Response to Comments from Reviewers

By the authors: Xijun Lai,Qiuhua Liang, Herve Yesou*

We appreciate the constructive comments from the two reviewers, which will certainly help to improve the quality of the paper. In this document, the authors will make efforts to answer/address all of the comments raised by the two reviewers.

Comments from Dr Guy Schumann:

-When the authors refer to water level from remote sensing, I believe they mean mostly indirect retrieval. In other words the focus is on the DEM and the inherent accuracy which of course impacts the results greatly since a remotely sensed flood edge is first retrieved and then fused with a DEM. I totally agree with the authors that in such a case, using only uncertain flood extent may be preferred. However, the situation completely changes and is turned around when water levels can be directly observed, such as from altimeter (laser and radar), the resolution of which is comparable with the MODIS image used by the authors. In this case, it might be much better to use direct water levels from remote sensing and as such their statements throughout the paper that water level accuracy is low and lower errors are achieved from assimilating extent, should be rephrased or removed.

Re: Yes. In the original manuscript, we referred to the indirect water level retrieval since it is more popularly used in flood related research. We agree with the reviewer that the recent development in direct water level retrieval should be included in the discussion (the authors greatly appreciated the discussion from Dr Sylviane DAILLET, a researcher in space hydrology and satellite geodesy from LEGOS/CNES, France, in direct water level retrieval for inland waters):

Satellite altimetry originally developed for open oceans can be now used to directly measuring inland water level. The database of altimetric water level for about 250 sites on large rivers in the world has been developed based on satellite altimetry missions (http://www.legos.obs-mip.fr/en/soa/hydrologie/hydroweb/). For oceans and great lakes, the accuracy of estimating water level is indeed very high, up to a few centimeters (Fu & Cazenave, 2001; Crétaux & Birkett, 2006). For rivers and floodplains, Alsdorf et al. (2007) showed that the accuracy of direct water level measurement using satellite altimetry may achieve up to 10 cm, but most typically 50 cm because of the radar echoes contaminated by vegetation canopy and rough topography. However, despite of its relative high-accuracy for large inland water bodies comparing with the indirectly retrieved water level, the present in-orbit satellite altimetry (four satellites including Saral/AltiKa, Jason-2, HY-2 and Cryosat-2) is still problematic because of the spatial and temporal resolutions and coverage for sampling relative small water bodies. It essentially provides only spot measurements of water surface elevations (Alsdorf et al., 2007). As a consequence, an exciting satellite mission SWOT using a swath-based technology has been proposed and will be launched for accurate monitoring of inland water bodies (https://directory.eoportal.org/web/eoportal/satellite-missions/s/swot). The SWOT mission provides great potential and new opportunity for data collection in the near future (in 2020). However, currently the rich optical and SAR images will be still main sources of remote sensing data for monitoring flood. Therefore, it is still of great interest to investigate the combined assimilation of the available multi-source satellite data. The present method provides an alternative way to use satellite images. The authors would like to further emphasize that we try to present in this work an alternative data assimilation approach using flood extent, but do not intend to state that the approach is better than all of the existing methods. We will include the above discussion and subsequently rephrase the statements related to low accuracy of water level retrieval following the reviewer's comment when we are asked to submit a revision.

In addition, we shall also clarify that the proposed method can assimilate flood extent (area) data from other available satellite images with high spatial resolution, not just the flood area extracted from MODIS image used here.

-The variational methods are actually governed pretty much by 1) the successful derivation of 'uncertainties' in the observations and 2) the associated weight as clearly shown in their equations. I can see that this could be a preferred choice over other types of assimilation in the presence of uncertain data (points). However, it is not clear to me what happens if many data points have extremely high uncertainty as is easily imaginable at flood boundaries as shown in their paper. Would the assimilation scheme not 'prevent' the model from flooding accurately in places where the data were wrong but flooding would have taken place. In other words, where there is a lot of emerging vegetation creating a high uncertainty situation at flood boundaries, what would happen to a simulation that attempts to accurately predict in those places.

