NASA's Science Mission Directorate Awards 28 Contracts for Advanced Information Systems Technology

The National Aeronautics and Space Administration (NASA) has awarded funding for 28 new investigations for information systems technology development, under the Advanced Information Systems Technology (AIST) Program, which supports NASA's mission to understand and protect our home planet. The proposals, selected from a field of 99 submitted proposals, cover a variety of topics pertaining to smart sensing, sensor web communications and enabling model interactions in sensor webs. The total funding for these investigations, over a period of three years, is approximately $31 million; investigators hail from 16 states.

The main purpose of AIST is to invest in research and development of new and innovative information technologies to support and enhance the NASA Science Mission Directorate's Earth science and applications objectives in the 21st century. AIST focuses on creating mature technologies leading to smaller, less resource-intensive and less expensive flight systems that can be built quickly and efficiently, and on more-efficient ground-based processing and modeling systems that improve the use of Earth science data.

This research opportunity focused on "sensor web" technology and is the latest component in a series of information technology research initiatives that will help NASA's Earth Science Division solve the massive challenge of collecting, processing, routing and storing Earth science measurement data. Of the 99 proposals submitted the 28 selected covered a variety of topics pertaining to smart sensing, sensor web communications and enabling model interactions in sensor webs.

With the increasing number of Earth observing satellites planned over the next decade, Information Technology will be the key to collecting and distributing Earth science data and information products to the global science community. "Sensor web" is the name given to the concept of integrating multiple Earth observing satellites and/or ground-based in-situ sensors into a cohesive network to provide timely, on-demand data and analysis to users. The goal of the sensor web approach is to employ new data acquisition strategies and systems for integrated Earth sensing that are responsive to environmental events for both applications and scientific purposes.

The investigations selected by NASA's Earth Science Division are:

Payman Arabshahi, University of Washington Applied Physics Laboratory, Seattle, WA

A Smart Sensor Web for Ocean Observation: System Design, Modeling, and Optimization

We propose a smart sensor web system composed of mobile and fixed underwater assets, combined with NASA satellite data, for ocean observation. The objectives of this task are to - Design, develop, and test an integrated satellite and underwater acoustic communications and navigation sensor network infrastructure and a semi-closed loop dynamic sensor network for ocean observation and modeling. - Perform science experiments in Monterey Bay, enabled by such a network, and evolve them to growing levels of sophistication over the period of performance (three years). Our approach is unique, in that it offers, for the first time: - A first-of-its-kind ad-hoc multi-hop satellite/acoustic sensor network, incorporating features such as reconfiguration of sensor assets, adaptive sampling and autonomous event detection, targeted observation, location-aware sensing, built-in navigation on mobile nodes (Seagliders), and high-bandwidth, high-power observation on cabled seafloor and moored nodes (mooring systems with vertical profilers). - Strong tie-in with the NASA satellite oceanography and ocean science community, in charge of carrying out new experiments which will overcome limitations in current approaches (undersampling of the ocean and aliasing of high frequency processes such as tides and internal waves). These experiments can also be used for in-situ calibration of data gathered via remote sensing by NASA satellites. This proposal addresses Topic Area 1, Smart Sensing, of the AIST Call.Proposed work will leverage extensive in-house expertise in acoustic networking and ocean science at the University of Washington, and the Jet Propulsion Laboratory. We project an entry of TRL-3 and an exit of TRL-7.

Mohammed Atiquzzaman, University of Oklahoma, Norman, OK

Implementation Issues and Validation of SIGMA in Space Network Environment

There is significant interest in deploying the Internet protocol in space. A number of NASA-funded projects are studying the possible use of Internet technologies and protocols to support all aspects of data communication, including handover, with spacecraft. A spacecraft or a constellation of spacecrafts containing Earth observing sensing equipment form a sensor web which has to be handed off between ground stations. Consequently, researchers at NASA and University of Oklahoma are developing a new handover scheme, called Seamless IP-diversity based Generalized Mobility Architecture (SIGMA). Although the results from simulation and laboratory prototyping have shown very promising performance of SIGMA, its performance in the real space environment has yet to be studied. The objective of this project is to investigate a number of implementation issues of SIGMA for space missions, and evaluate SIGMA on an experimental satellite network to make it ready for space flight missions. Implementation issues to be investigated include survivability, scalability, power awareness, security, and networks in motion using simulation and laboratory prototype testbeds. Evaluation in an experimental satellite involves testing SIGMA (in conjunction with NASA, Cisco and Surrey Satellite Technologies) on the experimental UK-DMC (Disaster Monitoring Satellite). The results of this project will be directly applicable to a number of NASA projects involved in sensing the Earth's environment using Internet protocol in space. This is a three-year project with entry and exit TRLs of 3/5 and 5/6, respectively.

