Institute for Internal Combustion Engines and Thermodynamics
Section Traffic and Environment

Graz University of Technology

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Dispersion modelling in complex terrain

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TAIEX-ECRAN Workshop on Air quality modelling
20/10/2015 - 21/10/2015
Ankara

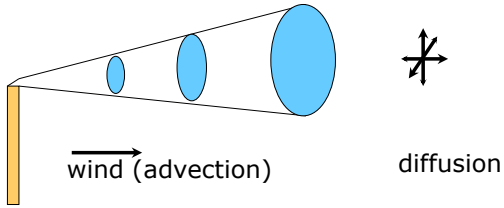
Why dispersion modelling?

- No measurements available (e.g. future)
- Gives area-wide information – measurements only at fixed locations
- Allows the addition of concentrations from different sources – measurements show only the total concentrations
- Costs!

Applications:
- Authorisation procedures
- Status reports, non-attainment areas
- Action plans
- Variation studies
- …

Atmospheric Dispersion

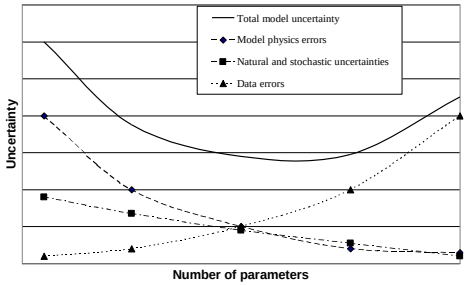
The atmospheric dispersion of air pollutants is determined by **advection** und **diffusion.**



Dispersion Models

- Simple models
  - Need less input data
  - Are more restricted to certain applications
- Complex models
  - Describe the mathematical/physical processes
  - Need much more input data
- Model uncertainty is a product of the quality of the model physics and the quality of the input data!

Dispersion Models



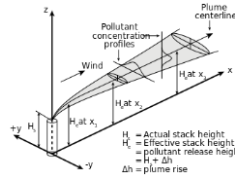
Source: Hanna 1989

Simple models:
- Big Errors because of model physics
- Small errors because of input data

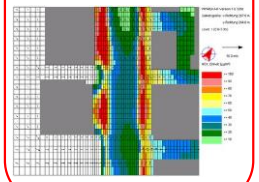
Complex models:
- Better description of physical processes
- Rising uncertainty because of input data

Dispersion Models

Gaussian model:
Analytic function with empiric parameters.

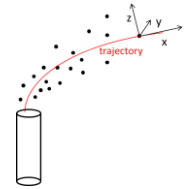


Eulerian model:
Numerical model with fixed coordinate system.



GRAMM

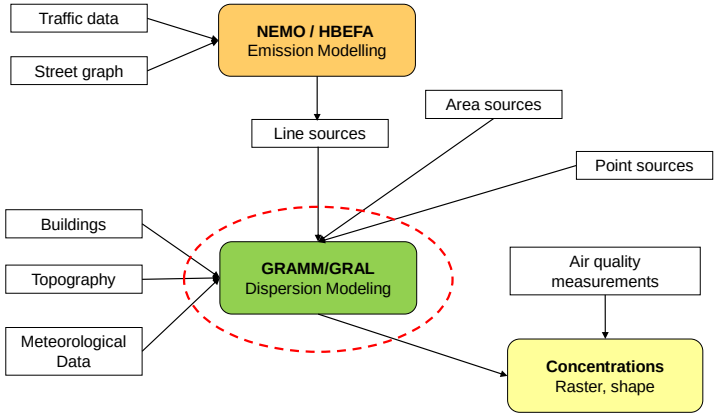
Lagrangian model:
Numerical model with coordinate system based on particles moving with flow field.



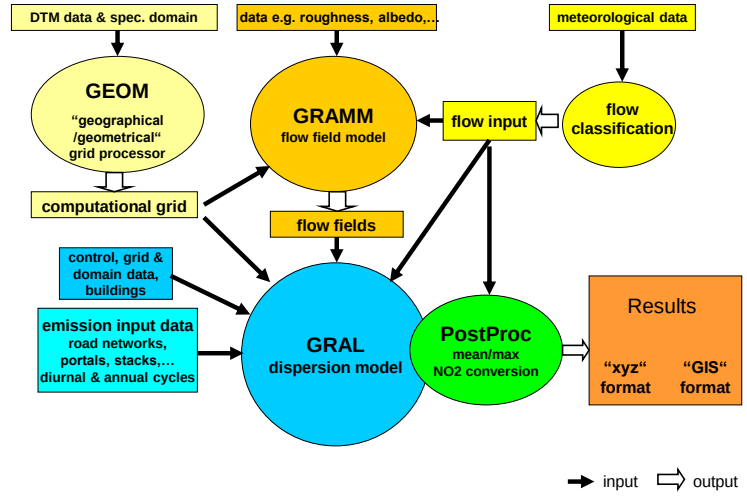
GRAL

Compared to common CFD models:
- special boundary conditions, turbulence and parameterisations for atmosphere
- Model simplifications (grid resolution, boundary conditions) because of computing time

GRAL Model System Simple



GRAL Model System Complex

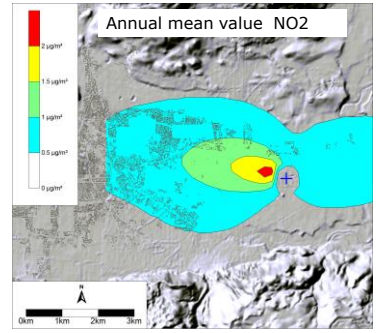


Application Examples

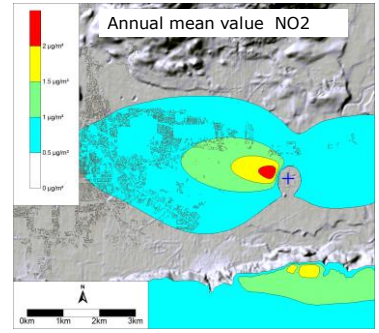
- Point sources
- Line sources + tunnel portals
- Tunnel portals
- Air quality inventories

