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# FORECASTING OF WEATHER BRINGING DISRUPTION TO AIRPORT OPERATIONS CAUSED BY TROPICAL CYCLONES

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## 1.INTRODUCTION

High impact weather due to tropical cyclones (TC) is a major factor causing significant flight delays and airport disruptions in Hong Kong.

Since the opening of the Hong Kong International Airport (HKIA) in 1998, a number of TCs brought significant disruptions to the operation of the airport due to the associated high crosswinds and/or severe turbulence. In some cases, for examples during Typhoon Utor (0104) and Typhoon Prapiroon (0606), the airport operation was disrupted for a few days and thousands of passengers were stuck at the airport.

In studying past cases of significant disruptions at HKIA, based on flight delay and cancellation data, TC bringing high crosswinds and/or severe turbulence stands out as the top weather factor causing the airport disruptions (Figure 1). Other weather conditions include thunderstorms and fog.

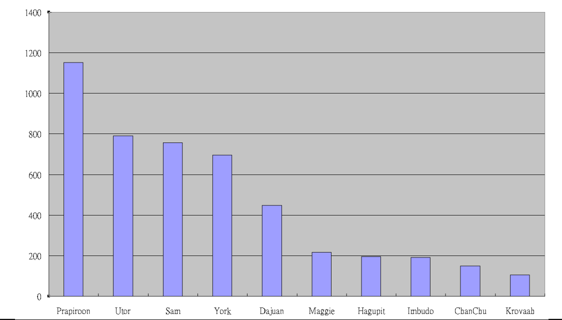


Figure 1 – Number of affected flights during TC situation.

The Hong Kong Observatory (HKO) provides aviation weather services to aviation users, including airlines, airport management and air traffic management, in support of their operational decision-making and planning.

In 2007, a new service was launched to alert users of sustained high crosswind (25kt) and severe turbulence in the next several hours.

This paper presents the design and performance of the forecasting tools for alerting high crosswinds and severe turbulence at HKIA brought by Tcs.

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## 2.FORECAST OF CROSSWIND AND TURBULENCE

To support the operation of the new service, HKO has extended a statistical method (Lee (2001); Lam (2004); Lau (2005)) for the forecasting of high winds in Hong Kong brought by TCs to cover crosswinds and severe turbulence at HKIA.

Based on historical wind and turbulence data associated with TCs, probability isopleths of crosswind/turbulence are derived such that given the forecast position and intensity of a TC, the probability of occurrence of crosswind and/or turbulence exceeding pre-defined thresholds at the airport can be derived.

In the original algorithm, statistical figures used to construct probability isopleths were calculated in 1-degree latitude by 1-degree longitude boxes. Consequently, for areas with less TC data available, huge jump of probabilities will occur between adjacent grid cells and much smoothing and subjective human interpretation were required to produce sensible probability isopleths. The situation is more noticeable when applying the algorithm to turbulence probability since the continuous record of turbulence at HKIA (e.g. from PIREPs) only started in 1998 when the airport opened. Crosswind information, on the other hand, has been available since 1979 when weather observations commenced at the remote Chek Lap Kok Island before it was levelled for construction of the airport.

To better utilize the limited data available, an enhanced "TC track following" algorithm has been developed to produce the statistics and automatically generate the probability isopleths using computer programs. Basically, best track data from HKO at 6 hourly intervals for every TC was traversed and for each of the TC's location, an effective radius of 60NM was searched for any other historical TCs located within the search area. For all the TCs found, the program counts how many of those TCs had caused crosswind or turbulence at HKIA exceeding some predefined thresholds. The ratio of the number of TCs meeting the criteria within that area to the total number of TCs in the same area was taken as the probability of occurrence of high crosswind at HKIA.

The probabilities found using the above mentioned process were distributed unevenly on the map. To re-grid it onto rectilinear coordinates, the "natural-neighbour" interpolation method was used. Conventional contouring technique was then applied on the resultant grid to derive the probability isopleths.

One such process in deriving the crosswind probability isopleths for 25kt southerly crosswind is illustrated in Figure 2a through Figure 2e.

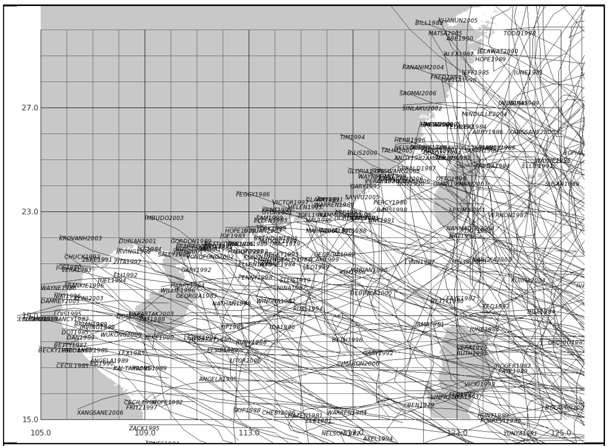

Figure 2a – Tracks of all Typhoons and Severe Tropical Storms in the Northwestern Pacific and South China Sea during the year 1979 to 2006.

