INVESTIGATING THE INFLUENCES OF DUST STORMS ON PRECIPITATION IN IRAN USING WRF-CHEM MODEL

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1. INTRODUCTION

Dust Storms are meteorological-terrestrial phenomena that have crucial impacts on the earth system, human health, and socioeconomic well-being. Wind erosion mechanisms, which are influenced by the geological properties and atmospheric variations, lead to dust particles entrain, transport, and deposit. This process intensified in arid and semiarid regions. Consequently, the dominant sources of dust storms are mainly in the Sahara, the Middle East, and Mongolia including, Sudan, Saudi Arabia, Iraq, Pakistan, Iran, and Afghanistan (Ke-Yi, 2010, Rezazadeh et al., 2013).

Aerosol particles comprise natural and anthropogenic origins and influence the earth's radiative budget, surface heat fluxes, and atmospheric heating rates. Also, aerosols alter the microphysical properties of clouds, precipitation processes, and hydrological cycle via ice nucleation, droplet formation, and water phase in clouds (Solomos et al., 2011; Creamean et al., 2013).

Dust Storms travel widely and move readily to high altitudes. These tiny particles can act as ice nuclei in the clouds depending on their chemical composition, cloud type and atmospheric conditions (DeMott et al., 2010). The droplet formation process relies on the cloud evolution stage (Van den Heever et al., 2006). A combination of cloud dynamics, cloud thermodynamic and microphysical processes provides the precipitation profiles (Liu and Fu, 2001).

Several studies have been conducted on the Middle East and Iran to determine the dust hotspots, characteristics and source apportionment (Farahat et al., 2016; Ashrafi et al., 2014). Moreover, the aerosol optical properties and radiative effects were assessed (Ashrafi et al., 2017; Gharibzadeh et al., 2017). However, few studies have concentrated on aerosol-cloud interactions and precipitation processes in recent years (Alizadeh-Choobari et al., 2018; Naimabadi et al., 2018).

This study aims to simulate the dust storm emissions based on the appropriately selected dust events and physical schemes over Iran, investigate the spatial and temporal distribution of precipitation and determine a logical relationship between the dust storm events and precipitation amounts.

2. METHODOLOGY

2.1 Study Region

The dust storm simulation over Iran was performed by using two domains including a parent and a nested domain (Fig. 1.) in which the Iran central point, which is located in Yazd city (52.155° E, 271.251° N) was considered as the center coordinates of domains. The parent domain encompasses vast areas of the Middle East and covers the primary dust sources affecting Iran, including North Africa, Saudi Arabia, Iraq, Turkmenistan, Afghanistan, Pakistan, Turkey, and Iran. This domain consists of 87 × 78 horizontal grids with a spatial resolution of 45 km. The nested domain was selected to cover the entire of Iran and contains 127 × 112 horizontal grids with a spatial resolution of 15 km.

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Fig. 1. Model Domains: (1) Parent Domain, (2) Nested Domain

2.2 Datasets

For determining the dust storm episodes and validating the model, two sets of data, including PM concentrations and meteorological parameters, were applied. The PM_{10}, $PM_{2.5}$ concentrations were collected for four consecutive years starting the year 2014 from the air quality monitoring stations of Iran's Environmental Protection Organization and Tehran Air Quality Control Company. Also, the NASA satellite observational data alongside Iran's Meteorological Organization's synoptic data in the same four-year period were gathered.

2.3 Dust Storms Periods

The dust events were chosen based on high PM concentrations and the intensity and the spread of dust storms in the study area. In other words, the days with concentrations higher than three times the permissible limit considered as the dusty days. Since Sistan and Baluchestan, and Khuzestan provinces experienced the highest concentrations, the PM concentrations higher than five times the allowable limit considered for finding dusty days in these provinces.

As the main focus of this study is the impact of dust storms on precipitation, another determining factor for finding the appropriate dust events is the rainfall parameter. Precipitation amounts were obtained from Iran's Meteorological Organization stations and NASA satellite maps. In this regard, the day-night "Dust Score" layers from Aqua/AIS satellite, day-night "Dust Surface Mass Concentration" layers from MERRA-2 satellite, and day-night "Precipitation Estimate" and "Cloud Cover" layers from Aqua/AIS satellite were used (Fig. 2, 3, 4.).

