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RESEARCH PAPER

Dust Distribution and Emission Modeling (Study Area: Khuzestan province)

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Abstract
Dust storms are one of the most significant challenges in the Western Asia region in recent years and have intensified because of drought. Emission of dust in a scattered and especially heterogeneous manner has made it difficult to determine the exact effect, so modeling is one of the best possible ways to quantify dust emission. Moreover, to deal with this phenomenon, it is necessary to identify the main and influential factors and, by combining these factors, we can predict dust storms using models. The purpose of this study is to model the distribution and emission of dust in two stormy days on the 26th and 27th of January 2017 in the arid and the hyper-arid region of Mahshahr. For this purpose, coding of each meteorological parameter (section 2.2), dust input concentration parameters, and in MATLAB R2014 software have been made. Also, dust input concentration maps were prepared for the two stormy days in the study area in ARCGIS 9.3 software. Finally, the results were evaluated with WRF model outputs. The efficiency of the developed model was also evaluated based on the hourly data of the dust input concentration for two stormy days in the study area. The evaluation of the model shows the ability of this model to modeling the dust distribution in the study area with high intensity of dust emitted and high accuracy. The R correlation index for the period under study was 0.84, which indicates the high accuracy of the model.

Keywords: Dust, Distribution Modeling, Arid region, Dust emission, MATLAB Software.

Introduction

Today, air pollution is one of the most important environmental problems. The dust storm is one of these problems that is associated with health risks and environmental consequences (Goudarzi *et al.*, 2018). Decreased vegetation in desert and arid regions, which occurs if the drought persists, exacerbates wind erosion, resulting in massive dust storms and dust emissions (Elmore *et al.*, 2008; Yu *et al.*, 2015). According to the definition of the World Meteorological Organization, a day with a dust storm is a day when the visibility at a station due to dust is below 1000 meters (Middleton, 1986). Statistics show the greater frequency of this phenomenon in arid and semi-arid regions such as Iran (Abbasi *et al.*, 2008). The occurrence of dust is mainly due to the two systems of earth and atmosphere, the main reasons for which are wind speeds above the threshold, lack moisture, and bare land (Shamshiri *et al.*, 2014) that the south and southwest of Iran, including Khuzestan province and Mahshahr city, has these conditions (Velayatzadeh, 2020). In densely populated areas, many contaminants are found in dust particles, including metals, herbicides, digoxin, and nuclear particles, so quantification of dust sources and estimation of dust concentrations is very important in air quality studies (Chan et al., 2005). One way to manage, control, and reduce the effects of dust storms is to use models that determine how dust is distributed

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around critical dust sources. Many models in this field have been developed by researchers, including the Gaussian diffusion model, which is discussed in this study. Particle flux modeling involves calculating the wind speed threshold using soil texture and moisture data. Since this phenomenon is dynamic and meteorological and climatic elements are constantly changing, Spatio-temporal models should be used to model and visualize it. For this purpose, in this research, using spatial-temporal modeling capabilities, the modeling of published fine dust using the Gaussian model has been done. The past decade has seen the development of numerical prediction models for the dust to improve understanding of the effect of dust particles in the atmosphere (Tegen and Fung, 1995; Ginoux et al., 2004; Shao et al., 2003; Uno et al., 2003). One of the similar studies is a study in which Rezazadeh et al. (2016) examined the performance of wind erosion models in Middle East dust simulations. To this end, they introduced and examined three Marticorena-Bergametti Lu-Shao, and Shao-2004 dust schemas, and the results showed that all three schemas estimated the same emission sources for this dust event; While at the beginning of the storm, the Marticorena-Bergametti schema reveals dust-scattering areas with greater extent and intensity than the other two schemas. From there, the city of Mahshahr is exposed to pollution due to being located in the path of one of the seven dust centers identified by Darvishi Khatooni (2015). In this research, for the first time, modeling the distribution of dust in this area and only for the local center, Effective parameters were examined using coding. The efficiency of the developed model was also evaluated based on hourly data of dust input flux for two stormy days in the Mahshahr region in 2017.