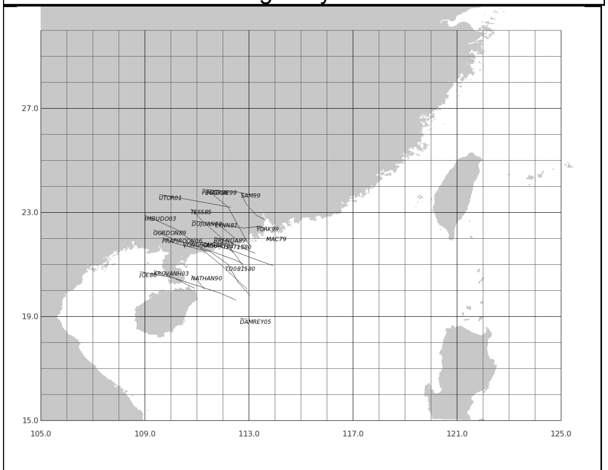

Figure 2b – Track of TCs causing southerly crosswind exceeding 25kt at HKIA.

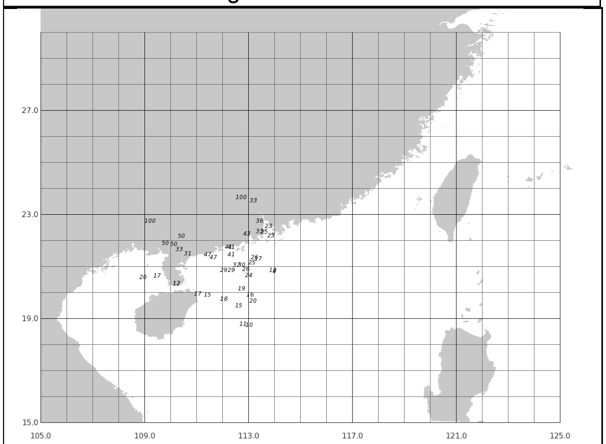

Figure 2c – Ratio of the number of TCs meeting 25kt southerly crosswind criteria to the total number of TCs within 60NM search radius.

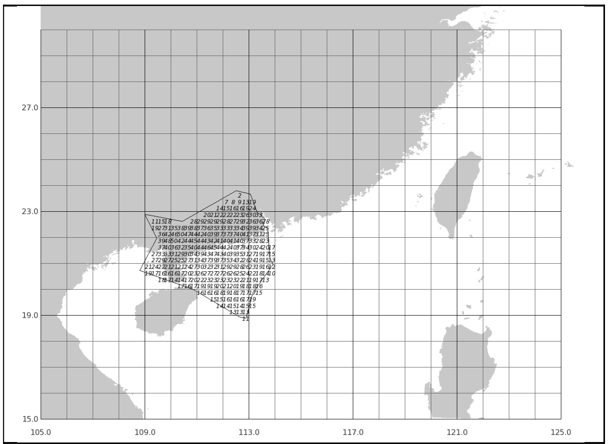

Figure 2d – Probabilities on a rectilinear grid after re-grid.

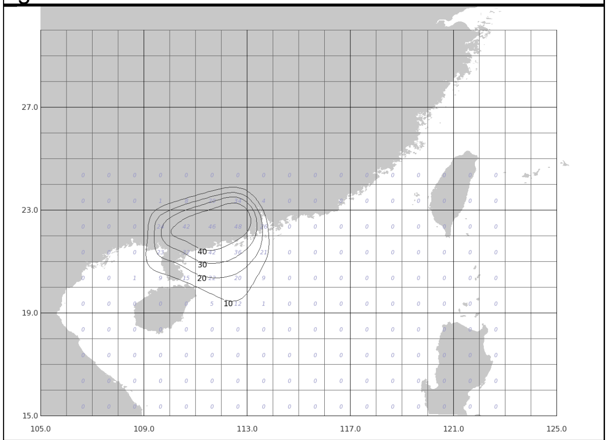

Figure 2e – Computer generated probability isopleths for 25kt southerly crosswind at HKIA due to TC.

After the automatic process, the probability isopleths are re-examined and fine tuned at 10 percent intervals. The tuning was performed manually based on forecasters experience and known wind/turbulence characteristic at HKIA due to terrain effect.