Finally, by comparing PM concentrations, synoptic data, satellite maps, and daily data of Aqua/AIS and MERRA-2 satellites, three dust events selected that each has the same period of four days:

1- 11-14 March 2017
2- 12-15 April 2017
3- 2-5 May 2017

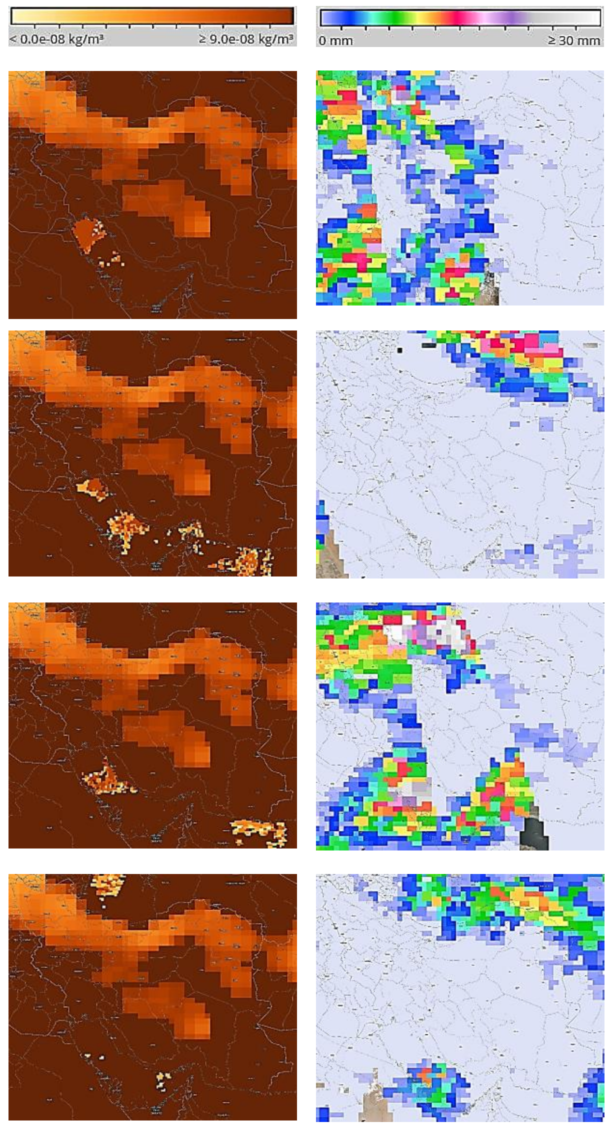


Fig. 2. Satellite images of four-day dust storm and precipitation layers of dust event no.1

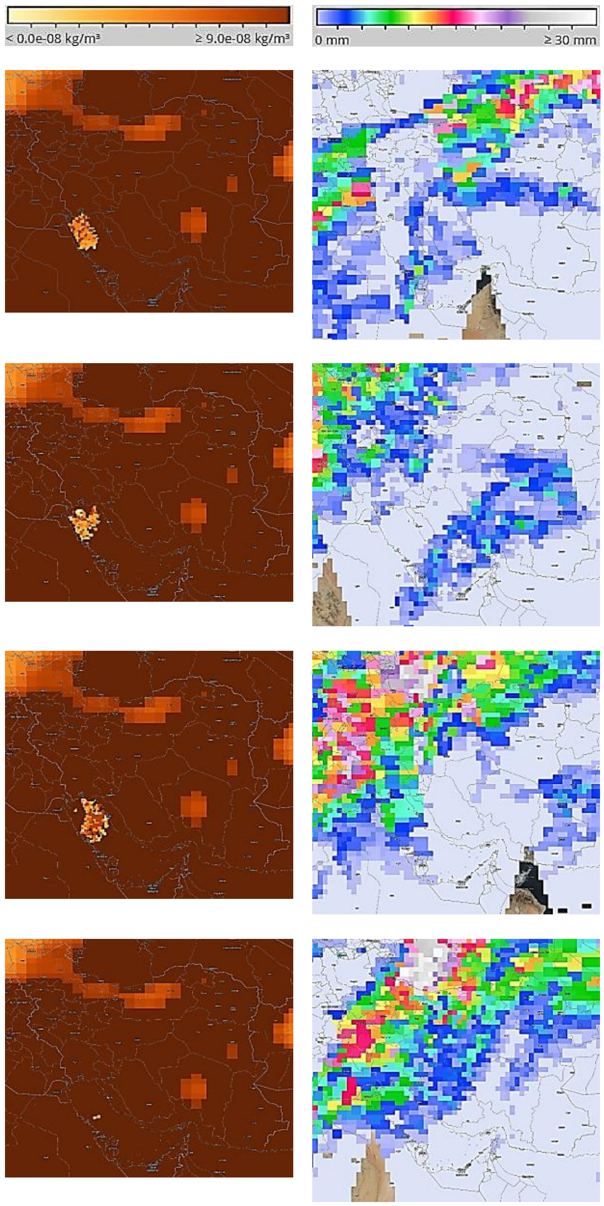
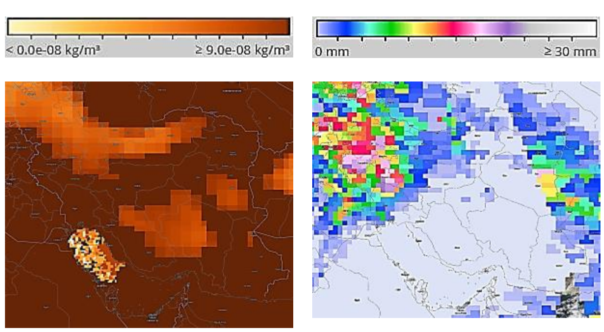


