Developing a Prototype Land Information Sensor Web (LISW)

Presented by Hongbo Su

LISW Team

- Paul Houser (PI)/ George Mason University
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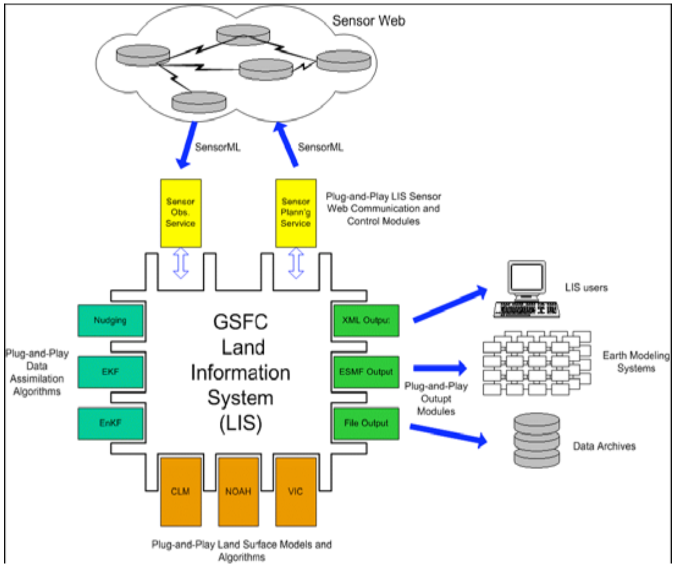
Date: June 25, 2008

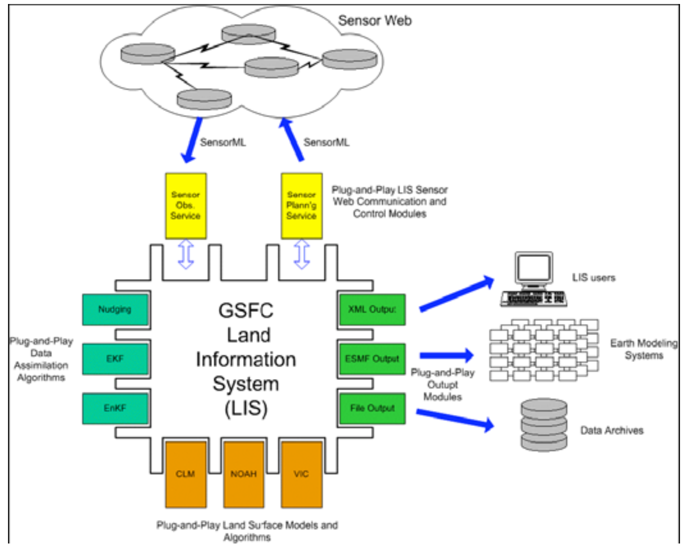


Earth Science Technology Office

Developing a Prototype Sensor Web in support of land surface studies

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.



Enabling LIS to interact with sensor webs with open protocols and web

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

Co-I's/Partners

- James Geiger / NASA-GSFC
- Sujay Kumar, Yudong Tian / GEST-UMBC

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
• Collaboration, Communication & Dissemination	August/2009

Publication and Presentation

1. S. Kumar, R. Reichle, C. Peters-Lidard, et al.A land surface data assimilation framework using the Land Information System: description and appilcaiton. Accepted by Advances in Water Resources.
2. H. Su, P. Houser, Y. Tian, J.V. Geiger, S. V. Kumar and D. R. Belvedere (2007). A prototype of land information sensor web (LISW) SPIE 0277-786X
3. P. Houser, H. Su, Y. Tian, S. Kumar, J. Geiger, D. Belvedere (2007) Integrating a Virtual Sensor Web with Land Surface Modeling, NSTC2007

Outline

I. Overview

II. Primary Findings

III. Future Work

Developing a Prototype Sensor Web in support of land surface studies

I. Overview

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

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***.

- 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.
- 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

