Exploring multiplexing tools for co-visualization in crisis units

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ABSTRACT

Natural hazards can generate damages in large inhabited areas in a very short time period. Crisis managers must plan interventions very quickly to facilitate the arrival of the first emergency. In a crisis unit, experts visualize heterogeneous visual representations of spatio-temporal information, in order to facilitate decision-making, based on various types of screens, i.e. laptops, tablets, or wall screens. Visualizing all this information at the same time on the same interface would lead to cognitive overload. In this paper, we assume that it could be of interest to provide innovative co-visualization models and tools, to bring hazard, geospatial and climate information together, in a shared interface. We propose to explore spatial and temporal multiplexing tools within a dedicated geovisualization environment, in order to help expert decision-making. The proposition is implemented with the case study of a tsunami event in the Caribbean sea.

Keywords

geovisualization, multiplexing tools, crisis management.

INTRODUCTION

Natural hazard management remains a major issue for populations and authorities. It relies on the capacities and the possibilities that scientific and operational have to simulate, predict and prevent natural phenomena in order to protect the impacted inhabitants and infrastructures. Decision-making processes can be complex and mostly depend on quickly transmitted information, based on massive raw data coming from sensors and geophysical models: this information is then often graphically represented as graphics and maps, enabling visualizations of the territories affected by an event, the dynamic evolution of this event in space and time, and its various possible impacts. In a crisis unit, the goals of the experts are to lead emergency and people security: they rely on information, coming from various sources, sensors, and other emergency centers, displayed on different screens, i.e. laptops, tablets or wall screens, variably arranged in the room, to take the better decisions (Cf. Figure 1).

Figure 1: Inside a crisis management unit (Photo Credit PREDICT Services[1])

For instance, when facing a tsunami event, emergency information is transmitted in a raw text format and are combined with pre-computed event forecast models to extract and derive the expected spatial extension and the related potential impacts. Figure 2 presents the example of a raw alert message in text from the Pacific Tsunami Warning Center (PTWC) (2-a) and one of a possible derived cartographic representation (2-b). At the same time, other information need to be visualized, in order to assess the dangerousness of an event, its extension and dynamics, for instance: meteorological information, i.e. wind, local and worldwide pluviometry at the time and the trends for the past two weeks, seismologic activity, etc.

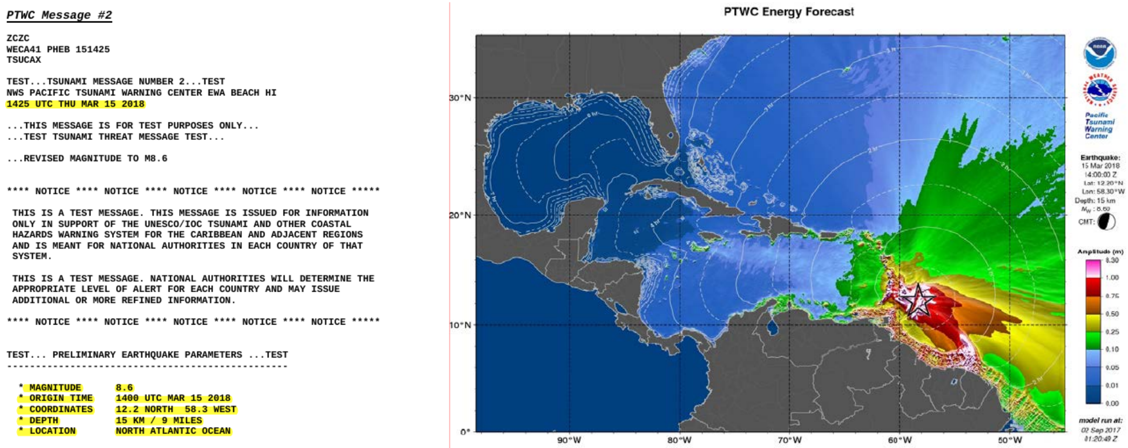

Figure 2: a) PTWC raw alert message and b) Maximum amplitude map for the Caribbean and Adjacent Regions (PTWC, 2018)

This research initially emerged during various visits of crisis units, where wall screens are used to represent heterogeneous spatio-temporal information useful for crisis management. During these visits, we observed that a lot of data are displayed on wall screens at the same time, in 2D or 3D, whatever spatio-temporal extents and scales. However, we have noticed several functional limits for the co-visualization and the navigation of information displayed on wall screens.

First of all, the representations displayed on a wall screen were independent one to each other, which did not allow an efficient cross-over between representations, and could generate too many unnecessary interactions with the representations. Independence and hermeticism of the representations (often provided in raw format by web services) prevented to display this information on a unique representation. Furthermore, a temporal interdependence exists between representations, which is fundamental in a crisis management context with strong temporal constraints. For example, synchronization between tsunami arrival, hourly weather conditions, and evacuation times to a safe place can not be considered separately. Moreover, the possibility of anticipating by taking advantages of the temporal relations between representations proves to be invaluable for crisis experts.

In the context of a catastrophic event, decision makers and experts in a crisis unit have to face significant temporal constraints, while acting on potentially vast areas. Wall displays offer a solution to co-visualize the various representations useful for decision-making, but at the same time, the difficulty of combining these

[1] http://www.predictservices.com

representations can amplify these constraints. It therefore seems necessary to identify geovisualization tools and methods to manage co-visualization of heterogeneous representations in crisis units. In this context, we assume that advances in Geographic Information Sciences could benefit crisis managers to better navigate, combine and synchronize information displayed on wall screen in crisis units.

Geographic Information (GI) sciences have facilitated the development of geovisualization design and use, enabling experts to conduct more elaborate actions for risk prevention and crisis management (Van Oosterom et al., 2005; Konecny et al., 2010). While *mapping* is a graphic representation of geographical spaces and phenomena more used to communicate and mediate, *geovisualization* regards the way data may be visualized based on data interaction, to lead to *visual analytics* capacities, i.e. to infer spatio-temporal knowledge from data exploration (Keim et al. 2008). Geovisualization issues mainly concern the handling of heterogeneous spatio-temporal data visualization and the design of suitable graphic choices when representing uncertainties and spatio-temporal evolutions and their adaptation to the potential final users (experts, public authorities, populations). Nevertheless, the development of geovisualization tools for crisis management remains complex because of the emergency context and time pressure, of the increasing amount of available data, and of the risk of a cognitive overload instead of the expected cognitive support. In crisis management units, in the usual way, in order to avoid these problems, information is split on several screens to facilitate their access and reading. Based on these observations, we have been wondering if another organization of graphic interfaces could be useful and relevant in order to support sophisticated cognitive processes of knowledge inference and decision-making about crisis management, coming from a facilitating co-visualization of heterogeneous spatio-temporal data. *Co-visualization* refers to the methods and tools to bring representations together, in a shared interface *(*Hoarau and Christophe, 2017). We assume that this visual data integration will better support visual analytics and could help in the earlier steps of decision-making in a crisis management context.

In this paper, we propose to initiate this research by a proper design experiment step to explore the potentialities of spatial and temporal multiplexing tools, associated with a dedicated geodata visualization environment. Our long-term purpose is to provide a suitable visual support for knowledge inference and decision-making on crisis management in the case of natural disasters. In the first step of this long-term research, we focus on the issues related to the proposition of interface tools design, which are our first contribution to solve the on-going research problem: user studies have not been conducted in this first step, because a proper design needs to first approach issues of how to visually integrate data and representations. We present the advances in geovisualization, and especially in co-visualization of data and graphic representations, and the visual possibilities enhanced by multiplexing tools, in our crisis management context. Afterwards, we propose a generic model to better co-visualize the geospatial and thematic data, based on various points of view that could be displayed in a same graphic interface. As an applicative use case, we consider a tsunami event in the Caribbean sea, with a focus on the Martinique island, with the help of an existing detailed scenario proposed as part of the crisis exercise *CARIBE WAVE 18* (PTWC, 2018). We detail the scenario and the dataset used to simulate the event. Finally, we demonstrate the implementation of multiplexing tools to handle heterogeneous data to better co-visualize information on a tsunami event.

