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Super high resolution numerical weather prediction model simulation of tiny anticyclones observed at the Hong Kong International Airport

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सार – हाँगकाँग अंतरराष्ट्रीय हवाई अड्डे पर लघु अवधि LIDAR द्वारा छोटे प्रति-चक्रवातों के प्रेक्षण के अनुवर्ती अध्ययन के रूप में, वायु प्रवाह के सुपर हाई मॉडल संख्यात्मक मौसम पूर्वानुमान मॉडल का अनुकरण 50 मीटर के स्थानिक विभेदन पर किया जाता है। छोटे प्रति-चक्रवाती प्रवाह को अनुकरण सफलतापूर्वक कैप्चर करता है, जिससे पता चल्ता है कि हवाई अड्डे में वायु प्रवाह पर भू-भाग के प्रभाव से ऐसा प्रवाह आंशिक रूप से उत्पन्न हो सकता है। पवनमापी द्वारा प्रेक्षित की गई हवाओं की परिवर्तिता और मॉडल द्वारा किए गए पूर्वानुमान की रूप में अच्छी तरह से तुलना करें तो यह पता चलता है कि अनुकरण वास्तविक हैं। दो ममलों का अध्ययन किया गया है। परिणाम में अन्य हवाई अड्डों पर मौसम पूर्वानुमानकर्ताओं और भू-भाग बाधित वायु प्रवाह की निगरानी के अध्ययन के लिए उपयोगी हो सकते हैं।

ABSTRACT. As a follow-up study of the observation of tiny anticyclones by short range LIDAR at the Hong Kong International Airport, super high model numerical weather prediction model simulation of the airflow is performed at a spatial resolution of 50 m. The simulation successfully captures the tiny anticyclonic flow, suggesting that such flow could partly arise from terrain effect on the airflow at the airport. The variability of winds as observed by an anemometer and as forecast by the model compare well, suggesting that the simulations are realistic. Two case studies are considered. The results could be useful for reference by weather forecasters at the other airports in monitoring and studying terrain-disrupted airflow.

Key words – Anticyclonic, Hong Kong International Airport (HKIA), WRF-LES.

1. Introduction

Terrain-induced airflow disturbances have been considered to be a major source of airflow disruption that may result in low-level windshear and turbulence to be encountered by the arriving and departing aircraft at the Hong Kong International Airport (HKIA). The matter has been studied extensively using meteorological instrumentation such as Doppler Light Detection and Ranging System (LIDAR), *e.g.*, Shun and Chan (2008) and high resolution numerical weather prediction model, *e.g.*, Chan and Hon (2016a,b). Following the implementation of short-range LIDAR(SRL) at HKIA (Hon *et al*., 2014; Hon and Chan, 2020), which has a radial resolution of about 30 m and scan revisit time of about 20s, some additional kinds of airflow disturbances have been observed. They occur in the form of tiny anticyclones in the background, south to southwesterly flow, with spatial scales of a few hundred metres and observed lifetime of a couple minutes within the SRL scanning range. These observations have been documented in Chan *et al*. (2020a). At first, such disturbances were believed to arise from buildings/man-made structures in view of their temporal and spatial scales. This has been considered plausible given the elevated level of turbulence over the corresponding stretch of aircraft flight path well known to pilots and also demonstrated recently using wind tunnel experiments (Chen *et al*., 2019).

In this short communication, we intend to see if the above-mentioned tiny anticyclones may arise partly from

