EVALUATING THE PHYSICS OPTIONS OF REGIONAL WEATHER MODELS FOR AREAS WITH COMPLEX LAND-USE CHARACTERISTICS

H. S. Badr [1], *H. A. Kandil* [2], *B. M. Elhadidi* [3], *A. O. Sherif* [3]

[1] National Authority for Remote Sensing and Space Sciences (NARSS), Cairo, Egypt
[2] Department of Mechatronics Engineering, German University in Cairo (GUC), Cairo, Egypt
[3] Department of Aerospace Engineering, Faculty of Engineering, Cairo University (CU), Giza, Egypt

ABSTRACT

The objective of this paper is to evaluate the effects of changing different physics schemes on the accuracy of weather simulations at different locations inside Egypt. The model sensitivity to physics options was tested in the four seasons and the results were compared to observations at different locations. Different physics packages were used based on different planetary boundary layer (PBL) and radiation schemes. The question to be answered in this study is: which scheme is the best scheme for certain location and/or weather regime?.

The paper presents the details of model configurations, the results of the carried out simulations, and the behavior of the model with different physics options and initializations at different locations. The best physics options for each location and how to get better solutions for areas with complex land-use characteristics was identified. This is beneficial in determining how to choose an optimal set-up for a forecasting system, especially in Egypt.

Index Terms — Short-Range Ensemble Forecasting, Data Assimilation, NWP, MM5, SREF, FDDA

1. INTRODUCTION

The atmosphere is a chaotic system and the numerical modeling of the atmospheric physics has many sources of errors. The main sources of errors are the model deficiencies and the uncertainty in the initial conditions. The model deficiencies can be tested by studying the model sensitivities to different physics options which are available in the regional NWP models, such as WRF and MM5. This involves cumulus parameterization, planetary boundary layer, moisture, radiation and surface physics schemes. The optimal set-up of the forecasting model, by selecting the best physics options and initializations for each location and/or weather regime, is a very important issue for accurate numerical weather forecasting.

The objective of this work was to test the sensitivity of different physics options and initializations on a NWP regional model for Egypt. This includes the study of the qualities of weather simulations/predictions for different weather regimes and at locations with complex land-use characteristics. Nine different physics options were used in this study based on three PBL schemes and three radiation schemes. Moreover, the performance of the model was tested for different initialization times and methods as well as in medium-range simulations. Nine observational stations inside Egypt, as shown in the station map in Fig. 1, were used for evaluation of the different model simulations.

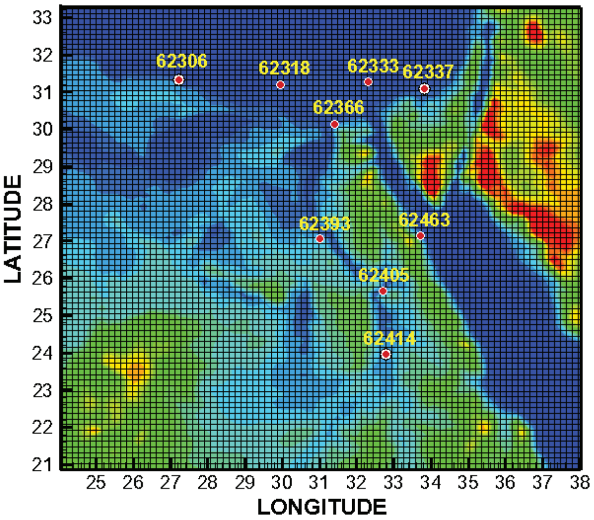

Fig. 1: Observational station map used for the evaluation.

2. METHODOLOGY

A numerical weather modeling system for Egypt was developed [1 & 2] and utilized for the modeling of local meteorological changes [3], the assessment of air pollution in mega cities [4], the investigation of wind and solar energy potentials [5], and the effects of data assimilation on the modeling system [6]. This work extends such efforts to test the effects of changing the initialization, time and/or method, and the different physics options of the model in order to find the optimum set-up of the model that will be of value to others performing similar work. This can be also utilized for a preliminary ensemble forecasting experiment for Egypt to cope with the uncertainties associated with the initial conditions of the model and the model itself [7].

