Predictive alerts and atmospheric data for airport windshear by CPAS 200m NWP model

https://cpas.earth/

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Abstract

Low-level wind shear (LLWS) at Hong Kong International Airport (HKIA) poses significant aviation risks, primarily driven by terrain-induced flow from Lantau mountains and land-sea breeze interactions. While current mitigation relies on real-time detection and short-term forecasting, for operational purposes, it is ideal to extend horizons to manage wind shear (WS). Sea breeze activity peaks during the early spring months, when prevailing background winds are weak, and typically intensifies in the early afternoon driven by diurnal solar heating (Hon & Chan, 2021). This study evaluates a 200-m resolution limited-area simulation using the MPAS-based ClusterTech Platform for Atmospheric Simulation (CPAS) to predict sea-breeze shear with a range of lead times based on prior success in resolving coastal and terrain features by the CPAS 200m model (Sze etal 2022).

Methodology

→ Initial condition uses for the next simulation

The **daily operational global CPAS run** covers a region of interest in China with 4.5km resolution. The Adaptive Mesh Refinement (AMR, Kam etal 2025) identifies **high vorticity regions** in a specified lat-lon box bounded within East Asia using TempestExtremes.

For each episode in this study, AMR generates a customized mesh according to weather conditions. This global model provides Initial and Boundary Conditions (IC & LBC) for the subsequent **200m-resolution limited-area simulation**. *For standalone operation, this AMR global run can form its own cycle.

In operation context, the high-resolution 200m model will only be triggered if potential LLWS is suggested by the 3.75km convection-permitting global model. **Here we study 13 days with WS and 3 days with non-WS**.

- The triggered 200m high resolution limited-area model over Lantau Island coarsens outward to 3.2km via a smooth transition.
- This boundary resolution aligns with the 3.75km driving resolution.
- Avoides abrupt resolution change at WRF lateral boundary.
- Balances high-resolution requirements for **complex terrain and coastline features** with the **limited computational cost** required for operational forecasting.

