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Investigation of dust storms in Ilam and the performance analysis of simulation of 6 numerical prediction models at a severe dust storm in west of Iran

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ABSTRACT:

Introduction: Many countries encounter dust storms phenomenon that is one of the meteorological problems leading to many disturbances.

Materials and methods: Although the dust storm is historically recorded as an old event in some provinces of Iran, but it becomes a new event in some parts such as Ilam province.

Results: After statistical investigation of dust storms in Ilam province, the dust storm from 3^{td} to 6th July 2016 are studied. The source of this dust storm was the eastern areas of Syria and central Iraq base on the satellite images, the outputs of HYSPLIT and WRF-Chem models.

Conclusion: Model outputs in intensity of surface dust concentration of MACC-ECMWF, NASA-GEOS, NCEP-NGAC, NMMB-BSC, and BSC-DREAM8b models are compared to the observation data in Ilam city and results show that NASA-GEOS model has better performance. In display of dust dispersion on Iran, the middle of all models is more compatible with reality.

Introduction

One of the atmospheric hazards is the dust storm phenomenon that causes high environmental and social damages in some parts of the world. Every year a huge amount of dust particles rise from different regions in The Middle East including Iran, North Africa, Arabian Peninsula, Iraq, and Syria. Dust particles penetrate to the higher levels of the atmosphere depend on the ground surface warming and the wind speed. These particles are transferred to the front regions, according to the atmospheric condition and synoptic patterns [1]. It seems that it is so vital to study and simulate dust storms in the West and SW of Iran Because of increasing of this phenomenon and its consequences about losses and damages of the people's lives in these areas. The Ilam province encounters to the dust storm problems recently and the num-

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ber of them increased rapidly in the last decade. One of the study methods of dust storm phenomenon that can be referred to is synoptic study that has been used in many researchers'papers [2,,3 4]. Also, the HYSPLIT trajectory model has been employed in many researches to determine the sources of dust particles. In a study, this model was set up in backward trajectory in order to determine the source of the dust storm phenomenon in Tehran for 48 h at 100 m, 500 m, and 1000 m heights. The results show that the sources of the dust storm are located in Iraq and Syria countries[5]. In another study, the event of a dust storm, occurred in west of Iran in July 2009 by HYSPLIT backward trajectory. Also it seems that the sources of such a severe dust storm were in the central and northern areas of Iraq and Syria 6]]. Furthermore, the transport and dispersion of dust particles are studied by numerical prediction models which many international institutes are actively involved all around the world. In Iran, WRF-Chem model was used with new land surface data including vegetation and the topography of The Middle East region that prepared by Modis Sensor and USGS1 data. By usage new data, little error is revealed in identifying the dust sources and in determining the dust transport and distribution [7].

MACC2 model was employed for north of Africa and The Middle East for 2 years and show that this model can not correctly indentify the sources of dust particles, but the dust dispertion is displayed well [8]. Also, this model estimates the surface concentration of the dust less than reallity especially in the winter and early spring. However, it simulated the changes correctly. The radiation effects of dust particles arisen from Sahara Desert was studied by using NASA GEOS-5 model and it was concluded that the shape of dust particles has a little impact on their transfer and dispersion. Also, the effect of dust particles shape on the short waves forcing is about 5% in the upper levels of the atmosphere [9]. The AOD values in a dust storm in Athens was compared to the dust load values of an atmospheric column, obtained from BSC-DREAM's output. The results show that the model under-estimated AOD values. Also, this model under-estiamted surface concentration of PM_{10} about 30% compare to observational data [10].

In this study firstly, the dust storm phenomenon and its effective elements are studied statistically over a period of 21 years at the synoptic station in Ilam city. Then the 29th June-3rd July 2016 dust storm are investigated which mostly affects the western areas of Iran. Consequently, the simulations of dust dispersion of 6 numerical prediction models are assessed for that case.

Materials and methods

Firstly for statistical investigation of dust storms in Ilam station, the present weather code and visibility data were taken from the Ilam synoptic station on 21 years duration (1997-2017). These data reported every 3 h.

Then some effective factors on dust storms such as the wind speed and rainfall anomaly are investigated with NCEP/NCAR reanalysis data with 2.5 degree resolution. These anomaly data was in the years with maximum frequency in dust storm from 2007 to 2013 compare to 30 years duration (from 1981 to 2000). Weakening vegetation in the areas prone to emission dust particles is very a important factor on the dust storm occurance. So VHI (vegetation health index) is examined in this paper. VHI was investigated in Al-Raqqa province in Syria and Al-Anbar province in Iraq which are turned into the dust active sources recently [11]. VHI index from AVHRR sensor was used for thermal stress investigatation.

The index of vegetation health or (VHI) is dependent on the vegetation properties in absorption and reflection of the sun light. When VHI index is under 40, it shows severe drought and poor vegetation cover. However, when drought doesn't occur, the green plants reflect a little amount of visible light due to sunlight absorbtion by chlorophyll and mostly their radiation happens in infrared light by dispersion of the inner filament of the leaf and water inside it. Therefore, a big difference is appeared between visible light spectrum and infrared light because of green coverage of plants. In the years of drought, the reflection of visible light increases and the intensity of infrared decreases, due to reduction of clorophyll and the water content of the plants.

The visibility and the temperature data of Ilam synoptic station and RGB images of satellite MGS are studied in order to investigation the dust storm phenomenon from 3 to 6 July 2016 which affected a large part of the western and south western of Iran. Then, The Hybrid Single-Particle Lagrangian Integrated Trajectories (HYSPLIT) model has been applied to calculate the dust particles sources. The synoptic analysis is done with ERA-Interim atmospheric data with a default resolution of 0.75x0.75 degrees. Then the produced of 6 Numerical Weather Prediction models is used. These models are ECMWF-MACC [12-15], GEOS model [16,17], NGAC model [18,19], NMMB-BSC model [20, 21], DREAM8b- BSC model [22,23]. All the model characteristics are shown in the Table 1. At last, the models output (dust concentration) are compared to dust concentration of the air quality station in Ilam station.

