H20-047
Comparison of the microscale flow and dispersion model MISKAM against a new wind tunnel validation dataset for an idealized built-up area

Dr.-Ing. Thomas Flassak[1], Dipl.-Ing. Helmut Lorentz[2]

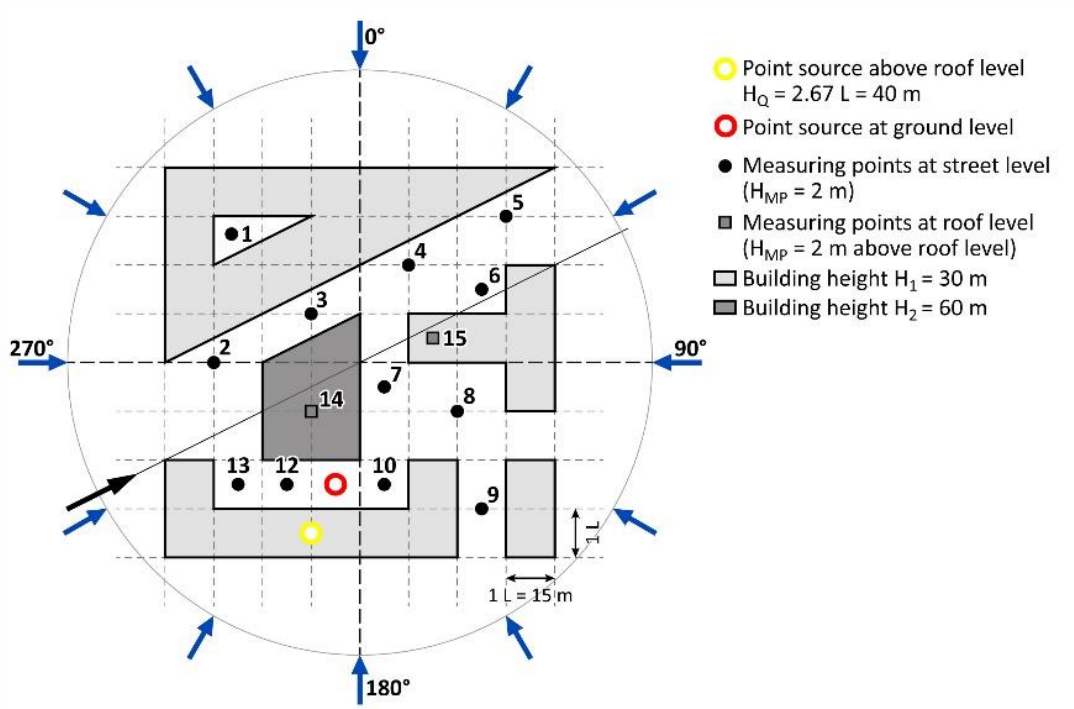
[1]Lohmeyer GmbH, An der Roßweid 3, D-76229 Karlsruhe, Germany
[2]Lohmeyer GmbH, Friedrichstr. 24, D-01067 Dresden, Germany

Lohmeyer

- The German standard VDI 3783 Part 9 (2017) provides criteria for the evaluation of obstacle-resolving prognostic microscale wind field models. (VDI = Verein Deutscher Ingenieure)
- Those models are used as part of licensing procedures in conjunction with the BImSchG (German Federal Immission Safety Act) and the TA Luft (German Regulation on Air Quality Control).
- 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.
- Simulation with the models MISKAM and AUSTAL2000/LASAT have been performed
- The quality of the model output compared to the wind tunnel data will be discussed in terms of the fractional bias FB and the normalized mean square error NMSE.

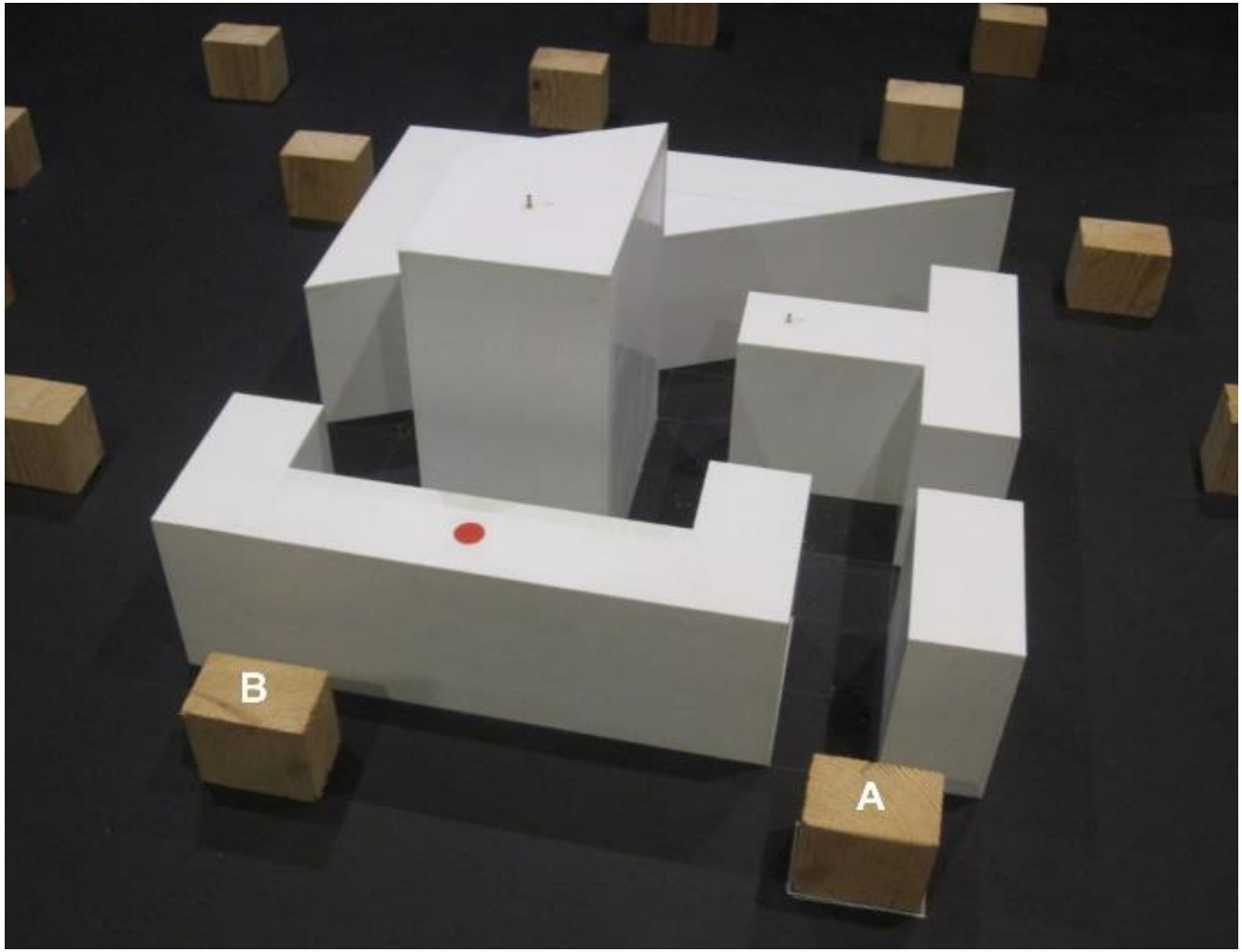
Lohmeyer

- As part of the revision of the standard VDI 3783 Part 12 (2000) a setup for an idealized built-up area has been defined.



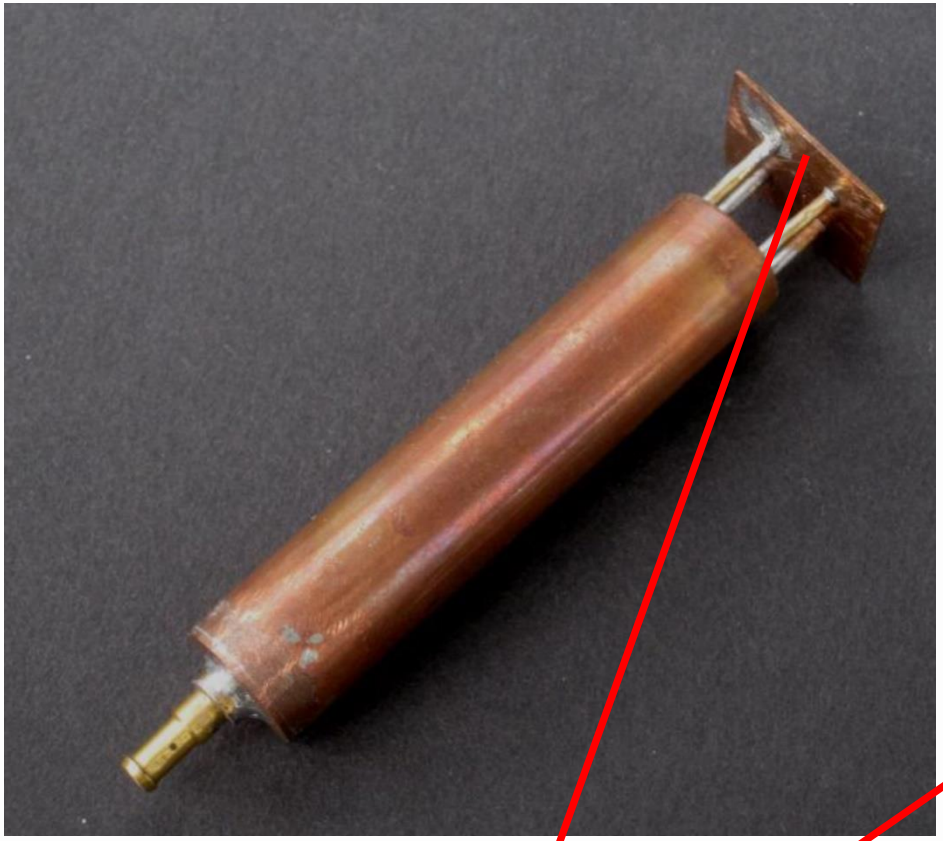
- 4 buildings with a height H_1 = 30 m (in natural dimensions) surround a fifth building with is twice as high (H_2 = 60 m).
- 2 source locations (designed as low momentum releases):
  - at ground level and
  - at a height of 40 m (10 m above the roof level of the 30 m high building)
- 14 measuring points, 12 at street and 2 at roof level
- Concentration measurements for 12 positions of the turntable of the wind tunnel.

