Research Article

Open Access

Evaluation of Weather Research and Forecasting (WRF) Model Simulations over Middle East

Thaer O. Roomi*, Kais J. Al-Jumaily, Rasheed H. Salih

Department of Atmospheric Sciences, Mustansiriyah University, IRAQ. *Correspondent author email: <u>thaerobaid2013@gmail.com</u>

ArticleInfo	Abstract
Submitted 16/08/2017	The Weather Research and Forecasting (WRF) model is an atmospheric simulation system designed for both research and operational applications. This worldwide used model requires a sophisticated modeling experience and computing skills. In this study, WRF model was used to predict many atmospheric parameters based on the initial conditions extracted from the datasets of NOMADS (NOAA National Operational Model Archive & Distribution System). The study area is basically the region surrounded by the longitudes 15° - 75° E and latitudes
Accepted 03/11/2017	10.5°-45° N which typically includes the Middle East region. The model was installed on Linux platform with a grid size of 10 km in the zonal and meridional directions. A low pressure trough was tracked in its movement from west to east via the Middle East during the period from 1 to 7 January 2010 as a case study of the WRF model. MATLAB and NCL (NCAR Command Language) were used to display the model output. To evaluate the forecasted parameters and patterns, some comparisons were made between the predicted and actual weather charts. The WRF model could give agreeable simulations to the weather conditions in the case study. Wind speeds and directions in the prognostic and actual charts of 700 hPa were adequate especially for the first 4 days. A further comparison between the results of WRF with the results of another model "Shallow Water Equations Model" for velocity and geopotential height shows that WRF gives better simulation. The predicted values of geopotential heights in WRF are somewhat overestimate the actual geopotential heights which may be attributed to the differences in the data sources and data analysis methods of the two data systems, NOMADS and ECMWF.
	Keywords: numerical weather prediction, WRF, NCL, Middle East
	الخلاصه ابنموذج البحث والتنبؤ عن الطقس (وورف) هو نظام محاكاة جوية مصمم لكل من التطبيقات البحثية والتشغيلية. هذا الإنموذج الواسع الاستخدام يتطلب خبرة نمذجية احترافية ومهارات برمجية. في هذه الدراسة، استخدم إنموذج وورف لغرض التنبؤ عن عدة باراميترات جوية اعتمادا على الشروط الأولية المستحصلة من مجاميع بيانات وكالة نومادس NOMADS (نظام الارشفة والتوزيع لإنموذج نوا التشغيلي الوطني). منطقة الدراسة تشمل بشكل رئيسي المنطقة المحصورة بخطوط الطول 15-75 درجة شرقاً ودوائر العرض 10.5 4 درجة شمالاً والتي هي نموذجياً تتضمن منطقة والزوالي. لقد تم منابعة تقعر المنخفض الجوي في حركته من الغرب الى الشرق مروراً بالشرق الأوسط خلال الفترة من 1 الشرق الاوسط. الإنموذج تم تنصيبه على برنامج التشغيل لينوكس واعتماد حجم خلية من 10 كم بالاتجاهين النطاقي والزوالي. لقد تم متابعة تقعر المنخفض الجوي في حركته من الغرب الى الشرق مروراً بالشرق الأوسط خلال الفترة من 1 الموذج. ولتقييم البار اميترات والانماط التنبوية جرى عقد مقارنات بين الخرائط الطقسية التنبوية والخرائط الطقسية الإموذج. ولتقييم البار اميترات والانماط التنبوية جرى عقد مقارنات بين الخرائط الطقسية التنوية والخرائط الطقسية وورف مع نتائج إنموذج آخر هو "إنموذج معادلات الجوية في الحالة الدراسية. ان سرع واتجاهات الرياح في الخرائط التنبوية والفعلية للمستوى 700 هكتوباسكال كانت كفوءة خاصة في الايام الاربعة الأولى. مقارنة أخرى بين نتائج وورف مع نتائج إنموذج آخر هو "إنموذج معادلات الجوية في الحالة الدراسية. ان سرع واتجاهات الرياح في وورف مع نتائج إنموذج آخر هو "إنموذج معادلات الموءة الحرائط الطقسية التنبوية والخرائط الطقسية وورف مع نتائج إنموذج آخر هو "إنموذج معادلات الموءة في الحالة الدراسية. ان سرع واتجاهات الرياح في وورف مع نتائج إنموذج آخر هو "إنموذج معادلات الموءة في ماليا الاربعة الأولى. مقارنة أخر هو أولي ال الرياح في وورف مع نتائج إنموذج آخر هو "إنموذج معادلات المياه الضحاة" للسرعة والاربية الأولى. مقارنة أخرى بين نتائج وورف مع نتائج إنموذج آخر هو "إنموذج معادلات المياه النصحاة" للسرعة والاربيا مالولي. مقارنة أخرى بين نتائج وورف مع نتائج إنموذج آخر هو "إنموذج معادلات المياه السرعة والايام الاربعة الأولى. مالي ورون الخرائط الطقسية الورئيا الفيري الربيات في كل من مجوعة بيانات المركز الاوربي جام