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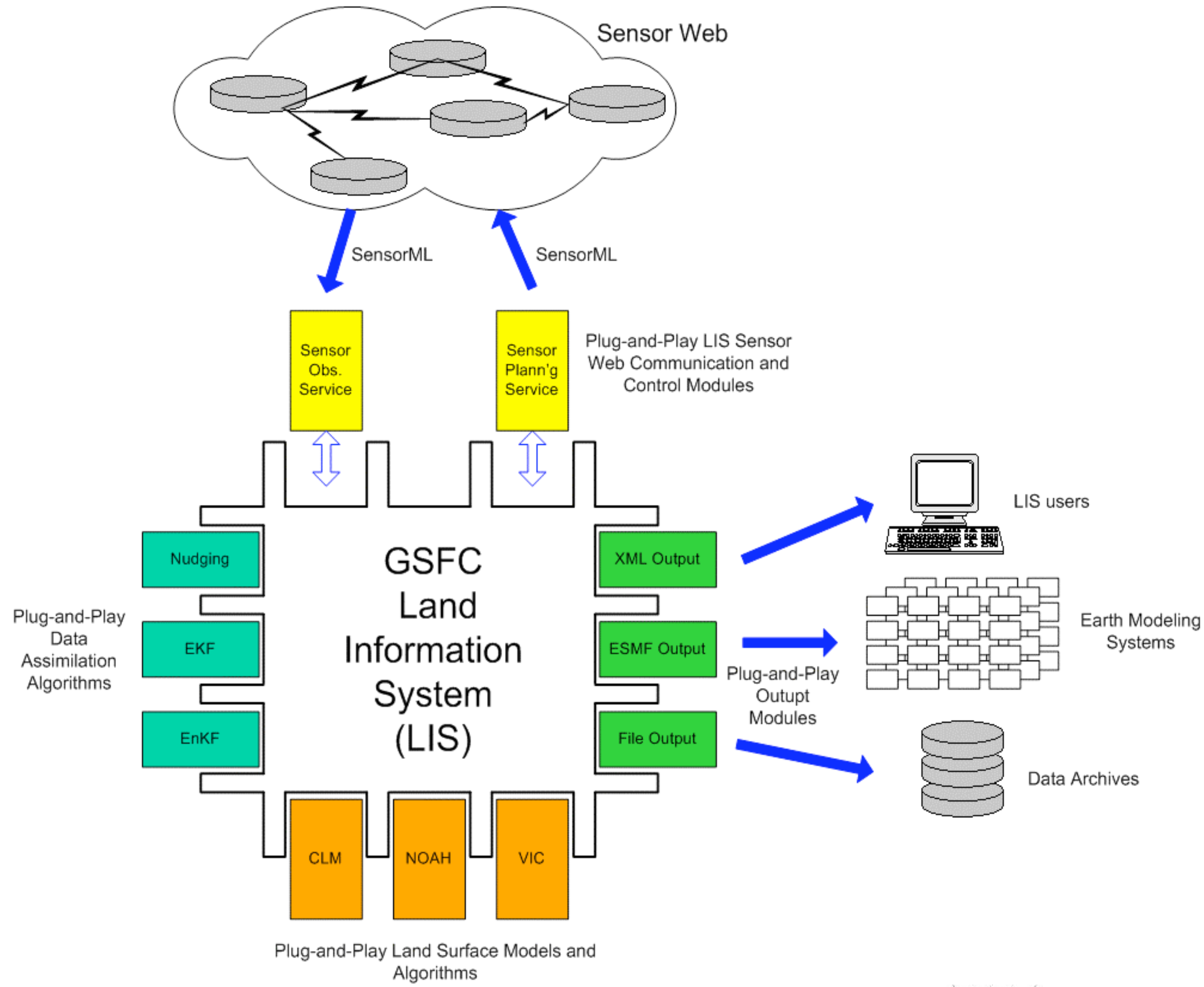
I. Overview

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



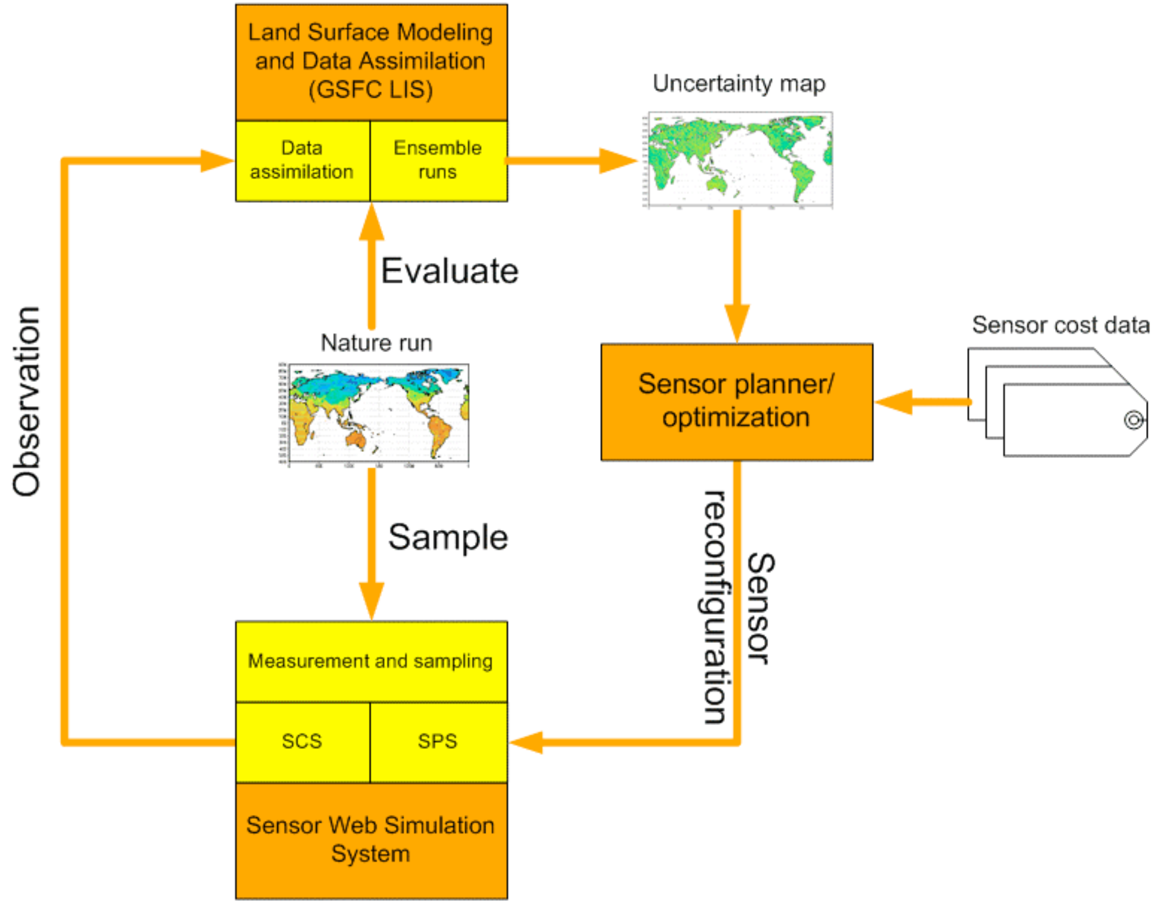
Subtasks and responsible persons:

