A case study: Dispersion of nitrogen oxides in the vicinity of the Plabutsch tunnel portal in Graz

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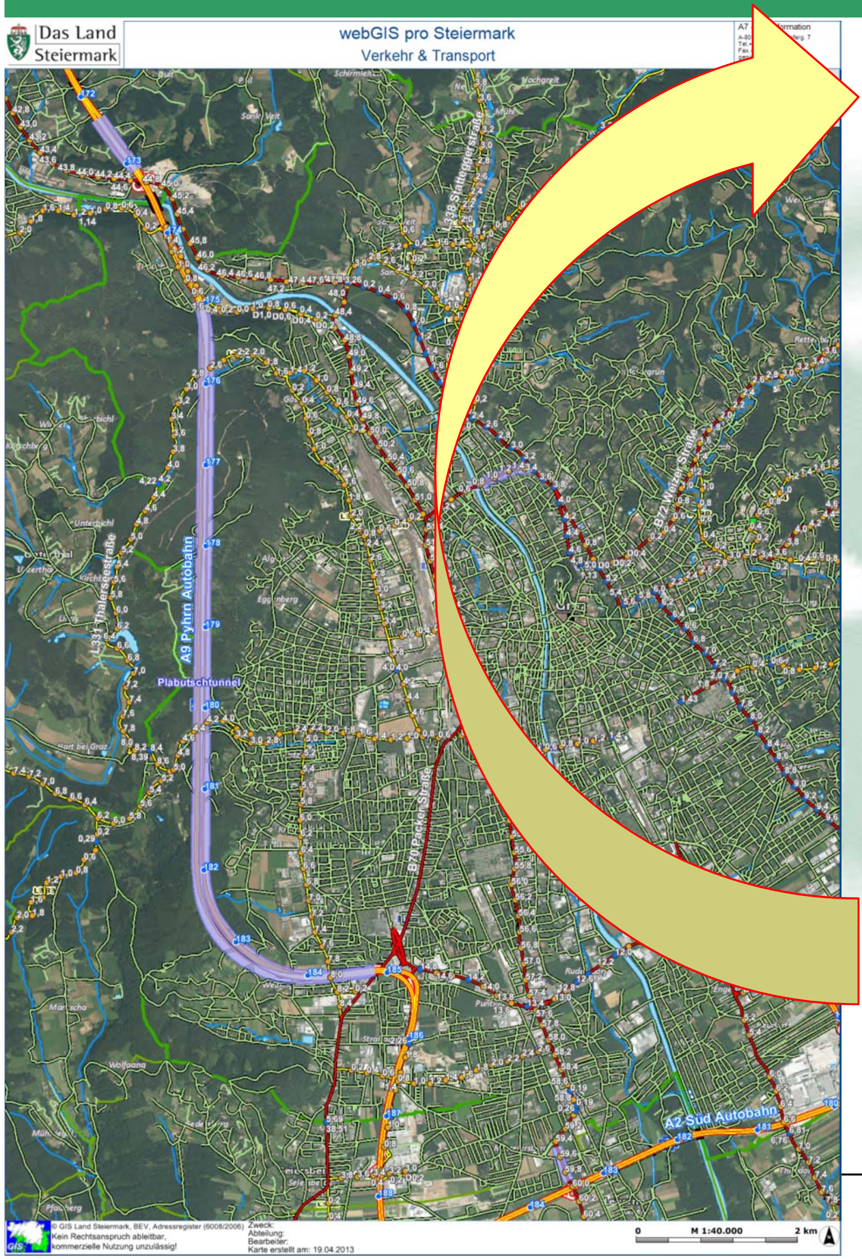
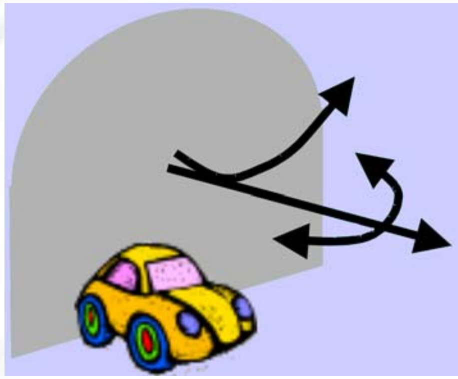
Some remarks



- Complaints of locals assuming exhaust stacks of tunnel causing bad air quality
- Since 2004: Second bore – tunnel is self ventilated – no exhausts at stacks
- High NO_2 burden at portals were simulated in 2010 (application of time extension)
- Municipal authorities ordered air quality measurements at the portal
- Due to the high observed NO_2 concentrations, tunnel ventilation shall be operated such that tunnel exhausts are emitted via the stacks

Introduction

Dispersion is assumed to be influenced mainly by:



- Horizontal exit velocity
- Buoyancy effects
- Interaction between ambient air and tunnel exhausts - ADAPT
- Traffic induced flows and turbulence