Introduction

The Weather Research and Forecasting (WRF) model is a numerical weather prediction and atmospheric simulation system designed for both research and operational applications. WRF is supported as a common tool for the university/research and operational communities to promote closer ties between them and to address their needs [1]. It is suitable for use in a broad spectrum of applications across scales ranging from meters to thousands of kilometers. Such applications include research and operational numerical weather prediction, data assimilation and parameterized-physics research, downscaling climate simulations, driving air quality models, atmosphere-ocean coupling, and idealized boundary-layer simulations (e.g., eddies. convection, baroclinic waves). These hallmarks make the WRF modeling system unique in the history of NWP in the United States [2].

WRF can be thought of as a software architectural framework in which different dynamical cores and model physics packages are housed under the same code [3]. WRF model contains two dynamic cores: the Nonhydrostatic Mesoscale Model (NMM) core developed at NCEP (National Centers for Environmental Prediction) [4] and the Advanced Research WRF (ARW) [2].

Many research works have been done by using WRF model in Middle East. El-Sammany used WRF over Wadi Watier - Sinai Peninsula. He showed a significant consistency between WRF model and real rainfall measurement results [5]. Ashrafi et al. studied the digital filter initialization methods with WRF model that are applied to eliminate non-physical and high frequency waves from numerical weather prediction models over the region of Iran [6]. Haggag and Badry used WRF model to study the atmospheric circulation and to reproduce the heavy rainfall over Oman on 4 June 2010 that triggers flash floods. All experiments resulted in analogous cyclone track and intensity that well conform to the observations [7].

Major Features of WRF Model

The major features of WRF model can be summarized by referring to its two components: The ARW Solver and the Model Physics as follows [8; 9; 10]:

The ARW Solver Deals with each of the following criteria and parameters: Equations, Prognostic Variables, Vertical Coordinate, Horizontal Grid, Time Integration, Lateral Boundary Conditions, Earth's Rotation, Mapping to Sphere, Nesting, Nudging, Global Grid. The ARW dynamics solver integrates the compressible, nonhydrostatic Euler equations. The equations are cast in flux form using variables that have conservation properties. The equations are formulated using a terrainfollowing mass vertical coordinate.

On the other hand, Model Physics deals with each of the following criteria and parameters:

- *Microphysics*: They are schemes that ranging from simple for idealized studies to sophisticated mixed phase physics.
- *Cumulus parameterizations*: represent the role that the cumulus clouds play in the dynamical-hydrological interactions in the atmosphere.
- *Surface physics*: include the models ranging from a simple thermal model to full vegetation and soil moisture models.
- Atmospheric radiation physics: deals with the longwave and shortwave schemes of solar radiation and their effects on the weather processes.

