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# WRF EVALUATION EXERCISE USING OPEN SEA IN SITU MEASUREMENTS AND LAND COASTAL DATA

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**Abstract:** The quality of the prediction of the atmospheric transport and dispersion of toxic, hazardous materials and pollutants strongly depends on the atmospheric forcing and in particular on the wind field. Especially in coastal regions, another important factor for correctly predicting the pollutant levels is the precise quantification of the sea aerosol particles formed predominantly by the action of the wind on the ocean surface. Furthermore, acting as a cloud condensation nuclei to form cloud drops, exchanging gases with the atmosphere and engaging other reactions, scattering lights and exchange moisture with the atmosphere, sea aerosol plays a fundamental role in the Earth's weather and climate regulation.
Despite its importance, no continuous and long term monitoring of sea aerosol emissions is available and the measurements performed during dedicated campaigns are extremely scarce and spotted. As a consequence, sea aerosol trends are mainly predicted by simulations whose skill and precision rely on the atmospheric forcing fields used to drive models.
The "Research on Energy Systems" (RSE S.p.A.) implemented the model system WRF-SMOKE-CAMx in order to simulate both concentration and deposition of pollutants in Italy. In particular, the WRF model was used for modeling the meteorological fields, the SMOKE model was selected to process the emission inventory and the CAMx was selected as the pollutant dispersion and chemical model to simulate different scenarios.
The paper addresses an analysis of the performance of two WRF model versions (WRF-ARW 3.0 and WRF-ARW 3.2.1) in the Ligurian sea area carried out by comparing model outputs against observations at five different monitoring sites, four along the coast and one in the open ocean.
The new parameterizations introduced in the 3.2.1 version of the WRF model contribute to improve the overall model performance although, for both the model releases, reproduction of the wind field shows criticisms due to the particularly complex orography of the Ligurian basin area. Nonetheless, the analysis evidences the feasibility of using the WRF model outputs as input meteorological fields to model the sea aerosol emissions.

***Key words:*** *model evaluation, WRF-ARW model, Ligurian Sea, coastal data, buoy data*

## INTRODUCTION

The present work regards a model evaluation exercise concerning the well known WRF meteorological model (http://wrf-model.org) and in situ measurements collected both on land and in open sea. In particular, this exercise is finalised to understand the skill of the model to act as meteorological pre-processor in order to simulate aerosol emissions from the sea (Lewis et al., 2004), an important factor to correctly predict pollutant levels. Performances of two model versions, WRF-ARW 3.0 and WRF-ARW 3.2.1, have been compared using mainly AMET 1.1 (Atmospheric Model Evaluation Tool, Appel et al., 2011), a suite of software specifically designed by CMAS to compare observations against meteorological (e.g. MM5, WRF) and air quality model (e.g. CMAQ, CAMx) predictions.

## METHODOLOGY

The WRF dynamics and physics options have been set up in the course of the studies performed by the "Research on Energy Systems" (RSE S.p.A.) in order to simulate the meteorological fields over two different domains. The master domain with a 45 km spatial resolution covers the whole Europe and it is intended to capture synoptic features and general circulation patterns, while a nested one covers the whole Italian Peninsula, with a grid step of 15 km (Figure 1). The input land use data were derived from the USGS global cover, while meteorological input was provided from the ECMWF global analysis with 0.5 deg spatial resolution and temporal resolution of 6 hours (http://www.ecmwf.int). Among the WRF outputs, the proposed analysis focuses on wind speed, temperature, pressure and mixing ratio, which are the most relevant parameters in order to understand the skill of the model to act as meteorological pre-processor to simulate aerosol emissions from the open sea (Smith and Harrison, 1998; Gong et al., 2002).