Re: First, we would like to give an overview of the components in the cost function in order to respond to this comment. In the variational methods, the cost function plays a vital role in the success of data assimilation, as well as the accuracy and detailed contents from observations. It normally includes three terms: 1) observation term; 2) background term; and 3) regularization term. Observation term describes the discrepancy between the predicted and observed states. Background term is generally a previously predicted or observed state to ensure no significant deviation in the current prediction with background values. The regularization term is used to improve ill-podeness of variational problems. The appropriate combination of these three terms proposes a balance between the physical dynamics, observation and background information by the error matrices (or weight).

The pixel uncertainty of being wet is calculated using the concept of fuzzy theory as shown in the manuscript. It is obvious that less weight (*w*, certainty degree of being wet) is obtained in locations with high uncertainty (Eq. 7). Less weight in assimilation subsequently means less information can be assimilated into the model. In other words, the information with high uncertainty will have less contribution to the estimate of flood states.

It should be also noted that another advantage of the variational method in this paper gives a strong constraint on the modeling state. It will keep the estimated flood states in the computational domain strictly satisfy shallow water equations, unlike the results obtained from using the filter-type assimilation method. Due to this constraint, assimilation of observation does not mean that the predicted flood extent strictly overlaps with the observed one. The assimilation may ignore the high uncertainty information, and keep flood state satisfying the dynamic conditions according the shallow water equations.

-As I understand the authors, flood extent-related information was assimilated (also I do not necessarily agree with this statement in the paper, please see next comment). Maybe I missed something, but why not assimilate flooded area? I'm asking this question from a model performance point of view. A model might get extent right since this is usually governed pretty much by large topographic constraints but might fail to predict inundated area patterns correctly because there are often micro-topographic features governing floodplain flow paths around small 'islands' or other features inside the inundated floodplain area that should remain dry but are flooded incorrectly by the model. Or maybe the authors mean 'area' and I completely misunderstood, in which case the term extent need to be replaced by area. If area was used, meaning every pixel present in the MODIS observation has a weight, how did the authors deal with the fact that many completely wet pixels inside the area of flooding (w = 1) are also very easily predicted by any model parameterization? This means that many of the weights of 1 do not help in constraining the parameter space during assimilation at all. However, I think the authors use extent information only and thus the next comment is of major concern

Re: The authors appreciate the reviewer in pointing out the difference between flood 'extent' and 'area' (in next comment). Indeed, we use the areal information (flood area) as described in the manuscript (see Box 1). The model mainly assimilates flood information near front by defining the wet-dry status of each cell, but not explicit locations along flood front (edge). The 'extent' used in the manuscript points to the range over which flood extends should be similar with the meaning of 'area' stated by the reviewer. If 'area' is more accurate word, we are very pleased to replace "extent" by "area" in the revised manuscript.

As shown in Box 1, not all of the cells in the flooded area are involved in the assimilation. Only part of area is active in the data assimilation and the active flood area that is involved in the assimilation automatically changes with the assimilation procedure, depending on the discrepancy between the predicted and observed flood area (please see more details in the response to another reviewer). Along with the run of optimization procedure, the active area decreases, until the minimum value of cost function is achieved. Thereafter, only small part in those locations with high uncertainty (reviewer's previous comment) or no flood area (perfect observation required) will be active in the computation of cost function.

-a)The authors claim they assimilate flood extent but when reading the text I strongly disagree. To me, and this was stated in previous reviews of this paper, the authors use depth at extent, rather than the extent information itself. Assimilating extent, in my view, would be to assimilate location (x, y coordinates at flood edge for instance) and not flood depth at extent. b) Moreover, the assumption that 'Herein it is assumed that the observed and predicted water depths are the same in those overlapping areas between the predicted and observed extents. In those non-overlapping regions, different assumptions have to be made, de-pending on the specific location under consideration' (P 11194) is very unlikely to be correct, given my first comment related to dependencies of DEM accuracy. In this case the authors relate flood extent from both model and observations to modelled depths where both extents overlay and argue that this is must then be the observed depth. Am I correct in formulating it this way? c) If this is true then why assimilate at all since you argue that your model gives you the correct depth when extents agree, just a simple calibration on extent would be enough. I do not see the benefit of assimilation in this case. But please correct me if I'm wrong. d) I think the real challenge would be to assimilate observed water surface elevation (from altimetry or post flood field surveys) or water depth (if this existed) because micro-topographic structures (often not present in DEMs and therefore missed in models) prevent extents from expanding but cause water depths (or stage) to rise. e) In your case, depth at extent from models and hence observations (since in your case the latter is made equal to the former by your assumption mentioned above) would nearly always be zero if extents overlap. This is in my opinion not a realistic formulation of the cost functional.

