A Regional Climate Simulation Study using WRF Model over the Arabian Peninsula for Temperatures Difference between (2006-2010) and (2056-2060)

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Abstract
The purpose of this study is to examine the impact of climate change on the changes on summer surface temperatures between present (2006-2010) and future (2056-2060) over the Arabian Peninsula and Kuwait. In this study, the influence of climate change in the Arabian peninsula and especially in Kuwait was investigated by high-resolution (48, 12, and 4 km grid spacing) dynamic downscaling from the Community Climate System Model (CCSM 4) using the WRF (Weather Research and Forecasting) model. The downscaling results were first validated by comparing NCEP model outputs with the observational data. The global climate change dynamic downscaling model was run using WRF regional climate model (WRF) simulations (2006-2010) and future projections (2056-2060). The influence of climate change in the Arabian Peninsula can be projected from the differences between the two period's model simulations. The regional model simulations of the average maximum surface temperature in summertime predicted an increase over the next 50 years.

Keywords: Climate change; CCSM4; Regional Climate modeling; WRF; Surface temperatures

Introduction
Global models can characterize the large scale weather systems that affect the Arabian Peninsula, but not the fine scale processes associated with local terrain and land cover. To capture these smaller scale features, a simulation at sufficiently high spatial resolution of the local complex terrain and the heterogeneous land surfaces is necessary [1]. Investigation of the climate change issue began with Global Climate Models (GCMs), but recently climate scientists took advanced a step by using high resolution dynamical downscaling models to investigate climate change in particular regions [2]. Using a higher resolution model to examine a regional will provide an enhanced results in terms of interactions between land, atmosphere, and ocean; convection and microphysics; and cloud, aerosol, and radiation [3]. In this study, we used the Weather Research and Forecasting (WRF) model as a Regional Climate Model (RCM), to dynamically downscale GCM output to the Arabian Peninsula, and especially, Kuwait using three nested domains at grid resolutions of 48 km, 12 km, and 4 km. The main motivation of this study is to use a high resolution regional model to investigate the changes in summer surface Temperatures in the future.

To address these, we will use output from a GCM to provide lateral forcing for WRF runs for two five-year periods, fifty years apart, to reveal signals of climate change. The first five-year period was from 2006-2010, while the second five-years were from 2056-2060. The purpose is to investigate the changes in temperatures in the first five years at the beginning of the 21st century comparing it with conditions fifty years later according to the model.

Global and regional surface temperature change
Changes in extreme temperatures over a long time period have been analysis by Yan et al. [4]. They determined that not only low temperatures have been decreasing and high temperatures have been increasing during the last decades, but also that there have been earlier changes in these extremes [5,6]. For example, between the period of 1900–2002, the surface temperature increased linearly by 0.069°C per decade. A high increase in temperature took place between 1910 and 1945 and from 1970 to the present, when the temperature increased by 0.16°C and 0.17°C per decade, respectively, which is about three times more than the increase during the past century [7,8]. Trenberth et al. [9] also showed that the global mean surface air temperature has risen around 0.74°C over the last 100 years (1906–2005), and that the rate of increase has grown from 0.07°C per decade over the last 100 years to 0.13°C per decade over the last 50 years. Surface air temperatures have increased more over land (0.27°C per decade) than over the ocean (0.13°C per decade) meaning that increases in the frequency of extremely high average temperatures are to be expected [10].

Looking at Kuwait International Airport (KIA) annual average temperature observation from 1968 to 2012 (Figure 1) shows an increase in temperatures in the last 44 years, and the annual maximum temperatures (Figure 2) indicates an increase in maximum temperatures in last 44 years. The average annual temperature from 1973 to 1983 is 25.6°C, where the average temperature from 2002 to 2012 is 27.05°C. In the summer time, the average temperature in summer from 1973 to 2012 is increasing in Kuwait (Figure 3) the average temperature from 1973 to 2012 is increasing in Kuwait (Figure 3) the average temperature from 1973 to 2012 increasing also in last 39 years in Kuwait (Figure 4) the average maximum temperature from 1973 to 1983 is 43.5°C, and from 2002 to 2012 is 45.7°C. The annual and summer average observation KIA temperature trends indicated a strong climate change signal.