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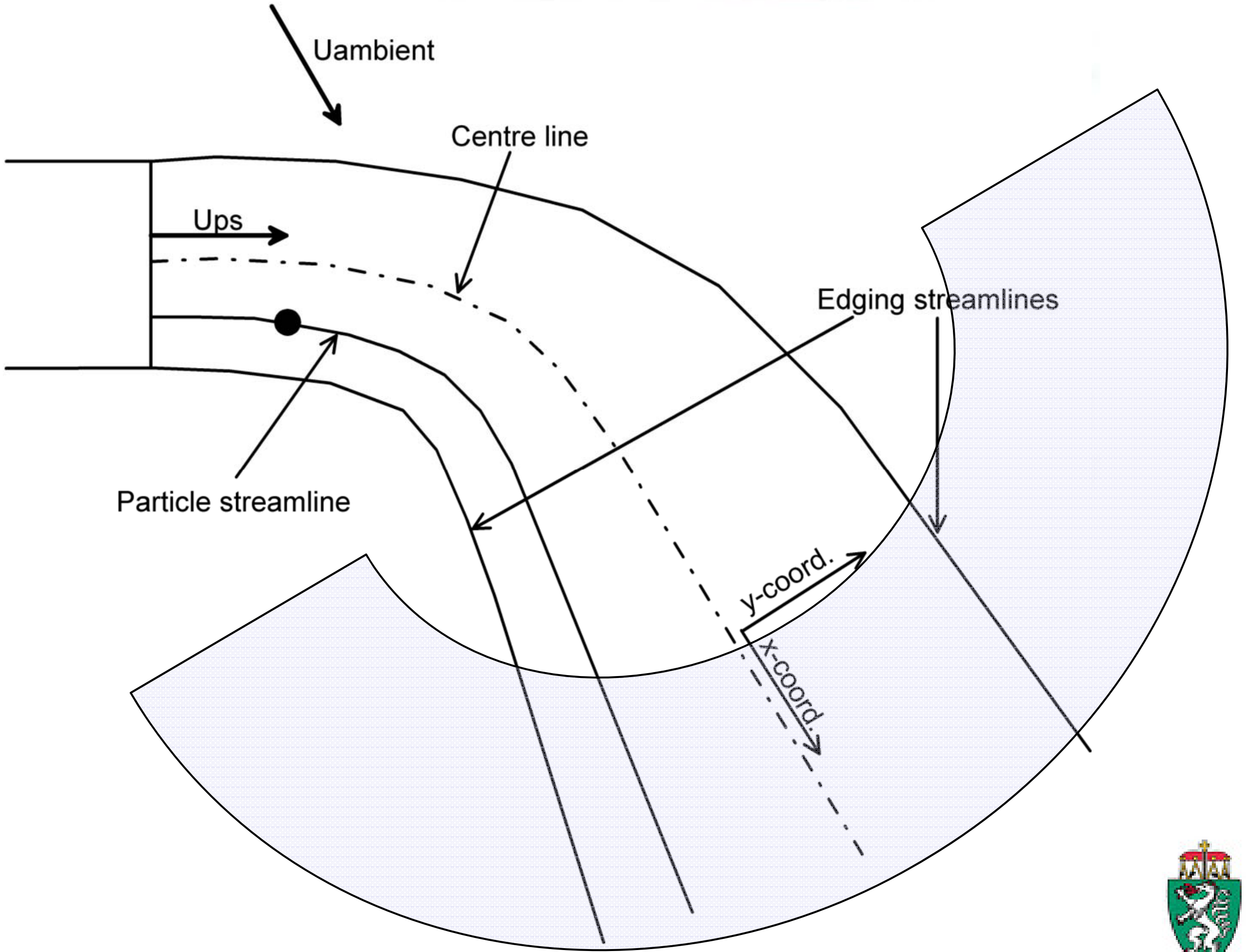
Model description – GRAL tunnel module

GRAL = Lagrangian particle model
Heuristic formulation of the dispersion process:



Model description – GRAL tunnel module

Physical effects	Model formulation
Jet stream geometry	**Assumed friction force according to:** $\frac{dU_p}{dt} = -K \frac{\partial^2 (U_p - U_{pA})}{\partial y^2}$ $K = 0.3 \cdot t$ **Bending:** $\frac{dU_n}{dt} = \frac{1}{2} \alpha U_{nA}^2$ $\alpha = 5 \cdot e^{-0.005 A_T U_0}$
Buoyancy	**Langevin Eq. for vertical turb. vel.:** $dw = -\frac{w}{T_w} dt + \varepsilon_w^{0.5} d\omega_w$ $T_w = 2 \frac{z}{U_p}$
ADAPT	**Gaussian p.d.f. for the horizontal wind component fluctuations of the ambient wind field.**