Re: a) As stated in above response, we assimilate flood areal information, instead of boundary location information and/or water depth. Water depth introduced in the cost function is just like the fuel of a car to drive the run of data assimilation (see also Box 1 and the response to another reviewer). But it does not determine the results of assimilation.

b) For those overlapping areas between the predicted and observed extents, no discrepancy information in the extent should be provided for assimilation. Thus, those cells should be deactivated in the assimilation because the predicted wet-dry status is same with the observed one. For convenience, we assume that the virtual observed water depth is equal to the computed one. This assumption is just for excluding those cells in the computation of cost function. Although the assumption in P11194 is 'unrealistic', it is mathematically reasonable and effective for flood extent assimilation done in the manuscript. We will revise the related sentences for easy understanding.

c) We assume that the flood extent data include hydraulic information. After assimilating these data, the predicted flood states (water depth and velocity) should be improved by fusing the implied flood routing information, as well as the improvement of the predicted flood extent. The twin experiments in the manuscript have confirmed this point.

d) The assimilation of water level (surface elevation) is not a technical problem if water level with acceptable accuracy can be acquired. The methods suggested by Lai & Monnier (2009) or others can achieve well such data assimilation. The real challenge of flood data assimilation, in our opinions, is to acquire reliable and abundant observations within a flood event that has a relative short time scale (few days for a large floodplain) of a flood comparing with the revisiting time (one or several weeks) for high resolution satellite images or altimetry. Thus the combined use of multi-sources data would be needed in real applications.

e) Water depth in our model can be an arbitrary value (not zero) if extents overlap because the cells in this area are deactivated automatically when the estimated wet-dry status is the same with the observed. The partially wet/dry cells (high uncertainty) in the observations are exceptional; the computed water depth may be thought to be nearly 'zero' for those cells. But, fortunately, the water areas limited by islands or dykes may have low uncertainty in wet-dry status because of high water depth. Even if it is invalid, the other constraints, such as physical laws of flood routing, in the method, can correct it to some extent. Examining our proposed method in details, the readers will find that the positions mentioned by the reviewer can be automatically inactivated, or discarded. For example, we assume the computational grids and the satellite image are in the same resolution and the topography is captured by the model as shown in Figure 1. Considering the cell adjacent to the river bank or an island, if the observed status of a cell is wet (high water depth because of the obstruction of the bank or island), the cell is inactive if the predicted status is wet according our method; but if the cell is predicted to be dry, the cost function as defined in the paper will influence the model to predict the flood dynamics into a right way. Consequently, the proposed method can be suitable for the flood routing prevented by islands or dykes.

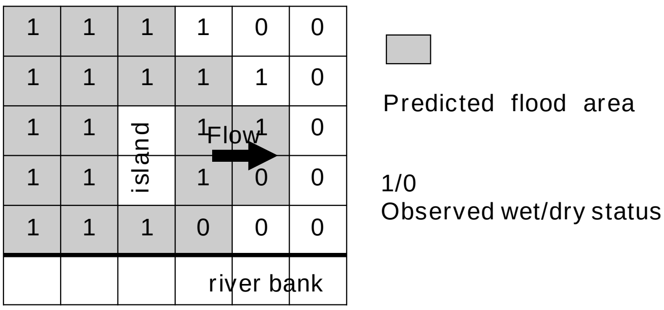


Figure 1 Predicted and observed flood extent near to a river bank and island.