Results and discussion

In the annual frequency of dusty days in Ilam station (Fig. 1), it is evident that the number of these days has been noticeably increased since 2007 and it reached to maximum numbers in 2011. However, the number of dusty days is reduced drastically in 2014, but it increased again since 2015.

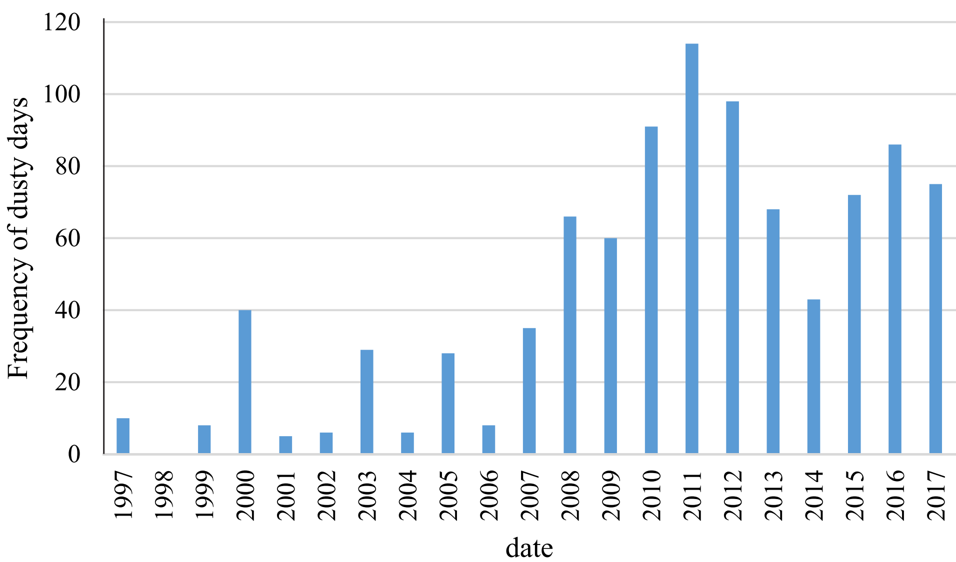


Fig. 1. The annual frequency of dusty days in Ilam station from 1997 to 2017

The monthly frequency of dust storms (Fig. 2) shows the number of dust event days was highest in July. Second and third grads were June and May. It can be concluded that the maximum of dust storm events in Ilam city are associated with the end of Spring and Summer seasons.

The Cumulative monthly precipitation in the spring and winter seasons are displayed in Fig. 3. The amounts of winter rainfall in 2008 and 2009 are the lowest for the entire duration of 21 years. The comparison of these values with the frequency of dust storm events shows that the number of dust storm events increased in 2010 when the precipitation reduced drastically in the previous years.

It is worth to mention that the most sources of dust particles in Ilam province are located outside of the province. So it is nessasary to study the precipitation anomaly in this area. Fig4 . shows the spring precipitation anomaly from 2007 to 2013 relative to the annual average for the period 30-years (1981 to 2010). The precipitation is less than the annual average for the period 30-years in east of Syria, north of Iraq and west and south west of Iran. This deficient precipitation is remarkable in north of Iraq and west of Iran.

The vegetation health index of Al-Raqqa province in Syria and Al-Anbar province in Iraq is displayed in Fig. 5. The figure shows that the vegetation health index had decreasing trend in the both Provinces. Also, the gragh shows that the index are sharply reduced which indicates that the reduction in vegetation cover was happened in these regions, especially in Al-Raqqa province. It is important to note that the number of dusty days in Ilam province shows sharp increase since 2006. Therefore, it can be said that the poor vegetation cover in Iraq and Syria is one the elements that effects the sharp increase of dusty days in the region.

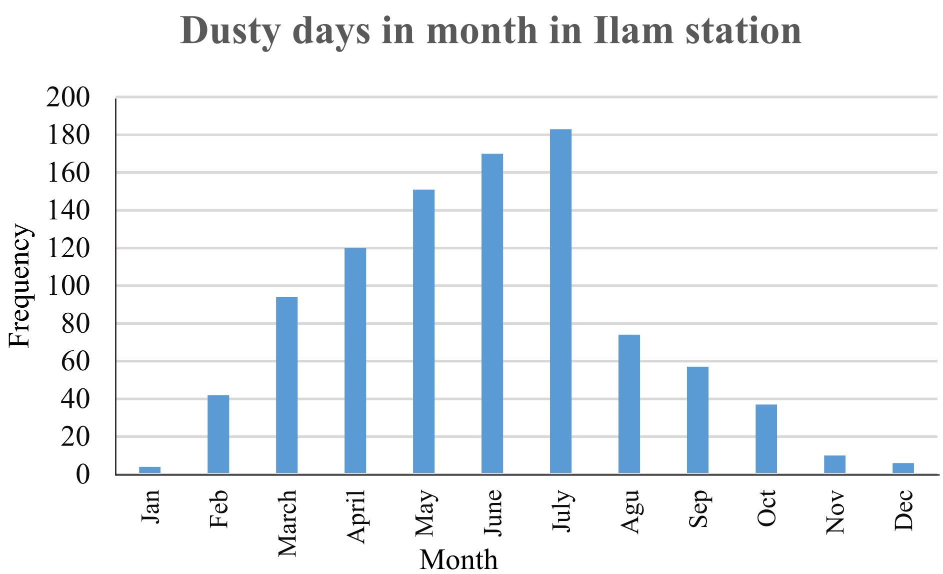


Fig. 2. The monthly frequency of dust event days in Ilam station in 21 years duration (1997 to 2017)

