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Research Article **Open Access**

Sensitivity of Different Physical Schemes in WRF Model of a Rainfall Event in Baghdad Station

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ABSTRACT

The Weather Research and Forecasting model (WRF) offers a number of physical options that let users modify it to different scales, regions, and applications. The aim of this study is to test the sensitivity of different physics schemes in the WRF model for rainfall events over Iraq. In this study, six different physics configurations of the climate version of WRF were evaluated for simulation of a rainfall event in Iraq. Possible combinations among two Planetary Boundary Layers (PBL), three Cumulus (CUM) and two Microphysics (MIC) schemes were tested. The study area is the region surrounded by the longitudes 35° E-55° E and latitudes 290° N–38° N, which typically includes the Iraq region. The WRF model is installed on a Linux platform with a 10 km grid size in the zonal and meridional directions. For the six different simulations and the process of choosing the best performing configuration for the Iraq region, the model outputs tested for a single grid point (Baghdad station) of the atmospheric parameters (temperature, pressure and total precipitation) with modeled data and ECMWF. Model outputs using statistical methods: Bias Error (BE), Mean Absolute Error (MAE) and Root Mean Square Error (RMSE). The results show All the simulations predict rainfall with values close to the actual but it was discovered that the cloud microphysics setup had the greatest impact on temperature biases, whereas the cumulus parameterization setup has the greatest impact on precipitation.

KEYWORDS: WRF, Physics schemes, Sensitivity, rainfall event, Iraq.

الخلاصـة

يقدم نموذج أبحاث الطقس والتنبؤ عددا من الخيارات الفيزيائية التي تتيح للمستخدمين تعديله وفقا لمقاييس ومناطق وتطبيقات مختلفة. الهدف من هذه الدراسة هو اختبار حساسية مخططات الفيزياء المختلفة في نموذج WRF لحدث هطول الأمطار على العراق. في هذه الدراسة، تم تقييم ست تكوينات فيزيائية مختلفة للنسخة المناخية من WRF لمحاكاة حدث هطول الأمطار في العراق. تم اختبار التوليفات الممكنة بين اختيار واحد للطبقة المحاددة وثلاثة الركام ((CUM واثنين من مخططات الفيزياء الدقيقة (MIC). منطقة الدراسة هي في الأساس المنطقة المحاطة بخطوط الطول ٣٥ درجة-٥٥ درجة وخطوط العرض ٢٩ درجة-٣٨ درجة والتي تشمل عادة منطقة العراق. تم تثبيت نموذج ورف على منصة لينكس مع حجم الشبكة ١٠ كم في المناطق والاتجاهات. بالنسبة لعمليات المحاكاة الست المختلفة وعملية اختيار أفضل تكوين أداء لمنطقة العراق، تم اختبار مخرجات النموذج لنقطة شبكة واحدة (محطة بغداد) لمعاملات الغلاف الجوي (درجة الحرارة والضغط وإجمالي هطول الأمطار) مع بيانات ECMWF. مخرجات النموذج باستخدام الأساليب الإحصائية: خطأ التحيز (BE)، متوسط الخطأ المطلق (MAE) ومتوسط الجذر التربيعي للخطأ (RMSE). أظهرت النتائج ان جميع عمليات المحاكاة تتنبأ بهطول الأمطار بقيم قريبة من القيم الفعلية ولكن تم اكتشاف أن إعداد الفيزياء الدقيقة السحابية له أكبر تأثير على تحيزات درجة الحرارة، في حين أن إعداد معلمات الركام له أكبر تأثير على هطول الأمطار.