Point Source – Gaussian Model

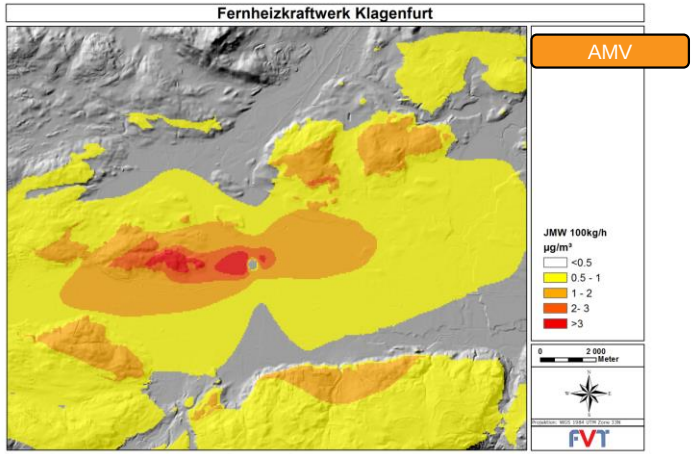
flat



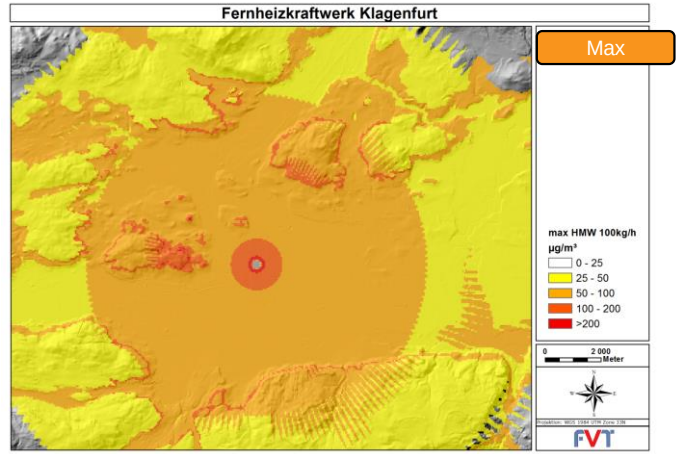
With terrain correction



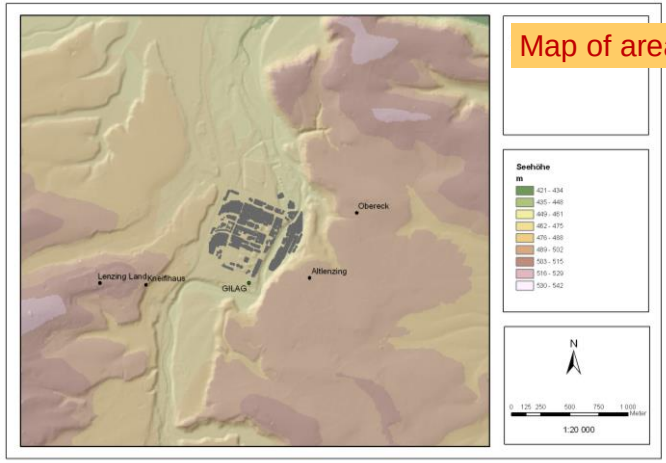
Point Source – Gaussian Model



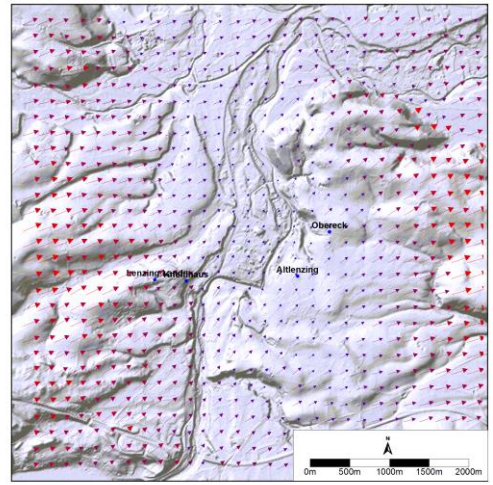
Point Source – Gaussian Model



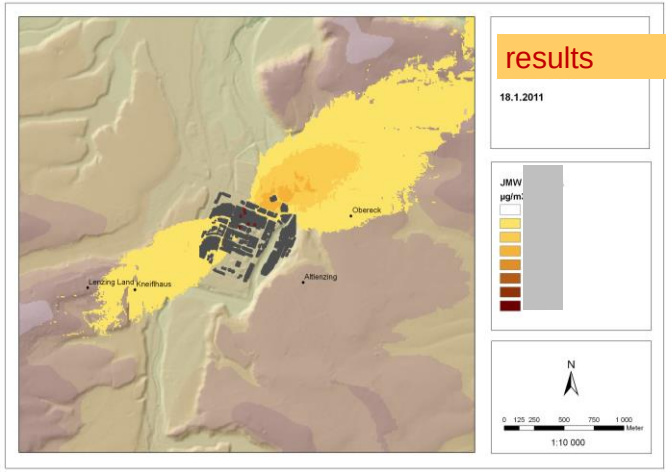
Point Sources – Particle Model



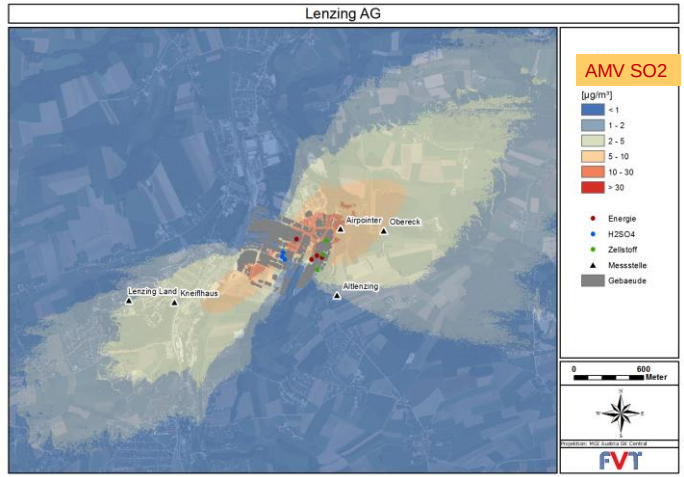
Point Sources – Particle Model



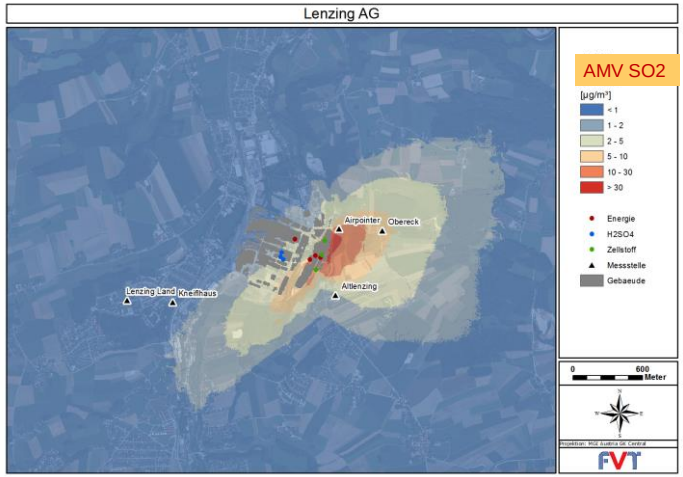
Point Sources – Particle Model



Point Sources – Particle Model

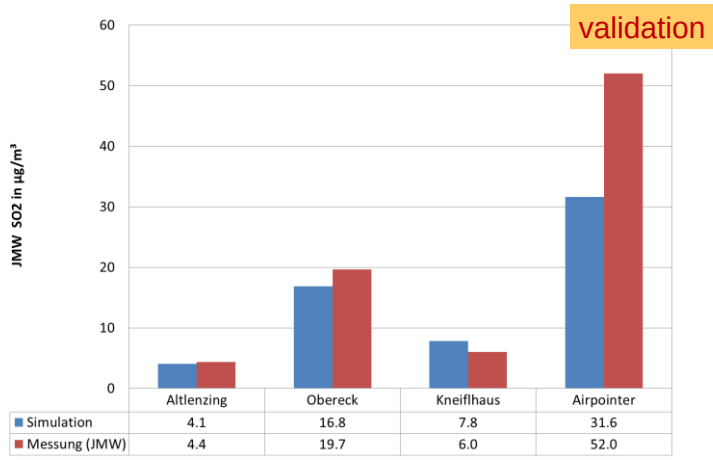


Point Sources – Particle Model



Point Sources – Particle Model

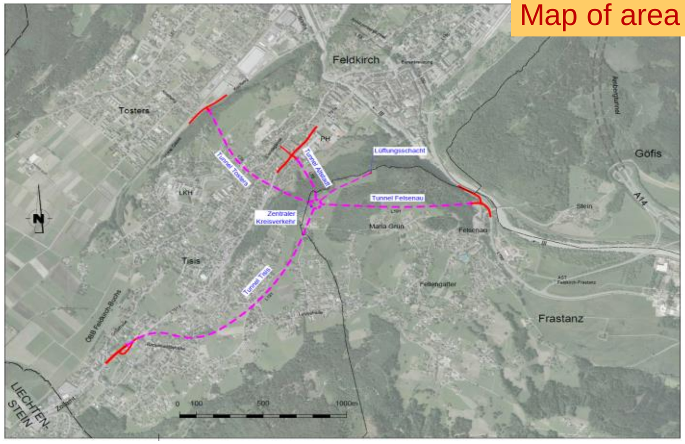
validation



	Altlenzing	Obereck	Kneiflhaus	Airpointer
Simulation	4.1	16.8	7.8	31.6
Messung (JMW)	4.4	19.7	6.0	52.0

Line Sources – Particle Model

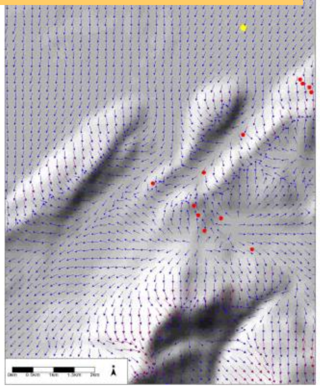
Map of area



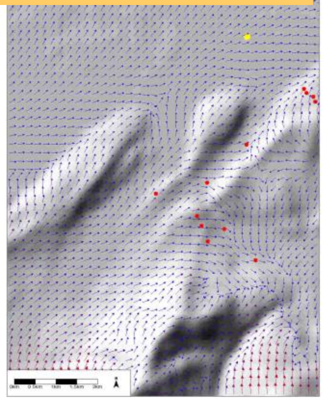