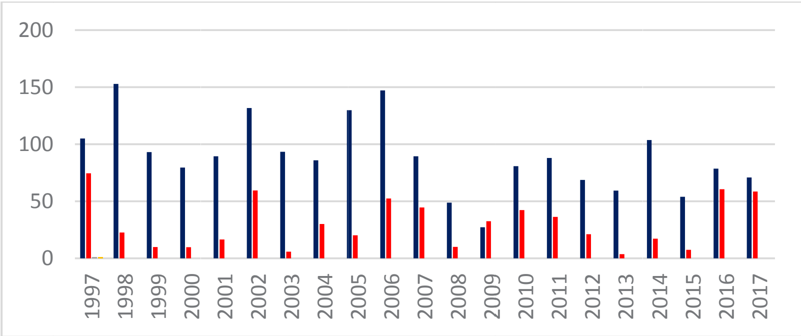


Fig. 3. The Cumulative monthly precipitation of Ilam's synoptic station in the 2 seasons of spring(red lines) and winter(blue lines) from 1997 to 2017

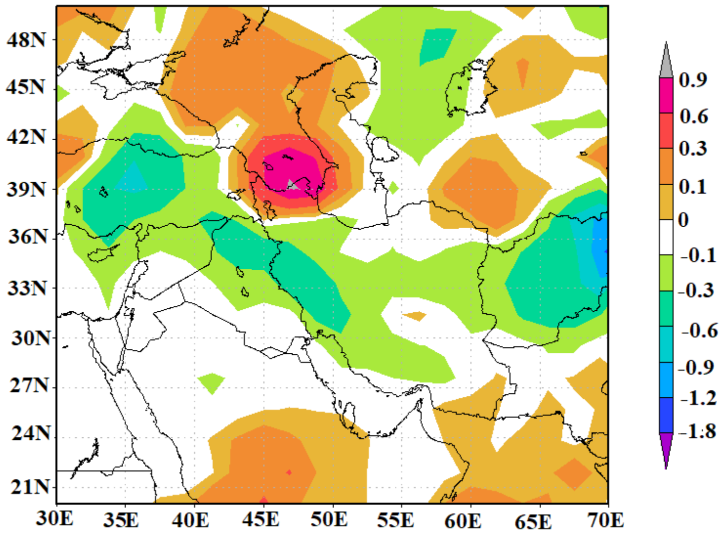


Fig. 4. The spring precipitation anomaly from 2007 to 2013 relative to the annual average for the period 30-years (1981 to

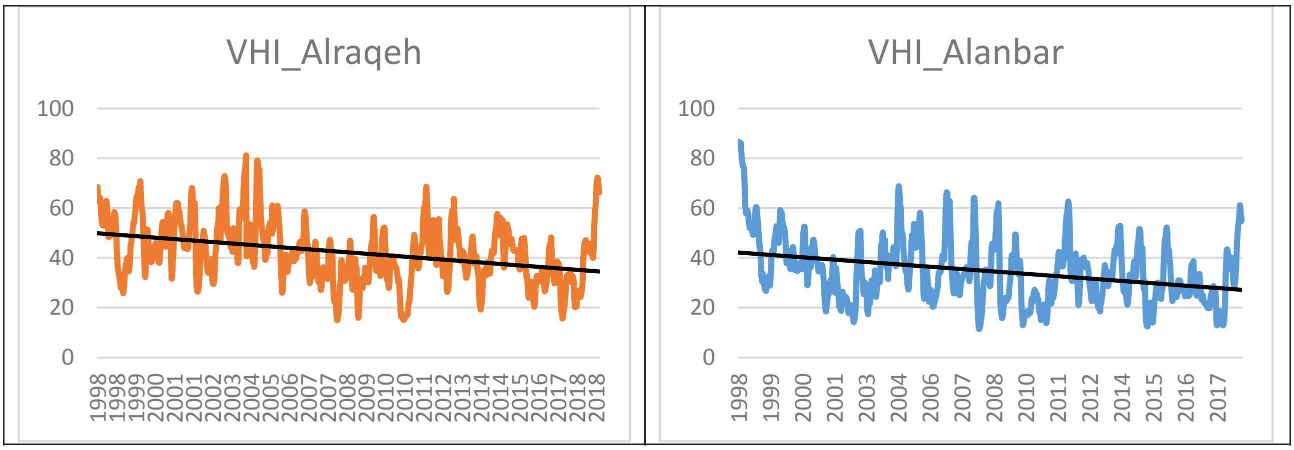


Fig. 5. The health vegetation index in a) Al Raqqa, Syria. b) Al Anbar, Iraq from 1998 to 2017

Case study

Fig. 6 shows the visibility data of Ilam station from 2 to 9 July 2016. At 18UTC 4 July visibility reduced to less than 4km, then it is increased again on 5 July. however, on the same day at 06UTC it decreased sharply and it reached to zero at 15UTC. The report of zero visibility might be due to monitoring error, however, a sharp reduction of visibility is observed at the next hours. An increasing trend occurred in visibility at the end of 6th July and it reached at its maximum value on 8th July. 2m temperature in Ilam station well shows the reduction of maximum temperature proportional to the visibility reduction which can express that the dust particles in the atmosphere absorbed the solar radiation and prevented the short wave radiation to reach the land surface. Dust particles reduced the maximum temperature, meanwhile the minimum temperature had a little increase over the same period which it might be due to the earth long waves absorption by the dust particles in the nights. Investigation of dust particle effects on both the short and long waves radiations can be found in some papers [24].

In Fig. 7 true color images of MODIS sensor on Terra and Aqua satellites is displayed on 4th July 2016. On 4th July Terra satellite cross the region at 8:25UTC and Aqua satellite at 10UTC. Figure 7a shows that on the early morning of 4thJuly thick dust transported from the east and south east of Syria and after a couple of hours a dust source was actived in the north east areas of Iraq and the thickness of it increased over Iraq.

