Prediction and forecast of daily PM10 concentrations in Brno and Graz

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Österr. Statistiktage 2011, Graz

9. September 2011

Contents

Situation in Graz and Brno

- Meteorological and anthropogenic factors
- Measuring stations in Graz and Brno

Statistical Prediction Models

- Multiple Linear Regression
- Generalized Linear Model

Quality of the Models

The general Situation

Graz (263k inhabitants): Basin Area

- Low wind velocities, low precipitation, temperature inversion
- Traffic, domestic fuel

Brno (430k inhabitants): Open Basin Area

- Concentration of industry, motor traffic, heating plants
- Temperature inversion

Consequence

- Treshold value daily mean PM10 $\geq 50 \mu g/m^3$ exceeded regularly
- **Graz:** 36 – 105 exceedances in winter seasons
- **Brno:** 55 – 70 exceedances

Stations in Graz

Forecast: Graz-Mitte (traffic area), Graz-Süd (industrial zone)
Precipitation: Graz-Nord
Temperature inversion: Kalkleiten

Graz-Mitte: Inversion and Weekend Effect

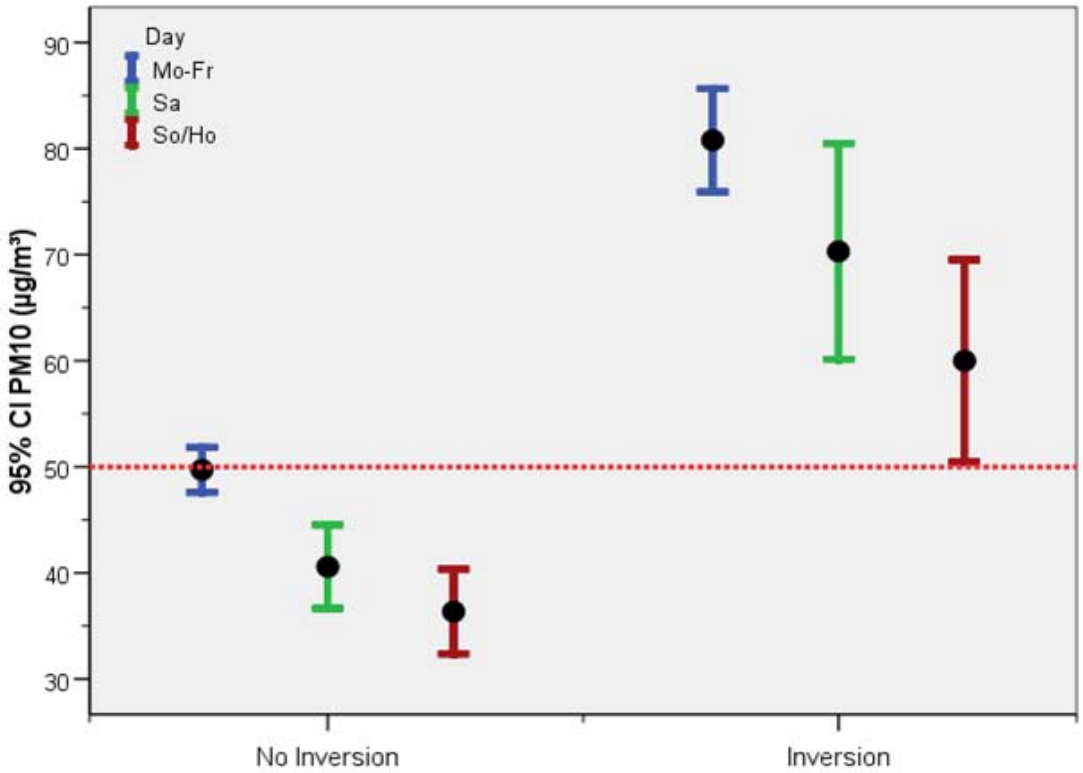


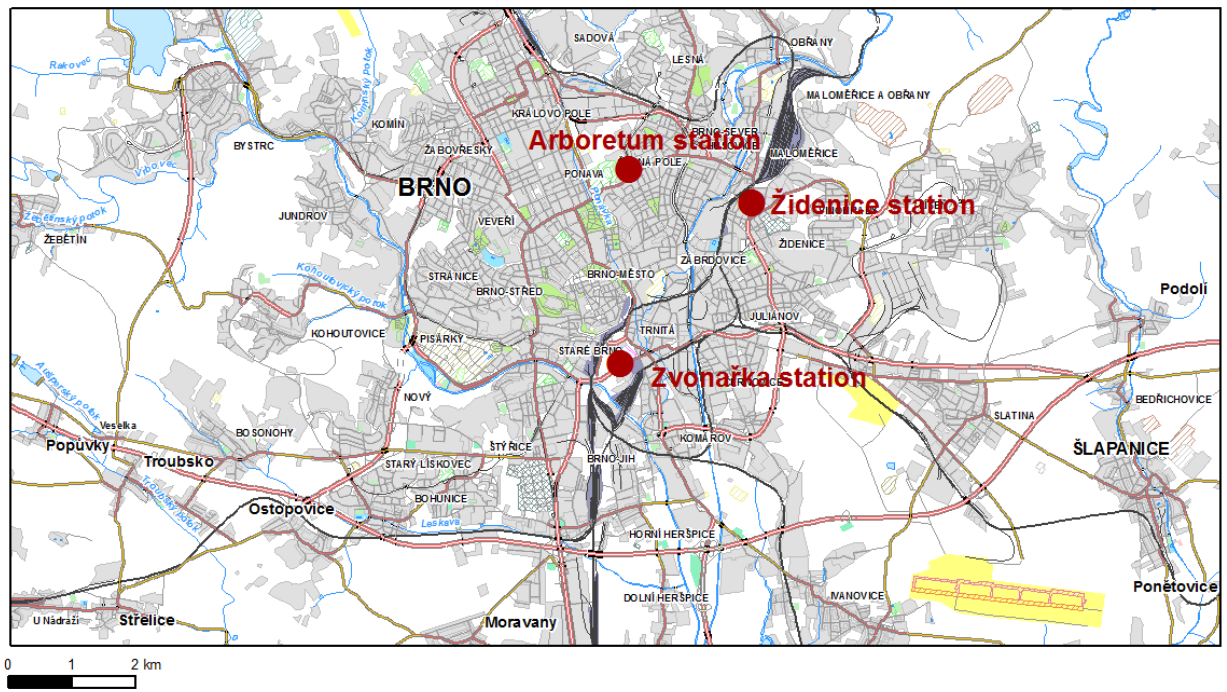
Figure: Graz-Mitte: Five winter seasons 02/03–06/07

