Use of Data Assimilation Products for Water Resources Management

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

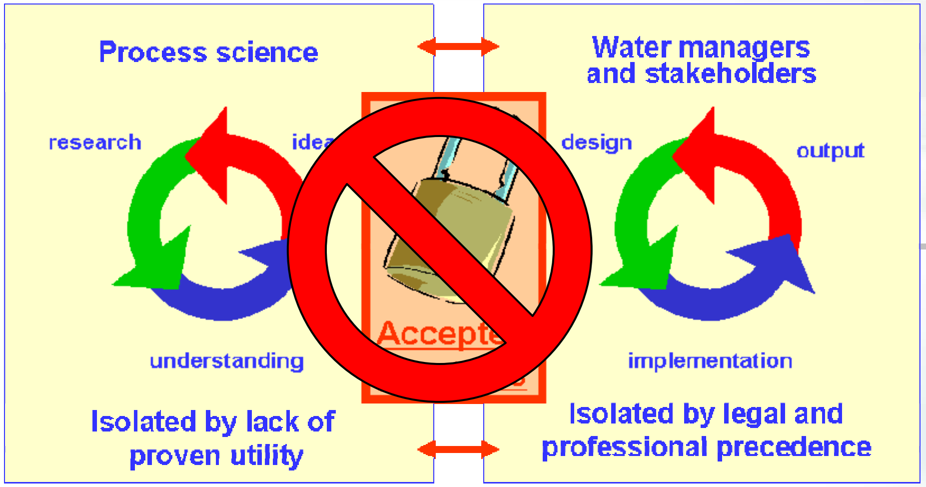
Acknowledgments: D. Toll (GSFC), A. Pinheiro (NRC), M. Rodell (GSFC), C. Peters-Lidard (GSFC), C. Schlosser (MIT)

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.

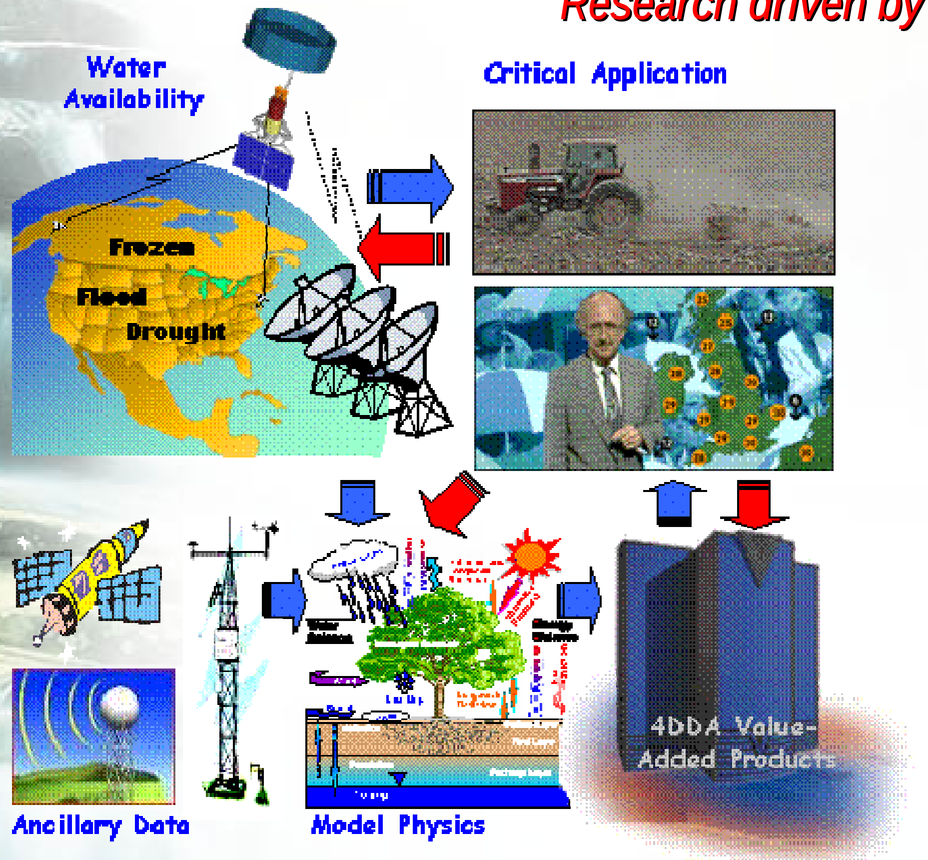
- Information about land surface conditions is **critical for real-world applications.**
- Users are **inundated with observations and model output** in disparate formats and locations.
- Science and technology has the potential to improve water management….
- So, why doesn't research and technology 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).
- Paradigm lock: (1) science lacks proven utility, (2) users isolated by 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



- 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



Use the adequate tool for the job…

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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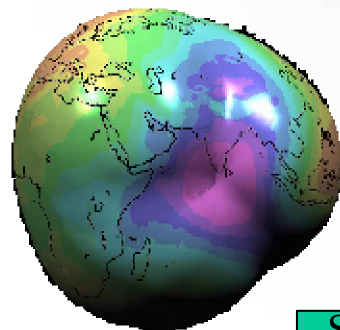
Strategy 1: NASA Water Management Strategy