Line Sources – Particle Model

Flow fields

Wind from north
(10°, 1m/s, unstable)

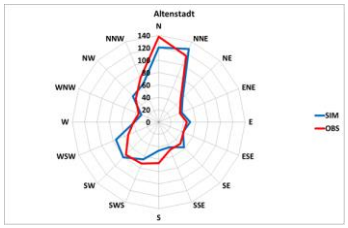


Wind from south
(200°, 1m/s, stable)



Line Sources – Particle Model

Validation of flow fields



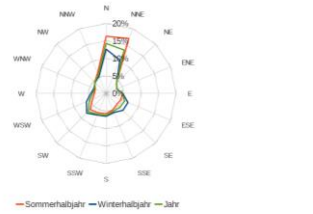
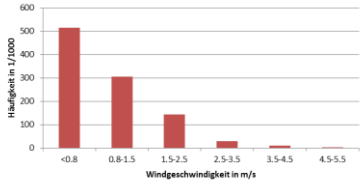


Abbildung 5.13: Windrose mit Häufigkeiten der Richtung in Prozent, unterteilt in 16 Richtungsklassen, der Station Feldkirch von 1994 bis 2010.



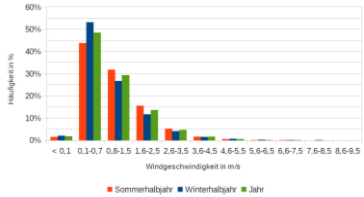
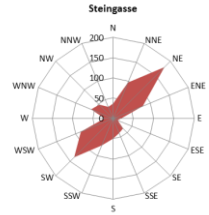


Abbildung 5.11: Geschwindigkeitsverteilung der Station Feldkirch von 1994 bis 2010.

Line Sources – Particle Model

Validation of flow fields



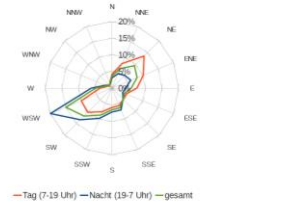
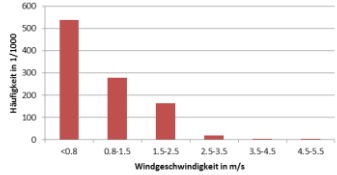
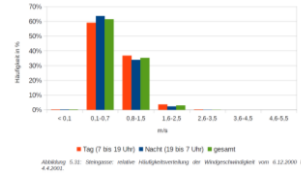


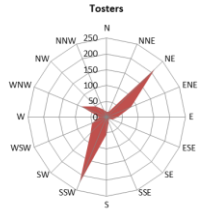
Abbildung 5.30: Steingasse: Windrose mit Häufigkeiten in % nach Windrichtungsklassen vom 6.12.2000 bis 4.4.2001.





