DECISION SUPPORT INTERFACE FOR TSUNAMI EARLY WARNING IN INDONESIA – DEALING WITH INFORMATION FUSION, UNCERTAINTY, AND TIME PRESSURE

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ABSTRACT

In recent years numerous tsunami events in the Indian Ocean, most prominent the December 2004 disaster, demonstrated the need for an effective tsunami early warning system. The work presented here is embedded in the German-Indonesian Tsunami Early Warning System (GITEWS) project. The system combines a variety of sensor technologies such as terrestrial observation networks of seismology and geodesy, marine measuring sensors, satellite technologies, and pre-calculated simulation scenarios. The versatile sensor and simulation data is integrated, processed, and assessed by the newly developed Decision Support System (DSS). The DSS aims at the best possible situation awareness and decision-making of the operator to enable him to disseminate an appropriate warning at the earliest point in time if required. For this purpose, we attach great importance to the DSS user interface. Due to a high degree of initial uncertainty, operation under time pressure, and the challenge of combining a considerable amount of data to a global picture following regular user interface design guidelines is not sufficient. In this work the main principles of situation awareness design are examined and mapped onto design decisions, work in progress, and future prospects.

KEYWORDS

Early Warning, Decision Support, Situation Awareness, Uncertainty, Information Fusion, Information Aggregation

1. INTRODUCTION

The capital tsunami of December 26, 2004 in the Indian Ocean has shown how vulnerable human society and the environment are to this sudden-onset type of disaster. Particularly in Indonesia which is most at risk given its immediacy to the seismologically active Sunda Arc there is a need for protection and effective early warning. The work presented here is embedded in the German-Indonesian Tsunami Early Warning System (GITEWS) project. GITEWS is funded by the German Federal Ministry of Education and Research (BMBF) to develop a Tsunami Early Warning System for the Indian Ocean in close cooperation with Indonesia.

1.1 The Challenge of Tsunami Early Warning in Indonesia

The extreme proximity of the Indonesian coastline to the geologically active Sunda Arc generating most of the tsunami incidents is what makes early warning for Indonesia unique and challenging. No more than a time frame of 20-40 minutes is available for tsunami detection, warning, and evacuation. In addition, sensor technologies which detect and measure tsunamis as such are sparse and insufficient which produces a considerable amount of uncertainty to deal with.

The GITEWS Early Warning and Mitigation System (EWMS) deployed in the BMKG Warning Center in Jakarta uses a range of intelligent sensor technologies in order to detect indicators or evidence for a tsunami. The system integrates terrestrial observation networks of seismology (SeisComP3 by GFZ Potsdam) and geodesy which detect and locate earthquakes and seafloor deformation very quickly with marine measuring sensors, satellite technologies and pre-calculated tsunami simulation scenarios. A Simulation System (SIM) performs a multi-sensor tsunami scenario selection, resulting in a list of best matching tsunami scenarios for a given set of sensor observations. As a central component, the newly developed Decision Support System (DSS) integrates large amounts of real-time and pre-processed data and generates an overall situational picture. Once the decision to warn has been made the DSS communicates with the dissemination systems for message distribution and delivery. The EWMS structure and in particular the SIM and the DSS have been elaborated in detail in earlier publications (Behrens, 2008, Raape, 2010).

1.2 Related Work

Within the Framework of UNESCO-IOC and its Intergovernmental Coordinating Group (ICG), various efforts on national and bilateral basis are coordinated and combined to ensure a fast and reliable tsunami warning for the whole Indian Ocean and its 27 rim countries. Lessons learned from established tsunami early warning systems of the Pacific Tsunami Warning Center (PTWC) and the Japanese counterpart (JMA) were incorporated into a comprehensive guide towards the development of an effective end-to-end tsunami warning system for the Indian Ocean (US IOTWS, 2007). The Distant Early Warning System (DEWS) project, funded under the 6th Framework Programme of the European Union, aims at building interoperable multi-sensor tsunami early warning systems for the Indian Ocean (Lendholt, 2010). Corresponding applied research, program and system development activities include a wide range of oceanographic and seismic research, data processing, modeling and social science issues such as warning dissemination.

