

Modeling and Integration of Severe Weather Advisories for Situational Awareness

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Abstract - Situational awareness systems rely on the integration of data and information from various sources. One key source is severe weather advisories. This paper discusses the information modeling of severe weather advisories from a number of countries to establish a common semantic framework. The goal is to enable effective integration of such critical information to lead to improved decision support for emergency and disaster stakeholders.

Keywords: information fusion, situational awareness, severe weather advisories, information modeling, standards, ontologies, architectures

1. Introduction

The disaster and emergency domain relies on effective information sharing regimes. However, information sharing in the disaster mitigation sector is difficult to coordinate due to the need to address the organisational issues as well as technical issues involved in such complex systems [1]. This poses great challenges to those that develop situational awareness systems across organisational boundaries.

Even what would be considered simple notifications for the disaster, incident, crisis, and emergency (DICE) sectors requires significant coordination of semantic definitions, messaging technologies, and standardisation processes [2].

However, the benefits of information sharing and exchange are critical to the DICE sector and form a significant part of the action priorities in the recent Hyogo Framework [3], including:

- “Support the development and improvement of relevant databases and the promotion of full and open exchange and dissemination of data for assessment, monitoring and early warning purposes, as appropriate, at international, regional, national and local levels”

- “Establish and strengthen the capacity to record, analyze, summarize, disseminate, and exchange statistical information and data on hazards mapping, disaster risks, impacts, and losses”

This paper will look at some of the information standards in the DICE area and their relevance to information fusion and situational awareness. A case study of modeling Severe Weather Advisories is discussed and used as an example for information integration with the use of ontologies and DICE architectures.

2. Emergency Information Standards

The OASIS Common Alerting Protocol [12] is a simple XML-based format for exchanging emergency alerts and public warnings over various networks and delivery mechanisms. The Common Alerting Protocol (CAP) is independent of any transport services and may be transferred using various Web Services or mobile technologies.

The primary objective of CAP is to provide a single view of alert information for internal and external warning systems. The normalised view can then assist in aggregating numerous CAP alerts into a single view for analysis. However, this depends on the level of semantics inherent in the values of the elements as well as the useful ability to merge certain elements.

Consider the below example taken from the National Oceanic and Atmospheric Administration's National Weather Service CAP feed (accessed 16-Dec 2005 from <http://www.weather.gov/alerts/fl.cap>):

```
<cap:info>
<cap:category>Met</cap:category>
<cap:event>Red Flag Warning</cap:event>
<cap:urgency>Unknown</cap:urgency>
<cap:severity>Unknown</cap:severity>
<cap:certainty>Unknown</cap:certainty>
<cap:effective>2005-12-15T19:28:00</cap:effective>
<cap:expires>2005-12-16T22:00</cap:expires>
```

```

<cap:headline>RED FLAG
WARNING</cap:headline>
<cap:description>
RED FLAG WARNING
NATIONAL WEATHER SERVICE TALLAHASSEE FL
228 PM EST THU DEC 15 2005
...A RED FLAG WARNING IS IN EFFECT FRIDAY
AFTERNOON FOR THE FLORIDA BIG BEND AND EAST-
ERN FLORIDA PANHANDLE DUE RELATIVE HUMIDITY
VALUES
BELOW 35 PERCENT FOR FOUR OR MORE HOURS...
. DRY AIR BEHIND A COLD FRONT THAT MOVE
THROUGH THE FORECAST AREA THIS AFTERNOON
WILL RESULT IN MUCH LOWER RELATIVE HUMIDI-
TIES. RED FLAG
CONDITIONS WILL ALSO BE POSSIBLE AT THE
COAST DUE TO OFFSHORE WINDS. INLAND
WALTON-HOLMES-WASHINGTON-JACKSON-BAY-CALHOUN
-GULF-FRANKLIN-GADSDEN-LEON-JEFFERSON-MADISO
N-LIBERTY-WAKULLA-TAYLOR-LAFAYETTE-
DIXIE-
128 PM CST THU DEC 15 2005 /228 PM EST THU
DEC 15 2005/...RED FLAG WARNING IN EFFECT
FROM 1 PM EST /12 PM CST/ TO 5 PM
EST /4 PM CST/ FRIDAY...
A RED FLAG WARNING IS IN EFFECT FROM 1 PM
EST /12 PM CST/ TO 5 PM EST /4 PM CST/ FRI-
DAY DUE RELATIVE HUMIDITY VALUES BELOW 35
PERCENT FOR FOUR OR MORE HOURS.
A RED FLAG WARNING MEANS THAT CRITICAL FIRE
WEATHER CONDITIONS ARE EITHER OCCURRING
NOW...OR WILL SHORTLY. A COMBINATION OF
WINDS AND
LOW RELATIVE HUMIDITY WILL CREATE EXPLOSIVE
FIRE GROWTH POTENTIAL.
</cap:description>