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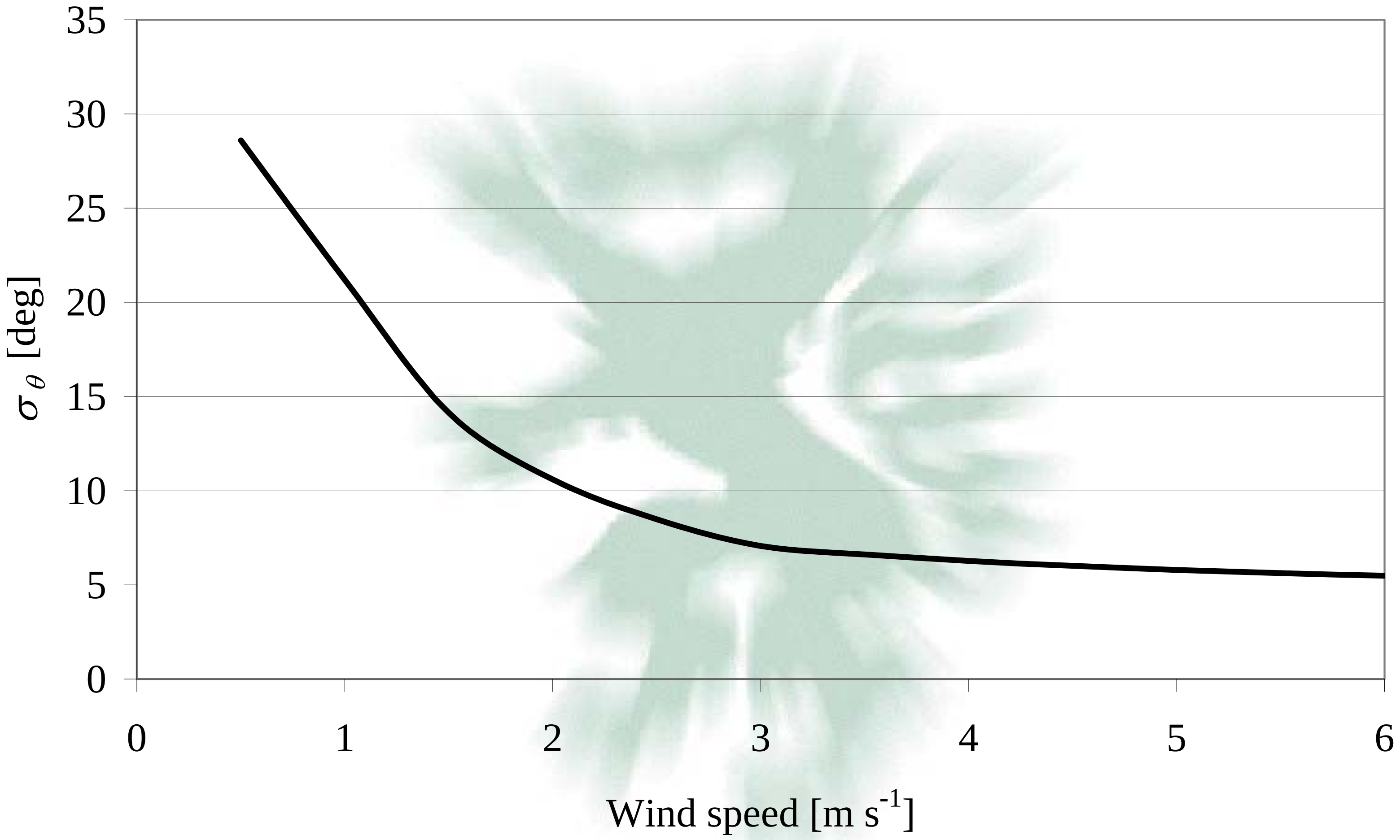