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

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

❖ **Scenario Development**

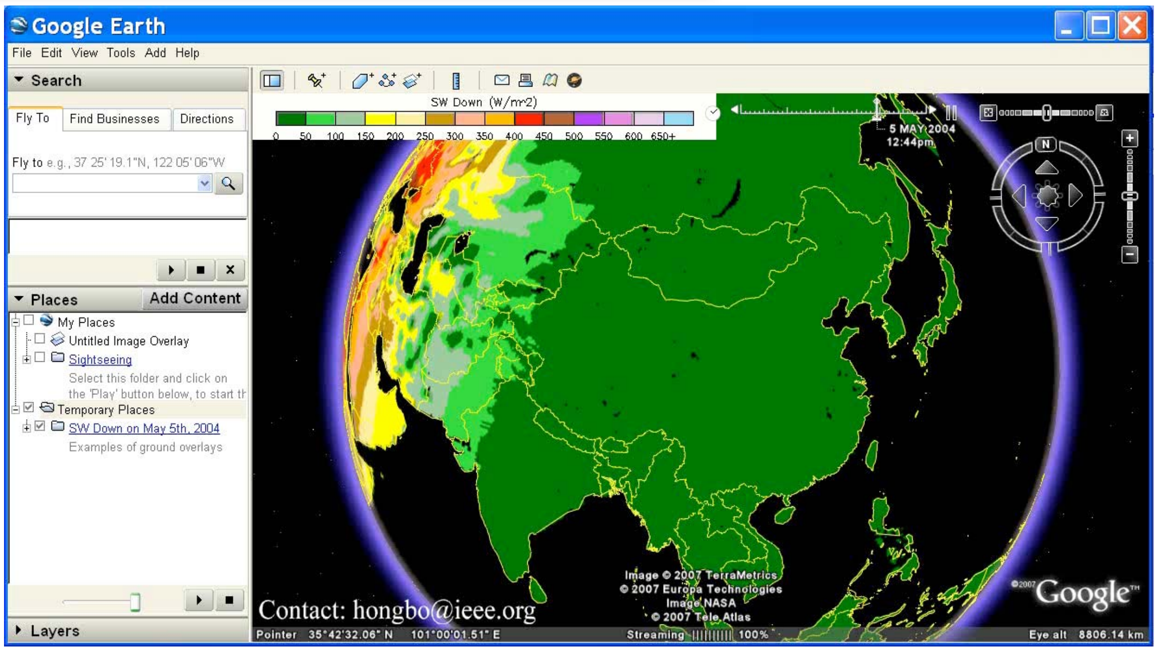
The 1st task: develop a “land surface truth”

- 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

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II. Primary Findings and Status

❖ **Scenario Development**

The 2nd task: establish optimization metrics based on the "land surface truth"

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.

II. Primary Findings and Status

❖ Sensor Web Simulation

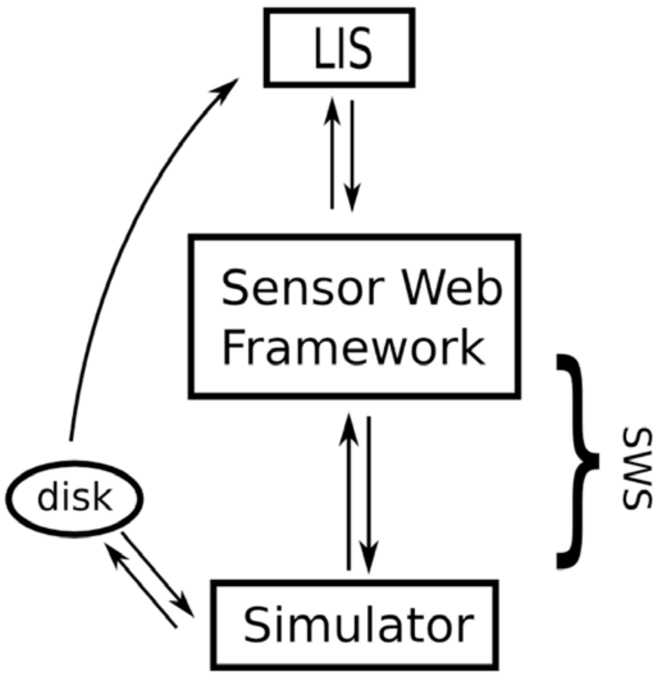
The simulator shall be a stand-alone system not directly coupled to any particular land surface model or system.

The simulator shall fulfil **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.

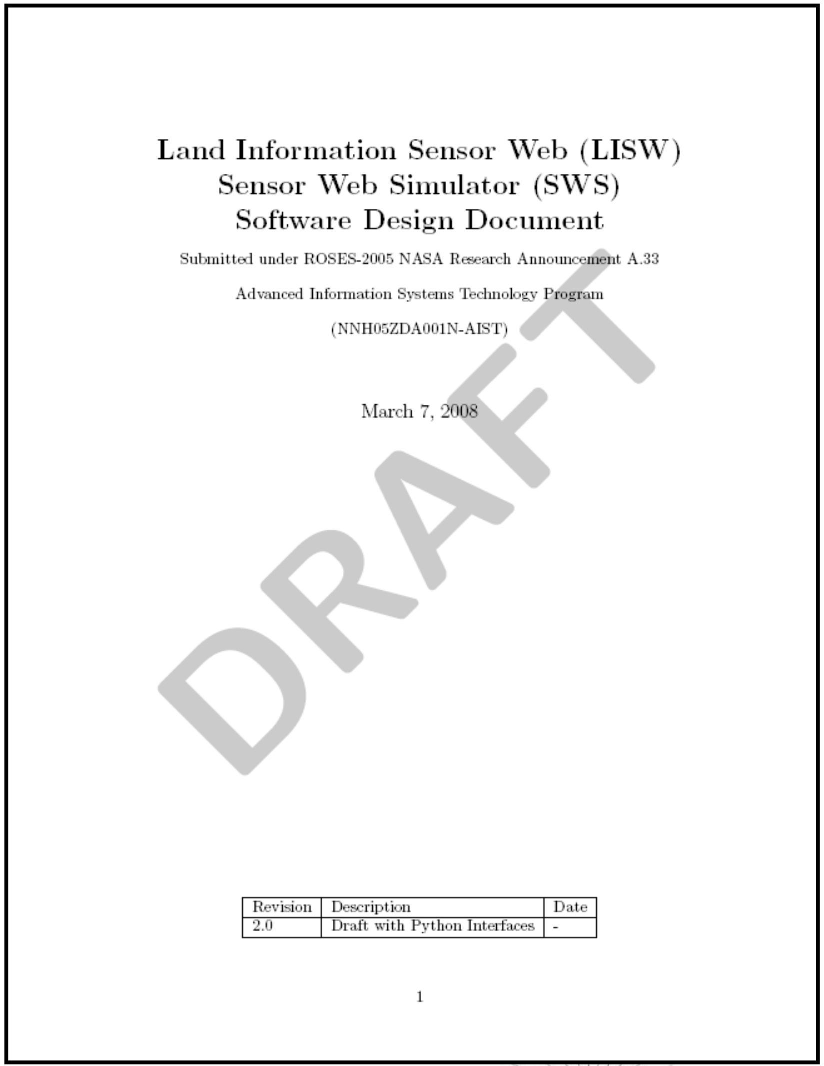
The interface provides:

