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Observation and numerical simulation of dust devils at the Hong Kong International Airport in sea breeze situation

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सार — इस शोध पत्र में हांगकांग की ग्रीष्म ऋतु में लगातार दो दिनों में हांगकांग अंतरराष्ट्रीय हवाई अड्डे पर आए अंधड़ों का दस्तावेजीकरण किया गया है। वे समुद्री हवाओं के अभिसरण रेखाओं से संबंधित पाए गए हैं और ये प्रति चक्रवातीय हैं। यहाँ मौसम संबंधी स्थितियों का दस्तावेजीकरण किया गया है जिनके तहत अंधड़ की घटनाएँ घटित होती हैं। समुद्री हवा अभिसरण रेखा पर छोटे प्रति चक्रवातीय प्रवाह के कंप्यूटर सिमुलेशन का अध्ययन किया गया है। इस शोध पत्र में असमान भूभाग में समुद्री हवा परिसंचरण के सूक्ष्म पैमाने के सिमुलेशन में कठिनाइयों और अंधड़ प्रवाह के घूर्णन की स्थिति के सफलतापूर्वक उत्पन्न होने पर चर्चा की गई है। आशा है कि यह शोध पत्र अंधड़ों के अध्ययन के साहित्य में एक उपयोगी संदर्भ बन सकेगा।

ABSTRACT. Dust devils at Hong Kong International Airport in two consecutive days in the summer of Hong Kong are documented. They are found to be related to the sea breeze convergence lines and are anticyclonic. The background meteorological conditions under which the dust devils occur are documented. The computer simulation of the tiny anticyclonic flow at the sea breeze convergence line is studied. This paper discusses the difficulties in the micro-scale simulation of the sea breeze circulation in an area of complex terrain and the successful reproduction of the sense of rotation of the dust devil flow. It is hoped that the paper could be a useful reference for the studies of dust devils in the literature.

Key words – Dust devils, Hong Kong International Airport (HKIA), Sea breeze.

1. Introduction

With the construction site of the third runway at the Hong Kong International Airport (HKIA), dust devils had been observed over there a few times. One case in the northeast monsoon was reported in Chan and Li (2021). This paper documents two more cases of dust devils at the airport, namely, on sea breeze days at the airport for two consecutive days 14 and 15 July, 2021 under prolonged periods of sunshine.

A dust devil was observed in near the eastern end of the central runway of HKIA in the early afternoon of 14 July, 2021 [Fig. 1(a)]. It extended to several hundred metres above the ground level and dissipated after a few minutes. But another dust devil was then formed at a couple of hundred metres away from it subsequently [Fig. 1(b)]. The second dust devil also dissipated after another few minutes. On the second day (15 July, 2021), at around 3 pm local time (0700 UTC, with Hong Kong time = UTC + 8 hours), a weaker dust devil (compared with the two in 14 July, 2021) was observed around similar location (Fig. 2). On both days, there were prolonged periods of sunshine at HKIA, with temperatures reaching 33-34 degrees Celsius. Sea breeze circulations were observed in the airport area and the dust devils appeared along the sea breeze fronts on these two days.

Due to complexity of the terrain, the sea breeze at HKIA takes on a number of different configurations and its airflow becomes more complicated with the construction of the third runway. High resolution

