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Hydrology and Earth System Sciences Discussions

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Interactive Comment

Interactive comment on "Cost-effective raingauge deployment and rainfall heterogeneity effect on hydrograph simulation in mountainous watersheds" *by* Jr-Chuan Huang et al.

Jr-Chuan Huang et al.

Received and published: 23 February 2009

Comment:

The paper describes the effect of subsampling from a radar rainfall image on the quality of streamflow predictions by a hydrological model based on the TOPMODEL subsurface runoff principles. I am not sure about the value of the paper. There are quite a lot of assumptions that are not necessary valid. They also make the results quite uncertain, and difficult to interpret and extrapolate. At this point it is difficult to see what the reader can really learn from the paper. My main points of critique are: - the paper assumes that radar rainfall represents the true rainfall, and that rain gauges can be simulated

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Discussion Paper

by sampling from the radar map. This is of course a very strong assumption. Radar represents a kind of average over a certain pixel size (in this case 1.3 km^2) which may be very different from the scale at which a raingauge works. Furthermore, raingauges are influenced by wind, topography (especially in mountainous areas!), vegetation, and other local conditions that are very differently picked up by radar. Although it is possible that the high intensity of torrential rains results in less errors between rain gauges and radar (e.g., no effect of drizzle and "horizontal" rain), still the extrapolation is a very tricky one that needs more attention in the paper.

Reply:

Reviewer's concern is ours and all modelers' concern. In previous studies, we had conducted point-to-point comparison between rainfall estimates derived from rain gauge data and radar (see Chang et al., 2008; Huang et al., 2008). We referred to the two papers. A strong positive correlation (R^2 around 0.7 -0.9) exists between the two data sources over a wide range of rainfall intensity, particularly, in typhoon cases in P.4, Lines 6-9. In this version, we provide more information for Doppler radar rainfall estimate system in Taiwan in Section 2-1 (in P.3, Line 20 to P.4, Line 8). Nevertheless, radar rainfall holds the highest resolution so far that we can use to evaluate rain gauge density effect on hydrograph simulation. We strengthen the effect of sampling representativeness on total rainfall estimate, rainfall field estimate and hydrograph simulation. The uncertainty of hydrograph simulation can be given in various rain gauge densities. Results are substantial and of course applicable to subtropical regions (or countries) where typhoon hit rates are high and economic support is insufficient.

Chang, K. T., Huang, J.C., Kao, S.J., Chiang, S.H. Radar Rainfall Estimates for Hydrologic and Landslide Modeling in Park, Seon K. and Xu, Liang (eds) Data Assimilation for Atmospheric, Oceanic, and Hydrologic Applications, Springer-Verlag. (ISBN: 978-3-540-71055-4)

Huang, J.C., Chang, K.T., Kao, S.J., Kuo, C.W., Lin, C.Y., 2008. Storm discharge

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simulation in subtropical mountainous watersheds based on radar and gauged rainfall inputs. 5th AOGS Annual Meeting, Busan, Korea.

Comment:

- As the other reviewer notes, extrapolation with Thiessen polygons is a strange choice for a mountainous area. It is quite likely that some spatial patterns are present, e.g., from the influence of topography, which may be incorporated in the interpolation. This may drastically increase the performance of the "rain gauges".

Reply:

We re-examined the original radar rainfall field in our study area and find no correlation with elevation and topography. As indicated by Goovaerts (2000), only when the correlation between rainfall and elevation is moderate (higher than 0.75), otherwise taking elevation into interpolation can't improve the rainfall estimates. Thus we did not take elevation into account. However, two extra methods, ordinary kringing and inverse distance interpolation, were added in this version. Opposite to our thoughts, interpolation method affects little on total rainfall estimates (Fig. 2). Besides, rainfall spatial patterns derived from different methods are distinctive only when rain gauge density is pretty high (Fig. 3), but it would not be the case for fewer raingauges.

Comment:

- I have some specific questions about the hydrological model, which are given in the section below. However, also the use of the model is not entirely clear to me. As the authors observe in the paper, hydrological models may act as a smoothing filter, which means that errors in precipitation may get smoothed out in the discharge prediction. But this is highly dependent on the model, and may introduce other errors.

Reply:

We added more details in Section 2-4 for model description. Any given spatially distributed model will give hydrograph output, of which positive and negative rainfall errors throughout spatial scale is accumulated and compensated during transferring into discharge over time scale. This is the main reason to reduce rainfall errors. Of course, model itself may introduce extra errors; however, the error should be consistent by a fixed model and a given parameter set.