Prasanta Bose, Lockheed Martin Advanced Technology Center, Sunnyvale, CA

Virtual Sensor Web Infrastructure for Collaborative Science (VSICS)

NASA envisions the development of smart sensor webs, intelligent and integrated observation network that harness distributed sensing assets, their associated continuous and complex data sets, and predictive observation processing mechanisms for timely, collaborative hazard mitigation and enhanced science productivity and reliability. The

LMSSC-led Virtual Sensor Web Infrastructure for Collaborative Science (VSICS) effort will design, implement, demonstrate and mature (from TRL 3 to TRL 4 and higher) infrastructure creating a virtual sensor web for sustained coordination of (numerical and distributed) model-based processing, closed-loop resource allocation, and observation planning. VSICS's key ideas include i) rich descriptions of sensors as services based on semantic markup languages like OWL and SensorML; ii) service-oriented workflow composition and repair for simple and ensemble models; iii) event-driven workflow execution based on event-based iv) distributed workflow management mechanisms; and v) development of autonomous model interaction management capabilities providing closed-loop control of collection resources driven by competing targeted observation needs. The VSICS team combines the models and applications knowledge of Dr. Peter Fox (NCAR) in earth science and Dr. Neal Hurlburt (LMSSC) in space science; constraints driven resource alloca-tion and scheduling expertise of Nicola Muscettella (LMSSC) and software architecture develop-ment strengths of Dr. Prasanta Bose (LMSSC). The project leverages model-interactions manage-ment and planning technologies being developed at LMSSC ATC.

Mike Botts, University of Alabama at Huntsville, Huntsville, AL

Increasing the Technology Readiness of SensorML for Sensor Webs

The Sensor Model Language (SensorML) defines an XML schema for describing any process, but is particularly adapted to the processes of measurement and the post-measurement processing of observations. In addition to defining the lineage of an observation, SensorML provides a web-friendly means for defining executable process chains for on-demand processing of sensor data to higher level observations. SensorML was developed by the PI and initially funded by the AIST program in 2000. SensorML is in the final stages of approval as an OpenGeospatial Consortium (OGC) Technical Specification. We propose to reduce the current challenges involved in implementing and utilizing SensorML by providing a collection of Open Source tools for creating, viewing, validating, mining, and executing SensorML processes. We will also demonstrate the application of these tools, and indeed the application of SensorML, in an end-to-end scenario of relevance to NASA's Earth Science community, including the derivation of SensorML documents by the initial sensor team, the configuration of OGC sensor web services, the development of product algorithms by research scientists, and the ultimate discovery and application of SensorML within the end user's Decision Support Tools. Most applications of SensorML technology, including discovery, implementation, and process execution, currently range in TRL levels from 4-6. During this 3 year effort, we intend to increase the TRL level of all facets of SensorML technology to at least 6, and in some cases 7. The entry TRL levels for the Open Source tools that we have proposed range from 2-4. These will be increased to TRL levels of 4-7.

Liping Di, George Mason University, Fairfax, VA

A General Framework and System Prototypes for the Self-Adaptive Earth Predictive Systems (SEPS)--Dynamically Coupling Sensor Web with Earth System Models

The Self-adaptive Earth Predictive System (SEPS) concept combines Earth System Models (ESM) and Earth Observations (EO) into one system. EO measures the Earth system state while ESM predicts the evolution of the state. A feedback mechanism processes EO measurements and feeds them into ESM during model runs or as initial conditions. A feed-forward mechanism analyzes the ESM predictions against science goals for scheduling optimized/targeted observations. The SEPS framework automates the Feedback and Feed-forward mechanisms (the FF-loop). Scientists from GMU, GSFC, and UBMC will collaborate to 1) develop a general SEPS framework for dynamic, interoperable coupling between ESMs and EO, based on open, consensus-based standards; 2) implement and deploy the framework and plug in diverse sensors and data systems to demonstrate the plug-in-EO-and-play capability; and 3) prototype a Bird-Migration-Model-to-aid-avian-influenza-prediction SEPS and an atmospheric chemistry composition SEPS using this framework, to demonstrate the framework's plug-in-ESM-and-play capability and its applicability as a common infrastructure for supporting the focus areas of NASA research. This project will significantly advance 1) dynamic, interoperable and live coupling of ESM with the sensor web; 2) the sensor web from concept to operation with existing sensors and data sources; and 3) the use of service-oriented architecture in modeling and integration. The project will improve the accuracy and timeliness of monitoring and predicting rapidly changing Earth phenomena, such as severe weather and air pollution. The 3-year project will start in October 2006. The entry TRL is 4 and the exit TRL is 7.

John M. Dolan, Carnegie Mellon University, Pittsburg, PA

Telesupervised Adaptive Ocean Sensor Fleet

Earth science research must bridge the gap between the atmosphere and the ocean to foster un-derstanding of Earth's climate and ecology. Typical ocean sensing is done with satellites or in-situ buoys and research ships which are slow to reposition. Cloud cover inhibits study of local-ized transient phenomena such as a Harmful Algal Bloom (HAB). A fleet of extended-deployment surface autonomous vehicles will enable in-situ study of surface and sub-surface characteristics of HABs, coastal pollutants, oil spills, and hurricane factors. To enhance the value of these assets, we propose a telesupervision architecture that supports adap-tive reconfiguration based on environmental sensor inputs (¿smart¿ sensing), increasing data-gathering effectiveness and science return while reducing demands on scientists for tasking, con-trol, and monitoring. We will autonomously reposition smart sensors for HAB study (initially simulated with rhoda-mine dye) by networking a fleet of NOAA surface autonomous vehicles. In-situ measurements will intelligently modify the search for areas of high concentration. Inference Grid techniques will support sensor fusion and analysis. Telesupervision will support sliding autonomy from high-level mission tasking, through vehicle and data monitoring, to teleoperation when direct human interaction is appropriate. Telesupervised surface autonomous vehicles are crucial to the sensor web for Earth science. We will integrate technologies ranging from TRL 4 into a complete system and reach TRL 6 within two years. In the third year, we will advance the system to TRL 7. This system is broadly appli-cable to ecological forecasting, water management, carbon management, disaster management, coastal management, homeland security, and planetary exploration.

