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Probability Forecast of Crosswinds at HKIA Due to

Tropical Cyclones

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PROBABILITY FORECAST OF CROSSWINDS AT HKIA DUE TO TROPICAL CYCLONES

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1. INTRODUCTION

On average, six tropical cyclones affect Hong Kong each year. Apart from severe weather, the passage of tropical cyclones may also bring high crosswinds at the airport. Crosswind is the component of the wind blowing perpendicular to the flight path. When the crosswind exceeds the operating limit, an aircraft should not take off or land. Thus when the crosswind is expected to change through values representing the main operating limits for typical aircraft operating at the aerodrome, a change group has to be included in the aerodrome forecast.

The Hong Kong International Airport (HKIA) at Chek Lap Kok (CLK) has two parallel northeast-southwest oriented runways. Since most of the flights operating at the airport are heavy category aircraft, the change group criterion for crosswind for inclusion in aerodrome forecast is taken to be 20 KT (10 ms^{-1}).

To support the preparation of aerodrome forecast, in particular the forecasting of crosswind during tropical cyclone situation, the Observatory has developed a statistical method for the forecasting of crosswinds due to tropical cyclones. Based on climatological wind data associated with past tropical cyclones, given the forecast position of the tropical cyclone, the probability of occurrence of crosswinds exceeding pre-defined thresholds were derived statistically. The technique has been extended lately to take into account the error in the forecast track. This method uses a combination of statistical and model forecast track to predict the probability of occurrence of crosswinds of over 20 and 25 KT (10 and 12.9 ms^{-1}) at HKIA. This is modeled on the probability forecasts of high winds and related warnings associated with tropical cyclones for public

weather forecasts (Lam and Tai 2004). This paper describes the new probability forecast tool using tropical storm Kompasu in 2004 as an example.

2. PROBABILITY ISOPLETHS

Wind measurement at CLK dates back to 1979 when the Government first considered building an airport there. The tropical cyclones that comes within 15-25N, 106-123E between 1979 and 2001 were thus used to derive the probability isopleths. Using the Observatory's best track positions, the total number of hours when a tropical cyclone fall within a 1 degree-latitude by 1 degree-longitude box were counted. The ratio of the number of hours the tropical cyclones within each 1-degree box that caused high crosswinds at CLK to the total number of hours of tropical cyclones within the same 1-degree box was then taken as the probability of occurrence of high crosswind at HKIA. While the crosswind criterion for change group for inclusion in aerodrome forecast is 20 KT (10 ms^{-1}), since many airline uses a crosswind limit of 25 KT (12.9 ms^{-1}), two sets of probabilities, one for 20 KT or above and the other for 25 KT or above have been developed.
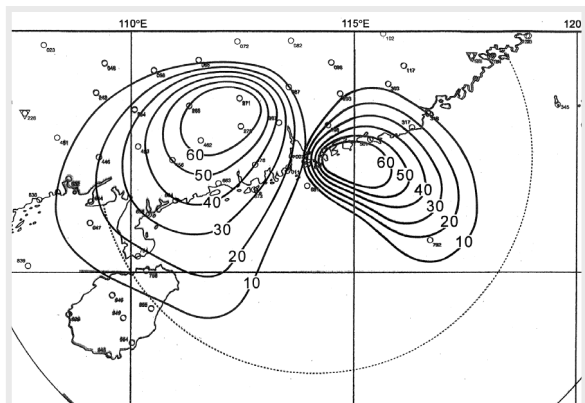

Figure 1. Isopleths of probability of occurrence of 10 ms^{-1} crosswind at HKIA based on tropical cyclones between 1979 and 2001.

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Maps of probability isopleths were then constructed and smoothed at 10 percent intervals (see Figure 1). It would be interesting to note that due to the local terrain effect, for the same probability, the area where a tropical cyclone might cause high crosswinds to HKIA is significantly larger for southerly crosswind than northerly crosswind. The probability isopleths were not further categorized according to the tropical cyclone intensity as the number of cases with high crosswinds at CLK in each category is too small. Using the latest tropical cyclone forecast track, the time when the probability of high crosswind exceeds a certain threshold can then be estimated.

