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)

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Challenge

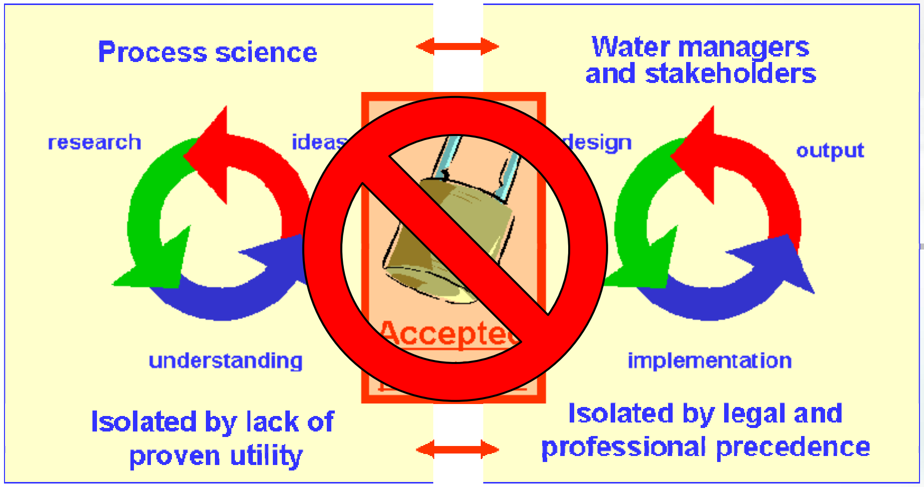
Conduct research that addresses end-user needs, and
nurture the transition of these research results into straightforward end-user solutions.

- 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

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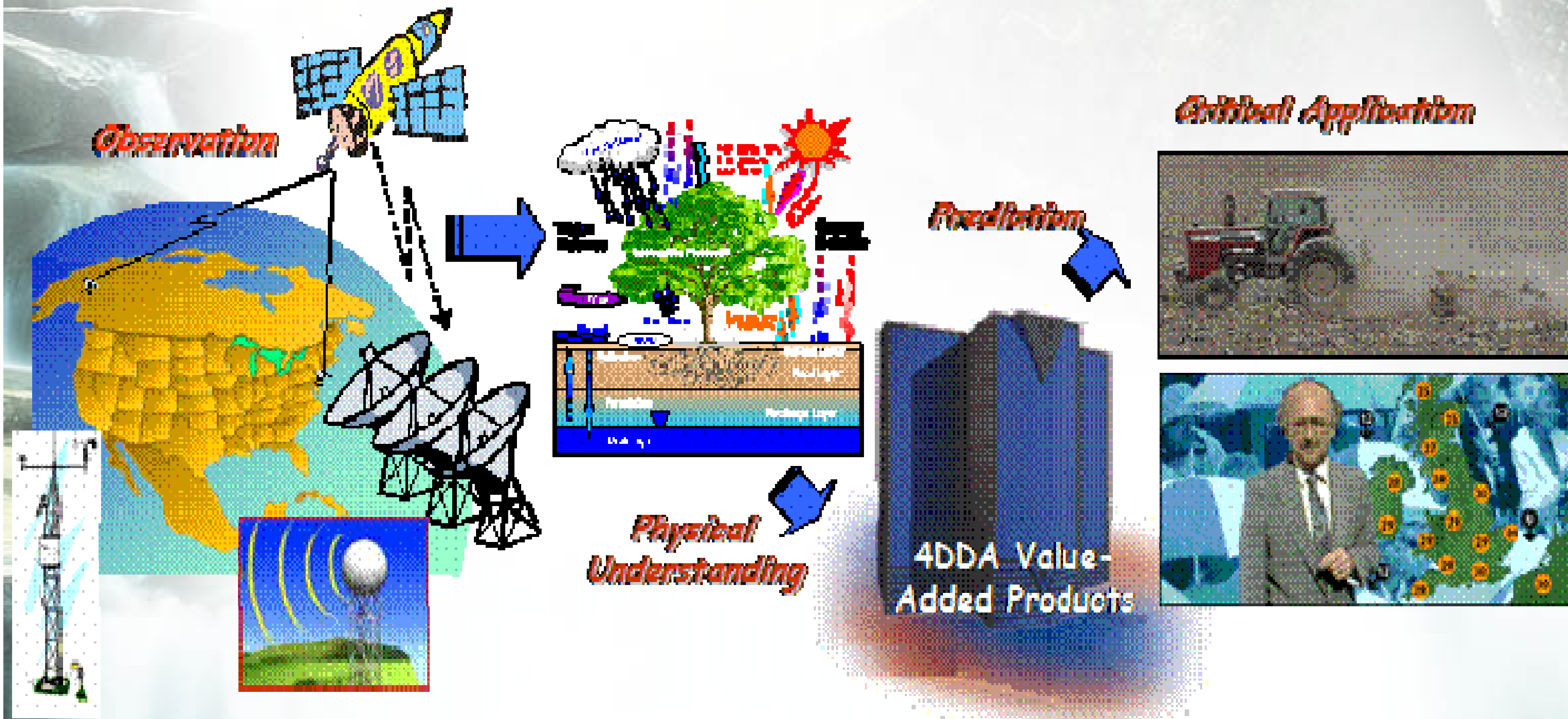
Linking Science to Consequences

