Enhancing water management applications with surface observation and modeling

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Outline: (1) Challenge, (2) Strategy, (3) Tools, (4) Case Studies

Acknowledgments: D. Toll (GSFC), A. Pinheiro (NRC), K. Arsenault (UMBC), M. Rodell (GSFC), C. Peters-Lidard (GSFC), A. Schlosser (MIT)

http://crew.iges.org
Challenge

Conduct research that addresses end-user needs, and nurture the transition of these research results into straightforward end-user solutions.

- Information about land surface conditions is of critical importance to real-world applications.
- A vast array of high-resolution global land surface data are becoming available from the next generation instruments and models.
- Water management practitioners are increasingly inundated with observations and model output in disparate formats and locations.

- We know science and technology has the potential to improve water management....
- So, why doesn’t research and technology advances always improve applications?
  - Inadequate application understanding produces non-optimal science/technology investment.
  - Inadequate technology (lack of useful water resource observations).
  - Inadequate integration of information (lack of informative predictions, or bottlenecks in software/hardware engineering).

- This leads to a paradigm lock where new science results are isolated by a lack of proven utility, and water management is isolated by legal and professional precedence

- So, what can we do about this?
  - Improved prediction of consequences is the key.
    - Define research priorities based on needs
    - Observe key environmental factors
    - Integrate information from diverse sensors
    - Assess the current environmental conditions
    - Predict future environmental possibilities
    - Link to decision and operation support systems

- Move from observation to predict consequences: Integrated environmental information systems adapt advanced sensor webs, high-performance prediction systems, and decision support tools to minimize uncertainties
Linking Science to Consequences

End-to-end coordination enabling understanding and prediction of the Earth system: 

*Research driven by the needs of society*

To deliver social, economic and environmental benefit to stakeholders through sustainable and appropriate use of water by directing towards improved integrated water system management
Use the adequate tool for the job…
Strategy 1: NASA Water Management Strategy

Terra

GRACE

Processing

Exploitation

EOSDIS & DAACs

Data Assimilation & Modeling

Societal Benefits

Riverware & AWARDS

Paul R. Houser, 22 December 2005
Strategy 2: Integrated Systems Solutions

Develop the required integration between research products and end-user solutions using a **modeling and analysis system**:

(a) **Customize, develop and test** modeling & analysis tools for use in specific DST solutions
(b) **Demonstrate** prototype solution in partnership with end-user: manage data, generate runs, make data available to users
(c) **Maintain** software, data, and visualization tools up-to-date, and answer user inquiries
(d) **Analysis, optimization, benchmarking**, evaluation and verification, of prototype solution
(e) **Document**, communicate, and disseminate.