Line Sources – Particle Model

Validation of flow fields



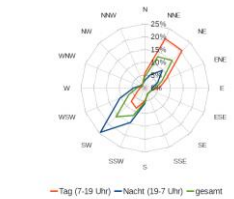
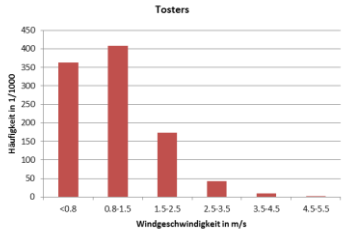


Abbildung 5.33: Relative Häufigkeitsverteilung der Windrichtung von 4.7.2011 bis 31.10.2011 in Tosters.



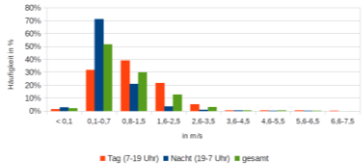
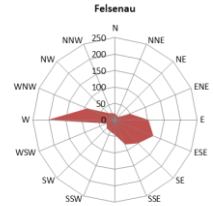


Abbildung 5.35: Relative Häufigkeitsverteilung der Windgeschwindigkeit in Tosters vom 4.7.2011 bis 31.10.2011.

Line Sources – Particle Model

Validation of flow fields



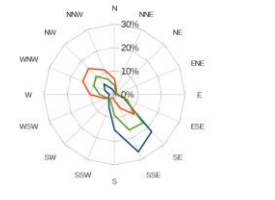
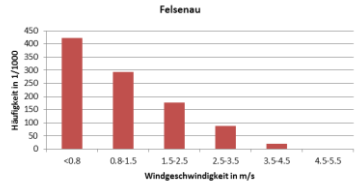
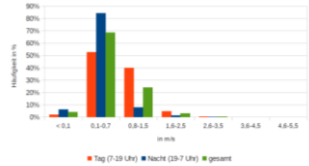
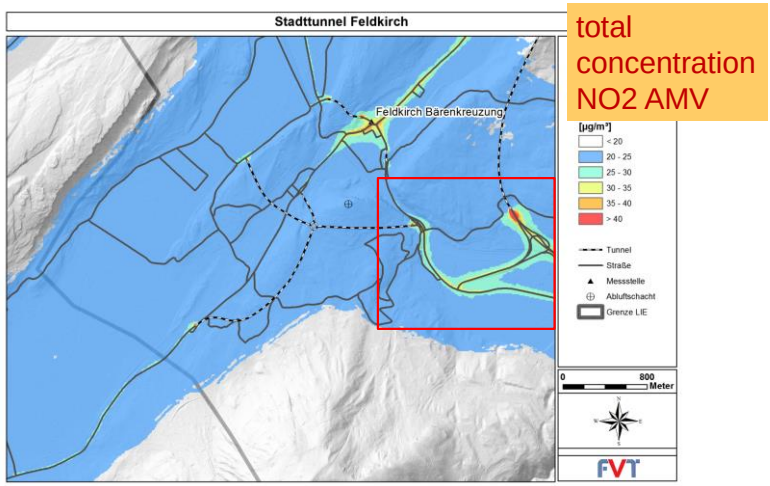


Abbildung 5.16: Häufigkeitsverteilung der Windrichtung in Felsenau von 4.7.2011 bis 31.10.2011.



