Earth Syst. Dynam. Discuss.,
https://doi.org/10.5194/esd-2019-28-AC1, 2019

Earth System Dynamics Discussions
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Interactive comment on "Organization of Dust Storms and Synoptic Scale Transport of Dust by Kelvin Waves" *by* A. K. Pokharel and M. L. Kaplan

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Received and published: 3 August 2019

Dear Sir/Madam,

We hereby submit our revised manuscript "Organization of Dust Storms and Synoptic Scale Transport of Dust by Kelvin Waves" to the Earth System Dynamics journal with revisions to be considered for publication after incorporating our response regarding comments and suggestions provided by the 1st referee as follows:

Referee comments (RC1) An attempt is made to investigate the role of Kelvin waves in the development of dust storms for three cases involving orography, with the aid of WRF model simulations and satellite images. Despite the fact that I recognize that the investigation of this role is very interesting, my basic comment is that the analysis

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lacks of important evidence of the development of Kelvin waves. More specifically: 1. The authors support their statement on the temperature distribution of Figure 6 and geopotential in Figure 7 and vertical cross sections of potential temperature in Figure 8. First of all, these distributions are very messy and it is hard to recognize any patterns. Second, I think that the waves should be identified as streamline patterns or as geopotential anomalies or as anomalies of meridional wind. These plots are missing. Similar comment for the third case 2. Page 7, lines 30-35: The station locations should be displayed on the map. Similarly with other locations referred in the manuscript 3. Section 2.2: I do not understand the reason for simply mentioning the finding that in the second case there is no evidence of development of Kelvin waves. The authors should get a better insight to investigate the reason for this, since the three cases are selected based on common criteria, involving the presence of orography. For instance, a first explanation could be related with the simulation of the case or with lack of data as compared to the other two cases. If not, the role of the orography is very likely to play a different role in this case. 4. I think that the structure of the paper should be modified. Section 3 should involve the Harmattan dust storm (3.1 Observational and model analysis, 3.2 WRF simulations) Section 4 should involve the second case and Section 3 the third case. 5. The conclusions are very poor and should be extended.

1 Referee comment: An attempt is made to investigate the role of Kelvin waves in the development of dust storms for three cases involving orography, with the aid of WRF model simulations and satellite images. Despite the fact that I recognize that the investigation of this role is very interesting, my basic comment is that the analysis lacks of important evidence of the development of Kelvin waves. More specifically: 1. The authors support their statement on the temperature distribution of Figure 6 and geopotential in Figure 7 and vertical cross sections of potential temperature in Figure 8. First of all, these distributions are very messy and it is hard to recognize any patterns. Second, I think that the waves should be identified as streamline patterns or as geopotential anomalies or as anomalies of meridional wind. These plots are missing. Similar comment for the third case.

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Our response: We appreciate your comments and suggestion. We would like to clarify that Figures 6a-c presented here are showing the wind flow pattern, but not the temperature distribution. This wind flow, which is shown by the blue arrow, is parallel to the mountains - a fundamental character of Kelvin waves formed along the boundaries of topography. Please note that we have drawn the two major streamlines that define Kelvin wave motion in the Figures 6b and 6c of the revised manuscript. First, the acceleration parallel to the mountain with a slight right turn in response to the Coriolis force. Second the mountain-perpendicular acceleration in response to the rapid mass build-up consistent with leeside cooling. Note that in response to your issue with the complexity of the height fields in the previous Figure 7 we removed that figure as well as the similar Figure 14. The streamline additions are added on the caption of Figures 6b-c of the revised manuscript. Similarly, new Figures 7a and 7b of the revised manuscript show blockage of the cold air column by the mountain range and generation of the initial mass impulse (consistent with Figure 6b). New Figures 7c and 7d are showing evolution of Kelvin waves, a cold edge wave after the excess mass release and new Figures 7e and 7f depict Kelvin waves as a northeasterly wind signal directed towards the southwest of the Atlas Mountains. New Figure 7g depicts the vertical stretching of isentropic surfaces consistent with dynamical destabilization and hence deep mixing, i.e., a favorable region of dust emission after the generation of significant turbulence kinetic energy with the interaction of Kelvin waves (wind shear) (new Figures 7e and 7f) with buoyancy (new Figure 7g) thus resulting in TKE generation. For the 3rd case (Bodele Depression case) similar explanations are applied as discussed for the case 1 (new Figures 6 - 7). New Figures 10 and 11 of the revised manuscript are for the similar explanations for the third case.

2 Referee comment: Page 7, lines 30-35: The station locations should be displayed on the map. Similarly with other locations referred in the manuscript.

Our response: The station locations for two cases (Harmattan and Bodele Depression cases) are displayed on the maps of the revised manuscript (Figures 2b and 8b).