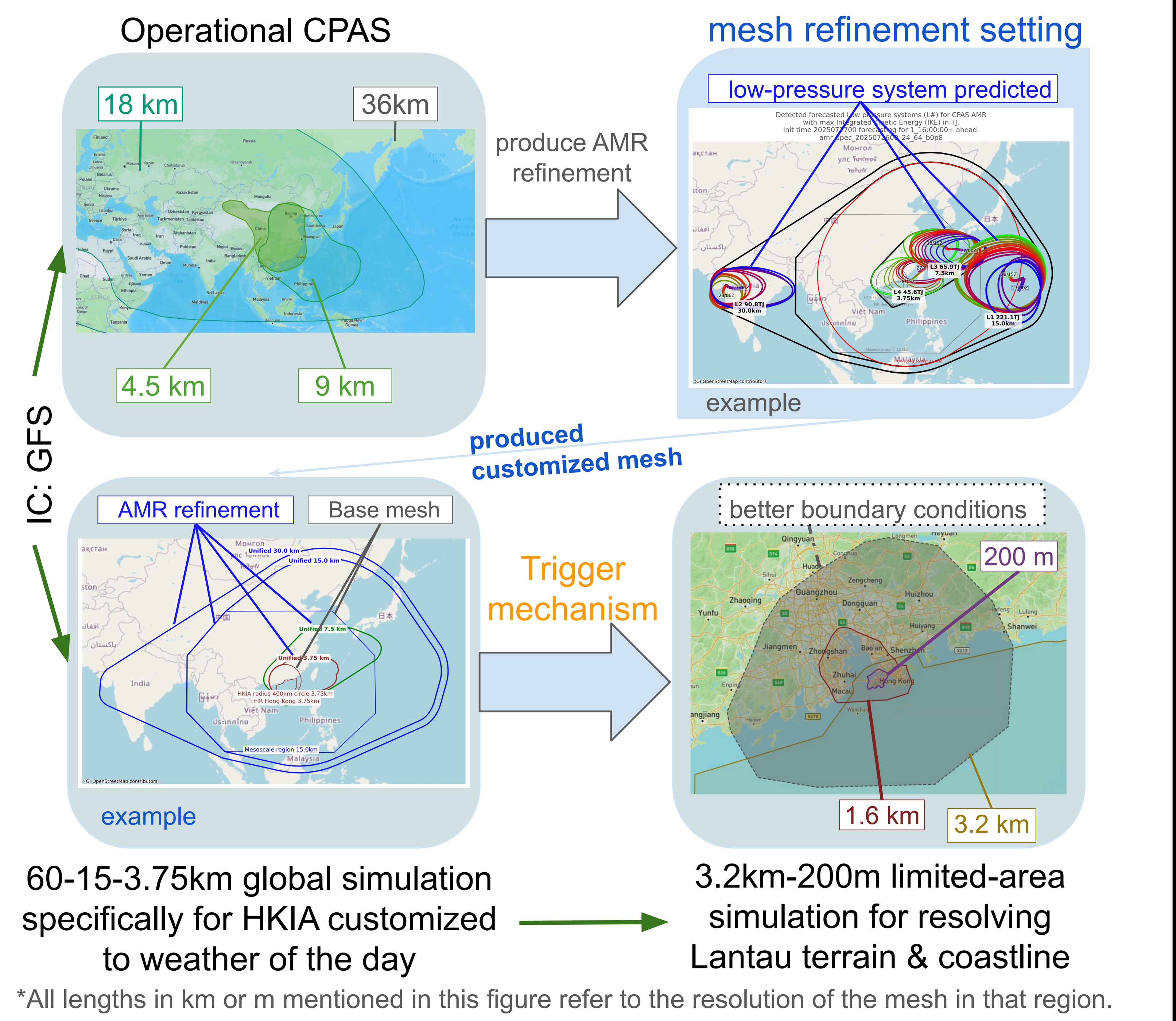

Fig. 1: HKIA wind shear forecast simulation workflow utilizing CPAS.

