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OGC® SWE Implementation Maturity Engineering Report

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Preface

An assessment of the maturity of implementations of OGC Sensor Web Enablement (SWE) standards is documented in this OGC Engineering Report (ER). The assessment was conducted using the OGC Request for Information (RFI) process. The RFI was supported by Envitia under contract by Defense Science and Technology Laboratory (DSTL), Advanced Geospatial information and Intelligence Services (AGIS) research program within Ministry of Defense (MoD).

Successful implementations of SWE were identified in order to provide the UK Ministry of Defense (MoD) with a “state of the practice” and benefits of using SWE. While all implementations of SWE were of interest, of particular interest to the RFI were operational implementations of SWE in the defense and space community, with direct interest in Intelligence, Surveillance, Target Acquisition, and Reconnaissance (ISTAR).

Beginning in 2001, there have been numerous implementations based on the SWE standards. Based on the contents of this Engineering Report, the current status of the maturity of SWE implementation can be summarized as:

- SWE Version 1 standards are mature specifications with approved OGC compliance test suites and implementations. There are tens of independent implementations of the standards that have been deployed in operational systems. SWE version 1 is at Technology Readiness Level 9 – the highest level – and can confidently be mandated in system procurements.

- SWE Version 2 standards are in-process to be approved in the first half of this year (2013). Building upon Version 1, the Version 2 specs have improved designs and additional functionality. Independent implementations have been developed and tested. Compliance tests are being finalized. SWE Version 2 is at Technology Readiness level 6 and has emerged for consideration in systems currently under development.

- Enhancements and coordination of the SWE standards are in a variety of states. In the OGC Interoperability Program initiatives, SWE has been used as a basis for a variety of topics: Workflows including SWE; Secure Sensor Web; Events and SWE; JPIP Streaming; Full Motion Video; Moving Object Indicators; GPS ephemeris/data, and more.

The SWE framework provides significant benefits for supporting the integration and fusion of a wide variety of assets, and readily enables a system that is able to sense and react to threats or opportunities. Very capable software components exist for supporting development of SWE implementations.

License Agreement

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SWE Implementation Maturity Engineering Report

1 Introduction

1.1 Scope

This report summarizes the outcomes of a process to assess the maturity of implementations based on SWE standards. This report covers the following areas:

- SWE standards overview
- Implementations of SWE in major systems
- SWE software implementations and compliance
- SWE implementations in IP
- Recommendations and Observations

A main outcome is the summary assessment of the SWE Implementation Maturity as presented in the Preface based on the body of the report.

1.2 Document contributor contact points

All questions regarding this document should be directed to the editor or the contributors:

Name	Organization
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1.3 Revision history

Date	Release	Editor	Primary clauses modified	Description
26Apr2013	0.1	G. Percivall	All New	Final draft prepared for sponsor review
30Apr2013	0.9	G. Percivall	Updates based on comments.	Approved by sponsor. First version posted to OGC Pending Documents.

1.4 Intellectual Property statement

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Recipients of this document are requested to submit, with their comments, notification of any relevant patent claims or other intellectual property rights of which they may be aware that might be infringed by any implementation of the standard set forth in this document, and to provide supporting documentation.

2 References

The following documents serve as basic references for SWE: referenced in this document.

- Sensor Web Enablement Architecture[1] – an OGC Best Practice
- OGC Sensor Web Enablement: Overview and High Level Architecture[2] – an OGC White Paper
- The SWE standards are on the OGC Standards list[3]

Additional References are provided through out the text of this ER

3 Terms and definitions

For the purposes of this report, the following terms and definitions apply.

[1] http://portal.opengeospatial.org/files/?artifact_id=29405

[2] http://portal.opengeospatial.org/files/?artifact_id=25562

[3] http://www.opengeospatial.org/standards

3.1 Actuator
A type of transducer that converts a signal to some real-world action or phenomenon.

3.2 Coordinate Reference System (CRS)
A spatial or temporal framework within which a position and/or time can be defined. According to ISO 19111, a **coordinate system** that is related to the real world by a **datum**.

3.3 Feature
Abstraction of real-world phenomena [ISO 19101:2002, definition 4.11]

Note: A feature may occur as a type or an instance. Feature type or feature instance should be used when only one is meant.

3.4 Location
A point or extent in space relative to a **coordinate system**. For point-based systems, this is typical expressed as a set of n-dimensional coordinates within the **coordinate system**. For bodies, this is typically expressed by relating the translation of the origin of an object's local **coordinate system** with respect to the origin of an external reference **coordinate system**.

3.5 Measurand
Physical parameter or a characteristic of a phenomenon subject to a **measurement,** whose value is described using a Measure (ISO 19103). Subset of **determinand** or **observable**. *[O&M]*

3.6 Measure (noun)
Value described using a numeric amount with a scale or using a scalar reference system *[ISO/TS 19103]*. When used as a noun, measure is a synonym for physical quantity

3.7 Measurement
An **observation** whose result is a **measure**

3.8 Observable, Observable Property
A parameter or a characteristic of a **phenomenon** subject to **observation.** Synonym for **determinand.** *[O&M]*

A property of a phenomenon that can be observed and measured (e.g. temperature, gravitational force, position, chemical concentration, orientation, number-of-individuals, physical switch status, etc.), or a characteristic of one or more feature types, the value for which must be estimated by application of some procedure in an observation. It is thus a physical stimulus that can be sensed by a detector or created by an actuator.

3.9 Observation

Act of observing a property or phenomenon (ISO/DIS 19156, definition 4.10)

Note: The goal of an observation may be to measure, estimate or otherwise determine the value of a property.

3.10 Position

The location and orientation of an object relative to an external coordinate system. For body-based systems (in lieu of point-based systems) is typically expressed by relating the object's local coordinate system to an external reference coordinate system. This definition is in contrast to some definitions (e.g. ISO 19107) which equate position to location.

3.11 Sensor

An entity capable of observing a phenomenon and returning an observed value. Type of observation procedure that provides the estimated value of an observed property at its output.

Note: A sensor uses a combination of physical, chemical or biological means in order to estimate the underlying observed property. At the end of the measuring chain electronic devices often produce signals to be processed.

3.12 Sensor Model

In line with traditional definitions of the remote sensing community, a sensor model is a type of Location Model that allows one to georegister or co-register observations from a sensor (particularly remote sensors). The sensor model characterizes the sensor sufficiently to allow registration of observations with a defined accuracy.

3.13 Transducer

An entity that receives a signal as input and generates a modified signal as output. Includes detectors, actuators, and filters.

4 Abbreviated terms

AGIS	Advanced Geospatial information and Intelligence Services
CRS	Coordinate Reference System
DISR	DoD Information Technology Standards Registry
DMAC	Data Management and Communication (NOAA)
DoD	Department of Defense (USG)
DSTL	Defense Science and Technology Laboratory (UK)
EEA	European Environment Agency
ER	Engineering Report
ESA	European Space Agency
GeoCENS	Geospatial Cyberinfrastructure for Environmental Sensing

GEOINT	GEOspatial INtelligence
GIS	Geographic Information Systems
GMTI	Ground Moving Target Indicator
GWG	Geospatial Intelligence Standards Working Group (DoD)
HMA	Heterogeneous Missions Accessibility (ESA)
IC	Intelligence Community
IOOS	Integrated Oceans Observing System (NOAA).
IoT	Internet of Things
ISTAR	Intelligence, Surveillance, Target Acquisition, and Reconnaissance
MARACOOS	Mid-Atlantic Coastal Ocean Observing System
MoD	Ministry of Defense (UK).
NASA	National Aeronautics and Space Administration (USG)
NOAA	National Ocean and Atmospheric Administration (USG)
O&M	Observations and Measurements
OGC	Open Geospatial Consortium
OWS	OGC Web Services
RFI	Request for Information
SANY	Sensors Anywhere
SAS	Sensor Alert Service
SoA	Service-Oriented Architecture
SOS	Sensor Observation Service
SPS	Sensor Planning Service
SWE	Sensor Web Enablement
SWIMA	Sensor Web Infrastructure Management (UK)
TRL	Technology Readiness Levels
USG	United States Government
VMTI	Video Moving Target Indicator
WCS	Web Coverage Service
WMS	Web Map Service
WNS	Web Notification Service
WPS	Web Processing Service

5 Process to assess SWE Implementation Maturity

5.1 RFI process

A Request for Information (RFI) was announced on 16 March 2013. The RFI was announced to multiple OGC mailing lists with a total of 1225 distinct addresses.

- OGC Conducted the RFI to support GEOCORE led by Envitia under contract by Defense Science and Technology Laboratory (DSTL), Advanced Geospatial information and Intelligence Services (AGIS) research program within Ministry of Defense (MoD)
- OGC was seeking information about maturity of Sensor Web Enablement (SWE) Standards.
- This RFI seeks asked for information about successful implementations of SWE to provide the UK Ministry of Defense (MoD) with a “state of the practice” and benefits of using SWE.
- While all implementations of SWE were of interest, of particular interest to the RFI were operational implementations of SWE in the defense and space community, with direct interest in Intelligence, Surveillance, Target Acquisition, and Reconnaissance (ISTAR) – See Figure 1.

Information received by OGC was used in a webinar and Engineering Report (ER) for MoD stakeholders

- Emphasis was on the maturity and benefits of SWE implementations.
- This OGC Engineering Report was prepared to summarize the implementations, identifying the benefits, the most appropriate standards, and where research is needed and could be exploited.

Responses to the RFI were due by 29 March 2013.

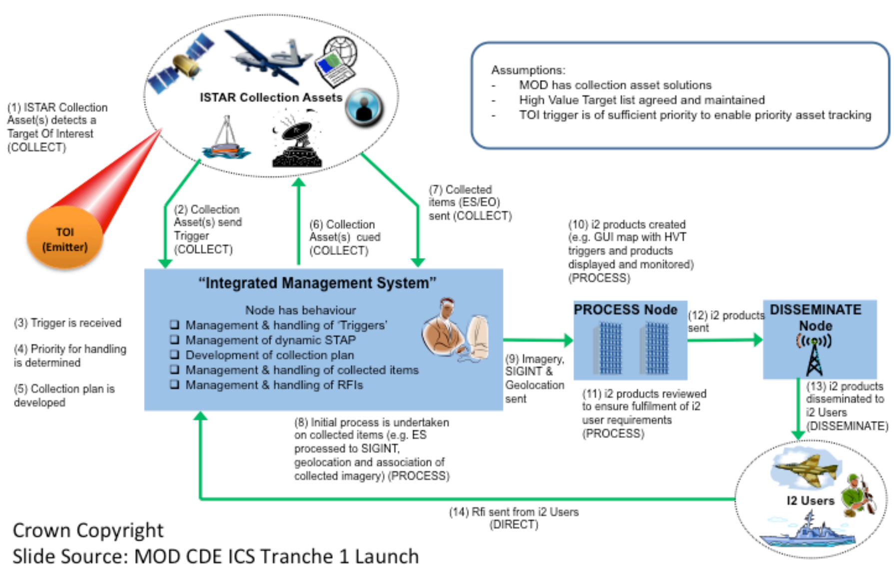

Figure 1. Context of SWE Maturity RFI: UK MOD – Layered ISTAR

5.2 RFI Responses

Responses to the RFI were received from the following OGC members:

- 52°North, GmbH
- Botts Innovative Research Inc.
- GeoSensorWeb Lab, University of Calgary
- WiSC Enterprises, Inc.

5.3 Stakeholders Webinar

To convey the status of SWE implementations to the MoD Stakeholders, OGC conducted a webinar on 16 April 2013. The agenda and content for the webinar (Table 1) was developed based on the responses to the RFI and additional information identified by OGC staff. For example, the recent GEOSS Future Products Workshop[4] provided relevant information and presentations.

The stakeholders were represented in the webinar by individuals from these organizations:

- UK MoD Defense Science & Technology Laboratory (DSTL)
- UK MoD Defense Authority for C4ISR
- Royal Air Force
- British Army
- Envitia

Table 1 Stakeholders Webinar Agenda

1. Introduction and Welcome	Richard Griffith & Gobe Hobona, Envitia
2. SWE Standards	Mike Botts, BIRI
3. US DOD SWE overview	Charlie Gates, WISC
4. NASA Sensor Web,	Dan Mandl, NASA
5. SWE for Maritime	Eoin Howlett, ASA Science
6. GEOCENS	Steven Liang, Univ. Calgary
7. 52°North SWE Implementation	Arne Bröring, 52°North
Further information and Next Steps	

[4] http://www.ogcnetwork.net/node/1872

6 OGC Sensor Web Enablement (SWE) Standards

6.1 SWE Overview

The SWE standards framework is to sensor resources what the WWW is to general information sources—an infrastructure allowing users to easily share their sensor resources in a well-defined way. It hides the underlying layers, the network communication details, and heterogeneous sensor hardware from the applications built on top of it. As the number of sensors in our world increases exponentially, this infrastructure for innovation will affect everyone's lives, though most people won't know any more about SWE standards than they know about TCP/IP and XML.

The SWE[5] initiative standardizes web service interfaces and data encodings that can be used as building blocks for a Sensor Web. Since 2001, the OGC has been engaged in developing a set of standards for web-enabling sensors and sensor observations. Versions 1.0 of the SWE standards were approved and released in 2007. Versions 2.0 of these standards have either been approved, or will be approved by Spring 2013.

Due to the large number of sensor manufacturers and differing accompanying protocols, integrating diverse sensors into observation systems is not straightforward. A coherent infrastructure is needed to treat sensors in an interoperable, platform-independent and uniform way. The concept of the Sensor Web reflects such a kind of infrastructure for sharing, finding, and accessing sensors and their data across different applications. A Sensor Web hides the heterogeneous sensor hardware and communication protocols from the applications built on top of it.

A sensor network is a computer accessible network of many spatially distributed devices using sensors to monitor conditions at different locations, such as temperature, sound, vibration, pressure, motion or pollutants. A Sensor Web refers to Web accessible sensor networks and archived sensor data that can be discovered and accessed using standard protocols and service interfaces.

