Developing a Prototype Sensor Web in support of land surface studies

Developing a Prototype Land Information Sensor Web (LISW)

Presented by Hongbo Su

LISW Team

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Objective
This project will develop a prototype Land Information Sensor Web (LISW) by integrating the Land Information System (LIS) in a sensor web framework. 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. In addition to providing critical information for sensor web design considerations, this prototype would establish legacy for operational sensor web integration with modeling systems.

Approach
This work will be performed in six steps:
- Scenario development: a synthetic global land “truth” will be established
- Sensor simulation: a model of a future land sensors will be established
- Sensor web framework: sensor web communication, reconfiguration and optimization will be developed
- Evaluation and optimization metrics: various land surface uncertainty, prediction and decision support metrics will be established
- LISW experiments: to exercise and evaluate the system.
- Sensor web design implications: design trade-offs

Key Milestones and Current Status (2nd yr of 3 years)
- Scenario development: March/2007
- Sensor simulation: Sept/2007
- Sensor web framework: March/2008
- Evaluation and optimization metrics: Sept/2008
- LISW experiments: March/2009
- Sensor web design implications: August/2009

Publication and Presentation

Co-I’s/Partners
- James Geiger / NASA-GSFC
- Sujay Kumar, Yudong Tian / GEST-UMBC
Outline

I. Overview
II. Primary Findings
III. Future Work
I. Overview

- **Background**
  - NASA is developing constellations of smart satellites in sensor web configurations
  - A high performance land surface modeling and data assimilation system (LIS) has been developed by NASA.
- **Framework**
  - There is a lack of two-way interactions between Land Surface Models (LSMs) and Sensors
  - LISW project aims to establish the capacity to:
    - On-the-fly sensor web reconfiguration enabling optimal response to science and application needs
    - Produce value-added sensor-web enabled products for distribution to the research community
    - Evaluate various sensor web design and performance considerations
    - Guide future sensor web development by establishing a legacy for sensor web-model integration

LISW project was started on October 1st, 2006. The overarching objective of this project is to develop a **prototype Land Information Sensor Web (LISW)** that will enable land model interactions in sensor webs by prototyping two-way interaction between the LIS land modeling and assimilation system and a reconfigurable sensor web framework that can minimize overall system uncertainty.
I. Overview

- **Background**
- **Framework**
- **Flowchart**

Subtasks and responsible persons:

- Scenario Development (Su)
- Sensor Simulation (Geiger)
- Sensor Web Framework (Tian)
- Evaluation and Optimization Metrics (Kumar)
- LISW Experiment (Su)
- Sensor Web Design Implications (Houser)
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I. Overview
- Background
- Framework
- Flowchart

Flowchart for public use.
II. Primary Findings

- Scenario development
- Sensor simulation
- Sensor web framework
- LISW experiments
II. Primary Findings and Status

- The synthetic global land surface truth was reproduced for years 2003 through 2005 using the CLM model
- The development of a global synthetic land truth simulation was completed in the previous report period.
- Part of the land surface truth has been imported to GoogleEarth, which can be animated and viewed by the general public.

The captured pictures from the GoogleEarth demonstration and their weblinks are provided below. The two pictures are examples of shortwave net radiation and latent heat fluxes overlaid on GoogleEarth respectively.
II. Primary Findings and Status

- Scenario Development

The links for Shortwave and Latent Heat Flux can be opened if a Google earth client is installed on your computer (may take minutes to load):
http://crew.iges.org/~hongbo/GE(animated_ground_overlay_01.kml
http://crew.iges.org/~hongbo/GE(animated_ground_overlay_QLE.kml
II. Primary Findings and Status

- **Scenario Development**

The following optimization metrics will be considered to evaluate the usefulness of sensor web simulations:

- **Regionally-averaged evaluation**: We will simulate this validation procedure by selecting a number of typically-spaced points for the nature run and develop model location time series (MOLTS) for each of these reference sites. These MOLTS will be compared to the reference sites as a component of the validation.

- **Snow extent and water equivalent validation**: Areal maps of snow water equivalent and snow extent will be used for regional validation. These products will be developed to include expected errors to improve their realism.

- **Long-term budget partitioning validation**: Over long time periods, the fused model-sensor web should estimate the partitioning of available surface energy into sensible, latent, and ground heat fluxes, and the partitioning of precipitation into evaporation, runoff, and groundwater recharge correctly.

- **End-use applications**: Land surface information has been shown to have great value for decision support, in the context of resources management. We will use proxies of these end-use needs to optimize the sensor web for use in their applications.

- **Ensemble spread**: This is basically the uncertainty map of land surface modeling, which has already been completed.