No Inversion: 40% lower than Inversion
Sun/Holiday: 30% lower than Working Day

Stations in Brno

Forecast: Arboretum (botanical garden)

Židenice (heavy traffic street), Zvonařka (traffic spot)



Training Data and Test Data for Graz

Model fits on Training Data

- Graz-Mitte: 7 winter seasons (23.10.02–31.3.09)
- Graz-Süd: 6 winter seasons (1.10.03–31.3.09)
- All models are fitted on observed covariates

Predictions (one-day forecasts) on Test Data

- Graz-Mitte,Graz-Süd: 1 winter season (3.11.09 - 31.3.10)

Covariates for Graz

- Ap_t: daily mean PM10 day t
- ΔT_t: mean temp diff to test point Kalkleiten day t
- V_t: mean wind speed day t (Graz Mitte for Graz Süd)
- $Prec_t$: 1 = prec., 0 = no prec. on day t (Graz Nord)
- Ap_{lag}: mean of PM10 (12.30 $(t-2)$ to 12.00 $(t-1)$)
- T_{lag}: categorized mean (temp means: 12.30 $(t-2)$ to 12.00 $(t-1)$) (= 0 temp$>$0, = 1 temp$\leq$0)
  (Graz Mitte for Graz Süd)
- saturday: (0/1)
- sunday: (0/1)
- febr: (0/1)
- march: (0/1)

Training Data and Test Data for Brno

Model fits on Training Data

- Arboretum: 2 winter seasons 11/06–03/07, 10/07–03/08
- Židenice, Zvonařka: 1 winter season 11/07–03/08
- All models are fitted on predicted covariates

Predictions (one-day forecasts) on Test Data

- Arboretum, Židenice, Zvonařka:
  1 winter season (1.10.08–31.3.09)

Covariates for Brno

- Ap_t: daily mean PM10 day t
- $V_t \sin D_t(\mathrm{pred})$: mean of 4 predictions (=velocity*sin(direction)) (0.00, 6.00, 12.00, 18.00 day t)
- $V_t \cos D_t(\mathrm{pred})$: mean of 4 predictions (=velocity*cos(direction))
- $T_t(\mathrm{pred})$: mean of 4 predictions of temperature
- $Cover_t(\mathrm{pred})$: mean of 4 predictions of coverage(values 1:10)
- Ap_{lag}: mean of PM10 (13.00 $(t-2)$ to 12.00 $(t-1)$)
- T_{lag}: mean of 4 measurements of temperature (18.00 $(t-2)$, 0.00, 6.00, 12.00 $(t-1)$)

Covariates for Brno - 2

- HS_t: activity of heating plants day t
  (Oct: 0.08, Nov: 0.14, Dec: 0.17,
  Jan; 0,19, Feb: 0.16, Mar: 0.14)
- weekend: (0/1)
- sunday: (0/1)
- febr: (0/1)
- march: (0/1)

Multiple Linear Regression

Dependent variable $\sqrt{Ap_t}$

Model assumption

- $x_t^{(i)}$ *($i = 1, 2, \ldots, m$) metric input variables*
- $d_t^{(j)}$ *($j = 1, \ldots, p$) dummy (0/1) input variables at day t*
- *Linear model for $\sqrt{Ap_t}$:*

$$\sqrt{Ap_t} = \beta_0 + \sum_{i=1}^{m} \beta_i x_t^{(i)} + \sum_{j=1}^{p} \beta_{m+j} d_t^{(j)} + \epsilon_t \qquad (1)$$

$$\text{where} \quad \epsilon_t \overset{iid}{\sim} N(0, \sigma^2)\,.$$

Multiple Linear Regression: Graz-Mitte

Variables x or d	beta	sd(beta)	t-value
const	7.41	0.12	61.5
ΔT_t	-0.30	0.018	-16.6
Ap_{lag}	0.02	0.001	15.1
V_t	-1.59	0.132	-12.0
T_{lag}	0.95	0.084	11.4
sunday	-0.97	0.085	-11.4
march	0.75	0.095	7.9
saturday	-0.69	0.094	-7.3
$Prec_t$	-0.51	0.071	-7.1
febr	0.34	0.090	3.8
	R^2	se	n
	0.63	1.10	1199

