The Decision Support System for improved Tsunami Early Warning in Indonesia: Approach and Implementation

T. RIEDLINGER, T. STEINMETZ, U. RAAPE, S. TESSMANN, M. WNUK, C. STROBL, E. MIKUSCH and S. DECH

German Remote Sensing Data Center (DFD), German Aerospace Center (DLR), Wessling, Germany – Torsten.Riedlinger@dlr.de

Abstract – As part of the German contribution to the Indonesian Tsunami Early Warning System InaTEWS, an innovative Decision Support System (DSS) has been developed in order to support the tsunami early warning process in a unique way. The paper describes the modular and open environment in which the DSS operates in, its main tasks and components, the Graphical User Interface (GUI) and the focus on standardization and interoperability which led the design and development of the DSS.

Keywords: Decision Support, Information Fusion, Tsunami Early Warning.

1. INTRODUCTION

In recent years numerous tsunami events in the Indian Ocean, and in particular along the Sunda Arc, have shown how vulnerable human society and the environment is to this sudden-onset type of disaster. Especially the December 2004 tsunami demonstrated the need for an effective tsunami early warning system for the Indian Ocean. 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.
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, the country most prone for tsunamis in the whole Indian Ocean. The system integrates terrestrial observation networks of seismology and geodesy with marine measuring sensors, satellite technologies and pre-calculated simulation scenarios. GITEWS is the German contribution to the Indonesian Tsunami Early Warning System InaTEWS.

2. THE CHALLENGE OF TSUNAMI EARLY WARNING IN INDONESIA

What makes tsunami detection for Indonesia unique and challenging is on the one hand the extremely short time window between tsunami generation (in most cases caused by an earthquake along the Sunda Arc) and the arrival time at the nearest Indonesian coastline, and on the other hand the lack of sensor technologies that detect and measure tsunamis as such. While promising technologies are being worked on that might allow holistic tsunami detection in the future, the GITEWS project uses the best sensor technologies available today to detect indicators or evidence for a tsunami, combining those information with up-to-date modelling techniques and integrating them in a newly developed Decision Support System. Combining a-priori knowledge, simulation runs and analysis results with real-time information from different types of sensors, the GITEWS Decision Support System (DSS) serve as a back-bone to allow an assessment for the tsunami threat at the earliest time possible and support the decision maker whether to issue a tsunami warning or not.
Unlike classical decision support problems, the process of combining sensor and additional information, generating situation awareness and assessing and proposing decision options is a slowly evolving process. Due to the fact, that sensor information becomes available 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.

3. THE EARLY WARNING AND MITIGATION SYSTEM

GITEWS´ novel “system of systems” concept is based on a modular and extensible architecture of different systems deployed in the BMKG Warning Center in Jakarta as part of the GITEWS Early Warning and Mitigation System (EWMS) / InaTEWS Earthquake Information and Tsunami Warning System (EITWS). Figure 1 show the EWMS concept which consists of following elements:

- A sophisticated Earthquake Monitoring System (SeisComP3 by GFZ Potsdam) collects data from seismic sensors in the region and worldwide in real-time and is able to detect and locate earthquakes very quickly;
- A continuous GPS System (CGPS) describes the seafloor deformation/rupture in (near) real-time based on very precise GPS measurements at smart land stations (stations equipped with GPS and other sensor technology).
- A Deep Ocean Observation System (DOOS) collects and processes sensor information transmitted from Ocean Bottom Units (OBUs, located on the seafloor underneath buoys) and Buoys equipped with tsunami-detecting instruments.
- A Tide Gauge System (TGS) collects and processes measurements of a network of tide gauges in order to detect sea level anomalies.
- An interface to future Earth Observation systems is provided.
- A central Tsunami Service Bus (TSB) collects information from the sensor systems and provides them to the DSS.
- A Simulation System (SIM) is able to perform a multi-sensor tsunami scenario selection, resulting in a list of best matching tsunami scenarios for a given set of observations.

The Decision Support System (DSS) receives sensor observations via the TSB, requests a scenario selection from the SIM for the current set of sensor observations and communicates with the dissemination systems for message distribution and delivery.

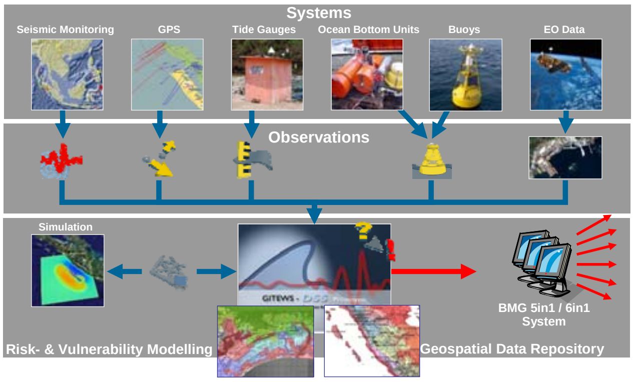

Figure 1. The Early Warning and Mitigation System Concept.

