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COMPARISON OF THE MICROSCALE FLOW AND DISPERSION MODEL MISKAM AGAINST A NEW WIND TUNNEL VALIDATION DATASET FOR AN IDEALIZED BUILT-UP AREA

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Abstract: The German standard VDI 3783 Part 9 (2017) provides criteria for the evaluation of obstacle-resolving prognostic microscale wind field models. This is important particularly when those models are used as part of licensing procedures in conjunction with the BImSchG (German Federal Immission Safety Act) and the TA Luft. Unfortunately, the standard VDI 3783 Part 9 gives an evaluation procedure only with respect to the flow, and not for the concentration field. Recently a wind tunnel dispersion experiment with a point source at two different heights (near the ground and above the roof of a building) in an idealized built-up area has been performed by Ingenieurbüro Theurer, Hanhofen, Germany. Concentrations are measured at 14 receptor points for 12 different wind directions. The results of the wind tunnel dispersion experiment will be presented here, as well as simulation results of MISKAM and other models (AUSTAL2000. LASAT). The quality of the model output compared to the wind tunnel data is discussed in terms of the fractional bias (FB) and the normalized mean square error (NMSE). Regarding FB and NMSE the comparison shows that the concentrations calculated with the prognostic model MISKAM are not satisfactory at every receptor point but are closer to the wind tunnel data compared to the models AUSTAL2000/LASAT which both use a diagnostic wind field model. We conclude that it would be desirable that in the future, analogous to the German standard VDI 3783 Part 9, a similar VDI standard should be developed which gives an evaluation procedure for dispersion models which are applied in built-up areas. The wind tunnel dataset presented here might therefore be one of the test cases for validation. The wind tunnel dataset is available for other interested research groups.

***Key words:** MISKAM, AUSTAL2000. LASAT, model comparison, wind tunnel, TA Luft, built-up area.*

INTRODUCTION

The German standard VDI 3783 Part 9 (2017) provides criteria for the evaluation of obstacle-resolving prognostic microscale wind field models. This is especially important when those models are used as part of licensing procedures in conjunction with the BImSchG (German Federal Immission Safety Act) and the TA Luft. Unfortunately, the standard VDI 3783 Part 9 gives an evaluation procedure only with respect to the flow and not for the concentration field. Recently a wind tunnel dispersion experiment with a point source at two different heights in an idealized built-up area has been performed by Ingenieurbüro Theurer, Hanhofen, Germany (IBT). The result of the wind tunnel dispersion experiment will be presented here, as well as simulation results of MISKAM and AUSTAL2000/LASAT. The quality of the model output compared to the wind tunnel data will be discussed in terms of the fractional bias and the normalized mean square error.

THE WIND TUNNEL EXPERIMENT

As part of the revision of the standard VDI 3783 Part 12 (2000) a setup for an idealized built-up area has been defined, cf. Figure 1. Four buildings with a height H_1 = 30 m (in natural dimensions) surround a fifth building with is twice as high (H_2 = 60 m). The floor plans of the buildings have acute and obtuse angles so that the buildings are not purely cuboid. In the IBT wind tunnel the buildings were reproduced on a scale of 1: 300. cf. Figure 2.

In addition Figure 1 shows the 2 source locations, at ground level and at a height of 40 m (10 m above the roof level of the 30 m high building, therefore source height = 1.33 times the building height) and the location of the 14 measuring points, 12 at street and 2 at roof level. The measuring height is 2 m above ground (MP1-13) and above roof level (MP14-15), respectively. Concentration measurements have been performed for 12 positions of the turntable of the wind tunnel. Therefore 12 inflow wind directions have been investigated.

The sources have been designed as low impulse releases with an average outlet velocity of approx. 2 cms^{-1} (on the natural scale). A square baffle plate with an area of 5 m times 5 m was set at a distance of 2.5 m and 42.5 m above ground, respectively. The inflow velocity profile in the wind tunnel experiment is best represented by a logarithmic wind profile with a roughness length of z_0 = 0.3 m and a displacement height of d_0 = 6 m.

In the following sections all concentations are given in non-dimensional form c* as defined in equation 1.

$$c^* = c\, u_{ref}\, {H_{ref}}^2/Q \qquad (1)$$

In equation (1) c is the concentration (in ppm), u_{ref} a reference velocity (= 2.94 ms^{-1}) at a reference height H_{ref} (= 30 m) and Q is the source strength (= $1.86\cdot10^{-6}$ m^3s^{-1}). Tables 2 and 3 give the non-dimensional concentration c* for the ground level point source and above roof level for the 14 measuring points and the 12 wind directions (WD) measured in the IBT wind tunnel.