Figs. 1(a&b). The photographs of the dust devils at HKIA on 14th July, 2021

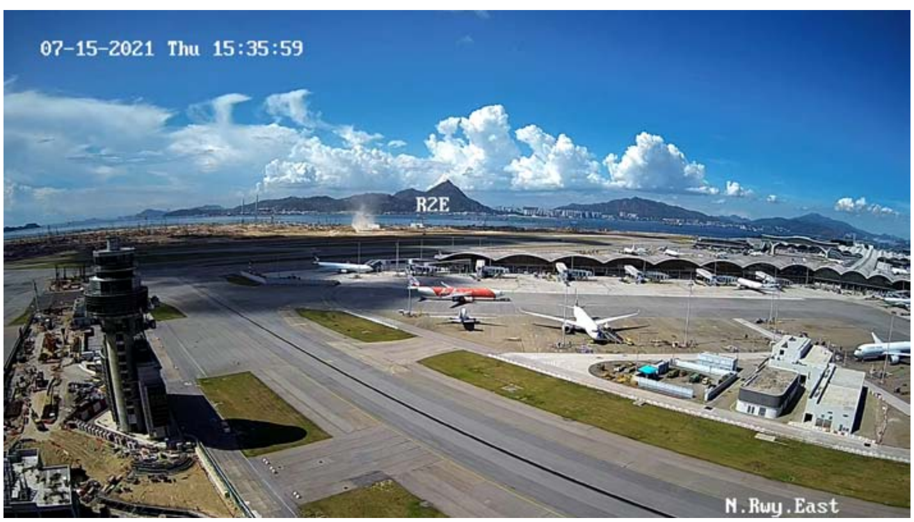
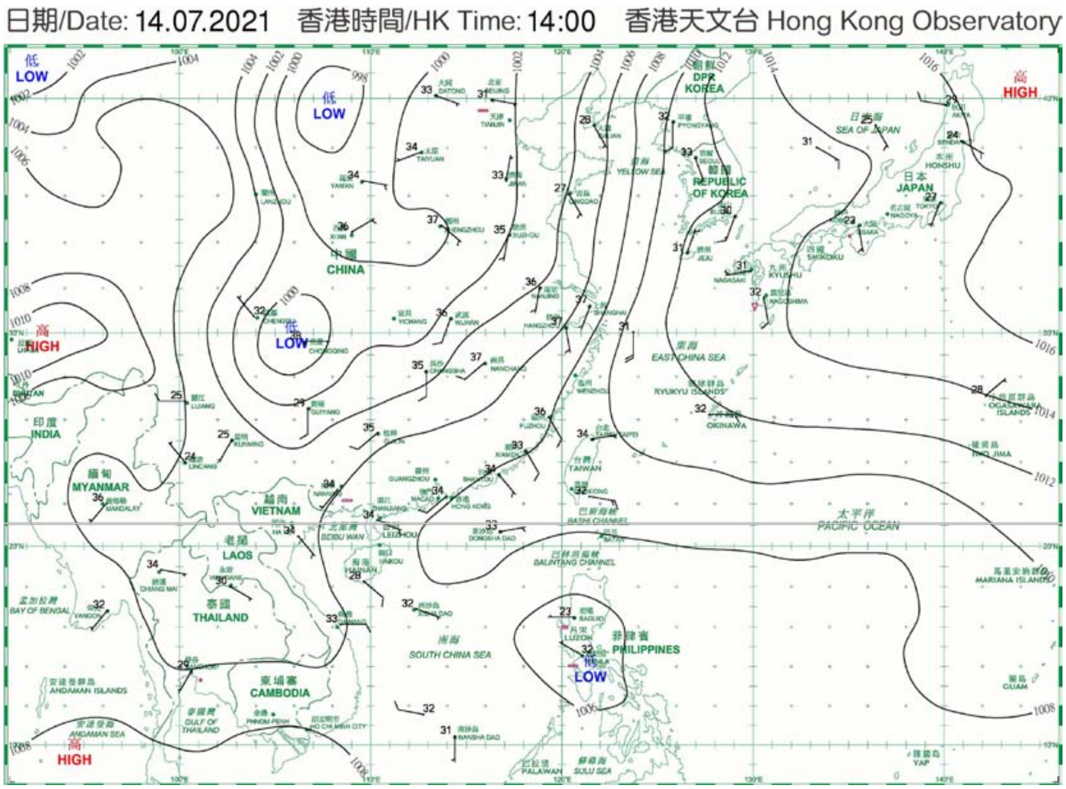
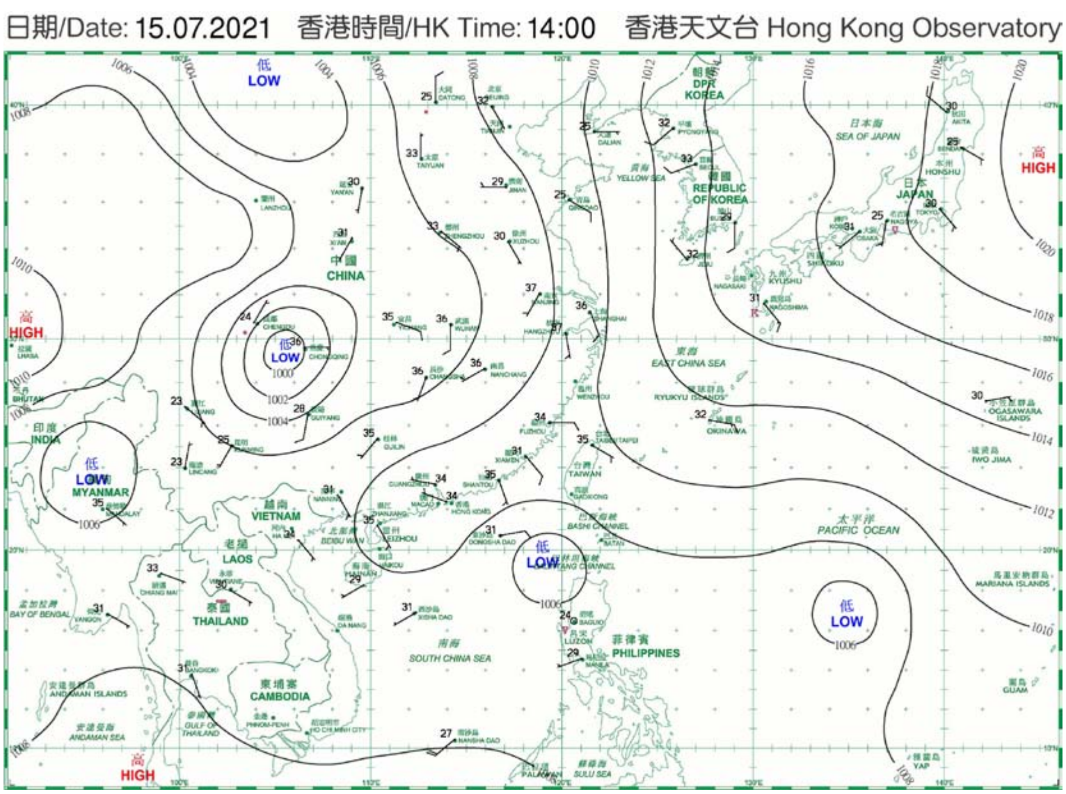


Fig. 2. The photograph of the dust devil at HKIA on 15th July, 2021

(a)

