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VigiFlood: evaluating the impact of a change of perspective on flood vigilance

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Abstract

Emergency managers receive communication training about the importance of being 'first, right and credible', and taking into account the psychology of their audience and their particular reasoning under stress and risk. But we believe that citizens should be similarly trained about how to deal with risk communication. In particular, such messages necessarily carry a part of uncertainty since most natural risks are difficult to accurately forecast ahead of time. Yet, citizens should keep trusting the emergency communicators even after they made forecasting errors in the past.

We have designed a serious game called VigiFlood, based on a real case study of flash floods hitting the South West of France in October 2018. In this game, the user changes perspective by taking the role of an emergency communicator, having to set the level of vigilance to alert the population, based on uncertain clues. Our hypothesis is that this change of perspective can improve the player's awareness of flood risk, and response to future flood vigilance announcements.

We evaluated this game through an online survey where people were asked to answer a questionnaire about flood risk awareness and behavioural intentions before and after playing the game, in order to assess its impact. The results are encouraging, showing improved risk awareness, protective intentions, vigilance, and trust after playing. However, it also suggests that the current "game design" is still poor and unable to engage the general public, in particular school students. Future research will therefore address this issue.

Keywords: crisis communication, trust, subjective risk, agent-based model, serious game

1 Introduction

- Natural disasters are increasingly frequent <https://public.emdat.be/data>; more and more floods are expected to happen in some parts of the world (Roudier et al. 2016; Kerr 2007; Schiermeier 2011)
- Disasters are costly as they affect more densely populated areas. Floods in particular make many victims and are very costly in economic damages (Duan, He, Nover, et al. 2016).
- Not all are predictable, and even those that are predictable are highly undeterministic, in particular in their exact location. The communication of meteorological vigilance is inherently probabilistic and uncertain (Meteo France gives a "trust index" for long-term previsions to make it clearer they are uncertain).
- This is the case for flash floods following intense rain and thunderstorm: if the occurrence of thunderstorms can be predicted more or less accurately, their exact trajectory is difficult to know in advance. Flash floods are difficult to predict (Duan, He, Takara, et al. 2014).
- Yet it is crucial to warn people so they can take protective actions soon enough, even though these precautions might end up unnecessary

- Consequently, weather forecasters are faced with a dilemma: either wait to have more certainty before announcing a weather event, at the risk of missing it or announcing it too late, possibly causing victims; or announce a probable event before being sure, at the risk of over-alerting the population.
- This second option is most often considered as more acceptable (Meteo France for instance tolerates about 15% of over-alerting, vs only 3% of under-alerting). + REF LE MONDE
- However, the population might lose trust after several over-alerts, that they might consider as "false alerts".
- This would result in not trusting subsequent alerts even when justified. This is for example what happened in recent floods in the South West of France in October 2018.
- CONCLUSION: The question of **when** to raise an early warning about a predictable natural disaster is crucial: too late, and there might be many victims; but too early, and the clues might not be very reliable, leading to possible false alarms and subsequent loss of trust (Pearson 2012; Geleta 2013).
- (Attansey 2012) also found that individuals might get desensitised after multiple occurrences of floods, and that communication has a role to play to maintain vigilance
- Other studies have shown the importance of communication in all sorts of disasters (REF BUSHFIRES HICSS) (De Boer, Wouter Botzen, and Terpstra 2014) communication should address the motivations of people to trigger prevention responses
- but also its difficulties, where the population's actual reaction does not always match what is recommended and expected by the authorities, for different reasons (Alan Rhodes 2014)
- reasons why people fail to act appropriately (Parker, Priest, and Tapsell 2009): lack of understanding, mistrust in authority, or not knowing what actions to take
- Investigated reasons include social attachment (making gathering with one's family more important than saving one's life (Bangate et al. 2017); cognitive biases (Murata, Nakamura, and Karwowski 2015; Arnaud, Adam, and Dugdale 2017); lack of personalisation of communication (Adam and Gaudou 2016); but also lack of trust in received messages, or lack of training about probabilistic information and risk communication
- There is therefore a misunderstanding between stakeholders: the population is persuaded that the weather forecasters do a poor job, without realising the underlying difficulties; and the weather forecasters do not understand why the population will not listen to the warnings.
- In such a situation, role-playing games have shown their interest for changing people's perspective and letting them understand other points of view (Bowman 2014). Indeed, as suggested by Shubik (Shubik 1971) "in many of the uses of gaming *seeing the other individual's point of view* by role playing his position appears to be of value" (p. 6).
- Our goal here is therefore to propose a role playing experience where the general public can take the role of a weather forecaster having to set the rain-flood vigilance level, and observe the reactions of a simulated population.

- We propose a serious game called **VigiFlood** where the player has to take on the role of an emergency communicator setting the level of vigilance based on uncertain weather forecast; they get feedback about the effect of their actions on the population (trust, evacuation decision). We expect this change of perspective to let the players gain awareness about the difficulty of flood risk prediction and communication (in line with (Bowman 2014) "Enhanced awareness of other perspectives"), and subsequently lead to a change in their own behaviour.
- We have implemented a first prototype of this serious game **CITE ISCRAM**. The game is based on a multi-agent model grounded on psychological and sociological theories, and on real hydrological and meteorological data from the geographical area. A first version is implemented, but improvements are still ongoing.
- We have also designed an online questionnaire to measure the objective impact of this change of perspective on the players' awareness of the challenges of flood risk communication. Concretely, we measured the players' risk awareness, trust, consciousness of their own responsibility for action, and protective actions intentions, both before and after playing the role of a weather forecaster. The first results show an improvement in these values, suggesting that such a serious game has an interest in raising awareness in the population and improving communication and prevention in case of floods.
- As a kind of "market research", we have also questioned the players about their opinion on the subjective interest of the game, and their will to see it implemented in their town or in schools. With no surprise, our first prototype is not engaging enough, but people are willing to see such a tool (or an improved version of it) implemented on the field. This is encouraging us to pursue research on this path.
- **This paper is structured as follows: TODO NEW OUTLINE** This paper is structured as follows. Section 4 introduces the context: flash floods, the French vigilance system, and our case study. Section 3 provides the reader with an overview of related literature in different areas: crisis communication, trust and risk theories, agent-based models of natural disasters, and serious games. Section 5 describes Vigi-flood, the underlying agent-based model, the implementation, and the game principles. Section 6 is the core contribution and presents our evaluation of Vigiflood, the questionnaire design, its ethical validation, and the results obtained from an analysis of 80 answers gathered during the month of June 2019. Finally, Section 7 concludes and discusses future prospects of this research. **update outline, sections 2-3 interverted**

2 Simulations and serious games

In this paper we want to provide a solution to improve communication and trust around flash flood risk in flood-prone areas. Our approach is to provide a computerised serious game offering a change of perspective to players from the population. This serious game is based on an agent-based simulation of the reaction of the population to the flood vigilance messages received. This section defines the concepts and reviews existing research in this field.