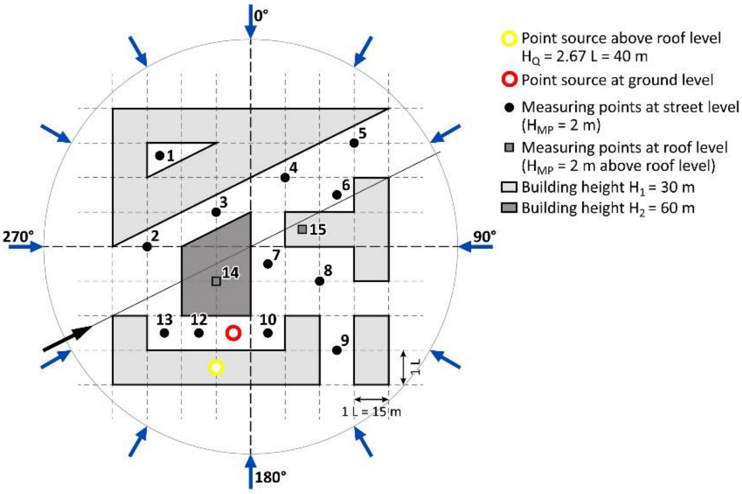

Figure 1. Point source location at ground (red circle) and above roof level (yellow circle). Measuring points at street (black dot) and roof level (grey square). Blue arrows: Inflow wind direction.

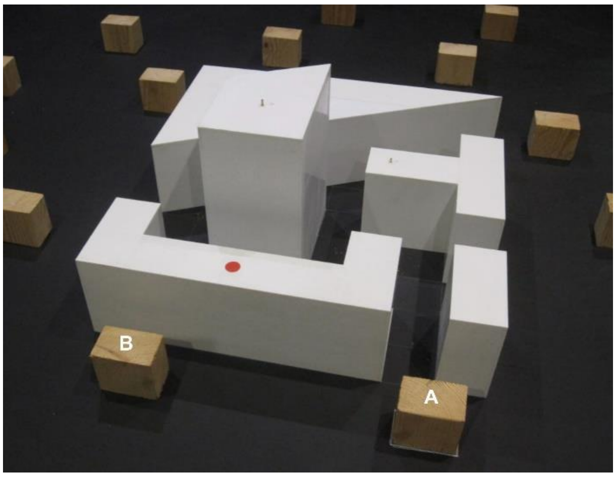

Figure 2. Picture of the IBT wind tunnel model (A,B: additional roughness elements)

Table 1. c* for the ground level point source

WD	MP1	MP2	MP3	MP4	MP5	MP6	MP7	MP8	MP9	MP10	MP12	MP13	MP14	MP15
0°	0.03	0.03	0.04	0.34	0.20	0.19	3.45	3.48	1.75	19.16	2.38	0.39	0.07	0.07
30°	0.01	0.18	0.00	0.01	0.00	0.00	0.01	0.00	0.09	0.03	27.31	6.19	0.06	0.08
60°	0.01	0.01	0.03	0.04	0.04	0.04	0.05	0.06	0.02	0.01	14.22	3.81	0.01	0.02
90°	0.01	2.42	0.00	0.01	0.00	0.00	0.00	0.00	0.09	0.09	35.89	13.50	0.17	0.05
120°	0.14	1.90	0.01	0.00	0.00	0.00	0.00	0.00	0.14	0.12	39.04	11.63	0.00	0.00
150°	0.19	3.18	0.03	0.00	0.00	0.02	0.03	0.02	0.00	0.04	5.70	6.67	0.00	0.00
180°	0.75	2.67	0.76	0.18	0.07	0.11	0.34	0.14	0.01	4.87	4.32	4.87	0.07	0.39
210°	0.03	0.04	0.05	0.42	0.37	0.68	1.73	0.94	0.06	4.17	0.07	0.04	0.05	1.20
240°	0.02	0.04	0.03	1.02	1.13	1.35	4.22	0.69	0.13	11.11	0.04	0.02	0.03	1.12
270°	0.00	0.00	0.00	0.50	1.08	2.25	8.46	0.34	0.04	13.50	0.03	0.04	0.05	1.32
300°	0.04	0.05	0.05	0.13	0.35	0.42	4.52	2.80	0.17	21.56	0.09	0.07	0.08	1.56
330°	0.02	0.03	0.03	0.06	0.05	0.07	0.61	5.54	1.01	45.86	0.03	0.02	0.11	0.34

