CITIZENS AS SENSORS FOR CRISIS EVENTS: SENSOR WEB ENABLEMENT FOR VOLUNTEERED GEOGRAPHIC INFORMATION

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ABSTRACT:
A set of developments within the field of geosensors is to engage citizens to act as sensors, thus providing so-called Volunteered Geographic Information (VGI). There is a long tradition of non specialists contributing to the collection of geo-referenced information. Furthermore thanks to recent convergence of greater access to broadband connections, the availability of Global Positioning Systems at affordable prices, and more participative forms of interaction on the Web (Web 2.0) vast numbers of individuals are able to create and share geographic information. The potential of up to 6 billion human sensors to monitor the state of the environment, validate global models with local knowledge, contribute to crisis situations awareness and provide information that only humans can capture (e.g. emotions and perceptions like fear of crime) is vast and has yet to be fully exploited. However, integrating VGI into Spatial Data Infrastructures (SDI) is a major challenge, as it is often regarded as insufficiently structured, documented or validated according to scientific standards. Early instances of SDIs used to have limited ability to manage and process geosensor-based data (beyond remotely sensed imagery snapshots), which tend to arrive in continuous streams of real-time information. The current works on standards for Sensor Web Enablement (SWE) aim to fill this gap. This paper shows how such SWE standards can be applied to VGI, thus converting it in a timely, cost-effective and valuable source of information for SDIs. By doing so, we extend previous works describing a workflow for VGI integration into SDI and further advance an initial set of VGI Sensing and event detection techniques. In particular, an example of how such VGI Sensing techniques can support crisis information system is provided.

INTRODUCTION

Since Web 2.0 provided Internet with colloquial read-and-write functionality, the quantity of digital information accessible online is growing at an overwhelming rate. As a consequence, scientists are faced with a 'data tsunami' from which it is increasingly arduous to extract valuable information (Shah et al. 2010). When this online information created by users has a geospatial reference, it is known as Volunteered Geographic Information (VGI – Goodchild 2007).

This paper contributes to the advance of VGI Sensing, an emergent research field, which aims at designing a set of standards and techniques to streamline geo-referenced contents published online by citizens as a valuable and timely source of spatio-temporal information (De Longueville et al. 2010b). Indeed such techniques are necessary to harness the potential of up to 6 billion human sensors to monitor the state of the environment, contribute to situation awareness for crisis, validate global models with local knowledge, and provide information that only humans can capture (Goodchild 2007, Jones 2009).

SDIs are expected to be increasingly able to manage and process geosensor-based data (beyond remotely sensed imagery snapshots), which tend to arrive in continuous streams of real-time information (Annoni et al. 2010). The current works on standards for Sensor Web Enablement (SWE) are aiming to fill this gap (Botts et al. 2008).

Just as we readily accept the processing of satellite data as an input to many geospatial analyses, we should also aim to better interpret the abundant and freely available signals provided by citizen-sensors (De Longueville et al. 2009). Sensor Web Enablement of VGI would be a major step in that direction. This paper aims at further studying how SWE concepts and standards could be applied to VGI in order to convert it in a timely, cost-effective and valuable information source for SDIs.

The remainder of this paper is structured as follows. In section 2, related works are outlined, and the process of streamlining VGI into SWE is detailed into section 3. An example of such integration is then described (section 4) and finally discussion and conclusion points are provided (section 5).

RELATED WORKS

1.1 Sensor Web Enablement

In order to improve interoperability between crisis management systems and sensor networks, the Open Geospatial Consortium (OGC)[1] provides standards for web-based SWE (Botts et al. 2008) run through a series of 'interoperability test-beds' from 2002 to the present. SWE provides a well structured framework, it is based on open standards, and it has a growing user community.