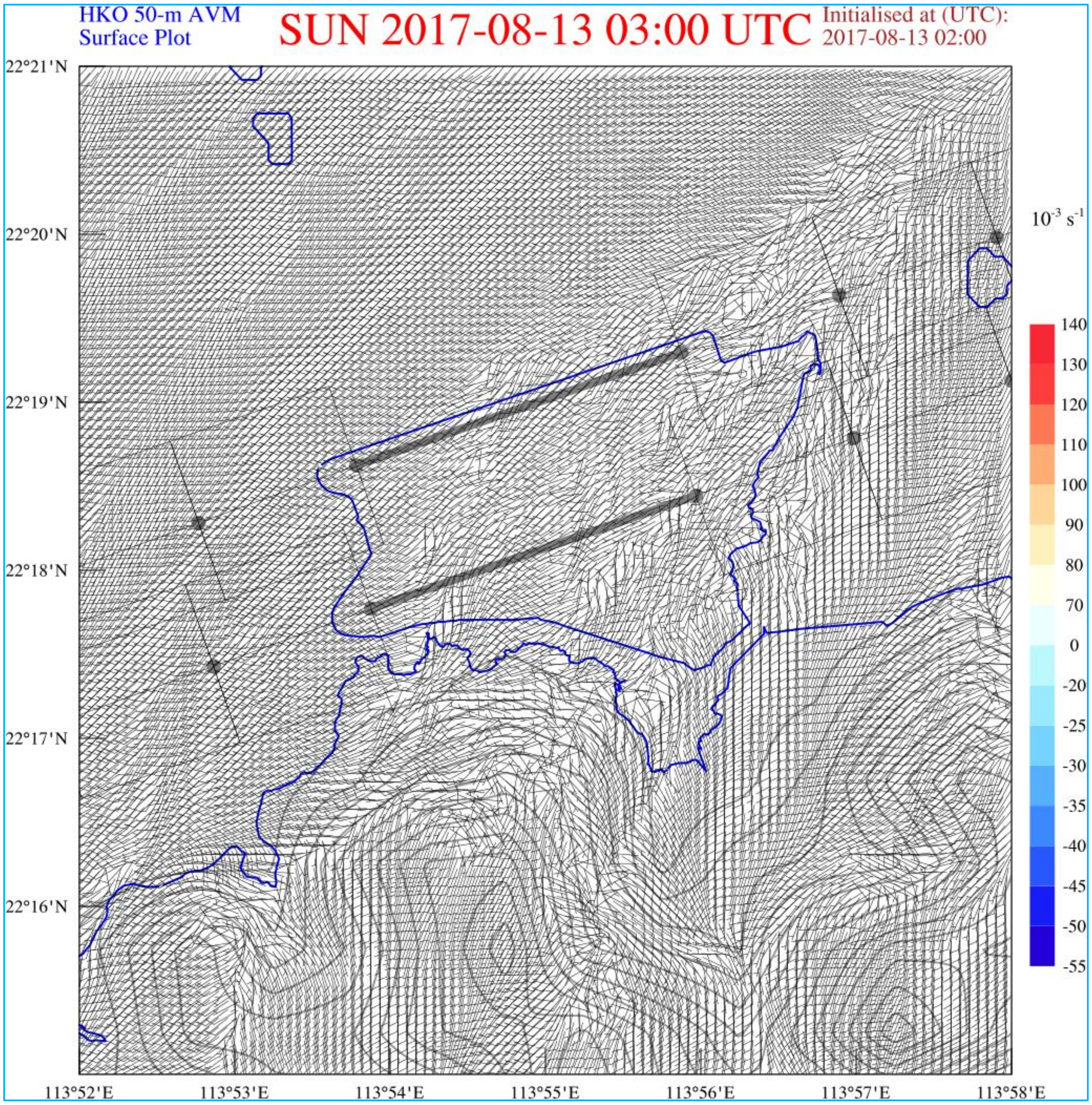

Fig. 1. WRF LES simulation for 2017 case. The wind barbs are the simulated winds at the surface. Height contours in 100 m. This is 1-hour simulation result

the terrain airflow disruptions, namely, airflow disturbances arising from terrain on Lantau Island, a mountainous island to the south of HKIA, in background moderate to fresh south to southwesterly flow. To this end, numerical simulations using the Weather Research and Forecasting (WRF) model in the large eddy simulation (LES) regime with horizontal grid spacing of 50 m were performed. The results of the simulations were compared with the short range LIDAR observations and wind measurements from an anemometer nearby. The objective of the study was to see if the terrain effect could partly explain the tiny anticyclones and variability of wind as measured by the various meteorological instruments.

2. Set-up of WRF-LES

The WRF model (Skamarock and Klemp, 2007) is a primitive equation, non-hydrostatic atmospheric model suitable for numerical weather prediction (NWP) and atmospheric simulations across a range of scales. The use

