

APPLICATION OF A PRIMITIVE EQUATION MODEL  
 IN A SIMULATION OF THE SEA BREEZE  
 CIRCULATION OF THE TOLO HARBOUR, HONG KONG

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**Abstract:** A three dimensional primitive equation model with hydrostatic and Boussinesq approximation was employed to simulate the complex sea breeze circulation at the Tolo Harbour of Hong Kong. In a case study, two circulations, one within the Tolo Harbour and another from the South China Sea were identified. Both circulations were found to play important roles in the evolution of the flow pattern inside the harbour and results compared favourably with observations.

1. **Introduction :**

The study of wind flow over Hong Kong is never an easy task to the experimenters or modellers because of its highly complex terrain and irregular coastline (Figure 1), let alone the much smaller Tolo Harbour. The Tolo Harbour resembles an elongated lake with a linear dimension of about 15 km. Apart from a narrow strait at its eastern edge which connects it to the open sea, it is completely surrounded by hills with heights ranging from a few hundred metres to a thousand metres, forming a basin-like air shed. These surrounding hills are themselves not extensive but are bounded by the Mirs Bay to the east, South China Sea to the south and the Pearl Estuary to the west. Inside the harbour, by terrain

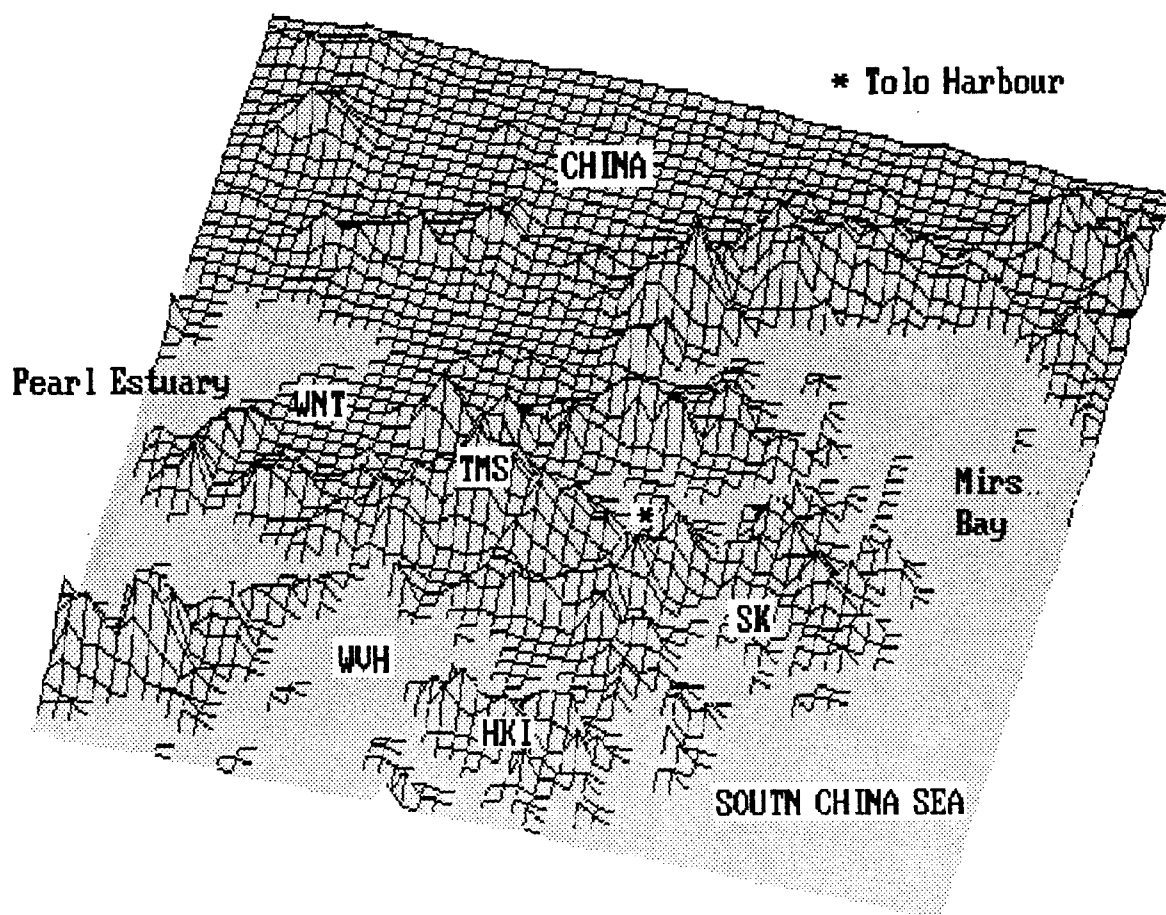


Figure 1 Terrain around the Tolo Harbour of Hong Kong at 1 km resolution

effect alone, wind directions at two locations separated by just a few kilometres could differ by 90 degrees. With diurnal heating, winds at some location could change direction by 180 degrees in a matter of an hour. Since the Tolo Harbour has recently become one of the most active development area of Hong Kong, a good knowledge of these wind flows would be of use to development planning and environment assessment studies of the area.

To resolve experimentally wind field of this complexity will require a rather dense anemometer network. Alternatively, one can make use of an appropriate wind model to simulate the flow. In the present study, the latter approach is chosen. To confine our target to an even smaller problem, only the sea breeze circulation is addressed here. Our main tool for this study is a primitive equation model described in Section 2. In order to provide ground truth for comparison with the model outputs, a surface meteorological station has been set up at a seaside site in the campus of the Chinese University of Hong Kong (CU site). A tethered sounding system has also been deployed to provide wind and temperature data for the lower boundary layer up to about 700 m.

