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Reply on RC2

Antonio Annis et al.

Author comment on "Simultaneous assimilation of water levels from river gauges and satellite flood maps for near-real time flood mapping" by Antonio Annis et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2021-125-AC2, 2021

ID: R2_01

Referee comments:

This study aims at simultaneously assimilating water level observations from static sensors and EO-derived flood extent for improving real-time flood modeling. I have really enjoyed reading this paper, which deals with a timely and important issue. The authors showed the potential of the joint assimilation of water level observations from both static sensors and satellite images. I think this study fits the overall focus of HESS. However, I do have a number of major comments that hopefully will help the authors in strengthening their manuscript.

Authors' reply: We thank the reviewer Dr. Maurizio Mazzoleni for the positive feedbacks and the useful suggested revisions that helped improving the manuscript

Actions: We isolated every Referee comment assigning a specific ID with a progressive number (e.g. R1_XX) and our point-by-point reply.

ID: R2_02

Referee comments:

-My first comment concerns the overall objective of this study. Personally, I would put more emphasis on the issue of the joint assimilation of water level observations in the 1-D and 2-D model rather than highlighting the innovation behind the proposed DA approach (line 57). Besides equations 5 and 6, and the definition of hko,t in equation 9 there is no much difference between a standard EnKF and the proposed DA method, which would not justify a publication on a high impact journal like HESS. To the best of my knowledge, this is the first study that assimilates heterogeneous observations in both 1D and 2D models and this must be better highlighted in the introduction (as novelty and the main objective of the paper) and throughout the paper.

Authors' reply: We agree with the Referee,'s comment: from the introduction, The EnKF

is, in fact, a consolidated methodology, therefore we underlined the joint assimilation of stage gauges and satellite derived flood extents adopting novel methodologies for updating the Quasi-2D hydraulic model.

Actions: We removed the "novel" word in line 111 and we better clarified the novel aspects of the proposed research*: ""Despite the remarkable progresses in the integration of remotely sensed observations in DA frameworks, there are still major challenges that need to be faced (Grimaldi et al., 2016). For example, there is not still in scientific literature an approach able to assimilate heterogeneous observations from both local and distributed datasets coming from different sources (i.e. traditional stage gauges and remotely sensed flood extents). Moreover, Quasi-2D and 2D hydraulic models can be sensitive to different simultaneous local state updating (i.e. water level corrections at specific time steps), because contiguous channel/floodplain cells can be characterized by different elevations, geometry and roughness, therefore instability issues can rise during the model corrections. Another critical issue is that large scale flood forecasting models need to provide timely predictions but their spatial resolution can limit the effectiveness of the assimilation of satellite derived flood extents (Hostache et al., 2018).*

In this work, a DA framework supported by heterogeneous observations coming from both local water level observations (i.e. stage gauges) and spatially distributed information gathered from satellite images - is proposed and tested. This research seeks to develop a more flexible DA scheme that may value all available sources of observations for distributed flood modelling updates. The aim of this work is to mitigate flood prediction uncertainties by combining heterogeneous data and an integrated topographic-hydrologic-hydraulic modelling approach, while maintaining inundation forecasting robustness, scalability and numerical stability. In achieving this goal, novel scientific advances and technical challenges of EO-driven DA approaches for flood prediction are investigated and in particular: A methodology for updating the state variable from multiple local stage gauges observations of a hydraulic model for distributed flood routing in floodplain domains; the gathering of spatially distributed water level observations by means of flood extension processing and detection from satellite images, also adopting GIS algorithms for overcoming the issues of the different resolutions between the ensembles of the flood extents retrieved from the satellite derived images and the ones generated from the hydraulic model simulations. "

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ID: R2_03

Referee comments:

- The proposed DA approach should be better described in the paper. What I think is still missing is the information about the size of each DA variable/matrix (e.g. the size of the model covariance matrix P) and how the merging between hydraulic model and DA is performed. Observations from static sensors are used to update the channel water level (1-D model), while satellite images are used for updating the floodplain water level (2-D model). The assimilation of one observation at a given time step allows updating not only the water level at that specific point along the channel but also upstream and downstream. This is partially solved by introducing the distributed gain (initially proposed in Madsen and Skotner, 2005), but how then the updated upstream flow will numerically influence the downstream water levels? It would be nice to show the covariance matrix P at different time steps in case of assimilation of only static sensor, only SI, and joint assimilation. This will allow visualizing the distributed effect of assimilating heterogenous observations at once.

Authors' reply and actions: We thank the referee for the useful comments. We

extended Section 2.2.1.1 for better explaining how the model updating is performed at the assimilation steps. The model updating are applied "serially", allowing to reduce the DA variable matrix to sequences of one observation at time and avoiding potential spurious correlations of observations located far from each other. This serial updating is commonly used also in observation localization techniques where, for example, at each point of the domain, the covariance of the observation is divided by a term that is inversely proportional to the inverse of a distance-based correlation. We also clarified that in both cases of assimilating satellite derived images or stage gauges observation, the model updating is performed in both channel and floodplain cells. We also set a new simulation in which only the upstream SG observations are observed in order to show the performance in the downstream part of the basin, far from the observation locations. Finally, we also add 2 new figures to show the distribution of the covariance matrix at specific time step

ID: R2_04

Referee comments:

- The abstracts read well but I would include a couple of brief sentences summarizing (quantitatively) the benefits of the joint assimilation (e.g. "Our findings reveal that assimilating observations from static sensors and satellite led to an overall reduction of the Bias and RMSE of about ---"). In addition, at the beginning and at the end of the abstract you referred to the issue of data scarcity. However, your approach is based on the case in which you have observations from static sensors, which may be not available in data-scarce regions.

