# Ensemble based probabilistic forecasting of meteorology and air quality in Oslo, Norway

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# Outline

- Background and purpose
- Models and data used
- Results
- Conclusions and further work

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# Background and purpose

- NILU calculates each year (1 Oct – 1 May) 48h daily forecasts of air quality ($NO_2$, $PM_{10}$, $PM_{2.5}$) for 6 Norwegian cities and urban areas, including Oslo, in cooperation with Met Norway and the Norwegian Public Roads Administration
- The current forecasts are of a deterministic nature, and are issued in the form of point predictions of conc. in grid and receptor points
- Currently, as part of our research, we are working towards establishing probabilistic forecasting of air quality, based on ensemble runs
- This will hopefully allow additional information concerning uncertainty to be provided and risk to be better assessed when e.g. making decisions to inform the public or implement local measures to reduce emissions
- Most of the research work presented here was done as part of the recent EU FP7 project UncertWeb for Oslo and Rotterdam. For more info on this project see the web site: www.uncertweb.org

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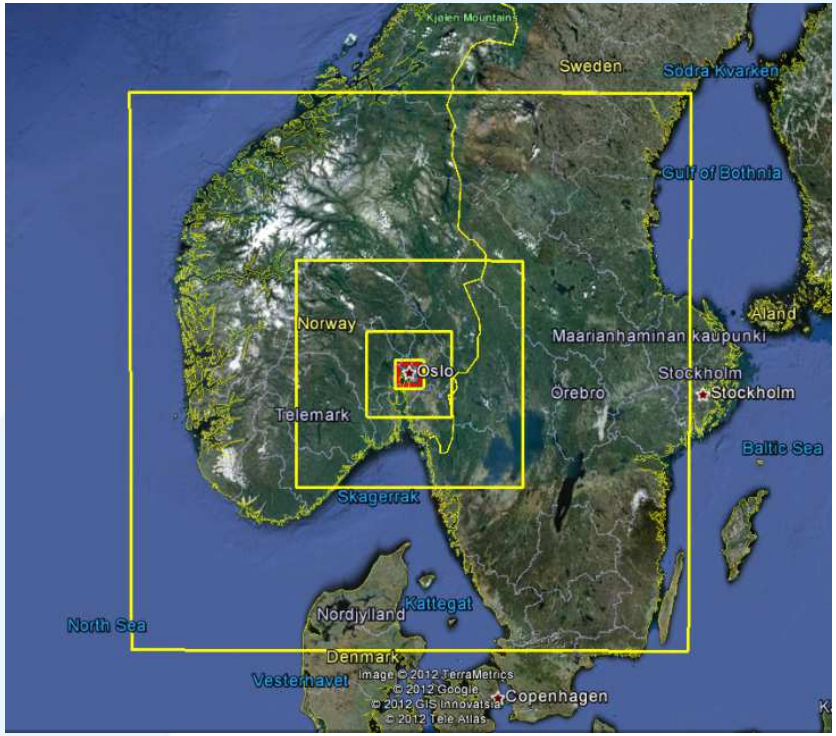
# Meteorological ensembles using 4-level nested TAPM model

**40 x 40**

**20 km**
**8 km**
**3 km**
**1 km**

**25 levels**

**10 m to 8000 m**




TAPM is a model from CSIRO, Australia (Peter Hurley et al.) [www.cmar.csiro.au/research/tapm](www.cmar.csiro.au/research/tapm)

**Input**: ECMWF control + 50 ensemble member synoptic scale 1-2 day forecasts (CNT + ENS) [www.ecmwf.int](www.ecmwf.int)

**Output**: Control + 50 ensemble member urban scale 1-2 day forecasts

Runs on a desktop Windows PC w. 4 Intel Core i7 processors @ 2.67 GHz, 12 GB RAM, 3 TB disk space

In Oslo, with snow and ice during winter, default sea surface temp. and deep soil temp. was adjusted down by -2.7 and -7 ˚C respectively in Dec.-Feb.

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# TAPM model main features

- 3-D Eulerian grid, nestable
- Incompressible and optionally non-hydrostatic
- Predicts winds, temperature, pressure, water vapour, cloud water/ice, rain and snow
- Prognostic turbulence scheme
- Surface scheme for soil, vegetation and urban categories
- Cloud microphysics scheme
- Radiation scheme
- Wind data assimilation option
- Based on globally defined databases for terrain, land use, soil type and synoptic analyses/forecasts
- The model has been verified for a number of industrial and urban regions mainly in Australia and the US

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# Emission ensembles of NO, $NO_2$ and PM