4. THE DECISION SUPPORT SYSTEM

As part of the Early Warning and Mitigation System (EWMS) the DSS is providing processing, assessment, visualization, decision support, analysis, warning and management functions for the purpose of supporting disaster management related activities regarding tsunami threats for the region of Indonesia.

Operational Prerequisites

In principle, the spatial situation awareness analysis and early warning process does not require shoreline segmentation, except when limited computational resources require aggregation and priorization or when mapping products to recipients or administrational structures.
A so-called Warning Segment is a well-defined segment of the shoreline defined according to administrational boundaries and is used as smallest warnable unit for which tsunami threat information is aggregated and to which warning products may be addressed.
A coastline segmentation workflow has been developed by BMKG and DLR; the current definition of warning segments for the coastline of Indonesia along the Indian Ocean covers 125 warning segments for Sumatra, Java and Bali (see Figure 2).

Figure 2. Warning Segments.

Warning segments can be set to specific states which are called warning levels in connection with the dissemination of warning products (e.g. warning messages). The warning levels depend on the expected or confirmed tsunami threat. Which warning level is assigned during the decision proposal generation process depends mainly on the height of wave at the coastline.

Table 1. Tsunami Warning Levels

Tsunami Category	Warning Level	Wave Height (WH) Range [m]	Color
<none>	<none>	0,0 ≤ WH < 0,1	Grey
Minor Tsunami	Advisory	0,1 ≤ WH < 0,5	Yellow
Tsunami	Warning	0,5 ≤ WH < 3,0	Orange
Major Tsunami	Major Warning	3,0 ≤ WH	Red

Wave heights of larger than 10cm are considered to require a warning level of Advisory (yellow). Warning segments which reach wave heights from 0.5 m up to 3 m are assigned a Warning level (orange level). Warning segments with a wave height of 3 m or more are assigned the level Major Warning (red) (see Table 1).

4.2 Core DSS Tasks

The decision process shall help the chief officer on duty (COOD) being aware of a current situation and assesses incoming information, exploit synergies of information fusion and analysis, assess impact and consequences and make informed decisions.
Unlike many other decision problems covered in the area of decision support, the situation evolves over a certain period of time, and the decision process itself must be time and space sensitive due to nature of the underlying physical phenomenon which may threaten widely dislocated places over a time period of several hours.
The core decision support loop consists of two major components (see Figure 3):

- *Situational Awareness*
- *Decide and Act*

Situation awareness in turn comprises the steps *perception* (gather information), *comprehension* (judge information) and *projection* (effect estimation / projection).

In the perception step the DSS receives sensor input, including results from the simulation system. Following the sensor input will be processed and analyzed. In the comprehension step there is further analyzing of sensor input across sensor types. The projection step comprises the projection of the current situation into the future. An assessment of consequences takes place. These three steps effect an improvement of situation awareness. While situation awareness focuses on understanding the situation that evolves and its consequences, this knowledge needs to be transformed in decisions and actions which is the focus of the second part of the core decision support loop:

- *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 COOD has made. Examples for such decisions are product dissemination or sensor (de-)activation.

The workflow is repeated each time new information is received by the DSS or a deadline has been reached. The workflow is terminated by the COOD if no tsunami threat exists anymore.

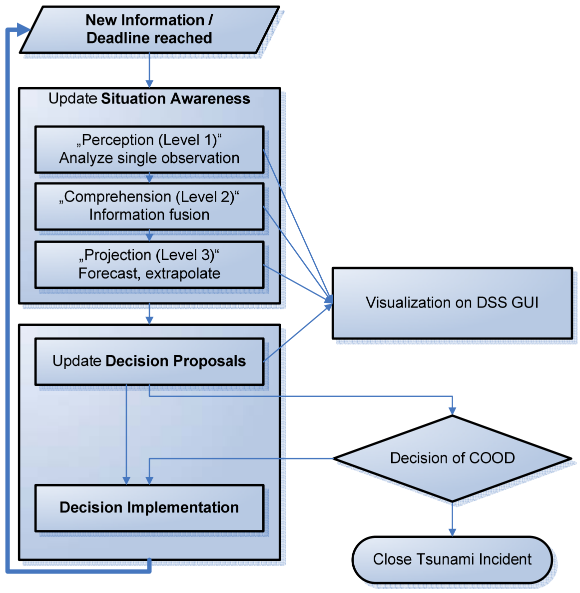

Figure 3. Core Decision Support Loop

4.3 Different Cases, Different Workflows

The DSS must be able to deal with a wide variety of possible situations:

- Is the earthquake inside the Area of Interest (AoI)?
- Is the earthquake on land so that tsunami generation is neglectable?
- If the earthquake is on sea and potentially tsunamigenic, is it in the area where simulation/modeling results are available (Area of Simulation Coverage, AoSC) to support prediction of arrival times and wave heights?