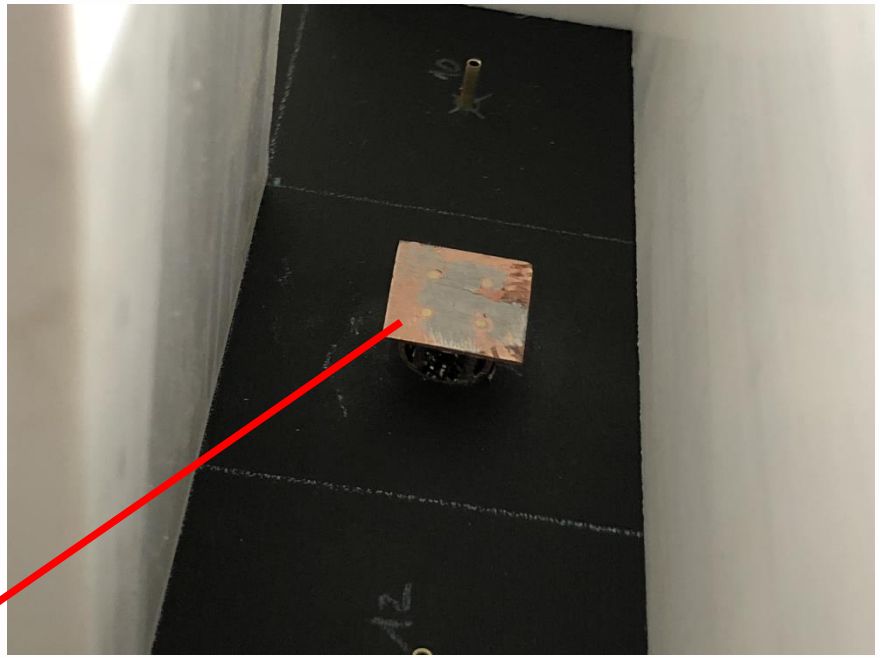
Lohmeyer



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

Lohmeyer





- Source
  - Flow rate: 6.7 l/h or $1.86 \cdot 10^{-6}$ m^3/s.
  - On natural scale: Average exhaust velocity: Approx. 2 cm/s. (Low momentum release)
  - Square baffle plate with an area of 5 m x 5 m in a distance of 2.5 m (on natural scale)

- Output: Non-dimensional concentations $c^* = c\, u_{ref}\, {H_{ref}}^2 / Q$
  - c : concentration (in ppm), u_{ref} : reference velocity
  - H_{ref} : reference height, Q : source strength

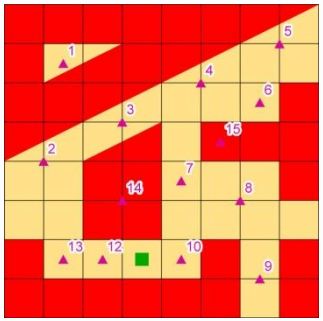


Table 1. c* for the ground level point source

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

Lohmeyer

- **AUSTAL2000 (Dr. Janicke, Ingenieurbüro Janicke, Überlingen)**
  - 3D Lagrangian dispersion model (subset of LASAT)
  - Diagnostic wind field model (flow around buildings and in complex terrain)
  - AUSTAL2000 is the official reference implementation of the instructions given in the German Regulation on Air Quality Control (TA Luft (2002), Appendix 3)
- **LASAT (Dr. Janicke, Ingenieurbüro Janicke, Überlingen)**
  - 3D Lagrangian dispersion model
  - Diagnostic wind field model (flow around buildings and in complex terrain)
  - More flexibility compared to AUSTAL2000, e.g., different boundary layer models selectable
- **MISKAM (Dr. Eichhorn, University of Mainz)**
  - 3D Eulerian air flow and dispersion RANS model (prognostic model)
  - Designed to describe the flow and the dispersion around buildings
  - K-ε-turbulence closure
  - No heat equation, no Coriolis force

Lohmeyer

- In Appendix 3, Section 10 the German Regulation on Air Quality Control (TA Luft (2002)) limits the scope of diagnostic wind field models.
- Diagnostic wind field models can be used
  - if the emission source height is at least 1.2 x building height and
  - higher buildings have a distance from the emission point of more than 6 times their building height
- In the case of source heights below 1.2 x building height and a distance of less than 6 times the building height, the TA Luft does not make any explicit specifications on how to proceed.
- However, the TA Luft (2002) notes: „Until a suitable VDI guideline is introduced, wind field models whose suitability has been verified by the responsible state authority must be used“. (e.g., the prognostic model MISKAM)

- 3 boundary layer models (BLM) 2.6, 2.8 and 5.2 have been tested against the wind tunnel data.
  - 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 switched off (this 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 BLM 5.3. (This BLM 5.3 is defined according to the German guideline VDI 3783 Part 8 (2017), which will also be referenced by the forthcoming edition of TA Luft.) With BLM version 5.2 turning of wind direction with height is switched off.
- horizontal numerical grid: 170 x 170 grid cells
- horizontal mesh width: 3 m
- vertical mesh width in the lowermost layer: 3 m
- constant vertical spacing of 2 m up to twice the height of the highest building (increasing spacing above)

Lohmeyer

- Simulations have been performed on 4 numerical grids with MISKAM 6.3
- Grid definition is given in following table

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

Lohmeyer

- In order to compare model output with the wind tunnel measurements, the concentrations calculated with MISKAM, AUSTAL2000/LASAT are converted into non-dimensional concentrations
- For the evaluation of the model output, the fractional bias (FB)

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

and the normalized mean square error (NMSE)

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

- Positive/negative FB: the model underestimates/overestimates
- 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: Model is perfect.
  - The larger the NMSE, the worse the model.

