A GRID SENSITIVITY ANALYSIS METHOD FOR THE CALIBRATION OF PROGNOSTIC METEOROLOGICAL MODELS IN AIR POLLUTION MODELING

Stamatis Zoras and Athanasios G. Triantafyllou
Laboratory of Atmospheric Pollution and Environmental Physics, Technological Education Institute (TEI) of West Macedonia, Kozani, Greece

INTRODUCTION

The objective of this study is the evaluation of model sensitivity due to grid size and resolution variation in complex terrain by the design of a screening experiment. Grid calibration, that in many cases involves the removal of complexities and insignificant terms, is the starting point in reducing meteorologically affected factors of uncertainty before any pollution predictions are attempted. The use of a calibrated grid is of paramount importance for repeated procedures by leaving unnecessary information unprocessed and inevitably reducing run times whilst the reliability of air quality modeling is preserved by the prognosis of accurate wind fields. In order to calibrate a model, sensitivity analysis SA must be carried out if uncertainty caused by the input data to a model's output is high. Generally, uncertainty is high at the edges of a grid and lower in the middle.

Identification and evaluation of local sensitivity and uncertainty elements is attempted by the design of a methodology. This could become very useful in cases where global methods are not applicable. The factors of varied grid size and resolution, based on a one-factor-at-a-time (OAT) approach, are used for the determination of local sensitivity in the area of interest. OAT experiments assume that the effects of an individual factor are the same at different settings of the other factors (*M.D. Morris*, 1991). Uncertainty driven by the factor of resolution at the grid edges is diminished by increasing the grid size and sensitivity in grid is significant when uncertainty is high i.e. at the edges of the inner grid.

SA coupled with real experimental meteorological data has been used for the calibration and validation of a selected model being The Air Pollution Model (TAPM V2, CSIRO). The observations were obtained from a network of surface monitoring stations located across a basin surrounded by mountains in the area between the cities of Kozani and Ptolemais, Greece (see Figure 1). More details on the area can be found elsewhere (*A.G. Triantafyllou,* 2003). Synoptic scale meteorological datasets in TAPM were provided by the Australian Bureau of Meteorology. The results presented here concern synoptic and experimental data in January of 2002.

THE MODEL

The Air Pollution Model (TAPM) is a PC-based, nestable, prognostic meteorological and air pollution model driven by a Graphical User Interface. TAPM solves fundamental fluid dynamics and scalar transport equations to predict meteorology and pollutant concentration for a range of pollutants important for air pollution applications. Details on the TAPM approach can be found at http://www.dar.csiro.au/TAPM.

METHODOLOGY

Screening design

Screening methods are designed to handle hundreds of model input factors in a sense that they can only provide qualitative sensitivity measures of the different sources that cause the variation in a model's output. A screening factor method is presented for grid calibration by the isolation of the most important factors amongst a large number. The following procedure might be useful for modelers who are unable to measure sensitivity from within the model's generic code by differential or Monte Carlo methods (*Saltelli, A., K. Chan and E.M. Scott*, 2000). Local sensitivity is estimated by the screening of grid factors. In specific, the OAT approach has been used in order to evaluate the impact of changing the values of each of the factors being grid size and resolution.