[5] http://www.ogcnetwork.net/swe

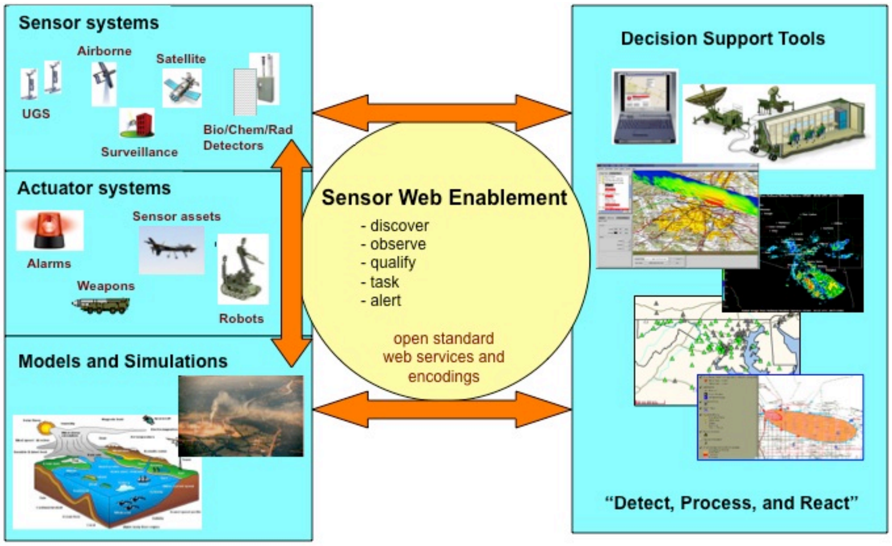

Figure 2. Sensor Web Enablement Framework (Source: M. Botts)

The members of the OGC have collaborated to define and document a unique and revolutionary framework of open standards for exploiting Web-connected sensors and sensor systems of all types: flood gauges, air pollution monitors, stress gauges on bridges, mobile heart monitors, Webcams, airborne and satellite-borne earth imaging devices and countless other sensors and sensor systems. A driving requirement for this work is to ease the ability to integrate diverse sensors into an integrated system. Due to the large variety of sensor protocols and sensor interfaces, prior to the availability of SWE, most application developers were integrating sensor resources through proprietary mechanisms instead of building upon a well-defined and established integration layer. This manual bridging between sensor resources and applications leads to extensive adaption effort, and is a key cost factor in large-scale deployment scenarios.

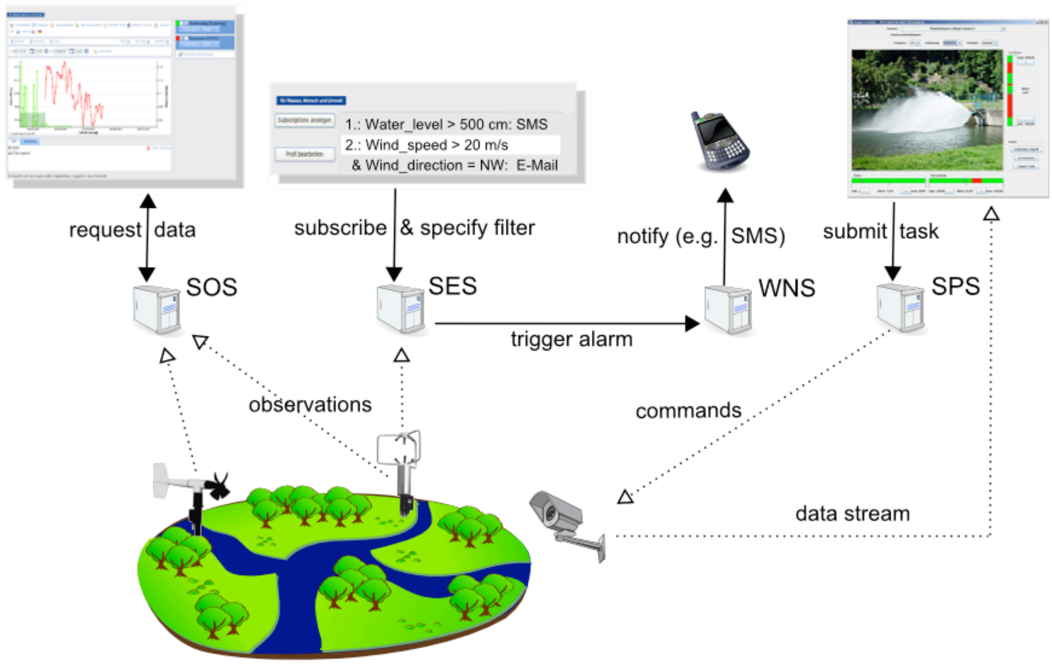

Figure 3. Deployment scenario for OGC Sensor Web Enablement (SWE) (Source: A. Bröring[6])

6.2 SWE Standards

The SWE standards baseline offers the following functionalities:

- Description of sensor data to enable further processing.
- Description of sensor metadata including properties and behavior of sensors, as well as correlating reliability and accuracy of collected measurements.
- Discovery of and access to observations and sensor metadata based on standardized data formats and appropriate query and filter mechanisms.
- Tasking of sensors for the acquisition of measurement data.

The suite of standards currently comprising SWE includes XML encodings and web service interfaces. These standards support discovery of sensors, observations, and processes surrounding measurement, as well as the tasking of assets, access to observations and observation streams, publication and subscription of sensor alerts, and on-demand processing of sensor observations. The standards include:

[6] Bröring, A. et al. (2011): New Generation Sensor Web Enablement. *http://www.mdpi.com/1424-8220/11/3/2652/*

SWE Encodings:

- **SWE Common** – common data models and schema used by all SWE standards
- **SensorML** – models and schema for describing sensor and actuator systems and processes surrounding measurement and the tasking of assets
- **Observations and Measurements (O&M)** – models and schema for packaging observations

SWE Services:

- **Sensor Observation Service (SOS)** – standard web interface for accessing observations and subscribing to alerts
- **Sensor Planning Service (SPS)** – standard web interface for tasking sensor system, models, and actuators
- **SWE Service Model** - defines eight packages with data types for common use across OGC Sensor Web Enablement (SWE) services.
- **PUCK** - Defines a protocol to retrieve a SensorML description, sensor "driver" code, and other information from the device itself, thus enabling automatic sensor installation, configuration and operation.

In the course of SWE development, OGC has addressed the need for event handling. The Sensor Alert Service and Web Notification service were developed as part of the SWE version 1 developments and both were released as OGC Best Practices. An event architecture, event notification service and sensor event service have been defined and in tested in both SWE threads and Aviation threads of in OWS-6 and OWS-7 Testbeds. An outcome is that the SWE Service Model, version 2.0, OGC document 09-001, includes Event handling that can be applied to the SWE services.

All of these standards are encoding and interface specifications for use by software developers. The standards are developed in an open process within the OGC governed by established policies and procedures. Many of the vendors and users who collaboratively develop them are influential industry "market makers." They have a stake in the SWE standards' widespread implementation and deployment, and thus the standards become "industry standards".

6.3 OGC Sensor Web for IoT

The Internet of Things (IoT) is “a dynamic global network infrastructure with self configuring capabilities based on standard and interoperable communication protocols where physical and virtual ‘things’ have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network”[7]. The Open Geospatial Consortium’s (OGC) latest developments aim to achieve the vision of an *Open IoT*. Interoperability of IoT devices based on open standards will be required to meet the vision of IoT. Based on a series of workshops,

[7] http://www.internet-of-things-research.eu/pdf/IoT_Cluster_Strategic_Research_Agenda_2009.pdf

OGC members chartered development of a *Sensor Web for IoT* standard. OGC's existing standards for location information and sensor observations are the basis for this work. OGC's Sensor Web Enablement (SWE) provides a rich basis for this new development. Two implementations from OGC members – TinySOS and SenseBox – provide implementation experience for this new standard. The OGC *Sensor Web for IoT* will enable many IoT applications based on sensors.

The Internet of Things (IoT) has moved from concept to initial deployment and will grow to 50 billion internet-connected sensors and devices[8]. IoT has the potential to change the world, just as the Internet and WWW did. A huge variety of day-to-day objects will become IoT enabled. A plethora of applications from personal interest to environmental monitoring will emerge by mix-and-match of different sensors, mobile devices, and cloud-based resources. Heterogeneity of devices and applications demands *interoperability*. Interoperability based on open standards will be a key factor for the success of IoT. The primary recommendation from OGC IoT workshops was to form a Standards Working Group (SWG). The new Sensor *Web for IoT SWG*[9] is to develop one or more standards based on existing protocols while leveraging the existing and proven OGC Sensor Web Enablement (SWE) family of standards.

The OGC SWE initiative[10] developed open standards to enable an interoperable access to sensors. SWE uses XML and robust Web service standards. For realizing an Open IoT, lightweight profiles of the established SWE standards are needed. Two examples motivate the OGC approach:

- TinySOS implemented the OGC Sensor Observation Service (SOS) directly on a class-1 IoT device (i.e., devices with about 10 Kbytes of RAM and 100 Kbytes of code space). This way, a TinySOS IoT device is not only self-describable but also inherits the comprehensive SWE model and interoperates with existing SWE applications.
- A similar approach takes the SenseBox project. However, while TinySOS keeps the XML communication of SOS, the SenseBox defines a new RESTful interface that allows communication through the more lightweight JSON protocol. The SenseBox is a generic hardware and software framework that can be setup for different use cases. In previous work, it has been evaluated e.g. as an air quality measurement station or to count cars in a Smart City environment based on an attached ultrasonic sensor

Building on SWE, TinySOS, SenseBox and other IoT protocols, the *OGC Sensor Web for IoT SWG* is developing a standard that makes observations captured by IoT devices easily

[8] http://www.cisco.com/web/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf

[9] http://www.opengeospatial.org/projects/groups/sweiotswg

[10] Bröring, A., et. al. (2011): New Generation Sensor Web Enablement. Sensors, 11(3), pp. 2652-2699

accessible. This functionality is defined as lightweight RESTful web interface using CRUD (i.e., create, read, update, and delete) functions on IoT resources. While nearly complete, SWE-IoT is ongoing and OGC invites others to join the process to define an easy-to-use interface for sensors to realize the Open IoT vision.

6.4 Benefits of using SWE

SWE is the only open international standards suite that provides a comprehensive platform for publishing, discovering, assessing, accessing and using sensors and sensor systems of all kinds, and the standards are open. The standards documents are freely available on the web. The consensus process in which SWE standards are created and maintained is open to all who want to participate, and the process guards against future intellectual property claims that would compromise the standards' openness. The encodings and interfaces are based on fundamental, widely used and open Internet and Web standards and best programming practices. Their use requires no proprietary platform support of any kind, and yet they can be implemented on platforms other than the open Internet and Web. Specifically, they can also be implemented in secure and closed networks.

- Sensor system agnostic - Virtually any sensor, actuator, or modeling system can be supported
- Net-centric, SOA-based
  - Distributed architecture allows independent development of services but enables on-the-fly connectivity between resources
- Semantically tied
  - Relies on online dictionaries and ontologies for semantics
  - Key to interoperability
- Traceability (using SensorML)
  - Observation lineage
  - Quality of measurement support
- Implementation flexibility
  - Wrap existing capabilities and sensors
  - Implement services and processing where it makes sense (e.g. near sensors, closer to user, or in-between)
  - Scalable from single, simple sensor to large sensor collections

Another unique feature of SWE standards is that they were developed by the principal international industry standards development organization focused on geospatial standards, and therefore sensor location information is an integral part of communications that use these standards. In most applications, sensor location is an important sensor attribute.

SWE incorporates models for describing sensor resources and sensor observations. Further, it defines web service interfaces leveraging the models and encodings to allow accessing sensor data, tasking of sensors, and alerting based on gathered sensor observations. One of the unique aspects of SWE standards is that they are being used for simple applications, such as logging temperatures, as well as highly complex applications such as scheduling the motions and other exposure parameters of satellite-mounted imaging systems. One recent study explored and demonstrated the potential for supporting ALL data files and data streams within the GPS delivery system using the OGC SWE Common Data standard and also the ability to describe GPS processing workflows using the OGC Sensor Model Language (SensorML) standard.

The SWE specifications provide the functionality to integrate sensors into just about any application or architecture. The integration of sensor assets into Spatial Data Infrastructures makes it possible to couple available sensor data with other spatio-temporal resources (e.g., maps, raster as well as vector data) at the application level, which maximizes the sensors' value and effectiveness for decision support. Due to this integration, Sensor Webs and the geosensors they comprise represent a real-time link of Geographic Information Systems (GIS) into the physical world.

The OGC has pioneered open service interface standards in the geospatial domain and the sensor domain, and the pioneering continues because both of these domains are dynamic, requiring agile and innovative standards development. OGC members' diversity of interests and commitment to innovation causes both the geospatial standards effort and the SWE effort to stay abreast of IT industry advances such as the Semantic Web, data provenance, RESTful web services, non-SQL databases, Big Data and applications with challenging transaction rates that may involve updates and alerts. The cross-fertilization between "geo" and SWE advances sensor integration state of the art as industry experts in the OGC membership track and innovate in emerging fields such as the Internet of Things, chaining of analytical model inputs and outputs, and the convergence of location, imaging and Point Of Interest data in Augmented Reality.

7 Implementations of SWE

SWE presents many opportunities for adding a real-time sensor dimension to the Internet and the Web. SWE standards have been implemented in hundreds of applications (from mobile to enterprise) in domains including disaster management, remote sensing (UAVs, satellites), environmental monitoring, transportation management, defense, security, public safety, meteorology, hydrology, alerting, and building monitoring systems.

7.1 US Department of Defense/IC SensorWeb

The United States Government (USG) Department of Defense (DoD) / Intelligence Community (IC) is conducting Sensor Web Enablement (SWE) research, development and demonstration through the 'SensorWeb' project which has identified accomplishments, future challenges and suggested ways forward. SensorWeb is a USG initiative supported by various USG agencies. All SensorWeb software and documentation is USG owned.

