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Hydrology and
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Discussions

Interactive comment on "Spatial characteristics of severe storms in Hong Kong" *by* L. Gao and L. M. Zhang

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Comments: In the paper the authors analyzed spatial variation of severe storms in Hong Kong. It is concluded that such spatial characteristics are due to the orographic effect (the local terrain) and meteorology factors (monsoon rainfalls instead of typhoons). My major concern is whether the interpretations and results will be robust and meaningful given the fact that rainfall data of only three severe storms were used in the entire study. Orographic effect of rainfall spatial distribution is a climatological phenomenon and should be dealt with using enough number of storm events. The concept of climatological variogram modeling (as opposed to event-specific variogram modeling) has been addressed in many studies including the following: - Bastin G, Lorent B, Duque C, Gevers M. 1984. Optimal estimation of the average areal rainfall

and optimal selection of raingauge locations. Water Resources Research 20(4): 463–470. -Lebel T, Bastin G, Obled C, Creutin JD. 1987. On the accuracy of areal rainfall estimation: a case study. Water Resources Research 23(11): 2123–2134. - Cheng, K.S., C. Wei, Y.B. Cheng, and H.C. Yeh, 2003. Effect of Spatial Variation Characteristics on Contouring of Design Storm Depth. Hydrological Processes, 17(9):1755-1769. The other concern is that the authors firstly established event-specific variograms of 4h, 12h, 24h, and 36h maximum rainfalls for individual storms and then 2nd order polynomial trend surface were fitted to spatial rainfall data. The major axes of trend surface mapping were then determined by results of anisotropic variogram modeling. The rainfall random fields were assumed stationary (or homogeneous) in space and exponential variogram model with an asymptotic sill was adopted. If the rainfall random fields are stationary, there is no need for trend surface mapping since the trend surface represents "expected value of the precipitation distributed over the rainfall domain" (as stated by the authors). Such a methodological problem needs to clearly explained.

Reply: We thank you for your valuable comments and suggestions, which help improve the quality of the paper.

The primary objective of the discussion paper is to quantify the spatial characteristics of severe rainstorms in Hong Kong. The main purpose is to provide information for hazard prediction and mitigation. Therefore three storms that caused the most severe landslide hazards in Hong Kong in the past 20 years are selected for study. In fact, the June 2008 storm is often used in Hong Kong as a reference storm in preparing engineering measures to mitigate landslide hazards caused by extreme storms.

We agree that the orographic effect of rainfall spatial distribution is a climatological phenomenon and should be dealt with using a large number of storm events. Besides the three severe rainstorm events described in this discussion paper, ordinary rainstorm events in Hong Kong have also been studied (Liu, 2013; AECOM, 2011). Liu (2013) proposed a framework for analyzing dynamic time-space evolution of rain-field in her PhD thesis. Four rainstorm events were chosen to illustrate the proposed method: 18

May 2007, 19 May 2007, 19 April 2008 and 15 September 2009 rainstorm evets in Hong Kong. The 2008-04-19 rainstorm event was under a combined effect of Typhoon Neoguri and a northeast monsoon, while the other three rainstorms were results of tropical depressions. The total rainfall amounts during the four storms of 18 May 2007, 19 May 2007, 19 April 2008 and 15 September 2009 were 67.0, 99.6, 157.9, and 130.3 mm, respectively. The spatial structures indicated by variogram ranges of four instantaneous rain-fields corresponding to the peak rainfall intensity (six minutes resolution) are plotted and examined here, as shown in Fig. 16 (in the attachment). According to the results from ellipse fitting, the principal directions of all the tropical depression storms (18 May 2007, 19 May 2007, and 15 September 2009) are around 45°; while that of the 19 April 2008 is not. The lengths of the principal axis of the tropical depression storms are within 25 km; while that of the 19 April 2008 storm is 40.8 km. The range values of the instantaneous rain fields are consistent with those of the storms in the discussion paper. It seems that the ranges of the extreme storms do not deviate greatly from the ones of ordinary storms. AECOM (2011) updated the 24-h PMP for Hong Kong with consideration of local orographic influence intensification factors. These orographic intensification factors of rainfall spatial distribution are developed based on historical hourly data. The 24-h orographic intensification factors at a resolution of 5 km×5 km are shown in Fig. 17 (in the attachment). The factors for the land area are overall larger than those for the sea area. The higher the elevation is, the larger the orographic intensification factors. Two of the highest intensity regions are located at Tai Mo Shan in New Territories and the Lantau Peak in Lantau Island. The trend of the factors coincides with the mountain range alignment; i.e., around N45°E. The conclusions in the discussion paper are consistent with the distribution of the orographic intensification factors.