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

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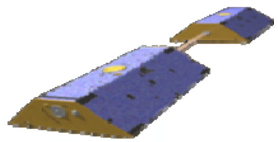
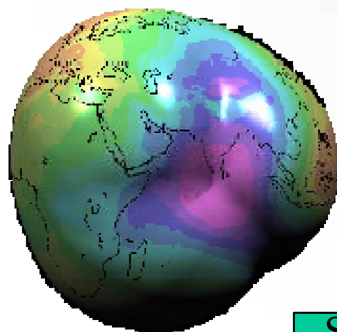
Use the adequate tool for the job…

Strategy 1: NASA Water Management Strategy

Terra

GRACE





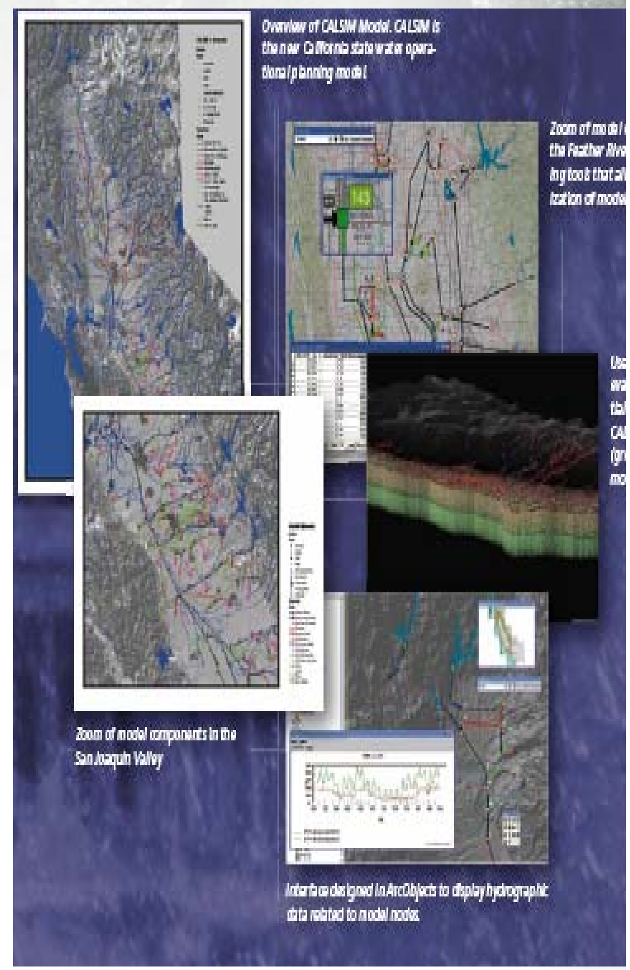
Processing

Societal Benefits

Exploitation

EOSDIS & DAACs

Data Assimilation & Modeling



Riverware & AWARDS

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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.

NASA & Partner Research

NASA & Partner Community Models

Atmospheric Forcing: GMAO, GDAS, NCEP, NCAR, ECMWF, AGRMET
Land: LIS (CLM, VIC, Noah, SSiB, HySSiB, Mosaic, CLSM, etc.), SAC
Coupled: GMAO, WRF, GCE, ESMF

Observation Methods & Platforms

Satellite: EOS Terra & Aqua, SSMI, SRTM, NPP, Landsat, ICESaT, GRACE, TRMM & GPM, CloudSAT, GOES, NPOESS, HYDROS, etc.
Sub-orbital: MW, Vis/IR, Lidar, UAVs
In-situ: Meso- and micronets, Surfrad, ARM, GTS, field campaigns, etc.

DST Partnership Opportunities

Observations & Predictions

Forcing: Radiation & Clouds, Water Vapor, Precipitation, Temperature, Winds, etc.
Parameters: Topography, Vegetation & Soil Properties
States: Snow Cover & Depth, Soil & Vegetation Moisture, Water Levels, Water Availability, Aquifer States
Fluxes: Radiation, Carbon, Evaporation, Transpiration, Precipitation, Runoff, etc.

Example Partner Agency DSTs

Agricultural Efficiency: USDA: NIDIS
Air Quality: USEPA: CMAQ
Aviation: NOAA NCEP: Eta & WRF
Carbon Management: GEWEX CEOP
Coastal Management: USACE: CWMS
Disaster Management: RMS RiskLink
Ecological Forecasting: USDA: AGWA
Energy Management: USBR: RiverWare
Homeland Security: Army: ARMS
Invasive Species: USBR: AWARDS
Public Health: USEPA: BASINS
Water Management: NOAA: NWSRFS

Value & Benefit

Policy Decisions: Flood and disease warning; Agricultural production & efficiency; Aircraft & travel safety; Weather warnings; Ecological diversity; Optimized energy production; Drinking water protection; Water use efficiency
Management Decisions: Energy & agricultural production; Land use allocation; Aircraft scheduling; Weather avoidance; Climate change mitigation; Disaster response; Community planning; Insurance issues
Exploration Decisions: Storm prediction; Search for water & life; Resource assessment.