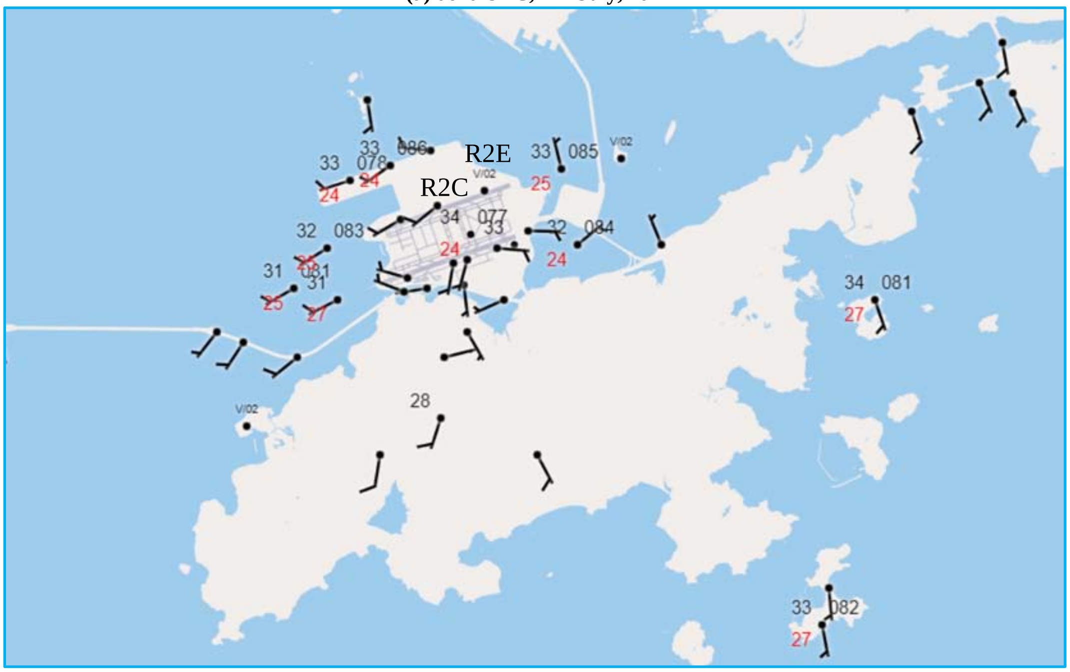


(b)

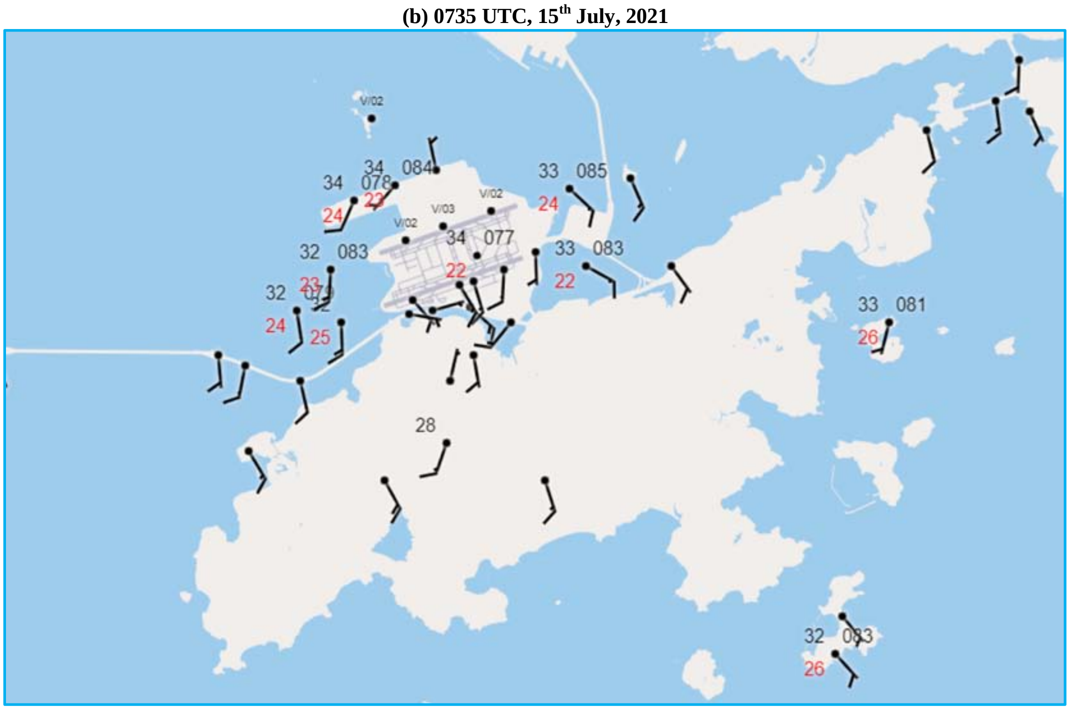


Figs. 3(a&b). The surface isobaric charts at 0600 UTC of 14th July, 2021 and 15th July, 2021

(a) 0610 UTC, 14th July, 2021



(b) 0735 UTC, 15th July, 2021



Figs. 4(a&b). The surface meteorological observations at the times of the dust devil observations. The dust devil occurred near R2C on 14th July & R2E on 15th July

numerical simulations are just performed to understand and predict the sea breeze circulation at HKIA under such conditions. This paper is also the first one documenting the sea breeze simulation at HKIA region under the three runway system. At the sea breeze front, it is common to small-scale cyclonic or anti-cyclonic circulations and they provide the background airflow for developing into dust devils under favourable meteorological conditions such as light winds in the background and super adiabatic lapse rate under the surface (Fujiwara, *et al*., 2011). The success and difficulties of sea breeze simulation at micro-scale at HKIA would also be briefly discussed in this paper.