- Road traffic and home heating are the two most important pollutant source categories in Oslo
- Emission from road traffic is defined in the form of individual line sources (road links) in our model system
- Home heating (oil and wood burning), and other industrial and shipping sources are defined as gridded data (1 km)
- Stochastic perturbations of the emissions are introduced based on normal distributions (after a cube-root trans.) with deterministic values as means and assuming a 10% relative SD at daily maximum emission levels (higher for lower levels)
- Based on this, 50 ensemble members are sampled each hour

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# MACC background ensemble of $NO_2$, $O_3$ and PM

- Forecasts of background conc. for Oslo is based on the MACC regional scale air quality model ensemble
  - CHIMERE; EMEP; EURAD; LOTOS-EUROS; MATCH; MOCAGE; SILAM
- This provides (up to) 7 different background conc. for the city each hour
- In order to obtain an ensemble of 50 members, we again use a normal distribution (after a cube-root trans.), with mean and SD equal to the MACC ensemble mean and SD, and sample 50 values from this each hour

**For more info on the MACC ensemble see: gmes-atmosphere.eu**

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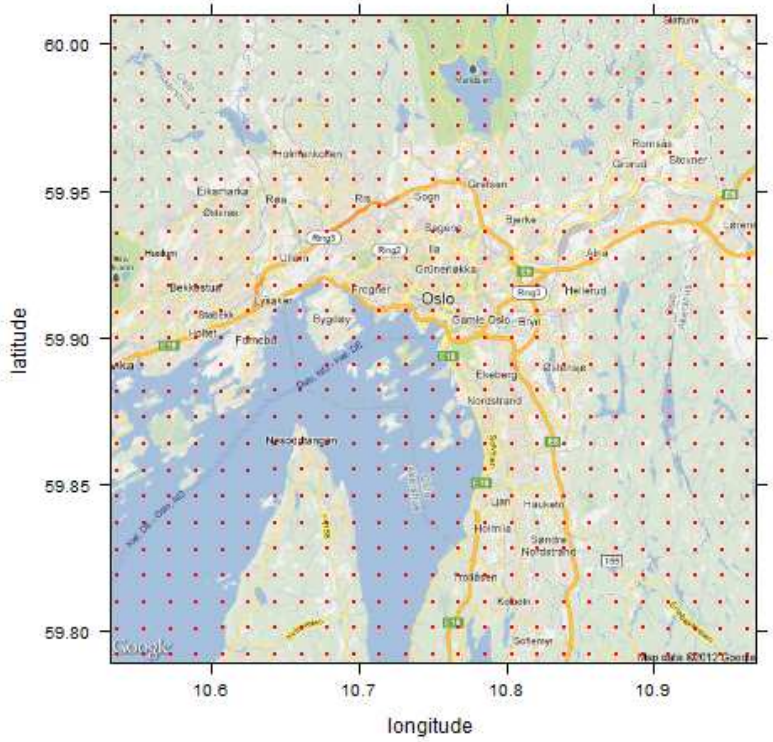
# Urban air quality modelling of $NO_2$ and PM using EPISODE model

**30 x 30**

**1 km**

**20 levels**

**10 m to 3750 m**




3D advection-diffusion model with $NO_2$-NO-$O_3$ chemistry and line and point source sub-grid models

**Input**: Ensembles of emissions, meteorology and background conc. (hourly data)

**Output**: Ensembles of 1-2 day forecasts of hourly conc. in grid and receptor points

**For more info on the EPISODE model see:**
**acm.eionet.europa.eu/databases/MDS/index.html**

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# Ensemble post-processing using non-homogeneous regression (NR)

Box-Cox power transformation

Adjustment of ensemble bias

Adjustment of ensemble spread

$$y_t^{(\lambda)} = N\left(\beta_0 + \beta_1 \overline{x}_{ENS,t}^{(\lambda)}, \sigma^2 + \gamma^2 V_{ENS,t}^{(\lambda)}\right)$$

Observation

Ensemble mean

Ensemble variance

Parameters found by minimizing the Continuous Ranked Probability Score (CRPS) using observations and predicted distributions over a given (sliding) training period (currently 6 days/144 hours)

