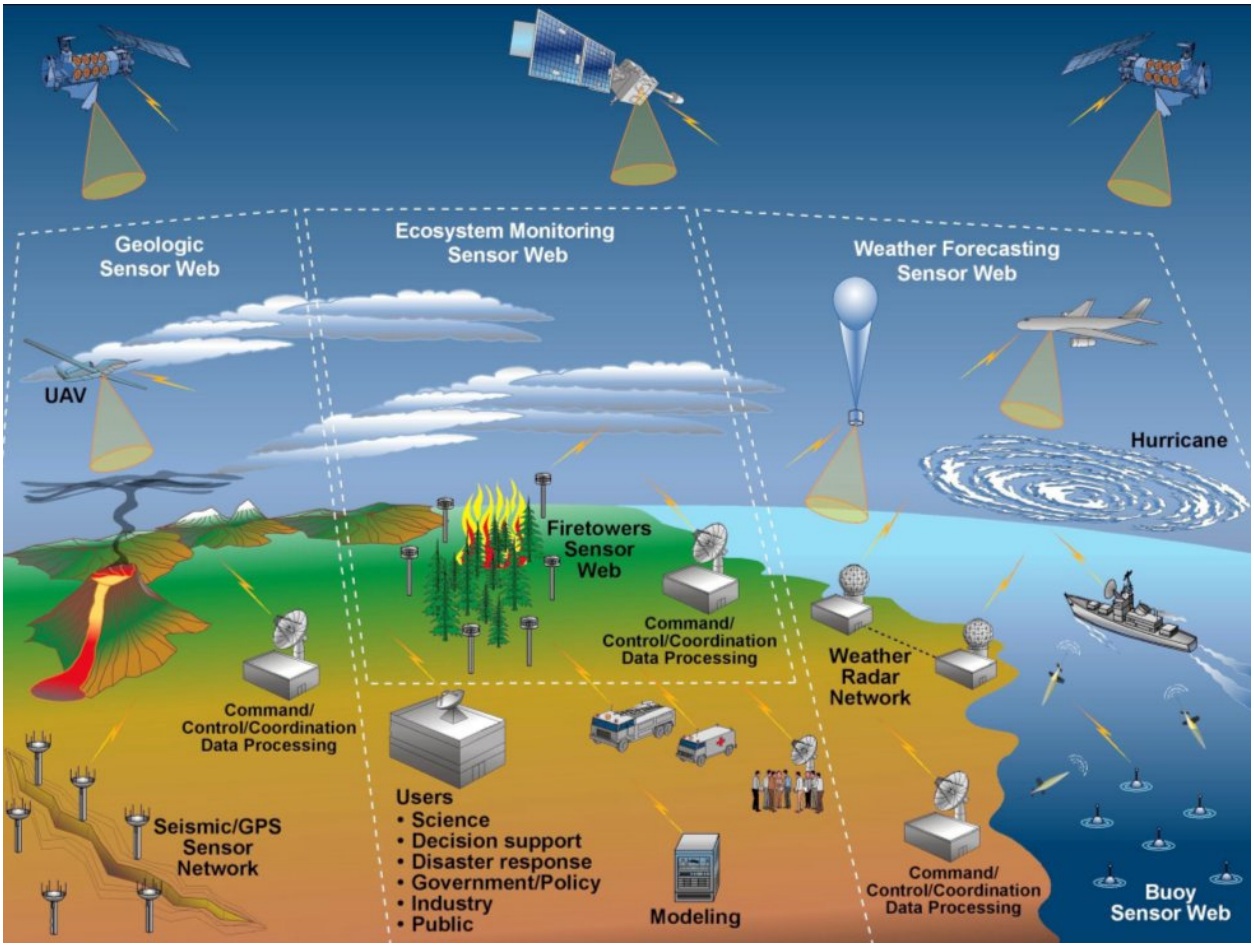
2008 Report from the Earth Science Technology Office (ESTO) Advanced Information Systems Technology (AIST) Sensor Web Technology Meeting

April 2-3, 2008



Acknowledgement

This report represents the extensive effort and support of many individuals both within and outside of the National Aeronautics and Space Administration (NASA) and from the sensor web community. The members of the Earth Science Technology Office (ESTO) Advanced Information Systems Technology (AIST) projects who attended the meeting are listed in the breakout group reports (Sections 3.1, 4.1 and 5.1). The editors would like to acknowledge the work of the AIST team lead, Karen Moe, and the primary authors, Bradley Hartman, April Gillam, and Thomas Eden, from The Aerospace Corporation.

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1 Executive Summary

This report documents the proceedings of the second NASA Earth Science Technology Office sponsored sensor web meeting, which took place on April 2 - 3, 2008. The primary objectives of this meeting were to:

- Increase the awareness and understanding of Earth science sensor web features and benefits within the investigator teams, for the Earth science community, and for NASA managers;
- Interactively explore and document sensor web use case scenarios for Earth science applications, including the Global Earth Observation System-of-System (GEOSS);
- Relate these use cases to the National Research Council's Decadal Survey [DEC 07]; and
- Provide a forum for collaboration and furthering the technology infusion goals of the AIST program, including plans for demonstrating use cases using prototype technology developed by the investigator teams.

Developing use cases as a means of capturing system requirements and processes is a leading edge application of modeling techniques to non-software systems. Traditionally, use cases capture system requirements prior to software development [BITTNER 02]. This technique is uniquely suited to describing the capabilities of the sensor web approach to Earth observation goals. The resulting use cases will serve ESTO's need to describe the benefits that the sensor web concepts bring to NASA's Earth science challenges. All seven (7) thematic focus areas identified in the Decadal Survey were addressed in the use cases developed during this conference, as indicated in Table 1.

Table 1. Decadal Survey Theme Coverage

Decadal Survey Theme	Use Cases
Earth-science applications and societal needs	28
Land-use change, ecosystem dynamics, and biodiversity	17
Weather (including space and chemical weather)	16
Climate variability & change	12
Water resources and the global hydrologic cycle	12
Human health and security	11
Solid-Earth hazards, resources, and dynamics	7

In all, 46 investigators from academia, NASA, and industry were in attendance, representing a broad cross-section of the research being conducted in science, sensor web technologies, and applications. During the meeting, the investigators were divided into three separate groups, each of which focused on a different technology area. These areas were:

1. Middleware 1 – Model Interoperability;
2. Middleware 2 – Systems Management; and
3. Smart Sensors.

While in the breakout groups, investigators presented their works-in-progress, depicting current use cases, from which lively discussions ensued. These use case scenarios were further refined by the investigators in real-time during the conference. After significant discussion and collaboration, several representative use cases were selected from each breakout session for presentation to the conference as a whole. The groups were asked to provide feedback on lessons learned and recommendations for promoting sensor web technologies.

This report describes the proceedings of the conference and also contains a compilation of all 41 sensor web use cases presented and developed during the conference. Key terms, features, architectures, and applications are documented throughout the use cases, which were grouped according to earth science theme, including Atmospheric Composition, Earth Surface & Interior, Climate Variability & Change, Carbon Cycle & Ecosystems, Weather, and Water and Energy Cycle. In addition, the patterns, themes, and technology gaps identified during the conference are documented.

The resulting use case scenarios developed during the conference represent fundamental and practical applications of sensor web technologies to Earth science challenges. Starting from the sensor web

concepts, which were clarified and described at the first meeting in 2007, these 2008 use case scenarios were developed to:

- Describe how a distributed collection of resources (e.g., sensors, satellites, forecast models, and supporting systems) can collectively behave as a single, autonomous, task-able, dynamically adaptive and reconfigurable observing system; and
- Describe how raw and processed data, along with associated meta-data, can be collected via a set of standards-based service-oriented interfaces.

The use case scenarios were developed to communicate key sensor web features, including the following:

- The ability to obtain targeted observations through dynamic tasking requests;
- The ability to incorporate feedback to adapt via autonomous operations and dynamic reconfiguration; and
- Improved ease of access to data and information.

Finally, scenarios were developed to highlight key sensor web benefits, such as the following:

- Improved resource usage where selected sensors are reconfigured to support new science questions;
- Improved ability to respond to rapidly evolving, transient phenomena via autonomous rapid reconfiguration, contributing to improved tracking accuracy;
- Demonstrate cost effectiveness, derived from the ability to assemble separate but collaborating sensors and data forecasting systems to meet a broad range of research and application needs; and
- Improved data accuracy, through the ability to calibrate and compare distinct sensor results when viewing the same event.

The NRC Decadal Survey provided the backdrop to the sensor web deliberations. In addition to recommending new Earth observation missions to NASA, the Decadal Survey panels highlighted the significance of the societal benefits resulting from an integrated strategy for science and applications from space. By projecting existing and near-term use cases into the future decade, the use case scenarios developed at this conference are an attempt to illustrate how the capabilities envisioned by the Decadal Survey might be employed.

The conference was successful in addressing all of the above features and benefits of sensor webs to future NASA Earth science goals. During the meeting discussions, additional capabilities were identified and some common themes emerged such as autonomous sensor operations, autonomous data productions, and user support (i.e., tools to support the design and management of sensor webs). The following list highlights the sensor web capabilities that the participants discussed in the use cases detailed in this report.

- Sensor webs, being system-of-systems, are scalable, and supporting technologies allow systems to interoperate, supporting disparate data content and interfaces.
- Sensor webs detect events and respond by autonomously tasking sensor resources and feeding results into models in near real-time.
- Sensor webs have been successfully used to support autonomous flight plans for unmanned aircraft.
- Sensor webs can support calibration and validation of future Decadal missions.
- Sensor web approaches enable autonomous management of sensor resources, notably power and communications for in situ sensors.
- Sensor observations can influence models to improve forecasts and how model predictions can influence sensor observations to collect the most relevant observations at the time they are most needed.

- Sensor webs can improve the accuracy of predictions and the handling of uncertainty in forecast models.
- Sensor webs can also validate model results and design field campaigns to optimize resource use and science results. This involves methods to enable smooth assimilation of in situ and satellite data into models.
- Sensor webs can be implemented using repeatable patterns of assembling sensors and data processing systems, reusing the same middleware systems for different application domains, such as monitoring and responding to a fire or a volcano or a flood.

The set of use case scenarios documented in this report exemplifies a full suite of capabilities to transform sensor data and model outputs into Earth observation information as recommended in the Decadal Survey.

2 Introduction

NASA's February 2005 publication, NASA's Direction 2005 & Beyond, stated, "NASA will develop new space-based technology to monitor the major interactions of the land, oceans, atmosphere, ice, and life that comprise the Earth system. In the years ahead, NASA's fleet will evolve into human-made constellations of smart satellites that can be reconfigured based on the changing needs of science and technology. From there, researchers envision an intelligent and integrated observation network comprised of sensors deployed to vantage points from the Earth's subsurface to deep space. This 'sensor web' will provide timely, on-demand data and analysis to users who can enable practical benefits for scientific research, national policymaking, economic growth, natural hazard mitigation, and the exploration of other planets in this solar system and beyond." [NASA 05]

"As the lead technology office within the Earth Science division of the NASA Science Mission Directorate, the Earth Science Technology Office (ESTO) is focused on the technological challenges inherent in space-based investigations of our planet and its dynamic, interrelated systems." [ESTO 06] The ESTO's Advanced Information Systems Technology (AIST) program, a program to identify, develop, and (where appropriate) demonstrate advanced information system technologies, released a solicitation, AIST Research Opportunities in Space and Earth Sciences (ROSES-05), to focus attention on technologies for sensor webs. The research announcement included the plan to host a series of principle investigator workshops to enhance collaboration and further the technology infusion goals of AIST. The ESTO AIST sensor web program consists of 35 projects, covering a range of topics including smart sensing, sensor web communications and middleware, and enabling model interactions in sensor webs.

In February 2007, the ESTO sponsored its first sensor web meeting, organized by the AIST team and led by Karen Moe. Consisting of the NASA-sponsored sensor web research community, the primary objectives of this meeting included increasing awareness and understanding of sensor webs amongst the participants and the Earth Science community, and defining a sensor web architectural concept (including high-level architectural figures, definitions, and a specification of the scope of the sensor web concept). Refer to the "Report from the Earth Science Technology Office (ESTO) Advanced Information Systems Technology (AIST) Sensor Web Technology Meeting" for more detail. [NASA 07]

In April 2008, the ESTO sponsored its second sensor web meeting, again organized by the AIST team, led by Karen Moe, and consisting of the NASA-sponsored sensor web research community. The primary objectives of this meeting were to define a set of use cases to illustrate how sensor web technology will be used, and to relate these use cases to the Decadal Survey. [DEC07] The goal was to achieve a shared view of sensor web features and benefits to NASA Earth science. This report summarizes the results of that meeting.

2.1 Meeting Preparation

The NASA ESTO invited all investigators from the 35 AIST research projects to participate in the meeting. Prior to the meeting, ESTO asked all investigators to:

- Review the material on use cases, including the NASA-provided use case template to be used during the meeting.
- Define and be prepared to discuss at least one use case.
- Prepare a project poster for the poster session.

The group also investigated the Decadal Survey. An annotated version of the full Decadal Survey report (ref web site) was developed by the ESTO staff to highlight the needs for information technology derived from the stated goals and objectives of the National Research Council panels that were established to create the Earth observations Decadal Survey. Furthermore, the group was aware of the international Group on Earth Observations initiative for the Global Earth Observation System-of-Systems (GEOSS, http://www.epa.gov/geoss) which issued a task to explore the use of sensor webs to achieve the stated societal benefits of GEOSS. NASA is involved with the Committee on Earth Observations (CEOS, http://www.ceos.org) which has committed to be the space research arm of GEOSS. Within the CEOS

Working Group on Information Systems and Services (WGISS, http://wgiss.ceos.org), chaired by Martha Maiden, NASA is a task team that is addressing the sensor web task, and some of the AIST projects are involved in planned demonstrations.

Finally, the ESTO team updated the AIST Capabilities and Needs database for community review, including the sensor web community. These three perspectives – the Decadal Survey, GEOSS and AIST Needs – provided the backdrop for the sensor web use case development. For this report, the results are also related to the NASA Strategic Plan [http://nasascience.nasa.gov/about-us/science-strategy and http://nasascience.nasa.gov/earth-science/focus_area_list] by organizing the use cases according to the six science focus areas.

2.2 Use Case Template

The use case template was designed to capture both the summary as well as information to characterize each case. A check list is included to identify the NASA missions applicable to the use case, whether from the Decadal Survey, or current or near-term future missions. The Decadal Survey was developed with seven societal challenges, reflecting the panels constituted by the National Research Council, which the template listed for use case tracking. Sensor web features and benefits identified in the 2007 report, and AIST Needs and goals rounded out the categorization check list. The contents of the sensor web use case template were modeled after the version in Wikipedia. [http://en.wikipedia.org/wiki/Use_cases]

For the sensor web meeting objectives, the emphasis was placed on the goal, summary, and basic flow of the use case. Traditionally use cases help system developers drive out requirements for software implementation. In this situation use cases help ESTO describe the benefits of the sensor web systems approach for NASA missions and science goals by documenting what the sensor web does in a particular applications but not how it is accomplished. Participants were guided to narrow the scope of their use cases to identify a simple case representative of their sensor web, but not comprehensive. In this way, the use case only tells part of the story regarding capability but it is simple enough to understand in 3 to 4 pages. By reading across use cases, a more complete picture of the sensor web concept is portrayed without getting lost in the details.

The template also included a resource listing that identifies the data and services needed to demonstrate a prototype of the use case. The resource tables include sensor and data types (e.g., satellite, in situ sensor), descriptions and owners, service types and owners for models, event notification (e.g., alerts from seismic monitoring systems), and applications.

