EVALUATION OF DATA ASSIMILATION ON NUMERICAL WEATHER PREDICTION FOR EGYPT

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ABSTRACT

The objective of this work is to evaluate the use of data assimilation in numerical weather prediction for Egypt. Effects of different data assimilation options were studied for different weather regimes and at locations with different observation site densities. Effects on accuracy at the observational-data-void areas and at the locations with complex terrain were of prime concern.

Five sets of simulations were performed based on different nudging options in summer and in winter. Four sets of observational stations were selected for data sampling locations based on their relative positions with respect to the assimilated observations. Errors were computed for the four observation sets. The best nudging options and areas with maximum effect on error were identified.

Index Terms **—** Data Assimilation, Nudging, Objective Analysis, NWP, MM5, FDDA, OA

1. INTRODUCTION

Egypt as a developing country has special needs for integrating Numerical Weather Prediction, NWP, to several of its national projects. Examples are the ambitious renewable energy plan to 2020 and beyond, the treatment of air pollution in Egypt's mega cities, the efforts of health sector to manage trans-boundary diseases and infections, the management of the agriculture and irrigation activities, and the needed optimal utilization of resources. Use of data assimilated NWP practices in developed countries results in better weather simulations. Accuracy of the computations is expected to increase with the density of the observations but may be countered by existing distributions of the observation sites and the grid sizes used.

Developing countries usually suffer from the scarcity of observations facilities. Figure 1 shows the distribution of the available observational stations in Egypt. The total number of stations is 24 stations for surface observations and 5 stations for upper-air observations. The objective of this work is to test the assimilation of their data in NWP regional model for Egypt. This includes the study of the qualities of weather simulations for different weather regimes. Special interest is given to the observational data-void areas and areas with difficult terrain properties.

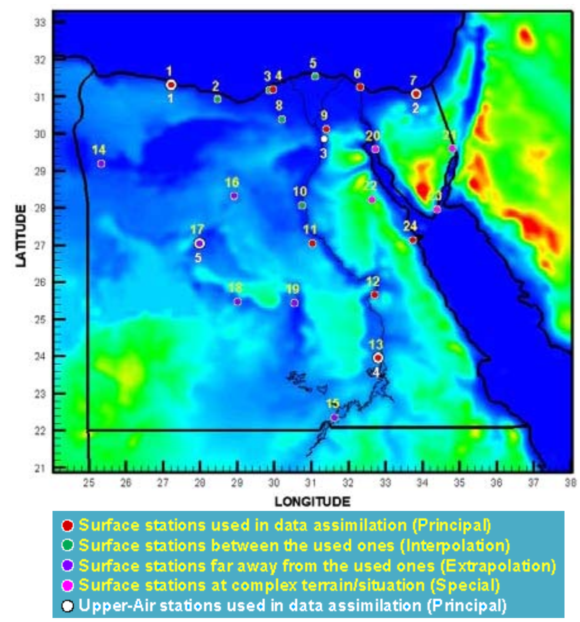

Figure 1 Distribution of observational stations in Egypt

2. METHODOLOGY

A numerical weather modeling system for Egypt was developed [1 & 2] and utilized for the modeling of local meteorological changes [3], assessment of air pollution in mega cities [4], and investigation of wind and solar energy potentials [5]. This work extends such efforts to test the effects of data assimilation on the modeling system.

Figure 2 shows the framework of the modeling system. It consists of five main components which were lately linked to automate the process using Linux scripts,

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 helps also to evaluate the model.
4. *Evaluation*: used to qualify the model and observations.
5. *Applications*: used to post-process the final outputs.

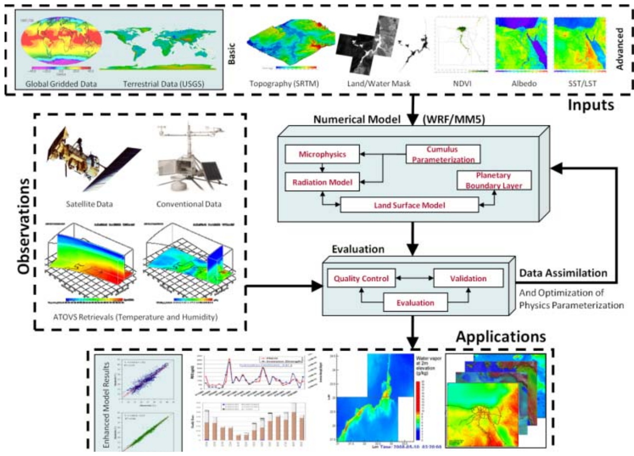

Figure 2 Framework of the numerical modeling system

In this work, the core of the modeling system utilized is the MM5 model [6]. The performance of this model was found to be sensitive to the technique of data assimilation used and the quality, quantity and distribution of the implemented observations [7].