Materials and Methodology

WRF Preprocessing System (WPS) is used to prepare the spatial domain for WRF. WRF and WPS are installed on Linux platform. Their source codes are available free in the internet as a compressed file [11].

As a case study, a series of weather simulations was made by using WRF model to investigate the track of the Mediterranean Sea low pressure system was tracked. The modelling carried out mainly to study the shifting of the trough axis on the 700 hPa upper level from west to east during the period of 1 to 7 January 2010. The study area is basically the Middle East $(15^{\circ}-75^{\circ} \text{ E and } 10.5^{\circ}-45^{\circ} \text{ N})$ with a grid cell size of 10 km.

The terrestrial input data were downloaded of NOAA from the dataset National Operational Model Archive & Distribution System (NOMADS). A high-performance computing computer was used with 48 processors and 6×500 GB hard disks, and 64 GB memory. The running process took about four hours and 20 minutes. The time interval was 6 hours for a domain of 200×100 grid cells.

Results and Discussion

In this study, two graphical tools were used: MATLAB and NCL (NCAR Command Language) to manipulate and plot the WRF output file. We visualized two sets of charts; the first to display the geopotential heights (using Matlab) and the second to display the wind speed and direction and air temperature (using NCL).

Running the model yielded a large size netcdf output file ($\cong 1.5 \ GB$) contained simulations of several weather parameters at successive six hours intervals for seven days.

The WRF model uses ETA-Type coordinate system for vertical dimension. For more convenient, however, pressure type coordinates are more common and easier to understand by most forecasters. Hence, the coordinates were converted from ETA type to pressure type.

To do this, a relationship between ETA coordinate level and pressure levels was tested to determine which ETA coordinate goes with 700 hPa pressure level. the relationship between these two coordinates indicated that 700 hPa level was corresponding to Eta level coordinate no.10 (see Figure 1).

Visualizing Geopotential Heights

In this part we focused on the simulation of geopotential heights and wind speed and direction. To evaluate the results, comparisons between the products of the model and the corresponding actual observed data were made by using Matlab to visualize the data. Figures (2 to 10) show the prognostic and actual geopotential height charts of 700 hPa of Middle East.



Figure 1: Eta vertical coordinate corresponds to 700 hPa pressure level

There is a trough of a low pressure system with an axis (represented by dotted line) located basically coincide with the longitude 50° in figure (2). This axis is moving easterly with a speed of one degree longitude each six hours (as indicted in the subsequent figures) suggesting that the motion is somewhat slow. The slow motion of trough axis is a characteristic feature of winter seasons. WRF simulations for the third day and the subsequent days show weaker agreement with the actual observations (not shown).

The 700 hPa prognostic chart valid to 01 Jan. 12 UTC was compared with the 2010. simulation run by Shallow Waters Equations Model achieved by Roomi [12] for the same time (See figure 8). It was found that the simulation of WRF ARW proves its preference on the Shallow Waters Equations Model simulations which is quite closer to the actual observation. The justification for this superiority lies in its sophisticated modeling which takes into accounts most of the weather operations. In comparison, the Shallow Water Equations Model is preliminary model of a dynamical nature only.

It is well known that the location of the pressure system at upper levels may precede or lag behind its location near the Earth's surface.





Copyright © 2018 Authors and Al-Mustansiriyah Journal of Science. This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International Licenses.

The prognostic charts are outputs of WRF-ARW model while the actual charts are drawn depending on the data taken from ECMWF dataset. Actually, there is some difference in the values that label the contour lines in each of the actual, initial charts, though the pattern is the same, as shown in the figures (2 and 3). The simulated values of geopotential heights by WRF are slightly overestimated the actual ones. This may due to one of the following reasons:

1. The differences in the methods of measurement, interpolation, and other preprocessing of the two agencies that the data were taken from NOMADS and ECMWF.