2.1 Agent-based simulations

Agent-based social simulations (Bonabeau 2002) are a computer science approach modelling the behaviour and interactions of autonomous entities called agents, each representing a human individual, in order to study the resulting behaviour of the global society. It is a very useful tool to understand the behaviour of a complex

system as emerging from the individual behaviours of its members, for instance how a crowd evacuates from a building, or how traffic jams appear on a busy road.

Axelrod ((Axelrod 1997)) defines 7 purposes of simulations, including **prediction** (simulate a system very realistically to predict its future behaviour, *e.g.* meteorology), **training** (provide a believable interactive environment to rehearse actions, *e.g.* flight simulator), or **education** (let the user learn by trying in a virtual world). Predictive simulations require a high degree of realism to lay valid predictions, while training and education simulations can be simpler and less realistic (they “need not be rich enough to suggest a complete real or imaginary world”). Besides, Axelrod also claims that “the simpler the model, the easier it may be to discover and understand the subtle effects of its hypothesized mechanisms”; educational simulations are therefore often quite simple.

Computer simulations allow to explore completely controlled scenarios, to repeat them as many times as necessary, at no cost and with no stakes, in order to gain simulated experience. As a result of such advantages, computer simulations have often been used in crisis management (Murakami et al. 2002) for various purposes. For instance (Yang et al. 2018) provide a very realistic model based on field data, to **predict** the impact of early warnings on population behaviour in terms of reducing material losses from floods. Others focus on realistically modelling the physical flood phenomenon in order to **support decisions** regarding early warnings for tsunamis (Friedemann et al. 2011), based on data from multiple sensors (Behrens et al. 2008).

Other simulations focus on communication, but not necessarily during floods. (Arru, Negre, and Rosenthal-Sabroux 2019) study if the population should be alerted or not of an ongoing crisis (*e.g.* terrorist attack), depending on the anticipation of their potential reaction (*e.g.* crowd panic), which is based on a psychological model. Since events considered are ongoing, they do not deal with false alarms and their potential impact on long-term trust. (Adam and Dugdale 2018) study the propagation of awareness in the Australian population after a bushfires warning, depending on its channel and (familiar vs unfamiliar) source. Since they consider a single event, they do not deal with long-term dynamics of trust over multiple (right and wrong) alerts.

Computer simulations are often designed and implemented by computer scientists, and then used on the field. Participatory simulation (Becu 2020) is an approach where the stakeholders or users are invited to participate in the entire process of designing, modelling and simulating a given problem. This co-construction lets participants share knowledge and points of view. This approach is very adapted to environmental stakes or urban planning, to accompany discussion between scientists, deciders and citizens.

2.2 Serious games

Clark Abt coined the term of “serious games” in 1970 (Abt 1970; Djaouti et al. 2011). This American researcher worked on computer simulation games for military training during the cold war, and supported the potential of games for serious applications, in particular for education. He defines serious games as games that “have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement” but insists that this does not and should not prevent serious games from being entertaining. He reviewed many examples of such serious games on various formats: board games, card games, outdoor games, or computer games, which we focus on here.

An important advantage of serious games compared to more traditional educative approaches is to favour the learners’ engagement (Garris, Ahlers, and Driskell 2002; Boyle et al. 2016). For instance (Burke et al. 2009) have obtained encouraging results when using video games to solve disengagement problems and motivate patients to stick with intensive and repetitive rehabilitation exercises. Many serious games are specifically targeted at children. It is argued that children are often more enthusiastic, motivated to learn, and receptive to new ideas (Izadkhah and Hosseini 2005) (p. 142). Besides, they are a good channel to reach (and convince) their parents, and spread the ideas to the wider society (Barreto 2014) (p. 19). (Fitzgerald et al. 2000) (p. 1) confirm that it is better to develop an active (rather than fatalistic) mind-set about disaster risks at an “early

age”, and a culture of prevention takes time to form. However, engaging children requires engaging their teachers first.

In crisis management and disaster prevention, serious games are often used to teach appropriate behaviours or to train deciders (see (Di Loreto, Mora, and Divitini 2012) for a review). Indeed, they are a good way to make the population aware of their responsibilities, and to promote their active participation, compared to more traditional or vertical approaches of imposing knowledge (Yamori 2012). For instance these authors have developed Crossroad, a card game for tsunami prevention in Japan where the players have to find their own viable solutions to social dilemmas, rather than accepting externally prescribed solutions. (Horita et al. 2014) also study the use of gamification to improve community knowledge, awareness and resilience in case of disasters; they have developed an online platform to foster collaboration.

Some serious games focus on communication. For instance (Adam, Bailly, and Dugdale 2019) proposed a serious game for trying various communication strategies to alert the population (focused vs wide targeting, information vs recommendations) before and during bushfires in Australia, but they do not deal with the timing of alerts nor the impact on trust. Indeed, they report no habituation phenomenon to fire alerts, which could be due to the easier predictability of fires compared to flash floods, or to normative and cultural differences.

Several serious games exist that address floods, with different targets and different formats. Anycare is a table-top role-playing game to involve stakeholders (Terti et al. 2019), and requires some organisation, a lot of time and an animator. LittoSIM (Becu et al. 2017) is very realistic and aimed at emergency managers; SPRITE (Taillandier and Adam 2018) teaches risk management to engineering students; however both games focus on longer-term management and protection against coastal submersion (*e.g.* building dykes) rather than communication.

2.3 Role playing

In serious games, the player can take their own normal role, an imaginary role (invented for the game), or another existing role. This change of perspective is a powerful tool to get people to understand the specific point of view and challenges of a different role, and can make it easier to accept decisions made by that role. Shubik (Shubik 1971) supports the usefulness of role playing a different position in order to understand another individual’s point of view. Also of benefit in his view is the ability for participants to watch how stakeholders make their decisions in the game. This suggests that observing people playing can also be of interest, and that not only the players themselves learn from the game. This is also in line with Bowman’s findings, that a “shift in perspective provides players with the opportunity to understand the motivations of others more clearly” (Bowman 2010), and that “the adoption of a role contributes to a greater awareness of one’s own perspective, but also leads to an increased understanding of the perspectives of others” (Bowman 2014).

Existing simulators are often aimed at training or supporting decisions of emergency managers. Here we adopt a different approach where we propose a serious game aimed at changing the population’s perspective by letting them play the role of an emergency manager confronted with difficult decisions. Our game will provide the players with feedback about the reaction of the simulated population. In order to make this simulated population representative of reality, the underlying model is grounded on literature from psychology and sociology, as discussed in the next section.

3 Related research

define the concepts measured later: awareness, self-efficacy, vigilance, protective actions = the goal of crisis communication - explain how/why these work ground our model, and how selected?

In order to simulate them accurately, it is essential to understand how people interpret crisis communications, what determines their trust, how they evaluate risks, and what motivates them to take protective actions before a possible natural disaster. Below we review related literature studying how people react to official crisis communication. This will provide the theoretical basis for modelling how the artificial population in Vigiflood reacts to the player's decisions in terms of communicating vigilance.