Multiple Linear Regression: Zvonařka in Brno

Variables x or d	beta	sd(beta)	t-value
const	8.78	0.543	16.2
$V_t \sin D_t$	0.36	0.059	6.0
Cover_t	-0.26	0.052	-5.0
march	-1.04	0.313	-3.3
T_{lag}	-0.19	0.058	-3.2
T_t	0.17	0.062	2.7
weekend	-0.63	0.242	-2.6
Ap_{lag}	0.01	0.005	2.1
$V_t \cos D_t$	-0.08	0.056	-1.5
β_{45}		0.37	
S		103 °	
	R^2	se	n
	0.54	1.24	132

- HS_t, sunday, febr not significant

GLM model with gamma distribution and log link

Dependent variable Ap_t is gamma distributed

Model assumption

- $x_t^{(i)}$ *$(i = 1, 2, \ldots, m)$ metric input variables*
- $d_t^{(j)}$ *$(j = 1, \ldots, p)$ dummy (0/1) input variables*
- Ap_t *has Gamma$(\phi\mu_t, 1/\phi)$ distribution, ϕ dispersion*

$$\ln(\mu_t) = \ln\left(E(Ap_t|S_t)\right) = \beta_0 + \sum_{i=1}^{m} \beta_i x_t^{(i)} + \sum_{j=1}^{p} \beta_{m+j} d_t^{(j)}\,, \qquad (2)$$

$E(Ap_t|S_t)$ cond. expect. of Ap_t for given set S_t of variables

GLM with gamma log link: Graz-Mitte

Variables x or d	beta	sd(beta)
const	3.12	0.081
ΔT_t	-0.08	0.005
$\ln(Ap_{\mathrm{lag}})$	0.31	0.020
V_t	-0.50	0.038
T_{lag}	0.27	0.024
sunday	-0.29	0.024
march	0.22	0.027
saturday	-0.21	0.027
$Prec_t$	-0.15	0.021
febr	0.09	0.026
χ^2_{ans}	115.08	
f	1189	
n	1199	

GLM with gamma log link: Zvonařka in Brno

Variables x or d	beta	sd(beta)
const	4.53	0.136
$V_t \sin D_t$	0.12	0.017
T_{lag}	-0.07	0.015
Cover_t	-0.07	0.016
march	-0.34	0.096
T_t	0.06	0.017
weekend	-0.17	0.069
febr	0.18	0.090
$V_t \cos D_t$	-0.02	0.016
$\hat{\beta}_S$	0.13	
S	101°	
χ^2_{ans}	17.98	
f	125	
n	134	

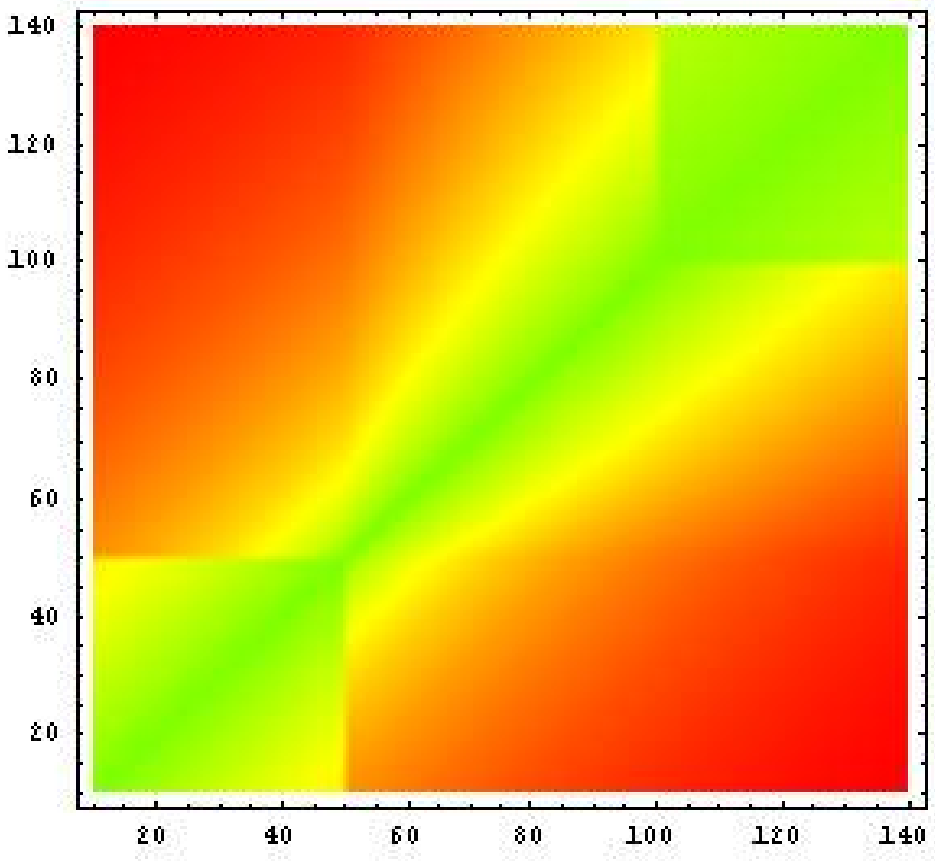
- Ap_{lag}, HS_t, sunday not significant

Quality of forecasting

- **Training data set** to compute estimates $\hat{\beta}_i$, $\hat{\beta}_{j+m}$
- Model LM applied to **test data** yield estimates $\widehat{\sqrt{Ap_t}}$
- $\widehat{Ap_t} = (\widehat{\sqrt{Ap_t}})^2$
- Model GLM applied to **test data** yield estimates $\widehat{\ln(Ap_t)}$
- $\widehat{Ap_t} = \exp(\widehat{\ln(Ap_t)})$