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.



Land Information Sensor Web (LISW)
Sensor Web Simulator (SWS)
Software Design Document

Submitted under ROSES-2005 NASA Research Announcement A.33

Advanced Information Systems Technology Program

(NNH05ZDA001N-AIST)

March 7, 2008

DRAFT

Revision	Description	Date
2.0	Draft with Python Interfaces	-

1

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

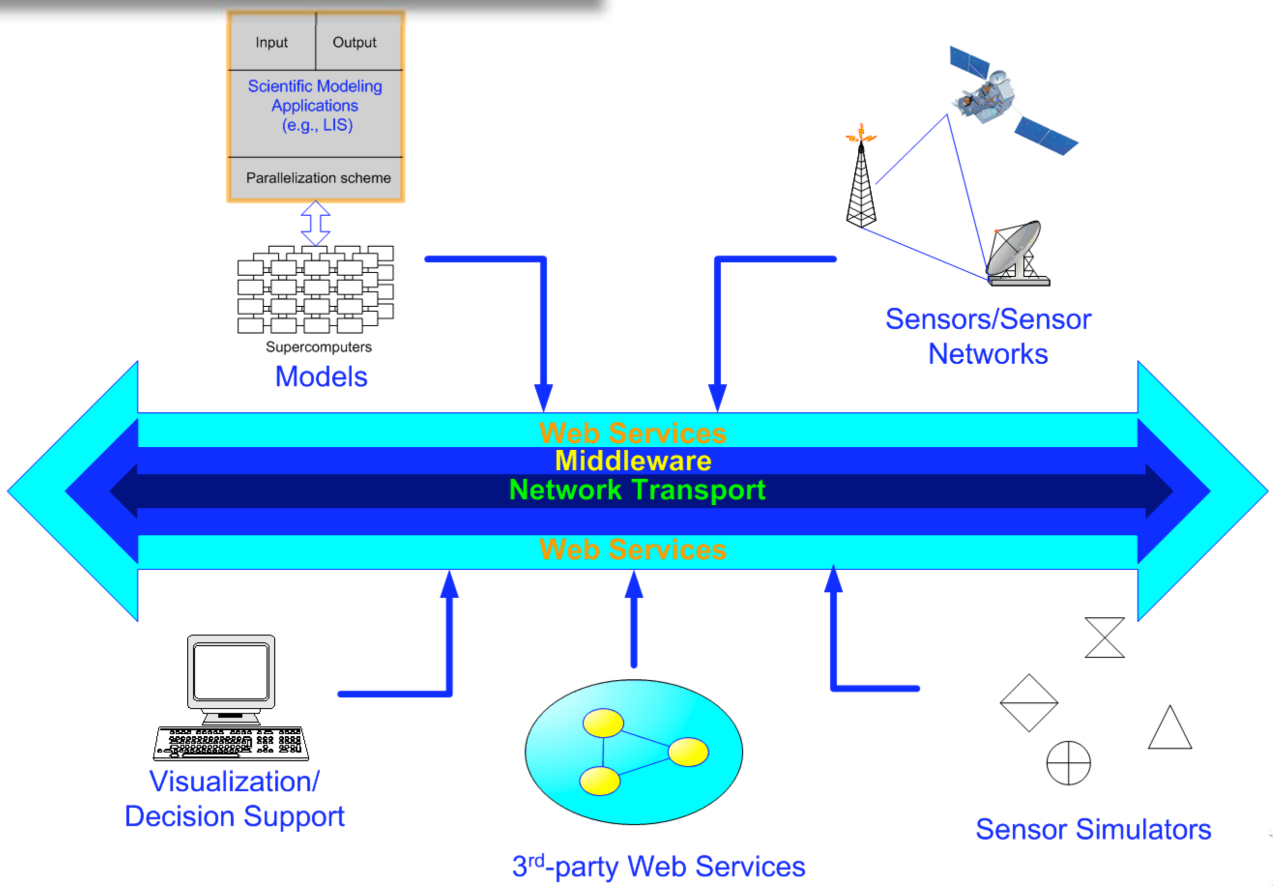
2. Our Approaches

- 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

Middleware type	TPM Transaction Processing Monitor	RPC Remote Procedure Call	MOM Message-oriented Middleware	ORB Object Request Broker
Target	transactions	procedures	messages	objects
Coupling	tight	tight	loose	tight
Synchronization	sync	sync	async	sync
Example	IBM CICS	DCE/RPC	WebSphere MQ	BEA Tuxedo