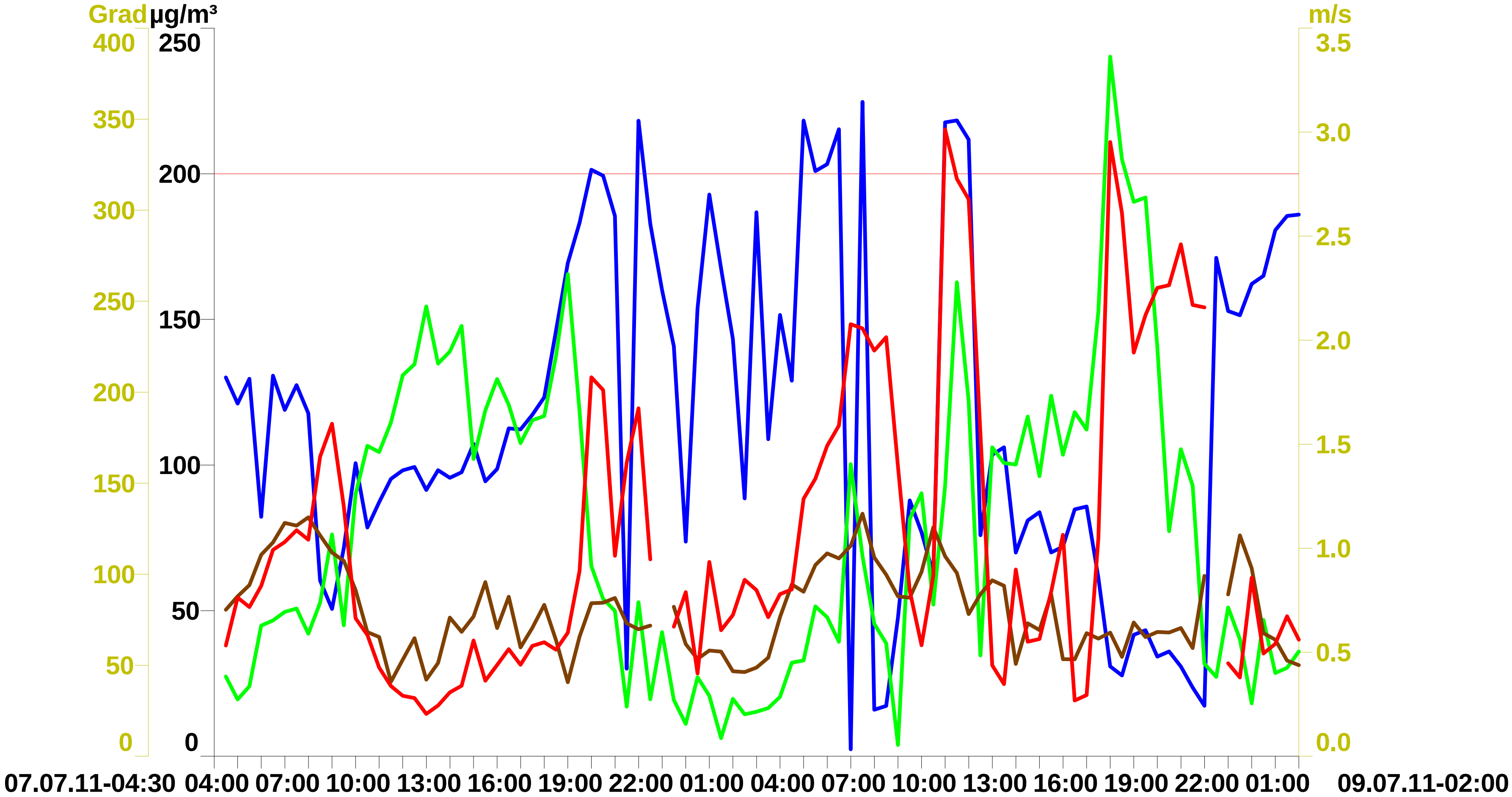
Typical observed wind direction fluctuations vs. wind speed