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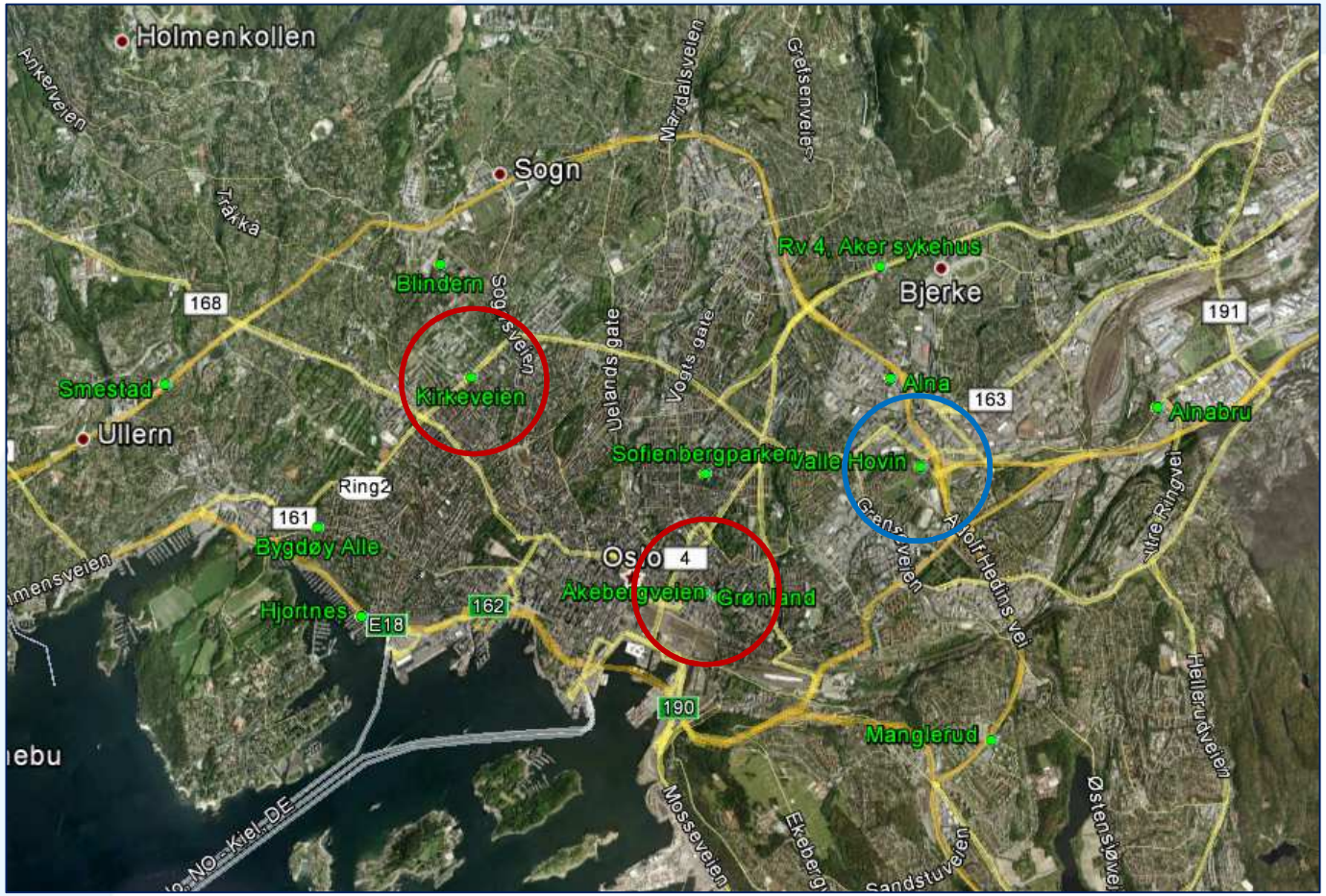
**Ref.: Gneiting, T. (2014) Calibration of medium-range weather forecasts. ECMWF TM 719, 18 March 2014.**

# Meteorological and air quality stations in Oslo (hourly obs.)




Temperature | Wind speed | NO2 | PM10

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# Temperature 2 m (°C) at Valle Hovin
# 3 – 15 January 2011 | 48 hour forecasts