3 Referee comment: Section 2.2: I do not understand the reason for simply mentioning the finding that in the second case there is no evidence of development of Kelvin waves. The authors should get a better insight to investigate the reason for this, since the three cases are selected based on common criteria, involving the presence of orography. For instance, a first explanation could be related with the simulation of the case or with lack of data as compared to the other two cases. If not, the role of the orography is very likely to play a different role in this case.

Our response: We appreciate your concerns. We also think that it is not worthwhile to include the Saudi case in section 2.2 (in old manuscript) for the convenience of readers since we do not have unambiguous signals of Kelvin waves formation in this case though we carried out detail analyses with the help of observational and WRF model data sets as we did for the other two cases (Harmattan and Bodele Depression). So, we have removed section 2.2 in the revised manuscript. This information is also included in the conclusion of the revised manuscript. Please do understand that all validation of the Saudi Case indicated that the simulation was accurate but the dynamics not necessarily the same as the other two case studies.

4 Referee comment: I think that the structure of the paper should be modified. Section 3 should involve the Harmattan dust storm (3.1 Observational and model analysis, 3.2 WRF simulations) Section 4 should involve the second case and Section 3 the third case.

Our response: Yes, we have modified the structure in the revised manuscript.

5 Referee comment: The conclusions are very poor and should be extended.

Our response: Yes. We have extended the conclusions in the revised manuscript.

Sincerely, Ashok Kumar Pokharel

Interactive comment on Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2019-28, 2019.

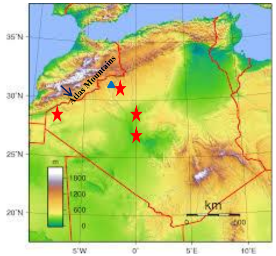
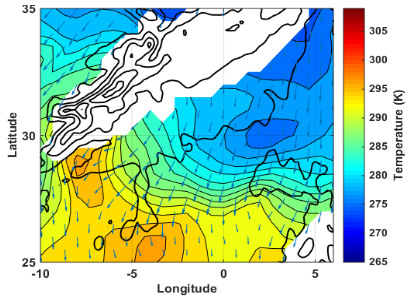


Figure 2b: Topographical map of Algeria (http://www.carte-algerie.com/carte-algerie/carte-topographique-algerie.jpg) in which the red star indicates surface stations (Bechar, Tindouf,Timimoun, and Adrar) which experienced the dust storms on 2 March 2004 (source: wunderground.com). The blue colored triangle indicates soundings station at Bechar in Algeria.

Fig. 1.

Figure 6



(a)

Fig. 2.

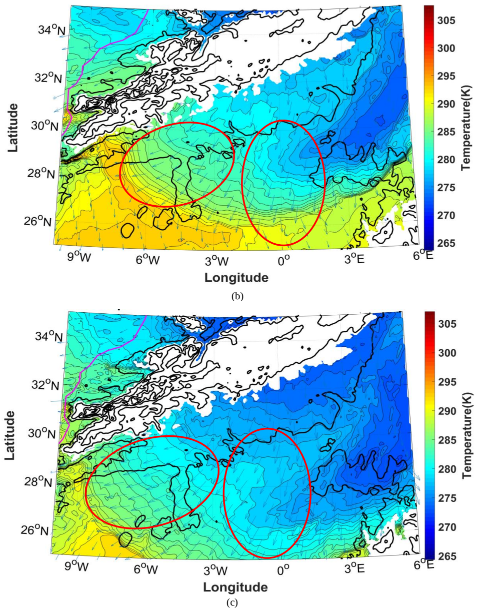


Figure 6 a. Temperature and wind speed/direction at 925 hPa on 1800 UTC March 2, 2004 (54 km resolution MERRA product) (Pokharel, 2016). Blue arrow lines indicate the wind flow. **b**. Temperature and wind speed/direction at 925 hPa on 1800 UTC March 2, 2004 (6 km resolution WRF product). Blue arrow lines indicate wind flow. The red circled areas represent the turning of the one wind component to the right in response to the Coriolis force and another component was turning to the left away from the mountains farther north and east as it goes south-southwestwards. **c.** Temperature and wind speed/direction at 925 hPa on 2200 UTC March 2, 2004 (6 km resolution WRF product). Blue arrow lines indicate wind flow. The red circled areas represent the turning of the one wind component to the right in response to the Coriolis force and another component was turning to the left away from the mountains farther north and east as it goes south-southwestwards.

Fig. 3.