Source: Leahey et al. (1994)

Observed NO_2 peaks

Station:	MOBILE 1	Graz-DB	MOBILE 1	MOBILE 1
Messwert:	NO2	NO2	WIGE	WIRI
Muster:				



Site map: Plabutsch South Portal

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Model input

Traffic volume: 18.800 veh./d/driving direction
HDV share: 13%
Emissions: modelled using NEMO2.0 (Rexeis and Hausberger, 2005) -> 161 kg/d NO_x

Cases: 1.009 (only northerly wind dir.)
Av. wind speed: 1.6 m/s
Stability classes: modified SRDT-method (US-EPA, 2000; Oettl, 2013)
Av. obs. NO_x: 227 µg/m³
Background NO_x: 33 µg/m³ (Graz-West)

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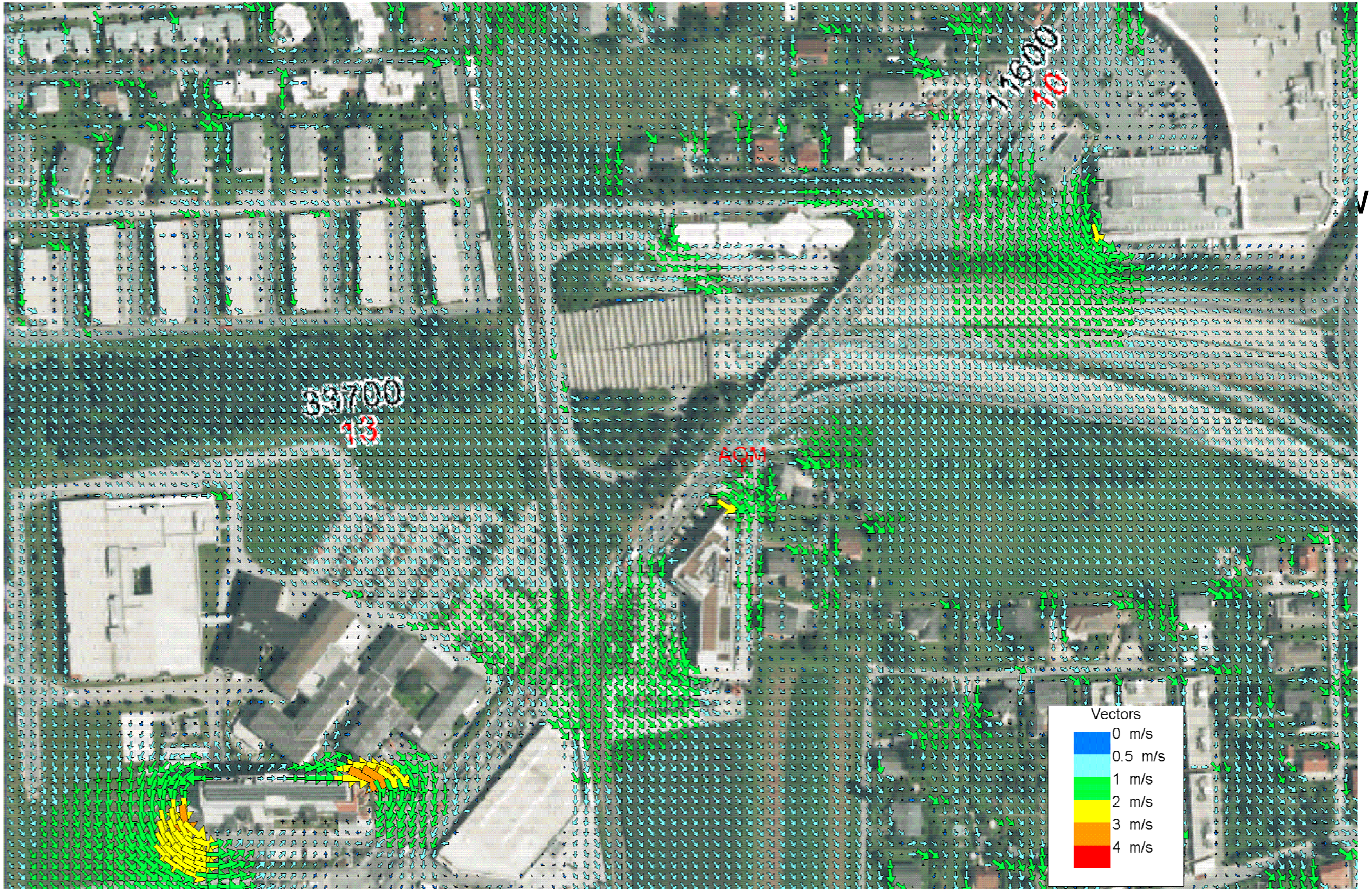
Model parameters



Model setups

Two slightly different model setups:
Standard model assumptions in appl. for regulatory purposes:
Constant exit velocity: 3.8 m/s
Temperature difference: 0 K