Communication is essential to maintain vigilance, etc. As a results, emergency managers are trained about efficient crisis communication,

Dans les faits, cet état de l'art n'est pas utile, à part à montrer que les décideurs sont formés à la communication de crise, mais pas la population à comment l'interpréter. VIRER ces paragraphes ! en ajouter sur la culture.

3.1 Crisis communication

Reynolds ((Reynolds 2010)) identifies 6 principles of efficient crisis emergency and risk communication (CERC): **Be First** (in times of crisis, people need information fast, and will often stick with the first source they get information from); **Be Right** (information should be accurate and transparent, explaining what is known or not, and what is being done to get more information); **Be Credible** (communicators should be honest and trustful, and avoid to promise what they cannot deliver, at the risk of losing the public's trust); **Express Empathy** (communicators should acknowledge the population feelings and challenges to build trust and a good relationship); **Promote Action** (messages should not only be informative but also action-oriented, to empower the population, give them a feeling of control, and release their anxiety); and **Show Respect** (communicators should account for the vulnerability of people during crises, their messages should be respectful and promote cooperation and rapport).

We believe a serious game such as Vigiflood could be used by weather forecasters to train and apply the above principles. However, our goal is rather to raise awareness in the population of the challenges faced by crisis communicators, and the way they react to the messages and evaluate risk subjectively.

3.2 Risk perception and evaluation

On the population side, receiving these messages does not mean understanding them. Indeed, risk perception and evaluation is highly subjective and emotional.

(Infanti et al. 2013) review the literature to explain the “complex and unpredictable ways that individuals perceive risk”, and find that risk communication is influenced by socio-cultural, environmental and linguistic factors. Covello *et al.* ((V. Covello and Sandman 2001; V. T. Covello 2003)) identify 4 factors of risk communication. First, **risk perception** is subjective, influenced by socio-cultural and cognitive factors (*e.g.* the individual feeling of agency or control). Second, **mental noise** created by stress and threat reduces the ability to process information: technical and scientific concepts must be “translated [...] into understandable messages”, which should be visual and repeated. Third, upset people focus more on negative (losses) than positive (gains) information (this is called **negative dominance**), so communication must counter-balance negative messages with many more positive, action-oriented messages, and focus on progress rather than failures. Fourth and last, upset people tend to not **trust** authority, so trust must be created well ahead of any crisis, through proactive community communication.

Further, (Hurnen and McClure 1997) discuss the importance of the locus of control of individuals: if **external** (*i.e.* they believe they have no control) they will feel helpless, and be less likely to take preventative action or react to warnings than if **internal** (*i.e.* they believe they can do something). This is in line with the CERC principle to 'promote action' and give people something to do so that they feel (more) in control. Similarly, (Khan, Crozier, and Kennedy 2012) discusses the lack of response of the population when the perceived risk

is either too high (fatalism) or too low (“blasé effect”): in both cases, people feel powerless. He concludes by recommending to pay careful attention to the level of risk that is communicated to the population in the warnings to avoid undesirable reactions or inertia.

The American Center for Disease Control and Prevention issued a report about Crisis and Emergency Risk Communication (Reynolds and Seeger 2014) focusing on specific psychological factors of information processing during a crisis, and how messages should be adapted subsequently. First, people **simplify** messages, might not hear, not remember, or misinterpret them; logical reasoning is impaired and decisions might rely more on habits, routines or imitation; messages should thus be simple. Second, people **hold** on to their current beliefs, and prefer trusted and familiar sources of information even if inaccurate and non-expert, to reputable experts who might disagree with each other; messages should therefore come from credible sources. Third, people try to **confirm** information before acting, via complementary information and additional opinions; messages should therefore be consistent between the different channels. Fourth, people believe the **first** message, and compare any further message with it; lack of information creates anxiety, speculation and rumors; accurate messages should therefore be released as early as possible.

These findings are also in line with research showing the importance of cognitive biases in disasters (Murata, Nakamura, and Karwowski 2015; Arnaud, Adam, and Dugdale 2017). (Attansey 2012) also found that individuals might get desensitised after multiple occurrences of floods, and that communication has a role to play to maintain vigilance. **TO KEEP**

3.3 Trust and risk

According to Slovic ((Slovic 2016)), risk management has become much more “contentious”, with risk managers blaming the public for being irrational, and the public blaming the stakeholders for their poor management. In his view risk communication, aiming at aligning population and experts’ perceptions with experts, has failed due to the lack of trust: “if trust is lacking, no form or process of communication will be satisfactory” (p. 410).

Slovic also explains that trust is “fragile”, builds up slowly but can be destroyed instantly and is then hard or impossible to regain (p. 319). He provides several reasons for this asymmetry:

- Negative events are more visible than positive ones (one missed alarm stands out in many days of correct predictions);
- Negative events have more weight because they have lower probability and higher consequences (a flood is rarer than a “normal day” and can do serious damage);
- The media also tends to give more coverage to bad news than good news;
- Sources of bad news are seen as more credible, less likely to lie, than sources of good news;
- Distrust strengthens itself, by limiting further interactions and biasing future interpretations towards the reinforcement of existing (distrustful) beliefs.

3.4 Culture

Section 3 would benefit from a subsection on culture and behavior in response to risk and threat. Readers may wonder to what extent VigiFlood is culturally portable. –¿ it is not as it strongly depends on the French vigilance system (detailed in section XXX)

3.5 Conclusion

NEW HERE Our approach of proposing a serious game is therefore also in line with the risk communication principles advocating transparency and empowerment of the population (Reynolds 2010), a field currently lacking research. Our claim is that such a game will improve the population's awareness of the difficulty to predict and announce natural disasters, and of their own responsibility to react despite a certain rate of (unavoidable) false alarms.

4 Context

MOVED for R1 but not sure it fits better here... I believe exposing the problem should come before exposing its solution... UNLESS this case study is selected as one particular illustration of a more general problem exposed in introduction.

4.1 Flash floods

Flash floods generally occur due to rapid rain on an already saturated soil (after a particularly wet period) or on a soil with a poor absorption capability (such as concrete, as is often the case in urbanised settings), or due to extensive rain because of a storm or hurricane. They can also occur from more occasional events such as a glacier melting after a volcanic eruption, an ice dam melting, or a man-made dam failing. In this paper we focus on rain-induced flash floods, whose prediction depends on the meteorological services. The indicators used by forecast services include: forecast quantity of rain (radar or satellite or model based), soil absorption capacity, soil moisture or dryness level, topography, basin or catchment capacity, etc (CEPRI 2008).