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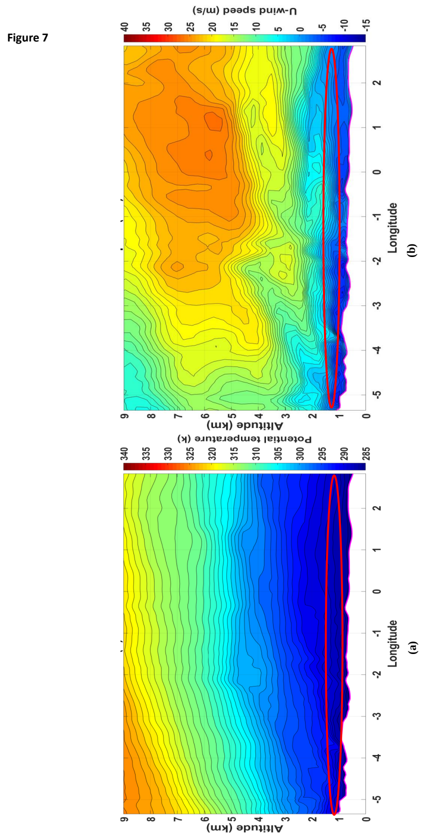

Fig. 4.

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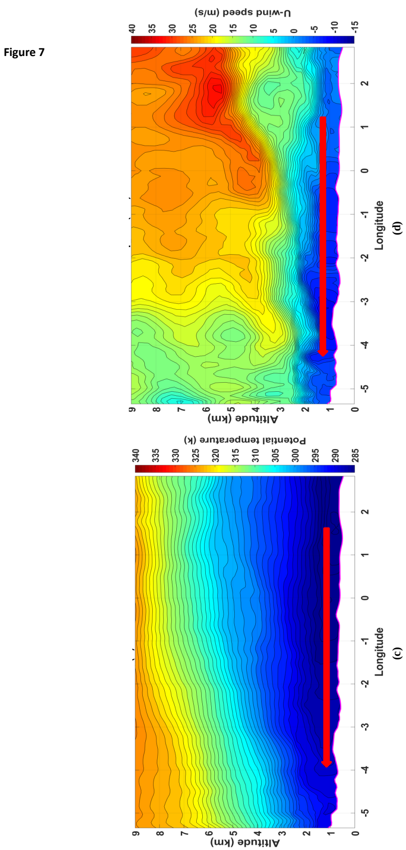

Fig. 5.

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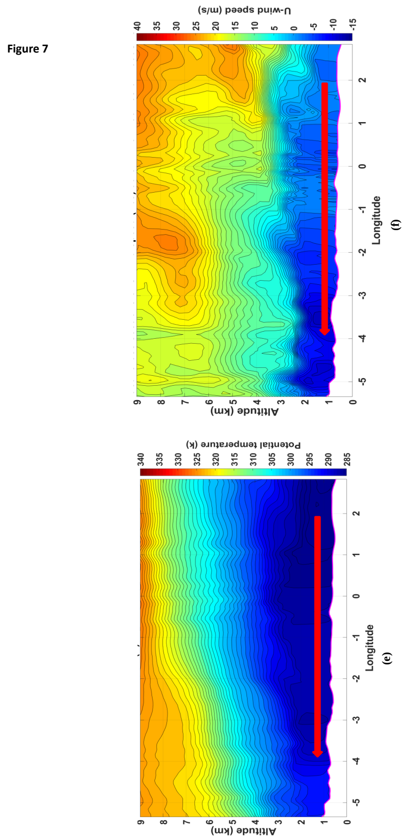

Fig. 6.

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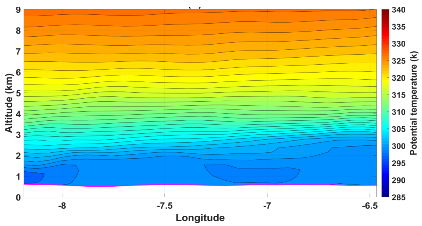

(g)

Figure 7 a. Vertical cross sections of potential temperature at 31.1° N on 0700 UTC March 2, 2004 (6 km resolution WRF product). Red circle indicates region of sinking of air column (blocking of air). **b.** Vertical cross sections of u-wind speed at 31.1°N on 0700 UTC March 2, 2004 (6 km resolution WRF product). Red circle indicates region of blocking of air. **c.** Vertical cross sections of potential temperature at 31.1°N on 1100 UTC March 2, 2004 (6 km resolution WRF product). Red arrow indicates generation of Kelvin waves (cold air surge). **d.** Vertical cross sections of u-wind speed component at 31.1° N on 1100 UTC March 2, 2004 (6 km resolution WRF product). Red arrow indicates generation of Kelvin waves. **e.** Vertical cross sections of potential temperature at 31.1°N on 1500 UTC March 2, 2004 (6 km resolution WRF product). Red arrow indicates Kelvin wave (cold air surge) over time. **f.** Vertical cross sections of u-wind speed at 31.1°N on 1500 UTC March 2, 2004 (6 km resolution WRF product). Red arrow indicates Kelvin wave over time. **g.** Vertical cross sections of potential temperature at 28.85°N on 1500 UTC March 2, 2004 (6 km resolution WRF product).

