4.15 A LAGRANGIAN FOOTPRINT MODEL FOR STRATIFICATIONS RANGING FROM STABLE TO CONVECTIVE

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1. INTRODUCTION

A quantitative description of the surface flux budgets of atmospheric trace gases on a regional scale is far from trivial, as any source near the ground could potentially contribute to a measured concentration or flux at a given receptor. The size of this upwind surface area of influence (footprint) for a measured trace gas flux or concentration is governed by the height of the measurement, the surface roughness, atmospheric stability and the turbulent velocity fluctuations.

Therefore, a model to predict the footprint of a measurement site should provide estimates under various environmental and experimental conditions (i.e., different measurement heights, thermal stratification and surface properties). However, most of the analytical footprint models are limited to the surface layer, whereas all the footprint models based on a Lagrangian particle model usually 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), satisfying 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 as in Desjardins et al., 1997).

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. The advantage of this model approach is the ability to get point estimates as particles coincide exactly in the measurement point. In the following, the model will be denoted as LPDM-B.

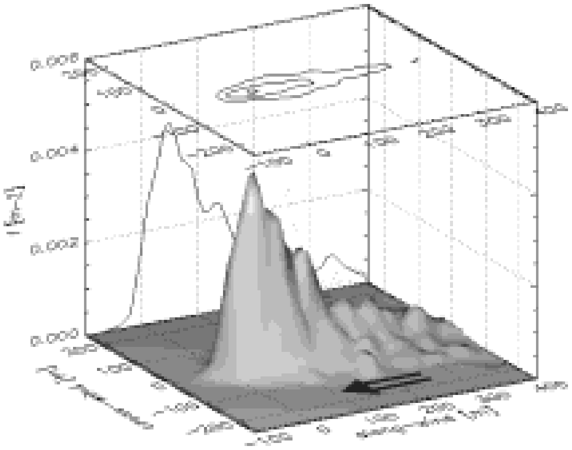

Figure 1: Footprint as predicted by LPDM-B for a measurement location at (0,0,20) under unstable conditions (case A in Table 1). The wind direction is indicated by an arrow.

For each particle, initial velocity, as well as touchdown locations and velocities are collected. Using this output, the flux footprint for a given receptor is determined according to Flesch (1996), giving an estimate of the relative importance of the sources in the upwind area to the measurement at the location of the receptor (see Figure 1 as an example for unstable stratification).

3. EVALUATION

For a so-called 'backward' model, the dependence of the simulated flux on the initial velocities is very high. Therefore, special emphasis must be given to the probability density functions of the initial velocities, as well as to their correlations (neutral and stable stratification). At first, initial velocities are attributed to each of the particles in such a way that

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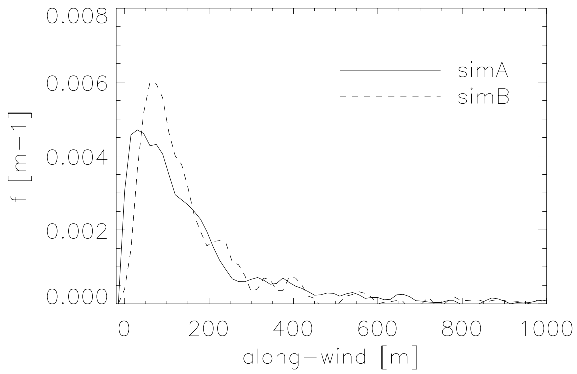

Figure 2: Crosswind integrated footprint calculated by LPDM-B for an unstable case and receptor height of 20m. Model run with (solid line, simA) and without warm-up loop (dashed line, simB). See text for further explanations.

their velocity probability density function approximately corresponds to that of the air at the sensor location. Then, during a 'warm-up loop', the particles are kept at the receptor location, still calculating the turbulence parameterizations (while setting the derivatives to zero). Thus, when the particles finally 'leave' the receptor, unrealistic velocity distributions caused by model artifacts are smoothed out and almost perfect density distributions are reached.

Figure 2 depicts the difference between a footprint simulation using 'warmed up' velocity distributions (simA) and a simulation run with the initial velocities given by the model itself (simB). The position of the maximum influence (peak of the footprint), as well as its magnitude can be significantly altered by starting with an imperfect velocity distribution. Note, that this is not a general property of Lagrangian Particle Dispersion Models (when used for [forward] dispersion calculations). Rather, this high sensitivity is due to the initial velocities being explicitly included in the footprint calculation (see Flesch, 1996).

It is difficult to validate a footprint model on observational data due to the very limited available data sets. Therefore, as a first step, 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. SIMULATIONS AND DISCUSSION

In this contribution, simulations are presented for a convective and a near-neutral case and receptor heights of 20 and 115m (see Table 1), using LPDM-B and FSAM, respectively.

The simulations indicate that generally, the two models are in good agreement within the surface layer (Figure 3a). 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.