<table>
<thead>
<tr>
<th>NASA &amp; Partner Research</th>
<th>DST Partnership Opportunities</th>
<th>Value &amp; Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NASA &amp; Partner Community Models</strong></td>
<td><strong>Example Partner Agency DSTs</strong></td>
<td><strong>Policy Decisions</strong></td>
</tr>
<tr>
<td><strong>Atmospheric Forcing:</strong> GMAO, GDAS, NCEP, NCAR, ECMWF, AGRMET</td>
<td>Agricultural Efficiency: USDA: NIDIS</td>
<td>Flood and disease warning; Agricultural production &amp; efficiency; Aircraft &amp; travel safety; Weather warnings; Ecological diversity; Optimized energy production; Drinking water protection; Water use efficiency</td>
</tr>
<tr>
<td><strong>Land:</strong> LIS (CLM, VIC, Noah, SSiB, HySSiB, Mosaic, CLSM, etc.), SAC</td>
<td>Air Quality: USEPA: CMAQ</td>
<td><strong>Management Decisions:</strong> Energy &amp; agricultural production; Land use allocation; Aircraft scheduling; Weather avoidance; Climate change mitigation; Disaster response; Community planning; Insurance issues</td>
</tr>
<tr>
<td><strong>Coupled:</strong> GMAO, WRF, GCE, ESMF</td>
<td>Carbon Management: GEWEX CEEP</td>
<td><strong>Exploration Decisions:</strong> Storm prediction; Search for water &amp; life; Resource assessment.</td>
</tr>
<tr>
<td><strong>Observation Methods &amp; Platforms</strong></td>
<td><strong>Coastal Management:</strong> USACE: CWMS</td>
<td><strong>Policy Decisions:</strong> Flood and disease warning; Agricultural production &amp; efficiency; Aircraft &amp; travel safety; Weather warnings; Ecological diversity; Optimized energy production; Drinking water protection; Water use efficiency</td>
</tr>
<tr>
<td><strong>Satellite:</strong> EOS Terra &amp; Aqua, SSMI, SRTM, NPP, Landsat, ICESat, GRACE, TRMM &amp; GPM, CloudSAT, GOES, NPOESS, HYDROS, etc.</td>
<td><strong>Disaster Management:</strong> RMS RiskLink</td>
<td><strong>Management Decisions:</strong> Energy &amp; agricultural production; Land use allocation; Aircraft scheduling; Weather avoidance; Climate change mitigation; Disaster response; Community planning; Insurance issues</td>
</tr>
<tr>
<td><strong>Sub-orbital:</strong> MW, Vis/IR, Lidar, UAVs</td>
<td><strong>Ecological Forecasting:</strong> USDA: AGWA</td>
<td><strong>Exploration Decisions:</strong> Storm prediction; Search for water &amp; life; Resource assessment.</td>
</tr>
<tr>
<td><strong>In-situ:</strong> Meso- and micronets, Surfrad, ARM, GTS, field campaigns, etc.</td>
<td><strong>Energy Management:</strong> USBR: RiverWare</td>
<td><strong>Policy Decisions:</strong> Flood and disease warning; Agricultural production &amp; efficiency; Aircraft &amp; travel safety; Weather warnings; Ecological diversity; Optimized energy production; Drinking water protection; Water use efficiency</td>
</tr>
<tr>
<td><strong>Forcing:</strong> Radiation &amp; Clouds, Water Vapor, Precipitation, Temperature, Winds, etc.</td>
<td><strong>Homeland Security:</strong> Army: ARMS</td>
<td><strong>Management Decisions:</strong> Energy &amp; agricultural production; Land use allocation; Aircraft scheduling; Weather avoidance; Climate change mitigation; Disaster response; Community planning; Insurance issues</td>
</tr>
<tr>
<td><strong>Parameters:</strong> Topography, Vegetation &amp; Soil Properties</td>
<td><strong>Invasive Species:</strong> USBR: AWARDS</td>
<td><strong>Exploration Decisions:</strong> Storm prediction; Search for water &amp; life; Resource assessment.</td>
</tr>
<tr>
<td><strong>States:</strong> Snow Cover &amp; Depth, Soil &amp; Vegetation Moisture, Water Levels, Water Availability, Aquifer States</td>
<td><strong>Public Health:</strong> USEPA: BASINS</td>
<td><strong>Policy Decisions:</strong> Flood and disease warning; Agricultural production &amp; efficiency; Aircraft &amp; travel safety; Weather warnings; Ecological diversity; Optimized energy production; Drinking water protection; Water use efficiency</td>
</tr>
<tr>
<td><strong>Fluxes:</strong> Radiation, Carbon, Evaporation, Transpiration, Precipitation, Runoff, etc.</td>
<td><strong>Water Management:</strong> NOAA: NWSRFS</td>
<td><strong>Management Decisions:</strong> Energy &amp; agricultural production; Land use allocation; Aircraft scheduling; Weather avoidance; Climate change mitigation; Disaster response; Community planning; Insurance issues</td>
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</tbody>
</table>

**INPUTS** **OUTPUTS** **OUTCOMES** **IMPACTS**

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Paul R. Houser, 22 December 2005, Page
Strategy 3: Solution Networks

A Solutions Network establishes pathways and partnerships between research investments and decision support needs.

1. **Evolve a network of partners**: identify and analyze community-of-practice organizations, DSTs and their requirements and develop well-constructed teams and partnerships to define collaboration pathways.

2. ** Routinely identify, prioritize, mine and communicate relevant research products and results**: develop operational information system pathways to provide timely user-community access.

3. **Optimize water cycle partner access** to research results and products, through developing prototypes, evaluation methods, verification procedures, and benchmarking standards to create an evolving and self-sustaining network.