Quality of forecasting - 2

Quality function $Q(x, y)$: (x =observation, y =forecast)



Quality: 5 levels green (1=excellent) to red (5=very bad)

Practical performance and comparison: Graz-Mitte

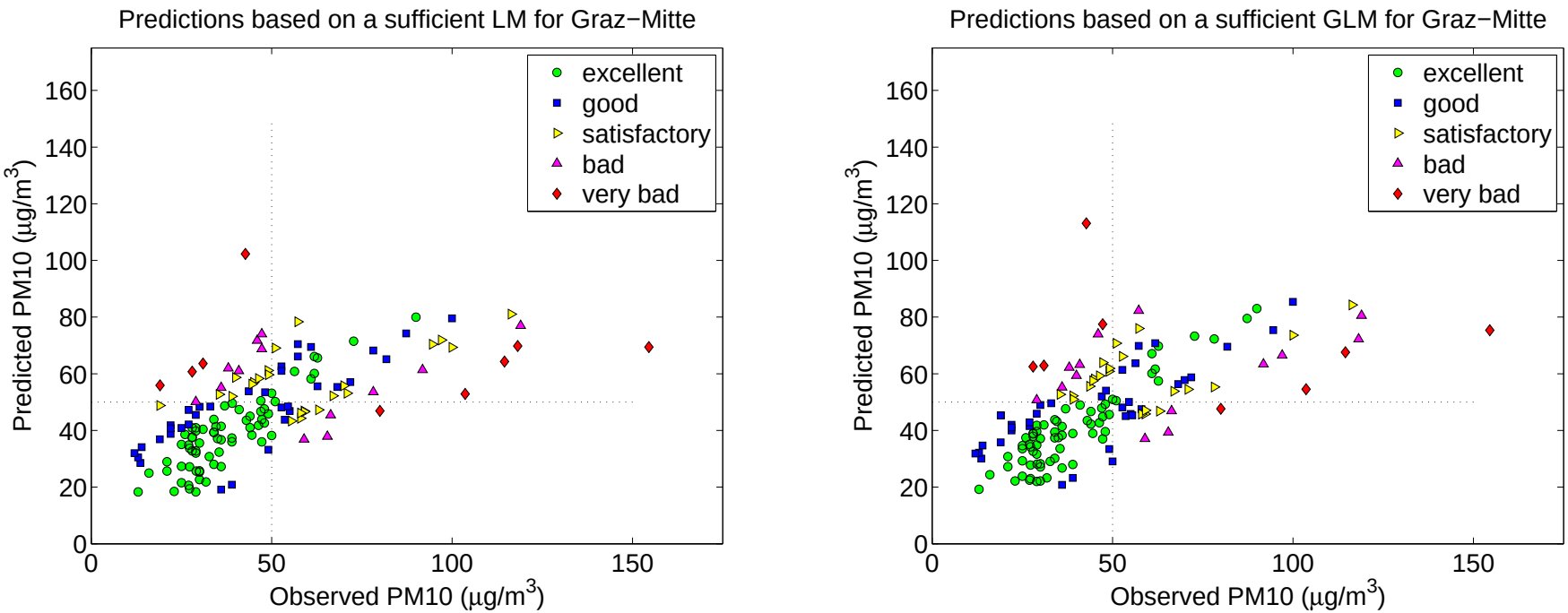


Figure: Graz-Mitte: Quality function of LM and GLM

Practical performance and comparison: Graz-Mitte - 2

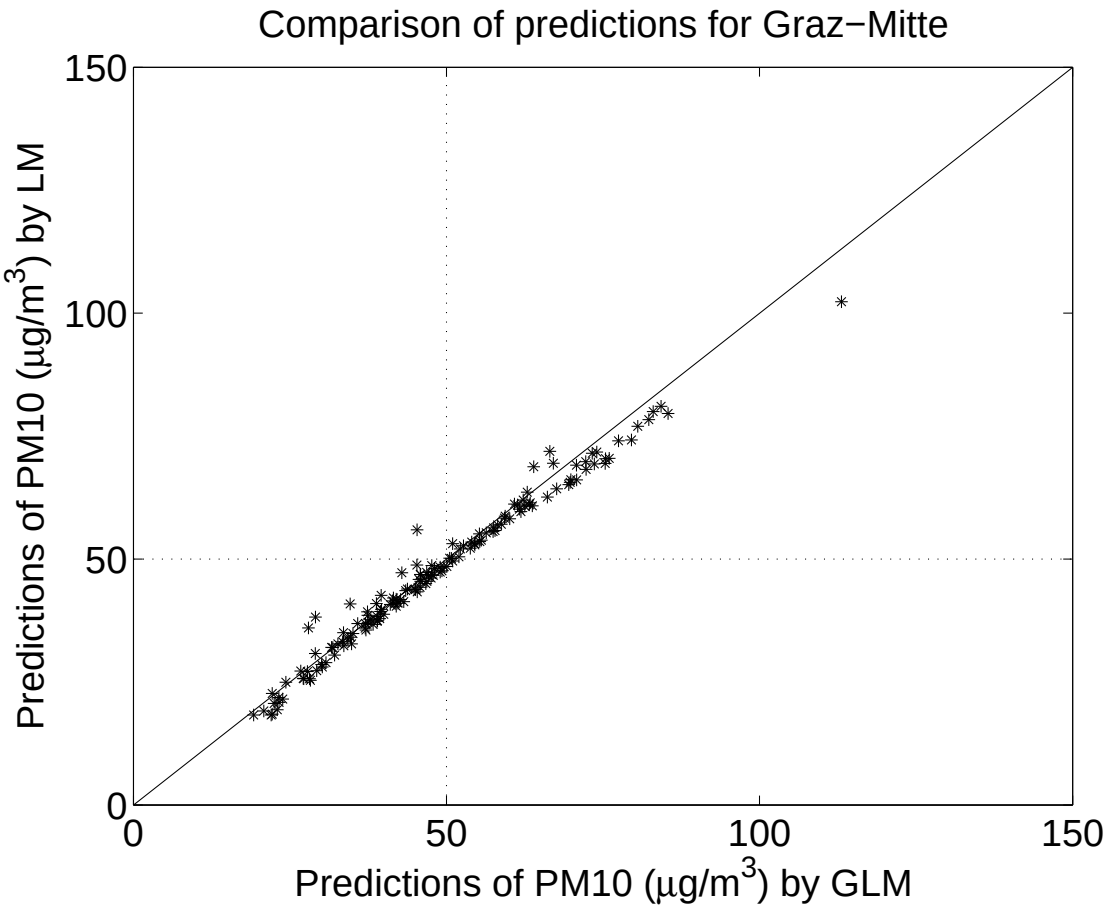


Figure: Graz-Mitte: Forecasts $\widehat{Ap_t}$ of GLM vs LM

Practical performance and comparison: Graz Mitte - 3