[1] http://www.opengeospatial.org/

The goal of SWE is to develop an architecture and supporting standards for distributed services related to sensors and observations. The key elements are:

- Sensor Observation Service (SOS – Na and Priest 2007, Bröring et al. 2010), a web interface for requesting observation data;
- Sensor Planning Service (SPS – Simonis 2007, Simonis and Echterhoff 2010), a web interface for tasking sensors;
- Sensor Event Service (SES – Echterhoff and Everding 2008) allows clients to subscribe to events, i.e. enables push-based communication; it generalizes over the Sensor Alert Service (SAS – Simonis 2006);
- Sensor Model Language (SensorML – Botts and Robin 2007), a model and encoding for describing sensors and sensor systems); and
- Observations and Measurements (O&M – Cox 2008, 2010a, 2010b), a model and encoding for observations and their specific metadata.

SWE is domain- and discipline-neutral and was designed and tested for in-situ, ex-situ and remote observations. The O&M information model is based around the notion of an observation event, and scopes the operation signature of SOS, using the key terms *procedure*, *observed-property*, *feature-of-interest* and *result*. The values of any of these may be highly structured internally, and in many contexts be sets or arrays of more primitive elements. The separation of the feature of interest, observation (event) and result are the keys to enabling O&M to support the different use cases, and the appearance of an explicit observed property and feature of interest are the keys to observation semantics and cross-domain information discovery and fusion. Furthermore, as the observed-property should be related to the type of the feature of interest, a data processing chain is also connected to a sequence of transformations of these.

Expressing VGI as a SWE application is essentially a matter of mapping the elements of a SWE system to the notions listed above. Such work on the human sensor web is ongoing. Jürrens and colleagues for example propose SES-based filtering and SOS-based storage of user contributed content that is represented in O&M (Jürrens et al. 2009). We follow a similar approach, but emphasizing the added value for the chain of geospatial information processing.

1.2 VGI: a Great Potential to be Harnessed

Different approaches describe the use of hybrid methodologies to integrate bottom-up and top-down methodologies where user generated information, scientific tools and official information (Jankowski 2009) can be integrated in the same geospatial infrastructure. In this context merging the top-down SDI model with VGI geo-infrastructures model is described in (Craglia 2007, Goodchild 2007, Gould 2007).

There is nowadays a growing consensus to recognize the role of VGI in support to crisis management activities. Numerous case studies stressed the added value of using VGI in various types of crisis events, such as earthquakes (De Rubeis et al. 2009), forest fires (De Longueville et al. 2009), political crises (Bahree 2008), hurricanes (Hughes and Palen 2009), floods (De Longueville et al. 2010a), and terrorist attacks (Palen et al. 2009).
However, quality concerns may mitigate the enthusiasm VGI raises. Data quality has been recognized as a major concern (Elwood 2008) resulting in a lack of credibility. Flanagin and Metzger (2008) argued that the credibility issue of VGI is mostly due to the apparent lack of control of the data creation process. In addition, the same authors argue that in the data abundance context that characterizes VGI, traditional mechanisms that tend to increase trust in data, such as authoritative sources, well-established data creation methodologies and certified information gatekeepers, are ineffective.

Examples showed several possible strategies to overcome VGI's credibility challenge. Firstly, it is possible to reinforce the control on the production chain by establishing a standardized data creation method and by working with a limited number of well-trained volunteers (Lee 1994). Secondly, the quality control itself can be set up as a volunteered process, and the community of users can act as quality filters for VGI as can be found for Wikipedia (Bishr and Mantelas 2008). A third option could be to turn the challenge of data abundance into an opportunity, where reliable information is extracted from vast amounts of VGI with uncertain quality from numerous sources by applying cross-validation mechanisms. In other words, the data quality problem of VGI can be addressed by 'aggregating input from many different people' (Mummidi and Krumm 2008, p. 215), and by processing these VGI clusters to evaluate their relevance in a given context.

This third option is a key concept of VGI Sensing, a set of standards, methods and techniques designed to streamline geo-referenced contents published online by citizens as a valuable and timely source of spatio-temporal information (De Longueville et al. 2010b). This paper aims at contributing to this emerging field of research.