However, monitoring and interaction user interfaces introduced focus primarily on functional requirements (what is presented or can be processed) rather than how those interfaces must be designed in order to enhance situational awareness and decision making in time-critical situations.

1.3 Decision Support and Early Warning

Our goal is to support effectively each step of the decision support loop with an intuitive and highly usable DSS user interface which provides a rich set of visual means to create situation awareness as best as possible and convey uncertainty information. Thereupon, the user interface helps the operator to assess the information, impact, and consequences with the objective to make suitable decisions. Thus, the two core components of the decision support loop are *situation awareness (SA)* and *decide and act*.

Situation awareness has been identified as *the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future* and therefore *a constantly evolving picture of the state of the environment* by Endsley et al. in their work *Designing for Situation Awareness* (Endsley, 2003). Accordingly, *perception*, *comprehension*, and *projection* can be differentiated as the three levels of situation awareness.

The second part of the core decision support loop involves the transformation of this knowledge into decisions and actions. *Decide* refers to the derivation of decision proposals from a given situation that the EWMS has become aware of. *Act* refers to the implementation of the decisions that the operator has made. Examples for such decisions are warning dissemination or sensor (de-)activation.

In the following chapters we will outline some of our design decisions related to the main principles of designing for situation awareness and will give an insight in ongoing and future efforts.

2. DESIGNING FOR SITUATION AWARENESS

Endsley at al. have defined design principles for increasing situation awareness and facilitating decision-making under uncertainty and time pressure (Endsley, 2003). Those principles include 1) organization of information around goals, 2) direct presentation of level 2 information, 3) provision of assistance for level 3 SA projections, 4) support of global SA presenting the „big picture“, 5) Support of trade-offs between goal-driven and data-driven processing, 6) making critical cues for schema activation salient, 7) taking advantage of parallel processing capabilities, 8) using information filtering carefully, 9) explicit identication of missing information, 10) support of sensor reliability assessment, 11) using data salience in support of uncertainty, 12) representation of information timeliness, 13) support of assessment of confidence in composite data, 14) support uncertainty management activities. SA Principles 9 to 14 address the representation of uncertainty and the increase of confidence in the context of decision support.

2.1 The DSS Graphical User Interface Screen Concept

The DSS GUI is designed as multiple-screen desktop application with four screens, so-called *perspectives*, a subset depicted in Figure 1. Those perspectives are shown to the operator simultaneously in a fix sequential order from left to right without the possibility to drag and overlap windows and modules within the screens.

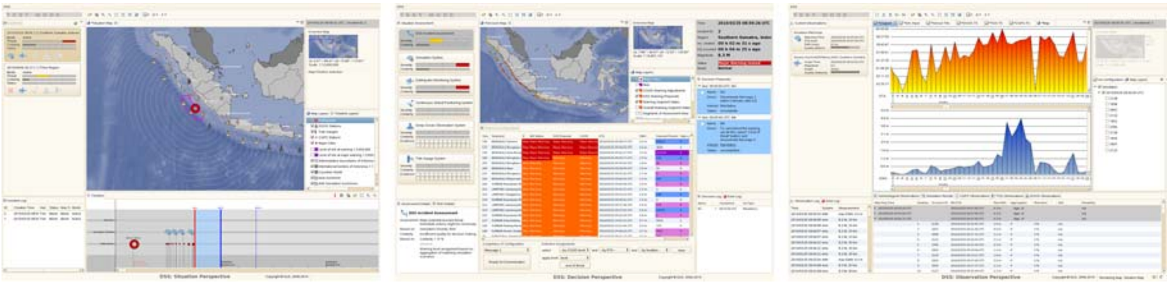

Figure 1. Three of four DSS graphical user interface screens.
From left to right: Situation Perspective, Observation Perspective, Decision Perspective

Each perspective groups a thematic set of modules called *views* serving the corresponding task. In order to provide visual consistency across all screens every perspective sticks to a general layout which defines a left-hand navigation area, map and other visualization modules, and areas for detailed textual information such as tables. Those layout predefinitions allow for an easier perception of the global picture at any time throughout the operation team and support workflows and standard operating procedures (SOPs).