Result

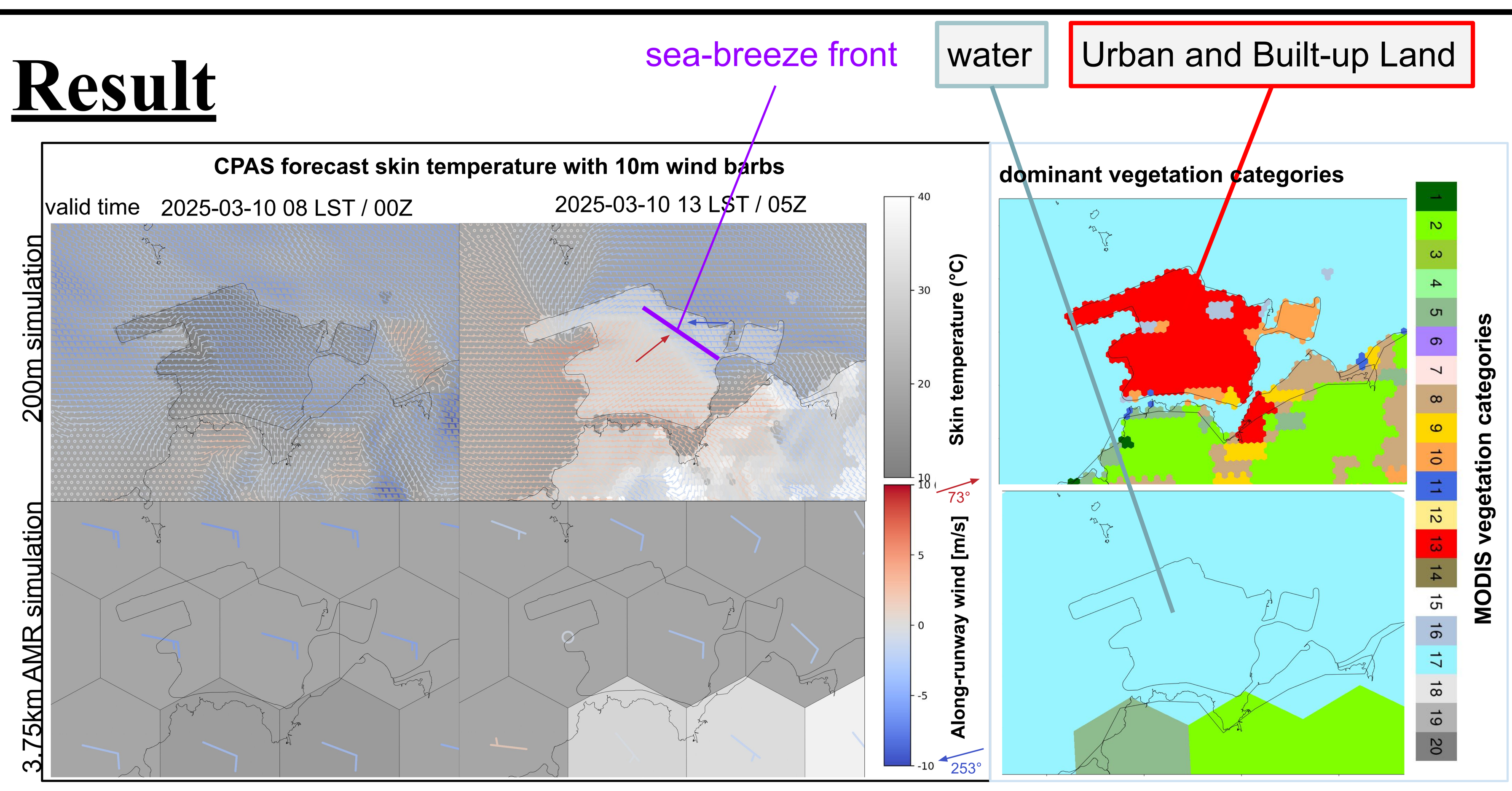

Fig. 2: Impact of grid resolution on boundary layer convergence and surface forcing.

- Comparison of 10m wind barbs and skin temperature variations between the **200m** (*upper row*) and **3.75km** (*lower row*) resolution simulations.
- Mesoscale background (*left column*): At 08 LST / 00Z on 10 March 2025, both simulations yield consistent easterly flow over the HKIA and North Lantau region, indicating the **background easterly wind direction**.
- Microscale development (*middle column*): At 13 LST / 05Z, the **200m simulation** demonstrates diurnal forcing, triggering a distinct **sea-breeze front** (purple line), manifested as a **westerly wind reversal** against the ambient easterlies.
- The discrepancy is attributed to land-use difference (*right column*); the 3.75km mesh is too coarse to resolve the HKIA landmass. The discrepancy in MODIS land use in **Category 13 (Urban and Built-Up Land)** and **Category 17 (Water)** near coast by the 3.75km run misses daytime **landmass heat-up** that can be resolved by the 200m run.