WATCHING AT VGI THROUGH SWE GOOGLES – CITIZENS AS SENSORS?

VGI Sensing provides a novel way of approaching VGI management and processing. In this section, we explain how SWE contributes to the conceptualization and implementation of VGI Sensing. General clarifications are followed by a detailed description of the involved processing steps.

The scenario considered in this paper is the use of VGI Sensing to support crisis event detection and characterization. The whole processing chain is thus designed to acknowledge the occurrence of a crisis event (a perdurant geospatial entity, such as a fire or flood). The measurement/observation of VGI flows (VGI Sensing) is separated from the detection of such events.

1.3 Principle and Overview

As a central principle, we monitor flows of VGI in order to detect events. In contrast to a trivial interpretation of the 'citizen as sensor' metaphor, we do not consider the individual citizen as a sensor making measurements on the observed property, but as an element of a (virtual) VGI sensor, where the actual observed property is the flow of VGI harvested under pre-defined conditions. This involves processing vast amounts of VGI, and applying statistical methods in order to derive knowledge, the same way as a remote sensing image is processed to translate the spectral signature and patterns of its pixels into geospatial knowledge.

Table 1 presents the central concepts of VGI Sensing and event extraction, as introduced by De Longueville et al. (2010b). We revise the notion of stimulus and sensor compared to the previous version of this table. The analogous process involving remote sensing is provided as a comparison. The various components described in this table have been created in analogy to human sensory system, but can be applied both for VGI- and Remote Sensing.

Each transition between rows is the table represents a processing step in the 'event detection with VGI Sensing' workflow. Figure 1 gives an overview. Each step is described in the following sub-sections. The next section provides a detailed example workflow.

	Event detection based on VGI Sensing	**Event detection based on Remote Sensing**
Stimulus	A new item of VGI is entered into a Web 2.0 platform.	Waves are reflected or emitted by a surface.
Sensor	VGI items entered by citizen are detected and 'discretized' according to a VGI sensor specific array/grid.	Waves are detected and digitized thanks to a satellite-mounted sensor, i.e. camera.
Sensation	Heterogeneous information is centralized and organized in a grid of measurement results, according to the VGI virtual sensor's specifications.	Series of remote sensing images are created according to the image sensor's specifications.
Perception	Patterns are found in results, and events and situations are identified thanks to prior knowledge.	Image series are processed to detect signals with specific characteristics leading to the identification of events of a specific type(s).
Attention	Alerting mechanisms are triggered according to context.	Alerts are triggered according to context.
Reaction	Sensor network information is integrated in information systems, where appropriate tasks are prioritized, related to: o early response to crises; o situation awareness, request for additional information; o monitoring of parameters; etc.	

Table 1: Event detection based on VGI Sensing compared to remote sensing (adapted from De Longueville et al. 2010b).

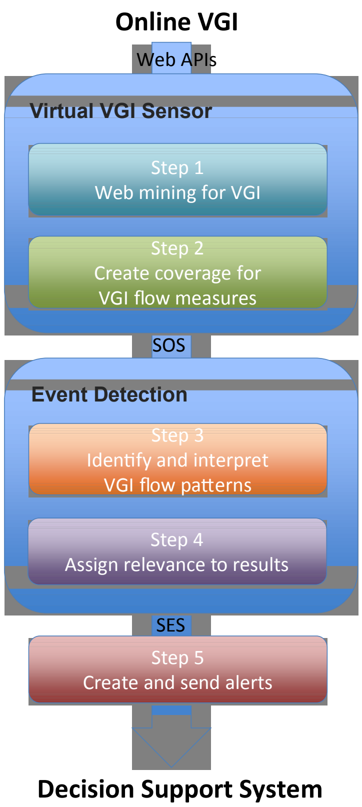

Figure 1: Overview of the VGI Sensing based event detection workflow.