2.3 Meeting Process

The meeting began with a brief orientation before dividing the participants into three breakout groups, Middleware 1 (MW1) Model Interoperability, Middleware 2 (MW2) Systems Management, and Smart Sensing (SS). Each breakout group consisted of investigators (approximately 15 per session), ESTO facilitators and staff, and an editor from The Aerospace Corporation. Based on their composition, breakout groups were assigned initial use case categories to help ensure broad coverage of the Decadal Survey, NASA science themes, types of sensor web applications, and features, as depicted in Table 2.

Table 2. Breakout Group Use Case Assignments

	MW1 – Model Interoperability	MW2 – System Management	SS – Smart Sensing
Decadal Survey Mission	DESdynI	HyspIRI	SMAP
Science Focus Area	Earth Surface & Interior	Carbon Cycle & Ecosystems	Water and Energy Cycle
Application	Forecasts	Rapid Response	Sensor Calibration / Validation
Sensor Web Feature	Data Assimilation	Workflow Management	Agent Autonomy

During the breakout sessions, investigators first discussed a single use case as a group. Following this discussion of a mature sensor web scenario that was documented in a sample use case, each group brainstormed additional use case topics before breaking into subgroups to develop those use cases in parallel. During this time, Peter Fox of UCAR, who has extensive experience in developing use cases as well as being a sensor web investigator, and Karen Moe provided consultation on the use case approach for documenting sensor web capabilities. They also looked at the emerging use cases to assess coverage between groups to ensure that a diverse set of use cases would result. Breakout groups MW1, MW2, and SS developed 16, 14, and 11 use cases respectively.

The groups were also tasked to capture lessons learned during the development of their use cases. This feedback included key findings, common use case themes, new themes or AIST needs, and unique perspectives and recommendations for ESTO. Each breakout group selected a subset of their use cases for presentation to the workshop participants during the plenary session at the end of the second day. This subset of use cases featured in this report, and all use cases may be found in Section 11, Appendix C – Use Cases.

Three invited speakers provided insights on relevant work outside of NASA:

- Timothy S. Stryker, National Land Imaging Program, U.S. Geological Survey, provided an overview on the Committee on Earth Observation Satellites (CEOS) and Earth Observations to benefit society. This plenary talk provided the context for developing use cases for GEOSS, which is also mentioned in the Decadal Survey. The societal benefits noted by GEO are very similar to the societal challenges delineated in the Decadal Survey.
- Scott Tilley, Software Engineering Institute, Carnegie Mellon University and the Department of Computer Sciences, Florida Institute of Technology, spoke about some lessons learned, especially identifying difficulties that are rarely reported upon, regarding the migration of legacy components to Service Oriented Architectures (SOA) environments. His presentation clarified what constitutes a SOA (namely operations to support service discovery, implementation and invocation), and addressed common misconceptions about the architecture, standards and technology involved. The sensor web concept takes advantage of the service based approach.
- John J. Garstka, Office of the Under Secretary of Defense (Policy), highlighted key issues associated with the implementation of network-centric operations within the U.S. DoD and how their sensor nets correspond to NASA sensor webs. He discussed the need to address Return On Investment strategies. Transforming the defense forces to use information technology in order to leverage situational awareness to their benefit has some parallels to the Earth observation sensor web monitoring and response capabilities.

The abstracts for these presentations are included in Section 9, Appendix A - Keynote Speakers' Abstracts; abstracts and presentations are available on http://esto.nasa.gov/sensorwebmeeting.

Additionally, the meeting included a poster session at the end of the first day, during which time investigators were given the opportunity to display a poster or set of slides describing their ESTO AIST-

funded sensor web research projects. The poster session provided the participants with a forum to discuss their sensor web capabilities and collaborate on future plans and demonstrations. Sharing technology insights and resources, and collaborating on demonstrations are ways the AIST program has sought to aide technology infusion, one of the broad goals of the sensor web solicitation.

2.4 Document Organization

This document is organized in the following manner:

- **Section 1** provides a high-level description of the 2008 Earth Science Technology Office Advanced Information Systems Technology workshop on sensor webs.
- **Section 2** provides some background, summarizes the process of the meeting and briefly describes each section of this report.
- **Section 3** summarizes the sensor web use themes that emerged during the meeting.
- **Sections 4, 5, and 6** summarize the results of the breakout sessions MW1, MW2, and SS respectively.
- **Section 7** summarizes use case coverage with respect to science theme, Decadal Survey categories, AIST needs, and sensor web benefits. This section also describes some next steps.
- **Section 8** contains a list of references used in the creation of this report.
- **Section 9, Appendix A** contains the keynote speakers' abstracts.
- **Section 10, Appendix B** contains a list of acronyms used in this report.
- **Section 11, Appendix C** contains all of the use cases that were developed during the meeting.
- **Section 12, Appendix D** contains brief descriptions of each of the investigators' AIST sensor web projects.

3 Sensor Web Use Themes

Of the more than 40 use cases that were developed, a number of themes have emerged. In these themes, some key capabilities are identified that are made possible by the use of sensor webs. The theme descriptions in this section are based on the use cases and are organized into the 3 groups: (1) Autonomous Sensor Operations, (2) Autonomous Data Production, and (3) User Support. For context, the themes are associated with the major components of the Global Earth Observing System-of-Systems Architecture, as seen in Figure 1. The GEOSS Architecture has three components – observation, data processing, and data exchange and dissemination that map to the architecture underlying many of the sensor web projects in the AIST program.

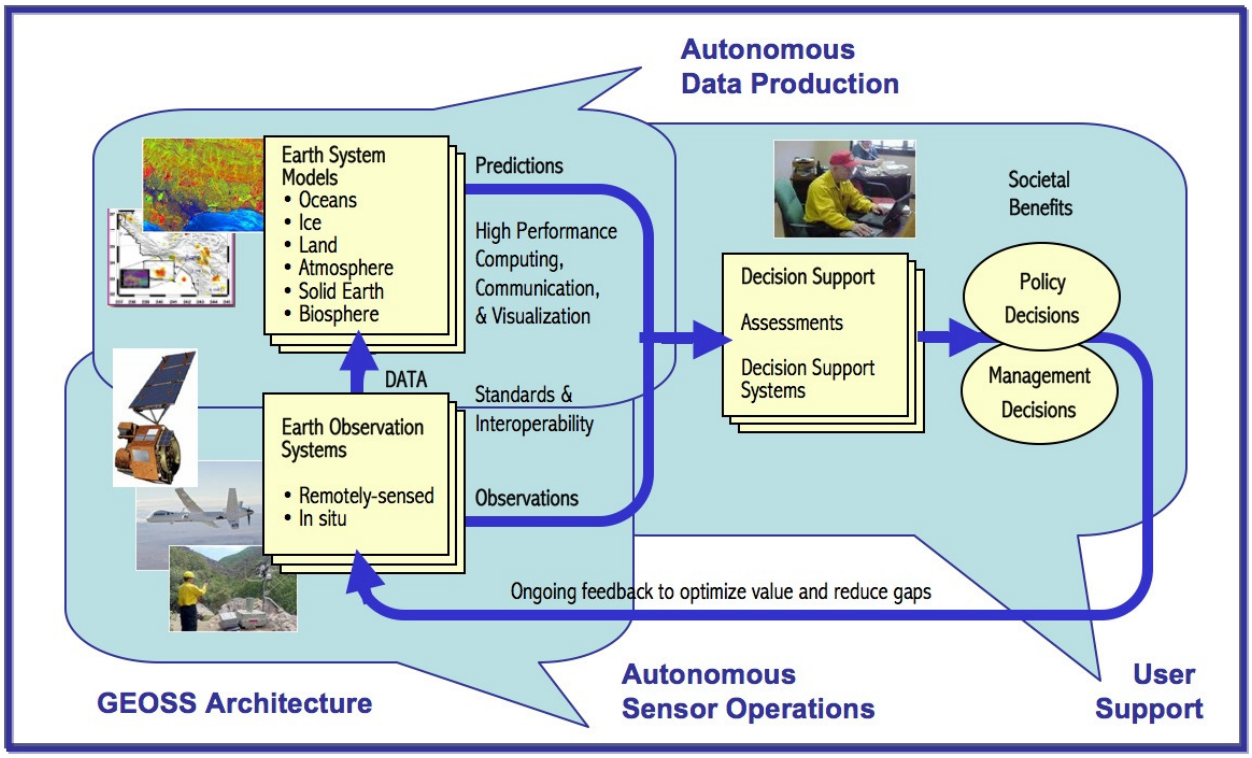

Figure 1. Sensor Web Enabled Themes

3.1 Autonomous Sensor Operations Themes

The autonomous sensor operations grouping addresses sensor web strategies that support the Earth observation component, namely satellites, other sensor platforms and their sensors. The associated ground systems that manage and control the remote sensing and in situ devices are part of this component. The following themes relate to this category of sensor web capabilities supporting sensor operations.

- Rapid response
- Autonomous tasking
- Calibration / validation
- Sensor management
- Improved data downlink

Rapid Response

Sensor webs make more information, and in particular, coordinated and directly relevant user-requested information, to be quickly available.

- **Rapid response** via timely assessment of disaster, situation, prediction of imminent phenomena (e.g., earthquake response including damage assessment and potential for subsequent earthquakes, forest fires, volcanic activity).
- **Improved rapid knowledge and prediction** of conditions and extremes (e.g., geomorphological-based landslide hazard maps and erosion).

Autonomous Tasking
A sensor web makes it possible to use one sensor, a combination of sensors, or a model to autonomously trigger other sensors and, task them to provide: rapid response, improved predictions, timelier sensor operation, better adaptation to the situation/environment, and better targeting of sensor observations.

- **Tasking observations**, **autonomously trigger** space asset data acquisition from in-situ network, monitoring indicates events used to trigger sensor with adjusted sampling rate (e.g., water quality)
- **Monitoring data used for predictions** (e.g., likelihood of volcanic eruptions - data must be rapidly downloaded, processed, and integrated with other data types)
- **Predictive, event-driven, targeted sensing** for use in coordinating the collection and analysis of other phenomena to improve predictions (e.g., improved Storm/Weather Prediction based on Lightning Monitoring and Prediction)
- **Detect and track satellite-observed phenomena**, use differences from forecasts to identify where more frequent observations are needed

Calibration/Validation (Cal/Val)
The calibration and validation of instruments is vital to ensure the quality of the data and the consistency of the results. Sensor webs provide a means whereby multiple sensors that make overlapping measurements can be used for cal/val.

- **Validation** of models (e.g., smoke forecast models, soil moisture).
- In-situ and UAV **calibration** processes for earth-observing instruments (e.g., for characterization of the ice-sheets, to see under tree canopy, soil moisture).
- **Cross-comparison** of readings from various instruments in complementary sensor webs.

Sensor Management
Management of limited resources, such as power, downlink bandwidth, and sensor operating times can increase sensor lifetime, availability, and effectiveness. With a sensor web, the communication among sensors can identify key times for sensor operation as well as when sensor operation is not productive (e.g., during cloud cover).

- **Sensor management**: conserve power and extend longevity of the instrument
- Generic **adaptive control and resource management** technology
- **Coordination of heterogeneous sensors**; monitoring is power, computationally, and bandwidth constrained

Improved data downlink capability
Sensor web technology and coordination can be applied to remote sensing assets and ground stations to increase the amount of data that can be seamlessly down linked.

- Reliable transmission of large data sets over **multiple ground stations** ("multihoming" for seamless handoff)

3.2 Autonomous Data Production Themes

The Earth system models and remote sensing data processing systems comprise the data processing component of the sensor web architecture. High performance processing and distributed analysis systems support the collaboration of interdisciplinary scientists who produce the data and information that

end users need to respond to societal needs of the Earth observations. This category of use case themes includes the following:

- Data assimilation
- Forecasting
- Reducing model uncertainty

Data assimilation
Data observations from in situ and remote sensing instruments is often captured at different sampling rates, locations, frequencies, scales, etc., which necessitates software tools to make it possible to assimilate the data into models that have specific data formats and other requirements. Once those tools are available, the power of the many observations that are produced by sensor webs can be exploited.

- **Autonomous ingestion** of space data into ground network decision making
- **Integration of large data volumes** from sensors on the different platforms with different observational constraints and data formats into a common processing system; smart assimilation workflow involves **mining forecasts for interesting weather phenomena**, then determining whether other observations are coincident with the detected events. The assumption is that assimilating other observations of anomalous conditions will improve the forecast (e.g., weather forecasting).
- Dynamic assimilation of data and observations from multi-sensors by re-using standard Web services and the rapid response to be achieved through live link between sensors and science applications.
- Acquisition of **complementary views of objects, events, and processes** using sensor webs of many different instruments, on many different platforms, and in many different modalities.

Forecasting
Sensor webs make possible the capture of a greater number of and multiple types of observations providing data and ultimately information that can be ingested into models to produce higher quality forecasts.

- Improved **model assessment** and **forecasting** (e.g., air quality, earthquake, transport of pollutants)
- **Real-time ("nowcast") and forecasting** for immediate use (e.g., integration of space-based sensor data with in-situ data for search and rescue)

Reduce uncertainties, improve measurement fidelity
Sensor webs provide more coordinated, better directed, improved sampling data in the regions of interest that can be used to reduce uncertainties and increase the accuracy and fidelity of the data used to produce forecasts and data products.

- **Reduced uncertainties in predictions**: predict global land surface conditions, ice sheets, and sea rise with more certainty
- Acquire **high fidelity measurements** to improve predictive skill in numerical model forecasts (e.g., wind)
- **Increased spatial resolution** by combining lower resolution high coverage products with **targeted sensing** higher resolution products
- Through model projections of future changes and assessment of uncertainties through ensemble predictions, perform feedback analysis to target future observations toward optimally reducing knowledge uncertainty.
- Bridging between sporadic observations of high-value sensors to provide temporally persistent observations.
- Making associations between observations of multiple instruments.

3.3 User Support Themes

The user support category addresses the needs of both the end users (i.e., the policy makers and responders) and users who design and configure the end-to-end Earth observing system-of-systems to support the science and societal goals. The following capabilities, enabled by sensor web use cases, emerged as themes:

- Workflow generation
- User access to sensors
- Campaign / mission design

Workflow

The ability to manage workflow in a sensor web facilitates the coordination of such things as (a) scheduling and orchestrated triggering of the operation of multiple instruments based on user requests, model results and needs, (b) platform and sensor configuration, (c) sensor data processing, and (d) automated data product generation.

- **Flight plan generation** (achieve mission goals while satisfying constraints)
- **Workflow generation** and execution (e.g., volcano alert, processing, and product delivery, regional vegetation trends and anomalies)
- **Workflow tasks** for identifying event triggers, tasking sensor assets, processing sensor data, and delivering multiple higher level detection products directly to end users

User Access to Sensors

The philosophy of sensor webs is built on providing users greater access to sensors, more ability to direct when and where they operate, greater coordination (e.g., with other users, with sensors, with models) through scheduling and workflow tools and autonomous operation capabilities.

- Provide users **easy and rapid access of available sensors** that can provide science data products to help manage phenomena and provide situational awareness (e.g., for fire emergency workers to manage wildfires)
- Users request sensor access and tasking with **network centric** system that **manage system constraints and safety**

Campaign / Mission Design Optimization

Campaign and mission design for sensor webs provides the opportunity to incorporate multiple sensors, models, simulation, people, and planning. The communication is automatic, some triggered by events and conditions, and some dependent on people-in-the-loop. This makes it possible to respond more quickly to opportunities and events, to autonomously plan a campaign, automatically process data, and disseminate information and data products from such end-to-end operations.