Dust devils have been studied extensively in the desert areas of the world and urban areas. A review of the devil studies, including observations and meteorological conditions, could be found in Lorenz *et al*. (2016). In this paper, references would be made to the other studies, such as by Sinclair (1969). Numerical simulation of dust devil like vortices by large eddy simulations could be found in, *e.g*., Fujiwara *et al*. (2011) and Kanak *et al*. (2000). It is hoped that the paper could add to the literature of dust devil studies in the world and could serve as a reference to the observation and numerical simulation of dust devils at HKIA as well as other flat areas with sand, such as large-scale construction sites for airports, in other places in the world under prolonged heating conditions.

2. Background meteorological conditions

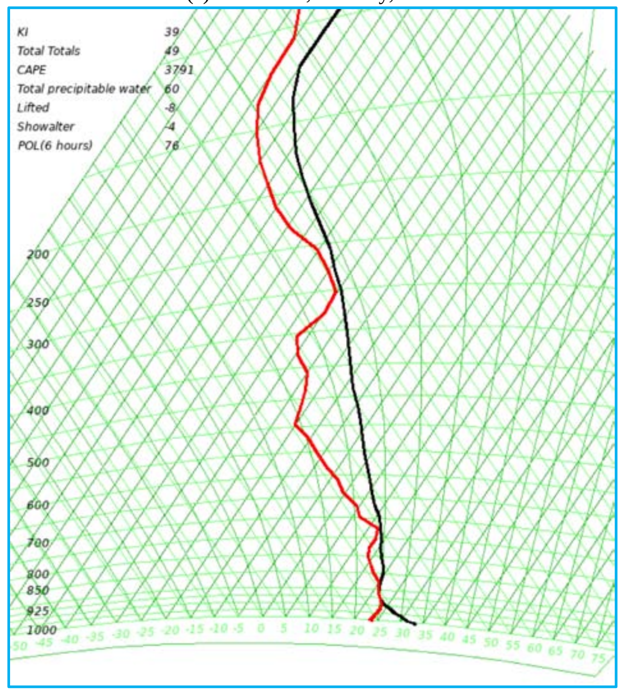
The synoptic weather conditions on 14 and 15 July, 2021 are summarized in the surface isobaric charts at 0600 UTC (2 pm local time) as shown in Figs. 3(a&b) respectively. The surface isobars are slackened along the south China coastal areas and there local winds were generally light south southeasterlies.

The wind data around the airport area in these two days are shown in Figs. 4(a&b). The winds were particularly light on 14 July, 2021, so that the sea breeze took on the form of west-southwesterly over most part of the airport [Fig. 4(a)]. At the same time, with the heating of the ground, the sea breeze took on the form of easterly on the eastern side of the airport. A north-south oriented sea breeze front occurred at the eastern part of the airport area. Over that region, dust devils appeared in the background cyclonic and anticyclonic circulations provided by the sea breeze convergence.

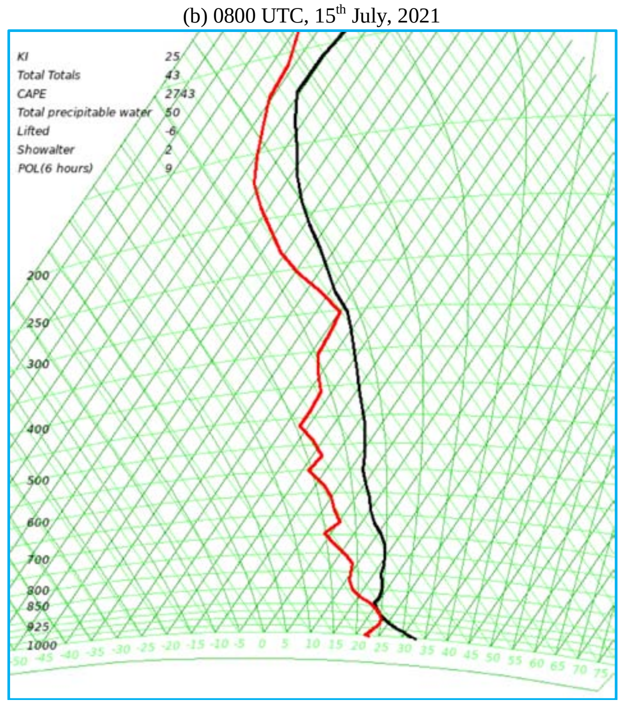
On the second day of 15 July, 2021, the background wind had more southerly component. The southerly flow passed through the gaps of Lantau Island (mountainous island to the south of HKIA) and prevailed over the southern part of HKIA [Fig. 4(b)]. With ground heating, sea breeze took on the form of light northerly at the northeastern part of the airport. Sea breeze convergence appeared at that part of the airport. Once again, the tiny cyclonic and anticyclonic circulations of the sea breeze convergence area provided the background for the appearance of dust devil.