Comment:

The authors seem to be most interested in the water balance, and the shape of the recession curve. For the first, why not compare directly between the precipitation input given by the subsampling, and by the radar grid itself? This reveals direct information on the sampling density that is required to get a certain quality of model input. In a second step, the model can be used to see whether output errors decrease when putting them through a model. But the latter conclusions will be conditional on the model that is used, as well as the characteristics of the rainfall event. This suggests that maybe more than two events will be needed to really characterize the impact of rainfall measurement errors on streamflow.

Reply:

As suggested, we added more rainfall events for this experiment. We believe this question is raised due to our incomplete description about how we implement rainfall input since Reviewer 2 asked the same question. In this study, the hourly rainfall input is pixel-based. Simply speaking, even we compare the rainfall input directly by using hyetograph over the total duration we still do not know rainfall errors are derived from which pixel. Accordingly, we use rainfall similarity (modified from Nash efficiency coefficient) to examine the error in rainfall estimate for specific event. Again, as mentioned earlier the positive/negative errors in rainfall images are compensated through model no matter which model is applied the error reducing trend will be the same though the magnitude is conditional.

Comment:

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I also wonder why the authors compare with the model results from the "true" model, i.e., the model forced with the radar data, rather than the measured streamflow data. In the end, it is the streamflow you want to predict, not some artificial benchmark. These remarks, together with the specific remarks given below, and a strong need to improve the clarity of the formulation and the language, make me recommend at least major revision. I can see value in the data and a large part of the work that is done. Therefore I suggest the following approaches to improve the paper: - Either the authors focus on the conceptual side of the paper, using the setup as a "virtual catchment" to test sampling and interpolation techniques. Now, they used only the simplest of these approaches, a random sampling and a nearest neighbour interpolation. As noted above, the value of these techniques is questionable. However, it would be interesting to see how a targeted sampling (e.g., covering different topographic elements) or a more complex interpolation method (e.g., kriging with external variables such as elevation) may improve the model performance. This will yield very useful information, not only about the number of rain gauges that are required, but also about their optimal location and the type of covariables that may help in improving the interpolation. As a suggestion, here are a few papers that might be of interest on the impact of rain gauge density and interpolation: A. Bárdossy and T. Das. Influence of rainfall observation network on model calibration and application. Hydrology and Earth System Sciences, 12:77-89, 2007. P. Goovaerts. Geostatistical approaches for incorporating elevation into the spatial interpolation of rainfall. Journal of Hydrology, 228:113-129, 2000. R. E. Chandler and H. S. Wheater. Analysis of rainfall variability using generalized linear models: A case study from the west of Ireland. Water Resources Research, 38:1192-2002, 2002.

- Another approach can be taken by looking more at the processes in the catchments. As noted by the other reviewer, extrapolation of the results is very questionable, given the low number of events. However, a more detailed study of the nature of the events may help understanding the processes. For instance, it is likely that the number of required raingauges for good prediction depend on the (spatial) size of the storm. Also, the torrential nature of the typhoon events may result in less discrepancy between raingauge readings and radar. Or how does the catchment land cover influence infiltration and routing? This is important, because the precipitation error will be smoothed out more for subsurface runoff than for surface runoff, and this may be related to the intensity of the event. Currently there is very little information in the paper to interpret the results in this light, which I think is necessary for interpolation.

Reply:

As replied above, our radar estimate is calibrated by widespread gauges. It means that the radar estimate is relatively reliable and holds the assumption. Besides, using those various imperfect rainfall estimates to calibrate the parameters by observed discharges may not obtain the consistent parameters and introduces parameter uncertainties. Even some imperfect rainfall estimates derives the more satisfied simulation than radar estimates do (comparing with the observed discharge), it is pseudo owing to the dimension reduction. Therefore, we prefer all hydrograph simulations from imperfect rainfall being compared with the reference one. Meanwhile, we can't find the coherence between rainfall and other variables (elevation, aspect) for the 8 events. Perhaps, this kind of rainstorm caused by tropical cyclones is very dynamic (each cyclone has its own wind field, vapor pressure, cyclone track and the interaction with landscape). Therefore, random sampling is applied. Reviewer's another approach is what we are doing now for another study. In this study, we aimed to explore effect of imperfect rainfall field on simulated hydrograph for practice and highlight the dimension reduction effect in hydrological modeling.

Specific comments:

- 2171/10: The paper by Celleri et al. (2007) is not about radar measurements (although it is a good example of how analysis of the spatial variability found in mountainous catchments can help to understand the processes that take place!)

Reply:

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Corrected.