- Simulators - **design space formulation and population of observation scenarios/systems,** virtual execution and science return validation of the populated observation scenario and observation system concepts (e.g., atmospheric chemistry)
- Planners can **detect** an event, **notify** a human planner who **schedules** observations, which could be **processed** on-board, and even to **autonomously retask** the sensors to obtain additional data; maximize the number of mission goals achieved while satisfying constraints; dynamically combine sensors into a sensor web (e.g., model-based volcano sensor web, disaster response, generate flight plans, response to volcanic eruptions by detecting and tracking the resultant ash clouds)

4 Breakout Group Middleware 1 (MW1) – Model Interoperability

This breakout session focused on developing use cases dealing with modeling and web services. Investigators in this group had expertise or insight into some of the Decadal Survey missions, notably DESDynI, CLARREO, 3-D Winds and others. They are working on sensor webs for use as mission or campaign design, and weather forecasting among other applications. The group was initially tasked to look at the role of forecast models and data assimilation for solid earth applications for the DESDynI. Other missions of keen interest to this group included CLARREO, SMAP and 3D Winds, and additional science domains such as carbon and air quality, ecosystems, and weather. Some of the key sensor web capabilities they are developing include data assimilation and fusion, and web service architectures. As a result, the effort was focused primarily on interoperability solutions for sensor webs and architectures, such as the Service Oriented Architecture (SOA).

4.1 Participants

This section enumerates all of the participants in Breakout Group MW1 and identifies each participant's organization and project title. Missing is one project, Sensor-Web Operations eXplorer (SOX), however a use case by the project lead, Meemong Lee of JPL, is included.

Table 3. Breakout Group MW1 Participants

Name	Organization	Project Title
Marge Cole	NASA ESTO AIST	AIST Facilitator
Vicki Oxenham	NASA ESTO Goddard Space Flight Center	AIST Staff
Thomas Eden	The Aerospace Corporation	Report Editor
Michael Burl	NASA Jet Propulsion Laboratory	Adaptive Sky
Liping Di Genong Yu	George Mason University George Mason University	A General Framework and System Prototypes for the Self-Adaptive Earth Predictive Systems (SEPS)--Dynamically Coupling Sensor Web with Earth System Models
Andrea Donnellan	NASA Jet Propulsion Laboratory	QuakeSim: Enabling Model Interactions in Solid Earth Science Sensor Webs
Stefan Falke Don Sullivan	Northrop Grumman IT, TASC Northrop Grumman IT, TASC	Sensor-Analysis-Model Interoperability Technology Suite
Michael Goodman Helen Conover	NASA Marshall Space Flight Center University of Alabama, Huntsville	Sensor Management for Applied Research Technologies (SMART) - On-Demand Modeling
Paul Houser Yudong Tian	Institute of Global Environment and Society, Inc.	Land Information Sensor Web

David Lary Oleg Aulov	University of Maryland, Baltimore County (UMBC) UMBC	An Objectively Optimized Sensor Web
John Moses	NASA Goddard Space Flight Center	The Detection and Tracking of Satellite Image Features Associated with Extreme Physical Events for Sensor Web Targeting Observing
Mike Seablom Steve Talabac	NASA Goddard Space Flight Center NASA Goddard Space Flight Center	End-to-End Design and Objective Evaluation of Sensor Web Modeling and Data Assimilation System Architectures

4.2 Use Case Challenge

Breakout group MW1 – Model Interoperability – developed a total of fifteen (15) use cases during the workshop, and one (1) additional use case was submitted after the conclusion of the workshop. Four (4) use cases were presented during the feedback plenary session and are featured in this section, with all of the use cases fully documented in Appendix C – Use Cases. The following table enumerates these use cases and indicates the page number of the start of the use case description. Featured use cases are identified by **bold text** in this table.

Table 4. MW1 Use Case Index

Use Case Name	Primary Points of Contact	Page #
Earthquake Response and Forecasting	**Andrea Donnellan**	**101**
Numerical Weather Prediction Doppler Wind Lidar	**Michael Seablom** **Steve Talabac**	**228**
Smart Assimilation of Satellite Data into Weather Forecast Model	**Michael Goodman** **Helen Conover**	**237**
Validating Smoke Forecast Models with Satellite, UAS and Surface Observations	**Stefan Falke** **Don Sullivan**	**95**
Adaptive Sky applied to detection, tracking, and reacquisition of volcanic ash clouds	Michael Burl	55
Carbon Cycle – Biomass	Paul Houser	180
Extreme Event Detection and Tracking for Targeted Observing	John Moses	216
Geomorphology	Paul Houser	107
Hydrology	Paul Houser	263
Predict Global Land Surface Soil Moisture with SMAP observing system simulation experiment (OSSE)	Paul Houser Yudong Tian	129
Quantifying Measurement Requirements for Atmospheric Chemistry Remote Sensing (NASA Atmospheric composition program NRA)	Meemong Lee	63
Satellite and UAS fire observation inputs to smoke forecast models	Stefan Falke Don Sullivan	69
SEPS (Self-Adaptive Earth Predictive Systems) Interoperation	Liping Di	74

for AutoChem Assimilation System	Genong Yu	
SEPS (Self-Adaptive Earth Predictive Systems) Interoperation for Bird Migration Modeling and Avian Flu Prediction	Liping Di Genong Yu	82
Tasking new satellite and UAS observations with smoke forecasts	Stefan Falke Don Sullivan	91
Volcanoes	Andrea Donnellan	142

4.2.1 Smart Assimilation of Satellite Data into Weather Forecast Model

4.2.1.1 Point of Contact

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256-961-7807

4.2.1.2 Use Case Goal

The goal of this use case is to improve the assimilation process of satellite data into numerical models. Because assimilation of these large datasets is computationally expensive, we use intelligent processes to determine when interesting weather phenomena are expected and where assimilating satellite observations can improve forecast accuracy. We intend to use community standard protocols for data access and alerts.

4.2.1.3 Use Case Summary

The integration of EOS satellite data from multiple platforms into forecast models is a critical component of NASA's Weather focus area. The complexity lies in the need to integrate large data volumes from sensors on the different platforms with different observational constraints and data formats into a common processing system. This use case identifies these limitations by implementing a SWE-based architecture to autonomously select the optimal observations for assimilation.

The Atmospheric Infrared Sounder (AIRS) creates 3-dimensional maps of air and surface temperature, water vapor, and cloud properties. With 2378 spectral channels, AIRS has a spectral resolution more than 100 times greater than previous IR sounders and provides more accurate information on the vertical profiles of atmospheric temperature and moisture. The AIRS retrieval algorithms provide vertical profiles of temperature and moisture at a 50 km horizontal spacing over a narrow swath. These data provide asynoptic observations to complement the standard radiosonde observing network. The profiles are most accurate in clear and partly cloudy regions and the quality of the AIRS retrieval is determined in real time and transmitted to the user. Note that the future PATH satellite will provide similar data.

AIRS data can provide a key input into the regional data assimilation procedures used to produce short-term regional weather forecasts with the Weather Research & Forecasting (WRF) model. However, the decision on when to include the data and where spatially it will have the most effect for the day-to-day weather conditions over the United States is not trivial. Routine daily assimilation is not performed because of the limited availability of resources and the operational requirement of the National Weather Service for improved forecasts of high impact events. Forecast improvements in low-impact weather systems may not be an effective use of resources, whereas appropriate data assimilation in evolving weather situations or with tropical systems such as hurricanes is likely a more effective use of computer

time and associated manpower because of its impact - a direct affect on loss of property and lives. The effective inclusion of AIRS data into regional forecast models could be made possible through autonomous processing of model data fields, Aqua satellite orbit predictions, AIRS instrument data, and required ancillary information through sensor web capabilities and services. Currently, modelers make judgments about when and where to assimilate satellite data after manual examination of near-term forecasts.

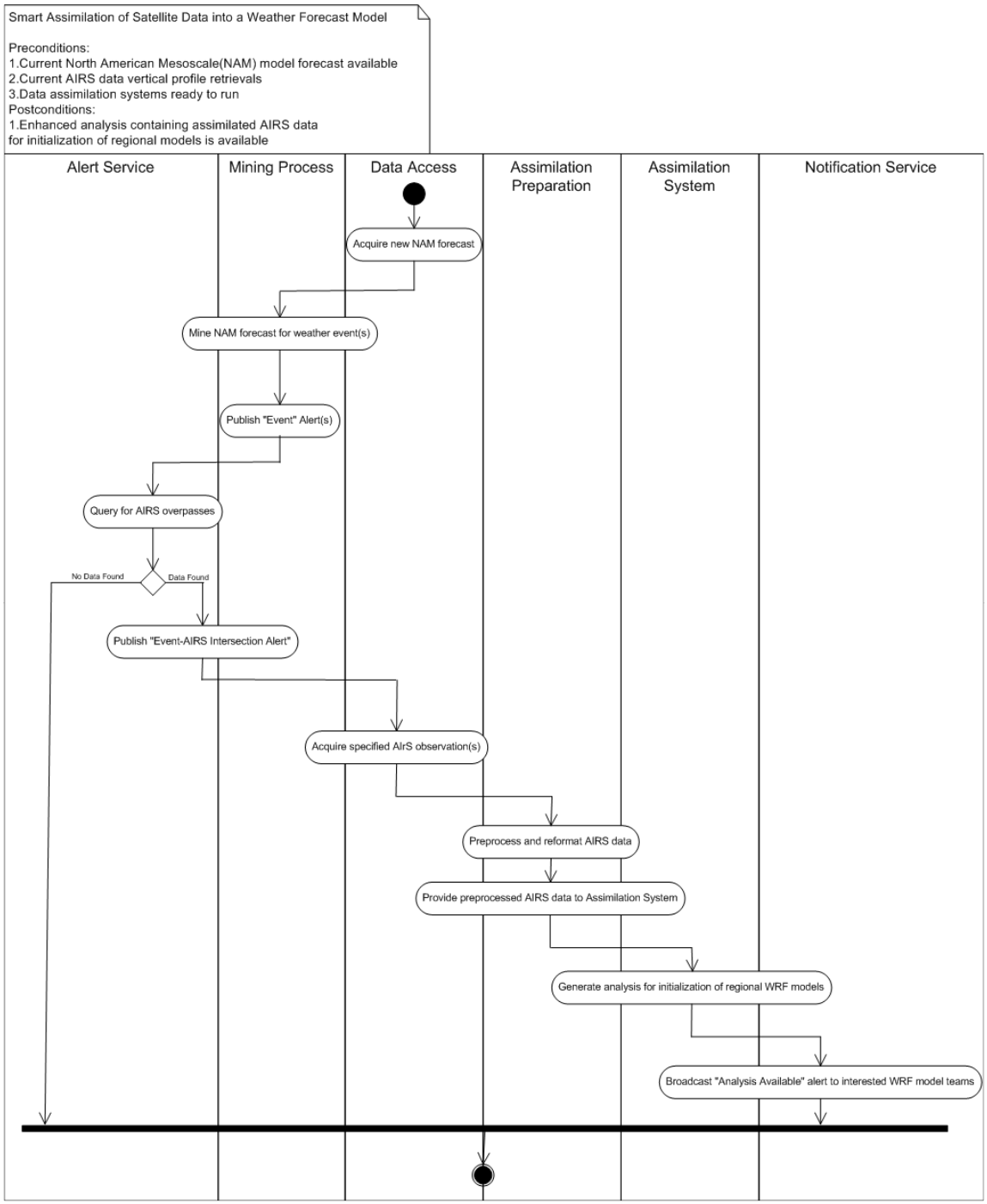

Figure 2. Weather Event Data Flow

Often, a North American Mesoscale (NAM) forecast is used as the initial conditions for a regional WRF model run. The addition of current weather observations (such as those from AIRS) can improve the accuracy of a WRF forecast, but assimilating voluminous satellite observations into the initial conditions is

computationally expensive. The smart assimilation workflow involves mining NAM forecasts for interesting weather phenomena, then determining whether AIRS observations are coincident with the detected weather events. The assumption is that assimilating AIRS observations of anomalous weather conditions will improve the forecast.

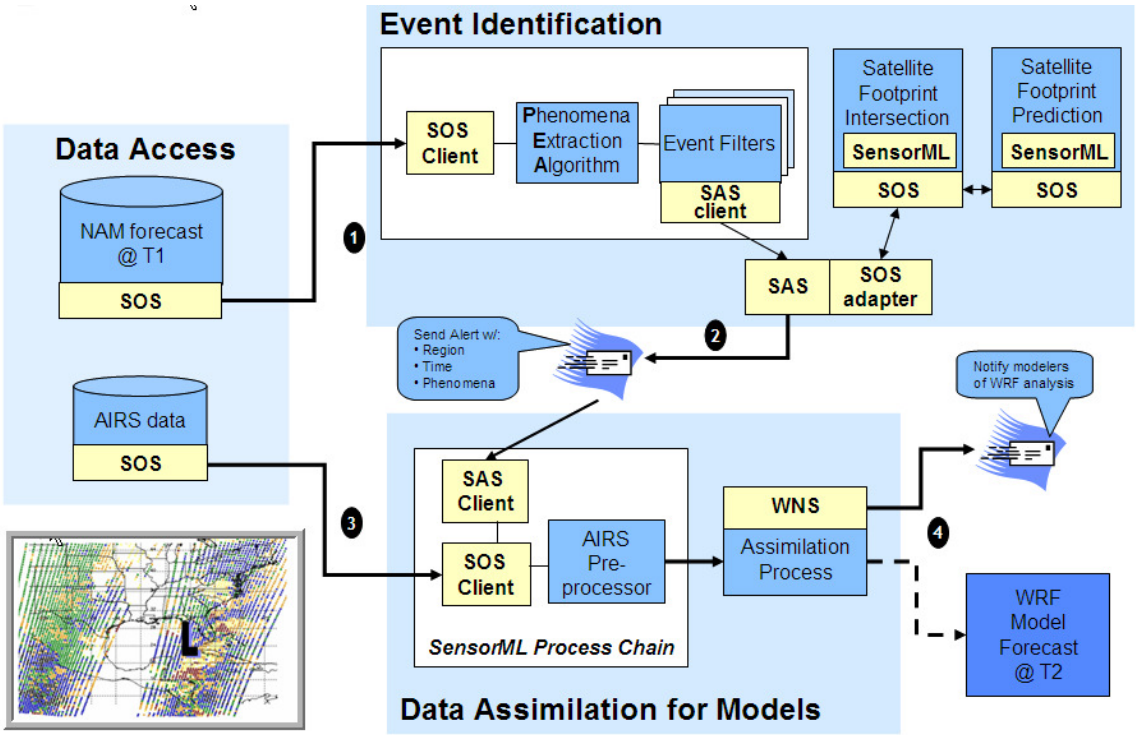

Figure 3. Weather Event System Flow

The use case begins with a forecast from the North American Mesoscale (NAM) model which provides a baseline first guess field for initializing the WRF model. The NAM model is run independent of the AIRS data assimilation system. The NAM forecast is mined for an interesting weather event (e.g., developing low pressure system, frontal system, vorticity maxima) within a selected region of interest using the Phenomena Extraction Algorithm. If a weather event of interest is detected an alert is issued identifying the event, date/time and location. A search is then initiated for coincident AIRS data within the region of interest and time threshold. If a coincident AIRS overpass is confirmed, then the AIRS data are obtained. The AIRS vertical profile data are pre-processed and reformatted for inclusion into the ARPS Data Assimilation System (ADAS). The assimilated data field is then made available as the initial condition field for the WRF model run. An alert is broadcast to WRF model users of the availability of the improved initial field for a WRF run.