Terra

GRACE

Processing

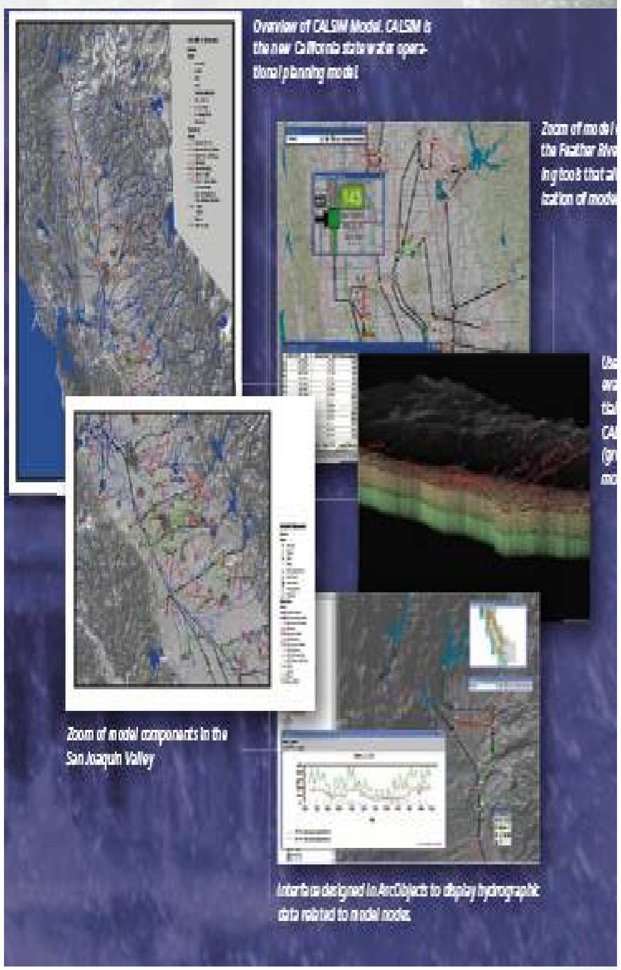


Societal Benefits

EOSDIS & DAACs

Exploitation

Data Assimilation & Modeling



Riverware & AWARDS

Strategy 2: Integrated Systems Solutions

Integrate research and end-user solutions build around a **modeling and analysis system**:

(a) Customize, **develop and test** modeling & analysis tools for use in specific DST solutions

(b) Demonstrate prototype solution: manage data, generate runs, make data available

(c) Maintain software, data, and visualization tools up-to-date, and answer user inquiries

(d) Analysis, optimize, **benchmark**, evaluate and verify, prototype, and **document** solutions.

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.

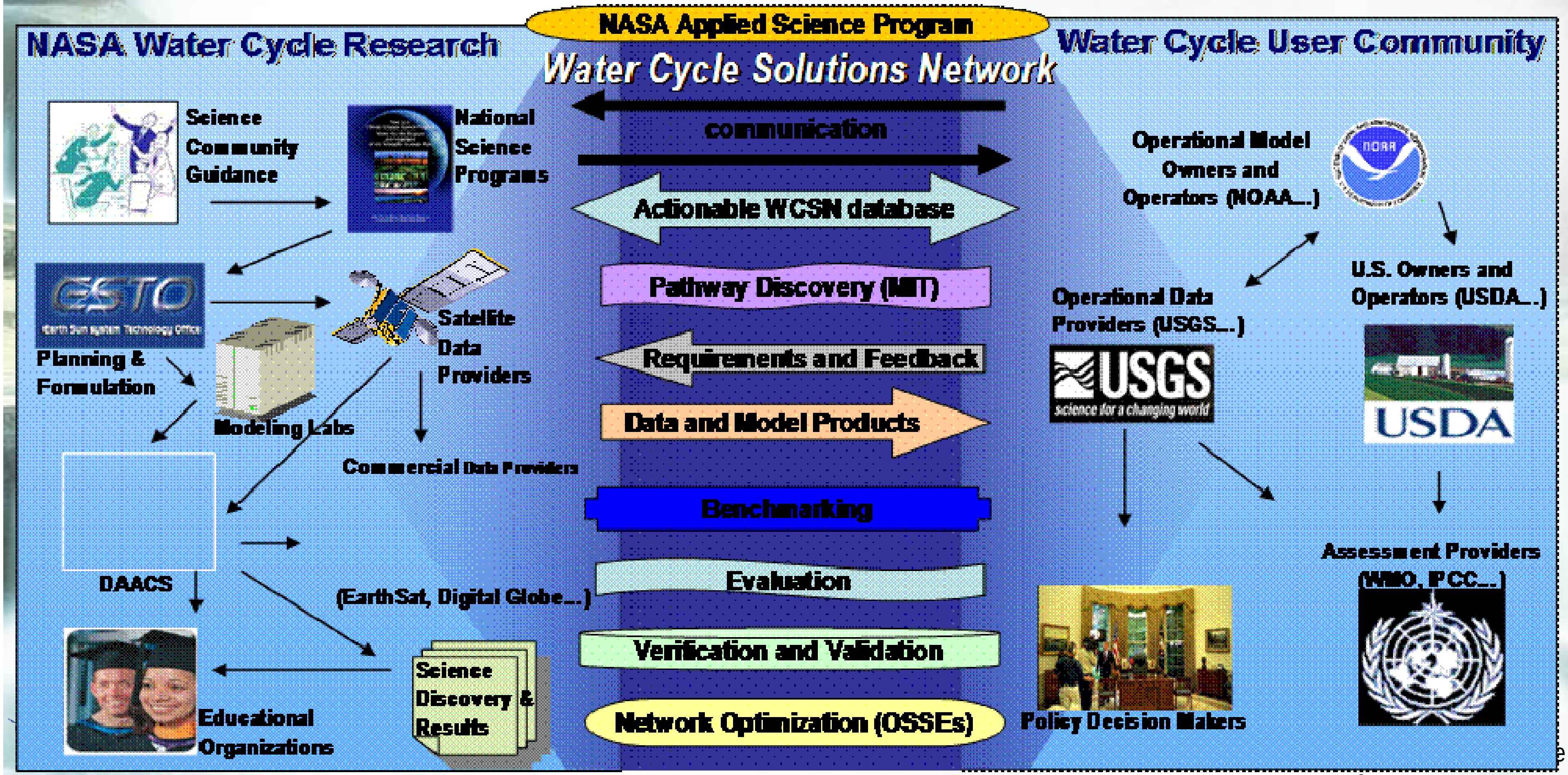
National Academy of Sciences & National Leadership Reviews