The global climate variability and the changes in the Indian
monsoon do affect the climate in the Arabian Peninsula which led into significant changes in the climate over a period of decades [11]. A study by Almazroui et al. [12], described about the recent changes that had occurred in the Arabian Peninsula, and how these changes have brought changes in the population growth, industrial development and expansion of irrigated agriculture. In the Arabian Peninsula 80% of the area is occupied by Saudi Arabia [13]. The climatic datasets from its 27 ground observations that were analyzed for the period 1978–2009, described the observed state and change of the present climate.

The data showed that the spatial distribution of mean annual temperature for the Arabian Peninsula, averaged for the period 1979–2009 was highest over the Rub Al-Khali, and was equally high temperatures in the southwest of the Peninsula, mainly along the Red Sea coast. The observation from periods 1978-2009 was broken down into two periods, the first half-period (1978–1993), and the second half-period (1994–2009). The temperatures observation from 1978-2009 indicates an increase in maximum temperature by 0.71°C, Mean temperature by 0.60°C, and minimum temperature by 0.48 °C, overall temperatures are increasing significantly in the region [14,15]. The average daily JJA 2 m temperatures observation from the World Meteorological Organization (WMO) at Kuwait international airport from (1960-1990) shows an increase in 2 m temperatures by 1.2°C from 1960 to 1967, and increase from 1968 to 1990 by 2°C [16]. In the summer, the average daily high temperature ranges from 42 to 46°C. Dust emission normally decreases Tmax and Tmin values by between 0.5°C [17], however the increase in temperatures can be an indications of decreasing dust emissions and an increase of the incoming shortwave radiation in the region.

**Experimental Design**

In this part of the study, a GCM was used to provide lateral forcing for WRF runs for two five-year time periods, fifty years apart, to allow any climate change signal to be revealed. The first five years run were in 2006-2010 and second five years are to run were in 2056-2060. The purpose is to investigate surface maximum temperatures comparing the present simulations with future simulations.

The Weather Research and Forecasting (WRF) Model was used to dynamically downscale the results of the CCSM4, to get higher resolution for analysis of data attained from study of the Middle East. The simulation of the WRF regional climate model was run using the same three nested domains at resolutions of 48, 12, and 4 km as for the previous reanalysis runs to keep simulated states close to the driving state at large scales, while still generating small-scale features (Figure 5). The goal of downscaling is to initiate mesoscale meteorological
features consistent with the large-scale state simulated using the global model [18].

For dynamical downscaling, data generated from 5 years of current climate simulations (2006–2010) using CCSM4 under the RCP8.5 scenario and 5 years simulations of future climate patterns (2056–2060) were used. The WRF runs were initialized at 0000 UTC, April 27 and ended on October 3 of each year covering the summer months (May–September). The WRF was run daily providing data every three hours a day.

Applying the WRF model for five years throughout the summer only is to ensure that we would capture the changes in maximum temperature. Five years at the beginning of the century will provide us with a reasonable estimate of the present climate in order to be able to compare it with future climate.

The second WRF run simulated weather patterns for a five year period in the middle of the century (2056–2060) during the summertime. These two five year periods (2006-2010 and 2056-2060) were chosen because going 50 years helps us to capture the long-term signal will be clearly distinguished from shorter-term climate variability. We will present the differences between these two periods to investigate climate changes in the region. The WRF was configured to perform long simulations and fully represent the climate system’s response to climate change forcing.

The WRF model has been improved over earlier versions (MM5 and MM4) the previous years, and used to simulate regional climate model in different regions. Because WRF is non-hydrostatic model it is very flexible to use in multiple physical parameterization and had the capability to simulate as RCM due to the scale ranging [19]. Downscaling reduce error in climatological means temperatures, wind victors, moister, and precipitations [20]. The process of downscaled global climate model will reduce the bias and provide more realistic simulations in summertime in the Arabian Peninsula in temperatures, Mean sea level pressure, and wind speed [21].

One useful capability of the WRF is its flexibility in choosing different dynamical and physical schemes [22]. The physical parameters that been used in this study captured the physical and the dynamical climate processes in the Arabian Peninsula more realistic (Table 1). We used the WRF downsampling model that had been used to analyze desert areas within the US for better results. We also tested the parameters in the verification process by comparing WRF outputs that is forced by NCEP with observation data.