Materials and Methods

Study Area

The study area is in the Mahshahr region, which is located along Mahshahr-Ahvaz road. Mahshahr port is a city located in the south of Khuzestan province of Iran with a longitude of 49 degrees and 13 minutes and a latitude of 30 degrees and 33 minutes. Mahshahr city is the center of Mahshahr port city. The height of this city is about 3 meters above sea level. The current Mahshahr consists of two parts, the old Mahshahr and the other called the industrial zone. Mahshahr port has an area of 2713 hectares, which is the largest city of Khuzestan after Ahvaz. This region is one of the most important centers of internal dust located in Khuzestan province and southeast winds can direct dust from this region in densely populated areas such as Ahvaz.

Methods

Modeling includes atmospheric models and schemas for wind processes and surface temperature and hydraulic processes. The atmospheric model acts as a host for other schemas, whether globally, regionally, or mid-scale. Today, most atmospheric models calculate the dynamic processes of the atmosphere numerically and consider the physical processes of the atmosphere, such as radiation, convective clouds, and turbulent scattering, very efficiently. Atmospheric models are usually paired with surface schemas, which parameterize the exchange of energy, momentum, and mass between the atmosphere and the earth's surface. To model wind erosion, ground surface schemas provide wind erosion threshold velocities and soil moisture. These parameters, along with other land surface parameters, are used in wind erosion schemas to quantify parameters such as dust emission. Transfer and sedimentation models also receive wind, turbulence, and precipitation data from the atmospheric model and the amount of dust emission and particle size information from the dust emission scheme and predict the concentration and deposition of dust. In this study, the Gaussian model was used to model the distribution of dust in the region, considering that the accuracy of the Gaussian model up to a distance of 50 km from the source is acceptable. For this purpose, in this study, coding of meteorological parameters, dust flux, and normal distribution in MATLAB R2014a software was performed on January 26th and 27th, 2017.

Meteorological parameters include radiation parameters, wind speed profile, temperature profile, and vertical and horizontal turbulence profile. The equations for each of the radiation parameters are given in Table 1, which includes Solar flux, Pure radiation, Sensible heat flux, Friction rate, Monin-Obukhov length, Albedo, critical solar height, convective velocity (vertical) in the unstable boundary layer, Friction speed at night in the mixing height and the height of the actual mixing layer. Given that the transfer of pollutants by wind is highly dependent on wind speed and most existing models such as Gaussian instantaneous and permanent models in this field consider a constant value for wind speed, but wind speed changes with altitude changes (Stull, 1988), the wind speed profile was also coded. These parameters include wind speed profile in three conditions: unstable, stable, and low stability, vertical speed variance in stable conditions, mechanical section estimation of vertical wind speed variance, vertical wind speed variance due to mixing layer turbulence, vertical wind speed variance due to residual turbulence, Horizontal turbulence profiles, and scattering or scattering parameters. Temperature profiles include parameters such as potential temperature gradient profiles at two altitudes less than 100 meters and more than 100 meters, reference potential temperature value, potential temperature profiles. Dust entry flux includes erosion threshold velocity, erosion threshold velocity for bare and dry soil, soil moisture correction function, soil roughness correction factor, horizontal flux parameters, and vertical flux parameters including White and Owen schematic, Marticorena and Bergametti schematic, Lu and Shao schematic is the scheme of Shao 2004. Horizontal flux (Q) is the mass of passing grains or lumps in units of time per unit length. This quantity is calculated in both schemes using the White (1979) sand flux equation (White, 1979). The horizontal flux based on Owen equations is given in Table 1 (Owen, 1964). In this study, both C_White and C_Owen flux functions are in the same set (Marticorena et al., 1997; Laurent et al., 2006; Darmenova et al., 2009). Vertical dust flux is defined as the mass of dust released per unit area over time. The Marticorena and Bergametti schemas determine the equation between the horizontal flux of sand and the vertical flux of dust with the clay content of the soil. Marticorena and Bergametti presented an equation for the ratio of the mean of the total vertical flux to the total horizontal flux versus soil clay content for soils with a clay content of less than 20%, which is presented in Table 1. Although this scheme simply shows the equation of vertical dust flux with threshold friction velocity for different soils, it does not apply to soils with a clay content greater than 20%, and no physical processes are included in this parameterization (Marticorena and Bergametti, 1995). In Lu and Shao schemes (1999), the vertical dust flux is estimated based on the volume of particles removed from the soil surface due to the mutation process. The amount of particles removed from the surface is proportional to the velocity of the particles during the jump. In this scheme, the experimental equation of vertical dust flux is obtained by modeling the mutation process for particles with an angle of a collision of 13. Shao (2001) proposed a new method for parameterizing dust emissions based on two mechanisms: jump bombardment and lump decay. The amount of dust emitted from the mutant bombardment is estimated by modeling the volume removed from the soil surface (Lu and Shao, 1999). In determining the amount of dust emission from the lump decay mechanism, it is assumed that the lump only occurs due to the disintegration of soil particles when it strikes the surface. Shao proposed an equation for dust emission and assumed in this equation that dust particles are divided into the size I range. Shao (2004) considered a further simplification of the equation and determined the emission rate of particles with diameter d_i, Which is obtained by mutating particles to diameter d_s (Shao, 2004). The equations for each of these parameters and schemas are given in Table 1. Finally, the results of the hourly data obtained from the model were compared with the data of the WRF model. The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications. For researchers, WRF can produce simulations based on actual atmospheric conditions (i.e., from observations and analyses) or idealized conditions (NCAR, 1990).

