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Hydrology and Earth System Sciences
Discussions

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

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General comments: The premise of the study is that the spatial structure of very extreme events might be different from that observed in more 'ordinary heavy rainfall'. However, no 'ordinary heavy rainfall' events were included in the analysis, so I cannot see how this hypothesis might reasonably be investigated. A more complete analysis would need to include samples of several events to enable a comparison. At present, the manuscript reports the results achieved by applying a set of standard statistical techniques to a limited number of events (three). However, it is not possible to put these result into any kind of context with, say, more ordinary events or extreme events from a different location. As such, the experimental design used in the study is not sufficient rigorous to draw the desired conclusions and consequently the results presented in

the manuscript are, in my opinion, of limited interest to an international audience. The study hypothesizes that elevation and 'varying meteorological conditions' – whatever they are - are important factors (page 6987, line 24 & Page 6989, line 23), but neither elevation nor other meteorological variables are considered as a covariate when developing the trend-surface in 3.2. But if these variables control rainfall amounts, then they should be included in Eq.4 rather than geographical location. In many places, the description of the procedures and statistical aspects of the analysis are not sufficiently precisely formulated.

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

The main purpose of this paper is to identify the spatial characteristics of severe rainfall and their impact areas. We focused on three extreme rainfall events, characterized by the maximum rolling rainfall, because such extreme rainstorms caused vast amounts of rain-induced hazards such as debris flows and landslides. Previous work (Liu, 2013; AECOM, 2011) on spatial characteristics of rainfall in Hong Kong studied the orographic factors of rainfall spatial distribution based on historical records, particularly elevation and meteorological conditions. Based on the work in the present study, the spatial structures of the three extreme events and four ordinary heavy rainfall events do not differ significantly (Fig. 16 in the reply to Reviewer #1, in the attachment). When coping with flood and landslide hazards induced by severe rainfall, engineering analogical comparison with historical severe events is required due to limited cases with severe consequences. For example, Typhoon Morakot enfolded Taiwan on 8 August 2009, dumping record-breaking rains in southern Taiwan. The heavy rainfall triggered enormous landslides in mountains and hills and severe flooding in low-lying areas. As indicated in an official report (National Disasters Prevention and Protection Commission, NDPPC, 2009), 769 people were reported dead or missing directly or indirectly caused by the typhoon. Since Hong Kong is quite near Taiwan, studies on rainfall depth-area-duration analyses with moisture maximization based on both local storms

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and typhoon Morakot were performed in Hong Kong (AECOM, 2011).

Based on previous study (AECOM, 2011), both the elevation and the meteorological conditions (e.g. moisture content) affect the rainfall amount. The trend surfaces of the three storms in this paper are derived by least squares fitting based on original rainfall data, because the main objective is to study the spatial characteristics. We agree that both the elevation and the meteorological variables should be taken into account if one wants to generate artificial rainfall scenarios.

We have modified the description of the analysis procedures and statistical aspects of the analysis according to the reviewer's suggestions. Again we thank the reviewer's efforts.

Specific comments: Page 6983, line 1-3: 'For a particular region. . .' A reference is needed for this statement.

Reply: We added a reference for the statement "For a particular region where the spatial rainfall variation is significant, a uniform representation of the spatial distribution is not reasonable since a storm has a center and influences a limited area (AECOM, 2011)". AECOM Asia Company Limited: 24-hour PMP Updating Study. Agreement No. CE 13/2011 (GE), Hong Kong: Geotechnical Engineering Office, Civil Engineering and Development Department, the Government of Hong Kong SAR, 2011.

Page 6983, line 7: '(presence of zero values): what values are being referred to here?

Reply: Thanks for pointing out this issue. We rewrote this sentence as "A storm is difficult to model due to its intermittence (no rainfall at a particular position during a particular short period) and strong spatial and temporal heterogeneity. . ." .

Page 6987, line 1: '. . .related to monsoons other than typhoons.' Do you mean that the three events were observed during the monsoon, and that no events occurred as a result of typhoons?

Reply: Yes. All the three severe storm events were related to the monsoon. Neither of

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them occurred as a result of typhoons.

Page 6987, line 6: Explain better how the maximum rolling rainfall values are defined. Does it matter if the rolling rainfall values (say 4hour) at different locations are not based on the same 4hour period? Fig. 3: Maybe add map outline behind gauge locations?