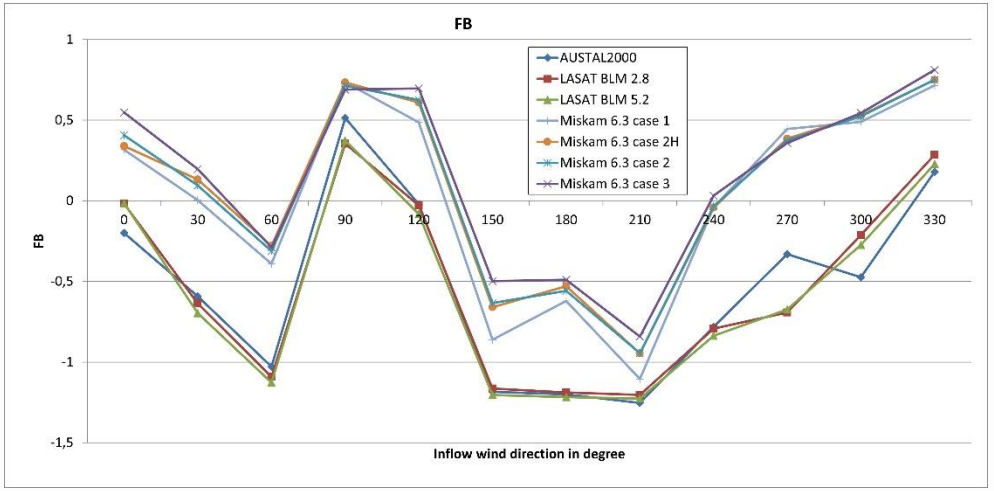
Lohmeyer

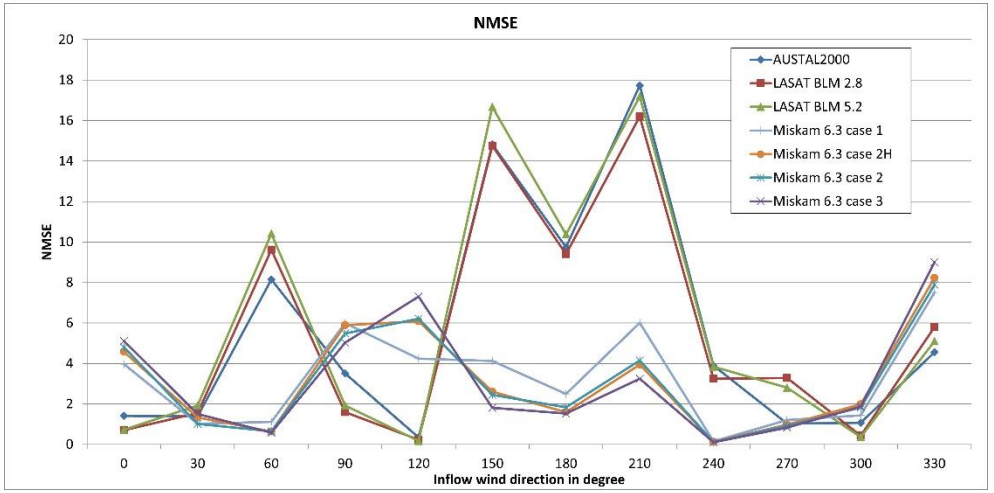
- FB of AUSTAL2000/LASAT is negativ. This means that in this case AUSTAL2000/LASAT overestimates, so in this case AUSTAL2000/LASAT is conservative
- FB of the MISKAM output gives for all 4 cases small positive values, therefore they slightly underestimate.
- In particular, the high-resolution case (case 1) does not automatically give the best results.
- NMSE of AUSTAL2000/LASAT is approx. twice the value of MISKAM.

	ground level point source	
Model	FB	NMSE
AUSTAL2000 BLM 2.6	-0.53	5.64
LASAT BLM 2.8	-0.53	5.57
LASAT BLM 5.2	-0.56	5.96
MISKAM 6.3 case 1	0.01	3.27
MISKAM 6.3 case 2H	0.09	3.17
MISKAM 6.3 case 2	0.08	3.11
MISKAM 6.3 case 3	0.15	3.16

Lohmeyer

- FB and NMSE for AUSTAL2000 and LASAT BLM 2.8 and 5.2 are grouped relatively close together: Selected BLM has only a minor influence on the result
- The same applies for the output for the 4 MISKAM runs: Selected grid resolution for the 4 cases has only a minor influence on the result
- 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°.
- Variation of NMSE of the MISKAM output is much lower than the variation of the AUSTAL2000/LASAT output.





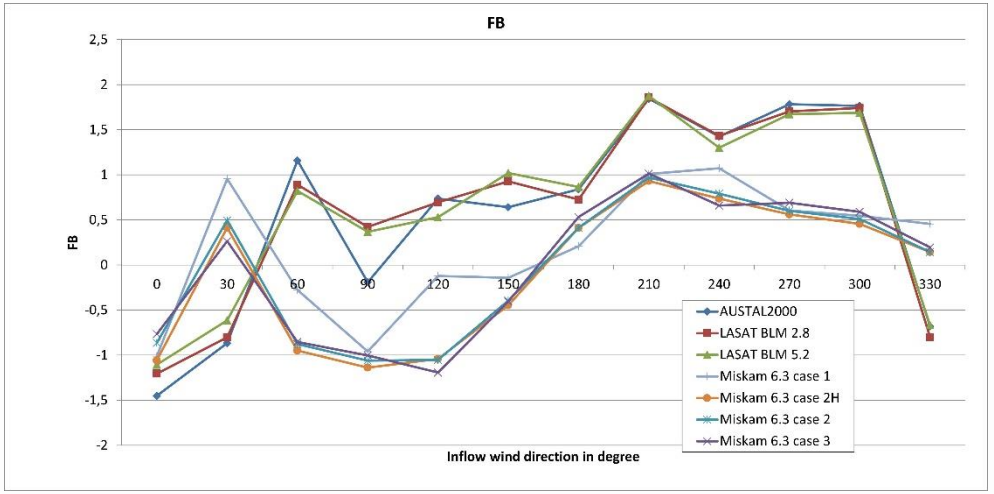
- FB of AUSTAL2000/LASAT is positiv. This means that in this case AUSTAL2000/LASAT underestimates (in contrary to the behaviour for the ground level point source)
- The MISKAM results give for case 1 positive values (therefore underestimation) and for the three other case negative values of the FB (slight 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.

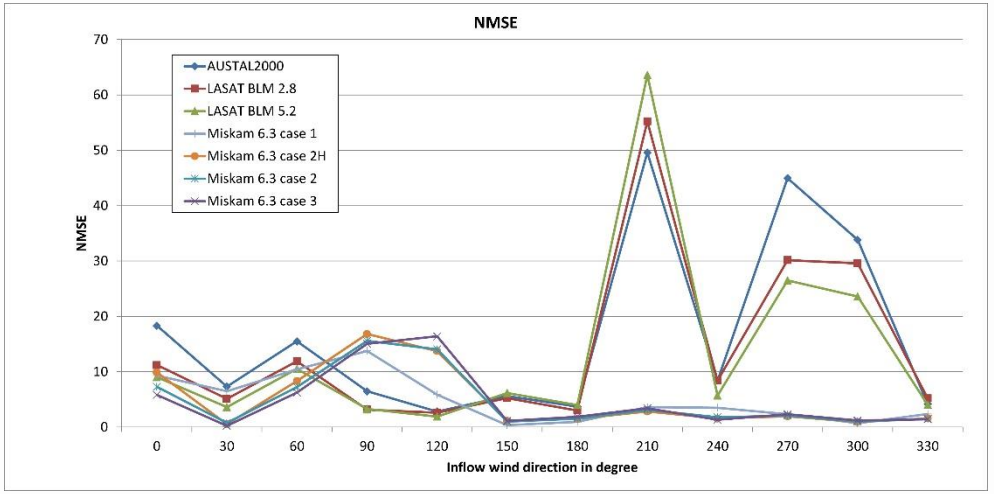
	point source location above roof level	
Model	FB	NMSE
AUSTAL2000 BLM 2.6	0.58	16.33
LASAT BLM 2.8	0.63	15.42
LASAT BLM 5.2	0.65	16.81
MISKAM 6.3 case 1	0.20	4.99
MISKAM 6.3 case 2H	-0.08	5.07
MISKAM 6.3 case 2	-0.03	4.76
MISKAM 6.3 case 3	-0.02	4.72

Results: FB and NMSE for the **point source above roof level**

Lohmeyer

- All models show a relatively similar dependence of FB on the inflow wind direction (similar to the case of the point source at ground level)
- Variation of NMSE of the MISKAM output is much lower than the variation of the AUSTAL2000/LASAT output,
- especially the AUSTAL2000/LASAT output gives high values for NMSE for inflow wind directions 210°, 270° and 300°





Lohmeyer

- Very often (not shown here): Measured and simulated concentrations differ more than a factor of 2.
- The high-resolution MISKAM case (case 1) does not automatically give the best results
- 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.

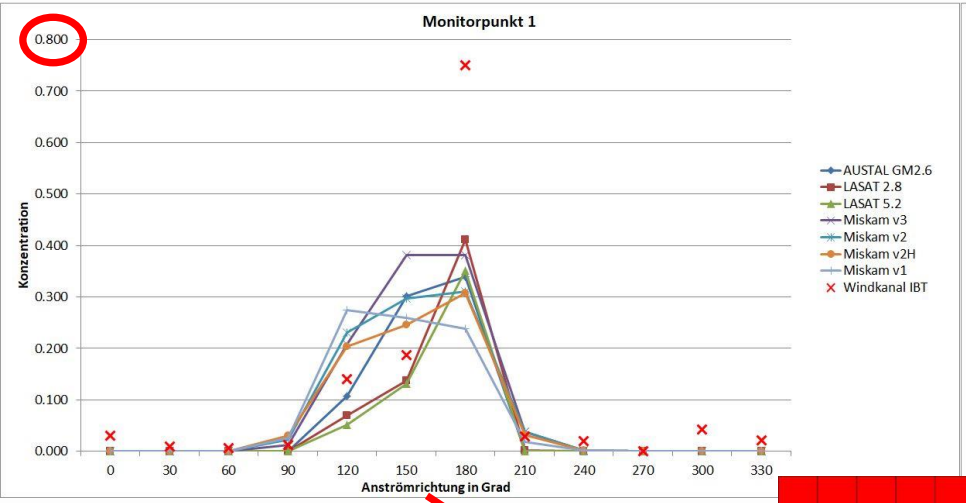
thomas.flassak@lohmeyer.de

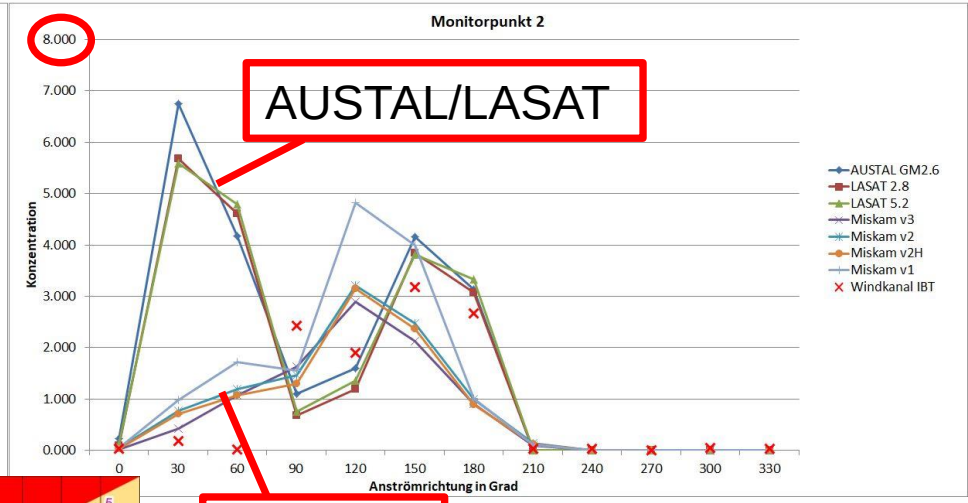
- Thank you for your attention!
- Questions?