Finally, we would like to point out that the flood extent data represents little dynamic information of a flood event if they are affected by steep slope (such as islands). Therefore, the assimilation of such flood extent data would have no improvement for the estimate of flood states as discussed in the manuscript (lines 17-30, Page 16). Such extent data are not worthy to be assimilated because these data do not actually represent the physical evolution of a flood event. For these cases, direct water level retrieval from satellite altimetry should be a good choice if in-orbit data are available.

-It is not clear to me how the authors can argue that the results are improved by showing very physically meaningless roughness values for the floodplain after assimilation?? This is the illustration of 'getting the right answer for the wrong reason' I feel. I think this highlights only that either the model built or the observation data are quite bad. I assume the model built is fine and that it is really the data that is problematic here and forcing the model to use an extremely high roughness value to 'reach' the observed 'uncertain' extent? Is the MODIS largely overestimating the flood extent or is it due to the 'uncertainty' estimation?

Re: We may not clearly state the improvement of flood routing analysis in the original manuscript. We will rewrite this paragraph when submitting a revision. The comparison of the flood extent before and after data assimilation was done in Fig. 8. After the assimilation, the well-consistent flood extents are achieved for different initial roughness coefficients (The filled coverage is the flood extent using the first guess of parameter; the lines are the boundary of flood extent using the optimal *n* after assimilation).

Not just the consistency was found in the identification of the unknown roughness parameter and predicted flood extent after assimilation, the improvement can be also seen by comparing Fig. 8 with the flood extent extracted from MODIS (Fig. 7). The predicted flood extent after assimilation agrees much more closely with the observations.

Concerning the identified manning roughness coefficient, it was recognized to be very large as stated in our manuscript, which may be caused by the loss of accuracy from the low resolution MODIS data and uncertainties in the domain topography, etc. Nevertheless, the Manning roughness coefficient, in certain cases, may reach this magnitude (0.04~0.25) for over-bank flows in the floodplain, as suggested by Maidment (1992)

-In some places, the language needs to be revised.

Re: The authors carefully proof-read the manuscript to improve the English before submitting a revision.

References:

Alsdorf DE, Rodríguez E and Lettenmaier DP. (2007). Measuring surface water from space. Reviews of Geophysics 45: RG2002.

Crétaux J-F, Birkett C, (2006). Lake studies from satellite radar altimetry, Comptes Rendus Geoscience, 338(4–15): 1098-1112.

Frappart F, Calmant S, Cauhope M, Seyler F, and Cazenave A. (2006). Preliminary results of ENVISAT RA-2-derived water levels validation over the Amazon Basin, Remote Sensing Environment, 100: 252-264.

Fu LL and Cazenave A. (2001). Satellite altimetry and earth sciences: a handbook of techniques and applications (Vol. 69). Academic Press, San Diego.

Maidment DR. (1992). Handbook of hydrology. McGraw-Hill, New York.

Comments from Anonymous Referee #2:

The manuscript aims at assimilating a flood extent image into a 2D shallow water model. The data assimilation method used is based on the adjoint method (4D-var method). The subject is currently relevant. The authors write they "explore a novel way of utilizing" the satellite image by defining a "new cost function" which is wrong. After an attentive reading of the manuscript and the articles Lai et al JoH 2009, Hostache et al JoH 2010 (articles cited), it appears that the present manuscript reproduces exactly the same method, the same equations, the same numerical schemes (the redaction is the same), and very probably the same software than these two articles. Despite what the authors claim, they do not assimilate the flood extent but the water depth for each mesh cell. Therefore, the authors use the same kind of data as in the articles mentioned above but in an unrealistic way, see Lai et al 2009 (e.g. p 8), Hostache et al 2010. No uncertainty estimation (deriving from the DEM and the image accuracy) is presented in this manuscript despite its crucial aspect. When reproducing the two articles mentioned above, the authors should have read that the present naive approach is not reliable. Indeed, as shown by some contributions (yet cited in the present manuscript), the image must be analyzed before extracting reliable water depth values. Typically, some areas must be excluded (eg vegetation) and an uncertainty reduction method have to be applied, see e.g. Raclot 2006, Schumann et al 2008, Schumann et al 2009 .