978-1-4577-1005-6/11/$26.00 ©2011 IEEE

Fig. 2 shows the framework of the modeling system. The system consists of five main components which were linked to automate the process using Linux scripts, namely:

1. *Inputs*: the basic inputs required to initialize the model and advanced inputs utilized from remotely-sensed data,
2. *Numerical Model*: the core of the system (MM5/WRF),
3. *Observations*: used to enhance the model results via data assimilation and help to evaluate the model,
4. *Evaluation*: used to qualify the model/observations, and
5. *Applications*: used to post-process the final outputs.

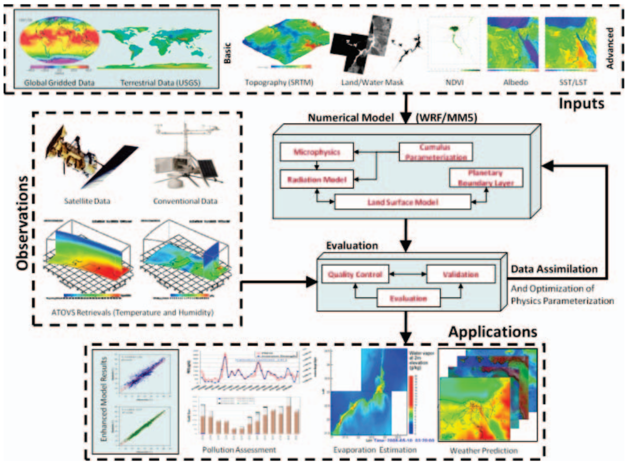

Fig. 2: The framework of the numerical modeling system.

In this work, the core of the modeling system utilized is the MM5 model [8]. Three nested domains were used as shown in Fig. 3. The horizontal resolutions and the grid sizes are listed in Table 1.

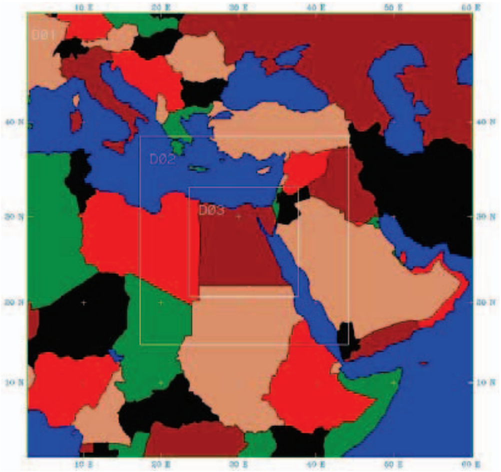

Fig. 3: The nested domains used in the MM5 model.

Table 1: Resolutions and grid sizes for the used domains.

Domain	Horizontal Resolution	Grid Size
D01	81 km	70 x 70 x 38
D02	27 km	96 x 96 x 38
D03	**09 km**	**174 x 174 x 38**

The inner, third, domain of a resolution of 9 km encompasses entire Egypt with horizontal and vertical grids shown in Fig. 4. Proper remotely-sensed data were used for each surface grid. The initial and boundary conditions for the outer domain were nested from NCEP Final Reanalysis (FNL) global gridded datasets (horizontal resolution ~111 km). One-way nesting type was used for all domains.

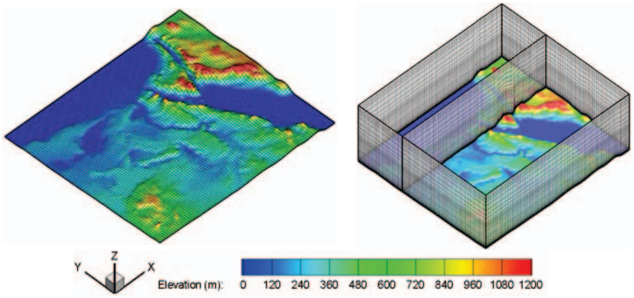

Fig. 4: The horizontal and vertical grids for Egypt domain.

The performance of the model was tested for different initialization times as well as in medium-range simulations. Then, the sensitivity of the model to different physics options was investigated in the four seasons. This may help in choosing the most appropriate physics package to be used for a single control forecast. Table 2 presents the selected time periods for the performed simulations.

Table 2: Selected time periods for the four seasons.

