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Wind weakening in a dense high-rise city due to over nearly five decades of urbanization

Lei Peng[a], Jia-Ping Liu[b], Yi Wang[c], Pak-wai Chan[d], Tsz-cheung Lee[d], Fen Peng[e], Man-sing Wong[f], Yuguo Li[a,*]

[a] Department of Mechanical Engineering, The University of Hong Kong, Pokfulam, Hong Kong, China
[b] College of Architecture, Xi'an University of Architecture and Technology, Xi'an, China
[c] School of Environmental and Municipal Engineering, Xi'an University of Architecture and Technology, Xi'an, China
[d] Hong Kong Observatory, Hong Kong, China
[e] Changsha University of Science and Technology, Changsha, China
[f] Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University, Hong Kong, China

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ABSTRACT

Decades of urbanization can lead to significant wind reduction in urban areas. At the King's Park meteorological station in the heart of the Kowloon Peninsula Hong Kong, a wind speed reduction of 0.6 m/s per decade was observed from 1968 to 1995, and -0.16 m/s per decade from 1996 to 2017. We obtained data on the changing three-dimensional urban morphology of Kowloon during the period of 1964–2010, and conducted computational fluid dynamics simulations on historical wind environment considering the prevailing winds. The wind speed and its loss were calculated as both intrinsic and comprehensive spatial averages within an elevation of 200 m. The results show that the overall mean wind speed in the studied urban areas gradually decreased due to the continuous urban development and elevation in building height. The total wind loss ratios at three representative locations have increased from less than 10% to greater than 20% during the study period. The total wind loss ratio may increase to about 40% by 2050 if the current weakening trend continues. The average wind speed at pedestrian level has significantly declined, and local acceleration of wind was only observed in some local areas. However, such accelerated airflow is only maintained around a few blocks of buildings. Our study demonstrates the impact of urbanization on the wind weakening in Hong Kong and reveals the importance and need of factoring in urban air ventilation into the design of urban morphology.

1. Introduction

Globally, the observed near-surface wind speed has significantly decreased over all continents [1–3]. The annual mean wind speeds declined at 73% of 822 surface stations over the 1979–2008 period [3]. In South Asia, Europe, Central Asia, Eastern Asia, and North America, the annual mean surface wind speed has decreased on average at a rate of −0.08, −0.09, −0.16, −0.12, and −0.07 m/s per decade, respectively (i.e. −5%, −2.9%, −5.9%, −4.2%, and −1.8% per decade). This represents a decrease of more than 10% in 30 years in Asia. From 1969 to 1990, the near-surface wind speed in China decreased by 0.031 m/year and 0.028 m/year at urban and rural stations, respectively [1]. However, none of the above-cited studies explored the exact causes of wind weakening.

The winds in cities are weakening at a much faster rate than in other areas. In Athens, Greece, winds can be reduced by up to 10 times in urban canyons compared with the undisturbed ambient wind [4]. The wind speed above buildings is predicted to be reduced by 40% in Lisbon if the aerodynamic roughness is increased from 0.02 m to 1.5 m [5]. The urban population worldwide has rapidly increased from only 30% in 1950 to 54% in 2014 [6]. The dense development in a crowded city may have significant impacts on the urban climate. In particular, the weakening of wind tends to hinder the removal of airborne pollutants, anthropogenic moisture, and heat, while exacerbating urban heat stress, and increasing the rate of energy consumption by buildings [7–10]. As such, with a view to mitigating these negative effects and improving the quality of living environment, sufficient wind is essential for the natural ventilation of the city.

As local wind is one of the key factors determining the urban microclimate and human thermal comfort, an in-depth understanding of the mechanism and extent of wind loss due to urbanization is increasingly important, especially for climate scientists, urban planners and

* Corresponding author.
E-mail address: liyg@hku.hk (Y. Li).