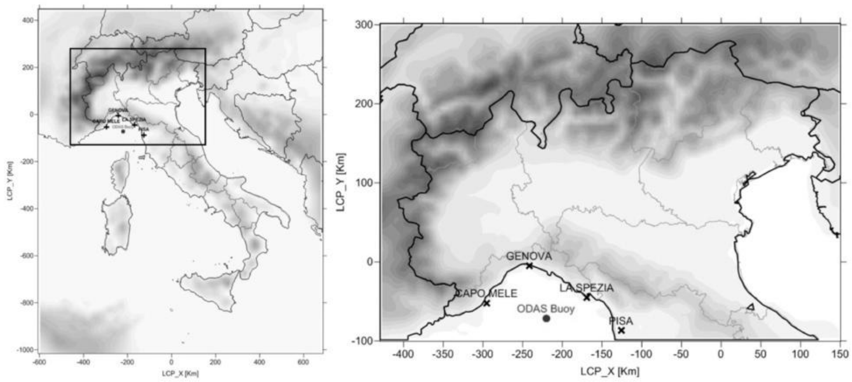


Figure1. The 15 km resolution nested domain (on the left), detail of the Northern Italy area where meteorological stations are located (on the right).

The test has been carried out for the period August-December 2005 over the Ligurian Sea, a very complex area where strong air-sea interactions and orography significantly affect the atmospheric circulation. Data for evaluation were collected both over land at four WMO meteorological coastal/inland stations and over the sea by the ODAS Italia 1 observing system (Table 1 and Figure 1).

Table 1. The four WMO meteorological coastal/inland stations.

| code | name | location | Longitude (degrees) | Latitude (degrees) | height a.s.l. (m) |
|---|---|---|---|---|---|
| 16120 | Genova/Sestri | coastal | 8.85 | 44.41 | 3 |
| 16129 | La Spezia - La Castellana | coastal | 9.81 | 44.06 | 521 |
| 16153 | Capo Mele | coastal | 8.18 | 43.95 | 221 |
| 16158 | Pisa/S. Giusto | inland | 10.38 | 43.68 | 6 |

Figure 2. ODAS Italia 1

The ODAS Italia 1 is the only spar buoy in the Mediterranean sea. It is moored in the Ligurian Sea at 43° 47.364′ N, 009° 09.798′ E, about 73 Km southward Genoa and at a water depth of 1377 m with no shield from winds and waves. It is about 50 m long and weighing 11 tons, with a small laboratory at the top, which is positioned at about 15 m above the average sea level. This buoy is a stable measuring platform for collecting both meteorological and sub-surface ocean data offshore.

The laboratory on its top is equipped with a set of meteorological sensors (Bozzano et al., 2004; Pensieri et al., 2010). It is composed by a precision spectral pyranometer, a precision infrared radiometer, a sonic anemometer, a barometer, a thermo-hygrometer and a compact weather station - which measures atmospheric pressure, wind speed and direction, dry temperature, relative humidity and rainfall. The compact weather station is used mainly for cross-checking (i.e., detection of bad values and failures of the stand-alone sensors). Among sub-surface sensors, a wave meter system, developed by CNR-ISSIA and composed by three echosounders, provides sea wave statistics (Kishcha et al., 2010). Furthermore, a web cam provides a qualitative visual check on the presence of whitecaps.

The ODAS Italia 1 measurements are continuously collected and transmitted in near real time to the station ashore at CNR in Genoa by means of a dedicated satellite phone link. Near real-time data and more detailed information on the observatory are available at the institutional website (http://www.odas.ge.issia.cnr.it).

This platform, for its capability of monitoring the ecosystem for long term period in open ocean in continuous and unmanned way, could be very suitable for studies about air-sea fluxes, in particular as far as the $CO_2$ cycle and the sea spray aerosols are concerned. The buoy has negligible movements and rotations with respect to sea wave thus it allows to collect data also with rough sea and strong wind, meteorological conditions that commonly don't permit the carrying out of dedicated cruises.

**RESULTS AND DISCUSSION**

We compared measured data collected every three hours with the corresponding outputs of both WRF-ARW 3.0 and WRF-ARW 3.2.1. The number of useful measurements in the period August-December 2005 was 1171 (96%) at the ODAS Italia 1 site, 1113 (91%) at the La Spezia - La Castellana station, and 1124 (92%) at Genova/Sestri, Capo Mele and Pisa/S. Giusto stations. The performance of the two models has been estimated through both metrics and graphical methodologies. Among the AMET 1.1 tools we show: i) BIAS, MNGE (Mean Normalized Gross Error) and AC (Anomaly Correlation) metrics (Table 2); ii) time series (Figures 3 and 4) and box whisker plots (Figure 4). Furthermore, we elaborated wind roses (Figure 6) to study the WRF performance about wind direction, even if wind direction is not used by the WRF-SMOKE-CAMx system to model sea aerosol emissions.