Model Evaluation

In this study the WRF model was downscaled from the National Centers for Environmental Prediction (NCEP)–NCAR Global Reanalysis Products (NNRP) to evaluate climate variability for three years 1997, 2000, and 2008. We illustrated climate variability by testing WRF as a Regional Climate model simulation in different time scales, hourly, daily means, and monthly means, in summertime from May to September. The WRF regional model performance did show the summertime variability, and the behavior of specific phenomena.

The dynamical downscaling model (WRF) was applied for the years 1997, 2000, and 2008, in which NCEP/NCAR reanalysis data were used to provide initial and lateral boundary conditions. The WRF runs were initialized at 0000 UTC, April 27 and ended on October 3 of each year giving complete coverage of the summer season (May through September) with output data eight times per day. The three-hourly values were then used to compute daily averages and monthly averages for further analysis. Daily maximum and minimum temperatures were the maximum and minimum, respectively, of the three-hourly temperatures and, as such, may not represent the actual maximum and minimum temperatures simulated by the model.

The WRF high resolution simulation results forced by NCEP reanalysis are compared with data coming from the local surface observations, using the nearest grid point of the model for the years 1997, 2000, and 2008. The NCEP runs were verified with the Kuwait International Airport (29°N, 48°E) observation data. The Kuwait airport is also an aviation station which provides METARS every 30 minutes for the World Meteorological Organization (WMO). The observation data at Kuwait International Airport are taken every half an hour, and analyzed to give hourly, daily, monthly, and yearly averages. The data are well organized for mesoscale phenomena and climatology studies. In this study we focused on the maximum temperature at 2 meters. Temperatures were measured at 2 m above the surface taking both the maximum and minimum temperature daily. This is very valuable data which can be compared with the 2 m maximum temperature data that has been simulated by the NNRP-forced WRF.

| Variable        | Value | Description                                                                 |
|-----------------|-------|-----------------------------------------------------------------------------|
| mp_physics      | 4     |                                                                            |
| sst_update      | 1     | allow sea surface temperature update                                        |
| ra_lw_physics   | 1     | (longwave radiation) RRTM scheme. Spectral scheme K-distribution Look-up table fit to accurate calculations. Interacts with clouds Ozone/CO2 from climatology |
| ra_sw_physics   | 1     | (short wave radiation) MMS shortwave (Dudhia) Simple downward calculation. Clear-sky scattering. Water vapor absorption. Cloud albedo and absorption |
| radt            | 20    | minutes between radiation physics calls                                      |
| sf_sfclay_physics | 1   | (surface layer) Monin-Obukhov similarity theory. Taken from standard relations used in MM5 MRF PBL. Provides exchange coefficients to surface (land) scheme. Should be used with bl_pbl_physics=1 or 99. |
| sf_surface_physics | 2   | (land surface) Noah Land Surface Model: Unified NCEP/NCAR/AFWA scheme with soil temperature and moisture in four layers, fractional snow cover and frozen soil physics |
| bl_pbl_physics  | 1     | (Planetary Boundary layer) Yonsei University scheme: Non-local-K scheme with explicit entrainment layer and parabolic K profile in unstable mixed layer. |
| bldt            | 0     | minutes between boundary-layer physics calls. 0=call every time step         |
| cu_physics      | 1     | (cumulus Parameterization) Kain-Fritsch scheme: Deep and shallow convection sub-grid scheme using a mass flux approach with downdrafts and CAPE removal time scale |
| cudt            | 5     | minutes between cumulus physics calls                                        |
| cloud           | 1     | cloud effect to the optical depth in radiation                             |
| num_soil_layers | 4     | number of soil layer or number in WPS output                               |

Table 1: Parameterizations used in WRF simulations for this study. For further information please see http://www.mmm.ucar.edu/wrf/users/docs/wrf-phy.html#physics_scheme
Daily maximum temperature simulation by NCEP for 12 Km domain and 4 Km domain at (29N, 48E) compare with Kuwait International airport (KIA) observations at (29N, 48E) for 3 years 1997, 2000, 2008. Calculating the Averages, Standard deviation, Bias, Mean absolute error, Root mean square error, and correlation.