	Starting Date and Time				Ending Date and Time			
	Year	Month	Day	Time	Year	Month	Day	Time
1	2006	1	1	Z00	2006	1	4	Z00
2	2006	4	1	Z00	2006	4	4	Z00
3	2006	7	1	Z00	2006	7	4	Z00
4	2006	10	1	Z00	2006	10	4	Z00
5	2008	8	1	Z12	2008	8	4	Z12

Nine different physics options were used based on three PBL schemes and three radiation schemes, as listed in Table 3. The MRF PBL scheme with the three different formulations (Carlson-Boland, Garratt, and Zilitinkevich formulations) for the thermal roughness length was used. Three different radiation schemes were used: Cloud-Radiation, CCM2-Radiation, and RRTM-Longwave. The other physical parameterizations utilized the Grell scheme, mixed-phase scheme, and NOAH land surface model.

Table 3: The nine physics options used in this study.

	MRF PBL	Radiation
1	Carlson-Boland	Cloud-Radiation
2	Garratt	Cloud-Radiation
3	Zilitinkevich	Cloud-Radiation
4	Carlson-Boland	CCM2-Radiation
5	Garratt	CCM2-Radiation
6	Zilitinkevich	CCM2-Radiation
7	Carlson-Boland	RRTM-Longwave
8	Garratt	RRTM-Longwave
9	Zilitinkevich	RRTM-Longwave

The available real-time conventional and satellite observations were implemented using objective analysis (OA) and four-dimensional data assimilation (FDDA). They were used to provide three different sets of initial conditions besides the reference set (DA0). The first set (DA1) was produced using OA of the first-guess, which interpolated from FNL datasets, and the available observations. The second and third sets (DA2, DA3) were produced using OA and FDDA dynamic initialization for 6 and 12 hours, respectively. In sum, there are four different initializations.

3. RESULTS AND DISCUSSIONS

Sample results for the different simulations at the selected stations are presented in this section. Fig. 5 shows the simulated and observed near-surface temperature and absolute bias error for 6-days simulations from Z12 January 1, 2006 at Alexandria/Nouzha station (ID 62318 in Fig. 1). It shows the effect of using FDDA dynamic initialization for 24 hours compared with the observations. When turning off FDDA after one day, the errors were reduced for the other days which indicate that dynamic initialization improves the accuracy of forecasts where it provides accurate and smooth initial conditions for the model run. It is clear that the bias error is limited within 4 °C for about 30 more hours.

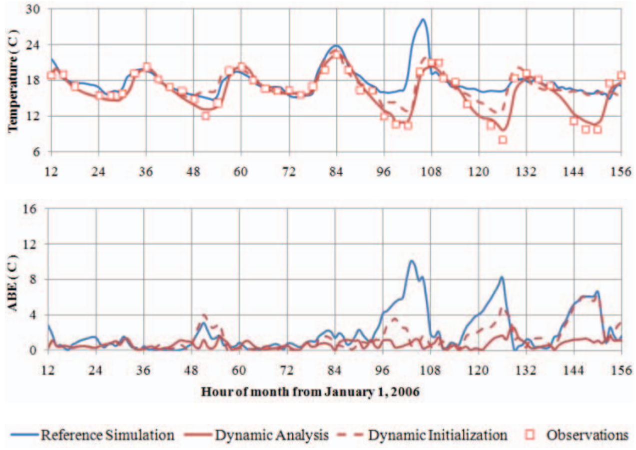

Fig. 5: Near-surface temperature and absolute bias error when using dynamic initialization for 24 hr.

Fig. 6 shows the total and daily RMSE of the near-surface temperature for 6-days simulations. The RMSE of the near-surface temperature was reduced by about 38% when using the dynamic initialization.

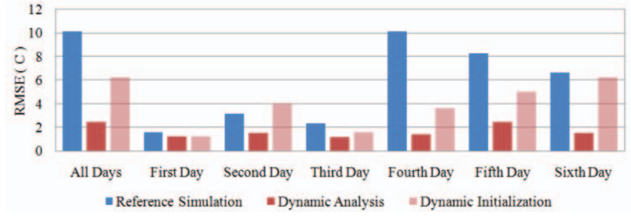

Fig. 6: RMSE when using dynamic initialization for 24 hr.