The vertical temperature profiles at the airport area are captured by the microwave radiometer installed at the airport, with the temperature retrieval method summarized by Chan and Lee (2015). The profiles at 2 pm, 14 July,

(a) 0600 UTC, 14th July, 2021

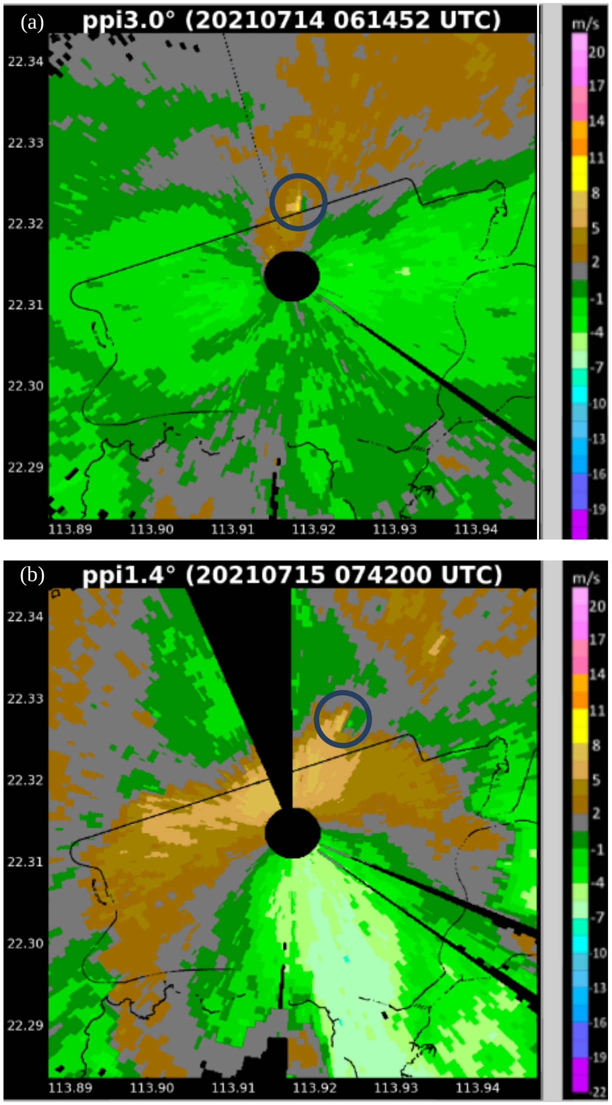


(b) 0800 UTC, 15th July, 2021



Figs. 5(a&b). Temperature (black) and dew point (red) profiles from the microwave radiometer at the airport

2021 and 4 pm 15 July, 2021 are shown in Figs. 5(a&b) respectively. Super-adiabatic lapse rates are observed in the surface layer of the airport. This is consistent with the observation of previous dust devil cases (Fujiwara *et al*., 2011) about the background meteorological conditions required for them to appear.



Figs. 6(a&b). Doppler velocity images from the north runway LIDAR at the times of dust devil observations on 14th July, 2021 and 15th July, 2021. The dust devil circulations are encircled

3. LIDAR observations

A number of Doppler Light Detection And Ranging (LIDAR) systems are operated at HKIA. The plan position indicator (PPI) scans from the north runway LIDAR are shown in Figs. 6(a&b) respectively for the dust devils on 14 and 15 July, 2021. 3-degree PPI scan is shown for the first case and 1.4-degree PPI scan is shown for the second case. The degree refers to the elevation angle from the horizon. The north runway LIDAR is located at tower at about 80 m above the ground surface. The line-of-sight velocity (or radial velocity) of the laser beam is shown in these figures. The red-shift colouring scheme is adopted, namely, brown/yellow meaning positive velocity, with the component of the velocity being away from the LIDAR location and green/blue meaning negative velocity, with the component of the velocity being towards the LIDAR location.

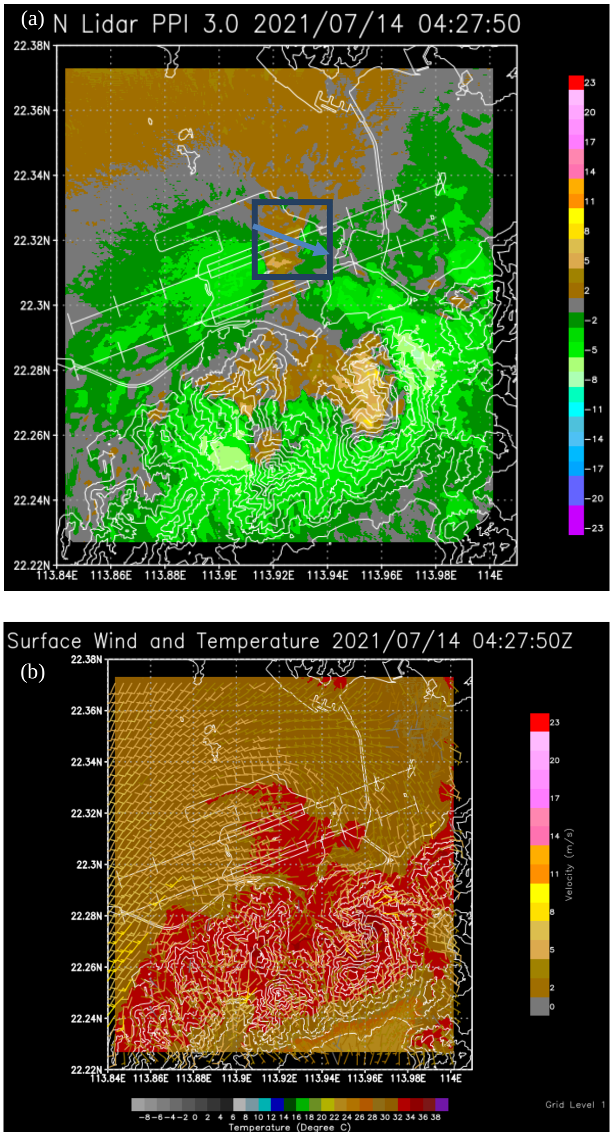
The LIDAR PPI velocity scans provide an overview of the velocity pattern at the airport area. Comparing Figs. 6 and 4, it could be seen that they are consistent with each other, showing the locations of the sea breeze convergence areas. At these sea breeze "fronts", tiny anticyclonic flow with a horizontal dimension of several hundred metres was observed and they are consistent with the observed location and sense of rotation of the dust devils by the weather observers stationed at the air traffic control tower of HKIA. The velocities of the dust devils were rather weak, with the radial velocities of several m/s only. This may partly be due to the averaging of the wind over the range gate of the LIDAR, which is configured to be around 100 m.

