Forecasting the ozone concentrations with WRF and artificial neural network based system

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1. Introduction

Ground level ozone (O_3) has serious adverse impacts on human health and ecosystems. Accurate tools that support human and ecosystem protection are necessary. The most often used are complex atmospheric chemistry models (Vieno et al. 2010), driven by off-line meteorology or integrated on-line to allow for two directional effects of atmospheric chemistry and meteorology. These tools need a significant amount of computational effort, but are able to provide information on spatial and temporal information on atmospheric ozone concentrations. Statistical methods, including regression models and artificial neural networks (ANN) are also often applied to provide information on spatial (Pfeiffer et al. 2009) and temporal variability of O_3. ANN were also found to be useful for O_3 forecasting, and were applied to e.g. metropolitan areas by local environmental or health agencies (Comrie 1997, Corani 2005, Ibarra-Berastegi et al. 2008, Yi and Prybutok 1996).

In this paper we present the preliminary results of the O_3 forecasting system for the city of Wrocław, SW Poland. Two main tools are used to estimate the hourly O_3 for the next 3 and 24 hours – the Weather Research and Forecasting (WRF) mesoscale meteorological model and an artificial neural network (ANN). WRF provides the meteorological variables for the next 3 and 24 hours, and the ANN is then applied to forecast the O_3 concentrations.

2.1 Ozone measurements and study periods

- One hour O_3 measurements gathered at an urban background site in the city of Wrocław, SW Poland
- Measurements for the years 2005-2009 used, data completeness was 96%
- All measurements divided into a learning (60% of the 2005-2009 observations) and test subsets (TP, 40%)
- The period 14.04 – 10.05.2009 was treated separately as a case study and excluded from the dataset used for ANN setting. The episode was selected because of high concentrations of ground level ozone, exceeding 100 μg m^{-3} during the day and the well represented diurnal cycle.

2.2. Meteorological data

The WRF model provided the meteorological data for ANN with 3h time step for the entire 2005-2009 period and 1h time step for the selected case study period. The model worked with three one way nested domains, with the innermost domain covering SW Poland with 2km x 2km spatial resolution. All the domains were composed of 35 vertical levels, with the top fix at 10hPa. Newtonian nudging was applied. The simulations were driven by the GFS FNL data, available every 6h.

2.3. Neural network model

- feed forward ANN network
- 26 input layer neurons
- 2 hidden layers (the first two with 10 and the second with 7 neurons)
- sigmoid transfer function

For the period 10.04 – 15.05.2009, the hourly meteorological data were used and the ANN provided O3 forecasts for the next 3h (FP 3h) and 24h (FP 24h). For network learning, the following input variables were used: cosine of day number in a year and week, cosine of hour (cos(2**hour/24)), sea level pressure (SLP), air temperature (T2), dew point temperature and relative humidity at 2m, wind speed (WSPD), u and v wind components of wind speed at 10m and boundary layer height. Additionally, the differences between the current and 3h back values and 24h mean SLP, T2 and relative humidity were included in the input layer. The analysis was performed with the Fast Artificial Neural Network library and FANN Tool 1.1 interface.

2.4. Evaluation of the WRF and ANN results

WRF results for the entire period were compared with meteorological measurements of air temperature, sea level pressure and wind speed gathered at Wrocław. The results were summarized for each year and for the ANN forecasting period. The ANN was evaluated by comparison with hourly O3 measurements separately for the TP, FP3h and FP24h. Common statistics were used to evaluate the WRF and ANN models, including mean bias (MB), mean absolute error (MAE) and the index of agreement (IOA). For ANN, the fraction of estimated values within a fraction two of the observed value (FAC2) was also provided.