Depending on the answers to these and additional questions, different workflows have to be triggered and different Standard Operating Procedures (SOPs) have to be followed (see Fig. 4 for an overview of major cases).

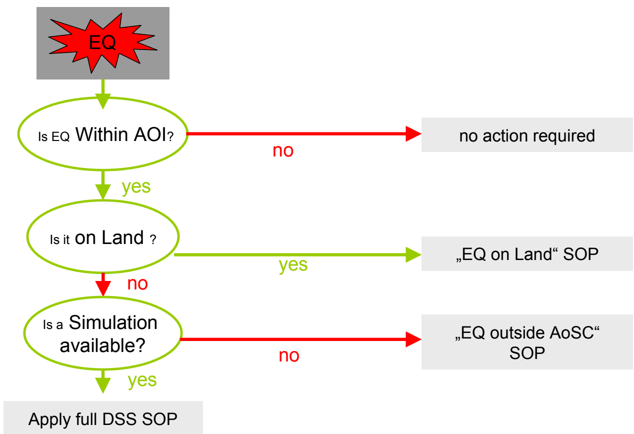

Figure 4. Main Classification of Cases

In Fig. 5 an example workflow is depicted for an earthquake within the AoI and on sea where simulation scenarios are available.

Currently the DSS supports not only tsunami cases, but also earthquake cases where no tsunami threat exists, but SOPs need to be followed (e.g. earthquake information need to be disseminated).

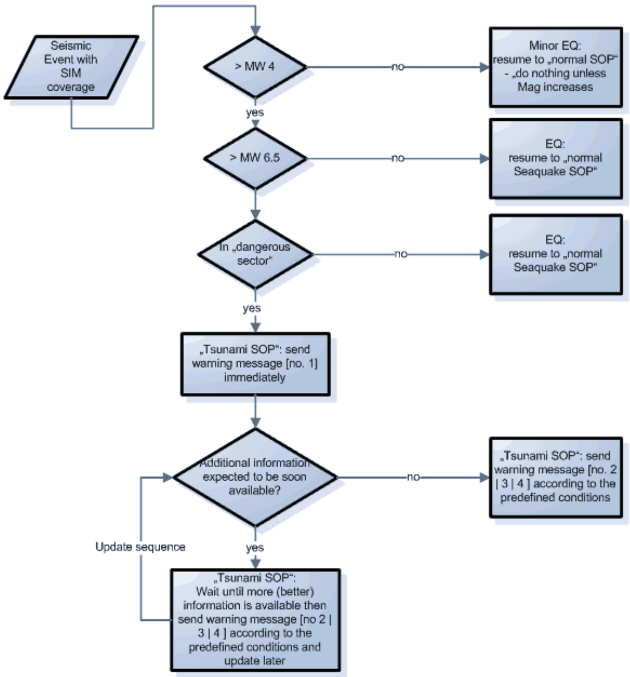

Figure 5. Example DSS workflow

4.4 Sources of Information

In addition to the collection of real time sensor observations, the DSS can access a huge collection of a-priori information and scenario data that helps interpreting the online input, assessing the tsunami threat and forecasting the consequences.

Using this approach, the information gap immanent to the first minutes of a potential tsunami is narrowed as much as possible.

The most important sources of information are

- A geospatial data infrastructure which allows the standard-based access to large databases of geospatial baseline data, such as administrational boundaries, topographic and bathymetric data etc.;
- Risk modeling and vulnerability assessment information which describe how high the tsunami risk at a particular location is and how vulnerable the people and infrastructure are there;
- The large number of tsunami scenarios contained in the Tsunami Scenario Repository (TSR) which is used by the SIM to perform the multi-sensor-scenario selection process.

Details about these sources and components are described in separate papers.

4.5 Graphical User Interface (GUI)

The user interface and process workflows of the DSS have been designed for decision making under uncertainty and time pressure [Endsley et.al. 2003]. Based on the large body of research literature on this topic and the results of an eye-tracking based study regarding a first DSS GUI version, it is now available in an improved and optimized version. The GUI consists of four displays (called perspectives) shown simultaneously to the decision maker (called chief officer on duty, COOD). The Situation Perspective illustrates the overall situation including higher-level spatial and temporal views of all facts of interest (e.g. observations, simulation forecasts, sensor system states).