For this work, three nested domains were used as shown in Figure 3. The horizontal resolutions and the grid sizes are listed in Table 1.

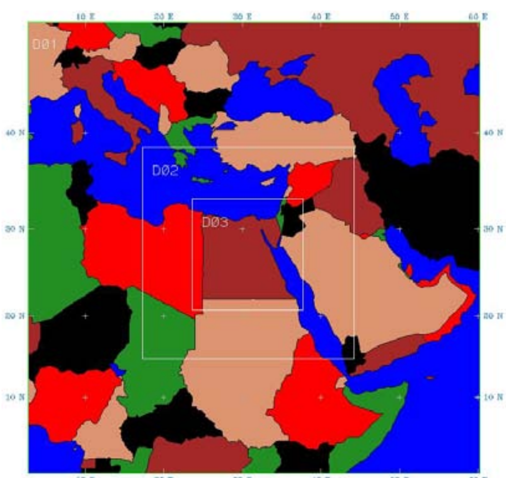

Figure 3 Nested domains used in the MM5

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 domain of resolution 9 km encompasses entire Egypt with horizontal and vertical grids shown in Figure 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.

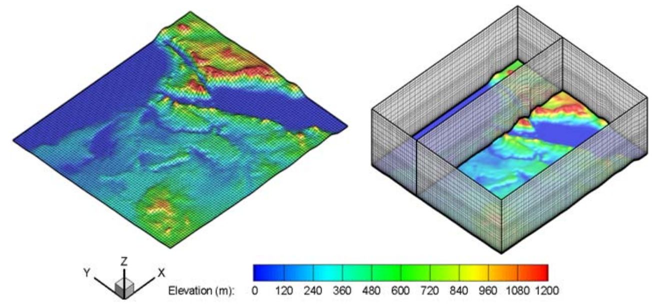

Figure 4 Horizontal and vertical grids for Egypt

Data assimilation was utilized from both objective analysis and nudging methods. In objective analysis, only those observations available at the time of analysis are used,

$$x^a = x^b + W[y^o - H(x^b)]$$

where x^a is the analysis, x^b is the background field (first guess), y^o is the observed variables, H is the forward operator, $y^o - H(x^b)$ is the innovations or observational increments, and W is the weight matrix. Four different techniques are used to determine the weights. Three techniques are based on the Cressman scheme. The fourth technique is based on Multiquadric scheme which uses hyperboloid radial basis functions [8].

In nudging, the temporal observations are included in predictor-corrector like steps:

- Forecast Step: (from time t_n to time t_{n+1})
$$x^b_{t_{n+1}} = M\left[x^a_{t_n}\right]$$
- Analysis Step: (at time t_{n+1})
$$x^a_{t_{n+1}} = x^b_{t_{n+1}} + W\left[y^o_{t_{n+1}} - H\left(x^b_{t_{n+1}}\right)\right]$$

The model state is “nudged” by observational increments in such a way that it remains close to the real atmosphere. It transports information from data-rich to data-poor regions and provides a complete estimation of the four-dimensional state of the atmosphere [9]. To test the sensitivity of the model to different nudging options and to find the best simulation set for different weather regimes, five sets of simulations were performed in winter and summer as described in Table 2.

Table 2 description of the performed simulations

Simulation	Description
Ref	Reference simulation, no nudging was utilized for all domains
No D3	Nudging was utilized for the coarser domains only with Multiquadric analysis
No PBL	Nudging was utilized for all domains not in the boundary layer with Multiquadric analysis
DA MQ	Nudging was utilized for all domains with Multiquadric objective analysis
DA CM	Nudging was utilized for all domains with Cressman analysis

Four sets of observational stations (totaling 24) were selected to test the qualities of simulations [Figure 1];

1. *Principal set*: stations used in data assimilation (9).
2. *Interpolation set*: stations located in-between the principal stations (5).
3. *Extrapolation set*: stations located far from the principal stations, out of interpolation zone (6).
4. *Special set*: stations located at complex terrain (4).