The left-most *Situation Perspective* (SP) outlines the overall situation by means of a spatiotemporal overview map combined with a *Timeline View* which shows the sequential course of actions. The map visualizes geospatial sensor data such as the earthquake event location, wave-travel-time isochrones, thematic maps (e.g. borders, geologic realities) and sensor status information. The timeline adds temporal information on the arrival of measurements and simulation results, on decisions made and deadlines to be reached such as estimated times of arrival (ETAs). The *Observation Perspective* (OP) collects all incoming sensor data and SIM matching results for the purpose of a deeper analysis and reassurance. The *Decision Perspective* (DP) contains all information necessary for the decision-making including highly-aggregated situation assessment information, decision proposals and an interface for the configuration of warning products. A detailed description of the perspectives can be found in earlier publications (e.g. Raape, 2010).

As a main goal, we wanted the operator to maintain a higher level of situation awareness (i.e. “big picture”, SA principle 4) without losing the possibility to gain sensor information in detail (*overview first, details on demand*). For this purpose, we tried to structure the user interface according to a multi-level data aggregation scheme and to establish a consistent navigation methodology between and within the screens.

The overall context of the four screens is defined by an *incident* which groups logical and system events and processes that belong to the same chain of events, e.g. the same potential tsunami monitored. Once the operator chooses to process an incident via pressing an *incident strip* (button) in the left-hand navigation of the SP he is provided with further lower-level information aggregation. Sensor observations are for instance grouped and aggregated to composite data such as maximum measured wave height according to sensor station, sensor system (e.g. earthquake monitoring system), or simulation system results.

User guidance is enhanced by the specified processing sequence from left to right screen which corresponds to the mentioned sequence of perception, comprehension, projection, decision and action. Furthermore, a clockwise high-to-low-level interaction paradigm has been implemented. The most aggregated information is located in the left part of each perspective whereas details can be explored on the right-hand side by pressing a strip in the left-hand navigation. Hence, the context of the OP (e.g. contents of tables) is changed by pressing an *observation strip* (e.g. representing a gauge station) in the left-hand navigation. Interaction between left and right is unilateral as contexts are changed via the aggregated elements only.

In order to allow the user to focus on his main tasks following SOPs in a short time frame he shall still be able to regain overview without making considerable interaction (SA principle 8). Thus, we tried to find a trade-off between filtering of information where beneficial and restricting the level of freedom where necessary to maintain or to reestablish easily the global picture. Zooming is for instance reduced by fix zoom levels in maps. However, as filtering can be a useful means to reduce cognitive effort we are currently working on filtering strategies such as showing the most relevant incidents (e.g. those with the highest magnitude and the smallest decision time budget) and hiding the less hazardous in the incident strip view.

2.2 Visualization of Uncertainty

Part of the global situational picture is the accuracy, timeliness, and reliability of information being displayed especially if the data are coming from multiple sources, or by their nature containing some inherent uncertainty such as noise. Unlike classical decision support problems, the combination of real-time sensor and pre-processed data, the generation of situation awareness and the assessment and proposing of decision options is a slowly evolving process. Due to the fact, that sensor information arrives in a non-deterministic irregular sequence, initially with considerable uncertainties, in arbitrary order and with major information gaps, uncertainties will still be present when deadlines for warning decisions are reached. Therefore, we evaluated on the one hand a row of presentation and mapping techniques to indicate missing information, likeliness of errors, quality and reliability. On the other hand, the DSS makes use of additional data such as pre-calculated simulation scenarios which describe the potential wave traversal culminating at the coastline in order to fill the gaps in the situational picture.