From the values of the statistical indices (Table 2) it is possible to state that:

- there is not systematic tendency of the models towards undestimation (BIAS < 0) or overestimation (BIAS > 0) of the measured values;
- AC ≥ 0.88 for temperature, mixing ratio and pressure;
- MNGE ≤ 1.05 % for temperature and pressure;
- WRF-ARW 3.2.1 overall performs better than WRF-ARW 3.0, in particular for temperature and wind speed simulation;
- wind speed simulation is the most critical one.

Furthermore, from the analysis of the diurnal trends of statistical indexes (not reported here) it is possible to remark that the model is able to correctly simulate both diurnal and monthly evolution of the studied quantities, all but temperature for which the model performance is worse at night.

Table 2. Bias (BIAS), mean normalized gross error (MNGE) and anomaly correlation (AC) statistics from the AMET software.

| Measurement site | ODAS-buoy | | Genova/Sestri 16120 | | La Spezia-La Cast. 16129 | | Capo Mele 16153 | | Pisa/S. Giusto 16158 | |
|---|---|---|---|---|---|---|---|---|---|---|
| **WRF Release** | **3.0** | **3.2.1** | **3.0** | **3.2.1** | **3.0** | **3.2.1** | **3.0** | **3.2.1** | **3.0** | **3.2.1** |
| **2 m Temperature** | | | | | | | | | | |
| *Mean measured (K)* | *290.9* | | *289.7* | | *289.0* | | *289.5* | | *288.5* | |
| BIAS | 0.81 | 0.69 | - 0.13 | - 0.22 | 2.34 | 2.16 | 0.60 | 0.47 | 2.12 | 1.55 |
| MNGE (%) | 0.36 | 0.30 | 0.45 | 0.39 | 1.05 | 0.93 | 0.47 | 0.36 | 0.99 | 0.73 |
| AC | 0.96 | 0.97 | 0.97 | 0.97 | 0.88 | 0.91 | 0.97 | 0.98 | 0.90 | 0.95 |
| **2 m Mixing Ratio** | | | | | | | | | | |
| *Mean measured (g kg$^{-1}$)* | *10.36* | | *8.39* | | *10.53* | | *9.00* | | *8.58* | |
| BIAS | - 0.02 | - 0.54 | 1.29 | 0.97 | - 0.49 | - 0.93 | 0.17 | 0.27 | 0.73 | 0.67 |
| MNGE (%) | 10.60 | 10.49 | 22.33 | 18.38 | 21.88 | 20.21 | 29.13 | 29.44 | 20.55 | 19.77 |
| AC | 0.95 | 0.93 | 0.88 | 0.91 | 0.93 | 0.90 | 0.92 | 0.92 | 0.90 | 0.91 |
| **10 m Wind Speed** | | | | | | | | | | |
| *Mean measured (m s$^{-1}$)* | *4.31* | | *4.68* | | *3.22* | | *5.04* | | *2.86* | |
| BIAS | 0.84 | 0.11 | 0.89 | - 0.83 | 0.88 | - 0.17 | 0.26 | - 0.97 | 1.81 | 0.98 |
| MNGE (%) | 88.06 | 69.43 | 71.15 | 56.26 | 88.78 | 55.34 | 72.54 | 58.29 | 164.6 | 122.43 |
| AC | 0.64 | 0.70 | 0.48 | 0.43 | 0.46 | 0.59 | 0.61 | 0.59 | 0.42 | 0.49 |
| **Sea Level Pressure** | | | | | | | | | | |
| *Mean measured (hPa)* | *1016.5* | | *1016.4* | | *n.a* | | *1016.0* | | *1016.6* | |
| BIAS | 0.25 | 0.36 | 1.01 | 1.08 | n.a | n.a | 0.37 | 0.38 | - 0.17 | - 0.03 |
| MNGE (%) | 0.05 | 0.05 | 0.13 | 0.13 | n.a | n.a | 0.07 | 0.07 | 0.07 | 0.06 |
| AC | 0.99 | 0.99 | 0.97 | 0.97 | n.a | n.a | 0.99 | 0.99 | 0.99 | 0.99 |