National Academy of Sciences & National Leadership Reviews

INPUTS | OUTPUTS | OUTCOMES | IMPACTS

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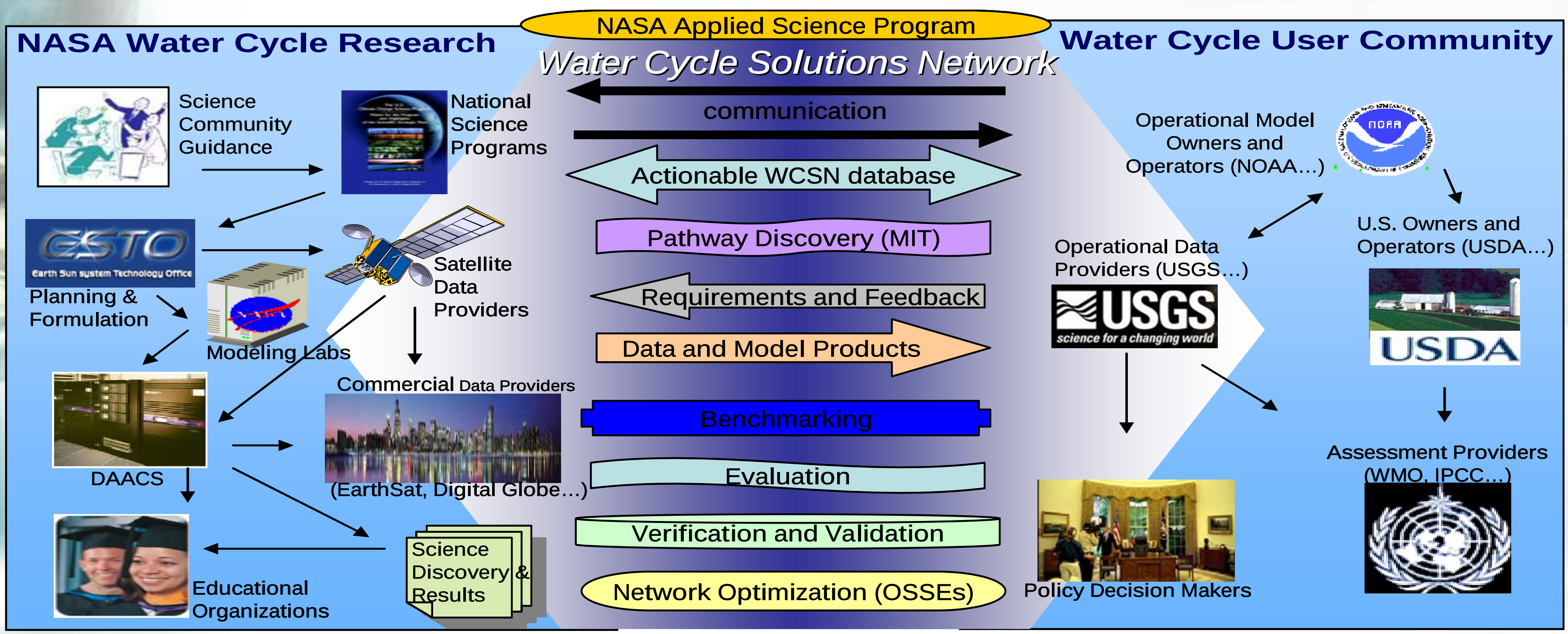
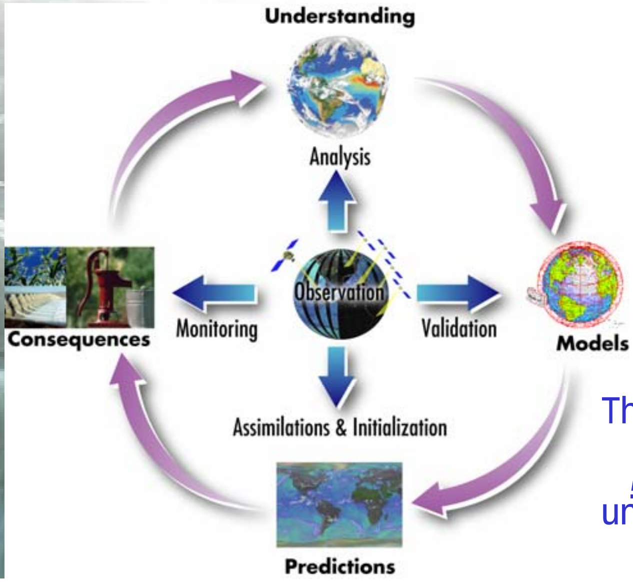
Strategy 3: Solution Networks

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

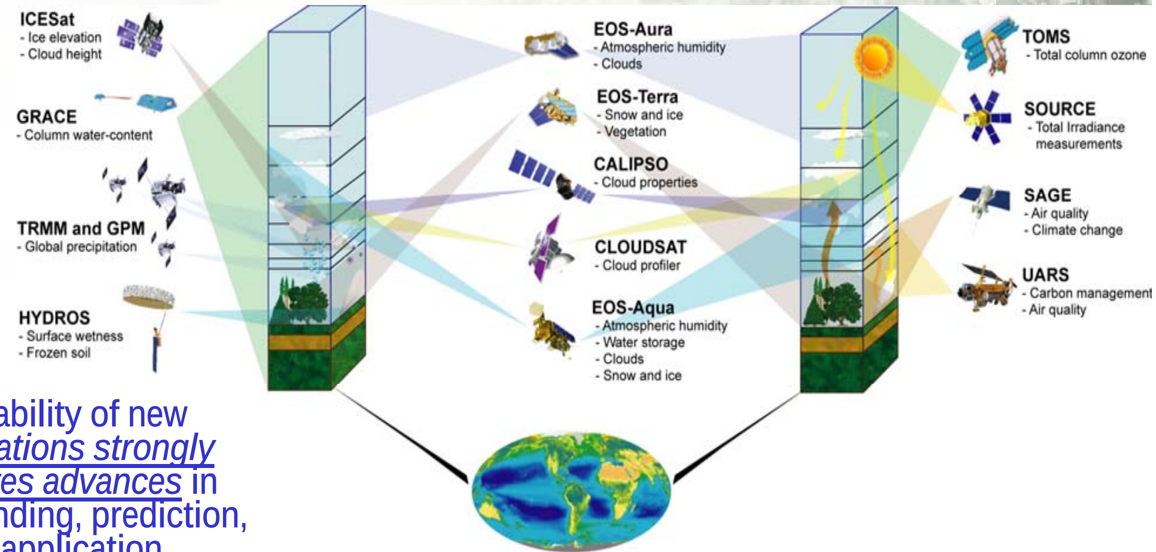
1. *Evolve a network of partners:* identify and analyze community-of-practice organizations, DSTs and their requirements and develop well-constructed teams and partnerships to define collaboration pathways.
2. *Routinely identify, prioritize, mine and communicate relevant research products and results:* develop operational information system pathways to provide timely user-community access.
3. *Optimize water cycle partner access* to research resultsand 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.