## 2. The numerical model

The computation here are made using a three dimensional primitive equation model. Detailed description of the formulation of this model can be found in Kikuchi et al. (1981), and Kimura (1983). The basic assumptions are that the atmosphere is hydrostatic and Boussinesq approximated. There are 60 x 60 grids in the horizontal and 16 layers in the vertical. The model top is set at 7.6 km above mean sea level. The layer thicknesses are not identical but increases with height so that half of the number of layers are within the lowest 1000 m. The model is written in a terrain following coordinate.

On the surface, temperatures are predicted by the Force Restore Method of Bhumralker (1975) and Deardorff (1978). Transfer of sensible and latent heat energy from ground to the surface layer is based on the similarity theory of Monin-Obukhov. In the boundary layer, turbulence is treated by the level-2 closure model of Mellor and Yamada (1974). The ground and top surfaces of the model are considered as a no-slip and a free surfaces respectively. For simulation using 2-km grid length, radiative boundary condition is applied at the lateral boundaries to control wave reflection back into the domain. For simulations using 1 km or 0.5 km grids, nesting technique is employed. In these cases, sponge type of boundary condition is applied and the boundary data is supplied by model outputs of a similar simulation using a larger domain and a coarser grid.

## 3. Description of the numerical experiment

Space limits the presentation to only one case study in this paper. The simulation is for a sunny day on 10 December 1990. The 00 GMT (8 a.m. local time) radiosonde ascent data of the day is used as input to the model. All grid values are linearly interpolated from the ascent data with respects to heights only. The exception is for the wind fields near the ground where observed winds from 15 anemometer stations around Hong Kong are included in the analysis to provide a more realistic initial field. In view of the fine terrain features of the harbour concerned, simulation at 1-km resolution is attempted. However, to avoid overlooking any larger or smaller scale circulations which may also be of importance to this type of study, two more simulations at 2 km and 0.5 km grid are also performed. computations are carried out for a forecast period of 12 hours ending on 8 p.m. local time.

## 4. Result and discussion

Figures 2a - 2b show the 8 a.m. and 2 p.m. wind fields for the 1-km run. These compare quite well with the actual wind fields observed (Figures 3a - 3b). Over the whole domain, the most striking part is the reversal of wind direction over the western part of the territory (WNT) from morning to midday.

Figure 2a

Sea breeze simulation for 10/12/1990  
Wind at 10.m above terrain. Data time 8H + 0 hour