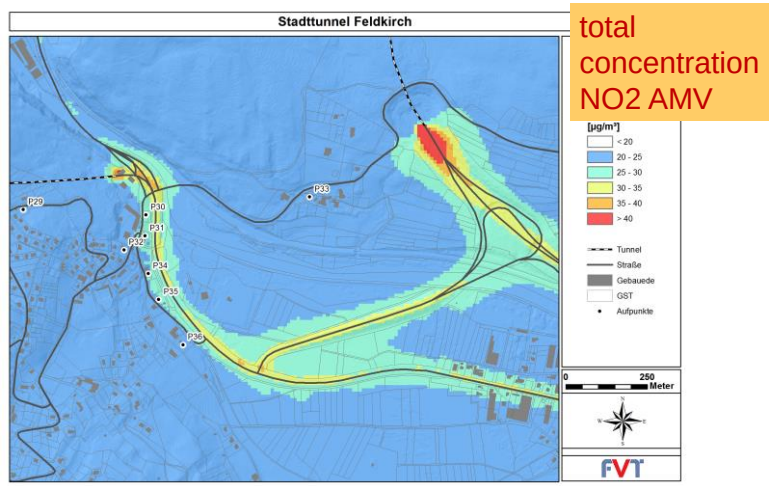


Line Sources – Particle Model



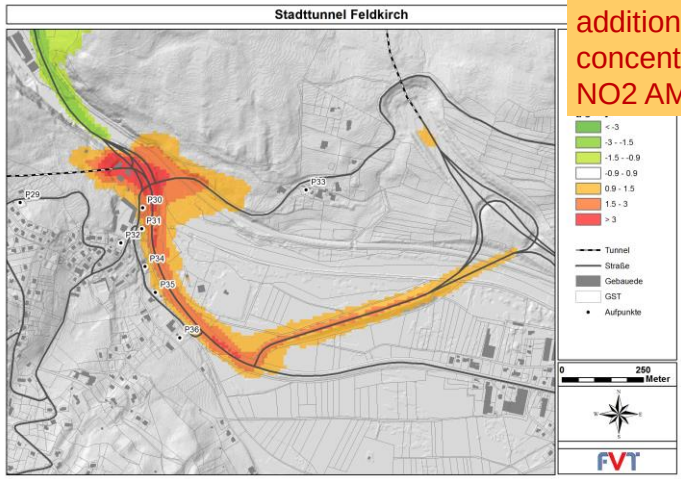
total concentration NO2 AMV

Line Sources – Particle Model



total concentration NO2 AMV

Line Sources – Particle Model



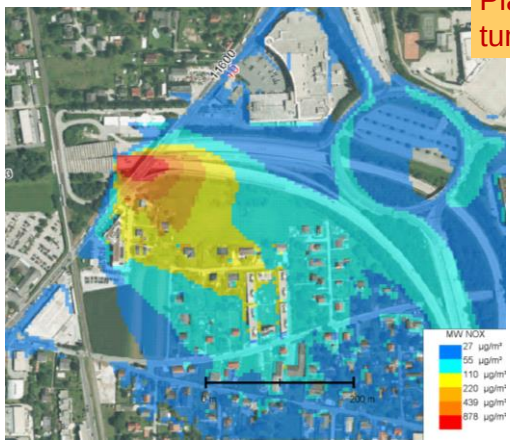
additional concentration NO2 AMV

Tunnel Portal– Particle Model

Plabutsch tunnel

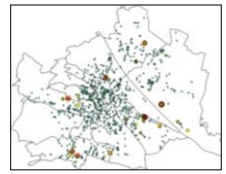
Tunnel Portal– Particle Model

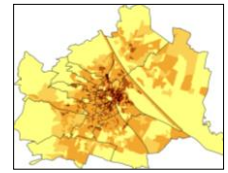
Plabutsch tunnel



Air Quality Inventory – Particle Model

setup





> 900 point sources

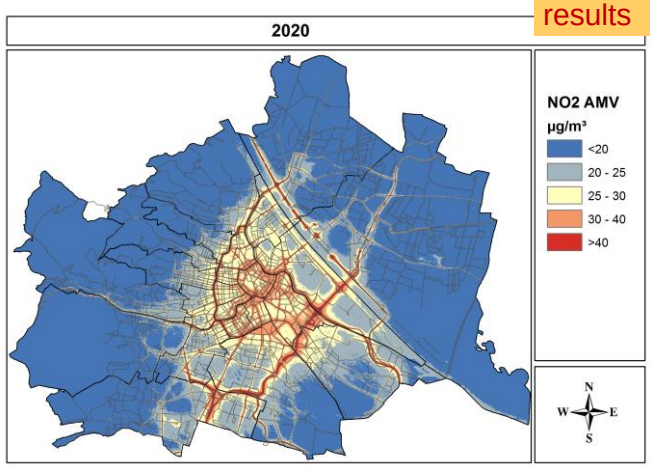
~ 6000 street sections with ~ 1500 km

6 categories of area sources (100x100m cells)