Andrea Donnellan, NASA Jet Propulsion Laboratory, Pasadena, CA

QuakeSim: Enabling Model Interactions in Solid Earth Science Sensor Webs

We propose to expand the development of our QuakeSim Web Services environment to integrate both real-time and archival sensor data with high-performance computing applications for data mining and assimilation. This work will substantially improve earthquake forecasts, which will ultimately lead to mitigation of damage from this natural hazard. We will federate sensor data sources, with a focus on InSAR and GPS data, for an improved modeling environment for forecasting earthquakes. Improved earthquake forecasting is dependent on measurement of surface deformation as well as analysis of geological and seismological data. Space-borne technologies, in the form of continuous GPS networks and InSAR satellites, are the key contributors to measuring surface deformation. These disparate measurements form a complex sensor web in which data must be integrated into comprehensive multi-scale models. In order to account for the complexity of modeled fault systems, investigations must be carried out on high-performance computers. We will build upon our "Grid of Grids" approach, which included the development of extensive Geographical Information System-based "Data Grid" services. In this project we will extend our earlier approach to integrate the Data Grid components with more improved "Execution Grid" services that are suitable for interacting with high-end computing resources. These services will be deployed on the Columbia computer at NASA Ames and the Cosmos computer cluster at JPL. Our period of performance is October 2, 2006 - Septemember 25, 2009. Entry level TRL of this project is 3 with an exit TRL at the end of the project of 5.

Aaron Falk, USC Information Sciences Institute, Los Angeles, CA

Satellite Sensornet Gateway (SSG)

ISI proposes a technology development program to make sensornets more usable, economical, and manageable for NASA and other Earth scientists by designing and prototyping an open, flexible, remotely-managed Satellite Sensornet Gateway. This gateway provides storage and aggregation of data from wireless sensors, reliable transmission to a central datastore, and sensor instrument management and control. This greatly simplifies sensornet design by isolating common communication and management functions into a flexible, extensible component that can support any in-situ sensornet. The result is that in-situ sensors will become easier to deploy and manage, expanding their use by Earth scientists and enabling new observation systems and datasets. This three year project, scheduled to start in CY08, will design and build a prototype sensornet gateway along with initial NOC and datalogger interface functions. This prototype will be capable of interfacing to NASA GOES and IEEE 802.11 networks.

Our assessment is that such a system is currently at TRL 3; our work will advance this concept beyond TRL 6. Our three science collaborators will assist in devising at least two field deployments of our gateway. Additionally, we will create an advisory group to leverage existing technology from the sensornet research community and ensure the prototype SSG is useful to Earth scientists and flexible in ways in which the field is expected to evolve.

Stefan R Falke, Northrop Grumman IT, TASC, St. Louis, MO

Sensor-Analysis-Model Interoperability Technology Suite

This proposal addresses NASA's requirements for enabling model interactions in sensor webs using service oriented architecture principles and geospatial interoperability standards. Sensor webs provide a new type of dynamic and real-time resource for earth science data analysis and modeling. The future interaction between sensors and models is expected to be bi-directional: sensors provide input data to models; model output provides information for planning where, when and what sensors will measure next. Today's earth science models are not capable of routinely assimilating sensor web observations and less capable of driving sensor measurements. The proposed project will use and extend geospatial interoperability and emerging sensor web standards, such as the Open Geospatial Consortium Sensor Web Enablement specifications, to bridge the gap between sensors and models. The proposed project will develop a Sensor-Analysis-Model Interoperability Technology Suite (SAMITS) that provides a package of standards, technologies, methods, use cases, and guidance for implementing networked interaction between sensor webs and models. SAMITS will foster seamless two-way data and control flow between active sensors and data analysis/modeling tools. SAMITS will be tested through use case applications that tie together atmospheric, air quality, and fire sensors with weather and smoke forecasting models. A tenant of the proposed approach is to reuse and extend existing technologies and development efforts. NASA's return on investment will be maximized and the time to implement two-way interaction between sensors and models minimized if the new technology development reuses existing distributed and interoperable information system components that are already available to assist in information flow between observation databases and models. Technology Readiness Level (TRL): Entry=2/3; Exit=6 Period of performance: 36 months.

Michael Goodman, NASA Marshall Space Flight Center, Hunstville, AL

Sensor Management for Applied Research Technologies (SMART) - On-Demand Modeling

The goal of the Sensor Management for Applied Research Technologies (SMART) On-Demand Modeling proposal is to develop and demonstrate the readiness of Open Geospatial Consortium (OGC) Sensor Web Enablement (SWE) capabilities that integrate both Earth observations and forecast model output into new data acquisition and assimilation strategies. The integrated SWE data assimilation and weather forecast package is relevant to NASA's Weather focus area and other Applications of National Priority (e.g., ecological forecasting through the SERVIR project) and will be responsive to environmental events for scientific research, applications and decision making processes. The proposal will plan, develop, and assimilate NASA satellite data sets into a regional weather forecast model over the southeastern U.S. The NASA Earth Observation System (EOS) satellites make real-time global observations of the Earth with revolutionary spectral and spatial fidelity on a continuous basis in support of NASA's research and applications programs. The challenge of accessing and integrating data from multiple sensors or platforms to address Earth system problems remains an obstacle because of the large data volumes, varying sensor scan characteristics, unique orbital coverage, and the steep learning curve associated with each sensor and data type. The development of sensor web capabilities to autonomously process these data streams (whether real-time or archived) presents an opportunity to overcome these obstacles and facilitate the integration and synthesis of Earth science data and weather model output. This three year proposal will advance information technology capabilities for adaptive data ingest and data fusion from TRL-3 to TRL-7. The first year will focus on the development and validation of the OGC compatible services and linkages (TRL-4/5). The second year will lead to the demonstration of the sensor web through the use of archived satellite data and model runs (TRL-6). The third year will culminate with the system prototype demonstration of real-time satellite assimilation into the WRF forecast model (TRL-7)

