DECISION SUPPORT FOR TSUNAMI EARLY WARNING IN INDONESIA: THE ROLE OF STANDARDS

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Abstract
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 and is a major contribution to the Indonesian Tsunami Early Warning System (InaTEWS) which has been inaugurated by the President of the Republic of Indonesia on November 11th, 2008. The system integrates terrestrial observation networks of seismology and geodesy with marine measuring sensors, satellite technologies and pre-calculated simulation scenarios. The GITEWS sensor systems integrate the respective sensor information and process them to aggregated sensor observations in real-time. The processed information from all these sensor systems is transmitted to the GITEWS Decision Support System (DSS) for further processing, analysis and decision support.
The paper describes the application of standards defined by the Open Geospatial Consortium (OGC) within the GITEWS context for integrating external sensor observation data as well as within the DSS for access to huge geodata, risk and vulnerability and sensor databases using an internal SDI. Especially the OGC Sensor Web Enablement (SWE) framework plays a major role in sensor data management. For map display and communication with the GITEWS simulation system OGC standards are applied, too. For warning message dissemination, the Common Alerting Protocol (CAP) standard is used to provide regionalized messages to numerous recipients.

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.

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 modeling 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) serves 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.

THE EARLY WARNING AND MITIGATION SYSTEM

GITEWS´ novel “system of systems” concept is based on an modular and extensible architecture of different systems deployed in the BMG 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 shows the EWMS concept which consists of following elements:

- A sophisticated Earthquake Monitoring System (SeisComP3 by GFZ Potsdam) collects real-time data from seismic sensors in the region and worldwide 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.

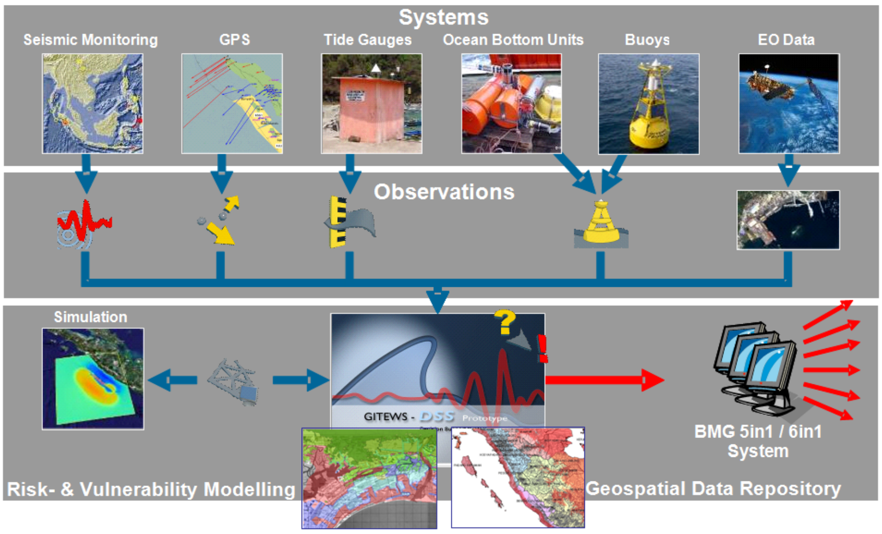

Figure 1. The Early Warning and Mitigation System Concept

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. This section will describe the resulting system requirements and solution approaches.

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 BMG 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.

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.

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

Table 1. Tsunami Warning Levels

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).

Core DSS Tasks

The decision process shall help the chief officer on duty (COOD) to become aware of a current situation, assess incoming information, exploit synergies of information fusion and analysis, assess impact and consequences and make informed decisions.

Unlike many other 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:

- *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 result in an improvement of situation awareness. While situation awareness focuses on understanding the situation that evolves and its consequences, this knowledge needs to be transformed into decisions and actions. This 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.

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.
- The large number of tsunami scenarios contained in the Tsunami Scenario Repository (TSR) which is used by the SIM to perform the online multi-sensor-scenario selection process.

Graphical User Interface (GUI)

The user interface and process workflows of the DSS have been designed for decision making under uncertainty and time pressure [1]. 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 (see Figure 2) consists of four displays (called perspectives) shown simultaneously to the decision maker (COOD). The DSS GUI was implemented as a set of plugins and extensions to the the uDIG Open Source GIS client.

The Situation Perspective (Figure 2, upper left) illustrates the overall situation including higher-level spatial and temporal views of all facts of interest (e.g. observations, simulation forecasts, sensor system states). 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. All incoming sensor observations and simulation results that are relevant for the selected incident are displayed in detail in the Observation Perspective (Figure 2, upper right). In addition, the user is provided with functionality to further explore single observations e.g. to view parameters, time series, plots, etc.