### Table 2: Daily maximum temperature simulation by NCEP for 12 Km domain and 4 Km domain at (29N, 48E) compared with Kuwait International airport (KIA) observations at (29N, 48E) for 3 years 1997, 2000, 2008. Calculating the Averages, Standard deviation, Bias, Mean absolute error, Root mean square error, and correlation.

| Arabian Peninsula Regions | May D01 | June D01 | July D01 | August D01 | Sept D01 |
|---------------------------|---------|----------|----------|------------|----------|
| North east                | +1°C    | +1°C     | +2-3°C   | +1-2°C     | +1°C     |
| North west                | +2-3°C  | +2°C     | +2°C     | +1-2°C     | +1°C     |
| Central                   | +1°C    | +1°C     | +1-2°C   | +1-2°C     | +1°C     |
| South east                | +1°C    | +1°C     | +1-2°C   | +1°C       | +1°C     |
| South west                | +1°C    | +1°C     | +1°C     | +1°C       | +1°C     |
| Kuwait                    | +1°C    | +1°C     | +2°C     | +2°C       | +1°C     |
| ESA                       | +1°C    | +1°C     | +1-2°C   | +1-2°C     | +1°C     |
| Qatar                     | +1°C    | +1°C     | +1°C     | +1-2°C     | +1°C     |
| UAE                       | +1°C    | +1°C     | +1-2°C   | +1-2°C     | +1°C     |

| Max T | 1997 | 2000 | 2008 |
|-------|------|------|------|
|       | Obs  | 4 km | 12 km | 48 km | Obs  | 4 km | 12 km | 48 km | Obs  | 4 km | 12 km | 48 km |
| AVE   | 45.2 | 43.8 | 42.7  | 30.39 | 46.8 | 44.5 | 42.5  | 30.4  | 45.7 | 43.7 | 42.7  | 31.53 |
| STDEV | 1.97 | 1.84 | 2.37  | 2.58  | 2.23 | 1.65 | 2.45  | 2.68  | 2.46 | 1.84 | 2.37  | 2.58  |
| MAE   | -1.42| -2.50| -14.85|       | -2.24| -4.21| -16.32|       | -2.00| -2.97| -14.20|       |
| RMSE  | 1.42 | 2.93 | 14.85 |       | 2.24 | 4.33 | 16.32 |       | 2.00 | 3.42 | 14.20 |       |
| CORR  | 0.24 | 0.20 | 0.34  |       | 0.43 | 0.47 | -0.01 |       | 0.29 | 0.28 | -0.09 |       |
| STDEV |       | 1.97 | 1.84  |       | 2.37 | 1.84 | 2.37  |       | 2.37 | 1.84 | 2.37  |       |

A preliminary verification was done to compare the output of the WRF model with observational data in Kuwait for the years 1997, 2000, and 2008. The verification of simulation results forced with reanalysis data show very similar trends. These data were tested and verified in each downscaling nested domain. Those three specific years of data were chosen because of their difference in climate variability. Choosing three different years with different climate history will make it possible to more fully test the reliability of the climate model outputs and give a better understanding of the model simulation under different climate regimes.

The verification is calculated in Table 2, which shows the averages and standard deviation for years 1997, 2000, and 2008. The verification of simulation results forced with reanalysis data show very similar trends. These data were tested and verified in each downscaling nested domain. Those three specific years of data were chosen because of their difference in climate variability. Choosing three different years with different climate history will make it possible to more fully test the reliability of the climate model outputs and give a better understanding of the model simulation under different climate regimes.

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### Dynamic downscaling model

The observations and the historical simulation of global climate models indicate an increase in global temperature. Examine regional temperature also shows an increase in global temperature. Simulate the temperature difference between present and future in WRF in the Arabian Peninsula using 3 downscaled domains will expect an increase in temperatures.