```

Clearly the text in the <cap:description> element contains information that is pertinent to the situation as well as the CAP message itself. The “Red Flag Warning” situation indicates critical fire weather conditions. However, the key and mandatory CAP elements of <urgency>, <severity>, and <certainty> are set to “unknown” and hence, do not truly represent what is indicated in the message description. This may unfortunately lead to situations being ignored (or put on low priority) when the opposite may be warranted.

To some extent the CAP message in this example is being used simply as a transport mechanism for the original plain text found in the <description> element. Unfortunately, this then does not exploit the potential processing of the rich XML structure.

The emerging OASIS Emergency Data Exchange Language [13] is focussed on being a general incident notification distribution structure. The main Emergency Data Exchange Language (EDXL) structure is based on information to distribute and route the message, rather than the semantics of the message itself. In fact, a CAP message could be the payload of the EDXL structure. Again, EDXL does not specify the mechanisms for the

actual transfer of the messages, but focusses on the spatial, role and identified targets of DICE messages.

3. Information Fusion & Situational Awareness

Information Fusion and Situational Awareness are two terms used frequently to describe how various sources of data/information are used (ie integrated) to build a bigger picture of the current situation. Information Fusion is primarily focussed on the processes of integration. Situational Awareness takes these results and focusses on its representation for the end user to comprehend the current artifacts that contribute towards the incident state and projection of their status in the near future.

Information fusion has been defined by the well-known JDL Data Fusion Model via a number of levels:

- Level 0 - estimation of states of sub-objects
- Level 1 - estimation of states of discrete physical objects
- Level 2 - estimation of relationships among entities
- Level 3 - estimation of impacts

One of the basic principles of the JDL Data Fusion Model is that the data is based on estimation and a level of uncertainty. Some new work on the JDL Data Fusion Model [4] has proposed extensions for capturing quality control, reliability, and ontology extensions. However, others note [11] the difficulties faced by information fusion systems from the low number of positive instances that make it difficult to detect the critical instances of data which must then be based on partially invalid assumptions.

Today, we have a new generation of data exchange based on greater semantic assurance developed via consensus processes in standards consortia like OASIS, W3C, and the Open GeoSpatial Consortium. This is based on the proliferation of information standards across industries utilising the common XML syntax. For example, the Sensor Model Language (SensorML), CAP, and EDXL now reflect a higher level of understanding and requirements for information from sensor devices and information sources. The effect of this is an improvement in the quality of data from some of the lower levels of the JDL Data Fusion Model. Ideally, this would then imply the potential for higher JDL Levels to be achieved more effectively. This is in contrast with the “implicit assumption” that the “vast majority of the data to be mined will be in free text format” [6]. This however does not imply that situational awareness and information fusion will become easier, just that there are now newer challenges to the mechanisms and algorithms required.

4. Case Study: Severe Weather Advisories

When catastrophic severe weather approaches, such as Cyclones, Hurricanes, and Typhoons, the local weather centres produce and disseminate Severe Weather Advisories (SWA) containing current status and predicted outcomes. These advisories usually appear more frequently as the danger increases. The advisories are primarily unstructured text messages but usually follow a common pattern to their wording and layout.

The example below is a small extract from the US National Hurricane Center advisory for Hurricane Katrina (28 August 2005):

A HURRICANE WARNING IS IN EFFECT FOR THE NORTH CENTRAL GULF COAST FROM MORGAN CITY LOUISIANA EASTWARD TO THE ALABAMA/FLORIDA BORDER...INCLUDING THE CITY OF NEW ORLEANS AND LAKE PONTCHARTRAIN. A HURRICANE WARNING MEANS THAT HURRICANE CONDITIONS ARE EXPECTED WITHIN THE WARNING AREA WITHIN THE NEXT 24 HOURS. PREPARATIONS TO PROTECT LIFE AND PROPERTY SHOULD BE RUSHED TO COMPLETION.