SOME FIGURES - (Svetlana, Radovan, and Ján 2015) : floods are the most common natural disasters and represent 40% of all natural disasters between the years 1985-2009 (Cunado and Ferreira, 2011 in Soukopová, Furová, 2012). - Using data compiled according to the Red Cross for the period 1971-1995 we find that the floods have killed annually on average more than 12,700 people worldwide, affected 60 million others and caused 3,2 million people to become homeless (Kundzewicz, 2004). Since 1990, there have been over 30 floods, in each of which either the material losses exceeded one billion USD, or the number of fatalities was greater than 1000, or both. The highest material flood losses, of the order of 30 billion USD, were recorded in China in the summer of 1998, while a storm surge in Bangladesh in April 1991 caused the highest number of fatalities (about 140 000). Flood damage in Europe in the period 1991-1995 reached the level of 99 billion EUR (EEA, 2001).

4.2 French flood vigilance system

In France, the agency in charge of forecasting the expected amount of rain is Meteo France¹. Weak rain is defined as 1 to 3 mm/h, moderate rain is between 4 and 7 mm/h, and heavy rain is over 8 mm/h. Another agency is in charge of monitoring the main waterways and broadcast their expected height and debit 3 to 6 hours ahead of time: Vigicrues². However, only part of the waterways are monitored, and the European Flood Risk Prevision Center (CEPRI³ notices that half of the 63 victims in the Languedoc-Roussillon region (south of France) alone between 1996 and 2006 died on catchment basins that were not monitored.

¹<http://www.meteofrance.com/previsions-meteo-france/previsions-pluie>

²www.vigicrues.gouv.fr

³<https://www.cepri.net/>

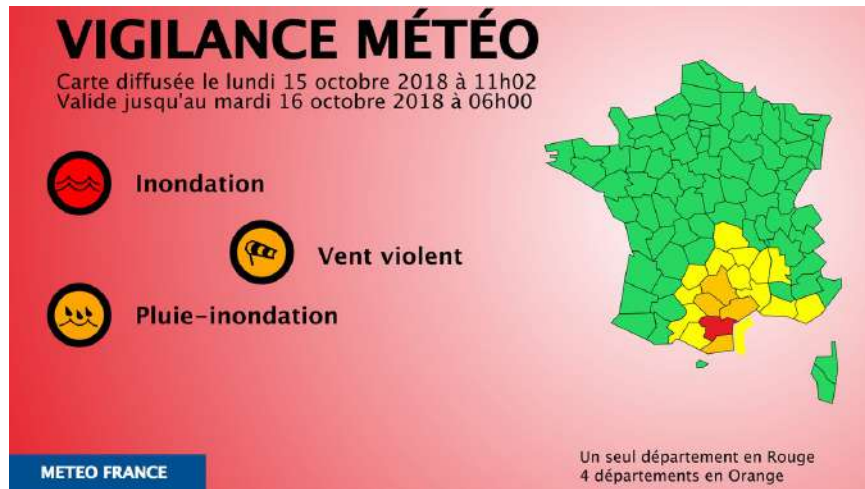


Figure 1: MeteoFrance vigilance map, 15 October, 11am (source: MeteoFrance)

The meteorological services in charge of the area then analyses these clues (rain forecast, waterway height and debit, etc) to define and announce a level of vigilance on a 4-colour scale, from green (no problem), yellow, orange, to red (higher risk). Table 1 gives the official⁴ definition of each level. This level of vigilance is publicly available online⁵ (example map on Figure 1). Each region has its particularities and can be more or less used to receiving heavy rain in a short amount of time, so that the vigilance thresholds are not the same everywhere.

Color	Definition
Green	No specific vigilance needed
Yellow	Be careful; if you engage in activities that are sensitive to the weather or near a shore or stream; common phenomena in the region but occasionally and locally dangerous are indeed predicted; keep abreast of developments.
Orange	Be very vigilant; dangerous phenomena are predicted; keep abreast of developments and follow the safety advice issued by the government.
Red	Absolute vigilance is required; dangerous phenomena of exceptional intensity are predicted; keep abreast of developments and be sure to follow the safety instructions issued by the government.

Table 1: Official definitions of flood vigilance levels (translated from Meteo France)

4.3 Over-alerting (false alerts) vs under-alerting

TODO: discuss false-alert vs under-alert, and the official probabilities allowed, from MeteoFrance quoted in Le Monde - transition to next section. over-alerting considered less risky in immediate lives lost (so 15% allowed) but can be risky over the long-term if the public loses trust; this is what we want to illustrate with the following case study. TODO TODO

⁴Translated from French from: <https://vigilance.meteofrance.com/html/vigilance/guideVigilance/vigilance.html>

⁵See: <http://vigilance-public.meteo.fr/> or <http://vigilance.meteofrance.com/>

4.4 Case study: Aude floods, October 2018

The Aude department in France (see map on Figure 2) depends on the CNP center in Toulouse; its critical rain threshold for the orange vigilance is 50-100 mm in 24 hours, with a regional record of 551 mm in 24 hours. On Sunday 14 October 2018 the meteorological station of Carcassonne received 139.8 mm of rain. The vigilance level was initially set to orange due to high uncertainty, then raised to red Monday 15 October morning at 6am. In the meantime, several towns were already flooded, roads and bridges destroyed, and some people had died. The final toll of these floods in the Aude department is 15 dead and 99 injured people, 204 towns classified as hit by “natural disaster”, and a total cost of damages estimated to 220 M€.



Figure 2: Map of the flooded area, with victim counts, and evacuated towns. Source: Préfecture de l’Aude

As a result, MeteoFrance vigilance system was harshly criticised in the media (Libération-AFP 2018). The representative of the Ministry of the Interior, Frédéric de Lanouvelle, interviewed on LCI-TV, evoked a “*weakness in the orange vigilance level which is used very often and when there is a real problem, people do not take it into account anymore*” (our translation). He adds that based on residents’ statements, the red vigilance level was indeed raised too late, but explains it is due to the difficulty in forecasting such a powerful episode.

ONGOING MODIF - repeats intro? This was felt as too late, despite the orange vigilance bulletin being already very clear.

However, as noted by the Major Risks Institute (IRMA) (Gominet 2018), there had only been 3 orange vigilance raised in 2018 in the Aude department for rain-floods before October 14: January 7-8; 28 February and 1st of March; and the last one on October 9-10, immediately following an orange vigilance for thunderstorms on October 8-9. Besides, this last episode probably influenced the dramatic floods of October 14-15 by saturating the soil with water. (Gominet 2018) therefore concludes that the general public must be made aware of their responsibilities, and be taught that several orange vigilance events in a row should make them particularly vigilant, instead of the opposite, dismissing the last vigilance because nothing serious happened during the previous ones.

TODO transition to model - Section 5 presents our game, before Section 6 describes the evaluation that we conducted to validate this claim.

5 VigiFlood

The VigiFlood serious game is based on a conceptual agent-based model of human behaviour in flash floods. The validity of the underlying behaviour model is ensured by its grounding on psychological and sociological theories of trust and risk communication described above. The physical model of flood on the other hand need not be extremely realistic to reach an educational goal, in line with (Axelrod 1997). This conceptual model has been described in (Adam and Andonoff 2019); the section provides a quick overview of the conceptual model and its implementation, before we proceed to describing its evaluation and concrete use, which are the core contributions of the current paper.