1.4 Step 1: from Stimulus to Signal

From here, we put a virtual VGI sensor in place, that is, software observing the publicly available information on the web to perform measurements related to specific VGI activity. Such VGI sensors may have diverse *features of interest*, e.g. the earth surface or the earth surface in a particular area/region. The *observed property* may be the occurrence or the density of VGI. The sensor may be specialized to VGI items including specific tags. VGI sensors are thus designed to detect particular types of VGI items, just as satellite-mounted image sensors are sensitive to particular wavelengths at a particular spatial resolution.

This first step is characterized by web mining processed aiming at gathering VGI related to the feature of interest and observed properties. Such capabilities correspond to the encoding capabilities of the virtual VGI sensor (i.e. the observation procedure, which may be described using SensorML).

1.5 Step 2: from Signal to Sensation

Sensors transform signals; traditionally analogue stimuli to digital values. In our case, the transformation is an assignment of VGI items in respect to a sensor specific 'grid'. This grid divides the geospatial region that is covered by the sensor. The allowed values for each grid cell depend on the selected *observed property*. A sensation results in a grid of values representing counts or densities, which implements a SWE coverage model, just as n-dimensional satellite image does. However, the grid cells of a virtual VGI sensor may be of any shape and size (e.g. a grid of square 'pixels', but also administrative or natural boundaries such as catchments). The definition of the grid is part of the measurement *procedure*.

For each cell of the grid, specific calibration rules may be applied so that results are comparable even if important factors are expected to influence the amount of expected VGI for each (e.g. population density, technology penetration rate, cultural inclination to report on the Internet). Calibrations may be performed using SPS capabilities. Also the specification of this discretisation method is part of the measurement *procedure*.

The restitution of harvested VGI as an organized set of measurements is the result of this second step. These organized observation *results* is represented in O&M. They may be served by a specialized SOS.

Steps 1 and 2 in combination define VGI Sensing. A possible mapping of sensor characteristics to SWE is presented in Table 2; again we use the remote sensing analogy.

SWE (O&M) element	VGI Sensing	Remote sensing
Feature of interest	Europe	Europe (earth surface)
Observed property	Density of VGI tagged with 'flood'	Power in a certain wavelength
Procedure	Calculating densities per grid cell	Assigning digital values to each pixel of the image sensor
Result	Cells are filled with data such as: flood; 2010-06-16; (-33, 135)	Satellite image product

Table 2: Mapping the sensing elements to SWE.

1.6 Step 3: from Sensation to Perception

Thanks to previous steps, vast amounts of heterogeneous VGI have been turned into an organized set of measurements. The next step is analogous to any signal processing. The grid of values provided by the virtual VGI sensor is analyzed in order to identify specific patterns (e.g. a significant raise of 'flood pictures' in the primary Donahue catchment or cluster of 'fire pictures' in adjacent grid cells). This can be compared to entity extraction in remote sensing. Just as the spectral signature that characterizes a satellite image pixel can be a rich source of information about the corresponding geographic area, analysis of contemporaneous VGI for a given grid cell (and of its neighbors) informs about the phenomenon of interest for this portion of the earth.

Ultimately, the goal of this step is to detect and characterize patterns from sensor's signal, spatiotemporal events (perdurant geospatial entity), for instance. The result of this step can be provided as part of (or close to) a SES.

1.7 Step 4: from Perception to Attention

This step aims at assigning levels of relevance for the events that have been identified. It allows to inform decision makers with the events that require most immediate attention and to filter irrelevant events. Depending on the constraint model, different decision makers may specify diverse conditions for notification.

The raw VGI data that contributed to the detection of an event can be further analyzed at this stage. The analysis may include data from additional sources (e.g. land use, soil moisture, or weather forecast data for assessing potential severity of floods).

For the events that fulfill any pre-defined condition, an alert can be triggered by a SES.