Bastin et al. (1984) proposed a time-varying estimator for variogram modeling which takes into account of the influences of the seasonal variations and apply this method to the optimal selection of rain gauge locations. Lebel et al. (1987) validated the scaled climatological variagram model using areal rainfall values computed with a very

high density network. Cheng et al. (2003) evaluated the effect of spatial variation characteristics on contouring of design storm depth, and concluded that the influence range of the design storm depth is dependent on the design duration and recurrence interval and is a key factor in developing design storm contours. Overall, the scaling factor introduced in the climatological variagram model mainly reflects the seasonal variation of the spatial structure of storm types. In Hong Kong, heavier storms usually occur in summer and are caused by monsoons or/and typhoons. In designing the extreme rainfall events for hazards assessment, event-based spatial characteristics are as useful as the statistical trend based on historic rainfall records.

Since the omnidirectional variogram method is based on the assumptions that the mean is space-stationary and the variogram is isotropic and space-stationary, the omnidirectional-variogram results listed in Table 2 show that the assumption is not reasonable for some conditions. Therefore anisotropic variogram analysis is conducted instead, which assumes that the rain field is stationary but not isotropic. The results are shown in Figs. 6-8. The major principle directions of range diagrams are between N 45° E and N 65° E. In terms of duration, the patterns of the maximum rolling 4-h rainfall show strongest evidence of anisotropy compared with those of longer durations. We would like to further determine if the stationary assumption is reasonable; hence further analysis on the trend surfaces and detrended residuals are carried out. The correlation structures of the three storms are analyzed. The principal major and minor axes of the trend surfaces are determined by least squares fitting of the original rainfall data. The rainfall field is obtained by removing the surface trend from the original data. The rainfall random fields (detrended rainfall residuals in this paper) are assumed stationary (or homogeneous) in space due to the expected-value trend surface mapping.

Specific comment 1. As described in the general comments, I would suggest using more events for characterizing rainfall spatial variation. If rainfalls of more events are used, the climatological trend surface mapping should be conducted, instead of trend surface mapping for individual events. After all, trend surface is the “expected value” surface.

Reply: Following your suggestion, four rainstorm events with ordinary magnitudes (Liu, 2013) have been used to illustrate their spatial structures (Fig. 16, in the attachment). As discussed earlier, the ranges of the extreme storms do not deviate greatly from the ones of ordinary storms.

We also agree that the trend surface is an expected-value surface. The trend surfaces of 24-h PMP with different storm centers have been updated by AECOM (2011), and the 24-h PMP centered at Hong Kong Island is shown in Fig. 18 (in the attachment). The trend surfaces are derived based on the historical hourly rainfall.

Specific comment 2. I also suggest the variogram modeling be conducted for residuals of the trend surface mapping. Such residuals can then be assumed stationary and isotropic since the trend surface mapping has taken care of the anisotropic variation.

Reply: Yes, the residuals of the trend surface mapping can be assumed stationary if the trend surface mapping is reasonable. We calculated the SoF values along eight directions, which are shown in Figs. 12-14. The trend surface analysis is more suitable for the 22-24 July 1994 storm, whose rainfall is quite concentrated at the storm center (Tai Mo Shan). We have conducted the variogram modelling for the residuals of the 22-24 July 1994 storm. The results are shown in Table 6 (in the attachment). The ranges and sills show regularity.

Specific comment 3. The variogram parameters in Table 2 seem unreasonable. Usually the range of longer duration (24h or 36h) rainfall fields are larger than the range of short duration (1h or 12 h) rainfall fields due to the longer duration of rainfall accumulation. In particular, the sill of 4h rainfalls is significantly larger than rainfalls of other durations for the 5–7 June 2008 storm. This is not possible since the sill represents variance of the random field and rainfalls of longer duration have larger expected values and variances than rainfalls of short durations. The very close sill values for 12h to 36h rainfalls are also not reasonable, as can be seen in sill values of other storms.

Reply: The sills of the 5-7 June 2008 storm show inconsistency. As described in section 2.1, the maximum rolling rainfall of the 5–7 June 2008 storm is extremely large, which has a return period of 1,100 years in terms of the 4-h rolling rainfall. Under the isotropic assumption, the range values are between 4.7 km and 15.9 km and show some inconsistency. However, based on results of the anisotropic analysis, the range values in different directions exhibit regularity.