The above process was repeated for the 20kt and 25kt crosswind thresholds, each sub-divided into Tropical Storm and Severe Tropical Storm (TS-STS), and Severe Tropical Storm and Typhoon (STS-TY) categories. A total of 4 sets of probability isopleths were produced for crosswinds over HKIA. Figure 3 shows the final probability isopleths for 25kt crosswind for STS-TY. It is worth noting that due to local terrain effect, the area for high southerly crosswind is significantly larger than northerly crosswind for the same probability level.

The probability isopleths for severe turbulence brought by STS-TY were also produced in the same manner (Figure 4). No turbulence probability isopleths for TS-STS could be produced as the number of TCs is too small for generating reliable results.

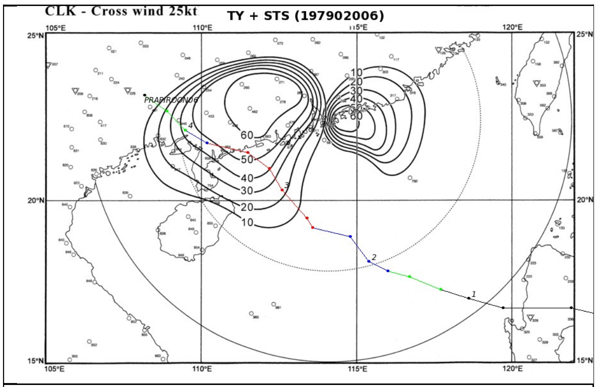


Figure 3 – 25kt crosswind probability isopleths for STS-TY. The track of Typhoon Prapiroon (0606) is also shown to illustrate the application of the probability isopleths. The different intensities of Prapiroon, TY, STS and TS, are indicated by red, blue and green respectively on the track.

Based on the probability isopleths for crosswinds and turbulence and the information on the forecast locations and intensities of a TC, a forecast time series of the probability of high crosswind and/or turbulence at HKIA could be derived.

In Figure 3, the track of Typhoon Prapiroon (0606) is plotted onto the 25kt STS-TY crosswind probability isopleths. One can easily see that according to the track, the probability of high crosswind at HKIA steadily increased to more than 50% when Prapiroon approached, especially as it traversed along a ridge of probability isopleths. Had it tracked a little more westward, high crosswind might not be able to affect HKIA at all. Therefore, the uncertainties in the forecast TC positions need to be addressed in order to make the probability assessment using this method more reliable.

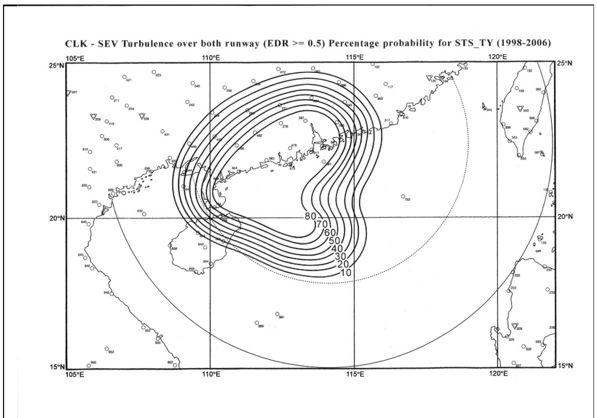


Figure 4 – Severe Turbulence probability isopleths for Severe Tropical Storm-Typhoon (STS-TY).

## 3. UNCERTAINTIES IN TC TRACK FORECAST

To account for the uncertainty of deterministic TC track forecasts, various perturbation schemes were experimented by Lam (2004) to derive error distribution of tropical cyclone forecast tracks.

Forecasting tools were developed to ingest the forecast track together with the forecast errors to produce a set of perturbed tracks and carry out integration over the corresponding probability isopleths to calculate a time series of the averaged forecast probability of, say, gale force wind over a certain area, or 25kt crosswind at the airport.

In addition to forecast track error statistics estimated from historical TCs, individual NWP ensemble members obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) can also be used to produce an ensemble probability time series. An ensemble probability time series can be generated by averaging all probability time series derived from individual ensemble members.

Figure 5 shows an example of all forecast tracks of STS Pabuk at 12UTC, 9 August 2007 based on the ECMWF ensemble forecasts. Figures 6 and 7 shows the hourly probabilities and total event probability of 20/25kt crosswind at the airport by averaging the probabilities associated with each of the ensemble forecast tracks in Figure 5, presented in time series and tabular form respectively.

## 4. PERFORMANCE

In the year 2007, Severe Tropical Storm Pabuk affected Hong Kong. Being a weak TC, Pabuk did not cause major disruption to the operation of HKIA despite the fact that it moved very close to Hong Kong on 10 August 2007 and its eye traversed the airport in the afternoon.

From Figures 6 and 7, it could be seen that the probability of high crosswind at HKIA during the period was actually rather low. The probability of occurrence of severe turbulence over HKIA, however, could not be assessed because when Pabuk came close to the territory, it weakened into a Tropical Storm (see Section 2 above on the limitation of turbulence statistics).