SensorWeb is currently built primarily using SWE version 1.0

- Sensor Instance Registry (SIR – WCS) – queries multiple SOS
- Sensor Observation Service (SOS) v 1.x
  - OGC Compliant Mode/Compile
  - DCGS Compliant Mode (SOAP, WSDL, etc.)
- Sensor Alert Service
  - SAS is not a standard, does not comply with DCGS Enterprise
  - Sensor Event and Alerting Service includes attributes of 52°North SES
- Sensor Planning Service v2.0
  - Tasking Engines
- Web Notification Service (See SAS Bullet)
- SensorML/O&M v1.0
- Sensor Data Transformation Element (Interfaces, SWEET/SIDs)
- Leverages WPS, WMS, WCS, OpenLayers, Google Earth, NASA WorldWind

SensorWeb has been used and been developed through participation in Empire Challenge and now Enterprise Challenge exercises as follows

- 2007 – Persistent Universal Layered Sensor Exploitation Network (PULSENet)
  - Northrop Grumman TASC Internal Research and Development
  - Full developing SWE schemas and services suite
  - Supported primarily corporate sensors provided by DIA
  - Sponsored by NGA, DIA, JFCOM – no funding provided
- 2008 – SensorWeb
  - Initial Proof of concept of non-proprietary USG version of SWE for DoD
  - Full support for USG Current Force Unattended Ground Sensors
  - NGA funded, DIA/NMO executed, DTRA participant (TML)
  - (See Section 9.3 for OGC's participation in EC'08)

- 2009 – SensorWeb
  - JAVA, Larger sensor modality support, DCGS Support
- 2011 – SensorWeb
  - Multi-Agency, tip/cue airborne assets using ACTM (ACTDF)
- 2013 – Participation planned with UGS and Rad/Nuc

Much of the Enterprise/Empire Challenge initiative cannot be published in this report. The previous PULSENet development was used by Northrop Grumman for civilian projects and has been published publically (Figure 4). The continued development of SensorWeb in Enterprise Challenge has been led by OUSD(I) which has driven timeline and surges, development, documentation and sensor integration.

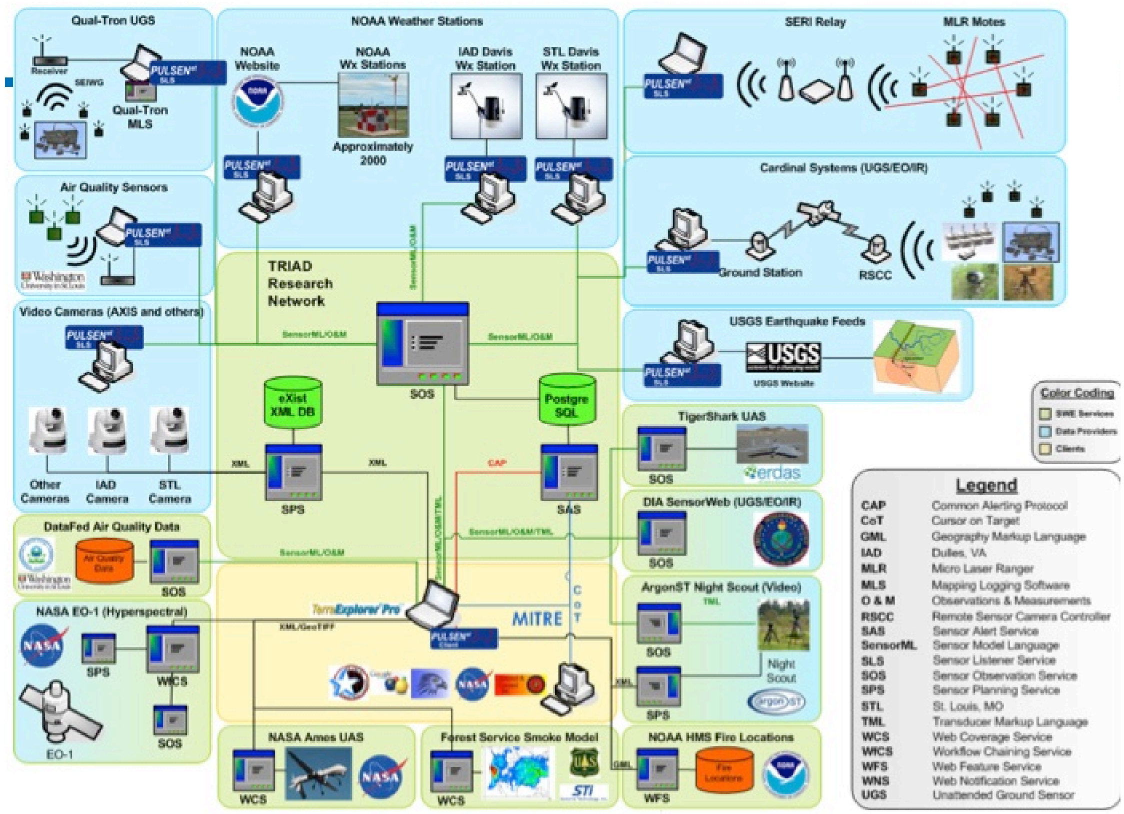

Figure 4. PulseNet implementation of OGC SWE (Source: Northrop Grumman)

7.2 US Geospatial-Intelligence Working Group

The Geospatial Intelligence Standards Working Group (GWG) serves as a U.S. Department of Defense (DoD), Intelligence Community (IC), Federal, and Civil community-based forum to advocate for IT standards and standardization activities related to geospatial intelligence (GEOINT). The GWG supports the GEOINT Functional Manager for GEOINT architecture and standards (NSG Directive FM100-Appendix K, 06 May 11).

The GWG conducts a Standards governance process by which it manages and votes GEOINT Standards Lifecycle. Approved standards are cited in US DoD Information Technology Standards Registry (DISR). Most of the SWE 1.0 standards are already cited in the DISR, with the GWG currently reviewing the SWE 2.0 standards for projected endorsement in 2013. Standards

Table 2. SWE Standards in DISR

Name of Standard	Current DISR Version	On Deck DISR 13-3	Change Required *
Observations and Measurements	v1 Emerging	v 2.0	Replace v1 With v2
Sensor Observation Service	v1 Mandated	v 2.0	Replace v1 with v2
Sensor Planning Service	v1 Mandated	v 2.0	Replace v1 with v2
Sensor ML	v1 Mandated	v 2.0	Replace v1 with v2
SWE Service Model	v2 Mandated	v 2.0	None
SWE Common	v2 Mandated	v 2.0	None

7.3 US DoD Joint C2 Objective Architecture

It is planned that the SWE 2.0 standards will be part of the US DoD Joint C2 Objective Architecture to be defined later this year. Parallel actions are being worked for the ISR side. This is consistent with the NATO Maritime ISR way forward. This is to support both military and military support to civil operations functions in classified and non-classified environments. This move is driven by the great work of OGC members who have been working with SWE into SWE 2.0.

7.4 US NASA SensorWeb[11]

The main objective of the NASA SensorWeb activity is to create an interoperable environment for a diverse set of Earth observing satellite sensors via the use of software and the Internet. This capability can be used to better understand physical phenomena, such as volcanic eruptions, fires and floods. Furthermore, it facilitates science investigation since it becomes much easier to enlist existing satellite, airborne and ground sensors for required observations and then to easily create custom data products that can be delivered via Web 2.0 tools. Popular tools such as Google Earth can be used to create mashups in which data sets are superimposed for purposes of visualization or calibration. The end goal is to make discovery and access to sensors as easy as finding and using websites on the Internet. Figure 5 shows the use of OGC SWE in the NASA SensorWeb.

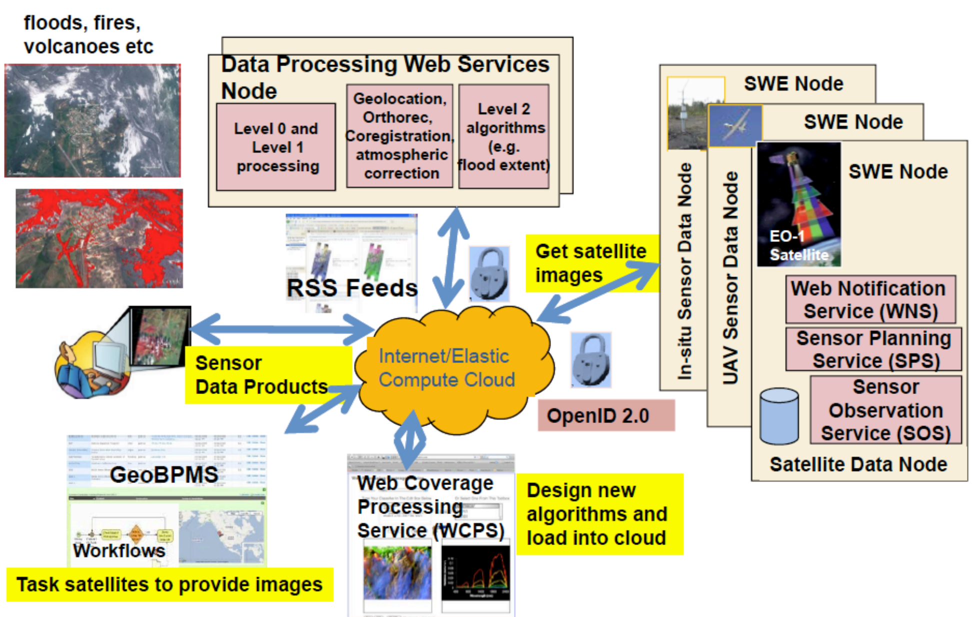

Figure 5. NASA SensorWeb High Level Architecture

Among its many features, is the GeoBliki service that allows NASA to task the EO-1 satellite through SWE-based interfaces. The service has been used in a variety of applications including for example the 2007 wild fires in California[12].

[11] http://sensorweb.nasa.gov/

[12] http://geobliki.com/tag/geoss

7.5 US IOOS

The US National Ocean and Atmospheric Administration (NOAA) is leading the development of an Integrated Oceans Observing System (IOOSIOOS). Central to the success of IOOS is the presence of a Data Management and Communication (DMAC)[13] system capable of delivering real-time, delayed-mode, and historical data for in-situ and remotely-sensed physical, chemical and biological observations. DMAC Recommended Web Services and Data Encodings, including SWE standards, are shown in Figure 6.

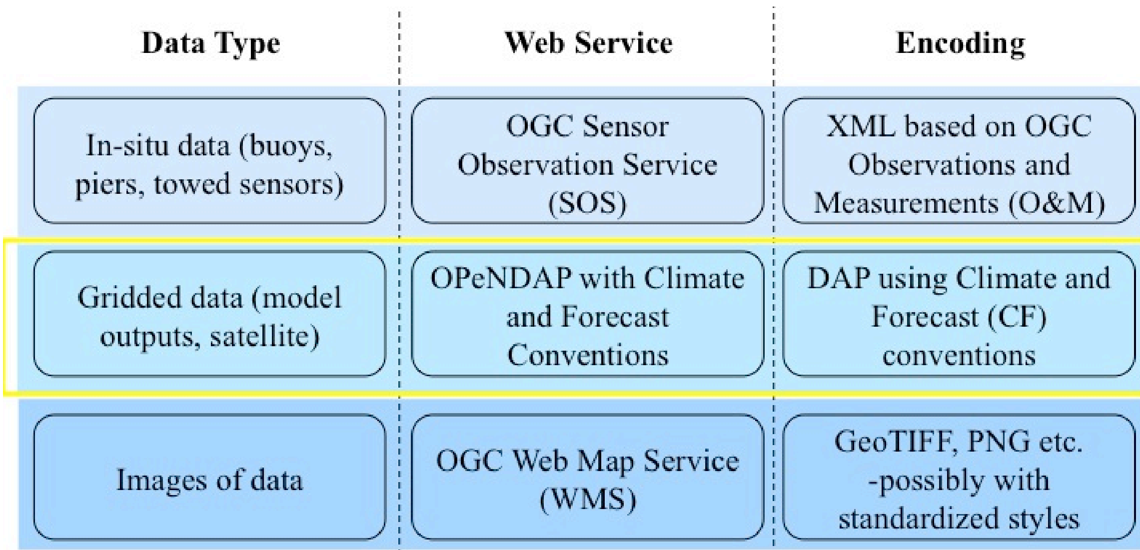

Figure 6 NOAA DMAC IOOS Recommended Web Services and Data Encodings

Regional U.S. IOOS provide increased observations, distinctive knowledge, and critical technological abilities, and apply these towards the development of products to meet regional and local needs. The Mid-Atlantic Coastal Ocean Observing System (MARACOOS) spans the coastal states from Cape Cod to Cape Hatteras. MARACOOS implementation of OGC SWE standards using a variety of clients (Figure 7) was demonstrated during the SWE Maturity Stakeholders Webinar[14].

[13] http://www.ioos.noaa.gov/data/dmac/

[14] https://portal.opengeospatial.org/files/?artifact_id=53564 Warning: It's 436MB!

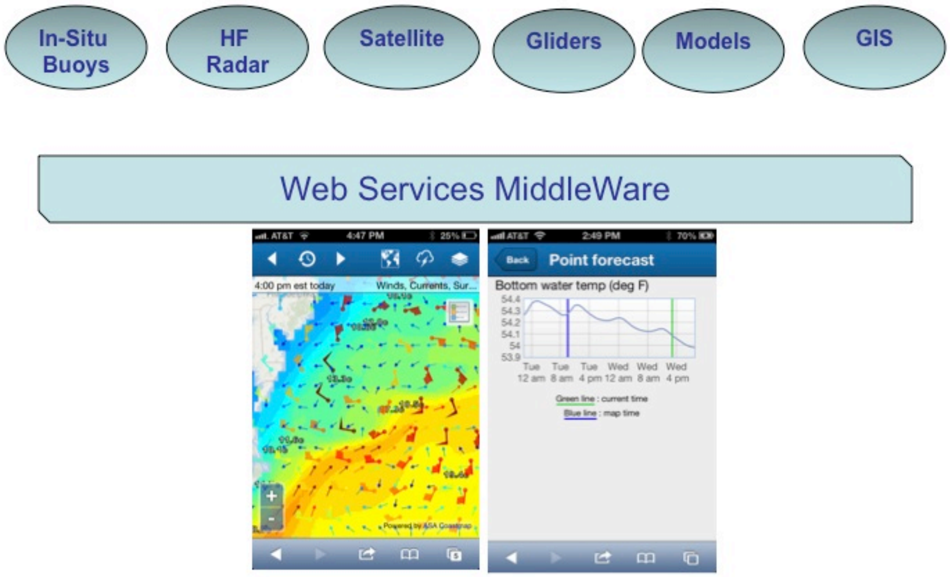

Figure 7. Mobile Client access to heterogeneous IOSS data sources

7.6 ESA SPS satellite tasking

The European Space Agency (ESA) has implemented the SPS standard for tasking of satellite assets as part of ESA Heterogeneous Missions Accessibility (HMA) project[15].