ADVANCES IN GEO-VISUALIZATION & CO-VISUALIZATION FOR CRISIS MANAGEMENT

Geovisualization refers to the “theory, methods and tools for visual exploration, analysis, synthesis, and presentation of geospatial data” (MacEachren & Kraak, 2001). As an interdisciplinary domain between GI sciences, geography, information visualization, image processing and computer graphics, geovisualization provides conceptual approaches, methods and tools to interact with geospatial data. Through this capacity to let the users explore the data and their representations, geovisualization tools aim at inferring knowledge and supporting visual reasoning (Yi et al. 2007). Nowadays co-visualization may benefit from the advances in the Human-Computer Interaction (HCI) scientific domain, providing spatial and temporal multiplexing tools to manipulate data ‘together’. In order to improve the usability of co-visualization tools to manage data in space and time, the main leads undergoing research are the following ones: the improvement of the perception of the dynamics of a phenomenon and the design of smooth navigation between data and representations.

Spatio-temporal geovisualization

Geovisualization has widely considered issues related to the representation and the interaction with spatio-temporal data (Andrienko & Andrienko 2005, Andrienko et al. 2008, amongst others). The first main approach is to animate the spatial or/and temporal dynamics at stake, in a continuous or pseudo-continuous manner (Andrienko et al., 2008; Keim et al., 2008). Many applications have been experimented, the water level rising simulation (Marcy et al., 2011; Nicholls et Cazenave, 2010; Yang et al., 2014), tsunami and marine submersion prevention (Allen et al., 2010), the modeling and visualization of currents and tides (Mengguo et al., 2000), the monitoring of sandbanks trajectories (Gierlinger et al., 2015) and seabeds (Tateosian et al., 2014), or the real-time representation of maritime traffic (Etienne et al. 2012, Marine Traffic[2]). These spatio-temporal animations are more and more used, thanks to the increasing rendering capacities of computers, in order to serve fluid and continuous animated visualizations. Nevertheless, even if animations are very useful to improve the global perception of a spatio-temporal phenomenon and its general patterns, such as demonstrated in a user study of geovisualization and assessment of a flood crisis (Leskens et al., 2015), it is mostly difficult to detect changes and to monitor a specific aspect of the phenomenon (Rensink et al., 1997). These previous work show that a dynamic visualization is a better way to understand, but also suggest that several points of view are required to observe and analyze a spatio-temporal phenomenon.

Co-visualization techniques from Geographic Information (GI) Sciences

Co-visualizing heterogeneous data raises issues on how it is possible to visualize data together, sharing the same interface side by side, overlapping each other, or being hybridized or merged in one new image. Map design researches have addressed for instance the design problem of visually mergin an ortho-image background with an abstract topographic map (Hoarau, 2012; Raposo and Brewer, 2013). While merging data, legibility issues appear, implying issues in graphic semiotics and its related visual variables, initially described by Bertin (1983), extended, revisited and experimented, by MacEachren (1995), Boukhelifa et al. (2015), Carpendale (2003), Slocum et al. (2009), Perin et al. (2014), amongst others. Issues on colors and color contrasts (Christophe, 2011; Harrower and Brewer, 2003; Patterson and Kelso, 2004; Patterson and Jenny 2013; Thyng et al. 2016 amongst others) may be also addressed in this co-visualization context, such as rendering techniques to variously blend geographical layers (Porter and Duff, 1984; Hoarau and Christophe, 2016; Lobo et al. 2015). The unique use of the transparency to blend data may cause visual cluttered information not legible and not usable: blending data require specific techniques mostly to handle contrasts (Hoarau et al., 2013; Murphy 2015). Therefore, the design of continuum of data and graphic representations has been explored as ‘a series of pictures, iteratively reduced in representation from its referent’ (Medley and Haddad, 2011). In GI sciences, the design of cartographic continuum aims for instance at navigating smoothly, between a map and orthoimagery according to the parametrization and interpolation of colors and textures to enhance photorealism (Hoarau & Christophe 2017) or smoothly between various representation scales to manage visual attention (Dumont et al., 2017). Managing progressive transitions between levels of abstraction allows navigating between different levels of abstraction in a same visualization, according to the distance from the image center or the saliency of rendered objects (Semmo et al., 2012), or according to the scene depth (Semmo and Döllner, 2014). Another example consists in generating masks according to relevant geographical objects and scene depth, in order to highlight specific objects as soon as the users perceive them (Trapp et al., 2011).

Multiplexing techniques

Navigating in large information spaces using zoomable user interfaces is a research question that has received a lot of attention in the Human-Computer Interaction (HCI) community, based on three main interface schemes: pan & zoom (Wijk and Nuij, 2003), focus+context and overview+detail (see Cockburn et al., 2009 for a comprehensive survey). The implementation of navigation techniques from HCI based on these schemes leads to a wide range of tools supporting multiplexing (Bottger et al. 2008; Brosz et al., 2013; Jakobsen et al. 2013; Reilly and Inkpen, 2004), i.e. tools conveying multiple information at the same time: such as magnifiers, lenses, swipes, or enslaved views (Appert et al. 2010; Pietriga et al. 2010; Pindat et al., 2012; Karnik et al., 2009; Lobo et al., 2015), evaluated in (Lobo et al., 2015). These spatial multiplexing tools may be divided into:

- Juxtaposition methods, i.e. two types of data are displayed in the same environment, but one besides the other, or one up the other: multiviews, overview and detail, split screen, portal.
- Superimposition methods, i.e. two types of data are overlaid, some of them may be hidden and visible with the help of an interface tool: mash-up, translucent overlay, swipe, dragmap (Ware & Lewis, 1995), lenses, as Smart Lenses (Thiede et al., 2008), Jelly Lens (Pindat et al., 2012), Detail Lenses (Karnick et al. 2010) amongst others (see Tominski et al., 2014 for a wider survey about lenses).

Co-visualization of heterogeneous data based on multiplexing techniques

[2] https://www.marinetraffic.com/en/ais/

Because of the amount of heterogeneous data that have to be handled, visualized and cognitively processed, together, in the same time, in a crisis unit, we may take advantages of the parallel advances in geovisualization and in HCI: they provide a strong state of the art to go further in the co-visualization of heterogeneous spatio-temporal data, based on multiplexing techniques for crisis management. A combination of juxtaposition methods, i.e. multiviews, overview and detail, and of superimposition methods, such as lenses, could allow to render the region of interest or any subregions, according to these constraints:

- With different input information: topographic, thematic regarding the event, climate, textual data, sociodemographic;
- With various points of view on the event: representation of hazard, potential issues, and elements at risk;
- At different time steps: before, during of after the event;
- At different spatial scales: international, regional, local, urban;
- For any natural event: tsunami, flood, water level raising, etc.;
- For distinct objectives: monitoring, evacuation, etc.

Taking into account these multi-dimensional constraints for the co-visualization of information in a crisis unit supposes the development of a generic model for the management of heterogeneous graphic representations.