1.8 Step 5: from Attention to Action

At this step, VGI Sensing information is integrated in a decision support system, thus helping crisis managers to plan the appropriate actions.

Acquisition of additional data, such as satellite imagery, can be part of such actions, thus emphasizing the complementarities between information sources and sensor types.

Notably, the results/impact(s) of actions may again be observed by citizens, who create VGI. Loops can be performed in the context of situation awareness, early response, and damage assessment.

USE CASE: A WORKFLOW TO DETECT FLOODS

This section presents an illustrative example of event extraction based on VGI Sensing, with a focus on data transformation that occurs at each step the process itself is further described in (De Longueville et al., 2010a). The aim is to detect and locate floods on a geographic zone, United Kingdom in this case. Flickr is used as VGI source. Flickr is an online application that allows uploading, store and organizing digital photographs[2]. It enables the creation, management and retrieval of the pictures' metadata, such as title, description, tags, and date, time and location the picture was taken. For reasons of unpredictability, we present the example based on historic data instead of describing a real-time monitoring case. All illustrations can be directly projected.

1.9 Virtual VGI Sensor for Flood Pictures in the UK

Flickr offers numerous features that make it an interesting VGI platform. The first of them is the multiplicity of uploading options, which includes direct upload from camera-enabled mobile phones. Such devices are becoming common in the mass market and many of them also include built-in GPS sensor, so it is expected that Flickr will contain in the future a growing number of geo-referenced contents that will be available within seconds after a photo has been taken. The possibility for users to assign a location to pictures – 'to geotag' - is another important feature. Indeed, the wide majority of cameras do not include a GPS device that automatically inserts picture location in the image file metadata. Flickr users can thus manually add this information using an online map interface. Flickr allows users to associate keywords – called 'tags' - to their pictures.

In the first step, we collect information about pictures related to floods, such as the time and place where they have been taken. During the retrieval phase, queries are submitted through the Flickr Application Programming Interface (API), and their results are saved locally for further processing. The Flickr API offers numerous options to submit queries using the *flickr.photos.search* method. Research parameters can include the date the picture has been taken, the date it has been uploaded, portions of text to be searched in its tile and description, the presence of one or several tags, the *id* of the group it belongs to, the *id* of the user that uploaded it, the place were it has been taken (bounding box or distance radius around a given location).

Figure 2 gives an overview of the spatio-temporal distribution for geotagged pictures taken between 01/01/2007 and 31/03/2009, and related to floods retrieved from Flickr.

2 http://www.flickr.com/about/

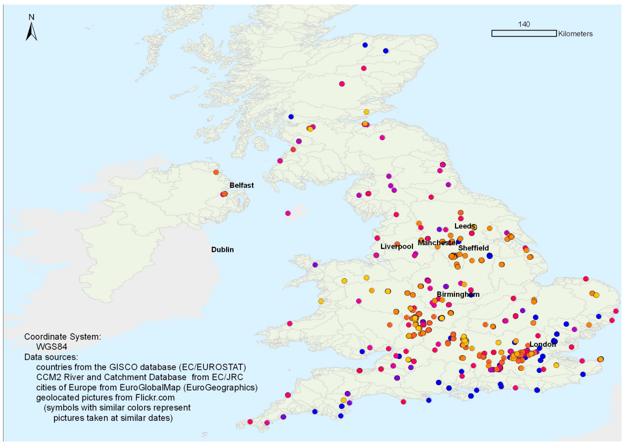

Figure 2: Spatio-temporal distribution of retrieved Flickr flood images (similar colors means similar acquisition time).

In the second step, the collected VGI items are captured using a 'grid'. The grid (including geospatial resolution), the temporal resolution, the *observed property*, and the discretization *procedure* are designed to fit a given purpose just as sensor specifications are set up to address a pre-define use for this sensor.

