Preprints of 15th AMS Symposium on Boundary Layers and Turbulence,
15-19 July 2002, Wageningen, the Netherlands, 293-294.

P3.14 EVALUATION OF THE LAGRANGIAN FOOTPRINT MODEL LPDM-B USING WIND-TUNNEL DATA SETS

Natascha Kljun[1]*, Petra Kastner-Klein[2], Mathias W. Rotach[1], and Evgeni Fedorovich[3]
[1]Institute for Atmospheric and Climate Science, ETH, Zurich, Switzerland
[2]School of Civil Engineering and Environmental Science, University of Oklahoma, Norman,OK
[3]School of Meteorology, University of Oklahoma, Norman, OK

1. INTRODUCTION

In recent years, several footprint models have been proposed. Yet, suitable experimental data are necessary to decide whether the footprint models yield the correct predictions. Although several attempts to evaluate footprint models against observations have been undertaken in the past, there is still a lack of reliable full-scale data. The reason often lies in the constraints that are given by the model assumptions (e.g., restriction to the surface layer). In particular, stationary turbulence and horizontal homogeneity are fundamental requirements for most of the footprint approaches and are difficult to meet. These requirements can easily be fulfilled in wind-tunnel or water-tank experiments.

In this contribution, we present an extensive evaluation of the 3-dimensional Lagrangian footprint model LPDM-B (Kljun et al., 2002) using the high-resolution datasets of the wind-tunnel experiment of Fedorovich and Thäter (2002). This wind-tunnel was especially designed to simulate dispersion processes in the CBL, capped by a temperature inversion (Fedorovich et al., 1996).

2. FOOTPRINT ESTIMATION

The present footprint model LPDM-B is valid for convective to stable stratification, including measurement heights above the surface layer. It employs an approach using backward trajectories of particles (Flesch et al., 1995), the density kernel estimation, and a spin-up routine. For a complete description of the model, see Kljun et al. (2002a).

For comparison of wind-tunnel and LPDM-B simulations, the flow parameters characterising the atmospheric counterpart of the wind-tunnel flow were determined. As similarity criteria, the Richardson number based on the temperature difference across the inversion layer $Ri_{\Delta T}$ and the ratio between friction velocity and convective velocity u_*/w_* were used. The wind-tunnel data as well as the results of the simulations are presented in normalised form using Deardorff scales.

When comparing the wind-tunnel turbulence profiles with the original set of LPDM-B profiles (based on weighted linear combinations of neutral and buoyancy contributions), substantial differences were found for the longitudinal, lateral and vertical velocity variances, the vertical velocity skewness, and the dissipation rate of turbulence kinetic energy. Accordingly, simulations of LPDM-B were performed with two versions of the model: (i) mode A employs the original turbulence parameterisations, (ii) mode B employs the profiles retrieved from the wind-tunnel observations. The concentration footprint as derived from the wind-tunnel data of the ground-level source were calculated for measurement heights $z_m/z_i =$ 0.09 - 0.95, z_i denoting the boundary layer height.

3. RESULTS AND DISCUSSION

In Figure 1 the concentration footprints predicted by LPDM-B mode A and mode B are compared to the wind-tunnel observations. In general, good correspondence is found in the peak location and footprint shape for the concentration footprints predicted by LPDM-B and derived from the wind-tunnel experiment. For small z_m/z_i LPDM-B is able to reproduce the peak location of the footprint, yet the peak value is too low. These differences might be due to discrepancies in the source design, or due to the large uncertainty when measuring in regions with large concentration gradients.

The wind-tunnel data allow the evaluation of LPDM-B for measurement heights above the surface layer ($z/zi > 0.1$ and $-z/L < 1$). This information is highly valuable, since LPDM-B can also be applied for footprint calculations above the surface layer, whereas analytical footprint models are generally restricted to the surface layer. Correspondingly, distinct discrepancies in the footprint predictions of LPDM-B and analytical models are found

---

* *Corresponding author address*: Natascha Kljun, Institute for Atmospheric and Climate Science, ETH, Winterthurerstrasse 190, 8057 Zurich, Switzerland, e-mail: nkljun@ethz.ch