Figure 7a (D01) 48 by 48 km grid resolution shows the difference of the mean maximum temperature in May, June, July, August, and September between present (2006-2010) and the future (2056-2060)
In May, the mean maximum temperature showed an increase of 1°C in the Arabian Peninsula, but the northwest of the Arabian Peninsula showed an increase of 2-3°C. In June (Figure 7b), the results showed a similar trend in the increase of surface temperature in the Arabian Peninsula, over the Arabian Peninsula an increase by 1°C, except the northwest regions in the Arabian peninsula were its indicating an increase of 2°C. July, which is considered to be the hottest month in the Arabian Peninsula (Figure 7c), showed that Tmax will increase by 2-3°C in the Northern region of Arabian Peninsula, central region an increase by 1-2°C, and in southeast regions of the Arabian peninsula an increase of 1-2°C, were the southwest is an increase of 1°C.

In August (Figure 7d), the model shows an increase of 1 2°C in the northern and central region of the Arabian Peninsula, and an increase by 1°C in southern region of the Arabian Peninsula. In the final month, which is September, the model indicates a 1°C increase all over the region (Figure 7e).

The second downscaling domain (D02) the 12 by 12 km high resolution in May (Figure 8a) showing an increase in maximum temperature by 1°C in the northeast, and 2-3°C increase in the northwest region of the Arabian peninsula. The model simulations indicate an increase by 1°C in southern region. In June (Figure 8b), D02 indicating 2-3°C increase in the northwest and an increase by 1°C in the northeast, central, southeast, and southwest regions of the Arabian peninsula. In July (Figure 8c), D02 showing an increase by 2-3°C in the northeast region, and an increase by 2°C in the northwest region of the Arabian peninsula. An increase by 1-2°C in the central region and the southeast region of the Arabian Peninsula, model simulated an increase by 1°C in the southwest of the Arabian Peninsula. In August (Figure 8d) D02 showing an average of 2°C increase in the northeast, were the northwest, central, and southeast region of the Arabian Peninsula model indicates an increase by 1-2°C. In September the (Figure 8e), indicating an increase by an average of 1°C all over the Arabian Peninsula.

The third downscaling domain D03 the 4 by 4 km high resolution...
in Figure 9a in May shows an increase by 1°C in Kuwait, eastern Saudi Arabia (ESA), Qatar, and UAE. In Figure 9b, showing a similar trends in June as seen in May. In July the D03 indicating an increase by 2°C in Kuwait, and an increase of 2-3°C in southern Iraq. The model simulation indicates an increase by 1°C in ESA, Qatar, and UAE. In July (Figure 9c), The model projections indicates an increase by 2°C in Kuwait, 1-2°C increase in ESA and UAE, were Qatar an increase by 1°C. In August (Figure 9d), Model simulations indicates an increase in Kuwait by 2°C, were model runs shows an increase by 1-2°C in ESA, Qatar, and UAE. In September the (D03) simulation shows an increase by 1°C all over the Arabian Peninsula (Figure 9e).

Summary and Conclusion

The WRF predicted during the whole summer an average increase between 0.5-2.5°C in Tmax in the next fifty years in the Arabian peninsula between the present (2006-2010) and the future (2056-2060) using the three high resolutions downscaling domains D01, D02, and D03 (Table 3). As in the study by [25] model projections results shows an increase by 3.1°C under B2 scenario , and an increase by 4°C under A2 scenario by the end of the century [25]. The increase of 1°C in the Arabian Peninsula would raise the evapotranspiration. The increase of 1°C in the Arabian Peninsula would raise the evapotranspiration by 1-4.5%, and with an increase of 5°C will increase the evapotranspiration by 6-19.5% [26]. Correlating both studies results into this study of WRF temperatures simulations indicating that an increase between 0.5-2.5°C in the Arabian Peninsula the next fifty years can affect the water resources in region.

The climate change impact on temperatures in the future can alter the temperature contrast in the region. Further action can take place in the Land/sea breeze circulation in the region, with an increase of inland temperature, and the gulf maintain its normal temperature could lead into intensifying the breeze in summertime. Other scenario is if both increased in the same rate there will be no further change in terms of intensifying or weakening in the future [26-29].

The second part of this research will be using high resolution WRF climate model to examine the impact of climate change on future dust storms frequent in summertime in Kuwait. The study will investigate the changes in the summertime Pressure gradient in the Arabian Peninsula and how will it affect the wind speed in Kuwait by midcentury.

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