HMA is the result of more than five years of coordination and harmonization efforts, under the auspices of and with the cooperation of the ESA Ground Segment Coordination Body in the critical area of ground segment interoperability

The ESA HMA Feasibility Analysis Service is an extension of the OGC Sensor Planning Service (SPS). The OGC SPS provides a standard interface to task any kind of sensor to retrieve collection assets (i.e. sensors and other information-gathering assets). Furthermore, a client can either determine collection feasibility for a desired set of collection requests for one or more sensors/platforms, or submit collection requests directly to these sensors/platforms. Different kinds of assets with differing capabilities as well as different kinds of request processing systems are supported.

[15] http://esamultimedia.esa.int/multimedia/publications/TM-21/TM-21.pdf

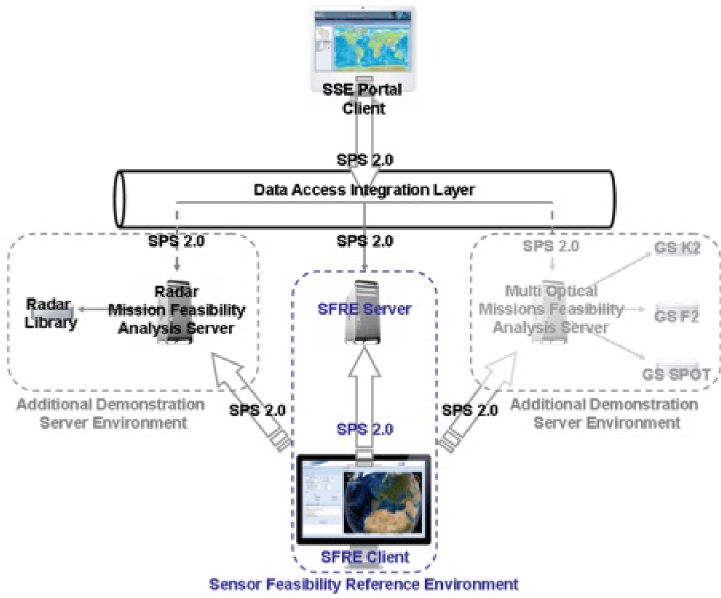

Figure 8. ESA HMA Feasibility Analysis Service implementation of SWE

The EO-SPS application profile is flexible enough to handle the variety of programming needs of most EO satellite systems. This means in particular the ability to support different configurations to access the different stages of planning, scheduling, tasking, collection, processing, archiving and distribution of requests, and the resulting observation data. The work culminated in open source implementations of the EO SPS extension v2.0 OGC 10-135 (extending SPS v2.0 OGC 09-000), as detailed at:

- http://code.google.com/p/sensor-feasibility-server/ (primarily Deimos Space)
- http://code.google.com/p/sensor-feasibility-client/ (primarily Astrium UK)

A reusable EO SPS v1.0 library, are detailed at:

- http://code.google.com/p/eo-sps-library/ (primarily SPOT Image)

The RADARSAT Constellation Mission (RCM) is a constellation of three synthetic-aperture radar imaging satellites. RCM is being developed for the Canadian Space Agency (CSA) by an industrial team led by MDA Systems Ltd. The mission will be providing distributed and concurrent access to the ordering system through both a web-based interface and an electronic-based interface. The electronic-based interface will be implemented based on a set of HMA standards for ordering SAR data acquisitions and SAR data products, and for browsing an archive of raw SAR data. RCM is plans to support a set of OGC standards.[16]

16 https://wiki.services.eoportal.org/tiki-view_forum_thread.php?forumId=2&comments_parentId=903&comments_per_page=1&thread_style=commentStyle_threaded

7.7 European Sensor Web Infrastructure Management (SWIMA) Project

The Sensor Web Infrastructure Management (SWIMA) Project[17] was a two-year project that started in September 2008 and partially funded by the UK Technology Strategy Board. The main goal was to research how an open, standards-based sensor web approach can provide the necessary capabilities to improve data gathering in complex natural environments such as rivers and lakes.

The full members of the consortium are: QinetiQ, the Environment Agency of England and Wales; South West Water; 1Spatial Group Limited; YSI Hydrodata Limited and the University of Nottingham's Centre for Geospatial Science.

The project's focus was on the provision of an innovative standards-based "middleware" layer between disparate sensor (and communication) networks and the associated control, management and user information services. The system was tested in a real-world environment by deploying a number of sensors for field trials between November 2009 and September 2010.

The main aim of the SWIMA project was to investigate the practical issues associated with the development of a generic Sensor-Web-based control and information system based on the use of SWE standards.

The main objectives were to:

- Investigate whether the standards are fit for purpose, i.e. whether they provide a viable and cost-effective solution for environmental monitoring systems;
- Investigate any interoperability issues relating to the different implementations of the specifications;
- Investigate the practical issues associated with a deployment of SWE enabled systems in a real environmental monitoring scenario.

The Project developed a web-based software testbed to provide a framework for the testing of the SWE Standards and for the management and control of the field-deployed sensors. gives an overview of the overall architecture.

[17] http://www.nottingham.ac.uk/ngi/research/geospatial-science/projects/swima.aspx

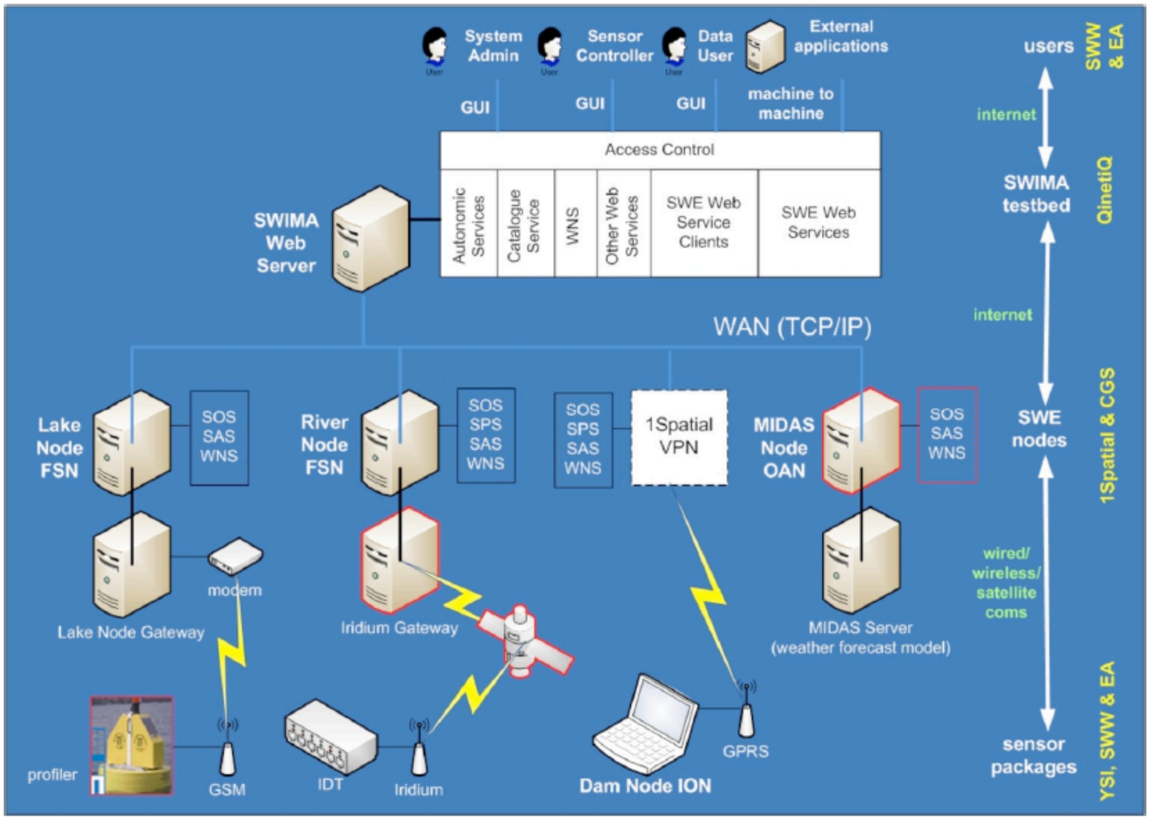

Figure 9. Overview of the UK SWIMA Architecture using SWE

In general, the SWE standards have been successfully used to implement the desired environmental monitoring system. The standards (and the associated software tools) are sufficiently mature to support operational systems although the standards are still evolving and the available software may not support all defined features of the standards, and may be "buggy". Implementing a system at this time may therefore have to overcome specification inconsistencies and software shortcomings. An example area where the client needed bespoke code to cope with differences in implementation of the standards was in the date & time format used in observations from different nodes.

The project concluded that use of SWE standards is gaining momentum internationally with operational systems being developed in the USA, Australia and Europe. The standards and software tools should therefore continue to improve and become easier to use.

7.8 European Research Projects implementing SWE

7.8.1 SANY

As a major Integrated Project in the Sixth Framework Programme of the European Commission, SANY (stands for "Sensors Anywhere") extends the interoperability advances into the domain of environmental sensor networks and standards-based sensor web enablement to support decision-making. OGC SWE standards were applied in SANY to three innovative risk management applications involving air pollution, marine risks and geohazards. These efforts yielded valuable reference implementations of sensor web services and geospatial processing Web services for decision support and data fusion.

SANY was the work of the SANY consortium, a group composed of 16 partners from seven EU member states (Austria, Belgium, Germany, Spain, France, Poland, United Kingdom) and one associated state (Switzerland).

The SANY book[18] provides an excellent introduction to OGC's Sensor Web Enablement (SWE) standards, which enable developers to make all types of sensors, transducers and sensor data repositories discoverable, accessible and useable via the Web. The book discusses in detail the approach and results of SANY.

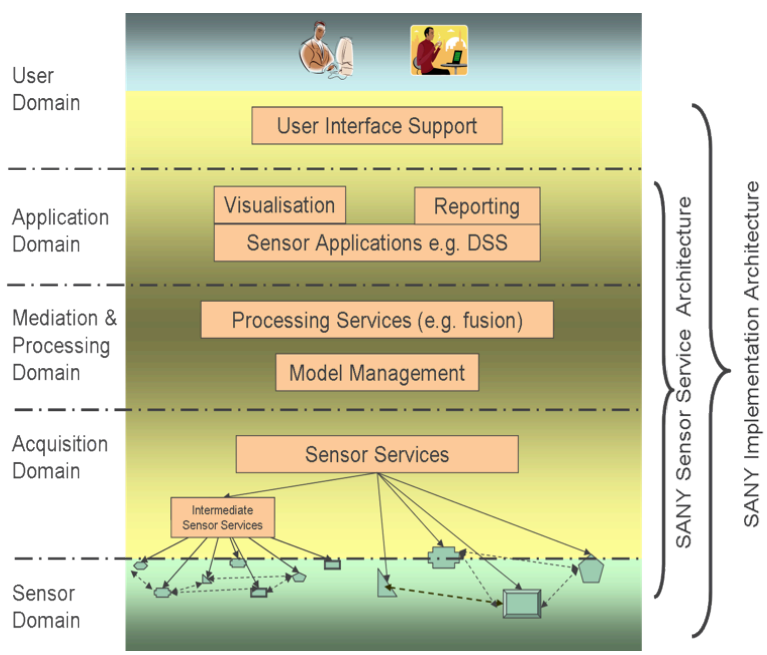

Figure 10. SANY Sensor Service Architecture using SWE

[18] https://portal.opengeospatial.org/files/?artifact_id=35024

7.8.2 GITEWS Project

The GITEWS project (*http://www.gitews.de/)*, an operational tsunami early warning system for the Indian Ocean, was developed as a Sensor Web infrastructure. The system integrates terrestrial observation networks of seismology and geodesy with marine measuring sensors, satellite technologies and pre-calculated simulation scenarios.

Tsunami detection for Indonesia is challenging since there is an 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. Hence, the GITEWS project uses the best sensor technologies available today to detect indicators for a tsunami and combines those information with up-to-date modeling techniques. To make the sensor data ad-hoc available, the OGC Sensor Web Enablement (SWE) framework plays a key role in the sensor data management of the GITEWS system. Based on SWE standards, other OGC Web services components are applied (e.g., Web Map Service) to display the current situation or communicate generated simulations.

The sensor systems utilized within GITEWS are the following:

- A continuous GPS System (CGPS) describes the seafloor deformation/rupture in (near) real-time based on highly accurate GPS measurements at smart land stations.
- 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.

Provision of observation data and sensor metadata is realized by the 52°North SOS implementation of version 1.0. Observation data is encoded using the O&M standard 1.0. Features are encoded as Geography Markup Language (GML) and also served via SOS (GetFeatureOfInterest operation). The SensorML standard is used to encode metadata of sensors. For performance reasons, there are several SOS instances setup and serving the different data sets.

Several of the SWE software components utilized within GITEWS are based on the open source SWE Implementation Suite from 52°North (developed in a subcontract commissioned by the GITEWS partner DLR).

See also: *Raape, U., S. Teßmann, A. Wytzisk, T. Steinmetz, M. Wnuk, M. Hunold, C. Strobl, C. Stasch, C., A.C. Walkowski, O. Meyer and S. Jirka (2010): Decision Support for Tsunami Early Warning in Indonesia: The role of standards. Geographic Information and Cartography for Risk and Crisis Management. Lecture Notes in Geoinformation and Cartography, 2010, 2, 233-247.*

7.8.3 SoKNOS Project

The Service-Oriented Architectures Supporting Networks of Public Security (SoKNOS) project (*http://www.soknos.de/*) was led by SAP and developed concepts to support governmental agencies, private companies, and other organizations in handling disastrous events. The SWE Implementation Suite from 52°North was used to integrate live sensor data into the situation map of a disaster management organization. Additionally, a concept for tasking mobile sensors and optimizing their coverage based on interpolation errors was developed (see figure below). A mobile sensor network was used to monitor air pollutants. The sensor nodes were provided by Scatterweb.