4.2.2 Validating Smoke Forecast Models with Satellite, UAS and Surface Observations

4.2.2.1 Point of Contact

Stefan Falke
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Don Sullivan

4.2.2.2 Use Case Goal

This air quality use case scenario envisions a sensor web that facilitates access, integration and use of multi-source data for purposes of air quality assessment and forecasting. A particular emphasis is placed on the retrospective analysis of large forest fires and the validation of forecast output with satellite and unattended aerial systems (UAS) to improve numerical smoke forecast models.

4.2.2.3 Use Case Summary

To better understand, forecast, and manage air pollution, air quality researchers and managers need to bring together information about a variety of atmospheric constituents from different observational platforms (surface monitoring networks, satellites, sondes, ground-based remote sensors, aircraft, etc.), nonlinear chemical and physical atmospheric processes from meteorological and chemical transport models, emissions and emissions-generating activities, population demographics, exposure-related behavior, and health impacts.

For scientific assessment and analysis of management strategies, this integration can be done using historical datasets. For air quality forecasting to inform the public and manage individual air pollution episodes or events, it is necessary to perform this integration in near real time.

Smoke from biomass burning is an important component of air quality. Quantifying air pollutant emissions from wildfires and prescribed burning is one of the more uncertain inputs to air quality forecasting. Satellite data are being used to help improve the ability to accurately estimate emissions from fires. However, the quality of satellite derived fire products for air quality applications is not well characterized:

- multiple sensors detect fires - which to use?
- missed detections (due to cloud cover)
- false detections
- spatial resolution limitations
- temporal resolution limitations
- size and types of fires detected
- derivation of smoke from satellite and aerial imagery

Types of analyses conducted on satellite derived fire and smoke information include:

- comparison of multiple satellite/aerial products (e.g., EO-1 fires compared with MODIS fires; UAS derived smoke compared with EO-1 or MODIS)
- agreement of satellite/aerial products with ground based observations
- agreement of forecast models with satellite/aerial products

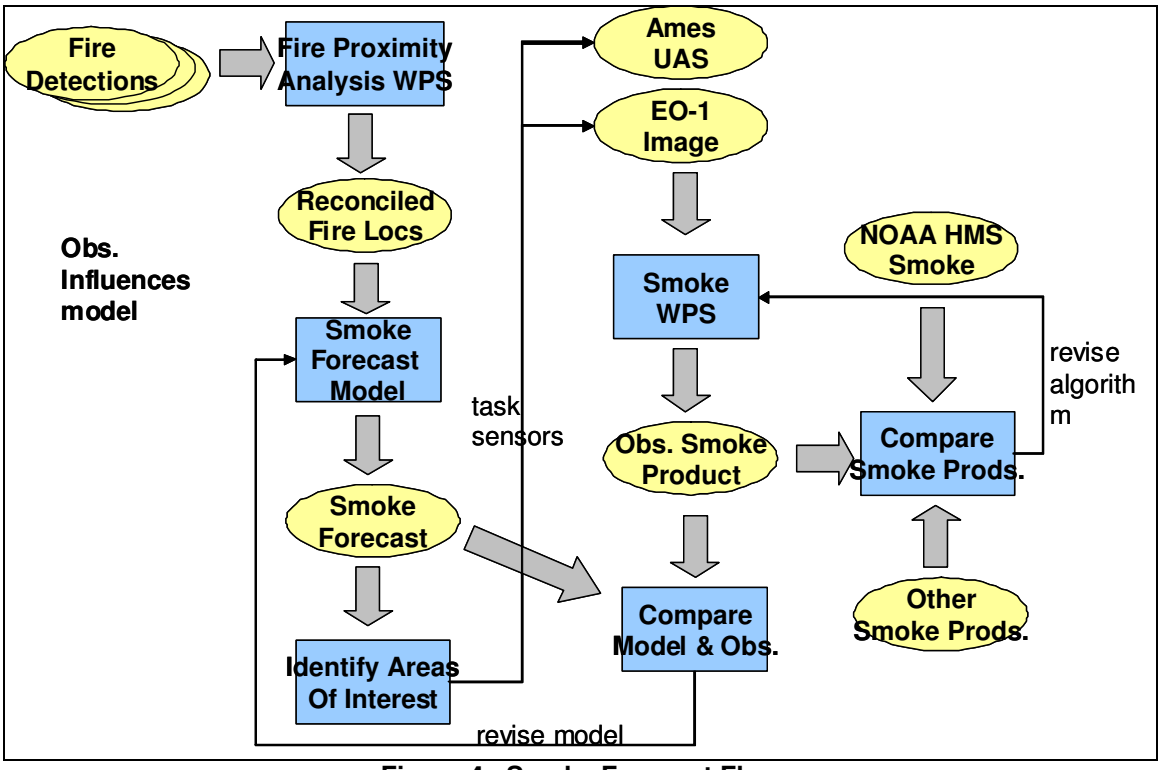

Figure 4. Smoke Forecast Flow

The Air Quality analyst needs to assess the extent and impact of detected wildfire smoke. Using an AQ portal the analyst identifies relevant satellite and aerial sensors to acquire new observations of the wildfire occurrence. The new data is used to validate and refine a smoke forecast, which is made available to analysts and AQ warning systems. The forecasts are used to request new observations from satellite, aerial and ground platforms and compare them with the forecasts.

4.2.3 Earthquake Response and Forecasting

4.2.3.1 Point of Contact

Andrea Donnellan
NASA Jet Propulsion Laboratory
Andrea.Donnellan@jpl.nasa.gov
818-354-4737

4.2.3.2 Use Case Goal

The goal of this Use Case is improved rapid response and earthquake forecasting from NASA's DESDynI mission.

4.2.3.3 Use Case Summary

DESDynI (Deformation, Ecosystem Structure, and Dynamics of Ice) is a combined InSAR/Lidar mission to study, among other things, tectonics surface deformation. Incorporation of surface deformation measurements into tectonic models is proving important for understanding earthquake processes and the resulting size and style of earthquakes. DESDynI will be the first InSAR mission to systematically and globally measure surface deformation at frequent intervals. An estimate 200 earthquakes per year or 1000 earthquakes will be detected over the 5-year duration of the mission. The mission will produce over 200 GB per day of crustal deformation data. These data must be incorporated into models and the large volumes of data drive the need to automated data processing. DESDynI InSAR surface deformation data will provide secular and time varying rates of deformation, which will improve our understanding of long

and short-term earthquake processes. Response will be required in the event of a large earthquake. The data must be rapidly downloaded, processed, and integrated with other data types. Earthquake response will include damage assessment and an assessment of stress changes and potential for subsequent earthquakes.

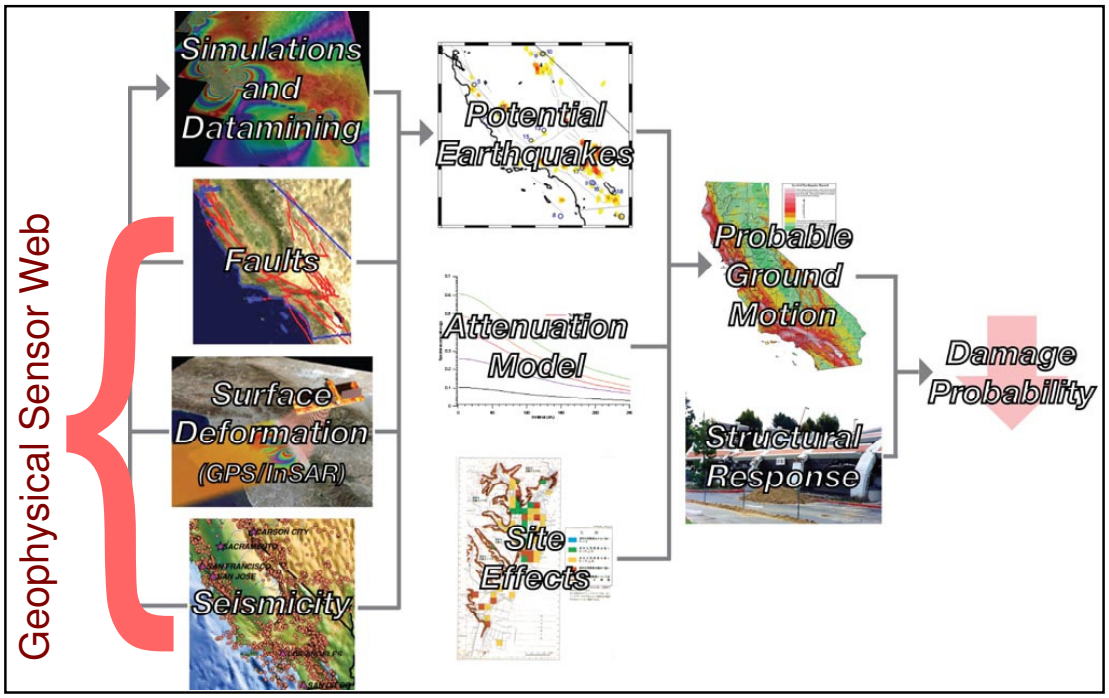

Figure 5. DESDynI Use Case Scenario

4.2.4 Numerical Weather Prediction Doppler Wind Lidar

4.2.4.1 Point of Contact

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4.2.4.2 Use Case Goal

The goal of this Use Case is to acquire high fidelity wind measurements to improve predictive skill in numerical model forecasts and conserve power and extend longevity of the instrument being used.

4.2.4.3 Use Case Summary

A wind lidar is proposed with an inherent ability to perform adaptive targeted measurements. This use case focuses on the “model-driven” sensor web ops concept wherein an atmospheric model is used to identify candidate regions of interest where the lidar may be potentially commanded to make measurements within regions where they would either otherwise not be made or, would be made using the default “survey” instrument measurement modes (e.g., unchanging pulse rate or frequency, power level, on/off duration, etc.). For this use case, we made use of the proposed Global Wind Observing Sounder (GWOS) instrument, depicted in the figure provided in the "Triggers" section. In order to obtain

complete vector wind components GWOS must sample an air parcel from at least two different perspectives. The instrument is comprised of multiple coherent and direct lidars that have the ability to operate through four telescopes. Two of the telescopes are oriented in a nominal ±45° azimuth pointing in front of the spacecraft, with the other two similarly oriented pointing aft. The combination of the fore and aft shots produces an estimated horizontal wind vector for multiple vertical levels. As currently designed the instrument can perform approximately 300 million shots in its lifetime with a pulse rates of 5Hz (coherent detection technique) and 100Hz (direct detection technique) respectively.

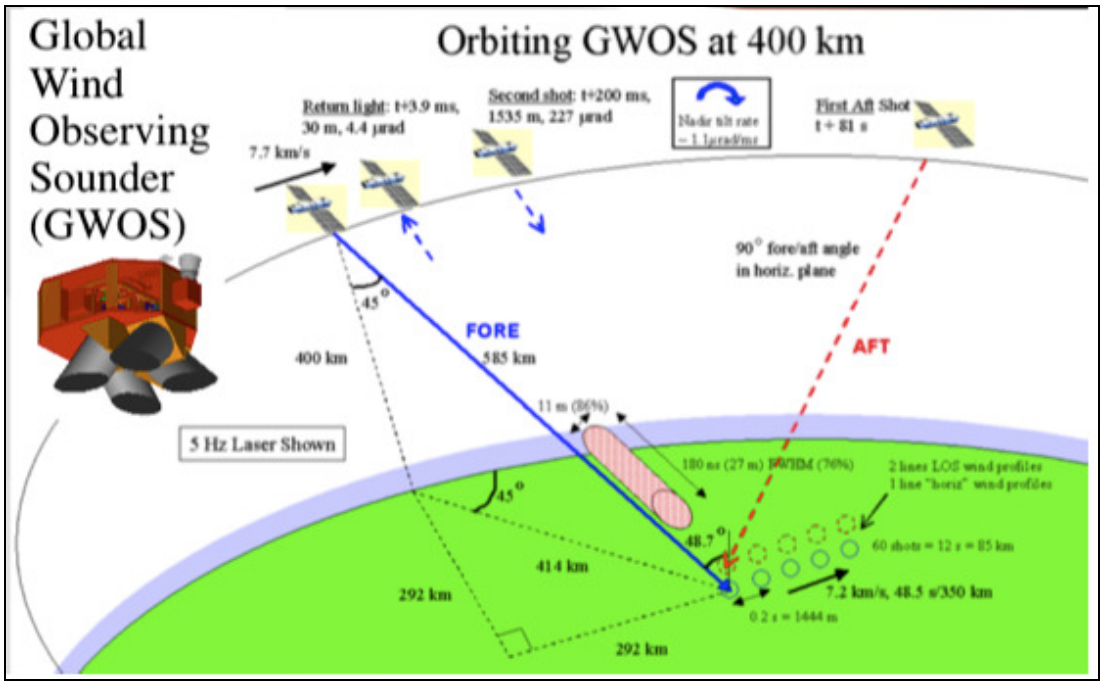

Figure 6. GWOS Operational Scenario

Using model-driven sensor web concepts we are proposing two sensor web scenarios that would modify the GWOS operations. Scenario (1) would minimize the required number of lidar shots without loss of information of the atmospheric state, and Scenario (2) would target data collection for specific regions of the atmosphere that would potentially have the greatest impact on forecast skill. For (1) GWOS would be provided the first guess wind field from a global forecast model. Observed line-of-sight (LOS) winds from the GWOS "fore shot" would be compared with the predicted winds from the model and valid at the time of the observation. If the winds were considered to be in adequate agreement the aft shot would not be performed. If such agreement were ubiquitous there could be a substantial reduction in the lidar's duty cycle, potentially extending the life of the instrument. For (2) we would use estimates of the model's forecast error to direct GWOS to target those regions of the atmosphere estimated to be in a state of low predictability, and/or target sensible weather features of interest. We assume to capture the maximum number of targets would require slewing of the spacecraft.

4.3 MW1 – Model Interoperability Conclusions

Two sets of patterns emerged as the participants presented their use cases during the MW1 breakout session. The first set of patterns related to observations and models:

- **Observations influence models**: Results of observations and measurements obtained from the sensor web devices can be effectively used as input to various modeling scenarios, refining the model input which can result in a higher fidelity model output.
- **Models influence observations**: Results obtained from modeling systems can be applied to sensor webs to identify specific events to monitor, resulting in better use of sensor resources.

- **Observations validate models**: Results of observations and measurements obtained from the sensor web devices provide significant correlation to the predicted outcomes from the modeling systems, thus validating the efficacy of the modeling system.