II. Primary Findings and Status

❖ Sensor Web Framework

3. Implementation Details

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

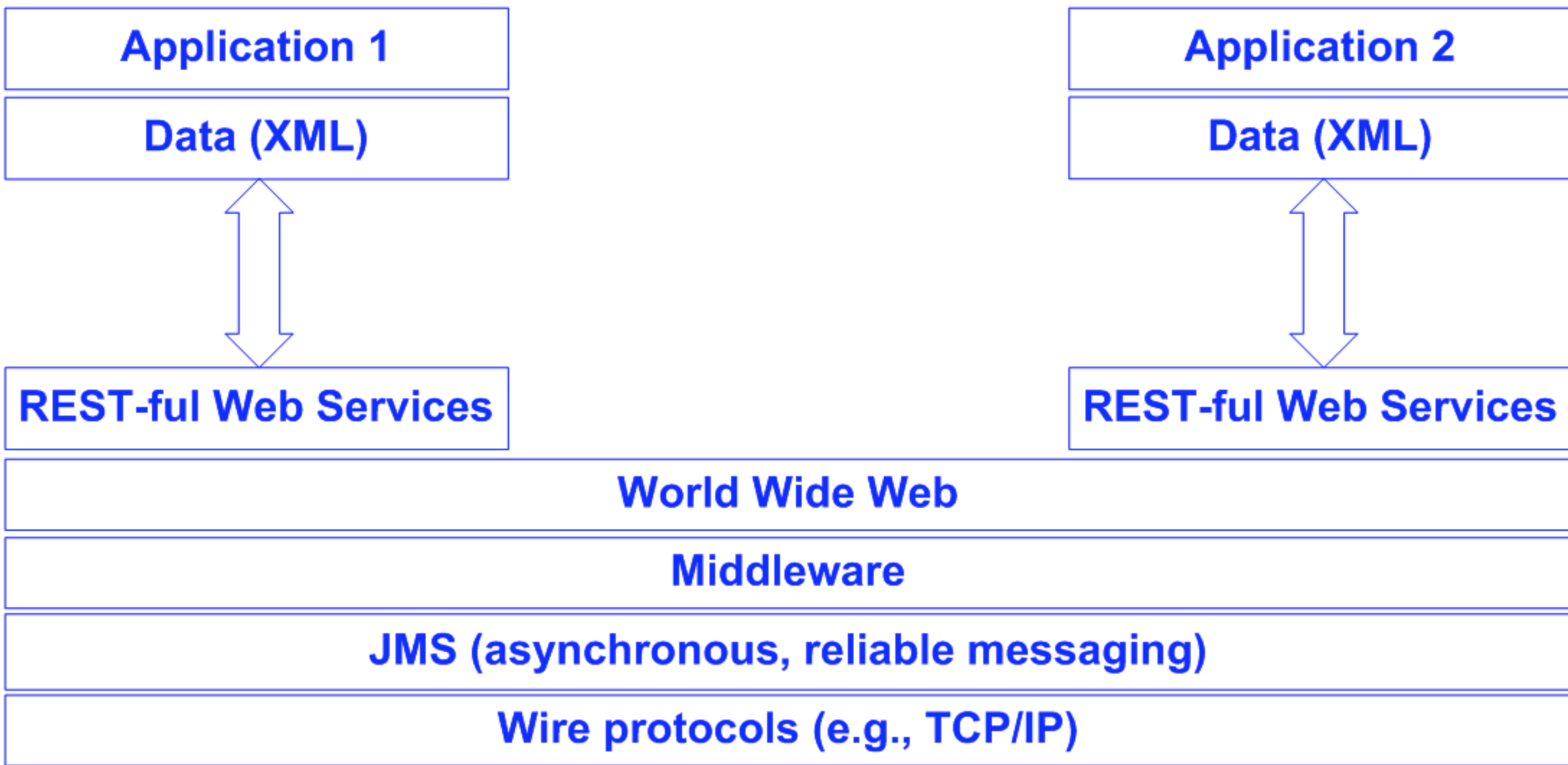
  Our choice: ActiveMQ from Apache.org, a Java Message Service (JMS)-based, open-source middleware which supports loosely coupled, asynchronous communications.

* Web Services: Java Servlet-based frontend connected to the backend message-oriented middleware (MOM).