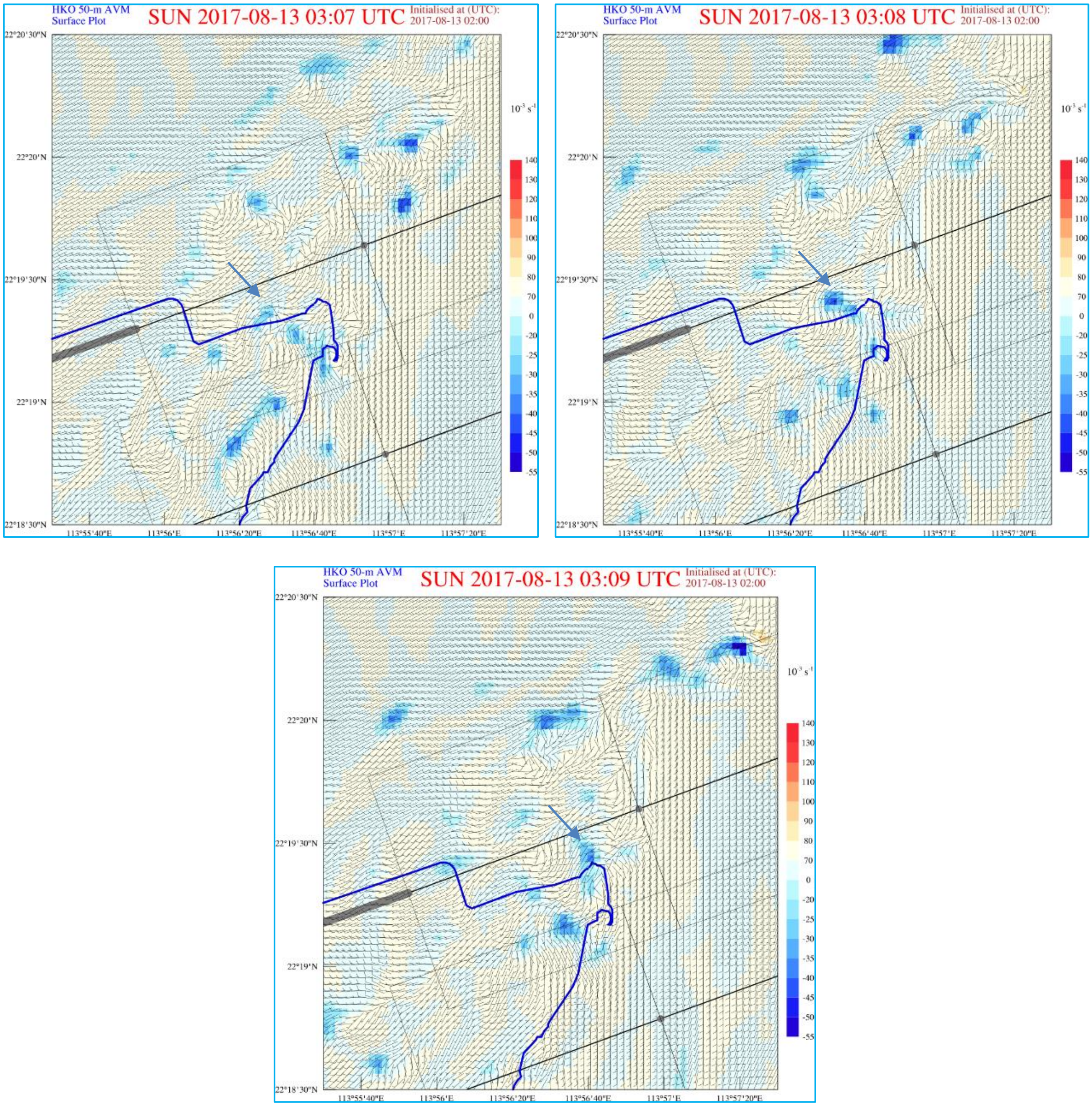

Fig. 2. Times sequence of the arrow-indicated anticyclonic flow for the 2017 case, which is highlighted in blue (vorticity). The separation of images is 1 minute

of WRF for weather forecasts and simulation studies in the LES regime have been documented in many studies, with horizontal grid spacing ranging from a few hundred meters down to a few meters (Talbot *et al*., 2012; Bao *et al*., 2018; Wiersma *et al*., 2020). Essentially the "LES" configuration for WRF refers to replacing, at sufficiently fine horizontal grid spacing, the use of boundary layer parameterization schemes by a Smagorinsky-like approach in the treatment of sub-grid scale turbulence.

In this study, the 50-m WRF-LES simulations are performed using two-way nesting from a parent domain at 200-m grid spacing. The 200-m outer domain has a size of three hundred and one × three hundred and one grid points