The second set of patterns that emerged during the discussion had to do with the relative maturity level of the use case and its related technology. For an example of a mature level, the air quality field has a robust suite of tools, data resources and sensors. Therefore the resulting use cases are likewise 'mature' because of the availability of mature models or decision support systems. For mature use cases it is more straightforward to build interoperable interfaces between those systems to create sensor webs. Conversely "developing" use cases are built on sensor web components (i.e., the models or sensors) that are still evolving. Table 5. Use Case Maturity Levels depicts this classification:

Table 5. Use Case Maturity Levels

Mature
Smart Assimilation of Satellite data into weather forecast model
Bird Migration and Avian Flu
AutoChem Atmospheric Chemistry Assimilation System
Satellite and UAS fire observation inputs to smoke forecast models
Tasking new satellite and UAS observations with smoke forecasts
Adaptive Targeting of Wind Lidar to Improve weather forecast skill
Earthquake response and forecasting
Volcanoes
Carbon Cycle Biomass
Developing
Extreme event detection and tracking for targeted observing
Validating smoke forecasts with satellite UAS observations
Detection, tracking, and reacquisition of volcanic ash clouds
Predict Global Land Surface Soil Moisture
Hydrology

Several challenges were also identified by the participants. Notable issues included the following:

- Better collaboration between technology developers and mission designers is needed to infuse sensor web technology into scientific observations.
- Tighter coupling between models driving observations for future mission design is desirable, for example, to enable carbon cycle science advances using DESDynI. Currently there's a one-way flow from sensors to models. For the sensor web concepts to progress, mission designers need to appreciate the benefits of having models provide a feedback loop into sensor operations.
- Sensor web enablement within the future missions, such as autonomous sensor response demonstrated in EO-1, is a significant infusion effort.
- Middleware – web services, portals, ontologies, etc., implementation will continue to be a challenge due to slowly maturing technologies.

It is worth noting that the luncheon address of Dr. Scott Tilley dealt directly with the promises and lessons learned from experience in implementing the Service Oriented Architecture. This talk was particularly insightful and timely, given the technology gap identified by the MW1 participants regarding middleware technologies, including web services and portals.

5 Breakout Group Middleware 2 (MW2) – Systems Management

While MW1 focused on models and interoperability, the MW2 – Systems Management breakout group focused on middleware that supports and enhances sensor capabilities. This includes planning and scheduling, adaptive sampling, tasking and feedback loops, and data flow and real-time data streaming within the context of ecology / land use and oceanography science themes. Their sensor webs are used for applications such as rapid response, unmanned vehicle flight planning in support of science campaigns, and coastal water science and management. Some of the key sensor web capabilities under development include operations and communication strategies and algorithms to optimize resource usage, planners and schedulers, and workflow management tools.

5.1 Participants

This section enumerates all of the participants in breakout group MW2 and identifies each participant's organization and project title.

Table 6. MW2 – Systems Management Participants

Name	Organization	Project Title
Phil Paulsen	NASA ESTO Glenn Research Center	AIST Facilitator
Glenn Prescott	NASA ESTO AIST	AIST Staff
April Gillam	The Aerospace Corporation	Report Editor
Payman Arabshahi Andrew Gray	University of Washington NASA Jet Propulsion Lab	A Smart Sensor Web for Ocean Observation: System Design, Modeling, and Optimization
Mohammed Atiquzzaman	University of Oklahoma	Implementation Issues and Validation of SIGMA in Space Network Environment
Prasanta Bose Peter Fox	Lockheed Martin Advanced Technology Center University Corporation for Atmospheric Research	Virtual Sensor Web Infrastructure for Collaborative Science (VSICS)
Michael Botts Susan Ingenthron	University of Alabama, Huntsville University of Alabama, Huntsville	Increasing the Technology Readiness of SensorML for Sensor Webs
William Ivancic Eric Miller	NASA Glenn Research Center General Dynamics General Dynamic Advanced information Systems	Secure, Autonomous, Intelligent Controller for Integrating Distributed Sensor Webs
Stephan Kolitz	Draper Labs	Sensor Web Dynamic Replanning

Dan Mandl Stuart Frye	NASA Goddard Space Flight Center Noblis Inc.	An Inter-operable Sensor Architecture to Facilitate Sensor Webs in Pursuit of GEOSS
Robert Morris	NASA Ames Research Center	Harnessing the Sensor Web through Model-based Observation
Antonio Ortega	University of Southern California	Efficient Sensor Web Communication Strategies Based on Jointly Optimized Distributed Wavelet Transform and Routing
Nikunj Oza	NASA Ames Research Center	Automated Data Assimilation and Flight Planning for Multi-Platform Observation Missions
Fabio Silva Wei Ye	USC Information Science Institute USC Information Science Institute	Satellite Sensornet Gateway (SSG)

5.2 Use Case Challenge

Breakout group MW2 developed fourteen (14) use cases during the meeting. The following three use cases were presented by the group during the feedback, plenary session and are featured in this section.

- A Smart Ocean Sensor Web to Enable Search and Rescue Operations
- Dynamic Plant Monitoring
- Hurricane Workflows

All use cases developed by MW2 may be found in Appendix C – Use Cases. The following table enumerates these use cases and indicates the page number of the start of the use case description. Use Cases featured in this set are identified by **bold text** in Table 7.

Table 7. MW2 Use Case Index

Use Case Name	Primary Points of Contact	Page #
A Smart Ocean Sensor Web to Enable Search and Rescue Operations	**Yi Chao, Andrew Gray, Payman Arabshahi**	**149**
Dynamic Plant Monitoring	**Wei Ye**	**185**
Hurricane Workflows	**Stuart Frye**	**258**
Collaborative Science Resource Allocation	Phil Paulsen, Eric Miller, Will Ivancic	286
Data Mining and Automated Planning for Mobile Instrument Operation	Nikunj C. Oza	159
Dynamic Soil Sampling	Wei Ye	188
Dynamically taskable sensors	Phil Paulsen, Eric Miller, Will Ivancic	289

Improved Storm/Weather Prediction based on Lightning Monitoring and Prediction	Prasanta Bose	222
Mount Saint Helen's Hazard Response	Peter Fox	119
North American Net Primary Production Comparison Using Automated Workflow Generation	Robert Morris, Jennifer Dungan	197
Operationally Responsive Space Element Tasking	Phil Paulsen, Eric Miller, Will Ivancic	119
Seamlessly Download Data	Mohammed Atiquzzaman	292
Water Quality Monitoring	Wei Ye	282
Wildfire Sensor Web	Dan Mandl	209

5.2.1 A Smart Ocean Sensor Web to Enable Search and Rescue Operations

5.2.1.1 Point of Contact

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Jet Propulsion Laboratory
aagray@u.washington.edu

Payman Arabshahi
University of Washington
payman@ee.washington.edu
206-221-6990

5.2.1.2 Use Case Goal

To deliver ocean nowcast and forecast in real-time to enable US Coast Guard's research and rescue operations by integrating in-situ measurements with satellite observations into a predictive Regional Ocean Modeling System (ROMS).

5.2.1.3 Use Case Summary

The sensor web achieves traceability to science through complimenting existing and planned space science missions. Specifically the web integrates space-based sensor data with in-situ data, these are integrated via the ROMS model, the output of which can be used for achieving a set of scientific objectives, including enhancing the science products of the stand-alone missions (e.g., QuikSCAT, Jason). These science applications (or use cases) may be categorized as indicated in the graphic below. Note that the output of the ROMS model (with integrated space-based and in-situ data) is also useful in planning future space-based missions (investment) dedicated to climate change science. The graphic below presents an overview of the large number of science applications (dozens of possible use cases)

for the sensor web being developed in the AIST task "A Smart Sensor Web for Ocean Observation: System Design, Modeling, and Optimization." The use case presented in this document focuses on one such use case in the **coastal disaster relief operations** category with a particular focus on the **search and rescue** operations.

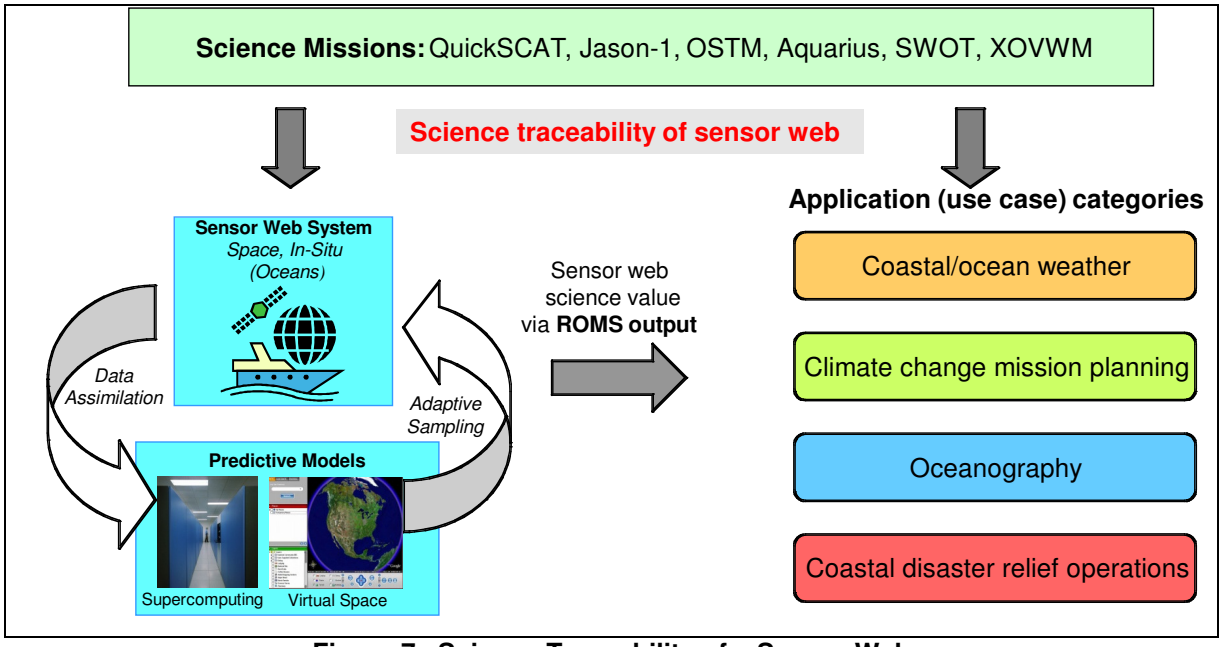

Figure 7. Science Traceability of a Sensor Web

5.2.2 Dynamic Plant Monitoring

5.2.2.1 Point of Contact

Wei Ye
USC Information Sciences Institute
weiye@isi.edu
(310) 448-9107

5.2.2.2 Use Case Goal

Multimodal sensing of plants bloom in response to precipitation.

5.2.2.3 Use Case Summary

The goal of this use case is to study the plants bloom in response to precipitation. Multimodal sensing is applied to capture the dynamic response of plants to seasonal rainfalls after a relatively long period of dry weather. Specifically, we deploy sap flow sensors on some branches of several different species of plants. This sap flow sensor detects the detailed internal activity of plants in response to the environment. In addition, we deploy imaging sensors (remotely-controlled cameras) to capture the bloom of plants. A weather station allows us to detect precipitation or solar radiation, etc.

In order to reduce energy usage—sap flow sensors are powered by batteries and use wireless communication. We will dynamically adjust their sampling period according to environmental events that have been detected. When there has been no rainfall for a relatively long period of time, the plants change very slowly. In this case the sap flow sensors are configured to sample at a low frequency (e.g., 1 sample every 5 or 10 minutes). The camera takes a picture of each plant once a week. When the weather station detects rainfall, we will reconfigure the system to sample more frequently. The sap flow sensor will take 1 sample per minute, and the camera will take a picture twice a day to capture the plants bloom.

An additional trigger is the solar radiation. The plants are much more active with sunlight during day time than during the night. Therefore, during the night, we can have even lower sampling rates (e.g., 1 sample every 30 minutes) than day time. The weather station is able to detect the solar radiation level, which will be used to trigger the change of sap flow sampling rate during the day and night.

5.2.3 Hurricane Workflows

5.2.3.1 Point of Contact

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5.2.3.2 Use Case Goal

This use case describes how an end user would adapt an existing workflow to accomplish a new observation goal.

5.2.3.3 Use Case Summary

Individual web services have been developed that accomplish individual tasks for identifying event triggers, tasking sensor assets, processing sensor data, and delivering multiple higher level detection products directly to end users. For a typical observation sequence, a series of activities has to be accomplished including sensor tasking, basic data processing, and customized detection data product generation and delivery. Users want to have a way to string together multiple services to accomplish these specific goals. Workflows provide this capability.

A wildfire monitoring workflow has been developed that allows a fire analyst to pick a region of interest for fire monitoring, retrieve MODIS hot pixel locations for that region, identify the highest threat location within that region, task the EO-1 satellite to target that location, and provide multiple EO-1 data products to that user. The products include a visible image, a SWIR image showing burned area and active fire that can be seen through clouds, and a hot pixel readout from the Hyperion hyperspectral imager.

If a user is concerned about triggering coverage of a hurricane instead of a wildfire, the user can adapt the wildfire workflow to monitor the hurricane aftermath by pointing the triggering part of the workflow at the National Hurricane Centers landfall prediction web site instead of pulling in MODIS hot pixels for targeting. The threat analysis part of the workflow would be modified to target the eye of the storm landfall point and the EO-1 satellite would be tasked to image that location and the earliest in-view time after landfall. Basic targeting and data processing would not be modified. Individual detection products could still include the set of fire products (visible, SWIR, and hot pixels), but a flood classification algorithm could be added. The user discovers which bands to select for the flood algorithm from the WPS description document.

To make the modifications to the workflow, the user would employ a workflow editor. The editor provides the capability to change the trigger selection and the threat calculation plus adding the new product to the workflow. The wildfire products could be deleted to reduce the delivered data volume.

5.3 MW2 – Systems Management Conclusions

The team identified some themes among the use cases. These include:

- **Workflows** that enable virtual observation, to decide which products to generate and make decisions when there are not sufficient resources to satisfy all user requests. The workflow makes more science and results or products possible at a lower cost. The expectation, for the wildfire

system currently being fielded and still under development, is that the sensor web approach will reduce costs by an order of magnitude.

- **Adaptive Sampling** is based on routine monitoring of the environment that detects events that trigger (a) other sensors to operate and (b) changes in sampling frequency. This makes it possible to reduce sensor energy consumption during routine times and to increase measurement frequency during interesting events.
- **Cross-coordination** of sensors makes it possible for in-situ sensors to trigger spacecraft instruments to operate in a given location.
- **Autonomous tasking** occurs when a model predicts events which can then be used to better target sensor resources. A feedback loop also makes it possible to use the observations taken during events to update the models to improve the predictions. Another application of tasking is in data transmission from satellites to ground stations, especially in Low Earth Orbit, to seamlessly handoff transmission from one ground station to another.

The participants in MW2 also provided some observations learned through creating the use cases. Several use cases addressed management issues for communications, sensors and workflow (as noted above). Indeed workflow management appeared in the majority of use cases so this area offers more opportunity for development.

In response to the question of recommendations for next steps, the MW2 group discussed the following points:

- Can a “value chain” analysis be applied to show how sensor webs can produce more science, better science results, or spend less to get the science results?
- The software principle of achieving simplification through abstraction may apply to sensor webs.
- Encourage continuing work to refine use cases, especially the relevance to the Decadal Survey goals. Since the language of computer science is sufficiently different from that used by the hardware and science researchers that the significance, issues, and needs in information systems may not be recognized or understood. The use case approach may help bridge this gap.
- Live demonstrations are good, but not easily duplicated. Capture demos on short DVD media or use animation to convey the capabilities of sensor webs.

Some in this group also noted that the final luncheon speaker, Mr. John Garstka, DoD Office of Force Transformation, spoke about the importance of demonstrating a return-on-investment for infusing technology. This is a strategy that ESTO may pursue to influence the planning for the Decadal Survey missions.

6 Breakout Group Smart Sensing (SS)

With a focus on flight, in-situ, and space borne platforms, Breakout Group SS was assembled to develop use cases having to do with smart sensing; namely, examining autonomous sensors and adaptive resource management and processing, agent technology and sensor fusion for the purpose of increasing the return on investment of sensing technologies. Their initial science themes for sensor web use cases included water and energy cycles, climate change and Earth surface & interior. Participants had insight into the Soil Moisture Active-Passive (SMAP) and Ice, Cloud, and Land Elevation Satellite (ICESat-II) missions from the Decadal Survey, among several others.