The full set of results [7] show that different radiation schemes produce different temperatures especially at day time while different PBL thermal roughness length formulations slightly change the simulated temperature for the same initial and boundary conditions. Moreover, using FDDA to produce different sets of initial conditions for the model run affects the behavior of the model. Different physics options produced different temperatures when the different initial conditions were used. Fig. 7 shows the near surface temperature for 36 simulations with 9 different physics options and 4 different initializations at Luxor station (ID 62405 in Fig. 1) in summer.

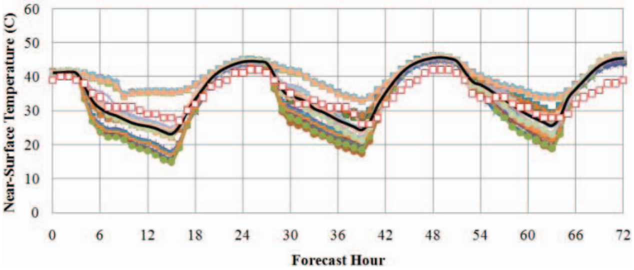

Fig. 7: Near-surface temperature at Luxor station in summer for nine physics options and four initializations.

It is also found that the ensemble mean, which is the average of all performed simulations for the same time, is the best forecast with small errors and it provides better estimation for the average, minimum and maximum temperatures at all locations for different weather regimes. Fig. 8 shows the minimum and maximum envelopes and the mean temperature at Luxor station in summer. It is clear that the ensemble mean (the black line) is closer to the observations (the red squares) while the minimum and maximum envelopes (blue and orange lines) are far from the observations by a range of about 20 degrees Celsius.

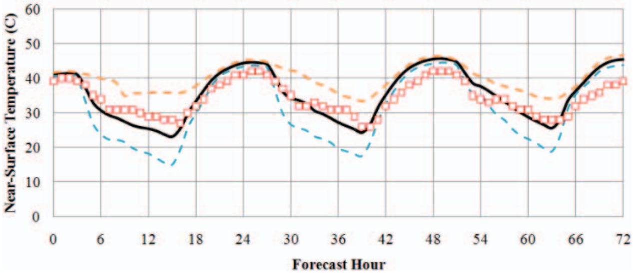

Fig. 8: The minimum and maximum envelopes and the mean temperature at Luxor station in summer.

Fig. 9 shows the percentage change in average and minimum temperatures, with respect to the average and minimum observed temperatures respectively, at Luxor station in summer. It is clear that the behavior of the model for each physics option changes when changing the initialization method/time providing different temperatures accuracies when compared with the observations. Moreover, the ensemble mean, again, provides the best results.

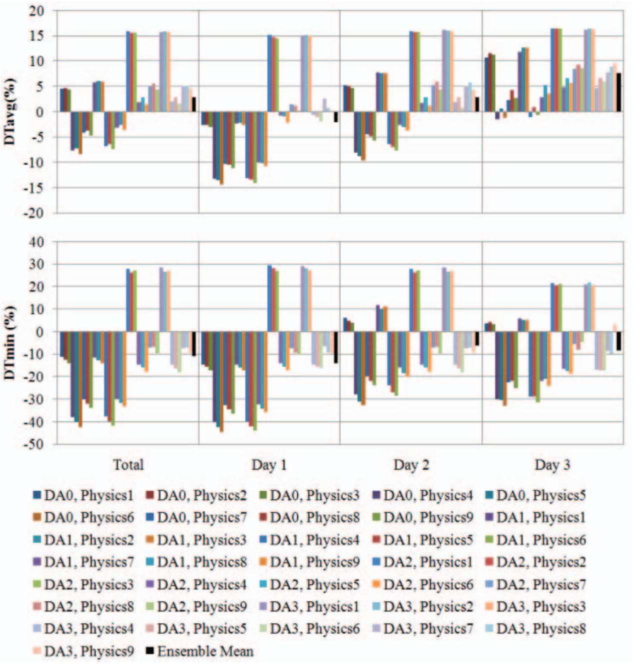

Fig. 9: Percentage change in average and minimum temperatures at Luxor station in summer.

In summary, the present paper presented sample results of the preliminary short-range ensemble forecasting (SREF) experiment for Egypt and its effects on the quality of the forecasts. It is found that the accuracy of the produced forecast, or the ensemble mean, is proportional to the number and quality of the ensemble members. The ensemble mean was evaluated based on the Root-Mean-Square Error, percentage change in average, minimum and maximum temperatures at 9 monitoring locations.

