Estimation of 4-hour probable maximum precipitation in Hong Kong using the revised statistical method and storm transposition

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Introduction

The data for calculating the probable maximum precipitation (PMP) of 24 h is abundant and the methods are mature. But short duration data of rainstorm are insufficient , especially the data of extraordinary storm , so calculating the PMP of short duration is relatively difficult and there is no mature method for it. However, if there is abundant short duration historical data and hourly data of typical short duration, the traditional methods including statistical method, storm transposition could be utilized in short duration PMP estimation. 24 h PMP estimation of Hong Kong is already completed with the statistical method, storm transposition, Duration Depth Area(DAD) method, moisture maximization. Therefore, the same as 24 h PMP estimation, with enough historical short duration data and hourly data of four outstanding storms ('Kalmaegi', 'Morakot', 'Fanapi', 'Herb'), the revised statistical method and storm transposition with adjustment will be used for 4 h PMP estimation of Hong Kong, and the results of the two method will be discussed.

Study Area and Data

As shown in Fig.1 the orographic characterization of Hong Kong is mountainous. The highest place is Tai Mo Shan (942m), while the second highest place is Lantau. And the two places are also the storm center of Hong Kong.

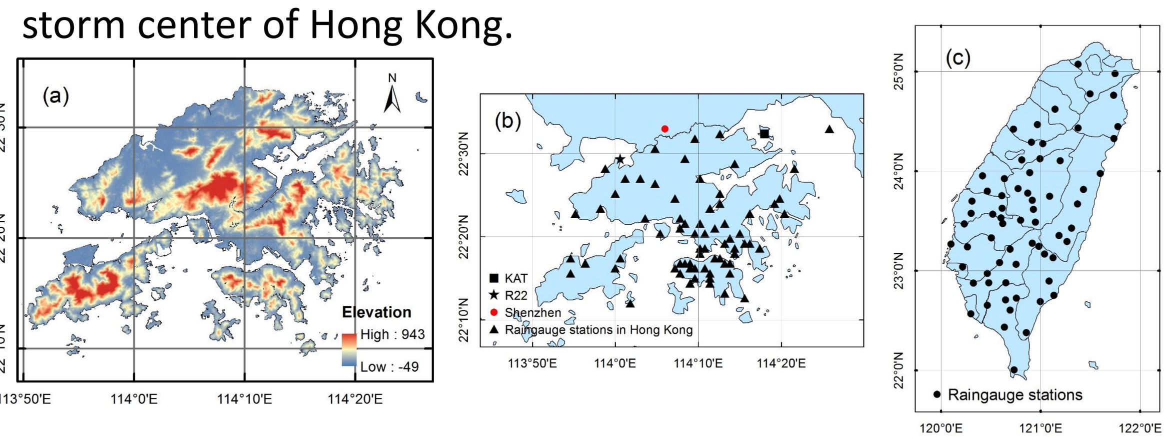

Fig.1 (a) Elevation map of Hong Kong ; (b) Locations of raingaugestations in Hong Kong and Shenzhen; (c) Locations of raingaugestaions in Taiwan, base stations with red square rectangle

Table 1 Detail of the data used in the study

NO.	Type	Location	Stations	Period/length	Resolution	
					Time	Space
1	Historical rainfall data	Hong Kong	74	1984-2015	5-min/1-min	
			HKO HQ	1885-2015	hourly	
		Taiwan	66	19-60	AMS	
		Shenzhen		1981-2005	AMS	
2	Outstangding Storm	Taiwan	Kalmaegi, Morakot, Herb, Fanapi	storm period	hourly	
3	Dewpoint	Hong Kong	HKO HQ	1884-2015	hourly	
			27 stations	1984-2015	hourly	
		Taiwan	Yong Kang, Gao xiong	storm period	hourly	
4	DEM	China				90m×90m
5	NCEP	Global			6 hours	2.5°× 2.5°