3. RESULTS AND DISCUSSIONS

Sample results for the different simulations and observation sets at selected stations are shown in Figure 5 for summer. Cairo International Airport station represents the principal set, Minya Station represents the interpolation set, Farafra station represents the extrapolation set, and Sharm Elsheikh station represents the Special set. The results at Cairo International Airport station were the best while the results at Sharm Elsheikh station were the worst. Minya and Farafra stations had almost similar quality.

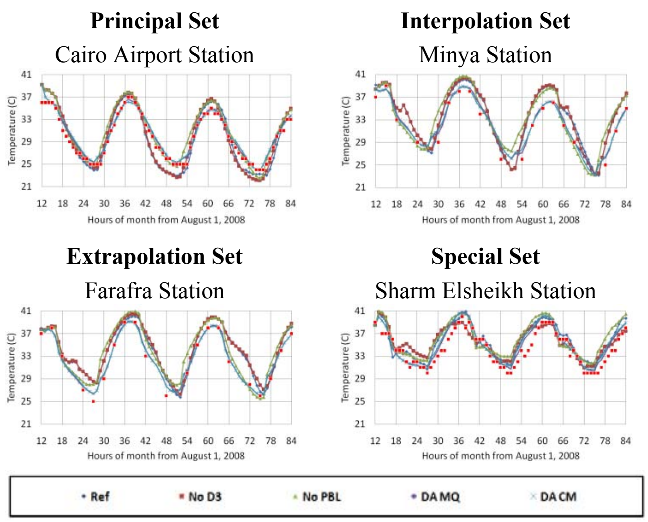

Figure 5 Sample results for the different simulations and observation sets in summer: August 1-4, 2008

Figure 6 shows the average RMSE for all simulations at the four observational sets in summer and winter.

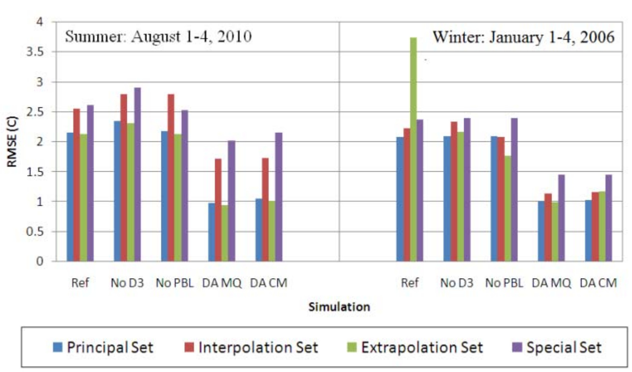

Figure 6 Average RMSE in summer and winter

The reference simulations at extrapolation set had the largest errors (in winter). These errors were reduced by about 56% in summer and 73% in winter when nudging with Multiquadric analysis was used. In general, the simulations had the best accuracies and correlations with the observations among all other simulations when nudging was used with Multiquadric analysis.

Figure 7 shows the scatter plots of the simulated and observed near-surface temperature for the four observation sets. The results for the principal set were the best. The accuracies of simulations when using nudging with Multiquadric or Cressman were better than the reference simulations for all observation sets. The worst results were associated with the special set, the winter simulations of the extrapolation set, and near the coast lines. The summer simulations of the extrapolation set were found to have relatively good results.