Windkanal- und Modellergebnisse (bodennahe Quelle)

Windkanal- und Modellergebnisse (bodennahe Quelle)

Lohmeyer

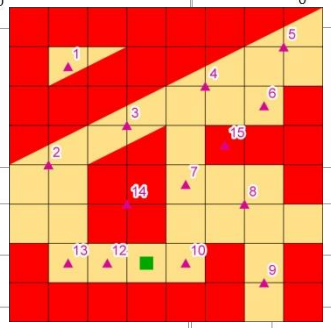


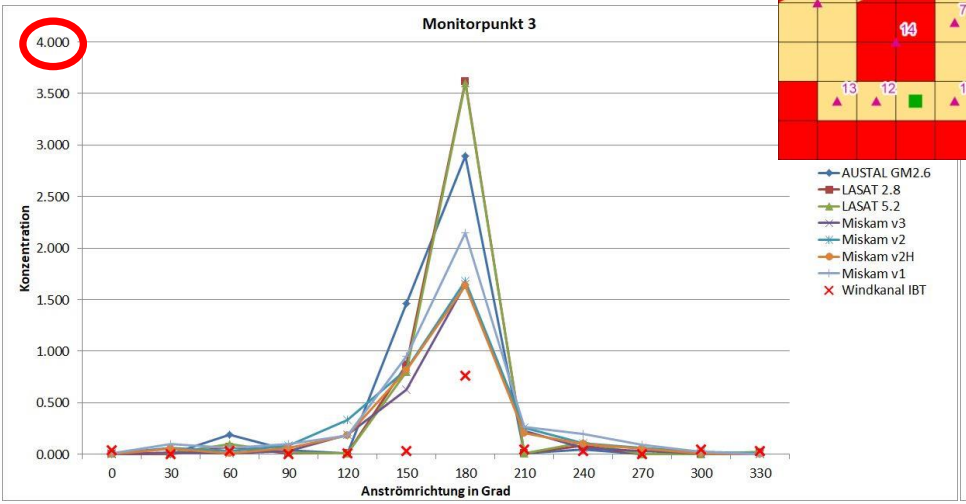


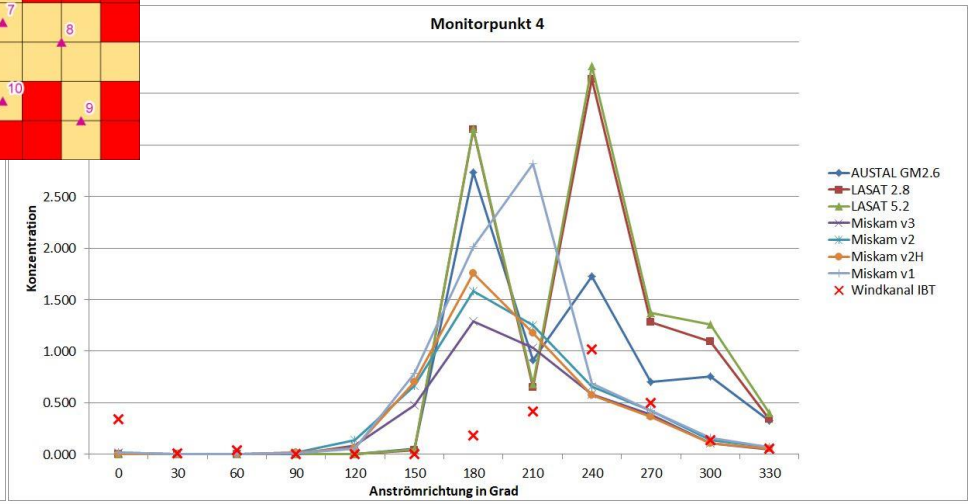
AUSTAL/LASAT

MISKAM

meteorologische WR

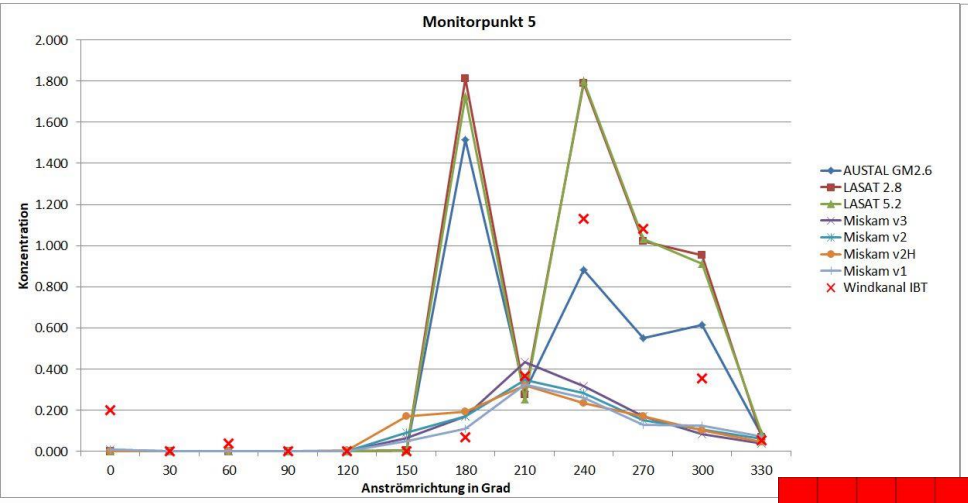


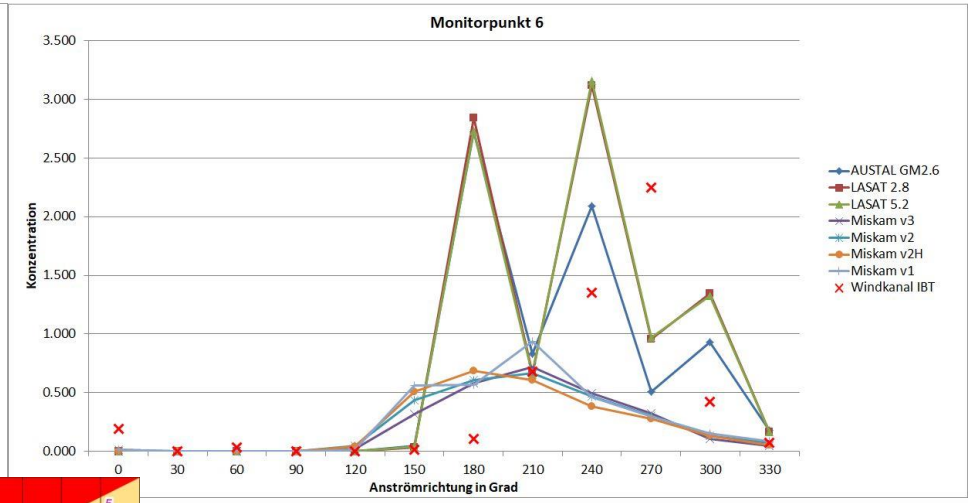


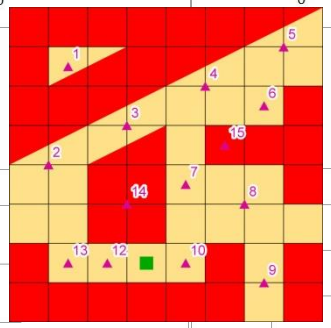


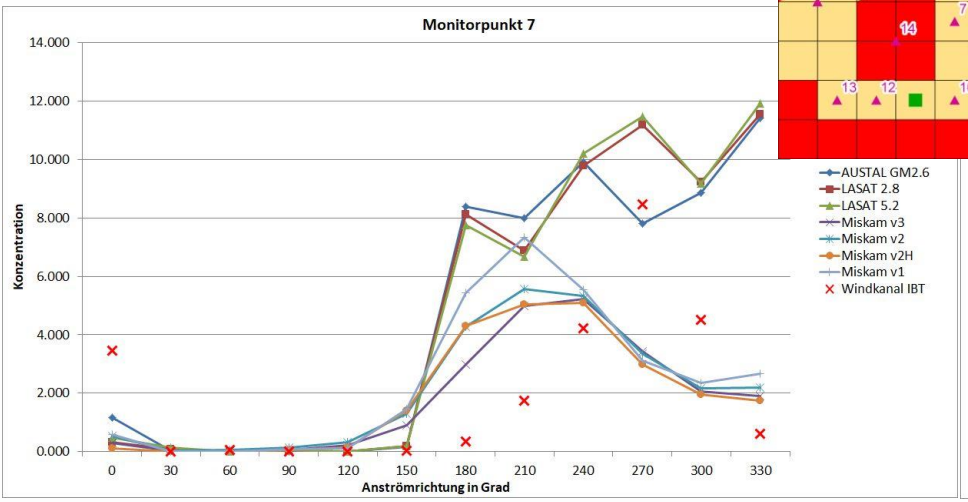
Windkanal- und Modellergebnisse (bodennahe Quelle)