GENERIC MODEL TO VISUALIZE INFORMATION IN VARIOUS WAY

To improve the co-visualization of heterogeneous data in a crisis context, we argue that the intended information to represent and the way it is displayed on various screens (wall screens, laptops, tablets, etc.) must be preliminarily identified. For example, in a crisis unit, at the beginning of an event, some information have to be visualized onto a wall screen, such as the source of the hazard, the impacted areas, alert messages, or climate data. This information must be displayed, at different scales (according to the spatial extension of the event) to make it possible for the operator to view the representations at different levels of detail. This raises both:

- User Interface (UI) issues: How to efficiently organize information displayed on the screen? Which tools can be used to better represent information?
- Geospatial issues: What kind of spatio-temporal (ST) relationships exist between representations? How to mash-up heterogeneous datasets with different scales and styles ?

A generic metamodel for interface handling

We propose a generic model to describe entities used in a particular hazard context (e.g. tsunami or flood). In this model, we need to consider interface issues, such as co-visualization of heterogeneous datasets. At the highest level, we have to manage the three concepts of interfaces, frames and scenes and their relationships, as modeled in Figure 3.

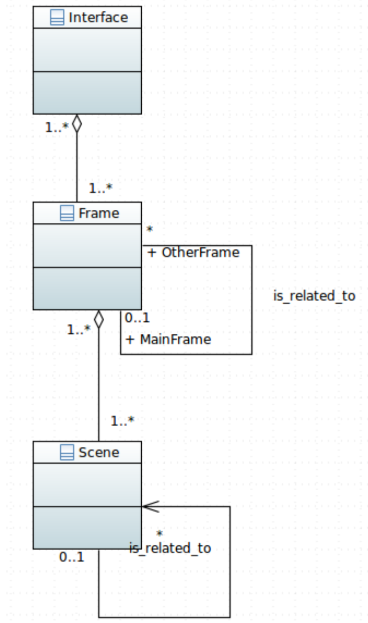

Figure 3: Generic metamodel of interfaces relationships interaction in a co-visualization framework (UML diagram)

An *interface* allows the users to interact with the information within a dedicated support (wall screens, tablets, etc.); a *frame* is a 2D visualization space inside the interface where contextual information is displayed; and a *scene* is a static or dynamic representation at one scale and for one particular time (before, during of after the event). In the context of crisis management, an interface must allow the experts to:

- Co-visualize heterogeneous, cartographic and thematic data (weather, alert message, topographic data, etc.);
- Hide / show / combine relevant information for the user;
- Put forward a frame or a scene that is considered as the main one, at a certain time t;
- Interact with data through multiplexing tools.

Interfaces are composed by frames and interaction components. Each frame constitutes a 2D visualization space in which different scenes are represented. Frames can be represented by windows, popup, widget, or any component of a GUI which allow displaying cartographic or thematic information. Frames can be related to each other. In particular, one frame is dedicated to be the main for displaying the most relevant scene for the operator at one time. This main frame can have some links with the others (e.g. zoom of a particular place, thematic information for a particular placemark, etc.). Spatial and temporal multiplexing tools can be used at this level, such as juxtaposition of several frames (multiview, split/merge, etc.), superimposition (dragmag, mash-up, etc.), or temporal synchronization of frames. In the frames, we have to represent one or more *scenes*, corresponding to a particular *spatial scale* (region, local, urban), at a particular time (synchronized with the event time). Scenes can be related to each other.

A model to manage scenes

At the scene level, we have to manage the graphic representation, the different link between them and the associated dataset. The Figure 4 presents a conceptual model (UML formalism) to describe the interaction and the relationships between entities at this level.

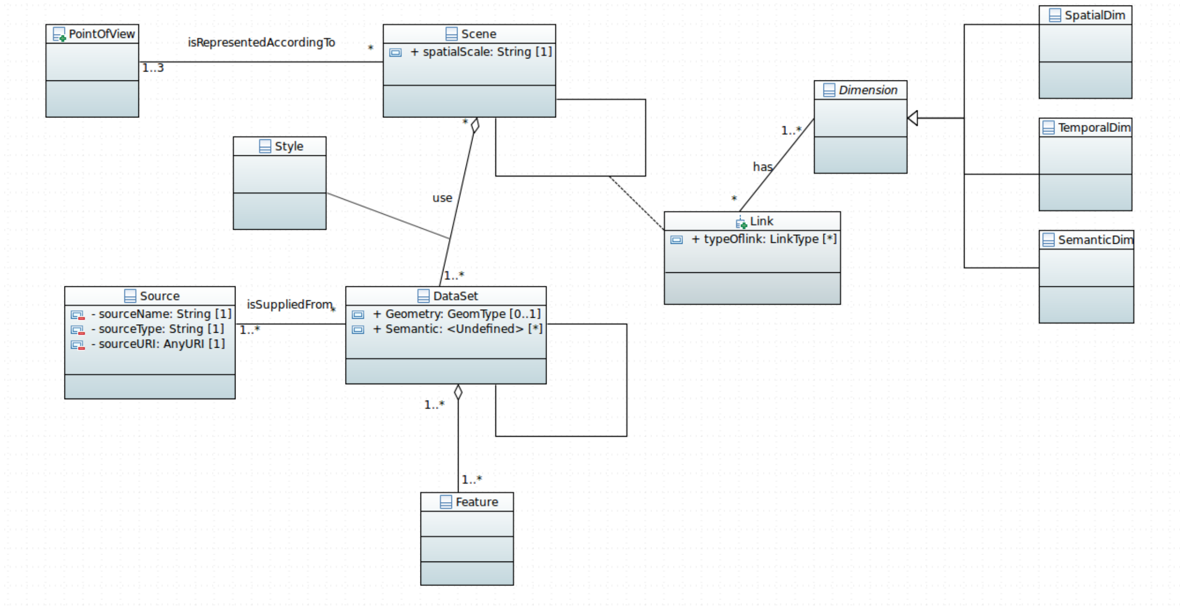

Figure 4: Scene level model (UML class diagram)

A *scene* is represented according to a *Point of view*. In our context, we consider diverse points of view: *Hazard, Potential Issue and Risk*. The *hazard* refers to the direct or indirect consequences of a catastrophic natural phenomenon. It can be amplified with other phenomenon, such as additional and cumulative rainfall for instance. *Potential Issue* contains information about people or infrastructures potentially exposed to the phenomena. *Risk* is the intersection between hazard and potential issues (e.g. submerged roads, destroyed buildings, etc.). For one scene, several *spatial or thematic datasets* are needed to graphically represent the information. A *style* depending on the scale of representation and the dataset used to display the information is applied. Datasets are supplied from different *sources* (databases, geoportal, etc.). Finally, spatial, temporal and semantic links can exist between scenes: for example, alert messages and estimated intensity of the hazard can be synchronized. These relationships will guide the use of multiplexing tools, to better combine the information to be disseminated. For instance, at the *hazard* point of view, data about the prediction of the impacted area can be easily found, and at the *potential issue* point of view, data on the impacted population in the same area are available. Lenses would potentially be helpful to see a specific aspect of the phenomenon (scale, data or view change) or of the impacts (affected population or infrastructures) or of the complementary thematic data (rainfall evolution, etc.) and to show how to reach quickly some refuge sites.

TSUNAMI CRISIS SCENARIO AND UNDERLYING DATASET

The crisis scenario is based on the Barbados earthquake scenario from the *CARIBE WAVE 18* exercise (PTWC, 2018). It relays on a rupture of a fault segment along the Caribbean coast of Barbados, occurred at 14:00 UTC, causing an earthquake with an 8.6 magnitude. The epicenter is located at the coordinates Long : 58.30°W, Lat : 12.20°N. With this scenario, the southern segment of the Lesser Antilles ruptures to create a tsunami. Expected impacts for this event are determined from pre-computed tsunami forecast models. For instance, Figure 5 shows tsunami travel time and water heights off the coast. Tsunami forecast models indicate a significant tsunami along several coasts in the Caribbean Sea. Threat messages and enhanced graphical products will be disseminated to officially designated agencies. The initial alert is disseminated at 14:05 UTC.