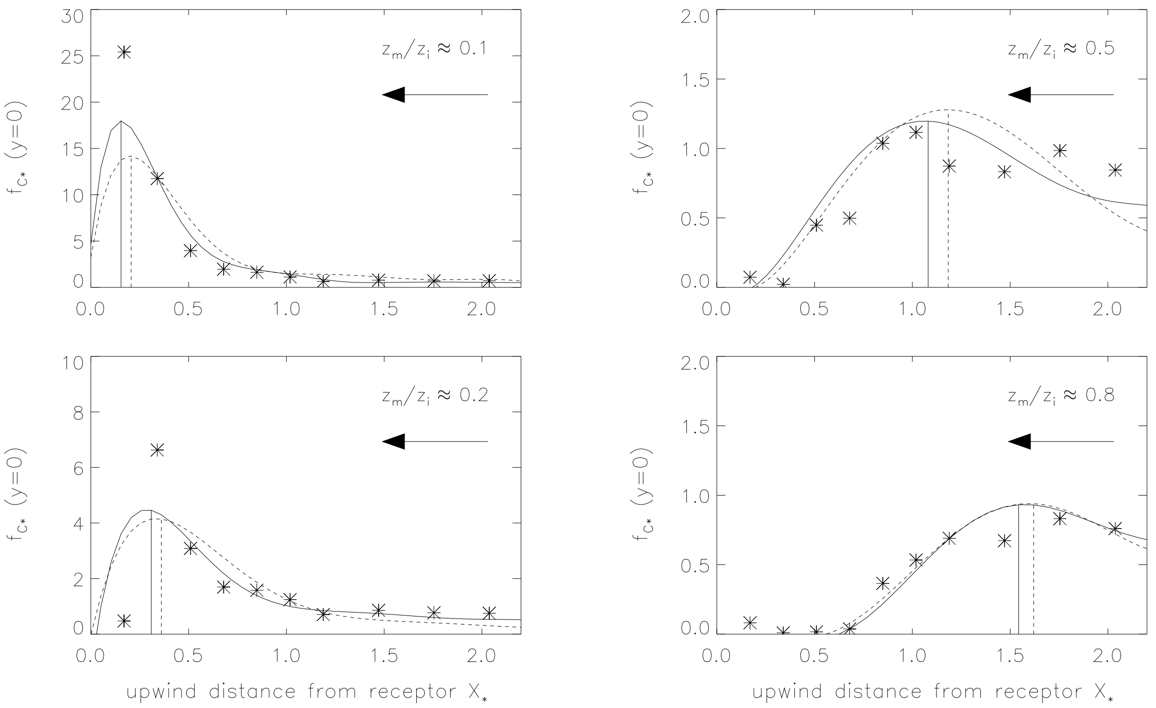

Figure 1: Concentration footprint f_{C_*} at $y = 0$ as predicted by LPDM-B mode A (dashed line), mode B (solid line) and as derived from the wind-tunnel experiment (symbols) for a measurement height of $z_m/z_i \approx$ 0.1, 0.2, 0.5, and 0.8 . The arrow indicates the wind direction and the vertical lines identify the peak location. The dimensionless distance to the source is given by $X_* = x \cdot w_* / (z_i \cdot \overline{u})$, where x denotes the actual distance, w_* the convective velocity scale, z_i the boundary layer height, and $\overline{u}$ the mean wind speed.

when applying them for receptors above the surface layer (Kljun et al., 2002a; 2002b). However, the results presented in Figure 1 ($z_m/z_i > 0.1$) illustrate that LPDM-B is able to reproduce the footprint estimates derived from the wind-tunnel at any height within the planetary boundary layer including the receptors above the surface layer.

For any of the measurement heights considered, the peak location of the footprint predicted by LPDM-B mode B is shifted slightly closer to the source as compared to the estimate of LPDM-B mode A. Even though the correspondence between LPDM-B mode B and observations is slightly better than with mode A's results, the footprint predictions of the different model versions do not significantly differ and exhibit very similar footprint shapes. It can therefore be concluded, that the footprint estimates are not very sensitive to the implemented turbulence parameterisations.

4. CONCLUSION

Concentration footprints of LPDM-B show satisfactory correspondence to the observations, both in peak location and shape. Furthermore, it is shown that the sensitivity of the footprint predictions on the implemented turbulence statistics is not large.

ACKNOWLEDGMENTS

This research was supported by the European Commission and the Swiss Ministry of Education and Science (#97.0136) within the TMR-project TRAPOS.

REFERENCES

Fedorovich, E., and Thäter, J., 2002: A Wind Tunnel Study of Gaseous Tracer Dispersion in the Convective Boundary Layer Capped by a Temperature Inversion. *Atmos. Environ.*, accepted.

Fedorovich, E., Kaiser, R., Rau, M., and Plate, E., 1996: Wind Tunnel Study of Turbulent Flow Structure in the Convective Boundary Layer Capped by a Temperature Inversion. *J. Atmos. Sci.* **53**, 1273-1289.

Flesch, T.K., Wilson, J.D., and Yee E., 1995: Backward-time Lagrangian stochastic dispersion models and their application to estimate gaseous emissions. *J. Appl. Meteorol.* **34**, 1320-1332.

Kljun, N., Rotach, M.W., and Schmid, H.P., 2002a: A 3D Backward Lagrangian Footprint Model for a Wide Range of Boundary Layer Stratifications. *Boundary-Layer Meteorol.* **103**, 205-226.

Kljun, N., Kormann, R., Rotach, M.W., and Meixner, F., 2002b: Comparison of the Lagrangian Footprint Model LPDM-B with an Analytical Footprint Model. *Boundary-Layer Meteorol.*, in press.