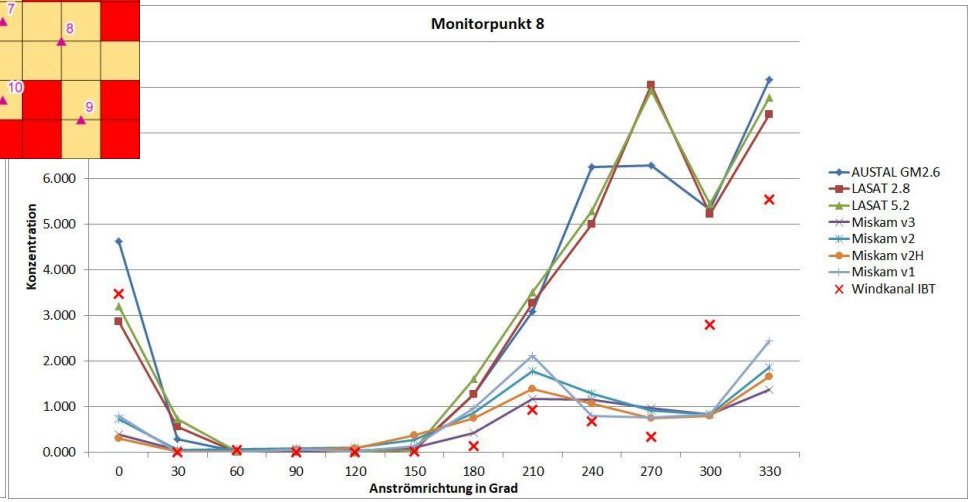
Lohmeyer





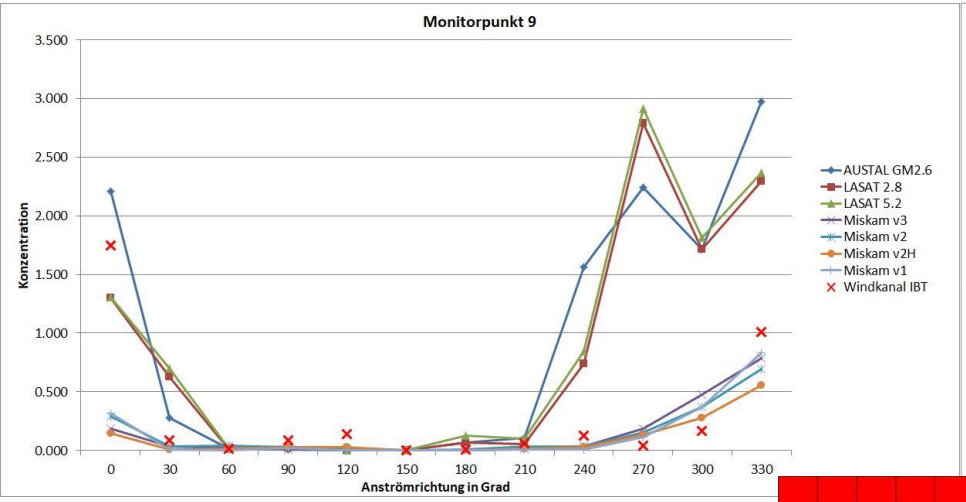


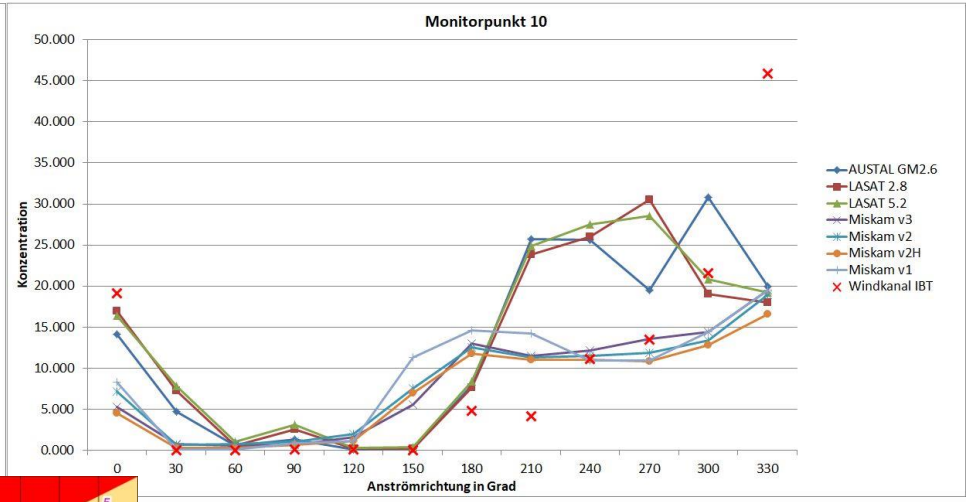


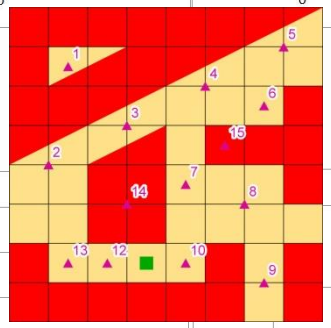


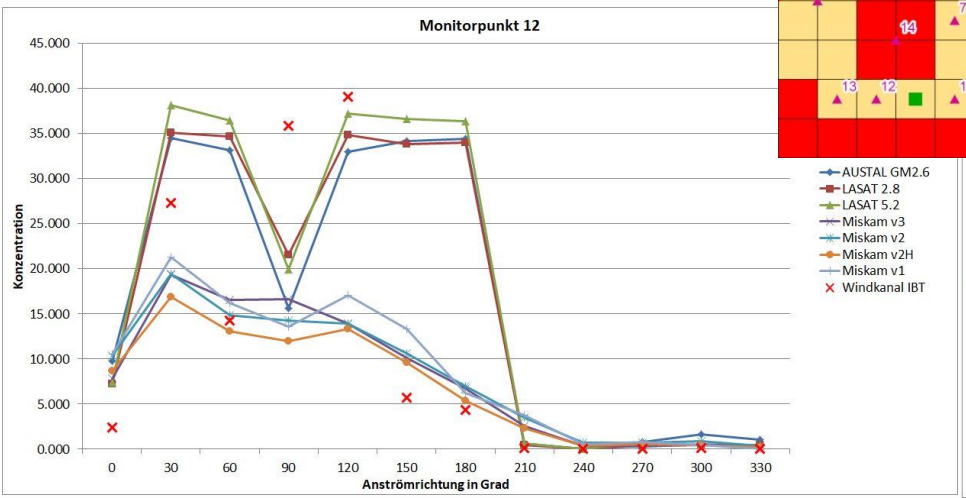
Windkanal- und Modellergebnisse (bodennahe Quelle)