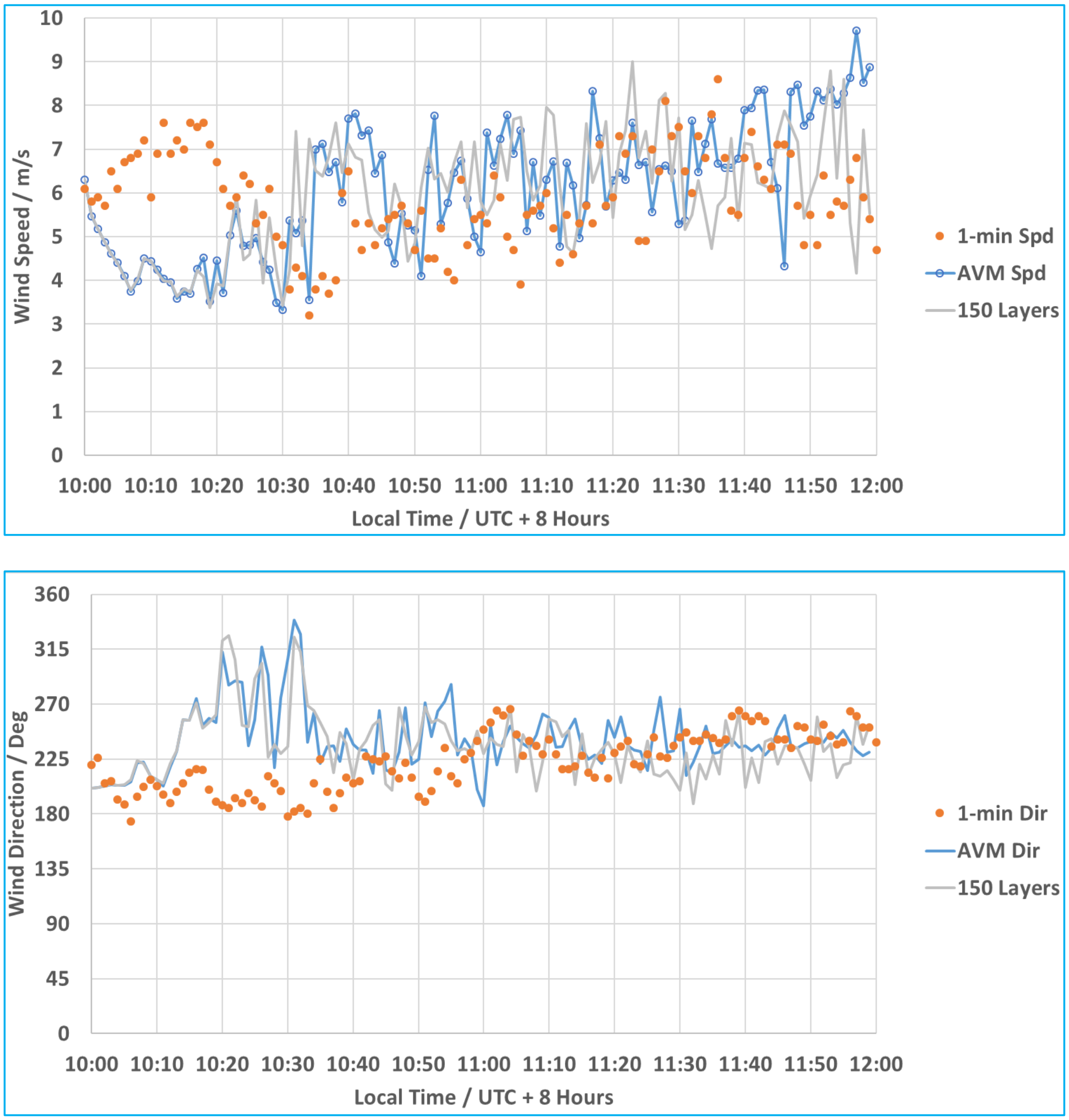

Fig. 3. Time series of model simulated wind at the location of the R2E anemometer (blue curve for 90 levels and grey curve for 150 levels) and the actual observations of 1-minute mean from that anemometer (orange dots) for the 2017 case. The upper image is the wind speed and the lower image is the wind direction. The model spin-up is about 40 minutes (starting from 10 am local time)

(*i.e.*, 60 km × 60 km) centered at the Hong Kong International Airport. The initial and boundary conditions were taken from the ECMWF IFS global model. Version 3.9.1 of the WRF software is used. The 200-m WRF follows Chan and Hon (2016a) and has been demonstrated to successfully predict many types of complex airflow around HKIA through comparison against LIDAR measurements (Chan *et al*., 2020b), case studies (Hon, 2018; Hon *et al*., 2019) and long-term verification (Hon, 2020). The 50-m WRF-LES domain comprises 401 × 401 grid points horizontally, covering a 20 km × 20 km area centered at HKIA. Vertically there are 90 eta levels of which at least 10 is within the lowest 1000 m of the atmosphere at the time of model initialization. The authors' experience in the choice of vertical resolution echoes reports from other parts of the world (Zhang *et al*., 2013) that further refinements vertically would provide little improvements in terms of the quality of the forecast. Key model configurations include the WRF double-moment 6-class microphysics (WDM6) scheme (Lim and Hong, 2010), RRTMG schemes for short- and long-wave radiation (Iacono *et al*., 2008) and the Noah land surface model (Niu *et al*., 2011). Given the high horizontal resolution, cumulus convection is not parameterized. The USGS 3-second topography and MODIS land use data are applied, having local adaptations to cater for urbanisation