EXPLAIN BETTER how it is related to the literature reviewed above

5.1 Underlying conceptual agent model

Our approach is to use an agent-based model of the population and their reaction to their environment (vigilance level, observed meteorological events). This section describes the agents representing the residents: their attributes, how they subjectively evaluate risk, how they update their trust, and how this subsequently impacts their behaviour.

5.1.1 Attributes

The population is composed of a number of heterogeneous resident agents, that have the same attributes but differ by their values:

- Subjective risk (can be over-estimated or under-estimated compared to -inaccessible- objective risk)
- Risk aversion threshold (what level of risk they can tolerate before they choose to evacuate)
- Trust in vigilance messages (how much they believe the level of risk announced by the authorities)
- Memory depth/experience (how many past flood or vigilance events they remember)
- Risk evaluation strategy (how they evaluate risk based on these events, in line with psychological theories saying that humans evaluate risk based on previous experience and emotions (Reynolds and Seeger 2014))

5.1.2 Subjective risk evaluation

Residents receive vigilance alerts, which indicate an 'official' level of risk, but not all residents equally believe in this level of risk. Indeed, each resident first subjectively evaluates risk (*i.e.* expected rain) based on their **memory depth** and on their **risk evaluation strategy** which reflects their personality:

- Optimistic (consider the minimum amount of rain observed during past events where the same vigilance colour was raised; if a false alarm was raised in the past this can lead to expect no or very little rain);
- Pessimistic (consider the maximum amount of rain; this is very forgiving to false alarms);
- Rational (consider an average of observed rain on remembered past occurrences of the same vigilance level);
- Short-memory (consider only the last occurrence; this simulates the loss of risk memory observed over time when no significant disaster happens (Fanta, Šálek, and Sklenicka 2019)).

5.1.3 Interleaving with trust

Trust and risk are interleaved:

- Trust mediates subjective risk assessment: each resident's ponders their personal risk assessment vs the official communicated risk based on their (dynamic) level of **trust** in the vigilance alerts. Concretely, if trust is 100%, the resident will fully trust the official risk and expect exactly the amount of rain corresponding to the vigilance colour; if it is 0% they will fully trust their own judgement and expect exactly the subjective value resulting from their past experience.
- Residents then observe real rain and compare it with their expectations. If they are surprised by the actual amount of rain (either because it is higher or lower than expected / announced), their trust in the forecast will decrease (more if a flood was un-announced than in case of false alarm; and more for higher impact events). On the contrary if the observation is in line with expectations, trust will only slightly increase, as this is judged as being normal.

5.1.4 Biased decision making

Finally the residents' decision to evacuate early is based on the comparison of their subjective risk value with their personal risk aversion threshold. They can also evacuate after directly observing high amounts of rain (exceeding their aversion threshold), but this often happens too late, hence the importance of maintaining trust in pre-flood warnings. Loss of trust pushes residents to neglect the official communicated risk, which can lead to two opposite situations:

- After false alerts, personal risk assessment is low (memory is full of events with high vigilance but low rain); neglecting official risk conduces to under-estimating risk. Potential consequences can be serious: failure to prepare and evacuate in time.
- After missed alerts, personal subjective risk assessment is high (memory contains events with low vigilance but high rain); neglecting official risk conduces to over-estimating risk. Potential consequences include over-reacting, which can be costly if it is not a resident but a stakeholder (mayor, etc) who takes unnecessary measures.

5.2 Game interface and gameplay

TODO: easy narrative to put first, before giving technical details + GIVE MORE screen captures

The conceptual model described above was implemented in Python in the form of a serious game (the game presented here is a slight extension of (Adam and Andonoff 2019)). The idea is that the player takes the role of risk communicator, having to decide the vigilance level (color between green, yellow, orange, red), based on uncertain clues (rain forecast). Their actions influence the population, whose trust and subjective risk level evolve over time, and who might or might not evacuate when floods are announced; they can also trigger various events simulating the reactions of institutional actors to the vigilance level (closing schools, stopping school bus services, closing roads, etc) and the impact of rain or floods on the environment (collapsed bridge, etc). The player can observe the impact of their actions through various information panels. The following paragraphs detail the interface of the game and its different phases.

5.2.1 Interface

The interface (shown on Figure 3) comprises several parts.

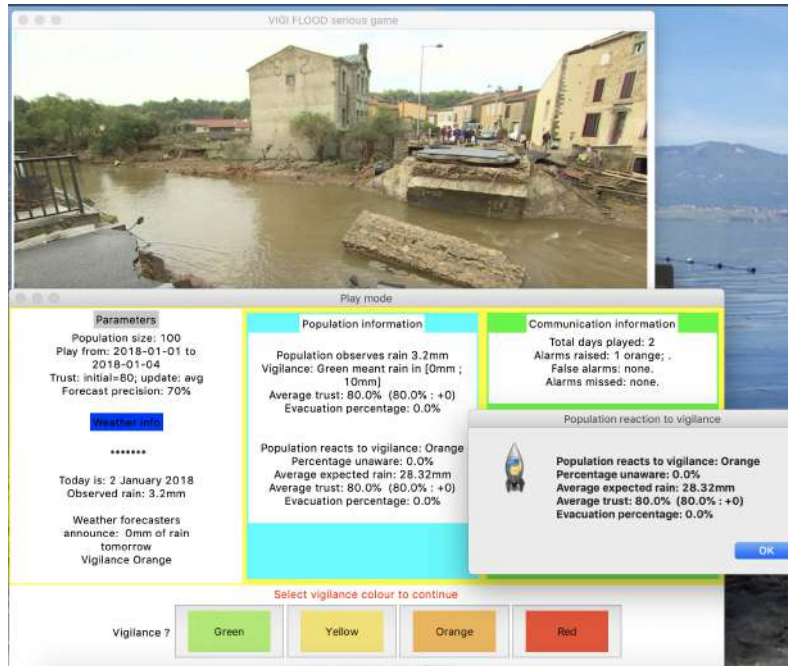


Figure 3: Screenshot of the game interface

- Weather tab: reminds the date, the observed rain, the forecast for the next day (mm of rain), and the announced vigilance colour.
- Population tab: details average subjective risk (expected rain) per vigilance colour, average trust in vigilance messages (with its last evolution), percentage of population that is unaware of risk (subjective risk is lower than objective risk), and evacuation percentage.
- Communication tab providing communication statistics: number of days played, and for each colour: number of vigilance days, number of false alarms (raised, but observed rain was lower than expected/ announced), number of alarms missed (not raised, and observed rain was higher than expected/ announced).
- Vigilance level selection buttons (green to red)
- Popups to display events triggered by the player's actions

5.2.2 Game phases

The game loop proceeds as follows:

1. The date of the day is displayed, as well as the observed amount of rain that day (in mm).
2. The residents react to the observation of the rain: they compare it with the current vigilance level (set the day before) to update trust, and they might evacuate if needed.
3. The player is provided with feedback about the population: average trust and its explanation (in terms of how much rain they expected based on the vigilance colour); and percentage of evacuated residents.