INTRODUCTION

Rainfall is one of the most significant categories of precipitation that affects human life directly. The daily rainfall behavior is critical for agricultural water use practices and future planning: planting, watering, and drainage. Extreme rain events can occur over most of the world and last for days, causing extensive flooding, infrastructure disruption, and even death. The primary source of water for terrestrial hydrological processes is rainfall, making it crucial for hydrologists to accurately measure and predict the spatial and temporal distribution of rainfall [1]. Enhanced rainfall prediction will enable people in various communities to be better prepared for extreme rainfall events, saving lives and minimizing infrastructure damage. In the twenty-first century, numerical weather prediction (NWP) models such as the WRF model have earned considerable interest in weather and climate prediction. These objective models [2] generate simulations by solving atmospheric governing equations [3]. The WRF model is NWP and atmospheric simulation system designed for research, climate studies, and numerical weather forecasting [4]. Microphysics is the process of removing moisture from the air using other thermodynamic and kinematic fields described in numerical models. The WRF model is one such tool for dynamical climate downscaling [5]. Among the most difficult issues in numerical modeling of the atmosphere and climate is the parameterization of phenomena at the sub-grid-scale [6]. Users of the WRF system can choose from a wide variety of physics parameterizations, including radiation schemes, land surface, boundary layer, and convection. The interest area's location, the application type, the horizontal and temporal resolutions, or the nature of the dominant weather phenomenon may influence this choice. Additionally, it had discovered that various climate variables are sensitive to various physical parameterizations [7], which increases the necessity for thorough sensitivity analyses and the difficulty of the physics parameterization selection process. The chosen schemes were widely used in the WRF community and show to perform well across a variety of regions. All simulations used the Noah land-surface model scheme and Rapid Radiative Transfer Model (RRTMG) schemes [8]. However, the selected schemes found commonly used in climate studies in the relevant literature or suggested in the model users' guide [9]. For example, Mooney et al. [10] suggest that CAM is the most suitable shortwave scheme for climate simulations as its ozone distribution varies during the simulation according to monthly zonal-mean climatology data. Similarly, Bukovsky and Karoly [11] indicate that the CAM long and shortwave radiation scheme is more appropriate for simulations of 30 - 90 km resolution. They also tested the KF and BMJ cumulus schemes and found that the former performs better in terms of precipitation over a domain covering North America.

NWP was used in numerous studies in Iraq to investigate a wide range of phenomena. Roomi 2013 [12-14] used the WRF-ARW Model, Nondivergent Barotropic Model and Shallow Water Equations Model to predict a wide range of weather parameters. The WRF model produced better results than the other two models. Mohammed *et al.* 2015 [15] used the BSC-DREAM8b v2.0 model to simulate an intense dust storm over West Asia in June 2012, with a focus on Iraq. The model simulates the synoptic patterns over the region with some respectable success. El Afandi, *et al.* (2013) investigated using the WRF Model heavy rainfall events that occurred over the Sinai Peninsula and caused flash floods. The results showed that the WRF model was effective at simulating the heavy rainfall events that took place in different parts of Sinai. Furthermore, it discovered that the WRF model could predict rainfall with accuracy based on actual measurements [16]. Zittis, *et al.* (2014) investigated the performance of 12 different physics configurations of the climate version of the WRF Model over the Middle East and North Africa (MENA) domain. Which found that the setup for cloud microphysics have the strongest impact on temperature biases while precipitation is most sensitive to the cumulus parameterization scheme and mainly in the tropics [17].

In this study, the initial and boundary conditions of the GFS model with horizontal resolution (0.25ºx0.25º) at 00 UTC and for 6-hour intervals for the Iraq region were used. According to Author's knowledge no previous study in Iraq has tested the sensitivity of physical schemes in forecasting weather phenomena. The main goal of the present study is to analyze the performance of WRF microphysics schemes during the rainfall event on 29 March 2019 over Iraq, especially Baghdad region. For this purpose, six simulations of different microphysics schemes performed on the atmospheric parameters (temperature, pressure and total precipitation) then compared it with model data from ECMWF.

MATERIALS AND METHODS

Location and Data

In order to simulate a rainfall event by WRF model over the Middle East, which is bounded by the longitudes (30º-55º) E and (25º-40º) N, which typically includes Iraq region in general and for Baghdad station in particular (see Figure 1). The National Centre for Environmental Prediction (NCEP) developed the Global Forecast System (GFS) as a weather forecasting tool, providing the

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initial and boundary conditions used in the simulations. The file form is GRIB2, and it contained information for four times on March 29, 2019, at 00, 06, 12, and 18 UTC.

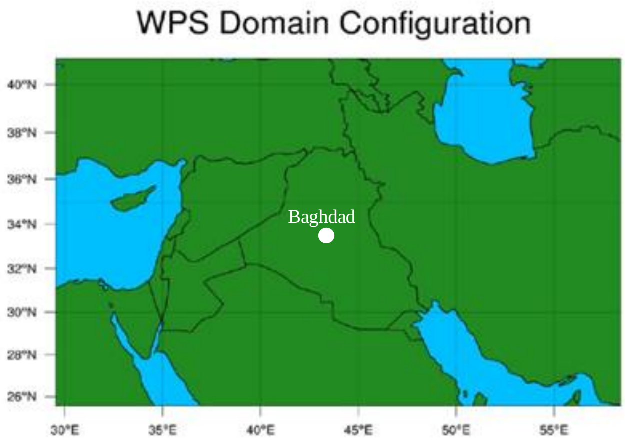

Figure 1. The studied geographical area.