The example below is a small extract from the Australian Tropical Cyclone Warning Centre for Cyclone Ingrid (9 March 2005):

A Cyclone WARNING is current for communities between Cape Grenville and Cape Flattery and extends inland across central Cape York Peninsula. A Cyclone WATCH is current for coastal and island communities on the eastern Gulf of Carpentaria between Weipa and Kowanyama. Ingrid has continued to weaken over the past few hours and is now classi-

fied as a category 3 tropical cyclone. The cyclone still poses a serious threat to far north Queensland with a very destructive winds near the centre and the potential to generate a dangerous storm tide.

To support better information fusion and subsequent situational awareness, SWAs will need to be formally modeled and represented in a machine-readable format. All of the SWAs from Hurricane Katrina (USA) and Cyclone Ingrid (Australia) were analysed and information models created from the core data and represented using UML. These are shown in Figure 1 (Katrina, USA) and Figure 2 (Ingrid, Australia). Additional SWAs from New Zealand, Fiji, and Hong Kong have also been modeled in this way.

As can be seen in the two SWA models, there are some key similarities and some key differences. Generally, both include metadata about the SWA itself, such as the number, date, time, and issuer. There are common entities such as Observation and Movement. And some entities are semantically the same, but use different terminology, such as Impact and Threat.

Both include the important entities of Watch and Warning but deal with them slightly differently. For example, in the Australian model there is an explicit cancellation of a warning or watch, but not always in the USA model. There are other subtle differences, such as the single Watch/Warning entities in the Australian model applying to multiple areas, whereas the USA model will have multiple Watch/Warning entities each applying to one general area.

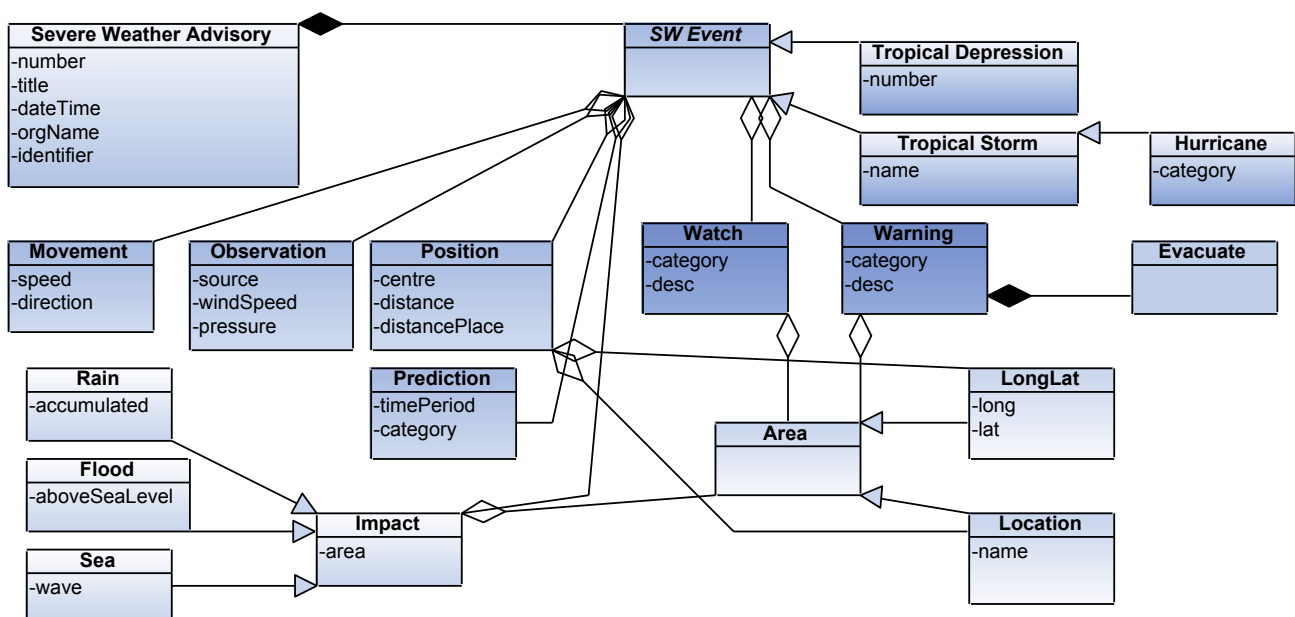


Figure 1: SWA Model (Katrina, USA)