	Ground Truth					CPAS Simulation						
							Predicted Positive		Predicted Negative			
No.	Date in 2025 (Spring)	Interested time period (UTC)	#WS	WS Info & Weather Condition (WS are mostly due to Land-sea breeze)	WS mechanism	Initial time, T dd_hhZ	#TP	#FP	*#TN*	*#FN*	Lead time before first actual WS (T+n hr)	Remarks
1	Jan 07	0100 - 0959	1	WS 0530Z; Easterly airstream	LSB	06_18Z	**0**	*4*	***13***	1	11.5	Temporal lag of WS_pred 0800Z-0930Z
2	Feb 17	0100 - 0959	2	WS 0430Z-0500Z; Easterly airstream	LSB	06_18Z	**2**	*15*	***1***	0	10.5	Prolonged westerly intrusion predicted wrongly
3	Feb 20	0100 - 0959	1	WS 0400Z; Northeasterly monsoon	LSB	19_18Z	**1**	*4*	***13***	0	10	WS_pred 0430Z - 0630Z
4	Mar 11	0100 - 0959	1	WS 05:30Z; Northeasterly wind	LSB+TIF	10_00Z	**1**	*4*	***13***	0	29.5	WS_pred 0500Z - 0900Z
5	Mar 26	0100 - 0959	8	WS 0430Z-0900Z; Southerly airstream, humid with rising temperature	LSB+TIF	25_18Z	**7**	*4*	***6***	1	10.5	WS_pred 0330Z - 0830Z
6	Apr 07	0600 - 0959	3	WS 0600Z-0730Z; Northeasterly wind	LSB	07_00Z	**0**	*2*	***3***	3	6	Temporal lag of WS_pred 0900Z-0930Z
7	Apr 16	0100 - 0959	5	WS 0500Z-0700Z; Easterly airstream, fine and dry weather	LSB	14_00Z	**2**	*5*	***8***	3	53	2-days ahead forecast with similar accuracy as below; WS_pred 0400Z - 0830Z
						15_00Z	**2**	*5*	***8***	3	29	1-day ahead forecast; WS_pred 0430Z - 0830Z
8	Mar 03	0100 - 0959	1	WS 0730Z; Maritime southerly airstream	TIF	02_18Z	**0**	*0*	***17***	1	13.5	Fail to predict WS
9	Mar 10	0100 - 0959	2	WS 0530Z-0537Z; Southwesterly airstream	TIF	09_18Z	**2**	*4*	***12***	0	11.5	WS_pred 0430Z - 0600Z
10	Apr 21	0100 - 0959	2	WS 0430Z,0800Z; Southwesterly airstream	TIF	20_00Z	**0**	*1*	***15***	2	28.5	Only NE wind invading HKIA east simulated, no WS over the correct corridors at the correct timing. False alarm at 0930Z
11	Jan 11	0600 - 0959	0	No WS	N/A	11_00Z	**0**	*0*	***8***	0	N/A	
12	Jan 23	0100 - 0959	0	No WS; Northeasterly monsoon	N/A	22_00Z	**0**	*9*	***9***	0	N/A	1-day ahead forecast; False alarm due to high temp contrast predicted
13	Mar 15	0600 - 0959	0	No WS; Rainstorm during cold front passed	N/A	15_00Z	**0**	*0*	***8***	0	N/A	
Sum		Total hours: 111; 31 WS and *191 non-WS* (222 samples)			All		**17**	*57*	***134***	14		Hit-rate [TP / (TP+FN)]: 17 / (17+14) = 54.8% *False alarm rate [FP / (FP+TN)]: 57 / (57+134) = 29.8%* Accuracy [(TP+FN) / (TP+FP+TN+FN)]: (17+134) / (17+57+134+14) = 68.0%

* Classification (T±30 mins difference) TP: True Positive (hit), FN: False Negative (miss), TN: True Negative (correct rejection), FP: False Positive (false alarm)

* WS mechanism: Land-Sea Breeze (LSB), Terrain-Induced Flow (TIF)