Scenario 2:
Varying exit velocity estimated with traffic-piston equation

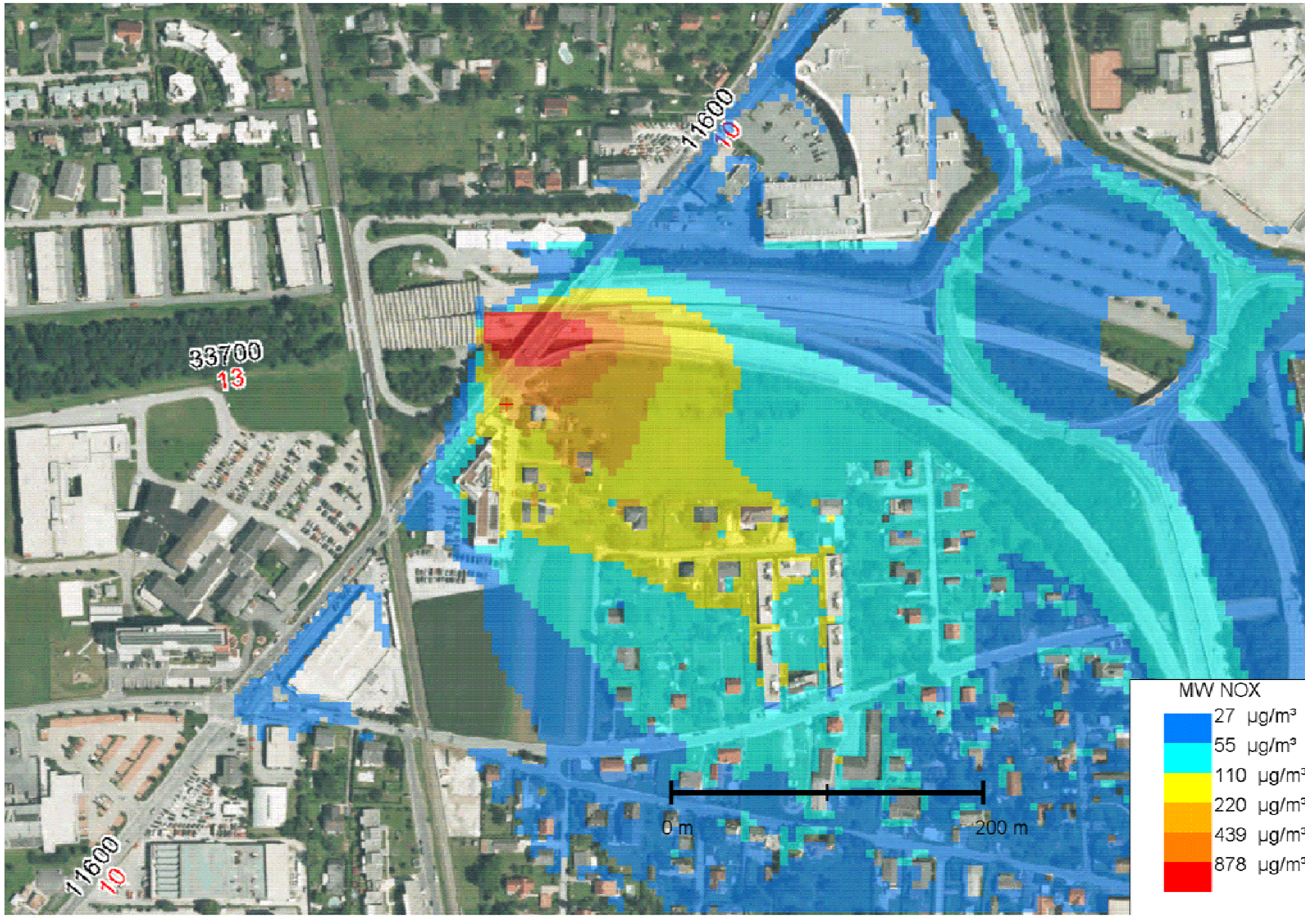
$$\left(1+\zeta_e+\lambda\frac{L}{D}\right)U_0^2=\frac{A_m\,n}{A_t}\left(V_t-U_0\right)^2$$

ζ_e	tunnel entrance loss coefficient (~ 0.2)
λ	tunnel wall friction loss coefficient (0.017)
L	tunnel length (10,000 m)
D	hydraulic diameter of the cross-section (= $4 \cdot A_t / C$ = 6.7 m)
C	circumference of the cross section (m)
A_t	tunnel cross sectional area (49 m^2)
V_t	traffic speed in the tunnel (27.8 $m\ s^{-1}$)
U_0	exit velocity ($m\ s^{-1}$)
n	number of vehicles in the tunnel, and
A_m	equivalent resistance area of the vehicles (m^2)

Hourly data wasn't available, but was estimated on typical diurnal traffic volume variations.

Average simulated NO_x concentration

Be aware of the limited spatial representativity of air quality observations near tunnel portals!