INPUTS	OUTPUTS	OUTCOMES	IMPACTS

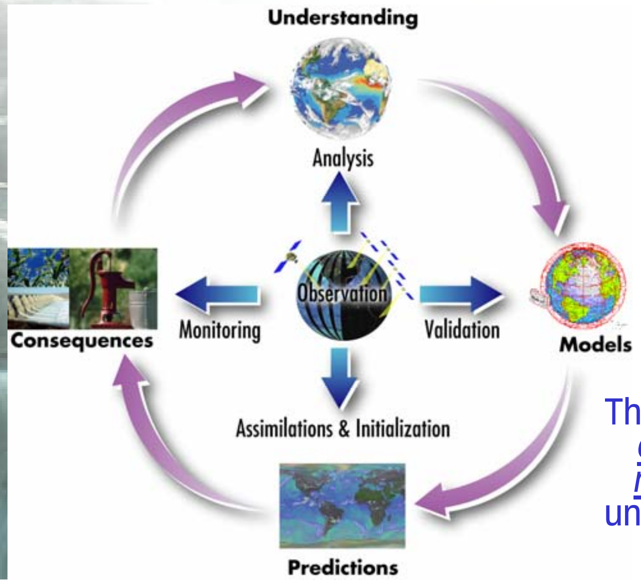
Strategy 3: Solution Networks

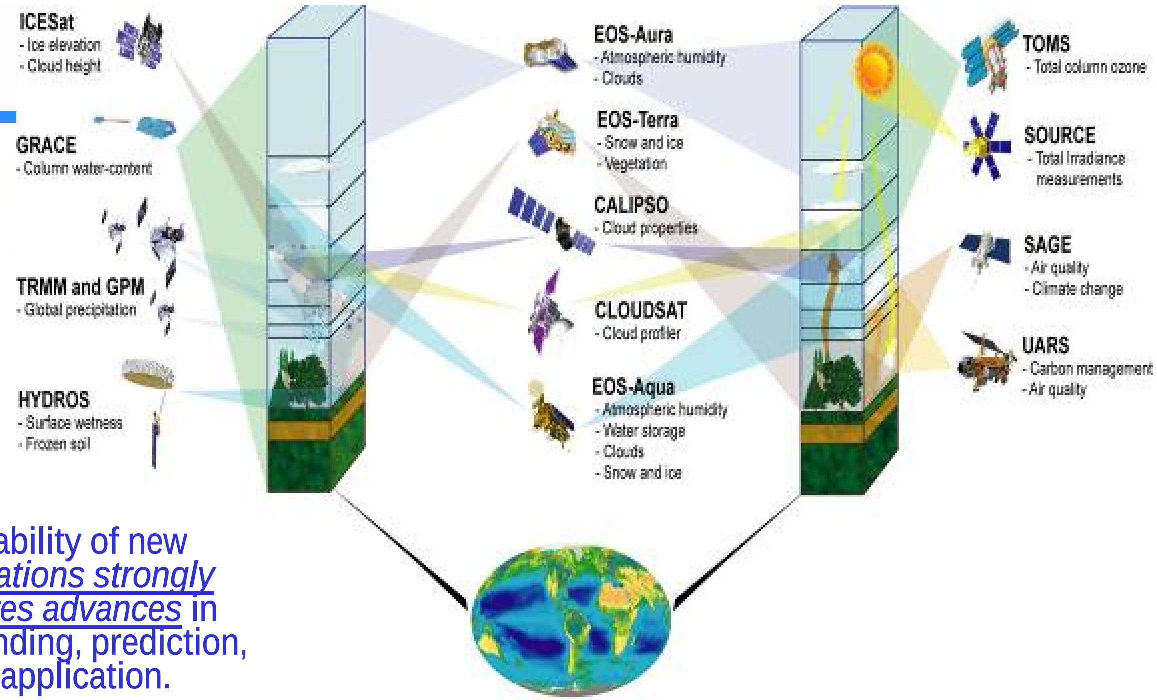
"A Water Cycle Solutions Network" was approved by NASA on June 3, 2005, to establish pathways and partnerships between NASA's water cycle research investments and decision support needs.

1. *Evolve a network of partners:* identify and analyze partner organizations to define collaboration pathways.
2. *Routinely identify, prioritize, mine and communicate relevant research products and results.*
3. *Optimize water cycle partner access* to research results and products to create a self-sustaining network.
4. *Analyze and document* the network effectiveness through metrics, resource estimates and documentation.
5. *Education and outreach* is important to help society understand and use the research in every-day application.



Tools 1: 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

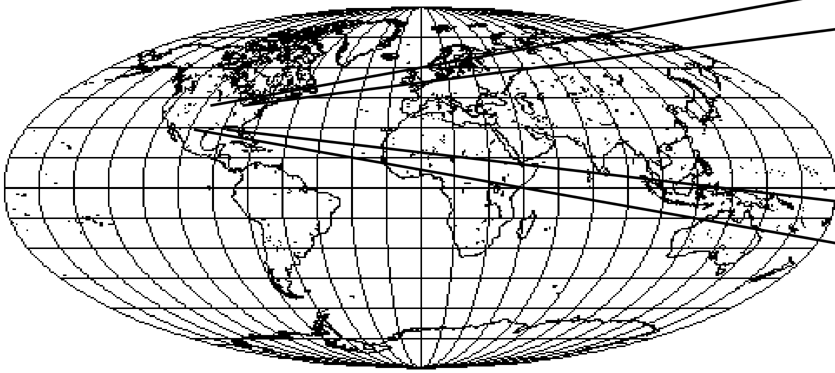
Tools 2: Decision Support Tools

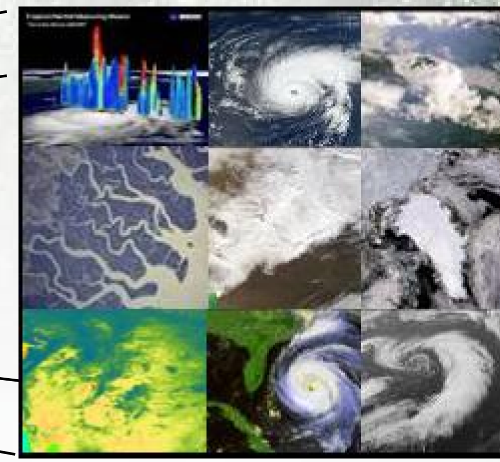
- Land surface conditions are of critical importance to a wide range of crosscutting applications of national priority, such as agricultural production, water resource management, flood prediction, water supply, etc.
- A sampling of water management DSTs is listed below.

Potential Partner Agencies and DSTs	Observations and Model Fields	Potential Value and Benefits to Citizens and Society
US Bureau of Reclamation, **RiverWare**	precipitation, runoff, soil moisture, snow states, and evapotranspiration	Reservoir regulation; water supply, hydrolelectric power and recreation; flood reduction; mitigation of drought.
US Army Corps of Engineers **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.
Combat Terrain Information System and **Army Remote Moisture System**	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, **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.
(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.
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	solar radiation, precipitation, runoff, snow states, evaporation and transpiration, and soil moisture	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.

Developing Advanced Process-Resolving Models

- 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, ti improve their realism and believability.

