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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "An agent-based model for flood risk warning" *by* Thomas O'Shea et al.

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RC2 – Response

The authors would like to extend their sincere thanks to the referee for their time and considered thoughts on the submission. All comments and corrections have been thoroughly considered, with our respective action and/or response to these outlined below.

This paper proposed an innovative approach to represent the complex human behaviour during flood evacuation in Carlisle by combining a hydraulic model (LISFLOOD-FP) and an Agent-Based Model (NetLogo). I have really liked the idea of using the Bass Diffusion Model to represent the agent's behaviour during flooding. The results of this study demonstrated the importance of using a holistic approach to flood management purposes. Overall, I have enjoyed reading the paper and I found the manuscript well

written, clear, and results are properly described and discussed. For this reason, I do recommend a minor revision before this paper can be accepted in NHESS. However, I still have a few comments which I hope will be useful to the author to strengthen the manuscript.

Author response: The authors appreciate the referee's kind comments and recognition of our efforts to holistically frame the dynamics of flood events using a combined socio-hydrological modelling tool. In sum, we have found the referee's thoughtful comments useful in strengthening the revised manuscript, to be uploaded following this period of interactive discussion.

1) It looks to me that one important aspect of the ABM is not included in your approach, i.e. the traffic model. In fact, during the evacuation process, traffic congestions can play a crucial role before the agents select to respond to the flood all at the same time. However, it is not clear to me what are the dynamic characteristics of the agents 'movement (e.g. speed) and how are the road features included in the ABM. In fact, evacuation strategies may change based on the direction, capacity, and maximum allowed speed of the road network in Carlisle.

Author response: The authors do agree with the referee that traffic models offer an important aspect to ABMs and can have impact on the response to flooding. In the first instance, it was felt that there was already a wealth of models that had implemented traffic flows in ABMs. We wanted to focus on developing something different and whilst traffic dynamics have been implemented in the latter iterations of the HABM, this was a matter of course rather than interest and has little impact on the novelty of findings outlined in this paper. Simulations were run where the dynamics of agent movement varied between 1m/s and 3.5 m/s, to represent 'walking' up to a 'brisk pace'. The exit from the DEM is the action towards which 'warned' agents will move. Not all agents will do this, some will just move to a safe distance and then re-interact with the routine in the following time-step. This is thought to best represent the dynamics of human response that people would give to a flood like that seen in 2005 Carlisle – relatively

slow onset and propagation. The road features were implemented from open street maps and these provided the avenues upon which agents could move and interact with the environment.

2) Why did the authors couple LISFLOOD-FP with the ABM if societal actions will not influence flood propagation (at least in this study)? Of course, the proposed coupling framework can allow simulating more complex situations, e.g. placing sandbags or other tools to protect from flooding, but it will drastically increase computational costs. I assume that such costs may reduce if the raster files are uploaded within the NetLogo framework each simulation time step. Moreover, what is the computational time for 1 simulation?

Author response: This flood event was a 1 in 150-year event which significantly overtopped the existing defences meaning that local and even large-scale management actions would have been of little consequence to the event dynamics. Furthermore, we are concerned with the process of in-event, societal response to the flood propagation. Of primary interest here was the modelling of communication dynamics. Whereas placing sandbags can indeed be defined as a routine, antecedent response that influences flood propagation, we suggest that the characteristics of responsive action (the patterns of inter-agent communication and subsequent action) taken by agents to the flood and in the simulations would not be present if the flood did not happen and so is analogous to the process of innovation. Here, we are framing response by adopting the terminology used by the governmental guidelines for flood planning in the sense of human, individual and community, 'plans' and we offer some insight into how the concepts and patterns of individual and community communication and response can be represented within an ABM. The time taken to model this process, over 1 complete simulation of the flood, without any variance in the parameters and dependent on the computer system used, has ranged from 45 seconds to 3 minutes 30 seconds. We found that implementing a dynamic flood wave within NetLogo exponentially increased computation time and thus moved to importing raster files which offered relatively faster

simulations, overall and at each time step, of the dynamics and interactions of interest.