Tools 1: Surface observations



The availability of new *observations strongly motivates advances* in understanding, prediction, and application.



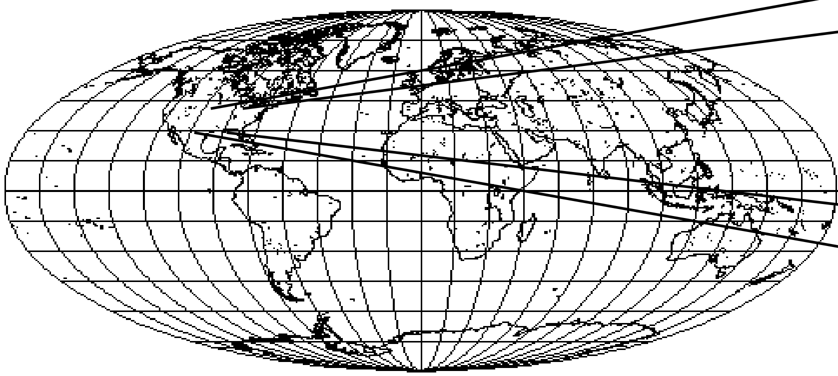
Class	Observation	Technique	Example Platform	Temporal	Spatial
Land Parameters	Leaf area and greenness	optical/IR	AVHRR, MODIS, NPOESS	weekly	1km
	Albedo	optical/IR	MODIS, NPOESS	weekly	1km
	Emissivity	optical/IR	MODIS, NPOESS	weekly	1km
	Vegetation structure	lidar	ICESAT, ESSP lidar mission	weekly-monthly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

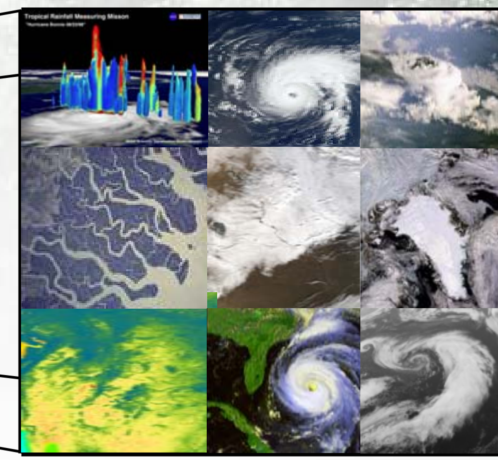
Tools 2: Decision Support Tools

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

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.

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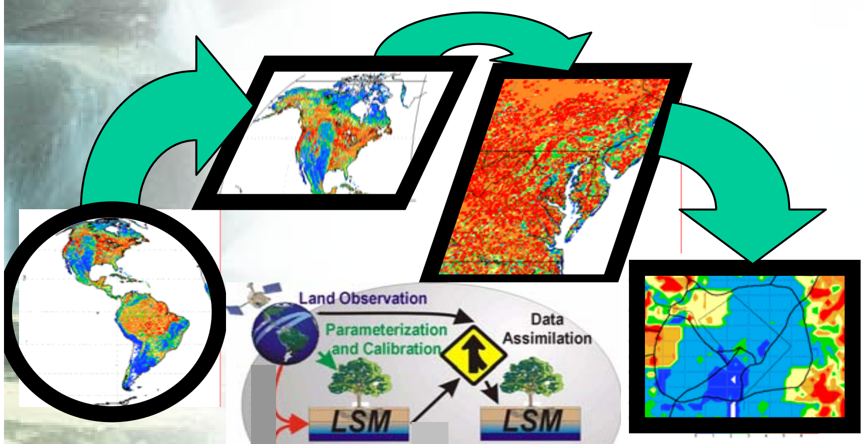
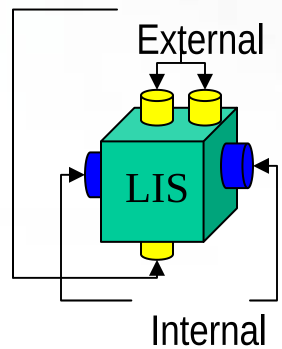
Land Information System http://lis.gsfc.nasa.gov