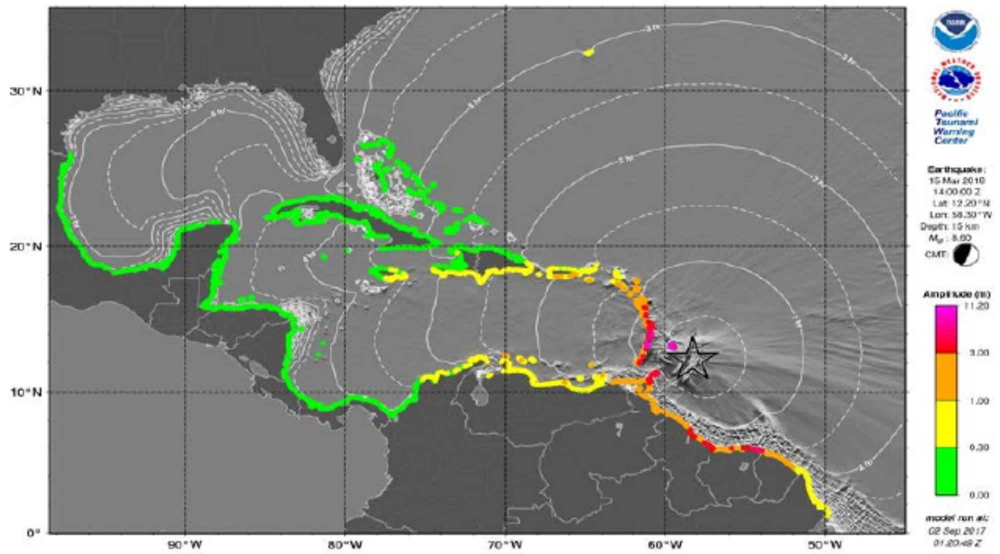

Figure 5 : Coastal tsunami amplitude map for the Caribbean and adjacent regions (PTWC, 2018)