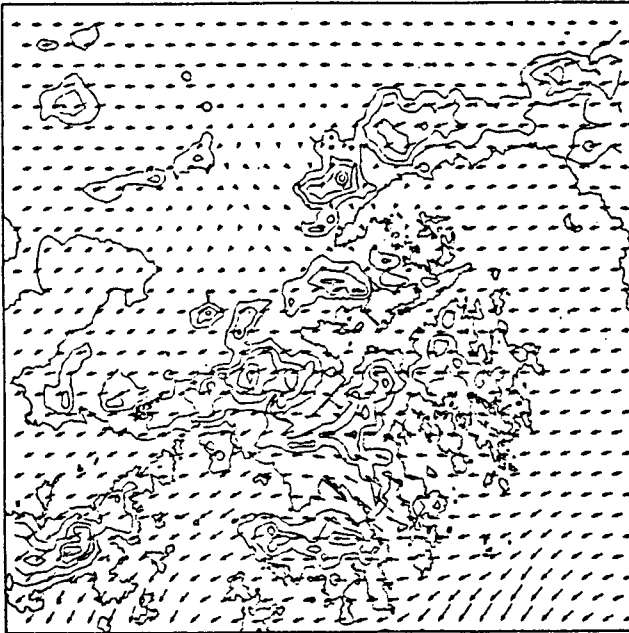
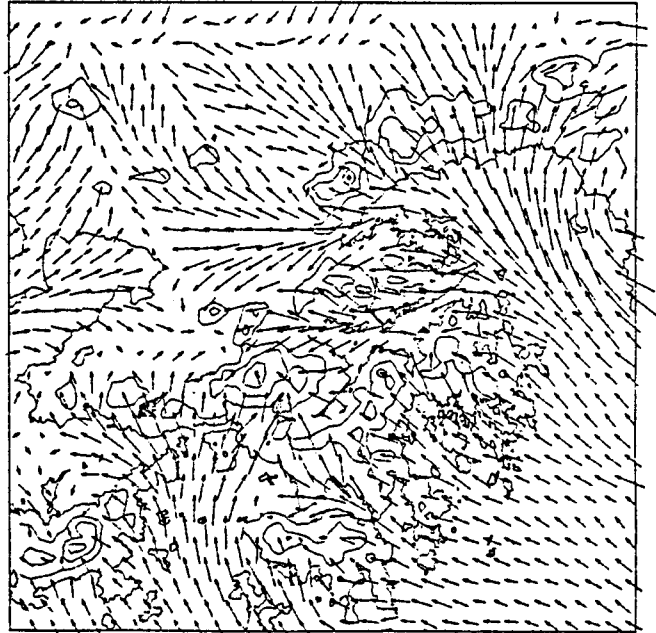


Figure 2b

Sea breeze simulation for 10/12/1990  
Wind at 10.m above terrain. Data time 8H + 6 hour



Figures 2a - 2b Model simulated wind field for 8 a.m. and 2 p.m.

( WNT = Westen territory; TH = Tolo Harbour; SK = Sai Kung  
WVH = Western Victoria Harbour; TMS = Tai Mo Shan )