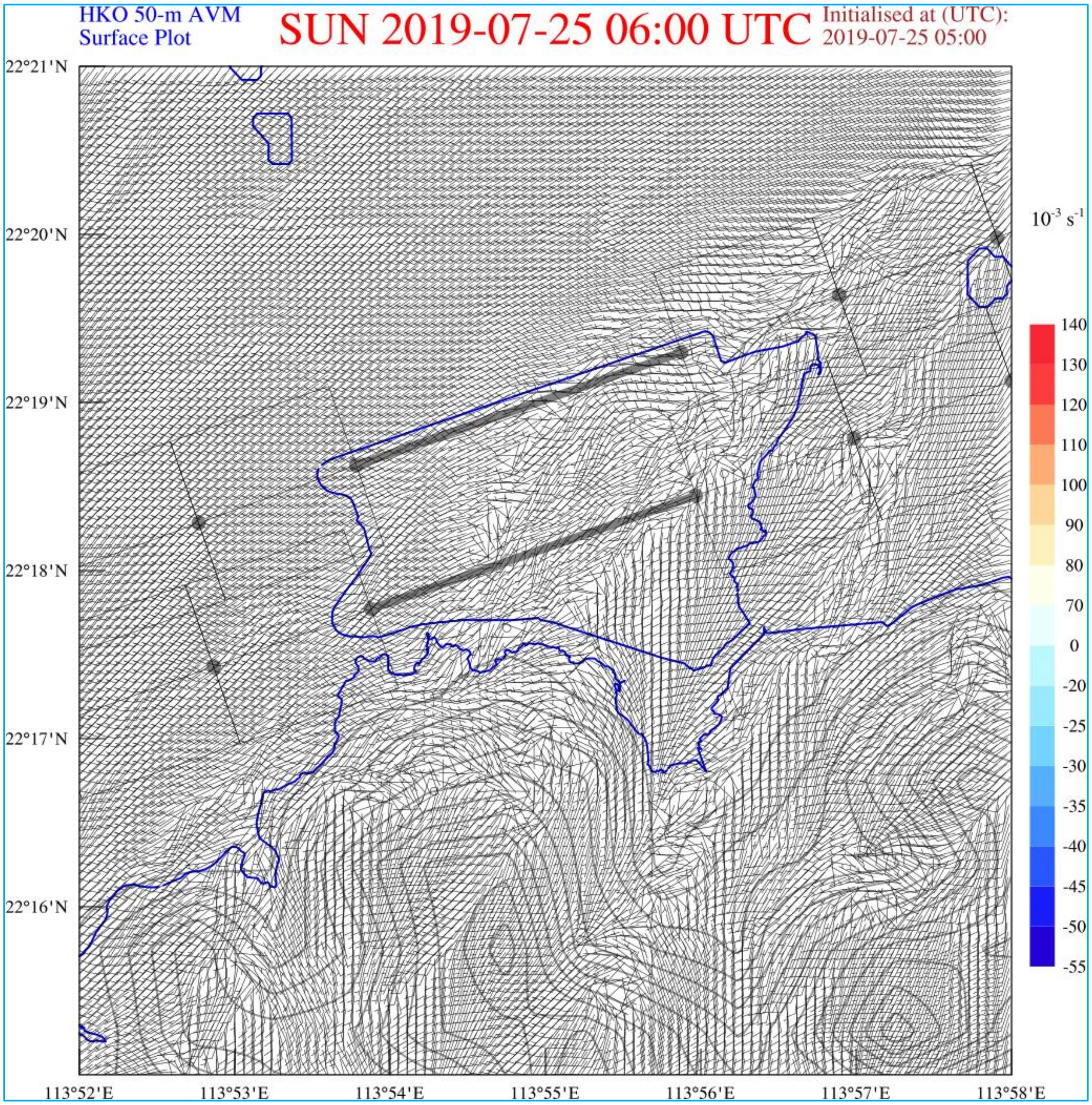

Fig. 4. The same as Fig. 1 but for the 2019 case

and changes in coastline. For the present two-way nesting runs, a fixed time step of 2s is prescribed for the 200-m domain and 0.5 s for the 50-m domain.

To allow sufficient spin-up of turbulence in the atmospheric boundary layer, the model runs described below are initialized at least 1 hour before the time of the respective events of interest. Given the surface wind speeds of around 6 - 8 m/s in both cases (equivalent to 21.6 - 28.8 km/hour), this would have allowed the simulated airflow to traverse horizontally at least once the whole model domain. To facilitate inspection of simulation results and comparison against nearby meteorological observations, output from the 50-m WRF-LES are generated in 1-minute time intervals in a manner similar to Hon and Chan (2017).

3. Case studies

The two cases in the paper Chan *et al.* (2020a) are considered in this paper. The first case occurred on 13th August, 2017 at about 11 am local time (= 0300 UTC,