As already said, the main goal of this work was to understand the capability of the model to act as meteorological pre-processor in order to simulate sea aerosol emissions in open sea; for this reason, we dedicated particular attention to the model performance at the buoy site. The following plots show the time series of the model outputs for the two versions and observations at the buoy monitoring site.

The time series analysis shows a good agreement between the output of the models and the measurements for pressure, while some discrepancies can be detected for temperature. As far as mixing ratio is concerned, there is a slight trend towards underestimation of the measured values (see the BIAS index in Table 2 as well). The simulated wind speed differs several times from the observed one.

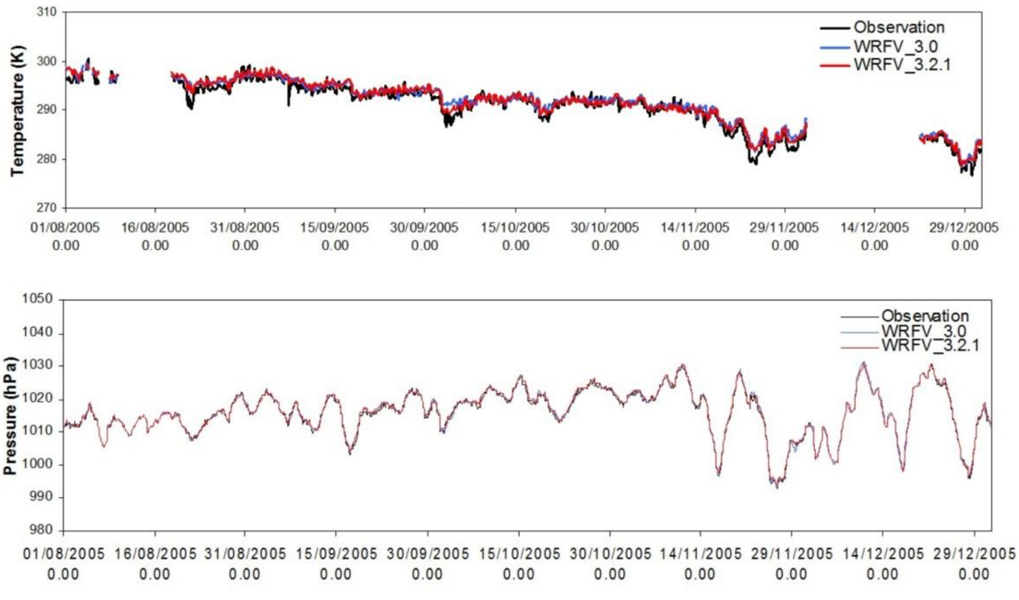


Figure 3. ODAS buoy site: comparison between measured and modelled data for 2 m temperature and sea level pressure.