The first tsunami threat message issued by PTWC is based on the earthquake magnitude (8.3 reevaluate in the second message) and the tsunami travel times (Figure 5). The other messages are based on tsunami wave forecasts that indicate the levels of threat that have been forecast and to which countries or places they apply. The messages cover a period of time between 5 minutes and 7-hours from earthquake origin time. The end of the event is scheduled at 18h00 UTC (PTWC, 2018). Based on this scenario, experts, in a crisis unit, and during the crisis period, have to manage emergency and people security for the french islands of Caribbean region, and in particular the Martinique island.

```
PTWC Message #1

ZCZC
WECA41 PHEB 151405
TSUCAX

...TSUNAMI MESSAGE NUMBER 1...
NWS PACIFIC TSUNAMI WARNING CENTER EWA BEACH HI
1405 UTC THU MAR 15 2018

...PRELIMINARY EARTHQUAKE PARAMETERS ...
-----------------------------------------------

  * MAGNITUDE        8.3
  * ORIGIN TIME      1400 UTC MAR 15 2018
  * COORDINATES      12.2 NORTH  58.3 WEST
  * DEPTH            15 KM / 9 MILES
  * LOCATION         NORTH ATLANTIC OCEAN

...EVALUATION ...
-------------------------

  * THIS IS A TEST MESSAGE. AN EARTHQUAKE WITH A PRELIMINARY
    MAGNITUDE OF 8.3 OCCURRED IN THE NORTH ATLANTIC OCEAN AT
    1400 UTC ON THURSDAY MARCH 15 2018.

  * THIS IS A TEST MESSAGE. BASED ON THE PRELIMINARY EARTHQUAKE
    PARAMETERS... WIDESPREAD HAZARDOUS TSUNAMI WAVES ARE
    POSSIBLE.

...ESTIMATED TIMES OF ARRIVAL ...
-----------------------------------------

  * THIS IS A TEST MESSAGE. ESTIMATED TIMES OF ARRIVAL -ETA- OF
    THE INITIAL TSUNAMI WAVE FOR PLACES WITHIN THE REGION
    IDENTIFIED WITH A POTENTIAL TSUNAMI THREAT. ACTUAL ARRIVAL
    TIMES MAY DIFFER AND THE INITIAL WAVE MAY NOT BE THE
    LARGEST. A TSUNAMI IS A SERIES OF WAVES AND THE TIME BETWEEN
    WAVES CAN BE FIVE MINUTES TO ONE HOUR.

    LOCATION         REGION            COORDINATES     ETA(UTC)
    ------------------------------------------------------------
    BRIDGETOWN       BARBADOS          13.1N  59.6W   1428 03/15
    KINGSTOWN        SAINT VINCENT     13.1N  61.2W   1448 03/15
    CASTRIES         SAINT LUCIA       14.0N  61.0W   1452 03/15
    PIRATES BAY      TRINIDAD TOBAGO   11.3N  60.6W   1459 03/15
    FORT DE FRANCE   MARTINIQUE        14.6N  61.1W   1500 03/15
    ROSEAU           DOMINICA          15.3N  61.4W   1500 03/15
    SAINT GEORGES    GRENADA           12.0N  61.8W   1506 03/15
    BASSE TERRE      GUADELOUPE        16.0N  61.7W   1509 03/15
    PLYMOUTH         MONTSERRAT        16.7N  62.2W   1517 03/15
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Figure 6 : PTWC Threat Message N°1: On the left, information are provided about the earthquake, on the right each line represents the estimate times of arrival of the Tsunami wave for different towns.

Table 1 describes our proposition of required information and multiplexing tools, according to three relevant spatial scales, regional, local and urban, and their related associated tasks: alertness, risks assessment and evacuation. For each spatial scale, several datasets are necessary to achieve these tasks: the row "Information to display" gives the relevant required information for each spatial scale, for all the points of view (Hazard, Potential Issues and Risk):

Spatial Scale	Regional ◀——▶	Local ◀——▶	Urban
Associated task	Alertness	Risk assesment	Evacuation
Information to display	Base Map + Épicenter information, Tsunami Travel Time, PTWC Messages,	Base Map + **Hazard**: submerged area + coastline water hight **Potentiel Issues**: Buildings, roads and population **Risk**: Refuge sites, area to evacuate **Weather**: Rainfall	Base Map + **Hazard**: Submerged area **Potential Issues**: Buildings, roads, population and boats **Risk**: Refuge sites, population and boats to evacuate
Multiplexing tools associated	**Spatial multiplexing**: *Swipe*: wave progression **Temporal multiplexing**: TTT *animation*.	**Spatial multiplexing** *Mash-up:* weather and topographic information **Temporal multiplexing** Rainfall *animation*	**Spatial multiplexing**: *Split-Merge*: Risks information *Lens*: ≠ Point of view

Table 1 : Datasets and multiplexing tools used according to the three spatial scale and their related tasks.

- At the regional spatial scale, the task is "alertness": the experts need to have a global vision of the event and its probable consequences. A base map of the whole region with the location of the epicenter, and the PTWC alert message are needed. Additionally, the Tsunami Travel Time (TTT) and the earthquake information must be displayed upon request. Data used at this level are extracted from the PTWC alert message.
- At the local spatial scale, the task is "risk assessment": the experts have to see information for the entire island to decide where to dispatch the rescues first. Thus, they need information about the three viewpoints:
  - For the *hazard* point of view, experts need to know the probable local tsunami height, in order to derive submerged areas. Water heights are extracted from the PTWC alert message and pre-computed tsunami forecast models. Submerged areas are locally derived using LITTO3D Digital Terrain Model.