4. Numerical simulations

As mentioned in Section 1, for the difficulty for the numerical simulation of the dust devils on the two days under consideration lies on the reproduction of the sea breeze circulations in the airport area. As in the previous study by Chan and Li (2021), the Regional Atmospheric Modelling System (RAMS) version 6.3 is used in the current simulation. The initial and boundary conditions are taken from the 25-km horizontal resolution Global Forecast Model (GFS) of the U.S. Five nestings are performed, with the horizontal resolution going down to 5 km, 1 km, 200 m and 40 m in the innermost domain. The first vertical level has a height of around 30 m, with the stretching ratio (ratio of the height of one vertical level with the one below it) of 1.05. The models are initialized at 0000 UTC of each day and run for 8 hours. The model simulations are observed to fully develop after simulations for a couple of hours.

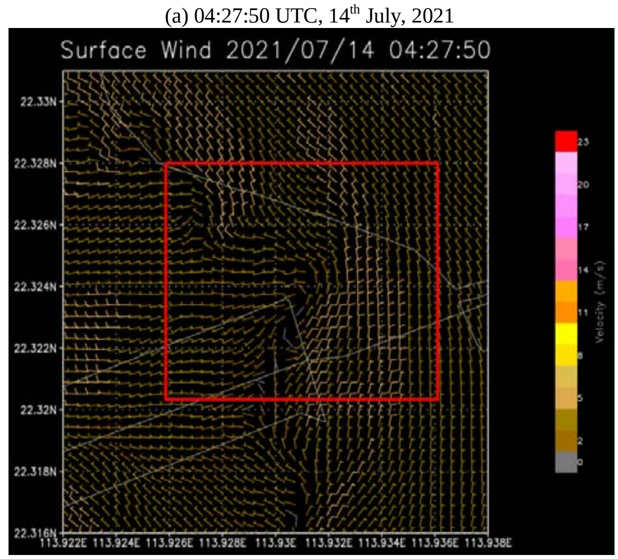
Turbulence parameterization schemes are critical for the success for the large eddy simulations. In the current setup, the Smagorinsky scheme is used in the first two nests and the Deardorff scheme is used in the latter three nests. The choice of such schemes is found to have success in reproducing the small-scale flow features at HKIA, *e.g.*, as reported in the severe windshear case in Chan *et al*. (2021).

The simulated LIDAR velocity imagery in the innermost nest is shown in Fig. 7(a). The simulation time of 0400 UTC is used, because the sea breeze convergence location is found to be very similar to the actual observation at 0600 UTC at this simulation time. Two

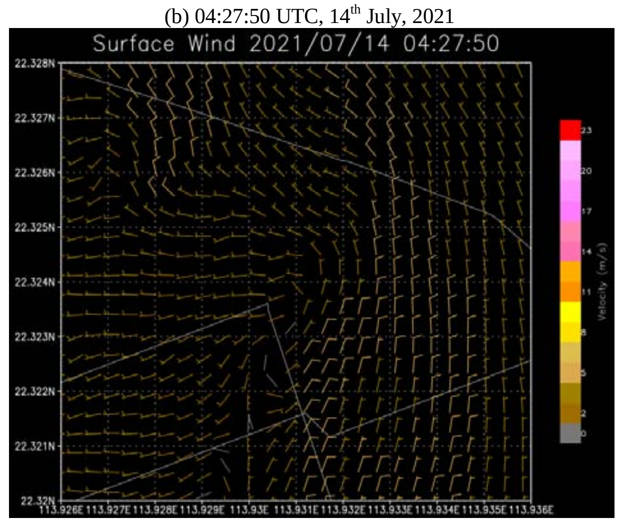


Figs. 7(a&b). For the 14th July, 2021 case, the simulated Doppler velocity from the LIDAR (a) and the simulated surface wind and temperatures and (b) Also shows the location of the zoom in area of Fig. 8 and vertical cross section of Fig. 9

(a) 04:27:50 UTC, 14th July, 2021



(b) 04:27:50 UTC, 14th July, 2021

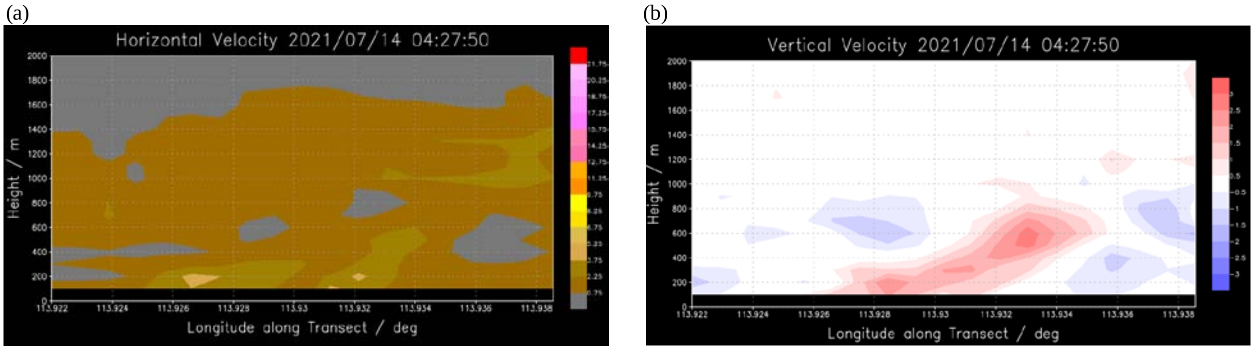


Figs. 8(a&b). The zoom in figures of the surface wind near the tiny anticyclonic circulation