Area sources outside Vienna based on municipality level

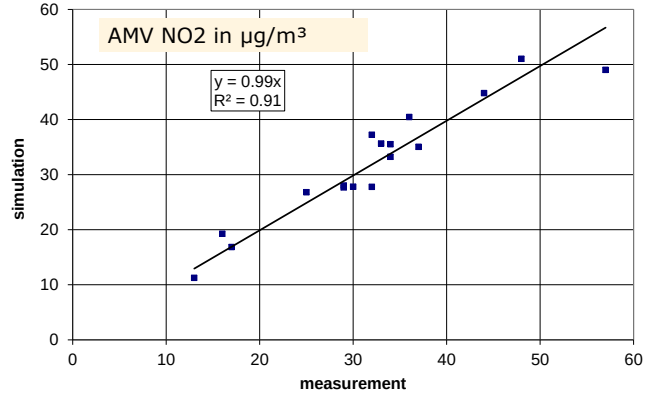
Air Quality Inventory – Particle Model

results



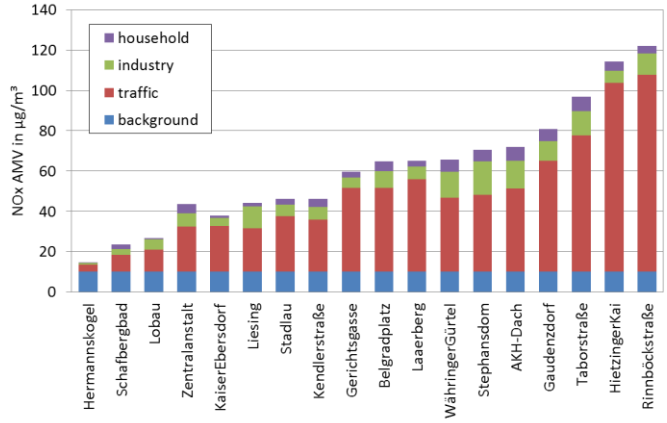
Air Quality Inventory – Particle Model

validation



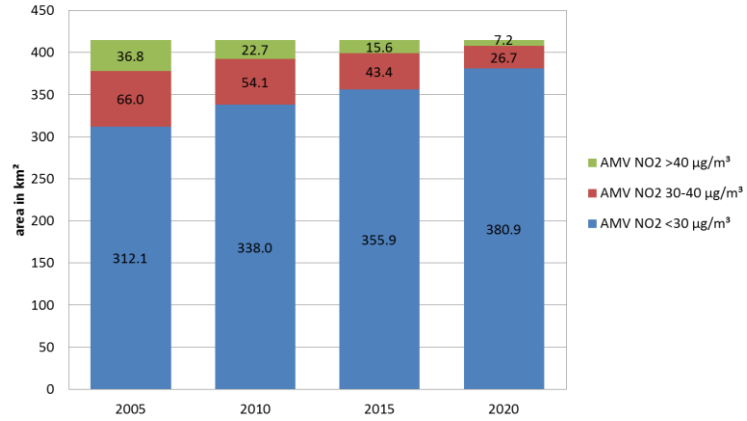
Air Quality Inventory – Particle Model

contribution of sources



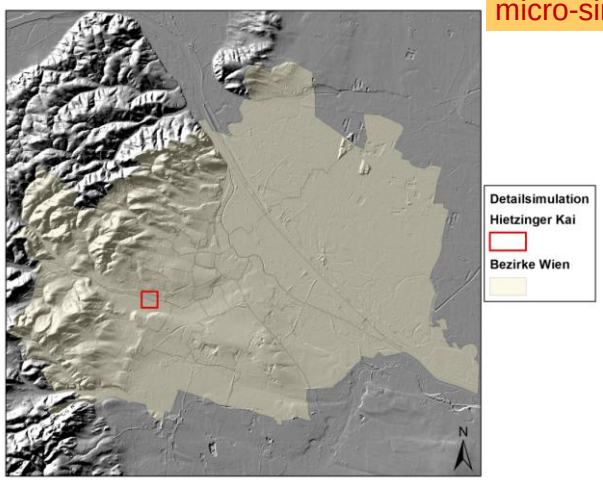
Air Quality Inventory – Particle Model

non-attainment zones



Air Quality Inventory – Particle Model

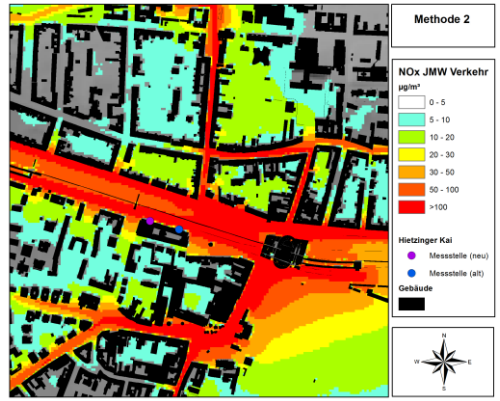
micro-simulation



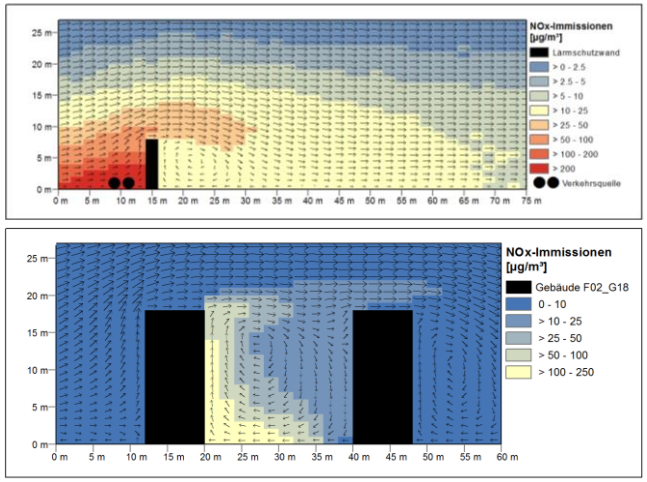
Micro-Simulation – Particle Model

flow field Vienna
200m x 200m

GRAL
5m x 5m

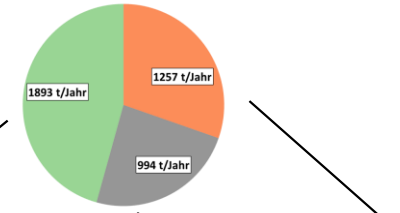


Micro-Simulation – Particle Model

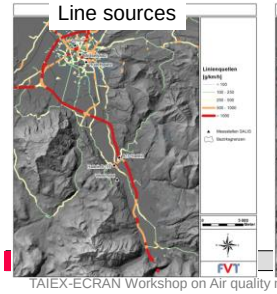


Air Quality Inventory – Particle Model

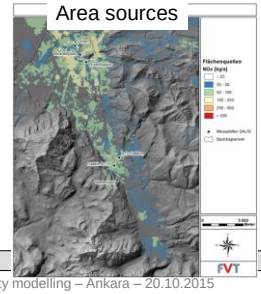
Emissionen (NOx)