In short, the "new cost function" proposed is only a different formulation of measuring the misfit between the water depth computed and "those observed" for all cells, hence not realistic . The data accuracy is not addressed here. The authors should (re)read the original papers they reproduce in view to understand this key issue and how to try to circumvent it.

Re: We emphasize here that the proposed method in the present manuscript is largely different from the previous approaches reported by the first author and other co-workers (Lai & Monnier 2009). For clarification, illustrative figures are plotted for both methods to show the difference in Box 1 and Box 2 at the end of this document.

The assimilation of water level is direct if we have observed data for water level and the related observation errors. The method reported in the previous papers (Lai & Monnier, 2009; Hostache et al., 2010) focused on two aspects: (1) assimilate spatially distributed water level derived from satellite imageries, though it is still sparse over computational domain; (2) overcome or improve the ill-posedness of assimilation problems with less available water level observations in practice, namely only little water level information can be extracted from satellite images at few positions in a large floodplain as shown by Hostache et al. (2010) and among others. The first paper proposed a method and verified it using twin experiments (synthetic observations without errors). The second one is partly for application in a real case. The demonstration of cost function and its associated observations are shown in Box 2. The observation space is just the dotted points where the water level with the acceptable accuracy can be extracted. In the method proposed by Lai & Monnier (2009), the water level values are directly used in the assimilation. The retrieved water level accuracy will directly affect the reliability of the assimilated results.

In this paper, we assimilate flood extent information into a 2D flood model. The observation space is dynamically changed with the assimilation procedure. Also, no real water level (or depth) observation is required. The function of the used predicted water depth in the present method is to drive the run of assimilation and its magnitude has no influence on the estimate of flood states.

The original idea of this paper is attributed to the rethinking of our previous work. When we assimilate the indirect retrieved water level from satellite images, it needs a procedure to extract water level with acceptable accuracy. Only information in few positions is retained in this step. So, the question of why not directly assimilate flood extent or even digital number of satellite image was raised. Unfortunately, there is no direct way to implement the assimilation of flood extent (or area) into a 2D flood model using a variational method. The main challenge comes from the construction of cost function. Flood extent is not a state variable of shallow water equations. No explicit expression of cost function considering flood extent information has been previously implemented in the framework of variational assimilation method. To overcome this difficulty, we tried to: (1) define a variable to describe dynamic change of flood fronts; and (2) construct an effective cost function that can include flood extent (or area) information. For the first point, we introduced a level-set method that tracking flood fronts and build the linkage between the level-set function and water depth variable. It facilitates the construction of cost function as normal because the level-set function of the observed flood front is zero. Thus, just flood fronts (boundary lines) information is assimilated in this level-set based method. As pointed out by Dr Schumann, high uncertainty may exist in boundaries and the information of flood fronts may be significantly contaminated. So in this manuscript, we also showed the second point that could partly overcome the impact of high uncertainty in certain conditions.

The proposed method directly assimilates flood extent (or area) information through an implicit way. Assuming we have a flood extent related observable quantity *f* with regard to state variables of water, *U* (e.g. water depth adopted in this paper).

$$f(U) = A(h)U$$

where *A* is the matrix with regard to water depth that describes the flood extent (area).

After getting the *f*, we can define cost function, *J*, directly as:

$$J = \int_0^T \|f - f^{obs}\|^2 dt$$

Normally, the wet-dry status of a computational cell can be determined by its water depth, *h*. It is dry if water depth is zero; otherwise it is wet. As described in the manuscript, a critical water depth, h_c, may be chosen as a threshold for defining wet-day status for real-world problems. For simplicity, *A*, describing the characteristics of the predicted flood extent (or wet-dry status of the computational cells), can be considered as the diagonal matrix and determined according to the predicted water depth as follows:

$$A(h) = \begin{bmatrix} a_{11} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & a_{nn} \end{bmatrix}, \quad a_{ii} = \begin{cases} 1, & h \geq h_c \\ 0, & h > h_c \end{cases}, i = 1,2, \dots, n$$

The matrix *A* dynamically changes with flood moving over a floodplain. Through this transformation, the flood extent related quantity *f* includes the evolution information of flood extent (or area).