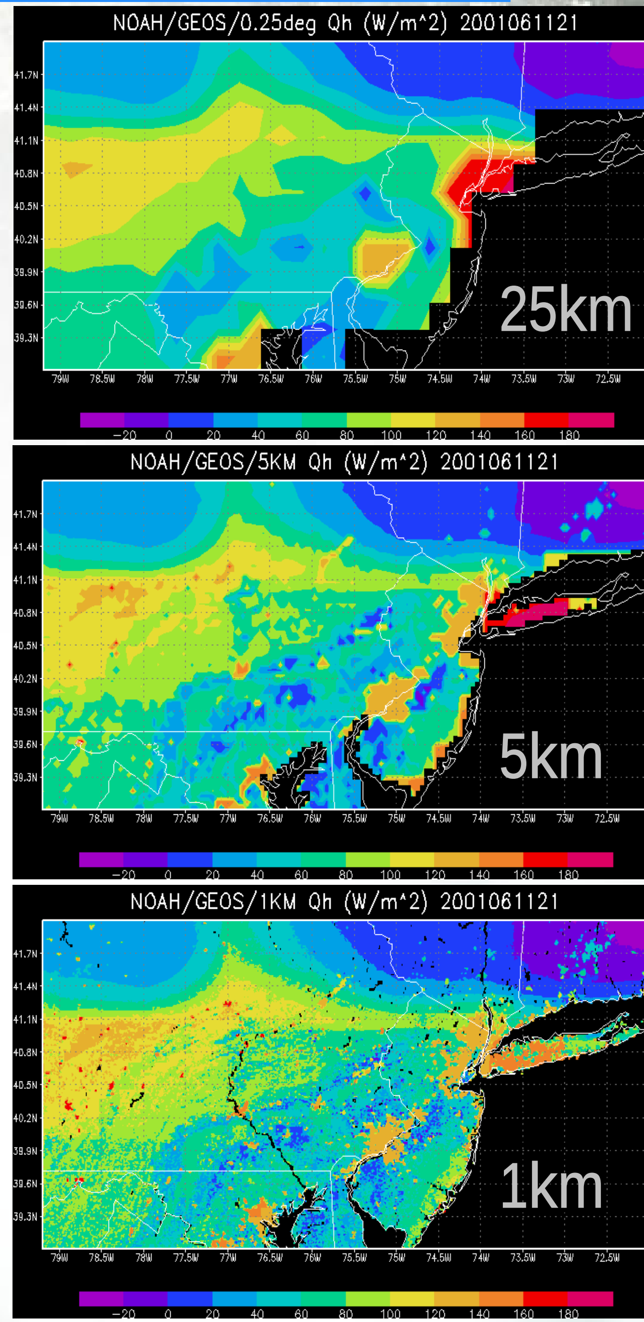
Co-PIs: P. Houser, C. Peters-Lidard

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 …







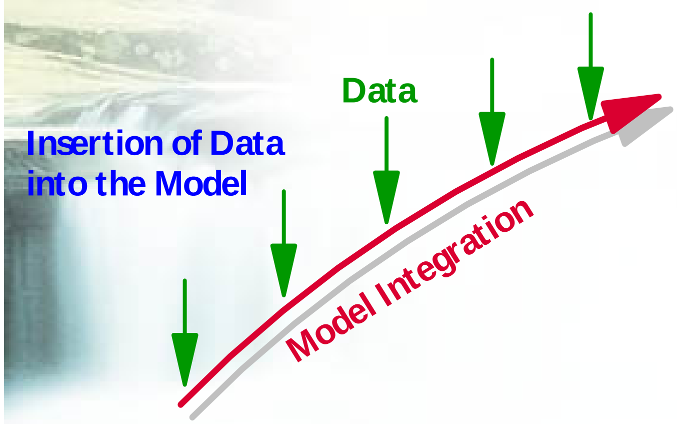
200 Node "LIS" Cluster
Optimized I/O, GDS Servers

	Memory (MB)	Wallclock time (minutes)	CPU time (minutes)
LDAS	3169	116.7	115.8
LIS	313	22	21.8
reduction factor	10.12	5.3	5.3

Tools 4: Observation Integration: Assimilation & Calibration

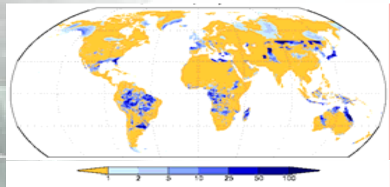
Due to its importance, hydrologic data availability will increase.

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

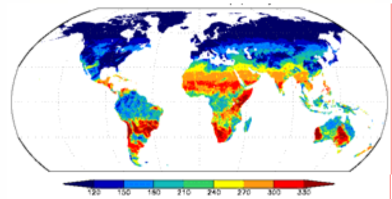


Hydrologic Quantity	Remote-Sensing Technique	Time Scale	Space Scale	Accuracy Considerations
Precipitation	Infrared	1hr	4km	Tropical convective clouds only
	Passive microwave	3hr	10km	Land calibration problems
	Active Microwave	10day	10m	Land calibration problems
Surface Soil Moisture	C or L-band radar	10day	10m	Significant noise from vegetation and roughness
	C- or L- band radiometer	1-3day	10km	limited to sparse vegetation, low topographic relief
Surface Skin Temperature	infrared	1hr	10m	soil/vegetation average, cloud contamination
Snow Cover	visible/infrared	1hr	10m	Cloud contamination, vegetation masking, bright soil problems
Snow Water Equivalent	passive microwave	1-3day	10km	Limited depth penetration
	active microwave	10day	10m	
Water level/velocity	laser	10day		Cloud penetration problems
	radar	10day		
Total water storage changes	gravity changes	30day	1000km	Bulk water storage change
Evaporation	IR and Models	1hour	4km	Significant assumptions