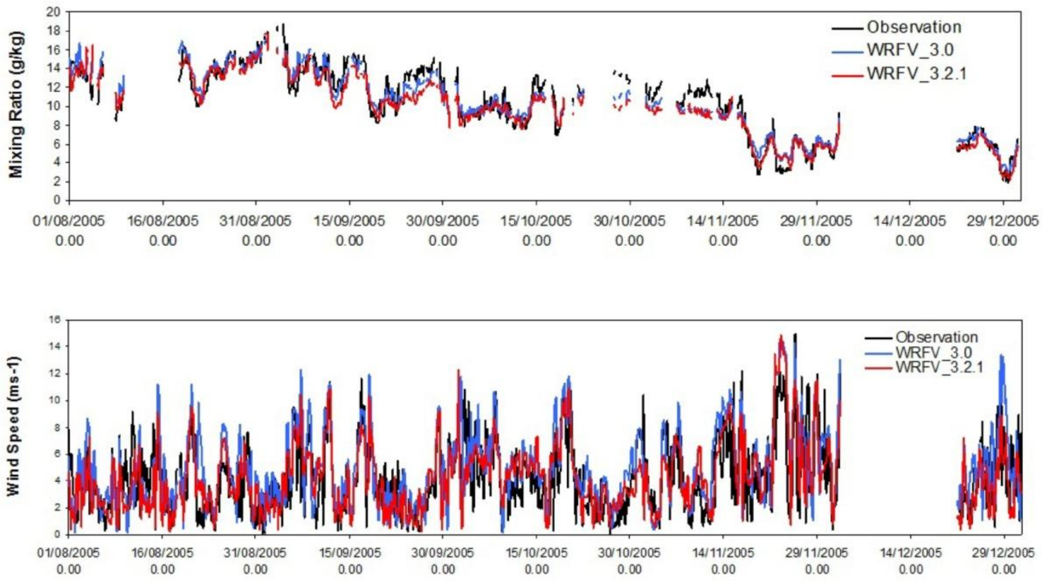


Figure 4. ODAS buoy site: comparison between measured and modelled data for 2 m mixing ratio and 10 m wind speed

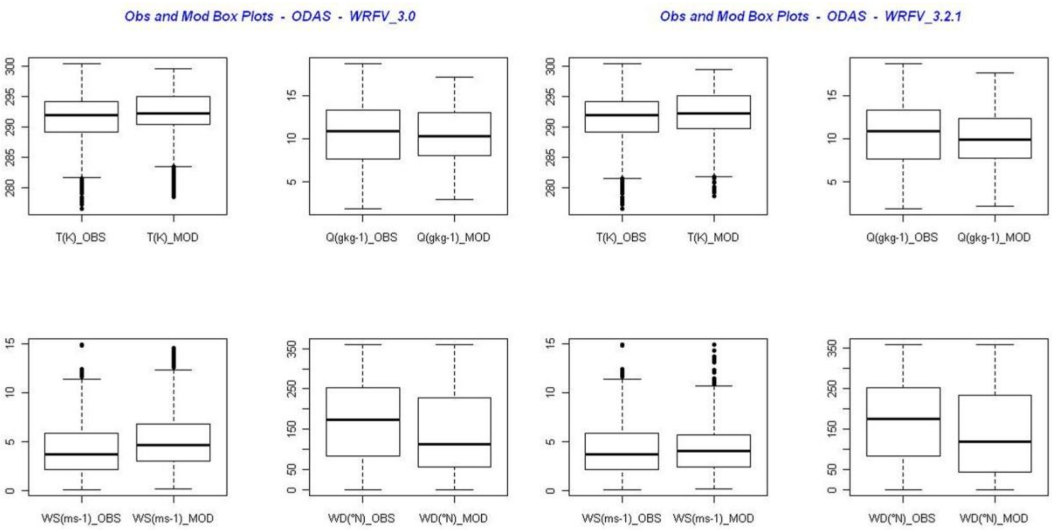


Figure 5. ODAS buoy site: box whisker plot for measured and modelled data.

The box whisker plots (Figure 5) highlight the difference between the two WRF versions compared to the buoy observations. The improvement of the performance of the 3.2.1 model version is quite evident.

Since, on the one hand, wind speed over the sea is the main relevant quantity in order to modelling sea aerosol emissions, and on the other hand, the WRF performance for the wind speed simulation is the most critical one, we are particularly interested in this issue. Therefore, we drew wind roses, even if wind direction is not used by the WRF-SMOKE-CAMx system to model sea aerosol emissions. Comparing the wind roses (Figure 6) of the ODAS buoy measurements and the corresponding estimates of the two model versions, we can notice that the models simulate quite satisfactory the South-Western component, but not the Eastern one, and the disagreement is particularly evident for Version 3.2.1.

Criticisms about wind field simulation could be due to the 15 km model domain spatial resolution that probably didn't allow an adequate description of both the indented shoreline and the coastal complex orography of the Ligurian basin. Therefore, we performed simulations on a nested domain with a 5 km horizontal grid step, first results (not showed) are encouraging.