For the flood extent observation derived from satellite images, A^{obs} denotes the certainty degree of a cell being wet and its covariance relationship with other adjacent cells that determined by the algorithm of extracting flood area. Actually, A^{obs} is an error matrix of observation describing wet-dry status information:

$$A^{obs} = \begin{bmatrix} a_{11} & \dots & a_{1n} \\ \dots & \ddots & \dots \\ a_{n1} & \dots & a_{nn} \end{bmatrix}$$

If considering only error variances, we can simplify A^{obs} as follows:

$$A^{obs} = \begin{bmatrix} a_{11} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & a_{nn} \end{bmatrix} = \begin{bmatrix} w_1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & w_n \end{bmatrix}$$

where the certainty degree (uncertainty), w_i is determined by the adopted flood extracting method. In our paper, the certainty degree of flood area extracted from satellite imageries is obtained using Eq.7. The high uncertainty positions will be assigned by a very low certainty degree. It will make the extent information in these positions take little effect on the estimate of flood states.

Obviously, if we just use $f(U) = A$ (namely, *U* = I) in the cost function, the adjoint model implemented with the variation method cannot be driven and the optimization algorithm will not run.

As stated in the paper, we express *f* as: $f(U) = Ah$, in which *h* is the water depth. The advantage of use water depth is that it can be interpreted physically to be the unit volume of water of cell. In fact, other state variables, such as velocity, may well effectively work as the adopted water depth.

The remaining issue is to define the water depth in the observations over a computational domain. The detailed description can be found at lines 2-16 in Page 9 of the manuscript. In view of the water depth in the cost function for driving the model, the "unrealistic" but mathematically reasonable assumption can be adopted as stated in the manuscript for flood extent assimilation.

In other respects, it is well-known (see e.g. Toro's book 2001, cited) that the HLLC finite volume solver the authors use requires a cut-off at wet-dry front. Then the flood dynamics, hence the water extension at image time, depends greatly on this numerical regularization. This crucial problem is not mentioned here. It is a well-known and difficult numerical problem which prevents to directly assimilate the flood extent using the present 2D shallow-water numerical model (even if it was a perfect observation).

Re: Flood propagation over dry bed is open challenging in numerical methods. We use normal wetting-drying treatment (namely a tiny water depth as tolerance to evaluate flood front, e.g., 0.0001m according to the numerical problems). Since this is a traditional approach used extensively in literature and it is not a focus of the current paper, it is therefore not necessary to include the details. But we will include new references to improve the readability of the paper in the revision.

Although water depth along flood fronts should be theoretically zero, it is not practical to use this theoretical flood fronts in real applications. It is reasonable to assume that a finite (small) water depth exists along the extracted flood fronts in the remote sensing data as described in the manuscript. This essential helps to minimize the effects of the disturbances from different land covers, the resolution of the image, and other sources of uncertainty as suggested by Aronica et al. (2002). Considering that, we introduce a critical water depth, h_c to define the wet and dry areas. If predicted water depth $h > h_c$, the cell is wet; otherwise, the cell is dry. Though it is small (e.g. 0.1 m), it is worth noting that this is much larger than the tolerance used in a flood model for wetting and drying treatment. In our model, we assign the wet-dry status to each computational cell according to its relative values between the predicted and critical water depth. The value of cost function is then achieved by its definition. No attention should be paid on the wetting and drying treatment.

In summary, the "novel way of utilizing" the satellite image presented is in fact an unreliable naive approach, demonstrating the misunderstanding of the authors of the crucial issues and a misunderstanding of the numerical model features used.
Re: Please refer to the above explanation.

The only new aspect of the present study is the application of the (unreliable) method presented here to a new (?) real data set (Section 5). But, again, the authors demonstrate their misunderstanding since they use the (heavy) adjoint method to identify one (1) parameter (the roughness coefficient supposed to be uniform). Assuming, the model and observations reliable, the authors could identify this scalar value by running direct models only, see Figure 9.
Re: Although simple numerical experiments were conducted in our manuscript, the proposed variational method can be used to identify more parameters (spatially distributed) that are hard to be calibrated manually in more complex cases.