Table 2. c* for point source location above roof level

WD	MP1	MP2	MP3	MP4	MP5	MP6	MP7	MP8	MP9	MP10	MP12	MP13	MP14	MP15
0°	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.05	0.00	0.00	0.00	0.00
30°	0.01	0.01	0.01	0.00	0.01	0.02	0.00	0.02	0.01	0.01	0.12	0.15	0.00	0.00
60°	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.05	0.02	0.01
90°	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
120°	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02
150°	0.26	0.61	0.08	0.06	0.05	0.04	0.03	0.01	0.02	0.04	0.15	0.32	0.01	0.00
180°	1.14	3.50	1.23	0.12	0.07	0.12	0.21	0.14	0.02	1.37	2.95	4.30	0.10	0.14
210°	0.01	0.04	0.11	0.76	0.81	1.07	2.59	1.71	0.08	3.77	1.01	0.64	0.03	1.31
240°	0.02	0.02	0.02	0.14	0.18	0.33	0.28	0.42	0.31	0.08	0.04	0.05	0.04	0.68
270°	0.03	0.03	0.03	0.04	0.08	0.18	0.23	0.71	0.64	0.01	0.00	0.01	0.00	0.28
300°	0.05	0.05	0.06	0.05	0.06	0.07	0.11	0.34	0.60	0.03	0.06	0.06	0.07	0.14
330°	0.02	0.00	0.00	0.01	0.02	0.01	0.02	0.10	0.07	0.07	0.03	0.02	0.05	0.08

MODEL DESCRIPTION

The models MISKAM, AUSTAL2000/LASAT have been applied in this study. In the following sections a brief model description is given. For further details see the literature in the references.

MISKAM

MISKAM is a three-dimensional Eulerian air flow and dispersion RANS model which is designed to describe the flow and the dispersion around buildings (e.g., Eichhorn 1989, Eichhorn and Kniffka, 2010). The flow model consists of the three-dimensional equations of motion, using the anelastic Boussinesq approximation. The Coriolis force is neglected. The heat equation is not included; the temperature field is assumed to be horizontally homogeneous. A constant thermal stratification may, however, be introduced into the turbulence equations for non-neutral conditions. MISKAM applies the k-ε-turbulence closure for calculation of the turbulent exchange coefficients. Detailed validations have been performed, see e.g., Flassak and Blessing (2009), Donnelly et al. (2009), Eichhorn and Kniffka (2010) and Flassak et al. (2010). In this study MISKAM 6.3 was applied.

LASAT

The dispersion model LASAT (Lagrangian Simulation of Aerosol-Transport, for further information see: https://www.janicke.de/en/lasat.html) computes the transport of trace substances in the atmosphere. It simulates the dispersion and the transport of a representative sample of tracer particles utilizing a random walk process (Lagrangian simulation). LASAT is a professional tool for the study of special dispersion situations. It is based on a research model which was developed in 1980 and tested in various research projects. Since 1990 LASAT is available as a software package and it is used by national authorities, consulting bureaus, and industrial companies in Germany. It served as the basis for the development of the dispersion model AUSTAL2000. LASAT conforms to guideline VDI 3945 Part 3 (2020) and provides a broad range of applications, among others: TA Luft, accidental releases, screening, radio nuclides, bioaerosols, odorants, moving sources.

AUSTAL2000

The Lagrangian particle model AUSTAL2000 is based on LASAT and calculates the time-dependent atmospheric dispersion of substances and odourants. AUSTAL2000 is the official reference implementation of the instructions given in the German Regulation on Air Quality Control (TA Luft, Appendix 3). The program system AUSTAL2000 includes a diagnostic wind field model (TALdia) as a pre-processor which calculates the three-dimensional wind fields and, in case of buildings, additional three-dimensional turbulence fields and provides them in the form of a wind field library to the actual dispersion program AUSTAL2000 (Janicke and Janicke, 2004). Alternatively, other externally generated wind and turbulence fields can be provided.