WRF Model Configuration

This study used the WRF model (version 4.4) to simulate a rainfall event in Iraq. For real-time data modeling, the WRF Preprocessing System (WPS) interpolates terrestrial and meteorological data. WRF offers multiple physics options that could be combined in any way. The options typically range from simple and efficient, to sophisticated and more computationally costly, and from newly developed schemes, to well-tried schemes such as those in current operational models. The proper treatment of these physics' schemes is essential for a realistic simulation and prediction of the WAM (WAM was a third-generation wave model. Solving the equation of advection of wave energy subject to input/output terms of: wind growth, energy dissipation and resonant nonlinear wave-wave interactions) and its associated dynamics because they all play significant roles in changing the atmospheric moisture and heat distribution. Our study includes six combinations of the following parameterizations (see also Table 1):

1. **Planetary Boundary Layer (PBL)**
   - Yonsei University (YSU) scheme [18] used. This non-local scheme, which is appropriate for weather forecasting and climate prediction models, explicitly treats entrainment processes at the top of the PBL.
2. **Cumulus physics (CUM)**
   - Kain-Fritsch (KF) scheme [19] used as a shallow sub-grid scheme for removing CAPE that makes use of downdrafts to estimate whether instability exists, whether any existing instability will become available for cloud growth, and what the properties of any convective clouds might be, a mass flux approach, and timescale closure. Included are both condensed and gaseous water detrainment.
   - Betts-Miller-Janjic (BMJ) scheme [20] used, which generates deep and shallow convection. The term "relaxing" used to describe variable temperature and humidity profiles derived from thermodynamic considerations.
   - Grell-Devenyi (GD) [21] was an ensemble scheme. Ensemble method with multiple closures and multiple parameters explicitly takes updrafts and downdrafts into account.
3. **Cloud Microphysics (MIC)**
   - WRF Single-Moment 6-class (WSM6) scheme [22] used. It is a six-class scheme that takes the formation of ice, snow, and glaciers into account.
   - Goddard (GCE) scheme [23] used. A 6-class saturation adjustment microphysics schedule with granite and time-separated fall terms with melting is used.
4. **Radiation (RAD)**
   - Community Atmosphere model (CAM) short and long wave radiation schemes [24]. Clouds, trace gases, and aerosols are all factors that both CAM spectral schemes take into account. These schemes are used in CLWRF modifications to offer a flexible way to change the greenhouse gas forcing in the model. All simulations used CAM radiation schemes because we intend to use these modifications for future climate projections.
5. **Land Surface Model (LSM)**
   - Noah LSM [25] used as a scheme, with soil moisture and temperature distributed over four layers below the surface. The effects of vegetation, snow cover that is only partially covered, and frozen soil physics are also included. All of the simulations used it. Due to the large number of WRF physics parameterizations available, which can produce hundreds of combinations, it is obvious that this selection does not include

the entire list. The chosen schemes, however, were discovered frequently employed in climate studies in the pertinent literature or recommended in the model user's guide [26].

Table 1. The selected physical schemes for each of the six simulations.

Simulation ID	1	2	3	4	5	6
PBL	YSU	YSU	YSU	YSU	YSU	YSU
CUM	KF	GD	BMJ	KF	GD	BMJ
MIC	WSM 6	WSM 6	WSM 6	GCE	GCE	GCE
LSM	NOAH	NOAH	NOAH	NOAH	NOAH	NOAH
RAD	CAM	CAM	CAM	CAM	CAM	CAM

Some statistics used to evaluate the estimates that resulted in the above combinations of physics schemes. These statistics include Root Mean Square Error (RMSE), Basis Error (BE) or Mean Error (ME), and Mean Absolute Error (MAE).

Statistical Error Analysis Method

Root Mean Square Error (RMSE)

Measures overall accuracy. It calculates the 'average' magnitude of errors, weighted by the square of the error. Given by the equation:

$$\text{RMSE} = \sqrt{\frac{1}{n}\Sigma_{i=1}^{n}(c_i - o_i)^2} \quad (1)$$

Where n is the number of predictions, c represents the predicted values, and o is the observed values. [22] RMSE is always non-negative, and a value of zero (almost never achieved in practice) would indicate a perfect fit to the data. In general, a lower RMSE is better than a higher one. However, comparisons across different types of data would be invalid because the measure is dependent on the scale of the numbers used.