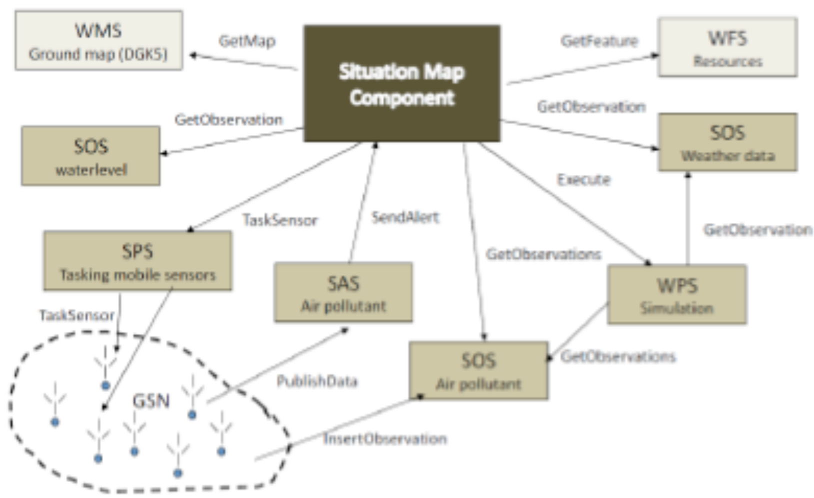

Figure 11. SoKNOS implementation using SWE

See also: *Stasch, Walkowski, Jirka (2008): A Geosensor Network Architecture for Disaster Management based on Open Standards. Digital Earth Summit on Geoinformatics, 12.-14. July, Potsdam (Germany). In: Digital Earth Summit on Geoinformatics 2008 – Tools for Climate Change Research: 54-59. Wichmann, Heidelberg.*

7.8.4 European Environment Agency SOS Project

European Environment Agency (EEA) receives environmental data (e.g., air quality, noise, or biodiversity) from different organizations of its 32 member states. Heterogeneous data formats and data transfer mechanisms make the data collection and integration a difficult task for the EEA. Hence, SWE technology has been introduced to facilitate the interoperable exchange of environmental data on a large scale.

As shown in the figure below, the data providing member state agencies are now in the process of changing to the standardized interface of the SOS to offer the data in the future to the EEA. On the side of the EEA, the member state data is collected, aggregated, and again offered via SOS interface. The data is encoded in O&M and metadata is given as

SensorML. The utilized SOS implementation from 52°North is based on ESRI's ArcGIS Server.

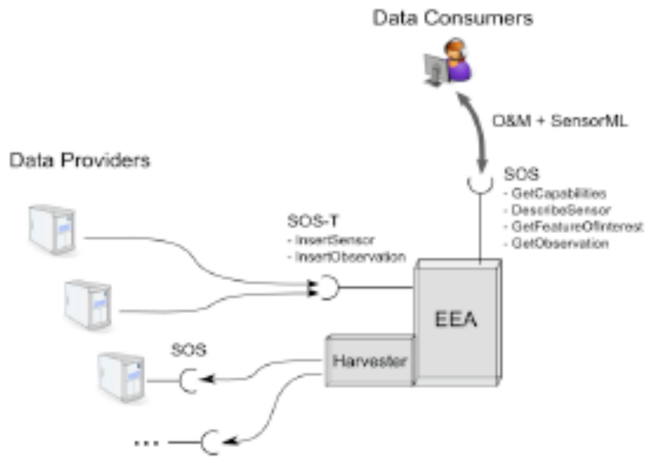

Figure 12 SWE Sensor Observation Service for European Environmental Agency

See also: *Jirka, S., A. Bröring, P.C. Kjeld, J. Maidens & A. Wytzisk (2012): A Lightweight Approach for the Sensor Observation Service to Share Environmental Data Across Europe. Transactions in GIS, 16(3), pp. 293-312.*

7.8.5 The OSIRIS Project

The OSIRIS project (http://www.osiris-fp6.eu/) has utilized SWE in multiple use cases:

- forest fire fighting
- air pollution monitoring and handling of accidents causing the release of air pollutants
- water quality monitoring as well as coordination in case of hydrocarbon pollutions of drinking water
- fire detection in industrial buildings

In all of these scenarios a broad range of sensors needs to be deployed. These sensor systems range from meteorological sensors, pollution sensors (i.e. air and water pollutants) to very complex systems such as unmanned aerial vehicles (UAVs) taking aerial probes and images for situational awareness. As all of these sensor systems rely on their own protocols and interfaces their integration into a common decision support platform for risk monitoring and emergency management becomes a challenging task. Thus, to overcome this issue, the OGC Sensor Web Enablement framework was chosen by the OSIRIS project. Besides contributing to the advancement of the OGC SWE standards, the OSIRIS project has utilized the 52°North SWE Implementation Suite consisting of SOS, SPS, SAS/SES, and SIR to implement four different use cases.

7.8.6 Sensor Web for the German Federal Waterways Administration

Together with the Service Centre Information Technology of the German Federal Ministry of Transport, Building and Urban Development at the Federal Waterways Engineering and Research Institute (DLZ-IT) and the Wupperverband, 52°North has conducted a project applying Sensor Web technology to hydrology.

Both, the Wupperverband and the DLZ-IT are dealing in their daily business with a broad range of sensor data. However, the structure of these sensor networks is very heterogeneous which makes their integration into the internal spatial data infrastructures and application systems a cumbersome task. To overcome the difficulties created by this heterogeneity the decision was taken to use Sensor Web technology. Especially the following two use cases had to be solved:

- Access to sensor data (i.e. time series data) and visualization of these data
- Dispatching of notifications (via e-mail or SMS) if certain user-defined measurement value combinations occur

For providing access to water level measurements, the 52°North Sensor Observation Service is coupled to the existing PEGELONLINE infrastructure of DLZ-IT. Furthermore, an additional generalization module speeds up the delivery of sensor data by reducing the amount of transmitted data.

The filtering of incoming sensor data streams in order to notify subscribers in case of critical measurements is achieved through the 52°North Sensor Event Service.

A Google Web Toolkit based web client application is available to display the water level data as diagrams and tables. Also a map view showing the sensor locations is included. Finally, the client allows users to flexibly define filter criteria describing measurement value constellations in which they would like to be notified.
The project can be characterized through the following key facts:

- Sensor Observation Service offering access to more than measurement stations (measuring multiple properties ranging from water level, conductivity to meteorological parameters)
- Update rates: one update every minute to one update every 15 minutes
- Client for time displaying series data (diagram and map views)
- Notification component for near-real time filtering of measurements (SMS and e-mail)
- Deployment of OGC Sensor Web components in order to ensure interoperability

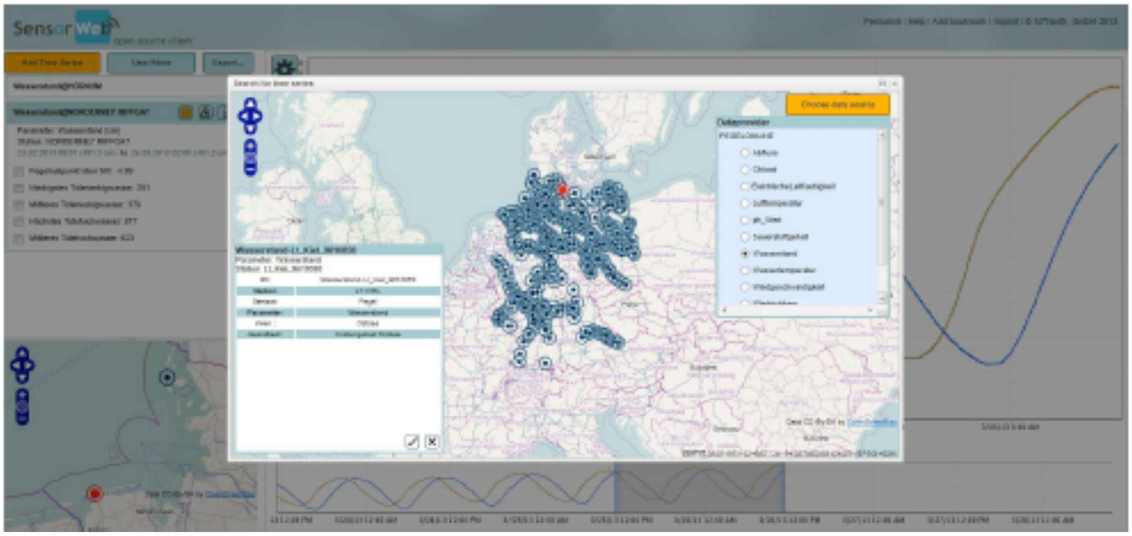

Figure 13. German Federal Waterways Administration implementation of SWE

7.9 GeoCENS

GeoCENS is an OGC SWE sensor web platform developed by the GeoSensorWeb Laboratory (GSWL) at the University of Calgary in Canada. Professor Liang from GSWL developed one of the first integrated sensor web client. The client (Figure 14) developed during the OGC Web Services, Phase 3 (OWS-3) Testbed supported OGC WMS, WCS, CS/W, SOS, SPS, and WNS standards[19].

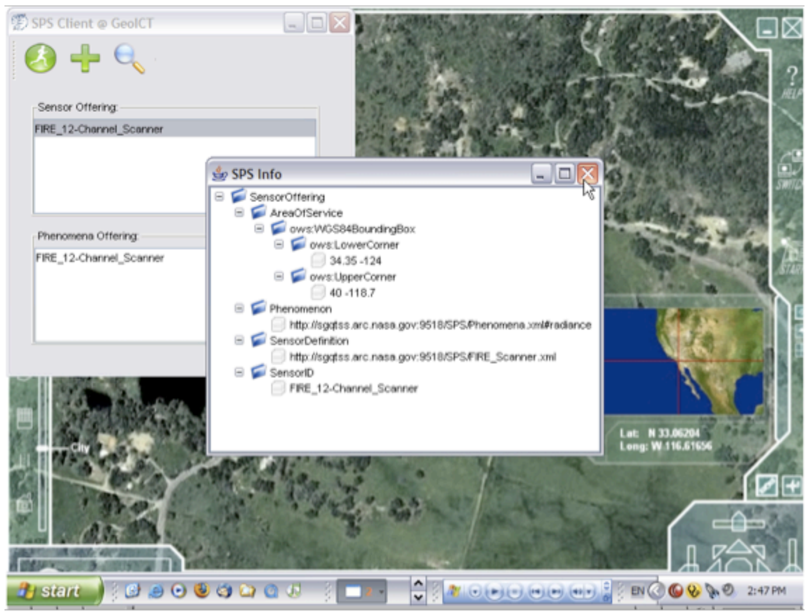

Figure 14. OWS-3 Integrated Sensor Web Client

The GeoCENS platform is a mature, hardened sensor web platform and has been adopted by many organizations to empower their sensor web systems and applications. Below lists some example GeoCENS applications.

Rockyview WellWatch for Groundwater Monitoring

- Users: Rockyview county, Groundwater well owners, and Hydrology Researchers
- Application: Long-term groundwater level monitoring
- Sensors: pressure transducer (e.g., Druck PDCR 950) and well owners (citizens as sensors)
- Demo URL: http://rockyview.geocens.ca

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[19] A demonstration video is available at http://goo.gl/Gj1p0.

RISMA: Real-time In-situ Soil Monitoring for Agriculture

- Users: Agriculture and Agri-Food Canada (AAFC) and NASA
- Application: Soil monitoring, and satellite remote sensing ground referencing
- Sensors: weather stations, soil-moisture probes, sensor health monitoring (e.g., battery power)
- Demo URL: http://aafc.geocens.ca

GeoCENS Sensor Web Pivot Viewer

- Users: Microsoft Research
- Application: Technology demonstration, Integration of Microsoft PivotViewer and Sensor Web
- Sensors: from various OGC SWE data sources
- Demo URL: http://dev.geocens.ca/pivot_viewer
- Demo Video: http://goo.gl/TcwcI

GeoCENS for Environmental Monitoring

- Users: Researchers at Biogeoscience Institute at University of Calgary, and Drought Research Initiative (DRI)
- Application: Environmental sensing
- Sensors: various in-situ sensors, including MICA2 motes, weather stations, snow depth sensors, soil moisture sensors, etc.
- Demo URL: http://dev.geocens.ca

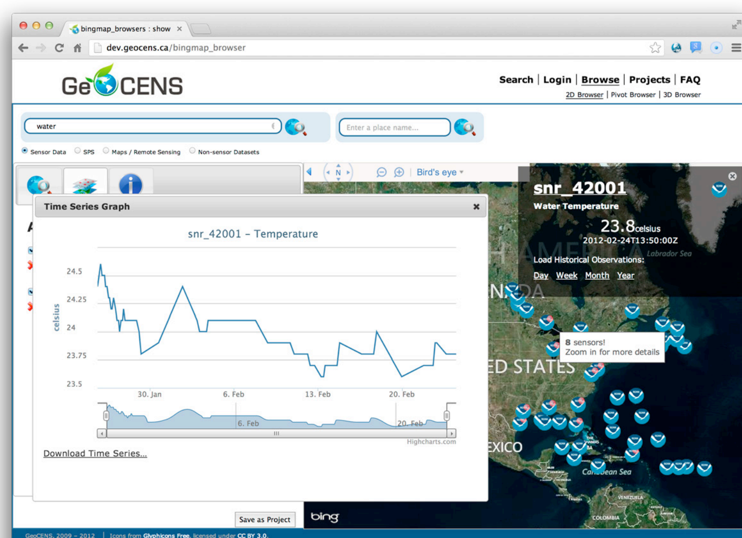

Figure 15. GeoCENS Client for Environment Sensors using SWE

GeoCENS includes the following major components:

- GeoCENS SOS Server
- GeoCENS 3D Browser
- GeoCENS 2D Browser and Online Platform
- GeoCENS Search Engine

The following table shows the SWE standards GeoCENS used and how they were used:

Figure 16 SWE Standards used in GeoCENS

	GeoCENS Sensor Web Browser	**GeoCENS 3D Virtual Globe**	**GeoCENS SOS Server**	**GeoCENS OWS Search Engine**
WMS	X	X		X
SOS	X	X	X	X
SPS	X	X		X
O&M	X	X	X	Not applicable
SensorML	X	X	X	Not applicable
SWE Commons	X	X	X	Not applicable
WaterML	X	X	X	Not applicable
PUCK	Not applicable	Not applicable	Not applicable	Not applicable

Citations for publications providing more detail about GeoCENS:

- Liang, S. H. L., S. Chen, C. - Y. Huang, R. - Y. Li, D. Y. C. Chang, J. Badger, and R. Rezel, "GeoCENS: Geospatial Cyberinfrastructure for Environmental Sensing ", GIScience 2010, Zurich, Switzerland, 09/2010

- Knoechel, B., C. - Y. Huang, and S. H. L. Liang, "Design and Implementation of a System for the Improved Searching and Accessing of Real-world SOS Services", International Workshop on Sensor Web Enablement 2011, Banff, Canada, 10/2011

- Jazayeri, M., C. - Y. Huang, and S. H. L. Liang, "TinySOS: Design and Implementation of Interoperable and Tiny Web Service for the Internet of Things", The First ACM SIGSPATIAL International Workshop on Sensor Web Enablement 2012 (SWE2012), Redondo Beach, California, ACM Digital Library, 2012

7.10 Additional Implementation Examples

Some additional example uses of the SWE standards include:

- CitySense sensor network City of Cambridge, MA: A real-time data integration and analysis system for air quality assessment.
- Smart Cities (various): An architecture implementation based on Sensor Web Enablement standard specifications and makes use of the Contiki Operating System for accomplishing the Internet of Things.
- Indian National Centre for Ocean Information Services (INCOIS): Tsunami Early Warning System
- Asian Institute of Technology, Thailand - Nepal Wireless Project: Monitoring Climate Change in the Himalayas
- Taiwan – Debris Flow Monitoring and Alerting system
- Japan National Institute of Advanced Industrial Science & Technology (AIST): Earthquake Monitoring and Warning System (QuiQuake)
- Europe Emergency Response: (http://www.ess-project.eu/ an infrastructure based on SOS, SPS, and SES to provide real-time information to crisis managers during abnormal events to improve the management between forces on the ground (e.g., police and firefighters) and the control centers.
- Climatology-Hydrology Information Sharing Pilot, Phase 1: US and Canadian agencies demonstrated cross-border hydrologic modeling for stream flow and also modeling and assessment of nutrient load into the Great Lakes using SWE standards with the OGC WaterML 2.0 Encoding standard to overcome delays and obstacles imposed by different and incompatible software systems, data stores, data models, sensor interfaces, etc.
- PATS and SAP: Systems designed at the Jet Propulsion Laboratory to meet the sensor web needs and requirements of wild land firefighters as defined by the Fire Research Working Group (FRWG) of the United States Department of Homeland Security (DHS). SAP can additionally post emergency management information, derived from PATS sensor data, to the Unified Incident Command and Decision Support (UICDS) network operated by DHS.