6.1 Participants

This section enumerates all of the participants in breakout group SS and identifies each participant's organization and project title.

Table 8. Breakout Group SS Participants

Name	Organization	Project Title
Rob Sherwood	NASA Jet Propulsion Laboratory	AIST Facilitator
Steve Smith	NASA ESTO	AIST Staff
Bradley Hartman	The Aerospace Corporation	Report Editor
Ashit Talukder	NASA Jet Propulsion Laboratory	Autonomous In-situ Control and Resource Management in Distributed Heterogeneous Sensor Webs: CARDS
Ashley G Davies	NASA Jet Propulsion Laboratory	Science Model-Driven Autonomous Sensor Web (MSW
Ayanna M Howard	Georgia Tech Research Corp	Reconfigurable Sensor Networks for Fault-Tolerant In-Situ Sampling
Costas Tsatsoulis	University of Kansas	An Adaptive, Negotiating Multi-Agent System for Sensor Webs
Dipa Suri Gautam Biswas	Lockheed Martin Space Systems Company Vanderbilt University	The Multi-agent Architecture for Coordinated, Responsive Observations
John Dolan Alberto Elfes	Carnegie Mellon University NASA Jet Propulsion Laboratory	Telesupervised Adaptive Ocean Sensor Fleet
Ken Witt Al Underbrink	Institute for Scientific Research, Inc. Sentar, Inc.	Using Intelligent Agents to Form a Sensor Web for Autonomous Mission Operations
Mahta Moghaddam	University of Michigan	Soil Moisture Smart Sensor Web Using Data Assimilation and Optimal Control

Matt Heavner	University of Alaska Southeast	SEAMONSTER: A Smart Sensor Web in Southeast Alaska
WenZhan Song	Washington State University	Optimized Autonomous Space - In-situ Sensorweb
Yunling Lou Steve Chien	NASA Jet Propulsion Laboratory NASA Jet Propulsion Laboratory	Autonomous Disturbance Detection and Monitoring System for UAVSAR
Larry Hilliard	NASA Goddard Space Flight Center	Developing an Expandable Reconfigurable Instrument Node as a Building Block for a Web Sensor Strand

6.2 Use Case Challenge

Breakout group SS on smart sensing developed eleven (11) use cases. Due to time constraints, however, the group decided to present only four (4) of these during the feedback, plenary session at the end of the meeting. Table 9 enumerates all use cases developed by breakout group SS. The four use cases that were presented during the plenary session are highlighted in the table in **bold text** and are also featured in this section. All use cases may be found in Appendix C – Use Cases.

Table 9. SS Use Case Index

Use Case Name	*Primary Points of Contact*	*Page #*
Forest Fire Sensor Web with UAVSAR	**Yunling Lou, Steve Chien**	**191**
Glacier Outburst Flood Water Quality Impact	**Matt Heavner, Dipa Suri, Gautam Biswas**	**253**
Model-based Volcano Sensor Web with Smart Sensors	**Ashley Gerard Davies, Steve Chien**	**111**
Soil Moisture Calibration and Validation for SMAP Products	**Mahta Moghaddam**	**202**
Calibration of Remote-Sensing Instruments Using Re-deployable In-Situ Sensor Networks for Ice Sheet Characterization	Ayanna Howard	155
Coastal Sensor Web for Short- and Long-Duration Event Detection	Ashit Talukder, John Dolan	246
ICESat-II and Deformation, Ecosystem Structure, and Dynamics (DESDynl) using ERINode for Passive Active Interferometric Radiometer w/Interleaved Radar	Larry Hillard	165
Snow and Cold Land Processes (SCLP) using ERINode for Passive Active Interferometric Radiometer w/Interleaved Radar	Larry Hillard	268
Snow Cover Resolution Enhancement Using Targeted Sensing	Steve Chien, Paul Houser, Christa Peters-Lidard	173

Soil Moisture Active-Passive (SMAP) high resolution foliage calibration	Larry Hillard	275
Volcanic hazard event ground-space-ground feedback cycle	Wenzhan Song	135

6.2.1 Model-based Volcano Sensor Web with Smart Sensors

6.2.1.1 Point(s) of Contact

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6.2.1.2 Use Case Goal

Time is of the utmost importance in a volcanic crisis for the purposes of hazard and risk assessment. The goal of the JPL Model-based Volcano Sensor Web (MSW) is to detect an alert of pending or current volcanic activity, obtain high-resolution data, process the data and disseminate the products to relevant scientists as rapidly as possible, ideally within hours to a few days. We are working towards a fully-autonomous system.

6.2.1.3 Use Case Summary

The MSW is an end-to-end product delivery service, aimed at effusive volcanic eruptions. When the African volcano Nyamulagira (a.k.a. Nyamuragira) in the Democratic Republic of Congo erupted in November 2006, the utility of such a system was demonstrated (illustrated in Figure 8). As local volcanologists were unable to determine the location of the vent, models of possible lava flow paths were poorly constrained. A call went out to the international community to obtain spacecraft data to allow accurate vent location. The autonomous MSW reacted faster than humans in the spacecraft command and control loop. A detection of a plume reported by the Toulouse VAAC was detected by a remote agent of the JPL MSW. The alert information was passed to a planner which inserted an observation (two days later) in the EO-1 observation sequence. Data obtained by the Hyperion visible-infrared hyperspectral imager were processed onboard by data classifiers. Thermal emission from the erupting lava was detected and a summary product down linked within 90 minutes of data acquisition, alerting JPL that onboard detection had been successful. EO-1 retasked itself to obtain additional data at the next possible opportunity. Within 24 hours the entire Hyperion dataset had been down linked and radiometrically corrected. The data underwent additional manual processing to generate image products showing detail of the vent area, which were then emailed to volcanologists in Italy, France and the D. R. Congo. The new flow model output is in the form of maps showing the application of models of lava flow emplacement, based on the updated vent location, knowledge of local topography and assuming an eruption rate based on previous behavior of the volcano. The new maps showed a greater likelihood of flows to the south west of the vent reaching the town of Sake and cutting an important road, and no flows to the east (predicted by models using the original estimated vent location some 2 km away from the location identified in the Hyperion data). This information allowed local authorities to amend disaster plans accordingly. In the end, the eruption was relatively short-lived and Sake was not directly threatened. EO-1 obtained a follow-up observation of Nyamulagira two days after the first, but the target was found to be cloud-covered. In the absence of further alerts, the system re-set itself.

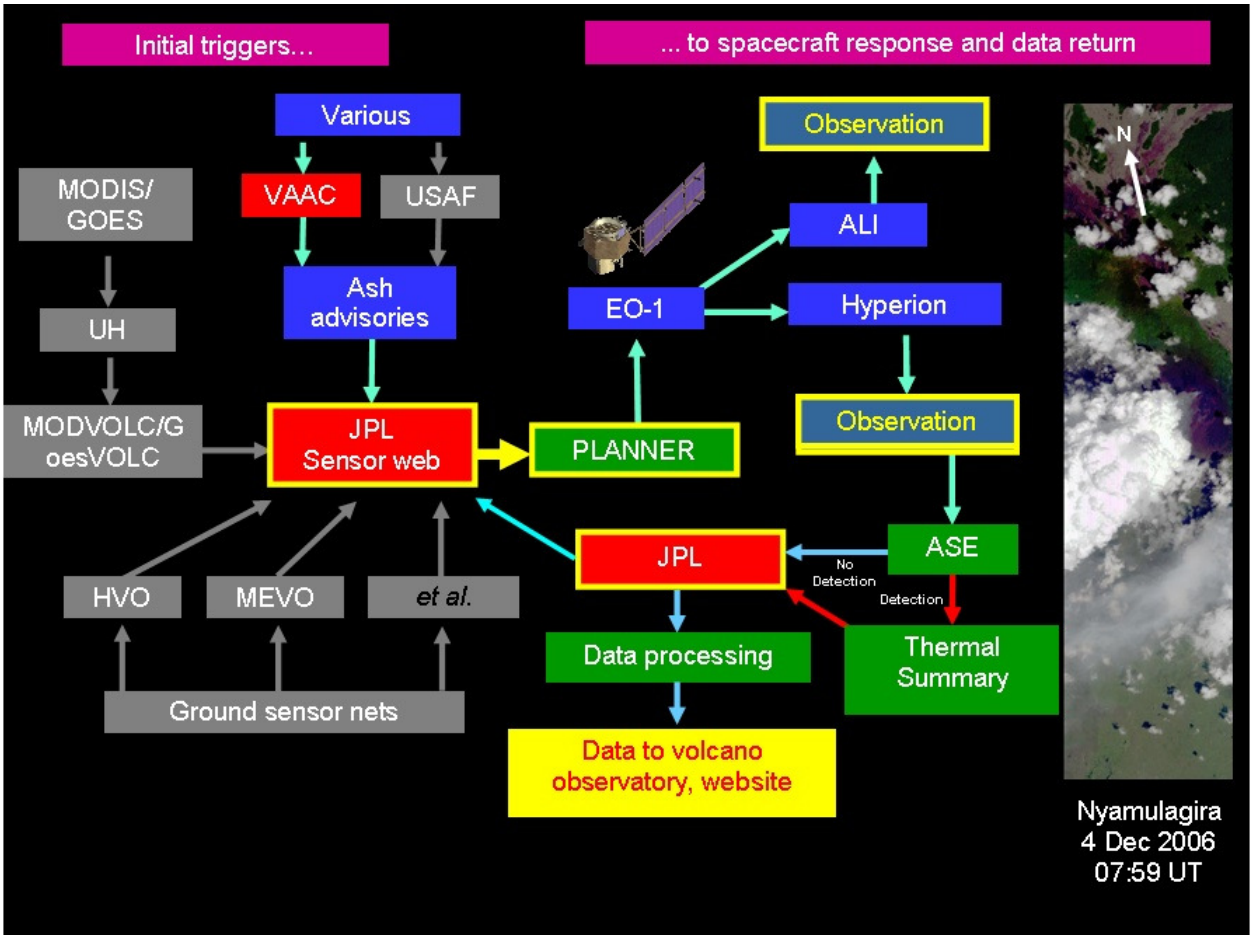

Figure 8. Sensor Web Actions During the 2006 Eruption of Nyamulagira

6.2.2 Soil Moisture Calibration and Validation for SMAP Products

6.2.2.1 Point(s) of Contact

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6.2.2.2 Use Case Goal

The goal of this use case is to provide accurate and cost-effective means of validating and calibrating satellite-derived soil moisture products through smart in-situ sensing.

6.2.2.3 Use Case Summary

This use case enables a guided/adaptive sampling strategy for a soil moisture sparse in-situ sensor network to meet the measurement validation objectives of the space borne radar and radiometer on SMAP with respect to resolution and accuracy. The sensor nodes are guided to perform as a macro-instrument measuring processes at the scale of the satellite footprint, hence meeting the requirements for the difficult problem of validation of satellite measurements. SMAP allows global mapping but with coarse footprints. The total variability in soil-moisture fields comes from variability in processes on various scales. Installing an in-situ network to sample the field for all ranges of variability is impractical. However, a sparser but smarter network can provide the validation estimates by operating in a guided fashion with

guidance from its own sparse measurements. A control system is developed and built to command the sensors to turn on at optimal times and locations. The feedback and control take place in the context of a dynamic data assimilation system, and enable a cost-effective and accurate means of accomplishing the validation task. This validation paradigm differs from the traditional one in that the in-situ sensor web optimizes its operation by turning on only a subset of the sensors and only when needed to minimize resource usage while maximizing the accuracy of validation data, as opposed to performing measurements round-the-clock, and over a dense grid.