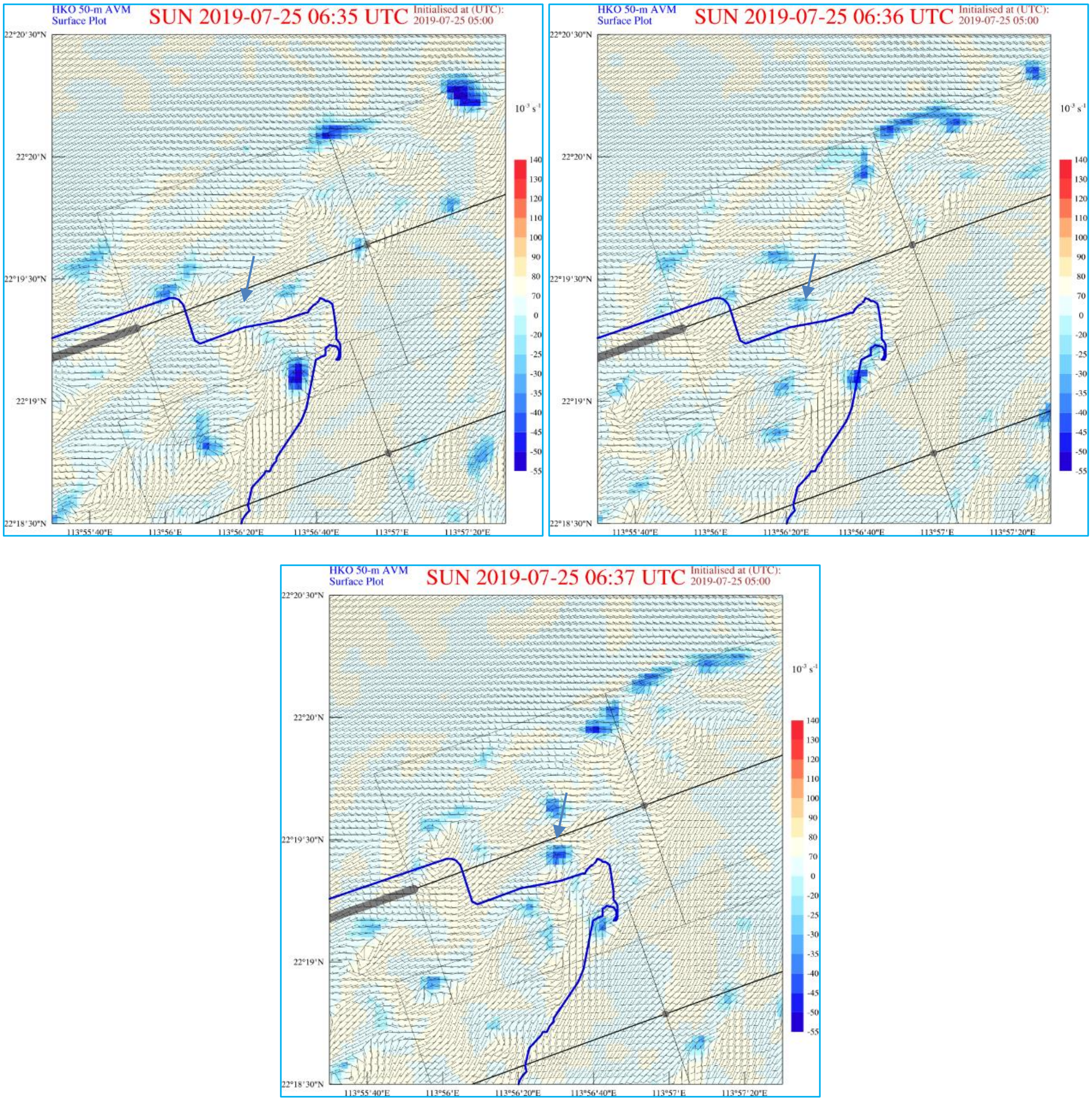

Fig. 5. The same as Fig. 4 but for the 2019 case

with HKT = UTC + 8 hours). The simulation result with the whole model domain is shown in Fig. 1. The model was initialized at 0200 UTC. It could be seen that airflow disturbances occurring at the northeastern corner of the airflow arise from airflow disruption by Nei Lak Shan (NLS). A zoom-in of the simulation result is shown in Fig. 2. It shows a sequence of simulated surface winds with the feature of tiny anticyclonic flow (highlighted in blue). It takes about a few minutes for the anticyclonic flow to move across the seas to the northeastern corner of the airport. In comparison with Fig. 7 of Chan *et al.* (2020a), the observations are very similar. It appears that a 50-m resolution simulation was able to show the tiny anticyclonic features observed by short range LIDAR, at least for those waves with a spatial size of a couple of hundred meters (*e.g.*, 200-300 m, which is 4 to 6 times the horizontal grid spacing of the 50 m WRF-LES simulation).

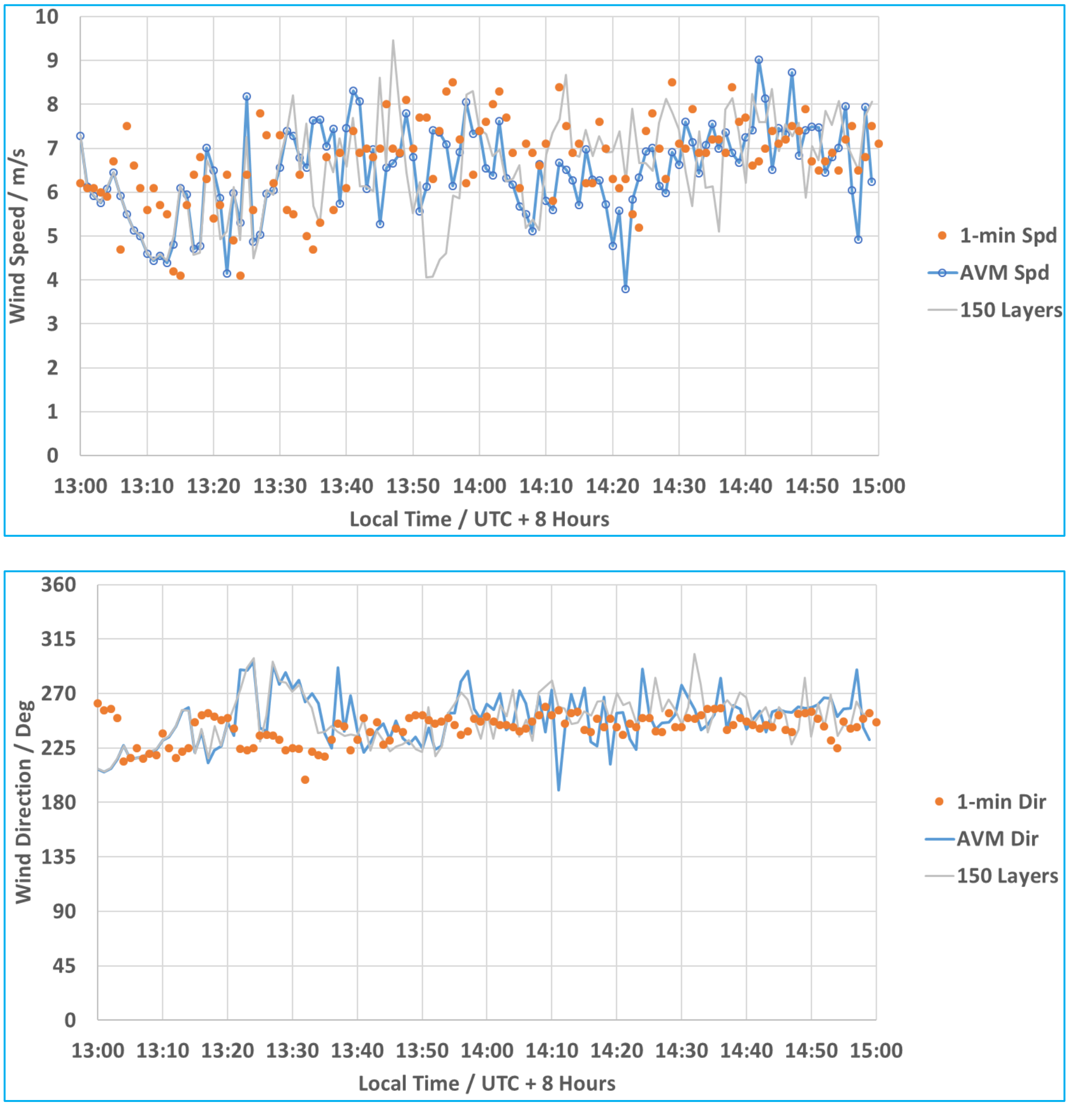

Fig. 6. The same as Fig. 3 but for the 2019 case

To justify the simulation result further, the variability of the wind speed and wind direction of an anemometer in the region is considered. Namely, the anemometer R2E, which is located at the eastern end of the north runway of HKIA (location in Fig. 1). The 1-minute mean wind speed and wind direction are considered and overlaid with the model simulated results (which are the standard 10 m wind output from WRF). The resulting time series is shown in Fig. 3. It could be seen that variability of the actual observations and simulation results are very similar. This adds further evidence that the 50-m simulation gives reasonable result.