8 Software Implementations

8.1 Certified and Registered Implementations

OGC maintains a registry[20] of publicly available implementations of the OGC Standards. The registry includes both 1) OGC Compliant implementations and 2) self-registered implementations. There is no requirement to register with OGC and many products that implement OGC standards are not registered. Vendors who have had their products passed the OGC compliance tests and who have obtained an OGC Trademark License may advertise their products as "OGC Compliant".

Table 3 provides summary statistics for the SWE standards implementations registered in the registry. The "n.a." indicates that compliance certification is not yet possible as the compliance test suite has not yet been deployed for that standard.

Table 3. Compliant and Registered Implementations of SWE

OGC Standard	Compliant Implementations	Registered Implementations
SOS v1.0.0	3	35
SOS v2.0	n.a.	4
SPS v1.0.0	3	14
SPS v2.0	n.a.	2
SensorML v1.0.1	n.a.	15
O&M Part 2 v1.0	n.a.	6
O&M XML v2.0	n.a.	4

As part of the Compliance Program reference implementations (Table 4) are confirmed as compliant and are freely available from the OGC for use by developers.

Table 4. SWE Reference Implementation

Standard	**Ver.**	**Product**	**Developed by**
SOS	**1.0.0**	52°North	52°North
SOS	**2.0**	52°North	52°North
SPS	**1.0**	52°North	52°North
SPS	**2.0**	52°North	52°North

[20] http://www.opengeospatial.org/resource

8.2 The 52°North SWE Implementation Suite

In response to the RFI, 52°North provided information about their implementation suite. 52°North has implemented all OGC SWE services (server as well as client implementations) as open source software. The 52°North suite has been used and customized in various projects by a variety of international clients (e.g., European Environment Agency (EEA), German Aerospace Agency, German Federal Waterways Administration, Rijkswaterstaat (part of the Dutch Ministry of Infrastructure and the Environment), Helmholtz Centre for Environmental Research (UFZ), Global Runoff DataCentra (GRDC)).

All relevant information on the 52°North SWE implementation projects can be found on the official website (http://52north.org/swe). Here, design descriptions, installation instructions, or code repositories are linked.

Table 5. 52°North SWE Implementations

Project	Supported Specs	CITE Tested
SOS Server	SOS 1.0 / 2.0	YES
SOS for ArcGIS Server	SOS 2.0	-
SPS Server	SPS 1.0 / 2.0	YES
SES Server	SES 0.0.1	-
WNS Server	WNS 0.0.9	-

	Client Software	
OX-Framework	SOS 1.0 / 2.0 SES 0.0.1	
Sensor Web Client	SOS 1.0 / 2.0 SES 0.0.1	
ArcMap SOS Adapter	SOS 1.0	

9 OGC Interoperability Program Implementations

9.1 SWE in OGC IP Initiatives

Development of the SWE suite of standards has been advanced by activities in the OGC Interoperability Program. SWE has been implemented in nearly every OGC Web Services (OWS) Testbed. OGC the (UAH)

SWE was part of the first OWS testbed beginning in 2001. Through a series of OWS-1.1, OWS-1.2, OWS-3 and OWS-4 testbeds, the specifications were refined, implemented and demonstrated. Extensive development by OGC members in OWS and outside of OWS initiatives culminated initiatives culminated in the adoption of SWE version 1.0 standards in 2007. (Figure 17)

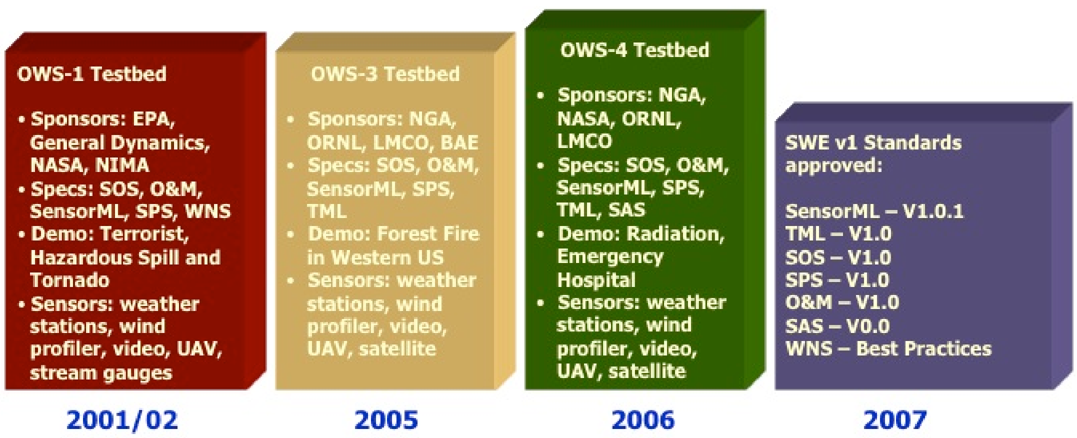

Figure 17. OWS Testbeds support of SWE Version 1. (Source: M. Botts)

Implementation of SWE continued after 2007 based on the version 1 standards. The OGC IP Initiatives contributed to the refinement of the SWE standards eventually leading to version 2 and also contributed to the uptake of SWE into operational programs Figure 18). Experience gained in the OGC Empire Challenge Pilot contributed to development of the DoD/IC SensorWeb (See section 7.1). Experience gained from two phases of the OGC Ocean Science Interoperability experiments contributed to development of the NOAA IOOS DMAC (See section 7.5). Experience gained in the OWS-5 Testbed contributed to development of the NASA EO-1 SensorWeb (See section 7.4).

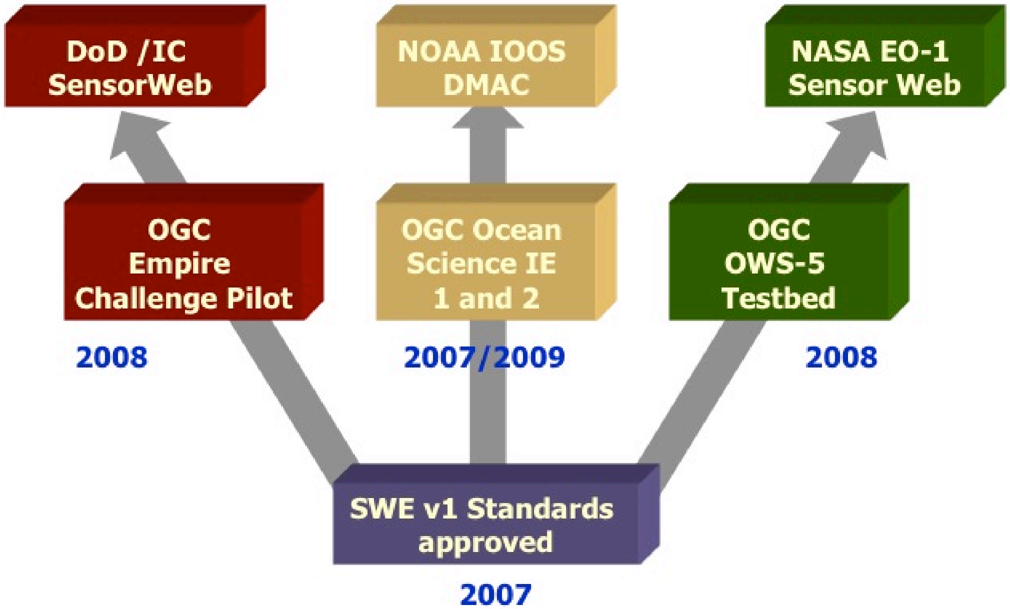

Figure 18. Examples of OGC IP influence SWE deployments

9.2 OWS-4 Testbed (2006)

The OWS-4 Testbed[21] contributed to the maturing implementation and testing of SWE components to support the adoption of SWE at the level of Version 1.0.

In OWS-4 the Sensor Web subtask focused on maturing the existing set of SWE work items to enable the federation of sensors, platforms and management infrastructure into a single sensor enterprise. This enterprise was envisioned to enable the discovery and tasking of sensors as well as the delivery of sensor measurements regardless of sensor type and controlling organization. The ultimate vision was of a sensor market place where users can identify, evaluate, select and request a sensor collection regardless of sensor type, platform or owner.

An objective in this testbed was to illustrate discovery, access to and fusing of disparate sensors (Figure 19). The figure shows the Space Time Toolkit client accessing observations from several distributed services using OGC service interfaces:

- SOS – in-situ radiation sensors
- SOS – Doppler Radar
- SOS – Lagrangian plume model

[21] http://www.opengeospatial.org/pub/www/ows4/index.html

- WCS – GOES weather satellite
- SensorML – discovery and on-demand processing
- WMS – Ortho Imagery

Videos of the overall demonstration[22] of OWS-4 testbed and a demonstration of the SWE plume integration[23] are available.

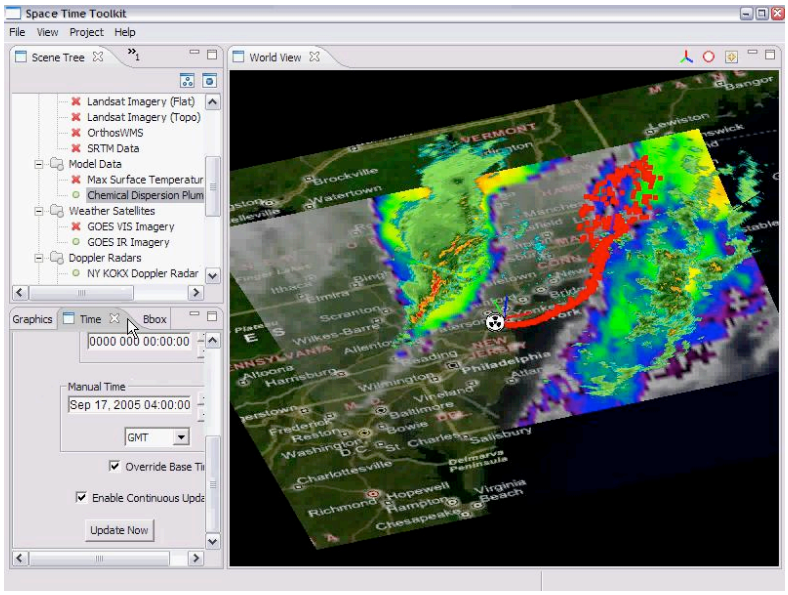

Figure 19. OWS-4 Testbed: Sensor and Model integration for simulated radiation attack

9.3 OWS-5 Testbed (2008)

The OWS-5 Testbed[24] focused on integrating the SWE interfaces and encodings into workflows to demonstrate the ability of SWE specifications to support operational needs.

Emphasis for SWE during OWS-5 was on:

- IEEE1451 Sensor Integration
- Geo-Referenceable Workflow (Figure 20)
- NASA EO Wildfire Scenario
- Web Coverage Processing Service (WCPS) Scenario

[22] http://www.opengeospatial.org/pub/www/ows4/index.html

[23] http://www.botts-inc.com/downloads/videos/UAH-ows4-demo-narrated.mp4

[24] http://www.opengeospatial.org/pub/www/ows5/index.html

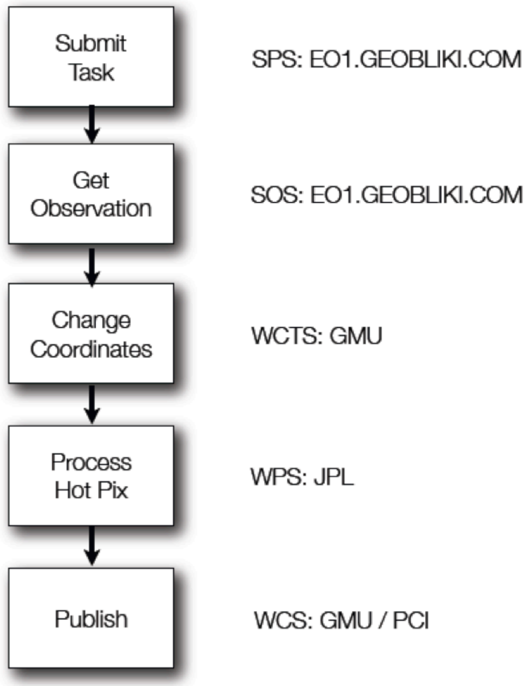

Figure 20. OWS-5 GeoReferenceable Workflow using EO-1 Imagery

9.4 Empire Challenge (2008)

The EC08 OGC Pilot examined the suitability and performance of SWE and OGC Web Service standards for providing open management of and access to sensors of varied types and Web service access by analysts to the resulting data and products. Several use cases and supporting workflows were provided to enable understanding of the design of the pilot. The use cases involved both sensor management and exploitation by a targeting analyst. Building upon a SensorWeb service oriented architecture that was demonstrated in EC 07, the goal in '08 was to put new services and sensors into the defense-themed SensorWeb. (See Section 7.1 for more about SensorWeb).