3. TRACK PERTURBATION

To account for the uncertainty of forecast track, two types of perturbation schemes are used to derive perturbed tropical cyclone tracks.

a) Statistical

Based on the mean forecast position errors of all the tropical cyclone warnings issued by the Observatory, the forecast position errors for 24- and 48-hour forecasts were derived. The position errors are then used to form the perturbation field.

b) Dynamical

In the past decade, numerical models have matured and become indispensable in weather forecasting. In particular, they become reliable means of improving the accuracy of tropical cyclone forecast tracks. Starting from 2002, the Observatory put into operation a multi-model ensemble method to help forecasters to determine the tropical cyclone forecast tracks. In the dynamical perturbation scheme, forecast position errors (in latitudinal and longitudinal directions) of all models used in the ensemble method are used to form the perturbation field.

Assuming the forecast error follows a Guassian distribution, for each of the above perturbation scheme, 25 perturbed tracks are constructed so that they fall within 85% of the bivariate Gaussian distribution for position uncertainties. The number of perturbed tracks and the 85th percentile were chosen to optimize the computational time.

4. PROBABILITY FORECAST OF CROSSWIND

The probability of occurrence of crosswinds at HKIA is generated at hourly intervals based on the perturbed tracks and probability isopleths. At any time t, the probability is :-

$$P(t) = \sum_{k=1}^{25} P_I(W \mid r_k)P(r_k(t))$$

where $P_I(W|r_k)$= probability of high crosswinds given the location of TC at r on the kth perturbed track.
W denotes 10ms^{-1} or 12.9 ms^{-1} crosswinds.

$P(r_k(t))$= probability of the TC at location r and time t on the kth perturbed track.

Probability forecasts in the form of a time series and a table are generated automatically on receipt of a new tropical cyclone warning track.

5. CASE ILLUSTRATION - KOMPASU

Kompasu developed into a tropical depression over the western North Pacific about 620 km east-southeast of Gaoxiong on the early morning of 14 July 2004. It took on a westerly track and intensified into a tropical storm. Upon entering the South China Sea, it adopted a northwestward course and headed towards the coast of Guangdong. It made landfall over Hong Kong at around 07UTC [1] 16 July and quickly dissipated over inland that evening. The best track of Kompasu is given in Figure 2.

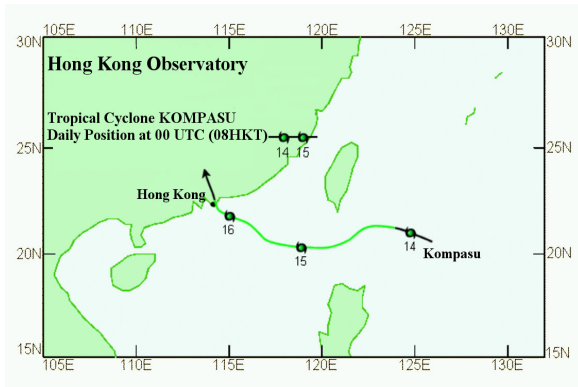[1] Local Time is 8 hours ahead of UTC.

Figure 2. Best analyzed track for Kompasu.

Figure 3a is the perturbed tropical cyclone track map derived from model spread at 00UTC 15 July 2004. As the different ensemble members agreed fairly well with each other, the spread of the 24 hour forecast positions was much smaller compared with that based on statistical method (Figure 3b).
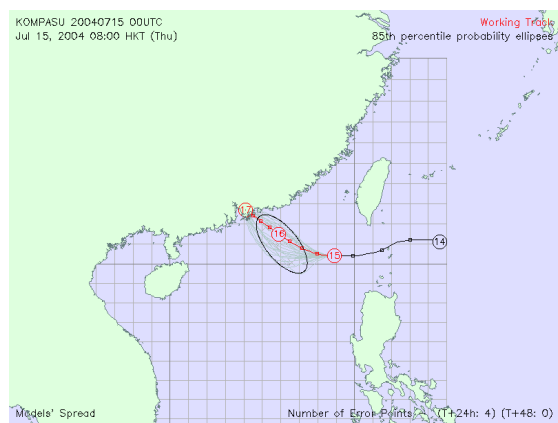
(a)
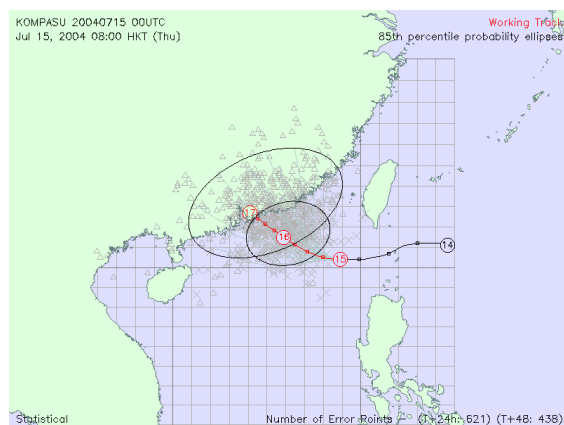
(b)

Figure 3. Forecast (red) and perturbed (grey) track of Kompasu.   The ellipses are the 85th percentile probability ellipses using (a) dynamical and (b) statistical perturbation schemes respectively.