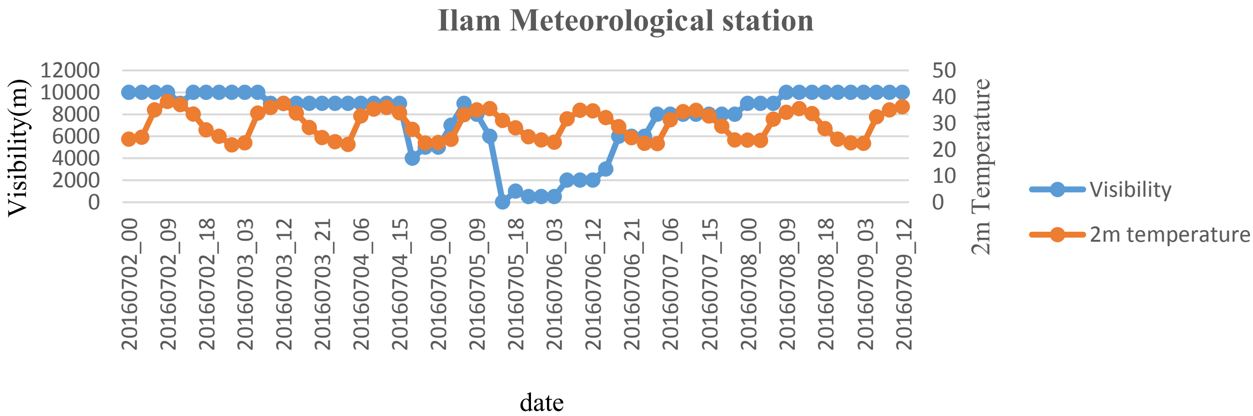


Fig. 6 . The 3 h visibility data (red lines) and temperature (blue lines) in Ilam station from 2 to 9 July 2016

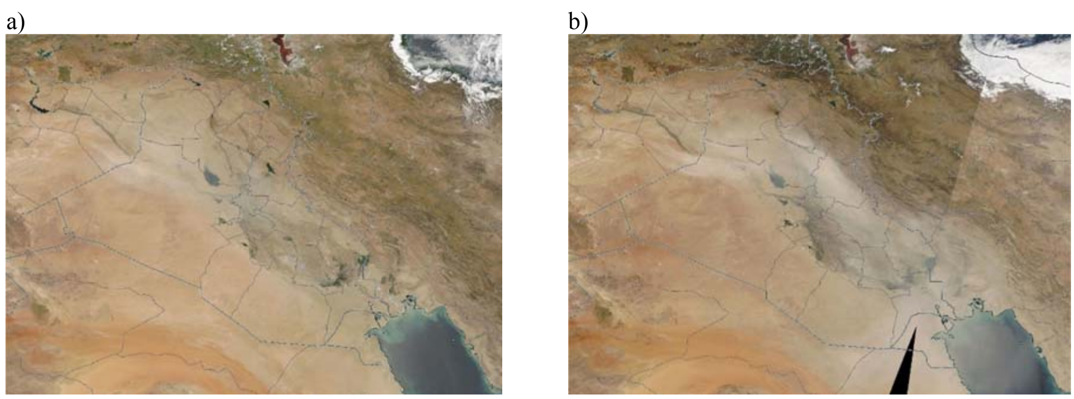


Fig. 7. The true color image of MODIS sensor in Terra and Aqua satellites in 4th.July 2016

The RGB images of MSG satellite (Fig. 8) show that at 12UTC 3th July a dust mass entered the western and central parts of Iraq and the dust thickness severely increased. Increasing dust concentration was due dust rising from the areas in the central and eastern Iraq. On 4 July a rotating motion is observed over Iraq. In the same day the dust enters the western areas of Iran and covers a large part of western edge of Iran. It is worth to mention that the Zagros mountains prevented to dust penteration to the central parts of Iran.

Fig. 9 shows the back trajectory of HYSPLIT Model, at 12UTC at height of 500 m above the ground on 4th July, 2016. The model is run by GDAS data with 0.5 degree horizontal resolution for 24 h. In this case study the sources of dust particle in west of Iran located in the east of Syria and in the northeast of Iraq which is in agreement with satellite images.

The product of CALIPSO satellite in 4th July is displayed in Fig. 10 for investigatation the vertical profiles of dust in the atmosphere. Fig. 10 (a) shows a part of Calipso path around the earth and the area under consideration was shown with the red square. In Fig (10 .b), aerosol particles suspended in the atmosphere elevated up to 4 km.

a) b)