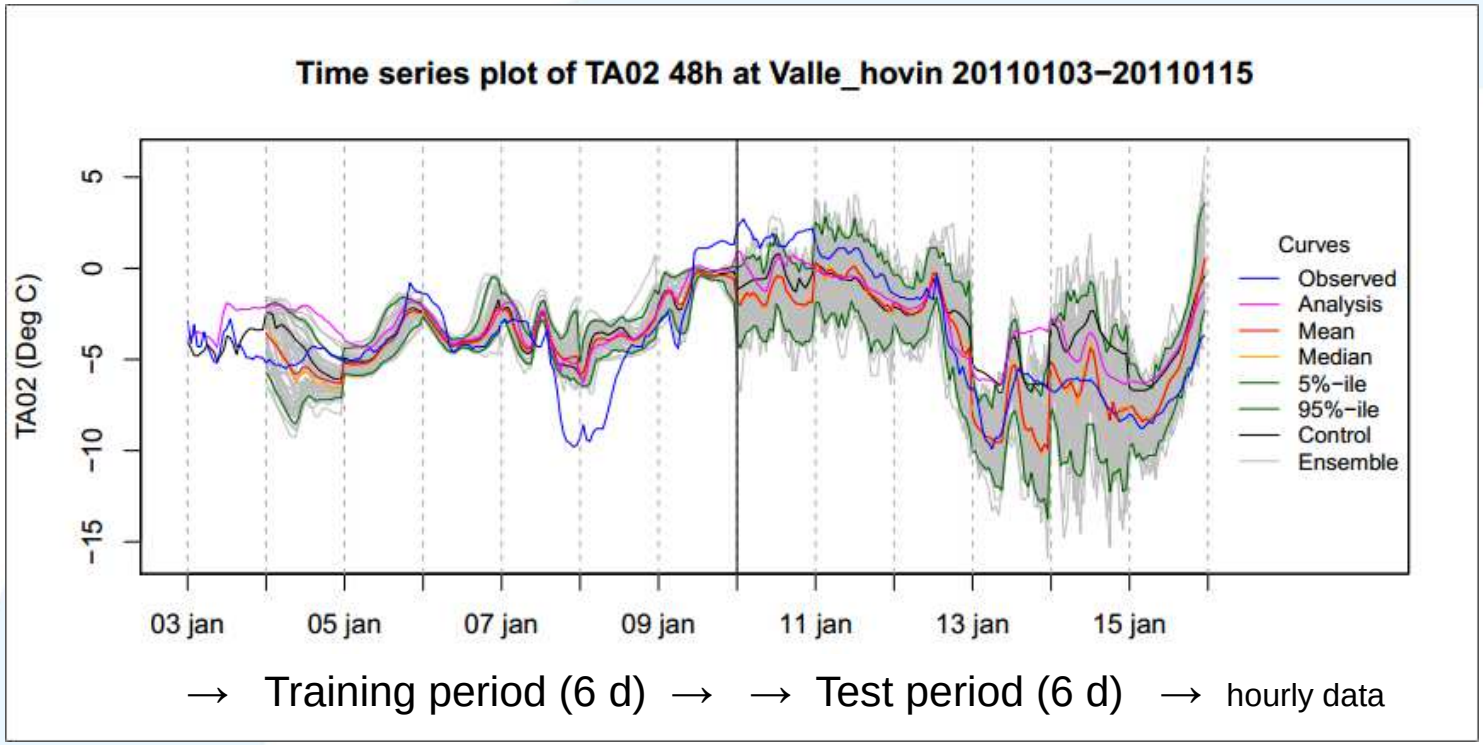
$\beta_0$ = 1.02

$\beta_1$ = 1.47

$\sigma$ = 0.93

$\gamma s$ = 0.87

$\lambda$ = 1



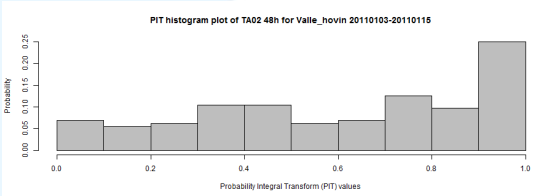

BIAS before +0.43 after -0.65

CRPS 1.13

CRPS Clim. 2.21

RELI 0.07

RESO 1.16




| % | Coverage |
|---|---|
| 75 | **62.5** |
| 90 | **78.5** |
| 95 | **81.3** |

| % of CRPS Obs. Clim. | | |
|---|---|---|
| CRPS | **52.2** | 0 best |
| RELI | **4.1** | 0 best |
| RESO | **52.0** | 100 best |

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# Temp. difference 25 m - 10 m (°C) at Valle Hovin
# 3 – 15 January 2011 | 48 hour forecasts