Fig. 3. Satellite images of four-day dust storm and precipitation layers of dust event no.2



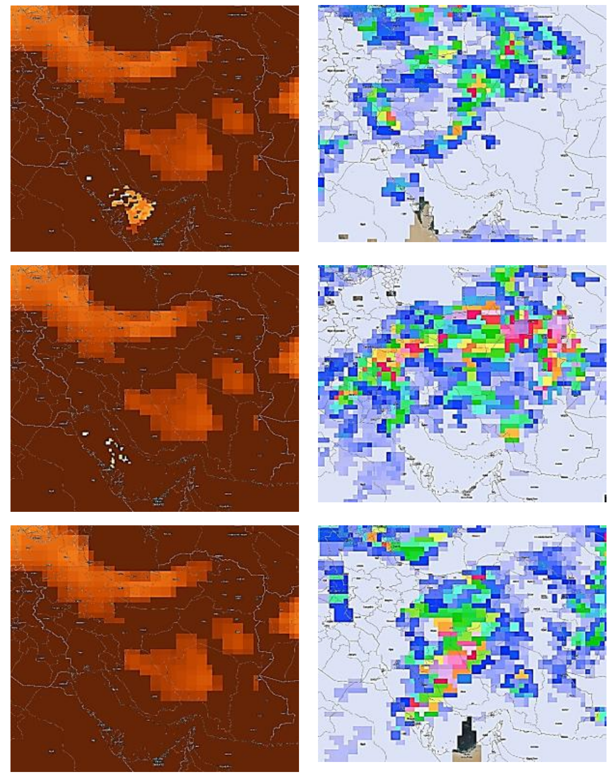


Fig. 4. Satellite images of four-day dust storm and precipitation layers of dust event no.3

2.4 Model Configuration

The weather research and forecasting model coupled with chemistry, version 3.6.1 (WRF-CHEM 3.6.1), was used to investigate and simulate the dust storm impacts on Iran's precipitation. The simulations are based on two scenarios. The difference between these two scenarios is considering the aerosol radiative feedbacks on clouds. According to the recent studies conducted on this region and the latest modified physical schemes, multiple schemes were tested to find the most suitable configuration. In brief, Aerosol-aware Thompson Scheme, Grell – Freitas Ensemble Scheme, Revised MM5 Scheme, Unified Noah Land Surface Model, Yonsei University Scheme, Goddard and Rapid Radiative Transfer Model selected for microphysics, cumulus parameterization, surface layer, land surface, planetary boundary layer, shortwave radiation, and longwave radiation, respectively. RETRO, EDGAR, and GOCART were chosen for anthropogenic, biogenic and dust emissions, as well.

3. RESULTS AND DISCUSSION

3.1 Model Validation

To determine the model's accuracy, air temperature, atmospheric pressure, wind speed, and wind direction values in the model compared with the observed data and the statistical errors (Root-Mean-Square Error), R-squared Value and Correlation Factors. Finally, Precipitation outputs and PM concentrations compared with the meteorological and air quality stations' observed data.

3.1.1 Temperature

According to the first dust event outputs, 87% of RMSE values were in the range of 0 and 1. Furthermore, 75% of simulated and observed data had more than 0.7 correlation, and 69% of the R-squared values were above 0.6.