The Revised Statistical Method

Hershfeild defined a statistical parameter, K_m,

$$K_m = (X_m - \bar{X}_{n-1})/S_{n-1}$$

K_m is the number of standard deviation to be added to $\bar{X}_n$ to get X_{PMP}. Therefore, X_{PMP} is computed by the following equation:

$$X_{PMP} = \bar{X}_n + K_m S_n = (1 + K_m C_{vn}) * \bar{X}_n$$

Here K_m represents a pseudo amplifier ratio. And this pseudo amplifier ratio will be used to mimic the future maximum. In order to reduce the error of K_m, the length of the stations should fit the conditions below:

(1) The minimum data size, N_m:

$$N_m = \Phi_m^2 + 2$$

where Φ_m is the standardized variable and is directly computed from the following equation: $\phi_m = (X_m - \bar{X}_n)/S_n$.

(2) The stable data size,which allows an error of within 10% in K_m, N_s:

$$N_s \geq 5.76(\Phi_m^2 + 2)$$

(3) If $N_s > 3.5n_s$, it may cause 50% error in K_m in terms of Φ_m, so

$$N_s \leq 3.5n$$

The SDOIF Method

The storm separation technique separates mountainous storm rainfall into components caused by atmospheric forcing and those caused by terrain forcing. Thus, it may be assumed that one can transpose the convergence component within a mountainous region in a larger area, merge with the designed local orographic component to make a PMP estimate for the designed mountainous areas. The following are the main equations of the method:

(1) $\bar{f}_{\Delta t}(x,y) \approx \frac{\bar{r}_{\Delta t}}{\bar{r}_{0,\Delta t}(x,y)}$ Δt: 1, 2, 4, 6, 12, 24 h

(2) $\bar{r}_{0,\Delta t}(x,y) \approx \frac{r_{\Delta t}(x,y)}{\bar{f}_{\Delta t}(x,y)}$

(3) $PMP_{\Delta t,A} = \frac{1}{m \times n} \sum_i^m \sum_j^n \bar{r}_{0,\Delta t}(x_i,y_j) \times \bar{f}_{\Delta t}(x_i,y_j)$

Moisture Maximization

$$R_2 = R_1 \left(\frac{w_2}{w_1}\right)$$

where w_2, the precipitable water the enveloping dewpoint in the design location, w_1 the precipitable water for the representative storm dewpoint, R_1, the transposed storm rainfall for a particular duration and size of area, and R_2 is the storm rainfall adjusted for transposition to the design area.

Results of the Revised Statistical Method

Table 2 The results of the revised statistical method applied in Hong Kong

No.	Stations	Yesrs	X_m (mm)	$\bar{X}'_n$	C_{vn}	K_m	Φ_m	N_m	N_s	$3.5N$	meeting the conditions
1	N14	32	349.0	**182.8**	0.41	4.09	3.25	13	73	112	Yes
2	N17	25	347.0	182.0	0.42	4.60	3.29	13	74	88	Yes
3	R14	31	329.5	134.6	0.49	7.05	4.26	21	116	109	No
4	H21	30	318.5	142.4	0.44	6.41	4.05	19	107	105	No
5	HKO	125	302.3	138.5	0.39	3.89	3.66	16	89	438	Yes
6	H01	31	296.0	156.7	0.41	3.99	3.17	13	70	109	Yes
7	H02	32	286.5	152.5	0.39	4.16	3.28	13	74	112	Yes
8	sek	19	282.5	158.2	**0.43**	4.65	3.05	12	66	67	Yes
9	R11	28	273.5	139.8	0.42	4.56	3.37	14	77	98	Yes
10	N11	32	273.0	144.2	0.35	**4.78**	3.57	15	85	112	Yes

Note: Red in bold are the maximum value of the parameter $\bar{X}'_n$, C_{vn}, K_m, respectively