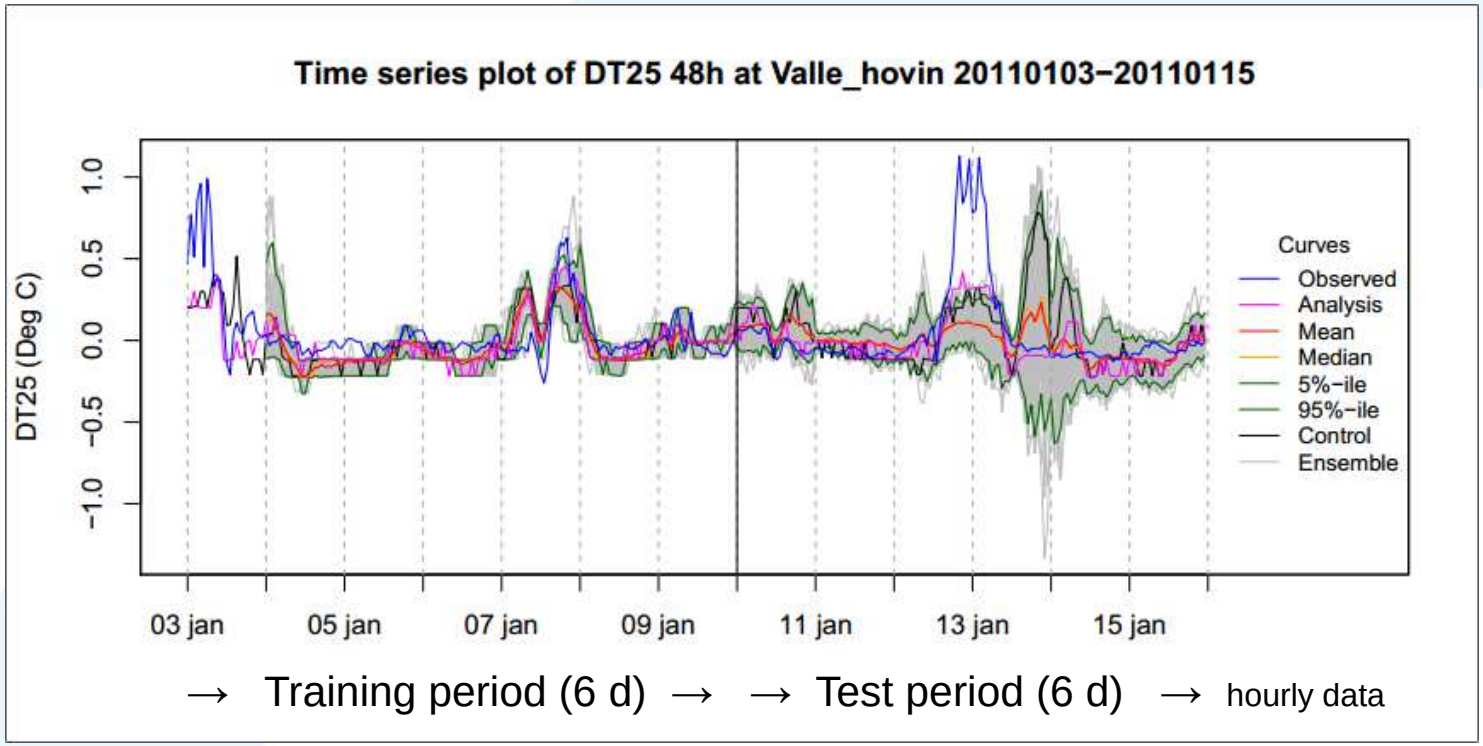
$\beta_0$ = 0.00

$\beta_1$ = 0.56

$\sigma$ = 0.022

$\gamma s$ = 0.078

$\lambda$ = 1



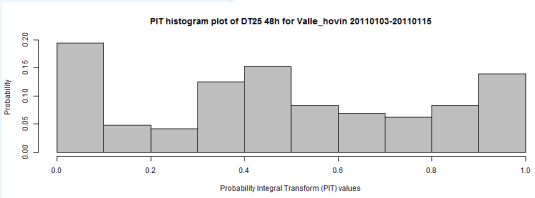

BIAS before -0.03 after -0.05

CRPS = 0.11

CRPS Clim. = 0.10

RELI = 0.007

RESO = -0.002




| % | Coverage |
|---|---|
| 75 | **62.5** |
| 90 | **77.1** |
| 95 | **81.3** |

| % of CRPS | Obs. | Clim. |
|---|---|---|
| CRPS | **109.2** | 0 best |
| RELI | **7.1** | 0 best |
| RESO | **-2.1** | 100 best |

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# Wind speed 25 m ($ms^{-1}$) at Valle Hovin
# 3 – 15 January 2011 | 48 hour forecasts