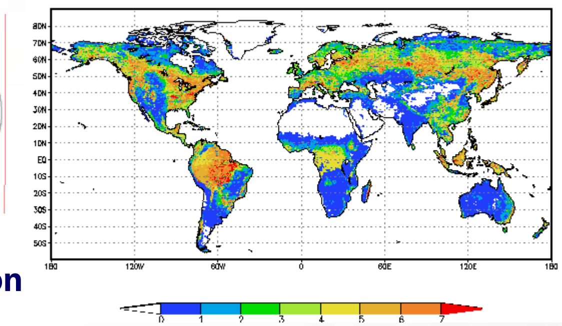
Case 1: Land observations leading to improved climate prediction (M. Rodell)



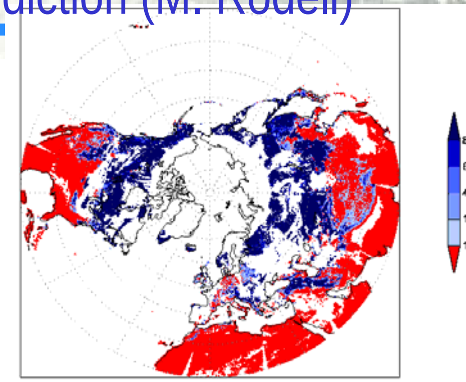
TRMM & IR total precipitation [mm]



Geostationary satellite daily mean downward SW radiation [W/m2]

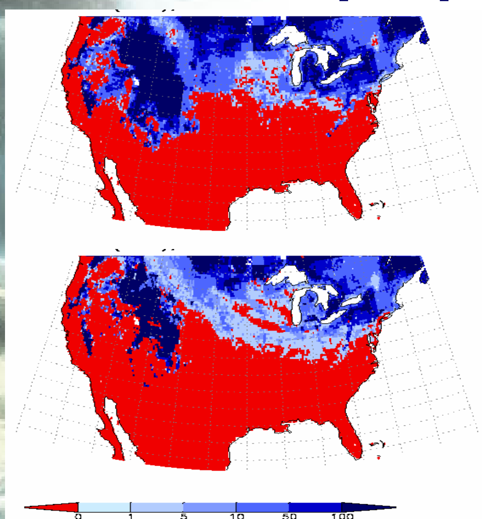


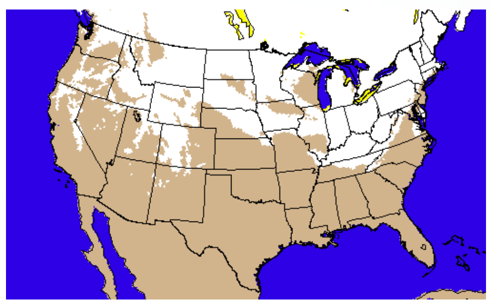
MODIS derived leaf area index



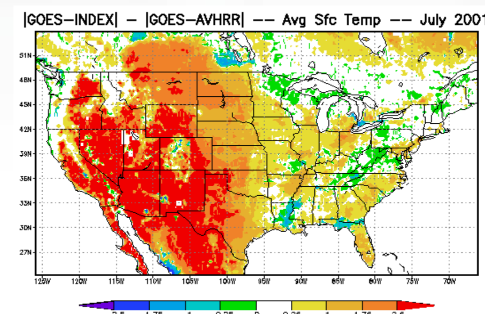
MODIS snow cover [%].

…RESULTS IN IMPROVED MODEL SIMULATIONS…

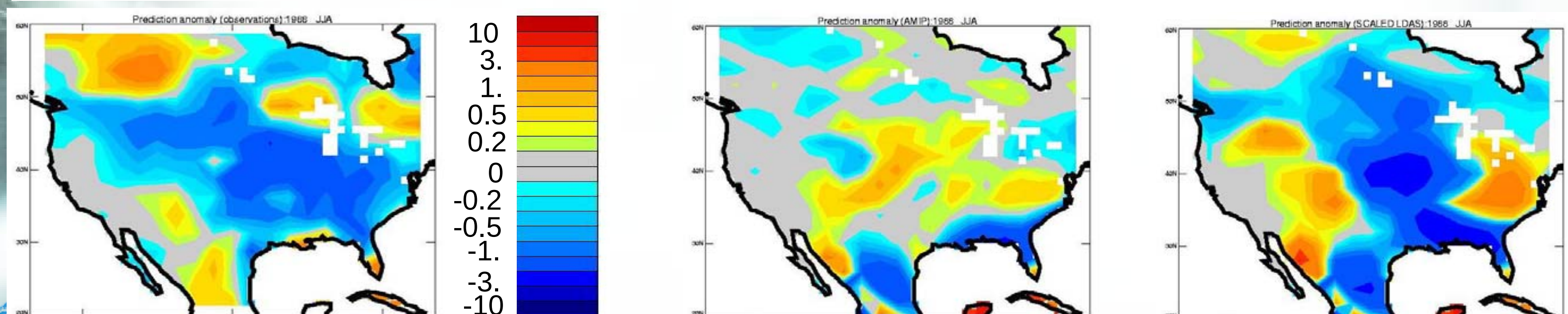




Model assimilation: LIS/LDAS snow water equivalent [mm] without (far left top) and with (far left bottom) assimilated MODIS snow cover; IMS snow cover “truth” (near left), 20 Jan 2003. Improvement in modeled surface temperature [C] when MODIS leaf area index is incorporated into the land surface model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