2. The process that was done to change the Eta coordinates to pressure coordinates.



Figure 2: Initial 700 hPa chart, 01 Jan. 2010, 00 UTC



Figure 3: Actual 700 hPa chart, 01 Jan. 2010, 00 UTC, (based on ECMWF data set



Figure 4: Prognostic 700 hPa chart, valid to 01 Jan. 2010, 06 UTC



Figure 5: Actual 700 hPa chart, 01 Jan. 2010, 06 UTC, (based on ECMWF data set)



Figure 6: Prognostic 700 hPa chart, valid to 01 Jan. 2010, 12 UTC



Figure 7: Actual 700 hPa chart, 01 Jan. 2010, 12 UTC, (based on ECMWF dataset)



Figure 8: Prognostic 700 hPa chart valid to 01 Jan. 2010, 12 UTC, by using *Shallow Waters Equations Model* (based on ECMWF dataset)



Figure 9: Prognostic 700 hPa chart, valid to 02 Jan. 2010, 00 UTC



Figure 10: Actual 700 hPa chart, 02 Jan. 2010, 00 UTC, (based on ECMWF data set)

Visualizing Geopotential Heights, Winds and Temperatures

Displaying geopotential height contours. temperature contours and winds by using NCL language were shown in the prognostic charts of Figures (11-15) and Figures (17, 19, 21, and 22) of the days from 1st January to 6th January 2010. Some other charts using ECMWF data and using MATLAB tools of drawing were used to make comparisons. Geopotential height contours were drawn with increments of 30 m in blue color. Air temperature contours (isotherms) were drawn with increments of 5° C in red color. The temperature contours (isotherms) bring benefits of knowing the positions of cold and warm air masses at the level of 700 hPa. The red thick line represents the 0°C.

NCL drawing tool gave more detailed graphs of 700 hPa pressure level. The isotherms show that there is a warm air mass accompanying to the low pressure trough. The cold air mass that dominated the Iraqi area during the time period of simulation characterized with northwest winds.

It was found that the simulation skill had been decreased starting from the fourth day (figures not shown). This due to the chaotic nature of the Earth's atmosphere and the imperfectness of initial conditions and modeling.



Figure 11: Prognostic 700 hPa charts depicting height contours, temperature contours, and winds on 1 Jan. 2010, 00 UTC



Figure 12: Same as Figure 11 but for 1 Jan. 2010, 12 UTC



Figure 13: Prognostic 700 hPa charts depicting height contours, temperature contours, and winds on 2 Jan. 2010, 00 UTC

30



Copyright © 2018 Authors and Al-Mustansiriyah Journal of Science. This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International Licenses.



Figure 14: Chart of 700 hPa of prognostic charts of height contours, temperature contours, and winds on 2 Jan. 2010, 12 UTC



Figure 15: Chart of 700 hPa of prognostic charts of height contours, temperature contours, and winds on 3 Jan. 2010, 00 UTC



Figure 16: Actual 700 hPa geopotential height chart on 3 Jan. 2010, 00 UTC



Figure 17: Chart of 700 hPa of prognostic chart depicting height contours, temperature contours, and winds on 4 Jan. 2010, 00 UTC



Figure 18: Chart of 700 hPa of prognostic chart depicting height contours, temperature contours, and winds for actual 700 hPa on 4 Jan. 2010, 00 UTC, (based on ECMWF data set)



Figure 19: Same as Figure 17, for 5 Jan. 2010, 00 UTC



Figure 2: Charts of 700 hPa of actual 700 hPa for 5 Jan. 2010, 00 UTC, (based on ECMWF data set).



Figure 3: Prognostic chart depicting height contours, temperature contours, and winds for 6 Jan. 2010, 00 UTC



Figure 4: Actual 700 hPa chart depicting height contours, temperature contours, and winds on 6 Jan. 2010, 00 UTC, (based on ECMWF data set)

Conclusions

- 1. The WRF model could give reliable simulations to the weather conditions in the case study. Its outputs were compared with actual observation especially for wind velocity and geopotential heights.
- 2. The comparison between the simulated velocity and geopotential heights charts by WRF and the corresponding actual observation charts was adequate for the first fourth days. The simulations of the subsequent days were in weaker agreement.
- 3. Comparison between the results of WRF with the results of the Shallow Water Equations Model for velocity and geopotential height shows that WRF gives

better simulation. This can be justified that WRF is an advanced sophisticated model when come to comparison with the Shallow Waters Equations Model which is of a dynamical nature only.