Under neutral (Figure 3b) and stable (not shown) conditions, the difference between LPDM-B and FSAM is similar but more pronounced than in the unstable run. The peak of the footprint predicted by LPDM-B still is located close to the receptor, unlike the peak predicted of FSAM. Also, LPDM-B's footprint does not extend equally far upwind as the footprint of FSAM. Ongoing investigations will show whether this still is a model artifact due to the initial velocity distribution of LPDM-B or whether this difference is caused by the neglected longitudinal turbulence in FSAM.

For high receptors (Figures 4a,b), the footprints as yielded by the two models can considerably differ. In case A (Table 1) with a relatively low boundary-layer height, the receptor at 115m clearly lies above the surface layer. The footprint as obtained from FSAM (which in this case is applied outside its range of applicability) can be seen from Figure 4a to have a much higher peak closer to the receptor than LPDM-B. For case B in turn, both models yield similar footprints due to the justified assumptions of surface layer scaling in FSAM. We conclude that the application of a footprint model which is restricted to the surface layer through its assumptions may lead to erroneous estimates when applied for too high receptors.

		u_*[m/s]	w_*[m/s]	z_i[m]	L[m]
A	unstable	0.7	2.3	810	-56
B	near-neutral	0.8	1.9	2090	-289

Table 1: Stability description for case A and case B.

5. SUMMARY AND CONCLUSION

A footprint model based on a Lagrangian Particle Dispersion Model is presented which is valid for the whole stability range between stable and convective and for receptor locations within the whole boundary layer. The model employs the backward trajectory approach according to Flesch et al. (1995). It is shown that with this approach, the resulting footprints are sensitive to the initial velocity distribution of particle velocities. Furthermore it is shown that footprints differ from those obtained using an ana-

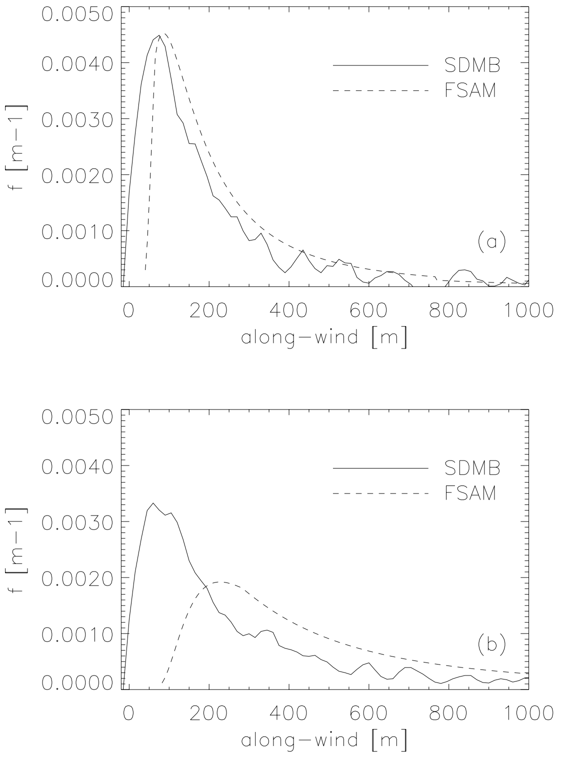

Figure 3: Crosswind integrated footprint predicted by LPDM-B (solid line) and FSAM (dashed line) for (a) unstable stratification, case A and (b) near-neutral stratification, case B. Receptor location at (0,0) at 20m height.

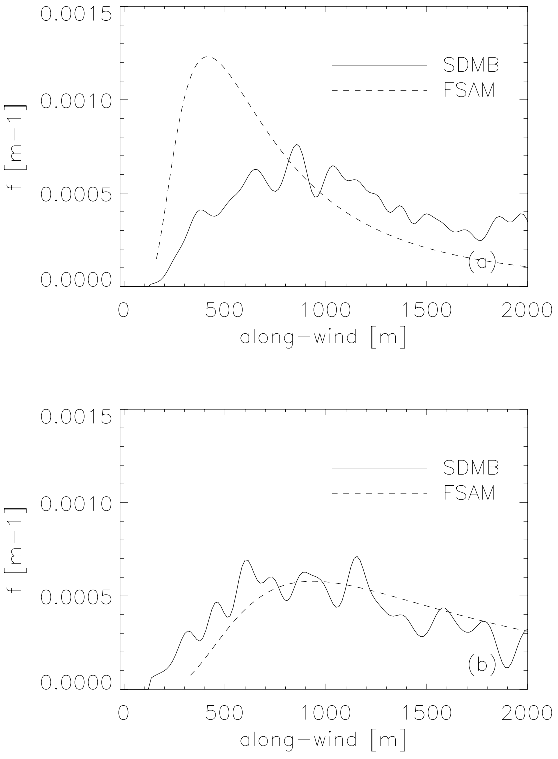

Figure 4: Same as Figure 3 but for a receptor location at 115m height.

lytical footprint model (valid for the surface layer). The Lagrangian model generally predicts the peak location to be closer to the receptor for low receptor locations. For an example of a receptor outside the surface layer, the analytical model predicts a too close and steep peak footprint due to the restrictions in its application regime.

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