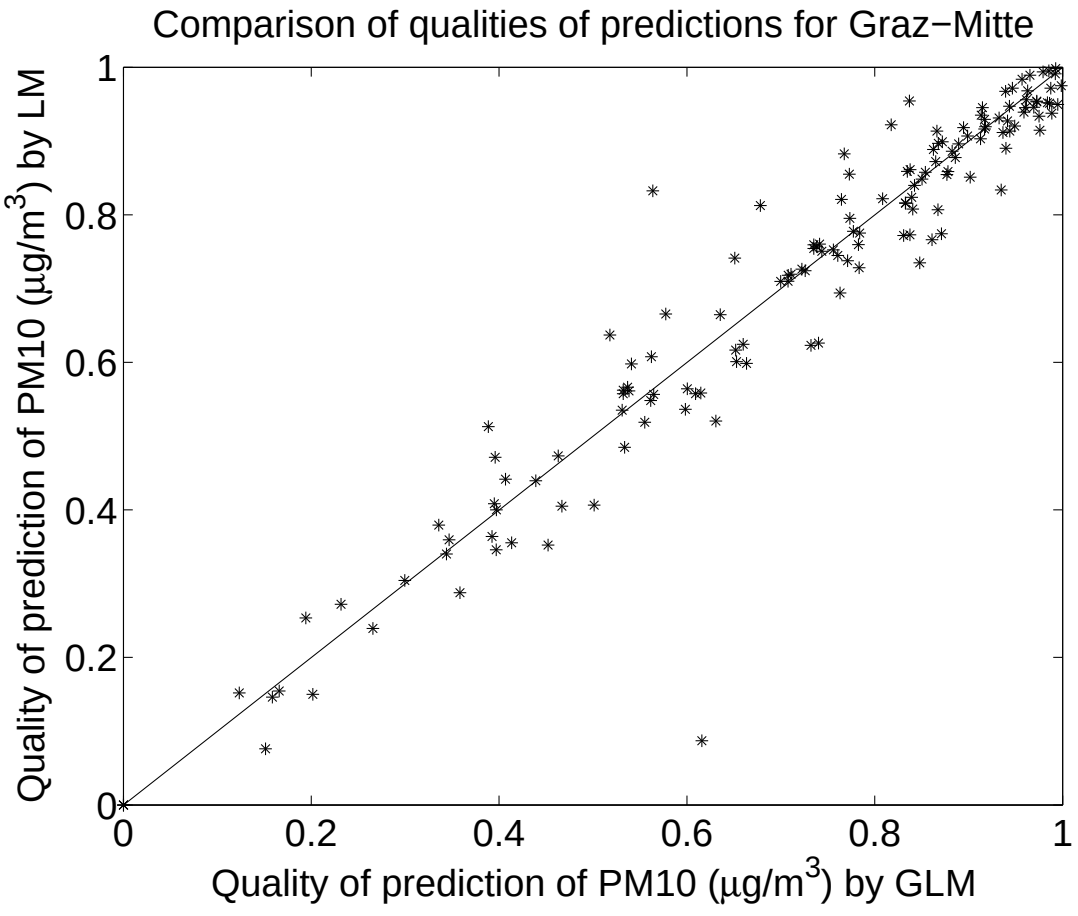


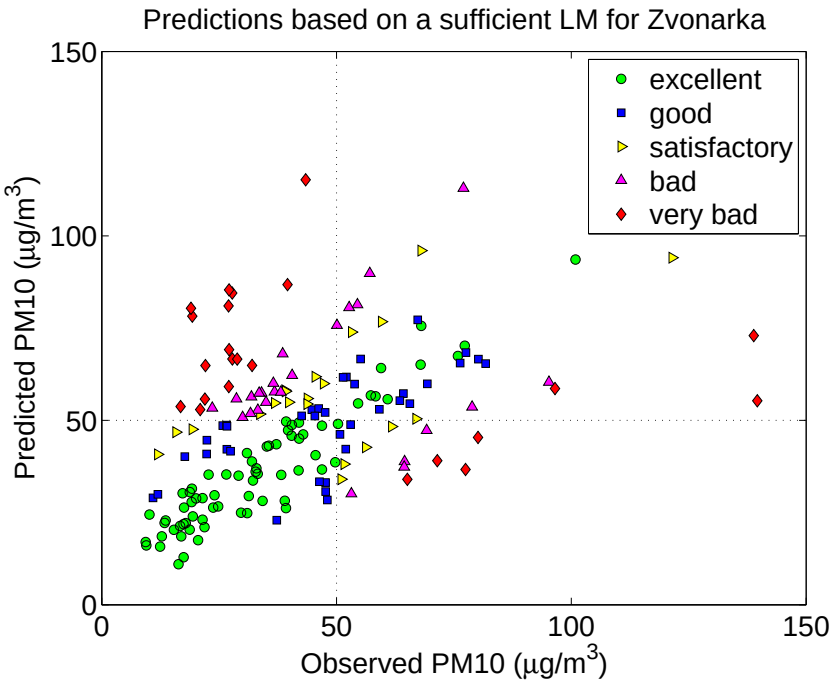
Figure: Graz-Mitte: Quality function GLM vs LM

Practical performance and comparison: Graz Mitte - 5

Table: Contingency table Graz-Mitte: Quality of GLM (rows) vs LM (columns), no. and perc. of quality 1 to 5

GLM/LM	1	2	3	4	5	sGLM	%	cum %
1	63	5	0	0	0	68	45.6	45.6
2	4	27	5	0	1	37	24.8	70.5
3	1	3	16	2	0	22	14.8	85.2
4	0	0	3	10	1	14	9.4	94.6
5	0	0	0	1	7	8	5.4	100.0
sLM	68	35	24	13	9	149		
%	45.6	23.5	16.1	8.7	6.0	100.0		
cum %	45.6	69.1	85.2	94.0	100.0			