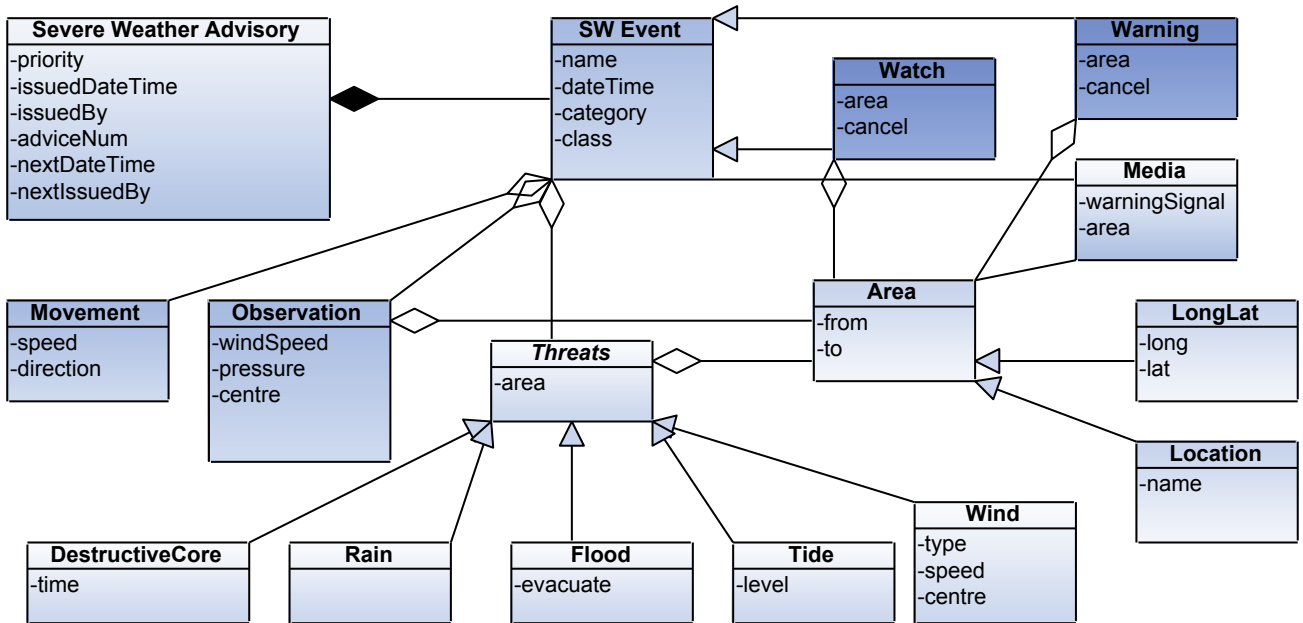


Figure 2: SWA Model (Ingrid, Australia)

There are also some features of each model that are unique to each, such as the Evacuate entity in the USA model and the Media entity in the Australian model. Also, the USA model focusses on the category of the SWA, such as Tropical Storm or Hurricane, whereas the Australian model focusses on warning and watches.

These two models are examples of formal representation of current information sources that play an important role in the DICE sector. The benefits of machine-readable SWAs then also allow for the SWA to be more readily mapped and/or converted for other purposes. For example, [5] describes some of the needs of local communities for weather information. Two of these include “plain English” warnings and “active warning images”. Both of these would now be possible with appropriate mappings of the model elements to plain English text fragments and specific images tailored for the local community.

5. SWA Integration

One of the challenges now is to integrate SWA instances. The first process is to produce an XML serialisation of the models. This is relatively straightforward with a mapping to XML Schema which then can be used to validate instances of SWAs.

Consider the simple scenario of merging two SWA instances, once from the USA model, and one from Australia. (For the purposes of this exercise we assume that this creates useful information, given that a hurricane in the USA is unlikely to impact Australia, and vice versa.)

In many cases, the integration is mechanical for parts of the model. For example, two XML fragments shown in Table 1 show Warnings that can be merged without any major semantic differences. This is assuming that the location elements use a well defined vocabulary, such as the Getty Thesaurus of Geographic Names (TGN), or long/lat values conforming to the same coordinate reference system, such as WGS84. In the examples in Table 1, either of these two options could easily be represented as attributes to the relevant elements. This would then inform the integration algorithm if any mapping or conversions would be required.