- 4. The simulated values of geopotential heights in WRF model are slightly overestimated the actual ones. This may belong to the differences in the methods of measurement, interpolation, and other preprocessing of the two agencies that the data were taken from: NOMADS and ECMWF data sets.
- 5. The simulation showed a warm air mass was accompanying to the low pressure trough which replaced with a significant cold air mass dominated the Iraqi area.

Acknowledgment

Firstly, we appreciate the National Center for Atmospheric Research (NCAR) and other agents in charge of developing WRF model. We thank European Center for Medium range Weather Forecasting (ECMWF) for offering data to be downloading freely via internet. Also, we are grateful for NOAA for offering its archive system (National Operational Model Archive and Distribution System, NOMADS) which is useful as initial conditions for WRF model running.

References

- [1] Skamarock, W. C., Klemp J. B., Dudhia J., "Prototypes for the WRF (Weather Research and Forecasting) model," in *Ninth Conf. on Mesoscale Processes*, Fort Lauderdale, FL, 2001.
- [2] Skamarock, W. C., Klemp J. B., Dudhia J., Gill D. O., Baker D. M., Wang W. Powers J. G., " A Description of the Advanced Research WRF Version 2. NCAR/TN-468+STR," NCAR Technical Note, USA, 2005.
- [3] Cheng, W. Y. Y., Steenburgh W. J., "Evaluation of Surface Sensible Weather Forecasts by the WRF and the Eta Models



over the Western United States," *Wea. Forecasting*, vol. 20, no. 1, pp. 812-821, 2005.

- [4] Janjic, Z., Black T., Rogers E., Chuang H., DiMego G., "The NCEP nonhydrostatic mesoscale forecasting model. Extended abstract," in 10th Conference on Mesoscale Processes, Portland, OR, 2003.
- [5] Sammany M. S. El-, "Forecasting of flash floods over Wadi Watier-Sinai Peninsula using the weather research and forecasting (WRF) model," *Engin. Tech.*, vol. 46, no. 1, pp. 996-1000, 2010.
- [6] Ashrafi, K., Azadi M., Sabetghadam S., "Effects of various digital filter initialization methods on results of weather research and forecasting (WRF) mode," *Iranian J. Geoph.*, vol. 5, no. 1, pp. 16-33, 2011.
- [7] Haggag M., Badry H., "Hydrometeorological modeling study of tropical cyclone Phet in the Arabian Sea in 2010," Atm. Climat. Sci., vol. 2, pp. 174-190, 2012.
- [8] Shamarock, W. C., ., Dudhia J., Gill D. O., Baker D. M., Wang W., Power J. G., "A Deescription of the Advanced Research WRF Version 3. NCAR/TN-475+STR," NCAR Technical Note, vol. 22, no. 22, pp. 50-62, 2008.
- [9] Wang, W., Bruyere, Duda M., Dudhia J., Gill D., Lin H., Michalaes J., Rizvi S., Zhang X., "ARW version 3 modeling system user's guide," National Center for Atmospheric Research, USA, 2011.
- [10] Laprise R., "The resolution of the global spectral models," Bull. Amer. Meteor. Soc., vol. 73, no. 2, pp. 1453-1454, 1992.
- [11] National Centre for Atmospheric Research (NCAR),"WRF Model Users' Page", "http://www2.mmm.ucar.edu/wrf/users/", Accessed on 2 Feb., 2012.
- [12] Roomi T. O., "Evaluation of three numerical weather prediction models over the Middle East," Ph. D. thesis, University of Mustansiriyah, Baghdad, Iraq.