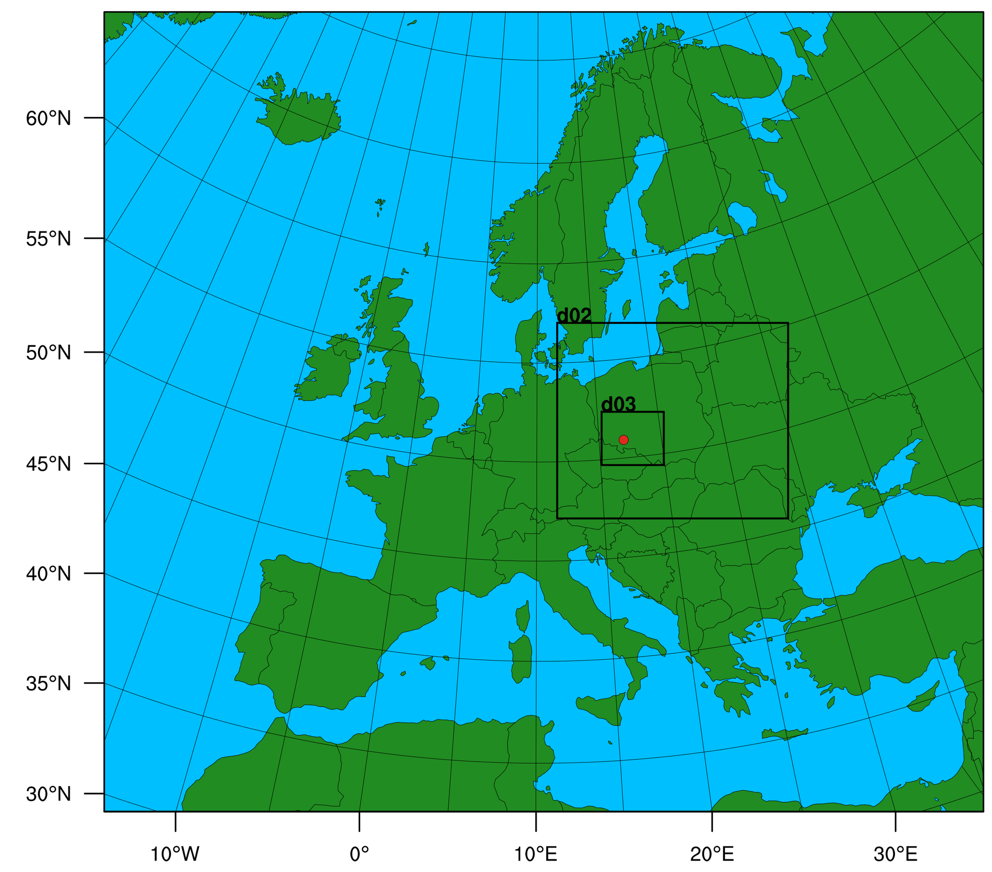

Fig. 1 Configuration of the WRF model domains and location of Wrocław (red dot)

Table 1 WRF model performance for each year and forecasting period, Wrocław station

		2005	2006	2007	2008	2009	FP
SLP	MB	1.44	1.58	1.45	0.63	0.55	-0.20
	MAE	1.48	1.61	1.51	0.86	0.83	2.11
	IOA	0.99	0.99	0.99	1.00	1.00	0.92
T2	MB	-2.13	-2.27	-1.96	-1.87	-1.98	-1.89
	MAE	2.98	3.24	3.02	2.71	3.12	2.76
	IOA	0.96	0.96	0.96	0.96	0.96	0.89
WSPD	MB	0.15	0.09	0.12	0.08	0.00	0.65
	MAE	1.01	1.03	1.15	1.12	1.09	1.79
	IOA	0.86	0.85	0.87	0.87	0.84	0.67

Table 2 Error statistics of ANN O_3 forecasts (3 and 24 hours) for training and forecast period

	MB	MAE	IOA	FAC2 (%)
TP 3h	-0.69	14.90	0.88	94
TP 24h	1.09	12.52	0.92	78
FP 3h	8.36	26.56	0.73	79
FP 24h	-17.33	25.45	0.68	75