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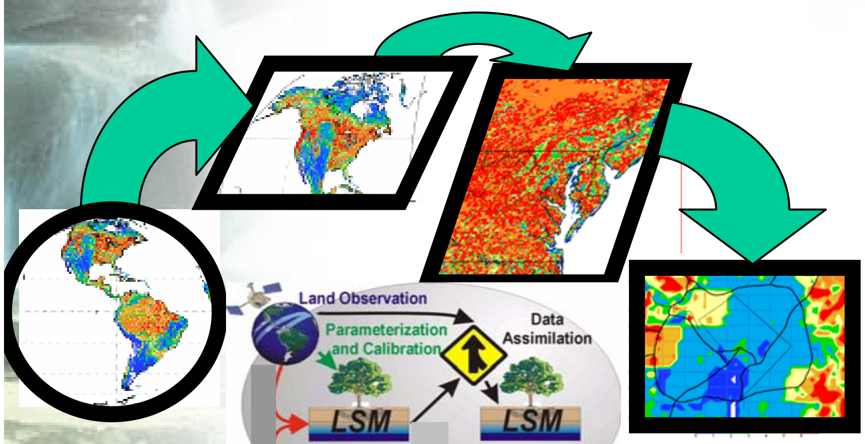
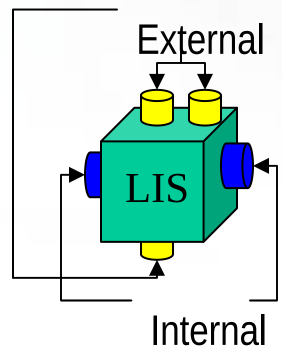
Land Information System http://lis.gsfc.nasa.gov

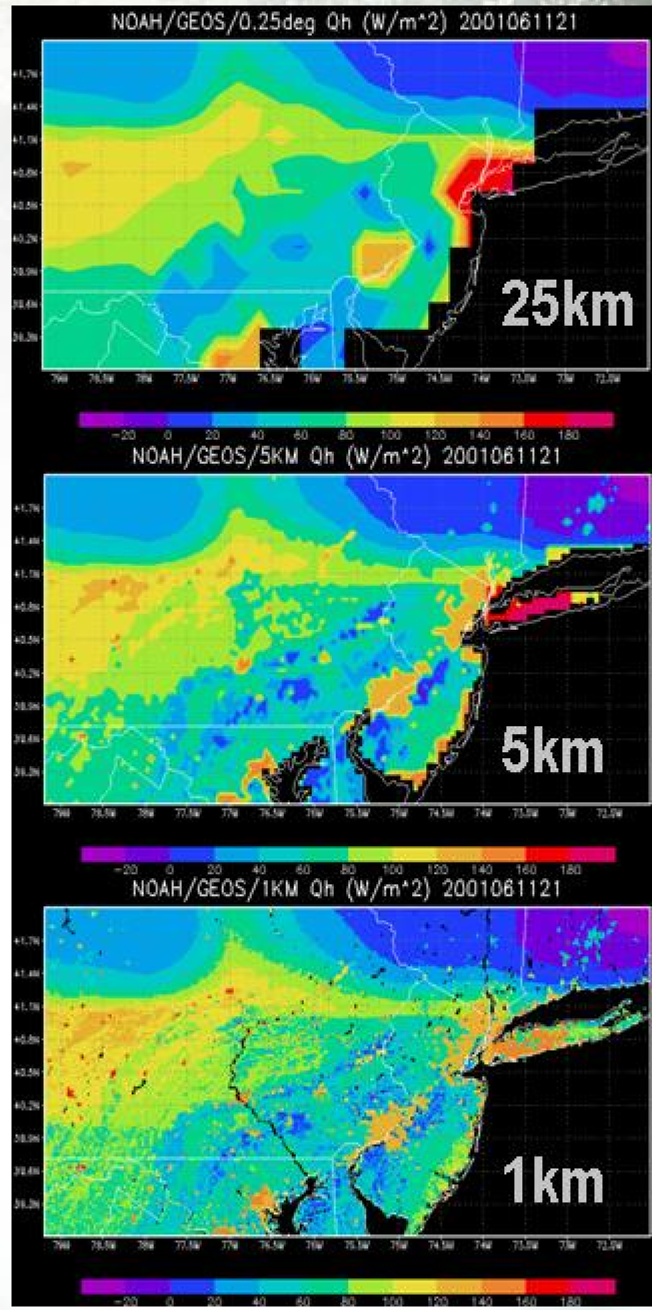
Co-PIs: P. Houser, C. Peters-Lidard

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 …





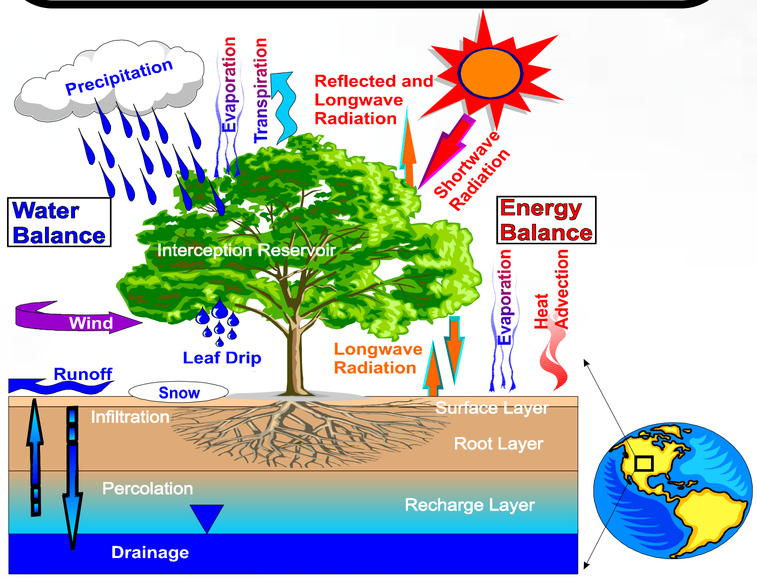


	Memory (MB)	Wallclock time (minutes)	CPU time (minutes)
LDAS	3169	116.7	115.8
LIS	313	22	21.8
reduction factor	10.12	5.3	5.3