4. **Analyze and document** the network effectiveness by developing metrics, standards, resource estimates and documentation procedures and guidelines.

5. **Education and outreach** is important to help society understand and use the research in every-day application.

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**NASA Water Cycle Research**

- Science Community Guidance
- National Science Programs
- DAACS
- Modeling Labs
- EarthSat Technology Office (ESSTO)
- Planning & Formulation

**Water Cycle Solutions Network**

- Actionable WCSN database
- Pathway Discovery (MIT)
- Requirements and Feedback
- Data and Model Products
- Benchmarking
- Evaluation
- Verification and Validation
- Network Optimization (OSSEs)

**Water Cycle User Community**

- Operational Model Owners and Operators (NOAA...)
- Operational Data Providers (USGS...)
- U.S. Owners and Operators (USDA...)
- Assessment Providers (WMO, IPCC...)
- Policy Decision Makers
- Education and Outreach
- Commercial Data Providers (EarthSat, Digital Globe...)
- Educational Organizations
- Science Discovery & Results
- Science Community Guidance

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Paul R. Houser, 22 December 2005, Page
The availability of new observations strongly motivates advances in understanding, prediction, and application.

<table>
<thead>
<tr>
<th>Class</th>
<th>Observation</th>
<th>Technique</th>
<th>Example Platform</th>
<th>Temporal</th>
<th>Spatial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Parameters</td>
<td>Leaf area and greenness</td>
<td>optical/IR</td>
<td>AVHRR, MODIS, NPOESS</td>
<td>weekly</td>
<td>1km</td>
</tr>
<tr>
<td></td>
<td>Albedo</td>
<td>optical/IR</td>
<td>MODIS, NPOESS</td>
<td>weekly</td>
<td>1km</td>
</tr>
<tr>
<td></td>
<td>Emissivity</td>
<td>optical/IR</td>
<td>MODIS, NPOESS</td>
<td>weekly</td>
<td>1km</td>
</tr>
<tr>
<td></td>
<td>Vegetation structure</td>
<td>lidar</td>
<td>ICESAT, ESSP lidar mission</td>
<td>weekly-monthly</td>
<td>100m</td>
</tr>
<tr>
<td></td>
<td>Topography</td>
<td>in-situ survey, radar</td>
<td>GTOPO30, SRTM</td>
<td>episodic</td>
<td>30m–1km</td>
</tr>
<tr>
<td>Land Forcings</td>
<td>Wind profile</td>
<td>radar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air Humidity and temperature</td>
<td>IR, MW</td>
<td>TOVS, GOES, AVHRR, MODIS, AMSR</td>
<td>hourly-weekly</td>
<td>5 km</td>
</tr>
<tr>
<td></td>
<td>Near-surface radiation</td>
<td>optical/IR</td>
<td>GOES, MODIS, CERES, ERBS, etc.</td>
<td>hourly-weekly</td>
<td>1km</td>
</tr>
<tr>
<td></td>
<td>Precipitation</td>
<td>microwave/IR</td>
<td>TRMM, GPM, SSMI, GEO-IR, etc.</td>
<td>hourly-monthly</td>
<td>10km</td>
</tr>
<tr>
<td>Land States</td>
<td>Temperature</td>
<td>IR, in-situ</td>
<td>IR-GEO, MODIS, AVHRR, TOVS</td>
<td>hourly-monthly</td>
<td>10m-4km</td>
</tr>
<tr>
<td></td>
<td>Thermal anomalies</td>
<td>IR, NIR, optical</td>
<td>AVHRR, MODIS, TRMM</td>
<td>daily-weekly</td>
<td>250m–1km</td>
</tr>
<tr>
<td></td>
<td>Snow cover and water</td>
<td>optical, microwave</td>
<td>SSMI, TM, MODIS, AMSR, AVHRR, etc.</td>
<td>weekly-monthly</td>
<td>1km</td>
</tr>
<tr>
<td></td>
<td>Freeze/thaw</td>
<td>radar</td>
<td>Quikscat, HYDROS, IceSAT, CryoSAT</td>
<td>weekly</td>
<td>3km</td>
</tr>
<tr>
<td></td>
<td>Total water storage</td>
<td>gravity</td>
<td>GRACE</td>
<td>monthly</td>
<td>1000km</td>
</tr>
<tr>
<td></td>
<td>Soil moisture</td>
<td>active/passive microwave</td>
<td>SSMI, AMSR, HYDROS, SMOS, etc.</td>
<td>3-30 day</td>
<td>10-100 km</td>
</tr>
<tr>
<td>Land Fluxes</td>
<td>Evapotranspiration</td>
<td>optical/IR, in-situ</td>
<td>MODIS, GOES</td>
<td>hourly-day</td>
<td>10m-4km</td>
</tr>
<tr>
<td></td>
<td>Solar radiation</td>
<td>optical, IR</td>
<td>MODIS, GOES, CERES, ERBS</td>
<td>hourly-monthly</td>
<td>10m-4km</td>
</tr>
<tr>
<td></td>
<td>Longwave radiation</td>
<td>optical, IR</td>
<td>MODIS, GOES</td>
<td>hourly-monthly</td>
<td>10m-4km</td>
</tr>
<tr>
<td></td>
<td>Sensible heat flux</td>
<td>IR</td>
<td>MODIS, ASTER, GOES</td>
<td>hourly-monthly</td>
<td>10m-4km</td>
</tr>
</tbody>
</table>
### Tools 2: Decision Support Tools