Another case occurred at about 2 pm (0600 UTC), 25th July, 2019. The model is initialized at 0500 UTC. The results of the model simulation domain are shown in Fig. 4. Comparing with the previous case, the airflow disruptions associated with Nei Lak Shan shifted more to the east. Downstream of the gap, the airflow is much smoother. The zoom-in at the northeastern corner of HKIA is shown in Fig. 5. Again, a sequence of images is shown. An anticyclonic flow feature is observed and the whole event lasts a few minutes. This is consistent with the actual observations by the short range LIDAR as reported in Chan *et al.* (2020a). The variability of R2E anemometer winds are shown in Fig. 6. Again, the actual observations and the simulation results are similar.

Two cases are considered in this paper. More cases may be reported in the future literature in considering other wind strength (*e.g.*, stronger winds) and wind

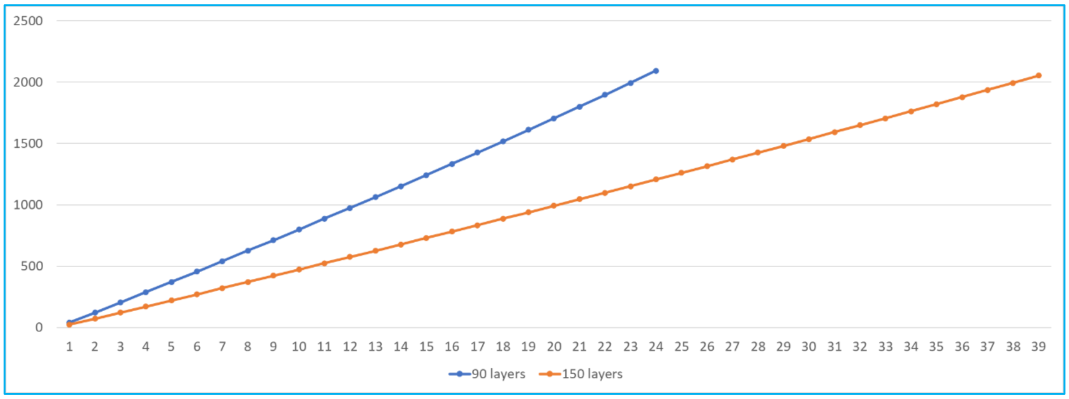

Fig. 7. The heights (m) of the model layers for 90 levels (blue) and 150 levels (orange). The *x*-axis is the level number and the *y*-axis is the height in m. Only those levels within the atmospheric boundary layer are shown