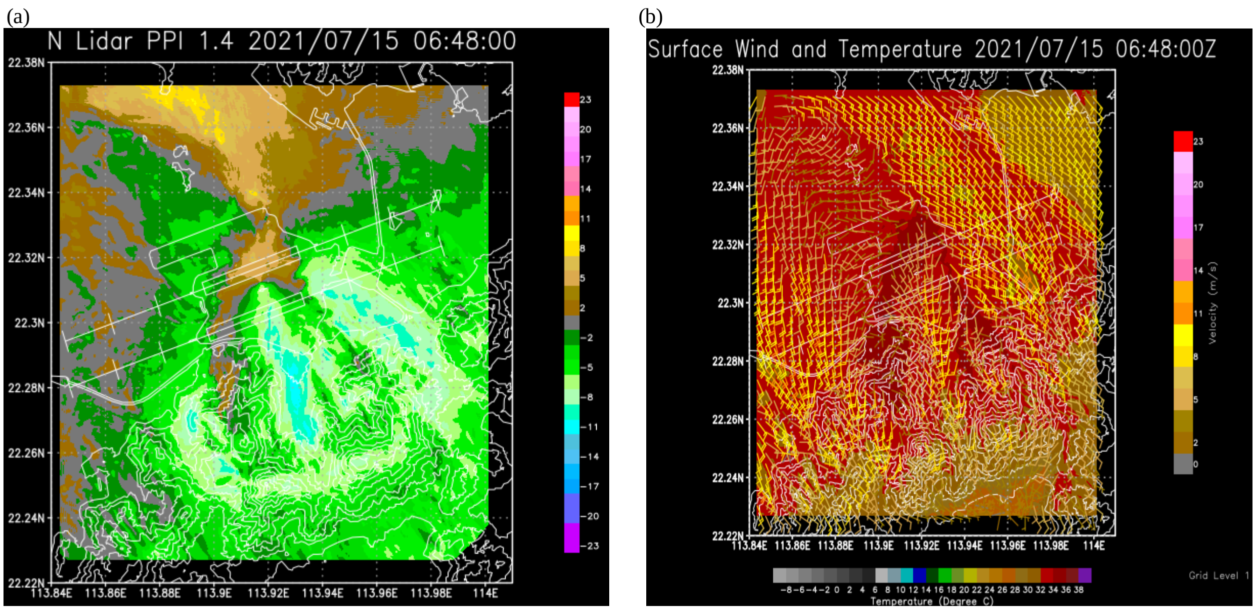
hours later, the simulated convergence area is found over the inner part of HKIA, *i.e.*, the easterly sea breeze at the eastern part of the airport appears to be too strong (not shown). This also points out the difficulty for the sea breeze simulation at an area with complex terrain, which is very sensitive to terrain features, surface conditions (land type to simulated temperature, roughness to simulated wind), etc. The simulated surface winds and temperatures are shown in Fig. 7(b), which clearly show the relationship between the sea breeze winds and the simulated high temperature areas.

A tiny anticyclonic circulation was simulated at the northern part of HKIA, Fig. 7(a). It is further zoomed in at Figs. 8(a&b). The horizontal resolution (40 m) of the simulation is not yet sufficient to resolve a closed circulation for this tiny anticyclone. This also points to the limitation of the present study, namely, even higher spatial resolution (*e.g.*, 10 m to 20 m) may be necessary in order to completely simulate the dust devil circulation, as reported in some previous dust devil studies in the literature.

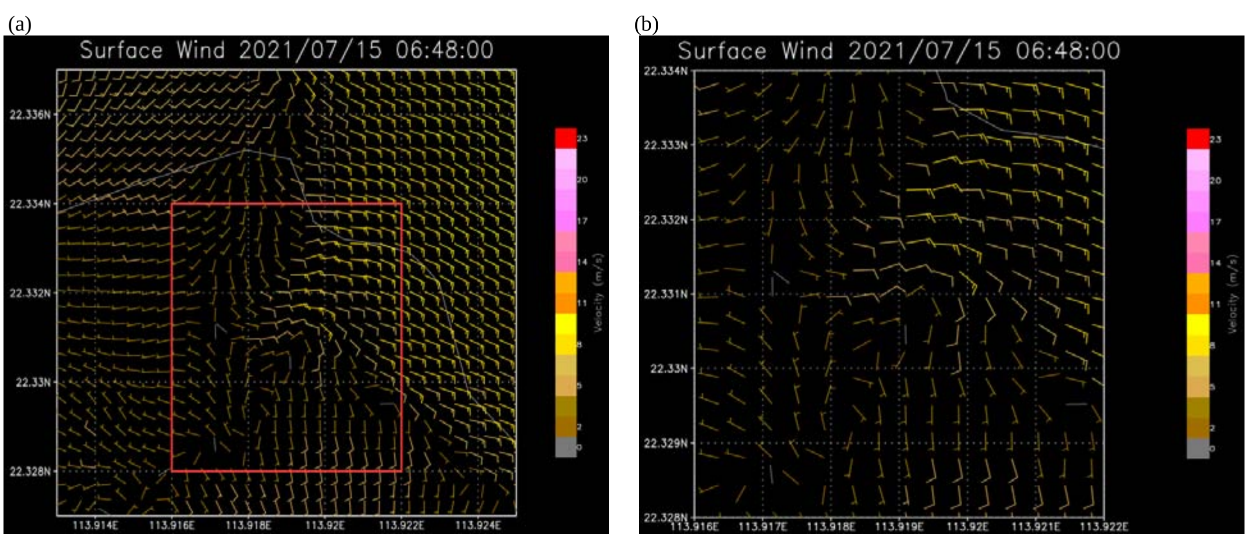
A vertical cross section [location in Fig. 7(a)] is made to the anticyclonic circulation and the distributions of horizontal wind speed and vertical velocity are shown in Figs. 9(a&b) respectively. The anticyclonic circulation