Matt Heavner, University of Alaska Southeast, Juneau, AK

SEAMONSTER: A Smart Sensor Web in Southeast Alaska

We will construct a smart sensor web in Southeast Alaska to serve four broad research applications--Science, telecommunications, education and monitoring--with three technological emphases: (1) Network adaptation in response to acquired data and detected events, (2) Network nodes that self-modify their power management strategy, and (3) Flexibility and adaptability to accommodate new sensors, applications, and investigators. The primary product of this project will be a wireless backbone that will drastically reduce operational cost of data return for a broad spectrum of field investigators in the environmental bellwether of Southeast Alaska. This network, anchored in Juneau and extending from the Juneau Icefield to Glacier Bay, will be constructed as an aggregate of subnets tied together by long-range communication technology, particularly radio modems or satellite links. The network will return data on glacier dynamics and mass balance, watershed hydrology, coastal marine ecology, and human impact/hazards monitoring. Additional features include a semi-closed network model that employs common communication standards to import data and export configuration directives, power-miserly nodes, redundant connectivity and a robust network transport protocol. New users will be added by "dry-connecting" at the University of Alaska before proceeding to field deployment. Acquired data will be integrated into environmental science programs in classrooms in Juneau. Project success metrics include area served, return data volume and breadth, installation survival rate and impact on our understanding of the study sites. The three-year project will commence at TRL 4 and conclude at TRL 7 with further latent capacity to support sensor web communications research.

Phyllis Hestnes, NASA Goddard Space Flight Center, Greenbelt, MD

Developing an Expandable Reconfigurable Instrument Node as a Building Block for a Web Sensor Strand

Developing an Expandable Reconfigurable Instrument Node as a Building Block for a Web Sensor Strand Abstract This document proposes the development of a Web Sensor Strand (WSS) that utilizes an Expandable Reconfigurable Instrument Nodes (ERIN) as a building block. The WSS would utilize multiple ERINs to tie distributed sensors together. Each ERIN would have the ability to know the relative position of at least two other ERINs and would have short-range communications ability with them. With a web of sensors (such as a web of Earth imaging and motion measurements, satellites) distributed either in a specified manner or in a random fashion it is important to make each member of the web radiate in coherence with other members. This enabling technology will be developed using wireless connectivity (a strand) between each node of a web. The Expandable Reconfigurable Instrument Node (ERIN) will provide a semi-closed loop system solution for a variety of sensors. The ERIN baselines a reconfigurable processing technology with required memory to allow on-board processing of science data. Standardized interfaces are provided to allow for interfacing to attitude control instrumentation such as Global Positioning Systems (GPS) and Inertial Measurement Units (IMU). A communications device will be added to the node that would allow for node-to-node communications. For low cost demonstration of the above concept, two Ground Penetrating Radars* separated by some distance on the ground will be used. Proper hardware (ERIN) and software (Web Sensor Strand) will be designed to operate these two physically separate transmitters in coherence with each other. *L-Band radar doesn't penetrate far (~20 cm) but is available through the DB-SAR IRAD (front end control). We want this to be compatible to many different wavelength front ends.

Paul R Houser, Institute of Global Environment and Society, Inc., Beltsville, MD

Land Information Sensor Web

This project will develop a prototype Land Information Sensor Web by integrating the Land Information System (LIS) in a sensor web framework will allow for optimal 2-way information flow that enhances land surface modeling using sensor web observations, and in turn allows sensor web reconfiguration to minimize overall system uncertainty. Through continuous automatic calibration techniques and data assimilation methods, LIS will enable on-the-fly sensor web reconfiguration to optimize the changing needs of science and solutions. This prototype will be based on a simulated interactive sensor web, which is then used to exercise and optimize the sensor web modeling interfaces. These synthetic experiments provide a controlled environment in which to examine the end-to-end performance of the prototype, and examine the impact of various design sensor web design trade-offs and the eventual value of sensor webs for particular prediction or decision support. In addition to providing critical Information for sensor web design considerations, this prototype would establish legacy for operational sensor web integration with modeling systems. Though the stand-alone LIS has achieved a TRL of 8, we determine our entry TRL to be 4 as other components are to be implemented and tested. This project will deliver an interoperable TRL 6 plug-and-play components based on LIS that enable data ingest and scientific analysis, the generation of new sensor web data products, connections to major spacecraft schedulers and task managers, metadata transformation and exchange, and data fusion techniques. This project directly addresses topic area 3: Enabling model interactions with sensor webs, and is expected to have a 3-year performance period starting from October 2006.