Specific comment 4. Anisotropic variogram modeling of the residuals of trend surface mapping is not reasonable as explained in comment #2. It can also be seen clearly from Eq. (3). Results of anisotropic variogram modeling shown in Figures 12 to 14 imply the residuals (epsilon) in Eq. (3) are anisotropic.

Reply: Yes. The SoF values shown in Figures 12 to 14 imply that not all of the residuals (epsilon) in Eq. (3) are isotropic. We have only conducted variogram modeling for the total amounts which are shown in Figs. 6-8.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 6981, 2015.

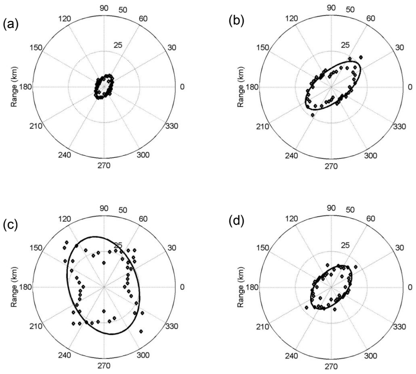
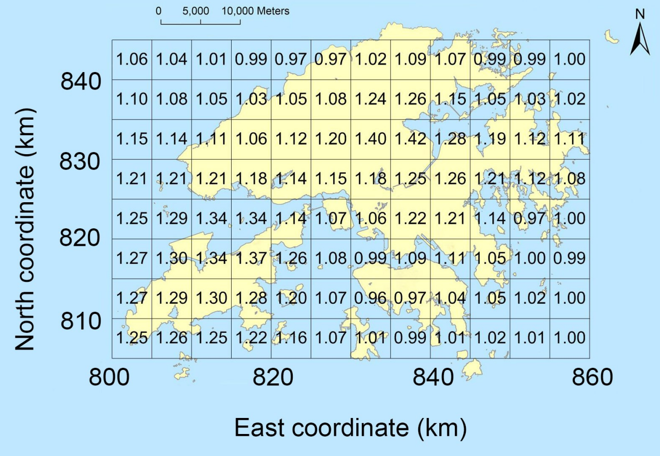


Fig. 16. Range values for (a) the 18 May 2007 storm (16:30 pm); (b) the 19 May 2007 storm (16:00 pm); (c) the 19 April 2008 storm (20:00 pm); (d) the 15 September 2009 storm (15:00 pm) (modified from Liu, 2013)

Fig. 1.



1.06	1.04	1.01	0.99	0.97	0.97	1.02	1.09	1.07	0.99	0.99	1.00
1.10	1.08	1.05	1.03	1.05	1.08	1.24	1.26	1.15	1.05	1.03	1.02
1.15	1.14	1.11	1.06	1.12	1.20	1.40	1.42	1.28	1.19	1.12	1.11
1.21	1.21	1.21	1.18	1.14	1.15	1.18	1.25	1.26	1.21	1.12	1.08
1.25	1.29	1.34	1.34	1.14	1.07	1.06	1.22	1.21	1.14	0.97	1.00
1.27	1.30	1.34	1.37	1.26	1.08	0.99	1.09	1.11	1.05	1.00	0.99
1.27	1.29	1.30	1.28	1.20	1.07	0.96	0.97	1.04	1.05	1.02	1.00
1.25	1.26	1.25	1.22	1.16	1.07	1.01	0.99	1.01	1.02	1.01	1.00

Fig. 17. 24-hour orographic intensification factors in Hong Kong (modified from AECOM, 2011)

Fig. 2.

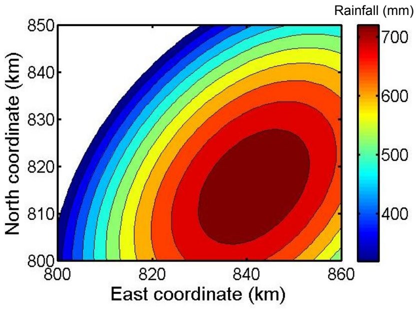


Fig. 18. 24-hour PMP with NE-SW orientation 45° centered at Hong Kong Island

Fig. 3.

Table 6. Omnidirectional parameters of range and sill for the detrended residuals

Duration	22-24 July 1994 storm	
	Range (km)	Sill (mm^2)
12-hour	9.6	11519
24-hour	9.4	16688
36-hour	8.1	23783

Fig. 4.