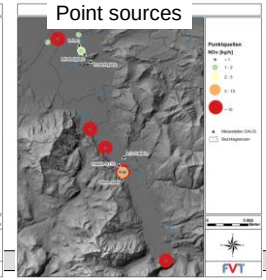
Line sources



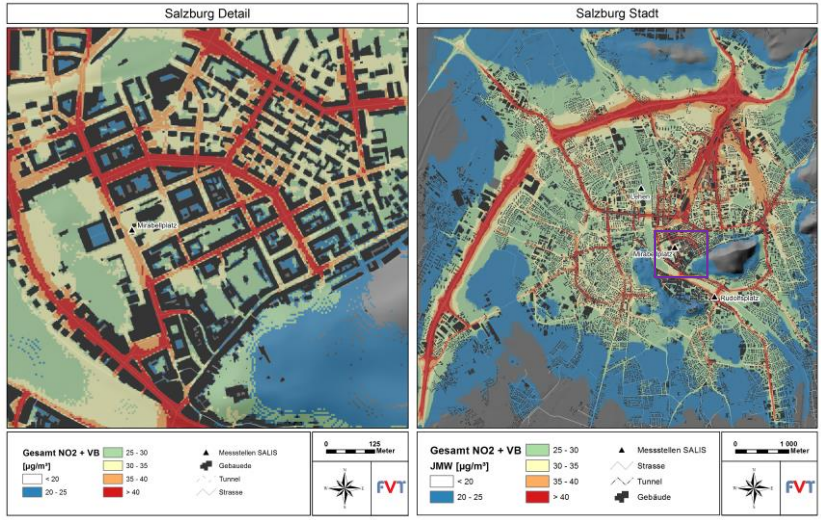
Area sources



Point sources

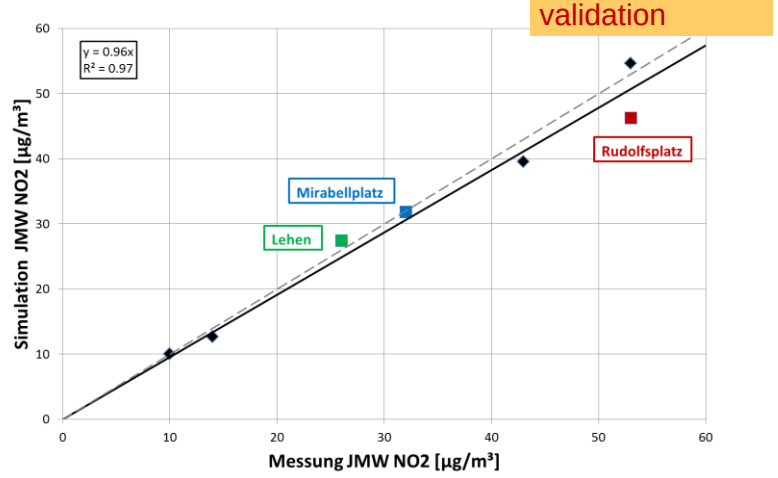


Air Quality Inventory – Particle Model



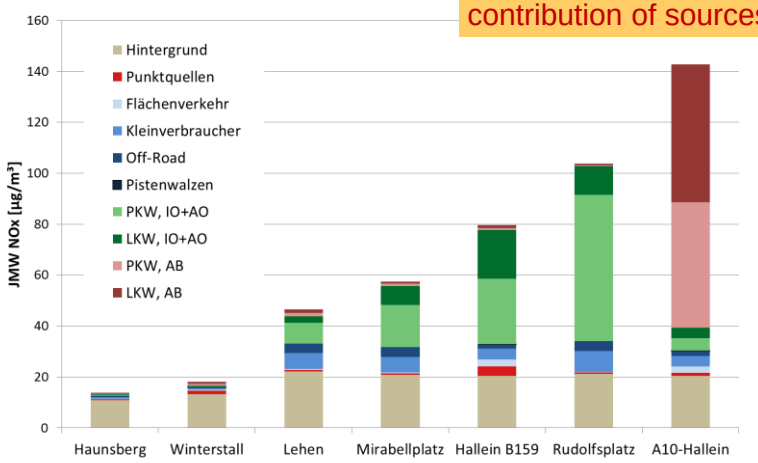
Air Quality Inventory – Particle Model

validation



Air Quality Inventory – Particle Model

contribution of sources



Air Quality Inventory – Particle Model

Domain Salzburg City with 7,5 km x 7,5 km

AMV NO2 in µg/m³	km²	percent
< 30	43.7	78 %
30 - 35	6.6	12 %
35 - 40	2.9	5 %
> 40	3.1	6 %

non-attainment zones

Validation

Errors because of:

- Input data (traffic, meteorology,…)
- Emission calculation (factors, fleet,..)
- Flow field
- Dispersion model
- Model simplifications

Error calculation not possible!

Validation with measurements

Standard data sets for validation

+

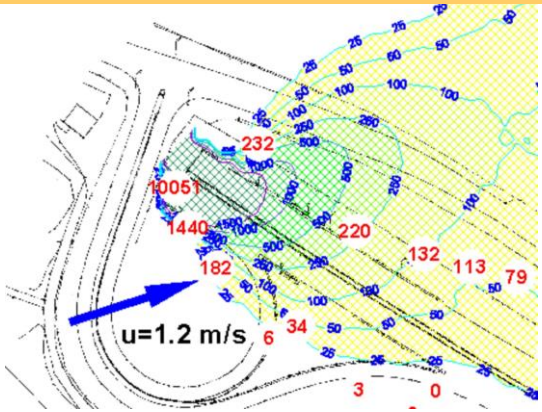
- Tunnel, luv-lee
- Meteorological monitoring sites
- Tracer gas

Validation data

Ehrentalerberg-tunnel experiment, 2001.

Validation data

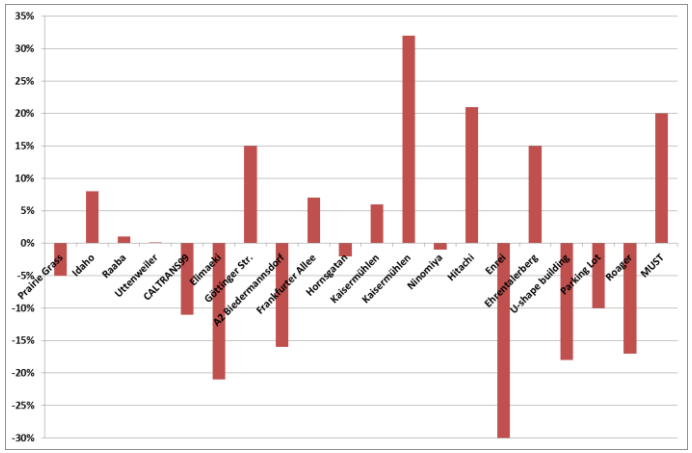
Result for the Ehrentalerberg-tunnel experiment, 2001 with the GRAL model



Validation

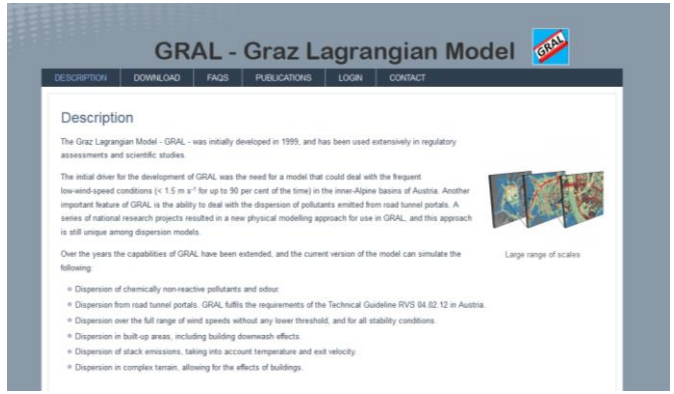
Data set	NMSE	Mean Dev.	Emission Type	Characteristics
Prairie Grass	1.1	-5%	tracer	plume near ground, flat terrain
Idaho	0.2	8%	tracer	release at flat plain 1500 m AGL
Raaba	1.4	1%	tracer	release near ground, flat terrain
Uttenweiler	0.9	0%	tracer	pig stable at roof ridge with ventilation
CALTRANS99	0.6	-11%	tracer	release near motorway
Elimaeki	0.2	-21%	NOx Emi comp	monitored at various heights
Göttinger Str.	1.7	15%	NOx Emi comp	street canyon
A2 Biedermannsdorf		-16%	NOx Emi comp	motorway, flat terrain
Frankfurter Allee	1	7%	NOx Emi comp	street canyon
Hornsgatan	1.6	-2%	NOx Emi comp	street canyon
Kaisermühlen	0.7	6%	tracer, NOx	tunnel westerly winds
Kaisermühlen	1.8	32%	tracer, NOx	tunnel easterly winds
Ninomiya	1.6	-1%	tracer	tunnel
Hitachi	2.4	21%	tracer	tunnel
Enrei	3.9	-30%	tracer	tunnel
Ehrentalerberg	2.2	15%	tracer	tunnel
U-shape building	1.7	-18%	tracer	wind tunnel experiment
Parking Lot	2	-10%	tracer	urban area
Roager	0.5	-17%	tracer	pig stable release at roof ridge
MUST	6.5	20%	tracer	wind tunnel building shaped obstacles

Validation

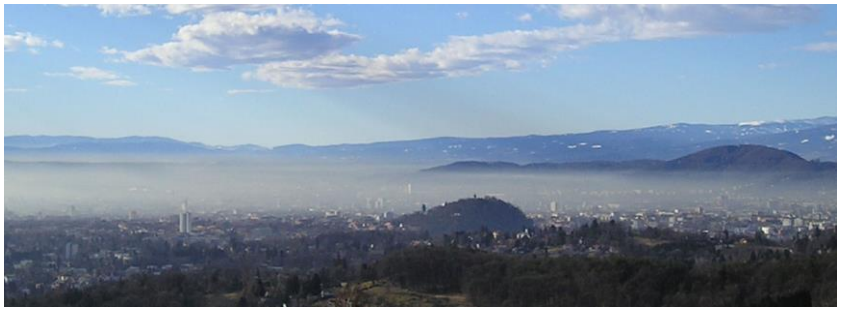


Free download GRAL

http://lampx.tugraz.at/~gral/



Thanks for your attention!