<table>
<thead>
<tr>
<th>Potential Partner Agencies and DSTs</th>
<th>Surface Observations and Model Fields</th>
<th>Potential Value and Benefits to Citizens and Society</th>
</tr>
</thead>
<tbody>
<tr>
<td>USDA Natural Resources Conservation Service (NRCS), Soil Climate Analysis Network (SCAN), National Integrated Drought Information System (NIDIS)</td>
<td>precipitation, runoff, evaporation and transpiration, and soil moisture</td>
<td>Assessment of water availability and shifts in wetlands; prediction of weather/climate; mitigation of drought; estimation of cropping system sustainability and crop irrigation requirements, production and seasonal yield; advance warning of food shortages.</td>
</tr>
<tr>
<td>US Bureau of Reclamation, Agriculture Water Resources Decisions (AWARDS) Evapotranspiration (ET) Toolbox</td>
<td>solar radiation, precipitation, runoff, snow states, evaporation and transpiration, and soil moisture</td>
<td>Assessment and forecasting of water availability; irrigation agriculture efficiency; optimization of hydropower production; reduction of greenhouse gas emissions.</td>
</tr>
<tr>
<td>US Bureau of Reclamation, RiverWare</td>
<td>precipitation, runoff, soil moisture, snow states, and evapotranspiration</td>
<td>Reservoir regulation; water supply for irrigation, hydroelectric power and recreation; flood reduction; mitigation of drought.</td>
</tr>
<tr>
<td>US Army Corps of Engineers (USACE), Corps Water Management System (CWMS)</td>
<td>solar radiation, precipitation, runoff, snow states, evaporation and transpiration, and soil moisture</td>
<td>Port and inland harbor operations; inland waterway navigation; water supply regulation; hydropower production; flood control and emergency response; environmental restoration; recreation.</td>
</tr>
<tr>
<td>US Army Engineering Research and Development Center (ERDC), Combat Terrain Information System (CTIS) and Army Remote Moisture System (ARMS)</td>
<td>precipitation, runoff, and soil moisture</td>
<td>Terrain trafficability for military vehicle mobility and logistics.</td>
</tr>
<tr>
<td>NOAA National Weather Service, River Forecast System (NWSRFS)</td>
<td>precipitation, runoff, soil moisture, and snow states</td>
<td>Rapid production of timely forecasts and warnings on local and regional scales.</td>
</tr>
<tr>
<td>US Environmental Protection Agency (EPA), Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)</td>
<td>precipitation, runoff, soil moisture, and evapotranspiration</td>
<td>Prediction of land-use impacts; assessment of ecosystem changes; management of protected areas; forecasting for marine fisheries.</td>
</tr>
<tr>
<td>US Environmental Protection Agency (EPA), Community Multiscale Air Quality (CMAQ) Model</td>
<td>precip, runoff, and soil moisture</td>
<td>Management of air quality for multiple pollutants; understanding of physical and chemical reactions in the atmosphere and land surface.</td>
</tr>
<tr>
<td>USDA Agricultural Research Service, Automated Geospatial Watershed Assessment (AGWA) and Soil &amp; Water Assessment Tool (SWAT)</td>
<td>solar radiation, precipitation, runoff, snow states, evaporation and transpiration, and soil moisture</td>
<td>Assessment of water availability and shifts in wetlands; prediction of weather/climate; estimation of crop irrigation requirements.</td>
</tr>
<tr>
<td>(UK) Risk Management Solutions, River Flood Model and RiskLink</td>
<td>precipitation, runoff, snow states, soil moisture</td>
<td>Flood inundation modeling, insurance coverage determination, disaster-oriented financial losses.</td>
</tr>
<tr>
<td>US Geological Survey, Vector-borne Disease Projects</td>
<td>precipitation, runoff and soil moisture</td>
<td>Outbreak assessment and investigation; increased warning time; reduced likelihood of pesticide resistance.</td>
</tr>
<tr>
<td>Global Energy and Water Cycle Experiment (GEWEX), Coordinated Enhanced Observation Program (CEOP)</td>
<td>solar radiation, precipitation, runoff, snow states, evaporation and transpiration, and soil moisture</td>
<td>Prediction of weather/climate; mitigation of atmospheric pollution; mitigation of drought water and food shortages.</td>
</tr>
<tr>
<td>NOAA National Weather Service, National Centers for Environmental Prediction (NCEP)</td>
<td>solar radiation, precipitation, runoff, snow states, evaporation and transpiration, and soil moisture</td>
<td>Assessment and forecasting of water availability; irrigation agriculture efficiency; optimization of hydropower production; mitigation of drought water and food shortages.</td>
</tr>
</tbody>
</table>
Tools 3: Advanced Process-Resolving Models

