International Civil Aviation Organization

WORKING PAPER

ASIA AND PACIFIC (APAC) FIFTEENTH MEETING OF THE METEOROLOGICAL REQUIREMENTS WORKING GROUP (MET/R WG/15)

Bangkok, Thailand, 07 April to 10 April 2026

Agenda Item 3: Collaboration between MET and ATM stakeholders

PROBABILISTIC LOW-LEVEL WINDSHEAR FORECASTING FOR HONG KONG INTERNATIONAL AIRPORT USING MACHINE LEARNING ALGORITHM

(Presented by Hong Kong, China)

SUMMARY

The occurrence of low-level wind shear at the Hong Kong International Airport can disrupt aircraft operations during their landing and take-off. A study was carried out to identify specific weather factors that cause windshear, and subsequently apply the XGBoost machine learning algorithm to generate hourly probability forecasts for windshear at the airport over the next 72 hours. The verification results show that these hourly forecasts could provide relevant stakeholders with early alerts regarding the potential impact of wind shear.

1. INTRODUCTION

1.1 The Hong Kong International Airport (HKIA) is built on an artificial island called Chek Lap Kok, located off the western coast of Hong Kong. To its south is the Lantau Island, which features mountainous terrain. This terrain creates complex airflow disturbances, leading to various types of low-level wind shear along the approach and departure corridors of the airport. Surrounded by sea and rugged terrain, the airport is susceptible to wind shear induced by various meteorological phenomena, such as airflows over mountains, sea breezes, and low-level jets.

1.2 Wind shear poses significant operational challenges for HKIA and Air Traffic Control (ATC) operations by directly reducing safety margins during take-off and landing. It lowers the Airport Acceptance Rate (AAR) and disrupts the planned sequence of traffic movement. Controllers may be compelled to alter their optimised traffic flow and abandon precious runway slots. Effective detection and timely alerting of wind shear are critical for aviation safety. The Hong Kong Observatory has implemented the Windshear and Turbulence Warning System (WTWS) to automatically generate alerts for aircraft arriving at or departing from the airport every minute, utilising data from a network of meteorological instruments. These alerts cover wind shear and turbulence within three nautical miles of each runway end.

1.3 Numerical weather prediction models offer a potential pathway to achieving forecasting capabilities. However, running high resolution models over complex terrain requires substantial computational resources, large volumes of observational data, and sophisticated data assimilation systems. Machine learning presents an alternative approach. By learning the nonlinear relationships between meteorological conditions and wind shear directly from historical observations, machine learning models can generate useful forecasts without replying on the explicit physical equations or costly computer simulations.

2. DISCUSSION

2.1 There are several types of wind shear that commonly occur at HKIA. Terrain-induced wind shear occurs when strong southerly or southeasterly winds flow over the mountainous terrain of Lantau Island. As the air is forced through gaps and over peaks, it creates shear in both wind speed and direction that can affect aircraft on approach and departure at the airport. During fine weather with light background winds, the sea breeze front can bring abrupt wind changes and wind shear to the runways. A low-level jet induced by an inversion layer can produce substantial headwind variations along the vertical layers. Intensive convection is conducive to thunderstorm-induced wind shear, including microbursts and gust fronts, which can lead to major disruptions to airport and ATFM operations.

2.2 Gradient boosting is a machine learning technique used for regression and classification problems. Notably, XGBoost, or Extreme Gradient Boosting, is well known for its scalability and efficiency in handling both types of tasks. Its flexibility enables it to capture the non-linear relationships between input features and the target variable, making it well-suited for complex prediction tasks.

2.3 The automatic WTWS alert is treated as the ground truth for wind shear occurrence in model training and verification. Sepecifically, whenever there are WTWS alerts lasting five minutes or more within a given hour, that hour is considered to have wind shear occurrence. Based on the types of wind shear commonly observed at HKIA, a specialised set of parameters was selected for model training. These include surface wind speed and direction, wind speed and direction at the 925 hPa pressure level, the predicted low-level inversion from numerical weather prediction (NWP) models, and the probability of sea breeze occurrence derived from other machine learning models. These inputs were used for hyperparameterization and tuning, based on the traning dataset from 2023 to 2024.