Authors' reply and actions: We added some lines in the abstract specifying some quantitative findings of the proposed approach. We mentioned the issue of data scarcity because our proposed methodology is able to work even if gauging stations are missing and satellite derived data are the only sources of observations.

ID: R2_05

Referee comments:

- In line 143 the authors state that "In case the observation is a stage gauge measurement, the state variable position is determined by identifying the closest channel cell". However, after a few lines (153) they stated "The updating of the water levels from Static Sensors (SH) […] aims to correct both the channel and the floodplain water level". Are the static water level observations used to update only channel water levels of also the ones in the floodplains?

Authors' reply: We better clarified this aspect in Section 2.2.1.1 (see also in Figure 2): the model updating when stage gauges observations are assimilated is performed both in the Channel and in the closest floodplain cells and is propagated upstream and downstream in both channel and floodplain. This helps preventing model instabilities if only channel cells are updated and not the adjacent floodplain cells.

Actions: We better specified this aspect referring to Section 2.2.1.1.: *"The correction is then applied also to the closest floodplain cells and propagated upstream and downstream as illustrated in Section 2.2.1.1 ."*

ID: R2_06

Referee comments:

- I like the way the different experiments are structured and described. However, I think that a more critical analysis of the results is needed. I would like to see more discussion on results achieved with the assimilation of SI observations. The description of the results is there but what is lacking is the "why" you got these results. For example, assimilating SG observations we see that the ensemble with DA is similar to the one of OL in the downstream area of Figure 6 (see lines in lines 385-388). However, this is not the case when assimilating SI observations (figure 9). Figure 6 is barely discussed in the paper, so figure 9. Including the spatial values of P and K may help in understanding this behavior and better describe the results.

Authors' reply and actions: We thank the Referee for the suggestion. We extended the description and the discussion on the results and we also added two Figures representing the spatial covariances at specific time steps.

ID: R2_07

Referee comments:

- Could you elaborate more on the impact of the low retrieval frequency of SI observations on the DA performances?

Authors' reply: Since our case study included the acquisition of only one satellite image, we could not analyze the impact on the low frequency acquisition of the SI observation. However, recent scientific literature provided some important findings on the frequency of the SI acquisition. For example, Dasgupta et al., 2021 found that the optimal strategy for the image acquisition depends on the river morphology and flood wave arrival timing. Moreover, it was found that the number of observations to significantly improve the performances of the DA model increase with the narrowing of the floodplain valley. Moreover, Giustarini et al., 2011 found that the frequency of their model corrections seems to be effective mostly during the rising limb of the flow hydrograph, while it seemed not to be significantly efficient during the recession limb.

Actions:

ID: R2_08

Referee comments:

- Is your DA approach efficient when dealing with high-dimensionality issues of the covariance matrix P?

Authors' reply: As specified in comment R2_03, the application of the DA model is performed applied "serially" for each observation, allowing to reduce the DA variable matrix to sequences of one observation and avoiding potential spurious correlations of observations located far from each other. Therefore, there are not high-dimensionality issues of the covariance matrix.

Actions: We specified this aspect in Section 2.2.1.1

ID: R2_09

Referee comments:

- What is the computational time required to run the DA approach in the selected case

study?

Authors' reply: Averagely, each simulation hour require a computational time equal to 3.7 minutes. This is a value averaged considering that the computational time is highly variable depending on the peak flow and on the extension of the flooded area in the computational domain

Actions: This information is added in the manuscript in Section 4.4

ID: R2_10

Referee comments:

- What is the difference between SH and SG? Try to avoid unnecessary acronyms if not used.

Authors' reply: We apologize for the typos

Actions: SH has been replaced with SG

ID: R2_11

Referee comments:

- Why do you get such an abrupt change in Figure 13?

Authors' reply: This abrupt change was in correspondence of the SI acquisition that determine an abrupt reduction of the ensemble spread

Actions: We changed the way of simulating the simultaneous assimilation of SG and SI observation without assuming SG failures, therefore new different results are showed.

ID: R2_12

Referee comments:

- Where is the text of sections 2.2.1 and 2.2.5?

Authors' reply: There was a mistake in the subsections labelling.

Actions: subsections' names have been corrected

ID: R2_13

Referee comments:

- Why are the results of OL in tables 1, 2, and 3 different? I would expect the same values if the sensor location and flood events are the same.

Authors' reply: The slight differences between the OL results in the three tables were due to the fact that we repeated three different sets of the 2021 flood event simulations even for the OL. Since the OL each time is characterized by the generation of the model and observation errors, slight difference may occur, mostly if the sample size is limited for computational reason.

Actions: We referred to the same OL simulation so as not to confuse the reader

ID: R2_14

Referee comments:

- Line 388: "The adopted updating procedure allows to increase the flood extent of 4 km2 a the time of the SI acquisition". Is this increment leading to better prediction or more false alarms?

Authors' reply: The updating procedure helped reducing the false negatives

Actions: We specified this aspect in Section 4.2