In this simple example, we are primarily appending information from different sources together, and ensuring that the end result is consistent in terms of the encoding schemes of the values. This will give us a more comprehensive view of the current state of the incident at a specific time point.

However, now consider a more complex scenario that aims at a comprehensive view across a larger time period. For example, there were over 60 public SWA issued over the 7 day period for Hurricane Katrina and 25 SWAs over 4 days for Cyclone Ingrid. What would be more useful in these cases for situational awareness is the ability to view the “differences” between SWAs to enable a progressive picture to be built up. This is potentially the greatest advantage to having machine readable SWAs.

Consider the six SWAs from Hurricane Katrina in Table 2 showing the Category, the Wind and Pressure observations, and the Rain and Flood predictions.

Table 1: XML Instance Examples

USA XML Instance	Australia XML Instance
<pre> <usa:hurricane> <usa:watch> <usa:category>Tropical Storm</usa:category> <usa:area> <usa:from> <usa:location>Key Largo</usa:location> </usa:from> <usa:to> <usa:location>Key West</usa:location> </usa:to> </usa:area> </usa:watch> </usa:hurricane> </pre>	<pre> <au:SWevent> <au:class>Severe Tropical Cyclone</au:class> <au:watch> <au:area> <au:from> <au:location>Cape Grenville</au:location> </au:from> <au:to> <au:location>Cooktown</su:location> </su:to> </au:area> </au:watch> </au:SWevent> </pre>

Now in a machine readable format, numerous visualisation techniques now can be used to present a clearer situational awareness picture. From Table 2, we can see the last 3 SWAs indicated a significant change in the Hurricane not only in the category and observations, but in the predictions. A challenge now would be to develop interfaces to present this information in a way that highlights these changes over time and presents this information to the user in an effective manner. This “difference” approach may be more useful and more graphical. For example, there was a significant jump in numbers from 7PM to 1AM in both the the wind speed and predicted flood levels. If this comprised the set of

Table 2: Katrina SWAs

Date Time	Cate gory	Wind (mph)	Rain (inch)	Flood (feet)	Pres- sure (MB)
27/8/2005 2AM	2	110	10	4	963
27/8/2005 5AM	3	115	10	4	945
27/8/2005 1PM	3	115	10	-	949
27/8/2005 7PM	3	115	15	12	944
28/8/2005 1AM	4	145	15	20	935
28/8/2005 7AM	5	160	15	25	908

critical data for alerting purposes, then an appropriate notification could be displayed and/or sent.

Ideally, it would be useful to move the SWAs into a single model, but this may end up resulting in missing information that is critical to certain geo-spatial and geo-political areas. With many models, the problem of integration becomes more tangible. A solution to this would be to investigate the use of more formal and generic ontologies.

Another advantage of using ontologies may be the ability to integrate across different types of alerts. For example, a multi-hazard approach may need to integrate SWAs with Tsunami warnings.

6. SWA Ontologies

The potential use of ontologies is widespread in the information fusion and situational awareness sector. The belief is that a formal more abstract layer of semantics can assist in defining and building the relationships with and between more concrete entities.

The SAWA ontology [7] is a high level framework that focusses on Objects, Relations and ending in a Goal. It is very abstract and provides core mechanisms to describe any basic Object with attributes and Relations with different Events. Quite clearly the SWA Models could be mapped to the SAWA ontology because of this generality.

For example, the SWA Rain class can be mapped to a SAWA Object and include the AboveSeaLevel SAWA attribute. This attribute could then be further refined with the SAWA Certainty Attribute Value.

The SNAP and SPAN basic formal ontology [8] are more specific to the DICE domain. The SNAP ontology

covers spatial items and the SPAN ontology covers temporal items. Both of these ontologies are very specific and include details on the concrete types in their domains.

For example, the SNAP ontology includes Civil Infrastructure (both Affected and Unaffected) such as Hospitals and Roads, including Evacuee and Casualty items. Additionally, there are Quality items such as Damage, and Capacity items, such as Transportation Systems. The SPAN ontology includes temporal items that could be Scattered or Connected and process items such as Delivery for Ambulances and the Growing or Shrinking of a Casualty Cluster.