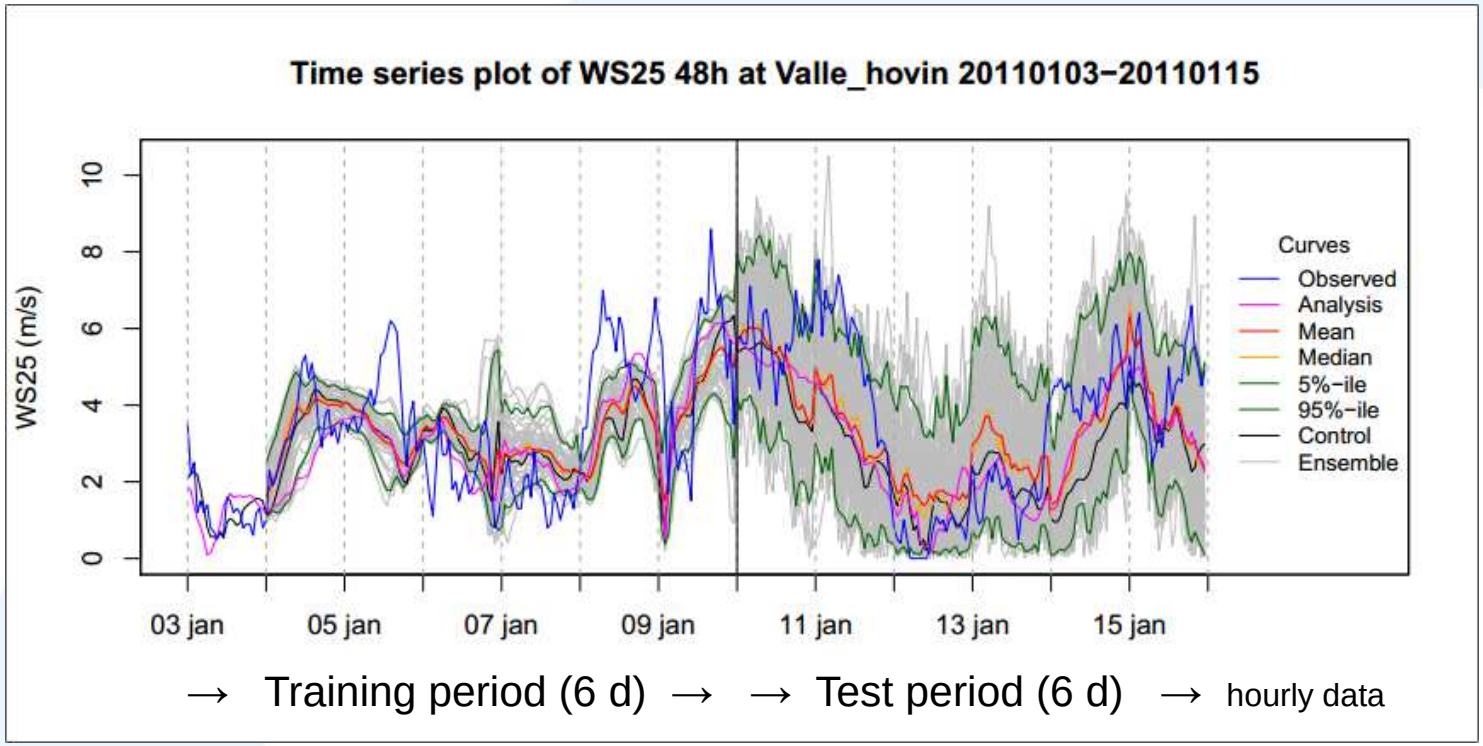
$\beta_0$ = -0.33

$\beta_1$ = 1.20

$\sigma$ = 1.46

$\gamma s$ = 0.27

$\lambda$ = 1



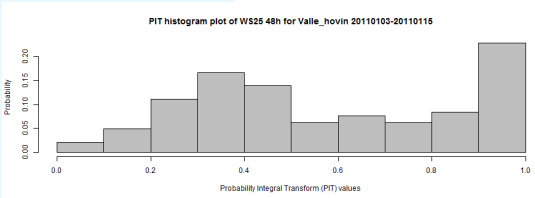

BIAS before -0.83 after -0.54

CRPS = 0.87

CRPS Clim. = 1.21

RELI = 0.04

RESO = 0.38




| % | Coverage |
|---|---|
| 75 | **69.4** |
| 90 | **82.6** |
| 95 | **87.5** |

| % of CRPS Obs. Clim. | | |
|---|---|---|
| CRPS | **71.9** | 0 best |
| RELI | **3.1** | 0 best |
| RESO | **31.2** | 100 best |

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# $NO_2$ concentrations ($\mu gm^{-3}$) at Kirkeveien
# 3 – 15 January 2011 | 48 hour forecasts