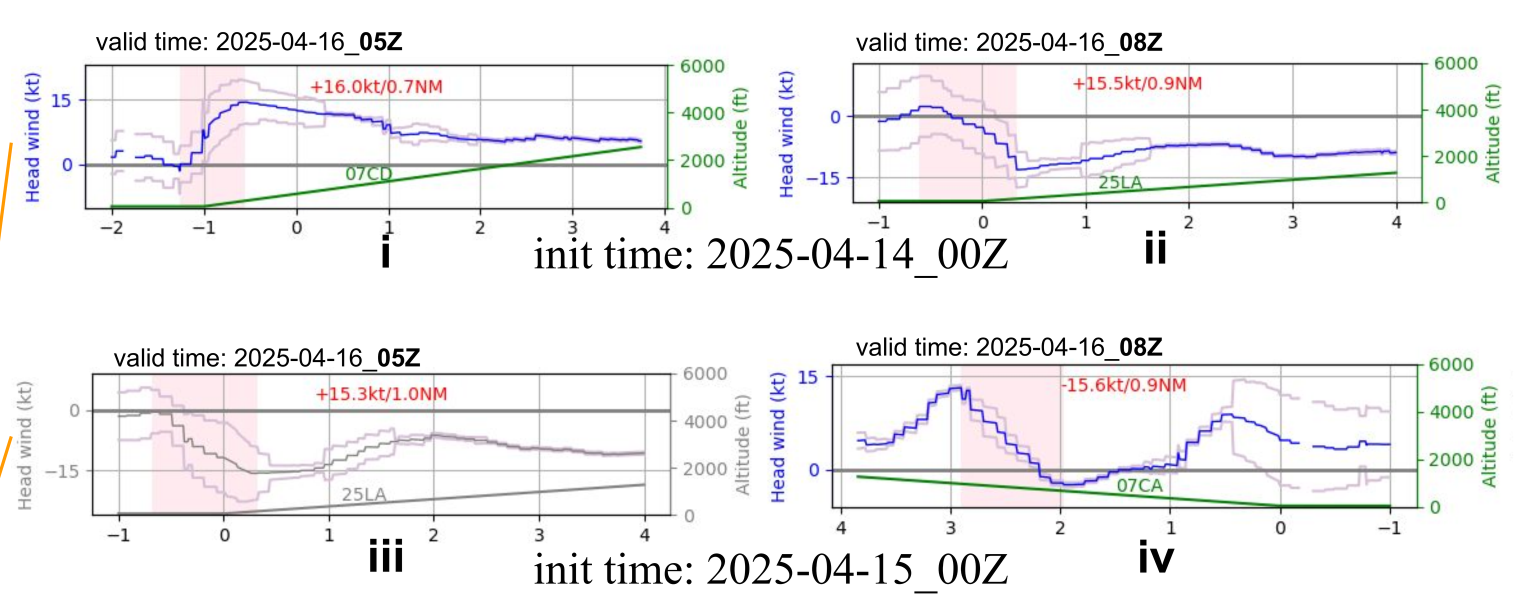

Fig. 3a: Headwind profiles and wind shear simulated along HKIA glide paths.

Headwind in simulations across two initial conditions at **(i, ii)** 2025-04-14_00Z and **(iii, iv)** 2025-04-15_00Z and valid times at 05:00 UTC (*left, a hit*) and 08:00 UTC (*right, a false alarm*) on April 16, 2025

16/04/2025 05:00	METAR VHHH 160500Z 30008KT 9999 FEW025 28/18 Q1012 **WS** R25R NOSIG=
16/04/2025 05:30	METAR VHHH 160530Z 30006KT 9999 FEW025 28/17 Q1011 **WS** R25R NOSIG=
16/04/2025 06:00	METAR VHHH 160600Z 30008KT 9999 FEW025 27/17 Q1011 **WS** R25R NOSIG=
16/04/2025 06:30	METAR VHHH 160630Z 28006KT 9999 FEW022 27/18 Q1011 **WS** ALL RWY NOSIG=
16/04/2025 07:00	METAR VHHH 160700Z 30006KT 270V340 9999 FEW025 27/18 Q1010 **WS** R25R NOSIG=
16/04/2025 07:30	METAR VHHH 160730Z 30007KT 9999 FEW025 27/18 Q1010 BECMG 10010KT=
16/04/2025 08:00	METAR VHHH 160800Z VRB06KT 9999 FEW025 26/18 Q1010 BECMG 10010KT=

Fig. 3b: Aviation weather report (METAR) at HKIA (VHHH) on 16 April 2025.

The sequence highlights persistent WS alerts (**red boxes**) between 0500Z and 0800Z.

Conclusion

- The high-resolution **200m mesh** is strategically triggered to **resolve sea-breeze fronts and terrain-induced WS** that can be missed by coarser models.
- **1-hour** windowing (T ± 30 minutes) yields **54.8% hit rate** and **29.8% false-alarm rate**. CPAS satisfactorily predicts the overall occurrence of springtime wind shear with occasional temporal offset of ~2-3 hours, a tolerable false alarm rate and some misses.
- This Jan–Apr 2025 study includes primary springtime topographical and land-sea breeze drivers, further studies are required to study WS caused by tropical cyclone and low-level jets – less frequent mechanisms, for a comprehensive study.

References: https://cpas.earth/technology/publications