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

Land Information System

Inputs	Physics	Outputs	Applications
Topography, Soils	Land Surface Models (LSM) Physical Process Models Noah, CLM, VIC, SiB2, Mosaic, Catchment, etc.	Energy Fluxes: Le & H	Water Supply & Demand,
Land Cover and Vegetation (MODIS, AMSR, TRMM, SRTM)		Biogeo-chemistry: Carbon, Nirtogen, etc.	Agriculture, Hydro-Electric Power, Endangered Species, Water Quality
Meteorology Modeled & Observed (TRMM, GOES, Station)		Water Fluxes: Runoff	
Observed Land States (Snow, ET, Soil Moisture, Groundwater, Carbon, etc.)	Data Assimilation Modules (EnKF, EKF) Physical Space Analysis System (PSAS) 3-D VAR Rule-based	Surface States: Moisture, Carbon, Ts	Improved Short Term & Long Term Predictions



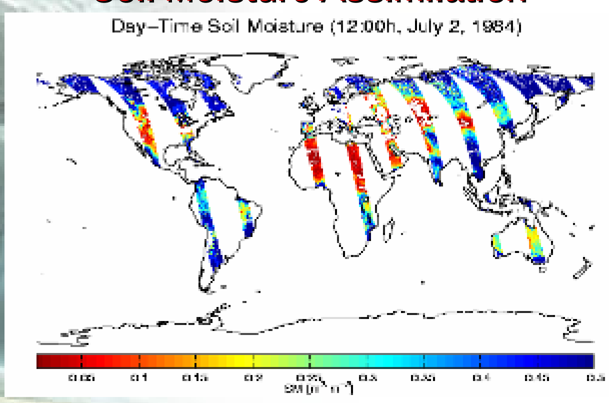
(Peters-Lidard, Houser, Kumar, Tian, Geiger)

Land Surface Data Assimilation Summary

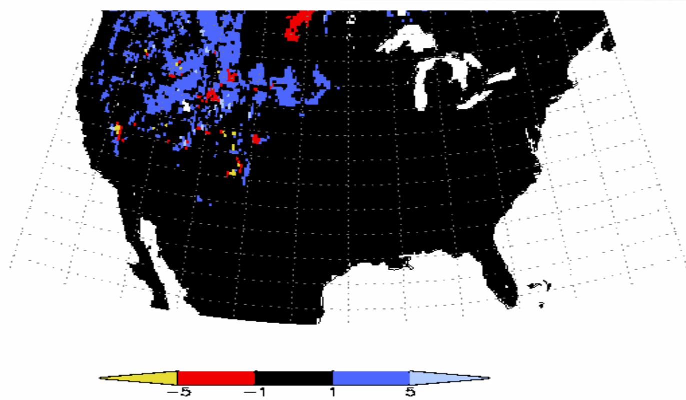
Data Assimilation merges observations & model predictions to provide a superior state estimate.

Remotely-sensed hydrologic state or storage observations (temperature, snow, soil moisture) are integrated into a hydrologic model to improve prediction, produce research-quality data sets, and to enhance understanding.

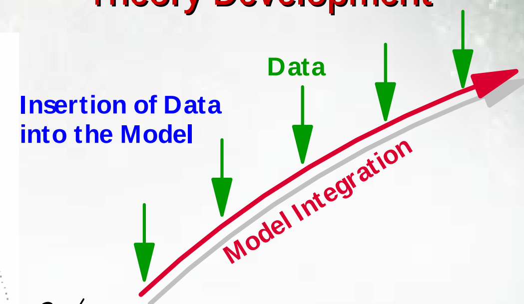
Soil Moisture Assimilation



Snow Cover Assimilation

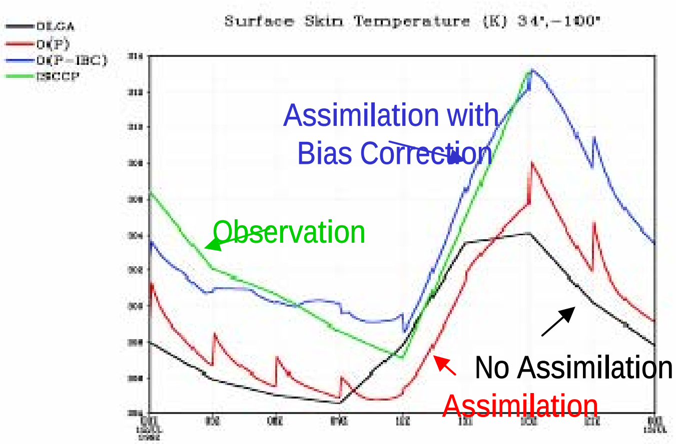


Theory Development

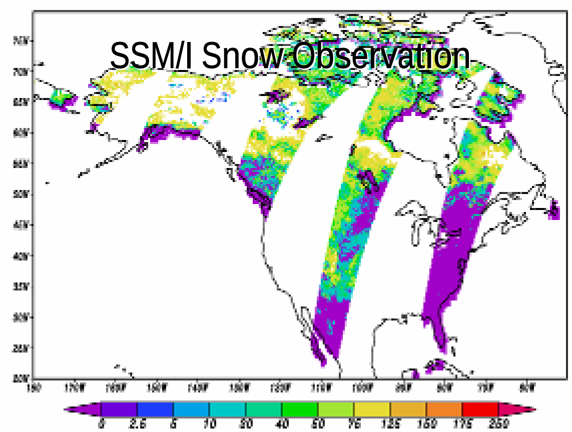


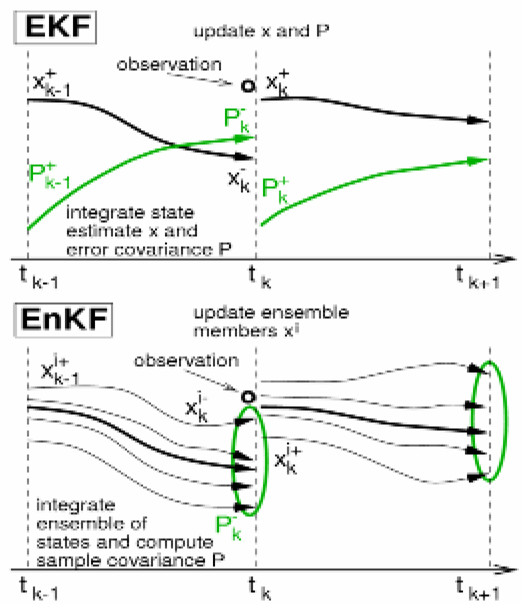
$$\partial x / \partial t = dynamics + physics + \Delta x$$