2.4 The wind shear forecasts were generated and presented on an hourly and probabilistic basis. An integrated webpage, as shown in Appendix A, Figure 1, was launch for internal trial in April 2025. It has been shared with the Air Traffic Flow Management (ATFM) and used on trial for ATM planning under specific weather conditions, particularly when flights are expected to be impacted by a tropical cyclone (TC) approaching the south China coastal region.

2.5 A case from September 2025 was reviewed when TC Tapah approached the vicinity of Hong Kong and skirting to its south. In the 00Z run on 6 September 2025, the XGBoost model showed an increasing probability as shown in Appendix A, Figure 2. The red dotted line depicts the forecast probability from that particular model run, indicating a high probability during 8–9 September 2025. This is consistent with the actual WTWS alert counts per hour shown in the box plot of the same figure. The sustained high probability toward the end of the forecast period such as 0900-1800 HKT on 9 September 2025 was due to discrepancies between the NWP model outputs and actual wind trends during that period. The green line, which applies the same algorithm but uses actual wind measurements instead of the model wind field, has reproducted a more accurate dcline in probability later on 9 September 2025.

2.6 The reliability diagram was used to evaluate how well the XGBoost wind shear forecasting model is calibrated. The diagram plots the observed frequency of wind shear against the predicted probability, providing a visual check of whether the model's probability estimates align with actual occurrences. Appendix A, Figure 3 shows that the model generally follows the diagonal line corresponding to perfectly reliable forecasts, with a slight shift to the underestimation side. The predicted probabilities generally align with the observed frequencies during the verification period from

April to December 2025. A Critical Success Index (CSI) of 0.4 was achieved for an optimal probability threshold, indicating that the model has potential for supporting the trial application of wind shear probability predictions.

2.7 Other meteorological conditions that can also generate wind shear, such as thunderstorm-induced wind shear, including microbursts, which can significantly impact aircraft operations. However, it remains challenging for model to predict such phenomena several days in advance. Qualitative verification suggests that the model demonstrates greater skill in forecasting terrain-induced and sea breeze-induced wind shear.

CONCLUSION

2.8 Wind shear remains one of the most significant threats to aviation safety and efficiency at HKIA operations. The advanced machine learning model developed in the study enables earlier and more reliable predictions of wind shear occurrence, extending the lead time up to 72 hours. This provides advance alerts to relevant stakeholders, allowing for timely preparation for flight adjustments in response to wind shear events. It also highlights the potential benefits of close collaboration between MET and ATM in providing the aviation services.

3. ACTION BY THE MEETING

3.1 The meeting is invited to:

a) note the information contained in this paper;

b) encourage States/Administrations to share their experiences in the collaboration between Air Navigation Service Providers and Meteorological Service Providers for demand-capacity balancing under wind shear scenario; and

c) discuss any relevant matters as appropriate.

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APPENDIX A

Windshear Probability at 2025-09-06 00Z

	20250906	20250907	20250908	20250909
00 HKT	N/A	12%	65%	86%
01 HKT	N/A	12%	65%	83%
02 HKT	N/A	17%	74%	80%
03 HKT	N/A	34%	74%	76%
04 HKT	N/A	18%	88%	76%
05 HKT	N/A	17%	88%	74%
06 HKT	N/A	10%	89%	69%
07 HKT	N/A	10%	89%	51%
08 HKT	4%	22%	89%	60%
09 HKT	4%	23%	89%	80%
10 HKT	6%	12%	89%	69%
11 HKT	5%	26%	89%	74%
12 HKT	4%	20%	89%	74%
13 HKT	4%	23%	89%	79%
14 HKT	4%	37%	89%	74%
15 HKT	4%	23%	89%	74%
16 HKT	9%	29%	89%	74%
17 HKT	16%	34%	89%	74%
18 HKT	7%	22%	89%	74%
19 HKT	5%	22%	88%	31%
20 HKT	19%	43%	88%	N/A
21 HKT	12%	44%	88%	N/A
22 HKT	7%	29%	83%	N/A
23 HKT	7%	56%	88%	N/A

Figure 1: An integrated webpage for showing the probability of wind shear in the next 72 hours.