The 2\textsuperscript{nd} task: establish optimization metrics based on the “land surface truth”
II. Primary Findings and Status

- Sensor Web Simulation

The simulator shall be a stand-alone system not directly coupled to any particular land surface model or system.

The simulator shall fulfill three primary tasks:

1. generate observation data
2. perform budget analysis of the sensor objects it is managing
3. analyze its generated observations
II. Primary Findings and Status

- **Sensor Web Simulation**

  - The Sensor Web Simulator is a system for generating observations. These observations will flow from the Observation Simulator through the Sensor Web Framework into LIS, where they will be assimilated into various experiments.
  
  - The Observation Simulator consists of a library written in Fortran and C and an interface written in Python.
  
  - The library provides support for simulating the functionality of a sensor web. It manages a collection of sensors that make up the sensor web, and it serves "observed values" taken from a truth run.
  
  - The Observation Simulator interface code establishes a connection with the Sensor Web Framework, it processes messages coming from and going to the Sensor Web Framework, and it drives the Observation Simulator.

The library currently provides:
1) support for stationary sensors arranged as individual platforms, arranged in a regular grid, or arranged as an ad-hoc group.
2) preliminary support for platforms moving with a constant velocity.
3) support for reconfiguring the reporting frequency of the sensors.

The interface provides:
1) the capability to initialize the Observation Simulator.
2) the capability to run the Observation Simulator.
3) the capability to shut down the Observation Simulator.
II. Primary Findings and Status

- **Sensor Web Simulation**

The Sensor Web Simulator has been implemented. The version of the SWS library is currently 2.0. The first page of the document for the SWS library is shown on the right.
II. Primary Findings and Status

- Sensor Web Framework

1. Objectives:

-- Integrate legacy or conventional scientific modeling applications (e.g., LIS) with sensor webs
-- Enable two-way, real-time interaction between models and sensors
-- Demonstrate the scientific potentials and benefits of sensor webs from such integration
II. Primary Findings and Status

- Sensor Web Framework

2. Our Approaches

- Integration: Service-oriented Architecture (SOA)

- Interoperability: Sensor Web Enablement (SWE) with web services.

- SWE web services: Built upon a message-oriented middleware (MOM) with a subscribe/publish model

- Service discovery: Web Service Description Language (WSDL) 2.0
II. Primary Findings and Status

- Sensor Web Framework

2. Our Approaches (cont’d)
## II. Primary Findings and Status

- **Sensor Web Framework**

## 2. Our Approaches -- Implementation Details:

Middleware is critical

<table>
<thead>
<tr>
<th>Middleware type</th>
<th>TPM Transaction Processing Monitor</th>
<th>RPC Remote Procedure Call</th>
<th>MOM Message-oriented Middleware</th>
<th>ORB Object Request Broker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>transactions</td>
<td>procedures</td>
<td>messages</td>
<td>objects</td>
</tr>
<tr>
<td>Coupling</td>
<td>tight</td>
<td>tight</td>
<td>loose</td>
<td>tight</td>
</tr>
<tr>
<td>Synchronization</td>
<td>sync</td>
<td>sync</td>
<td>async</td>
<td>sync</td>
</tr>
<tr>
<td>Example</td>
<td>IBM CICS</td>
<td>DCE/RPC</td>
<td>WebSphere MQ</td>
<td>BEA Tuxedo</td>
</tr>
</tbody>
</table>
3. Implementation Details

* Message-oriented middleware (MOM): key to the integration provides messaging substrate and subscribe/publish model support

Our choice: ActiveMQ from Apache.org, a Java Message Service (JMS)-based, open-source middleware which supports loosely coupled, asynchronous communications.

* Web Services: Java Servlet-based frontend connected to the backend message-oriented middleware (MOM).
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II. Primary Findings and Status
- Sensor Web Framework

3. Implementation Details (cont’d)

<table>
<thead>
<tr>
<th>Application 1</th>
<th>Application 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data (XML)</td>
<td>Data (XML)</td>
</tr>
<tr>
<td>REST-ful Web Services</td>
<td>REST-ful Web Services</td>
</tr>
</tbody>
</table>

World Wide Web
Middleware
JMS (asynchronous, reliable messaging)
Wire protocols (e.g., TCP/IP)
II. Primary Findings and Status

- **Sensor Web Framework**

4. Live demonstration

Integrating a web-based visualization/decision support system with remote sensor simulators

- Web visualization frontend taps into the prototype Sensor Collection Service (SCS) to receive sensor data.
- Sensor simulators provide data to SCS.
- Decision-support web interface also invokes Sensor Planning Service (SPS) to control sensor simulators upon user request.
- Sensor simulators receive instructions from SPS.
- Web interface uses AJAX technology to interact with sensor web services and user.