All the RMSE values of the second dust event were in the range of 0 and 1, and 75% were below 0.5. About 94% of the correlation factor values were higher than 0.7. Moreover, the R-squared results of this event were the same as the previous event.

The third dust event RMSE values had about 94% validity, and 75% of the values are below 0.5. Also, about 81% of the simulated and observed values had more than 0.7 correlation, and 56% of the R-squared values were above 0.6.

Ultimately, the model outputs of the temperature revealed the proper correlation with the observed data.

3.1.2 Pressure

Pressure outputs showed a correlation of higher than 0.7 for the first and second dust storms, and about 62% of the correlation factors for the third event were higher than 0.7. The percentage of R-squared values higher than 0.6 for the three dust periods was 92%, 94%, and 50%, respectively.

The pressure parameter directly depends on the altitude and topography. The WRF-CHEM version used in this research could not accurately account for the terrestrial features and estimate each cell's average height as the ground elevation. Moreover, this version of the model considers only the dominant land use for each cell and not the exact topography. Thus, there are smoother and more homogeneous surfaces in the simulations, leading to the differences between each station's height in the model and the actual elevation above sea level. As a result, the stations such as Zanjan, Sanandaj, Ghazvin, Arak, Kermanshah, which are located near the Alborz and Zagros mountain ranges and have higher altitudes in comparison to the flatter stations, experienced higher errors.

The pressure gradient in the atmosphere is a function of elevation from sea level. The first one kilometer height in the atmosphere decreases the pressure gradient from 1013 millibars near the ground, with an approximate slope of 0.113. After that, in the next one kilometer up to two kilometers height, the reduction slope changes to 0.105. Therefore, by considering the pressure gradient interpolation for each station, the outputs were optimized significantly.

3.1.3 Wind Speed and Direction

The wind speed outputs represented that 67% of RMSE amounts were below 0.5. On the other hand, the correlation and R-squared values were considerably low because of the model estimations. The other factor responsible for the lack of correlation was the coarse grids in this research.

Zahedan station located in Sistan and Baluchestan province had high correlations in three dust events. It is probably because of the smooth topography and extreme wind speeds.

Wind Direction experienced its highest variations in the stations with low wind speed. However, the simulated dominant wind direction was generally the same as observed wind roses.

3.2 Precipitation

The simulated precipitation outputs post processed with Grads and plotted for the three dust storm events in Iran (Fig. 5, 6, 7.). Furthermore, the simulated amount of each station compared with the observed values.

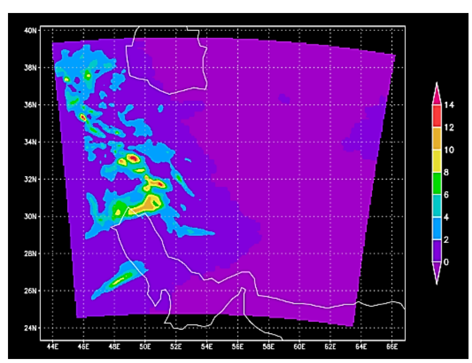


Fig. 5. Precipitation contours of dust event no.1

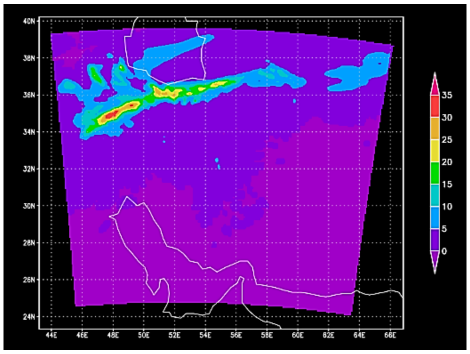


Fig. 6. Precipitation contours of dust event no.2

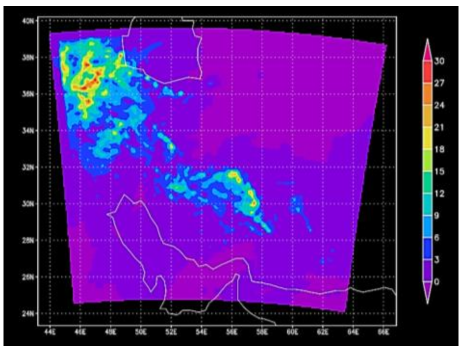


Fig. 7. Precipitation contours of dust event no.3

3.3 PM_{10} and $PM_{2.5}$ CONCENTRATIONS

The simulated PM concentrations were extracted, plotted, and lastly, compared with the observed values. The following figures are the PM_{10} concentration contours plotted to see the dust emission variations daily (Fig. 8, 9, 10.).