  - For the *potential issues* point of view, populations and infrastructures impacted by the tsunami have to be quickly identified. Infrastructures (e.g. buildings, roads) are extracted from the BDTOPO topographic database, and population density are derived from INSEE databases.
  - For the *risk* point of view, priority evacuations and secure areas should be identified, based on refuge sites and evacuation areas.
  - Additionally, rainfall at different periods of the crisis must be available to evaluate a potential amplified risk. Rainfall representations are generated from METEO FRANCE data.
- At the urban spatial scale, the task is "evacuation": the experts need to plan the evacuation of people and boats. For this, they have to display the same type of information than at the local level but with more accuracy and reliability details.

We propose some multiplexing tools that can be associated with the scene, at each spatial scale, in order to help the experts in their decision-making:

- At the regional level, spatial and temporal multiplexing tools, such as swipe or animation, could be used to display more efficiently the wave progression and the Tsunami Travel Time.
- At the local level, spatial multiplexing tools can be implemented for mashing-up topographic, weather and temporal information to animate the rainfall.
- At the urban level, lenses and split/merge tools could be used to display risks information with different points of view.

IMPLEMENTATION : A TSUNAMI GEO-VISUALIZING PROTOTYPE USING MULTIPLEXING TOOLS

We implement the prototype using the Java language and two libraries: ZVTM (Pietriga, 2005) which is dedicated to the display of 2D representations on several screens (laptop, tablets, wall screens), and JavaFX to manage the interface[3].

Architecture of the prototype

The architecture of our prototype is described in Figure 7 and contains three major packages: one dedicated to the ZVTM library, one to the interaction with a PostGis database where data are stored (topographic or statistic data for example), and one dedicated to the Graphical User Interface (GUI). This last package is based on the Model View Controller (MVC) pattern.

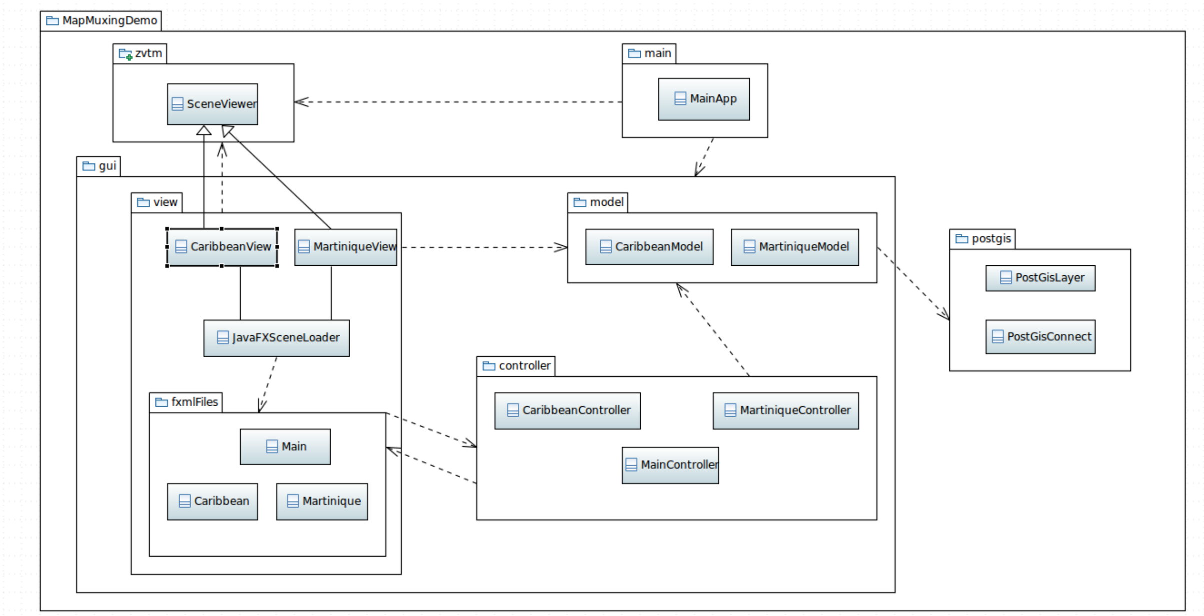

Figure 7 : Architecture of the prototype (UML package diagram)

Crisis unit user scenario at the regional level, the Caribbean region

We propose the following crisis unit user scenario, at the regional level, illustrated in Figure 8, when all of the frames are displayed: the screen is divided into several frames containing 1) a scene about Caribbean region for the hazard point of view on the left side, 2) the PTWC alert message on the right side (the message changes each time a new message is received), and 3) an overview to locate the scene in a largest region, on the bottom right side. This scene is composed by a tile map from the region (that can be changed by a menu), and some additional information about the earthquake (e.g. location and magnitude). The experts can see more information about the earthquake in an alert popup (4), by clicking on the epicenter placemark (5) or via a menu.

[3] http://www.oracle.com/us/technologies/java/050862.pdf

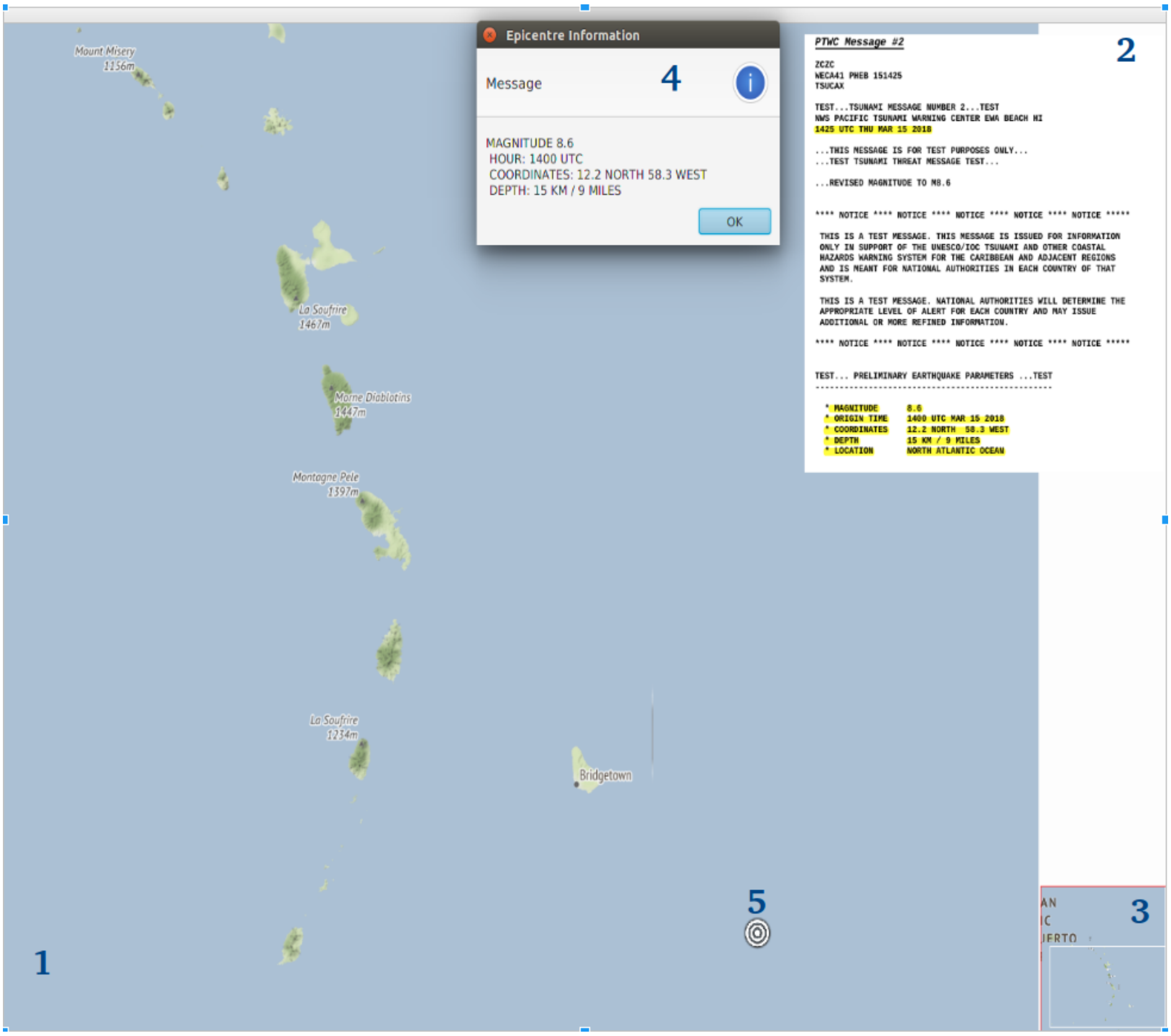

Figure 8 : Frames to be used for a user scenario at the regional scale: 1) Caribbean scene for the hazard point of view, 2) PTWC alert message, 3) Overview of a largest region, 4) Epicenter information, 5) Epicenter placemark

Additionally, experts can see via a menu, the Tsunami Travel Time (TTT) and the maximum predicted water height of the coast. This information gives the estimated time of arrival of the wave for all the Caribbean islands. Thus, they can decide to click on the Martinique island to see more information, and to decide where to dispatch the rescues. This action triggers the opening of a new frame on the Martinique scale.

Crisis unit user scenario: local level

The interface of the prototype is arranged in such a way that the frame of the Caribbean is not masked by the one of the Martinique (Figure 9). However, the main window is now the one of Martinique (but it is still possible to put forward the Caribbean one).

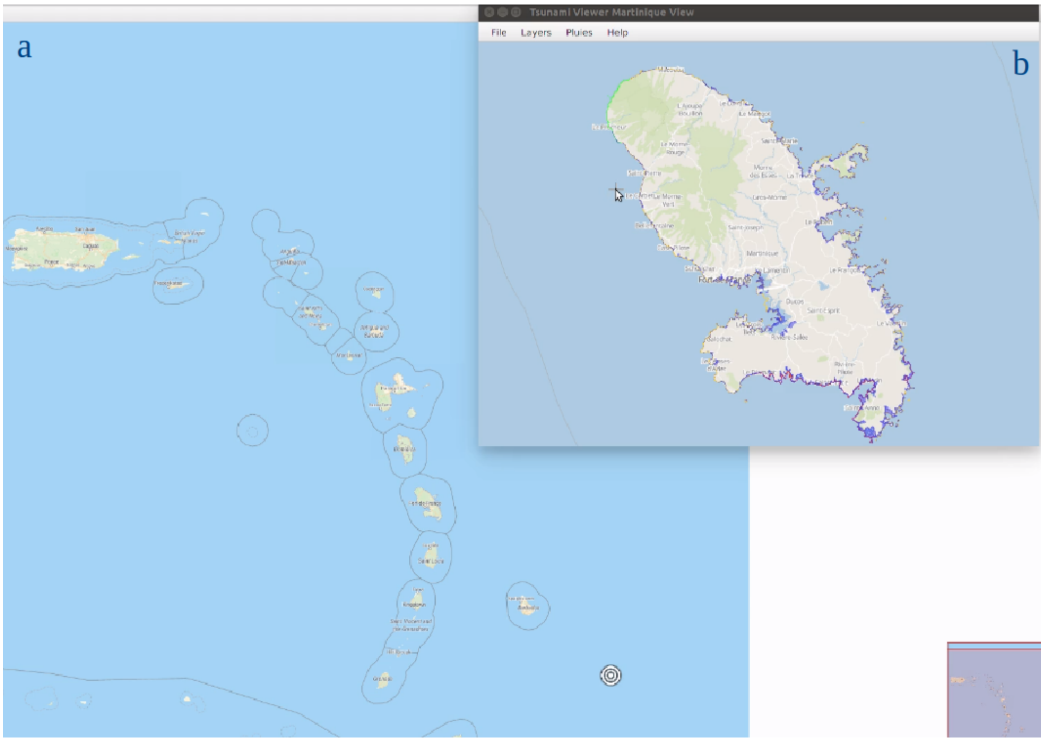

Figure 9: Space arrangement of the interface, with two frames at different scale: a) Regional scale, b) Local scale

The first frame displayed at the *Martinique* level is the hazard point of view (Figure 10a). At first sight, the experts can see the location of the main submerged area (colored in blue), and the water heights colored from green (low hazard) to red (significant hazard). By a menu, they can switch to the different viewpoints to navigate into scene from Hazard, Potential Issues or Risk. Figure 10b shows Potential Issues such as boats and buildings (in gray), and 10c shows the area to be evacuated (in green).

Figure 10: Martinique different scenes with: a) Hazard viewpoint, b) Potential Issue viewpoint and c) Risk viewpoint

Additionally, the experts can see the rainfall for each hour of the event (from 14h to 18h, figure 11b and 11c) or through an animation (Figure 11a). Rainfall accumulation for all day is also available. We use Meteo France semiology[4] to represent rainfalls, where in our simulation, light blue is less than 1mm and purple is higher than 10mm.