Figure 3a

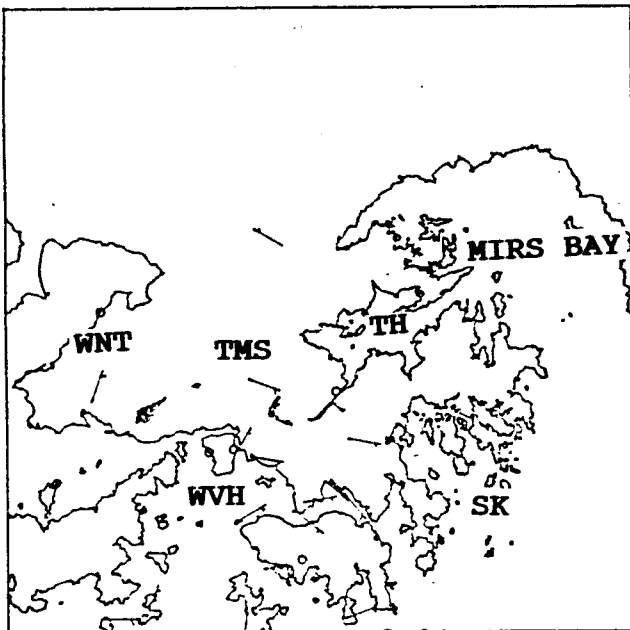


Figure 3b

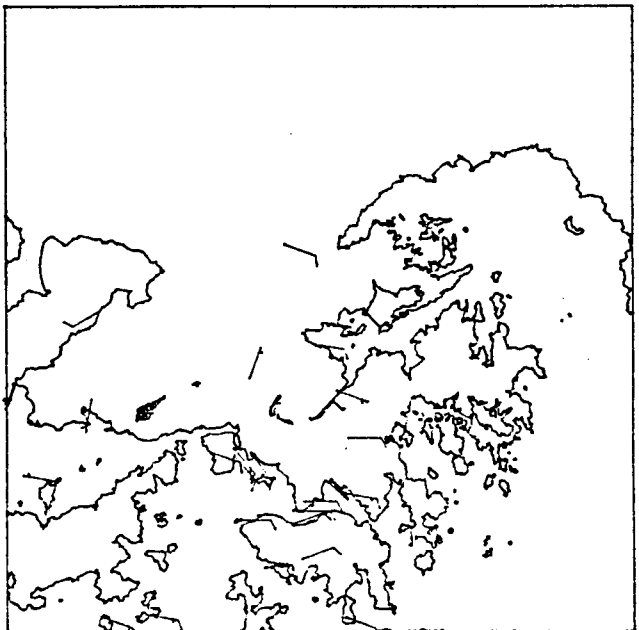


Figure 3a - 3b Winds observed at surface anemometer stations  
at 8 a.m. and 2 p.m.

Other significant changes are the rapid turning of winds from easterly to southerly over the western Victoria Harbour (WVH), the Sai Kung area (SK) and the Mirs Bay.

Figures 4a - 4d zoom in on the evolution of wind flows inside the Tolo

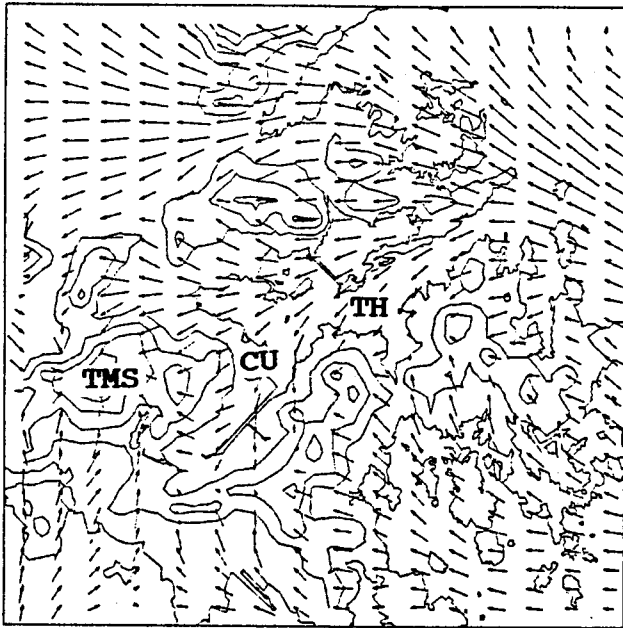


Figure 4a Wind field at 11 a.m.

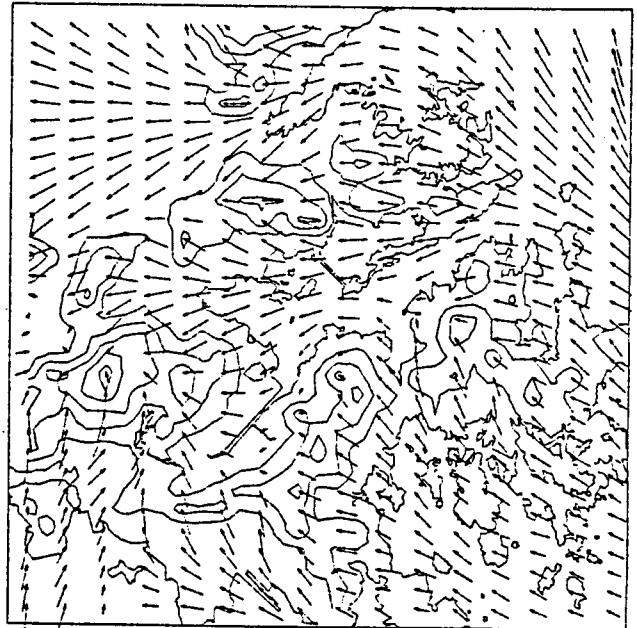
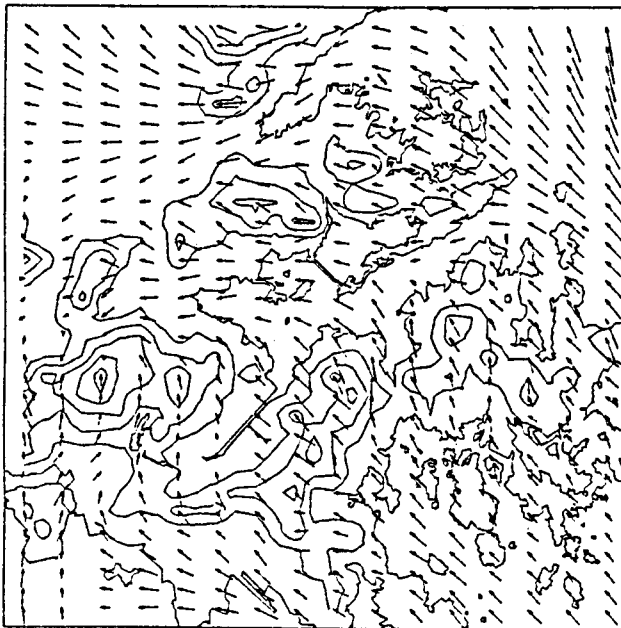