Results

Meteorological conditions dominant in the atmosphere at the time of the occurrence of the dust phenomenon in Khuzestan province, according to the Lashkari and Sabuei (2013) study, have 4 different patterns:

In the first model, at sea level, the low-pressure tongue along the southeast-northwest of the Pakistani low-pressure center, after passing through the south of the country, covers southwestern Iran and creates unstable conditions on the ground. These conditions dominant in the region before the onset of the storm, and as the days of the storm approached, the Pakistani low-pressure center shifted to the west and dominated southeastern Iran. At the levels of 850 and 700 hPa, the center of anticyclonic is located on the Arabian Peninsula, and despite the fact that at the above levels, a relatively deep trough dominates the study area and the study area is in front of the trough and has good instability, due to the establishment of the Saudi anticyclonic on the peninsula, prevents the supply of moisture into the transmission systems in the region and dry air prevails in the region, and due to strong winds and good instabilities in the region, dust rises in the south of Iraq and Khuzestan. In the second type of model, at sea level, the low-pressure tongue extends from the low-pressure center in northeastern Saudi Arabia and southeast of Iran to southwestern Iran, and this low-pressure thermal tongue causes instabilities on the ground that are accompanied by relatively strong winds. At the 850 hp level, the placement of a low tongue on the area indicates an instability depth of up to 850 hp. At the level of 700 hPa, a ridge along the high-pressure tongue, which in this model is located in North Africa, extends over the study area and provides dry and stable air at the level of 700 hPa and above. In this model, the predominant synoptic conditions are such that the prevailing instability is the lack of sufficient moisture in the system and manifests itself in the form of severe storms with dust. In the third type model, at sea level, the center of low pressure is located on the northeast and east of Saudi Arabia, whose tongue extends along the southeast-northwest to the south of Turkey. In this way, instabilities resulting from low thermal pressures prevailing in the region are created and cause relatively strong wind currents on the ground. However, at the levels of 850 and 700 hPa, due to the establishment of an anticyclonic center in Egypt and the north of the Red Sea, the ridge of it extends to the southwest of Iran and a stable climate prevails over the study area and western Iran. As a result, ground dust cannot be distributed and spread to higher layers and increases the concentration of pollution on the ground. In the fourth type model at sea level, the presence of a low-pressure dynamic center on the eastern Mediterranean and the presence of a high-pressure tongue from Siberia on Iran creates a strong thermal gradient on the region. However, despite the location of a trough at 850 and 700 hPa due to the location of the Saudi anticyclonic center on the Arabian Peninsula and the transfer of hot and dry air over the region and the prevention of moisture injection into the low surface pressure system, instabilities in the form of round storms and the dust pretends (Lashkari and Sabuei, 2013).

Results of meteorological parameters

Solar radiation flux

Figure 2 shows the amount of solar radiation flux overtime on the 26th and 27th of January. As shown in the figure, the solar radiation flux is minimum at 0 and 24 hours on the 26th and It is at the highest value at 24 on the 27th of January, and at noon on the 26th and 27th.