Clearly, the SNAP/SPAN ontology is focussed on the DICE domain, as compared to the SAWA ontology which is more high-level and abstract in nature.

In order to usefully deploy ontologies for information fusion, a mapping needs to be created between the ontology items and models of the underlying information sources. Those that match to a degree of certainty could then be integrated or merged with some specific algorithms.

Consider the SWA-USA and SWA-AU models in which there are some exact matches between entities, and hence no ontological representation is required. In some other cases, there are “close” similarities between some entities that only differ in language. These latter entities could be mapped to ontological entities, then used in fusion processes.

Table 3 below indicates a first-pass mapping between similar items in the two SWA models and the representative ontological item in the SNAP/SPAN ontologies taken from [8] and [9].

Table 3: SWA and Ontology Mapping

SWA-AU	SWA-USA	SNAP/SPAN
Impact	Threat	Affected
Area	Area	SpatialRegion
Tide	Sea	?
Level	Wave	?

It is clearly not an optimal mapping as there are key concepts that are not yet defined in the ontologies. These missing aspects would need to map “tide” with “sea” and “level” with “wave”.

However, assuming that the mapping was complete and sufficient, then appropriate action can be taken on the values for these data sources. The longer term benefits of reasoning with more formal ontologies can then be in-

vestigated including ontology-based service profiles for the discovery and capability of such data sources [10].

7. SWA Architecture

Semantic messages like SWAs need to exist within a consistent platform across the stakeholder groups. There are some underlying core technologies required for this architecture [2] and we are now seeing such platforms being proposed that are specific to the DICE sector, such as the ORCHESTRA Reference Model Architecture [14].

The ORCHESTRA Architecture follows the standard Open Distributed Processing viewpoints. In particular, the Information Viewpoint is key for the semantics of SWAs. The basic concept is the *feature* where a feature is an abstract view of a real-world entity described by common characteristics. Features can then be instantiated for specific instances.

ORCHESTRA is heavily based on the ISO standards for Geographic Information and utilises UML as its modeling language. Clearly then, with the SWAs modeled in UML, there is a direct path enabling the SWAs to be cast as ORCHESTRA features if the underlying SWAs can be based on the schemas defined by the Geography Markup Language (GML).

The Information viewpoint includes meta-information models that are used to capture specific *purposes* that are scenarios of how the resources can be used for a particular goal. One such purpose is the Integration Purpose that would be useful for information fusion and situational awareness. The meta-information model for integration is based on service composition. That is, defining services that accept certain inputs and the outputs are then feed into another services. This orchestration defines the rules, service interfaces, and protocols that would be used across institutional boundaries.

The Information viewpoint discusses the use of domain ontologies as a starting point for supporting more advanced ontological behaviour. The outlined process is similar to typical object-oriented analysis with the result in a semantic web language. The use of UML and semantic web languages (eg RDF, OWL) may cause serious modeling issues as the two styles of modeling do not provide any clear transformations between them [15].

Much debate will need to occur on the use of ontologies for DICE-domain architectures, versus more “structured” views with XML Schema. In the case of SWAs, the direction and requirements need to come from the stake holders that dictate if architectures are to be built on XML Schema and/or Semantic Web technologies.

For example, [16] argues that “subsumption reasoning” is a benefit of the semantic web over XML Schema, but

the relevance of this semantic feature to the DICE stake holders needs to be balanced with the clearness of an architecture based on a structured XML information model.

8. Summary

This paper has discussed the development of a new information model for severe weather alerts based on analysis of real data from recent events around the world. The benefits of a machine-readable SWA are clear and obvious for information fusion and integration with other sources in building a picture for situational awareness.

Future work on the SWA models will involve completing the models for a number of other countries and development of XML serialisations. The latter would align well as an Application Schema of GML including following the OGC Observations and Measurements model. This would then have the added benefit of fitting into the development model for the ORCHESTRA architecture.

A major challenge will be the use of, and mapping to, appropriate domain ontologies for the DICE sector. There are many new proponents for this path, such as the LEAD Ontology based on the Semantic Web for Earth and Environmental Terminology (SWEET), but it does put at risk the simplicity and the deployability of such implementations.

Early warning and multi-hazard approaches are becoming crucial in the mitigation of natural and human-made disasters. The information used in these scenarios need robust models and machine-readability to provide effective decision support. SWAs are a key contributor to equation and standardisation of the semantics and structure are warranted.

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