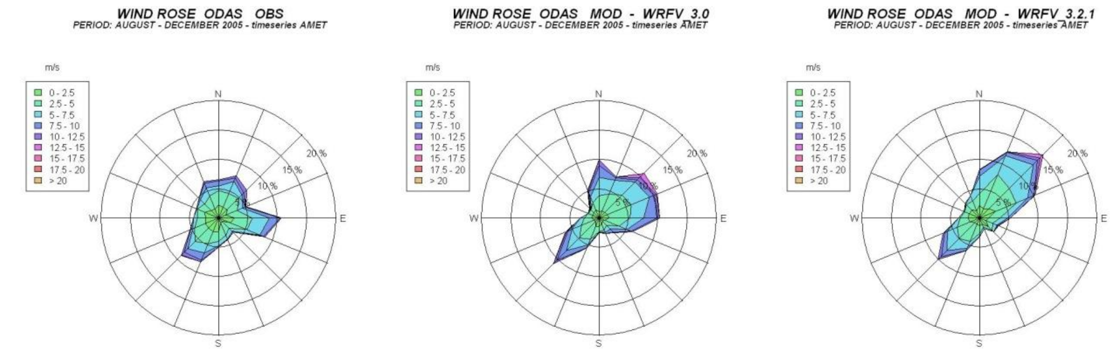


Figure 6. ODAS buoy site: wind rose for measured and modelled data at 10 m height.

## CONCLUSIONS

The obtained results show that the new parameterizations introduced in the 3.2.1 version of the WRF-ARW model improve the performance of the model.

The WRF-ARW model performs better in order to simulate pressure, temperature and mixing ratio than wind speed. The criticism revealed in this study may be ascribed to the used spatial domain resolution that doesn't allow an adequate description of both the indented shoreline and the coastal complex orography of the site under study.

This study evidences the feasibility of using the WRF-ARW model outputs as input meteorological fields for estimating the sea aerosol emissions, even if the consistency of the horizontal resolution of the model domain with the actual orographical complexity of the coastal regions should be analyzed.

## ACKNOWLEDGMENT

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## REFERENCES

Appel, K. W., R. C. Gilliam, N. Davis, A. Zubrow and S. C. Howard, 2011: Overview of the atmospheric model evaluation tool (AMET) v1.1 for evaluating meteorological and air quality models. *Environmental Modelling & Software*, **26**, 434-443. DOI: 10.1016/j.envsoft.2010.09.007.

Bozzano, R., A. Siccardi, M. E. Schiano, M. Borghini and S. Castellari, 2004: Comparison of ECMWF surface meteorology and buoy observations in the Ligurian Sea. *Annales Geophysicae*, **22**, 317-330.

Gong, S. L., L. A. Barrie and M. Lazare, 2002: Canadian Aerosol Module (CAM): A size-segregated simulatin of atmospheric aerosol processes for climate and air quality models 2. Global sea-salt aerosol and its budgets, *J. Geophys. Res*., **107**, 4779. DOI:10.1029/2001JD002004.

Kishcha, P., B. Starobinets, R. Bozzano, S. Pensieri, E. Canepa, S. Nickovic, A. di Sarra, R. Udisti, S. Becagli and P. Alpert, 2010: Sea-salt aerosol forecasts compared with sea-salt and wave height measurements in the open sea. Air Pollution Modeling and its Application, Volume XXI, ITM Series, Springer. Proceedings of 31st-ITM NATO Conference, 27 September – 01 October 2010, Torino, Italy.

Lewis, E. R., and S. E. Schwartz, 2004: Sea Salt Aerosol Production: Mechanisms, Methods, Measurements, and Models - A Critical Review. Geophysical Monograph Series Vol. 152, (American Geophysical Union, Washington), 413 pp. ISBN: 0-87590-417-3.

Pensieri, S., R. Bozzano and M. E. Schiano, 2010: Comparison between QuikSCAT and buoy wind data in the Ligurian Sea. *J. Mar. Syst.*, **81**, 286-296.

Smith, M. H. and N. M. Harrison, 1998: The sea spray generation function. *J. Aerosol Sci.*, **29**, 189-190.