Climate models’ grid-box representation of Earth’s processes...

Each grid-box can only represent the “average” conditions of its area.

However, controlling processes of the water cycle (e.g. precipitation) vary over much smaller areas.

- Useful prediction is critical – it is the link to stakeholders.
- We must move towards a new paradigm of climate models that produce useful weather-scale, process-scale, and application-scale prediction of local extremes (not just mean states).
- We must more fully constrain climate models with observations.
Land Information System  http://lis.gsfc.nasa.gov

Co-PIs:  P. Houser, C. Peters-Lidard

Summary: LIS is a high performance set of land surface modeling (LSM) assimilation tools.

Applications: Weather and climate model initialization and coupled modeling, Flood and water resources, precision agriculture, Mobility assessment ...

<table>
<thead>
<tr>
<th></th>
<th>Memory (MB)</th>
<th>Wallclock time (minutes)</th>
<th>CPU time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDAS</td>
<td>3169</td>
<td>116.7</td>
<td>115.8</td>
</tr>
<tr>
<td>LIS</td>
<td>313</td>
<td>22</td>
<td>21.8</td>
</tr>
</tbody>
</table>

reduction factor | 10.12 | 5.3 | 5.3 |

200 Node "LIS" Cluster
Optimized I/O, GDS Servers
Due to its importance, hydrologic data availability will increase.

Complete quantification of hydrologic variability requires innovative organization, comprehension, and integration of diverse hydrologic information due to disparity in observation type, scale, and error.