II. Primary Findings and Status

❖ Sensor Web Framework

3. Implementation Details (cont'd)



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

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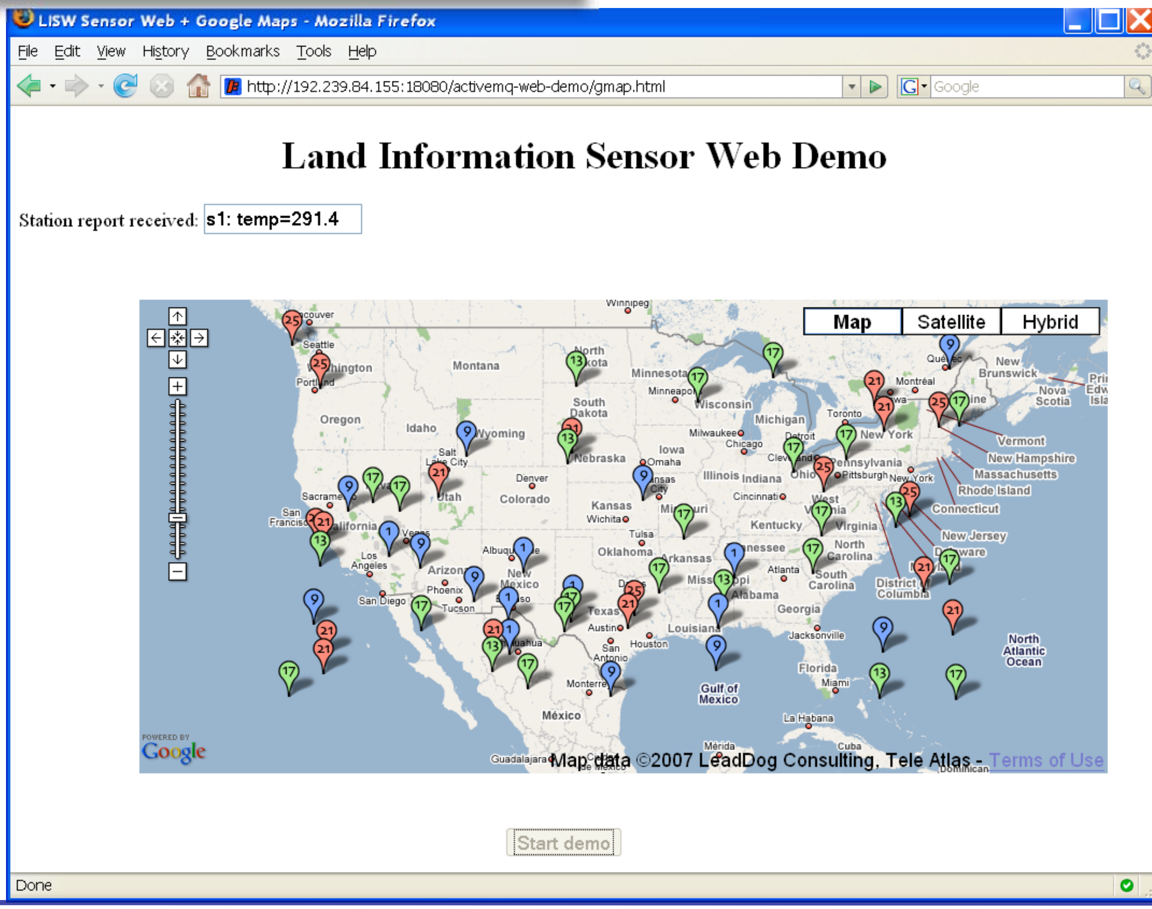
II. Primary Findings and Status

❖ Sensor Web Framework

4. Live demonstration



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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:

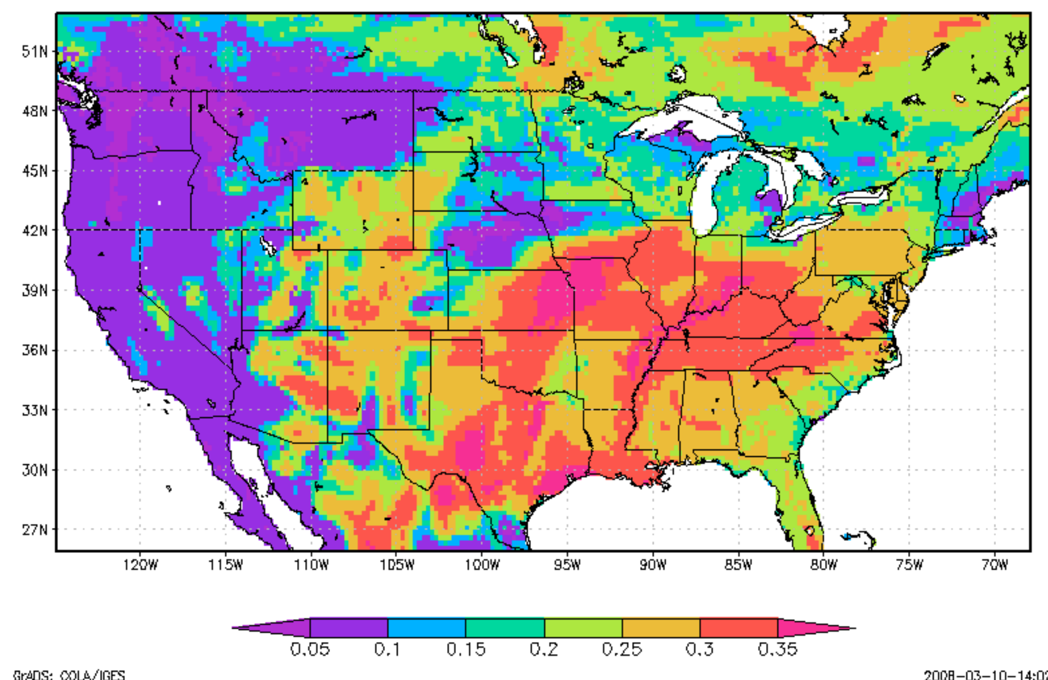
- New web services are hot-pluggable
- Any web-savvy device (sensors, models, cell phones, GUI tools) can become a service provider/consumer
- Loosely coupled interaction enhanced reliability
- Asynchronous communication supports interactive apps such as AJAX-based web apps.