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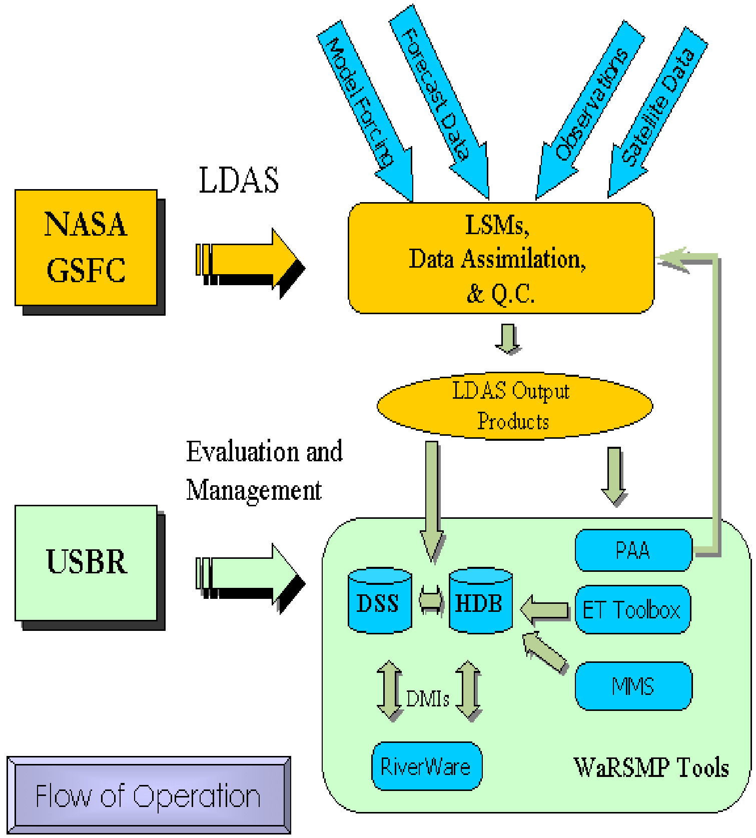
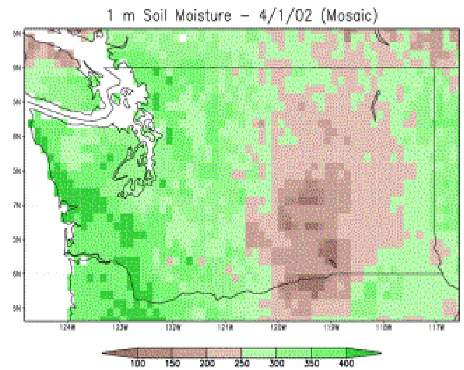
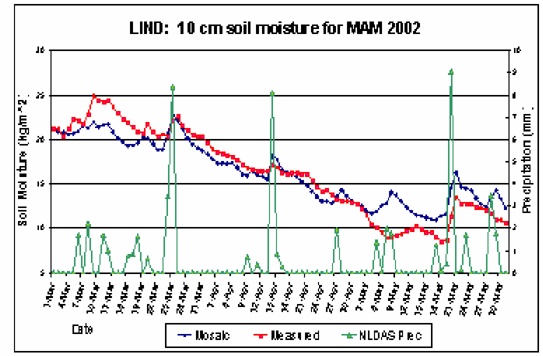
NASA – Bureau of Reclamation Study



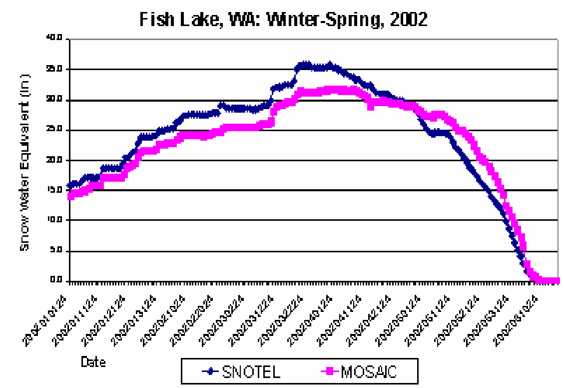
Soil Moisture Analysis





Columbia River Basin in Washington state

Initial in-situ observation and land surface model gridbox comparison for different state and atmospheric variables



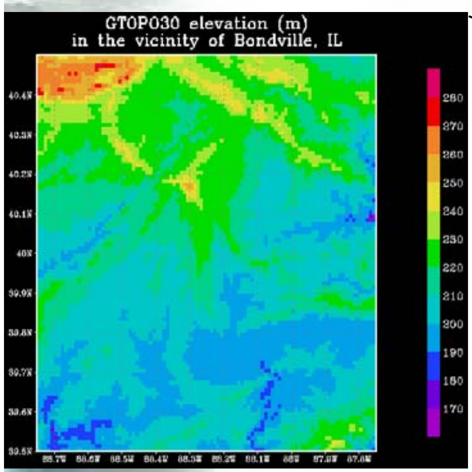
Snow Water Equivalent

Integration of NASA Products: Land Cover, Snow, Evapotranspiration, Streamflow, Soil Moisture, Other

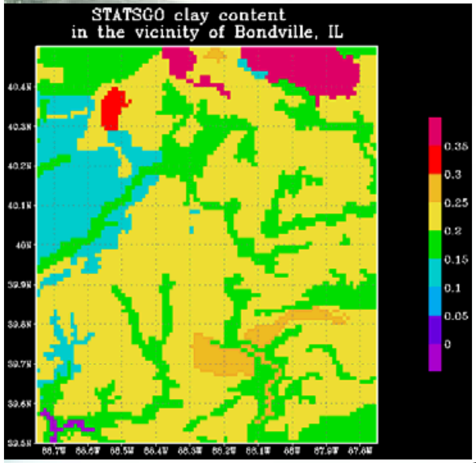
Goal to produce successful demonstration of these applications-based studies using NASA data for applications such as Hydro-energy management.