A VGI item, to be captured, needs to be validated. The validation is a formal step to control if the minimal information required to process the data is available in the proper format. We defined a set of validation criteria: geographic extent (some of the pictures uploaded have clearly invalid latitude and longitude, e.g. equal to 0), valid temporal extend (e.g. date of publication or creation has to be valid and it has to be provided), and a picture has to be tagged.

Validated VGI items are then allocated to grid cells (i.e. a spatio-temporal segmentation of the retrieved VGI lot is performed). In this work our spatio-temporal segmentation method is based on three hypothesis:

1. *Geospatial pattern*: A flood is an event that occurs in a defined area, i.e. pictures that record a single flood event have specific spatial relationship.
2. *Temporal pattern*: A flood is an event recorded in a discrete time period, i.e. flood pictures in the same area but at different times refer to different events.
3. *Event pattern*: A flood is an event that should be documented by significant images, i.e. the more there are people affected by the flood, and the more pictures will be uploaded on Flickr.

On this basis, we formulated 3 criteria we used to build relevant events:

1. *Geospatial Criteria*: The geospatial segmentation can be based on a regular grid of cells (e.g. square pixels) or using appropriate territorial units. For detecting floods, polygons representing catchments are a logical choice.
2. *Temporal Criteria*: The temporal segmentation is performed by creating time intervals, in accordance with the expected characteristics of the event of interest (e.g., a flood in Europe typically lasts several days – not seconds or months) and the expected sensitivity to temporal change of the system. Time slices can be created arbitrarily or with statistical methods. In this case, we used the Jenk's Natural Breaks (Jenks and Coulson 1963).
3. *Event criteria*: a flood with bigger impact is documented by more citizens.

These three criteria allow are used as specifications for our VGI virtual sensor. Figure 3 is a graphical representation of the results obtained for our VGI virtual senor for floods on Flickr, i.e. it represents the grid. The vertical dimension depicts the geographic segmentation (each position on the y-axis corresponding to a different catchment, ordered along a North-South axis) and the horizontal dimension depicts the temporal segmentation (each position on the x-axis corresponding to a time period defined in Step 2). The size of each bubble represents the amount of VGI retrieved for a given spatio-temporal cell (corresponding to the x and y values of its centre).

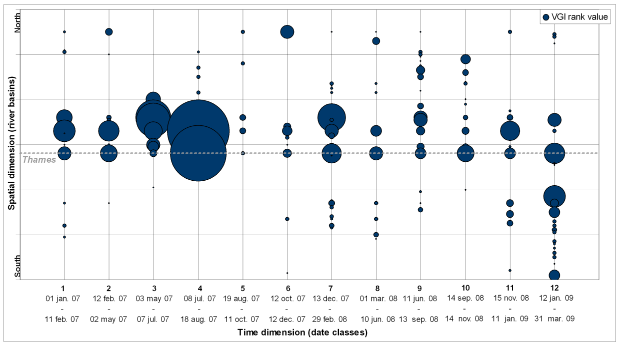

Figure 3; VGI virtual sensor results: spatio-temporal distribution of VGI aggregates.

1.10 Detecting Flood Events as Patterns in the Grid and Assessing Relevance of identified Flood Events

The grid of data provided by the virtual VGI sensor can be analyzed in a way analogous to classifying an array of measurements. In the floods case, a particular care will be given to the temporal distribution of VGI for each catchment separately (a peak in VGI flow corresponding most likely to a flood event), while analysis of geospatial distribution should take into account the hydrological relations (i.e. how catchments are connected to each other).

When a peak of VGI appears for a given spatio-temporal cell, further analysis can be performed in order to assess the likelihood this peak corresponds to an event of interest. For example, the semantic similarity between the tags associated with the photo and concepts associated to floods can be measured in order to establish a ranking of flood likelihood. In other words, the ranking reflects the likelihood the collected VGI pictures represents a *floods* (and not any other type of accumulation of water).