II. Primary Findings and Status

❖ LISW experiments

LIS/DA Experiment the whole domain

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

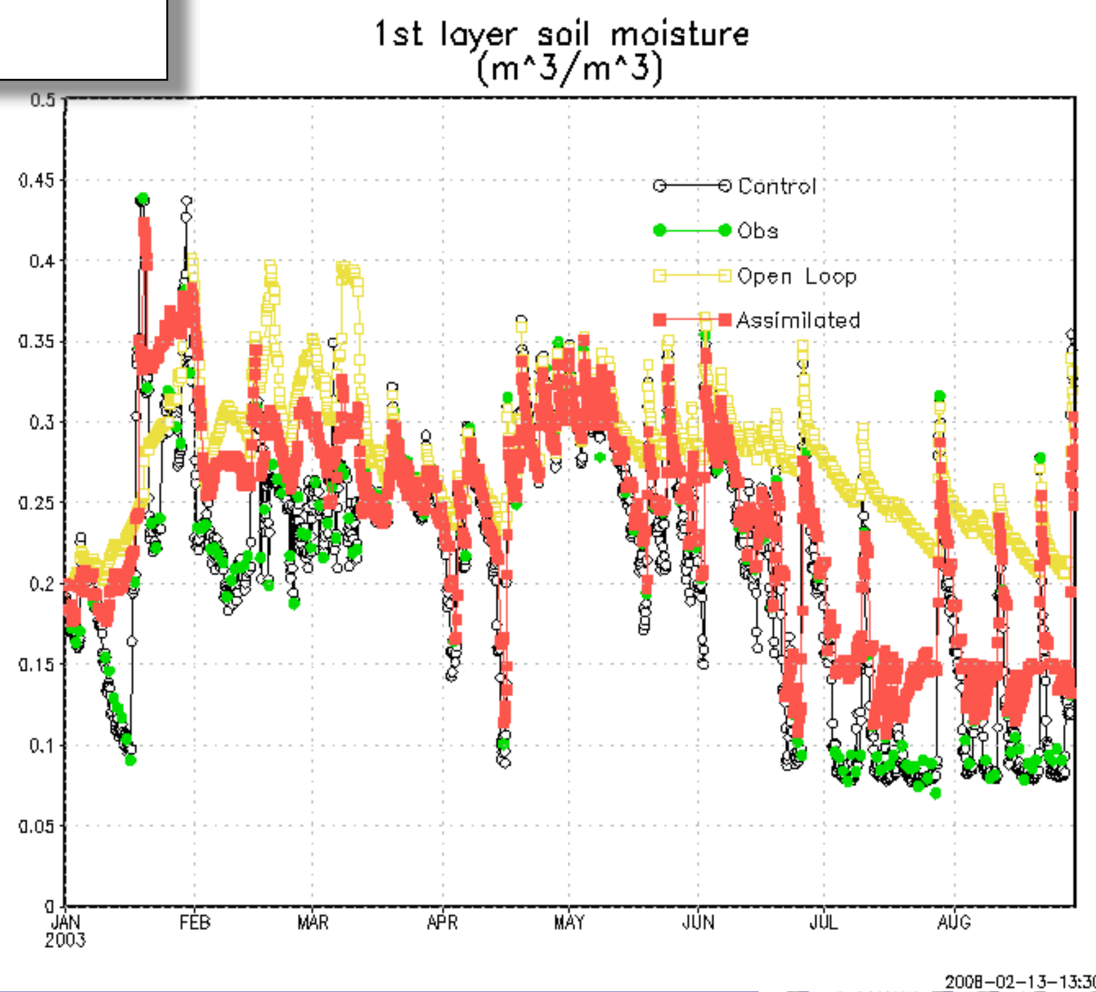


II. Primary Findings and Status

❖ LISW experiments

LIS/DA Experiment

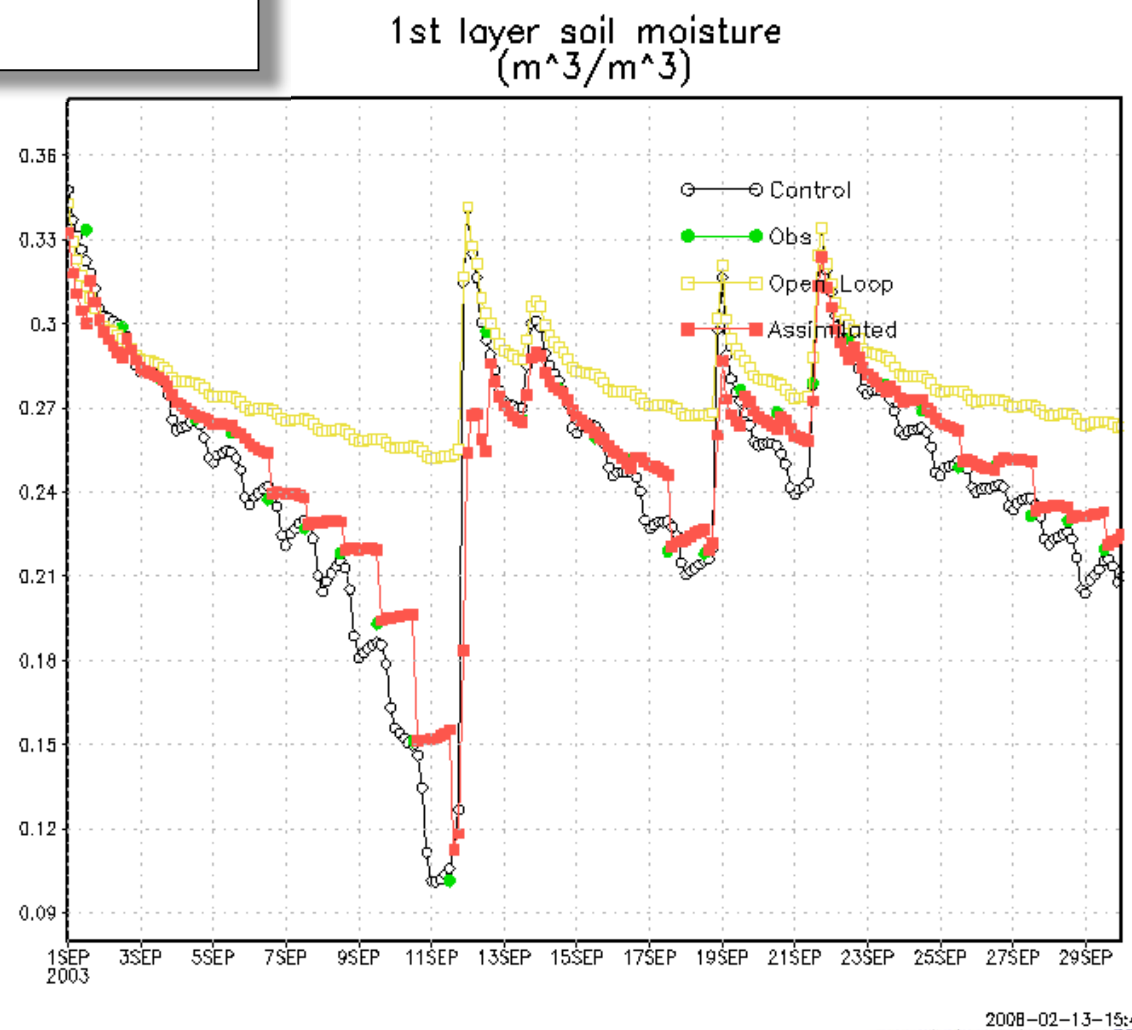
- Control: "virtual land truth" of 1st layer SM from CLM
- OBS: by adding random noise into the 1st layer soil moisture from the "virtual land truth"
- Openloop: Noah (operational model from NCEP) run
- Assimilated: OBS was assimilated to Noah
- OBS is daily, all others are 3 hrly
- The series are for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