Ayanna M Howard, Georgia Tech Research Corp, Atlanta, GA

Reconfigurable Sensor Networks for Fault-Tolerant In-Situ Sampling

The goal of this proposal is to develop and validate the core technologies needed to enable reconfigurable sensor networks for fault-tolerant in-situ sampling for Earth science applications. The key technologies, which build on prior work done by the proposers, focus on science-driven sensor network diagnosis and topological reconfiguration of sensor networks. Control of reconfigurable sensor networks is fundamentally a difficult problem in which the system must balance issues of power usage, communication versus control, the effectiveness of adapting to the environment as well as to changing science requirements. These issues generally arise due to the limited perception, precision, and range constraints on communication channels that comprise the network. Diagnosis involves identifying and communicating necessary changes in network topology required to achieve science goals and compensate for sensor failure or communication dropouts. Reconfiguration involves physically reconfiguring the network topology based on input from the diagnostic process, in effect establishing a self-adapting sensor network. The novelty of our approach is on the focus of a decentralized versus centralized method of control in which interactions between sensor nodes are modeled topographically and manipulated locally to produce desired global behavior. These technologies will be integrated and demonstrated using a network of mobile sensors applied to a representative Earth science investigation. This proposal is directly responsive to Topic Area 1: Smart Sensing of the NRA Call by enabling "autonomous event detection and reconfiguration of sensor assets." The period of performance is planned as a 36-month effort and has an entry TRL of 3, with a planned exit TRL of 5.

William D Ivancic, NASA Glenn Research Center, Cleveland, OH

Secure, Autonomous, Intelligent Controller for Integrating Distributed Sensor Webs

Glenn Research Center (GRC) proposes 3 year effort to develop key mobile networking technologies, information delivery protocols, and secure, autonomous, machine-to-machine communication and control technologies to enable an evolution of distributed Earth system sensors and processing components into sensor webs. This proposal concentrates on the architecture and development of system building blocks leading to autonomous sensor webs. In particular, GRC will leverage its existing relationships with Cisco Systems, General Dynamics, Universal Space Networks, the Army Battle Labs, the Air Force Battle Labs, Surrey Satellite Technology Limited, and the University of Oklahoma to develop a ground and space-based network and relevant protocols to enable and demonstrate time-critical interoperability between integrated, intelligent sensor webs consisting of space-based and fixed and mobile terrestrial-based assets. Furthermore, GRC plans on developing new relationships with existing sensor web operators and integrate their technologies and sensor webs into the overall system. GRC will first develop the necessary infrastructure and protocols to enable near real-time commanding and access to space-based assets. We shall then integrate General Dynamics' Virtual Mission Operation Center technology and open architecture interfaces with select terrestrial and/or aeronautics-base sensor web to demonstrate time-critical interoperability between integrated, intelligent sensor webs and knowledge generation. In parallel, GRC will work with Cisco Systems to research and deploy advanced mobile networking technology applicable to mobile sensor platforms. The Technology Readiness Level is 2 for all systems with an exit level for mobile network technology at 6 the file delivery and integrated intelligent sensor control at 8!

Stephan Kolitz, Charles Stark Draper Laboratory, Cambridge, MA

Sensor Web Dynamic Replanning

We will propose to extend the dynamic replanning capability of Draper's Earth Phenomena Observing System (EPOS), which has successfully demonstrated the capability to dynamically replan the activities of NASA space-based sensor assets to maximize the return of useful science measurements (e.g., ensure cloud free targeting). We will propose to enhance and extend EPOS to include the replanning of sensors on UAVs (Unmanned Aerial Vehicles) and USVs (Unmanned Surface Vessels) being fielded by NASA over the next few years. The new dynamic replanning capability will utilize complementary and cooperative suites of heterogeneous sensor assets that can be triggered by observation data and/or predictive models to adaptively respond to significant events and provide enhanced understanding of temporal Earth phenomena. An event-driven use of a sensor web would be to task sensor resources in response to observation-triggered cues for phenomenon, such as harmful algal bloom outbreaks. A model-driven use of a sensor web would be to task sensor resources in response to significant increases in meteorological forecast model error growth due to model sensitivities within specific atmospheric regions. The events and phenomena that present the largest potential payoff to the proposed replanning capability are characterized by being localized and transient and also capable of causing damage to both human life and property, e.g., weather (tornadoes, hurricanes, etc.), harmful algal blooms, volcanic eruptions, ice shelf break-up, seismic activities, oil spills, and search and rescue. In addition, the replanning capability will be enhanced to handle outages and failures of individual sensors.

David John Lary, Univ of Maryland, Baltimore County, Baltimore, MD

An Objectively Optimized Sensor Web

An autonomous Objectively Optimized Observation Direction System (OOODS) is of great utility for NASA's observation and exploration objectives. In particular, to have a fleet of smart assets that can be reconfigured based on the changing needs of science and technology. This proposal describes an OOODS designed as a sensor web element (plug-in) that is of use both now and for future NASA observing systems. The OOODS would integrate a modeling and assimilation system within the sensor web allowing the autonomous scheduling of the chosen assets and the autonomous provision of analyses to users. The OOODS operates on generic principles that could easily be used in configurations other than the specific examples described here. Metrics of what we do not know (state vector uncertainty) are used to define what we need to measure and the required mode, time and location of the observations, i.e. to define in real time the observing system targets. Metrics of how important it is to know this information (information content) are used to assign a priority to each observation. The metrics are passed in real time to the sensor web observation scheduler to implement the observation plan for the next observing cycle. The same system could also be used to reduce the cost and development time in an Observation Sensitivity Simulation Experiment (OSSE) mode for the optimum development of the next generation of space and ground-based observing systems. The entry TRL is 4 the exit TRL is 7.