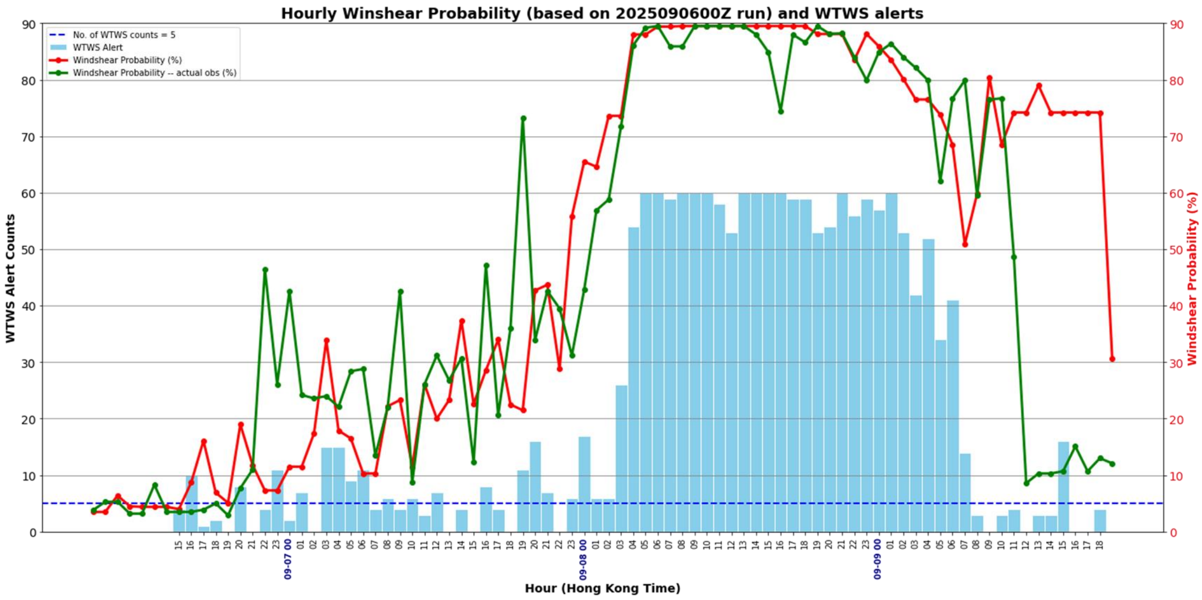
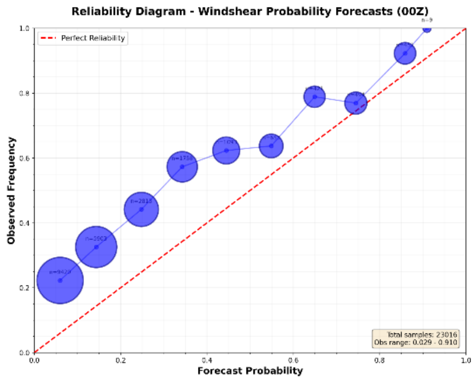
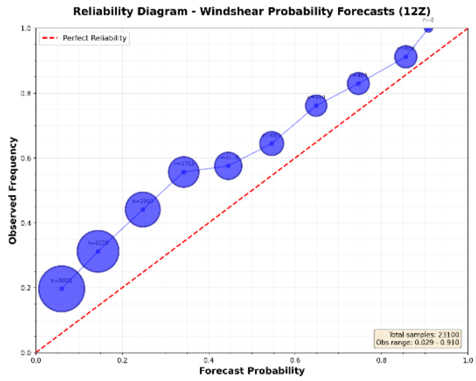


Figure 2: Verification of wind shear probability forecast at 00Z on 06 September 2025.



(a)



(b)

Figure 3: Reliability diagrams for the wind shear probability forecast from April to December 2025 for (a) 00Z and (b) 12Z model runs