Solar height

The amount of solar height (vertical axis) in terms of time (hour) on the 26th and 27th days of January 2017 is shown in Figure 3. The amount of solar height fluctuates regularly so that at 5 and 19 hours on the 26th of January, 5 and 19 hours on the 27th, it is zero and at noon on every two days, It's on the maximum value (80 degrees).

Critical solar height

The critical solar height for the period under study is shown in Figure 4. As shown in the figure, the changes in this parameter during this day's cycle are oscillating, so that at 0, 10, 14, and 24 hours on January 26th and at 9 to 15 and 24 hours on January 27th, this value is zero. And at 5, 19 hours, on 26th, and at 5 and 20 hours on January 27th, is on the maximum value (16.5 degrees).

Albedo coefficient

The figure below shows the amount of albedo (vertical axis) in terms of time (clock) on January 26 and 27, 2017. The changes in the albedo coefficient are similar to the changes in the critical solar height parameter. At 5, 19 on 26th, and at 5 ,20 hours on 27th, it has the highest value (0.65), and at 0, 10, 14, and 24 hours on the 26th of January, and 9 to 15 and 24hours on the 27th of January is zero.

Sensible heat flux

The rate of change in the Sensible heat flux (vertical axis) in terms of time (clock) on January 26th and 27th, 2017, from the early hours of the day to noon, shows an upward trend and after that a downward trend (Figure 6).

Net radiation flux

Figure 7 also shows the amount of net radiation flux in terms of time, which like the Sensible heat flux, reaches its maximum value at 12 hours every two days 26 and 27 (700 w/m2), and at 0 and 24 on 26th and 24 hours on 27th is the minimum.

Friction velocity

This parameter shows changes with more severe fluctuations on day 26 than on day 27. So that on day 27 at 1 to 12 o'clock the rate of friction is zero. The highest friction speed is related to the 26th day with a value of 0.75 m/s and the highest value on the 26th day is 0.37 m/s.

3-1-8 Monin Obukhov length

The rate of change in the length of the Monin-Obukhov over time is shown in Figure 9. This parameter shows an almost constant state for the period under study and has almost regular and constant changes. Except at 6 o'clock on January 26, when we see a sharp drop in this parameter.

Convective velocity

Figure 10 shows the rate of change in convective velocity over time. This parameter changes the instability at different times of the day, and on the 26th we see more fluctuations of this parameter than on the 27th. The maximum amount of convective speed (vertical) is 2 m/s, which is related to the 26th, and the lowest value of 0 is related to the 1 to 12 hours of the 27th of January.

Mixing height

As can be seen, this parameter fluctuates more sharply on the 26th than on the 27th, so that on 27th from 12 to 12 o'clock the mixing height is zero. The maximum mixing height is related to 26th with a value of 150 meters.

Wind speed and wind speed profile

Figure 12 shows changes in wind speed over time. The rate of change of this parameter is similar to the change in mixing height, and on the 26th day, this parameter is more unstable and has more fluctuations than on day 27. On day 27 at 1 to 12 o'clock, the wind speed is zero and the maximum wind speed is on day 26 with 14 meters per second. The wind speed profile is shown in Figure 13 at different times. As the altitude increases, the wind speed increases. At some times the velocity change was greater and at other times (t = 30 and t = 35) the velocity was zero.

Temperature and temperature profile

Temperature changes in different hours of January 26 and 27, in the early hours of the day, is up and afternoon. The highest temperature on the 26th and 27th days is at noon, and the lowest is at the 1 and 24 hours on the 26th day and at the 24 hours on the 27th of January. Temperature profiles are shown in Figure 15 at different times. As can be seen, the temperature changes are low because it has been studied up to a height of 100 meters and there is no noticeable temperature change up to this height.

Horizontal and vertical turbulence profiles

Figures 16 and 17 show the vertical and horizontal turbulence profiles at different times. As can be seen in the figure, the vertical and horizontal turbulence has changes that are due to the existence of stable conditions.

Dust emission results

Soil particle size distribution

Figures 18 and 19 show the changes in the soil particle size distribution at minimum disturbed and scattering in terms of particle diameter (micrometer). As can be seen in the figure, as the particle diameter increases, the amount of soil particle size distribution decreases in the case of minimally disturbed and fully disturbed. Smaller particles (10 and 60 micrometers) are more suitable for particle size distribution in the minimum scattering mode (Figure 18). Figure 20 shows the changes in the soil particle size distribution in the two modes of minimally disturbed and fully disturbed.