Therefore, $X_{\mathrm{PMP}} = (1 + 4.78 * 0.43) * 182.80 \approx 558.5$

4 h OIF of Taiwan and Hong Kong

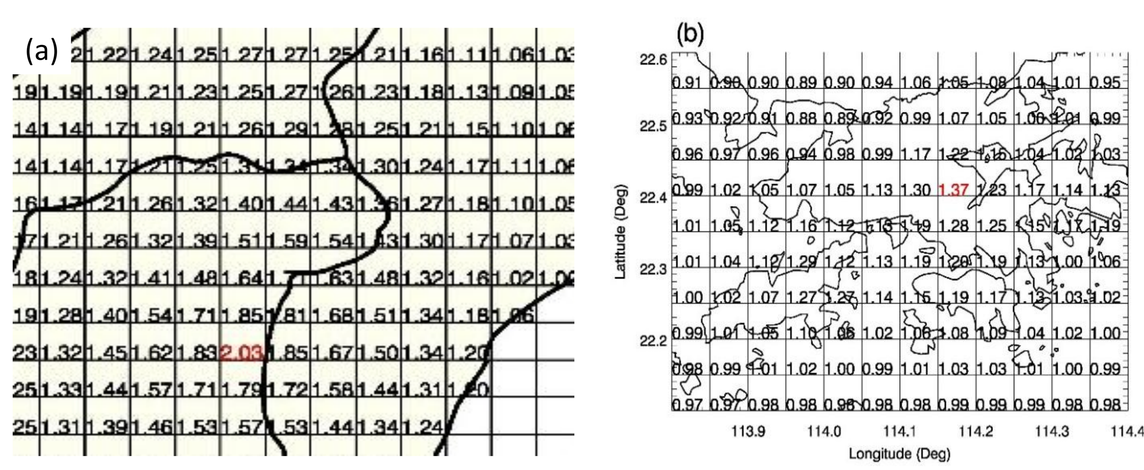

Fig.3 4 h OIF of Taiwan and Hong Kong (a: Taiwan b: Hong Kong)

The highest OIF of Taiwan and Hong Kong both are at the most highest places at Taiwan and Hong Kong, Alishan and Tai Mo Shan. It demonstrates that the orographic effect on rain is very obvious.

4 h OIF of Taiwan and Hong

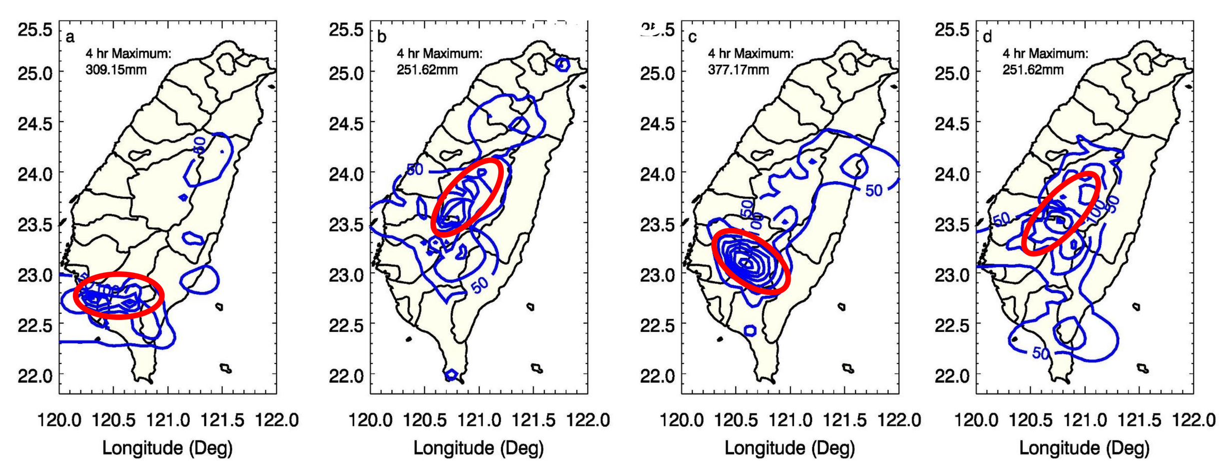

Fig. 4 Convergence Isohyets of four typical typhoon storms (a: Fanapi, r=2.31 b: Herb, r=2.06 C: Kalmaegi, r=2.20 d:Morakot, r=2.26)

The convergence rain of Kalmaegi is the most serious, so it is chosen as the convergence pattern with an suggested aspect ratio of 2.2.