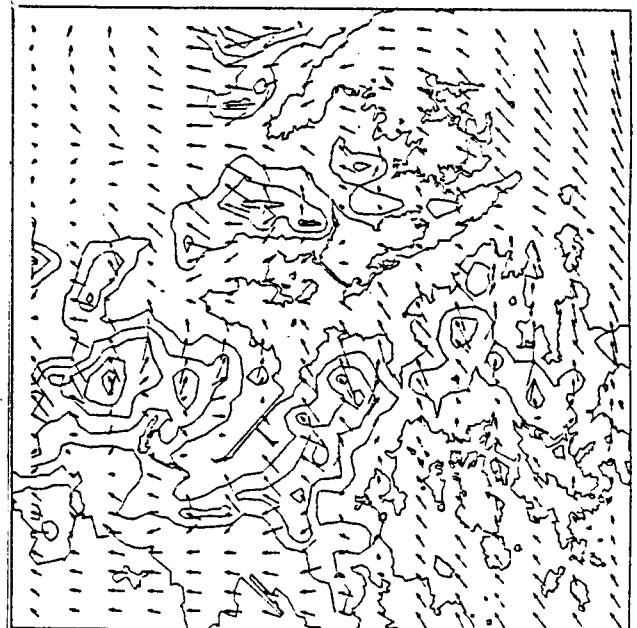
Figure 4b Wind field at 2 p.m.

o CU = CU site, TH = Tolo Harbour, TMS = Tai Mo Shan



Lowest contour = 150m, contour interval = 150m

Figure 4c Wind field at 5 p.m.



Lowest contour = 150m, contour interval = 150m

Figure 4d Wind field at 8 p.m.

Figures 4a - 4d Model simulated wind fields for 11 a.m., 2 p.m., 5 p.m. and 8 p.m. respectively.

Harbour. A complicated pattern is indeed found. In spite of the prevailing easterly flow in the initial field, the harbour flow becomes predominantly northeasterly following more or less the orientation of the Tolo harbour air shed. Due to the presence of Tai Mo Shan (TMS), flow in the west of the harbour splits into two branches. The southern branch maintains about the same direction but the northern branch becomes east to southeast. The differential land/sea heating during the day enhances this flow pattern initially causing an overall increase in wind speed. The flow direction also changes slightly towards the shore surrounding the harbour (Figure 4a). But later in the afternoon, a more dramatic change occurs in the southern part of the harbour. Wind direction of the southern branch switches rapidly to the southerly (Figures 4c, 4d). The southeast sea breeze originated from the South China Sea manages to penetrate the blocking ridges reaching most part of the Tolo harbour.

To study this phenomenon more closely, a time cross section at the CU site is plotted on Figure 5. The columns of arrows shown on the hours are model