Meemong Lee, NASA Jet Propulsion Laboratory, Pasadena, CA

Sensor-Web Operations Explorer(SOX)

We will develop a Sensor-web Operations Explorer (SOX) that can perform rapid exploration of dynamically configured air quality measurement scenarios and that can assess the optimality of a measurement scenario employing objective performance metrics (increased science information content, reduced uncertainty, and improved forecasting skill). The measurement scenarios will be executed on a high-fidelity sensor-web simulation system that integrates phenomena models, platform models, and instrument models. During field campaigns, adaptive measurement strategies are essential that account for changing atmospheric and meteorological conditions as well as the number and type of sensors, instruments, and platforms available at any given time. The goal of SOX is to enable users to plan measurement strategies that maximize science data return by identifying where and when specific measurements have the greatest impact. SOX will demonstrate both regional and global scale operations, helping to optimize satellite and sub-orbital resource usage. The SOX system architecture is organized around three sequential process groups: an Observation Design Process, an Observation Execution Process, and an Evaluation Process. The approach for developing SOX is to integrate existing, independently developed and validated high-TRL component modules using four interface subsystems that can be concurrently implemented and verified: - Sensor-Web Architecture Model (SWAM) - Sensor-Web Integrated-campaign Planner (SWIP) - Measurement Simulation and Distribution Service (MSDS) - Science Performance Metric Evaluator (SPME) We will develop the interface subsystems and provide overall system engineering. The work will be performed over a 3-year period. SOX maturity enters this project at TRL

Yunling Lou, NASA Jet Propulsion Laboratory, Pasadena, CA

Autonomous Disturbance Detection and Monitoring System for UAVSAR

We will develop an autonomous disturbance detection and monitoring system with imaging radar that directly addresses one of NASA's major objectives to develop new space-based and related capabilities to advance Earth observation from space and demonstrate new technologies with the potential to improve future operational systems. This new capability will provide key information for the rapid response of natural disasters, such as hurricane landfall and forest fire, and can be readily extended to other hazards such as earthquake, volcanic eruption, landslide, and flood. The autonomous system will enable targeted observation of short-lived science phenomena or specific geologic features on planetary missions without overwhelming onboard data storage or downlink capacity and will reduce mission operations cost. This system has the potential to benefit the commercial sector by effectively monitoring forest disturbance due to fire, hurricane, or disease infestation. The autonomous system combines the advantage of radar's all weather capability to penetrate through clouds and collect data at night with high fidelity, high throughput onboard processing technology and onboard automated response capability based on specific science algorithms. This smart sensing technology development (Topic Area 1 of the proposal call) leverages the interferometric synthetic aperture radar onboard processor development for the NASA AIST-02 program and onboard automated response experience from Autonomous Sciencecraft Experiment onboard the New Millennium Earth Observation One spacecraft. We will improve the fidelity of the interferometric SAR onboard processor by implementing polarimetric and interferometric calibration capabilities, science algorithms for forestry application, and artificial intelligence for onboard automated response capability. We will develop a prototype smart sensor for demonstration on NASA's UAVSAR, an L-band polarimetric repeat-pass interferometric SAR sys tem. We will use UAVSAR to demonstrate automated response based on its own prior observation and based on external triggers from other sensors in a sensor web. This technology will take three years to develop. We will enter the development at TRL 3. The technology will advance to TRL 4 after 18 months by completing the high fidelity onboard processor development and verifying the automated response capability in a laboratory environment. We will exit the program at TRL 5 by demonstrating the closed-loop smart sensor concept with the UAVSAR instrument. This will reduce the risk, cost, and development time for infusing the smart sensor technology into future spaceborne Earth observing mission.

Daniel Mandl, NASA Goddard Space Flight Center, Greenbelt, MD

An Inter-operable Sensor Architecture to Facilitate Sensor Webs in Pursuit of GEOSS

This project will develop the capability to generically discover and task sensors configured in a modular Sensor Web architecture, in space and in-situ, via the Internet. The proposed technology is thus well suited to assist future Earth science needs for integrating multiple observations without requiring the end-user to have intimate knowledge of the sensors being used. The project will also provide lessons for future mission design. The systems developed will be applicable to all six NASA science focus areas. For development, we will focus our efforts on two phenomena where the investigators have extensive experience within the context of land cover disturbance due to wildfires and severe storm events. Furthermore, the proposed technology will also be applicable to the support of calibration and validation activities of Committee of Earth Observing Satellites (CEOS). The proposed research will demonstrate and validate a path for rapid, low cost sensor integration, which is not tied to a particular system, and thus able to absorb new assets in an easily evolvable coordinated manner. The systems developed will be used to evaluate the efficiency of various sensor combinations and configurations in meeting real world science and applications goals. Finally, the proposed technology will facilitate the United States contribution to the Global Earth Observation System of Systems by defining a common sensor interface protocol based upon emerging community standards. We propose to enter at a TRL 3 and exit at TRL 6 during the three-year period of performance. This proposal is being submitted under topic area 1; smart sensing.