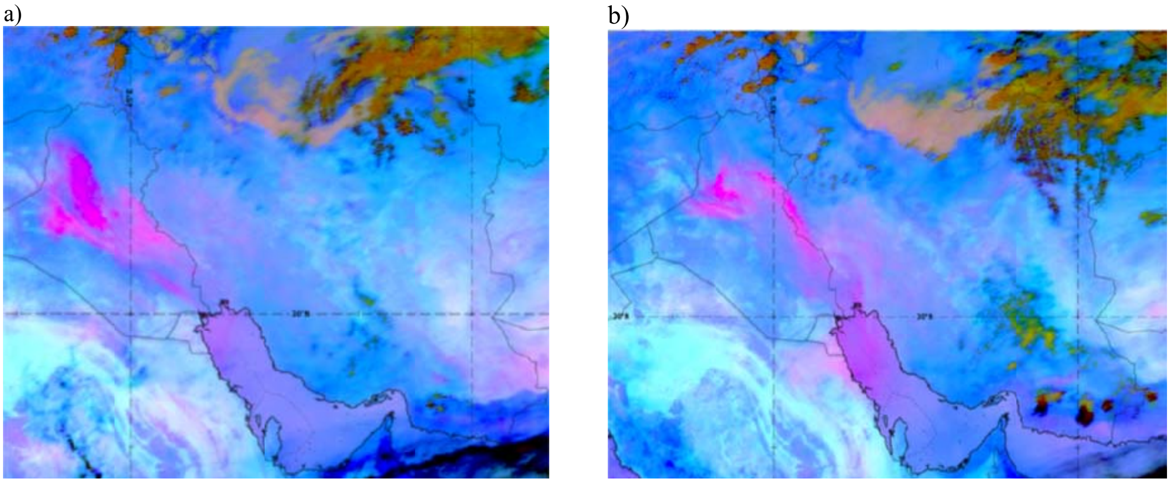


Fig. 8. RGB image of MSG satellite at 12 UTC in a) 3 July b) 4 July 2016

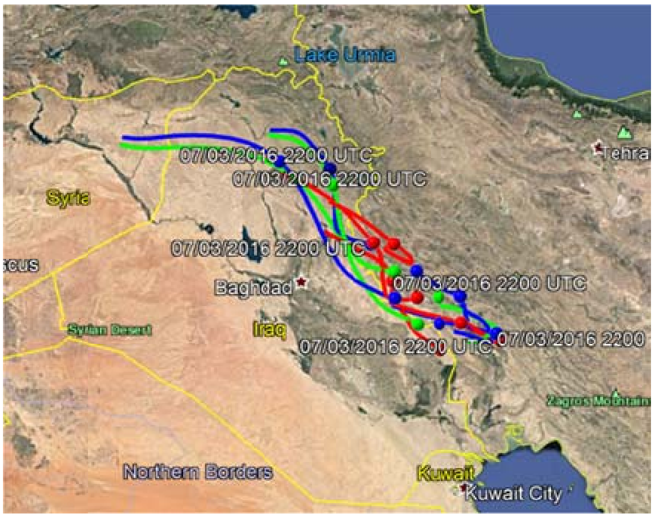


Fig. 9. The output of HYSPLIT Model, at 12UTC on 4th July, 2016.

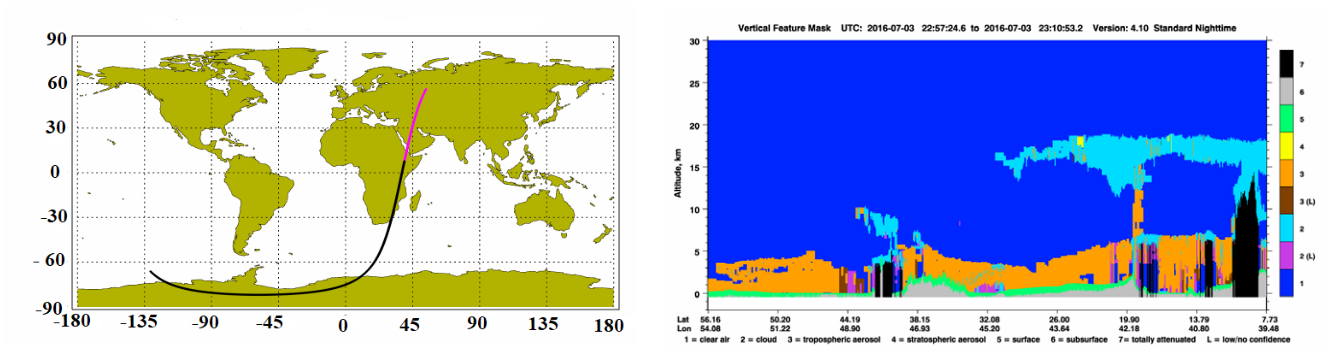


Fig. 10. (a): The Calipso path satellite in 3 July ; (b): the vertical profiles of dust at 23 UTC 4th July

On sea level pressure map At 12 UTC in 2 July, Fig. 11 (a) a center of dynamic low pressure was on the east of Syria and north of Iraq which was contributed to a low heat pressure system on the south east of Iran. The low pressure system stretched to southwest of Iran and it caused air vertical motion in Syria dry lands, so dust rising happened. Also the north- westerly wind blow over Syria and the wind transfer dust particles to the central areas of Iraq. On the 3th July, a center of low pressure was on north of Iraq. Consequently the pressure is reduced in the central areas of Iraq, Fig. 11 (b), which can lead to transport of dust from these areas and dust concentration icreased. Furthermore these new dust particles affected by the westerly and north-westerly winds over Iraq and enter the west and south-west of Iran.

The geopotential height of the 500 hPa pressure level at 12 UTC 2 July, Fig. 12 (a), shows a trough was on north of Caspian Sea and north of Iraq and Syria. Also a small trough associated with surface low pressure was on Iraq.

The subtropical highs tongue enters Iran from Saudi Arabia and reached to the north east of Iran. Also a ridge was in the south west of Iran. The trough moved to the east in 3 July, Fig. 12 (b), and part of its tongue reached to north west of Iran. The trough over Iraq intensified and moved to the east, so height decreasing is seen in the western areas of Iran.