Bias or Mean Error (BE)

Overall reliability measured by bias or mean (Algebraic) error, which may or may not accurately reflect the magnitude of the error but does indicate the average direction of the deviation from observed values. A zero bias represents the best value. The positive bias indicates that the forecast value exceeds the observed value on the average and the negative bias corresponds to under estimating the observed value on the average, given by Equation 2.

$$\text{BE} = \frac{1}{n}\sum_{1=1}^{n}(c_i - o_i) \quad (2)$$

where n is the number of predictions, ci represents the predicted values, and oi is the observed values [22].

Mean Absolute Error (MAE)

Mean Absolute Error (MAE) measures overall accuracy. It is a linear score, which gives the `average' magnitude of the errors, but not the direction of the deviation given by the Equation 3.

$$\text{MAE} = \frac{1}{n}\left[\sum_{i=n}^{n}|c_i - o_i|\right] \quad (3)$$

Where n is the number of predictions, ci represents the predicted values, and oi is the observed values [23].

RESULTS AND DISCUSSION

Many predictions were made and tested against modeled data from ECMWF to determine the sensitivity of various physics schemes used in the WRF model techniques to simulate some meteorological parameters (temperature, mean sea level pressure, and total precipitation) in Iraq from March 29 to 31, 2019. For the six different simulations and the process of choosing the best performing configuration for the Iraq region, the model outputs tested for a single grid point (Baghdad station) of the atmospheric parameters (temperature, pressure and total precipitation) with the fifth generation of the European Centre for Medium-Range Weather Forecast's (ECMWF) atmospheric reanalysis of the world's climate, known as ERA5. Model outputs using statistical methods: Bias Error (BE), Mean Absolute Error (MAE) and Root Mean Square Error (RMSE).

Simulation of Mean Sea Level Pressure (MSLP)

Mean Sea level pressure model output of different microphysics and observed data for each three hours are shown in Figure 2 which shows 66 hours of mean sea level pressure simulations with the WRF model using six different physics schemes compared with actual data from ECMWF for Baghdad station. The statistical evaluation summarized in Table 2. It found that the choice between the cumulus schemes selection appears to have a lower impact on MSL. According to the sensitivity plots, the differences between the three tested CUM schemes significantly affect the values

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of MSLP for the majority of the domain. The results show that all simulations predict MSLP with values close to the actual but the first simulation with (KF) for Cumulus physics (CUM) and (WSM6) for Cloud Microphysics (MIC) was found to yield the best performance.

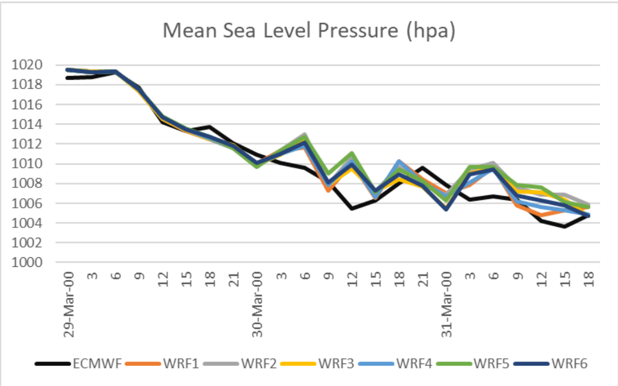

Figure 2. Shows 66 hours mean sea level pressure simulations with the WRF model using six different physics schemes compared with actual data from ECMWF the period (29-31) March 2019.

Table 2. Bias Error, Mean Absolute Error (MAE), and Root Mean Square Error (RMSE) for the Mean Sea Level Pressure (in hPa) between predicted values from the WRF and ECMWF models.

	1	2	3	4	5	6
BE	0.58	1	0.68	0.62	1.03	0.65
MAE	1.14	1.53	1.32	1.14	1.54	0.65
RSME	1.54	2.01	1.76	1.57	2.02	1.67

Air Temperature at 2m

Air temperature model was output for different microphysics and observed data for each three hours shown in Figure 3. This figure shows 66 hours of air temperature simulations with the WRF model using six different physical schemes compared with actual data from ECMWF for Baghdad station. The statistical evaluation summarized in Table 3. The table shows negative values of Bias Error (BE). Even though the Bias is nearly zero, the similarity would be preferable. Negative values indicate that the predicted values are underestimated. The sixth run of the WRF model, which includes choosing of (BMJ) for the CUM scheme, is where the values for MAE were showing the least error. The last one found to have a low RMSE value, which measures the average magnitude of the error. Our results show that air temperature is most sensitive to the microphysics parameterization selection. All simulations predict the temperature with values closed to the actual one, but the simulation number six with (BMJ) for Cumulus physics (CUM) and (GCE) for Cloud Microphysics (MIC) yield to the best performance.