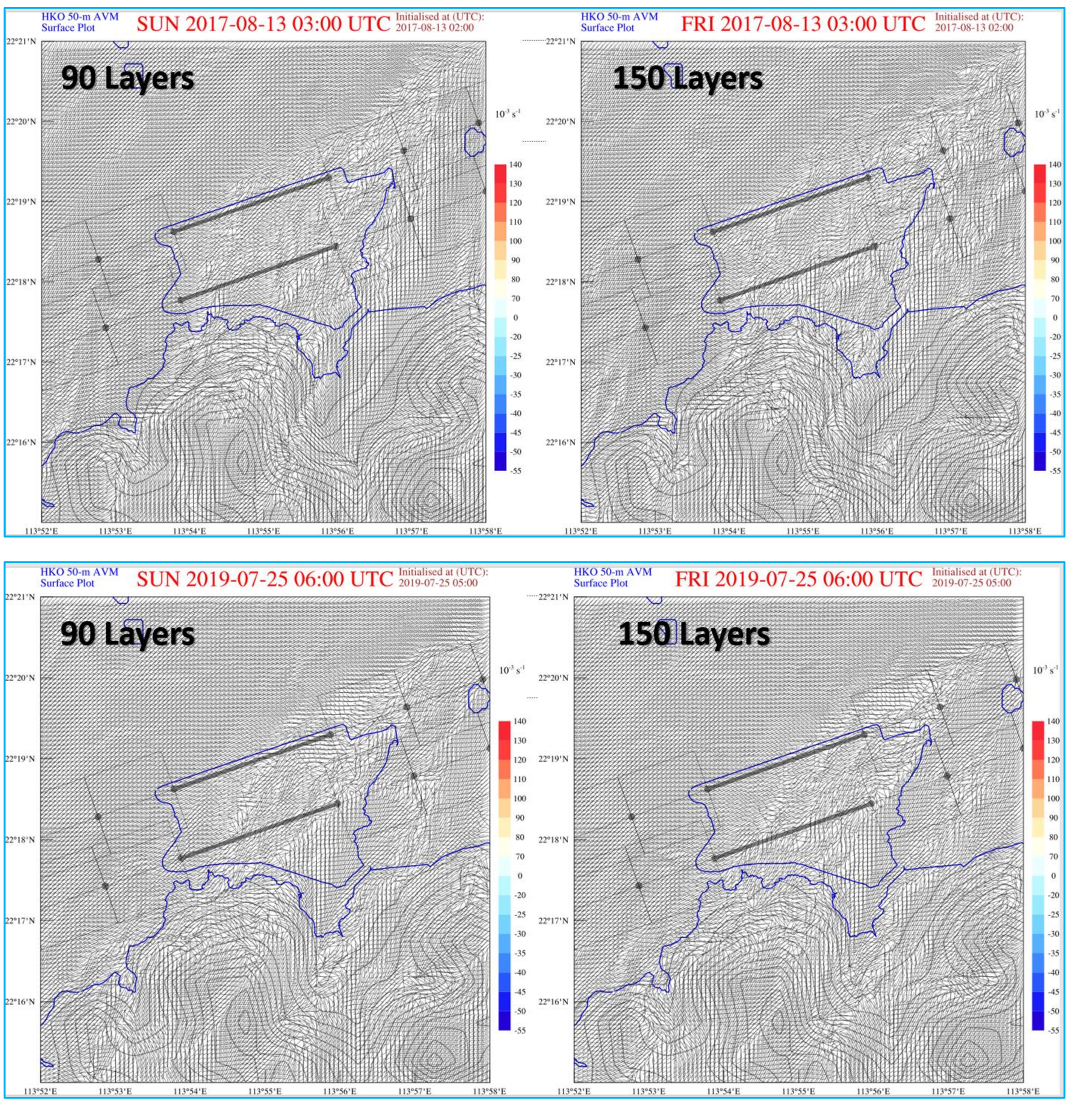

Fig. 8. The comparison of model-simulated surface winds for 90 layers (left) and 150 layers (right) for the 2017 case (higher panels) and 2019 case (lower panels)

TABLE 1

The impact of the forecast time (the first hour *vs* the second hour) and model level (90 levels - upper and 150 levels - lower) on the model accuracy, in terms of root-mean-square-error (RMSE) for wind speed (Spd, in m/s) and wind direction (Dir, in degrees) in comparison between the model's simulated winds and the actual anemometer readings

Forecast time	Spd	Dir
RMSE (90)		
1st hour	2.08	58.5
2nd hour	1.77	21.4
overall	1.92	44.1
RMSE (150)		
1st hour	2.11	56.0
2nd hour	1.61	24.0
overall	1.88	43.1

directions in the HKIA region (*e.g.*, south-southeasterly winds associated with tropical cyclones).

4. Impact of the model levels and forecast time

In order to study the impact of the model configuration on the forecast results, the LES simulation has been re-run with the increase of model levels from 90 in the above-mentioned setting to 150 in the present new setting. The model levels for the two settings in the atmospheric boundary layer (below around 2 km) are shown in Fig. 7.

The simulated surface wind patterns of 90 levels and 150 levels for the two cases of 2017 and 2019 are shown in Fig. 8. Qualitatively, we could see that the two patterns are very similar. The corresponding time series at the anemometer location is shown in Fig. 3 and Fig. 6 for the 2017 case and 2019 case respectively. Quantitatively, the root-mean-square-error (RMSE) of the model simulation results with the actual anemometer reading as reference are shown in Table 1. It could be seen that the RMSE values of 90 levels and 150 levels are very similar. As such, the 90-level simulation results are considered to be reasonable.

As for the forecast time, the RMSE for the first hour and the second hour simulations are shown in Table 1. It could be seen that the simulation appears to be converging with a drop of RMSE for second hour compared with the first hour. The simulation has been conducted for half hour more and the RMSEs in general remain at a similar level (not shown). As such, the 2-hour simulation results are considered to be already rather reasonable.

5. Conclusions

This short communication documents the LES simulations of WRF at 50 m horizontal grid spacing under background south to southwesterly flow. The objective is to study the possibility of terrain-induced airflow disturbances giving rise to the tiny anticyclones observed by short-range LIDAR at HKIA, as reported by Chan *et al*. (2020a). The simulation results indicate that the terrain-effect along may partly explain the occurrence of such airflow disturbances. To justify the simulation results further, the variability of wind speed and wind direction at the anemometer R2E is studied by comparing the observations and simulated winds. It happens that their variability is similar, at least in the range of wind speed and wind direction, even though not directly matching in the individual peaks and troughs, which may be expected from the nature of the LES simulations. The results are encouraging and they show that LES simulation with WRF may be possible to give further details about the variability of the wind at HKIA, in addition to the already rather high spatial resolution of the simulations (200 m) using WRF as reported in Chan *et al*. (2020b) in the study of Foehn effect and mountain waves.

To understand further the nature of the tiny anticyclones, the authors intend to couple WRF with other software, such as FLUENT, to study the effect of *both* buildings and terrain. If the simulation is successful, we may isolate the effect of either/both buildings or/and terrain in contributing to the airflow disturbances observed by short range LIDAR. The studies are being undertaken and the results will be reported 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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Highlight

- Anticyclones are observed by short range LIDAR at the Hong Kong International Airport
- Super high resolution NWP simulation at 50 m could successfully capture the anticyclonic flow
- The variability of the winds from simulation and anemometer reading compare well.

Graphical Abstract