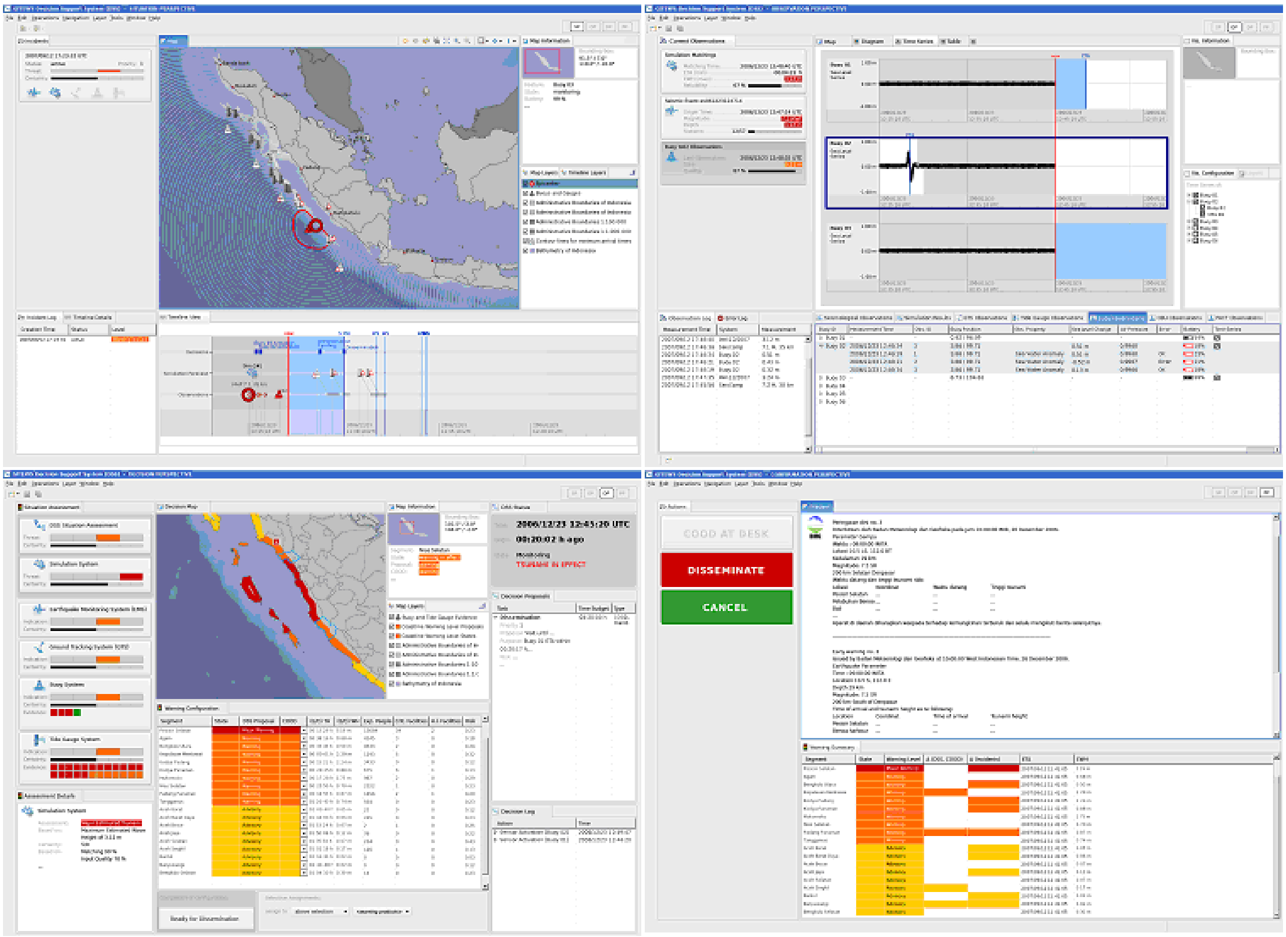

Figure 2. DSS Graphical User Interface (GUI) Perspectives.

The Decision Perspective (Figure 2, lower left) contains all information that is necessary for the COOD decision making process, including decision proposals and functionality for the configuration of warning products. This includes highly-aggregated classification bars for the individual sensor systems and the SIM to support the COOD in assessing the situation. A color code is used to represent the conclusions which may be drawn on the basis of the corresponding observations. Centered, a segment map and a list display the warning product proposals for each warning segment based on the simulation results. A similar color code is used here to graduate the warning levels.

Additionally, indexes for risk-relevant information are shown for each of the affected warning segments: e.g. number of exposed people, number of critical facilities, number of high loss facilities, response index and an overall risk factor.

The COOD may override the warning product proposals generated by the DSS. If the selected warning products should be sent, the button “Ready for Dissemination” needs to be pressed. The actual execution/confirmation of actions is performed on a separate perspective where a product preview and a summary of the actions that are about to be triggered is shown (Figure 2, lower right).