4. The weather forecast service announces a forecast amount of rain for the next day.
5. The player is asked to set a vigilance colour based on this forecast.
6. The population reacts to this vigilance level: compute subjective expected rain based on previous similar alerts, and might evacuate if this is above their risk aversion threshold;
7. The player receives feedback about the population's risk awareness percentage; their average expected rain (in mm); their average trust (in %); and the percentage that evacuated as a result of the alert.
8. Daily rain and vigilance are stored in game history, time moves forward to the next day.

5.3 Scenarios and data

The game can be played either with a realistic scenario using actual rain and vigilance data, or with a generated pedagogical scenario that places them in specific intended situations aimed at testing their reactions. The advantage of the generated scenario is to accelerate the game and control the desired pedagogical sequence. Real data was extracted with Python scripts, from public meteorological archive websites.

- Rain data from Infoclimat⁶, which provides archives of daily, monthly and yearly meteorological data (temperatures, wind, rain, etc) since 1973. We focused on Carcassonne-Salvaza, a meteorological station of the town of Carcassonne, the prefecture of the Aude department that was the most impacted by October 2018 floods. We extracted the following data for the years 2010-2018: normal monthly rain (seasonal norms computed by Infoclimat between 1981-2010), number of days of rain (at least 1 mm) per month, and actual daily readings of rain amounts.
- Vigilance data from Vigilance Public Meteo⁷ which provides maps and details of daily departmental vigilance alerts: time, level (green, yellow, orange, red), emitting agency (each covering a different region; Aude department depends on the CNP agency in Toulouse), and phenomenon concerned (floods, high winds, waves and coastal submersion, snow and black ice, etc). We extracted the daily rain and floods vigilance colours for the Aude department between 2010 and 2018 (green if no bulletin; higher colour if multiple ones).

6 Experimental evaluation

The game described above is designed to induce a change of perspective, where normal residents are put in a decider's shoes and faced with the responsibility to set the vigilance level themselves. Our **hypothesis** is that this change of perspective should improve users' awareness of the difficulty to set vigilance without mistakes, and of their own responsibility for being vigilant. As a result, we also expect a shift of behavioural intentions towards more protective actions. In order to test these hypotheses, we have designed a questionnaire simulating the game, and administered it online in order to reach a wide audience. **research question rather than hypothesis???**

The following paragraphs describe the questionnaire, the recruitment of participants, and the results along 2 axes: how the participants (subjectively) judged the game; and the (objective) impact that the game had on their awareness and intentions.

⁶Infoclimat: <https://www.infoclimat.fr>

⁷<http://vigilance-public.meteo.fr/>

6.1 Questionnaire

explain how each section relates to the hypothesis under investigation, what is measured The questionnaire is written in French. It was proof-read by a linguist, and validated by an ethics and data privacy consultant. It has also received the agreement of University Grenoble Alpes ethics committee⁸. It is designed to proceed in the following six phases:

1. Assess the responders' previous experience, knowledge of and trust in the French vigilance system.
2. Assess the responders' awareness of risk, challenges, own responsibility; and behavioural intentions in case of floods (before).
3. Change of perspective: exercise of setting vigilance level, in different more or less complex situations, with different clues.
4. Subjective evaluation of the game by responders: interest, usefulness, willingness to use it.
5. Re-assess the responders' awareness of risk, challenges, own responsibilities, and their behavioural intentions in case of floods (after).
6. Demographic questions to categorise responders.

The complete list of questions, translated into English, is available in Annex 1.

6.2 Recruitment of participants

We recruited adult participants by broadcasting the link to the questionnaire via email, through the author's professional and familial networks. The goal was to reach a wide audience, avoiding a classical bias of only testing software with computer scientists and students, and get answers from people with and without flood experience to enable comparisons.

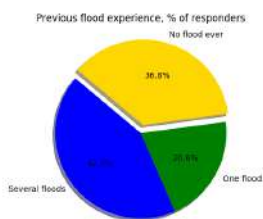


Figure 4: Experience

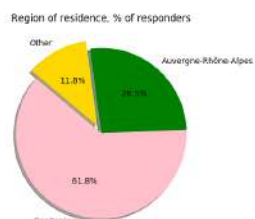


Figure 5: Residence

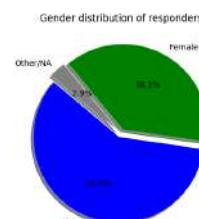


Figure 6: Gender

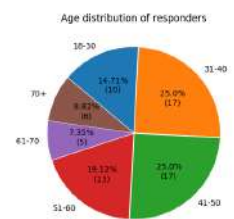


Figure 7: Age

The online questionnaire has received 80 answers. The pie charts in Figures 4 to 7 show that our sample was rather representative with responders from all age groups, slightly more males than females, and having different levels of experience with floods. Due to our mode of recruitment, the responders mainly live in 2 regions: Occitanie (South-West region of France where the October 2018 floods occurred, reached via familial network) and Auvergne-Rhône-Alpes (South-East region of France where the author works, reached via professional network).

⁸Agreement number CER Grenoble Alpes-Avis-2019-09-24-5

6.3 Results: subjective evaluation of the game

MOVE AFTER OBJECTIVE EVAL + explain how connected with our hypothesis: if we want the game to have an impact, it should be played, engaging, interesting. Progress is needed on these aspects. The responders were asked to score VigiFlood (in its simulated version administered via the online questionnaire) on 5 criteria:

- Interest: how interesting was it to answer or play?
- Boredom: how boring is the current gameplay?
- Usefulness: how useful is it to learn about floods, forecast and communication?
- Town training: how willing that such a game would be offered as training by the town council?
- School training: how willing that such a game would be offered to children as part of school programs about natural hazards?

Figure 8 summarises the results in the form of a boxplot diagram: the boxes extend from lower to upper quartile values of the scores, with a line at the median; the whiskers extend from the boxes to show the range of the data; outliers are not shown here.

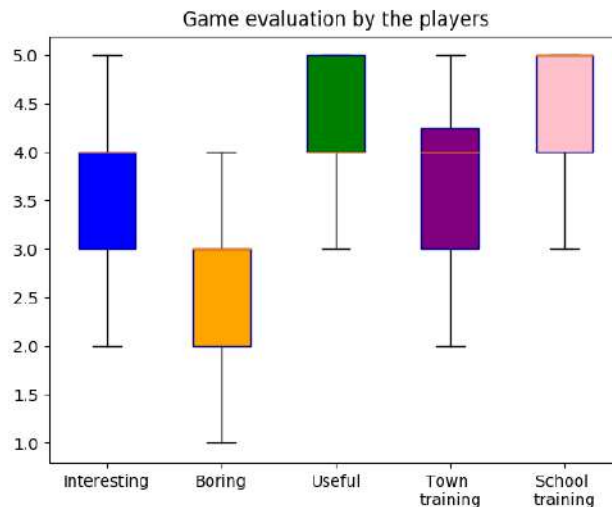


Figure 8: Evaluation of the game (5-point scale scores): interest, boredom, usefulness, willingness to use it for training of town residents (by town council), or for training of school children (by professors).

