Three Methods for TC Coast-Crossing Wind Gust Hazard Estimation Using Satellite-Based Data

Chi-hsiang Wang

CSIRO Sustainable Ecosystems, Melbourne, Australia, chi-hsiang.wang@csiro.au

1 INTRODUCTION

Satellite-based wind gust data derived by the Dvorak technique were used in [1] for coastal wind gust hazard estimation by considering the maximum gust speeds of all recorded tropical cyclones (TCs) falling in a circular sampling area centred at a location of consideration. The ball-park estimate in [1] uses the concept of one-dimensional geometrical probability in formulation to compute the gust hazard but inconsistently uses the concept of two-dimensional geometrical probability to choose the gust speeds for computation, thus it tends to overestimate the hazard.

This abstract presents three alternative methods for TC gust hazard estimation: (1) empirical probability distribution method (EDM) using the superstation concept [3], (2) sampling line method (SLM) using the concept of one-dimensional geometrical probability, and (3) sampling area method (SAM) using the concept of two-dimensional geometrical probability. The validity of the three methods is shown by analysing the gust hazard at Port Hedland, Western Australia.

2 EMPIRICAL PROBABILITY DISTRIBUTION

The gust speeds recorded along a length of coast of uniform climatology are treated by the superstation concept [3]; i.e. each TC gust is treated as the maximum gust speed recorded at the coast-crossing location by an imaginary anemometer over the period of data record. Let $v_i, i = 1, \ldots, N$, be *N* statistically independent gust speeds arranged in ascending order recorded over a period of *T* years. The *T*-year empirical cumulative distribution function (ECDF) of the *i*th observation is determined by a probability plotting position formula,

$$\mathrm{ECDF}_{T,i} = i/(N+1) \tag{1}$$

Each gust speed v_i may be regarded as the maximum gust speed at the coastal-crossing site in *T* years. By the theory of total probability and statistical independence among the gust speeds, the annual ECDF of v_i can be estimated by $\mathrm{ECDF}_{1,i} = \left[i/(N+1)\right]^{1/T}$. The empirical return period is then given by $\mathrm{ER}(v_i) = 1/\left\{1 - \left[i/(N+1)\right]^{1/T}\right\}$.

3 SAMPLING LINE METHOD

If a coastline of length *L*, as shown in Fig. 1, can be regarded as of uniform TC climatology, then the recorded TC coast-crossing gust speeds may be used for estimating the gust hazard of a point site on *L*.

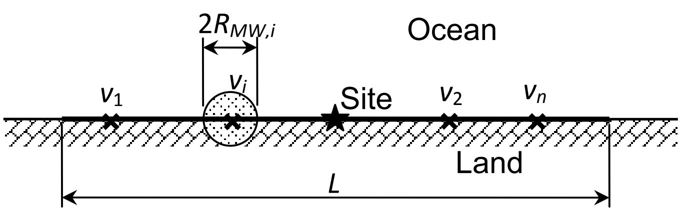


Fig. 1 Schematic of a sampling line.

Let $v_i, i = 1, \ldots, N$, be *N* statistically independent gust speeds arranged in ascending order recorded over a period of *T* years. By the theorem of total probability, the annual probability P_a that the gust speed *V* experienced by the point site reaches at least v^*, $P_a\left(V \geq v^*\right)$, is

$$P_a\left(V \geq v^*\right) = \lambda \sum_{\forall v_i \geq v^*} P\left(V \geq v^* \middle| v \in \left(v_i, v_{i+1}\right]\right) P\left(v \in \left(v_i, v_{i+1}\right]\right) \tag{2}$$

where $\lambda = N/T$ is the annual rate of occurrence of TCs, $P\left(v \in \left(v_i, v_{i+1}\right]\right)$ is the probability of wind speed $v \in \left(v_i, v_{i+1}\right]$ when a TC occurs, and the mathematical symbol $\forall$ means "for all."