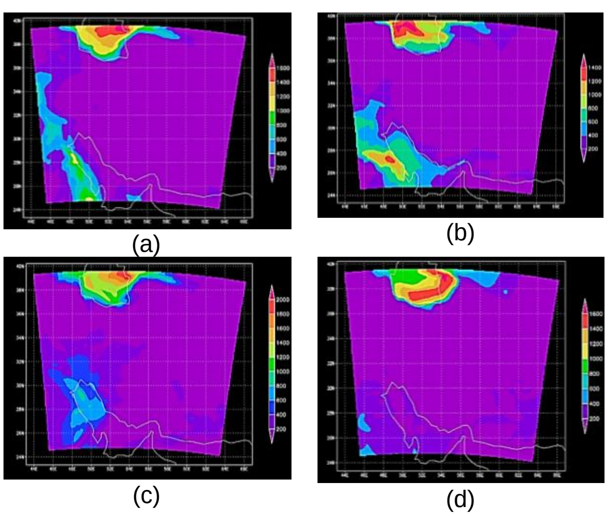


Fig. 8. PM_{10} concentration contours of the first to fourth day of dust event no.1

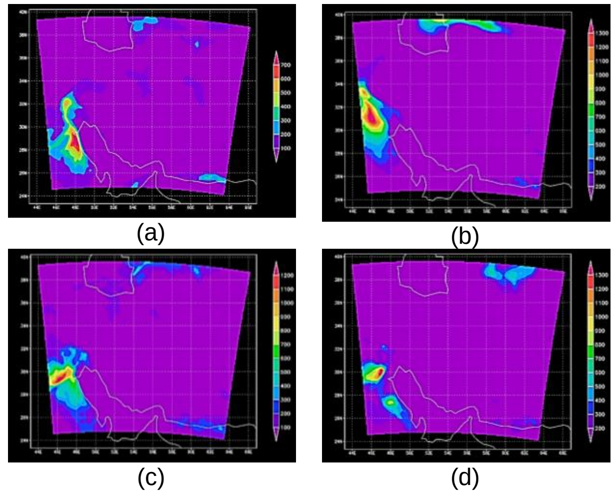


Fig. 9. PM_{10} concentration contours of the first to fourth day of dust event no.2

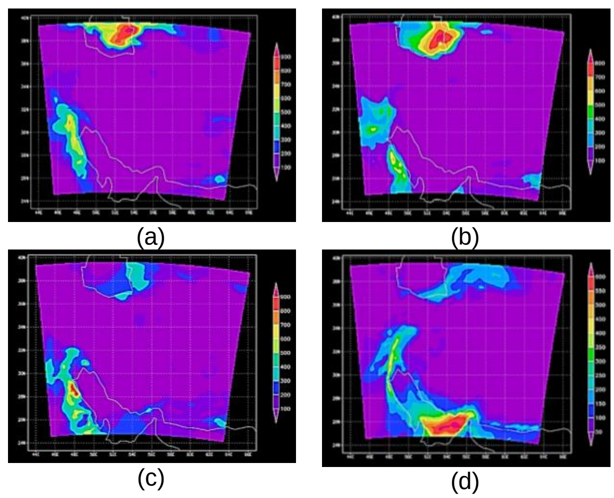


Fig. 10. PM_{10} concentration contours of the first to fourth day of dust event no.3

4. CONCLUSION

Two scenarios were defined to investigate the impacts of three dust storm events on precipitation using the WRF-CHEM model. There was a reduction in precipitation amounts in the second scenario, which considers aerosol radiative feedbacks on clouds compared to the first scenario that did not include aerosols' impact on clouds. These reductions occurred in the western, southern, and south-western parts of Iran, where exposed to severe dust storm events and at the last stages of each period (third and fourth day). The precipitation trends mostly increase in the first two days, followed by a decrease in the next two days. Due to aerosol-cloud feedbacks, the mean cumulative precipitation of the dust episodes during March, April, and May events changed from 12.45 mm to 12.84 mm, 31 mm to 30.86 mm, and 8.79 mm to 7.78 mm, respectively. The most considerable alteration seen in total cumulative precipitation values was 0.8 mm, which occurred on the last day of the May episode.

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