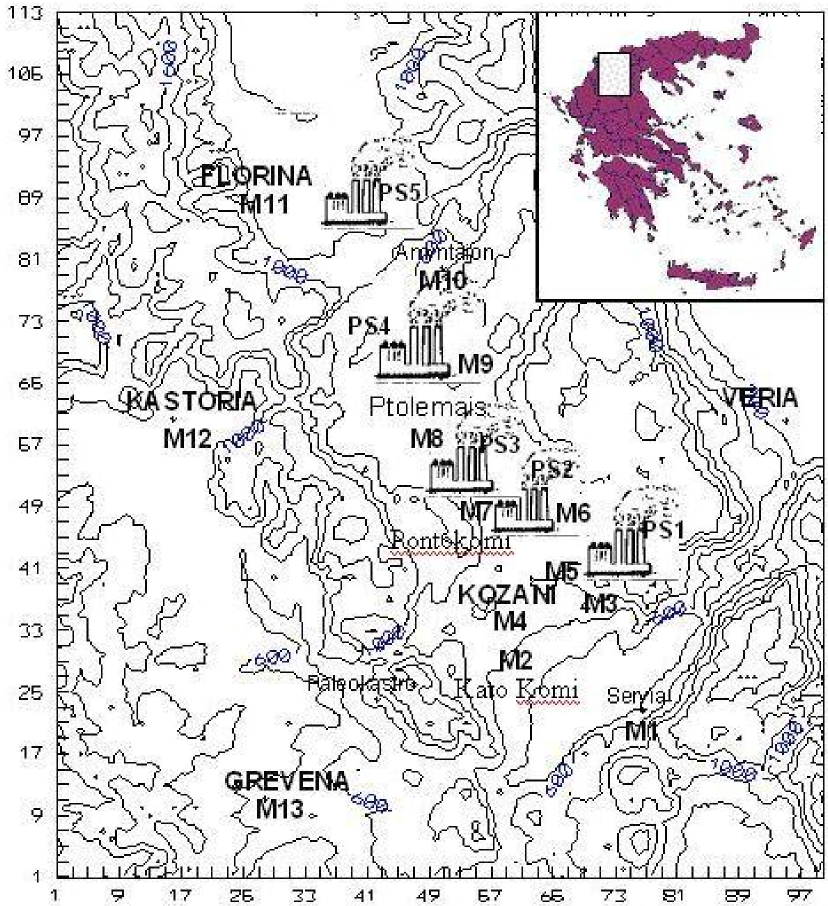

Fig. 8; Topography of the area (contours of terrain height in metres) covered by the inner grid of the model . Power stations (PS). Monitoring sites (MS). The insert (top right) shows the area within Greece.

SA was based on the selection of two meteorological parameters measured at the MS being temperature TEMP and wind speed WS10 at ten meters, respectively. However, grid sensitivity analysis did not show any significant variation for the rest of the model's outputs e.g. irradiation components. Testing of possible sources of variation (i.e. land surface heterogeneity e.g. between a lake and a mountain, locations at different distances from the grid edges, different periods of simulation and data sets) of the selected meteorological parameters when selecting grid size and resolution has shown that the most influential element in a grid point's sensitivity was its distance from the edges of the inner nested grid.

Three different grid sizes constituted three runs assuming the factor of resolution constant i.e. constant horizontal spacing. The standard grid size values were defined as the 'control experiment' with a triply nested grid of 25x25x25 points that adequately covers the required region at 30,000 m, 10,000 m and 3,000 horizontal grid spacing. Two larger domain sizes were also selected to be 29x29x25 and 33x33x25 grid points. The magnitude of residuals between the standard case and the larger domains is then used for the evaluation of model sensitivity and comparison with real experimental data. Note that, the inner grid in all cases covers the area from the northern MS (Amyntaion) to the southern one (Kato Komi).

In accordance with the OAT technique the grid resolution factor was treated separately through two runs. The first was the previously defined 'control experiment' and the second used 75x75x25 grid points and 10,000 m, 3,000 m and 1,000 horizontal spacing. This has been selected to clarify grid size sensitivity and keep the final calibrated grid simpler for future repeated simulations. During this run the grid size factor was held constant to cover the same grid domain as the control experiment that has 25x25x25 grid points.

A local method for measuring sensitivity or an OAT experiment can be applied when the relationship input-output is assumed to be linear. Moreover, the OAT approach is acceptable if the random error is small compared with Local Sensitivity S_i, which is calculated by *Capaldo, K.P. and S.N. Pandis's* (1997) equation as follows:

$$S_i = \frac{\ln y - \ln y_b}{\ln x_i - \ln x_{ib}} \qquad (1)$$

where x_i is the varied generic input factor around a baseline value x_{ib} that affects the variation of the output y around y_b.

Linearity assumption

Three monthly runs with different grid sizes have been carried out, at several locations, in accordance with the previous section. The results of wind speed were compared in pairs to check linearity between the input grid size factor and output. An indicative example is shown in Figure 2 for Pontokomi MS where the results from the 25x25x25 grid point run were plotted against the 29x29x25 run, and then against the 33x33x25 run. From the scatter plots it was concluded that the outputs between runs have good correlation, revealing the input-output degree of linearity. This means that a local sensitivity analysis method and more specifically an OAT technique could be applied in order to find those factors that significantly affect the model grid. The result was similar for constant grid size with varying resolution.