Practical performance and comparison: Zvonařka



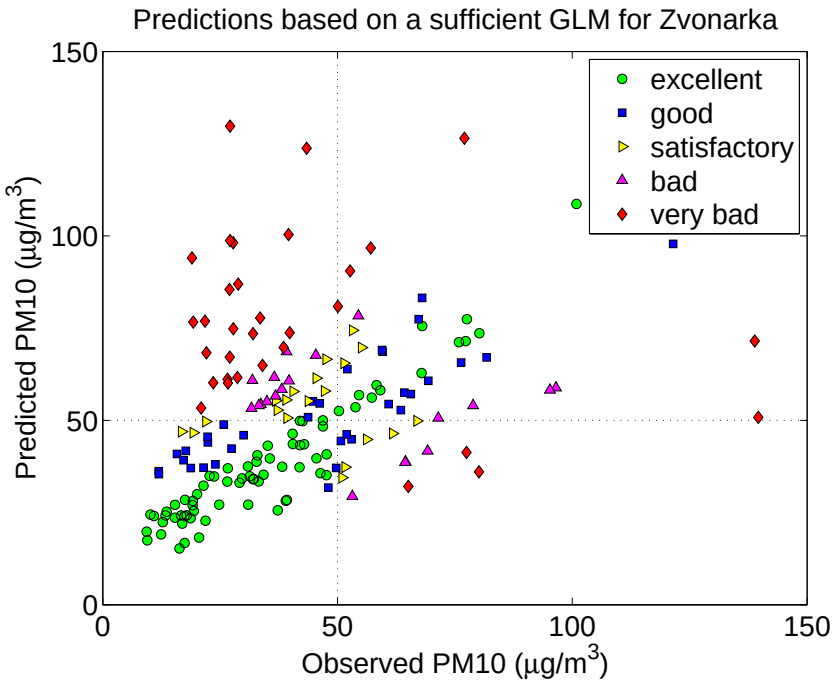


Figure: Zvonařka: Quality function of LM and GLM

Practical performance and comparison: Zvonařka - 2

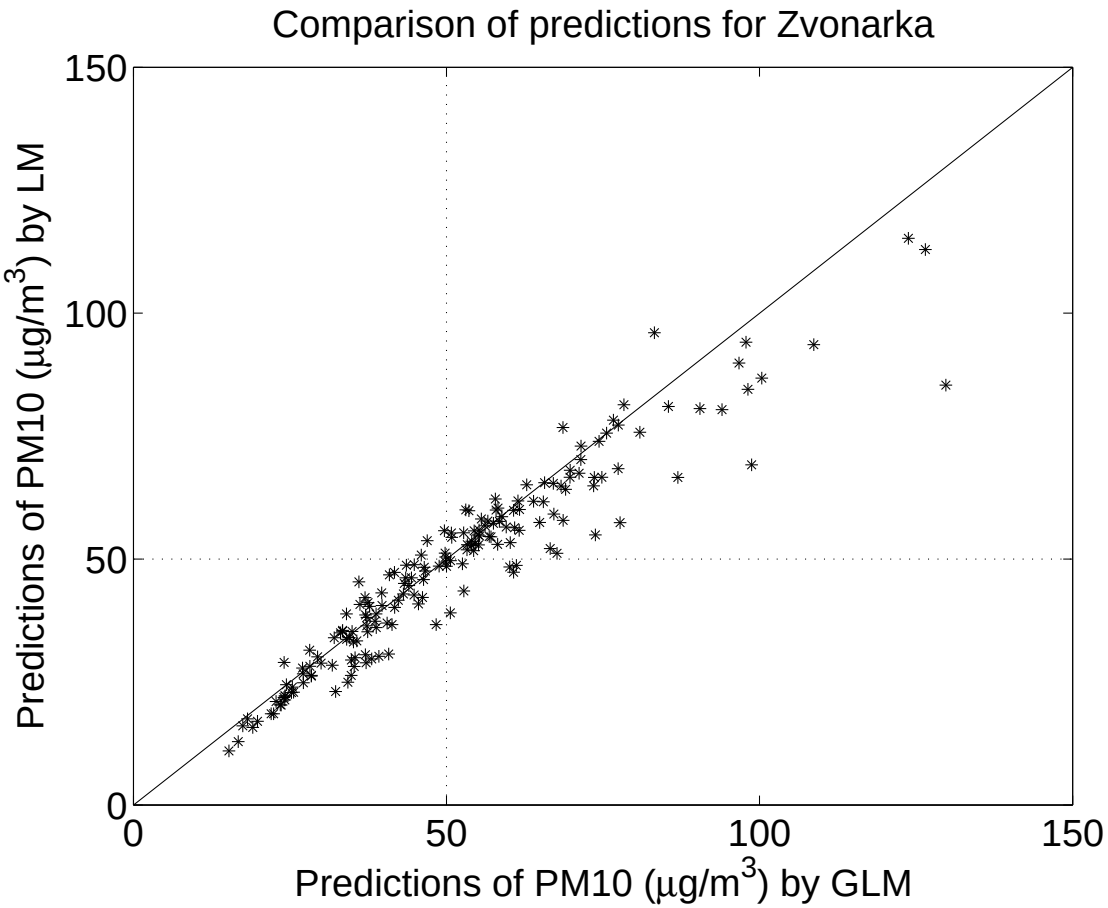


Figure: Zvonařka: Forecasts $\widehat{Ap_t}$ of GLM vs LM

Practical performance and comparison: Zvonařka - 3

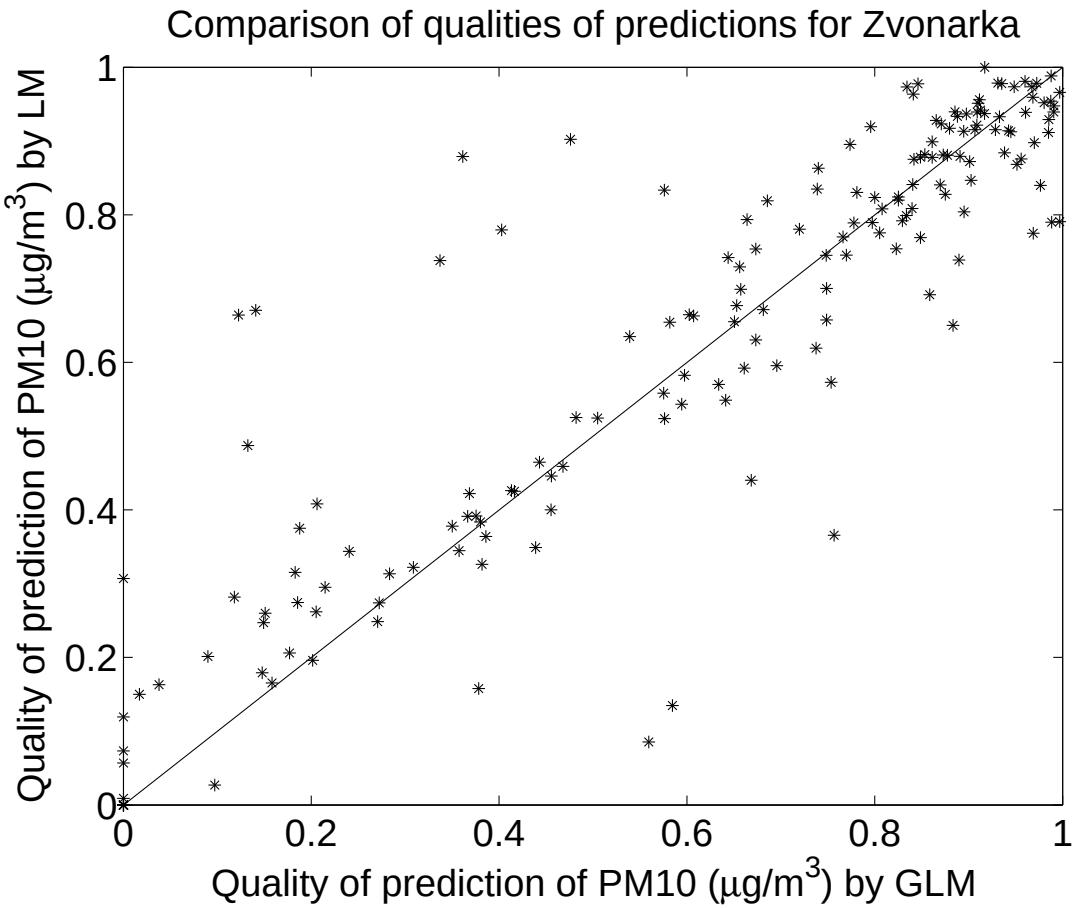


Figure: Zvonařka: Quality function GLM vs LM

Practical performance and comparison: Zvonařka - 4

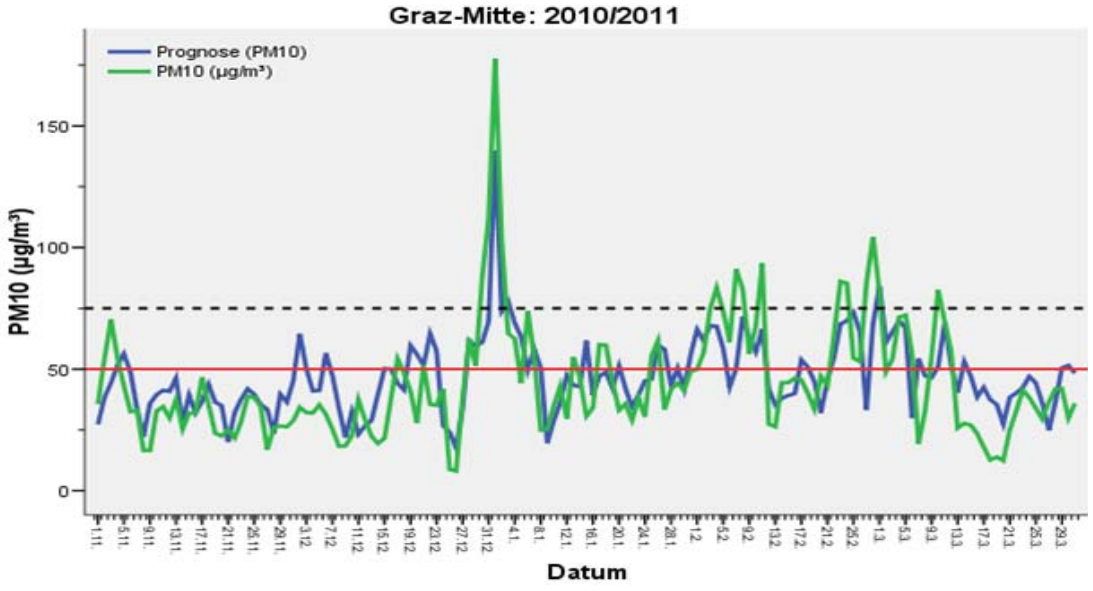
Table: Contingency table Zvonařka: Quality of GLM (rows) vs LM (columns), no. and perc. of quality 1 to 5