Key LIS Result: Bondville, IL, July-Sept 2001

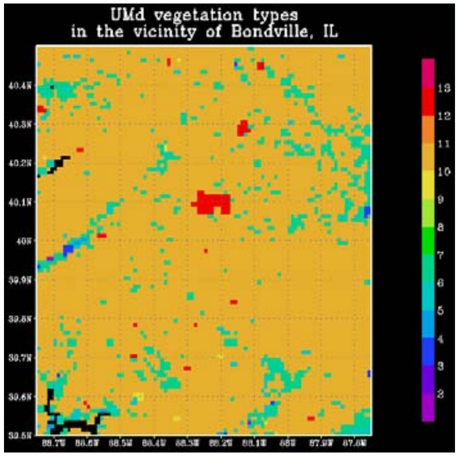
Topography



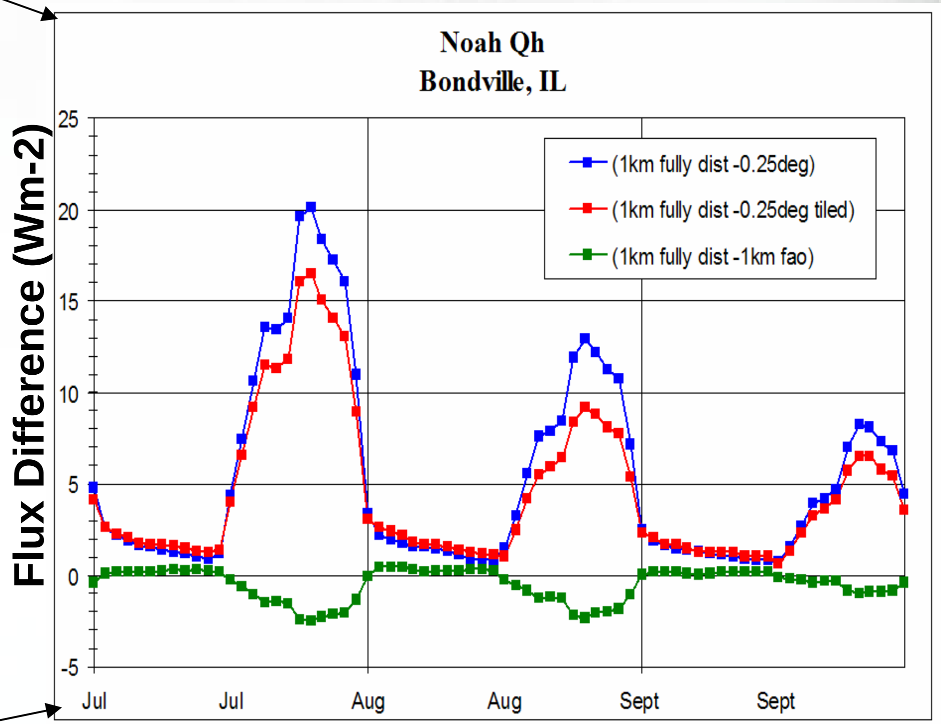
Soils



Land Cover



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



Monthly Average Diurnal Cycle

Challenge

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- 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.
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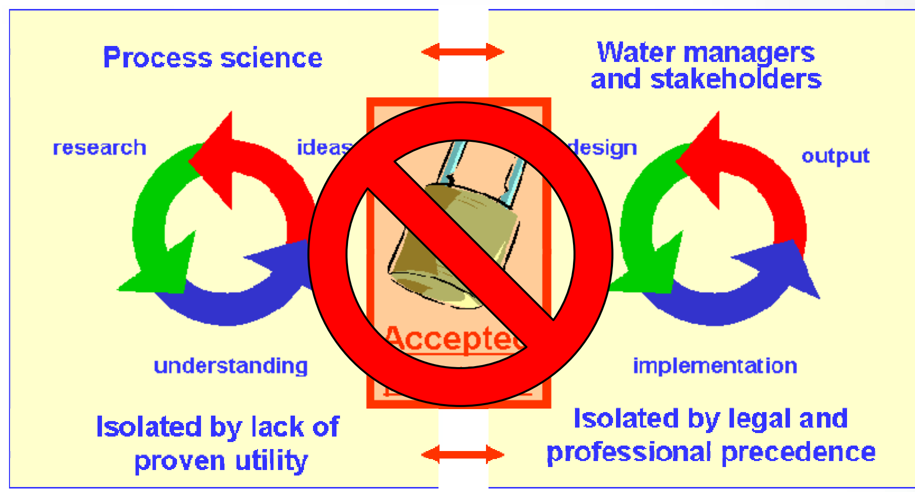

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