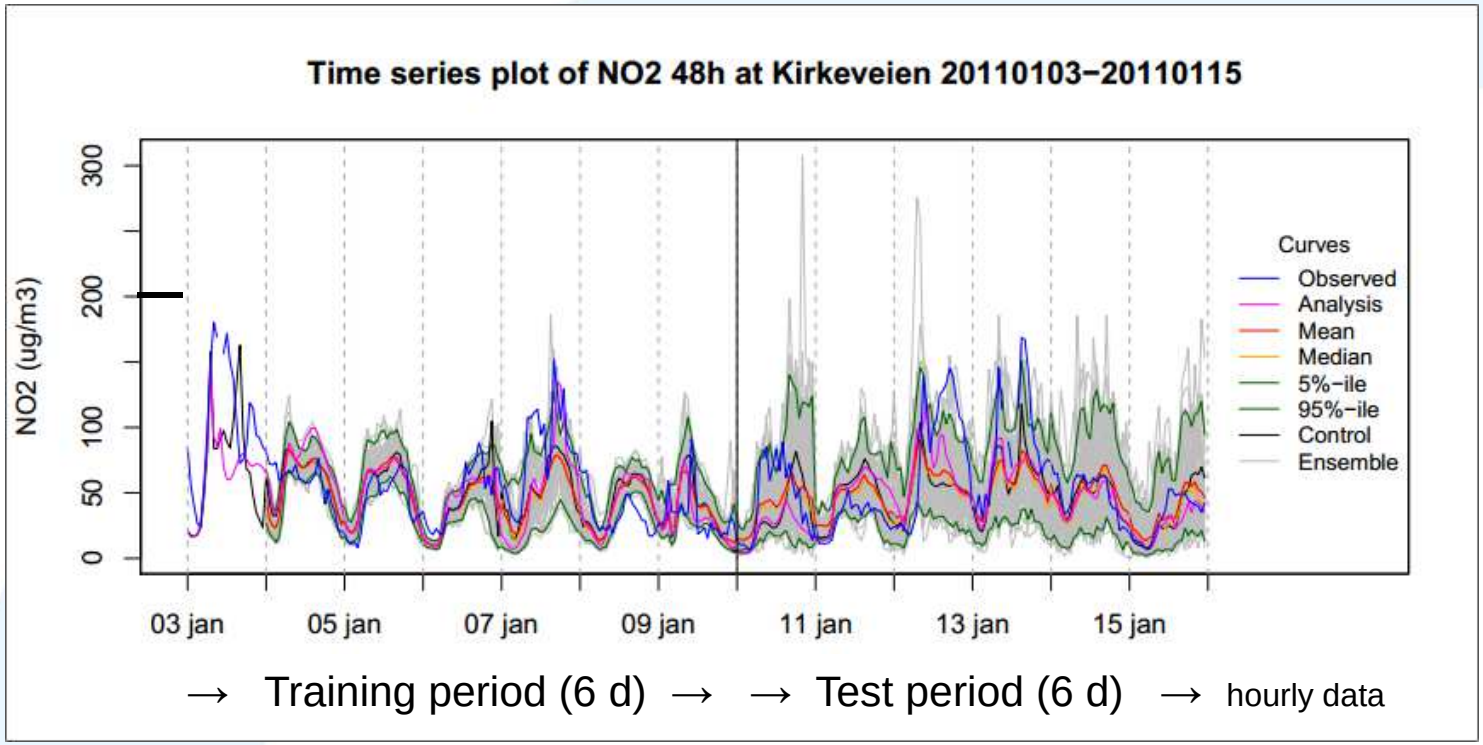
$\beta_0$ = 2.23

$\beta_1$ = 0.74

$\sigma$ = 1.40

$\gamma s$ = 0.69

$\lambda$ = 0.33



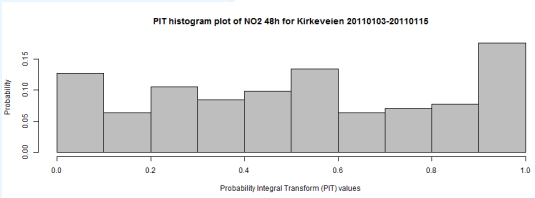

BIAS before -10.5 after -7.4

CRPS = 1.02

CRPS Clim. = 1.42

RELI = 0.02

RESO = 0.43




| % | Coverage |
|---|---|
| 75 | **64.8** |
| 90 | **77.5** |
| 95 | **85.9** |

| % of CRPS | Obs. | Clim. |
|---|---|---|
| CRPS | **71.8** | 0 best |
| RELI | **1.7** | 0 best |
| RESO | **29.9** | 100 best |

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# $PM_{10}$ concentrations ($\mu gm^{-3}$) at Åkebergveien
# 3 – 15 January 2011 | 48 hour forecasts