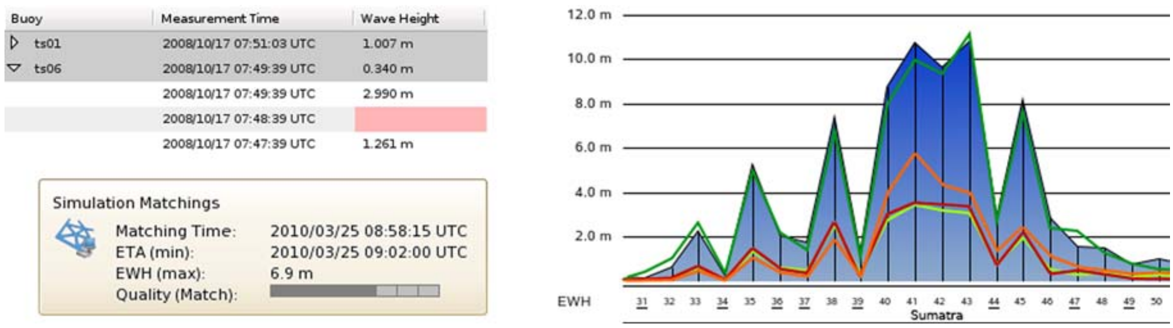

Figure 2: Uncertainty visualization examples. Top left: Buoy observation table extract with a pale-red cell indicating a missing wave height. Bottom left: Observation strip showing a fix-block certainty bar. Right: Simulation results visualization depicting the estimated wave heights (y-axis) for the coastline segments (x-axis).

Small-scale presentation techniques include for instance marking missing information with a pale-red color e.g. colored cell in table (see Figure 2) or colored sensor station in map which supports SA principle 9. In addition, we tried to map the versatile quality, error, and reliability information onto consistent values in the unit interval (value rises with amount of certainty) and to find an adequate visualization. There are several ways how inherent uncertainty can be visualized. One is by representing it separately whereas another is combining it into a visualization using for instance transparency, sharpness, or color (Pang, 2001). For a start, we decided to elaborate an independent classification bar visualization as depicted in Figure 2. A certainty value in the unit interval is mapped onto a bar which is subdivided into fixed blocks. The certainty mapping process is performed on sensor station level first, then aggregated on sensor system level and culminates in an overall DSS certainty level. This kind of large-scale uncertainty visualization discretely emphasizes sensor systems with incomplete or inaccurate information without making them the most prominent on the display (SA principle 11). In addition, it supports assessment of confidence in composite data (SA principle 13). On the one hand, the user is able to explore uncertainty information in detail by analyzing the small-scale information. On the other hand, the block categorization is an efficient means for the operator to assess and compare the reliability resp. credibility of sensors and sensor systems. Endsley and Kiris showed that a categorical (*high*, *medium*, or *low*) indication of system confidence in its recommendations led to slightly faster decision times when compared to numerical percentages or analog bars (Endsley, 1994).

By analyzing and appropriately visualizing the tsunami scenario selection which is performed with every new sensor data arrival significant uncertainty information can be revealed. The graph visualization in Figure 2 gives a short insight. The filled graph shows the estimated wave heights (y-axis) for all affected warning segments at the coastline (x-axis) based on an aggregation of the matched scenario list. The overlaid thicker graphs represent the ETAs of the single scenarios in the list. By combining single and aggregated results in one diagram the operator is able to assess the homo-/heterogenity of the result list and thus the quality of the matching. Details on our work on uncertainty mapping and result list visualization techniques will be presented in a separate publication.

2.3 Externalization of Information Timeliness

It's crucial for a time-critical early warning application to enable projections of future situations (SA principle 3). We do so by providing on the one hand explicit decision proposals which describe the required next steps, alternatives, and time budget. On the other hand, we use visual and behavioral patterns to facilitate recognition and assessment of temporal issues.