Grid sensitivity

From Equation (1) it was assumed that the baseline was the 25 grid point run and the local sensitivity was then calculated for a 29 grid point perturbation run, and a 33 grid point perturbation run. Figure 3 shows the local sensitivity on an hourly basis for one month of wind speed predictions in Amyntaion and Pontokomi. After the size has been increased from 29 to 33 grid points the model sensitivity remained generally the same. At the MS of Pontokomi, local sensitivity ranged within a narrower interval than at Amyntaion. This was due to the location of the MS being very close to the edge of the inner grid. In specific, when the grid size is increased, then the outer MS comes into interaction with neighboring synoptic meteorological data that have not been taken into account by the smaller grid, other than through nesting from a coarser grid. Under a small grid setup, points in the middle of the grid have already processed most of the information that can influence them.

For the factor of resolution, the baseline of the inner grid's horizontal spacing was assumed 3,000 m (i.e. 25 grid points) and changed to 1,000 m. Figure 4 shows the local sensitivity on an hourly basis for one month of wind speed predictions which was insignificant as the grid resolution became finer. It is also noted that the influence of grid size in the model was more important than the effect of resolution.

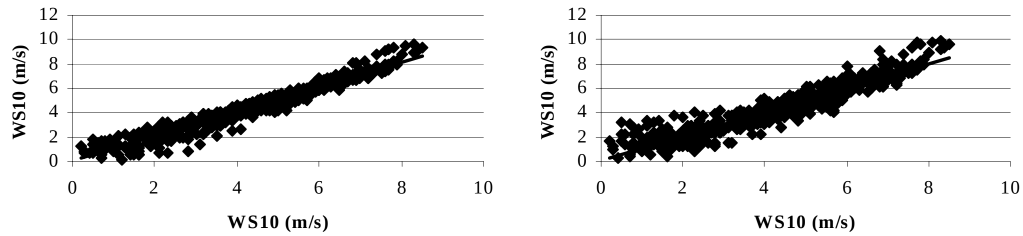

Fig. 2; Scatter plots of hourly wind speed outputs for January 2002 in Pontokomi MS. Left: 25x25x25 vs. 29x29x25. Right: 25x25x25 vs. 33x33x25.

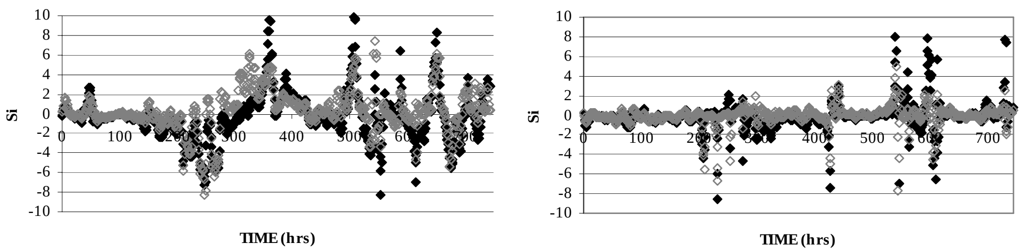

Fig. 3; Grid size local sensitivity based on hourly wind speed predictions during January 2002. Grey dots x_{ib} = 25 and x_i = 29 runs. Black dots x_{ib} = 25 and x_i = 33 runs. Left: Amyntaion MS. Right: Pontokomi MS.

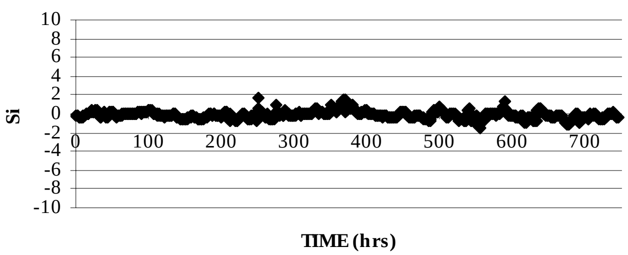

Fig. 4; Resolution local sensitivity based on hourly wind speed predictions during January 2002. Amyntaion: x_{ib} = 3,000 m and x_i = 1,000 m.

RESULTS

The results from the previously discussed simulations 25x25x25, 33x33x25 and 75x75x25 grid points were compared against observations. More specifically, in Tables 1 and 2 the model predictions of wind speed and temperature extracted from TAPM for the same grid points, in all runs, to describe the MS of Amyntaion and Pontokomi, respectively. At both sites RMSEs were below the standard deviation in the observations and the indexes of agreement were relatively high. The RMSEs in the middle of the grid, at Pontokomi MS, were smaller than at the edge in Amyntaion MS, possibly, due to increased uncertainty or sensitivity. The correlation coefficients and IOAs showed that the accuracy was better for the inner MS of Pontokomi. Note, that from the tables one can use any grid points setup as in all cases the degree of accuracy that the model predicted the real meteorological measurements was very high.