MODEL SETUP

With AUSTAL2000/LASAT three boundary layer models (BLM) 2.6, 2.8 and 5.2 have been tested against the wind tunnel data. All runs have been performed for a neutral atmospheric stratification. BLM version 2.6 is the official boundary layer model of AUSTAL2000. BLM version 2.8 is similar to BLM version 2.6 but turning of wind direction with height is omitted, which may lead to a better agreement with the wind tunnel data. The future standard boundary layer model within LASAT and the forthcoming version of AUSTAL2000 is defined according to the German guideline VDI 3783 Part 8 (2017), which will also be referenced by the forthcoming edition of TA Luft. It is addressed by BLM version 5.3. With BLM version 5.2. turning of wind direction with height is omitted. As mentioned before, this BLM version 5.2 is better suited for a comparison with wind tunnel data than BLM version 5.3. As BLM versions 2.8 and 5.2 are only availabe in conjunction with LASAT, the runs with these two boundary layer models have been performed with LASAT.

The AUSTAL2000/LASAT runs were performed with a numerical grid of 170 x 170 grid cells in the horizontal directions and with a mesh width of 3 m. In the vertical direction the grid was set automatically by AUSTAL2000 and then applied in LASAT, with a mesh width of 3 m in the lowermost layer, a constant spacing of 2 m up to twice the height of the highest building and then an increasing spacing above this.

For the MISKAM runs the grid definition is given in Table 3 for the four Cases 1. 2H, 2 und 3. The vertical grids for Case 1 and 2H (respectively 2 and 3) are identical.

Table 3. Grid definition for the MISKAM runs

Case name	Horizontal mesh width (m)	Vertical mesh width in the lowermost layer (m)	Number of grid cells in the two horizontal and the vertical direction
1	1	0.6	500x500x54
2H	1.88	0.6	266x266x54
2	1.88	0.8	266x266x43
3	3	0.8	167x167x43

RESULTS

In order to compare model output with the wind tunnel measurements, the concentrations calculated with MISKAM, AUSTAL2000/LASAT are converted to the non-dimensional form according to equation 1. For the evaluation of the model output, the fractional bias (FB, cf. equation 2 with WT = wind tunnel, M = model) and the normalized mean square error (NMSE, cf. Equation 3) have been used. A positive FB means that the model underestimates, while a negative FB means that the model overestimates; the model is conservative. FB = 0 mean that the model works well (but only on average, in detail, measured and calculated concentrations can vary widely). NMSE is a positiv number or zero. NMSE = 0 mean that the model is perfect. The larger the NMSE, the worse the model.

$$FB = (\overline{c_{WT}} - \overline{c_M})/\left(0.5(\overline{c_{WT}} + \overline{c_M})\right) \quad (2)$$

$$NMSE = \overline{(c_{WT} - c_M)^2}/(\overline{c_{WT}} \cdot \overline{c_M}) \quad (3)$$

Table 4 gives FB and NMSE for MISKAM, AUSTAL2000/LASAT for the ground level point source and the source above roof level.

For the ground level point source, the FB of AUSTAL2000/LASAT is negativ. This means that in this case AUSTAL2000/LASAT overestimates, so the models are conservative. The MISKAM output gives for all 4 cases small positive values of the FB, therefore they slightly underestimate. The NMSE of AUSTAL2000/LASAT is approx. twice the value of MISKAM.

Figure 3 and 4 show in detail the FB and NMSE with respect to the inflow wind direction. It can be seen that the curves for AUSTAL2000/LASAT with BLM 2.8 and 5.2 are grouped relatively close together, the same applies for the output for the 4 MISKAM runs. This means that for this case the selected BLM has only a minor influence on the result. Similarly for MISKAM, the selected grid resolution for the 4 cases has only a minor influence on the result. In particular, the high resolution case (case 1) does not automatically give the best results.

Interestingly, all models show a relatively similar dependence of FB on the inflow wind direction, e.g., a positive FB at 90° and negative FB between 150 and 210°. This is not the case for the NMSE. The variation of NMSE of the MISKAM output is much lower than the variation of the AUSTAL2000/LASAT output. E.g. the AUSTAL2000/LASAT output gives much higher values for NMSE for inflow wind directions 60°, 150° and 210°.

For the point source location above roof level, the FB of AUSTAL2000/LASAT is positiv. This means that in this case, in contrary to the behaviour for the ground level point source, AUSTAL2000/LASAT underestimates. The MISKAM results give for case 1 positive values (therefore underestimation) and for the three other case negative values of the FB (slight overestimation). The NMSE of AUSTAL2000/LASAT is approx. 3 times the value of MISKAM. Hence MISKAM shows a better performance compared to AUSTAL2000/LASAT not only for the ground level point source but also, and even more pronounced, for the point source location above roof level.