4. CONCLUSIONS AND FUTURE WORK

The dynamic initialization for one day improves the accuracy of forecasts by reducing the RMSE of the near-surface temperature by about 38% and limiting the bias error within 4 ℃ for about 30 more hours. This may be because it provides accurate and smooth initial conditions for the model run. The initialization time of forecasts, which is the ending time of dynamic initialization, must be taken into consideration where it affects the accuracy.

It is also found that The MM5 model is sensitive to the selected physics options. Different radiation schemes produce different temperatures especially at day time. Different PBL thermal roughness length formulations slightly change the simulated temperature for the same initial and boundary conditions.

The deterministic forecasting is not helpful in the applications where better accuracies are essential such as the pollution assessment and wind energy potential. The accuracy of the produced forecast, ensemble mean, is proportional to the number and quality of the ensemble members. The ensemble mean is the best forecast with small errors and it provides better estimation for the average, minimum and maximum temperatures at all locations for different weather regimes. Using FDDA to produce different sets of initial conditions for a model run affects the behavior of the model. Different physics options produce different temperatures when different initial conditions were used.

Expanding the comparison of the different physics options of regional models to explore more about individual schemes and the advanced construction of an ensemble are major recommendations of this work. Extension to advanced ensemble forecasting methods is planned.

5. ACKNOWLEDGMENTS

This work was partially supported by Cairo University (CU) and the National Authority for Remote Sensing and Space Sciences (NARSS). H. S. Badr would personally like to thank Prof. A. Eldessouki, NARSS Chairman, for providing the time, computational facilities, and remotely-sensed data required for performing most runs. He also would strongly appreciate Dr. J. Dudhia's help on revising his MSc thesis.

6. REFERENCES

[1] A.O. Sherif, H.A. Kandil, B.M. Elhadidi, A. Abdelmoaty, and M.M. Abdelkader, "*Using Remote Sensing Observations to Improve the Predictions of a High-Resolution Mesoscale Weather Modeling System for Egypt*", Cairo 9th International Conference on Energy&Environment, SharmElSheikh, Egypt, March 13-15, 2005.

[2] H.A. Kandil, M.M. Abdelkader A. Abdelmoaty, B.M. Elhadidi, and A.O. Sherif, "*Building an Accurate Weather Prediction Model for Egypt*", The Egyptian Journal of Remote Sensing and Space Sciences, ISBN 1110-9823, Volume IX, pp. 3-14, 2006.

[3] B.M. Elhadidi, M.M. Abdelkader A. Abdelmoaty, H.A. Kandil, and A.O. Sherif,"*Modeling the Possible Meteorological Changes Induced by the Formation of Toshka Lakes in Egypt*", Cairo 10th International Conference on Energy & Environment, Luxor, Egypt, March 13-15, 2007.

[4] M.M. Abdel-Kader, B.M. Elhadidi, and A.O. Sherif, "*Seasonal Evaluation of Temperature Inversion over Cairo*", Proceedings of the IEEE 2008 International Geoscience and Remote Sensing Symposium (IGARSS08), ISBN 978-1-4244-2807-6, Boston, USA, July 6-11, 2008.

[5] A.O. Sherif, "*NWP Potentials and Limitations for Egypt*", International Workshop on Wind Energy Development, Cairo, Egypt, March 22–24, 2010.

[6] H.S. Badr, B.M. Elhadidi, and A.O. Sherif, "*Evaluation of Data Assimilation on Numerical Weather Prediction for Egypt*", Proceedings of the IEEE 2010 International Geoscience and Remote Sensing Symposium (IGARSS10), ISBN 978-1-4244-9565-8, Honolulu, Hawaii, USA, July 25-30, 2010.

[7] H.S. Badr, "*Ensemble Forecasting and Data Assimilation in Numerical Weather Modeling for Egypt*", MSc Thesis, Aerospace Department, Faculty of Engineering, Cairo University, 2010.

[8] A.G. Grell, J. Dudhia, and R.D. Stauffer, "*A Description of the Fifth Generation Penn State/NACR Mesoscale Model (MM5)*", NCAR Technical Notes, June 1995.