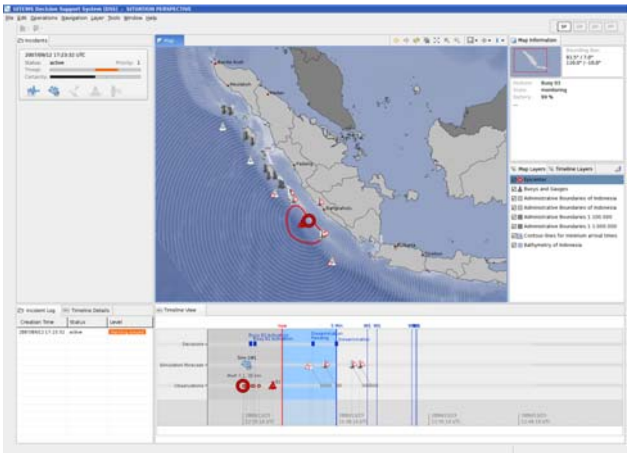

Figure 6. DSS Situation Perspective: Situational Overview

For this purpose, a map view acts as spatiotemporal information display visualizing geospatial sensor data such as the event location, travel-time isochrones, estimated times of arrival (ETAs), thematic maps (e.g. borders, geologic realities), and sensor status information. A timeline view maps the incident data onto a temporal scale (see Figure 6). All incoming observations (i.e. seismic, GPS, buoy, tide gauge) and simulation results that are relevant for the selected incident are displayed in detail in the Observation Perspective. In addition, the user is provided with functionality to further explore single observations e.g. to view parameters, time series, plots, etc. (see Figure 7).

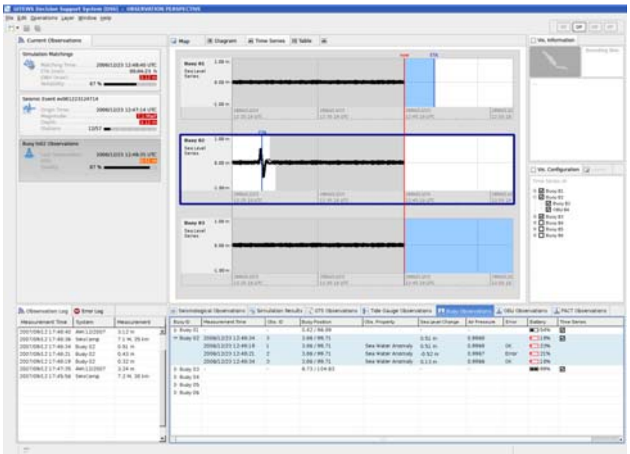

Figure 7. DSS Observation Perspective: Incoming Data in detail

4.6 Standards and Interoperability

A lot of effort is put into compliance to Interoperability Standards defined by Open Geospatial Consortium (OGC) for geospatial and sensor data. In particular the OGC initiative "Sensor Web Enablement" (SWE) that aims at defining standards to enable the discovery, exchange, and processing of sensor observations, as well as the tasking of sensor systems is applied in the context of GITEWS.
Within the context of GITEWS SWE will be used, where applicable, to integrate the various external sensor systems with the EWMS. This especially makes sense when additional sensors become available in the future, e.g. new tide gauge or buoy systems or even remote sensing or airborne sensor systems. By adhering to these standards GITEWS will remain open and extensible in the future.
The warning messages generated by the DSS are also provided in the Common Alerting Protocol (CAP) format, an open standard for disaster management message exchange [OASIS 2005, Incident 2008].

5. CONCLUSIONS AND OUTLOOK

As part of the German contribution to InaTEWS and embedded in an open and modular "system of systems" approach capable of integrating additional sensor and tsunami scenario sources, the Decision Support System presents a novel approach to support the tsunami early warning process. The decision maker is able to assess the situation and take decisions in a manner and based on information quantity and quality not possible before. The extension paths of the DSS are numerous, reaching from additional sensor and data sources to international coverage and functional extensions.

REFERENCES

Endsley, M.R.; B. Bolté, D.G. Jones (2003). *"Designing for Situation Awareness"*. Taylor and Francis, Boca Raton

OASIS (2005). *"Common Alerting Protocol, v.1.1"*. Oasis Standard CAP-V1.1, October 2005. Incident (2008). *"The CAP Cookbook"*. Online resource at http://www.incident.com/cook-book/index.php/Creating_CAP_Applications

ACKNOWLEDGEMENTS

GITEWS is being developed by a number of scientists and engineers of the Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences (GFZ, Project Lead), the Alfred Wegener Institute for Polar and Marine Research (AWI), the German Aerospace Center (DLR), the GKSS Research Centre (GKSS), the German Marine Research Consortium (KDM), the Leibniz Institute of Marine Sciences (IFM-GEOMAR), the United Nations University Institute for Environment and Human Security (UNU), the Gesellschaft für Technische Zusammenarbeit (GTZ) and the Federal Institute for Geosciences and Natural Resources (BGR) as well as Indonesian and international partners. The project is funded by the German Federal Ministry for Education and Research (BMBF), Grant 03TSU01.