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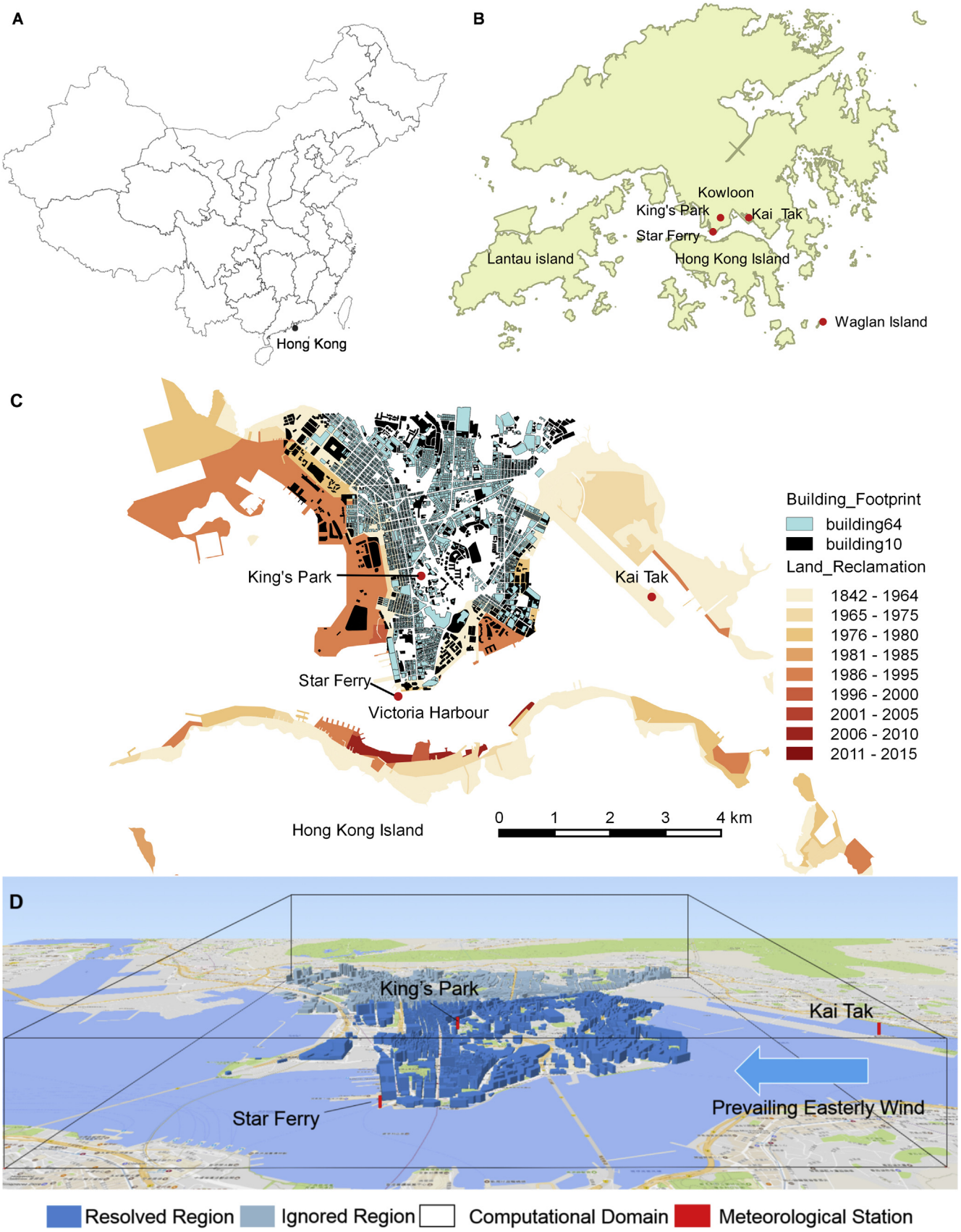

Fig. 1. (A) Location of Hong Kong; (B) location of King's Park (KP), Star Ferry (SF), Kai Tak (KT), and Waglan Island (WGL) meteorological stations; (C) building footprints in 1964 and 2010 and history of land reclamation; (D) perspective view of Kowloon Peninsula in 2010 and the locations of the meteorological stations.