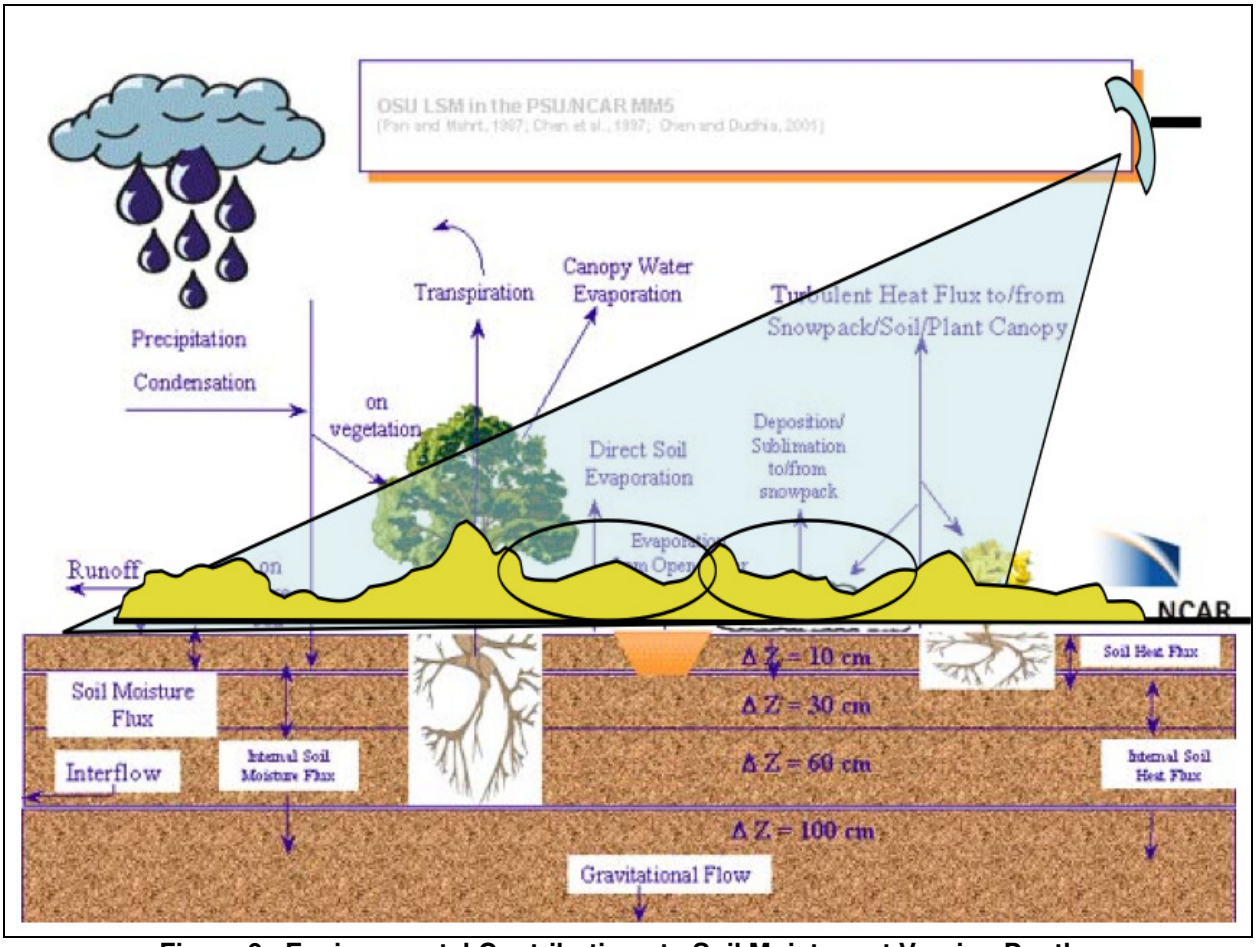

Figure 9. Environmental Contributions to Soil Moisture at Varying Depths

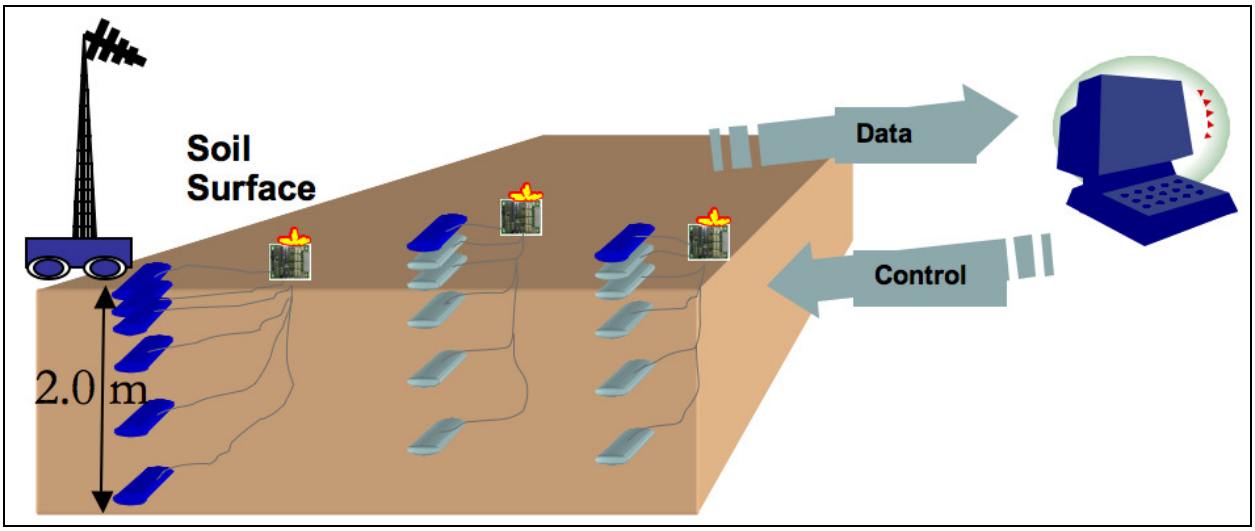

Figure 10. Soil Moisture Cal/Val Sensor Deployment

6.2.3 Forest Fire Sensor Web with UAVSAR

6.2.3.1 Point(s) of Contact

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6.2.3.2 Use Case Goal

Our goal is to provide critical information for rapid response during a forest fire. This forest fire sensor web is for UAVSAR to trigger on a forest fire alert, plan data acquisition with UAVSAR, collect radar data over the fire site, process data onboard to generate appropriate data products such as fuel load map, downlink the time critical information to disaster response agencies. The onboard automated response capability can also trigger other observational assets to collect data over the fire site.

6.2.3.3 Use Case Summary

We are developing a forest fire sensor web with UAVSAR to demonstrate the autonomous disturbance detection and monitoring system with imaging radars. This sensor web enhances UAVSAR (a high resolution polarimetric L-band imaging radar) with high throughput onboard processing technology and onboard automated response capability to detect wildfire and monitor forest fuel load autonomously. The smart sensor will be OGC compliant, thus allowing us to utilize other OGC compliant Sensor Alert Services and Sensor Observation Services to provide enhanced information such as precise fire location and fire progression prediction to enable autonomous response of other assets and disaster management agencies.

The timeliness of the smart sensor output products can be used for disaster management, agricultural irrigation, and transportation such as shipping. Onboard automated response will greatly reduce the operational cost of the smart sensor. This smart sensor technology is well suited for space flight missions such as DESDynI, SCLP, SMAP, and SWOT, and different science algorithms can be used for a variety of disturbances.

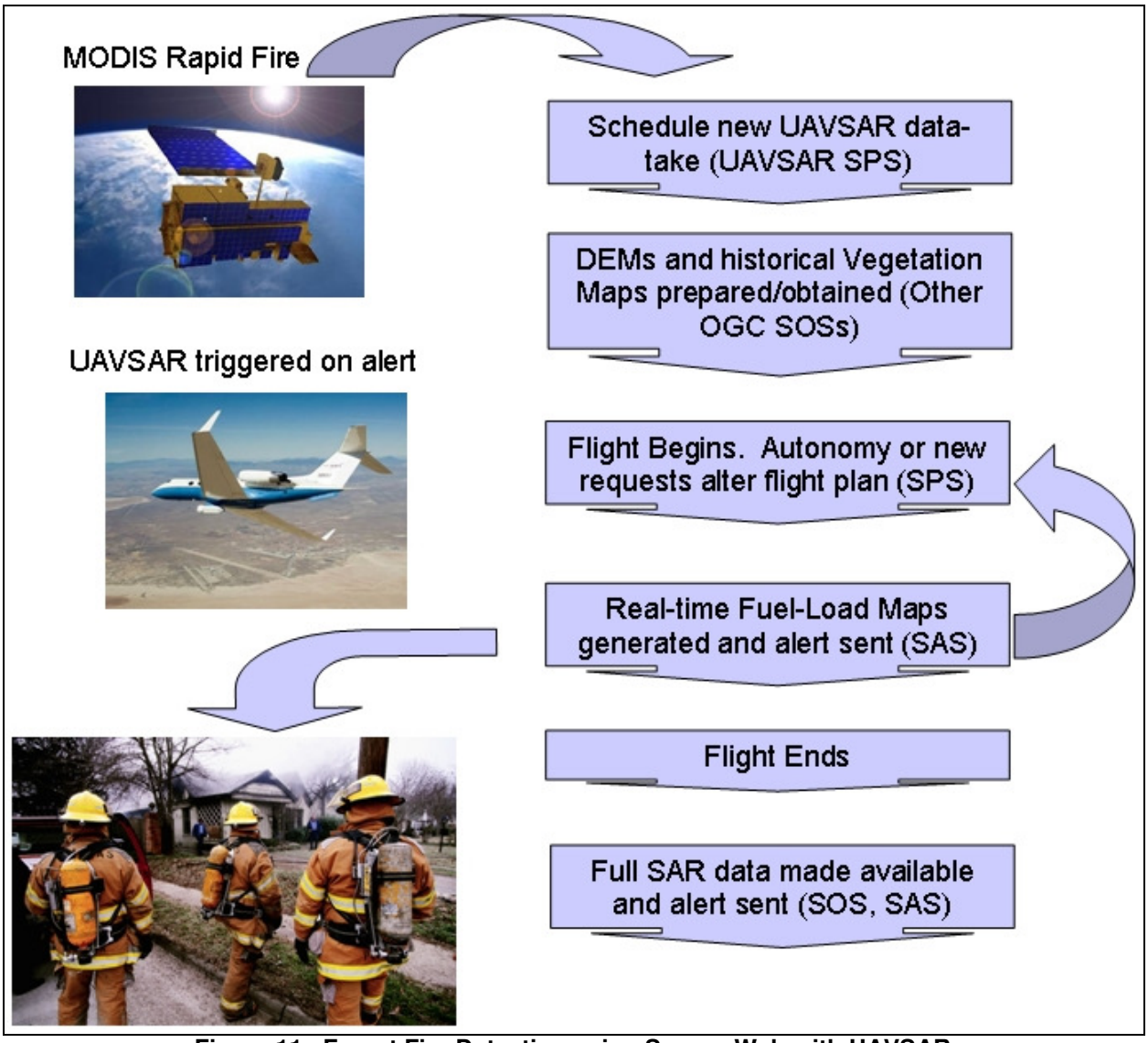

Figure 11. Forest Fire Detection using Sensor Web with UAVSAR

6.2.4 Glacier Outburst Flood Water Quality Impact

6.2.4.1 Point(s) of Contact

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6.2.4.2 Use Case Goal

Scientist needs to know when a glacial lake catastrophically drains and have data to understand impacts on water quality downstream and glacial dynamics while also collecting data to understand long term effects of increased glacial lake formation with climate change.

6.2.4.3 Use Case Summary

Climate change is increasing the amount of glacial lakes. Water quality has great significance for ecology e.g., salmon spawning and primary productivity in the near shore marine environment. Understanding the glacial lakes impacts on glacier dynamics, glaciated watershed, and coastal productivity motivates this use case. Heterogeneous measurements from the watershed need to be coordinated for intense observations when an unpredictable, transient event (outburst lake drainage) occurs. Long term monitoring is ongoing, but is power, computationally, and bandwidth constrained. Instrumentation includes a pressure transducer in the glacial lake; meteorological station for gathering parameters such as temperature, wind speed and direction, and precipitation; a steer able camera; and a water quality sonde. Some of the sensors (such as the pressure transducer) have minimal computation capability and only forward data while others are heterogeneous sensors and computational processors. These nodes are deployed and configured into subnets that are networked through both wired and wireless connections.

In keeping with the notion of a sensor web, these subnets are sources of data that is collected at and processed in a more computationally rich environment in order to facilitate high level analysis and decision making.

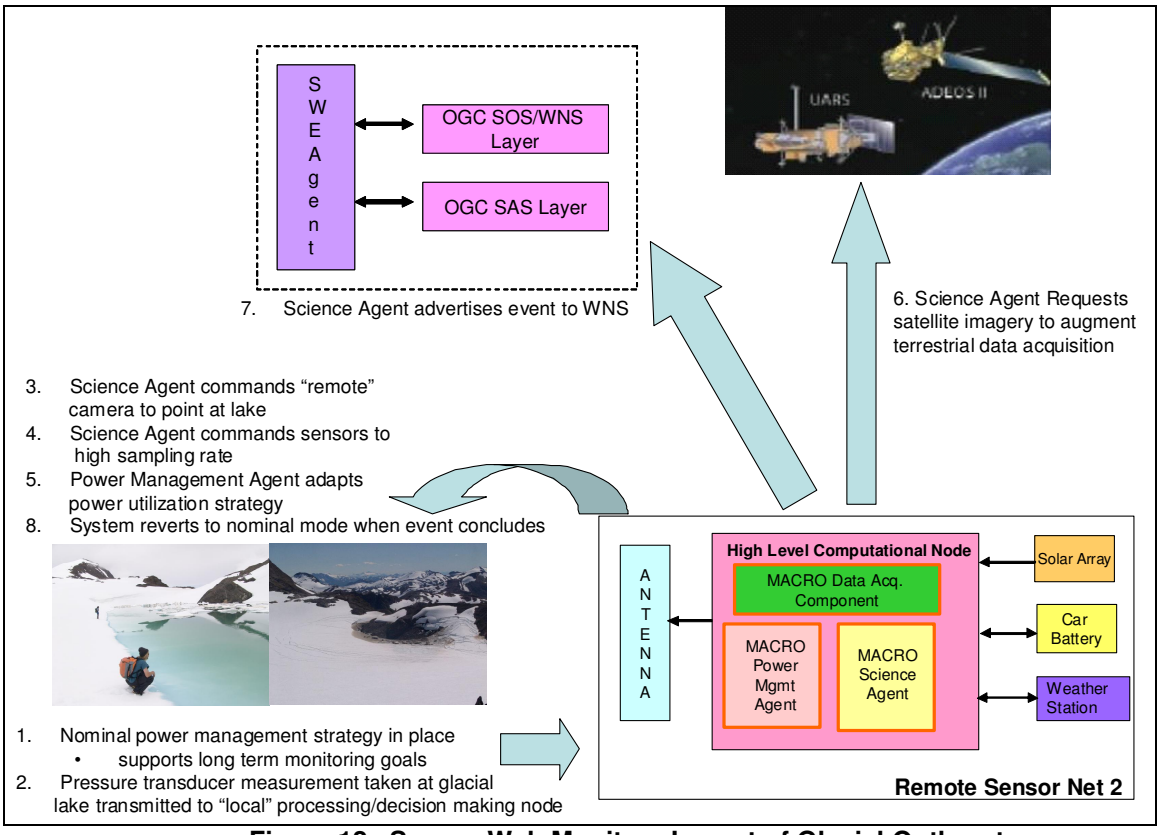

Figure 12. Sensor Web Monitors Impact of Glacial Outburst

6.3 SS – Smart Sensing Conclusions

While developing their use cases, the group noted that most of the use cases fell into at least one of three categories:

- **In-situ networks used for calibration/validation** – some of the use cases (e.g., refer to Section 6.2.2 on page 31) employ in-situ sensors to cost effectively calibrate and validate other sensors (e.g., satellites).
- **Airborne sensors used to increase modality or resolution** – some of the use cases (e.g., refer to Section 11.6.5 on page 268) employ airborne platforms for the purposes of calibration/validation and to increase the resolution of information in regions of interest.
- **Detection of events drives adaptation of sensor nodes** – some of the use cases detect events and adapt to dynamic situations (e.g., refer to Section 11.2.7 on page 135).

Additionally, participants spent some time brainstorming ideas regarding next steps. The following recommendations emerged from these discussions:

- Investigators and NASA/ESTO need to look more closely at the return on investment for the sensor web use cases. This will help to strengthen the business case for the necessity of sensor web technologies.
- Investigators and NASA/ESTO need to strengthen the relevance of the use cases to the Decadal Survey missions.

The group also discussed the following two ideas regarding the promotion of use cases. Both of these ideas were aimed at increasing the relevance and therefore the likelihood of stakeholder buy-in.

- Tailor each use case to the audience instead of developing a single, entirely reusable use case.
- Market use cases intelligently; namely, to market the use cases to the science discipline leads' most important projects.

7 Summary and Conclusions

As stated in Section 2, Introduction, the key outcomes of this meeting were to:

- Define a set of use cases to illustrate how sensor web technology will be used
- Relate these use cases to the Decadal Survey. [DEC07]

7.1 Coverage

The three breakout groups developed a total of 41 use cases. MW1 produced 16 use cases, MW2 produced 14, and SS produced 11. The use cases were placed in a single science theme category, as organized in Appendix C – Use Cases. As seen in the next table, these use cases cover all of the NASA science focus area themes, and in addition, there are 4 cross-cutting use cases that are applicable to all of the science themes.

Table 10. Use Case Coverage with Respect to Science Theme

Atmospheric Composition	Earth Surface & Interior	Climate Variability & Change	Carbon Cycle & Ecosystems	Weather	Water & Energy Cycle	Cross-Cutting
7	6	3	6	5	10	4

The Decadal Survey Categories follow:

- Earth Science Applications & Societal Benefits
- Land Use Change, Ecosystem Dynamics, Biodiversity
- Weather - Space & Chemical
- Climate Variability & Changes
- Water Resources & Global Hydrologic Cycle
- Human Health & Security
- Solid Earth Hazards, Resources, Dynamics

All of these Decadal Survey Categories are addressed by the use cases as well. The following table gives the number of use cases that address each category. Several use cases are cross-disciplinary and thus associated with multiple Decadal Survey Categories.

Table 11. Use Case Coverage with Respect to Decadal Survey Categories

Earth Science Applications & Societal Benefits	Land Use Change, Ecosystem Dynamics, Biodiversity	Weather - Space & Chemical	Climate Variability & Changes	Water Resources & Global Hydrologic Cycle	Human Health & Security	Solid Earth Hazards, Resources, Dynamics
28	17	16	12	12	11	7

One of the PIs indicated that the Decadal Survey has more of a focus on societal benefit whereas at NASA it is the science that has the highest priority. There was general consensus that this is the case.

Additionally, the AIST Needs (Data Collection; Transmission & Dissemination; Data & Information Production; Search, Access, Analysis, Display; and Systems Management) were all addressed by the use cases, as summarized in the following table, which indicates the number of use cases that address each AIST Need. Here again, use cases are associated with many of the Earth science information system needs identified in the AIST list.