We can see that responders find the game very useful (avg= 4.18; stdev= 0.98). They are willing to have it offered by their town council as training (avg= 3.79; stdev= 1.08), and even more willing to see it offered to children as part of school programs about natural hazards (avg= 4.35; stdev= 0.84). However, even though they found the concept of the game quite interesting (avg= 3.65; stdev= 1.04), they also judge the gameplay rather boring (avg= 2.51; stdev= 0.95). Future work is needed to improve immersion and engagement with the game. We will also further analyse if these scores are different between people with or without flood experience.

6.4 Results: objective impact of the game

Concepts measured here should be defined first !

THE MAIN GOAL of... Another goal of this questionnaire was to assess how playing the game (or its simulated version) can influence awareness. We measured a number of awareness criteria (risk awareness, awareness of own responsibility, intended actions in case of orange or red vigilance) before (phase 2) and after (phase 5) the change of perspective induced by the core of the questionnaire (phase 3).

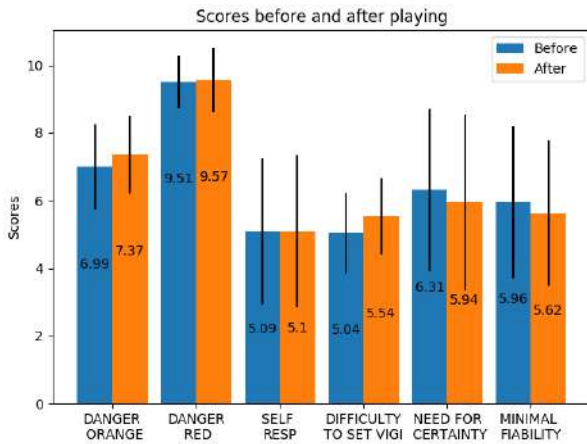


Figure 9: Evolution of awareness scores before/after playing

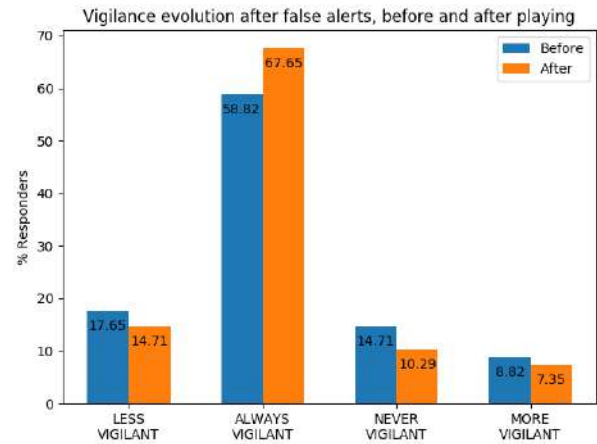


Figure 10: Evolution of loss of vigilance with false alerts, before/after playing

6.4.1 Impact on awareness

Figure 9 shows how awareness scores evolved between before and after the role-playing sequence. We can see that risk awareness increases for orange vigilance (that tend to be ignored when too frequent), which is a good thing. It does not increase for red vigilance, which are probably already alarming enough. The awareness of own responsibility in self protection does not change significantly after the game, probably because the focus was more on the alert phase, and the game does not show actions of the population; further developments of the software will try to focus more on the population side. Finally awareness of the difficulty of setting the right level of vigilance does increase, which we hope should limit the loss of trust induced when the vigilance colour is perceived as wrong.

6.4.2 Impact of 'false alerts' on trust

Figure 10 illustrates the dynamics of population vigilance over multiple alerts. It shows that before playing (blue bars) 17.65% of responders report being less vigilant after what they perceive as a "false alert", while 14.71% report never being vigilant anyway.

This is worrying for several reasons. First, "false alarms" can be quite frequent, because it is hard to predict such phenomena, and because the vigilance is set at the entire department level. Therefore even if a flood does indeed happen locally, it is possible that a large part of the department is spared and left to believe that it was a false alarm. Second, even if it is actually a false alarm and no flood happens this time, intense rain might leave the soils saturated and river levels very high, thus favouring future floods if more rain happens later. As a result, past alerts should increase vigilance rather than decreasing it.

On the figure we can see that after playing (orange bars), the percentage of responders reporting that they would be less vigilant or never vigilant have both dropped, while the percentage of responders intending to be always vigilant has risen from 58.82% to 67.65%.

The survey was administered to many people having recently lived the October 2018 floods, which explains why most users in our sample are already very vigilant. Further analysis is required to compare the dynamics of vigilance in responders with or without flood experience. It would also be interesting to compare with people having a less recent flood experience, as the literature reports how humans tend to cyclically forget about risk until a new crisis occurs.

6.4.3 Protective measures taken

Figure 11 illustrates the percentage of responders taking various protective measures, before (questions in phase 2 of the questionnaire) vs after playing (same questions in phase 5 of the questionnaire). The actions mentioned in the survey are: search information (INFORM); share information (SHARE); prepare house; gather with relatives and family (GATHER); park one’s car on higher ground (PROTECT CAR); evacuate; or do nothing special. In the figure, each bar shows in orange the percentage of responders saying they would take this action when an orange vigilance is announced, and in red at the top the additional percentage of responders saying they would take this action only when a red vigilance is announced. The left part of each bar is before the game, while the right part is after.

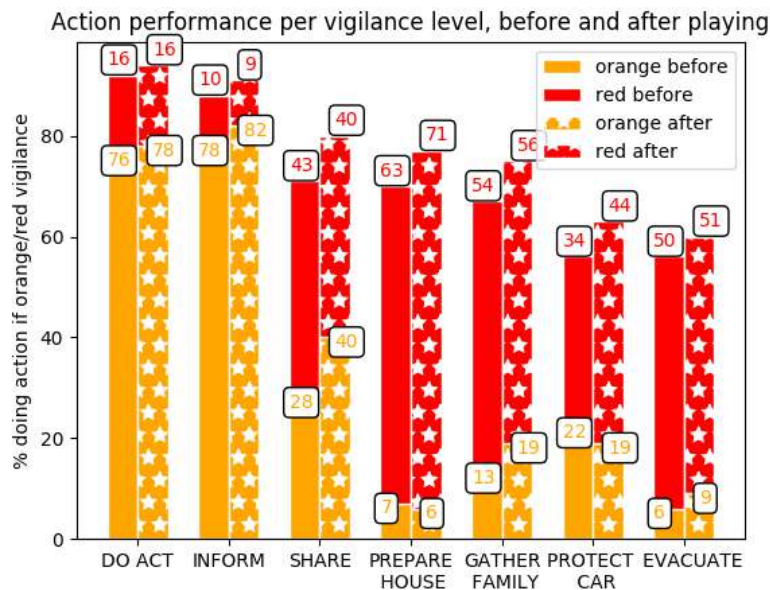


Figure 11: Evolution of actions performed/intended if orange/red vigilance, before/after playing

The left bar measures the percentage of responders doing “something” at all. We can see that about a quarter of the population would do nothing at all in case of orange vigilance (24% before the game, 22% after); very few would do nothing if there was a red vigilance (8% before the game, 6% after). This high level of behavioural intentions is probably due to our sample comprising more people with flood experience than the general population.