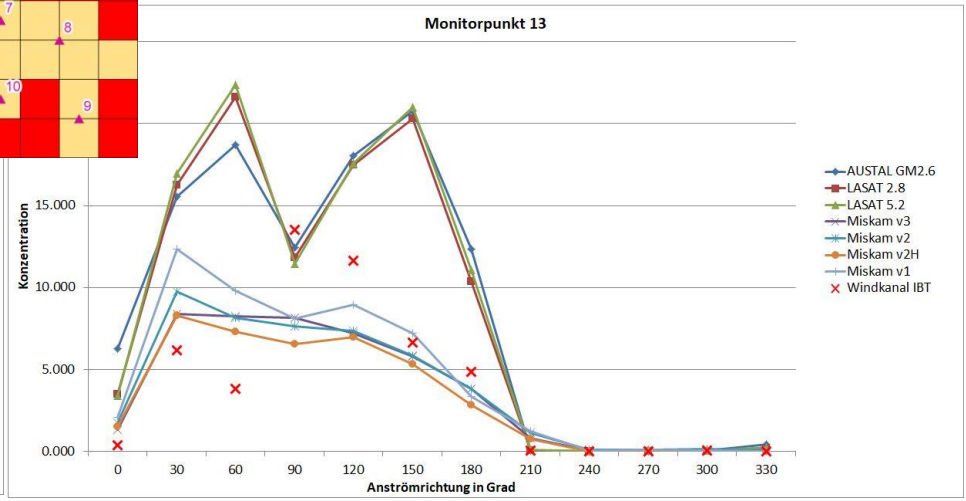
Lohmeyer



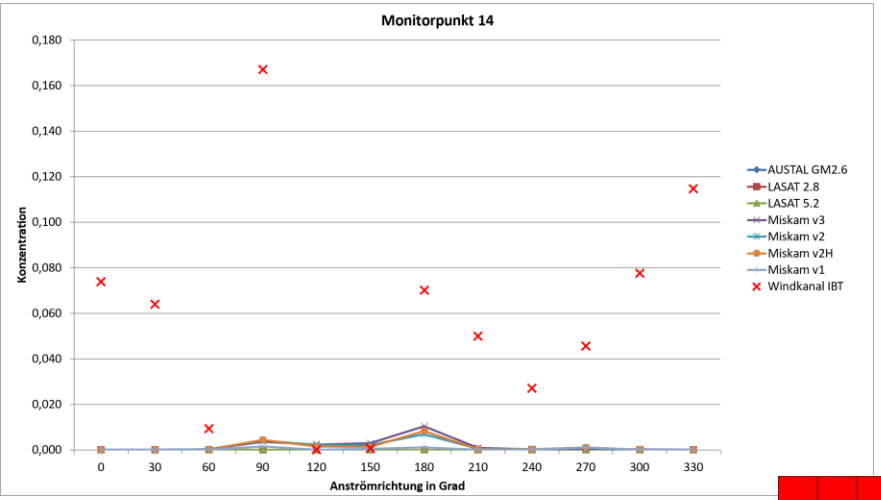


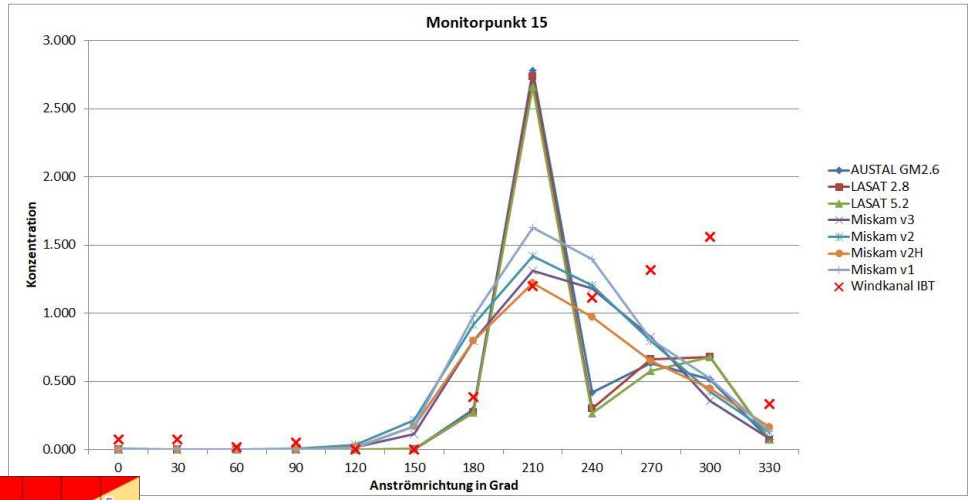


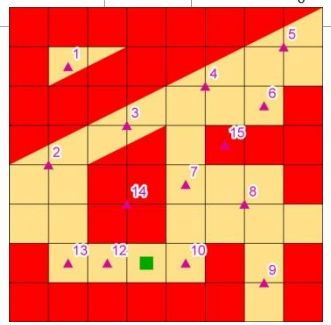




Windkanal- und Modellergebnisse (bodennahe Quelle)



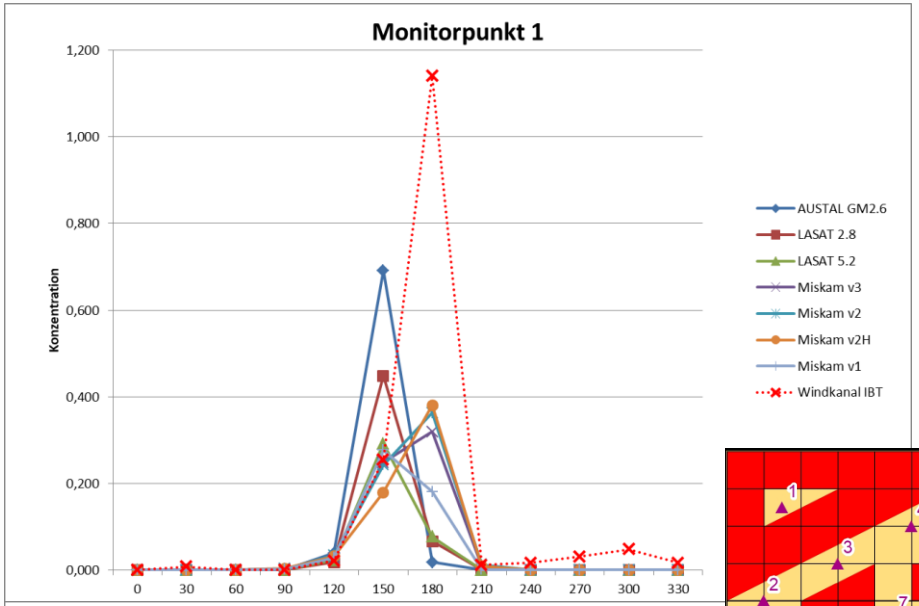


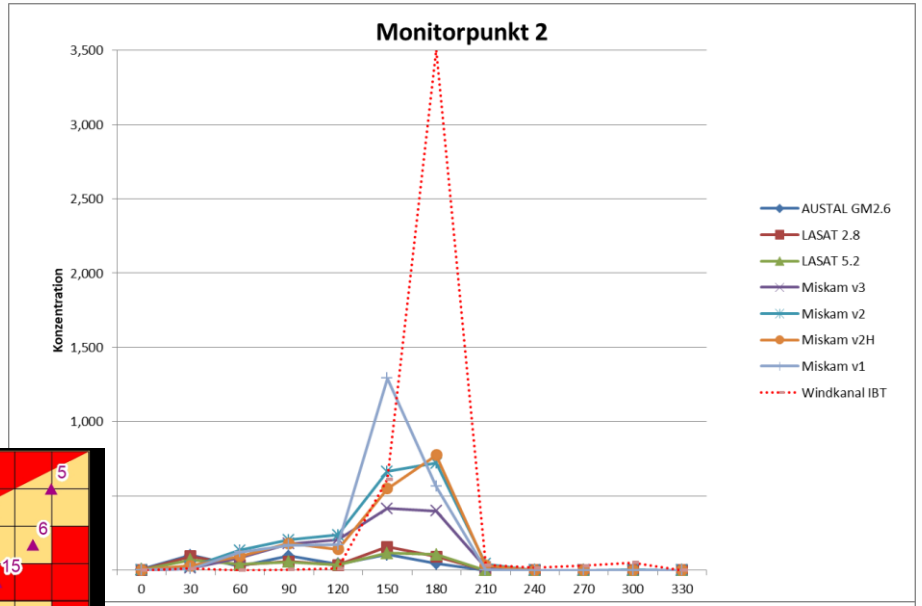


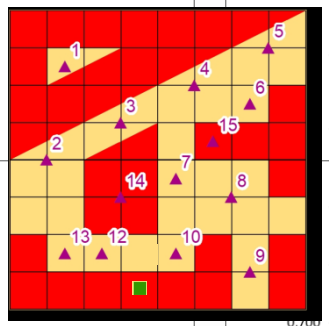
Windkanal- und Modellergebnisse
(Quellhöhe 40 m über Grund (10m über Gebäude))

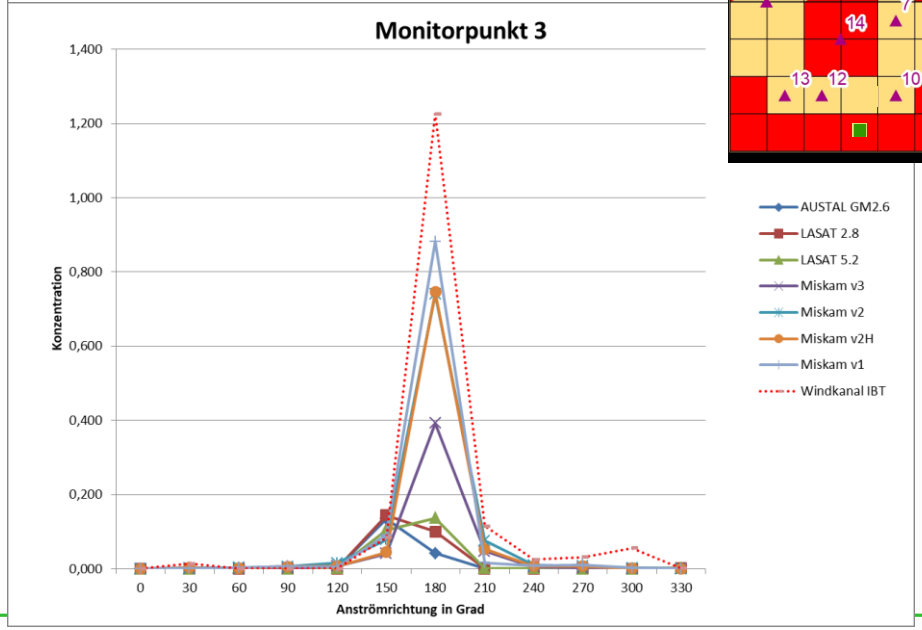
Windkanal- und Modellergebnisse (Quellhöhe 40 m über Grund (10m über Gebäude))