Mahta Moghaddam, University of Michigan, Ann Arbor, MI

Soil Moisture Smart Sensor Web Using Data Assimilation and Optimal Control

The proposed project addresses the topic of "Smart Sensing." It is motivated by a sensor-web measurement scenario including spaceborne and in-situ assets. The objective of the technology proposed is to enable a guided/adaptive sampling strategy for the in-situ sensor network to meet the measurement validation objectives of the spaceborne sensors 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. The science measurement considered is the surface-to-depth profiles of soil moisture estimated from satellite radars and radiometers, with calibration/validation using in-situ sensors. Satellites allow 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. Our hypothesis is that a sparser but smarter network can provide the validation estimates by operating in a guided fashion with guidance from its own sparse measurements. The feedback and control take place in the context of a data assimilation system. The design and demonstration of the smart sensor web including the control architecture, assimilation framework, and logic actuation are the goals of this project. The proposed technology enables, for the first time, a guided/adaptive sampling strategy for generating optimal, statistically unbiased, calibration/validation data for space-based measurements. The project duration is three years with entry and exit TRLs of 2 and 5, respectively.

Robert Allan Morris, NASA Ames Research Center, Mountain View, CA

Harnessing the Sensor Web through Model-based Observation

The objective of this project is to build, integrate and demonstrate automated capabilities for model-based observing. By model-based observing we mean the process of coordinating resources in a sensor web based on goals generated from Earth science investigations. Model-based observing will transform the sensor web into a cognitive web, a distributed, goal-directed sensing environment. The benefits of this work will be in improving the efficiency of the sensing resources as well as the science value of the data obtained. The work will significantly leverage the results of previous NASA-funded efforts, including successful efforts funded by the AIST program, as well as emerging web-based information retrieval technologies (SensorML). The work will address three technical challenges: 1) transforming Earth science goals into plans for accomplishing those goals, 2) reconfiguring the web through the execution of the plans, and 3) generating new or revised goals from the r esults of previous observations. This project realizes the NRA goal of "build[ing]" a direct two way interaction between forecast models and the observing system (topic area 3). This three-year project will solve the three technical challenges listed above in the first two years, resulting in a set of component capabilities that will be integrated and tested in realistic simulated scenarios in the third year. The entry TRL of the component technologies used in this project is 4; the expected exit level of the project is TRL 6. The interdisciplinary team includes expertise in planning/scheduling and Earth science to meet the technical challenges of this project.

Antonio Ortega, University of Southern California, Los Angeles, CA

Efficient Sensor Web Communication Strategies Based on Jointly Optimized Distributed Wavelet Transform and Routing

Sensor webs performing fine-grained spatiotemporal monitoring of environments have the potential to completely change many existing Earth Science tasks as well as enable new ones. Because power consumption is often a fundamental limitation faced by sensor web nodes, a key challenge in realizing the potential of a sensor web is to enable energy-efficient, high-fidelity transfer of information captured by the sensors. Researchers have noted that energy efficiency can be achieved by a tight coupling of routing and data compression strategies, but much of this work has been theoretical. We propose to develop practical algorithms for joint compression and routing based on distributed wavelet transform techniques. Wavelets are known to be an excellent tool for representation and compression of correlated data. Here we develop compression tools and routing techniques that are optimized for a distributed implementation in a wireless sensor web. Substantial reductions in energy consumption can be achieved with respect to systems that do not use an intra-network wavelet transform. This also leads to improved data fidelity or increased system lifetime for a given energy constraint. Our team brings together expertise in data compression, digital communications and wireless sensor networks. Our work leverages substantial ongoing work (TRL 2) at USC, which has already demonstrated the benefits of the proposed methods. By taking advantage of existing state-of-the-art wireless sensor network facilities at USC we will advance the technology to TRL 5 after the third year. Our deliverables include a demonstration of our proposed techniques in realistic testbed settings.

Michael Seablom, NASA Goddard Space Flight Center, Greenbelt, MD

End-to-End Design and Objective Evaluation of Sensor Web Modeling and Data Assimilation System Architectures

We propose to: (i) design a sensor web architecture that couples future Earth observing systems with atmospheric, chemical, and oceanographic models and data assimilation systems; and (ii) build a sensor web simulator (SWS) based upon the proposed architecture that would objectively quantify the scientific return of a fully functional model-driven meteorological sensor web. Our proposed work is based upon two ESTO-funded studies that have yielded a sensor web-based 2025 weather observing system architecture, and a preliminary SWS software architecture funded by RASC and other technology awards. Sensor Web observing systems have the potential to significantly improve our ability to monitor, understand, and predict the evolution of rapidly evolving, transient, or variable meteorological features and events. A revolutionary architectural characteristic that could substantially reduce meteorological forecast uncertainty is the use of targeted observations guided by advanced analytical techniques (e.g., prediction of ensemble variance). Simulation is essential: investing in the design and implementation of such a complex observing system would be very costly and almost certainly involve significant risk. A SWS would provide information systems engineers and Earth scientists with the ability to define and model candidate designs, and to quantitatively measure predictive forecast skill improvements. The SWS will serve as a necessary trade studies tool to: evaluate the impact of selecting different types and quantities of remote sensing and in situ sensors; characterize alternative platform vantage points and measurement modes; and to explore rules of interaction between sensors and with weather forecast/data assimilation components to reduce model error growth and forecast uncertainty. We will demonstrate key SWS elements using documented 2005 hurricane season events.