For all models for the point source location above roof level the dependence of FB on the inflow wind direction is relatively similar, but not as pronounced as in the case of the point source at ground level.

Additionally, the variation of NMSE of the MISKAM output is much lower than the variation of the AUSTAL2000/LASAT output. The AUSTAL2000/LASAT output gives high values for NMSE for inflow wind directions 210°, 270° and 300°.

Table 4. FB and NMSE for the ground level point source and the source above roof level

	ground level point source		point source location above roof level	
Model	**FB**	**NMSE**	**FB**	**NMSE**
AUSTAL2000	-0.53	5.64	0.58	16.33
LASAT BLM 2.8	-0.53	5.57	0.63	15.42
LASAT BLM 5.2	-0.56	5.96	0.65	16.81
MISKAM 6.3 case 1	0.01	3.27	0.20	4.99
MISKAM 6.3 case 2H	0.09	3.17	-0.08	5.07
MISKAM 6.3 case 2	0.08	3.11	-0.03	4.76
MISKAM 6.3 case 3	0.15	3.16	-0.02	4.72

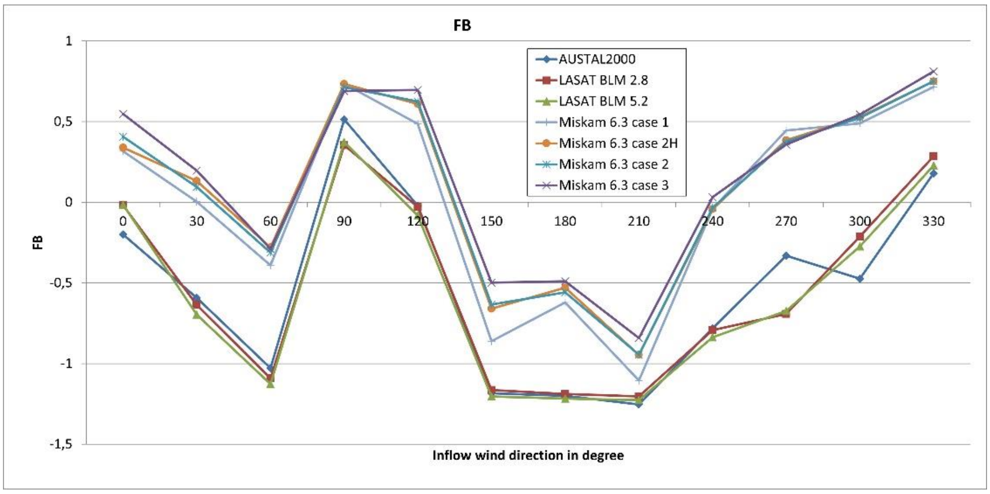

Figure 3. Fractial bias (FB) as a function of the inflow wind direction for the ground level point source

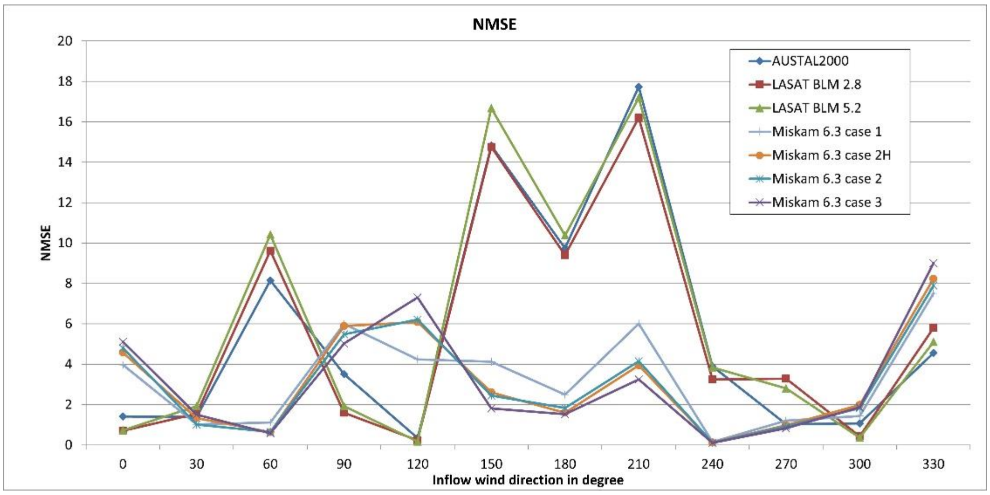

Figure 4. Normalized mean square error (NMSE) as a function of the inflow wind direction for the ground level point source