[4] http://www.meteofrance.com/previsions-meteo-france/simulations-numeriques-meteorologiques/france

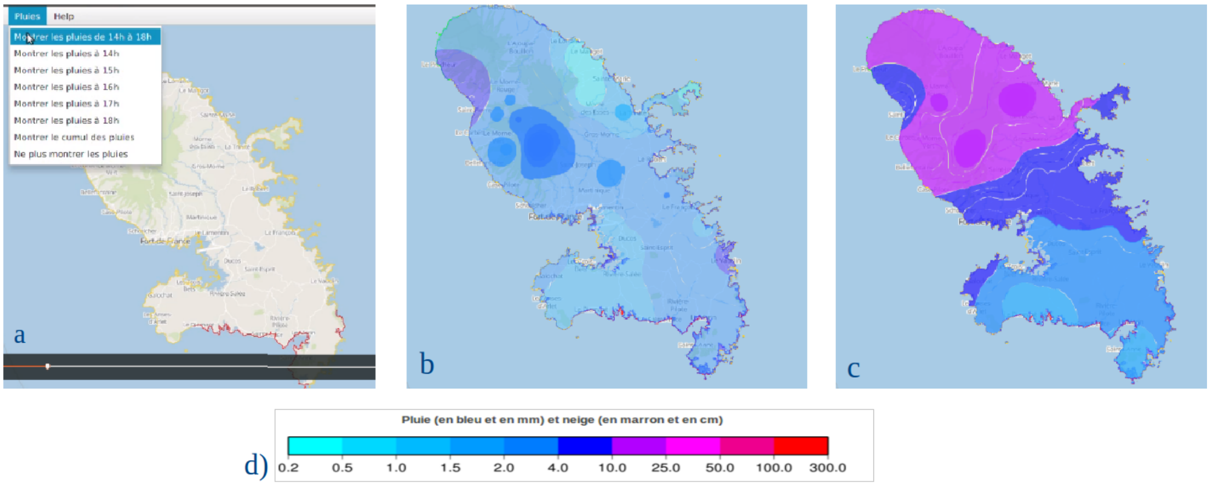

Figure 11: Rainfall animation during all the event (a), rainfall at 14h00 UTC (b), rainfall at 18h00 UTC (c) , and Meteo France scale semiology for rainfall display (d)

With all this information, the experts may notice that some strategic areas such as *Fort de France* town, the south of the island and the Atlantic ocean south coast will be more impacted by the tsunami than the north of the island. Thus, they have to zoom to these areas to check the potential issues and make the right decisions to keep people and boats safe. To illustrate this scenario, experts decide to click on the south of the island to see more details about the city of *Le Marin*.

Crisis unit user scenario: urban level

A new frame opens a display of an urban scene according to the hazard viewpoint. This new frame is located at the bottom left of the screen, allowing the visibility of both regional and local frames into the entire interface space (figure 12).

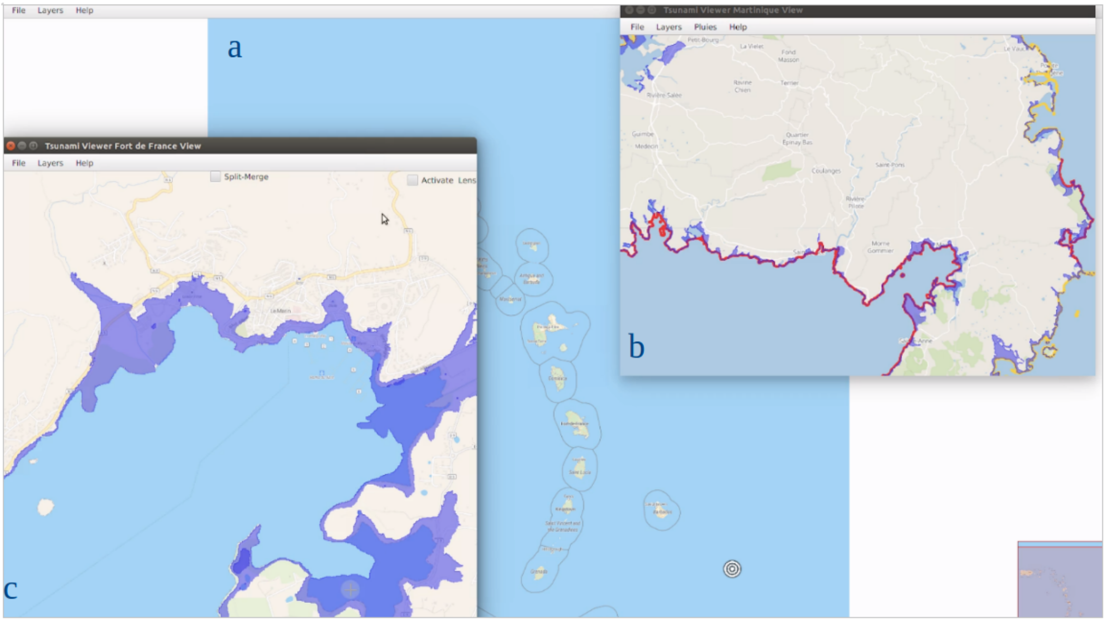

Figure 12: Frame spatial arrangement to see all scales : a) Regional level, b) Local level and c) Urban level

At this level, the experts may have to organize the pedestrian and boat evacuation. For that, they have to explore data from the three points of view (Hazard, Potential Issues and Risk). First, they may want to see data from two viewpoints in a single aggregated scene to assess which potential issues are impacted by the tsunami and evaluate how many people and boats to evacuate. To achieve this task, we propose to help the experts by the use of lenses multiplexing tool where one point of view is seen as the context and the over, inside the lens as the focus. Figure 13 gives an example of how we can use lenses at the urban level: in Figure 13-a, the *Potential*

Issue viewpoint is the focus inside the lens (showing people, road, buildings and boat that might be impacted by the wave), and the *Hazard* viewpoint is the context where we can see, the submerged area. In Figure 13-b, the context represents the *Potential Issues* and the focus is the *Hazard*. This example shows that the use of lenses can be potentially helpful in a crisis management context.

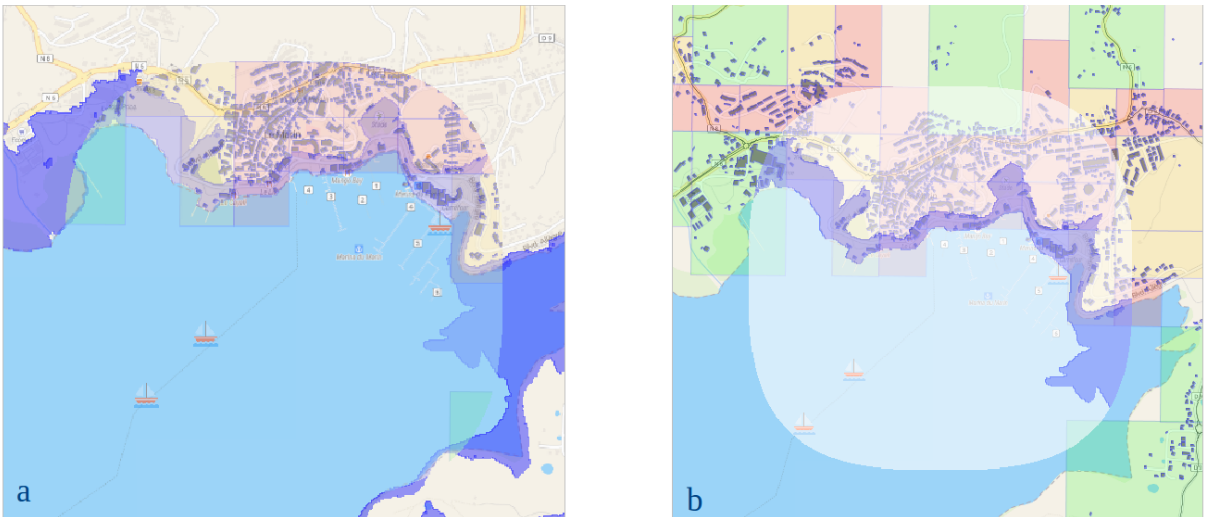

Figure 13 : Using lens to show different points of view into the same scene: a) Focus=Potential issues viewpoint, Context=Alea viewpoint; b) Focus=Alea viewpoint, Context=Potential issues viewpoint.

Additionally, the experts want to focus on the risk viewpoint to plan the evacuation. In this scene, superimposed datasets are displayed to the experts such as the population to evacuate (from green to red depending on the number of people impacted), submerged roads (in red), location of the refuge sites, or even boats to be evacuated offshore (Cf. Figure 14).

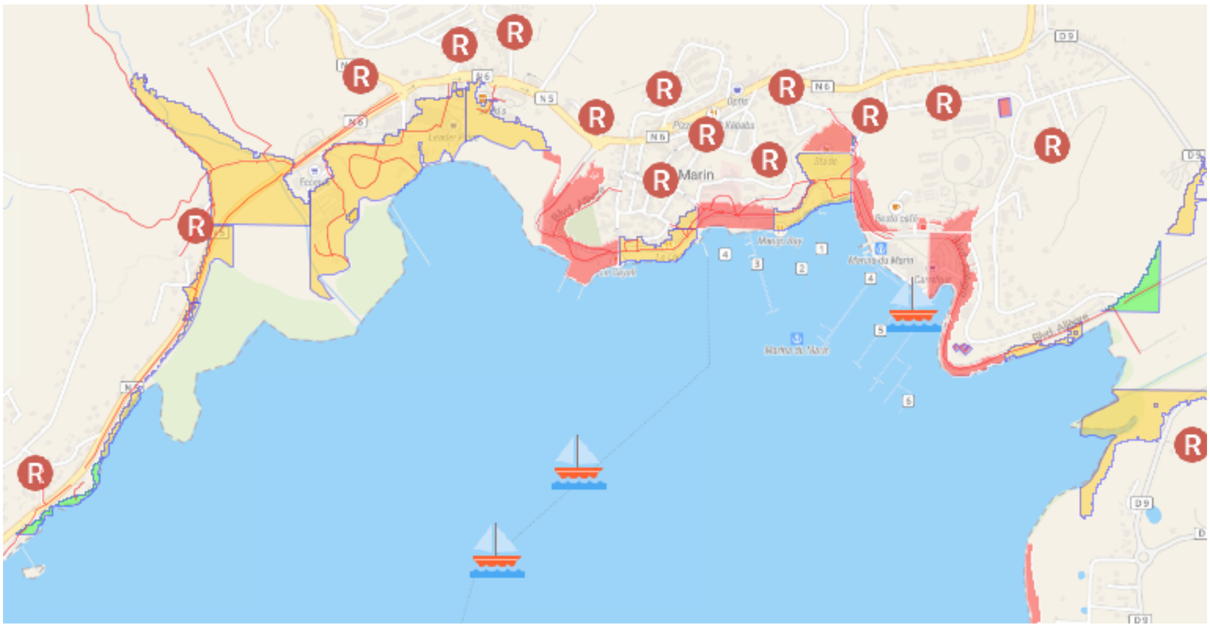

Figure 14 : Superimposition of several datasets for the risk point of view in the same scene

Visualizing all this superimposed information can lead to cognitive overload and is not efficient for the experts to perform their analysis in order to facilitate decision-making. To help the experts in this task, we propose to use a splitting multiplexing tool to break up the risk information into three distinct scenes: boats to evacuate, impacted population and submerged roads (Cf. Figure 15).

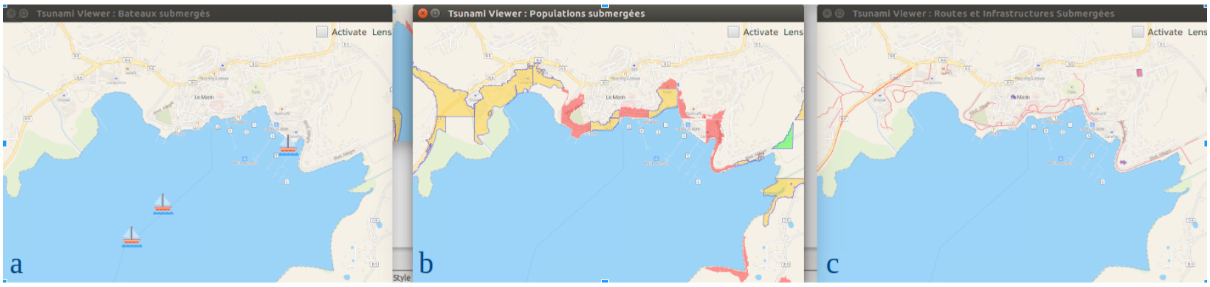

Figure 15 : Juxtaposition of scenes for the risk point of view by using a split/merge tool: a) boats to evacuate, b) impacted population, c) submerged roads.

By using this feature, the experts can focus on one major risk at a time, while keeping a view on other risks. With a menu button, the experts can easily switch from the merge to the split view. Using a split/merge multiplexing tool allows the experts to choose between aggregate or separate dataset. The separation reduces the graphic overload associated to the risk representation, and allows also experts to work collaboratively on different aspects of the crisis management. Additionally, expert can use a lens into one view to see for instance other information available (e.g. the refuge sites). We can easily assume that the use of a splitting multiplexing tool associated with a lens would be useful at the risk viewpoint to plan evacuation and lead people security.

DISCUSSION

The proposed model to manage multiple representations, as well as the developed prototype, already provide a formal framework for the co-visualization of information. Even if this contribution has not been completed by user tests, it offers potential answers to three limitations observed during our visits in crisis units:

- The difficulty to navigate efficiently from one visual representation to another,
- The difficulty of combining visual representations to extract new information,
- The impossibility of synchronizing spatio-temporal representations.