By the principle of geometrical probability [2], the probability of a point site on the sampling line being hit by a gust speed $v \in \left(v_i, v_{i+1}\right]$ is the ratio of the eyewall diameter $2R_{MW,i}$ to the sampling-line length *L*; i.e. $P\left(V \geq v^* \middle| v \in \left(v_i, v_{i+1}\right]\right) = 2R_{MW,i}/L$. By the ECDF given in Eq. (1), $P\left(v \in \left(v_i, v_{i+1}\right]\right) = 1/\left(N+1\right)$. The return period *R* of the gust speed v^* is, therefore,

$$R\left(v^*\right) = \frac{\left(N+1\right)TL}{2N \sum_{\forall v_i \geq v^*} R_{MW,i}} \cong \frac{TL}{2 \sum_{\forall v_i \geq v^*} R_{MW,i}} \tag{3}$$

4 SAMPLING AREA METHOD

The sampling area method considers a semi-circular sampling area bordering the coastline on which the point site is located, as shown in Fig. 2. Typically a maximum gust in the sampling area sustains a period of time; i.e. the footprint area A_{MW} of a maximum gust speed will stretch over a distance, say *d*; hence $A_{MW} \cong \left(\pi R_{MW} + 2d\right) R_{MW}$.

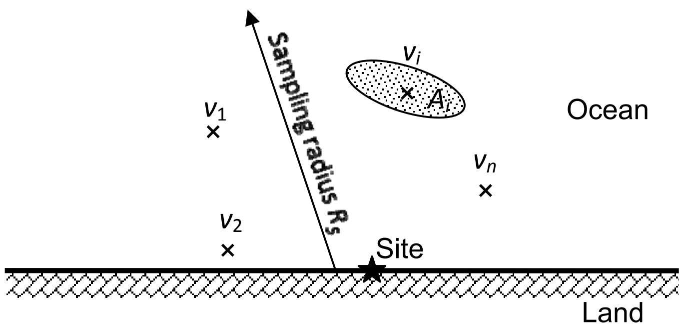


Fig. 2 Schematic of a sampling area using the footprint over which a maximum gust sustains.

Let $v_i, i = 1, \ldots, N$, be *N* statistically independent gust speeds arranged in ascending order collected in the sampling area over a period of *T* years. The annual probability P_a that the gust speed *V* experienced by the point site reaches at least v^*, $P_a\left(V \geq v^*\right)$, is formulated as in Eq. (2). By the ECDF of v_i in Eq. (1), we obtain $P\left(v \in \left(v_i, v_{i+1}\right]\right) = 1/\left(N+1\right)$. By the principle of geometrical probability [2], the probability of a point site being hit by a gust speed $v \in \left(v_i, v_{i+1}\right]$ is the ratio of TC footprint area A_i to the sampling area $S = \pi R_S^2/2$, then $P\left(V \geq v^* \middle| v \in \left(v_i, v_{i+1}\right]\right) = A_i/S$. The return period *R* of the gust speed v^* is, therefore,

$$R\left(v^*\right) = \frac{\left(N+1\right)TS}{N \sum_{\forall v_i \ge v^*} A_i} \cong \frac{TS}{\sum_{\forall v_i \ge v^*} A_i} \tag{4}$$

5 HAZARD ESTIMATION FOR PORT HEDLAND, WESTERN AUSTRALIA

Since the 1984–85 cyclone season the 10-min. mean wind speed estimated by the Dvorak technique became available, therefore the data maintained by the Australian Bureau of Meteorology (http://reg.bom.gov.au/weather/cyclone/tc-history.shtml) from the 1984–85 to the 2006–07 cyclone seasons, a period of 23 years, is used in this study. The following equation is used for determining $R_{MW,i}$ [5] for use in the SLM and SAM,

$$R_{MW,i} = 51.6\exp\left(-0.0223 v_i + 0.0281\left|\varphi\right|\right) \tag{5}$$