Erosion Threshold Speed

The erosion threshold velocity (threshold frictional velocity) is shown in Figure 21 in terms of particle diameter (micrometer). As can be seen, with increasing particle diameter, the rate of erosion threshold increases. But when the particle diameter is less than 50 micrometers, this is a downward trend, and as the particle diameter increases, the erosion threshold rate decreases.

White and Owen horizontal flux

Figures 22 and 23 show the horizontal flux of White and Owen according to the frictional velocity of the wind. As the wind frictional velocity increases, the horizontal flux from Marticorena-Bergametti, Lu, and Shao schemas also be increased.
After examining the horizontal flux of White and Owen in terms of speed, Figures 24 to 26 show these parameters in terms of time changes. On the 26th day, this parameter has more fluctuations than on the 27th day, and at noon on the 26th day, it has the highest value and in the first and last hours, it has the lowest value. On the 27th, only in the middle of the day, the value of these parameters is about 0.3(µg/s/m2), and in the rest of the hours, it is zero.

Vertical flux obtained from Martikorna-Bergamati and Lu and Shao

Figures 27 and 28 of the vertical flux from the Marticorena-Bergametti and Lu and Shao schemas are shown in terms of changes in wind frictional velocity. As the wind speed increases, the amount of vertical flux from the Marticorena-Bergametti and Lu and Shao schemas has increased. Figures 29 and 30 show the amount of vertical flux from the Marticorena-Bergametti and Lu and Shao schemas in terms of time changes. On the 26th, in the early hours, the amount of Vertical flux is upward and after 12 o'clock, it is declining, but on the 27th, the amount of vertical flux is zero except at 12 o'clock.

Dust concentration maps

Dust concentration maps were prepared in the study area on January 26 and 27, 2017, which are shown in Figures 31 to 45. The lowest dust concentration is 150.00 micrograms per cubic meter and the highest dust concentration is 5446.12 micrograms per cubic meter. In the early hours, the direction of the dust flux is northward and slightly inclined to the northwest, then at 8 o'clock it begins to change direction to the northwest, and at 4 pm it changes direction to the west and slightly inclined to the southwest.

From 5 pm on the 26th of this month until 1 pm on the 27th of January, the dust in the dust enters the zero zone, and the reason is that the frictional speed is zero in the periods mentioned. From 14:00 on the 27th of January, due to the change in wind direction and the presence of dust centers, the direction of the dust mass in the study area has changed to the east (39) and in the remaining hours, the direction and direction of the dust flux have shifted to the southeast.

Evaluate the results with WRF model outputs

In this study, to evaluate the results of the model obtained in the study area, the hourly data extracted from the analytical model obtained in the study were compared with the hourly data of the WRF model extracted from the Meteorological Center's National Dust Center website[†] , and was evaluated. The results were not evaluated with field data due to the lack of dust data on the 26th and 27th days of January. Evaluation of simulation and estimation data showed that the value of correlation coefficient (R) between hourly data extracted from the model and the hourly data of the WRF model was 0.84, which according to Sig. With less than 0.01, the correlation between them is significant with 99.99% confidence (Table 2). It is worth mentioning that the coefficient of determination has been obtained is R^2:0/70 and RMSE:11/1698. Figure 46 shows the evaluation diagram of the simulated results with WRF data.

Discussion and Conclusion

The purpose of this study is to determine the dust distribution model in the Mahshahr region. By reviewing and coding each of the meteorological parameters and dust flux on the 26 and 27 days of January 2017, the dust emission map of the study area and the evaluation of the resulting model with field data and WRF model have been prepared. The Mahshahr region was selected because it is one of the most important centers of domestic dust, and southeast winds can direct dust from this region in densely populated areas such as Ahvaz.