Reply: The 4-h maximum rolling rainfall value is calculated as the maximum values of rainfall in 4 consecutive hours on a hyetograph. The maximum rolling rainfall values at different locations may not be in the same period though most of them tend to be in the same period. Hazard consequences are more related to the maximum rolling rainfall values other than instantaneous one. In the formulations for a hydrological model, the effect of the time scale of aggregation of the rainfall data and the hydrological response of catchments of different sizes should be investigated in order to identify the critical scale at which the resulting discharge will be the largest and could potentially generate flash floods.

Thanks for the suggestion. We added the terrain outline behind the gauge locations in Fig. 3 (in the attachment).

Page 6988, line 2-3: '. . .which are the most important characteristics of a storm event': what characteristics are being referred to here?

Reply: "the most important characteristics of a storm event" refers to the precipitation amount. We revised this sentence as: "The first step is to recognize the spatial structures of precipitation amounts as represented by semivariograms in different durations."

Page 6988, line 1-6: It is not clear to me what will be achieved by this three step procedure other than a description of model parameters for three storms?

Reply: This paper aims to quantify the characteristic parameters of spatial properties of three severe storms in Hong Kong. First, the historic records of the three selected severe storms in Hong Kong are presented. Then the methods for assessing the rainfall distribution trend surface and describing the rainfall spatial correlations are described.

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Finally, the spatial properties of the precipitation amounts of the three severe storms are analysed.

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 in Table 2 show that the assumptions are not reasonable for some conditions. Therefore the anisotropic variogram analysis is conducted, which assumes that the rain field is stationary but not isotropic. The results are shown in Figs. 6-8. The major principle directions of the 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 verify if the stationary assumption is reasonable; hence analyses on trend surfaces and detrended residuals are carried out. The correlation structures of the three severe storms are analyzed based on all of the results.

Page 6988, line 17: What does it mean that N is a function of z, i.e. N(z)? Do you consider subsets of station pairs located a certain distance from reach-other? If yes, how do you determine the number of intervals? Eq. (1): In my copy it looks like some symbols are in bold (vectors) and some are not (scalars). Check that the notation is consistent.

Reply: N(h) is the number of the sample pairs.

It is true that binning (e.g. bin the data pairs at ($u\alpha$+h) and $u\alpha$ in Eq. (1)) is computed on a tolerance region. The maximum lag for binning is chosen as one half of the maximum lag in the dataset (Journel and Huijbregts, 1978).

Both the isotropic and anisotropic cases have been taken into consideration. h is not a vector for the isotropic case; while h in bold represents vectors in the anisotropic cases.

Page 6988, line 20: Define the meaning of stationarity in this context.

Reply: The z (h) is said to be stationary in this context when it fulfills the following

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assumptions (Bastin et al., 1984): (1) the mean is space stationary (independent of position u); (2) the variogram is space stationary; that is, it depends only on the Euclidean distance h between locations.

Page 6988 ,line 21: what is the 'spatial data' being referred to here? Spatial data in general, or rainfall specifically? Eq.(2): Why use exp(-3*h/a) rather than just exp(-h/a), absorbing the '3' into the constant?

Reply: The spatial data means the spatial rainfall data. We rewrote this sentence as "In fact, it is quite rare for the spatial rainfall data set to be absent of spatial correlation".

If we use just exp(-h/a), the parameter "a" in this expression does not denote the range, but approximately one thirds of the range (Goovaerts, 1997; Bastin et al., 1984). Therefore we use exp(-3*h/a), for convenience.

Page 6989, line 5: Why not consider the nugget? The semivariogram in Figure 5b looks like it could use a nugget?

Reply: The nugget effect is caused by measurement errors or spatial sources of variation at distances smaller than the sampling interval or both (Goovaerts, 1997). If the semivariogram value is 0 at zero separation distance (lag = 0), the nugget effect can be neglected. In the cases of the three storms, the nugget effects are rather small. For example, the semivariograms start from (0.2, 0) in Fig. 5. , and the semivariance of first point is nearly zero.

Page 6989, line 7: I don't understand the importance of the sentence starting 'The rainfall data are assumed. . .'?

Reply: The sentence "the rainfall data pairs are assumed to be similar in all directions" explains that the semivariance values depend only on the separation distance |h|. This sentence is not very important.