The timeline view shown in Figure 3 incorporates graphical elements for the differentiation between past and future such as a thick red line representing the current point in time ("Now"), important deadlines held in blue and a light blue area leading from the now-line to the first deadline (i.e. the due dissemination time). The "Now"-line is the counterpart of a thick red isochrone in the map which represents the current spatial position of the potential wave front. By graying out the background the area left of the "Now"-line is identified as past. That clustering of time helps to identify the available time frame at a glance. In case that the timeline is zoomed in by using the zoom control buttons in the top right corner, the overall context is maintained within a small abstract miniature of the timeline by the display of a gray counterpart of the currently visible area.

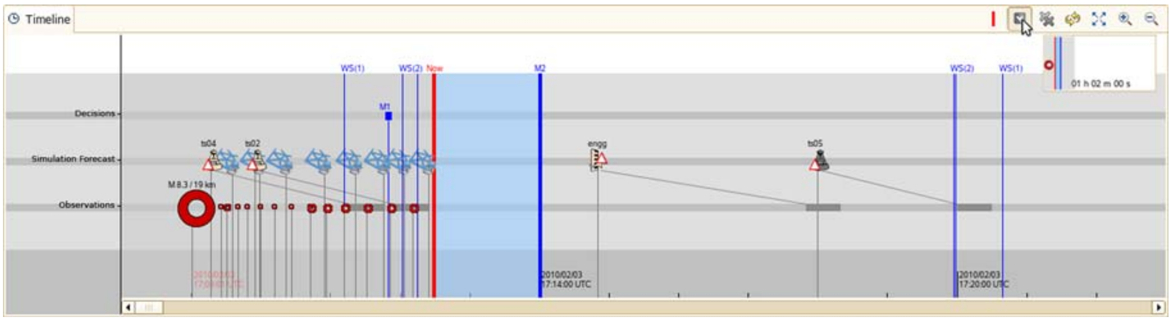

Figure 3: Timeline. Time proceeds from left to right. Deadlines appear in thick blue whereas the red "Now"-line represents the current point in time. Taken decisions are displayed above simulation results/forecasts. Incoming observations appear below. A timeline miniature in the upper right corner relates the visible area to the overall context.

By examining anticipated events placed in the future section of the timeline the operator is able to adjust his decisions. In case that a buoy or tide gauge sensor is expected to be reached shortly by the wave (sensor symbols on the *Simulation Forecast* lane) he can decide whether to wait for the likely sensor data update and substantiate his knowledge or to accelerate a warning action.

In continuous graph and timeseries visualizations depicting the measured gauge/buoy waveforms time generally proceeds from left to right throughout the user interface. More abstract information such as observation details listed in a table and condensed data as represented by strips are ordered according to the "newest on top" principle. People seem to weight information on the left hand side higher under time stress when presented in reading order (Endsley, 2003). Therefore, we have placed the most current information at the top of each information module. The *Observation Strip View* in the Observation Perspective for instance changes its ordering upon update. Once new sensor/system data is available the corresponding strip moves to the top indicating a data refresh and therefore risen sensor credibility.

The “left to right” and “newest on top” principles support sensor reliability assessment (SA principle 13) since the operator is quickly able to recognize time lags since the last data arrival, the frequency at which data is transmitted by a sensor, or the time he has left until the coastline is reached by the tsunami wave.

3. CONCLUSION

As part of GITEWS the Decision Support System deals with information quantity and quality which is novel in the context of early warning. The graphical user interface supports the operator in managing the multitude of real-time and pre-processed data in a short time frame with a global situational picture, clear decision process workflows, and a high degree of usability. Being deployed at the BMKG warning center in Jakarta, the DSS was tested during real significant earthquake events with regional tsunami impact among others the 7.6 magnitude event near Northern Sumatra on April, 6th 2010. The system’s behavior and user performance, acceptance, and feedback is continously examined in order to incorporate better solutions in the next design loops. Meanwhile, we’re facing new challenges such as the integration of the international early warning context into the national system in an intuitive and comprehensible manner which is entirely new in the tsunami domain. We are confident that due to its modular design and the ability to generate a high degree of situation awareness the DSS will be able to integrate additional sensor and tsunami scenario sources as well as being equipped for international coverage and multi-hazard scenarios in future.

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