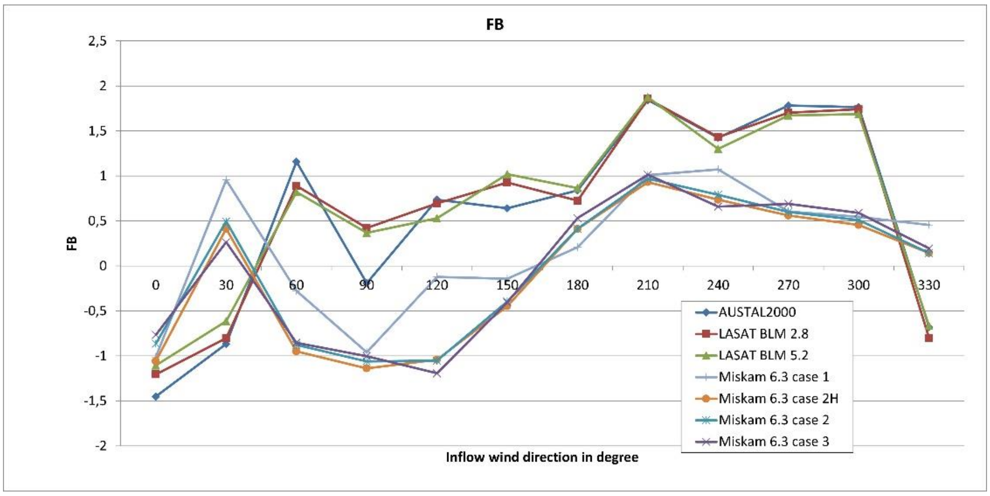

Figure 5. Fractial bias (FB) as a function of the inflow wind direction for the point source location above roof level

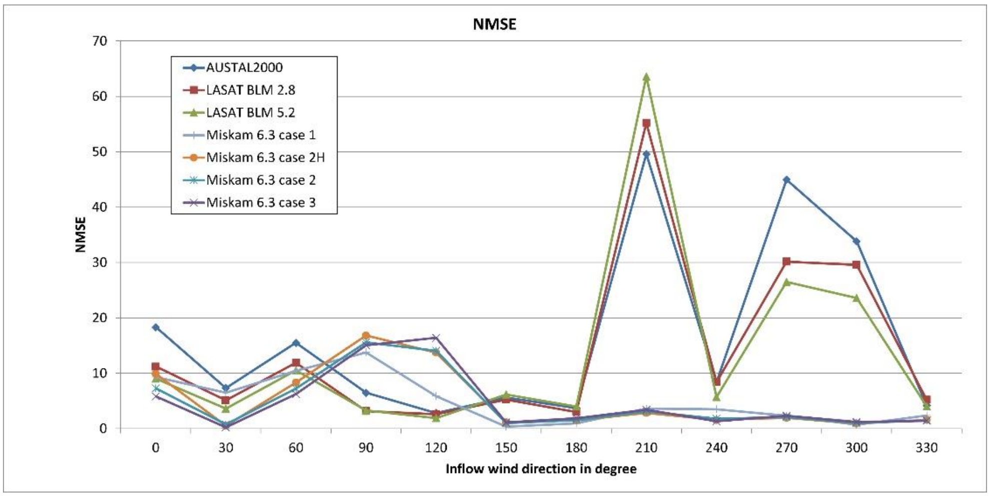

Figure 6. Normalized mean square error (NMSE) as a function of the inflow wind direction for the point source location above roof level

CONCLUSION

Regarding to FB and NMSE the comparison shows that the concentrations calculated with the prognostic model MISKAM are satisfactory not at every receptor point but are closer to the wind tunnel data compared to the models AUSTAL2000/LASAT which both use a diagnostic wind field model. We conclude that it would be desirable that in the future, analogous to the German standard VDI 3783 Part 9, a similar VDI standard should be developed which gives an evaluation procedure for dispersion models which are applied in built-up areas. The wind tunnel dataset presented here might therefore be one of the test cases for validation. The wind tunnel dataset is available for other interested research groups.

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