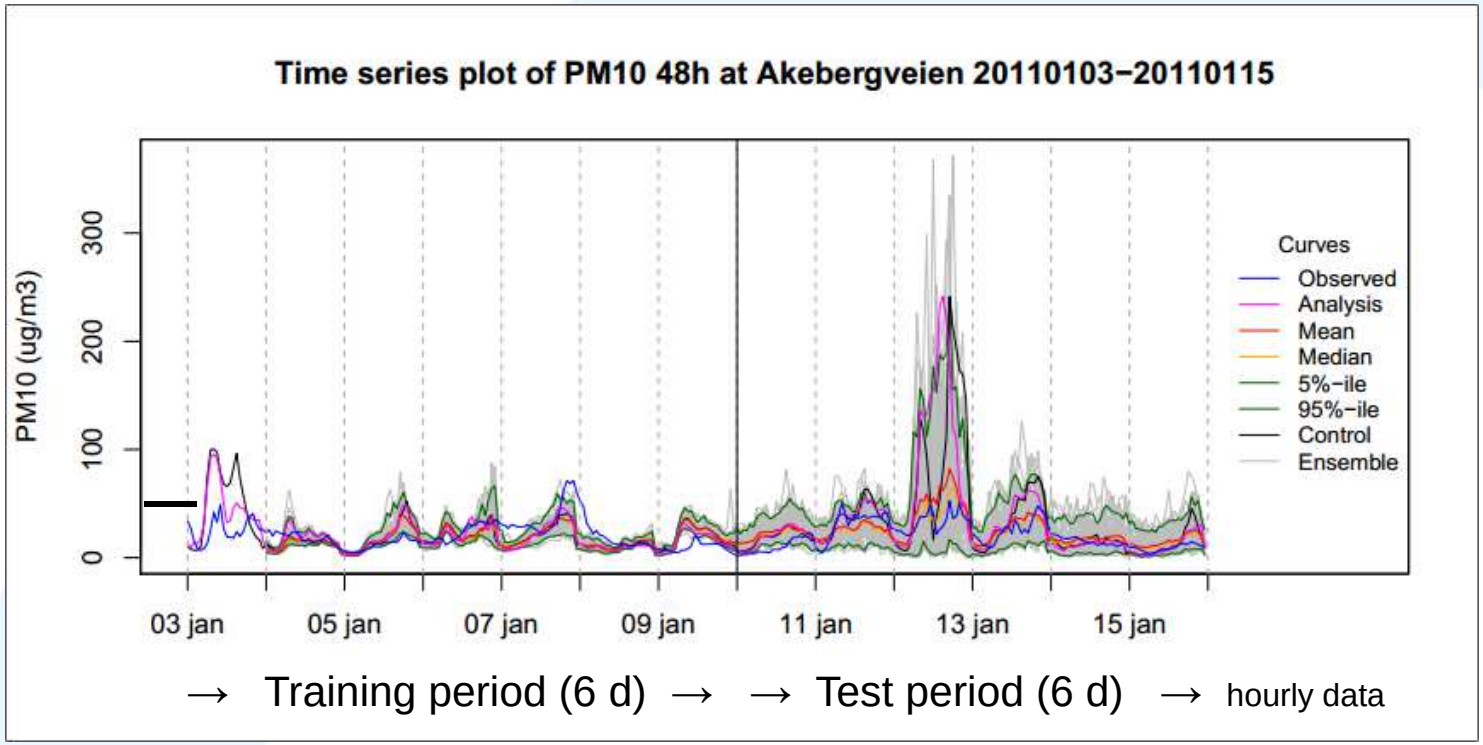
$\beta_0$ = 2.52

$\beta_1$ = 0.50

$\sigma$ = 1.39

$\gamma s$ = 0.23

$\lambda$ = 0.33



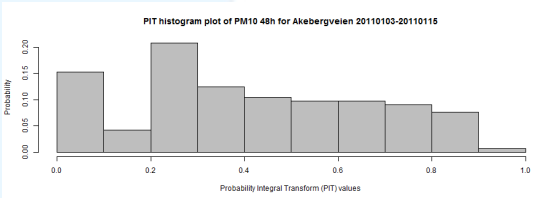

BIAS before +10.1 after +4.9

CRPS = 0.86

CRPS Clim. = 1.03

RELI = 0.05

RESO = 0.22




| % | Coverage |
|---|---|
| 75 | **81.3** |
| 90 | **86.8** |
| 95 | **88.2** |

| % of CRPS | Obs. | Clim. |
|---|---|---|
| CRPS | **83.8** | 0 best |
| RELI | **5.3** | 0 best |
| RESO | **21.5** | 100 best |

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# Conclusions

- Overall, 48h ensemble forecasts of meteorology and air quality in Oslo show a good correspondence with local obs., although the ensemble predictions are clearly under-dispersed and somewhat biased (most notably for AQ)
- Post-processing of ensembles using non-homogeneous regression, leads to fairly reliable probabilistic forecasts at the obs. sites (except for temp. and vert. temp. diff.)
- Improvement in bias for wind speed and AQ, but not for temp. and vert. temp. diff.
- Difficult to get highly resolved (sharp) probabilistic forecasts

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# Further work

- We will continue to test and improve the system
  - Use more recent ECMWF and MACC ensemble data
  - Add ECMWF HRES forecasts to the regression
  - Interpolate station predictions to arbitrary points (cross-val.)
  - Add post-processed met. uncertainty to the line source model
  - Improve and link emissions to the probabilistic meteorology
  - Post-process MACC ensembles using local background stations
  - Increase to 3d, 5d, or even longer forecasts
  - Move from TAPM to Harmonie (HarmonEPS)?
- Long term goal is to introduce such ensemble based prob. systems as part of the operational forecast system (in cooperation with Met Norway)

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# Thanks for your attention!

Contact email: sew@nilu.no

uncert|web
uncertainty-enabled model web

http://www.uncertweb.org

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For more information, www.nilu.no

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