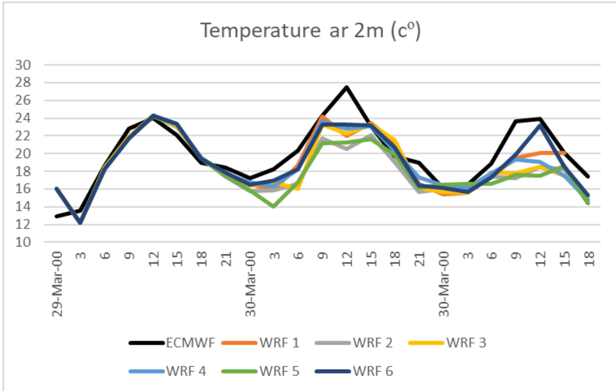

Figure 3. Shows 66 hours mean sea level pressure simulations with the WRF model using six different physics schemes compared with actual data from ECMWF for Baghdad station for the period (29-31) March 2019.

Table 3. Bias Error, Mean Absolute Error (MAE), and Root Mean Square Error (RMSE) for Air temperature (in °C) between predicted values from the WRF and ECMWF models.

	1	2	3	4	5	6
BE	-1.62	-1.71	-1.3	-1.07	-1.73	-0.8
MAE	2.23	2.13	1.9	1.6	2.23	1.39
RSME	4.16	2.86	2.56	2.14	2.94	1.77

Total Precipitation

The WRF model simulated daily rainfall distribution valid from 29 to 31 March 2019, simulated for 3 days based on the initial conditions 0000 UTC of 29 March 2019. presented in Figure 4. The figure shows 66 hours total precipitation simulations with the WRF model using six different physics schemes compared with actual data from ECMWF for Baghdad station. The statistical evaluation summarized in Table 4. Even though the Bias is nearly zero, the similarity would be preferable; this means that the first simulation was closer to the results than the rest of the runs. The presence of negative values indicates that the predicted values are lower than the observed ones or underestimated. The average magnitude of the error, as measured by RMSE, was found to be Uneven and far from zero. The result shows that the choice of cumulus and microphysics parameterizations is found to be the main factor that influences total precipitation. All the simulations predict rainfall with values close to the actual but the first simulation with (KF) for Cumulus physics (CUM) and (WSM6) for Cloud Microphysics (MIC) found to yield the best performance.

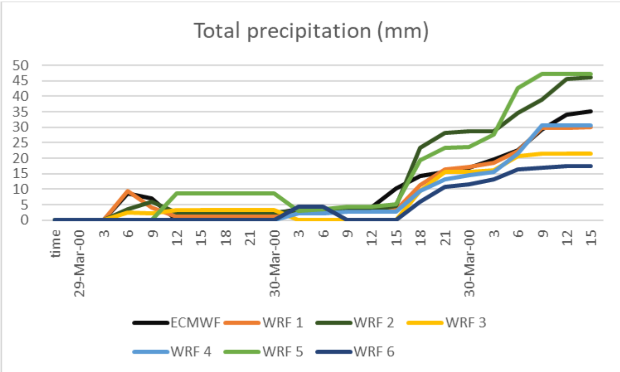

Figure 4. Shows 66 hours Total precipitation simulations with the WRF model using six different physics schemes compared with actual data from ECMWF for Baghdad station the period (29-31) March 2019.

Table 4. Bias Error, Mean Absolute Error (MAE), and Root Mean Square Error (RMSE) for the MSLP between predicted values from the WRF and ECMWF models.

	1	2	3	4	5	6
BE	-0.9	3.4	-3.03	-2.3	4.7	-4.9
MAE	1.35	4.7	4.05	-2.35	6.62	5.05
RMSE	2.26	6.66	5.48	3.49	8.58	7.19

CONCLUSIONS

The results of the study of sensitivity of six physics schemes on simulation of rainfall events showed that: Our results show that air temperature is most sensitive to the microphysics parameterization selection. Precipitation is more difficult to realistically model, as might be expected. All model physics combinations better simulated surface temperature and mean sea level pressure than precipitation, but with some biases. The choice of cumulus and microphysics parameterizations found to be the main factor that influences total precipitation. For mean sea level pressure and total precipitation, the first simulation with (KF) for Cumulus physics (CUM) and (WSM6) for Cloud Microphysics (MIC) was found to yield the best performance. As for the air temperature, the simulation number six with (BMJ) for Cumulus physics (CUM) and (GCE) for Cloud Microphysics (MIC) found to yield the best performance.

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