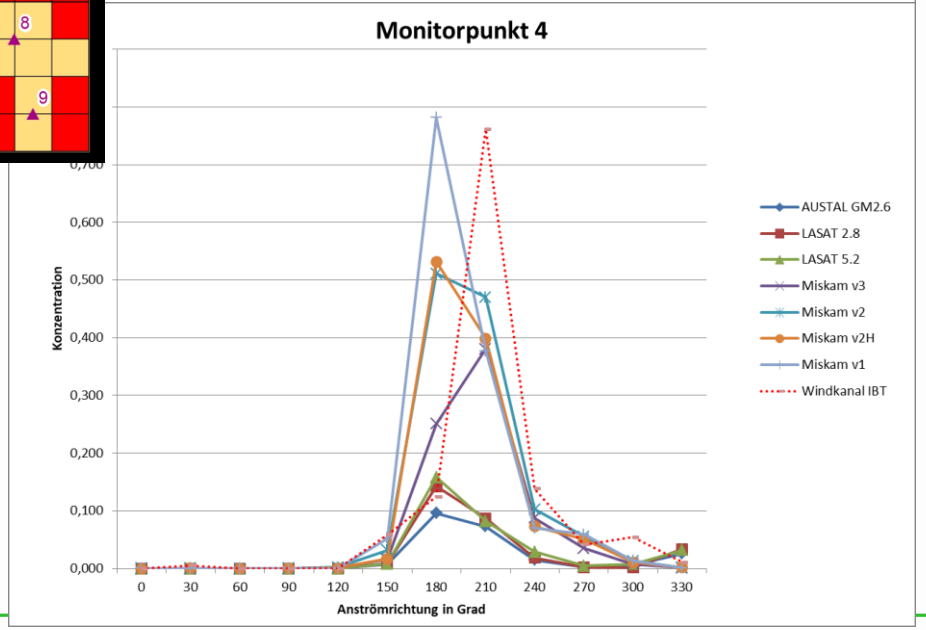
Lohmeyer





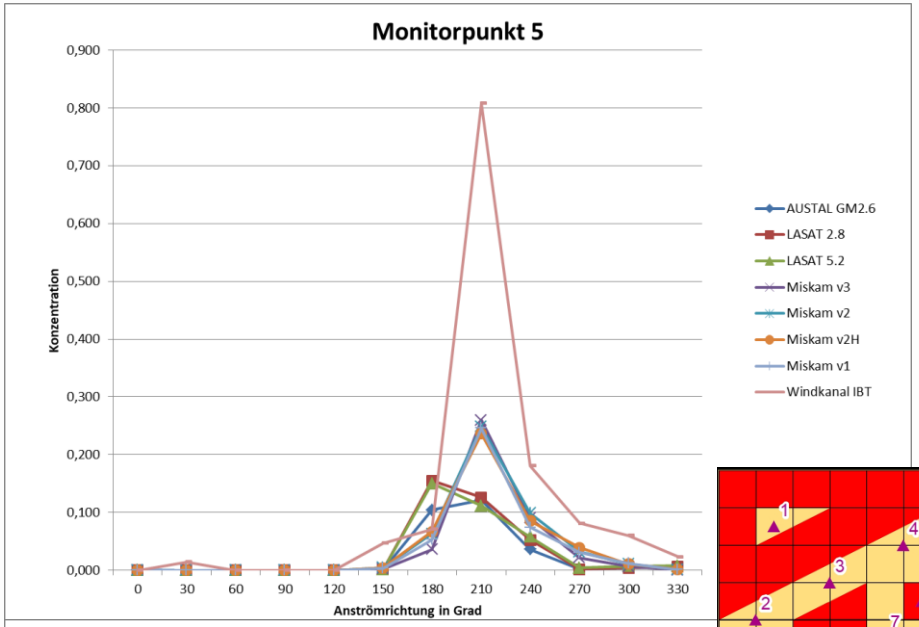


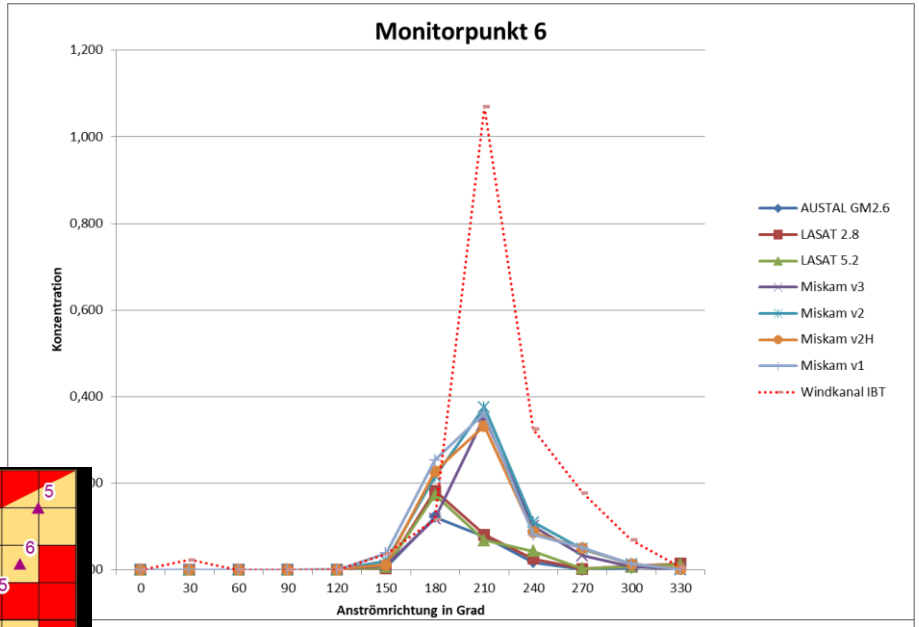


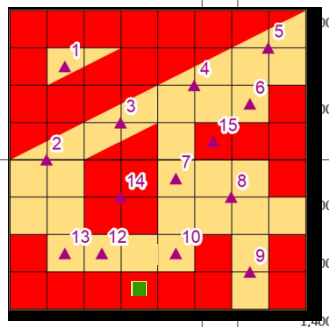


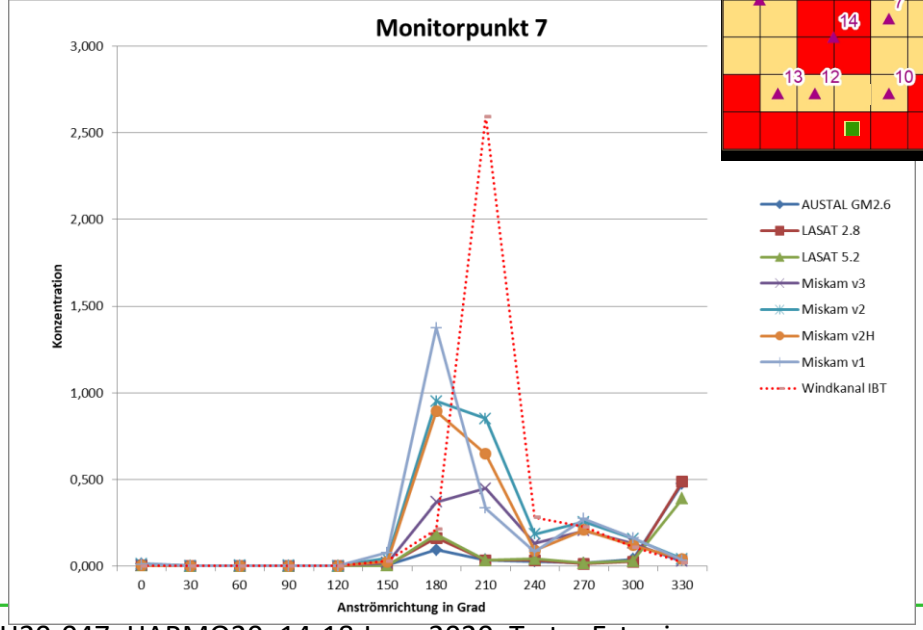
Windkanal- und Modellergebnisse (Quellhöhe 40 m über Grund (10m über Gebäude))