OGC members participated in an OGC pilot activity in the Empire Challenge event in 2008. The OGC members demonstrated on-demand geolocation and display of HD video from Tigershark UAV. As part of this pilot the Space Time Toolkit client was used to access a set of services using OGC interfaces:

- SOS – Tigershark video and navigation
- SOS – Troop Movement
- SensorML – On-demand processing

Videos demonstrating results from EC'08 are posted online.[25,26]

9.5 Oceans Science IE (2007/2009)

The Oceans Science Interoperability Experiments consolidated a portion of the Ocean-Observing community on its understanding of various OGC specifications, solidified demonstrations for Ocean Science application areas, harden software implementations, and produce a candidate OGC Best Practices document that can be used to inform the broader ocean-observing community.

In 2007, the Oceans IE phase 1 investigated use of OGC Web Feature Services (WFS) and SOS for representing and exchanging point data records from fixed in-situ marine platforms. The following topics for using SOS v1.1 were developed helping to improve existing standards and recommendations at OGC:

- Requesting a latest observation
- Encoding of OGC URNs when versioning is missing
- Publishing of URIs by service providers
- Using Semantic Web technologies to categorize SOS services
- Publishing an SOS as an HTTP-Get service
- Encoding vertical datums (Sea level based systems, geoid based systems and bottom based systems) in marine observations

In 2009, the Oceans IE Phase 2 addressed the following tasks:

- Automated metadata/software installation via PUCK protocol.
- Offering of complex systems (e.g. observations systems containing other systems) such as collection of stations.
- Linking data from SOS to out-of-band offerings.
- Semantic Registry and Services.
- Catalogue Service-Web Registry.
- IEEE-1451/OGC-SWE harmonization

9.6 OWS-6 Testbed (2009)

The OWS-6 Testbed[27] focused on integrating the SWE interfaces and encodings into cross-thread scenarios and workflows to demonstrate the ability of SWE specifications to

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[25] http://www.botts-inc.com/downloads/videos/STT_Tigershark_OnTheFlyGeolocation3.mp4

[26] http://www.botts-inc.com/downloads/videos/STT_Tigershark_OnTheFlyGeolocation4.mp4

[27] http://www.opengeospatial.org/pub/www/ows6/index.html

support operational needs. Among other security-focused demonstrations, the testbed included demonstrations of the use of the Common CBRN (Chemical, Biological, Radiological, Nuclear) Sensor Interface (CCSI). Emphasis for SWE during OWS-6 were:

- Apply GeoRM and Trusted Services in the SWE environment
- CCSI-Enabled CBRN Sensors into the SWE Environment
- Sensor parameter adjustability and error propagation for georeferenceable imagery. Build on Georeferenceable imagery accomplishments of OWS-5
- Harmonize SWE information models: SensorML, GML, UncertML
- Events-based architecture including WNS

Objectives in OWS-6 included illustrating dynamic query of SPS and showing on-demand geolocation of JPIP stream using SensorML (Figure **21**). The figure shows the Space Time Toolkit client interacting with several distributed services using OGC service interfaces in order to request image acquisition by a SPOTIMAGE satellite. Services included:

- SPS – satellite imagery feasibility
- WCS/JPIP server – streaming J2K image with CSM parameters encoded in SensorML
- SensorML – on-demand geolocation

A video demonstrating results from this portion of OWS-6 is posted online.[28]

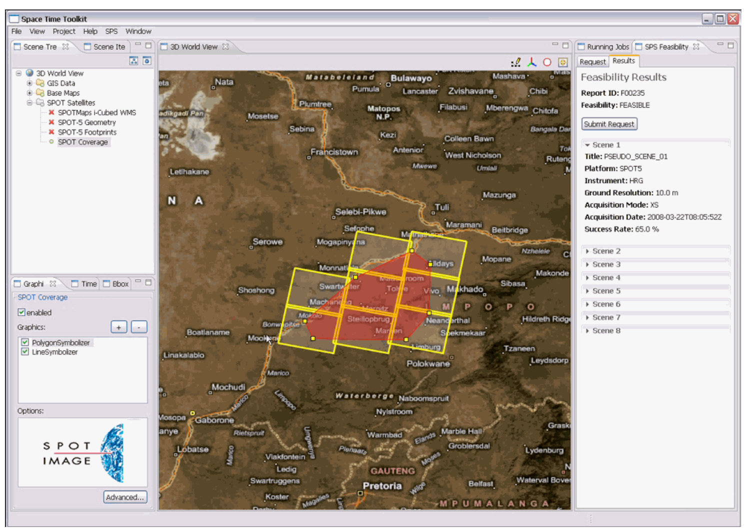

Figure 21**. OWS-6 Tasking SPOT Image Satellite**

A debris flow deployment and demonstration was conducted in OWS-6 including SWE and geoprocessing workflow elements. The Geographic Information Systems Research

[28] http://www.botts-inc.com/downloads/videos/spot-ows5-demo-1024-divx-audio.mp4

Center, Feng Chia University (GIS.FCU) in Taiwan implemented OGC services for use in the workflow of detecting and analyzing sensor data for emergency response (Figure 22. Landslides and flooding are a frequent threat on the mountainous island of Taiwan, due to typhoons and earthquakes. The OWS-6 Debris Flow[29] demonstration shows the working network of debris flow sensors, and examples of distributed services performing analysis and processing of the sensor data.

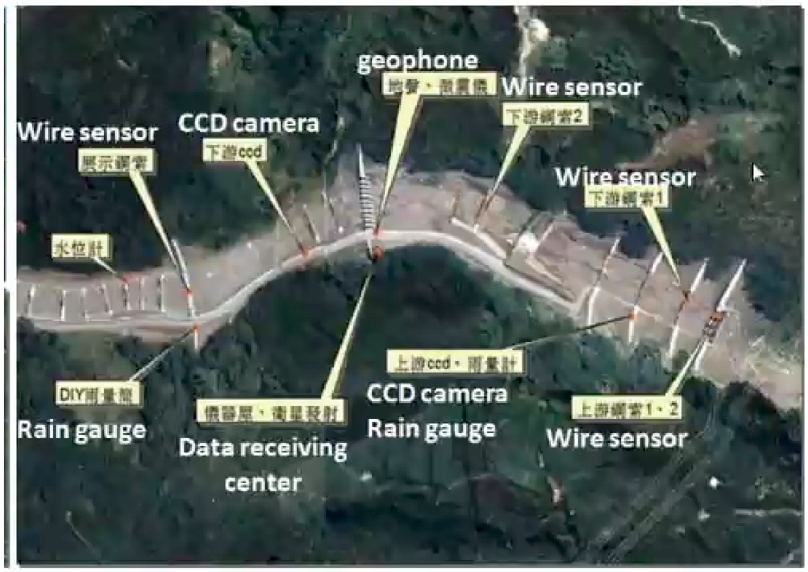

Figure 22. Debris flow monitoring station in OWS-6 demonstration (Source: GIS-FCU)

The OWS-6 Testbed developed the concept of Secure Sensor Web.[30] The main purpose was to introduce standards-based security solutions for making the existing OGC Sensor Web Services ready towards the handling of sensors in the intelligence domain. This brings in the requirement for handling sensors that eventually produce classified information and the main objective of accreditation. In order to fulfill this, it would require a holistic security approach, but as this report is documenting the scientific findings under the OWS-6 initiative, it is limited to the given use case and its scenarios as well as the underlying architecture.

The Engineering Report identified a firm set of requirements with the objective "classified information" and the Trusted Computer System Evaluation Criteria (TCSEC). The TCSEC (also called The Orange Book) defines the evaluation class "B" for trusted systems that are certified to handle classified information. In particular, the following requirements were considered in OWS-6 analysis:

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[29] http://www.opengeospatial.org/pub/www/ows6/web_files/ows6.html

[30] OWS-6 Secure Sensor Web Engineering Report (OGC Document 08-176r1)

- Mandatory Access Right Management
- Authorization based on user identity and resource classification / user clearance
- Integrity of the classification labels and its protection against modification
- Tracking of actions

For OWS-6, the Internet Threat Model, as defined in RFC 3552, was assumed. As outlined in the “Internet Threat Model”, it was assumed that an insecure network and the capabilities of an adversary to gain control over the communication and exercise different attacks towards espionage and sabotage. This requires additional and more specific requirements under consideration, as stated in (all parts of) ISO 10181, “SECURITY FRAMEWORKS FOR OPEN SYSTEMS”. Basically, the distributed property of the Sensor Web System might not take affect, compared to a non-distributed system. But due to the distributed property, the implementation of requirements such as persistent protection of classified information needs to be ensured not only for a local system but also for multiple systems that are connected with each other over insecure communication channels. And even more complex for a Service Oriented Architecture, as it is the basis for the Sensor Web Services, the orchestration of services is dynamic which limits the applicability of network- or transport layer security.

In order to propose a Secure Sensor Web, OWS-6 also analyzed the vulnerabilities and potential attacks that exist in the baseline and in the different ways of implementing the identified requirements. This was done for the baseline Sensor Web Services and the proposed security standards. Because this analysis is so exhausting the scope was limited to a given use case and its scenarios.

9.7 OWS-7 Testbed (2010)

The OWS-7 Testbed[31] including a Sensor Fusion Enablement (SFE) Thread built on the SWE framework of standards that has achieved a degree of maturity through previous OWS interoperability initiatives and deployments worldwide. SFE focused on integrating the SWE interfaces and encodings with workflow and web processing services to perform sensor fusion. SFE continued the development of interoperability of SWE and the Common CBRN (Chemical, Biological, Radiological, Nuclear) Sensor Interface (CCSI).

Emphasis for SFE during the OWS testbed was on the following:

- Motion Video Fusion. Geo-location of motion video for display and processing. Change detection of motion video using Web Processing Service with rules.
- Dynamic Sensor Tracking and Notification. Track sensors and notify users based on a geographic Area of Interest (AOI). The sensor and the user may be moving in space and time.

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[31] http://www.opengeospatial.org/pub/www/ows7/index.html

- CCSI-SWE Best Practice. Building on OWS-6, develop an ER to be considered by the OGC Technical Committee as a Best Practice.

An objective in the OWS-7 testbed was to illustrate ability to use SWE services and encodings to support temporal differencing of ground-based video to (Figure 23). The figure shows the Space Time Toolkit client interacting with several distributed services using OGC service interfaces in order to detect differences between video streams recorded at different times. Services included:

- SOS – video from vehicle-mounted camera
- SOS – camera navigation data
- WPS – Web Processing Service for change detection
- SensorML – On-demand processing

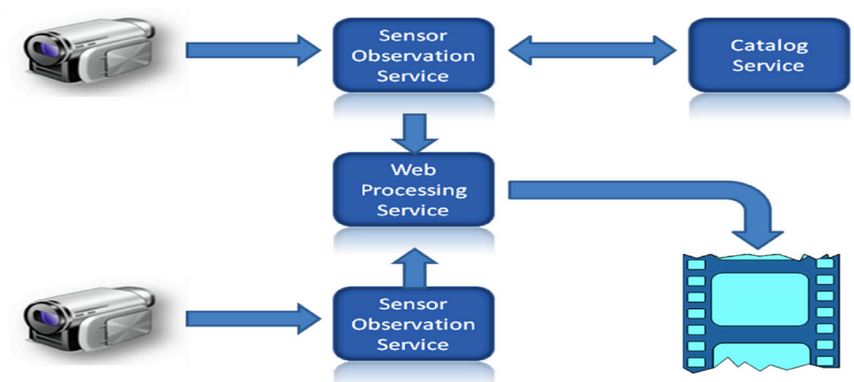

Figure 23. OWS-8 Testbed - Motion Video Change Detection using SOS and WPS

A video demonstrating results from this portion of OWS-6 is posted online.[32]

[32] http://www.opengeospatial.org/pub/www/ows7/web_files/OWS-7.html See SFE Scenario 4.

9.8 OWS-8 Testbed (2011)

The OWS-8 testbed[33] developed use of SWE standards in the detection, tracking, and bookmarking of moving objects in video. The activities were:

- In the context of OGC and ISO standards, provide an architectural viewpoint / information model for the usage of
  - video moving target indicator data (VMTI),
  - ground moving target indicator (GMTI) and
  - tracking information (NATO STANAGs 4607, 4609, 4676, MISB EG0903.03)
- Provide traceability from a moving object back to the original base data through the use of a "bookmark" concept.
- Implement OGC services and encodings, extended by the XML-Schema-based implementations; allow access to target information data and tracking data based on VMTI, GMTI, and STANAG 4676 information.
- Identify any recommendations for enhancements to OGC, MISB, NATO standards supporting tracking architecture.

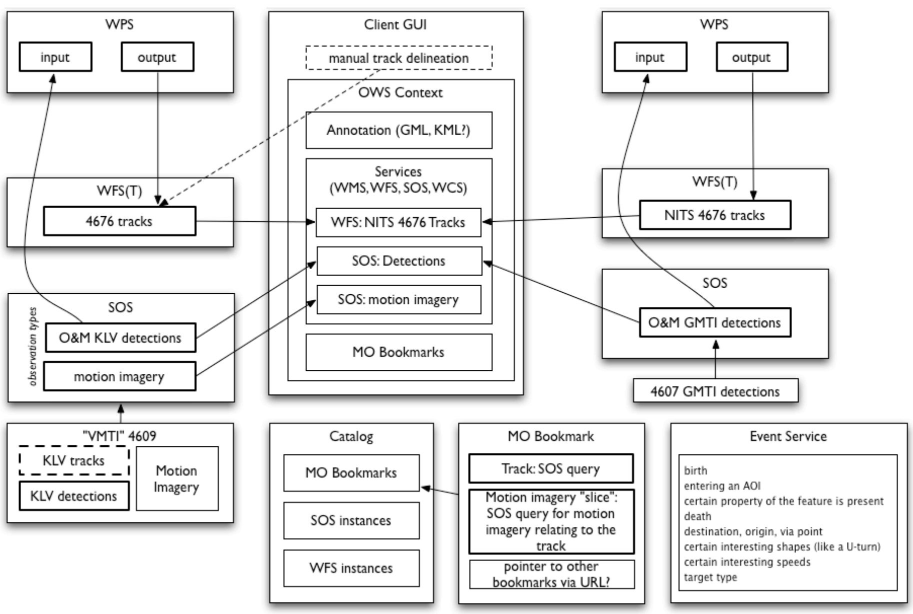

Figure 24. OWS-8 Video Tracking Architecture Diagram

Demonstrations of the implementation of the OWS-8 Video Tracking Architecture can be viewed on the OWS-8 YouTube Channel[34].