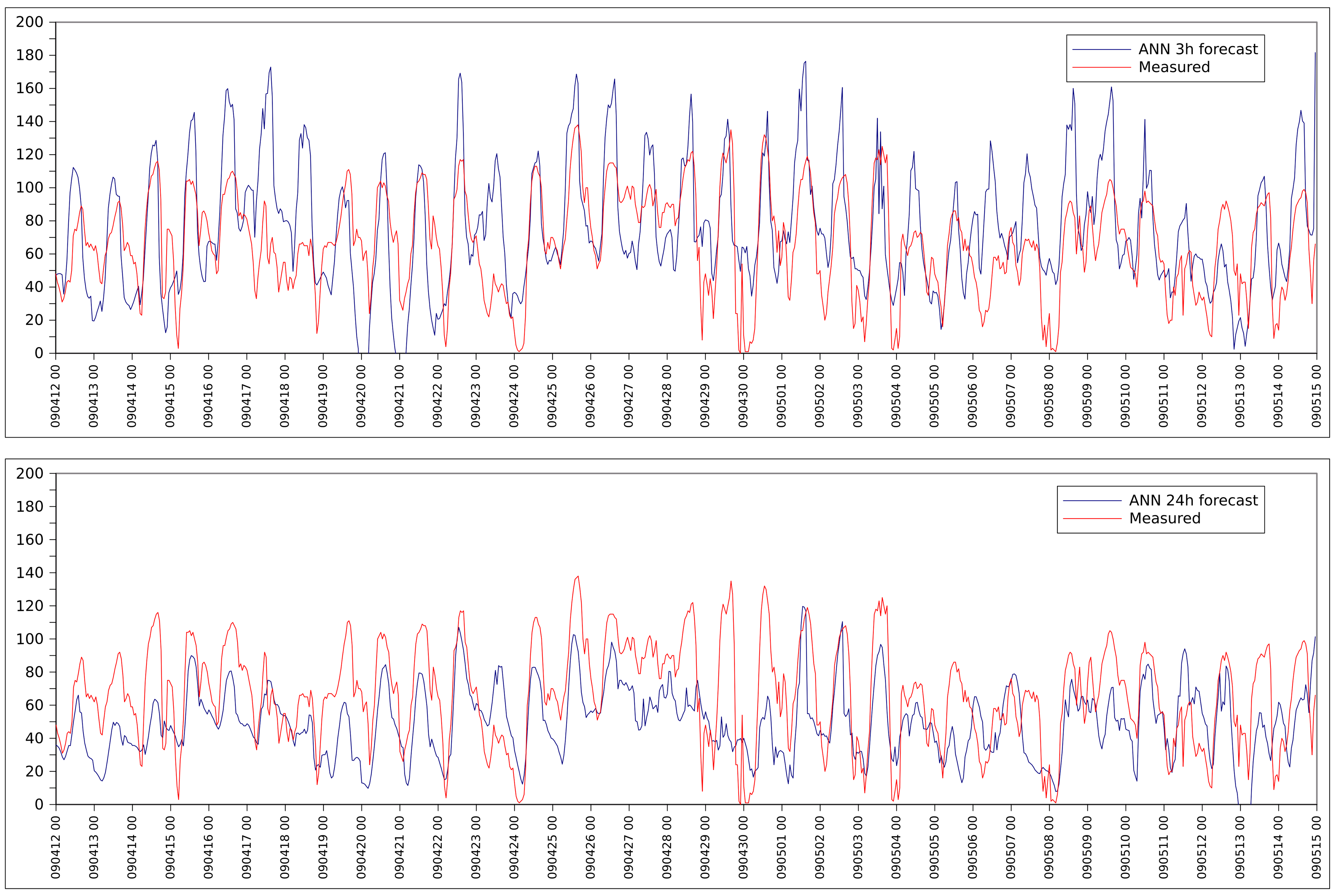

Fig. 2 Measured and ANN modelled O_3 concentrations

3. Results

WRF performance for the entire and ANN forecasting (FP) period is summarized in Table 1. There is an improvement in SLP model to measurement agreement after the year 2007. T2 is constantly underestimated, and WSPD overestimated, especially for the forecasting period.

ANN modelled O_3 for the period 10.04-15.05.2009 is presented in Fig. 2 for both 3h and 24h forecasts. The ANN error statistics are presented in Table 2 for test subset (TP) and forecasting period (FP), for 3h and 24h forecasts. The results are in close agreement with the O_3 measurements for the TP, for both forecasting periods. For the FP, the ANN 3h results are in reasonably good agreement with the measurements There is a large negative bias for 24h forecasts, but FAC2 is still above 50%.

4. Summary & conclusions

We used WRF meteorology as an input to a neural network to predict the hourly ground level O3 for the next 3 and 24 hours. Preliminary results show that the WRF model was able to provide reliable meteorological data, though with significant negative bias for air temperature estimates. ANN was reliable for short 3h forecasts, but significantly underestimated measured O3 for 24h forecasts.

Further steps will include improvements of WRF meteorology – preliminary results show that the MB for T2 can be decreased by changing the model configuration. ANN will be rerun with the improved meteorology, and tested for a larger number of sites. Finally, we will use the WRF-ANN approach for spatial, short term O3 forecasting and compare the results with atmospheric transport model.

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Acknowledgments: Calculations have been carried out in Wroclaw Centre for Networking and Supercomputing (http://www.wcss.wroc.pl), grant No. 170. The Voivodeship Inspectorate for Environmental Protection in Wroclaw provided O3 measurements data.