Figs. 9(a&b). The vertical cross sections of (a) horizontal velocity and (b) vertical velocity

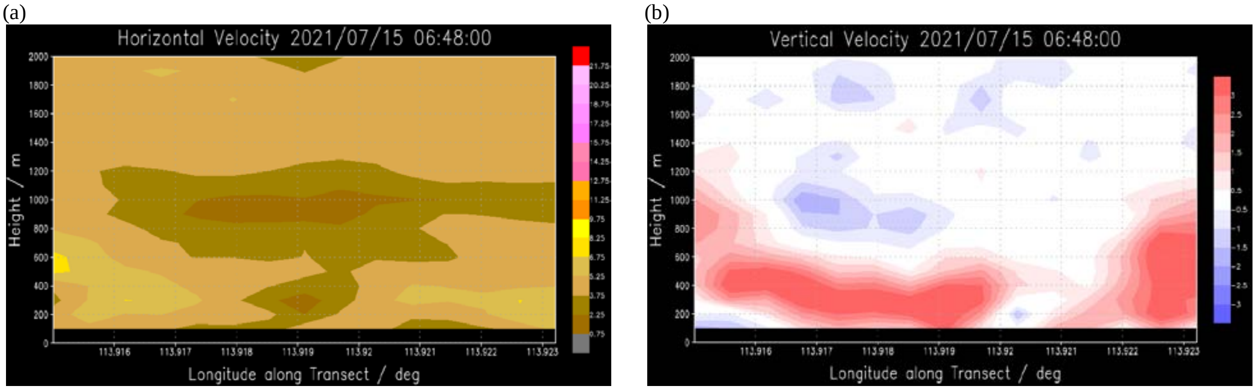


Figs. 10(a&b). (a) Simulated Doppler velocity from the LIDAR on 15th July, 2021 and (b) Simulated surface wind and temperatures on 15th July, 2021. Also shows the location of the zoom in area of Fig. 11 and vertical cross section of Fig. 12



Figs. 11(a&b). (a) Simulated Doppler velocity from the LIDAR on 15th July, 2021- Zoom in area and (b) Simulated surface wind and temperatures 15th July, 2021- Zoom in area

(a) (b)



Figs. 12(a&b). (a) The distributions of horizontal velocity on 15th July, 2021 and (b) The distribution of vertical velocity on 15th July, 2021

is found to have a vertical extent of several hundred metres. Updraft is simulated at the location of this circulation.

The simulation result of 15 July 2021 is shown in Fig. 10. This time, the simulated sea breeze circulation evolves quite in phase as the actual observations, so that the simulation result at around 0700 UTC is considered. The wind pattern at airport area, such as the Doppler winds in Fig. 10(a) and the simulated 2D wind in Fig. 10(b) are quite consistent with the actual observations in Figs. 6(b) and 4(b) respectively.

The difficult of this simulation is that, at the sea breeze convergence line, the majority of the tiny circulations in the simulation are cyclonic. It is very rare to observe anticyclonic circulation. One each case is shown in Fig. 10(a), with further zoom in figures in Figs. 11(a&b). A closed anticyclonic circulation is not yet obtained. Once again, similar to the case of 14 July, 2021, the horizontal resolution of the model may not be fine enough. Second, anticyclonic flow is very rare and the reasons for this are yet to be further investigated. In general, the anticyclonic flow is weaker on the second day than the first day, which is consistent with the human observations.

A vertical cross section is made, with location in Fig. 10(a). The distributions of horizontal wind speed and vertical velocity are shown in Figs. 12(a&b) respectively. Once again, the anticyclonic circulation has a height of several hundred metres and updraft is simulated at that location.

5. Conclusion

Dust devils were observed at HKIA on two consecutive days in July 2021, under hot weather with sea breeze circulations. The sea breeze flow and the dust devil circulations are documented in this paper for later reference, from the ground-based anemometer data and Doppler LIDAR velocities. In both cases, the dust devils are anticyclonic and have horizontal dimensions of several hundred metres.

The computer simulation of the sea breeze flow and dust devil circulations are presented in this paper. The difficulties of the computer simulation are discussed, *e.g.*, in the evolution of the location of the sea breeze convergence and the sense of rotation of the tiny circulations. It is hoped that the results could be useful for similar studies of dust devils in the future.

Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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