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[33] http://www.opengeospatial.org/pub/www/ows8/index.html

9.9 OWS-9 Testbed (2012)

A GPS Study was conducted in OWS-9 to Investigate and prototype the capabilities of OGC standards to support GPS data product and message requirements to include definition of a new one-size-fits-all Variable Message Format (VMF) message capable of supporting all potential GPS ephemeris/data.

The GPS study resulted in positive findings on the use of SWE to support GPS. SWE standards were found suitable for distributed post-processing of GPS information. SWE Common Data 2.0 encodings were demonstrated to support an interoperable messaging description and encoding for the next generation GPS message streams into and out of the GPS navigation accuracy improvement services. The connection of SWE Common to SensorML 2.0 and the application of SensorML to describe the processing surrounding GPS navigation improvement were shown.

[34] http://www.youtube.com/playlist?list=PL22A50B3A16E3C88A

10 Implementation Maturity summary

The different examples of listed projects within this document clearly show that the SWE standards help to realize various kinds of applications. In particular, they are instrumental for flexibly integrating various kinds of sensors and sensor data. The examples show the wide range of sensor information that can be provided via SWE services, from in-situ sensors (e.g. water gauges, weather stations) to mobile sensors (e.g., in the OSIRIS project: tracked firemen, air quality sensors on busses, as well as UAVs), to remote sensors (satellites).

One method to quantify the maturity is to assign Technology Readiness Levels (TRL) to the SWE standards.[35] TRLs range from 1 to 9 with 9 being best. Based on the information in this report, SWE Version 1 can be considered to be at TRL level 9, while SWE Version 2 is at level 6. It is anticipated that implementations of SWE Version 2 will rapidly advance its TRL to level 9.

Table 6. Technology Readiness Levels of SWE standards

OGC Standard	TRL level	Comments
SOS v1.0.0, SPS v1.0.0, SensorML v1.0.1	Level 9. Actual system proven through successful mission operations	Compliance tests have been approved. Several implementations have passed compliance testing. Versions are used in operational activities.
SOS v2.0, SPS v2.0	Level 6. System/subsystem model or prototype demonstration in a relevant environment	Several implementations have implemented the standard. Versions are used in demonstration activities.
O&M Part 2 v1.0, O&M XML v2.0	Level 7. System prototype demonstration in an operational environment.	Several implementations have implemented the standards. Implementations are used in operational activities.
SensorML v2	Level 4. Component and/or breadboard validation in laboratory environment	Standard has been developed based on previous version, but with major additions. Major additions have been tested in experimental environment.

[35] http://en.wikipedia.org/wiki/Technology_readiness_level#U.S._Department_of_Defense_.28DoD.29_definitions

The increased applications of SWE in commercial projects (e.g., projects with Wupperverband, EEA, Rijkswaterstaat, or DLZ-IT) demonstrate that SWE specifications are becoming more significant in practice. SWE enables the integration of (near) real-time data into spatial data infrastructures and GIS systems. SWE facilitates the integration of various sensors by providing a unified and vendor independent interface.

In conclusion, this study indicates that the OGC SWE specifications have reached a stable state and have been tested and operationally used in many applications and projects. Hence, the SWE specifications represent a meaningful and important extension to existing spatial data infrastructures, particularly, to flexibly and efficiently integrate sensor data and (near) real time data.

11 Future Work

11.1 Further Development of SWE Standards

After having SOS, SPS, O&M, as well as SWE Common models accepted as version 2.0 standards, and SensorML 2.0 being close to the final voting, the next focus of the SWE working group is on the eventing and alerting technologies. Although the SES (and also the SAS) were successfully tested in various projects (e.g., OWS testbeds), neither of them has reached the status of an adopted standard yet. Currently, the Pub/Sub working group at OGC is working on the next iteration of an eventing specification. This forms the basis of a generic eventing service – not restricted to sensors – and is an important current working field.

Further, the development of profiles for SWE specifications will be of relevance in the future. Through profiles, the applicability of specifications can be facilitated and their interoperability can be increased. An example profile is WaterML 2.0, an adopted standard which restricts and extends the O&M standard for the usage in the hydrology domain.

11.2 SWE Clients

As sensor assets are made available through the SWE services, it is important that they can immediately and readily be discovered, accessed, and integrated into visualization and analysis tools along with other sensor and Geospatial data. To support SWE-enabled assets, client capabilities should include:

- Enable web-service interface interaction with SOS and SPS
- Enable ability to parse SWE encodings (e.g. SensorML, SWE Common, O&M)
- Provide better support for handling highly-dynamic sensors and observations (for both real-time and archived modes)
- Enable default and configurable portrayal of sensor data, including for example, time plots, trajectories, vertical profiles, geolocated imagery and video
- Enable automatic and customized GUIs to support tasking of assets (SPS) and filtering of observations (SOS)
- Enable on-demand processing of observations within the client (more advanced)

Developing a SWE client that is able to accommodate various SOS server implementations remains very challenging. For some SWE implementations, the greatest technical challenges been encountered on the client side. The challenges are listed as follows.

- In SOS 1.0, there is no basic profile of the SensorML, which dramatically increases the complexity of client programs when parsing SensorML documents from SOS services.

- Most data owners have difficulties to relate the feature of interests and procedures to their physical setup of sensor networks. Therefore training of data owners is required.
- Sensor sampling frequency information is not defined in the SWE specifications (such as the Capabilities document). Sensors with high sampling rates can collect a large number of measurements in a short period of time. Without knowing the approximate data size to be requested from SOS servers, clients can be easily overwhelmed by very large responses from servers. Likewise, servers can also be overwhelmed by an unreasonable number of requests. Sensor sampling frequency information can help both clients and servers adapt to the capabilities of the other.

Further refinements of the standards as well as maturing implementations are needed to address these client-side challenges.

11.3 SWE Services Node

Enabling sensor operators to quickly and easily deploy and web-enable sensors is one of the most critical capabilities for SWE implementation. OpenGeo has defined a SWE-service node concept to support these needs. OpenGeo is the geospatial division of OpenPlans, a 501(c)(3) not-for-profit organization that is the originator of the GeoServer open source application. OpenGeo is a member of the OGC.

If properly designed, a SWE-service node would provide support for the discovery of dynamic assets and measurements, for access to real-time or archived observations, for tasking of sensors, models, or actuator systems, for publishing and subscribing to alerts, and for on-demand, on-board, configurable processing. In addition, such a node architecture would provide configurable security and plug-in-play modules to support an array of sensors and actuators. An architecture design is illustrated below.

The following diagram depicts a small footprint server node that can be easily configured to support a wide variety of sensor and actuator assets, as well as meet ancillary requirements for security, database storage, and communication. In addition, an internal SensorML process execution engine will enable uploadable and configurable processing at the node. Such software could be used to rapidly deploy new assets, as well as to support legacy sensor deployments without interfering with existing operations.

The diagram also illustrates interoperability of the SWE node with a larger Data Server perhaps built on OpenGeo GeoServer. In this approach, one can consider a large number of SWE node deployments providing access to lower-level assets, while the larger capacity Data Server could provide higher-level information based on integration and portrayal of these sensor data through a host of web services.

The core of many of the software components for such a SWE node exists to some degree within the open-source software available on Google Code and at 52N. Integrating the

SWE node with other OpenGeo technology, such as GeoServer and PostGIS, could also provide many of the components.

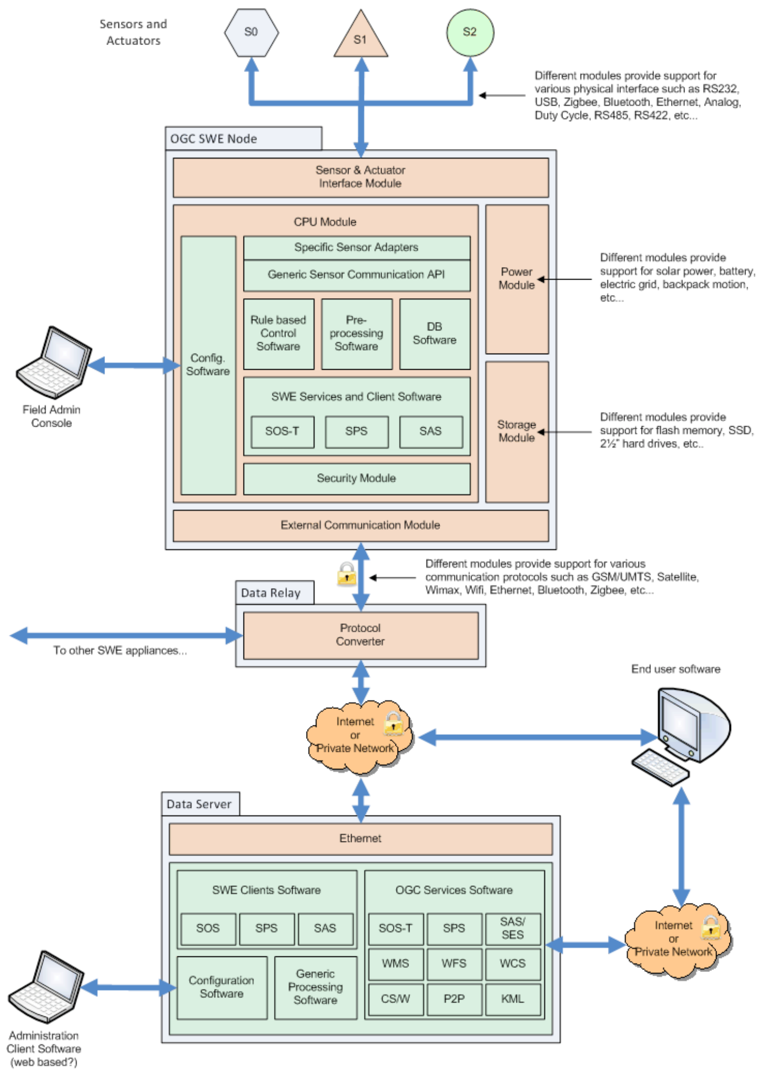

Figure 25. OGC SWE-based node attached to remote data server

11.4 SensorML Editor for Sensors and Processes

SensorML provides the ability to fully describe sensor systems and others assets, as well as define the processes surrounding measurement and processing of observations. In such, it can be used to provide:

- electronic spec sheets for sensor systems, specifying a wide range of characteristics and capabilities (e.g. sensitivity and operational limits), as well as position, contacts, references, history, and of course measured properties
- a full mapping of components within a sensor system including explicit flow of data between the components
- a complete description of the lineage or pedigree of an observation, including processes such as tasking request, sensor systems, processing, QA testing, and analysis
- a explicitly defined process flow that can be executed to enable on-demand processing of observations or cross-queuing of sensor-actuator assets

Currently, most SensorML descriptions are created in XML by using generic XML editors which can be a tedious and error-prone exercise, or by editing a previously-defined SensorML template file which is limited to only those systems where templates have been created. Because of these complication and limitations, SensorML descriptions are often not created at all or do not use the full potential of SensorML.

There is a strong need for SensorML editors that allow simple creation of sensor and process descriptions, as well as aggregate systems and processes. An initial open-source SensorML Process Editor was created at UAH but is in need of redesign, debugging, and refinement. This tool allows one to describe a single process or sensor component through a more human-friendly interface, and provides support for SensorML profiles defined in RelaxNG.

A simple tool for creating descriptions of complex sensor systems and aggregate processes is also needed and should actually be simpler to develop than the individual process editor.

In addition to editing, a very helpful tool is one that can parse a SensorML description and display the encoded information in a user-friendly view. Such a tool exists in the Open Source "Pretty View" tool developed at UAH and Botts-Inc., but it is in need of refinement and extension, and needs to be brought up to SensorML v2.0. It also needs to support a system or process network view that displays the components in an aggregate process, as well as the data flow between them.

11.5 Development of SWE-based Web Processing Services (SWE-WPS)

There is ongoing development of the OGC Web Processing Service (WPS) that is expected to be very general in its design. There is a strong need for a SWE-specific profile that is highly compatible with the SWE services and encoding. In particular, a SWE-WPS would constrain its input and output to being SWE Common Data and would utilize SensorML to define the process. This effort should define such a profile and develop software to support easy configuration and deployment of SWE-WPS instances.

11.6 SWE Discovery Services

The discovery capabilities for SWE need additional development to dealing with the dynamics and complexity of some sensor systems. Discovery in SWE can involve sensors and actuators, observations, alerts, processes, and of course the web services that enable these.

Discovery of SWE assets and products may be more complicated than most typical geospatial data due to the following characteristics:

- Sensor observations and tasking commands are typically highly dynamic and time-dependent, and thus vary on time frames as short as milliseconds.
- Sensor and actuator assets, themselves, are often highly dynamic. They may change location, orientation, modes, calibration, and other measurement parameters on scales of milliseconds to years. Thus, within any 5-minute period, the sensors available to a user at a particular location may partially or completely change.
- To be fully exploit a single observation, discovery requirements may include descriptions of the sensor and actuator assets involved, the set of tasking commands sent, related observation and alerts surrounding that measurement, the full lineage of that observation from tasking to measurement to processing to Q/A testing to analysis, and the availability of processes that can be applied to that observation in order to derive additional information.
- A coarse-grained discovery solution (typical for most geospatial data) is not by itself capable of fully supporting the needs for SWE

Discovery services for SWE may involve several technologies including:

- Traditional registries for sensors and services
- Tracking services that maintain a database of the state of all sensors
- Peer-to-peer (P2P) capabilities for querying a very large numbers of deployed sensors and actuators
- HTML-based textual discovery
- Semantic Mediation
- Other evolving technologies

It is critical that an integrated architecture be developed that can meet the requirements outline above and that easily-deployed services be provided in the open-source community. Such an architecture will most likely consist of coarse-grained components that may reside at large data or control centers, augmented by smaller-footprint capabilities that reside nearer to the assets themselves.