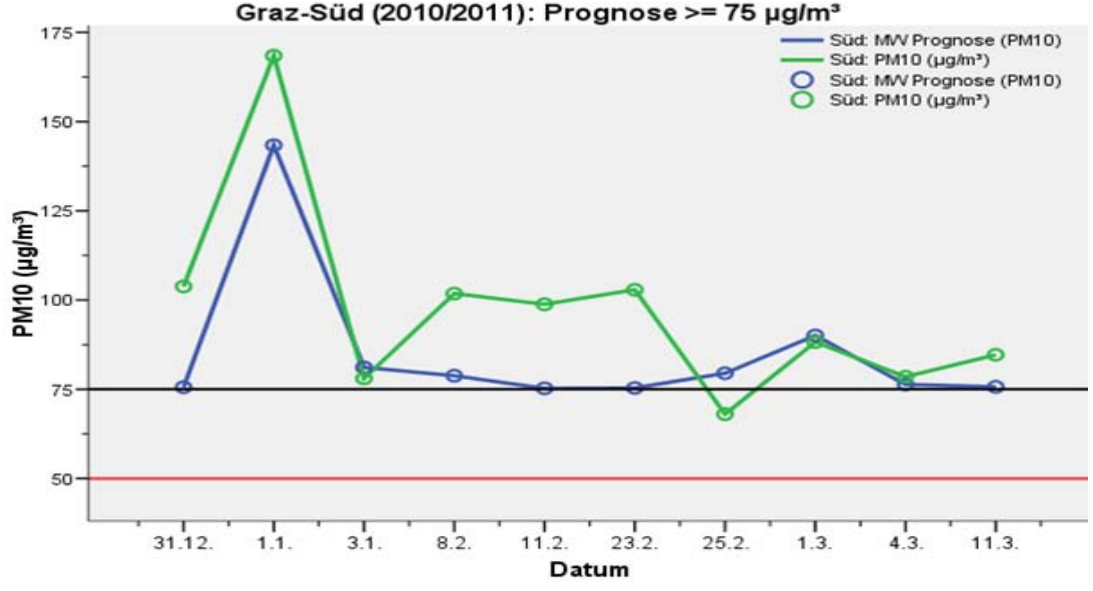
GLM/LM	1	2	3	4	5	sGLM	%	cum %
1	61	11	0	0	0	72	40.7	40.7
2	7	20	6	1	0	34	19.2	59.9
3	2	3	12	1	2	20	11.3	71.2
4	1	1	2	14	2	20	11.3	82.5
5	0	2	1	9	19	31	17.5	100.0
sLM	71	37	21	25	23	177		
%	40.1	20.9	11.9	14.1	13.0	100.0		
cum %	40.1	61.0	72.9	87.0	100.0			

Practical Experience Graz-Mitte and Graz-Süd

- Daily predictions of PM10 since winter season 04/05
- Meteorological forecasts by ZAMG Styria till 11 in the morning
- PM10-Prediction during 1 and 3 PM at www.oekostadt.graz.at
- Daily update: comparison of predictions with measured values (day $t-2$)
- e-mail with excel-file to Environmental Department of Graz
- 80 – 90% of the predictions at least satisfactory

Prediction Graz-Mitte, Graz-Süd 2010/2011





Conclusion

- LM and GLM models suitable for daily PM10 forecasts
- Results of models similar and comparable
- Brno: 1 or 2 seasons for training data, test data 2008/09
- Graz: 6 or 7 seasons for training data, test data 2009/10
- Brno: no measures for precipitation and inversion
  for each site specific selection of covariates
- Graz: all 9 covariates are significant
- Very Good quality: Arboretum (98% satisfactory)
- Good quality: Graz-Mitte, Graz-Süd (85%)
- Moderate quality: Zvonařka, Židenice (74%)