The COOD is required to confirm his choice (“Disseminate” button) in order to prevent unintended warning message dissemination; alternatively, the dissemination process can be cancelled (“Cancel” button).

Warning Product Generation and Dissemination

Regarding the generation of warning and other products generated by the DSS, a template-based approach is applied. For all products and each of the formats and languages a product shall be provided, templates are prepared that contain fixed elements (e.g. text) and keywords. At the time of product generation, the keywords are replaced with up-to-date information of the tsunami threat (e.g. magnitude, depth and location of the earthquake, warning levels for warning segments).

The generation of products is a two-stage process:

- In stage 1 the required basic products are generated (e.g. text warning messages);

- In stage 2 these basic products are embedded into an additional message formatted according to the CAP standard [2].

Once the required products (warning messages) have been generated, they are transmitted to the dissemination systems which are connected to the DSS. Currently two dissemination systems are connected to the DSS: the BMG dissemination system / 5-in-1 system and the 2wcom FM-RDS based dissemination system. The DSS sends the appropriate selection of products to the individual dissemination systems and initiates thereby the dissemination process which itself is outside the scope of the DSS.

STANDARDS AND INTEROPERABILITY

A lot of effort is put into compliance to interoperability standards defined by the 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 as a basis for integrating the various external sensor systems with the EWMS and to offer sensor observation data to DSS components for further processing. 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. For accessing geospatial information by the DSS GUI the established OGC standards Web Mapping Service (WMS) and Web Feature Service (WFS) are also used.

OGC Sensor Web Enablement (SWE)

For realizing the DSS sensor data center (SDC) presented here the SWE architecture specified by the OGC is an important foundation. Thus this section will shortly introduce the basics of the OGC SWE framework and will provide an introduction into those SWE components which were used for building the sensor data center.

The activities of the OGC, an international consortium consisting of more than 350 members, focus on the development of open standards that form the basis geospatial data infrastructures. Within these activities the SWE initiative deals with the integration of sensors and sensor data. In order to fully integrate sensors and their data into a geospatial data infrastructure the SWE framework provides a broad range of functionalities [4]. This includes the discovery of sensors and sensor data, the description of sensor metadata, access to sensor data (real time and historic), tasking of sensors and alerting mechanisms based on sensor measurements. For fulfilling this set of requirements a framework of standards has been developed. It comprises two aspects: the information model dealing with data formats and the service model describing service interfaces. The information model consists of the following standards:

- Sensor Model Language (SensorML): Metadata format for sensors and sensor systems
- Observations and Measurements (O&M): Data format for observations and measurements performed by sensors
- Transducer Markup Language (TML): Data format, optimized for data streaming, that allows encoding sensor data and metadata

The SWE service model provides standardized interfaces for accessing sensor data, alerting and controlling sensors:

- Sensor Observation Service (SOS): Pull based access to sensor data and metadata
- Sensor Alert Service (SAS): Alerting based on sensor data and user defined criteria (for example if a measurement value exceeds a certain threshold)
- Sensor Planning Service (SPS): Controlling sensors and their parameter
- Web Notification Service (WNS): Asynchronous communication between web services (e.g. a SAS or SPS) and/or clients.

For the DSS sensor data center two of the above mentioned standards are of special importance: the O&M and SOS standards. Thus these two specifications will be introduced in more detail in the next two paragraphs.

The O&M specification [5] defines a standardized format for observation and measurement results. It is based on the OGC Geography Markup Language (GML) as it specifies a GML application schema. The basic concept within O&M is the observation which is defined as an event that occurs at a certain point in time and which generates a value for an observed phenomenon. Besides time and value of measurements, O&M allows encoding further measurement properties like information about processes used for obtaining measurements or the location and quality of observations.

Another important concept of O&M is the binding of measurements to features of interest (FOI). These FOIs are used for describing the objects or the measurement locations (= features) at which the measurement was performed.

Whereas O&M describes the data format for sensor data, the SOS specification [8] standardizes an interface for accessing data gathered by sensors and sensor metadata [6]. Thus the SOS relies on O&M as a response format for returning measurement data (for sensor metadata SensorML is mostly used). The SOS specification is divided into three profiles: core profile, transactional profile and enhanced profile. Whereas the operations of the core profile comprise the mandatory functionality the operations of the other profiles are optional. The core profile provides the essential functionality of a SOS: access to a description of the service and the available data (GetCapabilities), access to measurement data (GetObservation) and retrieval of sensor metadata (DescribeSensor). For inserting data into a SOS instance the transactional profile provides the necessary operations: registering sensors (RegisterSensor) and inserting sensor data (InsertObservation). Finally, the enhanced profile offers additional optional functionalities like retrieving FOIs or information about time dependent data availability.