Table 1. Statistics for TAPM V2.0 25x25, 33x33 and 75x75 grid points runs at Amyntaion MS during January 2002.

OBS=Observations MOD=Model Predictions MEAN=Arithmetic mean CORR=Pearson Correlation Coefficient (0=no correlation,1=exact correlation) STD=Standard Deviation RMSE=Root Mean Square Error RMSE_S=Systematic Root Mean Square Error RMSE_U=Unsystematic Root Mean Square Error IOA=Index of Agreement (0=no agreement, 1=perfect agreement) SKILL_E=(RMSE_U)/(STD_OBS) (<1 shows skill) SKILL_V=(STD_MOD)/(STD_OBS) (near to 1 shows skill) SKILL_R=(RMSE)/(STD_OBS) (<1 shows skill)

25x25 Run	NUM_OBS	MEA_OBS	MEA_MOD	STD_OBS	STD_MOD	CORR	RMSE	RMSE_S	RMSE_U	IOA	SKILL_E	SKILL_V	SKILL_R
TEMP	719	2.12	5.08	5.57	4.82	0.87	4.06	3.27	2.41	0.85	0.43	0.87	0.73
WS10	719	2.33	3.41	3.09	1.97	0.65	2.57	2.10	1.49	0.75	0.48	0.64	0.83
33x33 Run													
TEMP	719	2.12	5.75	5.57	4.70	0.87	4.56	3.92	2.33	0.82	0.42	0.84	0.82
WS10	719	2.33	3.73	3.09	1.97	0.72	2.56	2.18	1.36	0.77	0.44	0.64	0.83
75x75 Run													
TEMP	719	2.12	6.61	5.57	4.94	0.88	5.22	4.65	2.36	0.79	0.42	0.89	0.94
WS10	719	2.33	4.12	3.09	2.02	0.67	2.91	2.49	1.50	0.73	0.49	0.65	0.94

Table 2. Statistics for TAPM V2.0 25x25, 33x33 and 75x75 runs at Pontokomi MS during January 2002.

25x25 Run	NUM_OBS	MEA_OBS	MEA_MOD	STD_OBS	STD_MOD	CORR	RMSE	RMSE_S	RMSE_U	IOA	SKILL_E	SKILL_V	SKILL_R
TEMP	737	2.98	4.38	6.39	4.94	0.91	3.08	2.34	2.00	0.93	0.31	0.77	0.48
WS10	737	2.37	2.69	2.80	1.75	0.73	1.95	1.54	1.19	0.81	0.43	0.63	0.70
33x33 Run													
TEMP	737	2.98	13.88	6.39	7.45	0.91	3.25	2.53	2.04	0.92	0.32	1.17	0.51
WS10	737	2.37	3.16	2.80	1.90	0.77	1.97	1.55	1.22	0.83	0.44	0.68	0.71
75x75 Run													
TEMP	737	2.98	5.93	6.39	5.14	0.92	3.94	3.39	2.02	0.89	0.32	0.80	0.62
WS10	737	2.37	2.74	2.80	2.14	0.75	2.24	1.50	1.67	0.78	0.60	0.76	0.80

CONCLUSION

SA based on the OAT technique has been conducted, and revealed that the factors of grid size and resolution have significantly impacted the variability of model (TAPM) output at locations with a high degree of uncertainty such as at the edges of the grid. A very good agreement against real measurements has been achieved in all cases, but was even better in the inner grid areas where uncertainty was low. In conclusion, the model was less sensitive to the factor of resolution, future simulations using a grid of 25x25 points, with horizontal grid spacing down to 3,000 m, would significantly reduce run times of prognostic modeling in air pollution calculations for the region, without significant loss of accuracy compared to using more computationally costly grid configurations.

REFERENCES

Capaldo, K.P. and S.N. Pandis, 1997: Dimethylsulfide chemistry in the remote marine atmosphere: Evaluation and sensitivity analysis of available mechanisms. *J. Geophys. Res.*, **102**, 23251-23267.

Morris, M.D., 1991: Factorial sampling plans for preliminary computational experiments. *Technometrics*, **33**, 161-174.

Saltelli, A., K. Chan and E.M. Scott, 2000: Sensitivity Analysis. Wiley, UK.

Triantafyllou, A.G., 2003: Levels and trend of suspended particles around large lignite power stations. *Env Monit and Assess.*, **89**, 15-34.