A pre-defined alert threshold is set, that can be subject to calibration based on socio-economic factors related to the likelihood of presence of citizens with appropriate devices and willingness to report the event. When a rank value exceeds this threshold, an alert is triggered.

In our flood example, we look for VGI amounts exceeding a threshold pre-calibrated for each catchment, on Flickr. The ranking value is calculated by processing the picture tags and it can be used to reduce noise (i.e. by eliminating pictures that are most likely not corresponding to flood event or evaluate the probability that an event can be confused with another type of flood.

Figure 4 shows the time series of VGI Sensing values for the Severn catchment, together with a possible alert threshold. In this case, alerts that would have been triggered correspond to two major flood events that took place between the 21st and the

30th of Jumy 2007, and between the 15th and the 26th of January 2008 (source: the Darthmouth Floods Observatory[3]). The figure provides an example of the value added information we are seeking for. Similar timelines could be provided by real time monitoring.

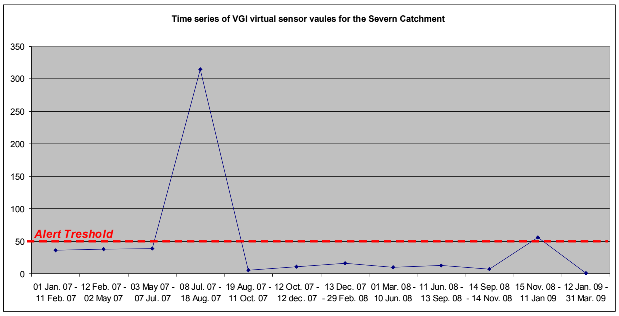

Figure 4: Example VGI Sensing time series with alert threshold.

1.11 Creating Flood Alerts

The flood alert can be propagated from the SES to relevant authorities. In addition to the alert itself, that may have been triggered earlier by other means (such as flow measurements of rivers and forecast models) the collection of spatio-temporally indexed VGI (text, picture, videos) that is associated to the event can contribute to situation awareness and support the early response phase of the event.

DISCUSSION AND CONCLUSIONS

The potential of up to 6 billion human sensors to monitor the state of the environment, validate global models with local knowledge, and provide information that only humans can capture is vast and has yet to be fully exploited. In this paper, we shifted the focus of attention form citizen as sensors to sensing of VGI flows. SWE proved useful for clarifications. We presented a mapping between central SWE concepts (such as *feature of interest* and *observed property*) and VGI Sensing, as well as a possible application of SWE technologies (such as O&M and SOS) to VGI. A workflow for event detection based on VGI Sensing was specified, including the role of (virtual) VGI sensors. An example walkthrough was provided for the case of flood detection based on Flickr images. All this presents a novel way for processing VGI.

Our work indicates that VGI Sensing can be complementary to remote sensing, and ‘traditional’ in situ sensors. It can provide high-scale value-added information at low cost. Furthermore this approach could be used as to enrich crisis management models inputs or to refine its output results. As a next step, we will investigate this relation, especially in respect to shared features of interest, observed properties and measurement procedures. VGI Sensing relies on human reporting changes in their environment and it is the human input to Web 2.0 that is sensed. ‘Classical’ sensing, on the contrary focuses on the environmental changes directly. It remains to be explored how both sensing principles can benefit from each other.

As argued previously (De Longueville et al. 2010b), sensor technology can be used at various abstraction levels. Especially the potential of cascading SOS remains to be investigated. Depending on the purpose, even events may be provided as a sensor, implementing notions such as ‘I observed a flood’ or ‘I observed a tiger’. Categorizing events as *features of interest* and the definition of according *observable properties* are topic to ongoing discussions. One key issue is to balance between reusability and efficiency when deciding on the level of abstraction. When features of interest remain close to the raw data being sensed the reusability of the exposed measurements is higher than that of measurements indicating detected events; although this would be more efficient in certain scenarios.

[3] http://www.dartmouth.edu/~floods/Archives/index.html

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