DSS Sensor Data Center (SDC)

The Sensor Data Center (SDC) is the core component of the DSS for ingestion of and provision of access to sensor data. The SDC is part of the DSS Data Management Center (DMC) which is responsible for managing all data relevant to the DSS operations (e.g. Crisis and Risk Products, Geospatial Data) and includes software components for ingestion and archive tasks. All incoming sensor observation data passes an ingestion process during which the data is validated, transformed into the DSS-internal O&M data model and forwarded to the SDC It provides mechanisms to store and access observation data as well as metadata about the used sensor systems. By implementing the open sensor web standards and models such as the SOS, O&M and SensorML specifications, it seamlessly integrates in the existing spatial data infrastructure (SDI).

The software components Feeder and SOS used in the SDC are further developments and adaptations of 52° North open-source SWE implementations.

Ingestion of observation data and sensor metadata into the SDC

In-situ observation data measured by the different sensor systems is sent to the SDC. After an ingestion component has verified and transformed the data it is forwarded to the Feeder component. This component acts as a Java Servlet and receives data transmitted through HTTP-POST. After validating the incoming data, the feeder determines the observation type. Depending on that type data is parsed and stored in a designated PostgreSQL database. All corresponding data, i.e. feature of interest (FOI), is being created and associated with the observation automatically. For each result element of such an observation a unique id will be generated that is returned to the plugin together with the corresponding pickup point for later service access to this specific observation.

The ingestion of SensorML data works analogous, but stores incoming SensorML files directly in a certain directory in the file system and not in a database. In both cases the SOS is being notified that new data is available by the Feeder components to update its service metadata.

Providing Observation Data and Sensor Metadata

Provision of observation data and sensor metadata is realized by a SOS. The service supports the implementation specification 1.0 (OGC 06-009r6) as defined by the OGC. Observation data is encoded using the O&M standard 1.0 (OGC 07-022r1). The SOS provides the operations defined in the core profile such as GetObservation, DescribeSensor and GetObservation. Furthermore it offers the GetFeatureOfInterest and GetObservationById operation as defined by the enhanced profile. The implementation is based on the data access object (DAO) pattern [7] and supports an implementation for a PostgreSQL database. Since the SOS runs as a Java Servlet, too, it is capable of receiving HTTP-GET and -POST requests. Incoming requests are analyzed and translated into SQL queries. After execution of these queries the response is encoded using the Geography Markup Language (GML) for feature requests or O&M for observation requests. SensorML documents are returned directly as stored in the file system and associated with the requested procedure. The SOS interface offers the possibility to query observation data by id or allows applying certain filters such as temporal or spatial constraints. Due to performance issues there is one SOS instance for each observation type.

Access to Observation Data

One of the main advantages of the applied OGC standards is having a unified access layer for the retrieval of spatial data which can be reused by server-side components as well as the GUI. Access to spatial data is realized in GITEWS by using uDig GIS. A plugin based on the 52° North OWS Access Framework (OX-Framework) for uDig allows retrieving observation data from a SOS. It provides mechanisms for creating SOS requests and parsing the O&M responses of the service. The encapsulated data is transformed into the uDIG data model and therewith accessible for further actions.

Beside in-situ data of the sensor systems the SDC is also able to store and provide simulation results. These contain a huge collection of a-priory information with best matching tsunami scenarios for a defined set of input parameters.

Common Alerting Protocol (CAP)

The warning messages generated by the DSS are provided in the Common Alerting Protocol (CAP) format, an open standard for disaster management message exchange [3]. CAP defines a standard for alerts and notifications in the public warning domain independent of the hazard type and the technology used for transmitting warning messages. The CAP XML structure allows the inclusion of event data, text, images and geospatial references.

The DSS Dissemination Component offers services for creating, updating and disseminating Warning Products. For dissemination systems connected to the DSS that are able to parse CAP the message including related geospatial references is encoded and transmitted in CAP XML.

CONCLUSIONS AND OUTLOOK

As part of the German contribution to InaTEWS and embedded in a 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. The use of OGC standards for implementing the DSS Data Management Center has proven beneficial for comfortable data access and extensibility.

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Simon Jirka works as community leader for the Sensor Web group of the Open Source initiative 52° North. Furthermore he is also employed as a research associate at the Institute for Geoinformatics (IfGI) and holds a master degree in geoinformatics. He is currently working on his Ph.D. His research activities focus on discovery mechanisms for sensor networks and on the simulation of autonomous sensor behaviour. At IfGI Simon Jirka is the project manager of the EU-funded projects OSIRIS and GENESIS, in which IfGI deals with the development of an interoperable architecture for sensor networks. Within the GENESIS project he is the work package leader for the technology research activities. In addition he is also involved in the Sensor Web Enablement initiative of the Open Geospatial Consortium (OGC) which aims at developing standards for the interoperable integration of sensor networks.

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