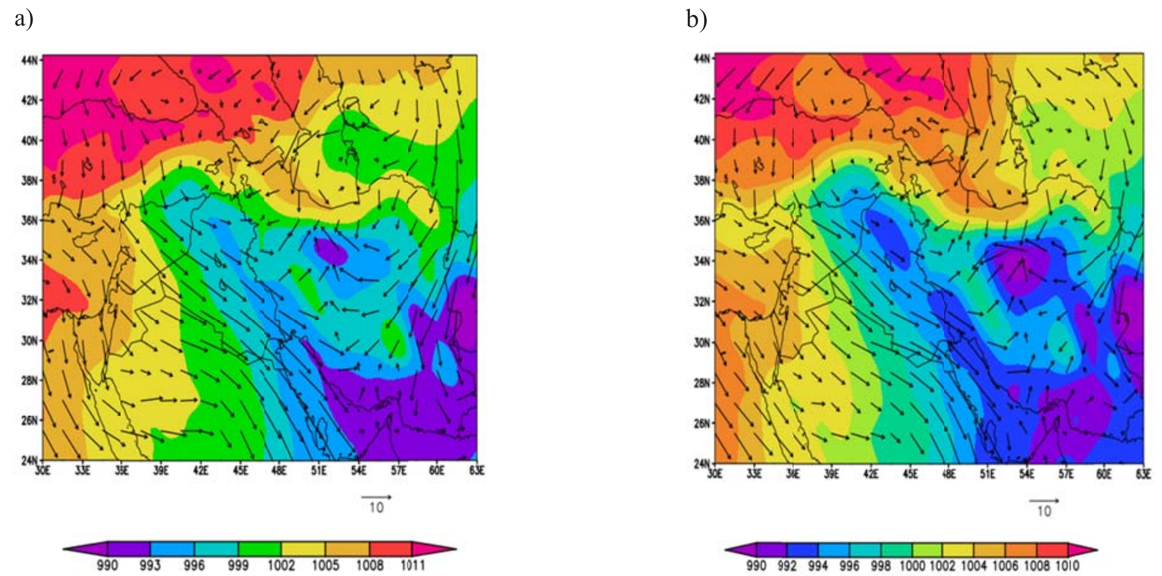


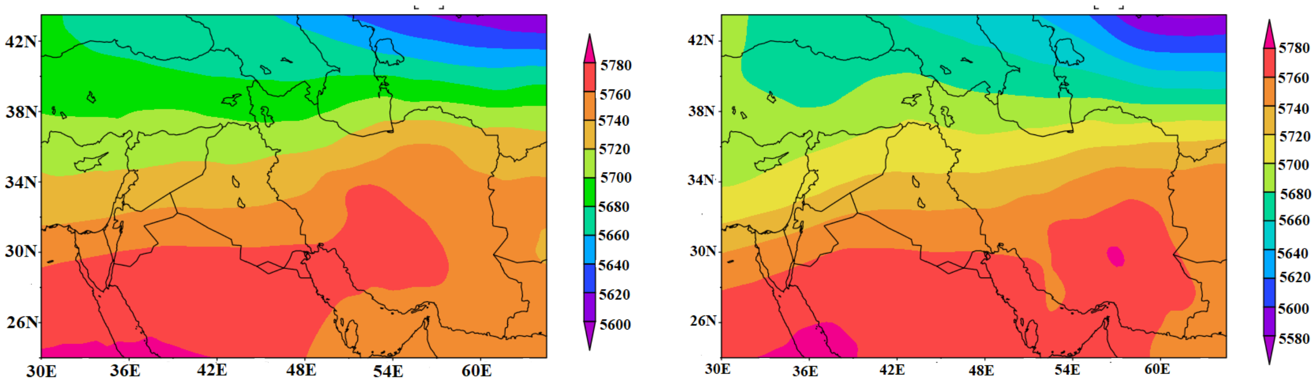
Fig. 11. Sea level pressure (hPa), wind vector at 850 hPa (m/s) at 12 UTC a) 2rd July and b) 3th July 2016

Simulated dust concentration at surface level of WRF-Chem model shows that particle transportation occurred from eastern Syria, as well as with more intensity from the central areas of Iraq at 6 UTC 3 July, Fig. 13 (a). At 12UTC 3 July the dust storm entered the south west areas of Iran, and then its thickness decreased in Iraq, Fig. 13 (b). At 6 UTC 4 July, once again the thickness of dust increased in Iraq especially in central areas, Fig. 13 (c). Then the dust storm enters western areas of Iran again and it covered the west and south west areas. It is worth to mention that at 12 UTC of the same day the surface thickness of dust decreased again, Fig. 13 (d). At 6 UTC 5 July, the thickness of dust decreased over Iraq and western areas of Iran comparing to the previous day and dust particles arised from the central areas of Iran, Fig. 13 (e). at 12UTC 5 July the thickness of dust gradually decreased in all over Iran, Fig. 13 (f).

Fig. 14 shows 5 different simulated dust concentration at surface level and their mean values in 4 July 2016, 18UTC. The visibility was the minimum value in Ilam station in that time. The comparison of simulation models shows that the models well simulated the transport of dust particles from the east of Syria and central of Iraq to the west and south west of Iran. MACC-ECMWF model, Fig. 14 (a) underestimated the dust surface concentration in the west and south west of Iran but it shows a mass of thick dust in the central areas of Iran, but satellite images did not show that. Meanwhile, NASA-GEOS model shows well the transfer of dust into the western areas of Iran and also correctly shows the maximum dust concentration in the western border of Iran. Furthermore, it shows a mass of thick dust over the Persian Gulf. So the model had more accurate simulation and it was more compatible with satellite images in this case.

The distribution of dust concentration of NCEP-NGAC model, Fig. 14 (c), is very smooth, and it shows three maximum amounts. Also it underestimated dust concentration over Iran so much. It can be said that this model has the worst simulation among 6 prediction models. NMMB-BSC model, Fig. 14 (d) shows well the dust storm intensity in the west of Iran however, it simulated high dust concentration in the east of Syria that it is not in agreement with satellite images.

The dust concentration simulation of DREAM8b model, Fig. 14 (e) presents an acceptable propagation, but it shows very little dust in the west of Iran. The mean of all the models, Fig. 14 (f) well present dust propagation and its simulation is better than most of the models in this case study.



(a) (b)

Fig. 12. Shows geopotential elevation of the level 500 hPa (gpm) at 12UTC on day: a) 2rd July; (b) 3th July 2016)