Skin Temperature Assimilation



Snow Water Assimilation





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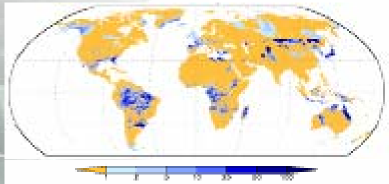
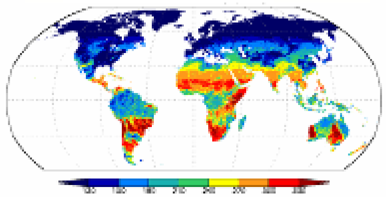
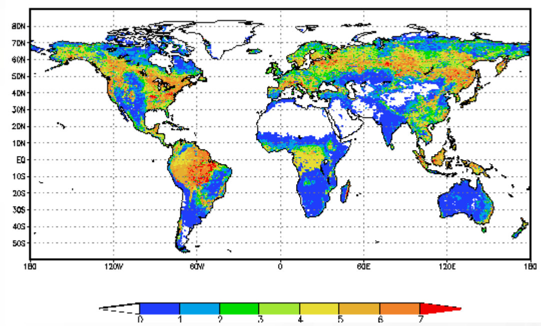
Case 1: Land observations leading to improved climate prediction (M. Rodell)



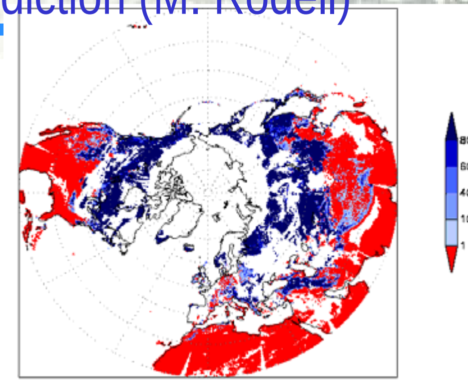
TRMM & IR total precipitation [mm]



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

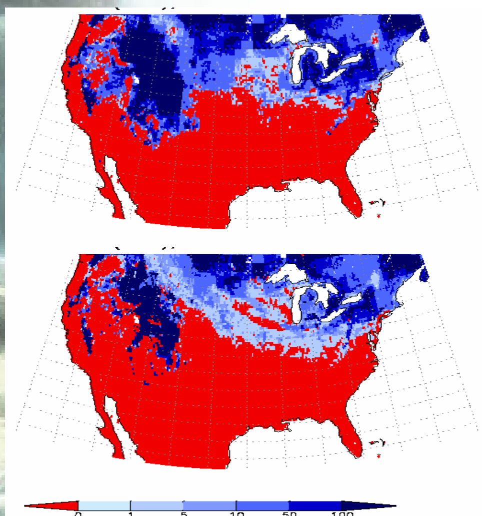


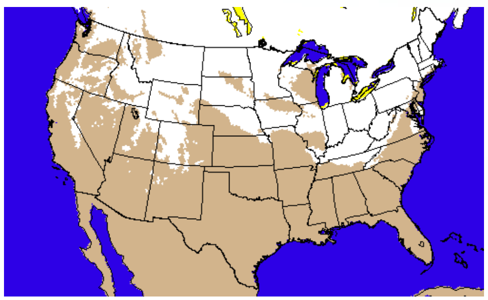
MODIS derived leaf area index



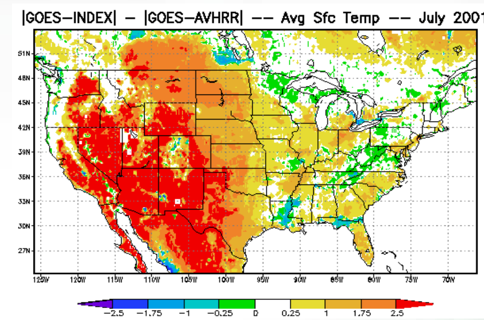
MODIS snow cover [%].

…RESULTS IN IMPROVED MODEL SIMULATIONS…

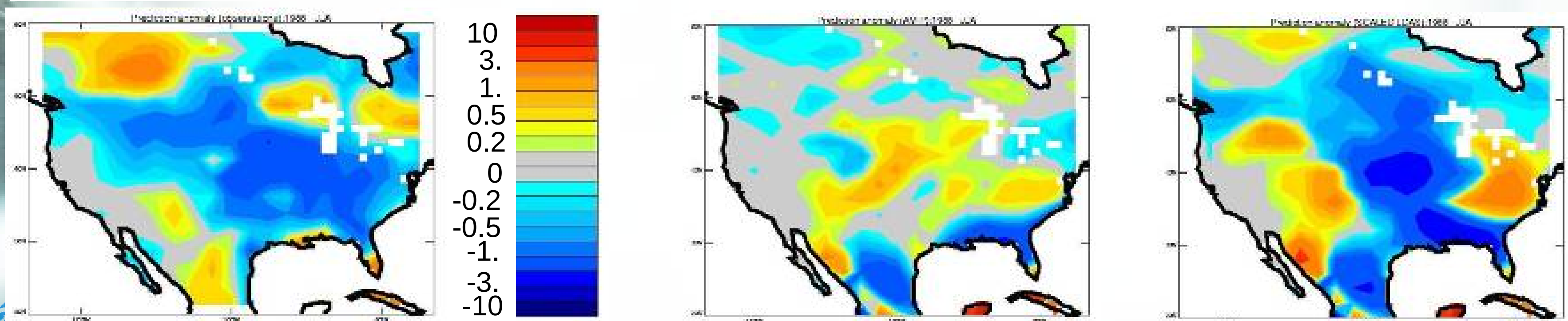




Model assimilation: LIS/LDAS snow water equivalent [mm] without (far left top) and with (far left bottom) assimilated MODIS snow cover; IMS snow cover "truth" (near left), 20 Jan 2003. Improvement in modeled surface temperature [C] when MODIS leaf area index is incorporated into the land surface model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



…AND LEADS TO MORE ACCURATE PREDICTIONS.