Page 6913, 13: 'which suggest better stronger spatial connectivity: : :' Table 2: Why is the sill larger for 2h than for 12h, 24h and 24h for the 2008 storm, when the opposite

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is true for the other storm? Presumably the numerical values of rainfall accumulations over longer durations are larger, so the variability (and thus) sill should also be larger? Please check.

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 clear exhibit regularity.

Page 6989, line 17-18: The text suggests Figure 5 contains data from three storms, but I think it only shows one storm (2008) for two different duration? Figure 4: I can't find a reference to this figure anywhere? And also, the y-axis label is missing.

R: Many thanks for pointing out this issue. The sentence is changed to "The results in Fig. 5 for the maximum rolling 4-h and 24-h rainfalls of the 5-7 June 2008 storm level off quickly, as in the cases of other periods and events.

We added a reference for Fig. 4 "AECOM, 2011". AECOM Asia Company Limited: 24-hour PMP Updating Study. Agreement No. CE 13/2011 (GE), Hong Kong: Geotechnical Engineering Office, Civil Engineering and Development Department, the Government of Hong Kong SAR, 2011.

Page 6990, line 12-16: This analysis appears to be based purely on a visual assessment of the plots. I think a more formal statistical analysis would be required here to make statements about similarity of difference between these sample estimates. Also, it is not known how robust these estimates are, and to what extend differences are due to particularly small or large observations in a short record. Later in line 20-21 the authors comment that this analysis is not sufficiently robust. But this is a critical observation, and should have initiated a revision of the methodology to be more robust.

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Reply: The major directions are indicated by larger range values.

The semivariogram analysis is based on the stationarity assumption, and is not sufficiently robust for all the rainfall events. As stated before, the assumption of stationarity led to irregularity and prompted the trend surface analysis. The correlation structures of the three storms are synthesized based on all of the results from the semivariograms, surface trends and SoF values.

Page 6991, line 6: I don't understand the reference to a shift of coordinate system. Eq.(7): Previously 'z' has been used as a reference to rainfall amounts. From Eq. 3 I think the de-trended rainfall (or residuals) is denoted 'epsilon'?

Reply: This "shift of coordinate system" is used to define stationarity. We have clarified the assumption of stationarity as mentioned above.

Yes. The detrended rainfall is denoted by "epsilon".

Page 6993, line 14-15: Is it not the residuals that are strongly correlated rather than the actual rainfall amounts?

Reply: The sentences in Page 6993, lines 14 and 15, "Within the scale of fluctuation, the rainfall property is strongly correlated" - in fact this is a definition of SoF. The SoF values are derived from the analysis on the residuals.

Page 6993, line 19: 'Same procedure' as what?

Reply: The three-step procedure.

Page 6993, line 20: How is the ellipse fitting done?

Reply: By fitting using the least squares method.

Page 6998, conclusion bullet 4: What does 'best spatial continuity' mean? Do you mean 'strongest spatial correlation'? Also, what does the term 'as time goes by' refers to?

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Reply: The best spatial continuity means the data change smoothly in a certain range. "As time goes by" refers to "as the duration becomes longer".

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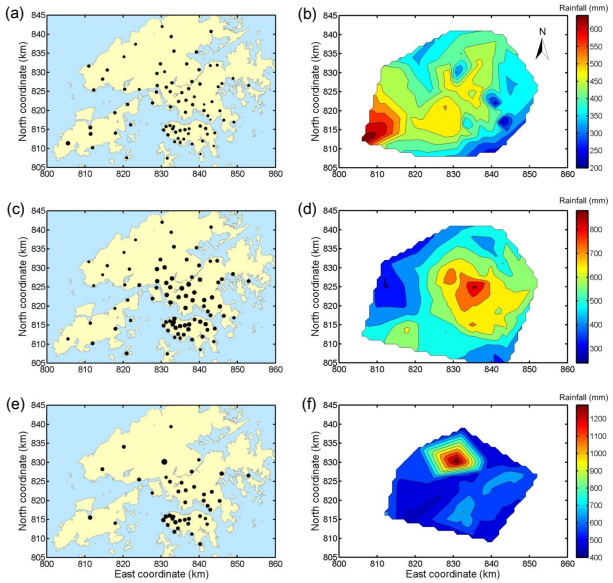

Fig. 3. Scatter and spatial distribution of the total rainfall amount: (a) and (b) the 5-7 June 2008 storm; (c) and (d) the 17-21 August 2005 storm; (e) and (f) the 22-24 July 1994 storm.

Fig. 1.

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