WenZhan Song, Washington State University, Pullman, WA

Optimized Autonomous Space - In-situ Sensorweb

In response to NASA's needs for Earth-hazard-monitoring sensor-web as formulated in NASA's New Age of Exploration study [1] ESTO's Hazard Monitoring [2] study, and NASA's Solid Earth Science Working Group Report [3], we propose to develop a prototype real-time Optimized Autonomous Space - In-situ Sensor-web, with a focus on volcano hazard mitigation and with the goals of: 1. Integrating complementary space and in-situ elements into an interactive, autonomous sensor-web. 2. Advancing sensor-web power and communication resource management technology. 3. Enabling scalability and seamless infusion of future space and in-situ assets into the sensor-web. To meet these goals, we will: 1. Develop a test-bed in-situ array with smart sensor nodes capable of making autonomous data acquisition decisions. 2. Develop new self-organizing topology management algorithms combining hierarchical control architecture with flat routing structure. 3. Develop new bandwidth allocation algorithms in which sensor nodes autonomously determine packet priorities based on mission needs and local bandwidth information in real-time. 4. Develop remote network management and reprogramming tools. 5. Integrate the space and in-situ control such that each element is capable of triggering by the other. 6. Synthesize the sensor-web data ingestion and dissemination through the use of SenosrML. 7. Demonstrate end-to-end system performance with the in-situ test-bed at Mount St. Helens, and NASA's Earth Observing One (EO-1) platform. The period of performance will be three years. The development will begin at TRL 2 and is planned to exit at TRL 5. The research will stipulate the "Smart Sensing" topic area.

Dipa Suri, Lockheed Martin Space Systems Company, Palo Alto, CA

The Multi-agent Architecture for Coordinated, Responsive Observations

Remote sensing missions for earth science provide a wealth of information to help us understand the dynamics of our planet. However, the current stovepipe operational model of remote sensing missions, i.e., a single spacecraft transmitting data to dedicated ground operations centers (Fig. 1), introduces untenable latencies in developing data prod-ucts that hinder model building and refine-ment as well as timely responses for hazard mitigation. Future missions will operate as part of a sensor web (Fig. 2) comprised of "interlinked platforms with onboard information processing systems capable of orchestrat-ing real-time collaborative operations" [1]. The Multi-agent Architecture for Coordi-nated, Responsive Observations (MACRO), an extension of our current work on the Adap-tive Network Architecture (ANA) is a natural technology for enabling the deployment and operation of a sensor web. The ANA software framework of multiple distributed agents provides localized autonomy on distributed sci-ence missions. The MACRO extensions will help overcome current mission limitations by facilitating real-time, reactive data acquisition, analysis, fusion and distribution which will greatly benefit society and scientific discovery/understanding. Our objective over a 3 year period is to ma-ture MACRO from TRL 2/4 to TRL 5 (Sec 2.4), by focusing on two main topics that provide significant value to NASA's earth science missions: - Incorporation of self-describing sensor, processing and measurement models (Sec. 2.2.1.1) - Collaborative observations between agents via on-board planning, scheduling, and re-source management (Sec. 2.2.1.2) - Validation on a representative hardware testbed with multiple demonstrations of a realistic earth science mission (Sec. 2.2.1.3).

Costas Tsatsoulis, University of Kansas, Lawrence, KS

An Adaptive, Negotiating Multi-Agent System for Sensor Webs

The Department of Electrical Engineering and Computer Science of the University of Kansas proposes to perform research under NRA NNH05ZDA001N-AIST. The proposed research develops and tests the technology that allows nodes (pods) in a Sensor Web to collaborate in a rational manner, thus achieving improved sensing through intelligent, informed changes to the behavior of parts of the Sensor Web. Our work treats pods as agents in a multi-agent environment, and uses the observations of a pod or of a group of pods to guide future data collection activities of the Sensor Web or of large pieces of it. We develop techniques to identify significant events in the sensed data, that trigger the need to adaptively form pod coalitions and to collaborate for more effective sensing and processing. We also develop task planning behavior, such that pods not only react to the world they sense, but use this information to plan the execution of their behavior now and in the future, and prepare the appropriate pod coalitions. Rational behavior is achieved through negotiation for sensing and processing resources, assuring that pods agree to collaborate only when it improves the utility of the whole Web. The proposed research involves the areas of multi-agent systems, event monitoring, coalition formation, and negotiation between autonomous agents that leads to maximizing the group utility. The proposed work is of three year duration (August 16, 2006-August 15, 2009). The entry TRL is 2, and the exit TRL is expected to be 5.

Kenneth J. Witt, Institute for Scientific Research, Inc., Fairmont, WV

Using Intelligent Agents to Form a Sensor Web for Autonomous Mission Operations

Our team proposes to develop an architecture which shifts sensor web control to a distributed set of intelligent agents versus a centrally controlled architecture. Constellation missions introduce levels of complexity that are not easily maintained by a central management activity. A network of intelligent agents reduces management requirements by making use of model based system prediction, and autonomic model/agent collaboration. The proposed architecture incorporates agents distributed throughout the operational environment that monitor and manage spacecraft systems and self-manage the sensor web system via peer-to-peer collaboration. The intelligent agents are mobile and thus will be able to traverse between on-orbit and ground based systems. This network of intelligent mobile agents will be capable of modeling the future behavior of the subsystems and components that they are assigned to. Using situational awareness, the agents will be able to negotiate activities to self-optimize their subsystem or component. Furthermore, presented with a set of system goals, the network of agents will collaborate within the system to arbitrate the best set of activities to achieve a more global set of goals. With an initial proof of concept already working (TRL 3), the project will build over its proposed three (3) year effort to an end result proof of concept demonstration, at TRL 7. The demonstration will exercise the architectural features and prove applicability across a broad spectrum of Earth Science missions. Building on the team¿s experience with EO-1 and ST-5, the new demonstration will take steps towards increased levels of autonomy in mission operations.