[Koster et al., 2003]

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Case 2: USBR Water Supply Forecasting

Reclamation DST for Using 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 remotely sensed and modeling products into Reclamation DSS's and modeling tools

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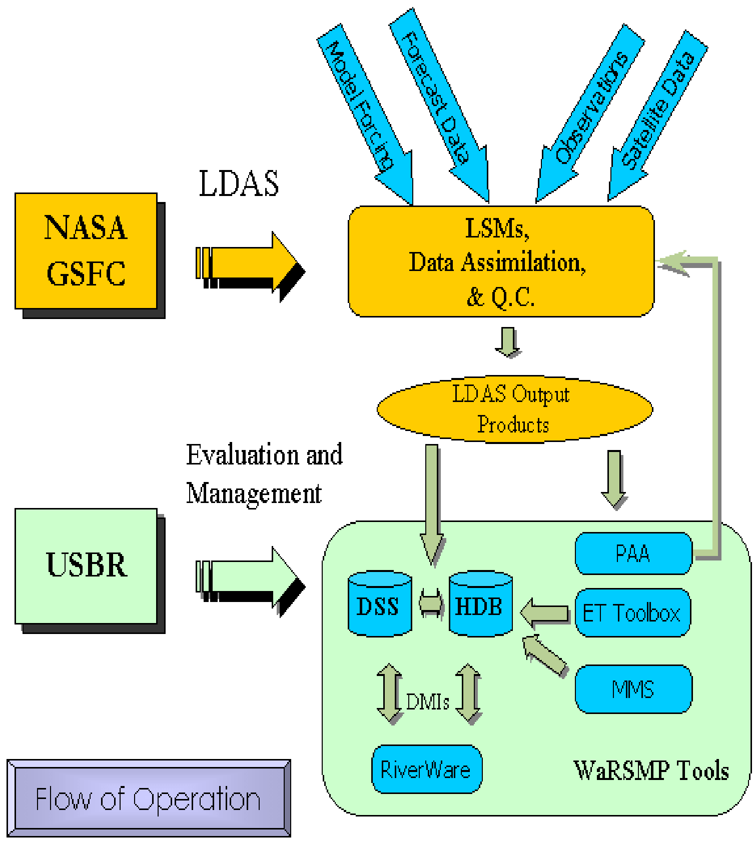
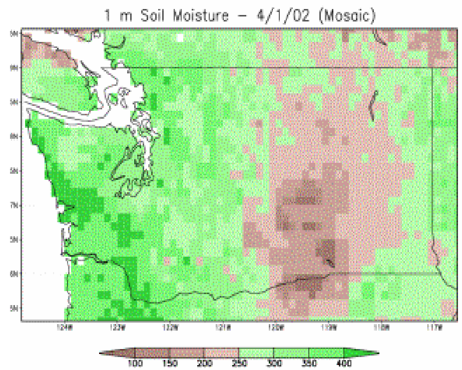
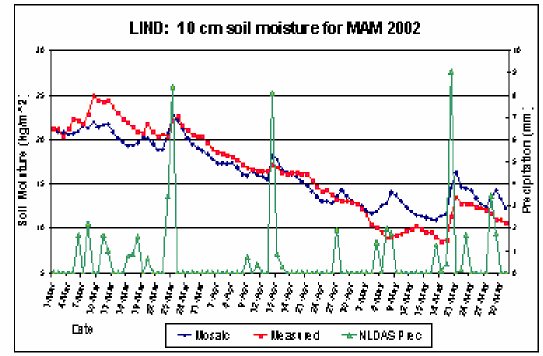
Bureau of Reclamation Study



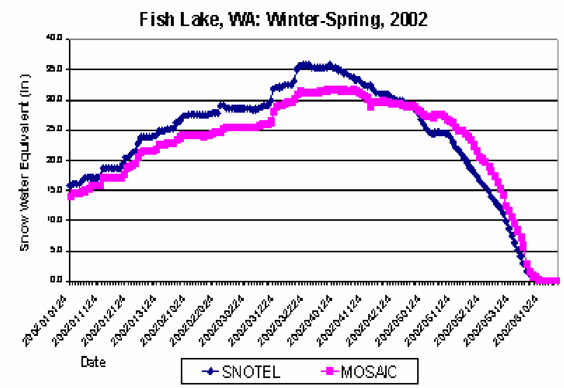
Soil Moisture Analysis





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 Land Products: Land Cover, Snow, Evapotranspiration, Streamflow, Soil Moisture, Other

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

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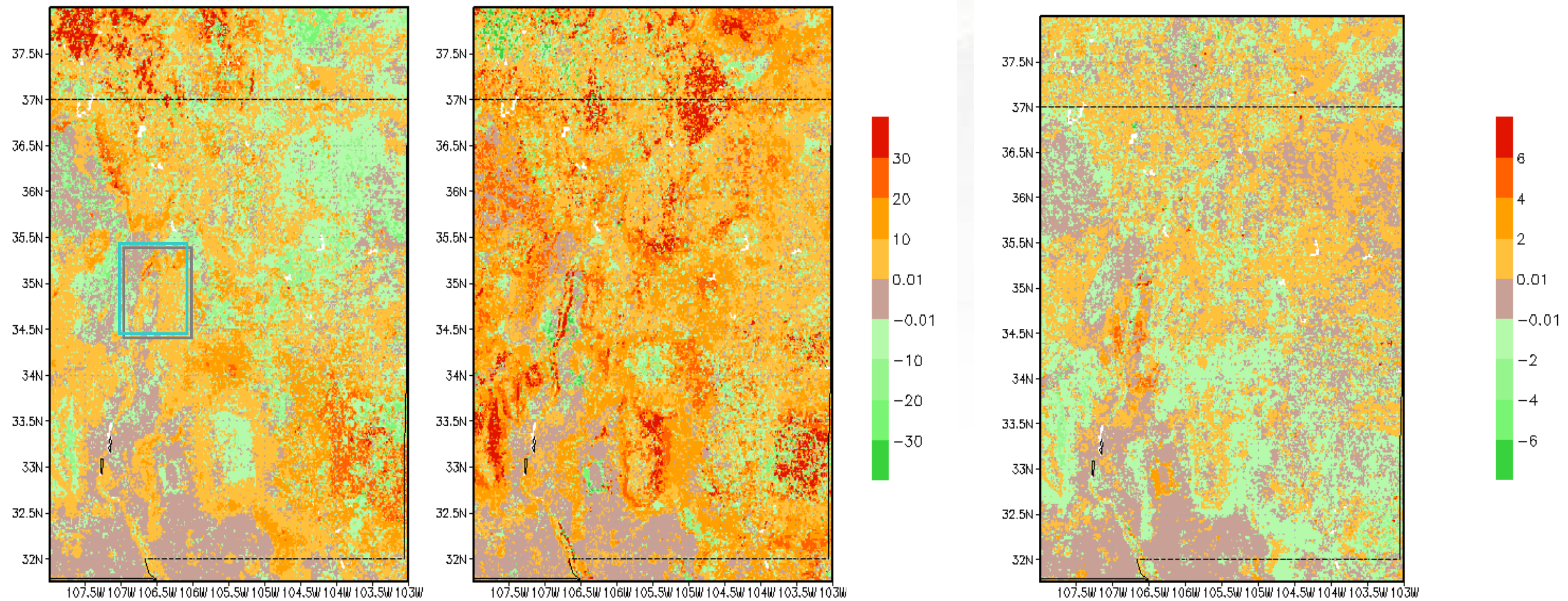
Differences between AVHRR run and MODIS-V3 LAI forcing (Noah land model)