Fig. 7.

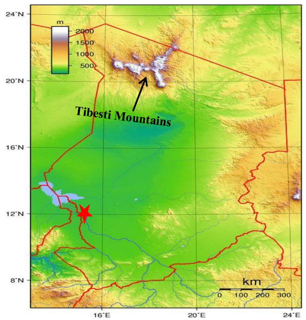

Figure 8b: Topographical map of Chad (https://www.pinterest.com.au/pin/510877151474548010/). The red star in this map shows surface station at Ndjamena in Chad which captured the dust storms from 0600 UTC on December 8 to December 9, 2011 (source: wunderground.com) (Pokharel et al., 2017b).

Fig. 8.

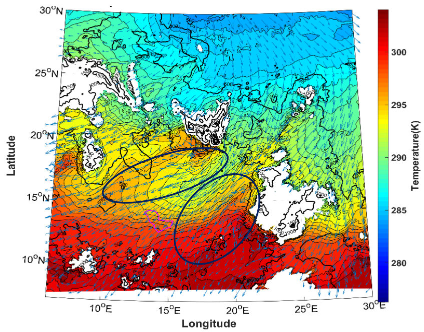

Figure 10. Temperature and wind speed/direction at 925 hPa at 1800 UTC on December 8, 2011(6 km resolution WRF product). Blue arrow lines indicate the wind flow. Blue circled areas indicate one wind component was flowing west-southwest close to the mountains as it turns to the right and the other wind component was turning to the left away from the mountains farther north and east as it goes south-southwestwards.

Fig. 9.

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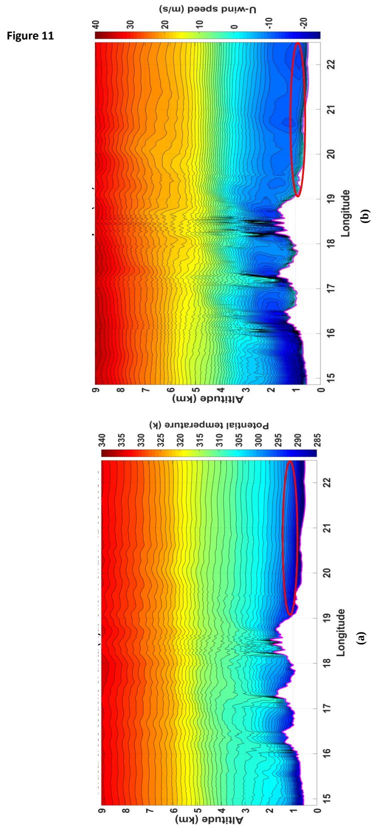

Fig. 10.

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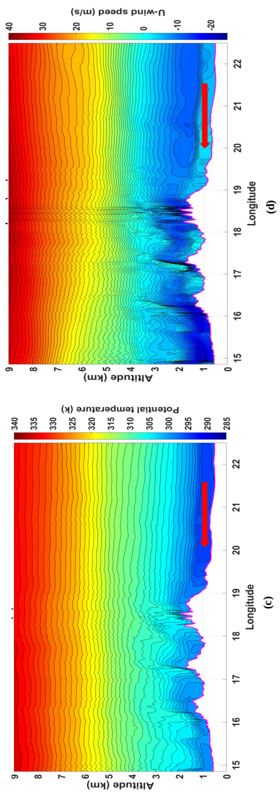

Fig. 11.

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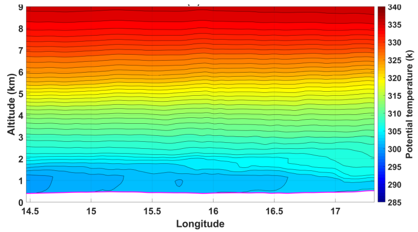

(e)

Figure 11 a. Vertical cross sections of potential temperature at 21.57° N on 0700 UTC December 8, 2011 (2 km resolution WRF product). Red circle indicates possible stability of the atmosphere. **b.** Vertical cross sections of u-wind speed at 21.57°N on 0700 UTC December 8, 2011 (2 km resolution WRF product). Red circle indicates blocking of the air. **c.** Vertical cross sections of potential temperature at 21.57°N on 1100 UTC December 8, 2011 (2 km resolution WRF product). Red arrow indicates Kelvin wave (cold air surge). **d.** Vertical cross sections of u-wind speed at 21.57° N on 1100 UTC December 8, 2011 (2 km resolution WRF product). Red arrow indicates Kelvin wave. **e.** Vertical cross sections of potential temperature at 18.89°N on 1500 UTC December 8, 2011 (2 km resolution WRF product).

Fig. 12.