Comment:

- 2174/11-15: this part is not clear. Does this mean that the evapotranspiration mechanism of TOPMODEL is replaced by something else in order to avoid the need for reference evapotranspiration data?

Reply:

Our statement is not clear enough in the original version. Evapotranspiration always exists. However, for event-based hydrograph simulations, particularly for episodic rainstorms, modelers often don't consider evapotranspiration due to its small fraction with respect to rainfall. Therefore, we eliminated the related sentences.

Comment:

- 2174/6: I guess this refers to the fact that TOPMODEL is based on the assumption that surface runoff is the result of saturation excess (hence the importance of the topographic index). Given the torrential nature of the typhoons I would expect infiltration excess overland flow to be an important process too. Is this represented in the model?

Reply:

In fact, we didn't observe the infiltration excess runoff in the forestry mountainous areas. Otherwise, we had evaluated the two runoff generation mechanisms in our recent modeling work and the saturation excess runoff is suitable (Huang et al., 2009). The details of the two reasons are below. First, due to fractured soil texture, excess surface runoff has rarely been found in the field. The measured infiltration rate is much higher than the maximum rainfall intensity (40 mm/hr) in historical records (Chuang et al., 2008). Second, we have evaluated the two runoff mechanisms (infiltration excess and saturation excess) previously. The result showed that saturation excess gives better performance, which is consistent with field observations. We also found that optimal values of saturated hydraulic conductivities in the two model structures are high, which

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indicate a high infiltration rate.

Chuang, Y.C., Liaw, S.C., Jan, J.F., Hwong, J.L. (2008) Dynamic Change of Hydrologically Sensitive Areas in the Lien-Hwa-Chi Watersheds, Journal of Geographical Science (51): 21-46 (in Chinese).

Comment:

-2174/19: This sentence is not clear. It suggests that RC in formula 1 is used to represent surface runoff at plot scale (i.e. an infiltration excess mechanism) rather than at catchment scale (where it would represent evapotranspiration and deep infiltration losses)?

Reply:

As mentioned above, we changed runoff mechanism to saturation excess and removed the RC parameter. This question no longer exists.

Comment:

2175/6: what does "accordingly" refer to? There are quite a few of such transitions between sentences that are not really clear and highlight the need for a thorough revision of the language.

Reply:

In this revised version, this manuscript had been polished by a native editor.

Comment:

2175/10-11: I am wondering whether this is a distributed model or not. It seems that surface routing is done in a distributed way (taking into account spatial variability in channel roughness for instance) but subsurface routing is not. Is this correct and what is the justification?

Reply:

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Subsurface flow routing is done by distributed approach under the steady state assumption. It is showed in Eq 2 and Eq 3 (P. 6, Line 18; P. 7, Line 2).

Comment:

2176 equation 5: Obviously this estimator does not take into account any spatial dependence between the samples, which certainly will be present. You may want to have a look at this paper (among others) for more advanced methods of comparing spatially correlated fields: M. Fuentes, P. Guttorp, and P. Challenor. Statistical assessment of numerical models. International Statistical Review, 71:201-221, 2003.

Reply:

As mentioned above, the spatial dependence of typhoon rainfall is not significant due to interactive meteorological condition, such as typhoon pathway, wind field, temperature and vapor pressure, capriciousness over time. To go into much detail to explore spatial dependence is somewhat out of the scope of this paper.

Comment:

2177/14-20: This is a quite confusingly written paragraph. I understand it is a random sampling from the radar map, but as noted above, I am not sure this is the best sampling procedure.

Reply:

In fact, we think the random sampling is a suitable sampling procedure if spatial dependence is insignificant, however, as reviewer pointed out the random sampling should not be the most cost-effective way to do rain gauge site selection. Based on this comment and extra works, we changed the title. We eliminated "Cost-effective rain gauge deployment". The new title is now "Response of simulated hydrograph to imperfect rainfall during tropical cyclones in mountainous catchment", which is much proper for the issue we addressed.

Comment:

2178/13: redundant sentence

Reply:

Removed.

Comment:

2178: it should be "classes"

Reply:

Corrected.

Comment:

- 2191 caption figure 3: "Some dots outside the axes were not shown." Does this mean there are (large) outliers? Why is this?

Reply:

This figure was removed.

Comment:

- 2197 caption figure 9: Reformulate as: "(a) relation between rainfall amount ratio and covering area; (b) relation between...". Please also explain Rs and Rr. What exactly is the rainfall amount ratio?

Reply:

This figure was removed.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 5, 2169, 2008.

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