The embryonic PMP

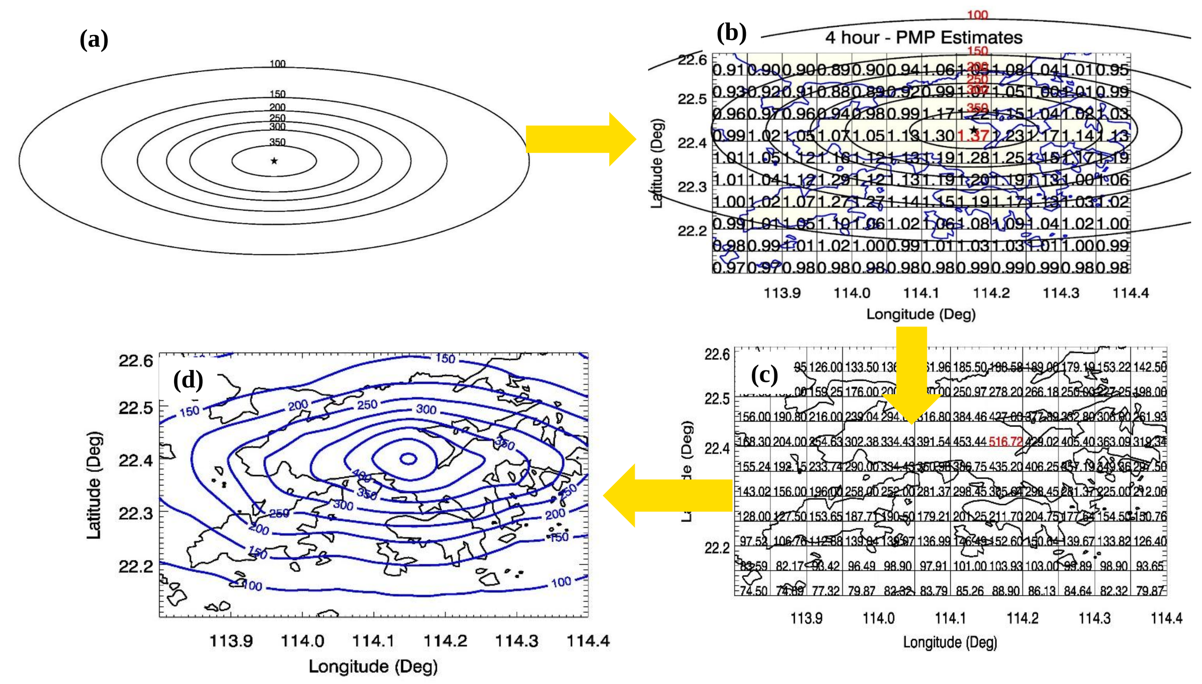

Fig. 5 a: 4 h generalized convergence pattern for Taiwan storms b: Generalized convergence component pattern superposed on OIF grid centered at Tai Mo Shan (E-W Orientation 0°) c: Grid map of embryonic 4 h PMP centered at Tai Mo Shan d: Isohyets of embryonic 4 h PMP centred at Tai Mo Shan

The embryonic PMP = 1.37 × 377.17 = 516.72mm (centred at Tai Mo Shan area (the highest OIF cell for the entire Hong Kong))

Moisture Maximization

r = W2 / W1 = W27.17 / W24 = 81.43 / 58.45 = 1.39

If the embryonic PMP is superposed on Tai Mo Shan, the center point value is:

516.72 mm × 1.39 = 718.2 mm

Conclusions and Discussions

- The revised statistical method and storm transposition based on SDOIF with moisture maximization could be used in short duration PMP estimation.
- The estimation value 558.5mm and 718.2mm are both smaller than the world 4 h rain record. Therefore, they are both reasonable. However, in the design of a project, the result of the revised statistical method just for reference while the result of storm transposition will be used as design standard.
- Storm transposition based on SDOIF could not only get the point value of the transposition center, but also the spatial distribution pattern of PMP.
- However, it will combine the generalized convergence storm with OIF centred at Lantau Island and make an orientation adjustment of the major ellipse axis to get the worst scenario.

Acknowledgments

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