II. Primary Findings and Status

❖ LISW experiments

LIS/DA Experiment



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

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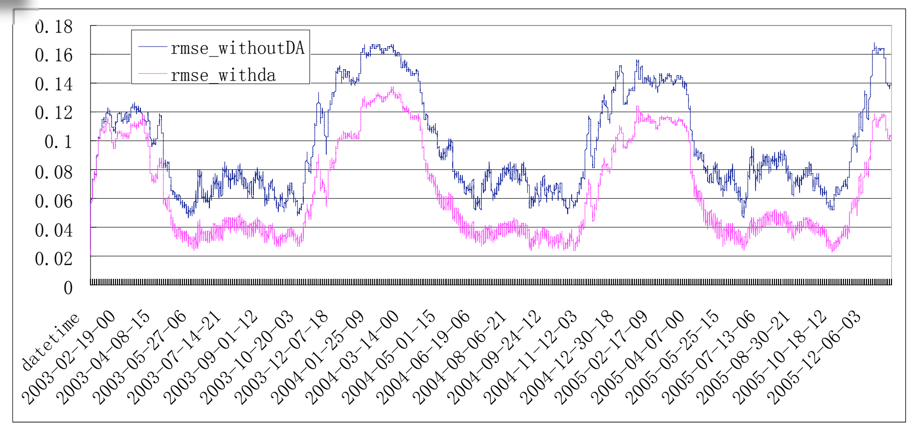
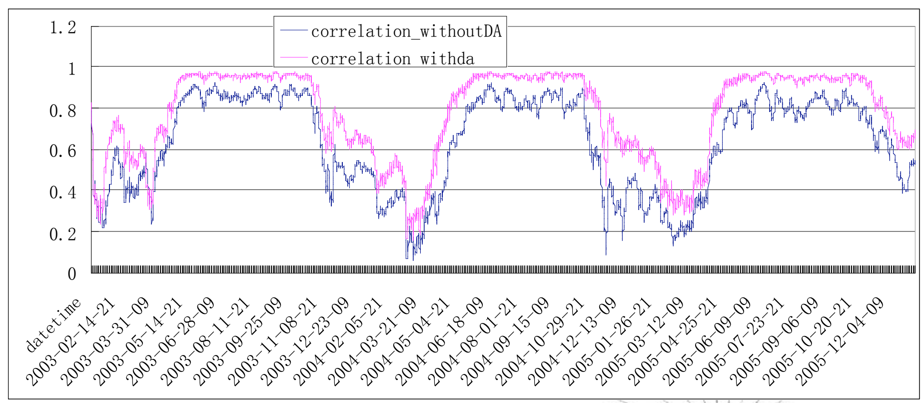
II. Primary Findings and Status

❖ 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.





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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.

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

Recent Publications from the LISW team:

1. Hongbo Su, Paul R. Houser, Yudong Tian, James V. Geiger, Sujay V. Kumar and Deborah R. Belvedere. A Land Information Sensor Web (LISW) study in support of land surface STUDIES, submitted to *IGARSS2008*.
2. Tian, Y., J. V. Geiger, S. Kumar, P. R. Houser, and H. Su. (2008), Land Information Sensor Web Service-oriented Architecture (LISW-SOA), Version 1.0. *NASA Disclosure of Invention and Technology*, Case No. GSC15517-1.
3. Kumar, S.V., R.H. Reichle, Peters-Lidard, C.D., Koster, R.D., X. Zhan, W.T. Crow, J.B. Eylander, P.R. Houser, "A Land Surface Data Assimilation Framework using the Land Information System: Description and Applications", special issue on Hydrological Remote Sensing in *Advances in Water Resources*, 2007 (Accepted)
4. Tian, Y., P. R. Houser, H. Su., S. V. Kumar and J. V. Geiger, Jr. (2008), Integrating sensor webs with modeling and data-assimilation applications: An SOA implementation. *Proceedings of the 2008 IEEE Aerospace Conference*, accepted.
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
6. Hongbo Su, Paul R. Houser, Yudong Tian, James V. Geiger, Sujay V. Kuma, and Deborah R. Belvedere, A prototype of land information sensor web (LISW) *Proc. SPIE 6684*, 668415 (2007).
7. Houser, P; Su, H; Tian, Y; Kumar, S; Geiger, J (2007), "Integrating a virtual sensor web with land surface modeling", *NSTC2007 Conference* in June 2007.

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