box method' is applied: laying a grid over the area of interest, counting the particles and summing their weight (in this case the footprint value)

Corresponding author address: Natascha Kljun, Swiss Federal Institute of Technology, Institute for Climate Research, Winterthurerstrasse 190, 8057 Zurich, Switzerland, e-mail: kljun@geo.umnw.ethz.ch

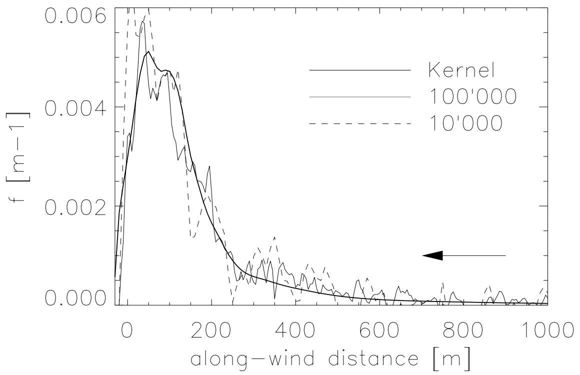

Figure 2: Crosswind integrated footprint predicted by LPDM-B using the kernel method for 10'000 particles (thick solid line) and the box method for 100'000 particles (thin solid line) and 10'000 particles (dashed line), grid spacing is 10m. Unstable stratification and receptor location at (0,0,20).

within the grid cells (boxes). This method shows strong dependence of the result on the selected grid spacing and on the number of particles released in the simulation. Figure 2 displays the difference of a crosswind integrated footprint predicted by simulations with a release of 10'000 and 100'000 particles, respectively. In both cases, a grid spacing of 10m is applied.

On the other hand, when using the kernel method, the footprint predicted by a simulation with 10'000 particles already shows a good correspondence to the simulation using the box method with 100'000 particles. Also, this footprint is much smoother and easier to interpret.

Simulations indicate that generally, FSAM and LPDM-B are in good agreement for a receptor within the surface layer (Figure 3). Unlike FSAM, LPDM-B predicts a small flux contribution downwind of the receptor location, especially for simulations under unstable and low wind conditions. This difference is due to the neglected longitudinal turbulence in FSAM. For high receptors, the footprints as yielded by the two models can considerably differ, especially if the receptor clearly lies above the surface layer (Kljun et al., 2000).

In conclusion, a footprint model based on a Lagrangian Particle Dispersion Model in a backward time frame (LPDM-B) is presented which is valid for the whole stability range between stable and convective and for receptor locations within the whole boundary layer. It is shown that applying the kernel method allows for a significant reduction in the number of simulated particles (and thus, saves a considerable amount of CPU time) for the same accuracy. Within the surface layer, the coincidence of the footprints predicted by LPDM-B and the analytical FSAM is satisfying. This is generally not the case for footprint predictions under conditions of extreme stability or outside (above) the surface layer.

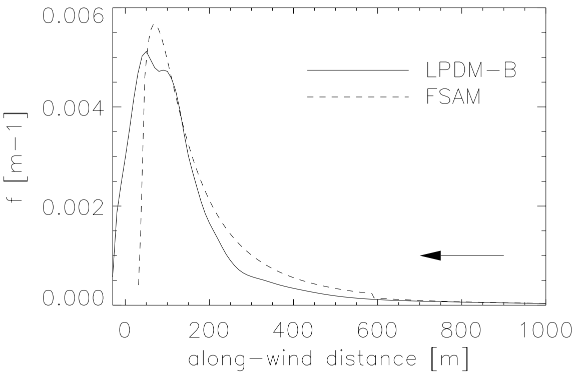

Figure 3: Crosswind integrated footprint predicted by LPDM-B (solid line) and by FSAM (dashed line) for unstable stratification. Receptor location at (0,0) at 20m height. The wind direction is indicated by an arrow.

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