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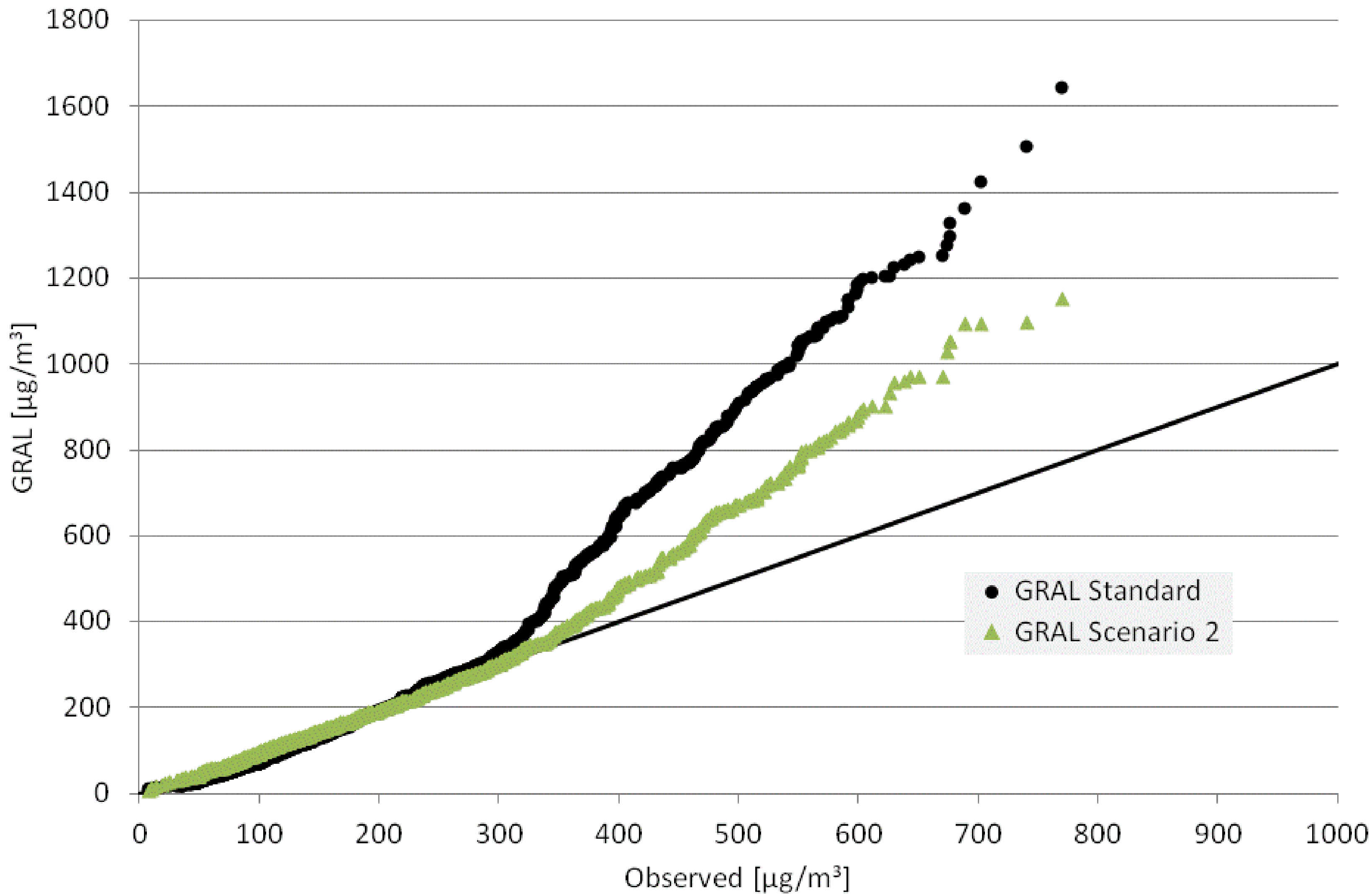
Quantile-quantile plots



Statistical measures

	Mean [µg m^{-3}]	Max [µg m^{-3}]	Fractional bias	Normalized mean square error	Corr.
Observed	227	770			
Standard	295	1645	-0.26	0.93	0.63
Scenario 2	257	1154	-0.12	0.61	0.54

Chang and Hanna, 2004:
FB within ±0.3
NMSE ≤ 4.0

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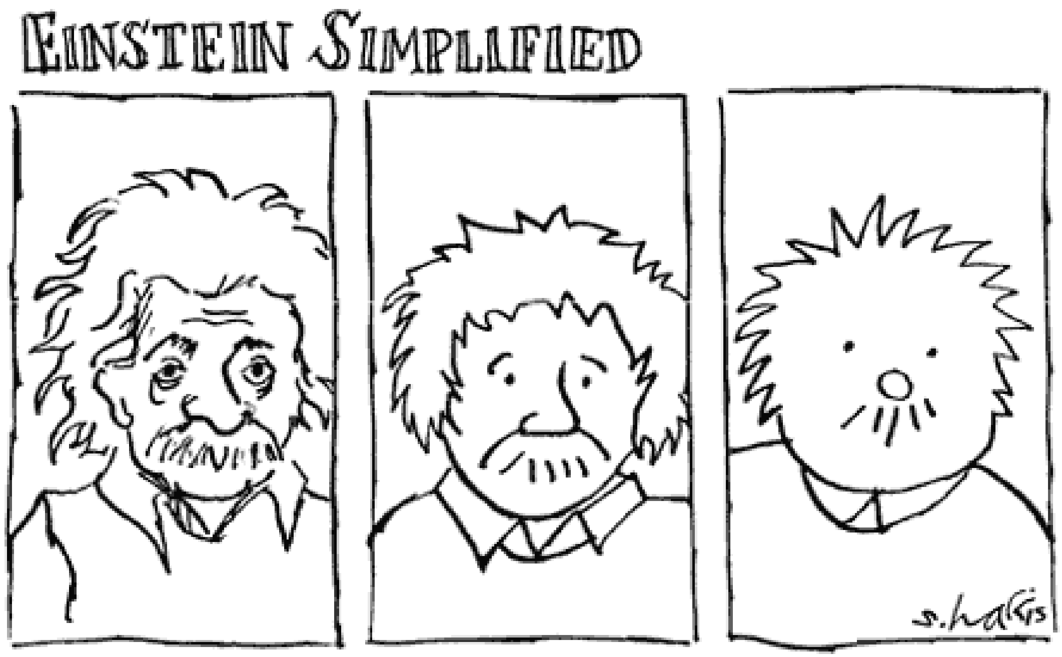
Conclusions

- Bending plume approach and the additional dispersion due to wind direction fluctuations seems to lead to a realistic plume representation
- Model is much faster than CFD models
- High concentration variations in the vicinity of the tunnel portal → high grid resolution, monitoring stations have very limited spatial representativity
- Applying constant exit velocities in applications for regulatory purposes is in principal sufficient when using GRAL

Proper simplification is the art of modelling.