First of all, given that the proposed model formalizes the spatial relations between frames, it facilitates navigation between scales (as shown by the application example between Caribbean and Martinique representations), as well as the co-visualization of information on the same scale at the same time, using spatial multiplexing tools (for example using lenses).

Secondly, the formalization of spatial and semantic relations between scenes in the proposed model is supposed to facilitate the combination of information to deduce a new one. This has been illustrated by the crossing of hazards and issues to deduce elements at risk, but it was also observed in another visit on the intersection between atmospheric pressure and temperatures to deduce precipitations. As a perspective, it may be judicious to perform a user test in order to assess the capabilities offered by spatial multiplexing tools, such as lenses, to extract information inherited from multiple representations.

Finally, the model also proposes to formalize temporal relations between representations, which can be added to the spatial and semantic relationships already described. If the current model is conceptually able to link multiple representations by temporal relations, the operational implementation of these relations within the prototype is not yet effective. This question also raises issues related to the visual interpretation of the combination of animated phenomena. Indeed, it can on the one hand allow a crisis manager to anticipate (by observing the evolution of a phenomenon and by extending it cognitively), while also being able to disturb its capacity of decision-making because of the potential visual overload implied by these animated evolutions.

The current progress of this work leaves us to think that the field of crisis management can benefit from advances in terms of geo-visualization, and more particularly multiplexing techniques (spatial and temporal) to better manage heterogeneous representations used in an emergency and decision-making context. For this purpose, this work must be enriched with real uses cases experiments, in order to evaluate the benefits of the developed tools and methods to improve co-visualization of information for crisis management.

CONCLUSION

In this article we propose to explore spatial and temporal multiplexing techniques in order to improve co-visualization between visual representations of heterogeneous spatiotemporal data. This project is born during the visit of several crisis units. During these visits, we observed that many cartographic representations were displayed on wall screens in order to facilitate the process of decision-making. However, we identified that these representations remained independent, which made navigation between representations difficult, and that the information represented remained difficult to combine, as it was often transmitted through raw data flows. If the visualization of these different representations could thus prove benefits in a context of crisis management, we could note that the lack of interdependence, and the impossibility of combining this information could also prove to disturb crisis managers. Therefore, we propose in this article (1) to elaborate a generic model allowing to formalize the relations (spatial, temporal and semantic) between representations, (2) to explore spatial and temporal multiplexing techniques in order to facilitate the co-visualization between heterogeneous spatiotemporal data, (3) to implement the model and the multiplexing techniques within a prototype software.

To illustrate the functioning of this prototype, we used a case study on a tsunami in the Caribbean region. Information on this scenario is coming from the *CARIBE WAVE 18* crisis exercise. This case study proved to be relevant to illustrate how the prototype works, since a tsunami can have catastrophic consequences over large areas in a very short time, which leads crisis managers to plan interventions on different areas. In terms of geovisualization, it involves experts to navigate between different scales of representation, and to combine different points of view (Hazards, Potential Issues and Elements at Risk). The proposed prototype, which includes a model for the formalization of the spatial relations between representations, associated with multiplexing techniques (spatial and temporal), offers a first contribution to manage these multi-dimensional constraints associated with the co-visualization of information for the crisis management.

Improvements still need to be integrated in these developments, particularly on the handling of the temporal dimension between representations, in order to allow experts to anticipate the consequences of a phenomenon in its dynamics characteristics. In addition, user tests should also be conducted in order to validate the benefits of the spatial and temporal multiplexing techniques in a crisis management context.

Obviously, this work leaves us to think that the field of crisis management can benefit from the advances in the fields of Geovisualization and Human Computer Interactions to better manage the co-visualization of information in a crisis management context related to natural disaster events.

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