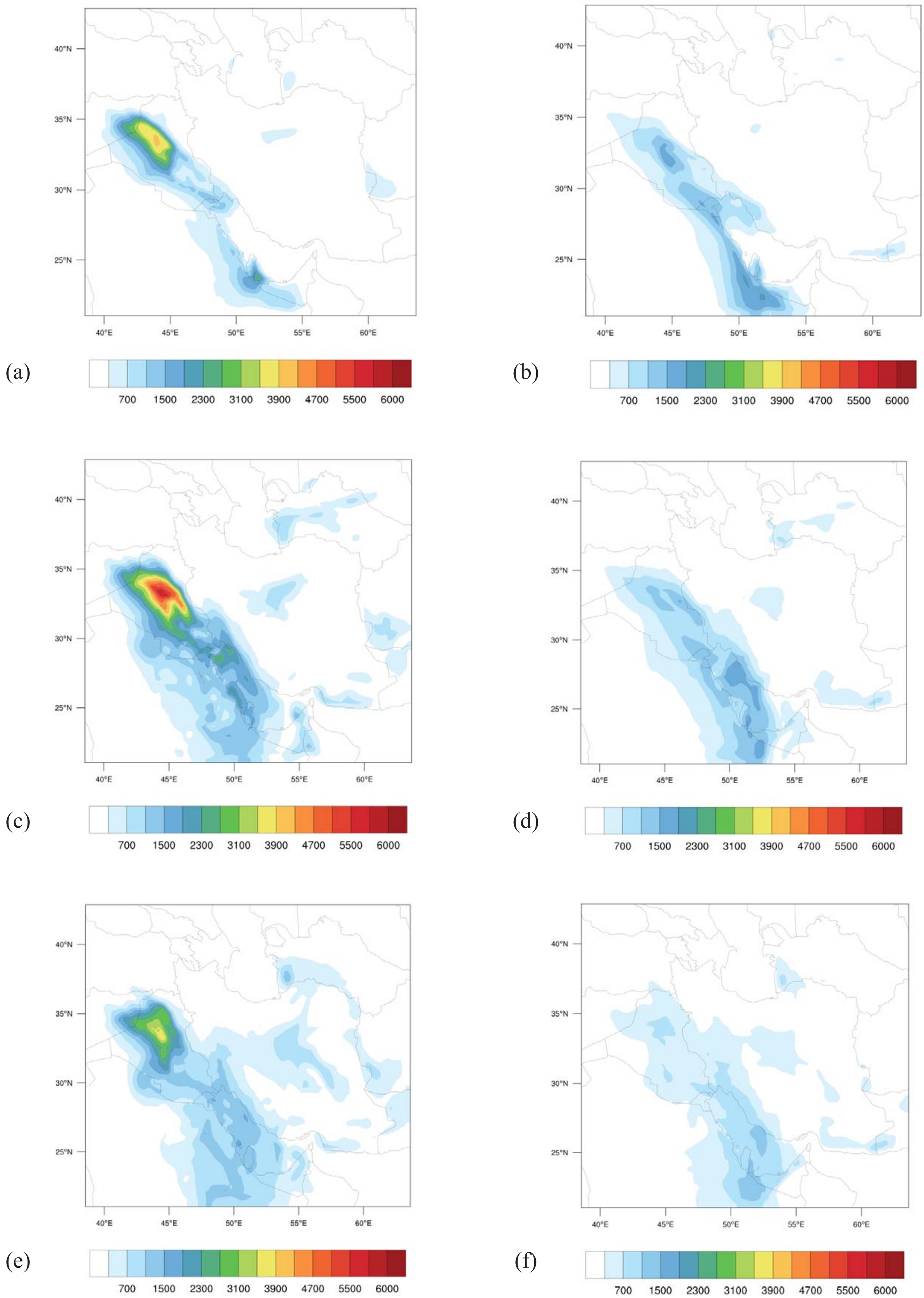


Fig. 13. Simulated dust concentration at surface level of WRF-Chem model in: (a) 3th July, 6UTC; (b) 3th July, 12 UTC; (c) 4th July, 6 UTC; (d) 4 th July, 12 UTC; (e) 5th July, 6 UTC; (f) 5th July 2016, 12 UTC.

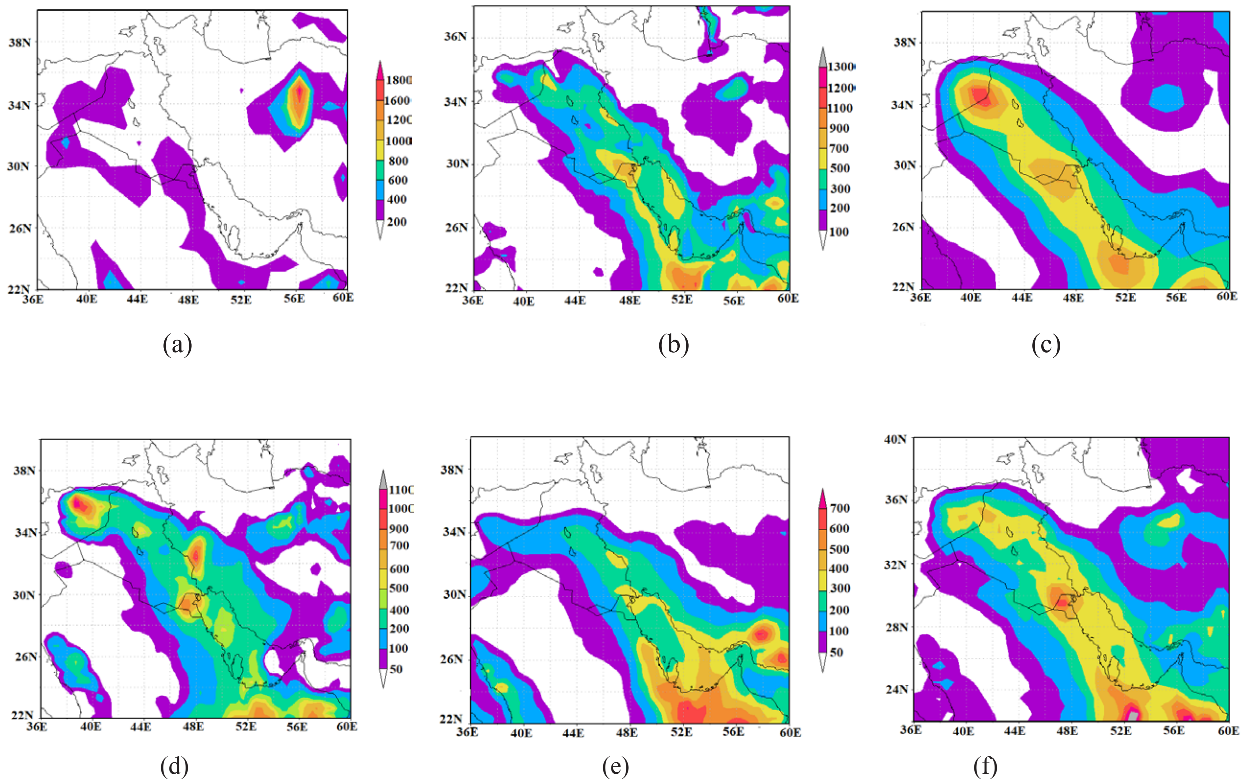


Fig. 14. The dust concentration in 4 July 2016, 18UTC for (a) MACC-ECMWF (b) NASA-GEOS (c) NCEP-NGAC (d) NMMB-BSC (e) DREAM- BSC (f) the mean of all the models

comparison of PM_{10} concentration outputs of various model and the values observed at air quality monitoring stations in Ilam, Fig. 15 shows that models underestimated PM_{10} concentration in Ilam station very much. But NASA-GEOS model has better performance in predicting the trend of concentration variations. It is worth to mention, NMMB-BSC model shows the maximum concentration more than the others but the time of maximum concentration is not compatible to the reality.