3) How the working locations for all the agents are assigned? From what I could understand from the manuscript, the daily routine is randomly assigned at each simulation based on the census information of the specific commercial area in Carlisle for 2005. Is this valid also for the working locations?

Author response: The daily routine is present throughout the whole simulation for all agents to carry out. Yes, this is valid for the working locations also and is sourced from the census flow dataset.

4) When an agent receives the warning and decides to act immediately it will then exit the DEM using available network road. Is this a realistic situation? If yes, please provide a reference to support your choice.

Author response: With respect to the ABM outlined in this manuscript, we chose to develop and focus on the aspects of community, individual choice and action. This was justified through reference to the UK Government's 'personal flood plan'. To ensure that these aspects were as dynamic as possible we recognised that we needed to give the agents the choice to 'respond' to the flood propagation based on proximity to flood waters and/or on inter-agent communication but also the choice to not respond and continue with their daily routine. Being 'pre-warned' simply gives an agent the option to immediately seek an exit from the DEM as they are aware of the impending flood. In terms of this being a realistic response, the authors inferred this process of moving away from the flood waters as being realistically representative of a choice people would make based upon reference to The Environment Agency's 'Flooding: what to do before, during and after a flood' document from 2015. This will be added as a reference in the updated document.

5) Can you provide an example of the "innovative knowledge to respond to the flood upon onset" that a pre-prepared agent can use? (line 579) Maybe I have missed some details.

Author response: Upon deliberation, the authors suspect they might have explicated this in a clearer fashion for the reader. Here, we explain that the knowledge of the flood and thus the requirement to respond in a fashion which is beyond that of the daily routine is innovative in its own right, or at least is analogous to the essence of an innovation. This is different to undertaking an action which you might class as an implementation of a 'hard-engineered' innovation and is linked to the terminology of The Bass Model and Tarde's terminology for the laws of imitation. The format of human response and communication is necessarily innovative owing to the relatively infrequent unification of human and natural environments in the format of a flood event.

6) Besides for the DEFRA estimation for Carlisle at line 756-758, did you evaluate the model results with other observation data (e.g. tweets or report for some specific parts of the city)? I have found some (maybe useful) information in this webpage http://www.intrescue.info/hub/index.php/carlisle-floods-8th-january-2005/

Author response: This is a very useful source. However, it seems that the information in this source does overlap with that provided within the DEFRA reports, which were used to inform the dynamics of interaction within the HABM. We feel that the information contained in the source provided by the referee could be useful for informing and developing a sub model routine for agents who choose to remain in their properties during flood propagation. Aside from DEFRA, local and national tabloid accounts were used in cross-referencing event timelines and these were found to be useful in the absence of twitter or indeed any digital footprint of note for the event in 2005.

7) The authors stated that "The only study to date to drive an ABM with a hydrodynamic model was that of Dawson (et al., 2011)." This is not totally correct. Also, in Medina et al. (2016) an ABM and a hydraulic model were coupled to test large scale evacuation strategies in coastal cities under threat of imminent flooding due to extreme hydro-meteorological events. Moreover, other studies coupled ABM with a hydraulic model for flood risk management purposes (Abebe et al., 2019).

Author response: This statement has been revised to indicate that there are indeed other examples of ABMs driven by hydrodynamic models. In making this statement, the authors were referring to a model which they felt would be directly comparable by scale and computability, this could have been made clearer. We also feel that these references are good additions to the paper and so they have been included in the revised manuscript.

8) Try to improve the quality of figures 8 and 9

Author response: Yes, this will be implemented in the revised manuscript.

References: Abebe Y.A., Ghorbani, A., Nikolic, I., Vojinovic, Z. and Sanchez, A. (2019) A coupled flood-agent-institution modelling (CLAIM) framework for urban flood risk management, Environmental Modelling & Software, 111, 483-492. Medina, N., Sanchez, A. and Vojinovic, Z. (2016) The Potential of Agent Based Mod- els for Testing City Evacuation Strategies Under a Flood Event, Procedia Engineering, 154, 765-772, https://doi.org/10.1016/j.proeng.2016.07.581.

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