In summary, the authors demonstrated they did not understand the key issues of the problem addressed nor the key points presented in the articles cited (in addition to reproduce very closely existing redaction and using the corresponding numerical model without understanding its advantages and limitations). This manuscript does not deserve to be published in any scientific research journal.
Re: By answering/addressing the reviewer's comments, we hope that we have clarified the novelty and significance of this work.

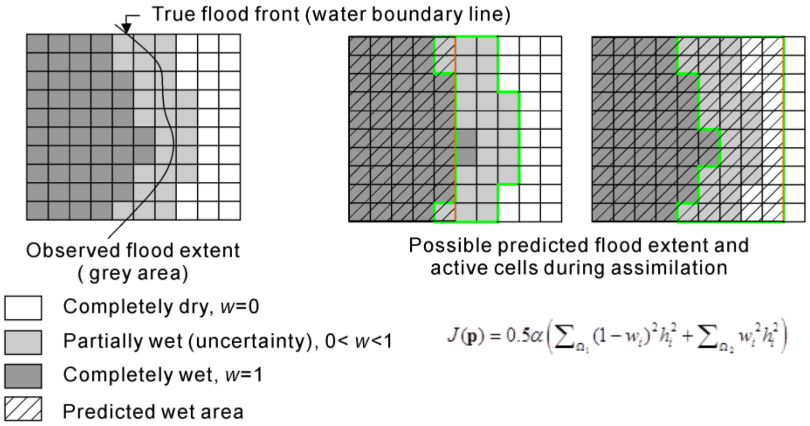
References:

Aronica, G., Bates, P. D. and Horritt, M. S. (2002). Assessing the uncertainty in distributed model predictions using observed binary pattern information within

GLUE, Hydrol. Process., 16(10): 2001–2016.
Hostache, R., Lai, X., Monnier, J. and Puech, C. (2010). Assimilation of spatially distributed water levels into a shallow-water flood model. Part II: Use of a remote sensing image of Mosel River, J. Hydrol., 390(3-4): 257–268.
Lai, X. and Monnier, J. (2009). Assimilation of spatially distributed water levels into a shallow-water flood model. Part I: Mathematical method and test case, J. Hydrol., 377(1-2): 1–11.

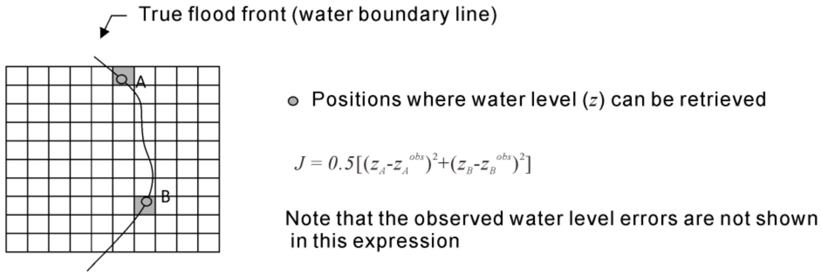
Present method

(1) **Areal information**: Flood extent (or area) information is assimilated. As shown below figures, cells enclosed by thick green line are activated in the assimilation according our definition in the manuscript. The active area that really used in assimilation dynamically changes with the predicted flood state. If the predicted flood extent is far away from the observation, the active area is large. It decreases with the assimilation procedure, until the predicted state is closest with the true one and satisfy other constraints .
(2) **No real water level (depth) observation required:** The function of the used predicted water depth in the present method is to drive the run of assimilation. Please see the explanations in the text.



Box 1. The current method for flood extent assimilation.

Lai & Monnier, 2009; Hostache et al. , 2010



(1) **Dotted points information**: For most of real cases, water level with acceptable accuracy just can be retrieved in limited positions. These observed water levels (z^{obs}) retrieved from satellite imageries are still very sparse in space (e.g. two points in the above figure).
(2) **Direct use of water level values** extracted from satellite imageries.

Box 2. The method reported by Lai&Monnier (2009) for water level assimilation.