Conclusion

The study of the frequency of dusty days in Ilam station shows that the number of these days remarkably increased since 2007. Also the most dust events occurred in Ilam station during the late springs and in the summers. Rainfall deficiency is one of the effective elements on the formation of a dust phenomenon that affects on soil moisture and vegetation cover. precipitation rate were minimum amonts in 2008 and 2009 compare the total period of 21 years in Ilam station. Consequently the amount of dusty days was maximum in the Ilam station in 2011. The precipitation anomaly in the springs from 2007 to 2013 shows that rainfall amounts are less than the mean value of the 30-year rainfall at eastern Syria, mid-north of Iraq and the west and southwest of Iran. Especially rainfall deficiency was in the north of Iraq and west of Iran. Moreover, the vegetation health index had descending trend in Al-Raqqa province in Syria and Al-Anbar province in Iraq that indicating lack of vegetation cover in these regions. Meanwhile, it is worth to mention, the increase of number of dusty days in Ilam since 2007 coincided with the decreasing of vegetation health index in Al-Raqqa province.

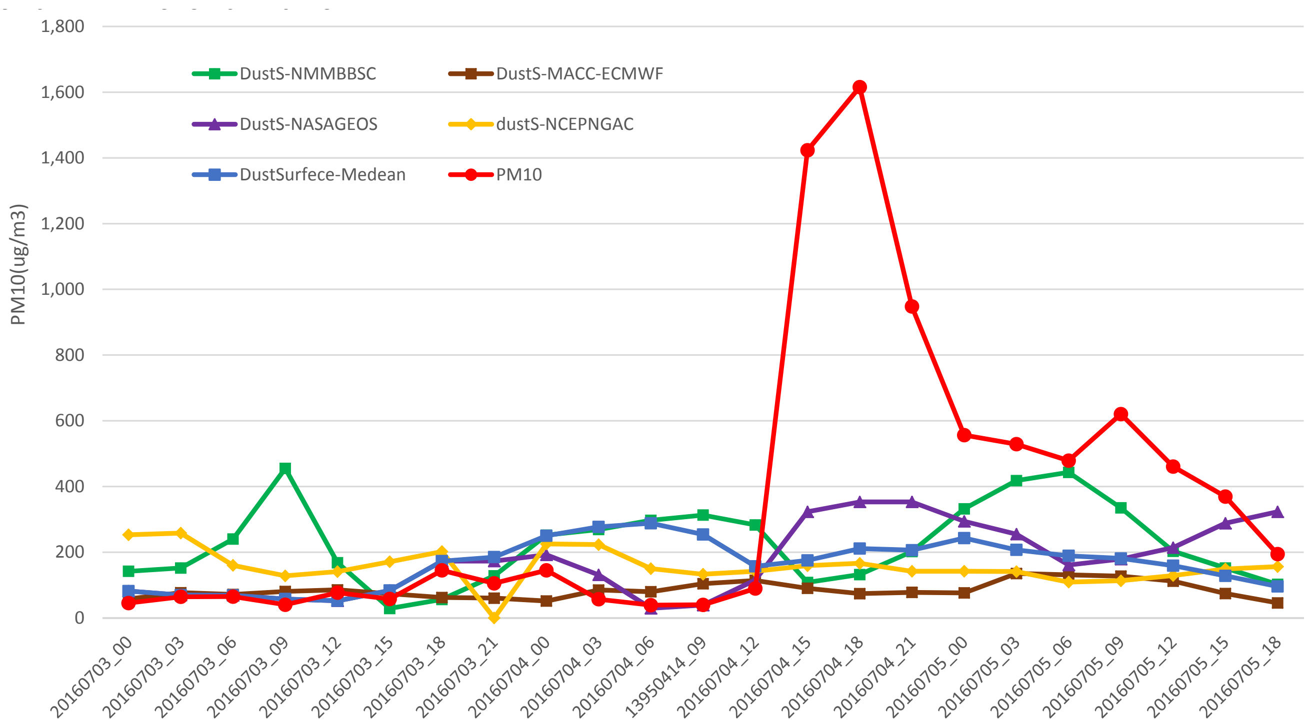


Fig. 15. PM_{10} concentration (µg/m³) outputs of various models in Ilam station from 3 to 5 July 2016.

After statistical investigation of dust storms in Ilam station, a severe dust storm was studied from 3 July to 6 2016. The visibility reduced drastically in Ilam from 4 July to 5 July. The satellite images showthat dust particles transported from the eastern and southeastren Syria and then a source of dust activated in the northeast of Iraq, too. Consequently the dust thickness increased over Iraq. HYSPLIT trajectory model shows that the source of the dust particles was in the eastern areas of Syria, and in central Iraq. WRF-Chem model simulate the dust emission from east of Syria and central Iraq. It also shows the dust transportation to the east of Iraq and west and southwest of Iran which is in agreement with the satellite images, the trend of Ilam station visibility and the outputs of HYSPLIT model. The highest amount of dust particles observed at Ilam province, and the reported visibility in Ilam station was much lower than other provinces like Khuzestan.

The quantity comparison of the models outputs with PM_{10} dust concentration at in Ilam station shows that all the models understimated the dust concentration in Ilam station. But GEOS-NASA model had better performance at the prediction of the dust concentration trend variations.

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Competing interests

The authors have no competing interests.

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Ethical considerations

The authors state that ethical considerations are fully respected in this study.

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