Table 12. Use Case Coverage with Respect to AIST Needs

Data Collection	Transmission & Dissemination	Data & Info Production	Search, Access, Anlys, Disp	Systems Mgmt
28	13	22	21	9

7.2 Sensor Web Benefits

The "Report from the Earth Science Technology Office (ESTO) Advanced Information Systems Technology (AIST) Sensor Web Technology Meeting" [NASA 07] identified the following sensor web benefits: (1) improved use and reuse of sensor assets and software services, (2) improved sensor return on investment and cost effectiveness, and (3) improved data quality and value to science. During the meeting there was discussion about sensor web benefits, specifically pointing out that they also provide the ability to improve the accuracy of predictions, handle uncertainty, and are scalable. A sensor web approach can also make systems interoperable, supporting disparate content and interfaces.

In 2008, ESTO updated and restated the Earth science information system goals in the AIST Needs. All of these goals are addressed by the use cases, as summarized in Table 13.

Table 13. Use Case Coverage With Respect to AIST Goals

Increase science data value thru autonomous use	Coordinate multiple observations for synergistic science	Improve interdisciplinary science production environments	Improve access, storage, delivery	Improve system interoperability, standards use	Decrease mission risk/cost thru autonomy
26	**28**	**12**	**18**	**18**	**16**

Easy Does It

A principle that was mentioned more than once during the sensor web meeting is that it is useful to identify what sensor webs provide that makes life easier. Programs should not have to learn a new way to do things each time. Unless there is a clear value, programs with tight budgets and schedules are not likely to support new operating efforts. A number of people at the meeting were in agreement that **one should not have to make major changes to existing systems to join a sensor web**. This approach enhances the value of the program while facilitating access to new and existing resources. By increasing value and decreasing effort, NASA improves its overall return on investment.

Another participant discussed the dichotomy between what the user sees and what is happening in the background. "The latter is what we supply to make the former stuff easy." **It is important for users to understand what goes on, without all the detail**, ensuring that they are not overwhelmed. Just as a user recognizes they do not understand the complexity of their own computer while still being able to search the world over for products or task the system to create digital files, a user of a sensor web does not need to understand the technological complexity, only that they may search for resources, gather data, and task the system to produce information.

Black Box Analogy

A concept espoused in a similar vein, was to look at the sensor web as a black box. Users interface with the system, solely looking at the capabilities that are external to the black box and not needing to look at the internal structure. Sensor webs can be built in to enable discovery of sensor capabilities, and automatically provide fault tolerance and reconfiguration of resources.

This was illustrated when in a wildfire use case, a PI indicated that firemen want a fire map to know where the fire is now; they do not care about the sensors. To this end, participants discussed the need to set up the mechanisms for sensor web services, and to be able to tailor the sensor web to support a fire scenario, a flood scenario or some other application area.

7.3 Next Steps

Print and Web Media

In the final session of the meeting, discussions were open to recommendations and action items. The discussion topics included print and web media for informing others about sensor webs. Some projects have successfully developed short narrated movies, 3 – 7 minutes long, which include satellite orbit animations or screen captures of user interactions with proposed tools for sensor web users. These animated scenarios are a very effective means of conveying the sensor web capabilities. These movies can be easily migrated to YouTube or posted on project web sites. ESTO also has a sensor web meeting web site (http://esto.nasa.gov/sensorwebmeeting) for hosting demonstration movies. The movies can be easily shared at technical or scientific conferences in oral or poster sessions if live demos are risky. A sensor web poster and brochure would be worth following up by ESTO for these conferences or whenever there is a NASA booth.

Technology Infusion

The Technology Infusion Working Group collaboration web site was successfully used during the generation of the use cases. A wiki has been established to continue dialogue on related topics of sensor web definition and capabilities, benefits and uses, as well as infusion. Final documents and lessons learned can be posted to the public version of the web site for publication. The tech infusion group provides a continued focus on outreach and identifies science and technology conferences which feature geospatial information systems where sensor web topics would be of interest. The group also looks for opportunities to provide coordinated feedback to various standards bodies, particularly the Open Geospatial Consortium (OGC) and the IEEE and ISO standards activities. Sensor web enablement within the future missions, such as autonomous sensor response demonstrated in EO-1, is a significant infusion effort. Finally, the monthly sensor web teleconference forum will continue, nominally on the 4th Tuesday at 2:00 pm eastern time.

Standards

One meeting participant indicated that a good direction for the sensor web approach to take is **web technology and ISO**. Reference implementations are needed. He also pointed out that there are discontinuities in the way NASA funds development between TRL 4 or 5 up to 8; i.e., there isn't funding for the intervening TRL development. Managers want an operating production service rather than demonstrations that have a single instantiation. NASA succeeds very well when the technology is taken on as operations with outside grant funding. Another participant pointed out that an area where the users concerns have not been addressed is mission operations readiness and suggested that NASA needs a Mission Operations Readiness Level in addition to a Technical Readiness Level.

Use Case Refinement

The group discussed the value of refining the use cases and using the template to document scenarios for demonstrating prototypes. Refinement should involve a close look at the NASA business strategy and address return on investment. Strengthening the relevance of the use case to the goals and missions recommended by the Decadal Survey will help. One suggestion is to perform a value-chain analysis to show how sensor webs can produce more science, better science results or provide a faster or cheaper way to get the science results. In the meeting it was recommended that a future sensor web forum be provided to enable more cross-cutting teams of PIs. From an engineering perspective, engaging the science and end users early is invaluable to identify their needs.

Use Case Promotion

There were suggestions to increase the relevance and stakeholder buy-in when taking the use cases to the science community. Consider the audience and tailor the sensor web message accordingly. Focus on appropriate science themes and applications and look to the Decadal Survey for guidance. Since the language of computer science is sufficiently different from that used by the hardware and science researchers that the significance, issues, and needs in information systems may not be recognized or understood. The use case approach is intended to help bridge this gap.

8 References

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[DEC 07] National Academy of Sciences, "Earth Science and Applications from Space; National Imperatives for the Next Decade and Beyond," The National Academies Press, Washington, D.C., ISBN 13:978-0-309-10387-9, 2007.

[ESTO 06] National Aeronautics and Space Administration, "ESTO Home Page," http://esto.nasa.gov/about_esto.html.

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[NASA 07] National Aeronautics and Space Administration, "Report from the Earth Science Technology Office (ESTO) Advanced Information Systems Technology (AIST) Sensor Web Technology Meeting," The Aerospace Corporation, ATR-2007(2105)-1, El Segundo, CA, May 2007.

9 Appendix A - Keynote Speakers' Abstracts

The meeting consisted of the following three keynote speakers:

Table 14. Keynote Speakers

Speaker	***Organization***	***Keynote Title***
Timothy S. Stryker	U.S. Geological Survey (USGS)	Earth Observations to Benefit Societies – A Briefing on the Activities of CEOS
Scott Tilley	Software Engineering Institute, Carnegie Mellon University and Florida Institute of Technology	Migration of Legacy Components to SOA Environments: Some Lessons Learned
John J. Garstka	Office of the Under Secretary of Defense (Policy)	Network-Centric Operations: Insights and Challenges

This appendix contains abstracts provided by each of the keynote speakers.

April 2nd Plenary Speaker

Timothy S. Stryker
National Land Imaging Program
U.S. Geological Survey
Department of the Interior

Title: Earth Observations to Benefit Societies – A Briefing on the Activities of CEOS

Abstract: Mr. Stryker's remarks will provide an overview of the Committee on Earth Observation Satellites (CEOS), and its support to the U.N. Framework Convention on Climate Change (UN FCCC) and the intergovernmental Group on Earth Observations (GEO). He will describe CEOS initiatives vis-à-vis these organizations, and CEOS member agencies' work to implement the space-based component of the Global Earth Observation System of Systems (GEOSS). It is hoped that these remarks will provide a useful context for the development and coordination of sensor webs as critical components of GEOSS.

April 2nd Luncheon Speaker

Scott Tilley
Visiting Scientist
Software Engineering Institute
Carnegie Mellon University
and
Professor & Director of Software Engineering
Department of Computer Sciences
Florida Institute of Technology

Title: Migration of Legacy Components to SOA Environments: Some Lessons Learned

Abstract: Service-Oriented Architecture (SOA) is a way of designing, developing, deploying, and managing enterprise systems where business needs and technical solutions are closely aligned. SOA offers a number of potential benefits, such as cost-efficiency and agility. However, adopting SOA is not without considerable challenges. For example, the most common way to implement a SOA-based system is with Web services, but the standards that define Web services are evolving rapidly and many of the tools are still somewhat immature. There is also the question of how to leverage existing legacy assets within a SOA context. The Software Engineering Institute (SEI) has been developing the Service-Oriented Migration and Reuse Technique (SMART) to help organizations analyze legacy systems to determine whether their functionality, or subsets of it, can be reasonably exposed as services in a SOA environment. This talk provides an overview of some of the lessons learned in using SMART. Based on this experience, we have also been developing a SOA research agenda that addresses engineering, business, and operational issues. Selected aspects of this research agenda that are applicable to sensor networks and NASA Earth Science will also be discussed.

April 3rd Luncheon Speaker

John J. Garstka
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Office of the Under Secretary of Defense (Policy)

Title: Network-Centric Operations: Insights and Challenges

Abstract: This presentation will highlight key issues associated with implementation of network-centric operations within the U.S. DoD. Insights from network-centric operations case studies will be presented, along with an overview of key implementation challenges faced by military organizations.

10 Appendix B - Acronyms

Acronyms

Table 15. Acronyms

Acronym	Definition
ADAS	ARPS Data Assimilation System
AIRS	Atmospheric Infrared Sounder
AIST	Advanced Information Systems Technology - http://esto.nasa.gov/info_technologies_aist.html
API	Application Programming Interface
APRS	Advanced Regional Prediction System
ARC	Ames Research Center - http://www.nasa.gov/centers/ames/home/index.html
Cal/Val	Calibration & Validation
CEOS	Committee on Earth Observing Systems
CMU	Carnegie Mellon University – http://www.cmu.edu
CONUS	Contiguous United States
DAAC	Distributed Active Archive Center
DESDynI	Deformation, Ecosystem Structure, and Dynamics of Ice
DoD	Department of Defense
DTN	Delay Tolerant Networking
EROS	Earth Resources Observation and Science
ESA	European Space Agency
ESTO	Earth Science Technology Office - http://esto.nasa.gov
FCCC	Framework Convention on Climate Change
FFRDC	Federally Funded Research Data Center
GEO	Group on Earth Observations
GIS	Geographic Information System
GMU	George Mason University – http://www.gmu.edu
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GRC	Glenn Research Center - http://www.nasa.gov/centers/glenn/home/index.html
GSFC	Goddard Space Flight Center - http://www.gsfc.nasa.gov
GTRC	Georgia Tech Research Corporation - http://www.gtrc.gatech.edu
GUI	Graphical User Interface
GWOS	Global Wind Observing Sounder
IC	Intelligence Community
ICESat	Ice, Cloud, and land Elevation Satellite - http://icesat.gsfc.nasa.gov
IGES	Institute of Global Environment and Society - http://www.iges.org
IGRA	Integrated Global Radiosonde Archive
InSAR	Interferometric Synthetic Aperture Radar
IR	Infrared
ISO	International Organization for Standardization
JPL	Jet Propulsion Laboratory - http://www.jpl.nasa.gov
K index	Quantifies disturbances in the horizontal component of earth's magnetic field

Acronym	Definition
KML	Keyhole Markup Language
LEO	Low Earth Orbit
Lidar	Light Detecting and Ranging
LMSSC	Lockheed Martin Space Systems Company - http://www.lockheedmartin.com/wms/findPage.do?dsp=fec&ci=14699&sc=400
MODIS	Moderate Resolution Imaging Spectroradiometer
MOPITT	Measurements of Pollution in the Troposphere
MOZART	Model for Ozone And Related chemical Tracers
MSFC	Marshall Space Flight Center – http://www.msfc.nasa.gov
MW1	Middleware 1
MW2	Middleware 2
NAM	North American Mesoscale model
NASA	National Aeronautics and Space Administration - http://www.nasa.gov
NCEP	National Centers for Environmental Prediction
NG	Northrop Grumman
NGA	National Geospatial Intelligence Agency - http://www.nga.mil
NOAA	National Oceanic and Atmospheric Administration
NOSS	Network of Sensor Systems
NPP	Net Primary Production
NRA	NASA Research Announcement
NRCS	Natural Resources Conservation Service
NSF	National Science Foundation - http://www.nsf.gov
NSSTC	National Space Science and Technology Center
OGC	Open Geospatial Consortium - http://www.opengeospatial.org
OWL	Ontology Web Language - http://www.w3.org/2004/OWL
OWL-S	Ontology Web Language for Services - http://www.w3.org/Submission/OWL-S
PATH	Precipitation All-weather Temperature and Humidity mission
PI	Principal Investigator
PWV	Precipitable Water Vapor
RADAR	Radio Detection and Ranging
RDF	Resource Description Framework - http://www.w3.org/RDF
ROI	Return on Investment
ROMS	Regional Ocean Modeling System
ROSES	Research Opportunities in Space and Earth Sciences
RSAC	Remote Sensing Applications Center (Forest Service)
SAR	Synthetic Aperture Radar
SCLP	Snow and Cold Land Processes
SMAP	Soil Moisture Active-Passive
SMART	Sensor Management for Applied Research Technologies project
SNOTEL	SNOw TELemetry - an automated system of snowpack and related climate sensors
SOA	Service Oriented Architecture

Acronym	Definition
SoS	System-of-Systems
SOS	Sensor Observation Service (OGC)
SPoRT	Short-term Prediction and Research Transition center
SPS	Sensor Planning Service (OGC)
SRTM	Shuttle Radar Topography Mission
SS	Smart Sensing
SUA	Special Use Airspace
SWE	Sensor Web Enablement (OGC)
SWIR	Short-wave Infrared
SWOT	Surface Water Ocean Topography
TOPS	Terrestrial Observation and Prediction System
TTNT	Tactical Targeting Network Technology
UAH	University of Alabama - http://www.uah.edu
UAS	Unattended Aerial System
UAS	University of Alaska - http://www.alaska.edu
UAV	Uninhabited Aerial Vehicle
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UCAR	University Corporation for Atmospheric Research
UCLA	University of California, Los Angeles
UCSD	University of California, San Diego - http://www.ucsd.edu
UDDI	Universal Description, Discovery, & Integration - http://www.uddi.org
UMBC	University of Maryland, Baltimore County - http://www.umbc.edu
USC	University of Southern California – http://www.usc.edu
USC ISI	University of Southern California, Information Sciences Institute - http://www.isi.edu
USFS	Unites States Forest Service
USGS	United States Geological Survey
UW	University of Washington
UWi	University of Wisconsin
VIS/IR	Visible infrared
VMOC	Virtual Mission Operations Center
VSICS	Virtual Sensor Web Infrastructure for Collaborative Science
WCS	Web Coverage Service - http://www.opengeospatial.org/standards/wcs
WFS	Web Feature Service - http://www.opengeospatial.org/standards/wfs
WMS	Web Map Service - http://www.opengeospatial.org/standards/wms
WoW	Web of Webs
WPS	Web Processing Service (OGC)
WRF	Weather & Research Forecasting Model
WRF	Weather Research & Forecasting
WSDL	Web Services Description Language - http://www.w3.org/TR/wsdl
WVHTC	West Virginia High Technology Consortium - http://www.wvhtf.org