Comparing the forecast track for 00UTC 15 July 2004 with the best track analysis (Figure 2), the general direction of motion agreed reasonably well with each other though the forecast track had put Kompasu slightly to the east of actual. The forecast speed of movement was also slower than actual.

Based on model spread and the 00UTC forecast track on 15 July 2004, probability of crosswind rising above 10ms^{-1} would increase to above 30% at around 22UTC 15 July, rising to around 50% probability by 04UTC (Figure 4). The crosswind measured at the official anemometer at HKIA did exceed 10ms^{-1} at around 04UTC (Figure 5).
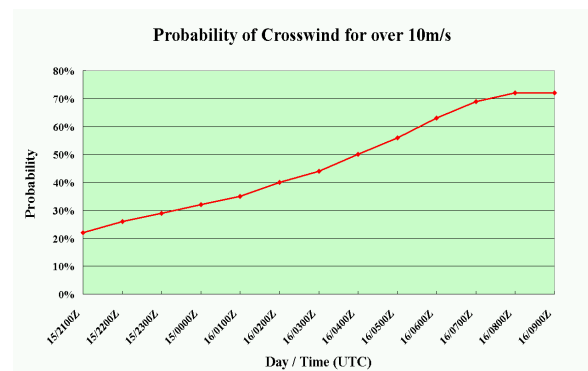

Figure 4. Probability of crosswind above 10ms^{-1} estimated using model spread and Kompasu forecast track valid for 00 UTC 15 July 2004.
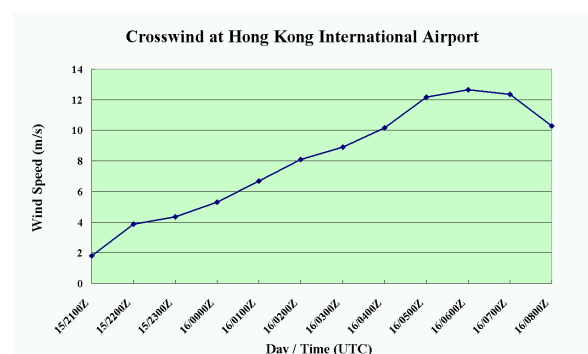

Figure 5. Crosswind observed at HKIA between 21 UTC 15 July and 08 UTC 16 July 2004.

The probability forecast at a later time suggested that the probability of crosswind rising above 10ms^{-1} would increase further over the evening. In fact, the crosswind had quickly died down after the tropical cyclone made landfall. This is probably due to the fact

that the forecast speed was too slow as discussed above and also the scheme currently does not take the intensity of the tropical cyclone into consideration.

6. DISCUSSION AND CONCLUSIONS

The probability forecast of high crosswind at HKIA has been automated to assist forecasters in the preparation of aerodrome forecasts. The probability is derived from climatological data taking the uncertainty of the forecast track into account through perturbing the track based on either past statistics or model spread.

The existing probability forecast tool however has the following limitations :

(i) Due to limited statistics, the probability isopleths map has not been further separated according to the intensity of the tropical cyclone. The probability of high crosswind for strong tropical cyclones could be very different from that of weaker cyclones. Currently a lower probability threshold would be considered for stronger cyclones. In the future, the probability isopleths map would be further refined as more data are collected.

(ii) The size of the tropical cyclone, in particular, the strong and gale wind radius, would have significant impact on the probability of high crosswind. Due to limited statistics, this has also not been taken into account in this method.

(iii) The asymmetric structure of tropical cyclones has not been taken into account. Some tropical cyclones may have higher winds in a certain sector, e.g. over the southwest sector, and may thus lead to a much longer high crosswind period than estimated by this probability forecast tool.

(iv) The arrival or presence of northeast monsoon during the approach of a tropical cyclone could also result in the onset of high crosswind earlier than given by the probability forecast too.

In spite of the above limitations, the approach did show some promise in capturing the timing of high crosswind during the passage of tropical cyclones. The probability derived from the tool could serve as an objective guide for forecasting the probability of crosswind in aerodrome forecast. The performance of the tool would be further evaluated and refined in the coming years as more statistics are collected.

REFERENCES

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