The most frequently intended action is to search for information: 78% will try to get more information in case of an orange vigilance, and an additional 10% (so a total of 88%) in case of a red vigilance. These percentages rise to 82% and 91% after playing the game. We see a similar impact on the actions of sharing information, gathering with family, or evacuating (which is mostly envisaged in case of red vigilance). On the other hand, intentions for preparation actions (preparing house and protecting car) decrease slightly in case of orange vigilance, but increase in case of red vigilance.

This hence shows that changing perspective through the questionnaire has modified the intentions of the responders. However, these are only declared intentions, they might be influenced by a willingness to give the “right” or expected answer; they might also be actual intentions but that do not lead to actions once under stress in a real flood situation. In any case, it at least shows an improvement after the game of the awareness of actions that should or should not be performed.

6.5 Conclusion of the evaluation and future work

This survey was intended to show the potential of such a serious game for getting the population of flood-prone areas to change perspective. Since the software is still under development, and to allow for a wider participation in different regions, it was decided to run the survey online via a questionnaire that simulates the intended functioning of the Vigiflood game. This is a first limitation, since we evaluated a slightly different process than that of the actual game. However, we believe that both versions do induce the same change of perspective, which is the key element of our approach.

The survey measured the impact of this role-playing exercise on the users’ awareness, trust, and protective actions intentions. Our results show a positive impact on these indicators, which is encouraging. Another limitation of this survey comes from our sample of responders. Only people who felt concerned with floods and motivated by the topic would take the time to answer the survey, given its repetitiveness and lack of engaging features. We hope that the final software, once we make it less boring and more immersive, will do even better in allowing the users to change perspective and to gain insight about flood risk communication. The gameplay design and implementation will be subject to future work, before we can use this serious game with high school students.

Further analysis will also be performed on the answers, for instance to categorise the users’ risk evaluation strategies (what strategy do they use to choose a vigilance level), or to compare answers of different profiles of responders (with or without flood experience; by age or gender; etc). This should lead to a better understanding of the population’s subjective risk analysis and the factors influencing it.

Overall, what is missing from this analysis is what it all means and the implications. It does not seem like the game produced much effect at all. Can you characterize this more? Section 5.5 gets at this issue a little, but more should be said. How do your findings, for example, relate to the findings of other game-oriented studies (see Yamori’s work)? What is the significance of your findings? What are the implications?

PROBABLY the lack of engagement in the game impedes more visible effect

7 Conclusion and prospects

In this paper we presented Vigiflood, a serious game for raising awareness about the challenges of flood risk communication. It relies on an agent-based model of the population’s trust and decisions, itself grounded in psychology and sociology of human behaviour. A first prototype of the game is implemented and functional. It lets the player choose the flood vigilance colour (green, yellow, orange, red) based on the weather forecast (generated from real meteorological data extracted from archives for the target area). It is therefore a role-playing game where the users (residents in flood prone areas) take on a different role in the game (that of

weather forecasters) than in real life. The main idea behind this game design is that the change of perspective induced by playing a different role will lead to a better understanding of the difficulties of this role, specifically here the challenges of announcing the “right” level of vigilance.

The main contribution of this paper is the evaluation of the concept of the game. We ran an online survey replicating the role-playing part of the game, preceded and followed by questions evaluating the user’s awareness of risks, understanding of difficulties, vigilance, and behavioural intentions in case of flood risk. This evaluation shows encouraging results, where the change of perspective does induce better awareness of risks, more protective actions intentions, and better vigilance and trust in the forecast. However, only very motivated users would answer the survey or play with the prototype, due to its boring and repetitive design. More work is needed to improve the game design and playability, in order to allow Vigiflood to be played by the general public, and in particular by high school students. This is essential to guarantee that this serious game can have an actual beneficial impact during future flood events.

The underlying population model can also be turned into an interactive simulator to train weather forecasters to take the subjective reactions of the population into account when announcing a forecast. This alternative version of Vigiflood is also under work **in collaboration with Meteo France**. At a time when more and more floods are expected to happen in some parts of the world (Roudier et al. 2016; Kerr 2007; Schiermeier 2011), we believe that agent-based simulation can provide very useful tools to train and educate both the population and the deciders in order to reduce impact of these floods.

Acknowledgements

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Annex1: list of questions (translated from French)

- Phase 1: experience, awareness and trust
 1. Have you experienced floods before?
 2. Did these floods affect your residence?
 3. Were these floods announced in advance?
 4. Did these floods require your evacuation?
 5. Do you know about MeteoFrance vigilance system?
 6. Do you know about Vigicrues monitoring website?
 7. Do you trust these meteorological forecast in case of floods?
 8. Do you trust the local authorities to warn and protect you in case of floods?
- Phase 2: awareness of risk, challenges, and self responsibility; intended actions (BEFORE)
 9. Who do you think is responsible for your information and protection in case of floods?
 10. How easy/hard do you think it is to announce the right level of vigilance?
 11. What information do you think the authorities rely on to set the vigilance level?
 12. How important is it to be certain of a forecast before announcing a vigilance level to the population?
 13. What is the minimal reliability required before announcing a level of vigilance?
 14. In your opinion, what level of danger does an orange flood vigilance indicate?
 15. In your opinion, what level of danger does a red flood vigilance indicate?
 16. In case of orange/red flood vigilance, what do you do? (check all actions among: search information, share information, prepare house, gather with relatives, park car higher, evacuate, nothing special)
 17. During the last 2 orange vigilances, there were no flood in the end. What is your reaction to the next orange vigilance? (trust it anyway, distrust it anyway, trust it more, trust it less)
- Phase 3: change of perspective, setting vigilance in different situations:
 18. Series of questions of the form: the weather forecast services announce XXX mm of rain with a confidence index of XXX %. Which vigilance colour do you wish to announce?
 19. Series of similar questions with additional contextual elements
 20. Series of similar questions with additional information about previous false alarms and population trust
- Phase 4: evaluating the game (rate on a 5-point scale):
 21. Such a game would be interesting to play
 22. Such a game would be boring and repetitive
 23. Such a game would be useful to learn and understand the vigilance system
 24. You would like your town council to offer such a game as part of its flood risk prevention plan
 25. You would like schools to offer such a game to children as part of their program about natural hazards
- Phase 5: re-assessing awareness and intentions (AFTER):
 26. Same questions as in phase 2
 27. Have you discovered new criteria for the definition of the flood vigilance level that you had not considered before? If yes, which ones?
 28. Free comments
- Phase 6: demographic questions: region of residence, age, gender, job (if related with weather forecast or depending on weather conditions)