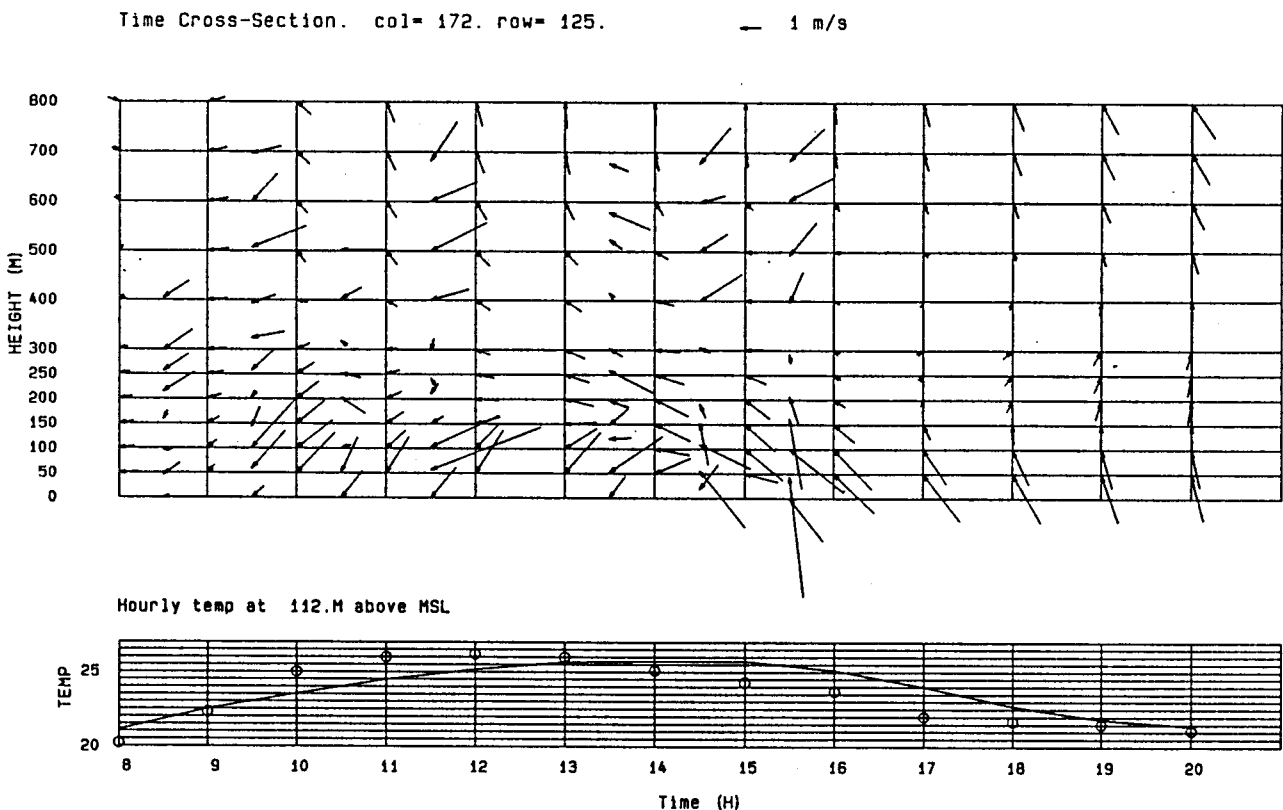


Figure 5 A time cross section of wind and surface temperature for the CU site

winds while those shown in between the hours are observed winds from tether sonde soundings. Comparison is quite good below 300 m height. The strengthening of the northeast winds around 10 a.m. as well as the turning to southerly near 3 p.m. are well predicted. The surface winds being the strongest which is a typical feature of the sea breeze effect is present. Also, both model output and observed data show a near-calm wind region at 300 m. This is probably the level delineating the beginning of the return flow. There are areas which the model is not doing well. The penetrating southerly is much weaker than observed and the return flow

direction above 300 m is far out. For the latter, it is possible that the input data at that level is misrepresented. Discrepancy in fact occurs as early as 10 a.m. and remains so for the whole period.

The model predicted and the observed surface temperatures at the CU site are shown in the bottom graph of Figure 5. Circle and the solid line represent the observed values and the model prediction respectively. Both maximum temperature and trend are well predicted.

Space does not allow the presentation of outputs for the 2 km and 0.5 km runs. A careful Comparison of the three simulations suggests that the best result is from the 1-km grid. The reason for the less successful attempt using the 2-km grid is that at such resolution, the Tolo harbour becomes rather ill-represented, so much so that the sea breeze circulation within the harbour becomes too weak to be identified. The failure of the 0.5-km grid test is a surprise at first. It is later confirmed that the problem is not due to resolution but the smaller domain covered by the 60 x 60 grids. In this domain, the South China Sea occupies only a small part of the model area and sea breeze originated from the Tolo harbour dominates the entire evolution. The latter is of course not a limitation to the choice of the 0.5 km grid for any further studies. There is no real reason not to use a fine grid and a large domain simultaneously if one can afford the longer computation time. Nevertheless, the present finding reminds us again of the importance of making a correct choice of grid resolution and domain for simulations of this kind.

## 5. Conclusion

The present study has shown that primitive equation model with appropriate parameterization and resolution could give credible prediction of the sea breeze circulation of the Tolo Harbour of Hong Kong. Although using a finer grid resolution can produce more realistic terrain effects, it is found that the choice of an appropriate model area is of equal importance for studies with differential land and sea heatings.

## 6. Acknowledgement

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