<table>
<thead>
<tr>
<th>Hydrologic Quantity</th>
<th>Remote-Sensing Technique</th>
<th>Time Scale</th>
<th>Space Scale</th>
<th>Accuracy Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Infrared</td>
<td>1hr</td>
<td>4km</td>
<td>Tropical convective clouds only</td>
</tr>
<tr>
<td></td>
<td>Passive microwave</td>
<td>3hr</td>
<td>10km</td>
<td>Land calibration problems</td>
</tr>
<tr>
<td></td>
<td>Active Microwave</td>
<td>10day</td>
<td>10m</td>
<td>Land calibration problems</td>
</tr>
<tr>
<td>Surface Soil Moisture</td>
<td>C or L-band microwave</td>
<td>10day</td>
<td>10m</td>
<td>Significant noise from vegetation and roughness</td>
</tr>
<tr>
<td></td>
<td>C- or L-band radiometer</td>
<td>1-3day</td>
<td>10m</td>
<td>limited to sparse vegetation, low topographic relief</td>
</tr>
<tr>
<td>Surface Skin Temperature</td>
<td>infrared</td>
<td>1hr</td>
<td>10m</td>
<td>soil/vegetation average, cloud contamination</td>
</tr>
<tr>
<td>Snow Cover</td>
<td>visible/infrared</td>
<td>1hr</td>
<td>10m</td>
<td>Cloud contamination, vegetation masking, bright soil problems</td>
</tr>
<tr>
<td>Snow Water Equivalent</td>
<td>passive microwave</td>
<td>1-3day</td>
<td>10km</td>
<td>Limited depth penetration</td>
</tr>
<tr>
<td>Water level/velocity</td>
<td>active microwave</td>
<td>10day</td>
<td>10m</td>
<td></td>
</tr>
<tr>
<td>Total water storage changes</td>
<td>gravity changes</td>
<td>30day</td>
<td>1000km</td>
<td>Bulk water storage change</td>
</tr>
<tr>
<td>Evaporation</td>
<td>IR and Models</td>
<td>1hour</td>
<td>4km</td>
<td>Significant assumptions</td>
</tr>
</tbody>
</table>
**Case 1:** Land observations leading to improved climate prediction (M. Rodell)

- **TRMM & IR total precipitation [mm]**
- **Geostationary satellite daily mean downward SW radiation [W/m²]**
- **MODIS derived leaf area index**
- **MODIS snow cover [%]**

...RESULTS IN IMPROVED MODEL SIMULATIONS...

Model assimilation: LIS/LDAS snow water equivalent [mm] without (far left top) and with (far left bottom) assimilated MODIS snow cover; IMS snow cover “truth” (near left), 20 Jan 2003. Improvement in modeled surface temperature [°C] when MODIS leaf area index is incorporated into the land surface model (right).

...AND LEADS TO MORE ACCURATE PREDICTIONS.

Seasonal forecast model initialization: JJA 1988 observed seasonal precipitation anomaly [mm/day] (above left); NSIPP model prediction without (above center) and with (above right) LDAS initial soil moisture [Koster et al., 2003]
Case 2: USBR Water Supply Forecasting

Reclamation DST for Using NASA Modeling and Satellite Data for US Bureau of Reclamation Water Supply Forecasting

**INPUTS**
- Science Models
- Land Information System (LIS)
- Land Data Assimilation System (LDAS)
- Satellite Data
  - MODIS, ETM+, ASTER, IKONOS, SRTM, TRMM, AMSR, etc.

**OUTPUTS**
- Improved RiverWare & ET Toolbox Forcing:
  - Snowmelt, ET, Precipitation, Runoff, Soil Moisture
- Improved RiverWare & ET Toolbox Parameters:
  - Snow Water Equivalent, Land Use/Cover

**OUTCOMES**
- Reclamation’s Decision Support Tools
  - RiverWare & ET Toolbox
- Improved Water Supply & Forecasting
- Improved Short-Term & Long-Term Predictions

**IMPACTS**
- Improved Water Availability For Water Management
  - Including Reservoir Regulation for:
    - Hydroelectric Power,
    - Flood Control,
    - Irrigated Agriculture
    - Public Use,
    - Endangered Species,
    - Clean Water,
    - Industrial Usage

Schematic of the approach for developing and implementing NASA remotely sensed and modeling products into Reclamation DSS’s and modeling tools.
Integration of NASA Products: Land Cover, Snow, Evapotranspiration, Streamflow, Soil Moisture, Other

Goal to produce successful demonstration of these applications-based studies using NASA data for applications such as Hydro-energy management.

Paul R. Houser, 22 December 2005, Page 15
Key LIS Result: Bondville, IL, July-Sept 2001

LIS’s ability to represent 1km & finer heterogeneity, produces differences in 0.25 degree mean sensible heat flux ($Q_h$)

Topography

Land Cover

Soils
Challenge

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- So, what can we do about this?
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    - Define research priorities based on needs
    - Observe key environmental factors
    - Integrate information from diverse sensors
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