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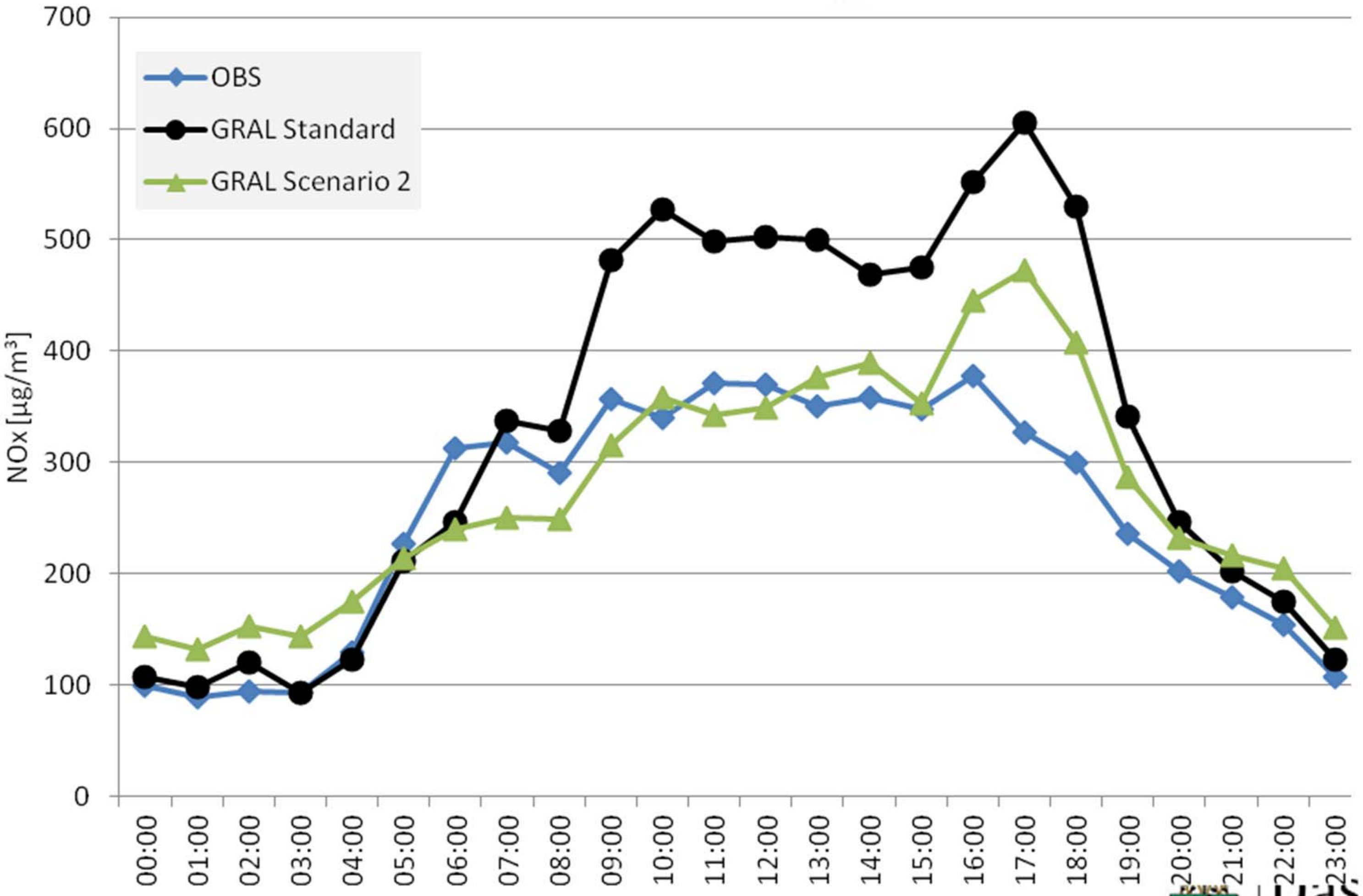
Diurnal NO_x variation



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Model description – GRAL model

Ehrentalerberg-tunnel experiment, 2001.

Model description – GRAL model

Result for the Ehrentalerberg-tunnel experiment, 2001 with the GRAL model