Title: Technical note: Analysis of observation uncertainty for flood assimilation and forecasting
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We thank the reviewer for their positive comments, which will help improve the manuscript. Below we give each comment in bold (abridged where appropriate) and describe how we plan to alter the manuscript to address the reviewer's concern. We give suggested changes to the manuscript in italic font. We note that several of the comments ask for clarification/additional details about the derivation of the water level observations and their associated uncertainties. To address these comments we would replace Section 3 by a methodology section with the following subsections:

3.1 Derivation of water level observations.

3.2 Model and data assimilation.

3.3 Quality control and data thinning.

3.4 Potential observation error sources.

3.5 Experimental design.

The section would contain material from the current Section 3, some of the material that is currently in the introduction and include some new additional material that describes in more detail the observation derivation process and the possible sources of observation uncertainty.

Response

From the reviewer's comments we have identified the following points that need to be addressed.

1. **P 5 lines 4-6: As the standard deviation of the WLOs is estimated using rather strong hydraulic hypotheses, I would suggest to change the word measured by estimated for instance.**

   We would use *'calculated'* rather than *'measured'*.

2. **The way the 59cm is estimated is not so clear to me.**

   In the proposed Section 3.3 we would state that *'The measured standard deviation for the thinned data set is calculated by fitting a plane by linear regression to the WLOs. The variance of the difference between the WLO and planar surface can be used as an estimate of the observation error variance'*.

   When discussing the assumed observation error we would state that *'The assumed standard deviation for the WLOs is 59cm; this is calculated as described in Section 3.3.'*

3. **P 4 equation 3: could you please elaborate a little more on the second term. It does not look so straightforward to me.**

   In data assimilation it is assumed that any systematic error is removed from an observation before assimilation. We clarify this in Section 2: *'The observation-minus-background residuals* $\mathbf{d}_b^o = \mathbf{y} - \mathcal{H}(\mathbf{x}^b)$*, also known as the innovations, are assumed to be unbiased. Hence any bias should be removed before assimilation [Dee, 2005].'*

In Section 2 we would elaborate on the second term of equation (3) by stating that:

'It is assumed that the observation-minus-background and observation-minus-analysis residuals are unbiased, but this is not guaranteed. Hence the second term of equation (3) .... '

4. **P4 lines 30-32: I found this sentence a little difficult to read. Could you please try to clarify it?**

   Please see response to Reviewer 1 comment 19 as they asked for the same clarification.

5. **P6 lines 7-10: Could you please try to clarify?**

   We would rephrase as follows: *'We first use all available data to calculate the average horizontal error variance and correlations. We then consider if the observations of the flood on the Severn have similar error characteristics to the observations of the flood on the Avon. Finally we consider if the error statistics vary for different periods of the flood. For all cases the observation error correlations are calculated at a 1km bin spacing.'*

6. **Could you please mention as well how you estimate the error spatial correlation from the covariance in the bin?**

   We would include that *'To calculate the spatial correlation, the covariance in each bin, $cov(\beta)$, is divided by the estimated variance (the covariance at zero distance, $cov(0)$).'*

7. **P6 lines 13-15: What is meant by error of representation is not clear to me. Could you please clarify?**

   We would include an improved description of representation error in the introduction.

   'The observation error statistics are the sum of the instrument error and representation error [Janjić et al., 2017]. The error of representation arises due to the mismatch in the observation and its model equivalent and it is often correlated and state dependent [Waller et al., 2014, Hodyss and Nichols, 2015].'

   We also propose to add a new section (3.4) that discusses the potential sources of observation errors. We would clarify, that in addition to instrument or measurement error, *'observation errors can be a result of:*

   - *Pre-processing/QC error: Errors introduced during the observation pre-processing or quality control procedures.*
   - *Observation operator error: Error that arises due to approximations in the mapping between model and observation space.*
   - *The error due to unresolved scales and processes: Error that results from the mismatch between the scales represented in the model field and the observations.'*

   We would then discuss how the WLOs may be affected by each of these errors. This would include that:

   - Correlated pre-processing error may exist due to errors in flood extent caused by, for example, high backscatter as a result of emergent vegetation or rough water surfaces. However the procedures in Mason et al. [2012] provide an estimated standard deviation for this error and thin the data to ensure that the errors are uncorrelated.

- The ‘nearest wet pixel’ observation operator, which would be described in Section 3.2 (See response to Reviewer 1 comment 6), is a potential source of correlated error for WLOs. It is possible that in locating the nearest wet pixel and extrapolating information we introduce correlated error.
- The error due to unresolved scales and processes is also a possible source of observation error correlations. Although in this case the model is of relatively high resolution, there are still scales that are unresolved. Previous studies that have considered these scale mis-match errors have found that they are typically correlated [Janjć and Cohn, 2006, Waller et al., 2014].

In Section 3.5, we refer the reader back to the details in Sections 3.3 and 3.4.

‘The assumed standard deviation for the WLOs is 59cm; this is calculated as described in Section 3.3. The value accounts only for the preprocessing error, and not for any error introduced by the approximations in the observation operator or scale mis-match errors and, therefore, may be an underestimate of the true error standard deviation.’

8. **The Authors should try to elaborate a little more on how the WLOs are obtained and what could be the sources of the error spatial correlation. Authors should in my opinion refer to some interesting remarks with that respect in Mason et al 2012.**

   We note that Reviewer 1 also asked for some elaboration on how the WLOs are derived. We would include this information in the new Sections 3.1, 3.2 and 3.3 (see response to Reviewer 1 Comment 6). In section 3.4 we would discuss the possible sources of the error spatial correlation (see response to comment 7).

References

D. P. Dee. Bias and data assimilation. *Quarterly Journal of the Royal Meteorological Society*, 131(613): 3323–3343, 2005. doi: 10.1256/qj.05.137.

D. Hodyss and N. K. Nichols. The error of representation: basic understanding. *Tellus A*, 67, 2015. doi: http://dx.doi.org/10.3402/tellusa.v67.24822.

T. Janjć and S. E. Cohn. Treatment of observation error due to unresolved scales in atmospheric data assimilation. *Monthly Weather Review*, 134:2900–2915, 2006.

T. Janjić, N. Bormann, M. Bocquet, J. A. Carton, S. E. Cohn, S. L. Dance, S. N. Losa, N. K. Nichols, R. Potthast, J. A. Waller, and P. Weston. On the representation error in data assimilation. *Quarterly Journal of the Royal Meteorological Society*, n/a(n/a):n/a – n/a, 2017. doi: 10.1002/qj.3130.

D. Mason, G.-P. Schumann, J. Neal, J. Garcia-Pintado, and P. Bates. Automatic near real-time selection of flood water levels from high resolution synthetic aperture radar images for assimilation into hydraulic models: A case study. *Remote Sensing of Environment*, 124(Supplement C):705 – 716, 2012. doi: https://doi.org/10.1016/j.rse.2012.06.017.

J. A. Waller, S. L. Dance, A. S. Lawless, N. K. Nichols, and J. R. Eyre. Representativity error for temperature and humidity using the Met Office high-resolution model. *Quarterly Journal of the Royal Meteorological Society*, 140(681):1189–1197, 2014. doi: 10.1002/qj.2207.