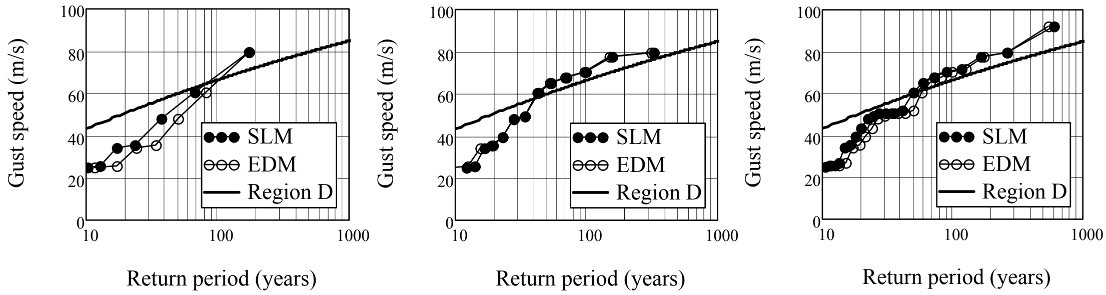
where φ is the latitude (°S) of the site location. A gust factor of 1.4 is used to convert the 10-min. mean wind speeds to the 3-second wind gusts, as discussed in [4].

Fig. 3 shows the TC coast-crossing locations along the Australian coast and the location of Port Hedland. It indicates that the stretch of coastline near Port Hedland, WA, has the highest frequency of TC coastal crossings. The gust hazard around Port Hedland is evaluated by the three estimation methods described above and the results of which are compared.

Fig. 3 Locations of Port Hedland and TC coast-crossings.

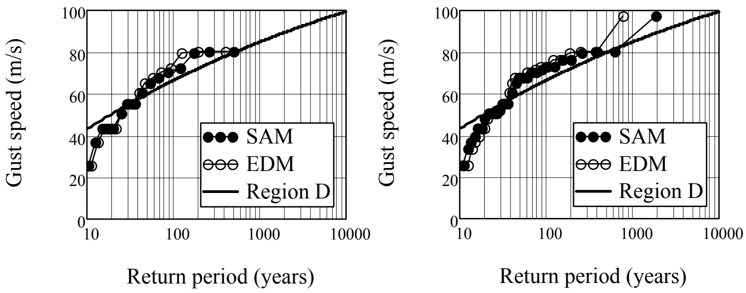
Fig. 4 shows the estimated results by the EDM and SLM for a sampling line of length 200, 400, and 600 km, centred at Port Hedland and, for comparison, the Region-D gust hazard specified in AS/NZS 1170.2:2002. We see that the two methods give similar results for the three sampling lengths. In addition, the hazards estimated using the three different sampling lengths are close to each other, indicating that a stretch of coastline up to 600 km around Port Hedland may be treated as of uniform climatology.

Next the SAM is compared to the EDM. Application of the SAM involves satisfactory estimation of the maximum gust footprint area, which is difficult based on the discrete best-track data. As an approximation, we consider two sampling radii, R_S = 200 and 300 km, and assume an approximate A_{MW} value by comparing the SAM-estimated hazard to the EDM-estimated one. The results are shown in Fig. 5, in which A_{MW} are assumed to be 3.5 and 4.5 times of the circular area πR_{MW}^2 for R_S = 200 and 300 km, respectively. For R_{MW} = 20 km, for example, it means that the maximum gust speeds travel a distance of 78 and 110 km, respectively, for R_S = 200 and 300 km.



(a) L = 200 km (b) L = 400 km (c) L = 600 km

Fig. 4 Estimated hazard for Port Hedland by empirical distribution method (EDM) and sampling line method (SLM).



(a) R_S = 200 km (b) R_S = 300 km

Fig. 5 Estimated hazard for Port Hedland by empirical distribution method (EDM) and sampling area method (SAM).

6 CONCLUDING REMARKS

The estimated results for Port Hedland, WA, show that the three hazard estimation methods described in this abstract are equally valid methods. Note in Figs. 4 and 5 that the estimated hazard curves intercept the standard-specified curve. This is due to the fact that the satellite-based data recorded only the eyewall gust speeds, meaning that the wind field is treated as a step function with the maximum gust speed in the eyewall region but with gust speed of zero beyond the eyewall. As a result, consideration of only the eyewall gust speed gives a lower-bound estimate of the actual gust hazard.

The point hazard estimates obtained by one of the three methods may be used to estimate the hazards at high return periods (e.g. < 500 years) by a plausible probability model; e.g. a peaks-over-threshold method or one of the extreme value distributions, as shown in [4].

7 REFERENCES

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