Click URL below to start demo:

http://192.239.84.155:18080/activemq-web-demo/gmail.html
II. Primary Findings and Status

- Sensor Web Framework

4. Live demonstration
II. Primary Findings and Status

- **Sensor Web Framework**

5. Summary

- A service-oriented architecture is implemented to connect a sensor web with a modeling system (LIS)
- Prototype SWE services (SCS, SPS) are built with REST-style web services.
- A demonstration is given to illustrate the coupling between SWE services, a sensor web and 3rd-party web services (Google Maps).

**Key Features:**

- New web services are hot-pluggable
- Any web-savvy device (sensors, models, cell phones, GUI tools) can become a service provider/consumer
- Loosely coupled interaction enhanced reliability
- Asynchronous communication supports interactive apps such as AJAX-based web apps.
2. Primary Findings and Status

- **LISW experiments**

- **Control:** “virtual land truth” of 1st layer SM from CLM
- At 0z01Sep2005

![Map of the United States with color scale showing water content values from 0.05 to 0.35.](image-url)
II. Primary Findings and Status

- **LISW experiments**

- Control: “virtual land truth” of 1st layer SM from CLM
- OBS: by adding random noise into the 1st layer soil moisture from the “virtual land truth”
- Openloop: Noah (operational model from NCEP) run
- Assimilated: OBS was assimilated to Noah
- OBS is daily, all others are 3 hrly
- The series are for a point at (40N, -95W)
- Unit: volumetric, m^3/m^3
- Noise level: ~N(0, 0.02)
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II. Primary Findings and Status

- LISW experiments

To see more the details of the assimilation in one month (September, 2003) data

LIS/DA Experiment

1st layer soil moisture (m^3/m^3)
II. Primary Findings and Status

- **LISW experiments**

How DA contribute to minimize the overall uncertainty of the land surface modeling?

- Variation of Bias, RMSE and Correlation based on instantaneous 3 hrly prediction, compared with the control run

- It shows some seasonal variation (summer v.s. winter) of modeling and DA performance: revealing that the physics of Noah is more different than that of CLM in the winter season.

- In spinning up period, the rmse and bias are both low, because the initial condition is similar for two LSMs (CLM and Noah)

- Correlation, bias and rmse, all demonstrate that DA improved the soil moisture prediction

- It suggests more frequent observations in winter season be necessary to improve the overall prediction.
III. Summary & Future Work

- **Summary**

- The **Scenario Development** was completed: Design a global land surface scenario. It has been achieved. The synthetic global “land truth” reference acts as a LISW evaluation and optimization environment.

- The **design and implementation of SWS and Sensor Web Framework** has been finished. SWS and Sensor Web Framework extend capacity of the land surface modeling and make it possible to have a two-way interaction between LSMs and sensor web on the fly.

- **Data Assimilation Framework** in LIS has been established and tested.

- Some preliminary research results were presented (5 conference presentations) or to be published (1 journal paper). One case of NASA Disclosure of Invention and Technology was filed.
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III. Summary & Future Work

Future Work

- Generate global synthetic land truth (with Uncertainty Estimation) for a longer time period (2003-2006) and do Sensor Reconfiguration Tests on NASA Supercomputer
- Develop models for various classes of sensor nodes
- Develop a sensor communication prototype
- Explore use of operational spacecraft control software (STK) in SWS
- Establish sensor observation, planning service
- Establish web notification service
- Develop sensor web management software
- Disseminate model code and data
- Collaborate with NASA land projects and teams
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Recent Publications from the LISW team:


5. Su, H; Houser, P; Tian, Y; Kumar, S; Geiger, J; Belvedere, D (2007), Comparison of two perturbation methods to estimate the land surface modeling uncertainty, Eos Trans. AGU, 88(52), Fall Meet. Suppl., Abstract H31H-0765


Appendix I: Acronyms

AJAX: Asynchronous JavaScript™ and XML
ALMA: Assistance for Land-surface Modelling Activities
CLM: Community Land Model
DI: Direct Insertion
EKF: Extended Kalman Filter
EnKF: Ensemble Kalman Filter
GDAS: Global Data Assimilation System
LIS: Land Information System
LISW: Land Information Sensor Web
LSM: Land Surface Model
Noah: NCEP, Oregon State University, Air Force, Hydrologic Research Lab
OGC: OpenGIS Consortium
REST: Representational State Transfer
SCS: Sensor Collection Service
SOA: Service Oriented Architecture
SPS: Sensor Planning Service
SWE: Sensor Web Enablement
SWS: Sensor Web Simulator