The results of the meteorological parameter evaluation showed that the solar radiation flux has an upward trend in the early hours of the day and a downward trend afternoon, The solar height at noon on January 26th and 27th are at its highest value, changes in the amount of critical solar height during these two days are fluctuating, the amount of albedo coefficient changes a lot during the day, It has a maximum value at 4 and 18 hours and averages 0.29 units during the day, It is consistent with other studies such as Hejazizadeh et al. (2017), which addressed the spatial-temporal modeling of Albedo in the scope of Iran and according to which the average Albedo for Khuzestan province is 0.236. Sensible flux shows an upward trend from the first hours of the day to noon and then a downward trend. During the period under study in the half of each day (noon), the amount of net radiation flux reaches its maximum value (700 w/m2), and early and late in the day is the minimum amount, which compared with the research Roshani et al. (2014) that calculated for Khuzestan province in March at noon with a net radiation level of less than 500 w/m2 it's reasonable; Changes in the rate of friction speed on day 26 show more severe fluctuations than on day 27, the length parameter of Monin Obukhov length shows almost constant stability during the day and has almost regular changes instability. The convection velocity has unstable changes at different times of the day and has more fluctuations on the 26th day. The mixing height on the 26th day has more severe changes than on the 27th day. The wind speed parameter has more severe and unstable fluctuations on the 26th day than on the 27th day. And on average, the calculated

[†] http://dust.irimo.ir/far/

wind speed for the 26th day is 8.3 and the 27th day is 3.4 meters per second. This calculated value is consistent with a study conducted by Khosravi et al. (2016) to investigate the wind energy situation in Khuzestan province.

The results of the evaluation of dust input parameters to the study area showed that as the particle diameter increases, the amount of soil particle size distribution decreases in the minimum scattering mode and complete scattering, and smaller particles (10 and 60 μm) are more suitable for particle size distribution in the minimum scattering mode. Also, the study of erosion threshold velocity (threshold frictional velocity) in terms of particle diameter (micrometer) showed that with increasing particle diameter, the rate of erosion threshold increases, Nourafar et al. (2014) also stated that, If the diameter particles increase, the rate of erosion threshold will also increase. In this study, this trend is except that when the particle diameter is less than 50 micrometers, in this case, the trend is declining and smaller particles require a higher erosion threshold speed. Research by Bagnold et al have shown that if the diameter of the particles is 0.1 or less, the rate of erosion threshold will increase (Refahi, 1999). The study of dust concentration maps of the study area on 26 and 27 January 2017 showed that the lowest dust concentration is 150.100 micrograms per cubic meter and the highest dust concentration is 544.12 micrograms per cubic meter. In the early hours, the direction of the dust flux is northward and slightly inclined to the northwest, then at 8 o'clock it begins to change direction to the northwest, and at 4 pm it changes direction to the west and slightly inclined to the southwest. From 5:00 PM on the 26th of January to midnight on the 27th of January, the dust entering the area is zero, and the reason is that the frictional speed is zero in the mentioned periods. Since 13:00 on the 27th of January, due to the change of wind direction and the presence of dust centers, the direction of the dust flux in the study area has changed to the east and in the remaining hours, the direction and direction of the dust flux have shifted to the southeast. The study of the amount of accumulated dust entering the Mahshahr region showed that the lowest dust concentration is 150.00 micrograms per cubic meter and the highest dust concentration is 13090.04 micrograms per cubic meter. In the early hours of the 26th of January, the direction of the dust flux is to the north and slightly inclined to the northwest, and then it is inclined to the northwest to the dust flux. And this shows that the dust entering the study area on the two days of the 26th and 27th of January is due to internal centers and the presence of westerly winds. Due to the mathematical nature of the model, access to more accurate data is necessary to achieve a result that is more consistent with reality. In other words, although the identification of equations and relationships between natural phenomena, such as wind speed and erosion rate, temperature intensity and air rise rate, soil type and texture, and their resistance to erosion and other factors play an important role in predicting dust, Accurate results cannot be obtained to predict when model inputs differ from reality. The R correlation index for the period under study was 0.84, which indicates the high accuracy of the model.

One of the advantages of the Gaussian model is that it can provide simulation results on an hourly basis. Control of dust storms and movement of sand dunes in the springs is the most basic way to control them. One of the most important results of this study is that the source of dust particles in the study area is determined and it is possible to estimate the number of dust particles in different sizes by this method and identify the critical center of dust. Evaluation of the model using WRF data suggests that the model can model the dust.

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