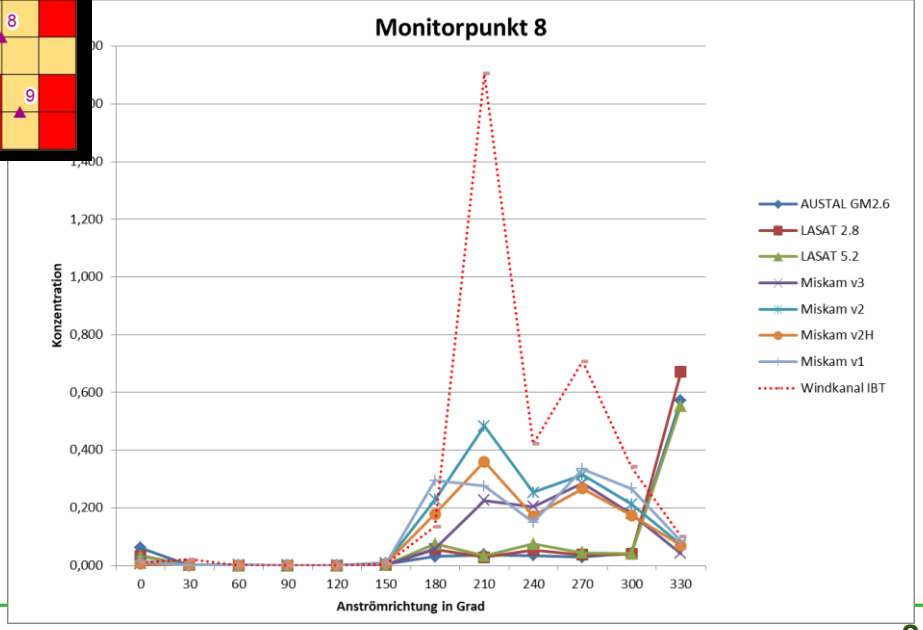
Lohmeyer





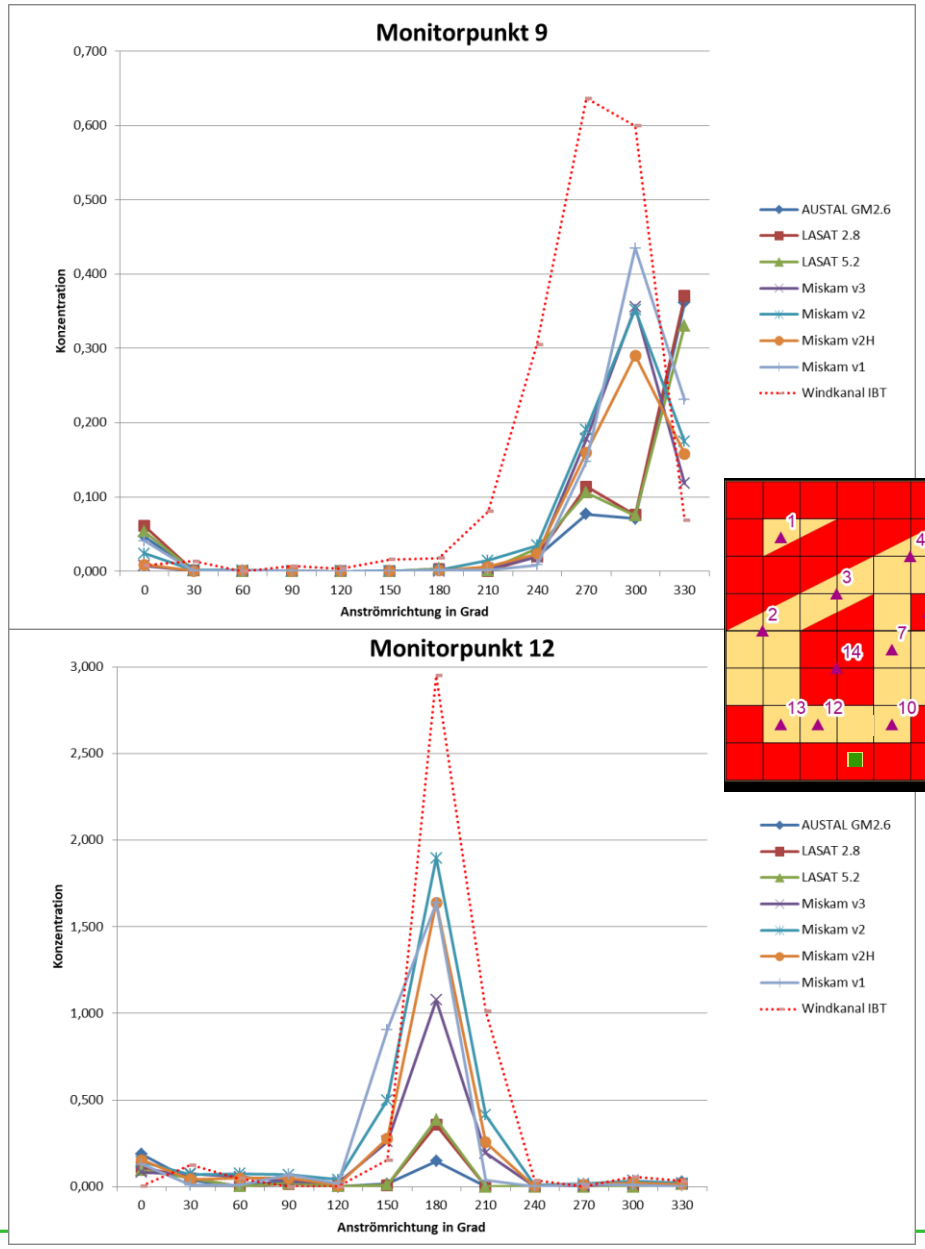


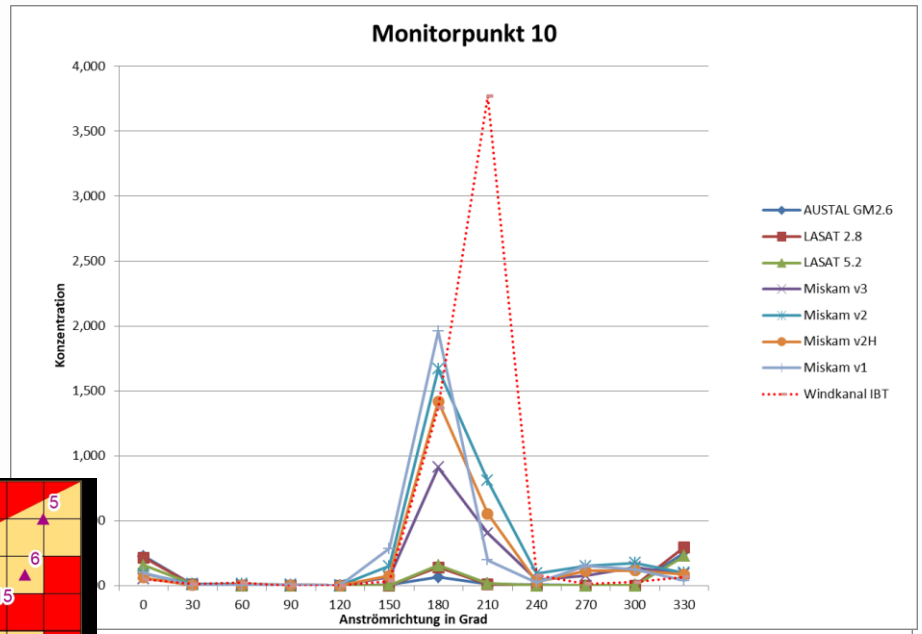


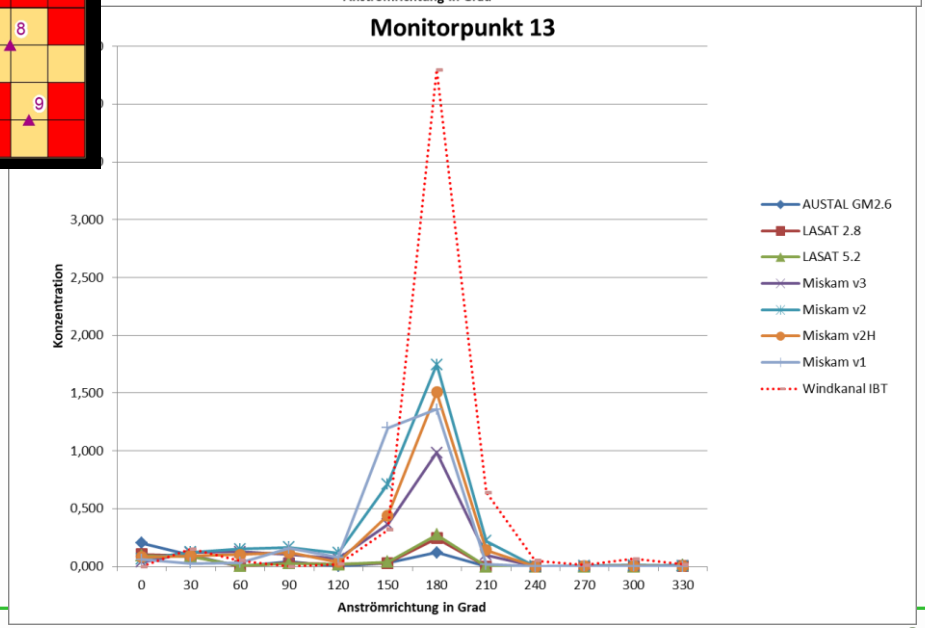


Windkanal- und Modellergebnisse (Quellhöhe 40 m über Grund (10m über Gebäude))

Lohmeyer







Windkanal- und Modellergebnisse (Quellhöhe 40 m über Grund (10m über Gebäude))

Lohmeyer