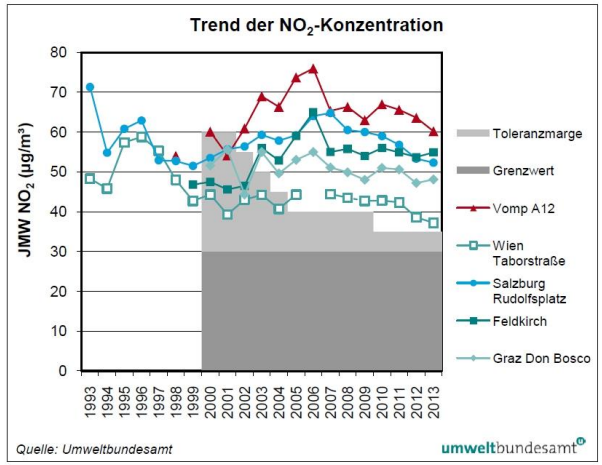
Threshold values

- Austrian legislation (IG-L) more stringent than EU Directive!

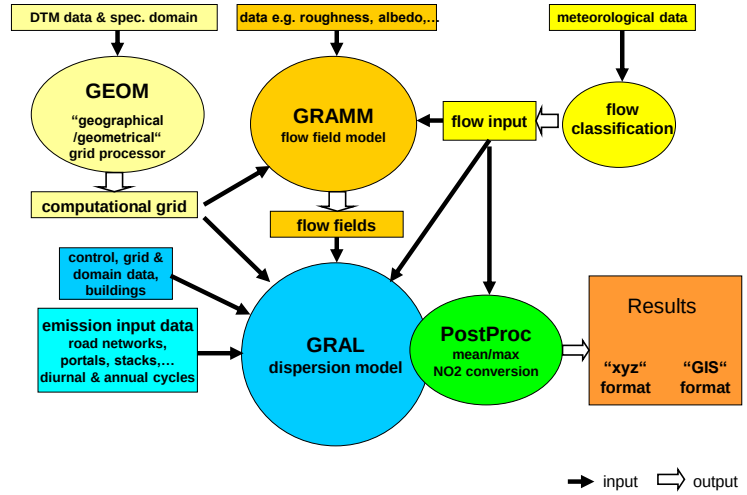
		EU Directive	IG-L
NO2	Annual mean (µg/m³)	40	30 (+ 5)
	Maximal value (µg/m³)	200 (1h)	200 (1/2 h)
	Tolerated exceedances	18	0

2013:
Exceedances at 34 Monitoring sites!

Trend

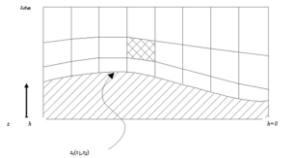


GRAL Model System Complex



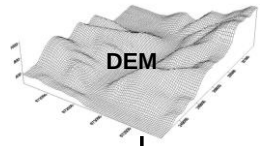
Main Features GRAMM (flow field model)

- Prognostic non-hydrostatic (**Gra**z **M**esoscale **M**odel)
- Terrain-following grid



- Implicit time integration (stability)
- Computation of surface energy balance
- Land surface scheme
- Forcing with 1 representative measuring station

GRAMM



flow classification

- **wind speed classes (j~4-6)**
- **wind directions (k~36)**
- **stability classes (l~3/7)**

→ j x k x l ~ 300 – 1000 fields

GEOM grid processor

land use, buildings

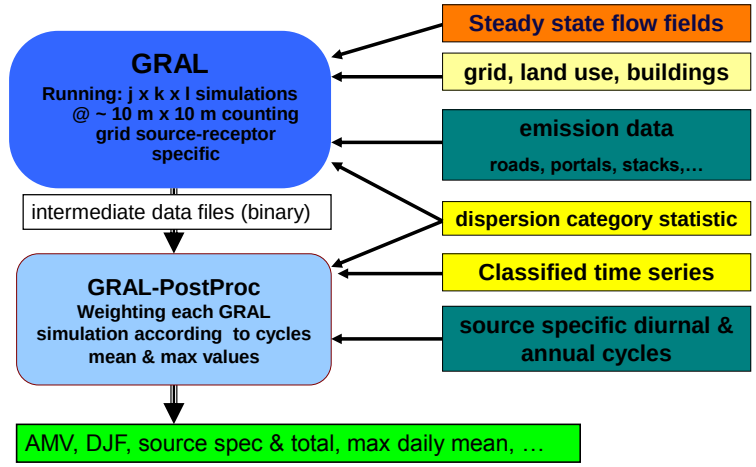
GRAMM 3d flow fields

Steady state flow fields

Main Features GRAL

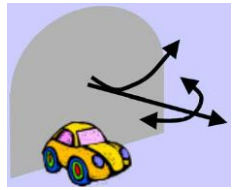
- 3-d Lagrangian particle model (**Gra**z **L**agrangian Model)
- Special algorithms for low wind speeds and complex terrain
- Consideration of buildings
- Different source types (point, line and area)
- Output data corresponds to air quality standards (annual mean, maximum daily mean, percentiles)
- Tunnel module for portals

GRAL



GRAL Tunnel Module

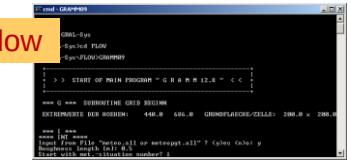
Dispersion is assumed to be influenced mainly by:



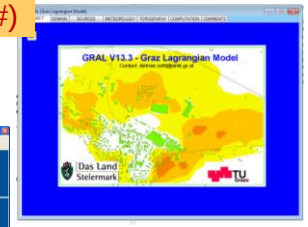
- Horizontal exit velocity
- Buoyancy effects
- Interaction between ambient air and tunnel exhausts - ADAPT
- Traffic induced flows and turbulence

GRAMM/GRAL- user interfaces

1. Windows command window



2. GUI by D. Öttl (freeware C#)



3. Module of SoundPLAN