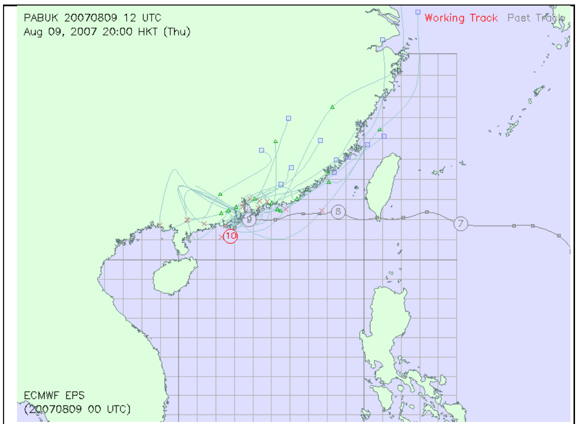


Figure 5 – ECMWF ensemble forecast tracks for STS Pabuk at 12UTC based on model runs at 00UTC 9 August 2007.

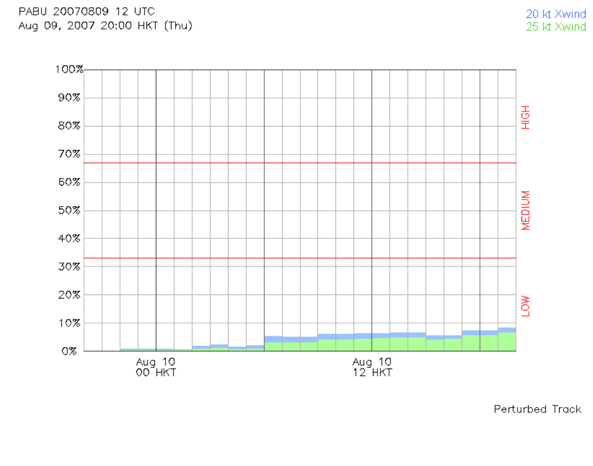


Figure 6 – Probability time series forecasts of 20/25kt crosswind at HKIA for STS Pabuk. The time series was generated based on averaging the probabilities associated with the ensemble forecast tracks in Figure 5.

**20/25KT Cross Wind Probabilities for PABUK @ 2007080912UTC / EPS**

| | Working Track | | | | | | Perturbed Track | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Valid Time (Local Time) | South Xwind 20kt | North Xwind 20kt | South Xwind 25kt | North Xwind 25kt | 20KT Xwind Prob | 25KT Xwind Prob | South Xwind 20kt | North Xwind 20kt | South Xwind 25kt | North Xwind 25kt | 20KT Xwind Prob | 25KT Xwind Prob |
| Total_Event | 0% | 0% | 0% | 0% | 0% | 0% | 8% | 5% | 7% | 3% | 8% | 7% |
| Aug/09 20 - 21H | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Aug/09 21 - 22H | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Aug/09 22 - 23H | 0% | 0% | 0% | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 1% | 0% |
| Aug/09 23 - 00H | 0% | 0% | 0% | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 1% | 0% |
| Aug/10 00 - 01H | 0% | 0% | 0% | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 1% | 0% |
| Aug/10 01 - 02H | 0% | 0% | 0% | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 1% | 0% |
| Aug/10 02 - 03H | 0% | 0% | 0% | 0% | 0% | 0% | 2% | 0% | 1% | 0% | 2% | 1% |
| Aug/10 03 - 04H | 0% | 0% | 0% | 0% | 0% | 0% | 2% | 0% | 1% | 0% | 2% | 1% |
| Aug/10 04 - 05H | 0% | 0% | 0% | 0% | 0% | 0% | 2% | 0% | 1% | 0% | 2% | 1% |
| Aug/10 05 - 06H | 0% | 0% | 0% | 0% | 0% | 0% | 2% | 1% | 1% | 1% | 2% | 1% |

Figure 7 – Hourly probability forecast of 20/25kt crosswind at HKIA for STS Pabuk presented in tabular form. The probabilities under "Perturbed Track" are the same as those shown in Figure 6 .

## 5.CONCLUSIONS

A statistical method developed by HKO for high wind forecasting in Hong Kong due to TCs has been extended to also cover crosswinds and severe turbulence at the airport. Forecasting tools were developed such that given the forecast positions and intensities of a TC, the probability of occurrence of crosswind and turbulence exceeding pre-defined thresholds at the airport can be derived.

The cases of Papiroon and Pabuk show that the new forecasting tool is useful for accessing the operational impacts of TCs to HKIA. However, more cases are needed to further assess the performance of this new forecasting tool.

It is noted that the current treatment on the uncertainties in TC forecast only considers the errors in position forecast. Methods to address uncertainties in intensity forecast will be studied in the future.

## ACKNOWLEDGEMENT

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