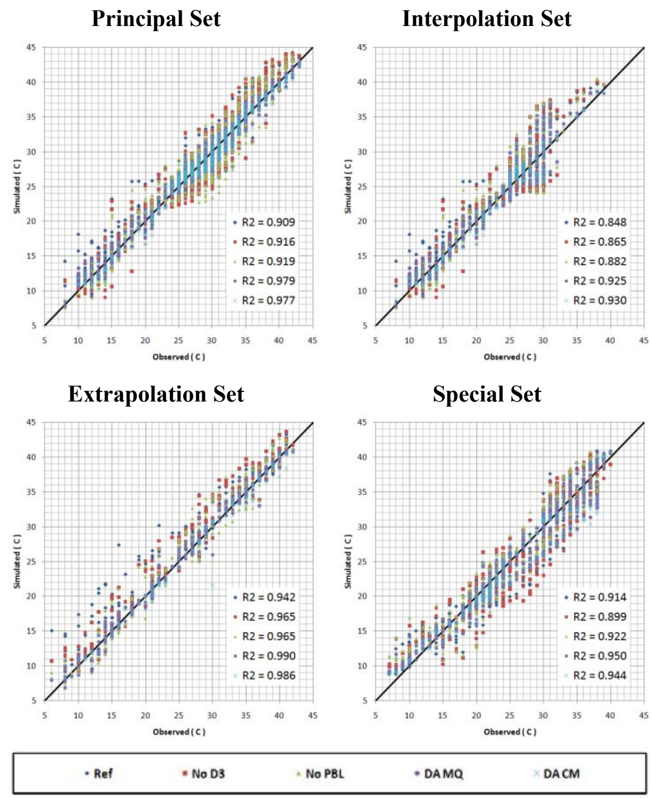

Figure 7 Scatter plots of near-surface temperature for the different observation sets

The results of the interpolation set were good when the station is located between observation sites with almost similar surface boundary conditions (terrain and land-use). This set includes the stations near coast lines which were found to have large errors. Figure 8 shows the scatter plots for the interpolation set with and without the coastal stations. It is clear that the correlations were better when the coastal stations were excluded from the evaluation of simulations at the interpolation set areas.

Interpolation Set

a) with coastal stations b) without coastal stations

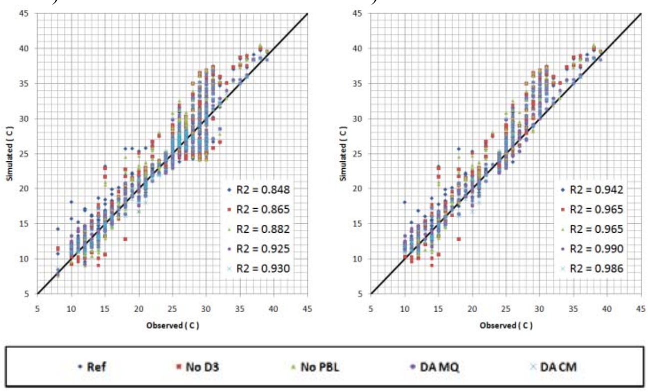

Figure 8 Scatter plots for the interpolation set with/without stations near coast lines

Figure 9 shows the spatial distribution of the near-surface temperature difference between the reference simulations and the simulations when nudging was used with Multiquadric analysis. Summer simulations are in the left of the figure while winter simulations are in the right. Both are after 24 hours from the initial time. The maximum errors were associated with the special set areas and near coast lines. Also, large errors were associated with the extrapolation set in winter.

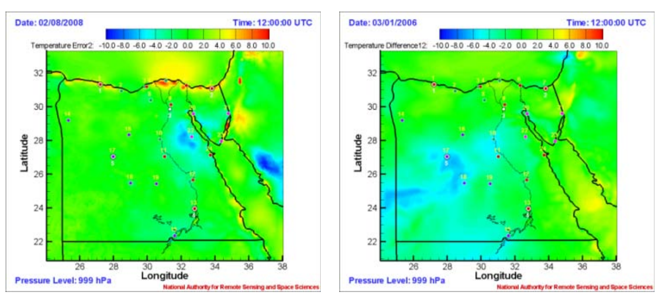

Figure 9 Temperature difference between reference and nudging with Multiquadric analysis simulations

4. CONCLUSIONS AND FUTURE WORK

The accuracy of simulations when using nudging with Multiquadric or Cressman analysis was found to be almost the best simulations for all observation sets. The accuracy of the simulations when nudging was turned off for the finest domain and the simulations with no nudging in the planetary boundary layer were found to be sensitive to the location and weather regime but probably will produce better results when finer resolutions and better surface boundary conditions are used.

It is found that the principal set provided the best accuracies and correlations with observations. The main reason for this is that it is used to nudge the model state during the integration time. The results of the interpolation set were found to be good provided that the stations have similar surface boundary conditions as the neighboring principal stations. This is also apparent for the extrapolation set. The worst results were found to be at the locations with complex terrain/land-use (special set) and near the coast lines for all simulations. This is expected to be improved by increasing the density and quality of observations [10].

Determination of the optimal number, locations, and types of new additional observational stations is a major recommendation of this work. Extension to adaptive (targeted) observations is planned.

5. ACKNOWLEDGMENTS

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