Latent Heat Flux (W m^{-2}) | Sensible Heat Flux (W m^{-2}) | Top 10 cm Soil Temperature (Celsius)



May 30, 2002 (18 Z) Albuquerque and Middle Rio Grande region

Impact of MODIS LAI vs. AVHRR on ET at Bondville, IL (July-Sept 2001, CLM model).

	RMS (Wm-2)	Bias (Wm-2)
AVHRR	62	14
MODIS	50	-5

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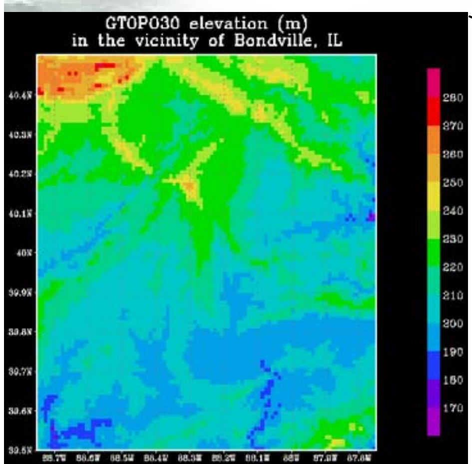
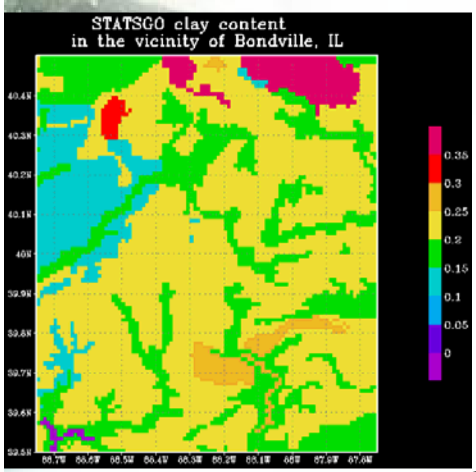
Key LIS Result: Bondville, IL, July-Sept 2001

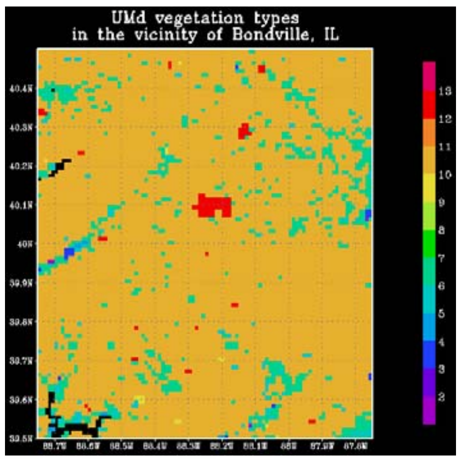
Topography



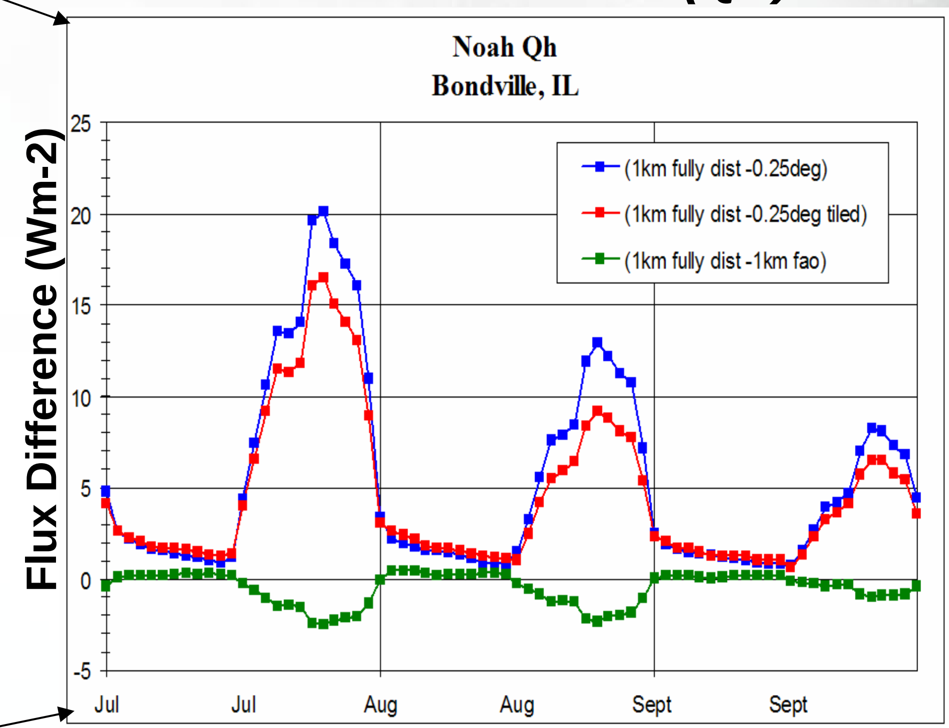
Soils



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

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Conclusion

Variations in greenhouse gases, aerosols,
and solar activity force changes in climate…

…but, consequences of climate change are realized through the water cycle.

Thus, we must *characterize*, *understand*, and *predict* variations in the global water cycle.

Challenge:

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

- How do we coordinate the research community to answer the grand challenge water cycle research questions?
- How do we turn these answers into knowledge that can be acted on?
- *Improved **prediction** of consequences is the key.*
- *Must work in close **partnership** with end-users.*
- ***Education** of scientists, users, and future generations*

CREW Center for Research on Environment and Water